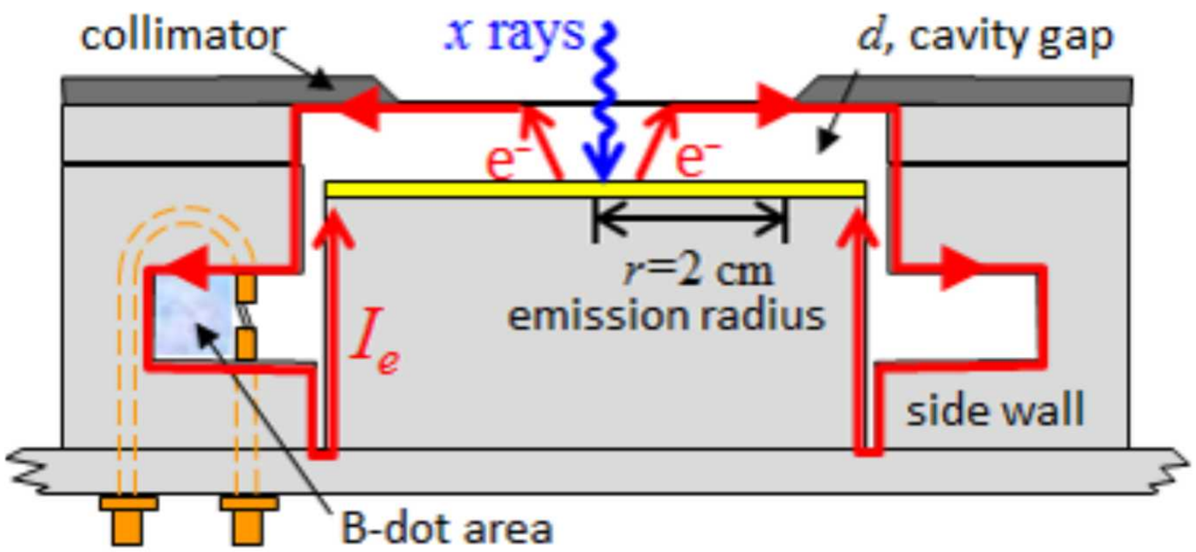
SAND2017-13268PE

Modeling e-Beam Interaction with Argon in 1D

Matthew Hopkins, CEA visit, 2017-12-07

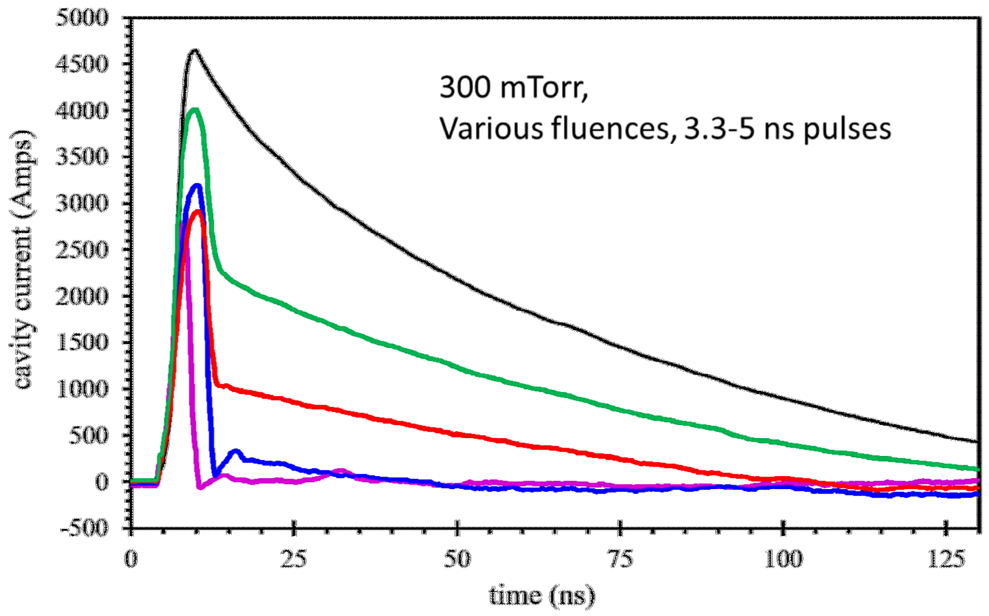
Extra thanks to: Ben Yee, Andy Fierro, Chris Moore, Ed Barnat

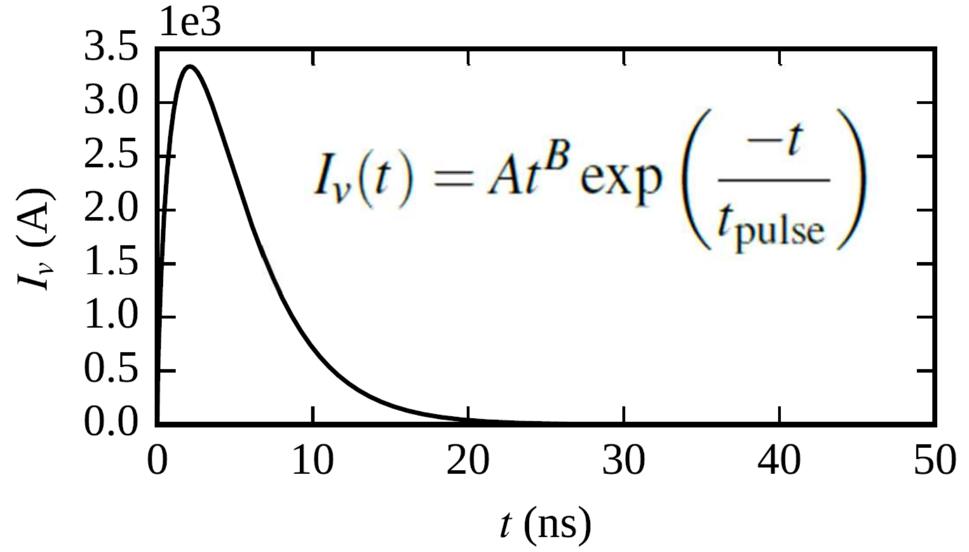
Goals

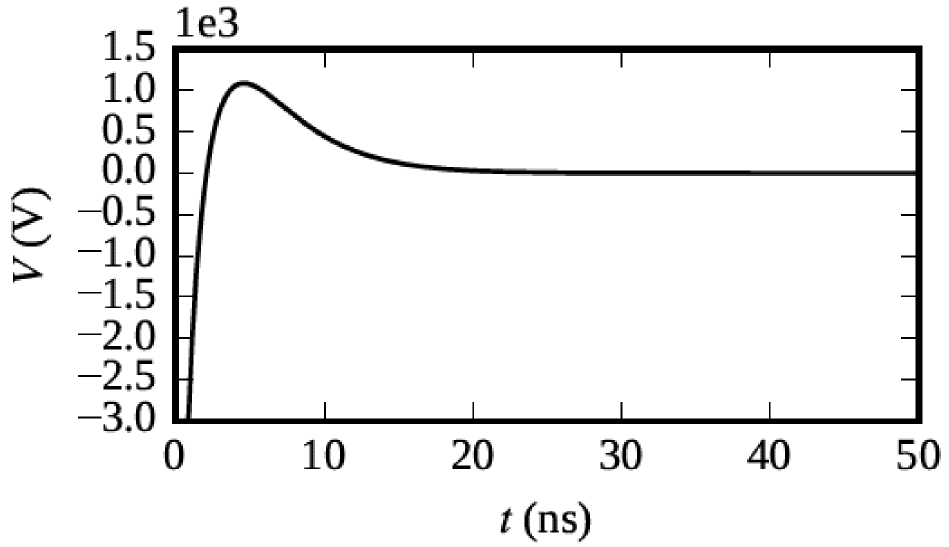


- Develop high fidelity model for comparison to benchtop experiments.
- Understand the importance of more vs. less detailed plasma chemistry models.
- Stepping stone to full 3D EM-PIC-DSMC simulations.
- There has been prior work on less resolved 2D and 3D EM-PIC-MCC simulations, not presented here.

1D Model Setup





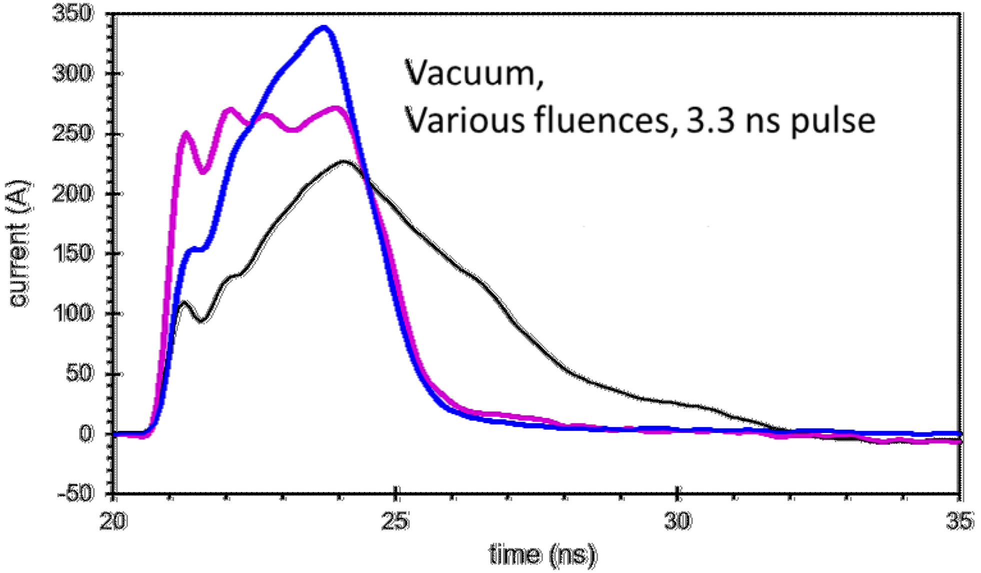


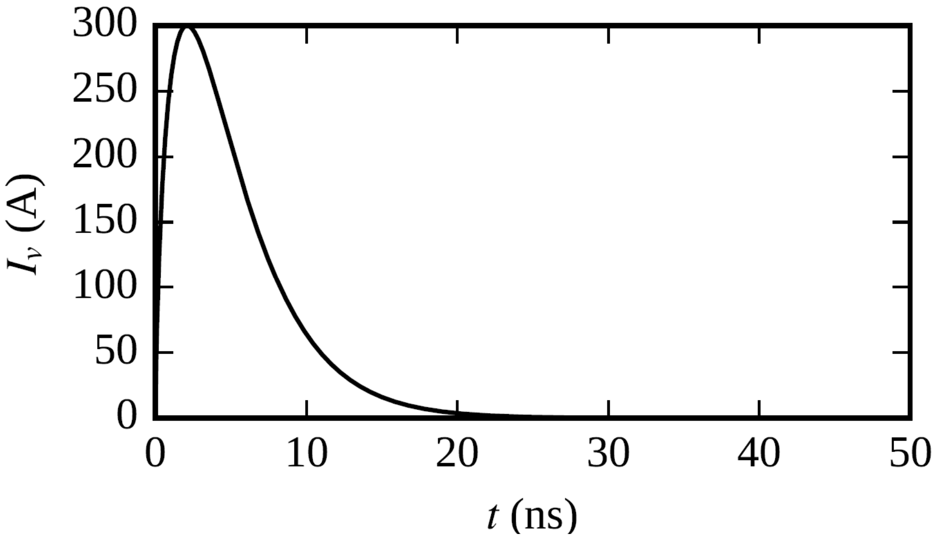
- Based on current measurements for pressurized system, set up an applied voltage waveform,

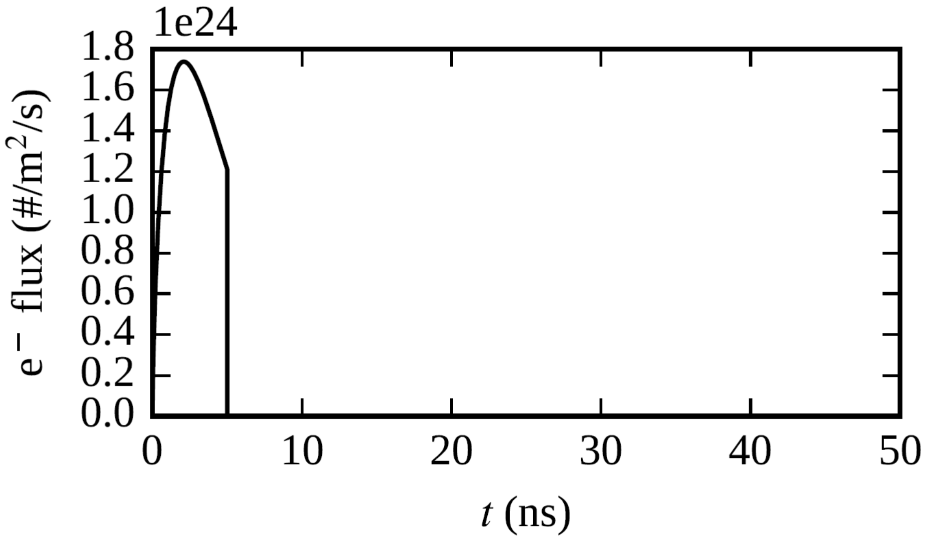
$$V(t) = L * dI_v(t)/dt$$

We are electrostatic!

1D Model Setup

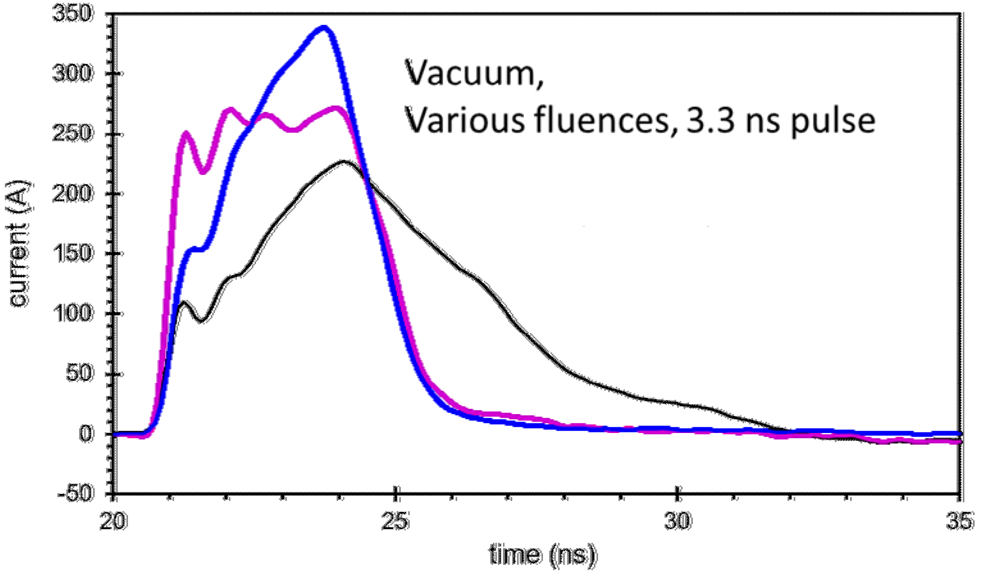


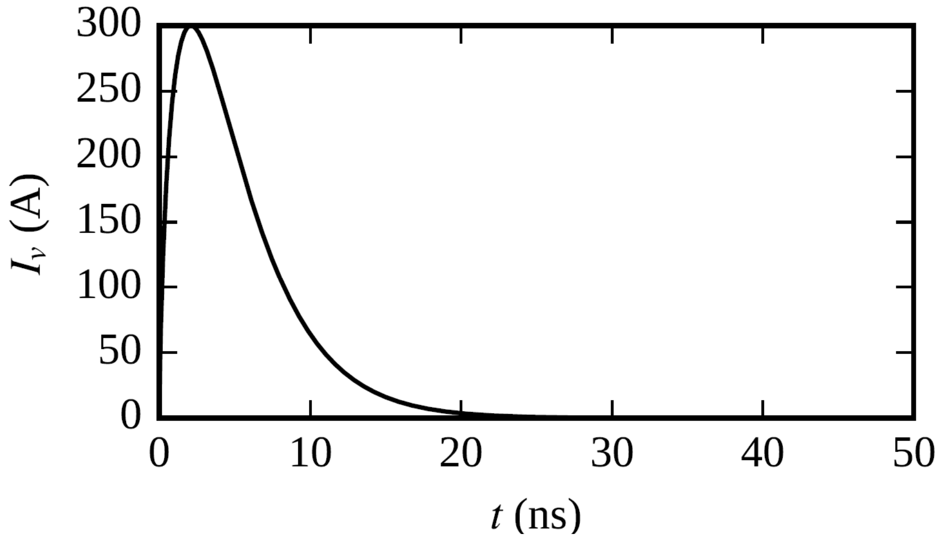


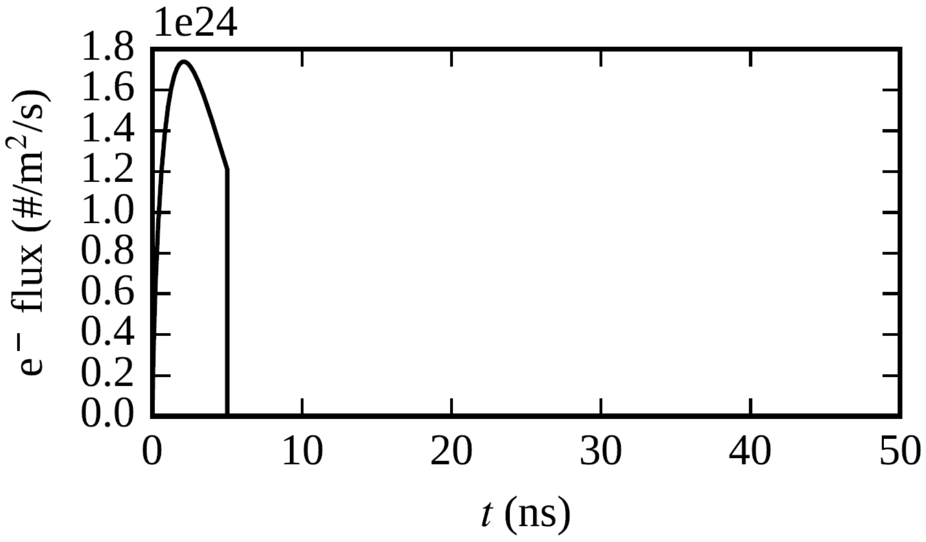


- Based on current measurements for vacuum system, set up an e- injection flux

1D Model Setup







- Based on current measurements for vacuum system, set up an e- injection flux

1D Model Setup

Chemistry to start with:

e- + Ar → e- + Ar (elastic)

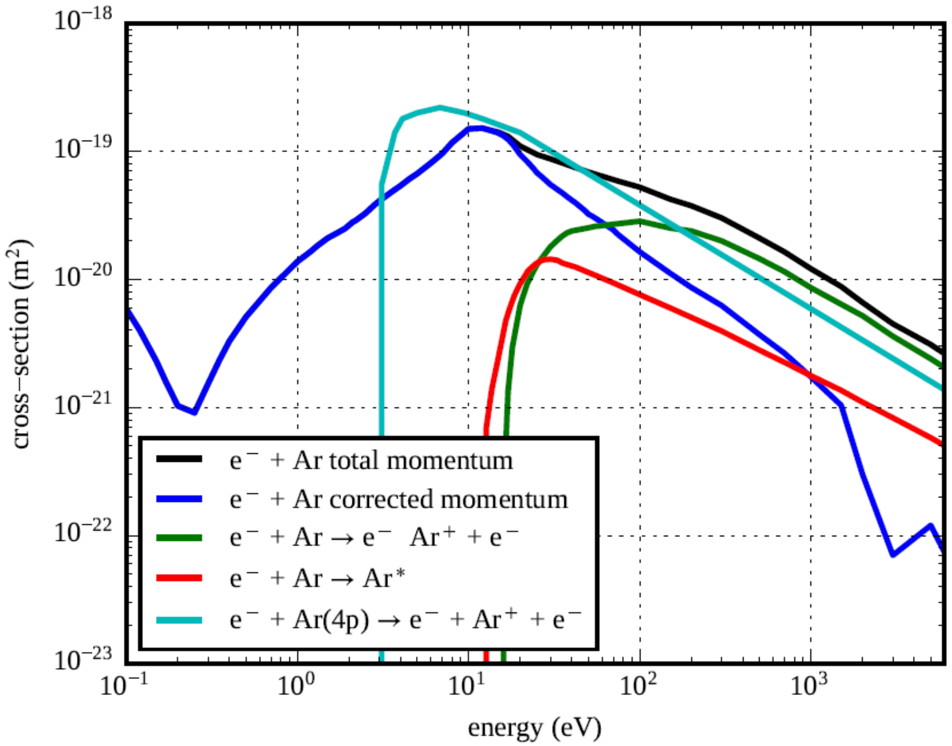
e- + Ar → e- + Ar* (excitation)

e- + Ar → e- + Ar+ + e- (ionization)

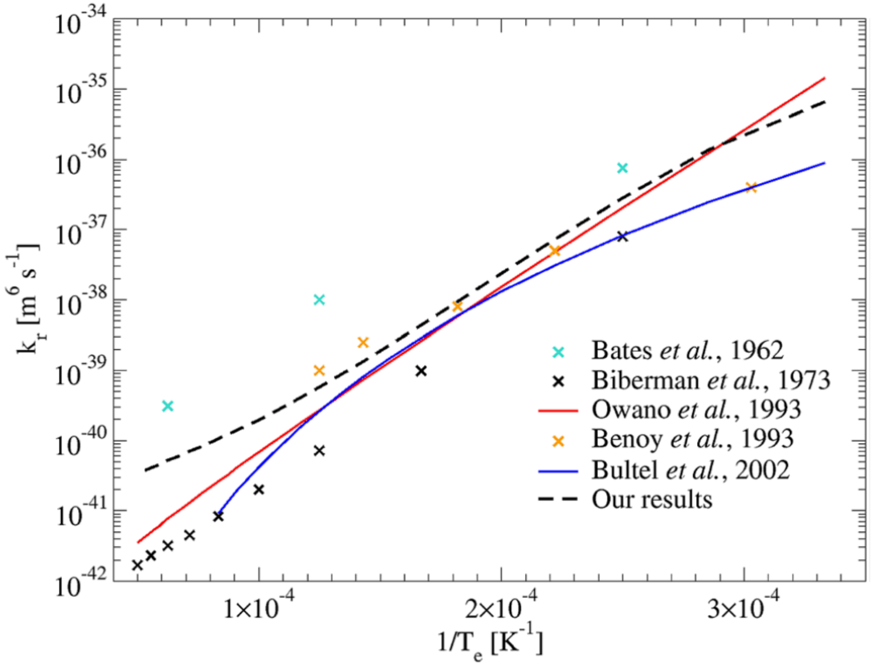
e- + Ar* → e- + Ar+ + e- (ionization)

e- + e- + Ar+ → e- + Ar (recombination)

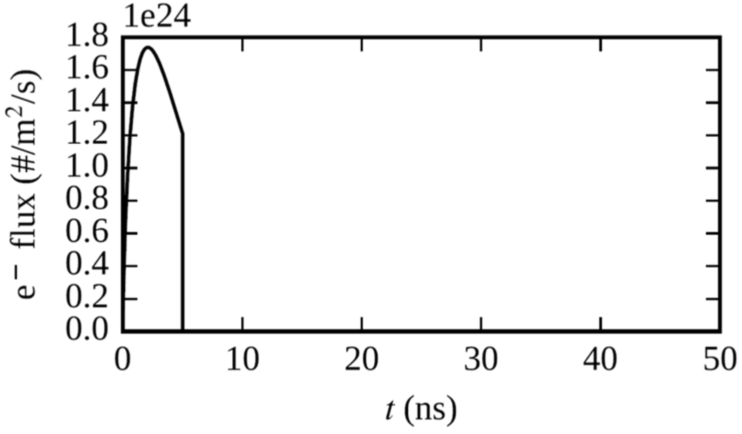
Recombination rates are complicated...



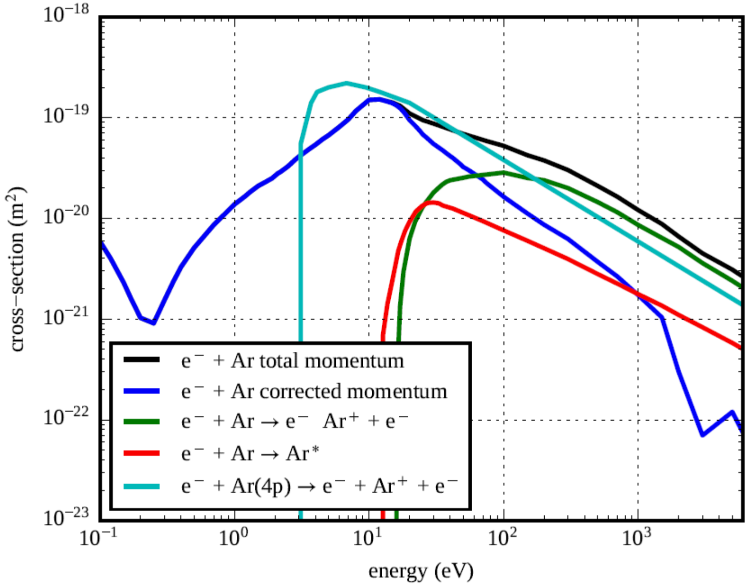
From Annaloro, Phys. Plasmas, 2012

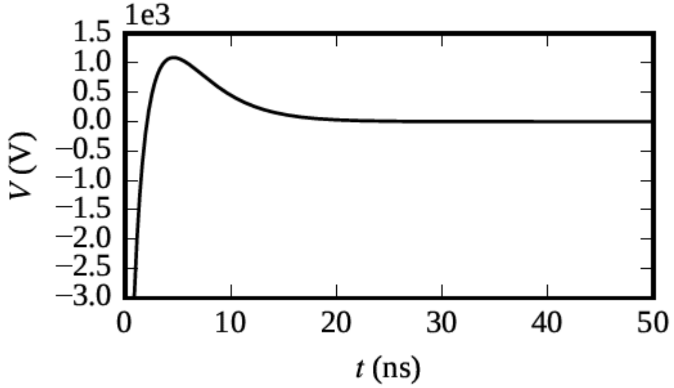


1D Model Setup



100-300 mTorr Ar





e- flux at v_x = 5 kV

$V(t)$

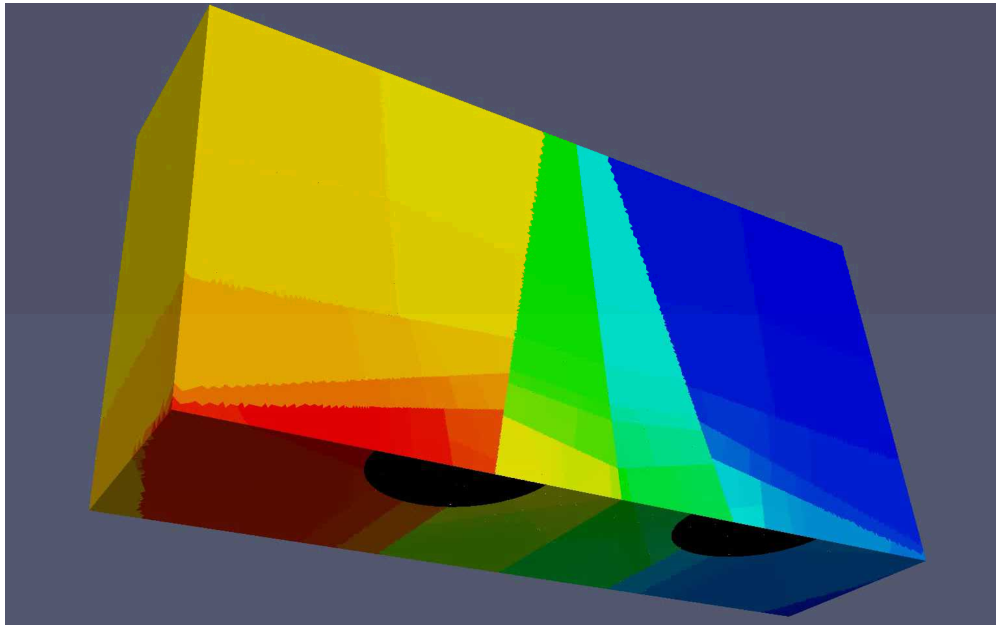
$x = 0$

$V = 0$

$x = 1$ cm

$V(t) = L\,dI(t)/dt$

Description of Aleph



- 1, 2, or 3D Cartesian
- Unstructured FEM (compatible with CAD)
- Massively parallel
- Hybrid PIC + DSMC (PIC-MCC)
- Electrostatics
- Fixed B field
- Solid conduction
- Advanced surface (electrode) models
- e- approximations (quasi-neutral ambipolar, Boltzmann)
- Collisions, charge exchange, chemistry, excited states, ionization
- Photon transport, photoemission, photoionization
- Advanced particle weighting methods
- Dual mesh (Particle and Electrostatics/Output)
- Dynamic load balancing (tricky)
- Restart (with all particles)
- Agile software infrastructure for extending BCs, post-processed quantities, etc.
- Currently utilizing up to 64K processors (>1B elements, >1B particles)

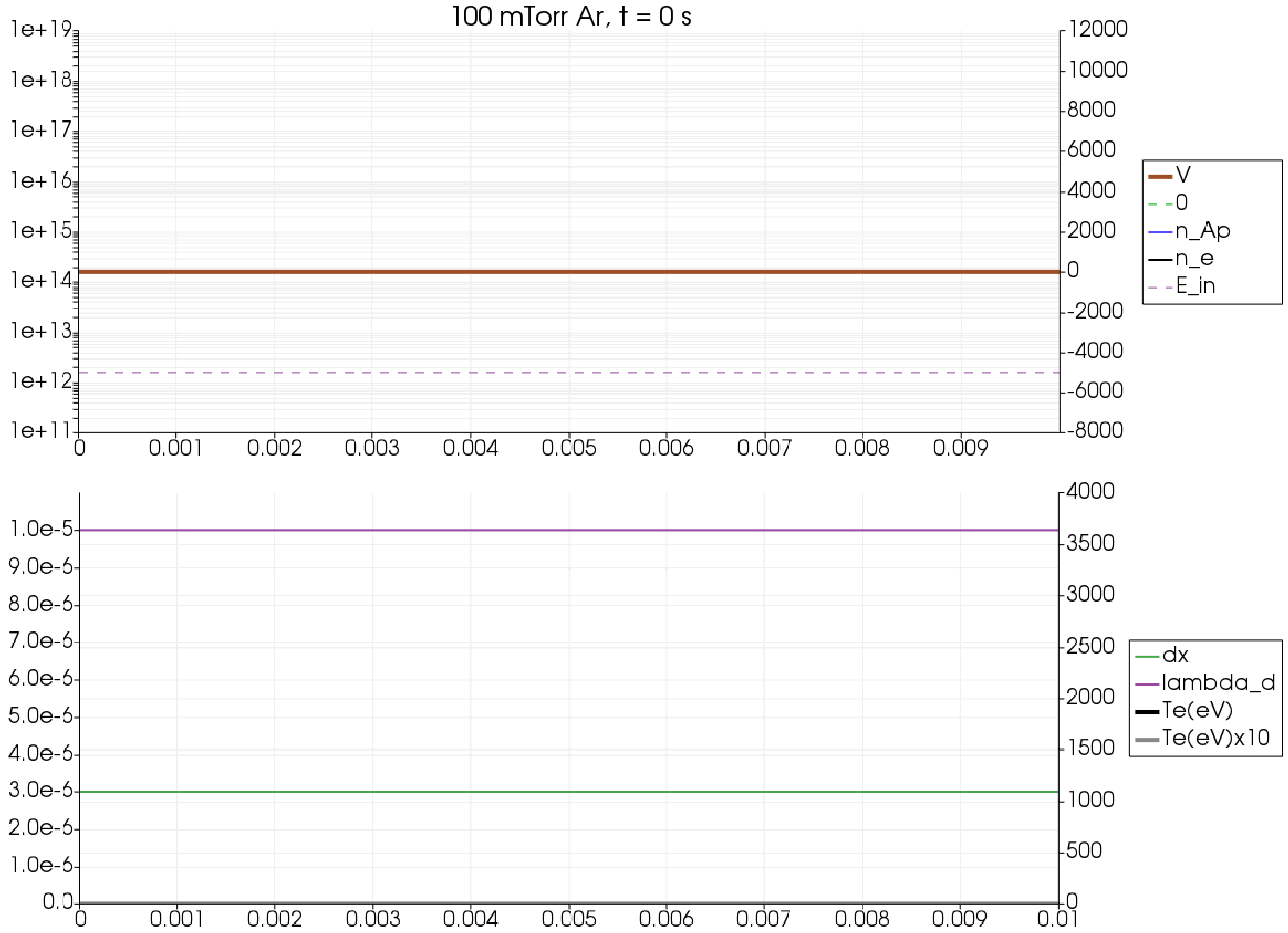
Simulation Parameters

Constraint	Requirement
Debye length	$\Delta x < \lambda_D = \sqrt{\frac{k_B T_e \varepsilon_0}{n_e q_e^2}}$
Collision mfp	$\Delta x < \lambda_c = \frac{1}{n_{\text{bg}} \sigma_{\text{max}}}$
Particle CFL	$\Delta t < \frac{v_{\text{max}}}{\Delta x}$
Plasma frequency	$\Delta t < 2/\omega_p = 2\sqrt{\frac{\varepsilon_0 m_e}{n_e q_e^2}}$
Collision frequency	$\Delta t < 1/\omega_c = \frac{1}{n_{\text{bg}} \sigma_{\text{max}} v_{\text{max}}}$

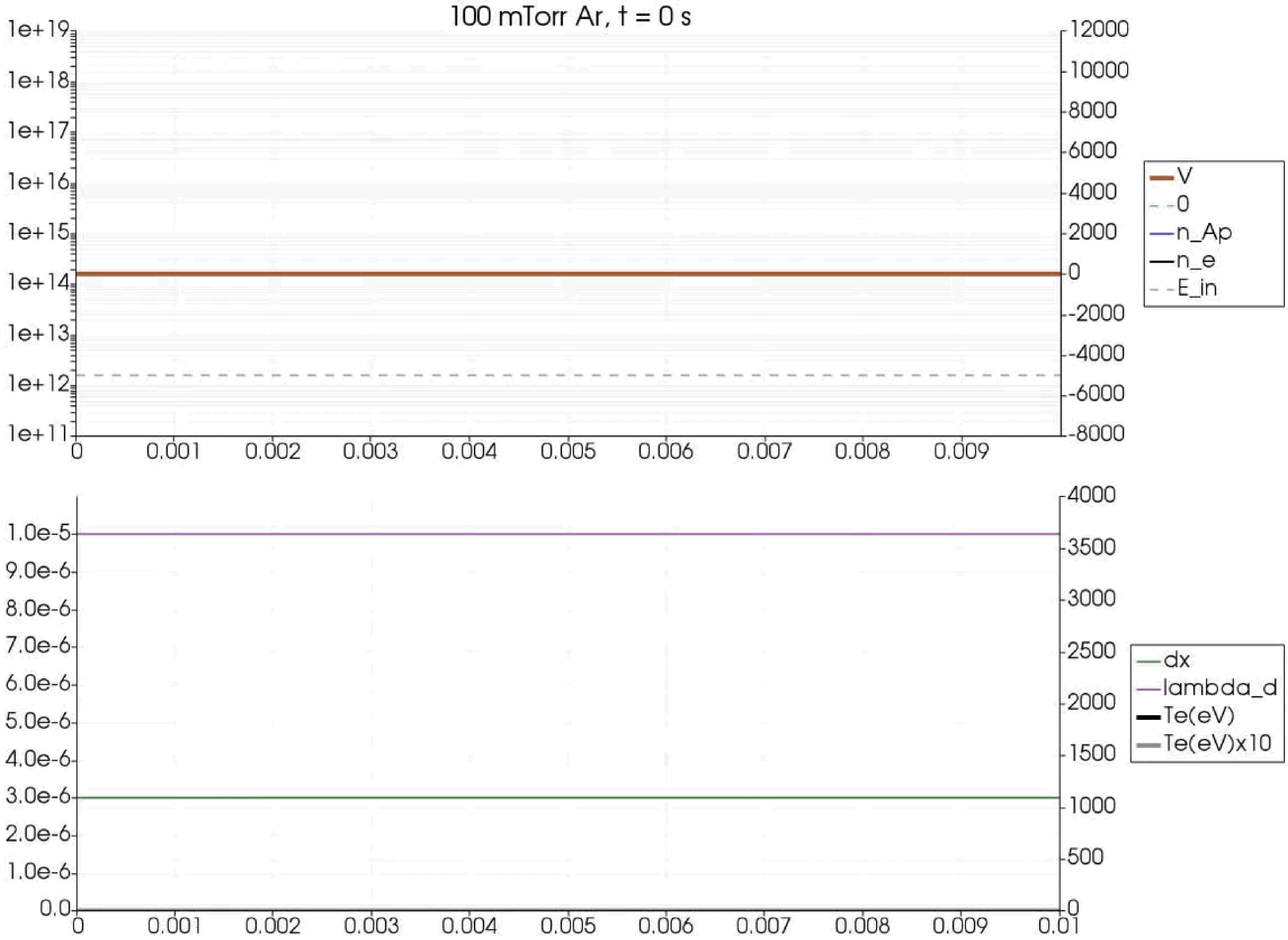
At T_e = 2 eV, $n_e = 10^{-19}$ m^{-3}, $\sigma_{max} = 2 \times 10^{-19}$ m^2, and $n_{bg} = 9.7 \times 10^{21}$ m^{-3}, $v_{max} = 4.2 \times 10^7$ m/s,

λ_D = 3.2 um, λ_c = 500 um → Δx = 3 um

$v_{max}/\Delta x$ = 40 fs, $2/\omega_p$ = 11 ps, $1/\omega_c$ = 12 ps → Δt = 80 fs



100 mTorr Ar, t = 0 s
1e+19
1e+18
1e+17
1e+16
1e+15
1e+14
1e+13
1e+12
1e+11
12000
10000
8000
6000
4000
2000
0
-2000
-4000
-6000
-8000
0
0.001
0.002
0.003
0.004
0.005
0.006
0.007
0.008
0.009
V
0
n_Ap
n_e
E_in
1.0e-5
9.0e-6
8.0e-6
7.0e-6
6.0e-6
5.0e-6
4.0e-6
3.0e-6
2.0e-6
1.0e-6
0.0
4000
3500
3000
2500
2000
1500
1000
500
0.01
dx
lambda_d
Te(eV)
Te(eV)x10


100 mTorr Ar, t = 0 s
1e+19
1e+18
1e+17
1e+16
1e+15
1e+14
1e+13
1e+12
1e+11
12000
10000
8000
6000
4000
2000
0
-2000
-4000
-6000
-8000
V
0
n_Ap
n_e
E_in
0
0.001
0.002
0.003
0.004
0.005
0.006
0.007
0.008
0.009
1.0e-5
9.0e-6
8.0e-6
7.0e-6
6.0e-6
5.0e-6
4.0e-6
3.0e-6
2.0e-6
1.0e-6
0.0
4000
3500
3000
2500
2000
1500
1000
500
0
dx
lambda_d
Te(eV)
Te(eV)x10
0.01

More Results