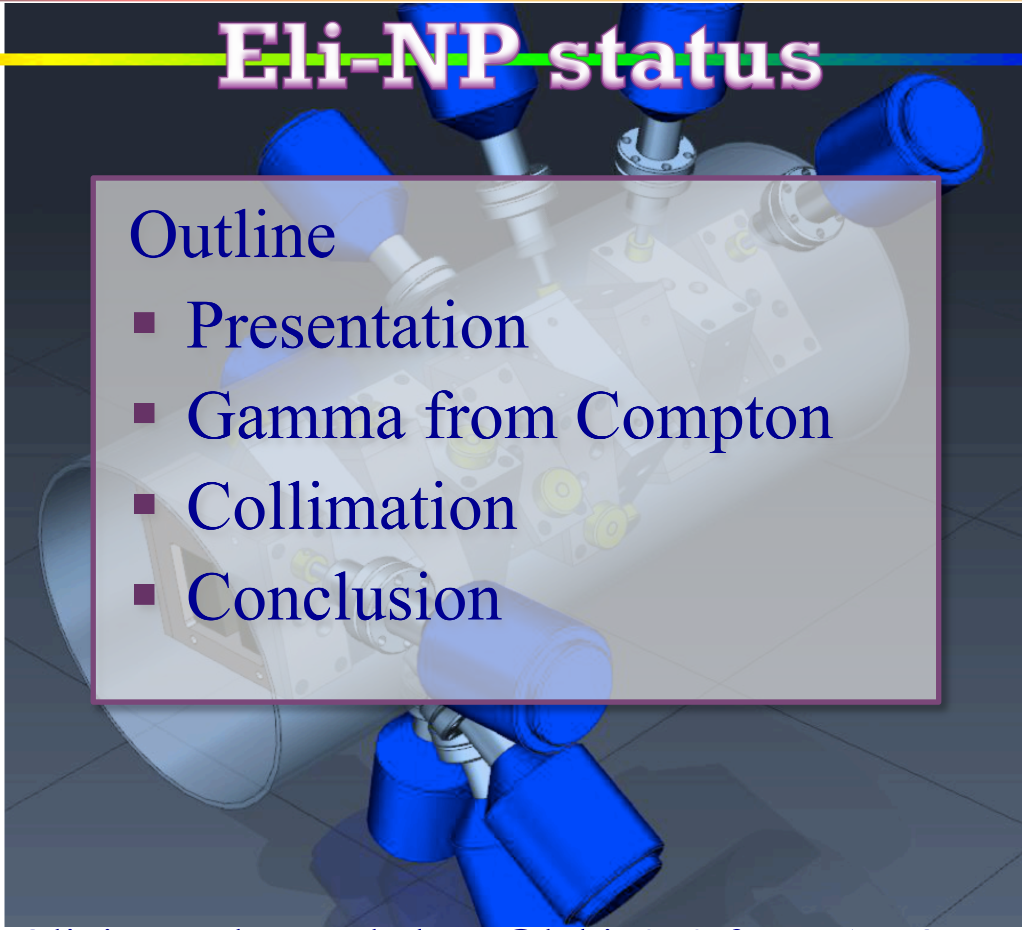
Nuclear Physics

European Collaboration for the proposal of a Gamma-Beam System to the ELI-NP Project

http://www.e-gammas.eu

http://www.eli-np.ro

# Eli-NP status



Outline

- Presentation
- Gamma from Compton
- Collimation
- Conclusion

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POSIPOL 2012 Workshop, DESY-Zeuthen

# ELI : an Extreme Light Infrastructure

ELI is on the research priority list of the European Strategy Forum on Research Infrastructures

eli delivery consortium

## 3 facilities for 3 pillars


Fyzikální ústav Akademie věd ČR, v. v. i.

projekt podporovaný: EVROPSKÁ UNIE EVROPSKÝ FOND PRO REGIONÁLNÍ ROZVOJ INVESTICE DO VAŠÍ BUDOUCNOSTI

OP Výzkum a vývoj pro inovace

Courtesy L. Palumbo

# ELI : an Extreme Light Infrastructure

ELI is on the research priority list of the European Strategy Forum on Research Infrastructures

It consists on 3 pillars

- Atto-second Laser Science (Szeged, Hungary)
- Laser matter interaction (Prague, Czech Republic)
- Laser based Nuclear Physics (Magurele, Romania)

2 sources of "extreme light" with 8 experimental areas

- 2 Multi-PW Apollon type lasers
- Brillant $\gamma$ beam facility up to 20 MeV produced by Compton scattering

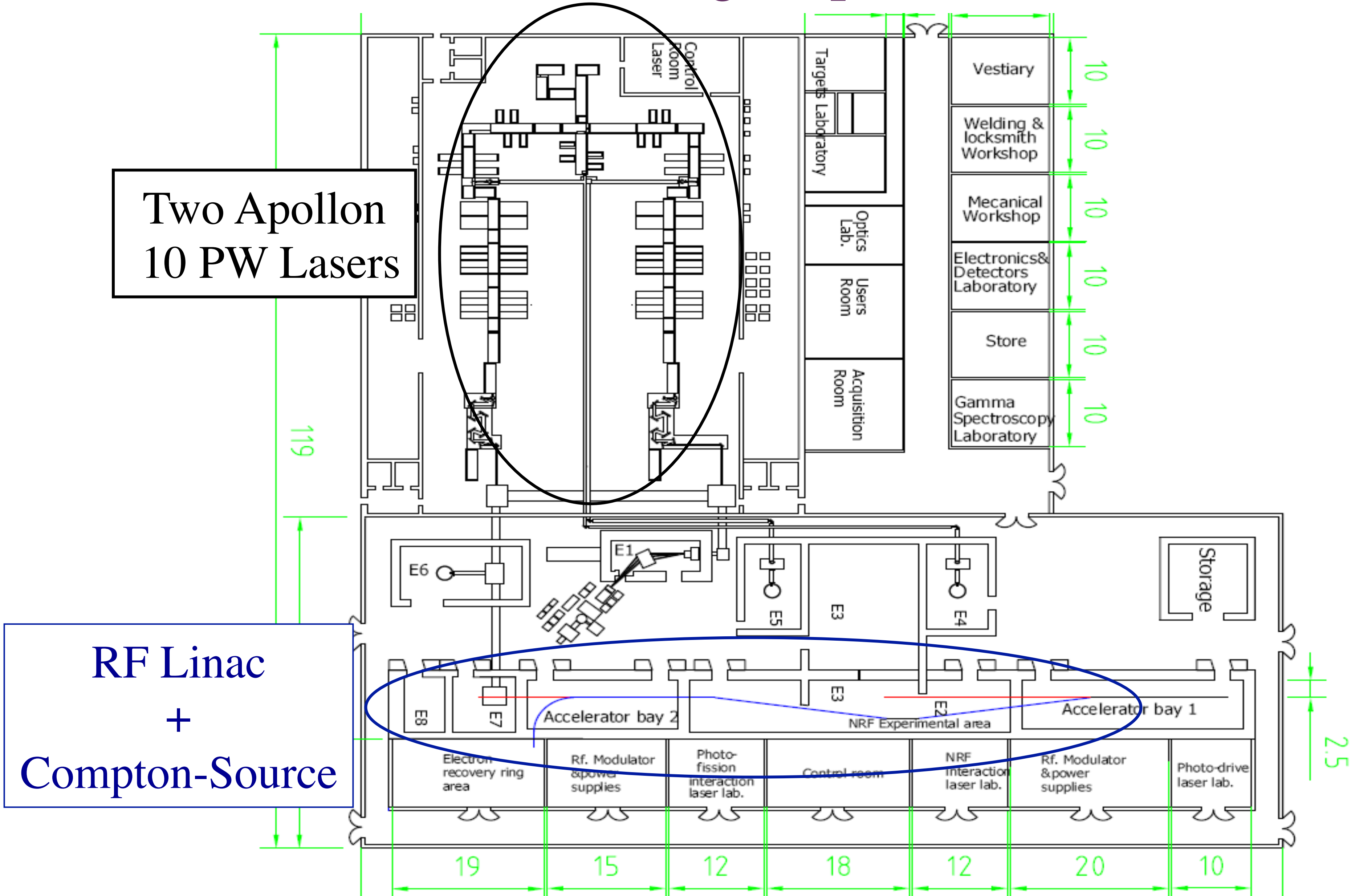
# Some Eli-NP research

At the ELI-NP pillar is approached a new frontier in physics - the laser-nuclear physics frontier:

- Laser induced nuclear reactions
- Nuclear resonance fluorescence and applications
- Positrons source
- Accelerated particle beams induced by high power laser beams (0,1/1 PW) at high repetition rates
- Intense electron and gamma beams induced by high power (multi-PW) laser
- Experiments with combined laser and gamma beams
- Nuclear reactions induced by high energy gamma beams

# The building

# Eli-NP building map view

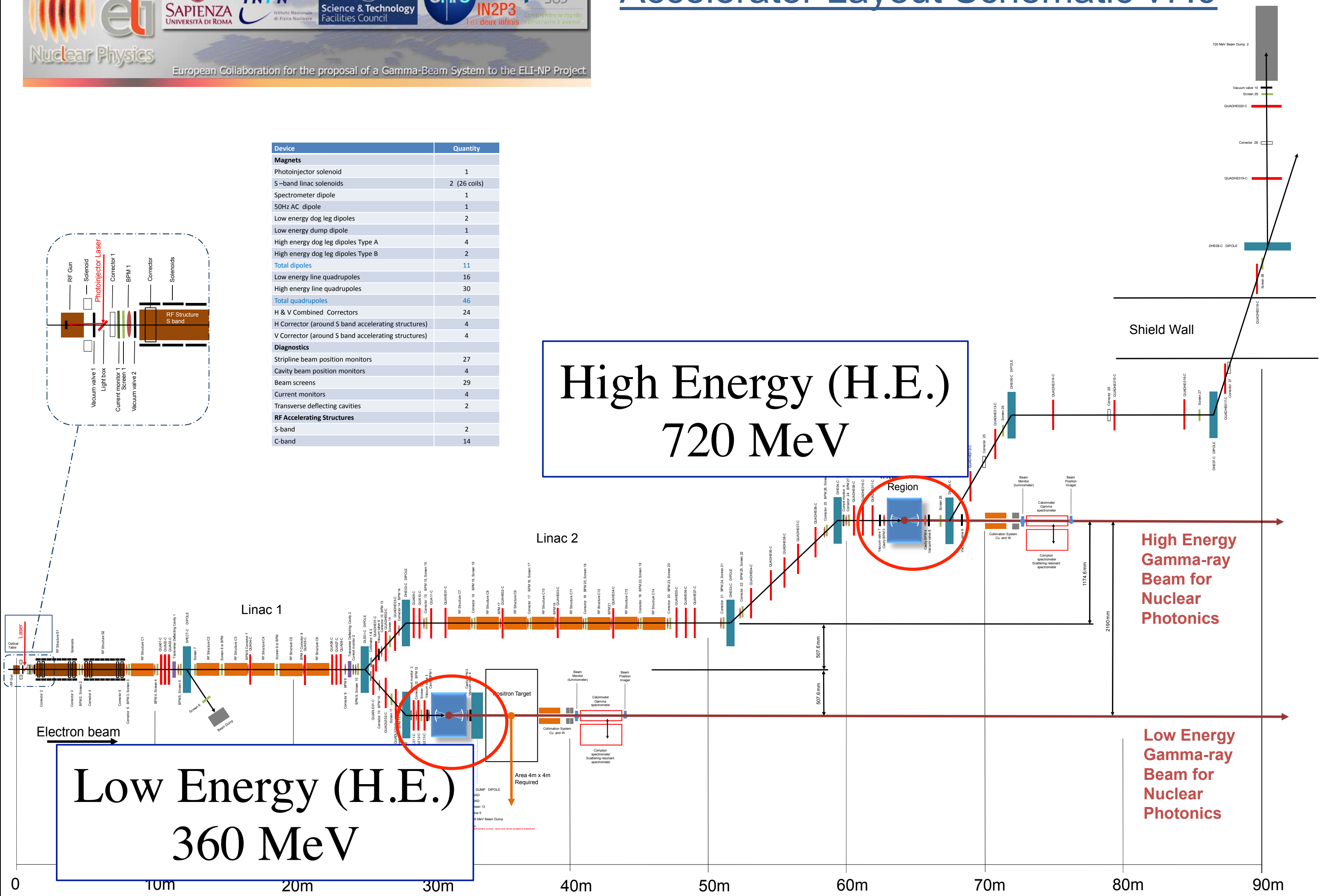


# Eli-NP : advance source of gamma-ray photons 1 - 20 MeV

European Collaboration for the proposal of a Gamma-Beam System to the ELI-NP Project

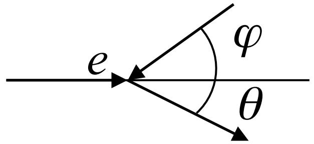
## Accelerator Layout Schematic v7.0

| Device | Quantity |
|---|---|
| **Magnets** | |
| Photoinjector solenoid | 1 |
| S-band linac solenoids | 2 (26 coils) |
| Spectrometer dipole | 1 |
| 50Hz AC dipole | 1 |
| Low energy dog leg dipoles | 2 |
| Low energy dump dipole | 1 |
| High energy dog leg dipoles Type A | 4 |
| High energy dog leg dipoles Type B | 2 |
| Total dipoles | 11 |
| Low energy line quadrupoles | 16 |
| High energy line quadrupoles | 30 |
| Total quadrupoles | 46 |
| H & V Combined Correctors | 24 |
| H Corrector (around S band accelerating structures) | 4 |
| V Corrector (around S band accelerating structures) | 4 |
| **Diagnostics** | |
| Stripline beam position monitors | 27 |
| Cavity beam position monitors | 4 |
| Beam screens | 29 |
| Current monitors | 4 |
| Transverse deflecting cavities | 2 |
| **RF Accelerating Structures** | |
| S-band | 2 |
| C-band | 14 |



# ELI-NP gamma beam production

$$E_\gamma = n \cdot 2\gamma_e^2 \cdot \frac{1+\cos\varphi}{1+(\gamma_e\theta)^2 + a_0^2 + \dfrac{4\gamma_e E_0}{mc^2}} \cdot E_0$$




$n = \text{harmonic number}; \quad \frac{4\gamma_e E_0}{mc^2} = \text{recoil parameter}; \quad a_0 = \frac{eE}{m\omega_0}; \quad E_0 = \hbar\omega_0$

Compton backscattering is the most efficient « frequency amplifier »

$w_{diff} = 4\gamma_e^2 w_{laser}$

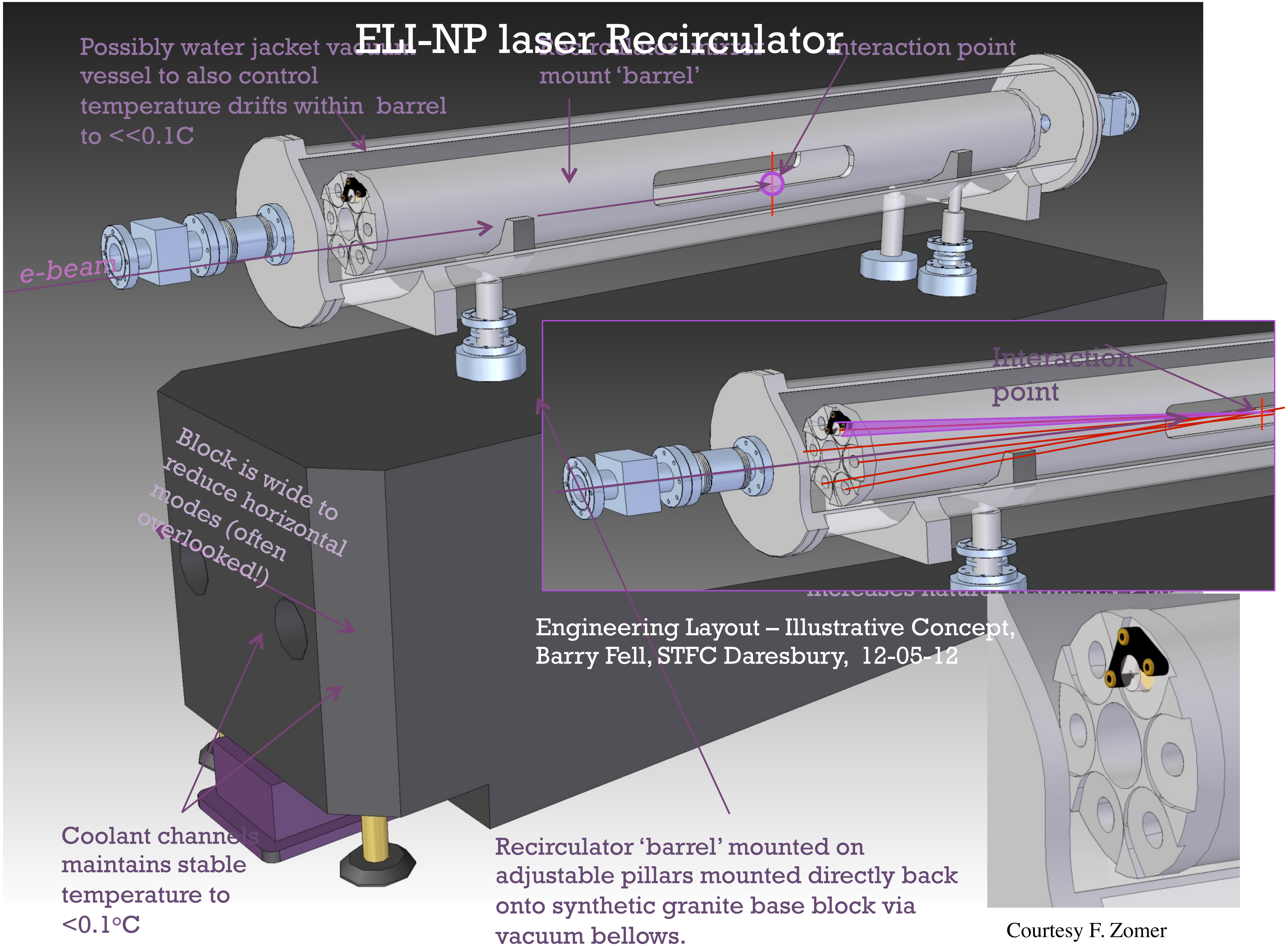
$E_e$ [360 - 720 MeV] with $w_{laser}$ ~ few eV => Eγ [1 – 20 MeV]

BUT very weak cross section ~ $10^{-25}$ cm$^2$

For a powerful γ beam, one needs:

- high intensity electron beams
- very brilliant optical photon beams
- very small collision volume
- very high repetition frequency

# ELI-NP laser Recirculator




Courtesy F. Zomer

# Main γ characteristics

**Table 4b: Gamma-ray beam for 3 selected collision examples (from Start-to-end simulations)**

| all quantities are rms | Low Energy Interaction | High Enegy Interaction | High Enegy Interaction |
|---|---|---|---|
| Energy (*MeV*) | 4.6 | 9.73 | 19.1 |
| Spectral Density ( *ph/sec.eV*) | $4.5 \cdot 10^4$ | $2.1 \cdot 10^4$ | $1.1 \cdot 10^4$ |
| Bandwidth (%) | 0.3 | 0.3 | 0.3 |
| # photons per shot within FWHM | $2.1 \cdot 10^5$ | $2.0 \cdot 10^5$ | $2.2 \cdot 10^5$ |
| # photons/sec within FWHM | $6.2 \cdot 10^8$ | $6.0 \cdot 10^8$ | $6.3 \cdot 10^8$ |
| Source rms size ($\mu m$) | 15 | 15 | 12 |
| Source rms divergence ($\mu rad$) | 47 | 35 | 25 |
| Peak Brilliance ($N_{ph}/sec \cdot mm^2 mrad^2 \cdot 0.1\%$) | $1.4 \cdot 10^{23}$ | $2.9 \cdot 10^{23}$ | $6.7 \cdot 10^{23}$ |
| Average Brilliance ($N_{ph}/sec \cdot mm^2 mrad^2 \cdot 0.1\%$) | $4.2 \cdot 10^{14}$ | $8.7 \cdot 10^{14}$ | $1.7 \cdot 10^{15}$ |
| Rad. pulse length (rms, *psec*) | 0.95 | 0.95 | 0.9 |
| Linear Polarization (%) | 95 | 95 | 95 |
| Macro rep. rate (*Hz*) | 100 | 100 | 100 |
| # of pulses per macropulse | 32 | 32 | 32 |
| Pulse-to-pulse sep. ( *nsec*) | 16 | 16 | 16 |



Courtesy L. Serafini

# Eli-NP : advance source of gamma-ray photons 1 - 20 MeV

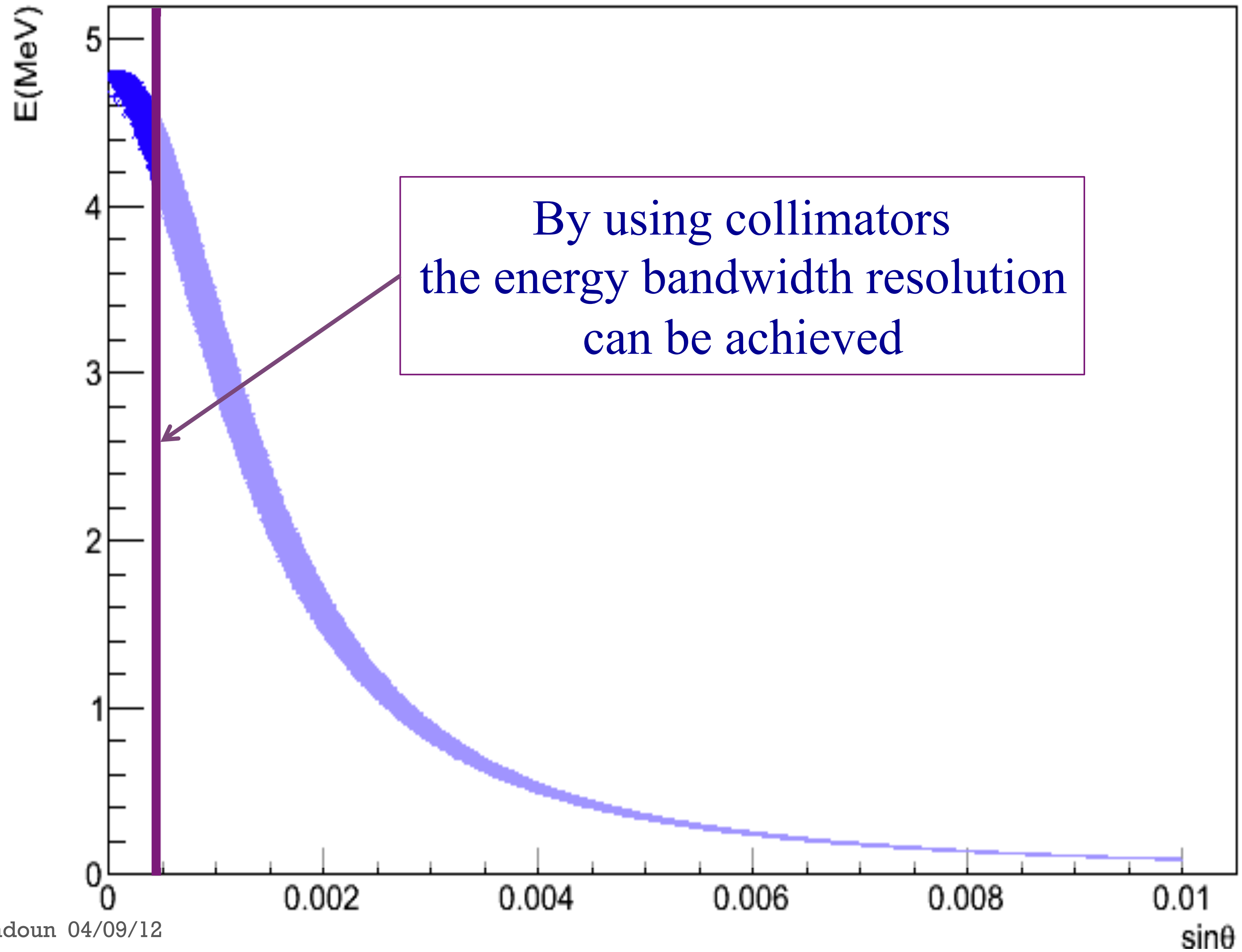
Specification 1-2 orders of magnitude better than the state of art

- Spectral density $10^4 \rightarrow 10^6$ $\gamma$ /s/eV
- Energy bandwidth (= rms/$E_{max}$) : 0.3% → 0.1%

Source based on Compton back-scattering source using 2 different $e^-$ beam energy colliding a laser beam in 2 interactions regions

# Gamma @ the IP: energy vs angle (low energy)

$e^-$ drive beam energy 360 MeV



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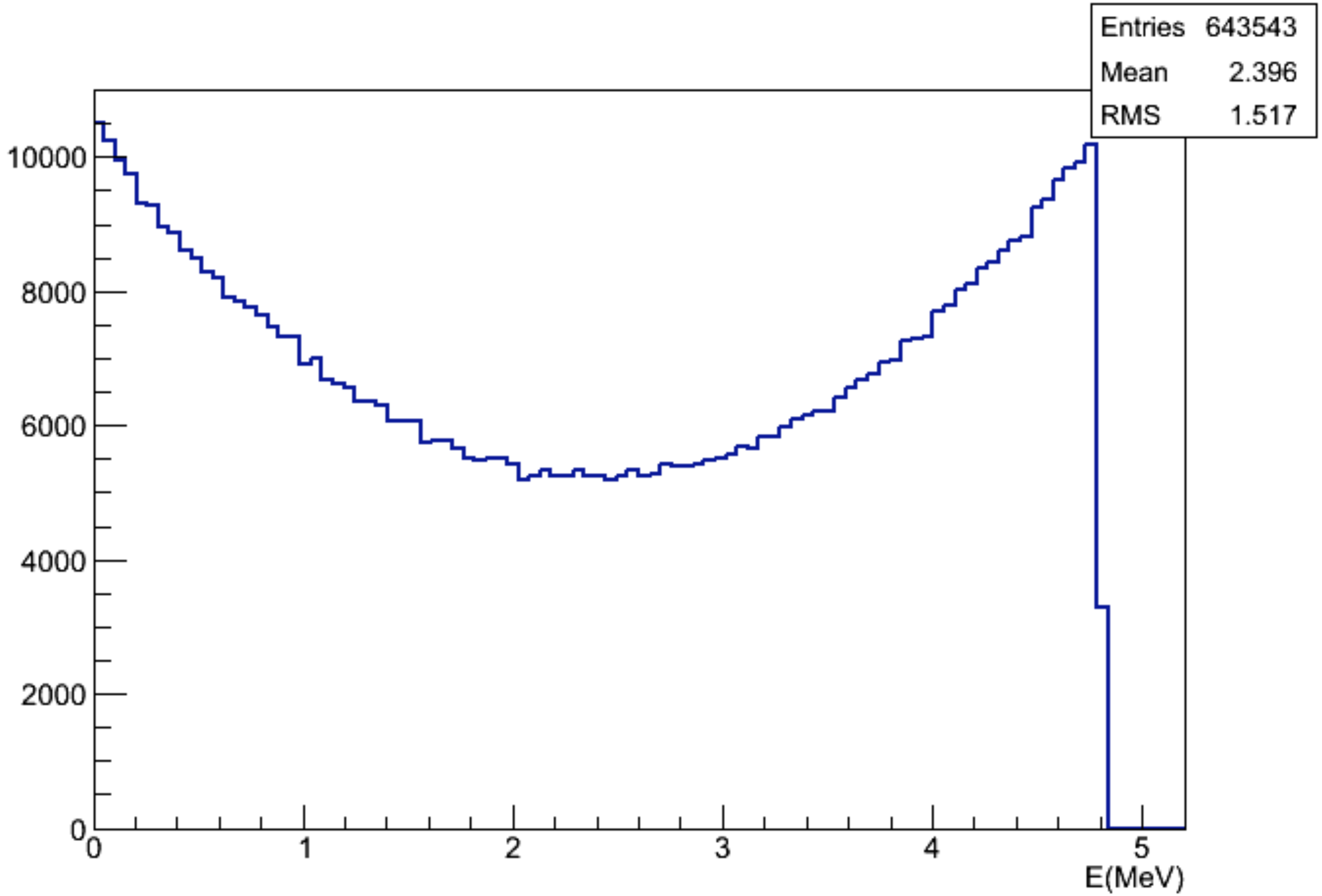
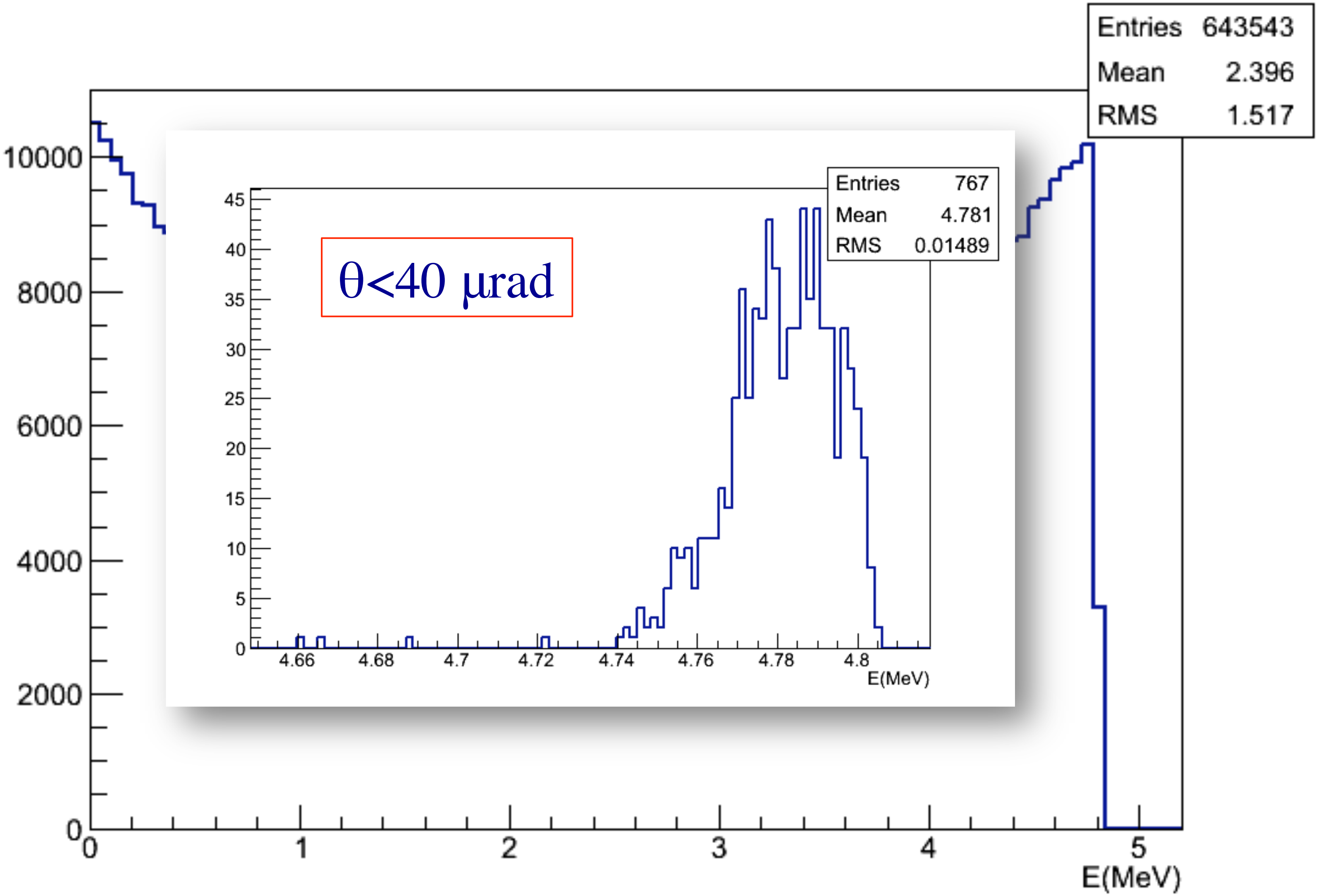
To achieve this energy bandwidth collimation is needed in the gamma extraction line

- Type, material, size, location …
- Limited space between the IP and experimental areas

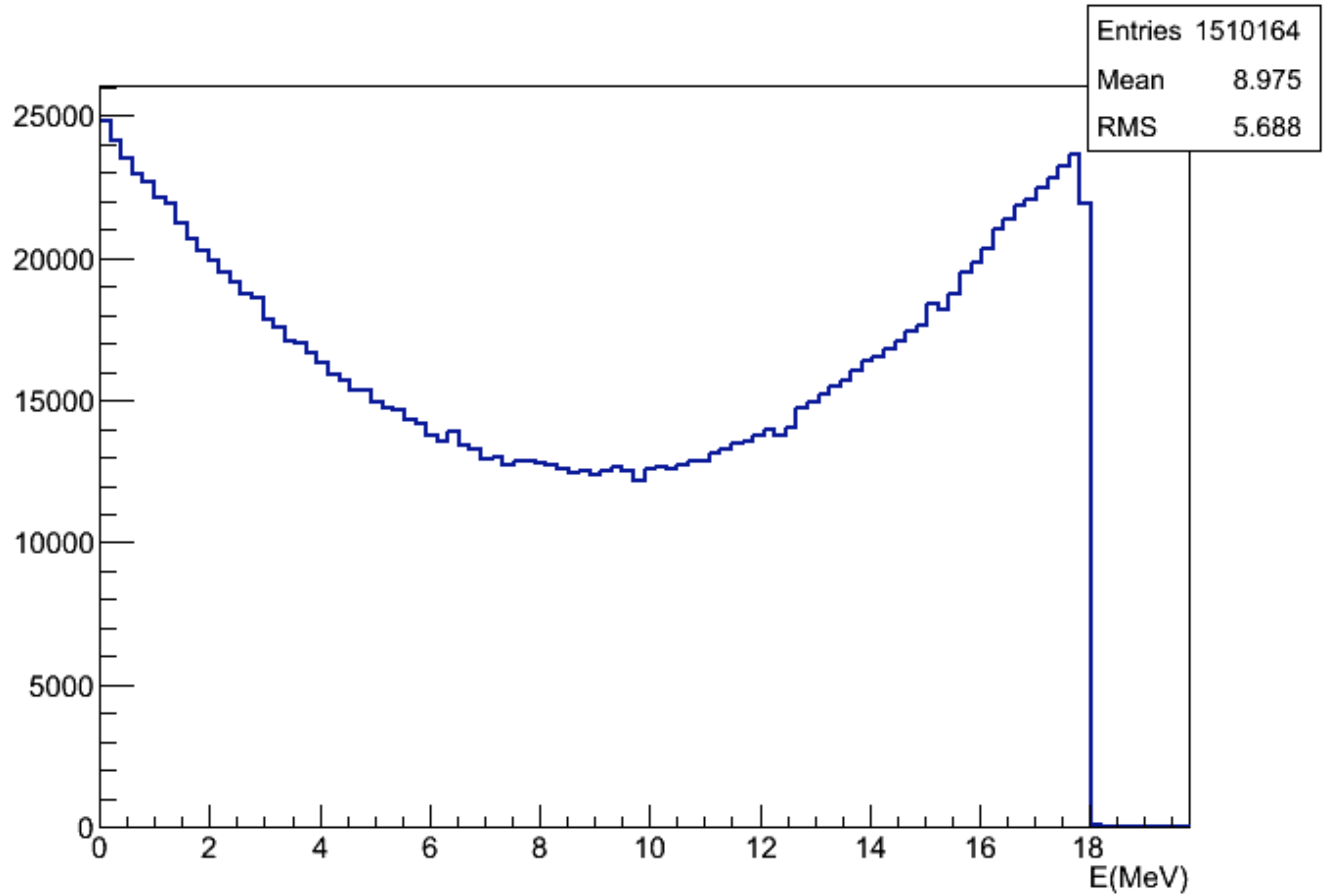
# Gamma @ the IP (L.E)



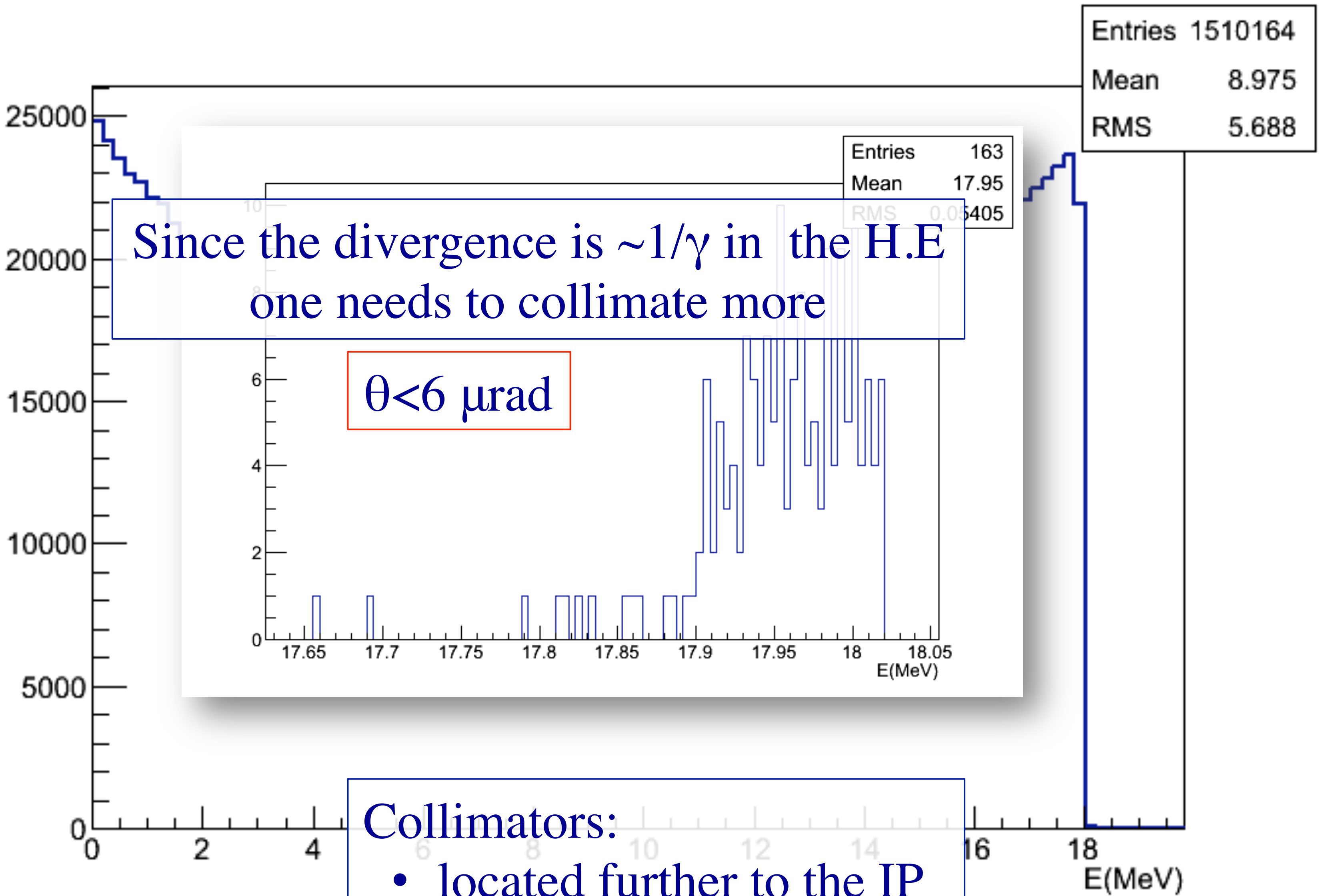
# Gamma @ the IP (L.E)



# Gamma @ the IP (H.E)



# Gamma @ the IP (H.E)



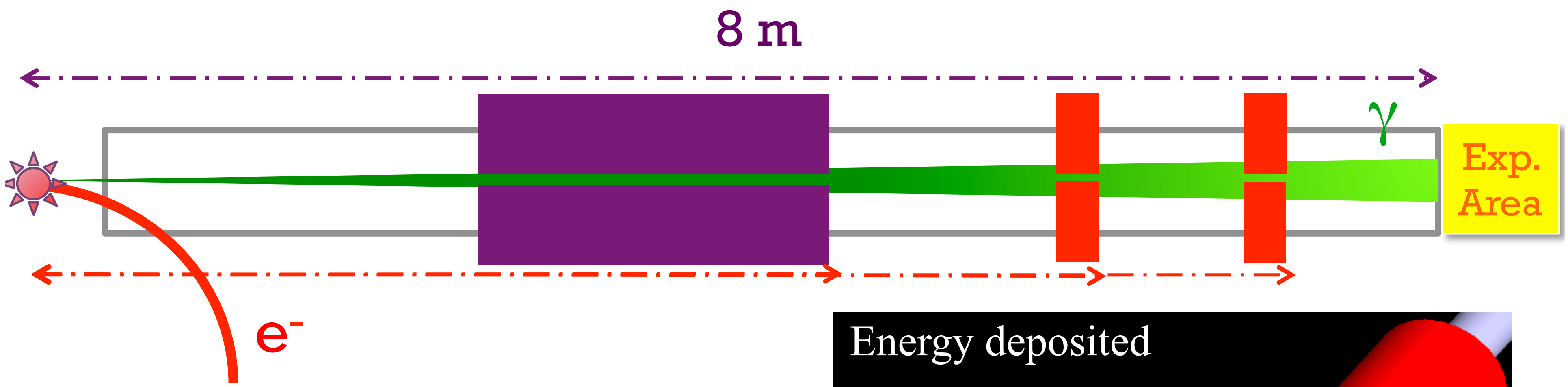

Since the divergence is ~1/γ in the H.E one needs to collimate more

θ<6 μrad

Collimators:

- located further to the IP
- aperture smaller

# Geant4 collimation line simulation (first baseline)




- Collimator 1 [Cu]

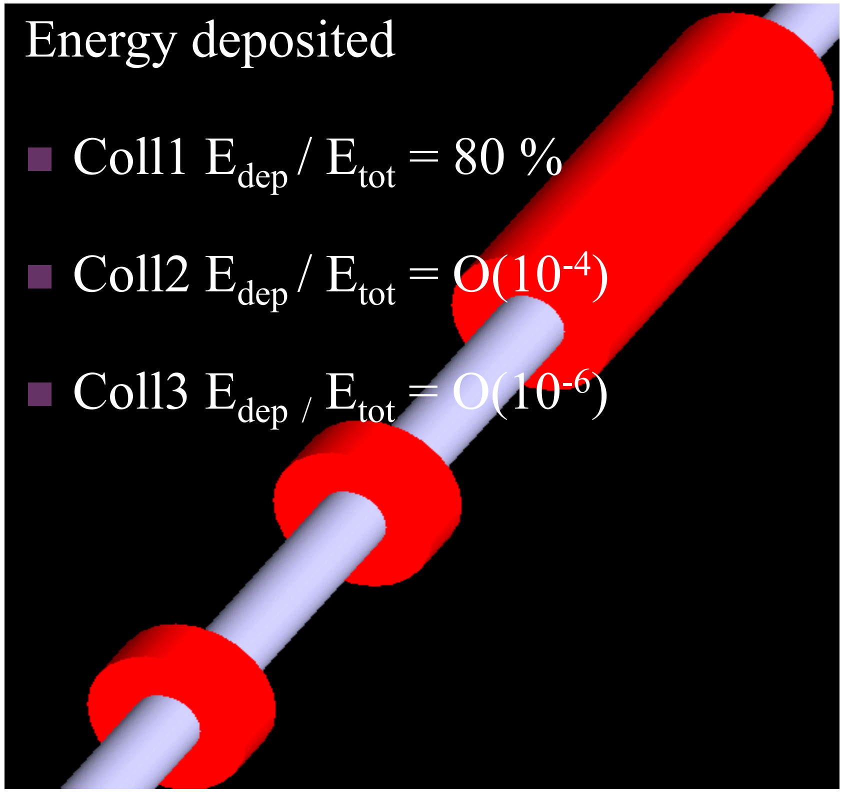
  d = 6 m, r = 0.4 mm, l = 30 cm
  used @ E166 (r = 0.425 mm)

- Collimator 2 & 3 [W]

  d = 6.5 & 7.0m, r = 0.4 mm, l = 4 cm

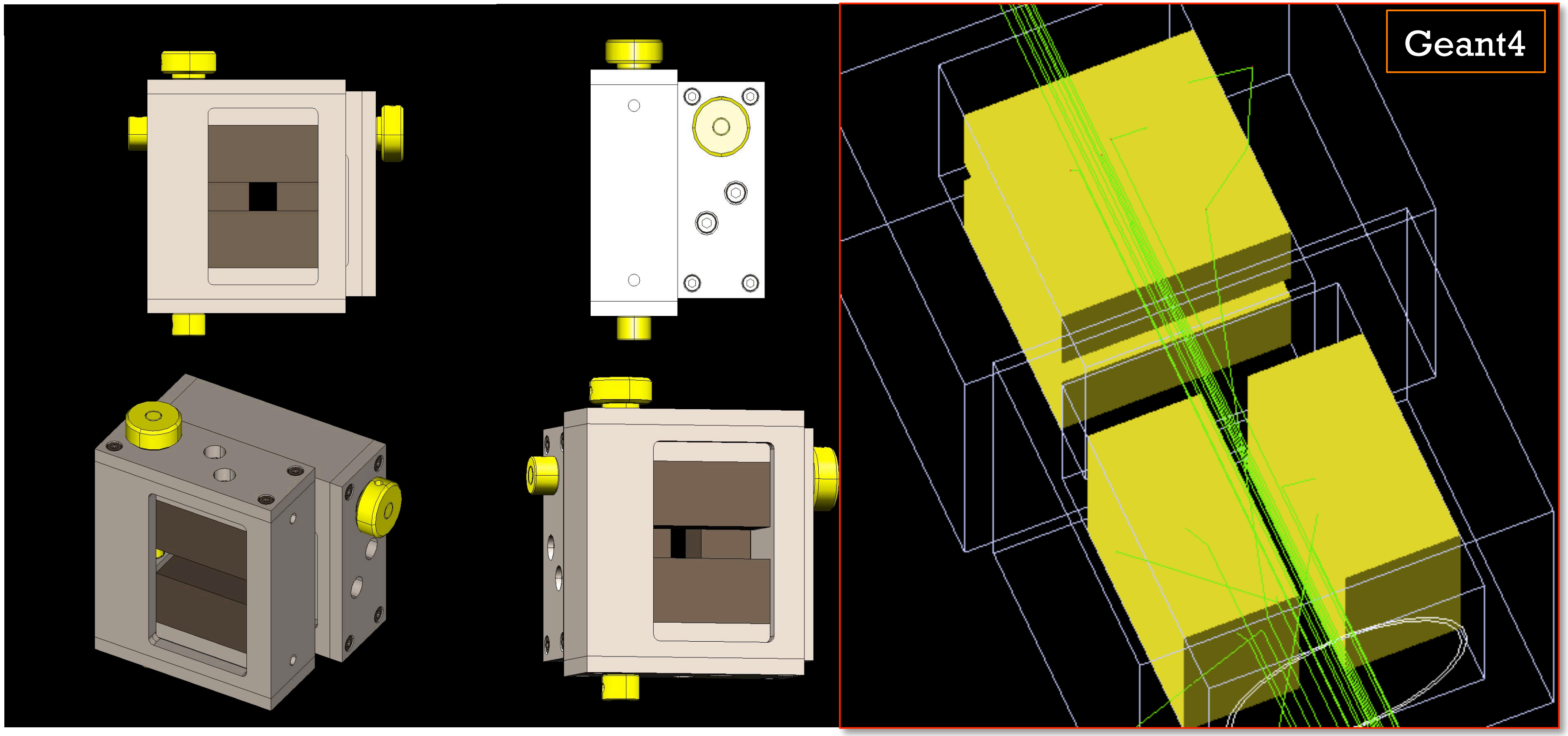
- Beam pipe [Fe]

  r = 2 cm, t = 0.1 cm



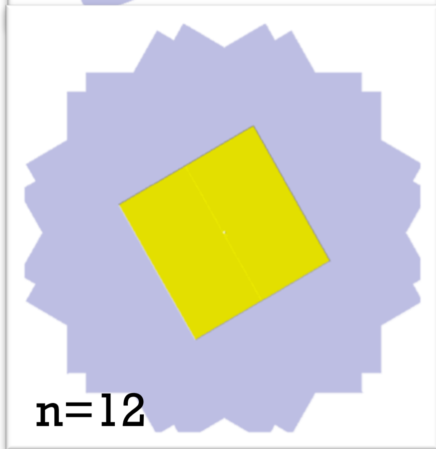
# Actual baseline : dual slit collimator [W]

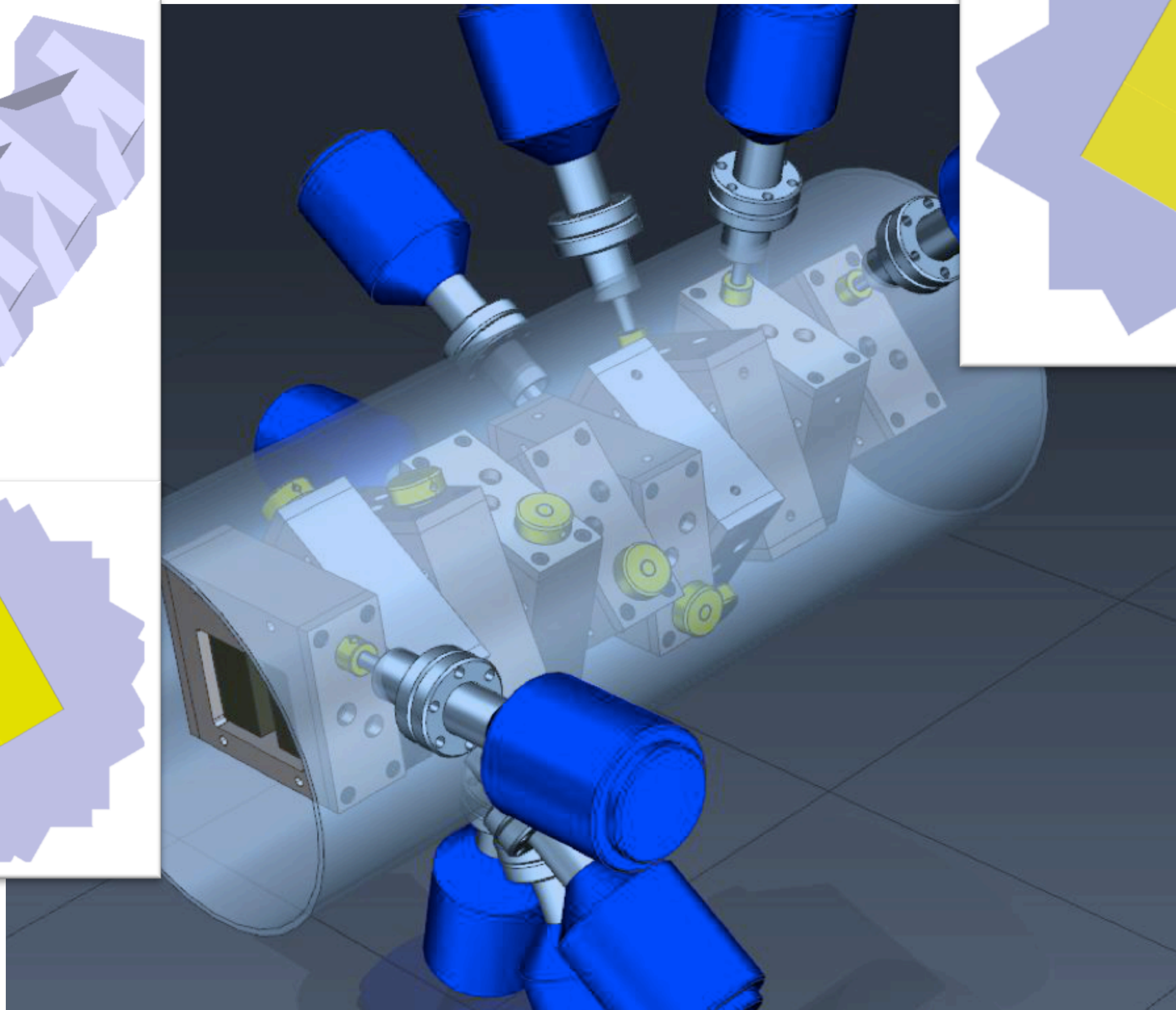
The choice has been made on a dual slit collimator already designed and assembled at INFN-Ferrara for a high energy X ray experiment [NIM-B Gambaccini et al]

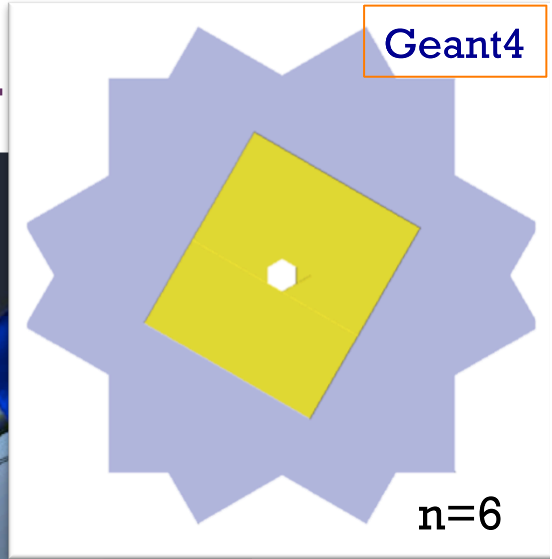



Very high energy and intensity gamma beam need an association of multi-dual slit collimator

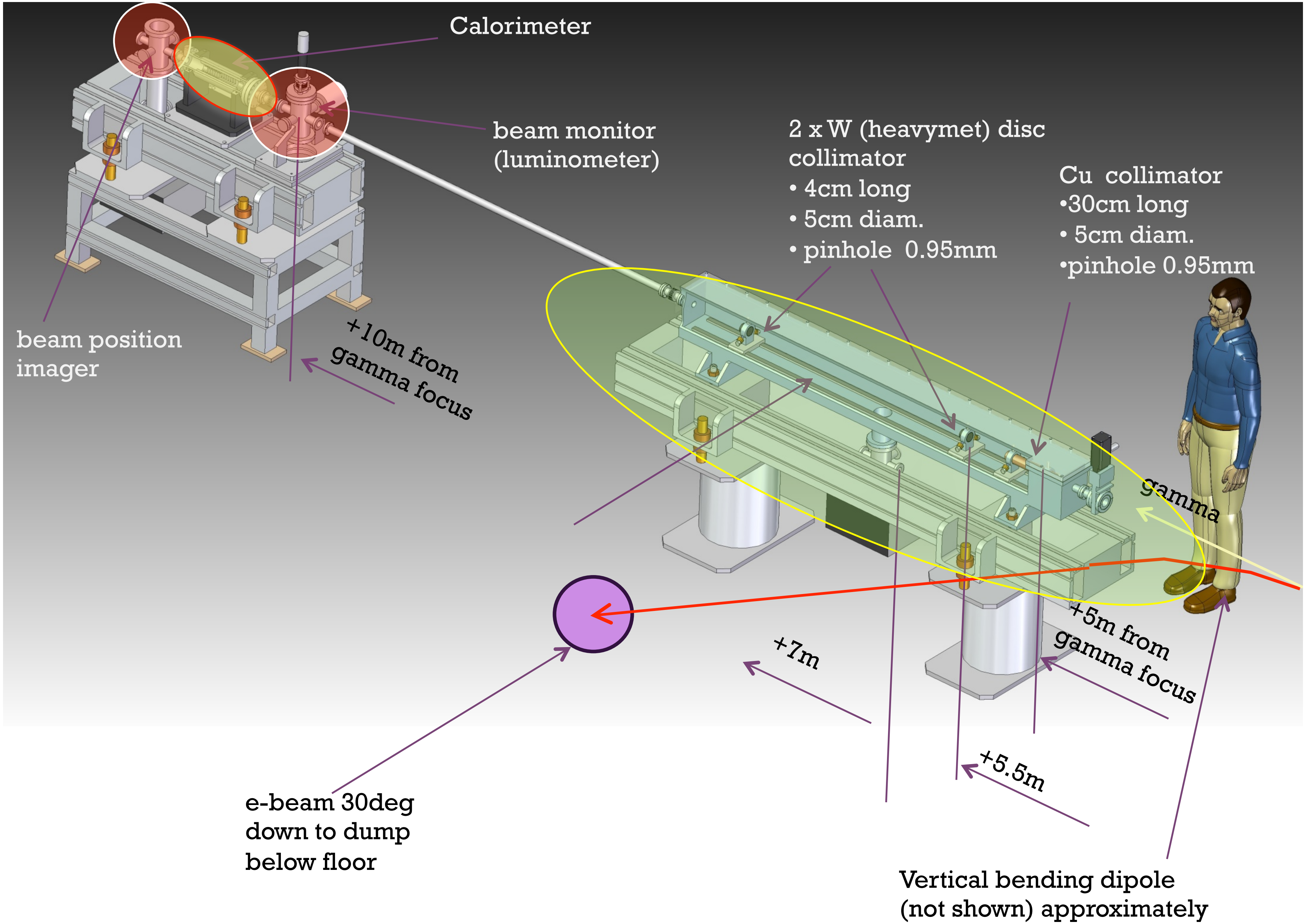
# Multi dual slit collimator




Two set of collimators parameters (L.E. & H.E.) have been found which satisfied the bandwidth requirement




Design based on Layout emails received 6th & 7th May (old scheme)

Courtesy M. Gambaccini

# Conclusions

- 80 collaborators elaborating the CDR/TDR
  - Italy : INFN, Sapienza
  - France : IN2P3, Univ. Paris Sud
  - UK : ASTeC/STFC

ELI-NP is a game changer (ref. T. Tajima) in nuclear physics and engineering as well as in fundamental science and its applications of a broad range

- look for radically different ways to seek fundamental physics via photons, rather than charged particles in high energies

- represents Nuclear Photonics, an emerging brand new discipline to explore and control nuclei by photons (unlike the standard approach using charged particles)