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Sandia National Laboratories

Progress Understanding Anode-Initiated Vacuum Insulator Flashover

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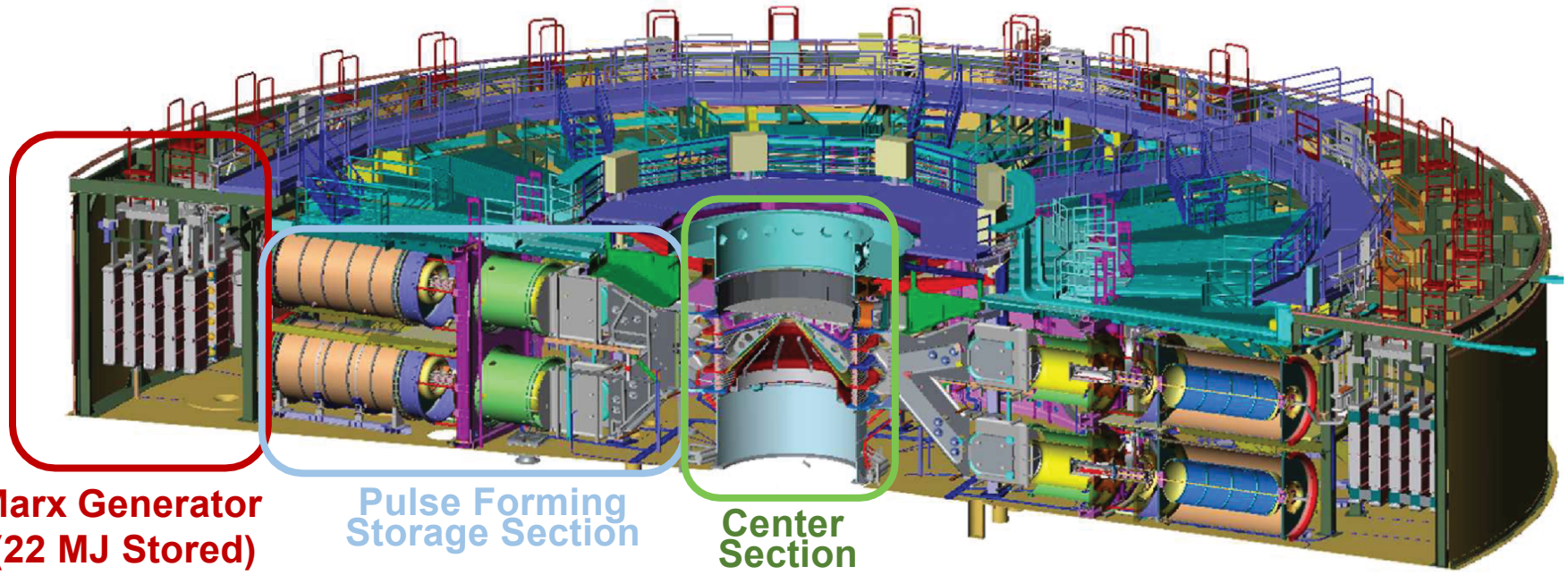
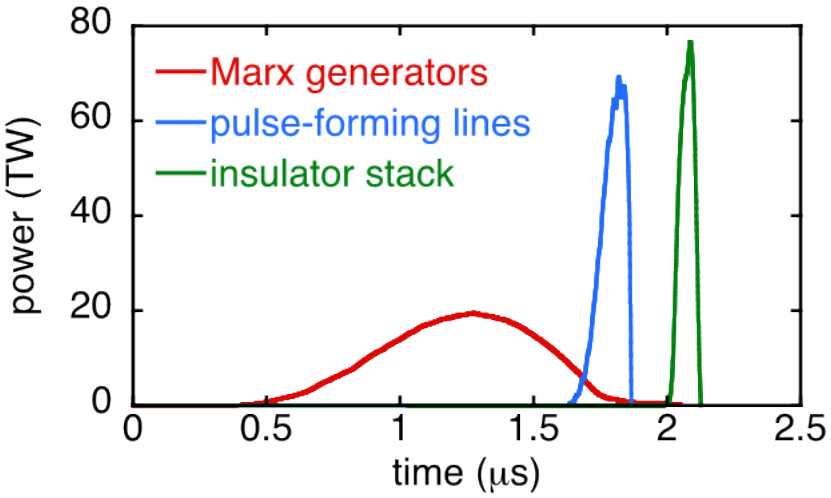
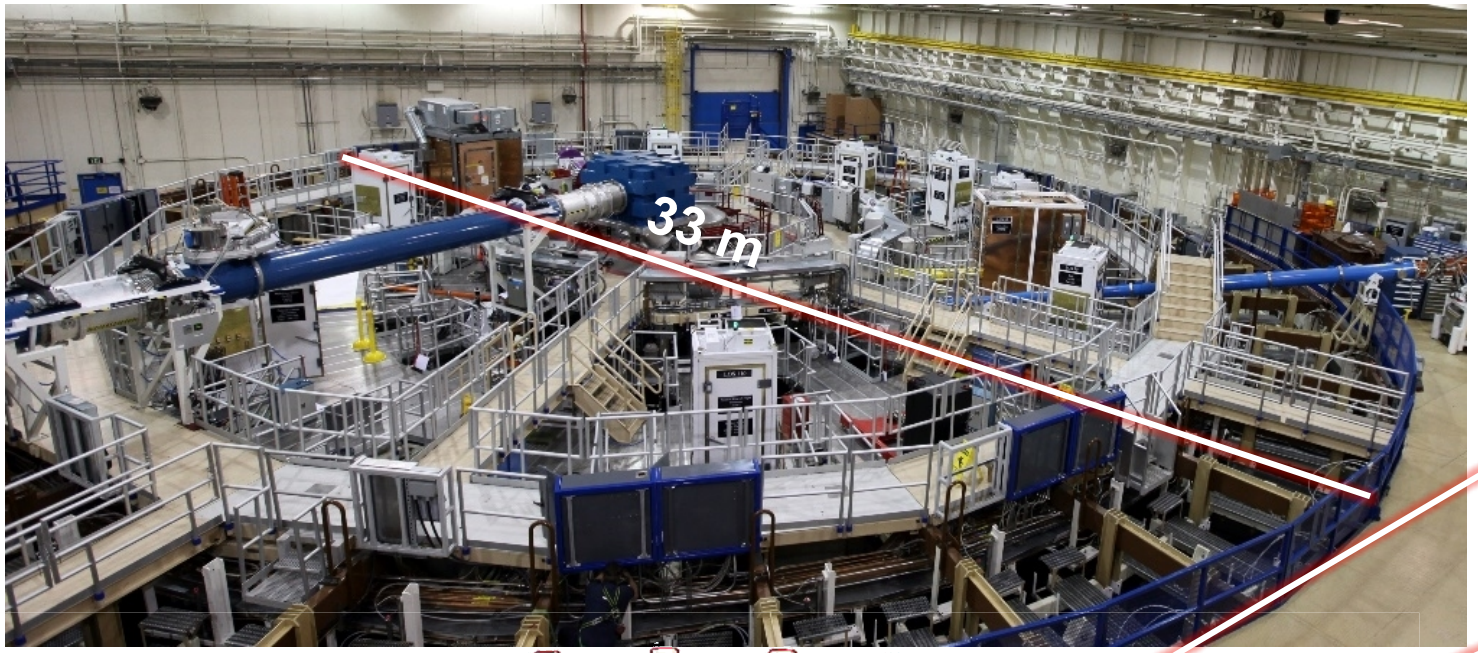
Sandia's Z Machine

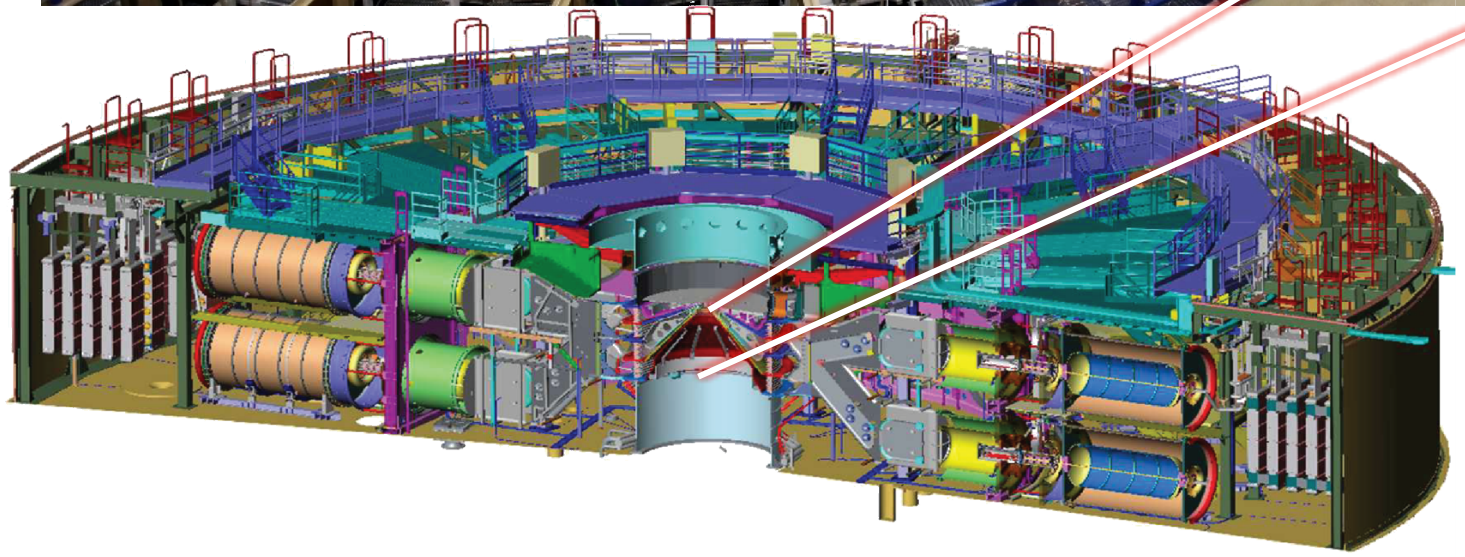


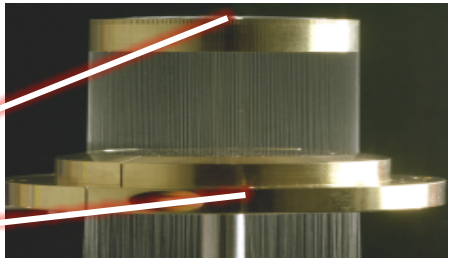


Z, the world's largest pulsed power machine, delivers 80-100 TW and 6 MJ of electrical energy to its center section in ~150 ns. X-ray pulse has ~300 TW. World's power grid is ~4 TW.

Sandia's Z Machine

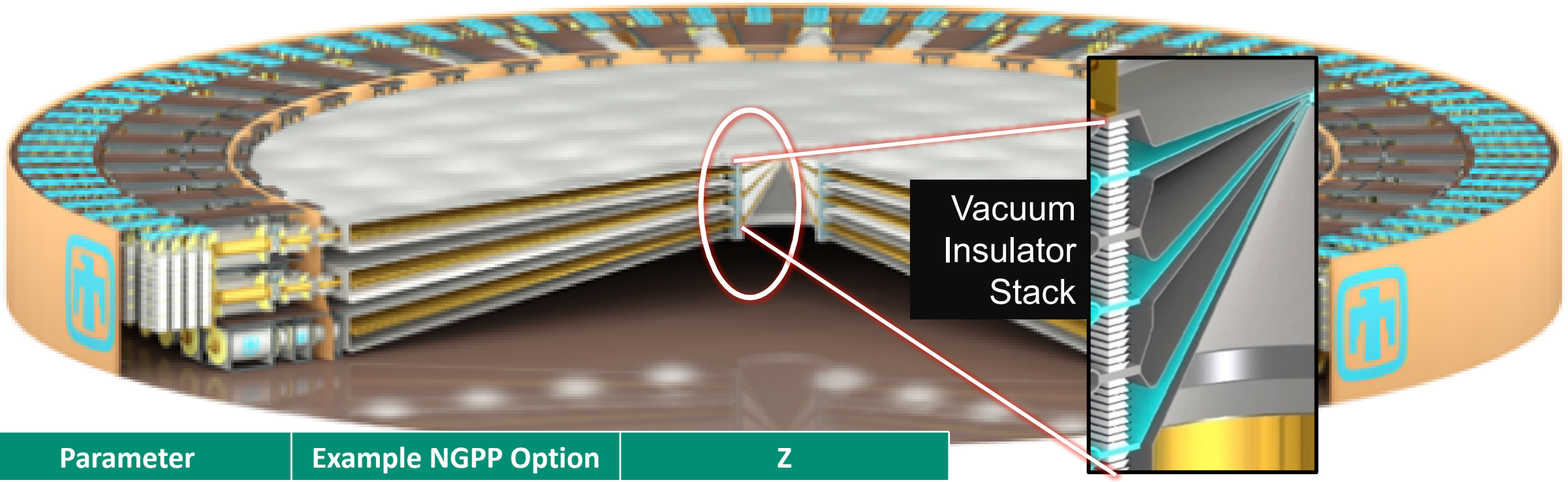






Send 20 MA through this 2 cm radius x 1.4 cm height hohlraum!

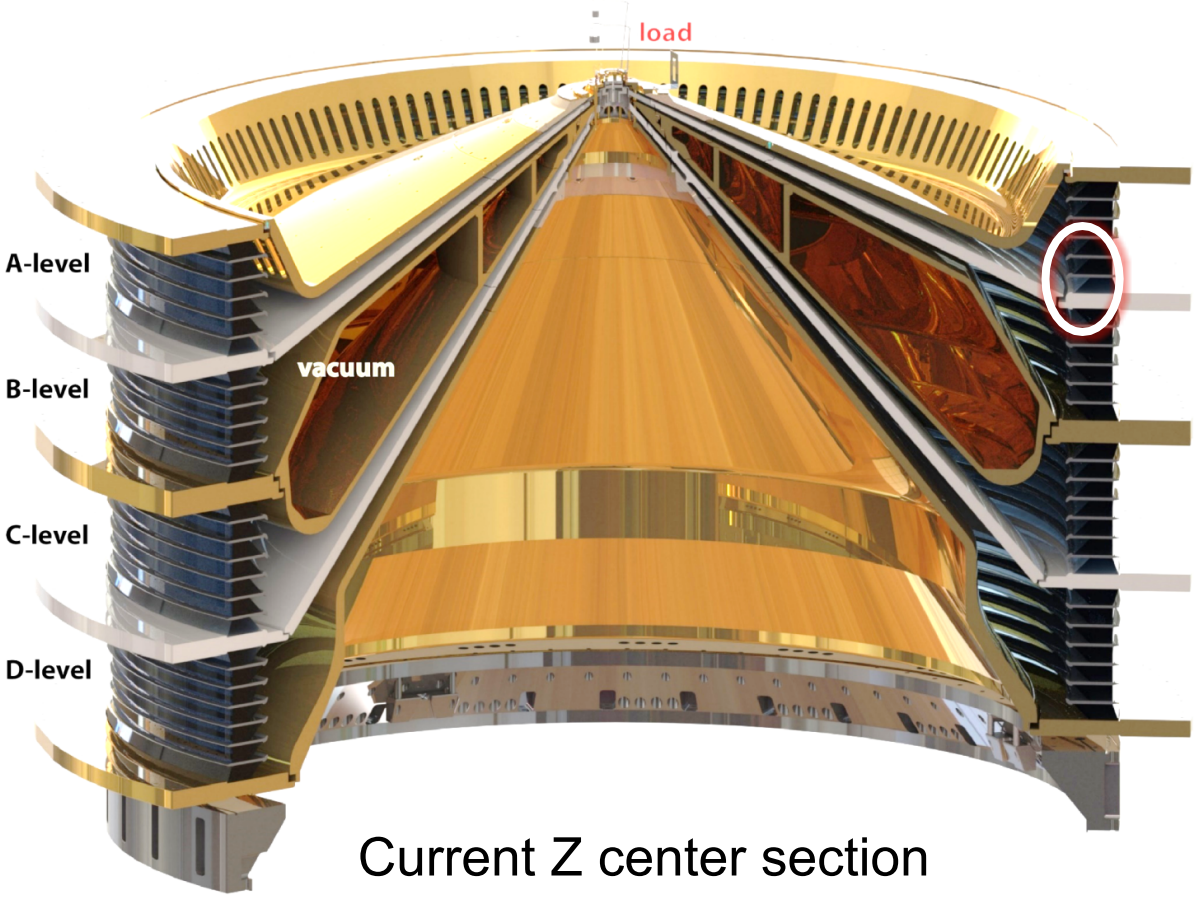
Sandia's "Next Z Machine": Next Generation Pulsed Power (NGPP)



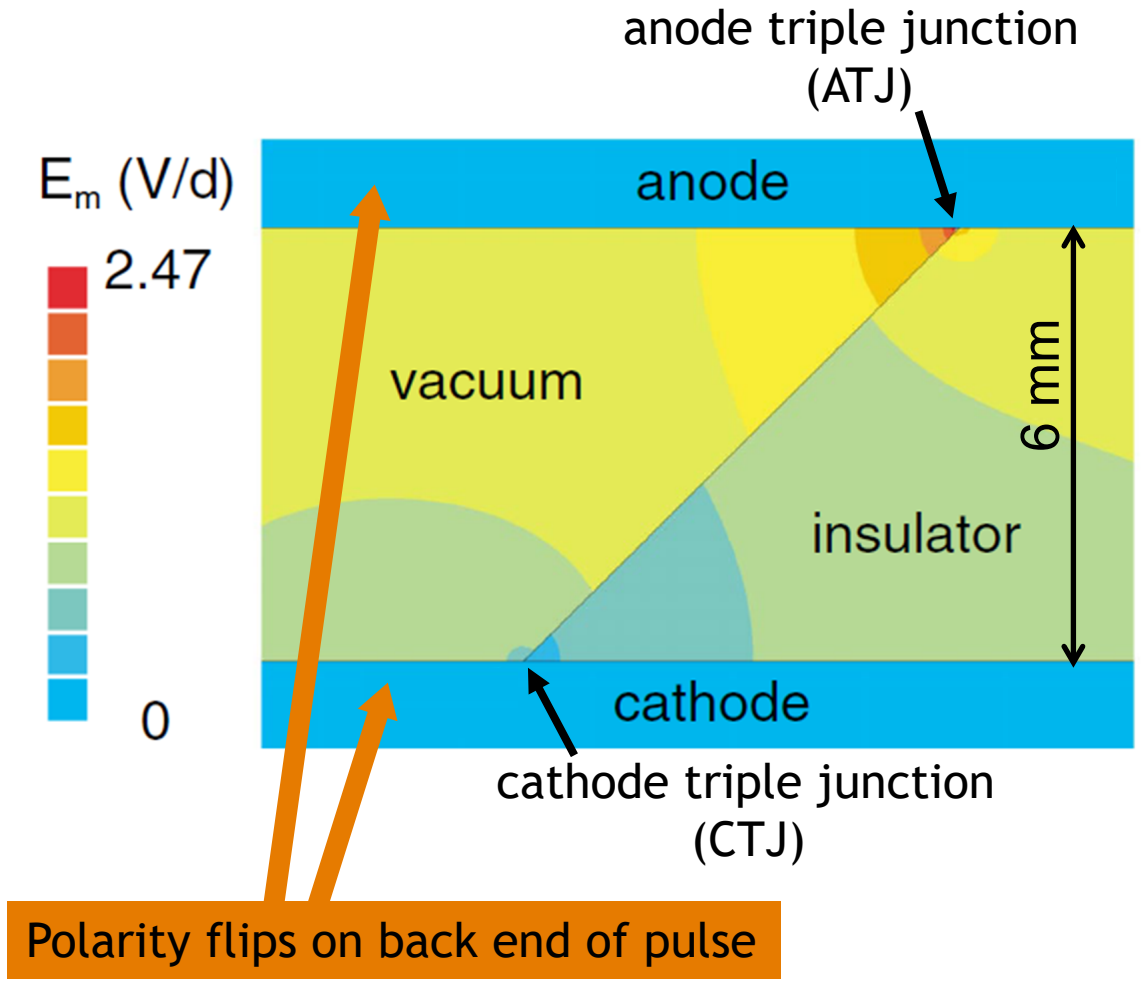
Parameter	Example NGPP Option	Z
Diameter	90 m	30 m
Marxes	75 @ 2400 kJ (180 MJ)	36 @ 600 kJ (22 MJ)
Capacitors	13,500 @ 2.95 µF	2,160 @ 2.65 µF
Power at Stack	602 TW	85 TW
Forward Energy at Stack	54 MJ (short pulse)	6 MJ (short pulse)

Height of vacuum insulator stack is a critical constraint. Smaller gaps – requiring higher breakdown strengths – will lead to $100M's of savings and enable new class of designs.

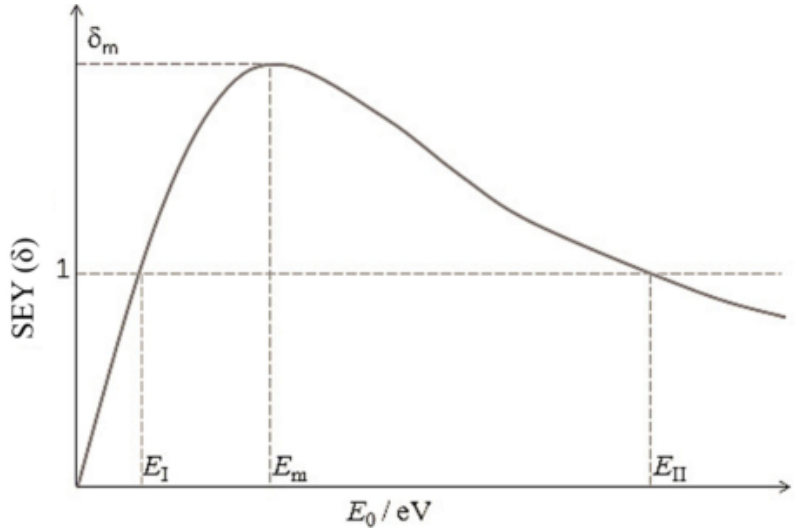
Vacuum Insulator Flashover

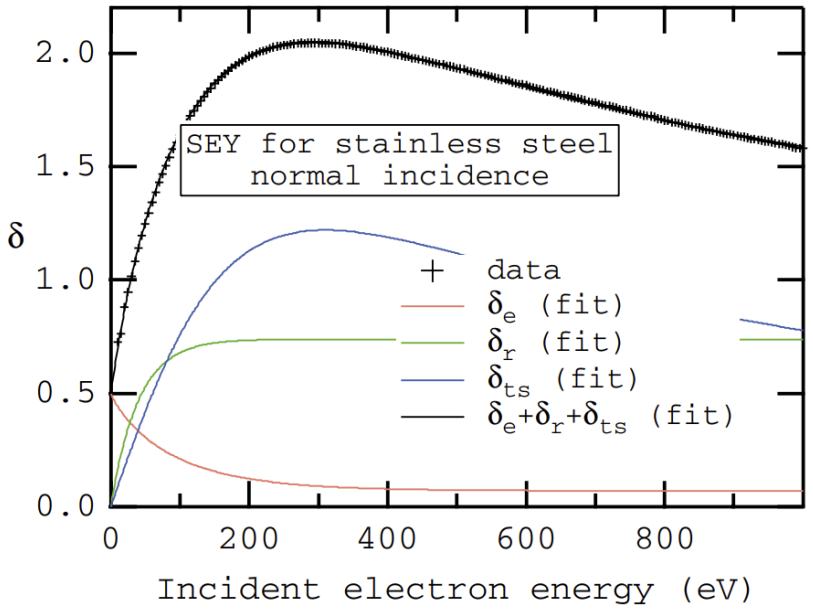


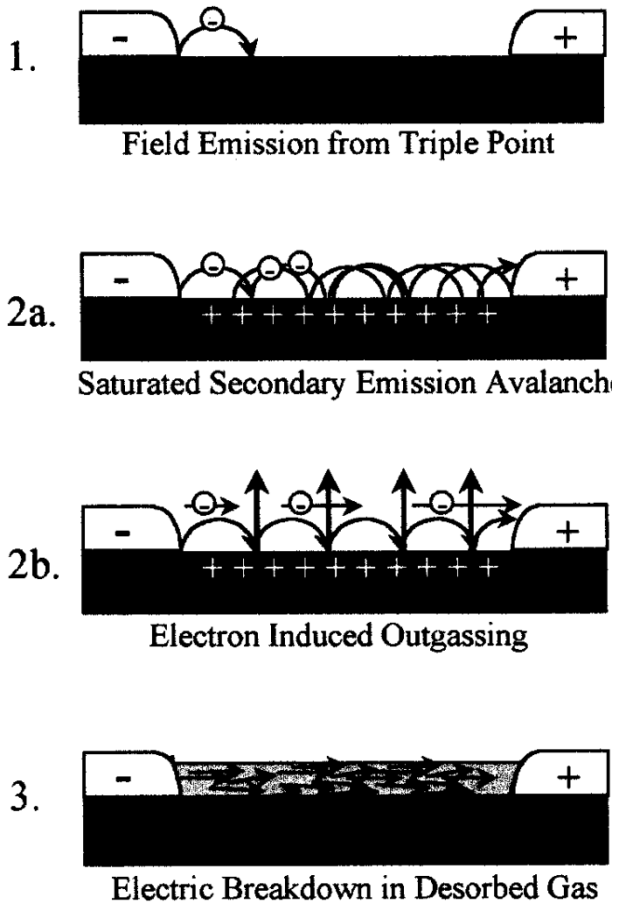
Current Z center section

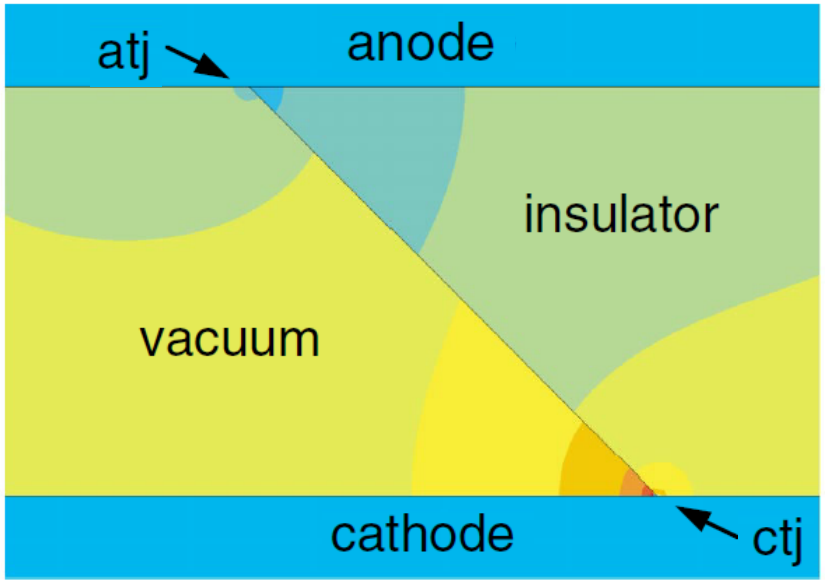


Cathode-Initiated Breakdown



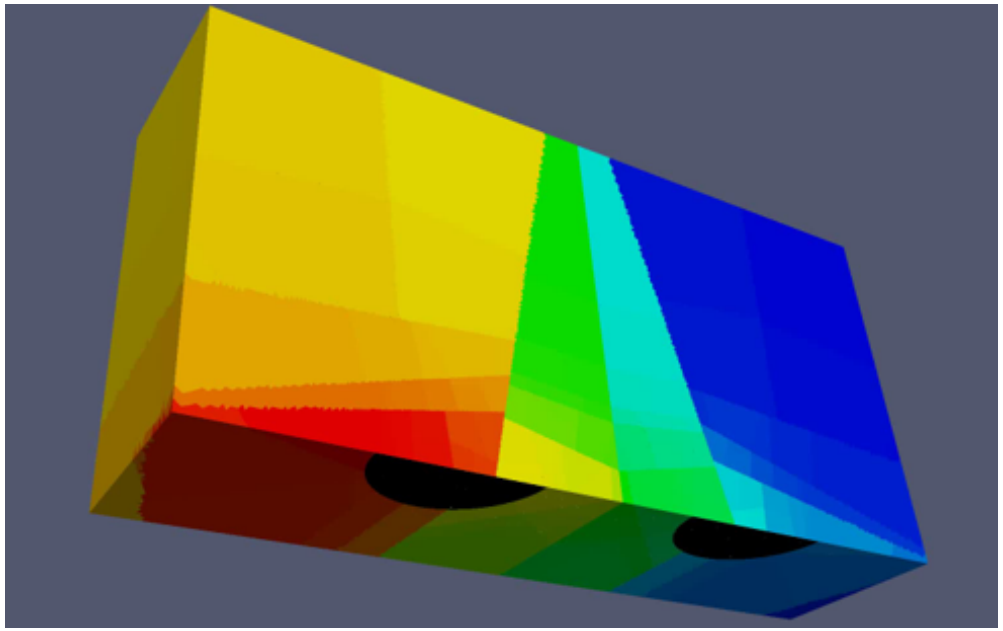






Furman, Phys. Rev. STAB, 2002
Jenkins, Electron and Ion Emission from Solids, 1965
Neuber, IEEE Trans. Plasma Sci., 2000
Stygar, Phys. Rev. STAB, 2005

Aleph Simulation Tool

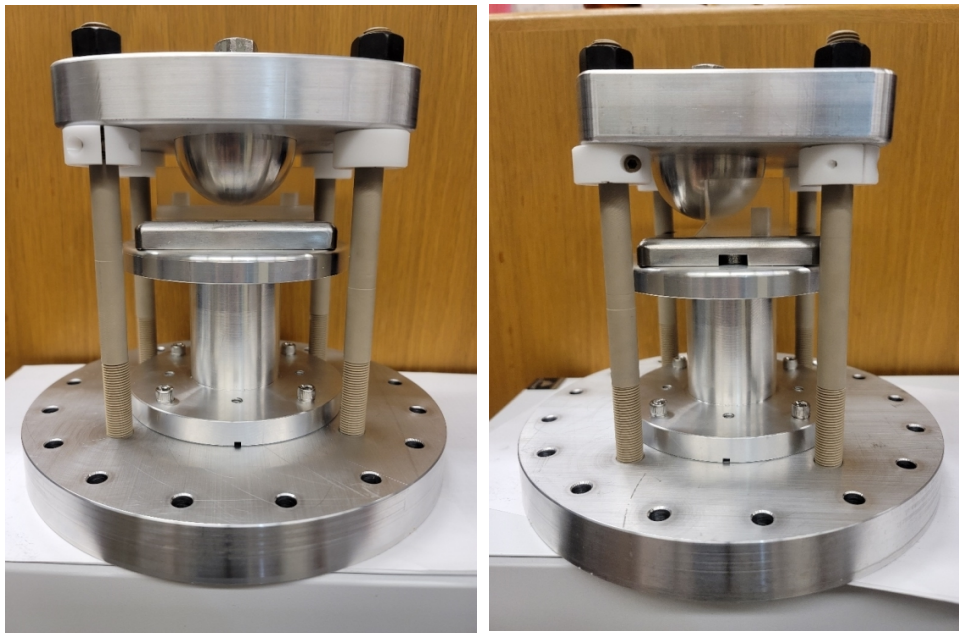


- 1, 2, or 3D Cartesian
- Unstructured FEM (compatible with CAD)
- Massively parallel
- Hybrid PIC + DSMC (PIC-MCC)
- Electrostatics
- Fixed B field
- Solid conduction
- Advanced surface (electrode) models
- e- approximations (quasi-neutral ambipolar, Boltzmann)
- Collisions, charge exchange, chemistry, 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 (>200M elements, >1B particles)

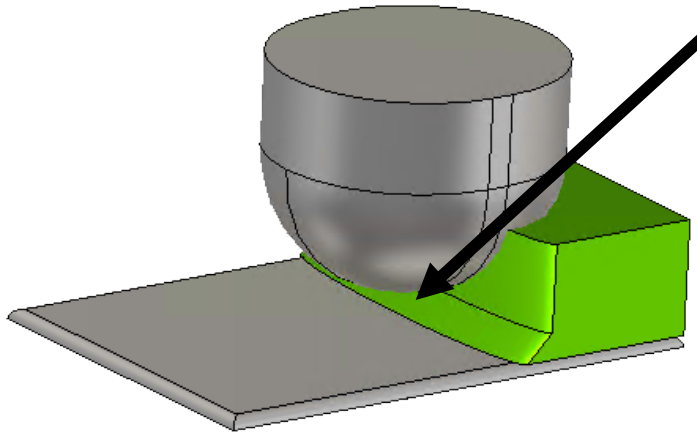
Anode-Initiated Flashover: Experiments

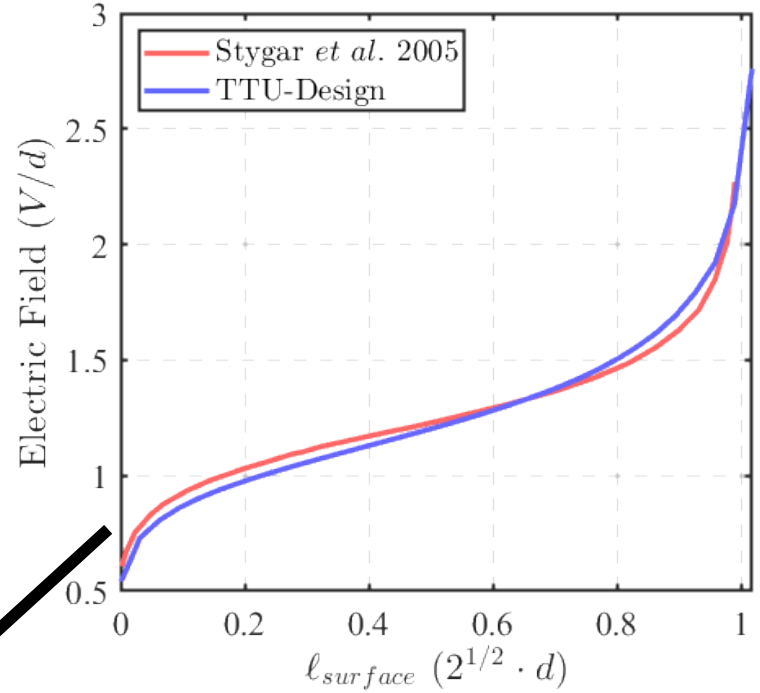
Wish to reproduce some of the environment on Z. Do achieve fields ~400 kV/cm. Have shorter pulse (~25 ns vs. ~150 ns). Would also like to be amenable to modeling for validation.

Use new diagnostics on system!



Front Side

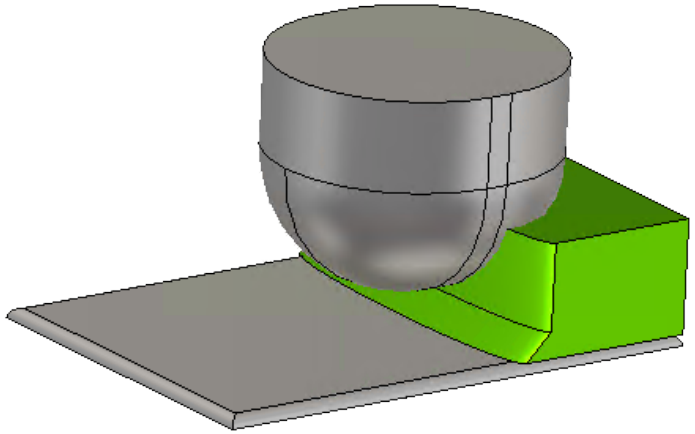




240 kV/0.6 cm = 400 kV/cm
(hope for 500 kV by end)

Refining Insulator Configurations

1st Generation

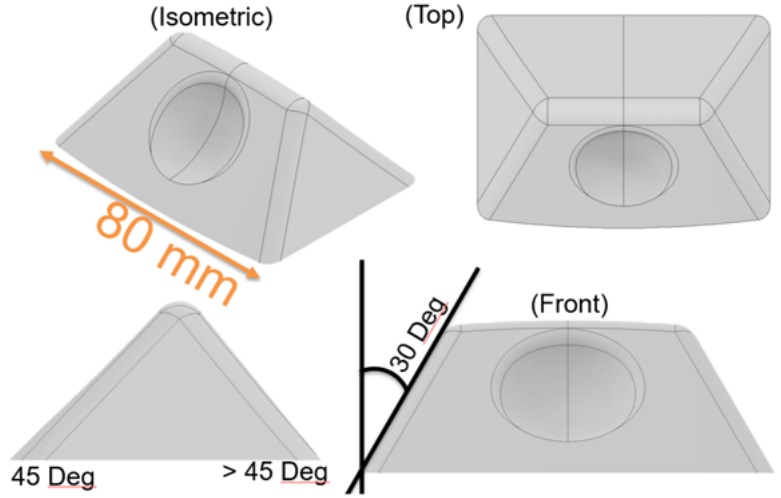


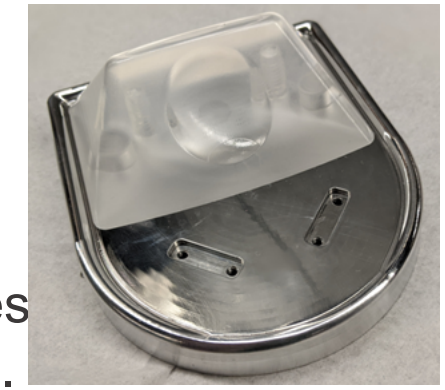
45° wedge, straight sides.
Subject to breakdown along back/side

2nd Generation

Entire front is angled. Smoothed edges
Still some breakdown along back/side.
Requires wire “field enhancer”

3rd Generation



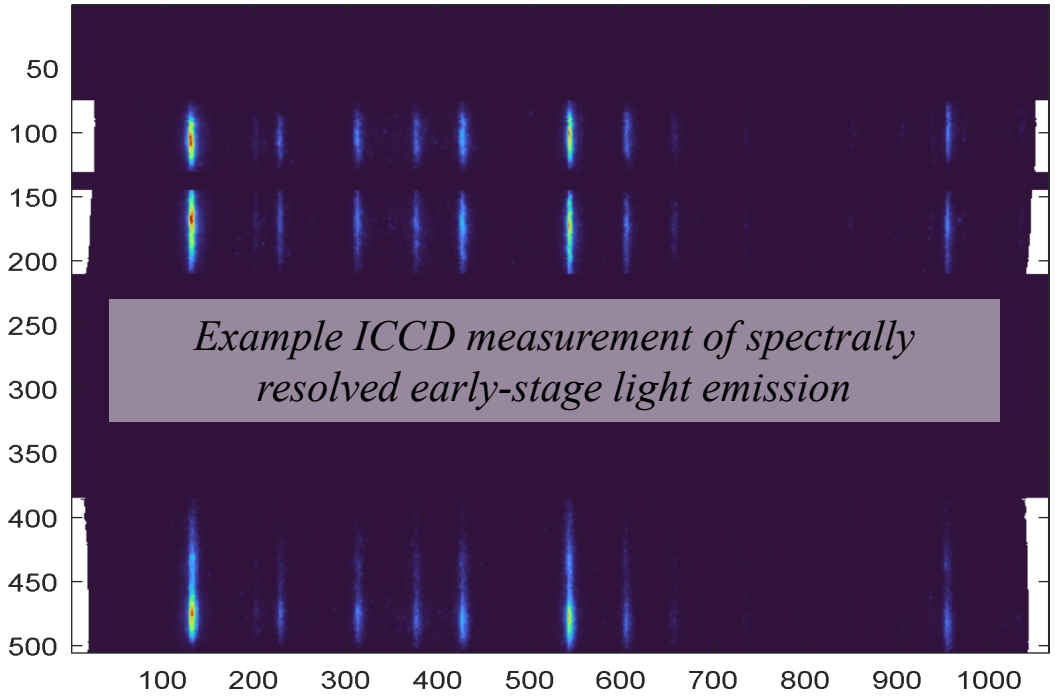


Fully seated anode.
Variable fillet around anode.
No wire?

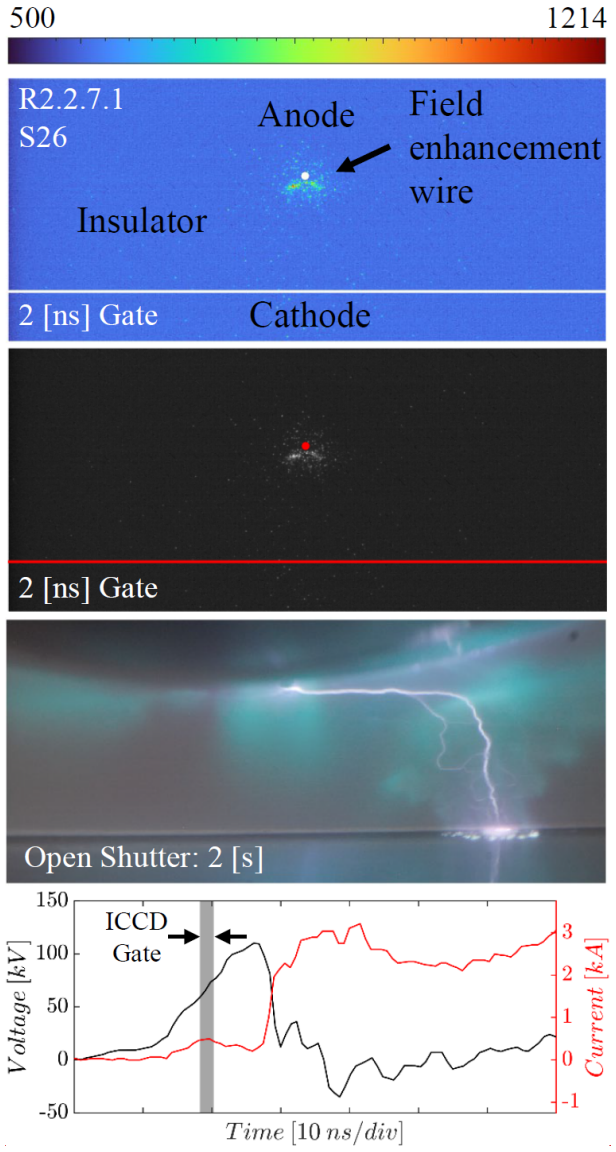
Spatially, Spectrally, and Temporally Resolved Light Emission

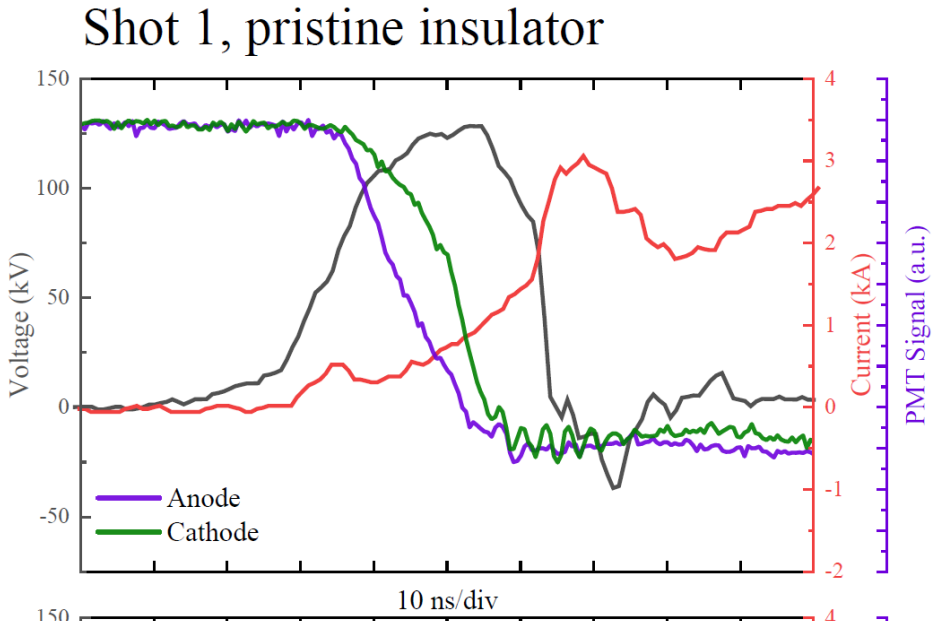
- Light from the cathode and anode regions are collected via a pair of fibers
- Fibers connect to a spectrograph with ICCD detector
  - Use a 5 ns ICCD gate to observe light in the *early-stage* of flashover formation

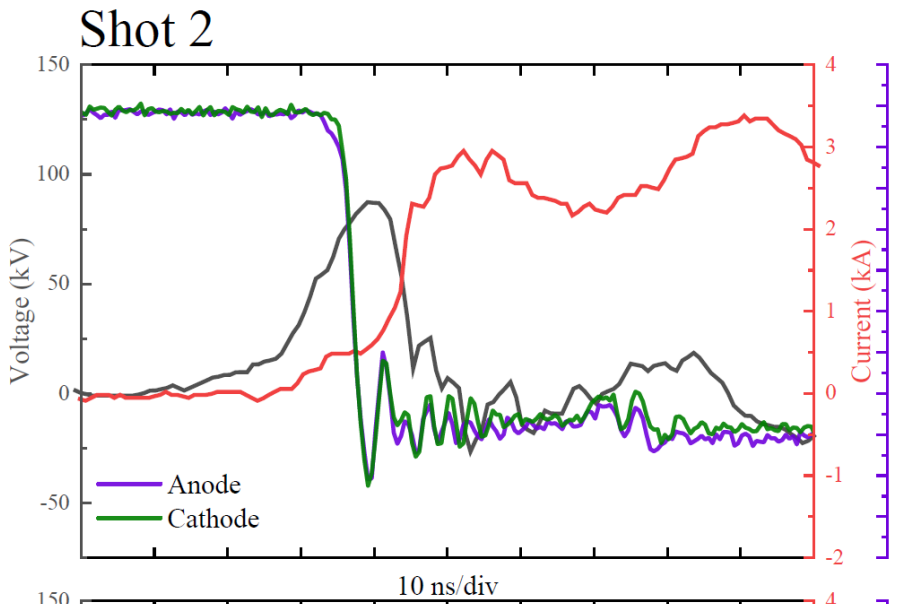
Observation window of the anode and cathode fibers

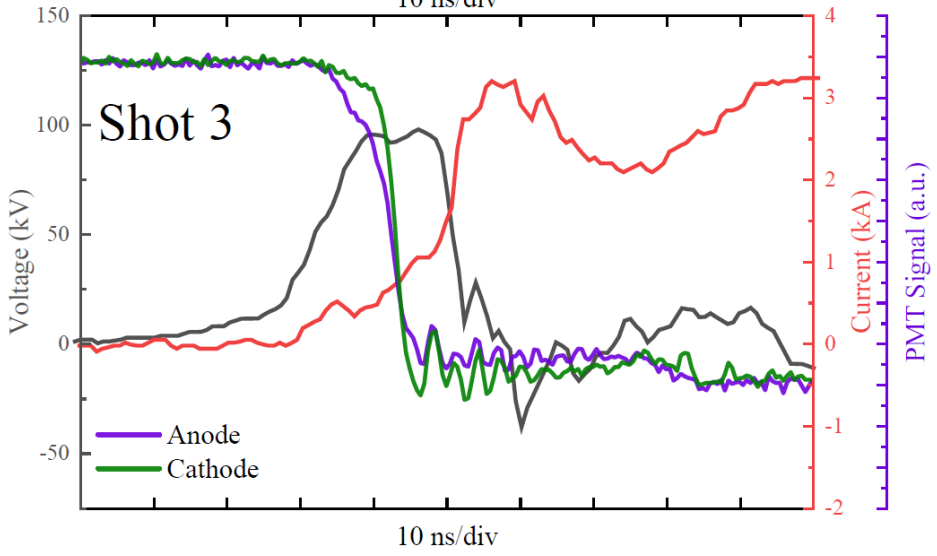


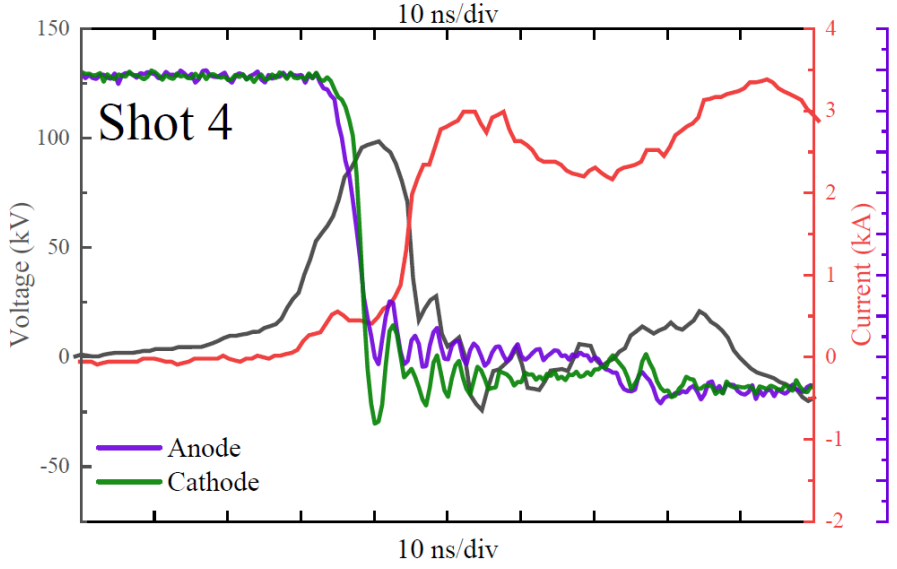
Anode-Initiated Breakdown: Early Light











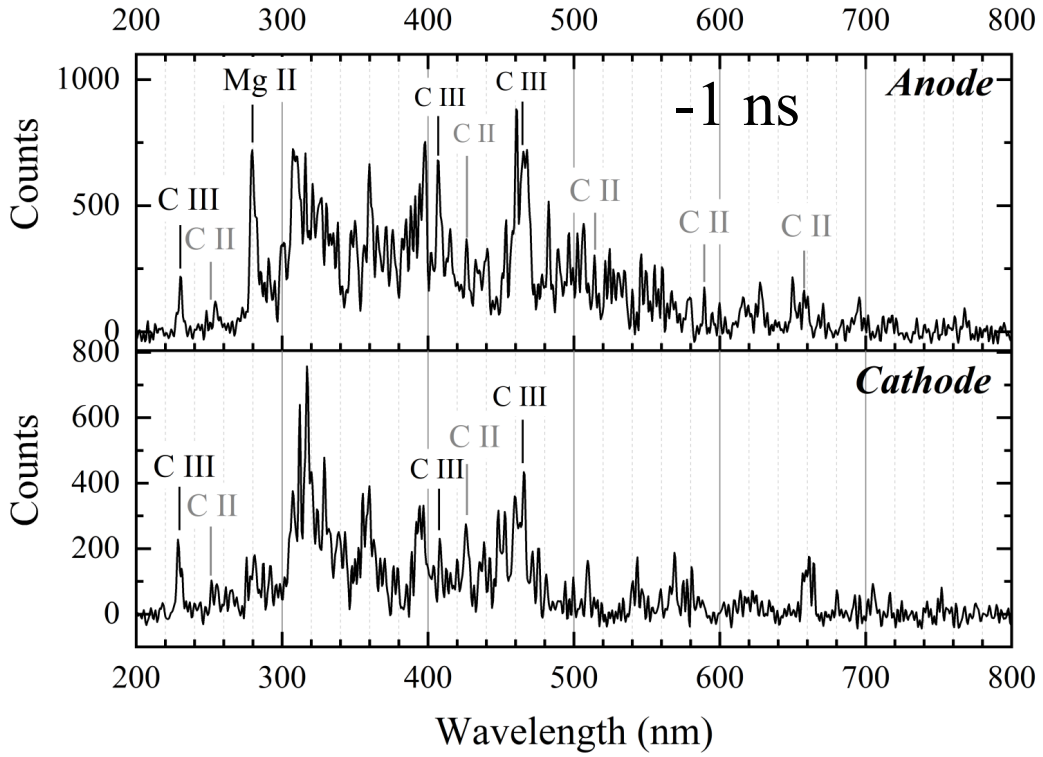
OES Time Series (t = -1 ns)

High confidence transitions (nm):

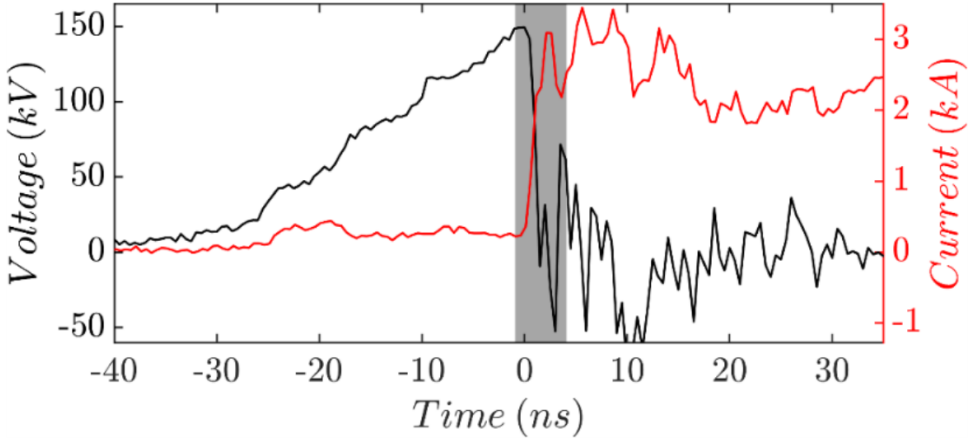
- C III – **229.7**, **406.9**, 418.7, **464.8**
- Mg II – **279.7**, 448.1

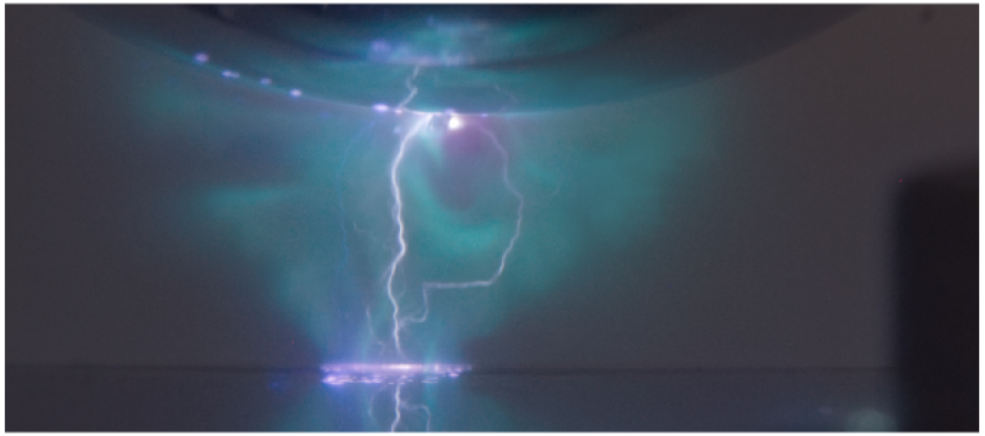
Possible transitions (nm):

- C II – **251.1**, 283.7, 392.0, **426.7**, **514.5**, **589.0**, **657.9**



Optical gate (5 ns width)





Black: High degree of confidence

Gray: Lesser degree of confidence

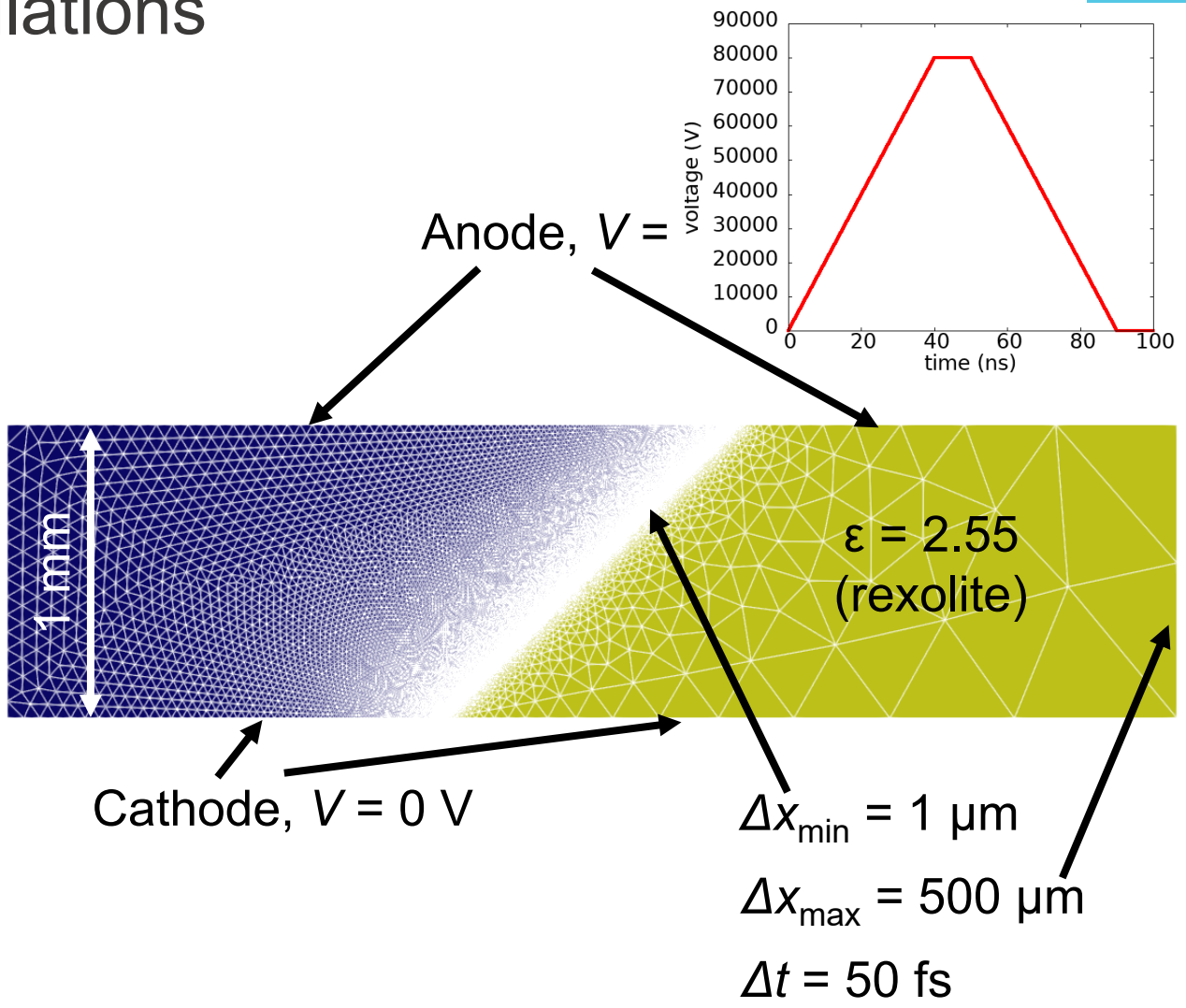
Anode-Initiated Breakdown: Simulations

Goals:

- Provide insights into breakdown phenomena roles
- Provide framework to study design ideas (predict impacts on operation)

Anode Triple Junction (ATJ) Aleph modeling:

- Fowler-Nordheim emission of e-, with surface charging on dielectric
- Neutral emission scaled to Fowler-Nordheim emission on dielectric for H_2, C, O_2, H_2O, CO_2 (1e4)
- e-heavy ionization, dissociations
- e-heavy elastic/excitation for H, H+, C, C+, O, O+, CO2, CO2+, CO, CO+, H2, H2+, H2O, H2O, H2O+, O2, O2+, OH
- e- secondary emission from above ion species
- Radiative decay, photoemission from surfaces



Geometries

0 degrees

15 degrees

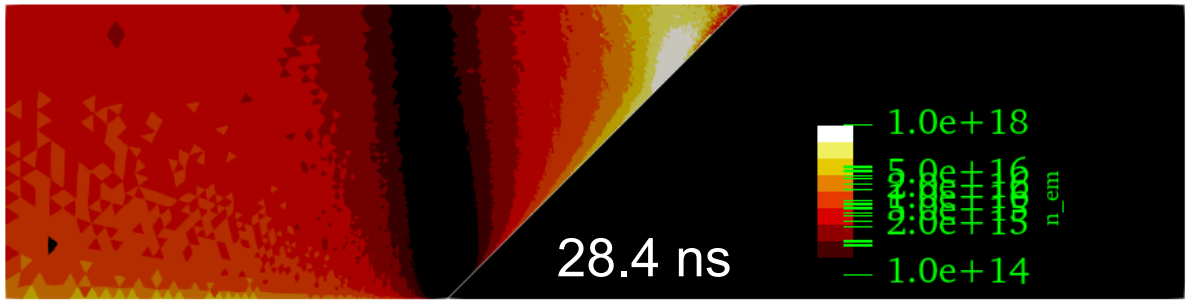
30 degrees

45 degrees

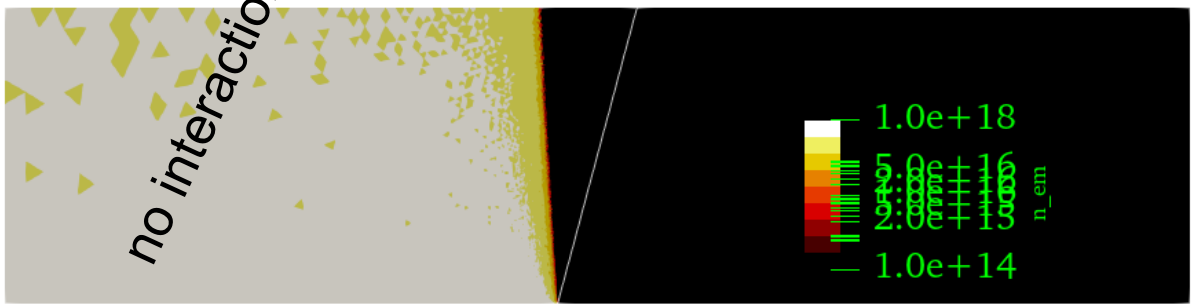
60 degrees

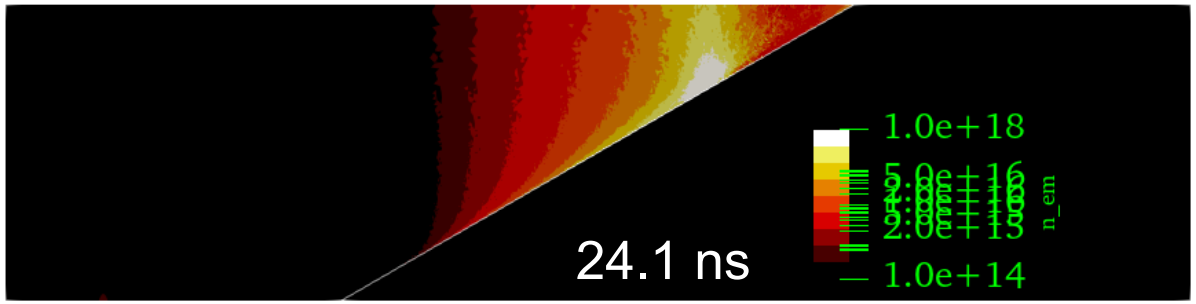
75 degrees

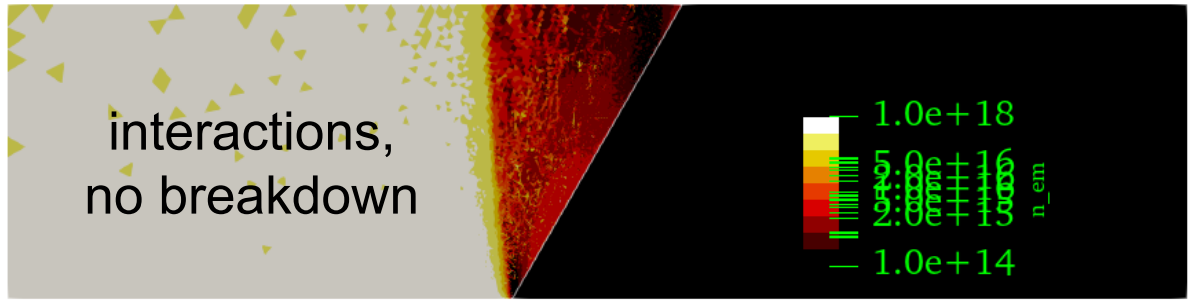
n_e at t = 50 ns or at breakdown (if earlier)

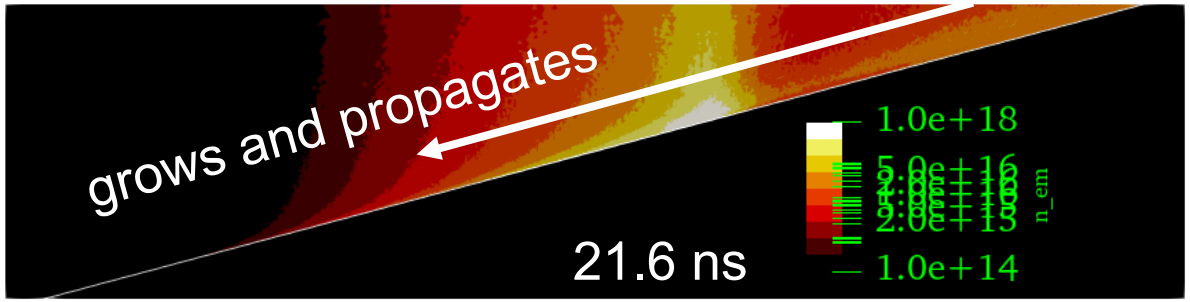


no interactions, no breakdowns









Summary

Developing multiple approaches to investigate anode- and cathode-initiated breakdown for pulsed power systems. Mechanisms of anode-initiated are not understood. We are identifying time-resolved species to indicate material source.

Other project investigating different insulator materials (inclusions).

Experiments not discussed here:

- X-ray measurement for high energy electron locations
- Laser deflection measurements for n_e and n_n
- Secondary electron emission

Modeling not discussed here:

- Full geometry (3D)
- Photon processes
- More detailed species chemistry