WG2 – Computations for Accelerator Physics
Summary Presentation

David Bruhwiler and Zenghai Li

Advanced Accelerator Concepts
University of Texas at Austin
June 15, 2012

32 participants: Weiming An, Alexey Arefiev, Carl Bauer, David Bruhwiler, John Cary, Estelle Cormier-Michel, Benjamin Cowan, Paul Cummings, Emmanuel d'Humières, Bela Erdelyi, Frederico Fiúza, Ricardo Fonseca, Cameron Geddes, Spencer Gessner, Daniel Gordon, Frank Lee, Zenghai Li, Vasiliy Morozov, J. Paxon Reyes, Francesco Rossi, Sergey Rykovanov, Brad Shadwick, Chukman So, Peter Stoltz, Jean-Luc Vay, Seth Veitzer, Faya Wang, Jonathan Wurtele, Peicheng Yu, S. AustinYi, Andrey Zhmoginov, W. Zhu

Leaders of other groups who helped to organize 6 joint sessions: Carl Schroeder , Mike Helle, Mike Fazio, Scott Anderson , Patric Muggli, Joel England, Sergei Tochitsky, Manuel Hegelich , Sergey Nagaitsev, Scott Berg , Erhard Gaul , Csaba Toth

Parallel and Multicore Programming for EM PIC

- 1 plenary and 2 WG talks presented on the use of GPUs, >100K cores in parallel, dynamic load balancing, performance optimization
  - Plenary: "Frames per Second Laser Plasma Simulations – Making large-scale Simulations really fast ... or slow" – PIConGPU – Michael Bussman
  - "Modeling LWFA on Tier-0 Systems" – Osiris – Ricardo Fonseca
  - "Robust algorithms for current deposition and efficient memory usage in a GPU particle in cell code" – Jasmine – Francesco Rossi
- Themes and future directions
  - Manycore programming is here and must be embraced
    - algorithmic developments for GPU are intrinsically valuable, although details are important and we will have to cope with multiple/changing APIs
    - data structures and data management are key
    - details of the computing hardware must be directly addressed
  - Massively-parallel programming offers tremendous benefits
    - new problems can be solved; higher-resolution enabled; interactivity
    - ~10 ns per particle push is possible; 100x faster than SOA from 5 years ago
    - going from ~10^5 cores to 10^{6+} cores will be challenging; the path is not clear

Frames per Second Laser Plasma Simulations — Making large-scale Simulations really fast ... or slow

Michael Bussmann[1], Florian Berninger[1], Heiko Burau[1], Thomas E. Cowan[1], Alexander Debus[1], Axel Hübl[1], Thomas Kluge[1] , Richard Pausch[1], Ulrich Schramm[1], René Widera[1]

Wolfgang Hönig[2], Guido Juckeland[2], Wolfgang Nagel[2], Felix Schmitt[2]

[1] Helmholtz-Zentrum Dresden-Rossendorf
[2] Zentrum für Informationsdienste und Hochleistungsrechnen

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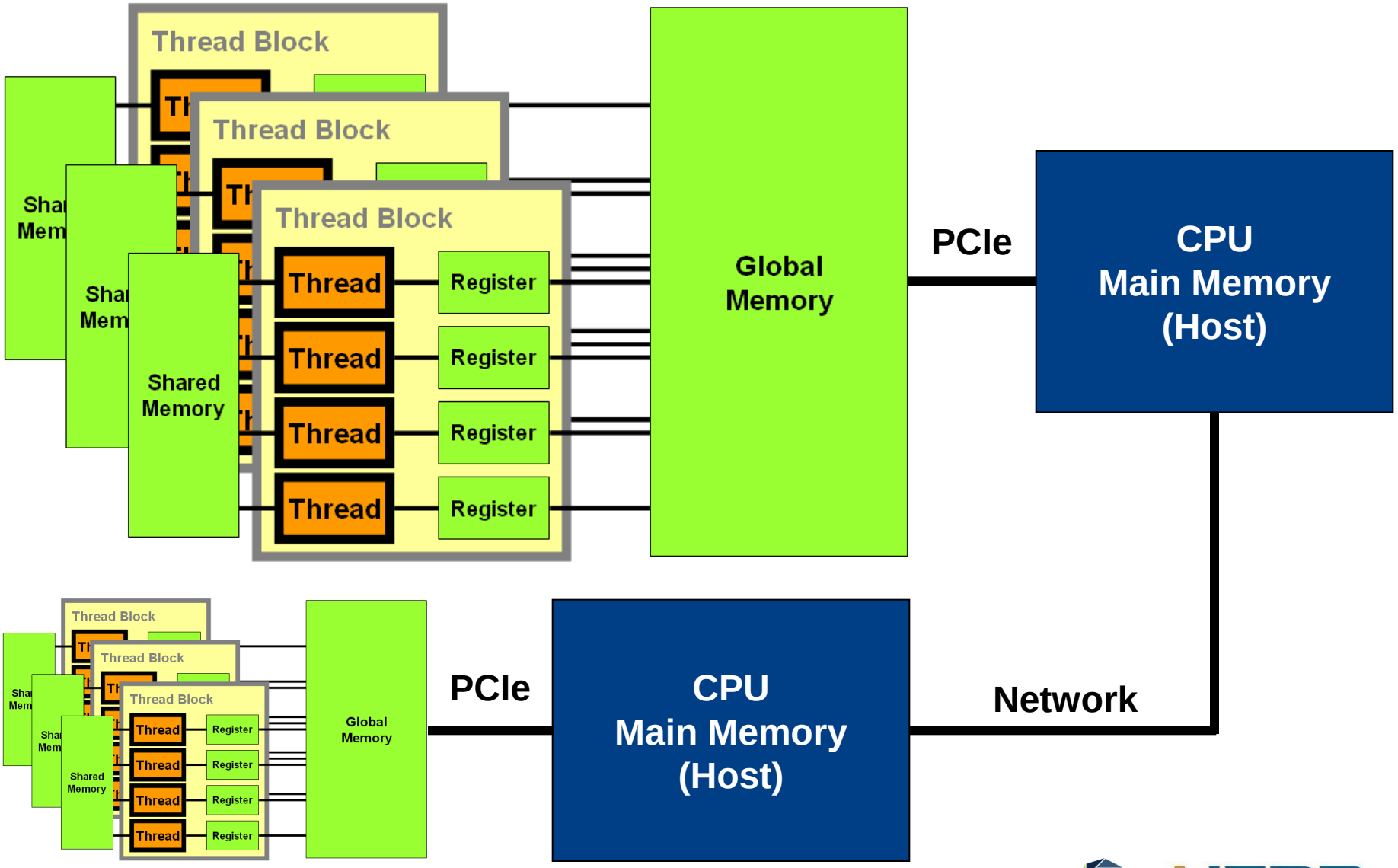
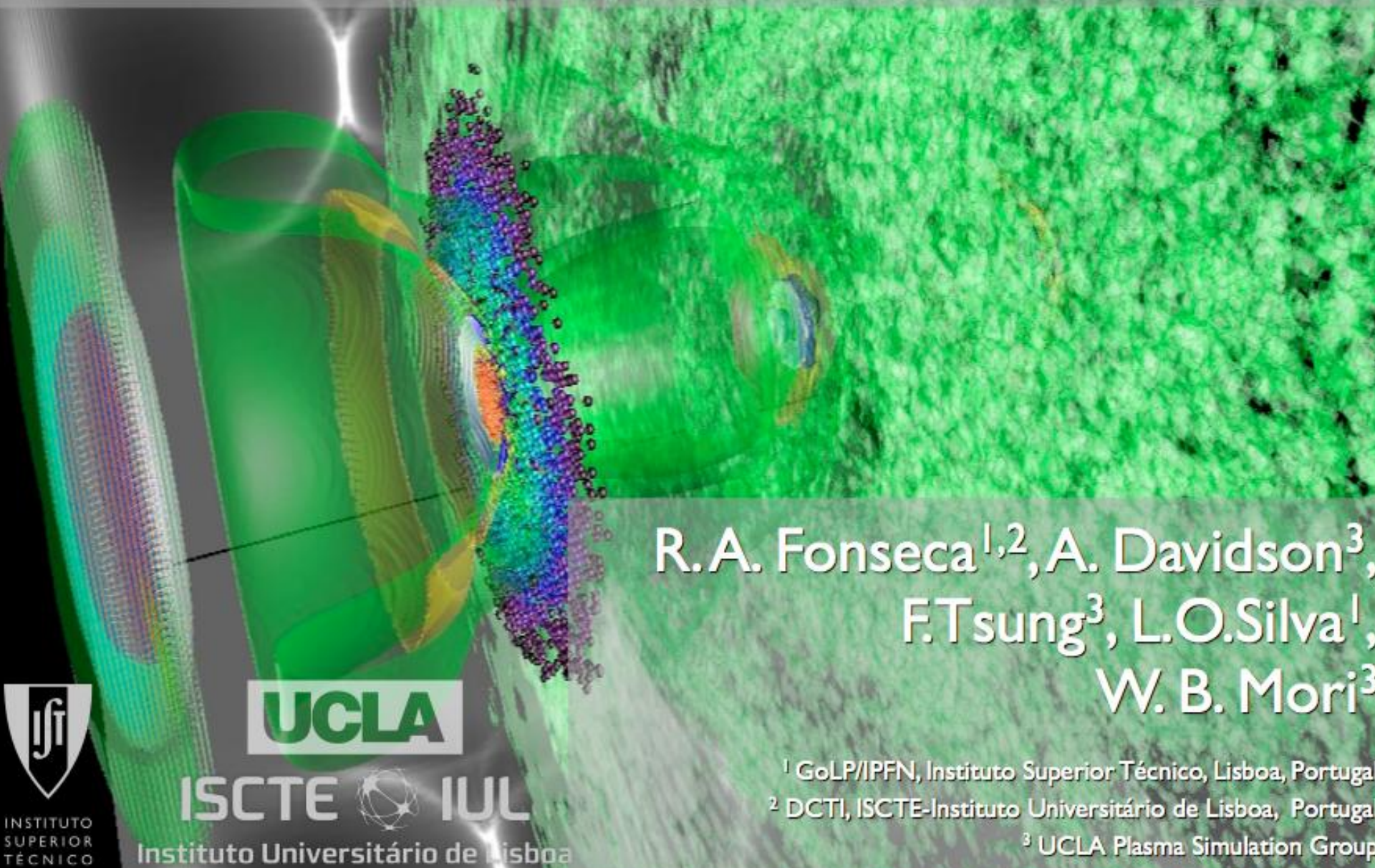
"Almost all Programming can be viewed as an Exercise in Caching"



Michael Bussmann · Computational Radiation Physics · www.hzdr.de/crp
m.bussmann@hzdr.de
Mitglied der Helmholtz-Gemeinschaft

Modeling LWFA on Tier-0 systems



R. A. Fonseca[1,2], A. Davidson[3], F. Tsung[3], L. O. Silva[1], W. B. Mori[3]

[1] GoLP/IPFN, Instituto Superior Técnico, Lisboa, Portugal
[2] DCTI, ISCTE-Instituto Universitário de Lisboa, Portugal
[3] UCLA Plasma Simulation Group

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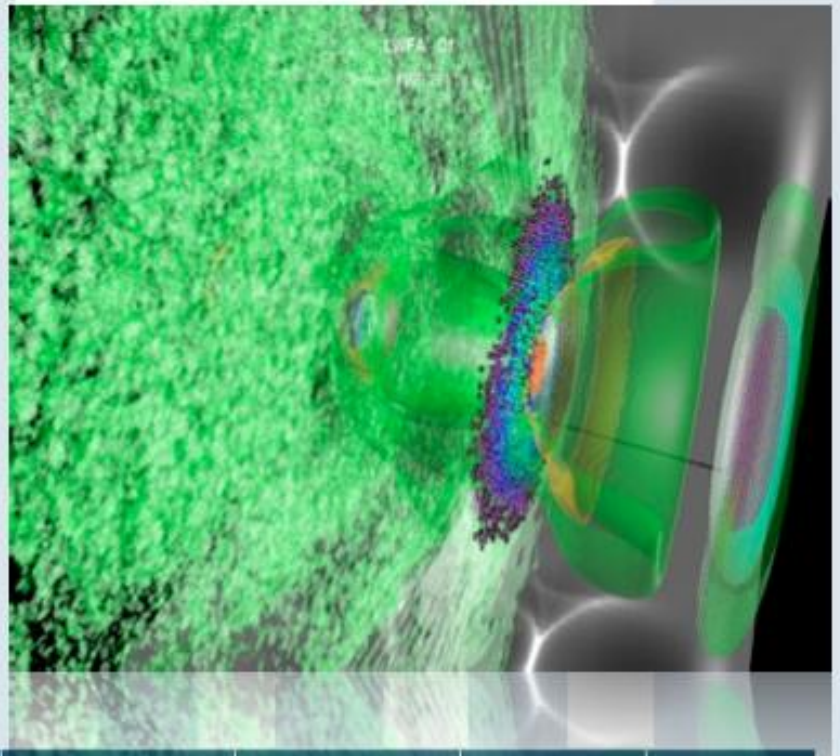
ISCTE IUL
Instituto Universitário de Lisboa

Q2 Test Problems

- Warm plasma, baseline code performance
- 200 TW (6 Joule) → $1.5 \times 10^{18}\,cm^{-3}$ uniform plasma
- 1 PW (30 Joule) → $0.5 \times 10^{18}\,cm^{-3}$ uniform plasma
- Run in ~ 1/4 of Jaguar
  - 55296 cores
  - 20 hours wall clock
  - 1.1 M cpu hours



Run	Grid	Simulation Box [c/ω_0]	Particles	Iterations	Laser a_0	Ions
Warm test	6144 × 6144 × 1536	614.4 × 614.4 × 153.6	4.46×10^{11}	5600	n/a	n/a
Run 1	8064 × 480 × 480	806.4 × 1171.88 × 1171.88	3.72×10^{9}	41000	4.0	fixed
Run 2	8832 × 432 × 432	1766.4 × 2041.31 × 2041.31	6.59×10^{9}	47000	4.58	fixed
Run 3	4032 × 312 × 312	806.4 × 1171.88 × 1171.88	1.26×10^{10}	52000	4.0	moving

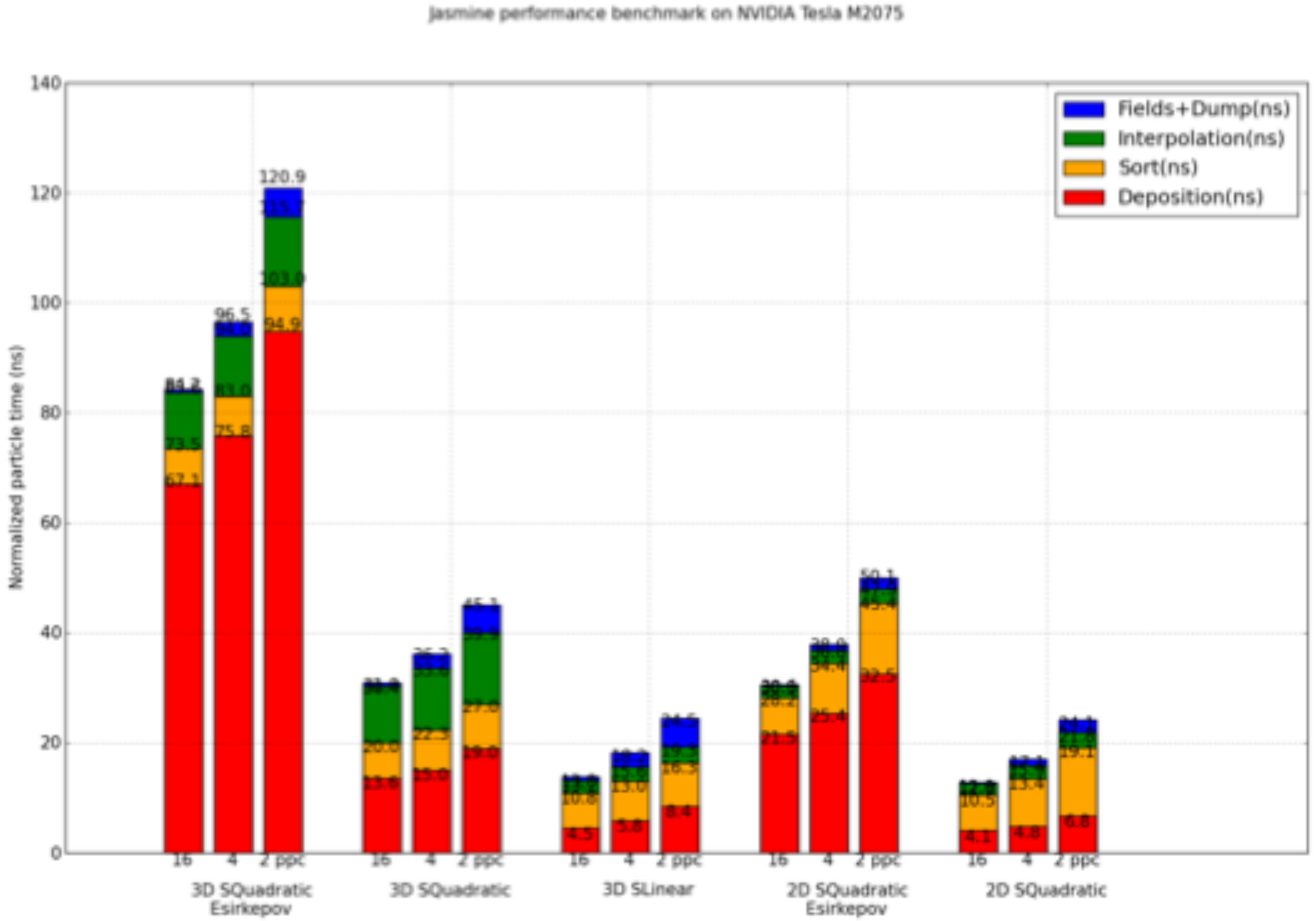
Robust algorithms for current deposition and efficient memory usage in a GPU Particle In Cell code

Francesco Rossi [1], P. Londrillo [1], A. Sgattoni [2], S. Sinigardi[1] and G. Turchetti[1]

[1] University of Bologna and INFN
[2] Politecnico di Milano and CNR INO Pisa

15th Advanced Accelerator Concepts Workshop (AAC 2012)

Performance



LASER: a=7.7, waist=9.0 mum, fwhm=24.0 fs PLASMA: density=1.00e+19 1/cm^3. Simulation run for $ct = 60\mu m$, double precision. Note: 3D test with Esirkepov method runs stretched grid

Reduced Algorithms for Plasma Accelerators

- 1 plenary and 4 WG talks on the Lorentz boosted frame, quasistatic PIC & other algorithms to speed up plasma sim's
  - Plenary: "Efficient Particle-In-Cell algorithms for the modeling of advanced accelerators" – Warp, Osiris, QuickPIC, H-VLPL3D, Vorpal, Inf&rno, Calder-Circ, TurboWAVE – Jean-Luc Vay *et al*.
  - "Low-noise Particle-in-Cell simulations of laser-plasma 10 GeV stages" – Vorpal – E. Cormier-Michel
  - "Numerical instability due to relativistic plasma drift in EM-PIC code" – Osiris – Peicheng Yu
  - "Simulation Study on the Proton Beam Self Modulation in the Plasma Wakefield Using Osiris and QuickPIC" – QuickPIC and Osiris – Weiming An ** Covered by WG4 Summary **
  - "An unconditionally-stable numerical method for laser-plasma interactions" – unnamed code – J. Paxon Reyes
- Theme
  - With sufficient effort, one can neglect all backward-going radiation/info and speed up PIC simulations by many orders of magnitude

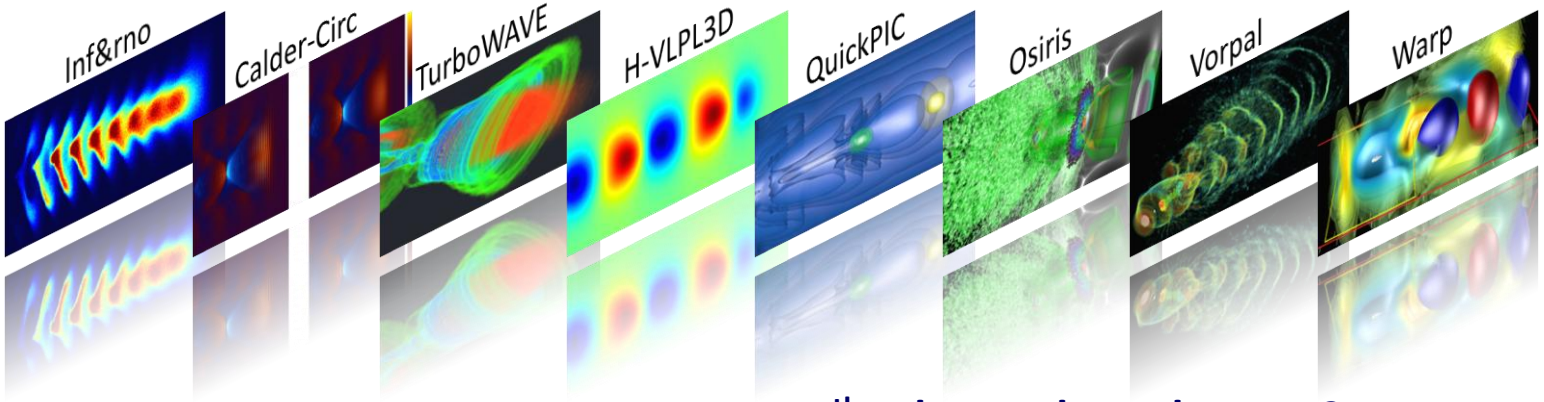
Efficient Particle-In-Cell algorithms for the modeling of advanced accelerators

J.-L. Vay

Lawrence Berkeley National Laboratory, CA, USA

with contributions from

C. Benedetti, D. Bruhwiler, E. Cormier-Michel, B. Cowan,
R. Fonseca, D. Gordon, A. Lifschitz, W. Mori



15th Advanced Accelerator Concepts Workshop

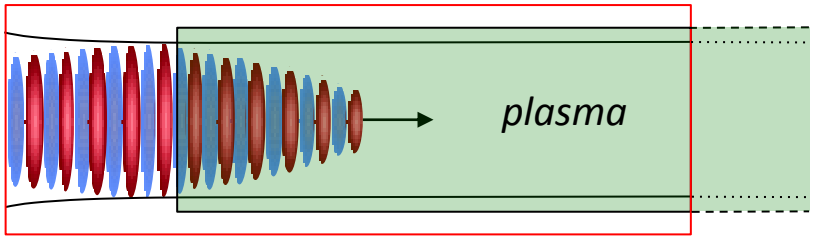
University of Texas, Austin, Texas, USA – June 10-15, 2012

jlvay@lbl.gov

Laser injection through moving plane solves initialization issue in LBF

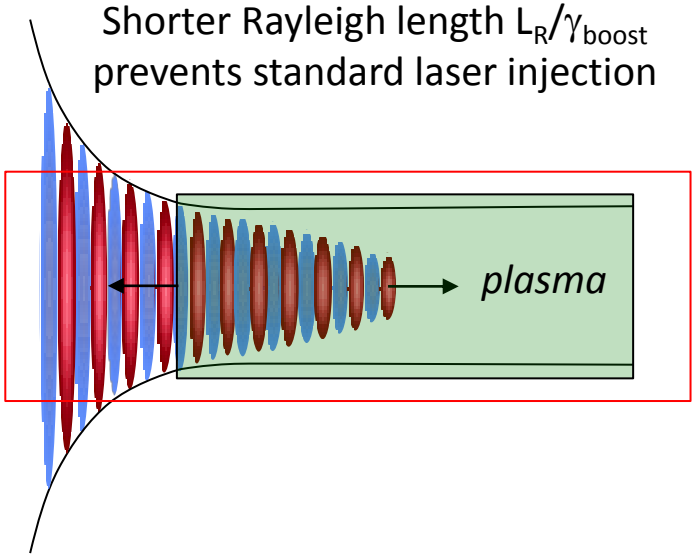
Lab frame

Standard laser injection
from left boundary or all at once

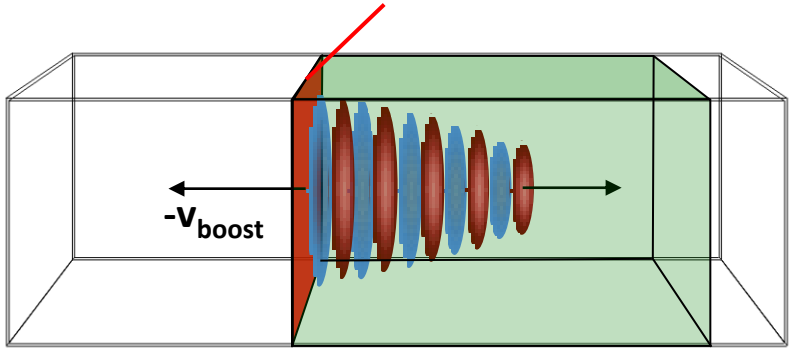


Boosted frame

Shorter Rayleigh length L_R/γ_{boost}
prevents standard laser injection



Solution: injection through a **moving planar antenna** in front of plasma*



- Laser injected using macroparticles using Esirkepov current deposition ==> verifies Gauss' Law.
- For high γ_{boost}, backward radiation is blue shifted and unresolved.

Method has been developed in Warp*, and implemented in Osiris and Vorpal.

*J.-L. Vay, et al., *Phys. Plasmas* **18**, 123103 (2011)

Low noise Particle-In-Cell simulations of laser-plasma 10 GeV stages

E. Cormier-Michel, D.L. Bruhwiler, E.J. Hallman, B.M. Cowan, J.R. Cary
Tech-X Corporation

C.G.R. Geddes, J.-L. Vay, E. Esarey, C.B. Schroeder, W.P. Leemans
Lawrence Berkeley National Laboratory

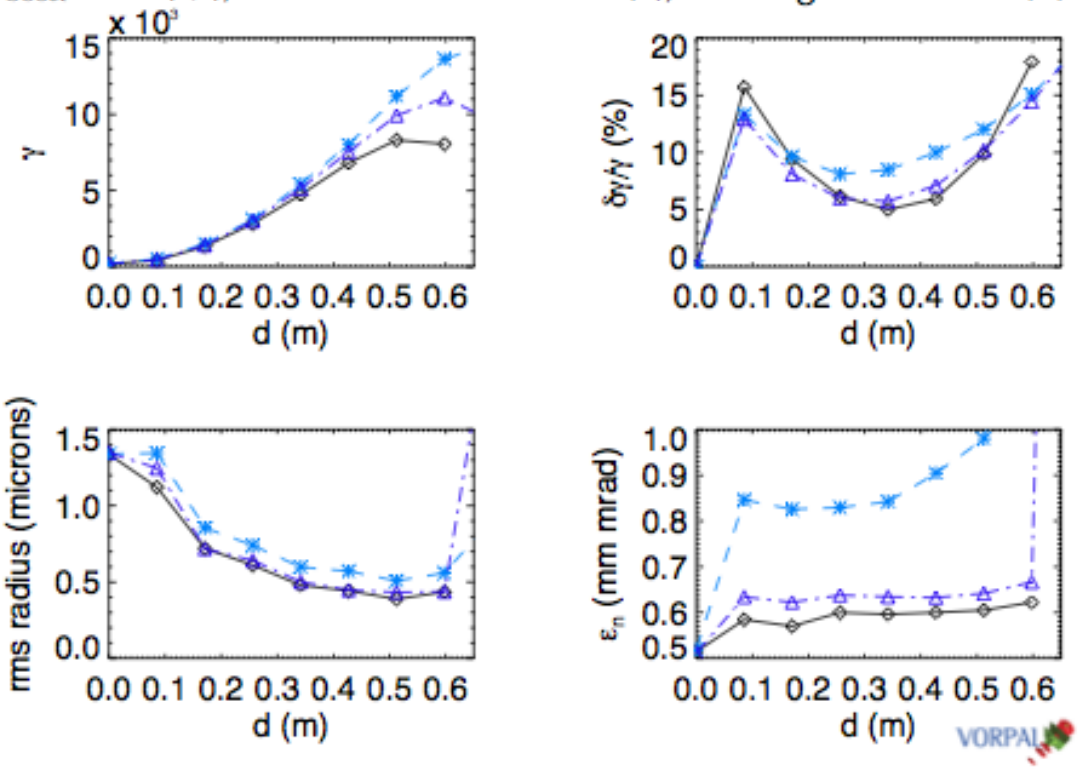
Work supported by the US DOE Office of Science, Office of High-Energy Physics under grant No.'s DE-FC02-07ER41499 (SciDAC-2; ComPASS Project), DE-SC0004441 (SBIR), and DE-AC02-05CH11231 (LBNL).

This research used resources of the National Energy Research Scientific Computing Center, which is supported by US DOE Office of Science under Contract No. DE-AC02-05CH11231.

Large γ_{boost} needs higher resolution to reduce noise, decreases effective speed-up

- Simulation at $\gamma_{boost} = 1$ (full scale-stage): estimated 2.5×10^6 proc.h
- $\gamma_{boost} = 75$: 706 proc.h ➜ ×3,500 speed-up
- Higher γ_{boost} requires higher resolution to reduce noise and artificially high emittance, effective speed-up × 550 (4,500 proc.h)

Υ_{boost} = 25 (◇), 75 - normal resolution (∗), 75 - high resolution (Δ)



Numerical instability due to relativistic plasma drift in EM-PIC code

Peicheng Yu*, Xinlu Xu, Frank S. Tsung, Wei Lu,
Viktor K. Decyk, Warren B. Mori

Jorge Vieira, Ricardo A. Fonseca, Luis O. Silva

University of California Los Angeles, Los Angeles, CA 90095, USA

Tsinghua University, Beijing 100084, China

Instituto Superior Tecnico, Lisbon, Portugal

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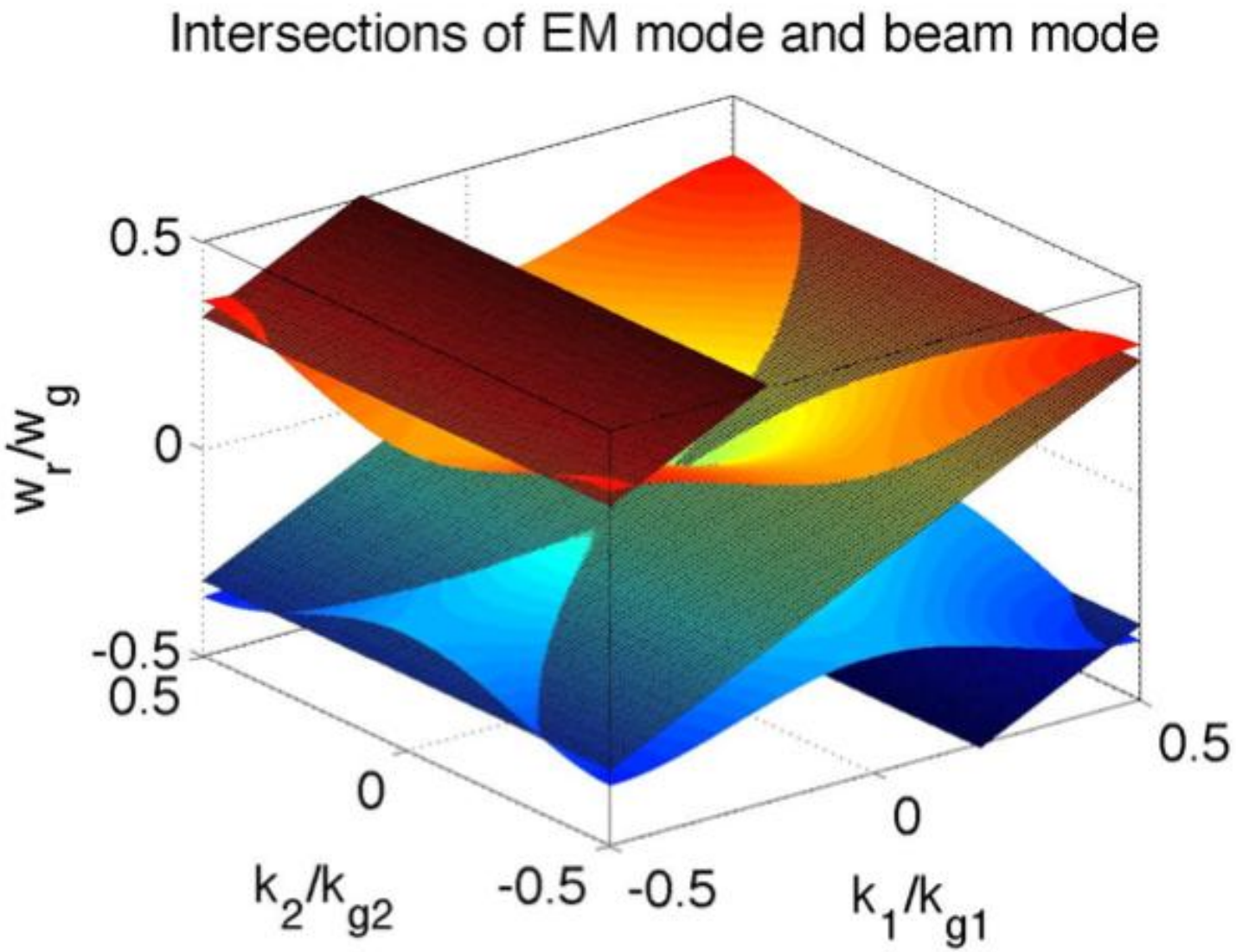
Intersections between EM and beam mode: Yee

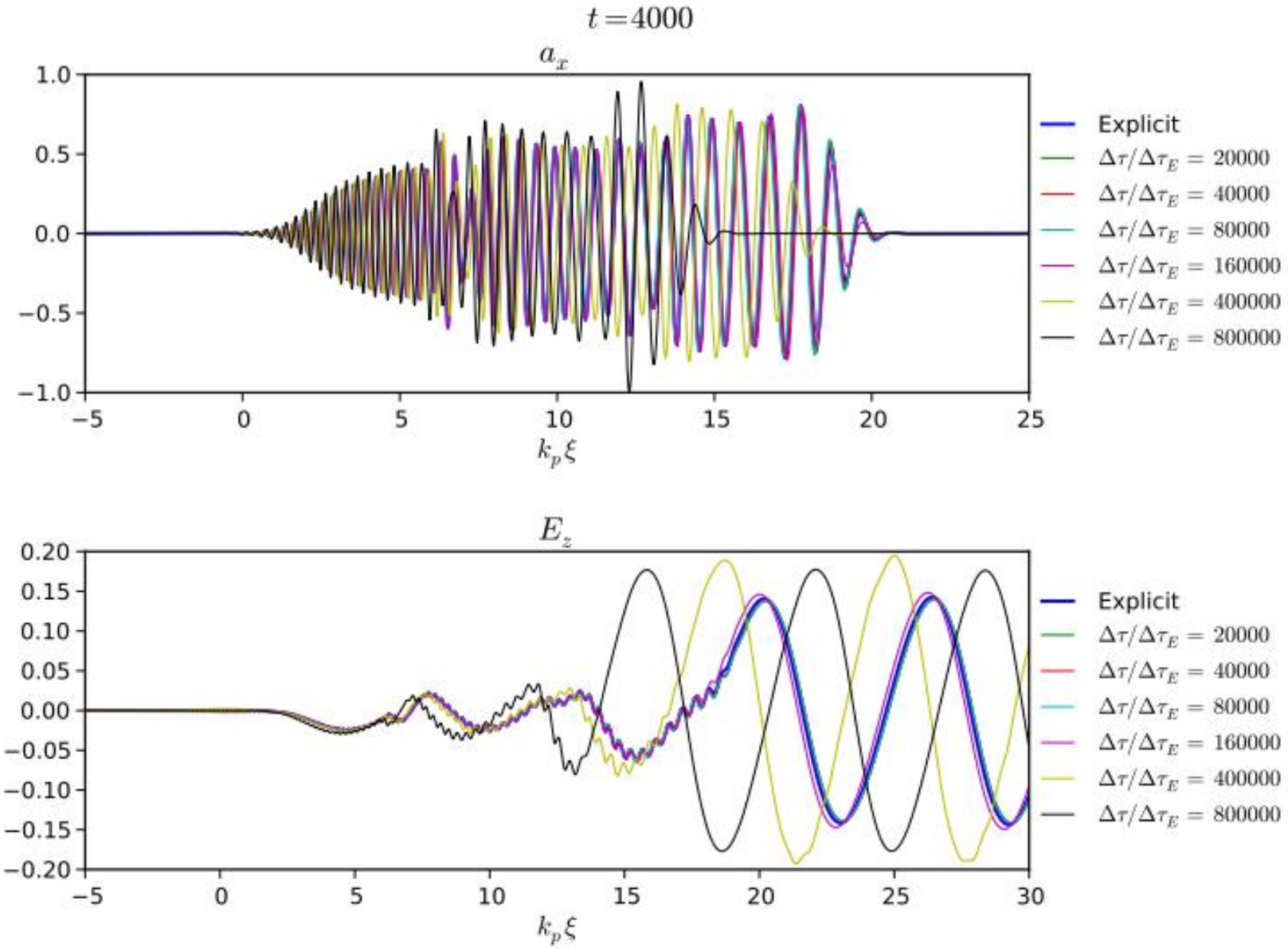


An unconditionally-stable numerical method for laser-plasma interactions

J. Paxon Reyes B. A. Shadwick

University of Nebraska - Lincoln

Advanced Accelerator Concepts Workshop, 2012


$t = 4000$
a_x
1.0
0.5
0.0
−0.5
−1.0
−5
0
5
10
15
20
25
$k_p\xi$
Explicit
$\Delta\tau/\Delta\tau_E = 20000$
$\Delta\tau/\Delta\tau_E = 40000$
$\Delta\tau/\Delta\tau_E = 80000$
$\Delta\tau/\Delta\tau_E = 160000$
$\Delta\tau/\Delta\tau_E = 400000$
$\Delta\tau/\Delta\tau_E = 800000$
E_z
0.20
0.15
0.10
0.05
0.00
−0.05
−0.10
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−0.20
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30
$k_p\xi$
Explicit
$\Delta\tau/\Delta\tau_E = 20000$
$\Delta\tau/\Delta\tau_E = 40000$
$\Delta\tau/\Delta\tau_E = 80000$
$\Delta\tau/\Delta\tau_E = 160000$
$\Delta\tau/\Delta\tau_E = 400000$
$\Delta\tau/\Delta\tau_E = 800000$

Multiphysics: Ionization and Radiation

- 2 talks specifically on modeling ionization and its effects on laser-plasma simulations; 2 specifically on modeling radiation
  - "Ionization Physics and Laser Acceleration of Electrons" – (new code to solve the Schroedinger equation for ionization physics) – Dan Gordon
  - "Numerical modeling of laser tunneling ionization in explicit particle-in-cell codes" – VLPL and Vorpal – Cameron Geddes
  - "Virtual Detection of Synchrotron Radiation (VDSR) – the C++ parallel code for particle tracking and radiation calculation" – VDSR – S. Rykovanov
  - "Computational Investigation of Synchrotron-Like Radiation Generation in LWFA Experiments" – Osiris – Paul Cummings
- Theme
  - Ionization & radiation models are common for underdense LPA simulations
    - they are ubiquitous in overdense laser-plasma ion simulations
  - The parametric models are increasing in sophistication & are being tested
  - Probably adequate for many applications, but ADK model is a strong approximation and can be wrong by 2x (integrated) and in angular details

NRL
Plasma Physics
Division

Ionization Physics and Laser Acceleration of Electrons

Daniel Gordon, Antonio Ting, Dmitri Kaganovich, Michael Helle, Bahman Hafizi*

Naval Research Laboratory, Plasma Physics Division, Washington DC
* Icarus Research Inc., Bethesda, MD

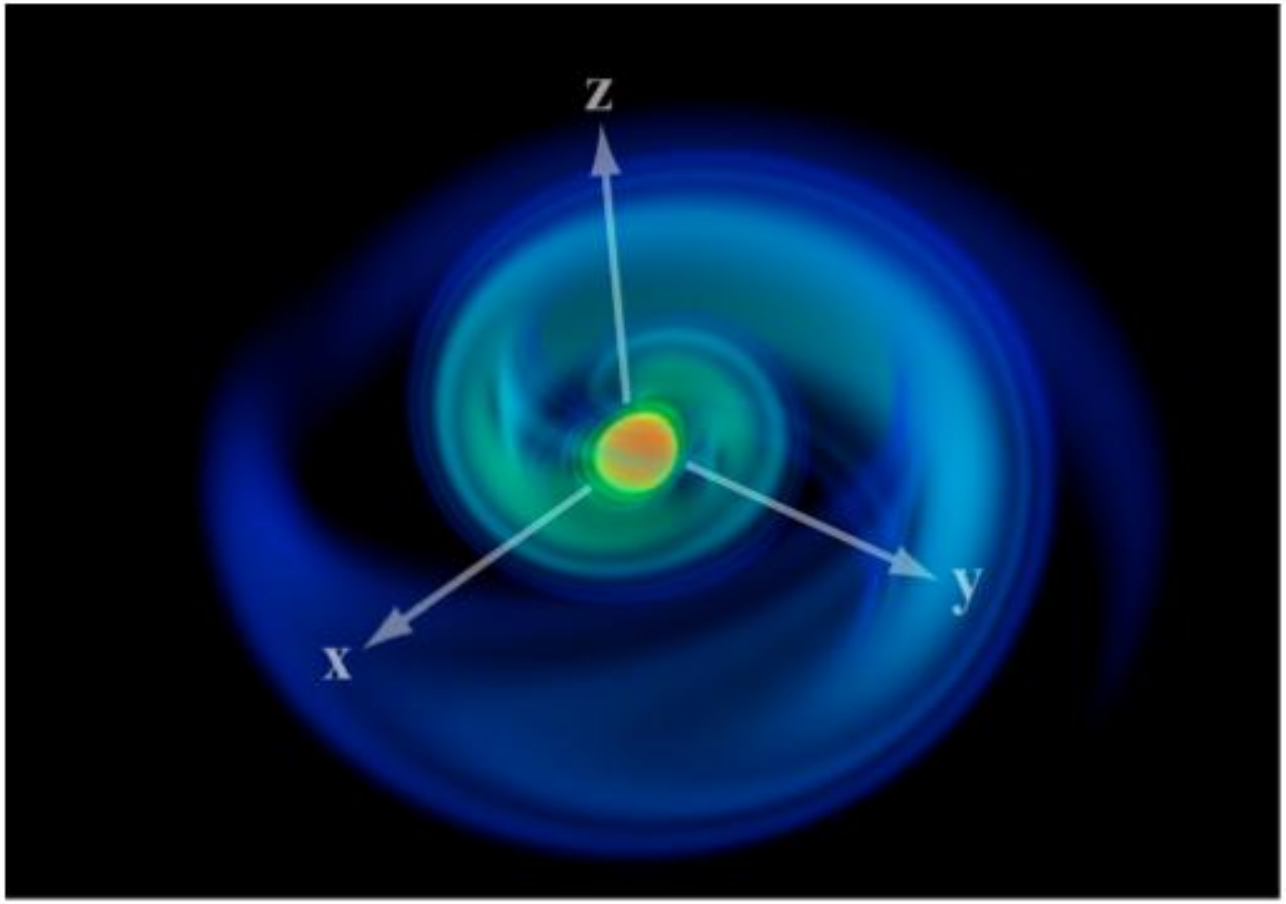
Advanced Accelerator Concepts Workshop
Austin, Texas, June 10-15, 2012

Supported by NRL 6.1 Base Funds and Department of Energy

Hydrogen Atom Illuminated by Circularly Polarized Light (0.16 μm)

NRL Plasma Physics Division

$\omega = 0.288$ $E = 0.10$



Numerical modeling of laser tunneling ionization in explicit particle-in-cell codes

[1]M. Chen, [2]E. Cormier-Michel, [1]C.G.R. Geddes, [2]D. Bruhwiler,
[1]L.L. Yu, [1]E. Esarey, [1]C.B. Schroeder,
and [1]W.P. Leemans

[1]Lawrence Berkeley National Laboratory
[2]Tech-X Corporation

AAC 2012
June 11 - 15, 2012

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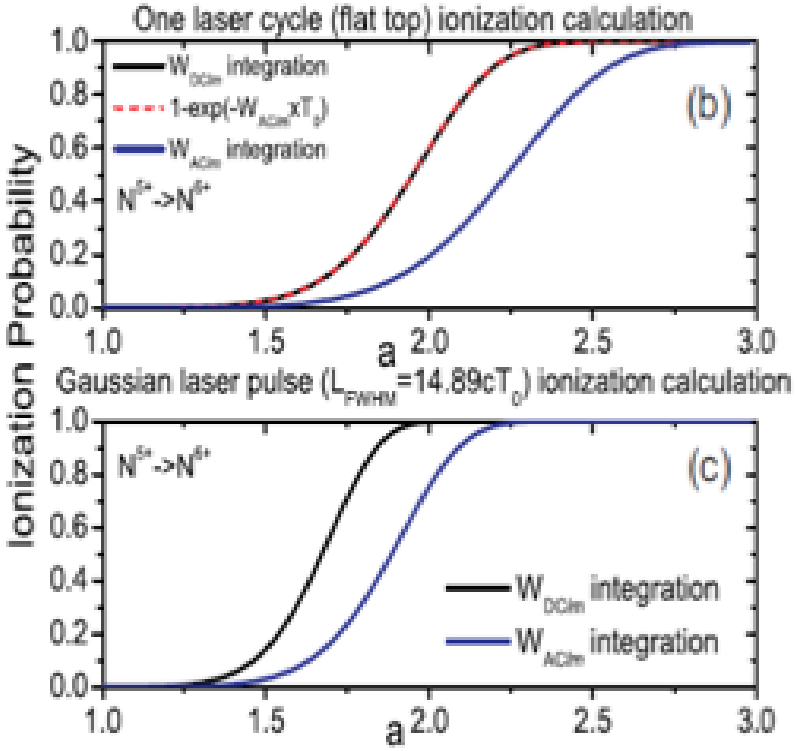
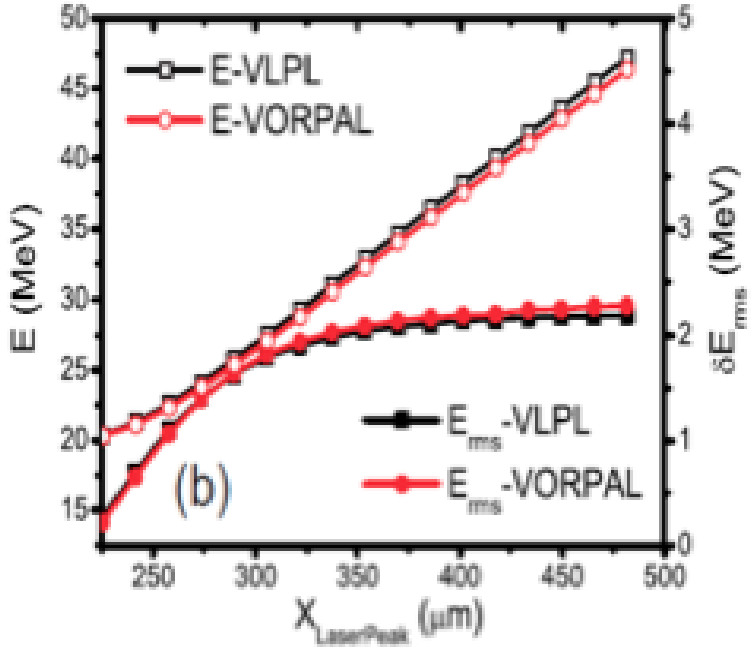
Numerical modeling of ionization injection: strong benchmark & ionization physics

DC ionization formula must be used for accurate explicit simulations



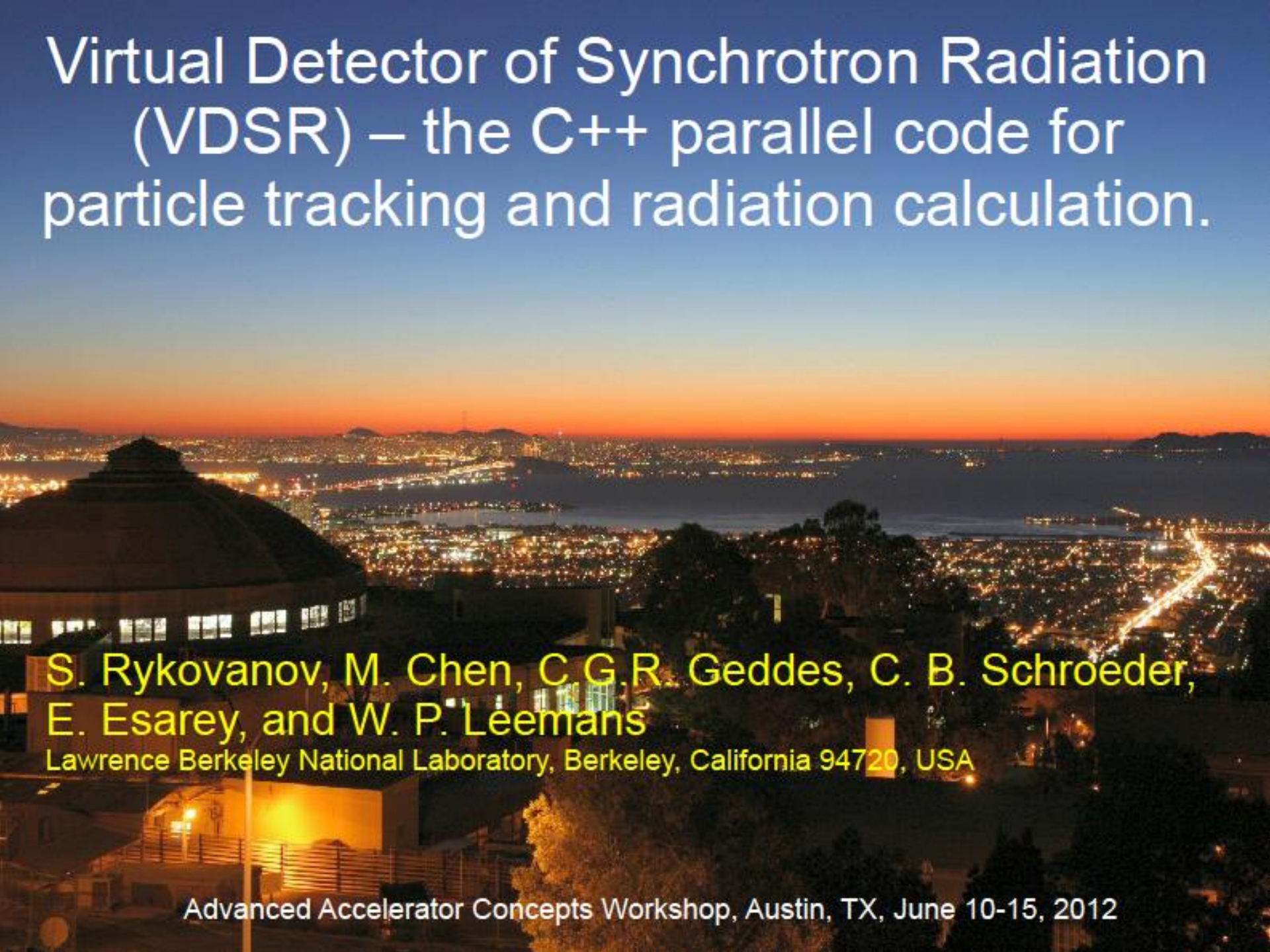
Ionization injection benchmark: Agreement of energy, energy spread and other beam parameters



Residual ionization momentum used to increase charge in transverse colliding pulse injector

M. Chen et al., Phys. Plasmas 19, 033101 (2012) & to be submitted
M. Chen et al., J. Appl. Phys., 99, 056109 (2006)

Virtual Detector of Synchrotron Radiation (VDSR) – the C++ parallel code for particle tracking and radiation calculation.



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

Advanced Accelerator Concepts Workshop, Austin, TX, June 10-15, 2012

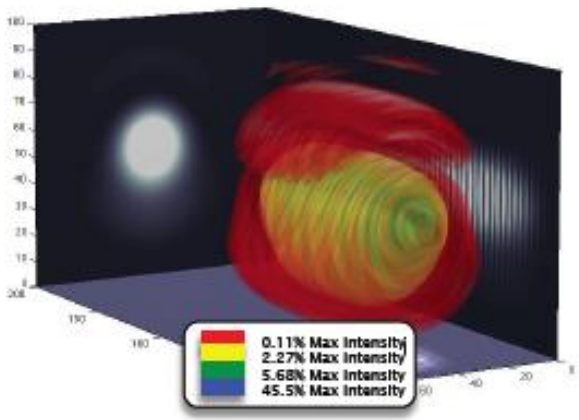
Summary

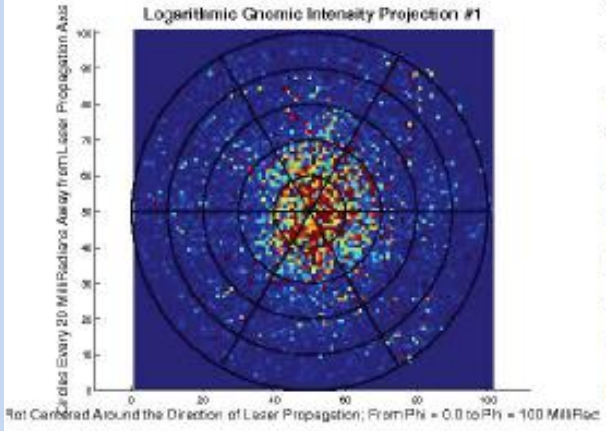
- A C++ object-oriented parallel code VDSR has been introduced
- Examples of application of VDSR have been shown
- Classical radiation calculation has been used for beam radius detection inside the wakefield
- Radiation reaction effects on particle motion have been discussed
- Thomson scattering spectrum can be used to detect beam properties
- Quantum calculations have been benchmarked
  - Nonlinear Compton effect implementation in progress

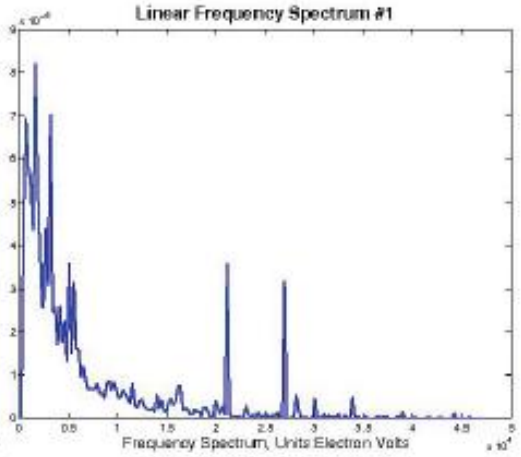
A Computational Investigation of Synchrotron-Like Radiation Generation in Laser Wake-Field Experiments Experiments

P.G. Cummings[1], A. G. R. Thomas[1]

[1]Center for Ultrafast Optical Sciences, University of Michigan, Ann Arbor, MI







- The PIC code OSIRIS 2.0 was modified to simulate the comatic aberration (above)
- Additionally, OSIRIS 2.0 was modified with an approximate Monte Carlo algorithm for simulating the generation of synchrotron-like radiation (shown to the right)
- The impact of the severity of the coma on the generated radiation was computationally investigated.

- Computational model (Monte-Carlo algorithm) for calculating synchrotron radiation implemented in PIC code OSIRIS
- Use to model Laser plasma acceleration experiments

Laser-Plasma Acceleration of Ions

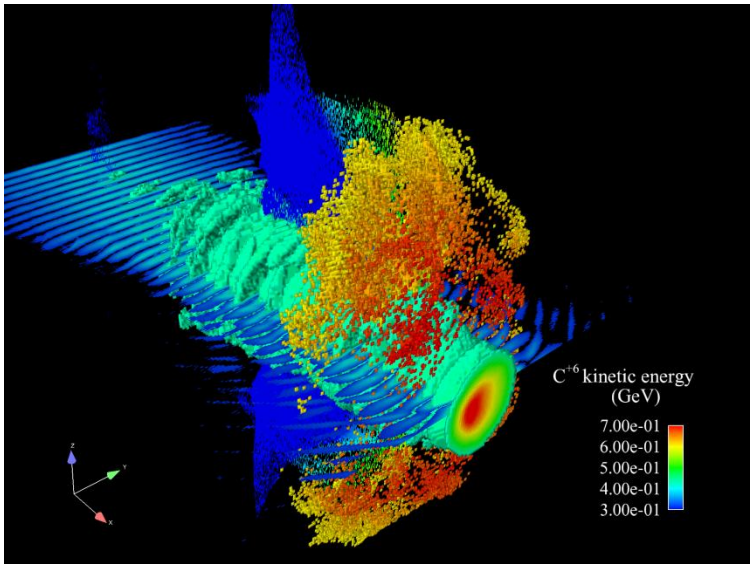
- 4 presentations on laser-thin-film interactions for ion acceleration
  - "Review of multi-dimensional large-scale kinetic simulation and physics validation of ion acceleration in relativistic laser-matter interaction" – VPIC – Manuel Hegelich
  - "Laser ion acceleration in the ultra high laser intensity regime" – PICLS – Emmanuel d'Humières
  - "Full-scale modeling of ion acceleration from laser-solid interactions" – Osiris – Frederico Fiúza
  - "Parametric amplification of laser-driven electron acceleration in a plasma channel" – *code?* – Alexey Arefiev
- Themes
  - TNSA to BOA to RPA offers better scaling at cost of greater complexity
  - VPIC / LANL approach is to use ~1,000 ptcls/cell to resolve Debye scales
    - cautions that cold-start and smoothing sometimes is misleading
    - they show impressive agreement between simulation and experiment
  - Hybrid treatment of underdense/overdense shows tremendous speed up
  - Radiation reaction effects change the physics for $I \sim 10^{23}$ W/cm^2
    - quantum effects in radiation are important for $I > 4\ 10^{23}$ W/cm^2

Review of multi-dimensional large-scale kinetic simulation and physics validation of ion acceleration in relativistic laser-matter interaction

XCP-6: L. Yin, B. J. Albright, K. J. Bowers, C.-K. Huang, T. J. T. Kwan

P-24: H.-C. Wu, **B. M. Hegelich**, J. C. Fernández, R. Shah, S. Palaniyappan, D. Jung

Los Alamos National Laboratory, NM

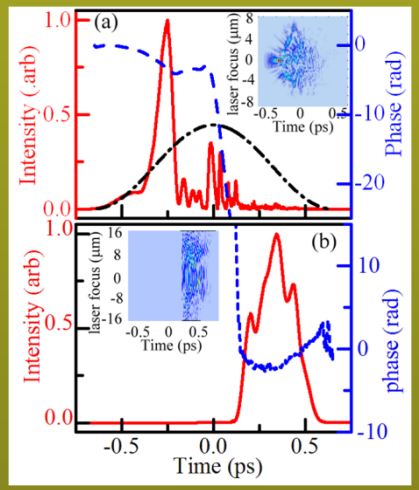


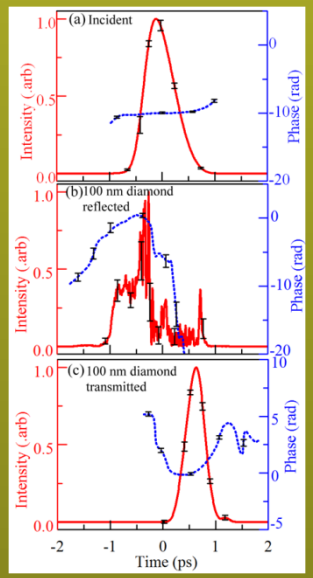
VPIC simulation made quantitative predictions for laser pulse, electrons, ions

Laser Pulse

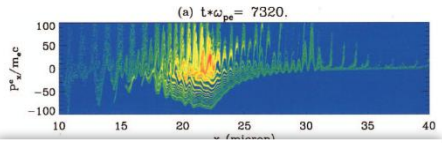
Experiment

VPIC

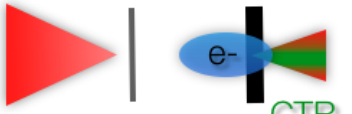


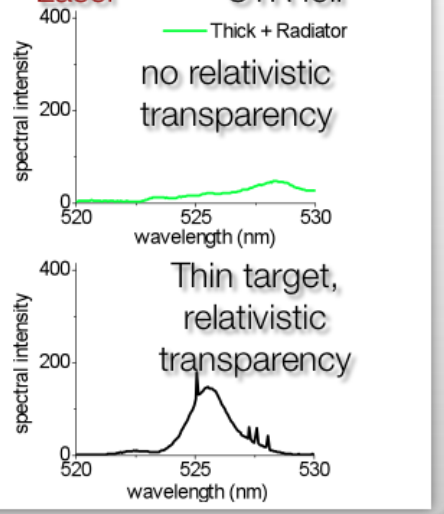


Electrons

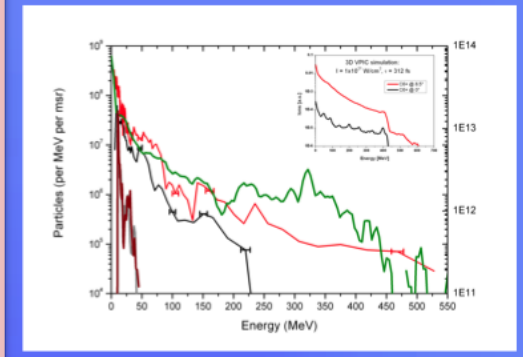


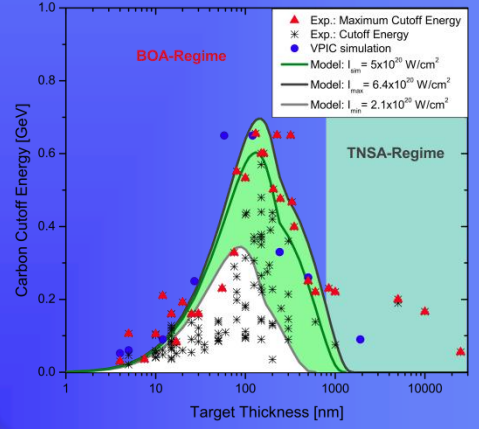
Measurement





Ions

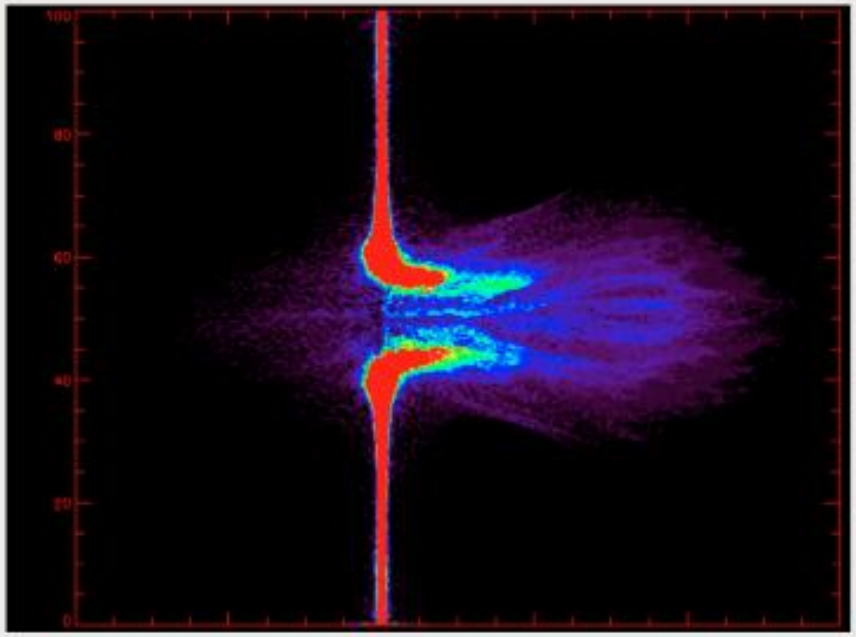




hegelich@gmail.com

LASER ION ACCELERATION IN THE ULTRA HIGH LASER INTENSITY REGIME

Emmanuel d'Humières, Rémi Capdessus and Vladimir T. Tikhonchuk
CELIA, Université Bordeaux-CNRS-CEA, 33405 Talence, France

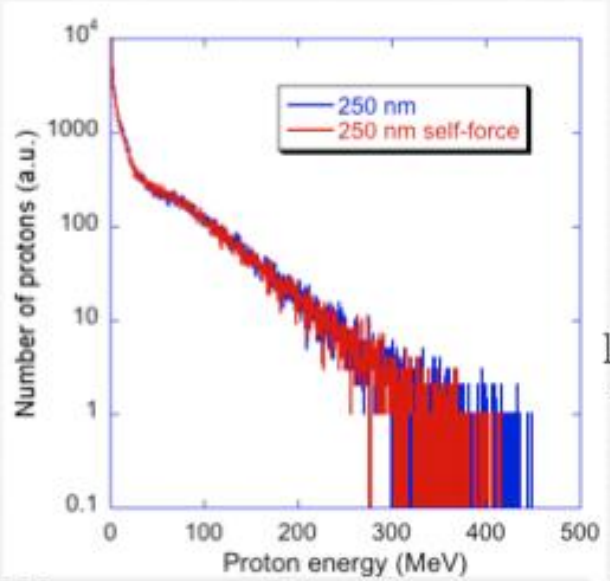


Outline

- Context and motivations.
- Models (PICLS and Self-force).
- High intensity regime with various targets in 1D.
- High intensity regime with various targets in 2D.
- Summary and perspectives.

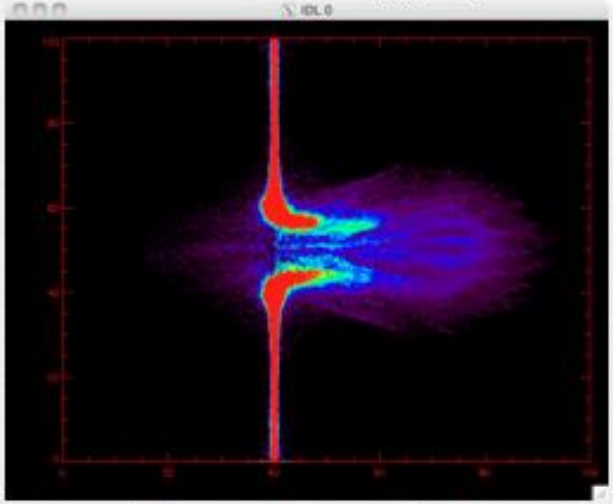
UHI regime with self-force included

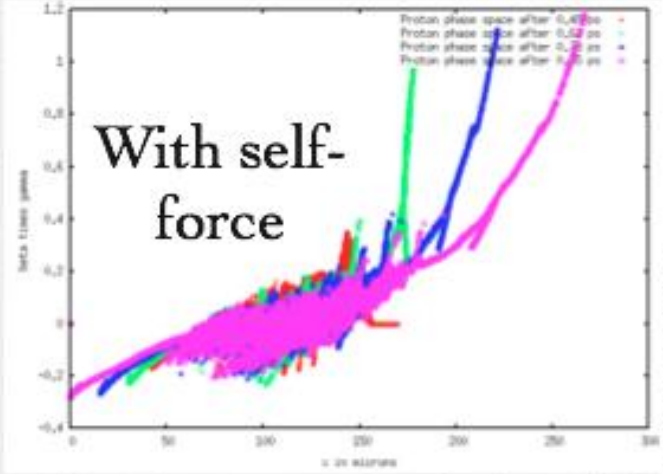
2D results



Transparency regime: efficient proton acceleration after the laser has propagated through the target. The acceleration in very thin targets is too fast to have important radiation losses.

a_0=107.6, τ=8T_0, 6λ FWHM



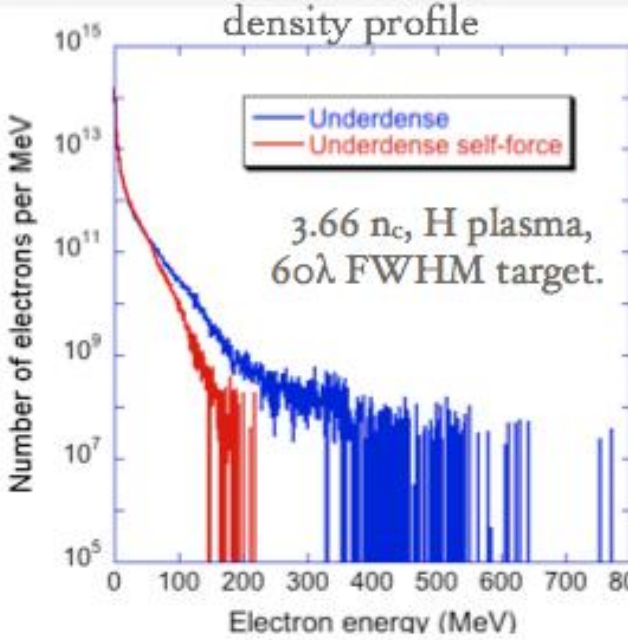


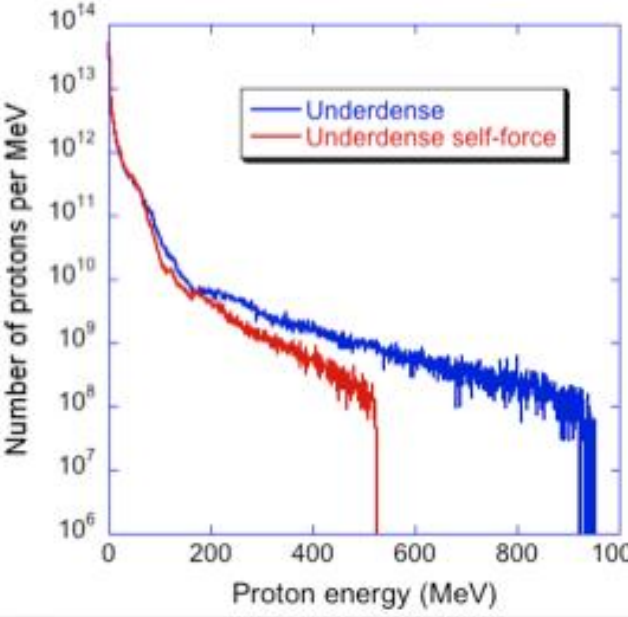
Higher thicknesses lead to lower maximum proton energies as the accelerating field is decreased.

E. d'Humières et al., submitted to EPJ - WoC.

Very high laser absorption is achieved and very high hot electron density and temperature are obtained. Highest energy protons are accelerated by plasma expansion in the decreasing density gradient. Thinner targets could allow strong shocks to occur. Radiation losses have a significant impact. n_{max}=3.66n_c (see gaz nozzles developed at LOA)

Underdense targets with a $\cos^2$ density profile





Full-scale modeling of ion acceleration from laser-solid interactions

Frederico Fiúza[1]

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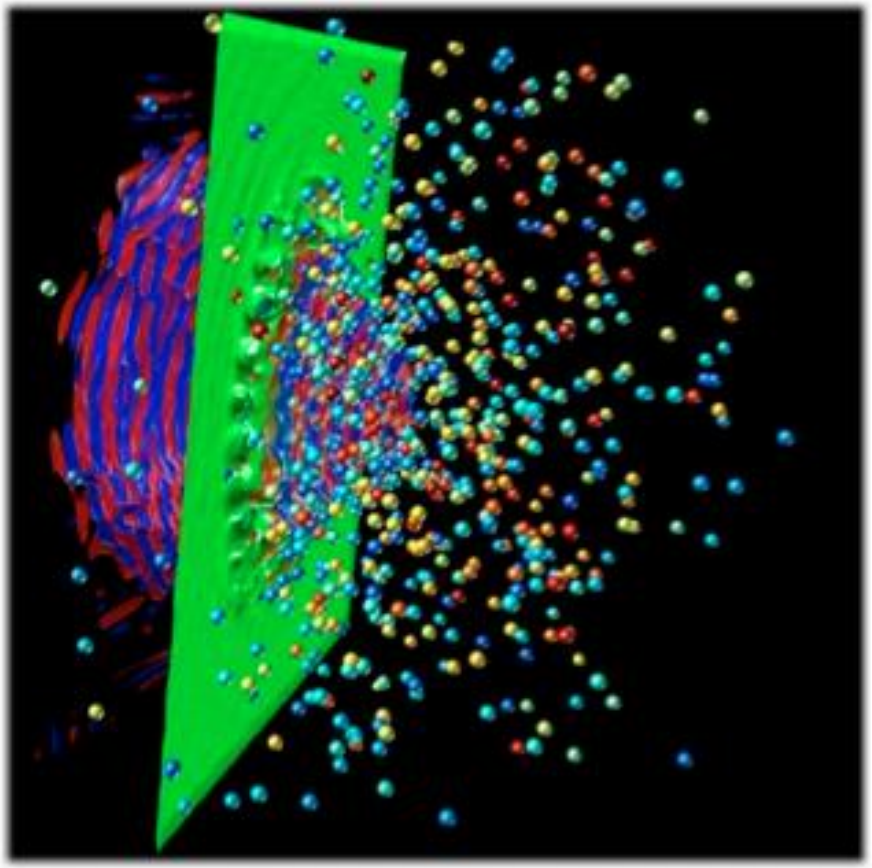
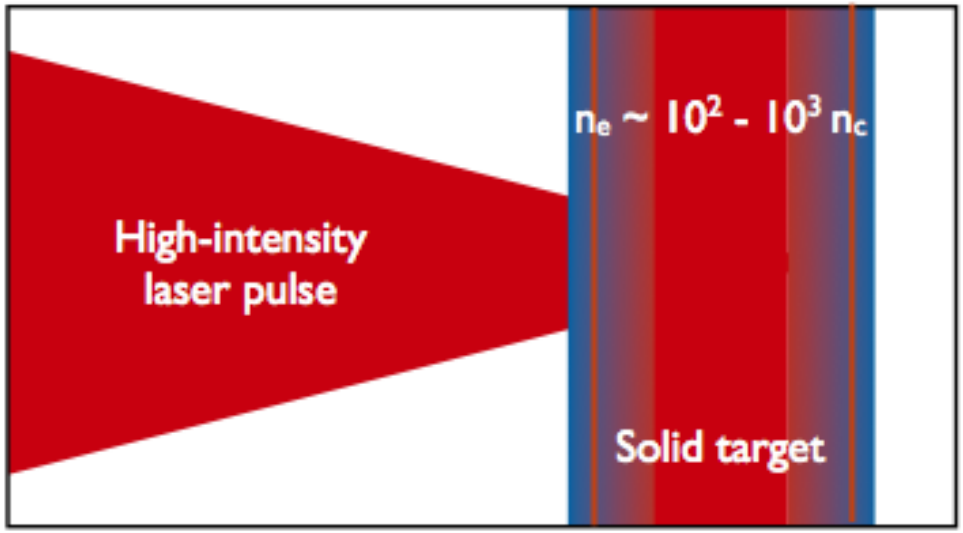


New hybrid-PIC framework*



Full-PIC algorithm

- Full Maxwell's equations
- Kinetic species
- $n_0 < 10^{23}$ cm^{-3}
- $\omega_p \Delta t < O(1)$
- $\Delta x \omega_p / c < O(1)$
- $c\Delta t/\Delta x < 1$

If resistivity (Ohm's law) matches collisional model transition is natural and self-consistent

Hybrid-PIC algorithm

- Maxwell's equations + Ohm's law (inertialess)
- Kinetic species
- $n_0 > 10^{23}$ cm^{-3}
- $\nu_{ei} \Delta t < O(1)$
- $c\Delta t/\Delta x < 1$

* B. Cohen, A. Kemp, and L. Divol, J. Comp. Phys. 229, 4591 (2010)

Parametric amplification of laser-driven electron acceleration in a plasma channel

Alexey Arefiev
Boris Breizman
Vladimir Khudik

Institute for Fusion Studies,
The University of Texas at Austin

Marius Schollmeier

Sandia National Laboratories

Parametric amplification of oscillations

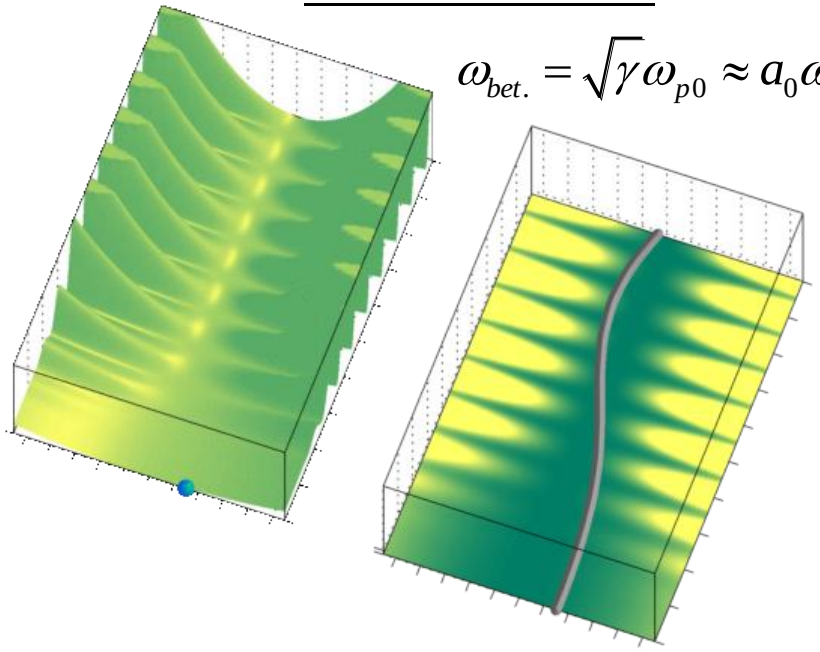
- Ultrarelativistic axial motion enhances the ion density in a co-moving frame:

$$\frac{d^2 y}{d\tau^2} + \gamma\omega_{p0}^2 y = 0$$

- Axial acceleration and deceleration modulate the perceived ion density.
- Oscillations become unstable when the period of the modulations becomes comparable to the period of the betatron oscillations: $\omega_{bet.} \approx c/\lambda$

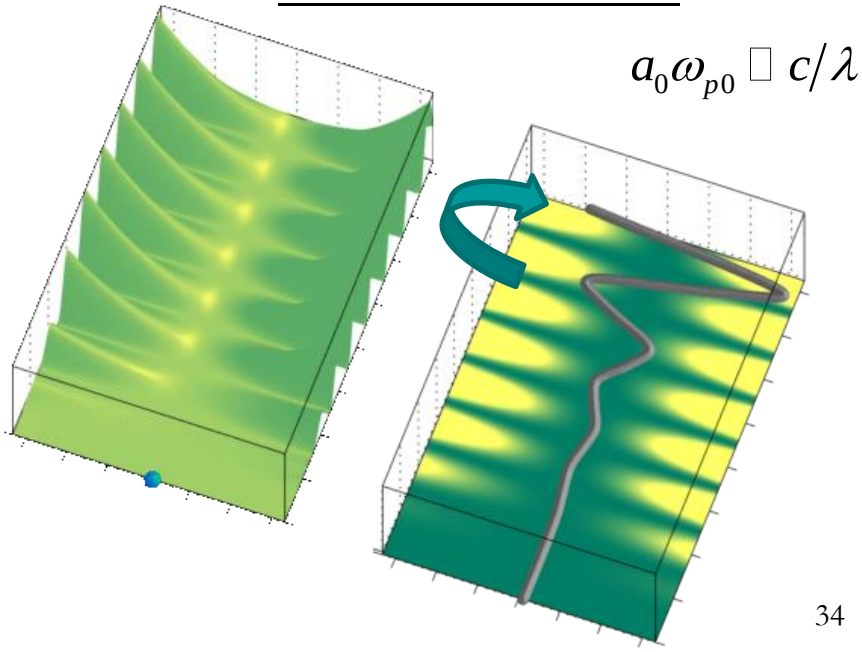
Stable oscillations

$$\omega_{bet.} = \sqrt{\gamma}\,\omega_{p0} \approx a_0\omega_{p0}$$



Unstable oscillations

$$a_0\omega_{p0} \gtrsim c/\lambda$$



High Gradient Structures

- 4 talks presented on high gradient accelerator structure design and analysis using high performance electromagnetic modeling tools
  - "Low surface field 805-MHz muon cooling cavity - optimization and multipacting analysis" – ACE3P (Omega3P and Track3P) – Zenghai Li
  - "New approaches to multipacting modeling with application to high gradient structures" – Vorpal – Peter Stoltz
  - "Origin and mitigation of trapped modes between multicell accelerator cavities" – Vorpal – Ben Cowan ** Covered by WG3 Summary **
  - "Wakefields in hybrid dielectric photonic crystal cavities" – Vorpal – Carl Bauer ** Covered by WG3 Summary **
- Themes
  - Multipacting continues to be very important for a wide range of structures
    - has to be considered for every new geometry
    - multiple talks in other working groups
  - Cavity design with parallel codes is important and saves time/money
    - wakefield damping, peak surface fields, multipacting, trapped modes

Low Surface Field 805-MHz Pillbox Cavity

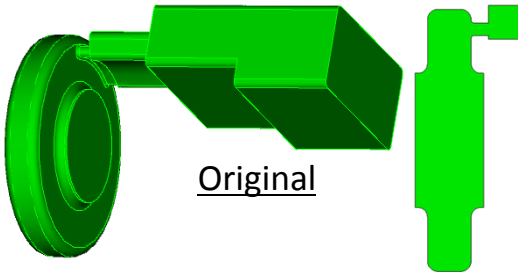
Zenghai Li, Lixin Ge, Chris Adolphsen, SLAC, Menlo Park, CA 94025
Derun Li and Daniel L. Bowring, LBNL, 1 Cyclotron Road, Berkeley, CA 94720

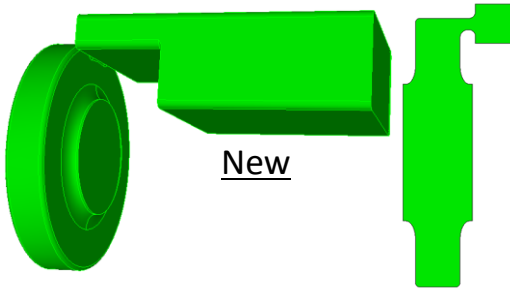
AAC12, Austin, Texas, June 10-15, 2012

Low Surface Field 805-MHz Pillbox Cavity

Shape Optimization and MP Analysis

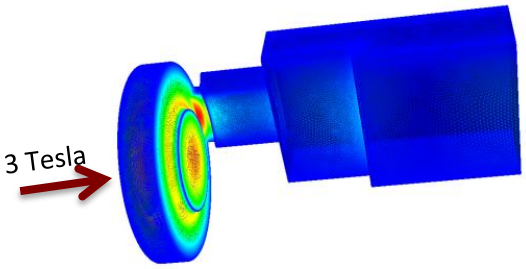
- Cavity optimization
  - » Original cavity suffered from severe gradient degradation and surface damage.
  - » New design significantly reduces peak surface field by rounding coupling slot and using elliptical disk.
  - » Coupler waveguide is simplified with smaller slot opening.

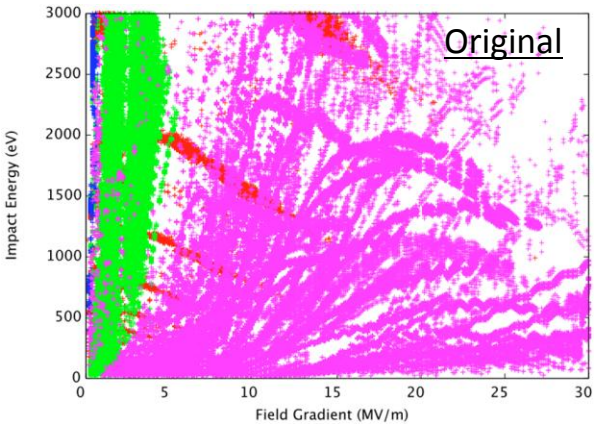


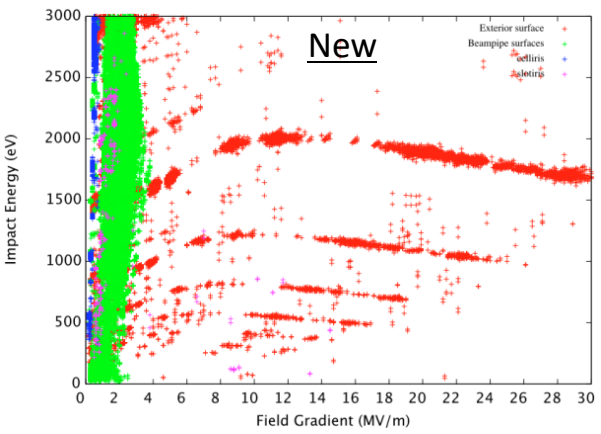


	Emax on slot (cav side)	slot (WG side)	Emax on disk	Emax on window	Hmax	Qext	Q0	Coupling beta
Original	69.81		44.95	32.88	0.304	12899	16007	1.24
NEW	16.09	8.40	31.75	33.38	0.122	15043	16761	1.11
New with	16.26	8.93	33.27	48.24/27.68	0.124	12662	16717	1.32

- Multipacting analysis
  - » New design eliminates major MP activities.

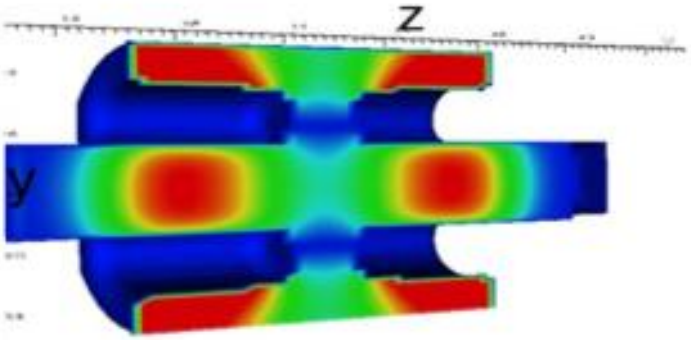






MP locations: Window; Disk rounding; Coupling iris; Others.

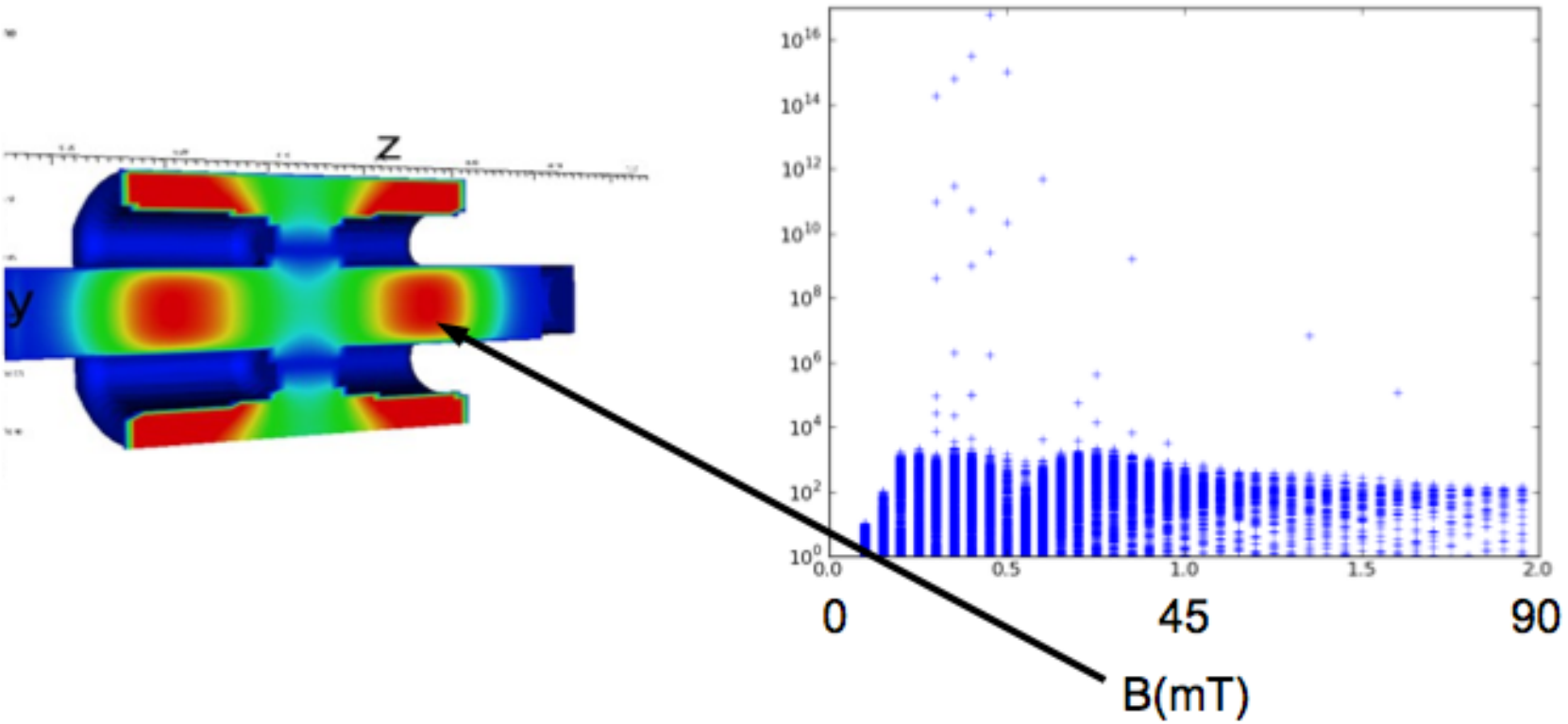
New Approaches to Multipacting Modeling with Application to High Gradient Structures



Peter Stoltz and Chet Nieter
Tech-X Corp.

Work funded by DoE Office of Nuclear Physics Grant DE-SC0006243
and Office of Naval Research Grant N66001-11-M-5101

Simulation shows multipacting at all field levels but particularly around 20mT



However, complex structures make interpretation more difficult. Multipacting could be due to gyromotion in the magnetic field rather than resonance with rf.

Beam Dynamics

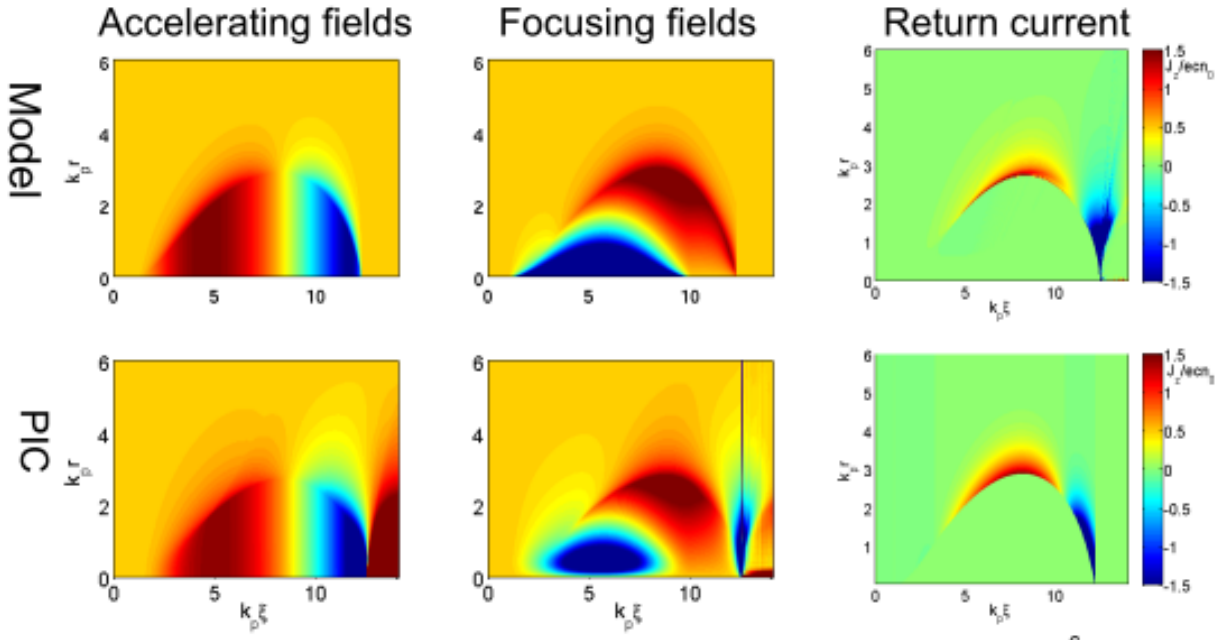
- 4 presentations were made on a variety of beam dynamics topics
  - "Parametric-resonance Ionization Cooling (PIC) of Muon Beams" – G4beamline – Vasiliy Morozov ** Covered by WG7 Summary **
  - "Analytic model of electron self-injection in a plasma wakefield accelerator in the bubble regime" – QuickPIC – S. Austin Yi
  - "Application of New Simulation Algorithms for Modeling rf Diagnostics of Electron Clouds" – Vorpal – Seth Veitzer
  - "Suppressing Transverse Beam Halo with Nonlinear Magnetic Fields" – PyORBIT – David Bruhwiler ** Covered by WG7 Summary **
- Themes
  - Tracking with multiphysics (materials, cavities, plasma dynamics, complex magnetic fields, synchrotron radiation, etc.) essential for muon colliders
  - Theoretical work in concert with simulations, Hamiltonian dynamics, emittance exchange concepts are central to moving forward
  - Helping HEP community reach the intensity frontier is now part of our job
    - beam halo studies for proton linacs and rings must be reactivated
    - electron cloud dynamics is important for Project X, maybe LHC upgrade

Analytic model of electron self-injection in a plasma wakefield accelerator in the bubble regime

S. Austin Yi, V. Khudik, G. Shvets
The University of Texas-Austin

Advanced Accelerator Concepts Workshop
June 14, 2012

Analytic model of electron self-injection in a plasma wakefield accelerator in the bubble regime



S.A. Yi, V. Khudik, G. Shvets

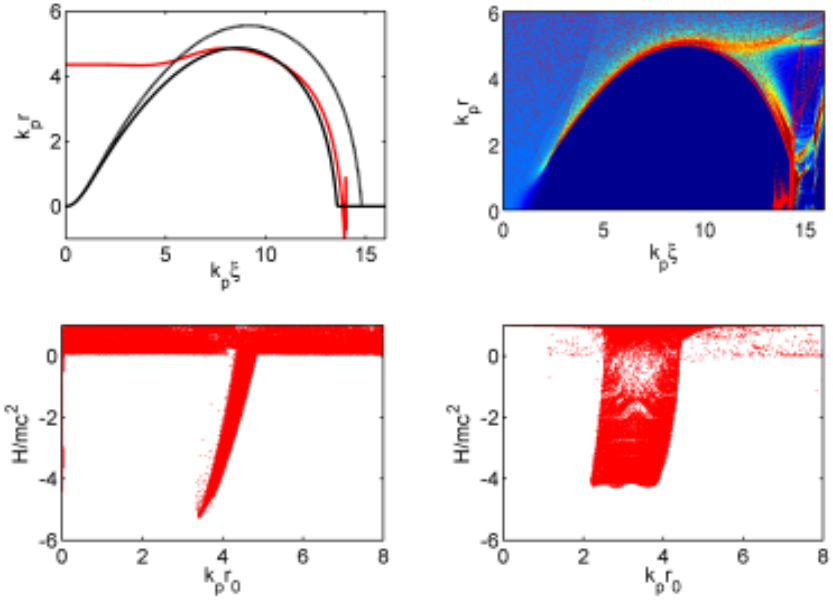
$$J_z = J_{\rm beam} + J_p(\xi) e^{-(r-r_b)/\Delta_s} \theta(r - r_b)$$

$$E_r = B_\theta = 0 \rightarrow \int_0^\infty J_z r dr = -\int_0^\infty \frac{d^2\psi}{d\xi^2} r dr$$

$$J_p(\xi) = \frac{\lambda(\xi) - \int_0^\infty r dr d^2\psi/d\xi^2}{\Delta_s(r_b + \Delta_s)}$$

Plasma return current must be included in model in order for accurate fields outside bubble. These fields play a crucial role in determining the trajectory of self-injected electrons. For accurate trajectories, return current layer must be thicker than density sheath layer.

Model fields and injected electron trajectories are in quantitative agreement with PIC (WAKE) simulations.



Application Of New Simulation Algorithms For Modeling rf Diagnostics Of Electron Clouds

Seth A. Veitzer*

David N. Smithe*

Peter H. Stoltz*

15th Advanced Accelerator Concepts Workshop

Austin, TX

June 11, 2012

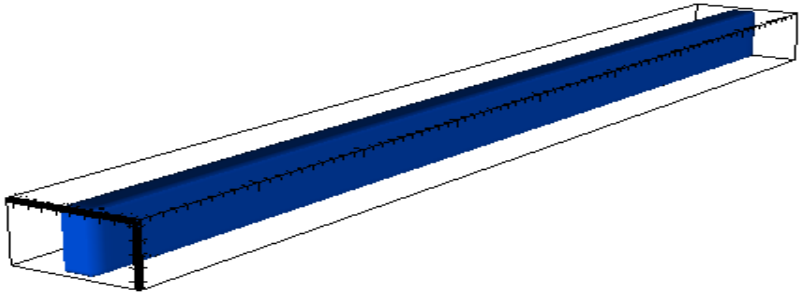
This work was performed under the auspices of the Department of Energy as part of the ComPASS SCiDAC-2 project (DE-FC02-07ER41499)

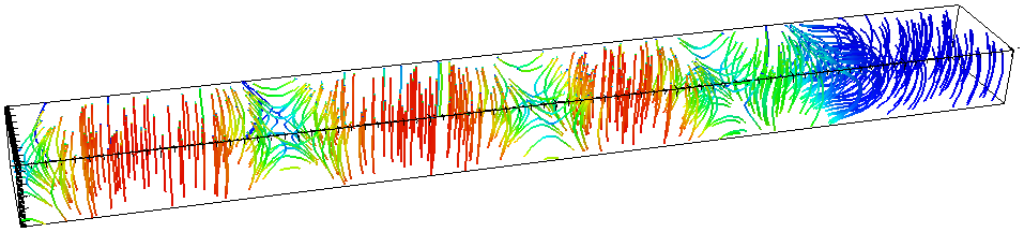
Tech-X Corporation, Boulder, CO

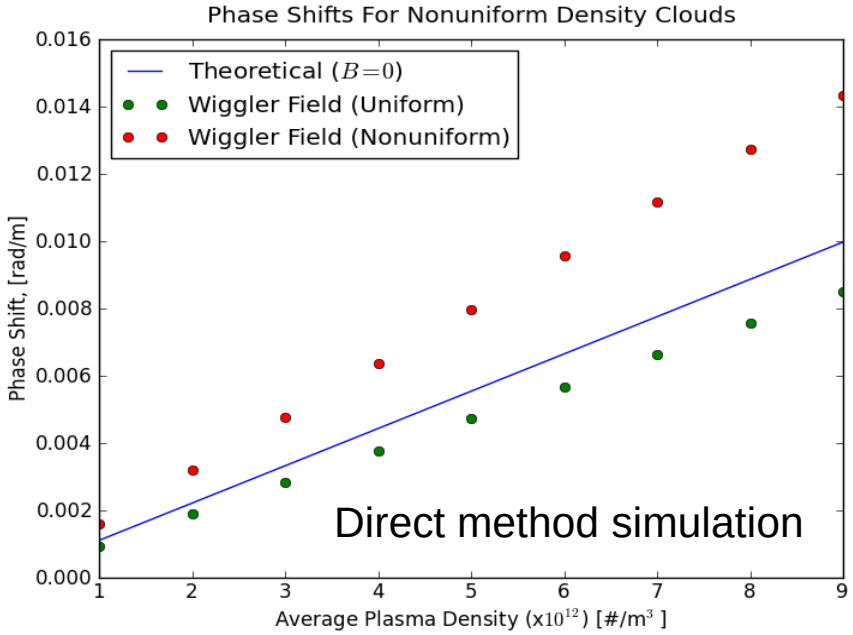
TECH-X CORPORATION

Regarding Non-Uniform Cloud Densities and Variable B Fields

- 3-Dimensional Simulations (256x8x8)
- Reduce volume of plasma dielectric, but increase the dielectric strength, so overall equivalent density is the same
- Also added a highly non-uniform magnetic field (CESR wiggler) – dielectric tensor







Modulated dielectric simulations are still in progress.

- Fields are stable and accurate at dielectric boundaries
- Should have results in the next two weeks

Anti-atom Traps

- 2 talks were presented on the simulation of anti-atom traps
  - "Ergodicity of Atom Trajectories in Magnetostatic Traps" – Andrey Zhmoginov
  - "Simulating autoresonant injection of antiprotons into positrons using numerical Vlasov solver" – C. So ** Covered by WG7 Summary **

- Themes and future needs
  - Long trapping times and sensitive dynamics require symplectic integrators
  - Sophisticated scatttering, ionization and recombination algorithms need to be developed and implemented
  - Charged particles are present at early times, so both charged and neutral dynamics is required in general

Ergodicity of Atom Trajectories in Magnetostatic Traps

A. Zhmoginov, J. S. Wurtele, J. Fajans and A. Charman

UC Berkeley

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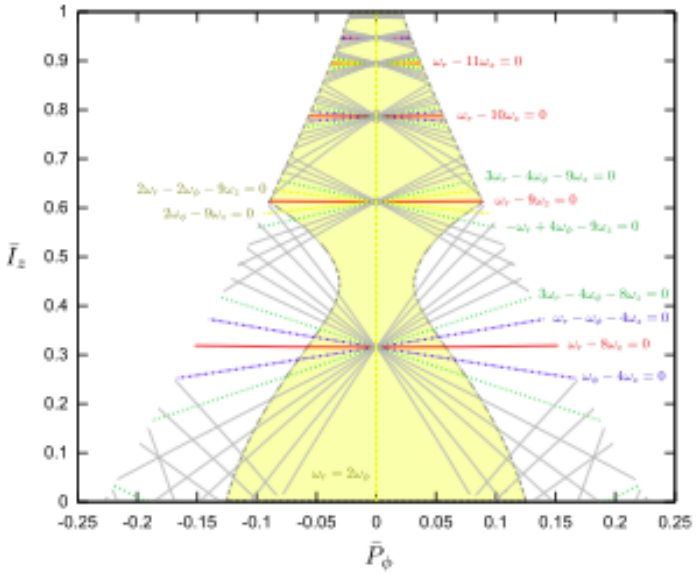
AAC Workshop, June 2012

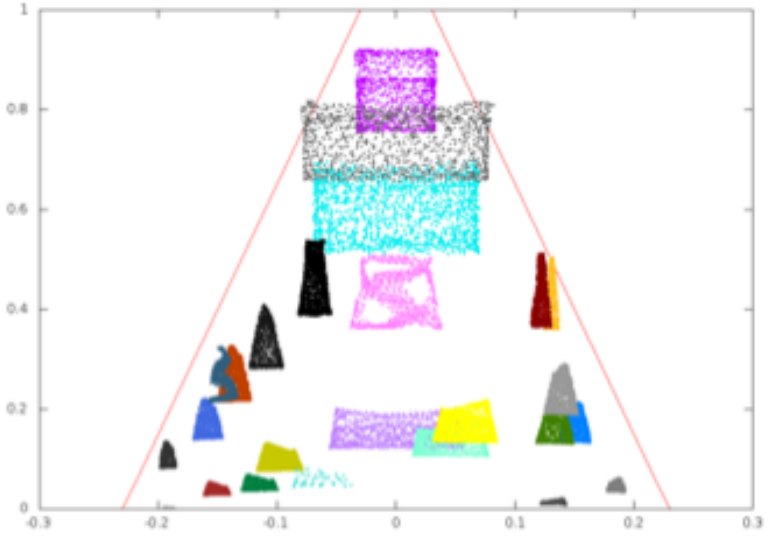
Resonances and Stochasticity

- Frequencies $\boldsymbol{\omega}(\boldsymbol{I})$ entering the resonance condition $\boldsymbol{\ell} \cdot \boldsymbol{\omega} = 0$ can be calculated as:

$$\omega_k = \frac{\partial H_0}{\partial I_k}$$

- The resonance width is proportional to $|\delta U_{\boldsymbol{\ell}}|^{1/2} (\boldsymbol{\ell} \cdot \nabla_{\boldsymbol{I}} \boldsymbol{\omega})^{-1/2}$
- Resonances and their widths can then be plotted for states with a fixed energy:





- Comparison shows good agreement even though $\varepsilon \sim 1$

Novel Algorithms

- 5 talks presented on a variety of new algorithms
  - "The Fast Multipole Method for N-Body Problems" – code? – Bela Erdelyi
  - "Nonlinear Optics in a PIC Framework" – Wake – Dan Gordon
  - "Modeling Asymmetric Beams Using Higher-order Phase-space Moments" – code? – Frank Lee
  - "A Reduction of the Vlasov-Maxwell System using Phase Space Blobs" – code? – Brad Shadwick
  - "Improved particle statistics for laser-plasma self-injection simulations" – Vorpal – Ben Cowan
    - TBD…

The Fast Multipole Method for N-Body Problems

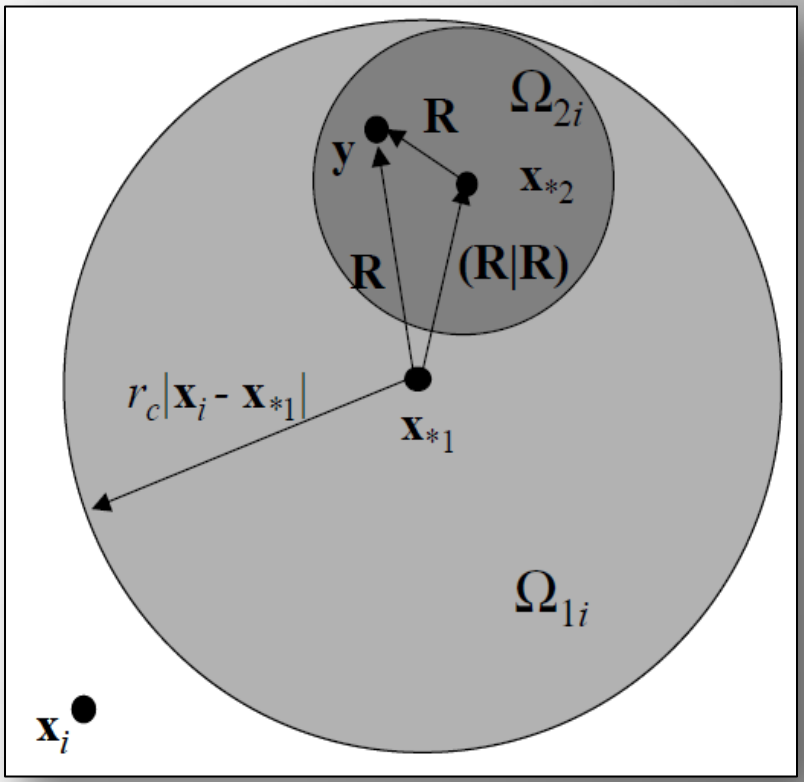
Bela Erdelyi

AAC 2012, Austin, TX

June 10-15, 2012

How Does It Work?

1. Enclose all particles in a cube
2. Divide each cube $l_{\max}$ times
3. Compute multipole expansions for every leaf node (C →M)
4. Upward pass: shift expansions to parents (M→M)
5. Convert multipole expansion to local expansions in the far region (M→L)
6. Downward pass: shift expansions to children (L→L)
7. Final summation: add near neighbors (particle-particle direct) to local expansion evaluation (L+N →C)



Shifting the local expansion centers reduce their domain of validity

NRL
Plasma Physics
Division

Nonlinear Optics in a PIC Framework

Daniel Gordon, Michael Helle, Joe Penano, Bahman Hafizi*, Antonio Ting, Dmitri Kaganovich

Naval Research Laboratory, Plasma Physics Division, Washington DC
**Icarus Research Inc., Bethesda, MD*

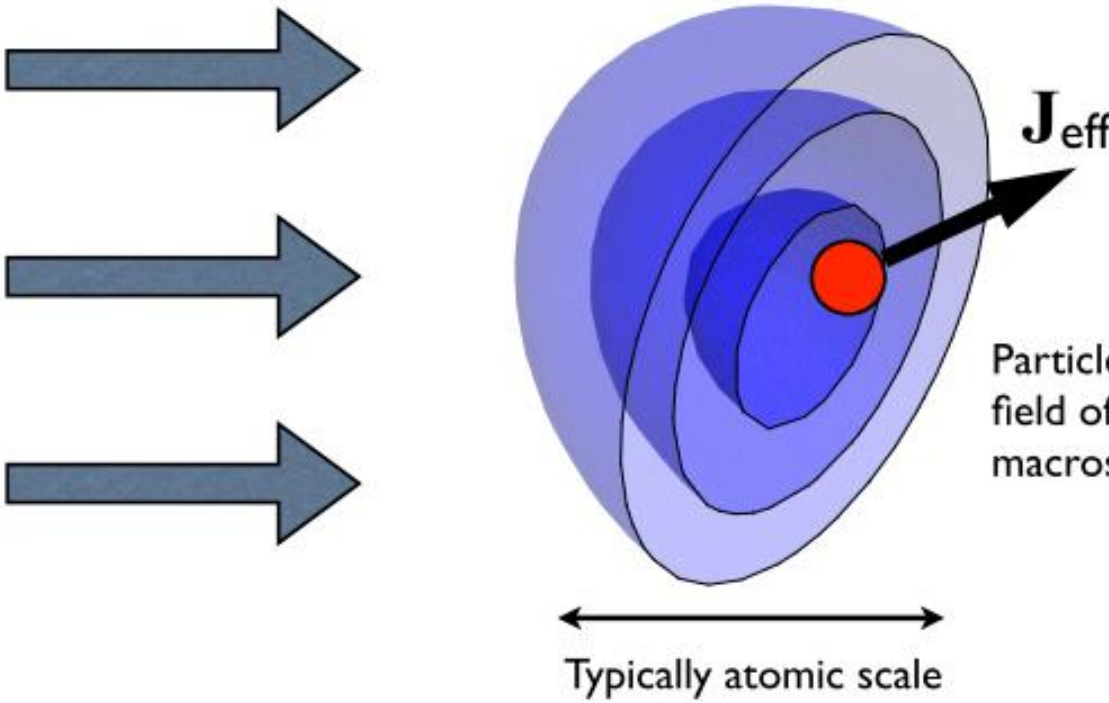
2012 Advanced Accelerator Concepts Workshop, Austin, TX, June 10-15

Supported by Department of Energy and NRL 6.1 Base Program

Effective Particle in Potential Well

Macroscopic Field
(full Maxwell)

Microscopic Field
(electrostatic potential)



Distribution of effective particles → dispersion + nonlinearity

Modeling Asymmetric Beams Using Higher-order Phase-space Moments

Frank M. Lee[1], B. A. Shadwick[2]

[1]Department of Physics, University of Texas-Austin
[2]Department of Physics & Astronomy, University of Nebraska-Lincoln

Representing an Asymmetric Beam

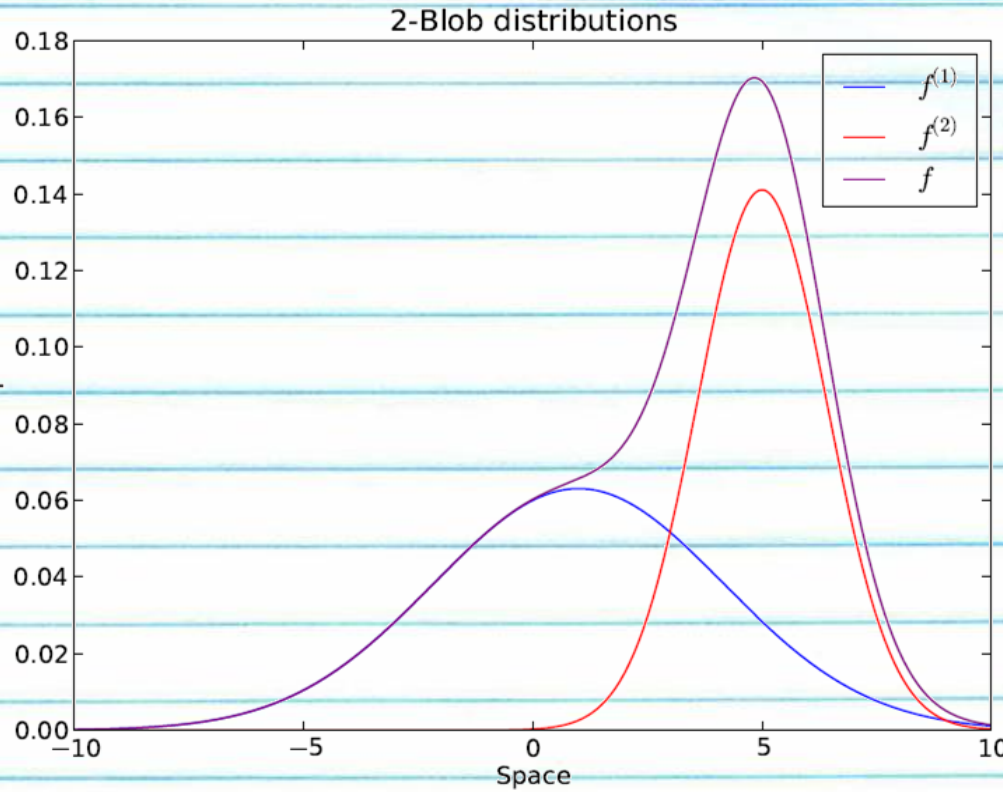
- The asymmetric distribution function is given by a sum of symmetric gaussians offset with different parameters. This allows us to use some previous results for the single gaussian.

$$f(x,p) = \frac{1}{2}(f^{(1)} + f^{(2)})$$

$$f(x,p) = \frac{1}{2}\left[\frac{n_b}{2\pi\sqrt{|M_{(1)}|}} exp\left(-\frac{1}{2}\delta_1\xi_i M^{-1}_{(1),ij}\delta_1\xi_j\right) + \frac{n_b}{2\pi\sqrt{|M_{(2)}|}} exp\left(-\frac{1}{2}\delta_2\xi_i M^{-1}_{(2),ij}\delta_2\xi_j\right)\right]$$

$$M_{(k)} = \begin{bmatrix} \Sigma^{(k)}, \Xi^{(k)} \\ \Xi^{(k)}, \Pi^{(k)} \end{bmatrix}$$

$$\delta_k\xi = \xi - \langle\xi^{(k)}\rangle$$



A Reduction of the Vlasov–Maxwell System Using Phase-Space Blobs[†]

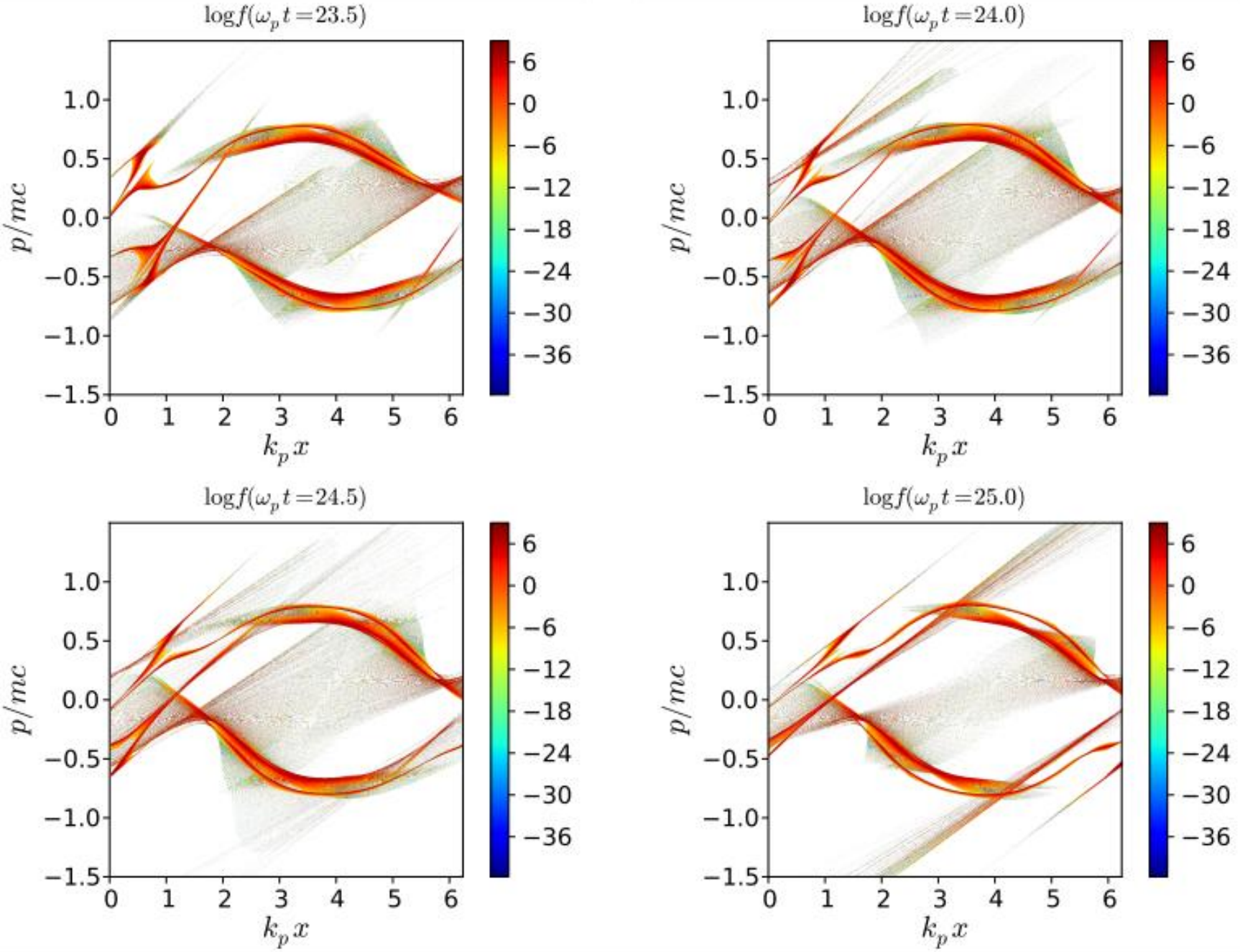
B. A. Shadwick[1] and Frank M. Lee[2]

[1]Department of Physics and Astronomy, University of Nebraska – Lincoln

[2]Department of Physics, The University of Texas at Austin

AAC 2012, Austin, TX

[†]Supported by the U.S. DoE under Contract DE-FG02-08ER55000


$\log f(\omega_p t = 23.5)$
$\log f(\omega_p t = 24.0)$
$\log f(\omega_p t = 24.5)$
$\log f(\omega_p t = 25.0)$
p/mc
$k_p x$
1.0
0.5
0.0
−0.5
−1.0
−1.5
0
1
2
3
4
5
6
6
0
−6
−12
−18
−24
−30
−36

Improved particle statistics for laser-plasma self-injection simulations

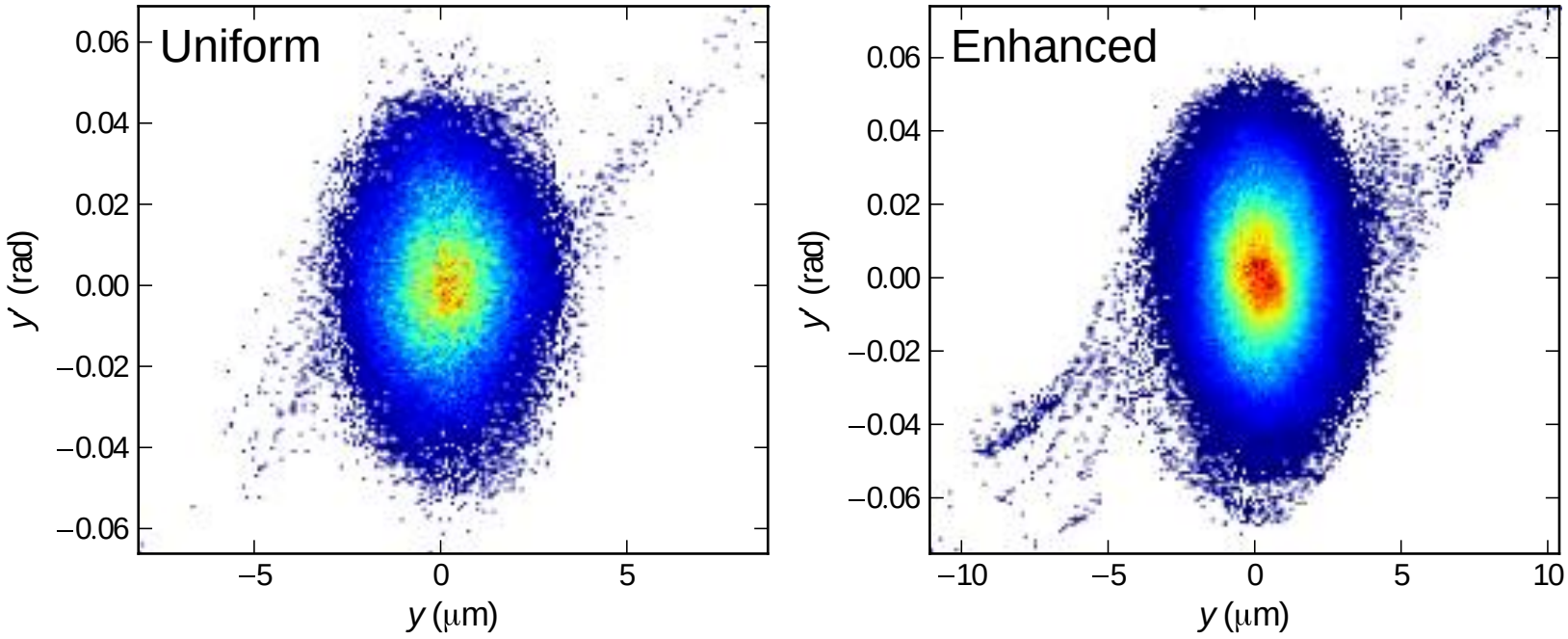
B. M. Cowan[1], S. Y. Kalmykov[2], B. A. Shadwick[2], K. Bunkers[2], D. L. Bruhwiler[1], and D. P. Umstadter[2]

[1]*Tech-X Corporation*

[2]*University of Nebraska, Lincoln*

3D comparison

- For uniform loading, used 4 PPC everywhere
- For enhanced loading, used 16 PPC (1 × 4 × 4) inside collection volume (radius 7–10 μm), 1 PPC outside
- Compared transverse phase space
  - Better definition of halo for enhanced loading
  - Cleaner resolution of Gaussian core



Modeling Future High-Power Laser Systems

- 45 minute discussion between WG2 and WG8
- Overview of present status
  - High-end: very sophisticated codes like Miro and Prop92
    - Not widely available, long pulse bias, very hard to use → not widely used
  - Low-end: Excel spread sheets to account for theory, thresholds, scalings
    - cumbersome, no multiphysics
  - Middle: wide variety of *ad hoc* approaches and codes
    - optics design: Zemax, Oslo
    - CAD, layout: Code5, Fred
    - attempts at multiphysics: CST, Comsol, *ad hoc* code coupling
    - there is a need here
- How to move forward?
  - Need a 2 or 3 day workshop just to define the problem
    - Appropriate organizers would be ICFA-ICUIL; http://www.icuil.org/
  - One idea: create a flexible software framework for the community
    - problems: funding source? getting community buy-in to support standards