Computational Accelerator Physics Working Group

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Goals

- Summary
- Verification: Are we correctly solving the model?
- Validation: Does the model represent reality?
- Determine frontiers
- Determine needs

Particle beam physicists: goal to understand, predict, improve beams - use computation

- Many applications
  - High-energy physics
  - Light sources
  - Semiconductor processing
  - Electron microscopes
- Difficult
  - Highly nonlinear
  - Collective
  - Long-range (Maxwell/Coulomb)

Computational talks covered wide range of beam physics issues

V&V

Fonseca: *Standard problems in advanced acceleration*

Reduced models

Hur: *Averaged-PIC simulation of laser-plasma interaction: pulse amplification by Raman backscattering and wake field*

Shadwick: *Thermal Effects in Intense Laser-Plasma Interactions*

Antonsen: *Progress in Quasistatic Modeling of Plasma-Based Accelerators: QUICKPIC*

Laser interaction with solids

Bowes: *Ultrafast 2-D radiative transport in a micron-scale aluminum plasma excited at relativistic intensity*

De Silva:*PIC modeling of overdense interactions*

Modeling space charge

Bohn: *Collective Modes and Colored Noise as Beam-Halo Amplifiers*

Fubiani: *Studies of space charge effects in ultrashort electron bunches*

Chang: *Compensation for bunch emittance in a magnetization and space-charge dominated beam*

LWFA

Dimitrov: *Particle-in-cell simulations of intense laser pulses coupling into plasmachannels*

Cooley: *Broad-Energy Electron Beam Injection and Loading in Laser Wakefield Accelerators*

Reitsma: *Laser wakefield acceleration - a fully self-consistent analysis*

Milchberg:*Hydrodynamical evolution of plasma channels*

PWFA

Rosenzweig: *Energy Loss of a High Charge Bunched Electron Beam in Plasma: Simulations, Scaling, and Accelerating Wake-fields*

Bruhwiler: *Simulation of Ionization Effects for High-Density Positron Drivers in future Plasma Wakefield Experiments*

Dimitrov: *The IONPACK Library of Ionization Algorithms for PIC Codes*

Other

- Kesar: *Time and frequency domain models for Smith-Purcell Radiation from a two dimensional charge moving above a short grating*
- Fukui (Cline):*A Muon Cooling Ring with Lithium Lenses*
- Lewellen: *High-Brightness Injector Modeling*

We heard from

- Review/plenary
  - Mori: *Advances in Simulation Capability*
  - Mima: *PIC simulation and experimental research on high energy particle generation and their applications*
  - Kishek: *Modeling of halos and intense beams*
  - Lewellen: *Modeling injectors*

Why do we compute?

- Discover new physics
- Design
- Check theory

- Failure analysis
- Optimization
- Check experiment

What does this require?

Faithfully model the physics

OR (and)

Faithfully model the experiment

Code fidelity standard is Verification and Validation (V&V)

- “Benchmarking” is not specific
- Verification: the code correctly solves the model
  - The implementation of the algorithm is correct
  - The algorithm is correctly used (parameters okay)
- Validation: the model is faithful to the system
  - The inputs to the model are correct
  - The model includes relevant physics

Verification needed to know whether we can believe predictions of large acceleration

- From linear theory
- Assume 100% modulation
- Take plasma wavelength of 40 microns
- E=3MeV/40μ=75Gev/m
- Drive these plasma waves with now available TTT lasers

$$kE = n_{e1}e/\varepsilon_0$$

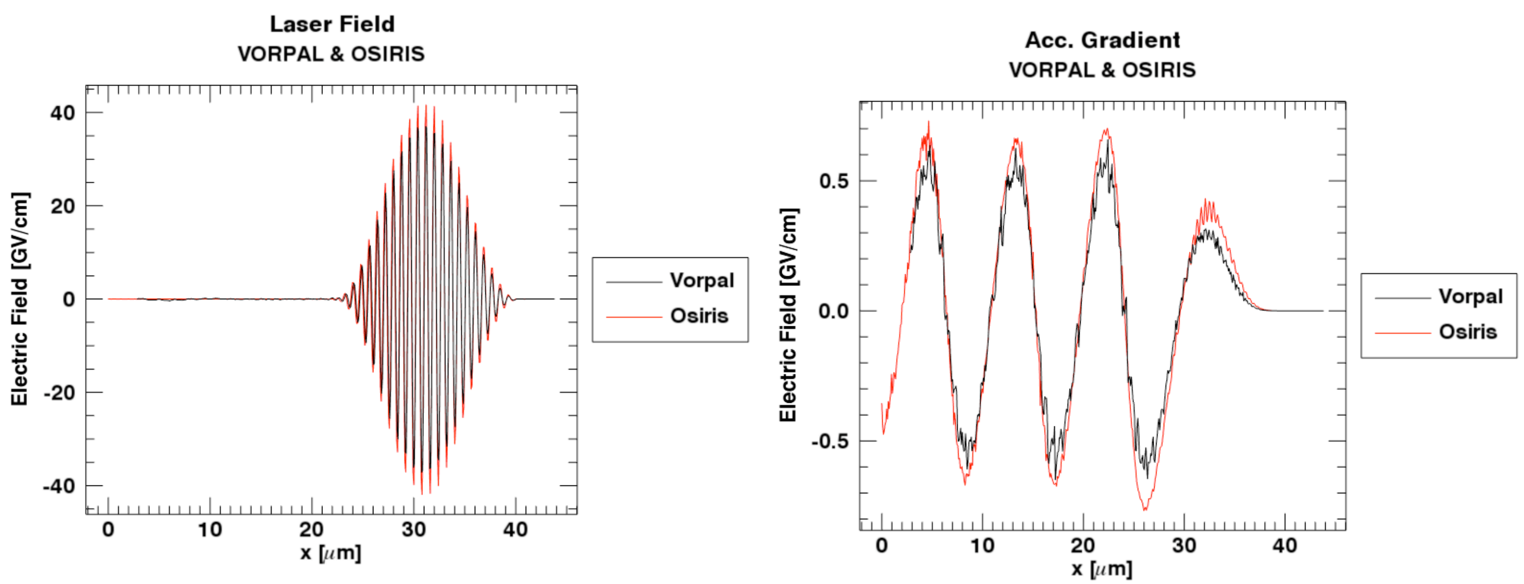
$$\frac{\omega_p}{c} eE = m\omega_p^2$$

$$eE = 2\pi mc^2 / \lambda_p$$

Computer simulations are need to computer the highly nonlinear physics needed for assessing these systems

EM-PIC codes have been verified (Fonseca)

- Model = self-consistent particle motion in electromagnetic field
- Linear regime: analytic models exist, comparisons in papers
- Cold 1D: analytic models exist, comparisons in papers
- Verification of the nonlinear regime one result of this conference
- http://zamb.ist.utl.pt/aac/



Differences believed understood and subject of future work.

Injector codes have been verified (Bohn/Mihalcea - Fermilab/NIU injector)

	Q(nC)	ϵ_x	ϵ_y	ϵ_y/ϵ_x
Astra	0.6	0.48	27.28	56.8
Parmela no SC	0.6	0.50	28.60	57.2
Parmela with 3DSC	0.6	0.51	28.64	56.2
Parmela no SC	1.0	1.11	28.89	26.0
Parmela with 3DSC	1.0	1.13	28.99	25.7

(for RMS parameters, insignificant space charge)

Verification requires a detailed comparison of parameters and capabilities

- Laser Parameters
  - Temporal Profile
  - Transverse profile definitions
  - Launch Methods
- Plasma Parameters
  - Ramp/edge geometries
- Particle Loading
  - Different noise properties
- Required modifications of
  - Input files
  - Code capabilities

Standard WF test suite
http://zamb.ist.utl.pt/aac/

- LWFA: 512x128(x128)
  - 2D fully ionized (40 mins on laptop)
  - 3D fully ionized (80 node hours)
  - 2D neutral gas (needs ionization)
  - 3D neutral gas (needs ionization)
- PWFA:
  - 2D-cyl fully ionized (40 mins on laptop)
  - 3D fully ionized (80 node hours)
  - 2D-cyl neutral gas (needs ionization)
  - 3D neutral gas (needs ionization)

Problems and results provided as service to community

Will also enable understanding of differences due to approximations (2d-cyl versus 3D)

With just verification: much can be done

Verified in limits

- Bohn: Oscillations and colored noise can cause dramatic growth of beam halos
- Kesar: The emission per unit length from short Smith Purcell radiation generators can be 4x larger than for very long systems
- Shadwick: For typical plasma temperatures, pressure effects are not important in the determination of the wake field produced by a laser

Code to code verification

- Rosenzweig: the $1/\sigma_z^2$ scaling of effect peak field behind a short beam in a plasma breaks down as $\sigma_z \rightarrow 0$. Analytic calculation, Oopic simulation.
- Cheng: For a strongly magnetized beam, the emittance growth in $\langle\omega\rangle$ frame is dominated by angular emittance growth.

Validation: Is the model correct?

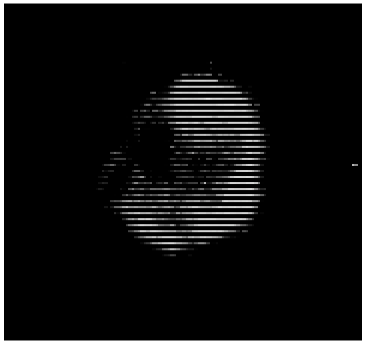
- Estimation and inclusion is one way to determine whether to add to the model

  Bruhwiler: Failure to include tunneling ionization due to wake fields underpredicts PWFA performance for neutral targets

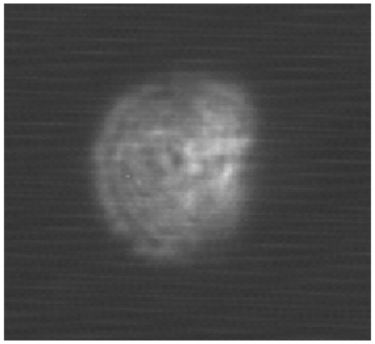
- Comparison with experiment identifies problems in the modeling

  Bohn, Haber: Failure to get the beam initial conditions right (modeling the emission) underestimates the final emittance

	Q(nC)	ϵ_x	ϵ_y	ϵ_y/ϵ_x
exp	0.6	1.68	27.71	16.5
Astra	0.6	0.48	27.28	56.8
Parmela no SC	0.6	0.50	28.60	57.2
Parmela with 3DSC	0.6	0.51	28.64	56.2

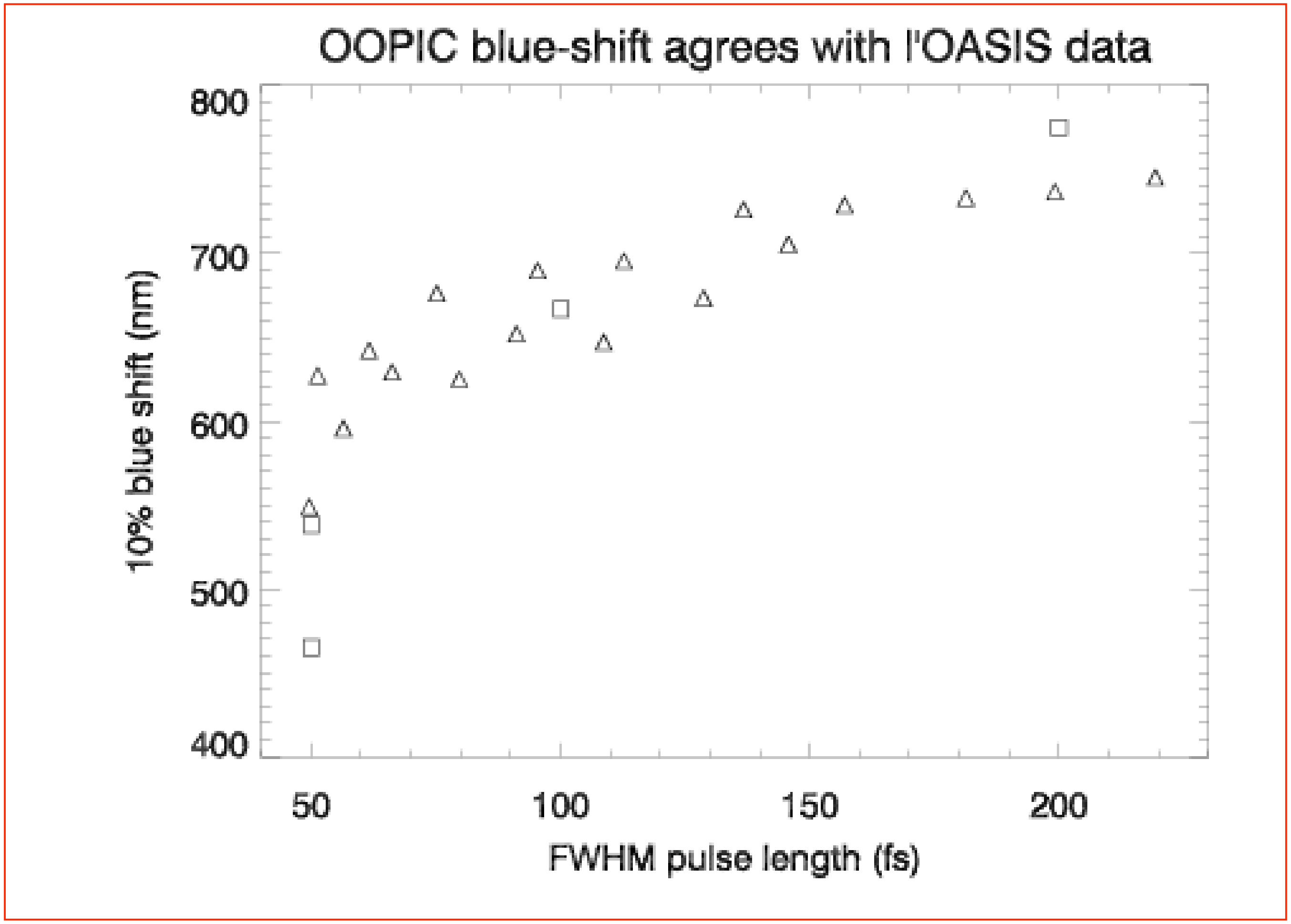


nonuniform



quasi-uniform

Validation of ionization modeling carried out



Going farther will require a "standard set of experiments"

- Code authors often not next to experiments
- All parameters
  - Relevant
  - Potentially relevant
  - Detail
- Need mechanism for iteration
- May need diagnostics modeling
- Challenge to the experimental community

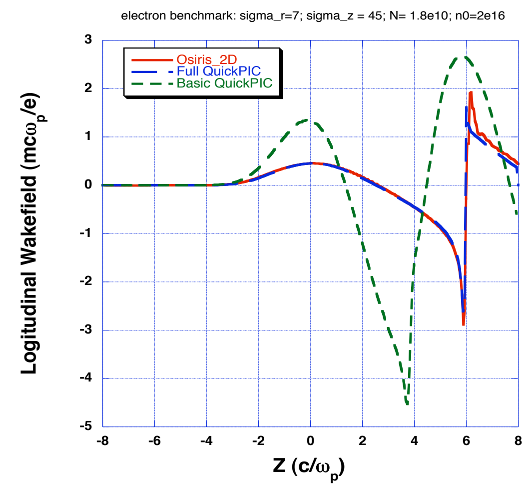
Determine frontiers in computing

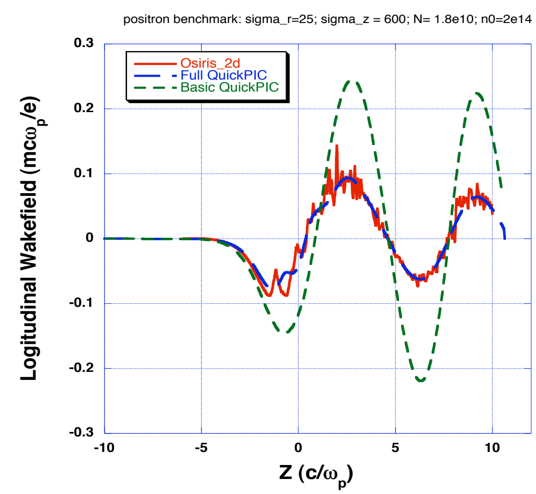
- Reduced methods
- Ionization

Community developing approaches that remove fast time scales

- Antonsen/Mori: QuickPIC
  - Assumes dynamics static over pulse focusing time
  - Particles propagated through the beam
  - Faithful for 1% the computational time
  - Needs development re self trapped particles
- Hur: averaged PIC
  - Removes the fast laser oscillation time scale
- Reitsma: photon kinetics
  - Dynamics followed over focusing time (photons), synchrotron/betatron time (particles)
  - 1D now; 2D under development

Longitudinal Wakefield





Community rapidly developing codes for ionization effects

- Bruhwiler: Validation of ionization models through blueshifting calculations. PWFA beam can self ionize to create the plasma it needs for wake field generation
- OSIRIS Team: Field and impact ionization either in or nearly in and undergoing testing
- Dimitrov: SBIR-funded libraries being developed for tunneling and impact ionization
  - C-language methods can be called from F90, F77, C++, Java - in single or double precision
  - Cross platform: Linux, Mac OS X, Windows, AIX, web portal
  - No longer a need for each group to code up the interaction basics
  - Used in VORPAL, OOPIC Pro
  - Certified for use in LSP
  - http://www.txcorp.com/technologies/IONPACK/

Simulation needed beyond the frontiers

- Cold beams (injectors, intense beams)
  - Lewellen notes that constant-size meshes will not allow modeling of ultra cold beams coming on line
  - Modeling of intense-beam halos needs to predict losses of one part in (10^{6-8}) per period. Hybrid/Vlasov/δf methods?
- LWFA/PWFA
  - More work on ionization. (validation!)
  - Dugan & Cline: start work on elastic scattering
- Laser-solid interactions (ion injectors)
  - Bowes: Radiative transport codes needed for computing interaction at solid densities. How can we handle hot electrons?
  - DeSilva: Low density finds ion beams coming off shocks
  - PIC modeling extremely challenging at high densities
  - What algorithms can capture collective effects in highly collisional regimes?
- Multiphysics: emission models, halo-wall interactions, integration

Working group also identified features needed for code release

- V&V
  - Regression tests: versus analytic or other solutions
  - Validation tests (help from experiment!)
- Documentation
  - Examples (some above)
  - User manual
  - Discussion lists
- User assistance
  - GUI's: generate input files, monitor runs
  - Sanity checking: boundaries (particles), stability limits,
- New features
  - Import from exp. Data
  - Parsers
  - CAD input
  - Standard data formats? (Photoinjector markup language?)

Will our community find a web model of use?

- No software building
- Need to figure out the resource model
- See OopicWeb at www.txcorp.com

Computation alive and well in accelerator physics

- Well
  - Leading to new ideas for advanced acceleration
  - Verification showing that equations are being solved correctly
  - Validation showing that models are correct
- Alive
  - New methods continually being developed
  - Plenty of challenges
  - Can predict using validated models at new spatial scales
- BUT there are needs
  - Modeling of modern injectors that produce very cold beams
  - Modeling of intense beams with large space charge
  - Modeling of laser-solid interactions for ion sources
  - Reduced models