Optimization of magnetic field in ELITPC detector for ELI-NP with GEANT4 simulation toolkit

Jerzy Mańczak

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Obertrubach-Bärnfels

NARODOWE CENTRUM BADAŃ JĄDROWYCH ŚWIERK

ELI – NP facility

Extreme Light Infrastructure – Nuclear Physics

- 2 Lasers with 10 PW power

- Experiments with very brilliant gamma beam:

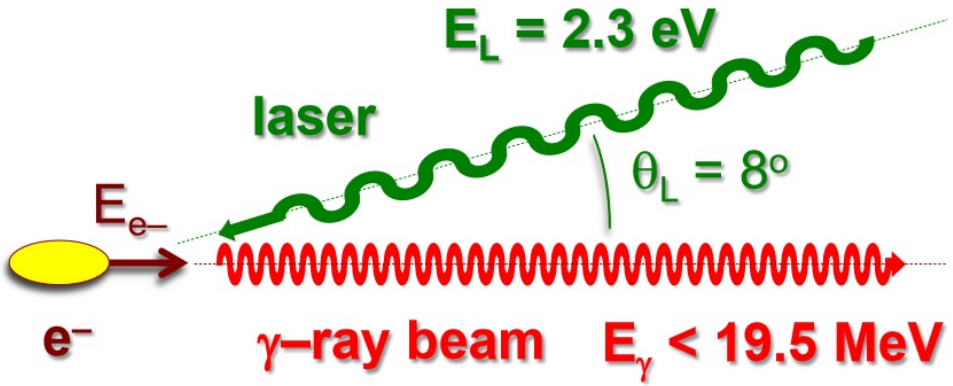
- Photodesintegration
- Photon-nucleon collisions
- Nuclear resonance fluorescence
- Nuclear astrophysics

http://www.eli-np.ro/

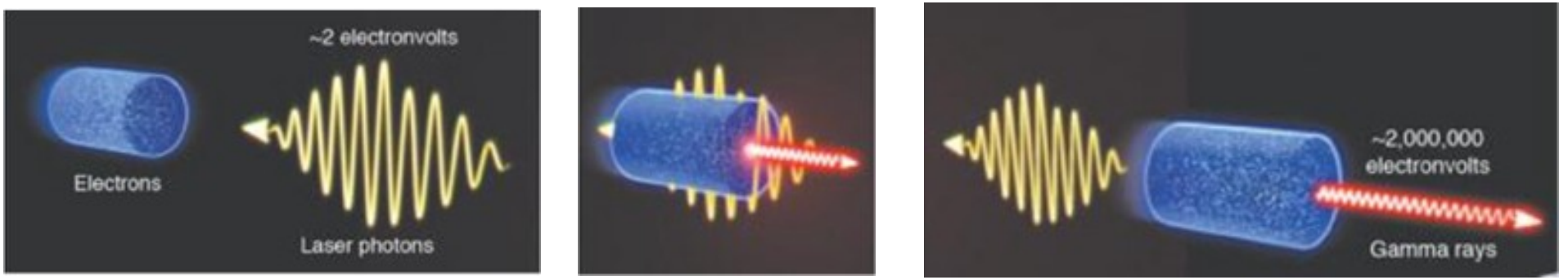
Romania, Măgurele
First measurements planned for late 2018

The gamma beam

- Photon energy 0,2-19.5 MeV
- Macropulse frequency 100 Hz
- Energy bandwidth ΔE/E~ 0.5 %
- >99% linear polarization

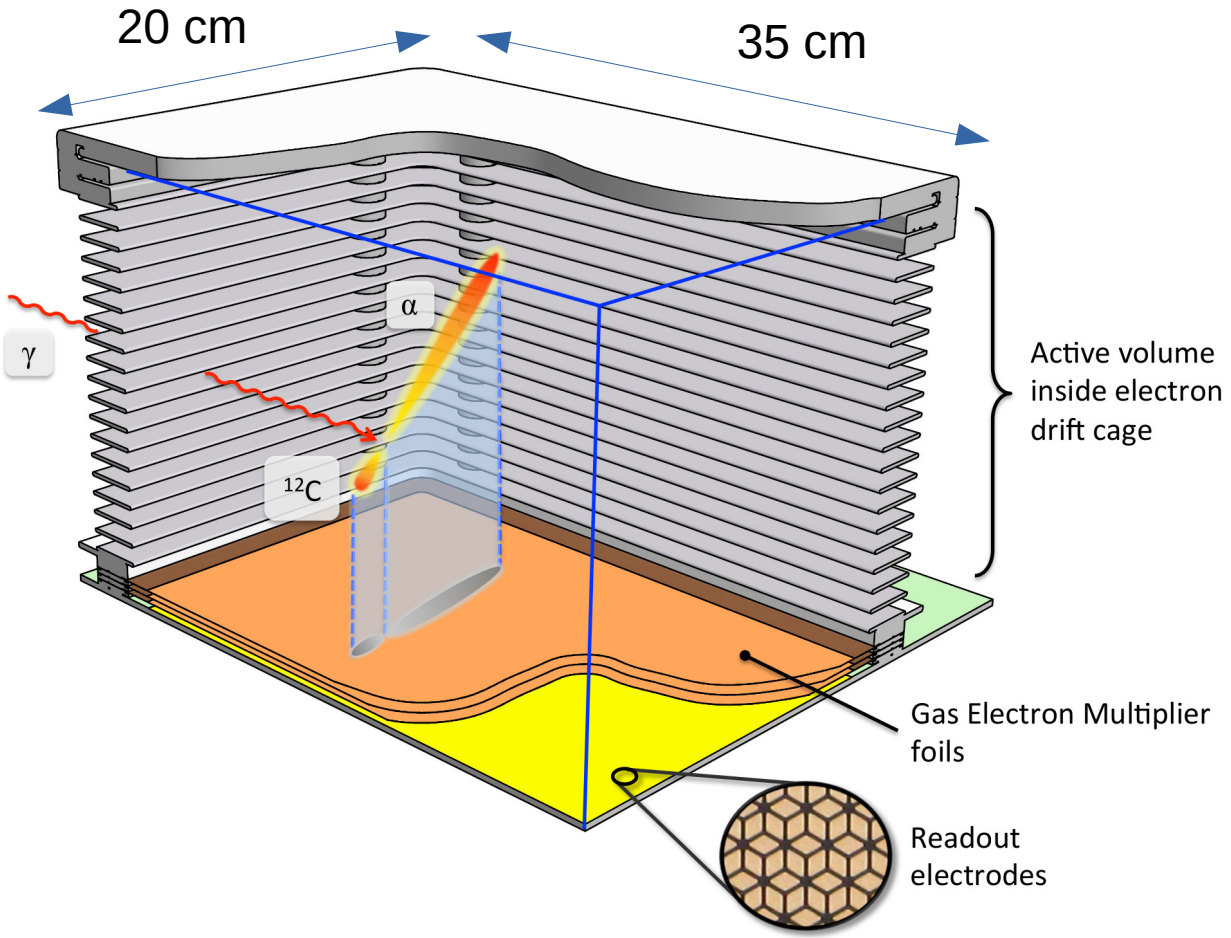


Compton backscattering of photons on electrons with energy up to 700 MeV



[1] Technical Design Report, EuroGammaS proposal for the ELI-NP Gamma beam System
[2] D.Filipescu et al., Eur. Phys. J. A51 (2015) 185

ELITPC Detector



- Under construction at Faculty of Physics, University of Warsaw
- Gaseous active-target detector
- Low pressure ~100 mbar
- 3 coordinate planar strip readout
- Various experiments with the Gamma Beam

[3] O.Tesileanu et al., *Charged Particle Detection at ELI-NP*, Romanian Rep. in Phys. 68, Supplement (2016) S699

The Flagship Reaction

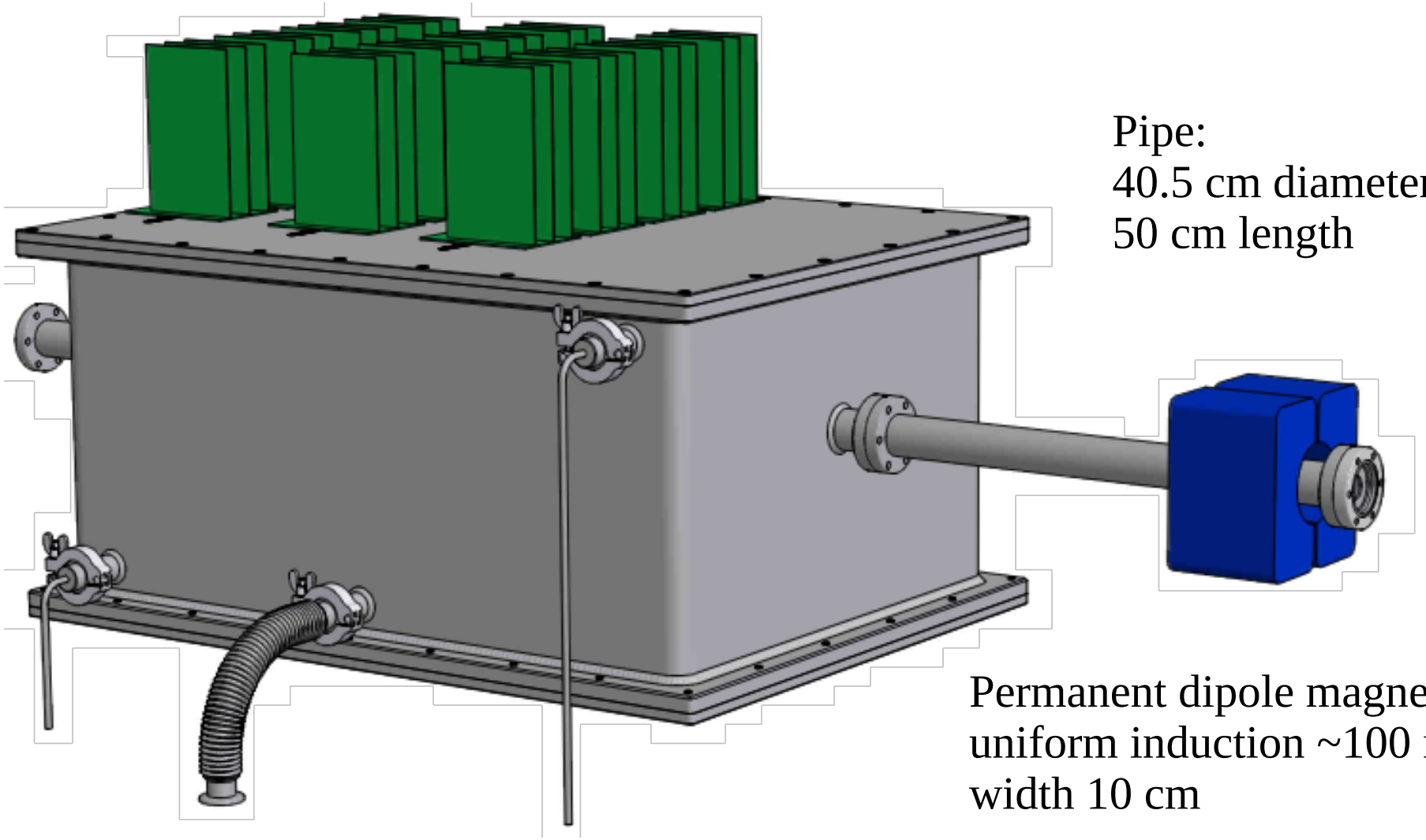
$$\gamma + {}^{16}O \longrightarrow {}^{12}C + \alpha$$

Cross section measurement for the inverse reaction (helium burning) via detailed balance principle – strong and e. m. interactions invariant with respect to time reversal

Astrophysical motivation: Measure astrophysical S-factor in the Gamow peak region for better understanding of the C/O ratio in the stellar evolution

[4] S.Gales et al., *New frontiers in nuclear physics with high-power lasers and brilliant monochromatic gamma beams*, 2016 Phys. Scr. 91 093004, 8 August 2016

Detector Geometry

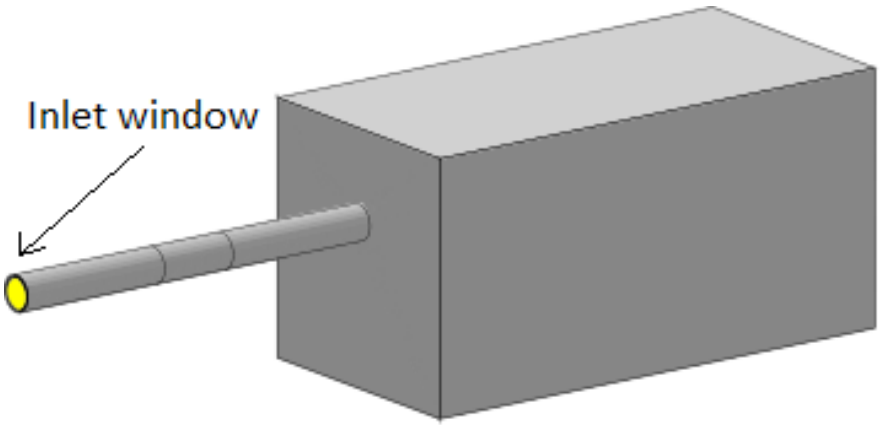


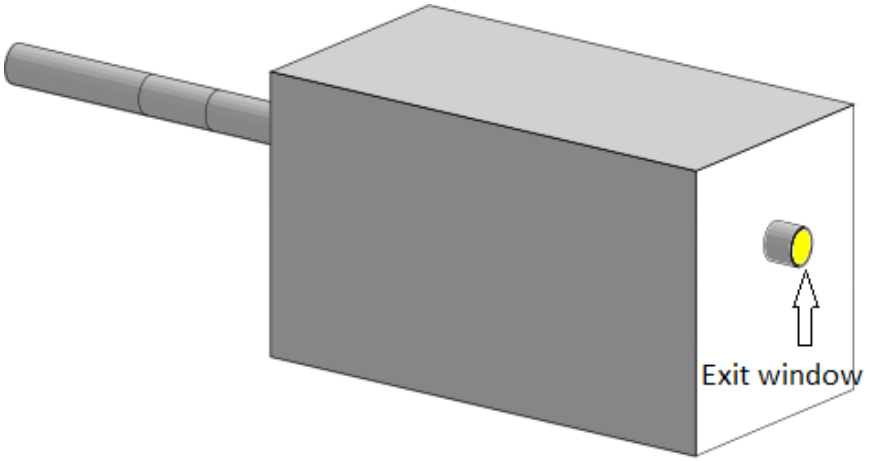
Pipe:
40.5 cm diameter
50 cm length

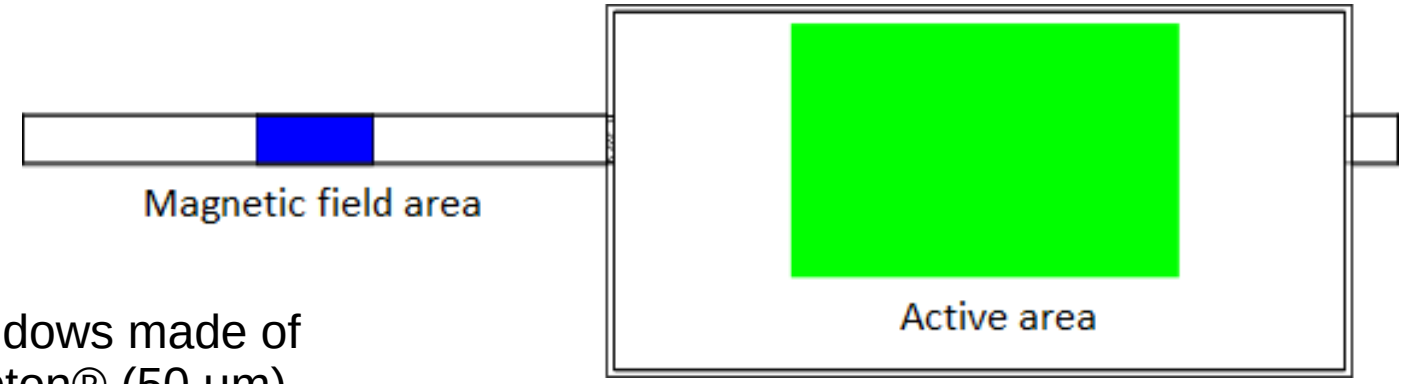
Permanent dipole magnet
uniform induction ~100 mT
width 10 cm

We need a magnet to reduce the background signal from electrons/positrons !!

Simplified detector geometry

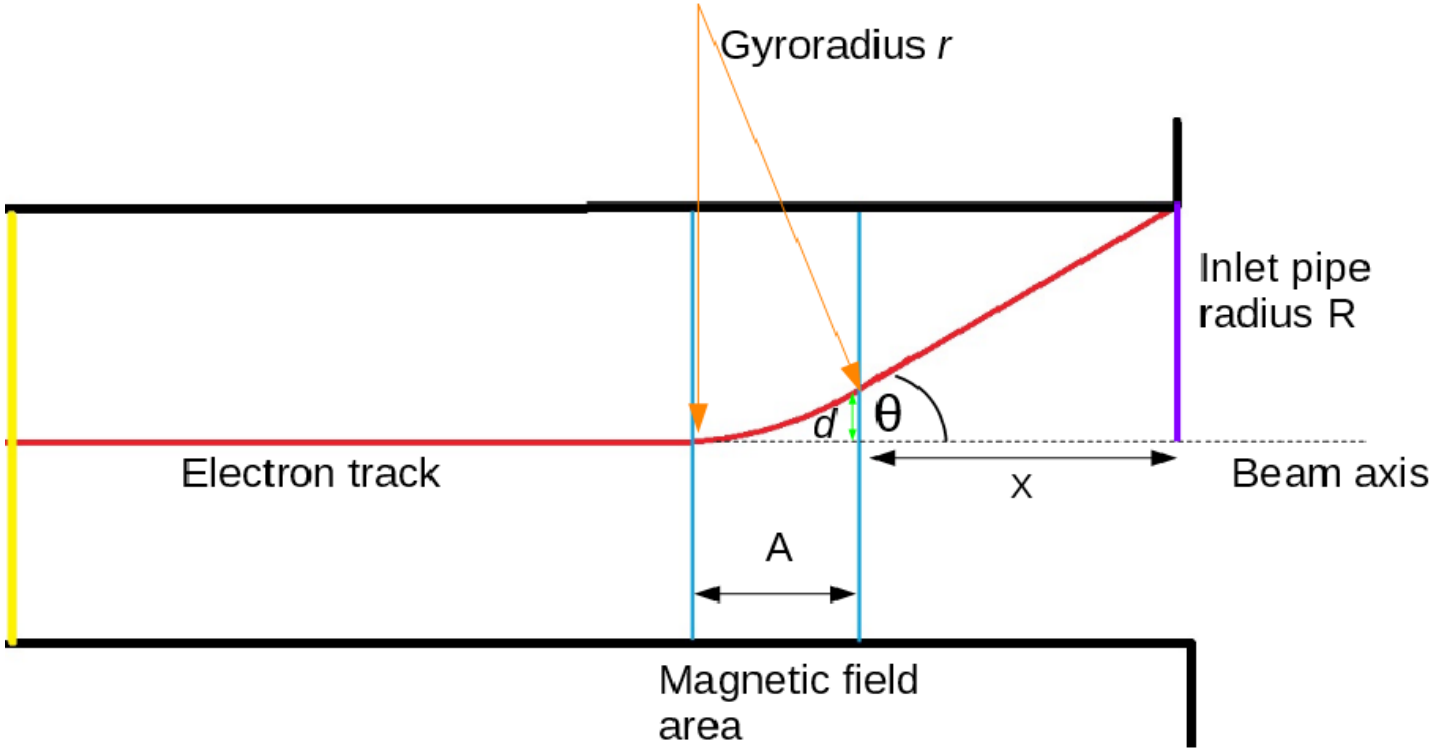






Windows made of
Kapton® (50 µm)

Track bending scheme



Assumptions:

- Uniform magnetic field
- Gyroradius > magnetic field width
- Liminal angle θ is small, so

$$tg(\theta) = \frac{R}{A+x} = \frac{d}{A}$$

$$r = \frac{p_e}{qB} = \frac{\sqrt{E^2 - m^2}}{qB}$$

For example values A=10 cm, x=20cm and p_e=20 MeV

Liminal radius r=74.41 cm

To reach that radius B=89.6 mT needed

Simulation model

Interactions of photons included:

- Photoelectric effect
- Compton scattering
- Pair production

Interactions of electrons and positrons:

- Bremstrahlung
- Ionization
- Coulomb scattering with multiple scattering included
- Synchrotron radiation

Path step calculation cuts for different regions:

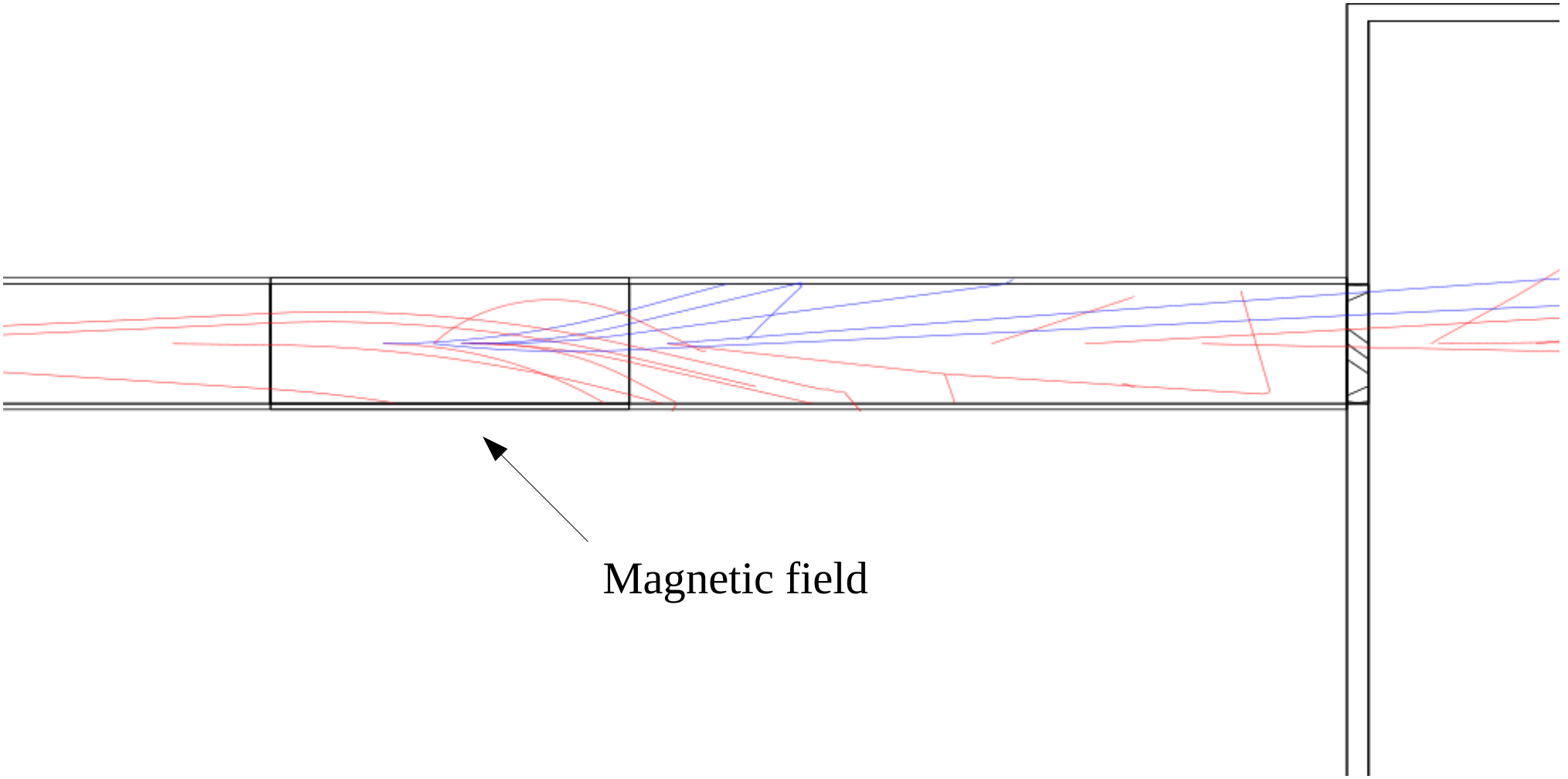
- Inlet window – 2.5 μm
- Walls of the steel inlet pipe – 0.2 mm
- Detector chamber – 1 cm
- Detector chamber steel walls – 0.2 mm

*Based on simulation code developed by Piotr Podlaski

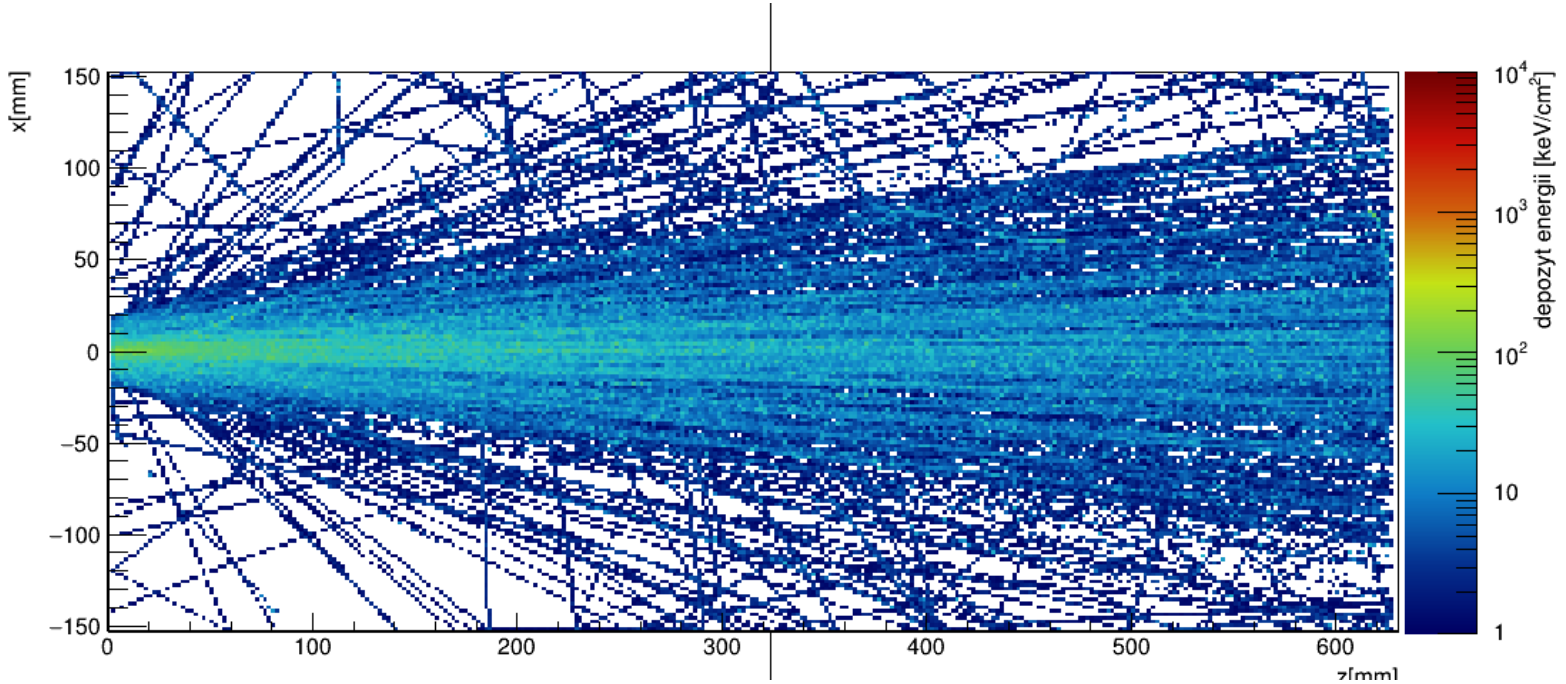
Simulation procedure

- For each simulation run 10^7 photons were shot
- 3 beam energies: 5, 10 and 20 MeV, precise E values, monochromatic and point-like beam
- 2 gas mixtures: pure CO_2 (100 mbar) and CO_2-He (50:50, 200 mbar)
- Magnetic field is (width 10 cm) moving along the pipe with 5 cm steps

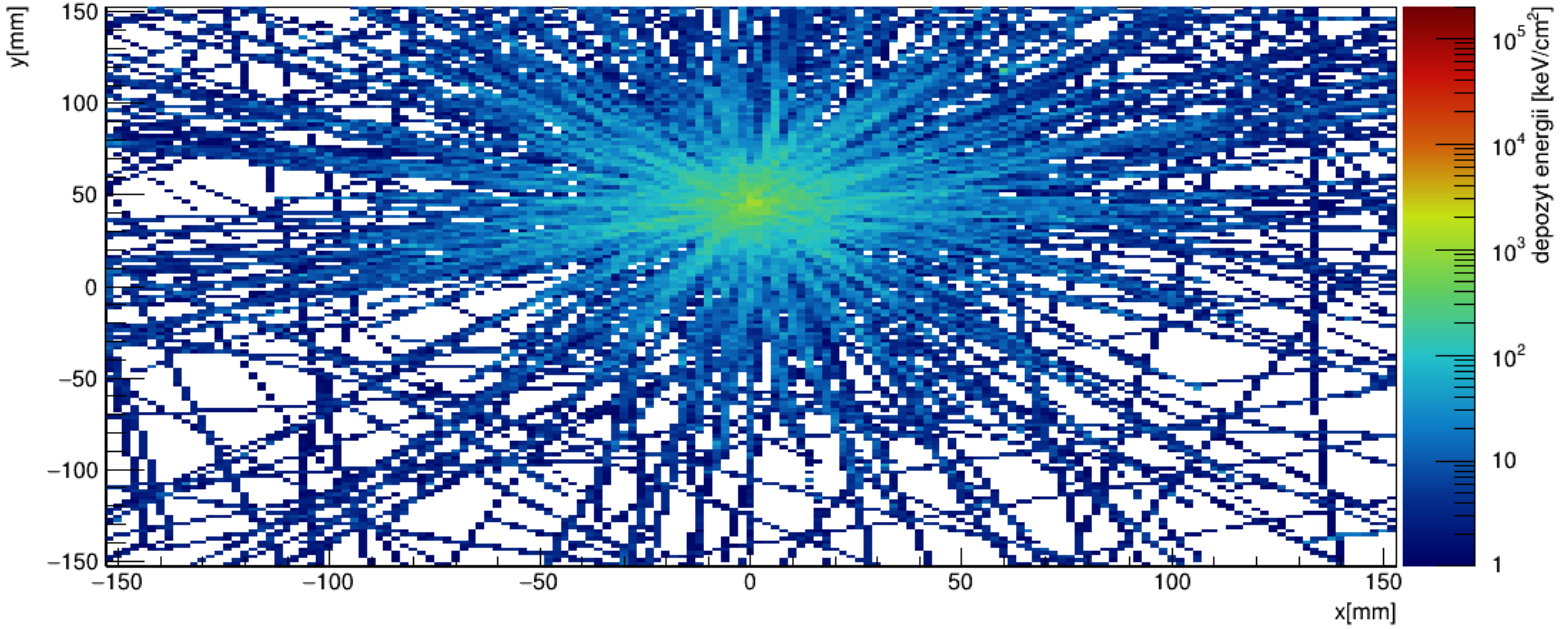
Example of interactions



Example simulation result

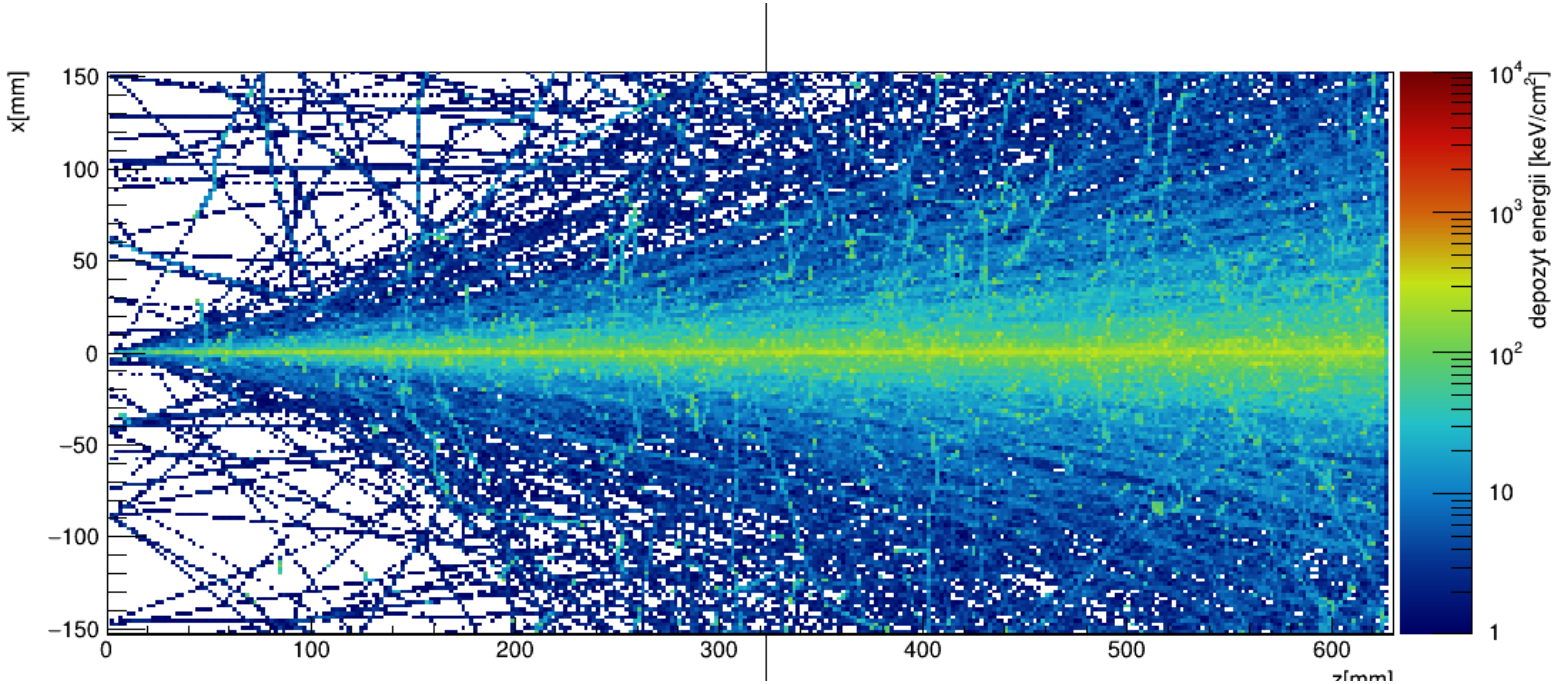


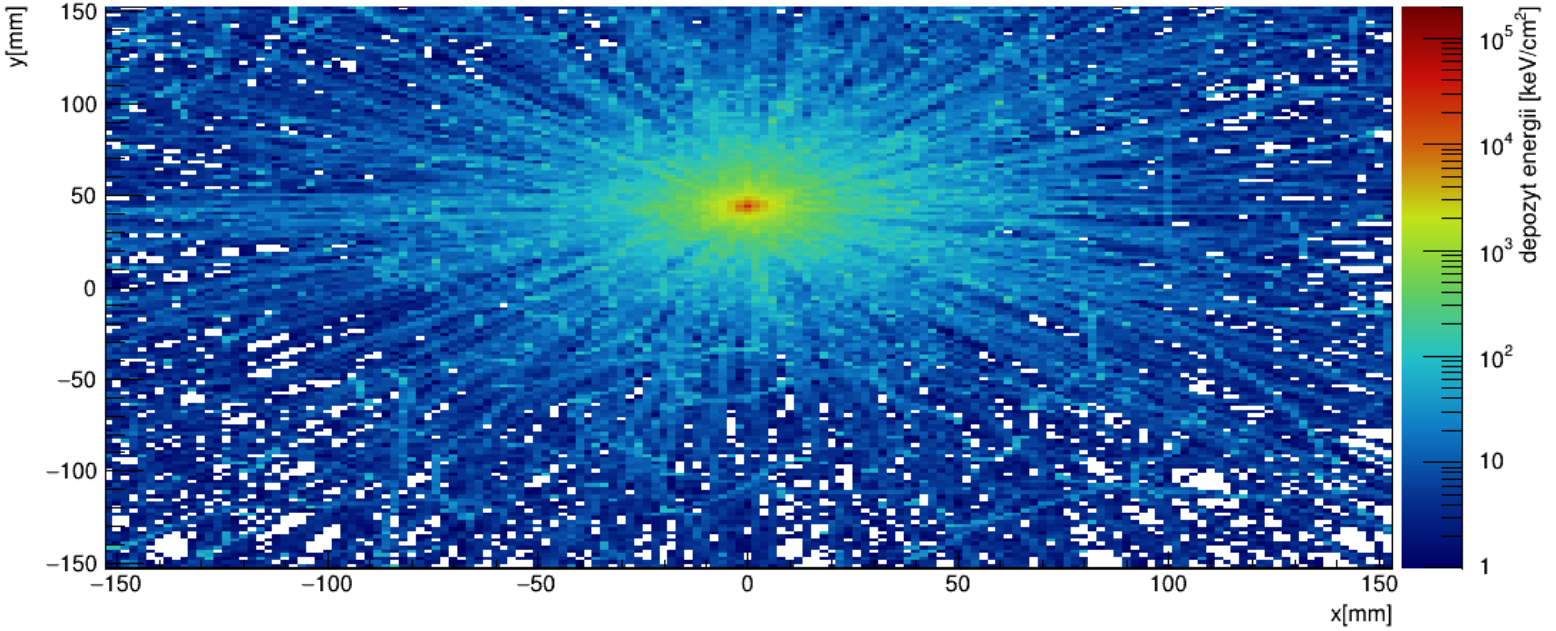
10 MeV Gamma
C02 100 mbar
Pipe origin only



Integrated deposit ~20 MeV

Example simulation result

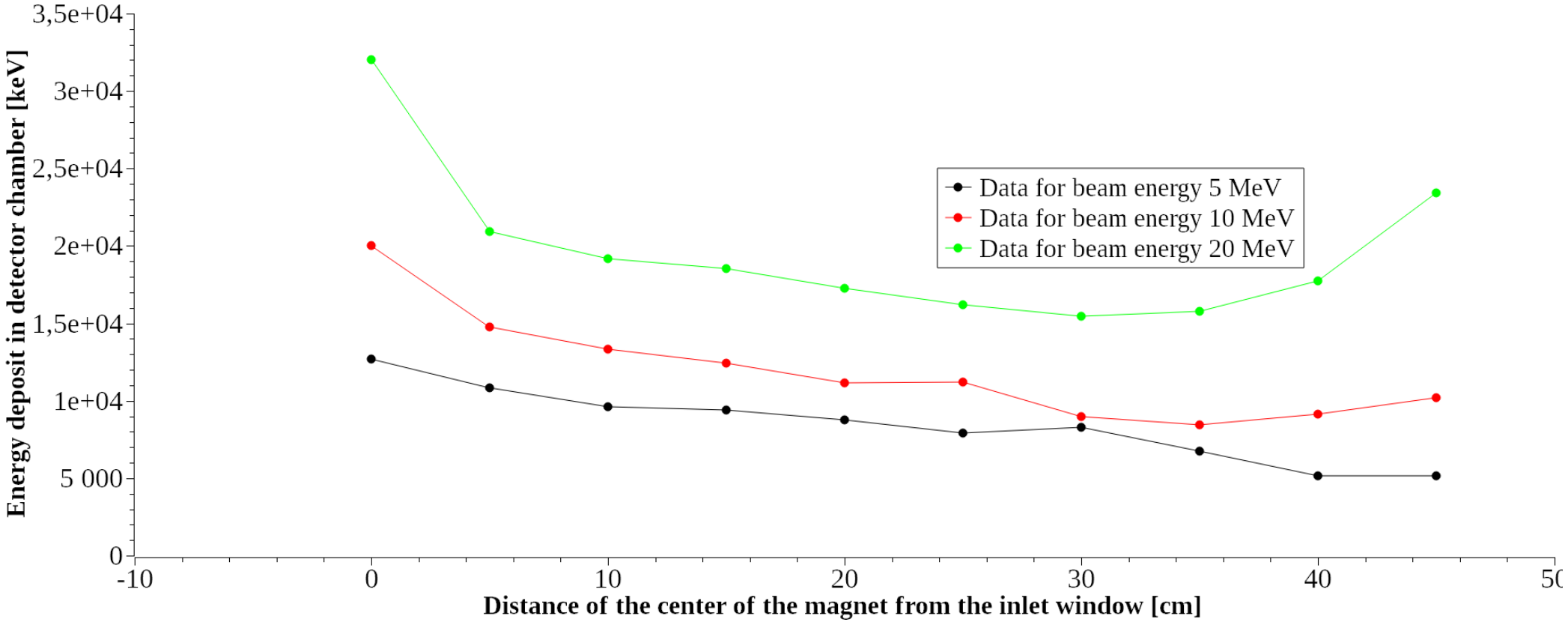




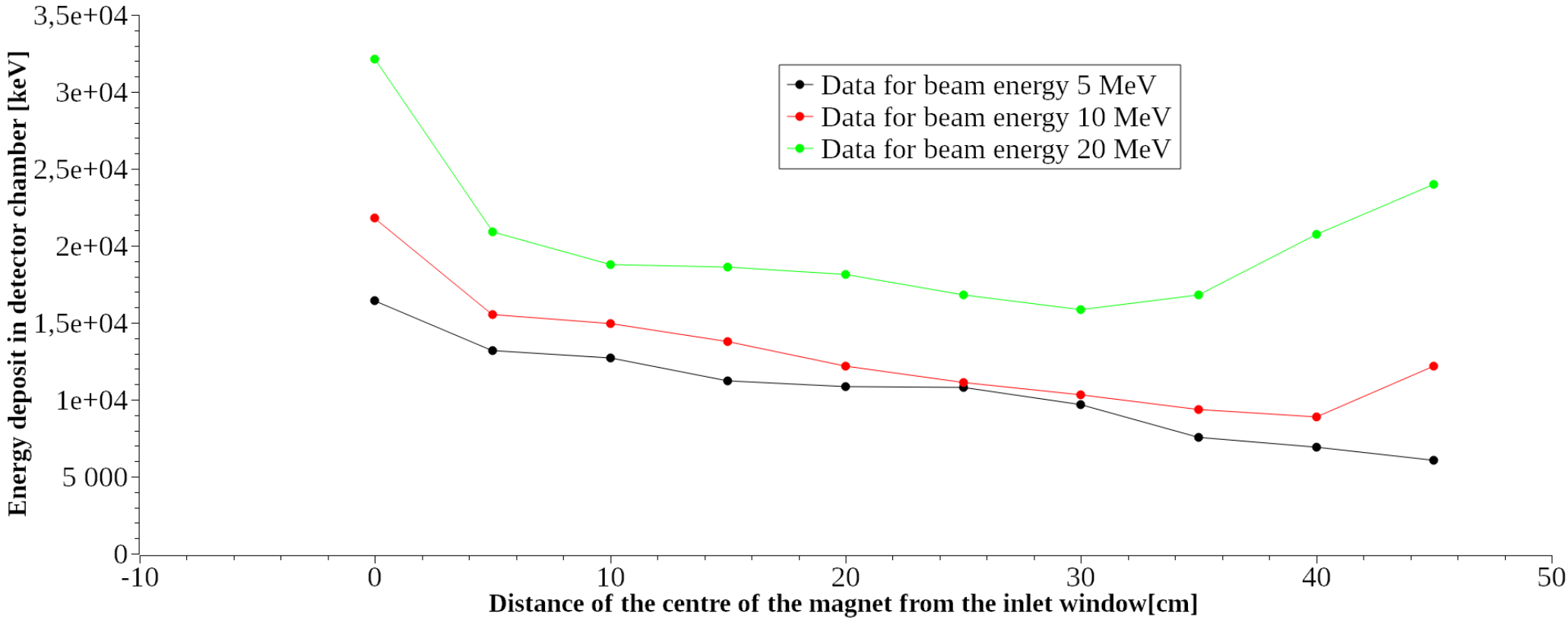
10 MeV Gamma
C02 100 mbar
Chamber origin only

Integrated deposit ~29 MeV

Results for CO_2



Results for CO_2-He



Summary

- Magnet can significantly reduce background signal
- The tool for further optimization was developed
- Current status: prototype detector is being tested in Romania
- First beam energy ~8 MeV

Thank you for your attention !

References

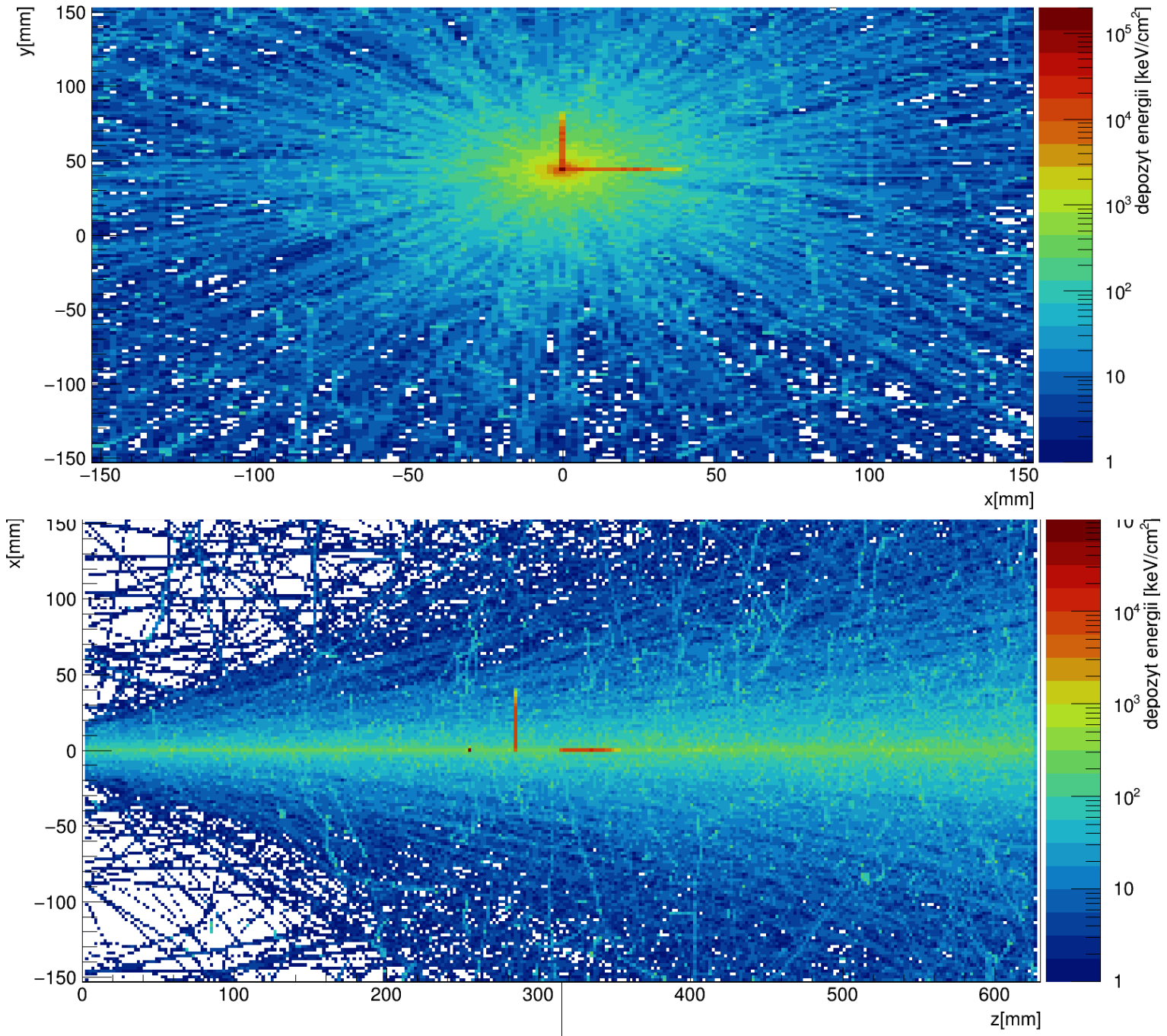
[1] *Technical Design Report*, EuroGammaS proposal for the ELI-NP Gamma beam System [access on-line: https://arxiv.org/ftp/arxiv/papers/1407/1407.3669.pdf

[2] D.Filipescu et al., Eur. Phys. J. A51 (2015) 185 [access on-line: http://link.springer.com/article/10.1140/epja/i2015-15185-9

[3] O.Tesileanu et al., *Charged Particle Detection at ELI-NP*, Romanian Rep. in Phys. 68, Supplement (2016) S699 [full text: http://www.rrp.infim.ro/IP/S13.pdf]

[4] S.Gales et al., *New frontiers in nuclear physics with high-power lasers and brilliant monochromatic gamma beams*, 2016 Phys. Scr. 91 093004, 8 August 201 [full text: http://www.eli-np.ro/scientific-papers/ps_91_9_093004.pdf]

Reaction signal with expected background



Backup – GBS parameters

Parameter [units]	Value
Photon energy [MeV]	0.2 – 19.5
Spectral density [ph/s/eV]	> 10^4
Bandwidth	< 0.5 %
# photons / shot FWHM bdw.	1.0 – $4.0 \cdot 10^5$
# photons/sec FWHM bdw.	2.0 – $8.0 \cdot 10^8$
Source rms size [μm]	10 – 30
Source rms divergence [μrad]	25 – 250
Peak brill. [N_{ph}/sec·mm²mrad²·0.1%]	10^{22}– 10^{24}
Radiation pulse length [ps]	0.7 – 1.5
Linear polarization	> 99 %
Macro repetition rate [Hz]	100
# of pulses per macropulse	>31
Pulse–to–pulse separation [ns]	16

Taken from presentation by Catalin Matei "Electronics & Integration of Gamma Beam Monitoring Instruments at ELI-NP", ELI-NP Electronics Workshop, 09/2017