Simulations on Pair Creation in Collisions of γ-Beams Produced with High Intensity Lasers

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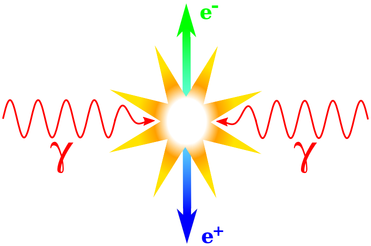
Overview

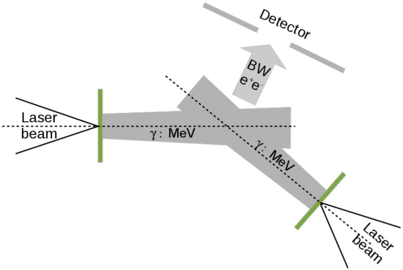
The linear Breit-Wheeler process, recently in focus of astrophysics[1], has not been observed in a laboratory, yet.



A promising experiment and a new simulation method aim to help investigating the process in lab conditions.

[1] T. Piran, Rev. Mod Phys, **76**, 1143 (2004)
R. Ruffini *et al.*, Physics Reports **487**, 1-140 (2010)

A possible realisation of the experiment includes two γ beam sources, spatially separated.
The best possible sources seem to be laser-matter interaction[1].



[1] X.Ribeyre, E. d'Humières, O. Jansen, S. Jequier, V.T. Tikhonchuk, PRE **93**, 013201 (2016)

What are the optimal parameters for the sources?

Where and how large should the detectors be?

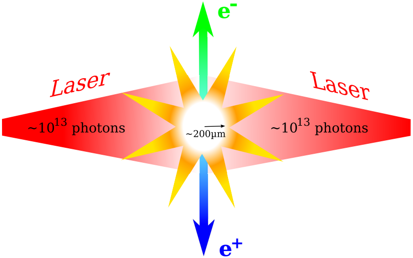
What is the number of created pairs ($\rightarrow$ theory)?

Where should the optimal interaction volume be?

Simulations can help to verify theoretical predictions and add details to certain answers.
PIC simulations are well enough suited for the sources.
Beam interaction would be challenging, though.

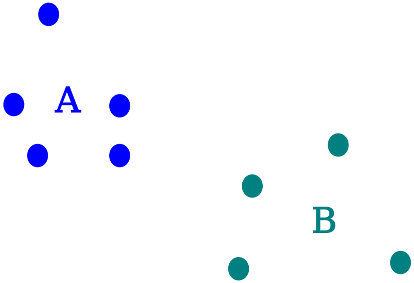
Simulation Code

Depending on the exact geometry, the simulation domain can be much larger than the interaction volume, leaving most of the particles in a few cells of a PIC simulation.



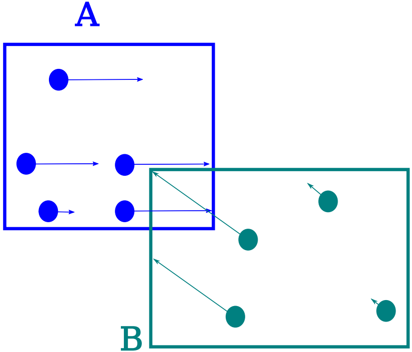
Collision detections among N particles leads to N^2 queries. Even for $N = 10^6$ this would be unacceptable.

We would like to present, for the special case of photon collisions, a novel approach to handle collision detections of large number of particles in 3D, .

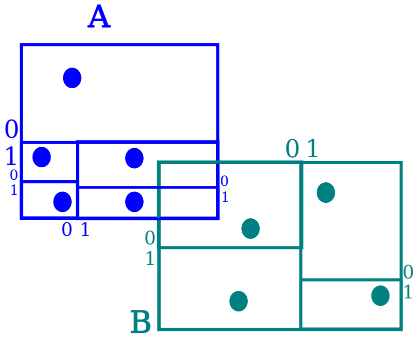


Two groups of particles are about to collide. 5×4 queries are needed to test all possible collisions between the two groups or 9^2 between all particles individually.

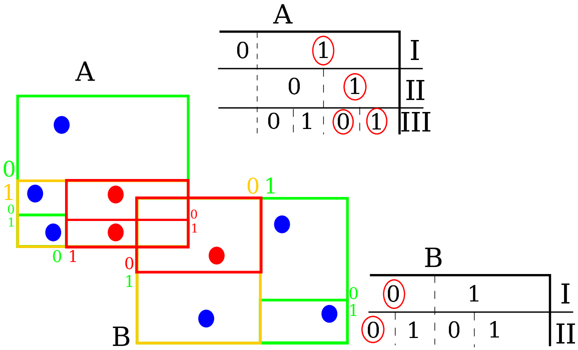
First, we encapsulate both groups with *Bounding Volumes*. This is because particles of one group move more or less parallel and therefore, will not collide with each other.



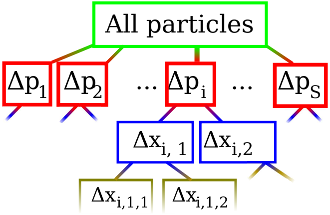
Next, we subdivide both groups into smaller BVs in order to reduce the number of particle per BV. This is similar to the attempt to have a small number of particles per cell equally shared among all cells in a PIC simulation.



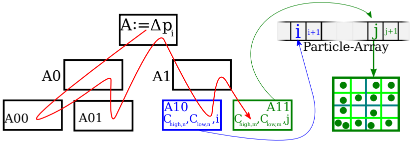
Subdividing the BVs creates a hierarchy structure. Traversing this structure according to overlaps reveals, which BVs actually overlap and hence, which particles might collide.



Partitioning phase space gives a tree hierarchy for all particles.



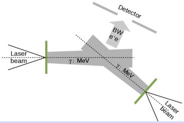
Furthermore, combining real photons into macro-particles enables nested hierarchies or purely statistical collisions.



The Breit-Wheeler Process

Defining "parallel moving groups" by the strict condition

$$E_{\gamma 1} E_{\gamma 2} \geq \frac{2\mathrm{m}_e^2 c^4}{1 - \cos\phi}$$



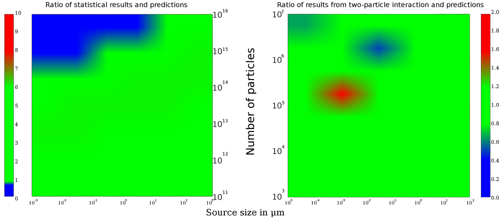
and the total cross-section[1] for a two-particle collision by

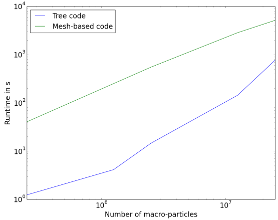
$$\sigma_{\gamma\gamma} = \frac{\pi}{2} r_e^2 (1 - \beta) \left[-2\beta(\beta - \beta^2) + (3 - \beta^4) \ln\left(\frac{1 + \beta}{1 - \beta} \right) \right]$$

enables us to have a detailed analysis of the Breit-Wheeler process.

[1] $\beta = \sqrt{1 - 1/s},\ s = E_{\gamma 1} E_{\gamma 2} (1 - \cos\phi)/(2\mathrm{m}_e^2 c^4)$

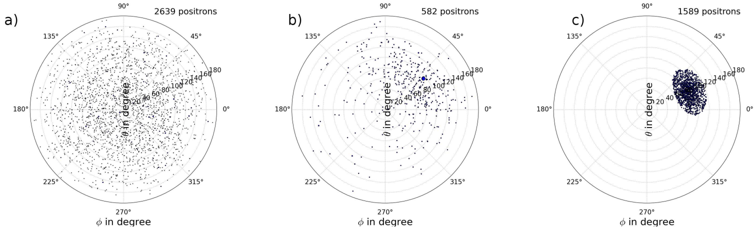
The results from the simulations agree well with analytical predictions, both in the statistical picture (large number of particles) as well as in the detailed description.





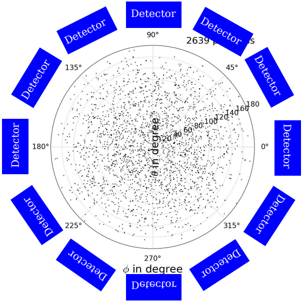
The performance of the tree code exceeded the one of the mesh-based code by far.

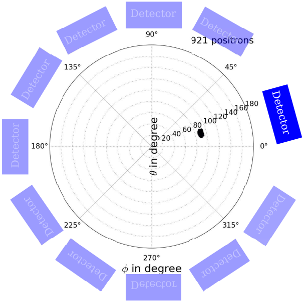
First results suggest, that the angle between the two beams can be used to collimate the created pairs.
a) $\Delta\phi = 180°$, b) $\Delta\phi = 90°$, c) $\Delta\phi = 45°$.



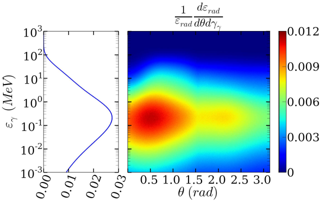
We used optimistic, but realistic parameters: $\gamma_{photons} = 4$ and $N_{photons} = 2.5 \times 10^{13}$ (equivalent to a $8J$ beam), source radius of $R = 2\mu m$ and divergence $= 20°$:

Best results so far with $\Delta\phi = 30°$. Electrons **and** positrons are well collimated.





The next step is to use profiles of realistic sources (Bremsstrahlung, synchrotron,...) in our simulations.



Conclusions

We developed a new simulation code in order to deal with collisions between large numbers of photons ($\rightarrow$ Breit-Wheeler process).

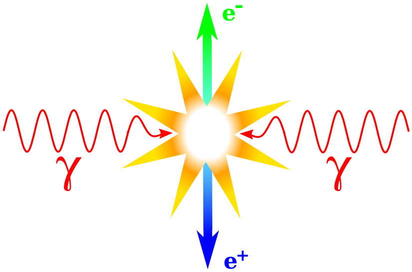
This tree code can easily achieve significantly shorter run-times than mash-based codes with the same accuracy.

Analytical predictions about the Breit-Wheeler process are in good agreement with simulation results.

Moreover, simulations already give first indications on how to optimise the set-up of an experiment on the Breit-Wheeler process.

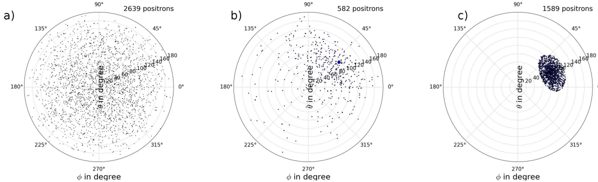
The use of results from PIC simulations in order to investigate radiation from realistic sources is about to commence.

Thank you for your time!



Always keep in mind:
Paris is for (particle) pairs!

The reason for the difference in the number of created pairs in the case of $\Delta\phi_b = 90°$, $\Delta\phi_c = 135°$ and $\Delta\phi_c = 45°$ is challenging to handle analytically.



Different angles not only lead to different interaction volumes, but also, depending on co- or counter-propagating beams, to different interaction times.