Theoretical and Experimental Studies of Negative Ions in IEC devices at UW – Madison:

Current Results and Plans for Future Work

By: Eric C. Alderson

21/10/2010

12th US Japan Workshop on Inertial Electrostatic Confinement Fusion

Outline

Background
- Negative Ion Reaction Physics
- Previous Measurements

Theory
- Simulation of Currents born in the IEC Core
- Integral Code Negative Ion Implementation

Experimental
- Faraday Cup
- Radial Scan Results

Future Work
- Integral Code
- System Parametrics
- Longitudinal Scan
- Alternate Cathode

Outline

Background
- Negative Ion Reaction Physics
- Previous Measurements

Theory
- Simulation of Currents born in the IEC Core
- Integral Code Negative Ion Implementation

Experimental
- Faraday Cup
- Radial Scan Results

Future Work
- Integral Code
- System Parametrics
- Longitudinal Scan
- Alternate Cathode

Outline

Background
- Negative Ion Reaction Physics
- Previous Measurements

Theory
- Simulation of Currents born in the IEC Core
- Integral Code Negative Ion Implementation

Experimental
- Faraday Cup
- Radial Scan Results

Future Work
- Integral Code
- System Parametrics
- Longitudinal Scan
- Alternate Cathode

Outline

Background
- Negative Ion Reaction Physics
- Previous Measurements

Theory
- Simulation of Currents born in the IEC Core
- Integral Code Negative Ion Implementation

Experimental
- Faraday Cup
- Radial Scan Results

Future Work
- Integral Code
- System Parametrics
- Longitudinal Scan
- Alternate Cathode

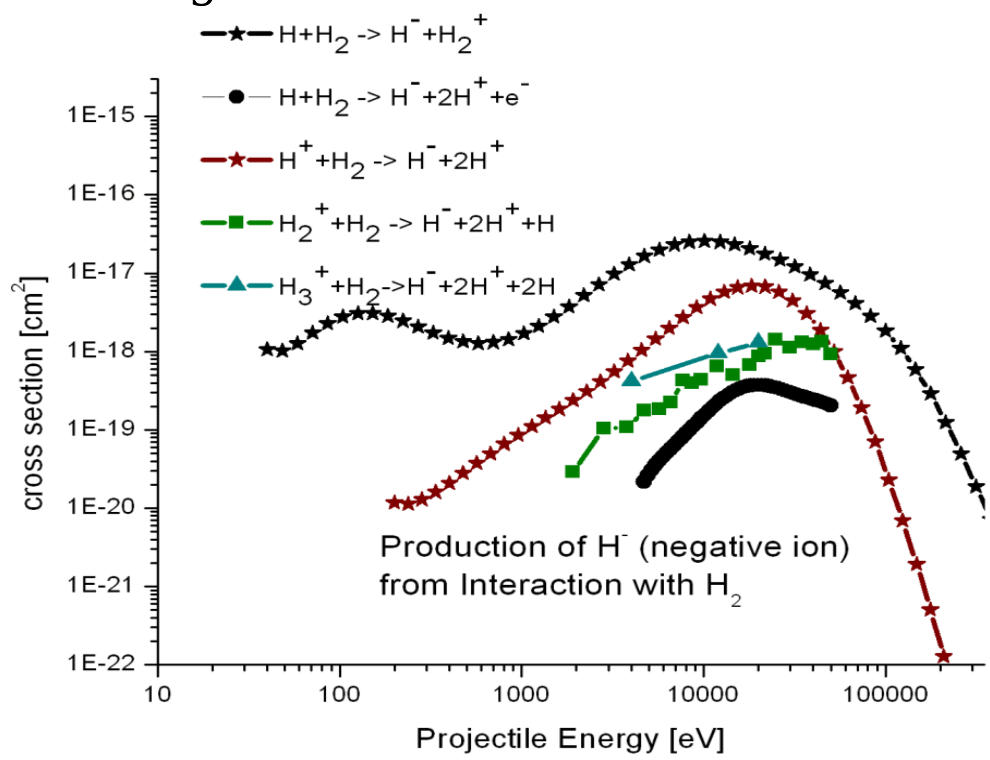
Negative ions can be created and stripped by collision with background gas.

A variety of reactions relevant to the IEC give rise to negative ions.

Dissociative Charge Exchange Reactions

Thermal Electron Attachment

Negative Ion Creation



Occurring wherever there are energetic nuclei

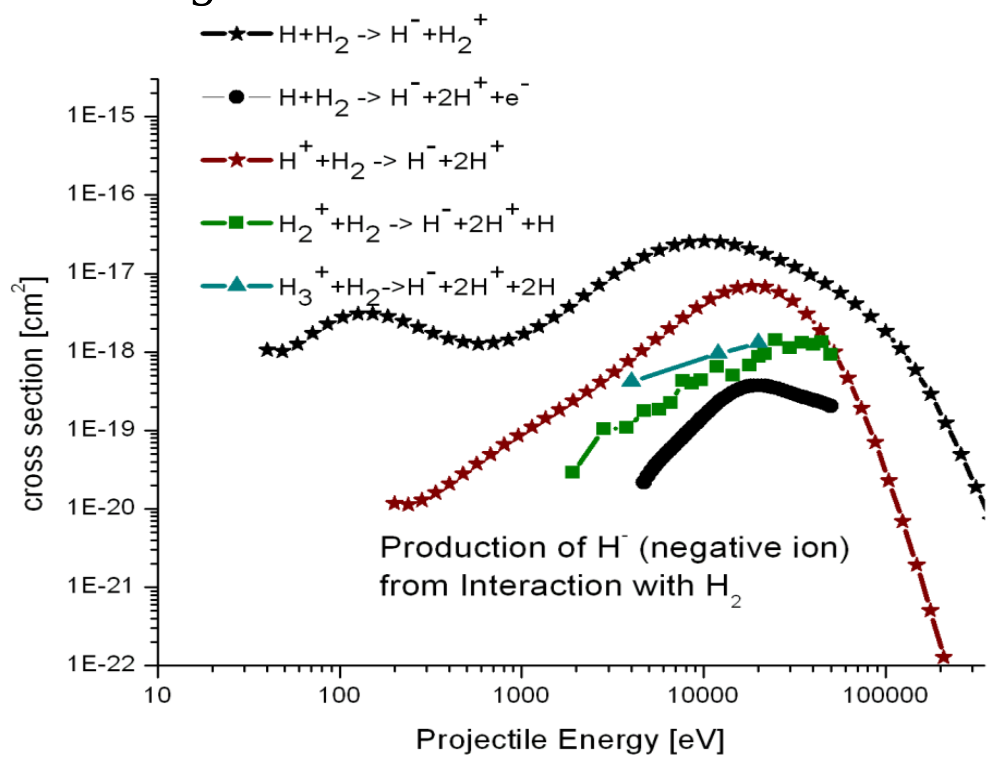
Negative ions can be created and stripped by collision with background gas.

A variety of reactions relevant to the IEC give rise to negative ions.

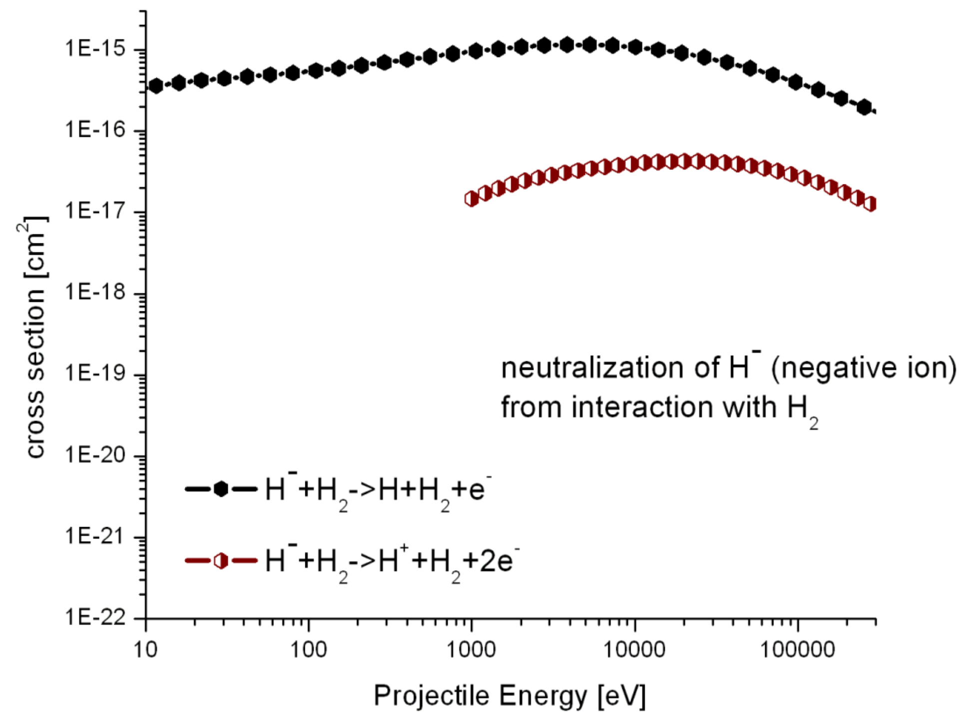
Dissociative Charge Exchange Reactions

Thermal Electron Attachment

Negative Ion Creation



Negative Ion Stripping



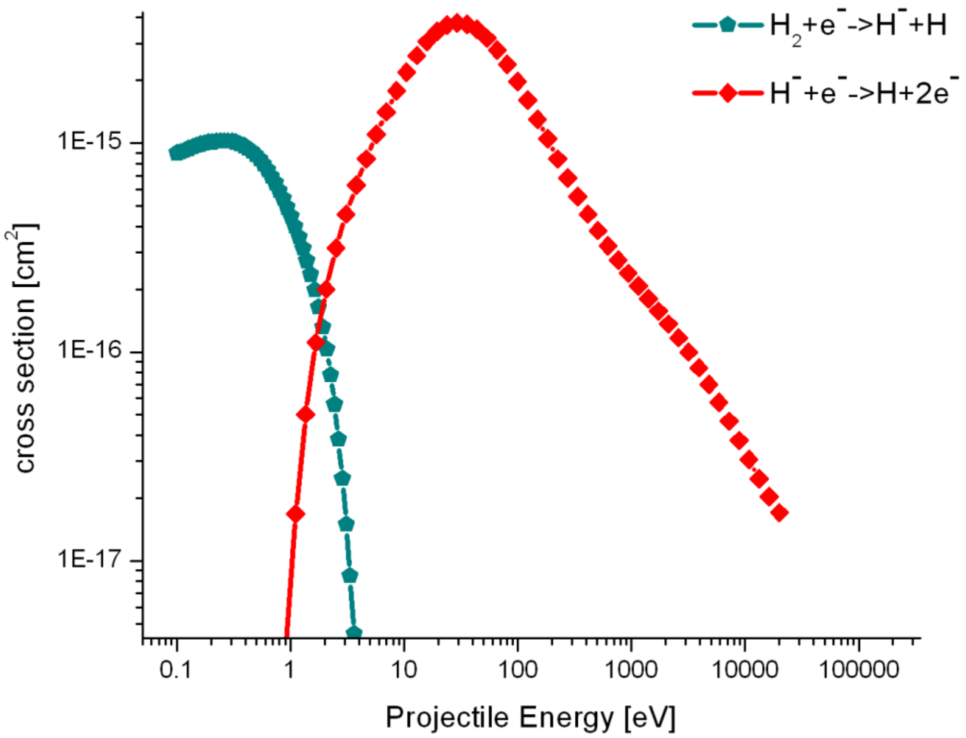
Occurring wherever there are energetic nuclei

Negative ions can be created and stripped by collision with electrons.

A variety of reactions relevant to the IEC give rise to negative ions.

Dissociative Charge Exchange Reactions

Thermal Electron Attachment

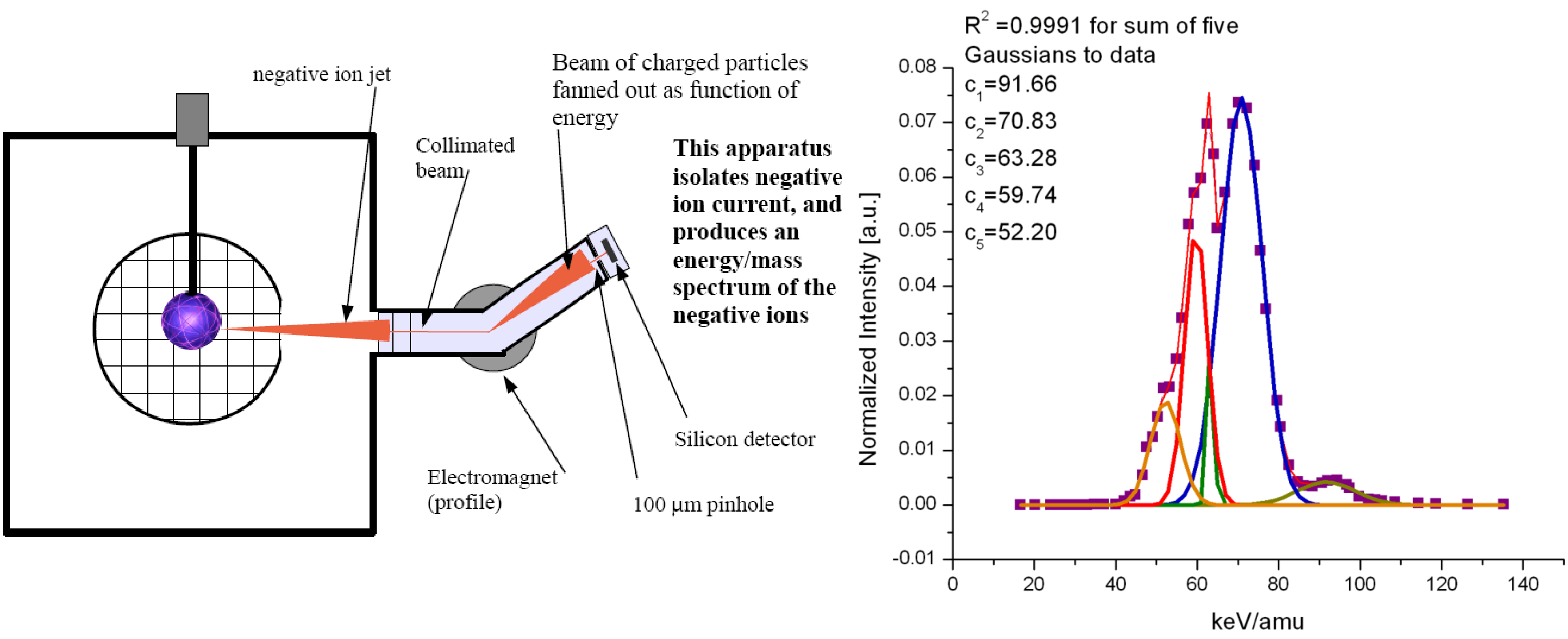


Electron attachment

Electron stripping

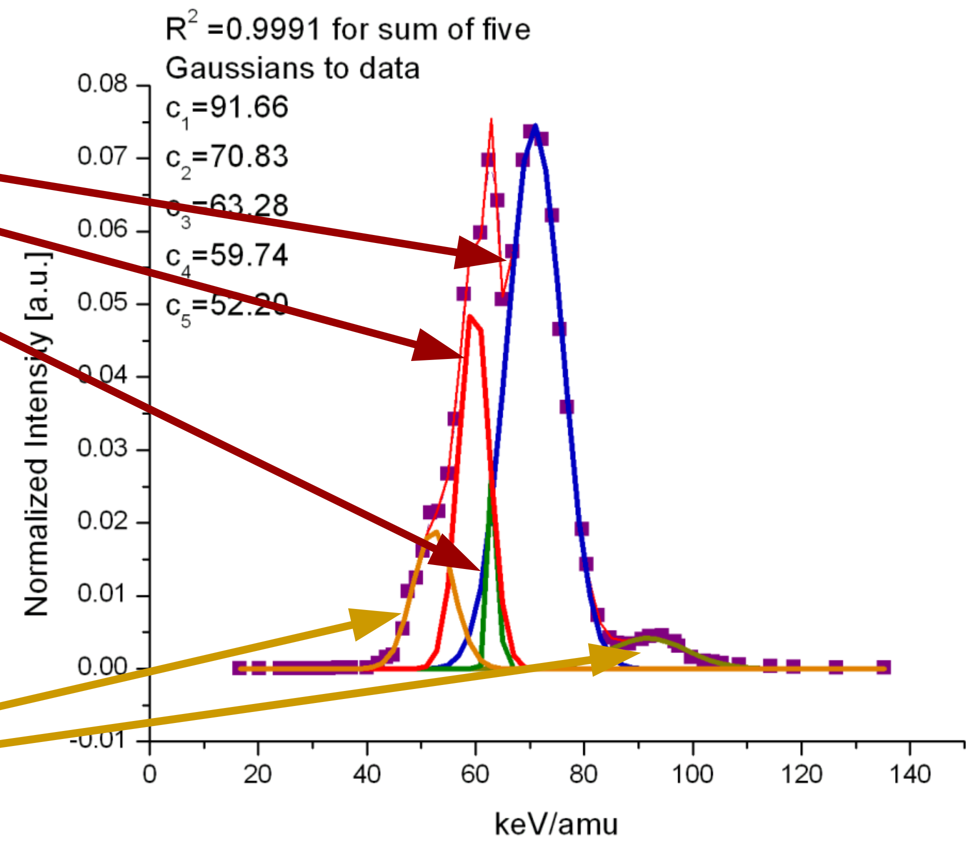
Occurring inside the cathode, where there are thermal electrons

Negative ion currents in IEC discovered in 2009 by D. Boris using a bending arm to isolate negative ion currents and provide Energy/Mass decomposition.



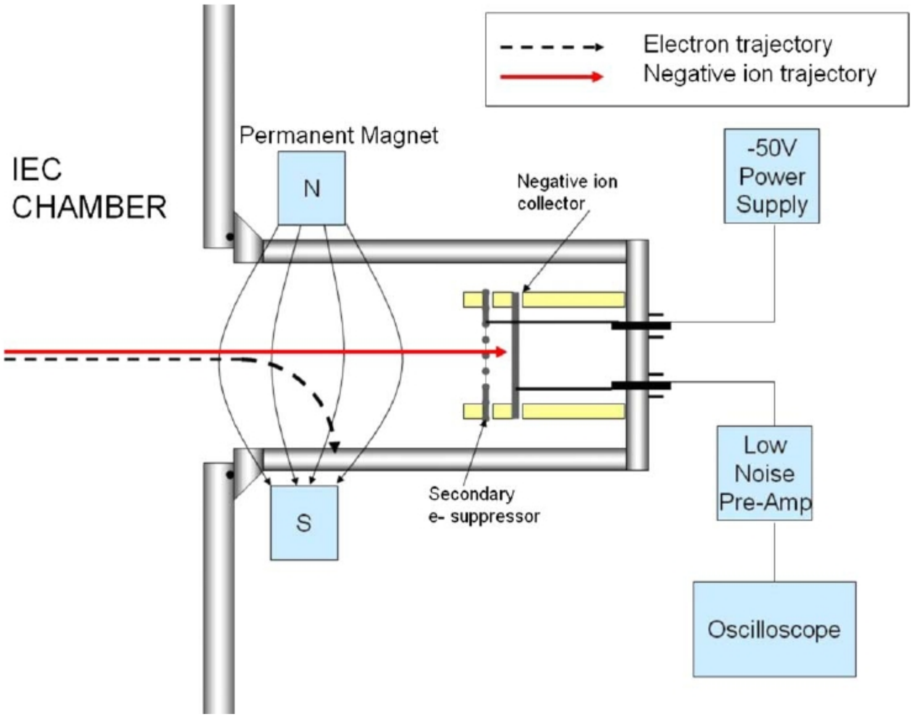
Analysis shows evidence of the negative ion origins.

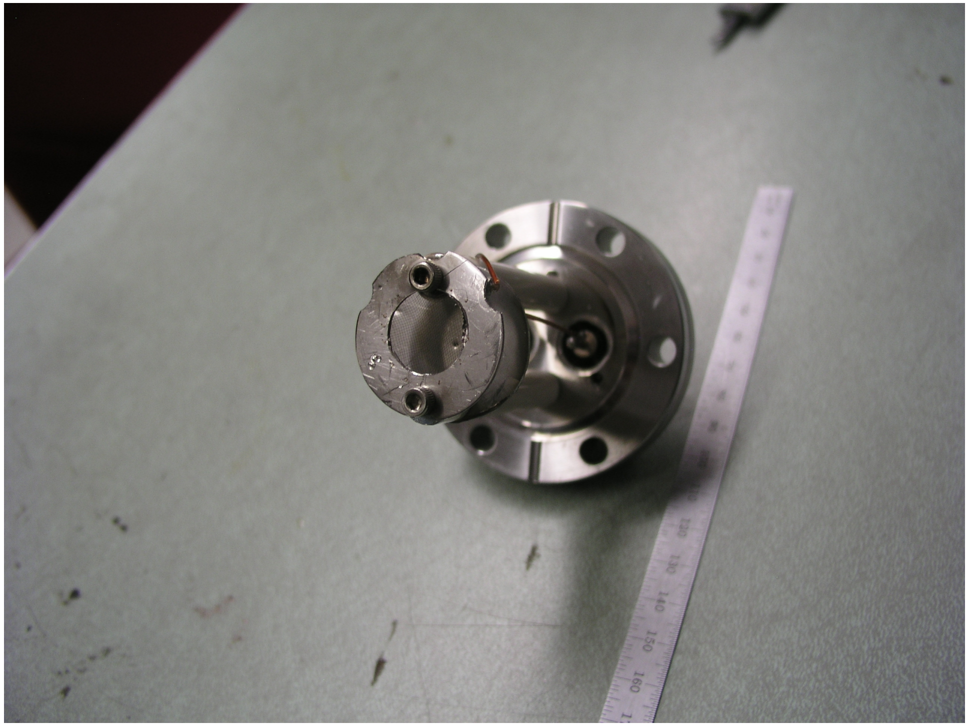
Negative ions born from dissociative charge exchange



Negative ions born in the core from electron attachment

Negative ion parametrics were carried out by D. Boris using a "Faraday Trap"

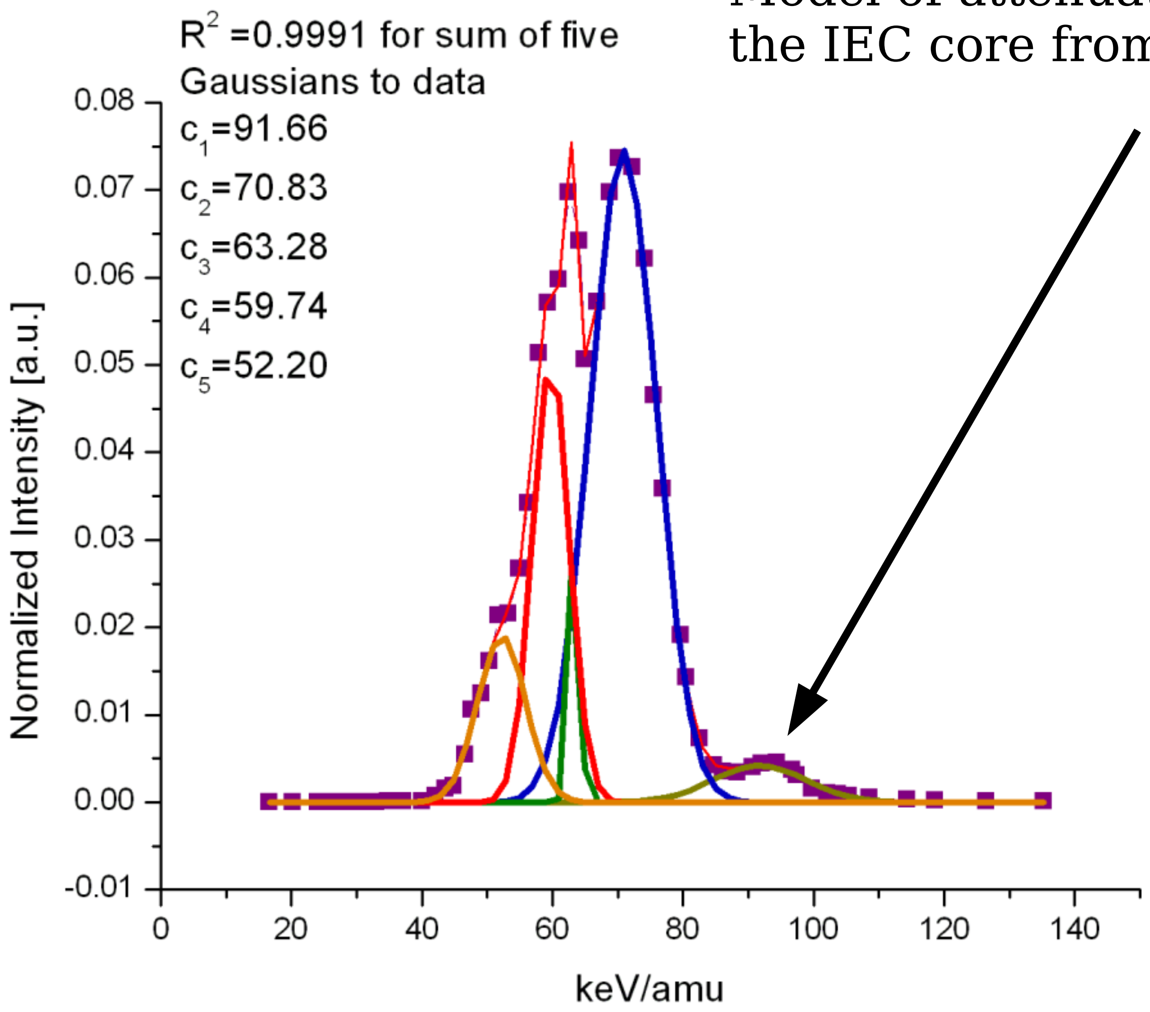




Acceptance aperture roughly 2 [cm^2]

D.R. Boris, et al., "Deuterium anions in inertial electrostatic confinement devices" Phys Rev. E 80, (2009)

Theory work has examined survival of negative ions born in the core.



Model of attenuation of negative ions born in the IEC core from thermal electron attachment

If this intensity was measured at the chamber wall, what was the negative ion current born at the cathode?

How much survived to reach the anode?

Measured intensity 0.0042 [a.u.] *(arbitrary units)*

Attenuation of negative ions born in the core is a tractable problem.

The change in current is described by this differential equation:

$$\frac{dI}{dr} = -I_0 n_g \sigma[E(r)]dr$$

Where the Energy of the particles born in the cathode at zero is described by the potential as a function of radius

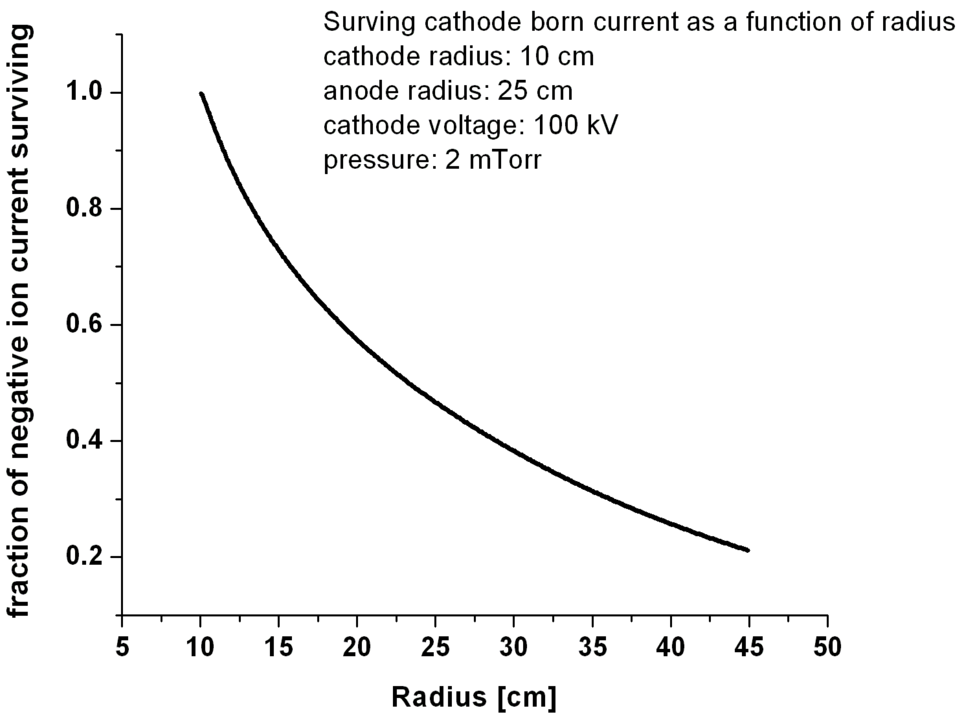
$$E = V_c - V_c \frac{(r_a - r) r_c}{(r_a - r_c) r}$$

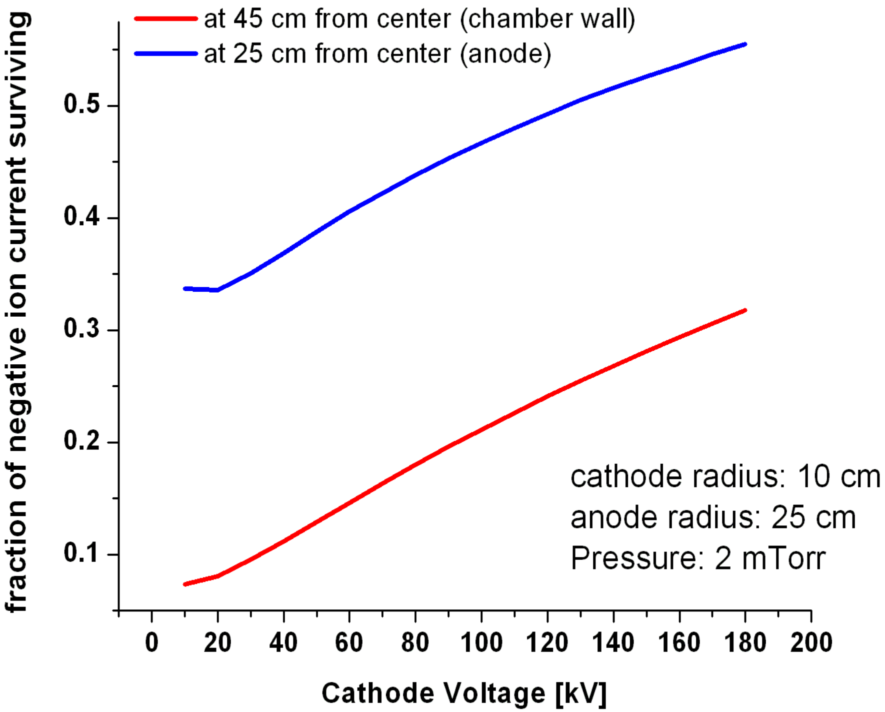
The above is solved as an integral equation:

$$I(r) = I_0 e^{-n_g \int_{r_c}^{r} \sigma(r') dr'}$$

A code has been developed to simulate attenuation of negative ions born in the IEC core.

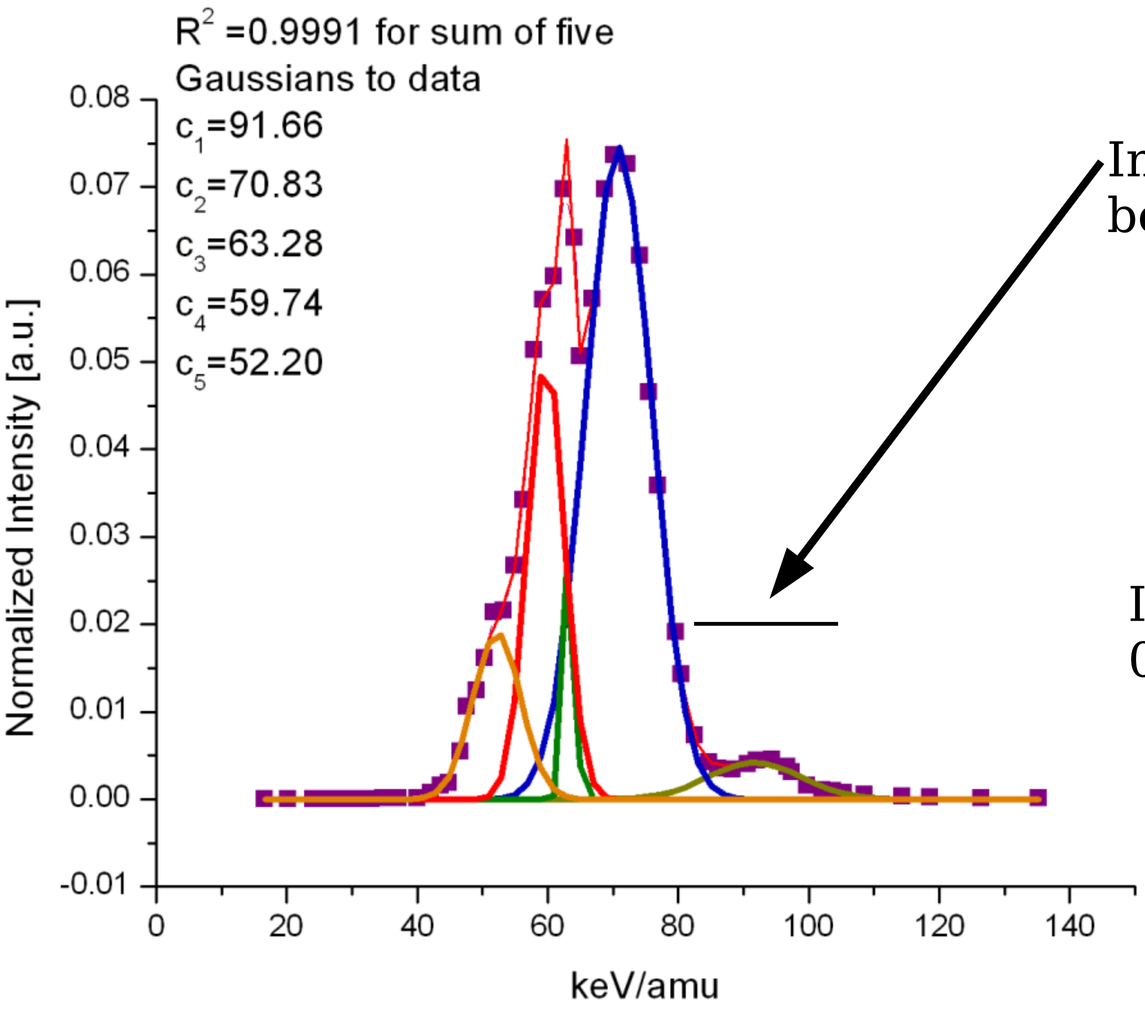
Surviving negative ion fraction from a 20 cm diameter cathode and 50 cm anode at 2 mTorr





2 mTorr = 0.267 Pa

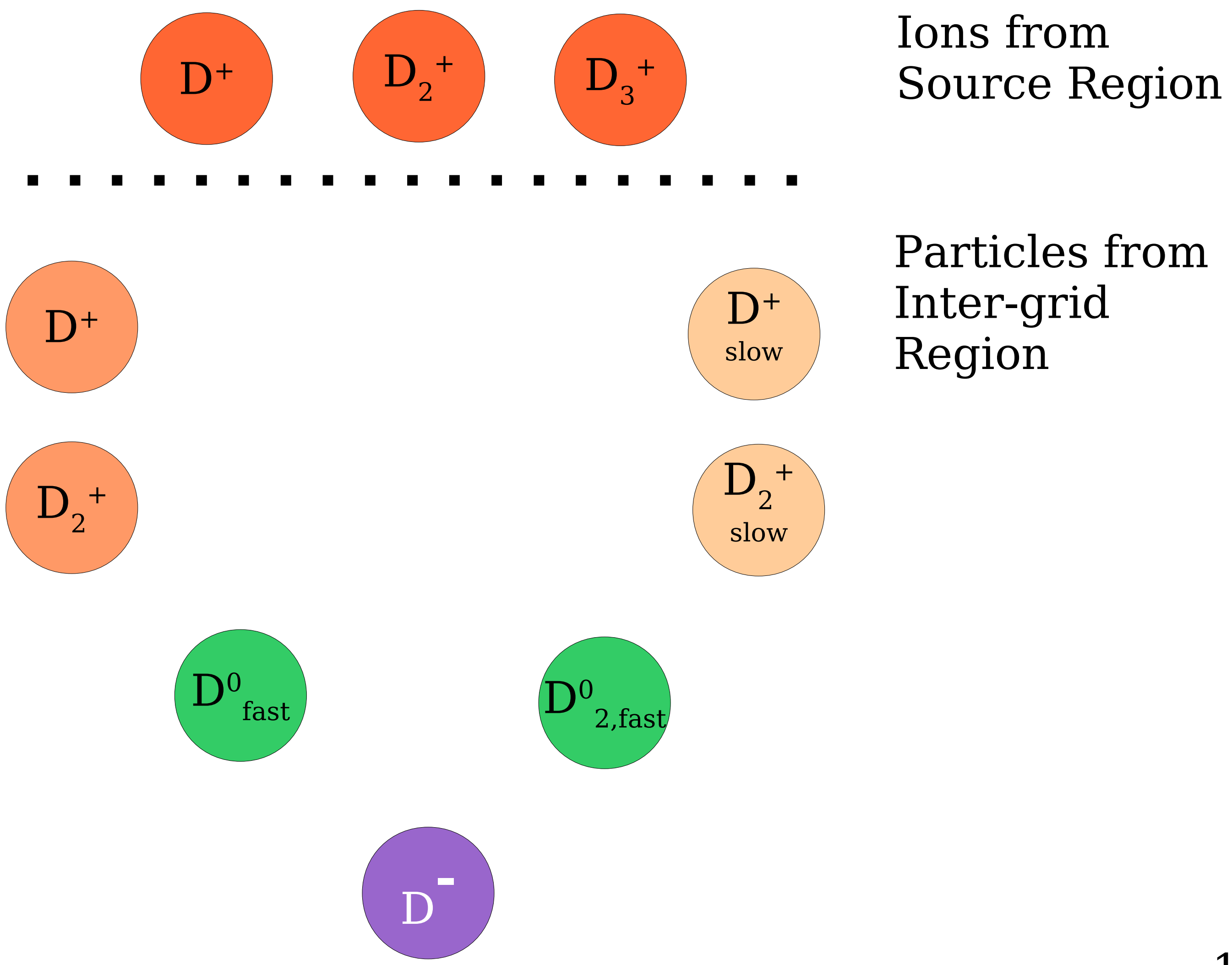
The measured negative ion current was ~80% stronger leaving the cathode.



Intensity of negative ion current born from cathode in a.u.

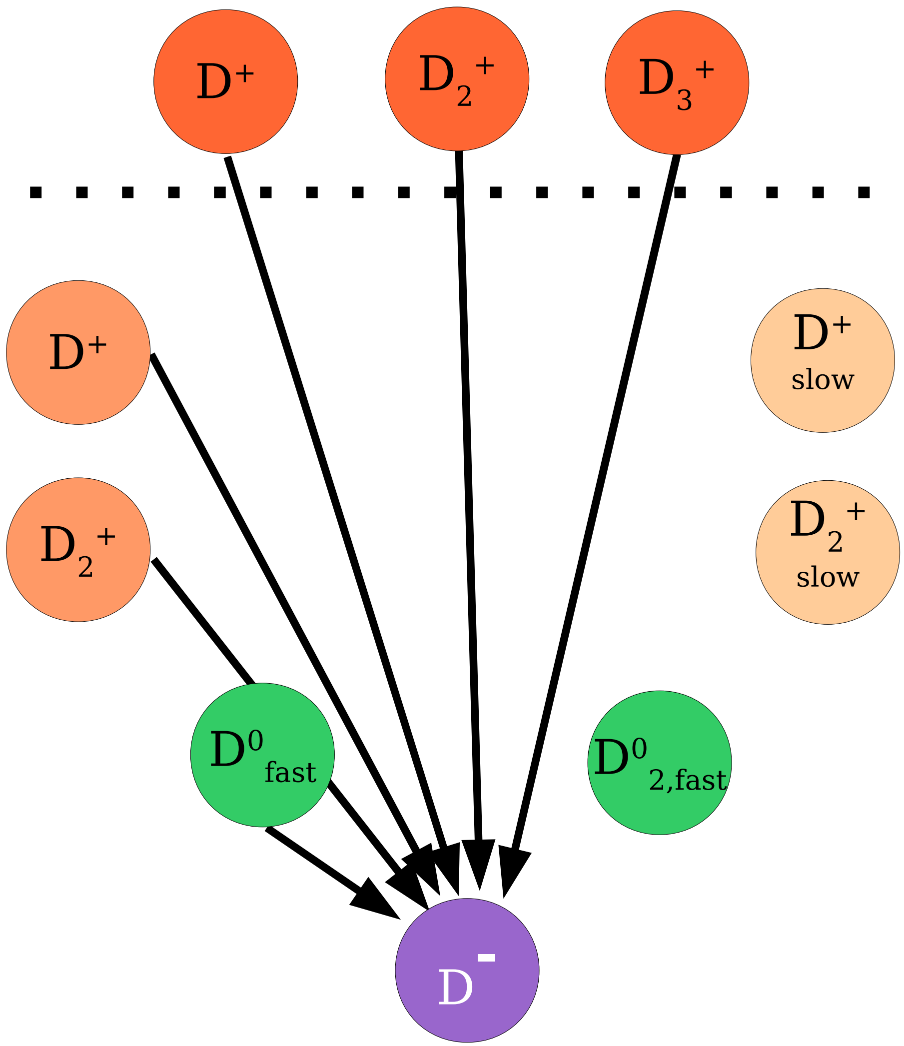
Initial intensity at cathode 0.02 [a.u.]

Negative ion physics is being added to the UW-Madison Integral Equation Code.



Negative ion physics is being added to the UW-Madison Integral Equation Code.

This function consists of two parts
Negative ion:
  Generation
  Propagation

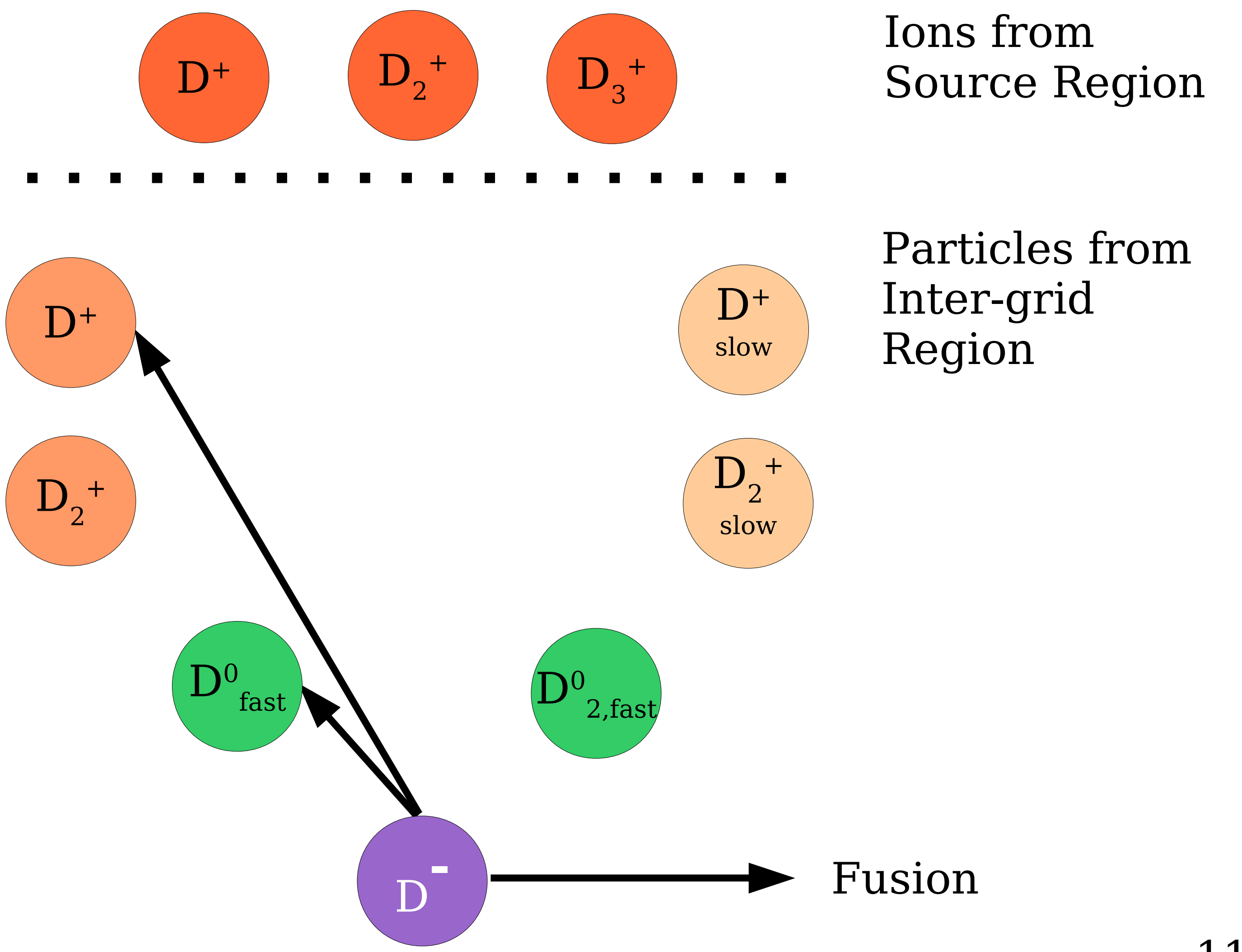


Ions from Source Region

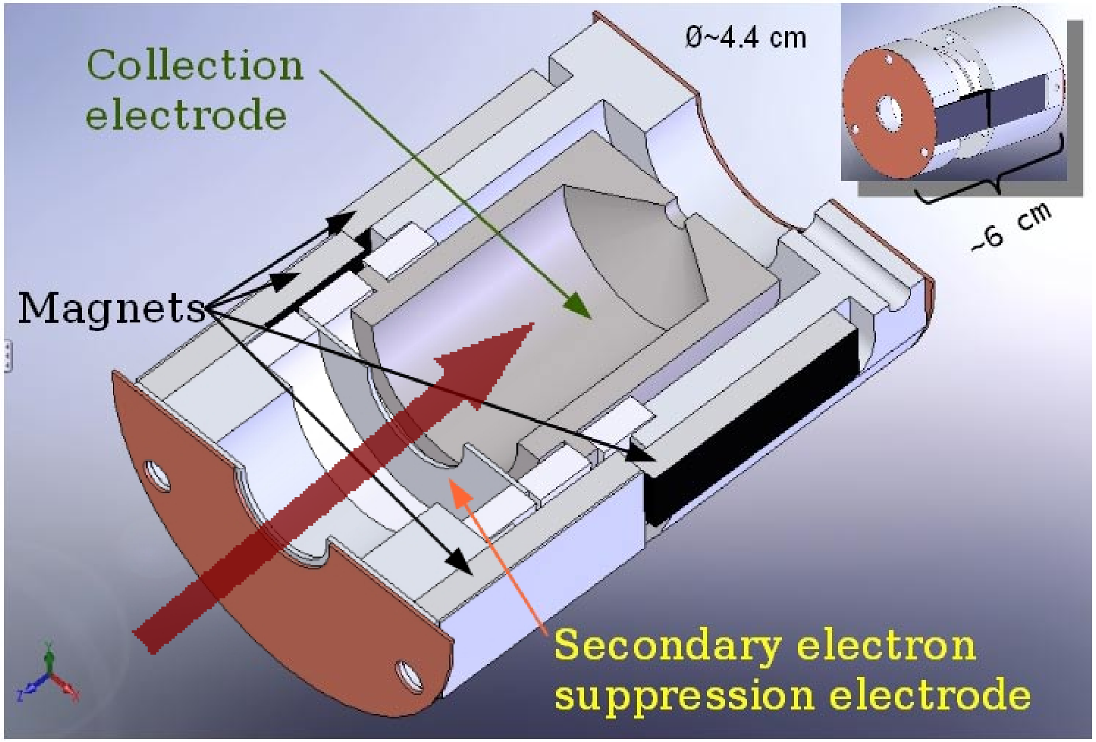
Particles from Inter-grid Region

Negative ion physics is being added to the UW-Madison Integral Equation Code.

This function consists of two parts
Negative ion:
- Generation
- **Propagation**



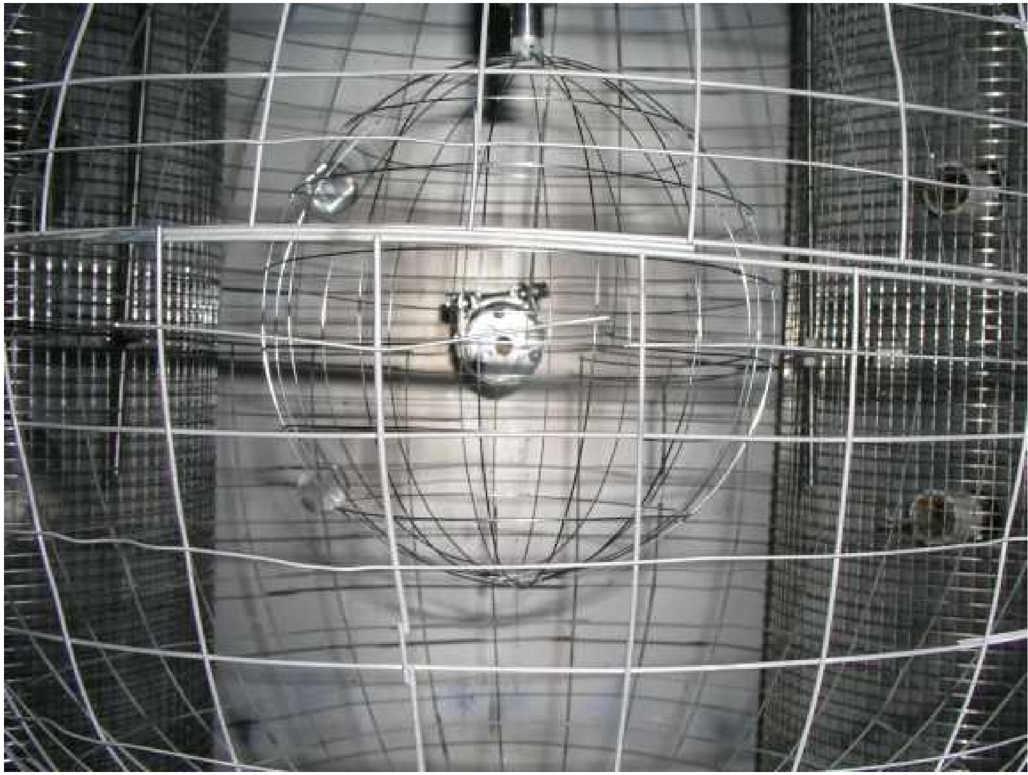
An enclosed Faraday Cup has been designed and constructed for negative ion measurement.



Negative Ion Current

The enclosed Faraday Cup has been installed in the IEC.

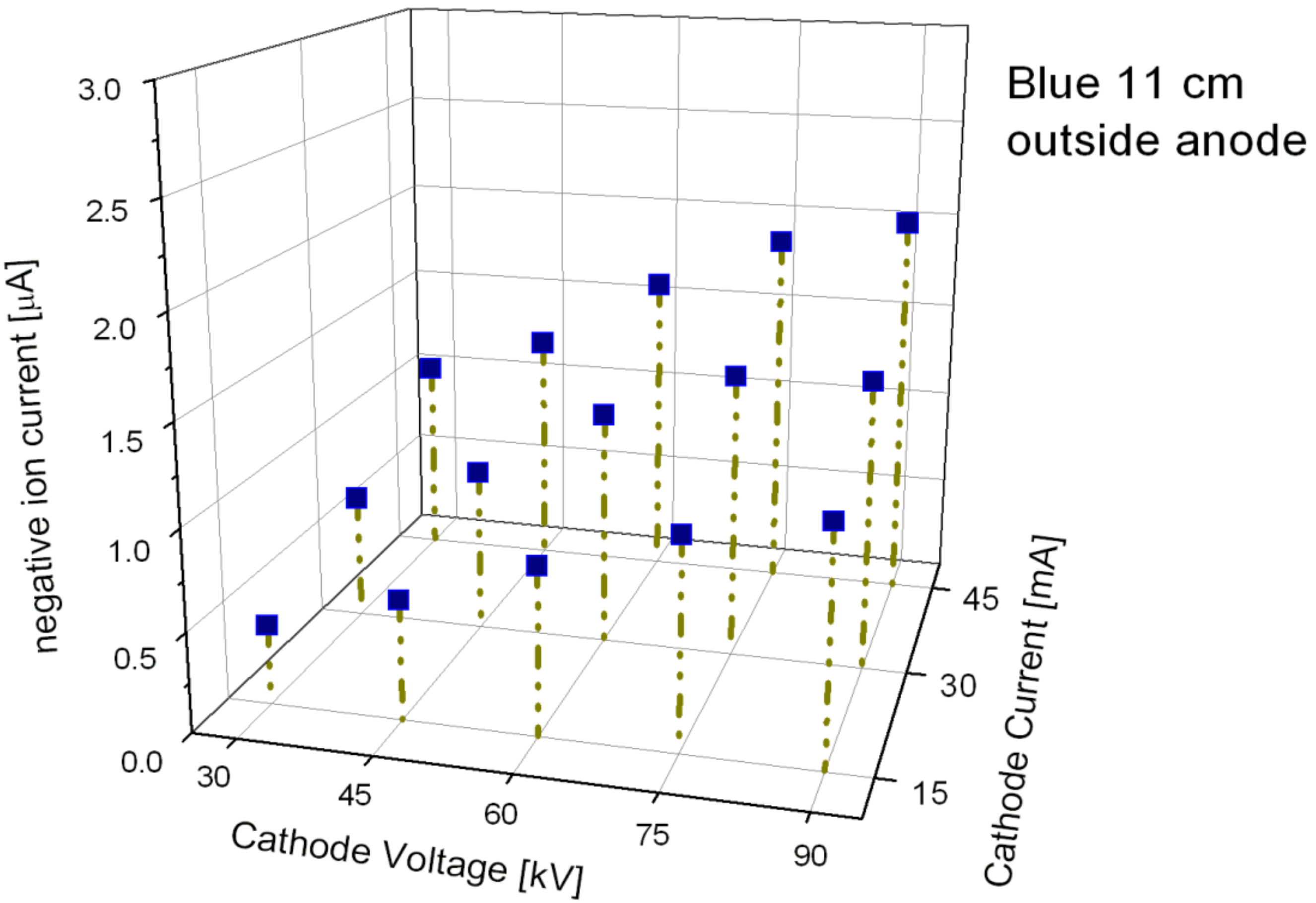
View from angle



View from across chamber

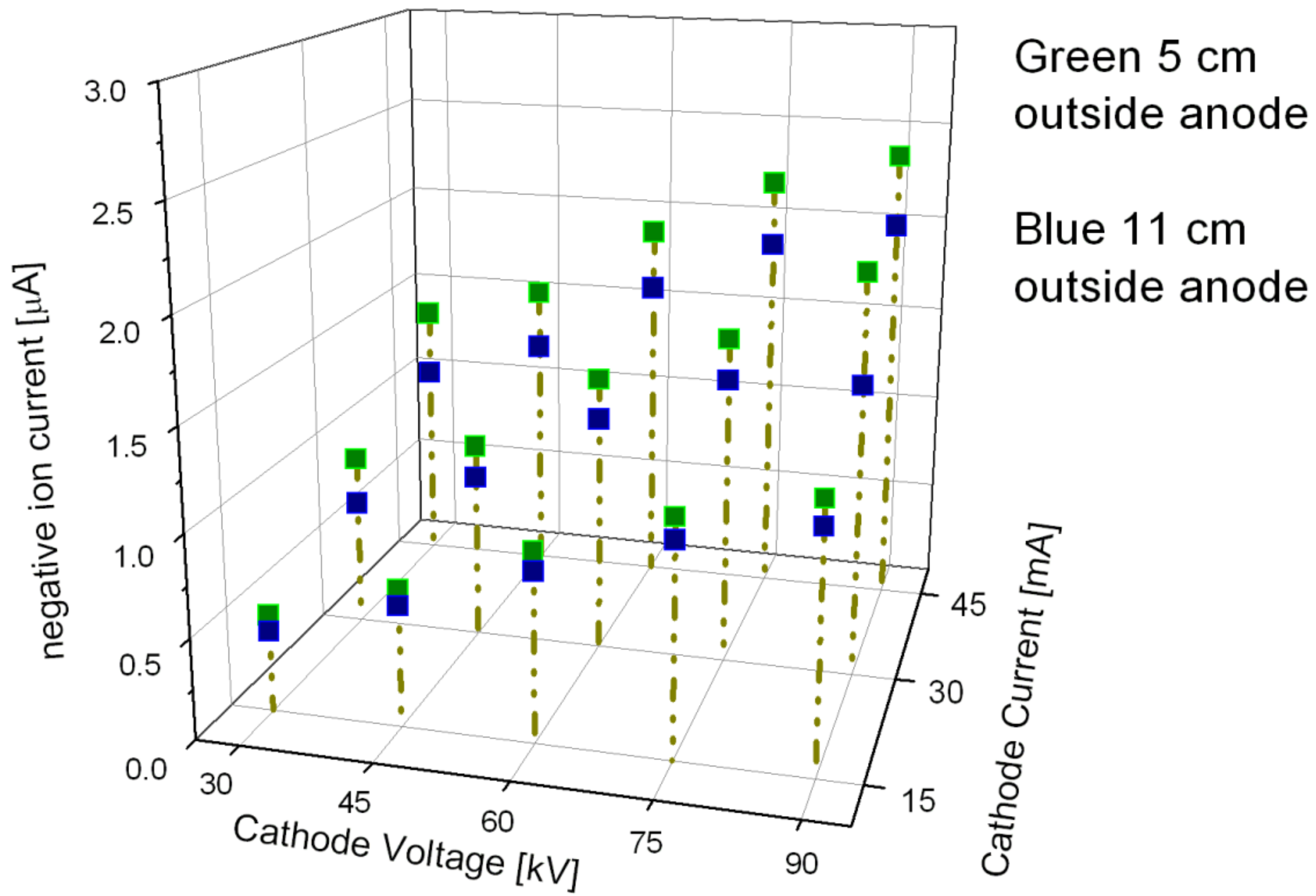
Faraday Cup Current Results
Current and Voltage Parametrics

Anode-cathode: 50-20 cm; Pressure: 2 mTorr; aligned with jet



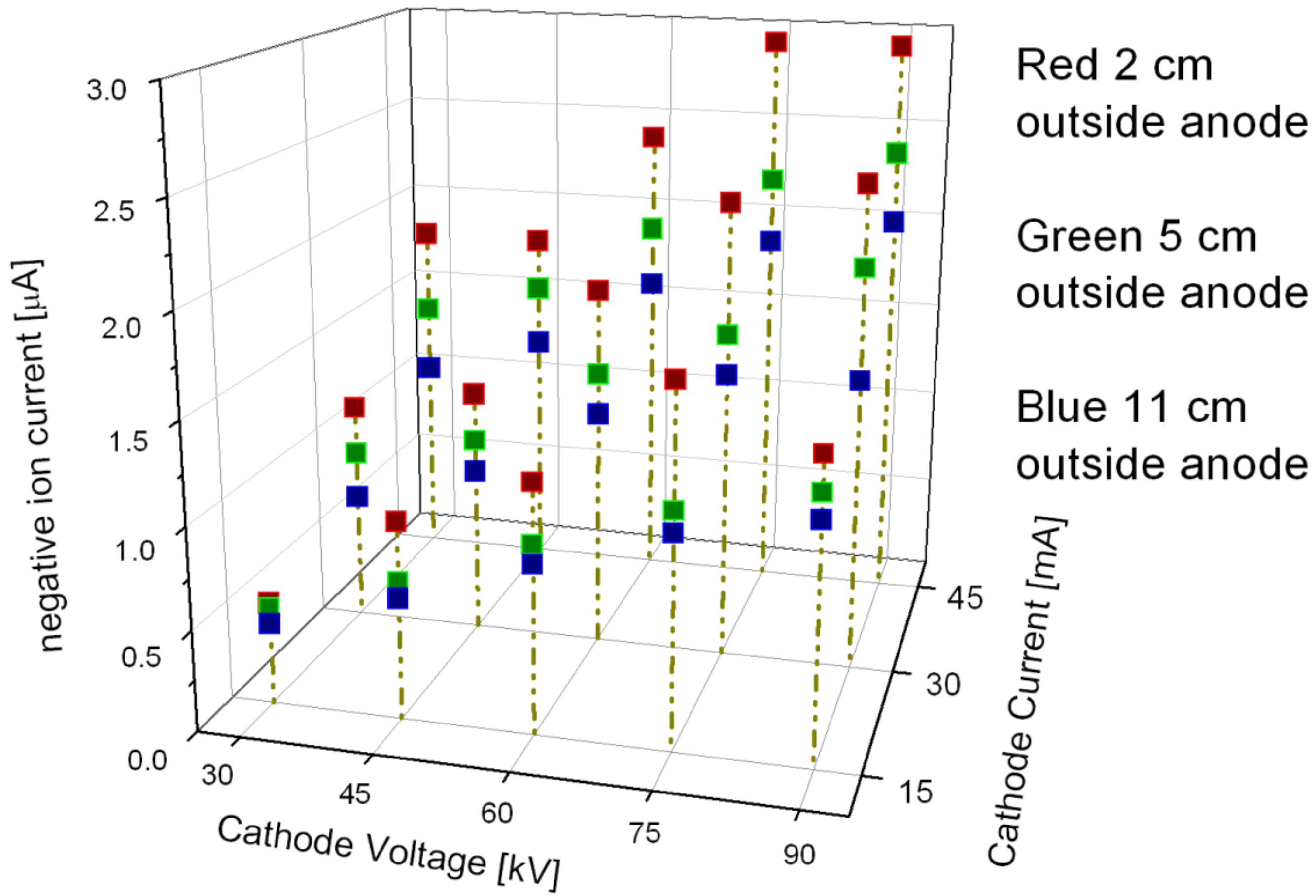
Faraday Cup Current Results
Current and Voltage Parametrics

Anode-cathode: 50-20 cm; Pressure: 2 mTorr; aligned with jet



Faraday Cup Current Results
Current and Voltage Parametrics

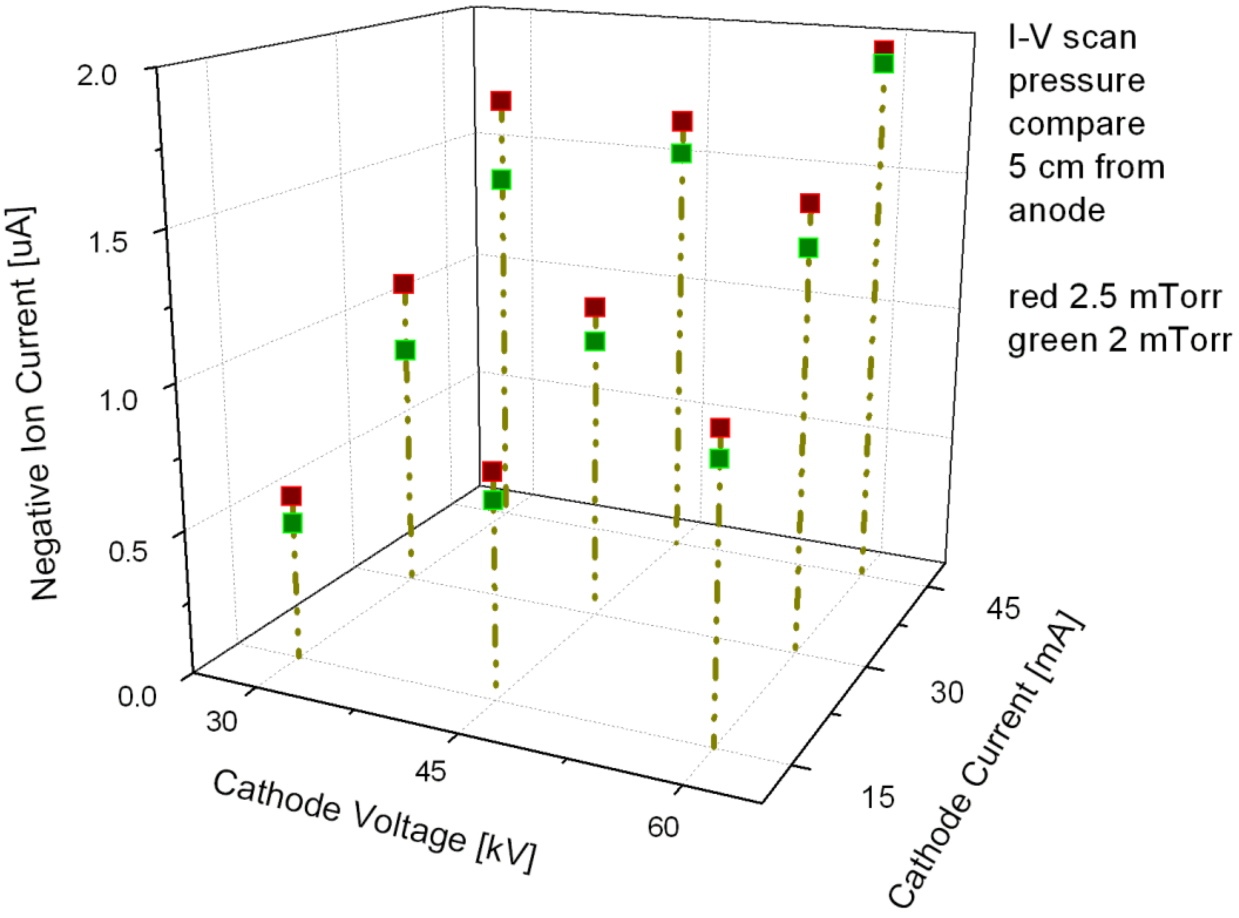
Anode-cathode: 50-20 cm; Pressure: 2 mTorr; aligned with jet



Faraday Cup Current Results Pressure Comparison

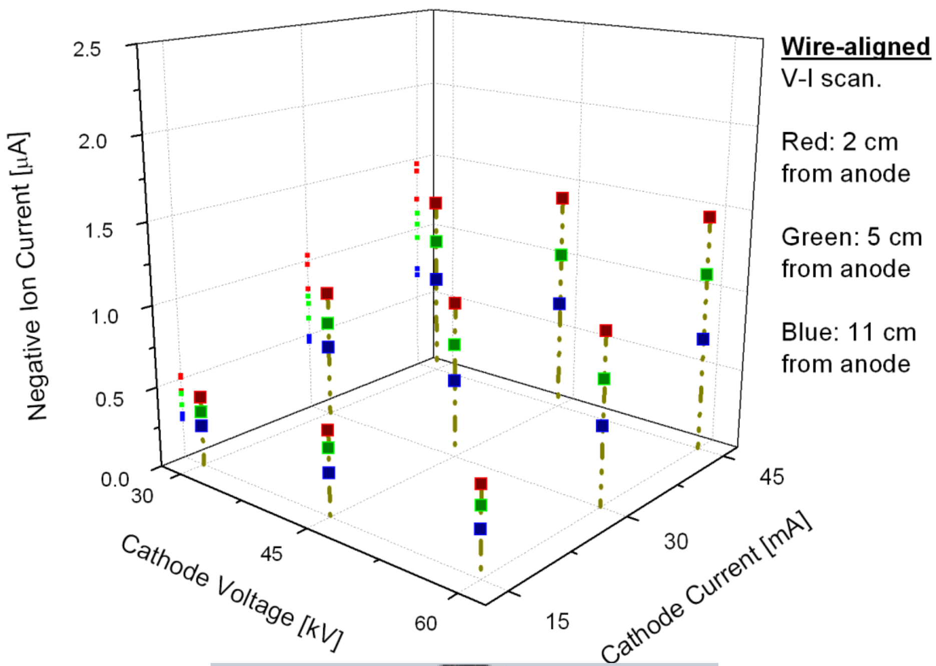
Anode-cathode: 50-20 cm;
Pressure: 2, 2.5 mTorr comparison;
aligned with jet

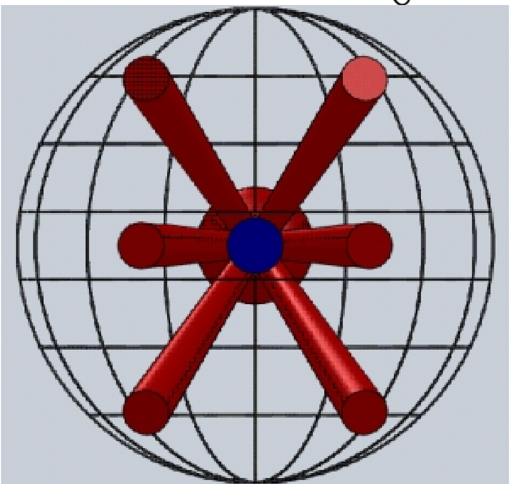
The Faraday cup has show slight but consistent increase in collected negative ion current at 2.5 mTorr over 2 mTorr

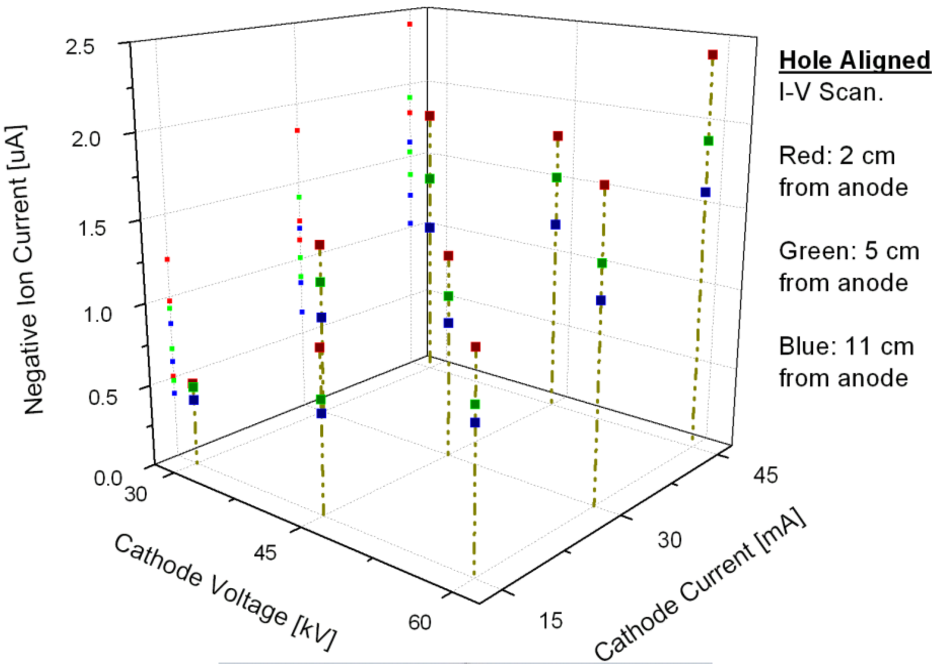


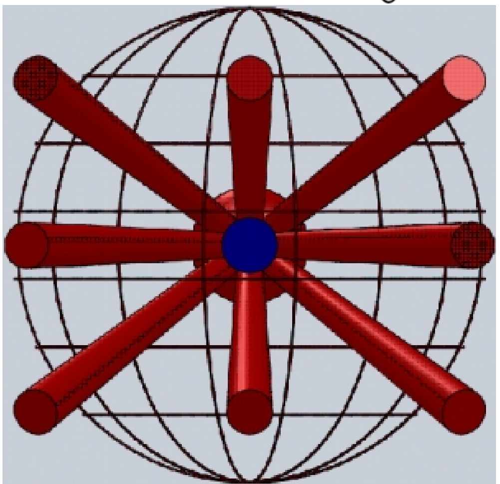
Alignment comparison shows there is 19%-135% more negative ions on jet than off.

Anode-cathode: 50-20 cm; Pressure: 2 mTorr; jet alignment comparison









Future Work

Integral Code

Complete negative ion propagation and integrate in main code

Parametrics

Extend Voltage – Current data

Pressure

Anode-Cathode

Longitudinal Scan

Determine total negative current in a jet

Alternate Cathode

Look for superior focusing and generation of negative ions

Explore application potential

Future Work

Integral Code

Complete negative ion propagation and integrate in main code

Parametrics

Extend Voltage – Current data

Pressure

Anode-Cathode

Longitudinal Scan

Determine total negative current in a jet

Alternate Cathode

Look for superior focusing and generation of negative ions

Explore application potential

Future Work

Integral Code

- Complete negative ion propagation and integrate in main code

Parametrics

- Extend Voltage – Current data
- Pressure
- Anode-Cathode

Longitudinal Scan

- Determine total negative current in a jet

Alternate Cathode

- Look for superior focusing and generation of negative ions
- Explore application potential

Future Work

Integral Code
- Complete negative ion propagation and integrate in main code

Parametrics
- Extend Voltage – Current data
- Pressure
- Anode-Cathode

Longitudinal Scan
- Determine total negative current in a jet

Alternate Cathode
- Look for superior focusing and generation of negative ions
- Explore application potential

Future Work

Integral Code

Complete negative ion propagation and integrate in main code

Parametrics

Extend Voltage – Current data

Pressure

Anode-Cathode

Longitudinal Scan

Determine total negative current in a jet

Alternate Cathode

Look for superior focusing and generation of negative ions

Explore application potential

Future Work

Integral Code
- Complete negative ion propagation and integrate in main code

Parametrics
- Extend Voltage – Current data
- Pressure
- Anode-Cathode

Longitudinal Scan
- Determine total negative current in a jet

Alternate Cathode
- Look for superior focusing and generation of negative ions
- Explore application potential

Future Work

Integral Code

Complete negative ion propagation and integrate in main code

Parametrics

Extend Voltage – Current data

Pressure

Anode-Cathode

Longitudinal Scan

Determine total negative current in a jet

Alternate Cathode

Look for superior focusing and generation of negative ions

Explore application potential

Conclusions

Measurements of negative ion current aligned with cathode jet show:
- Clear dependence on cathode voltage and current
- Reduction in current collected with increasing distance from anode
  - but without clear radial scaling
- Dependence on pressure that requires greater study

Measurements of negative ion current not aligned with cathode jet show:
- Reduced negative ion current compared with jet aligned measurements
- Much less dependence on cathode voltage

Forthcoming parameterization should reveal:
- Improved understanding of IEC physics

Conclusions

Measurements of negative ion current aligned with cathode jet show:

- Clear dependence on cathode voltage and current
- Reduction in current collected with increasing distance from anode
    - but without clear radial scaling
- Dependence on pressure that requires greater study

Measurements of negative ion current not aligned with cathode jet show:

- Reduced negative ion current compared with jet aligned measurements
- Much less dependence on cathode voltage

Forthcoming parameterization should reveal:

- Improved understanding of IEC physics

Conclusions

Measurements of negative ion current aligned with cathode jet show:

- Clear dependence on cathode voltage and current
- Reduction in current collected with increasing distance from anode
  - but without clear radial scaling
- Dependence on pressure that requires greater study

Measurements of negative ion current not aligned with cathode jet show:

- Reduced negative ion current compared with jet aligned measurements
- Much less dependence on cathode voltage

Forthcoming parameterization should reveal:

- Improved understanding of IEC physics

Conclusions

Measurements of negative ion current aligned with cathode jet show:
- Clear dependence on cathode voltage and current
- Reduction in current collected with increasing distance from anode
  - but without clear radial scaling
- Dependence on pressure that requires greater study

Measurements of negative ion current not aligned with cathode jet show:
- Reduced negative ion current compared with jet aligned measurements
- Much less dependence on cathode voltage

Forthcoming parameterization should reveal:
- Improved understanding of IEC physics

Conclusions

Measurements of negative ion current aligned with cathode jet show:

- Clear dependence on cathode voltage and current
- Reduction in current collected with increasing distance from anode
  - but without clear radial scaling
- Dependence on pressure that requires greater study

Measurements of negative ion current not aligned with cathode jet show:

- Reduced negative ion current compared with jet aligned measurements
- Much less dependence on cathode voltage

Forthcoming parameterization should reveal:

- Improved understanding of IEC physics

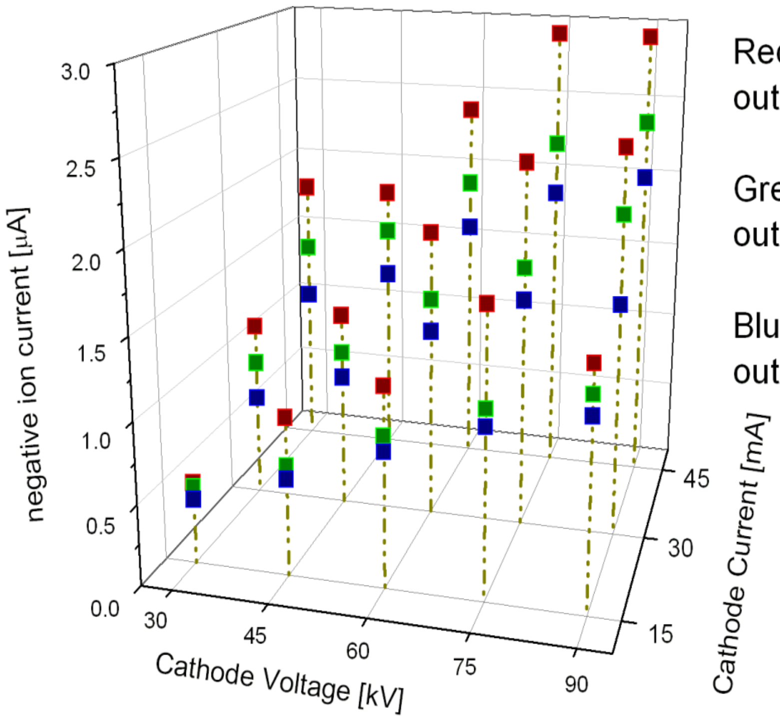
Conclusions

Measurements of negative ion current aligned with cathode jet show:
- Clear dependence on cathode voltage and current
- Reduction in current collected with increasing distance from anode but without clear radial scaling
- Dependence on pressure that requires greater study

Measurements of negative ion current not aligned with cathode jet show:
- Reduced negative ion current compared with jet aligned measurements
- Much less dependence on cathode voltage

Forthcoming parameterization should reveal:
- Improved understanding of IEC physics

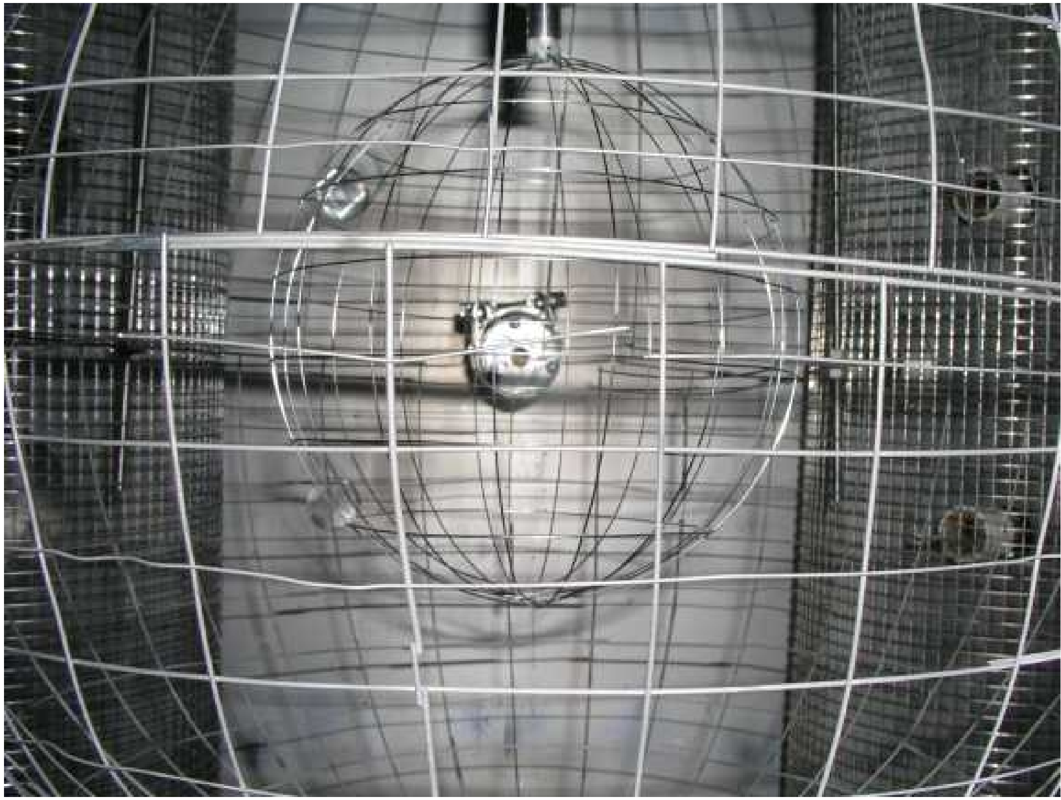
Questions?



Red 2 cm outside anode

Green 5 cm outside anode

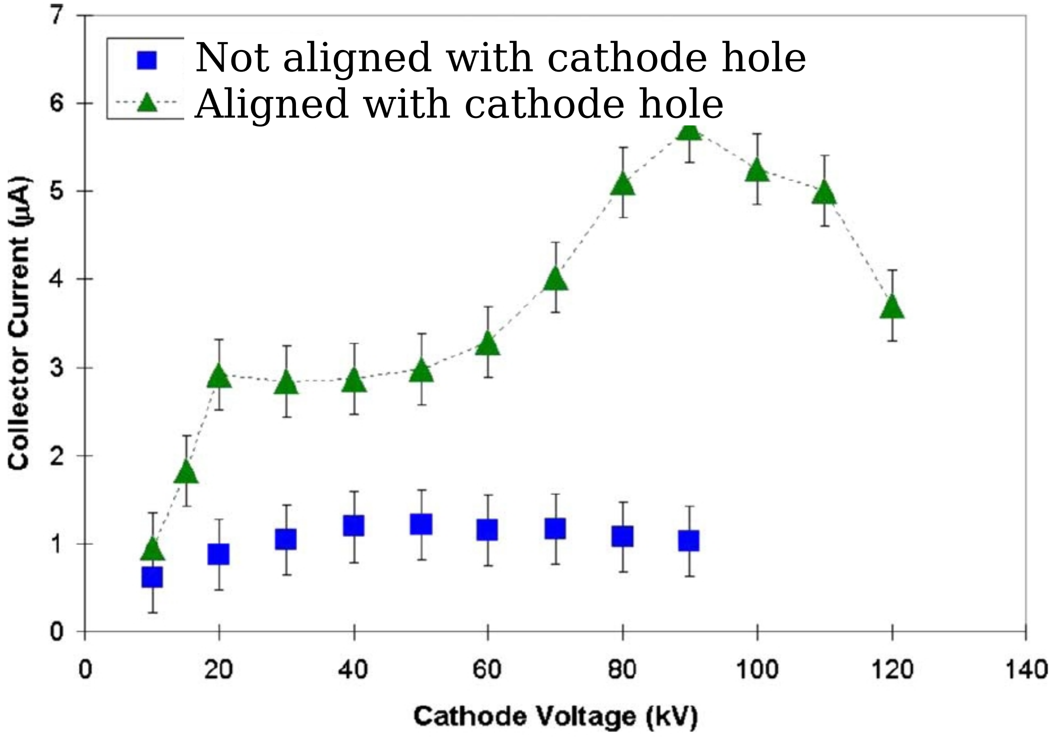
Blue 11 cm outside anode



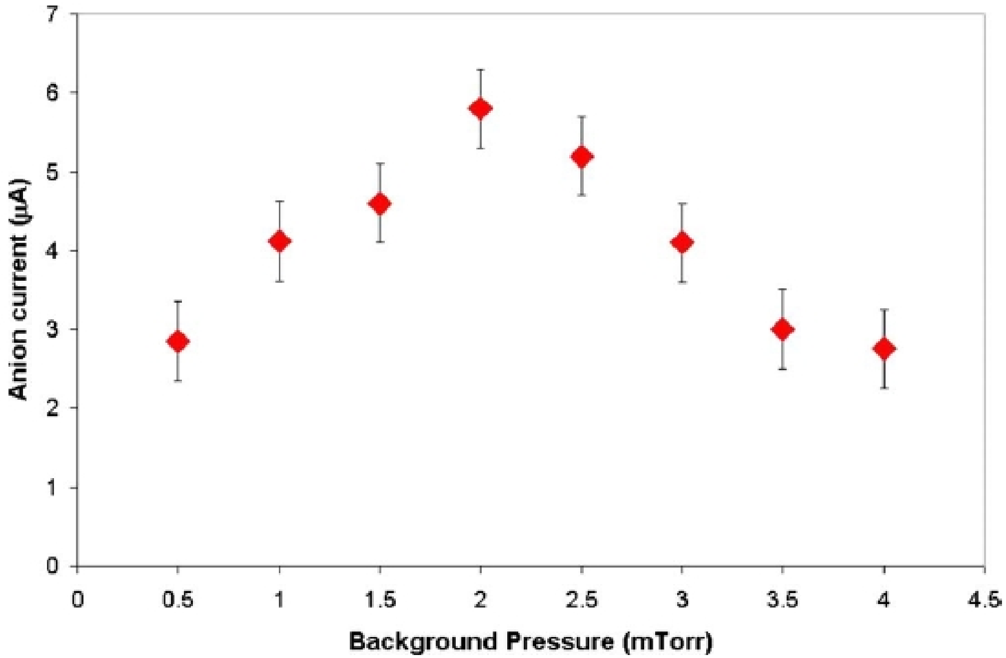
Thank you for your attention.

Negative Ion Parametrics
Anode-Cathode: 50-20 cm

30 mA; 2 mTorr



100 kV; 30 mA,



Current collected in Faraday Trap

Potential Applications

IEC Physics diagnostic

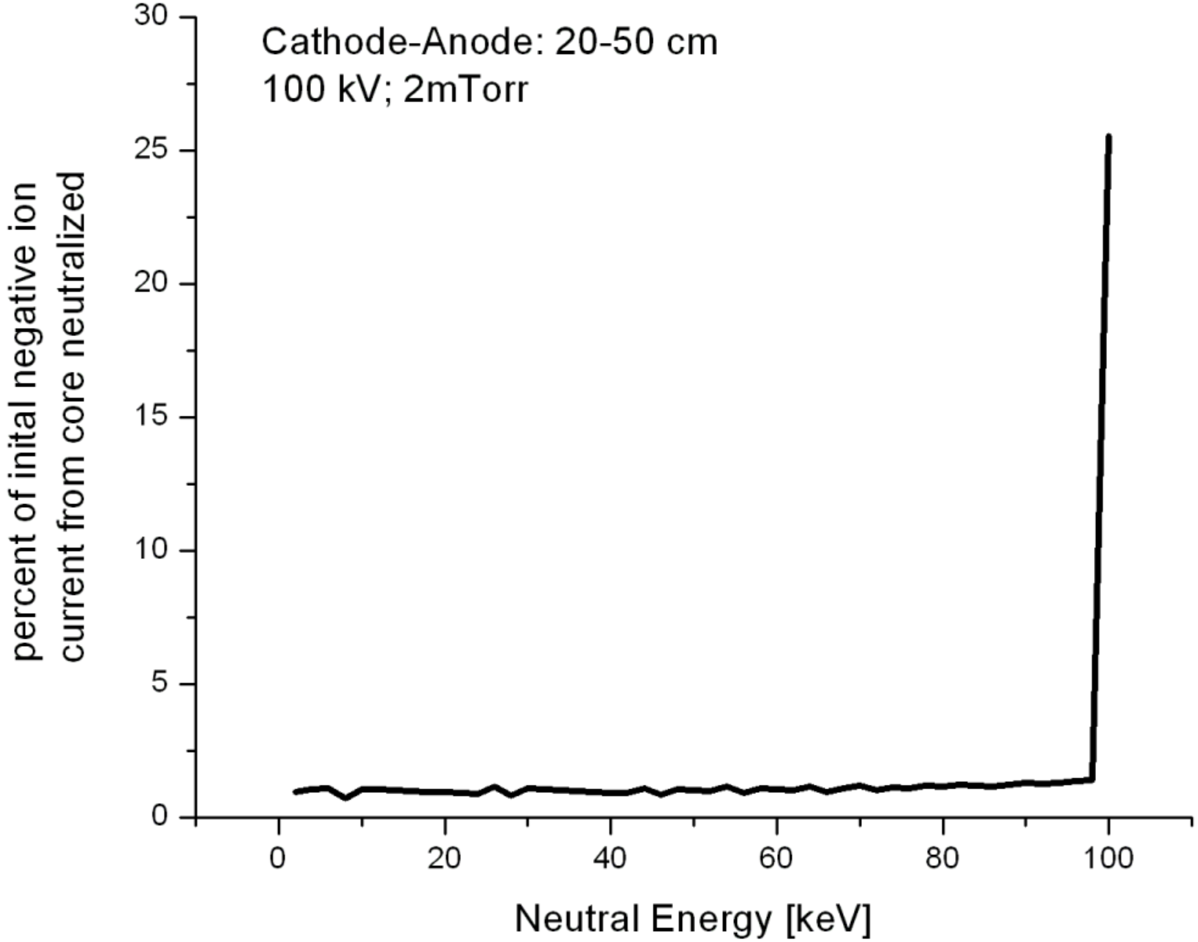
Atomic and Molecular Physics

Space Thruster

Plasma Processing

Fusion Technology

Fast Neutral from Cathode Born Negative Ion Spectrum



Radial Dependence Plots