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THE DEVELOPMENT OF A NOVEL ARRAY DETECTOR FOR OVERCOMING THE DOSIMETRY CHALLENGES OF MEASURING IN VERY SHORT PULSED CHARGED PARTICLE BEAMS - THE ELIDOSE PROJECT

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ELIDOSE - the project

- October 2016: the project “ELIDOSE” was approved, in the frame of the 5/5.1/ELI-RO programme

- **Main goal**: the development of a prototype array detector for overcoming some of the difficulties of the dosimetry measurements in short pulsed beams of charged particles

Laser accelerated particle beams

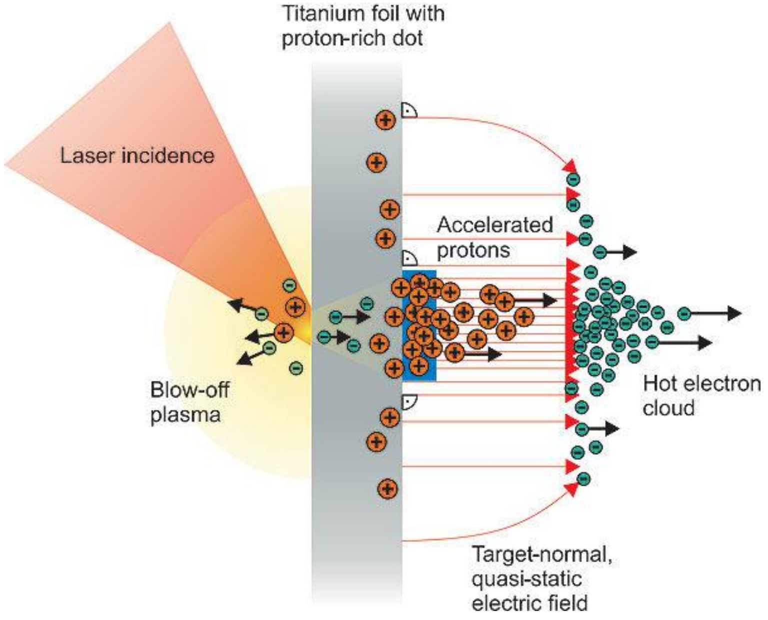
The ELI-NP project (ELI-NP white book):

-Two 10 PW lasers coherently added to the high intensity of 10^{23}-10^{24} W/cm^2, **pulse width 20 fs**

The CETAL project (http://cetal.inflpr.ro/node/73):

-A 1 PW laser, **pulse width 25 fs**

Both lasers have the capacity to generate accelerated particle beams. The time width of the accelerated particle pulses is in the range of some **10ths of picoseconds**



H. Schwoerer et al., Laser-plasma acceleration of quasi-monoenergetic protons from microstructured targets, Nature 439, 445–448 (26 January 2006)

Challenges for dosimetry measurements

- Very short pulse duration
  - High recombination rates for protons
  - Difficult to determine the recombination correction factor
  - Difficult to determine the polarity (bias) correction factor (which can be rather important for charged particles)

- Unknown energies: not so easy to determine the Bragg peak position
  - **For the reasons related to the above and the low repetition rate the measurements spill – by – spill are not feasible**

The dosimetry measurements

The corrected reading (IAEA TRS 398):

$$M = (M_{uncorr} - M_0) \times k_{elec} \times k_Q \times k_{TP} \times k_S \times k_{pol} \times k_h$$

where:

-k_{elec}: calibration factor (Gy/C) @ reference energy

-k_Q: energy correction

-k_{TP}: air density correction

-k_S: ion recombination correction

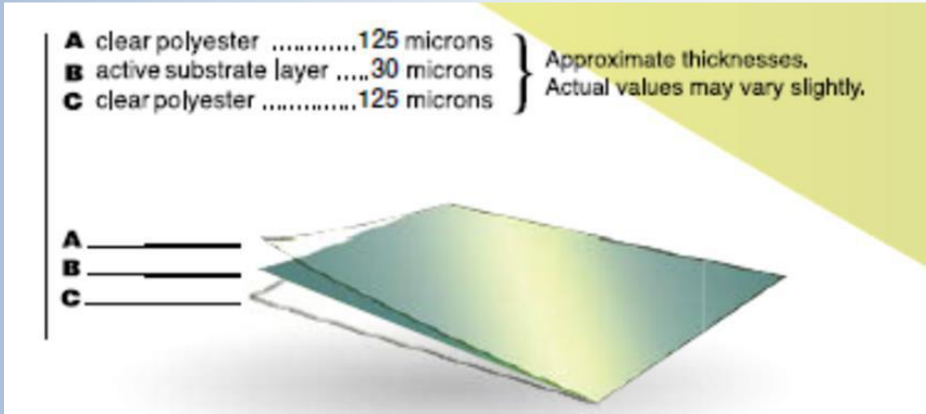
-k_{pol}: polarity (bias) correction

-k_h: humidity correction

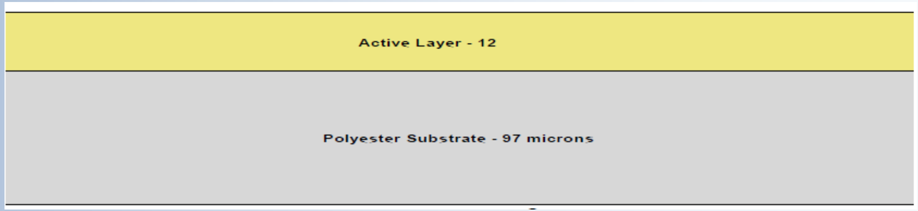
Beam analysis & Energy measurements

RCFs

- Gafchromic MD-V3:
  - dynamic dose range 1 Gy a- 100 Gy
  - spatial resolution < 15 μm
  - < 5% energy over 100 keV - 18 MeV
- Gafchromic EBT3
  - dynamic range 0.01 Gy - 40 Gy,
  - same energy dependence and spatial resolution as the MD-V3
- Gafchromic HD-V2:
  - Dynamic dose range: 10 Gy to 1 kGy
  - spatial resolution < 5 μm
  - same energy dependence as the two above
- Gafchromic EBT-XD
  - dynamic range 0.01 Gy - 200 Gy
  - spatial resolution of 5 μm
  - same energy dependence as the three above



Gafchromic EBT3 (above) and HD-V2 (below) componence. One can immediately see that the thickness of the film requires build up material for the expected proton energies. At low energies, however, the HD-V2 is at a clear adavantage
www.ashland.com



The recombination correction factor

For pulsed beams [IAEA TRS 398, J.W. Boag & J. Currant, Brit. J. Radiol. **53** (1980)]:

$$k_s = a_0 + a_1\left(\frac{M_1}{M_2}\right) + a_2\left(\frac{M_1}{M_2}\right)^2$$

- a_0, a_1 *and* a_2 are tabulated in TRS 398 for pulsed and pulsed scanned beams, vs. V_1/V_2
- The measurements should be made at least at two polarising voltages, the second one being at most 1/3 of the first
- The polarity effect changes with the voltage, thus the readings should also be corrected for polarity effect.

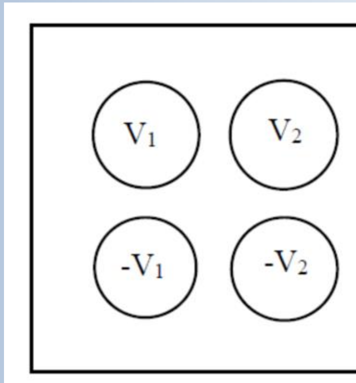
The polarity correction factor

- For charged particle beams the polarity effect may be important
- The polarity effect will depend on the energy
- The correction factor recommended by TRS 398

$$k_{pol} = \frac{|M_+| + |M_-|}{2M}$$

The prototype detector array

- To overcome these difficulties we propose a chamber array
- The array should include at least 4 identical chambers, each with a different bias and polarity
- Grouping them in combinations of two, we can measure recombination and polarity corrections in a single measurement
- For higher dose and higher energy, the 99% saturation voltage should be arround 800 V



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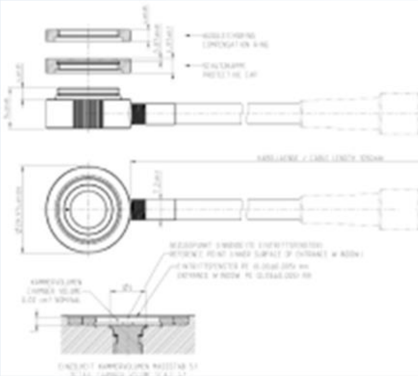
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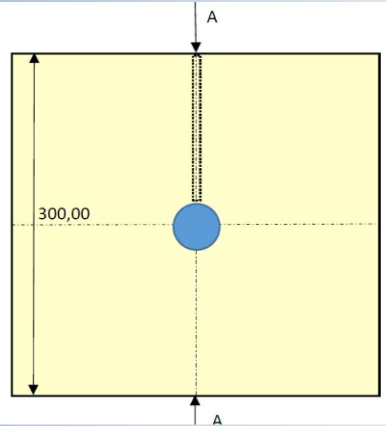
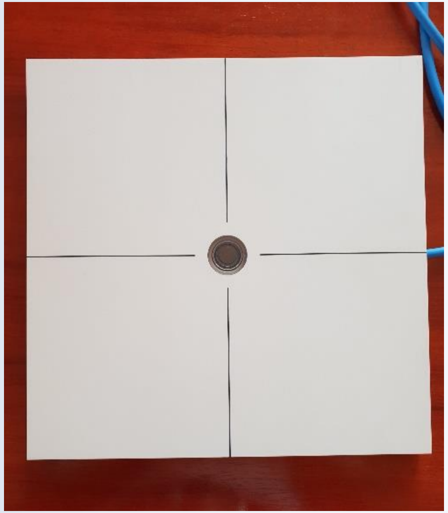
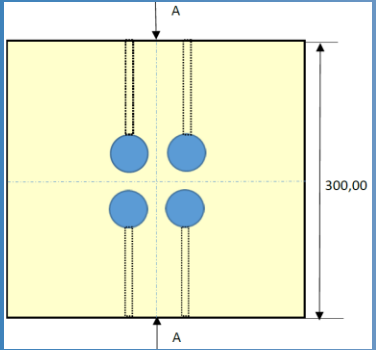
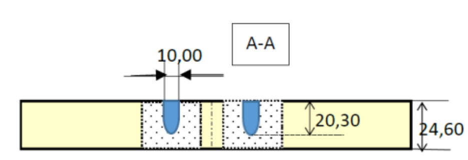
a) Schematic drawing of the array detector, consisiting of 4 identical plane parallel ion chambers, mounted in PMMA, each one with a different bias.
b) The advanced Markus chamber

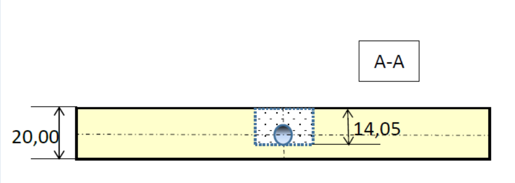
The prototype detector array – first model











Preliminary results – proton irradiation

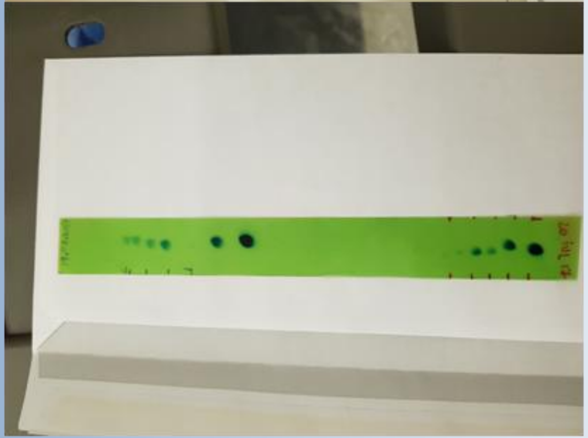
- Beams: Tandetron^{TM} 3 MeV and Tr19 cyclotron 18 MeV (IFIN-HH) – continuous beam
- Used to tune the FLUKA simulations for the Advanced Markus chamber
- The beam was characterised with Gafchromic EBT2 and HD-V2 films

Preliminary results – proton irradiation

Used to tune the FLUKA simulations for the Advanced Markus chamber

Irradiation conditions:

- 3 MeV protons, TandetronTM of IFIN-HH
- 2.8 cm distance from the exit window
- Correction factors calculated according to IAEA TRS 398 & Paganetti (ed.) “Proton Therapy Physics”
- Particle fluence measured via backscatter from a thin gold foil (RBS standard geometry)



Preliminary results – proton irradiation: correction factors

1. Calibration factor for Co-60 in air

$N_{d,w}^{Co}$ = 1.34E+03 Gy/microC

$S_{w,air}^{Co}$ = 1.133

$N_{d,air}^{Co}$ = 1.18E+03 Gy/microC

2. Stopping power and mean energy for ion pair production for protons:

$S_{w,air,}^{p}(E)$ = 1.1545555

$W_{air,}^{p}(E)$ = 35.3374 J/C

$$S_{w,air,}^{p}(E) = \frac{aE}{(E-b)^{(1+n)}}$$

a = 1.1425

b = 0.025

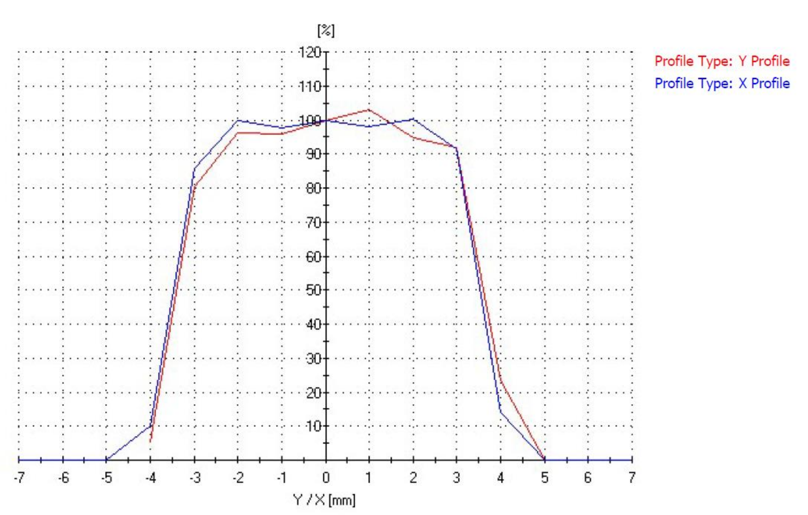
n = 0.0012

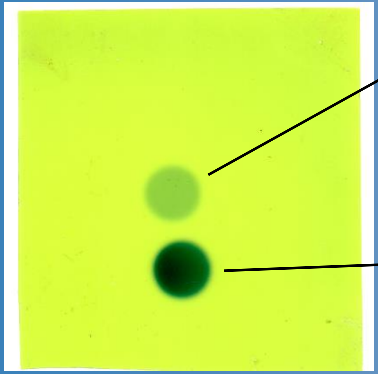
3. Correction factor for proton measurement with Co-60 calibrated chamber

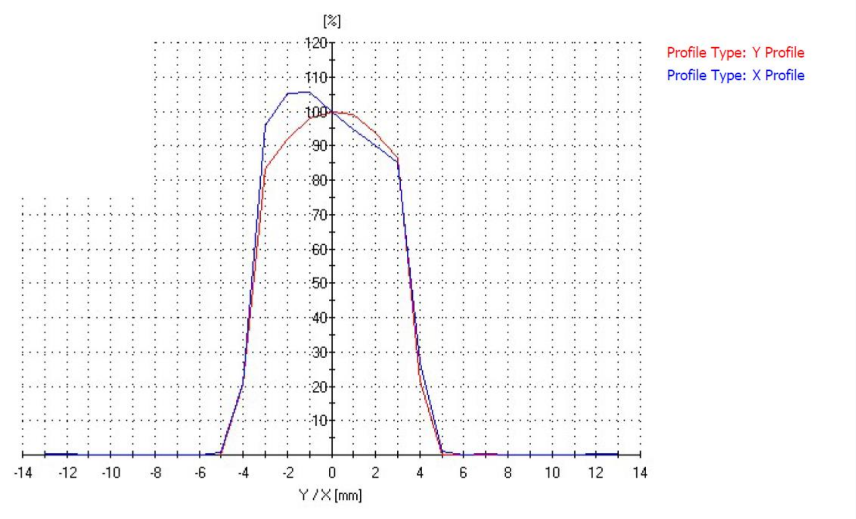
k_p^{Co} = 1.060044*

(*compared to J. Besserer et al., Dosimetry of low-energy protons and light ions, Phys. Med. Biol. **46** (2001), k_p^{Co} = 1.036)

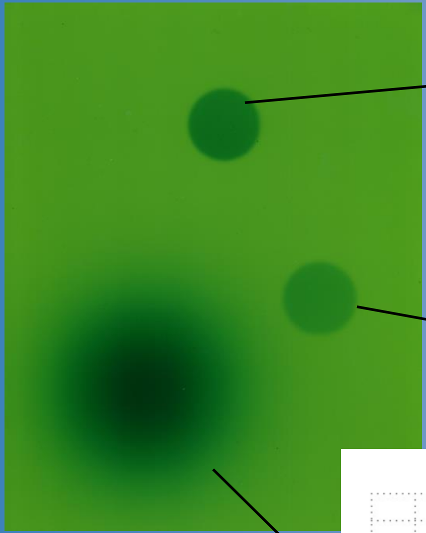
Beam characterisation – 3 MeV beams

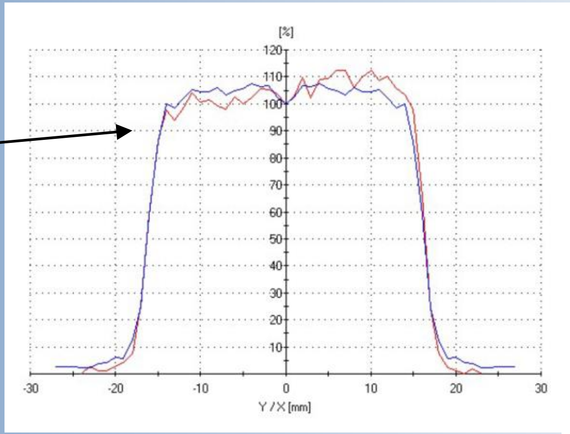


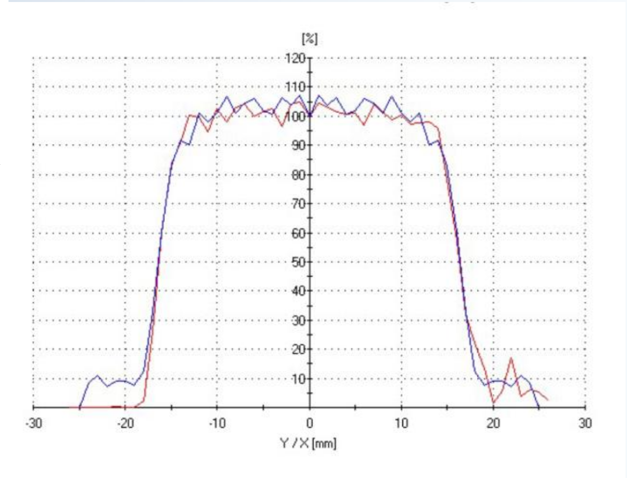


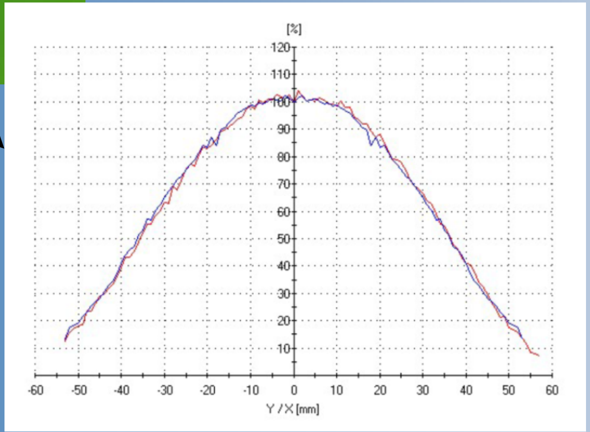


Beam characterisation – 18 MeV beams



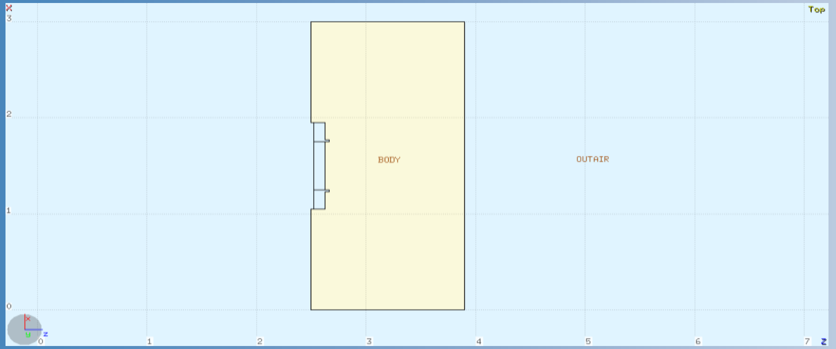


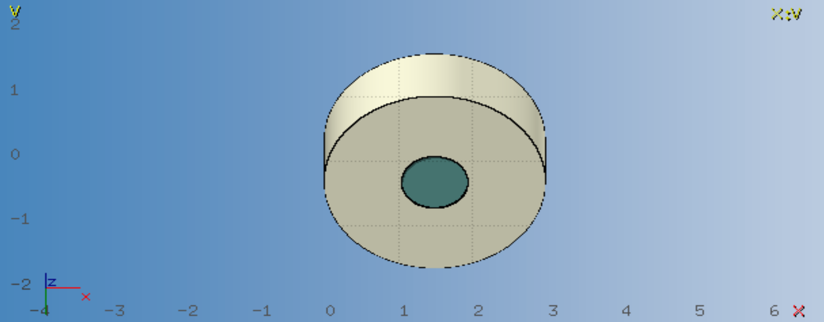


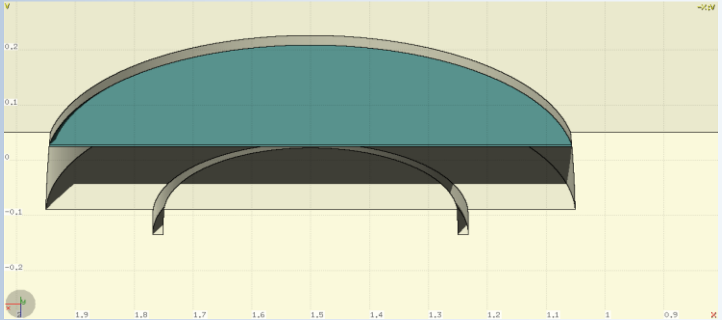


FLUKA Results - Markus advanced chamber
Source: 3 MeV proton beam (1)

Fluka geometry for a single detector; data are from the technical data sheet







FLUKA Results – particle flux vs. energy

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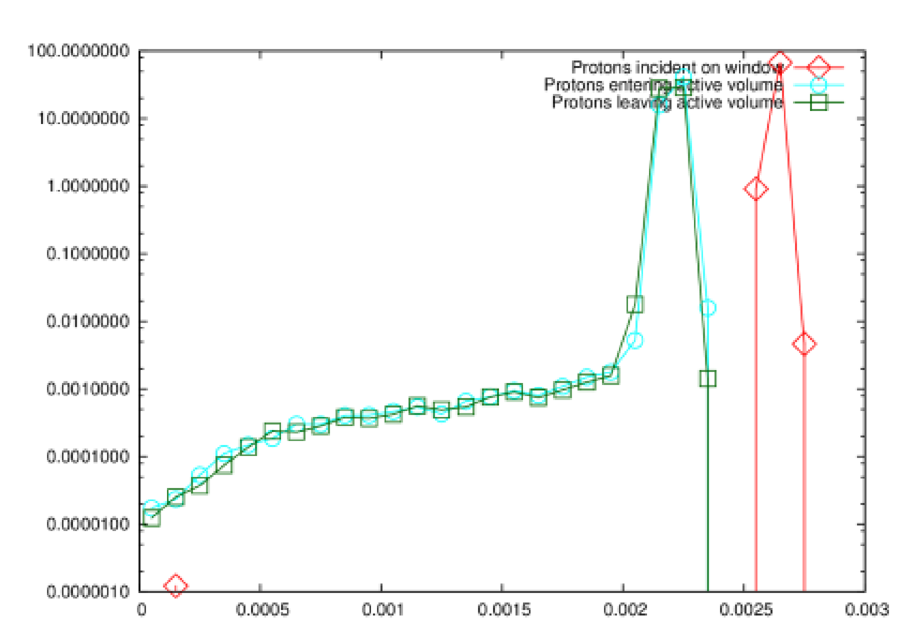
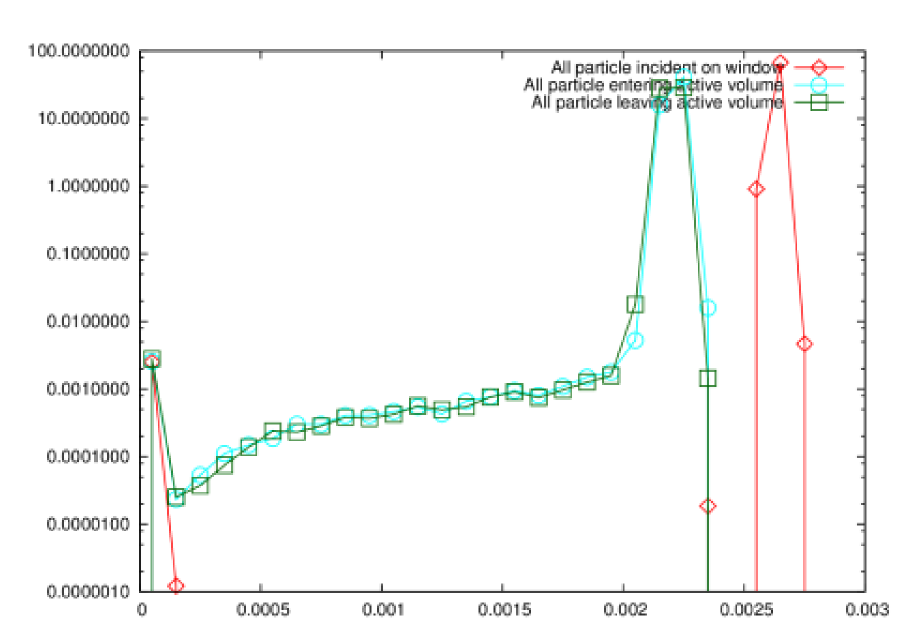




Particle energy (GeV)

Preliminary results – dose calculations

1. From the Advanced Markus™ measurements – 12.45 mGy/s

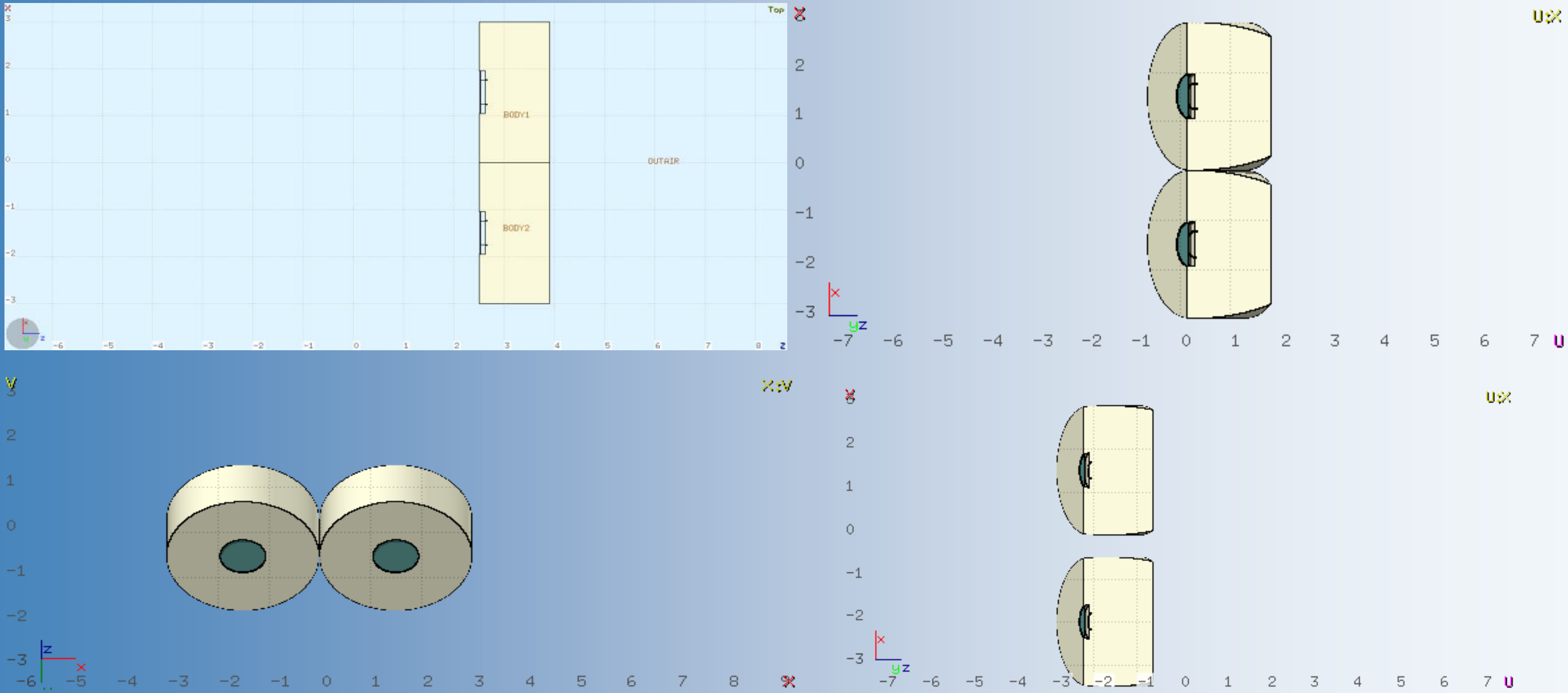
Crt. No.	Beam intensity at target (fA)	Meas. av. current (pA)	Avedev (%)	Irrad. time (s)	$M_{(int.)}$ (nC)	D_{air} (mGy)	Dose rate (mGy/s)
1	80	9.864	0.33%	6	0.059184	74.68	12.446
2	80	9.864	0.33%	32	0.315648	398.28	12.446
3	80	9.864	0.33%	64	0.631296	796.55	12.446
4	80	9.864	0.33%	192	1.893888	2,389.65	12.446

2. Calibration factor from the FLUKA simulations vs. experimental

- 1.312×10^6 Gy/C FLUKA simulation
- 1.251×10^6 Gy/C experimental
- 1.222×10^6 Gy/C Besserer et al

FLUKA Simulations next step - Markus advanced chamber

Fluka geometry for a system of two detectors; by producing controlled displacements of one of the detectors, the change in dose is quantified.



Preliminary conclusions

1. The Fluka model for the Markus chamber is properly built, the small differences in calculated vs. experimental calibration factor are due to some uncertainties in the entry parameters (beam energy & divergence, windows thicknesses) for the calculations
2. The Fluka model can be used with good confidence for assessing the reciprocal influence of the chambers in the array
3. The prototype can be used with good results in measurements in the existing beams, although for measurements at CETAL and ELI-NP a new prototype, of smaller dimensions, will have to be developed

Acknowledgements

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Thank you!