Capability of WARP-POSINST for ILC Electron Cloud Calculations

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What do we bring?

(1) Posinst Code (Furman, Pivi):

Main Strength: Build-up and decay of e^- cloud

Detailed model of secondary emission

Good agreement with measurements at APS and PSR

however: many input parameters not well known

2D, and not self-consistent

Applied to PEP-II, LHC, RHIC, FNAL MI

(2) Plasma Physics Code, WARP (Vay, Friedman, Grote) :

self-consistent physics (beam ⇔ electrons) – PIC code

3D

accurate space charge calculation

good accelerator model

WARP has many well-tested features …

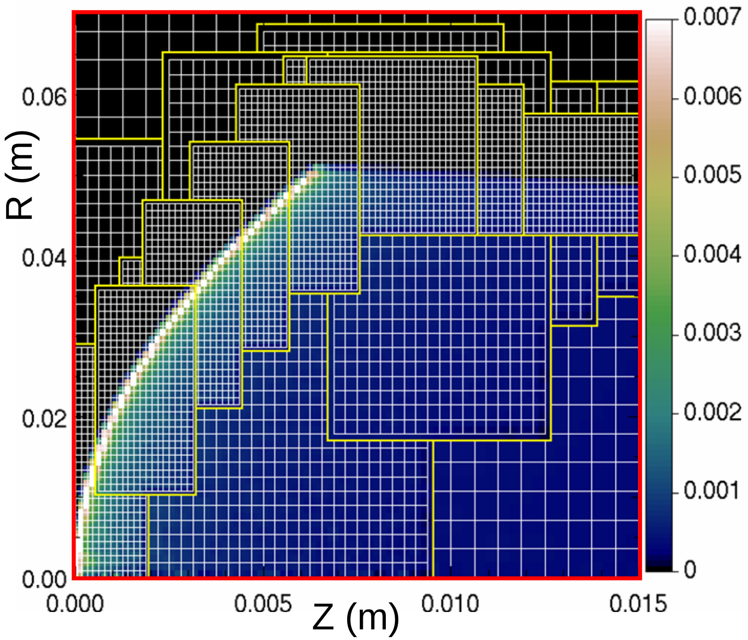
- **Geometry:** **3D, (x,y), or (r,z)**
- **Field solvers:** **FFT, capacity matrix, multigrid**
- **Boundaries:** **“cut-cell” --- no restriction to “Legos”**
- **Bends:** **“warped” coordinates; no “reference orbit”**
- **Lattice:** **general; takes MAD input**
  - **solenoids, dipoles, quads, sextupoles, …**
  - **arbitrary fields, acceleration**
- **Diagnostics:** **Extensive snapshots and histories**
- **Parallel:** **MPI**
- **Python and Fortran:** **“steerable,” input decks are programs**
- **Gas desorption & ionization**

and *new features* advancing the state of the art ...

- **Adaptive mesh refinement**

  x 20,000 speedup for LHC

Beam coming off source
x 11 speedup



- **New electron mover**

  solution to following electrons without resolving gyromotion

  x 25 speedup

Interpolating between drift kinetics and full PIC enables efficient following of particles in regions of weak and strong B

Problem: **Electron gyro timescale << other timescales of interest**

Solution: **Interpolation between full-particle dynamics (Boris mover) and drift kinetics (motion along B plus drifts).**

$$\mathbf{v}_{new} = \mathbf{v}_{old} + \Delta t \left(\frac{d\mathbf{v}}{dt}\right)_{Lorentz} + (1-\alpha)\left(\frac{d\mathbf{v}}{dt}\right)_{\mu\nabla B}$$

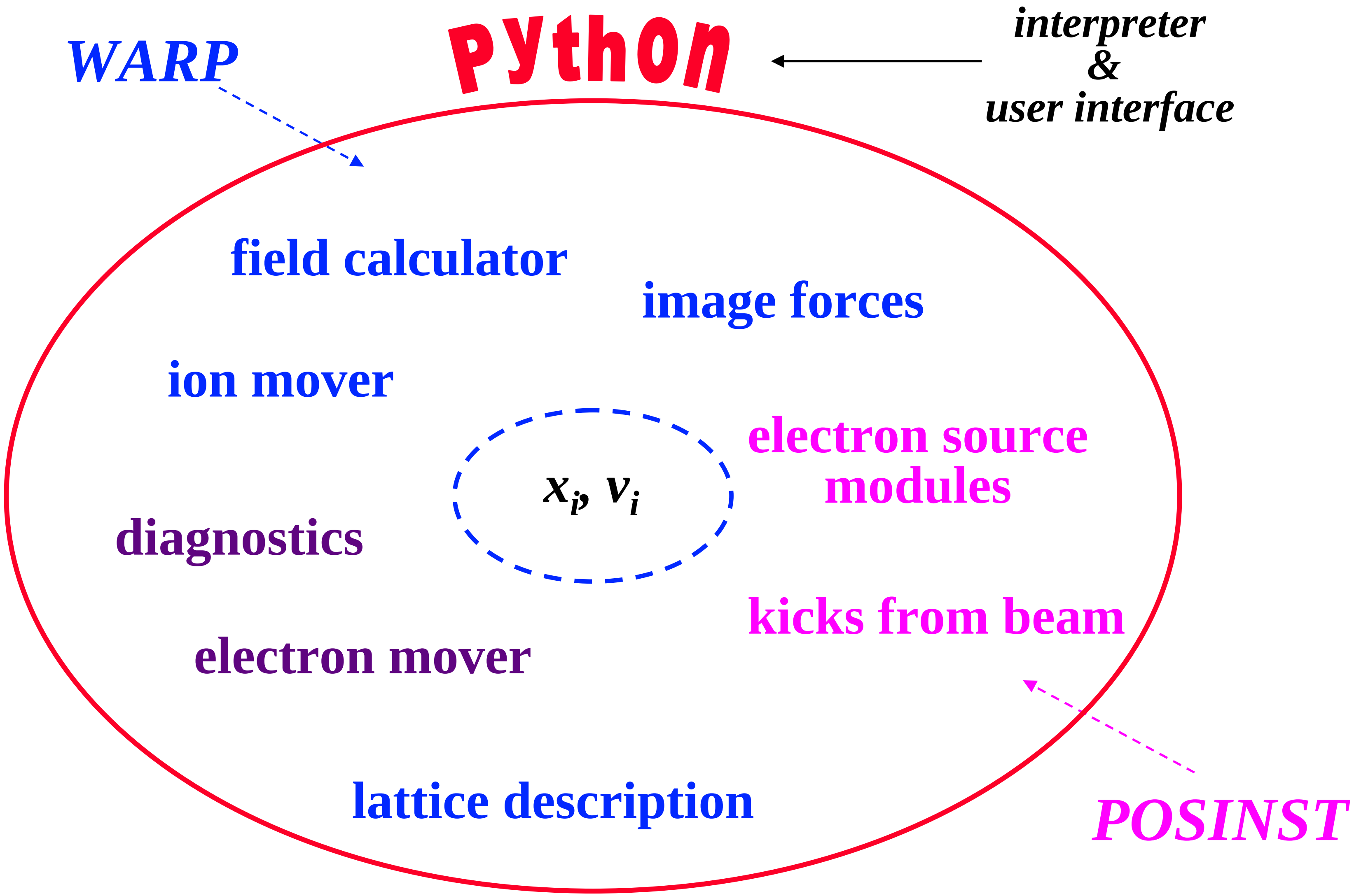
$$\mathbf{v}_{eff} = \mathbf{b}(\mathbf{b}\cdot\mathbf{v}) + \alpha\mathbf{v}_{\perp} + (1-\alpha)\mathbf{v}_d$$

Particular choice: $\alpha=1/[1+(\omega_c\Delta t/2)^2]^{1/2}$ gives:

- physically correct “gyro” radius at large $\omega_c\Delta t$
- correct drift velocity and parallel dynamics

Speedup of factor of 25 without loss in accuracy!

We have merged WARP and POSINST



The code has several models of different complexity

(1) POSINST mode

electrons evolve (full space charge model),
beam non-dynamic

(2) Slice mode

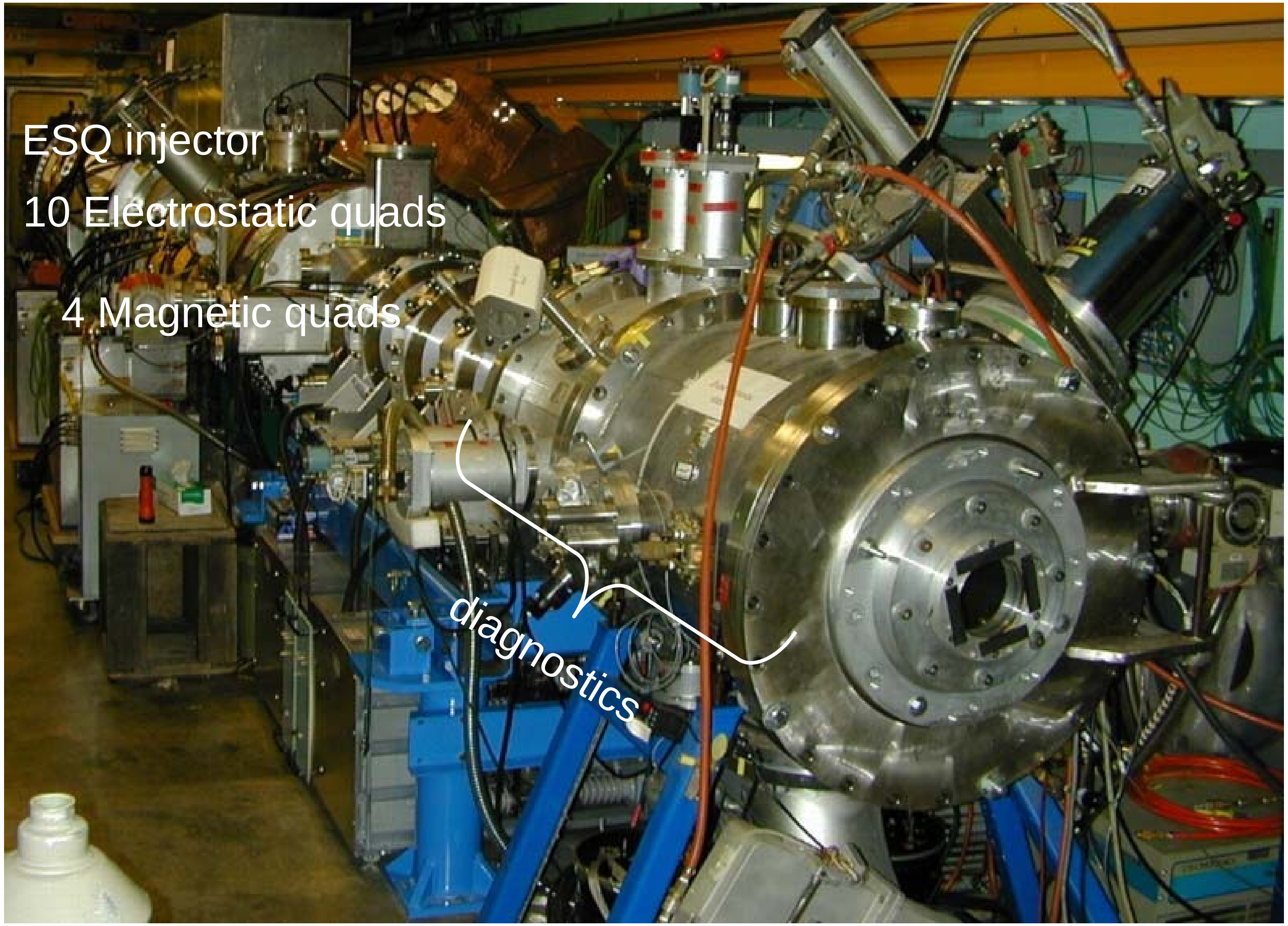
2D transverse slice of beam followed

(3) Quasistatic mode (like Headtail, Quickpik)

assumes steady flow of “new” electrons
electrons evolved using 2D forces of (static) beam
then beam evolved using 3D forces due to electrons

(4) 3D, self-consistent space charge

WARP-POSINST has been benchmarked by the High Current Experiment (HCX) at LBNL



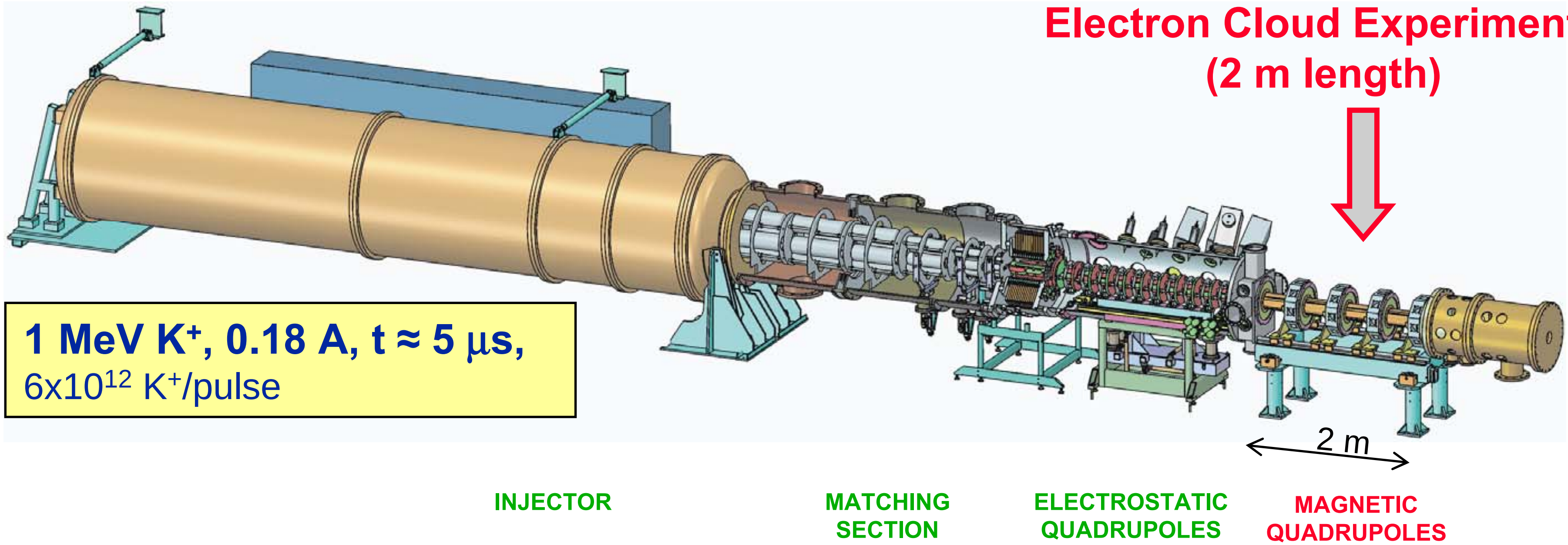
See talk by Art Molvik

Parameters

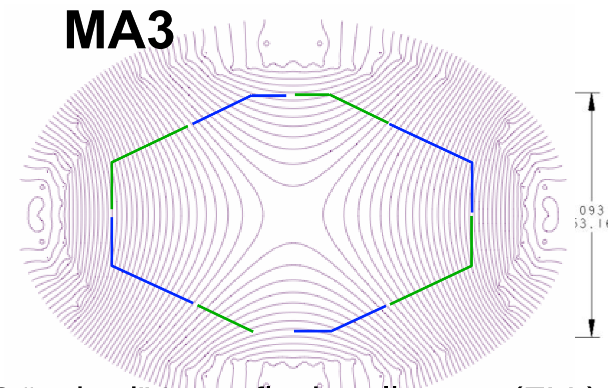
K^+ Beam
0.2 - 0.5 Amp
1 - 1.7 MeV
4.5 μs pulse

A short quadrupole section is heavily instrumented for ecloud experiments

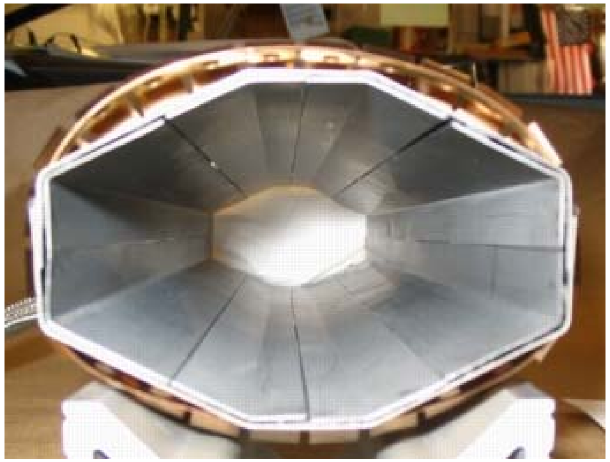
low energy heavy ions

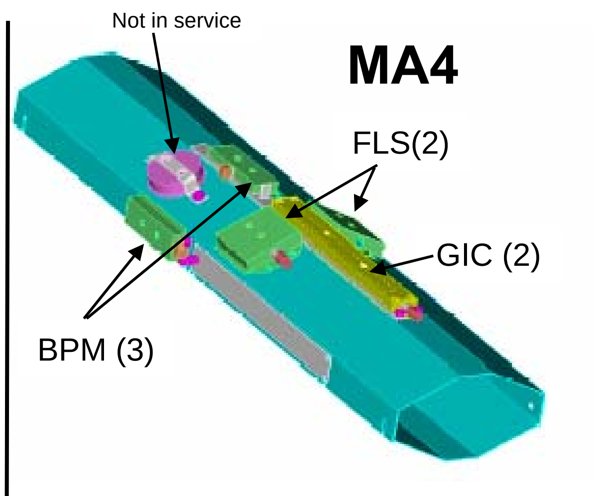


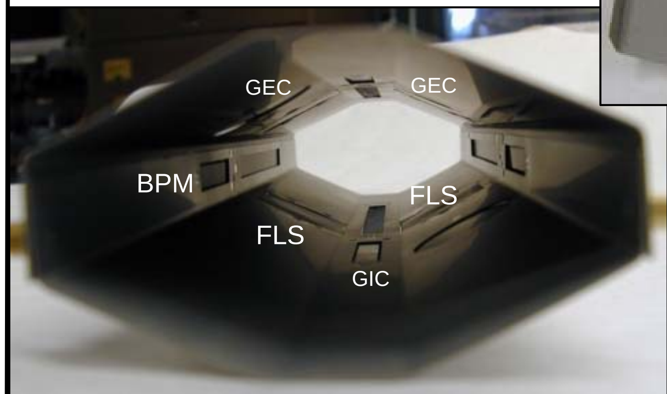
Diagnostics in two magnetic quadrupole bores, & what they measure.



8 “paired” Long flush collectors (FLL): measures capacitive signal + collected or emitted electrons from halo scraping in each quadrant.







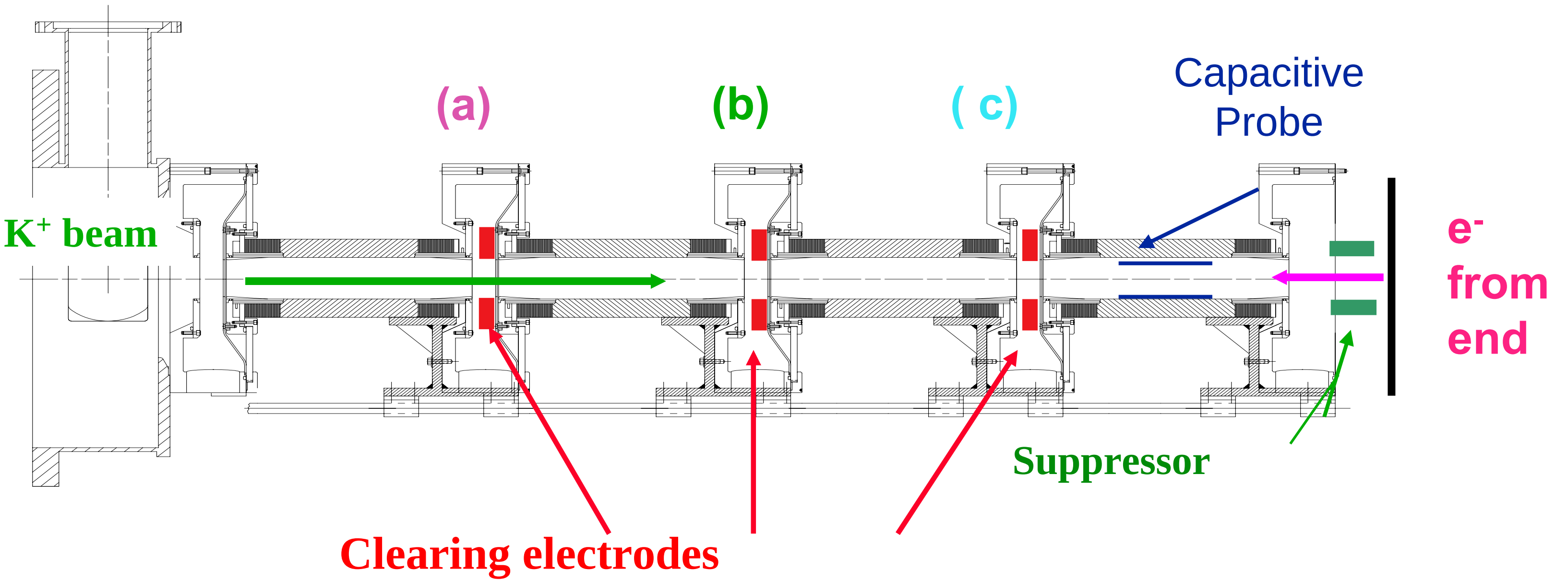
3 capacitive probes (BPM); beam capacitive pickup $((n_b - n_e)/n_b)$.

2 Short flush collector (FLS); similar to FLL, electrons from wall.

2 Gridded e^- collector (GEC); expelled e^- after passage of beam

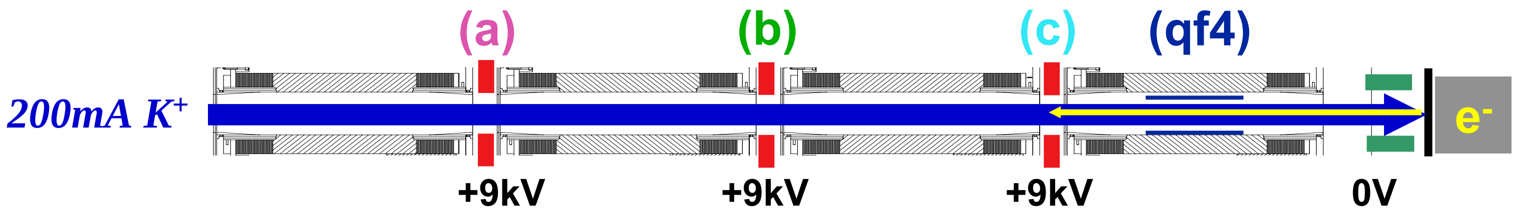
2 Gridded ion collector (GIC): ionized gas expelled from beam

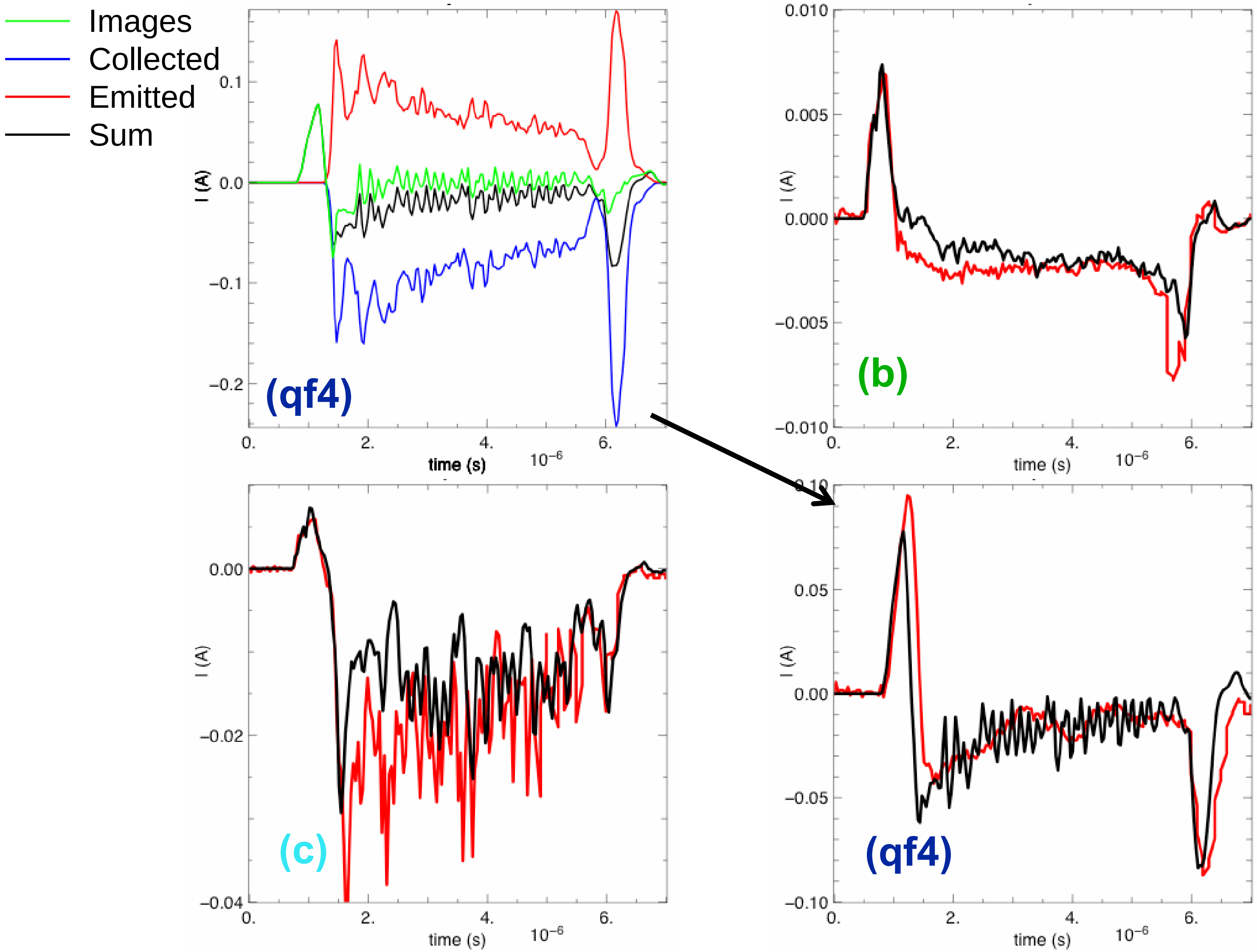
Biased rings work as both electron suppressors and diagnostics



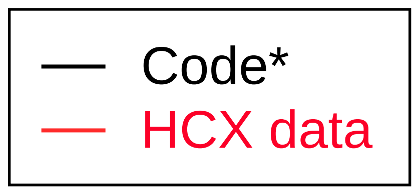
One experiment: Ion beam hits plate at experiment end. Copious electrons flow upstream through the beam.

Agreement between simulation & data is very good



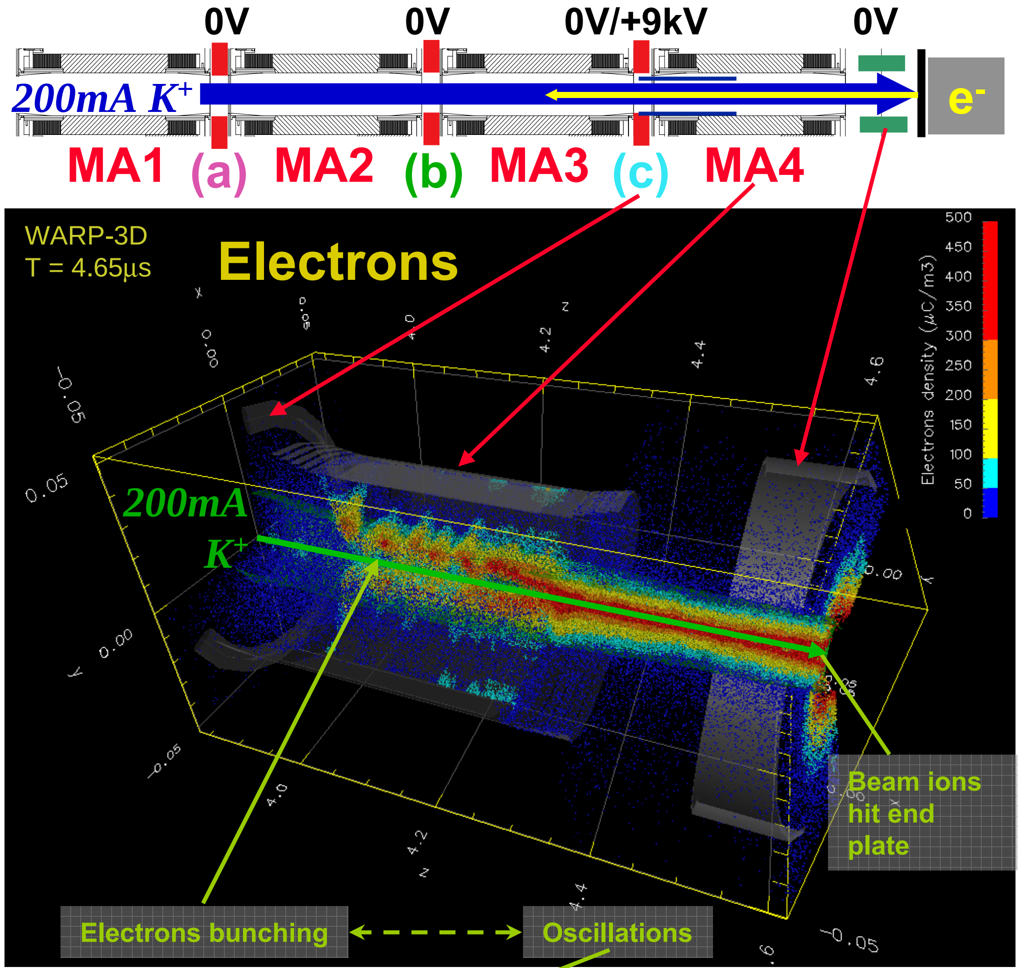


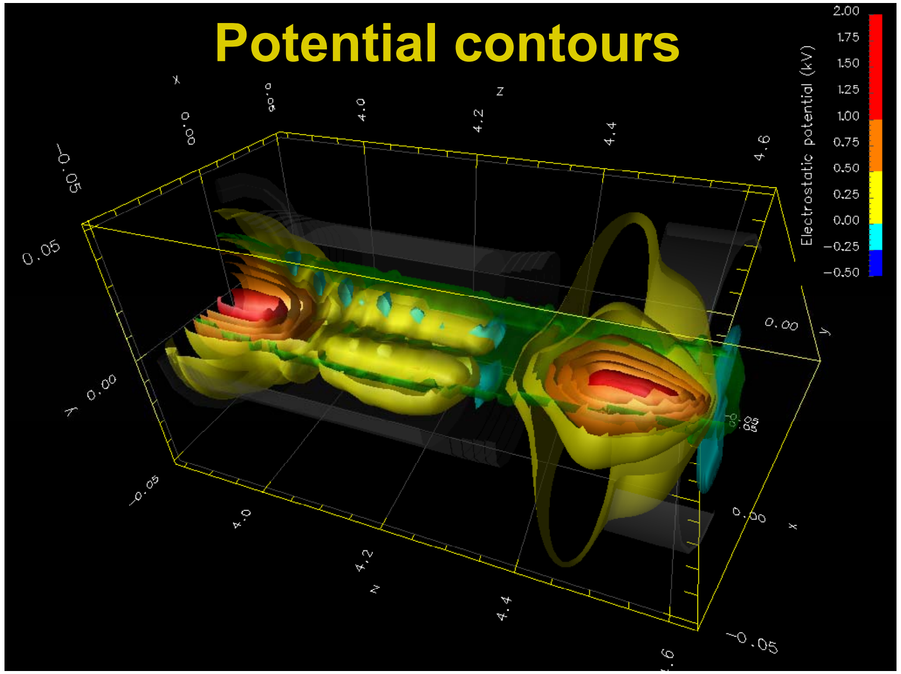
End suppressor off. Electrons flood end of machine.

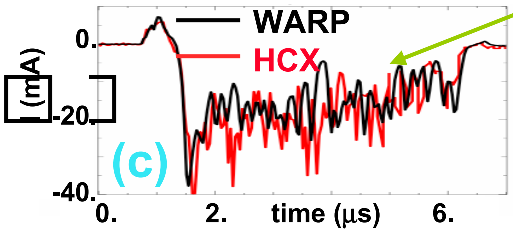


* WARP-POSINST

Simulation discovered oscillation (λ~5 cm) growing from near center of 4th quad. magnet. Seen also in experiment.

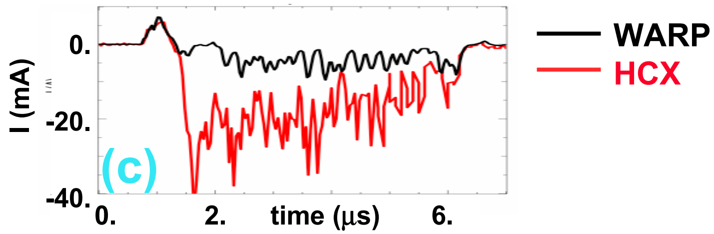






~6 MHz signal in (C) in simulation AND experiment

1. Good test of secondary module
   - no secondary electrons:



2. Simulation run time ~3 days (Mac),
   - without new electron mover and MR, run time would be ~1-2 months!

WARP/POSINST is being used to study e-cloud in LHC FODO cell (Vay, Furman)

SPS sees surprisingly long-lasting e-cloud (~ second)
"Slow" (10% in 10^6 turns) emittance growth may be a problem

The problem:

Simulate "multibunch, multiturn" passage of beam through FODO cell (100 m):

dipoles
quadrupoles
drifts

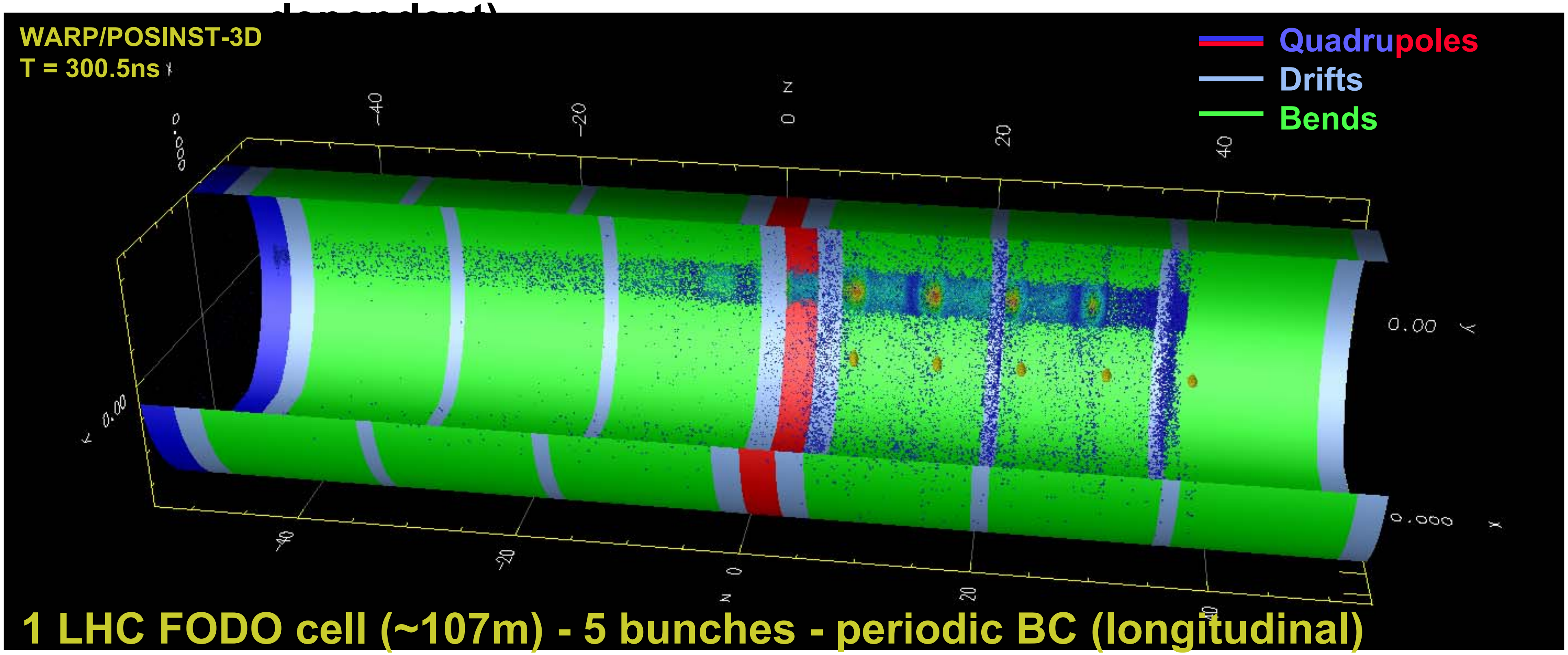
Electrons $\Leftarrow$ synchrotron radiation, secondary emission

Study:

Electron accumulation and trapping in quads
Power deposition from electrons
Emittance growth

WARP-POSINST LHC Simulation (Vay, Furman)

- **Three-dimensional fully self-consistent (t-dependent)**



5 Bunches. Electrons color-codes for density. Beam bunches yellow.

Proposed Program - Ecloud in DR Wiggler

All are self-consistent, and 3D unless noted otherwise.
Ecloud only in wiggler.

1. **2D vs. 3D** - 1 bunch pass through wiggler ⇒ How good are 2D calculations?

   then: add more bunches, offset some bunches

2. **Head-tail instability** - 1 bunch through wiggler ~1000 times. “New” electrons each time.

   Benchmarks code vs. other codes & checks for new effects

3. **Effect of gaps and resultant ecloud** - bunch train with gaps

4. **Electron cloud & beam in wiggler** - single bunch train with ecloud from #3. Follow for ~1000 turns.

Computer Time will be Requested ('07)

	Processor hours per run
1. 2D vs. 3D	*120*
2. Head-tail instability	*5600*
3. Effect of gaps and resultant ecloud	*16,000*
4. Electron cloud & beam in wiggler	*60,000 - 270,000*

CPU time is estimate-- depends on problem.

We will need NERSC processor hours!

Summary

- **We have a unique capability in POSINST + WARP: a 3-D code with accurate space charge & good electron models, benchmarked against experiment.**
- **The code suite incorporates new algorithms that, depending on the problem, can make it factors of up to ~ 40,000 x faster than other 3D codes.**
- **It can be used to benchmark codes using more approximate models, and to investigate problems that require exact models or 3D.**
- **We must start with simple problems to first obtain correct numerical parameters. We have a step-by-step program then to investigate DR ecloud physics.**