support the size and complexity of multiphysics calculations performed in this project.

NEXT GENERATION WORK

With almost 90% parallel efficiency on 100,000 XE6 cores, Alya has a potential to scale to a million cores on the next Track-1 system. Among many exciting possibilities, this would allow direct numerical simulation of turbulence on larger fluid domains, or directl modeling of meso-scale phenomena in many materials, and thus provide great validation tools for today's approximate continuum research methods such as large eddy simulation turbulence or multiscale methods.

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TRANSFORMATIVE PETASCALE PARTICLE-IN-CELL SIMULATIONS OF HIGH ENERGY DENSITY PLASMAS

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EXECUTIVE SUMMARY

The goal of this project is to use state-of-the-art simulation tools to unravel the complex physics that is inherent in high-energy density plasma physics. The simulations performed on Blue Waters are helping to answer important questions related to developing new accelerator technology that could be the basis of a next generation linear collider or a highly compact coherent x-ray source, and to successfully achieving inertial confinement fusion in the laboratory.

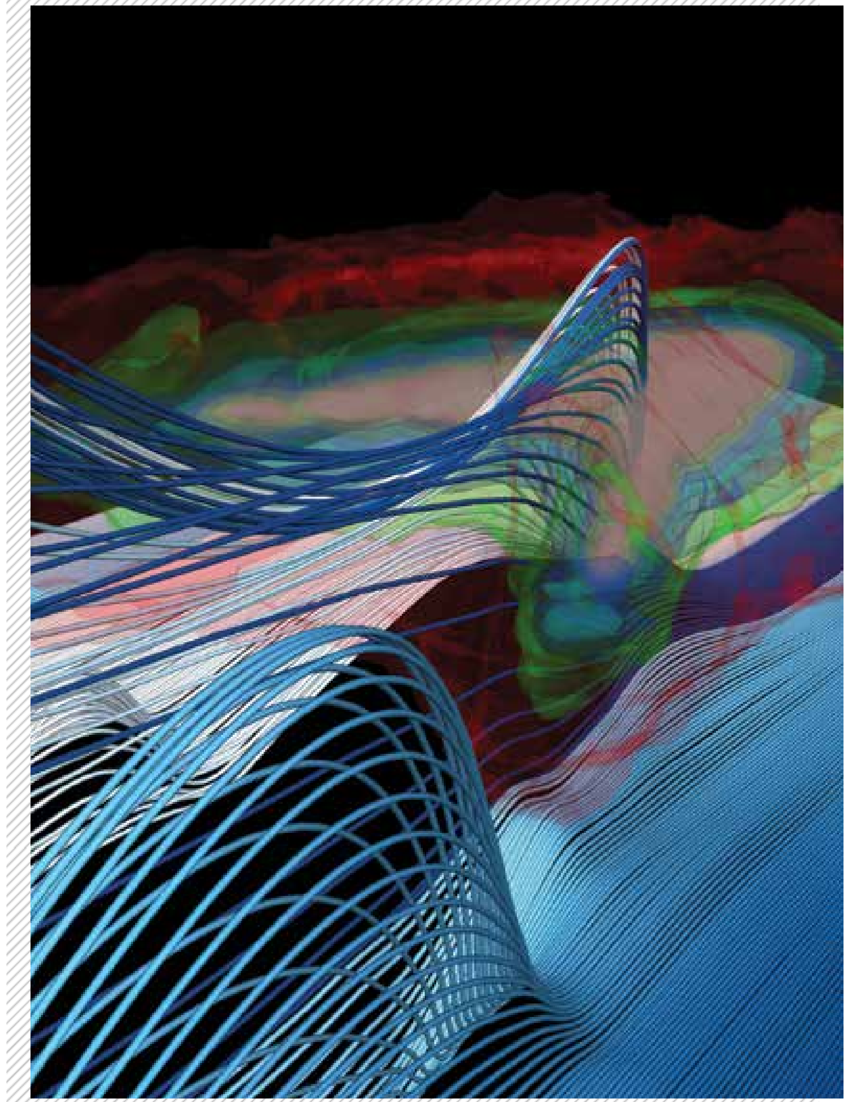

FIGURE 1: QuickPIC simulations of positron accelerations using plasmas. The figure shows isosurfaces of plasma density and positron trajectories (as blue lines).

INTRODUCTION

Our current focus is to unravel key physics within two areas of high energy density plasma physics. Particle accelerators at the energy frontier are the most complex tools built and have been the tool for discovery in high-energy physics for nearly the past 100 years. The newest of these machines is the Large Hadron Collider at CERN, which is 30km in circumference and collides 7 TeV proton beams together that cost billions of dollars. The cost and size of these machines makes it unlikely that a next-generation machine will be built in the foreseeable future.

One option to continue further investigations with existing machines is to use relativistically moving plasma waves as the accelerating structure, or plasma-based acceleration. The space charge force of a relativistic charged particle beam or the radiation pressure of a laser can excite these waves as wakefields behind the beam or laser. These wakefields can support acceleration gradients more than three orders of magnitude larger than current technology. These plasma wave wakefields can also be the basis for building a compact coherent x-ray source that could fit in universities. We are

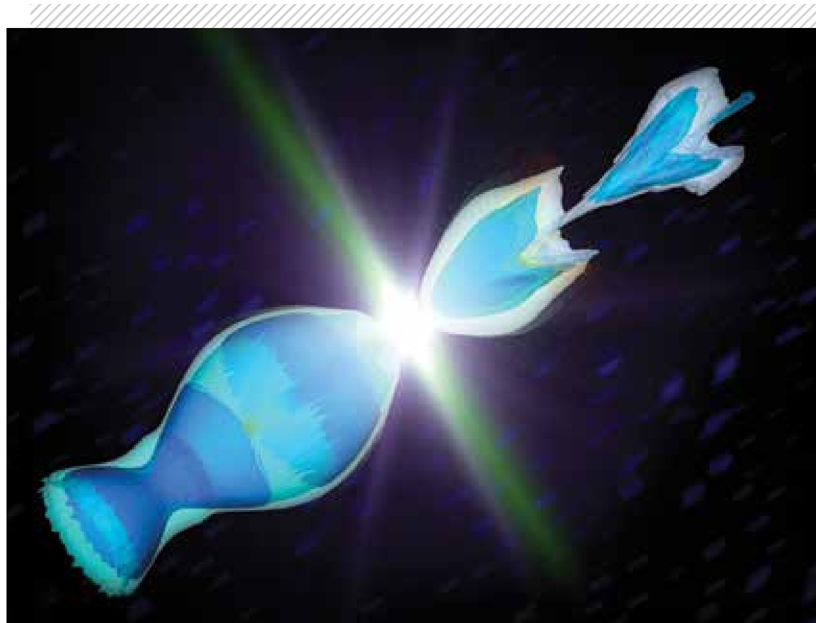

FIGURE 2: QuickPIC simulations of an electron and positron collider using plasmas. In the figure, electrons are moving right left (from the lower left corner of the plot) and positrons are moving left (from the upper right corner). The two bunches meet in the center and collides.

using Blue Waters and highly accurate computer simulation software to study the physics that need to be understood to enable a collider or a compact coherent x-ray source to be designed and built based on plasma-based acceleration.

Controlled fusion energy offers the possibility of an unlimited supply of relatively clean energy. In laser-driven inertial fusion energy, lasers either directly or indirectly drive the spherical implosion of a small amount of deuterium and tritium to densities more than 1000 times solid density and to temperatures exceeding 106 °K. This requires the implosion be very symmetric and that the lasers hit the target accurately. The lasers need to propagate through high energy density plasma where they are susceptible to a host of "instabilities" that can absorb, reflect, and bend them before they hit their target. We use highly accurate models to understand laser-plasma interactions in high energy density plasmas. The goal is to use this understanding to develop ways to control and eliminate the deleterious instabilities.

METHODS & RESULTS

In the past 18 months our major results include:

- QuickPIC simulations of an experiment at SLAC show that a single positron beam can evolve into a self-loaded configuration leading to some positrons forming a monoenergetic tail. This work may point towards developing beam loading configurations for the positron arm of a future linear collider based on plasma wave wakefields [1],
- Highly resolved QuickPIC Simulations that show ion motion within the trailing bunch does not necessarily lead to catastrophic emittance (which measures the angular divergence of the beam) growth for plasma based acceleration based linear collider designs. Simulations using Blue Waters indicate that there are fully self-consistent beam loading scenarios for the electron arm for a future linear collider based on plasma wave wakefields,
- OSIRIS simulation of injection schemes to produce high brightness beams with unique characteristics. Plasma wave wakefields may also be a component in a compact coherent x-ray source. Using Blue Waters we have found that using ionization injection or down ramp transition region in front of an accelerator section permits the controlled injection of kA of higher current of electron beams with very small angular divergences and energy spreads. These beams can have three orders of magnitude higher brightnesses than conventional electron beam sources. Also, the macrobunches can be prebunched on nanometer scales,
- Quasi-3D OSIRIS simulations using Blue Waters allowed us to explore laser wakefield accelerators (LWFA) in the self-guided nonlinear blowout regime for current high power lasers. We found by using a 30 Joule laser it is possible to generate 8 GeV electron beams without the need for plasma channels [2],
- 3D OSIRIS simulations of Lawrence Livermore LWFA experiments in the self-modulated regime [3]. Using Blue Waters we carried out fully resolved 3D simulations of a ~pico-second class laser undergoing self-modulation. These lead to a broad spectrum of hundreds of MeV electrons from a combination of acceleration in the plasma waves and laser fields (including backscattered or reflected laser light). These electrons radiate a broad spectrum of incoherent x-rays. This scheme could lead to the development of a directional, small-divergence, and short-duration picosecond x-ray probe beam with an energy greater than 50 keV, which is desirable for high energy density science experiments.

WHY BLUE WATERS

Blue Waters provides a unique platform that enables us to perform many large scale simulations and support ongoing experiments promptly and produce works which appear in journals such as *Nature* and *Physical Review Letters*.

NEXT GENERATION WORK

Future track-1 supercomputers will most likely build on GPU or Intel Phi based hardwares with many levels of parallelism, and the UCLA simulation group have been very actively porting our codes to these architectures. In the past few years we have developed algorithms which can be optimized on generic many core architectures, including GPU's and Intel Phi's. Adding these algorithms to our production codes will allow us to investigate physics relevant to plasma-based accelerators and laser fusion. With the increased memory and processing speed of future track-1 supercomputers, we plan to investigate:

- Beam loading scenarios for linear collider designs based on plasma wakefields, including Ion effects in plasma wakefield accelerators (PWFA) with very narrow beams,
- LWFA's and PWFA's with high brightness beams,
- The long time behavior of relativistic shocks and their generation of energetic particles,
- Laser plasma interactions relevant to inertial fusion energy in two and three dimensions.

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