



# Measurement of azimuthal anisotropy of muons from charm and bottom hadrons in Pb+Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV with the ATLAS detector

The ATLAS Collaboration \*

## ARTICLE INFO

### Article history:

Received 8 March 2020

Received in revised form 10 June 2020

Accepted 24 June 2020

Available online 29 June 2020

Editor: M. Doser

## ABSTRACT

Azimuthal anisotropies of muons from charm and bottom hadron decays are measured in Pb+Pb collisions at  $\sqrt{s_{NN}} = 5.02$  TeV. The data were collected with the ATLAS detector at the Large Hadron Collider in 2015 and 2018 with integrated luminosities of  $0.5 \text{ nb}^{-1}$  and  $1.4 \text{ nb}^{-1}$ , respectively. The kinematic selection for heavy-flavor muons requires transverse momentum  $4 < p_T < 30$  GeV and pseudorapidity  $|\eta| < 2.0$ . The dominant sources of muons in this  $p_T$  range are semi-leptonic decays of charm and bottom hadrons. These heavy-flavor muons are separated from light-hadron decay muons and punch-through hadrons using the momentum imbalance between the measurements in the tracking detector and in the muon spectrometers. Azimuthal anisotropies, quantified by flow coefficients, are measured via the event-plane method for inclusive heavy-flavor muons as a function of the muon  $p_T$  and in intervals of Pb+Pb collision centrality. Heavy-flavor muons are separated into contributions from charm and bottom hadron decays using the muon transverse impact parameter with respect to the event primary vertex. Non-zero elliptic ( $v_2$ ) and triangular ( $v_3$ ) flow coefficients are extracted for charm and bottom muons, with the charm muon coefficients larger than those for bottom muons for all Pb+Pb collision centralities. The results indicate substantial modification to the charm and bottom quark angular distributions through interactions in the quark-gluon plasma produced in these Pb+Pb collisions, with smaller modifications for the bottom quarks as expected theoretically due to their larger mass.

© 2020 The Author(s). Published by Elsevier B.V. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>). Funded by SCOAP<sup>3</sup>.

## 1. Introduction

The paradigm for the time evolution of heavy-ion collisions at the Relativistic Heavy Ion Collider (RHIC) and the Large Hadron Collider (LHC) involves the formation and hydrodynamic expansion of a region of hot and dense quark-gluon plasma (QGP) with a small ratio of the shear viscosity to entropy density. In this paradigm, the QGP is considered to be a nearly perfect fluid [1,2]. Initial geometric inhomogeneities of the QGP are translated into momentum anisotropies of the final-state hadrons via large pressure gradients. Extensive measurements of light-hadron azimuthal anisotropies have been performed, in which the single-particle azimuthal distributions are expressed in terms of a Fourier expansion:

$$\frac{dN}{d\phi} \propto 1 + 2 \sum_{n=1}^{\infty} v_n \cos(n(\phi - \Psi_n)), \quad (1)$$

where the event-plane angle,  $\Psi_n$ , specifies the orientation of the initial density profile in the transverse plane [3], and Fourier coefficients,  $v_n$ , quantify the magnitude of the modulation with respect to the event-plane angle. The second- and third-order  $v_n$  coefficients are referred to as elliptic ( $v_2$ ) and triangular ( $v_3$ ) flow coefficients, respectively, with the term ‘flow’ invoking the hydrodynamic paradigm.

Heavy-flavour (charm and bottom) quarks have masses much larger than the temperature of the QGP ( $m_{c,b} > T$ ), with maximum temperatures at early times ranging between 300 and 500 MeV [4]. Thus, thermal production of heavy quarks during the QGP phase is highly suppressed. Instead, heavy quarks are typically produced at the earliest times via high-momentum-transfer collisions between incoming partons. Once created, the heavy quarks persist throughout the dynamical time evolution of the QGP and thus act as sensitive probes of the hot and dense medium.

Owing to their larger masses, radiative energy loss of heavy quarks in the QGP is suppressed relative to that of light quarks [5]. However, it was still postulated that charm quarks interact strongly enough to flow with the QGP [6]. Experimental data at RHIC and then at the LHC reveals that heavy-quark hadrons, as well as their decay leptons, have transverse momentum ( $p_T$ ) distributions

\* E-mail address: [atlas.publications@cern.ch](mailto:atlas.publications@cern.ch).

that are strongly modified by the QGP relative to observations in proton–proton ( $pp$ ) collisions [7–12]. Charm hadrons [13,14] and heavy-quark hadron decay leptons [7,15] are also observed to have significant azimuthal anisotropies, suggesting that they participate in the overall collective flow of the medium. For recent reviews of heavy-flavour measurements in heavy-ion collisions, see Refs. [16–18].

For  $p_T \lesssim 4\text{--}6$  GeV, it was proposed that heavy quarks can be described via a Langevin approach with drag and diffusion terms [19]. Modified  $p_T$  distributions and azimuthal anisotropies of  $D$  mesons have been used to constrain heavy-quark transport coefficients [20,21]. Other models of heavy-flavor kinematics in the QGP, including a Boltzmann approach, have also been explored [22–26]. At higher momenta  $p_T \gtrsim 5\text{--}10$  GeV, heavy-quark energy loss is thought to dominate, with collisional and induced radiative processes both contributing [27]. At intermediate  $p_T$  hadronization effects can be important as azimuthal anisotropies for the deconfined heavy-quark is transferred to the heavy-flavor hadron [28]. There are numerous theoretical predictions for the azimuthal anisotropies of bottom quarks, e.g. in Refs. [29–31]; however, only limited experimental data are currently available. Precision experimental data for  $p_T$  distributions and azimuthal anisotropies is crucial as this over-constrains the calculations that depend on the heavy-quark to QGP coupling as well as the QGP space-time evolution.

The flow coefficients  $v_2$ ,  $v_3$ , and  $v_4$  of inclusive heavy-flavour muon production, which includes both muons from charm hadron decays (“charm muons”) and muons from bottom hadron decays (“bottom muons”), have been measured by the ATLAS experiment [7] and ALICE experiment [32] in Pb+Pb collisions at  $\sqrt{s_{NN}} = 2.76$  TeV. The measurement indicates significant elliptic flow for heavy-flavour muons with  $4 < p_T < 10$  GeV. Recently, the heavy-flavour muon  $v_2$  has also been measured in high-multiplicity  $\sqrt{s} = 13$  TeV  $pp$  collisions [33]. Unlike the earlier Pb+Pb measurement, the  $pp$  measurement examined charm muons and bottom muons separately, finding a non-zero  $v_2$  for charm muons while the  $v_2$  for bottom muons is consistent with zero within uncertainties.

In the measurement presented in this paper, the procedure of the previous  $\sqrt{s_{NN}} = 2.76$  TeV Pb+Pb analysis using the event-plane method is followed [7], and is extended to extract separate flow coefficients for charm and bottom muons. These measurements extends the previously published ones to the higher  $\sqrt{s_{NN}} = 5.02$  TeV Pb+Pb beam energy, using a larger event sample provided by the 2015 and 2018 combined data sets. The larger data sample enables measurements over a larger momentum range  $4 < p_T < 30$  GeV for inclusive heavy-flavour muons. It also allows the separation of the inclusive heavy-flavour muons into charm and bottom contributions. Results for charm and bottom muon elliptic  $v_2$  and triangular  $v_3$  flow coefficients are presented as a function of muon  $p_T$  for various ranges of overlap between the colliding nuclei, referred to as “centrality”.

## 2. ATLAS detector

The ATLAS detector [34–36] at the LHC is a multipurpose particle detector with a forward–backward symmetric cylindrical geometry and a near  $4\pi$  coverage in solid angle.<sup>1</sup> It consists of an inner tracking detector surrounded by a thin superconducting solenoid

<sup>1</sup> ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the centre of the detector and the  $z$ -axis along the beam pipe. The  $x$ -axis points from the IP to the centre of the LHC ring, and the  $y$ -axis points upwards. Cylindrical coordinates  $(r, \phi)$  are used in the transverse plane,  $\phi$  being the azimuthal angle around the  $z$ -axis. The pseudorapidity is defined in terms of the polar angle  $\theta$  as  $\eta = -\ln \tan(\theta/2)$ . Angular distance is measured in units of  $\Delta R \equiv \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$ .

providing a 2 T axial magnetic field, electromagnetic and hadron calorimeters, and a muon spectrometer. The inner tracking detector (ID) covers the pseudorapidity range  $|\eta| < 2.5$ . It consists of silicon pixel, silicon microstrip, and transition radiation tracking (TRT) detectors. The calorimeter system covers the pseudorapidity range  $|\eta| < 4.9$ . Within the region  $|\eta| < 3.2$ , electromagnetic calorimetry is provided by barrel and endcap high-granularity lead/liquid-argon (LAr) calorimeters, with an additional thin LAr presampler covering  $|\eta| < 1.8$ , to correct for energy loss in material upstream of the calorimeters. Hadronic calorimetry is provided by the steel/scintillator-tile calorimeter, segmented into three barrel structures within  $|\eta| < 1.7$ , and two copper/LAr hadronic endcap calorimeters. The solid angle coverage is completed with forward copper/LAr and tungsten/LAr calorimeter modules (FCal) optimised for electromagnetic and hadronic measurements respectively. The muon spectrometer (MS) comprises separate trigger and high-precision tracking chambers, covering  $|\eta| < 2.4$  and  $|\eta| < 2.7$  respectively, and measures the deflection of muons in a magnetic field generated by superconducting air-core toroids. The field integral of the toroids ranges between 2.0 and 6.0 Tm across most of the detector. The minimum-bias trigger scintillators (MBTS) detect charged particles over  $2.07 < |\eta| < 3.86$  using two hodoscopes of 12 counters positioned at  $z = \pm 3.6$  m. The zero-degree calorimeters (ZDC) measure neutral particles at pseudorapidities  $|\eta| \geq 8.3$  and consist of layers of alternating quartz rods and tungsten plates. A two-level trigger system [37] is used to select events. The first-level trigger (L1) is implemented in hardware and uses a subset of the detector information to reduce the accepted rate to below 100 kHz. This is followed by a software-based high-level trigger (HLT) stage that reduces the accepted event rate to 1–4 kHz depending on the data-taking conditions during Pb+Pb collisions.

## 3. Event selection

Data used in this analysis were recorded with the ATLAS detector in 2015 and 2018 from Pb+Pb collisions at  $\sqrt{s_{NN}} = 5.02$  TeV with integrated luminosities of  $0.5 \text{ nb}^{-1}$  and  $1.4 \text{ nb}^{-1}$ , respectively. Events were selected online using a set of muon triggers that require a muon at the HLT stage with  $p_T$  larger than 3, 4, 6, or 8 GeV [37]. The muon trigger selecting  $p_T > 8$  GeV sampled the full luminosity in both 2015 and 2018, while triggers with lower  $p_T$  thresholds were prescaled to reduce the overall data rate. Thus the higher-threshold triggers are utilised at a given muon  $p_T$  to sample a larger fraction of the full luminosity. The resulting sampled luminosities are  $0.3 \text{ nb}^{-1}$ ,  $0.6 \text{ nb}^{-1}$ , and  $1.9 \text{ nb}^{-1}$  for muons with  $4 < p_T < 6$  GeV,  $6 < p_T < 8$  GeV and  $p_T > 8$  GeV, respectively. The selected events are further required to satisfy offline minimum-bias Pb+Pb collision criteria to reject pile-up based on a combination of the total transverse energy measured in the FCal, denoted by  $\Sigma E_T^{FCal}$ , and the ZDC energy.

The centrality of each Pb+Pb event is characterised by its  $\Sigma E_T^{FCal}$ . For the results shown here, the minimum-bias  $\Sigma E_T^{FCal}$  distribution is divided into percentiles ordered from the most central (large  $\Sigma E_T^{FCal}$ , small impact parameter) to the most peripheral (small  $\Sigma E_T^{FCal}$ , large impact parameter): 0–10%, 10–20%, 20–30%, 30–40%, and 40–60%, where 0–100% corresponds to the total Pb+Pb inelastic cross section. A Monte Carlo Glauber [38] calculation is used to characterise each centrality interval [39]. The above centrality intervals have an average number of participating nucleons  $\langle N_{part} \rangle = 358.8 \pm 2.3$ ,  $264.1 \pm 2.9$ ,  $189.2 \pm 2.8$ ,  $131.4 \pm 2.6$ , and  $70.5 \pm 2.2$  respectively.

Muons with  $4 < p_T < 30$  GeV and  $|\eta| < 2.0$  reconstructed in both the ID and the MS are selected and required to pass ‘medium’ selection requirements, detailed in Ref. [40], without any requirement on the number of TRT hits, due to the high occupancy in heavy-ion running. Candidate muons are required to be matched

with a muon reconstructed by the event trigger. Each muon is assigned a weight given by the inverse of the reconstruction and trigger efficiency for the specific muon kinematics.

The muon reconstruction and trigger efficiencies are determined using the  $J/\psi \rightarrow \mu^+\mu^-$  tag-and-probe method as detailed in Ref. [40]. The muon reconstruction efficiency is factorised as the product of ID and MS reconstruction efficiencies. The ID reconstruction efficiency is obtained from Pb+Pb data directly, while the MS reconstruction efficiency is obtained both from Pb+Pb data and by overlaying Pb+Pb minimum-bias events on simulated  $J/\psi$  produced by PYTHIA 8 [41] with the CTEQ6L1 [42] parton distribution functions, using the same tag-and-probe method. The events in overlay simulations are then given weights such that the  $\Sigma E_T^{FCal}$  distribution matches the muon-triggered Pb+Pb data distribution. The MS reconstruction efficiency obtained from simulation is used as the central value for MS reconstruction, with additional data-to-MC scale factors applied to account for residual differences between data and overlay simulation. The same  $J/\psi \rightarrow \mu^+\mu^-$  tag-and-probe method is used to determine the muon trigger efficiency. The central value of the single-muon trigger efficiency correction is obtained from simulations without overlaying Pb+Pb minimum-bias events. Additional correction factors of order 1–10% are obtained from data and applied to the selection to correct for trigger detector performance differences between data and simulation, as well as the centrality dependence of the muon trigger efficiency in Pb+Pb data.

#### 4. Analysis procedure

The analysis follows the event-plane method for measuring flow coefficients as used in previous ATLAS measurements [7,39] and is briefly summarised here. Each Pb+Pb event has a geometric orientation of the impact parameter vector, and the event can also have a tilt relative to that due to fluctuations in the geometry of the resulting QGP. In any particular Pb+Pb collision, one can estimate the orientation, represented by the FCal-determined  $n^{\text{th}}$ -order event-plane angle  $\Psi_n$ . The azimuthal distribution of transverse energy deposited in the forward and backward rapidity FCal is used to determine the event plane. A comparison of event planes, as measured separately in the forward-rapidity FCal and the backward-rapidity FCal, enables a determination of the event-plane resolution  $\text{Res}\{n\Psi_n\}$  as detailed in Ref. [39]. In each Pb+Pb centrality interval and in each muon  $p_T$  selection, the muons are divided into a finite number of intervals in  $\phi - \Psi_n$ , where  $\phi$  is the azimuthal angle of the muon. As different harmonic orders are orthogonal to each other, the Fourier decomposition of the angular distribution (introduced in Eq. (1)) at a given order  $n$  can be expressed as

$$\frac{1}{N_X^\mu} \frac{dN_X^\mu}{d(n(\phi - \Psi_n))} = 1 + 2v_n^{\text{raw}} \cos(n(\phi - \Psi_n)),$$

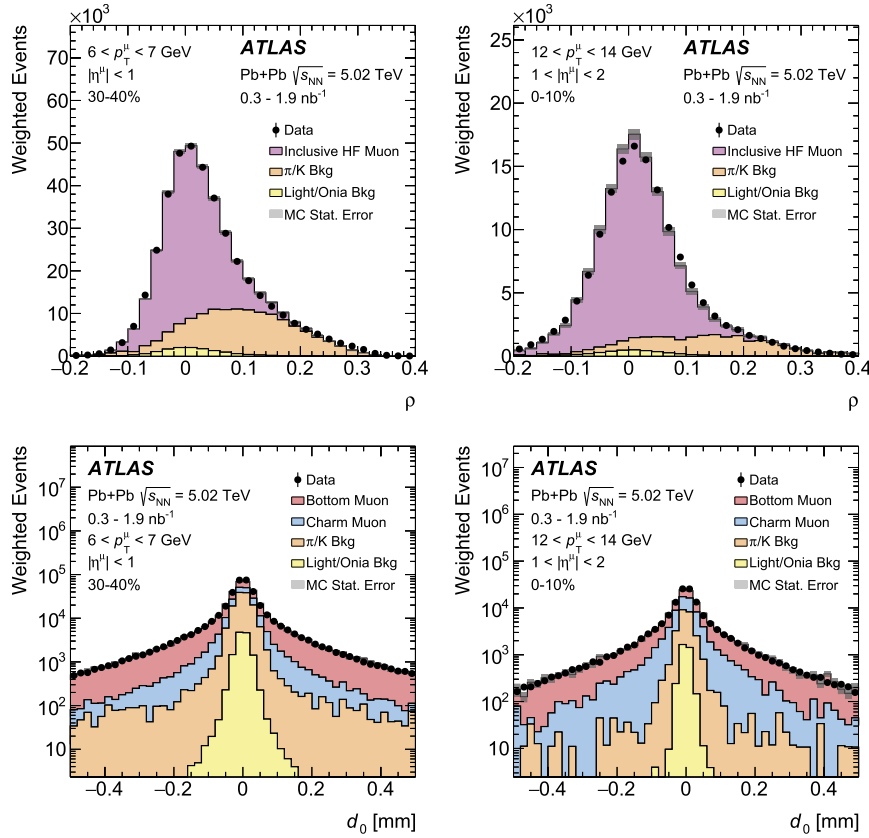
where the  $v_n^{\text{raw}}$  are the raw flow coefficients and the  $N_X^\mu$  are the extracted yields for the muons of interest. Three types of signal are considered in this measurement ( $X = \text{charm, bottom, and inclusive heavy-flavour}$ ). The final  $v_n$  coefficients are obtained by correcting for the event-plane resolution:  $v_n = v_n^{\text{raw}} / \text{Res}\{n\Psi_n\}$ . The leading sources of background contribution in the selected muon samples are muons from decay-in-flight and punch-through of  $\pi$  and  $K$  ( $\pi/K$  background) and muons from non-heavy-flavour components such as direct quarkonia, low-mass resonances,  $\tau$ -leptons and  $W/Z$  decays (labelled “light/onia background”). Other sources of background from hadronic showers and fake muons are found to be very small and are only considered in systematic uncertainties.

Similarly to previous ATLAS publications [7,33,43], different sources of muons are separated using two variables. The first is the momentum imbalance,  $\rho = (p^{\text{ID}} - p^{\text{MS}}) / p^{\text{ID}}$ , where  $p^{\text{ID}}$  is the muon momentum measured in the ID, and  $p^{\text{MS}}$  is that measured in the MS corrected for the energy loss inside the calorimeter. Real muons have a  $\rho$  distribution peaked around zero while the  $\pi/K$  background has a broader  $\rho$  distribution that is shifted toward higher values. The different shapes of the  $\rho$  distribution for the  $\pi/K$  background and other muons enable the isolation of the  $\pi/K$  background muons. The analysis is repeated using the transverse momentum imbalance, as opposed to the total momentum imbalance  $\rho$ , and no difference is observed. The second variable is the transverse impact parameter,  $d_0$ , relative to the event’s primary vertex [44]. Charm and bottom muons have different  $d_0$  distributions due to the different decay lengths of charm and bottom hadrons.

A two-step fit in  $\rho$  and  $d_0$  is performed in data, using  $\rho$  and  $d_0$  line-shape templates for different sources of muons obtained from simulations. First, the yields of inclusive heavy-flavour and  $\pi/K$  background muons are extracted from a fit to the  $\rho$  distribution. The relative yields of light/onia background muons and inclusive heavy-flavour muons are fixed to the fractions obtained from PYTHIA 8 simulations, which are approximately 4% on average. Then, with the extracted  $\pi/K$  background yields fixed, a fit to the  $d_0$  distribution is performed to determine the relative fraction of charm and bottom muons within the yield of inclusive heavy-flavour muons.

The muon ID momentum resolution in PYTHIA 8 simulations overlaid with minimum-bias Pb+Pb events is found to be worse than the resolution in Pb+Pb data. Thus, the  $\rho$  templates are obtained from simulation without Pb+Pb event overlay. The single-muon ID and MS momentum responses in the PYTHIA 8 simulation are shifted and smeared in order to match those in Pb+Pb data. The single-muon momentum shift and smearing parameters are determined by comparing the invariant mass resolution of simulated  $J/\psi \rightarrow \mu^+\mu^-$  events in PYTHIA 8 with that from Pb+Pb data at different centralities. The charm and bottom muon  $\rho$  templates are determined from multijet hard-scattering  $pp$  collision events at  $\sqrt{s} = 13$  TeV filtered on the presence of a generator-level muon in PYTHIA 8 with parameter values as in the A14 tune [45] and using the NNPDF23LO parton distribution functions [46]. The  $\pi/K$  background  $\rho$  templates are obtained from non-diffractive QCD simulations of  $pp$  collisions at  $\sqrt{s} = 13$  TeV in PYTHIA 8, also with the A14 tune and NNPDF23LO parton distribution functions. The  $\rho$  templates for the light/onia background contribution are obtained from simulations of direct  $J/\psi$  in  $pp$  collisions at  $\sqrt{s} = 5.02$  TeV. No differences in the template shapes were observed between simulations at  $\sqrt{s} = 13$  TeV and  $\sqrt{s} = 5.02$  TeV. The signal muon  $\rho$  distribution shape shows no obvious dependence on muon  $p_T$ , but is found to be broader in the endcap muon detector and in most central events due to poorer muon momentum resolution in the ID.

As the  $d_0$  resolution is sensitive to the primary vertex position resolution, the  $d_0$  templates are all obtained from PYTHIA 8 simulations at  $\sqrt{s} = 5.02$  TeV overlaid with minimum-bias Pb+Pb events to best approximate the primary vertex resolution. The distributions of  $d_0$  are shifted and smeared to remove residual differences between overlay simulations and Pb+Pb data. The  $d_0$  shift and smearing parameters are found by comparing the distributions of high-quality prompt-tracks between Pb+Pb data and overlay simulations. The charm and bottom muon  $d_0$  templates are obtained from multijet hard-scattering simulations filtered on the presence of a generator-level muon, whereas the  $\pi/K$  background  $d_0$  templates are from non-diffractive QCD simulations, and the templates for light/onia background are obtained from direct  $J/\psi$  simulations. The signal muon  $d_0$  distribution shape shows no dependence



**Fig. 1.** Example fits to  $\rho$  (top) and  $d_0$  (bottom) for muons with  $6 < p_T < 7$  GeV and  $|\eta| < 1$  in 30–40% centrality Pb+Pb collisions (left) and  $12 < p_T < 14$  GeV and  $1 < |\eta| < 2$  in 0–10% centrality Pb+Pb collisions (right) both integrated over  $n|\phi - \Psi_n|$ . Muon trigger and reconstruction efficiency corrections are applied to the data.

on muon  $p_T$  or event centrality but a moderate dependence on parent charm and bottom hadron  $p_T$  due to the strong correlation between decay length and particle velocity. Additional reweighting is applied to the charm and bottom muon signal samples to match the input charm and bottom hadron  $p_T$  spectra to those measured in Pb+Pb collisions by ALICE [11] and CMS [8,47].

The fits are performed independently in differential intervals of muon  $p_T$ , centrality,  $n|\phi - \Psi_n|$  and two intervals of muon  $\eta$ . The two muon  $\eta$  intervals ( $|\eta| < 1$  and  $1 < |\eta| < 2$ ) are fitted independently to minimise residual data/MC difference in the barrel and endcap muon detectors separately, and then combined to obtain charm, bottom, and inclusive heavy-flavour muon yields in the given  $p_T$ , centrality, and  $n|\phi - \Psi_n|$  intervals as reported in the results. Fluctuations in the simulation templates are incorporated in the fitting procedure. Examples of selected fits in  $\rho$  and  $d_0$  based on simulation templates are shown in Fig. 1 for two different muon  $p_T$  selections ( $6 < p_T < 7$  GeV and  $12 < p_T < 14$  GeV) integrated over  $n|\phi - \Psi_n|$ .

The top row of Fig. 2 shows the inclusive heavy-flavour muon yield as a function of  $2|\phi - \Psi_2|$  (left) and  $3|\phi - \Psi_3|$  (right), and the bottom row shows the charm and bottom muon yields as a function of  $2|\phi - \Psi_2|$  (left) and  $3|\phi - \Psi_3|$  (right). The lines indicate the second (left) and third (right) extracted Fourier harmonics from which the  $v_2^{\text{aw}}$  and  $v_3^{\text{aw}}$  coefficients are extracted.

## 5. Systematic uncertainties

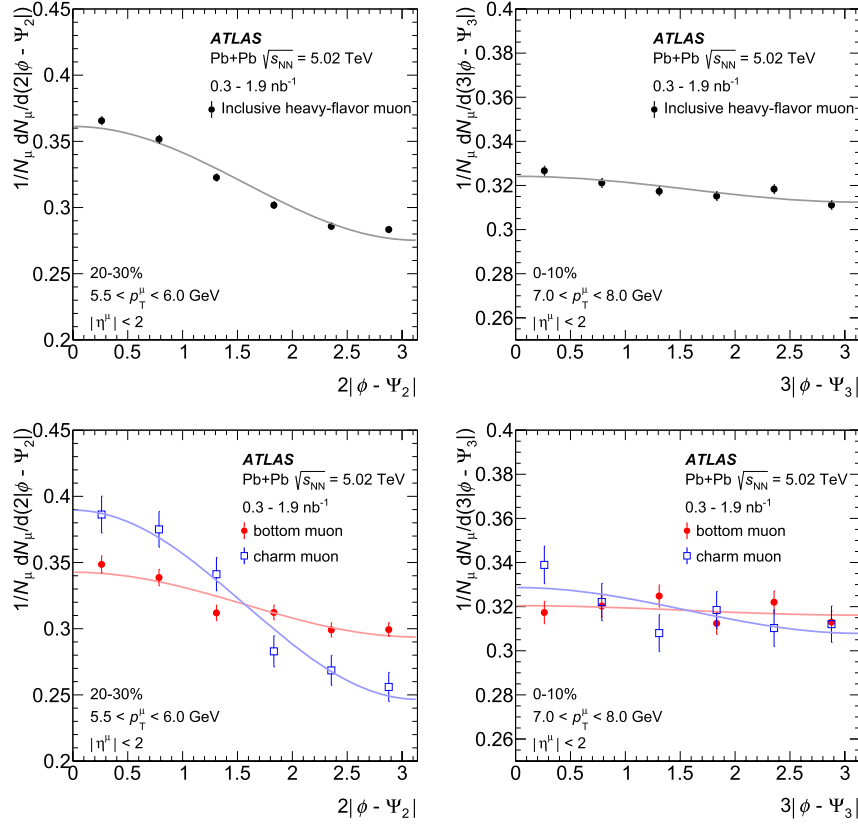
Systematic uncertainties are presented for different categories covering each step of the analysis procedure: 1) muon efficiency; 2)  $\rho$  fit; 3)  $d_0$  fit; 4) light/onia background; 5) other background; 6)  $\rho$ - $d_0$  correlation; 7) event-plane resolution; and 8) jet bias. Table 1 summarises the contributions from different sources of sys-

tematic uncertainty to the final flow-coefficient results. Systematic uncertainties from all sources are summed in quadrature to determine the total uncertainty.

The systematic uncertainties from the MS reconstruction efficiency and muon trigger efficiency corrections are dominated by the uncertainty in determining the data-to-MC scale factor. The scale factor uncertainties are evaluated following the procedure from previous ATLAS measurements [40] including variations in the tag-and-probe efficiency extraction method, object-matching resolution, and purity of the sample. The systematic uncertainty in the muon trigger efficiency also includes the determination of the centrality-dependent correction factors. The uncertainty on the flow coefficients resulting from uncertainties in the muon ID reconstruction efficiency is evaluated by comparing the results with and without the ID efficiency correction, as the ID efficiency is approximately 99% for all centralities. The muon efficiency systematic uncertainties are correlated between the resulting charm and bottom muon results.

The systematic uncertainty of the  $\rho$  fit is due to the uncertainty in the shifts and smearing parameters for single-muon momentum response in simulation, which is evaluated by comparing the nominal results with those 1) without any shifts or smearing, 2) only applying shifts and smearing to the signal muons, and 3) incorporating additional smearing of the background  $\rho$  distributions in simulation to match data distributions in the background-enriched region ( $\rho > 0.2$ ). The changes resulting from these variations are combined in quadrature. The combined uncertainty from the  $\rho$  fit is 1%–10% for the charm and bottom muon results, depending on the muon  $p_T$  and  $\eta$ , but without dependence on centrality. The relative systematic variations are found to be the largest at low  $p_T$  and large  $\eta$ . The  $\rho$  fit systematic uncertainties are correlated between the resulting charm and bottom muon results.





**Fig. 2.** Examples of Fourier decomposition of inclusive heavy-flavour muon yields (top) and bottom/charm muon yields (bottom) in Pb+Pb collisions at  $\sqrt{s_{\text{NN}}} = 5.02$  TeV as a function of  $2|\phi - \Psi_2|$  (left) and  $3|\phi - \Psi_3|$  (right) for two selected intervals in muon  $p_T$  and centrality. The inclusive heavy-flavour muon yields are obtained from  $\rho$  template fits, while the bottom and charm muon yields are further separated using  $d_0$  fits. In all cases the error bars on data indicate the statistical uncertainties obtained from the  $\rho$  or  $d_0$  fit. The lines indicate the extracted second (left) and third (right) Fourier harmonics.

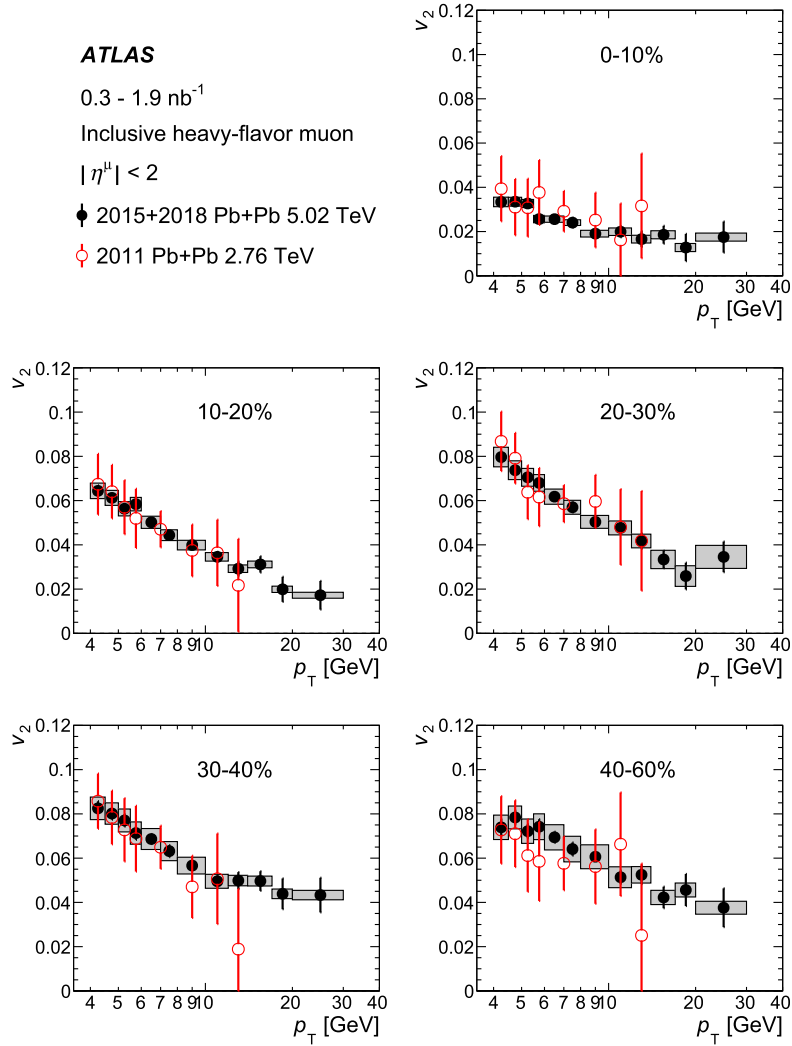
**Table 1**

Summary of the typical sizes of the absolute systematic uncertainties of all categories for the flow coefficient results. The  $d_0$  related systematic uncertainties are not relevant for the heavy-flavour inclusive flow measurements as the  $d_0$  fit is not utilised for these results. Systematic uncertainties from the event-plane resolution and jet bias are negligible and not included in the final uncertainties, and therefore are not shown in the table. The “<” symbol indicates the provided values are the maximum systematic variation for a given category.

Category	Inclusive heavy-flavour muon $v_2$ ( $v_3$ )	Charm muon $v_2$ ( $v_3$ )	Bottom muon $v_2$ ( $v_3$ )
Muon efficiency	< 0.0002 (0.0006)	< 0.006 (0.001)	< 0.001 (0.001)
$\rho$ fit	< 0.004 (0.006)	< 0.009 (0.01)	< 0.005 (0.003)
$d_0$ fit	N/A	< 0.02 (0.03)	< 0.01 (0.01)
Light/onia bkg	< 0.004 (0.002)	< 0.02 (0.01)	< 0.008 (0.004)
Other bkg	< 0.000001 (0.000001)	< 0.002 (0.004)	< 0.001 (0.0004)
$\rho$ - $d_0$ correlation	N/A	< 0.01 (0.004)	< 0.007 (0.005)

The uncertainty in the  $d_0$  template shift and smearing parameters is tested by comparing results when determining the parameters using 2018 data (as in the nominal results) with results when using the 2015 Pb+Pb data to determine the parameters, which covers the slightly different detector alignment between the two data sets. Sensitivity to the charm and bottom hadron  $p_T$  spectra reweighting in simulation is covered by a variation in which the  $p_T$  spectra are reweighted to agree with those from PYTHIA 8 simulations without any modification due to QGP. The variations in the results due to  $d_0$  template shift and smearing and  $p_T$  spectra reweighting are considered to be uncorrelated and are combined in quadrature, and the combined systematic uncertainty is 1%–20% for the charm and bottom muon results, depending on muon  $p_T$  and centrality. The relative systematic variations are found to be the largest at high  $p_T$  and in more peripheral events. The  $d_0$  fit systematic uncertainties are anti-correlated between the resulting charm and bottom muon results.

The magnitude of the light/onia contribution is held at a fixed fraction relative to the inclusive heavy-flavour muon contribution, based on the PYTHIA 8 MC sample. The analysis is repeated to study this choice, first ignoring the light/onia contribution and then fixing it to twice the fraction predicted by PYTHIA 8. As is shown in Ref. [48], PYTHIA overestimates prompt quarkonium production at the LHC, and thus these variations of the light/onia contribution are large enough to not underestimate the uncertainty. Each nominal result is assigned a systematic uncertainty equal to the larger of the changes from the two variations. For the nominal results, light/onia muons are assumed to have the same  $v_2$  and  $v_3$  as the inclusive heavy-flavour muons. The analysis is repeated with variations assuming light/onia muons have zero flow coefficients or double the inclusive heavy-flavour muon flow coefficients. The larger of the resulting changes is assigned as the systematic uncertainty. The light/onia systematic uncertainties are anti-correlated between the resulting charm and bottom muon results.



**Fig. 3.** Inclusive heavy-flavour muon  $v_2$  as a function of  $p_T$  in the combined 2015 and 2018  $\sqrt{s_{NN}} = 5.02$  TeV Pb+Pb data compared with the results in the  $\sqrt{s_{NN}} = 2.76$  TeV Pb+Pb data [7]. Statistical uncertainties are shown as vertical lines and systematic uncertainties as boxes for the  $\sqrt{s_{NN}} = 5.02$  TeV results. For better visibility the statistical and systematic uncertainties of the  $\sqrt{s_{NN}} = 2.76$  TeV data are combined in quadrature and shown as vertical lines. Each panel represents a different centrality interval.

The contributions of hadronic showers are ignored in the nominal analysis. They were included in the analysis based on  $\rho$  and  $d_0$  templates from the PYTHIA 8 simulation with a fixed relative fraction of a few percent also obtained from PYTHIA 8 simulation. The deviation from the nominal result is found to be negligible for the inclusive heavy-flavour muon flow coefficients, and approximately 8% at low  $p_T$  ( $< 8$  GeV) and less than 1% at high  $p_T$  ( $> 12$  GeV) for charm and bottom muon flow coefficients.

All muons are assumed to have independent  $\rho$  and  $d_0$  distributions in the nominal results, which is only true for signal muons. To test the sensitivity to this assumption,  $d_0$  fits in data are repeated with a requirement of  $\rho < 0.1$  on the sample, thus significantly reducing the background contribution. The difference between results with and without the restriction on  $\rho$  is assigned as a systematic uncertainty to cover the systematic effect of ignoring any correlation between  $\rho$  and  $d_0$  for background muons.

The systematic uncertainty associated with the event-plane angle resolution is evaluated by measuring the event-plane resolution in two subregions of the FCal ( $3.2 < |\eta| < 4.0$  and  $4.0 < |\eta| < 4.8$ ), following a previous ATLAS flow analysis [39]. The systematic uncertainties are evaluated independently for  $\Psi_2$  and  $\Psi_3$ . The maximum difference between these two variations and the nominal results is considered as a systematic uncertainty. The uncertainty associated with the event-plane angle resolution is found to be

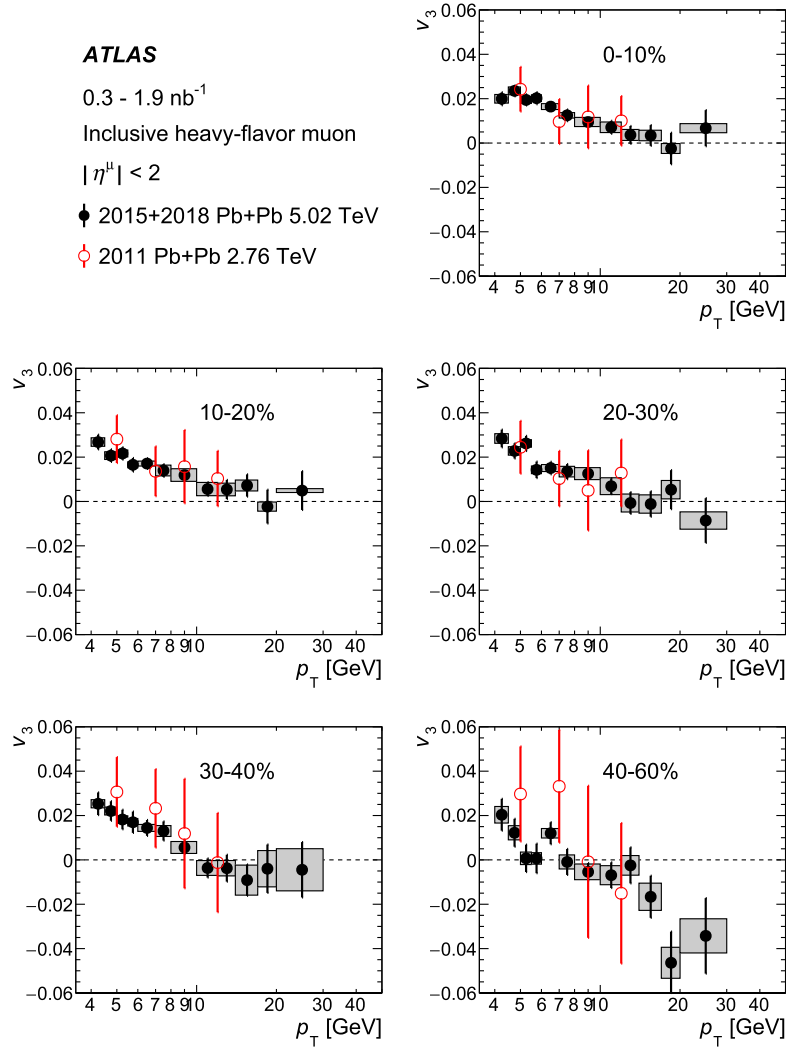
negligible compared to other systematic uncertainties, and thus is not included in the results.

The charm and bottom muons are often produced with a recoil jet. The orientation of  $\Psi_n$  could be biased to align with the signal muon if the recoil jet reaches the FCal [7]. The magnitude of this bias in muon  $v_2$  and  $v_3$  is studied with PYTHIA generator-level muon flow in samples overlaid with Pb+Pb data. The bias is found to be 0.3%–0.4% for  $v_2$  and  $v_3$ , and it is larger in peripheral events than in more-central events. This small bias is negligible and is not included as a systematic uncertainty.

## 6. Results

Fig. 3 shows the inclusive heavy-flavour muon elliptic flow coefficient  $v_2$  as a function of  $p_T$  in the  $\sqrt{s_{NN}} = 5.02$  TeV Pb+Pb data. Each panel corresponds to a different Pb+Pb centrality interval. The  $v_2$  results decrease steadily with  $p_T$  over the entire  $p_T$  range and in all centrality intervals. The overall magnitude of  $v_2$  is smaller in the most central 0–10% selection, as expected since the corresponding smaller impact parameter Pb+Pb collisions have smaller initial geometric ellipticity.

Fig. 4 shows the inclusive heavy-flavour muon triangular flow coefficient  $v_3$  as a function of  $p_T$  in the  $\sqrt{s_{NN}} = 5.02$  TeV Pb+Pb data. Each panel corresponds to a different Pb+Pb centrality in-



**Fig. 4.** Inclusive heavy-flavour muon  $v_3$  as a function of  $p_T$  in the combined 2015 and 2018  $\sqrt{s_{NN}} = 5.02$  TeV Pb+Pb data compared with the results in the  $\sqrt{s_{NN}} = 2.76$  TeV Pb+Pb data [7]. Statistical uncertainties are shown as vertical lines and systematic uncertainties as boxes for the  $\sqrt{s_{NN}} = 5.02$  TeV results. For better visibility the statistical and systematic uncertainties of the  $\sqrt{s_{NN}} = 2.76$  TeV data are combined in quadrature and shown as vertical lines. Each panel represents a different centrality interval.

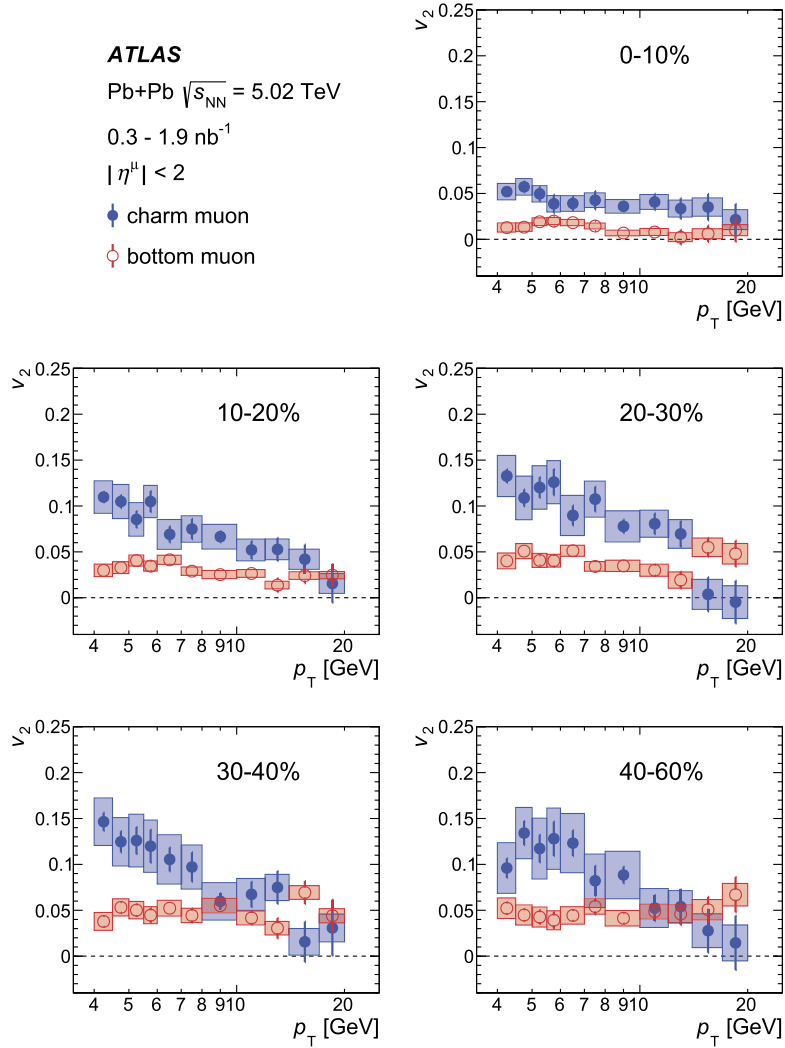
terval. The  $v_3$  results decrease steadily with  $p_T$  over the entire  $p_T$  range in all centrality intervals within statistical and systematic uncertainties. The overall magnitude of  $v_3$  is quite similar in all centrality intervals, as expected since triangular deformations of the initial geometry are primarily the result of fluctuations and are generally unrelated to any intrinsic geometry from the colliding nuclei [49].

Each panel of Figs. 3 and 4 also presents previous ATLAS results from  $\sqrt{s_{NN}} = 2.76$  TeV Pb+Pb data [7]. Compared to the earlier result, the present  $\sqrt{s_{NN}} = 5.02$  TeV results significantly improve the statistical precision of the measurements and extend the  $p_T$  range. The  $\sqrt{s_{NN}} = 5.02$  TeV and  $\sqrt{s_{NN}} = 2.76$  TeV Pb+Pb data inclusive heavy-flavour muon  $v_2$  and  $v_3$  coefficients are consistent with each other within uncertainties. Indeed, according to hydrodynamical models, no significant differences are expected between Pb+Pb collisions at the two different energies [50]. Thus the observed consistency between  $\sqrt{s_{NN}} = 2.76$  TeV and  $\sqrt{s_{NN}} = 5.02$  TeV data is in agreement with expectations. The inclusive charged-particle flow coefficients are also observed to be nearly identical at the two collision energies [39].

Fig. 5 shows the separated charm and bottom muon  $v_2$  as a function of  $p_T$ , with each panel presenting a different Pb+Pb centrality interval. The charm and bottom flow coefficients are extracted only up to  $p_T = 20$  GeV, since above that transverse mo-

mentum range the inclusive heavy-flavour  $v_2$  values are small and the charm-to-bottom separation procedure becomes sensitive to fluctuations in data and yields unstable results. The results indicate a non-zero  $v_2$  for both the charm and bottom muons, with substantially larger elliptic flow coefficients for charm muons. The statistical and systematic uncertainties have a significant contribution that is anti-correlated between the charm and bottom  $v_2$ , i.e. an upward fluctuation in the charm  $v_2$  in a particular  $p_T$  bin will be correlated with a downward fluctuation in the bottom  $v_2$  in the same bin and vice versa. For  $p_T < 14$  GeV, both charm and bottom muon  $v_2$  increase from central to mid-central events, reaching maximum between 20% and 40% centrality. Over the range of  $p_T > 14$  GeV, the charm and bottom muon  $v_2$  show no obvious centrality dependence with larger uncertainties.

Qualitatively, the charm and bottom  $v_2$  ordering matches theoretical expectations where the heavier bottom quarks have a smaller modification to their initial momentum trajectories due to their larger masses. Light quarks and heavy quarks can lose energy in traversing the QGP via induced gluon radiation [51]; however, heavy quarks with momentum less than or approximately equal to the quark mass ( $p \lesssim m$ ) radiate less than light quarks due to a suppression of radiation at small angles relative to the quark direction, referred to as the ‘dead-cone’ effect [5]. Thus, at high  $p_T \gg m$ , all quark flavors should lose comparable energy in the



**Fig. 5.** Charm and bottom muon  $v_2$  as a function of  $p_T$  in the combined 2015 and 2018  $\sqrt{s_{NN}} = 5.02$  TeV Pb+Pb data. Statistical uncertainties are shown as vertical lines and systematic uncertainties as boxes for charm and bottom muons. The charm and bottom muon uncertainties are partially anti-correlated. Each panel presents a different centrality interval.

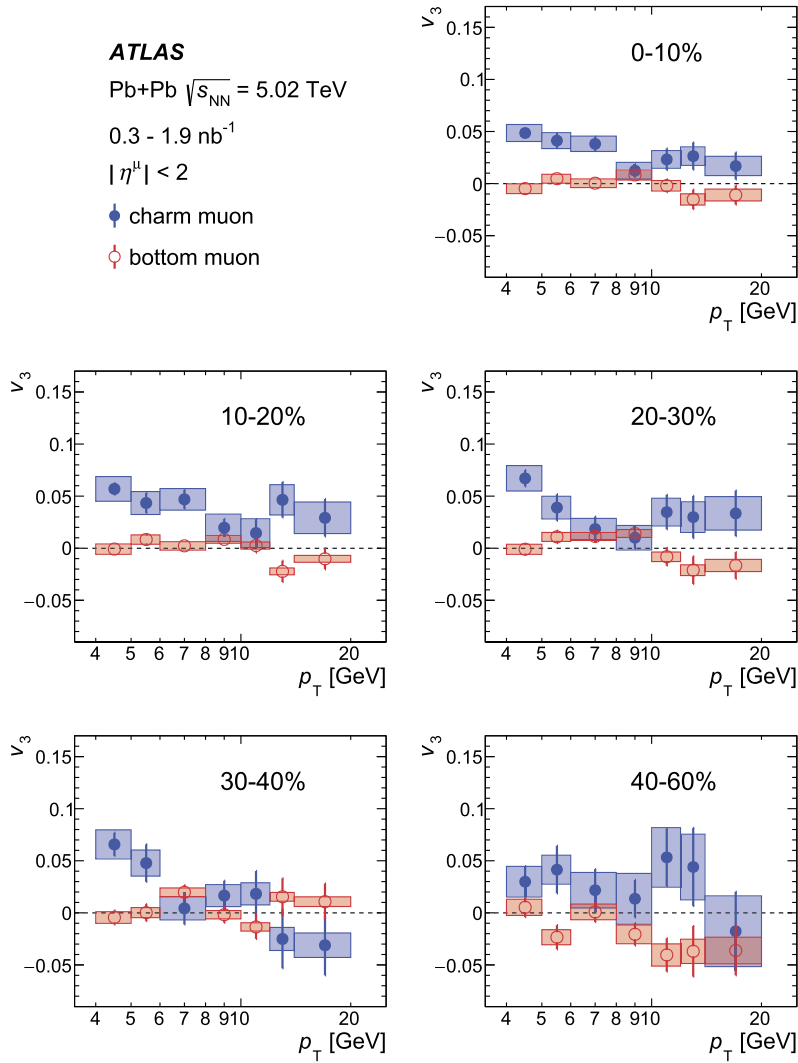
QGP, while at lower  $p_T$  there should be a hierarchy with light quarks losing the most energy, then charm quarks, and finally bottom quarks losing the least energy. Thus the heavier bottom quarks with  $p_T \lesssim 20 - 30$  GeV are expected to lose less energy in the QGP and thus have a smaller azimuthal anisotropy.

Fig. 6 shows the separated charm and bottom muon  $v_3$  as a function of  $p_T$ , with each panel presenting a different Pb+Pb centrality interval. The charm muons show significant non-zero  $v_3$  values, which are independent of centrality. The bottom muons have  $v_3$  values that are significantly below that of charm muons at all  $p_T$  and in all centrality intervals.

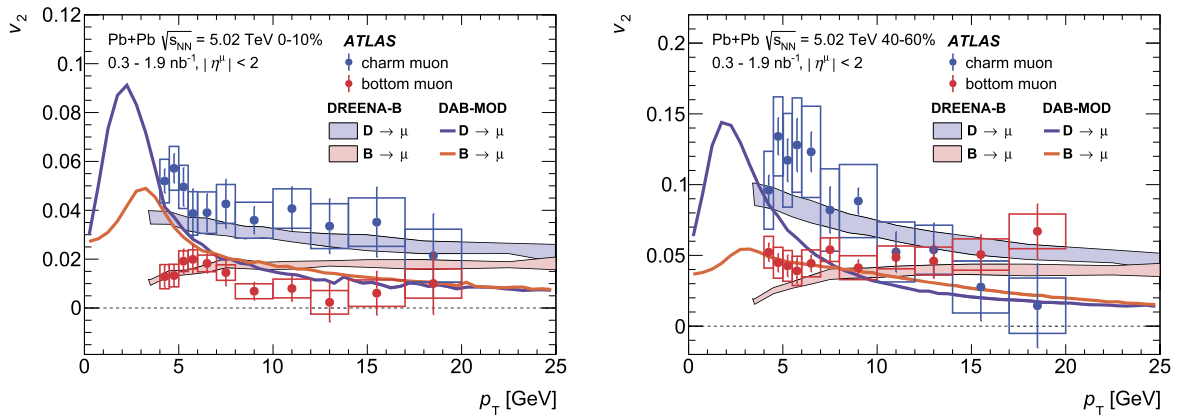
Fig. 7 shows the results for  $v_2$  versus  $p_T$ , from Fig. 5, compared with theoretical calculations: DREENA-B from Ref. [30], and DAB-MOD from Refs. [29,52] for charm and bottom decay muons in the Pb+Pb 0–10% (left) and 40–60% (right) centrality intervals. The DREENA-B calculation includes radiative and collisional energy loss of the heavy quarks traversing the QGP, the latter modelled via a 1 + 1D Bjorken expansion [53]. The DREENA-B theoretical uncertainties reflect the range of magnetic to electric screening masses as constrained by non-perturbative calculations [53]. The predicted  $D$  meson  $v_2$  is higher than the  $B$  meson  $v_2$ , with the two converging at  $p_T \approx 25$  GeV as expected when the  $p_T$  is much larger than the charm and bottom quark masses. Using PYTHIA 8 for decay kinematics, the charm muon and bottom muon  $v_2$  results are

calculated and shown. The predominant effect in going from the parent meson  $v_2(p_T)$  to the daughter muon  $v_2(p_T)$  is a shift downward in  $p_T$ . The predictions are in reasonable agreement with the experimental data, although they overestimate the  $v_2$  at high  $p_T$  of bottom muons in central events. The DAB-MOD framework includes calculations with only Langevin drag and diffusion contributions. The curves shown here are obtained with TRENTO geometric initial conditions [54], heavy-quark Langevin dynamics with the Moore and Teaney parameterisation [19], and coupling values for charm (bottom) of  $D/2\pi T = 2.23$  (2.79), where  $D$  is the spatial diffusion coefficient and  $T$  is the temperature. The decoupling temperature of heavy quarks from the medium is  $T = 160$  MeV and both coalescence and fragmentation are implemented for hadronisation. The DAB-MOD predictions with only Langevin dynamics are roughly a factor of three (two) lower for charm (bottom) muons compared with DREENA-B. Additional energy loss contributions to DAB-MOD, not included here, tend to increase the high  $p_T$  anisotropies. At lower  $p_T$ , the DREENA-B  $v_2$  results rise significantly. A key component of these calculations is the modelling of the QGP transverse





**Fig. 6.** Charm and bottom muon  $v_3$  as a function of  $p_T$  in the combined 2015 and 2018  $\sqrt{s_{NN}} = 5.02$  TeV Pb+Pb data. Statistical uncertainties are shown as vertical lines and systematic uncertainties as boxes for charm and bottom muons. The charm and bottom uncertainties are partially anti-correlated. Each panel presents a different centrality interval.



**Fig. 7.** Charm and bottom muon  $v_2$  as a function of  $p_T$  in the  $\sqrt{s_{NN}} = 5.02$  TeV Pb+Pb data for the 0–10% (left) and 40–60% (right) centrality interval, compared with theoretical predictions based on DREENA-B [30] and DAB-MOD [29,52] in the same centrality intervals for charm and bottom muon  $v_2$ . For the data, statistical uncertainties are shown as vertical lines and systematic uncertainties as boxes. The charm and bottom uncertainties are partially anti-correlated.

expansion, and thus it will be instructive in the future to compare the calculations with a common QGP model to test whether the differences arise from the QGP modelling or the energy-loss implementation.

## 7. Conclusion

In summary, a measurement of elliptic and triangular flow coefficients for heavy-flavour decay muons in Pb+Pb collisions at

$\sqrt{s_{NN}} = 5.02$  TeV is presented, including a separation between charm and bottom contributions. The measurement uses a combined 2015 and 2018 data set corresponding to a total integrated luminosity of up to  $1.9 \text{ nb}^{-1}$  recorded by the ATLAS experiment at the LHC. The inclusive heavy-flavour muon  $v_2$  and  $v_3$  values measured in  $4 < p_T < 30$  GeV are observed to decrease with  $p_T$  for all centrality intervals. The  $v_2$  and  $v_3$  values are consistent within uncertainties with previous Pb+Pb measurements at  $\sqrt{s_{NN}} = 2.76$  TeV. Further separating the inclusive heavy-flavour muons into charm and bottom muons reveals a significantly larger  $v_2$  and  $v_3$  for charm muons than for bottom muons. The results indicate that while both the charm and bottom quarks have their trajectories and momenta modified when traversing the QGP, the effect is stronger for the charm quarks. At fixed  $p_T$ , the charm and bottom muon  $v_2$  values decrease from 40-60% to 0-10% centrality intervals as observed in charged hadron elliptic-flow measurements [55]. Theoretical calculations have a similar qualitative trend with smaller flow coefficients for muons from decays of the heavier bottom quarks. The results can significantly discriminate between models of heavy-quark energy loss and constrain heavy-quark transport coefficients in the QGP.

### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

### Acknowledgements

We thank CERN for the very successful operation of the LHC, as well as the support staff from our institutions without whom ATLAS could not be operated efficiently.

We acknowledge the support of ANPCyT, Argentina; YerPhI, Armenia; ARC, Australia; BMWFW and FWF, Austria; ANAS, Azerbaijan; SSTC, Belarus; CNPq and FAPESP, Brazil; NSERC, NRC and CFI, Canada; CERN; CONICYT, Chile; CAS, MOST and NSFC, China; COLCIENCIAS, Colombia; MSMT CR, MPO CR and VSC CR, Czech Republic; DNRF and DNSRC, Denmark; IN2P3-CNRS and CEA-DRF/IRFU, France; SRNSFG, Georgia; BMBF, HGF and MPG, Germany; GSRF, Greece; RGC and Hong Kong SAR, China; ISF and Benozijyo Center, Israel; INFN, Italy; MEXT and JSPS, Japan; CNRST, Morocco; NWO, Netherlands; RCN, Norway; MNiSW and NCN, Poland; FCT, Portugal; MNE/IFA, Romania; MES of Russia and NRC KI, Russia Federation; JINR; MESTD, Serbia; MSSR, Slovakia; ARRS and MIZŠ, Slovenia; DST/NRF, South Africa; MINECO, Spain; SRC and Wallenberg Foundation, Sweden; SERI, SNSF and Cantons of Bern and Geneva, Switzerland; MOST, Taiwan; TAEK, Turkey; STFC, United Kingdom; DOE and NSF, United States of America. In addition, individual groups and members have received support from BCKDF, CANARIE, Compute Canada and CRC, Canada; ERC, ERDF, Horizon 2020, Marie Skłodowska-Curie Actions and COST, European Union; Investissements d'Avenir Labex, Investissements d'Avenir IDEX and ANR, France; DFG and AvH Foundation, Germany; Herakleitos, Thales and Aristeia programmes co-financed by EU-ESF and the Greek NSRF, Greece; BSF-NSF and GIF, Israel; CERCA Programme Generalitat de Catalunya and PROMETEO Programme Generalitat Valenciana, Spain; Göran Gustafssons Stiftelse, Sweden; The Royal Society and Leverhulme Trust, United Kingdom.

The crucial computing support from all WLCG partners is acknowledged gratefully, in particular from CERN, the ATLAS Tier-1 facilities at TRIUMF (Canada), NDGF (Denmark, Norway, Sweden), CC-IN2P3 (France), KIT/GridKA (Germany), INFN-CNAF (Italy), NL-T1 (Netherlands), PIC (Spain), ASGC (Taiwan), RAL (UK) and BNL (USA), the Tier-2 facilities worldwide and large non-WLCG resource

providers. Major contributors of computing resources are listed in Ref. [56].

### References

- [1] P. Romatschke, U. Romatschke, *Relativistic Fluid Dynamics in and Out of Equilibrium*, Cambridge Monographs on Mathematical Physics, Cambridge University Press, 2019. arXiv:1712.05815 [nucl-th].
- [2] U. Heinz, R. Snellings, Collective flow and viscosity in relativistic heavy-ion collisions, *Annu. Rev. Nucl. Part. Sci.* 63 (2013) 123, arXiv:1301.2826 [nucl-th].
- [3] S. Voloshin, Y. Zhang, Flow study in relativistic nuclear collisions by Fourier expansion of azimuthal particle distributions, *Z. Phys. C* 70 (1996) 665, arXiv:hep-ph/9407282 [hep-ph].
- [4] M. Habich, J.L. Nagle, P. Romatschke, Particle spectra and HBT radii for simulated central nuclear collisions of C + C, Al + Al, Cu + Cu, Au + Au, and Pb + Pb from  $\sqrt{s} = 62.4\text{--}2760$  GeV, *Eur. Phys. J. C* 75 (2015) 15, arXiv:1409.0040 [nucl-th].
- [5] Y.L. Dokshitzer, D.E. Kharzeev, Heavy quark colorimetry of QCD matter, *Phys. Lett. B* 519 (2001) 199, arXiv:hep-ph/0106202 [hep-ph].
- [6] S. Batsouli, S. Kelly, M. Gyulassy, J.L. Nagle, Does the charm flow at RHIC?, *Phys. Lett. B* 557 (2003) 26, arXiv:nucl-th/0212068 [nucl-th].
- [7] ATLAS Collaboration, Measurement of the suppression and azimuthal anisotropy of muons from heavy-flavor decays in Pb+Pb collisions at  $\sqrt{s_{NN}} = 2.76$  TeV with the ATLAS detector, *Phys. Rev. C* 98 (2018) 044905, arXiv:1805.05220 [hep-ex].
- [8] CMS Collaboration, Nuclear modification factor of  $D^0$  mesons in PbPb collisions at  $\sqrt{s_{NN}} = 5.02$  TeV, *Phys. Lett. B* 782 (2018) 474, arXiv:1708.04962 [hep-ex].
- [9] CMS Collaboration, Studies of beauty suppression via nonprompt  $D^0$  mesons in PbPb collisions at  $\sqrt{s_{NN}} = 5.02$  TeV, *Phys. Rev. Lett.* 123 (2019) 022001, arXiv:1810.11102 [hep-ex].
- [10] CMS Collaboration, Measurement of  $B^\pm$  meson nuclear modification factor in PbPb collisions at  $\sqrt{s_{NN}} = 5.02$  TeV, *Phys. Rev. Lett.* 119 (2017) 152301, arXiv:1705.04727 [hep-ex].
- [11] ALICE Collaboration, Measurement of  $D^0$ ,  $D^+$ ,  $D^{*+}$  and  $D_s^+$  production in Pb-Pb collisions at  $\sqrt{s_{NN}} = 5.02$  TeV, *J. High Energy Phys.* 10 (2018) 174, arXiv:1804.09083 [nucl-ex].
- [12] STAR Collaboration, J. Adam, et al., Centrality and transverse momentum dependence of  $D^0$ -meson production at mid-rapidity in Au+Au collisions at  $\sqrt{s_{NN}} = 200$  GeV, *Phys. Rev. C* 99 (2019) 034908, arXiv:1812.10224 [nucl-ex].
- [13] ALICE Collaboration,  $D$ -meson azimuthal anisotropy in mid-central Pb-Pb collisions at  $\sqrt{s_{NN}} = 5.02$  TeV, *Phys. Rev. Lett.* 120 (2018) 102301, arXiv:1707.01005 [nucl-ex].
- [14] CMS Collaboration, Measurement of prompt  $D^0$  meson azimuthal anisotropy in Pb-Pb collisions at  $\sqrt{s_{NN}} = 5.02$  TeV, *Phys. Rev. Lett.* 120 (2018) 202301, arXiv:1708.03497 [hep-ex].
- [15] ALICE Collaboration, Elliptic flow of electrons from heavy-flavour hadron decays at mid-rapidity in Pb-Pb collisions at  $\sqrt{s_{NN}} = 2.76$  TeV, *J. High Energy Phys.* 09 (2016) 028, arXiv:1606.00321 [nucl-ex].
- [16] R. Averbeck, Heavy-flavor production in heavy-ion collisions and implications for the properties of hot QCD matter, *Prog. Part. Nucl. Phys.* 70 (2013) 159, arXiv:1505.03828 [nucl-ex].
- [17] X. Dong, Y.-J. Lee, R. Rapp, Open heavy-flavor production in heavy-ion collisions, *Annu. Rev. Nucl. Part. Sci.* 69 (2019) 417, arXiv:1903.07709 [nucl-ex].
- [18] A. Andronic, et al., Heavy-flavour and quarkonium production in the LHC era: from proton-proton to heavy-ion collisions, *Eur. Phys. J. C* 76 (2016) 107, arXiv:1506.03981 [nucl-ex].
- [19] G.D. Moore, D. Teaney, How much do heavy quarks thermalize in a heavy ion collision?, *Phys. Rev. C* 71 (2005) 064904, arXiv:hep-ph/0412346 [hep-ph].
- [20] S. Cao, et al., Toward the determination of heavy-quark transport coefficients in quark-gluon plasma, *Phys. Rev. C* 99 (2019) 054907, arXiv:1809.07894 [nucl-th].
- [21] R. Rapp, et al., Extraction of heavy-flavor transport coefficients in QCD matter, *Nucl. Phys. A* 979 (2018) 21, arXiv:1803.03824 [nucl-th].
- [22] M. He, R.J. Fries, R. Rapp,  $D_s$  meson as a quantitative probe of diffusion and hadronization in nuclear collisions, *Phys. Rev. Lett.* 110 (2013) 112301, arXiv:1204.4442 [nucl-th].
- [23] W. Alberico, et al., Heavy-flavour spectra in high energy nucleus-nucleus collisions, *Eur. Phys. J. C* 71 (2011) 1666, arXiv:1101.6008 [hep-ph].
- [24] J. Uphoff, O. Fochler, Z. Xu, C. Greiner, Elliptic flow and energy loss of heavy quarks in ultrarelativistic heavy ion collisions, *Phys. Rev. C* 84 (2011) 024908, arXiv:1104.2295 [hep-ph].
- [25] P.B. Gossiaux, R. Bierkandt, J. Aichelin, Tomography of quark gluon plasma at energies available at the BNL relativistic heavy ion collider (RHIC) and the CERN large hadron collider (LHC), *Phys. Rev. C* 79 (2009) 044906, arXiv:0901.0946 [hep-ph].
- [26] B. Zhang, L.-W. Chen, C.-M. Ko, Charm elliptic flow at RHIC, *Phys. Rev. C* 72 (2005) 024906, arXiv:nucl-th/0502056 [nucl-th].
- [27] S. Wicks, W. Horowitz, M. Djordjevic, M. Gyulassy, Elastic, inelastic, and path length fluctuations in jet tomography, *Nucl. Phys. A* 784 (2007) 426, arXiv:nucl-th/0512076 [nucl-th].

- [28] M. He, R.J. Fries, R. Rapp, Heavy flavor at the large hadron collider in a strong coupling approach, *Phys. Lett. B* 735 (2014) 445, arXiv:1401.3817 [nucl-th].
- [29] R. Katz, C.A.G. Prado, J. Noronha-Hostler, J. Noronha, A.A.P. Suaide, DAB-MOD sensitivity study of heavy flavor  $R_{AA}$  and azimuthal anisotropies based on beam energy, initial conditions, hadronization, and suppression mechanisms, arXiv:1906.10768 [nucl-th], 2019.
- [30] D. Zigic, I. Salom, J. Auvinen, M. Djordjevic, M. Djordjevic, DREENA-B framework: first predictions of  $R_{AA}$  and  $v_2$  within dynamical energy loss formalism in evolving QCD medium, *Phys. Lett. B* 791 (2019) 236, arXiv:1805.04786 [nucl-th].
- [31] W. Ke, Y. Xu, S.A. Bass, Linearized Boltzmann-Langevin model for heavy quark transport in hot and dense QCD matter, *Phys. Rev. C* 98 (2018) 064901, arXiv:1806.08848 [nucl-th].
- [32] ALICE Collaboration, Elliptic flow of muons from heavy-flavour hadron decays at forward rapidity in PbPb collisions at  $\sqrt{s_{NN}} = 2.76$  TeV, *Phys. Lett. B* 753 (2016) 41, arXiv:1507.03134 [nucl-ex].
- [33] ATLAS Collaboration, Measurement of azimuthal anisotropy of muons from charm and bottom hadrons in  $pp$  collisions at  $\sqrt{s} = 13$  TeV with the ATLAS detector, *Phys. Rev. Lett.* 124 (2020) 082301, arXiv:1909.01650 [hep-ex].
- [34] ATLAS Collaboration, The ATLAS experiment at the CERN large hadron collider, *J. Instrum.* 3 (2008) S08003.
- [35] ATLAS Collaboration, ATLAS insertable B-layer technical design report, ATLAS-TDR-19, <https://cds.cern.ch/record/1291633>, 2010, Addendum: ATLAS-TDR-19-ADD-1, <https://cds.cern.ch/record/1451888>, 2012.
- [36] B. Abbott, et al., Production and integration of the ATLAS insertable B-layer, *J. Instrum.* 13 (2018) T05008, arXiv:1803.00844 [physics.ins-det].
- [37] ATLAS Collaboration, Performance of the ATLAS trigger system in 2015, *Eur. Phys. J. C* 77 (2017) 317, arXiv:1611.09661 [hep-ex].
- [38] M.L. Miller, K. Reygers, S.J. Sanders, P. Steinberg, Glauber modeling in high energy nuclear collisions, *Annu. Rev. Nucl. Part. Sci.* 57 (2007) 205, arXiv:nucl-ex/0701025 [nucl-ex].
- [39] ATLAS Collaboration, Measurement of the azimuthal anisotropy of charged particles produced in  $\sqrt{s_{NN}} = 5.02$  TeV Pb+Pb collisions with the ATLAS detector, *Eur. Phys. J. C* 78 (2018) 997, arXiv:1808.03951 [hep-ex].
- [40] ATLAS Collaboration, Muon reconstruction performance of the ATLAS detector in proton-proton collision data at  $\sqrt{s} = 13$  TeV, *Eur. Phys. J. C* 76 (2016) 292, arXiv:1603.05598 [hep-ex].
- [41] T. Sjöstrand, et al., An introduction to PYTHIA 8.2, *Comput. Phys. Commun.* 191 (2015) 159, arXiv:1410.3012 [hep-ph].
- [42] J. Pumplin, et al., New generation of parton distributions with uncertainties from global QCD analysis, *J. High Energy Phys.* 07 (2002) 012, arXiv:hep-ph/0201195.
- [43] ATLAS Collaboration, Measurements of the electron and muon inclusive cross-sections in proton-proton collisions at  $\sqrt{s} = 7$  TeV with the ATLAS detector, *Phys. Lett. B* 707 (2012) 438, arXiv:1109.0525 [hep-ex].
- [44] ATLAS Collaboration, Vertex reconstruction performance of the ATLAS detector at  $\sqrt{s} = 13$  TeV, ATLAS-PHYS-PUB-2015-026, <https://cds.cern.ch/record/2037717>, 2015.
- [45] ATLAS Collaboration, ATLAS Pythia 8 tunes to 7 TeV data, ATLAS-PHYS-PUB-2014-021, <https://cds.cern.ch/record/1966419>, 2014.
- [46] R.D. Ball, et al., Parton distributions with LHC data, *Nucl. Phys. B* 867 (2013) 244, arXiv:1207.1303 [hep-ph].
- [47] CMS Collaboration, Measurement of prompt and nonprompt charmonium suppression in PbPb collisions at 5.02 TeV, *Eur. Phys. J. C* 78 (2018) 509, arXiv:1712.08959 [hep-ex].
- [48] CMS Collaboration, Prompt and non-prompt  $J/\psi$  production in  $pp$  collisions at  $\sqrt{s} = 7$  TeV, *Eur. Phys. J. C* 71 (2011) 1575, arXiv:1011.4193 [hep-ex].
- [49] B. Alver, G. Roland, Collision-geometry fluctuations and triangular flow in heavy-ion collisions, *Phys. Rev. C* 81 (2010) 054905, arXiv:1003.0194 [nucl-th], Erratum, *Phys. Rev. C* 82 (2010) 039903.
- [50] W. Zhao, H. Xu, H. Song, Collective flow in 2.76 and 5.02 A TeV Pb+Pb collisions, *Eur. Phys. J. C* 77 (2017) 645, arXiv:1703.10792 [nucl-th].
- [51] R. Baier, Y.L. Dokshitzer, S. Peigne, D. Schiff, Induced gluon radiation in a QCD medium, *Phys. Lett. B* 345 (1995) 277, arXiv:hep-ph/9411409 [hep-ph].
- [52] C.A.G. Prado, et al., Event-by-event correlations between soft hadrons and  $D^0$  mesons in 5.02 TeV PbPb collisions at the CERN large hadron collider, *Phys. Rev. C* 96 (2017) 064903, arXiv:1611.02965 [nucl-th].
- [53] J.D. Bjorken, Highly relativistic nucleus-nucleus collisions: the central rapidity region, *Phys. Rev. D* 27 (1983) 140.
- [54] J.S. Moreland, J.E. Bernhard, S.A. Bass, Alternative ansatz to wounded nucleon and binary collision scaling in high-energy nuclear collisions, *Phys. Rev. C* 92 (2015) 011901, arXiv:1412.4708 [nucl-th].
- [55] ATLAS Collaboration, Measurement of the azimuthal anisotropy for charged particle production in  $\sqrt{s_{NN}} = 2.76$  TeV lead-lead collisions with the ATLAS detector, *Phys. Rev. C* 86 (2012) 014907, arXiv:1203.3087 [hep-ex].
- [56] ATLAS Collaboration, ATLAS computing acknowledgements, ATLAS-SOFT-PUB-2020-001, <https://cds.cern.ch/record/2717821>.

## The ATLAS Collaboration

G. Aad<sup>102</sup>, B. Abbott<sup>128</sup>, D.C. Abbott<sup>103</sup>, A. Abed Abud<sup>36</sup>, K. Abeling<sup>53</sup>, D.K. Abhayasinghe<sup>94</sup>, S.H. Abidi<sup>166</sup>, O.S. AbouZeid<sup>40</sup>, N.L. Abraham<sup>155</sup>, H. Abramowicz<sup>160</sup>, H. Abreu<sup>159</sup>, Y. Abulaiti<sup>6</sup>, B.S. Acharya<sup>67a,67b,n</sup>, B. Achkar<sup>53</sup>, S. Adachi<sup>162</sup>, L. Adam<sup>100</sup>, C. Adam Bourdarios<sup>5</sup>, L. Adamczyk<sup>84a</sup>, L. Adamek<sup>166</sup>, J. Adelman<sup>121</sup>, M. Adersberger<sup>114</sup>, A. Adiguzel<sup>12c</sup>, S. Adorni<sup>54</sup>, T. Adye<sup>143</sup>, A.A. Affolder<sup>145</sup>, Y. Afik<sup>159</sup>, C. Agapopoulou<sup>65</sup>, M.N. Agaras<sup>38</sup>, A. Aggarwal<sup>119</sup>, C. Agheorghiesei<sup>27c</sup>, J.A. Aguilar-Saavedra<sup>139f,139a,ae</sup>, F. Ahmadov<sup>80</sup>, W.S. Ahmed<sup>104</sup>, X. Ai<sup>18</sup>, G. Aielli<sup>74a,74b</sup>, S. Akatsuka<sup>86</sup>, T.P.A. Åkesson<sup>97</sup>, E. Akilli<sup>54</sup>, A.V. Akimov<sup>111</sup>, K. Al Khoury<sup>65</sup>, G.L. Alberghi<sup>23b,23a</sup>, J. Albert<sup>175</sup>, M.J. Alconada Verzini<sup>160</sup>, S. Alderweireldt<sup>36</sup>, M. Aleksa<sup>36</sup>, I.N. Aleksandrov<sup>80</sup>, C. Alexa<sup>27b</sup>, T. Alexopoulos<sup>10</sup>, A. Alfonsi<sup>120</sup>, F. Alfonsi<sup>23b,23a</sup>, M. Alhroob<sup>128</sup>, B. Ali<sup>141</sup>, M. Aliev<sup>165</sup>, G. Alimonti<sup>69a</sup>, C. Allaire<sup>65</sup>, B.M.M. Allbrooke<sup>155</sup>, B.W. Allen<sup>131</sup>, P.P. Allport<sup>21</sup>, A. Aloisio<sup>70a,70b</sup>, F. Alonso<sup>89</sup>, C. Alpigiani<sup>147</sup>, A.A. Alshehri<sup>57</sup>, E. Alunno Camelia<sup>74a,74b</sup>, M. Alvarez Estevez<sup>99</sup>, M.G. Alviggi<sup>70a,70b</sup>, Y. Amaral Coutinho<sup>81b</sup>, A. Ambler<sup>104</sup>, L. Ambroz<sup>134</sup>, C. Amelung<sup>26</sup>, D. Amidei<sup>106</sup>, S.P. Amor Dos Santos<sup>139a</sup>, S. Amoroso<sup>46</sup>, C.S. Amrouche<sup>54</sup>, F. An<sup>79</sup>, C. Anastopoulos<sup>148</sup>, N. Andari<sup>144</sup>, T. Andeen<sup>11</sup>, C.F. Anders<sup>61b</sup>, J.K. Anders<sup>20</sup>, S.Y. Andrean<sup>45a,45b</sup>, A. Andreazza<sup>69a,69b</sup>, V. Andrei<sup>61a</sup>, C.R. Anelli<sup>175</sup>, S. Angelidakis<sup>38</sup>, A. Angerami<sup>39</sup>, A.V. Anisenkov<sup>122b,122a</sup>, A. Annovi<sup>72a</sup>, C. Antel<sup>54</sup>, M.T. Anthony<sup>148</sup>, E. Antipov<sup>129</sup>, M. Antonelli<sup>51</sup>, D.J.A. Antrim<sup>170</sup>, F. Anulli<sup>73a</sup>, M. Aoki<sup>82</sup>, J.A. Aparisi Pozo<sup>173</sup>, M.A. Aparo<sup>155</sup>, L. Aperio Bella<sup>15a</sup>, J.P. Araque<sup>139a</sup>, V. Araujo Ferraz<sup>81b</sup>, R. Araujo Pereira<sup>81b</sup>, C. Arcangeletti<sup>51</sup>, A.T.H. Arce<sup>49</sup>, F.A. Arduh<sup>89</sup>, J-F. Arguin<sup>110</sup>, S. Argyropoulos<sup>52</sup>, J.-H. Arling<sup>46</sup>, A.J. Armbruster<sup>36</sup>, A. Armstrong<sup>170</sup>, O. Arnæz<sup>166</sup>, H. Arnold<sup>120</sup>, Z.P. Arrubarrena Tame<sup>114</sup>, G. Artoni<sup>134</sup>, S. Artz<sup>100</sup>, S. Asai<sup>162</sup>, T. Asawatavonvanich<sup>164</sup>, N. Asbah<sup>59</sup>, E.M. Asimakopoulou<sup>171</sup>, L. Asquith<sup>155</sup>, J. Assahsah<sup>35d</sup>, K. Assamagan<sup>29</sup>, R. Astalos<sup>28a</sup>, R.J. Atkin<sup>33a</sup>, M. Atkinson<sup>172</sup>, N.B. Atlay<sup>19</sup>, H. Atmani<sup>65</sup>, K. Augsten<sup>141</sup>, G. Avolio<sup>36</sup>, M.K. Ayoub<sup>15a</sup>, G. Azuelos<sup>110,an</sup>, H. Bachacou<sup>144</sup>, K. Bachas<sup>161</sup>, M. Backes<sup>134</sup>, F. Backman<sup>45a,45b</sup>, P. Bagnaia<sup>73a,73b</sup>, M. Bahmani<sup>85</sup>, H. Bahrasemani<sup>151</sup>, A.J. Bailey<sup>173</sup>, V.R. Bailey<sup>172</sup>, J.T. Baines<sup>143</sup>, C. Bakalis<sup>10</sup>, O.K. Baker<sup>182</sup>,

P.J. Bakker<sup>120</sup>, D. Bakshi Gupta<sup>8</sup>, S. Balaji<sup>156</sup>, E.M. Baldin<sup>122b,122a</sup>, P. Balek<sup>179</sup>, F. Balli<sup>144</sup>,  
 W.K. Balunas<sup>134</sup>, J. Balz<sup>100</sup>, E. Banas<sup>85</sup>, M. Bandieramonte<sup>138</sup>, A. Bandyopadhyay<sup>24</sup>, Sw. Banerjee<sup>180,i</sup>,  
 L. Barak<sup>160</sup>, W.M. Barbe<sup>38</sup>, E.L. Barberio<sup>105</sup>, D. Barberis<sup>55b,55a</sup>, M. Barbero<sup>102</sup>, G. Barbour<sup>95</sup>,  
 T. Barillari<sup>115</sup>, M-S. Barisits<sup>36</sup>, J. Barkeloo<sup>131</sup>, T. Barklow<sup>152</sup>, R. Barnea<sup>159</sup>, B.M. Barnett<sup>143</sup>,  
 R.M. Barnett<sup>18</sup>, Z. Barnovska-Blenessy<sup>60a</sup>, A. Baroncelli<sup>60a</sup>, G. Barone<sup>29</sup>, A.J. Barr<sup>134</sup>,  
 L. Barranco Navarro<sup>45a,45b</sup>, F. Barreiro<sup>99</sup>, J. Barreiro Guimarães da Costa<sup>15a</sup>, S. Barsov<sup>137</sup>, F. Bartels<sup>61a</sup>,  
 R. Bartoldus<sup>152</sup>, G. Bartolini<sup>102</sup>, A.E. Barton<sup>90</sup>, P. Bartos<sup>28a</sup>, A. Basalae<sup>46</sup>, A. Basan<sup>100</sup>, A. Bassalat<sup>65,aj</sup>,  
 M.J. Basso<sup>166</sup>, R.L. Bates<sup>57</sup>, S. Batlamous<sup>35e</sup>, J.R. Batley<sup>32</sup>, B. Batool<sup>150</sup>, M. Battaglia<sup>145</sup>, M. Bauce<sup>73a,73b</sup>,  
 F. Bauer<sup>144</sup>, K.T. Bauer<sup>170</sup>, H.S. Bawa<sup>31</sup>, J.B. Beacham<sup>49</sup>, T. Beau<sup>135</sup>, P.H. Beauchemin<sup>169</sup>, F. Becherer<sup>52</sup>,  
 P. Bechtle<sup>24</sup>, H.C. Beck<sup>53</sup>, H.P. Beck<sup>20,q</sup>, K. Becker<sup>177</sup>, C. Becot<sup>46</sup>, A. Beddall<sup>12d</sup>, A.J. Beddall<sup>12a</sup>,  
 V.A. Bednyakov<sup>80</sup>, M. Bedognetti<sup>120</sup>, C.P. Bee<sup>154</sup>, T.A. Beermann<sup>181</sup>, M. Begalli<sup>81b</sup>, M. Begel<sup>29</sup>,  
 A. Behera<sup>154</sup>, J.K. Behr<sup>46</sup>, F. Beisiegel<sup>24</sup>, A.S. Bell<sup>95</sup>, G. Bella<sup>160</sup>, L. Bellagamba<sup>23b</sup>, A. Bellerive<sup>34</sup>,  
 P. Bellos<sup>9</sup>, K. Beloborodov<sup>122b,122a</sup>, K. Belotskiy<sup>112</sup>, N.L. Belyaev<sup>112</sup>, D. Benchekroun<sup>35a</sup>, N. Benekos<sup>10</sup>,  
 Y. Benhammou<sup>160</sup>, D.P. Benjamin<sup>6</sup>, M. Benoit<sup>54</sup>, J.R. Bensinger<sup>26</sup>, S. Bentvelsen<sup>120</sup>, L. Beresford<sup>134</sup>,  
 M. Beretta<sup>51</sup>, D. Berge<sup>19</sup>, E. Bergeaas Kuutmann<sup>171</sup>, N. Berger<sup>5</sup>, B. Bergmann<sup>141</sup>, L.J. Bergsten<sup>26</sup>,  
 J. Beringer<sup>18</sup>, S. Berlendis<sup>7</sup>, G. Bernardi<sup>135</sup>, C. Bernius<sup>152</sup>, F.U. Bernlochner<sup>24</sup>, T. Berry<sup>94</sup>, P. Berta<sup>100</sup>,  
 C. Bertella<sup>15a</sup>, I.A. Bertram<sup>90</sup>, O. Bessidskaia Bylund<sup>181</sup>, N. Besson<sup>144</sup>, A. Bethani<sup>101</sup>, S. Bethke<sup>115</sup>,  
 A. Betti<sup>42</sup>, A.J. Bevan<sup>93</sup>, J. Beyer<sup>115</sup>, D.S. Bhattacharya<sup>176</sup>, P. Bhattarai<sup>26</sup>, R. Bi<sup>138</sup>, R.M. Bianchi<sup>138</sup>,  
 O. Biebel<sup>114</sup>, D. Biedermann<sup>19</sup>, R. Bielski<sup>36</sup>, K. Bierwagen<sup>100</sup>, N.V. Biesuz<sup>72a,72b</sup>, M. Biglietti<sup>75a</sup>,  
 T.R.V. Billoud<sup>110</sup>, M. Bindi<sup>53</sup>, A. Bingul<sup>12d</sup>, C. Bini<sup>73a,73b</sup>, S. Biondi<sup>23b,23a</sup>, M. Birman<sup>179</sup>, T. Bisanz<sup>53</sup>,  
 J.P. Biswal<sup>3</sup>, D. Biswas<sup>180,i</sup>, A. Bitadze<sup>101</sup>, C. Bittrich<sup>48</sup>, K. Bjørke<sup>133</sup>, T. Blazek<sup>28a</sup>, I. Bloch<sup>46</sup>,  
 C. Blocker<sup>26</sup>, A. Blue<sup>57</sup>, U. Blumenschein<sup>93</sup>, G.J. Bobbink<sup>120</sup>, V.S. Bobrovnikov<sup>122b,122a</sup>, S.S. Bocchetta<sup>97</sup>,  
 A. Bocci<sup>49</sup>, D. Boerner<sup>46</sup>, D. Bogavac<sup>14</sup>, A.G. Bogdanchikov<sup>122b,122a</sup>, C. Bohm<sup>45a</sup>, V. Boisvert<sup>94</sup>,  
 P. Bokan<sup>53,171</sup>, T. Bold<sup>84a</sup>, A.E. Bolz<sup>61b</sup>, M. Bomben<sup>135</sup>, M. Bona<sup>93</sup>, J.S. Bonilla<sup>131</sup>, M. Boonekamp<sup>144</sup>,  
 C.D. Booth<sup>94</sup>, H.M. Borecka-Bielska<sup>91</sup>, L.S. Borgna<sup>95</sup>, A. Borisov<sup>123</sup>, G. Borissov<sup>90</sup>, J. Bortfeldt<sup>36</sup>,  
 D. Bortoletto<sup>134</sup>, D. Boscherini<sup>23b</sup>, M. Bosman<sup>14</sup>, J.D. Bossio Sola<sup>104</sup>, K. Bouaouda<sup>35a</sup>, J. Boudreau<sup>138</sup>,  
 E.V. Bouhova-Thacker<sup>90</sup>, D. Boumediene<sup>38</sup>, S.K. Boutle<sup>57</sup>, A. Boveia<sup>127</sup>, J. Boyd<sup>36</sup>, D. Boye<sup>33c,ak</sup>,  
 I.R. Boyko<sup>80</sup>, A.J. Bozson<sup>94</sup>, J. Bracinik<sup>21</sup>, N. Brahimi<sup>102</sup>, G. Brandt<sup>181</sup>, O. Brandt<sup>32</sup>, F. Braren<sup>46</sup>,  
 B. Brau<sup>103</sup>, J.E. Brau<sup>131</sup>, W.D. Breaden Madden<sup>57</sup>, K. Brendlinger<sup>46</sup>, L. Brenner<sup>46</sup>, R. Brenner<sup>171</sup>,  
 S. Bressler<sup>179</sup>, B. Brickwedde<sup>100</sup>, D.L. Briglin<sup>21</sup>, D. Britton<sup>57</sup>, D. Britzger<sup>115</sup>, I. Brock<sup>24</sup>, R. Brock<sup>107</sup>,  
 G. Brooijmans<sup>39</sup>, W.K. Brooks<sup>146d</sup>, E. Brost<sup>29</sup>, J.H. Broughton<sup>21</sup>, P.A. Bruckman de Renstrom<sup>85</sup>,  
 D. Bruncko<sup>28b</sup>, A. Bruni<sup>23b</sup>, G. Bruni<sup>23b</sup>, L.S. Bruni<sup>120</sup>, S. Bruno<sup>74a,74b</sup>, M. Bruschi<sup>23b</sup>, N. Bruscinò<sup>73a,73b</sup>,  
 L. Bryngemark<sup>97</sup>, T. Buanes<sup>17</sup>, Q. Buat<sup>36</sup>, P. Buchholz<sup>150</sup>, A.G. Buckley<sup>57</sup>, I.A. Budagov<sup>80</sup>, M.K. Bugge<sup>133</sup>,  
 F. Bühner<sup>52</sup>, O. Bulekov<sup>112</sup>, T.J. Burch<sup>121</sup>, S. Burdin<sup>91</sup>, C.D. Burgard<sup>120</sup>, A.M. Burger<sup>129</sup>, B. Burghgrave<sup>8</sup>,  
 J.T.P. Burr<sup>46</sup>, C.D. Burton<sup>11</sup>, J.C. Burzynski<sup>103</sup>, V. Büscher<sup>100</sup>, E. Buschmann<sup>53</sup>, P.J. Bussey<sup>57</sup>,  
 J.M. Butler<sup>25</sup>, C.M. Buttar<sup>57</sup>, J.M. Butterworth<sup>95</sup>, P. Butti<sup>36</sup>, W. Buttinger<sup>36</sup>, C.J. Buxo Vazquez<sup>107</sup>,  
 A. Buzatu<sup>157</sup>, A.R. Buzykaev<sup>122b,122a</sup>, G. Cabras<sup>23b,23a</sup>, S. Cabrera Urbán<sup>173</sup>, D. Caforio<sup>56</sup>, H. Cai<sup>172</sup>,  
 V.M.M. Cairo<sup>152</sup>, O. Cakir<sup>4a</sup>, N. Calace<sup>36</sup>, P. Calafiura<sup>18</sup>, G. Calderini<sup>135</sup>, P. Calfayan<sup>66</sup>, G. Callea<sup>57</sup>,  
 L.P. Caloba<sup>81b</sup>, A. Caltabiano<sup>74a,74b</sup>, S. Calvente Lopez<sup>99</sup>, D. Calvet<sup>38</sup>, S. Calvet<sup>38</sup>, T.P. Calvet<sup>154</sup>,  
 M. Calvetti<sup>72a,72b</sup>, R. Camacho Toro<sup>135</sup>, S. Camarda<sup>36</sup>, D. Camarero Munoz<sup>99</sup>, P. Camarri<sup>74a,74b</sup>,  
 D. Cameron<sup>133</sup>, C. Camincher<sup>36</sup>, S. Campana<sup>36</sup>, M. Campanelli<sup>95</sup>, A. Camplani<sup>40</sup>, A. Campoverde<sup>150</sup>,  
 V. Canale<sup>70a,70b</sup>, A. Canesse<sup>104</sup>, M. Cano Bret<sup>60c</sup>, J. Cantero<sup>129</sup>, T. Cao<sup>160</sup>, Y. Cao<sup>172</sup>,  
 M.D.M. Capeans Garrido<sup>36</sup>, M. Capua<sup>41b,41a</sup>, R. Cardarelli<sup>74a</sup>, F. Cardillo<sup>148</sup>, G. Carducci<sup>41b,41a</sup>,  
 I. Carli<sup>142</sup>, T. Carli<sup>36</sup>, G. Carlino<sup>70a</sup>, B.T. Carlson<sup>138</sup>, E.M. Carlson<sup>175,167a</sup>, L. Carminati<sup>69a,69b</sup>,  
 R.M.D. Carney<sup>152</sup>, S. Caron<sup>119</sup>, E. Carquin<sup>146d</sup>, S. Carrá<sup>46</sup>, J.W.S. Carter<sup>166</sup>, M.P. Casado<sup>14,e</sup>,  
 A.F. Casha<sup>166</sup>, F.L. Castillo<sup>173</sup>, L. Castillo Garcia<sup>14</sup>, V. Castillo Gimenez<sup>173</sup>, N.F. Castro<sup>139a,139e</sup>,  
 A. Catinaccio<sup>36</sup>, J.R. Catmore<sup>133</sup>, A. Cattai<sup>36</sup>, V. Cavaliere<sup>29</sup>, E. Cavallaro<sup>14</sup>, M. Cavalli-Sforza<sup>14</sup>,  
 V. Cavasinni<sup>72a,72b</sup>, E. Celebi<sup>12b</sup>, L. Cerda Alberich<sup>173</sup>, K. Cerny<sup>130</sup>, A.S. Cerqueira<sup>81a</sup>, A. Cerri<sup>155</sup>,  
 L. Cerrito<sup>74a,74b</sup>, F. Cerutti<sup>18</sup>, A. Cervelli<sup>23b,23a</sup>, S.A. Cetin<sup>12b</sup>, Z. Chadi<sup>35a</sup>, D. Chakraborty<sup>121</sup>, J. Chan<sup>180</sup>,  
 W.S. Chan<sup>120</sup>, W.Y. Chan<sup>91</sup>, J.D. Chapman<sup>32</sup>, B. Chargeishvili<sup>158b</sup>, D.G. Charlton<sup>21</sup>, T.P. Charman<sup>93</sup>,  
 C.C. Chau<sup>34</sup>, S. Che<sup>127</sup>, S. Chekanov<sup>6</sup>, S.V. Chekulaev<sup>167a</sup>, G.A. Chelkov<sup>80,ah</sup>, B. Chen<sup>79</sup>, C. Chen<sup>60a</sup>,  
 C.H. Chen<sup>79</sup>, H. Chen<sup>29</sup>, J. Chen<sup>60a</sup>, J. Chen<sup>39</sup>, J. Chen<sup>26</sup>, S. Chen<sup>136</sup>, S.J. Chen<sup>15c</sup>, X. Chen<sup>15b</sup>,  
 Y-H. Chen<sup>46</sup>, H.C. Cheng<sup>63a</sup>, H.J. Cheng<sup>15a</sup>, A. Cheplakov<sup>80</sup>, E. Cheremushkina<sup>123</sup>,



R. Cherkaoui El Moursli <sup>35e</sup>, E. Cheu <sup>7</sup>, K. Cheung <sup>64</sup>, T.J.A. Chevaléras <sup>144</sup>, L. Chevalier <sup>144</sup>, V. Chiarella <sup>51</sup>, G. Chiarelli <sup>72a</sup>, G. Chiodini <sup>68a</sup>, A.S. Chisholm <sup>21</sup>, A. Chitan <sup>27b</sup>, I. Chiu <sup>162</sup>, Y.H. Chiu <sup>175</sup>, M.V. Chizhov <sup>80</sup>, K. Choi <sup>11</sup>, A.R. Chomont <sup>73a,73b</sup>, S. Chouridou <sup>161</sup>, Y.S. Chow <sup>120</sup>, M.C. Chu <sup>63a</sup>, X. Chu <sup>15a,15d</sup>, J. Chudoba <sup>140</sup>, J.J. Chwastowski <sup>85</sup>, L. Chytka <sup>130</sup>, D. Cieri <sup>115</sup>, K.M. Ciesla <sup>85</sup>, D. Cinca <sup>47</sup>, V. Cindro <sup>92</sup>, I.A. Cioară <sup>27b</sup>, A. Ciocio <sup>18</sup>, F. Ciotto <sup>70a,70b</sup>, Z.H. Citron <sup>179,j</sup>, M. Citterio <sup>69a</sup>, D.A. Ciubotaru <sup>27b</sup>, B.M. Ciungu <sup>166</sup>, A. Clark <sup>54</sup>, M.R. Clark <sup>39</sup>, P.J. Clark <sup>50</sup>, C. Clement <sup>45a,45b</sup>, Y. Coadou <sup>102</sup>, M. Cobal <sup>67a,67c</sup>, A. Coccaro <sup>55b</sup>, J. Cochran <sup>79</sup>, R. Coelho Lopes De Sa <sup>103</sup>, H. Cohen <sup>160</sup>, A.E.C. Coimbra <sup>36</sup>, B. Cole <sup>39</sup>, A.P. Colijn <sup>120</sup>, J. Collot <sup>58</sup>, P. Conde Muiño <sup>139a,139h</sup>, S.H. Connell <sup>33c</sup>, I.A. Connelly <sup>57</sup>, S. Constantinescu <sup>27b</sup>, F. Conventi <sup>70a,ao</sup>, A.M. Cooper-Sarkar <sup>134</sup>, F. Cormier <sup>174</sup>, K.J.R. Cormier <sup>166</sup>, L.D. Corpe <sup>95</sup>, M. Corradi <sup>73a,73b</sup>, E.E. Corrigan <sup>97</sup>, F. Corriveau <sup>104,ac</sup>, M.J. Costa <sup>173</sup>, F. Costanza <sup>5</sup>, D. Costanzo <sup>148</sup>, G. Cowan <sup>94</sup>, J.W. Cowley <sup>32</sup>, J. Crane <sup>101</sup>, K. Cranmer <sup>125</sup>, S.J. Crawley <sup>57</sup>, R.A. Creager <sup>136</sup>, S. Crépe-Renaudin <sup>58</sup>, F. Crescioli <sup>135</sup>, M. Cristinziani <sup>24</sup>, V. Croft <sup>169</sup>, G. Crosetti <sup>41b,41a</sup>, A. Cueto <sup>5</sup>, T. Cuhadar Donszelmann <sup>170</sup>, A.R. Cukierman <sup>152</sup>, W.R. Cunningham <sup>57</sup>, S. Czekierda <sup>85</sup>, P. Czodrowski <sup>36</sup>, M.M. Czurylo <sup>61b</sup>, M.J. Da Cunha Sargedas De Sousa <sup>60b</sup>, J.V. Da Fonseca Pinto <sup>81b</sup>, C. Da Via <sup>101</sup>, W. Dabrowski <sup>84a</sup>, F. Dachs <sup>36</sup>, T. Dado <sup>28a</sup>, S. Dahbi <sup>33e</sup>, T. Dai <sup>106</sup>, C. Dallapiccola <sup>103</sup>, M. Dam <sup>40</sup>, G. D'amen <sup>29</sup>, V. D'Amico <sup>75a,75b</sup>, J. Damp <sup>100</sup>, J.R. Dandoy <sup>136</sup>, M.F. Daneri <sup>30</sup>, N.S. Dann <sup>101</sup>, M. Danninger <sup>151</sup>, V. Dao <sup>36</sup>, G. Darbo <sup>55b</sup>, O. Dartsis <sup>5</sup>, A. Dattagupta <sup>131</sup>, T. Daubney <sup>46</sup>, S. D'Auria <sup>69a,69b</sup>, C. David <sup>167b</sup>, T. Davidek <sup>142</sup>, D.R. Davis <sup>49</sup>, I. Dawson <sup>148</sup>, K. De <sup>8</sup>, R. De Asmundis <sup>70a</sup>, M. De Beurs <sup>120</sup>, S. De Castro <sup>23b,23a</sup>, S. De Cecco <sup>73a,73b</sup>, N. De Groot <sup>119</sup>, P. de Jong <sup>120</sup>, H. De la Torre <sup>107</sup>, A. De Maria <sup>15c</sup>, D. De Pedis <sup>73a</sup>, A. De Salvo <sup>73a</sup>, U. De Sanctis <sup>74a,74b</sup>, M. De Santis <sup>74a,74b</sup>, A. De Santo <sup>155</sup>, K. De Vasconcelos Corga <sup>102</sup>, J.B. De Vivie De Regie <sup>65</sup>, C. Debenedetti <sup>145</sup>, D.V. Dedovich <sup>80</sup>, A.M. Deiana <sup>42</sup>, J. Del Peso <sup>99</sup>, Y. Delabat Diaz <sup>46</sup>, D. Delgove <sup>65</sup>, F. Deliot <sup>144,p</sup>, C.M. Delitzsch <sup>7</sup>, M. Della Pietra <sup>70a,70b</sup>, D. Della Volpe <sup>54</sup>, A. Dell'Acqua <sup>36</sup>, L. Dell'Asta <sup>74a,74b</sup>, M. Delmastro <sup>5</sup>, C. Delporte <sup>65</sup>, P.A. Delsart <sup>58</sup>, D.A. DeMarco <sup>166</sup>, S. Demers <sup>182</sup>, M. Demichev <sup>80</sup>, G. Demontigny <sup>110</sup>, S.P. Denisov <sup>123</sup>, L. D'Eramo <sup>135</sup>, D. Derendarz <sup>85</sup>, J.E. Derkaoui <sup>35d</sup>, F. Derue <sup>135</sup>, P. Dervan <sup>91</sup>, K. Desch <sup>24</sup>, C. Deterre <sup>46</sup>, K. Dette <sup>166</sup>, C. Deutsch <sup>24</sup>, M.R. Devesa <sup>30</sup>, P.O. Deviveiros <sup>36</sup>, F.A. Di Bello <sup>73a,73b</sup>, A. Di Ciaccio <sup>74a,74b</sup>, L. Di Ciaccio <sup>5</sup>, W.K. Di Clemente <sup>136</sup>, C. Di Donato <sup>70a,70b</sup>, A. Di Girolamo <sup>36</sup>, G. Di Gregorio <sup>72a,72b</sup>, B. Di Micco <sup>75a,75b</sup>, R. Di Nardo <sup>75a,75b</sup>, K.F. Di Petrillo <sup>59</sup>, R. Di Sipio <sup>166</sup>, C. Diaconu <sup>102</sup>, F.A. Dias <sup>40</sup>, T. Dias Do Vale <sup>139a</sup>, M.A. Diaz <sup>146a</sup>, J. Dickinson <sup>18</sup>, E.B. Diehl <sup>106</sup>, J. Dietrich <sup>19</sup>, S. Díez Cornell <sup>46</sup>, A. Dimitrievska <sup>18</sup>, W. Ding <sup>15b</sup>, J. Dingfelder <sup>24</sup>, F. Dittus <sup>36</sup>, F. Djama <sup>102</sup>, T. Djobava <sup>158b</sup>, J.I. Djuvsland <sup>17</sup>, M.A.B. Do Vale <sup>81c</sup>, M. Dobre <sup>27b</sup>, D. Dodsworth <sup>26</sup>, C. Doglioni <sup>97</sup>, J. Dolejsi <sup>142</sup>, Z. Dolezal <sup>142</sup>, M. Donadelli <sup>81d</sup>, B. Dong <sup>60c</sup>, J. Donini <sup>38</sup>, A. D'onofrio <sup>15c</sup>, M. D'Onofrio <sup>91</sup>, J. Dopke <sup>143</sup>, A. Doria <sup>70a</sup>, M.T. Dova <sup>89</sup>, A.T. Doyle <sup>57</sup>, E. Drechsler <sup>151</sup>, E. Dreyer <sup>151</sup>, T. Dreyer <sup>53</sup>, A.S. Drobac <sup>169</sup>, D. Du <sup>60b</sup>, Y. Duan <sup>60b</sup>, F. Dubinin <sup>111</sup>, M. Dubovsky <sup>28a</sup>, A. Dubreuil <sup>54</sup>, E. Duchovni <sup>179</sup>, G. Duckeck <sup>114</sup>, A. Ducourthial <sup>135</sup>, O.A. Ducu <sup>110</sup>, D. Duda <sup>115</sup>, A. Dudarev <sup>36</sup>, A.C. Dudder <sup>100</sup>, E.M. Duffield <sup>18</sup>, L. Duflot <sup>65</sup>, M. Dührssen <sup>36</sup>, C. Dülsen <sup>181</sup>, M. Dumancic <sup>179</sup>, A.E. Dumitriu <sup>27b</sup>, A.K. Duncan <sup>57</sup>, M. Dunford <sup>61a</sup>, A. Duperrin <sup>102</sup>, H. Duran Yildiz <sup>4a</sup>, M. Düren <sup>56</sup>, A. Durglishvili <sup>158b</sup>, D. Duschinger <sup>48</sup>, B. Dutta <sup>46</sup>, D. Duvnjak <sup>1</sup>, G.I. Dyckes <sup>136</sup>, M. Dyndal <sup>36</sup>, S. Dysch <sup>101</sup>, B.S. Dziedzic <sup>85</sup>, K.M. Ecker <sup>115</sup>, M.G. Eggleston <sup>49</sup>, T. Eifert <sup>8</sup>, G. Eigen <sup>17</sup>, K. Einsweiler <sup>18</sup>, T. Ekelof <sup>171</sup>, H. El Jarrari <sup>35e</sup>, R. El Kosseifi <sup>102</sup>, V. Ellajosyula <sup>171</sup>, M. Ellert <sup>171</sup>, F. Ellinghaus <sup>181</sup>, A.A. Elliot <sup>93</sup>, N. Ellis <sup>36</sup>, J. Elmsheuser <sup>29</sup>, M. Elsing <sup>36</sup>, D. Emelianov <sup>143</sup>, A. Emerman <sup>39</sup>, Y. Enari <sup>162</sup>, M.B. Epland <sup>49</sup>, J. Erdmann <sup>47</sup>, A. Ereditato <sup>20</sup>, P.A. Erland <sup>85</sup>, M. Errenst <sup>36</sup>, M. Escalier <sup>65</sup>, C. Escobar <sup>173</sup>, O. Estrada Pastor <sup>173</sup>, E. Etzion <sup>160</sup>, H. Evans <sup>66</sup>, M.O. Evans <sup>155</sup>, A. Ezhilov <sup>137</sup>, F. Fabbri <sup>57</sup>, L. Fabbri <sup>23b,23a</sup>, V. Fabiani <sup>119</sup>, G. Facini <sup>177</sup>, R.M. Faisca Rodrigues Pereira <sup>139a</sup>, R.M. Fakhrudinov <sup>123</sup>, S. Falciano <sup>73a</sup>, P.J. Falke <sup>5</sup>, S. Falke <sup>5</sup>, J. Faltova <sup>142</sup>, Y. Fang <sup>15a</sup>, Y. Fang <sup>15a</sup>, G. Fanourakis <sup>44</sup>, M. Fanti <sup>69a,69b</sup>, M. Faraj <sup>67a,67c,r</sup>, A. Farbin <sup>8</sup>, A. Farilla <sup>75a</sup>, E.M. Farina <sup>71a,71b</sup>, T. Farooque <sup>107</sup>, S.M. Farrington <sup>50</sup>, P. Farthouat <sup>36</sup>, F. Fassi <sup>35e</sup>, P. Fassnacht <sup>36</sup>, D. Fassouliotis <sup>9</sup>, M. Fauci Giannelli <sup>50</sup>, W.J. Fawcett <sup>32</sup>, L. Fayard <sup>65</sup>, O.L. Fedin <sup>137,o</sup>, W. Fedorko <sup>174</sup>, A. Fehr <sup>20</sup>, M. Feickert <sup>172</sup>, L. Felgioni <sup>102</sup>, A. Fell <sup>148</sup>, C. Feng <sup>60b</sup>, M. Feng <sup>49</sup>, M.J. Fenton <sup>170</sup>, A.B. Fenyuk <sup>123</sup>, S.W. Ferguson <sup>43</sup>, J. Ferrando <sup>46</sup>, A. Ferrante <sup>172</sup>, A. Ferrari <sup>171</sup>, P. Ferrari <sup>120</sup>, R. Ferrari <sup>71a</sup>, D.E. Ferreira de Lima <sup>61b</sup>, A. Ferrer <sup>173</sup>, D. Ferrere <sup>54</sup>, C. Ferretti <sup>106</sup>, F. Fiedler <sup>100</sup>, A. Filipčić <sup>92</sup>, F. Filthaut <sup>119</sup>, K.D. Finelli <sup>25</sup>, M.C.N. Fiolhais <sup>139a,139c,a</sup>, L. Fiorini <sup>173</sup>, F. Fischer <sup>114</sup>, W.C. Fisher <sup>107</sup>, I. Fleck <sup>150</sup>, P. Fleischmann <sup>106</sup>, T. Flick <sup>181</sup>, B.M. Flierl <sup>114</sup>, L. Flores <sup>136</sup>, L.R. Flores Castillo <sup>63a</sup>, F.M. Follega <sup>76a,76b</sup>, N. Fomin <sup>17</sup>, J.H. Foo <sup>166</sup>, G.T. Forcolin <sup>76a,76b</sup>, A. Formica <sup>144</sup>,



F.A. Förster<sup>14</sup>, A.C. Forti<sup>101</sup>, A.G. Foster<sup>21</sup>, M.G. Foti<sup>134</sup>, D. Fournier<sup>65</sup>, H. Fox<sup>90</sup>, P. Francavilla<sup>72a,72b</sup>, S. Francescato<sup>73a,73b</sup>, M. Franchini<sup>23b,23a</sup>, S. Franchino<sup>61a</sup>, D. Francis<sup>36</sup>, L. Franconi<sup>20</sup>, M. Franklin<sup>59</sup>, A.N. Fray<sup>93</sup>, P.M. Freeman<sup>21</sup>, B. Freund<sup>110</sup>, W.S. Freund<sup>81b</sup>, E.M. Freundlich<sup>47</sup>, D.C. Frizzell<sup>128</sup>, D. Froidevaux<sup>36</sup>, J.A. Frost<sup>134</sup>, C. Fukunaga<sup>163</sup>, E. Fullana Torregrosa<sup>173</sup>, T. Fusayasu<sup>116</sup>, J. Fuster<sup>173</sup>, A. Gabrielli<sup>23b,23a</sup>, A. Gabrielli<sup>18</sup>, S. Gadatsch<sup>54</sup>, P. Gadow<sup>115</sup>, G. Gagliardi<sup>55b,55a</sup>, L.G. Gagnon<sup>110</sup>, B. Galhardo<sup>139a</sup>, G.E. Gallardo<sup>134</sup>, E.J. Gallas<sup>134</sup>, B.J. Gallop<sup>143</sup>, G. Galster<sup>40</sup>, R. Gamboa Goni<sup>93</sup>, K.K. Gan<sup>127</sup>, S. Ganguly<sup>179</sup>, J. Gao<sup>60a</sup>, Y. Gao<sup>50</sup>, Y.S. Gao<sup>31.1</sup>, C. García<sup>173</sup>, J.E. García Navarro<sup>173</sup>, J.A. García Pascual<sup>15a</sup>, C. Garcia-Argos<sup>52</sup>, M. Garcia-Sciveres<sup>18</sup>, R.W. Gardner<sup>37</sup>, N. Garelli<sup>152</sup>, S. Gargiulo<sup>52</sup>, C.A. Garner<sup>166</sup>, V. Garonne<sup>133</sup>, S.J. Gasiorowski<sup>147</sup>, P. Gaspar<sup>81b</sup>, A. Gaudiello<sup>55b,55a</sup>, G. Gaudio<sup>71a</sup>, I.L. Gavrilenko<sup>111</sup>, A. Gavrilyuk<sup>124</sup>, C. Gay<sup>174</sup>, G. Gaycken<sup>46</sup>, E.N. Gazis<sup>10</sup>, A.A. Geanta<sup>27b</sup>, C.M. Gee<sup>145</sup>, C.N.P. Gee<sup>143</sup>, J. Geisen<sup>97</sup>, M. Geisen<sup>100</sup>, C. Gemme<sup>55b</sup>, M.H. Genest<sup>58</sup>, C. Geng<sup>106</sup>, S. Gentile<sup>73a,73b</sup>, S. George<sup>94</sup>, T. Gerialis<sup>44</sup>, L.O. Gerlach<sup>53</sup>, P. Gessinger-Befurt<sup>100</sup>, G. Gessner<sup>47</sup>, S. Ghasemi<sup>150</sup>, M. Ghasemi Bostanabad<sup>175</sup>, M. Ghneimat<sup>150</sup>, A. Ghosh<sup>65</sup>, A. Ghosh<sup>78</sup>, B. Giacobbe<sup>23b</sup>, S. Giagu<sup>73a,73b</sup>, N. Giangiacomi<sup>23b,23a</sup>, P. Giannetti<sup>72a</sup>, A. Giannini<sup>70a,70b</sup>, G. Giannini<sup>14</sup>, S.M. Gibson<sup>94</sup>, M. Gignac<sup>145</sup>, D. Gillberg<sup>34</sup>, G. Gilles<sup>181</sup>, D.M. Gingrich<sup>3.an</sup>, M.P. Giordani<sup>67a,67c</sup>, P.F. Giraud<sup>144</sup>, G. Giugliarelli<sup>67a,67c</sup>, D. Giugni<sup>69a</sup>, F. Giuli<sup>74a,74b</sup>, S. Gkaitatzis<sup>161</sup>, I. Gkialas<sup>9.g</sup>, E.L. Gkoukousis<sup>14</sup>, P. Gkoutoumis<sup>10</sup>, L.K. Gladilin<sup>113</sup>, C. Glasman<sup>99</sup>, J. Glatzer<sup>14</sup>, P.C.F. Glaysheer<sup>46</sup>, A. Glazov<sup>46</sup>, G.R. Gledhill<sup>131</sup>, I. Gnesi<sup>41b</sup>, M. Goblirsch-Kolb<sup>26</sup>, D. Godin<sup>110</sup>, S. Goldfarb<sup>105</sup>, T. Golling<sup>54</sup>, D. Golubkov<sup>123</sup>, A. Gomes<sup>139a,139b</sup>, R. Goncalves Gama<sup>53</sup>, R. Gonçalves<sup>139a</sup>, G. Gonella<sup>131</sup>, L. Gonella<sup>21</sup>, A. Gongadze<sup>80</sup>, F. Gonnella<sup>21</sup>, J.L. Gonski<sup>39</sup>, S. González de la Hoz<sup>173</sup>, S. Gonzalez Fernandez<sup>14</sup>, C. Gonzalez Renteria<sup>18</sup>, S. Gonzalez-Sevilla<sup>54</sup>, G.R. Gonzalvo Rodriguez<sup>173</sup>, L. Goossens<sup>36</sup>, N.A. Gorasia<sup>21</sup>, P.A. Gorbounov<sup>124</sup>, H.A. Gordon<sup>29</sup>, B. Gorini<sup>36</sup>, E. Gorini<sup>68a,68b</sup>, A. Gorišek<sup>92</sup>, A.T. Goshaw<sup>49</sup>, M.I. Gostkin<sup>80</sup>, C.A. Gottardo<sup>119</sup>, M. Gouighri<sup>35b</sup>, A.G. Goussiou<sup>147</sup>, N. Govender<sup>33c</sup>, C. Goy<sup>5</sup>, E. Gozani<sup>159</sup>, I. Grabowska-Bold<sup>84a</sup>, E.C. Graham<sup>91</sup>, J. Gramling<sup>170</sup>, E. Gramstad<sup>133</sup>, S. Grancagnolo<sup>19</sup>, M. Grandi<sup>155</sup>, V. Gratchev<sup>137</sup>, P.M. Gravila<sup>27f</sup>, F.G. Gravili<sup>68a,68b</sup>, C. Gray<sup>57</sup>, H.M. Gray<sup>18</sup>, C. Greife<sup>24</sup>, K. Gregersen<sup>97</sup>, I.M. Gregor<sup>46</sup>, P. Grenier<sup>152</sup>, K. Grevtsov<sup>46</sup>, C. Grieco<sup>14</sup>, N.A. Grieser<sup>128</sup>, A.A. Grillo<sup>145</sup>, K. Grimm<sup>31.k</sup>, S. Grinstein<sup>14.x</sup>, J.-F. Grivaz<sup>65</sup>, S. Groh<sup>100</sup>, E. Gross<sup>179</sup>, J. Grosse-Knetter<sup>53</sup>, Z.J. Grout<sup>95</sup>, C. Grud<sup>106</sup>, A. Grummer<sup>118</sup>, L. Guan<sup>106</sup>, W. Guan<sup>180</sup>, C. Gubbels<sup>174</sup>, J. Guenther<sup>36</sup>, A. Guerguichon<sup>65</sup>, J.G.R. Guerrero Rojas<sup>173</sup>, F. Guescini<sup>115</sup>, D. Guest<sup>170</sup>, R. Gugel<sup>52</sup>, T. Guillemain<sup>5</sup>, S. Guindon<sup>36</sup>, U. Gul<sup>57</sup>, J. Guo<sup>60c</sup>, W. Guo<sup>106</sup>, Y. Guo<sup>60a</sup>, Z. Guo<sup>102</sup>, R. Gupta<sup>46</sup>, S. Gurbuz<sup>12c</sup>, G. Gustavino<sup>128</sup>, M. Guth<sup>52</sup>, P. Gutierrez<sup>128</sup>, C. Gutsche<sup>95</sup>, C. Guyot<sup>144</sup>, C. Gwenlan<sup>134</sup>, C.B. Gwilliam<sup>91</sup>, A. Haas<sup>125</sup>, C. Haber<sup>18</sup>, H.K. Hadavand<sup>8</sup>, A. Hafez<sup>60a</sup>, M. Haleem<sup>176</sup>, J. Haley<sup>129</sup>, G. Halladjian<sup>107</sup>, G.D. Hallewell<sup>102</sup>, K. Hamacher<sup>181</sup>, P. Hamal<sup>130</sup>, K. Hamano<sup>175</sup>, H. Hamdaoui<sup>35e</sup>, M. Hamer<sup>24</sup>, G.N. Hamity<sup>50</sup>, K. Han<sup>60a,w</sup>, L. Han<sup>60a</sup>, S. Han<sup>15a</sup>, Y.F. Han<sup>166</sup>, K. Hanagaki<sup>82.u</sup>, M. Hance<sup>145</sup>, D.M. Handl<sup>114</sup>, B. Haney<sup>136</sup>, R. Hankache<sup>135</sup>, E. Hansen<sup>97</sup>, J.B. Hansen<sup>40</sup>, J.D. Hansen<sup>40</sup>, M.C. Hansen<sup>24</sup>, P.H. Hansen<sup>40</sup>, E.C. Hanson<sup>101</sup>, K. Hara<sup>168</sup>, T. Harenberg<sup>181</sup>, S. Harkusha<sup>108</sup>, P.F. Harrison<sup>177</sup>, N.M. Hartman<sup>152</sup>, N.M. Hartmann<sup>114</sup>, Y. Hasegawa<sup>149</sup>, A. Hasib<sup>50</sup>, S. Hassani<sup>144</sup>, S. Haug<sup>20</sup>, R. Hauser<sup>107</sup>, L.B. Havener<sup>39</sup>, M. Havranek<sup>141</sup>, C.M. Hawkes<sup>21</sup>, R.J. Hawkings<sup>36</sup>, D. Hayden<sup>107</sup>, C. Hayes<sup>106</sup>, R.L. Hayes<sup>174</sup>, C.P. Hays<sup>134</sup>, J.M. Hays<sup>93</sup>, H.S. Hayward<sup>91</sup>, S.J. Haywood<sup>143</sup>, F. He<sup>60a</sup>, M.P. Heath<sup>50</sup>, V. Hedberg<sup>97</sup>, S. Heer<sup>24</sup>, K.K. Heidegger<sup>52</sup>, W.D. Heidorn<sup>79</sup>, J. Heilman<sup>34</sup>, S. Heim<sup>46</sup>, T. Heim<sup>18</sup>, B. Heinemann<sup>46.al</sup>, J.J. Heinrich<sup>131</sup>, L. Heinrich<sup>36</sup>, J. Hejbal<sup>140</sup>, L. Helary<sup>61b</sup>, A. Held<sup>125</sup>, S. Hellesund<sup>133</sup>, C.M. Helling<sup>145</sup>, S. Hellman<sup>45a,45b</sup>, C. Helsens<sup>36</sup>, R.C.W. Henderson<sup>90</sup>, Y. Heng<sup>180</sup>, L. Henkelmann<sup>32</sup>, A.M. Henriques Correia<sup>36</sup>, H. Herde<sup>26</sup>, Y. Hernández Jiménez<sup>33e</sup>, H. Herr<sup>100</sup>, M.G. Herrmann<sup>114</sup>, T. Herrmann<sup>48</sup>, G. Herten<sup>52</sup>, R. Hertenberger<sup>114</sup>, L. Hervas<sup>36</sup>, T.C. Herwig<sup>136</sup>, G.G. Hesketh<sup>95</sup>, N.P. Hessey<sup>167a</sup>, H. Hibi<sup>83</sup>, A. Higashida<sup>162</sup>, S. Higashino<sup>82</sup>, E. Higón-Rodríguez<sup>173</sup>, K. Hildebrand<sup>37</sup>, J.C. Hill<sup>32</sup>, K.K. Hill<sup>29</sup>, K.H. Hiller<sup>46</sup>, S.J. Hillier<sup>21</sup>, M. Hils<sup>48</sup>, I. Hinchliffe<sup>18</sup>, F. Hinterkeuser<sup>24</sup>, M. Hirose<sup>132</sup>, S. Hirose<sup>52</sup>, D. Hirschbuehl<sup>181</sup>, B. Hiti<sup>92</sup>, O. Hladik<sup>140</sup>, D.R. Hlaluku<sup>33e</sup>, J. Hobbs<sup>154</sup>, N. Hod<sup>179</sup>, M.C. Hodgkinson<sup>148</sup>, A. Hoecker<sup>36</sup>, D. Hohn<sup>52</sup>, D. Hohov<sup>65</sup>, T. Holm<sup>24</sup>, T.R. Holmes<sup>37</sup>, M. Holzbock<sup>114</sup>, L.B.A.H. Hommels<sup>32</sup>, S. Honda<sup>168</sup>, T.M. Hong<sup>138</sup>, J.C. Honig<sup>52</sup>, A. Hönle<sup>115</sup>, B.H. Hooberman<sup>172</sup>, W.H. Hopkins<sup>6</sup>, Y. Horii<sup>117</sup>, P. Horn<sup>48</sup>, L.A. Horyn<sup>37</sup>, S. Hou<sup>157</sup>, A. Hoummada<sup>35a</sup>, J. Howarth<sup>57</sup>, J. Hoya<sup>89</sup>, M. Hrabovsky<sup>130</sup>, J. Hrdinka<sup>77</sup>, I. Hristova<sup>19</sup>, J. Hrivnac<sup>65</sup>, A. Hrynevich<sup>109</sup>, T. Hryn'ova<sup>5</sup>, P.J. Hsu<sup>64</sup>, S.-C. Hsu<sup>147</sup>, Q. Hu<sup>29</sup>, S. Hu<sup>60c</sup>, Y.F. Hu<sup>15a,15d</sup>, D.P. Huang<sup>95</sup>, Y. Huang<sup>60a</sup>, Y. Huang<sup>15a</sup>, Z. Hubacek<sup>141</sup>, F. Hubaut<sup>102</sup>, M. Huebner<sup>24</sup>, F. Huegging<sup>24</sup>,

T.B. Huffman<sup>134</sup>, M. Huhtinen<sup>36</sup>, R.F.H. Hunter<sup>34</sup>, P. Huo<sup>154</sup>, N. Huseynov<sup>80,ad</sup>, J. Huston<sup>107</sup>, J. Huth<sup>59</sup>, R. Hyneman<sup>106</sup>, S. Hyrych<sup>28a</sup>, G. Iacobucci<sup>54</sup>, G. Iakovidis<sup>29</sup>, I. Ibragimov<sup>150</sup>, L. Iconomidou-Fayard<sup>65</sup>, P. Iengo<sup>36</sup>, R. Ignazzi<sup>40</sup>, O. Igonkina<sup>120,z,\*</sup>, R. Iguchi<sup>162</sup>, T. Iizawa<sup>54</sup>, Y. Ikegami<sup>82</sup>, M. Ikeno<sup>82</sup>, D. Iliadis<sup>161</sup>, N. Ilic<sup>119,166,ac</sup>, F. Iltzsche<sup>48</sup>, G. Introzzi<sup>71a,71b</sup>, M. Iodice<sup>75a</sup>, K. Iordanidou<sup>167a</sup>, V. Ippolito<sup>73a,73b</sup>, M.F. Isacson<sup>171</sup>, M. Ishino<sup>162</sup>, W. Islam<sup>129</sup>, C. Issever<sup>19,46</sup>, S. Istin<sup>159</sup>, F. Ito<sup>168</sup>, J.M. Iturbe Ponce<sup>63a</sup>, R. Iuppa<sup>76a,76b</sup>, A. Ivina<sup>179</sup>, H. Iwasaki<sup>82</sup>, J.M. Izen<sup>43</sup>, V. Izzo<sup>70a</sup>, P. Jacka<sup>140</sup>, P. Jackson<sup>1</sup>, R.M. Jacobs<sup>24</sup>, B.P. Jaeger<sup>151</sup>, V. Jain<sup>2</sup>, G. Jäkel<sup>181</sup>, K.B. Jakobi<sup>100</sup>, K. Jakobs<sup>52</sup>, T. Jakoubek<sup>140</sup>, J. Jamieson<sup>57</sup>, K.W. Janas<sup>84a</sup>, R. Jansky<sup>54</sup>, M. Janus<sup>53</sup>, P.A. Janus<sup>84a</sup>, G. Jarlskog<sup>97</sup>, A.E. Jaspan<sup>91</sup>, N. Javadov<sup>80,ad</sup>, T. Javůrek<sup>36</sup>, M. Javurkova<sup>103</sup>, F. Jeanneau<sup>144</sup>, L. Jeanty<sup>131</sup>, J. Jejelava<sup>158a</sup>, A. Jelinskas<sup>177</sup>, P. Jenni<sup>52,b</sup>, N. Jeong<sup>46</sup>, S. Jézéquel<sup>5</sup>, H. Ji<sup>180</sup>, J. Jia<sup>154</sup>, H. Jiang<sup>79</sup>, Y. Jiang<sup>60a</sup>, Z. Jiang<sup>152</sup>, S. Jiggins<sup>52</sup>, F.A. Jimenez Morales<sup>38</sup>, J. Jimenez Pena<sup>115</sup>, S. Jin<sup>15c</sup>, A. Jinaru<sup>27b</sup>, O. Jinnouchi<sup>164</sup>, H. Jivan<sup>33e</sup>, P. Johansson<sup>148</sup>, K.A. Johns<sup>7</sup>, C.A. Johnson<sup>66</sup>, R.W.L. Jones<sup>90</sup>, S.D. Jones<sup>155</sup>, S. Jones<sup>7</sup>, T.J. Jones<sup>91</sup>, J. Jongmanns<sup>61a</sup>, P.M. Jorge<sup>139a</sup>, J. Jovicevic<sup>36</sup>, X. Ju<sup>18</sup>, J.J. Junggeburth<sup>115</sup>, A. Juste Rozas<sup>14,x</sup>, A. Kaczmarska<sup>85</sup>, M. Kado<sup>73a,73b</sup>, H. Kagan<sup>127</sup>, M. Kagan<sup>152</sup>, A. Kahn<sup>39</sup>, C. Kahra<sup>100</sup>, T. Kaji<sup>178</sup>, E. Kajomovitz<sup>159</sup>, C.W. Kalderon<sup>29</sup>, A. Kaluza<sup>100</sup>, A. Kamenshchikov<sup>123</sup>, M. Kaneda<sup>162</sup>, N.J. Kang<sup>145</sup>, S. Kang<sup>79</sup>, Y. Kano<sup>117</sup>, J. Kanzaki<sup>82</sup>, L.S. Kaplan<sup>180</sup>, D. Kar<sup>33e</sup>, K. Karava<sup>134</sup>, M.J. Kareem<sup>167b</sup>, I. Karkanias<sup>161</sup>, S.N. Karpov<sup>80</sup>, Z.M. Karpova<sup>80</sup>, V. Kartvelishvili<sup>90</sup>, A.N. Karyukhin<sup>123</sup>, A. Kastanas<sup>45a,45b</sup>, C. Kato<sup>60d,60c</sup>, J. Katzy<sup>46</sup>, K. Kawade<sup>149</sup>, K. Kawagoe<sup>88</sup>, T. Kawaguchi<sup>117</sup>, T. Kawamoto<sup>144</sup>, G. Kawamura<sup>53</sup>, E.F. Kay<sup>175</sup>, V.F. Kazanin<sup>122b,122a</sup>, R. Keeler<sup>175</sup>, R. Kehoe<sup>42</sup>, J.S. Keller<sup>34</sup>, E. Kellermann<sup>97</sup>, D. Kelsey<sup>155</sup>, J.J. Kempster<sup>21</sup>, J. Kendrick<sup>21</sup>, K.E. Kennedy<sup>39</sup>, O. Kepka<sup>140</sup>, S. Kersten<sup>181</sup>, B.P. Kerševan<sup>92</sup>, S. Ketabchi Haghighat<sup>166</sup>, M. Khader<sup>172</sup>, F. Khalil-Zada<sup>13</sup>, M. Khandoga<sup>144</sup>, A. Khanov<sup>129</sup>, A.G. Kharlamov<sup>122b,122a</sup>, T. Kharlamova<sup>122b,122a</sup>, E.E. Khoda<sup>174</sup>, A. Khodinov<sup>165</sup>, T.J. Khoo<sup>54</sup>, E. Khramov<sup>80</sup>, J. Khubua<sup>158b</sup>, S. Kido<sup>83</sup>, M. Kiehn<sup>54</sup>, C.R. Kilby<sup>94</sup>, E. Kim<sup>164</sup>, Y.K. Kim<sup>37</sup>, N. Kimura<sup>95</sup>, O.M. Kind<sup>19</sup>, B.T. King<sup>91,\*</sup>, D. Kirchmeier<sup>48</sup>, J. Kirk<sup>143</sup>, A.E. Kiryunin<sup>115</sup>, T. Kishimoto<sup>162</sup>, D.P. Kisliuk<sup>166</sup>, V. Kitali<sup>46</sup>, O. Kivernyk<sup>24</sup>, T. Klapdor-Kleingrothaus<sup>52</sup>, M. Klassen<sup>61a</sup>, C. Klein<sup>34</sup>, M.H. Klein<sup>106</sup>, M. Klein<sup>91</sup>, U. Klein<sup>91</sup>, K. Kleinknecht<sup>100</sup>, P. Klimek<sup>121</sup>, A. Klimentov<sup>29</sup>, T. Klingl<sup>24</sup>, T. Klioutchnikova<sup>36</sup>, F.F. Klitzner<sup>114</sup>, P. Kluit<sup>120</sup>, S. Kluth<sup>115</sup>, E. Kneringer<sup>77</sup>, E.B.F.G. Knoop<sup>102</sup>, A. Knue<sup>52</sup>, D. Kobayashi<sup>88</sup>, T. Kobayashi<sup>162</sup>, M. Kobel<sup>48</sup>, M. Kocian<sup>152</sup>, T. Kodama<sup>162</sup>, P. Kodys<sup>142</sup>, D.M. Koeck<sup>155</sup>, P.T. Koenig<sup>24</sup>, T. Koffas<sup>34</sup>, N.M. Köhler<sup>36</sup>, M. Kolb<sup>144</sup>, I. Koletsou<sup>5</sup>, T. Komarek<sup>130</sup>, T. Kondo<sup>82</sup>, K. Köneke<sup>52</sup>, A.X.Y. Kong<sup>1</sup>, A.C. König<sup>119</sup>, T. Kono<sup>126</sup>, V. Konstantinides<sup>95</sup>, N. Konstantinidis<sup>95</sup>, B. Konya<sup>97</sup>, R. Kopeliansky<sup>66</sup>, S. Koperny<sup>84a</sup>, K. Korcyl<sup>85</sup>, K. Kordas<sup>161</sup>, G. Koren<sup>160</sup>, A. Korn<sup>95</sup>, I. Korolkov<sup>14</sup>, E.V. Korolkova<sup>148</sup>, N. Korotkova<sup>113</sup>, O. Kortner<sup>115</sup>, S. Kortner<sup>115</sup>, V.V. Kostyukhin<sup>148,165</sup>, A. Kotschechagia<sup>65</sup>, A. Kotwal<sup>49</sup>, A. Koulouris<sup>10</sup>, A. Kourkouveli-Charalampidi<sup>71a,71b</sup>, C. Kourkouvelis<sup>9</sup>, E. Kourlitis<sup>148</sup>, V. Kouskoura<sup>29</sup>, A.B. Kowalewska<sup>85</sup>, R. Kowalewski<sup>175</sup>, W. Kozanecki<sup>101</sup>, A.S. Kozhin<sup>123</sup>, V.A. Kramarenko<sup>113</sup>, G. Kramberger<sup>92</sup>, D. Krasnopevtsev<sup>60a</sup>, M.W. Krasny<sup>135</sup>, A. Krasznahorkay<sup>36</sup>, D. Krauss<sup>115</sup>, J.A. Kremer<sup>84a</sup>, J. Kretzschmar<sup>91</sup>, P. Krieger<sup>166</sup>, F. Krieter<sup>114</sup>, A. Krishnan<sup>61b</sup>, K. Krizka<sup>18</sup>, K. Kroeninger<sup>47</sup>, H. Kroha<sup>115</sup>, J. Kroll<sup>140</sup>, J. Kroll<sup>136</sup>, K.S. Krowpman<sup>107</sup>, U. Kruchonak<sup>80</sup>, H. Krüger<sup>24</sup>, N. Krumnack<sup>79</sup>, M.C. Kruse<sup>49</sup>, J.A. Krzysiak<sup>85</sup>, T. Kubota<sup>105</sup>, O. Kuchinskaia<sup>165</sup>, S. Kuday<sup>4b</sup>, J.T. Kuechler<sup>46</sup>, S. Kuehn<sup>36</sup>, A. Kugel<sup>61a</sup>, T. Kuhl<sup>46</sup>, V. Kukhtin<sup>80</sup>, R. Kukla<sup>102</sup>, Y. Kulchitsky<sup>108,af</sup>, S. Kuleshov<sup>146b</sup>, Y.P. Kulinich<sup>172</sup>, M. Kuna<sup>58</sup>, T. Kunigo<sup>86</sup>, A. Kupco<sup>140</sup>, T. Kupfer<sup>47</sup>, O. Kuprash<sup>52</sup>, H. Kurashige<sup>83</sup>, L.L. Kurchaninov<sup>167a</sup>, Y.A. Kurochkin<sup>108</sup>, A. Kurova<sup>112</sup>, M.G. Kurth<sup>15a,15d</sup>, E.S. Kuwertz<sup>36</sup>, M. Kuze<sup>164</sup>, A.K. Kvam<sup>147</sup>, J. Kvita<sup>130</sup>, T. Kwan<sup>104</sup>, L. La Rotonda<sup>41b,41a</sup>, F. La Ruffa<sup>41b,41a</sup>, C. Lacasta<sup>173</sup>, F. Lacava<sup>73a,73b</sup>, D.P.J. Lack<sup>101</sup>, H. Lacker<sup>19</sup>, D. Lacour<sup>135</sup>, E. Ladygin<sup>80</sup>, R. Lafaye<sup>5</sup>, B. Laforge<sup>135</sup>, T. Lagouri<sup>146b</sup>, S. Lai<sup>53</sup>, I.K. Lakomic<sup>84a</sup>, S. Lammers<sup>66</sup>, W. Lampl<sup>7</sup>, C. Lampoudis<sup>161</sup>, E. Lançon<sup>29</sup>, U. Landgraf<sup>52</sup>, M.P.J. Landon<sup>93</sup>, M.C. Lanfermann<sup>54</sup>, V.S. Lang<sup>46</sup>, J.C. Lange<sup>53</sup>, R.J. Langenberg<sup>103</sup>, A.J. Lankford<sup>170</sup>, F. Lanni<sup>29</sup>, K. Lantsch<sup>24</sup>, A. Lanza<sup>71a</sup>, A. Lapertosa<sup>55b,55a</sup>, S. Laplace<sup>135</sup>, J.F. Laporte<sup>144</sup>, T. Lari<sup>69a</sup>, F. Lasagni Manghi<sup>23b,23a</sup>, M. Lassnig<sup>36</sup>, T.S. Lau<sup>63a</sup>, A. Laudrain<sup>65</sup>, A. Laurier<sup>34</sup>, M. Lavorgna<sup>70a,70b</sup>, S.D. Lawlor<sup>94</sup>, M. Lazzaroni<sup>69a,69b</sup>, B. Le<sup>101</sup>, E. Le Guirriec<sup>102</sup>, A. Lebedev<sup>79</sup>, M. LeBlanc<sup>7</sup>, T. LeCompte<sup>6</sup>, F. Ledroit-Guillon<sup>58</sup>, A.C.A. Lee<sup>95</sup>, C.A. Lee<sup>29</sup>, G.R. Lee<sup>17</sup>, L. Lee<sup>59</sup>, S.C. Lee<sup>157</sup>, S. Lee<sup>79</sup>, B. Lefebvre<sup>167a</sup>, H.P. Lefebvre<sup>94</sup>, M. Lefebvre<sup>175</sup>, C. Leggett<sup>18</sup>, K. Lehmann<sup>151</sup>, N. Lehmann<sup>20</sup>, G. Lehmann Miotto<sup>36</sup>, W.A. Leight<sup>46</sup>, A. Leisos<sup>161,v</sup>, M.A.L. Leite<sup>81d</sup>, C.E. Leitgeb<sup>114</sup>, R. Leitner<sup>142</sup>, D. Lellouch<sup>179,\*</sup>, K.J.C. Leney<sup>42</sup>, T. Lenz<sup>24</sup>, R. Leone<sup>7</sup>, S. Leone<sup>72a</sup>, C. Leonidopoulos<sup>50</sup>,

A. Leopold<sup>135</sup>, C. Leroy<sup>110</sup>, R. Les<sup>166</sup>, C.G. Lester<sup>32</sup>, M. Levchenko<sup>137</sup>, J. Levêque<sup>5</sup>, D. Levin<sup>106</sup>,  
 L.J. Levinson<sup>179</sup>, D.J. Lewis<sup>21</sup>, B. Li<sup>15b</sup>, B. Li<sup>106</sup>, C-Q. Li<sup>60a</sup>, F. Li<sup>60c</sup>, H. Li<sup>60a</sup>, H. Li<sup>60b</sup>, J. Li<sup>60c</sup>, K. Li<sup>147</sup>,  
 L. Li<sup>60c</sup>, M. Li<sup>15a,15d</sup>, Q. Li<sup>15a,15d</sup>, Q.Y. Li<sup>60a</sup>, S. Li<sup>60d,60c</sup>, X. Li<sup>46</sup>, Y. Li<sup>46</sup>, Z. Li<sup>60b</sup>, Z. Li<sup>104</sup>, Z. Liang<sup>15a</sup>,  
 B. Liberti<sup>74a</sup>, A. Liblong<sup>166</sup>, K. Lie<sup>63c</sup>, S. Lim<sup>29</sup>, C.Y. Lin<sup>32</sup>, K. Lin<sup>107</sup>, T.H. Lin<sup>100</sup>, R.A. Linck<sup>66</sup>,  
 R.E. Lindley<sup>7</sup>, J.H. Lindon<sup>21</sup>, A.L. Lioni<sup>54</sup>, E. Lipeles<sup>136</sup>, A. Lipniacka<sup>17</sup>, T.M. Liss<sup>172,am</sup>, A. Lister<sup>174</sup>,  
 J.D. Little<sup>8</sup>, B. Liu<sup>79</sup>, B.L. Liu<sup>6</sup>, H.B. Liu<sup>29</sup>, H. Liu<sup>106</sup>, J.B. Liu<sup>60a</sup>, J.K.K. Liu<sup>37</sup>, K. Liu<sup>60d</sup>, M. Liu<sup>60a</sup>,  
 P. Liu<sup>15a</sup>, Y. Liu<sup>46</sup>, Y. Liu<sup>15a,15d</sup>, Y.L. Liu<sup>106</sup>, Y.W. Liu<sup>60a</sup>, M. Livan<sup>71a,71b</sup>, A. Lleres<sup>58</sup>,  
 J. Llorente Merino<sup>151</sup>, S.L. Lloyd<sup>93</sup>, C.Y. Lo<sup>63b</sup>, E.M. Lobodzinska<sup>46</sup>, P. Loch<sup>7</sup>, S. Loffredo<sup>74a,74b</sup>,  
 T. Lohse<sup>19</sup>, K. Lohwasser<sup>148</sup>, M. Lokajicek<sup>140</sup>, J.D. Long<sup>172</sup>, R.E. Long<sup>90</sup>, L. Longo<sup>36</sup>, K.A. Looper<sup>127</sup>,  
 I. Lopez Paz<sup>101</sup>, A. Lopez Solis<sup>148</sup>, J. Lorenz<sup>114</sup>, N. Lorenzo Martinez<sup>5</sup>, A.M. Lory<sup>114</sup>, P.J. Lösel<sup>114</sup>,  
 A. Lösle<sup>52</sup>, X. Lou<sup>46</sup>, X. Lou<sup>15a</sup>, A. Lounis<sup>65</sup>, J. Love<sup>6</sup>, P.A. Love<sup>90</sup>, J.J. Lozano Bahilo<sup>173</sup>, M. Lu<sup>60a</sup>,  
 Y.J. Lu<sup>64</sup>, H.J. Lubatti<sup>147</sup>, C. Luci<sup>73a,73b</sup>, A. Lucotte<sup>58</sup>, C. Luedtke<sup>52</sup>, F. Luehring<sup>66</sup>, I. Luise<sup>135</sup>,  
 L. Luminari<sup>73a</sup>, B. Lund-Jensen<sup>153</sup>, M.S. Lutz<sup>103</sup>, D. Lynn<sup>29</sup>, H. Lyons<sup>91</sup>, R. Lysak<sup>140</sup>, E. Lytken<sup>97</sup>,  
 F. Lyu<sup>15a</sup>, V. Lyubushkin<sup>80</sup>, T. Lyubushkina<sup>80</sup>, H. Ma<sup>29</sup>, L.L. Ma<sup>60b</sup>, Y. Ma<sup>95</sup>, G. Maccarrone<sup>51</sup>,  
 A. Macchiolo<sup>115</sup>, C.M. Macdonald<sup>148</sup>, J. Machado Miguens<sup>136</sup>, D. Madaffari<sup>173</sup>, R. Madar<sup>38</sup>,  
 W.F. Mader<sup>48</sup>, M. Madugoda Ralalage Don<sup>129</sup>, N. Madysa<sup>48</sup>, J. Maeda<sup>83</sup>, T. Maeno<sup>29</sup>, M. Maerker<sup>48</sup>,  
 V. Magerl<sup>52</sup>, N. Magini<sup>79</sup>, J. Magro<sup>67a,67c,r</sup>, D.J. Mahon<sup>39</sup>, C. Maidantchik<sup>81b</sup>, T. Maier<sup>114</sup>,  
 A. Maio<sup>139a,139b,139d</sup>, K. Maj<sup>84a</sup>, O. Majersky<sup>28a</sup>, S. Majewski<sup>131</sup>, Y. Makida<sup>82</sup>, N. Makovec<sup>65</sup>,  
 B. Malaescu<sup>135</sup>, Pa. Malecki<sup>85</sup>, V.P. Maleev<sup>137</sup>, F. Malek<sup>58</sup>, U. Mallik<sup>78</sup>, D. Malon<sup>6</sup>, C. Malone<sup>32</sup>,  
 S. Maltezos<sup>10</sup>, S. Malyukov<sup>80</sup>, J. Mamuzic<sup>173</sup>, G. Mancini<sup>51</sup>, I. Mandić<sup>92</sup>,  
 L. Manhaes de Andrade Filho<sup>81a</sup>, I.M. Maniatis<sup>161</sup>, J. Manjarres Ramos<sup>48</sup>, K.H. Mankinen<sup>97</sup>, A. Mann<sup>114</sup>,  
 A. Manousos<sup>77</sup>, B. Mansoulie<sup>144</sup>, I. Manthos<sup>161</sup>, S. Manzoni<sup>120</sup>, A. Marantis<sup>161</sup>, G. Marceca<sup>30</sup>,  
 L. Marchese<sup>134</sup>, G. Marchiori<sup>135</sup>, M. Marcisovsky<sup>140</sup>, L. Marcocchia<sup>74a,74b</sup>, C. Marcon<sup>97</sup>,  
 C.A. Marin Tobon<sup>36</sup>, M. Marjanovic<sup>128</sup>, Z. Marshall<sup>18</sup>, M.U.F. Martensson<sup>171</sup>, S. Marti-Garcia<sup>173</sup>,  
 C.B. Martin<sup>127</sup>, T.A. Martin<sup>177</sup>, V.J. Martin<sup>50</sup>, B. Martin dit Latour<sup>17</sup>, L. Martinelli<sup>75a,75b</sup>, M. Martinez<sup>14,x</sup>,  
 V.I. Martinez Outschoorn<sup>103</sup>, S. Martin-Haugh<sup>143</sup>, V.S. Martoiu<sup>27b</sup>, A.C. Martyniuk<sup>95</sup>, A. Marzin<sup>36</sup>,  
 S.R. Maschek<sup>115</sup>, L. Masetti<sup>100</sup>, T. Mashimo<sup>162</sup>, R. Mashinistov<sup>111</sup>, J. Masik<sup>101</sup>, A.L. Maslennikov<sup>122b,122a</sup>,  
 L. Massa<sup>23b,23a</sup>, P. Massarotti<sup>70a,70b</sup>, P. Mastrandrea<sup>72a,72b</sup>, A. Mastroberardino<sup>41b,41a</sup>, T. Masubuchi<sup>162</sup>,  
 D. Matakias<sup>29</sup>, A. Matic<sup>114</sup>, N. Matsuzawa<sup>162</sup>, P. Mättig<sup>24</sup>, J. Maurer<sup>27b</sup>, B. Maček<sup>92</sup>,  
 D.A. Maximov<sup>122b,122a</sup>, R. Mazini<sup>157</sup>, I. Maznas<sup>161</sup>, S.M. Mazza<sup>145</sup>, S.P. Mc Kee<sup>106</sup>, T.G. McCarthy<sup>115</sup>,  
 W.P. McCormack<sup>18</sup>, E.F. McDonald<sup>105</sup>, J.A. Mcfayden<sup>36</sup>, G. Mchedlidze<sup>158b</sup>, M.A. McKay<sup>42</sup>,  
 K.D. McLean<sup>175</sup>, S.J. McMahon<sup>143</sup>, P.C. McNamara<sup>105</sup>, C.J. McNicol<sup>177</sup>, R.A. McPherson<sup>175,ac</sup>,  
 J.E. Mdhluli<sup>33e</sup>, Z.A. Meadows<sup>103</sup>, S. Meehan<sup>36</sup>, T. Megy<sup>38</sup>, S. Mehlhase<sup>114</sup>, A. Mehta<sup>91</sup>, T. Meideck<sup>58</sup>,  
 B. Meirose<sup>43</sup>, D. Melini<sup>159</sup>, B.R. Mellado Garcia<sup>33e</sup>, J.D. Mellenthin<sup>53</sup>, M. Melo<sup>28a</sup>, F. Meloni<sup>46</sup>,  
 A. Melzer<sup>24</sup>, S.B. Menary<sup>101</sup>, E.D. Mendes Gouveia<sup>139a,139e</sup>, L. Meng<sup>36</sup>, X.T. Meng<sup>106</sup>, S. Menke<sup>115</sup>,  
 E. Meoni<sup>41b,41a</sup>, S. Mergelmeyer<sup>19</sup>, S.A.M. Merkt<sup>138</sup>, C. Merlassino<sup>134</sup>, P. Mermod<sup>54</sup>, L. Merola<sup>70a,70b</sup>,  
 C. Meroni<sup>69a</sup>, G. Merz<sup>106</sup>, O. Meshkov<sup>113,111</sup>, J.K.R. Meshreki<sup>150</sup>, A. Messina<sup>73a,73b</sup>, J. Metcalfe<sup>6</sup>,  
 A.S. Mete<sup>6</sup>, C. Meyer<sup>66</sup>, J-P. Meyer<sup>144</sup>, H. Meyer Zu Theenhausen<sup>61a</sup>, F. Miano<sup>155</sup>, M. Michetti<sup>19</sup>,  
 R.P. Middleton<sup>143</sup>, L. Mijović<sup>50</sup>, G. Mikenberg<sup>179</sup>, M. Mikesikova<sup>140</sup>, M. Mikuž<sup>92</sup>, H. Mildner<sup>148</sup>,  
 M. Milesi<sup>105</sup>, A. Milic<sup>166</sup>, C.D. Milke<sup>42</sup>, D.W. Miller<sup>37</sup>, A. Milov<sup>179</sup>, D.A. Milstead<sup>45a,45b</sup>, R.A. Mina<sup>152</sup>,  
 A.A. Minaenko<sup>123</sup>, M. Miñano Moya<sup>173</sup>, I.A. Minashvili<sup>158b</sup>, A.I. Mincer<sup>125</sup>, B. Mindur<sup>84a</sup>, M. Mineev<sup>80</sup>,  
 Y. Minegishi<sup>162</sup>, L.M. Mir<sup>14</sup>, A. Mirto<sup>68a,68b</sup>, K.P. Mistry<sup>136</sup>, T. Mitani<sup>178</sup>, J. Mitrevski<sup>114</sup>, V.A. Mitsou<sup>173</sup>,  
 M. Mittal<sup>60c</sup>, O. Miu<sup>166</sup>, A. Miucci<sup>20</sup>, P.S. Miyagawa<sup>148</sup>, A. Mizukami<sup>82</sup>, J.U. Mjörnmark<sup>97</sup>,  
 T. Mkrtychyan<sup>61a</sup>, M. Mlynarikova<sup>142</sup>, T. Moa<sup>45a,45b</sup>, K. Mochizuki<sup>110</sup>, P. Mogg<sup>114</sup>, S. Mohapatra<sup>39</sup>,  
 R. Moles-Valls<sup>24</sup>, M.C. Mondragon<sup>107</sup>, K. Mönig<sup>46</sup>, J. Monk<sup>40</sup>, E. Monnier<sup>102</sup>, A. Montalbano<sup>151</sup>,  
 J. Montejo Berlingen<sup>36</sup>, M. Montella<sup>95</sup>, F. Monticelli<sup>89</sup>, S. Monzani<sup>69a</sup>, N. Morange<sup>65</sup>, D. Moreno<sup>22a</sup>,  
 M. Moreno Llácer<sup>173</sup>, C. Moreno Martinez<sup>14</sup>, P. Morettini<sup>55b</sup>, M. Morgenstern<sup>159</sup>, S. Morgenstern<sup>48</sup>,  
 D. Mori<sup>151</sup>, M. Morii<sup>59</sup>, M. Morinaga<sup>178</sup>, V. Morisbak<sup>133</sup>, A.K. Morley<sup>36</sup>, G. Mornacchi<sup>36</sup>, A.P. Morris<sup>95</sup>,  
 L. Morvaj<sup>154</sup>, P. Moschovakos<sup>36</sup>, B. Moser<sup>120</sup>, M. Mosidze<sup>158b</sup>, T. Moskalets<sup>144</sup>, H.J. Moss<sup>148</sup>,  
 J. Moss<sup>31,m</sup>, E.J.W. Moyse<sup>103</sup>, S. Muanza<sup>102</sup>, J. Mueller<sup>138</sup>, R.S.P. Mueller<sup>114</sup>, D. Muenstermann<sup>90</sup>,  
 G.A. Mullier<sup>97</sup>, D.P. Mungo<sup>69a,69b</sup>, J.L. Munoz Martinez<sup>14</sup>, F.J. Munoz Sanchez<sup>101</sup>, P. Murin<sup>28b</sup>,  
 W.J. Murray<sup>177,143</sup>, A. Murrone<sup>69a,69b</sup>, M. Muškinja<sup>18</sup>, C. Mwewa<sup>33a</sup>, A.G. Myagkov<sup>123,ah</sup>, A.A. Myers<sup>138</sup>,  
 J. Myers<sup>131</sup>, M. Myska<sup>141</sup>, B.P. Nachman<sup>18</sup>, O. Nackenhorst<sup>47</sup>, A. Nag Nag<sup>48</sup>, K. Nagai<sup>134</sup>, K. Nagano<sup>82</sup>,



Y. Nagasaka<sup>62</sup>, J.L. Nagle<sup>29</sup>, E. Nagy<sup>102</sup>, A.M. Nairz<sup>36</sup>, Y. Nakahama<sup>117</sup>, K. Nakamura<sup>82</sup>, T. Nakamura<sup>162</sup>,  
 H. Nanjo<sup>132</sup>, F. Napolitano<sup>61a</sup>, R.F. Naranjo Garcia<sup>46</sup>, R. Narayan<sup>42</sup>, I. Naryshkin<sup>137</sup>, T. Naumann<sup>46</sup>,  
 G. Navarro<sup>22a</sup>, P.Y. Nechaeva<sup>111</sup>, F. Nechansky<sup>46</sup>, T.J. Neep<sup>21</sup>, A. Negri<sup>71a,71b</sup>, M. Negrini<sup>23b</sup>,  
 C. Nellist<sup>119</sup>, M.E. Nelson<sup>45a,45b</sup>, S. Nemecek<sup>140</sup>, M. Nessi<sup>36,d</sup>, M.S. Neubauer<sup>172</sup>, F. Neuhaus<sup>100</sup>,  
 M. Neumann<sup>181</sup>, R. Newhouse<sup>174</sup>, P.R. Newman<sup>21</sup>, C.W. Ng<sup>138</sup>, Y.S. Ng<sup>19</sup>, Y.W.Y. Ng<sup>170</sup>, B. Ngair<sup>35e</sup>,  
 H.D.N. Nguyen<sup>102</sup>, T. Nguyen Manh<sup>110</sup>, E. Nibigira<sup>38</sup>, R.B. Nickerson<sup>134</sup>, R. Nicolaidou<sup>144</sup>, D.S. Nielsen<sup>40</sup>,  
 J. Nielsen<sup>145</sup>, N. Nikiforou<sup>11</sup>, V. Nikolaenko<sup>123,ah</sup>, I. Nikolic-Audit<sup>135</sup>, K. Nikolopoulos<sup>21</sup>, P. Nilsson<sup>29</sup>,  
 H.R. Nindhito<sup>54</sup>, Y. Ninomiya<sup>82</sup>, A. Nisati<sup>73a</sup>, N. Nishu<sup>60c</sup>, R. Nisius<sup>115</sup>, I. Nitsche<sup>47</sup>, T. Nitta<sup>178</sup>,  
 T. Nobe<sup>162</sup>, Y. Noguchi<sup>86</sup>, I. Nomidis<sup>135</sup>, M.A. Nomura<sup>29</sup>, M. Nordberg<sup>36</sup>, T. Novak<sup>92</sup>, O. Novgorodova<sup>48</sup>,  
 R. Novotny<sup>141</sup>, L. Nozka<sup>130</sup>, K. Ntekas<sup>170</sup>, E. Nurse<sup>95</sup>, F.G. Oakham<sup>34.an</sup>, H. Oberlack<sup>115</sup>, J. Ocariz<sup>135</sup>,  
 A. Ochi<sup>83</sup>, I. Ochoa<sup>39</sup>, J.P. Ochoa-Ricoux<sup>146a</sup>, K. O'Connor<sup>26</sup>, S. Oda<sup>88</sup>, S. Odaka<sup>82</sup>, S. Oerdek<sup>53</sup>,  
 A. Ogrodnik<sup>84a</sup>, A. Oh<sup>101</sup>, S.H. Oh<sup>49</sup>, C.C. Ohm<sup>153</sup>, H. Oide<sup>164</sup>, M.L. Ojeda<sup>166</sup>, H. Okawa<sup>168</sup>,  
 Y. Okazaki<sup>86</sup>, M.W. O'Keefe<sup>91</sup>, Y. Okumura<sup>162</sup>, T. Okuyama<sup>82</sup>, A. Olariu<sup>27b</sup>, L.F. Oleiro Seabra<sup>139a</sup>,  
 S.A. Olivares Pino<sup>146a</sup>, D. Oliveira Damazio<sup>29</sup>, J.L. Oliver<sup>1</sup>, M.J.R. Olsson<sup>170</sup>, A. Olszewski<sup>85</sup>,  
 J. Olszowska<sup>85</sup>, D.C. O'Neil<sup>151</sup>, A.P. O'Neill<sup>134</sup>, A. Onofre<sup>139a,139e</sup>, P.U.E. Onyisi<sup>11</sup>, H. Oppen<sup>133</sup>,  
 M.J. Oreglia<sup>37</sup>, G.E. Orellana<sup>89</sup>, D. Orestano<sup>75a,75b</sup>, N. Orlando<sup>14</sup>, R.S. Orr<sup>166</sup>, V. O'Shea<sup>57</sup>, R. Ospanov<sup>60a</sup>,  
 G. Otero y Garzon<sup>30</sup>, H. Otono<sup>88</sup>, P.S. Ott<sup>61a</sup>, G.J. Ottino<sup>18</sup>, M. Ouchrif<sup>35d</sup>, J. Ouellette<sup>29</sup>,  
 F. Ould-Saada<sup>133</sup>, A. Ouraou<sup>144</sup>, Q. Ouyang<sup>15a</sup>, M. Owen<sup>57</sup>, R.E. Owen<sup>21</sup>, V.E. Ozcan<sup>12c</sup>, N. Ozturk<sup>8</sup>,  
 J. Pacalt<sup>130</sup>, H.A. Pacey<sup>32</sup>, K. Pachal<sup>49</sup>, A. Pacheco Pages<sup>14</sup>, C. Padilla Aranda<sup>14</sup>, S. Pagan Griso<sup>18</sup>,  
 M. Paganini<sup>182</sup>, G. Palacino<sup>66</sup>, S. Palazzo<sup>50</sup>, S. Palestini<sup>36</sup>, M. Palka<sup>84b</sup>, D. Pallin<sup>38</sup>, P. Palni<sup>84a</sup>,  
 I. Panagoulas<sup>10</sup>, C.E. Pandini<sup>36</sup>, J.G. Panduro Vazquez<sup>94</sup>, P. Pani<sup>46</sup>, G. Panizzo<sup>67a,67c</sup>, L. Paolozzi<sup>54</sup>,  
 C. Papadatos<sup>110</sup>, K. Papageorgiou<sup>9,g</sup>, S. Parajuli<sup>42</sup>, A. Paramonov<sup>6</sup>, D. Paredes Hernandez<sup>63b</sup>,  
 S.R. Paredes Saenz<sup>134</sup>, B. Parida<sup>165</sup>, T.H. Park<sup>166</sup>, A.J. Parker<sup>31</sup>, M.A. Parker<sup>32</sup>, F. Parodi<sup>55b,55a</sup>,  
 E.W. Parrish<sup>121</sup>, J.A. Parsons<sup>39</sup>, U. Parzefall<sup>52</sup>, L. Pascual Dominguez<sup>135</sup>, V.R. Pascuzzi<sup>18</sup>,  
 J.M.P. Pasner<sup>145</sup>, F. Pasquali<sup>120</sup>, E. Pasqualucci<sup>73a</sup>, S. Passaggio<sup>55b</sup>, F. Pastore<sup>94</sup>, P. Pasuwan<sup>45a,45b</sup>,  
 S. Patariaia<sup>100</sup>, J.R. Pater<sup>101</sup>, A. Pathak<sup>180,i</sup>, J. Patton<sup>91</sup>, T. Pauly<sup>36</sup>, J. Pearkes<sup>152</sup>, B. Pearson<sup>115</sup>,  
 M. Pedersen<sup>133</sup>, L. Pedraza Diaz<sup>119</sup>, R. Pedro<sup>139a</sup>, T. Peiffer<sup>53</sup>, S.V. Peleganchuk<sup>122b,122a</sup>, O. Penc<sup>140</sup>,  
 H. Peng<sup>60a</sup>, B.S. Peralva<sup>81a</sup>, M.M. Perego<sup>65</sup>, A.P. Pereira Peixoto<sup>139a</sup>, L. Pereira Sanchez<sup>45a,45b</sup>,  
 D.V. Perepelitsa<sup>29</sup>, F. Peri<sup>19</sup>, L. Perini<sup>69a,69b</sup>, H. Pernegger<sup>36</sup>, S. Perrella<sup>139a</sup>, A. Perrevoort<sup>120</sup>,  
 K. Peters<sup>46</sup>, R.F.Y. Peters<sup>101</sup>, B.A. Petersen<sup>36</sup>, T.C. Petersen<sup>40</sup>, E. Petit<sup>102</sup>, A. Petridis<sup>1</sup>, C. Petridou<sup>161</sup>,  
 P. Petroff<sup>65</sup>, F. Petrucci<sup>75a,75b</sup>, M. Pettee<sup>182</sup>, N.E. Pettersson<sup>103</sup>, K. Petukhova<sup>142</sup>, A. Peyaud<sup>144</sup>,  
 R. Pezoa<sup>146d</sup>, L. Pezzotti<sup>71a,71b</sup>, T. Pham<sup>105</sup>, F.H. Phillips<sup>107</sup>, P.W. Phillips<sup>143</sup>, M.W. Phipps<sup>172</sup>,  
 G. Piacquadio<sup>154</sup>, E. Pianori<sup>18</sup>, A. Picazio<sup>103</sup>, R.H. Pickles<sup>101</sup>, R. Piegai<sup>30</sup>, D. Pietreanu<sup>27b</sup>, J.E. Pilcher<sup>37</sup>,  
 A.D. Pilkington<sup>101</sup>, M. Pinamonti<sup>67a,67c</sup>, J.L. Pinfold<sup>3</sup>, C. Pitman Donaldson<sup>95</sup>, M. Pitt<sup>160</sup>,  
 L. Pizzimento<sup>74a,74b</sup>, M.-A. Pleier<sup>29</sup>, V. Pleskot<sup>142</sup>, E. Plotnikova<sup>80</sup>, P. Podberezko<sup>122b,122a</sup>, R. Poettgen<sup>97</sup>,  
 R. Poggi<sup>54</sup>, L. Poggioli<sup>135</sup>, I. Pogrebnyak<sup>107</sup>, D. Pohl<sup>24</sup>, I. Pokharel<sup>53</sup>, G. Polesello<sup>71a</sup>, A. Poley<sup>18</sup>,  
 A. Policicchio<sup>73a,73b</sup>, R. Polifka<sup>142</sup>, A. Polini<sup>23b</sup>, C.S. Pollard<sup>46</sup>, V. Polychronakos<sup>29</sup>, D. Ponomarenko<sup>112</sup>,  
 L. Pontecorvo<sup>36</sup>, S. Popa<sup>27a</sup>, G.A. Popeneciu<sup>27d</sup>, L. Portales<sup>5</sup>, D.M. Portillo Quintero<sup>58</sup>, S. Pospisil<sup>141</sup>,  
 K. Potamianos<sup>46</sup>, I.N. Potrap<sup>80</sup>, C.J. Potter<sup>32</sup>, H. Potti<sup>11</sup>, T. Poulsen<sup>97</sup>, J. Poveda<sup>36</sup>, T.D. Powell<sup>148</sup>,  
 G. Pownall<sup>46</sup>, M.E. Pozo Astigarraga<sup>36</sup>, P. Pralavorio<sup>102</sup>, S. Prell<sup>79</sup>, D. Price<sup>101</sup>, M. Primavera<sup>68a</sup>,  
 S. Prince<sup>104</sup>, M.L. Proffitt<sup>147</sup>, N. Proklova<sup>112</sup>, K. Prokofiev<sup>63c</sup>, F. Prokoshin<sup>80</sup>, S. Protopopescu<sup>29</sup>,  
 J. Proudfoot<sup>6</sup>, M. Przybycien<sup>84a</sup>, D. Pudzha<sup>137</sup>, A. Puri<sup>172</sup>, P. Puzo<sup>65</sup>, J. Qian<sup>106</sup>, Y. Qin<sup>101</sup>, A. Quadt<sup>53</sup>,  
 M. Queitsch-Maitland<sup>36</sup>, A. Qureshi<sup>1</sup>, M. Racko<sup>28a</sup>, F. Ragusa<sup>69a,69b</sup>, G. Rahal<sup>98</sup>, J.A. Raine<sup>54</sup>,  
 S. Rajagopalan<sup>29</sup>, A. Ramirez Morales<sup>93</sup>, K. Ran<sup>15a,15d</sup>, T. Rashid<sup>65</sup>, S. Raspopov<sup>5</sup>, D.M. Rauch<sup>46</sup>,  
 F. Rauscher<sup>114</sup>, S. Rave<sup>100</sup>, B. Ravina<sup>148</sup>, I. Ravinovich<sup>179</sup>, J.H. Rawling<sup>101</sup>, M. Raymond<sup>36</sup>, A.L. Read<sup>133</sup>,  
 N.P. Readioff<sup>58</sup>, M. Reale<sup>68a,68b</sup>, D.M. Rebuffi<sup>71a,71b</sup>, G. Redlinger<sup>29</sup>, K. Reeves<sup>43</sup>, L. Rehnisch<sup>19</sup>,  
 J. Reichert<sup>136</sup>, D. Reikher<sup>160</sup>, A. Reiss<sup>100</sup>, A. Rej<sup>150</sup>, C. Rembser<sup>36</sup>, A. Renardi<sup>46</sup>, M. Renda<sup>27b</sup>,  
 M. Rescigno<sup>73a</sup>, S. Resconi<sup>69a</sup>, E.D. Resseguie<sup>18</sup>, S. Rettie<sup>95</sup>, B. Reynolds<sup>127</sup>, E. Reynolds<sup>21</sup>,  
 O.L. Rezanova<sup>122b,122a</sup>, P. Reznicek<sup>142</sup>, E. Ricci<sup>76a,76b</sup>, R. Richter<sup>115</sup>, S. Richter<sup>46</sup>, E. Richter-Was<sup>84b</sup>,  
 O. Ricken<sup>24</sup>, M. Ridel<sup>135</sup>, P. Rieck<sup>115</sup>, O. Rifki<sup>46</sup>, M. Rijssenbeek<sup>154</sup>, A. Rimoldi<sup>71a,71b</sup>, M. Rimoldi<sup>46</sup>,  
 L. Rinaldi<sup>23b</sup>, G. Ripellino<sup>153</sup>, I. Riu<sup>14</sup>, J.C. Rivera Vergara<sup>175</sup>, F. Rizatdinova<sup>129</sup>, E. Rizvi<sup>93</sup>, C. Rizzi<sup>36</sup>,  
 R.T. Roberts<sup>101</sup>, S.H. Robertson<sup>104,ac</sup>, M. Robin<sup>46</sup>, D. Robinson<sup>32</sup>, C.M. Robles Gajardo<sup>146d</sup>,  
 M. Robles Manzano<sup>100</sup>, A. Robson<sup>57</sup>, A. Rocchi<sup>74a,74b</sup>, E. Rocco<sup>100</sup>, C. Roda<sup>72a,72b</sup>, S. Rodriguez Bosca<sup>173</sup>,

A. Rodriguez Perez <sup>14</sup>, D. Rodriguez Rodriguez <sup>173</sup>, A.M. Rodríguez Vera <sup>167b</sup>, S. Roe <sup>36</sup>, O. Røhne <sup>133</sup>,  
 R. Röhrig <sup>115</sup>, R.A. Rojas <sup>146d</sup>, B. Roland <sup>52</sup>, C.P.A. Roland <sup>66</sup>, J. Roloff <sup>29</sup>, A. Romaniouk <sup>112</sup>,  
 M. Romano <sup>23b,23a</sup>, N. Rompotis <sup>91</sup>, M. Ronzani <sup>125</sup>, L. Roos <sup>135</sup>, S. Rosati <sup>73a</sup>, G. Rosin <sup>103</sup>, B.J. Rosser <sup>136</sup>,  
 E. Rossi <sup>46</sup>, E. Rossi <sup>75a,75b</sup>, E. Rossi <sup>70a,70b</sup>, L.P. Rossi <sup>55b</sup>, L. Rossini <sup>69a,69b</sup>, R. Rosten <sup>14</sup>, M. Rotaru <sup>27b</sup>,  
 B. Rottler <sup>52</sup>, D. Rousseau <sup>65</sup>, G. Rovelli <sup>71a,71b</sup>, A. Roy <sup>11</sup>, D. Roy <sup>33e</sup>, A. Rozanov <sup>102</sup>, Y. Rozen <sup>159</sup>,  
 X. Ruan <sup>33e</sup>, F. Rühr <sup>52</sup>, A. Ruiz-Martinez <sup>173</sup>, A. Rummler <sup>36</sup>, Z. Rurikova <sup>52</sup>, N.A. Rusakovich <sup>80</sup>,  
 H.L. Russell <sup>104</sup>, L. Rustige <sup>38,47</sup>, J.P. Rutherford <sup>7</sup>, E.M. Rüttinger <sup>148</sup>, M. Rybar <sup>39</sup>, G. Rybkin <sup>65</sup>,  
 E.B. Rye <sup>133</sup>, A. Ryzhov <sup>123</sup>, J.A. Sabater Iglesias <sup>46</sup>, P. Sabatini <sup>53</sup>, S. Sacerdoti <sup>65</sup>, H.F-W. Sadrozinski <sup>145</sup>,  
 R. Sadykov <sup>80</sup>, F. Safai Tehrani <sup>73a</sup>, B. Safarzadeh Samani <sup>155</sup>, M. Safdari <sup>152</sup>, P. Saha <sup>121</sup>, S. Saha <sup>104</sup>,  
 M. Sahinsoy <sup>61a</sup>, A. Sahu <sup>181</sup>, M. Saimpert <sup>36</sup>, M. Saito <sup>162</sup>, T. Saito <sup>162</sup>, H. Sakamoto <sup>162</sup>, D. Salamani <sup>54</sup>,  
 G. Salamanna <sup>75a,75b</sup>, J.E. Salazar Loyola <sup>146d</sup>, A. Salnikov <sup>152</sup>, J. Salt <sup>173</sup>, A. Salvador Salas <sup>14</sup>,  
 D. Salvatore <sup>41b,41a</sup>, F. Salvatore <sup>155</sup>, A. Salvucci <sup>63a,63b,63c</sup>, A. Salzburger <sup>36</sup>, J. Samarati <sup>36</sup>, D. Sammel <sup>52</sup>,  
 D. Sampsonidis <sup>161</sup>, D. Sampsonidou <sup>161</sup>, J. Sánchez <sup>173</sup>, A. Sanchez Pineda <sup>67a,36,67c</sup>, H. Sandaker <sup>133</sup>,  
 C.O. Sander <sup>46</sup>, I.G. Sanderswood <sup>90</sup>, M. Sandhoff <sup>181</sup>, C. Sandoval <sup>22a</sup>, D.P.C. Sankey <sup>143</sup>, M. Sannino <sup>55b,55a</sup>,  
 Y. Sano <sup>117</sup>, A. Sansoni <sup>51</sup>, C. Santoni <sup>38</sup>, H. Santos <sup>139a,139b</sup>, S.N. Santpur <sup>18</sup>, A. Santra <sup>173</sup>, A. Saprosov <sup>80</sup>,  
 J.G. Saraiva <sup>139a,139d</sup>, O. Sasaki <sup>82</sup>, K. Sato <sup>168</sup>, F. Sauerburger <sup>52</sup>, E. Sauvan <sup>5</sup>, P. Savard <sup>166,an</sup>, R. Sawada <sup>162</sup>,  
 C. Sawyer <sup>143</sup>, L. Sawyer <sup>96,ag</sup>, C. Sbarra <sup>23b</sup>, A. Sbrizzi <sup>23a</sup>, T. Scanlon <sup>95</sup>, J. Schaarschmidt <sup>147</sup>, P. Schacht <sup>115</sup>,  
 B.M. Schachtner <sup>114</sup>, D. Schaefer <sup>37</sup>, L. Schaefer <sup>136</sup>, J. Schaeffer <sup>100</sup>, S. Schaepe <sup>36</sup>, U. Schäfer <sup>100</sup>,  
 A.C. Schaffer <sup>65</sup>, D. Schaile <sup>114</sup>, R.D. Schamberger <sup>154</sup>, N. Scharmberg <sup>101</sup>, V.A. Schegelsky <sup>137</sup>,  
 D. Scheirich <sup>142</sup>, F. Schenck <sup>19</sup>, M. Schernau <sup>170</sup>, C. Schiavi <sup>55b,55a</sup>, L.K. Schildgen <sup>24</sup>, Z.M. Schillaci <sup>26</sup>,  
 E.J. Schioppa <sup>68a,68b</sup>, M. Schioppa <sup>41b,41a</sup>, K.E. Schleicher <sup>52</sup>, S. Schlenker <sup>36</sup>, K.R. Schmidt-Sommerfeld <sup>115</sup>,  
 K. Schmieden <sup>36</sup>, C. Schmitt <sup>100</sup>, S. Schmitt <sup>46</sup>, S. Schmitz <sup>100</sup>, J.C. Schmoeckel <sup>46</sup>, L. Schoeffel <sup>144</sup>,  
 A. Schoening <sup>61b</sup>, P.G. Scholer <sup>52</sup>, E. Schopf <sup>134</sup>, M. Schott <sup>100</sup>, J.F.P. Schouwenberg <sup>119</sup>, J. Schovancova <sup>36</sup>,  
 S. Schramm <sup>54</sup>, F. Schroeder <sup>181</sup>, A. Schulte <sup>100</sup>, H-C. Schultz-Coulon <sup>61a</sup>, M. Schumacher <sup>52</sup>,  
 B.A. Schumm <sup>145</sup>, Ph. Schune <sup>144</sup>, A. Schwartzman <sup>152</sup>, T.A. Schwarz <sup>106</sup>, Ph. Schwemling <sup>144</sup>,  
 R. Schwienhorst <sup>107</sup>, A. Sciandra <sup>145</sup>, G. Sciolla <sup>26</sup>, M. Scodreggio <sup>46</sup>, M. Scornajenghi <sup>41b,41a</sup>, F. Scuri <sup>72a</sup>,  
 F. Scutti <sup>105</sup>, L.M. Scyboz <sup>115</sup>, C.D. Sebastiani <sup>73a,73b</sup>, P. Seema <sup>19</sup>, S.C. Seidel <sup>118</sup>, A. Seiden <sup>145</sup>,  
 B.D. Seidlitz <sup>29</sup>, T. Seiss <sup>37</sup>, C. Seitz <sup>46</sup>, J.M. Seixas <sup>81b</sup>, G. Sekhniaidze <sup>70a</sup>, S.J. Sekula <sup>42</sup>,  
 N. Semprini-Cesari <sup>23b,23a</sup>, S. Sen <sup>49</sup>, C. Serfon <sup>77</sup>, L. Serin <sup>65</sup>, L. Serkin <sup>67a,67b</sup>, M. Sessa <sup>60a</sup>, H. Severini <sup>128</sup>,  
 S. Sevova <sup>152</sup>, F. Sforza <sup>55b,55a</sup>, A. Sfyrla <sup>54</sup>, E. Shabalina <sup>53</sup>, J.D. Shahinian <sup>145</sup>, N.W. Shaikh <sup>45a,45b</sup>,  
 D. Shaked Renous <sup>179</sup>, L.Y. Shan <sup>15a</sup>, M. Shapiro <sup>18</sup>, A. Sharma <sup>134</sup>, A.S. Sharma <sup>1</sup>, P.B. Shatalov <sup>124</sup>,  
 K. Shaw <sup>155</sup>, S.M. Shaw <sup>101</sup>, M. Shehade <sup>179</sup>, Y. Shen <sup>128</sup>, A.D. Sherman <sup>25</sup>, P. Sherwood <sup>95</sup>, L. Shi <sup>157</sup>,  
 S. Shimizu <sup>82</sup>, C.O. Shimmin <sup>182</sup>, Y. Shimogama <sup>178</sup>, M. Shimojima <sup>116</sup>, I.P.J. Shipsey <sup>134</sup>, S. Shirabe <sup>164</sup>,  
 M. Shiyakova <sup>80,aa</sup>, J. Shlomi <sup>179</sup>, A. Shmeleva <sup>111</sup>, M.J. Shochet <sup>37</sup>, J. Shojaii <sup>105</sup>, D.R. Shope <sup>128</sup>,  
 S. Shrestha <sup>127</sup>, E.M. Shrif <sup>33e</sup>, E. Shulga <sup>179</sup>, P. Sicho <sup>140</sup>, A.M. Sickles <sup>172</sup>, P.E. Sidebo <sup>153</sup>,  
 E. Sideras Haddad <sup>33e</sup>, O. Sidiropoulou <sup>36</sup>, A. Sidoti <sup>23b,23a</sup>, F. Siegert <sup>48</sup>, Dj. Sijacki <sup>16</sup>, M.Jr. Silva <sup>180</sup>,  
 M.V. Silva Oliveira <sup>81a</sup>, S.B. Silverstein <sup>45a</sup>, S. Simion <sup>65</sup>, R. Simoniello <sup>100</sup>, C.J. Simpson-allso <sup>21</sup>,  
 S. Simsek <sup>12b</sup>, P. Sinervo <sup>166</sup>, V. Sinetckii <sup>113</sup>, S. Singh <sup>151</sup>, M. Sioli <sup>23b,23a</sup>, I. Siral <sup>131</sup>, S.Yu. Sivoklokov <sup>113</sup>,  
 J. Sjölin <sup>45a,45b</sup>, E. Skorda <sup>97</sup>, P. Skubic <sup>128</sup>, M. Slawinska <sup>85</sup>, K. Sliwa <sup>169</sup>, R. Slovak <sup>142</sup>, V. Smakhtin <sup>179</sup>,  
 B.H. Smart <sup>143</sup>, J. Smiesko <sup>28b</sup>, N. Smirnov <sup>112</sup>, S.Yu. Smirnov <sup>112</sup>, Y. Smirnov <sup>112</sup>, L.N. Smirnova <sup>113,s</sup>,  
 O. Smirnova <sup>97</sup>, J.W. Smith <sup>53</sup>, M. Smizanska <sup>90</sup>, K. Smolek <sup>141</sup>, A. Smykiewicz <sup>85</sup>, A.A. Snesarev <sup>111</sup>,  
 H.L. Snoek <sup>120</sup>, I.M. Snyder <sup>131</sup>, S. Snyder <sup>29</sup>, R. Sobie <sup>175,ac</sup>, A. Soffer <sup>160</sup>, A. Søgaard <sup>50</sup>, F. Sohns <sup>53</sup>,  
 C.A. Solans Sanchez <sup>36</sup>, E.Yu. Soldatov <sup>112</sup>, U. Soldevila <sup>173</sup>, A.A. Solodkov <sup>123</sup>, A. Soloshenko <sup>80</sup>,  
 O.V. Solovyanov <sup>123</sup>, V. Solovyev <sup>137</sup>, P. Sommer <sup>148</sup>, H. Son <sup>169</sup>, W. Song <sup>143</sup>, W.Y. Song <sup>167b</sup>, A. Sopczak <sup>141</sup>,  
 A.L. Soppio <sup>95</sup>, F. Sopkova <sup>28b</sup>, C.L. Sotiropoulou <sup>72a,72b</sup>, S. Sottocornola <sup>71a,71b</sup>, R. Soualah <sup>67a,67c,f</sup>,  
 A.M. Soukharev <sup>122b,122a</sup>, D. South <sup>46</sup>, S. Spagnolo <sup>68a,68b</sup>, M. Spalla <sup>115</sup>, M. Spangenberg <sup>177</sup>, F. Spanò <sup>94</sup>,  
 D. Sperlich <sup>52</sup>, T.M. Spieker <sup>61a</sup>, G. Spigo <sup>36</sup>, M. Spina <sup>155</sup>, D.P. Spiteri <sup>57</sup>, M. Spousta <sup>142</sup>, A. Stabile <sup>69a,69b</sup>,  
 B.L. Stamas <sup>121</sup>, R. Stamen <sup>61a</sup>, M. Stamenkovic <sup>120</sup>, E. Stanecka <sup>85</sup>, B. Stanislaus <sup>134</sup>, M.M. Stanitzki <sup>46</sup>,  
 M. Stankaityte <sup>134</sup>, B. Stapf <sup>120</sup>, E.A. Starchenko <sup>123</sup>, G.H. Stark <sup>145</sup>, J. Stark <sup>58</sup>, P. Staroba <sup>140</sup>,  
 P. Starovoitov <sup>61a</sup>, S. Stärz <sup>104</sup>, R. Staszewski <sup>85</sup>, G. Stavropoulos <sup>44</sup>, M. Stegler <sup>46</sup>, P. Steinberg <sup>29</sup>,  
 A.L. Steinhebel <sup>131</sup>, B. Stelzer <sup>151</sup>, H.J. Stelzer <sup>138</sup>, O. Stelzer-Chilton <sup>167a</sup>, H. Stenzel <sup>56</sup>, T.J. Stevenson <sup>155</sup>,  
 G.A. Stewart <sup>36</sup>, M.C. Stockton <sup>36</sup>, G. Stoica <sup>27b</sup>, M. Stolarski <sup>139a</sup>, S. Stonjek <sup>115</sup>, A. Straessner <sup>48</sup>,  
 J. Strandberg <sup>153</sup>, S. Strandberg <sup>45a,45b</sup>, M. Strauss <sup>128</sup>, P. Strizenec <sup>28b</sup>, R. Ströhmer <sup>176</sup>, D.M. Strom <sup>131</sup>,



R. Stroynowski<sup>42</sup>, A. Strubig<sup>50</sup>, S.A. Stucci<sup>29</sup>, B. Stugu<sup>17</sup>, J. Stupak<sup>128</sup>, N.A. Styles<sup>46</sup>, D. Su<sup>152</sup>, W. Su<sup>60c</sup>, S. Suchek<sup>61a</sup>, V.V. Sulin<sup>111</sup>, M.J. Sullivan<sup>91</sup>, D.M.S. Sultan<sup>54</sup>, S. Sultansoy<sup>4c</sup>, T. Sumida<sup>86</sup>, S. Sun<sup>106</sup>, X. Sun<sup>101</sup>, K. Suruliz<sup>155</sup>, C.J.E. Suster<sup>156</sup>, M.R. Sutton<sup>155</sup>, S. Suzuki<sup>82</sup>, M. Svatos<sup>140</sup>, M. Swiatlowski<sup>167a</sup>, S.P. Swift<sup>2</sup>, T. Swirski<sup>176</sup>, A. Sydorenko<sup>100</sup>, I. Sykora<sup>28a</sup>, M. Sykora<sup>142</sup>, T. Sykora<sup>142</sup>, D. Ta<sup>100</sup>, K. Tackmann<sup>46,y</sup>, J. Taenzer<sup>160</sup>, A. Taffard<sup>170</sup>, R. Tafirout<sup>167a</sup>, R. Takashima<sup>87</sup>, K. Takeda<sup>83</sup>, T. Takeshita<sup>149</sup>, E.P. Takeva<sup>50</sup>, Y. Takubo<sup>82</sup>, M. Talby<sup>102</sup>, A.A. Talyshev<sup>122b,122a</sup>, N.M. Tamir<sup>160</sup>, J. Tanaka<sup>162</sup>, R. Tanaka<sup>65</sup>, S. Tapia Araya<sup>172</sup>, S. Tapprogge<sup>100</sup>, A. Tarek Abouelfadl Mohamed<sup>107</sup>, S. Tarem<sup>159</sup>, K. Tariq<sup>60b</sup>, G. Tarna<sup>27b,c</sup>, G.F. Tartarelli<sup>69a</sup>, P. Tas<sup>142</sup>, M. Tasevsky<sup>140</sup>, T. Tashiro<sup>86</sup>, E. Tassi<sup>41b,41a</sup>, A. Tavares Delgado<sup>139a</sup>, Y. Tayalati<sup>35e</sup>, A.J. Taylor<sup>50</sup>, G.N. Taylor<sup>105</sup>, W. Taylor<sup>167b</sup>, H. Teagle<sup>91</sup>, A.S. Tee<sup>90</sup>, R. Teixeira De Lima<sup>152</sup>, P. Teixeira-Dias<sup>94</sup>, H. Ten Kate<sup>36</sup>, J.J. Teoh<sup>120</sup>, S. Terada<sup>82</sup>, K. Terashi<sup>162</sup>, J. Terron<sup>99</sup>, S. Terzo<sup>14</sup>, M. Testa<sup>51</sup>, R.J. Teuscher<sup>166,ac</sup>, S.J. Thais<sup>182</sup>, N. Themistokleous<sup>50</sup>, T. Theveneaux-Pelzer<sup>46</sup>, F. Thiele<sup>40</sup>, D.W. Thomas<sup>94</sup>, J.O. Thomas<sup>42</sup>, J.P. Thomas<sup>21</sup>, P.D. Thompson<sup>21</sup>, L.A. Thomsen<sup>182</sup>, E. Thomson<sup>136</sup>, E.J. Thorpe<sup>93</sup>, R.E. Ticse Torres<sup>53</sup>, V.O. Tikhomirov<sup>111,ai</sup>, Yu.A. Tikhonov<sup>122b,122a</sup>, S. Timoshenko<sup>112</sup>, P. Tipton<sup>182</sup>, S. Tisserant<sup>102</sup>, K. Todome<sup>23b,23a</sup>, S. Todorova-Nova<sup>142</sup>, S. Todt<sup>48</sup>, J. Tojo<sup>88</sup>, S. Tokár<sup>28a</sup>, K. Tokushuku<sup>82</sup>, E. Tolley<sup>127</sup>, K.G. Tomiwa<sup>33e</sup>, M. Tomoto<sup>117</sup>, L. Tompkins<sup>152</sup>, P. Tornambe<sup>103</sup>, E. Torrence<sup>131</sup>, H. Torres<sup>48</sup>, E. Torr o Pastor<sup>147</sup>, C. Toscir i<sup>134</sup>, J. Toth<sup>102,ab</sup>, D.R. Tovey<sup>148</sup>, A. Traeet<sup>17</sup>, C.J. Treado<sup>125</sup>, T. Trefzger<sup>176</sup>, F. Tresoldi<sup>155</sup>, A. Tricoli<sup>29</sup>, I.M. Trigger<sup>167a</sup>, S. Trincaz-Duvoid<sup>135</sup>, D.A. Trischuk<sup>174</sup>, W. Trischuk<sup>166</sup>, B. Trocm e<sup>58</sup>, A. Trofymov<sup>144</sup>, C. Troncon<sup>69a</sup>, F. Trovato<sup>155</sup>, L. Truong<sup>33c</sup>, M. Trzebinski<sup>85</sup>, A. Trzupek<sup>85</sup>, F. Tsai<sup>46</sup>, J.C-L. Tseng<sup>134</sup>, P.V. Tsiarehka<sup>108,af</sup>, A. Tsigirigotis<sup>161,v</sup>, V. Tsiskaridze<sup>154</sup>, E.G. Tskhadadze<sup>158a</sup>, M. Tsopoulou<sup>161</sup>, I.I. Tsukerman<sup>124</sup>, V. Tsulaia<sup>18</sup>, S. Tsuno<sup>82</sup>, D. Tsybychev<sup>154</sup>, Y. Tu<sup>63b</sup>, A. Tudorache<sup>27b</sup>, V. Tudorache<sup>27b</sup>, T.T. Tulbure<sup>27a</sup>, A.N. Tuna<sup>59</sup>, S. Turchikhin<sup>80</sup>, D. Turgeman<sup>179</sup>, I. Turk Cakir<sup>4b,t</sup>, R.J. Turner<sup>21</sup>, R.T. Turra<sup>69a</sup>, P.M. Tuts<sup>39</sup>, S. Tzamarias<sup>161</sup>, E. Tzovara<sup>100</sup>, G. Ucchielli<sup>47</sup>, K. Uchida<sup>162</sup>, F. Ukegawa<sup>168</sup>, G. Unal<sup>36</sup>, A. Undrus<sup>29</sup>, G. Unel<sup>170</sup>, F.C. Ungaro<sup>105</sup>, Y. Unno<sup>82</sup>, K. Uno<sup>162</sup>, J. Urban<sup>28b</sup>, P. Urquijo<sup>105</sup>, G. Usai<sup>8</sup>, Z. Uysal<sup>12d</sup>, V. Vacek<sup>141</sup>, B. Vachon<sup>104</sup>, K.O.H. Vadla<sup>133</sup>, A. Vaidya<sup>95</sup>, C. Valderanis<sup>114</sup>, E. Valdes Santurio<sup>45a,45b</sup>, M. Valente<sup>54</sup>, S. Valentinetti<sup>23b,23a</sup>, A. Valero<sup>173</sup>, L. Val ry<sup>46</sup>, R.A. Vallance<sup>21</sup>, A. Vallier<sup>36</sup>, J.A. Valls Ferrer<sup>173</sup>, T.R. Van Daalen<sup>14</sup>, P. Van Gemmeren<sup>6</sup>, I. Van Vulpen<sup>120</sup>, M. Vanadia<sup>74a,74b</sup>, W. Vandelli<sup>36</sup>, M. Vandembroucke<sup>144</sup>, E.R. Vandewall<sup>129</sup>, A. Vaniachine<sup>165</sup>, D. Vannicola<sup>73a,73b</sup>, R. Vari<sup>73a</sup>, E.W. Varnes<sup>7</sup>, C. Varni<sup>55b,55a</sup>, T. Varol<sup>157</sup>, D. Varouchas<sup>65</sup>, K.E. Varvell<sup>156</sup>, M.E. Vasile<sup>27b</sup>, G.A. Vasquez<sup>175</sup>, F. Vazeille<sup>38</sup>, D. Vazquez Furelos<sup>14</sup>, T. Vazquez Schroeder<sup>36</sup>, J. Veatch<sup>53</sup>, V. Vecchio<sup>75a,75b</sup>, M.J. Veen<sup>120</sup>, L.M. Veloce<sup>166</sup>, F. Veloso<sup>139a,139c</sup>, S. Veneziano<sup>73a</sup>, A. Ventura<sup>68a,68b</sup>, N. Venturi<sup>36</sup>, A. Verbytskyi<sup>115</sup>, V. Vercesi<sup>71a</sup>, M. Verducci<sup>72a,72b</sup>, C.M. Vergel Infante<sup>79</sup>, C. Vergis<sup>24</sup>, W. Verkerke<sup>120</sup>, A.T. Vermeulen<sup>120</sup>, J.C. Vermeulen<sup>120</sup>, C. Vernieri<sup>152</sup>, M.C. Vetterli<sup>151,an</sup>, N. Viaux Maira<sup>146d</sup>, T. Vickey<sup>148</sup>, O.E. Vickey Boeriu<sup>148</sup>, G.H.A. Viehhauser<sup>134</sup>, L. Vigani<sup>61b</sup>, M. Villa<sup>23b,23a</sup>, M. Villaplana Perez<sup>3</sup>, E. Vilucchi<sup>51</sup>, M.G. Vincter<sup>34</sup>, G.S. Virdee<sup>21</sup>, A. Vishwakarma<sup>46</sup>, C. Vittori<sup>23b,23a</sup>, I. Vivarelli<sup>155</sup>, M. Vogel<sup>181</sup>, P. Vokac<sup>141</sup>, S.E. von Buddenbrock<sup>33e</sup>, E. Von Toerne<sup>24</sup>, V. Vorobel<sup>142</sup>, K. Vorobev<sup>112</sup>, M. Vos<sup>173</sup>, J.H. Vosseveld<sup>91</sup>, M. Vozak<sup>101</sup>, N. Vranjes<sup>16</sup>, M. Vranjes Milosavljevic<sup>16</sup>, V. Vrba<sup>141</sup>, M. Vreeswijk<sup>120</sup>, R. Vuillermet<sup>36</sup>, I. Vukotic<sup>37</sup>, S. Wada<sup>168</sup>, P. Wagner<sup>24</sup>, W. Wagner<sup>181</sup>, J. Wagner-Kuhr<sup>114</sup>, S. Wahdan<sup>181</sup>, H. Wahlberg<sup>89</sup>, R. Wakasa<sup>168</sup>, V.M. Walbrecht<sup>115</sup>, J. Walder<sup>90</sup>, R. Walker<sup>114</sup>, S.D. Walker<sup>94</sup>, W. Walkowiak<sup>150</sup>, V. Wallangen<sup>45a,45b</sup>, A.M. Wang<sup>59</sup>, A.Z. Wang<sup>180</sup>, C. Wang<sup>60c</sup>, F. Wang<sup>180</sup>, H. Wang<sup>18</sup>, H. Wang<sup>3</sup>, J. Wang<sup>63a</sup>, J. Wang<sup>61b</sup>, P. Wang<sup>42</sup>, Q. Wang<sup>128</sup>, R.-J. Wang<sup>100</sup>, R. Wang<sup>60a</sup>, R. Wang<sup>6</sup>, S.M. Wang<sup>157</sup>, W.T. Wang<sup>60a</sup>, W. Wang<sup>15c</sup>, W.X. Wang<sup>60a</sup>, Y. Wang<sup>60a</sup>, Z. Wang<sup>60c</sup>, C. Wanotayaraj<sup>46</sup>, A. Warburton<sup>104</sup>, C.P. Ward<sup>32</sup>, D.R. Wardrope<sup>95</sup>, N. Warrack<sup>57</sup>, A. Washbrook<sup>50</sup>, A.T. Watson<sup>21</sup>, M.F. Watson<sup>21</sup>, G. Watts<sup>147</sup>, B.M. Waugh<sup>95</sup>, A.F. Webb<sup>11</sup>, C. Weber<sup>182</sup>, M.S. Weber<sup>20</sup>, S.A. Weber<sup>34</sup>, S.M. Weber<sup>61a</sup>, A.R. Weidberg<sup>134</sup>, J. Weingarten<sup>47</sup>, M. Weirich<sup>100</sup>, C. Weiser<sup>52</sup>, P.S. Wells<sup>36</sup>, T. Wenaus<sup>29</sup>, T. Wengler<sup>36</sup>, S. Wenig<sup>36</sup>, N. Wermes<sup>24</sup>, M.D. Werner<sup>79</sup>, M. Wessels<sup>61a</sup>, T.D. Weston<sup>20</sup>, K. Whalen<sup>131</sup>, N.L. Whallon<sup>147</sup>, A.M. Wharton<sup>90</sup>, A.S. White<sup>106</sup>, A. White<sup>8</sup>, M.J. White<sup>1</sup>, D. Whiteson<sup>170</sup>, B.W. Whitmore<sup>90</sup>, W. Wiedenmann<sup>180</sup>, C. Wiel<sup>48</sup>, M. Wielers<sup>143</sup>, N. Wieseotte<sup>100</sup>, C. Wigglesworth<sup>40</sup>, L.A.M. Wiik-Fuchs<sup>52</sup>, H.G. Wilkens<sup>36</sup>, L.J. Wilkins<sup>94</sup>, H.H. Williams<sup>136</sup>, S. Williams<sup>32</sup>, C. Willis<sup>107</sup>, S. Willocq<sup>103</sup>, I. Wingerter-Seez<sup>5</sup>, E. Winkels<sup>155</sup>, F. Winklmeier<sup>131</sup>, B.T. Winter<sup>52</sup>, M. Wittgen<sup>152</sup>, M. Wobisch<sup>96</sup>, A. Wolf<sup>100</sup>, T.M.H. Wolf<sup>120</sup>, R. Wolff<sup>102</sup>, R. W lker<sup>134</sup>, J. Wollrath<sup>52</sup>, M.W. Wolter<sup>85</sup>, H. Wolters<sup>139a,139c</sup>, V.W.S. Wong<sup>174</sup>, N.L. Woods<sup>145</sup>, S.D. Worm<sup>46</sup>, B.K. Wosiek<sup>85</sup>, K.W. Woźniak<sup>85</sup>,

K. Wraight<sup>57</sup>, S.L. Wu<sup>180</sup>, X. Wu<sup>54</sup>, Y. Wu<sup>60a</sup>, T.R. Wyatt<sup>101</sup>, B.M. Wynne<sup>50</sup>, S. Xella<sup>40</sup>, Z. Xi<sup>106</sup>, L. Xia<sup>177</sup>, X. Xiao<sup>106</sup>, I. Xiolidis<sup>155</sup>, D. Xu<sup>15a</sup>, H. Xu<sup>60a</sup>, H. Xu<sup>60a</sup>, L. Xu<sup>29</sup>, T. Xu<sup>144</sup>, W. Xu<sup>106</sup>, Z. Xu<sup>60b</sup>, Z. Xu<sup>152</sup>, B. Yabsley<sup>156</sup>, S. Yacoub<sup>33a</sup>, K. Yajima<sup>132</sup>, D.P. Yallup<sup>95</sup>, N. Yamaguchi<sup>88</sup>, Y. Yamaguchi<sup>164</sup>, A. Yamamoto<sup>82</sup>, M. Yamatani<sup>162</sup>, T. Yamazaki<sup>162</sup>, Y. Yamazaki<sup>83</sup>, J. Yan<sup>60c</sup>, Z. Yan<sup>25</sup>, H.J. Yang<sup>60c,60d</sup>, H.T. Yang<sup>18</sup>, S. Yang<sup>60a</sup>, T. Yang<sup>63c</sup>, X. Yang<sup>60b,58</sup>, Y. Yang<sup>162</sup>, Z. Yang<sup>60a</sup>, W.-M. Yao<sup>18</sup>, Y.C. Yap<sup>46</sup>, Y. Yasu<sup>82</sup>, E. Yatsenko<sup>60c,60d</sup>, H. Ye<sup>15c</sup>, J. Ye<sup>42</sup>, S. Ye<sup>29</sup>, I. Yeletsikh<sup>80</sup>, M.R. Yexley<sup>90</sup>, E. Yigitbasi<sup>25</sup>, K. Yorita<sup>178</sup>, K. Yoshihara<sup>79</sup>, C.J.S. Young<sup>36</sup>, C. Young<sup>152</sup>, J. Yu<sup>79</sup>, R. Yuan<sup>60b,h</sup>, X. Yue<sup>61a</sup>, M. Zaazoua<sup>35e</sup>, B. Zabinski<sup>85</sup>, G. Zacharis<sup>10</sup>, E. Zaffaroni<sup>54</sup>, J. Zahreddine<sup>135</sup>, A.M. Zaitsev<sup>123,ah</sup>, T. Zakareishvili<sup>158b</sup>, N. Zakharchuk<sup>34</sup>, S. Zambito<sup>59</sup>, D. Zanzi<sup>36</sup>, D.R. Zaripovas<sup>57</sup>, S.V. Zeißner<sup>47</sup>, C. Zeitnitz<sup>181</sup>, G. Zemaityte<sup>134</sup>, J.C. Zeng<sup>172</sup>, O. Zenin<sup>123</sup>, T. Ženiš<sup>28a</sup>, D. Zerwas<sup>65</sup>, M. Zgubič<sup>134</sup>, B. Zhang<sup>15c</sup>, D.F. Zhang<sup>15b</sup>, G. Zhang<sup>15b</sup>, H. Zhang<sup>15c</sup>, J. Zhang<sup>6</sup>, Kaili Zhang<sup>15a</sup>, L. Zhang<sup>15c</sup>, L. Zhang<sup>60a</sup>, M. Zhang<sup>172</sup>, R. Zhang<sup>180</sup>, S. Zhang<sup>106</sup>, X. Zhang<sup>60c</sup>, X. Zhang<sup>60b</sup>, Y. Zhang<sup>15a,15d</sup>, Z. Zhang<sup>63a</sup>, Z. Zhang<sup>65</sup>, P. Zhao<sup>49</sup>, Z. Zhao<sup>60a</sup>, A. Zhemchugov<sup>80</sup>, Z. Zheng<sup>106</sup>, D. Zhong<sup>172</sup>, B. Zhou<sup>106</sup>, C. Zhou<sup>180</sup>, H. Zhou<sup>7</sup>, M.S. Zhou<sup>15a,15d</sup>, M. Zhou<sup>154</sup>, N. Zhou<sup>60c</sup>, Y. Zhou<sup>7</sup>, C.G. Zhu<sup>60b</sup>, C. Zhu<sup>15a,15d</sup>, H.L. Zhu<sup>60a</sup>, H. Zhu<sup>15a</sup>, J. Zhu<sup>106</sup>, Y. Zhu<sup>60a</sup>, X. Zhuang<sup>15a</sup>, K. Zhukov<sup>111</sup>, V. Zhulanov<sup>122b,122a</sup>, D. Zieminska<sup>66</sup>, N.I. Zimine<sup>80</sup>, S. Zimmermann<sup>52</sup>, Z. Zinonos<sup>115</sup>, M. Ziolkowski<sup>150</sup>, L. Živković<sup>16</sup>, G. Zobernig<sup>180</sup>, A. Zoccoli<sup>23b,23a</sup>, K. Zoch<sup>53</sup>, T.G. Zorbas<sup>148</sup>, R. Zou<sup>37</sup>, L. Zwalinski<sup>36</sup>

<sup>1</sup> Department of Physics, University of Adelaide, Adelaide; Australia

<sup>2</sup> Physics Department, SUNY Albany, Albany NY; United States of America

<sup>3</sup> Department of Physics, University of Alberta, Edmonton AB; Canada

<sup>4</sup> (a) Department of Physics, Ankara University, Ankara; (b) Istanbul Aydin University, Application and Research Center for Advanced Studies, Istanbul; (c) Division of Physics, TOBB University of Economics and Technology, Ankara; Turkey

<sup>5</sup> LAPP, Université Grenoble Alpes, Université Savoie Mont Blanc, CNRS/IN2P3, Annecy; France

<sup>6</sup> High Energy Physics Division, Argonne National Laboratory, Argonne IL; United States of America

<sup>7</sup> Department of Physics, University of Arizona, Tucson AZ; United States of America

<sup>8</sup> Department of Physics, University of Texas at Arlington, Arlington TX; United States of America

<sup>9</sup> Physics Department, National and Kapodistrian University of Athens, Athens; Greece

<sup>10</sup> Physics Department, National Technical University of Athens, Zografou; Greece

<sup>11</sup> Department of Physics, University of Texas at Austin, Austin TX; United States of America

<sup>12</sup> (a) Bahcesehir University, Faculty of Engineering and Natural Sciences, Istanbul; (b) Istanbul Bilgi University, Faculty of Engineering and Natural Sciences, Istanbul; (c) Department of Physics, Bogazici University, Istanbul; (d) Department of Physics Engineering, Gaziantep University, Gaziantep; Turkey

<sup>13</sup> Institute of Physics, Azerbaijan Academy of Sciences, Baku; Azerbaijan

<sup>14</sup> Institut de Física d'Altes Energies (IFAE), Barcelona Institute of Science and Technology, Barcelona; Spain

<sup>15</sup> (a) Institute of High Energy Physics, Chinese Academy of Sciences, Beijing; (b) Physics Department, Tsinghua University, Beijing; (c) Department of Physics, Nanjing University, Nanjing;

(d) University of Chinese Academy of Science (UCAS), Beijing; China

<sup>16</sup> Institute of Physics, University of Belgrade, Belgrade; Serbia

<sup>17</sup> Department for Physics and Technology, University of Bergen, Bergen; Norway

<sup>18</sup> Physics Division, Lawrence Berkeley National Laboratory and University of California, Berkeley CA; United States of America

<sup>19</sup> Institut für Physik, Humboldt Universität zu Berlin, Berlin; Germany

<sup>20</sup> Albert Einstein Center for Fundamental Physics and Laboratory for High Energy Physics, University of Bern, Bern; Switzerland

<sup>21</sup> School of Physics and Astronomy, University of Birmingham, Birmingham; United Kingdom

<sup>22</sup> (a) Facultad de Ciencias y Centro de Investigaciones, Universidad Antonio Nariño, Bogotá; (b) Departamento de Física, Universidad Nacional de Colombia, Bogotá; Colombia

<sup>23</sup> (a) INFN Bologna and Università di Bologna, Dipartimento di Fisica; (b) INFN Sezione di Bologna; Italy

<sup>24</sup> Physikalisches Institut, Universität Bonn, Bonn; Germany

<sup>25</sup> Department of Physics, Boston University, Boston MA; United States of America

<sup>26</sup> Department of Physics, Brandeis University, Waltham MA; United States of America

<sup>27</sup> (a) Transilvania University of Brasov, Brasov; (b) Horia Hulubei National Institute of Physics and Nuclear Engineering, Bucharest; (c) Department of Physics, Alexandru Ioan Cuza University of Iasi, Iasi; (d) National Institute for Research and Development of Isotopic and Molecular Technologies, Physics Department, Cluj-Napoca; (e) University Politehnica Bucharest, Bucharest; (f) West University in Timisoara, Timisoara; Romania

<sup>28</sup> (a) Faculty of Mathematics, Physics and Informatics, Comenius University, Bratislava; (b) Department of Subnuclear Physics, Institute of Experimental Physics of the Slovak Academy of Sciences, Kosice; Slovak Republic

<sup>29</sup> Physics Department, Brookhaven National Laboratory, Upton NY; United States of America

<sup>30</sup> Departamento de Física, Universidad de Buenos Aires, Buenos Aires; Argentina

<sup>31</sup> California State University, CA; United States of America

<sup>32</sup> Cavendish Laboratory, University of Cambridge, Cambridge; United Kingdom

<sup>33</sup> (a) Department of Physics, University of Cape Town, Cape Town; (b) iThemba Labs, Western Cape; (c) Department of Mechanical Engineering Science, University of Johannesburg, Johannesburg; (d) University of South Africa, Department of Physics, Pretoria; (e) School of Physics, University of the Witwatersrand, Johannesburg; South Africa

<sup>34</sup> Department of Physics, Carleton University, Ottawa ON; Canada

<sup>35</sup> (a) Faculté des Sciences Ain Chock, Réseau Universitaire de Physique des Hautes Energies – Université Hassan II, Casablanca; (b) Faculté des Sciences, Université Ibn-Tofail, Kénitra;

(c) Faculté des Sciences Semlalia, Université Cadi Ayyad, LPHEA, Marrakech; (d) Faculté des Sciences, Université Mohamed Premier and LPTPM, Oujda; (e) Faculté des sciences, Université Mohammed V, Rabat; Morocco

<sup>36</sup> CERN, Geneva; Switzerland

<sup>37</sup> Enrico Fermi Institute, University of Chicago, Chicago IL; United States of America

<sup>38</sup> LPC, Université Clermont Auvergne, CNRS/IN2P3, Clermont-Ferrand; France

<sup>39</sup> Nevis Laboratory, Columbia University, Irvington NY; United States of America

<sup>40</sup> Niels Bohr Institute, University of Copenhagen, Copenhagen; Denmark

<sup>41</sup> (a) Dipartimento di Fisica, Università della Calabria, Rende; (b) INFN Gruppo Collegato di Cosenza, Laboratori Nazionali di Frascati; Italy

<sup>42</sup> Physics Department, Southern Methodist University, Dallas TX; United States of America

<sup>43</sup> Physics Department, University of Texas at Dallas, Richardson TX; United States of America

<sup>44</sup> National Centre for Scientific Research "Demokritos", Agia Paraskevi; Greece

<sup>45</sup> (a) Department of Physics, Stockholm University; (b) Oskar Klein Centre, Stockholm; Sweden

- 46 Deutsches Elektronen-Synchrotron DESY, Hamburg and Zeuthen; Germany
- 47 Lehrstuhl für Experimentelle Physik IV, Technische Universität Dortmund, Dortmund; Germany
- 48 Institut für Kern- und Teilchenphysik, Technische Universität Dresden, Dresden; Germany
- 49 Department of Physics, Duke University, Durham NC; United States of America
- 50 SUPA – School of Physics and Astronomy, University of Edinburgh, Edinburgh; United Kingdom
- 51 INFN e Laboratori Nazionali di Frascati, Frascati; Italy
- 52 Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg; Germany
- 53 II. Physikalisches Institut, Georg-August-Universität Göttingen, Göttingen; Germany
- 54 Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève; Switzerland
- 55 (a) Dipartimento di Fisica, Università di Genova, Genova; (b) INFN Sezione di Genova; Italy
- 56 II. Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen; Germany
- 57 SUPA – School of Physics and Astronomy, University of Glasgow, Glasgow; United Kingdom
- 58 LPSC, Université Grenoble Alpes, CNRS/IN2P3, Grenoble INP, Grenoble; France
- 59 Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge MA; United States of America
- 60 (a) Department of Modern Physics and State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China, Hefei; (b) Institute of Frontier and Interdisciplinary Science and Key Laboratory of Particle Physics and Particle Irradiation (MOE), Shandong University, Qingdao; (c) School of Physics and Astronomy, Shanghai Jiao Tong University, KLPPAC-MoE, SKLPPC, Shanghai; (d) Tsung-Dao Lee Institute, Shanghai; China
- 61 (a) Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg; (b) Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg; Germany
- 62 Faculty of Applied Information Science, Hiroshima Institute of Technology, Hiroshima; Japan
- 63 (a) Department of Physics, Chinese University of Hong Kong, Shatin, N.T., Hong Kong; (b) Department of Physics, University of Hong Kong, Hong Kong; (c) Department of Physics and Institute for Advanced Study, Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong; China
- 64 Department of Physics, National Tsing Hua University, Hsinchu; Taiwan
- 65 IJCLab, Université Paris-Saclay, CNRS/IN2P3, 91405, Orsay; France
- 66 Department of Physics, Indiana University, Bloomington IN; United States of America
- 67 (a) INFN Gruppo Collegato di Udine, Sezione di Trieste, Udine; (b) ICTP, Trieste; (c) Dipartimento Politecnico di Ingegneria e Architettura, Università di Udine, Udine; Italy
- 68 (a) INFN Sezione di Lecce; (b) Dipartimento di Matematica e Fisica, Università del Salento, Lecce; Italy
- 69 (a) INFN Sezione di Milano; (b) Dipartimento di Fisica, Università di Milano, Milano; Italy
- 70 (a) INFN Sezione di Napoli; (b) Dipartimento di Fisica, Università di Napoli, Napoli; Italy
- 71 (a) INFN Sezione di Pavia; (b) Dipartimento di Fisica, Università di Pavia, Pavia; Italy
- 72 (a) INFN Sezione di Pisa; (b) Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa; Italy
- 73 (a) INFN Sezione di Roma; (b) Dipartimento di Fisica, Sapienza Università di Roma, Roma; Italy
- 74 (a) INFN Sezione di Roma Tor Vergata; (b) Dipartimento di Fisica, Università di Roma Tor Vergata, Roma; Italy
- 75 (a) INFN Sezione di Roma Tre; (b) Dipartimento di Matematica e Fisica, Università Roma Tre, Roma; Italy
- 76 (a) INFN-TIFPA; (b) Università degli Studi di Trento, Trento; Italy
- 77 Institut für Astro- und Teilchenphysik, Leopold-Franzens-Universität, Innsbruck; Austria
- 78 University of Iowa, Iowa City IA; United States of America
- 79 Department of Physics and Astronomy, Iowa State University, Ames IA; United States of America
- 80 Joint Institute for Nuclear Research, Dubna; Russia
- 81 (a) Departamento de Engenharia Elétrica, Universidade Federal de Juiz de Fora (UFJF), Juiz de Fora; (b) Universidade Federal do Rio de Janeiro COPPE/EE/IF, Rio de Janeiro; (c) Universidade Federal de São João del Rei (UFSJ), São João del Rei; (d) Instituto de Física, Universidade de São Paulo, São Paulo; Brazil
- 82 KEK, High Energy Accelerator Research Organization, Tsukuba; Japan
- 83 Graduate School of Science, Kobe University, Kobe; Japan
- 84 (a) AGH University of Science and Technology, Faculty of Physics and Applied Computer Science, Krakow; (b) Marian Smoluchowski Institute of Physics, Jagiellonian University, Krakow; Poland
- 85 Institute of Nuclear Physics Polish Academy of Sciences, Krakow; Poland
- 86 Faculty of Science, Kyoto University, Kyoto; Japan
- 87 Kyoto University of Education, Kyoto; Japan
- 88 Research Center for Advanced Particle Physics and Department of Physics, Kyushu University, Fukuoka; Japan
- 89 Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La Plata; Argentina
- 90 Physics Department, Lancaster University, Lancaster; United Kingdom
- 91 Oliver Lodge Laboratory, University of Liverpool, Liverpool; United Kingdom
- 92 Department of Experimental Particle Physics, Jožef Stefan Institute and Department of Physics, University of Ljubljana, Ljubljana; Slovenia
- 93 School of Physics and Astronomy, Queen Mary University of London, London; United Kingdom
- 94 Department of Physics, Royal Holloway University of London, Egham; United Kingdom
- 95 Department of Physics and Astronomy, University College London, London; United Kingdom
- 96 Louisiana Tech University, Ruston LA; United States of America
- 97 Fysiska institutionen, Lunds universitet, Lund; Sweden
- 98 Centre de Calcul de l'Institut National de Physique Nucléaire et de Physique des Particules (IN2P3), Villeurbanne; France
- 99 Departamento de Física Teórica C-15 and CIAFF, Universidad Autónoma de Madrid, Madrid; Spain
- 100 Institut für Physik, Universität Mainz, Mainz; Germany
- 101 School of Physics and Astronomy, University of Manchester, Manchester; United Kingdom
- 102 CPPM, Aix-Marseille Université, CNRS/IN2P3, Marseille; France
- 103 Department of Physics, University of Massachusetts, Amherst MA; United States of America
- 104 Department of Physics, McGill University, Montreal QC; Canada
- 105 School of Physics, University of Melbourne, Victoria; Australia
- 106 Department of Physics, University of Michigan, Ann Arbor MI; United States of America
- 107 Department of Physics and Astronomy, Michigan State University, East Lansing MI; United States of America
- 108 B.I. Stepanov Institute of Physics, National Academy of Sciences of Belarus, Minsk; Belarus
- 109 Research Institute for Nuclear Problems of Byelorussian State University, Minsk; Belarus
- 110 Group of Particle Physics, University of Montreal, Montreal QC; Canada
- 111 P.N. Lebedev Physical Institute of the Russian Academy of Sciences, Moscow; Russia
- 112 National Research Nuclear University MEPhI, Moscow; Russia
- 113 D.V. Skobeltsyn Institute of Nuclear Physics, M.V. Lomonosov Moscow State University, Moscow; Russia
- 114 Fakultät für Physik, Ludwig-Maximilians-Universität München, München; Germany
- 115 Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München; Germany
- 116 Nagasaki Institute of Applied Science, Nagasaki; Japan
- 117 Graduate School of Science and Kobayashi-Maskawa Institute, Nagoya University, Nagoya; Japan
- 118 Department of Physics and Astronomy, University of New Mexico, Albuquerque NM; United States of America
- 119 Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen; Netherlands
- 120 Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam; Netherlands

- 121 Department of Physics, Northern Illinois University, DeKalb IL; United States of America
- 122 <sup>(a)</sup> Budker Institute of Nuclear Physics and NSU, SB RAS, Novosibirsk; <sup>(b)</sup> Novosibirsk State University, Novosibirsk; Russia
- 123 Institute for High Energy Physics of the National Research Centre Kurchatov Institute, Protvino; Russia
- 124 Institute for Theoretical and Experimental Physics named by A.I. Alikhanov of National Research Centre "Kurchatov Institute", Moscow; Russia
- 125 Department of Physics, New York University, New York NY; United States of America
- 126 Ochanomizu University, Otsuka, Bunkyo-ku, Tokyo; Japan
- 127 Ohio State University, Columbus OH; United States of America
- 128 Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman OK; United States of America
- 129 Department of Physics, Oklahoma State University, Stillwater OK; United States of America
- 130 Palacký University, RCPTM, Joint Laboratory of Optics, Olomouc; Czech Republic
- 131 Institute for Fundamental Science, University of Oregon, Eugene, OR; United States of America
- 132 Graduate School of Science, Osaka University, Osaka; Japan
- 133 Department of Physics, University of Oslo, Oslo; Norway
- 134 Department of Physics, Oxford University, Oxford; United Kingdom
- 135 LPNHE, Sorbonne Université, Université de Paris, CNRS/IN2P3, Paris; France
- 136 Department of Physics, University of Pennsylvania, Philadelphia PA; United States of America
- 137 Konstantinov Nuclear Physics Institute of National Research Centre "Kurchatov Institute", PNPI, St. Petersburg; Russia
- 138 Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh PA; United States of America
- 139 <sup>(a)</sup> Laboratório de Instrumentação e Física Experimental de Partículas – LIP, Lisboa; <sup>(b)</sup> Departamento de Física, Faculdade de Ciências, Universidade de Lisboa, Lisboa; <sup>(c)</sup> Departamento de Física, Universidade de Coimbra, Coimbra; <sup>(d)</sup> Centro de Física Nuclear da Universidade de Lisboa, Lisboa; <sup>(e)</sup> Departamento de Física, Universidade do Minho, Braga; <sup>(f)</sup> Departamento de Física Teórica y del Cosmos, Universidad de Granada, Granada (Spain); <sup>(g)</sup> Dep Física and CEFITEC of Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Caparica; <sup>(h)</sup> Instituto Superior Técnico, Universidade de Lisboa, Lisboa; Portugal
- 140 Institute of Physics of the Czech Academy of Sciences, Prague; Czech Republic
- 141 Czech Technical University in Prague, Prague; Czech Republic
- 142 Charles University, Faculty of Mathematics and Physics, Prague; Czech Republic
- 143 Particle Physics Department, Rutherford Appleton Laboratory, Didcot; United Kingdom
- 144 IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette; France
- 145 Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz CA; United States of America
- 146 <sup>(a)</sup> Departamento de Física, Pontificia Universidad Católica de Chile, Santiago; <sup>(b)</sup> Universidad Andres Bello, Department of Physics, Santiago; <sup>(c)</sup> Instituto de Alta Investigación, Universidad de Tarapacá; <sup>(d)</sup> Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso; Chile
- 147 Department of Physics, University of Washington, Seattle WA; United States of America
- 148 Department of Physics and Astronomy, University of Sheffield, Sheffield; United Kingdom
- 149 Department of Physics, Shinshu University, Nagano; Japan
- 150 Department Physik, Universität Siegen, Siegen; Germany
- 151 Department of Physics, Simon Fraser University, Burnaby BC; Canada
- 152 SLAC National Accelerator Laboratory, Stanford CA; United States of America
- 153 Physics Department, Royal Institute of Technology, Stockholm; Sweden
- 154 Departments of Physics and Astronomy, Stony Brook University, Stony Brook NY; United States of America
- 155 Department of Physics and Astronomy, University of Sussex, Brighton; United Kingdom
- 156 School of Physics, University of Sydney, Sydney; Australia
- 157 Institute of Physics, Academia Sinica, Taipei; Taiwan
- 158 <sup>(a)</sup> E. Andronikashvili Institute of Physics, Iv. Javakhishvili Tbilisi State University, Tbilisi; <sup>(b)</sup> High Energy Physics Institute, Tbilisi State University, Tbilisi; Georgia
- 159 Department of Physics, Technion, Israel Institute of Technology, Haifa; Israel
- 160 Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv; Israel
- 161 Department of Physics, Aristotle University of Thessaloniki, Thessaloniki; Greece
- 162 International Center for Elementary Particle Physics and Department of Physics, University of Tokyo, Tokyo; Japan
- 163 Graduate School of Science and Technology, Tokyo Metropolitan University, Tokyo; Japan
- 164 Department of Physics, Tokyo Institute of Technology, Tokyo; Japan
- 165 Tomsk State University, Tomsk; Russia
- 166 Department of Physics, University of Toronto, Toronto ON; Canada
- 167 <sup>(a)</sup> TRIUMF, Vancouver BC; <sup>(b)</sup> Department of Physics and Astronomy, York University, Toronto ON; Canada
- 168 Division of Physics and Tomonaga Center for the History of the Universe, Faculty of Pure and Applied Sciences, University of Tsukuba, Tsukuba; Japan
- 169 Department of Physics and Astronomy, Tufts University, Medford MA; United States of America
- 170 Department of Physics and Astronomy, University of California Irvine, Irvine CA; United States of America
- 171 Department of Physics and Astronomy, University of Uppsala, Uppsala; Sweden
- 172 Department of Physics, University of Illinois, Urbana IL; United States of America
- 173 Instituto de Física Corpuscular (IFIC), Centro Mixto Universidad de Valencia – CSIC, Valencia; Spain
- 174 Department of Physics, University of British Columbia, Vancouver BC; Canada
- 175 Department of Physics and Astronomy, University of Victoria, Victoria BC; Canada
- 176 Fakultät für Physik und Astronomie, Julius-Maximilians-Universität Würzburg, Würzburg; Germany
- 177 Department of Physics, University of Warwick, Coventry; United Kingdom
- 178 Waseda University, Tokyo; Japan
- 179 Department of Particle Physics, Weizmann Institute of Science, Rehovot; Israel
- 180 Department of Physics, University of Wisconsin, Madison WI; United States of America
- 181 Fakultät für Mathematik und Naturwissenschaften, Fachgruppe Physik, Bergische Universität Wuppertal, Wuppertal; Germany
- 182 Department of Physics, Yale University, New Haven CT; United States of America

<sup>a</sup> Also at Borough of Manhattan Community College, City University of New York, New York NY; United States of America.

<sup>b</sup> Also at CERN, Geneva; Switzerland.

<sup>c</sup> Also at CPPM, Aix-Marseille Université, CNRS/IN2P3, Marseille; France.

<sup>d</sup> Also at Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève; Switzerland.

<sup>e</sup> Also at Departament de Física de la Universitat Autònoma de Barcelona, Barcelona; Spain.

<sup>f</sup> Also at Department of Applied Physics and Astronomy, University of Sharjah, Sharjah; United Arab Emirates.

<sup>g</sup> Also at Department of Financial and Management Engineering, University of the Aegean, Chios; Greece.

<sup>h</sup> Also at Department of Physics and Astronomy, Michigan State University, East Lansing MI; United States of America.

<sup>i</sup> Also at Department of Physics and Astronomy, University of Louisville, Louisville, KY; United States of America.

<sup>j</sup> Also at Department of Physics, Ben Gurion University of the Negev, Beer Sheva; Israel.

<sup>k</sup> Also at Department of Physics, California State University, East Bay; United States of America.

- <sup>l</sup> Also at Department of Physics, California State University, Fresno; United States of America.
- <sup>m</sup> Also at Department of Physics, California State University, Sacramento; United States of America.
- <sup>n</sup> Also at Department of Physics, King's College London, London; United Kingdom.
- <sup>o</sup> Also at Department of Physics, St. Petersburg State Polytechnical University, St. Petersburg; Russia.
- <sup>p</sup> Also at Department of Physics, University of Adelaide, Adelaide; Australia.
- <sup>q</sup> Also at Department of Physics, University of Fribourg, Fribourg; Switzerland.
- <sup>r</sup> Also at Dipartimento di Matematica, Informatica e Fisica, Università di Udine, Udine; Italy.
- <sup>s</sup> Also at Faculty of Physics, M.V. Lomonosov Moscow State University, Moscow; Russia.
- <sup>t</sup> Also at Giresun University, Faculty of Engineering, Giresun; Turkey.
- <sup>u</sup> Also at Graduate School of Science, Osaka University, Osaka; Japan.
- <sup>v</sup> Also at Hellenic Open University, Patras; Greece.
- <sup>w</sup> Also at IJCLab, Université Paris-Saclay, CNRS/IN2P3, 91405, Orsay; France.
- <sup>x</sup> Also at Institutio Catalana de Recerca i Estudis Avancats, ICREA, Barcelona; Spain.
- <sup>y</sup> Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg; Germany.
- <sup>z</sup> Also at Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen; Netherlands.
- <sup>aa</sup> Also at Institute for Nuclear Research and Nuclear Energy (INRNE) of the Bulgarian Academy of Sciences, Sofia; Bulgaria.
- <sup>ab</sup> Also at Institute for Particle and Nuclear Physics, Wigner Research Centre for Physics, Budapest; Hungary.
- <sup>ac</sup> Also at Institute of Particle Physics (IPP), Vancouver; Canada.
- <sup>ad</sup> Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku; Azerbaijan.
- <sup>ae</sup> Also at Instituto de Física Teórica, IFT-UAM/CSIC, Madrid; Spain.
- <sup>af</sup> Also at Joint Institute for Nuclear Research, Dubna; Russia.
- <sup>ag</sup> Also at Louisiana Tech University, Ruston LA; United States of America.
- <sup>ah</sup> Also at Moscow Institute of Physics and Technology State University, Dolgoprudny; Russia.
- <sup>ai</sup> Also at National Research Nuclear University MEPhI, Moscow; Russia.
- <sup>aj</sup> Also at Physics Department, An-Najah National University, Nablus; Palestine.
- <sup>ak</sup> Also at Physics Dept, University of South Africa, Pretoria; South Africa.
- <sup>al</sup> Also at Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg; Germany.
- <sup>am</sup> Also at The City College of New York, New York NY; United States of America.
- <sup>an</sup> Also at TRIUMF, Vancouver BC; Canada.
- <sup>ao</sup> Also at Università di Napoli Parthenope, Napoli; Italy.
- \* Deceased.