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Extreme Light Infrastructure - Nuclear Physics *(ELI-NP) – Phase I*

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High Field Physics and Quantum Electrodynamics at ELI-NP

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The new ELI-NP facility, under construction, will provide for the first time laser intensities above 5 x 10^{22} W/cm^2 with two powerful 10 PW laser beams to study High Field Physics and Quantum Electrodynamics. One beam (pump beam) accelerates the electrons in solid or gas targets to relativistic energies and the second focused beam (probe beam) submits them to a very high electromagnetic field.

A dedicated experimental area (E6) was designed for this purpose: a quasi-octagonal interaction chamber of 4.5m diameter with the pump-probe laser beams interacting on the target in the center of the chamber. A flexible layout allows the two-beam pump-probe focusing geometry for different interaction configurations. A multi-GeV electron spectrometer and diagnostics tools will be available for: gamma-rays, electrons and positrons, protons and ions, plasma characterization and transmitted and reflected laser beam.

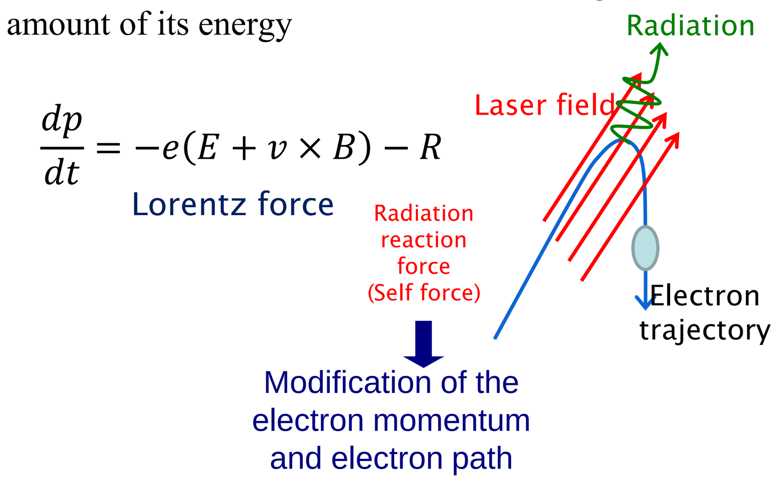
ELI-NP Working Group 2 for Strong Field Physics and QED:

D. Jaroszynski, P. McKenna (conveners)
E. Turcu, F. Negoita (liaisons)
S. Balascuta, D. Neely, C. Diplasu, M. Kaluza, C. Ciocirlan, C. Ticos, M. Hegelich, C. Ridgers, C. D. Murphy, A. Ilderton, M. Zepf , G. Sarri

High-field physics processes

Radiation reaction - Electron radiates large amount of its energy

$$\frac{dp}{dt} = -e(E + v \times B) - R$$



If radiated energy during acceleration time is smaller than electron kinetic energy, the radiation reaction is negligible.

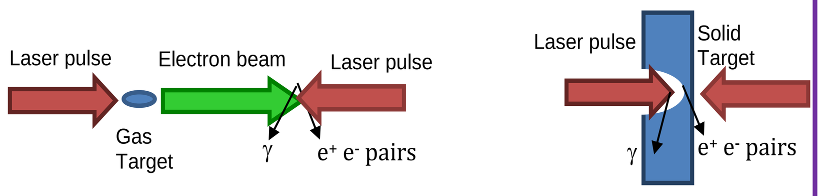
If radiated energy during acceleration is close to its kinetic energy, the radiation reaction is important

Becomes important at ultrahigh laser intensities, ~above 10^{22} Wcm^{-2}

Concepts for experimental demonstration

Require electrons with a large Lorentz factor interacting with strong electromagnetic fields. Ultra-intense lasers should be able to provide both the electrons accelerated to large Lorentz factor and the large EM fields.

Interaction of GeV electron beam generated in the gas target by the first 10 PW-laser with the EM field of the second 10 PW-laser. The electron Lorenz factor is very high.



10^{23} Wcm^{-2} → γ=300 → η≈0.2

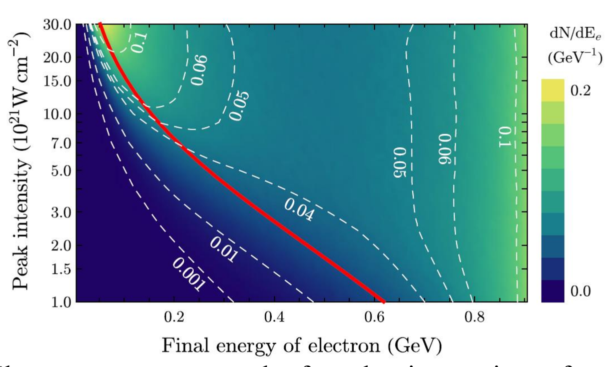
10 PW laser pulse interactions with dense plasma from solid target. Two Pump-Probe laser will provide independent control of the two interactions. Reaction rates are high due to the high electron density in such plasmas although the Lorentz factor is lower.

QED plasma regime

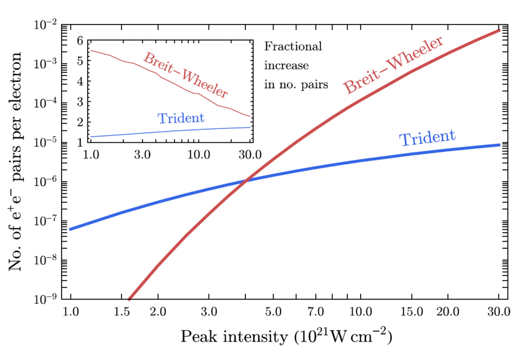
- Radiation Reaction
- Multiphoton Breit-Wheeler process: g + nω → e⁺ + e⁻
- Laser provides electron acceleration and the high field
- Above 10^{21} Wcm^{-2} rapid increase in pair production rate
- Pairs accelerate and generate additional photons and more pairs

Laser beam - e-beam interactions (C.D. Murphy et al.)

Experiments are proposed to observe the transition to the nonlinear Compton scattering regime, radiation reaction and the transition of radiation reaction from a classical to a quantum force and measure the cross-section for strongly nonlinear Breit-Wheeler pair production. The broadening of the gamma ray spectrum and the strong reduction in radiation reaction below the classical prediction will mark the transition to the quantum regime.



Electron energy spread after the interaction of a 1GeV monoenergetic beam with a diffraction-limited laser pulse and the classical prediction (red line)

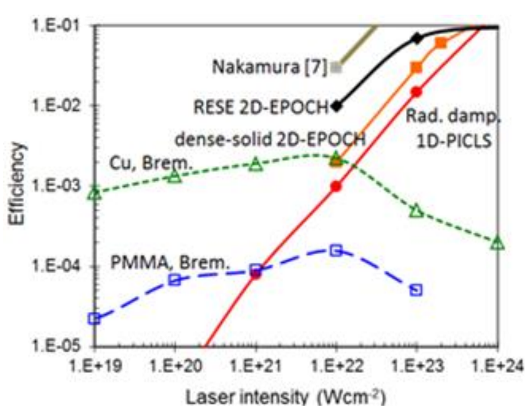


Pair production by the Breit-Wheeler and Trident mechanisms. Inset - enhancement due to quantum stochastic effects.

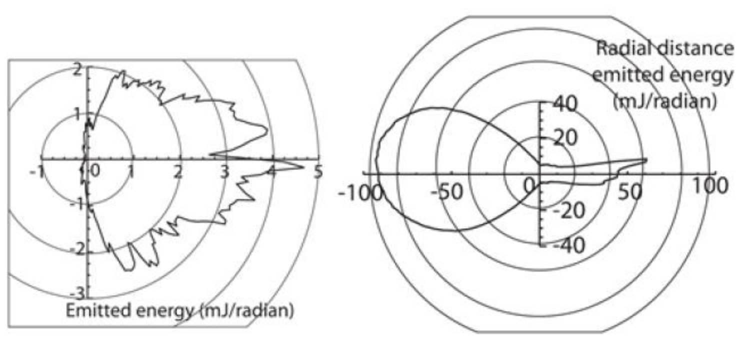
3D simulations: T. G. Blackburn et al., PRL 112 (2014)

Dense plasma interactions (P. McKenna et al.)

Highly nonlinear QED processes are expected in high density plasma. Experiments are proposed to test for the onset of the radiation reaction force, and to investigate the feedback on the hole-boring and relativistic-induced transparency plasma processes, in solids and other dense targets [Ridgers et al, PRL 108(2012) , Brady et al, PRL 109 (2012)]. The experiments will look for three signatures: a strong increase of energetic photon emission with peak laser intensity, a strongly modified angular profile of photon emission and a considerable loss in the maximum charge particle energy.



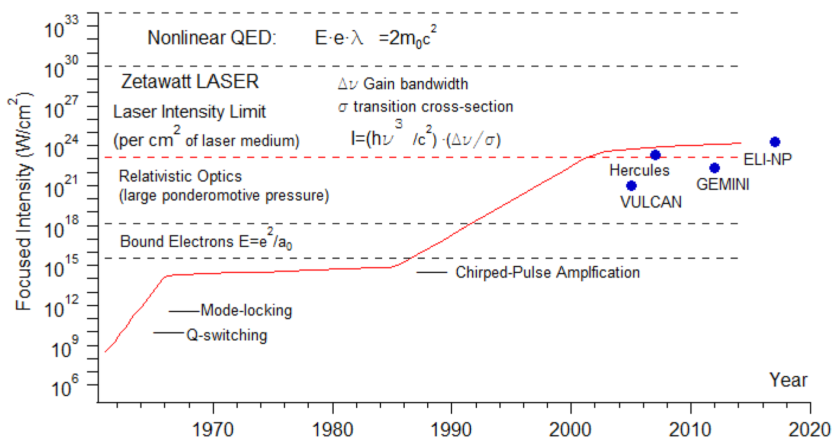
Calculations of the efficiency of energetic photon emission give a very clear signature of the onset of radiation reaction. [Nakamura et al PRL 108(2012)].



Simulation results of the angular distribution of energetic photons produced by (a) skin depth emission in a solid targets, and (b) the RESE mechanism in which electrons propagate backwards into the incoming laser light. [Brady et al. Phys. Plasmas 21 (2014)]

ELI Project is Leading the Scaling of laser power

Gerard Mourou 1985: Chirped Pulse Amplification (CPA)



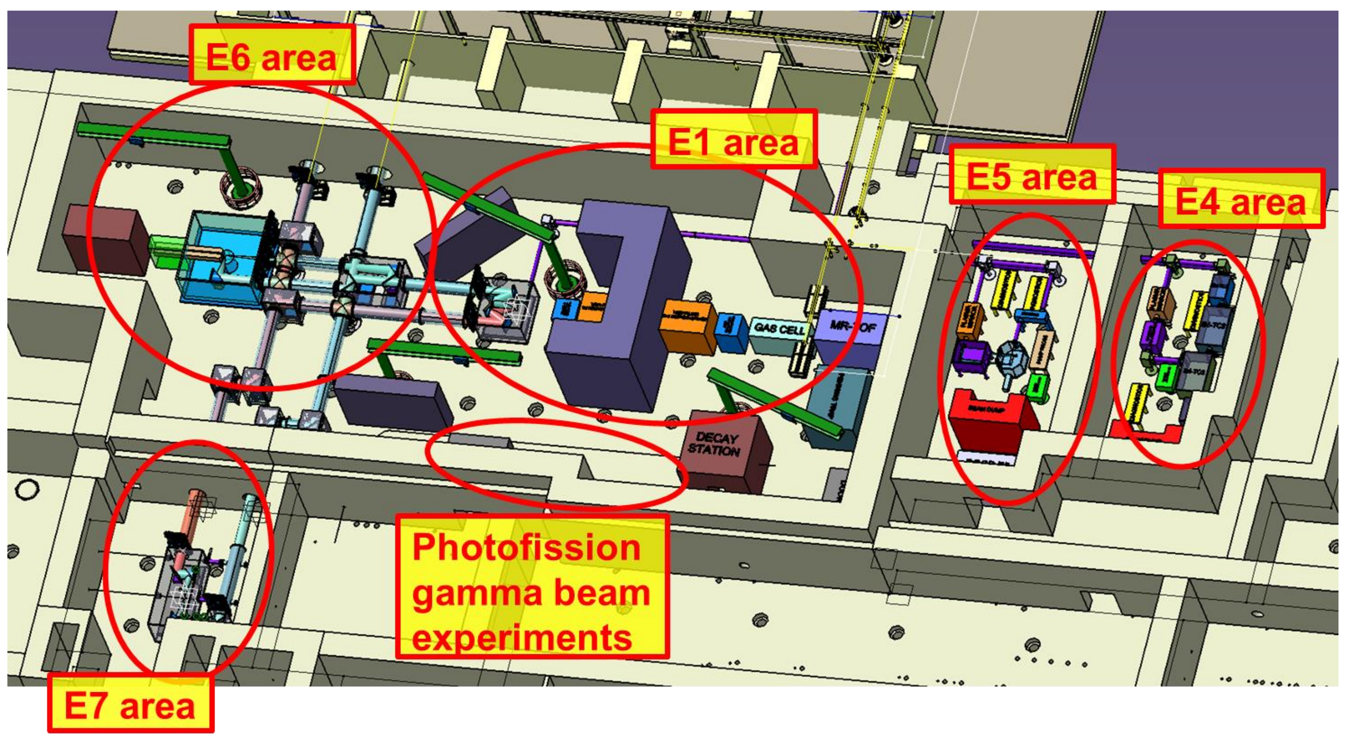
Laser electric field $E(\mathrm{V/m}) = 27.4 \cdot \sqrt{I\left(W/cm^2\right)}$

For I=10^{23} W/cm^2, E=8.7 x 10^6 (MV/cm)

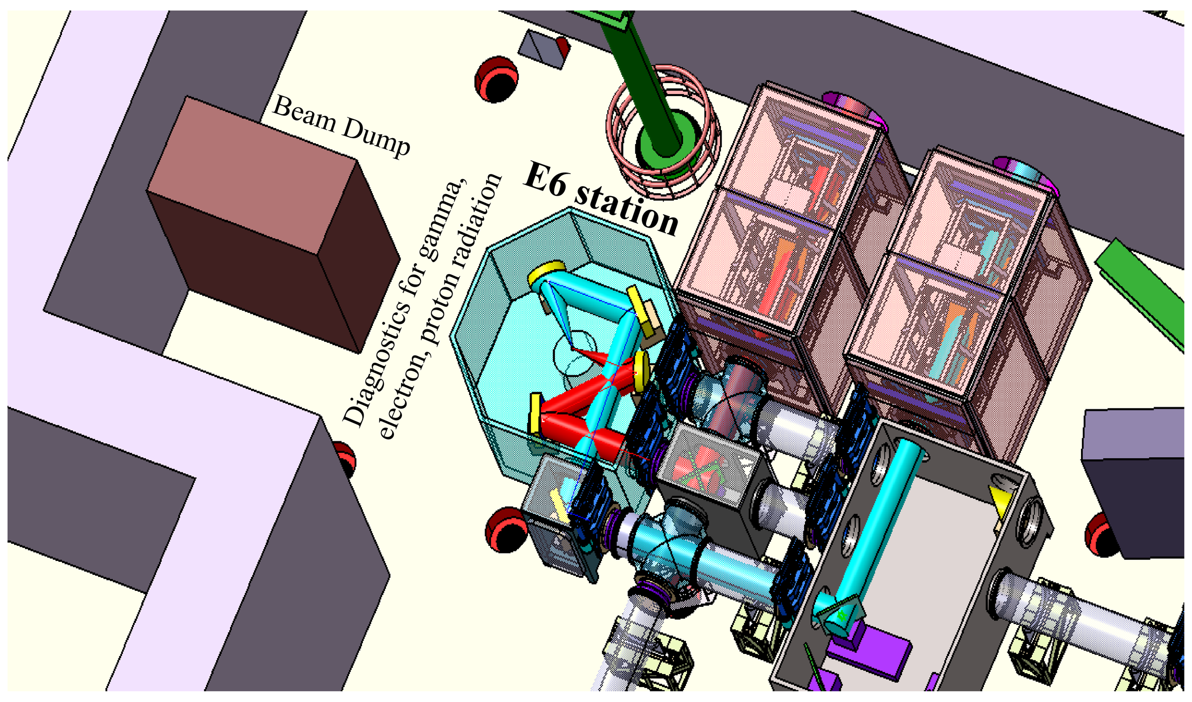
$I_{Schwinger}$ = 2.3 x 10^{29} W/cm^2 needs

E_S = 1.3x10^{16} V/cm

ELI-NP Facility: High Power Laser Interaction Areas

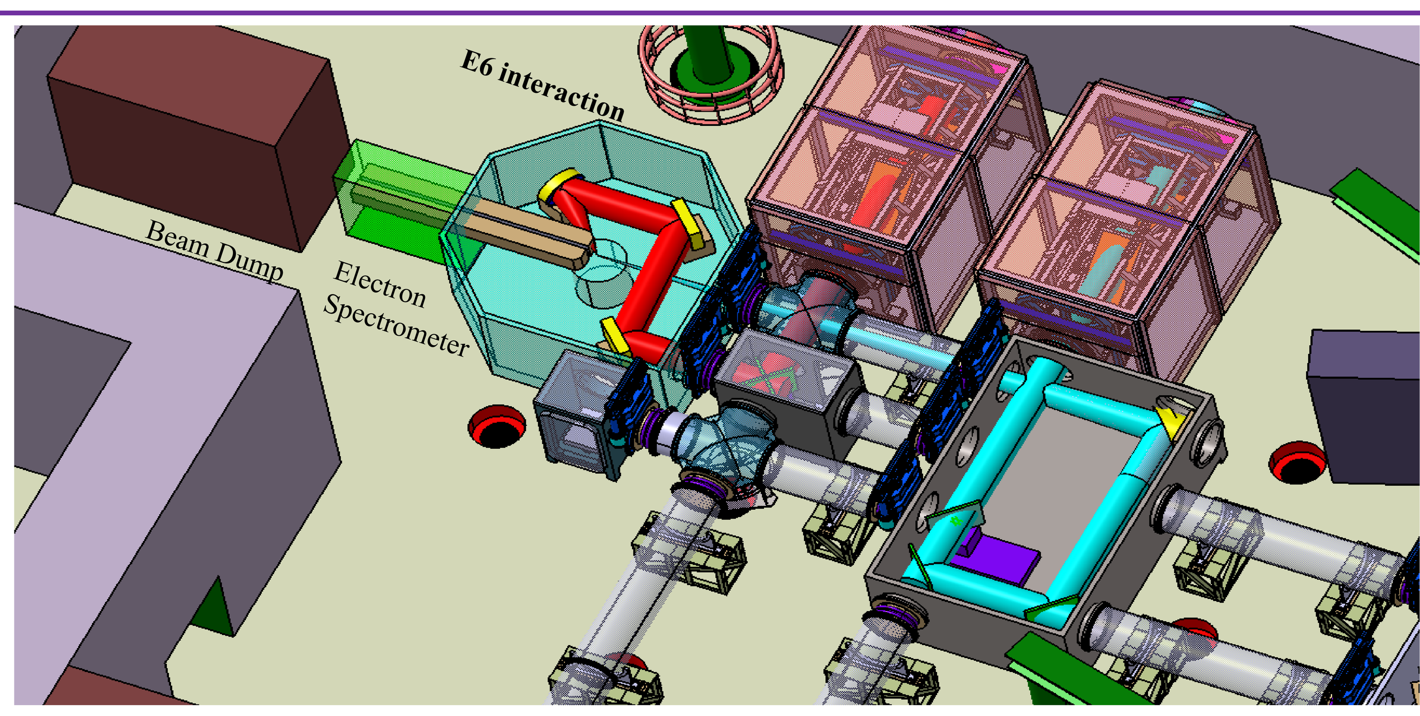


Experimental setup of E6 experiments for two laser beams incident on solid target



10 PW Pump beam focused with a short focal length mirror on a solid foil target accelerates electrons to relativistic energies. 10 PW Probe beam focused from opposite direction with short focal length mirror provides the strong electromagnetic field to the electrons. A second focusing configuration sends the Probe beam at small angle to the Pump beam direction. The interaction station E6 has dimensions of 4.5 m between the two opposite sides of the octagon.

Engineering draft design of E6 Experiments for beam-beam experiment in a gas target



10 PW Pump beam focused with a long focal length mirror on a gas target ,accelerates an electron bunch to relativistic energies. 10 PW Probe beam focused from opposite direction with short focal length mirror provides the strong electromagnetic field to the electrons. In a second focusing configuration, the Probe beam is sent at small angle relative to the Pump beam.

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