Brilliant gamma-ray emission driven by laser and electron beams in plasma

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Currently, the photon energy from from synchrotrons and XFELs is generally limited to the range of a few keV to hundreds of keV. There is a huge demand and significant interest in developing compact radiation sources and extending photon energy to well beyond MeV with high efficiency and high brilliance. In the past three decades, plasma-based accelerators driven by either intense laser pulses or high-energy particle beams are being developed as compact accelerators and x/gamma-ray sources [1]. The x-ray emission is produced either via betatron radiation, nonlinear Thomson, or inverse Compton scattering. So far, the photon energy obtained via the betatron radiation is limited to the level of a few keV to hundreds of keV, the peak brilliance is limited to the order of 10^{23} photons s^{-1} mm^{-2} $mrad^{-2}$ per 0.1% bandwidth (BW), and the energy conversion efficiency is generally on the order of 0.001%. For nonlinear Thomson and inverse Compton scattering, the peak brilliance and the energy conversion efficiency are also relatively low, even though this mechanism has the potential to produce gamma-rays above MeV. Gamma-rays can also be produced by bremsstrahlung of energetic electrons. However, these sources are normally subject to large divergence and large size, severely limiting their brilliance and efficiency. In this talk, some recent theoretical and numerical studies on brilliant gamma-ray emission driven by intense laser and electron beams in plasma will be presented.

Firstly, we numerically demonstrate an all-optical scheme to generate bright GeV γ-photon and positron beams with controllable angular momentum by use of two counter-propagating circularly-polarized lasers in a near-critical-density plasma [2]. The plasma acts as a ‘switching medium’, where the trapped electrons first obtain angular momentum from the drive laser pulse and then transfer it to the γ-photons via nonlinear Compton scattering. This opens up a promising to produce ultra-bright GeV γ-photons with desirable angular momentum for a wide range of scientific research and applications.

Secondly, a scheme to efficiently produce collimated ultrabright γ-ray beams with photon energies tunable up to GeV by focusing a multi-petawatt laser pulse into a two-stage wakefield accelerator [3]. This high-intensity laser enables efficient generation of a multi-GeV electron beam with a high density and tens-nC charge in the first stage. Subsequently, both the laser and electron beams enter into a higher-density plasma region in the second stage. Numerical simulations demonstrate that more than 10^{12} γ-ray photons/shot are produced with energy conversion efficiency above 10% for photons above 1 MeV, and the peak brilliance is above 10^{26} photons s^{-1} mm^{-2} $mrad^{-2}$ per 0.1% bandwidth at 1 MeV.

Finally, we have developed new schemes to generate γ -rays via collective interaction between high density electron beams with plasma targets. In one case, when an ultrarelativistic electron beam with nC charge incident onto a solid surface at grazing incidence, extreme high quasistatic magnetic fields up to the gigagauss level are induced by the background electron backflows at the target surface. Subsequently, the electron beam is strongly focused by such fields by over an order of magnitude to submicrometer diameter [4,5], and its density is increased beyond the solid density; the induced effective fields are high enough to trigger quantum electrodynamics (QED) effects. These result in the production of extremely brilliant dense γ -ray beams with photon energy reaching multi-GeV, where the electron-to-photon energy conversion efficiency can exceed 60%.

In another case, when injecting a GeV electron beam into a submillimeter plasma with an upramp density profile, violent beam pinching is found to occur rapidly. During this process, a burst of collimated gamma-rays is efficiently produced with photon energy up to GeV, energy conversion efficiency exceeding 30%, and peak brilliance exceeding 10^{28} photons s^{-1} mm^{-2} $mrad^{-2}$ per 0.1% bandwidth at 1 MeV. All of these are several orders of magnitude higher than existing gamma-ray sources.

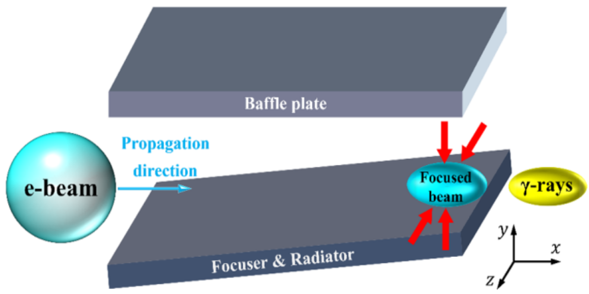

Figure 1. Schematic diagram to generate γ-rays by injecting a relativistic electron beam onto a solid surface at grazing incidence, where strong beam focusing and subsequent QED effects are triggered.

References

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