9th Asia-Pacific Conference on Plasma Physics, 21-26 Sep, 2025 at Fukuoka

Laser wakefield based axion-like particle generation and detection

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Axion is a hypothetical pseudoscalar particle proposed to resolve the strong CP problem[1-5]. More generally, axion-like particles (ALPs) offer a natural extension to the Standard Model, with their coupling ($g_{a\gamma\gamma}$) to photons inversely related to their mass. Beyond solving fundamental particle physics puzzles, axions are also predicted to permeate the universe as the cold dark matter, driving extensive experimental efforts to detect their feeble interactions with electromagnetic fields.

Conventional axion searches rely on electromagnetic coupling effects. Haloscope experiments exploit resonant cavities to convert galactic axions into microwave photons under strong magnetic fields, while helioscopes aim to detect solar axions via X-ray production in magnetic setups. Laboratory-based approaches, such as "light shining through wall" (LSW) experiments, employ lasers and magnetic fields to generate axions, which subsequently traverse a barrier and reconvert into detectable photons. Polarization-based methods, including vacuum birefringence measurements (e.g., PVLAS), further probe axion-induced modifications to photon propagation. However, these techniques face critical challenges that the axion-photon coupling is extraordinarily weak, demanding extreme laser and magnetic field strength and interaction length to achieve detectable signals.

In recent years, the ultrashort ultraintense laser development has made significant advancement on the laser plasma based particle acceleration. The plasma wave carries very intense electric and magnetic fields, which is not only useful for particle acceleration, but also for other applications. In this talk, we propose a laser-plasma wakefield based schemes for in situ axion generation and detection through the Primakoff process. We use the particle-in-cell code with integrated axion electrodynamics [6, 7] to numerically prove the scheme of in situ axion generation and conversion. Strong electromagnetic fields ($\gtrsim 10^9$ V/cm) in the wakefield can enhance axion production rates by 2 orders of magnitude compared to conventional LSW experiments. By replacing the axion generation stage with laser-wakefield interaction and a currently feasible interaction length of laser-wakefield interaction, the axion-photon coupling constraints can achieve the level of $g_{a\gamma\gamma} \sim 10^{-12}$ GeV^{-1}. Besides, the generated axions can convert back into photons in the background fields, leading to axion-regenerated electromagnetic fields (AREM) with unique polarization, frequency, and transverse modes. This provides a new scheme to search axions by detecting the filtered AREM fields from the background laser and plasma fields.

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