Progress in e-cloud studies in both solenoids and quads

Outline

1. Accomplishments
2. Why we made progress
3. Opportunities on HCX, STX, NDCX,…
4. Planning for future

Art Molvik

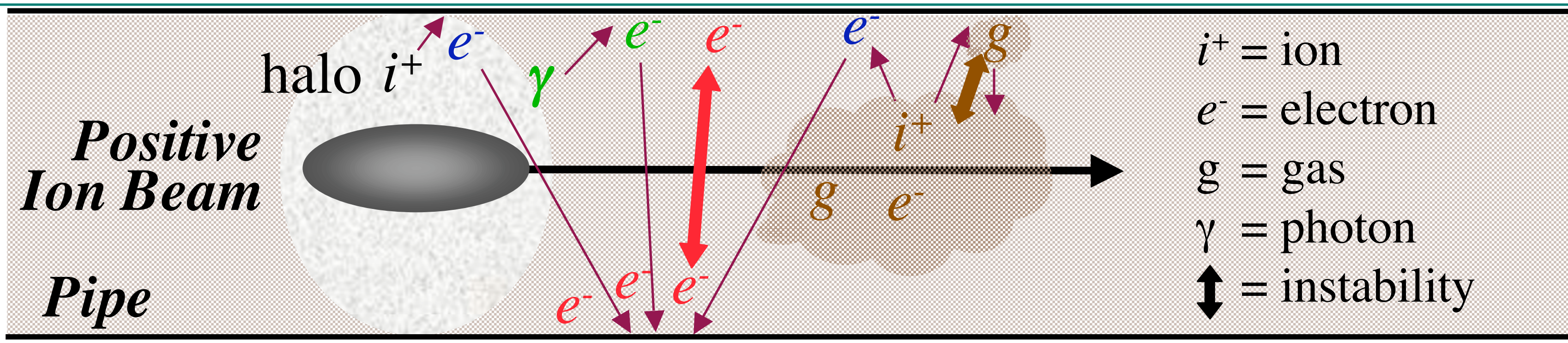
for the

Heavy Ion Fusion Science Virtual National Laboratory

Program Advisory Committee Review

August 9-10, 2006

Sources of electron clouds



Primary:

- Ionization of
  - background gas
  - desorbed gas
- ion induced emission from
  - expelled ions hitting vacuum wall
  - beam halo scraping
- photo-emission from synchrotron radiation (HEP)

Secondary:

- secondary emission from electron-wall collisions

HIFS-VNL has unique tools to study ECE

WARP/POSINST code goes beyond previous state-of-the-art

- **Parallel 3-D PIC-AMR code with accelerator lattice follows beam self-consistently with gas/electrons generation and evolution**

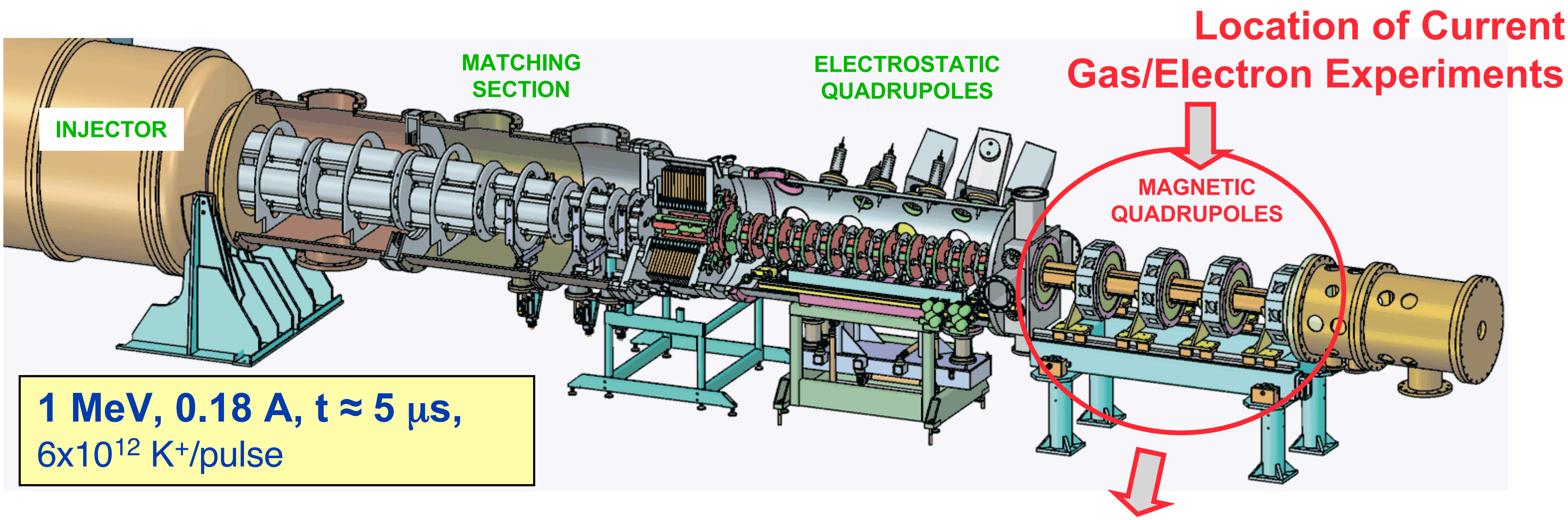
HCX experiment addresses ECE fundamentals relevant to HEP (as well as WDM and HIF)

- **trapping potential ~2kV with highly instrumented section dedicated to e-cloud studies**

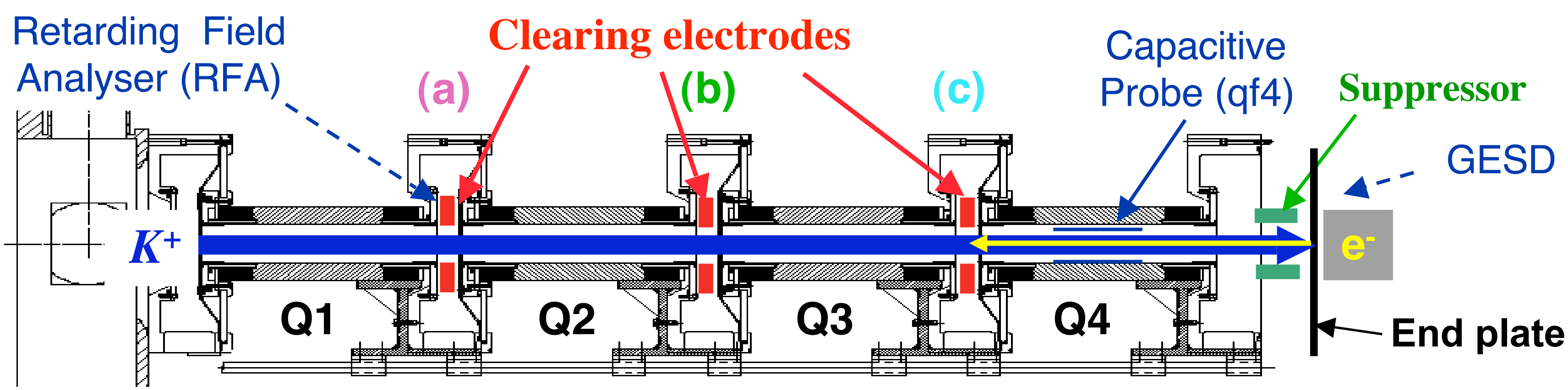
Combination of models and experiment unique in the world

- **unmatched benchmarking capability essential to our credibility**
  'Benchmarking' can include: a. Code debug
  b. validate against analytic theory
  c. Comparison against codes
  d. Verification against experiments
- **enabled us to attract work on LHC, FNAL-Booster, and ILC problems**

HCX is now dedicated to gas/electron effects studies

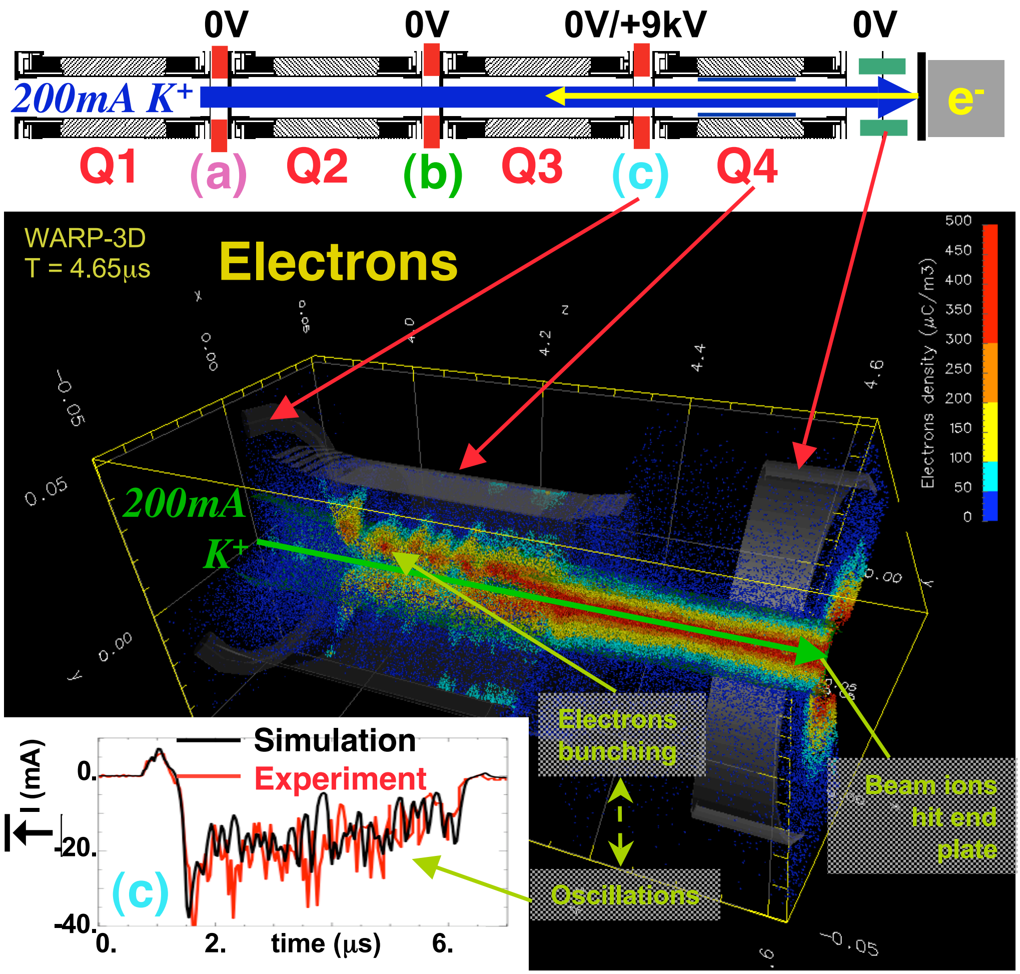


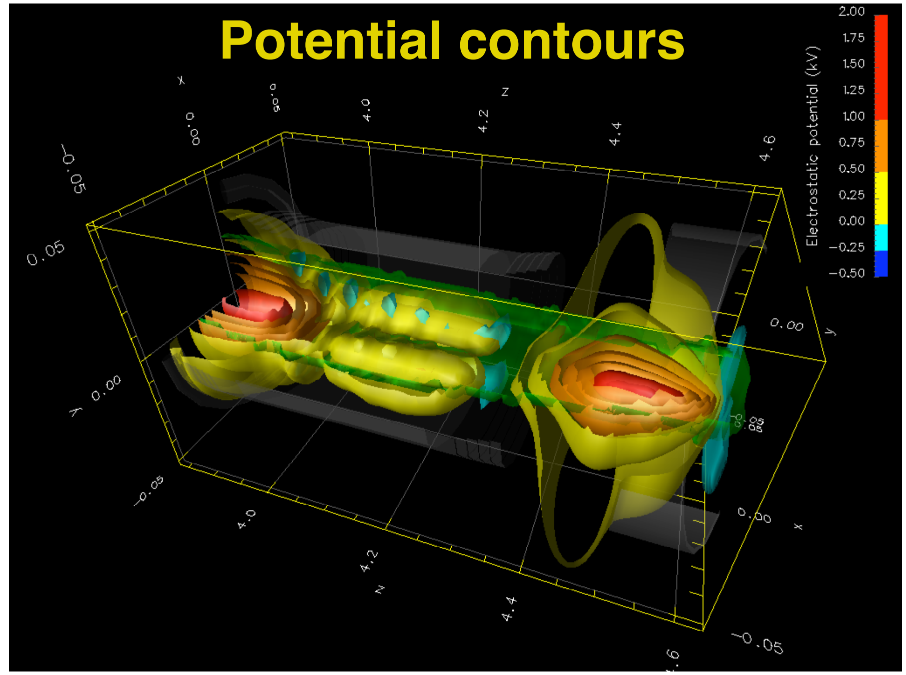
1 MeV, 0.18 A, t ≈ 5 μs,
6×10^{12} K^+/pulse



Short experiment => need to deliberately amplify electron effects:
let beam hit end-plate to generate copious electrons which propagate upstream.

~6 MHz signal is observed in simulation & experiment

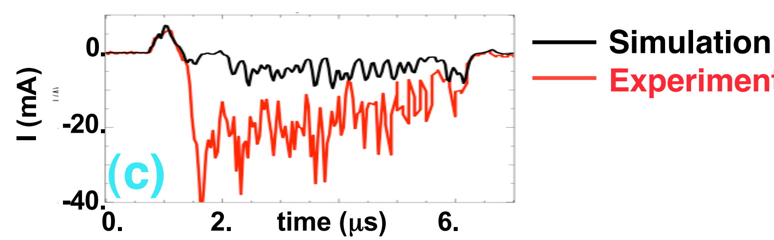




"Most successful benchmarking result in the world!"

M. Furman

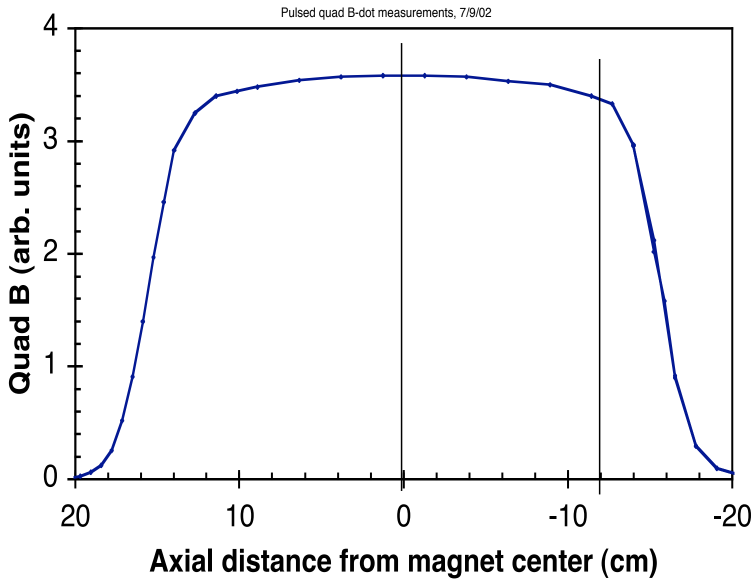
1. **Good test of secondary module** -
   secondary electron emission turned off:

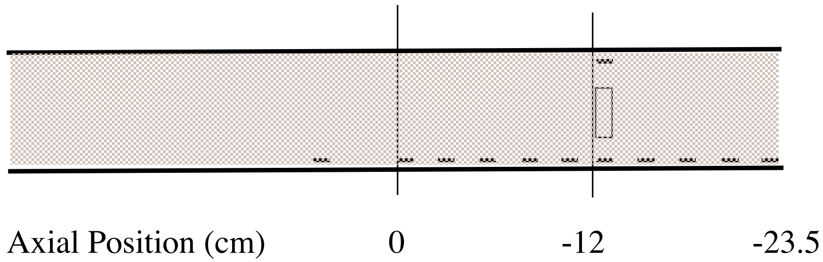


2. **run time ~3 days,**
   - without new electron mover and MR, run time would be ~1-2 months!

Array of BPMs in Quad 4 verified simulation results

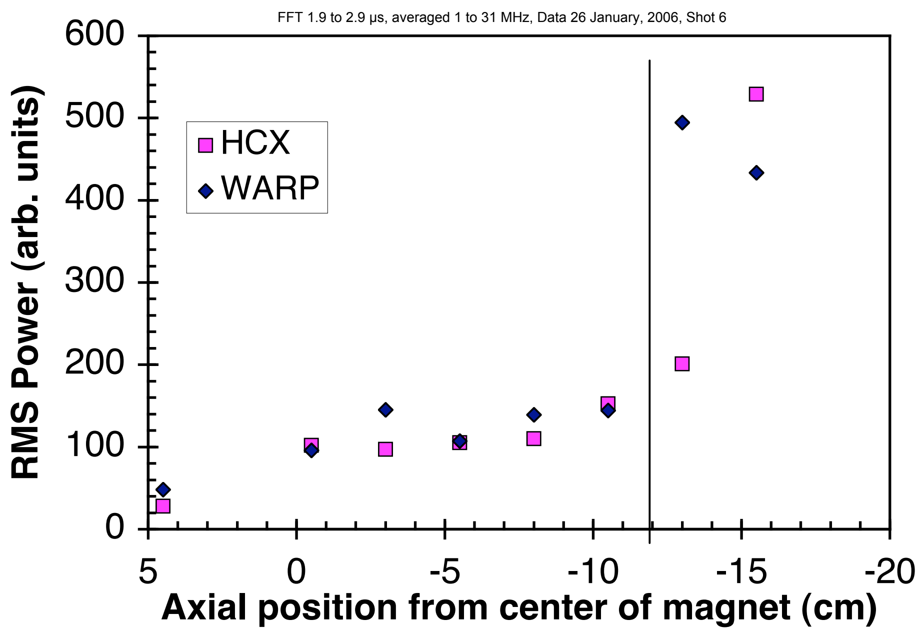
Beam Position Monitor (BPM):
electrode capacitively coupled to beam



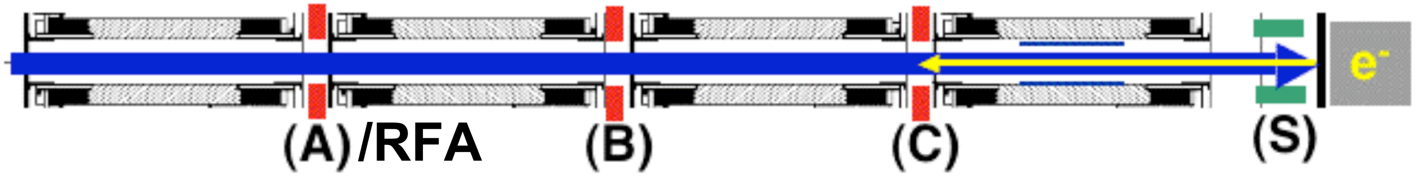


HCX experiment and WARP simulations agree quantitatively on oscillation

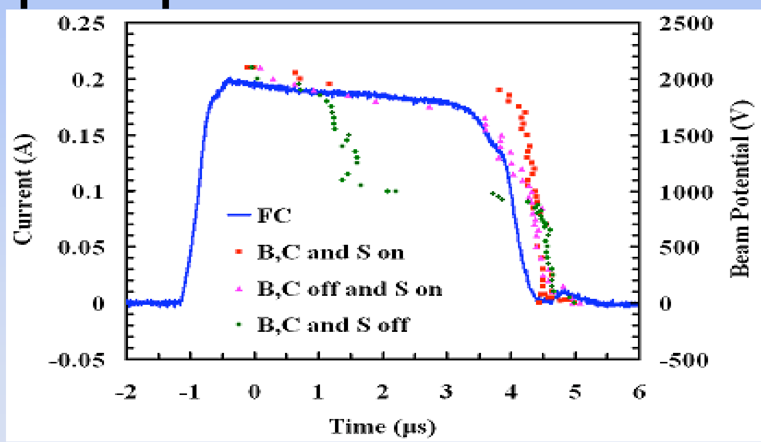
- frequency
- wavelength
- amplitude



First time-dependent measurement of absolute electron cloud density & major discrepancy with simulation



Retarding field analyzer (RFA) measures potential on axis = ion-repeller potential



+ beam/e- distr. => $f=N_e/N_{beam}$

- **Clearing electrodes provide independent measurement of e^- density, confirms RFA**
- **Both RFA and clearing electrodes measure unattenuated transport of electrons through 3 quads whereas WARP finds x0.5 attenuation at each gap.**
- **We are adding diagnostics and a controllable source of electrons (e-gun) to study electron transport and compare with WARP to resolve discrepancy.**

Absolute electron fraction can be inferred from RFA and clearing electrodes

Michel Kireeff Covo, PRL 97, 54801 (2006)

Beam neutralization	B, C, S on	B, C off S on	B, C, S off Sim~89%
Clear ElectrodeA	~ 7%	~ 25%	~ 89%
RFA	(~ 7%)	~ 27%	~ 79%

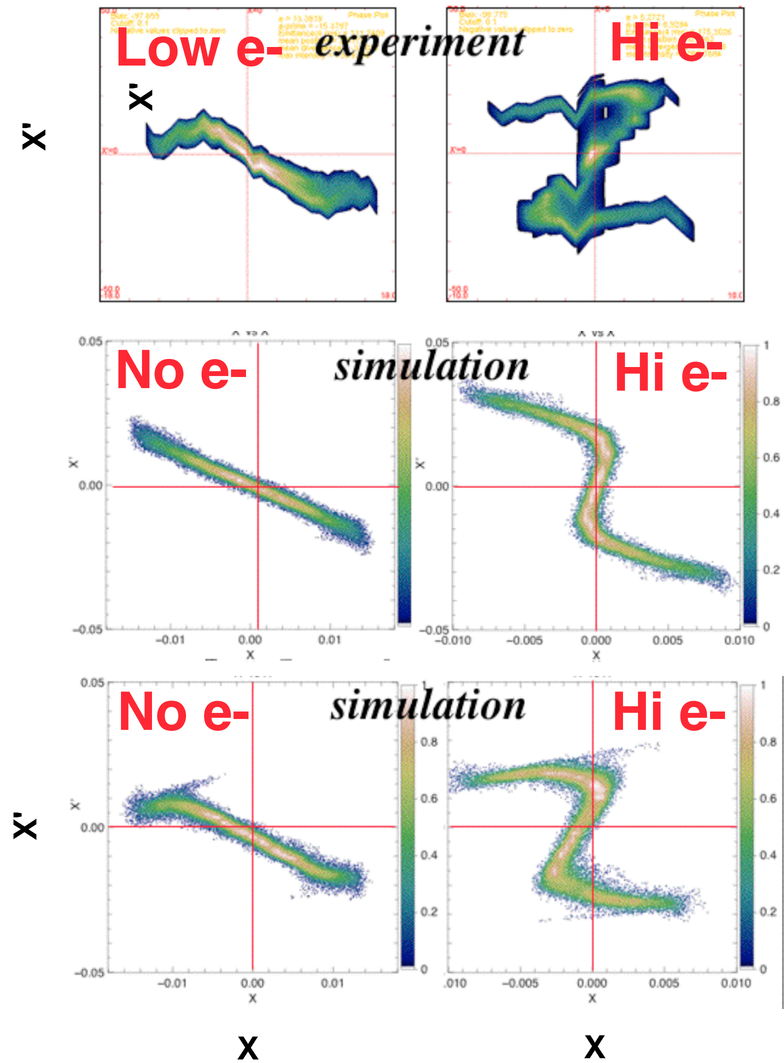
Electron effects on beam more accurately simulated

Beam loading in simulation now uses reconstructed data from slit-plate measurements

leads to improved agreement between simulation and experiment

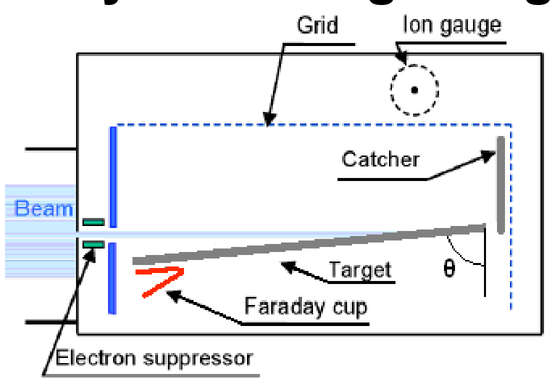
Semi-gaussian load =>

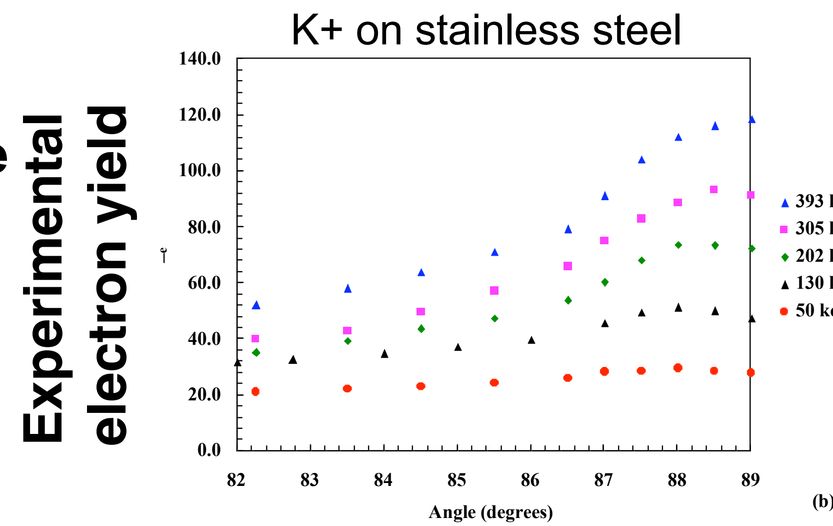
New load from reconstructed data =>



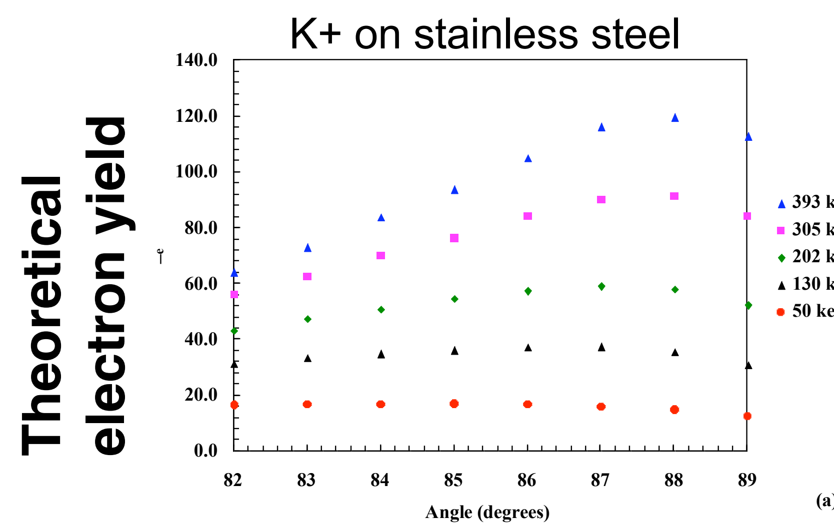
Improved model for beam energy and angle of incidence scaling of ion-induced electron yield*

Gas-Electron Source Diagnostic (GESD) measures ion-induced electron yield near grazing incidence





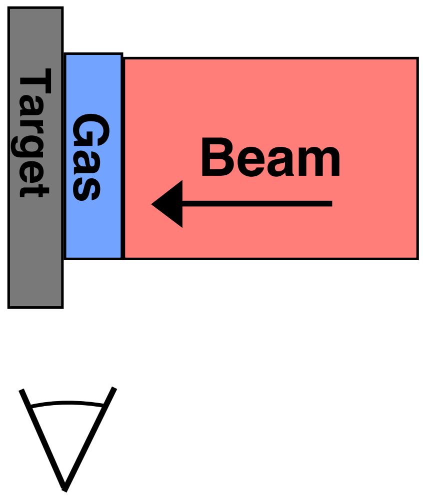
Better agreement with data at low-energy (≤400 keV) range where 1/cos(θ) dependency breaks



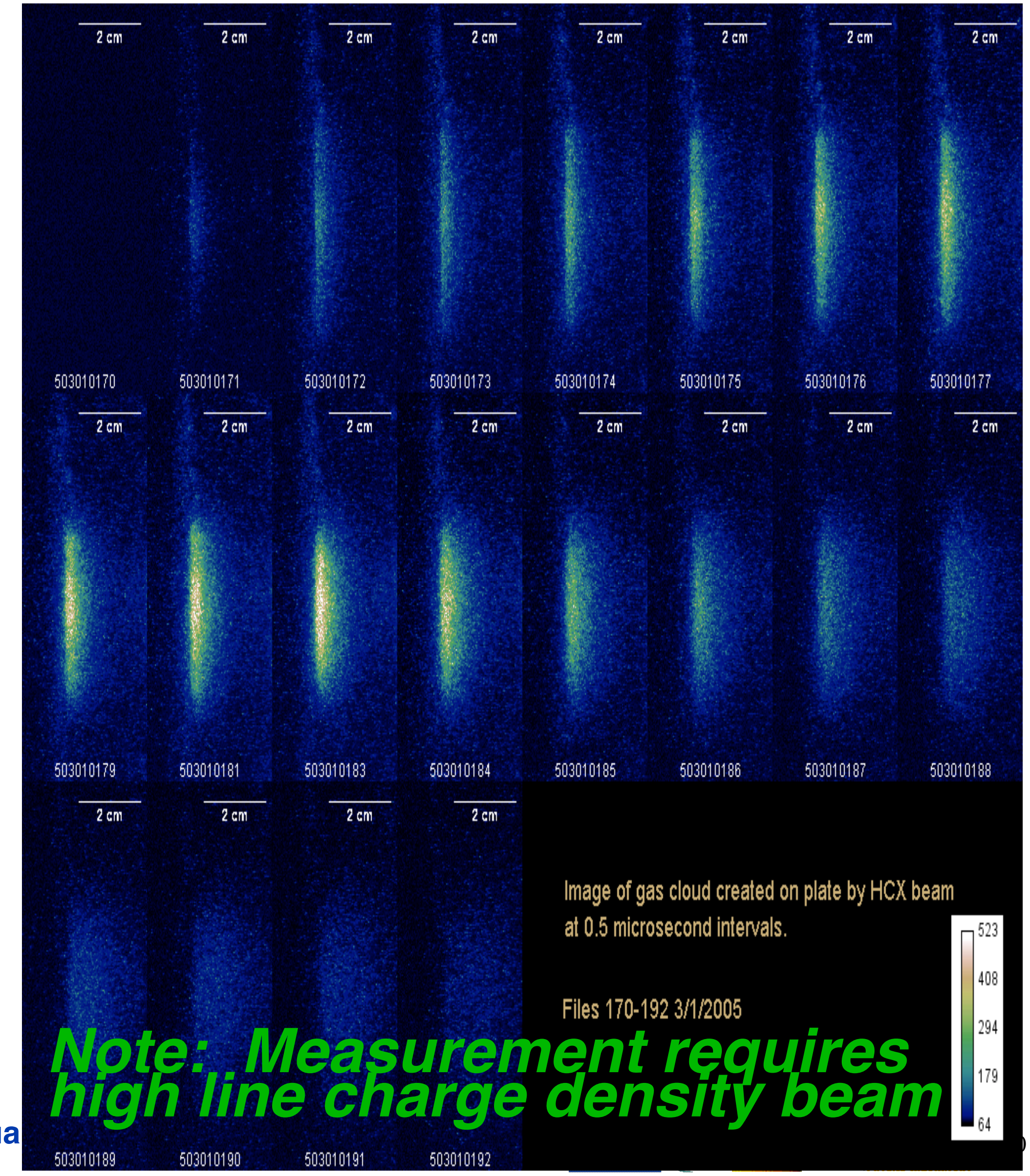
***Michel Kireeff Covo, PRSTAB 9, 063201 (2006).**

Intense beam excitation of gas – enabled measuring velocity distribution of desorbed gas

Observation: desorbed gas in beam emits light



View expanding gas cloud from side – $f(v_0)$ normal to hole plate [with gated camera or streak camera]

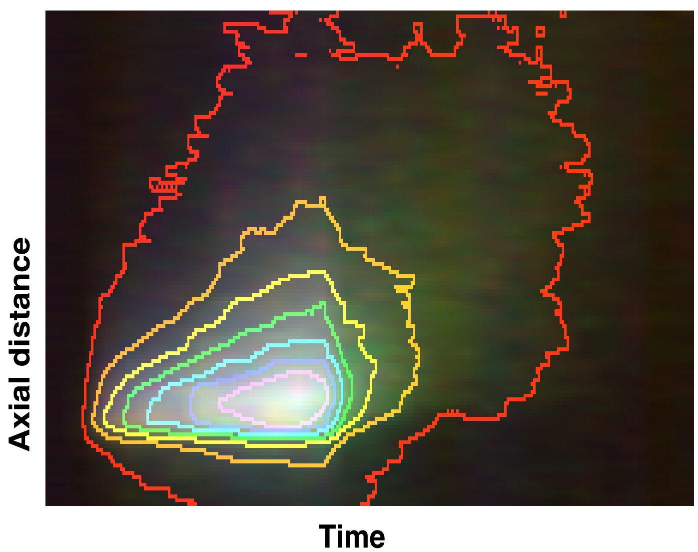


Note: Measurement requires high line charge density beam

Optical gas measurement has other applications

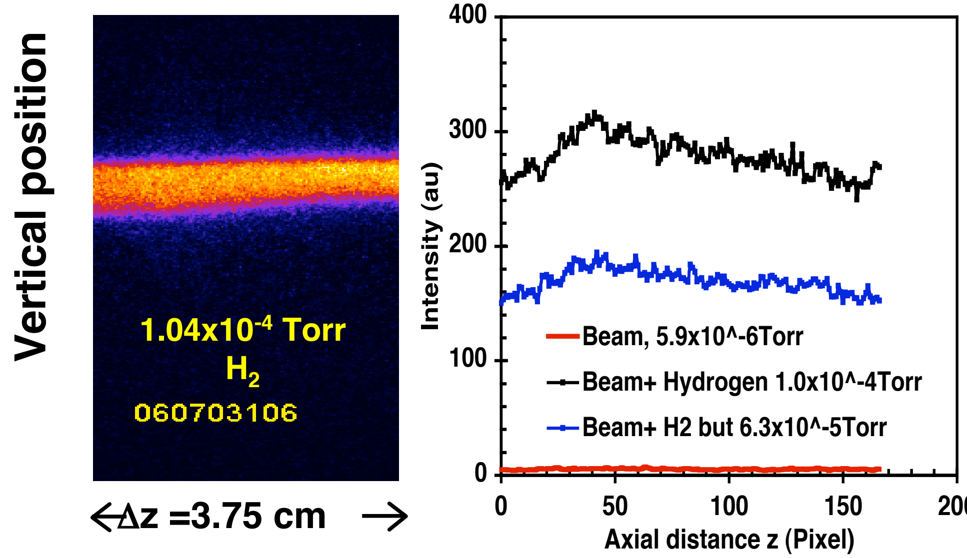
Velocity distribution of desorbed gas measured

[Further details from Frank Bieniosek]

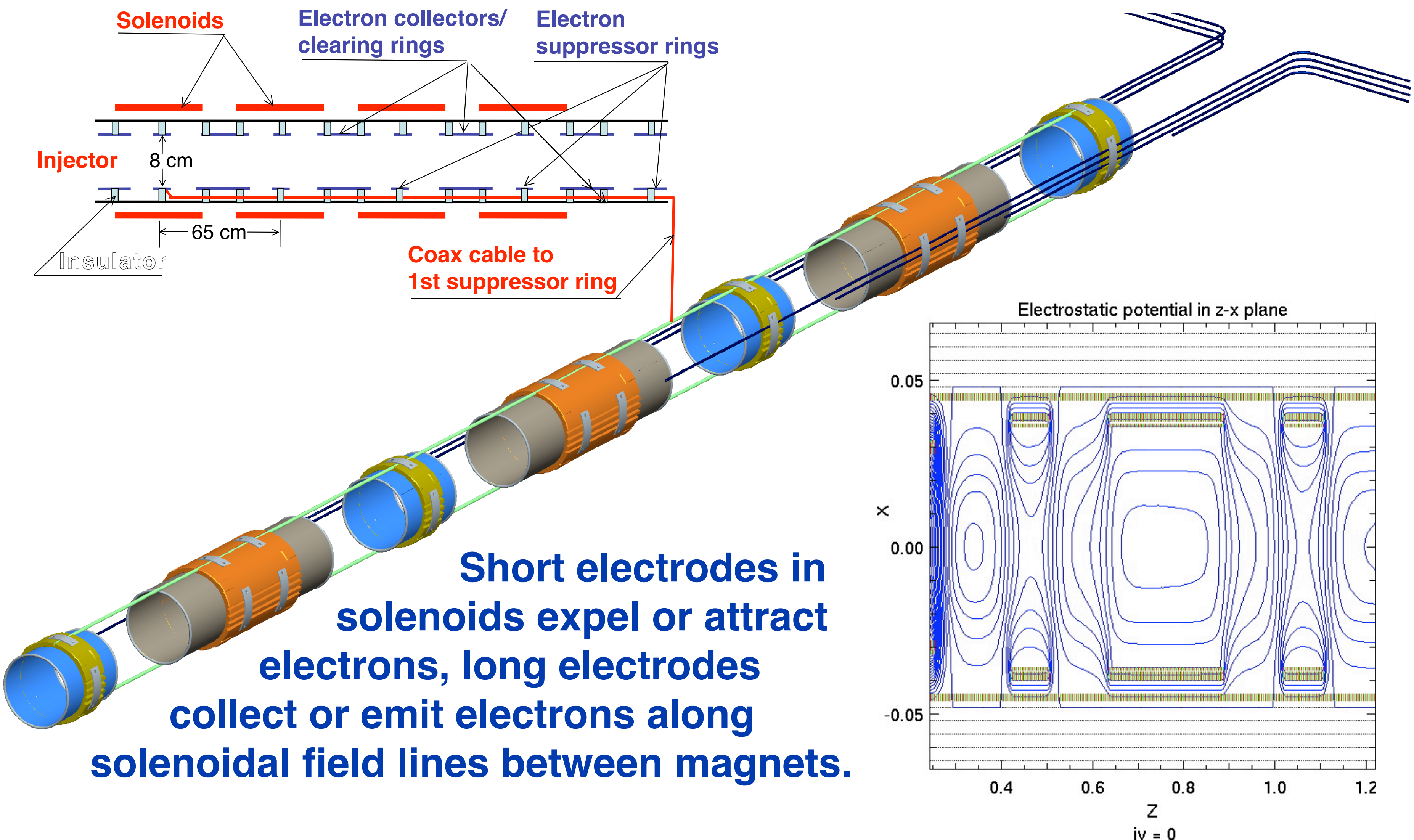


Future plans:

- **Absolute calibration to obtain desorption coef. by injecting beam through gas of known pressure**
- **Then can measure desorption from Non-evaporable Getter (NEG), …
[Collaborate with GSI vacuum group]**



Electron accumulation and effects on beam transport in solenoidal field – commissioning

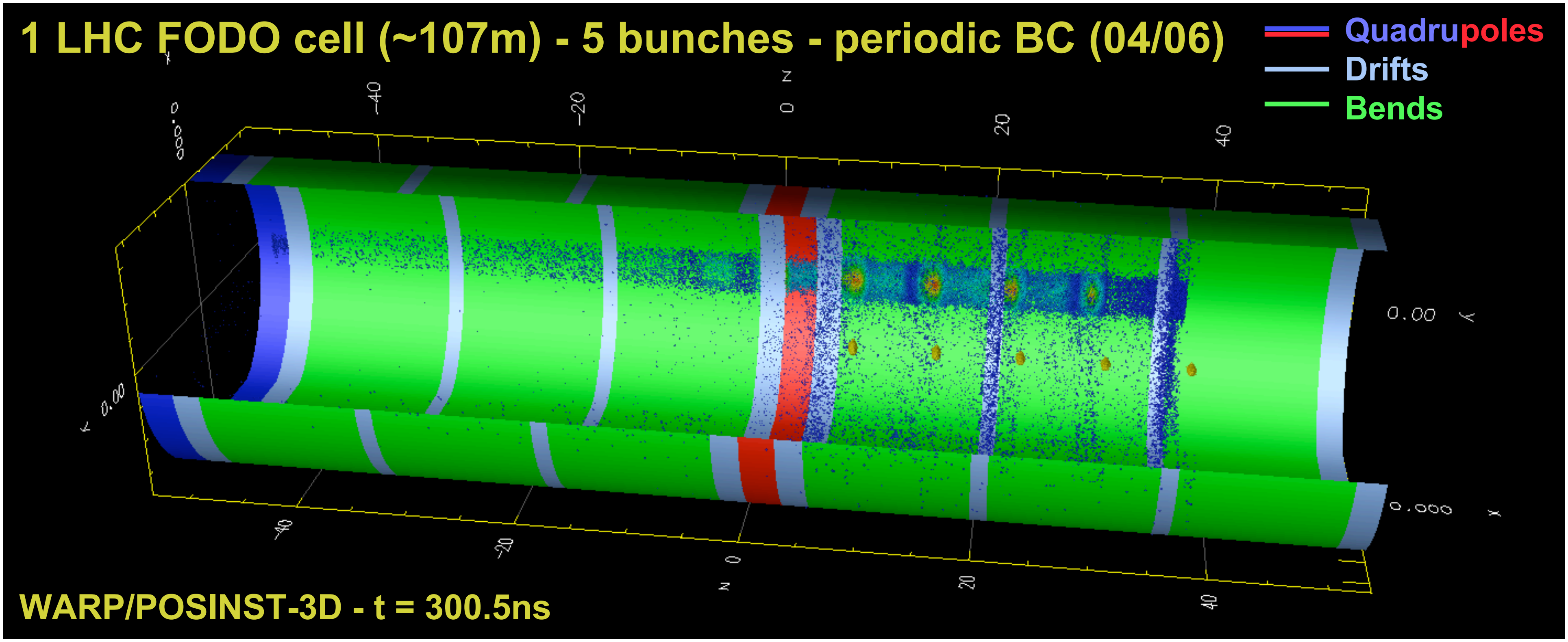


Short electrodes in solenoids expel or attract electrons, long electrodes collect or emit electrons along solenoidal field lines between magnets.

WARP/POSINST applied outside HIF program

In collaboration with CBP (M. Furman)

LARP funding (started FY06, 0.2 FTE): simulation of e-cloud in LHC



FNAL funding: study of e-cloud in MI upgrade (hiring post-doc)

ILC (with C. Celata, M. Venturini): start work this summer

CERN staff interested in our capabilities

Simulations show tenuous electron clouds (below instability threshold) increase emittance of LHC beam.

- Request from Frank Zimmermann and Elena Benedetto to compute initial electron distribution for her simulation starting point, using our self-consistent 3-D code WARP.
- Repeat simulation with WARP, when it can do many turns in LHC.
- Jean-Luc Vay invited to speak at CERN Oct. 6, 2006.

Above results may increase interest of CERN management

VNL has capabilities for High-Brightness Studies

Issues	HCX	NDCX	
		STX (Solenoid)	NDCX (quads)
Beam potential	2 kV	0.4 kV	0.4 kV
Beam transport	Quads	Solenoids	Quads
Duration (μs)	5	≤~20	≤~20
Access	Between quads and ends	End	End

Exploit other capabilities such as Paul Trap at PPPL or UMER at Univ. Maryland for testing some slowly-growing phenomena, to supplement our short accelerators.

Expectations for electrons in quadrupoles and solenoids

Transport	Axial flow	Radial flow
Quadrupoles	Electrons drift slowly	Electron flow along B is slightly impeded by magnetic gradient
Solenoids (⇑⇑)	Electrons flow freely over entire length	Electron flow suppressed
Solenoids (⇑⇓)	Electrons flow freely for 1-magnet length	Electron flow suppressed except between magnets

Not yet clear which is superior for WDM/HIF needs, motivates present STX-ECE experiments

Our present plan for future

WDM/HIFS

- Continue coordinated experiments and simulation of electrons and gas effects on HCX magnetic quads in search of complete quantitative agreement – publish areas of agreement and work on areas of disagreement
- Beginning solenoid studies, for near-term support of WDM
- Study mitigation techniques

HEP

- implement hybrid (3-D beam though 2-D e- slabs) “quasi-static” mode to study slow e-cloud driven emittance growth, which is a growing concern for LHC
- study e-cloud in ILC, FERMILAB, possibly RHIC
- develop experiments/diagnostics on HCX/NDCX relevant to HEP
- Collaborate with GSI to study beam-induced desorption from Non-Evaporable Getters (NEG).

Reconvene High-Brightness Planning Group

Goal: What do we need to know to initiate larger HIF facility ~2010 [After NIF ignition and ITER spending-peak]

Or – Learn enough to add validated effects into IBEAM systems code

& – Apply to near term WDM accelerators

Issues:

- **E-cloud, gas-cloud (quads vs sols, transport, conditions to assure non-degraded operation)**
- **Halo**
- **Beam transport limits**
- **Emittance growth**
- **Mitigation …**

Strategy:

- **Benchmark codes over wide parameter range for verified predictive capability**
- **Verify codes with HCX, NDCX, STX, PTSX, UMER… (The Paul Trap Simulation Experiment and U-Maryland Electron Ring can test effects that occur over 100's of lattice periods).**
- **Use lists of issues from previous workshops**

External recognition of High Brightness program

Significant publications:

- PRL – Measure electron cloud density
- PRSTAB – Measure & model e- emission by ion impact
- POP – e- mover successes

Recognition with invited papers

PAC05	2
HB2006	2
HIF06	3
CAARI-06	1
ICAP06	1
DPP05/06	1/1
AVS06	1

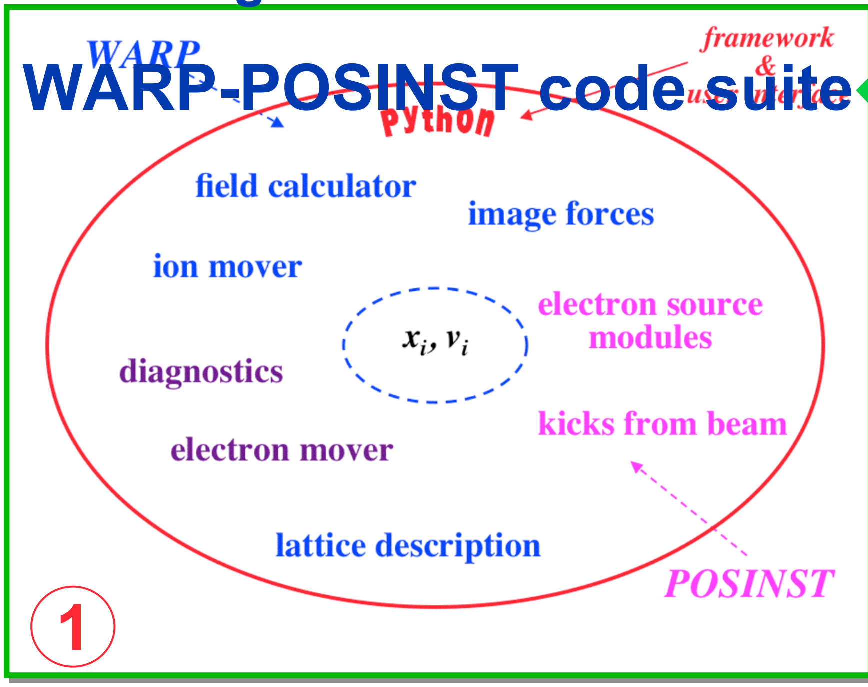
Invitations from CERN, FNAL for talks and assistance

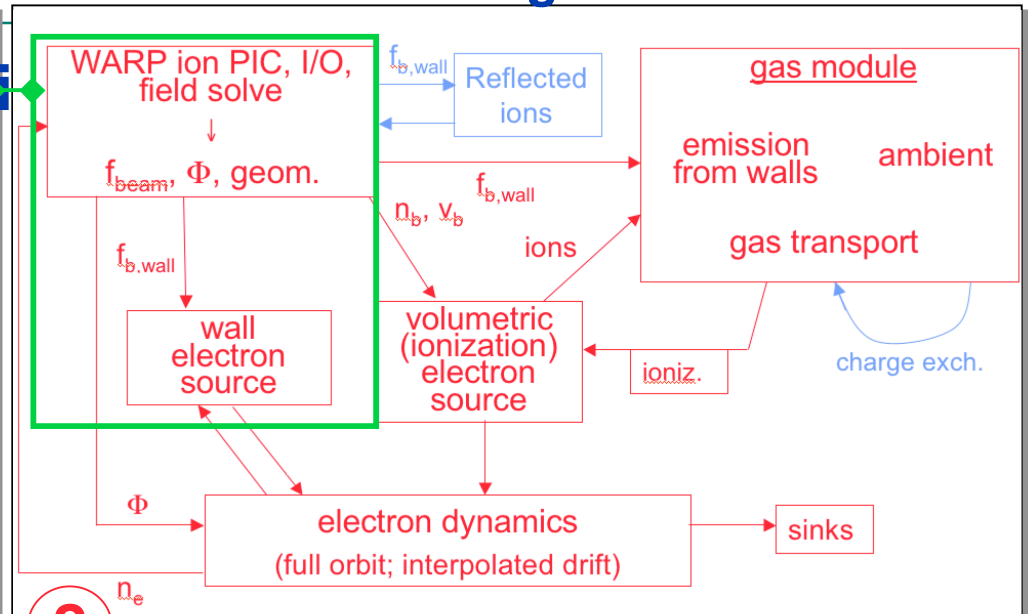
BACKUP

Slides

WARP-POSINST code suite

merge of WARP & POSINST + new e-/gas modules

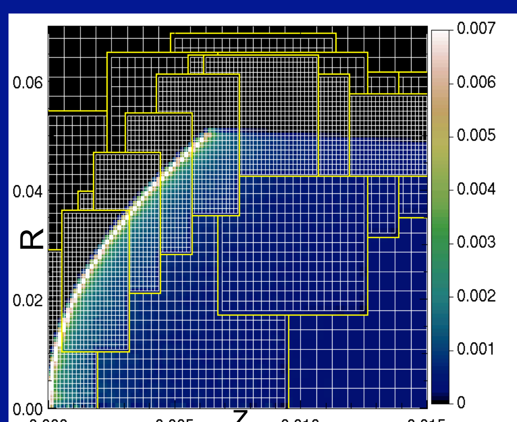




Key: operational; partially implemented (4/28/06)

+ Adaptive Mesh Refinement

concentrates resolution only where it is needed

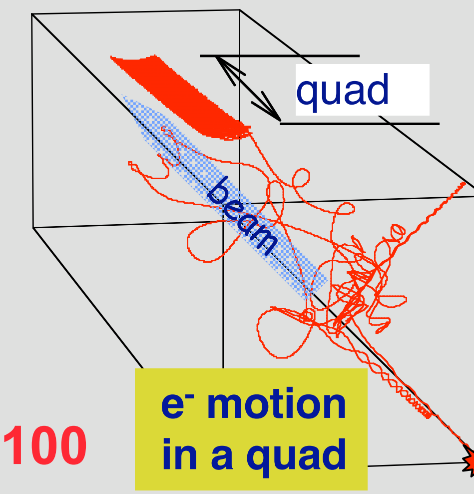


Speed-up

3 **x10-10^4**

+ New e- mover

Allows large time step greater than cyclotron period with smooth transition from magnetized to non-magnetized regions



4 **Speed-up x10-100**