Modeling D-D Operation of the UW IEC Experiment

J.F. Santarius, R.P. Ashley, G.L. Kulcinski, B.B. Cipiti, S.Krupakar Murali, G.R. Piefer, R.F. Radel, J.W. Weidner

Fusion Technology Institute
University of Wisconsin

US-Japan IEC Workshop , University of Wisconsin, October 9-10, 2002

Outline

- **Atomic physics and current generation considerations**
- **Improvements to speed of code**
- **Results of modeling ion and electron currents in the UW IEC device**
- **Neutron and proton production predictions and comparison with experiment**

Atomic Physics Cross Sections Were Corrected to Use keV/amu

Example: D^+ D^0 Charge Exchange as Implemented in Mathematica Notebook

■ H^+ charge-exchange with H^0(G)

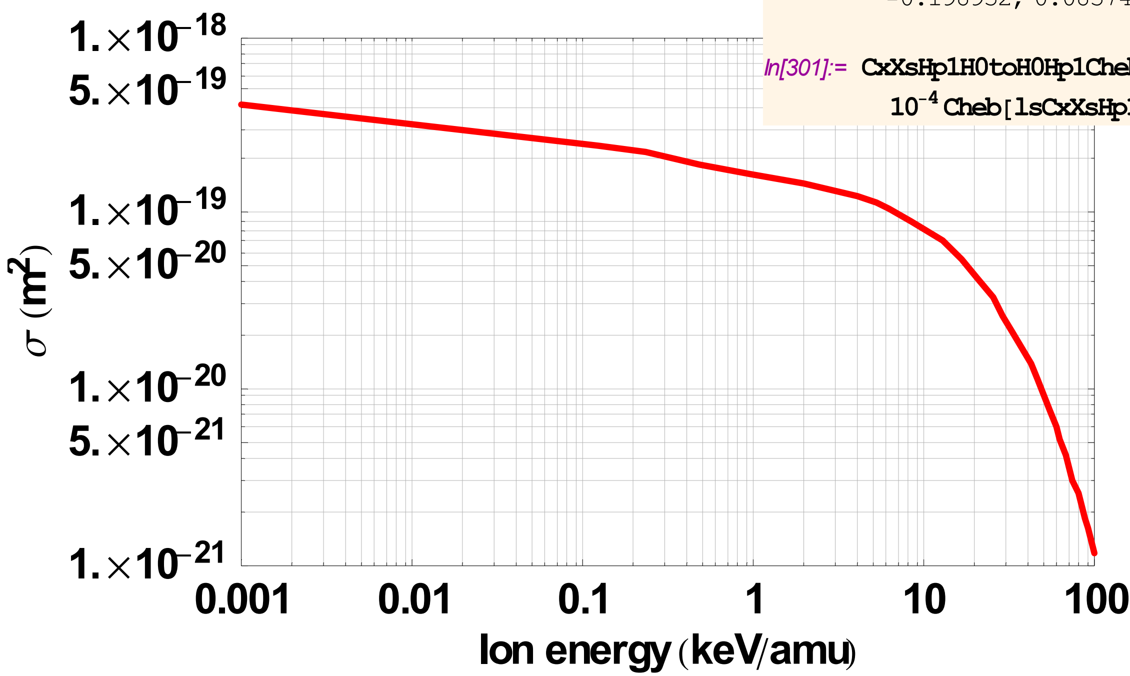
■ σ

□ Chebyshev fit

```
In[300]:= lsCxXsHp1H0toH0Hp1Cheb =
            Import[dataDir <> "cx_xs_H+H0toH0H+_cheb.dat"][[{3, 4}]] //
             Flatten

Out[300]= {-72.6656, -5.49142, -3.42948, -1.98377, -0.878009,
            -0.198932, 0.0837431, 0.121252, 0.0827182, 0.12, 630000.}

In[301]:= CxXsHp1H0toH0Hp1Cheb[amu_, EkeV_] =
            10^-4 Cheb[lsCxXsHp1H0toH0Hp1Cheb, EkeV / amu];
```



Data comes from the IAEA AMDIS database.

Many Atomic Physics Reactions Have Been Implemented

THE UNIVERSITY of WISCONSIN MADISON

Fitting functions and data input directory

Neutral-neutral and ion-neutral elastic collisions

Charge exchange

- H^+ charge-exchange with H^0(G)
- H^+ charge-exchange with H_2^0(G)
- H^+ charge-exchange with He^0(G)
- H^+ charge-exchange with He^+(G)
- He^+ charge-exchange with H^0(G)
- He^+ charge-exchange with He^0(G)
- He^+ charge-exchange with He^+(G)
- Combined H^+ charge-exchange plots
- Combined H^+ and He^+ charge-exchange plots

Dissociation

- H^0 ionization and dissociation of H_2^0(G)
- H^+ ionization and dissociation of H_2^0(G)
- He^+ ionization and dissociation of H_2^0(G)
- e^- ionization and dissociation of H_2^0(G)

Ionization

- H^0 ionization of H_2^0(G)
- H^+ ionization of H^0(G)
- H^+ ionization of H_2^0(G)
- H^+ ionization of He^0(G)
- H^+ ionization of He^+(G)
- Combined H^+ ionization plots
- He^+ ionization of H^0(G)
- He(2s1) Penning ionization of H^0(G)
- He^+ ionization of He^0(G)
- He^+ ionization of He^+(G)
- He^{+2} ionization of He^0(G)
- He^{+2} double ionization of He^0(G)
- Combined He^+ and He^{++} ionization plots
- e^- ionization of H^0(G)
- e^- ionization of H_2^0
- e^- ionization of He^0
- e^- ionization of He^+
- Combined monoenergetic e^- ionization cross-section plots
- Combined Maxwellian e^- ionization reaction rate plots

Secondary electron emission

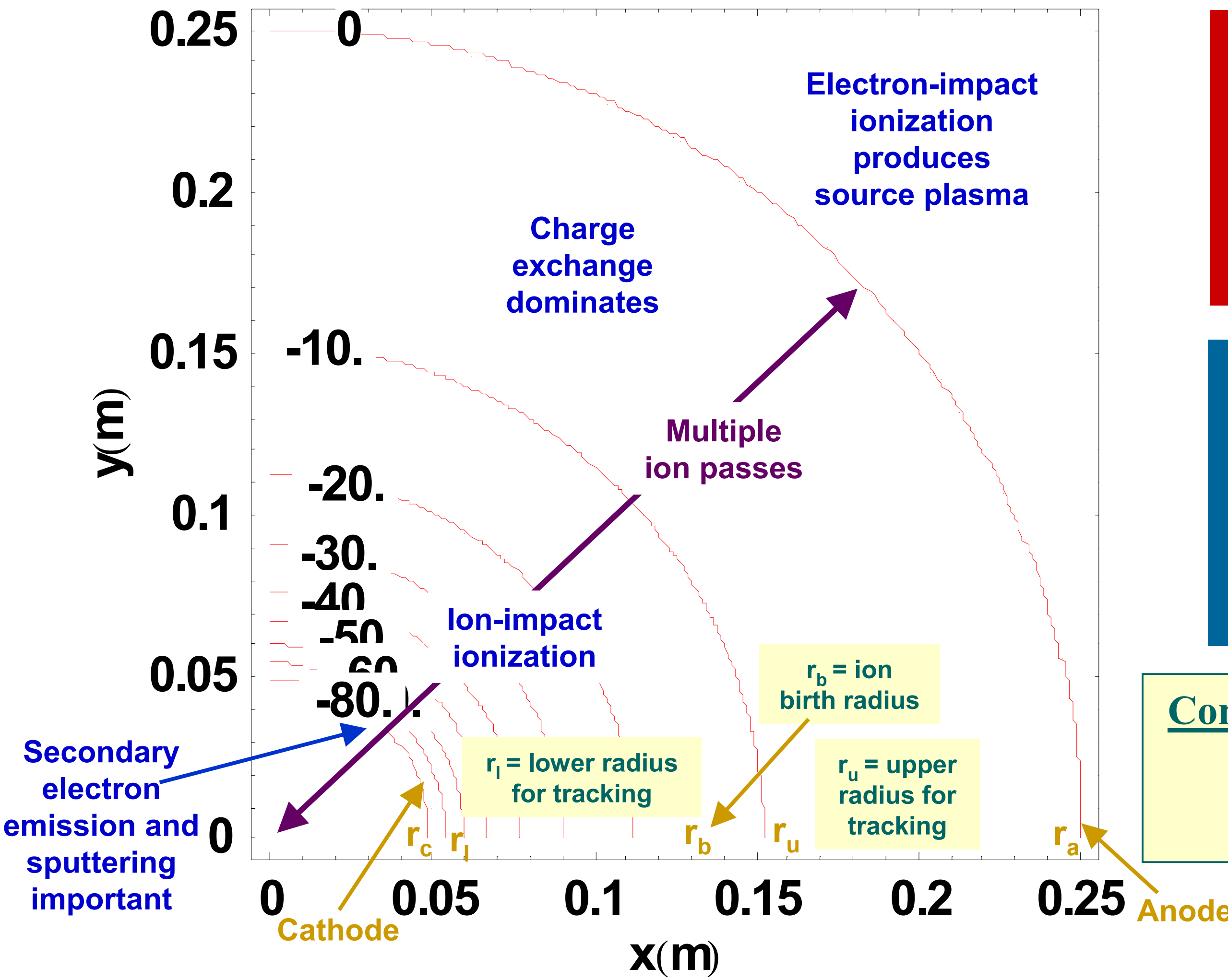
Sputtering

UW Experiment
Key Modeling Input Parameters

Fuel	D only
Neutral gas pressure	0.27 Pa (2 mtorr)
Neutral gas density	6.4×10^{19} m^{-3}
Anode radius	0.25 m
Cathode radius	0.05 m
Grid potential difference	80 kV

THE UNIVERSITY of WISCONSIN MADISON

Atomic Physics Effects Dominate the Present Operating Regime



Child-Langmuir potential contours shown in red

0.1-1 Pa (~1-10 mtorr) moderately collisional plasma

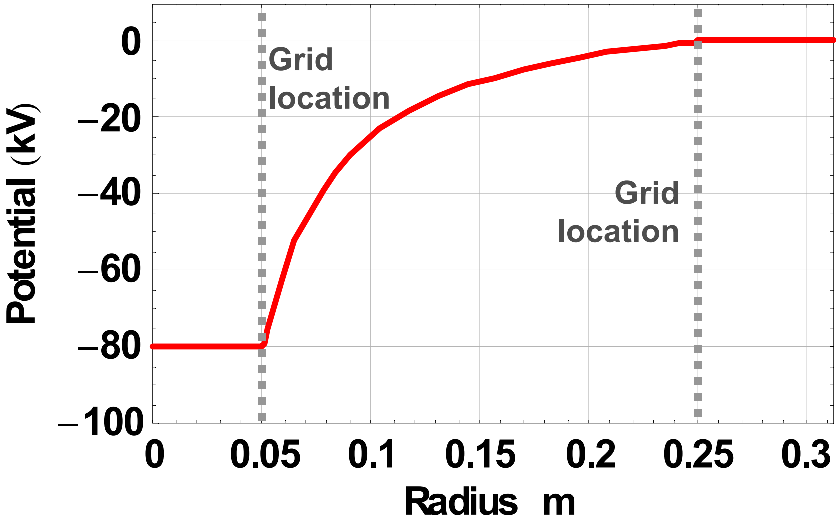
<u>Conditions for ion tracking</u>

$V_a - V(r_u) = 10$ kV

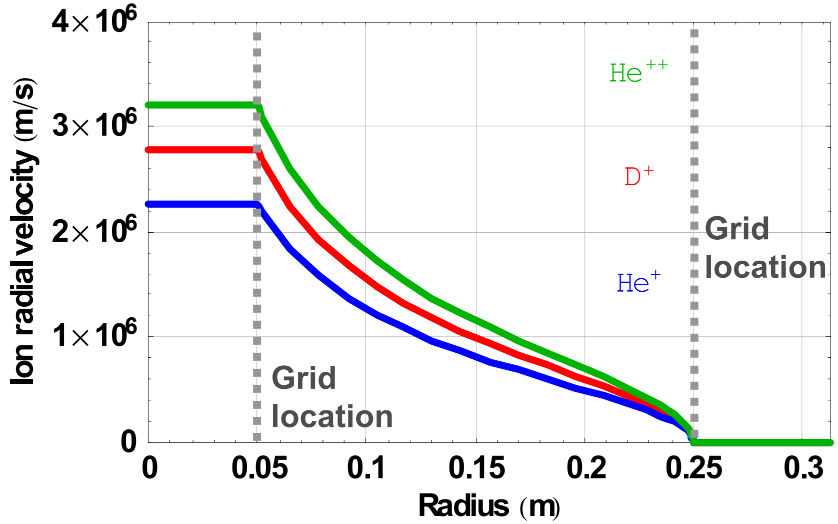
$V(r_l) - V_c = 10$ kV

Child-Langmuir Electrostatic Potential Profile Is Calculated and Used to Generate Radial Velocity Profile

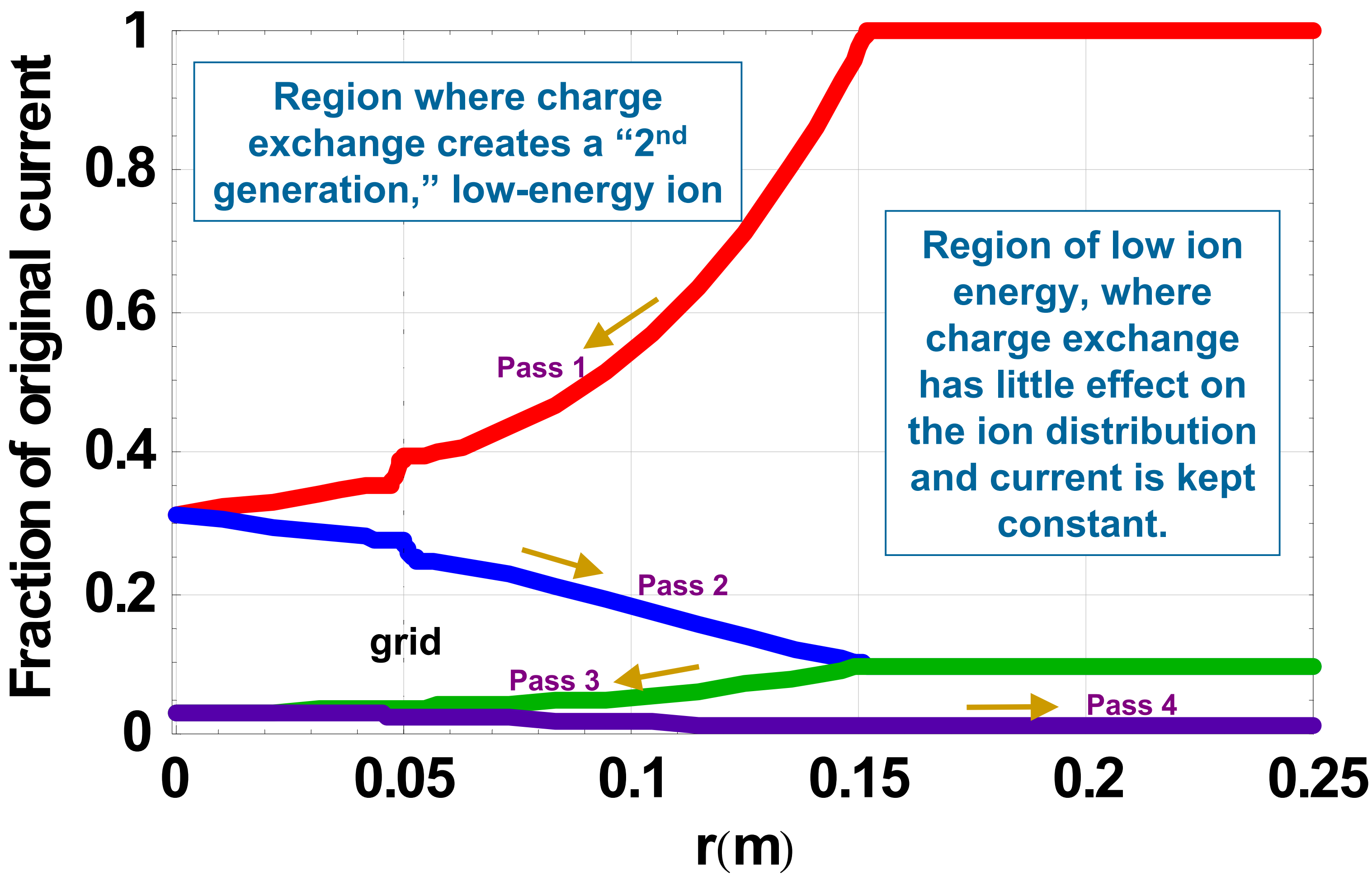
Child-Langmuir radial potential profile



Resulting radial velocity profile

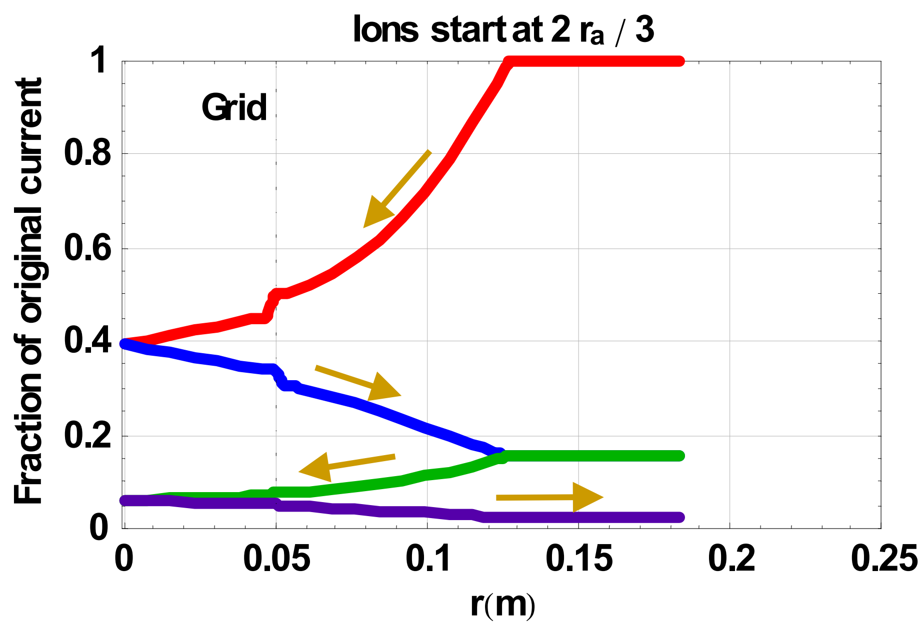


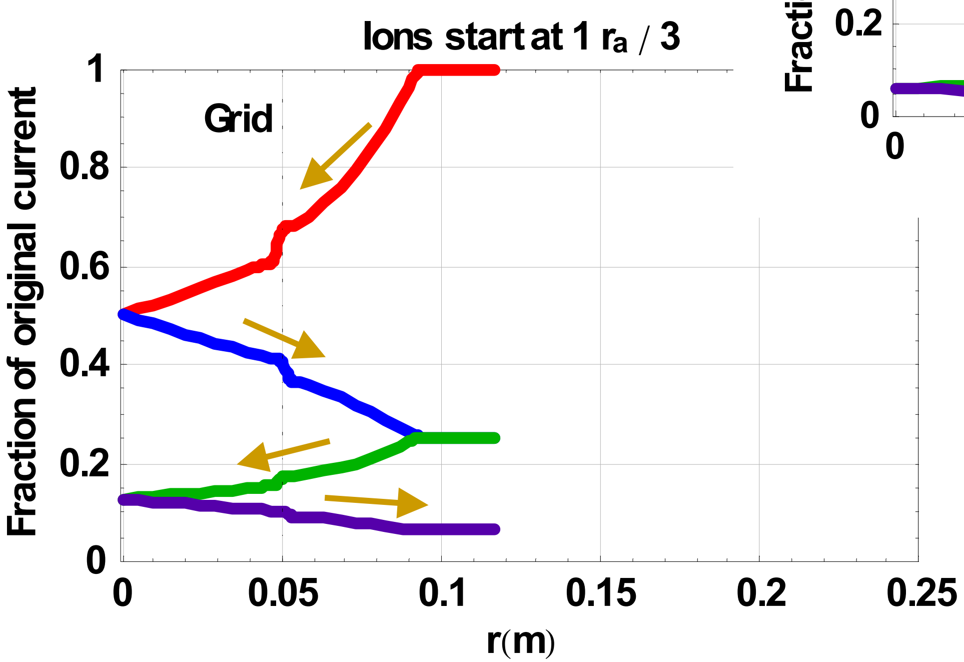
Charge Exchange "Attenuates" Initial Ion Current as Ions Oscillate Radially



Similar, but Not the Same, Behavior Occurs for Ions Born at Radii Smaller than the Anode Radius

Evolution of ions that start at $r_a/3$ or $2r_a/3$

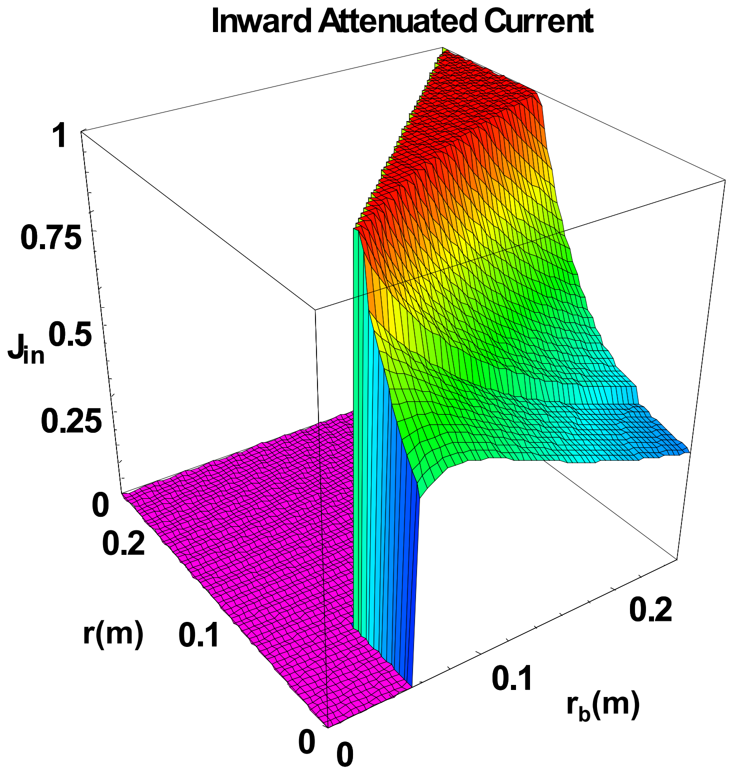




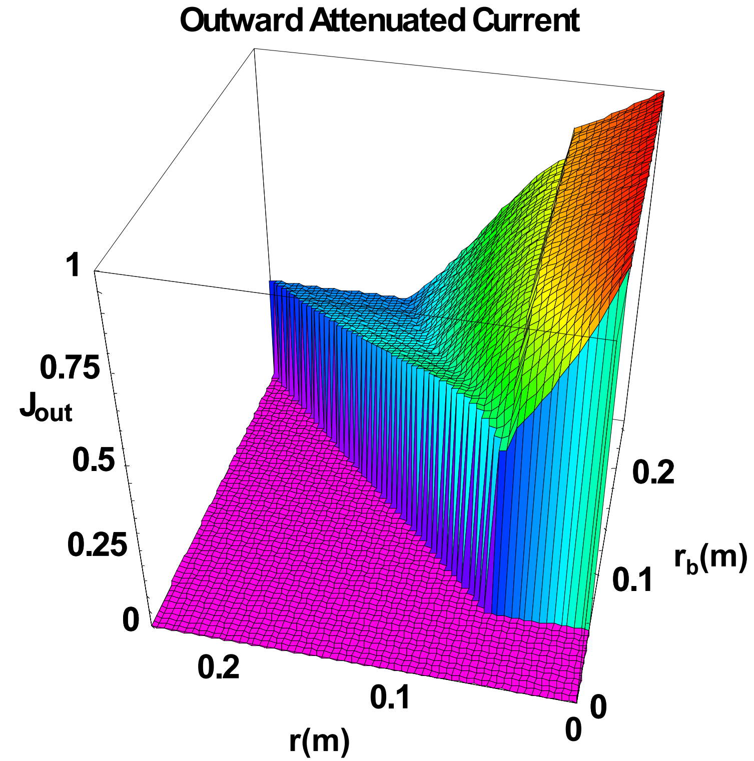
Ion-Current at Radial Position *r* Can Be Calculated for Arbitrary Birth Position r_b

- Fitting these functions (using Mathematica's *ListInterpolate* function) sped up key calculations by >500 times.

Ions starting at $r = r_b$



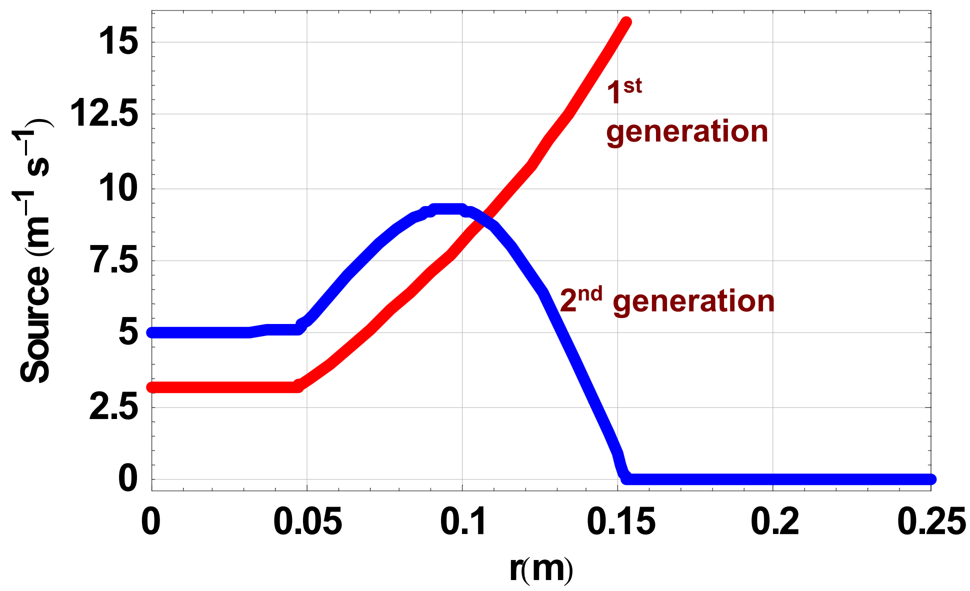
Ions starting at $r = 0$



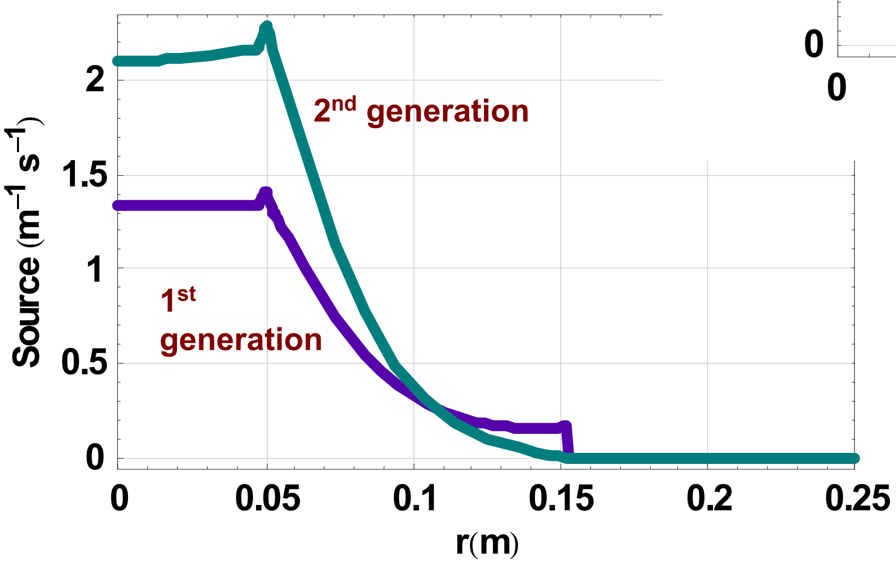
Charge-Exchange and Ionization Events Create New-Generation Deuterons and Electrons

Creation rates for first two generations of deuterons and electrons

New-Generation Deuteron Production Rate



New-Generation Electron Production Rate



Two-Generation Calculation of Proton Production Falls Short of Experimental Value

- Experimental D-D proton production at 80 kV and 30 mA is 2×10^7 protons/s
- Two-generations of the present computational method give $\sim 10^6$ protons/s total
  - Main contribution stems from charge-exchange neutrals and radially moving ions reacting with background gas.
  - Converged-core and counter-streaming-ion fusion terms give very small contributions.
- Following several generations of ions may pick up the factor of ~20 required to agree with experiment.
- Neglected effects, such as fusion of embedded ions, may also contribute.

Summary

- **Fitting current attenuation functions instead of calculating integrals as needed sped up code by >500 times.**
- **Fusion product production as a function of radius has been estimated.**
  - **Using only the initial current plus first and second generations of created ions gives values ~20 times lower than those found in the UW IEC experiments.**
  - **Preliminary indications are that following several more generations of ion production may reconcile these differences.**