Supplemental Material

Collimated ultrabright gamma rays from electron wiggling along a petawatt laser-irradiated wire in the QED regime

Wei-Min Wang, Zheng-Ming Sheng, Paul Gibbon, Li-Ming Chen, Yu-Tong Li, and Jie Zhang

Impacts of the misalignment between the wire and the laser

We performe a few additional simulations with different misalignment angles between the wire and the laser propagation direction, as shown in Fig. S1 below. The results show that if the misalignment can be controlled less than 3 degrees, the generated photons still have good directivity along the wire [Fig. S1(A)] and they have similar spectra to that in the case without misalignment [Fig. S1(B)]. The energy conversion efficiency also remains around 8%. However, with larger misalignment angles, e.g., 4 and 5 degrees, the efficiency is decreased to 5.5% and 3.6%, respectively, which corresponds to the spectra shown in Fig. S1(B). The reason is easy to understand. Misalignment causes that the laser interactions with the wire become weaker with the propagation distance. After a propagation distance of 5 Rayleigh lengths (22 μm) to the focusing plane, the displacement between the wire and the laser propagation axis reaches 1.15 μm (close to the laser spot radius) with a misalignment angle of 3 degrees (note that the displacment of misalignment at the focusing plane should be less than the laser spot radius). Therefore, the distance from the wire fore-end to the laser focusing plane could not be too large if the misalignment cannot be well controlled in experiments.

www.pnas.org/cgi/doi/10.1073/pnas.1809649115

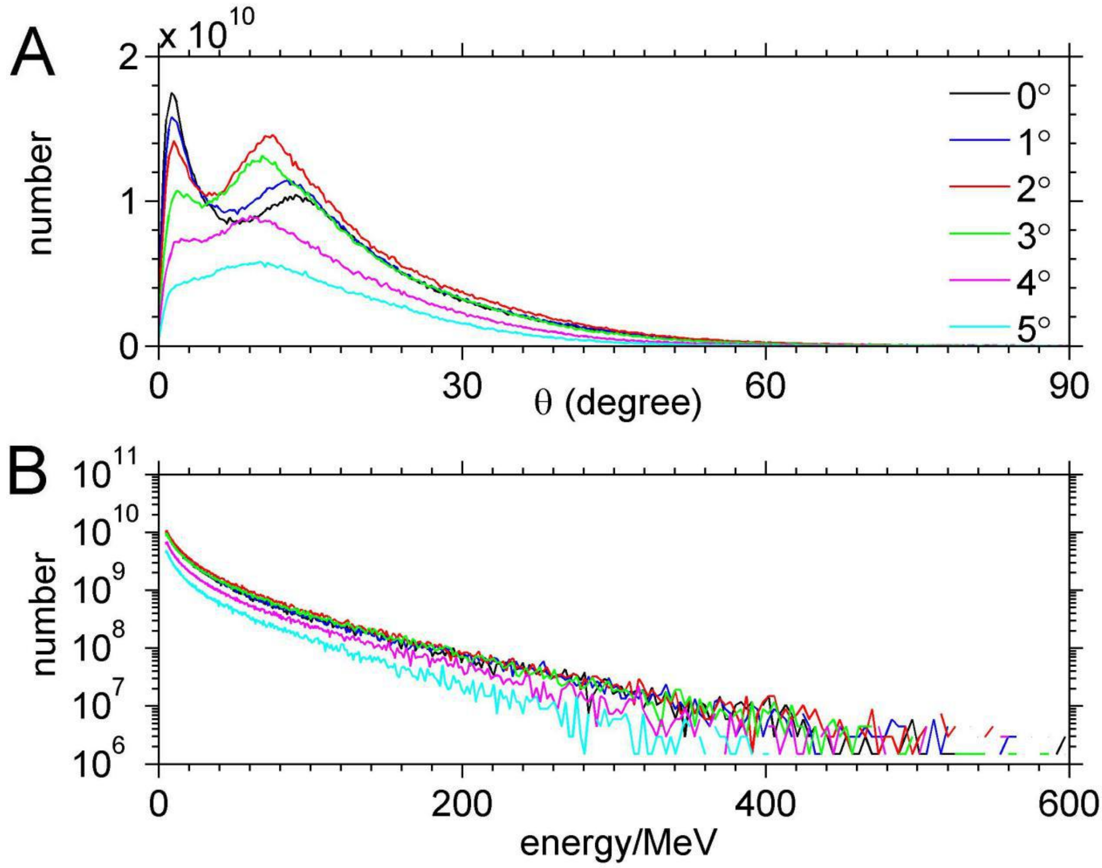

Fig. S1: (*A*) Angular distributions and (*B*) energy spectra of gamma-rays with different misalignment angles between the wire and the laser propagation direction, where the laser power is fixed at 2.5 PW and the wire width is fixed at 0.6 μm.

Trajectories and energy evolution of some electrons

In Fig. S2 we show the trajectories and energy evolution of some electrons selected randomly from those with energies >200 MeV and QED parameters χ>0.04 (they contribute to high-energy photon generation). Figure S2 (B) illustrates that these electrons gain energies >200 MeV at positions near the wire front, showing that their energies are increased as the laser pulse approaches to the focusing plane around x=26 μm. These elections contributing to high-energy photon emission should be mainly from the wire front and then they are trapped and accelerated at a suitable phase of the laser pulse as their speed approaches to light speed and they can move with the laser together.

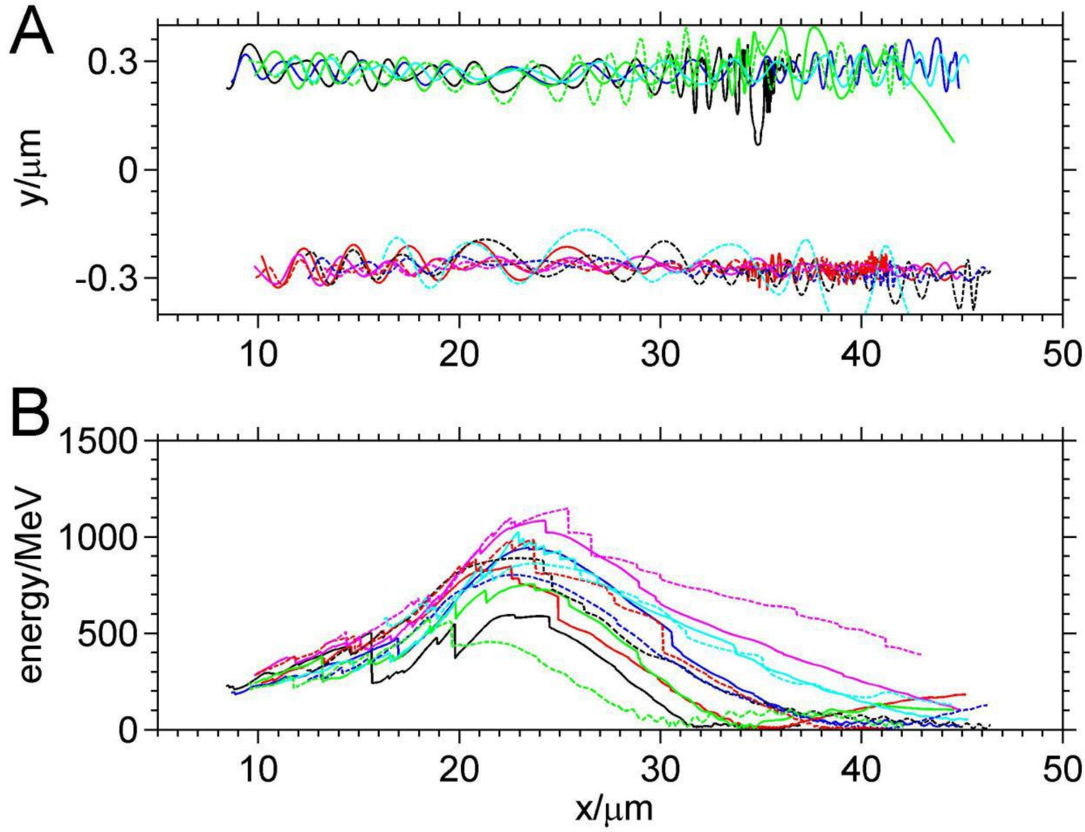

Fig. S2: Selected electron trajectories in the xy plane and their energy evolution along the wire obtained from our simulation, where the laser power is 2.5 PW and the wire width is 0.6μm.

Gamma-ray spectrum evolution with time

Figure S3 shows the gamma-ray spectrum evolution. The spectra appear similar after the time of 35 τ_0 when the laser pulse has passed the laser focusing plane.

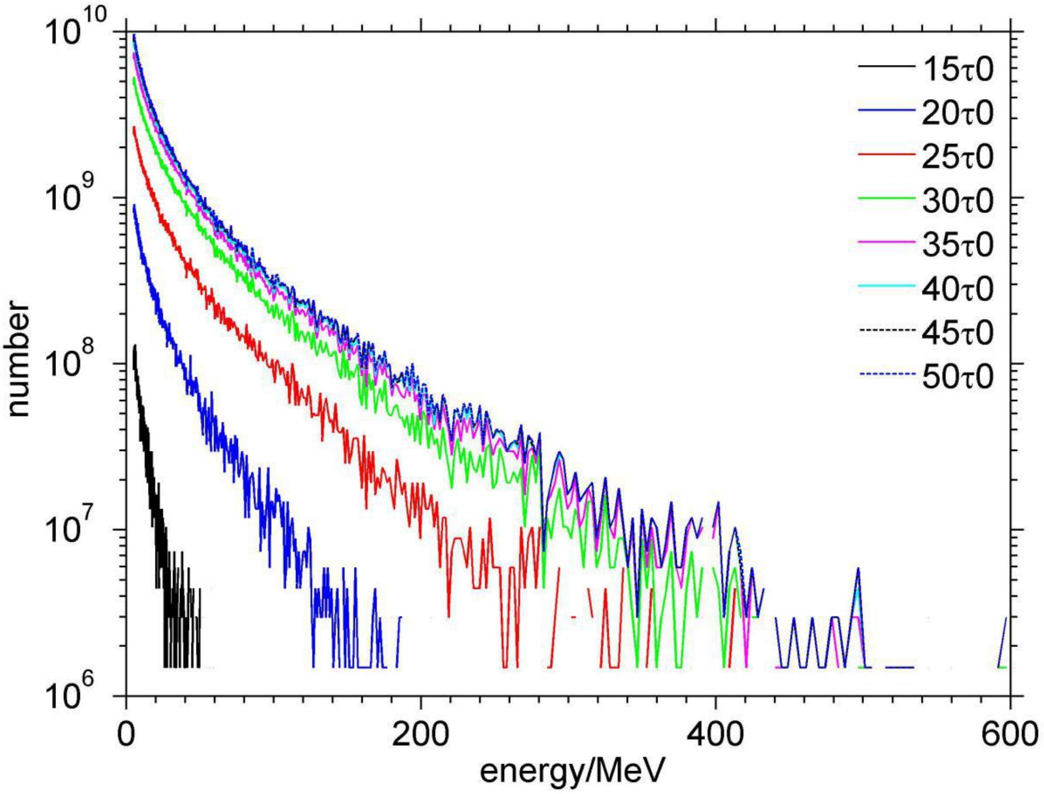

Fig. S3: Energy spectra of gamma-rays at different times, where the laser power is 2.5 PW and the wire width is 0.6 μm.

Impacts of the laser duration

We perform a few additional simulations with different laser durations of 20 fs, 30 fs, 40 fs, and 50 fs while keeping the peak laser intensity [note the duration is taken as 20 fs in our original manuscript], as shown in Fig. S4. From Fig. S4 (B), one can see the maximum energy of the photons slightly enhances with the laser duration while the photon number obviously grows. The number is 1: 2.03: 3.23: 4.55 with the durations of 20 fs, 30 fs, 40 fs, and 50 fs, which shows a roughly linear scaling. The enhanced duration results in the increase of the laser depletion length or the laser wire interaction zone, which can explain the photon number growth. On the other hand, we do not observe significant enhancement of the peak laser intensity and the maximum electron energy around the focusing plane when increasing the duration. Basically, the peak laser intensity determines electron energies and the QED parameters of electrons around the focusing plane, where the strongest radiation occurs and the photons with the maximum energies are generated. This can explains why the maximum photon energy just slightly enhances with the laser duration, as shown in Fig. S4 (B).

According to the results above, we expect that a longer wire is required to generate more photons if a longer pulse is taken [when the misalignment between the wire and the laser is ignored]. However, to achieve higher-energy photons, the laser intensity should be enhanced, rather than the laser duration.

For a given laser energy, is it better to have higher intensity or longer pulse duration? The photon number scales roughly linearly with the duration, as presented above. According to Eq. [5], the number roughly scales with $I_0^{3/2}$. One can expect that it is better to have higher laser intensity than longer duration to generate more photons The photon energy roughly scales with I_0 according to Eq. [4] while it slightly depends on the laser duration. Therefore, it is better to have higher laser intensity than longer duration for higher photon energy.

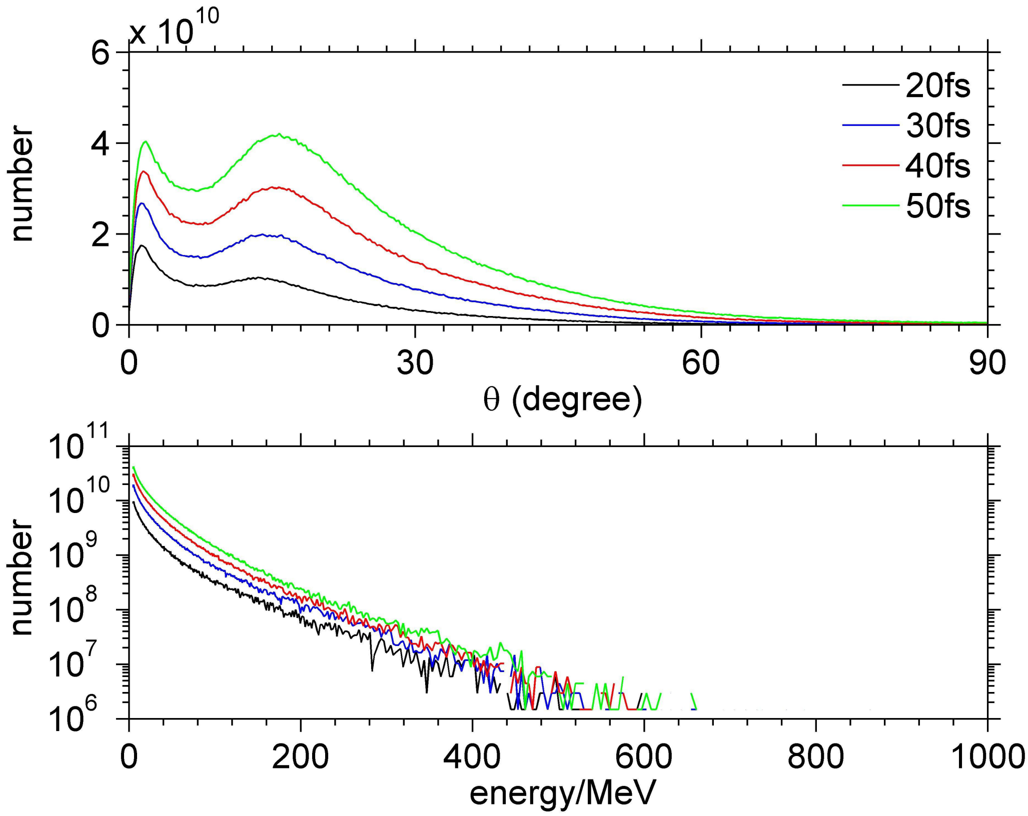

Fig. S4: (*A*) Angular distributions and (*B*) energy spectra of gamma-rays with different laser pulse durations at 20, 30, 40, and 50 fs, where the laser intensity is fixed and the wire width is fixed at 0.6 μm.

Impacts of the laser spot radius

Finally, we also perform a simulation with an increased laser spot radius r_0. When r_0 is increased to 2.4 μm (10 PW) from 1.2 μm (2.5 PW), the generated photons still have good directivity as observed in Fig. S5 (A). The maximum and average energy is enhanced but not so significantly, as shown in Fig. S5(B). The photon number is enhanced by 5.3 times and energy conversion efficiency is 11%. These values suggest that our wire scheme still works with the laser spot size much larger than the wire size.

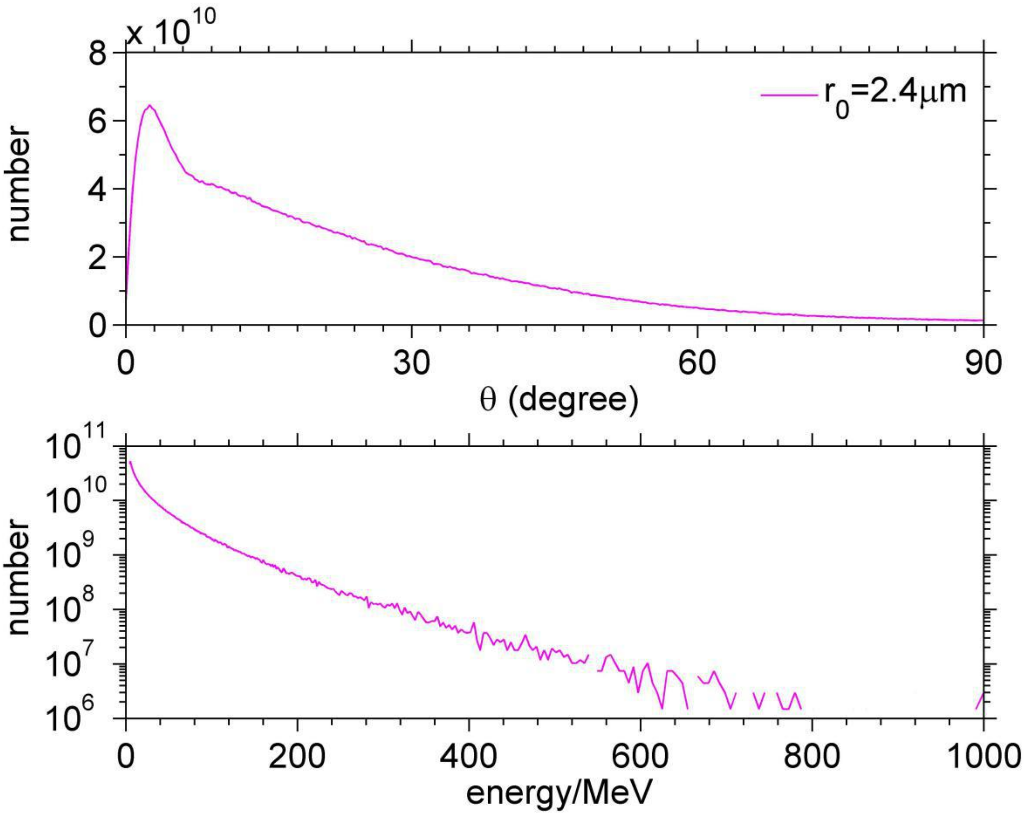

Fig. S5: (*A*) Angular distribution and (*B*) energy spectrum of gamma-rays with the laser spot radius r_0=2.4 μm and pulse duration of 20 fs.