Pic3P – Electromagnetic Particle-In-Cell

Advanced Computations

SLAC National Accelerator Laboratory

CW10, Stanford, September 20, 2010

Pic3P - EM PIC Method

Self-consistent Loop:

1) Push (Macro-)Particles

2) Deposit Charges

3) Calculate Fields

$$\frac{d\mathbf{p}}{dt} = q(\mathbf{E} + \mathbf{v} \times \mathbf{B})$$

$$\mathbf{J} = \rho\mathbf{v}$$

$$\oint_{\partial A} \mathbf{E} \cdot \mathbf{ds} = -\int_A \frac{\partial \mathbf{B}}{\partial t} \cdot d\mathbf{A}$$

$$\oint_{\partial A} \mathbf{H} \cdot \mathbf{ds} = \int_A \left(\frac{\partial \mathbf{D}}{\partial t} + \mathbf{J}\right) \cdot \mathbf{dA}$$

$$\oint_{\partial V} \mathbf{D} \cdot \mathbf{dA} = \int_V \rho \, dV$$

$$\oint_{\partial V} \mathbf{B} \cdot \mathbf{dA} = 0$$

$$\mathbf{B} = \mu \cdot \mu_0 \mathbf{H} \,, \qquad \mathbf{D} = \epsilon \cdot \epsilon_0 \mathbf{E}$$

Full-wave "EM" PIC, in contrast to electrostatic PIC

Unconditionally stable time integration, implicit method (Ax=b)

$$\left(\varepsilon \frac{\partial^2}{\partial t^2} + \sigma \frac{\partial}{\partial t} + \nabla \times \mu^{-1} \nabla \times\right) \int^t \mathbf{E}(\mathbf{x}, \tau)\, \mathrm{d}\tau = -\mathbf{J}(\mathbf{x}, t)$$

Pic3P is charge-conserving, and typically uses point particles:

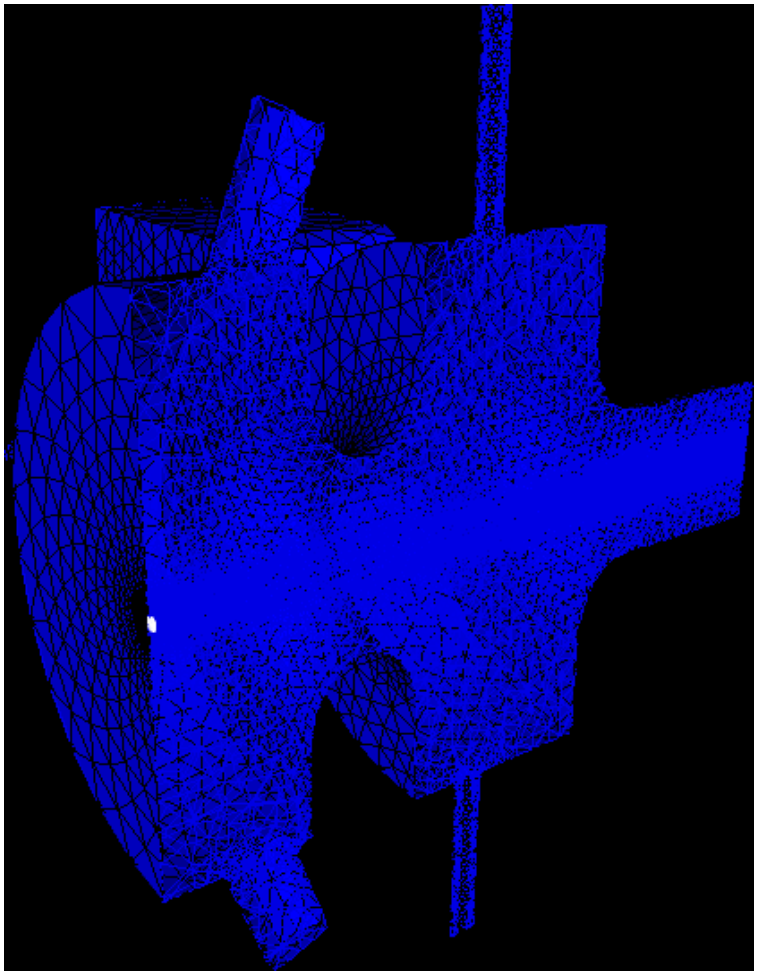
$$\mathbf{J}(\mathbf{x}, t) = \sum_i q_i \cdot \delta(\mathbf{x} - \mathbf{x}_i(t)) \cdot \mathbf{v}_i(t)$$

Pic3P - Capabilities

- **Pic3P** self-consistently models beam-cavity interactions in space-charge dominated regimes with the electromagnetic Particle-In-Cell method

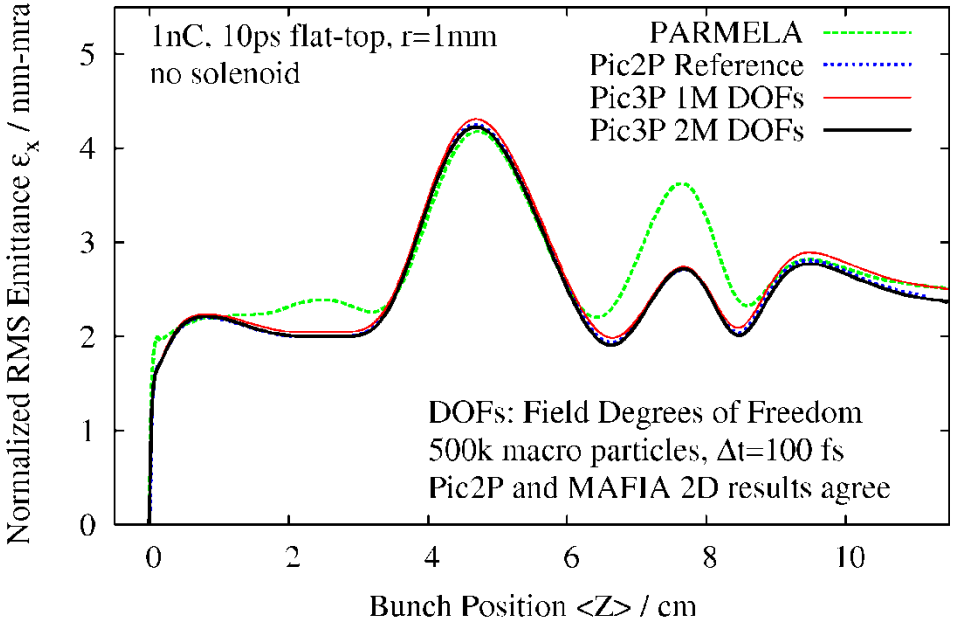
- **Low-energy space-charge calculations**
  - Self-consistent modeling of RF guns up to ~ 10 MeV
  - Space-charge, image charge effects, time retardation and wakefield effects included
  - Read RF map (Omega3P or ASCII file) and/or solenoid map (ASCII)
  - Causal moving window technique for efficiency

Pic3P – LCLS RF Gun



Temporal evolution of electron bunch and scattered self-fields

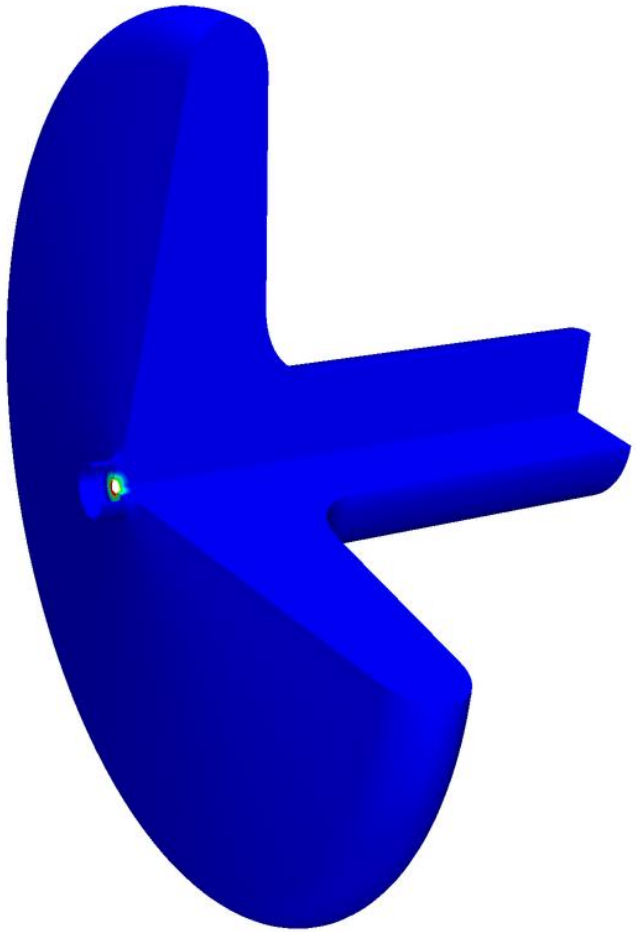
Racetrack cavity design: Almost 2D drive mode. Cylindrical bunch allows benchmarking of 3D code Pic3P against 2D codes Pic2P and MAFIA



Unprecedented Accuracy thanks to Higher-Order Particle-Field Coupling and Conformal Boundaries

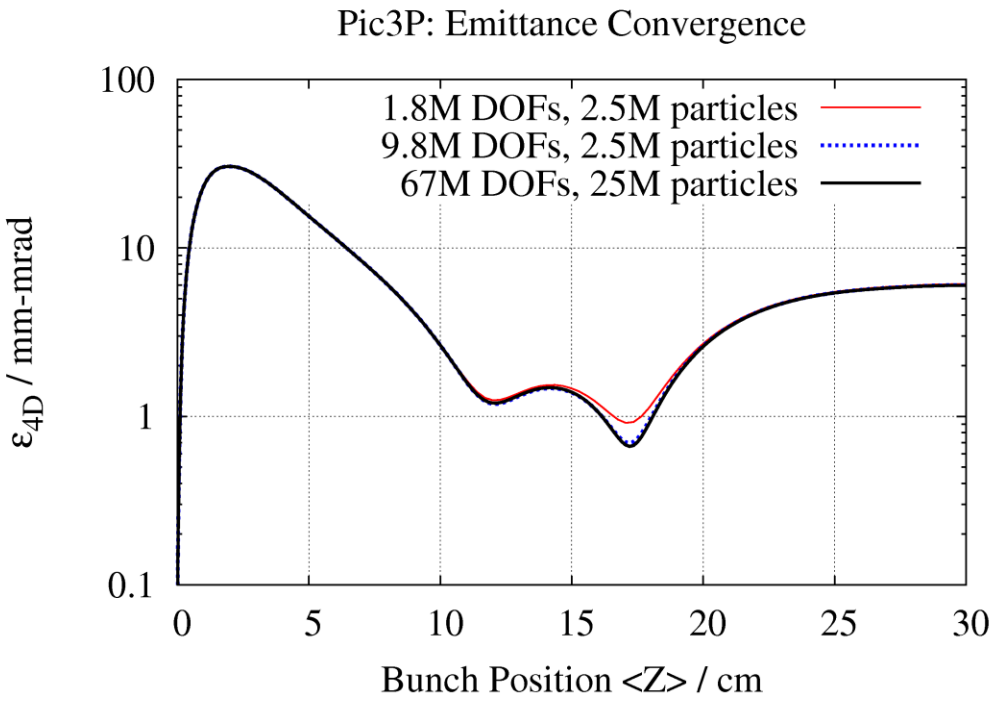
Pic3P – BNL Polarized SRF Gun

Bunch transit through SRF gun (only space-charge fields shown)

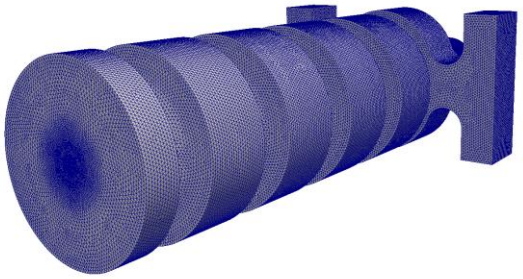


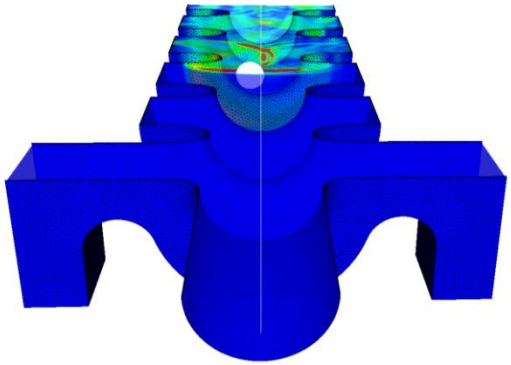
BNL Polarized SRF Gun:

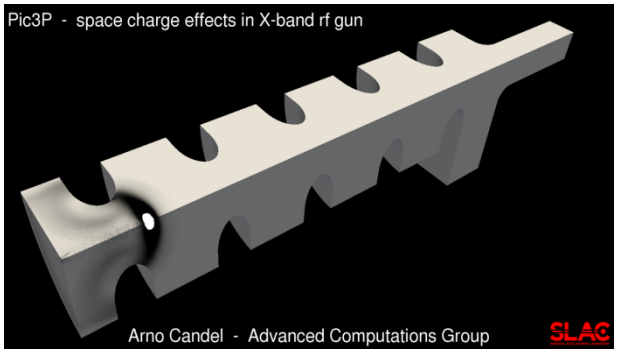
½ cell, 350 MHz, 24.5 MV/m, 5 MeV, solenoid (18 Gauss), recessed GaAs cathode at T=70K inserted via choke joint, cathode spot size 6.5 mm,



Pic3P – SLAC/LLNL X-Band Gun

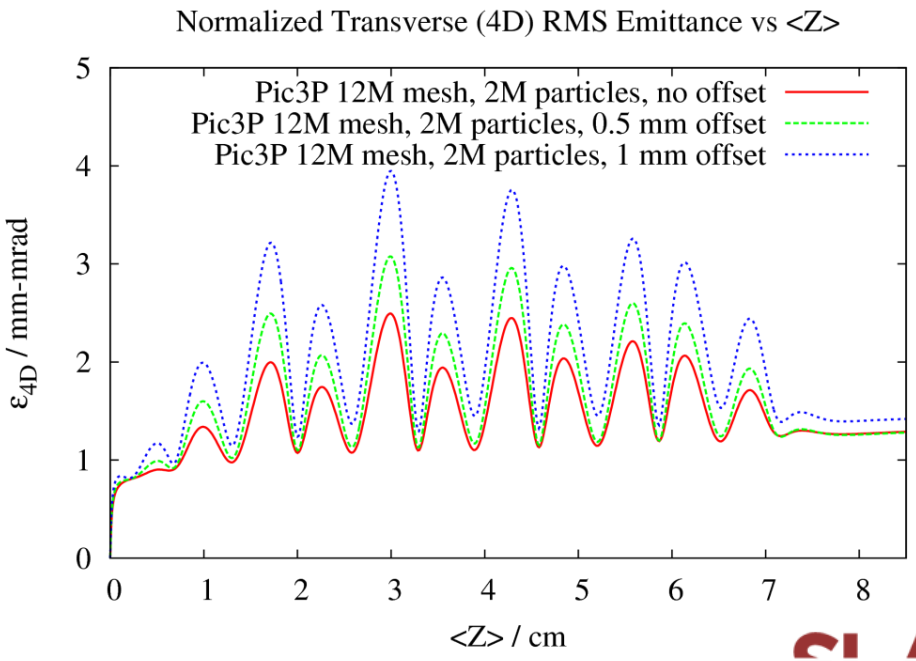






3D Emittance Calculations for Bunch with Offset

- f=11.424 GHz, 200 MV/m peak Ez on cathode
- Solenoid Bz_max = 0.5658 T at Z=6.3 cm
- Beer can (r=0.5 mm, 2 ps flat top, 0.4 ps rise time), 250 pC
- Bunch injected 30 degrees after zero-crossing



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