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BREMSSTRAHLUNG DIODE DOSE IMPROVEMENTS USING SHAPED ANODE AND CATHODE GEOMETRIES

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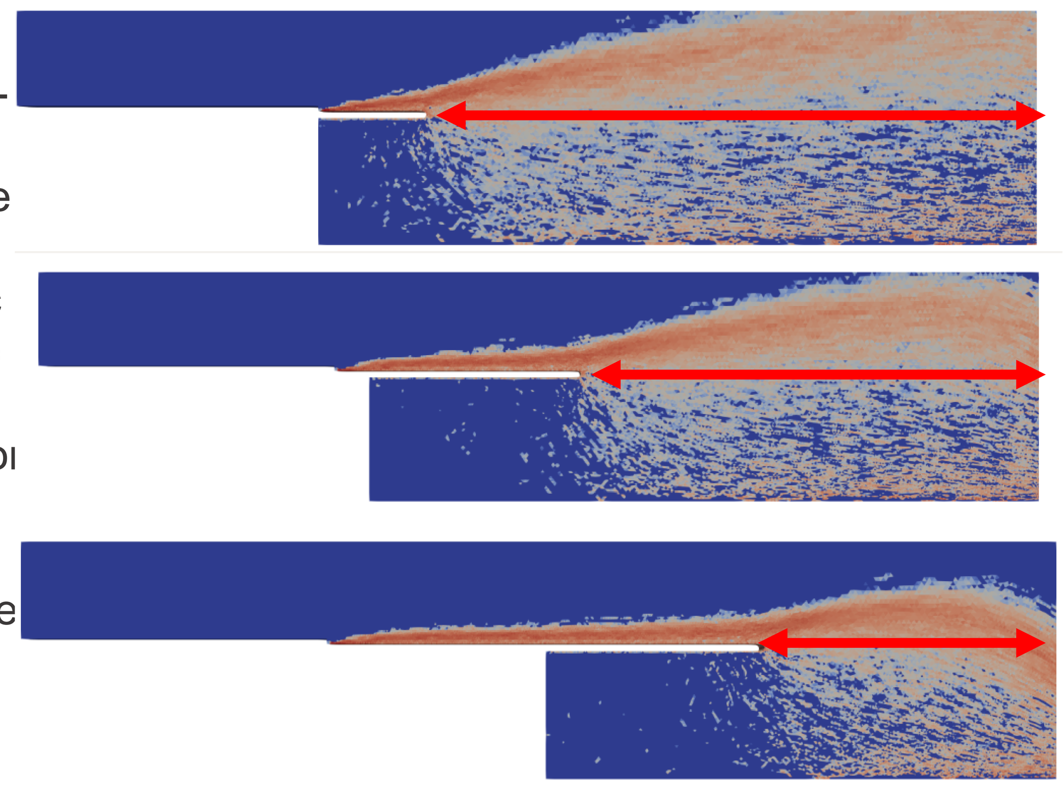
Annular-to-planar diodes generally used in HERMES-III and similar high-current accelerators have a strong correlation between diode impedance and electron incident angle, or the beam pinch angle. The self-magnetic field of the beam causes the beam to pinch radially inwards (on a coaxial geometry). This causes relatively poor far-field dose rates due to high beam divergence. Sanford has empirically derived this relation in the small-angle p

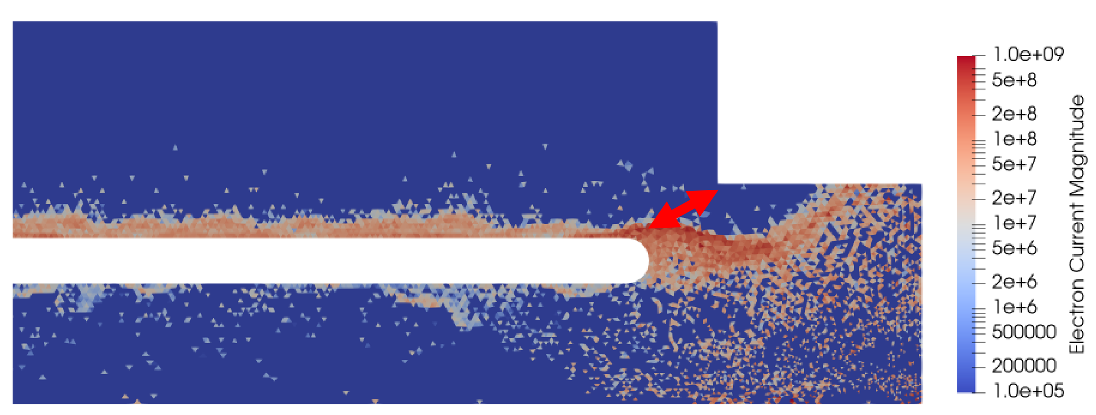
$$\frac{D}{Q} = (1.7\times10^3)V^{2.65}e^{-\theta V/2.1}$$



The indented-anode diode has been shown by Sanford [2] and this work to decouple the impedance and incident angle. Current loss to the indent is also considered. Characterizing the loss and minimizing it is important for real diode testing.

We use a parameterization that keeps the indent radius, R_I, constant and varies the cathode radius. The anode radius varies to maintain constant coaxial impe... ection.

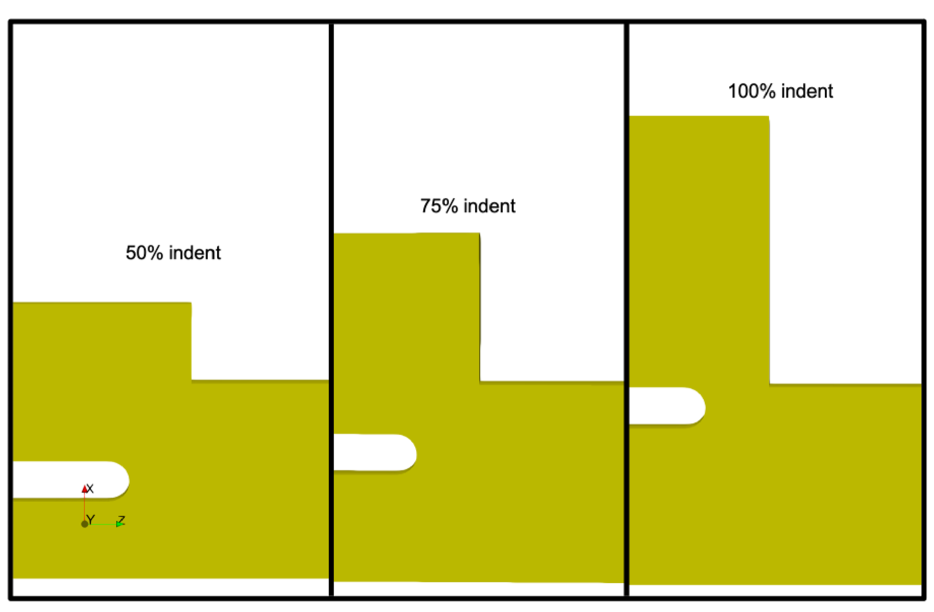
$$Z_0 = \frac{1}{2\pi}\sqrt{\frac{\mu_0}{\epsilon_0}}\ln\left(\frac{R_A}{R_K}\right)$$



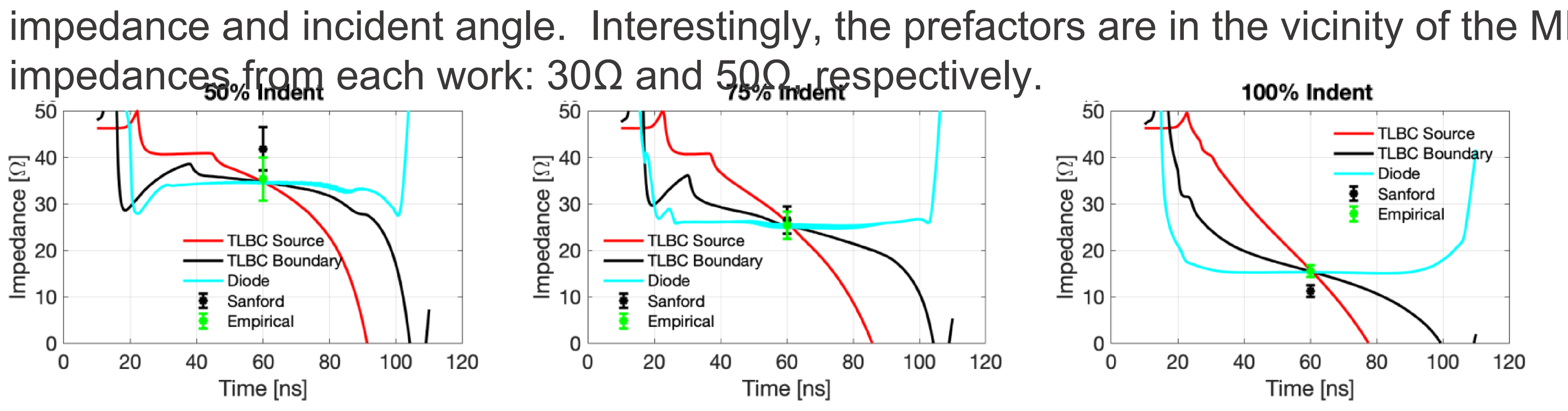
The impedance decreases with a higher indent percentage in acco... 's relation [2]:

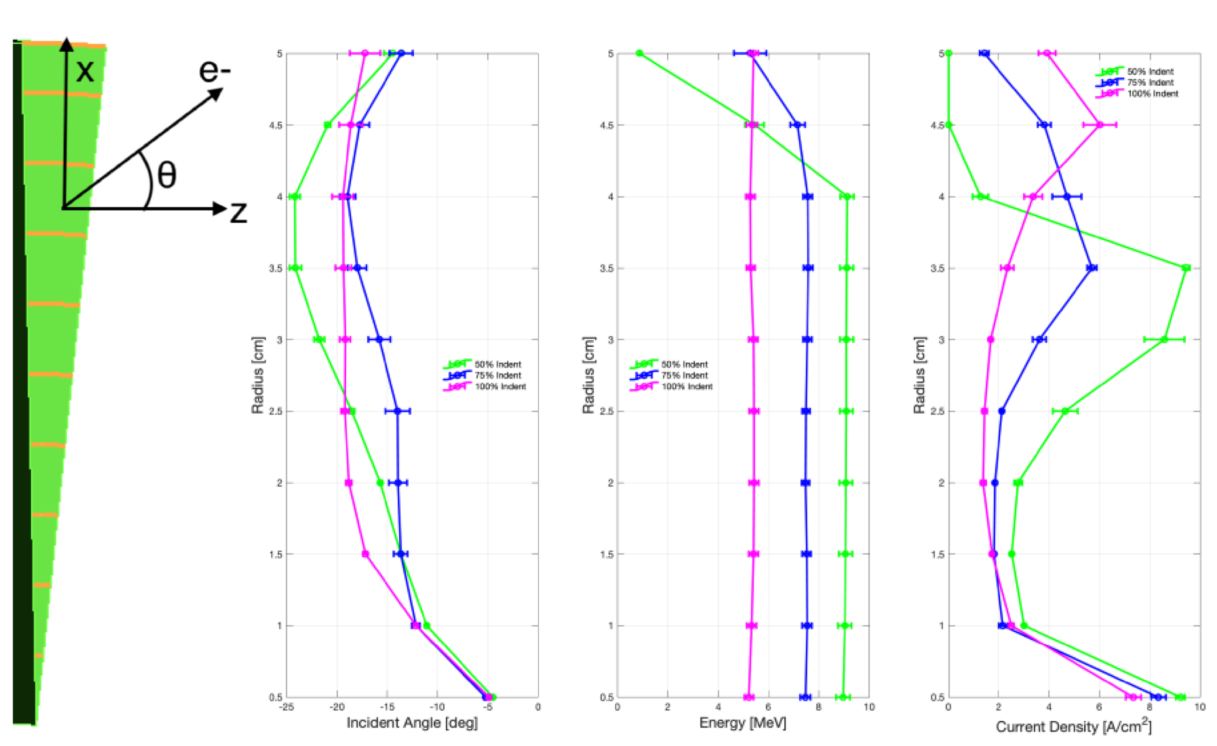
$$Z_S = (36\pm4)\frac{D_1+R_1}{R_K}$$

$$Z_{empirical} = (50\pm4)\frac{D_1+0.3R_1}{R_K}$$



We have eye-balled an empirical impedance relation for our geometries outlined in green above and shown as green dots below. The impedance decreases with R1 and increases with R_K while the incident angle decreases to some extent. This demonstrates a successful decoupling of the impedance and incident angle. Interestingly, the prefactors are in the vicinity of the MITL impedances from each work: 30Ω and 50Ω, respectively.

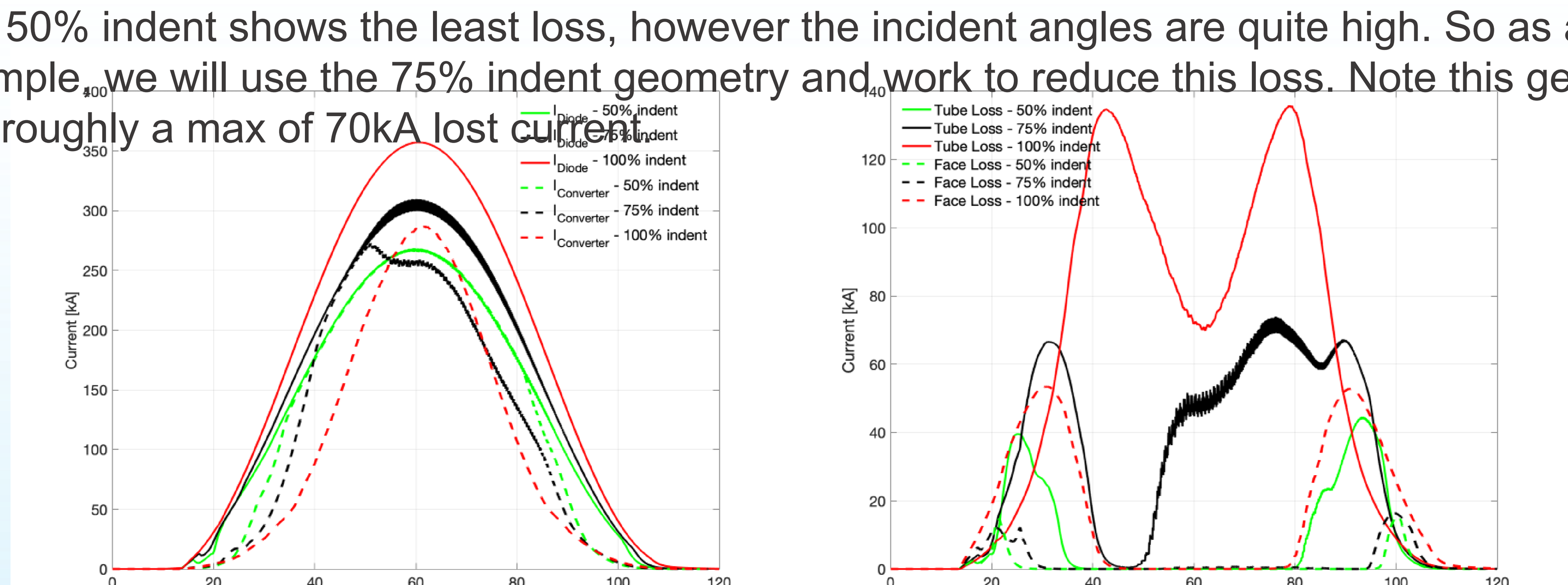




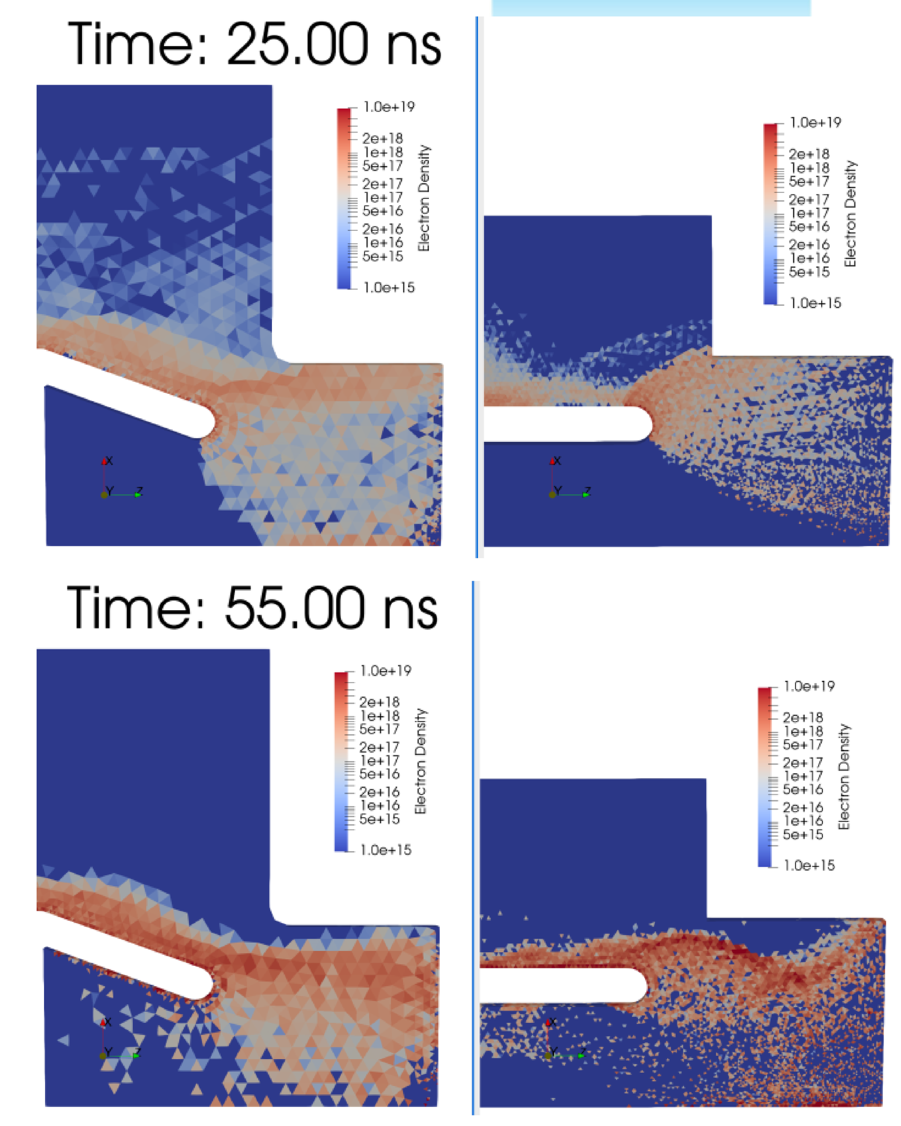
Reducing the diode impedance has negative effects. The reflection coefficient due to the impedance mismatch between the diode and MITL increases, causing poor endpoint energy.

Not all of the current makes it to the converter. This can cause emission of knock-on ions in the diode. If the ion presence in the diode is large enough, the electron beam can short into the indent causing catastrophic damage to the anode surface. Thus the loss to the indent needs to be characterized and minimized.

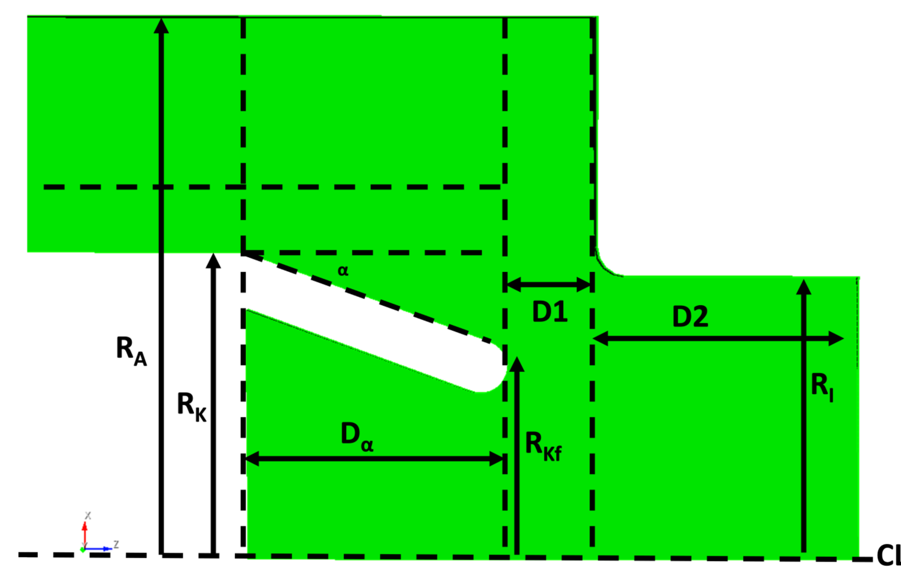
Shown below is the current loss characterization. The 100% indent shows massive current loss. The 50% indent shows the least loss, however the incident angles are quite high. So as an example, we will use the 75% indent geometry and work to reduce this loss. Note this geometry has roughly a max of 70kA lost current.



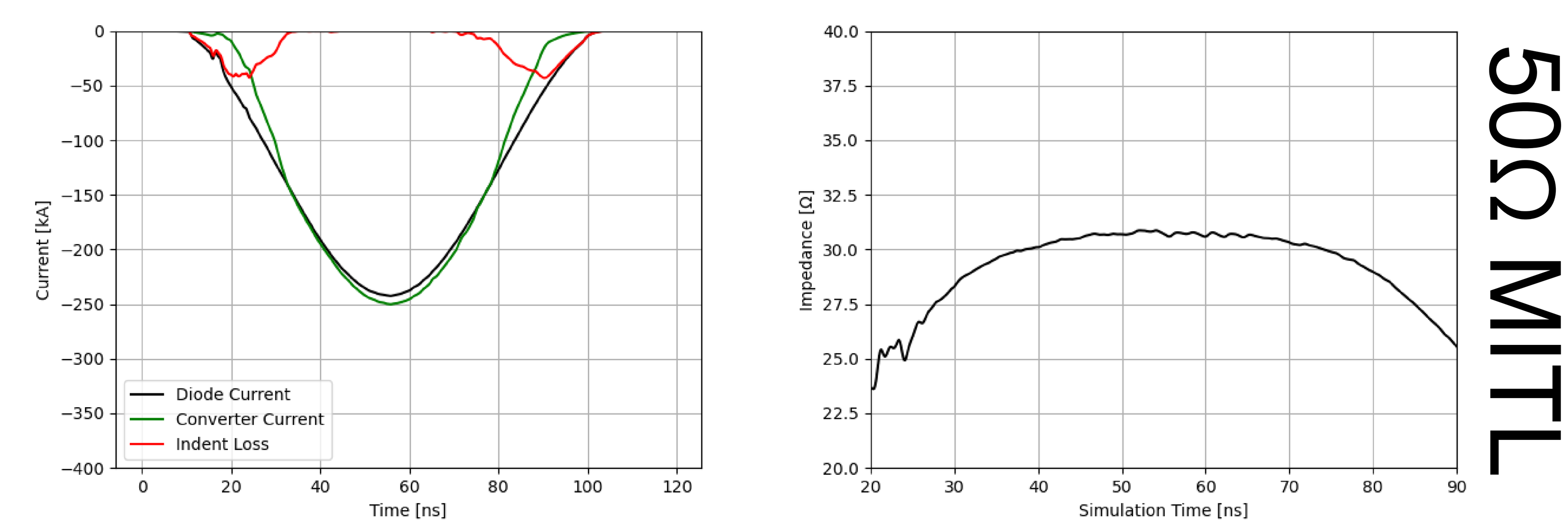
Based on Sanfords work [3], a shaped cathode can be used to help shape the electron beam. The below geometry uses a frustum-tipped cathode with the same final cathode radius. Indeed the only difference is now the MITL radii and the cathode frustum itself.



The intent is to direct the electron beam radially inwards to help shield the indent corner from the beam.



This approach seems to help immediately. The loss current vanished in the mid-pulse, and the loss front doesn't reach 50kA. However, the diode impedance does increase in this configuration. The cathode frustum decreases the ratio of the anode radius to the cathode radius. This is likely the cause for the increased impedance.



To better understand the impact of the MITL impedance, it was also varied. Decreasing it down to the standard HERMES-III MITL impedance of 34Ω, (a 32% reduction in impedance), the system operating impedance decreases from impedance from 31Ω to 26Ω (a 16% reduction). The reflection coefficient also decreases as there is less of an impedance mismatch. This yields a 14% increase in diode voltage and a 15% increase in diode current.

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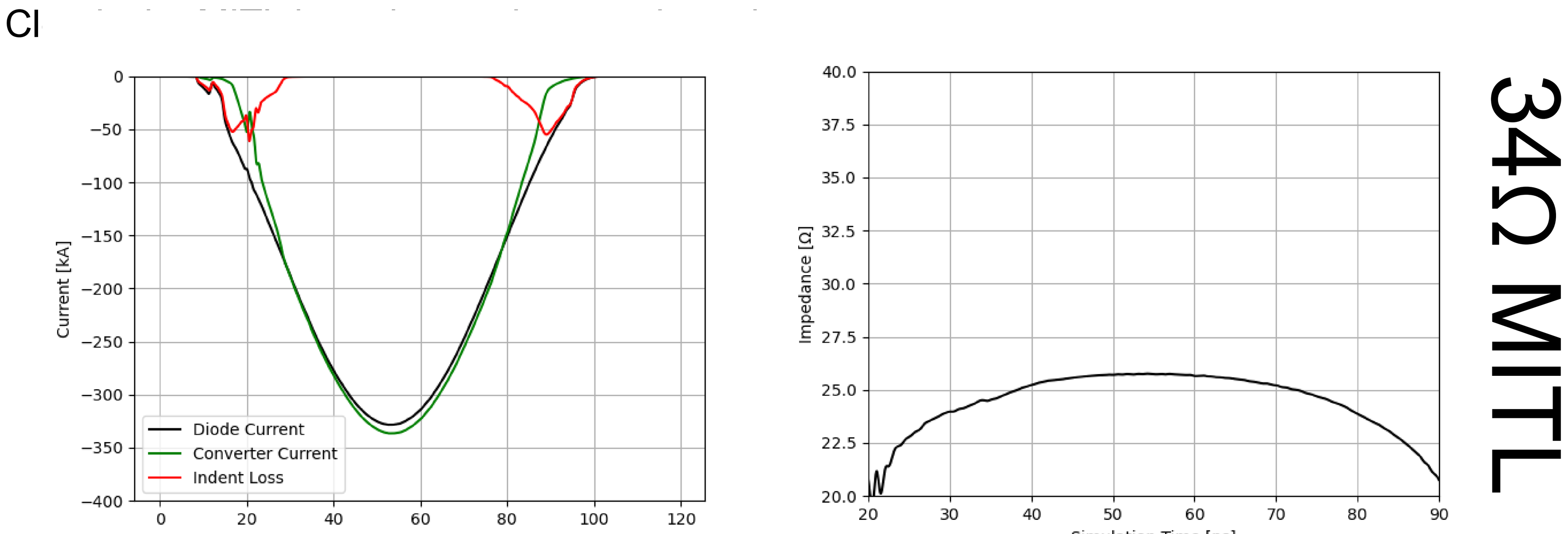
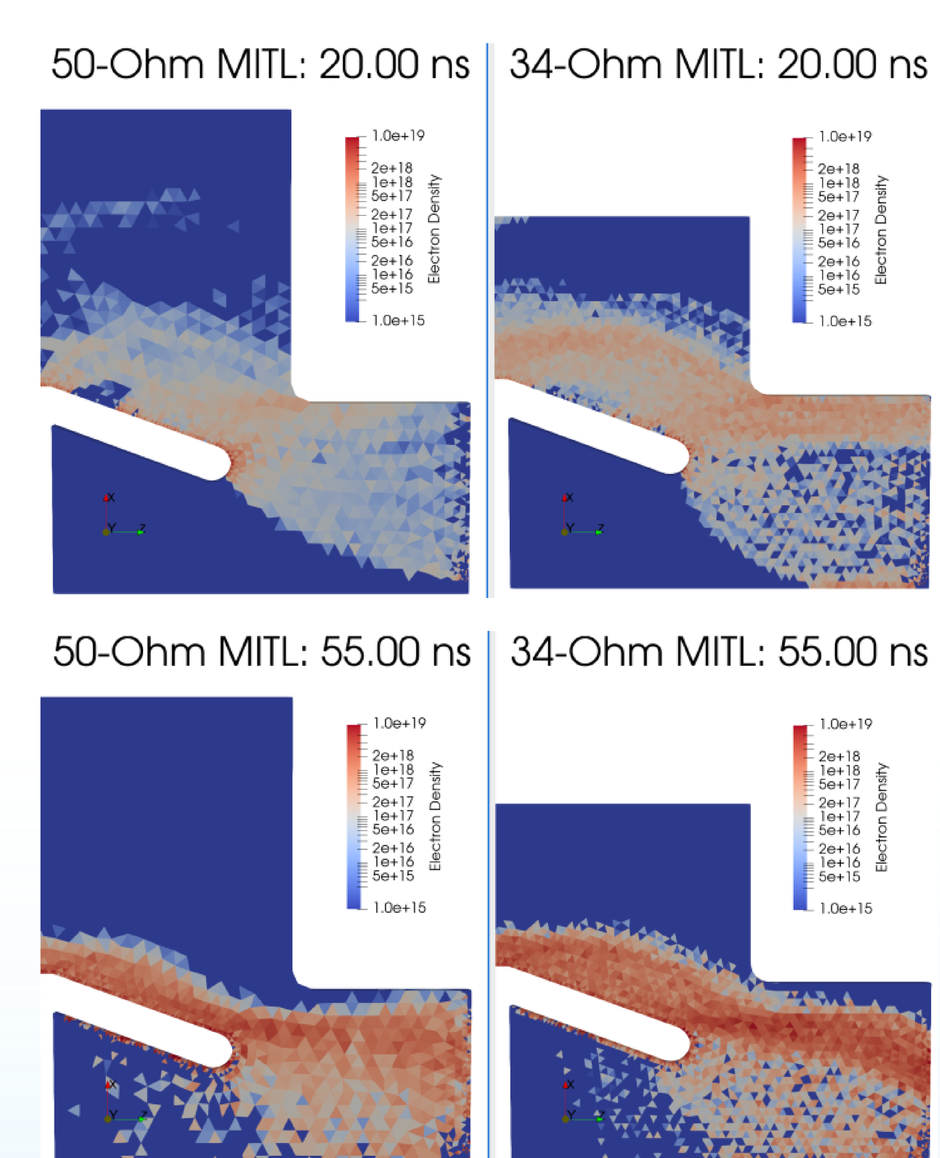


Conclusions and Future Work



We have demonstrated successful decoupling of incident angle and diode impedance. The impedance of the base indented-anode geometry scales with Sanfords equation. With some minor modification, we can fit Sanfords impedance equation to our own.

Introducing a cathode taper decreases the loss front. This also increases operating impedance, which seems to be directly related to the MITL impedance.

Future work:

- Vary D1, R1, α, and Z_0 to further understand impedance relation
- Vary driving voltage
- Introduce knock-on ions into simulation

[1] - T.W.L. Sanford, D.E. Beutler, J.A. Halbleib, and D.P. Knott. Experimental Verification of Bremsstrahlung Production and Dosimetry Predictions for 15.5 MeV Electrons. IEEE Transactions on Nuclear Science, 38(6):1160–1170, Dec 1991.

[2] - T. W. L. Sanford, J. W. Poukey, T. P. Wright, J. Bailey, C. E. Heath, R Mock, P. W. Spence, J. Fockler, and H. Kishi. Impedance of an Annular-Cathode Indented-Anode Electron Diode Terminating a Coaxial Magnetically Insulated Transmission Line. Journal of Applied Physics, 63(3):681–688, 1988.

[3] - J. M. Creedon. Relativistic brillouin flow in the high ν/γ diode. Journal of Applied Physics, 46(7), July 1875.

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NNSA National Nuclear Security Administration

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