SAND2008-4001P

Rod-pinch source characterization on RITS and Cygnus

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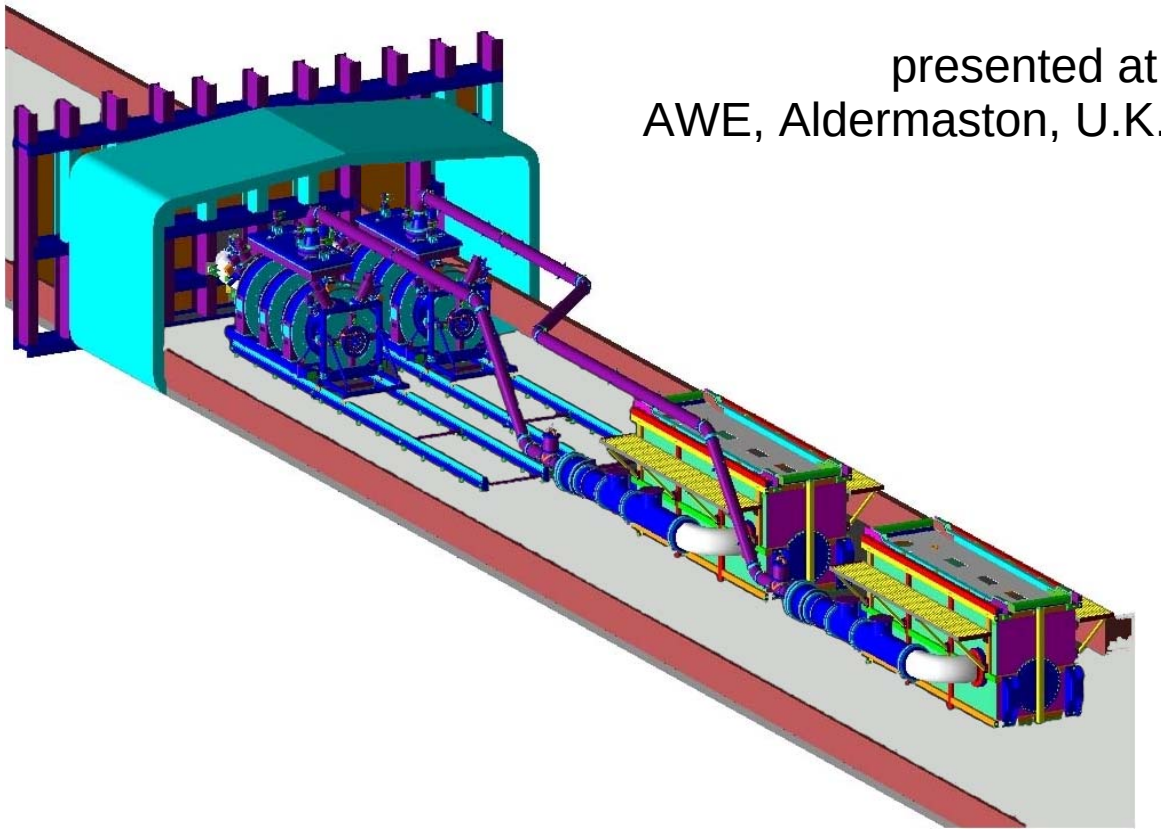
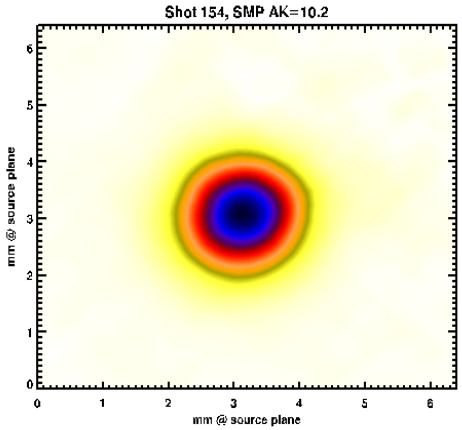


presented at the
AWE, Aldermaston, U.K. June 23, 2008



National Nuclear Security Administration

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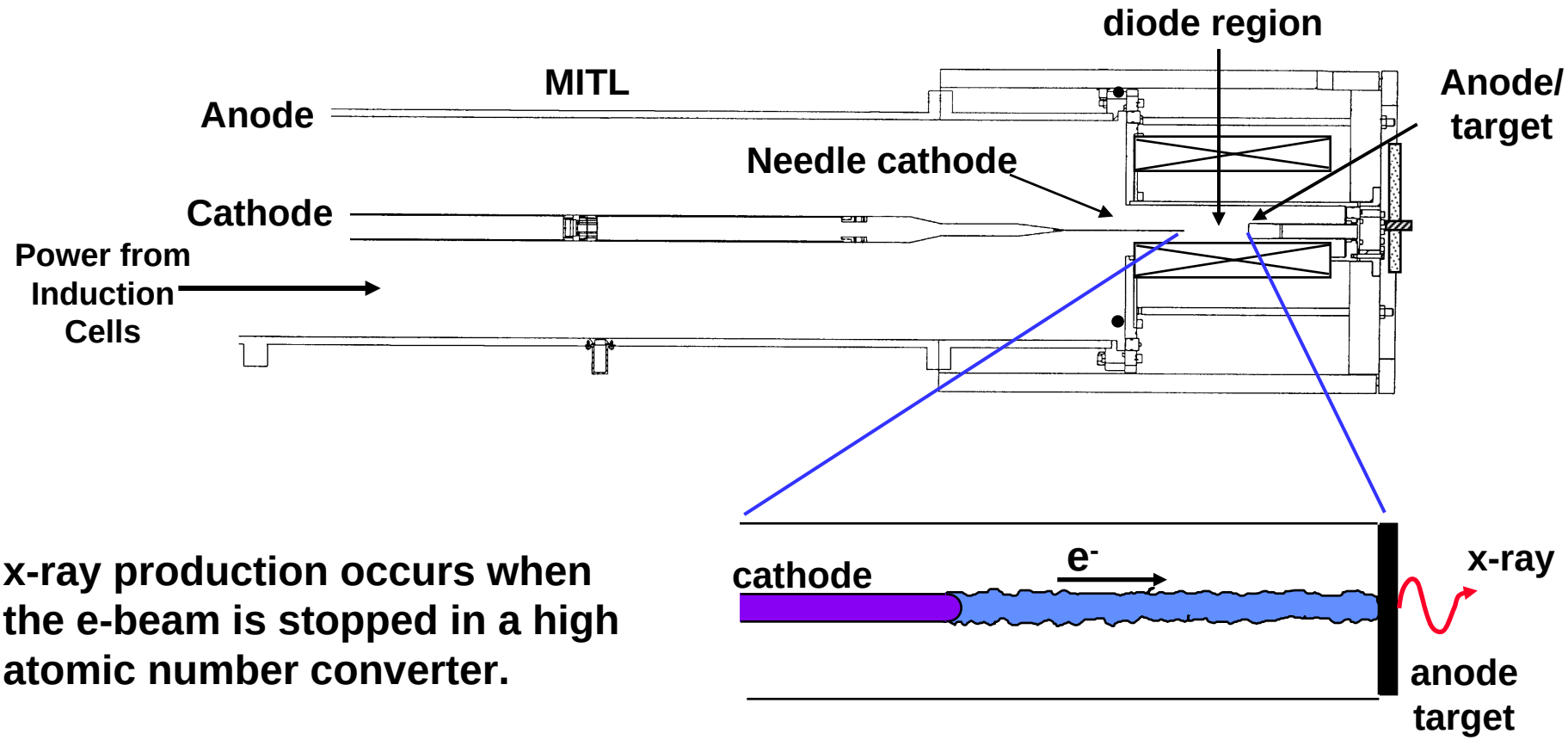
Inductive Voltage Adder (IVA) based e-beam driven radiography

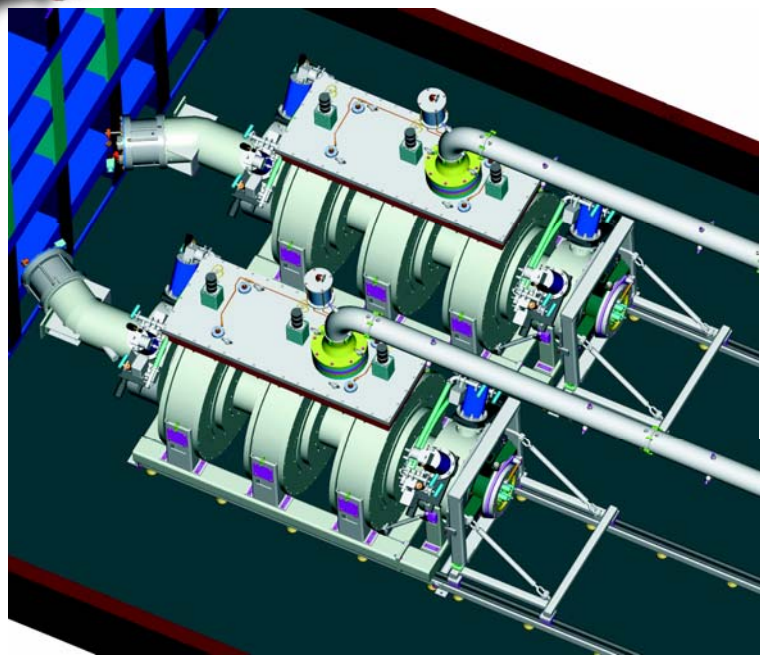
The electron beam is created in the accelerating gap of a high current diode. Power is coupled from induction cells to the diode via a magnetically insulated transmission line (MITL) V=2-10 MeV, I=20-200 kA.

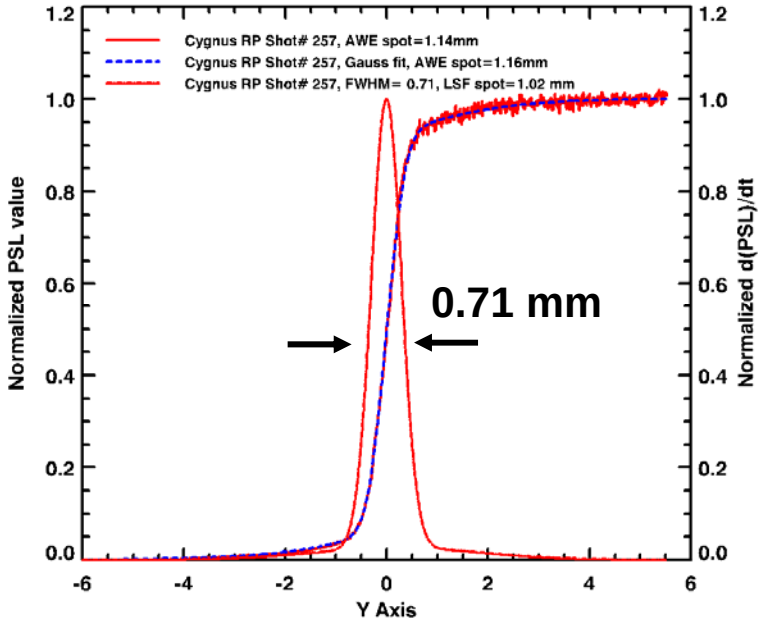


x-ray production occurs when the e-beam is stopped in a high atomic number converter.

Lower voltage but higher current than a LIA design e.g. DAHRT

Cygnus is an IVA-driven Sub-Critical Experiment radiographic system





Radiograph of Thermos confirmatory

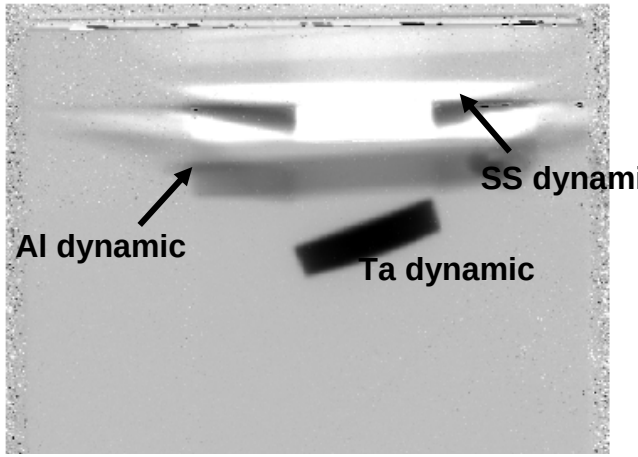


Fig. courtesy T. Haines LANL

- **Provides dual axis radiographs at NTS, U1a**
- **Armando SCE studied spall.**
- **Used on 12 Thermos experiments (Pu recovery) and upcoming Barolo series.**
- **Each 2.2 MV axis produces a > 4 rad@m, 1.1mm spot from a rod-pinch x-ray source.**

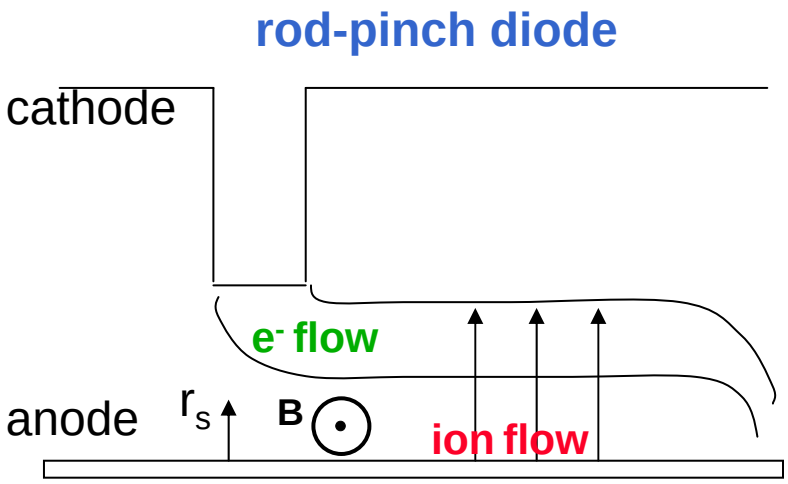
The Cygnus X-ray source is a Rod-Pinch diode.

Operation is described by self-insulated flow theory with the inclusion of ions[1,2].

Diode current well modeled by critical current formulation:

$$I = \alpha I_{crit}, \qquad 2.0 < \alpha < 2.6$$

$$I_{crit} = 8.5 \frac{\sqrt{\gamma^2 - 1}}{\ln(r_c / r_a)} \quad kA, \qquad \gamma = 1 + eV/mc^2$$



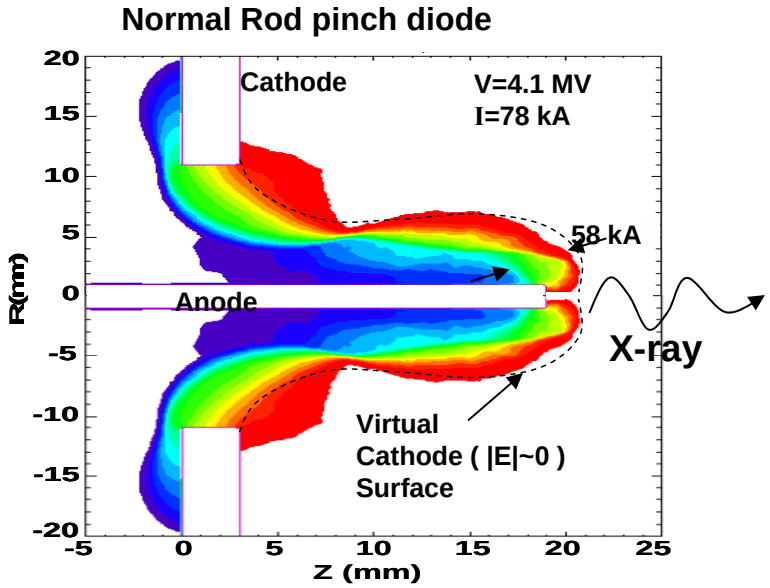


Fig. courtesy of S. Swanekamp, NRL

1. G. Cooperstein et al. Phys. Plasmas, **8**, 4618 (2001)
2. B.V. Oliver et al. Phys. Plasmas, **11**, (2004);

Modeling of the Rod-Pinch diode operation is accurate when diode performance is nominal.

$$I = \alpha I_{crit}$$

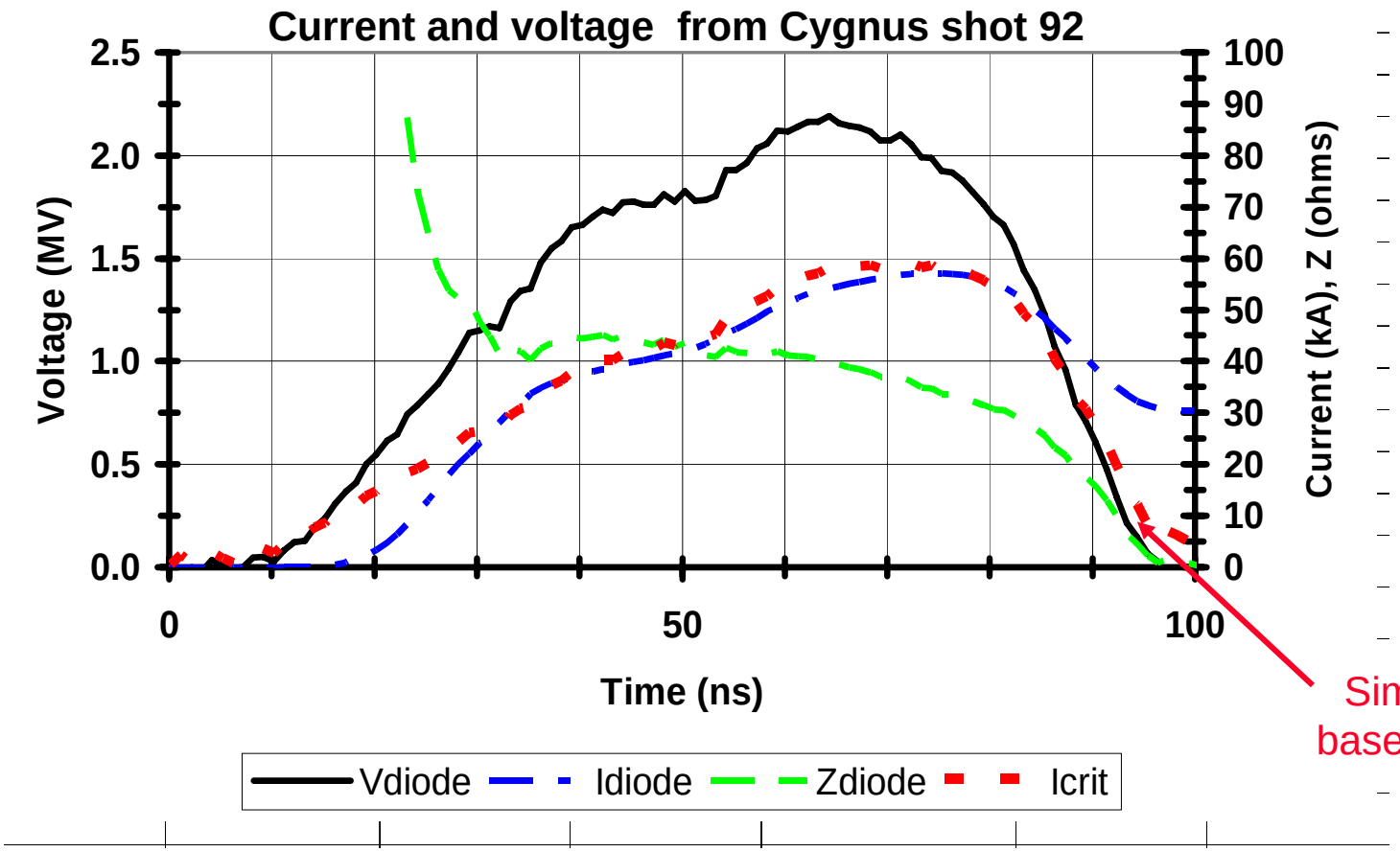
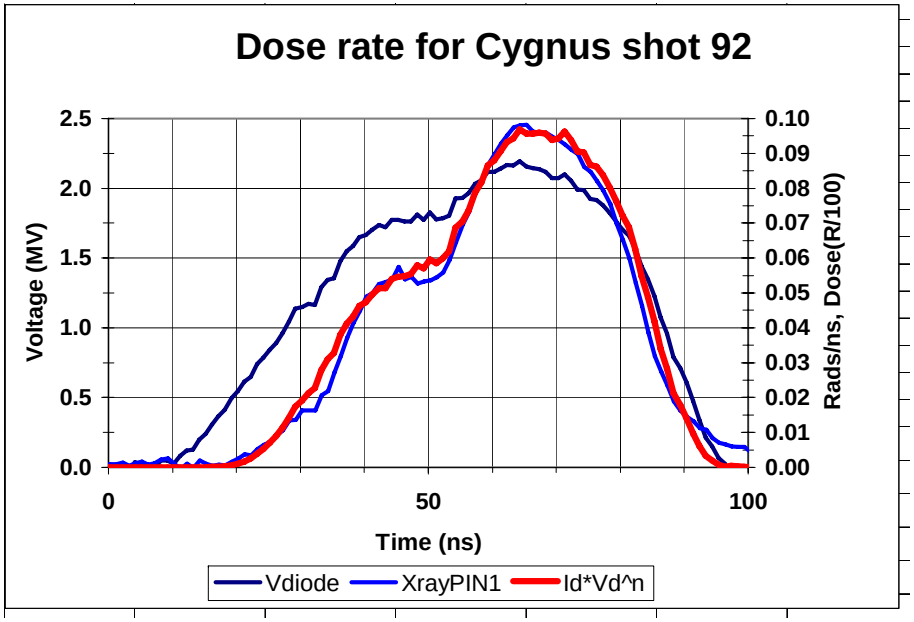


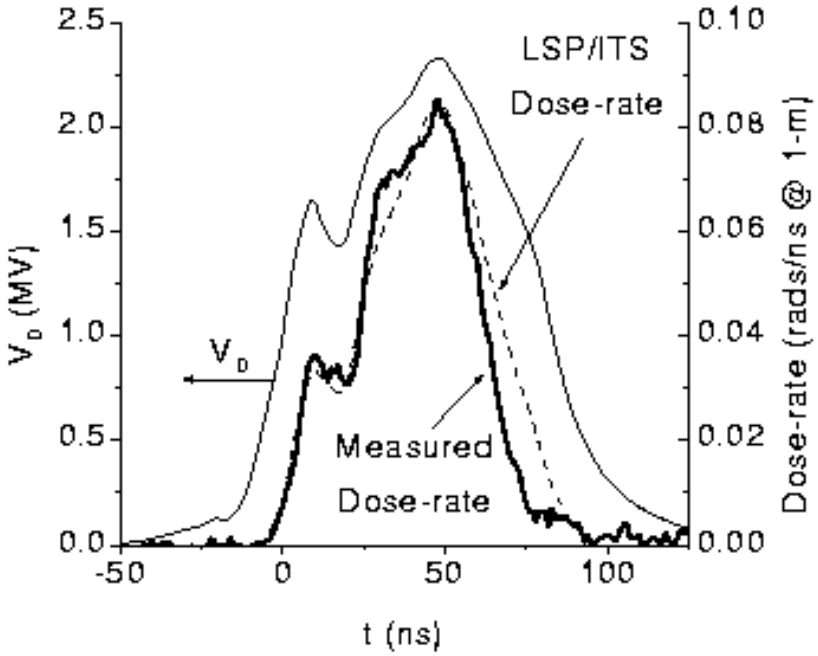
Fig. courtesy of G. Cooperstein, NRL

We have developed accurate modeling of the radiation production.



Detailed coupled PIC/Monte Carlo simulations used for generating radiogrpaher equations[1]:

Dose at 0^0: $D\ (rad) \propto \int I_e V^{1.25}\, dt$

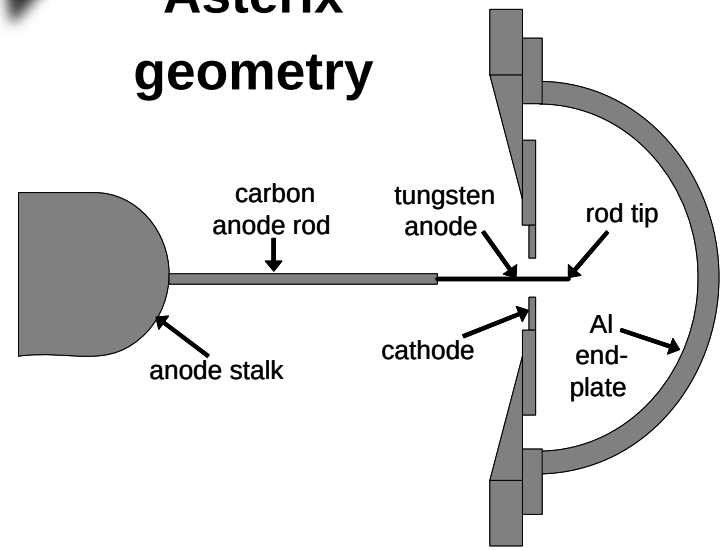


Radiographers equations comparison to SABRE rod-pinch data

1. D.V. Rose et al. JAP,**91**,3328 (2002)

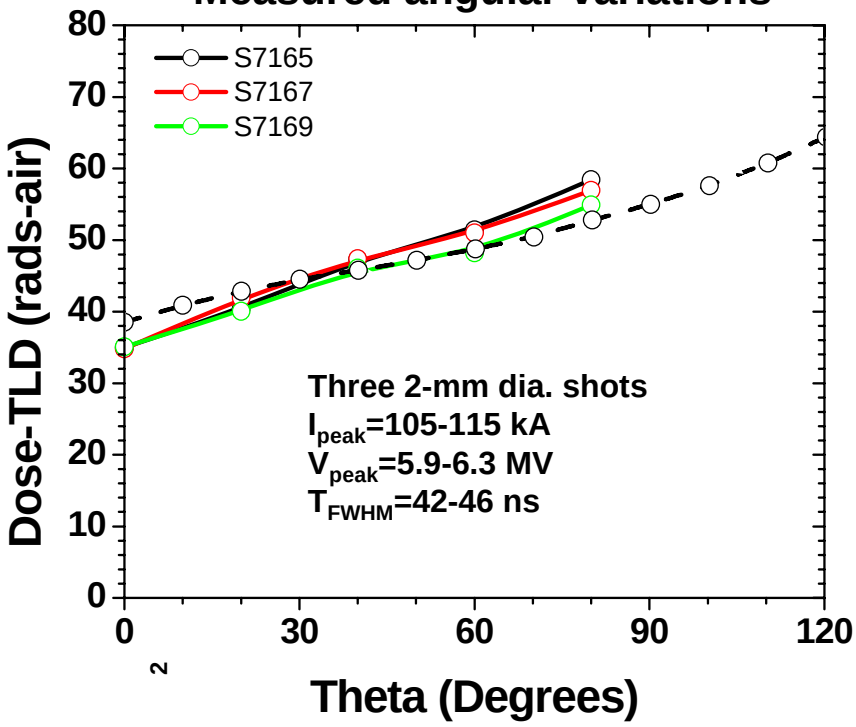
LSP/ITS analysis of 6 MV Asterix rod-pinch data validates code predictions.

Asterix geometry



Joint SNL/NRL/DGA expt.

Simulations compare well to Measured angular variations

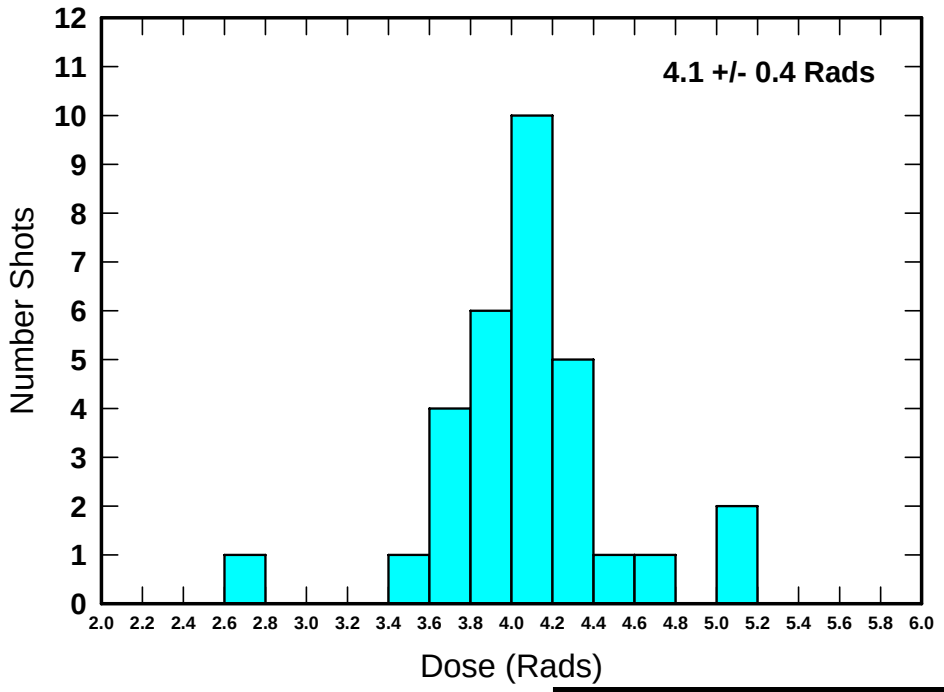


Implies we are modeling the spectral (electron angles of incidence) correctly! However, we have not considered details of shot to shot variation

1. S.B. Swanekamp, et al. Proc. 14th IEEE International Pulsed Power Conference, Dallas, TX, June 2003, IEEE Cat. No. 03CH371472, p. 483-486.

Cygnus dose has 7-10% variation

(4a) Cygnus 2 Dose Distribution - Step Wedge

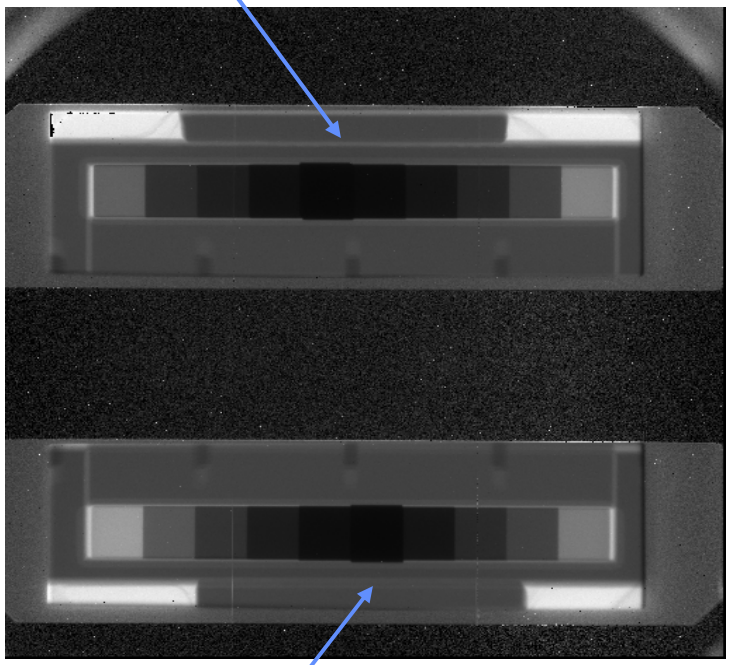


	Cygnus 1 Dose (Rad)	Cygnus 2 Dose (Rad)
Armando	**4.13 ± 0.44**	**4.02 ± 0.46**
Step Wedge	**4.31 ± 0.32**	**4.10 ± 0.27**
Thermos	**4.21 ± 0.30**	**4.09 ± 0.27**
All Shots	**4.21 ± 0.35**	**4.08 ± 0.32**

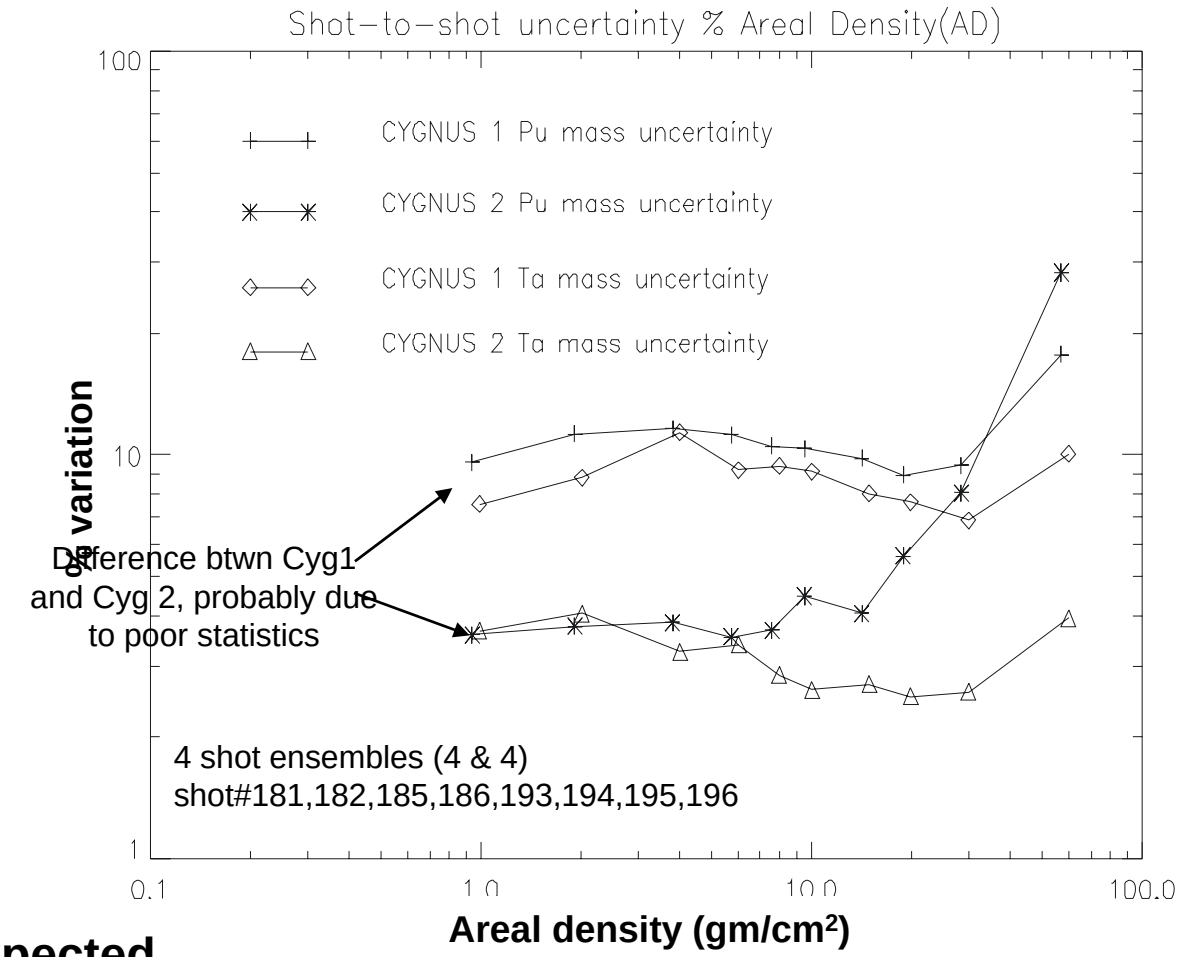
Data courtesty J. Smith, LANL

Analysis of Pu and Ta step wedge data suggests Shot-to-Shot Attenuation Variance of 4-10%

Pu Wedge



Ta Wedge



spectrum is also softer than expected based on electron endpoint energy

Fig. courtesy S. Lutz, NSTec

Presently Looking to Optimize the Sources

LANL desire to optimize Cygnus to improve radiographic data reduction.

Concentrate on spectral and spot variation:

more reproducible spectrum (5%)

Increase dose (10%)

decrease spot

bring sources closer together

Cygnus spectral studies

- **SNL, LANL, NSTec and NRL are teaming to optimize the spectral output:**

  Expts. to be conducted on Cygnus in June-July of ‘08

  improve the source characterization

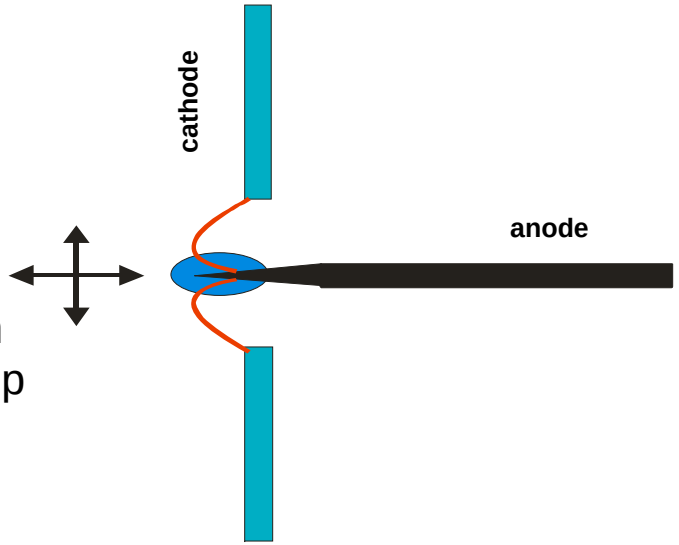
  understand spectral variation and modify radiographic chain modeling

  propose and implement changes to source and pulsed power for future sub-crits

Possible sources of Spectral variation:

diode voltage fluctuations.

variable beam attenuation due to changing electron beam position or expanding plasma from cathode tip



Presently Looking to Optimize Cygnus

Pulsed power output variation can account for spectral variation

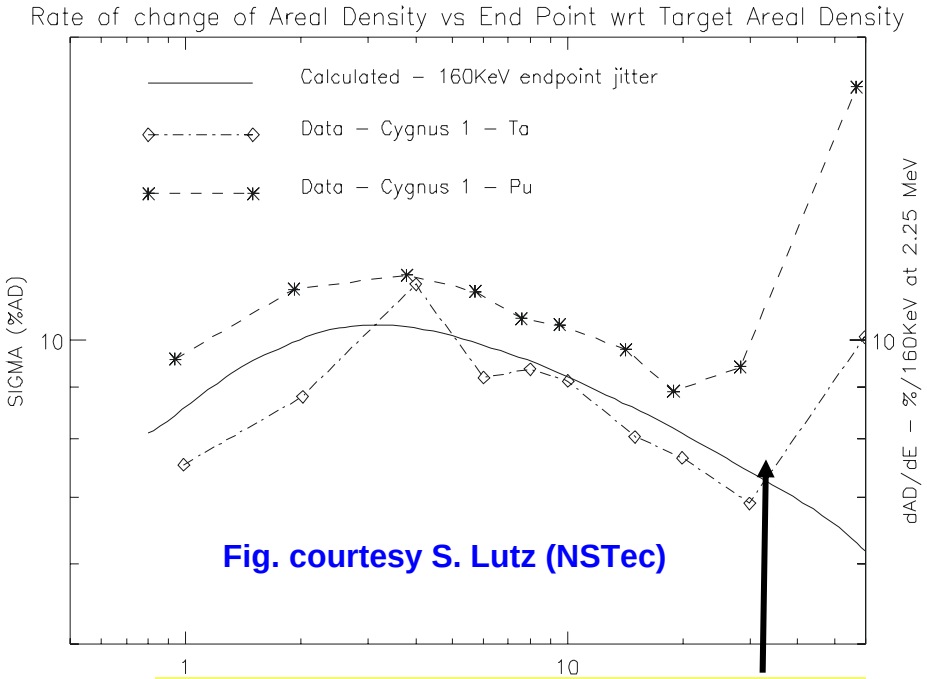
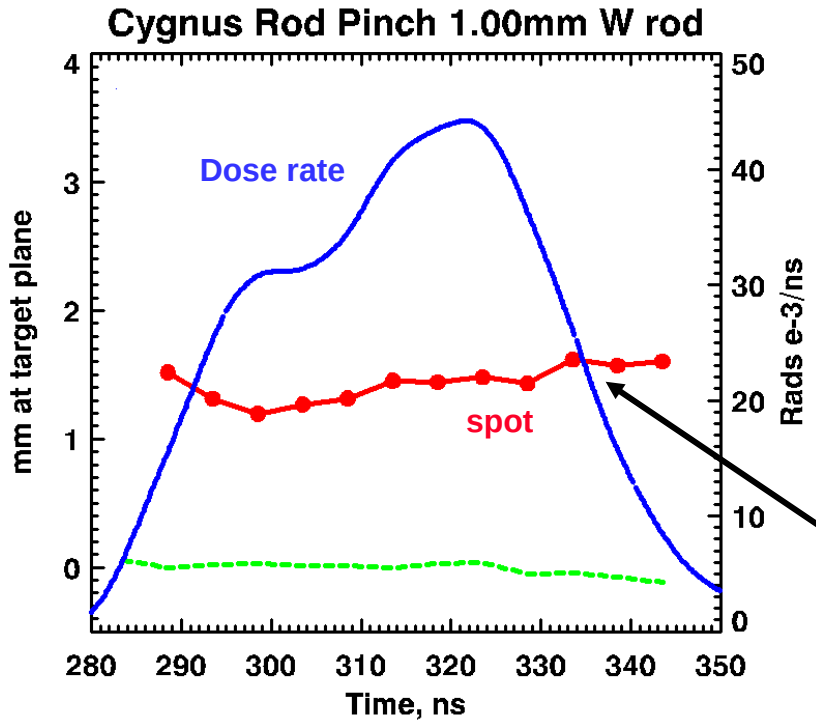


Fig. courtesy S. Lutz (NSTec)

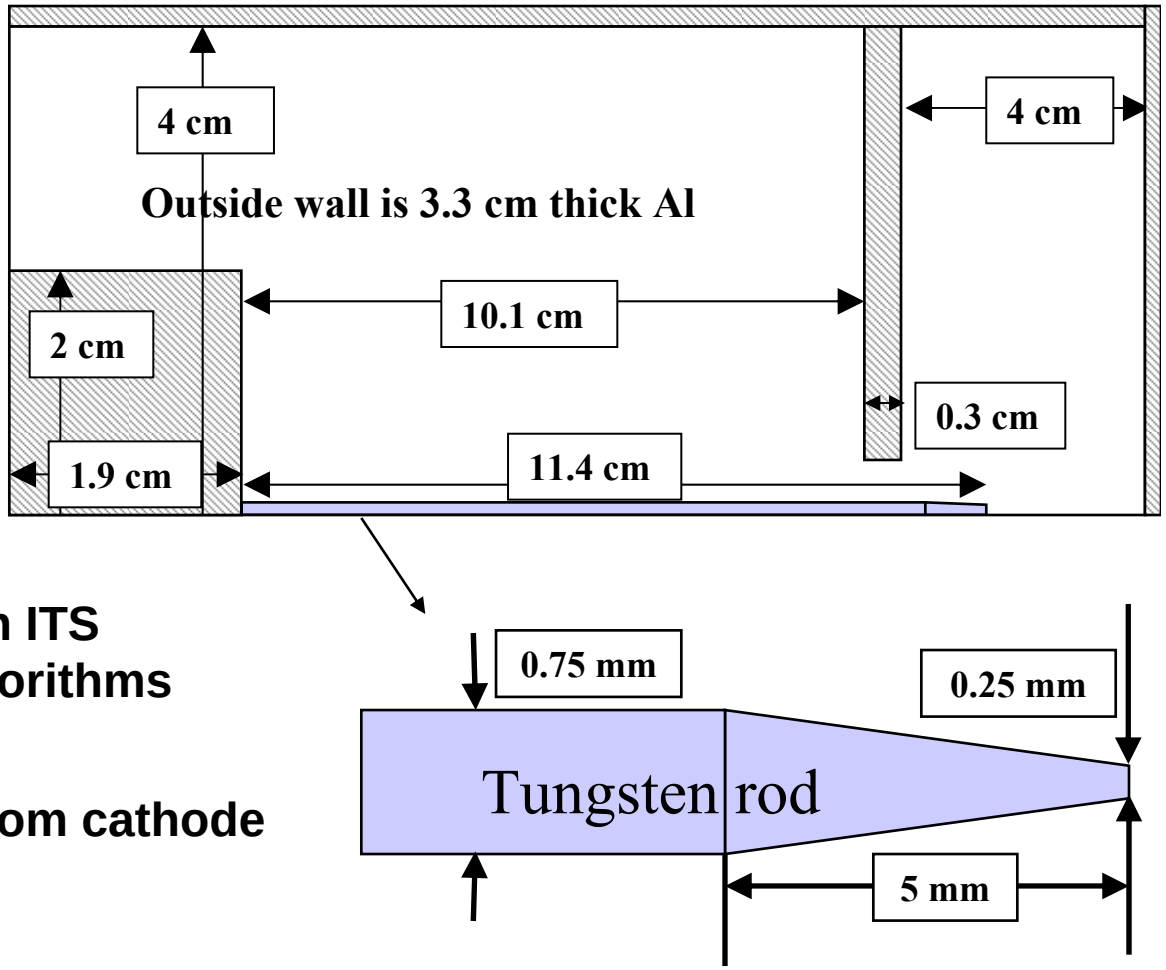
5-10% transmission variation due to 160 KeV (7%) voltage variation.

Rod dynamic evolution can alter electron angles of incidence and influence spectra:



Spot growth late in time

Utilizing PIC/Monte Carlo calculations to generate false spectrum for Cygnus geometries

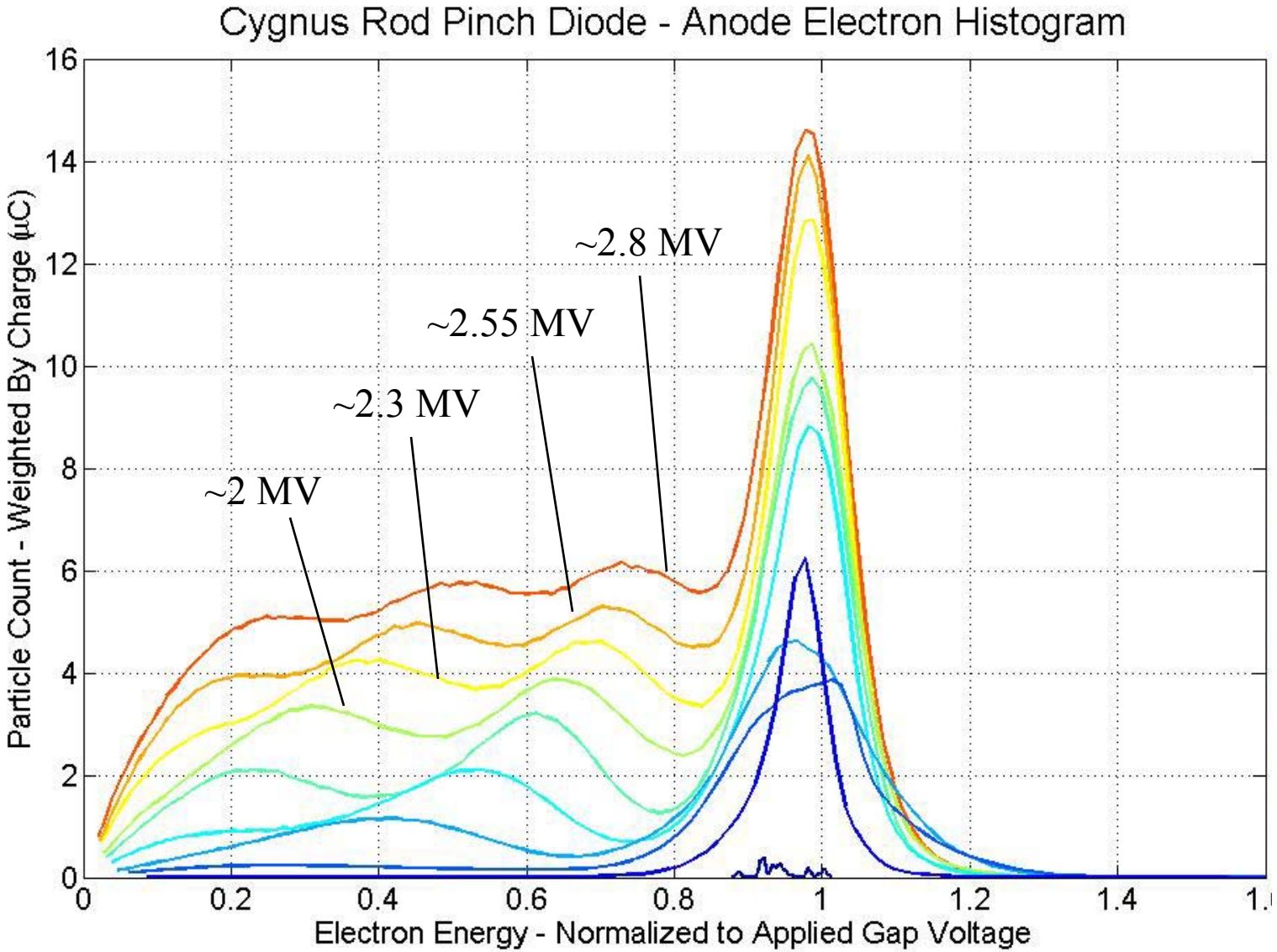


All solid material are treated with ITS electron/photon Monte Carlo algorithms

Child-Langmuir field emission from cathode at a threshold of 100 kV/cm

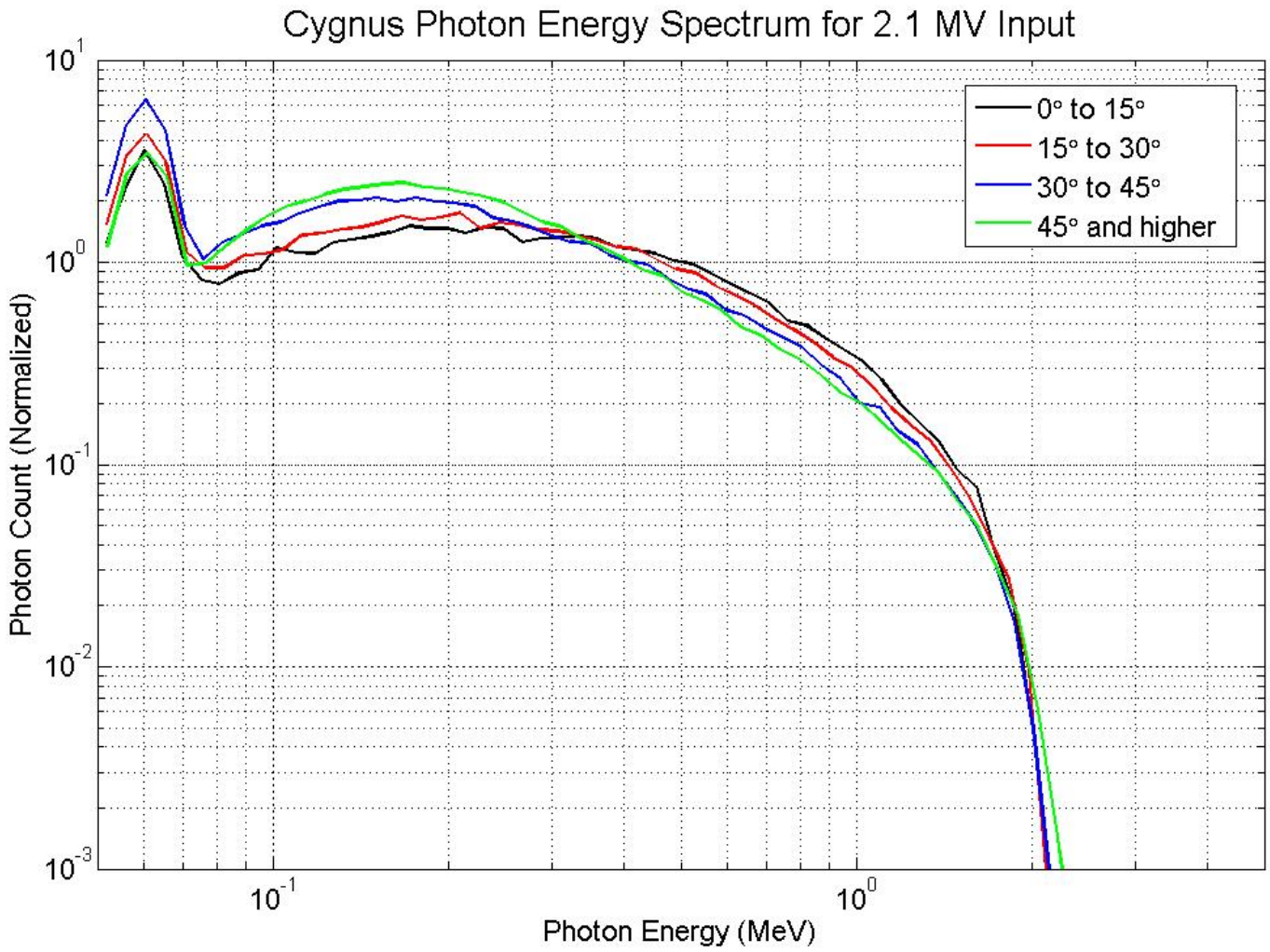
Thermal emission of protons from Tungsten anode rod at a threshold of 400 C

Electron scattering and reflexing through the rod, create low energy electron distributions.

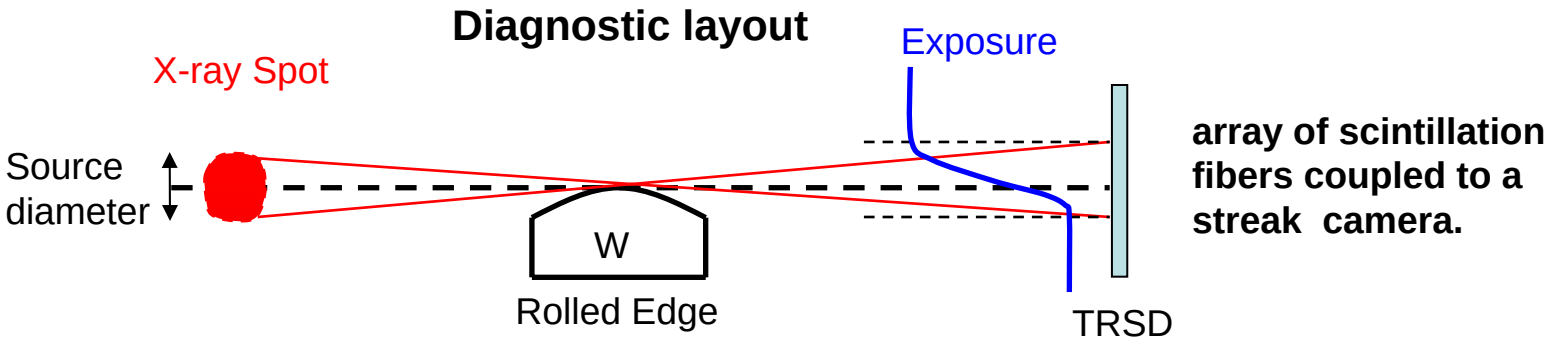


Energy spectra for electrons incident onto rod – normalized to V_0

False spectrum are softer than typical Bremms with 2.1 MeV endpoint and are softer at large angles.



Time-resolved x-ray spot diagnostic can measure rod-pinch expansion and spot growth



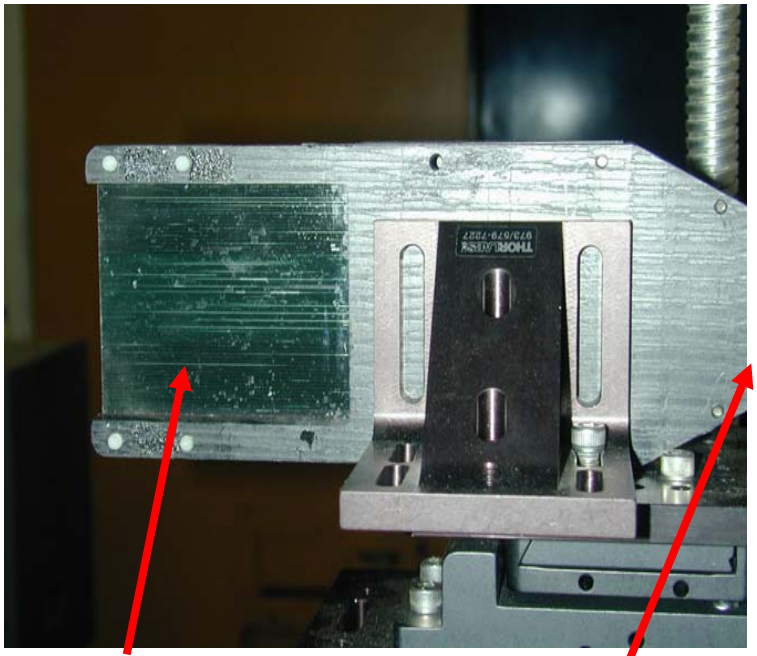
Detector Response

Blur from contact shot=1.28mm, compares to the blur from Imaging Plate of ~1mm

Minimum Dose on detector~3 Rads

Maximum Dose On Array=12 Rads

Temporal Resolution~4 ns, streak camera limited



Scintillation Fibers

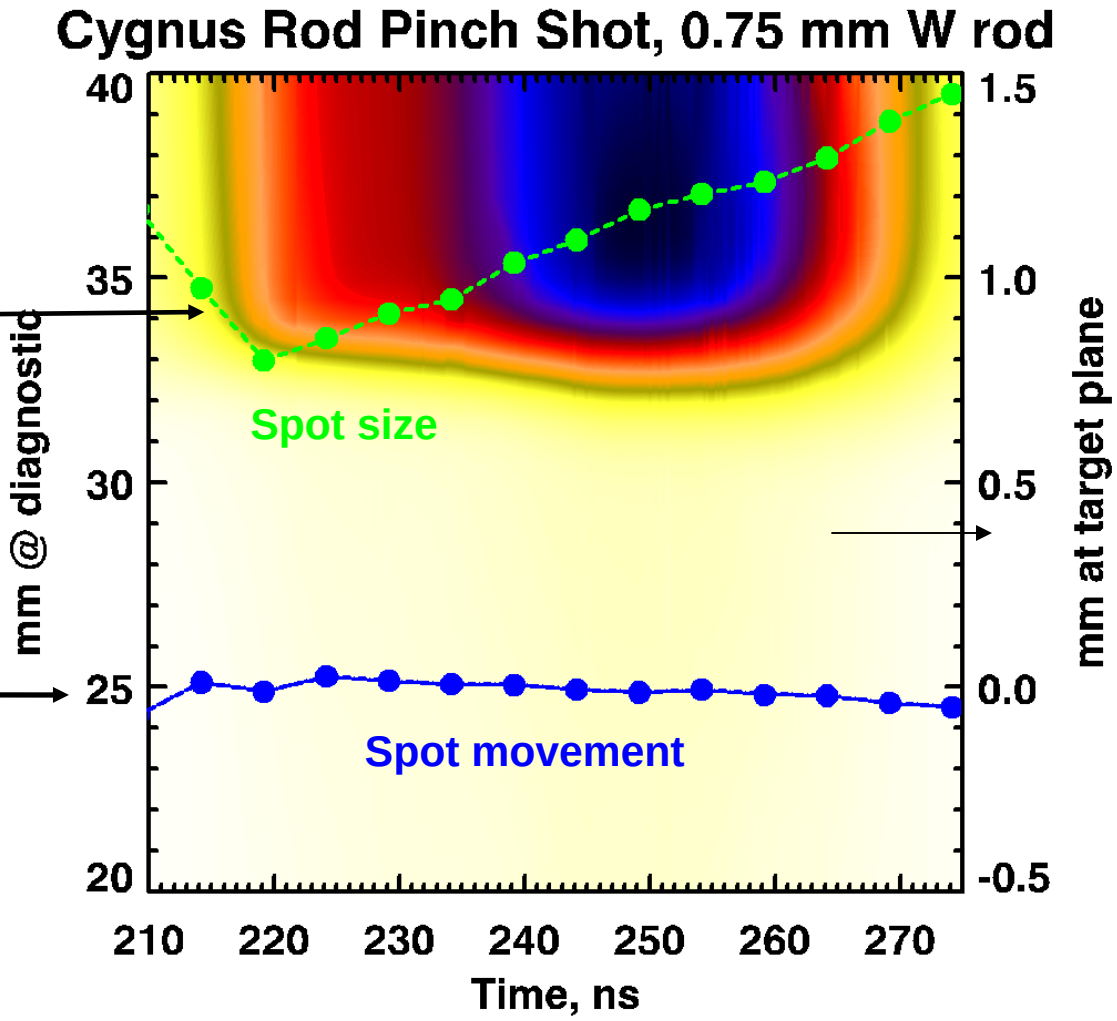
Streak Camera

End on imaging shows spot growth on typical shot.

Cygnus Rod Pinch Shot, 0.75 W tapered rod- “Armando Configuration”.

Spot growth = 0.012 mm/ns

Stable Diode, micron sized movement from center.



Would like to observe side on imaging to try and quantify possible self-absorption affects

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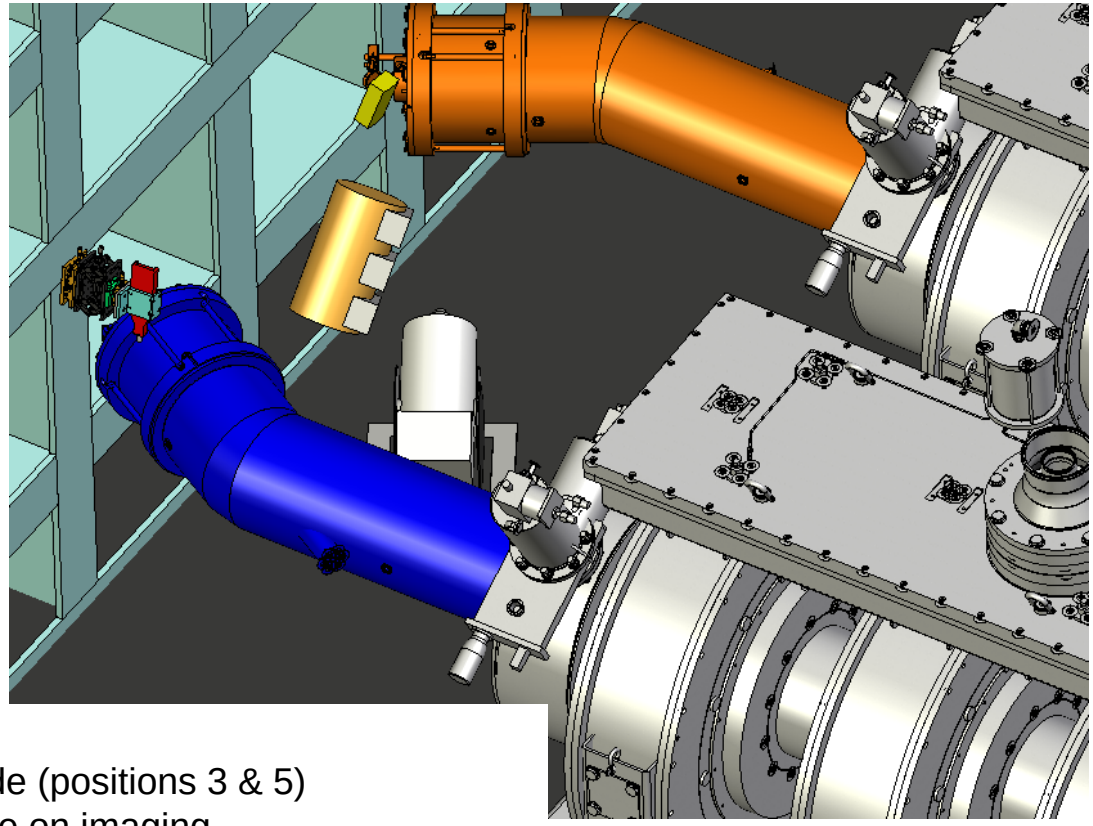
We will conduct experiments in June-July on Cygnus to better characterize the source



Diagnostics:

- Accurate Voltage and Current at diode (positions 3 & 5)
- Time integrated spot, end on and side on imaging
- TRSD and pinhole, side on imaging.
- Pin-diode array for spectral variation measurements

Shots:

- Base-line data set with standard Cygnus set-up. Expect 4-6 weeks.
- Decrease voltage on Cygnus 1 to emulate Cygnus 2
- Test Object Data (to be taken in standard configuration)
- Geometric variations for optimization

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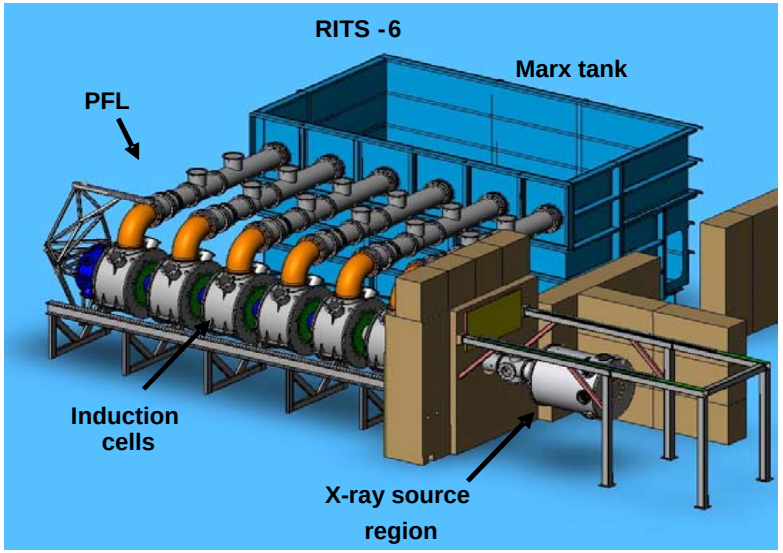
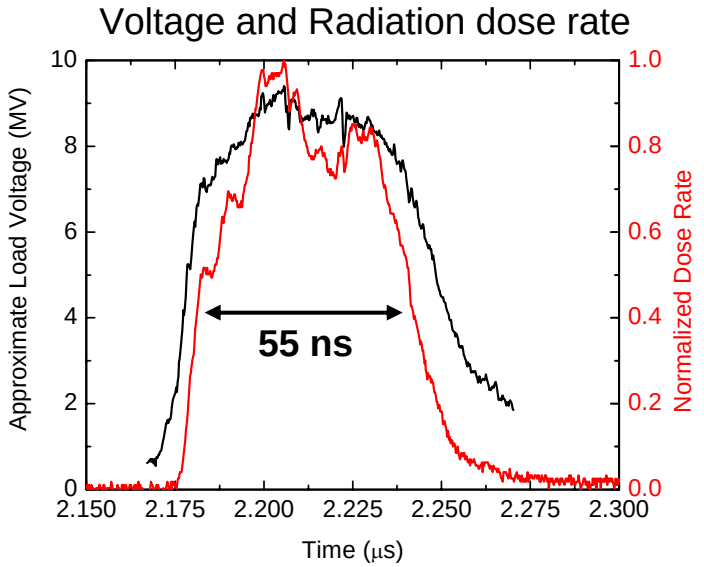
RITS-6: Sandia's Radiographic Integrated Test Stand

E-beam driven x-ray radiography system based on Induction Voltage Adder (IVA) technology.

Flexible accelerator producing 5-10 MV, 125-190 kA, 55 ns radiation pulses and capable of generating > 400 rad@m.

We are using RITS and Mercury (NRL) to investigate the Neg. Polarity Rod Pinch at Voltages ~ 6.5 MeV.





Alternative source development for the future: Negative Polarity Rod-Pinch

Dose at 0^0 scales weakly with voltage[1]!

$$D\ (rad) \propto \int I_e V^{1.25}\, dt$$

Dose at 180^0 in backwards direction is maximized[2]

$$D\ (rad) \propto \int I_e V^{2.22}\, dt$$

Dose rate dependence on angle

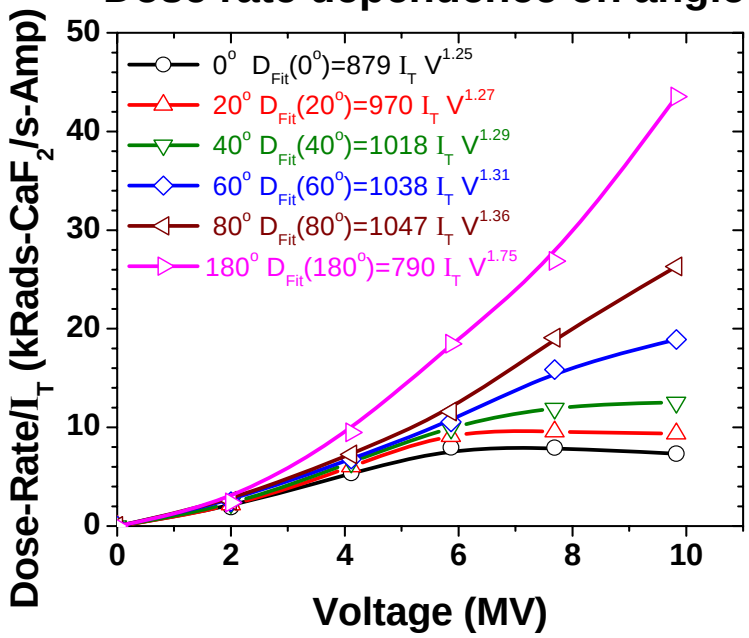
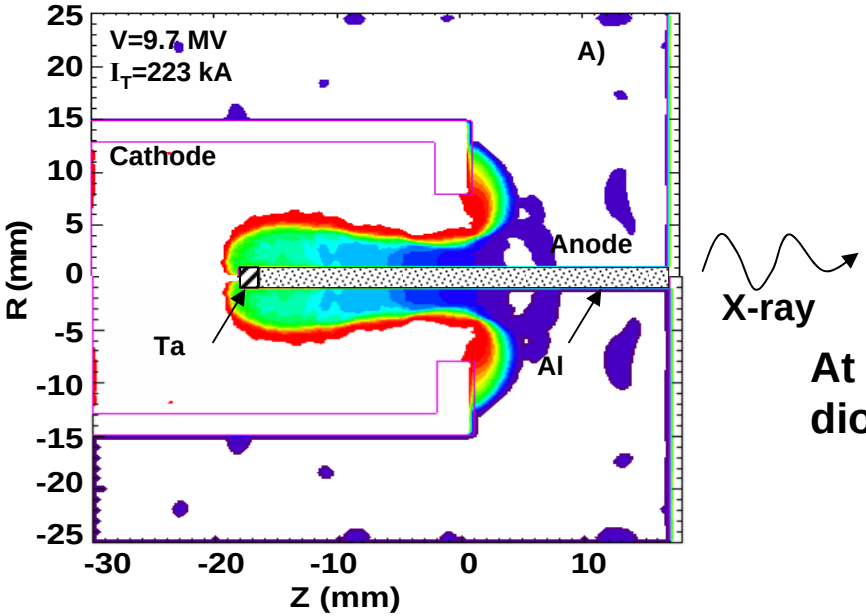


Fig. courtesy of S. Swanekamp, NRL

Reentrant Rod pinch diode



X-ray

At high voltages the Rod-pinch diode dose is maximized at 180^0

1. D.V. Rose et al. JAP,**91**,3328 (2002)
2. S.B Swanekamp, G. Cooperstein, J.W Schumer et al. IEEE Trans. Plasma Sci. **32**, 2004 (2004)

Negative Polarity Rod-Pinch results @ 6.5 MV

Collaboration with NRL.

Rod on-axis, with hollow Al tube and W plug

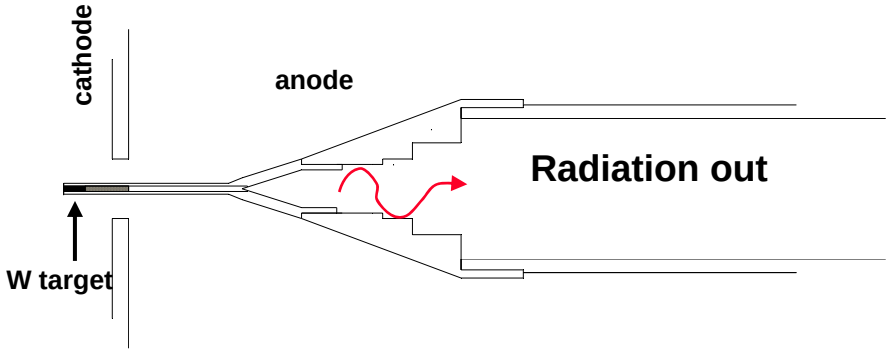
Radiation in the backward direction is 2.5x higher than the forward direction at 6.5 MV

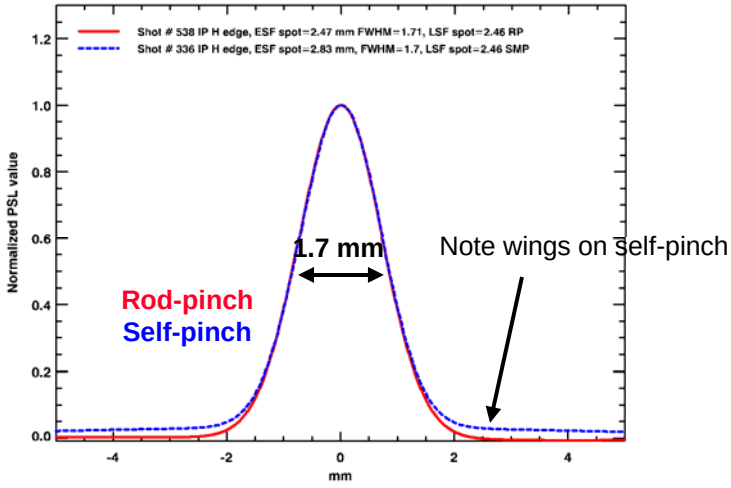
Demonstrated 120 rad@m, 2.4 mm spot (RITS)

110 rad@m, 1.8 mm spot (RITS)

75 rad@m, 2.0 mm spot (Mercury, NRL)

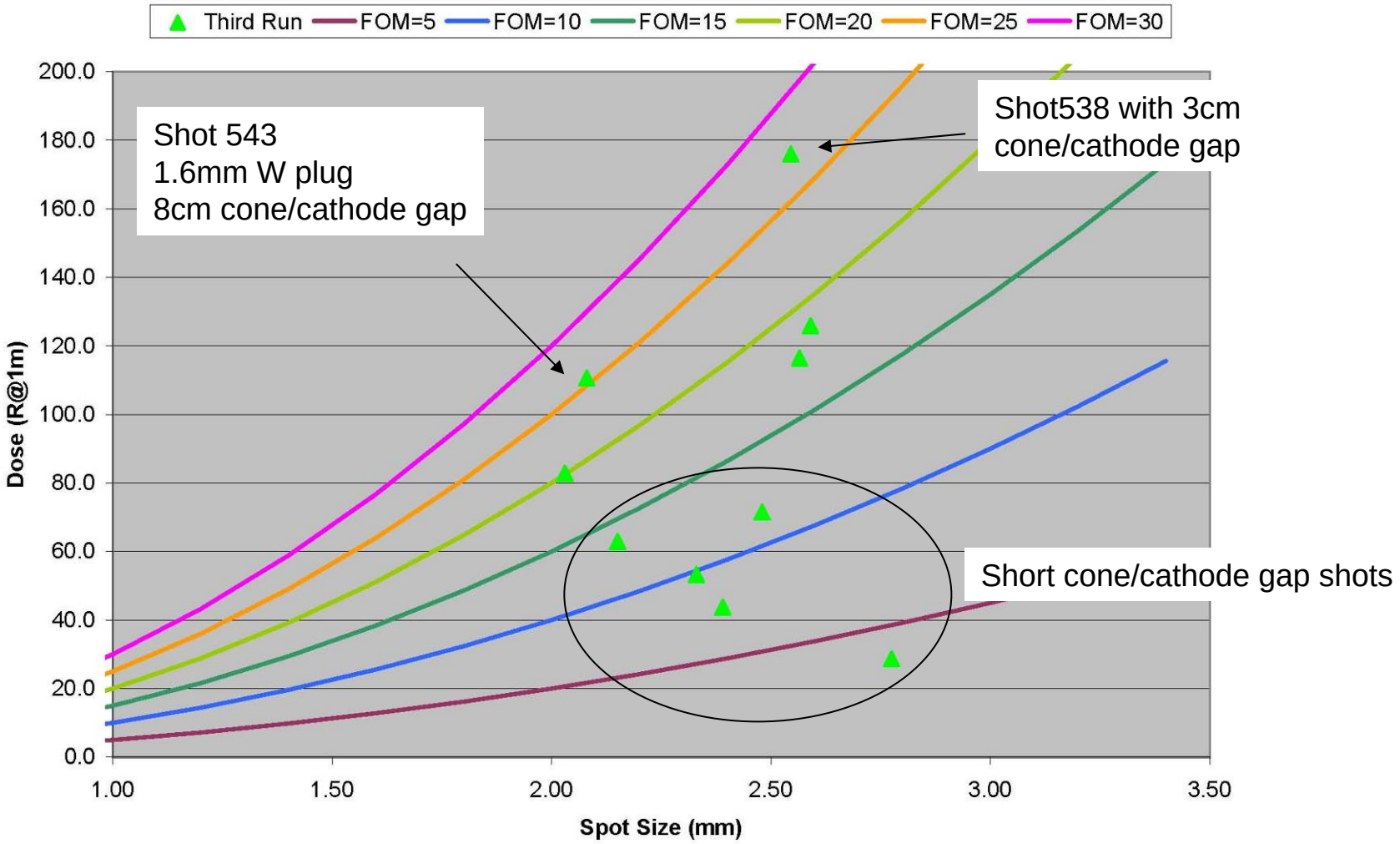
6 times brighter source than Cygnus





Comparison of Self-pinch and Neg. Polarity rod-pinch source distribution

We are reaching figure of merits near 30 rad/mm^2.

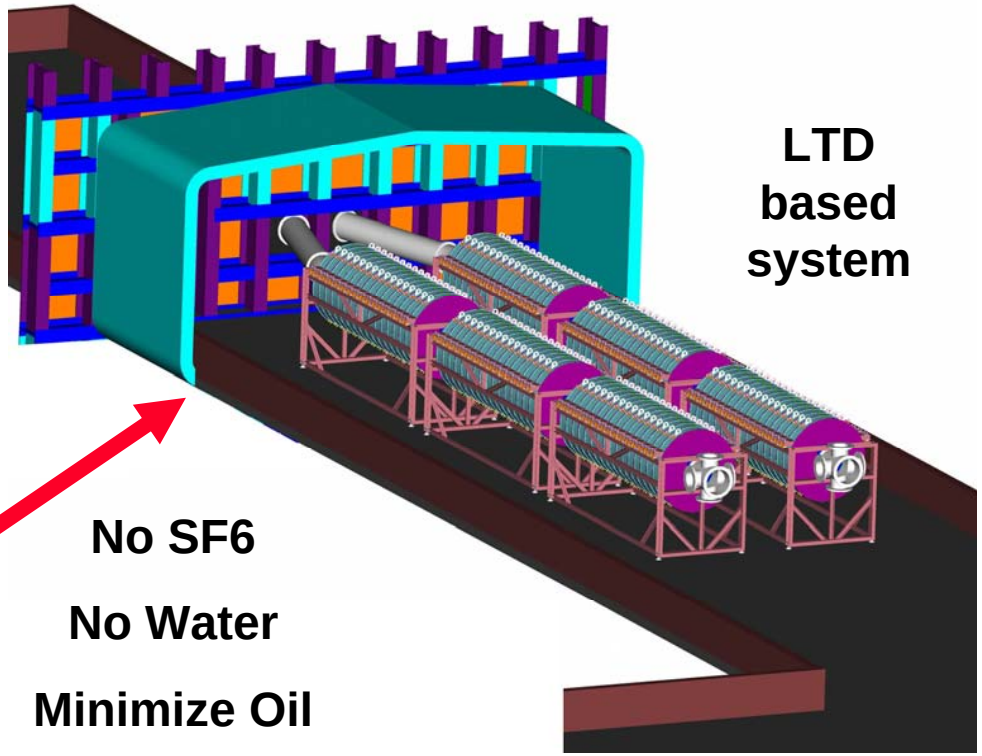


A 2-axis LTD architecture can provide 6.5 MV system driver in same foot print as Cygnus

12’ wide x 50’ long x 6’ high

Can replicate existing Cygnus capability

With significantly increased driver capability (6-7 MeV).



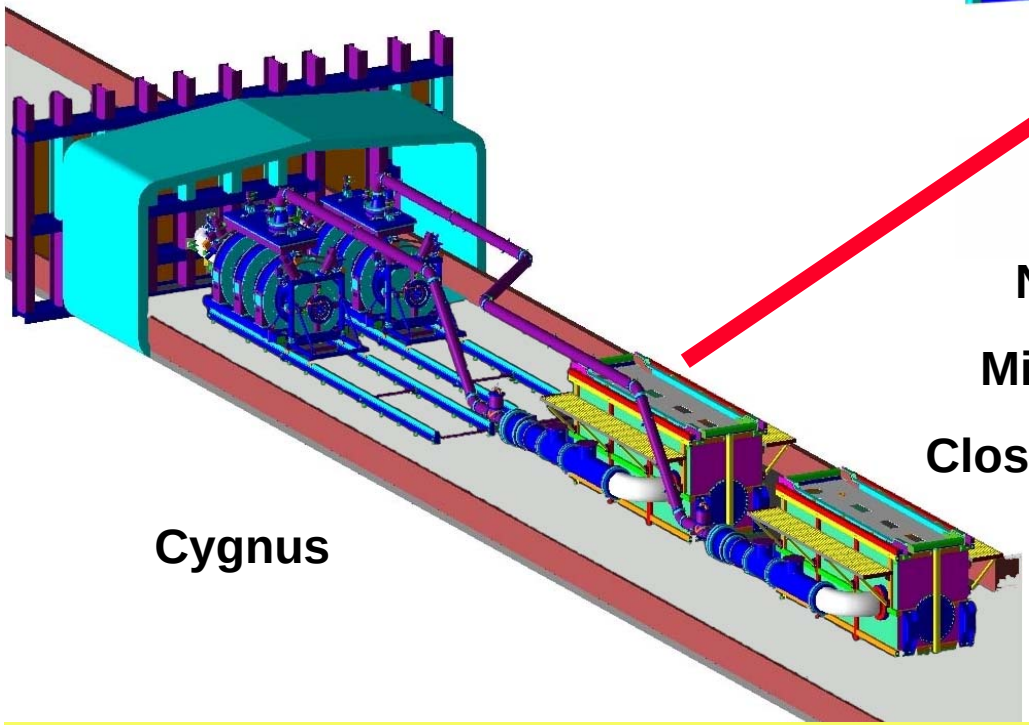
LTD based system

No SF6

No Water

Minimize Oil

Closed geometry



Cygnus

The negative polarity rod-pinch configuration coupled to an LTD architecture is showing significant promise as a future sub-crit radiographic source at U1a.

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