Working Group 2:

Computations for Accelerator Physics

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Abstract Index

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Abstract Title	**Simulation Study On The Proton Beam Self Modulation In The Plasma Wake Field Using OSIRIS and QuickPIC**
Author/Affiliation listing	**Weiming An**, Chan Joshi, Warren Mori (University of California Los Angeles) J. Thangaraj, P. Spentzouris, C. Park, J.D. Lewis (Fermilab)
Abstract	The proton beam self modulation in the plasma wake field is investigated with computational simulation. The focal length (beta star) of the proton beam is considered in the simulation since it is comparable with the beam length. A condition for the self modulation is given based on the linear theory.
Summary	
A long pulse proton beam may be self modulated when propagating in a plasma. The focal length (beta star) of the beam needs to be considered when it is less than the self-modulation distance. In addition, it is typically smaller than the bunch length for parameters at the FNAL. We show that the a condition for significant self-modulation is that a few e-foldings of growth occurs at the back of the beam within a propagation distance of 2 beta star. We describe how OSIRIS and QuickPIC are both modified for initializing the beam with the twiss parameter, through which can adjust the position of the beam focus. We use OSIRIS and QuickPIC to simulate how a 120 GeV proton beam at FNAL will self-modulate. An energy modulation ~1 GeV is observed in the simulation for reasonable emittances and spot sizes.	

Name of submitting author	Dr. Alexey Arefiev
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Abstract Title	**Parametric Amplification of Laser-Driven Electron Acceleration in a Plasma Channel**
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Abstract	The betatron frequency in a plasma channel is strongly modulated by the laser at ultrarelativistic intensities. Such modulation makes betatron oscillations parametrically unstable. The resulting amplification of the oscillations decreases electron dephasing and significantly enhances electron energy gain. The threshold is determined by a product of intensity and ion density.
Summary	
Electron heating in laser-irradiated targets is crucial for production of energetic ions and other applications, including x-ray generation and fast ignition. Electron quiver energy in a laser beam is of the order of the ponderomotive potential, which is typically below the energy range of interest. This talk will present a new collisionless mechanisms that allows electrons to gain energies significantly higher than the ponderomotive potential [Phys. Rev. Lett. 108, 145004 (2012)]. The mechanism involves an under-dense preplasma in front of a target. The laser beam creates a positively charged channel in this preplasma, so that an electron accelerated by the laser performs betatron oscillations across the channel while moving along with the beam. The betatron frequency is strongly modulated by the laser field in the ultrarelativistic limit. It has been previously overlooked that such modulation makes the oscillations parametrically unstable. T he resulting amplification of the oscillations decreases electron dephasing from the laser and thereby significantly enhances the electron energy gain. The threshold for this mechanism is determined by a product of beam intensity and ion density. This work was supported by Sandia National Laboratories, U.S. DoE, and NNSA.	

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Abstract Title	**Wakefields in photonic crystal cavities**
Author/Affiliation listing	Gregory R. Werner, University of Colorado at Boulder John R. Cary, University of Colorado at Boulder and Tech-X Corporation
Abstract	Wakefields due to low-group-velocity modes can be troublesome in photonic-crystal-based accelerating structures. We compare wakefields in hybrid dielectric-metal photonic crystal cavities and the waveguide-damped CLIC cavity.

Summary

Future particle accelerator cavities may use dielectric photonic crystals to reduce harmful wakefields and increase the accelerating electric field (or gradient). Reduced wakefields are predicted based on the bandgap property of some photonic crystals (i.e. frequency-selective reflection/transmission). Larger accelerating gradients are predicted based on certain dielectrics' strong resistance to electrical breakdown. Using computation, this work investigated a hybrid design of a 2D sapphire photonic crystal and traditional conducting cavity. The goals were to test the claim of reduced wakefields and, in general, judge the effectiveness of such structures as practical accelerating cavities. In the process, we discovered the following: (1) truncated photonic crystal cavities may confine radiation weakly compared to conducting cavities (depending on the level of truncation); however, confinement can be dramatically increased through optimizations that break lattice symmetry (but retain certain rotational symmetries); (2) photonic-crystal-based cavities do not ideally reduce wakefields; using band structure calculations, we found that flat portions of the frequency dispersion (i.e. low-group-velocity modes) increase wakefields.

cavities and the copper cavities for the Compact Linear Collider (CLIC); CLIC is one of the candidates for a future high-energy electron-positron collider that will study in greater detail the physics learned at the Large Hadron Collider. We found that the photonic crystal cavity, when compared to the CLIC cavity: (1) can lower maximum surface magnetic fields on conductors (growing evidence suggests this limits accelerating gradients by inducing electrical breakdown); (2) shows increased transverse dipole wakefields but decreased longitudinal monopole wakefields; and (3) exhibits lower accelerating efficiencies (unless a large photonic crystal is used).

Name of submitting author	David Bruhwiler
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Abstract Title	**Suppressing Transverse Beam Halo with Nonlinear Magnetic Fields**
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Abstract	Nonlinear magnetic lattices with large tune spreads and with integrable, nearly-integrable, and chaotic-but-bounded dynamics have been proposed to maximize dynamic aperture and minimize particle loss. Recent simulations of proton dynamics in such lattices, including the effects of transverse space charge, show that transverse beam halo can be suppressed.

Summary

High intensity proton storage rings are central for the development of advanced neutron sources, drivers for the production of pions in neutrino factories or muon colliders, and transmutation of radioactive waste. Fractional proton loss from the beam must be very small to prevent radio-activation of nearby structures, but many sources of beam loss are driven by collective effects that increase with intensity. Recent theoretical work has shown how to use nonlinear magnetic fields to design periodic
integrable [1], nearly-integrable [2], or chaotic-but-bounded [1] transverse dynamics. Using the parallel PyORBIT code [3], we show that these ideas remain valid in the presence of finite beam current. One such collective effect is the formation of beam halo, where particles are driven to large amplitude oscillations by coherent space charge forces. The strong variation of particle oscillation frequency w tune results in nonlinear de-coherence that is observed to suppress transverse halo development in the cases studied. We also present a necessary generalization of the Kapchinskij-Vladimirskij equilibrium distribution [4], which was introduced over 50 years ago for modeling linear dynamics in particle accelerators.

[1] V. Danilov and S. Nagaitsev, PR ST-AB 13 084002 (2010)
Cary,Phys. Rev. E 69 056501 (2004)
of IPAC (2009), p. 351. [4] I. M. Kapchinskij and V. V. Vladimirskij, in Proc. of Int'l. Conf. on High Energy Acc. (1959) p. 274.

This work was supported in part by the US Department of Energy's Office of Science, Office of High Energy Physics, under grant No. DE-SC0006247.

Name of submitting author	Dr. Min Chen
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Abstract Title	**Numerical modeling of laser tunneling ionization in explicit particle-in-cell codes**
Author/Affiliation listing	**M. Chen[1]**, E. Cormier-Michel[2], C.G.R. Geddes[1], D. Bruhwiler[2], L.L. Yu[1], E. Esarey[1], C.B. Schroeder[1], W.P. Leemans[1] 1Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA 2Tech-X Corporation, 5621 Arapahoe Ave, Suite A, Boulder, CO 80303, USA
Abstract	Methods for calculation of laser tunneling-ionization in explicit particle-in-cell codes used for modeling laser-plasma-interactions are compared against theoretical predictions. The effects of grid resolution and macro-particles numbers are examined. Implementation of the ionization algorithm in two particle-in-cell codes is compared for cases of ionization-based electron injection in a laser-plasma accelerator.

Summary

Implementation of laser tunneling ionization rate formulae in explicit PIC codes has been examined. The originally published ionization rate formulae were reviewed, and corrections noted. It was shown, by comparison to theoretical predictions, that the DC form of the ionization rate provides improved accuracy. The effect of PIC numerical parameters, such as grid resolution and number of macro-particles per cell, on the calculated ionization probability was studied. It was found that the ionization probability is sensitive to the grid resolution, and increased number of macro-particles per cell can reduce the simulation noise. Modeling the ionization injection in a laser-plasma accelerator was used to benchmark the ionization algorithm implemented in two PIC codes.

Supported by the U.S. Department of Energy under contract No. DE-AC02-05CH11231, DE-SC0004441 and DE-FC02-07ER41499, and by the COMPASS SciDAC project. Computational resources of the National Energy Research Scientific Computing Center were used to perform the simulations. We acknowledge the assistance of the VORPAL development team.

Name of submitting author	Dr. Estelle Cormier-Michel
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Abstract Title	**Low noise particle in cell simulations of laser plasma accelerator 10 GeV stages**
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Abstract	We present simulations of laser plasma accelerator stages, relevant to future BELLA experiments, with the emphasis on beam emittance evolution. Boosted frame simulations, in the VORPAL framework, are used to model full-scale 10 GeV stages. A method for numerical noise reduction is also presented.
Summary	
Because of their ultra-high accelerating gradient, laser plasma based accelerators (LPA) are contemplated for the next generation of high-energy colliders and light sources. The upcoming BELLA project will explore acceleration of electron bunches to 10 GeV in a 1 meter long plasma, where a wakefield is driven by a PW-class laser. Particle-in-cell (PIC) simulations are used to design the upcoming experiments. Here, we will focus on the emittance evolution of the accelerated beam, where boosted frame simulations are used to model the full-scale stages. Benchmarking between different boosted frames of reference and laboratory frame simulations validate the results. beam emittance become more stringent, PIC simulations become more challenging as high frequency noise artificially increases those quantities. We show that calculating the beam self-fields using a static Poisson solve in the beam frame dramatically reduces particle noise, allowing for more accurate simulation of the beam evolution. In particular, this method gets correct cancellation of the transverse self- electric and magnetic fields of the beam, eliminating artificial self-forces, which is usually not true when using the standard PIC algorithm based on the staggered (“Yee”) electromagnetic field solver. Work supported by DOE/HEP, under grants DE-SC0004441 and DE-FC02-07ER41499, including use of NERSC under DE-AC02-05CH11231.	

Name of submitting author	Benjamin Cowan
Institution	Tech-X Corporation
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Abstract Title	**Improved particle statistics for laser-plasma self-injection simulations**
Author/Affiliation listing	**B. M. Cowan** (1), S. Y. Kalmykov (2), B. A. Shadwick (2), K. Bunkers (2), D. L. Bruhwiler (1), and D. P. Umstadter (2) (1) Tech-X Corporation (2) University of Nebraska, Lincoln
Abstract	We describe methods for improving the accuracy of injected particle beams by selectively enhancing the particle statistics in PIC simulations, using reduced model computations as a guide. We demonstrate convergence of key beam parameters in 2D, and show improved noise properties in 3D.

Summary

Laser-plasma acceleration (LPA) has seen remarkable progress in recent years, with production of quasi-monoenergetic electron bunches of ever-improving energy and quality. These beams are now being investigated for use in a number of applications, including light sources and high-energy colliders. As the range of applications has increased, so have the demands on beam quality and stability. Simulations play a key role in understanding the effect of initial conditions on injected beam parameters.
challenge of simulation techniques is in obtaining accurate results that are free of numerical artifacts, while at the same time being computationally tractable. Here we present a method for improving the accuracy of simulated particle beams from the LPA self-injection process. We recently demonstrated the ability to compute the collection volume of an injection process -- the range of initial locations of injected particles [1, 2]. We find that the collection volume consists of an annular region around the propagation axis. By loading this region with higher particle statistics than in other locations, we can significantly increase the number of macroparticles in the injected beam. We show that this technique captures much finer detail of particle phase space than does uniform loading, and results in lower noise. We demonstrate convergence of key beam parameters in 2D, and present results of full 3D simulations. This technique in fact results in a lower comput ational burden, since it allows reducing particle statistics outside the collection volume.
deform and split if they expand, effectively self-generating statistics. We find that this method yields a much lower phase space volume, as well as lower charge, than conventional PIC, and also reveals much finer structure of particle phase space.

[1] B. M. Cowan et al., "Computationally efficient methods for modeling laser wakefield acceleration in the blowout regime," accepted for publication in J. Plasma Phys. (2012)
[2] S. Y. Kalmykov et al., New J. Phys. 14, 033025 (2012)

Name of submitting author	Benjamin Cowan
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Abstract Title	**Origin and mitigation of trapped modes between multicell RF accelerator cavities**
Author/Affiliation listing	**B. M. Cowan** (1), P. J. Mullowney (1), G. R. Werner (2), and J. R. Cary (1, 2) (1) Tech-X Corporation (2) University of Colorado, Boulder
Abstract	We demonstrate that the photonic bandgap effect can trap an electromagnetic mode between two multicell RF cavities. From this information we devise a simple modification to the structure geometry that eliminates such trapped modes.

Summary

Long range wakefields are generated when a particle bunch excites a resonant mode in an RF structure. Such modes can then affect subsequent bunches degrading beam quality. This is especially serious in high-energy colliders, where luminosity is achieved in part by the use of long bunch trains. It is therefore critical to understand and mitigate, to the extent possible, deleterious long range wakefields.

trapped resonant mode could exist in a beam pipe between a pair of multicell RF cavities [1]. Here we pinpoint the origin of that mode as confinement due to the one-dimensional photonic bandgap effect of the quasi-periodic, 9-cell ILC accelerator structure. We first show computations of the longitudinal bandstructure of the ILC cavity, using the Vorpal time-domain code [2] together with the filter diagonalization method for frequency extraction [3]. We then compute the trapped mode, showing that its frequency lies within the 1D bandgap of the cavity and that additional modes arise as the pipe is lengthened so that additional resonances enter the bandgap. We demonstrate that the trapped mode can be eliminated by narrowing the beam pipe, increasing its cutoff frequency into the passband of the cavity.

which were conducted using the Vorpal implementation of electromagnetics on graphics processing units.

Work supported by U. S. Department of Energy, Office of Science/High Energy Physics grant DE-FC02-07ER41499 (SciDAC).

[1] C. Ng et al., "State of the art in EM field computation," SLAC-PUB-12020 (2006).
[2] C. Nieter and J. R. Cary, J. Comput. Phys. 196, 538 (2004)
[3] G. R. Werner and J. R. Cary, J. Comput. Phys. 227, 5200 (2008).

Name of submitting author	Mr. Paul Cummings
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Abstract Title	**A Computational Investigation of Synchrotron-Like Radiation Generation in LWFA Experiments**
Author/Affiliation listing	**Paul G. Cummings**, University of Michigan CUOS Alec G. R. Thomas, University of Michigan CUOS
Abstract	The generation of synchrotron radiation in LWFA experiments is investigated computationally. A novel computational model for explicitly simulating synchrotron radiation is derived and validated. Results from simulations run using this model within the PIC code OSIRIS 2.0 are presented.

Summary

A promising application of laser-wake-field acceleration (LWFA) technology is as a tunable source of x-ray and gamma radiation, via synchrotron-like radiation. Such a source could have many potential applications, including microscale imaging of advanced -tomo compo challenge, as an exact self-consistent solution involves a path inte time particles' entire trajectories. Consequently, a novel computational model which approximates this process using a -carlo algorithm to generate particle-like "macrophotons" was developed, and integrated into the well-known, robust -in-part cell (PIC) code OSIRIS 2.0. Validation of this algorithm was performed using a separate, skeleton particle-tracking code; validation results, resulting from integrating the algorithm into OSIRIS 2.0, will also be presented. Finally, preliminary results from simulations of recent LWFA experiments [1], which investigated the generation of synchrotron-like radiation, are presented and discussed.

1: Mangles, S. P. D., et al. "Controlling the spectrum of x-rays generated in a laser-plasma accelerator by tailoring the laser wavefront." Applied Physics Letters 95 (2009).

Name of submitting author	Prof. Emmanuel d'Humières
Institution	Univ. Bordeaux / CNRS / CEA - CELIA, Talence, France.
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Abstract Title	**Laser ion acceleration in the ultra-high laser intensity regime**
Author/Affiliation listing	R. Capdessus - Univ. Bordeaux / CNRS / CEA - CELIA, Talence, France. V. T. Tikhonchuk - Univ. Bordeaux / CNRS / CEA - CELIA, Talence, France.
Abstract	Radiation losses of electrons in ultra-intense laser fields constitute a process of major importance when considering laser-matter interaction at ultra-high intensities. A study of the effect of radiation friction on the electron and ion dynamics in various regimes of ion acceleration is presented.

Summary

Radiation losses of electrons in ultra-intense laser fields constitute a process of major importance when considering laser-matter interaction at ultra-high intensities. Radiation losses can strongly modify the electron (and in turns ion) dynamics, and are associated with intense and directional emission of high energy photons. Accounting for such effects is therefore necessary to obtain a correct modeling of electron and ion acceleration and creation of secondary photon sources at the forthcoming ultra-high power laser facilities. To account for radiation losse -in-code PICLS, we have introduced the radiation friction force obtained by Sokolov [1] using a renormalized Lorentz-Abraham-Dirac model. The associated angular and energy spectra of the radiated high-energy photons are also computed. A study of the effect of radiation friction on the electron and ion dynamics in various regimes of ion acceleration is presented [2]. A wide range of laser intensity, target thickness and target density is explored, allowing for the study of directed-Coulomb-explosion (DCE) of nanometric targets, radiation pressure acceleration (RPA) of thin foils, and hole-boring (HB) of semi-infinite targets. We will discuss the effect of radiation losses on the electron heating and accelerated ion energy spectrum. In particular, we will show that the piston velocity in the HB regime is reduced, and that its correct modeling requires to account for the high-energy photon momentum flux in the pressure balance [3]. The regime of low density targets has also been investigated. Finally, the angular and energy spectra of high-energy photons for all three overdense interaction regimes (DCE, RPA and HB) will also be discussed.

1. V. Sokolov et al, Phys. Rev. E 81, 036412.
2. R. Capdessus, et al., submitted to Phys. Rev. E, Modeling of radiation losses in ultra-high power laser matter interaction. E. d'Humières, et al., proceding IFSA 2011, Laser ion acceleration in the high laser energy and high laser intensity regimes.
3. R. Capdessus, et al., proceding IFSA 2011, Modeling of radiation losses for ion acceleration at ultra-high laser intensities.

Name of submitting author	Bela Erdelyi
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Abstract Title	**The Fast Multipole Method for N-Body Problems**
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Abstract	Many collective beam effects can be formulated as N-body problems. Along with advances in computing technologies, algorithmic improvements allow accurate and efficient solutions for very large N. We will present the fast multipole method, one of the most important advances towards that end.

Summary

The Fast Multipole Method (FMM) [1] has been called one of the Top 10 algorithms of the 20th century [2] and many experts hold that regarding numerical methods generically "the future belongs to multipole methods" [3]. In general terms, from the simulation point of view, the system can be stated as follows: given N particles with strengths q_i, they are undergoing mutual interaction based on their relative positions mediated by a kernel K with particles of strength q_j for i, j=1,2,…,N, j≠i. Therefore, the problem can be thought of as being a generic N-body problem. Each particle in the beam interacts with every other particle, for example through long-range Coulomb forces. Therefore, if there are N particles in the beam, there are a total of N(N-1) total interactions. We say that the operation count to solve such a system scales with the square of the number of particles, O(N^2). For large N, this quickly becomes intractable even for today's fastest and largest computers. Over the last couple of decades, new algorithms have been developed to reduce the O(N^2) scaling to O(NlogN), or even O(N). These new methods allowed the increase of the system sizes that one can study due to the improved scaling and reduced running times. One of the most important such method is the fast multipole method, deemed one of the Top 10 algorithms of the 20th century by SIAM. Since the late eighties several groups have further modified, enhanced and adapted the method to different circumstances. Among other things, implementation on parallel architectures such as CPU, GPU and hybrid clusters have been reported, and became winners of the prestigious Gordon Bell prize. This talk will present work in progress towards application of the FMM in beam dynamics, including some algorithmic improvements.

References:

1. L. Greengard and V. Rokhlin, A Fast Algorithm for Particle Simulations, J. Comp. Phys. 73 (1987) 325-348.
2. J. Dongarra and F. Sullivan, The Top 10 Algorithms, Computing Science & Eng., 2(1) (2000) 22-23.
3. V. Rokhlin, Response to 2001 Steele Prize Seminal Contribution to Research; L.N. Trefethen, Prediction for Scientific Computing Fifty Years From Now, Math. Today

(2000).

Name of submitting author	Frederico Fiuza
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Abstract Title	**Full-scale modeling of ion acceleration from laser-solid interactions**
Author/Affiliation listing	**F. Fiuza** / GoLP - Instituto de Plasmas e Fusão Nuclear, Instituto Superior Tecnico (Portugal) R. A. Fonseca / GoLP - Instituto de Plasmas e Fusão Nuclear, Instituto Superior Tecnico (Portugal) L. O. Silva / GoLP - Instituto de Plasmas e Fusão Nuclear, Instituto Superior Tecnico (Portugal) W. B. Mori / UCLA
Abstract	We show that a new hybrid-PIC framework, that couples collisional full-PIC and MHD algorithms can be used to model in full-scale ion acceleration from laser-solid interactions, providing important insight on the impact of the collisional transport and of multi-dimensional effects on the ion beam characteristics.

Summary

Ion acceleration from the interaction of ultrahigh intensity lasers with solid-density targets is a promising approach for compact and bright ion sources. Numerical simulations play an important role in understanding the underlying physics and optimizing the ion beam energy and quality of these experiments. However, the different spatial and temporal scales involved make this modeling extremely demanding and multi-dimensional full-scale simulations are not yet possible to accomplish. The understanding of the importance of multi-dimensional effects and the self-consistent coupling of the different scales has been a long-standing problem.

proposed a novel framework for modeling inhomogeneous plasmas that merges accurate collisional PIC models between regions where only the field solver is reduced in the collisional region. This framework has been integrated into OSIRIS 2.0 [2], which together with higher order particle shapes and dynamic load balancing is allowing the first multi-dimensional simulations of ion acceleration in solid targets over full density and time scales. We will demonstrate how OSIRIS can be used to perform for the first time three-dimensional (3D) full-scale simulations of ion acceleration, where the critical issues of laser absorption, electron transport in the collisional plasma, and ion acceleration will be addressed in a fully self-consistent manner. Our results, for different laser intensities, target thicknesses and compositions, shed light on the importance of multi-dimensional effects in the different ion acceleration mechanisms, and provide an integrated physical picture of the overall interaction and clear directions for future experiments.

[1] B. Cohen, A. Kemp, L. Divol, J. Comp. Phys. 229, 4591 (2010)
[2] F. Fiuza et al. Plasma Phys. Control. Fusion 53, 074004 (2011)

Name of submitting author	Ricardo Fonseca
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Abstract Title	**Modeling Laser Wakefield Acceleragtion on Tier-0 systems**
Author/Affiliation listing	**R.A.Fonseca** (1,2), A. Davidson(3), F.S.Tsung (3), L.O.Silva (1), W.B.Mori (3) 1 – IPFN/IST, Lisbon 2 – DCTI/ISCTE - Lisbon University Institute 3 – UCLA
Abstract	Large scale modeling of LWFA using particle-in-cell codes on Tier-0 systems, with core counts the order of ~10^5, requires extreme scalability and high single core efficiency. In this work we discuss the algorithms we have implemented to address these issues, presenting recent results from the 2011 OASCR Joule project.
Summary	
Fully relativistic particle-in-cell codes such as OSIRIS [1] have established themselves as the tool of choice for modeling plasma based accelerators, but given the computational requirements of these algorithms detailed full scale 3D modeling of these scenarios require efficient use of Tier-0 supercomputing systems throughout the full simulation, not only at a single CPU level, but also ensuring good parallel scalability to hundreds of thousands of computing cores. For laser wakefield acceleration (LWFA) this is a particularly difficult task given the particle dynamics involved, since there will be a significant accumulation of particles in a small region of space trailing the laser pulse. With core counts the order of 105, this causes a significant load imbalance to occur, significantly degrading code performance. We report on the new developments in the OSIRIS framework implemented to address these issues, extending our previous work on dynamic load balance [2] to work with 3D partitions. We also discuss a hybrid distributed / shared memory parallelization strategy for this problem. The performance of the new features implemented was tested on the full Jaguar system at the Oak Ridge Natl. Lab. in the US, within the 2011 OASCR Joule Software Effectiveness Metric project, that aims to analyze/improve applications requiring high capability/capacity HPC systems. We will present the results obtained focusing on the numerical performance and efficiency of the solutions implemented and finally we will discuss the differences observed from lower resolution runs, in terms of energy distribution, charge and emittance of self injected beams in the LWFA scenarios analyzed. [1] R. A. Fonseca et al., LNCS 2331, 342 (2002) [2] R. A. Fonseca et. al., PPCF 50, 124034 (2008)	

Name of submitting author	Mr. Spencer Gessner
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Abstract Title	**Simulations of Positron Beams at FACET**
Author/Affiliation listing	SLAC: Erik Adli, Sebastien Corde, Joel England, Joel Frederico, Mark Hogan, Selina Li, Michael Litos, Ziran Wu UCLA: Warren Mori, Weiming An
Abstract	We rely heavily on particle-in-cell simulations, such as QuickPIC, to provide insight into the evolution of a high charge density positron beam in a plasma. These studies are interesting in the context of both electron-positron plasma wakefield colliders and for modeling proton beams in plasmas.

Summary

FACET is uniquely equipped to deliver high energy, high charge density positron bunches for plasma wakefield acceleration experiments. We look forward to studying the interaction between positron beams and plasmas in a number of different contexts.
toward the beam axis, creating a region of extremely large charge density with complicated, nonlinear fields. Few analytic solutions exist to describe these fields, and this necessitates the use of simulations to model positron beam and plasma interactions. This presentation will cover recent work on positron PWFA simulations using the QuickPIC* particle-in-cell code. I will discuss the computational challenges associated with positron PWFA and specific applications of the simulations for future experimental tests at the FACET user facility at SLAC.
positron beams to model proton-plasma interactions, due to the prospect of a new plasma wakefield experiment at CERN. The betatron frequency of the beam in plasma is the scaling parameter that allows us to compare the evolution of positron and proton beams at different energies and plasma densities. I will compare the evolution of a positron beam in a typical FACET plasma with a density of ~10^17 cm^-3 to the proton beam described in Caldwell's paper**. Of particular interest is the distance required for an underdense positron bunch to evolve and drive a nonlinear wake.

* C. Huang et al., "QuickPIC: A highly efficient particle-in-cell code for modeling wakefield acceleration in plasmas," J. Comp. Phys. 217, 658 (2006).

** A. Caldwell et al., "Proton-driven plasma-wakefield acceleration," Nature Physics 5, 363-367 (2009).

Name of submitting author	Dr. Daniel Gordon
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Abstract Title	**Ionization Physics and Laser Acceleration of Electrons**
Author/Affiliation listing	Antonio Ting, Michael Helle, Dmitri Kaganovich, Bahman Hafizi* Naval Research Laboratory, Washington, DC Icarus Research, Inc., Bethesda, MD
Abstract	Tunneling ionization is characterized using an ab initio quantum mechanical numerical model. Numerical ionization rates are compared with theoretical ones. The ionized phase space distribution is characterized by computing the Wigner transform of the simulated wave function. The implications for PIC simulations are discussed.
Summary	
Laser acceleration of electrons is often most successful when the pre-pulse is small, so that the main pulse interacts with neutral gas. This suggests that the ionization process plays a role in electron trapping. Indeed, tunneling ionization is cited as playing a major role in various laser acceleration experiments [Moore et al., Phys. Rev. Lett. 82, 1688 (1999), Kaganovich et al., Phys. Rev. Lett. 100, 215002 (2008), Pollock et al., Phys. Rev. Lett. 107, 045001 (2011)]. An important tool for modeling laser acceleration of electrons is the Particle-in-Cell (PIC) code. When tunneling ionization is important, PIC codes are usually modified to spawn macro-particles at rest at a rate given by some simple tunneling theory, such as the ADK model [M.V. Ammosov et al., Sov. Phys. JETP 64, 1191 (1986)]. Such models are arrived at only after many approximations are made. It is of interest, therefore, to characterize the ionization process using a numerical model that makes very few approximations. For this purpose, we have developed a full-scale model for an atom in an arbitrary applied field that solves the exact non-relativistic time dependent Schroedinger equation. Since the output is the full electronic wave function, all parameters characterizing the ionized electrons can be determined. Of particular interest is the classical phase space distribution of the particles, which can be determined by evaluating the Wigner distribution in the quasi-classical region (far from the atom). We will compare the numerical ionization rates of hydrogen and helium with those derived from a variety of ionization theories. The phase space distribution of the ionized electrons will be given, and the implications for PIC simulations will be discussed. This work is supported by the Naval Research Laboratory Base Program, the Department of Energy, and by NERSC	

Name of submitting author	Dr. Daniel Gordon
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Abstract Title	**Nonlinear Optics in a PIC Framework**
Author/Affiliation listing	Michael Helle, Joe Penano, Bahman Hafizi*, Antonio Ting, Dmitri Kaganovich Naval Research Laboratory, Washington, DC *Icarus Research, Inc., Bethesda, MD
Abstract	A numerical model that incorporates nonlinear optical materials into a particle-in-cell (PIC) framework is described. In terms of advanced accelerators, the model is useful for modeling the interaction of ultra-short electron bunches with electro-optic crystals, or dielectric structures. The algorithm is detailed, and results pertaining to advanced accelerators are presented.
Summary	
The interaction of an ultra-short electron bunch with nonlinear optical materials is of interest in connection with a variety of acceleration and radiation generation processes, such as electro-optic sensing, acceleration in dielectric structures, transition radiation processes, or Smith-Purcell processes. To model the fields due to an ultra-short, relativistic, electron bunch, the particle-in-cell technique is often used. Many of the techniques that are used to model free charges can be adapted to model bound charges in anharmonic, anisotropic, potential wells. By loading a multi-species population of such bound charges onto the numerical grid, one may simulate the dielectric response of a real material over a broad range of frequencies. The numerical dispersion relation and stability criterion are discussed in relation to those of an ordinary PIC code. Source deposition techniques for bound charges are compared with those for free charg es. Results from the code are presented, illustrating ordinary nonlinear optics, the nonlinear optics of nano-composites, and the interaction of an ultra-short electron bunch with electro-optic crystals [M.H. Helle et al., Phys. Rev. ST/AB, accepted]. This work is supported by the Naval Research Laboratory Base Program, the Department of Energy, and by NERSC	

Name of submitting author	Aydin Keser
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Abstract Title	**Role of Nottingham and Thomson effects in heating of micro-protrusion in high-gradient accelerating structures.**
Author/Affiliation listing	**A. C. Keser** (1), G. S. Nusinovich (1), D. G. Kashyn (1), and T. M. Antonsen, Jr.(1) (1)Institute for Research in Electronics and Applied Physics University of Maryland MD 20742, USA
Abstract	RF field penetration inside protrusion of a metal with finite conductivity is considered. Field profile is obtained and heat equation is simulated on a Finite Element Analysis framework. Thomson Effect and Nottingham heating cooling is coupled to the model and their effects on the heating and field profiles are discussed.

Summary

Role of Nottingham and Thomson effects in heating of micro-protrusion in high-gradient accelerating structures. Keser, G. S. Nusinovich, D. G. Kashyn, and T. M. Antonsen, Jr.

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appearance of the RF breakdown which limits operation of high-gradient accelerating structures is the electron dark current [1]. This field-emitted current, usually considered as a precursor of the breakdown, can be emitted from apexes of microprotrusions on a structure surface. Therefore field and thermal processes in such protrusions deserve careful studies [2, 3]. The goal of our first study [3] was to analyze 2D process of RF field penetration inside protrusion of a metal with finite conductivity and to study corresponding Joule heating. In the present study, we include into consideration, first, the Nottingham effect, which may significantly change the protrusion heating. Then, since protrusion heating in high-power, short-pulse operation can be strongly non-uniform, we include into consideration also Thomson effect, which predicts additional heating/cooling in non-uniformly heated conductors.

[1] Wang and Loew, SLAC PUB 7684 October 1997

[2]K.L.Jensen,Y.Y. Lau, D.W. Feldman, P.G. O'Shea, Phys. Rev. ST Accel.Beams 11, 081001(2008)

[3] Kashyn et al, AAC-2010.

Name of submitting author	Frank Lee
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Abstract Title	**Modeling Asymmetric Beams with Higher-order Phase-space Moments**
Author/Affiliation listing	B. A. Shadwick, G. M. Tarkenton, E. Esarey, P. J. Morrison
Abstract	Previously, Shadwick et al. introduced a phase-space-moment description of electron beam acceleration. The method was limited to beams with symmetric phase-space distribution. Here, we expand upon that work by describing the distribution as a sum of symmetric phase-space "blobs" to account for asymmetric beams.
Summary	
Previously, Shadwick et al. introduced a phase-space-moment description of electron beam acceleration. The method was limited to beams with symmetric phase-space distribution. Here, we expand upon that work by describing the distribution as a sum of symmetric phase-space "blobs" to account for asymmetric beams.	

Name of submitting author	Dr. Vasiliy Morozov
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Abstract Title	**Parametric-Resonance Ionization Cooling of Muon Beams**

Author/Affiliation listing	**V.S. Morozov**, Ya.S. Derbenev, Jefferson Lab, Newport News, VA A. Afanasev, George Washington University, Washington, D.C. K.B. Beard, R.P. Johnson, Muons, Inc., Batavia, IL B. Erdelyi, J.A. Maloney, Northern Illinois University, DeKalb, IL

Abstract	Combining muon ionization cooling with parametric resonant dynamics should allow much smaller final transverse muon beam sizes than ionization cooling alone. This resonant cooling scheme should provide equilibrium transverse emittances that are at least an order of magnitude smaller than those achievable with conventional ionization cooling.

Summary

Proposed next-generation muon collider will require major technical advances to achieve the rapid beam cooling requirements. Parametric-resonance Ionization Cooling (PIC) is proposed as the final 6D cooling stage of a high-luminosity muon collider. Combining muon ionization cooling with parametric resonant dynamics should allow much smaller final transverse muon beam sizes than conventional ionization cooling alone high luminosity would be achieved in a collider with fewer muons. -resonance Ionization Cooling (PIC) is accomplished by inducing a half-integer parametric resonance in a muon-cooling channel. The beam is then naturally focused with a period of the channel's free oscillations. The channel is designed with correlated values of the horizontal and vertical betatron periods so that focusing occurs in both planes simultaneously. Absorber plates for ionization cooling followed by energy-restoring RF cavities are placed at the beam focal points. At the absorbers, ionization cooling limits the angular spread while the parametric resonance causes a strong reduction of the beam spot size. This resonant cooling scheme should provide equilibrium transverse emittances that are at least an order of magnitude smaller than those achievable with conventional ionization cooling. A twin-helix cooling channel design has been proposed for the implementation of PIC. This channel utilizes pairs of helical magnetic fields with matching field strengths and periodicities but opposite helicities. Continuous multipole fields are also superimposed on the channel. This channel can be adjusted to meet the correlated optics requirements when the horizontal and vertical betatron tunes are integer multiples of each other and of the dispersion function of the beam. Parametric resonances are introduced in both planes inside the channel using additional pairs of helical magnets. Initial cooling simulation results are presented. The problem of aberration compensation is discussed. Possible practical

implementations of a twin-helix channel are suggested.

Name of submitting author	Jonathan Reyes
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Abstract Title	**An unconditionally-stable numerical method for laser-plasma interactions**
Author/Affiliation listing	**J. Paxon Reyes** / University of Nebraska - Lincoln B. A. Shadwick / University of Nebraska - Lincoln
Abstract	We present an implicit midpoint method for solving the cold Maxwell-fluid equations in a co-moving coordinate system in one dimension. The method's stability and accuracy are compared to a purely explicit method. This work is motivated by our research in laser-plasma accelerators.

Summary

We have previously presented results from a survey of various numerical methods to solve the one-dimensional cold Maxwell-fluid equations [1]. Here we discuss an implicit midpoint method that allows computations with appropriately large time steps. Using explicit methods, temporal step sizes are constrained by stability conditions and are much smaller than the time scales involved in the evolution of the fields. We introduce an unconditionally-stable midpoint method, allowing much larger time steps than is possible by explicit methods. The extra cost in solving implicit equations is negligible compared to the speed up in computational efficiency. The numerical dispersion relation identifies not only the stability of the method but also its accuracy. We consider a laser pulse propagating through a linearized plasma and calculate its numerical group velocity. The wave equation supports counter propagating waves and we show that the respective group velocities depend on the size of the time step: the forward-moving wave is insensitive to the step size but the backward-moving wave has a strong step size dependence. Since we use the moving coordinates specifically to follow the seeded forward-moving wave, we are not so concerned with the errors in the backward wave.

benchmark, we compare results from the midpoint method, showing that for the same level of accuracy the midpoint method can utilize much larger step sizes in time and is far more computationally efficient.

[1] J. Paxon Reyes and B. A. Shadwick, AIP Conf. Proc. 1299, pp. 256-261

Name of submitting author	Mr. Francesco Rossi
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Abstract Title	Robust algorithms for current deposition and efficient memory usage in a GPU Particle In Cell code
Author/Affiliation listing	Francesco Rossi, Stefano Sinigardi ,Giorgio Turchetti (University of Bologna and INFN Bologna); Pasquale Londrillo (INFN Bologna); Andrea Sgattoni (Politecnico di Milano and CNR INO Pisa)
Abstract	We present a 3D relativistic electromagnetic Particle-In-Cell (PIC) code, running simulations in various laser-plasma acceleration regimes on Graphics-Processing-Units (GPUs) clusters, using standard FDTD schemes in double precision with quadratic particle shape functions. We discuss our strategies for robust particle-to-grid operations, asynchronous particle streaming (overcoming GPU memory limitations) and meta-programming. Detailed benchmarks are presented.

Summary

We present 'Jasmine', an implementation of a fully relativistic, 3D, electromagnetic Particle-In-Cell (PIC) code, capable of running simulations in various laser plasma acceleration regimes on Graphics-Processing-Units(GPUs) HPC clusters. -Standard energy/charge prese -based algorithms have been implemented using double precision and quadratic rather than linear shape functions for the particle weighting.

environment), the particle-to-grid operations (e.g. the evaluation of the current density) need special care to avoid memory inconsistencies and conflicts.

that is efficient for any number of particles per cell and particle shape function order. Our algorithm exploits the exposed GPU memory hierarchy and avoids the use of atomic operations, which can hurt performance especially when many particles lay on the same cell. Running demanding simulations on GPUs comes with the great advantage of the high processing power available on the graphic boards at the expense of the rather limited memory available per board. We have tackled the GPU memory limitation problem streaming particle chunks asynchronously from the main node memory to the GPUs. This chunking technique can also be used to hide the network transfer overhead occurring in the multi-GPU parallelization.

high level of modularity and allows for easy performance tuning and simple extension of the core algorithms to various simulation schemes.

their detailed setup information, performance analysis and relative speedup factors versus our CPU PIC code ALaDyn.

References:

Birdsall,Langdon. Plasma physics via computer simulation.

Benedetti,Sgattoni,Turchetti,Londrillo. ALaDyn: A High-Accuracy PIC Code for the Maxwell-Vlasov Equations. IEEE Transactions on Plasma Science, 36(4),2008.

Burau,Widera,Hönig,Juckeland,Debus,Kluge,Schramm,Cowan,Sauerbrey,Bussmann. PIConGPU: A Fully Relativistic Particle-in-Cell Code for a GPU Cluster, IEEE Transactions on Plasma Science 38(10).

Abreu,Fonseca Pereira,Silva. PIC Codes in New Processors:A Full Relativistic PIC Code in CUDA-Enabled Hardware With Direct Visualization.IEEE Transactions on Plasma Science,vol.39,issue 2.

Kong,Huang,Ren,Decyk.Particle-in-cell simulations with charge-conserving current deposition on graphic

processing units. J.Comput.Phys.230,4(February2011).
Sengupta,Harris,Zhang,Owens.Scan primitives for GPU computing.In Graphics Hardware 2007, Aug.2007.
*Hoberock,Bell.Thrust:A ParallelTemplat

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Abstract Title	**Virtual Detector of Synchrotron Radiation (VDSR) – the C++ parallel code for particle tracking and radiation calculation**
Author/Affiliation listing	**S. Rykovanov,** M. Chen, C.G.R. Geddes, C. B. Schroeder, E. Esarey, and W. P. Leemans Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA
Abstract	A parallel computer code for the calculation of radiation emitted from single particles or a particle beam moving in given electro-magnetic fields is described. The application of the code to the calculation of betatron radiation from LPA electrons as well as Thomson and Compton scattering is discussed.

Summary

The Virtual Detector for Synchrotron Radiation (VDSR) is a parallel C++ code developed to calculate the incoherent radiation from a single charged particle or a beam moving in given external electro-magnetic fields. We introduce the code structure and features and present the results of calculations for different cases relevant to the activities of the LOASIS group. That includes the Laser Plasma Acceleration (LPA) of the electrons and the betatron radiation generated in this process, as well as x-ray and gamma-ray sources based on Thomson and Compton scattering. We present parameter studies of the radiation, and discuss the differences in the radiation spectrum for classical particle motion and particle motion that includes the radiation reaction.

Supported by the U.S. Department of Energy under contract No. DE-AC02-05CH11231 and DOE NNSA DNN.

Name of submitting author	Yasuhiko Sentoku
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Abstract Title	**Numerical modeling of proton acceleration by micro-focusing ultra-intense laser pulses**
Author/Affiliation listing	**Y. Sentoku**[1], M. Nakatsutsumi[2], J. Fuchs[2] 1) Department of Physics, University of Nevada, Reno, Nevada 89557, USA 2) LULI, École Polytechnique, CNRS, CEA, UPMC, 91128 Palaiseau Cedex, France
Abstract	Micro-focusing of ultra-intense laser light has been demonstrated by using plasma re-focusing mirrors. It is observed that the resulting laser intensity increase allows pushing up the maximum energy of protons accelerated to multi-MeV energies from solid targets, as well as the conversion efficiency from laser to protons.
Summary	
With the advent of high-powered, short pulse lasers, it becomes possible to extend laser intensities to 10^21 W/cm^2. By applying a micro-focusing device such as the recently developed elliptical plasma mirror, it is possible to focus the beam to a micron-scale spot, thus enhancing the intensity more than an order of magnitude [1]. Boosting proton acceleration by such micro-focusing ultra-intense laser pulses has been demonstrated by M. Nakatsutsumi, et al. [2] with the LULI 100 TW laser system. Also we had been working on numerical modeling of the ultra-intense laser matter interaction to study absorption, transport and particle acceleration. Our modeling is based on Particle-in-Cell scheme (PICLS), which includes atomic physics such as the Coulomb collision, ionizations, and radiation. Especially when the laser pulse interacts with a high Z target such as a gold, the atomic physics becomes important to determine the plasma condition in the interaction region and also the energy transport inside the target. Two-dimensional PICLS simulation explains well the proton energy observed in the micro-focusing experiment. The experimental results, modeling details and also the speculation for the future parameters are discussed in this talk. [1] M. Nakatsutsumi, A. Kon, S. Buffechoux et al., Opt. Lett. 35, 2314 (2010). [2] “Boosting proton acceleration by micro-focusing ultra-intense laser pulses”, M. Nakatsutsumi, S. Buffechoux, Y. Sentoku et al., submitted to PRL.	

Name of submitting author	Prof B. A. Shadwick
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Abstract Title	**A Reduction of the Vlasov-Maxwell System Using Phase-Space Blobs**
Author/Affiliation listing	**B. A. Shadwick**, Department of Physics and Astronomy, University of Nebraska - Lincoln Frank M. Lee, Department of Physics, The University of Texas at Austin
Abstract	We develop a new computational approach to the Vlasov-Maxwell equation, representing the distribution by a superposition of extended phase-space "blobs." The primary advance of this technique over traditional particle methods is the near elimination of macro-particle "noise." Furthermore, the distribution function can be readily reconstructed at any instant.

Summary

We develop a new computational approach to solving the Vlasov-Maxwell equation by representing the distribution function by a supper-position of finite-extent phase-space "blobs." Each blob evolves as a warm beamlet [1] driven by the collective plasma fields. The underlying approximation treats each blob as a different plasma species and, as such, makes a counting error, which we expect to be reflected in the system entropy. This approach results in a non-canonical Hamiltonian model, inheriting various properties of the original system. The primary advance of this technique over traditional Lagrangian particle methods is the near elimination of macro-particle ``noise." Since we are evolving elements of phase-space, the distribution function can be readily reconstructed at any instant. We discuss the performance and convergence of this model using a variety of standard examples.

[1] B. A. Shadwick, et al., "Hamiltonian Reductions for Modeling Relativistic Laser-Plasma Interactions," Commun. Nonlinear Sci. Numer. Sim.} 17, 2153 (2012).

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Name of submitting author	Mr. Chukman So
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Abstract Title	**Simulating Autoresonant Phase Space Manipulation of Antiprotons for Antihydrogen Synthesis**
Author/Affiliation listing	ALPHA Collaboration, Cern, Switzerland William Bertsche, Swansea University and University of Manchester, United Kingdom Joel Fajans, University of California Berkeley, United States, Lazar Friedland, The Hebrew University, Israel **Chukman So**, University of California Berkeley, United States, Jonathan Wurtele, University of California Berkeley and Lawrence Berkeley National Laboratory, United States
Abstract	The autoresonant phase space manipulation of antiprotons and positrons in a nested Penning-Malmberg trap in ALPHA is simulated with a one-dimensional Vlasov-Poisson solver that employs the Piecewise Parabolic Method for reconstruction. The simulation results are compared with experimental measurements and benchmarked against other numerical schemes and theory.

Summary

In the ALPHA antihydrogen experiment, antiprotons are prepared axially next to a cold positron plasma in a nested Penning-Malmberg trap. A superimposed magnetic minimum trap with well depth of O(1e-4) eV is energised before the antiprotons are mixed with positrons to form antihydrogen. Since the species have a self-field of O(0.1) V and a shot-to-shot fluctunation of ~5%, and the external confining potential has O(1) V of potential, a straight-forward injection by morphing the nested wells will produce antihydrogen way beyond the magnetic minimum trap energy. ALPHA overcomes the problem by autoresonantly exciting the axial oscillation of the antiproton plasma though a weak perturbation until it crosses into the positrons. Once injection occurs, phase lock between the antiproton and the perturbation is lost and antiproton energy will no longer increase[1][2]. We developed a numerical model to understand the phase space excitation and mixing dynamics, and to optimise antiproton injection efficiency and temperature. The model assumes a strong axial magnetic field which suppresses transverse dynamics. The bunch is regarded as collection of concentric radial tubes, in each of which antiprotons are constrained to move in only the axial direction, and is described by a distribution in 1D phase space. These distributions evolve according to the 1D Vlasov equation, which is discretised using the Piecewise Parabolic reconstruction Method[3]. These tubes couple with each other electrostatically through the Poisson equation, which is solved with a numerical Greens function. The neighboring positrons are modeled as a zero-temperature water bag plasma and react to the perturbation quasi-statically. The simulation results are compared with (i) the analytic expressions for autoresonant excitation of a non-linear oscillator, (ii) a single-partic le solver that ignores collective effect of the antiprotons, (iii) a spectral 1D Vlasov solver used in [4], and (iv)

experimental data.
G. Andresen et al. (ALPHA Collaboration), Nature Phys. 7, 558 (2011)
Woodward, J. Compu. Phys. 54, 174-201 (1984)
(2009)

Name of submitting author	Dr. Peter Stoltz
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Abstract Title	New approaches to multipacting modeling with application to high gradient structures
Author/Affiliation listing	**Peter Stoltz**/Tech-X Chet Nieter/Tech-X
Abstract	We discuss a new approach to multipacting modeling that allows modeling of multiple power levels in one simulation. This allows one to quickly scan power levels to find levels that may be susceptible to multipacting. We demonstrate this capability on a coax damping structure designed for high gradient crab cavities.

Summary

We discuss a new approach to multipacting modeling that allows modeling of multiple power levels in one simulation. This allows one to quickly scan over power levels to find levels that may be susceptible to multipacting. We demonstrate this capability on a coax damping structure designed for high gradient crab cavities.

Name of submitting author	Dr. Seth Veitzer
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Abstract Title	**Application Of New Simulation Algorithms For Modeling rf Diagnostics Of Electron Clouds**
Author/Affiliation listing	**Seth A. Veitzer**/Tech-X Corporation David N. Smithe/Tech-X Corporation Peter H. Stoltz/Tech-X Corporation
Abstract	Modeling traveling wave rf diagnostics of electron clouds in accelerators is challenging due to large differences in scales required to describe both rf propagation and simultaneously resolve spectral sidebands at low frequencies. We present applications of advanced algorithms for simulating electron clouds including modulated plasma dielectric and port boundary models.

Summary

Traveling wave rf diagnostics of electron cloud build-up show promise as a non-destructive technique for measuring plasma density and the efficacy of mitigation techniques. However, it is very difficult to derive an absolute measure of plasma density from experimental measurements for a variety of technical reasons. Detailed numerical simulations are vital in order to understand experimental data, and have successfully modeled build-up. Such simulations are limited in their ability to reproduce experimental data due to the large separation of scales inherent to the problem. Namely, one must resolve both rf frequencies in the GHz range, as well as the plasma modulation frequency of tens of

microseconds.

that allow us to bridge the simulation scales

be directly compared to experiments. The first method is to use a plasma dielectric model to measure plasma-induced phase shifts in the rf wave. The dielectric is modulated at a low frequency, simulating the effects of multiple bunch crossings. This allows simulations to be performed without kinetic particles representing the plasma, which both speeds up the simulations as well as reduces numerical noise from interpolation of particle charge and currents onto the computational grid. Secondly we utilize a port boundary condition model to

to launch the rf into the simulation. This

by restricting rf frequencies better than adding an external (finite) current source to drive rf, and absorbing layers at the boundaries. We also explore the effects of non-uniform plasma densities on the simulated spectra.

Name of submitting author	Sunghwan Yi
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Abstract Title	**Analytic model of electron self-injection in a plasma wakefield accelerator in the strongly nonlinear bubble regime**
Author/Affiliation listing	**S.A. Yi**, V. Khudik, G. Shvets The Department of Physics and Institute for Fusion Studies, The University of Texas at Austin
Abstract	Self-injection of background plasma electrons in plasma wakefield accelerators in the highly nonlinear bubble regime is analyzed using particle-in-cell and semi-analytic modeling. It is shown that the return current in the bubble sheath layer is crucial for accurate determination of the trapped particle trajectories.
Summary	
We study self-injection into a plasma wakefield accelerator (PWFA) in the blowout (or bubble) regime with an inhomogeneous background plasma density. Using an analytic model and particle-in-cell simulations, we explore an injection mechanism into a PWFA, where a growing bubble causes reduction of the electron Hamiltonian in the co-moving frame, which leads to electron trapping [1,2]. In contrast to earlier work with steep density gradients, growth of the blowout region is caused by a slow decrease in plasma density along the propagation direction. To demonstrate this trapping mechanism, we generalize an analytic model for the wakefields inside the bubble [3], to derive expressions for the fields outside. With this extended model, we study the trapping of initially quiescent plasma electrons into the growing ultra-relativistic bubble, and show that a return current in the bubble sheath layer plays an important role in determining the trapped electron trajectories. We estimate the plasma density gradients and driver beam parameters required for self-injection, and compare our results with particle-in-cell simulations. This work is supported by the US DOE grants DE-FG02-04ER41321 and DE-FG02-07ER54945. [1] S. Kalmykov, S.A. Yi, V. Khudik, and G. Shvets, Phys. Rev. Lett. 103, 135004 (2009). [2] S.A. Yi, V. Khudik, S. Kalmykov, and G. Shvets, Plasma Phys. Contr. Fus. 53, 014012 (2011). [3] W. Lu, C. Huang, M. Zhou, M. Tzoufras et al., Phys. Plasmas 13, 056709 (2006).	

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Abstract Title	**Modeling of laser wakefield acceleration in the Lorentz boosted frame using OSIRIS**
Author/Affiliation listing	**P. Yu**, F. S. Tsung, X. Xu, W. Lu, V. Decyk, W. B. Mori / UCLA, USA J. Vieira, R. A. Fonseca, L. O. Silva / Instituto Superior Tecnico, Portugal
Abstract	We present recent results for various modeling cases on the use of the Lorentz boosted frame to model laser wakefield acceleration using OSIRIS. We will also discuss the observed short wavelength noise that is present for relatively high gamma_boost, and compare the numerical noise against the theoretical prediction.
Summary	
We present recent results on the use of the Lorentz boosted frame to model laser wakefield acceleration using OSIRIS. These include the modeling cases where there are no self-trapped electrons for gamma_boost near gamma_group where gamma_group is the linear group velocity of the laser, and modeling the self-trapped regime for gamma_boost between 10 and 30. Detailed comparison between different gamma_boost for the same lab frame parameters will be given. We also will discuss the observed short wavelength noise that is present for relatively high gamma_boost, including detailed comparison between three FDTD solvers in OSIRIS and a spectral solver from the UPIC Framework. Results on the numerical noise are compared against theoretical predictions for some parameters.	

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Abstract Title	**Ergodicity of atom trajectories in magnetostatic traps**
Author/Affiliation listing	**A. I. Zhmoginov** (UC Berkeley) J. Fajans (UC Berkeley) J. S. Wurtele (UC Berkeley)
Abstract	Recent advancements in antihydrogen trapping pave a road to accurate gravitational and spectroscopic measurements. Here, stochasticity of atom trajectories in magnetostatic traps leading to energy exchange between different particle degrees of freedom is studied. Implications for gravitational measurements and laser cooling are discussed.

Summary

The ALPHA collaboration reported [1] trapping of 37 antihydrogen atoms with trapping times of order 0.17s. Soon after, longer trapping times, up to 1000s, were reported [2]. The longer times ensured that the anti-atoms are in their ground state. More recently, ALPHA demonstrated [3] that it could switch the hyperfine state of antihydrogen with microwaves. In all these experiments, anti-atoms (trapped one at a time) are slowly released from a magnetic minimum well. The anti-atom is observed when it hits the confining electrodes and the decay products are observed in a silicon vertex detector with spacial and temporal resolution. Under certain conditions, studied here, the release time of an antihydrogen is well-correlated with its energy and thus low-energy anti-atoms leave the trap at late times. This correlation can be exploited to find bounds on the limits of the ratio between the gravitational and inertial masses of antihydrogen. In this w ork, stochasticity of atom trajectories in quadrupole and octupole magnetostatic traps is studied both numerically and analytically. It is also demonstrated that Arnold diffusion, playing an important role in accelerator and storage ring physics, may have a profound effect on particle trapping in magnetostatic fields. We compare horizontally and vertically oriented traps and elucidate the key role of transverse-longitudinal coupling in the dynamics. A recent report by ATRAP of trapping antihydrogen [4] included a short paragraph on gravitational measurements. We examine this in the context of our analysis of vertical traps.

[1] G.B. Andresen, et al. Nature 468, 673 (2010)
[2] G.B. Andresen, et al. Nature Physics 7, 558 (2011)
[3] C. Amole, et al. Nature 483, 439 (2012)
[4] G. Gabrielse, et al. Phys. Rev. Lett. 108, 113002 (2012)

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Abstract Title	**Studies of Spectral Modification and Limitations of the Modified Paraxial Equations in the Laser Wakefield Simulations**
Author/Affiliation listing	**Wenxi Zhu**, John Palastro, Thomas Antonsen
Abstract	Spectral shift, energy depletion, and action conservation of nonlinear laser pulses were examined using the modified paraxial equation (MPE) implemented in WAKE. For large red shifts, the numerical damping and slowing down of the group velocity result in action decay. Modifications to the WAKE numerical algorithm have improved the performance.
Summary	
Spectral broadening of intense laser pulses propagating in plasma in the regime where the pulse energy is strongly depleted and spectral shifts are large has been studied using WAKE, a two-dimensional, quasi-static simulation code. For the parameters considered there was complete cavitation of the plasma, large wavenumber shifts, equal or greater than 50% of the laser central wavenumber, and depletion of a similar fraction of the laser pulse energy. The first part of the investigation was devoted to analysis of the laser field propagation algorithm in WAKE, which solves the modified paraxial equation (MPE) using forward differencing in the laser frame time coordinate. Studies indicated that higher order differencing could reduce artificial numerical damping in the wave equation that occurs when the wave envelope acquires fine structure due to large wavenumber shifts. Implementing a more accurate (four point) fitting scheme to evaluate the temporal derivative, remarkably reduced numerical damping for a given resolution in space and time, and greatly enhanced simulation efficiency. The MPE gives an inaccurate group velocity when wavenumber shifts are comparable to the central wavenumber. Implementing a full wave equation (FWE) solver is promising in this situation. Finally, we have investigated the effect of tapering the density profile on the efficiency of energy extraction from and the spectral shift of the laser pulse.	