LUXE challenges, simulation and overall plans

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LUXE Workshop
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Outline

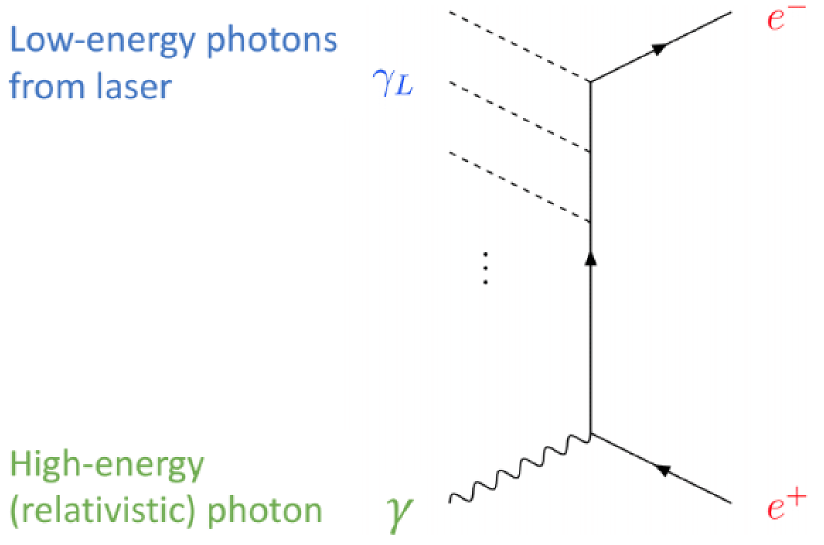
LUXE – **L**aser **U**nd **X**FEL **E**xpriment

- Introduction
- Design of experimental setup
- MC simulation
- Occupancy of LUXE subsystems

Laser-assisted pair production

$$\gamma + n\omega \rightarrow e^+ e^-$$

One photon pair production (OPPP) at ultra high intensity - non-perturbative physics



The rate of laser-assisted (OPPP) rate:

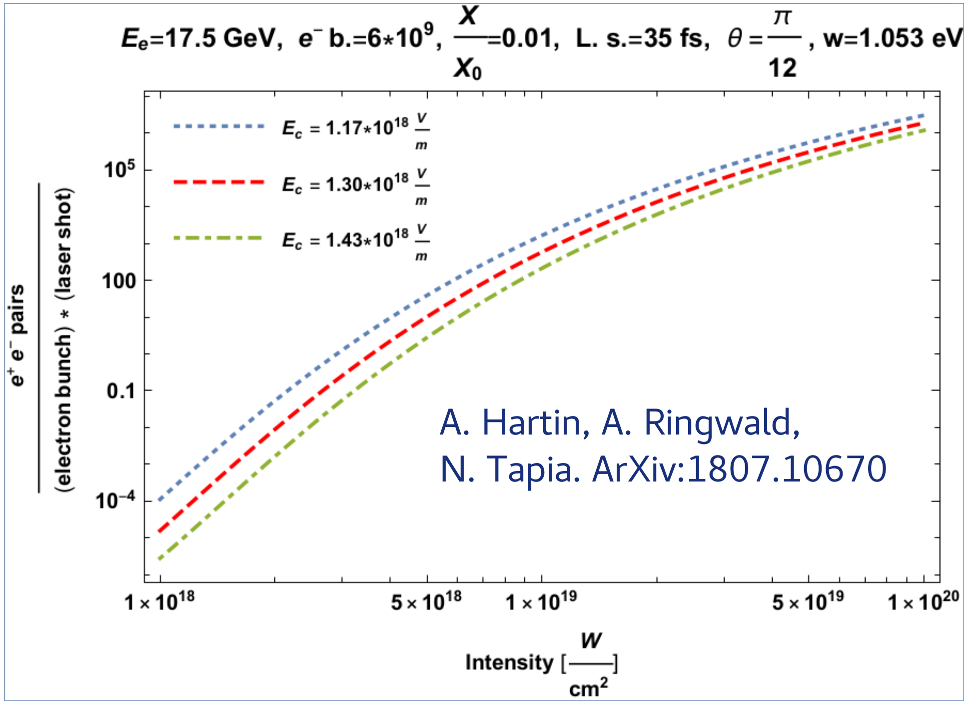
$$\Gamma_{\rm OPPP} = \frac{\alpha m_e^2}{4\,\omega_{\rm i}} F_\gamma(\xi, \chi_\gamma)$$

$$\xi \equiv \frac{e\,|\mathbf{E}|}{\omega m_e} = \frac{m_e}{\omega}\frac{|\mathbf{E}|}{\rm E_c}\,, \qquad \chi_\gamma \equiv \frac{k\cdot k_i}{m_e^2}\,\xi = (1+\cos\theta)\,\frac{\omega_i}{m_e}\frac{|\mathbf{E}|}{\rm E_c}$$

Use bremsstrahlung photons produced by XFEL beam hitting tungsten target.

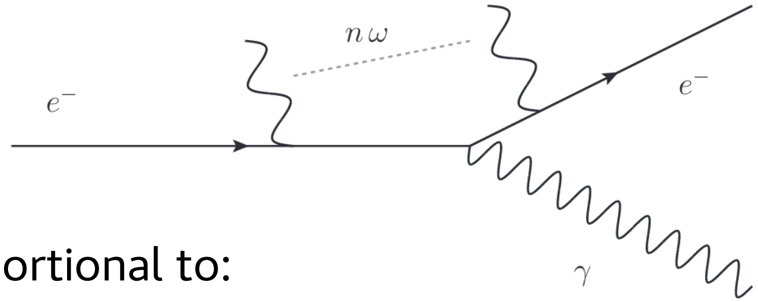
$$\Gamma_{\rm BPPP} = \frac{\alpha\, m_e^2}{4}\int_0^{E_e} \frac{{\rm d}\omega_i}{\omega_{\rm i}}\frac{{\rm d}N_\gamma}{{\rm d}\omega_i} F_\gamma(\xi, \chi_\gamma(\omega_i))$$

$$\Gamma_{\rm BPPP} \rightarrow \frac{\alpha\, m_e^2}{E_e}\frac{9}{128}\sqrt{\frac{3}{2}}\,\chi_e^2\, e^{-\frac{8}{3\chi_e}\left(1-\frac{1}{15\xi^2}\right)}\frac{X}{X_0}$$



High Intensity Compton Scattering

$$e^- + n\omega \to e^- + \gamma$$



The rate of High Intensity Compton Scattering (HICS) proportional to:

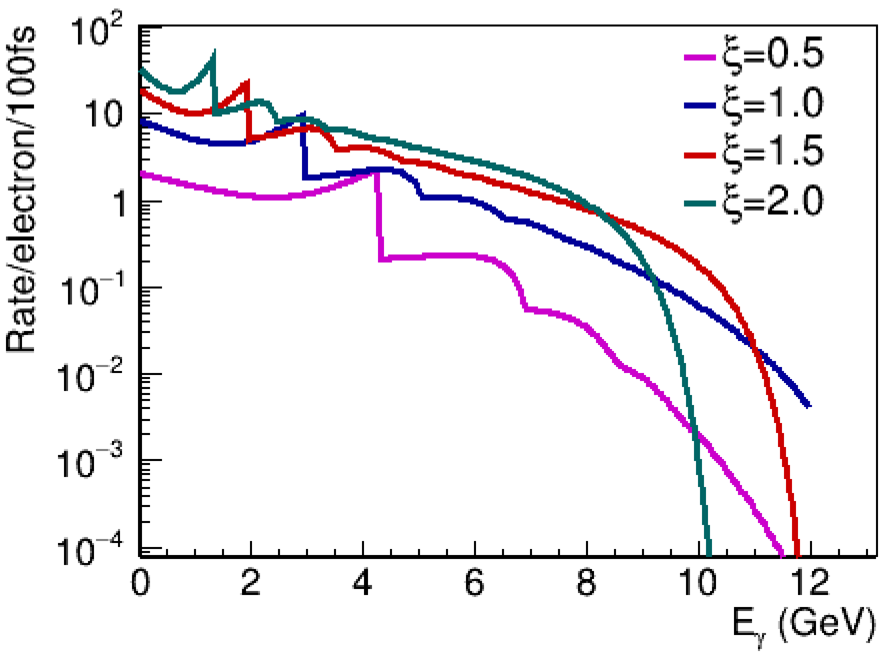
$$\sum_n \delta^{(4)}\left[p_i + k\frac{\xi^3}{2\chi_i} + nk - p_f - k\frac{\xi^3}{2\chi_f} - k_f\right]$$

Momentum conservation is a sum over external field photon contributions, *nk*

Even for *n=0* there is an irreducible contribution:

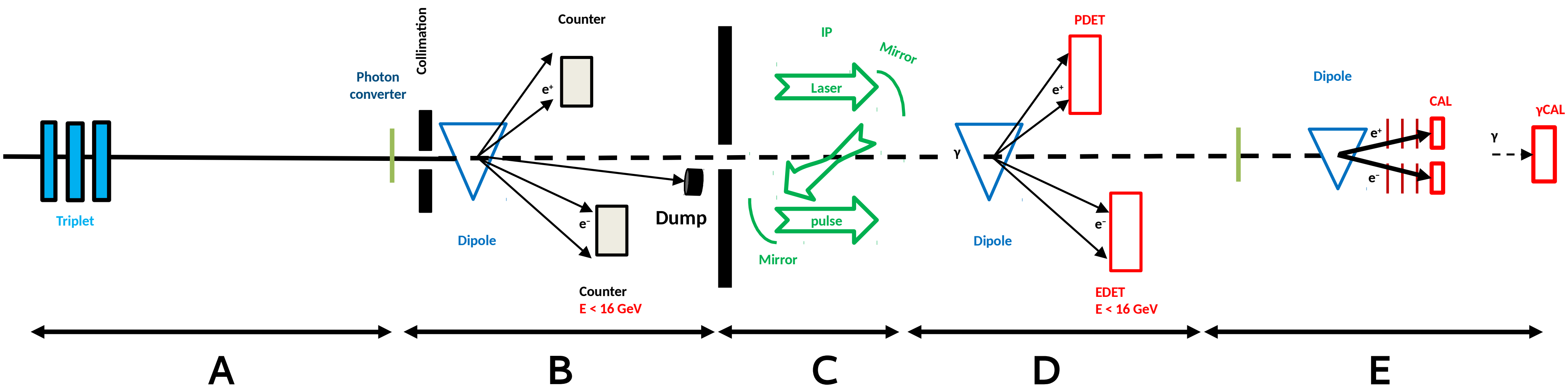
$$p_i + k\frac{\xi^3}{2\chi_i} \to p_i^2 = m^2(1+\xi^2)$$

Observation of Compton edge shift

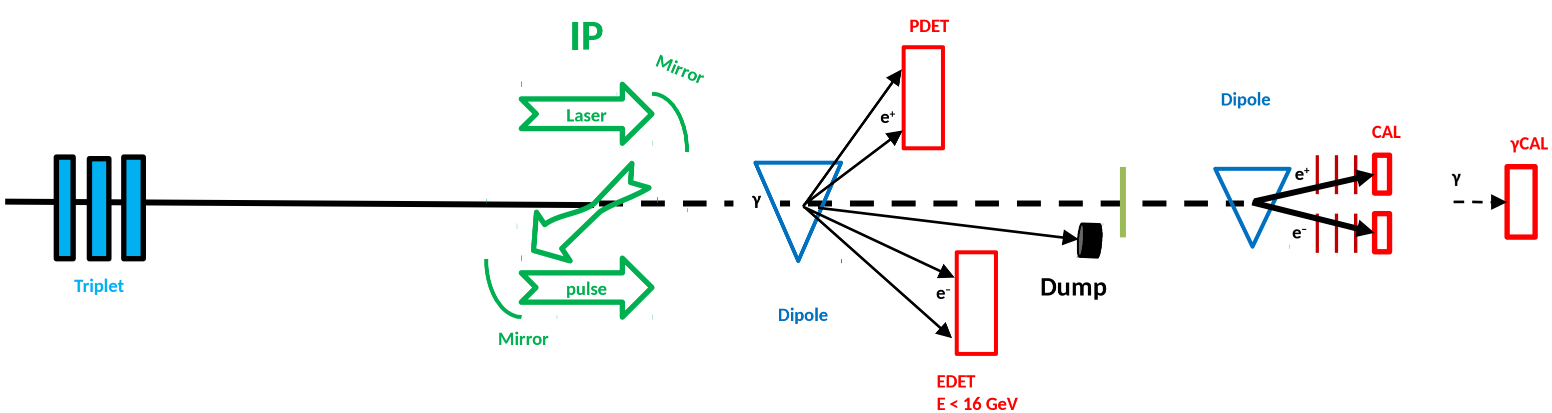


LUXE Setup

Photon-Photon collisions at LUXE (OPPP)



Electron-Photon collisions at LUXE (HICS)



Electron and laser beam parameters

E_pulse, J	Crossing angle, rad	Laser σ_{xy}, µm	Laser σ_z, ps	N Electrons	Electron σ_x, µm	Electron σ_y, µm	Electron σ_z, ps
3.5	0.3	10	0.035	6.25E+09	5.0	5.0	0.08

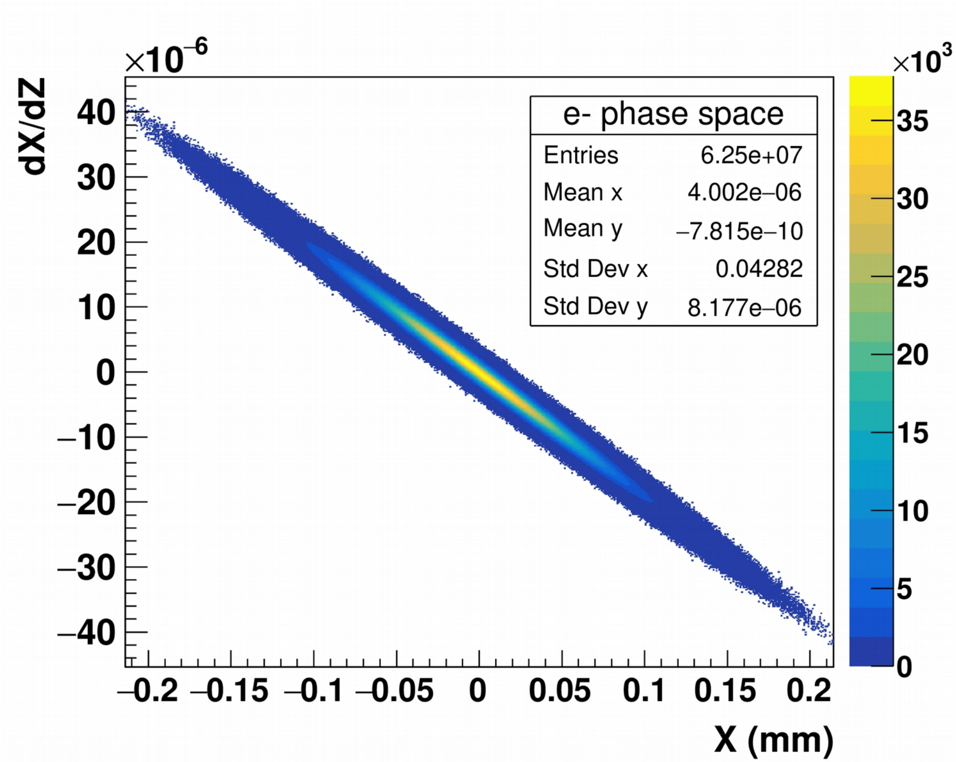
<u>EU.XFEL electron beam:</u>

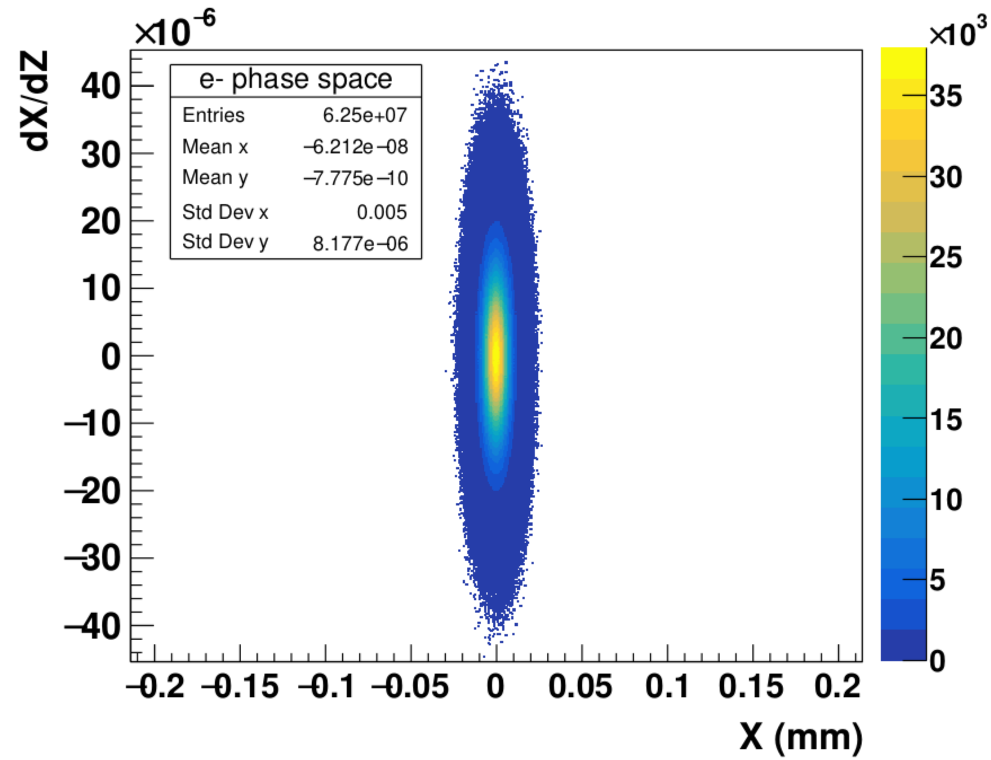
- Electron beam parameters are defined by EU.XFEL;
- Energy 17.5 GeV;
- Emittance 1.4 mm mrad.

<u>Laser:</u>

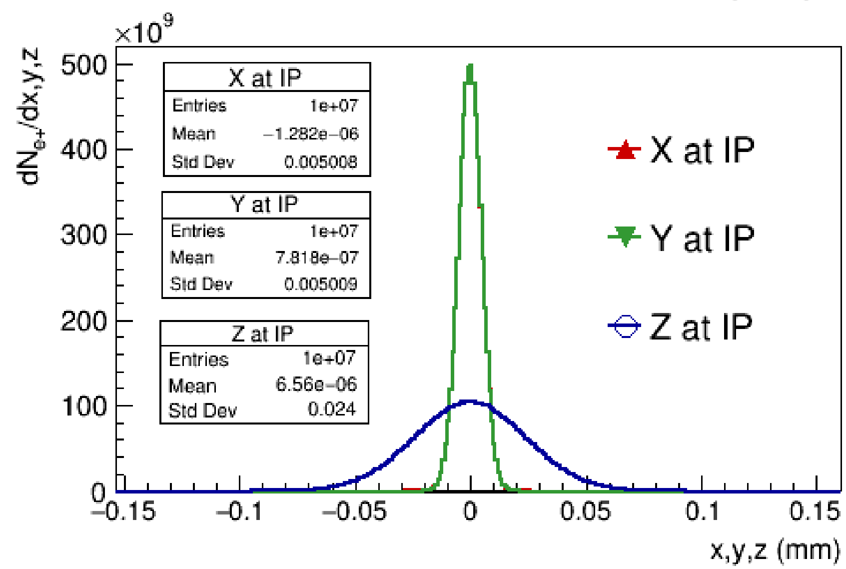
- Laser wavelength = 800.00 nm (1.5498 eV);
- Circular polarized;
- Power:
  - Stage_0: 1.0e19 W/cm^2, (0.35J, 100 µm^2, 35 fs);
  - Stage_0.5: 2.9e19 W/cm^2, (1.0J, 100 µm^2, 35 fs);
  - Stage_1: 1.0e20 W/cm^2, (3.5J, 100 µm^2, 35 fs);

Electron beam settings for simulation





- Gaussian distribution;
- Beam emittance: 1.4 mm mrad;
- Focus at IP;
- Target: 5 m upstream of IP.

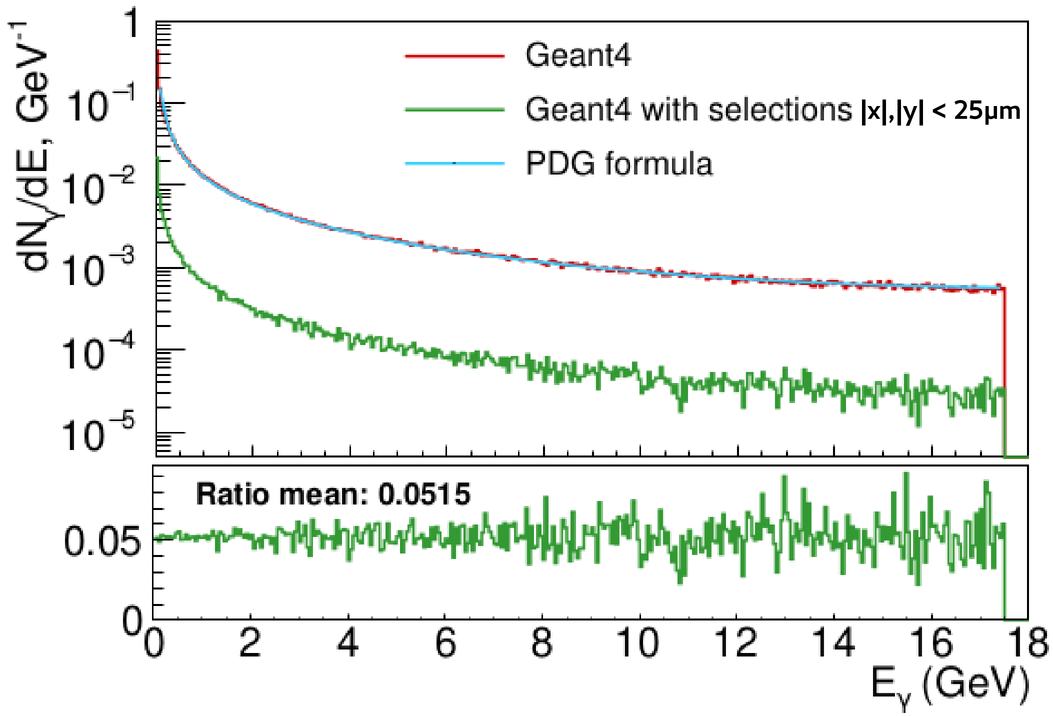


Bremsstrahlung production Gent4 vs PDG formula

PDG formula for bremsstrahlung production:

$$\omega_i \frac{dN_\gamma}{d\omega_i} \approx \left[\frac{4}{3} - \frac{4}{3}\left(\frac{\omega_i}{E_e}\right) + \left(\frac{\omega_i}{E_e}\right)^2\right] \frac{X}{X_0}$$

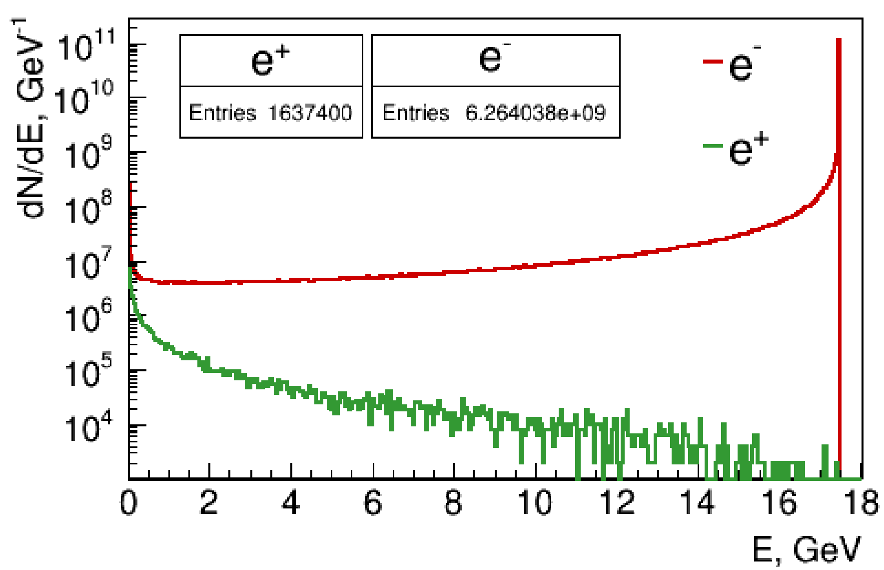
- Gaussian beam;
- Tungsten target 1%X0 (35μm), 2m from
- Two histograms are compered:
  - |x| < 1mm and |y| < 1mm (read);
  - |x| < 25μm and |y| < 25μm (green).



Nγ	4.91E+06
Nγ, E >7GeV	4.66E+05

- Electrons and positrons observed after the target (θ<17°).
- Spectra and table data correspond to one BX.

N e-	6.26E+09
N e-, < 16 GeV	1.80E+08
N e+	1.62E+06

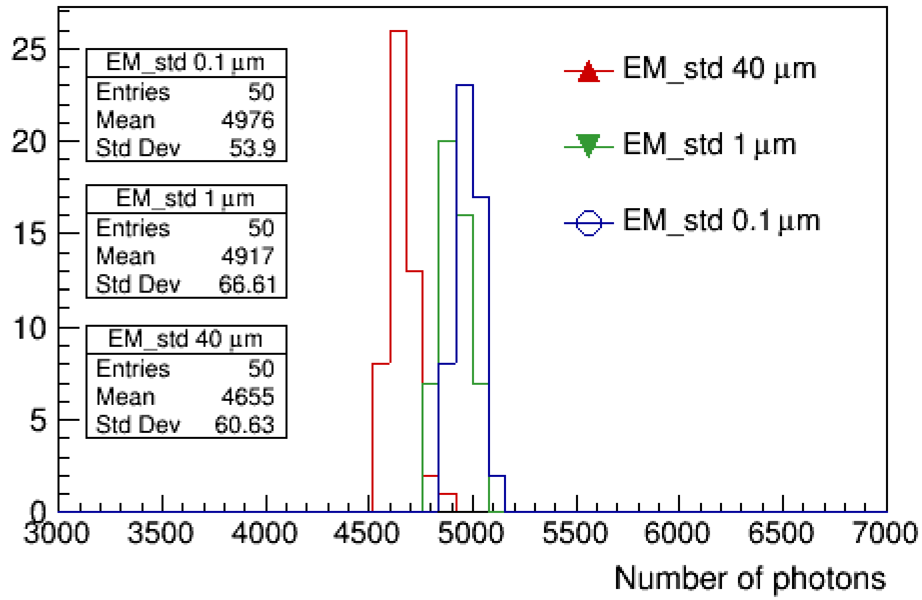


Geant4 simulation with different step, different physics lists, different beam

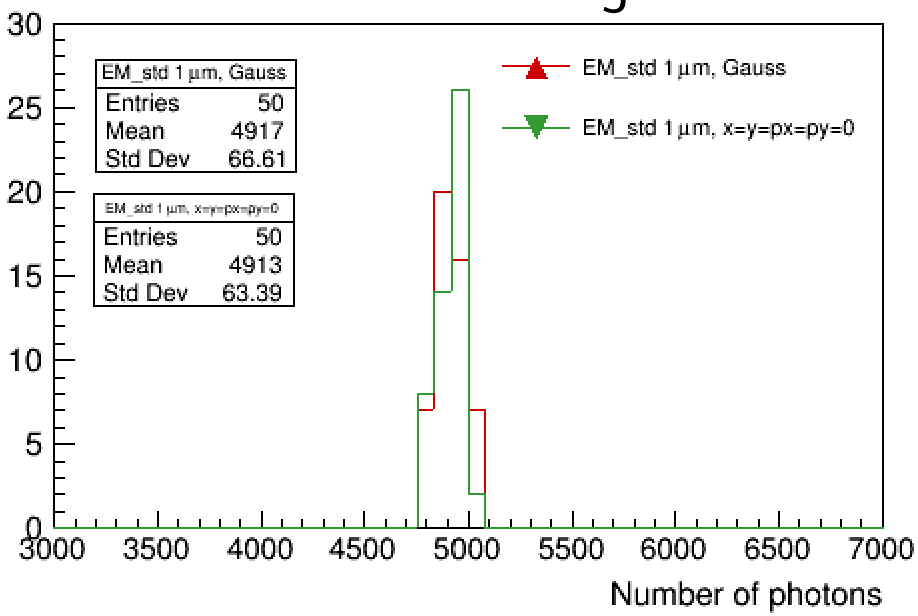
- Gaussian beam, focused on IP;
- Tungsten target 1%X0 (35µm) thickness
- 5 m from IP;
- 6.25 M electrons (BX/1000);
- Production cut: 1 µm.

Number of photons inside
|x|<25um and
|y|<25um;

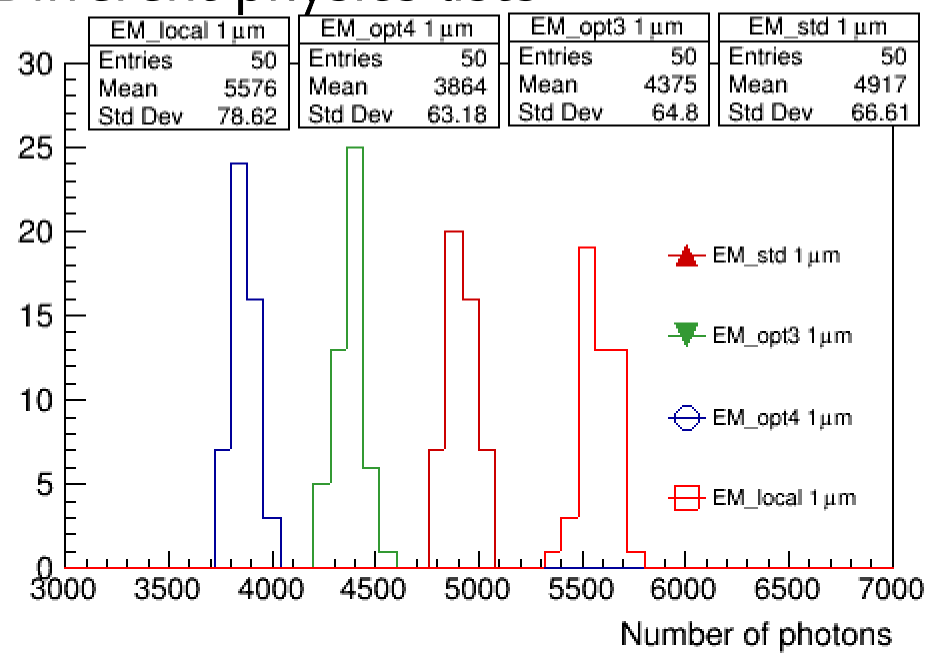
Different step



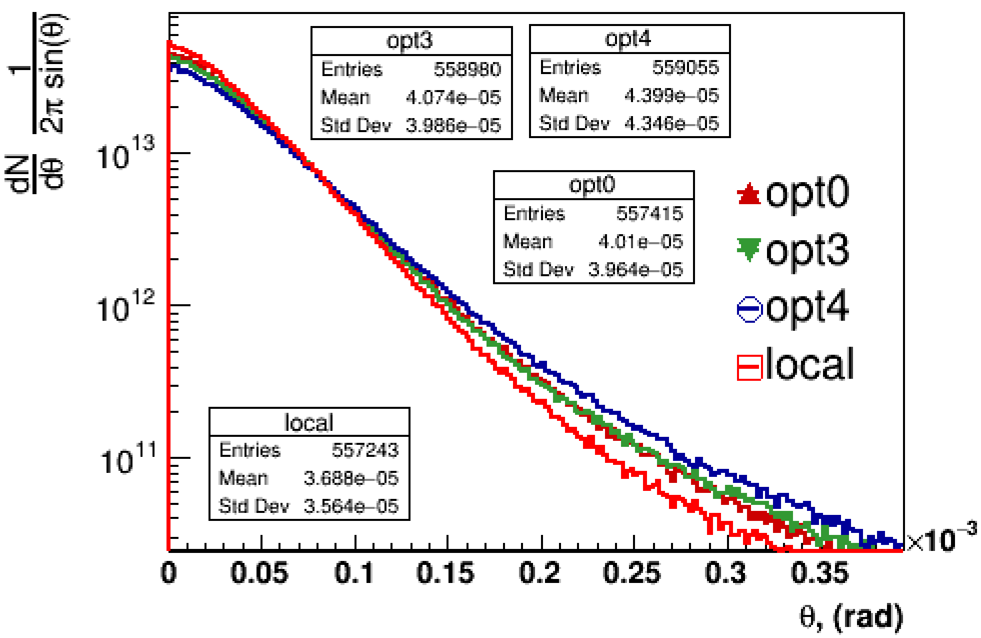
Different beam settings

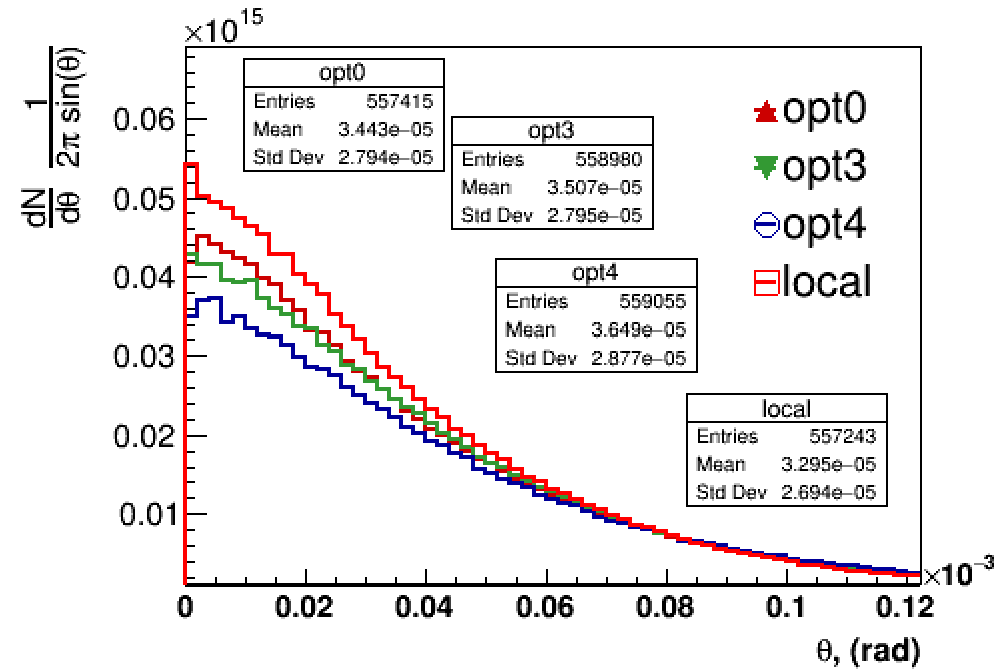


Different physics lists

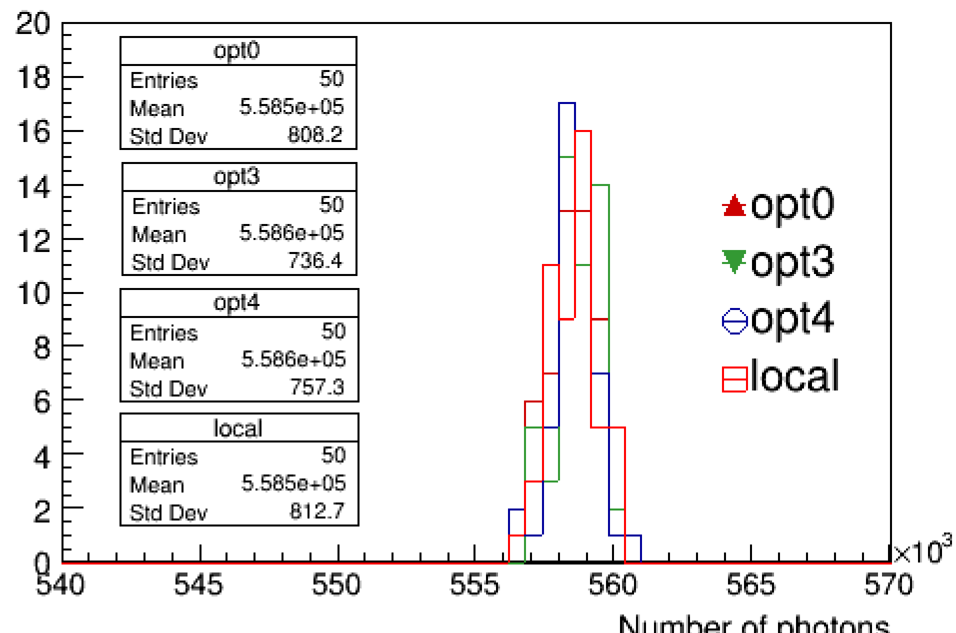


γ angular distribution for different physics lists





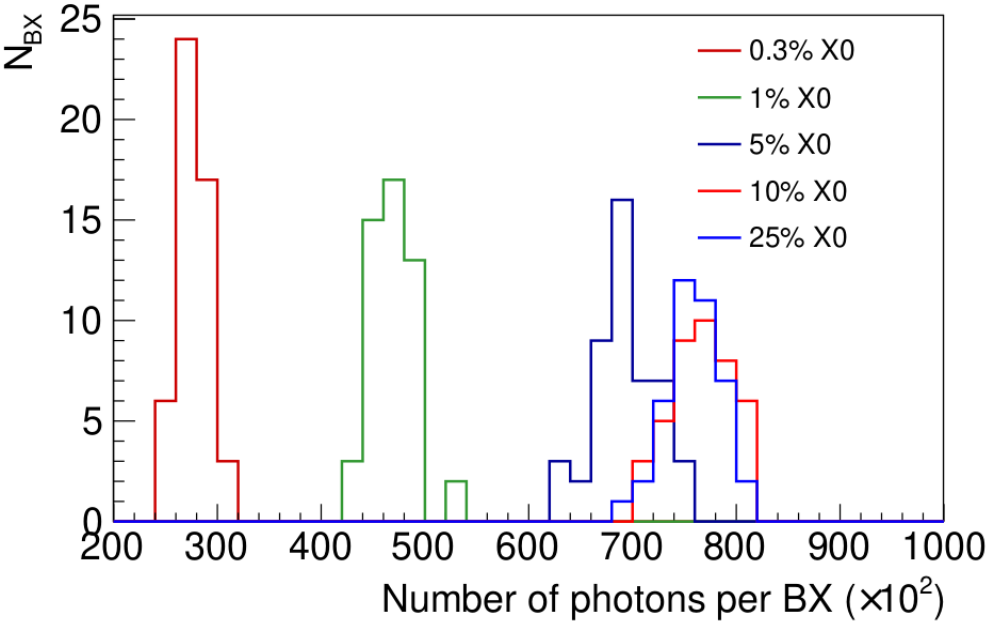
- Angular distribution is the widest for option_4 physics list.
- The difference in angular distribution explains the observed difference in the number of photons at IP.
- Total number of photons in forward region is identical for all physics lists.



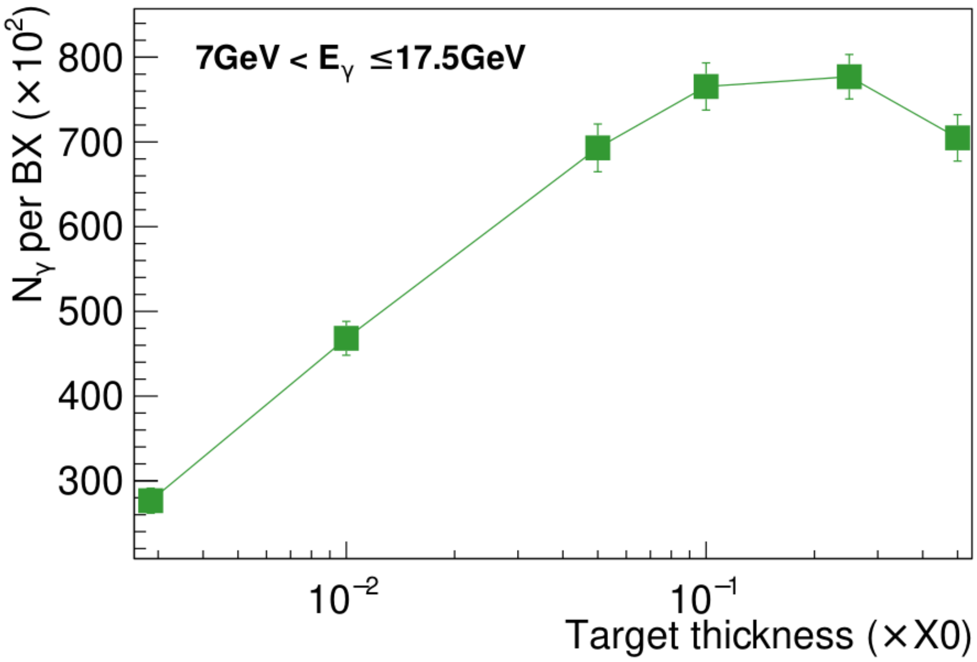
Number of photons inside
|x|<1.5 m and
|y|<1.5 m

Different target thickness

- Gaussian beam;
- Tungsten target 5m from IP;
- Photons selection :
  - |x| < 25um and |y| < 25um
  - E > 7 GeV.

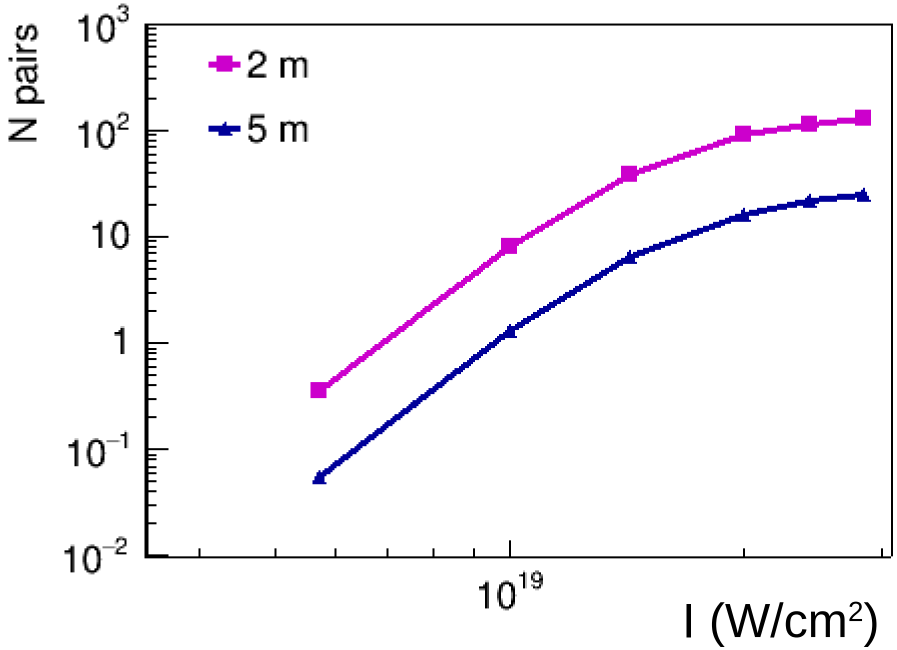


- By changing a target thickness (to some extent) for a given distance between target and IP the photon flux and pairs production rate can be set at reasonable level.

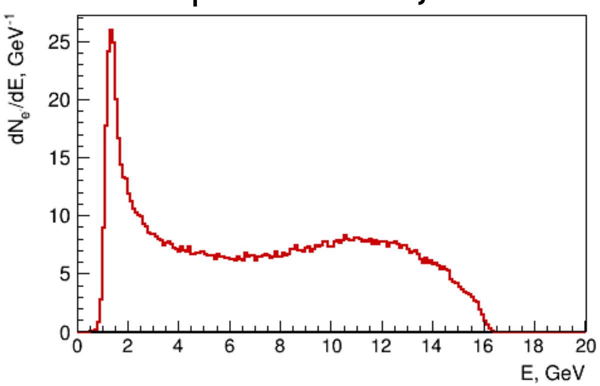


One photon pair production in MC study

- Tungsten target 35 μm (1%X0) for bremsstrahlung production;
- Target is 5 m and 2 m upstream of IP;



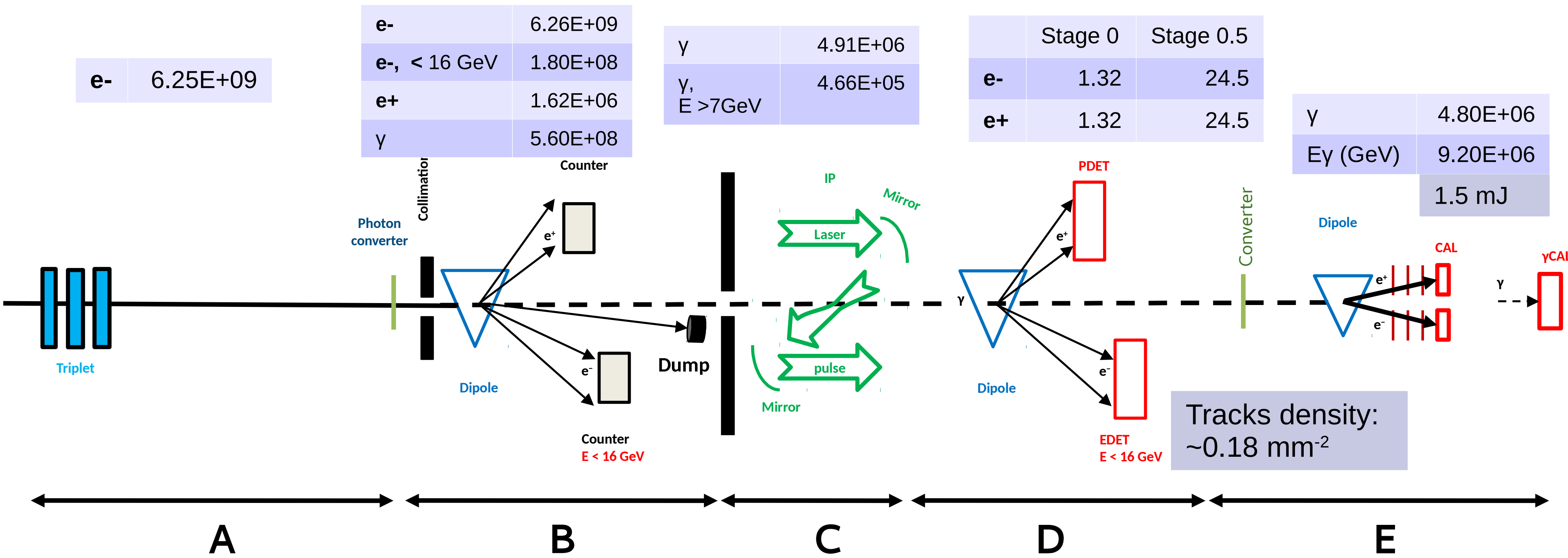
e- spectrum at ξ=2.4



ξ	I (W/cm²)	N pairs 2m	N pairs 5m	N2/N5
1.16	5.71E+018	0.356	0.0557408	6.39
1.54	1E+019	7.89241	1.31872	5.98
1.84	1.429E+019	37.7175	6.52168	5.78
2.18	2E+019	89.0315	16.3754	5.44
2.4	2.429E+019	114.31	21.6355	5.28
2.6	2.857E+019	128.306	24.5345	5.23

$$N \sim \frac{1}{L^2}$$

Photon-Photon collisions at LUXE



Area	Description	e-	e+	γ	Notes
A	Incident beam	6.25E+09			XFEL beam sigma_xy = 5µm, emittance: 1.4e-3 mm mrad
B	Target	6.26E+09	1.62E+06	5.60E+08	Tungsten 35 µm, (1%X0), 5 m upstream of IP
C	IP			4.91E+06	Geometrical cut |x|<25µm && |y|<25µm is applied to match laser transverse size
	E > 7 GeV			4.66E+05	
	E > 12 GeV			1.92E+05	
D	Detectable				
	Stage 0	1.32	1.32		Laser: 1.0e19 W/cm², (0.35J, 100µm², 35 fs)
	Stage 0.5	24.5	24.5		Laser: 2.6e19 W/cm², (1.0J, 100µm², 35 fs); Track density up to 0.18 mm^{-2}
E	γ detector			4.80E+06	Total energy: 9.2e6 GeV = 1.5mJ
	Wire target	~100	~100		Tungsten wire converter target, D=10 µm

Photon-Photon collisions at LUXE

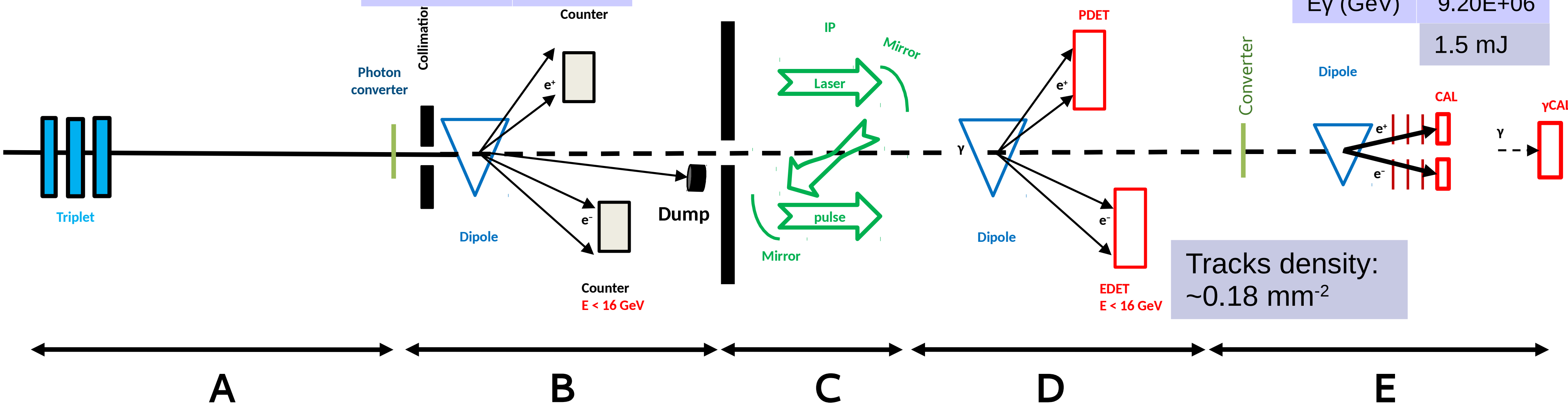
e-	6.25E+09

e-	6.26E+09
e-, < 16 GeV	1.80E+08
e+	1.62E+06
γ	5.60E+08

γ	4.91E+06
γ, E >7GeV	4.66E+05

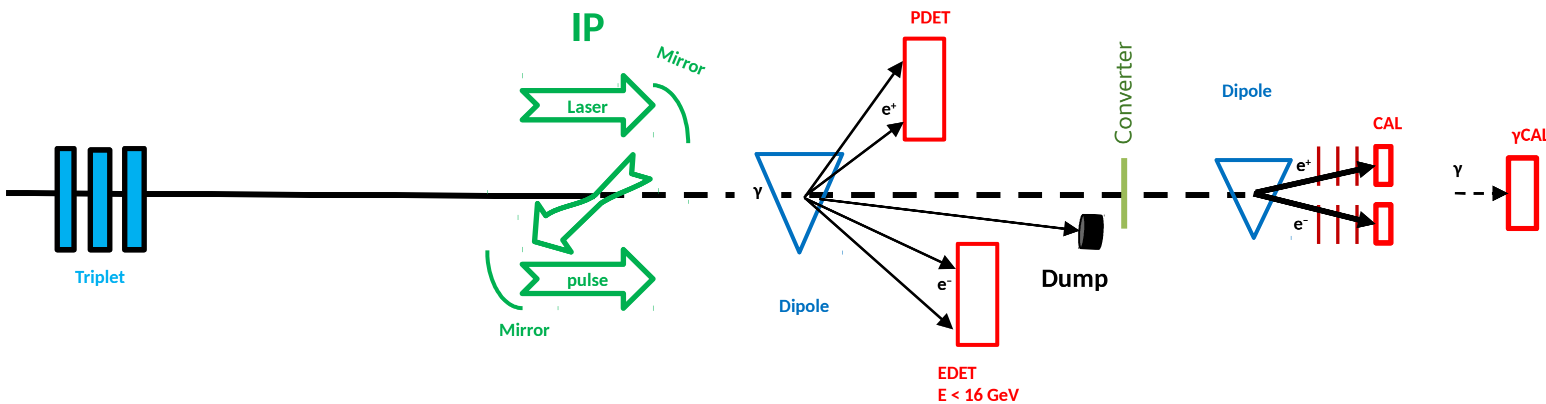
	Stage 0	Stage 0.5
e-	1.32	24.5
e+	1.32	24.5

γ	4.80E+06
Eγ (GeV)	9.20E+06
	1.5 mJ



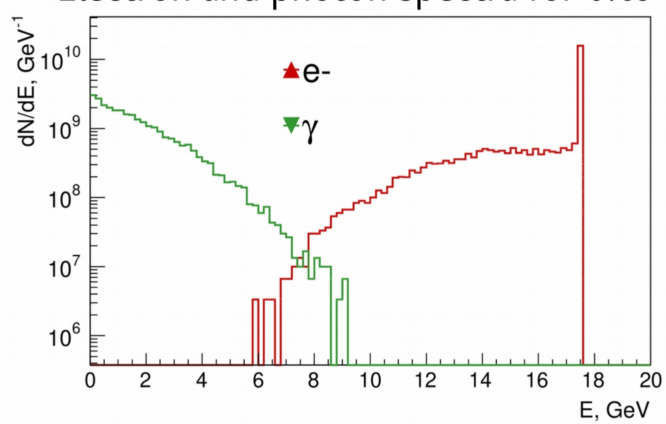
- Bremsstruhlung production monitor (section B): Cherenkov counters and calorimiters;
- OPPP measurements (section D): spectrometer (dipole + few layers of tracking detectors) and calorimiters;
- Forward detector (section E): low X0 target, spectrometer (dipole + few layers of tracking detectors), Cherenkov counters and calorimiters;
- γCAL: calorimeter capable of handling high photon flux.

Electron-Photon collisions at LUXE



MC simulation with 6E9 electrons per bunch;

Electron and photon spectra for 0.6J laser



Laser Power, J	Number of e- E < 16.GeV	Number of γ
0.6	2.18E+09	5.74E+09
0.2	1.16E+09	2.31E+09
0.1	6.82E+08	1.24E+09
0.01	8.47E+07	1.35E+08

- Electron detection: dipole with Cherenkov counters;
- Trident positron detection (~0.1 per BX at 0.6J observed): spectrometer (dipole + few layers of tracking detectors) and calorimiter.
- Forward detector: low X0 target, spectrometer (dipole + few layers of tracking detectors), Cherenkov counters and calorimiters;
- γCAL: calorimeter capable of handling high photon flux.