

LUXE challenges, simulation and overall plans

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LUXE

LUXE Workshop
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Outline

LUXE – Laser Und XFEL Experiment

- Introduction
- Design of experimental setup at EU.XFEL

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:

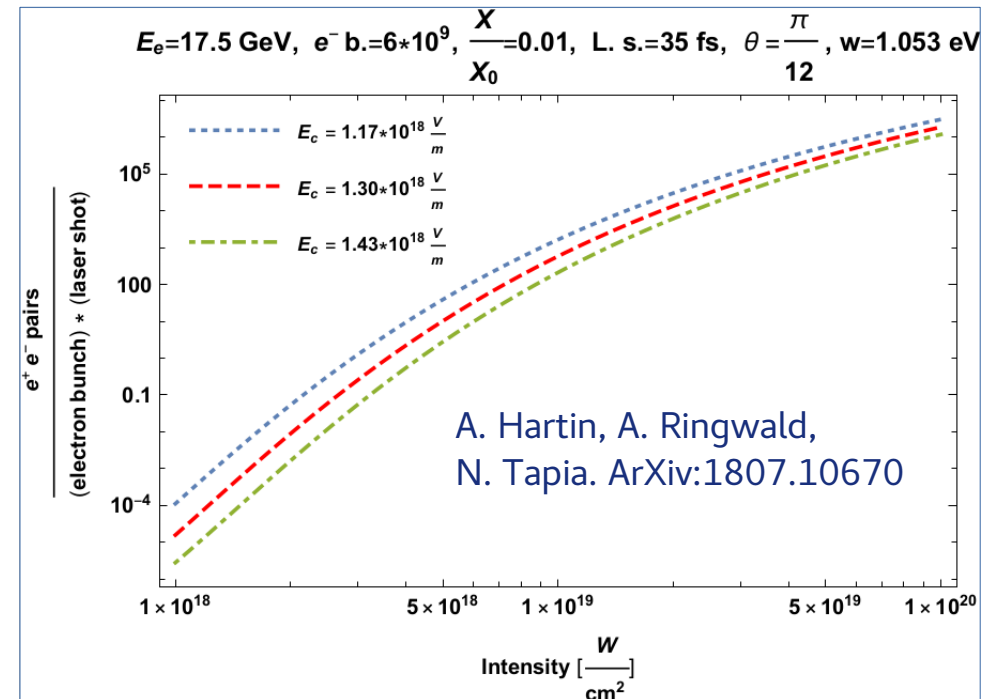
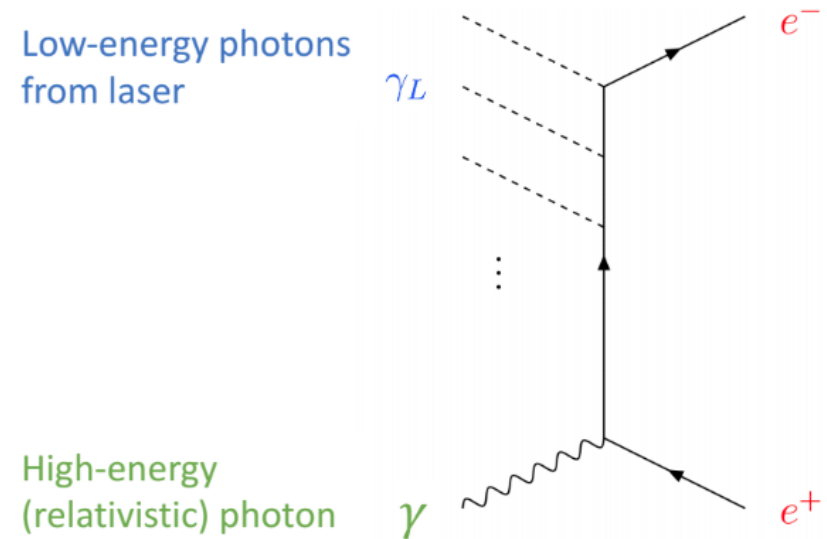
$$\Gamma_{\text{OPPP}} = \frac{\alpha m_e^2}{4\omega_i} F_\gamma(\xi, \chi_\gamma)$$

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

Use bremsstrahlung photons produced by XFEL beam hitting tungsten target.

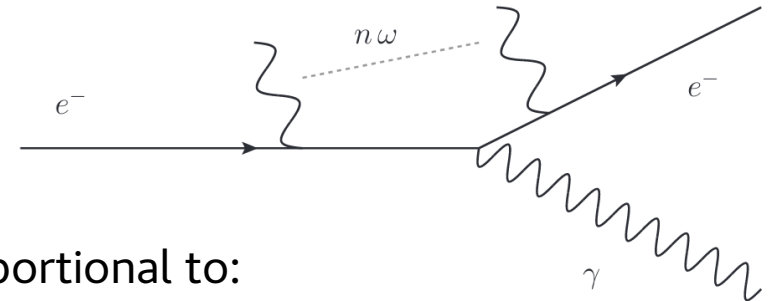
$$\Gamma_{\text{BPPP}} = \frac{\alpha m_e^2}{4} \int_0^{E_e} \frac{d\omega_i}{\omega_i} \frac{dN_\gamma}{d\omega_i} F_\gamma(\xi, \chi_\gamma(\omega_i))$$

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



High Intensity Compton Scattering

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



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

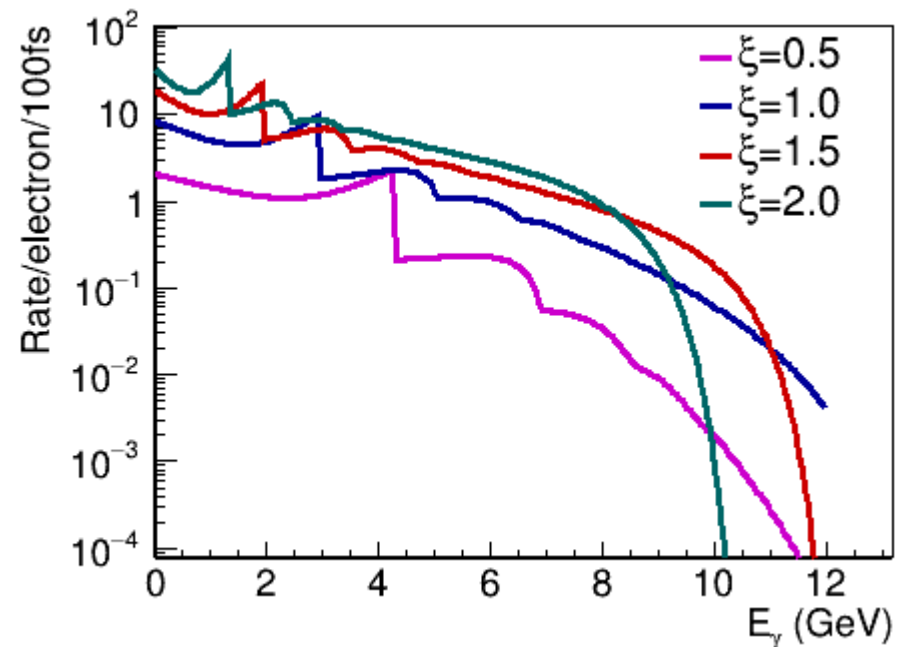
$$\sum_n \delta^{(4)} \left[p_i + k \frac{\xi^3}{2\chi_i} + nk - p_f - k \frac{\xi^3}{2\chi_f} - k_f \right]$$

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

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

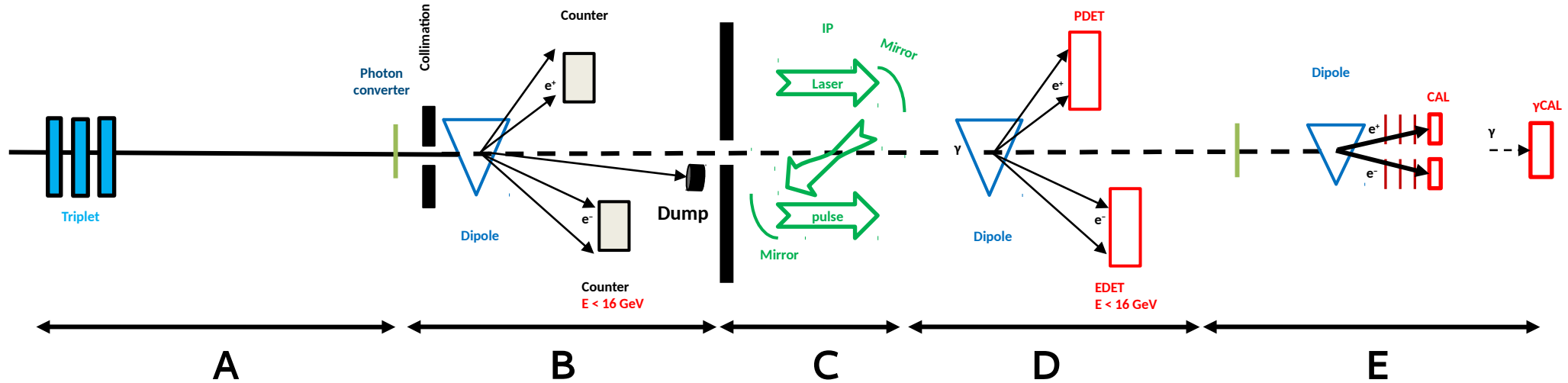
$$p_i + k \frac{\xi^3}{2\chi_i} \rightarrow p_i^2 = m^2 (1 + \xi^2)$$

Observation of Compton edge shift

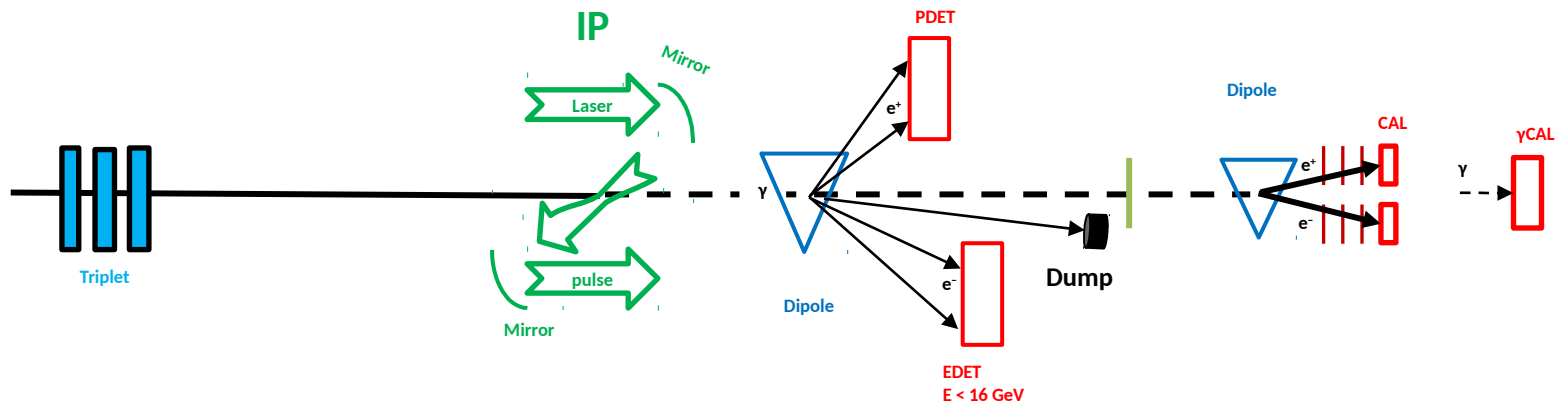


LUXE Setup

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

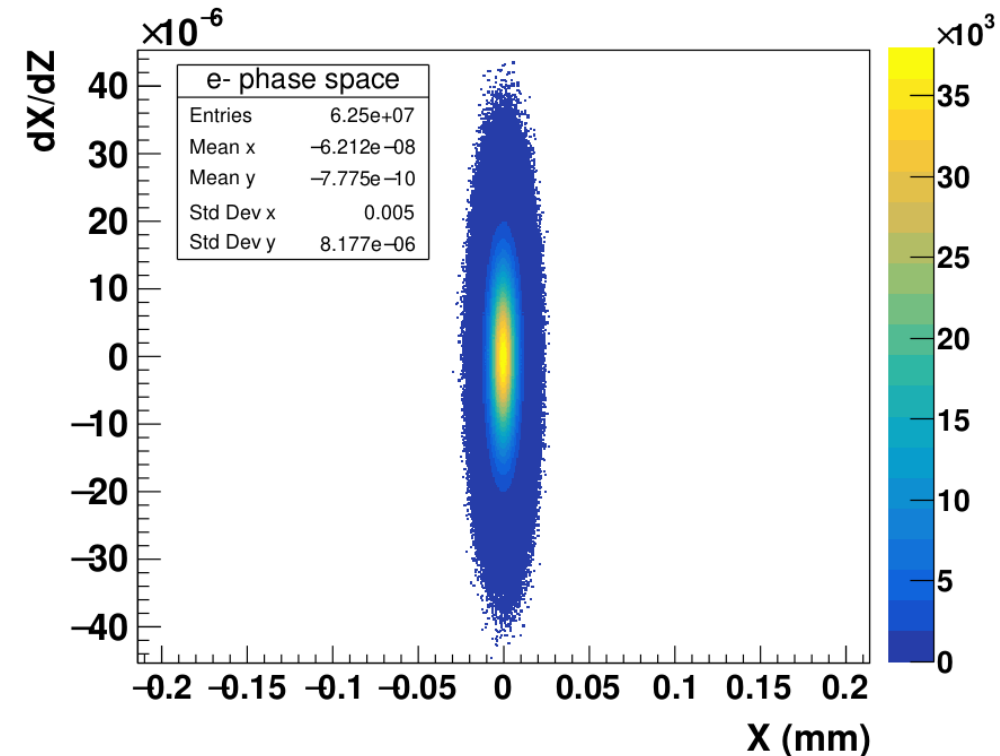
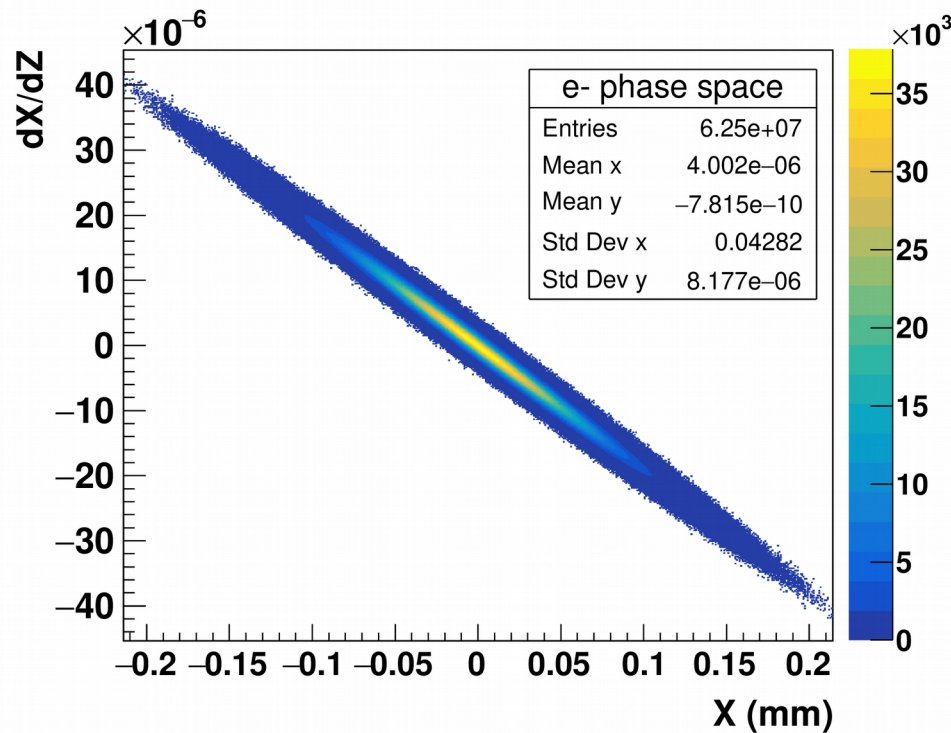
EU.XFEL electron beam:

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

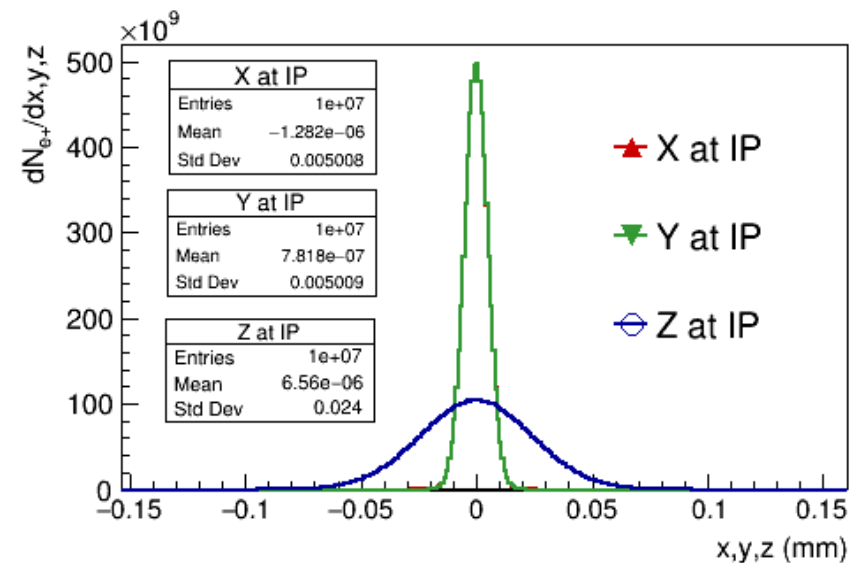
Laser:

- Laser wavelength = 800.00 nm (1.5498 eV);
- Circular polarized;
- Power:
 - Stage_0: 1.0e19 W/cm², (0.35J, 100 μm^2 , 35 fs);
 - Stage_0.5: 2.6e19 W/cm², (1.0J, 100 μm^2 , 35 fs);
 - Stage_1: 1.0e20 W/cm², (3.5J, 100 μm^2 , 35 fs);

Electron beam settings for simulation



- Gaussian distribution;
- Beam emittance: $1.4 \mu\text{m rad}$;
- Focus at IP;
- Target: 5 m upstream of IP.

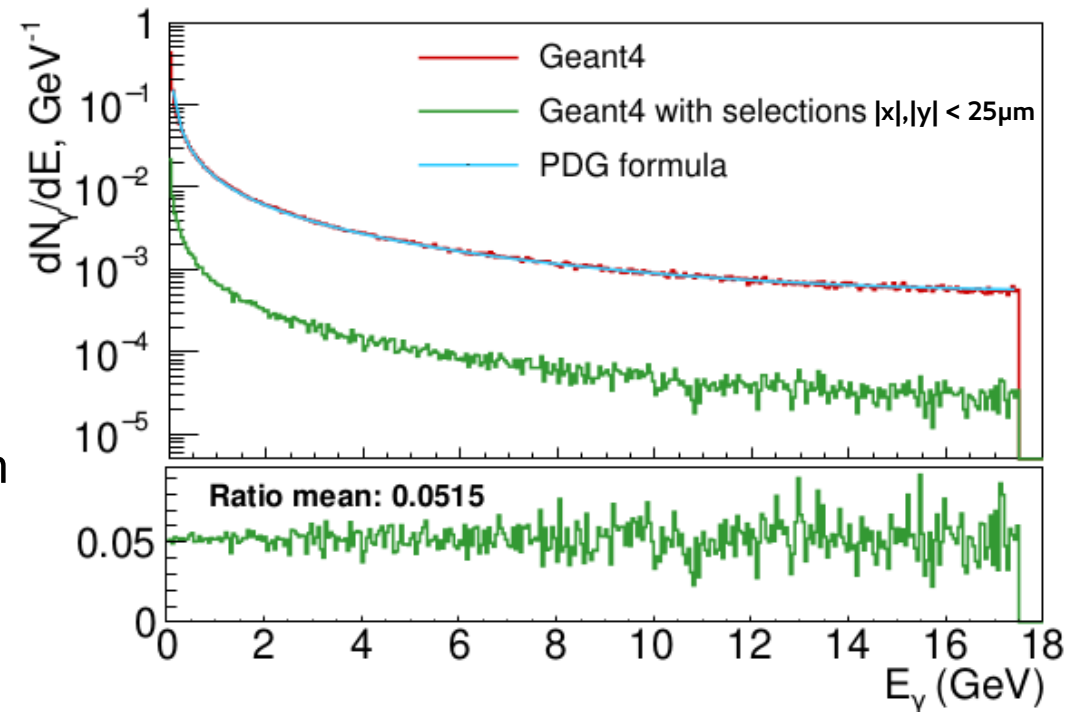


Bremsstrahlung production Gent4 vs PDG formula

PDG formula for bremsstrahlung production:

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

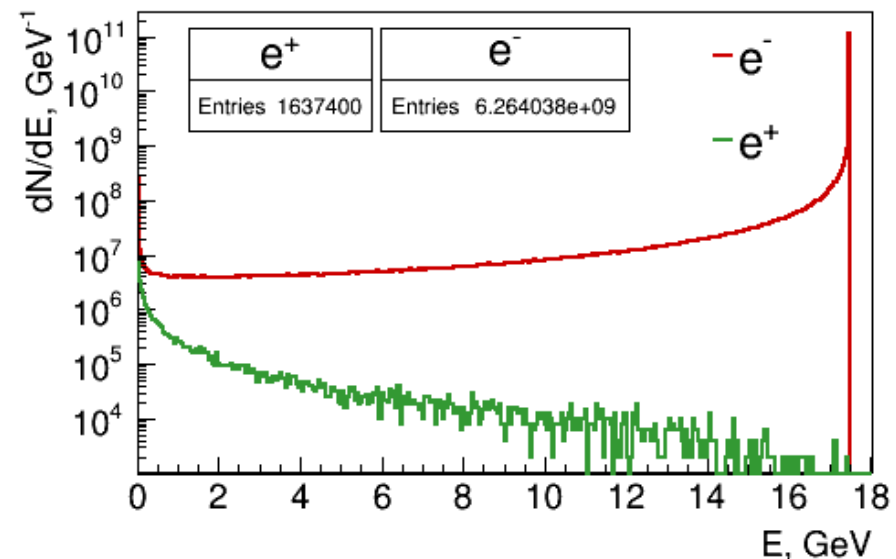
- Gaussian beam;
- Tungsten target 1%X₀ (35μm), 2m from
- Two histograms are compared:
 - |x| < 1mm and |y| < 1mm (red);
 - |x| < 25μm and |y| < 25μm (green).



N _γ	4.91E+06
N _γ , E >7GeV	4.66E+05

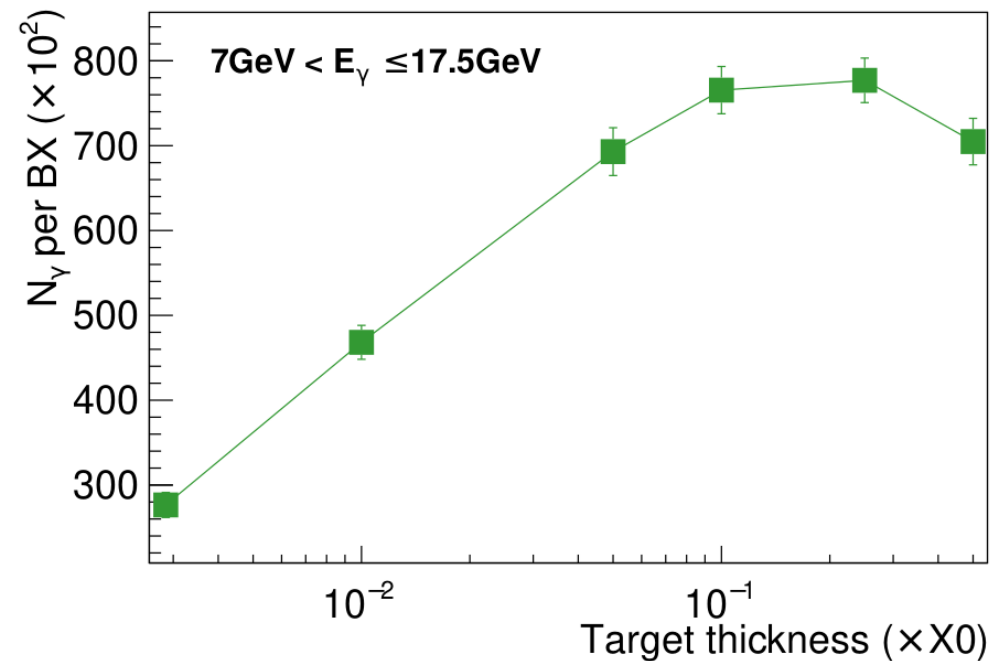
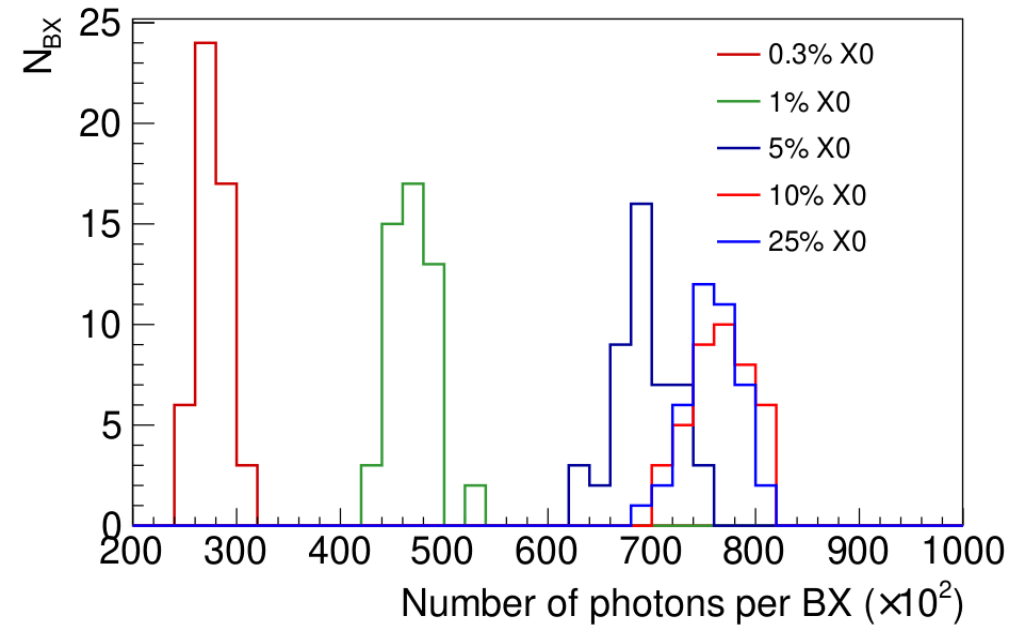
- Electrons and positrons observed after the target ($\theta < 17^\circ$).
- Spectra and table data correspond to one BX.

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



Different target thickness

- Gaussian beam;
- Tungsten target 5m from IP;
- Photons selection :
 - $|x| < 25\mu\text{m}$ and $|y| < 25\mu\text{m}$
 - $E > 7\text{ GeV}$.

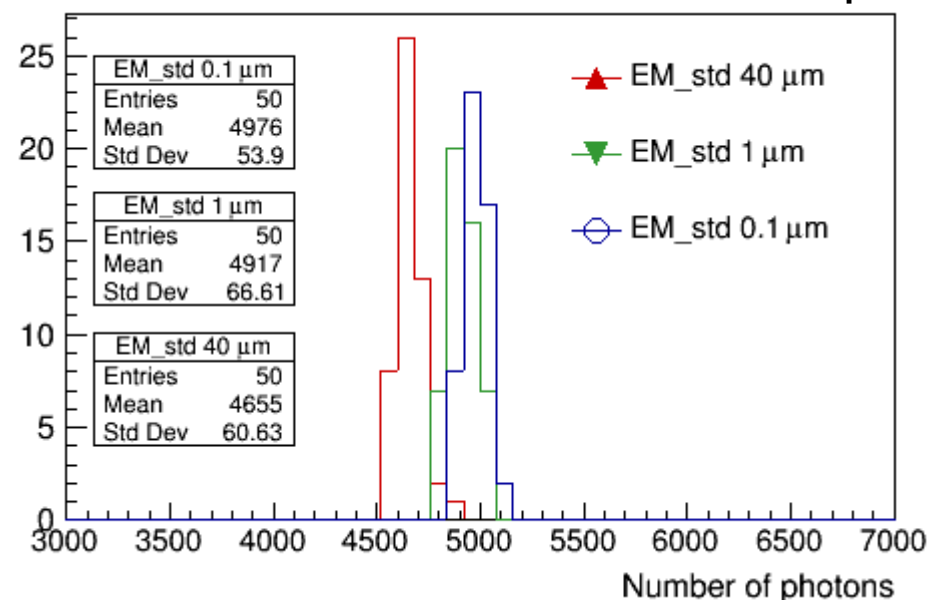


Geant4 simulation with different step, different physics lists, different beam

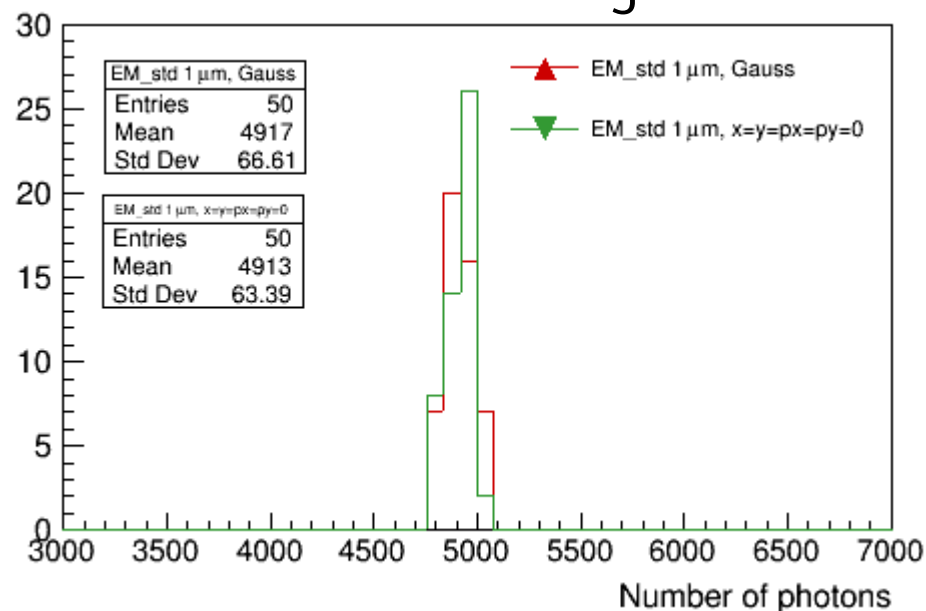
- Gaussian beam, focused on IP;
- Tungsten target 1%X0 (35 μ m) thickness
- 5 m from IP;
- 6.25 M electrons (BX/1000);
- Production cut: 1 μ m.

Number of photons inside
 $|x| < 25 \mu\text{m}$ and
 $|y| < 25 \mu\text{m}$;

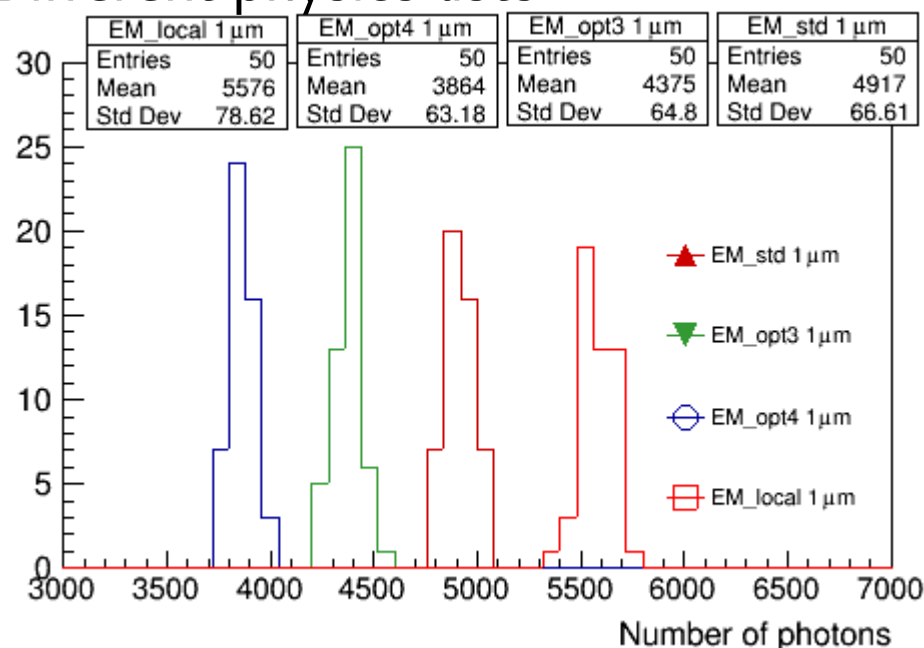
Different step



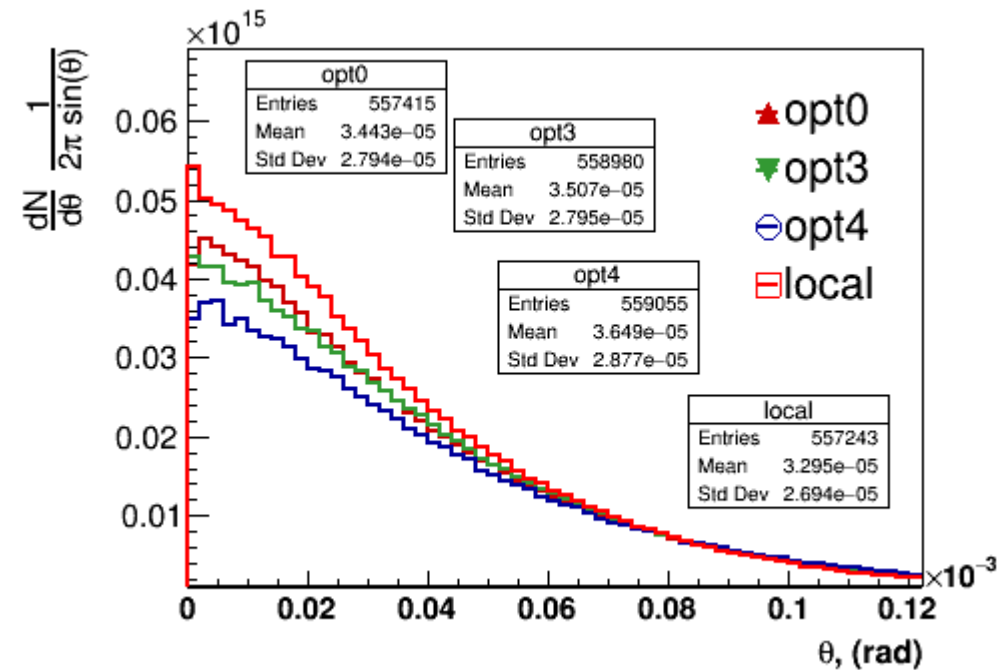
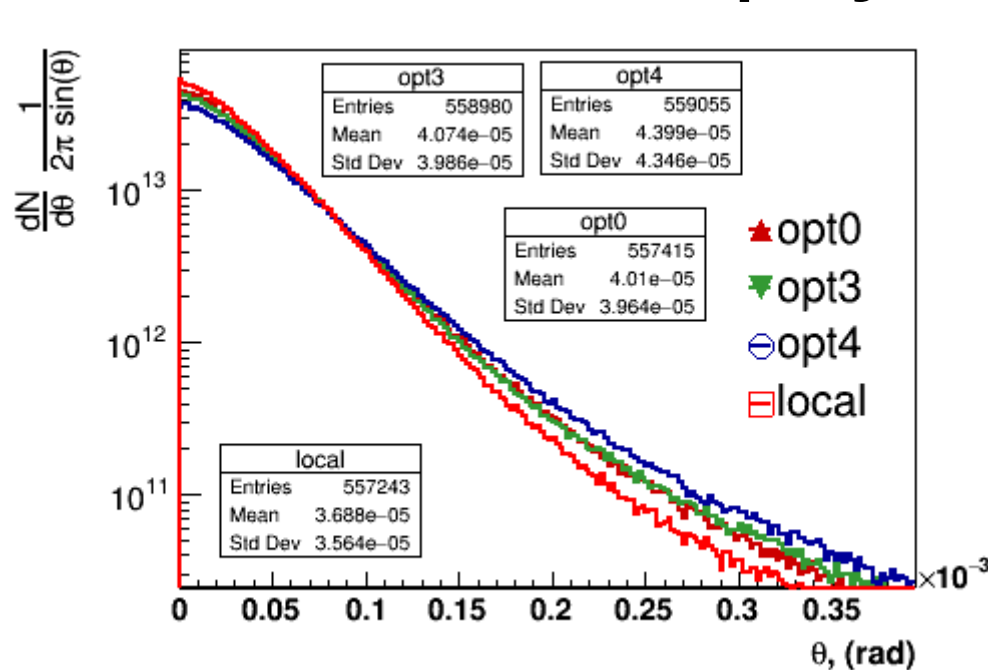
Different beam settings



Different physics lists

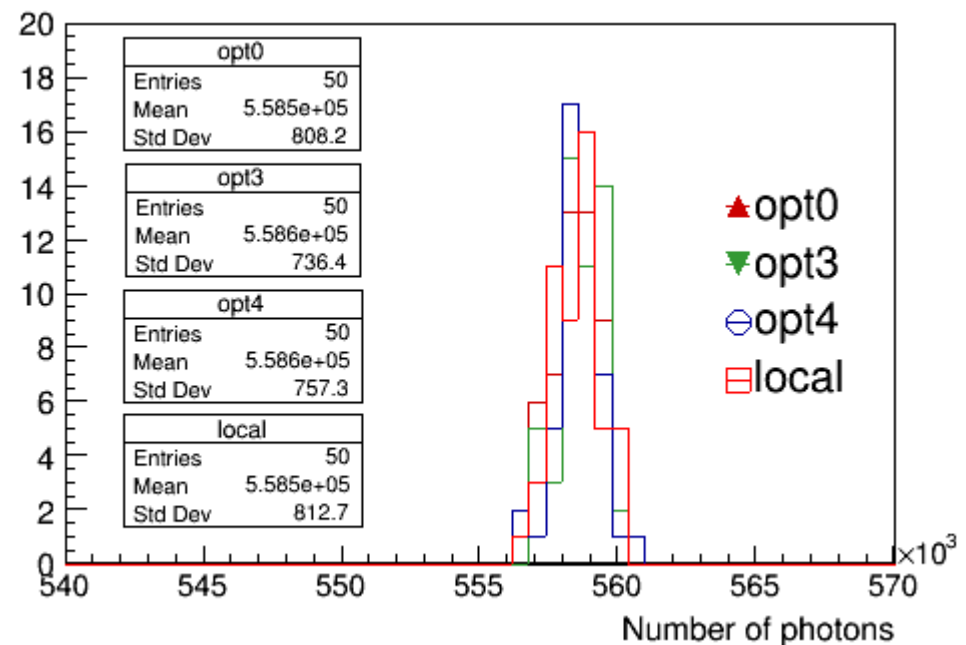


γ angular distribution for different physics lists



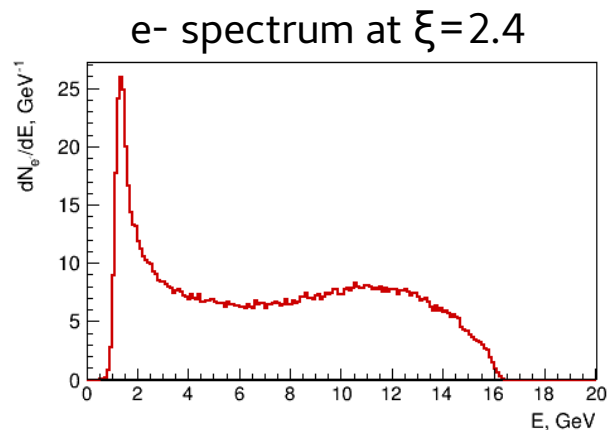
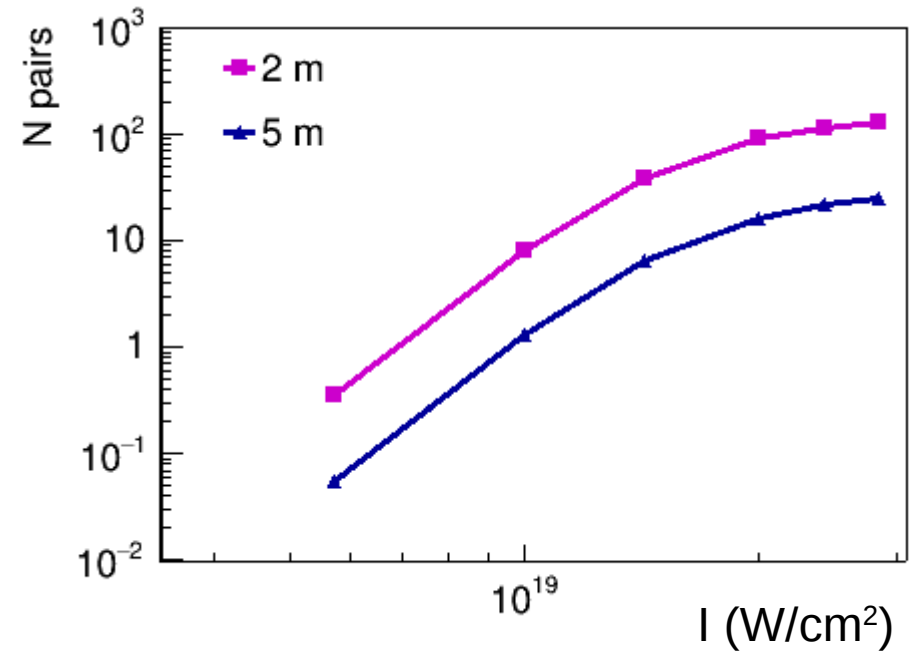
- Angular distribution is the widest for option_4 physics list.
- The difference in angular distribution explains the observed difference in the number of photons at IP.
- Total number of photons in forward region is identical for all physics lists.

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



One photon pair production in MC study

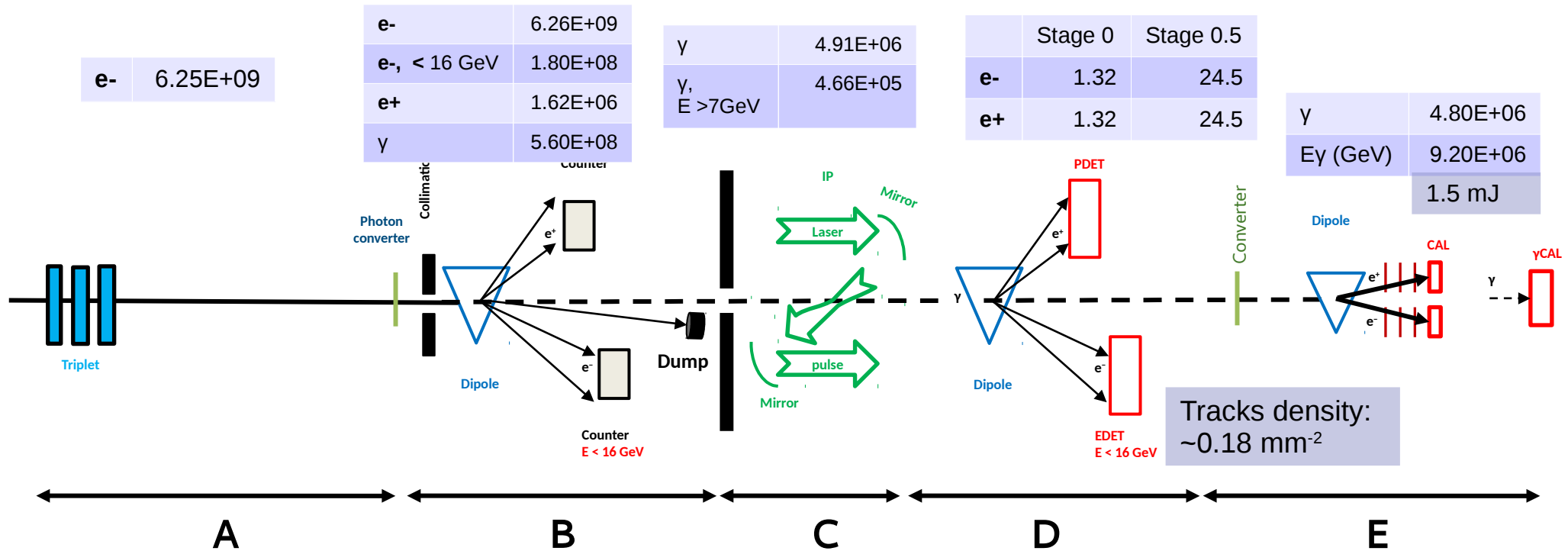
- Tungsten target 35 μm (1%X0) for bremsstrahlung production;
- Target is 5 m and 2 m upstream of IP;
- By changing a target thickness (to some extent) for a given distance between target and IP the photon flux and pairs production rate can be set at reasonable level.



ξ	I (W/cm^2)	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

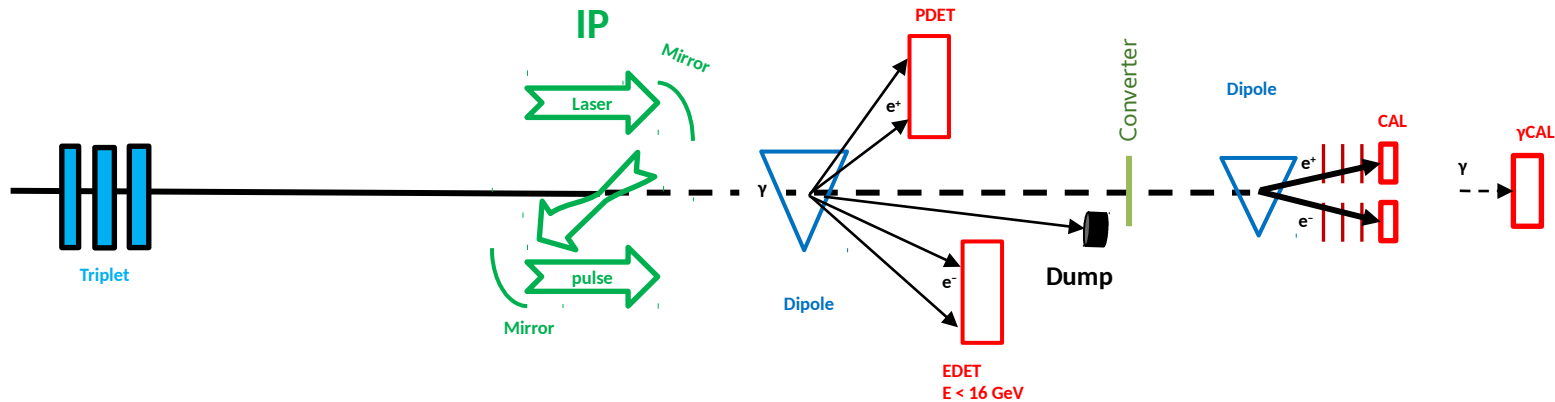
$$N \sim \frac{1}{L^2}$$

Photon-Photon collisions at LUXE

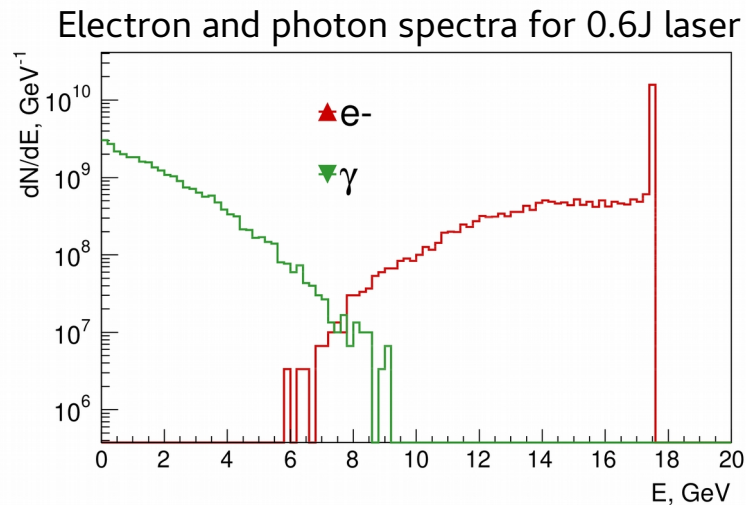


Area	Description	e-	e+	γ	Notes
A	Incident beam	6.25E+09			XFEL beam sigma _{xy} = 5μm, emittance: 1.4e-3 mm mrad
B	Target	6.26E+09	1.62E+06	5.60E+08	Tungsten 35 μm, (1%X0), 5 m upstream of IP
C	IP			4.91E+06	Geometrical cut x <25μm && y <25μm is applied to match laser transverse size
	E > 7 GeV			4.66E+05	
	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

Electron-Photon collisions at LUXE



MC simulation with $6E9$ electrons per bunch;



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

Back up