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A FLUKA STUDY OF CROSSTALK BETWEEN MEASURING VOLUMES IN A 2D ION CHAMBER ARRAY UNDER PROTON IRRADIATION

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In this paper we present a study of the crosstalk of the individual measuring volumes in a 2D ion chamber array (QUADRO-fm detector) under proton irradiation. This is the follow-up of the similar study performed for this detector in the case of electron beams. The goal of the paper is to assess the applicability of the proposed array for measurements in charged particle beams generated by ultra-high-power laser - target interactions. Using FLUKA calculations and similar geometry conditions as for the electrons, we obtained relative dose deviation values in a 250 MeV monoenergetic proton beam. The results show low values for this quantity, in the case of the selected parameters. We can conclude that the QUADRO-fm detector can be successfully used in any type of charged particle beams generated at ELI-NP and that the calibration of the array can be performed relative to the central dose.

Keywords: QUADRO-fm detector, crosstalk in proton beam, FLUKA, relative dose deviation

1. Introduction

Two important research projects – CETAL and ELI-NP were initiated in Romania, both aiming at physics with high power lasers. They both make use of PW class lasers (1 PW for CETAL and 10 PW for ELI-NP), with pulse widths in the range of some 20 fs and repetition rates of 0.1 Hz at the peak power. Both lasers have the capacity to generate pulses of accelerated particle beams with an estimated time width in the range of some tenths of picoseconds. Making use of these beams will require precise dosimetry but, due to the very short duration of the pulse, combined with the low repetition rate, the use of the ion chambers (which are still considered as the golden standard in dosimetry) is particularly difficult due to the high recombination corrections, which cannot be determined in the traditional way – as described, for instance, in the IAEA TRS 398 [1]. Under

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these circumstances, we propose to use an array detector with 4 ion chambers – the QUADRO- fm detector (Quad Array Detector for RecOmbination factor measurement) – in a geometry described in the following chapter, one chamber being used for dose measurements, while the other 3 are used for simultaneous measurement of the recombination and polarity corrections. One of the factors that could influence the proper functionality of such an array detector is the cross talk between the chambers when measuring in various fields. We have already demonstrated in [2] that the cross talk between the chambers in electron beams is negligible.

The present paper shows that the same conclusion is valid also in proton fields, meaning that the technical demonstrator we built can be used for measurements in any type of charged particle beams.

2. Methods and results

2.1. The principle of the QUADRO-fm detector

Whenever a dose is measured with an ion chamber, one of the correction factors that needs to be determined is the recombination correction factor, which account for the signal loss due to the recombination of carriers inside the chamber's active volume.

For the recombination correction in pulsed beams, the method recommended by IAEA TRS 398 [1] is the so-called two voltage methods, where the chamber is biased at two different voltages, and then the correction is given by:

$$k_s = a_o + a_1(M_1/M_2) + a_2(M_1/M_2)^2 \quad (1)$$

where M_1 and M_2 are the dosimeter readings and voltage biases V_1 and, respectively, V_2. The parameters a_0, a_1 and a_2 are tabulated in TRS 398 for pulsed and pulsed scanned beams, vs. V_1/V_2. For the method to work best, the ratio between the two bias voltages must be at most 1/3.

Another correction factor that needs to be taken into account is the polarity correction, which accounts for the differences in the measurements with the chamber polarized at negative and at positive bias. This correction factor is known to be dependent on the energy and voltage bias and can be calculated with the formula given by the same IAEA TRS 398 [1]:

$$k_{pol} = (|M_+| + |M_-|)/2M \quad (2)$$

where M_+ and M_- are, respectively, the dosemeter reading for positive and negative polarity bias applied to the ion chamber while M is the dosemeter reading for the recommended polarity for the specific detector used (positive, in the case of the Advanced Markus chamber).

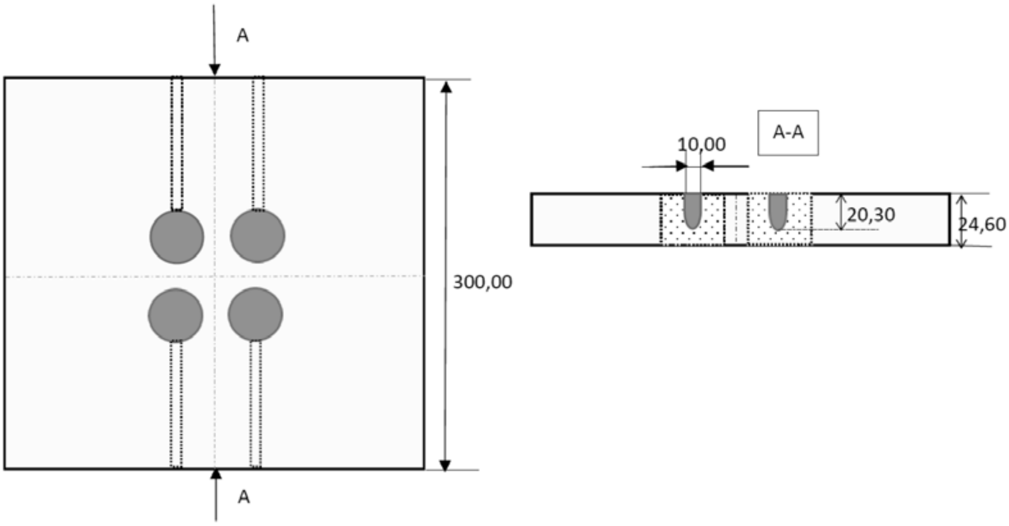

Fig. 1. Schematic drawing of the prototype array detector, consisting of 4 identical PTW Advanced Markus™ ion chambers, mounted in PMMA. Dimensions are given in millimetres. [3]

Because in short pulsed beams, with low repetition rate (like those generated at ELI and CETAL) multiple measurements to determine the correction factors are not practical,
we proposed the QUADRO-fm detector [3], the drawing of the technical demonstrator being presented in figure 1 below.
The array consists of four identical plane parallel chambers, type PTW Advanced Markus™, set up in two pairs, each pair allowing the measurement of the two correction factors – the recombination correction factor and the polarity correction, each of the four chambers having a different bias, at the values V_1, V_2, $-V_1$ and $-V_2$, respectively. Chamber 1 (polarized at V_1) will be considered as the reference chamber and will also be used for dose measurement, whilst the other three chambers are meant to provide the values for the calculation of the correction factor. All four chambers are mounted in a PMMA frame.

2.2. The geometry and beam parameters for the FLUKA simulation

The geometry of the Advanced Markus chamber used in the FLUKA simulation was the one described in the PTW chamber manual version D661.131.00/05.

Also, in the manual are detailed the materials of the walls, electrodes and window. Figure 2 below shows the FLUKA geometry for the QUADRO-fm detector also used for the crosstalk calculations in electron beams [2].

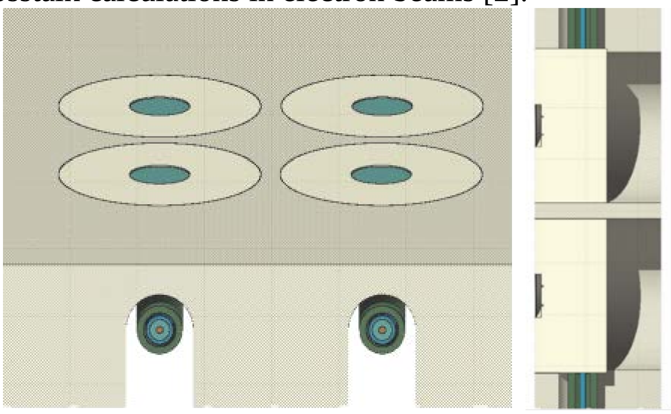

Fig. 2. FLUKA geometry for the array simulation, using the FLAIR code [4].

The beam used in the simulations was a 250 MeV monoenergetic proton beam, with a 10 x 10 cm cross - sectional area. The beam axis was perpendicular on the detector plane and centered on the detector center. FLUKA simulations were done using the latest available version of the code, FLUKA 2011.2x.5 [5], [6].

The study was performed in a similar way as the one for electrons, reported in [2]. In this case, a first set of calculations were performed with only one detector placed in central position, at a 0.5 cm distance from the source plane, in order to maintain a similar geometry as for the electrons. Since the divergence of the proton beam produced by ultrahigh power laser pulses interacting with targets is expected to be rather large, we have calculated the detector response over a half divergence varying from 0^o to 40^o, again maintaining a similar geometry with the one from the electron experiment [2]. As for the electrons, similar calculations were done for 50 cm and 100 cm distances between the source and the detector.

3. Results and discussion

A graph representation of the dose value scored in the active volume of the detector as a function of the primary proton beam divergence is shown in Figure 3 below. The dose is expressed in the customary FLUKA units: GeV/g/primary proton.

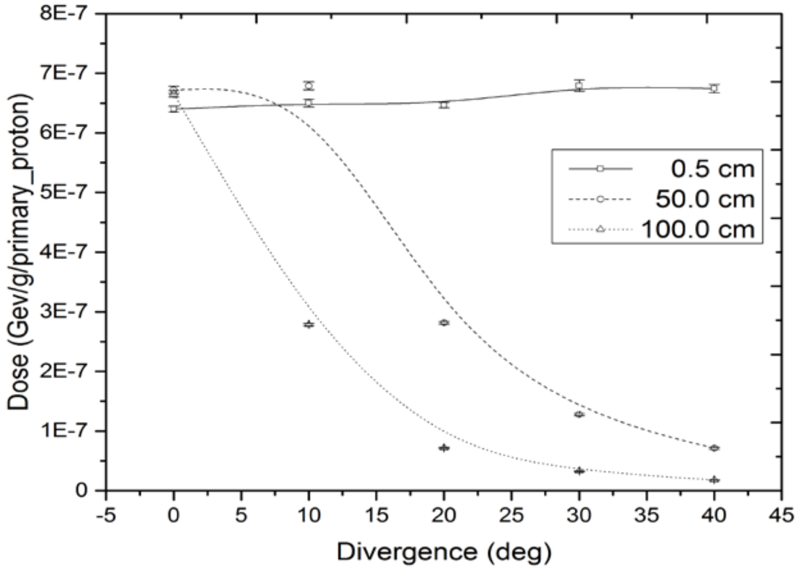

Fig. 3. Dose values (GeV/g/primary proton) scored in the active volume of a central detector, as a function of the half-divergence angle (degrees); the ionizing chamber was placed at 3 positions with respect to the extended source: 0.5cm, 50cm, and 100cm.

As in the case of the electron beam [2], the doses calculated at 0.5 cm are almost independent of the beam divergence, except for a small increase at higher divergence, which can be explained by the large dimensions of the source field as compared to the detector dimensions. Compared to the electron beam, at low divergence, the doses at 50 cm and 100 cm are higher than the doses at 0.5 cm due to the stronger build-up produced by the directional proton beam. We can also observe that the negative gradient of the dose increases with the distance from the source.

The reciprocal influence of the detectors in the QUADRO-fm array was studied by using the same method as in [2], i.e. by calculating the relative deviation

$$\varepsilon_{\mathrm{rA,B,C,D}} = \frac{D_{\mathrm{A,B,C,D}} - D_0}{D_0} \times 100 \tag{3}$$

where $D_{\mathrm{A,B,C,D}}$ are the dose values in the 4 measuring volumes, and D_0 is the dose obtained in the case of a central ion chamber. The numerical results calculated for the 0.5 cm distance between the array entrance plane and the source are presented in Table 1, and represented in Figure 4. The distance between the array measuring volumes is 0.1 cm.

The relative dose deviations take random low values, ranging -1.43% to 2.84%, without any functional dependency on the divergence in the four measuring volumes, as it was to be expected given the results shown in figure 3 for 0.5 cm distance. The small relative differences between the central dose value and the array dose values are due to field non-uniformity as well as the reciprocal influences of the chamber volumes. The span of the deviations does not significantly differ from what we have obtained for electrons. Thus, we can conclude that beam type does not have an important bearing on the crosstalk of the array chambers at this particular distance between the measuring volume

Table 1

Relative dose deviation in detectors A/4 to D/4 vs the dose in a central detector 1/1, as a function of the primary proton beam divergence. The distance from the source to the detector entrance plane is 0.5 cm and the distance between the edges of the measuring volumes is 0.1 cm

Divergence (deg)	0°	10°	20°	30°	40°
$\varepsilon_{rA}(\%)$	+2.81	-0.27	+2.84	-1.43	-0.43
$\varepsilon_{rB}(\%)$	+0.95	+0.18	+1.22	-0.75	+0.19
$\varepsilon_{rC}(\%)$	+0.64	+0.50	+2.69	-2.06	-0.63
$\varepsilon_{rD}(\%)$	+0.72	-0.17	+1.19	-0.73	+0.37

Table 2

Relative dose deviation in detectors A/4, B/4, C/4 and D/4 vs. the dose in a central detector 1/1 as a function of the external distance between adjacent detecting volumes. The distance from the source to the detector entrance plane was 5.0 cm.

Distance (cm)	**0.1**	**0.5**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**
$\varepsilon_{rA}(\%)$	-0.03	-0.26	+0.44	-0.09	-1.18	+1.03	+0.87
$\varepsilon_{rB}(\%)$	+0.64	+0.91	+1.16	+0.62	+2.00	-0.86	+1.56
$\varepsilon_{rC}(\%)$	+0.89	+1.67	+0.70	+0.74	+1.73	+0.99	+1.56
$\varepsilon_{rD}(\%)$	-0.69	+0.01	-0.38	+1.53	+0.59	+2.49	+2.95

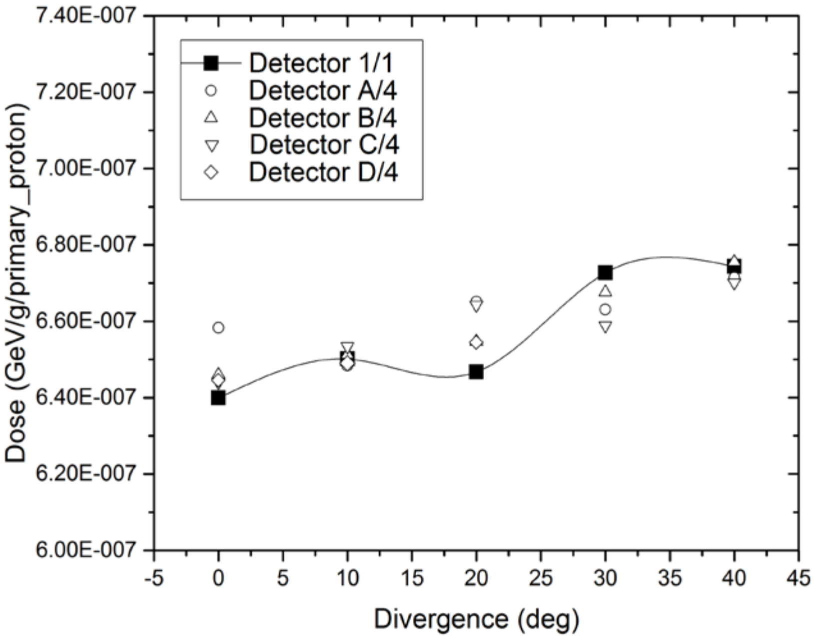

Fig. 4. Comparative representation of the dose scored in a central detector (Detector 1/1) and in the four scoring volumes of the array (Detector A/4 - Detector D/4); for guidance an interpolated curve corresponding to the central detector is presented. The distance from the source to the detector entrance plane was 0.5cm. The number of primaries in the FLUKA runs were chosen such that the statistical errors were less than 2% in each case.

To verify the influence of the distance between the measuring volumes on verify the influence of the distance between the measuring volumes on their crosstalk, we used a zero divergence proton beam, with the array entrance surface placed at 5 cm from the extended source. As in the electron case, the 0^o divergence was considered, to avoid overlapping of effects. Table 2 presents the results of these calculations.

It can be observed that the relative dose deviations display random values at different distances between the detecting volumes. Thus, for the selected distance range between the volumes and selected beam energy there is no direct relation between the two quantities. Furthermore, the values of the relative dose deviations are very small, not exceeding 2.95%, with most of them less than 2%. Again, we can conclude that the measuring volumes can be brought as close as 1 mm external distance between them, thus allowing the construction of an array with reduced dimensions designed for measurements in small fields.

4. Conclusions

The crosstalk of the individual measuring volumes composing the QUADRO-fm detector has been studied using FLUKA simulations, for a 250 MeV proton beam with a half-divergence angle in the range between 0^o and 40^o, covering the typical divergences encountered both at therapy proton beams and laser generated proton beams.

The results indicate that, under proton irradiation, the relative dose deviation in the 4 volumes composing the array vs. the central dose is very small (not larger than 2.95%), similarly to the case of electron irradiation. Also, no significant dependency either on the beam divergence or on the external distance between the detectors has been demonstrated, again similar to the results obtained for electrons.

Thus, we can conclude that, both for electron and proton beams the measuring volumes can be brought as close as 1 mm external distance between them and consequently the array dimensions can be minimised to be used in small fields.

Considering the results of the crosstalk for protons and taking into account the results for electrons reported in [2], we can conclude that the QUADRO-fm detector can be successfully used in any type of charged particle beams generated at ELI-NP and the calibration of the array can be performed relative to the central dose.

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R E F E R E N C E S

[1] *IAEA TRS-398*, Absorbed Dose Determination in External Beam Radiotherapy, IAEA Vienna, 2000

[2] *Maria – Ana Popovici, Radu A. Vasilache, Daniela Buzatu*, A FLUKA study of crosstalk between measuring volumes in a 2D ion chamber array, January 2018 UPB Scientific Bulletin, Series A: Applied Mathematics and Physics 80(4):301-308

[3] *Radu A. Vasilache, Maria – Ana Popovici, Mihai Straticiuc, Mihai Radu, Andreea Groza*, The Development of Novel Array Detector for Overcoming the Dosimetry Challenges of Measuring in Very Short Pulsed Charged Particle Beams - The ELIDOSE Project, Radiation Protection Dosimetry (2019), Vol. 183, No. 1–2, pp. 285–289

[4] *V. Vlachoudis*, FLAIR: A Powerful But User Friendly Graphical Interface For FLUKA, Proc. Int. Conf. on Mathematics, Computational Methods & Reactor Physics (M&C 2009), Saratoga Springs, New York, 2009

[5] *Ferrari, P.R. Sala, A. Fasso, J. Ranft*, FLUKA: a multi-particle transport code", CERN-2005-10, 2005, INFN/TC_05/11, SLAC-R-773

[6] *T.T. Böhlen, F. Cerutti, M.P.W. Chin, A. Fassò, A. Ferrari, P.G. Ortega, A. Mairani, P.R. Sala, G. Smirnov, V. Vlachoudis*, The FLUKA Code: Developments and Challenges for High Energy and Medical Applications, Nuclear Data Sheets vol. 120, 2014, pp. 211-214