Absolute Measurement of Electron Cloud Density

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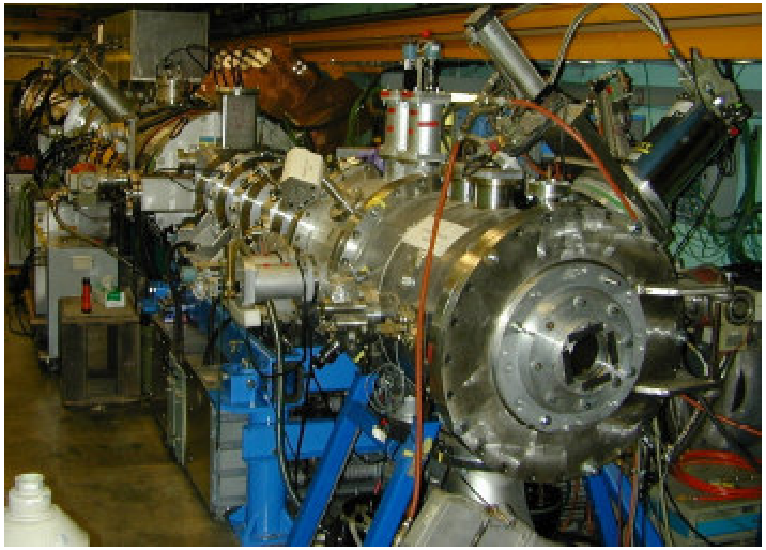
LLNL and UCB



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HIFS e-cloud effort

HIFS-VNL

Experiment	Simulation
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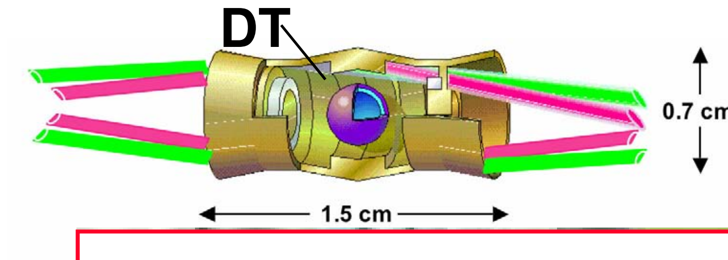
Outline

1. E-cloud issues and tools
2. Retarding Field Analyzer
   a. Electron mode
   b. Ion mode
3. E-cloud density measurement
4. Conclusions

Heavy Ion Inertial Fusion or "HIF" goal is to develop an accelerator that can deliver beams to ignite an inertial fusion target

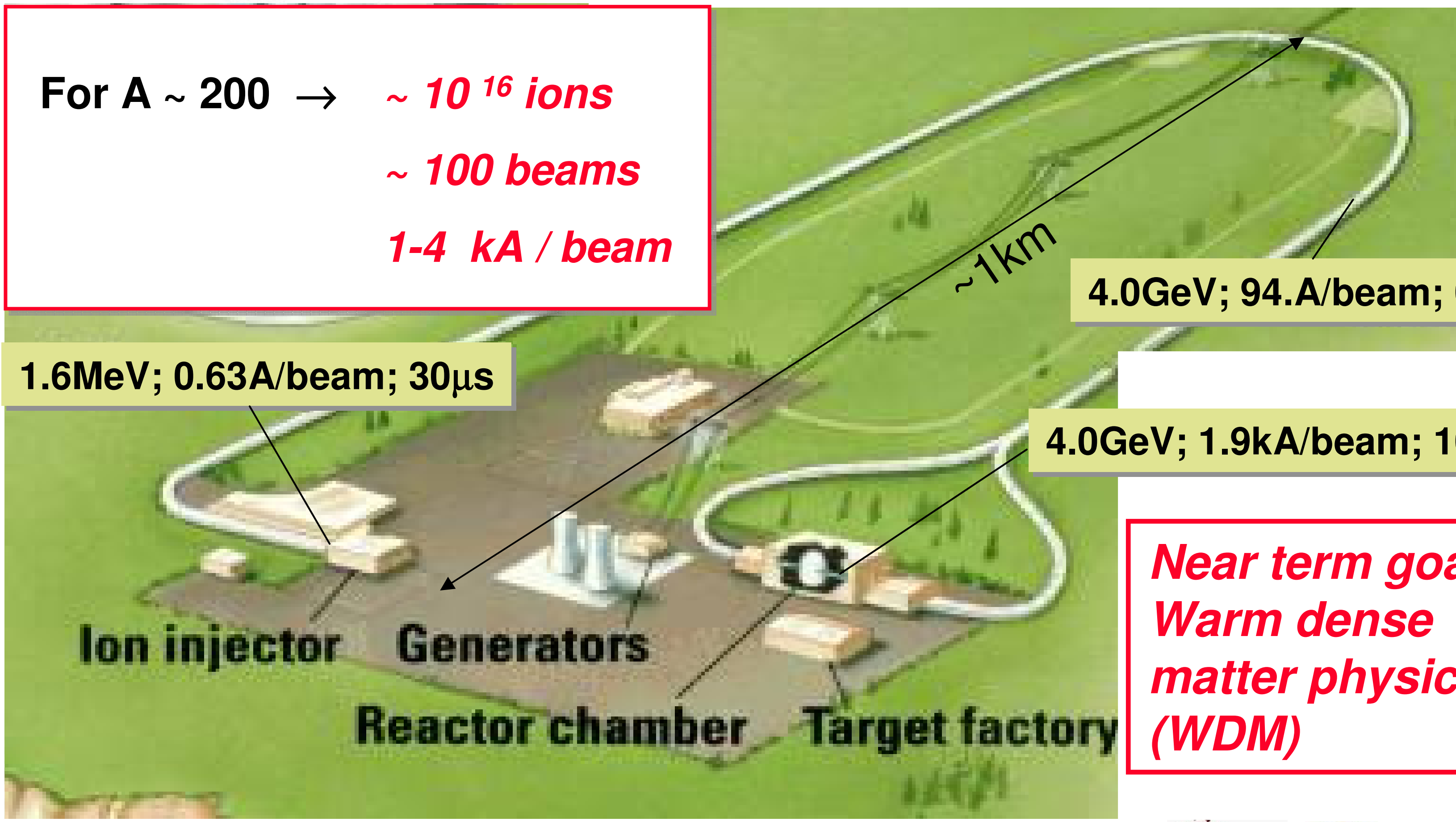


Target Requirements:

3 - 7 MJ x ~ 10 ns ⇒ *~ 500 Terawatts*

Ion range: 0.02 - 0.2 g/cm^2 ⇒ *1- 10 GeV*

Ion charge: 7 MJ/few GeV ⇒ *few mCoul*



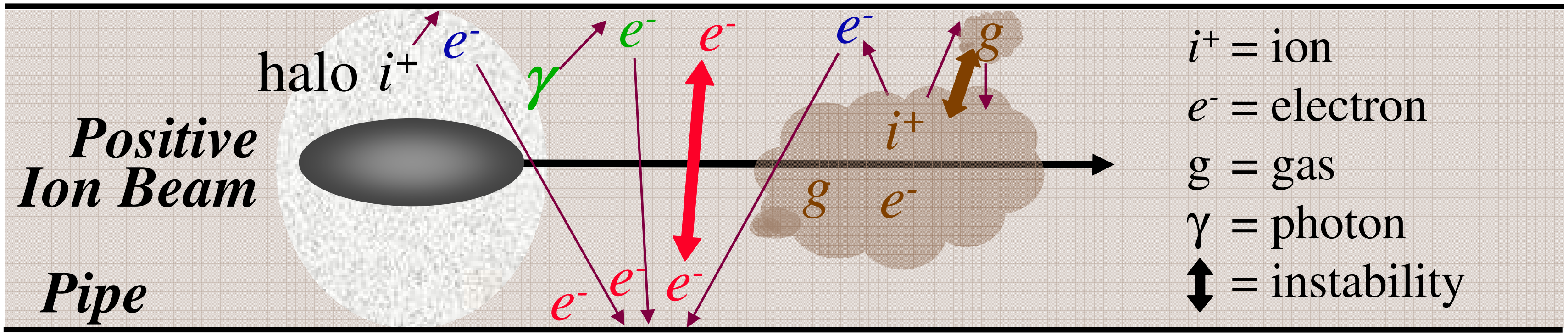
For A ~ 200 → *~ 10 [16] ions*

~ 100 beams

1-4 kA / beam

Near term goal: Warm dense matter physics (WDM)

Sources of electron and gas clouds



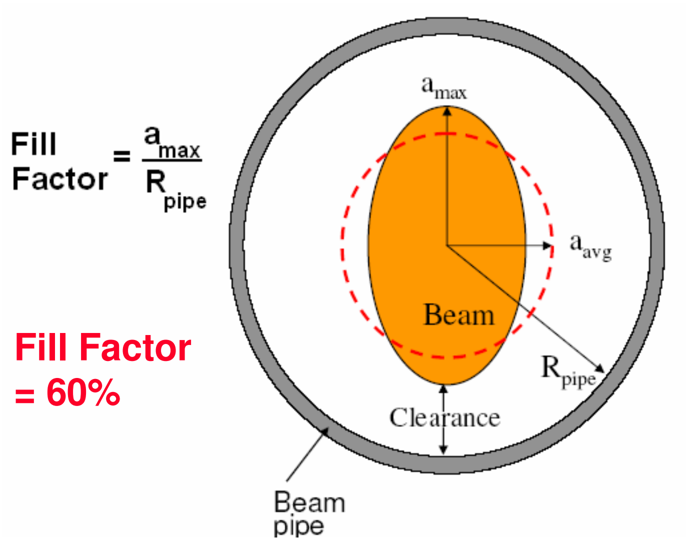
Primary:

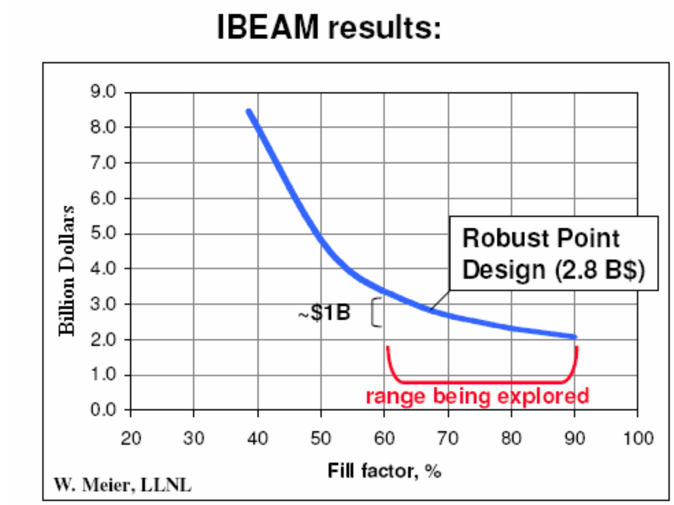
- Ionization of
  - background gas
  - desorbed gas
- ion induced emission from
  - expelled ions hitting vacuum wall
  - beam halo scraping
- photo-emission from synchrotron radiation (HEP)

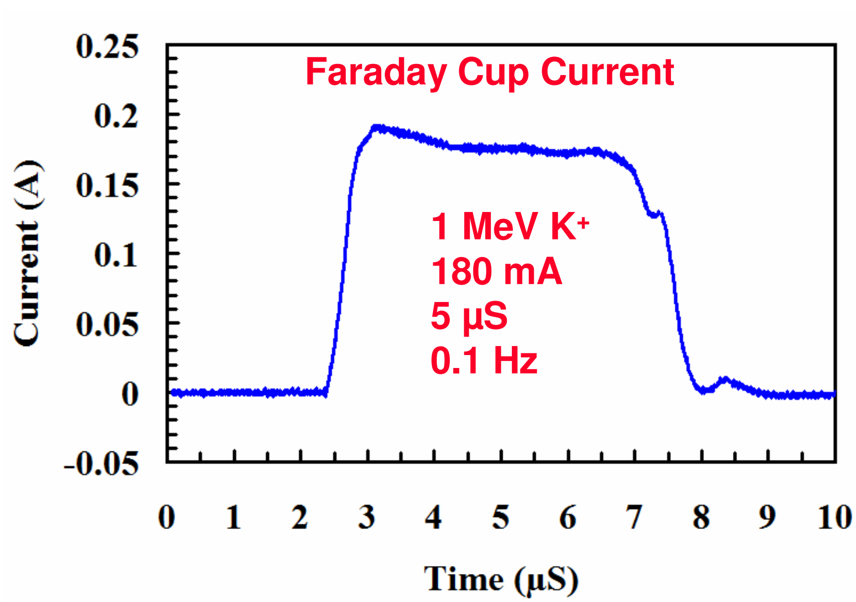
Secondary:

- secondary emission from electron-wall collisions

HCX beam features







Characteristics:

- **Do not have synchrotron radiation and electron multipacting, but**
- **Have large beam interaction with background gas and walls**

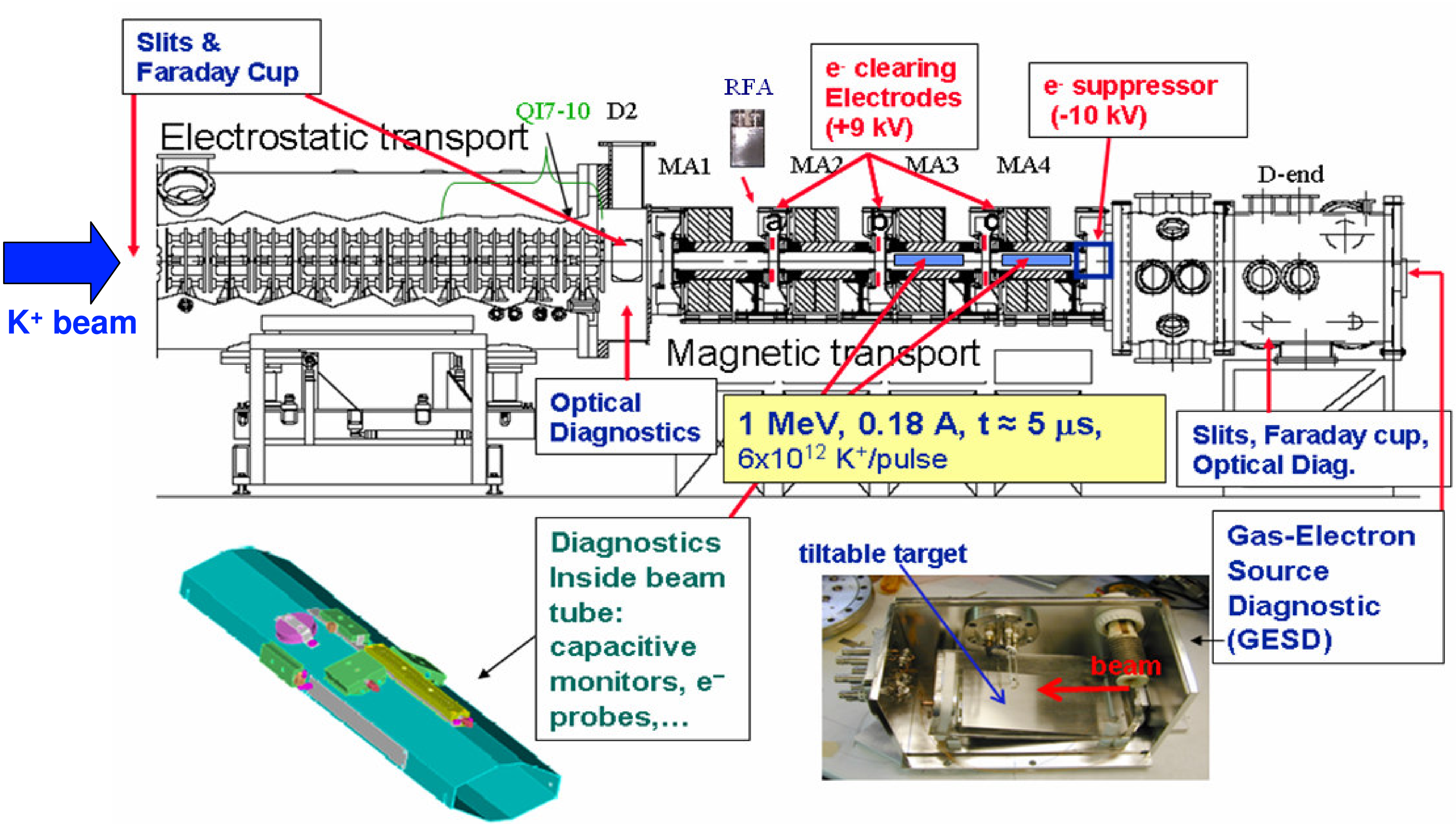
Electron Clouds are an issue

Electron clouds are an issue in major HEP accelerators and potentially in WDM and HIF accelerators

- **Electron Cloud Effects (ECE) were observed in the:**
  - **Proton Storage Rings at BINP,**
  - **Intersecting Storage Rings at CERN,**
  - **Proton Storage Ring at LANL,**
  - **Relativistic Heavy Ion Collider at BNL,**
  - **Positron Ring at KEKB, etc.**
- **ECE can potentially limit the performance of the:**
  - **International Linear Collider,**
  - **Large Hadron Collider (LHC) at CERN,**
  - **Proton Recycler Ring at FNAL (after 2009),**
  - **WDM and HIF accelerators.**

Understanding and mitigation of electron clouds will increase the performance of present and future accelerators

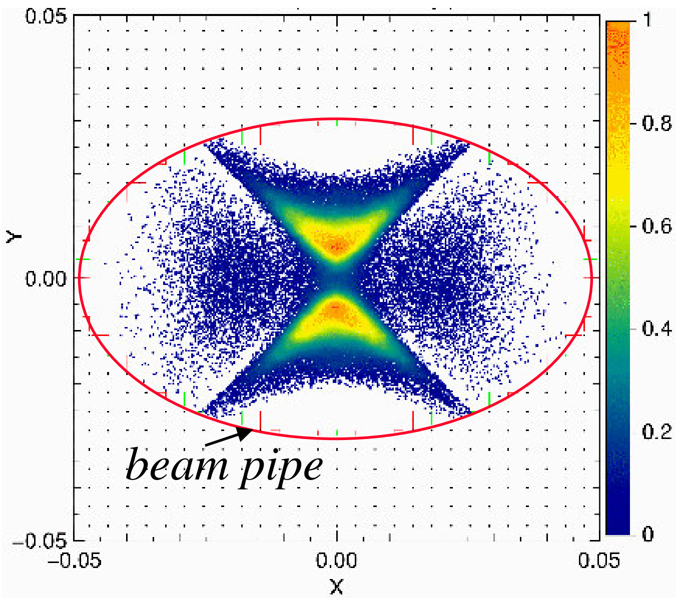
HCX dedicated to studies of gas and electron effects



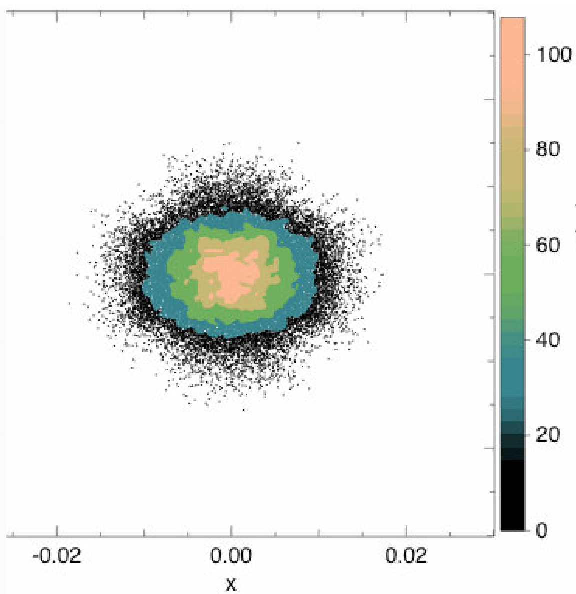
Transverse electron density distributions inside the magnetic quadrupoles of HCX (simulated using WARP)*

E-cloud in a Quadrupole

Electrons ejected from end wall

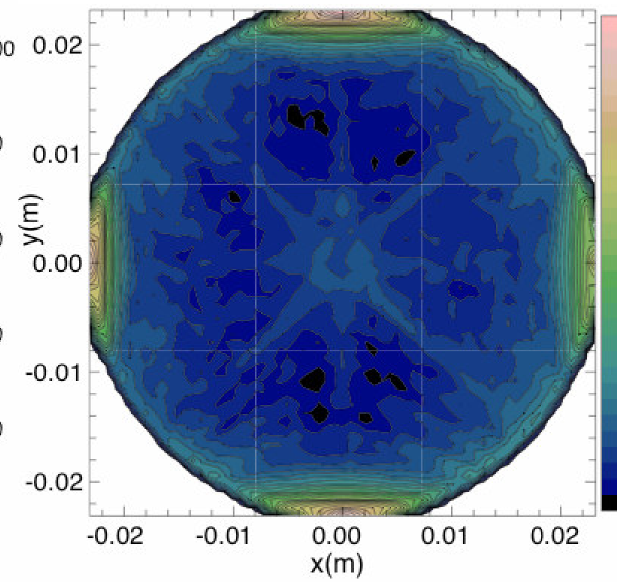


Electrons from ionization of gas



Deeply trapped electrons

Electrons desorbed from beam pipe in quad upon ion impact



Weakly trapped electrons

*** R. H. Cohen et al., PRSTAB 7, 124201 (2004).**

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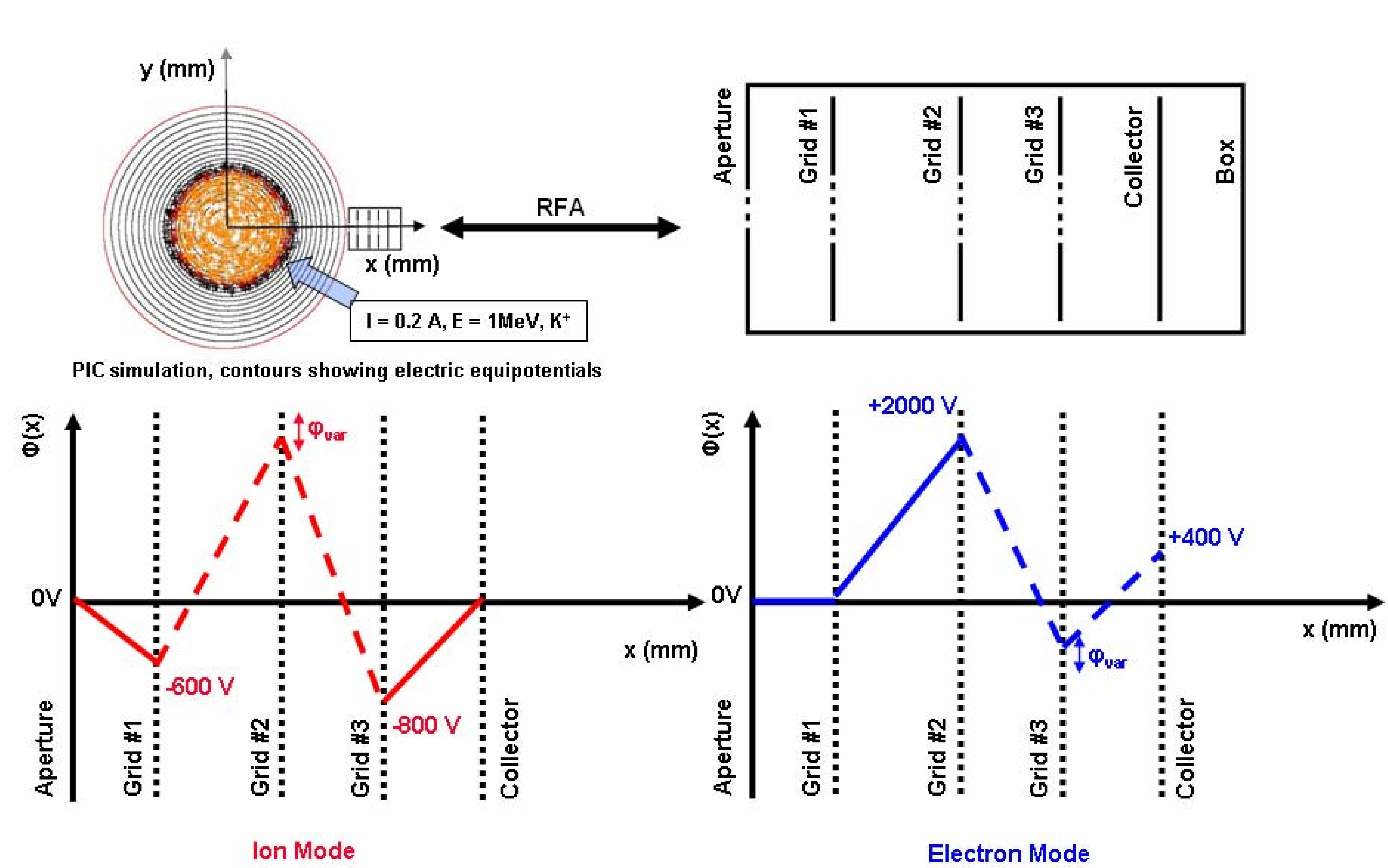
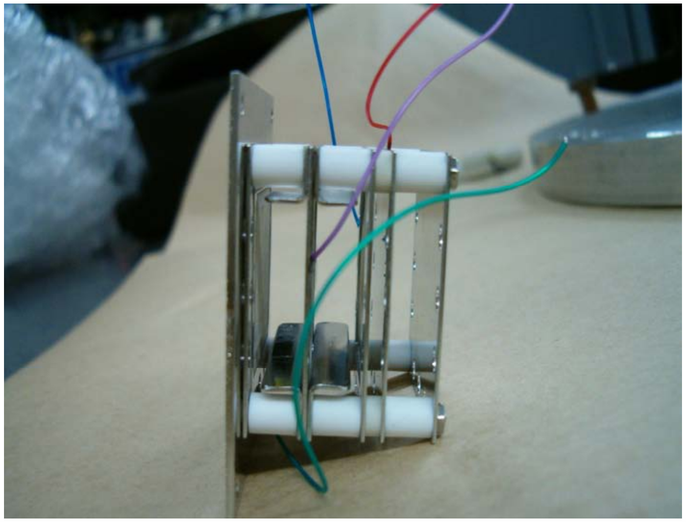
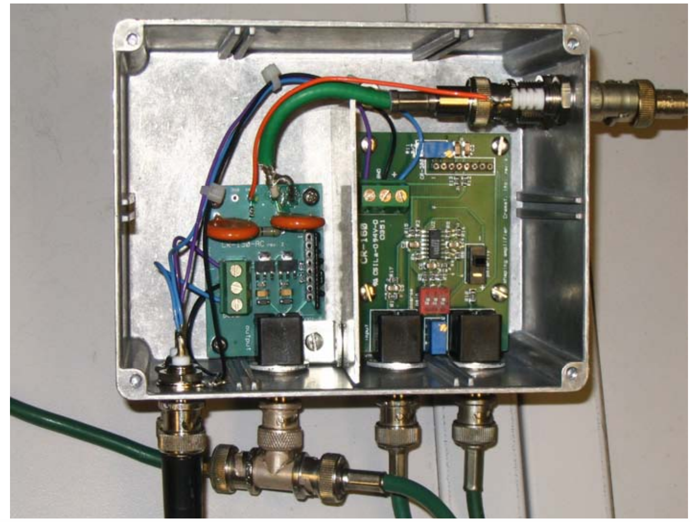
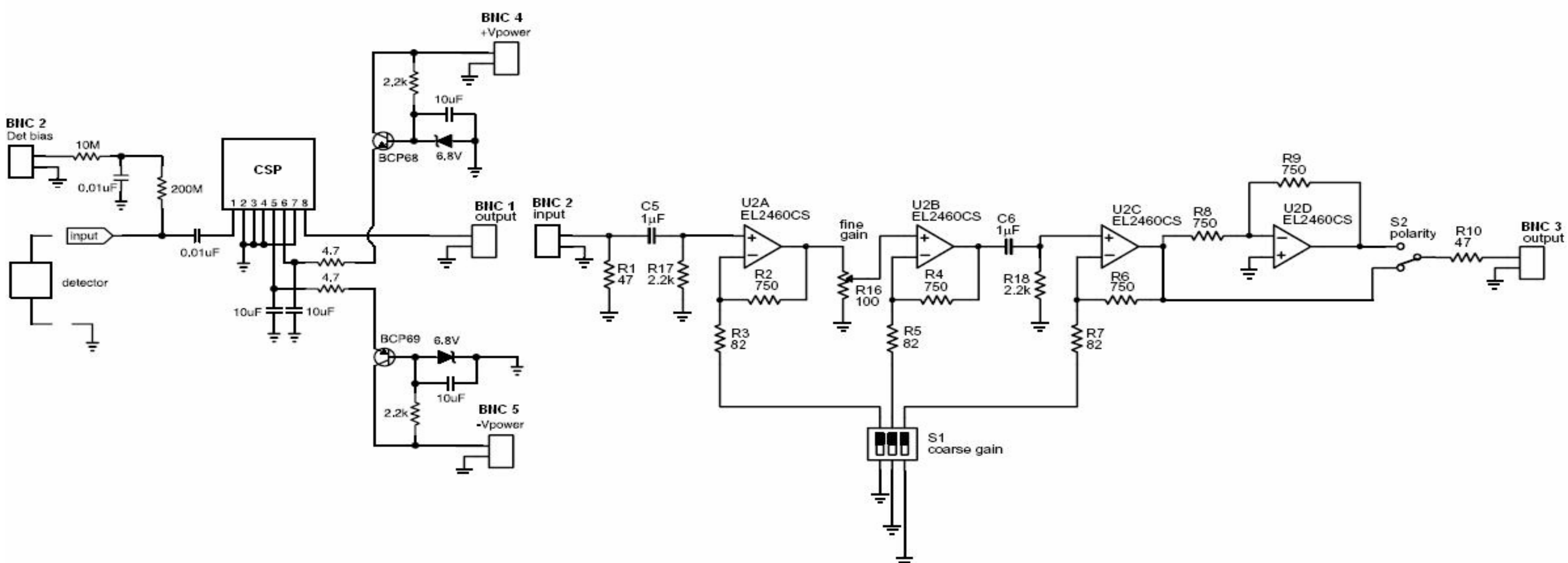
Retarding Field Analyzer (RFA) design



RFA assembly and electronics







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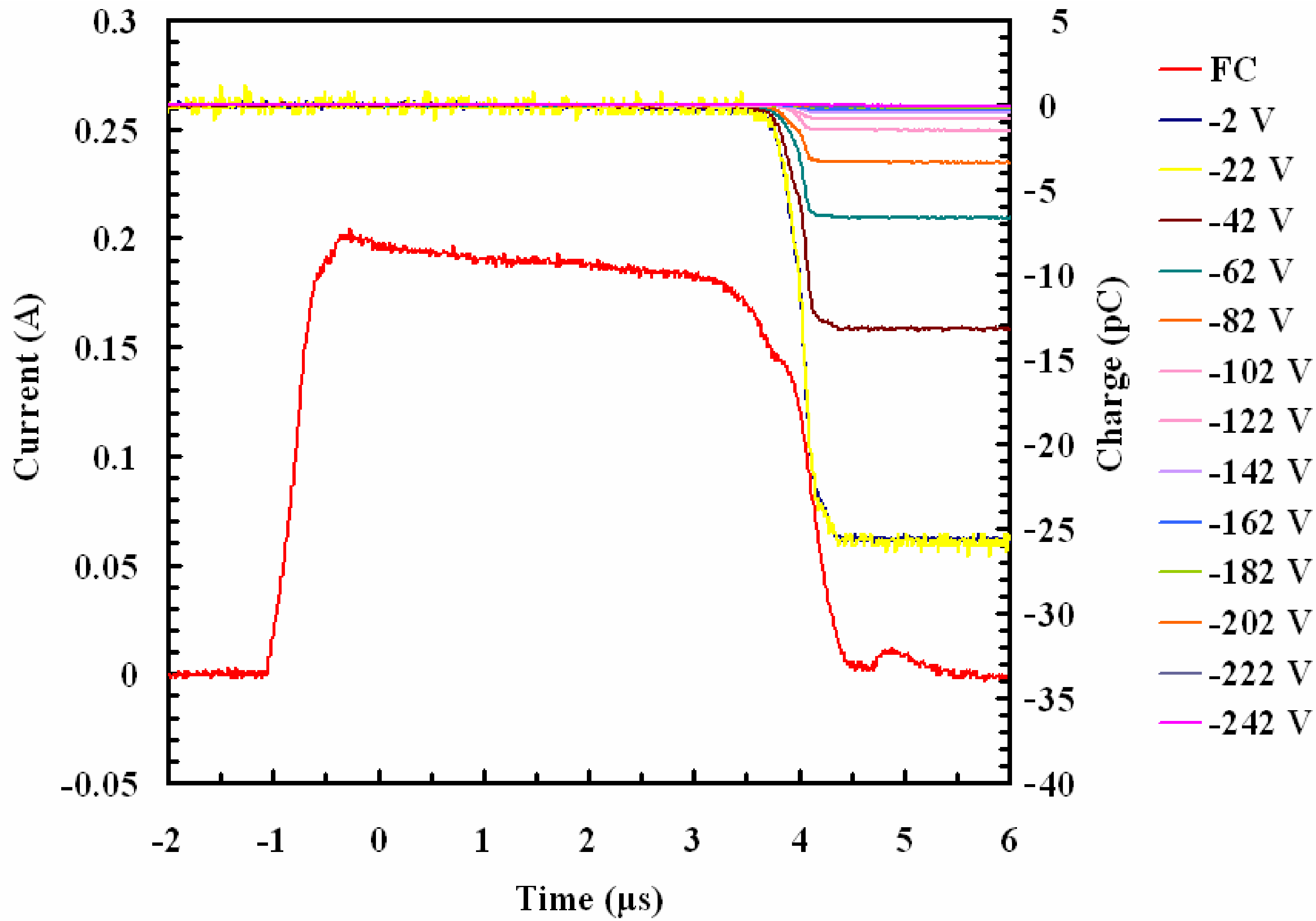
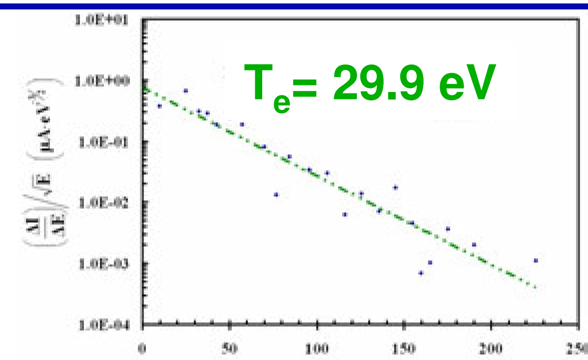
Expelled electrons charge at the end of the beam



Ion-induced electron energy distribution is Maxwellian

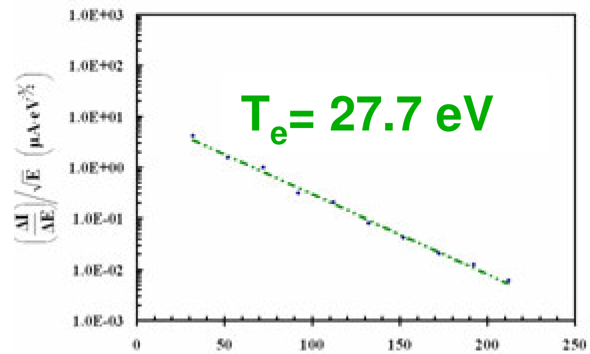
- **Method 1: Gas electron source diagnostic**

The grid surrounding the target was used to filter ion-induced electron energy from K^+ ion impact on the stainless steel target



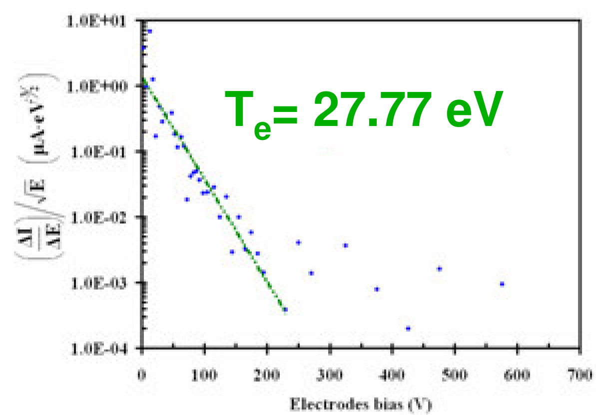
- **Method 2: RFA diagnostic**

The retarding grid of a RFA was used to measure the energy distribution of electrons produced and/or expelled at the end of the beam



- **Method 3: Clearing Electrode diagnostic**

An external C-shaped clearing electrode positively biased was used to suppress electrons from entering a RFA, working as an energy filter



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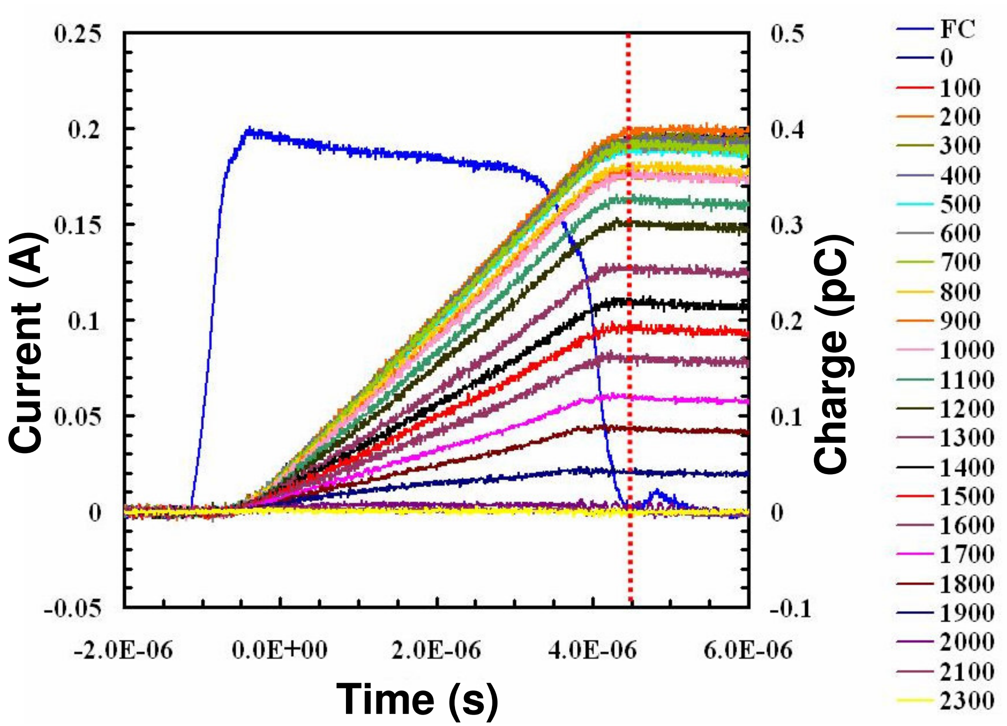
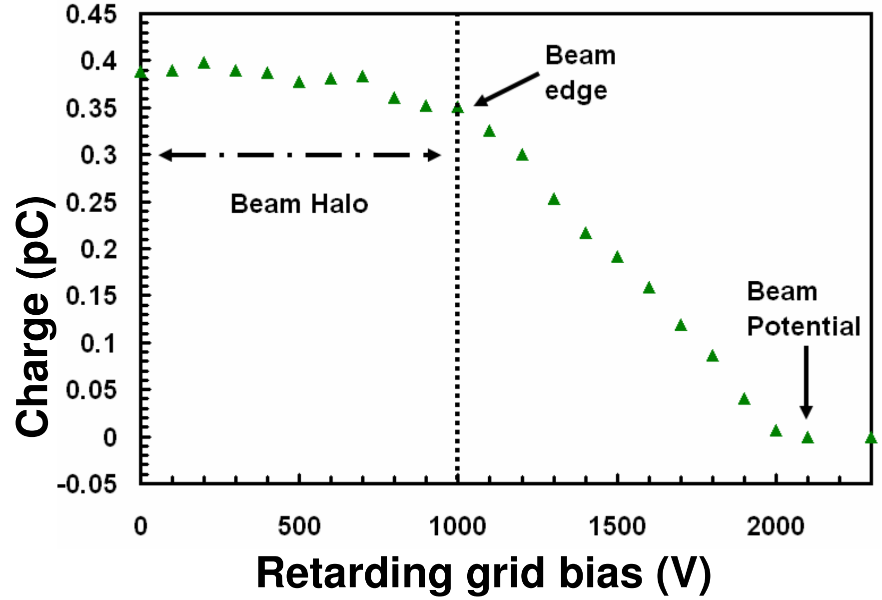
RFA measures energy distribution of expelled ions*

- **Potential of beam edge is ~1000 V, and beam axis is ~ 2100 V**

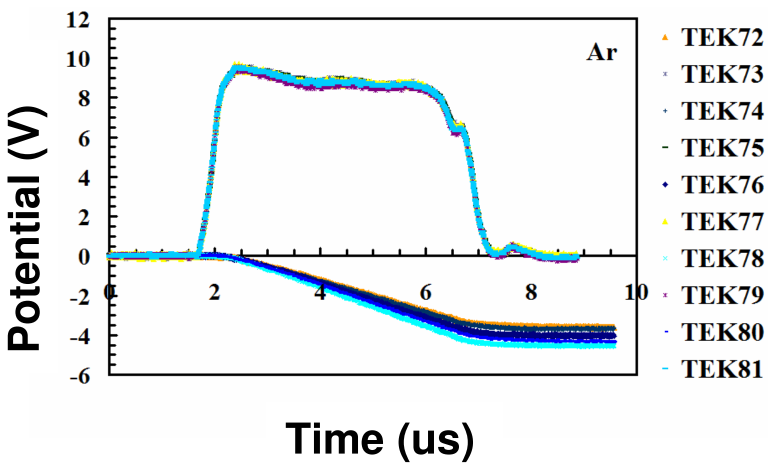


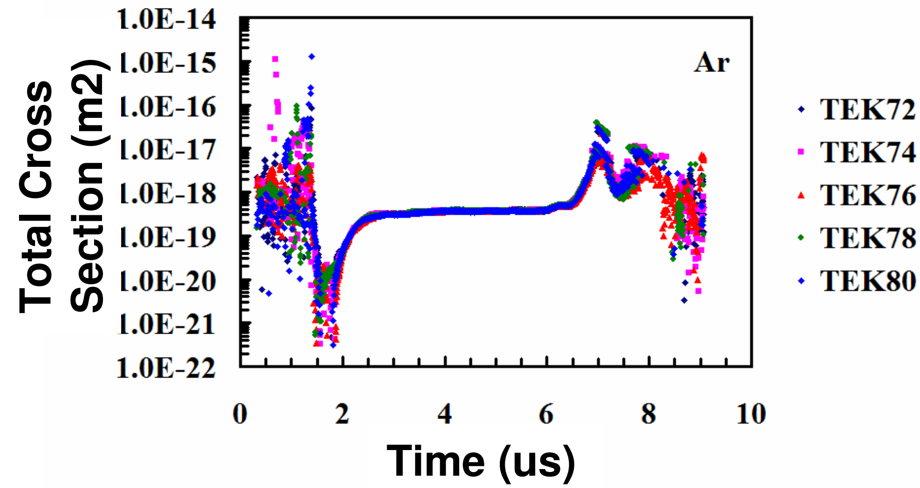


*M. Kireeff Covo et al., Nucl. Instr. and Meth. A 577 (2007) 139.

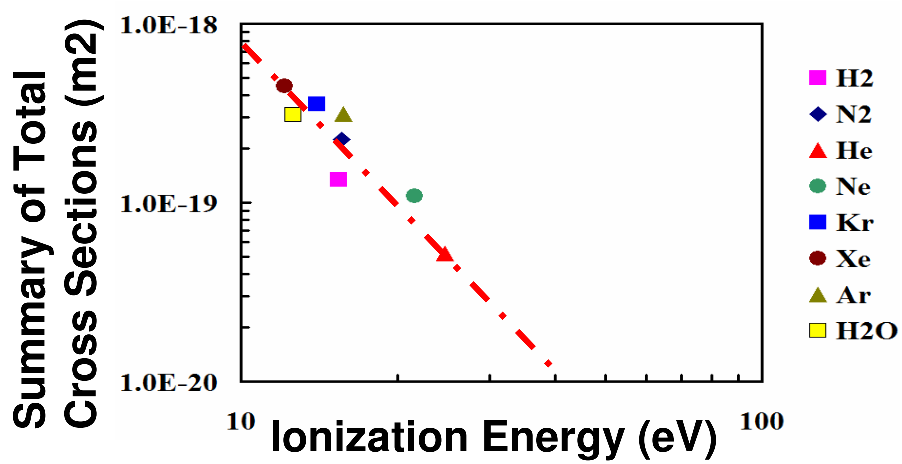
RFA measures total cross sections (ionization + charge exchange)

$$I_{G^+} = I_{K^+} \times {}^{P}\!/_{kT} \times \sigma_{Total} \times l \times \varphi$$





Gas	Total Cross Section (m^2)
H2	1.35E-19
N2	2.26E-19
He	5.17E-20
Ne	1.09E-19
Kr	3.54E-19
Xe	4.49E-19
Ar	2.79E-19
H2O	3.11E-19



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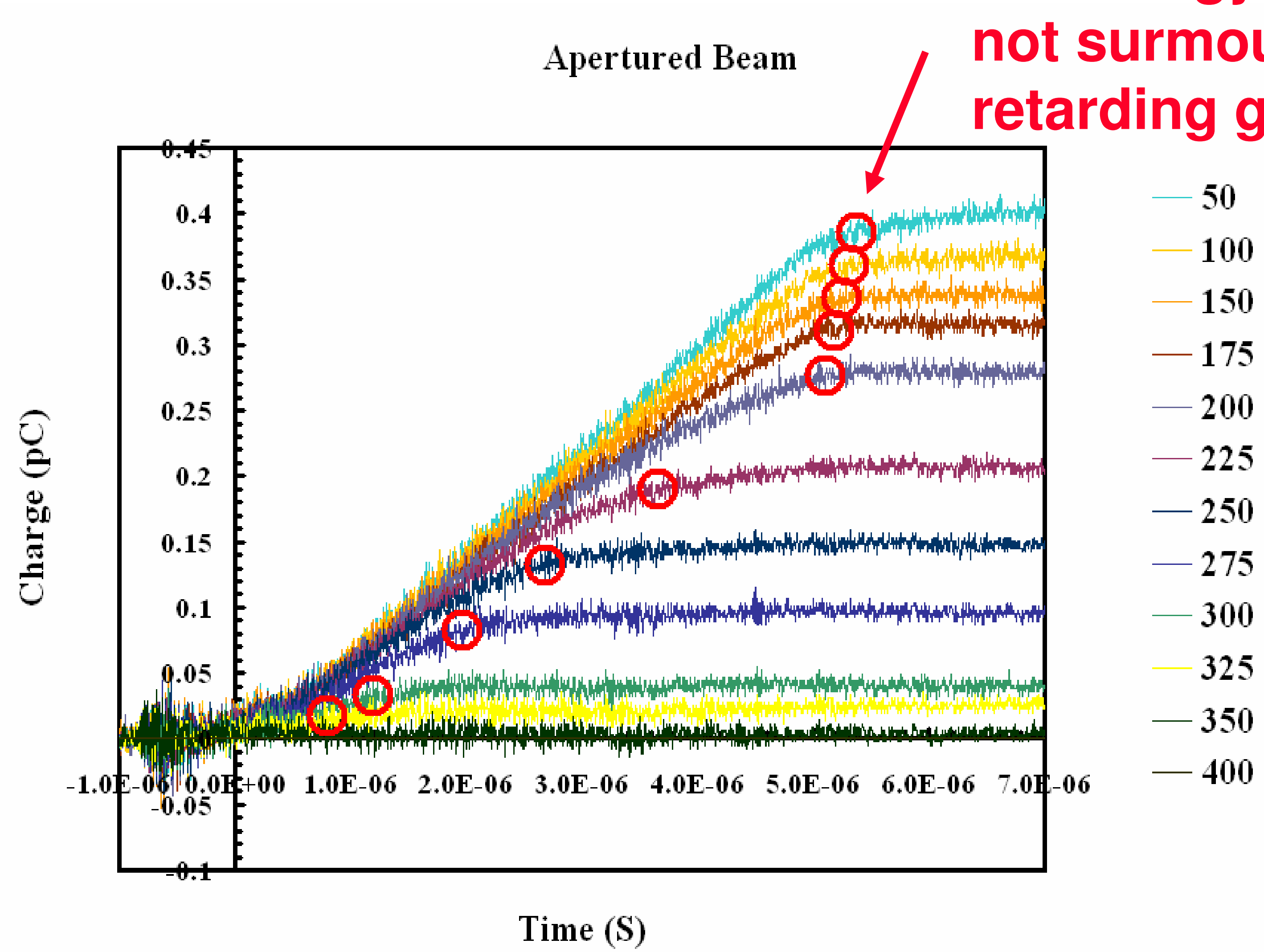
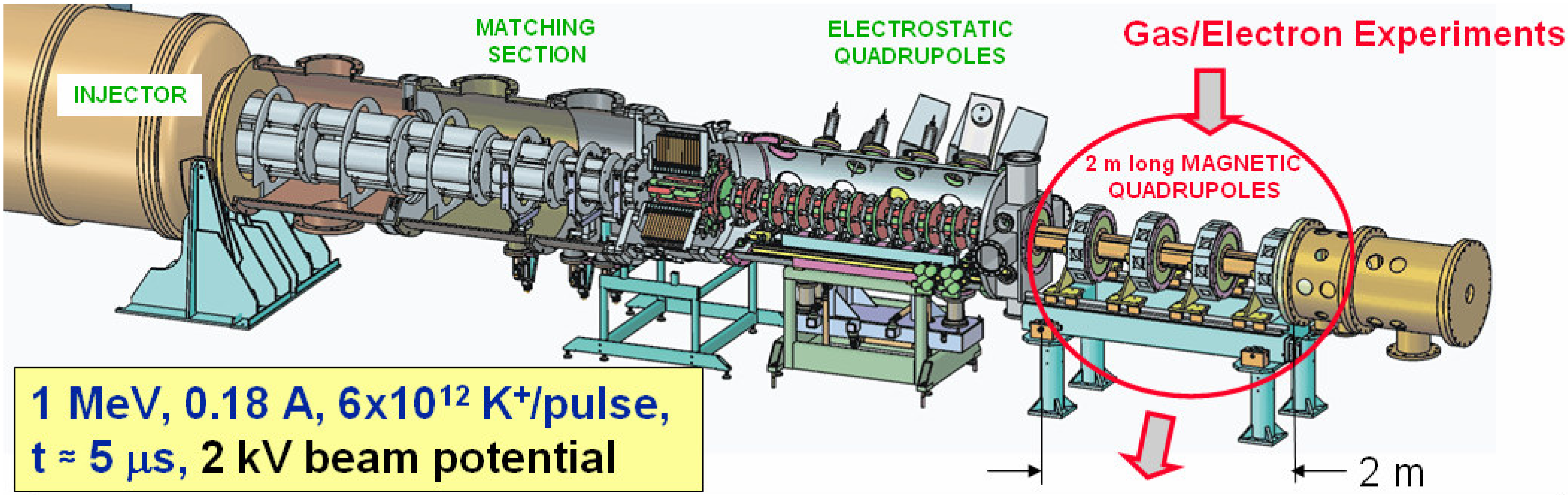
Illustrative “beam potential versus time” raw data

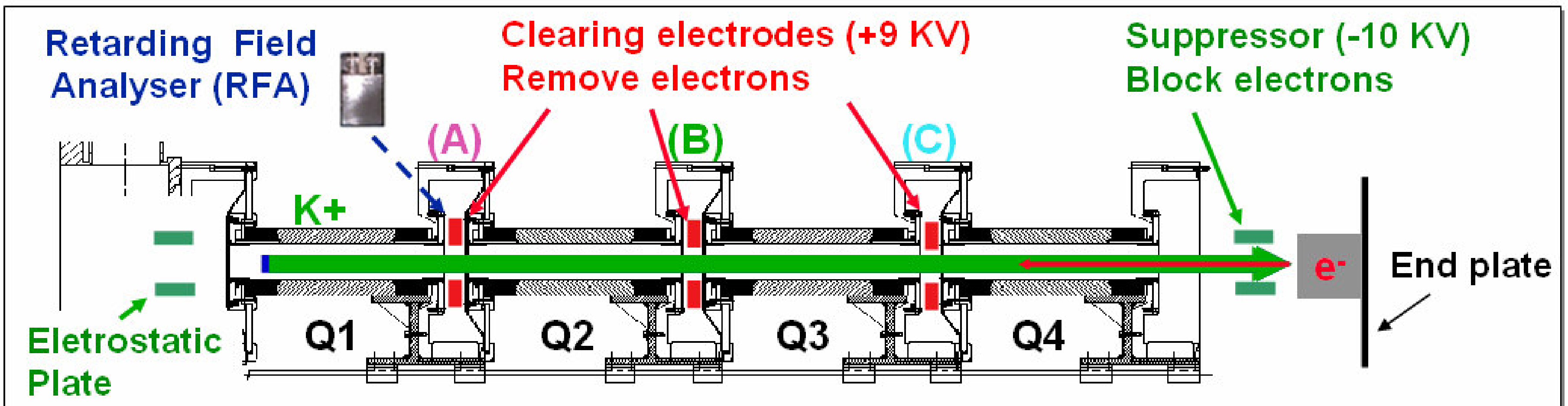
Ion energy does not surmount the retarding grid bias



The High Current Experiment (HCX) is a small, flexible heavy-ion accelerator (at LBNL)

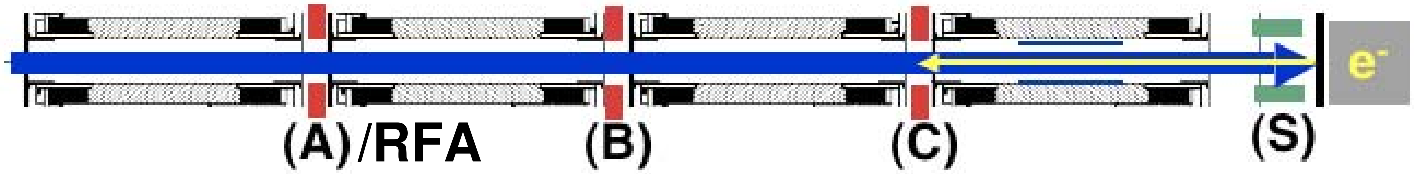


1 MeV, 0.18 A, 6x10^{12} K^{+}/pulse,
t ≈ 5 μs, 2 kV beam potential

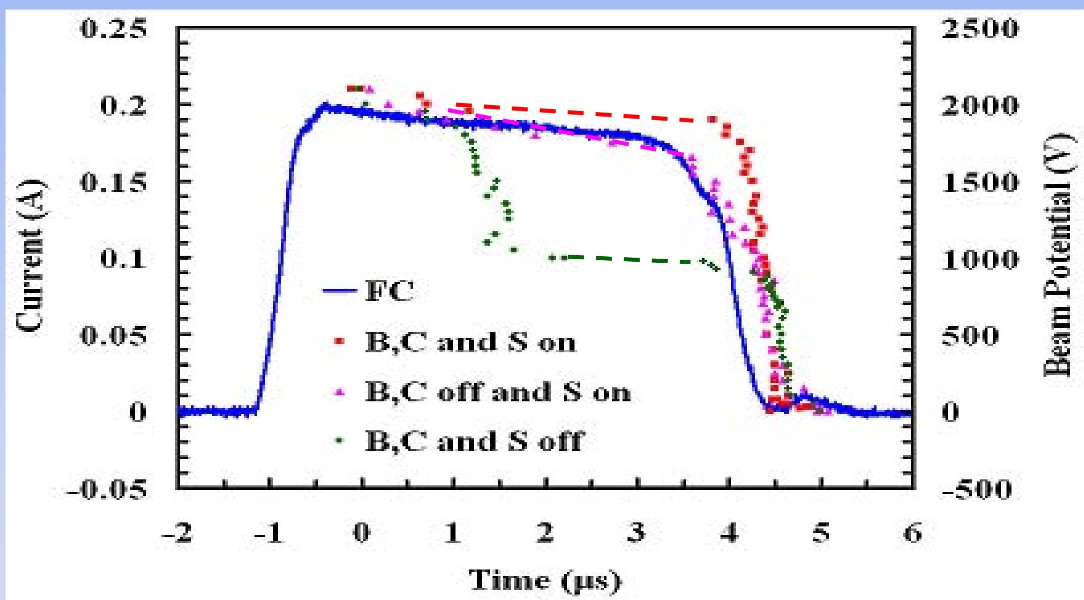


Quadrupole magnets Q1 - Q4 for beam transport

A first time-dependent measurement of absolute electron cloud density* (I)



Retarding field analyzer (RFA) measures beam potential on axis



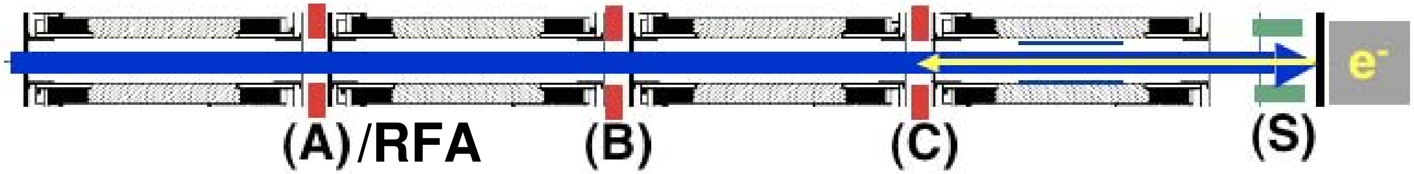
P_b = initial beam potential

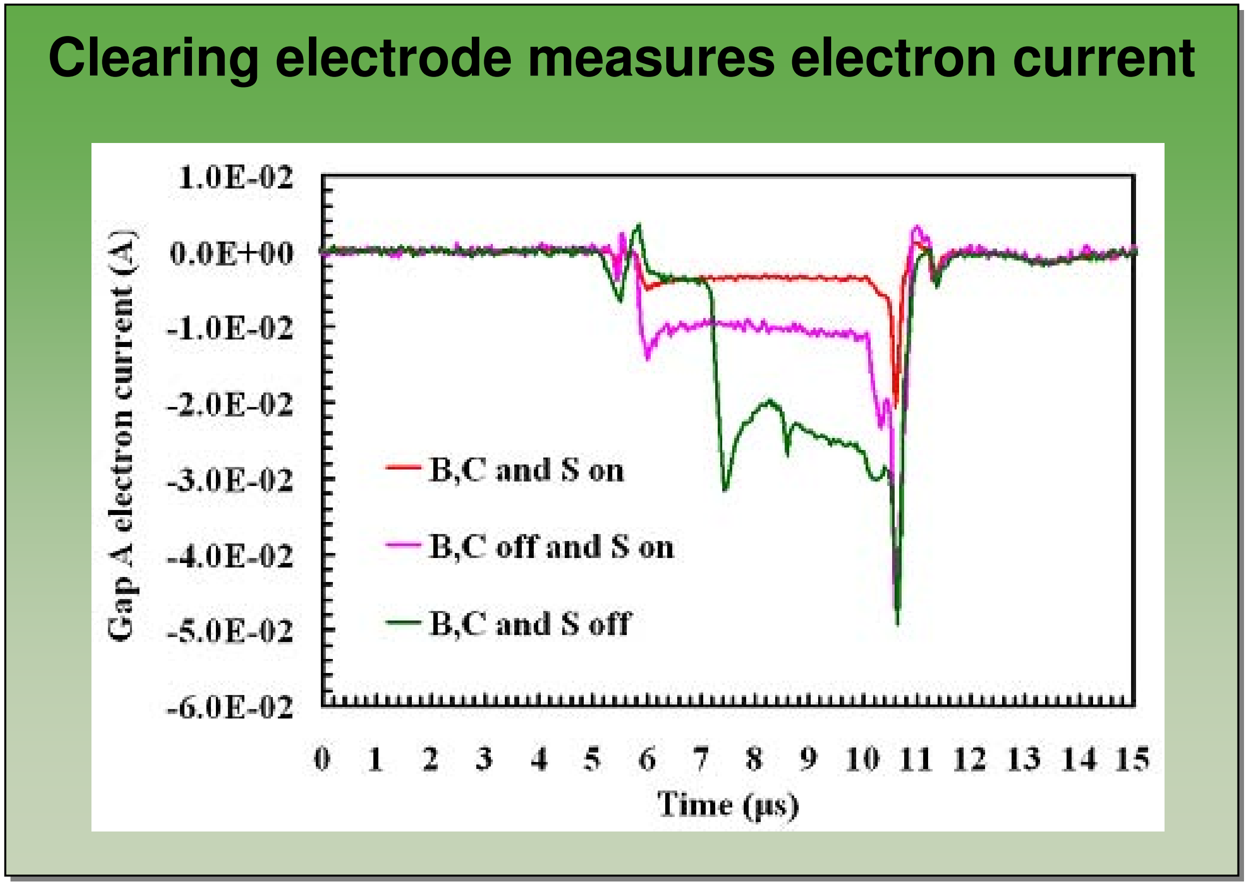
$P_e = P_b$ – depressed beam potential

Neutralization = $\frac{P_e}{P_b} * 1.64$ + initial neutralization

*M. Kireeff Covo et al., Phys. Rev. Lett. 97, 054801 (2006).

A first time-dependent measurement of absolute electron cloud density* (II)





$$\lambda_e = \frac{I_e}{V_d}$$

$$\text{Neutralization} = \frac{\lambda_e}{\lambda_b}$$

where:

I_e – electron current

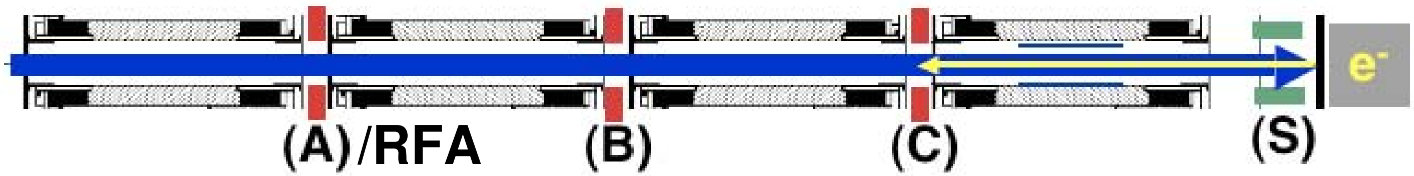
V_d – electron drift velocity

λ_e – electron line charge density

λ_b – beam line charge density

*M. Kireeff Covo et al., Phys. Rev. Lett. 97, 054801 (2006).

A first time-dependent measurement of absolute electron cloud density* (III)



Comparison of the Beam Neutralization inferred from RFA and clearing electrodes

Beam neutralization	B, C, S on	B, C off S on	B, C, S off
Clear. Electrode A	~ 7%	~ 25%	~ 89%
RFA	(~ 7%)	~ 27%	~ 79%

*M. Kireeff Covo et al., Phys. Rev. Lett. 97, 054801 (2006).

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Conclusions

- The RFA demonstrated to be a versatile tool that allowed to:
  - Measure ion and electron energy distribution;
  - Determine beam-background gas interaction cross section;
  - Benchmark simulation tools, enabling to model experiments with high fidelity; and
  - Obtain first absolute measurement of electron cloud density in a magnetic transport section.