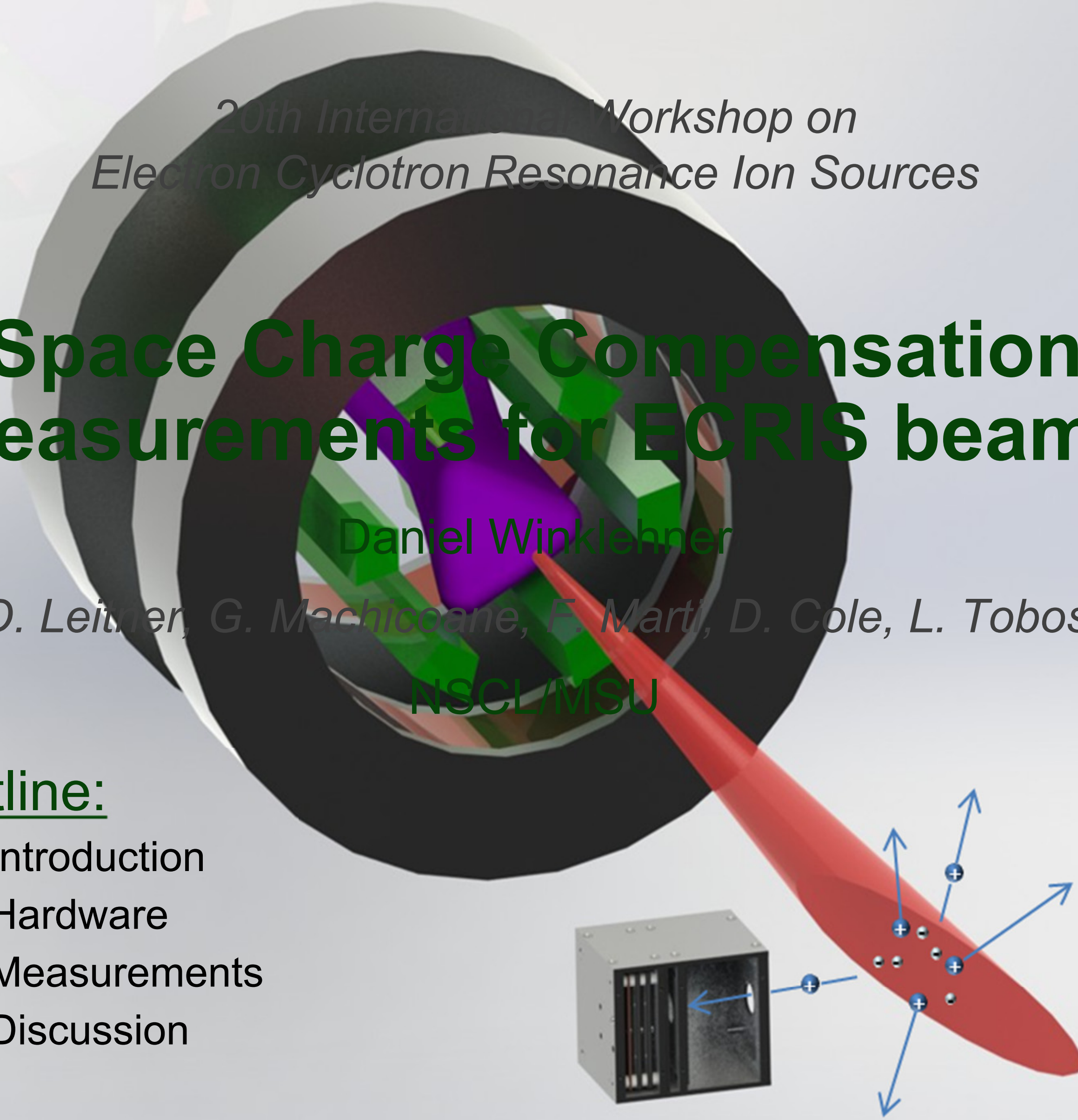


20th International Workshop on
Electron Cyclotron Resonance Ion Sources

Space Charge Compensation Measurements for ECRIS beams

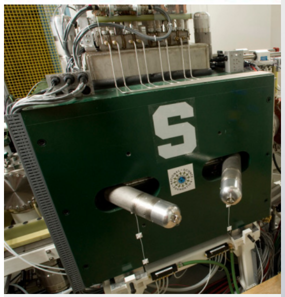
Daniel Winklehner

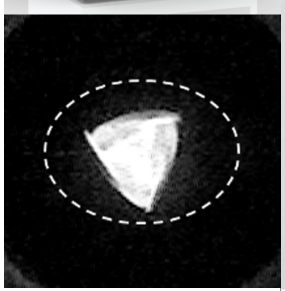
D. Leitner, G. Machicoane, F. Marti, D. Cole, L. Tobos

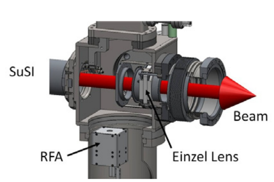
NSCL/MSU

Outline:

- Introduction
- Hardware
- Measurements
- Discussion







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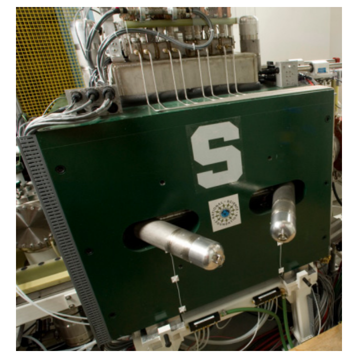
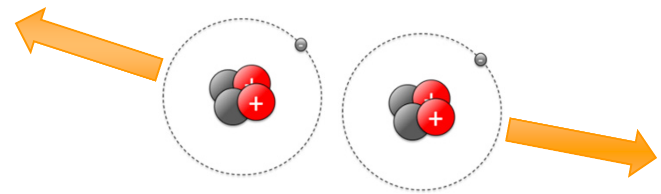
ECRIS and LEBT

- Current ECR ions sources like Venus and SuSI are able to create up to 20 mA of beam
- Next (4th) generation ECRIS even more!
- These are regimes, where space-charge effects become important factors for:
  - Beam size
  - Beam quality
  - Transmission
- Especially in the Low Energy Beam Transport (LEBT) system before the analyzing magnet
- Have to consider SC in design and simulations
- What is space-charge?



For next generation ECRIS see other talks at this workshop

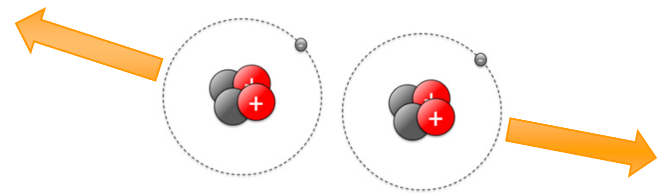
Space Charge (SC)



$$E_r = \frac{I}{2\pi\varepsilon_0\beta c}\frac{r}{a^2}$$

$$\Phi(r) = \Delta\phi\left(1 + 2\ln\frac{b}{a} - \frac{r^2}{a^2}\right) \quad \Phi(r) = 2\Delta\phi\ln\left(\frac{b}{r}\right) \quad \Delta\phi = \frac{I\cdot(1-f_e)}{4\pi\varepsilon_0\beta c}$$

Space Charge (SC)

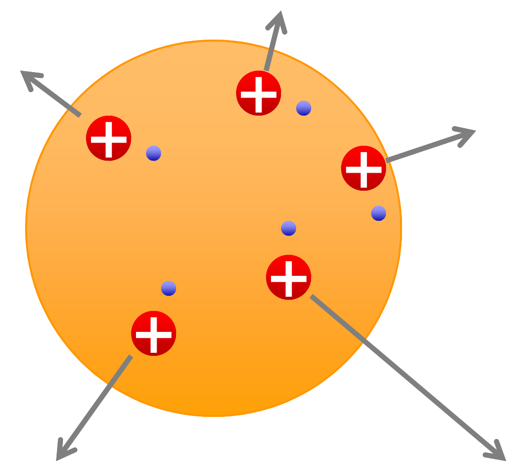


- Coulomb repulsion between beam ions
- Collective effect – creates self-field of the beam
- Defocusing term in Hill's equation – beam growth
- Simple model of the beam: Uniformly charged cylinder
  - Radial electric field: $E_r = \frac{I}{2\pi\varepsilon_0 \beta c} \frac{r}{a^2}$
  - Radial Potential: $\Phi(r) = \Delta\phi\left(1 + 2\ln\frac{b}{a} - \frac{r^2}{a^2}\right); \Phi(r) = 2\Delta\phi \ln\left(\frac{b}{r}\right)$; with $\Delta\phi = \frac{I \cdot (1 - f_e)}{4\pi\varepsilon_0 \beta c}$

  (a = beam radius, b = beam line radius, I = beam current, βc = velocity)
- If the beam were to experience the full self-field at all times bad for beam transport of high current beams! – Luckily: Compensation

Space Charge Compensation (SCC)

- As the beam goes through the residual gas in the beam line – interaction:
  - Collisions
  - Charge exchange
- Electrons are separated from gas atoms/molecules
- electrons are trapped in beam potential, ions are expelled
- Electrons effectively lower the beam potential
- Process is steady-state, governed by rates of electrons created and captured and electrons leaving the beam.
- From Soloshenko#:



$$\Delta\phi = \sqrt{3\mathcal{L}}\left(\frac{M}{m}\right)^{1/2}\left(\frac{\varphi_i}{V_0}\right)^{1/2} n_+^{1/2}\left(\frac{1}{n_0\sigma_e} + \frac{v_+\sigma_i r_0}{2v_i\sigma_e}\right)^{1/2} \cdot e$$

I. A. Soloshenko, Rev. Sci. Instrum. 67(4) (1996) 1646.

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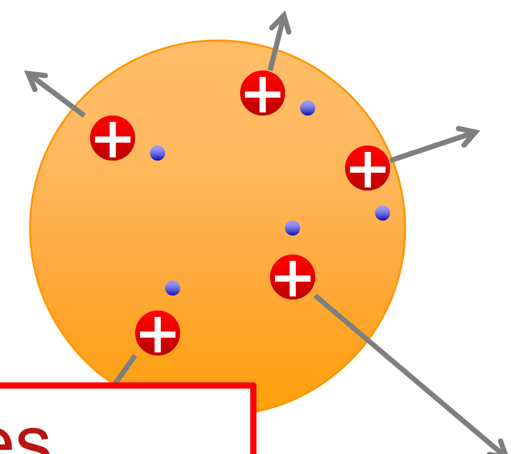
Beam end view



Dominates for low pressures

$\Delta\Phi$ increases when n_0 decreases

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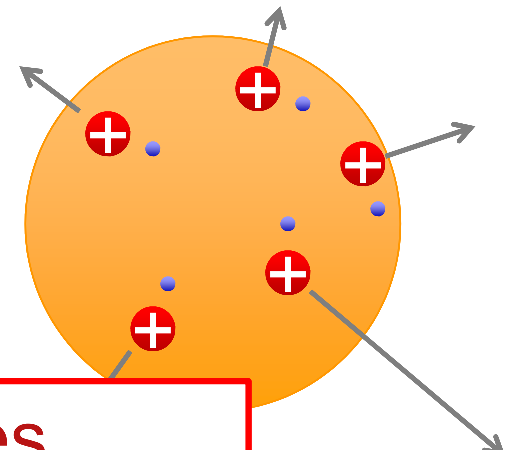

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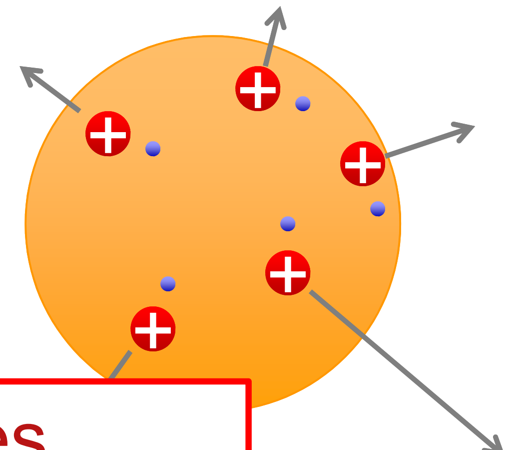

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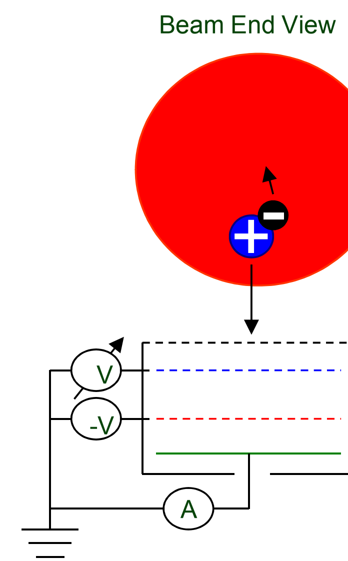
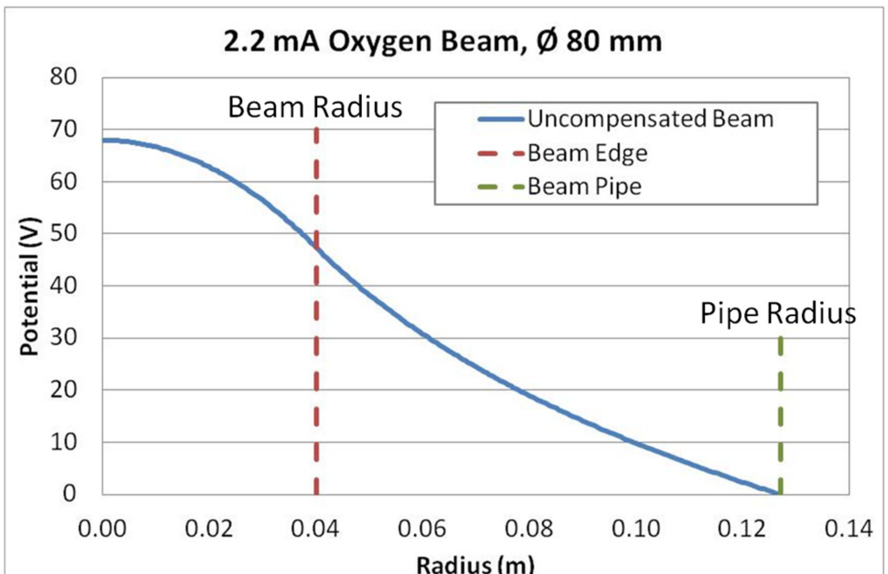
Measuring Space Charge Compensation

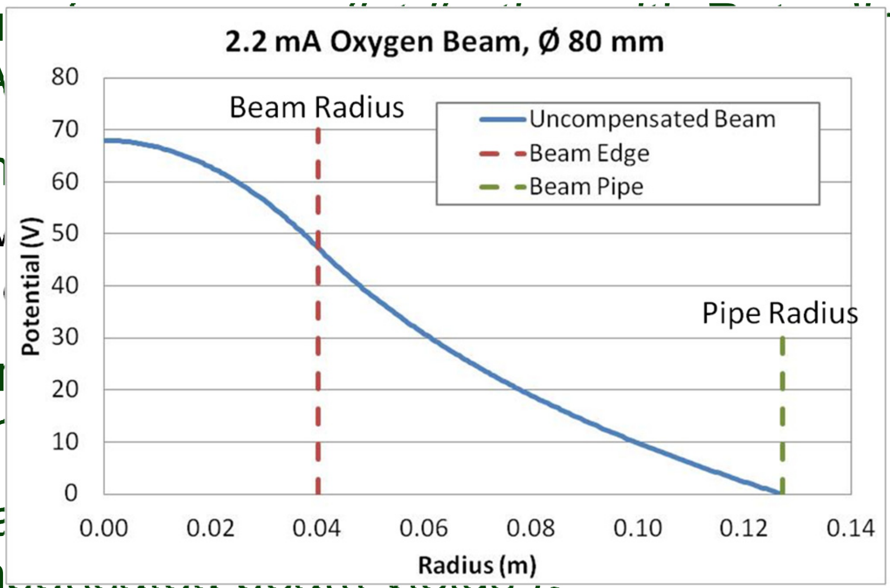


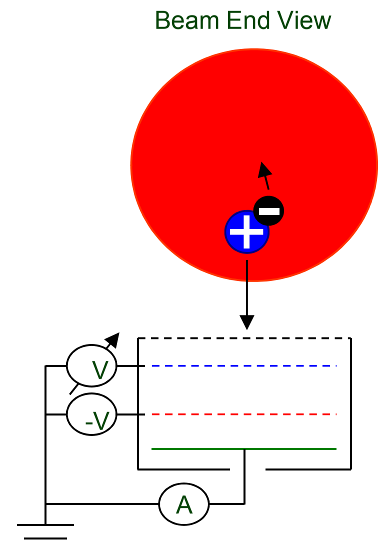
$$\overline{E}_{kin} = \frac{5}{2} k_B T \longrightarrow \text{~65 meV}$$



Measuring Space Charge Compensation

- Secondary Ions have energy depending on distance from beam center at time of ionization
- Assumptions:
  - Very low initial kinetic energy (dimolecular gas, T = 293 K) $\overline{E}_{kin} = \frac{5}{2} k_B T \longrightarrow$ ~65 meV
  - Secondary ions do not gain significant energy through collisions
- Measu… ng Field A…
- Design…
  - Flat v…
  - Singl…
- ΔΦ ca… resultir…
- Compa… uncom… e





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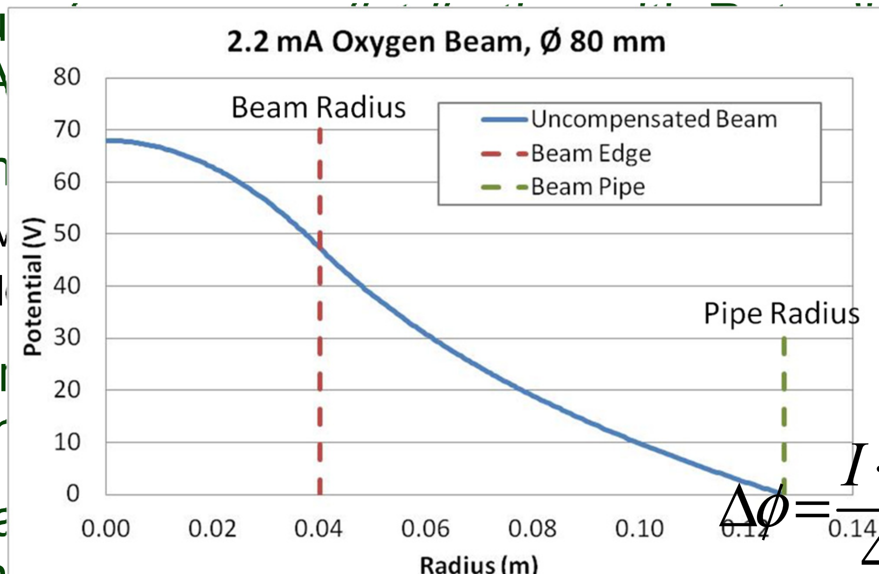
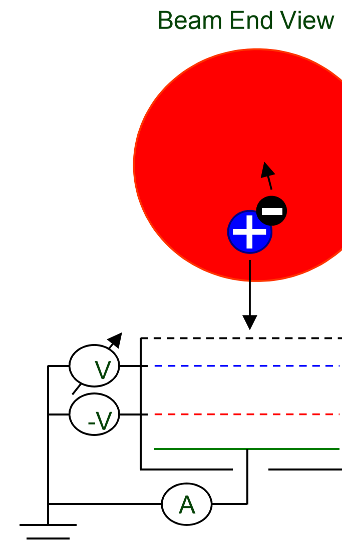
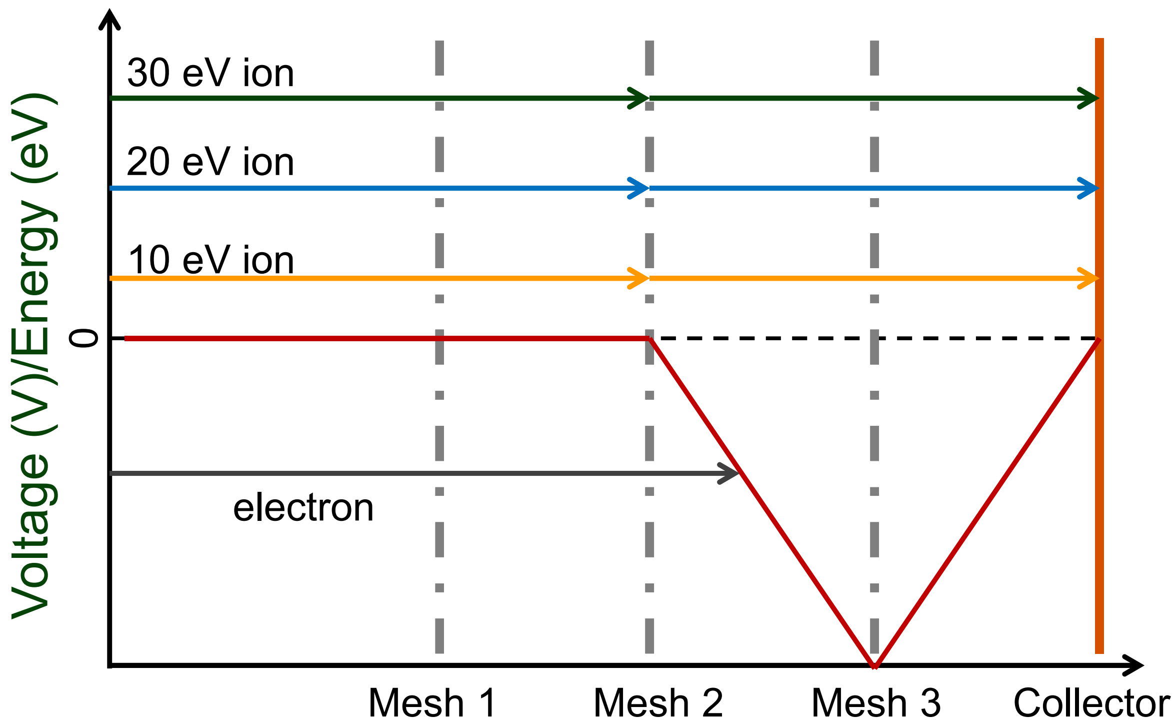


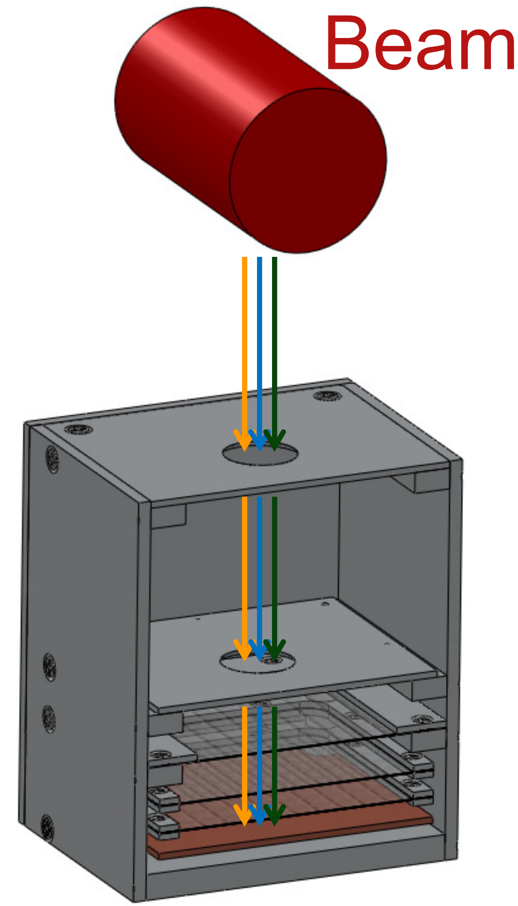
$$\Delta\phi = \frac{I \cdot (1 - f_e)}{4\pi\varepsilon_0 \beta c}$$



Retarding Field Analyzer (RFA)

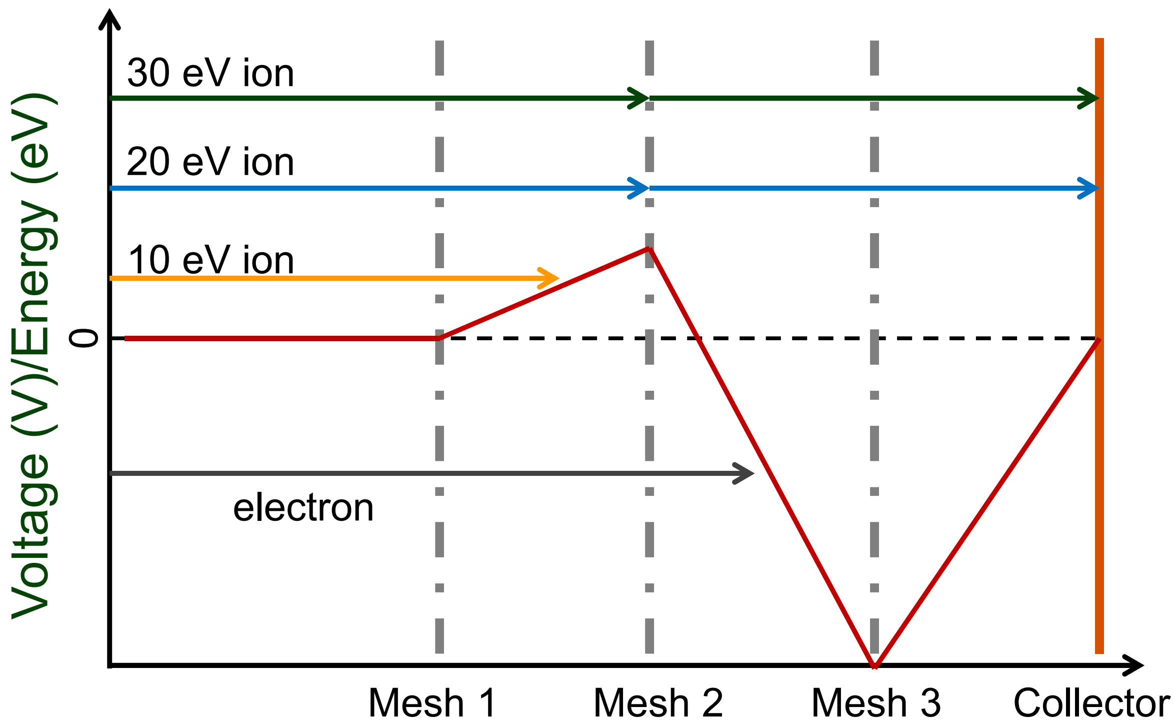
- Mesh 1 voltage = 0 V
- Mesh 2 voltage = 0 V
- Mesh 3 voltage = - 450 V

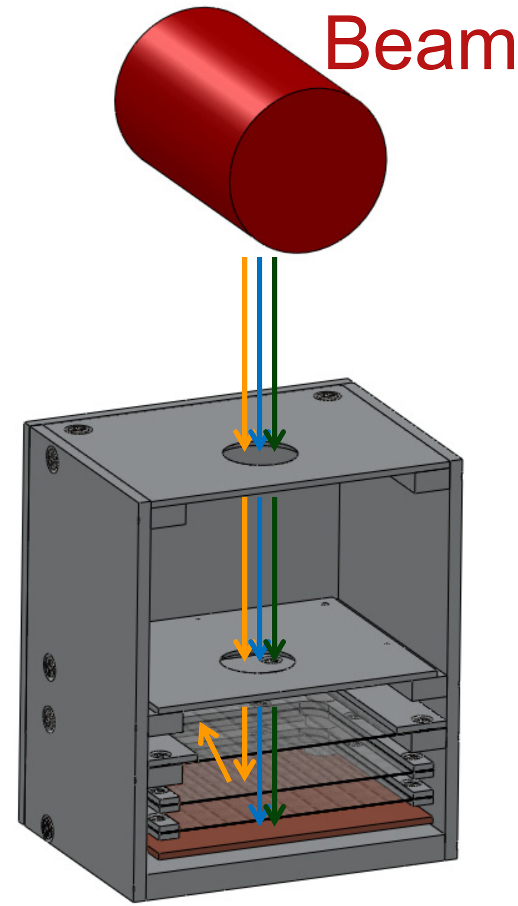




Retarding Field Analyzer (RFA)

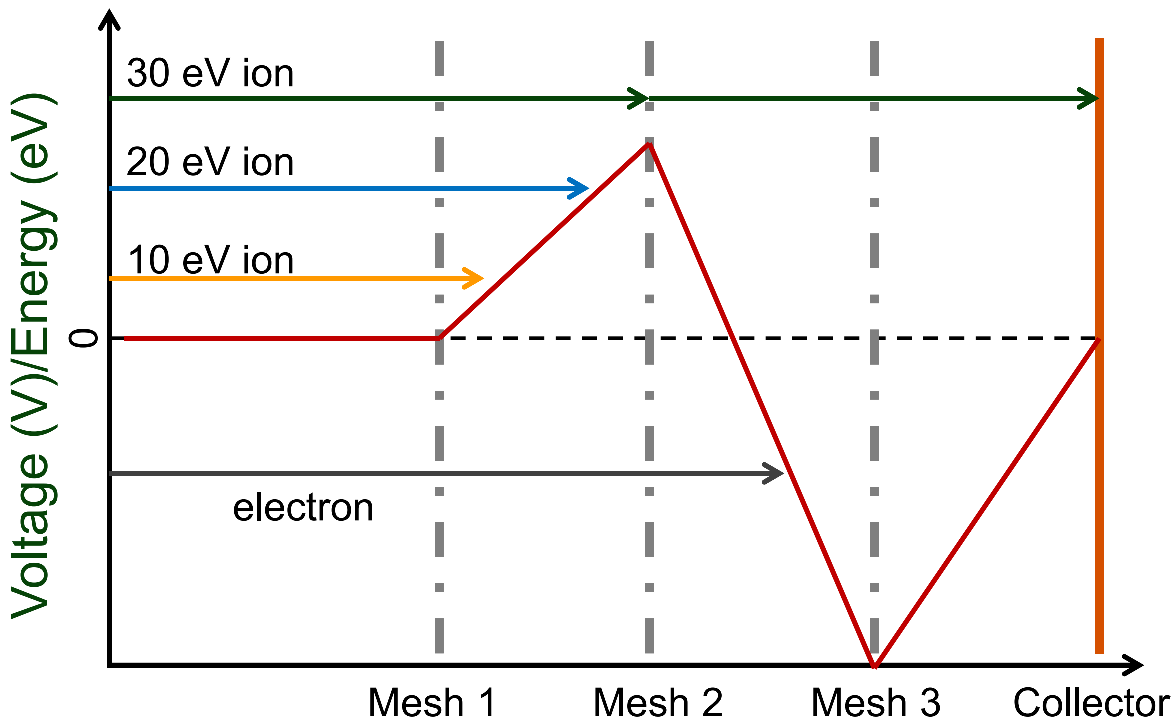
- Mesh 1 voltage = 0 V
- Mesh 2 voltage = 15 V
- Mesh 3 voltage = - 450 V

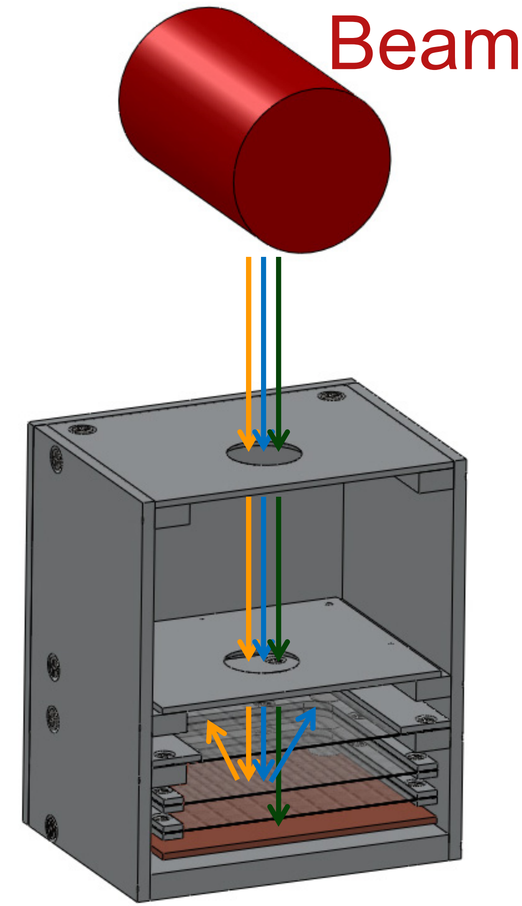




Retarding Field Analyzer (RFA)

- Mesh 1 voltage = 0 V
- Mesh 2 voltage = 25 V
- Mesh 3 voltage = - 450 V





Retarding Field Analyzer (RFA)

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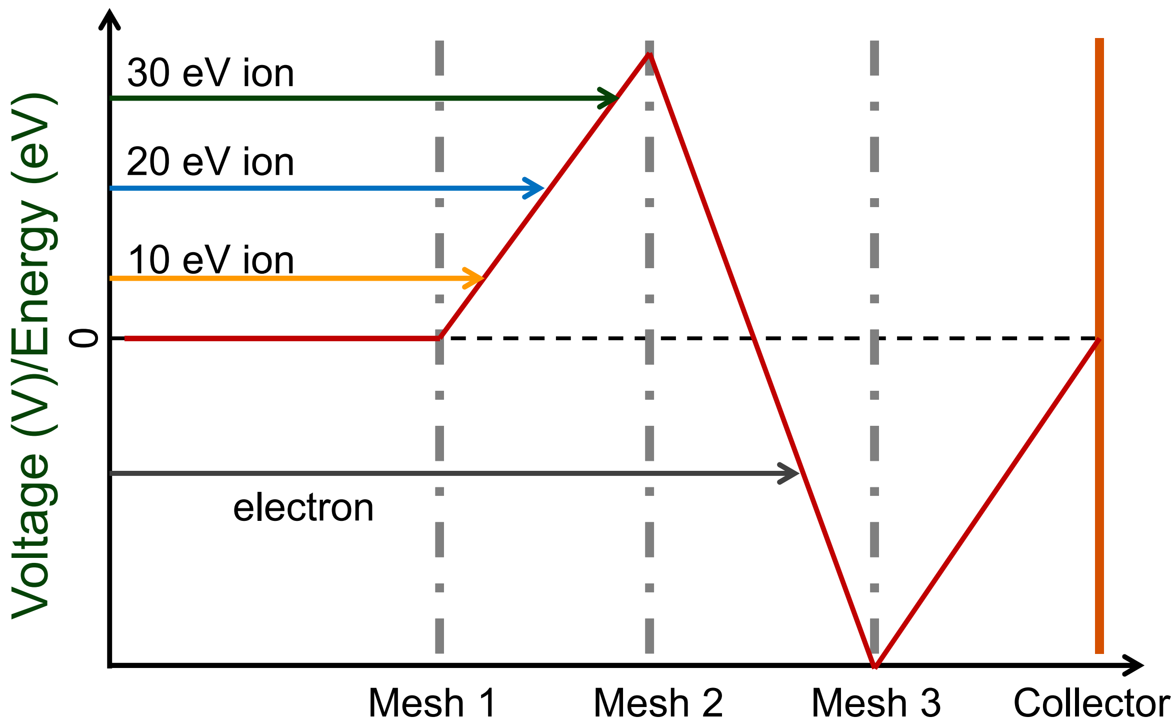
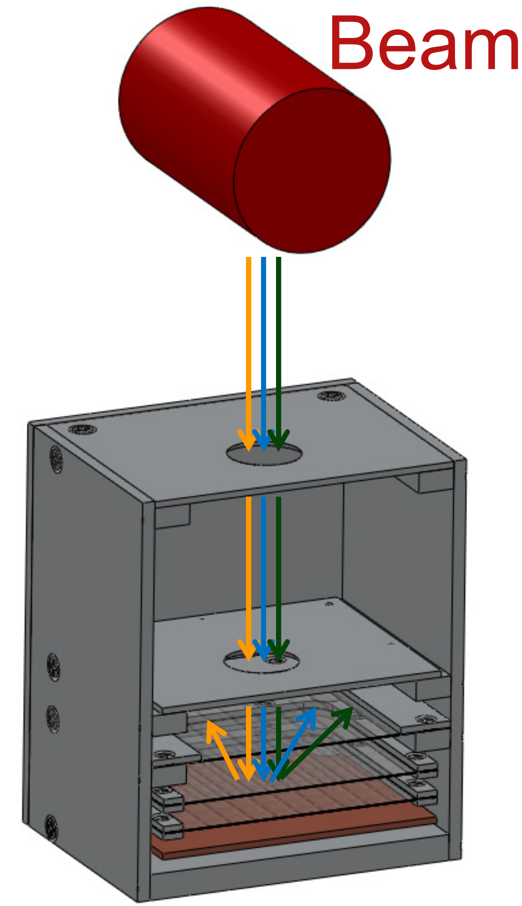
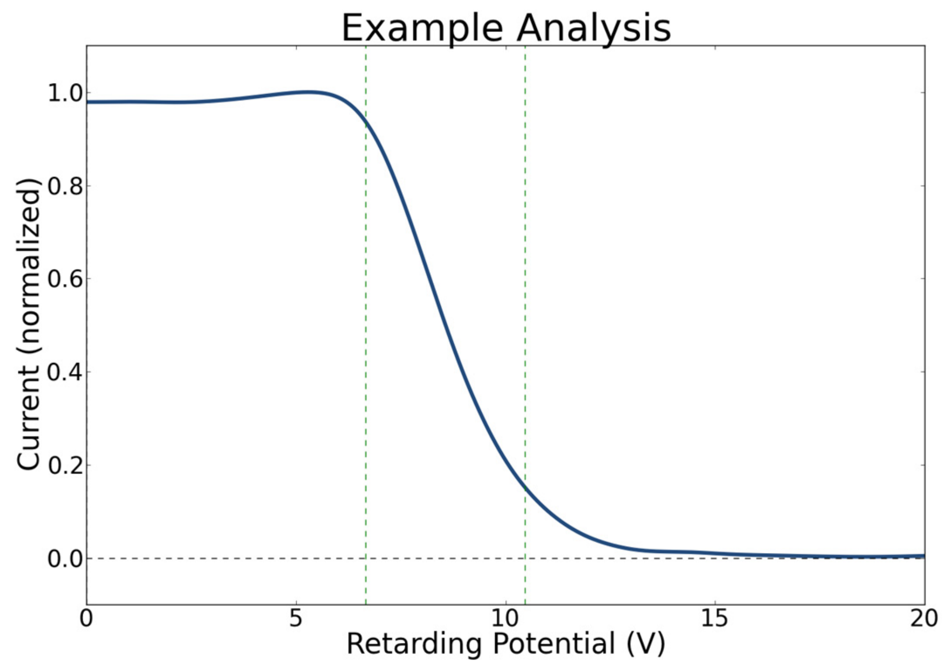
- Mesh 2 voltage = 35 V
- Mesh 3 voltage = - 450 V





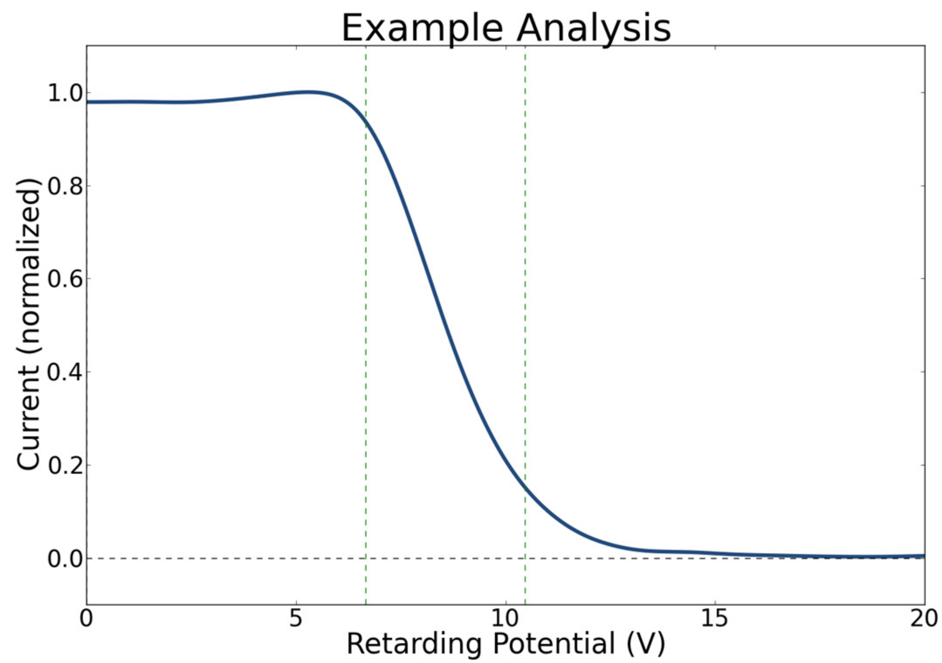
Analysis (LEDA source example)



Analysis (LEDA source example)

- Typical RFA spectrum
- 2 Methods of analysis:
  - Take dI/dV and use base width (subtract 1.2 V for detector resolution)
  - Fit the graph with 3 straight lines to obtain Φ_{center} and Φ_{edge}
- Result:
  - Meth. 1: $\Delta\Phi$ ~ 4.6 V
    Neutralization ~78.4%
  - Meth. 2: $\Delta\Phi$ ~ 3.8 V
    Neutralization ~83.0%

(Closer for lower beam currents in the same measurement set)



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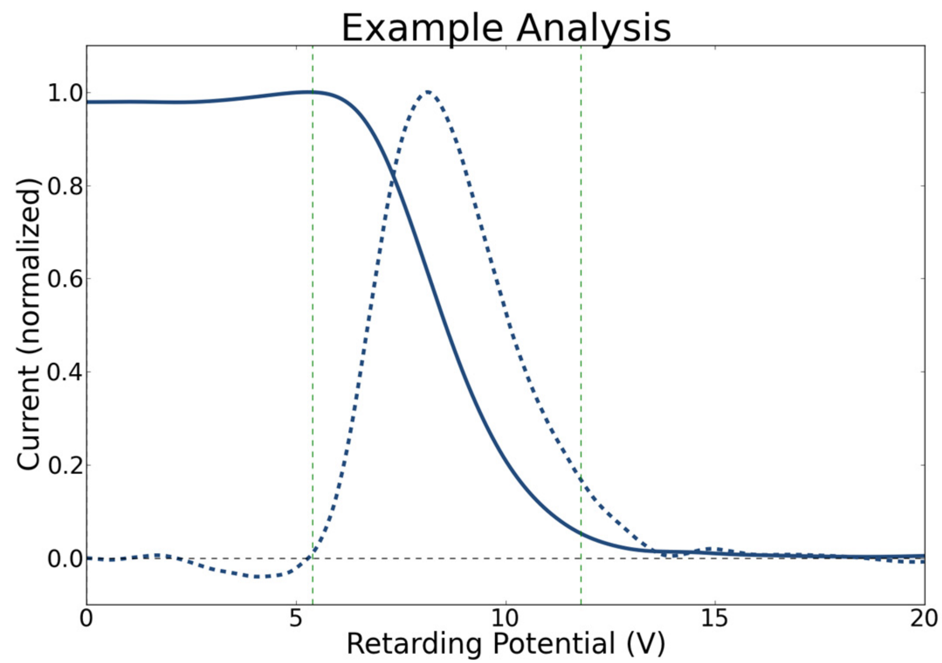

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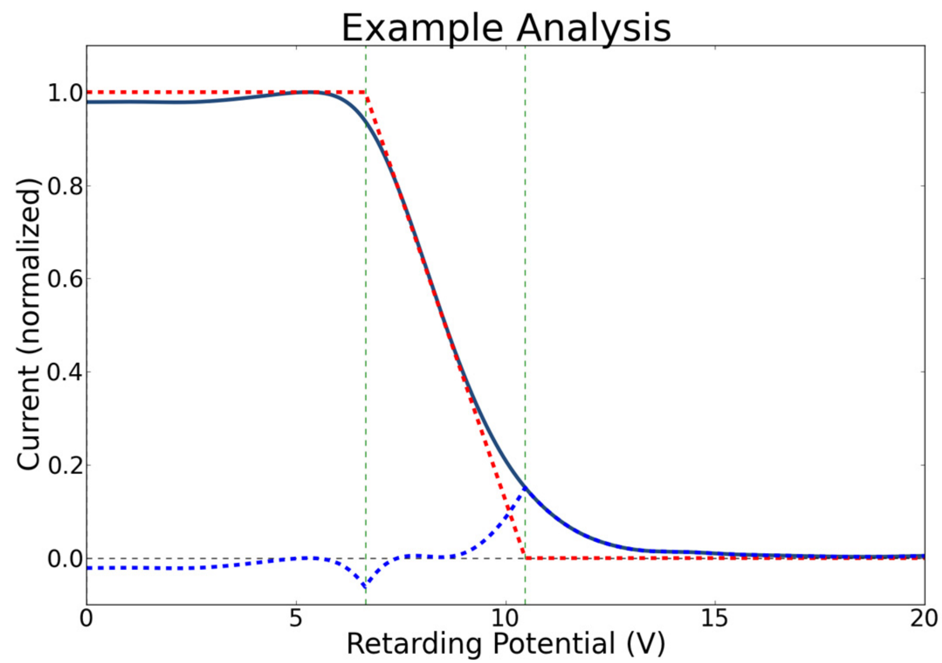

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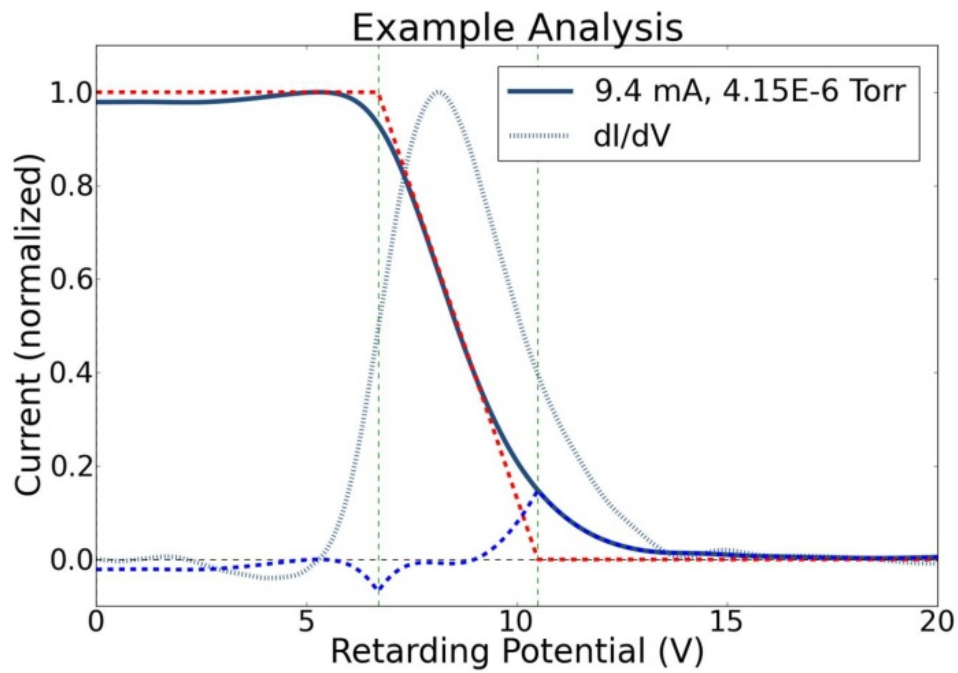

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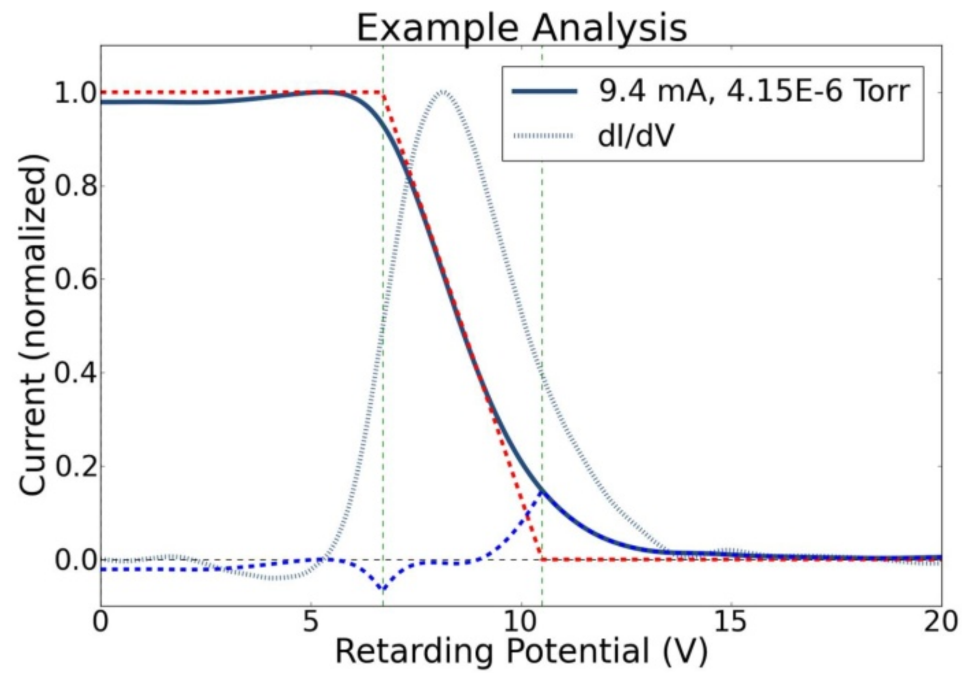
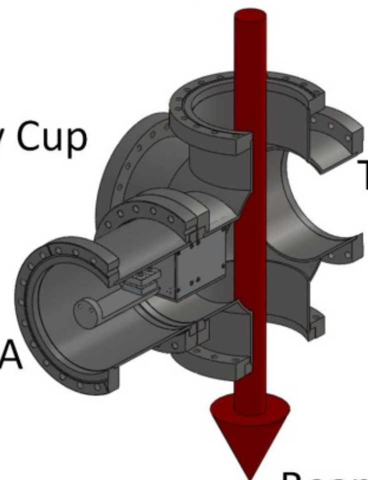
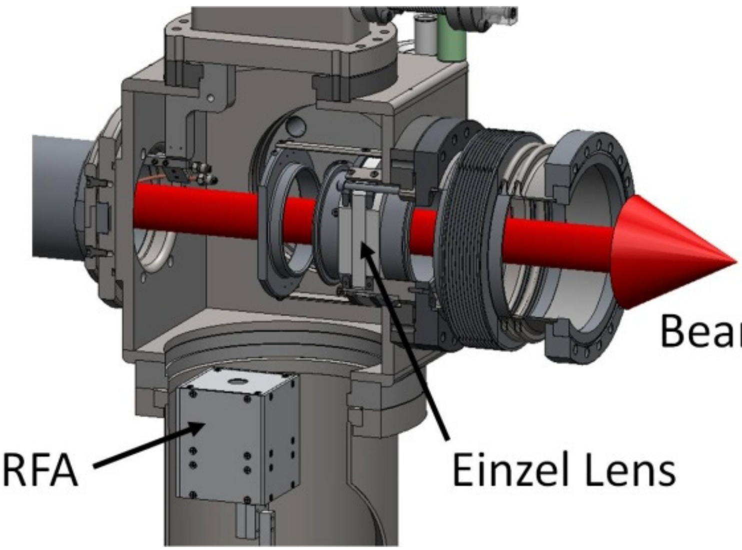


$$\Delta\phi = \frac{I \cdot (1 - f)}{4\pi \cdot \varepsilon_0 \cdot \beta c}$$

RFA Measurement Positions (Artemis A, SuSI, LEDA)

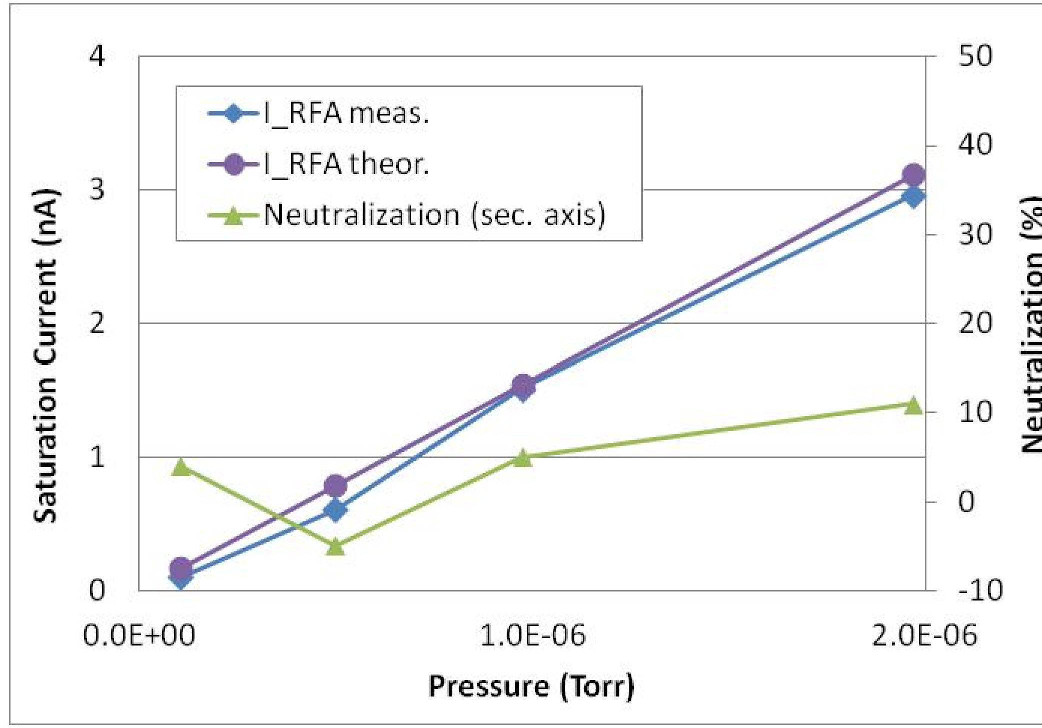




- Artemis A: The RFA is located between source and the analyzing magnet after an electrostatic quadrupole doublet.
- SuSI: RFA is located in diagnostic box 1 ~46 cm after the plasma aperture
- LEDA injector source: RFA is located in a diagnostic box ~50 cm after the plasma aperture

Artemis Measurements

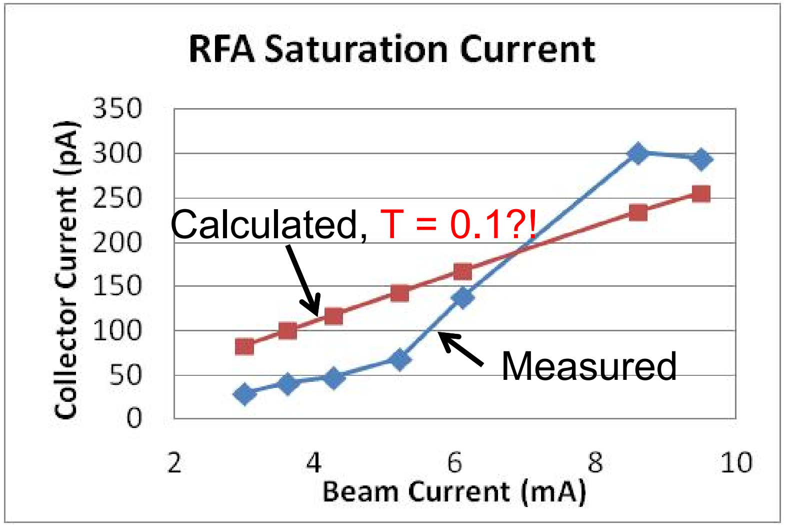
- First measurements
- Only one aperture in Retarding Field Analyzer
- Electrostatic Quadrupole settings to maximize current in Retarding Field Analyzer
- Beam current measured with Faraday Cup = 550 μA
- Saturation Current in agreement with theoretical prediction from continuity equation with 40% transmission

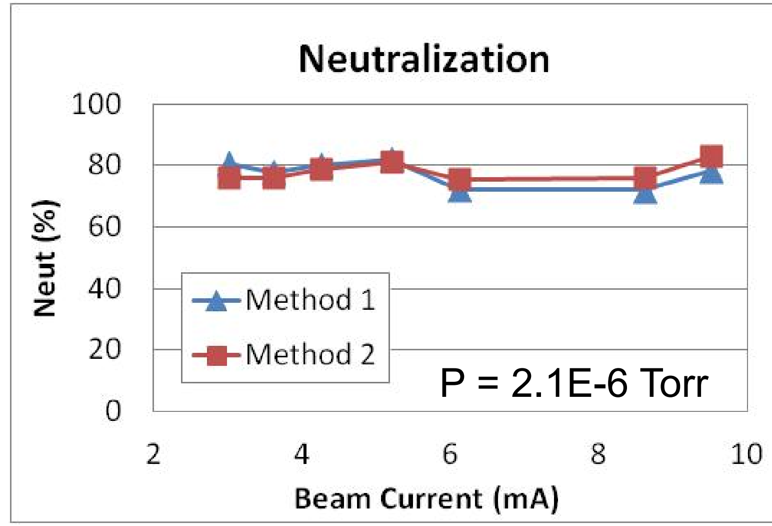


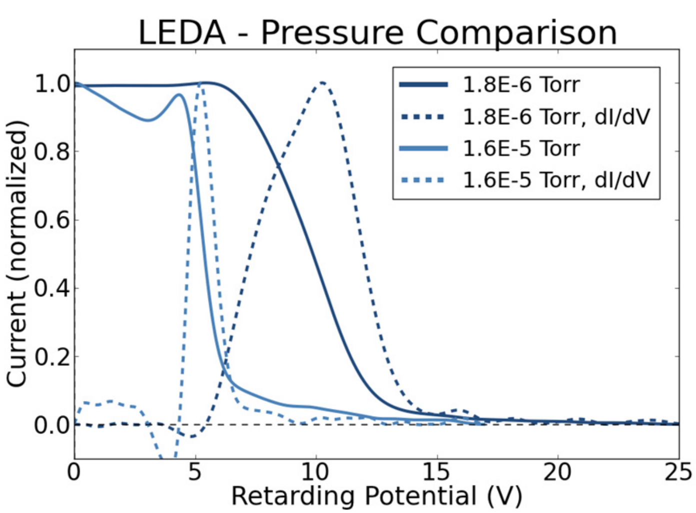
$$(I_{RFA})_s = \frac{r_a{}^2 \cdot T \cdot I \cdot \left(\sum n_g \sigma_i\right)}{2d} \;;\; T = 0.4$$

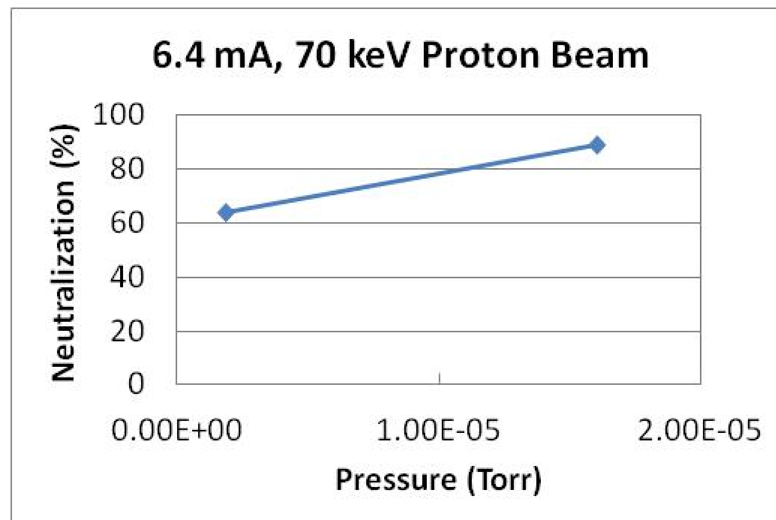
- More or less 0% neutralization, maybe slightly increasing tendency

LEDA Measurements
2 Aperture Collimation

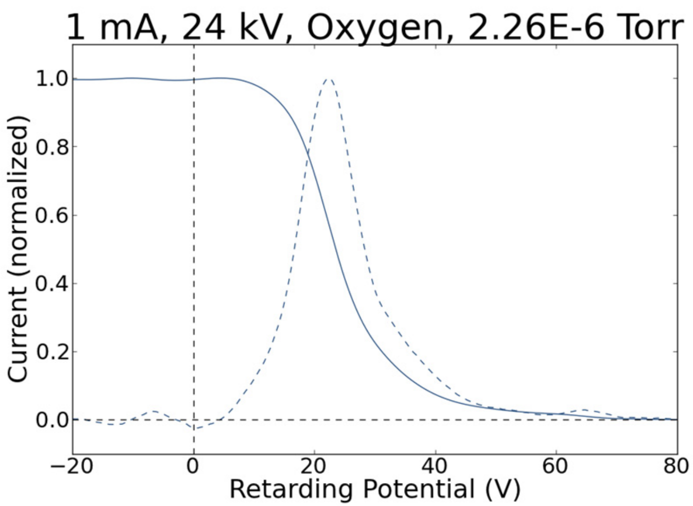


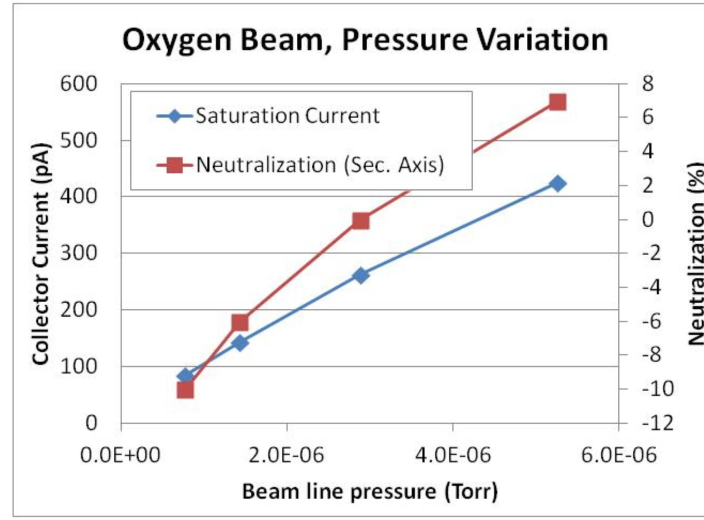


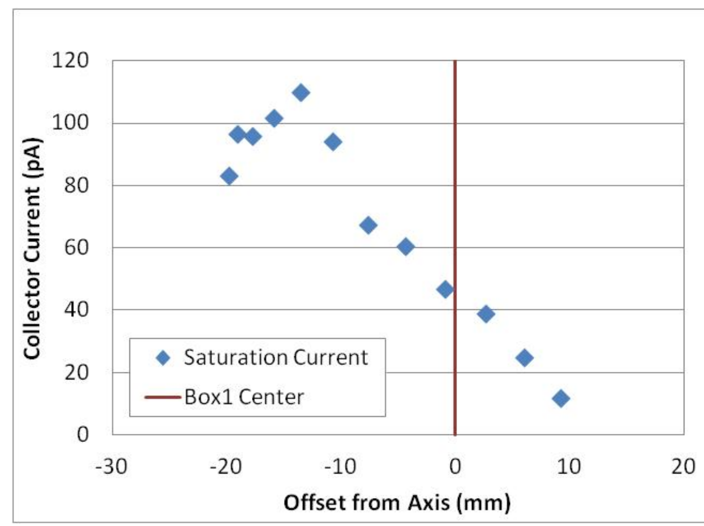




SuSI Measurements



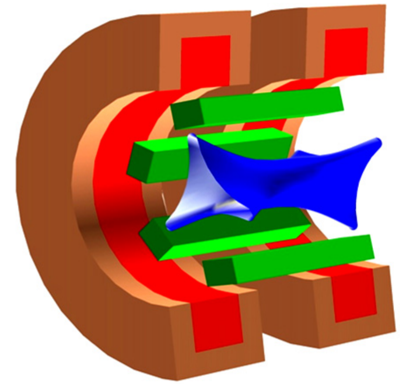


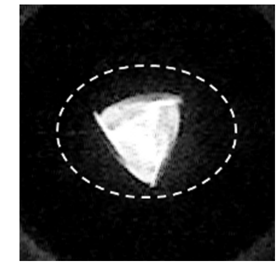


- $\Delta\Phi_{measured} > \Delta\Phi_{uncompensated}$
  →"negative" neutralization ✘
- Moving Retarding Field Analyzer perpendicular to beam: Asymmetry

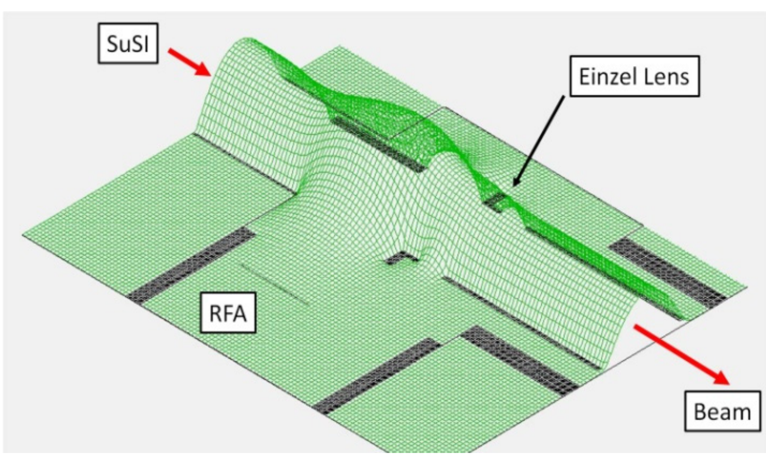
Complexity of Measuring ECR neutralization

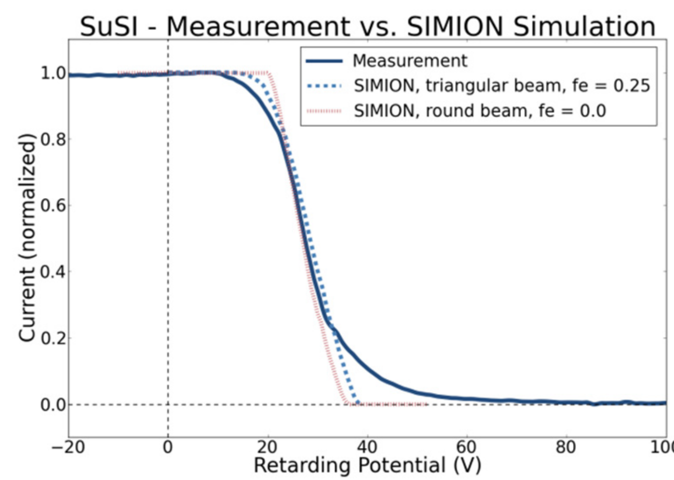
- Triangular Beams
- Multiple Species
  - ionization cross-sections depend on charge state
- Beam lines not infinite pipes concentric with beam!
  - -> Longitudinal v-component





- Simulations show large difference in obtained neutralization value for triangular or round beams…





Summary and Conclusions

- A new Retarding Field Analyzer was built at the NSCL
- Extensive Simulations have been conducted to determine the feasibility of the design and the theoretical resolution.
- Preliminary measurements have been carried out at three different sources (SuSI, Artemis and LEDA injector source), all three currently at the NSCL.
- The measurements showed trends that neutralization increases with pressure and/or beam current, which is in accord with previous results by other groups.
- These measurements also suggest, that in the current low energy beam line configurations of SuSI and Artemis only low neutralization can be observed.
- But: Some behaviors unexplained → future work

Outlook

- Measure Beam Cross-Sections with Quartz or KBr beam viewer
- As the neutralization can change throughout the LEBT, alternative positions for the retarding field analyzer will be explored in order to obtain a more complete picture of neutralization in ECR LEBTs
- Investigate asymetic beams further through simulation (and possibly running ECR sources with and without sextupole).
- Further investigate current reduction with 2nd aperture.
- Build/borrow? a small electron gun to do calibration measurements in order to confirm the theoretical accuracy and resolution.

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And thank you for your attention…Questions?