Novel high intensity gamma-source at CERN: the Gamma Factory Initiative

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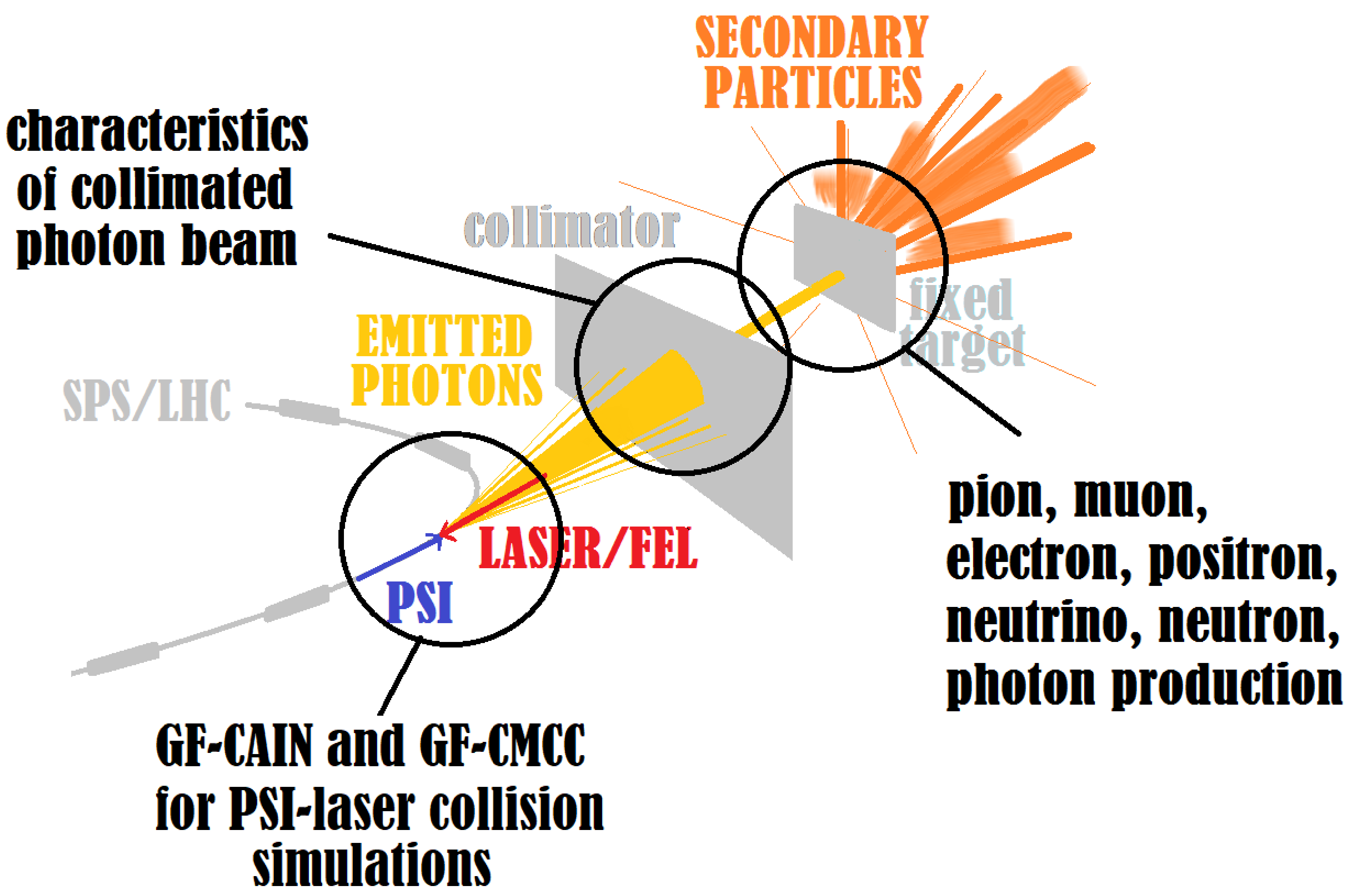
INTRODUCTION

The collisions of Partially Stripped Ions (PSI) with laser light to produce high intensity gamma-ray beams are the backbone of the Gamma Factory (GF) initiative [1, 2, 3]. The source, if realised at LHC, could significantly push up the intensity limits of the presently operating ones, reaching the flux of the order of 10^{17} photons/s, in the particularly interesting gamma-ray energy domain of 1 to 400 MeV. The unprecedented-intensity, energy-tuned gamma beams, together with the gamma-beams-driven secondary beams of polarized positrons, polarized muons, neutrinos, neutrons and radioactive ions would constitute the basic research tools of the proposed Gamma Factory. We discuss the GF concept and the preliminary estimates of the emitted gamma beams phase spaces given by two newly developed Monte Carlo codes which simulate the PSI-laser interactions.

GAMMA FACTORY SKETCH



PSI-LASER INTERACTION

- Idea: PSI resonant absorption & spontaneous photons emission
- Resonance cross section ∼ giga-barn (7-9 orders higher ICS off e^-, 13-15 orders higher ICS off protons)
- Laser photons energy (tuned to hit resonance) in PSI rest frame

  $$E'_L = (1 - \underline{\beta_i} \cdot \underline{e_k})\ \gamma_i\ E_i \simeq 2\ \gamma_i\ E_L$$

  with $\underline{\beta_i}$ ion velocity and $\underline{e_k}$ photon direction
- High energy photons emitted by spontaneous emission: isotropic emission ⇒ flat differential cross section
- Max energy of the emitted photons (emitted forward in PSI frame) $E^{max}_\gamma = 4\gamma_i^2 E_L = 2\gamma_i E'_L$

MONTE CARLO CODES

Newly developed Monte Carlo codes to simulate the PSI-laser interaction:

GF-CAIN

Monte Carlo code Cain [4] modified for
PSI-laser collisions by W. Placzek

GF-CMCC

Monte Carlo event generator CMCC [5] modified for
PSI-laser collisions by C. Curatolo

TWO EXAMPLES: Xe^{39+} AND Pb^{81+} – LASER LIGHT COLLISION

Two specific examples of interaction between Xe^{39+}, Pb^{81+} and laser light: parameters reported in Table 1. For the Xenon PSI, SPS-like paramenters have been adopted, while for Lead PSI typical LHC parameters. In the first case the collision is performed with a green laser, in the latter case with a free electron laser. All the parameters are purely indicative.

Table 1: Parameters for the two simulated examples of PSI-laser collisions.

PSI Beam	Xe^{39+}	Pb^{81+}
M_i mass of one ion	120 GeV/c^2	193 GeV/c^2
E_i energy of one ion	4.19 TeV	579 TeV
$\gamma_i = E_i/M_i$ relativistic factor	34.66	3000
$\Delta\gamma/\gamma$ rel. en. spread ion beam	$3 \cdot 10^{-4}$	0
N_i number of ions per bunch	$2 \cdot 10^9$	$9.4 \cdot 10^7$
ϵ^n normalized transverse emittance	2 mm mrad	9 mm mrad
$\beta_x = \beta_y$ beta function	50 m	0.5 m
σ_x rms transverse size	1.7 mm	38.7 μm
σ_z rms bunch lenght	12 cm	15 cm
Laser	Green	FEL
λ_L (E_L) wavelength (energy)	532 nm (2.33 eV)	108.28 nm (11.45 eV)
N_L number of photons per pulse	$8.73 \cdot 10^{14}$	$3 \cdot 10^{13}$
U_L laser energy	0.33 mJ	56 μJ
w_0 laser waist at IP (2 σ_L)	3.4 mm	50.84 μm
R_L Rayleigh lenght ($\pi\ w_0^2/\lambda_L$)	68.23 m	7.5 cm
σ_t rms pulse lenght	1 m	15 cm
γ photons		
$E_{res} = E'_L$	161.5 eV	68.7 keV
E^{max}_γ	11.2 keV	412 MeV

Fig. 1 shows the angular distribution, the angle-energy correlation and the energy ditribution of the emitted photons: in both cases half of the photons are emitted within a cone of $1/\gamma$ aperture around the incoming PSI direction. The lower emittance of the Xenon beam with respect to the Lead beam is mapped onto the photons as we can see in the second and third columns (energy-angle correlation). The simulations have been performed with two independent codes: the comparison of the data for the Lead-FEL collision case is reported in Fig. 2.

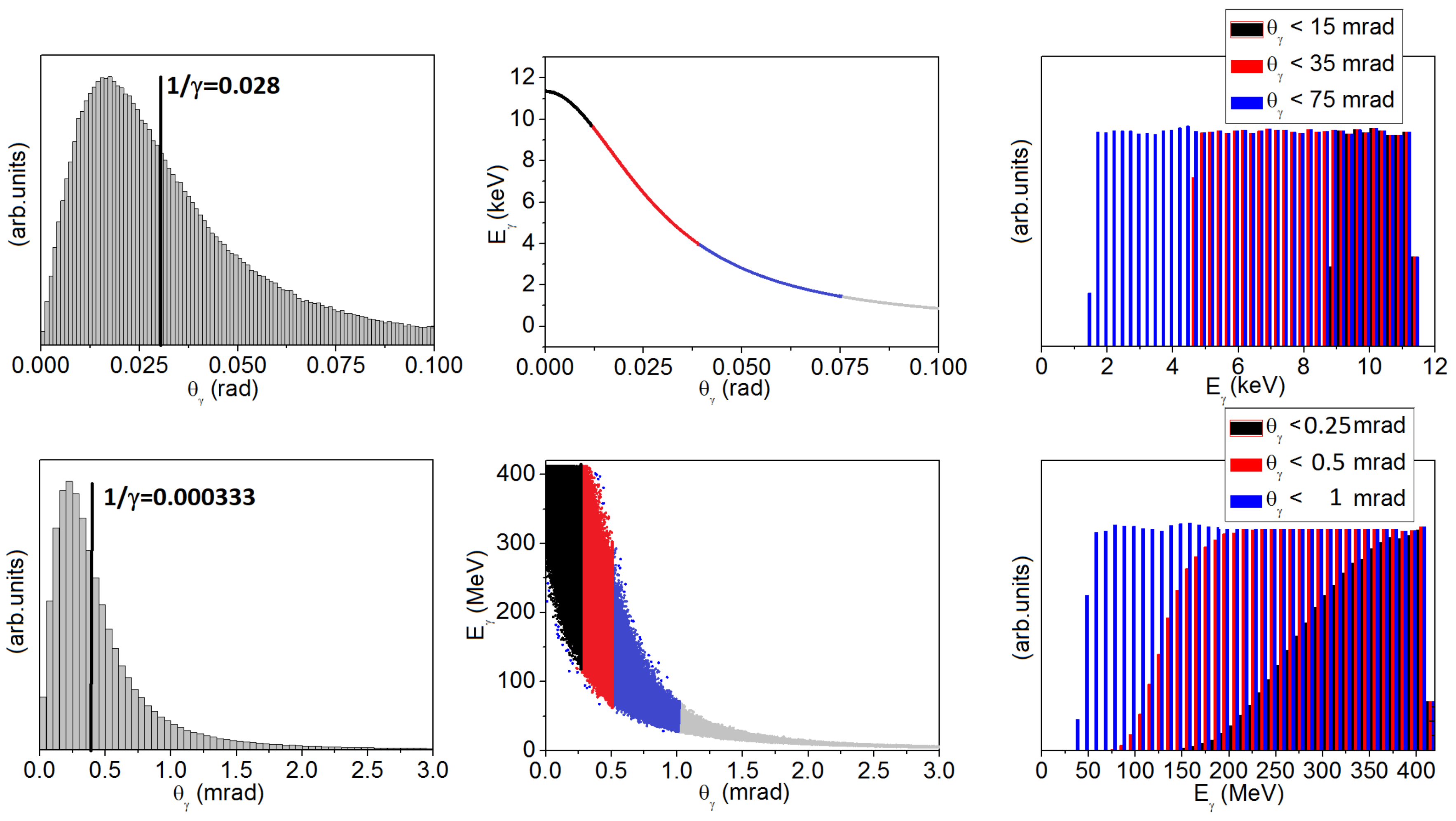


Figure 1: Xe^{39+} and Pb^{81+} - laser collision respectively first and second line.

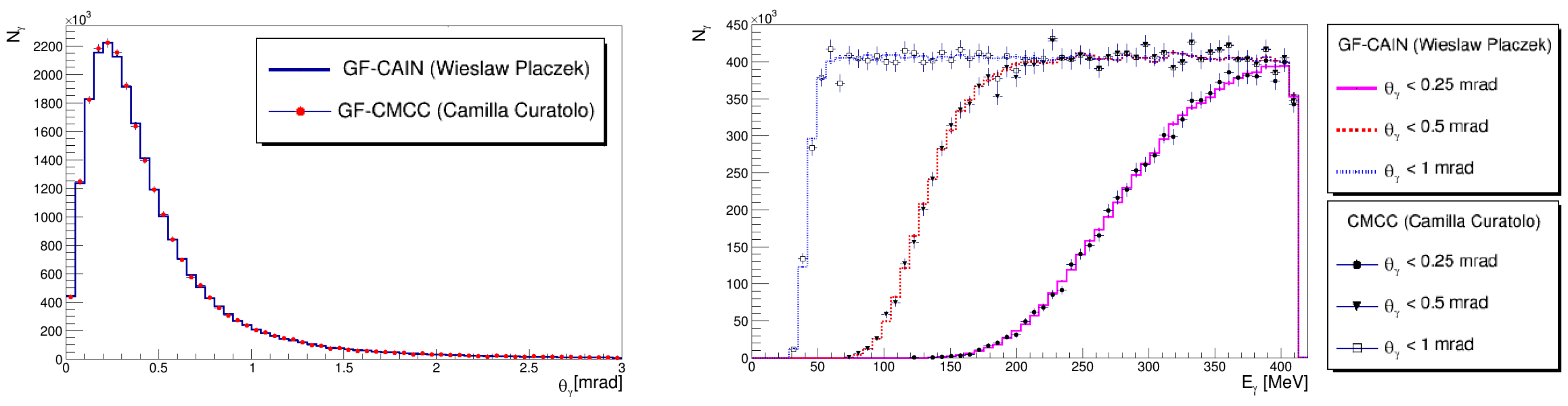


Figure 2: GF-CAIN and GF-CMCC comparision for Pb^{81+} - laser collision.

GF STUDY MILESTONES

- Understanding of production, acceleration and storage of the PSI beams in the CERN accelerator complex: choice of ions, ion stripping schemes, beam transfers, understanding the PSI beam dynamics and particles losses. SPS and LHC test runs with Xe and Pb PSI in 2017 and 2018 [6].
- Development of the simulation tools for collisions of photon and ion bunches. First preliminary attempt: very good agreement between GF-CAIN and GF-CMCC [7]. The details of the interaction have to be considered more carefully, need to insert the correct density, spectrum and temporal shape of the incoming photon beam in order to have a reliable estimation of the total number of emitted photons.
- Study of the concrete GF implementation scenarios: SPS, LHC and variants of 100 TeV muon colliders based on the FCC and Gamma Factory concepts [8]. Choice of ions, choice of lasers and collision geometry.
- POP experiment in the SPS ring including PSI beam cooling demonstration.
- Evaluation of the physics highlights of the Gamma Factory research programme and Gamma Factory project TDR.

CONCLUSION

The Gamma Factory initiative at CERN may turn out not only to be scientifically attractive but also costeffective because it proposes to re-use, in a novel manner, the existing CERN accelerator infrastructures. It may be considered as complementary to the present hadron-collision programme and could be performed at any stage of the LHC lifetime. It would provide a variety of novel research tools capable to open new research opportunities in a very broad domain of basic and applied science, industrial and medical applications.

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