Possible Electron-Cloud Tasks

Miguel Furman

Summary

- Proposed tasks to LARP: status
- My wish list for this trip
- New stuff: 3D simulations/work at HCX
- What we could do in FY06

Background for this visit

- LARP collaboration meeting April 6-8, 2005 (BNL)
  - —I'd like to make a strong case for LARP funding for e-cloud and strong-strong beam-beam
  - —Status of e-cloud work here at CERN
- New e-cloud effort (since Oct. 2002) at HIF group (LBNL+LLNL)
  - —Measurements, diagnostics, simulations
  - —Based on heavy ions
  - —Funding ends Sep. 30 2005
  - —We'd like to continue and expand it

E-cloud LARP milestones
(as listed in task sheet Oct. 2004)

- Report on simulations & experiments at SPS: apr. 05
  - M. Furman & M. Pivi; promised for PAC05
  - we are late
- Install e-cloud detector in RHIC: ~aug. 05
- Report on applicability of Iriso-Peggs maps to LHC: ~sep. 05
- Report on simulated EC at LHC IR4 diagnostic bench: ~oct. 05
- Report on simulations & measurements of e-cloud at RHIC: ~jul. 06

My wish list for this trip: collect information

- what is status of e-cloud detector for RHIC?
  - (J. M. Jiménez)
- what is status of e-cloud data analysis from SPS measurements
  - strip det., cold & warm calorimeters, and various other detectors?
    - especially e^- spectrum
  - any puzzles remaining?
  - results from last summer's e-cloud SPS runs
  - COLDEX
  - WAMPAC
  - strip detector in quad
  - 25/75 interleaved batches
  - how much is understood about e-cloud in a cold region, especially conditioning effect?
    - (F. Zimmermann, D. Schulte, G. Arduini, V. Baglin, JM Jimenez, E. Benedetto ?)

Wish list - contd.

- What is known about the LHC optimal conditioning scenario?
  — how much freedom will the LHC have to vary the bunch train pattern during the first 2-3 years?
- heavy ions in LHC:
  — gas desorption issues?
  — e-cloud issues?
- interplay between gas desorption/ionization and e-cloud (Gröbner HHH2004; Vincent's measurements of ions at the wall)
  — can you explain long-lived e-cloud at SPS?

New work at LBNL: HCX

(High-Current eXperiment)

- LDRD (coordinated LBNL-LLNL) since Oct. ‘02
  - ~$120k/yr (LBNL) + ~$180k/yr (LLNL)
  - supports EC work at CBP and HIF, and LLNL
  - FY05 is 3rd (and last) year
  - integrated program (simulation, diagnostics and measurements)
  - produce a <u>3D self-consistent</u> code
    - based on code “WARP” (self-consistent, parallel, MAD input,…)
    - and POSINST e^- emission models, gas, ionization,..
  - centered around the HCX driver at LBNL
    - E=1.8 MeV K^+ ions, ~10-m long machine
    - detectors: electrons, gas, ions at the wall
  - HCX can be simulated end-to-end!
  - main goals:
    - measure various quantities (e^- and gas yields, ion-wall scattering,…)
    - validate code and understand EC details via comparisons against expts
    - ultimately: <u>predictive simulation tool</u> of general applicability

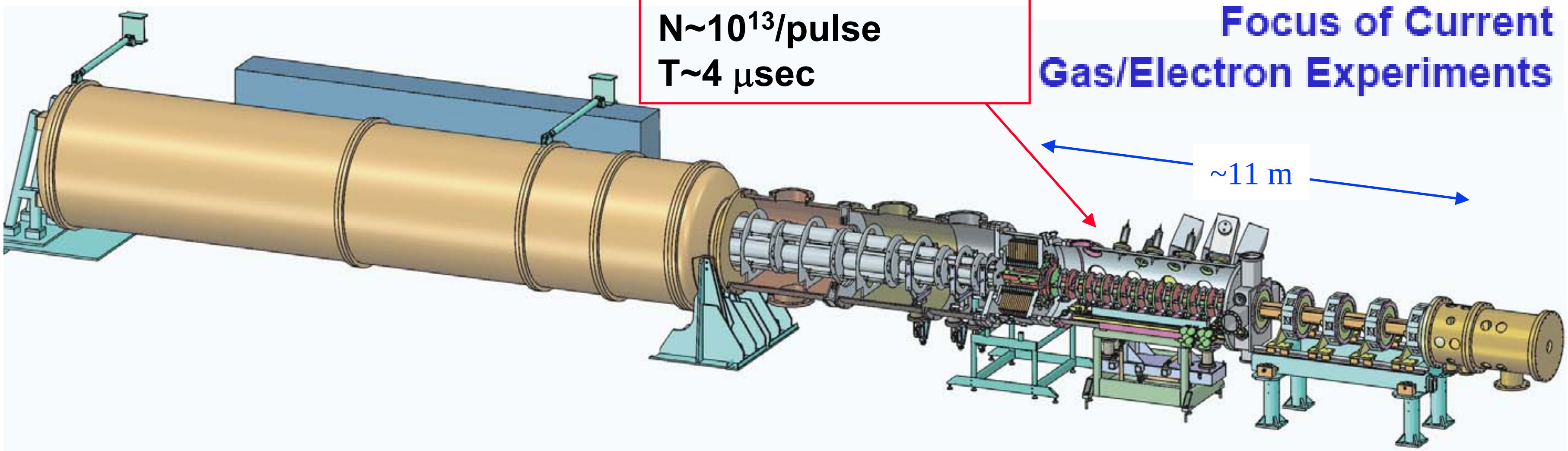
participants

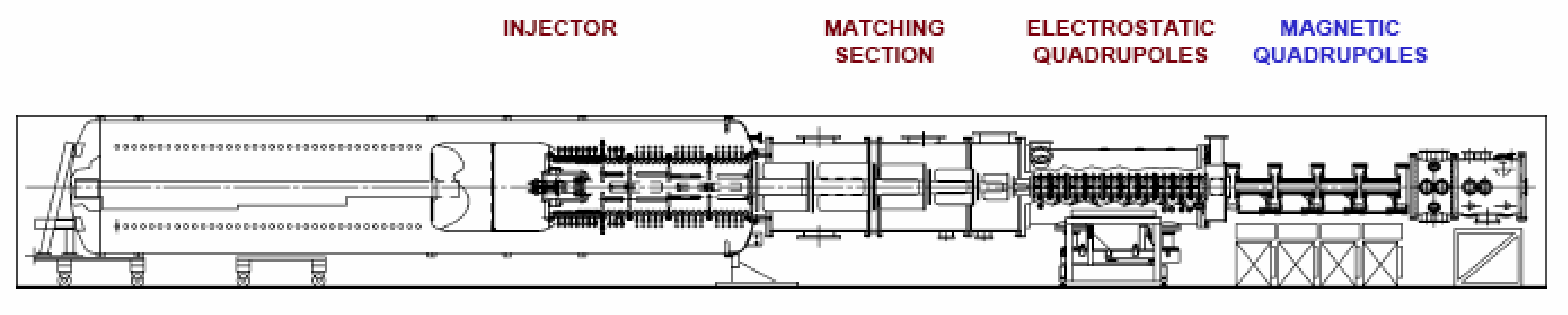
- Jean-Luc Vay (Berkeley) (PI)
- Miguel Furman (Berkeley) (co-PI)
- Alex Friedman (Berkeley/Livermore)
- Ron Cohen (Berkeley/Livermore)
- Art Molvik (Livermore)
- Peter Stoltz (Tech-X)
- Michel Kireeff-Covo (UCB student)
- Tony Azevedo (UCB student)
- John Verboncoeur (UCB faculty)
- …

The HCX: prototype driver for HIF

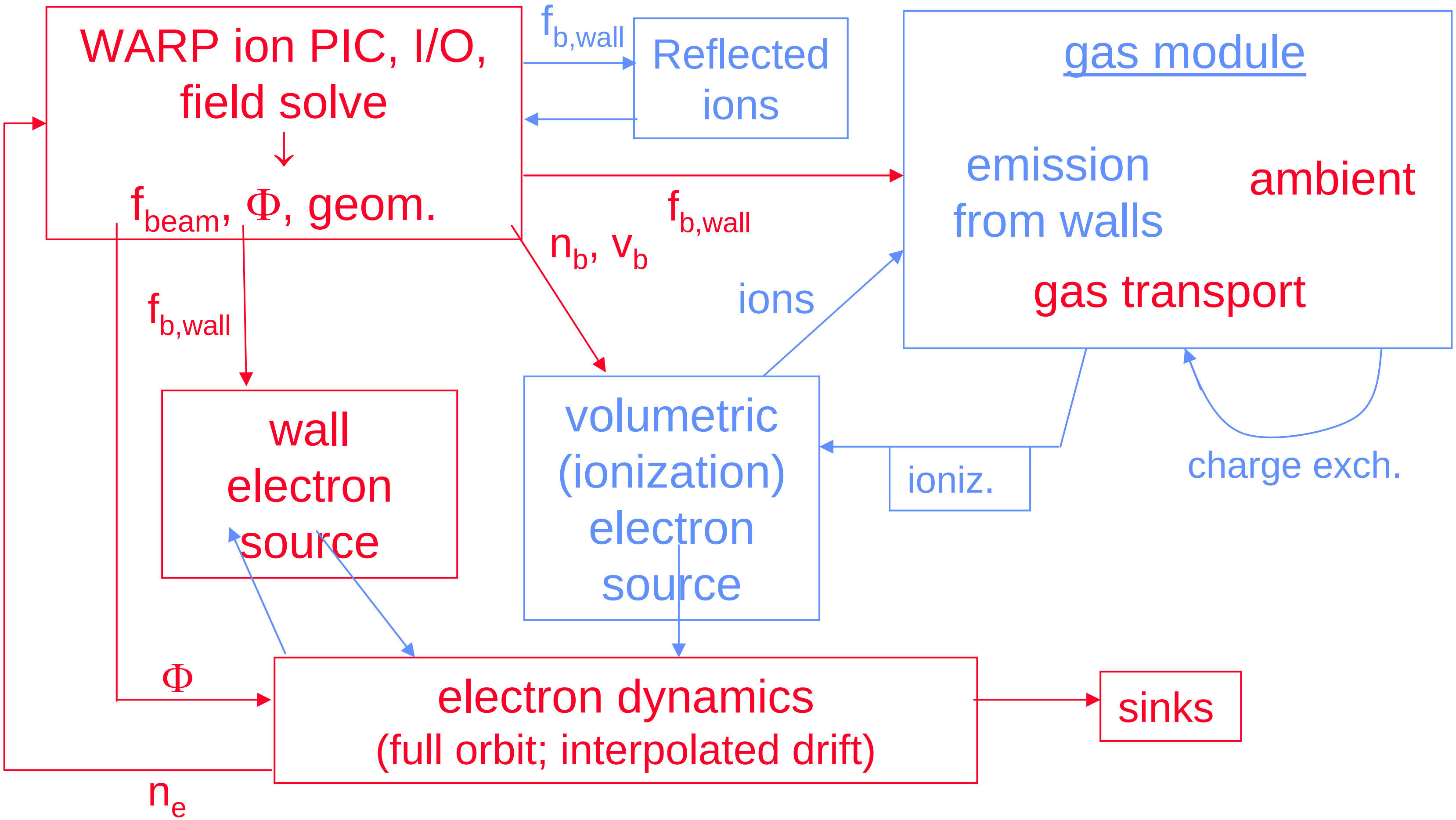
E~1-1.8 MeV K^+ ions
N~10^{13}/pulse
T~4 μsec

Focus of Current Gas/Electron Experiments





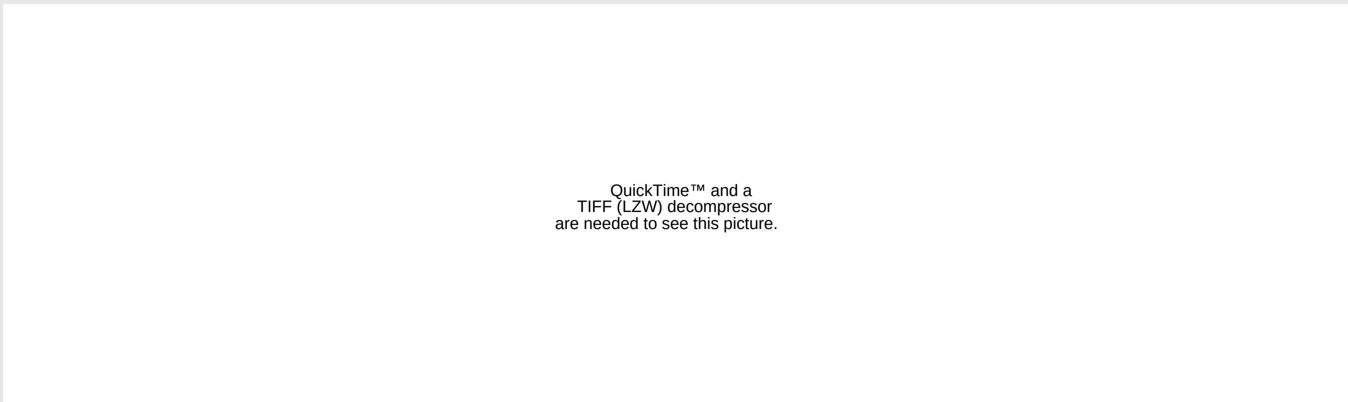
WARP/POSINST: 3D self-consistent model of electron cloud and gas effects–code structure



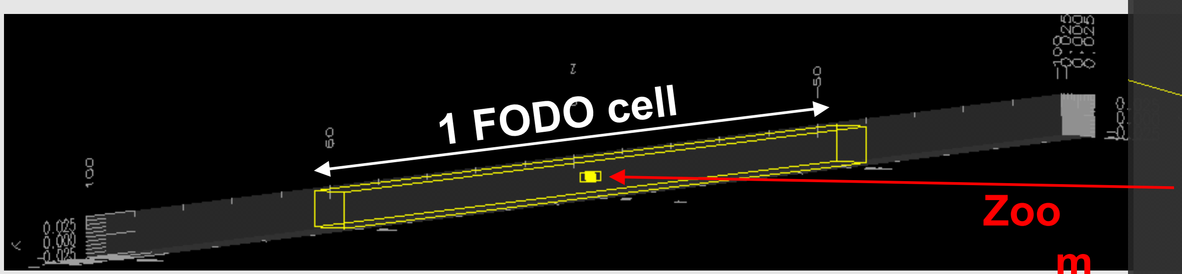
Key: operational; partially implemented (3/9/05)

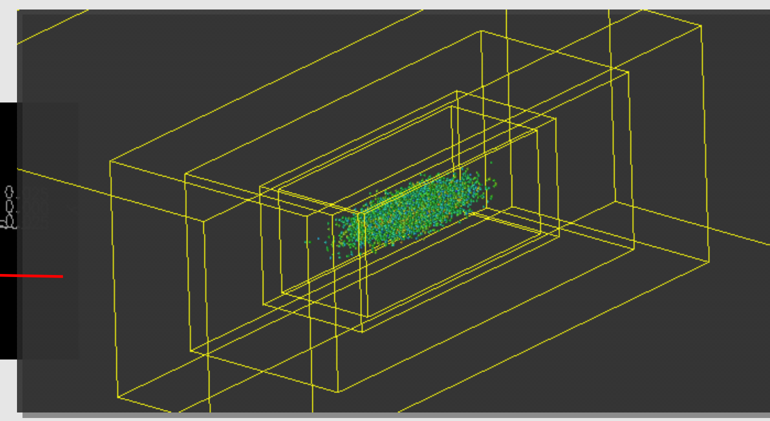
Two different strategies to reduce computing requirements

- QUICKPIC: reduced model



- WARP: mesh refinement





(for LHC parameters, savings by three to four orders of magnitude on field solve in computer time and memory)

Invention of an efficient electron integrator

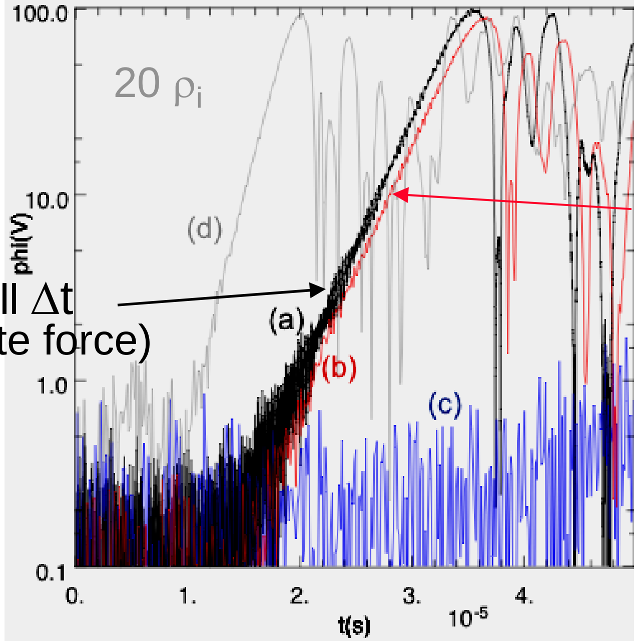
(R. Cohen et al.)

- Problem: wide range of time scales (electrons move fast!)
- ⇒ brute force integration requires small Δt when $B \neq 0$ ⇒ slow
- Our 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
- Ref. Cohen et al, Phys. Plasmas May '05
- Test problem: 2 stream instability of counter-streaming pencil (10 gyroradii) beams

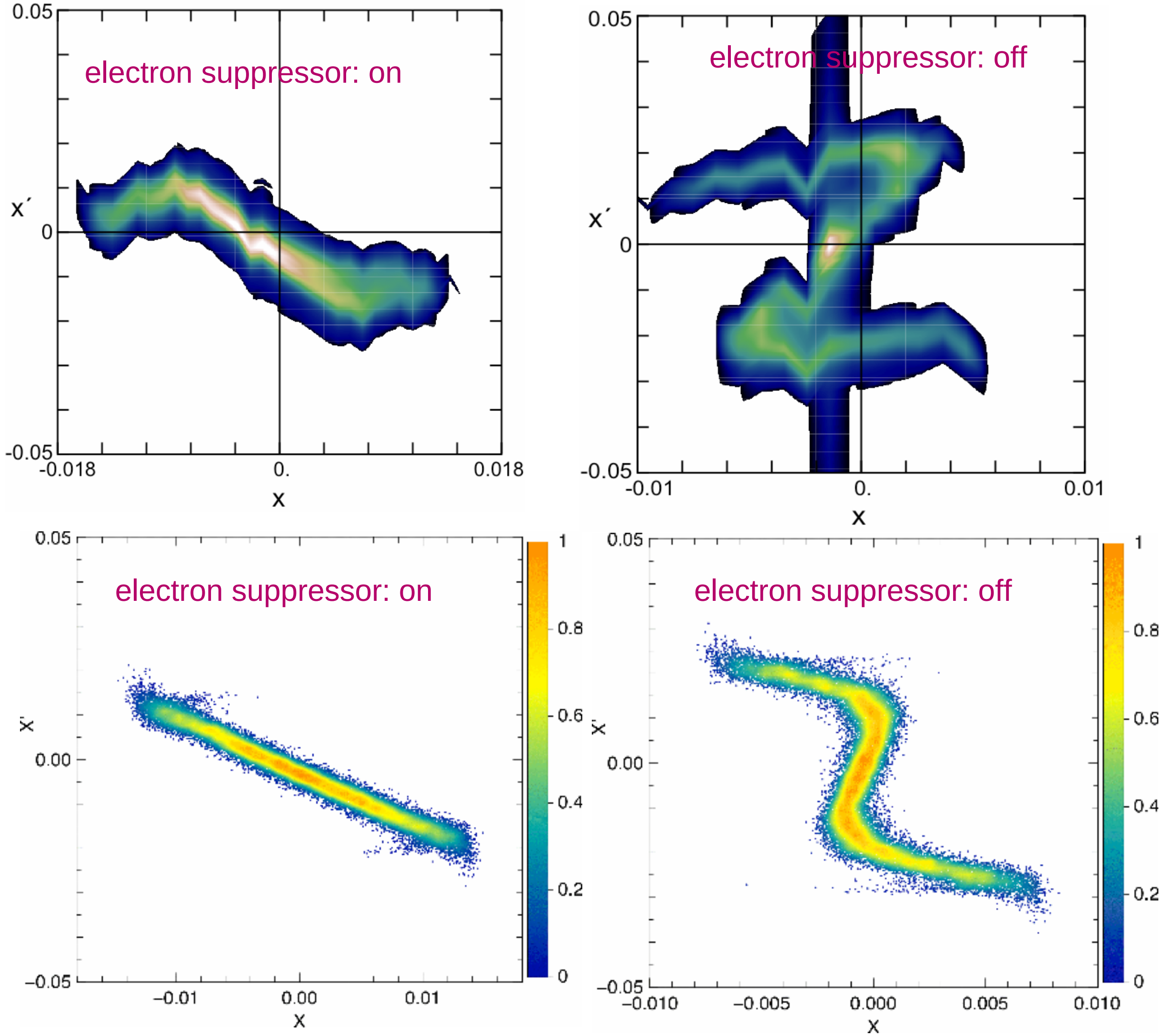


Speed-up by ~x25, ~no loss of accuracy

WARP/POSINST e-i simulations vs. experiments: 4-magnet section of HCX **(R. Cohen)**

HCX measurement

Phase space reconstruction from scintillator images of slit scan



3-D WARP simulation with:

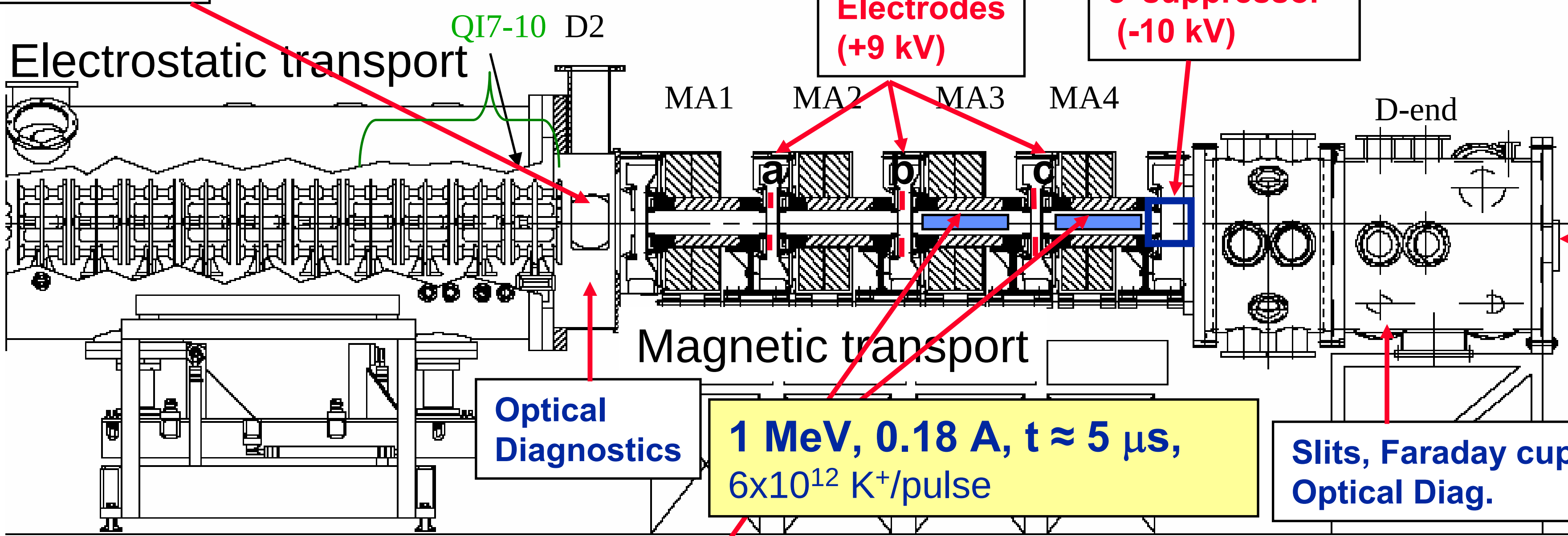
Electron desorption at end wall matching desorption rate from separate experiments.
Secondary emission when electrons hit radial pipes.
NO local sources of electrons

HCX instrumentation to carry out electron cloud (and gas desorption) experiments (A. Molvik)

Slits & Faraday Cup

e⁻ clearing Electrodes (+9 kV)

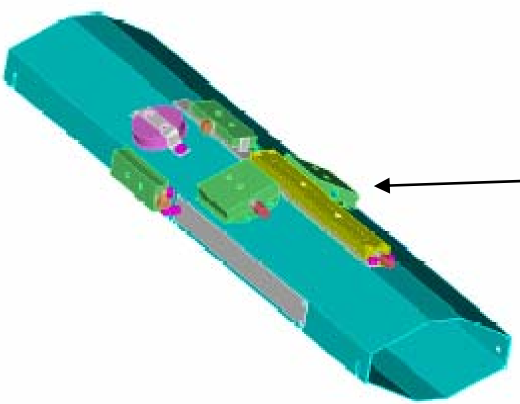
e⁻ suppressor (-10 kV)



Optical Diagnostics

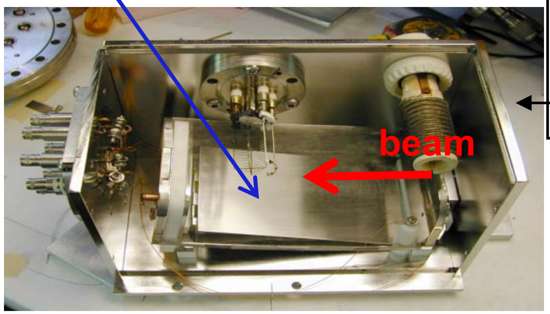
1 MeV, 0.18 A, t ≈ 5 μs,
6×10^{12} K^+/pulse

Slits, Faraday cup, Optical Diag.



Diagnostics Inside beam tube: capacitive monitors, e⁻ probes,…

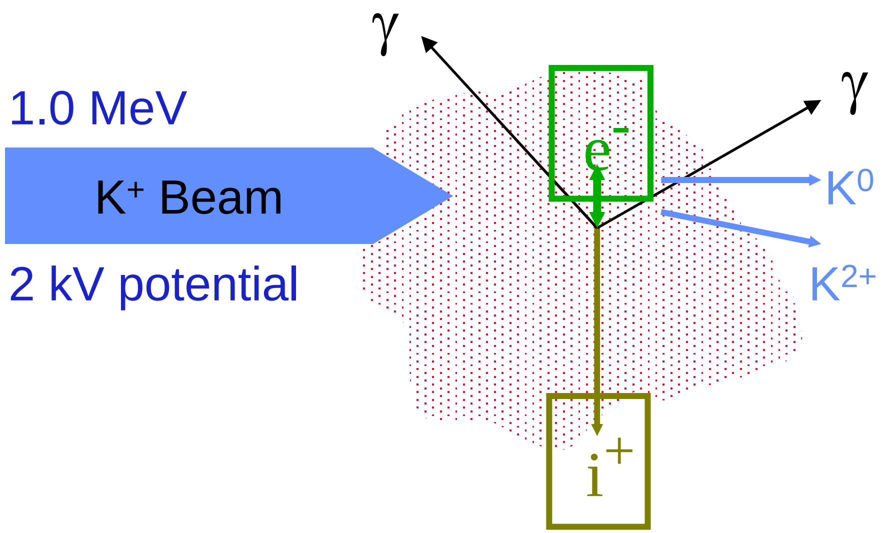
tiltable target



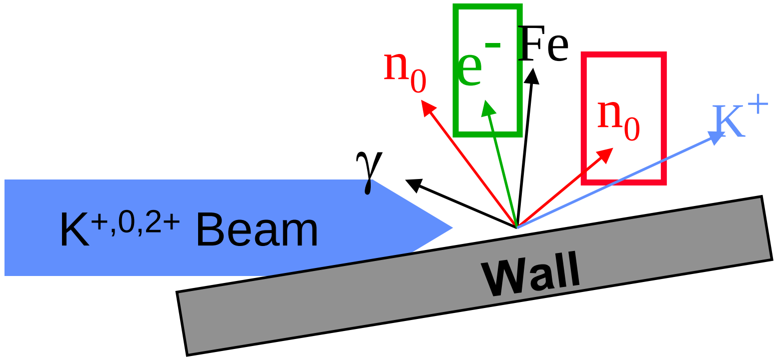
Gas-Electron Source Diagnostic (GESD)

Beam hitting gas or walls creates electrons and gas (A. Molvik)

Beam on gas



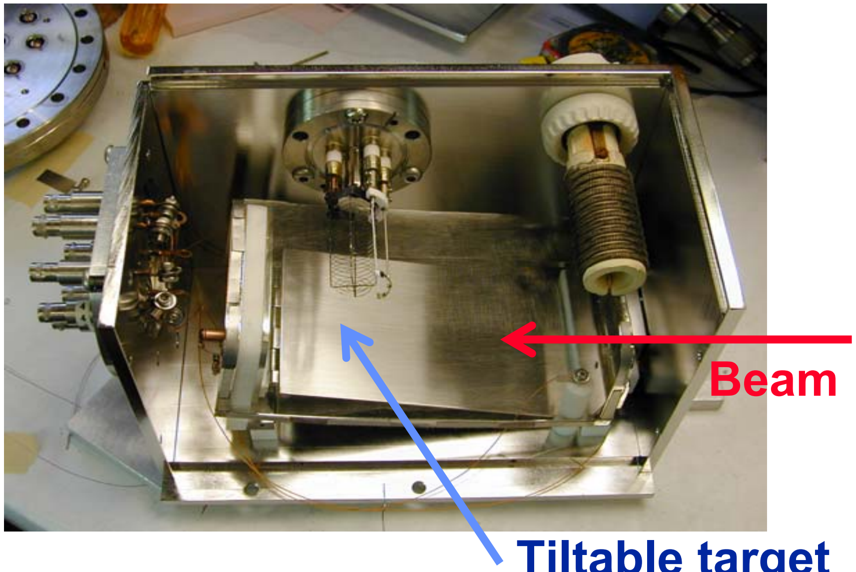
Beam to walls

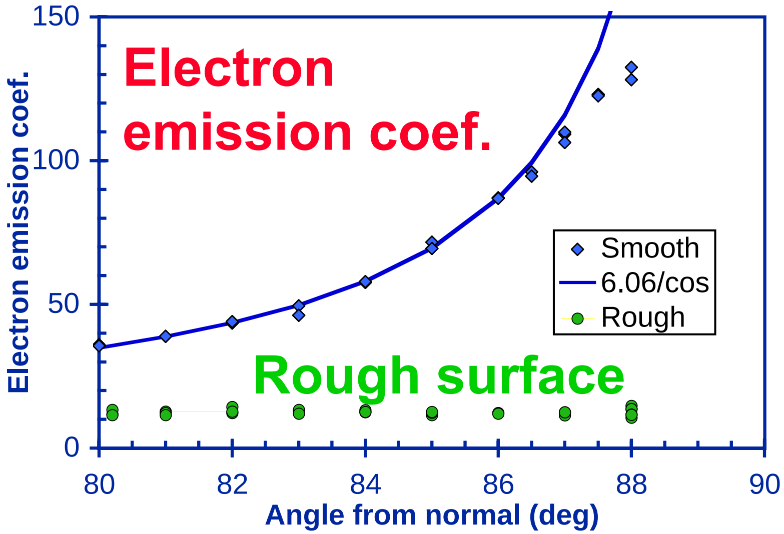


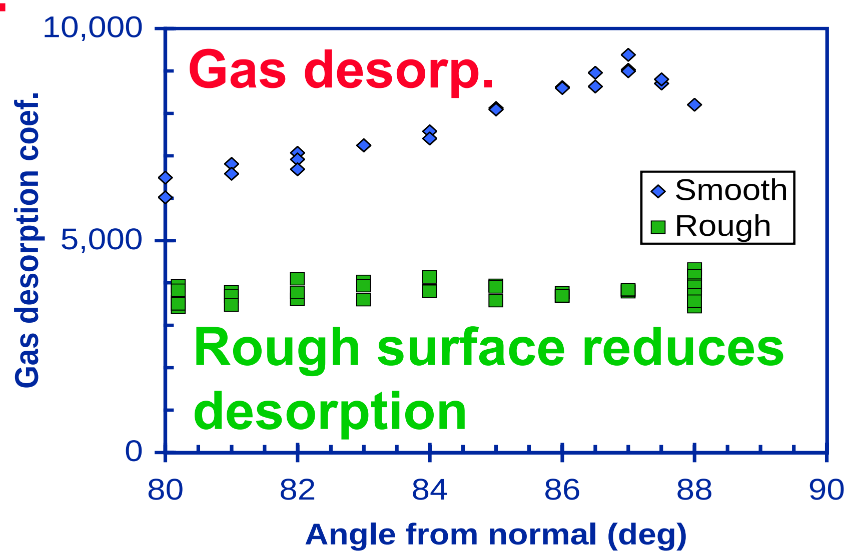
These interaction products create rich opportunities for diagnostics along with problems for diagnostics and beams

Gas desorption / electron emission measurements

Gas-Electron Source Diagnostic (GESD)

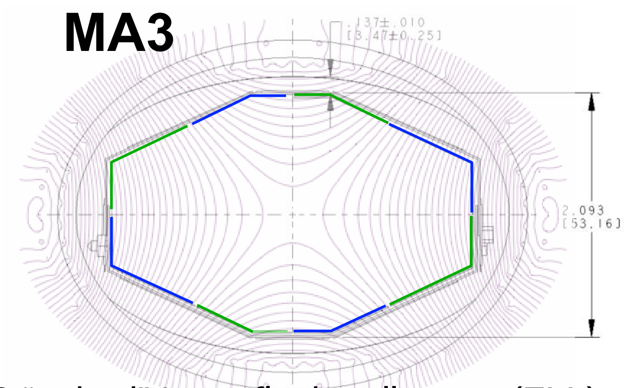




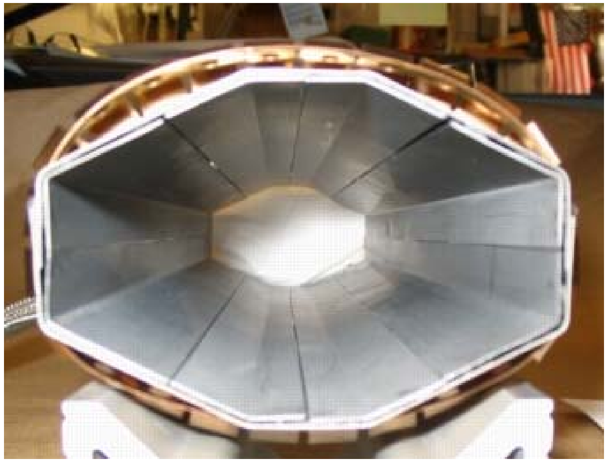


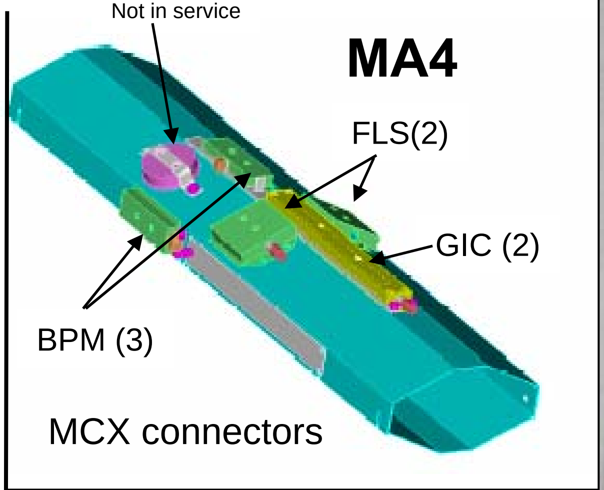
Target surface roughened by glass-bead blasting – grazing incidence ions now hit rims of craters.

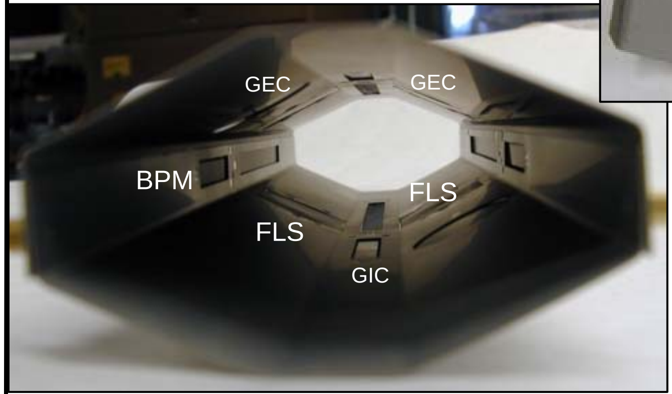
Diagnostics in two magnetic quadrupole bores: what they measure.



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







3 capacitive probes (BPM) – measure $(n_b - n_e)/ n_b$

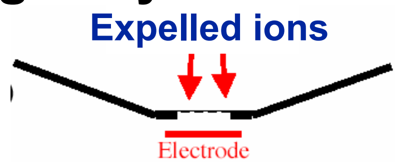
2 Short flush collector (FLS); similar to FLL. Elec from wall

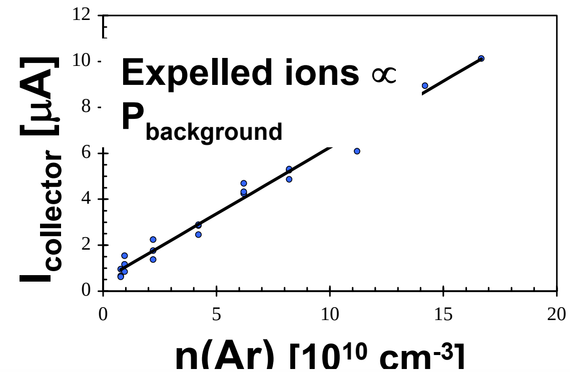
2 Gridded e^- collector (GEC); trapped e^- after passage of beam

2 Gridded ion collector (GIC): n_{gas} in beam, ionization rate

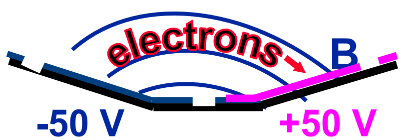
Accomplishment: all sources of electrons can be measured

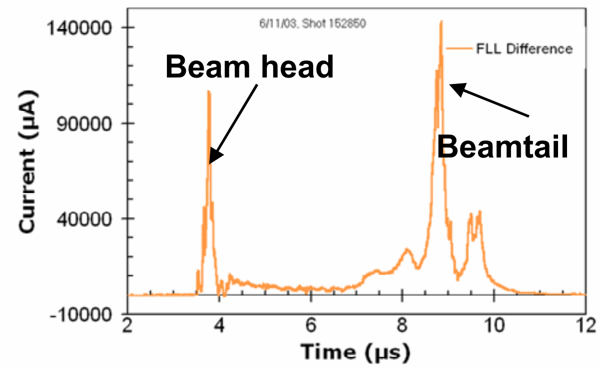
1. **Ionization of gas by beam**



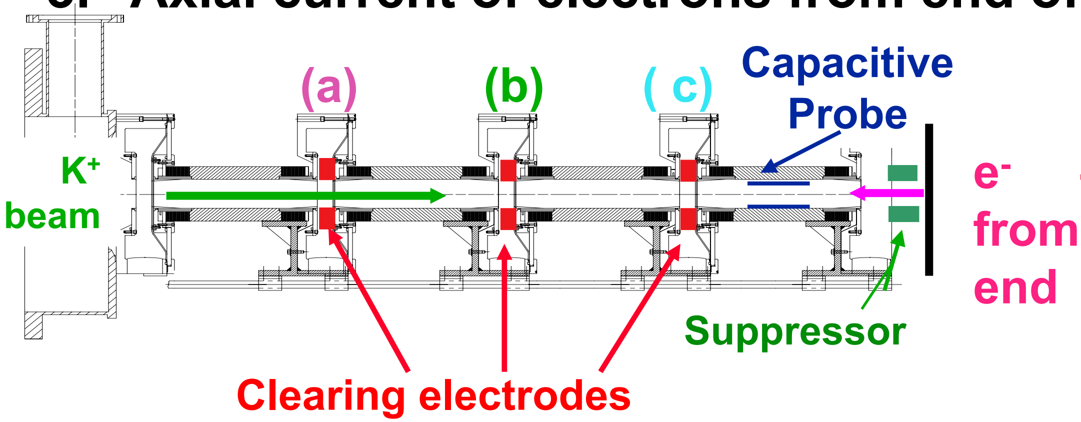


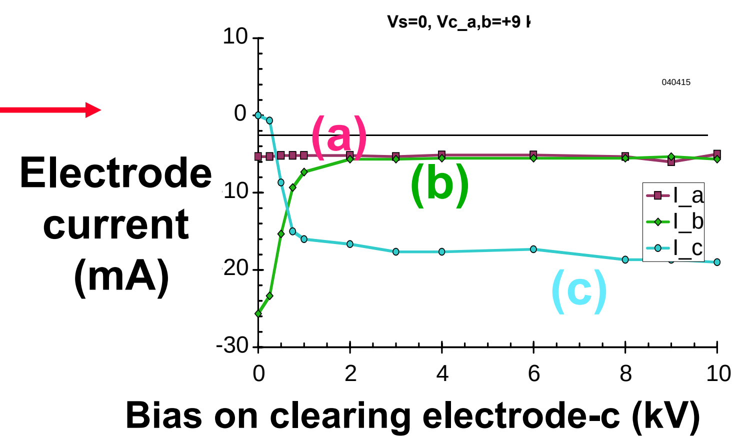
2. **Electron emission from beam tube**





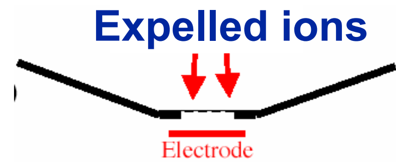
3. **Axial current of electrons from end of linac**





Several diagnostics have potential to measure accumulation of electrons [$dn_e/dt = I_e/V - n_e/\tau$]

- **Capacitive probes** to measure beam potential [$\propto (n_b - n_e)/n_b$]
- **Gridded electron collectors (GEC)** collect electrons along magnetic field lines as they are expelled by the falling beam potential at the end of a pulse (expulsion potential implies depth of trapping)
- **Gridded ion collectors (GIC)** →



- **Retarding potential analyzer** between magnets to measure expelled ions or electrons (at end of pulse) [infer above]
- **Imaging diagnostics** show beam focusing to small spot with e^- present – may to able to calibrate this, or **slit scanners** (beam location and angle) to obtain average electron density.

- **Space charge wave propagation velocity** - some effects seen
- **Interferometry?** Maybe – but $n_b \sim 10^8 - 10^9$ cm^{-3}, $n_e \leq n_b$ so need to measure very small phase shift or find way to use very low freq.

Retarding potential analyzer (RPA) measures energy distribution of expelled ions

- **RPA an extension of ANL design (Rosenberg and Harkay)**
- **Can measure either ion or electron distributions**
- **Potential of beam edge ~1000 V, beam axis ~ 2000 V**

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

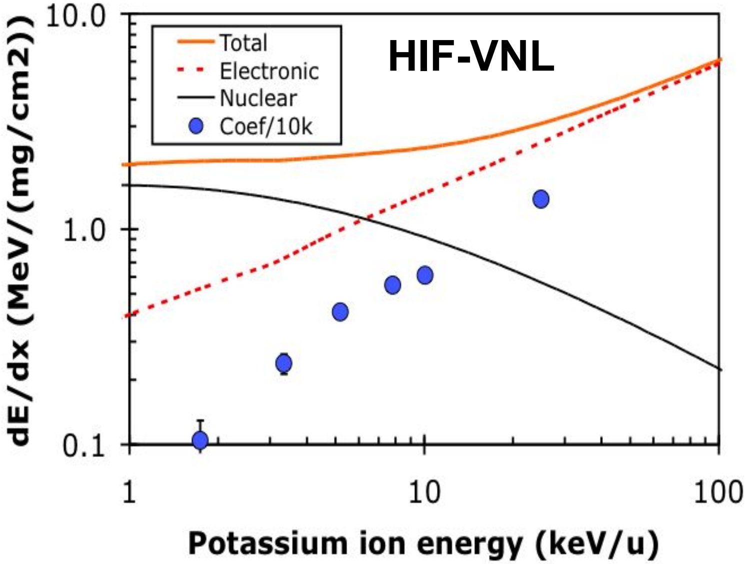
QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

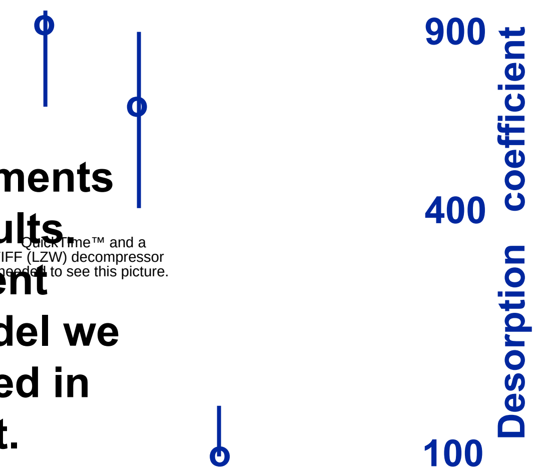
Ref: Michel Kireeff Covo, to be published.

Major discovery: copious gas desorption in accelerators due to electronic sputtering*

* Suggested by Thomas Schenkel, LBNL EBIT

Gas desorption scales with electronic component of dE/dx





GSI augments VNL results. Consistent with model we suggested in 1/03 visit.

QuickTime™ and a TIFF (LZW) decompressor are needed to see this picture.

- **Conventional Sputtering** – driven by nuclear scattering of ions in matter
- **Electronic sputtering** – driven by electronic slowing of ions in matter

Desorption not due to nuclear or total slowing. GSI results confirm.

HIF-VNL facilities ideal: energy range from nuclear dominating to electronic slowing dominating.

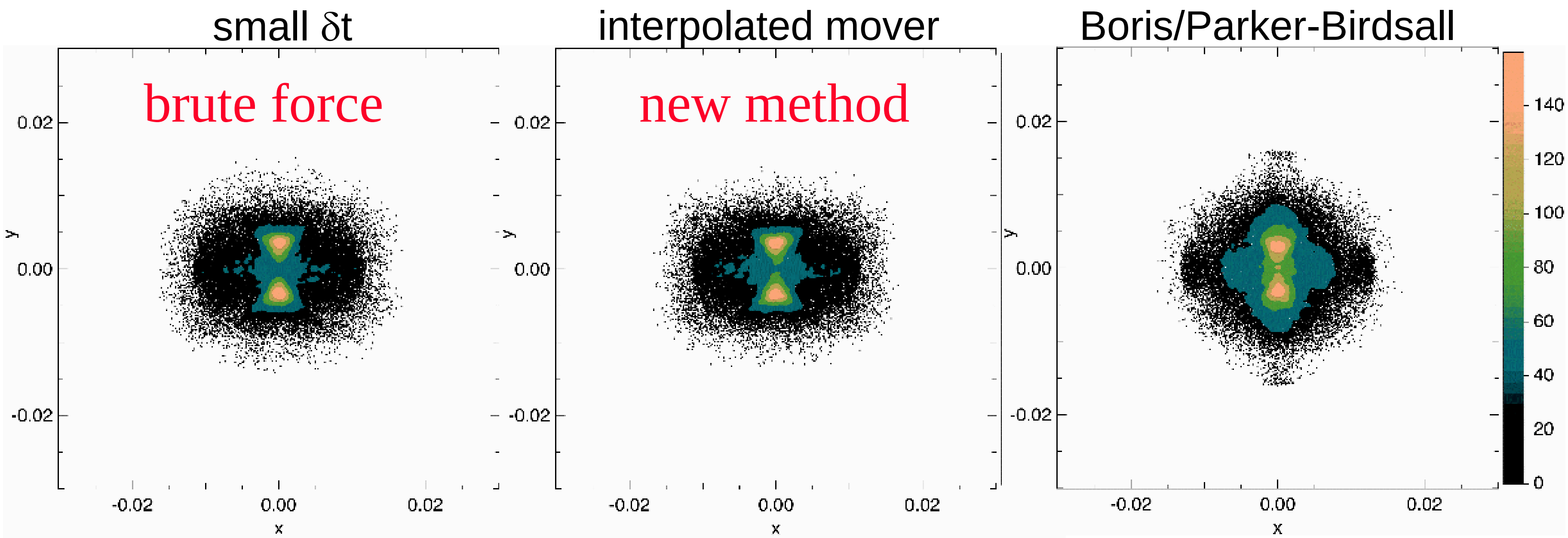
Our mission…

"PARTICLES, PARTICLES, PARTICLES."

Backup material

Key simulation invention: large Δt electron pusher for non-uniform B-fields (eg., quads) (R. Cohen)

- Choice $\alpha=1/[1+(\omega_c\Delta t/2)^2]^{1/2}$ gives physically correct "gyro" radius at large $\omega_c\Delta t$ and also produces correct drift velocity and parallel dynamics.
- E-cloud produced by injection (at t=0) of T=10 eV electrons uniform out to nominal beam radius (e.g. ionization of neutral gas). Not stationary. Snapshot at fixed time (~50 τ_{bounce}):
- Factor ~25 increase in speed, little degradation of accuracy



WARP/POSINST vs QUICKPIC

Functionality	QUICKPIC	WARP/POSINST
Particles	Ions: x,y,z,p_x,p_y,p_z Electrons: x,y,p_x,p_y	All: x,y,z,p_x,p_y,p_z
Particle pusher	Boris corrected for ω_0	Boris/drift hybrid for e- in magnetic field (bridges ion/e- time scales)
Self-fields	Ions: 3-D from multiple 2-D Poisson Electrons: 2-D Poisson	All: 3-D with AMR (2-D XY and RZ available)
Lattice description	Uniform and constant focusing + dispersion	MAD-like(+more) description includes gaps, dipoles, quadrupoles, sext., …
Pipe geometry	Rectangle	Any
Particle/Wall interaction	Specular reflection	Absorption, Secondary emission, neutral emission, gas model
Photoemission	no	Simple model
Parallel	Using MPI	Using MPI, different decomposition for fields and particles

• WARP/POSINST package also includes envelope/fluid solvers, a MAD-to-"WARP MAD-like" lattice description translator, a Python interface and a GUI
• all pieces needed to reproduce QUICKPIC framework available in WARP package (implementation in WARP of correction to ω_0 for Boris is trivial)

Selected Meetings and Websites

Meetings Fully or Partially Dedicated to Electron-Cloud Physics

Santa Fe Workshop on Electron Effects in High-Current Proton Rings, SNS/LANL (Santa Fe, NM, Mar 4-7, 1997); LA-UR-98-1601.

Workshop on Multibunch Instabilities "MBI97" (KEK, Tsukuba, Japan, July 15-18, 1997); KEK Proc. 97-17 (1997);
http://www-acc.kek.jp/www-acc-exp/Conferences/MBI97-N/MBI97.html

ICFA Workshop on Two-Stream Instabilities in Particle Accelerators and Storage Rings (Santa Fe, NM, Feb 16-18, 2000); http://www.aps.anl.gov/conferences/icfa/two-stream.html

Int'l Workshop on Two-Stream Instabilities in Particle Accelerators and Storage Rings (KEK, Tsukuba, Japan, Sept 11-14, 2001); http://conference.kek.jp/two-stream/

20th ICFA Advanced Beam Dynamics Workshop on High Intensity High Brightness Hadron Beams "HB2002" (Fermilab, April 8-12, 2002); http://www-bd.fnal.gov/icfa/workshops/20/

Mini-Workshop on Electron-Cloud Simulations for Proton and Positron Beams "ECLOUD02" (CERN, April 15-18, 2002); http://slap.cern.ch/collective/ecloud02/

13th ICFA Beam Dynamics Mini-Workshop on Beam-Induced Pressure Rise in Rings (BNL, Dec. 9-12, 2003);
http://www.c-ad.bnl.gov/icfa/

31st ICFA Advanced Beam Dynamics Workshop on Electron-Cloud Effects "ECLOUD04" (Napa, California, April 19-23, 2004); http://icfa-ecloud04.web.cern.ch/icfa-ecloud04/

33rd ICFA Advanced Beam Dynamics Workshop on High Intensity and High Brightness Hadron Beams "ICFA-HB2004" (Bensheim, Germany, October 18-22, 2004)
http://www.gsi.de/search/events/conferences/ICFA-HB2004/index_e.html

First CARE-HHH-APD Workshop on Beam Dynamics in Future Hadron Colliders and Rapidly Cycling High-Intensity Synchrotrons "HHH2004" (CERN, 8-11 November, 2004);
http://care-hhh.web.cern.ch/care-hhh/HHH-2004/

Some Websites Dedicated to Electron-cloud Physics

Electron Cloud in the LHC (CERN):
http://wwwslap.cern.ch/collective/electron-cloud/electron-cloud.html

Two-stream instability studies at PPPL:
http://w3.pppl.gov/~nnp/TwoStream.htm

Electron Cloud Studies at the Advanced Photon Source (ANL):
http://www.aps.anl.gov/asd/physics/ecloud/ecloud.html

Comparison of Electron-Cloud Simulations (CERN):
http://wwwslap.cern.ch/collective/ecloud02/ecsim/index.html