White Paper for *Frontiers of Plasma Science Panel*

Date of Submission:	***6/19/2015***

Indicate the primary area this white paper addresses by placing "P" in right column.
Indicate secondary area or areas by placing "S" in right column

	"P", "S"
• Plasma Atomic physics and the interface with chemistry and biology	
• Turbulence and transport	
• Interactions of plasmas and waves	P
• Plasma self-organization	S
• Statistical mechanics of plasmas	

Indicate type of presentation desired at Town Hall Meeting.

	"X"
Oral	X
Poster	
Either Oral or Poster	
Will not attend	

Title:	Strong field quantum electrodynamic effects in plasma
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**(Limit text to 3-pages including this form. Font Times Roman size 11.
1 page of references and 1 page of figures may also be included. *Submit in PDF format.*)**

- ***Describe the research frontier* and importance of the scientific challenge.**

For laser-plasma interactions involving the next generation of very high intensity lasers, non-linear feedback between quantum electrodynamic processes, such as pair creation and radiation reaction, with the collective dynamics of the plasma medium will result in dramatically modified dynamics compared with standard plasma kinetic models and therefore ***new plasma behavior.***

In the experimental collaboration using the SLAC linear particle accelerator designated E-144 [1], matter was created from the interaction of light with light through a multiphoton version of the Breit-Wheeler process [2,3]. A highly energetic beam of electrons from the two mile long accelerator collided with an intense (~10^{18} W cm^{-2}) infrared laser pulse. Photons from the laser pulse were Compton scattered from the electrons to much higher frequencies. These scattered photons, now extremely energetic gamma rays, subsequently interacted simultaneously with many laser photons to create electron-positron pairs. This was a first demonstration of the creation of matter from light-by-light interaction. One important feature of this experiment was that in the rest frame of the 50 GeV electron beam, the laser field was Lorentz boosted to a strength approaching the critical, or "Schwinger" field of quantum electrodynamics (QED), $E_c = 1.3 \times 10$ Vm^{-1} [7]. This field is the threshold at which strong-field QED effects start to become important [8–11].

There is a lot of interest worldwide in high intensity laser-plasma interactions. This is evidenced by numerous construction projects, particularly in Europe and Asia, to build laser systems exceeding current laser intensities. Such projects are motivated by applications such as understanding extreme astrophysical environments, developing next generation particle accelerators and radiation sources. However, when the next generation of 10 PW lasers currently under construction are built [2–6], there are likely to be a few surprises in the way that they interact with matter. This is because at the extreme intensities expected to be reached in the laser focus the electrons in the resulting plasma are accelerated to such ultra-relativistic energies that the electric field they experience in their rest frame may reach E_c without the necessity of the externally accelerated beam, as in E-144. It is interesting that significant effects on the plasma behavior are expected at surprisingly low laser intensities ($\sim 10^{23}$ Wcm^{-2}) [11, 14–19].

The new plasma state that is created is similar to that thought to exist in extreme astrophysical environments including the magnetospheres of pulsars and active black holes [12, 13]. Collective plasma processes are strongly affected by pair creation and radiation reaction [11, 14–19] because such processes modify the local plasma density and effective forces experienced by plasma particles. Such modifications to the plasma particle dynamics will affect the structure and strength of the electromagnetic fields and therefore the strong field interaction rates (such as pair production), thereby leading to feedback between the QED processes and collective plasma dynamics and therefore ***new plasma behavior.***

- ***Describe the approach to advancing the frontier and indicate if new research tools or capabilities are required.***

The ***coupling*** of strong-field QED effects with plasma is a new area of research and therefore both theory and experiments are in an early phase of development. On the theory side, the development of advanced kinetic simulation codes capable of simulating both the relativistic plasma behavior along with accurate strong-field QED interaction models is required. In terms of experimental capabilities, very high power laser systems greatly exceeding a PetaWatt in power will achieve the focused intensities capable of producing such a plasma state. These could be similar to the ELI project in Europe, for example.

- ***Describe the impact of this research on plasma science and related disciplines and any potential for societal benefit.***

High intensity laser–plasma based techniques provide sources of high-energy charged particle and photon beams that may be useful for a wide range of future applications. These include compact electron and positron acceleration, high energy ion beam acceleration, coherent X-ray generation or the production of attosecond light pulses to name but a few. Understanding the physics of these interactions at the highest intensities is clearly important to development of these sources. In addition, studying such a state of matter is important for understanding extreme astrophysical environments such as the magnetospheres of pulsars and active black holes.

References (Maximum 1 page)

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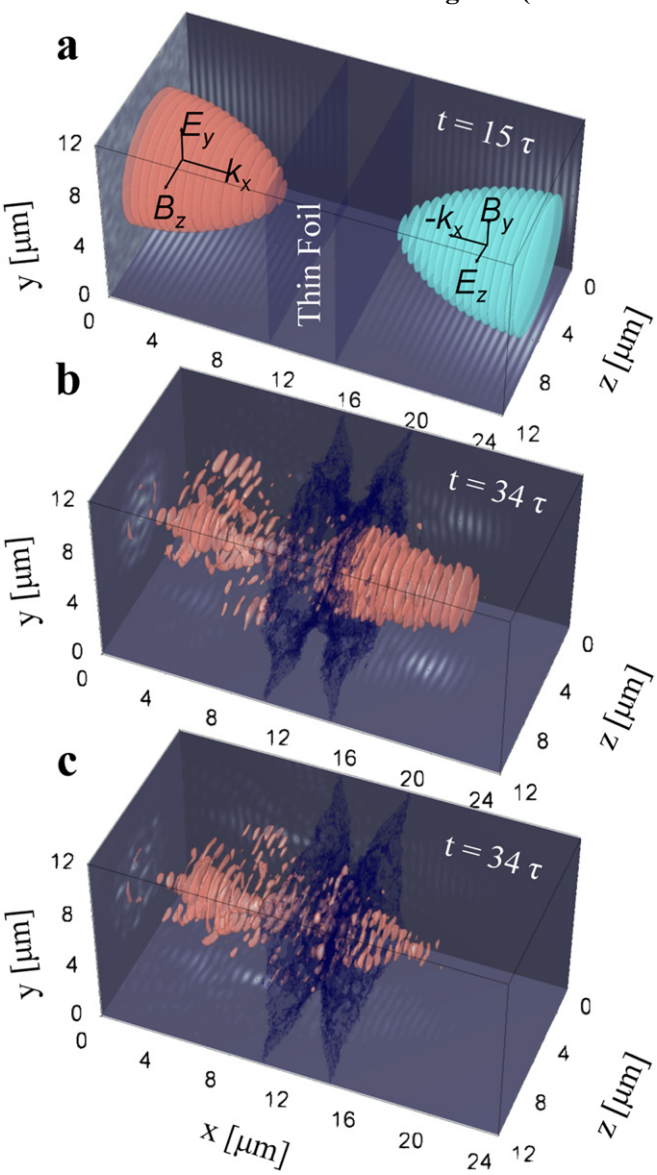
Figures (maximum 1 page)



3D QED-PIC simulation [19]. (a) two laser pulses illuminate a thin foil from both sides. The left pulse is linearly polarized in the y- direction, and the right pulse is linearly polarized in the z-direction. (b)–(c) The red isocontours show the magnitude of left pulse electric field, $|E\ y|$ and the blue isocontours show the electron number density, all at $t = 34\tau$, for the QED-off and QED-on simulations, respectively. Side panels display slices of E 2 through the planes that bisect the center of the box. The isocontours are $y(z)$ taken at 33% of the maximum value.