

Modeling D-D Operation of the UW IEC Experiment

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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⁺ D⁰ Charge
Exchange as
Implemented in
Mathematica Notebook**

■ H⁺ charge-exchange with H⁰ (G)

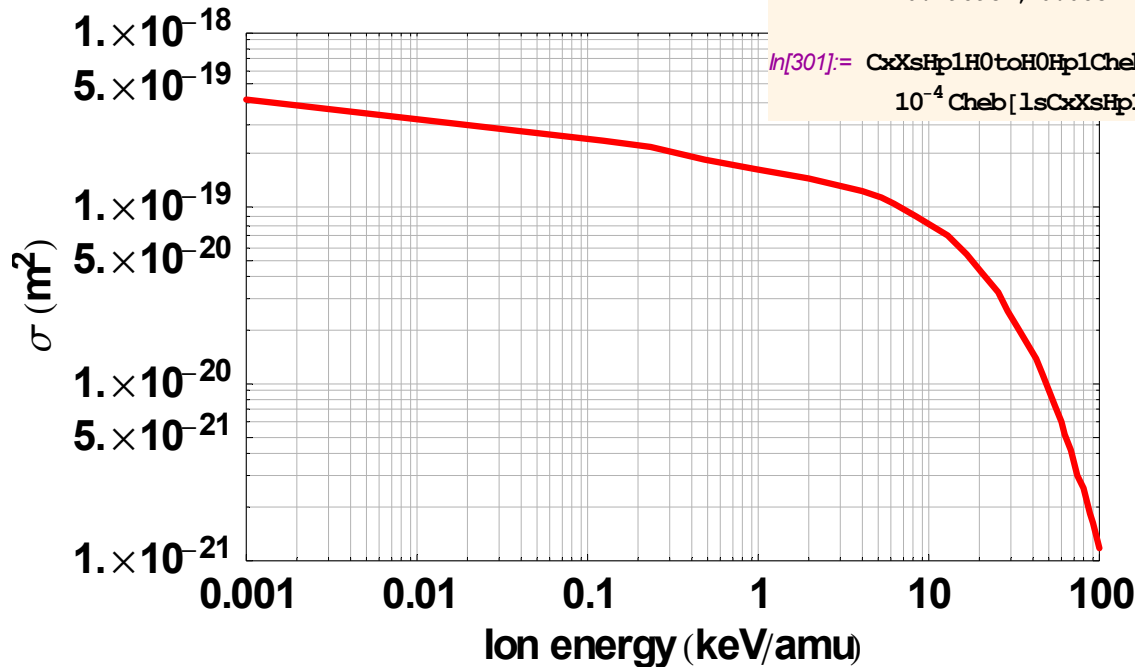
■ σ

□ 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

Fitting functions and data input directory

Neutral-neutral and ion-neutral elastic collisions

Charge exchange

- H⁺ charge-exchange with H⁰(G)
- H⁺ charge-exchange with H₂⁰(G)
- H⁺ charge-exchange with He⁰(G)
- H⁺ charge-exchange with He⁺(G)
- He⁺ charge-exchange with H⁰(G)
- He⁺ charge-exchange with He⁰(G)
- He⁺ charge-exchange with He⁺(G)
- Combined H⁺ charge-exchange plots
- Combined H⁺ and He⁺ charge-exchange plots

Dissociation

- H⁰ ionization and dissociation of H₂⁰(G)
- H⁺ ionization and dissociation of H₂⁰(G)
- He⁺ ionization and dissociation of H₂⁰(G)
- e⁻ ionization and dissociation of H₂⁰(G)

Ionization

- H⁰ ionization of H₂⁰(G)
- H⁺ ionization of H⁰(G)
- H⁺ ionization of H₂⁰(G)
- H⁺ ionization of He⁰(G)
- H⁺ ionization of He⁺(G)
- Combined H⁺ ionization plots
- He⁺ ionization of H⁰(G)
- He(2s1) Penning ionization of H⁰(G)
- He⁺ ionization of He⁰(G)
- He⁺ ionization of He⁺(G)
- He⁺² ionization of He⁰(G)
- He⁺² double ionization of He⁰(G)
- Combined He⁺ and He⁺⁺ ionization plots
- e⁻ ionization of H⁰(G)
- e⁻ ionization of H₂⁰
- e⁻ ionization of He⁰
- e⁻ ionization of He⁺
- Combined monoenergetic e⁻ ionization cross-section plots
- Combined Maxwellian e⁻ ionization reaction rate plots

Secondary electron emission

Sputtering

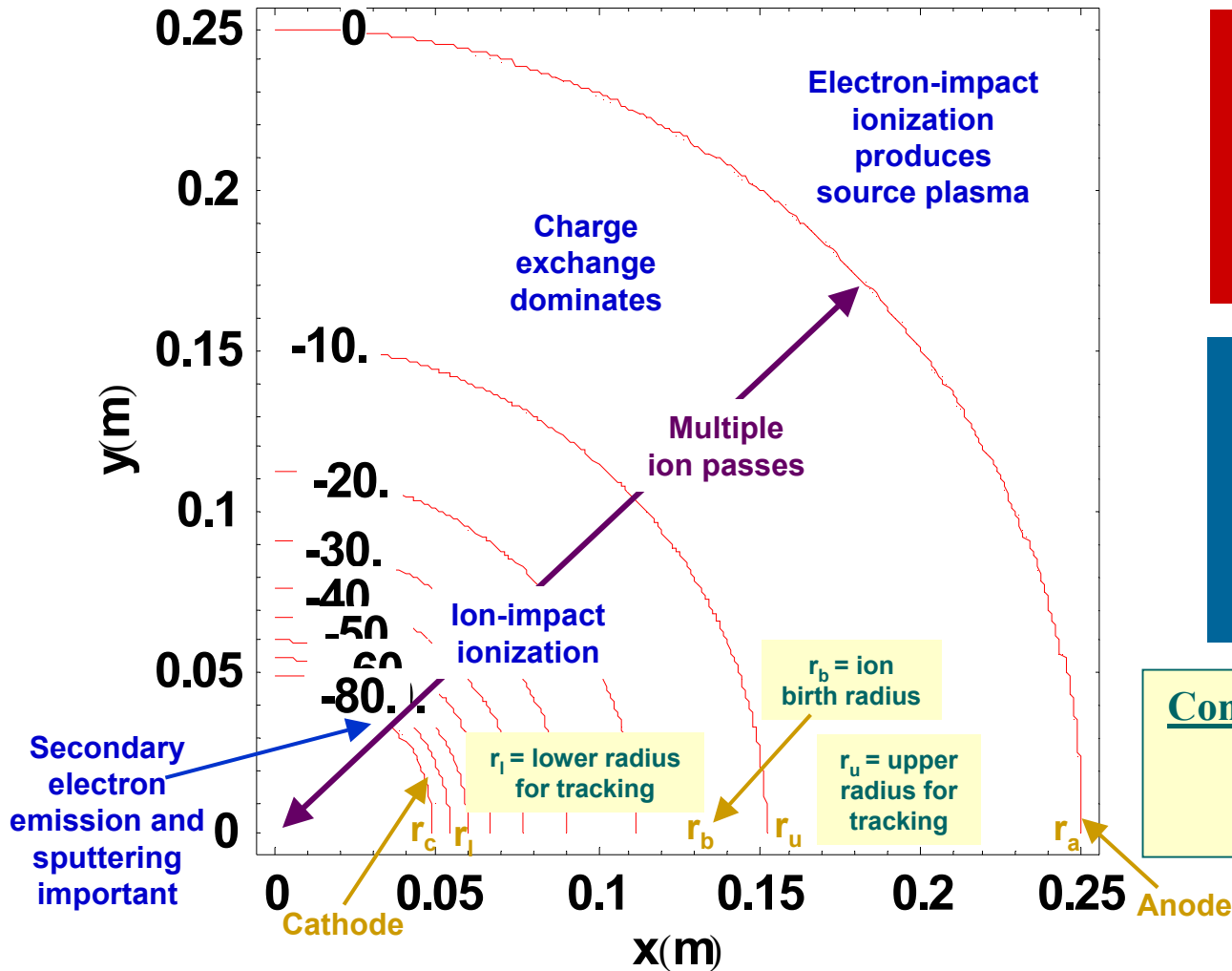
UW Experiment

Key Modeling Input Parameters

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

Atomic Physics Effects

Dominate the Present Operating Regime



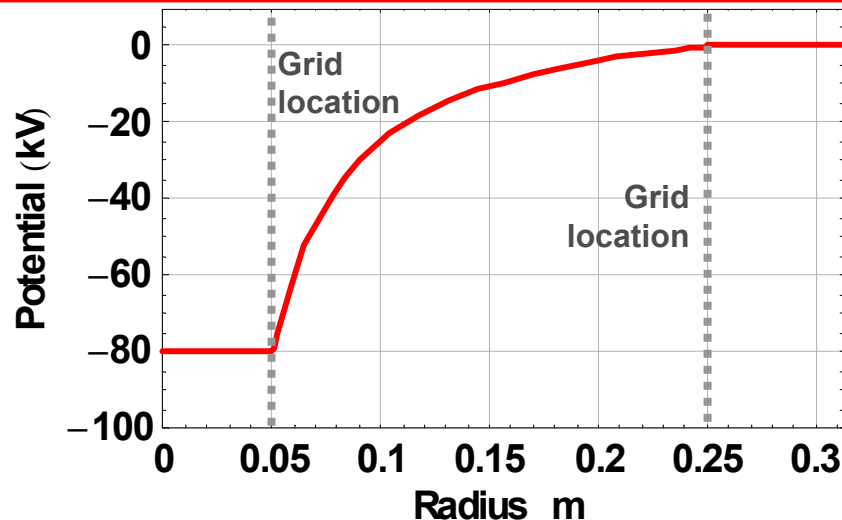
Child-Langmuir potential contours shown in red

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

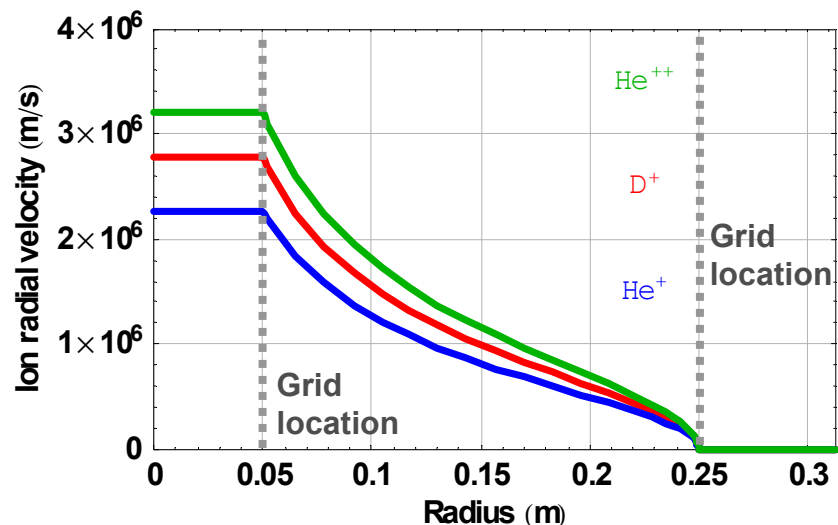
Conditions for ion tracking
 $V_a - V(r_u) = 10 \text{ kV}$
 $V(r_l) - V_c = 10 \text{ kV}$

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

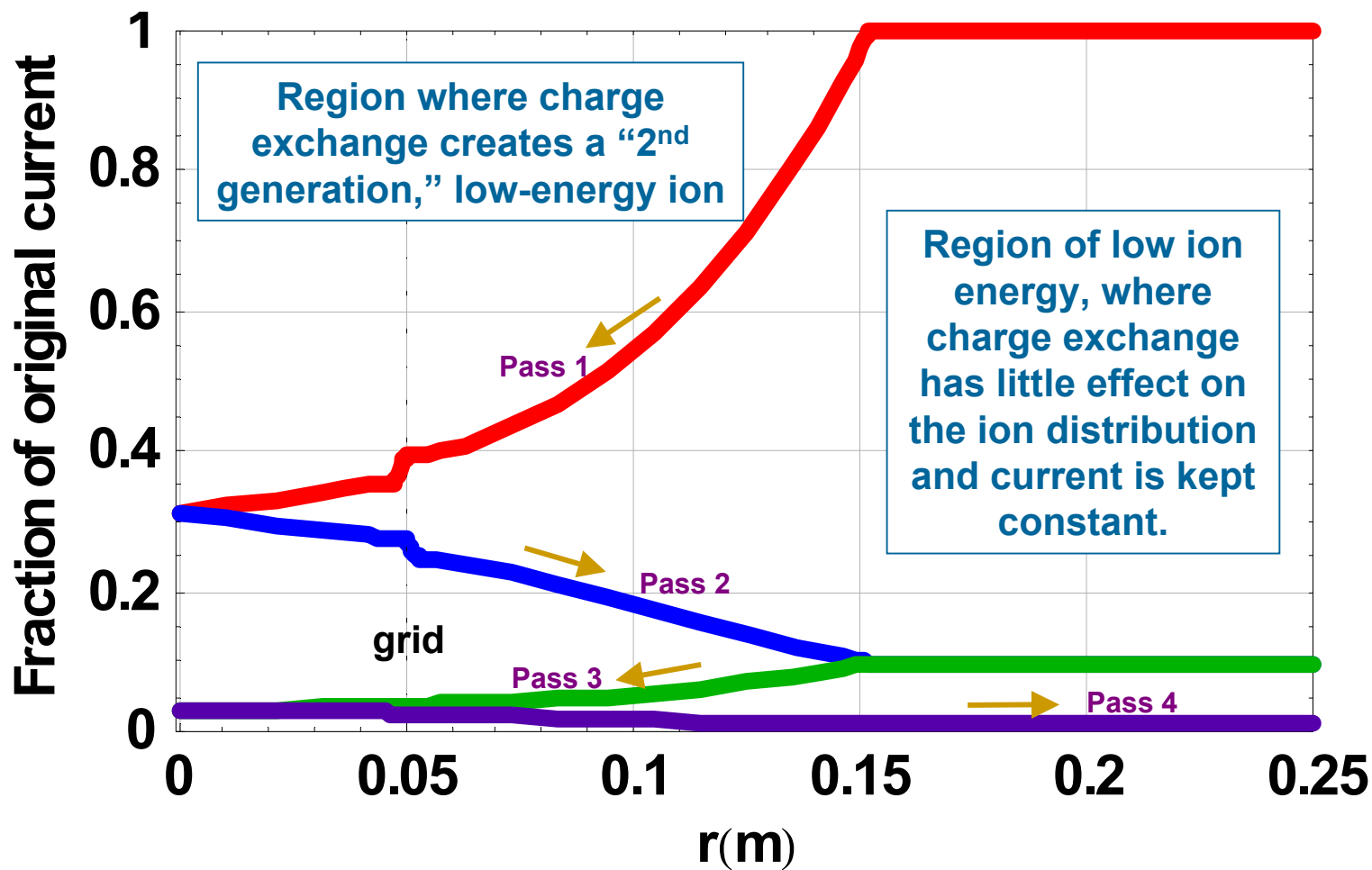
Child-Langmuir
radial potential
profile



Resulting radial
velocity profile

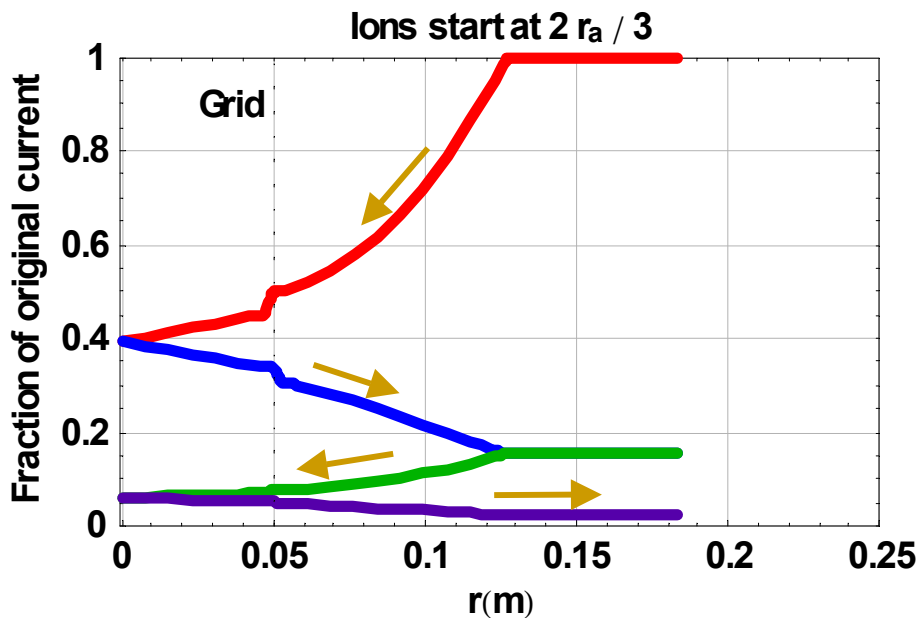
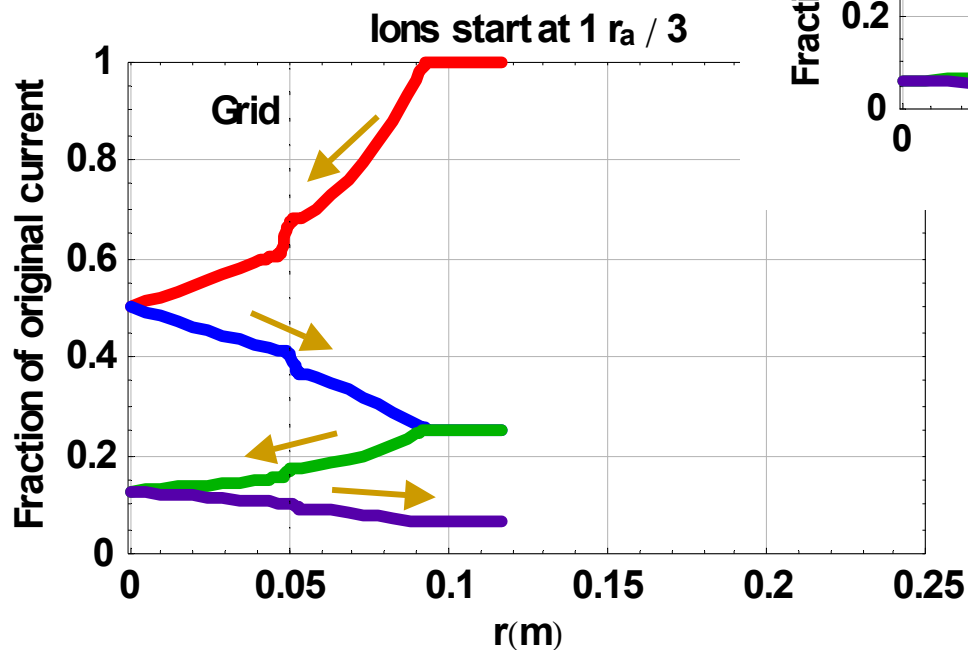


Charge Exchange “Attenuates” Initial Ion Current as Ions Oscillate Radially



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

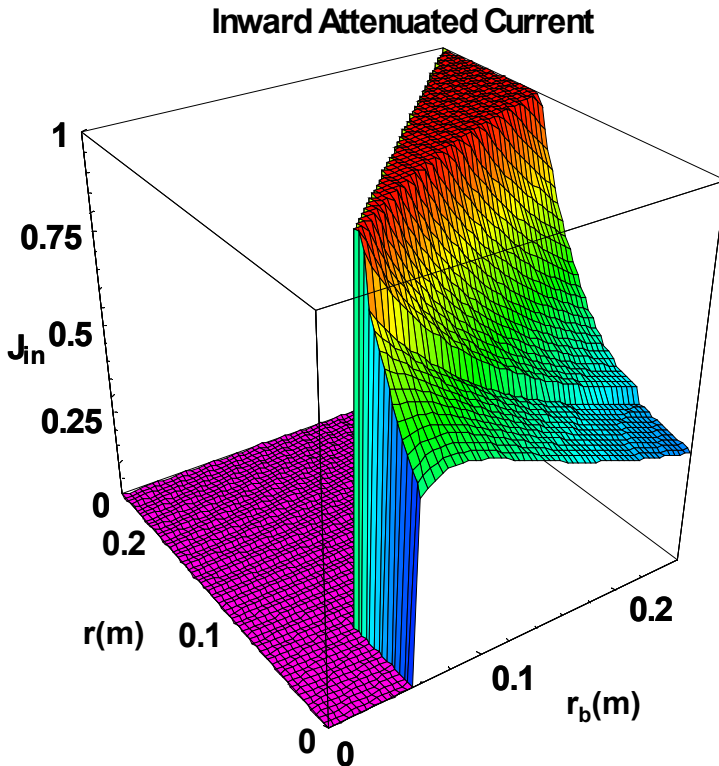
Evolution of ions that start at $r_a/3$ or $2r_a/3$



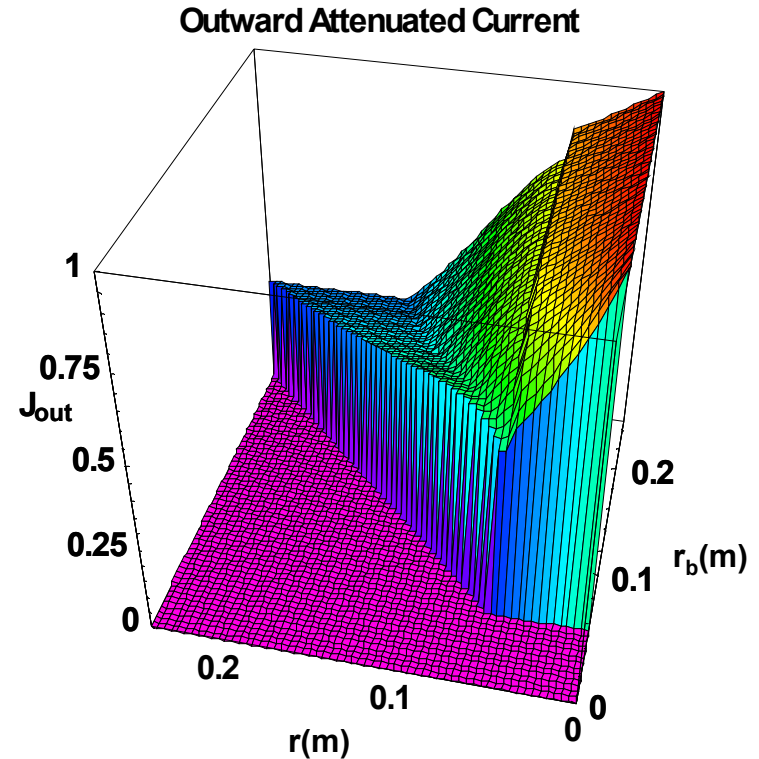
Ion-Current at Radial Position r Can Be Calculated for Arbitrary Birth Position r_b

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

Ions starting at $r = r_b$

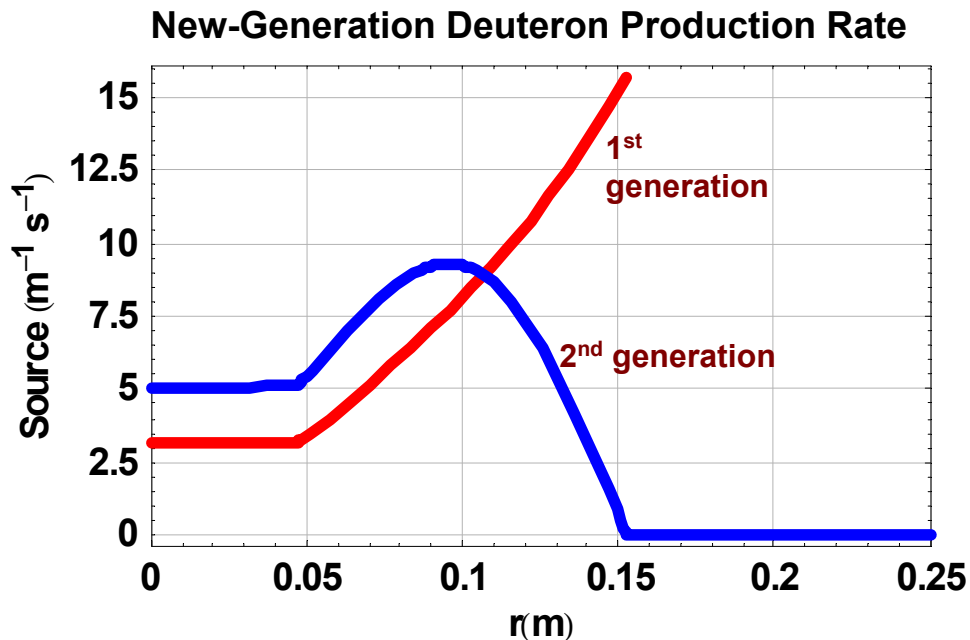
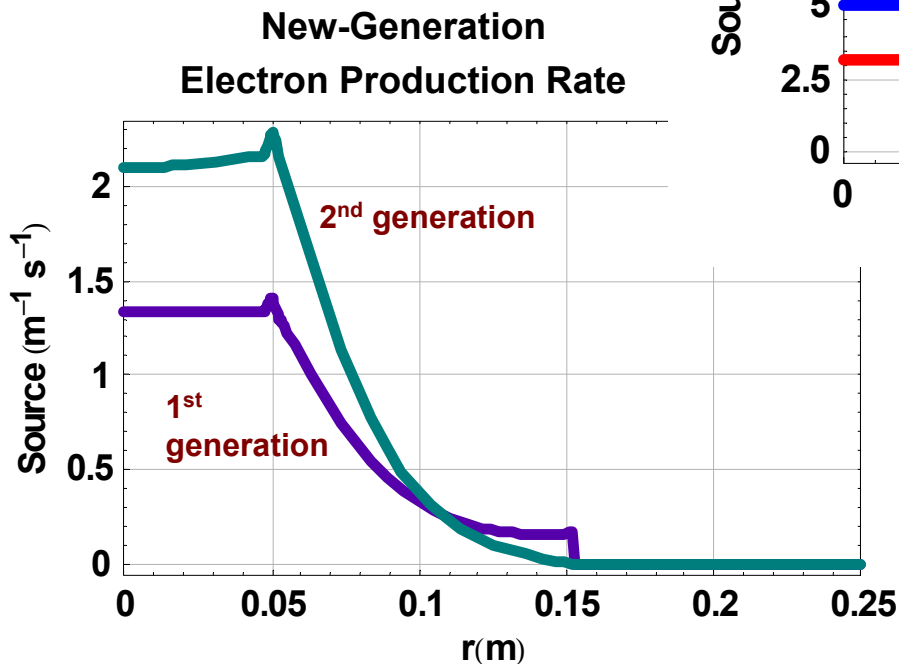


Ions starting at $r = 0$



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

Creation rates for first two generations of deuterons and electrons



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.**