Channeling 2014
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Capri-Naples, Italy

Monte Carlo simulation of a collimation system for low-energy beamline (1-5 MeV) of ELI-NP Gamma Beam System

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EuroGammas

The Extreme Light Infrastructure – ELI Project

ELI is a **European Project**, involving nearly 40 research and academic institutions from 13 EU Members Countries, forming a pan-European Laser facility, that aims to host frontier **high-power lasers**, as well as various **radiation beam-lines** (electrons, protons, x-rays and gamma rays) for different applications.

- **ELI-Nuclear Physics** (Bucharest, Romania): dedicated to the development of laser beams and the generation of **high-intensity gamma beams** for frontier research in nuclear physics.

- **ELI-Beamlines** (med-biomed) (Prague, Czech Republic)

- **ELI-Attosecond** (Szeged, Hungary)

EuroGammas for ELI-NP gamma beam system

One of the goals of ELI-NP infrastructure is the production of gamma beam (ELI-NP-GBS) using inverse Compton scattering of laser light from an accelerated electron beam for nuclear physics experiments.

- **The gamma beam produced is expected to have:**

- Energy tunable in the interval between **1 MeV and 20 MeV**,

- Energy bandwidth **$\Delta E/E < 0.5\%$**,

- About **10^8 photons per second within FWHM**

- EuroGammaS Association is composed by INFN, as leader, the Università degli Studi di Roma "La Sapienza", CNRS, ACP S.A.S., Alsyom S.A.S., Comeb Srl, ScandiNova Systems AB.
- **EuroGammaS will provide the design, manufacturing, delivery, installation, testing, commissioning and maintenance of the Gamma Beam System (GBS),** for the benefit of the ELI-NP project, managed by the Horia Hulubei National Institute for Physics and Nuclear Engineering Bucharest - Magurele, ROMANIA.

EuroGammas

http://www.e-gammas.com

ELI-NP gamma beam system parameter list

Table 63. Gamma-ray beam for selected collision examples (from Start-to-end simulations)

all quantities are rms	Low Energy Interaction	Low Energy Interaction	High Energy Interaction	High Energy Interaction
Energy (MeV)	2.00	3.45	9.87	19.5
Spectral Density (ph/sec.eV)	39,760	21,840	16,860	8,400
Bandwidth (%)	0.5	0.5	0.5	0.5
# photons per shot within FWHM	$1.2\cdot10^{5}$	$1.1\cdot10^{5}$	$2.6\cdot10^{5}$	$2.5\cdot10^{5}$
# photons/sec within FWHM	$4.0\cdot10^{8}$	$3.7\cdot10^{8}$	$8.3\cdot10^{8}$	$8.1\cdot10^{8}$
Source rms size (μm)	12	11	11	10
Source rms divergence (μrad)	140	100	50	40
Peak Brilliance (N_{ph}/sec·mm^{2}mrad^2·0.1%)	$9.1\cdot10^{21}$	$1.9\cdot10^{22}$	$1.8\cdot10^{23}$	$3.3\cdot10^{23}$
Average Brilliance (N_{ph}/sec·mm^{2}mrad^2·0.1%)	$2.9\cdot10^{13}$	$6.2\cdot10^{13}$	$5.9\cdot10^{14}$	$1.1\cdot10^{15}$
Rad. pulse length (rms, psec)	0.92	0.91	0.95	0.9
Linear Polarization (%)	> 99.8	> 99.8	> 99.8	> 99.8
Macro rep. rate (Hz)	100	100	100	100
# of pulses per macropulse	32	32	32	32
Pulse-to-pulse sep. (nsec)	16	16	16	16
Contrast ratio 1^{st} / 2^{nd} harmonic	$1.5\cdot10^{5}$	$8.5\cdot10^{4}$	$7.0\cdot10^{4}$	$4.4\cdot10^{4}$
Luminosity @ (1,0.5) psec delay	(94,99) %	(92,98) %	(91,98) %	(85,96) %
Lumin. @ (5,2) μm misalignment	(98,99) %	(96,99) %	(90,97) %	(87,95) %

Gamma beam specifications

Photon energy	0.2-19.5 *MeV*
Spectral Density	$0.8\text{-}4\cdot10^{4}$ *ph/sec.eV*
Bandwidth (rms)	$\leq$ 0.5%
# photons per shot within FWHM bdw.	$\leq 2.6\cdot10^{5}$
# photons/sec within FWHM bdw.	$\leq 8.3\cdot10^{8}$
Source rms size	10 - 30 μm
Source rms divergence	25 - 200 μrad
Peak Brilliance (*N_{ph}/sec·mm^{2}mrad^2·0.1%*)	10^{20} - 10^{23}
Radiation pulse length (rms, *psec*)	0.7 - 1.5
Linear Polarization	> 99 %
Macro rep. rate	100 *Hz*
# of pulses per macropulse	$\leq$ 32
Pulse-to-pulse separation	16 *nsec*

Technical Design Report

EuroGammaS proposal for the ELI-NP Gamma beam System

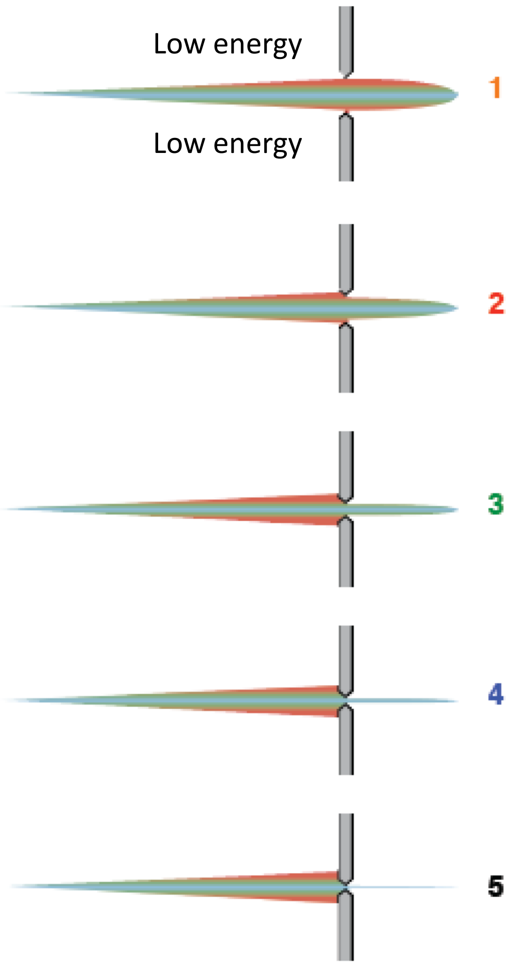
With 73 tables and 230 figures

O. Adriani, S. Albergo, D. Alesini, M. Anania, D. Angal-Kalinin, P. Antici, A. Bacci, R. Bedogni, M. Bellaveglia, C. Biscari, N. Bliss, R. Boni, M. Boscolo, F. Broggi, P. Cardarelli, K. Cassou, M. Castellano, L. Catani, I. Chaikovska, E. Chiadroni, R. Chiche, A. Cianchi, J. Clarke, A. Clozza, M. Coppola, A. Courjaud, C. Curatolo, O. Dadoun, N. Delerue, C. De Martinis, G. Di Domenico, E. Di Pasquale, G. Di Pirro, A. Drago, F. Druon, K. Dupraz, F. Egal, A. Esposito, F. Falcoz, B. Fell, M. Ferrario, L. Ficcadenti, P. Fichot, A. Gallo, M. Gambaccini, G. Gatti, P. Georges, A. Ghigo, A. Goulden, G. Graziani, D. Guibout, O. Guilbaud, M. Hanna, J. Herbert, T. Hovsepian, E. Iarocci, P. Iorio, S. Jamison, S. Kazamias, F. Labaye, L. Lancia, F. Marcellini, A. Martens, C. Maroli, B. Martlew, M. Marziani, G. Mazzitelli, P. McIntosh, M. Migliorati, A. Mostacci, A. Mueller, V. Nardone, E. Pace, D.T. Palmer, L. Palumbo, A. Pelorosso, F.X. Perin, G. Passaleva, L. Pellegrino, V. Petrillo, M. Pittman, G. Riboulet, R. Ricci, C. Ronsivalle, D. Ros, A. Rossi, L. Serafini, M. Serio, F. Sgamma, R. Smith, S. Smith, V. Soskov, B. Spataro, M. Statera, A. Stecchi, A. Stella, A. Stocchi, S. Tocci, P. Tomassini, S. Tomassini, A. Tricomi, C. Vaccarezza, A. Variola, M. Veltri, S. Vescovi, F. Villa, F. Wang, E. Yildiz, F. Zomer

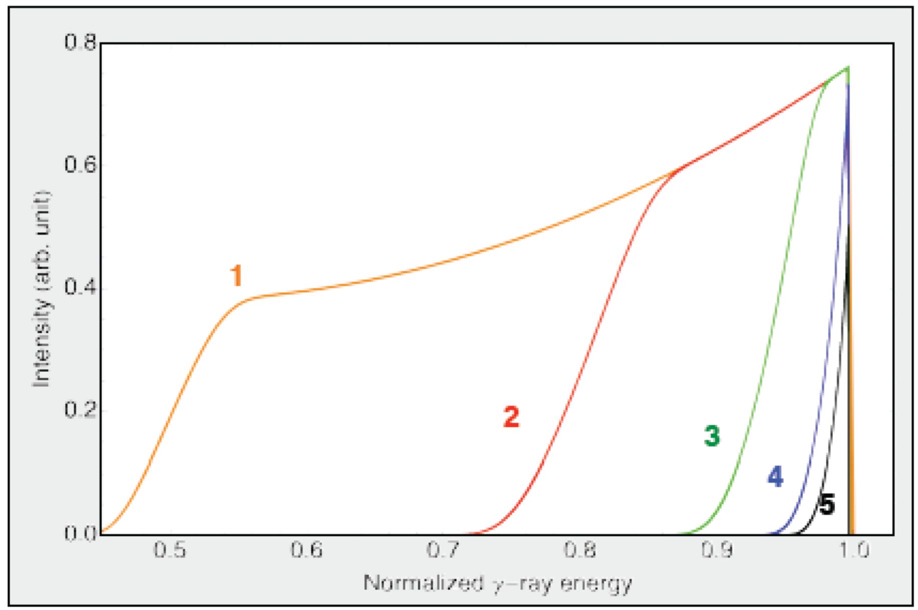
IC Gamma beam collimation system

Inverse Compton radiation is not intrinsically monochromatic, the energy is related to the emission angle.

The required **energy band-width** can be obtained only by developing specific methods of **collimation of gamma beam**.



$$\Delta\theta \approx \frac{1}{\gamma}\ ;\ \Delta\nu_{\gamma} \approx 50\%$$



$$\Delta\theta \approx \frac{\varepsilon_n}{\sigma_x \gamma}; \Delta\nu_{\gamma} \approx \left(\frac{\varepsilon_n^2}{\sigma_x^2}\right)$$

no red shift considered

Courtesy C. Barty –LLNL

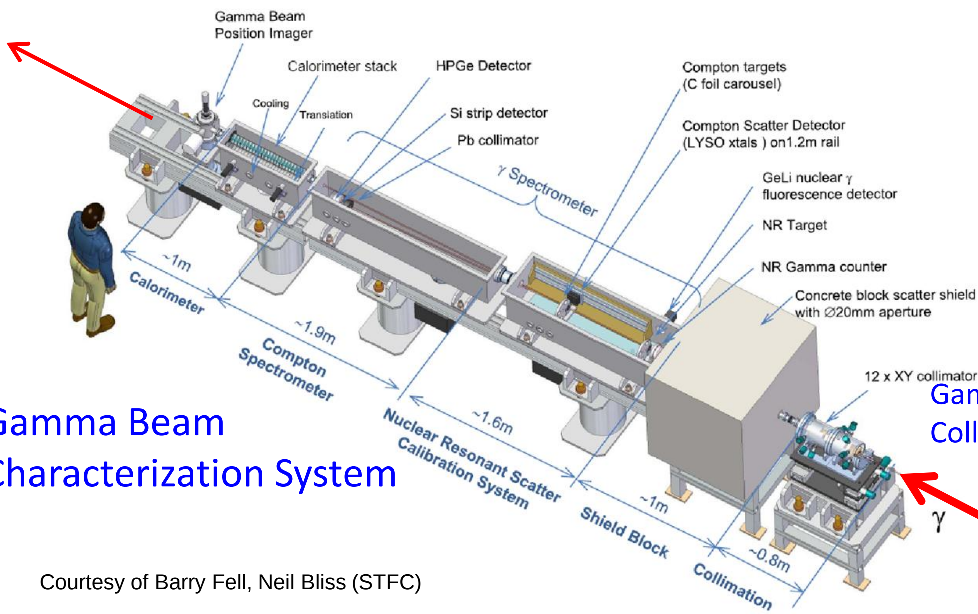
EuroGammas WP09 and collimation system

- To obtain the desired **energy bandwidth < 0.5 % at 20 MeV a collimation at 40 μrad semi-divergence** is needed, demanding a very challenging design
- These divergence corresponds to **collimation apertures that varies from few mm to less than 0.7 mm**, depending on the distance IP-CS and on the selected beam energy

Main requirements of the collimation system:

- **Low transmission of gamma photons** (high density and high atomic number)
- **Continuously adjustable aperture** (to adjust the energy band-width in the entire energy range)
- **Avoid contamination of the primary beam** with production of secondary radiation

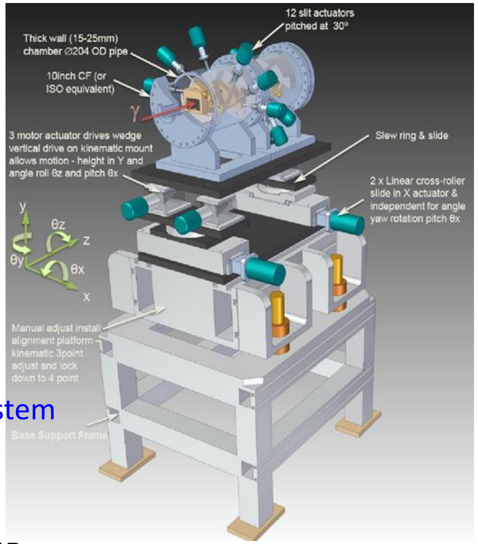
to user area



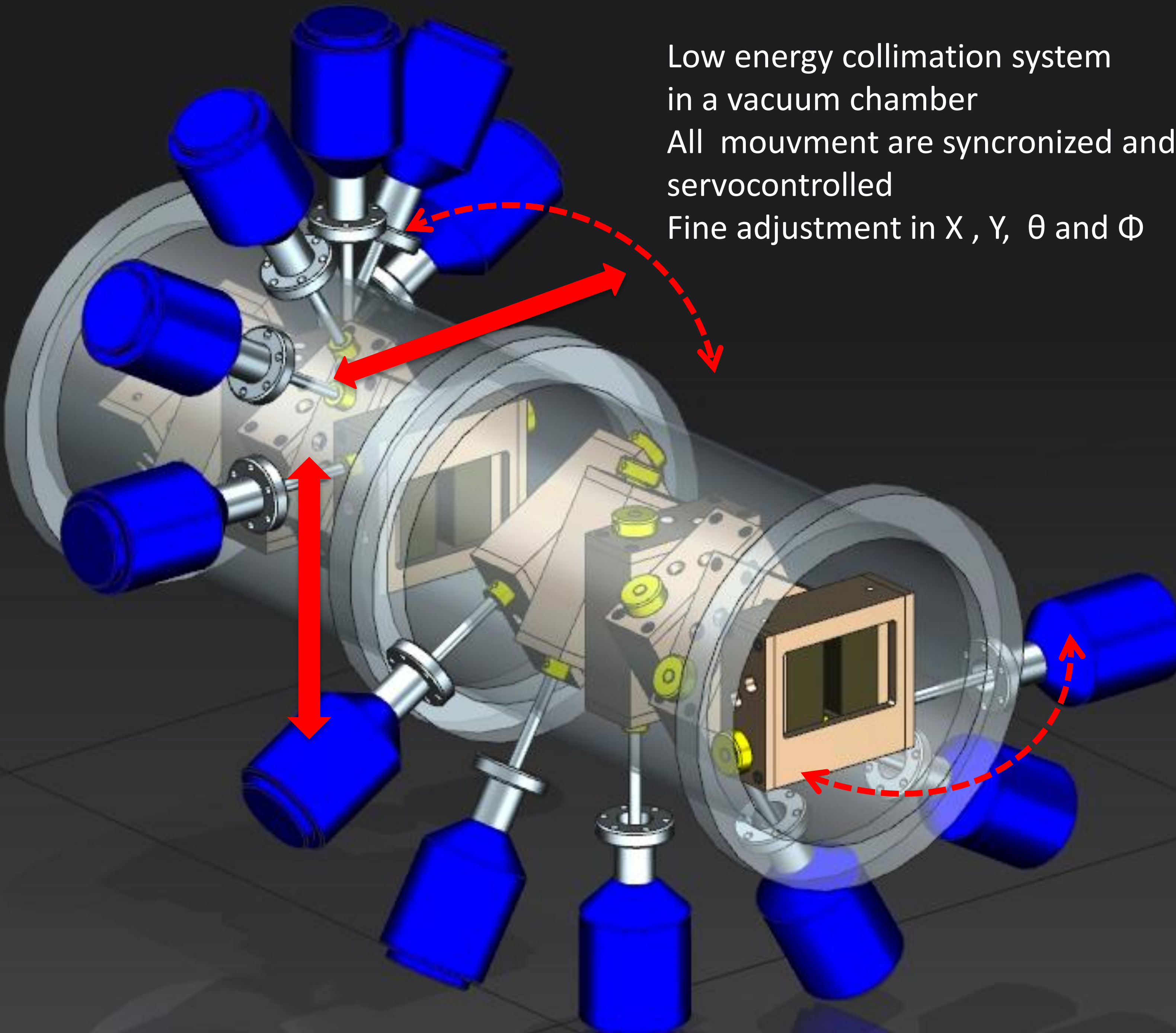
Gamma Beam Characterization System

Courtesy of Barry Fell, Neil Bliss (STFC)

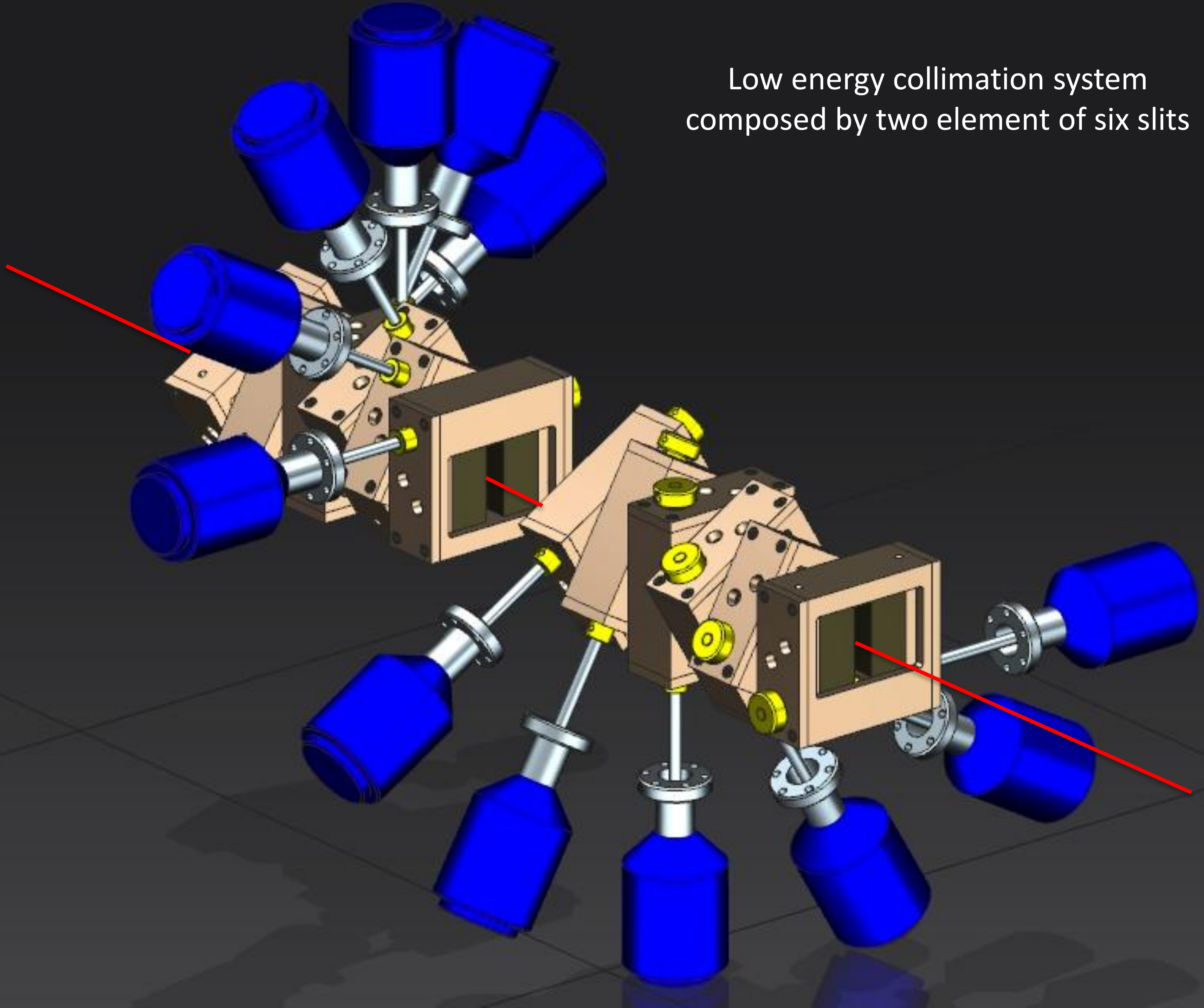
Gamma Beam Collimation System

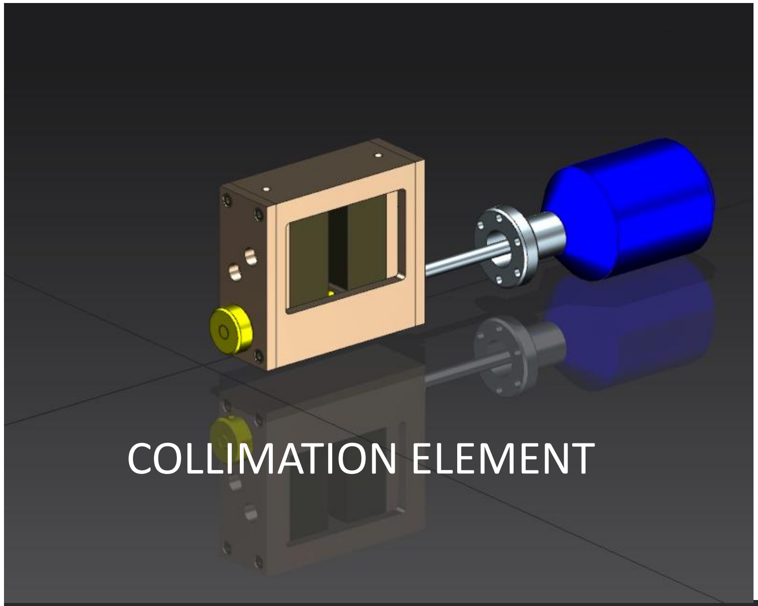


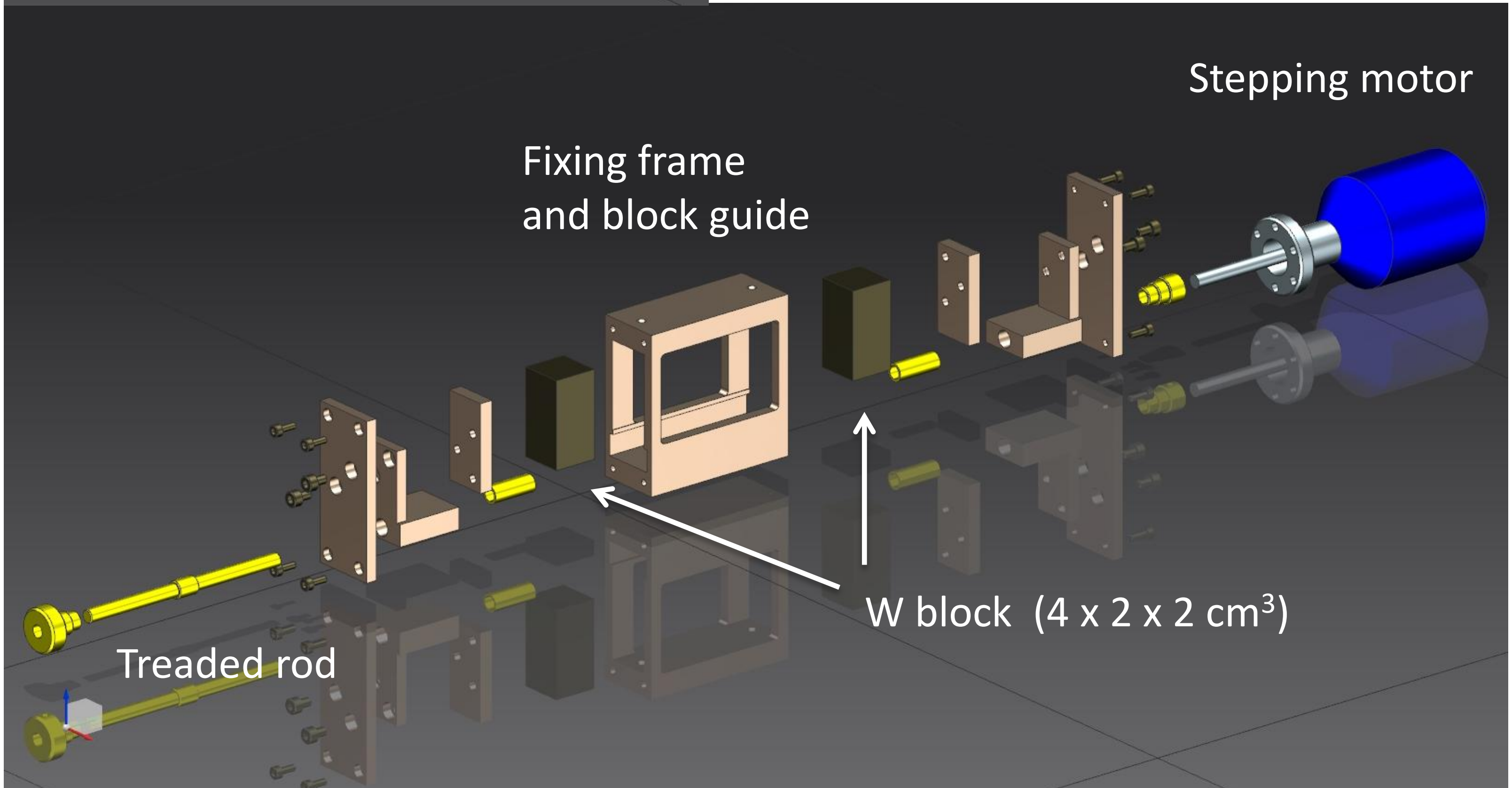
from IP


Low energy collimation system
in a vacuum chamber
All mouvment are syncronized and
servocontrolled
Fine adjustment in X , Y, θ and Φ

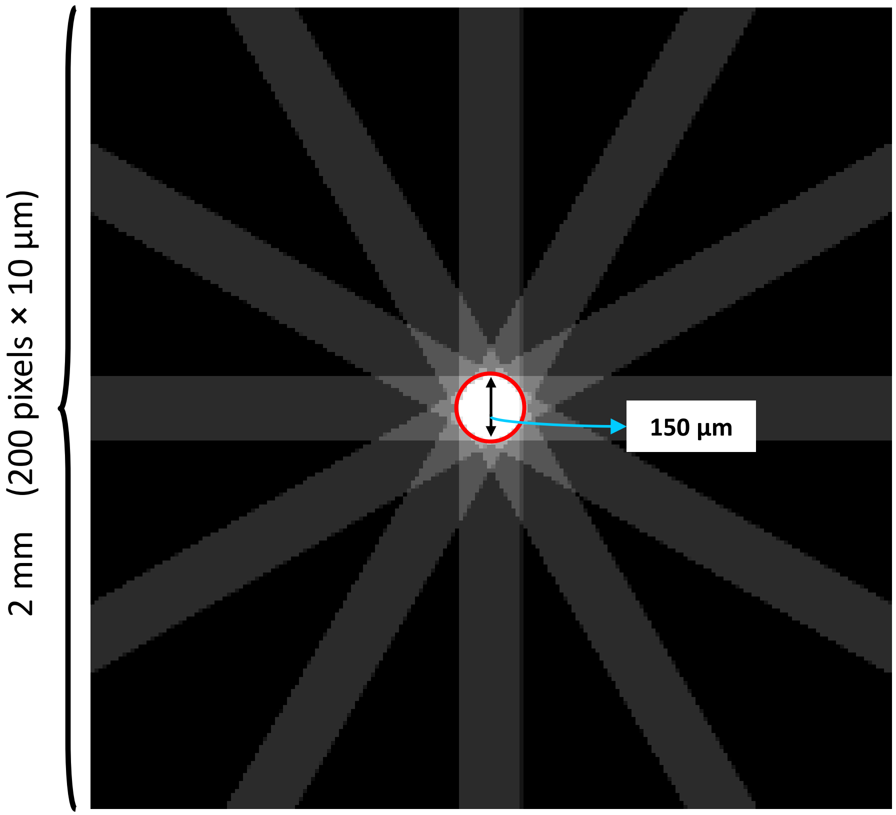
Low energy collimation system
composed by two element of six slits



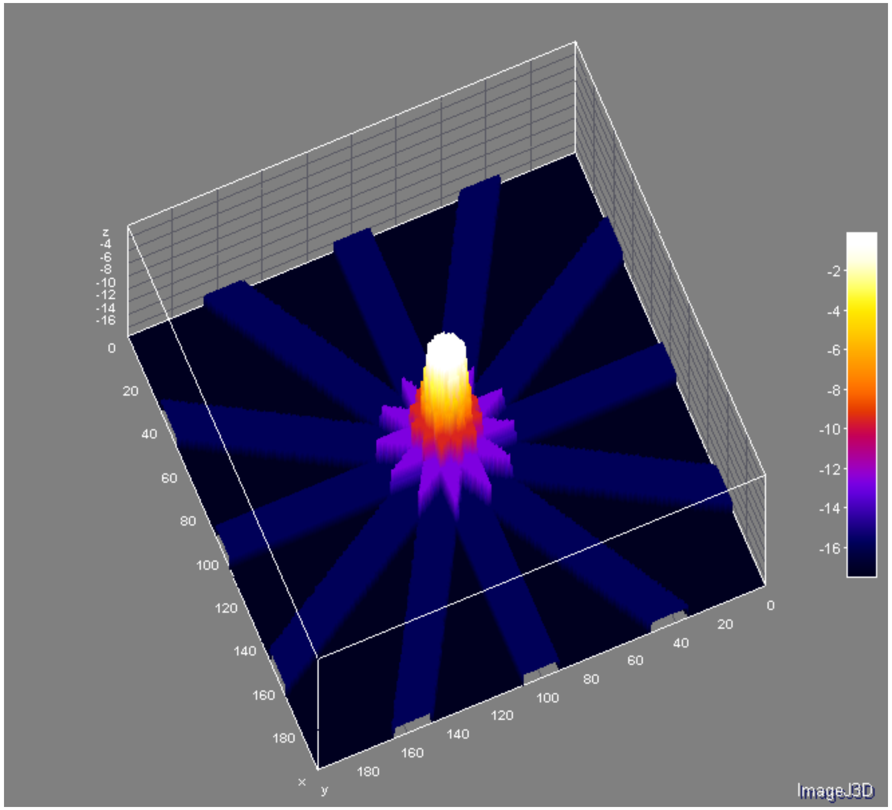

COLLIMATION ELEMENT


Stepping motor
Fixing frame
and block guide
W block (4 x 2 x 2 cm3)
Treaded rod

MC simulation for LE (~5 MeV)

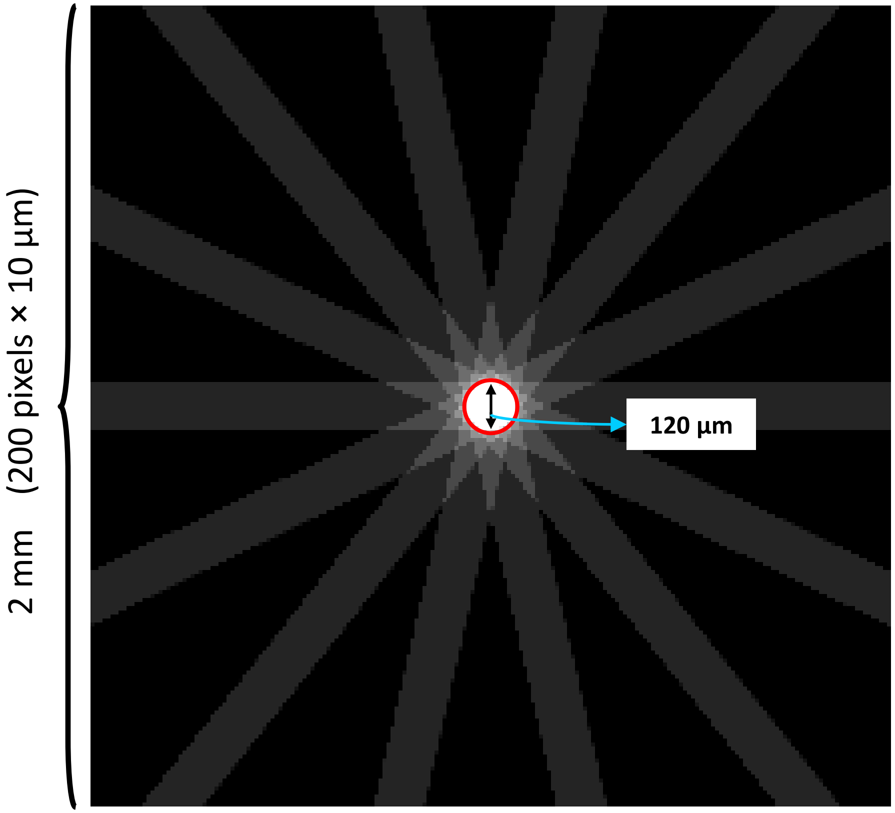


Simulated radiography of the collimator assembly (log scale)

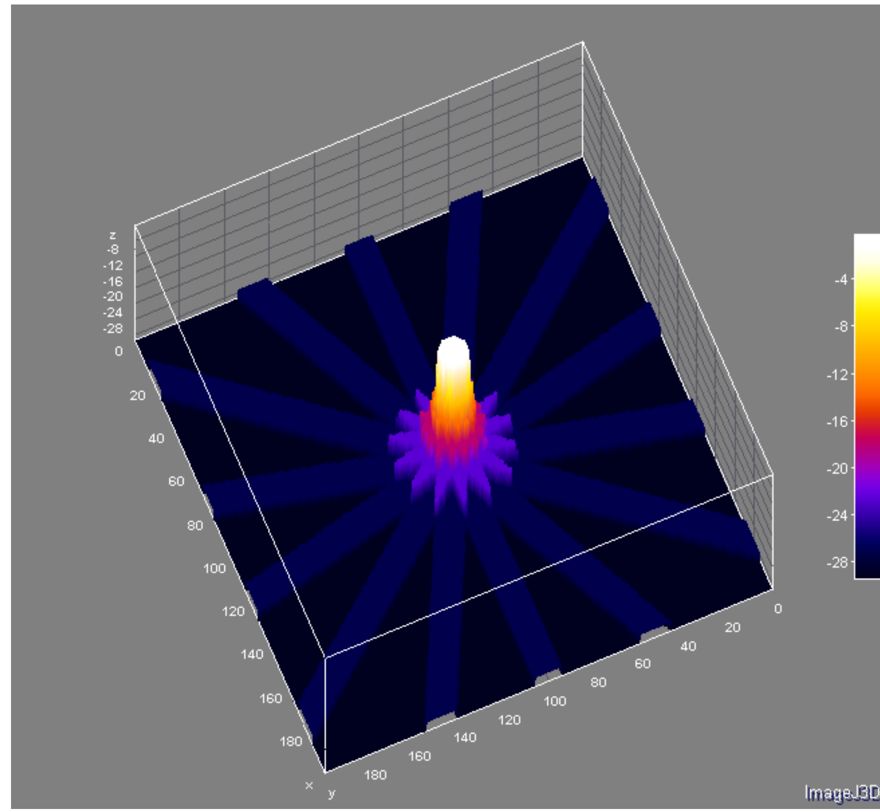


3D plot

MC simulation for HE (~19.5 MeV)

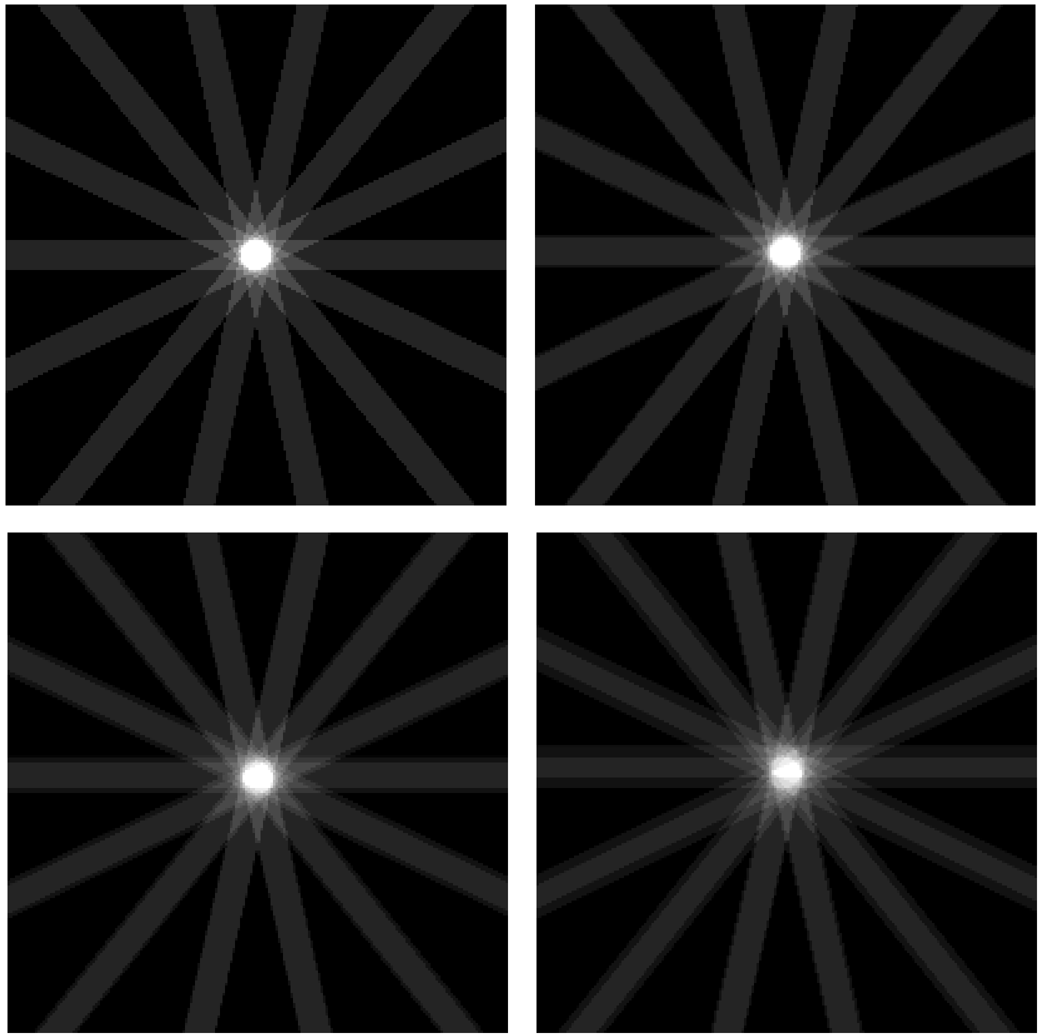


Simulated radiography of the collimator assembly (log scale)



3D plot

Alignment accuracy for the collimation system structure at HE (~19.5 MeV)



5 µrad

50 µrad

100 µrad

200 µrad

(angles with respect to the center of the structure)

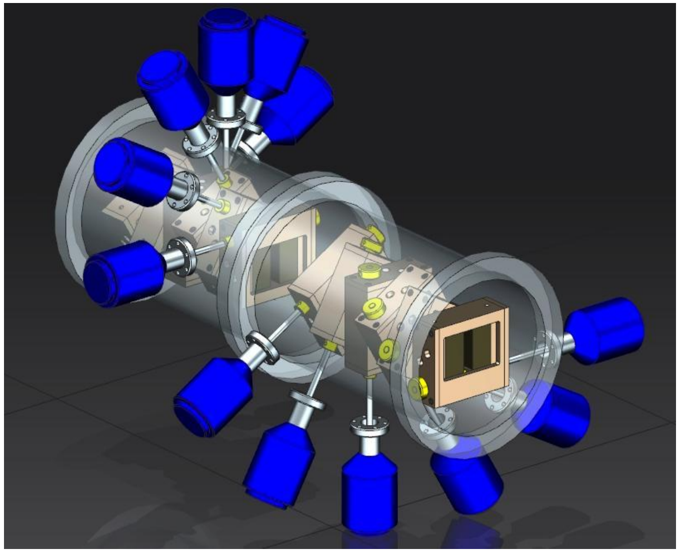
MC simulations of collimation system

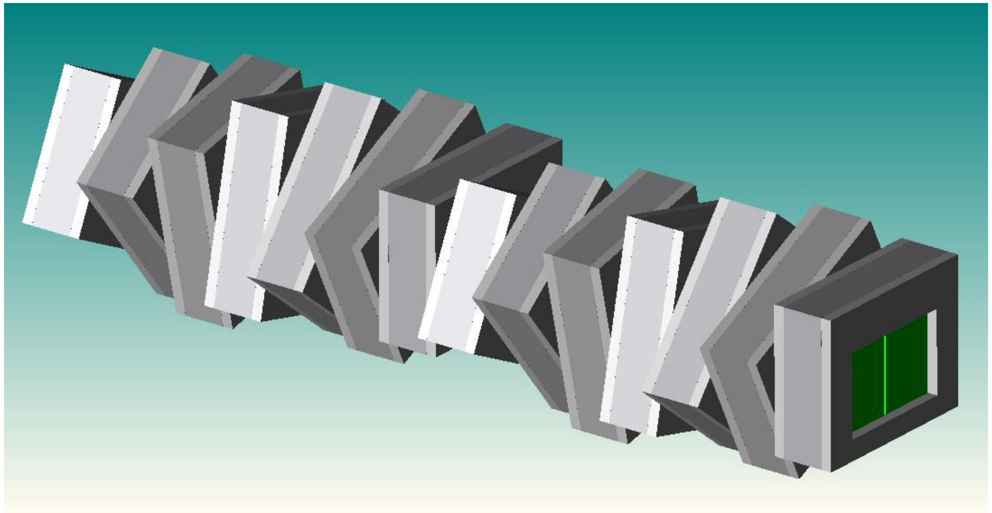
- In order to define the specifications and to design the collimation system for the low-energy beamline (1-5 MeV), a detailed MC simulation activity has been carried out using **MCNPX and Geant4**.

- The simulation consists in transporting a realistic gamma beam produced in the IP through the vacuum pipes and chambers, the collimation system and the concrete shielding.

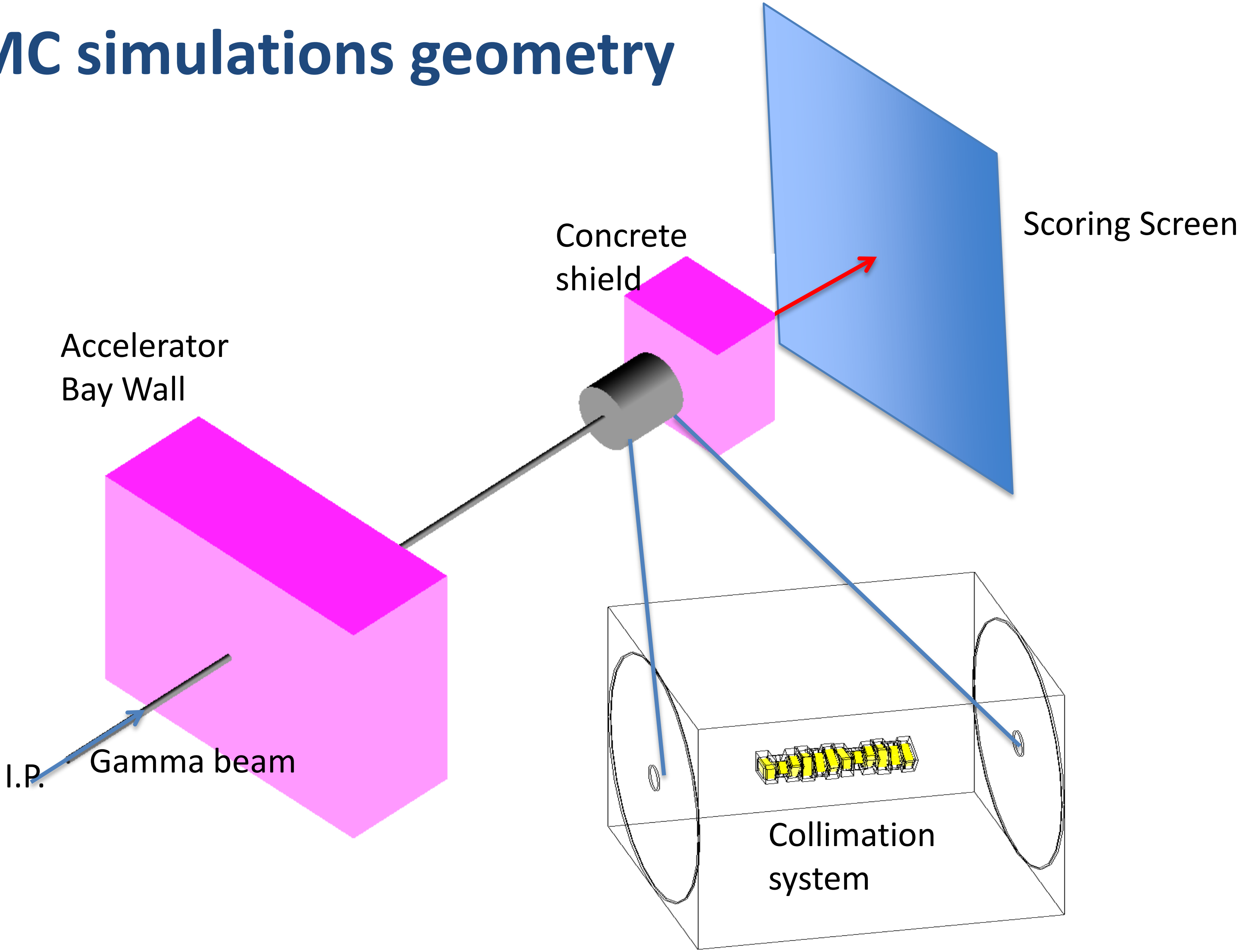
- The gamma beam used as input was obtained performing a simulation of the interaction transported electron beam with the laser pulse using CAIN (Petrillo, Drebot, Curatolo)

- Performed simulations of beam with energies of **2.5 and 5.0 MeV**

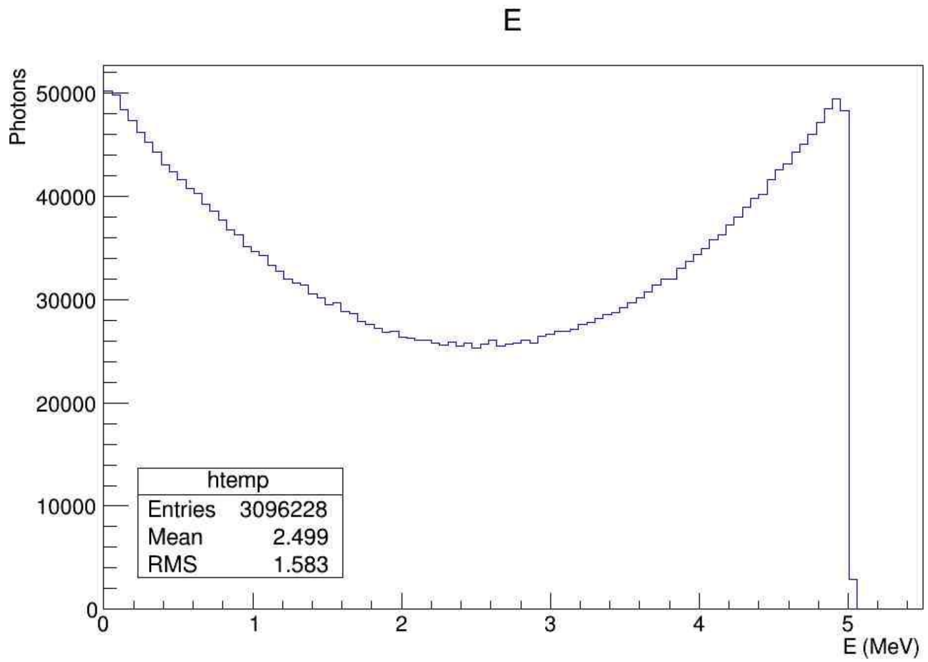




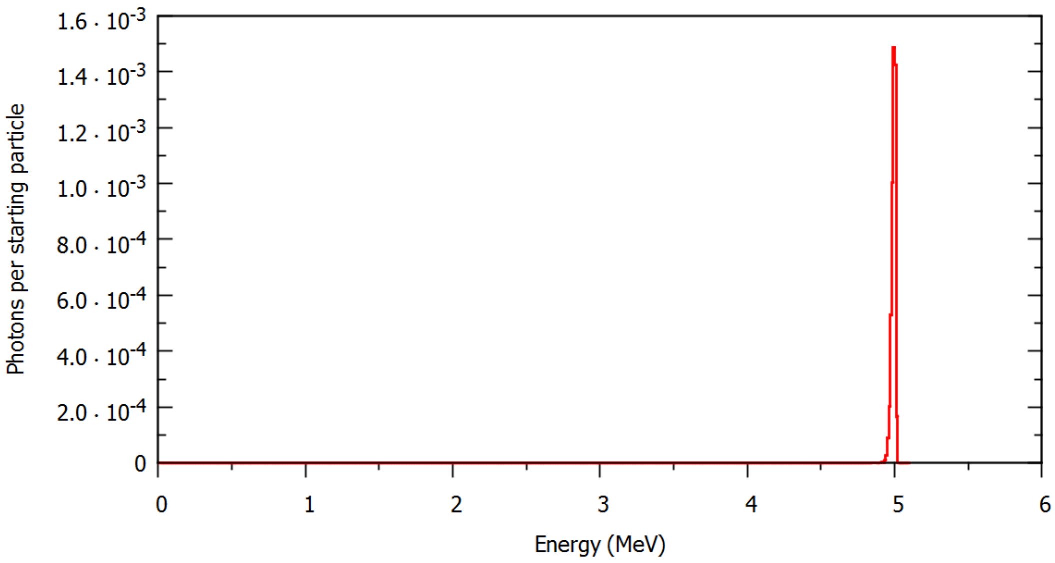
MC simulations geometry



5 MeV collimation results (MCNPX)



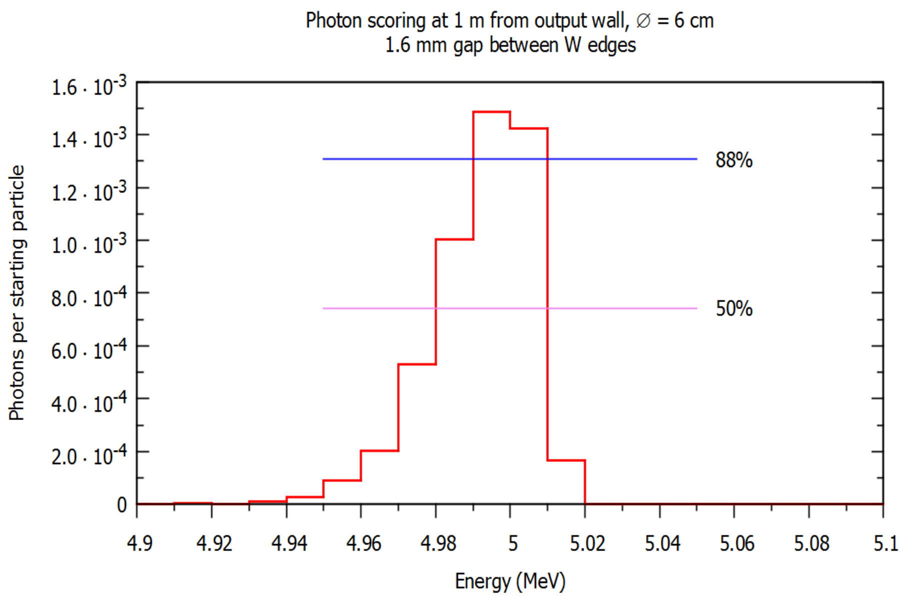
CAIN output



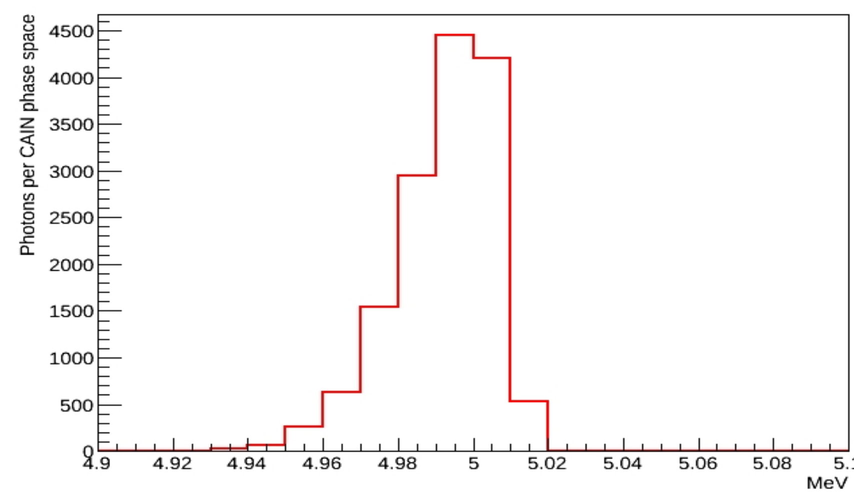
After collimation

5 MeV collimation results (MCNPX and Geant4)

- Collimation aperture corresponding to 80 µrad semiaperture
- ΔE/E obtained = 0.44%
- Results from MCNPX and Geant4 completely compatible



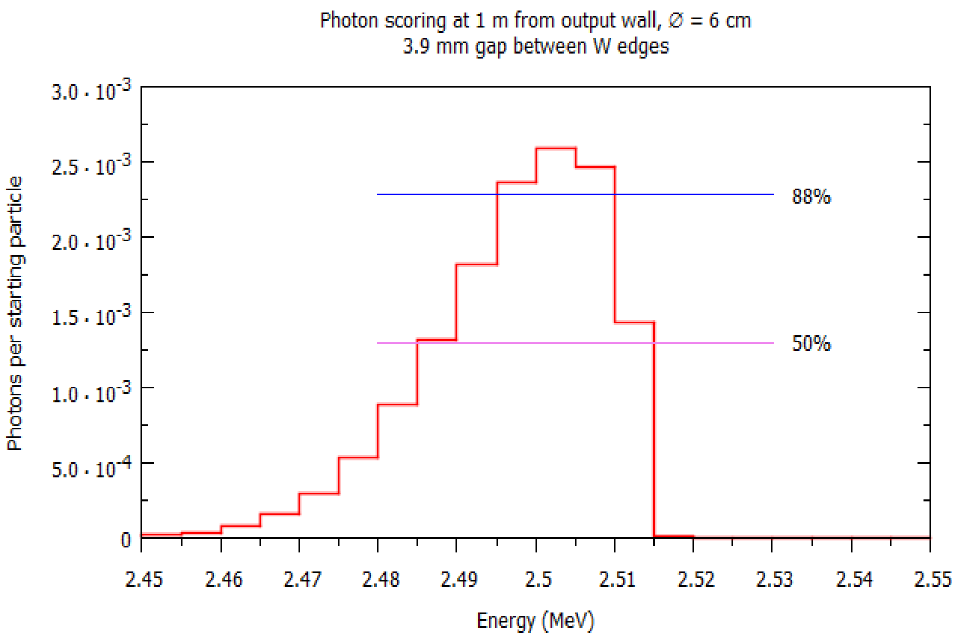
MCNPX



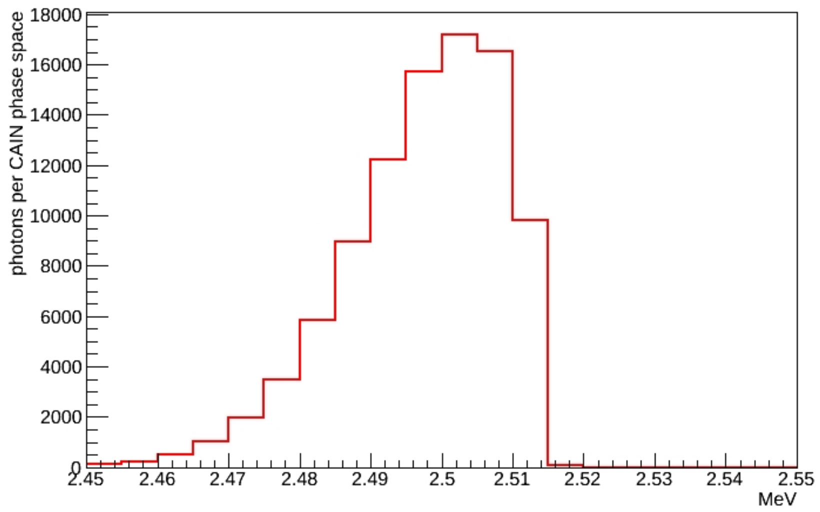
Geant4

2.5 MeV collimation results (MCNPX and Geant4)

- Collimation aperture corresponding to 200 μrad semiaperture
- ΔE/E obtained = 0.3%
- Results from MCNPX and Geant4 completely compatible



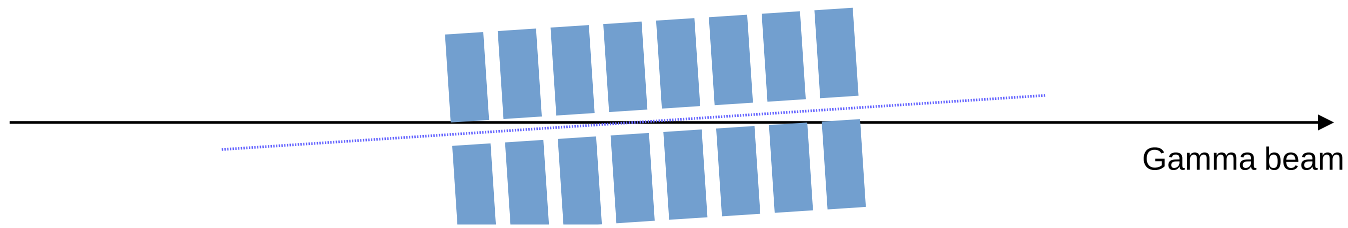
MCNPX

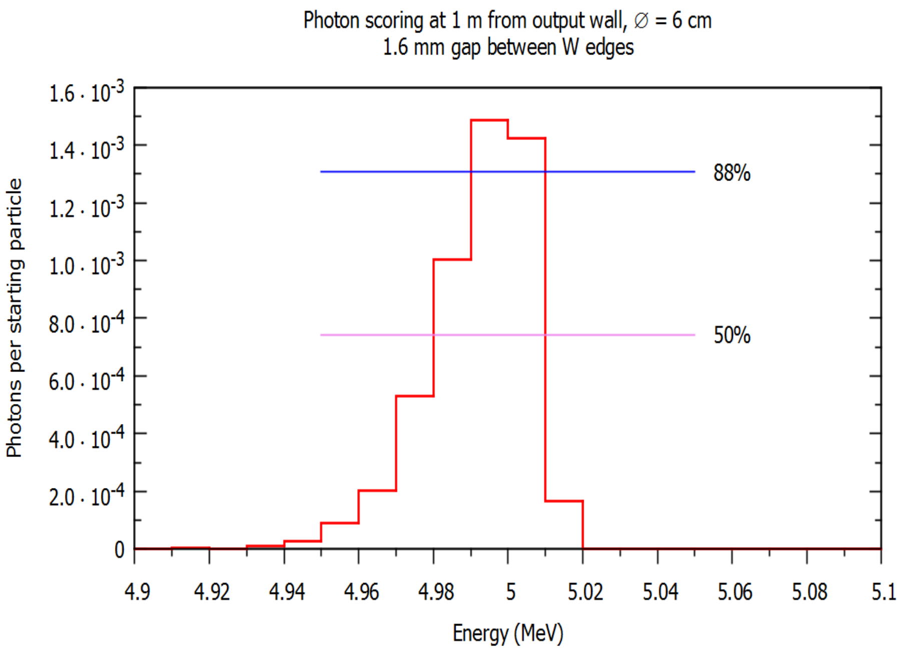


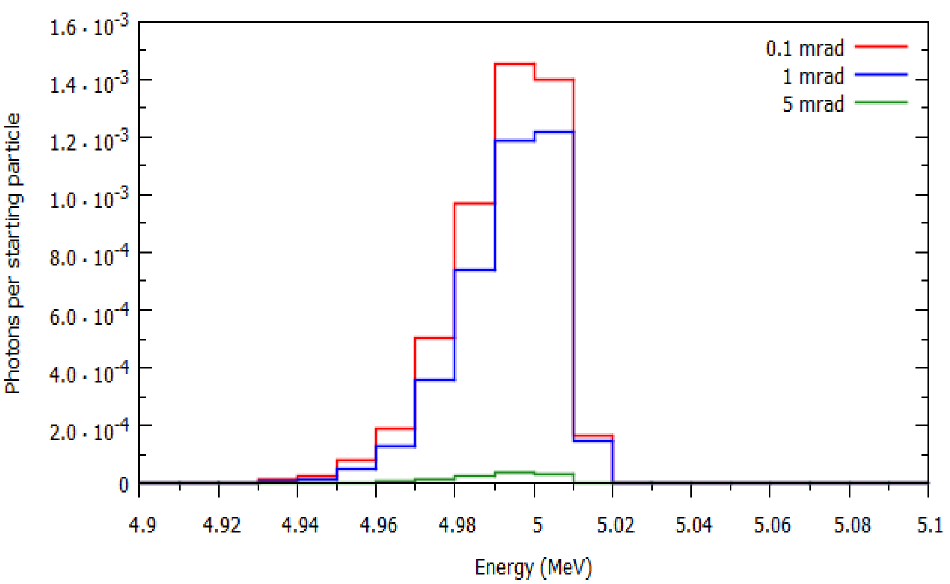
Geant4

Collimation system misalignment simulation

- To evaluate effects of misalignment, simulation has been performed rotating the whole slits stack on its center, with respect to the beam axis direction

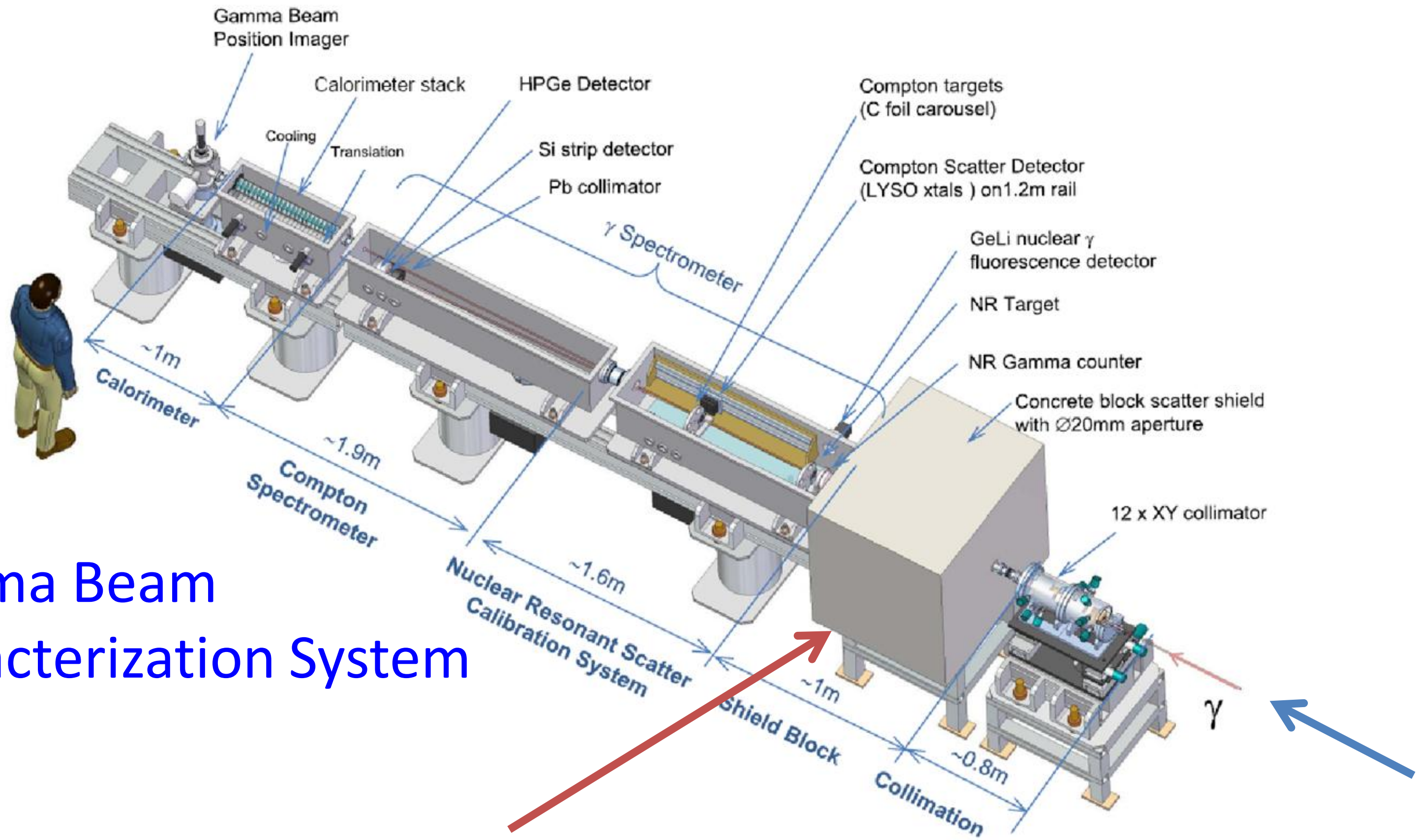






Collimation system scattering shielding

• To **avoid scattered radiation and secondary particles** to reach the experimental area and the gamma beam characterization system, a **concrete block** ($2x2x1\ m^3$) will be placed after the colli

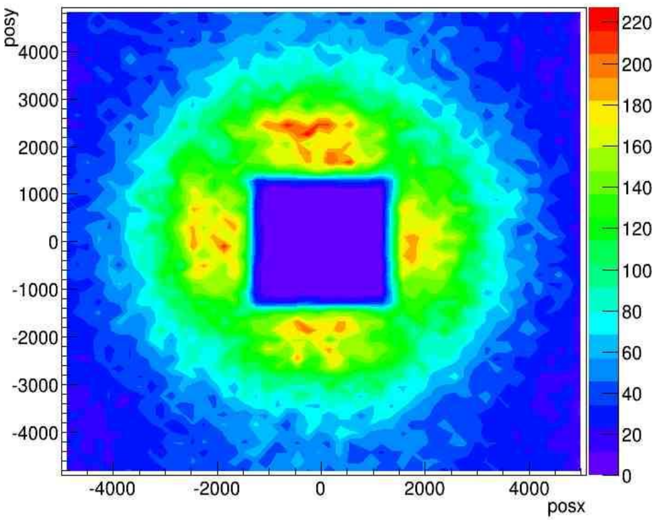


Gamma Beam Characterization System

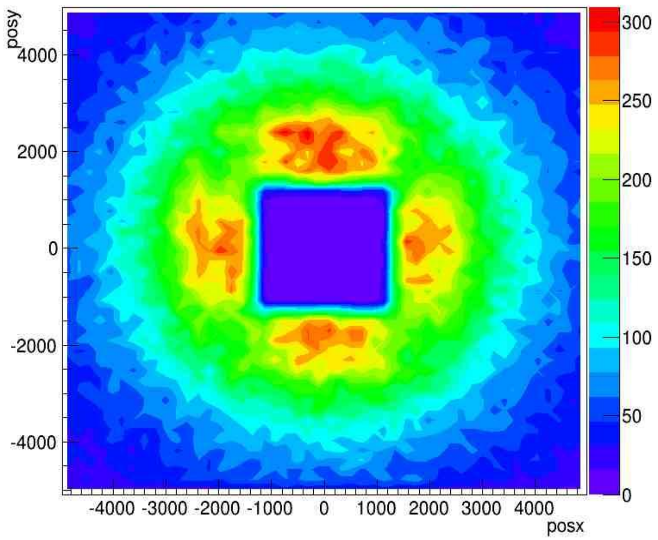
Shielding concrete

Collimation system shielding results

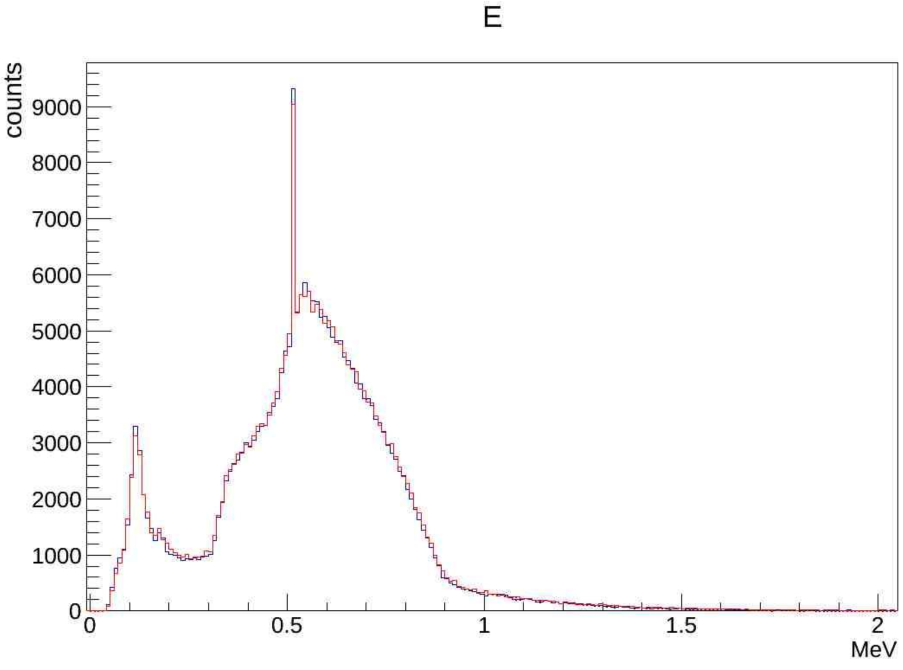
Scattered radiation for 2.5 MeV gamma beam



Scattered radiation for 5 MeV gamma beam



- Scoring screen (10 m x 10 m) at the exit from the concrete block
- On the left surface plots, photons/pulse over an area of 20x20 cm^2
- Below, the energy distribution of the background radiation over the entire 10 m x 10 m scoring screen.



Conclusions

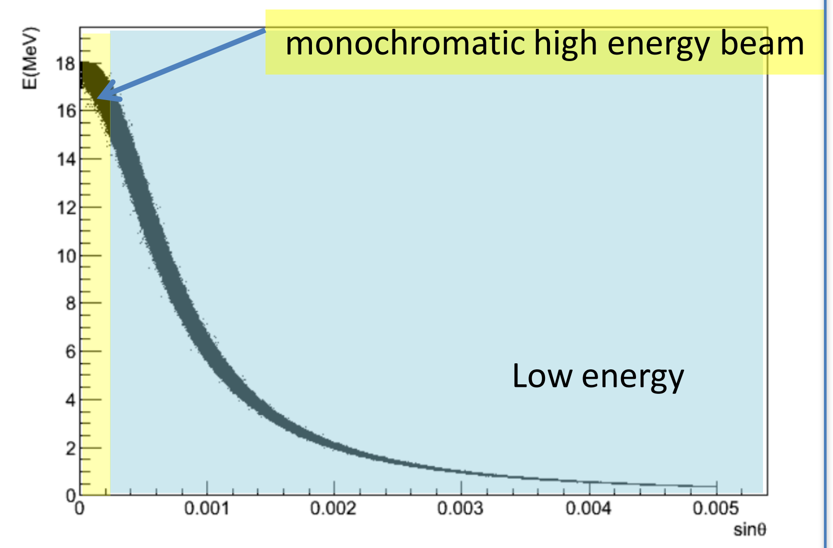
- The results of the simulations carried out show that the collimation system allows to obtain monochromatic beams with an energy distribution compatible to the parameters required ($\Delta E/E < 0.5$ %)
- The study of the effect of misalignment has been fundamental to define the specifications of tolerancies and stability, required to finalize the mechanical engineering and realisation of the system
- The simulation of a realistic collimated beam it is been necessary to evaluate the expected perfomances of the detectors composing the characterisation system downstream the beam line and to finalise the design
- Also, the results of the background radiation produced were used to evaluate the effect of the background signal on these detectors to optimise the performances in a realistic operating situation

Thank you very much
for your attention

Gamma beam collimation system

Inverse Compton radiation is not intrinsically monochromatic, the energy is related to the emission angle.

The required **energy band-width** can be obtained only by developing specific methods of **collimation of gamma beam**.



Typical energy distibution of a Compton source as a function of angular divergence