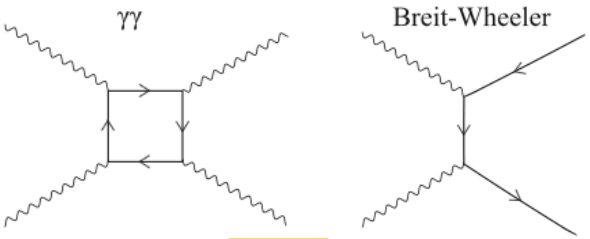
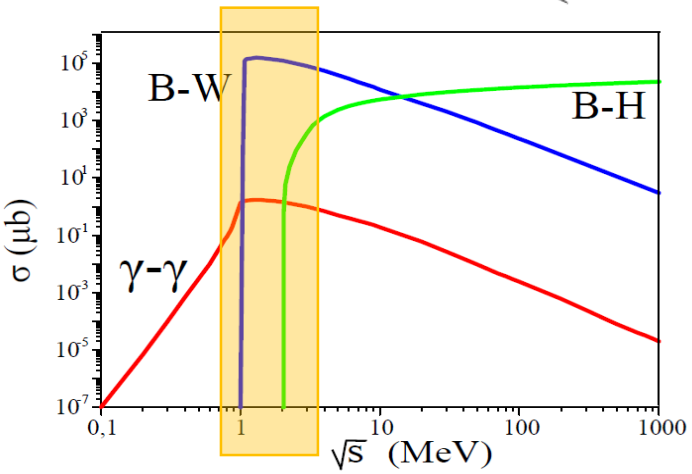
Machine Design and Monte-Carlo Simulations for a Low Energy (MeV-class) Gamma-Gamma Collider

Illya Drebot, A. Bacci, D. Micieli, E. Milotti,
V. Petrillo, E. Tassi, and L. Serafini

Photon-photon elastic scattering

Firstly considered in 1933 by Halpern.
Halpern, *Phys. Rev.* **44**, pp. 855-856 (1933)

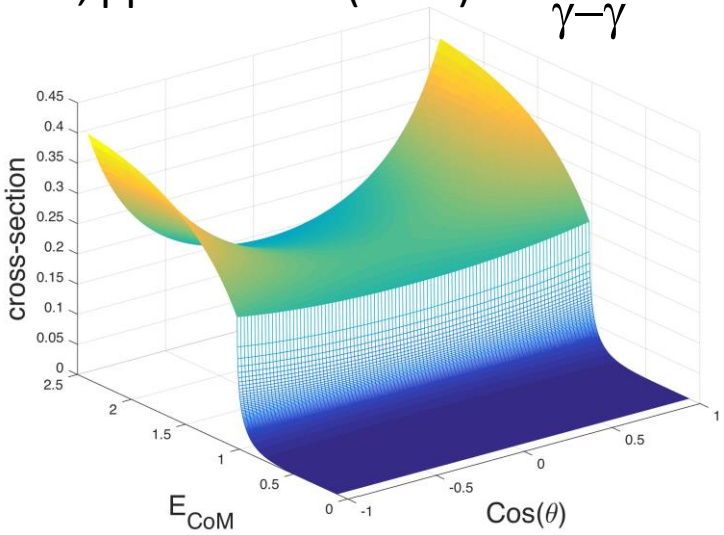




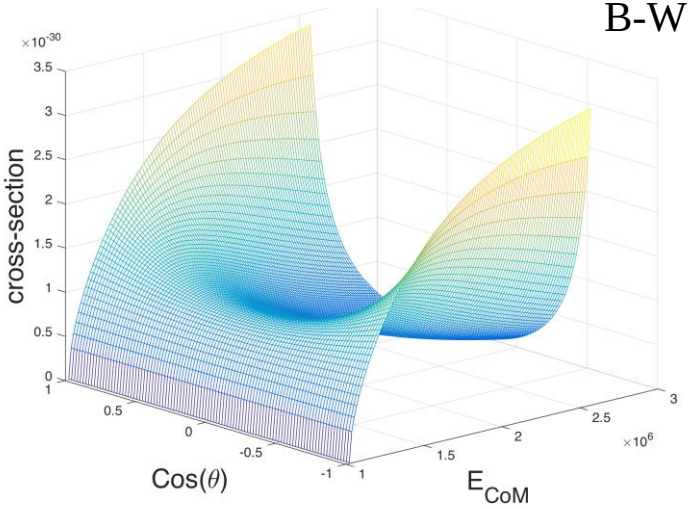
γ–γ: 1.5 μb @ 1.6 MeV

Comparison between γ–γ , Breit-Wheeler and triplet pair production (TPP or B-H) cross sections for unpolarized photons.

γ–γ



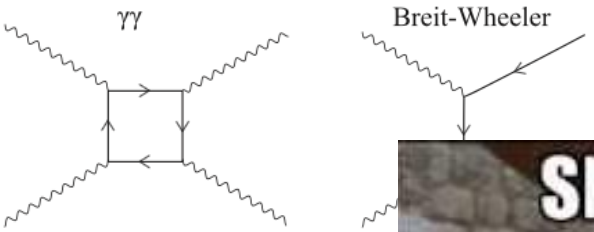
B-W



Differential cross section in the plane E_{CoM}, Cos(θ)

Acknowledgments to D. Micieli, E. Tassi

Photon-photon elastic scattering



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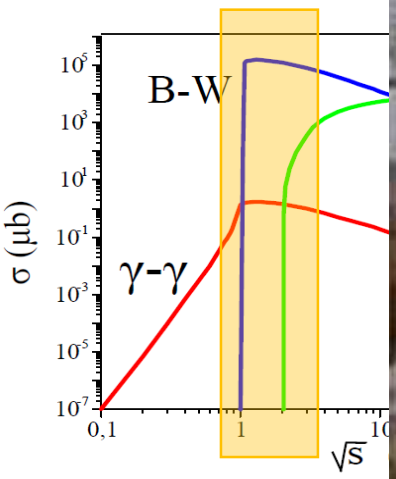

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Comparison between γ-
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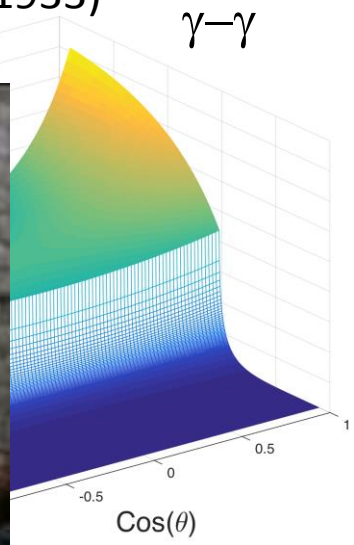

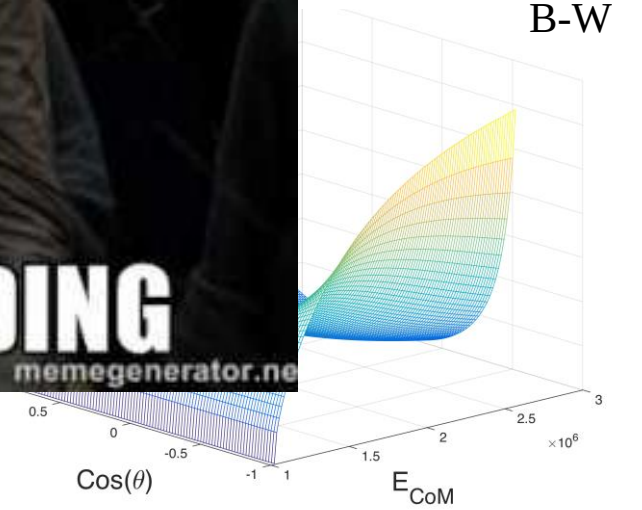

Differential cross section in the plane E_{CoM}, Cos(θ)

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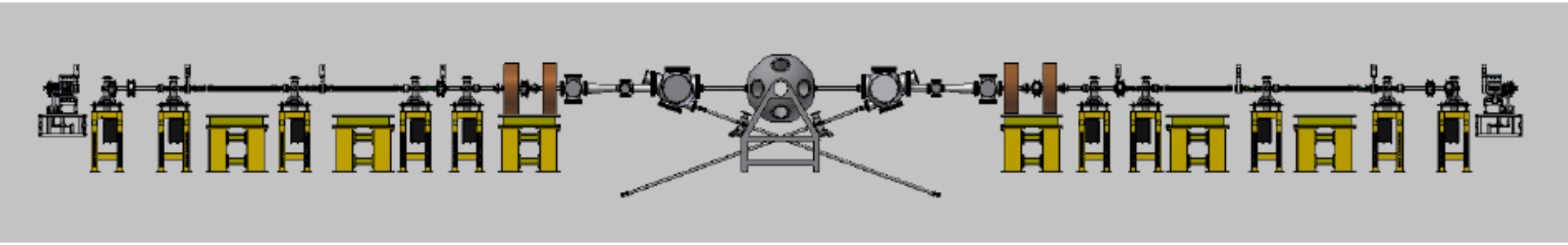
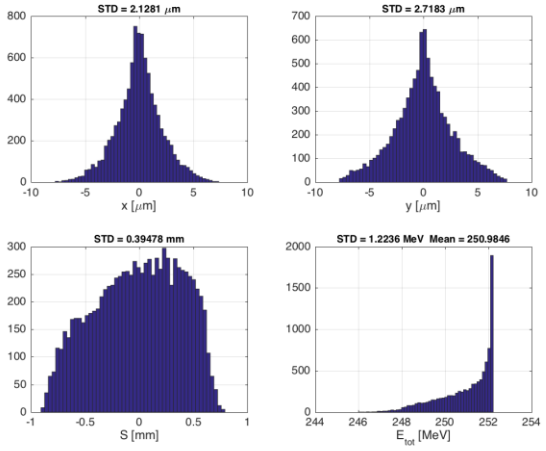
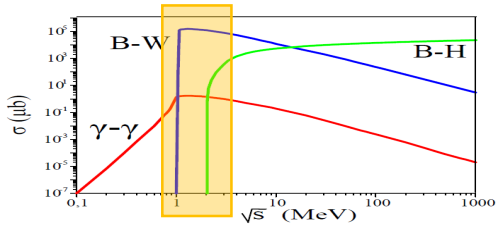
Scheme and layout of cascaded γ–γ collider



Electron bunch profile

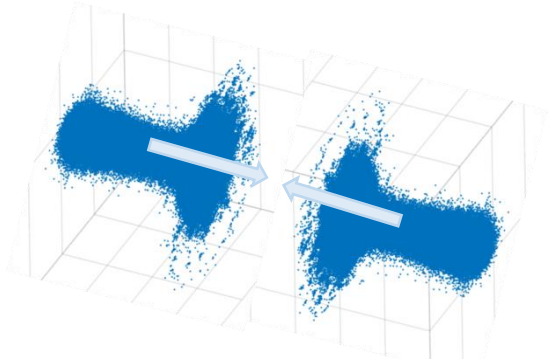




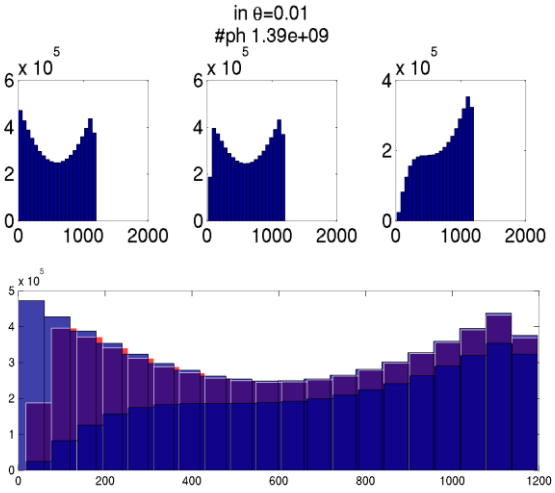
γ–γ: 1.5 μb @ 1.6 MeV

Parameter of the Compton sources

Total energy of the γ–γ system: 2 MeV
Electron energy: 250 MeV (260 MeV B-W)
Electron emittance: 0.4 mm mrad
Electron energy spread: 0.7 10^{-4}
Charge: 250 pC
Transverse electron width: 2.5 μm (5 μm B-W)
Laser wavelength: 1030 nm
Laser waist: 10 micron
Laser Energy: 1 J (2J B-W)
Photon energy: 1 MeV
Transverse photon beam dimension: 1 μm
Transverse photon beam dimension at IP: 10 μm
Repetition rate *f*: 100 Hz

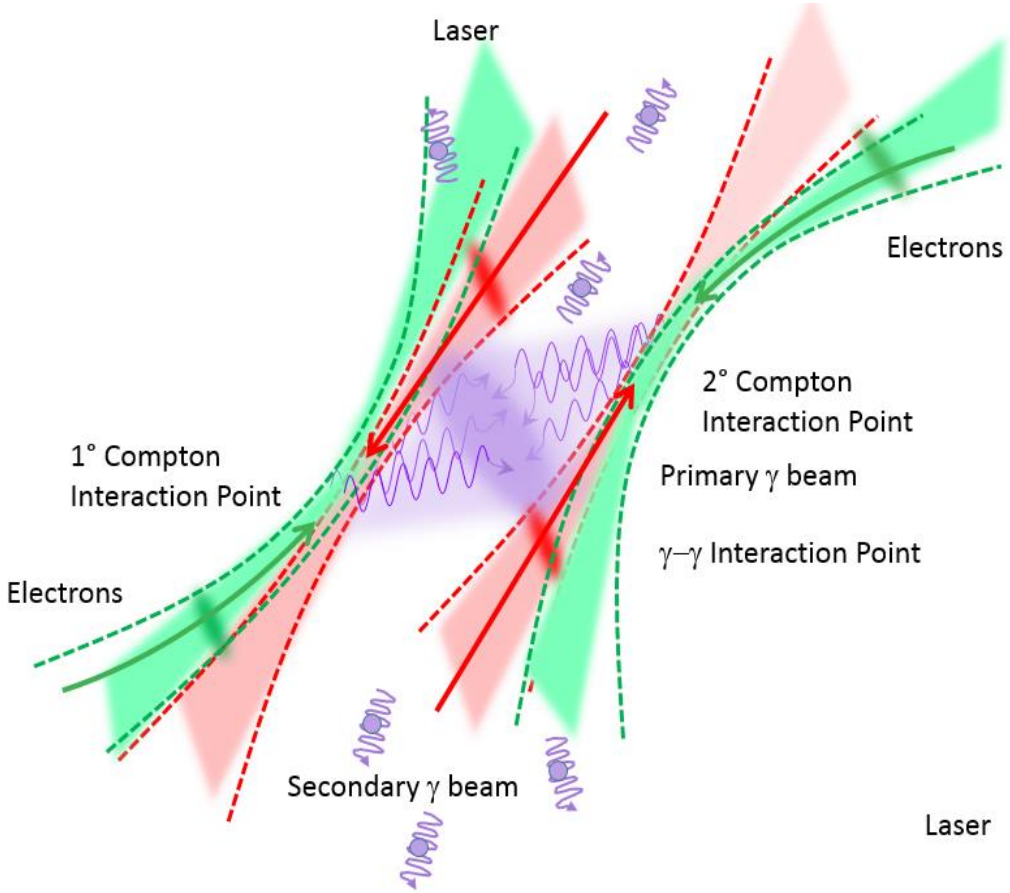


Energy spectrum of Compton back scattered Photons



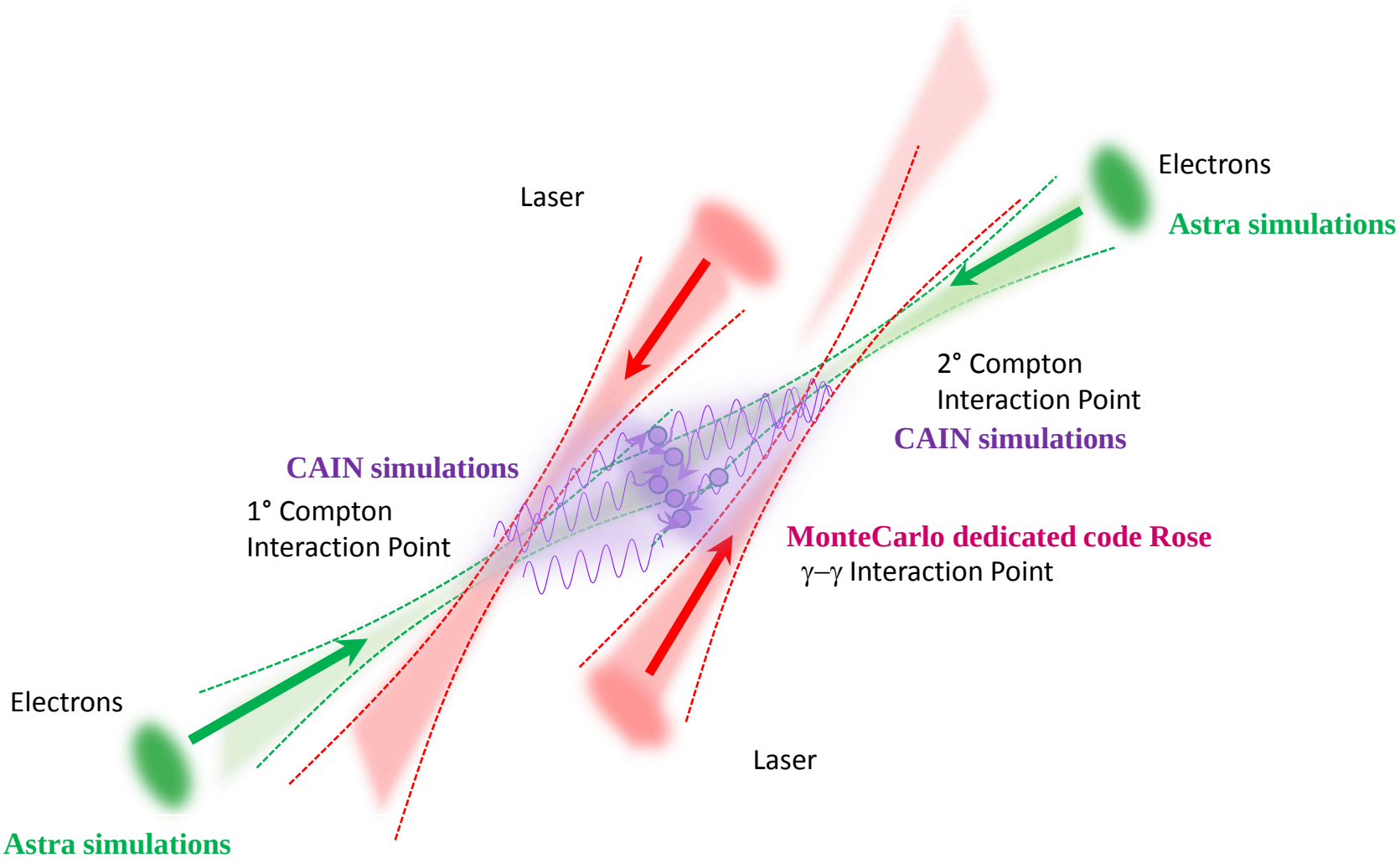
The setup chosen is based on room temperature X-band linac and an amplified laser (like ELI-NP-GBS)

Gamma-gamma collider for the study of γ–γ events generation

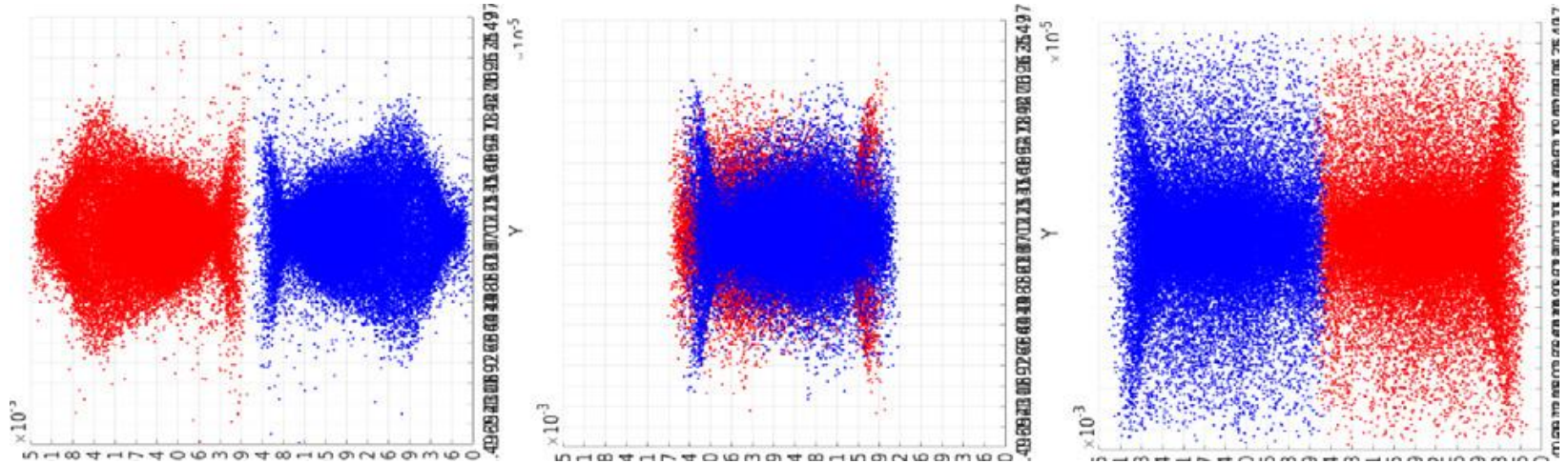


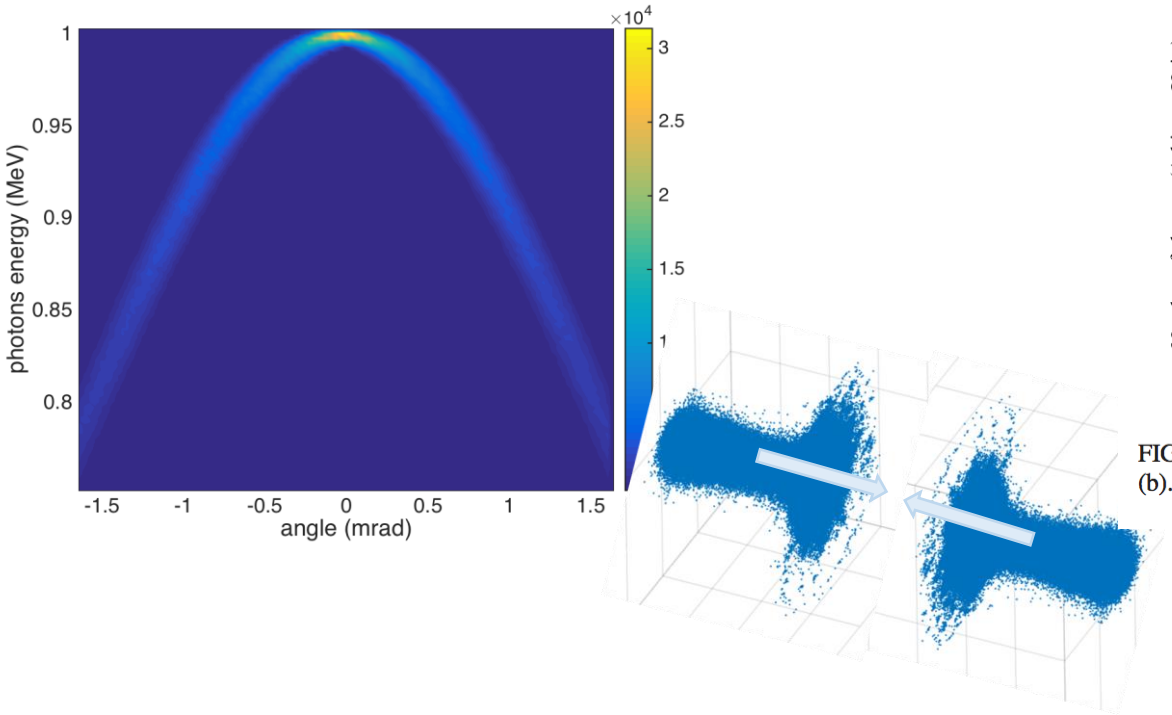
Scheme of the γ–γ interaction. Two lasers (in red) impinge on two electron beams (in green) in two interaction points (Compton IP), generating primary gamma rays (in violet). The primary gamma rays interact in the γγ IP, generating secondary gammas.

Gamma-gamma collider for the study of γ–γ events generation



Code ROSE (Rate Of Scattering Event)





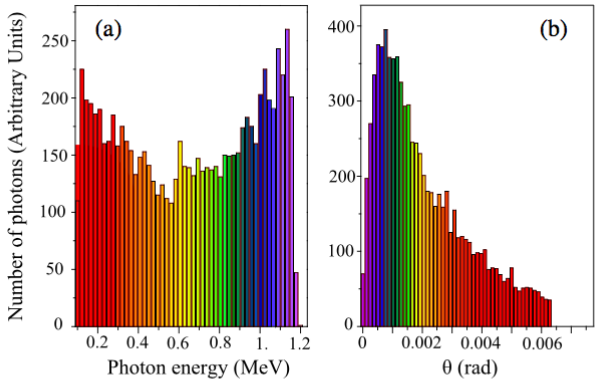
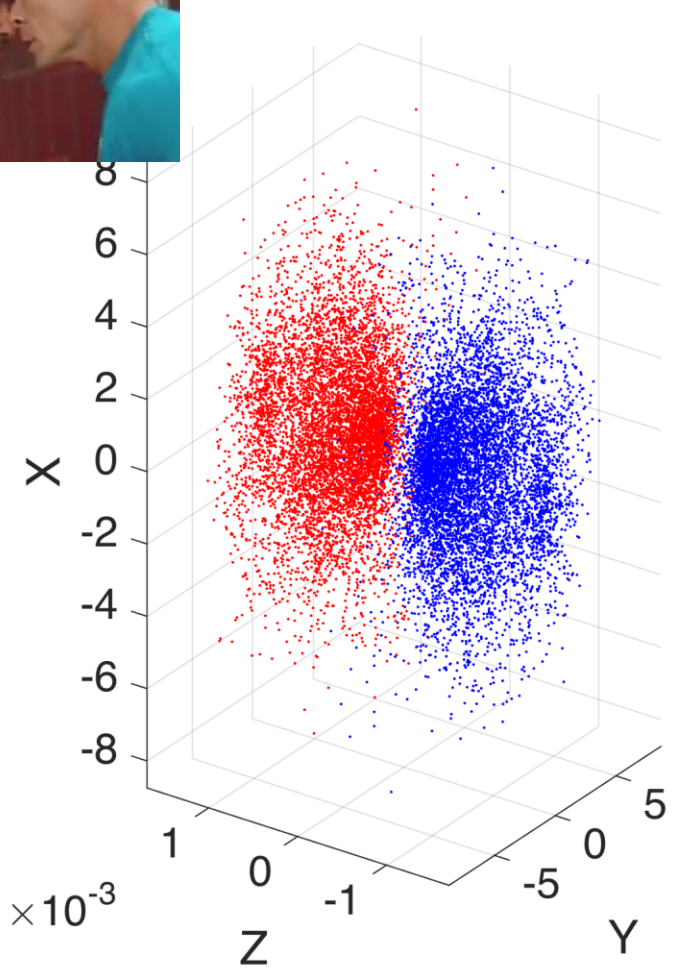
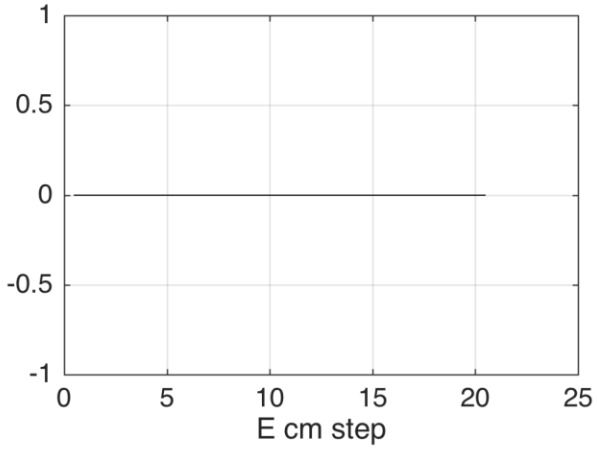
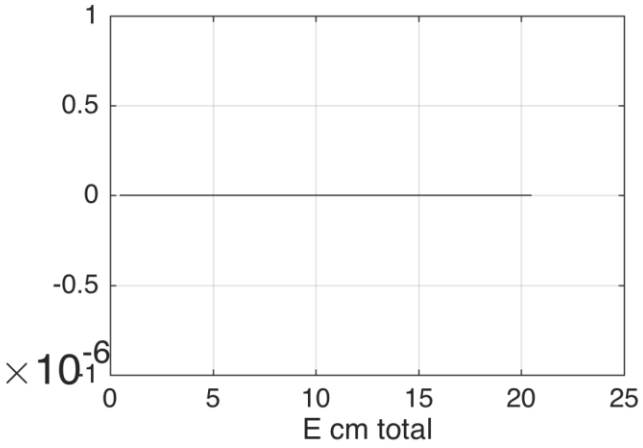


FIG. 4. Spectrum of the radiation (a) and angular distribution (b). Similar colors code similar groups of photons.

Simulations of dynamics in the ROSE code







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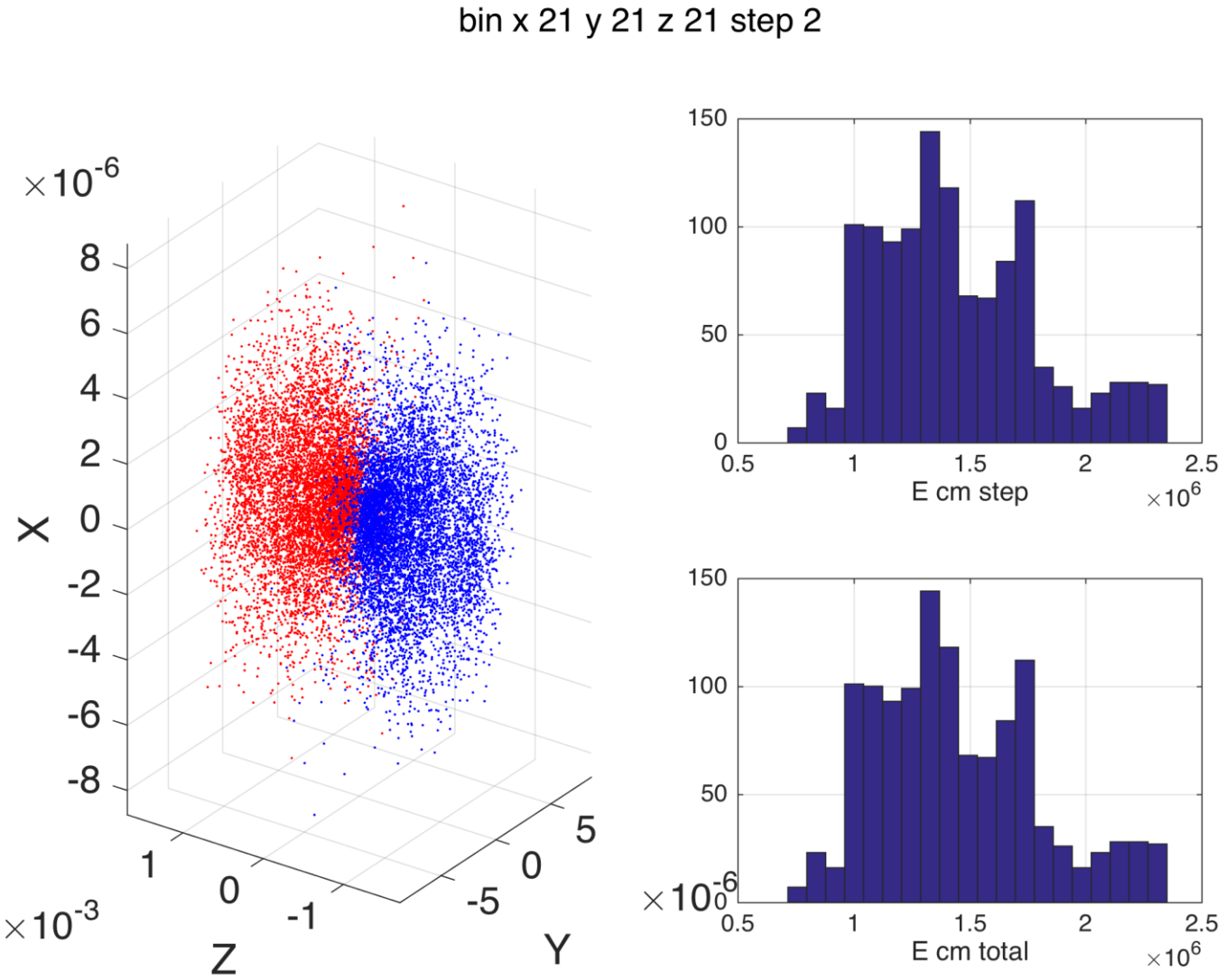

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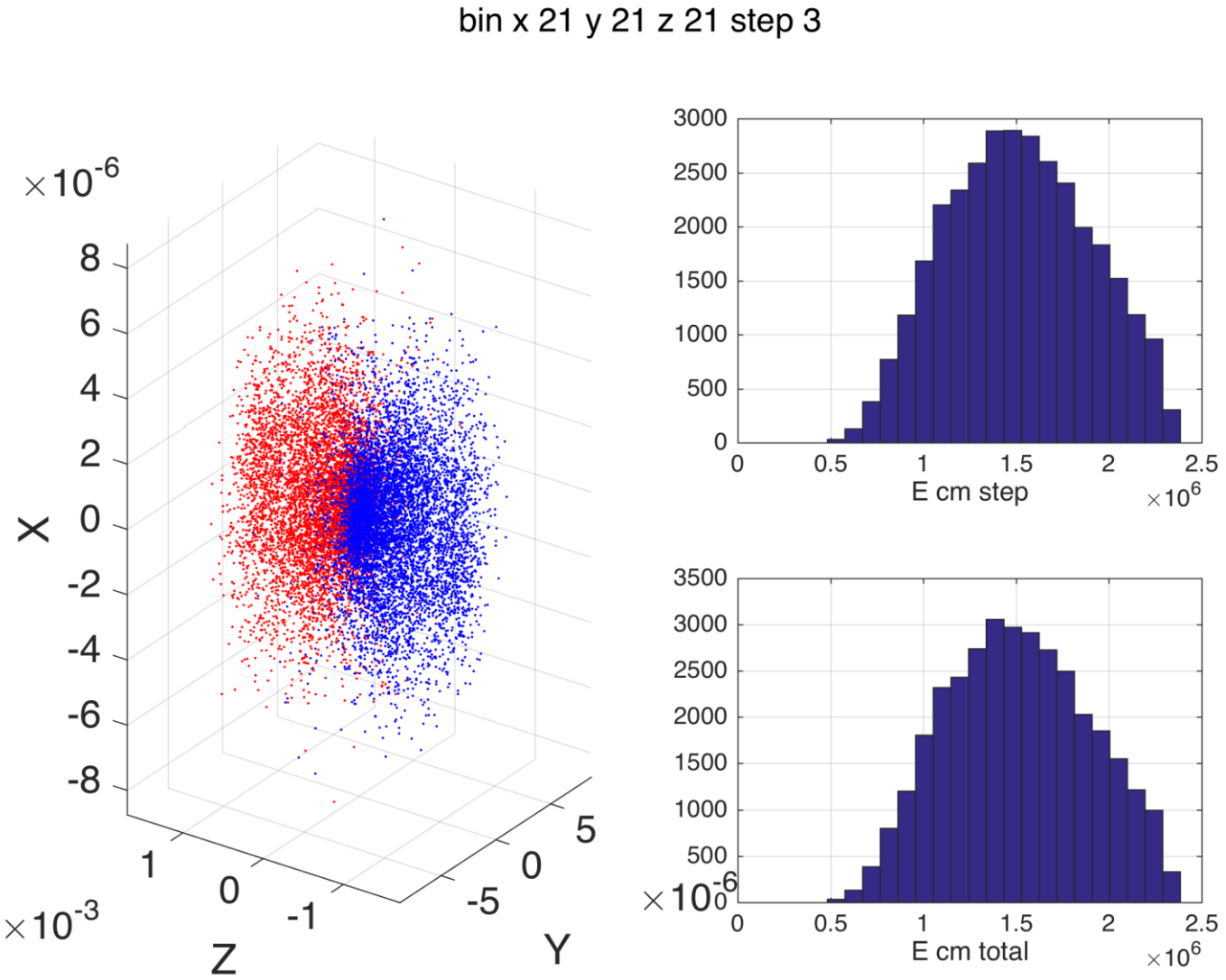

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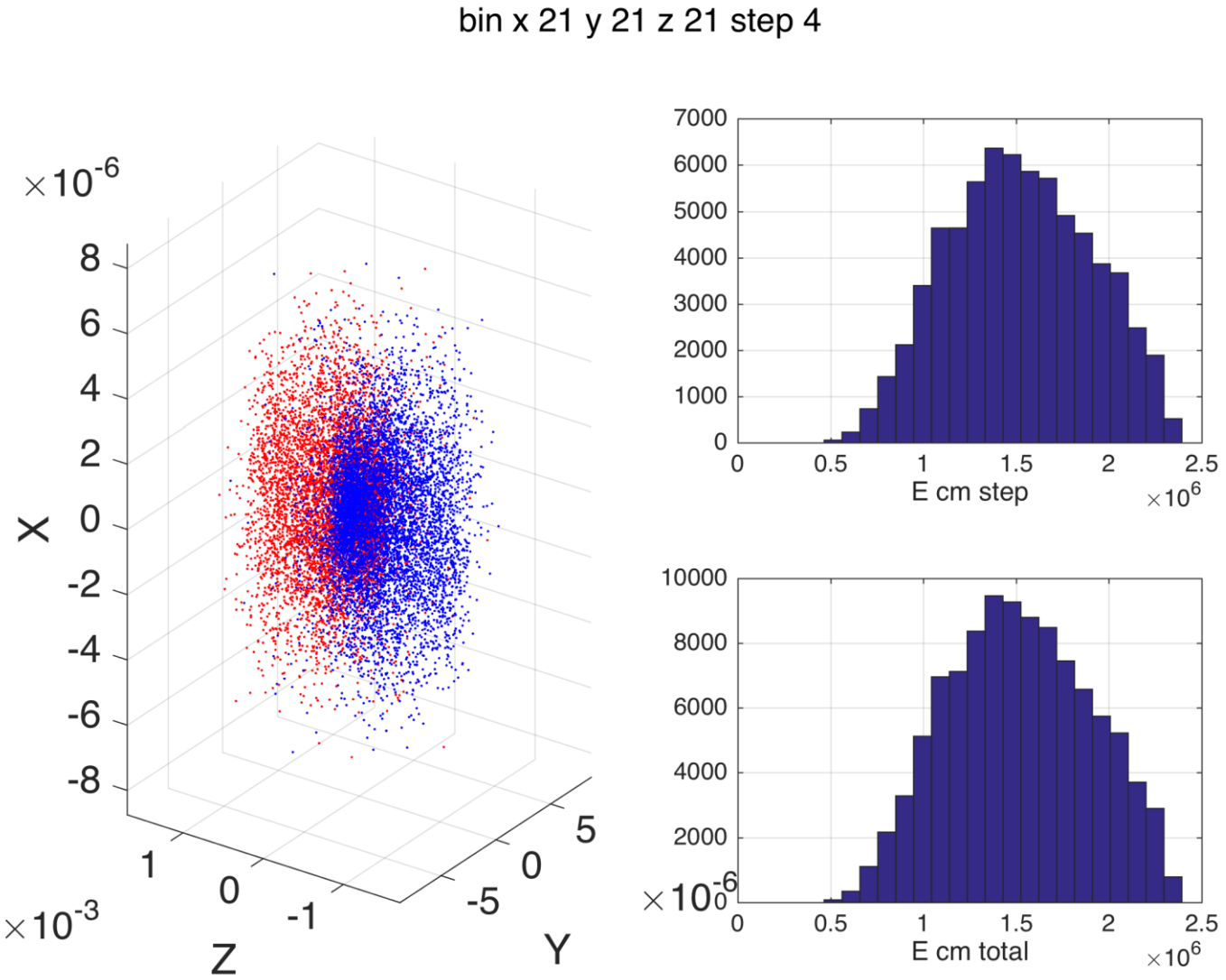

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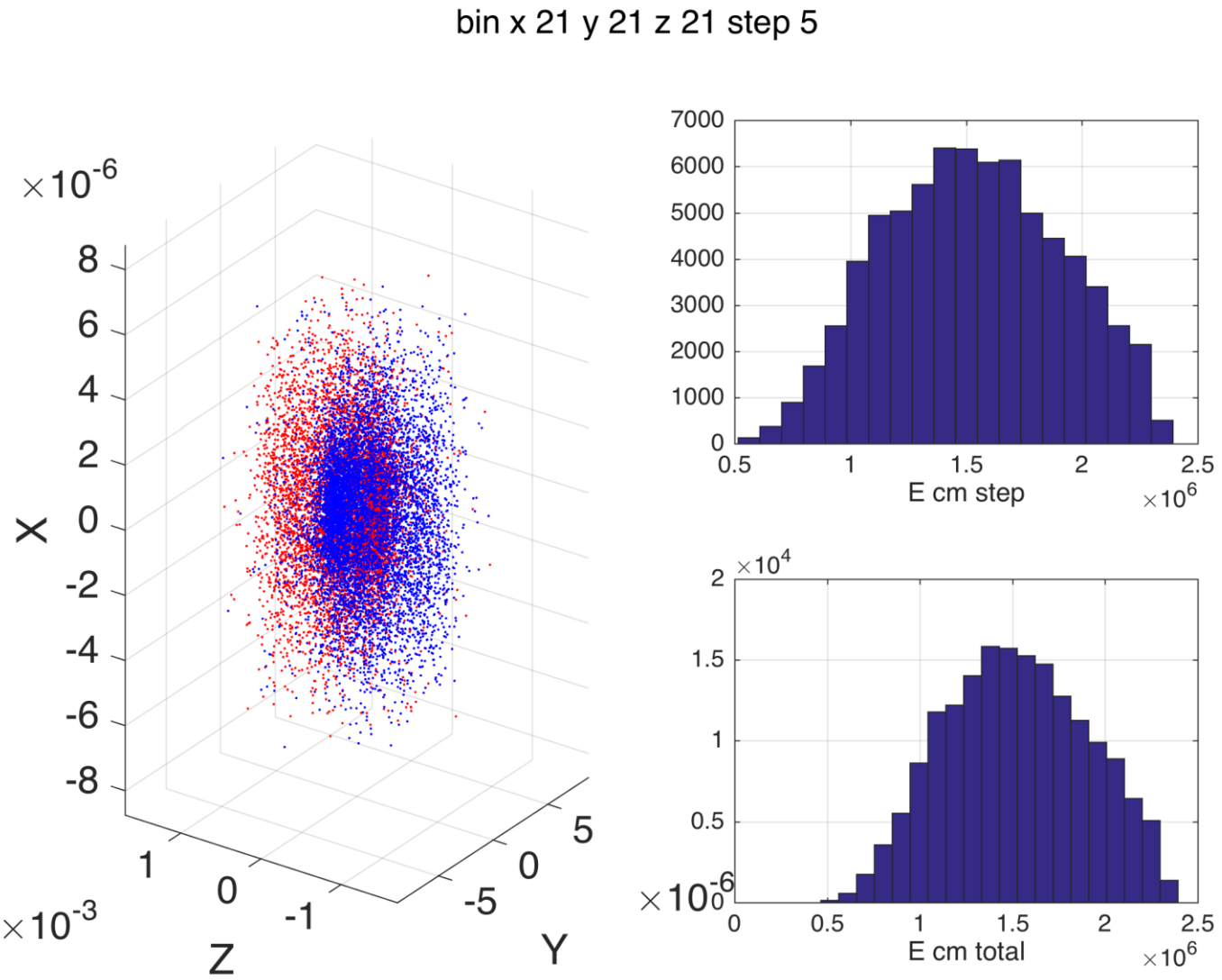

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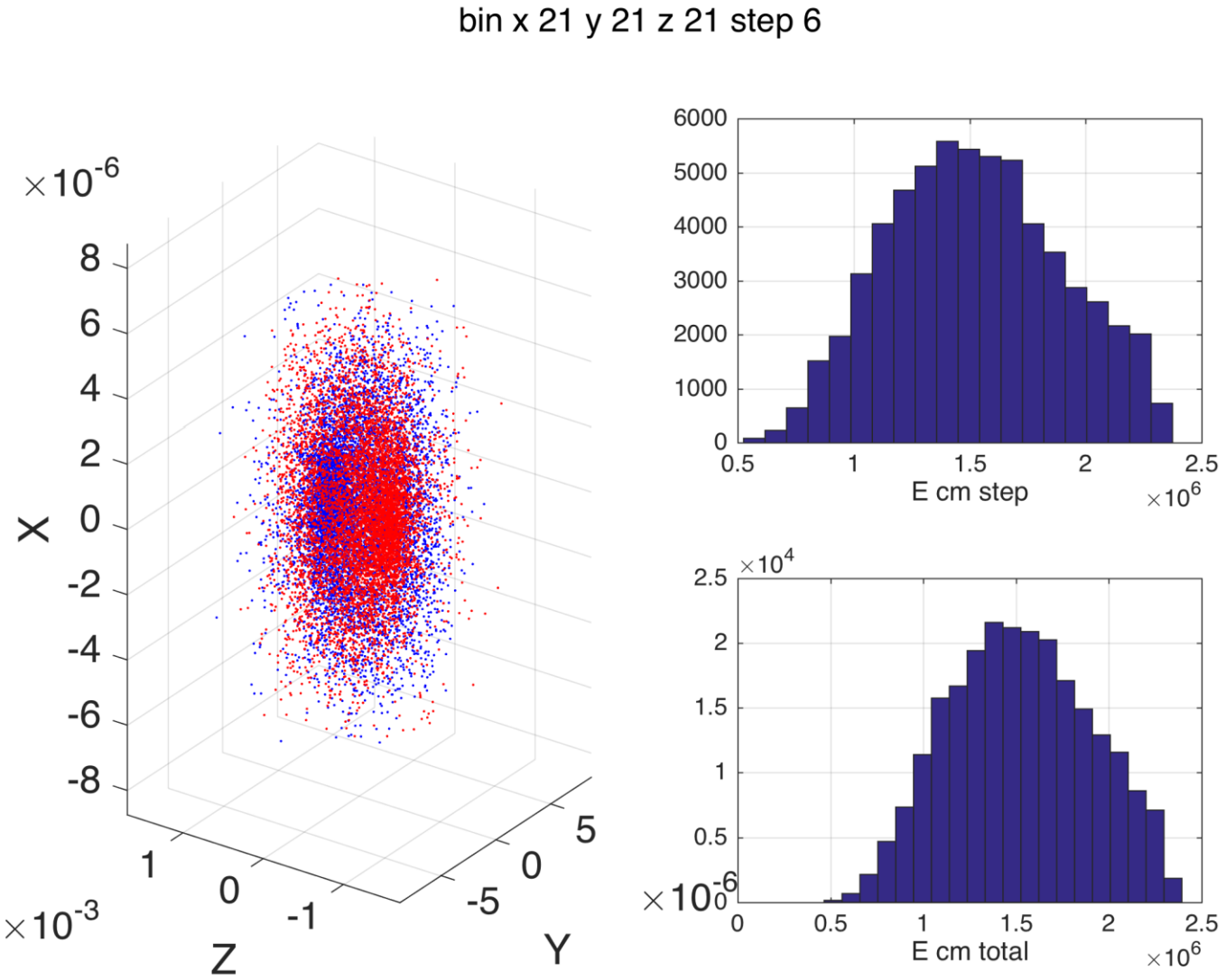

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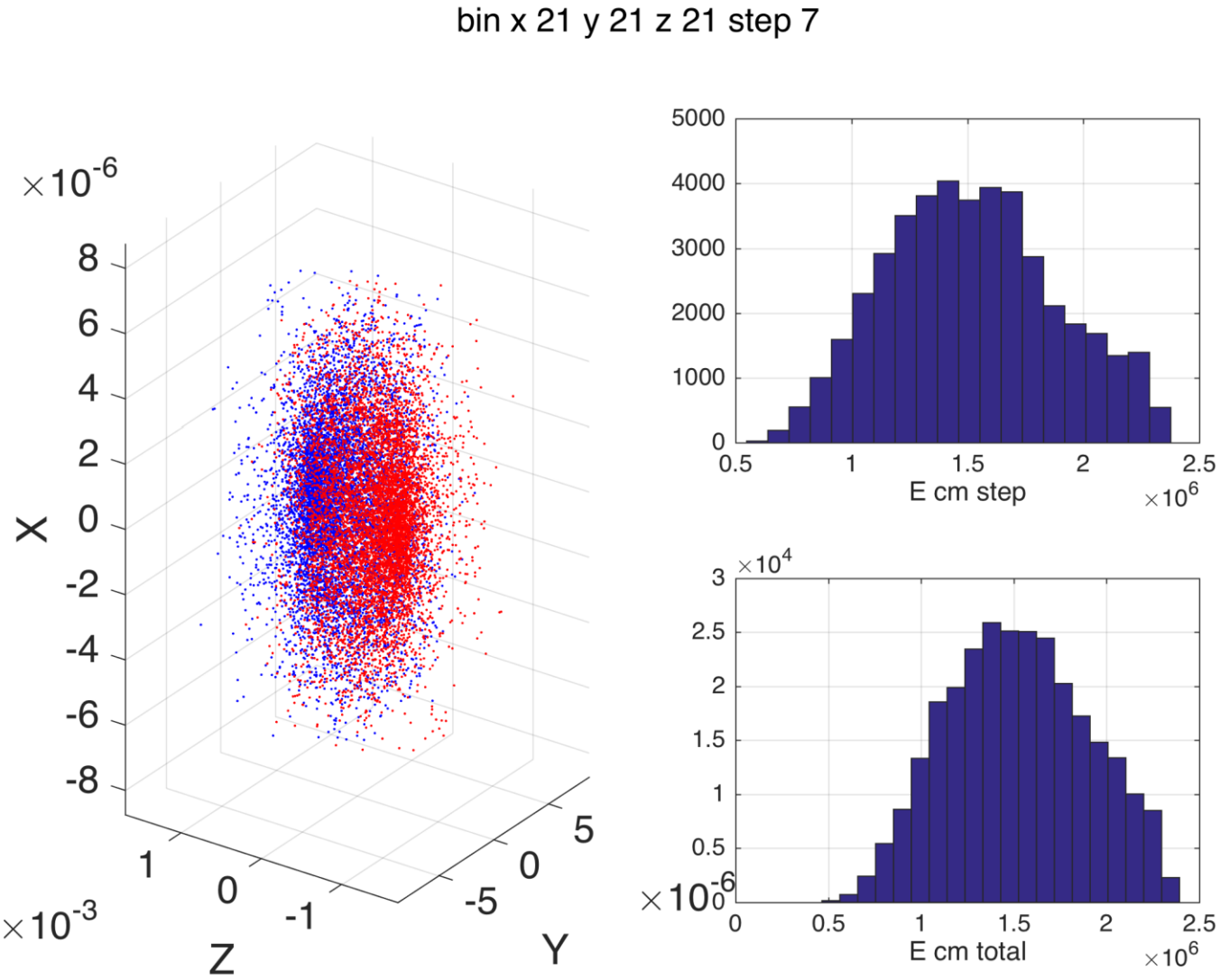

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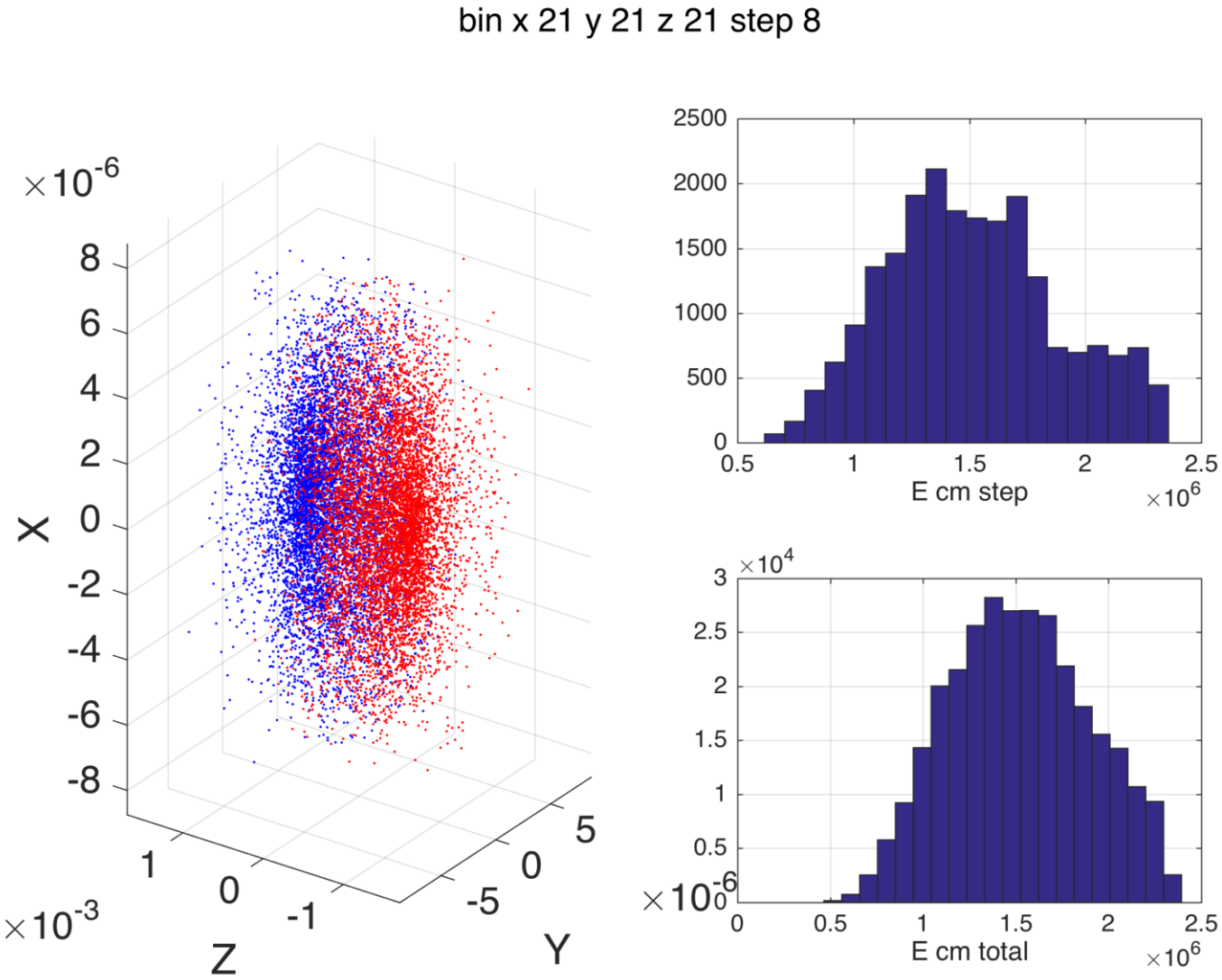

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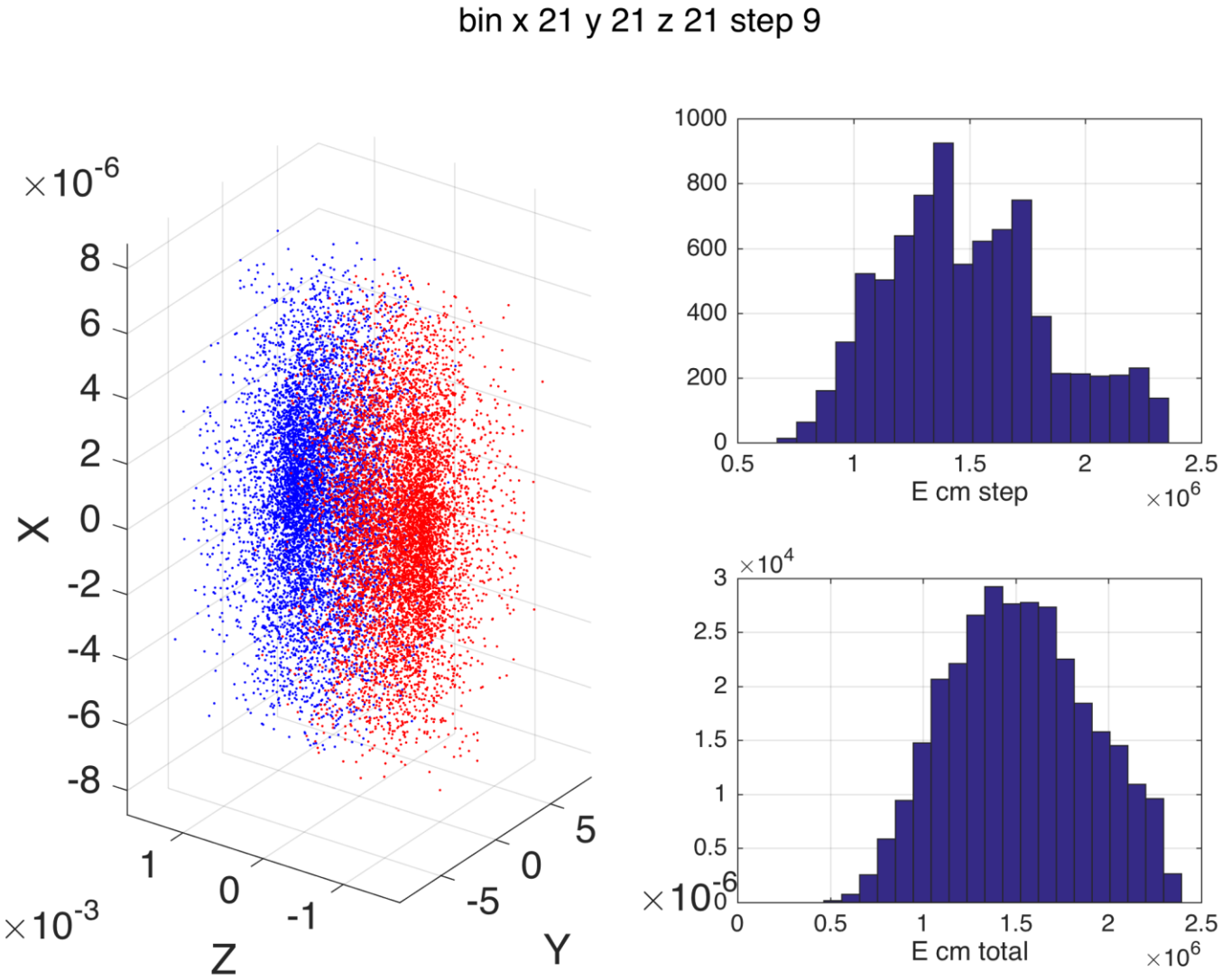

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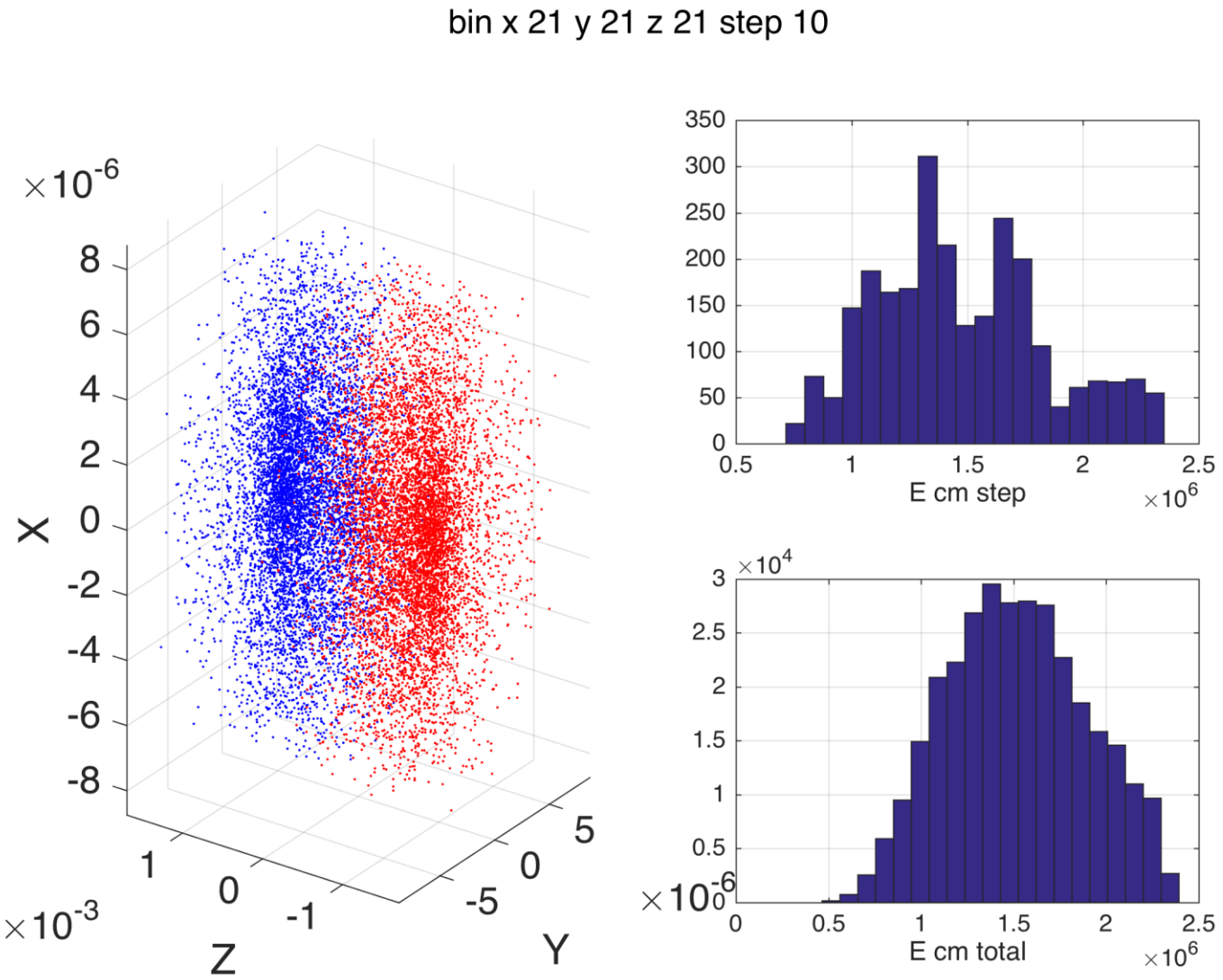

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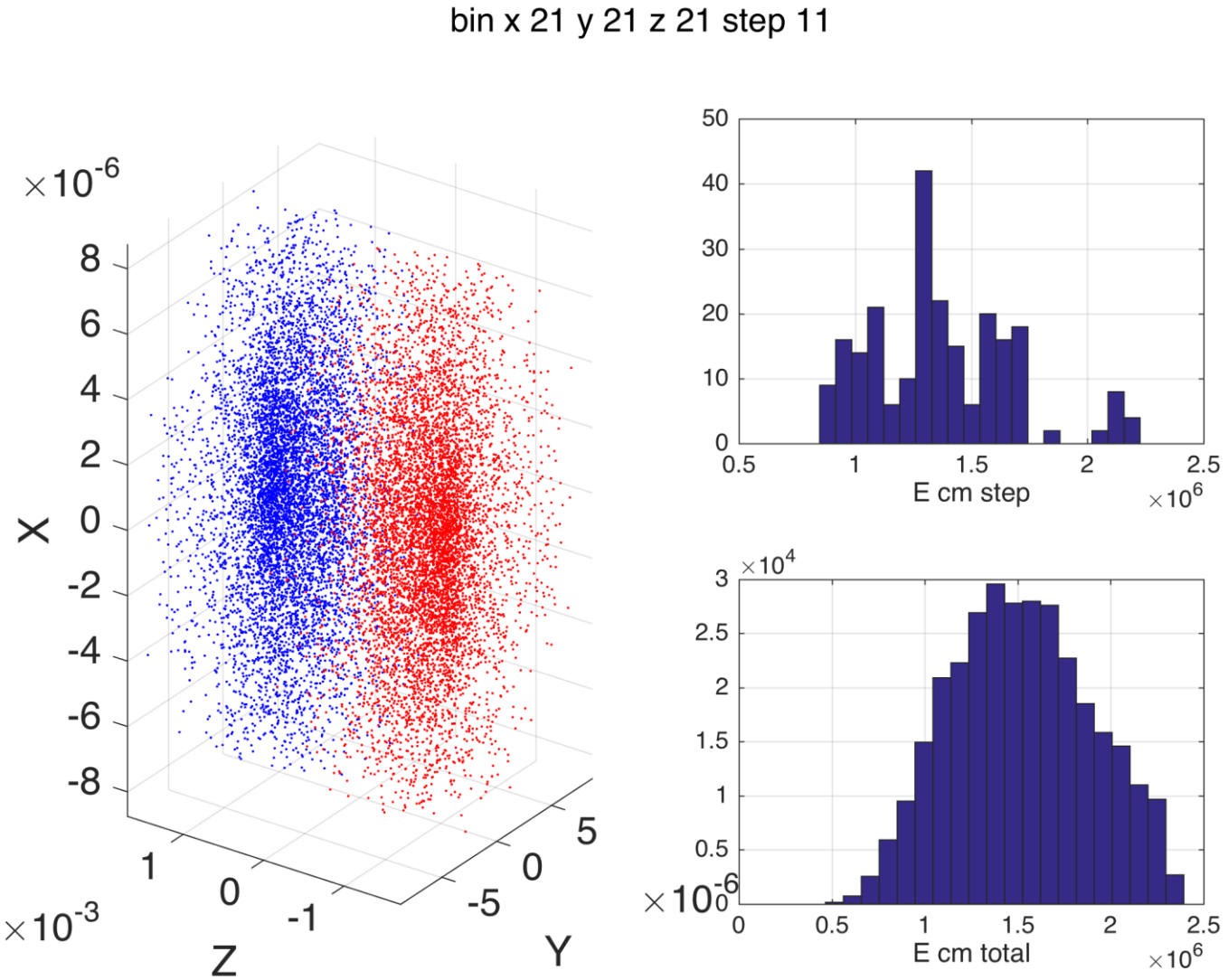
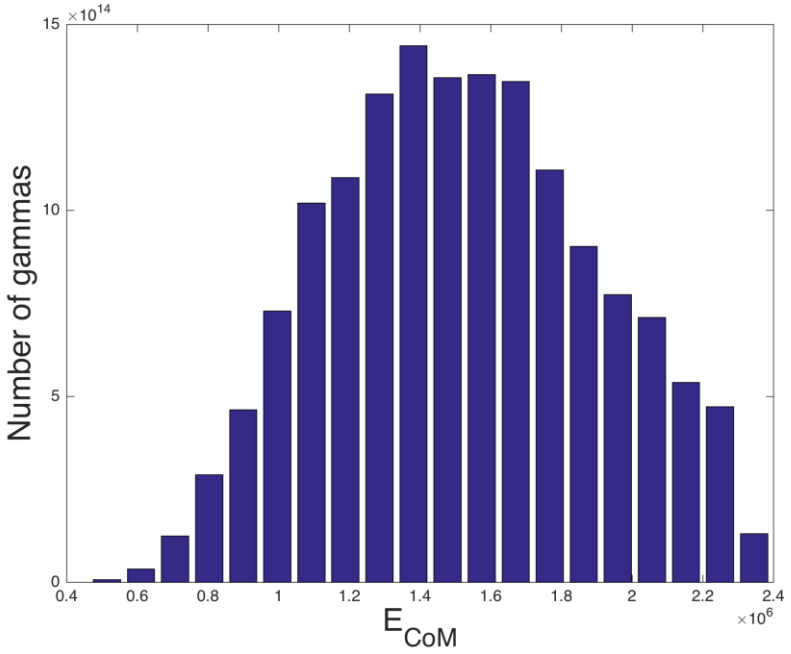
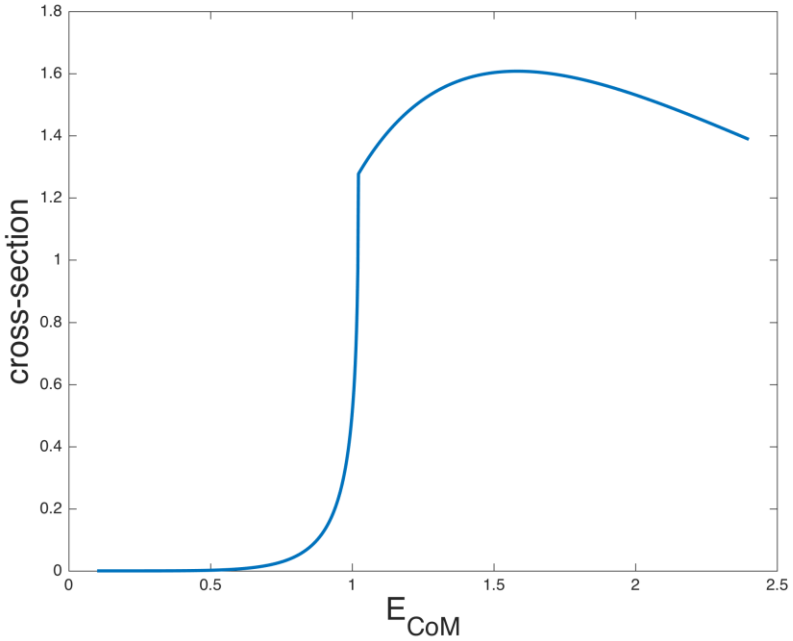


Δ

Simulations of dynamics in the ROSE code

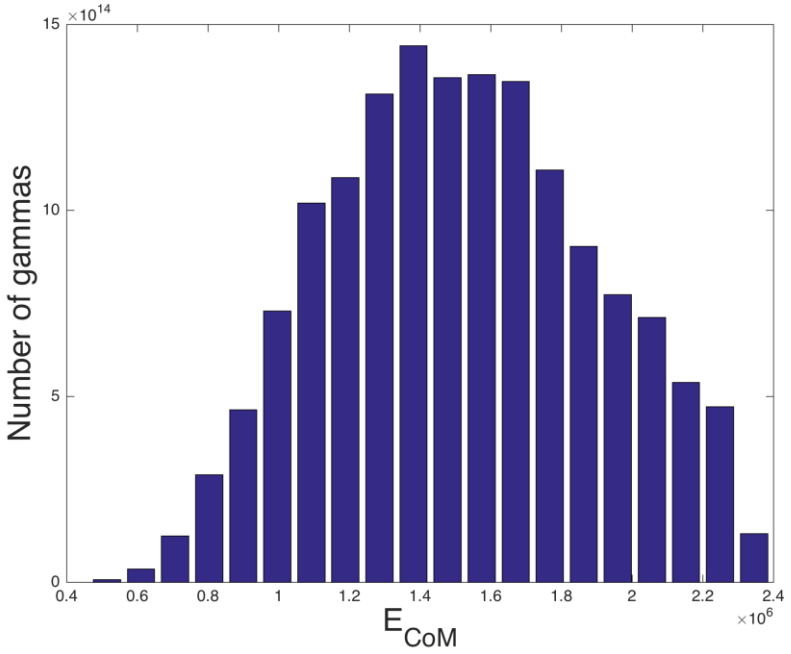


Build a histogram of the energy in the center of mass (CoM) for all possible pairs.

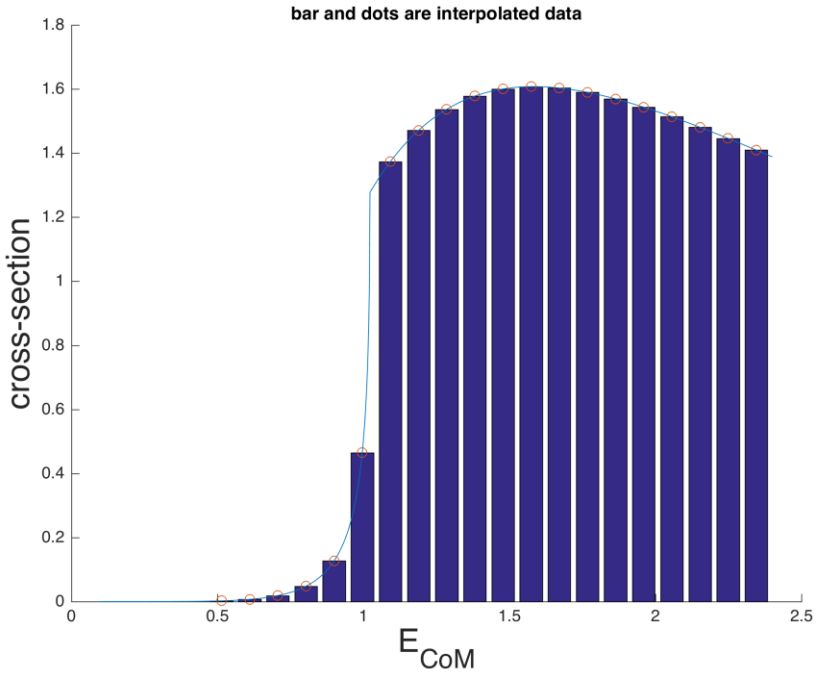


Differential cross section in the plane E_{CoM} (integrated on θ)

Simulations of dynamics in the ROSE code

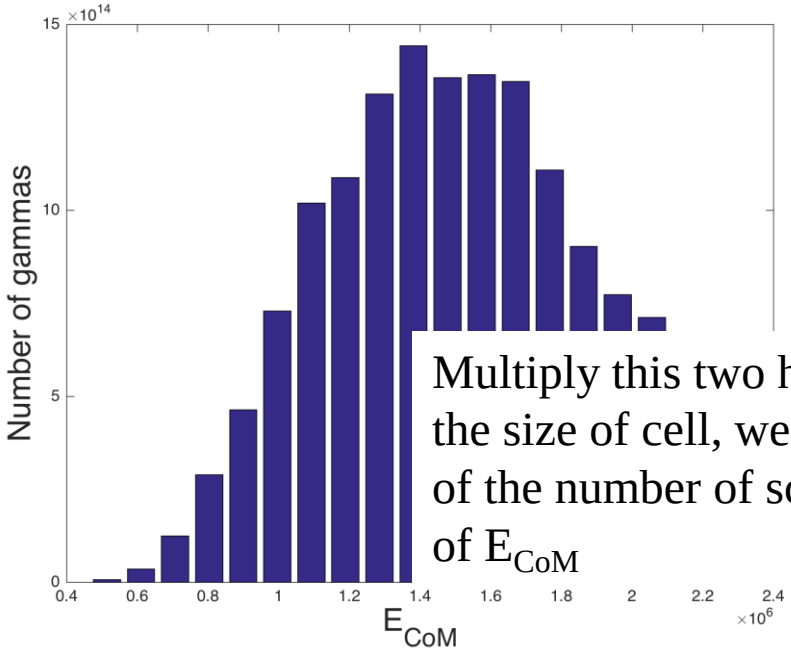


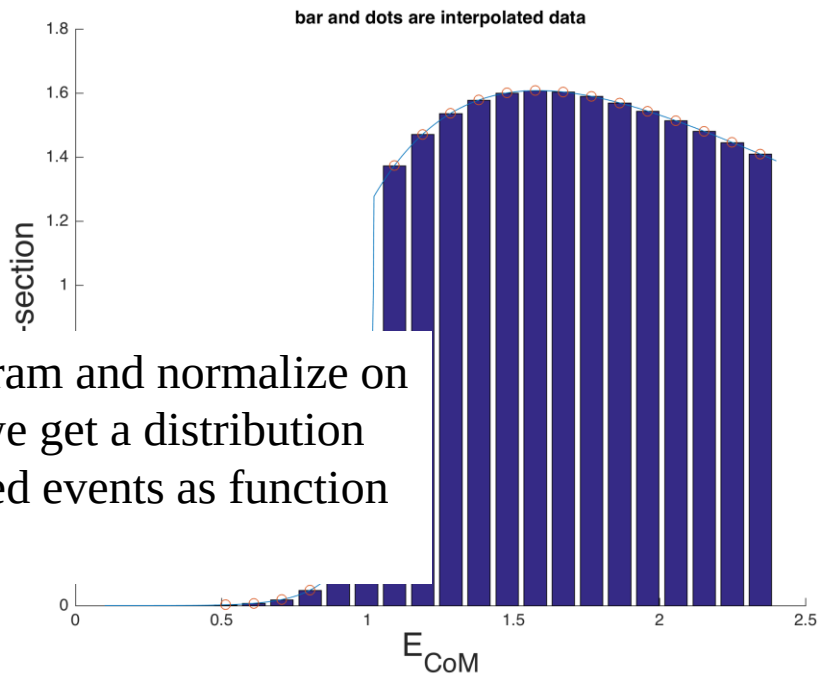
The histogram of the energy <u>in</u> the center of mass (CoM) for all possible pairs.



Build a histogram for total cross-section with exactly the same width of bin that in the number of gammas

Simulations of dynamics in the ROSE code





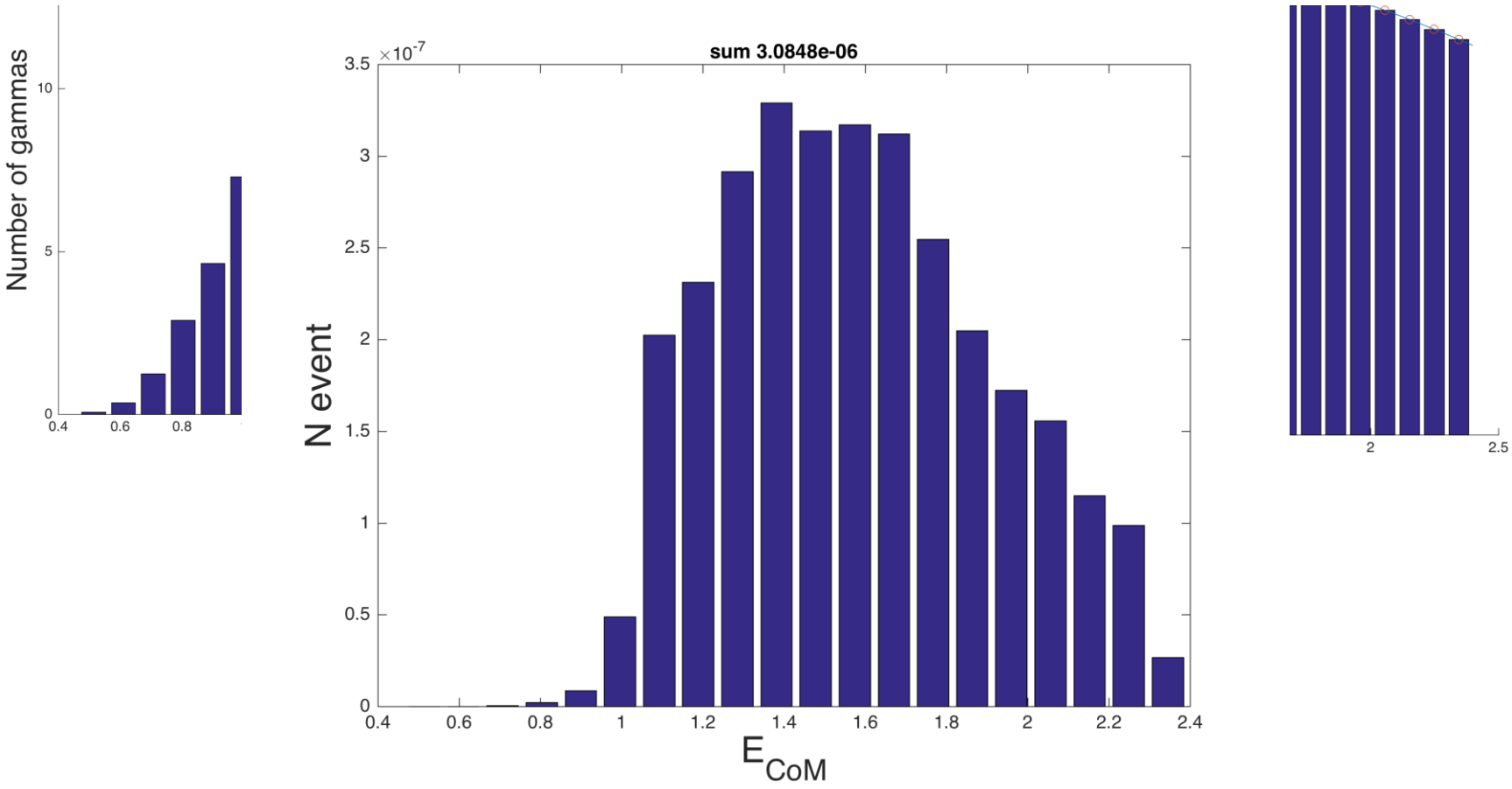
Multiply this two histogram and normalize on the size of cell, weight we get a distribution of the number of scattered events as function of E_{CoM}

The histogram of the energy of center of mass (CoM) for the all possible pair.

Build a histogram for total cross-section with exactly the same width of bin that in the number of gammas

Simulations of dynamics in the ROSE code

Distribution of the number of scattered events as function of E_{CoM}



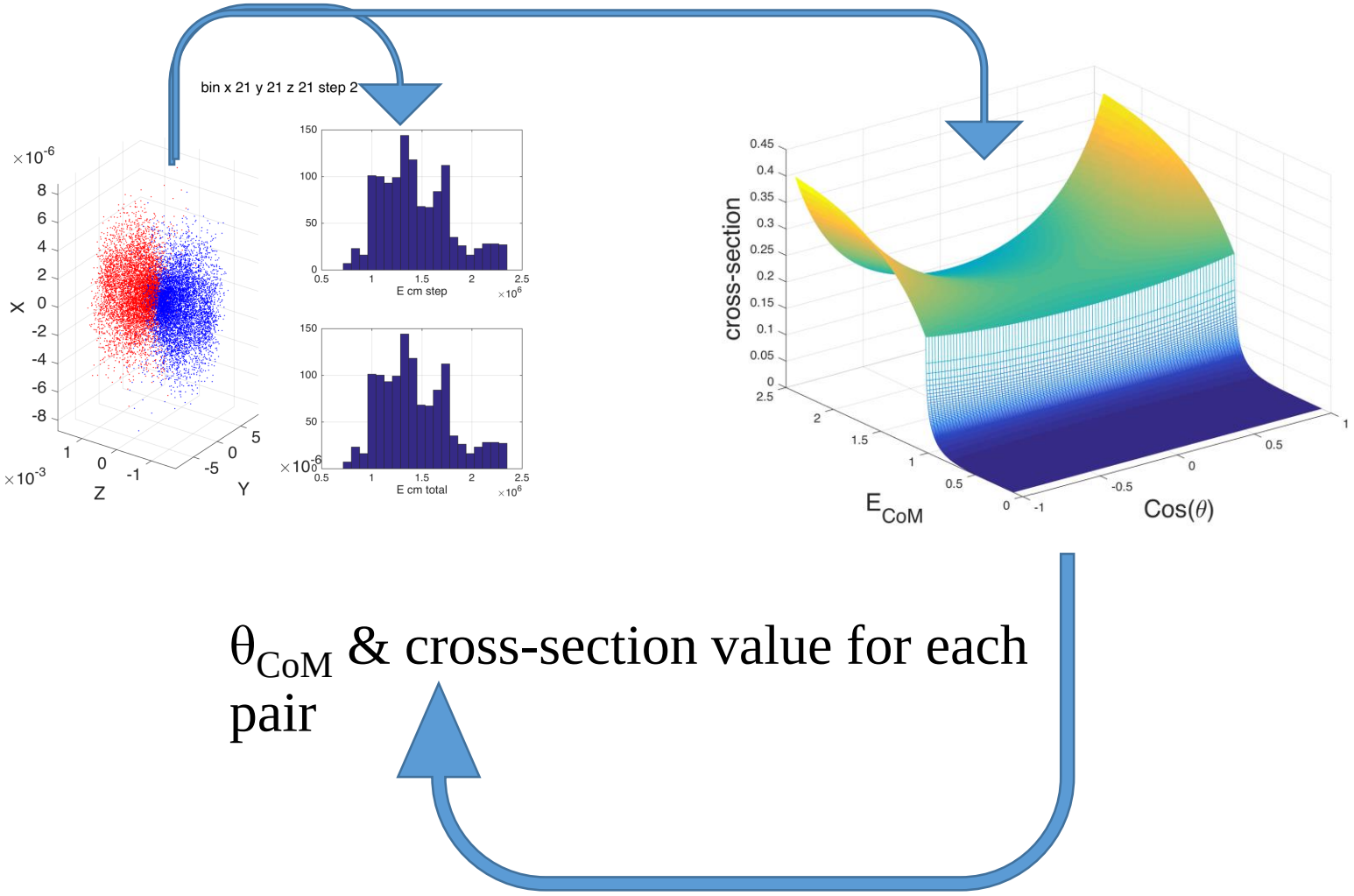
$3*10^{-6}$ per 1 shot * 100 Hz repetition rate => 1 event per hour

Simulations of dynamics in the ROSE code

Monte-Carlo???

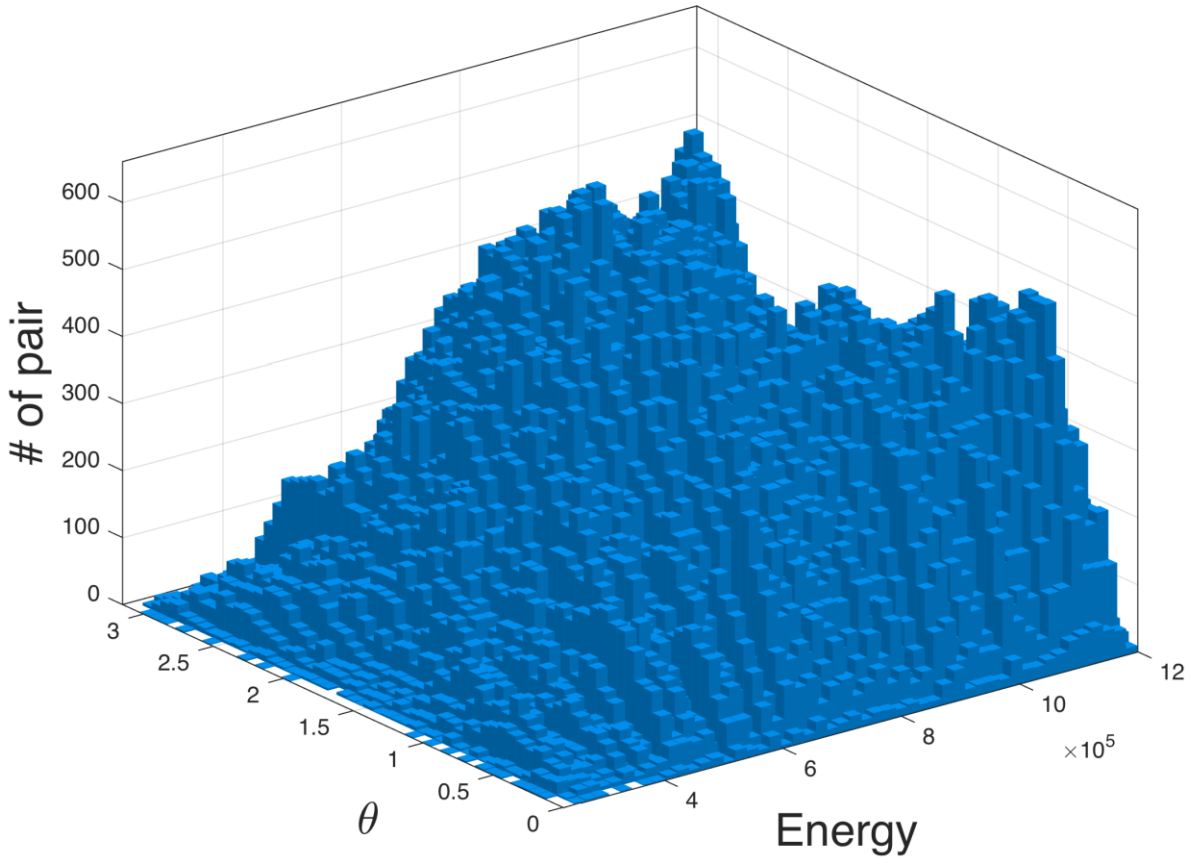
Simulations of dynamics in the ROSE code

Monte-Carlo



θ_{CoM} & cross-section value for each pair

Distribution of the γ-γ events in the laboratory as a function of the energy of the secondary particles $E=E_{3,4}$ and of the zenith angle θ.



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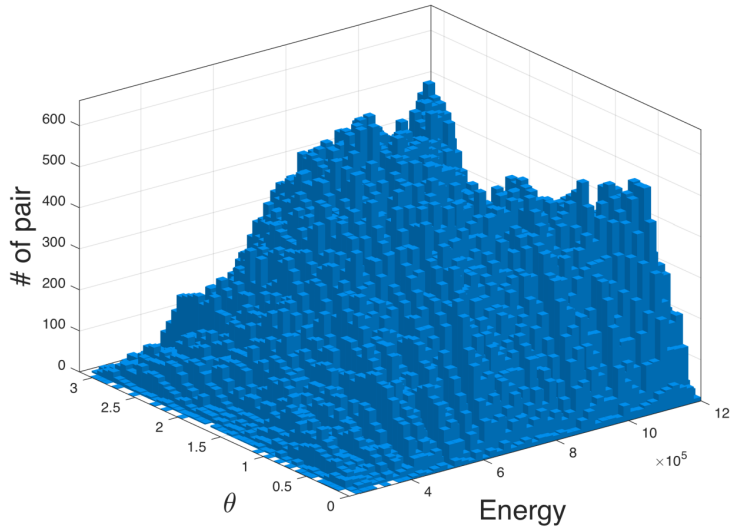

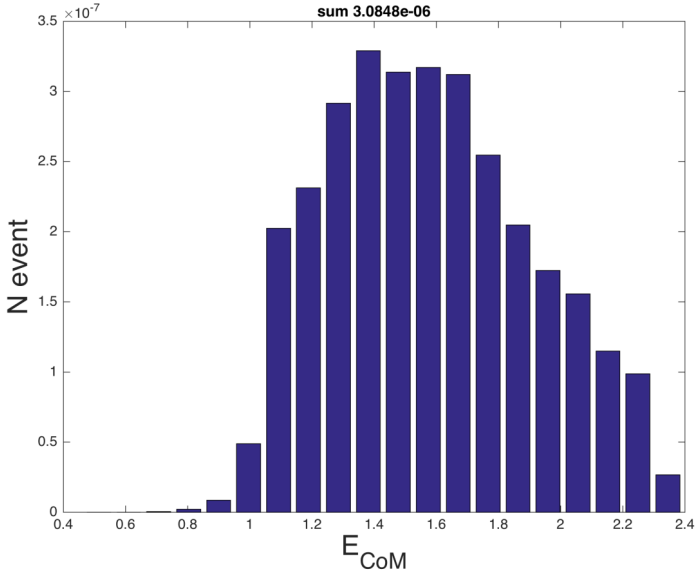

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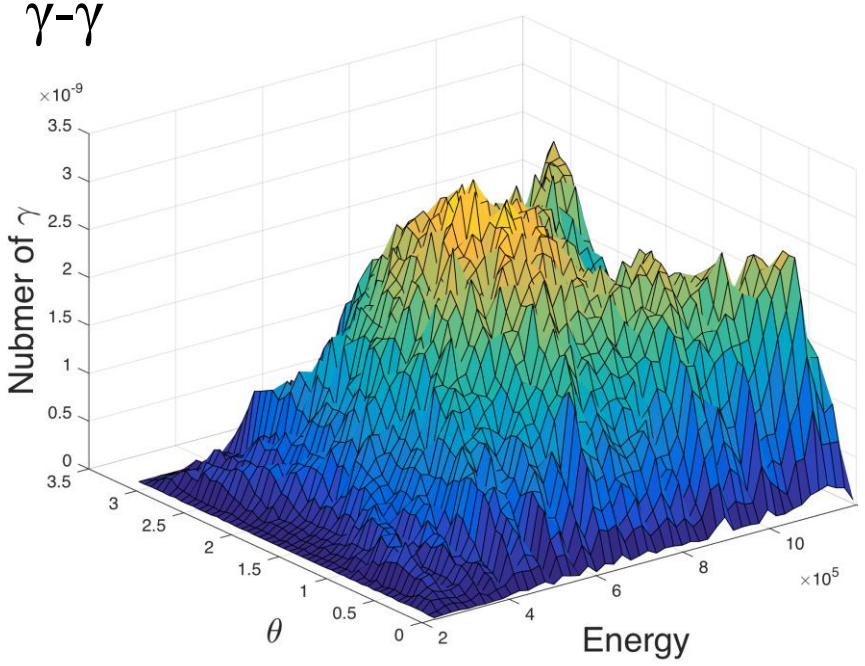
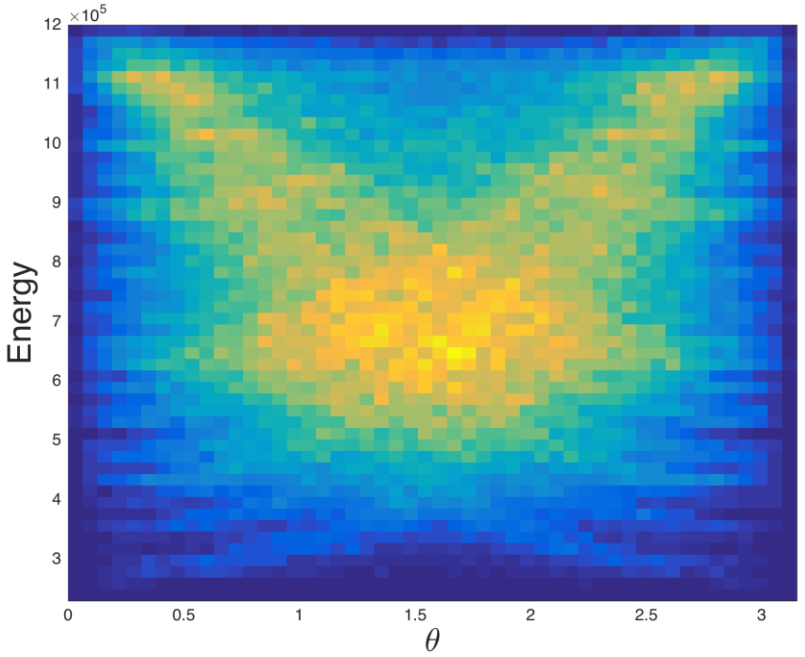
γ-γ





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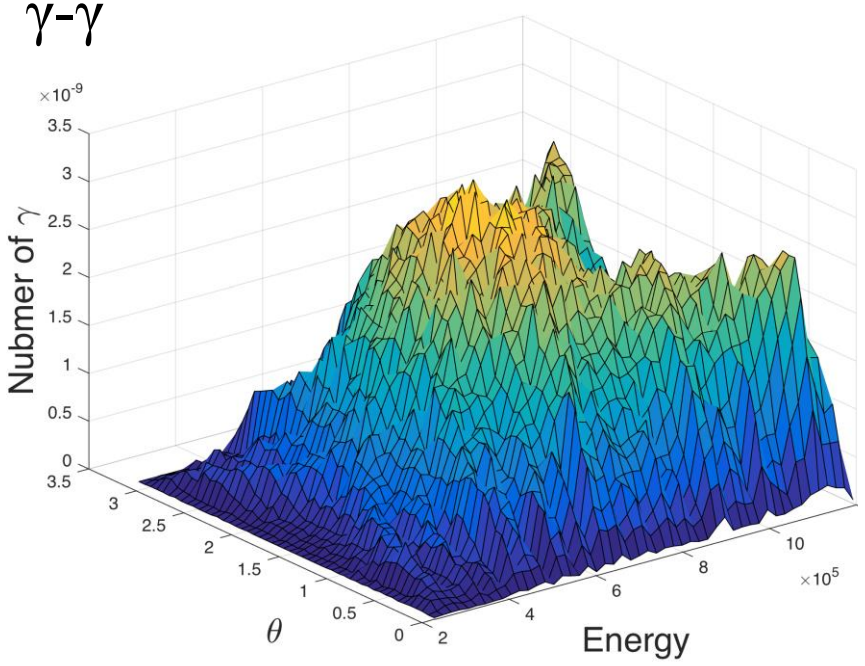
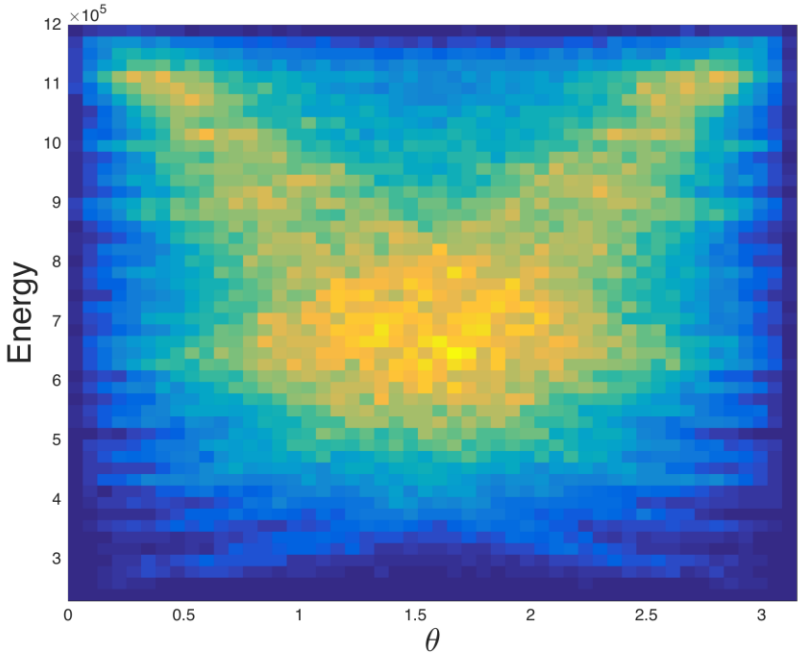
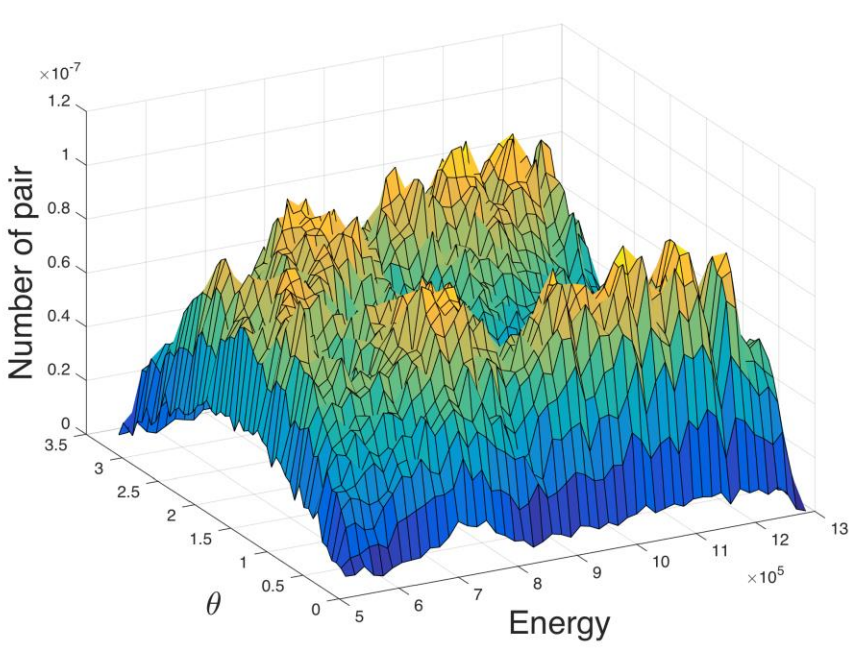
γ-γ

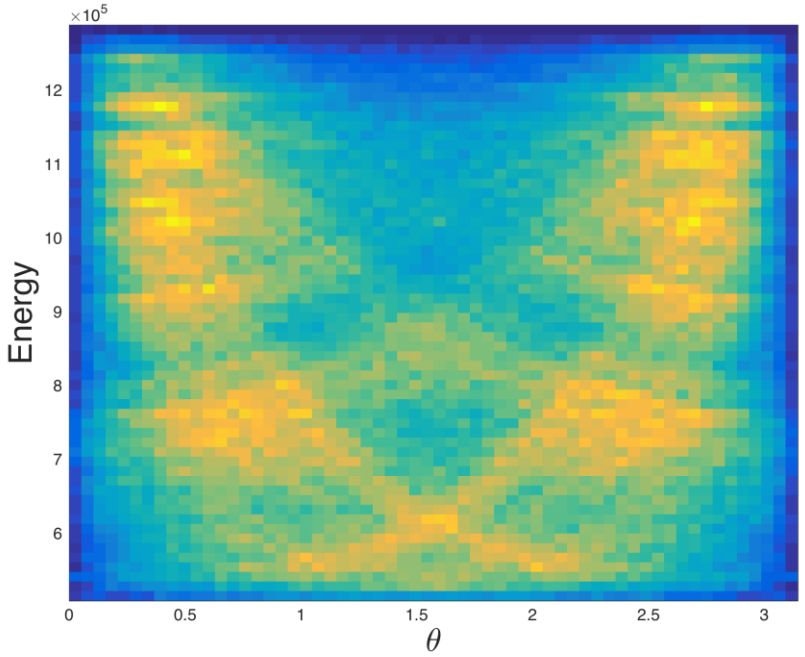




Distribution of the e^+-e^- events in the laboratory as a function of the energy of the secondary particles E=E3,4 and of the zenith angle θ.

B-W





Distribution of the e^+-e^- events in the laboratory as a function of the energy of the secondary particles E=E3,4 and of the zenith angle θ.

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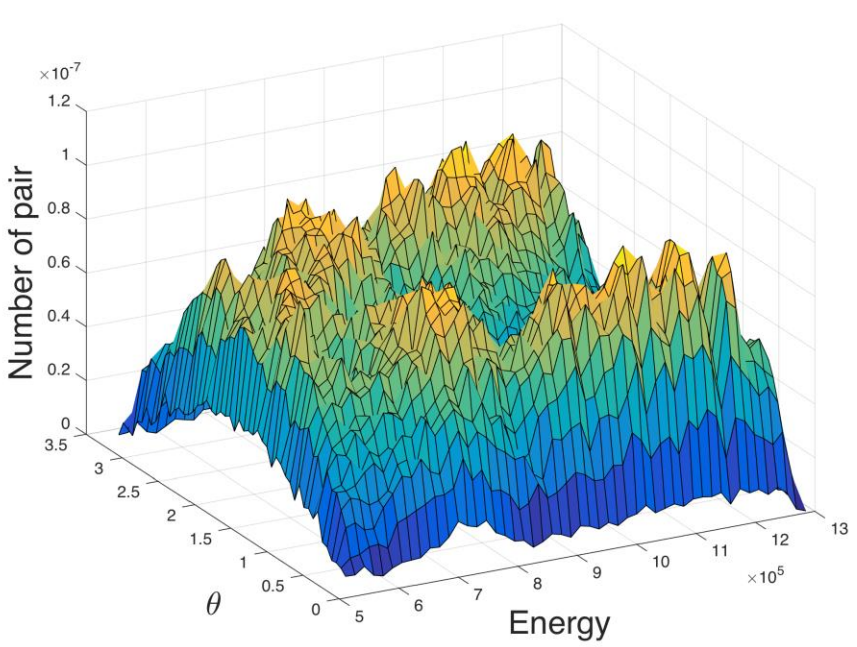
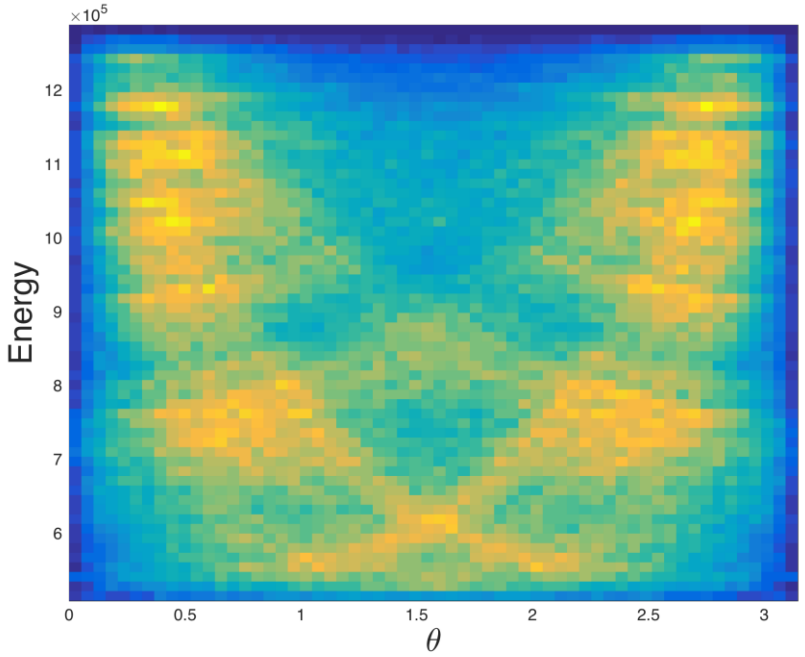
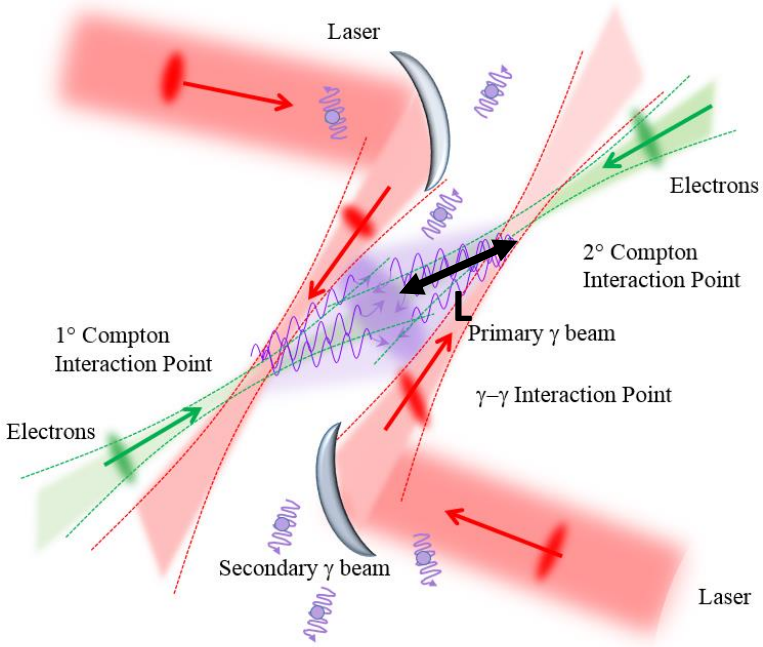
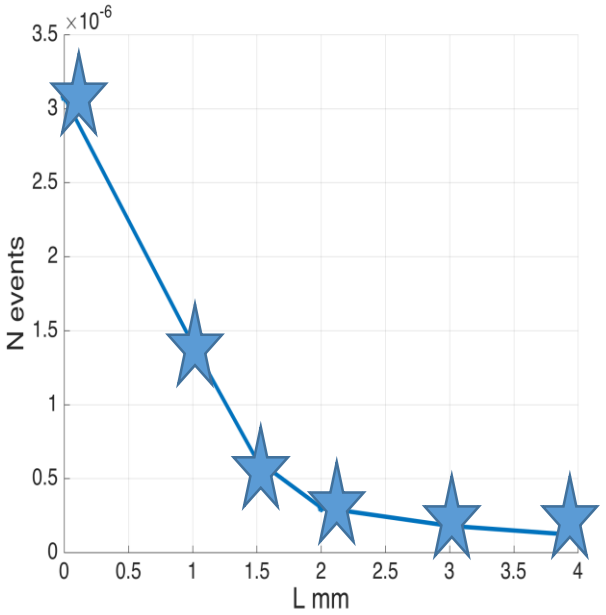




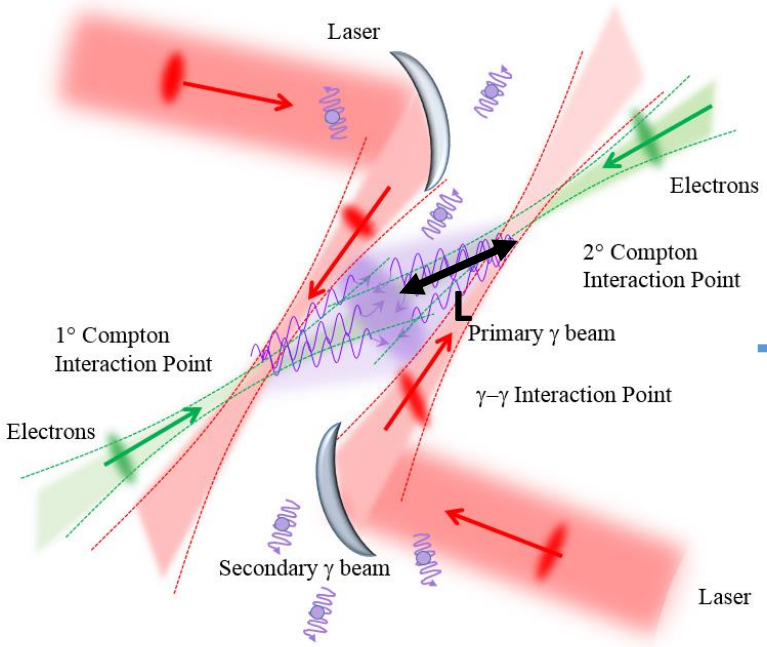
Results of a Monte Carlo dedicated ROSE code the γ-γ elastic scattering



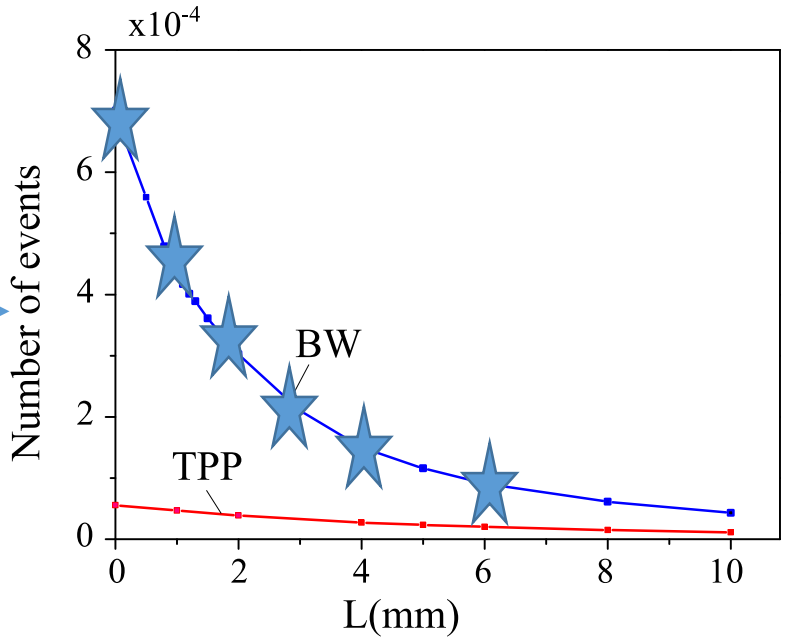
1 event/h



Results of a Monte Carlo dedicated ROSE code
Breit-Wheeler scattering

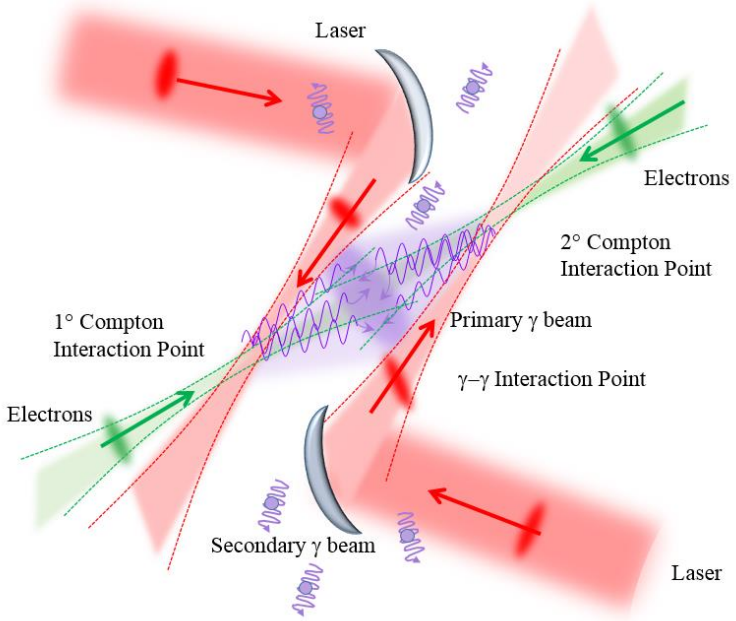


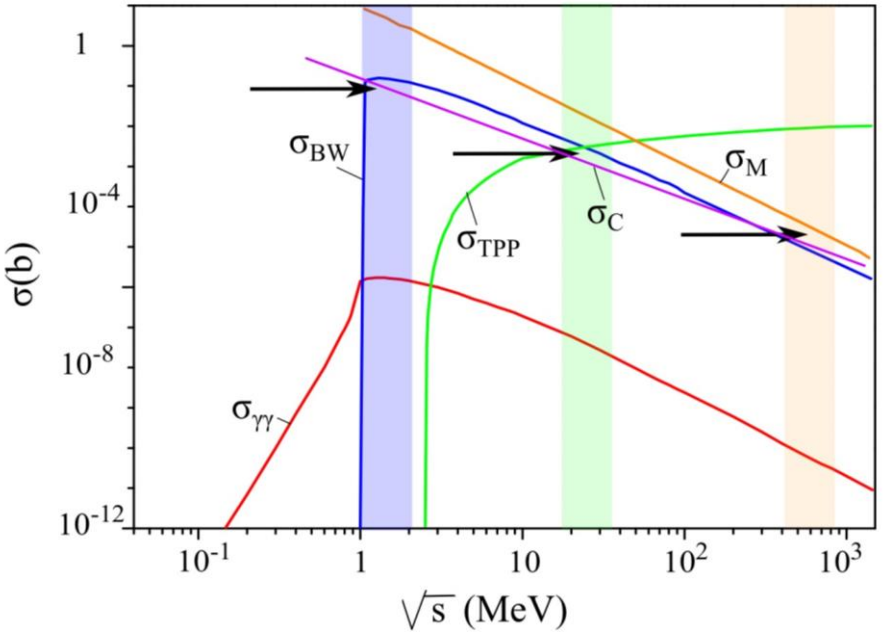
100 event/h



Results of a Monte Carlo dedicated ROSE code for treatment of the **background processes**

secondary Compton ($e^-\gamma \rightarrow e^-\gamma$), Møller scattering ($e^-e^- \rightarrow e^-e^-$),
triplet pair (TPP, $\gamma e^- \rightarrow e^-e^+e^-$), muon pair photo-production (MPP, $\gamma e^- \rightarrow e^-\mu^+\mu^-$)



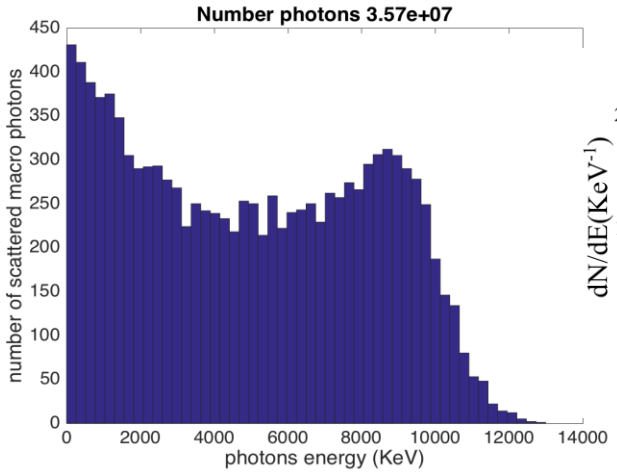


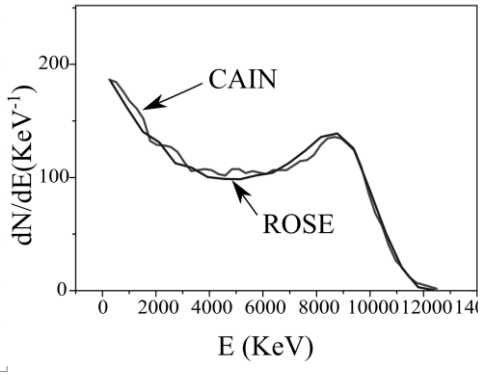
Number of events for single shot, $L = 4$ mm.

Event type	Breit-Wheeler	Compton	$\gamma\gamma$ pairs	Triplet pairs	Møller	Muon pairs
Number of event	1.6×10^{-4}	8×10^{-6}	$< 10^{-8}$	2.6×10^{-5}	1.5×10^{-6}	0

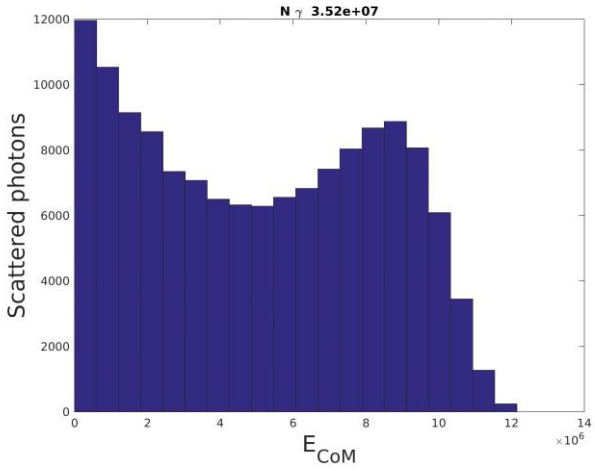
Benchmark with CAIN

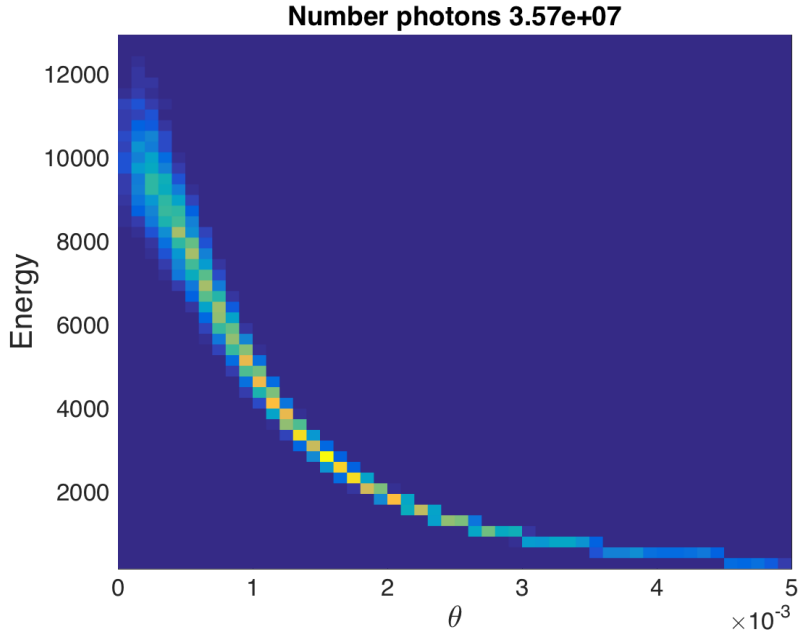
CAIN

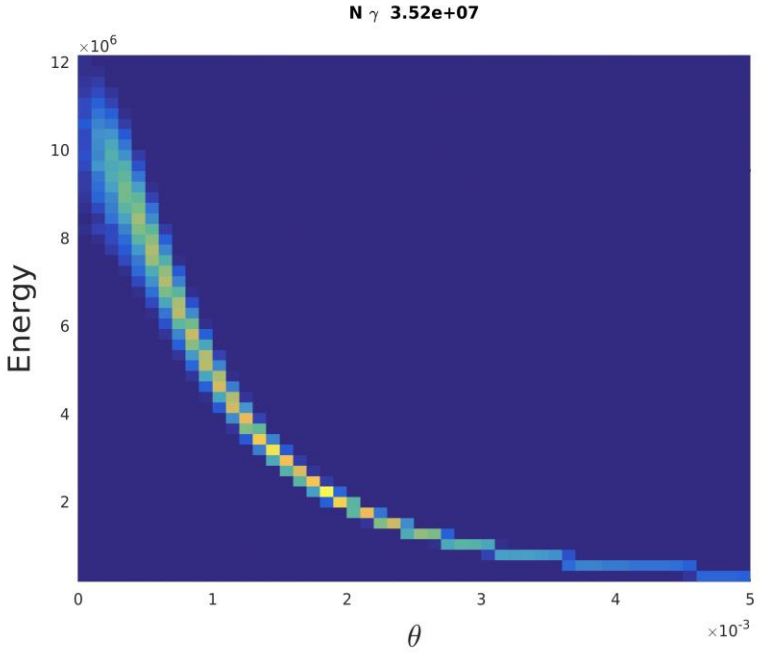




ROSE code

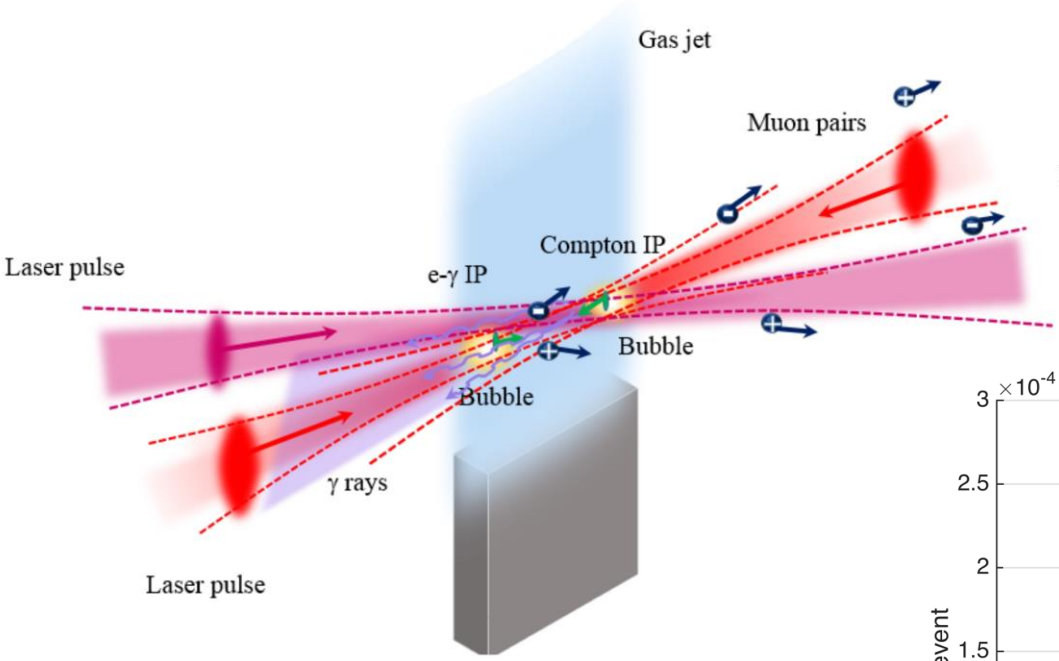


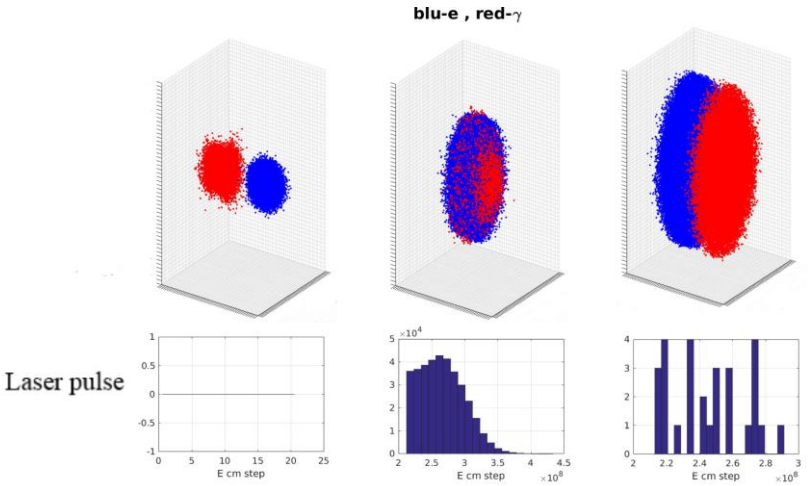


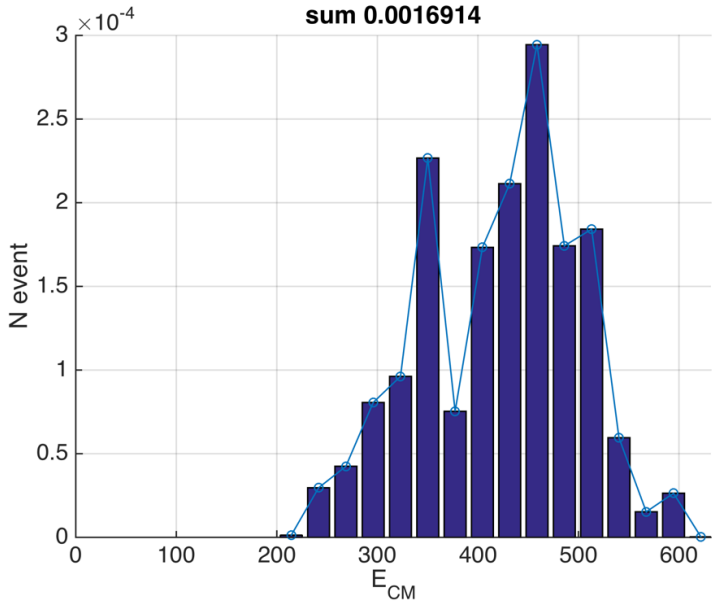


A muon source based on plasma accelerators

In publishing now in NIMA
In arxiv.org/abs/1711.06022







Conclusions

- A design of a cascaded γ-γ collider based on conventional Compton gamma sources was presented for the first observation of the elusive *scattering of light by light*.

- Our code ROSE, developed *ad hoc*, allow a set of simulations of the γ-γ interactions, Breit-Wheeler ($\gamma\,\gamma \rightarrow e^- e^+$), scattering, Compton scattering ($e^-\gamma \rightarrow e^-\gamma$), Møller scattering ($e^-e^- \rightarrow e^-e^-$), triplet pair (TPP, $\gamma e^- \rightarrow e^-e^+e^-$), muon pair photo-production (MPP, $\gamma e^- \rightarrow e^-\mu^+\mu^-$) and allows evaluation of the event rate and energy-angular distributions of the scattered gammas and particles.

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- I. Drebot, A. Bacci, et al. "*Study of photon-photon scattering events*", Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 2016, ISSN 0168-9002, DOI: 10.1016/j.nima.2016.07.039.
- D. Micieli, I. Drebot, et al."*Compton sources for the observation of elastic photon-photon scattering events*", Phys. Rev. Accel. Beams 19, 093401, September 2016
- L. Serafini, I. Drebot, et al. “A muon source based on plasma accelerators”. arXiv:1711.06022

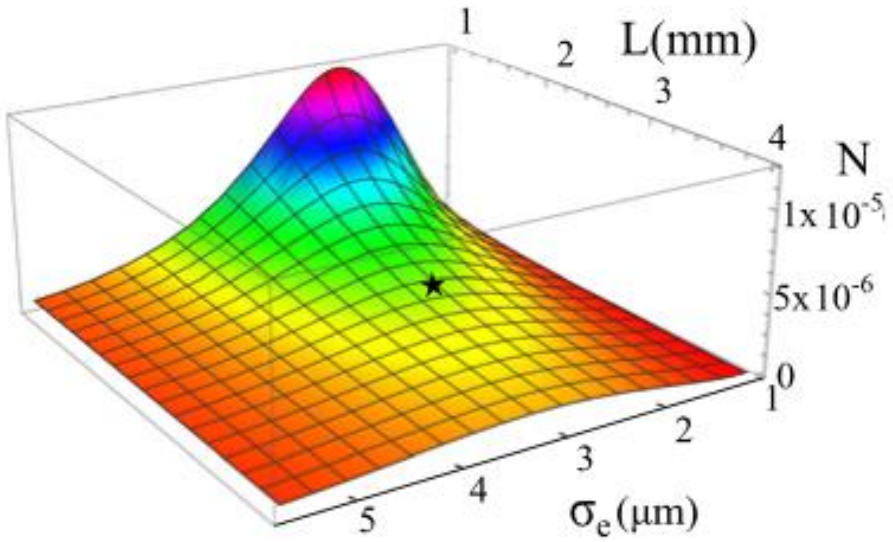

FIG. 5. Single shot number of events N as function of the rms transverse dimension of the electrons and of the distance L between Compton and $\gamma\gamma$ IP.

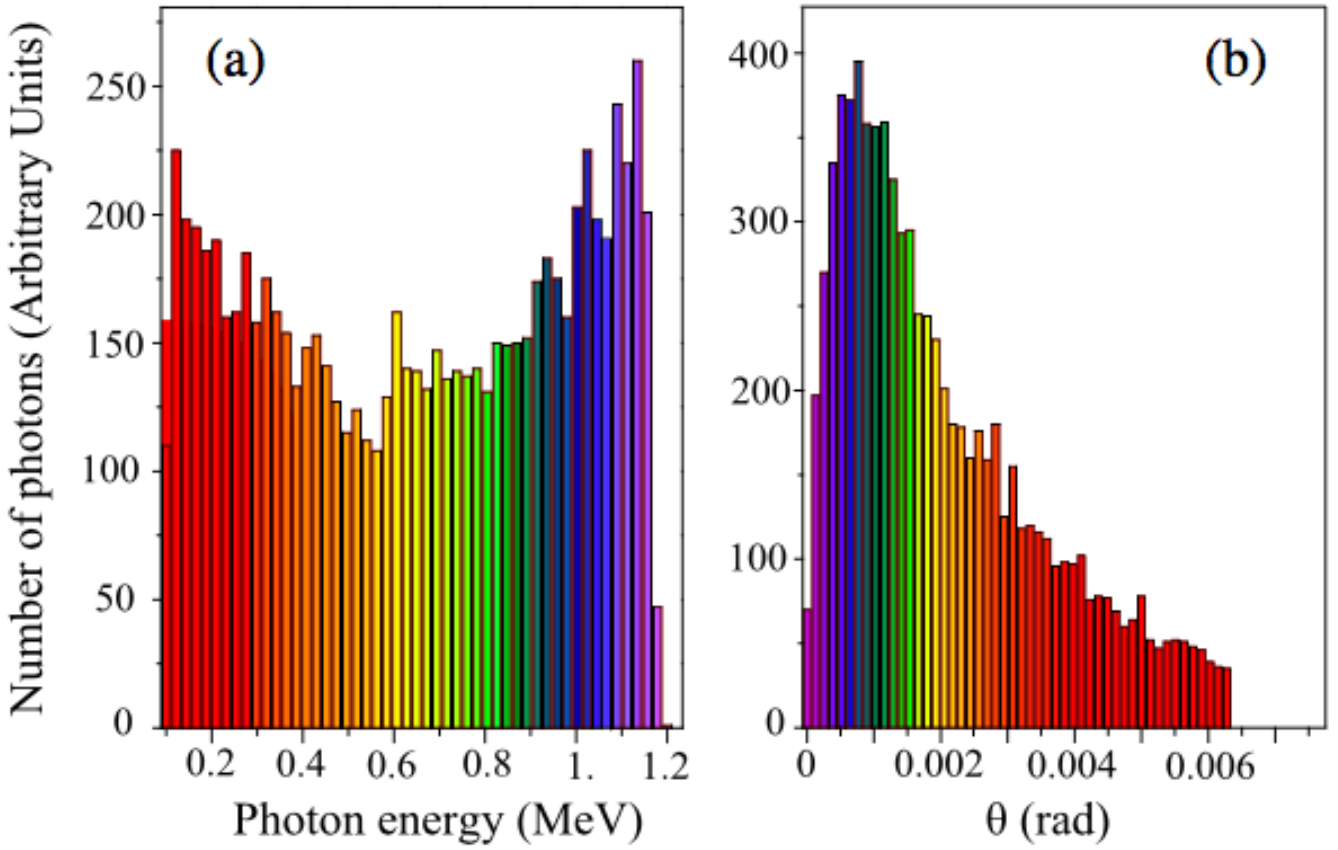

FIG. 4. Spectrum of the radiation (a) and angular distribution (b). Similar colors code similar groups of photons.

Outline

1. Kinematics and cross-section
2. Scheme and layout
3. Simulations ROSE code
4. Result