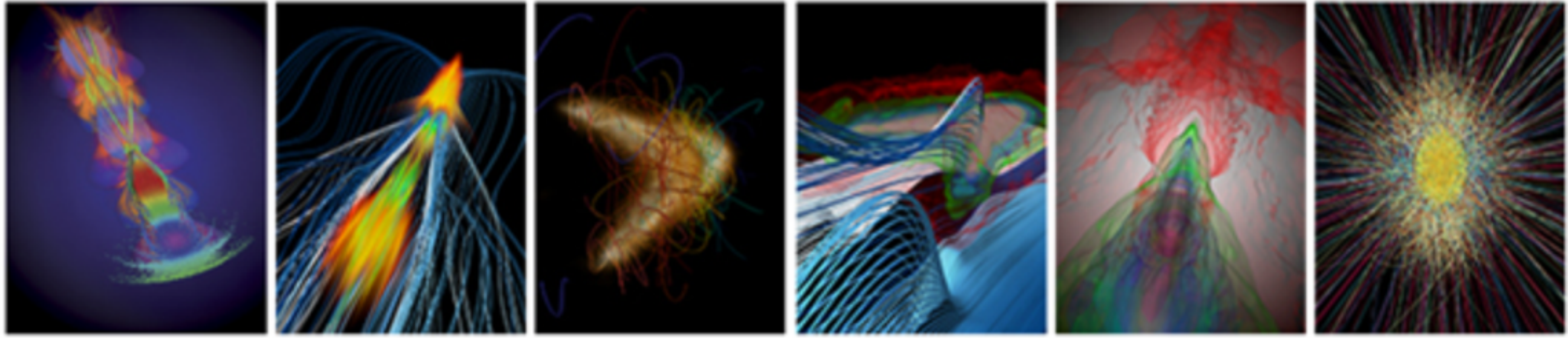

Current Status and Near Term Needs for Modeling FACET-II

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PICKSC
http://picksc.idre.ucla.edu

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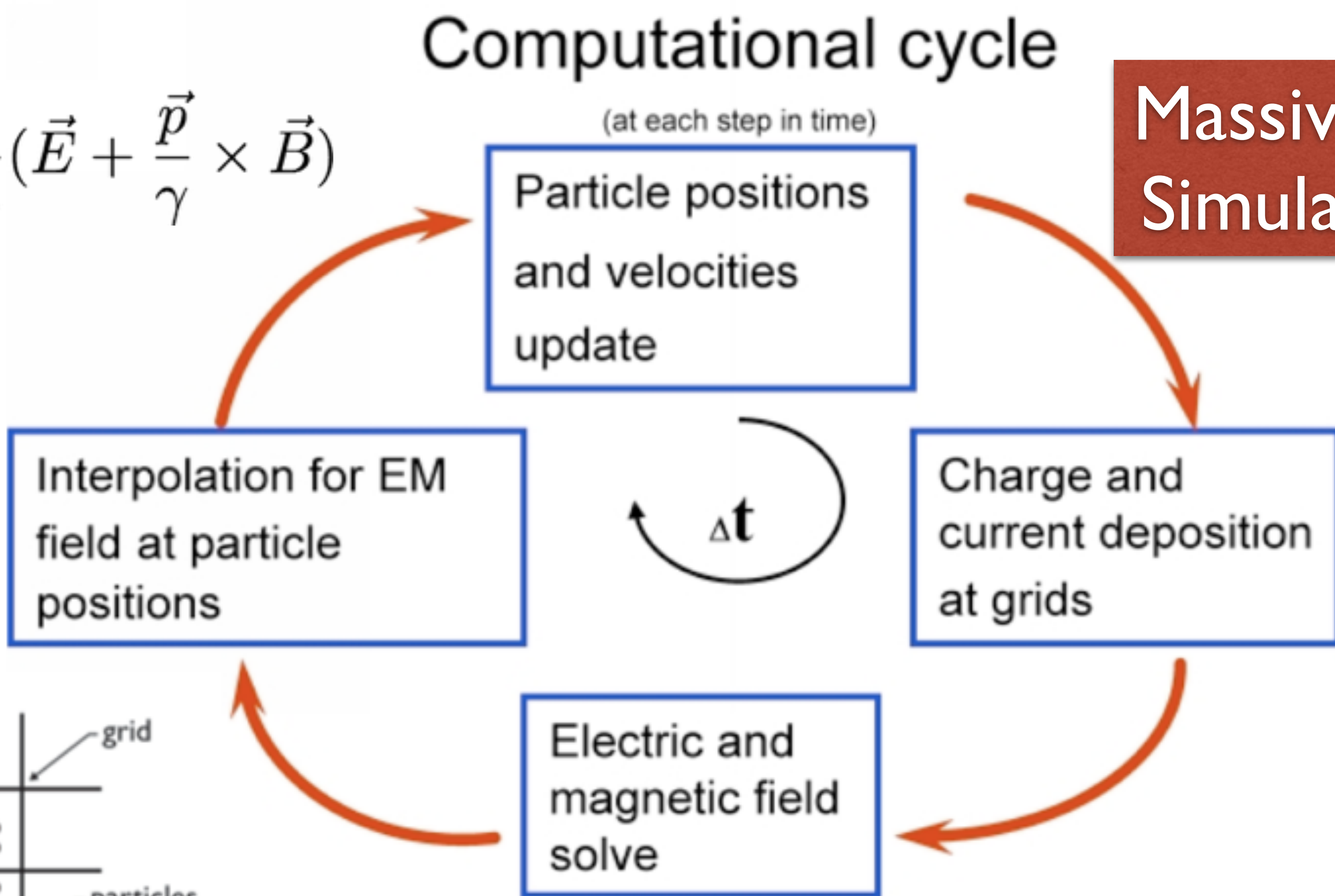
How to Simulate Plasma Based Accelerator?

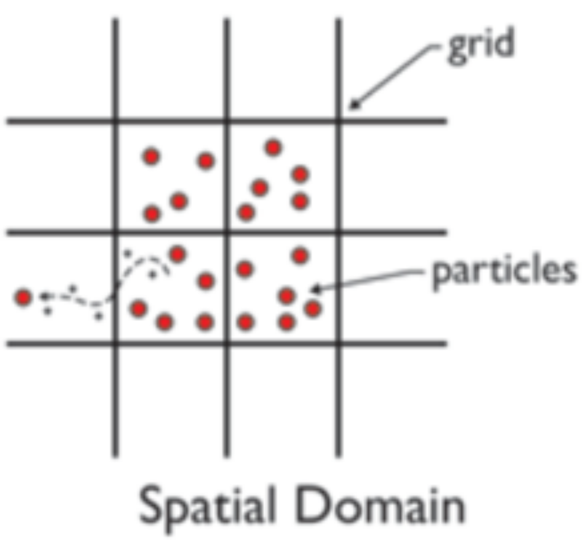
Particle-In-Cell Simulation

Massively Parallel Simulation Code

$$\frac{d\vec{p}}{dt} = \frac{q}{m}(\vec{E} + \frac{\vec{p}}{\gamma} \times \vec{B})$$



$$\begin{cases} \nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} \\ \nabla \times \vec{B} = \frac{\partial \vec{E}}{\partial t} + \vec{J} \\ \nabla \cdot \vec{E} = \rho \\ \nabla \cdot \vec{B} = 0 \end{cases}$$



* J. Dawson, Review of Modern Physics, Vol. 55, No. 2, April 1983.
* C. K. Birdsall, L.A. Bruce, Plasma physics via computer simulations. New York: McGraw-Hill, 1985.

Simulation of PBA

Beam Particles: $10^8 \sim 10^9$

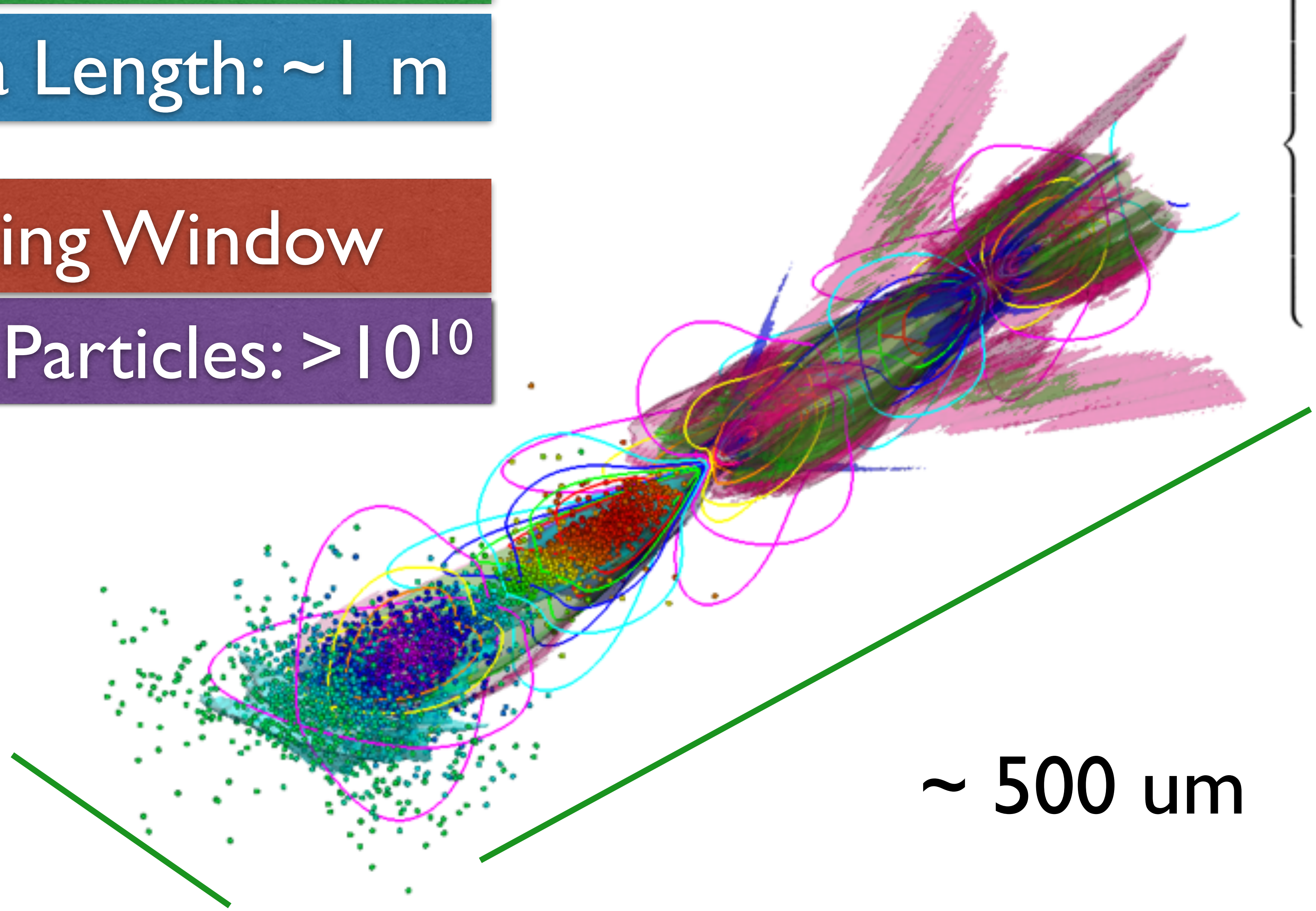
Plasma Length: ~1 m

Moving Window

Plasma Particles: $>10^{10}$

Maxwell's Eqns

$$\begin{cases} \nabla \times \vec{E} = -\dfrac{\partial \vec{B}}{\partial t} \\ \nabla \times \vec{B} = \dfrac{\partial \vec{E}}{\partial t} + \vec{J} \\ \nabla \cdot \vec{E} = \rho \\ \nabla \cdot \vec{B} = 0 \end{cases}$$

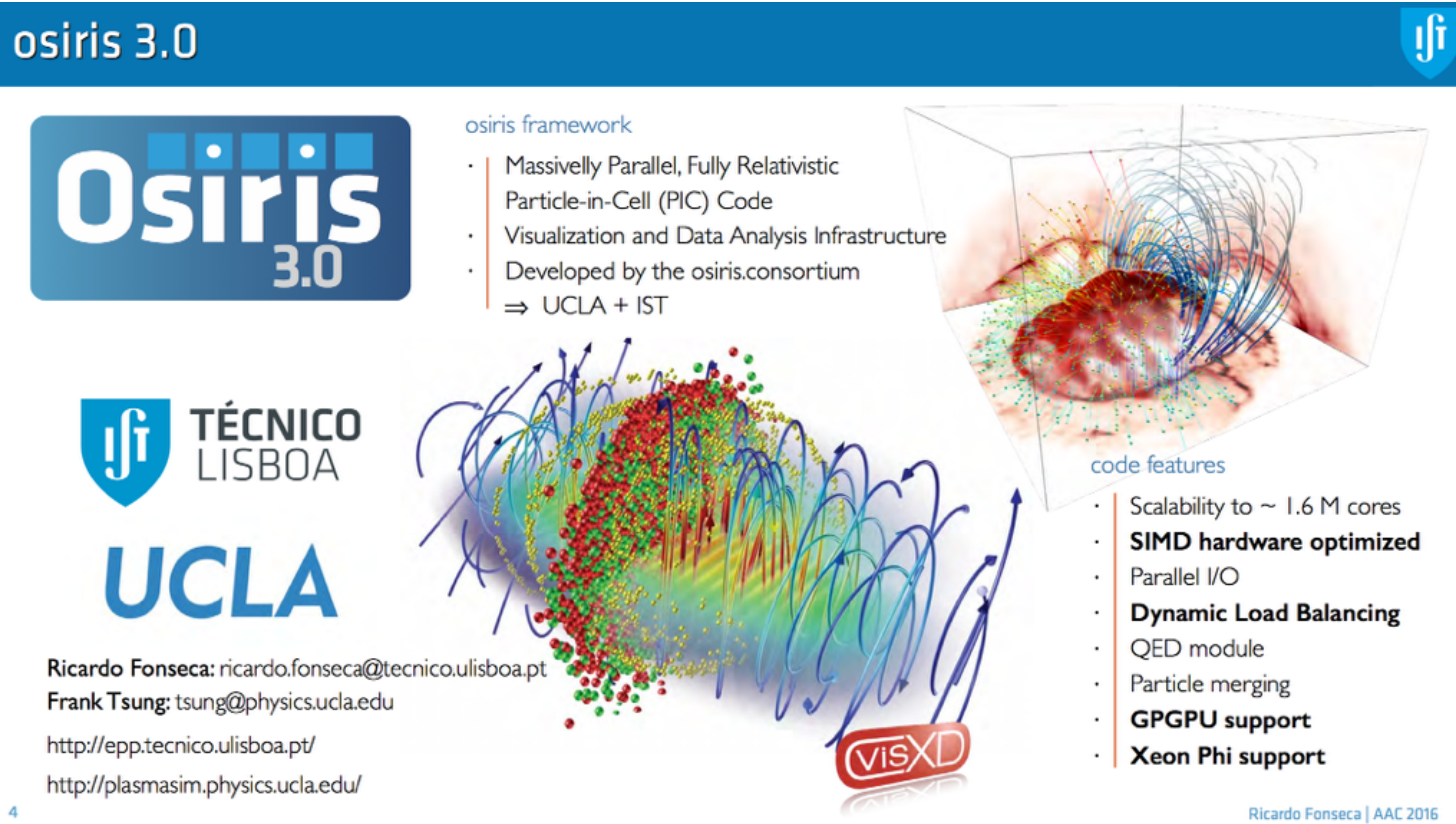


~ 500 um

~ 500 um

All particles move self-consistently

Osiris



Osiris 4.0 under development

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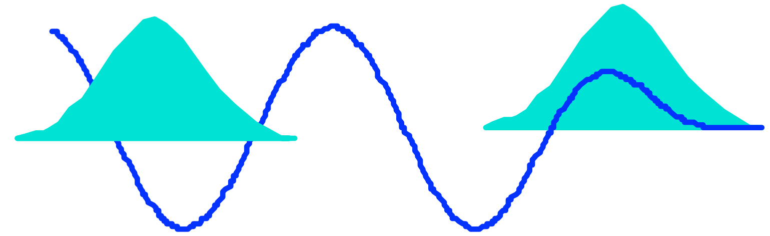
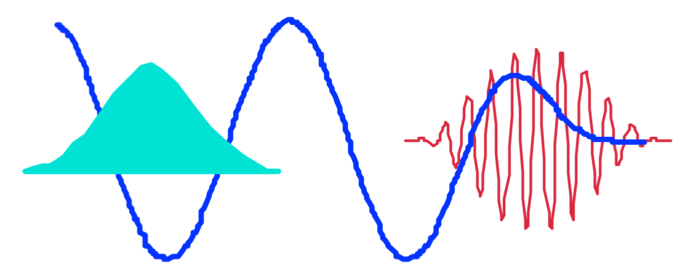
QuickPIC

QuickPIC[1,2] is a 3D parallel Quasi-Static PIC code, which is developed based on the framework UPIC[3].

Full PIC(Osiris): $dt \sim 0.02\omega_p^{-1}$ Courant Condition

QS PIC(QuickPIC): $dt \sim 20.0\omega_p^{-1}$ Free of CC!

$\sim \sqrt{\gamma \text{ of the beam}}$ $\quad \sim \omega_0/\omega_p$

1000 Times Faster

[1] C. Huang et al., J. Comp. Phys. 217, 658 (2006).

[2] W. An et al., J. Comp. Phys. 250, 165 (2013).

[3] V. K. Decyk, Computer Phys. Comm. 177, 95 (2007).

Equations in QuickPIC

Quasi-Static Approximation*

(x, y, z; t)

↓

(x, y, ξ=ct-z, s=z)

↓

$\partial_s << \partial_\xi$

↓

Plasma: (x, y; ξ)

↓

Beam: (x, y, ξ, s)

$$\begin{cases} \nabla \times \vec{E} = -\dfrac{\partial \vec{B}}{\partial t} \\ \nabla \times \vec{B} = \dfrac{\partial \vec{E}}{\partial t} + \vec{J} \\ \nabla \cdot \vec{E} = \rho \\ \nabla \cdot \vec{B} = 0 \end{cases} \qquad \begin{cases} \nabla_\perp \times \vec{E} = -\dfrac{\partial}{\partial \xi}(\vec{B} - \hat{z} \times \vec{E}) \\ \nabla_\perp \times \vec{B} - \vec{J} = \dfrac{\partial}{\partial \xi}(\vec{E} + \hat{z} \times \vec{B}) \\ \nabla_\perp \cdot \vec{E} - \rho = \dfrac{\partial}{\partial \xi}\hat{z} \cdot \vec{E} \\ \nabla_\perp \cdot \vec{B} = \dfrac{\partial}{\partial \xi}\hat{z} \cdot \vec{B} \end{cases}$$

$$\frac{\partial}{\partial z} = -\frac{\partial}{\partial \xi} + \frac{\partial}{\partial s} \quad , \quad \frac{\partial}{\partial t} = \frac{\partial}{\partial \xi}$$

*P. Sprangle, et al., PRA 41, 4463 (1990)

Equations in QuickPIC

$$\vec{E}_\perp + \hat{z} \times \vec{B}_\perp = -\nabla_\perp \cdot \psi$$

$$\nabla_\perp^2 \psi = -(\rho - J_z)$$

$$\nabla_\perp^2 \vec{B}_\perp = \hat{z} \times (\frac{\partial}{\partial \xi} \vec{J}_\perp + \nabla_\perp \cdot J_z)$$

$$\nabla_\perp^2 B_z = -\nabla_\perp \times \vec{J}_\perp$$

$$\nabla_\perp^2 E_z = \nabla_\perp \cdot \vec{J}_\perp$$

plasma: $$\frac{d\vec{p}}{d\xi} = \frac{q/m}{1 - v_z} \left[\vec{E} + \vec{v} \times \vec{B} \right]$$

Iteration Required! Coupled with equation of motion.

$$\frac{\partial}{\partial \xi}(\rho - J_z) + \nabla_\perp \cdot \vec{J}_\perp = 0$$

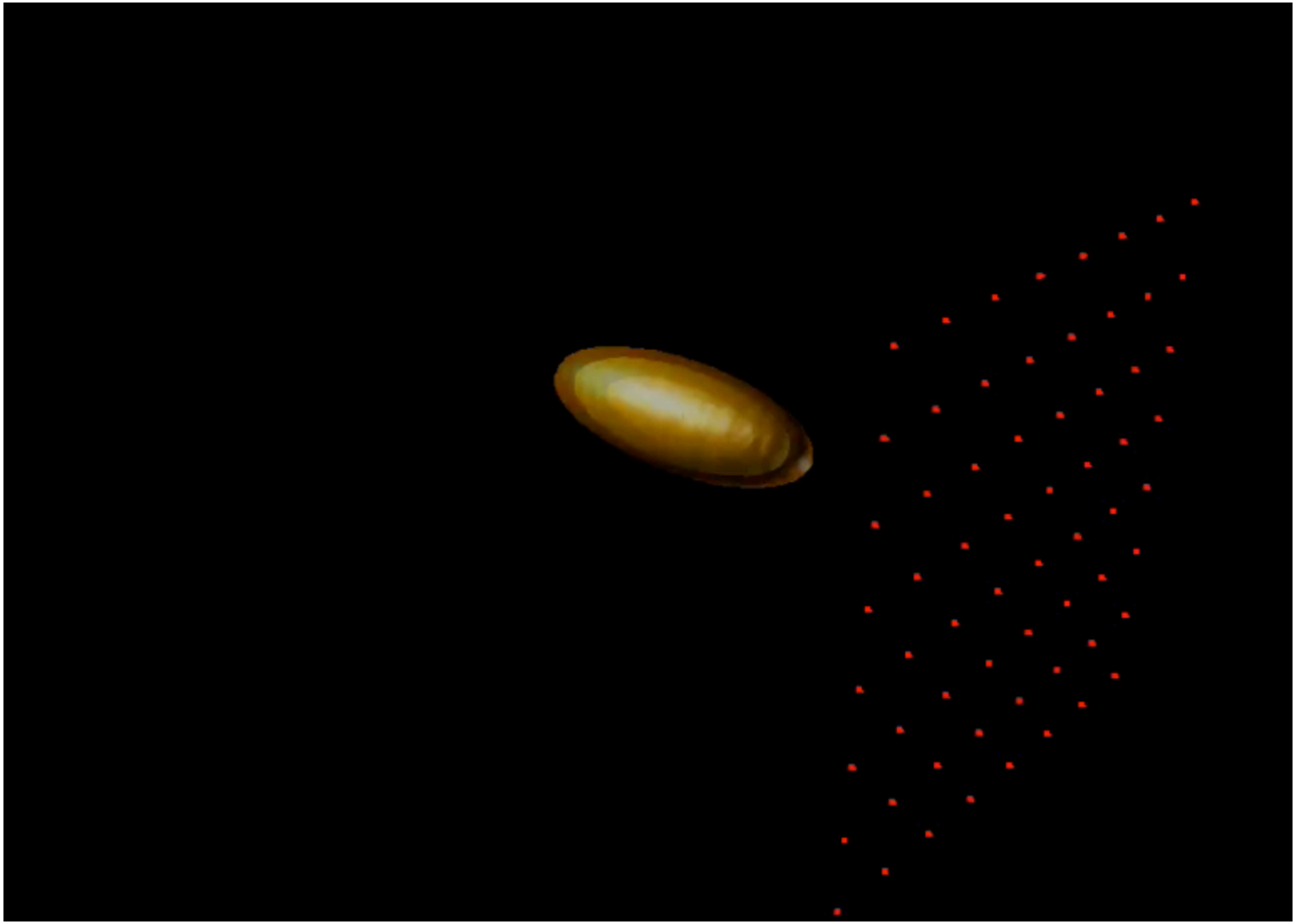
$$\frac{\partial}{\partial \xi} \int (\rho - J_z) d\vec{x}_\perp + \int \nabla_\perp \cdot \vec{J}_\perp d\vec{x}_\perp = 0$$

$$\frac{\partial}{\partial \xi} Q(1 - v_z) = 0 \quad *$$

For each plasma particle: Q varies along ξ according to its v_z

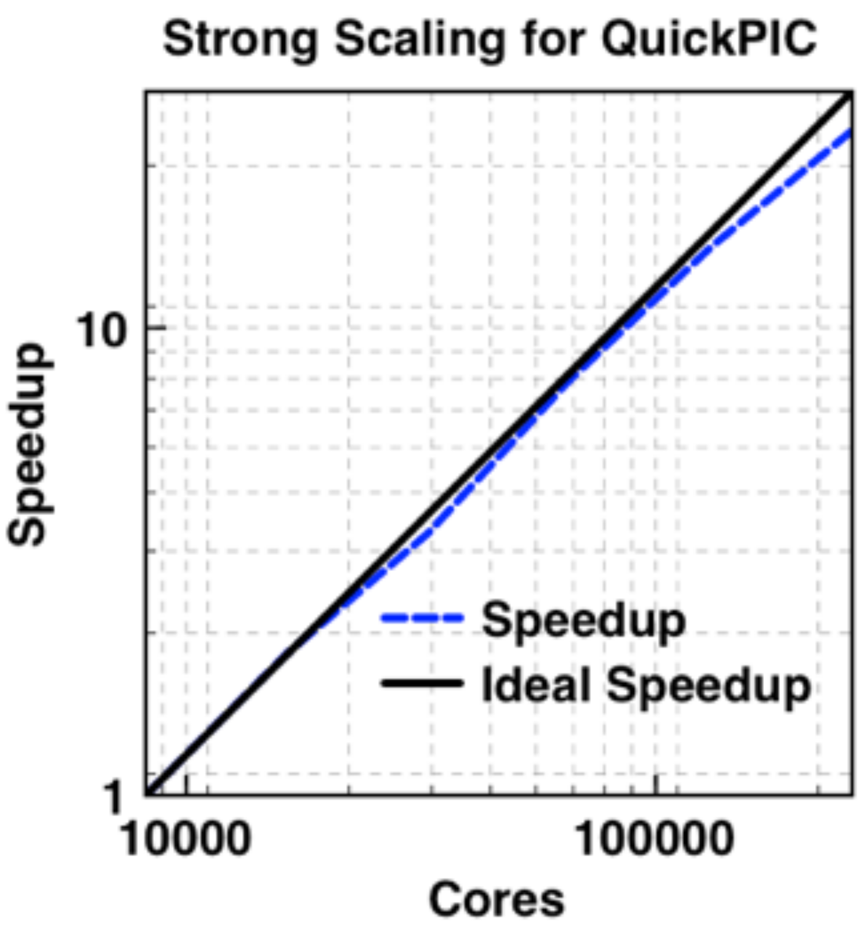
* P. Mora and T. Antonsen, Phys. Plasmas 4, 217 (1996)

How QuickPIC Works



Embeds a 2D PIC code inside a 3D PIC code based on UPIC Framework.

Current Status of QuickPIC



Time for pushing one particle for one step using a single processor (double precision): ~770 ns

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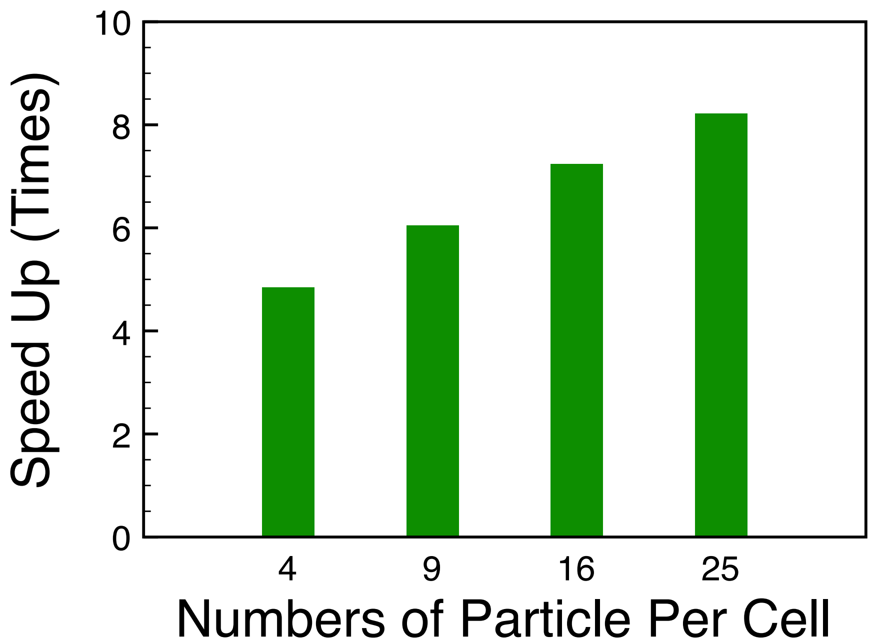
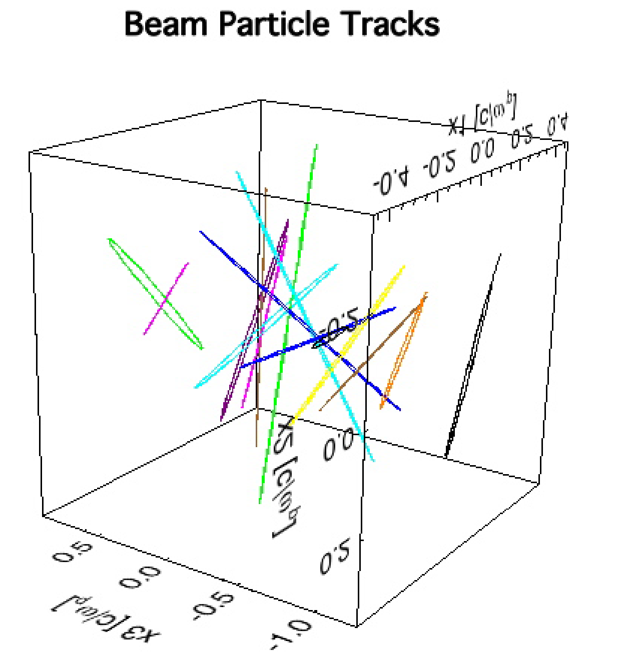
Current Status of QuickPIC

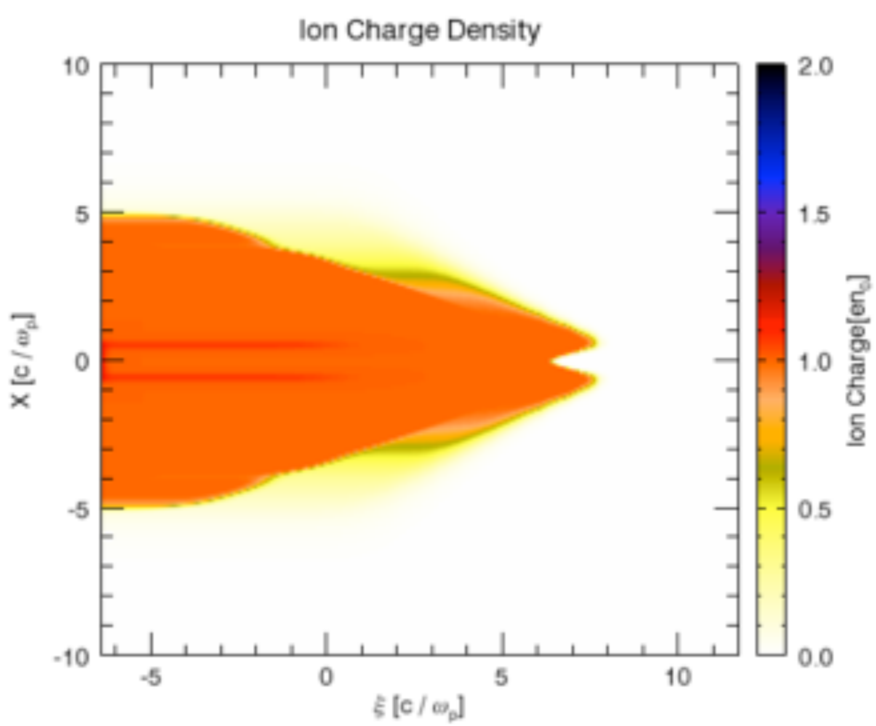
1. Improved Iteration Loop



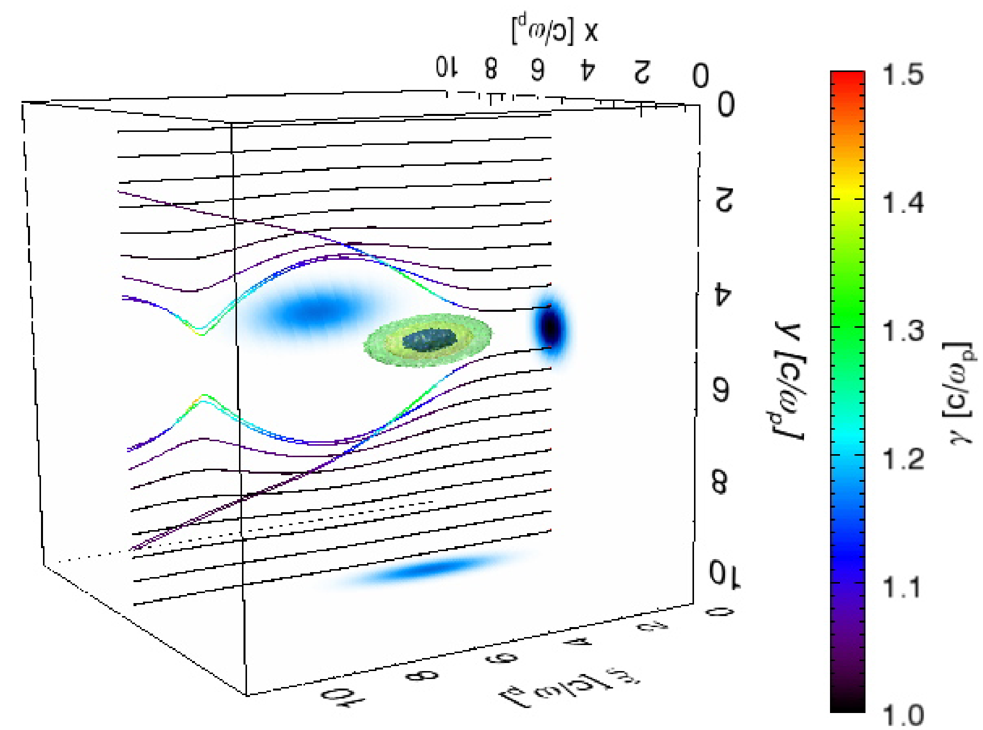
3. Beam Particle Tracking



2. Multiple Field Ionization Module



4. Plasma Particle Tracking



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QuickPIC with MPI+OpenMP

PICKSC

Particle-in-Cell and Kinetic Simulation Software Center

Viktor K. Decyk

Weiming An

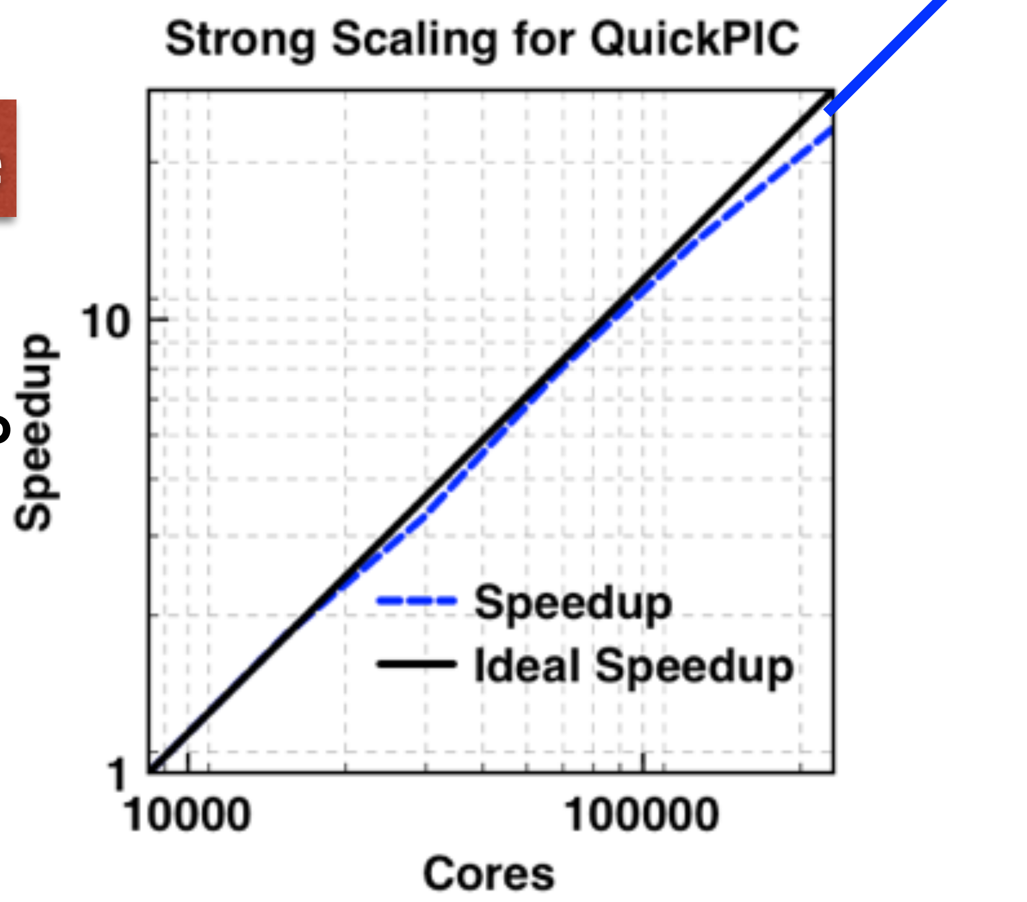
UPIC Skeleton: MPI+OpenMP

Open Source

UPIC with wrappers: MPI+OpenMP

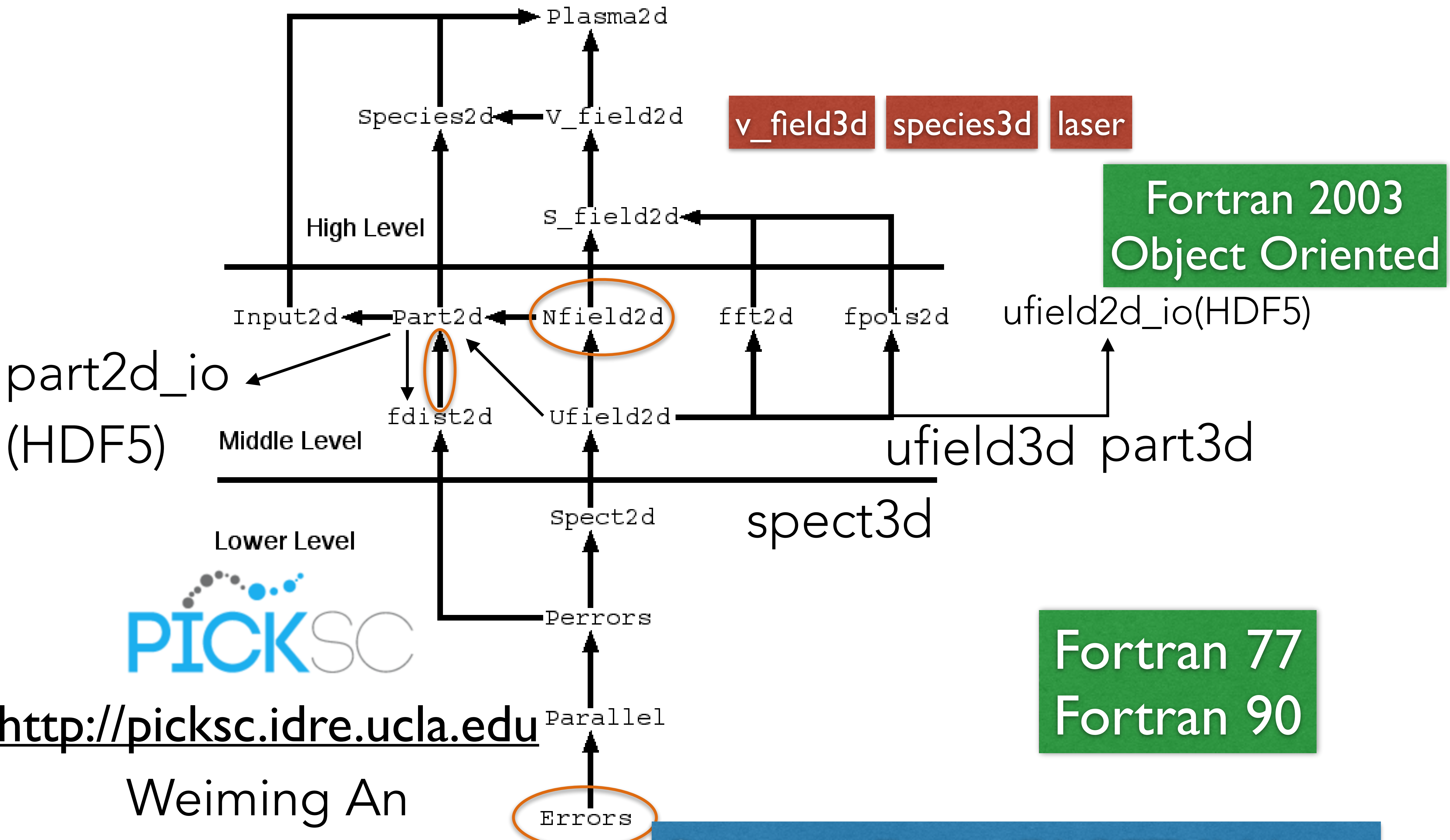
QuickPIC with MPI+OpenMP

1M Cores



Intel Phi in the future!

QuickPIC Open Source



http://picksc.idre.ucla.edu

Weiming An
anweiming@ucla.edu

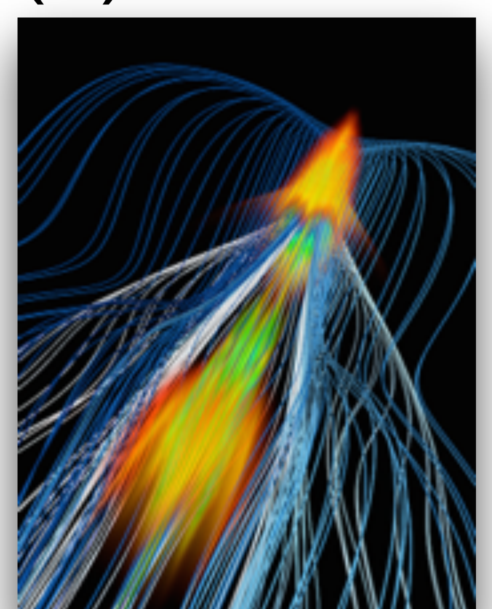
Open to Every FACET II Users

UCLA

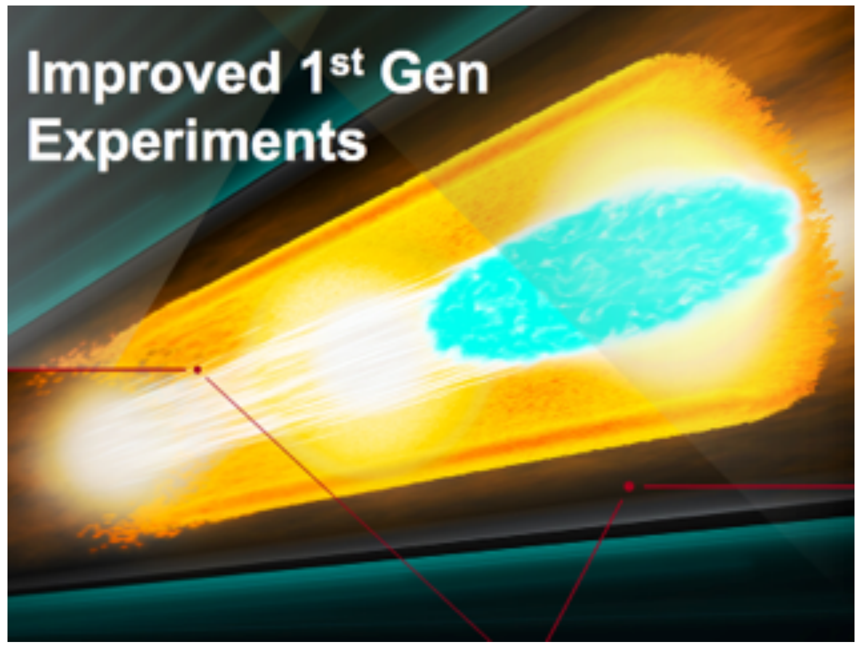
QuickPIC @ FACET E200

(1)

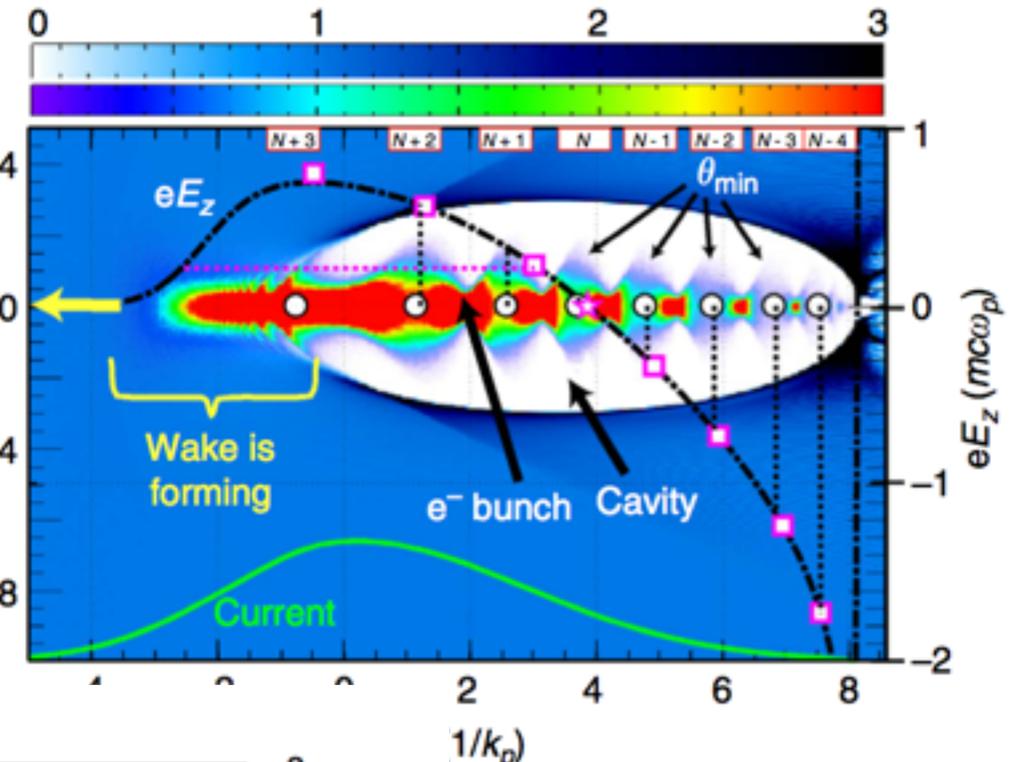
(2)



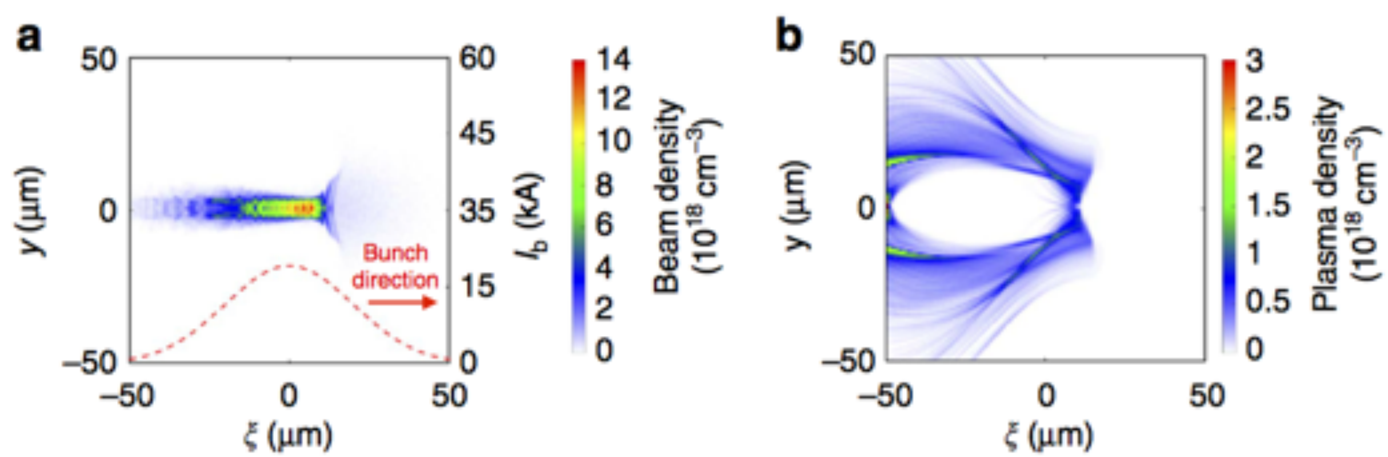
(3)



(4)

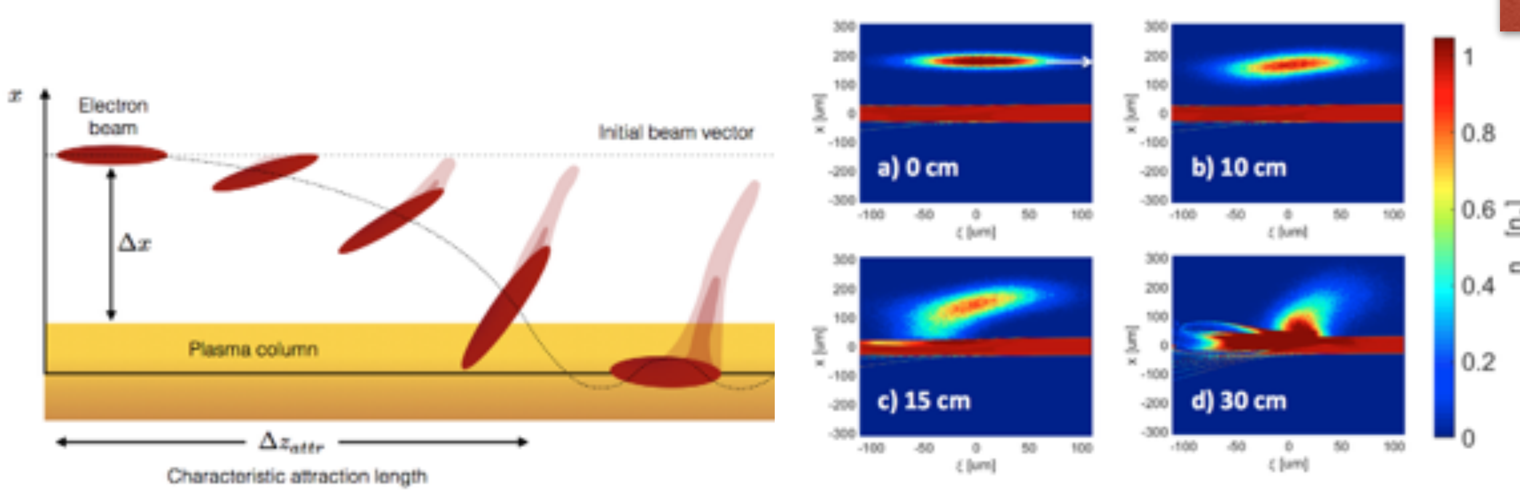


(5)



Highly Nonlinear
Nonuniform
Asymmetric
Field Ionization
Well Agreement

(6)

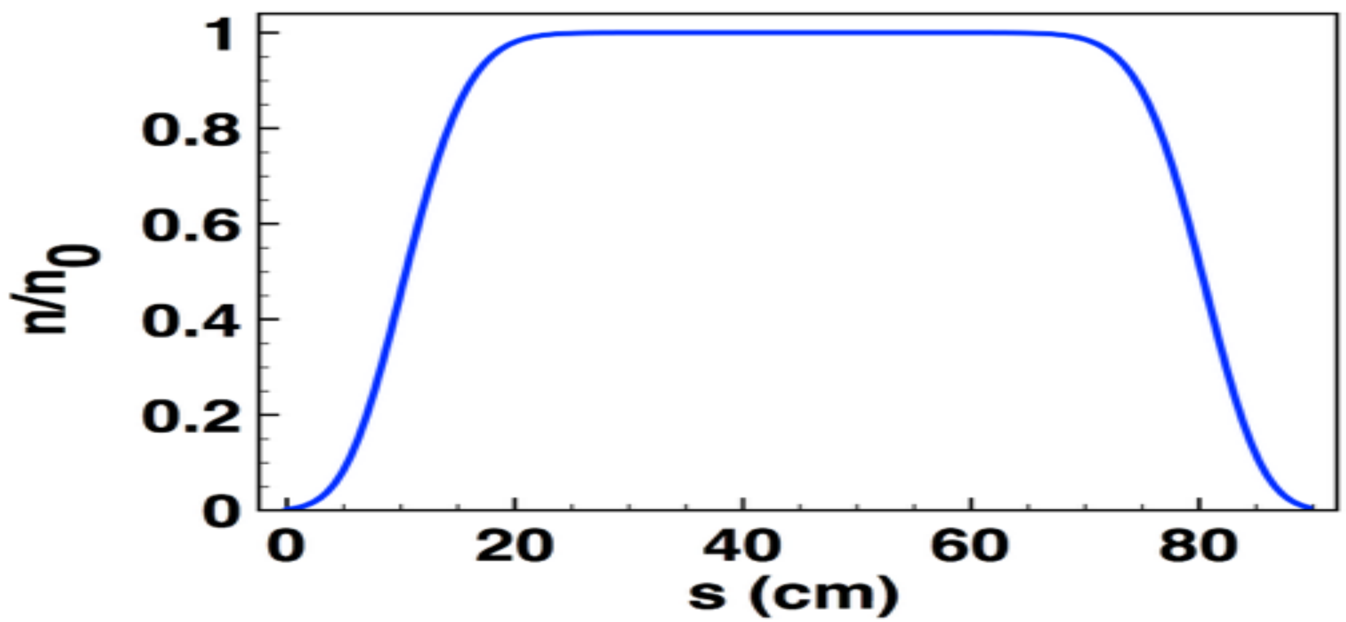


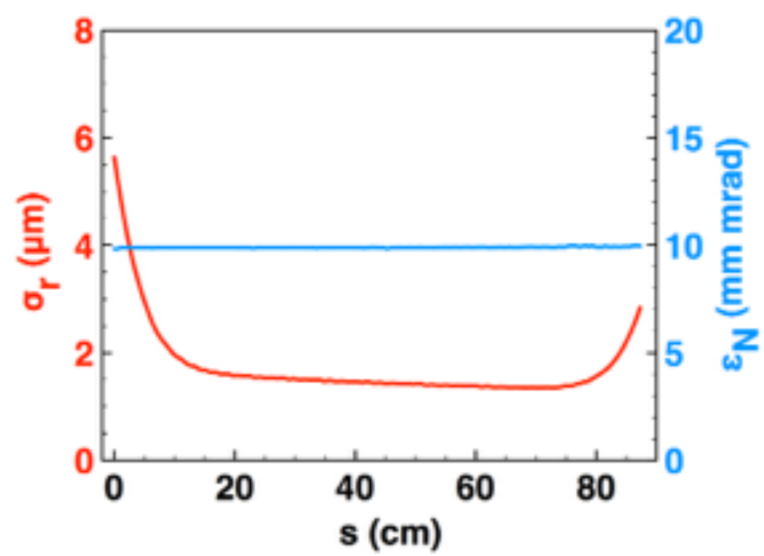
Osiris 3D is used for comparison

FACET II with QuickPIC

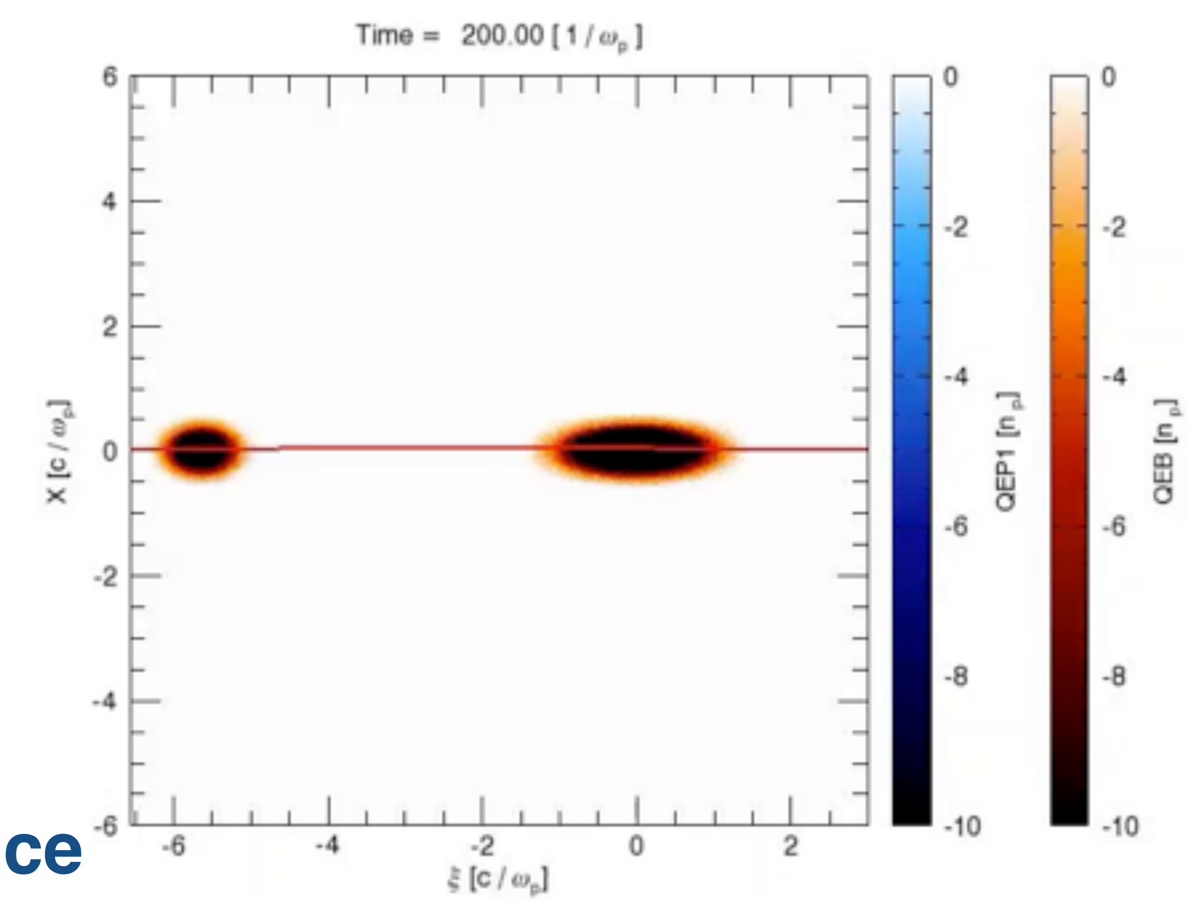
Drive Beam: E = 10 GeV, I_{peak}=15 kA
β = 89.61 cm, α = 0.0653,
σ_r = 21.17 μm, σ_z = 12.77 μm ,
N =1.0 x 10^{10} (1.6 nC),
ε_N = 10 μm
Trailing Beam: E = 10 GeV, I_{peak}=9 kA
β = 89.61 cm, α = 0.0653,
σ_r = 21.17 μm, σ_z = 6.38 μm ,
N =0.3 x 10^{10} (0.48 nC),
ε_N = 10 μm
Distance between two bunches: 150 μm
Plasma Density: 4.0 x 10^{16} cm^{-3} (with ramps)

Plasma Density Profile



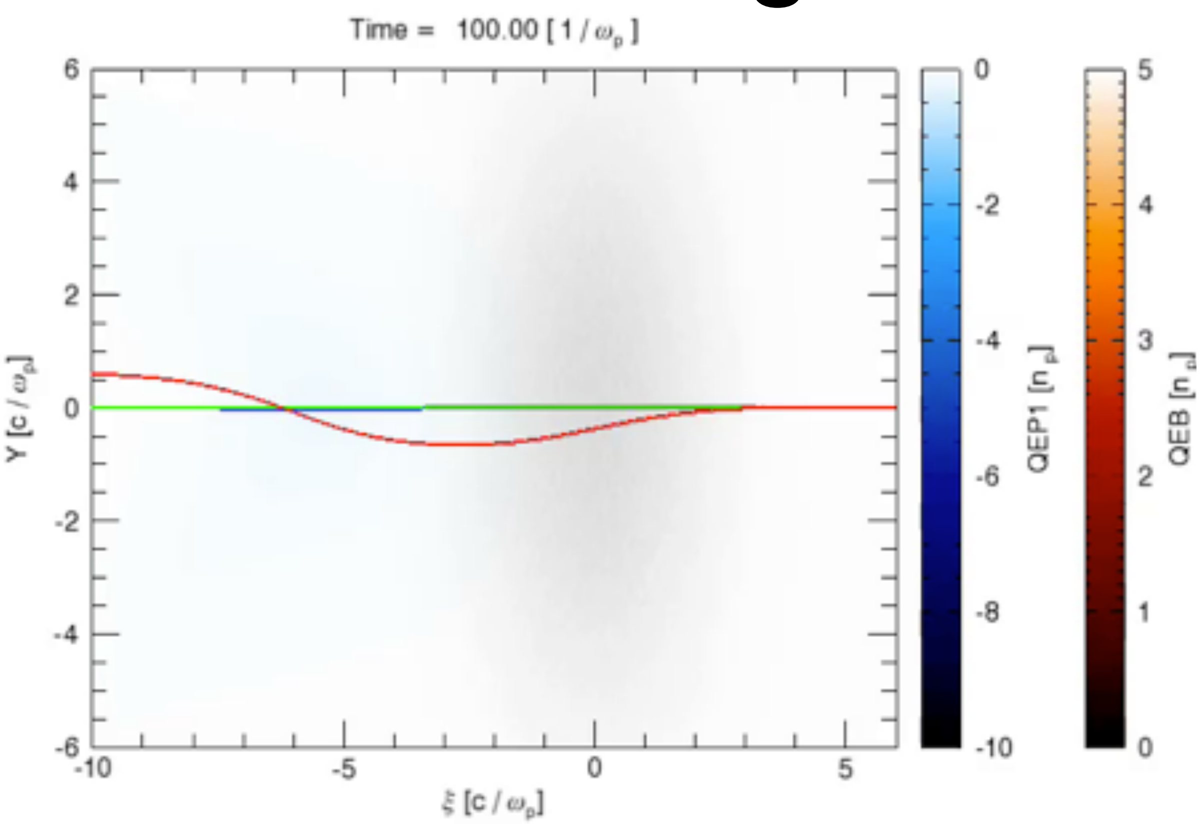


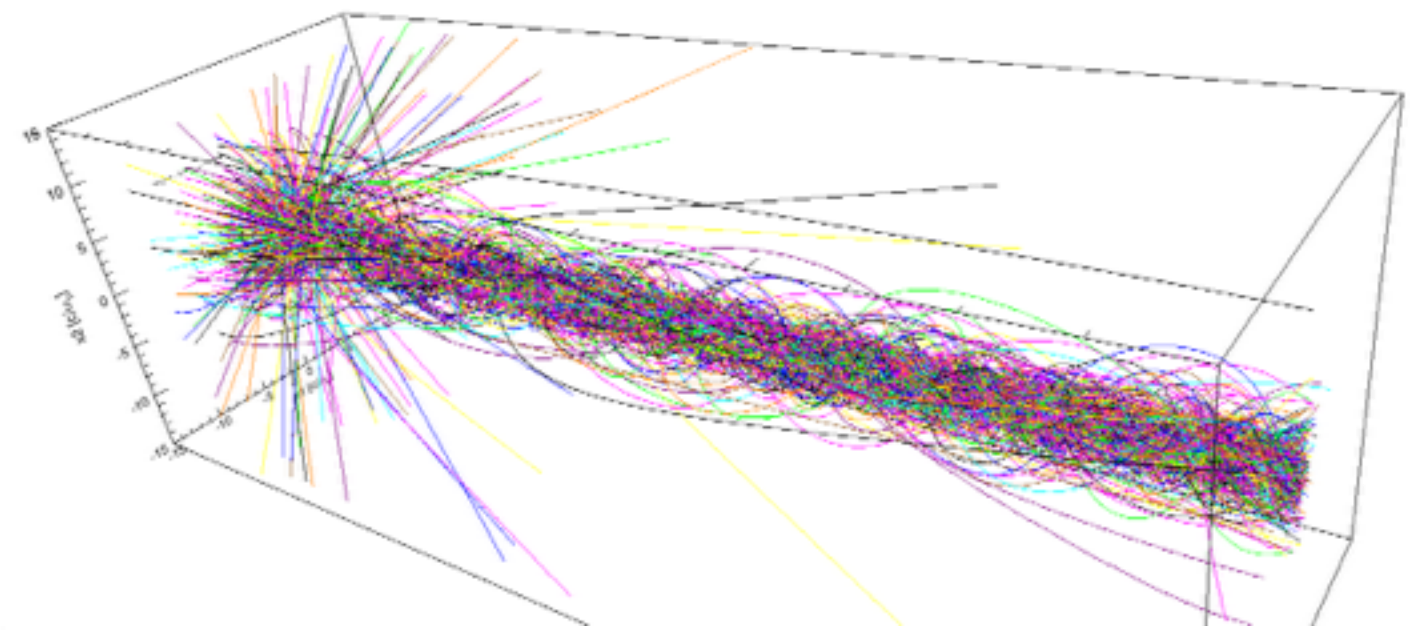
The projected beam spot size and emittance

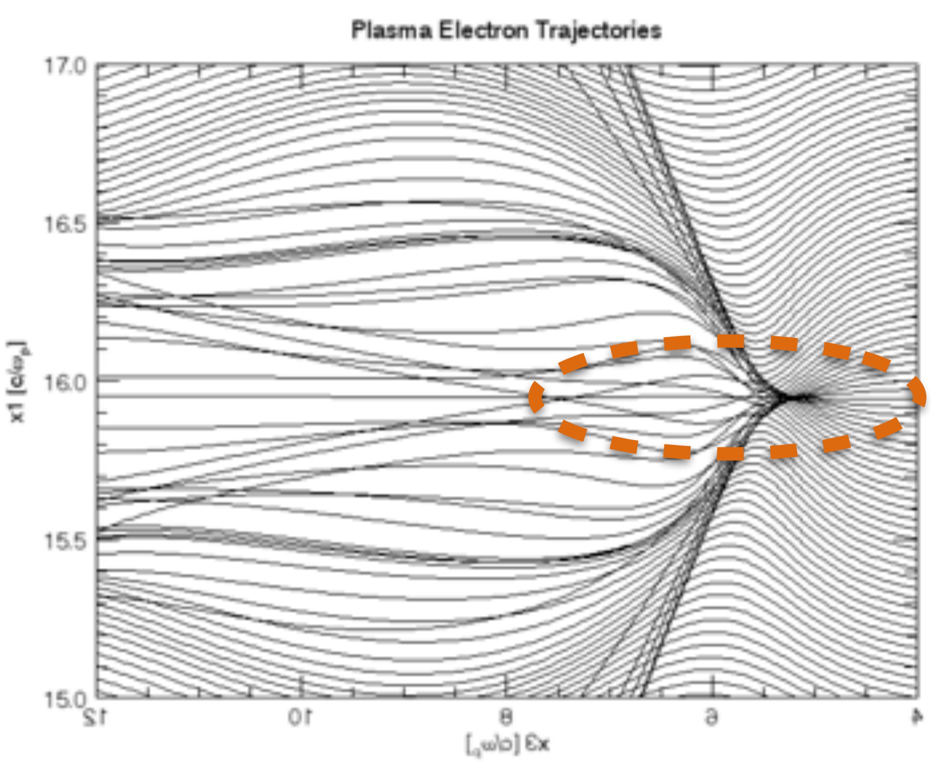


FACET II with QuickPIC

Particle Tracking for Both plasma and beam particles





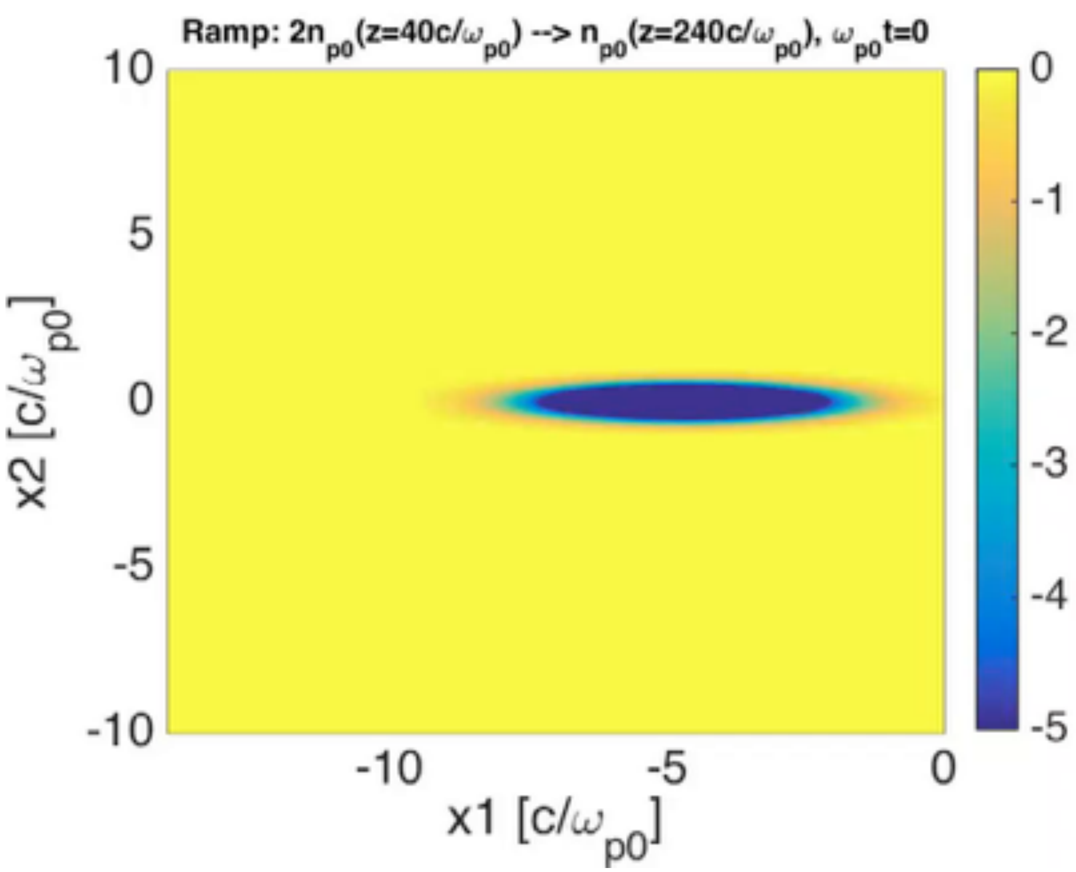


Beam Trajectories can be used for radiation calculation.

JRAD by Joana Martins @IST

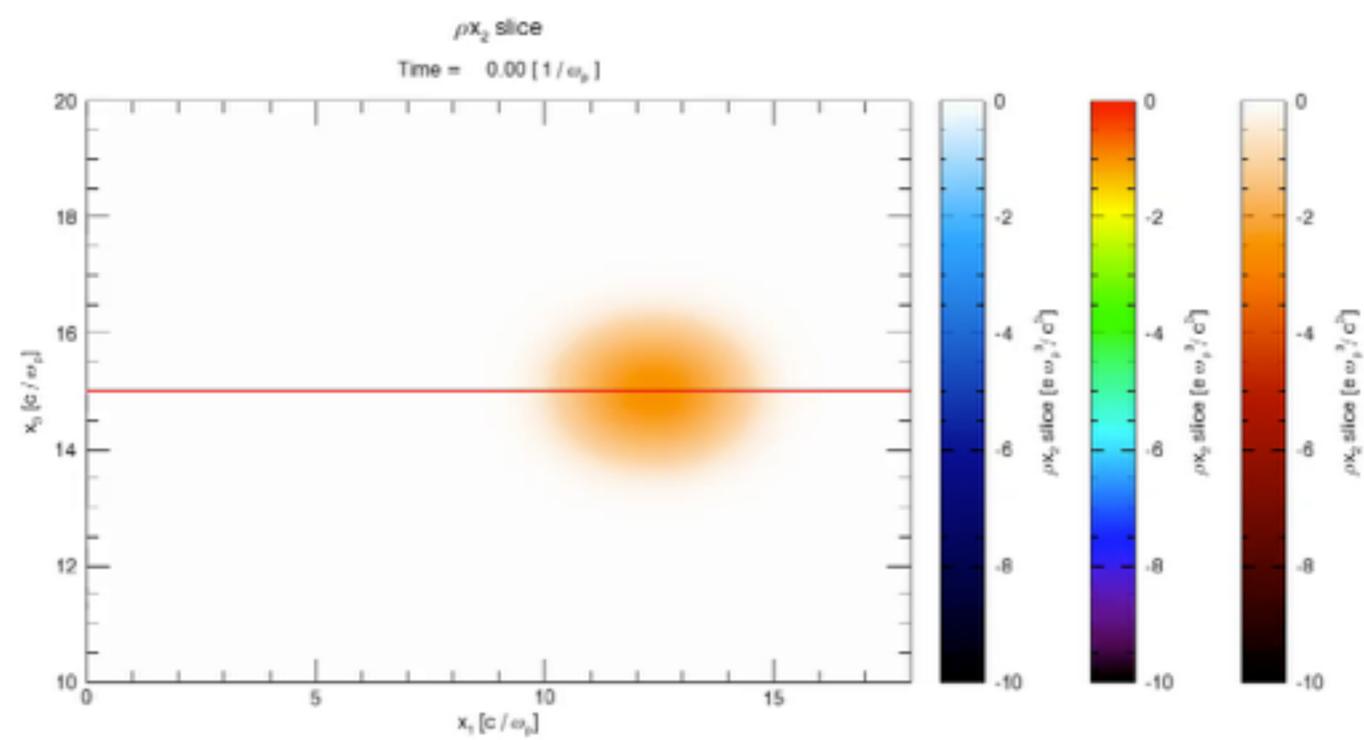
FACET II with Osiris

Preliminary Downramp injection Example



Simulated by Xinlu Xu

Field Ionized Plasma



Simulated by Weiming An

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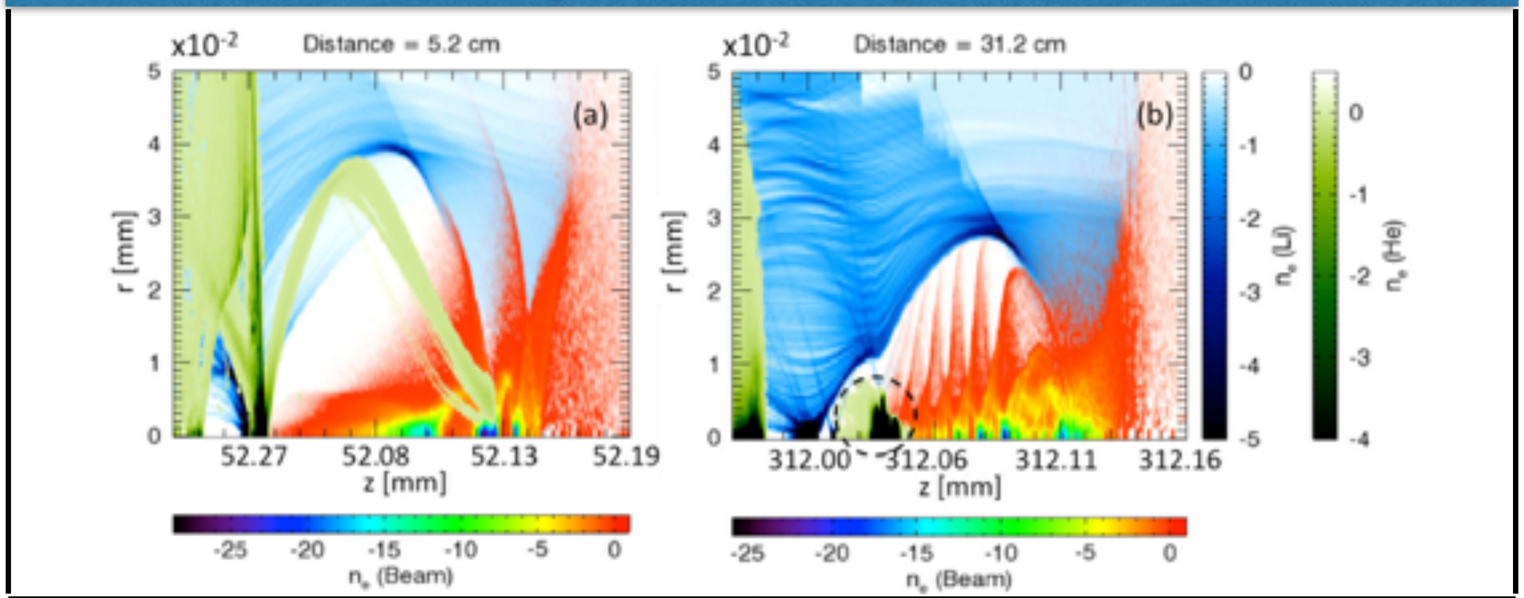
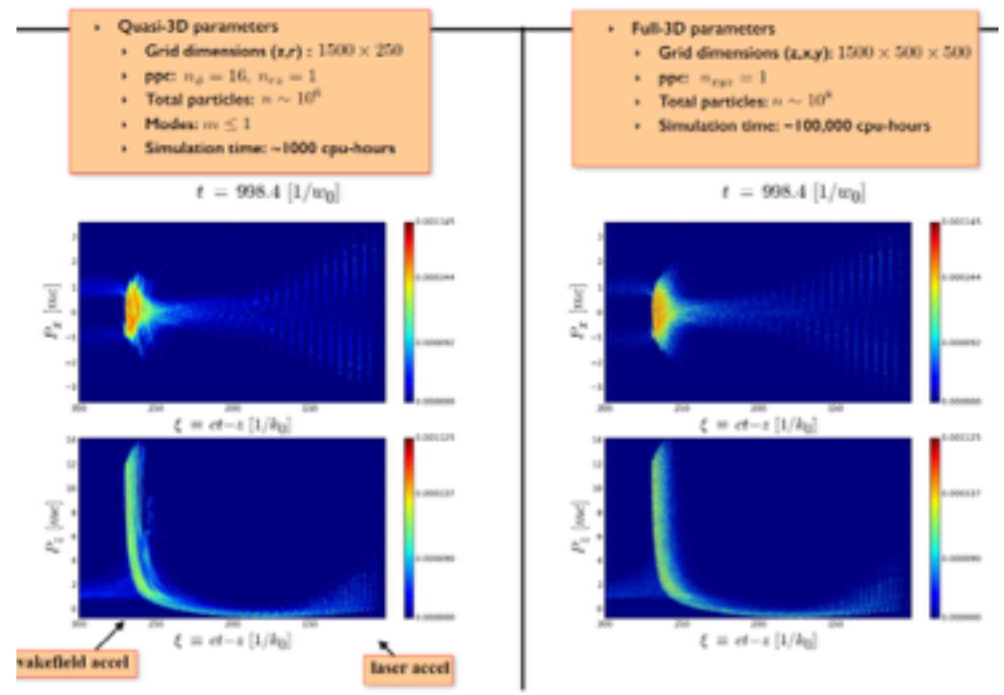
FACET II with Osiris

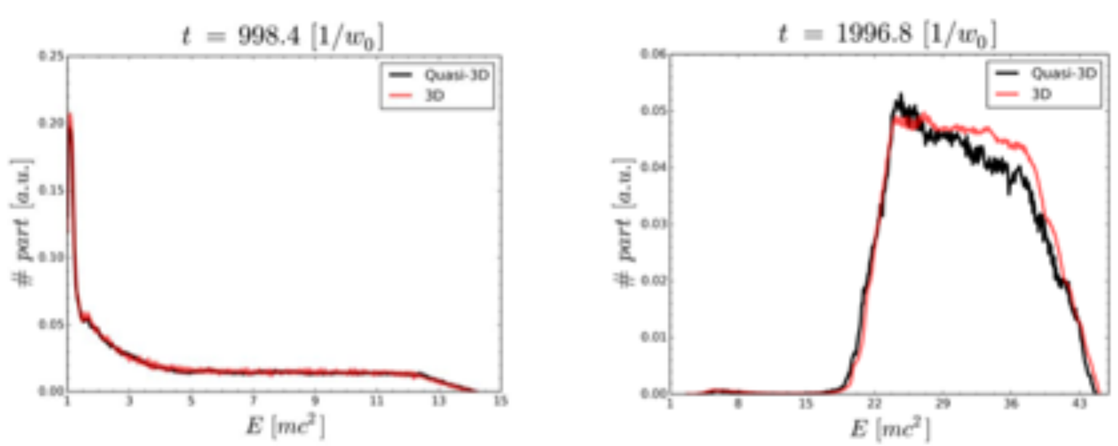
Ionization Injection (Osiris 2D r-z)



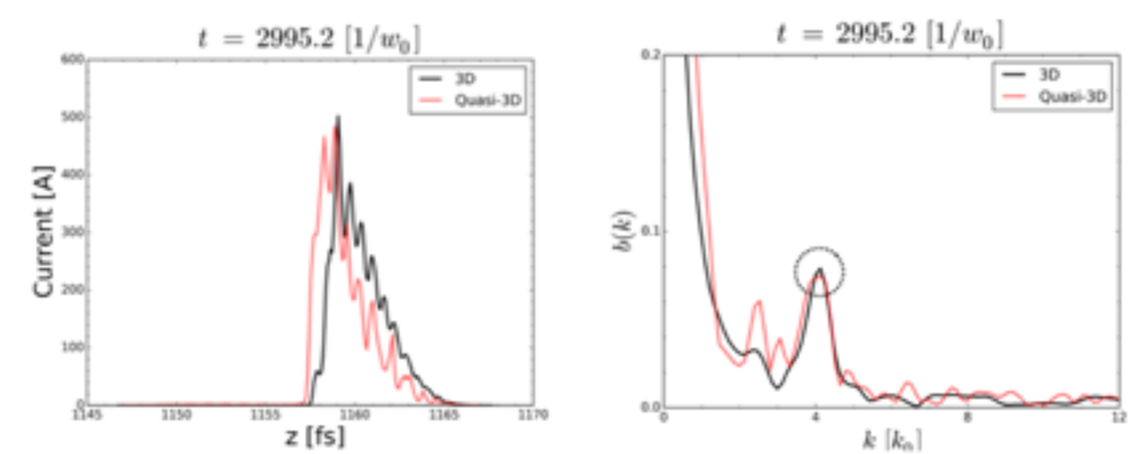


Osiris Quasi - 3D with field ionization

Comparing Energy distributions



Comparisons of charge bunching



Bunching factor: $b(k) = \int dz\, n(z) exp(ikz)$
Nanoscale bunching at $k = 4k_0$

T.N. Dalichaouch, et al., "Using Quasi-3D OSIRIS Simulations of LWFA to Study Generating High Brightness Electron Beams Using Ionization and Density Downramp Injection" NA-PAC 2016

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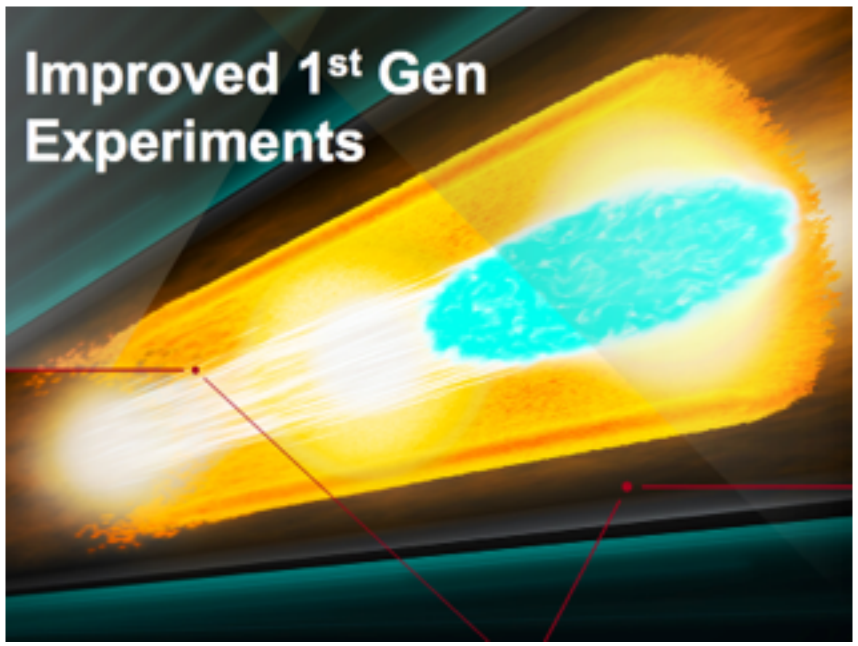
Near Term Requirements: FACET II

Soft Boundary for Hollow Channel



Osiris 3D & Quasi 3D

QuickPIC Open Source:
Varying particl Charge

Visualization Tools

Other Requirements:

PICKSC

http://picksc.idre.ucla.edu

QuickPIC

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UCLA

Long Term Needs for QuickPIC

- Dynamic load balancing
- Intel Phi Algorithm
- Adaptive 2d and 3d time steps
- Adaptive particle loading
- Adaptive mesh refinement

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Summary

In the near term

- QuickPIC and Osiris are well prepared for FACET II simulations.
- We are working on QuickPIC Open Source. And it will be available at the end of this month. All FACET II users are welcome to use it.