7th Asia-Pacific Conference on Plasma Physics, 12-17 Nov, 2023 at Port Messe Nagoya

Experimental studies on the electron acceleration and positron generation in the interaction of Petawatt femtosecond lasers with gas targets

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The invention and application of the chirped pulse amplification technique in short-pulse lasers has led to unprecedented ultra-high laser peak powers. After more than three decades of development, petawatt (10^{15}W) class lasers, with pulse durations varying from a few femtoseconds to several picoseconds, have been constructed around the world. These ultra-high power lasers have many applications, such as high-energy ion acceleration, laser-driven electron acceleration, ultrafast x-rays, and fast ignition.

In 2016, the construction of the ultrahigh-power laser facility, SILEX-II, of 4.9PW power and 18.6fs duration, was completed in Laser Fusion Research Center, China Academy of Engineering Physics [1]. Due to the employment of the complete optical parametric chirped-pulse amplification (OPCPA) technique, the SILEX-II laser has both high peak power and high temporal contrast, thus providing a good experimental platform for studying ultra-intense laser plasma physics.

A commissioning experiment was firstly conducted on the SILEX-II laser facility with a peak power of about 1PW and duration of 30fs [2]. A set of comprehensive diagnostics were set up in order to infer the on-target laser spot size, laser intensity, and prepulse level of the SILEX-II laser. The experimental results suggest that the laser can reach an intensity of 5×10^{20}W/cm^2 with a focus of 5.8μm (FWHM). The relativistic transparency is observed to occur for a foil thickness of 20 nm, indicating that the laser also has a high temporal contrast. The maximum proton energy obtained was about 21 MeV.

We have also performed the experimental studies of electron acceleration and positron generation on the SILEX-II laser facility [3]. It is observed that MeV electrons with a high charge of several tens of nC can be well generated from petawatt femtosecond laser interacting with a high-density gas jet. Furthermore it is found that the existence of the gas density down-ramp region is detrimental to the propagation of the high-charge electron beam. This is because an electrostatic potential will build up in the density down-ramp region, thus refluxing the energetic electrons. This effect is clearly unfavorable to the production of secondary particles. Consequently, by using an integrated nozzle-converter design to eliminate the density falling ramp of the gas target such that the electron refluxing is inhibited, we demonstrate a significant enhancement of positron yield (up to a factor of 15), finally reaching a positron yield of 5×10^8sr^{-1}.

References

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[2] W. Hong *et al.*, Matter Radiat. Extremes 6, 064401 (2021).
[3] Z. M. Zhang *et al.*, Plasma Phys. Control. Fusion 64, 095015 (2022).

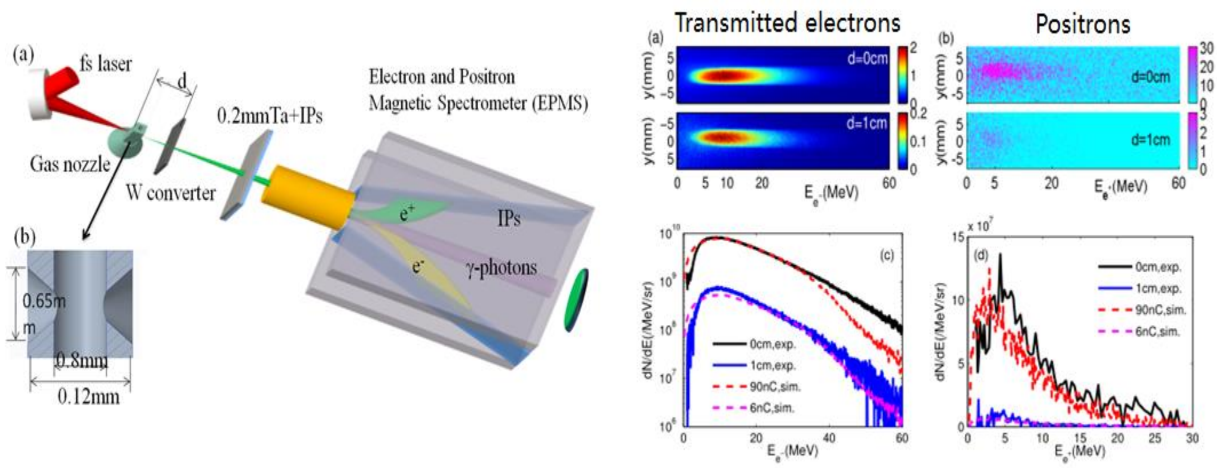

Figure 1 Experimental setup (left) and the experimental results of the transmitted electrons and positrons generated from two different gas-converter target configurations, which indicate that the positron yield is greatly inhibited due to the electron refluxing in the gas density down-ramp region.