Laser-proton and laser-PSI collisions simulation

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November 28, 2017
ARIES Photon beams workshop, Padova, Italy

Many thanks for the collaboration to: Luca Serafini, Vittoria Petrillo, Fabrizio Castelli, Francesco Broggi, Witold Krasny, Wieslaw Placzek

PRESENTATION OUTLINE

- Laser-proton collision for Hadron-Photon Collider (HPC) conceptual study [see Luca Serafini's talk]: scheme, relevant reactions and simulation tools

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- PSI-Laser collisions simulation: preliminary results

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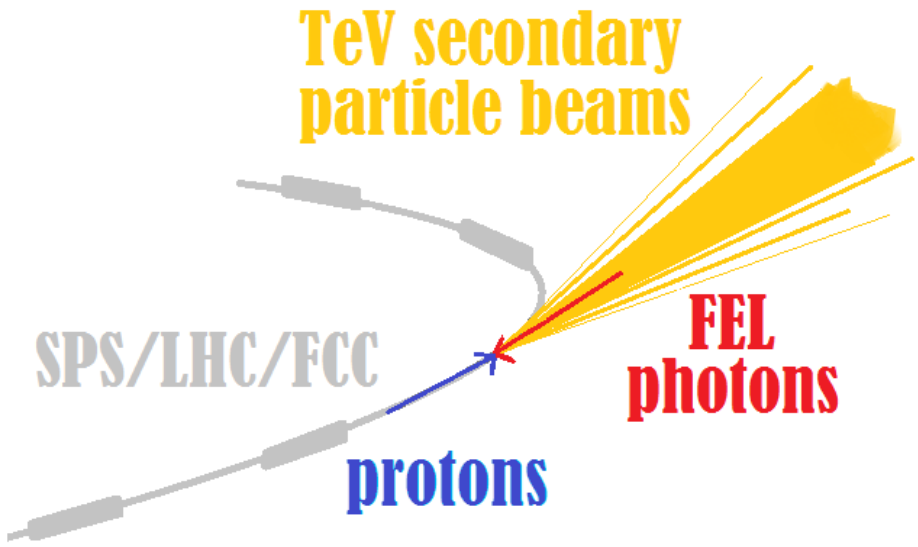
- How those tools can be usefull for the GAMMA-FACTORY
- PSI-Laser collisions simulation: preliminary results
- Work done and to do list

HPC: INTRODUCTION



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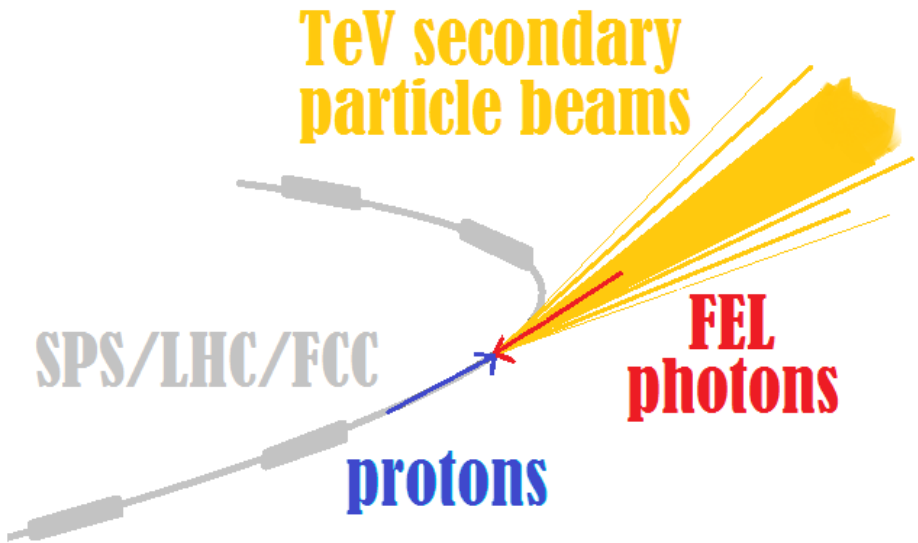

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high Lorentz boost imparted to secondary beams:
high energy, very collimated and low transverse emittance

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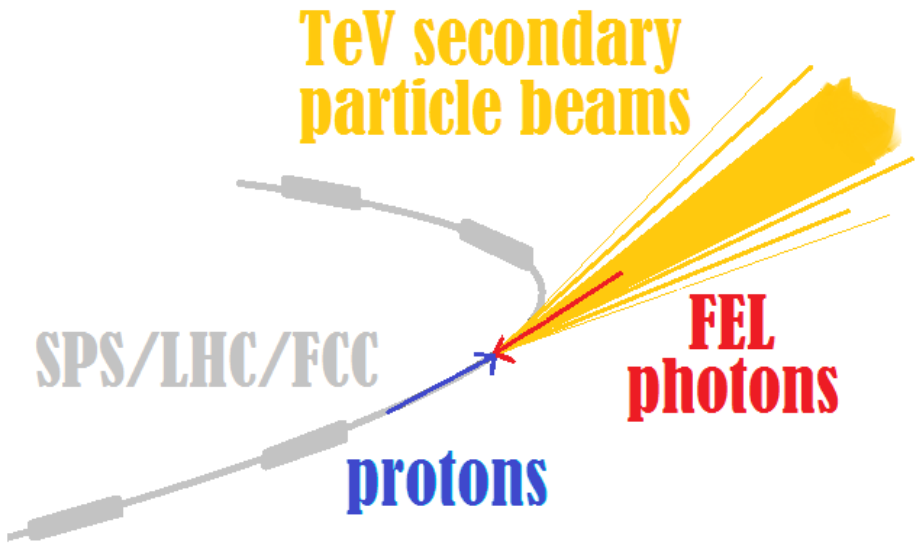

- TeV protons keV photons: very asymmetrical collision ($\gamma_{CM} \simeq \gamma_{pr}$) $\Rightarrow$ high Lorentz boost imparted to secondary beams: high energy, very collimated and low transverse emittance
- energy of photons in protons rest frame much higher than in laboratory

incoming photon energy seen by the proton:

$$E'_{ph} = E_{ph}\gamma(1 - \underline{\beta} \cdot \underline{e}_k) \simeq 2\gamma E_{ph}$$

- E_{ph}: photon energy in lab
- γ: proton gamma
- $\underline{\beta}$: proton velocity
- $\underline{e}_k$: photon direction
- $2\gamma E_{ph}$: head-on collision, $E_{ph} \ll E_{pr}$

HPC: MAIN REACTIONS

PRoton source	E_{pr} (TeV)	N_{pr}	σ_0 (μm)	PHoton source	E_{ph} (keV)	N_{ph}
SPS	0.4	$2 \cdot 10^{12}$	18	TCS	350	10^{8-9}
LHC	7	$2 \cdot 10^{11}$	7	FEL	$6 - 20$	10^{13}
FCC	50	10^{11}	1.6	FEL	$2 - 12$	10^{13-14}

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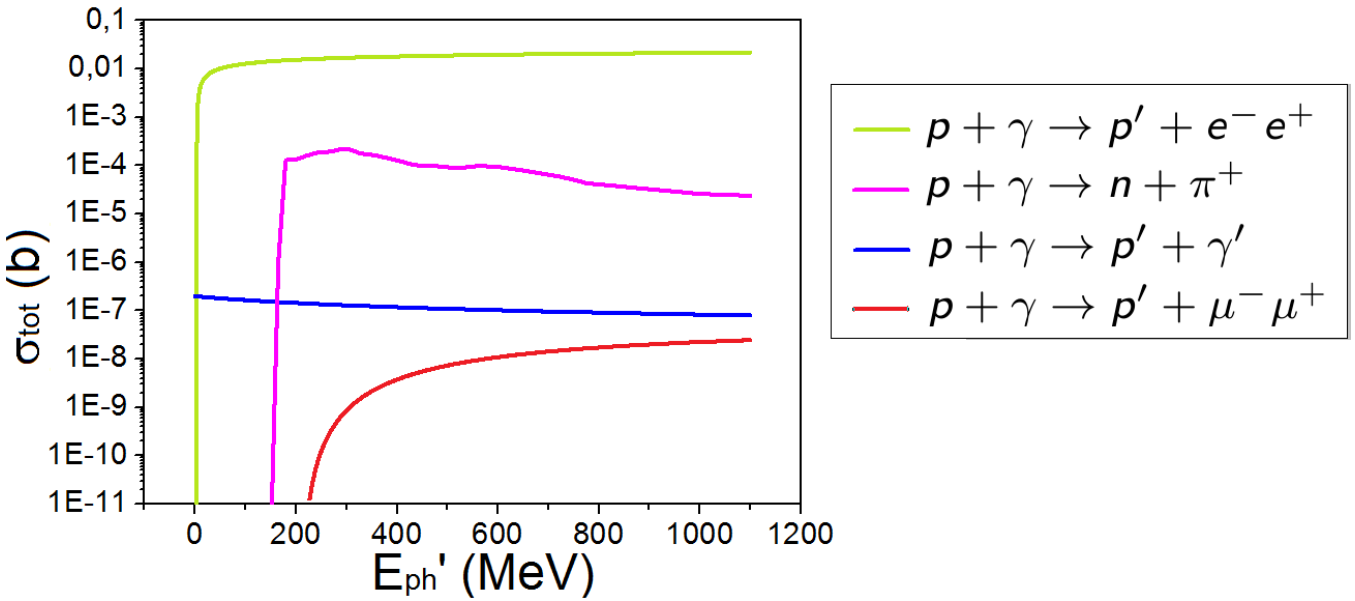
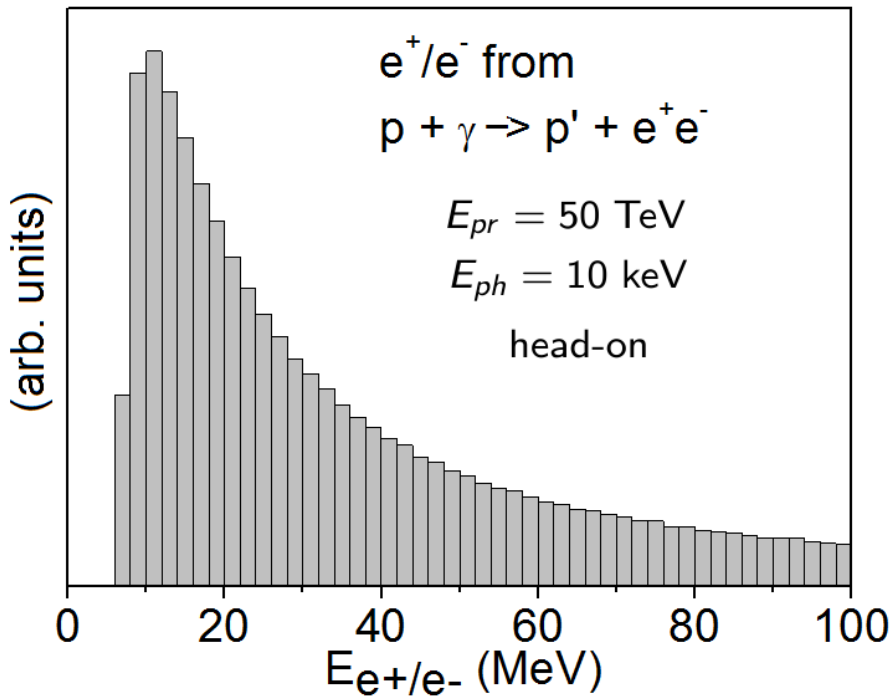


HPC: SIMULATION TOOLS

$p + \gamma \rightarrow p' + e^- e^+$ Homemade event generator based on Geant4 differential cross sections: calculation in PRF + Lorentz transformation to LAB



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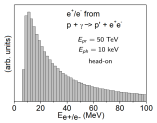
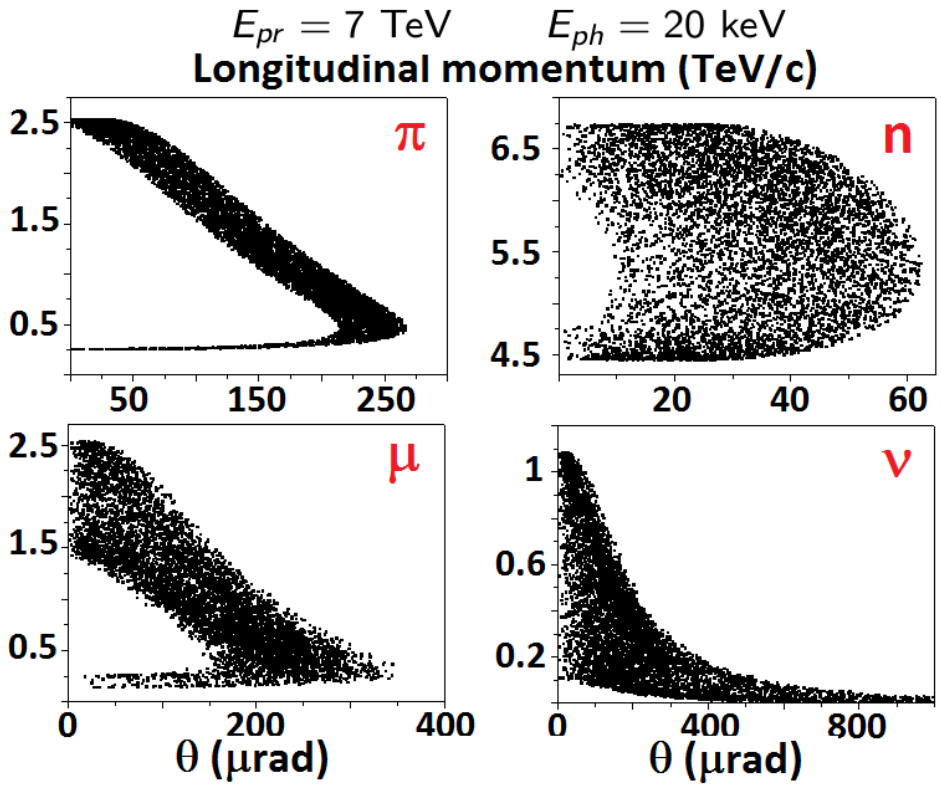


$p + \gamma \to \pi^+ + n \to \mu^+ + \nu_\mu + n$
Homemade event generator with correct differential cross sections: generation of pion + neutron and decay of pion into muon + neutrino



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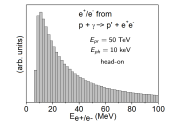
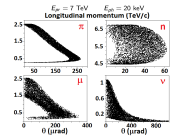
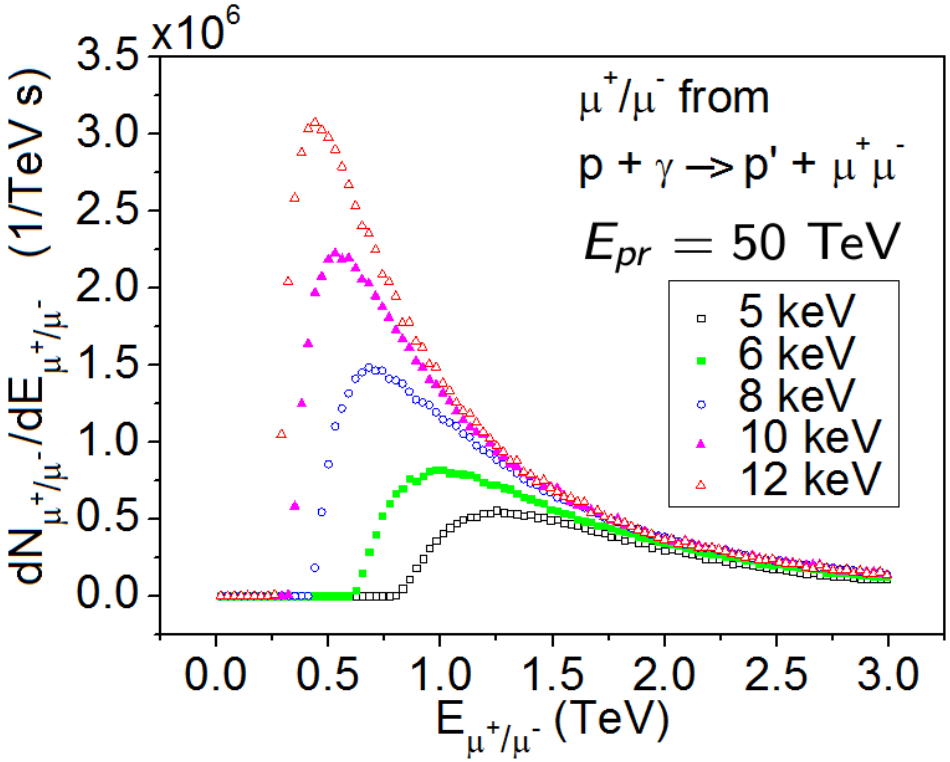




$p + \gamma \rightarrow p' + \mu^- \mu^+$ Close to muon production threshold: homemade event generator based on flat differential cross section. Far from threshold: homemade event generator based on Geant4 approach with correct differential cross section: calculation in PRF + Lorentz transformation to LAB



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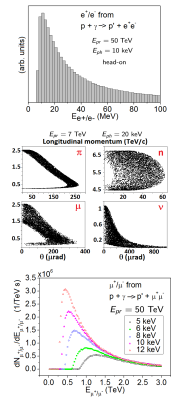
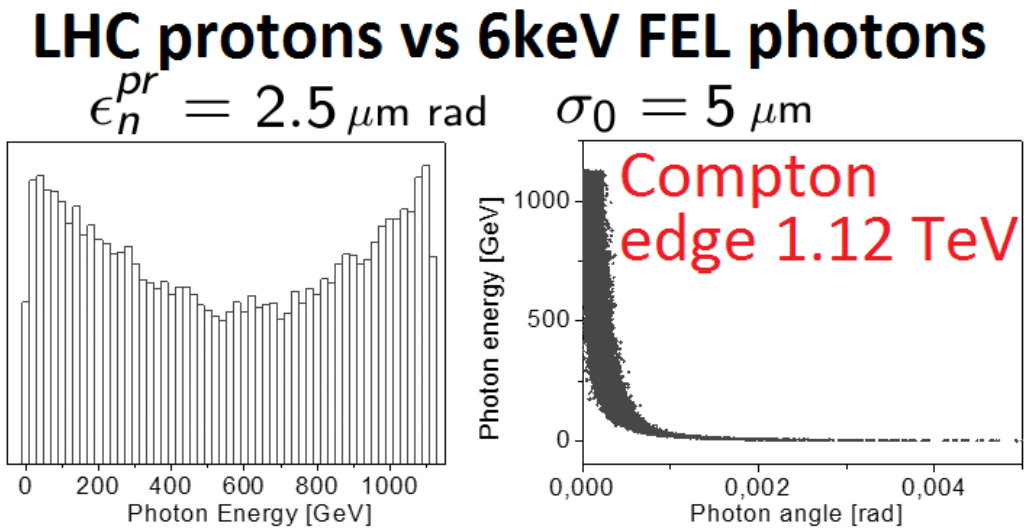


$p + \gamma \to p + \gamma'$
Homemade event generator CMCC: calculation in CM + Lorentz transformation to LAB



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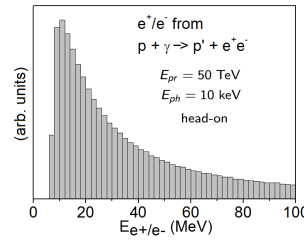

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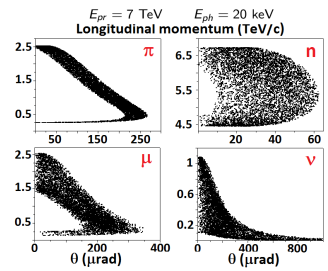

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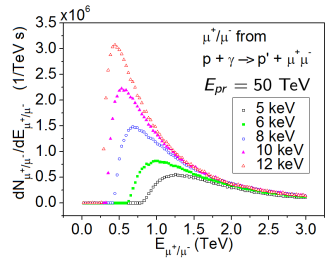
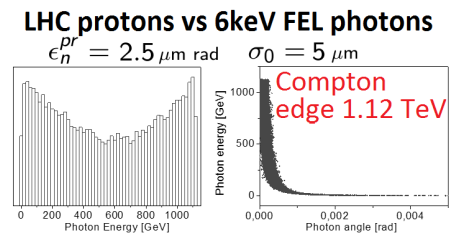
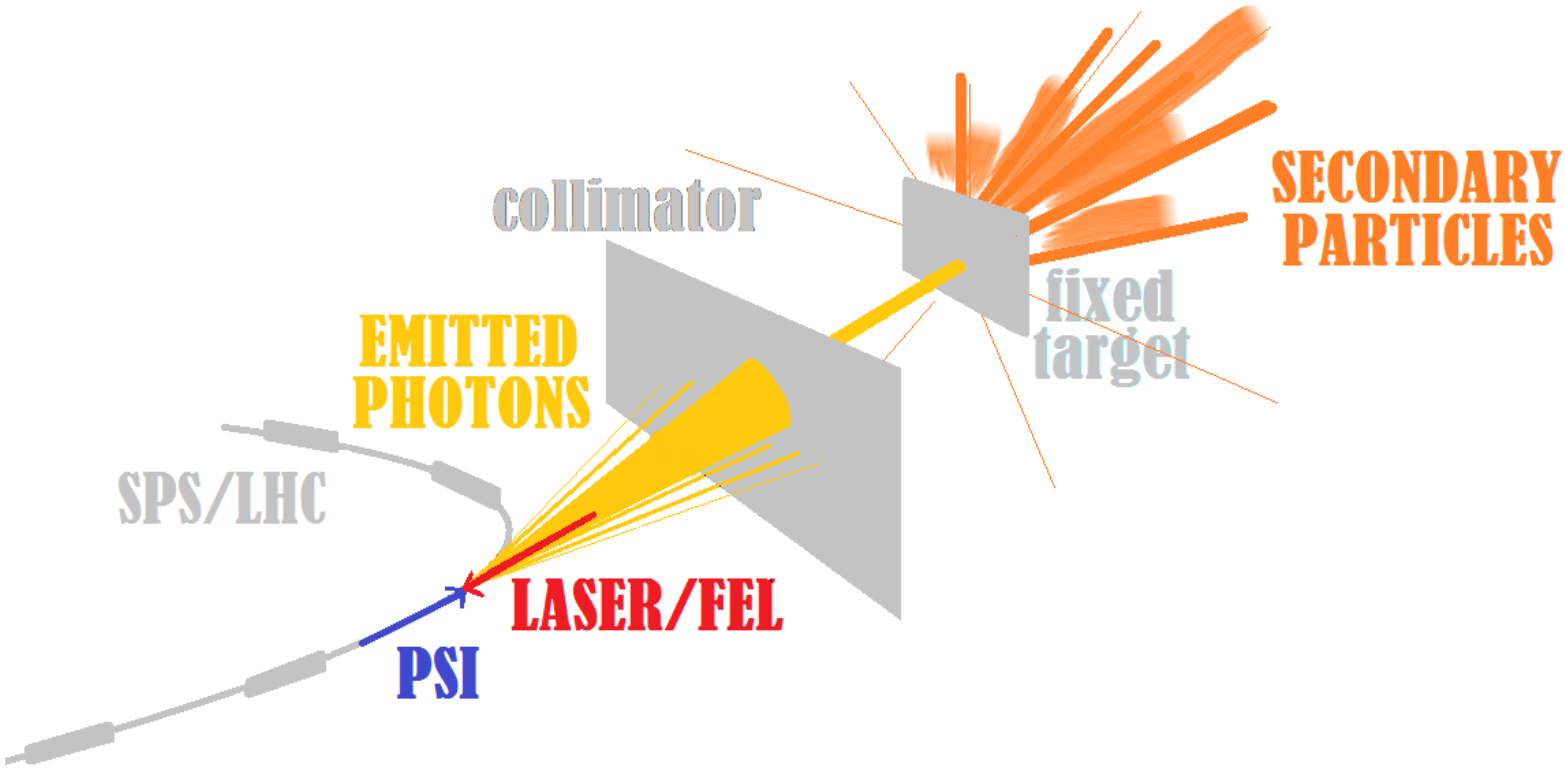


$p + \gamma \rightarrow p + \gamma'$ Homemade event generator CMCC



GAMMA FACTORY



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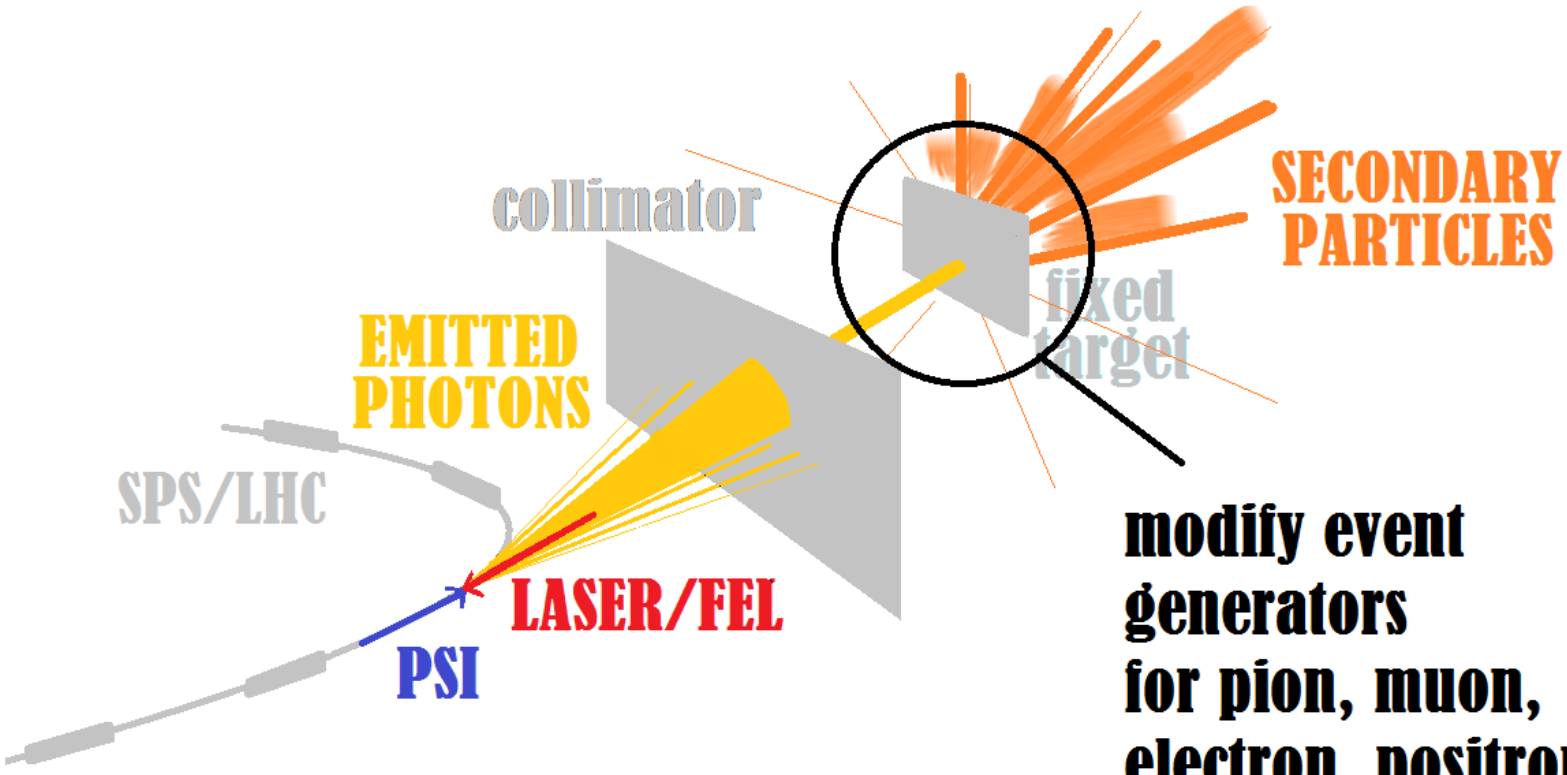

modify event generators for pion, muon, electron, positron, neutrino, neutron, photon production

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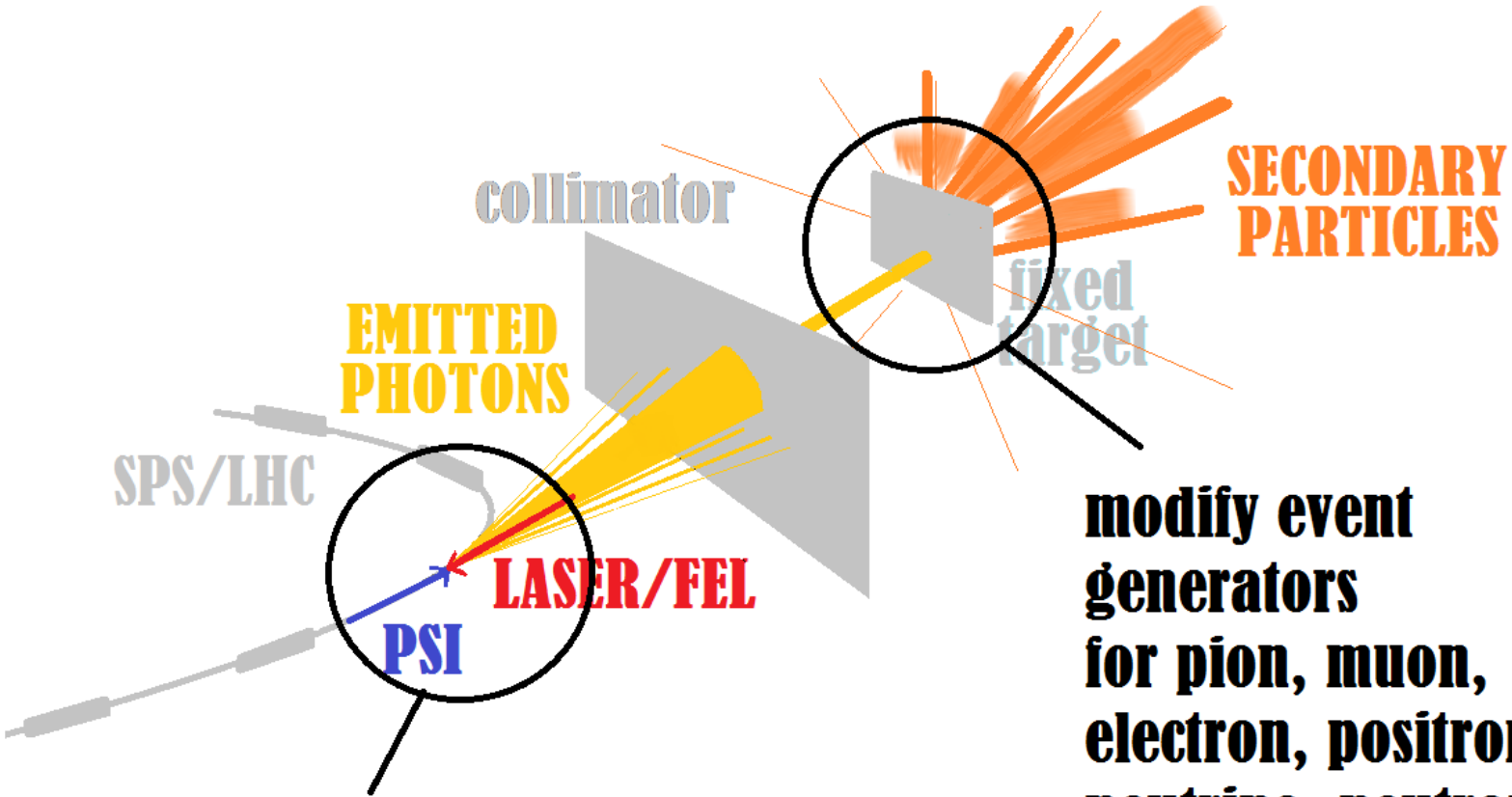

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characteristics
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photon beam
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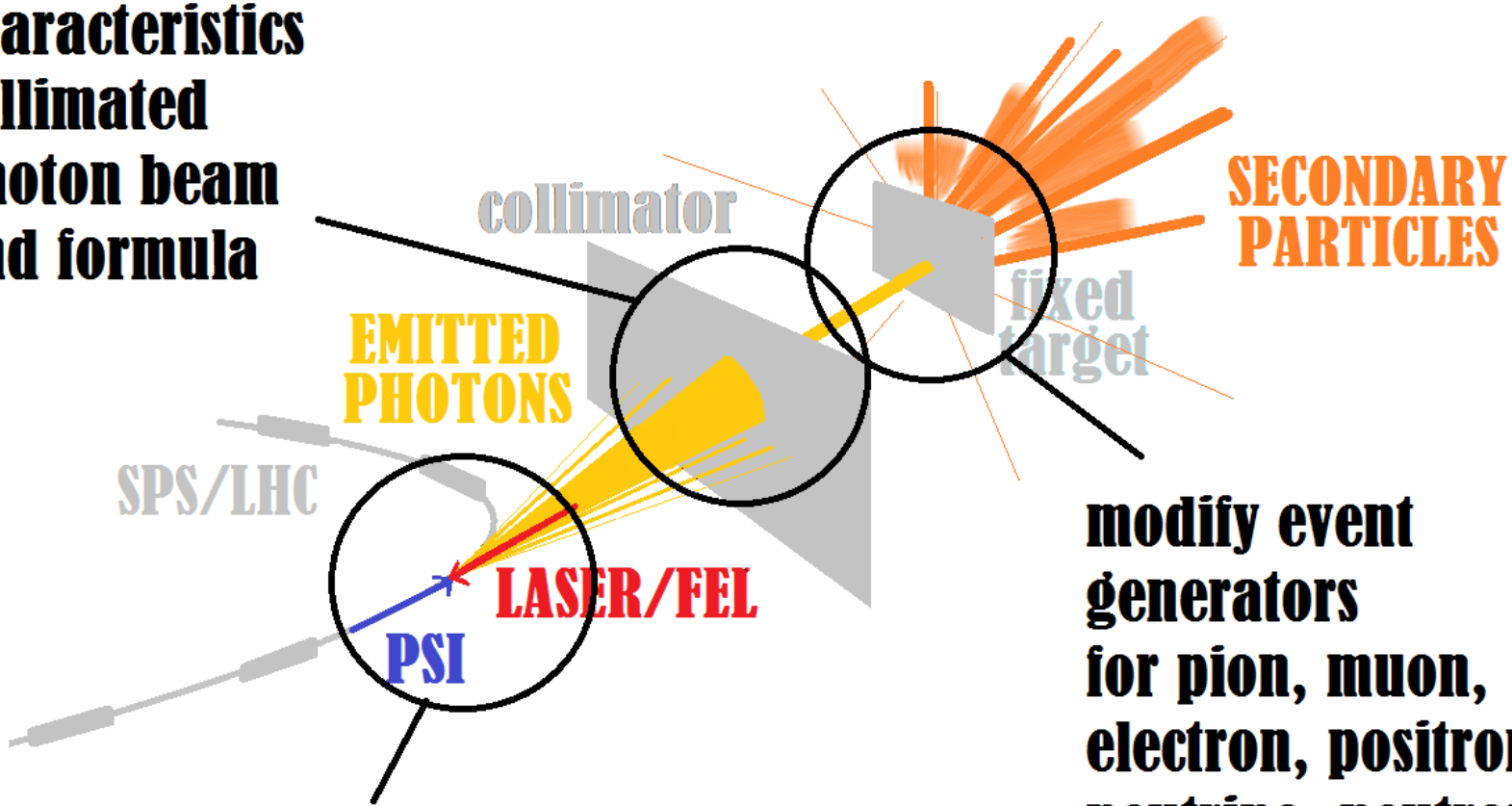

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modify CMCC for
ICS off protons
to PSI-laser
collision simulator

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• CMCC event generator modified for PSI-Laser collisions:
two examples Xe^{39+} and Pb^{81+}

GAMMA FACTORY: Xe^{39+} EXAMPLE

PSI Beam	Xe^{39+}
M_i mass of one ion	120 GeV/c^2
γ_i relativistic factor	34.66
E_i energy of one ion	4.19 TeV
$\Delta\gamma/\gamma$ rel. en. spread ion beam	$3 \cdot 10^{-4}$
N_i number of ions per bunch	$2 \cdot 10^9$
ϵ^n normalized transverse emittance	2 mm mrad
$\beta_x = \beta_y$ beta function	50 m
σ_x rms transverse size	1.7 mm
σ_z rms bunch lenght	12 cm
Laser	**Green**
λ_L (E_L)	532 nm (2.33 eV)
N_L number of photons per pulse	$8.73 \cdot 10^{14}$
U_L laser energy	0.33 mJ
w_0 laser waist at IP (2 σ_L)	3.4 mm
R_L Rayleigh lenght ($\pi\ w_0^2/\lambda_L$)	68.23 m
σ_t rms pulse lenght	1 m

$$E_{res} = E'_L = 161.5 \text{ eV}$$

$$N_\gamma \text{ per shot} = \frac{N_i N_L}{2\pi(\sigma_x^2 + \sigma_L^2)}\bar{\sigma} = \frac{2 \cdot 10^9\ 8.73 \cdot 10^{14}}{4\pi(1.7 \cdot 10^{-3})^2} 5.89 \cdot 10^{-20} = 2.83 \cdot 10^9$$

[$\bar{\sigma}$ value from Evgeny Bessonov's]

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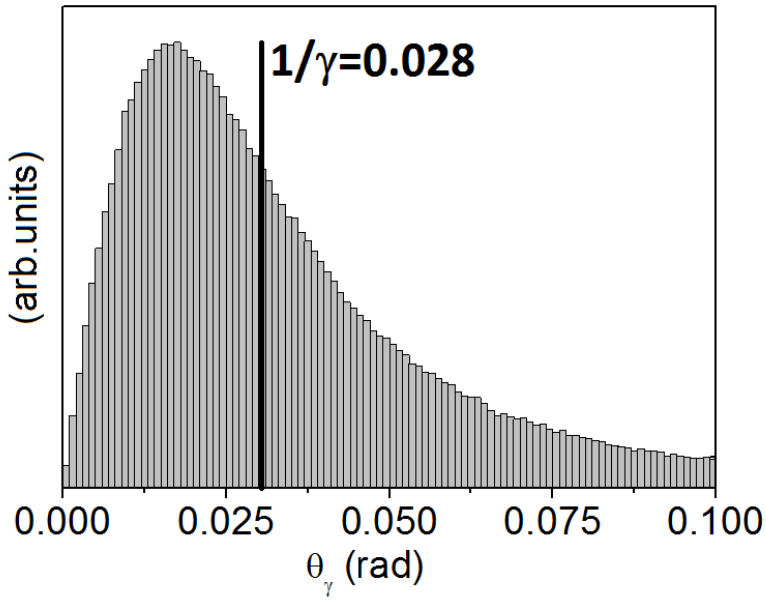

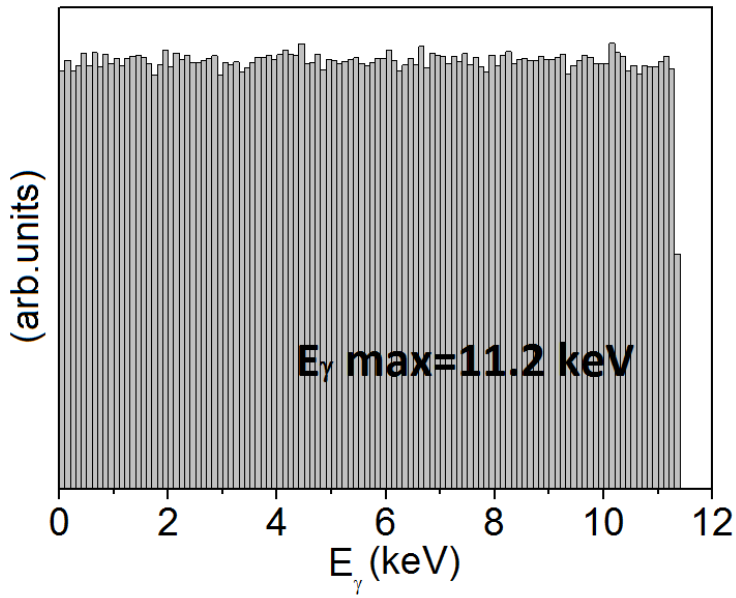

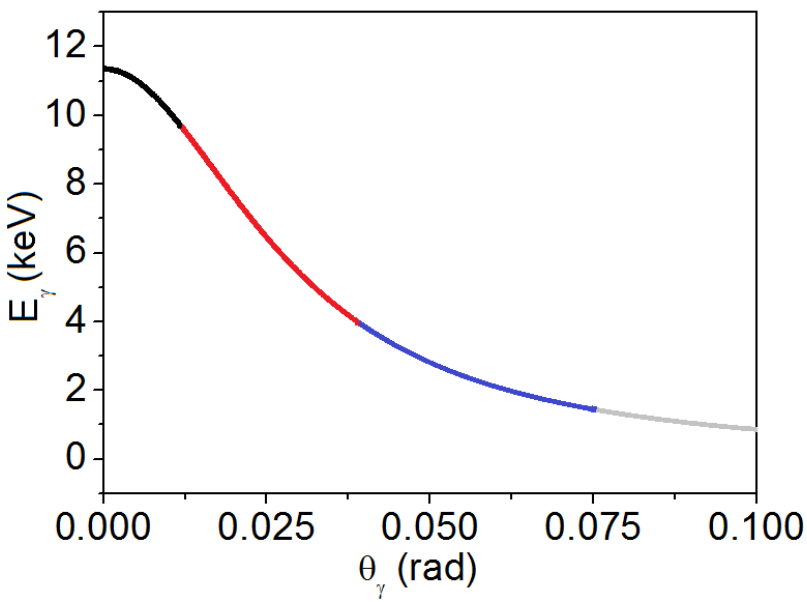

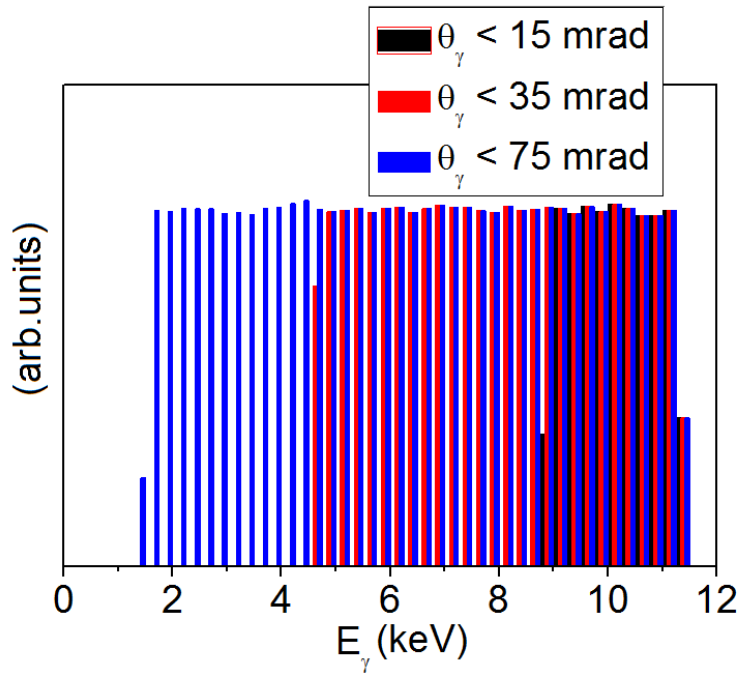

GAMMA FACTORY: Pb^{81+} EXAMPLE

PSI Beam	Pb^{81+}
M_i mass of one ion	193 GeV/c^2
γ_i relativistic factor	3000
E_i energy of one ion	579 TeV
$\Delta\gamma/\gamma$ rel. en. spread ion beam	0
N_i number of ions per bunch	$9.4 \cdot 10^7$
ϵ^n normalized transverse emittance	9 mm mrad
$\beta_x = \beta_y$ beta function	0.5 m
σ_x rms transverse size	38.7 μm
σ_z rms bunch lenght	15 cm
Laser	**FEL**
λ_L (E_L)	108.28 nm (11.45 eV)
N_L number of photons per pulse	$3 \cdot 10^{13}$
U_L laser energy	56 μJ
w_0 laser waist at IP (2 σ_L)	50.84 μm
R_L Rayleigh lenght ($\pi\ w_0^2/\lambda_L$)	7.5 cm
σ_t rms pulse lenght	15 cm

$$E_{res} = E'_L = 68.7 \text{ keV}$$

$$N_\gamma \text{ per shot} = \frac{N_i N_L}{2\pi(\sigma_x^2 + \sigma_L^2)}\bar{\sigma} = \frac{9.4 \cdot 10^7\ 3 \cdot 10^{13}}{2\pi((38.7 \cdot 10^{-6})^2 + (25.42 \cdot 10^{-6})^2)} 3.32{\cdot}10^{-22} = 6.9{\cdot}10^7$$

[$\bar{\sigma}$ value from Evgeny Bessonov's]

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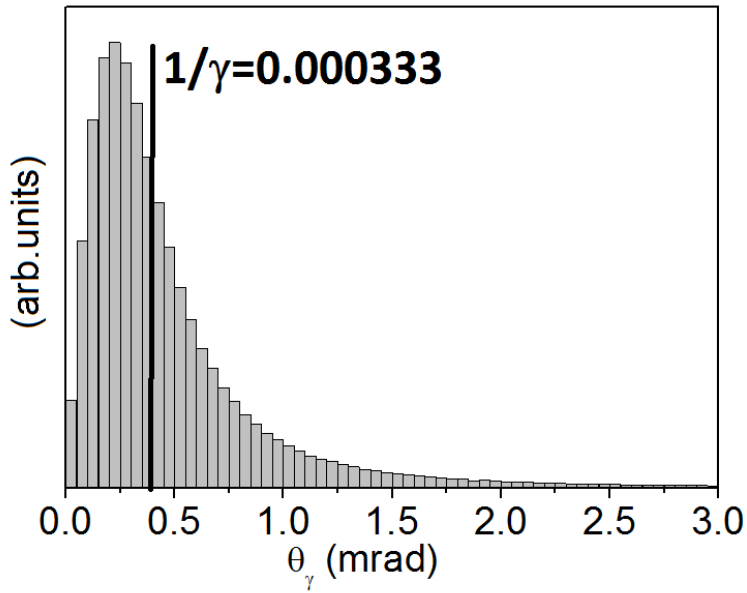
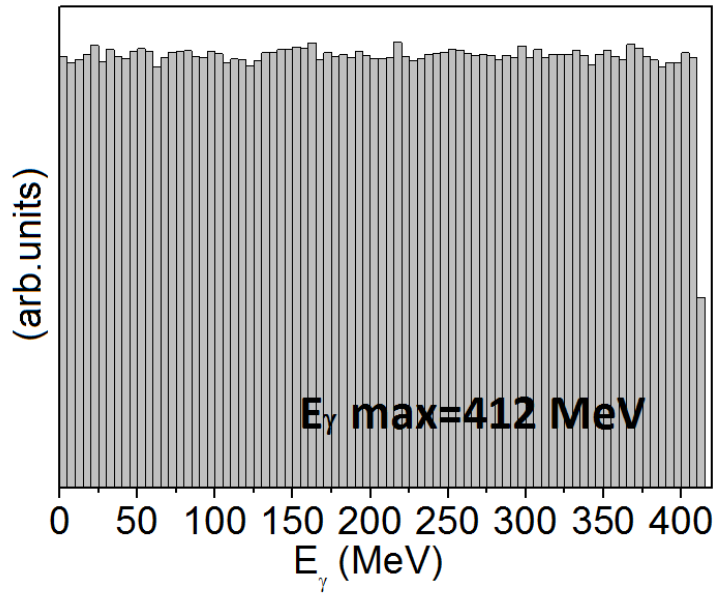
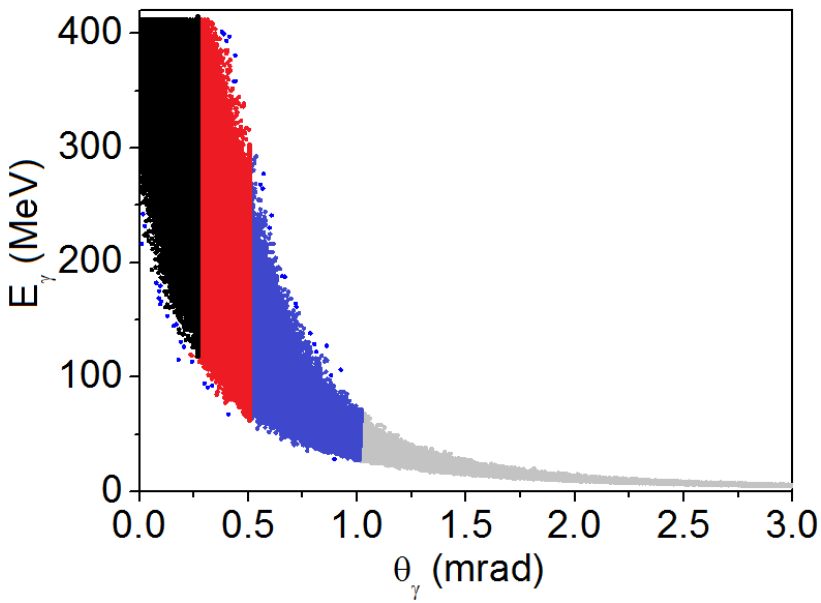
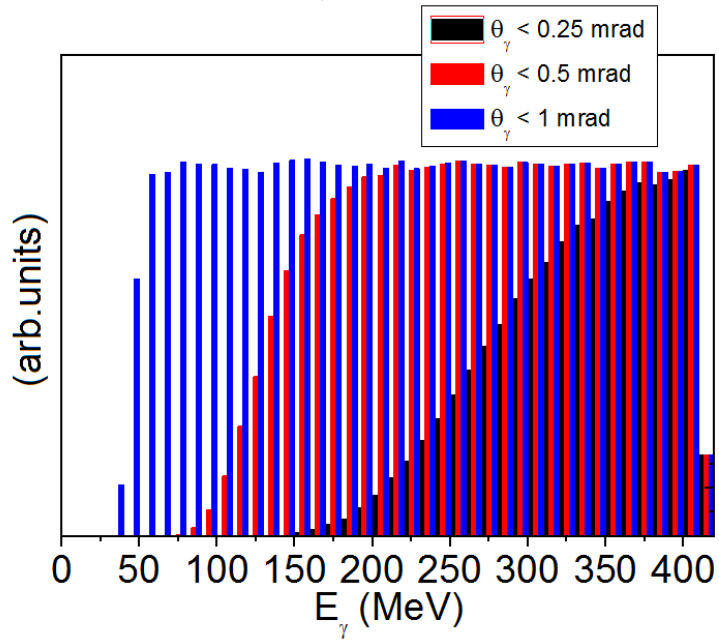








GAMMA FACTORY: BW SIMULATION VS FORMULA

acceptance angle $\Psi = \gamma_{CM}\theta_{max}$

relative energy spread

beam quality factor

laser wavelength

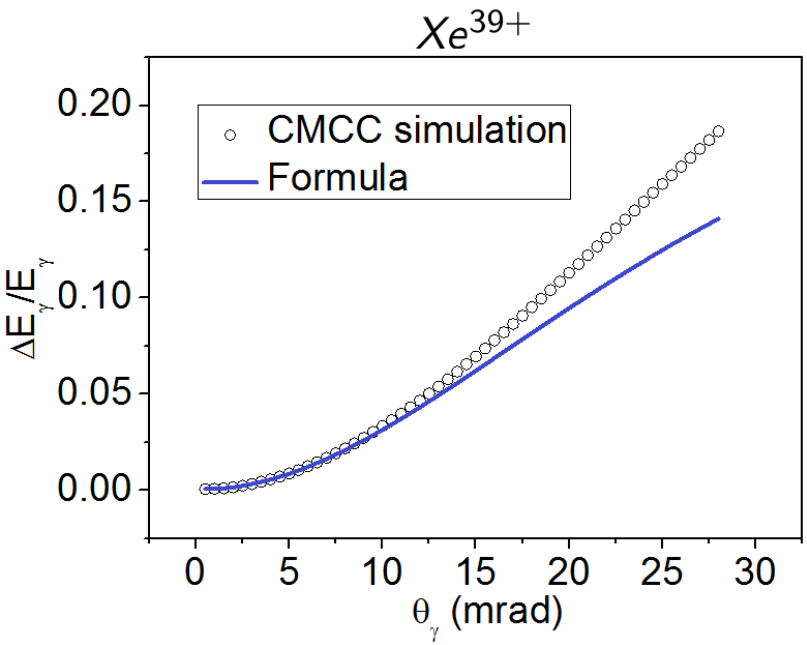
$$\frac{\Delta E_{ph}}{E_{ph}} \simeq \sqrt{\left[\frac{\Psi^2/\sqrt{12}}{1+\Psi^2} + \frac{\bar{P}^2}{1+\sqrt{12}\bar{P}^2}\right]^2 + \left[\left(\frac{2+X}{1+X}\right)\frac{\Delta\gamma}{\gamma}\right]^2 + \left(\frac{1}{1+X}\frac{\Delta E_L}{E_L}\right)^2 + \left(\frac{M^2\lambda_0}{2\pi w_0}\right)^4 + \left(\frac{a_0^2/3}{1+a_0^2/2}\right)^2}$$

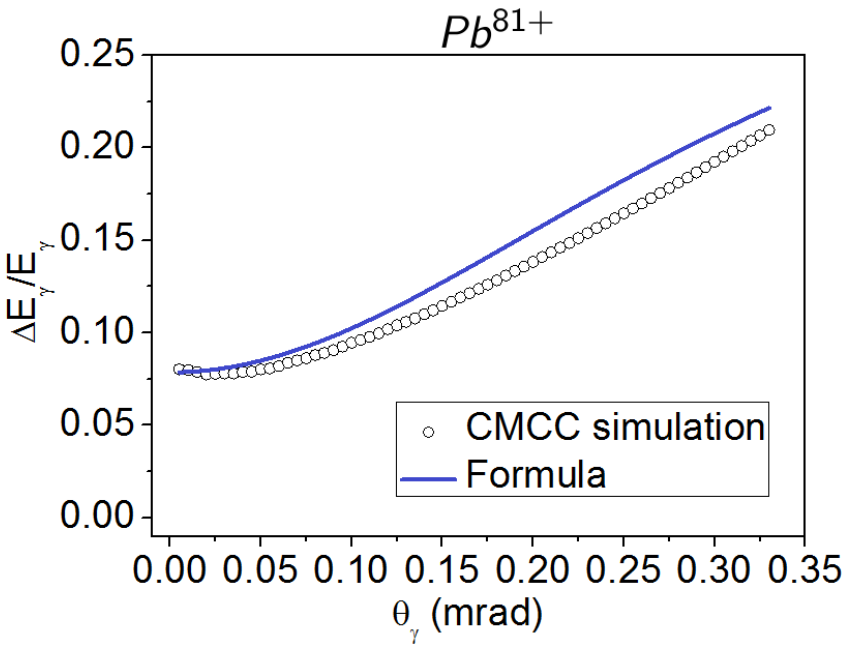
$$\bar{P} = \gamma_{CM}\frac{\sqrt{2}\epsilon_x}{\sigma_x} = \frac{\sqrt{2}\epsilon_n}{\sigma_x\sqrt{1+X}}$$

laser bandwidth

laser focal spot size

laser parameter





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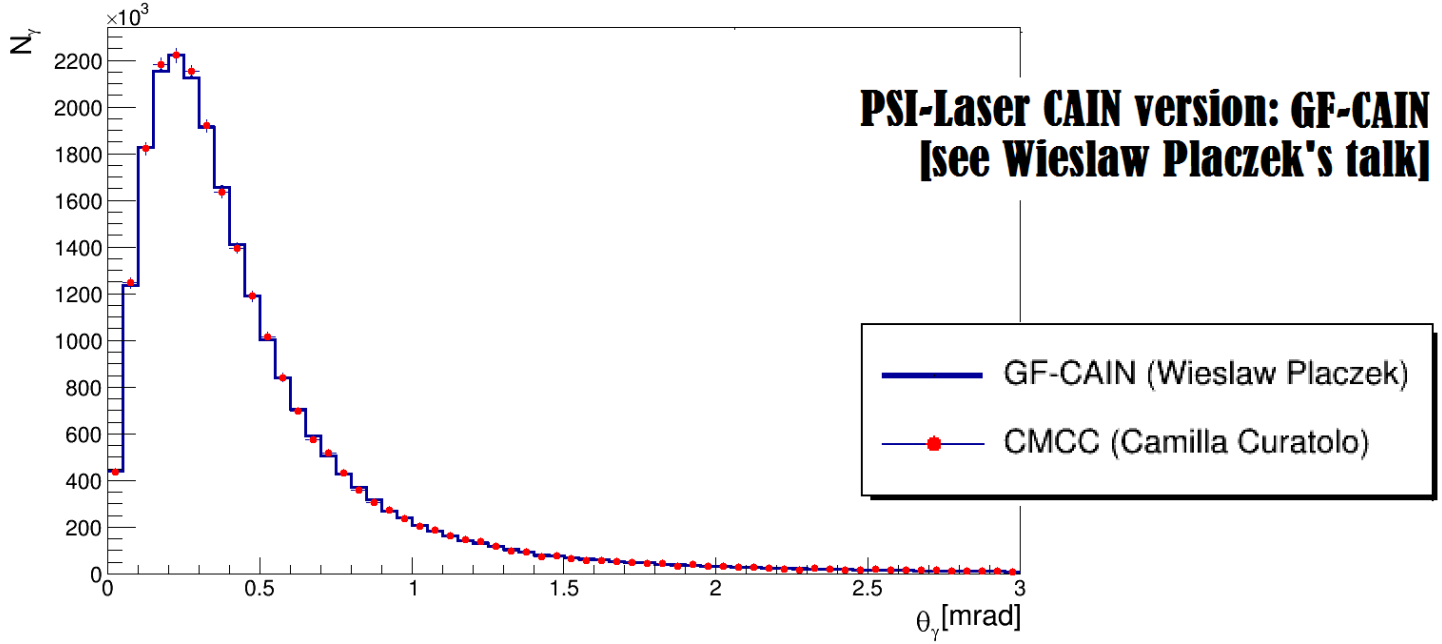

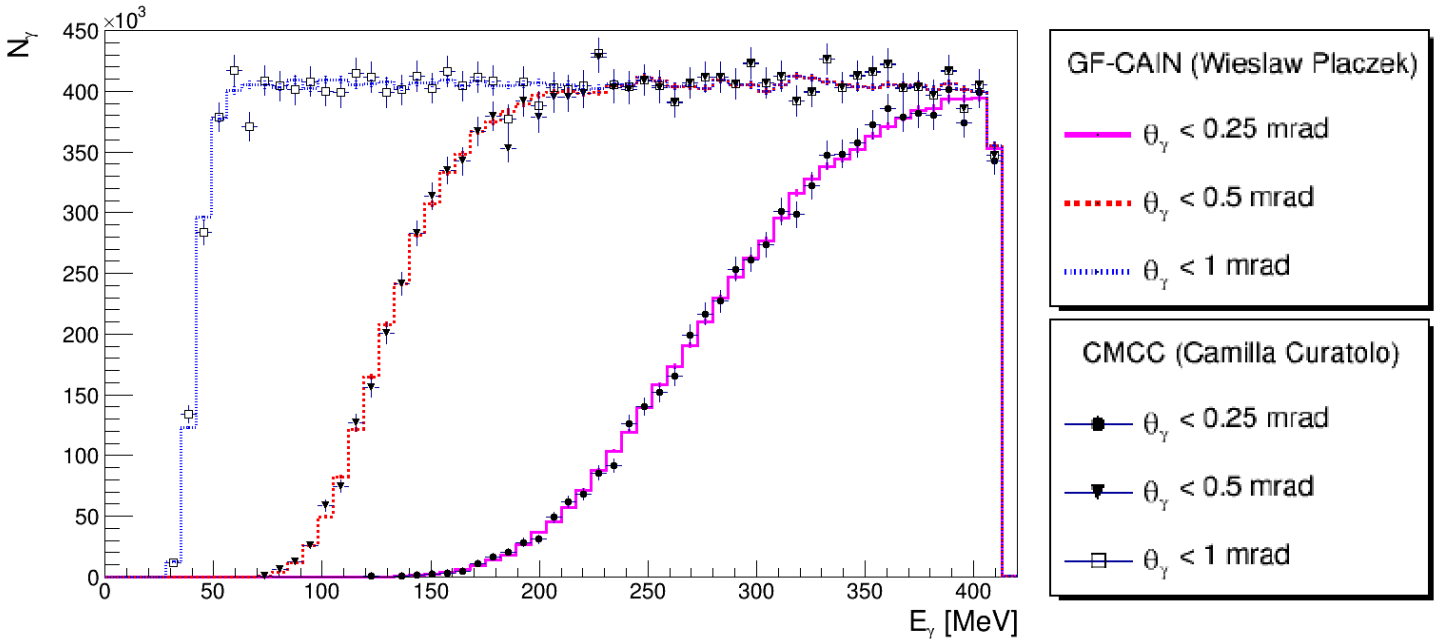

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TO DO:

- We will have to insert in CMCC the correct calculation of the total number of emitted photons by taking into account the density and the spectrum of the incoming photon beam [see Vittoria Petrillo's talk]

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- We have modified the CMCC event generator for PSI-laser collision
- We have evaluated the relative bandwidth of the emitted photon beams for different collimation angles and we have compared the simulation results with the analytical formula: very good agreement
- We have compared the results obtaneid by Wieslaw Placzek with GF-CAIN and the results of CMCC: perfect agreement!

TO DO:

- We will have to insert in CMCC the correct calculation of the total number of emitted photons by taking into account the density and the spectrum of the incoming photon beam [see Vittoria Petrillo's talk]
- The event generators we developed for HPC can be modified to simulate the emitted photon beam collision on fixed target (in particular the muon pair production close to threshold)

Thank you for your attention!


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