Contribution ID: **51** Type: **not specified**

Charged particle detector for Breit-Wheeler pair-production experiments

Wednesday, January 29, 2020 6:25 PM (5 minutes)

We present a device for positron detection in the framework of quantum-electrodynamics (QED) laser experiments. This instrument is a crucial element of a large project aiming at demonstrating for the first time the creation of electron-positron pairs via the so-called Breit-Wheeler (BW) process in the laboratory. This QED phenomenon occurs when the collision of two high-energy photons gives rise to the creation of an electron and a positron [1]. The cross section of the BW process is in the order of 10-25 cm2, and the product of the photon energies must be above a threshold of 0.25 MeV2 in the optimal case of a head-on collision. In the proposed experimental scheme [2], the two necessarily intense gamma-ray sources are driven by ultra-high-intensity (UHI) laser pulses. Furthermore, the large gamma-ray flux being generated can also cause pair productions via other processes (Bethe-Heitler and multiphoton-collision) which are irrelevant in our study. In a nutshell, the small production of BW pairs, the typical electronic noise of UHI laser experiments and the "pollution"by other pair-production processes make the detection of BW pairs a highly challenging task.

To address the electronic noise issue, the instrument must be capable of segregating positrons from electrons. An appropriate design is the magnetic lens, it consists of an assembly of electromagnetic coils ordered so that the magnetic field lines form a quasi-circular loop. Iron cores can be placed within the coils for their magnetic susceptibility properties strengthening the field intensity. As a result, charged particles entering the device are deflected according to the polarity of their charge in- or outwards with respect to the optical axis, or line of sight. Moreover, magnetic lenses allow us for compensating the small pair production with large numerical apertures.

The next step towards detection consists in the conversion of particles into light signal for their monitoring on a camera device. We plan to address the parasitic pair production problem at this stage. We will realize a photon counting channel in a glass medium by utilizing the Cherenkov effect, whose assets are its short-lived nature and the linearity of its response. Then, the light signal is being conducted thanks to an optical fiber to a streak camera, performing a time-resolved detection. Overall, we will be able to know the energy of the detected positrons and when they were produced, which speaks whether they qualify or not for a BW origin. Furthermore, this method prevents from disruption due to electromagnetic pulses as the electronic parts can be set away from the laser interaction area.

We will present simple methods that help for dimensioning the instrument, from the physics laws that govern the magnetic lens optics to numerical tools that simulate its behavior. We have also performed measurements on a prototype, and we will discuss the results.

This project is supported by the French National Research Agency (Nr. ANR-17-CE30-0033 –Project Leader: Xavier Ribeyre).

[1] Breit, G., and J. A. Wheeler. "Collision of two light quanta." Physical Review 46.12 (1934): 1087.
[2] Ribeyre, X., et al. "Pair creation in collision of γ-ray beams produced with high-intensity lasers." Physical Review E 93.1 (2016): 013201.

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Session Classification: Poster Session