Commissioning of the 2.0 MeV URSA-Minor LTD

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Advanced Radiographic Technologies R&D at Sandia

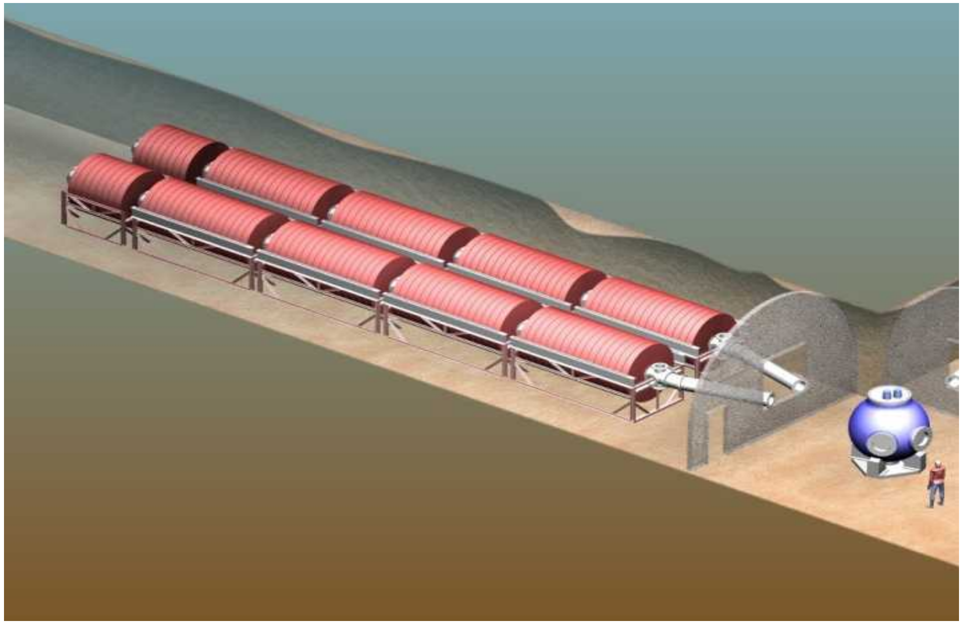
- **Research and Development of advanced pulsed power technologies for high brightness flash x-ray radiography.**
  - X-ray source development (electron beam diodes)
    - Conducted primarily on the RITS-6 accelerator. See talks at this JOWOG (Johnston and Webb)
  - Accelerator R&D (Inductive Voltage Adders)
    - This talk

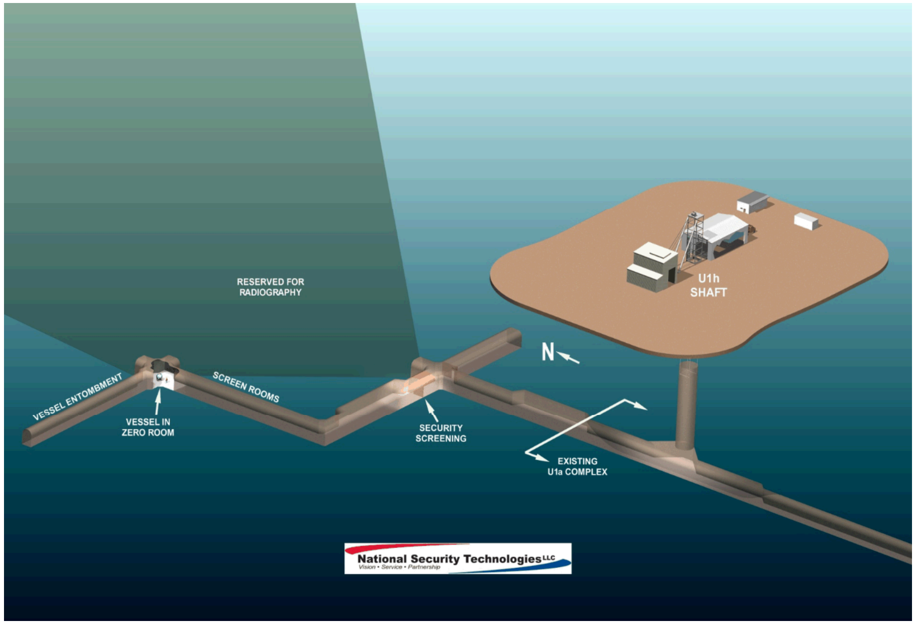
- **One of our proposals for the scaling and surrogacy initiative requires development of a new pulsed power accelerator based on Linear Transformer Driver (LTD) Technology.**
  - The LTD is a more compact architecture of a traditional Inductive Voltage Adder, e.g. Hermes III, RITS-6, U.K. Tuetates
  - Design parameters for scaled radiography:
    - 7-8 MeV, 160-200 kA

- **The URSA-Minor LTD has been commissioned at Sandia.**
  - 2.4 MeV, 80 kA test bed for driving radiographic diodes
  - R&D will focus on defining the capabilities for a higher voltage accelerator

LTD based option for radiography underground at Nevada

- We are conducting research to develop a new accelerator for 7-8 MeV radiographic system.
  - Proposal given to DOE in Oct. 2011.
  - 2 x single pulse LTD based accelerators driving Self-Magnetic Pinch x-ray sources at 7 MeV
  - Partnering with NSTec at Nevada
  - Targeting 2017 readiness
  - $120 M cost for procurement and assembly of accelerators (includes tunnel costs)

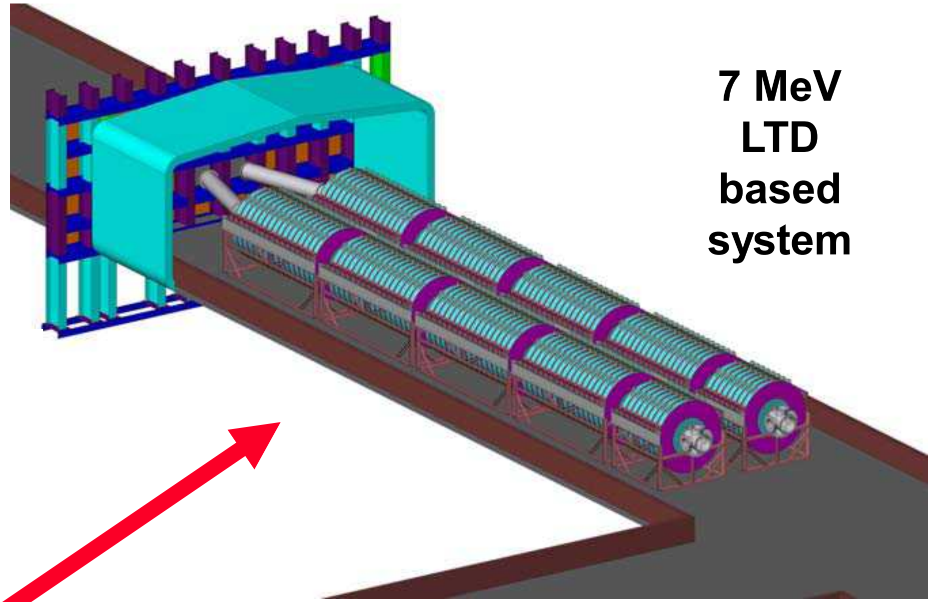




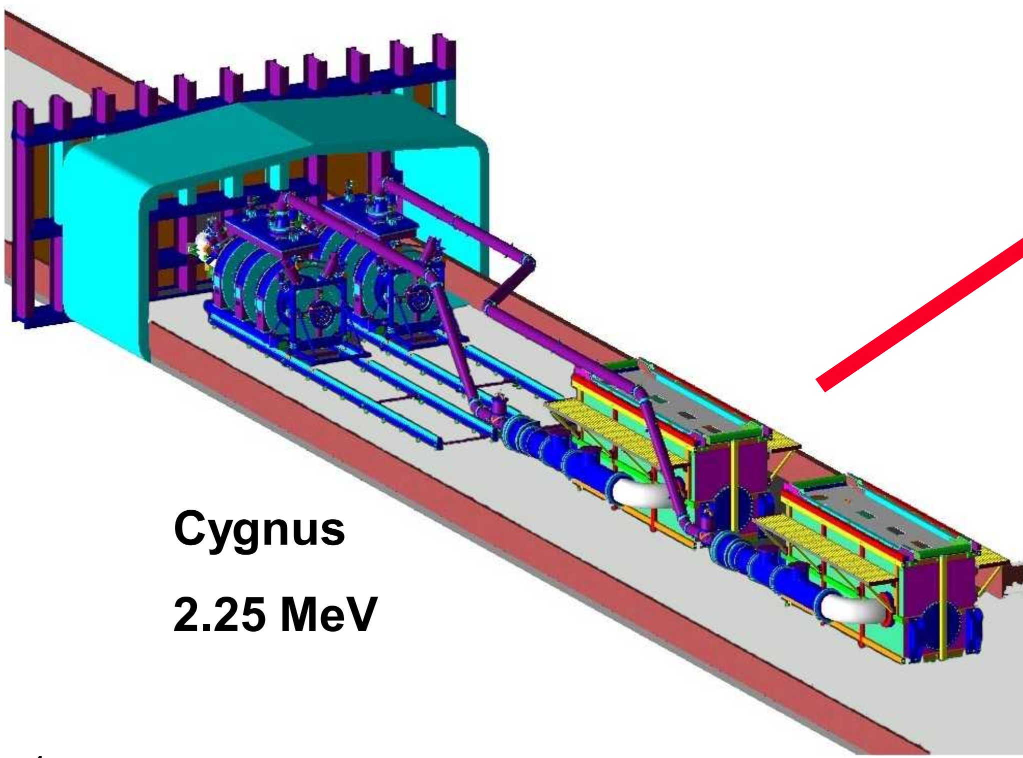
Schematic of a dual axis LTD accelerator system

The Dual Pulsed Power Accelerator Option is Compatible with the U1a '05 Drift

The Cygnus '05 drift



7 MeV LTD based system

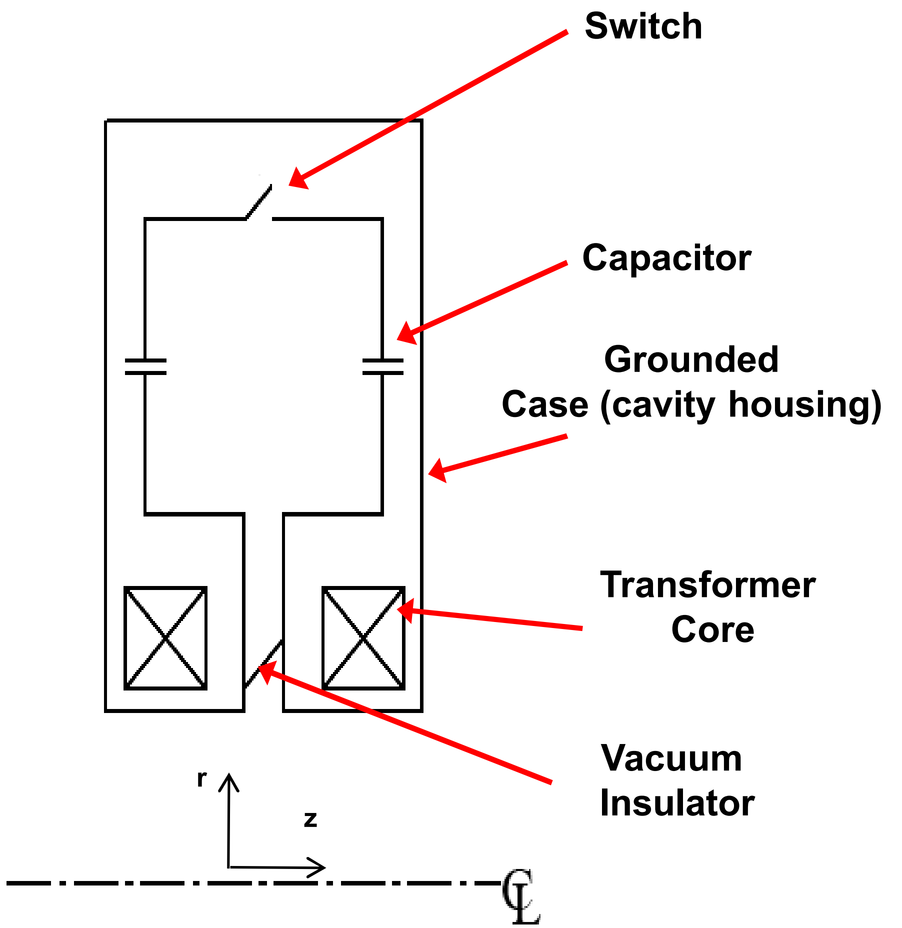


Cygnus

2.25 MeV

The architecture of a Linear Transformer Driver

- The basic building block of a LTD circuit, the "Brick," is a single stage Marx generator with two capacitors and one switch.
- A "Cavity," is a single LTD stage with several parallel brick elements.
- LTD cavities are encased in a grounded metal case with inductive isolation.
- Cavities are stacked in series to form a voltage adder.



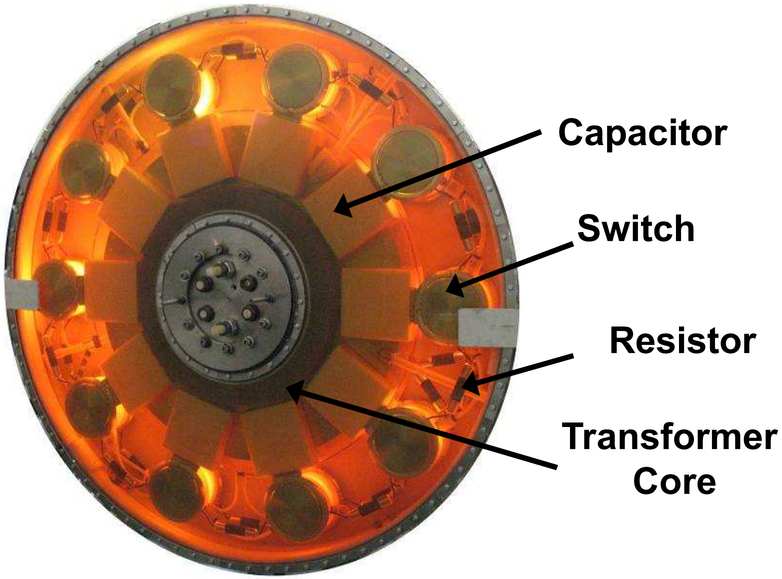
Previously commissioned a 1 MeV system

Demonstrated both single and stacked-cavity performance up to 800 kV.

Each cavity is composed of 10 bricks (2 capacitors + 200kV switch)

7 cavities are stacked in series via a coaxial transmission line threading the center.

Fielded a blade load electron beam diode on the 800 kV system.

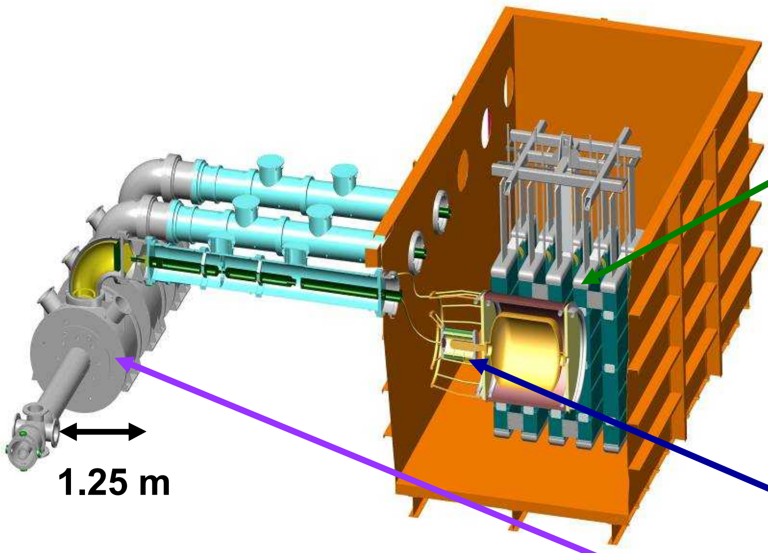


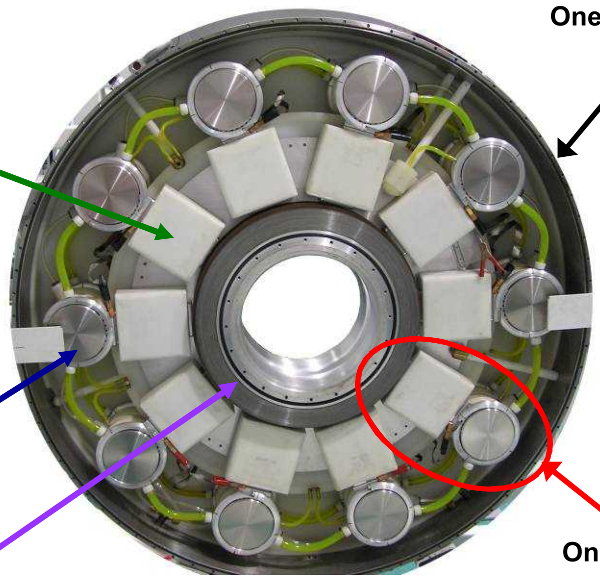
Single cavity


7 cavity system

The LTD is much more compact than conventional IVAs

Inductive Voltage Adder (IVA) | **Linear Transformer Driver (LTD)**





Capacitors

Switches

Inductive isolation

10 m

1.25 m

Remove pulse formation and compression hardware

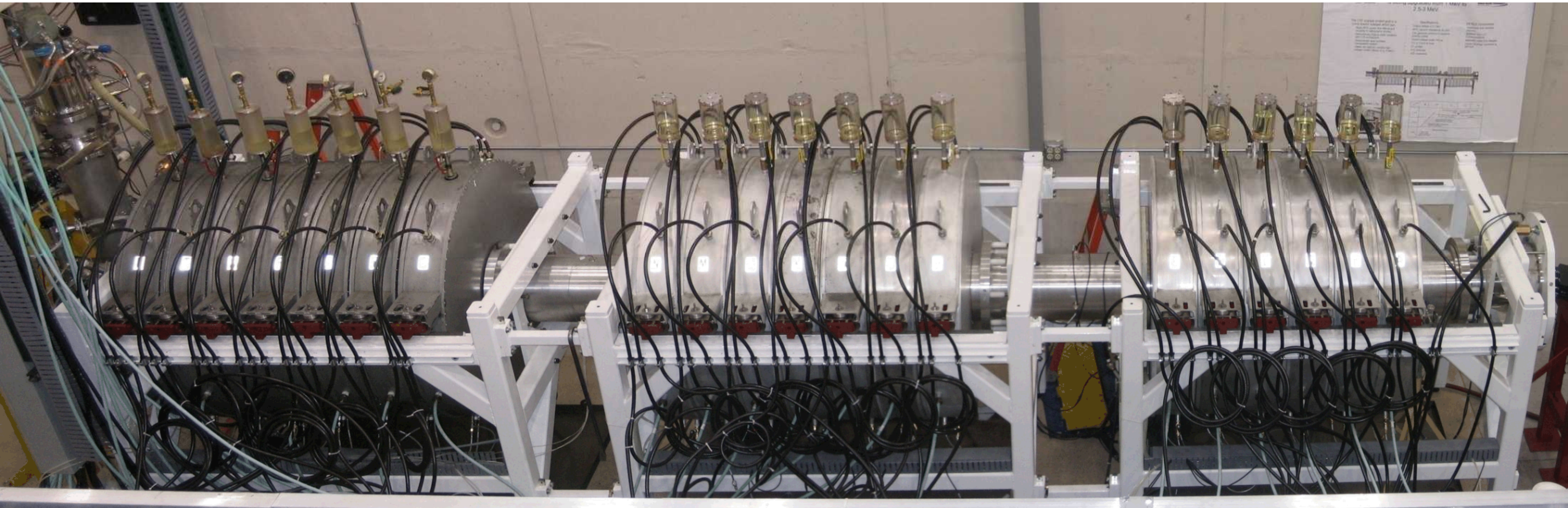
Underground Radiographic Source Accelerator (URSA)- Minor

The Sandia 800 kv LTD has been upgraded from 7 to 21 cavities

Cavities are assembled in groups of 7

Dimensions: 7.5 m long and 1.5 m wide

Total of 210 switches and 420 capacitors



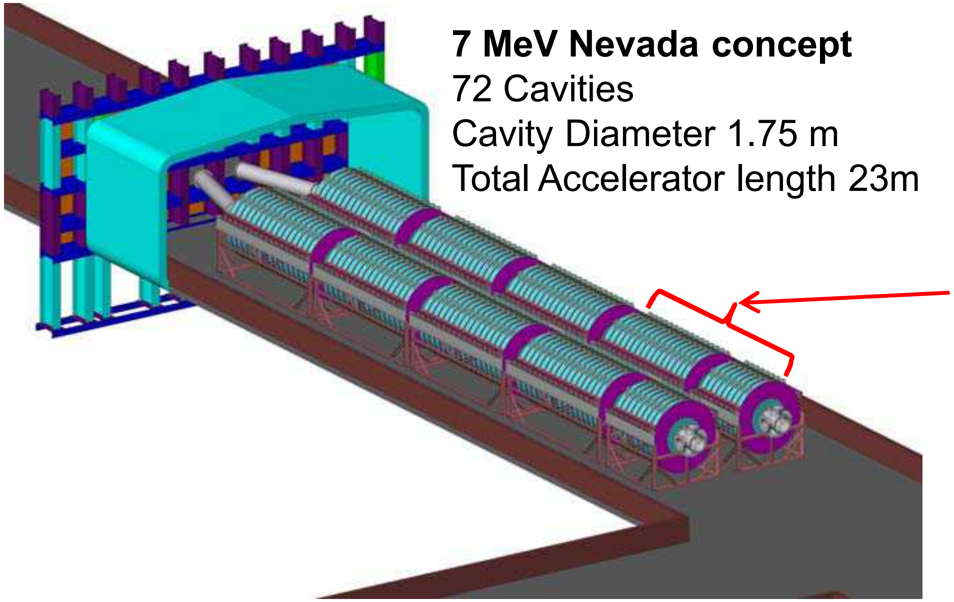
Research on URSA-minor will inform the design for a 7 MeV accelerator

Teaming with NSTec.

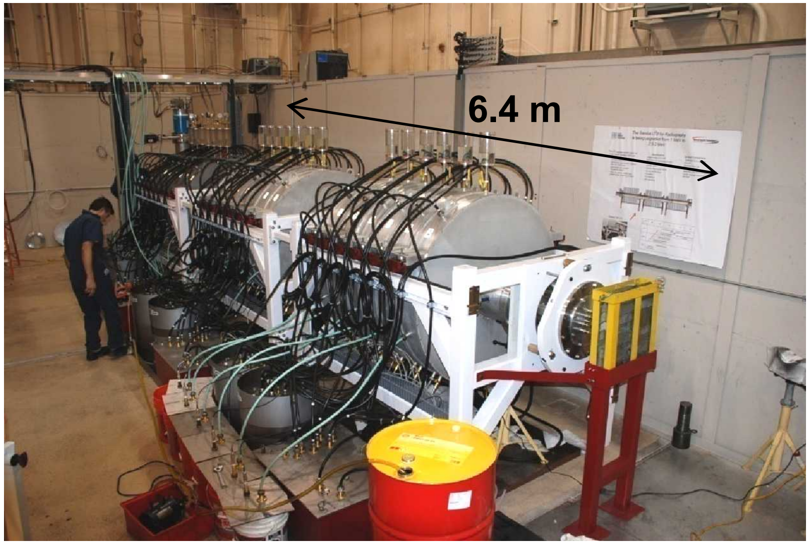
Manufactured with all U.S. parts.

Experimental results will validate computational models and inform the design scaling to higher voltage.

We have coupled the radiographic LTD to a Self-pinch diode source



7 MeV Nevada concept
72 Cavities
Cavity Diameter 1.75 m
Total Accelerator length 23m



URSA-minor

URSA-Minor Program Activities

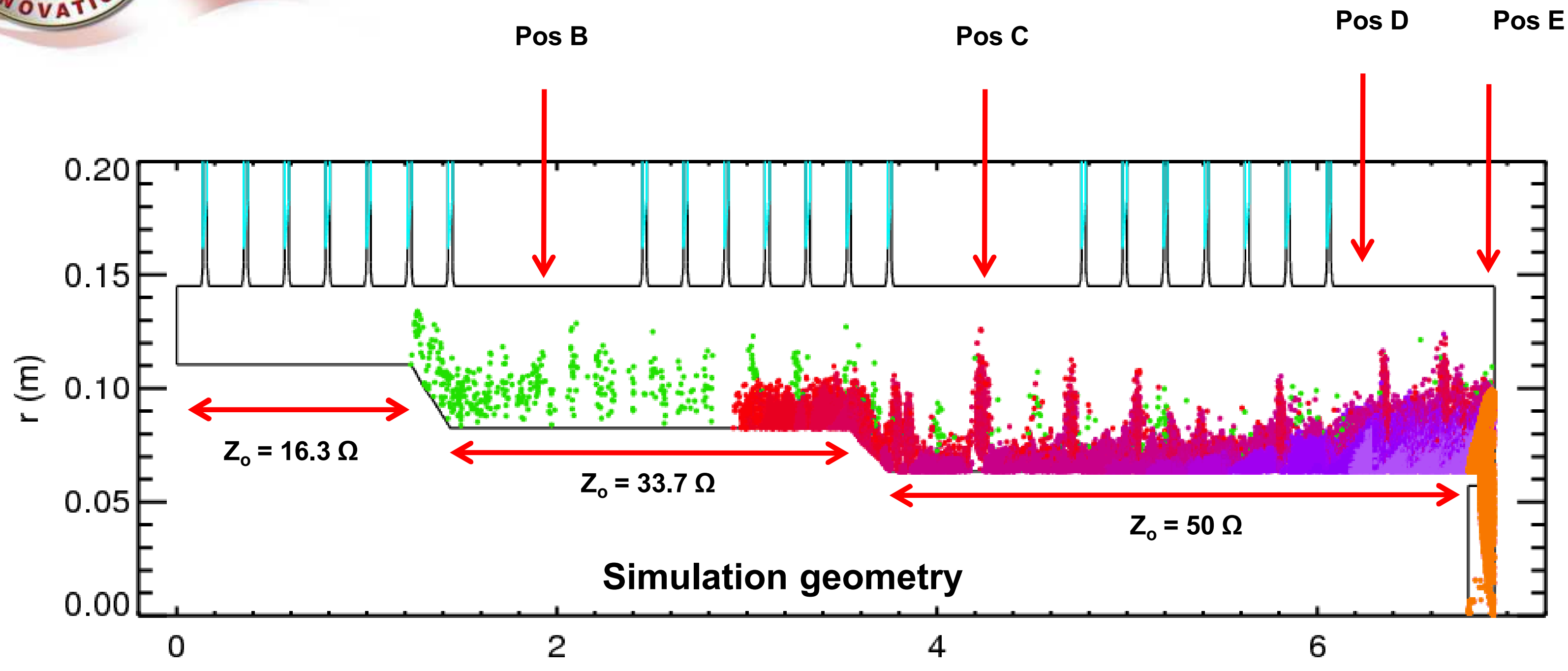
Research and Development

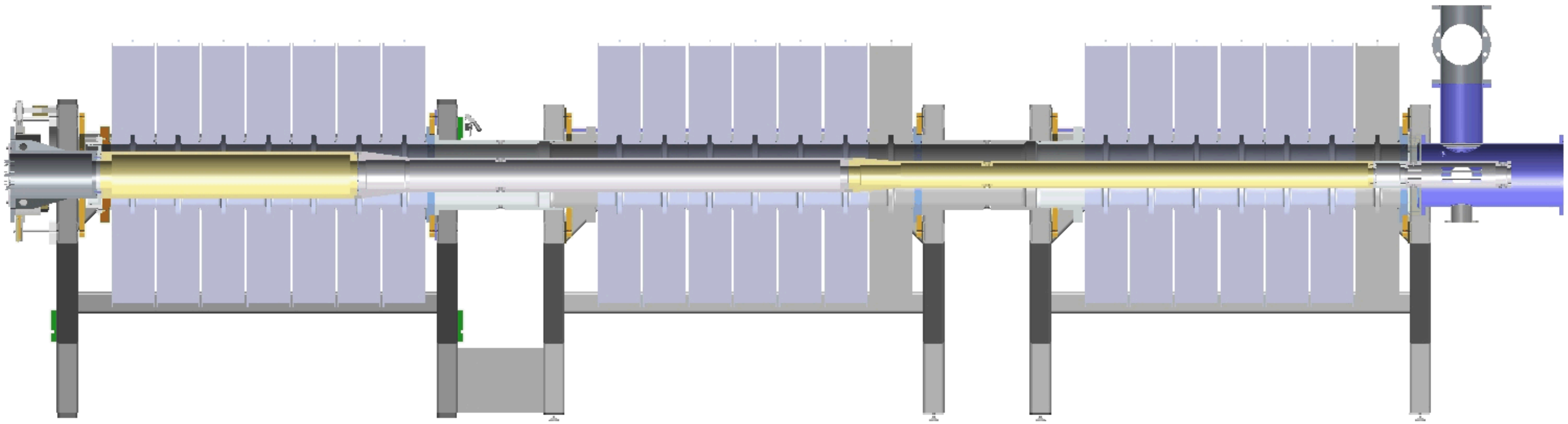
1. Triggering large system
2. Power flow coupling
3. Diode coupling
   - Z(t)
   - pulse shape
   - debris mitigation.
4. System characterization
   - Reproducibility
   - Switching
   - Maintenance
5. 7 MeV System Design
   - Rough design (complete)
   - Cavity details
   - Trigger system
   - MITL
   - Drawing package (engineered design)
   - Pulse shape
   - Control system

Data from URSA-minor here is necessary to inform 7 MeV design

Goal: reproducible, 150-300 rad, < 2mm spot, diode driven by 7+ MeV compact accelerator

MITL geometry and location of current measurements



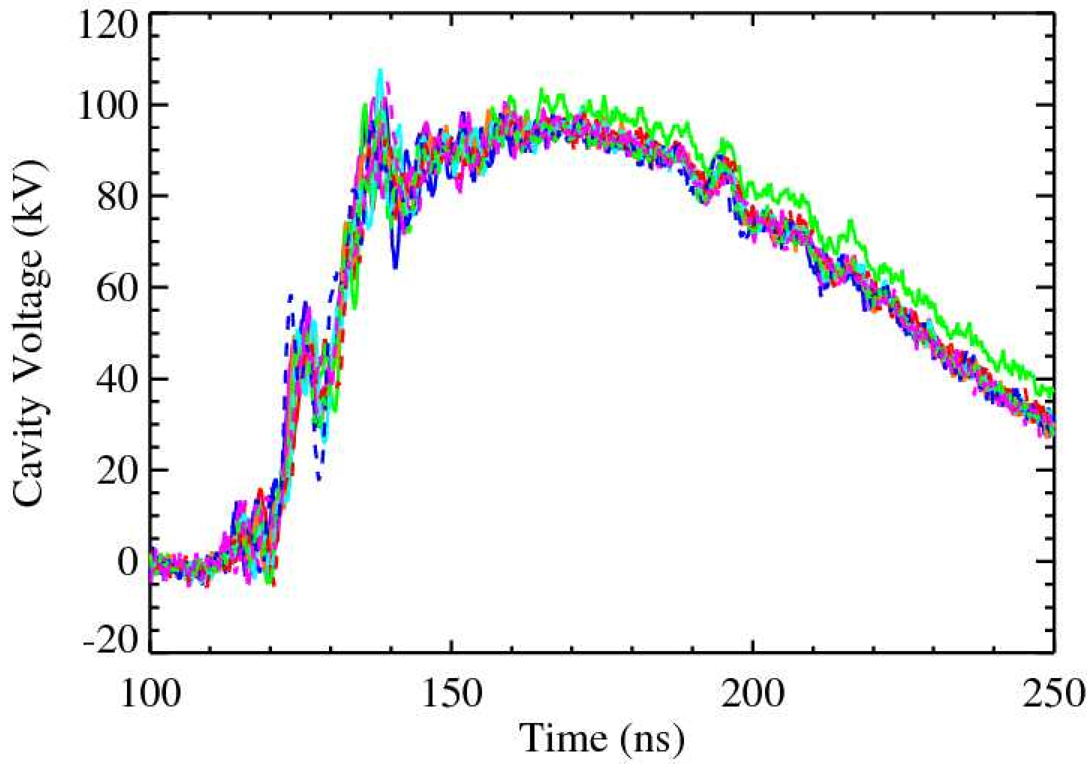


Jitter in single cavity tests is 2.0 ns or less

After assembly, each cavity was charged to +/- 90 kV and tested into a resistive load

Individual cavity jitters are in the range 0.5-2.0 ns

Plot shows 10 consecutive shots with a single cavity. Jitter is 0.75 ns.



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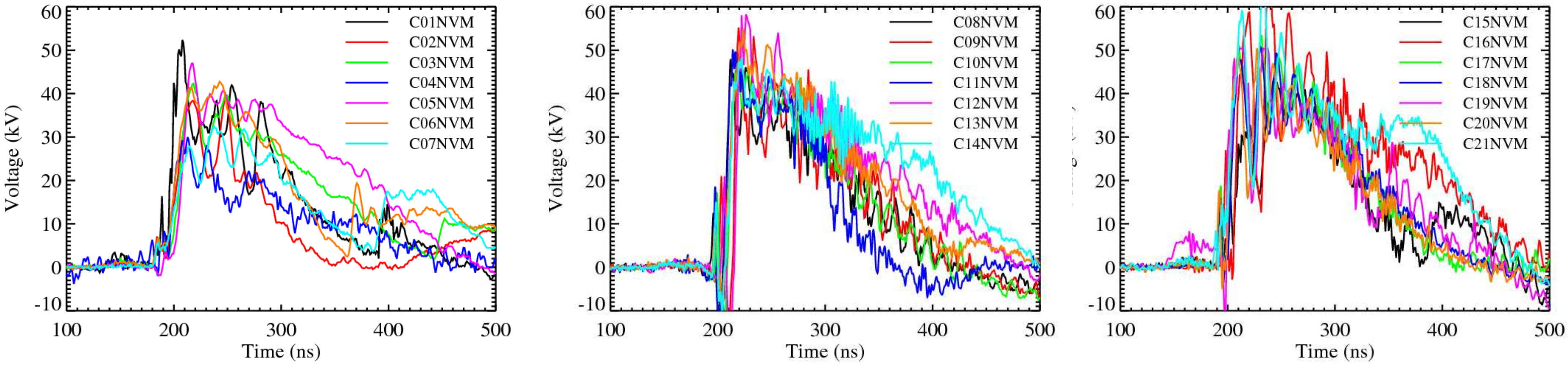
Cavity timing is good, but pulse shape varies between cavities

- Plots show cavity half voltages from a single shot with 21 cavities
- Pre-pulse and oscillations vary between cavities
- Some variation caused by differences in core materials in different cavities
- In some cavities, switches do not all fire at the same time, degrading pulse shape and peak power.



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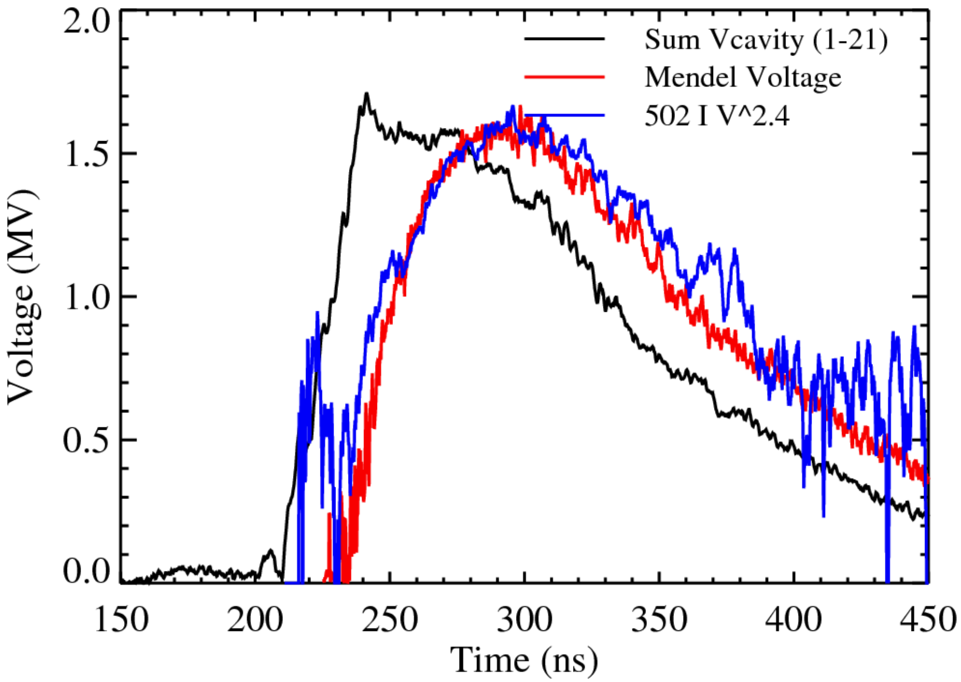
At 75 kV charge, 1.6 MeV inferred voltage from circuit and radiation output.

- **Plot shows a comparison of the accelerator voltage based on the sum of the cavity voltages to the Mendel voltage calculation and a voltage calculation based on the radiographers equation.**
- **The radiographers equation was derived using MCNPX calculations of the actual diode geometry.**

$$d = 502 I V^{2.4}$$

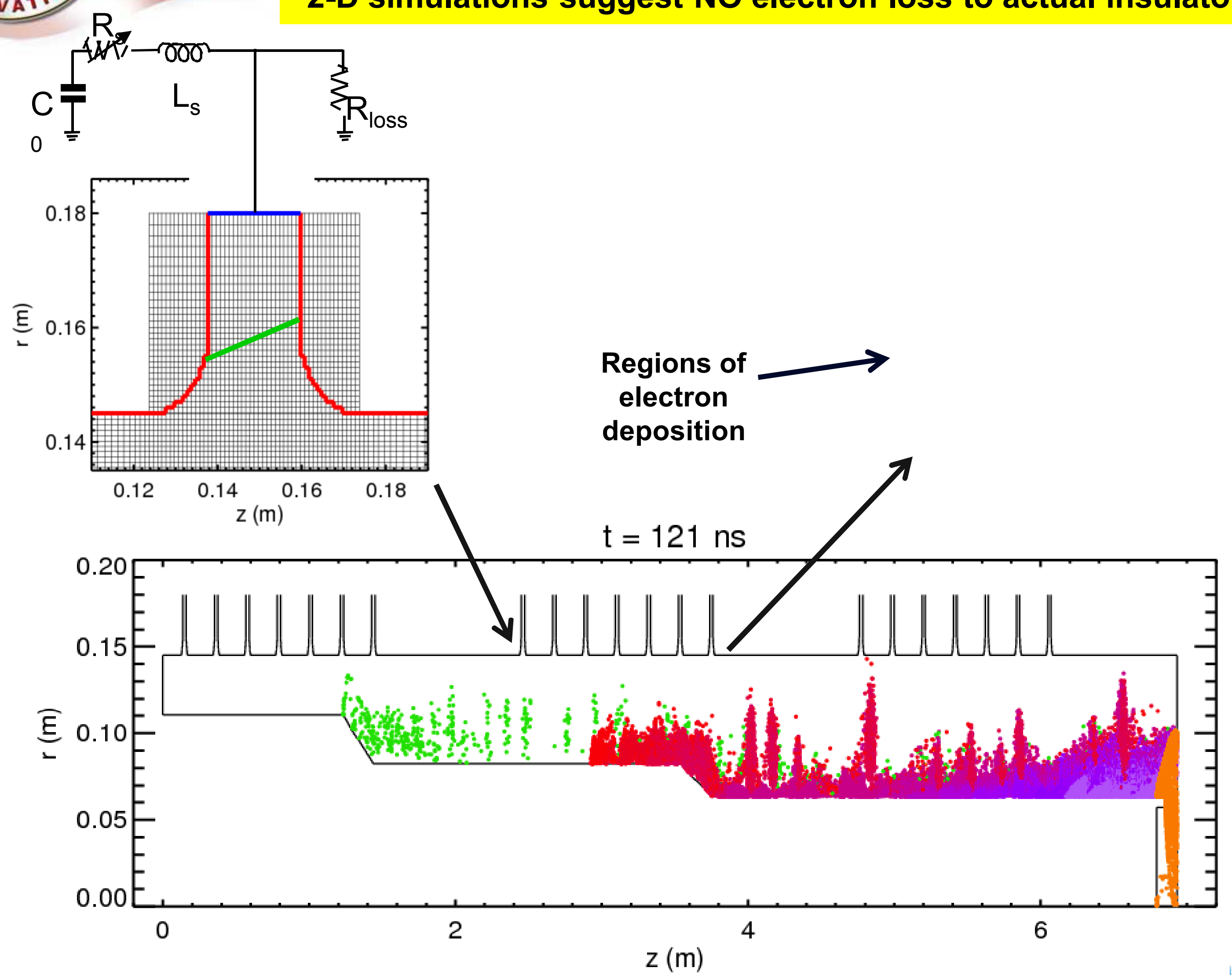
- **The Mendel voltage calculated from MITL currents at position D using the equation:**

$$V = Z\left(I_a^2 - I_c^2\right)^{\frac{1}{2}} - \frac{mc^2}{e}\left(\frac{I_a}{I_c} - 1\right)\left(\left[2\left(\frac{I_a}{I_c} + 1\right)\right]^{\frac{1}{2}} - 1\right)$$



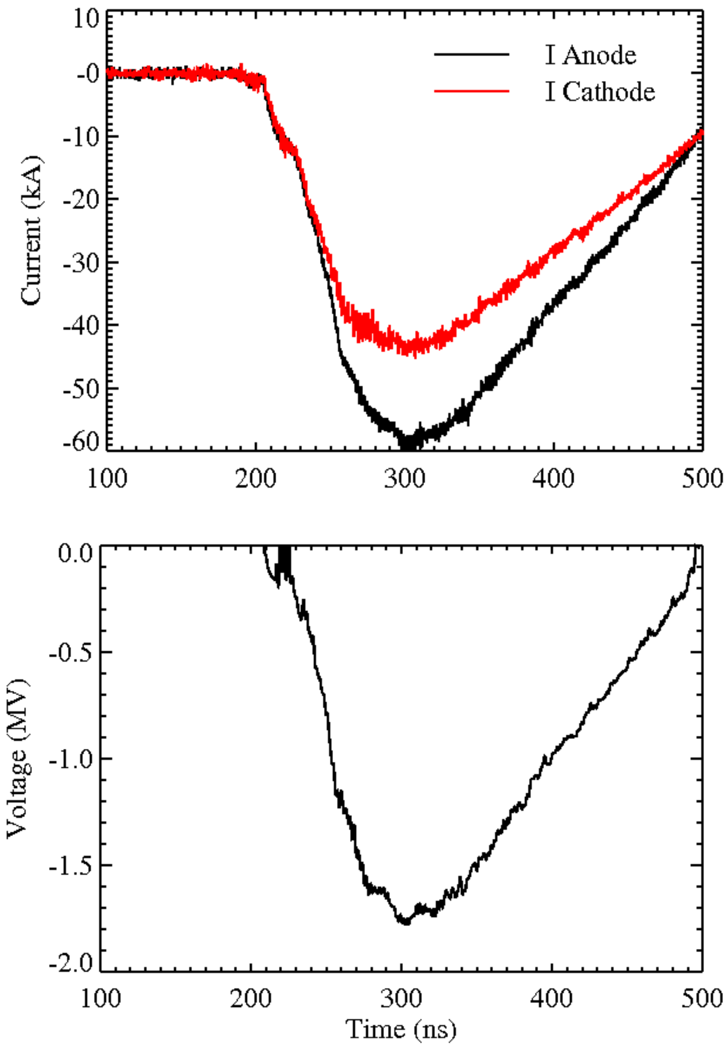
Modeling and experiments conducted to study power-flow and source coupling

2-D simulations suggest NO electron loss to actual insulators



At 75kV charge (1.5 MeV), experiment and modeling in good agreement.

URSA-minor current and voltage at 75 kV with blade load



Quicksilver PIC simulation of URSA-minor with 75 kV into a blade load

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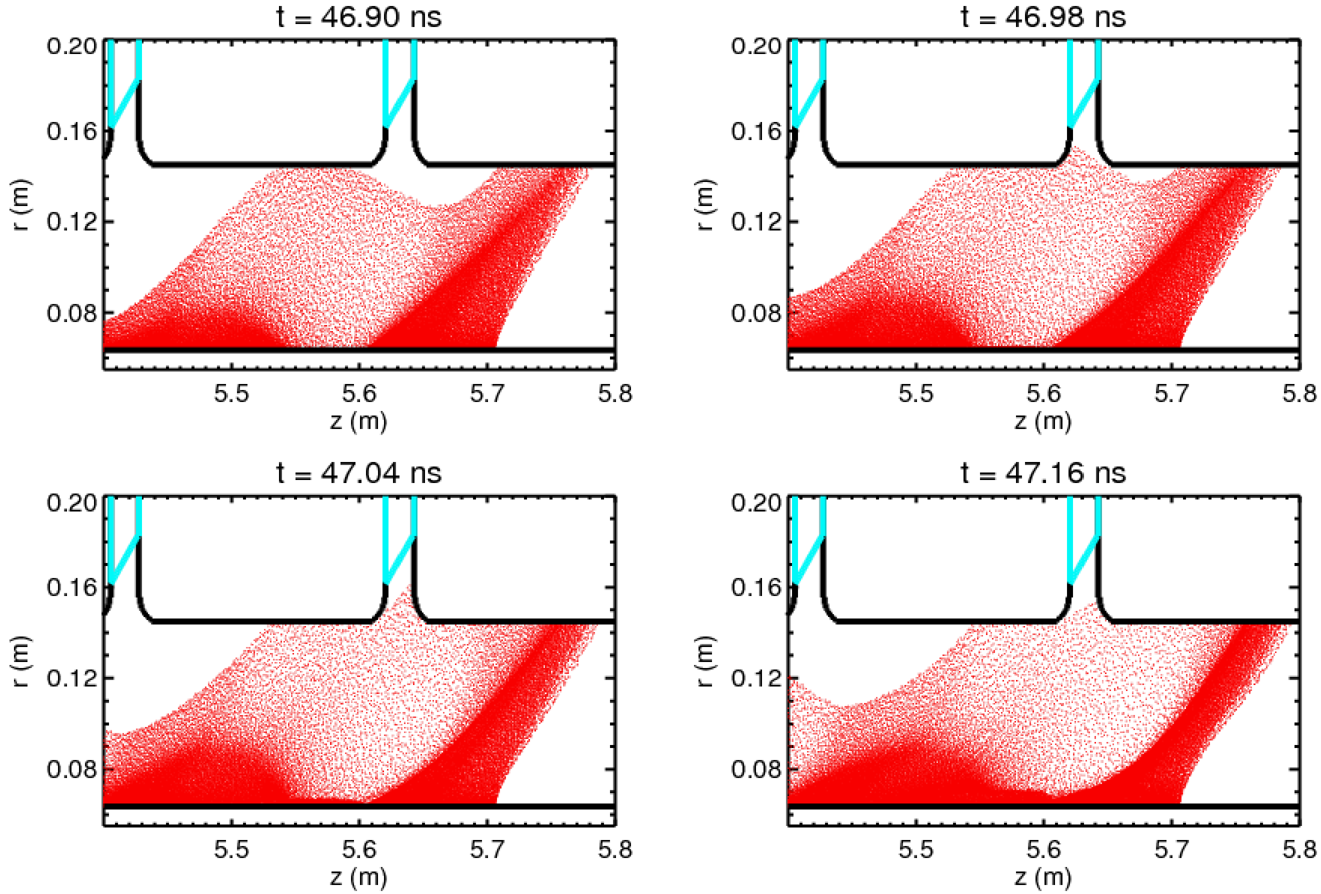
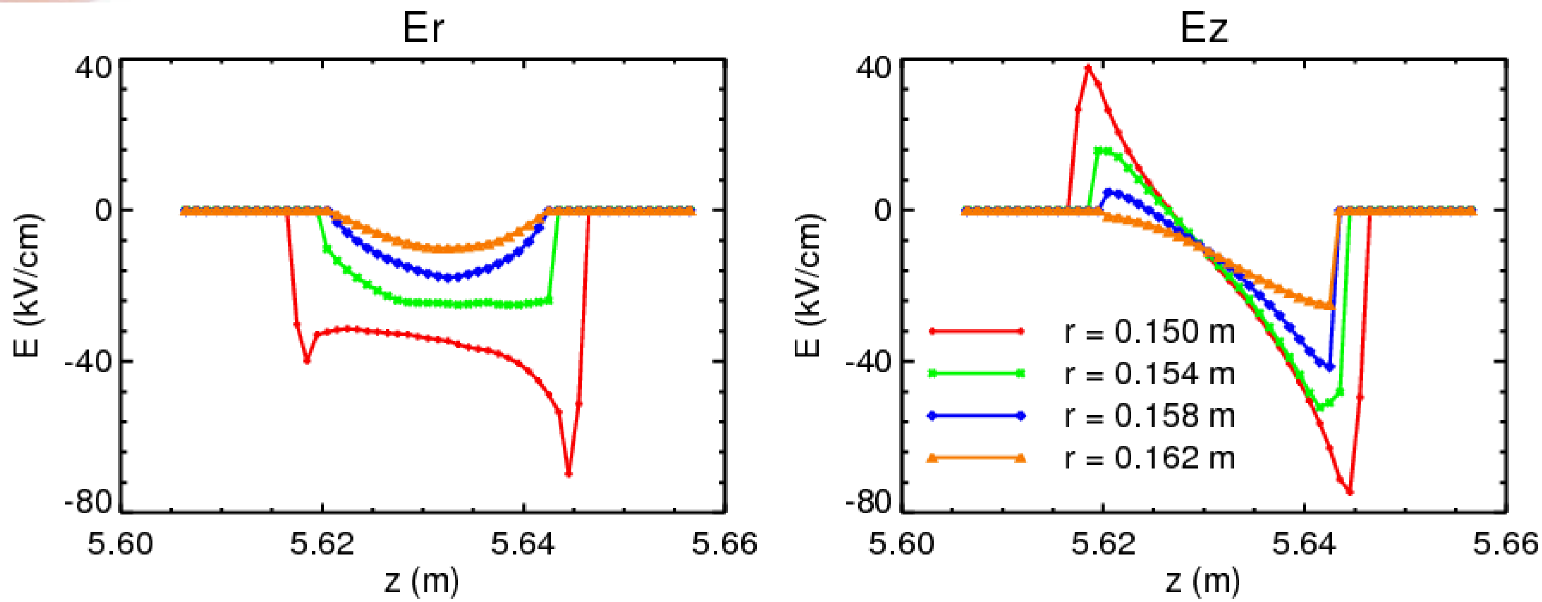
High-resolution animations show electrons avoiding the insulators



Electron loss front moving past cavity 19: maximum penetration into feed at t = 47.04 ns, then receding by 47.16 ns

EM fields in the cavity accelerate particles away from the insulator



Axial lineouts of E_r and E_z near the entrance to the cavity

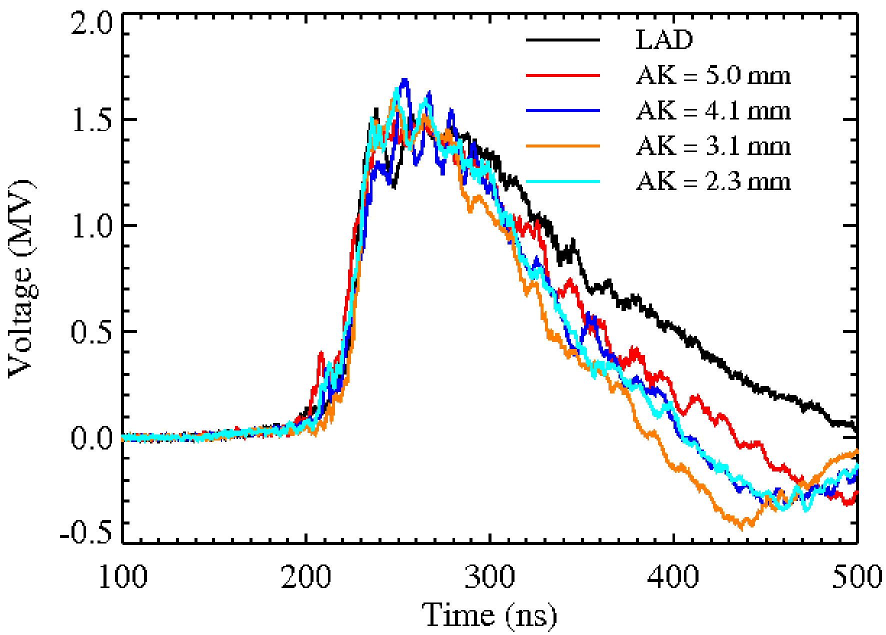
- **$E_z < 0$ is accelerating electrons to the downstream cavity wall**
- **$E_r < 0$ is driving electrons to the insulator…but << E_z for r > 0.16 m**

Furthermore $B_\phi < 0$ everywhere: $F = -ev \times B$ has $F_r < 0$ and $F_z > 0$

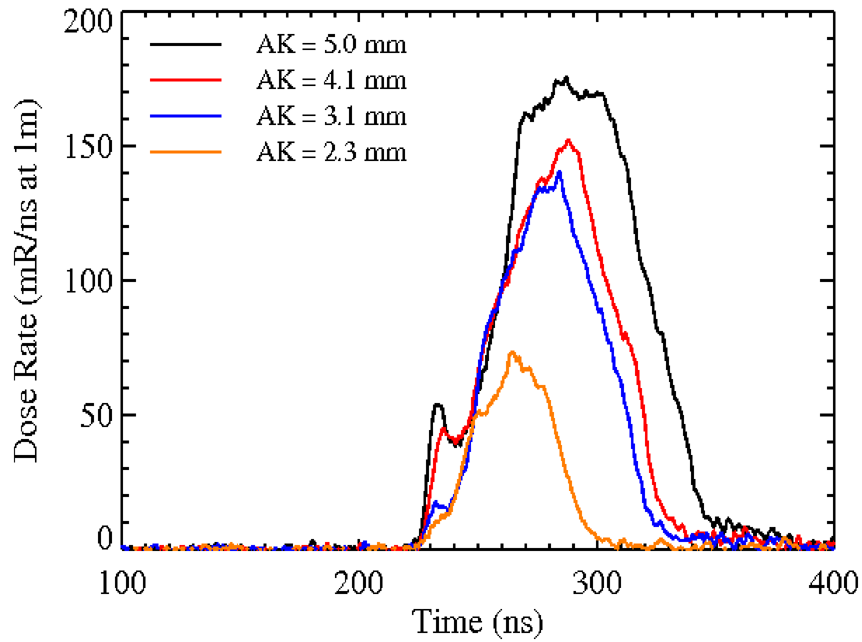
- **As B increases, this force drives electrons out of the cavity**

SMP radiographic diode has been fielded

Diode voltage vs. A-K gap



Diode dose-rate vs. A-K gap



Dose rates of ~ 150 mrad/ns achieved at endpoint energies of 1.5 MeV. Anticipate > 7 rad/ns at enpoint energies of 7 MeV

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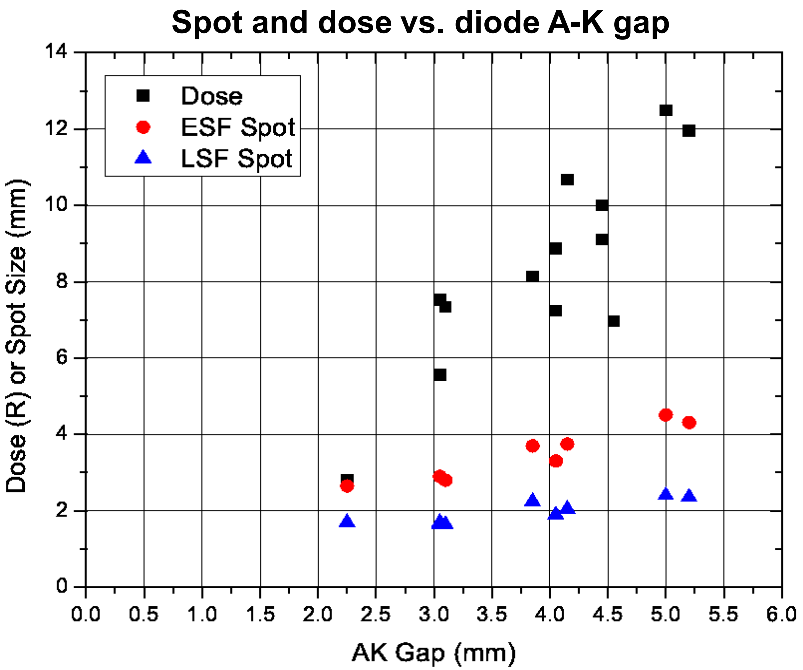
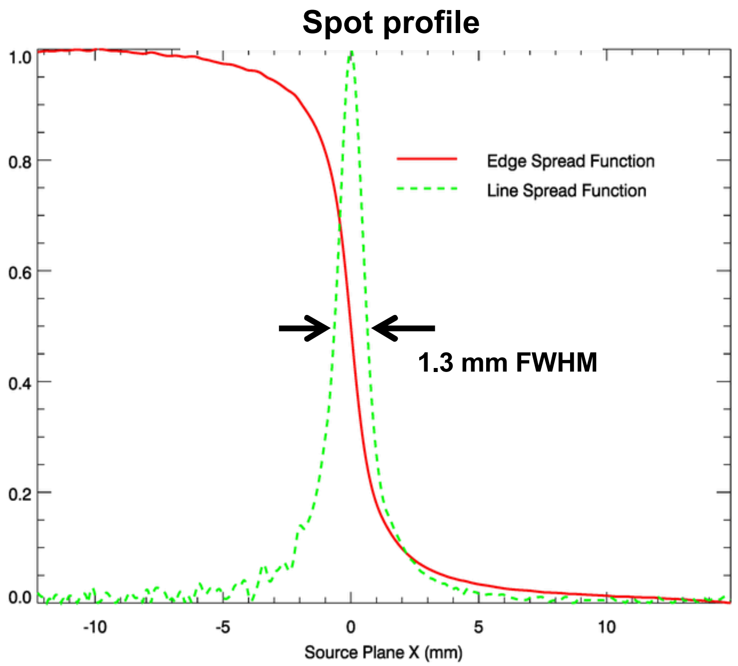
Spot and dose are consistent with modeling.





Spots with ~ 1.3 mm full-width-half-maximum of the line spread function (LSF) with 8 rad@m radiation output.

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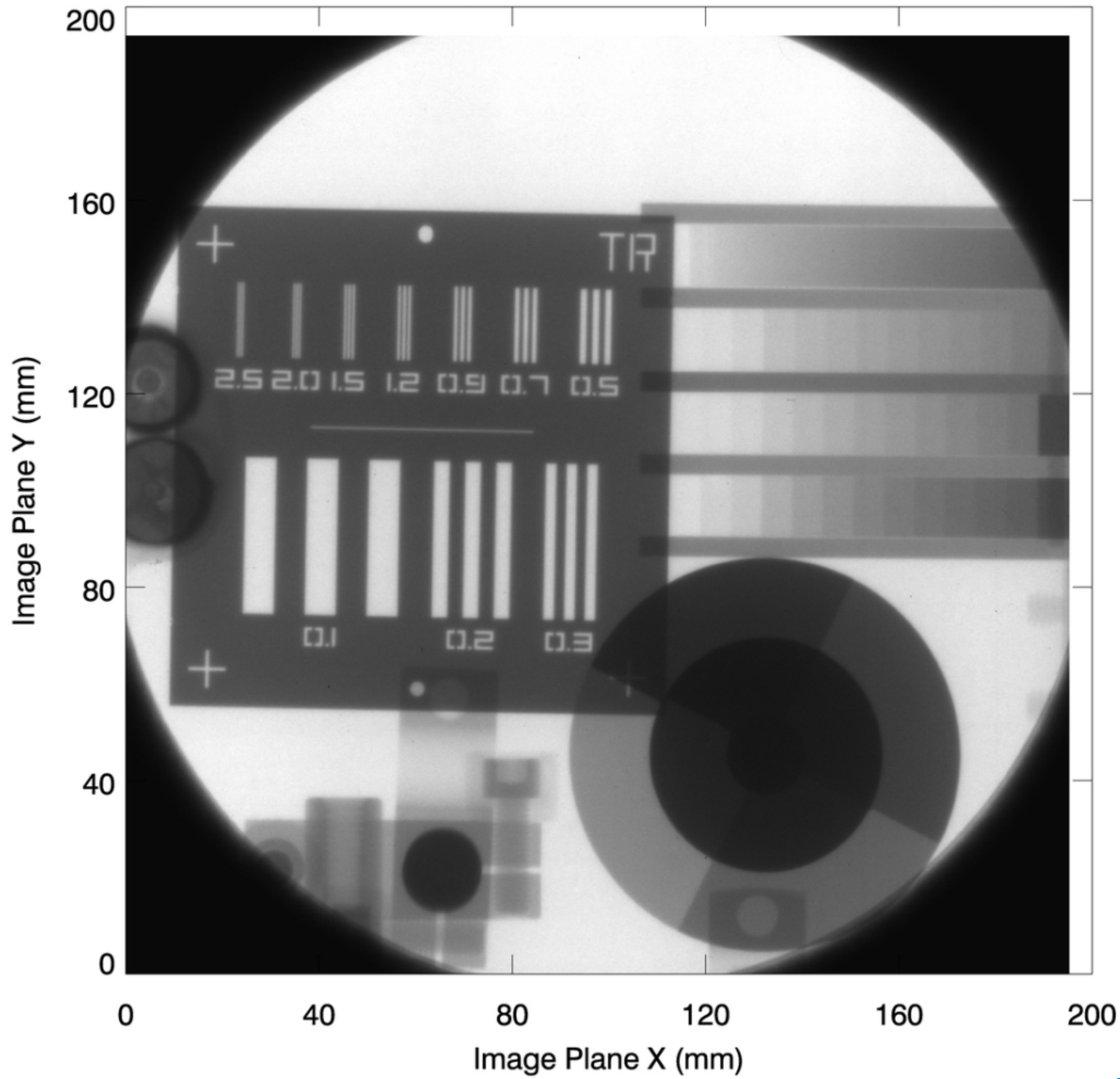
We are now conducting radiography on URSA-minor with an SMP diode.



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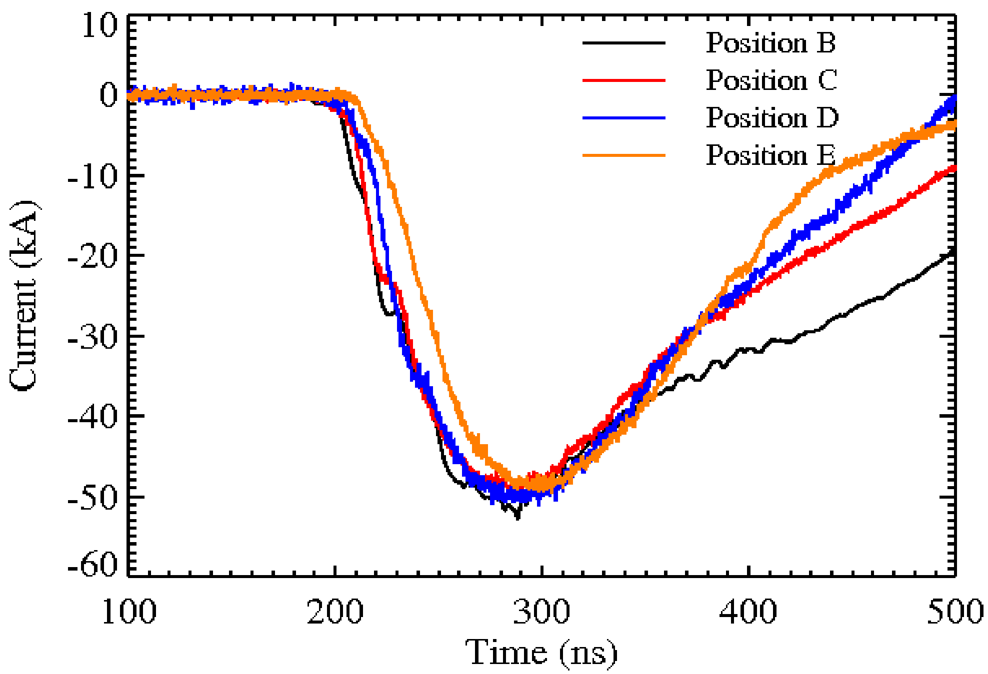
At 90kV charge (2 MV) there is evidence of current and power loss

URSA-minor anode current at 90 kV



Pos. B = Cavity 7
Pos C = cavity 14
Pos D = cavity 21
Pos E = load

Current loss along the line occurs after peak power.
Suspect either early time electron loss or debris on insulators causing late time insulator flash-over

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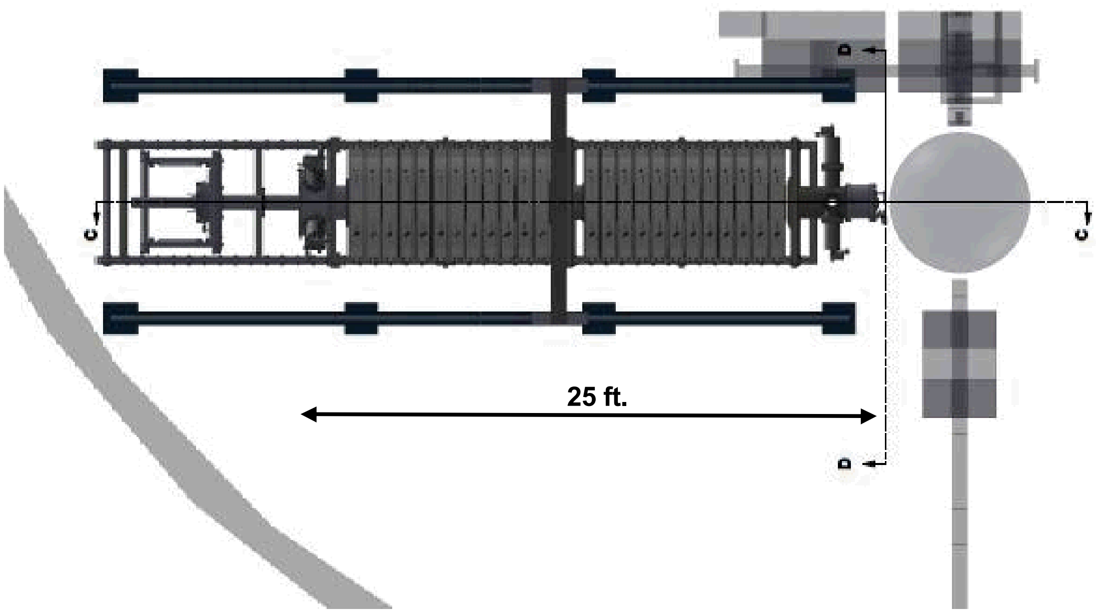
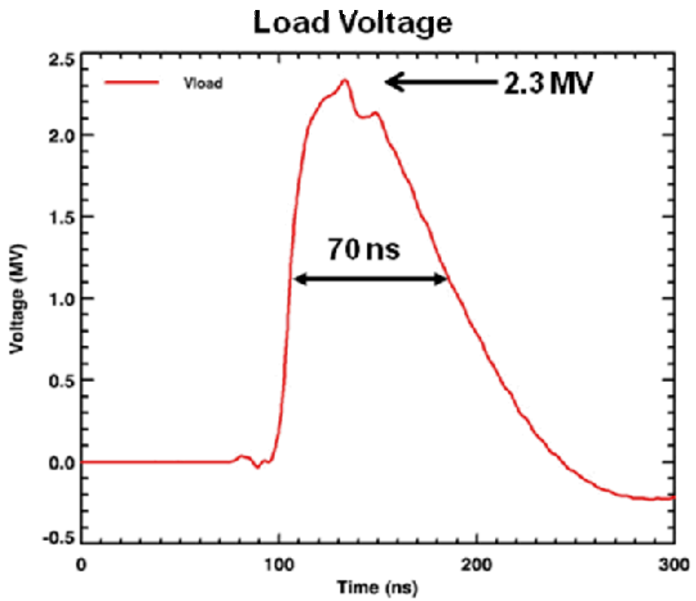
The LTD can scale to replicate Cygnus as well

- Design Study in 2010 for pRad applications
- Run 24 Cell LTD in Positive Polarity as a 60 Ohm vacuum line
- Drive a rod-pinch diode
- Dimensions of Cavity similar to 7 MeV system, overall accelerator is shorter.





Need to consider additional Transmission Line and Engineering to swap between high voltage and low voltage system

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Conclusions

URSA-minor is operational and has driven a radiographic diode at 1.6 MeV

It is the first radiographic accelerator based on LTD technology

At 75 kV charge on the capacitors, no electron loss is observed along the MITL. However, switch timing (triggering) is not ideal, reducing power output.

At 90 kV charge, there is evidence current loss after peak power. We suspect that debris from the diode settling on the insulators is causing flashover late in the pulse

Research on the test-bed will inform the design for a larger scale, 7-8 MeV accelerator.