Program for Plasma-Based Concepts for Future High Energy Accelerators

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The USC program is focused on advancing plasma-based concepts for future high-energy accelerators. We are actively pursuing this goal through experiments, advanced computational modeling and theory.

Recent Accomplishments:

Highlights of accomplishments in this period include:

- Performance of the E-162 Plasma Wakefield Accelerator Experiment at the Stanford Linear Accelerator Center.
- Development of the Plasma Afterburner concept for doubling the energy of a future linear collider.
- Development and application of advanced 3-D particle simulation tools (OSIRIS and QuickPIC) on high-performance platforms for modeling current plasma accelerator experiments with unscaled parameters and unprecedented fidelity, including self-consistent plasma ionization, beam and plasma imperfections, aperturing effects of the diagnostics, etc.
- Development of a novel circular accelerator simulation code exploiting the power of plasma wakefield algorithms to model the dynamics and stability of circulating beams in electron clouds.

The E-162 Plasma Wakefield Accelerator experiment was designed to demonstrate high-gradient electron and positron acceleration at energies of relevance to high-energy colliders and over meter length scales. This experiment has produced a wealth of spectacular results and physics milestones. As described in the references that follow, the collaboration between USC, UCLA and SLAC achieved a number of firsts: These include the acceleration of electrons in the tail of a 30 GeV SLAC bunch by up to 280 MeV over 1.4 meters of plasma. The experiment ran parasitically with PEP-II operation at SLAC. In this mode, the SLAC linac delivered stably 2×10^{10} electrons per bunch which was a factor of two lower than the original design. Consequently, the acceleration measured was lower than the design by a similar factor but in very good agreement with the simulations performed for the actually delivered beam parameters. The good agreement bodes well for the collaboration's next experiment – E-164. Preliminary simulations indicate that the wakefield amplitude and acceleration gradient increase as the inverse square of the bunch length, and E-164 will test this scaling with bunch lengths 6 times shorter or more in upcoming runs in 2003-2004.

If plasma accelerators are to have an impact in future high energy physics colliders, they must address not only the need for high-gradients but also the need for high beam quality and the need to accelerate positrons as well as electrons. E-162 accomplished important firsts on both of these fronts. By designing the incoming beam optics to match the theoretical Twiss parameters associated with the plasma's strong transverse focusing fields, the first demonstration of matched beam propagation and acceleration were achieved. Such matching will be important to preserving beam emittance in future plasma accelerators such as an Afterburner in which the beam may propagate over a hundred betatron oscillations. The E-162 experiment also exploited the unique capability of the SLAC facility to deliver positron beams in order to perform the first plasma acceleration test of positrons. The results confirmed that the physics of positron acceleration and focusing is significantly different from that of electrons in the nonlinear regime, but showed excellent agreement with detailed PIC simulations (Fig. 1).

The plasma afterburner is a concept for impacting the energy frontier with a plasma accelerator placed at the interaction point of a linear collider. The concept is described in the USC thesis of Ms. Seung Lee who graduated during this contract period. Ms. Lee used simulations to support key foundations of the afterburner such as the scaling of the wakefields with shortened bunch length well into the non-linear regime, the beam loading of a signficant number of particles (10^{10}) with modest energy spread, and the recovery of luminosity through plasma lensing. The interest in this original proposal has been spurred by experimental results on E-162 and elsewhere and is leading to work on a challenging but finite spectrum of remaining issues. Key among these are beam jitter and alignment tolerances, hosing instability limits and plasma source development.

The interaction between a positively charged high current beam with the low density electron cloud they create in circular accelerators has become a major concern in existing accelerators at high current and in the design of future circular accelerators (particularly LHC at CERN). Recently a meeting held at CERN under the title ECLOUD02 highlighted the fact that electron clouds lead to emittance blow-up and instability of beams in a number of accelerators world-wide, that the mechanisms of the e-cloud interaction are not well understood and that predictive models are greatly needed. The challenge for computational modeling of e-clouds arises from the need to model beam propagation over hundreds of thousands of kilometers while resolving the self-consistent space charge fields of the cloud on cm scales. But just such a predictive model now appears possible feasible using high-performance parallel computing techniques and advanced algorithms developed for plasma wakefield studies.

A collaboration of the plasma wakefield accelerator groups at USC and UCLA has now adapted a code which they have been using for plasma based accelerators studies over the past decade, to the electron cloud problem (the electron cloud is after all a non neutral plasma problem). Their code, QuickPIC, is based on Viktor Decyk's (UCLA) Framework for developing parallel PIC codes. This includes highly optimized components and parallelization. In order to properly model the e-cloud problem, the capability of QuickPIC to model the cloud interaction needed to be combined with algorithms from the circular accelerator community to track particles in the external magnets and RF fields. Particularly synchrotron and betatron motions are added to the code and the chromaticity is also included to take care of the changes in the betatron frequency due to momentum spread of the beam. To this end, G. Rumolo from CERN visited USC for a month to collaborate on the code. An early milestone was reached recently: Using 16 processors at NERSC, the propagation of the beam through 50 turns (350 km) of the SPS at CERN was modeled. This is the relevant number of turns to begin to see the tune shift due to the cloud. Based on this preliminary work, it appears to be possible to develop a high-fidelity model capable of simulating hundreds or even a thousand turns in the near future. The goal is to develop predictive capability to ensure the performance of major upcoming facilities such as the LHC and SNS.

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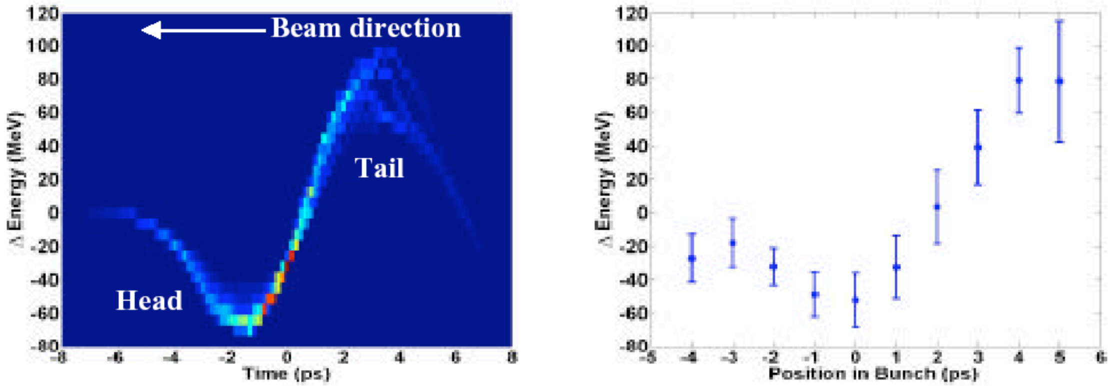

Figure 1 shows results of a 3-D OSIRIS simulation of the E-162 experiment (left) and the experimental data (right) for *positrons*. Plotted are the time-resolved energy loss and gain along the bunch. The tail was accelerated by 80 MeV in 1.4 meters.

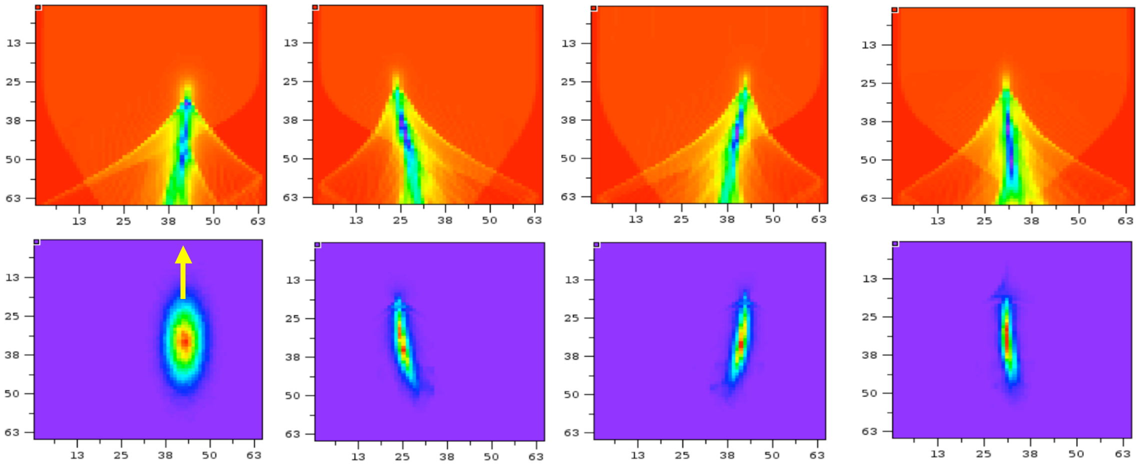

Figure 2 shows snapshots of off-centered (by $3\sigma_r$) beam and electron cloud interaction over 1 turn (27Km) of SPS storage ring at CERN. The upper figures show cloud density and the lower ones show the corresponding beam density. The snapshots from (a) to (d) are taken at propagation distances of Z=0, 15.3, 20.4 and 27 km. The beam is oscillating over the center of the pipe due to the space charge of the cloud and the machine magnets. Small head-tail phase mixing due to the cloud compression behind the beam is observed. Beam and cloud are initialized with SPS storage ring parameters at CERN.