Radiation Reaction of Electrons at Laser Intensities up to 10^{25} W/cm^2

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Summary

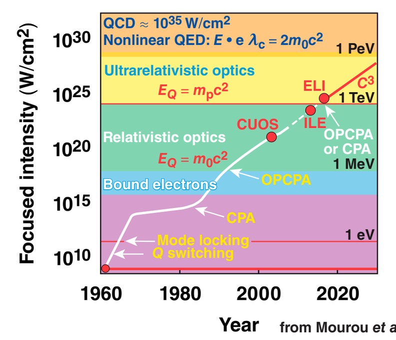
The radiation-reaction force can significantly alter electron trajectories at laser intensities above 10^{23} W/cm^2

The effects of the radiation-reaction (RR) force have been simulated for two scenarios

- Highly charged ion scenario
  - little difference with and without RR
- Counter-propagating electron-beam scenario
  - significant difference with and without RR

TC12751

Proposed laser developments promise to deliver ultrahigh laser intensities above 10^{23} W/cm^2



from Mourou *et al.***

CPA: chirped-pulse amplification
OPCPA: optical parametric chirped-pulse amplification
CUOS: Center for Ultrafast Optical Science, University of Michigan
ILE: Institute of Laser Engineering, University of Osaka
ELI: Extreme Light Infrastructure (Europe)
QED: quantum electrodynamics
QCD: quantum chromodynamics

- OMEGA EP optical parametric amplifier line (OPAL)*
  - pulse energy: $E = 1.6$ kJ
  - pulse duration: $\tau = 20$ fs
  - wavelength: $\lambda = 910$ nm
  - focused intensity: $I = 10^{24}$ W/cm^2
- ELI and beyond**
  - pulse energy: $E = 10$ kJ
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  - wavelength: $\lambda = 1250$ nm
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*D. D. Meyerhofer *et al.*, presented at the 56th Annual Meeting of the APS Division of Plasma Physics, New Orleans, LA, 27–31 October 2014.
**G. A. Mourou *et al.*, Opt. Commun. 285, 720 (2012).

I2205a

Electron trajectories were calculated using the relativistic equation of motion including the radiation-reaction force

$$dp/dt = -e\left(E_L + E_C + p \times B_L / m_e \gamma c\right) + F_{RR}$$

Coulomb field if present

The radiation-reaction force* is given by

$$F_{RR} \cong -\left(2e^4 / 3m_e^2 c^5\right)\gamma^2 v\left[\left(E + v \times B/c\right)^2 - \left(E \cdot v\right)^2 / c^2\right]$$

A fifth-order expansion of Maxwell's equations was used for the focused laser field (E_L, B_L)**

*L. D. Landau and E. M. Lifshitz, in The Classical Theory of Fields, 3rd rev. ed. (Pergamon Press, Oxford, 1971), Vol. 2, Chap. 9, pp. 170–224.
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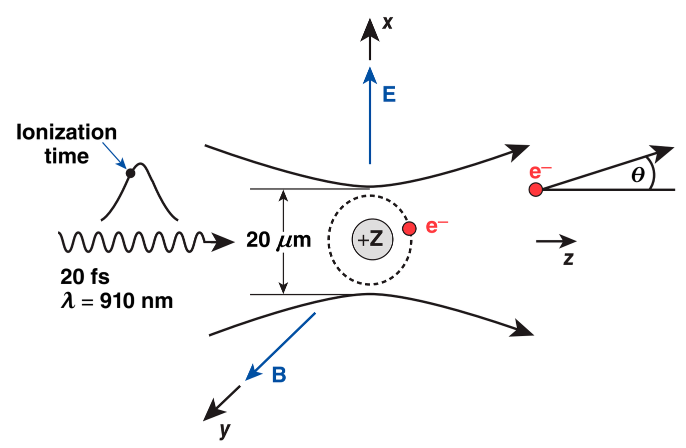
TC12752

Abstract

Recent developments in high-power laser technology make focused laser intensities from 10^{22} W/cm^2 to 10^{25} W/cm^2 feasible in the near future, opening up the study of the superintense laser acceleration of electrons to tens of GeV energies. Previous work on this subject has not accounted for the radiation-reaction force, which is the recoil force caused by the electromagnetic radiation emitted by an accelerating charged particle. In this work, two possible scenarios (an electron originally bound in a highly charged ion and a counter-propagating 1-GeV electron pulse) were simulated. In the first scenario, little difference was found between simulations with and without the radiation-reaction force. In contrast, the second scenario, involving the counter-propagating 1-GeV electron pulse, showed the electrons losing significant amounts of energy when the radiation-reaction force was taken into account.

Highly Charged Ion

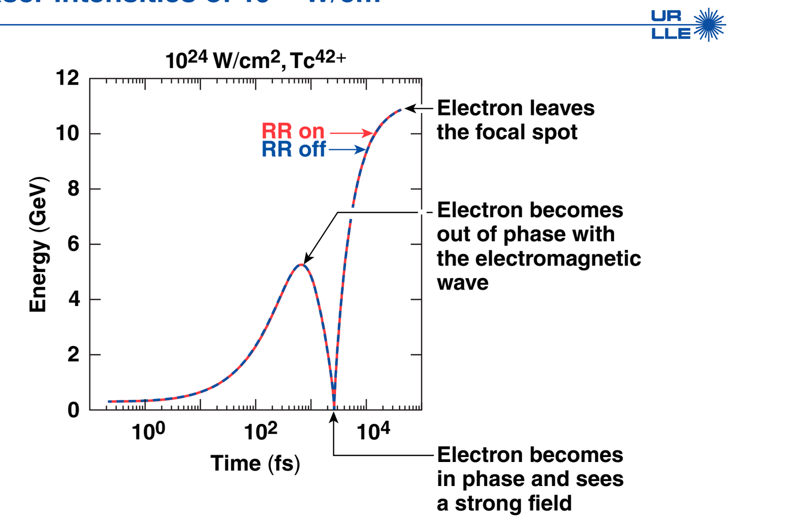
The electron stays bound to the highly charged ion until the laser pulse reaches its peak intensity



- The electron also experiences the Coulomb force of the ion

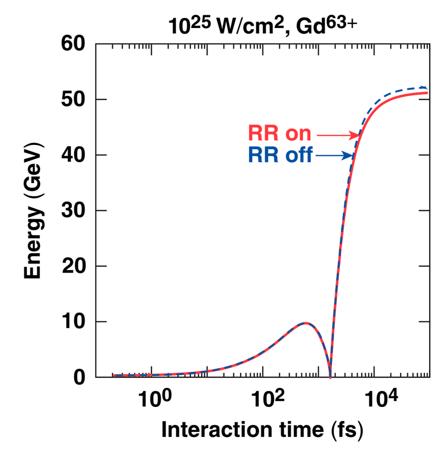
TC12753

Single-trajectory simulations of electron accelerations from highly charged ions show little difference even at laser intensities of 10^{24} W/cm^2



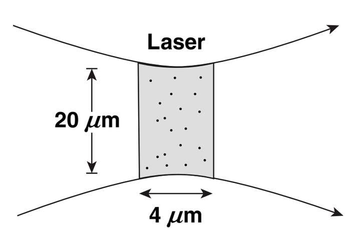
TC12754

The radiation-reaction effects are just noticeable at 10^{25} W/cm^2

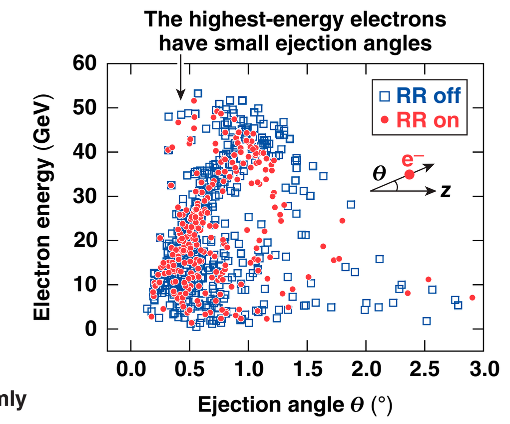


TC12755

Monte Carlo simulations at 10^{25} W/cm^2 also show little difference when radiation reaction is included



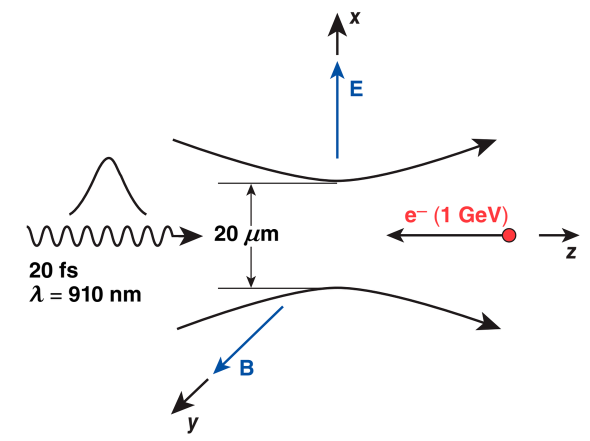
- The ions are located randomly in the shaded area



TC12756

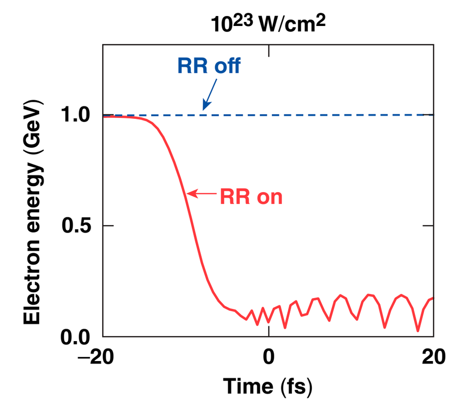
Counterpropagating Electron Beam

A 1-GeV beam of electrons is aimed to meet the peak of the laser pulse at $z = 0$



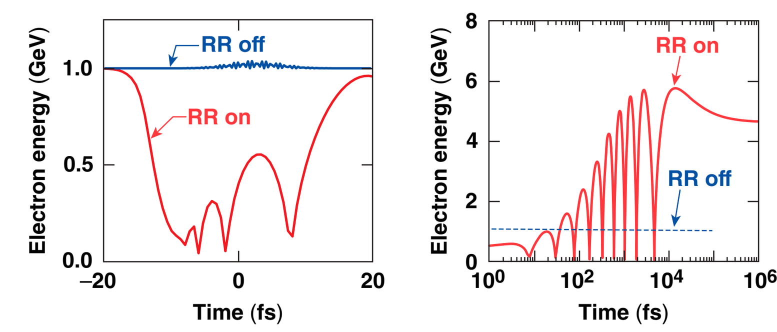
TC12757

Single-trajectory simulations show significant differences at 10^{23} W/cm^2 with or without radiation reaction



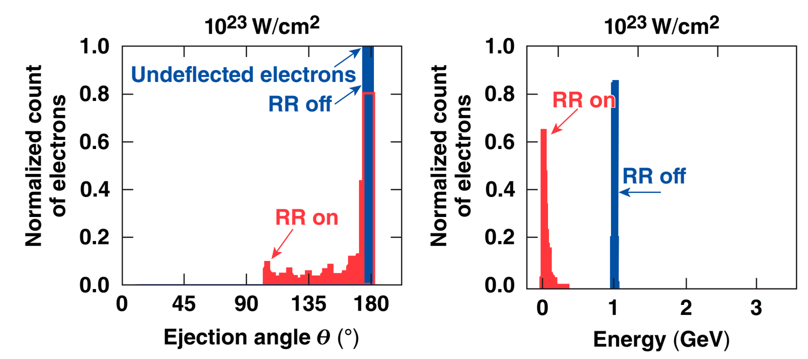
TC12758

The electron is turned around and reaccelerated at 10^{24} W/cm^2 with radiation reaction included



TC12759

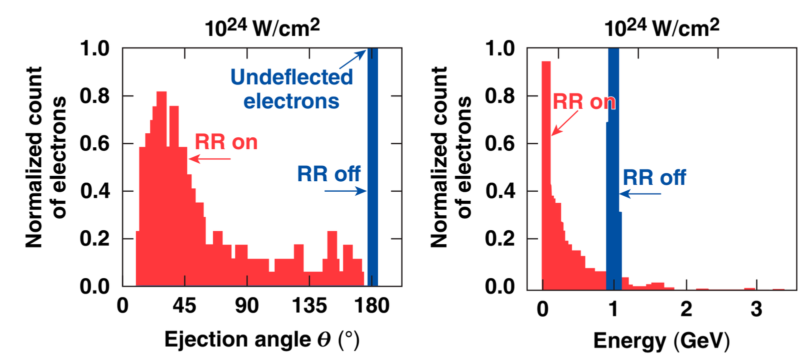
Monte Carlo simulations at 10^{23} W/cm^2 with radiation reaction show the scattering of electrons



- The electrons were chosen to meet the peak of the laser pulse at random points within the same 20×4-μm region
- The electrons were also given a 2% momentum spread in the z direction

TC12760

Most electrons are turned around at 10^{24} W/cm^2



TC12761

UNIVERSITY of ROCHESTER

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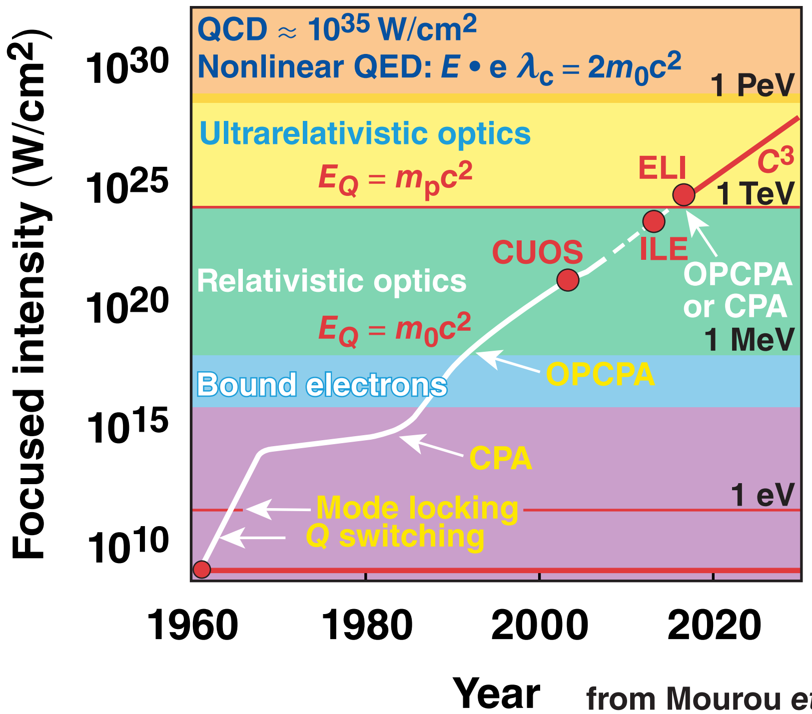

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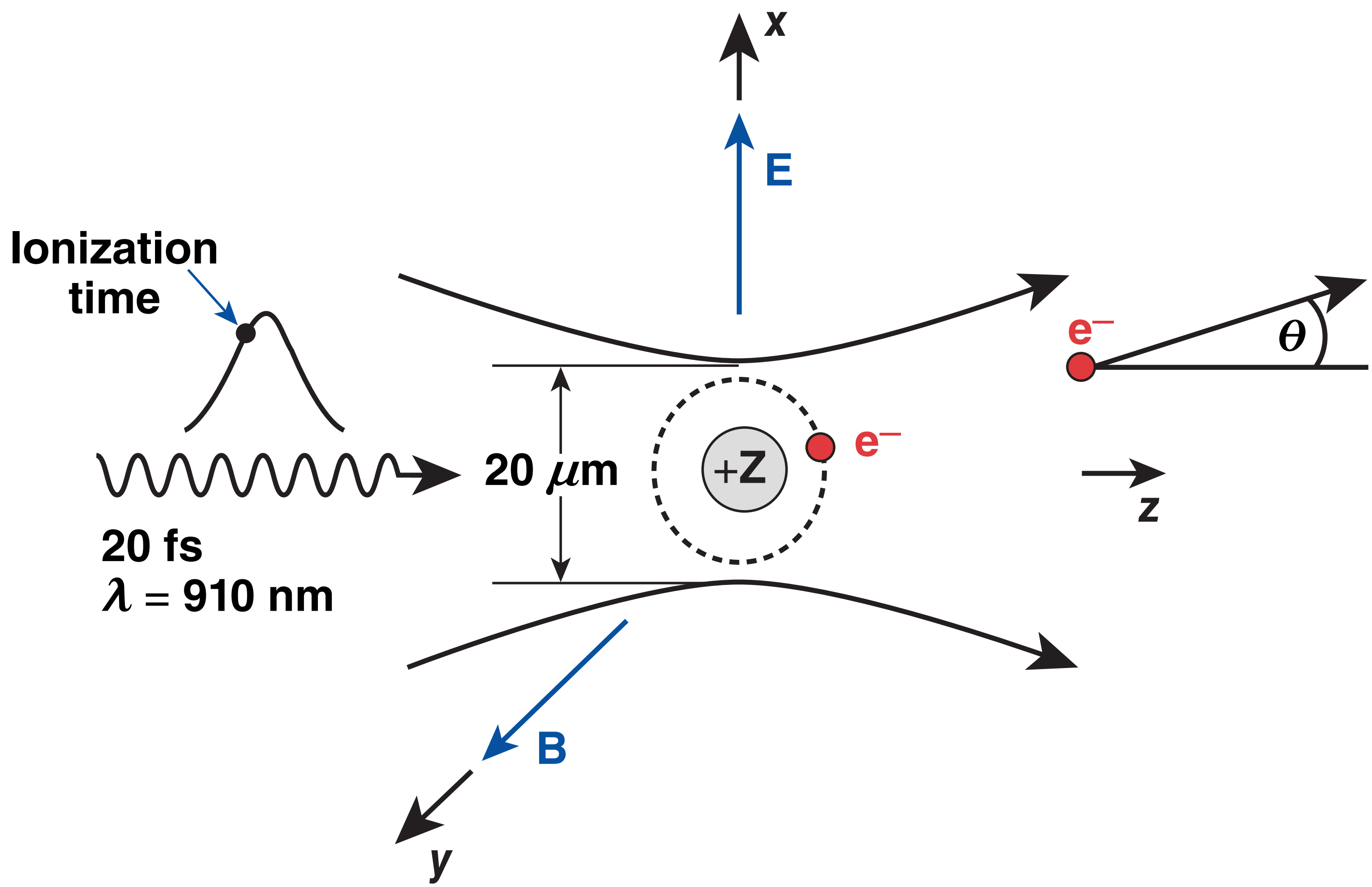

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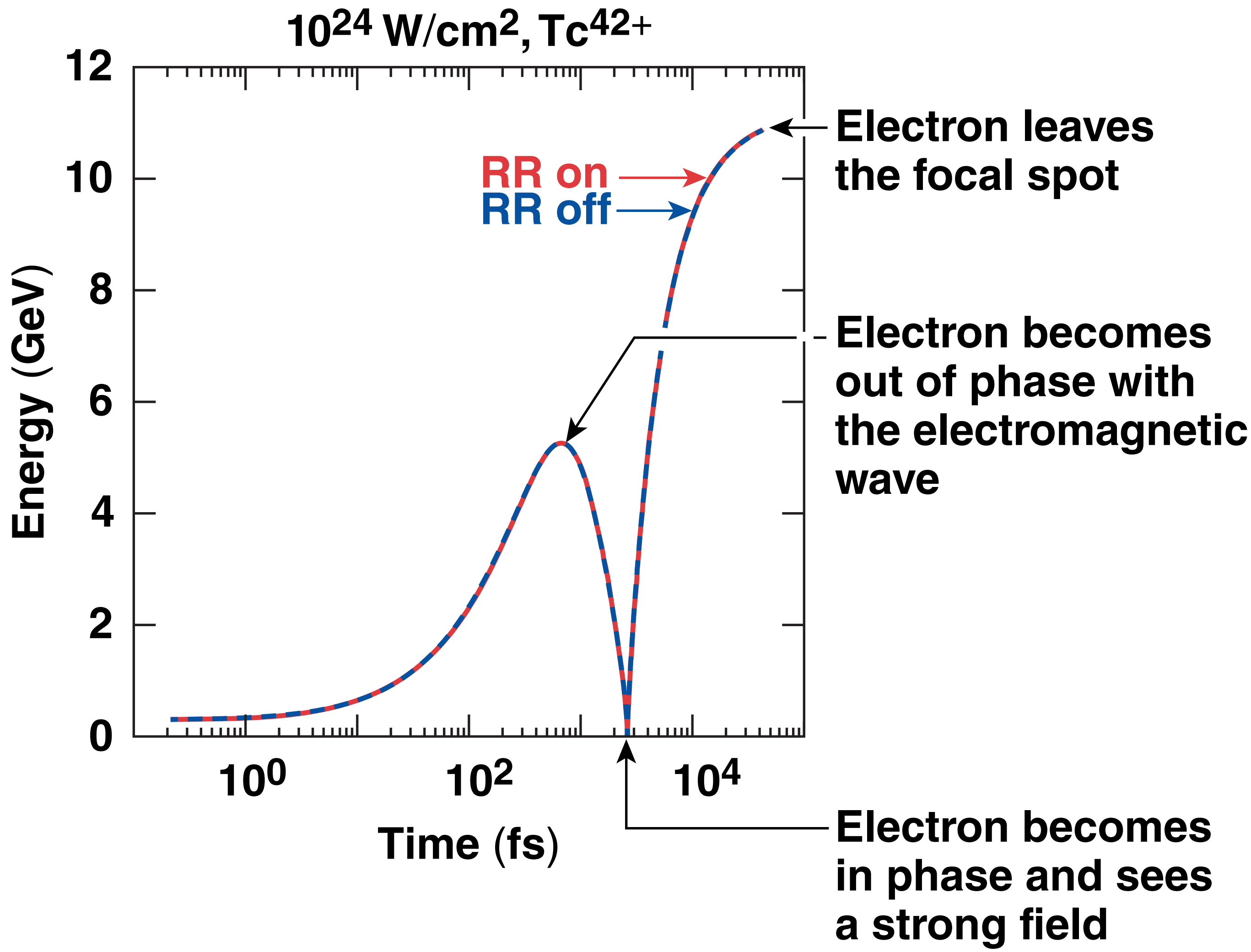

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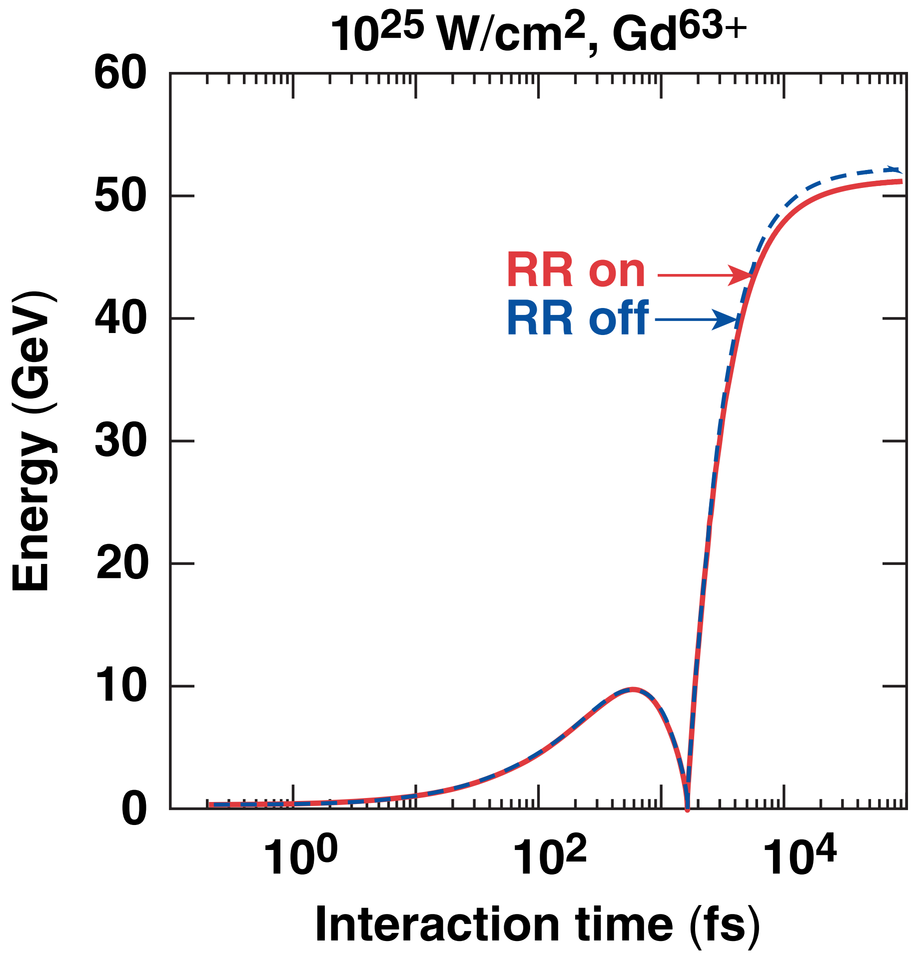

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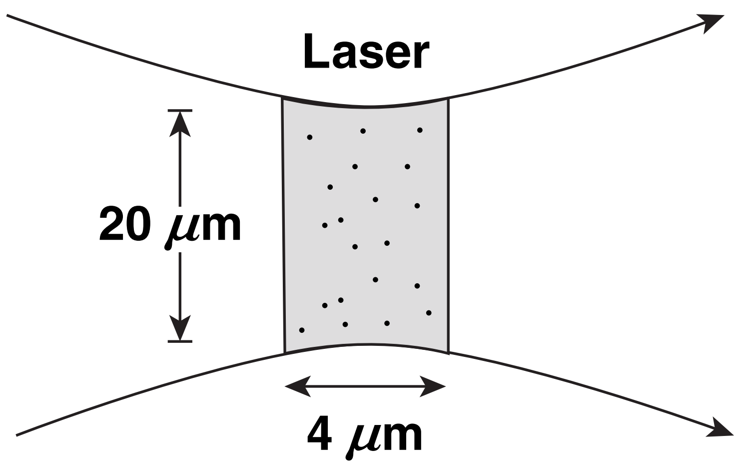

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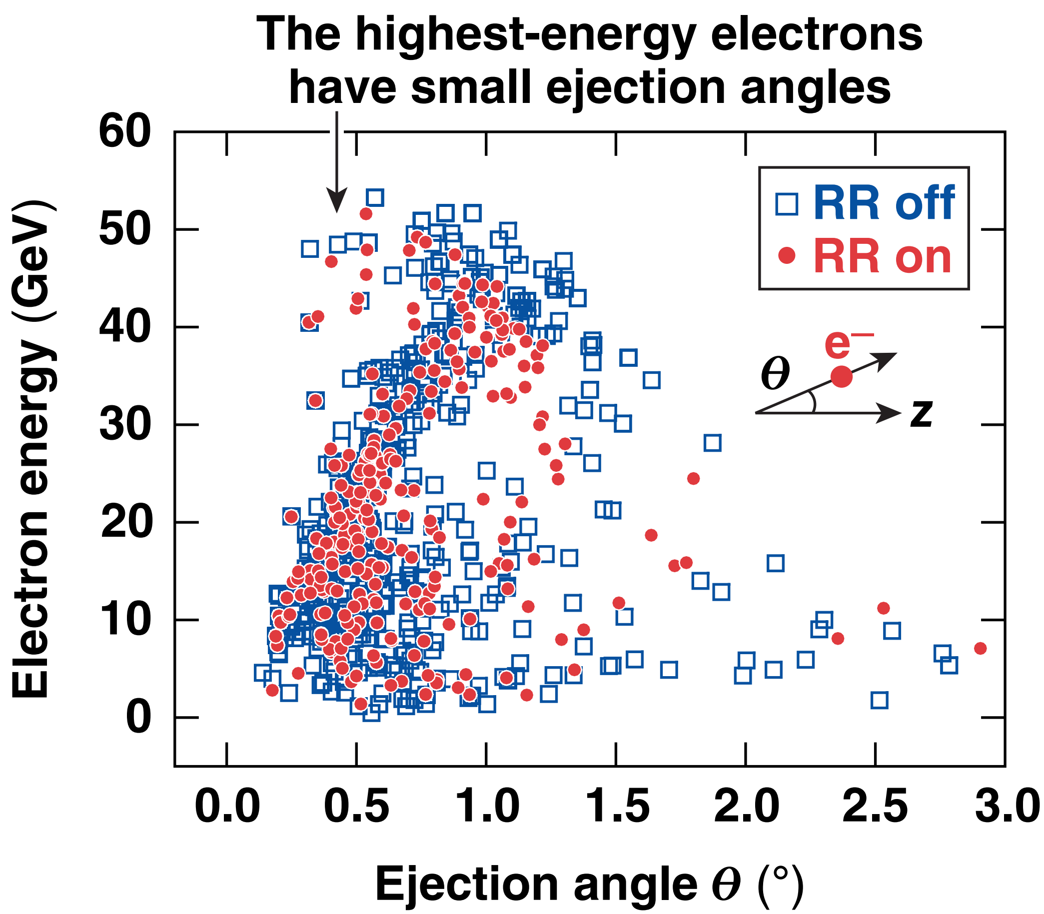

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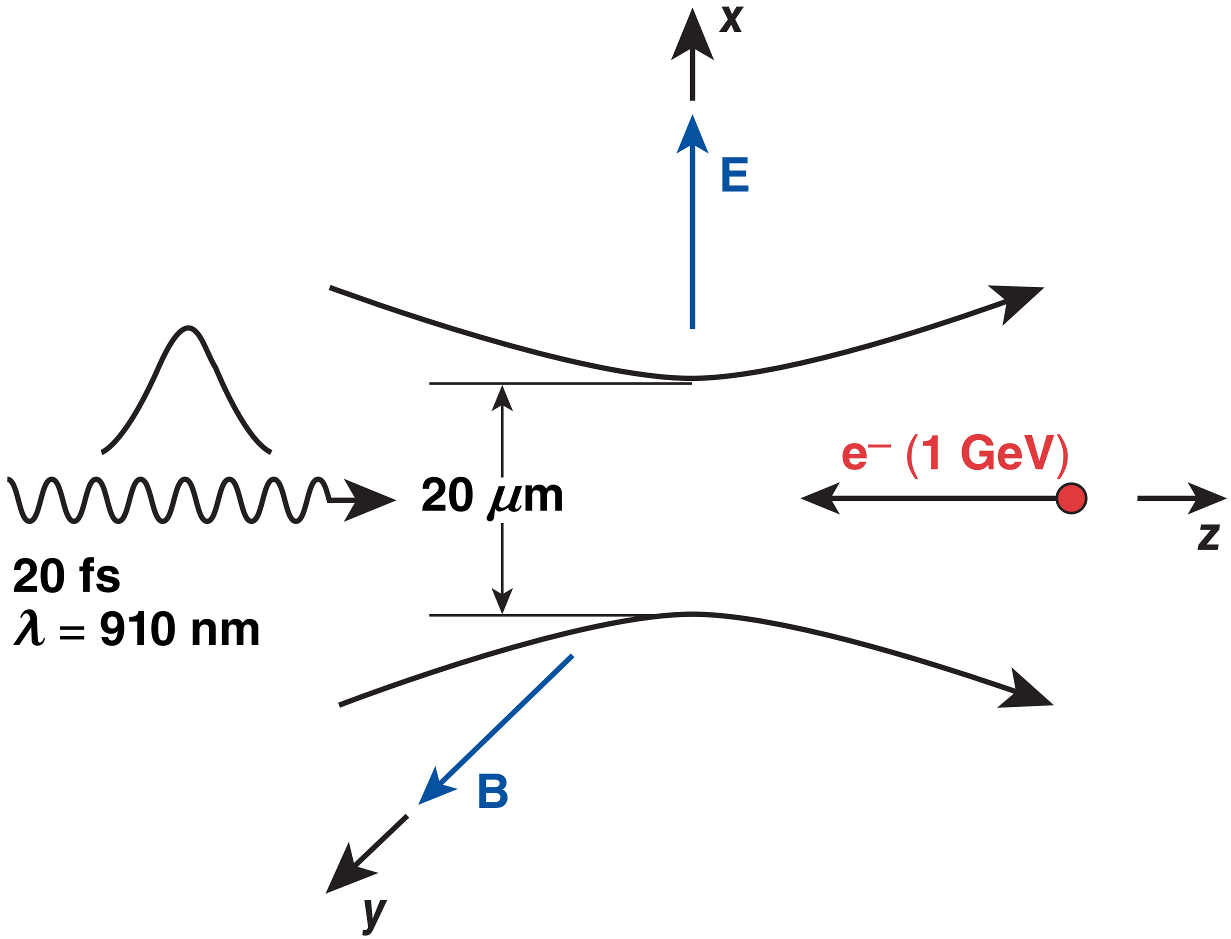

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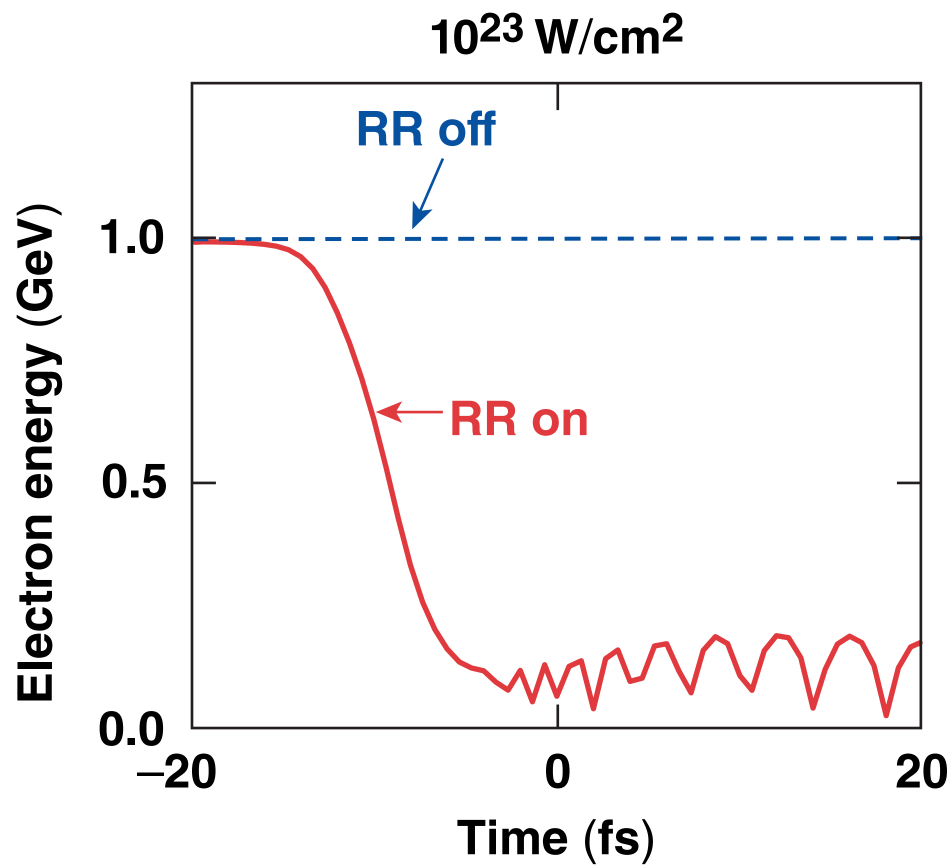

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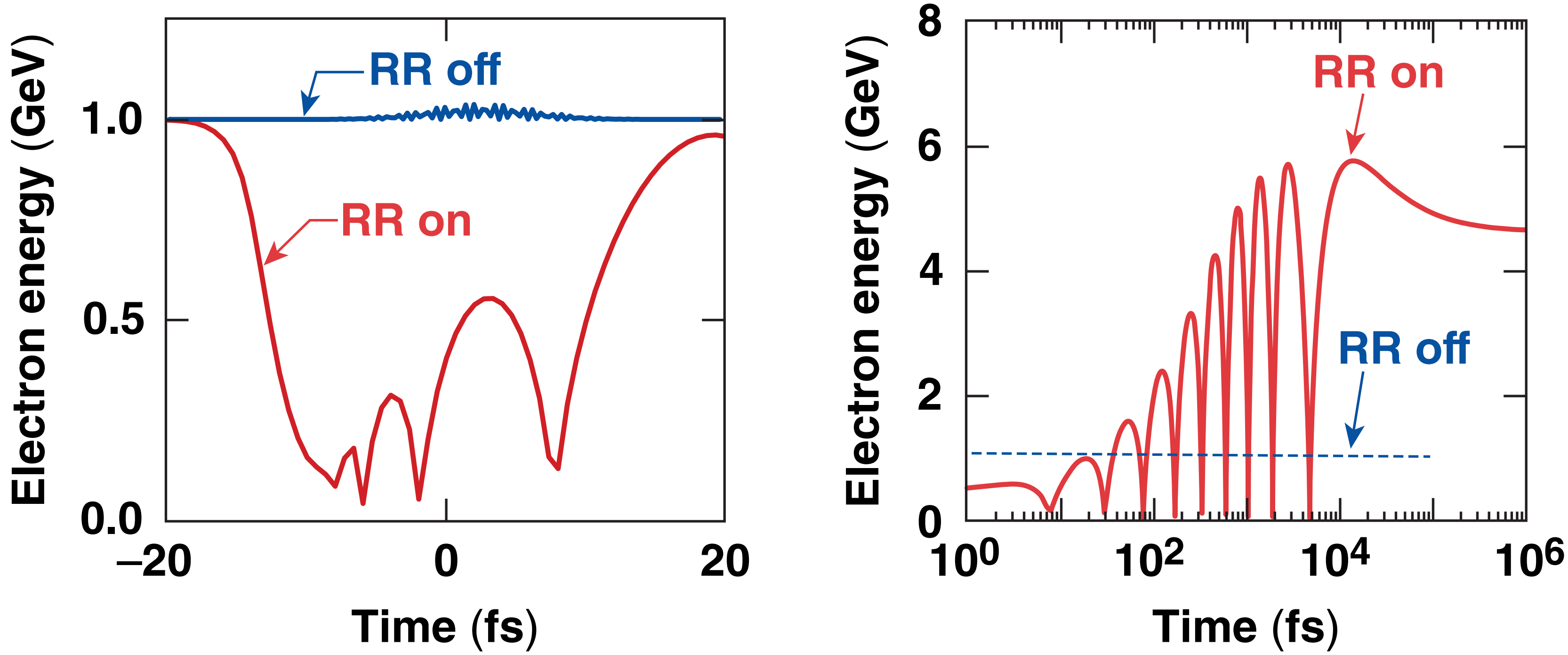

TC12759

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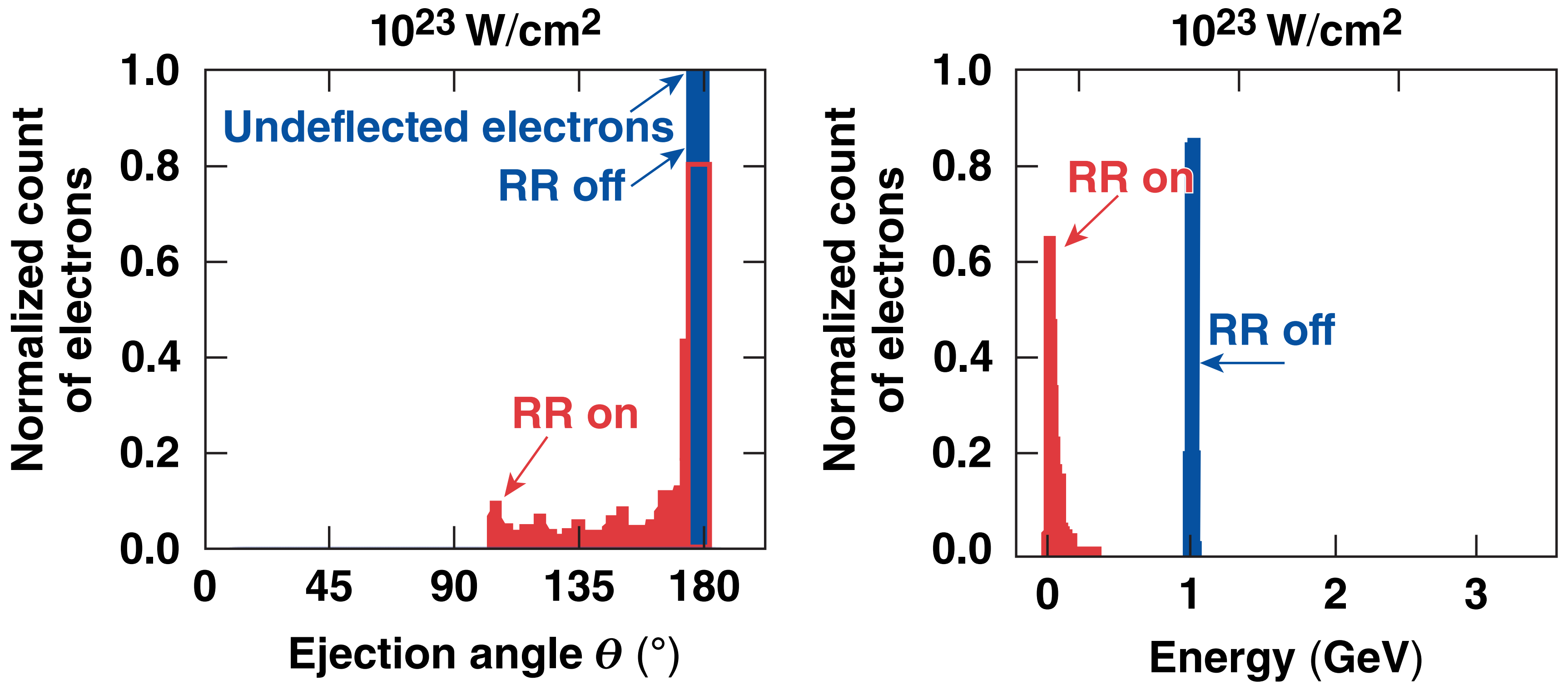

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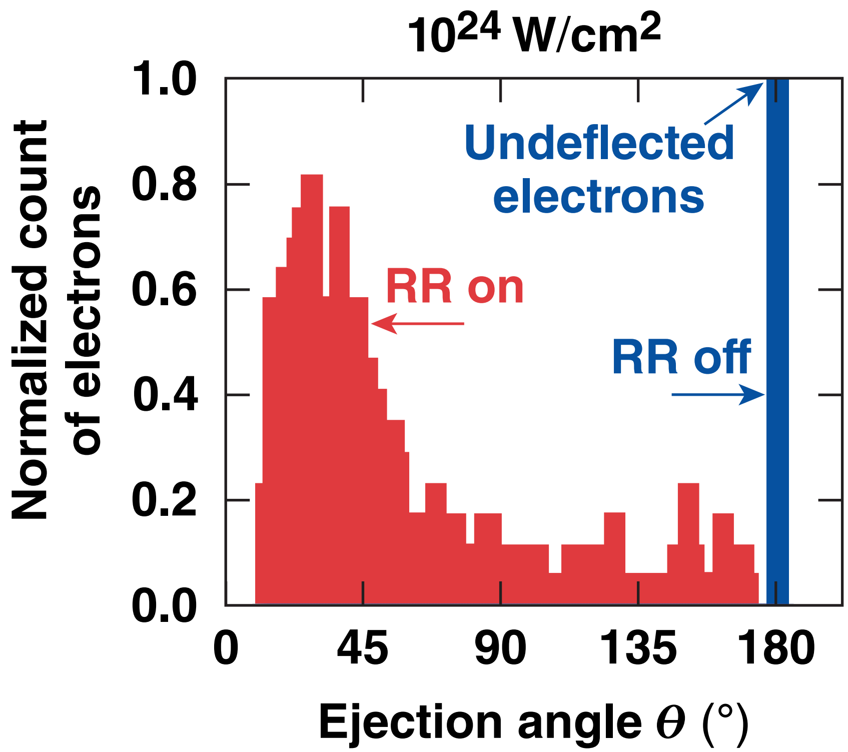

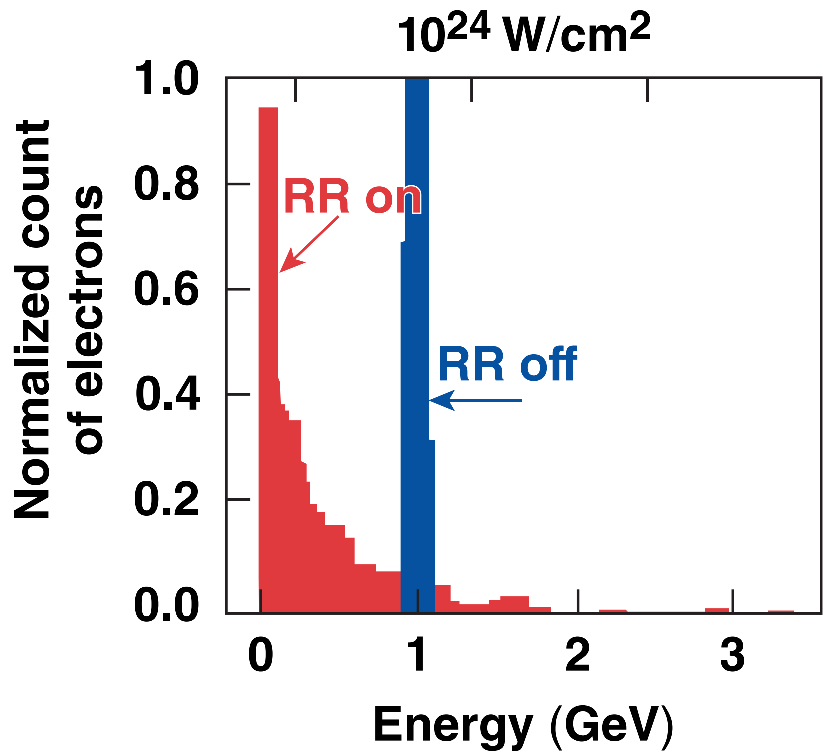

TC12761