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Extremely bright GeV gamma-rays from laser-driven plasma accelerators

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Bright high-energy radiation sources have a wide range of applications from fundamental research to medical imaging and industrial radiography. At present, widely used synchrotrons and X-ray free-electron lasers (XFELs) can deliver X-ray pulses with peak brilliance in the range of $10^{19–24}$ and $10^{27–32}$ photons s^{-1} mm^{-2} $mrad^{-2}$ per 0.1% bandwidth (BW), respectively. However, they are normally limited to photon energies ranging from a few keV to hundreds of keV. In addition, the size and cost of these large facilities limit access to the sources.

Recent progress in laser-plasma accelerators has led to compact ultrashort X/γ-ray sources [1, 2] that can deliver peak brilliance comparable with synchrotron sources [3]. However, it is well known that a low-density plasma is beneficial for accelerating trapped electrons to high energies because the dephasing length scales as $1/n_e$, while strong betatron oscillations preferentially occur in a high-density plasma that can greatly enhance the energy of emitted photons. This contradiction seriously limits betatron radiation in the wakefield to photon numbers in the range $10^{7–8}$ and photon energy in the hundreds of keV range, limiting their wide applications.

To overcome these limitations, we propose a novel scheme to produce collimated beams of γ-rays with photon energies tunable up to GeV and peak brilliance reaching up to XFEL level, by using a multi-PW laser pulse in a two-stage wakefield accelerator [4] (see Fig. 1). This results in the efficient generation of a tens-nC multi-GeV electron beam in the first stage. Subsequently, both the laser and electron beams enter into a higher-density plasma region in the second stage, where high-energy photons are emitted when the energetic electrons interact with the highly intense quasi-static electromagnetic fields self-induced in this stage. More than 10^{12} γ-ray photons/shot are produced with energy efficiencies beyond 10% for photons above 1 MeV, and with unprecedented peak brilliance of over 10^{26} photons s^{-1} mm^{-2} $mrad^{-2}$ per 0.1% bandwidth at 1 MeV, as shown in Fig. 2. This makes them unique high-energy photon sources suitable for many applications and may offer the basis for future compact GeV photon colliders [5-9].

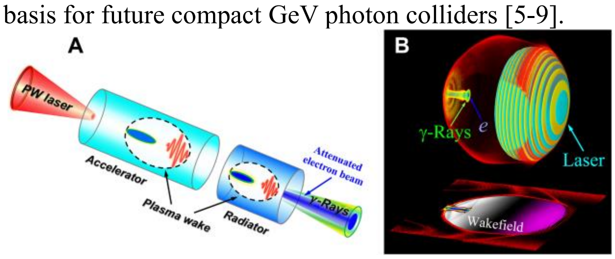

Fig. 1. (A) Schematic diagram of the two-stage scheme. (B) 3D view of the γ-ray radiation in laser-driven plasma wakefield using a 3D PIC simulation.

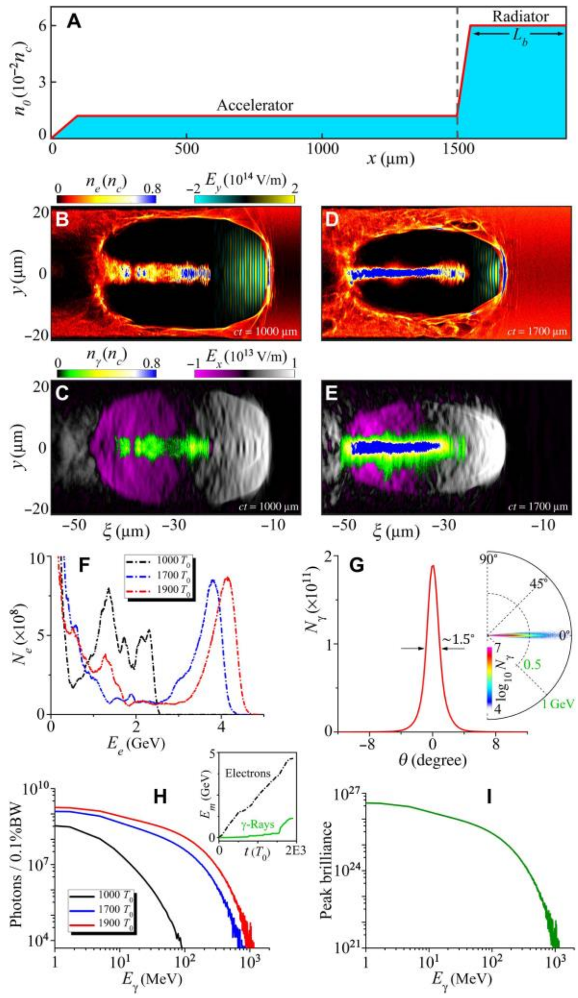

Fig. 2. The laser-plasma accelerator-radiator setup and 3D PIC simulation results.

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