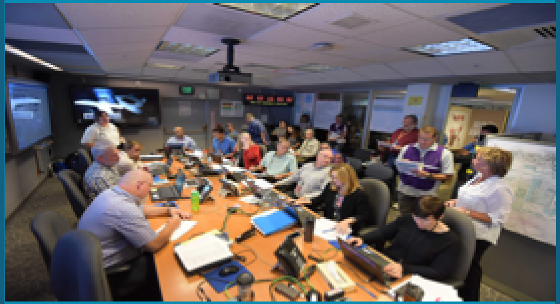
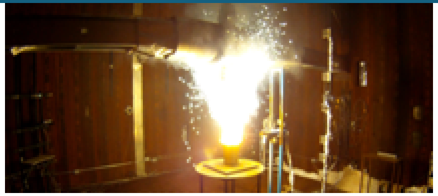
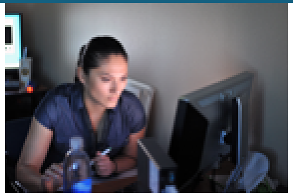
SAND2023-04537C

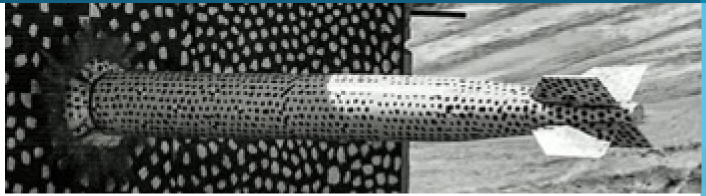
Sandia National Laboratories

Secondary Ion Generation in an 18MV, 650kA Bremsstrahlung Diode









Authors:

Troy Powell, Adam Darr, Keith Cartwright

U.S. DEPARTMENT OF ENERGY NNSA

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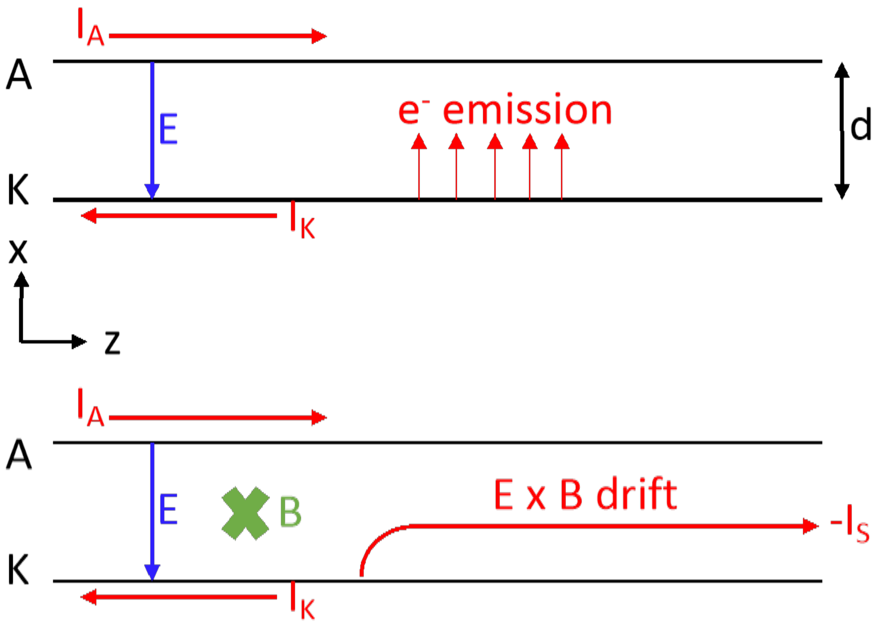
Intro: Magnetic Insulation



Magnetic (Hull) cutoff (classical)[1]:

$$B_H = \sqrt{\frac{2mV}{ed^2} + \left[\frac{mv_0}{ed}\right]^2}$$

Hull cutoff (relativistic)[2]:

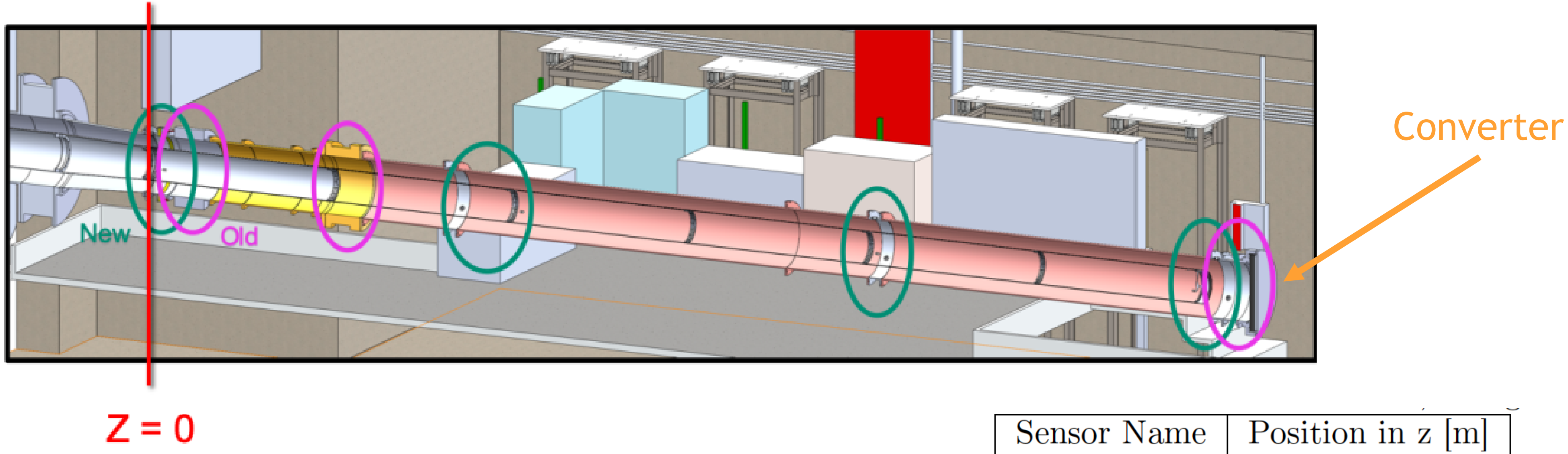
$$\left(\frac{eB_H d}{mc}\right)^2 = \frac{2eV}{mc^2} + \left(\frac{eV}{mc^2}\right)^2$$

Magnetically Insulated Transmission Line (MITL) Voltage[3]:

$$V = Z_0\sqrt{I_A^2 - I_K^2} - \frac{mc^2}{2e}\frac{I_A^2 - I_K^2}{I_K^2}$$

[1]: A. W. Hull, “The effect of a uniform magnetic field on the motion of electrons between coaxial cylinders.,” Phys. Rev, vol. 18, pp. 31–57, Jul 1921.
[2]: R. V. Lovelace and E. Ott, “Theory of magnetic insulation,” The Physics of Fluids, vol. 17, p. 1263, 1974.
[3]: C. W. Mendel, M. E. Savage, D. M. Zagar, W. W. Simpson, and T. W. Grasser, “Experiments on a current-toggled plasma opening switch,” Journal of Applied Physics, vol. 71, April 1992.

HERMES-III: Extended MITL



Use constant impedance

Maintain R_A/R_K ratio constant

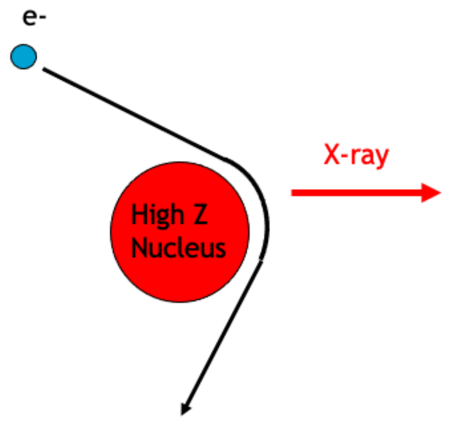
Cathode was a feat of mechanical engineering

$$Z_0 = \frac{1}{2\pi}\sqrt{\frac{\mu}{\epsilon}}\ln\left(\frac{R}{r}\right)$$

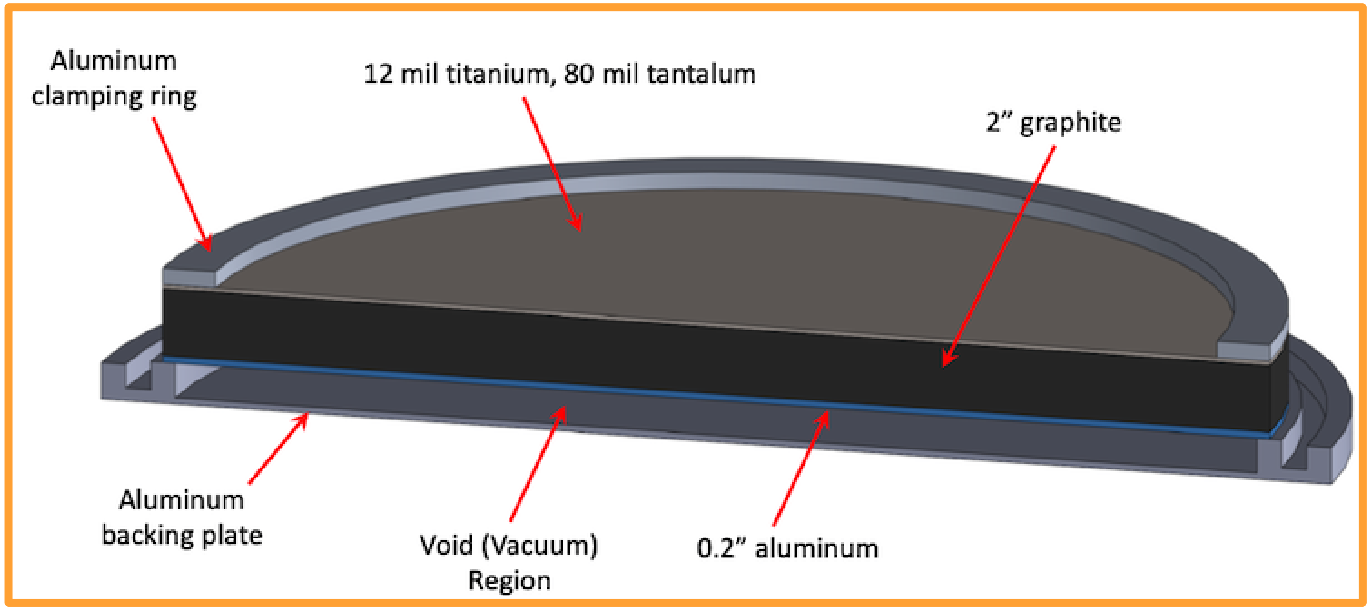
Sensor Name	Position in z [m]
XAB1	0.072
XKB1	0.146
IAS1	0.245
IAS2	2.219
IAS3	2.58
XKB3	8.825
XAB3	8.861
XKB4	12.667
XAB4	13.064
IAS4	13.337
IAS5	13.379

Intro: Bremsstrahlung

Bremsstrahlung “braking radiation”

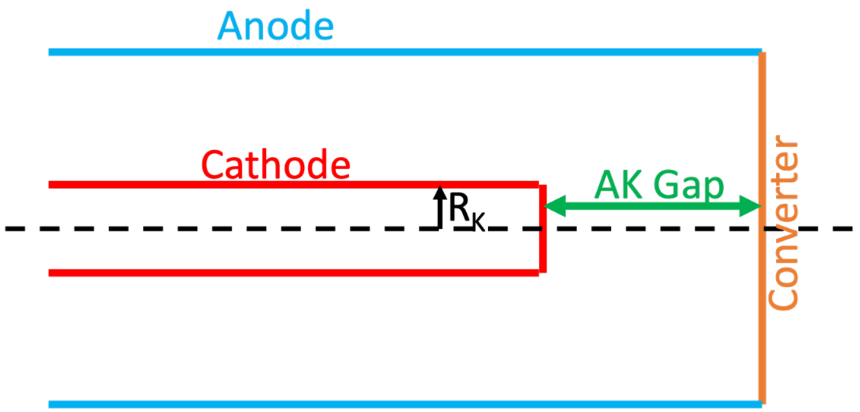


Converter



Bremsstrahlung diode dose optimization

- Diode geometry
- Converter pack



Theory: Self-Limited MITL Current

Start with Mendel. We want $f_{SL} = Z_0/Z_{flow}$
Pointon [1] solved this numerically, and here we solve it analytically

$$V = Z_0\sqrt{I_A^2 - I_K^2} - \frac{mc^2}{2e}\frac{I_A^2 - I_K^2}{I_K^2}$$

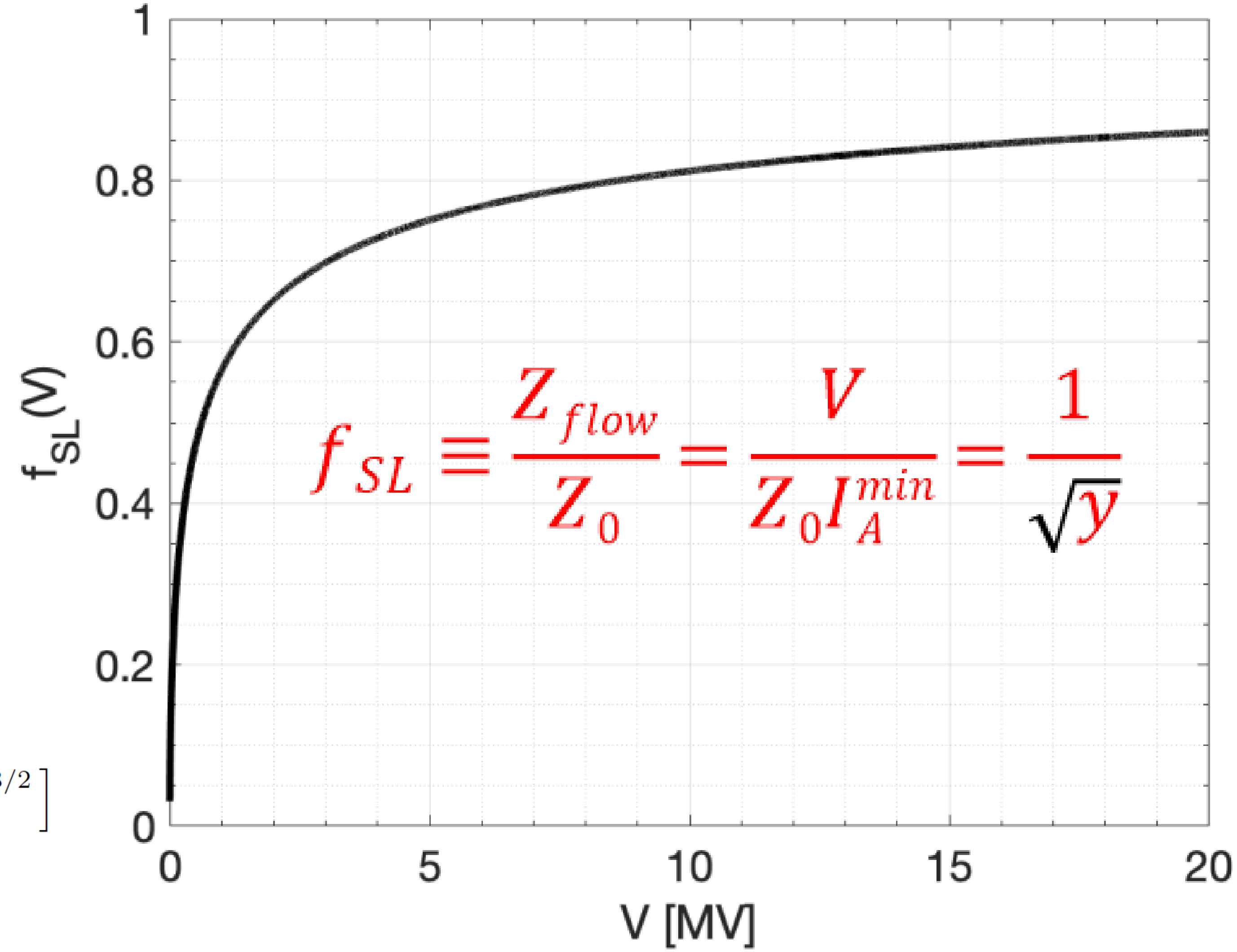
Nondimensionalize.

$$y = \frac{Z_0^2 I_A^2}{V^2}; x = \frac{Z_0^2 I_K^2}{V^2}; \kappa = \frac{mc^2}{2eV}$$

Optimize and solve for analytic y(k).

$$y = \frac{1}{32\kappa^2}\left[32\kappa + 6\alpha\kappa^{3/2}(\kappa+2)^2 - 2\kappa^2(\kappa-14)(3\kappa+2) - \sqrt{\alpha\sqrt{\kappa}(\kappa+2) - \kappa(\kappa+6)}\left(\alpha\sqrt{\kappa}(\kappa+2) - \kappa(\kappa-10)\right)^{3/2}\right]$$

$$\alpha = \sqrt{\kappa + 8}$$



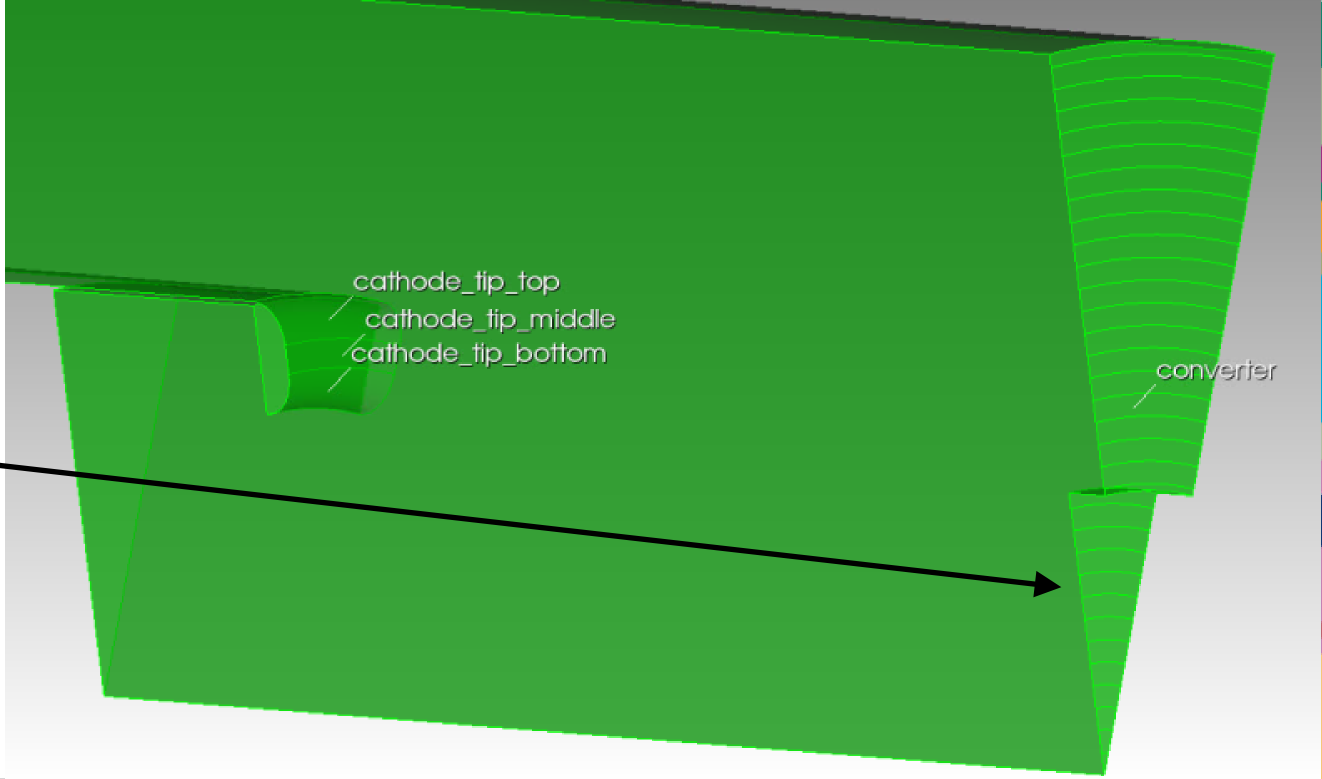
[1]: T. D. Pointon, K. L. Cartwright, T. J. Renk, and B. T. Yee, “Coupled em-pic/radiation transport simulations of hermes courtyard experiments,” Tech. Rep. SAND2018-12578, Sanida National Laboratories, October 2018.

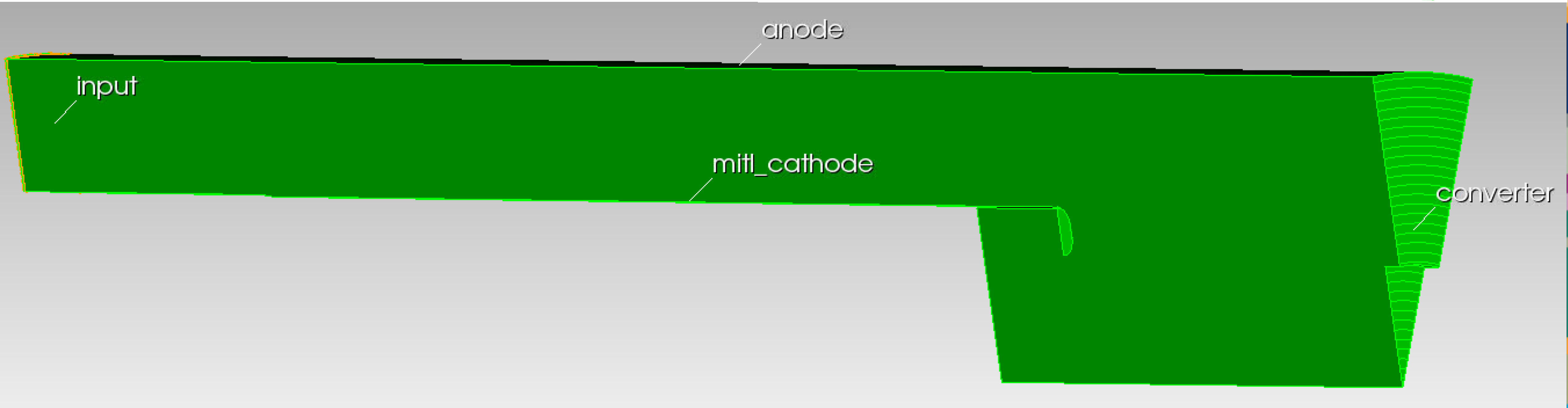
Simulating Shots 11132-36, 11146 in EMPIRE

Model

Wedge angle 22.5º

Graphite plug modeled with PEC





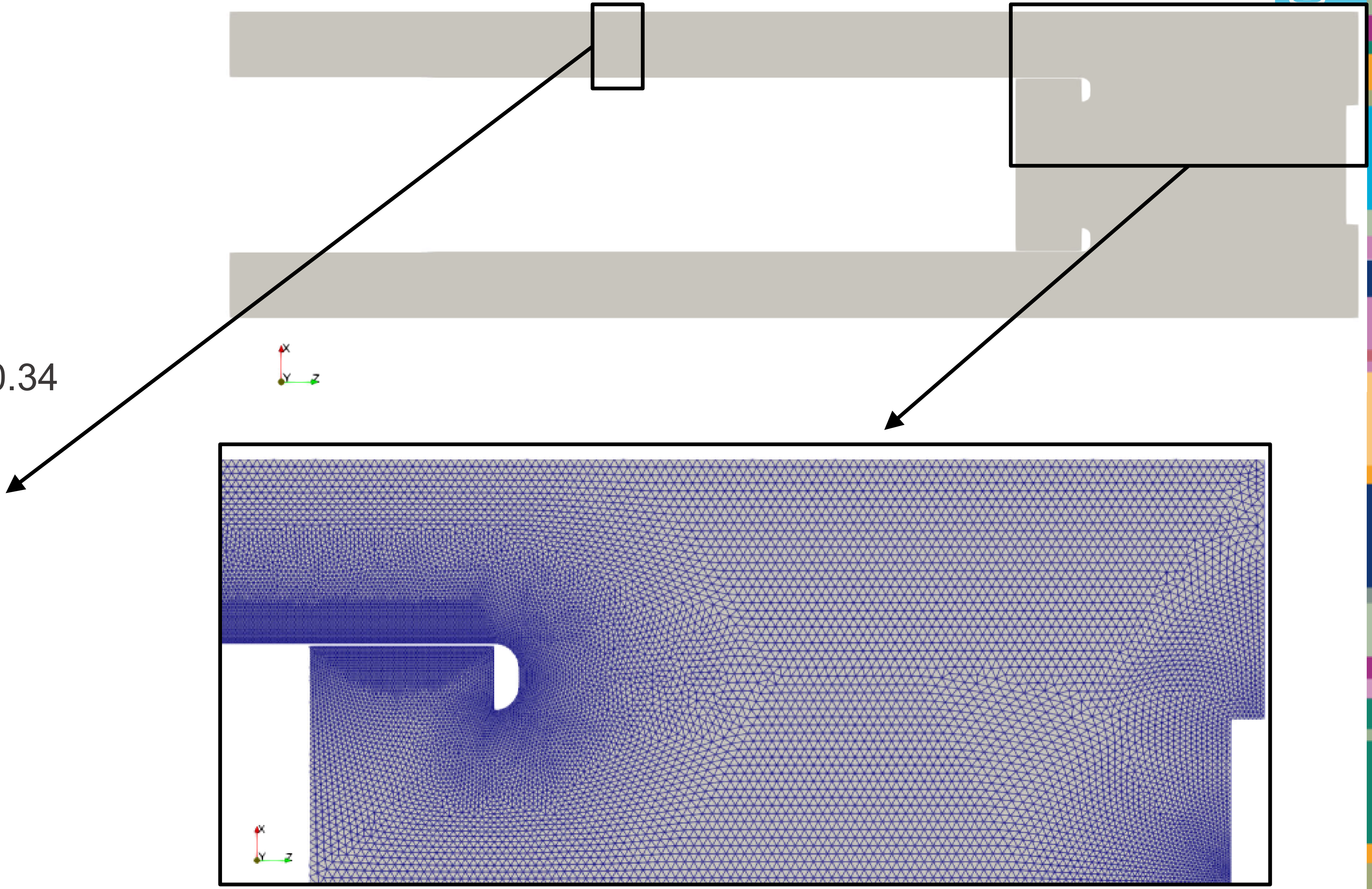
Resolution

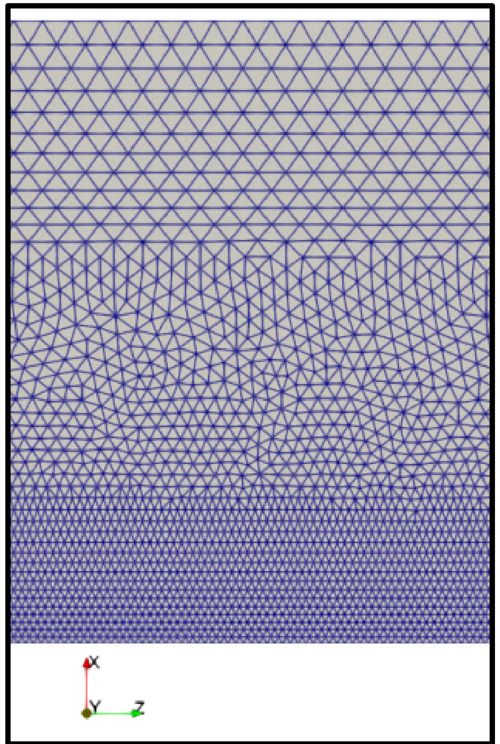
$dx_{max} = (R_A - R_K)/20 =$ 0.705cm

$dx_{cathode} = 0.25^* dx_{max} =$ 0.17625cm

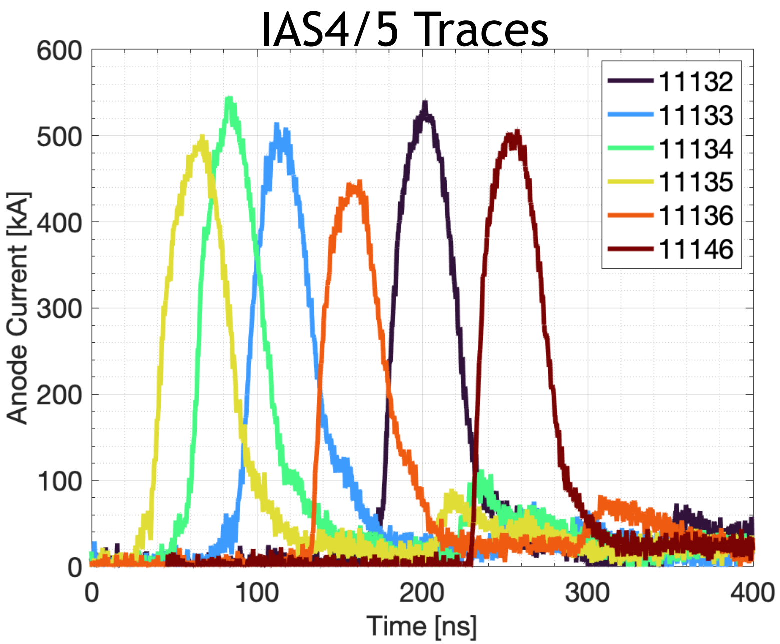
dt = 2.0ps

CFL = c*dt/dx = 0.085-0.34



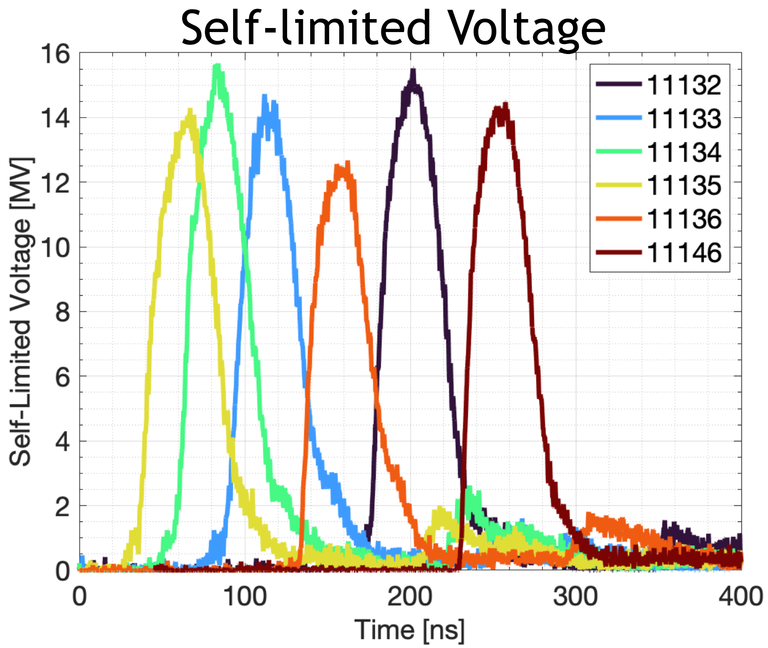


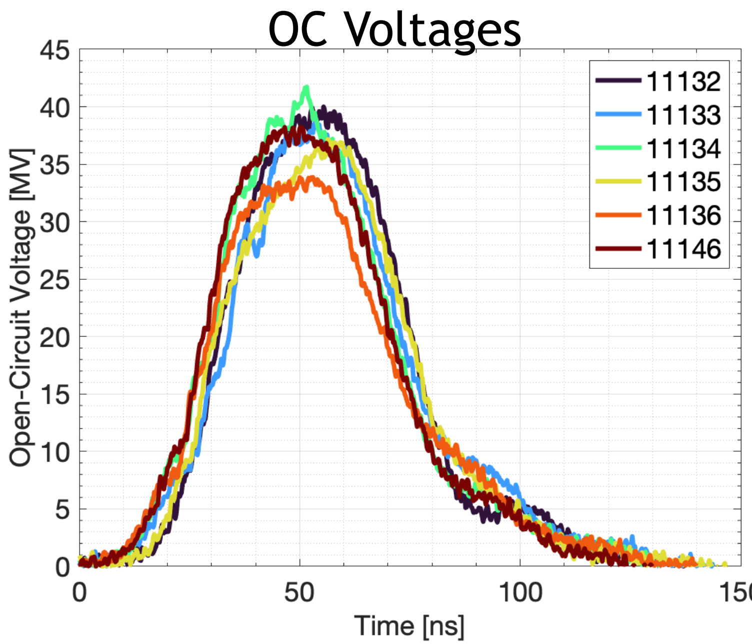
Driving the Diode



pulse arrival time is arbitrary

$f_{SL}(V)$

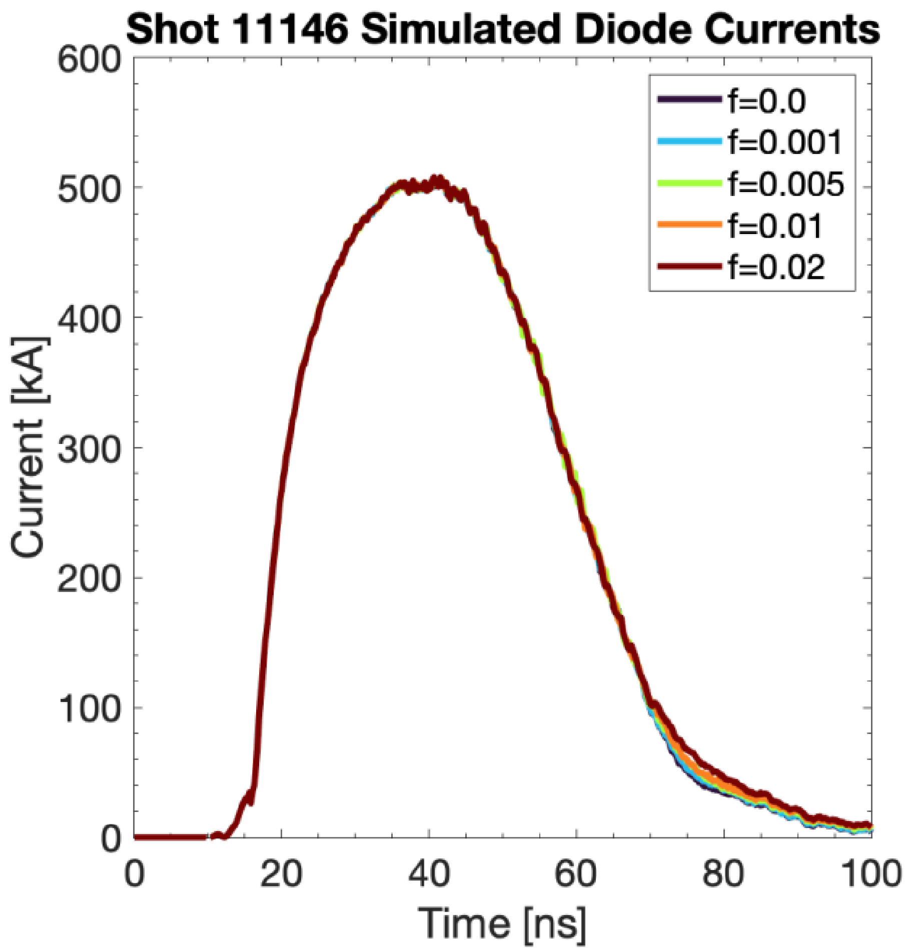


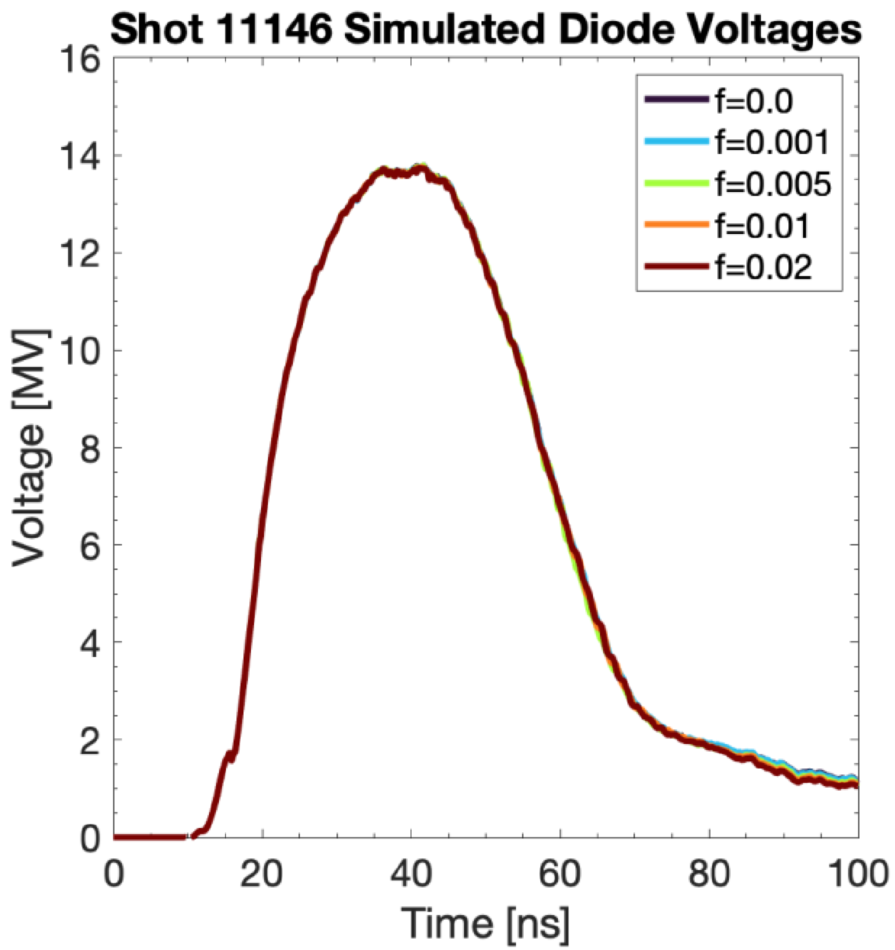


$V_{OC} = V_{SL} + Z_0 * I_A$
temporally aligned

Ion Effect on Diode Current

f = ion injection fraction





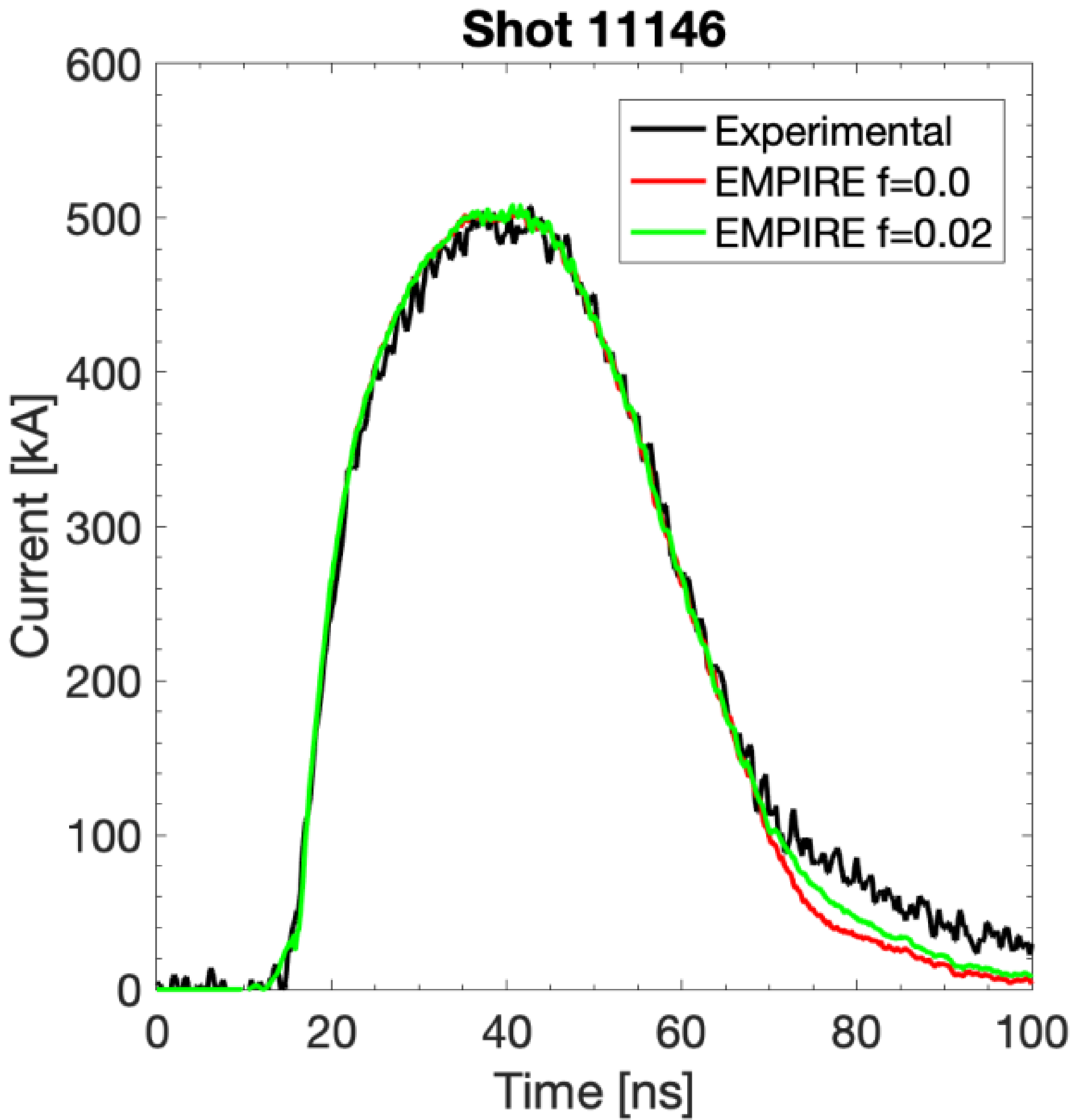
Killed electrons re-injected as ions with fraction f
Expect ions in the range of 0-2% due to results from Mercury [1]
Ions only affect the tail of the pulse

[1] -

Simulated Diode vs Theory - 11146

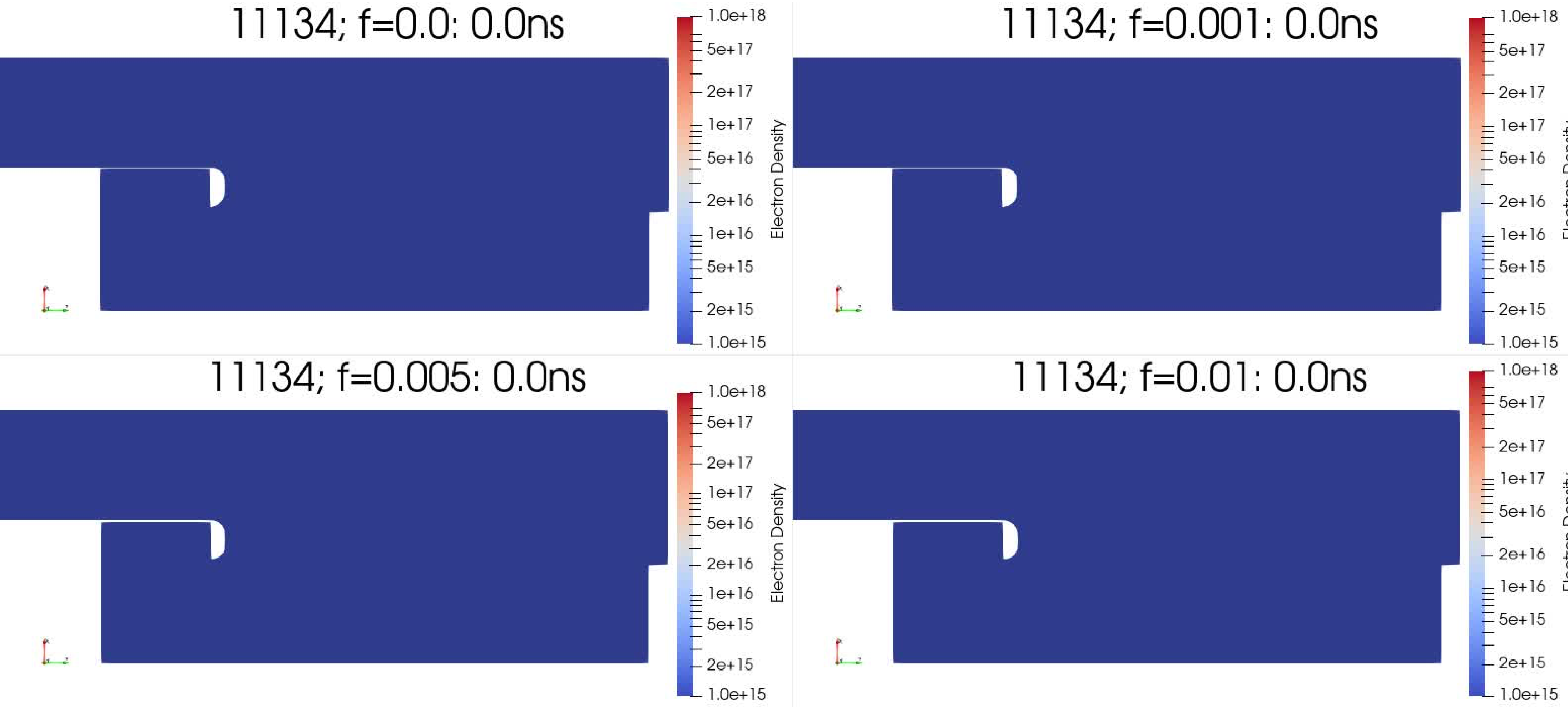
f=0.02 gave the closest agreement

- Future work: increase ions to match tail
- This is the largest fraction we have tried so far
- Increasing ions will impact dose profile

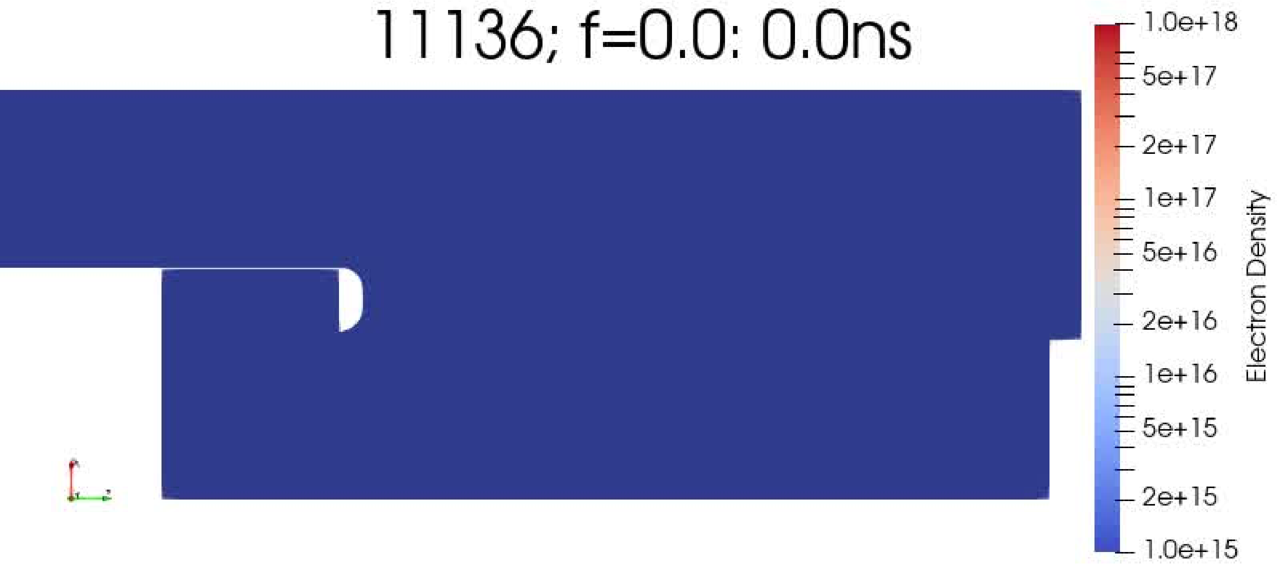


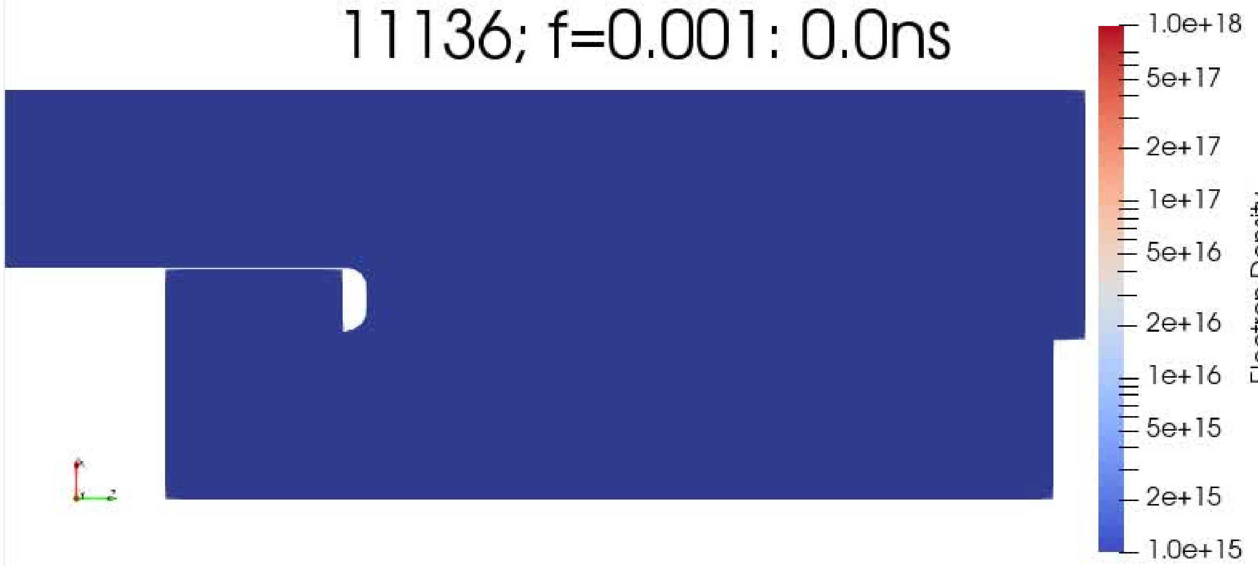
11134 electron flow

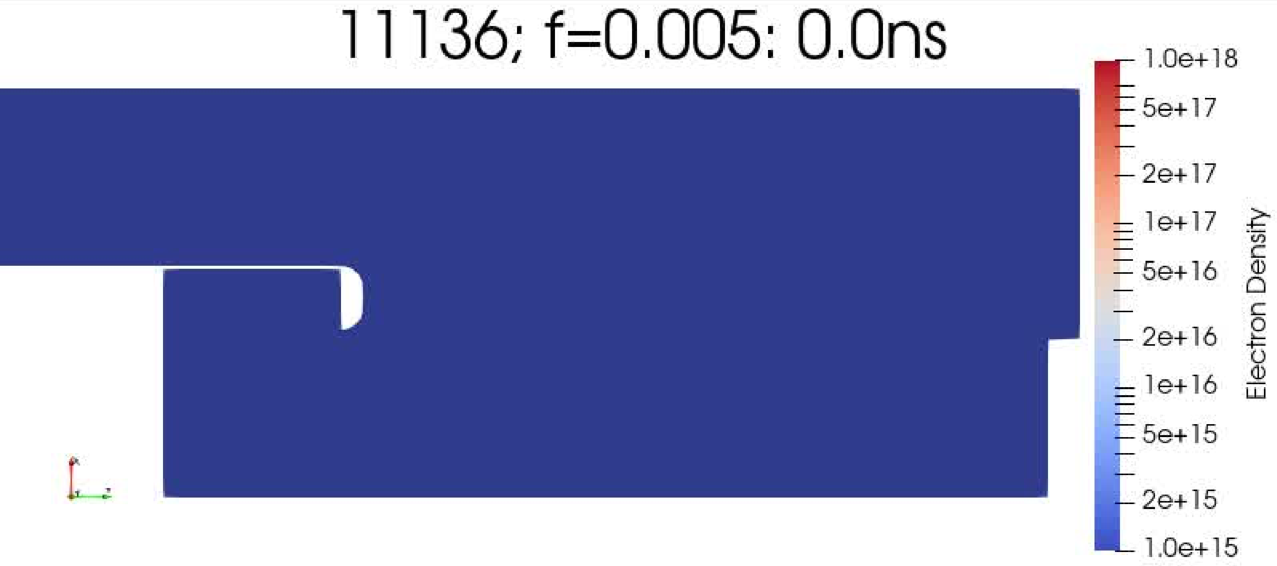
shorten and loop videos
plot 11146 f=0.001 and 0.01 electrons and ions



11136 electron flow







Converter Modeling in ITS

Converter Geometry

1” Graphite plug (10” OD)

12 mil Ti (33.75” OD)

80 mil Ta

2” Graphite beamstop

3/16” Al clamping plate

1/2” Vacuum

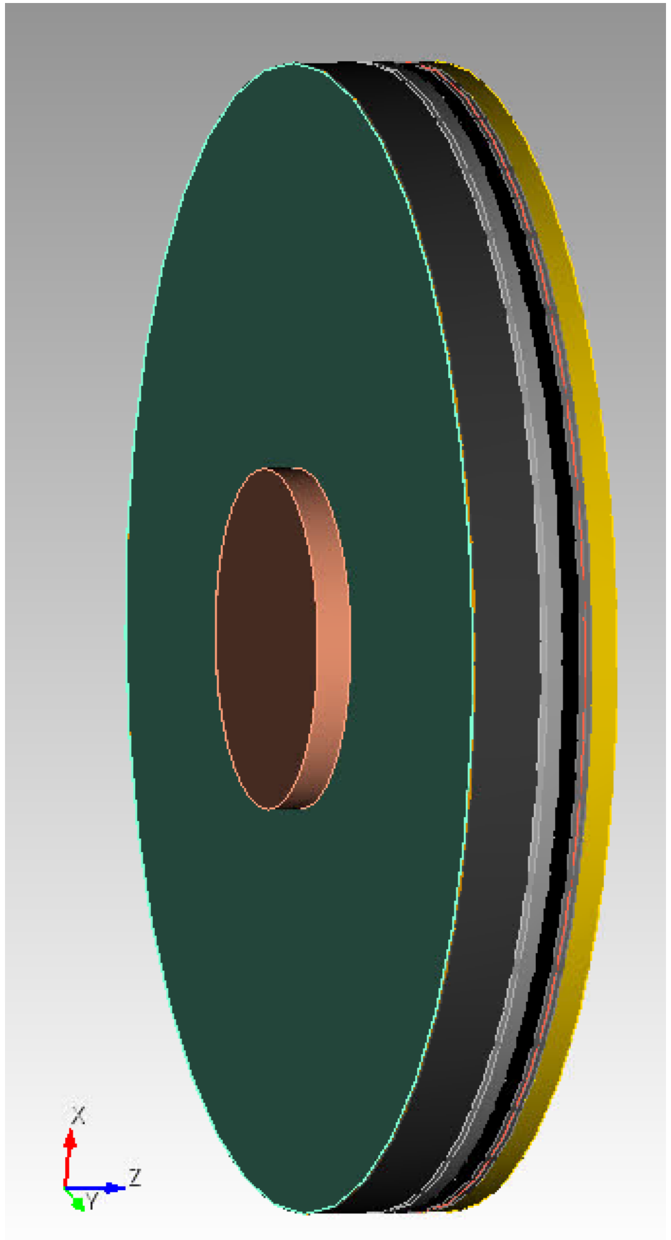
1/2” Al Faceplate

0.17” Al equilibrator (has Si, Mn, Fe, and Cu)

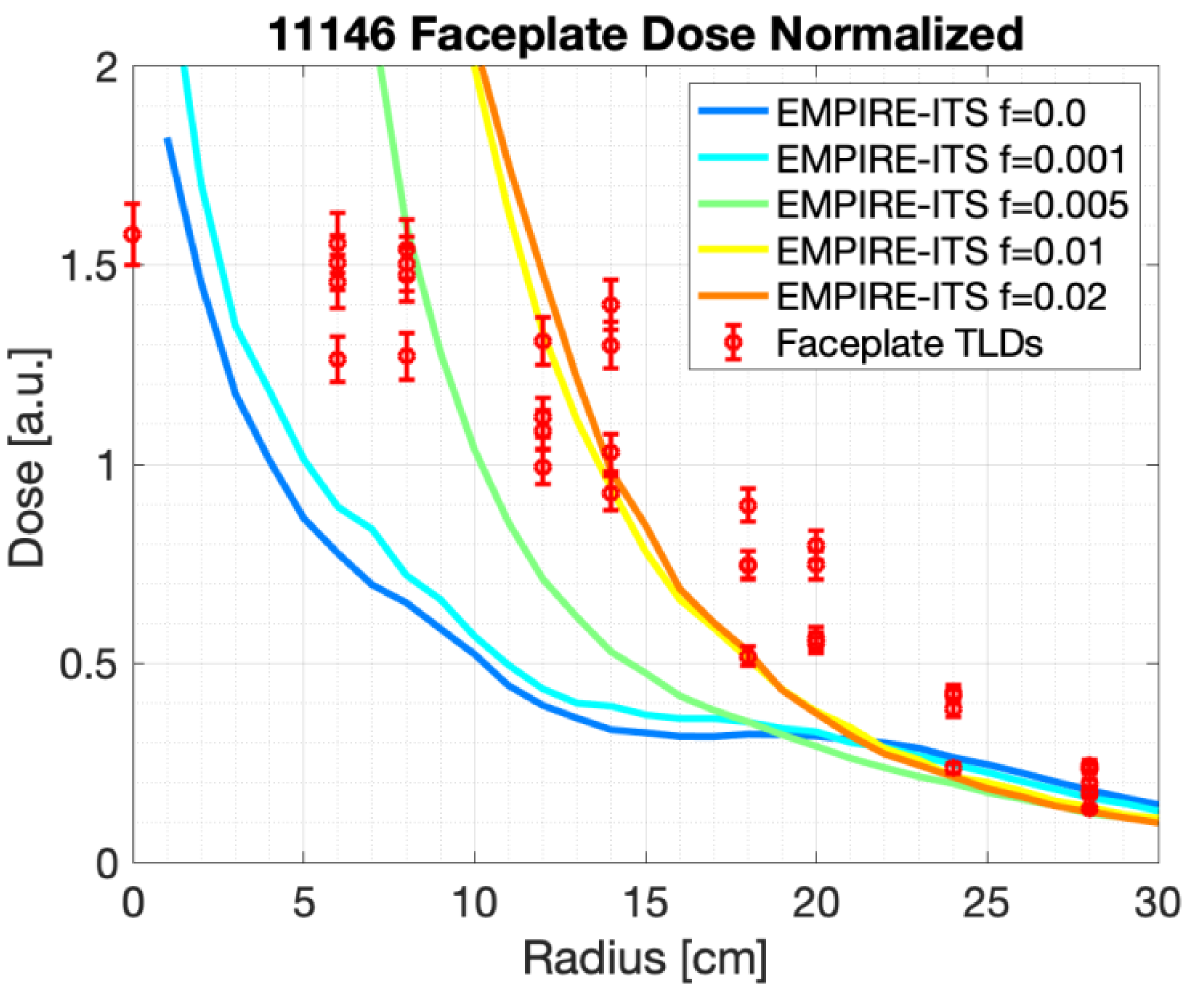
0.035” CaF_2

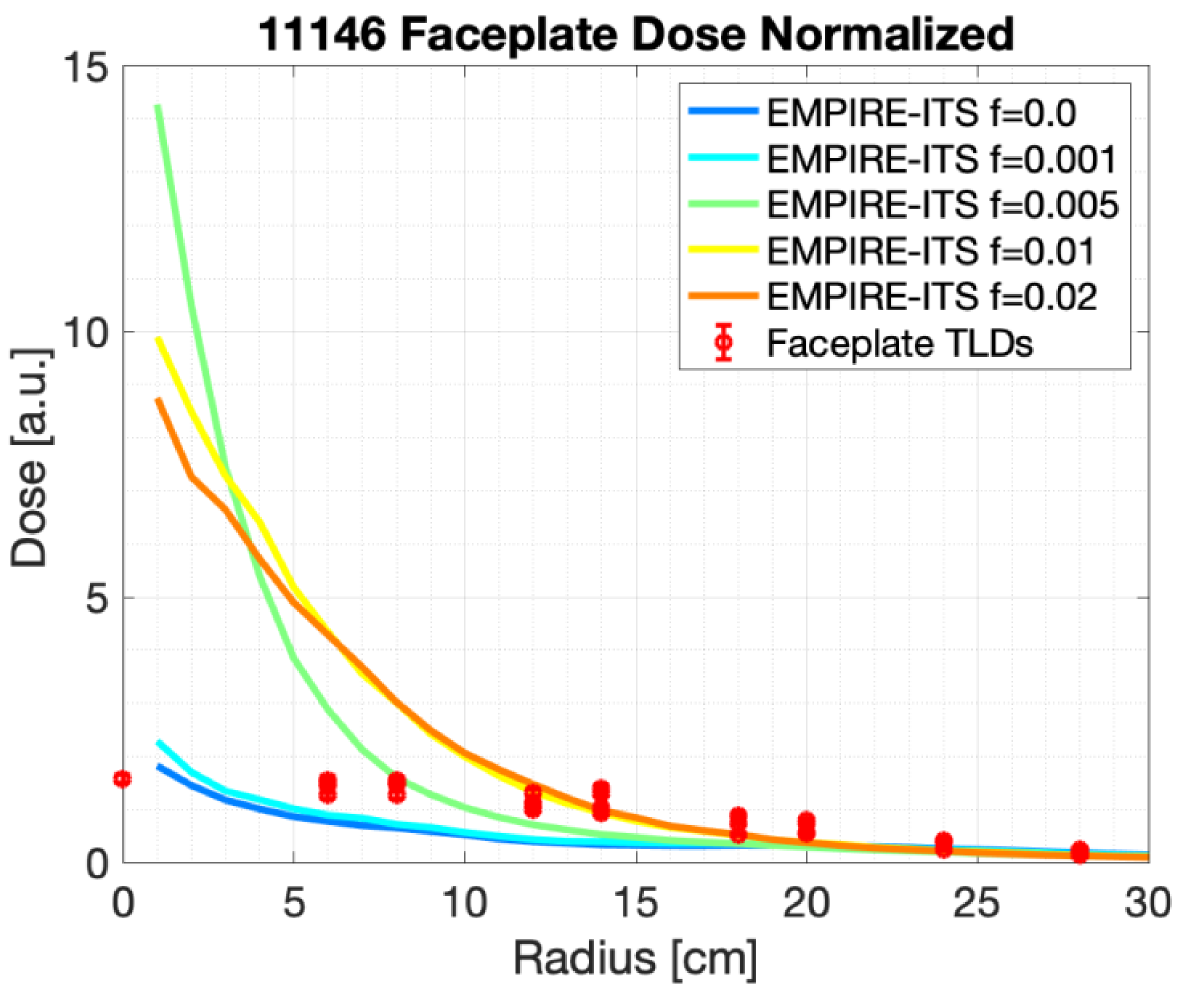
0.17” Al equilibrator

TLD-400



Shot 11146 Faceplate





Conclusions

Mendel's theory was used to interpret experimental sensor current into open-circuit simulation voltage waveform input

This workflow can be utilized to accurately simulate select shots

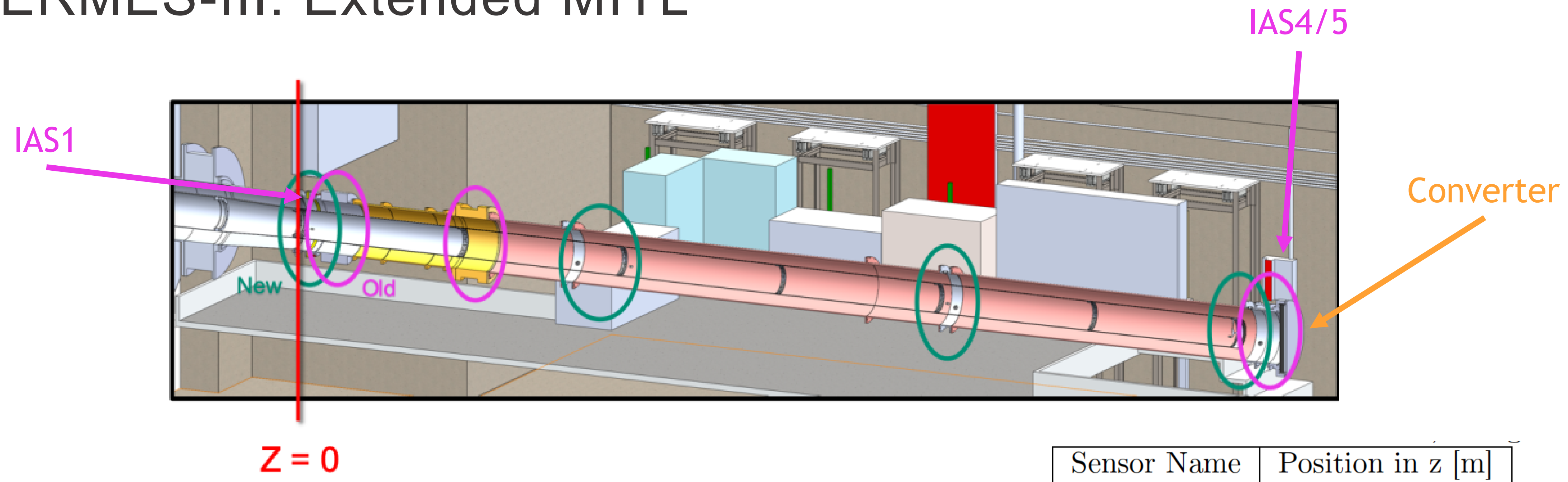
Even a small amount of ions barely changed the diode current, but drastically changed the diode flow pattern and the dose pattern

The EMPIRE-ITS workflow can be used to model and replicate Bremsstrahlung dose patterns for specific shots

- Future work: add in calibration factor to IAS5 traces
- Future work: increase ion injection fraction (to match tail)

HERMES-III Extended MITL Validation

HERMES-III: Extended MITL



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XAB4	13.064
IAS4	13.337
IAS5	13.379

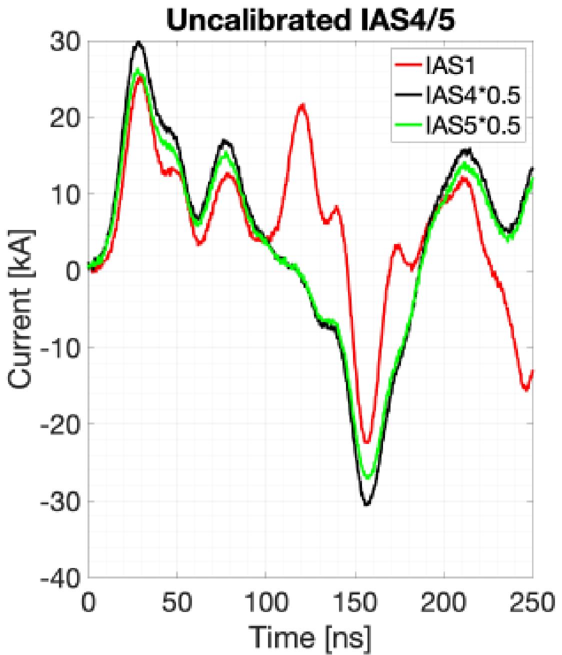
HERMES-III: IAS4/5 Calibration

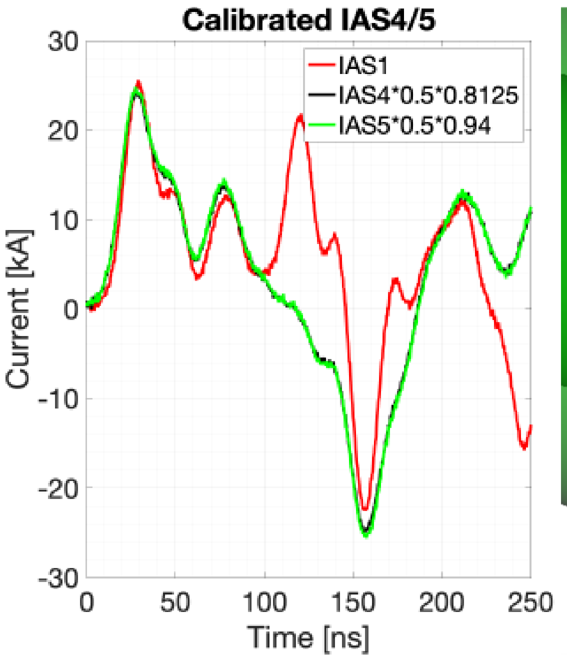
Short shots 11154 and 11155

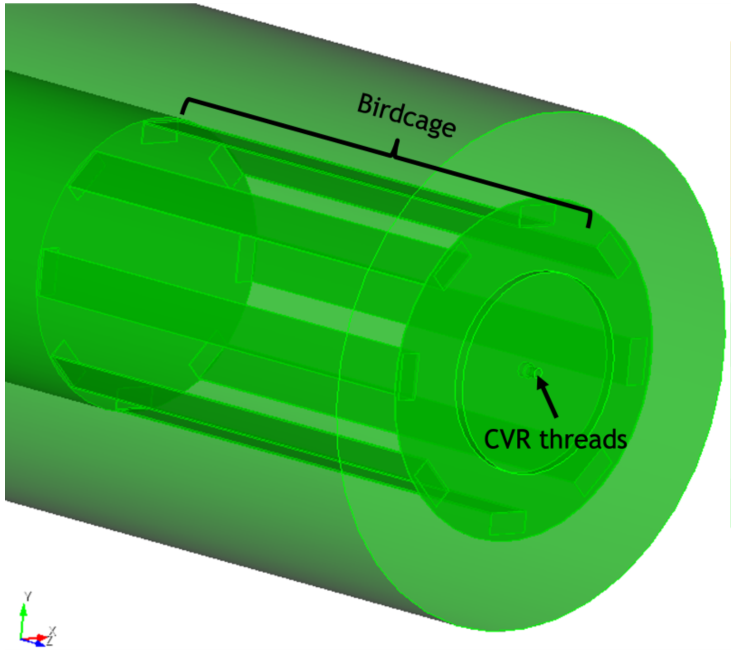
Only first peaks of IAS4/5 calibrated to IAS1 (trusted legacy diagnostic)

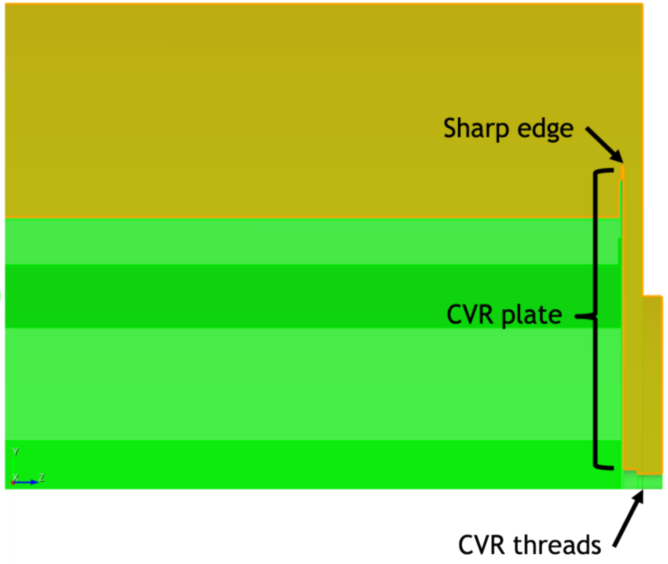
Multiply IAS4 by 0.8125

Multiply IAS5 by 0.94





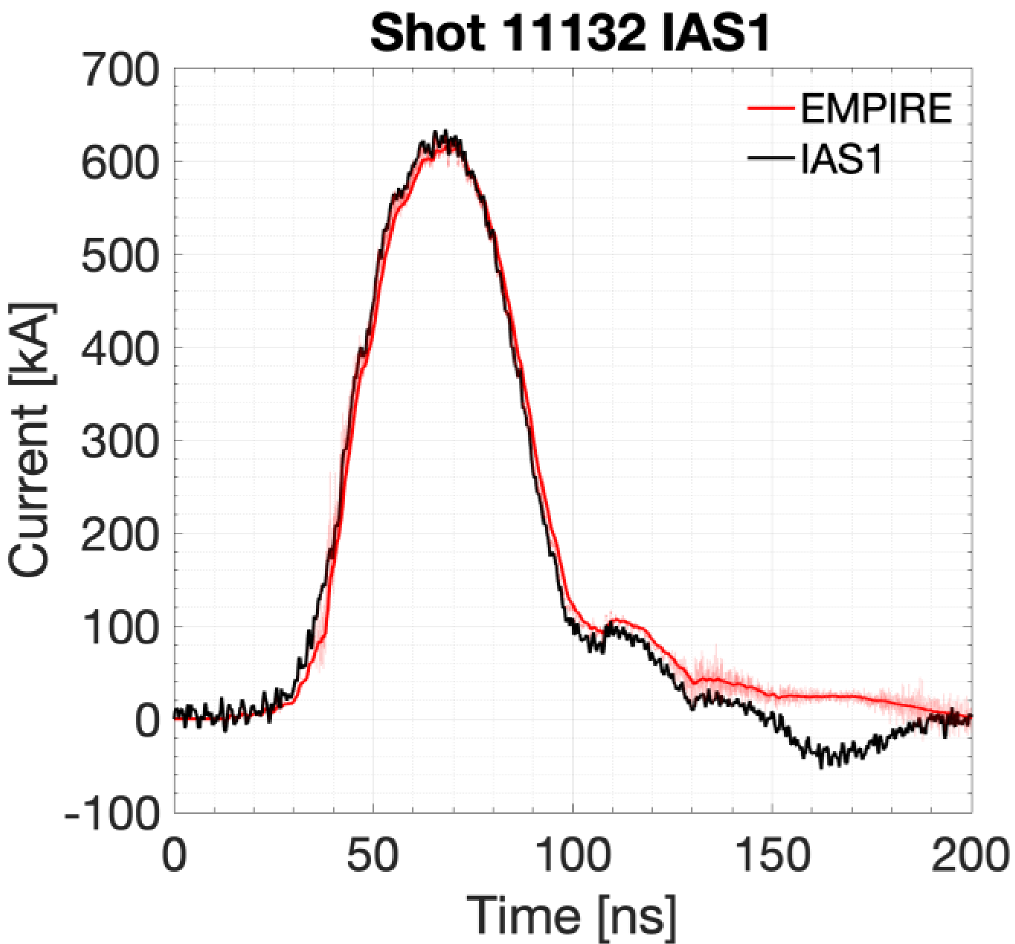


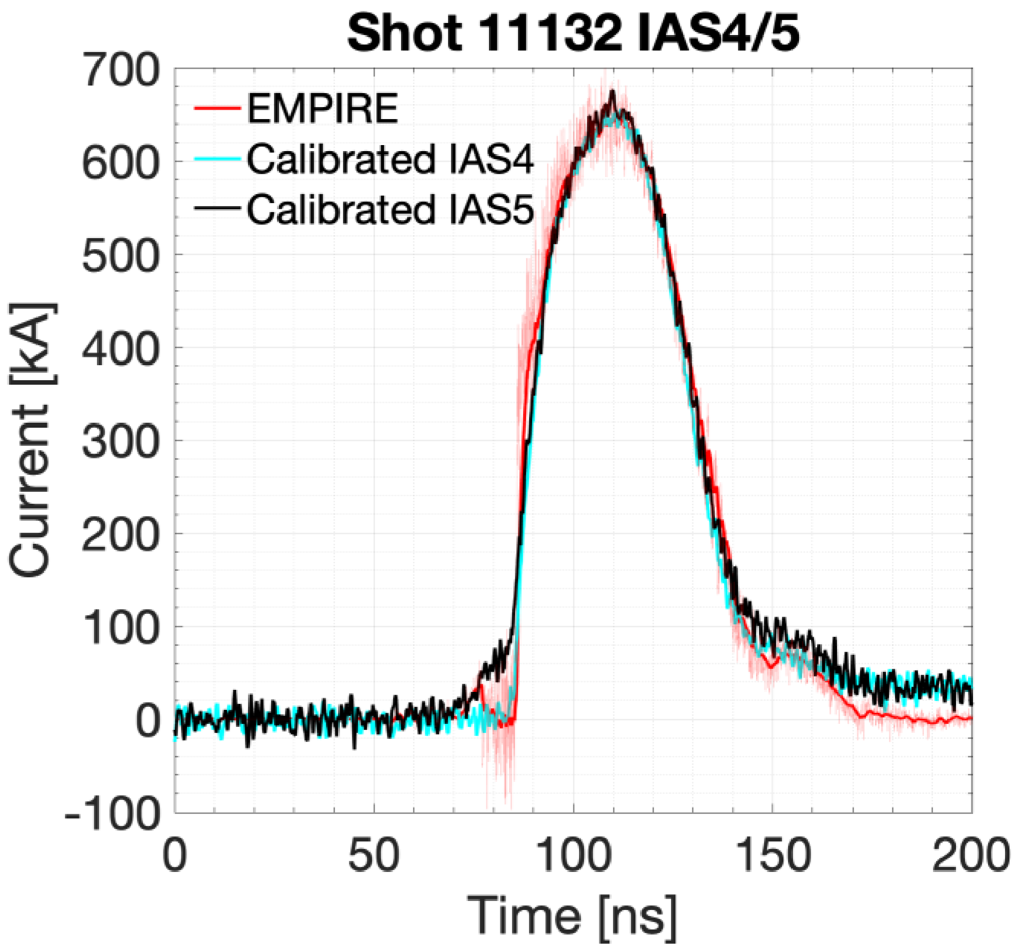


HERMES-III: Extended MITL Validation of shot 11132

Shots 11132-36 and 11146 used for validation

EMPIRE simulation driven with f_{SL} described earlier





HERMES-III: Extended MITL Validation of shot 11132

Signals integrated from t=0 to 80ns after peak current

Simulation data points move left along isopotentials as the pulse rolls down the MITL