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SPOT SIZE MEASUREMENTS IN THE ELI-NP COMPTON GAMMA SOURCE

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Abstract

A high brightness electron Linac is being built in the Compton Gamma Source at the ELI Nuclear Physics facility in Romania. To achieve the design luminosity, a train of 32 bunches with a nominal charge of 250 pC and 16 ns spacing , will collide with the laser beam in the interaction point. Electron beam spot size is measured with an OTR (optical transition radiation) profile monitors. In order to measure the beam properties, the optical radiation detecting system must have the necessary accuracy and resolution. This paper deals with the studies of different optic configurations to achieve the magnification, resolution and accuracy desired considering design and technological constraints; we will compare several configurations of the optical detection line to justify the one chosen for the implementation in the Linac.

INTRODUCTION

The goal of this paper is the characterization of different lenses in terms of resolution and magnification for the optical diagnostics for the ELI-NP-GBS LINAC.

The optical diagnostics systems in ELI-NP-GBS will provide an interceptive method to measure beam spot size and beam position in different positions along the LINAC. In a typical monitor setup, the beam is imaged via OTR using standard lens optics, and the recorded intensity profile is a measure of the particle beam spot [1]. In conjunction with other accelerator components, it will also possible to perform various measurements on the beam, namely: its energy and energy spread (with a dipole or corrector magnet), bunch length (with a RF deflector) and the Twiss parameters (with quadrupoles).

The expected beam rms size along the Linac, provided by preliminary beam dynamics simulation, will vary in the 30µm - 1000µm range (as reported in Fig.1).

An evaluation has been done in order to find the best lenses setups and to find a compromise between resolution, magnification and costs for each position.

The optical acquisition system is constituted by a camera Basler scout A640-70 gm with a macro lens (see Fig.2). It has been seen, during the experimental tests, the macro lens is most suitable in order to obtain the requirements of high resolution and magnification. A movable slide is used to move the system between 60 cm and 130 cm of distance from target. These values represent the maximum and minimum distance between the camera sensor and the OTR.

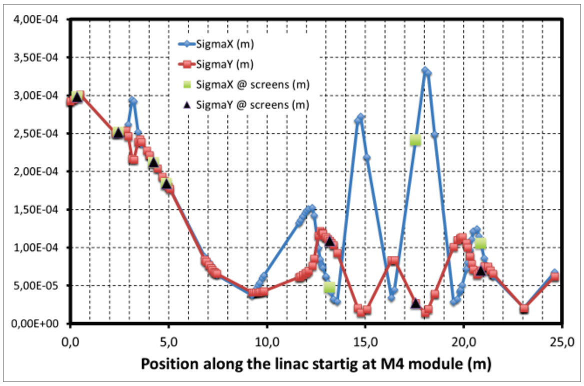

Figure 1: Spot size of the beam in the low energy line after S-band photoinjector.

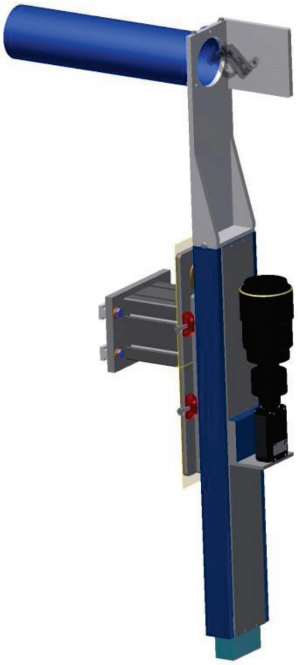

Figure 2: The ELI-GBS optic setup with a camera "Basler Scout A640 70 gm" and a macro lens mounted in a movable slide.

OPTICS CONFIGURATION

For each ELI-GBS diagnostics station the camera system can be regulated at a distance between 60 and 130 cm from the OTR. The reasons of these values are linked at mechanical and geometric constraints because the beam line is placed at 1.5 meters from the floor (see Fig.3).

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Therefore, in order to avoid the possible damage of the optics devices due to the radiation emitted by the beam, each system must to be positioned at minimum 60 cm from the target and the maximum reachable distance to obtain the required magnification values is 130 cm from the target.

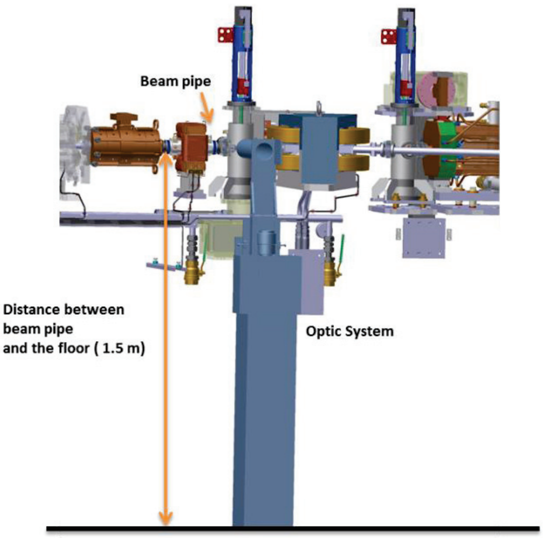


Figure 3: 3D model an optic system along the LINAC.

The maximum magnification (1:1) was tested and compared to the one indicated in the datasheet in order to validate the measure procedure.

The magnification and the resolution of the images at the minimum and the maximum distances (60 and 130 cm) for various lens setup have been measured. In order to do so, we used a “Thorlabs" Calibration target based on the “USAF 1951" target (see Fig. 4).

Figure 4: Test-bench with a 50mm microscope lens mounted on a Basler camera.

MAIN PARAMETERS

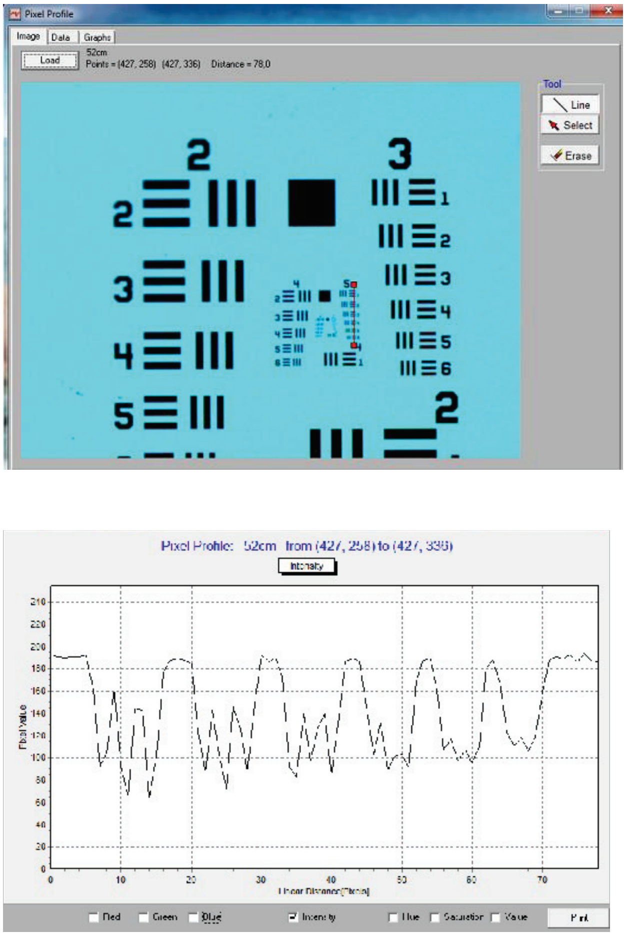
Resolution

The “USAF 1951” target allows to test the resolution of the optic setup. It consists of reference line patterns with well-defined thicknesses and spacings to be placed in the same plane as the object being imaged. By identifying the largest set of non-distinguishable lines, one determines the resolving power of a given system.

A pixel profiling procedure has been implemented by using a simple image software ("Pixel Profile"). We estimate the contrast value by evaluating the rate between the difference in intensity values of the pixels corresponding to the black lines and the one corresponding to the white spaces, and their sum; we consider the lines resolved if the contrast value is above 0.1. In the example of figures 5, the line series that respect the specification is the element 1 of the group 5: therefore, we have $x = 32$ and a resolution of $31\ \mu m$.

An equivalent method is instead based on the evaluation of the edge profile of a black rectangle in the calibration target: we can apply the Fourier transform to the lines spread function, which is the derivative of the edge profile [2]. The result is the so called Modulation Transfer Function (MTF) which is equivalent to the contrast function: therefore, if we take its abscissa when the MTF is equal to 0.1, we have the number of line pairs per millimeter; of course the resolution will be the inverse.

Moreover, the use of better camera with half of the resolution ($3.75\ \mu mpx^{-1}$ instead of $7.4\ \mu mpx^{-1}$) does not increase too much the overall resolution.



52cm
Points = (427, 258) (427, 336) Distance = 78,0

Pixel Profile: 52cm from (427, 258) to (427, 336)

Figure 5: Screen-shots of “Pixel Profile" (“Image" (U) and “Graph" (D) screens): drawing a line on the image

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produce the intensity graph and a table of all the pixels values.

Magnification

The USAF target is composed by group of lines of known size: if we define a parameter x given by $x = 2^{Group+(Element-1)/6}$ that represents the number of line pairs per millimeters, the resolution in millimeters can be calculated as is $1/x$; and the sizes of each line which are $L = \frac{2.5}{x}$ for the length, and $W = ½x$ for the width [3]. Making a line profiling from the images that we acquire (see Fig. 5), we can measure the size in pixels of the line (N) and, knowing the pixel size of the camera sensor (7.4x7.4 µm), the size of the line in the image plane. Therefore, the magnification is $M = \frac{L}{7.4N}$.

In ELI-NP GBS being the size of the beam variable the range of magnification required goes from 1: 1 to 1: 5. The “USAF 1951" calibration target is useful for the study of the magnification as a function of the distance between the target and the sensor, and the focal length.

OPTICS MEASUREMENTS

Several lens with different focal lengths have been tested and for each commercial lens, at the same distance, the resolution and magnification have been calculated. Table 1 shows the kind of objectives tested and the two main parameters with relative field of view. The field of view is simply what the lens together with the camera can see from left to right and from top to bottom (see Fig.6).

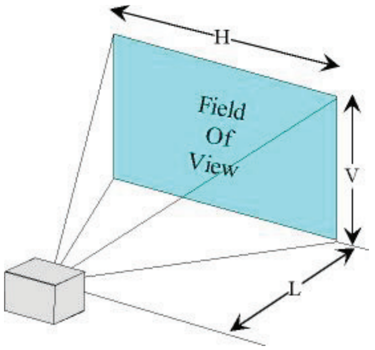

Figure 6: H is horizontal field of view from left to right and V is the vertical field of view from bottom to top.

This parameter depends on two factors: the focal length of the lens and the physical size of the camera sensor. Since it depends on sensor size it's not a fixed characteristic of a lens and it can only be defined if the size of the sensor that will be used is known. Therefore, once we know the magnification, we can evaluate the achievable field of view multiplying the resolution of the camera sensor (*659 px x 494 px*) with the magnification and the pixel size (*7.4 µm per px*). This parameter is very important in order to know how much of the screen target we can see and, therefore, to be sure to see the whole beam. Hence, if the beam is large, we need a high value of magnification in order to see a big portion of the screen target; however, if the field of view is too low, there might be the chance that we cannot see an off center beam. This is not the case of our machine, since the expected misalignment is well below the case of a beam outside the area seen by the camera, even in the case of the lower field of view achievable which is *5 mm x 4 mm*.

During the measurements, several optics configuration have been tested in order to evaluate a good magnification and resolution: camera with lens or camera with lens and tele-converter. The tele-converter allows us to obtain a macro lens comparable to a telephoto lens with the advantage in terms of cost, magnification and high resolutions. Thus using the tele-converter, we achieve the covered area is four times increased , the focal length is double but there is only one disadvantage in terms of aperture namely the fall of light is equal to two diaphragms. However, in our case this disadvantage is not a problem because the decrease of the luminosity is more evident for greater focal length. As we can see in the table 1 the best results are obtained with a *180 mm* lens with tele-converter (2x) that gave us the magnification of 1; also the *180 mm* lens with tele-converter (1.4x) gave us good results since it allows us to obtain the 1:5.

Table 1: Comparison Between Different Lens at 60 mm and 130 mm of Distance from the Target

Lens [mm]	**Distance [cm]**	**Resolution [µm]**	**M**	**Field of View [mm]**
50	60	223	8.33	40x30
105	60	88	4	21x16
	130	198	12	59x44
105 + tele-conv.2x	60	39	1.9	9x7
	130	111	5.5	27x20
180	60	44	2	10x7
	130	125	6	31x23
180+tele-conv. 2x	**60**	**31**	**1**	**5x4**
	130	**70**	**3**	**15x11**
180 + tele-conv.1.4x	60	321	1.3	6x5
	130	111	5	24x18

We also have tested a lens with variable focal length between *75 mm* and *200 mm* in order to estimate the chance to change the focus in function of the beam dimension along the LINAC supposing a greater versatility of the lens in several situations. We have supposed that a variable focus would have allowed to use the same objective along the LINAC but we saw with the test bench that the results, in terms of magnification and resolution, did not meet our expectations. Certainly is possible to achieve even better results with a *300 mm* lens: however, the *300 mm* lens cannot be used due to the limited dimension of the diagnostic station.

CONCLUSION

In general, the relation between the magnification and the distance is quasi-linear and the slope decreases with the focal length as it can be seen in Fig. 7. Therefore, the best solution in our case is shown by the black line. In this case we do not have the large possibility to change the magnification but, in function of the requirements of this accelerator, this lens is a valid device to study the characteristics of the beam.

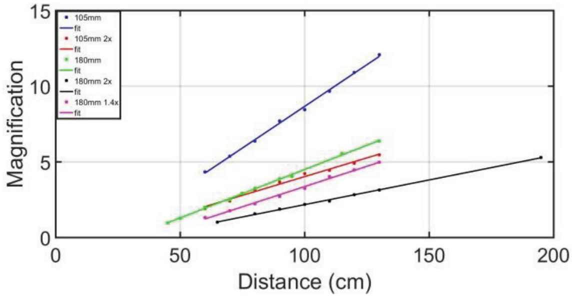

Figure 7: Magnitude as a function of the distance between camera sensor and the target for different lenses: it's clear that for bigger focal length we have a lower slope.

A camera system configuration has been selected considering the ratio between magnification, resolution (see red line Fig. 8) and the costs, consisting of a Basler Scout A640-70 gm camera equipped with *105 mm* lens while *180 mm* lens with tele-converter 2x will be used in the diagnostic stations collocated in the more critical points along the LINAC (see Tab. 2).

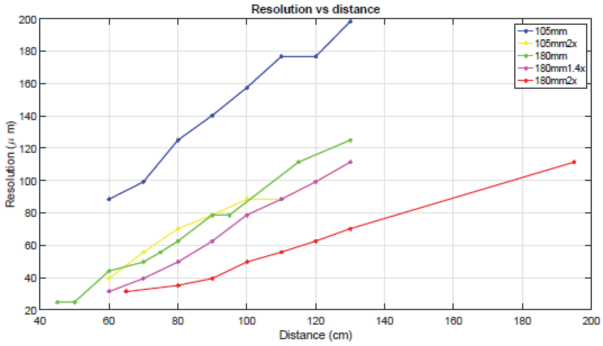

Figure 8: Resolution as a function of the distance between camera sensor and the target for different lenses.

Table 2: Optical System Proposed for ELI-NP-GBS in Order to Measure the Spot Size of the Beam

Station	Beam Size (um)		Solution proposed n.1
	X	Y	
LELDIASCN002 (energy measurements)	1000	1000	Camera Lens 105 mm+ tele-converter 2x
LELDIASCN003	500	500	Camera Lens 105 mm+ tele-converter 2x
LELDIASCN004	400	400	Camera Lens 105 mm+ tele-converter 2x
LELDIASCN005	280	280	Camera Lens 105 mm+ tele-converter 2x
LELDIASCN006	250	250	Camera Lens 105 mm+ tele-converter 2x
LELDIASCN007 (energy measurements)	180	180	Camera Lens 180 mm+tele-converter 2x
LELDIASCN008 (quad scan, long. measurements)	220	220	Camera Lens 180 mm+tele-converter 2x
LELDIASCN09	100	100	Camera Lens 105 mm+ tele-converter 2x
LETDIASCN01 (beam size under 0.1mm)	80	80	Camera Lens 180 mm+tele-converter 2x
LETDIASCN02 (beam size under 0.1mm)	27	27	Camera Lens 180 mm+tele-converter 2x
LEDDIASCN01 (beam size under 0.1mm)	65	65	Camera Lens 180 mm+tele-converter 2x
LEDDIASCN02	100	100	Camera Lens 105 mm+ tele-converter 2x

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[3] Thorlabs App Note: "*Resolution Test Targets*", `https://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=4338`