SAND2010-4615P

The Rod-Pinch Diode as a Possible Warm Dense Matter Environment.*

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Presented at the
37th IEEE International Conference on Plasma Science
Norfolk VA, USA,
June 21, 2010

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Introduction

Warm dense matter (WDM) is characterized as the transitional state between solid and plasma near solid densities with thermal energies on order of the Fermi energies (typically a few eV)[1]

Equation of State studies

Opacities

Conductivities and transport phenomena

Creating WDM is typically conducted on large accelerator or laser facilities with relatively small volumes of material and short timescales.

We propose creating warm dense matter environments using a high power electron beam diode fielded on an inductive voltage adder (IVA) pulsed-power accelerator.

Inexpensive

Relatively large volume of material (>10 mm^3)

Long timescales (10^s of ns)

1. [S. Ichimaru, Rev. Mod. Phys. **54**, 1017 (1982)].

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We propose using the Rod-pinch diode to create WDM environments

It is a self-magnetically insulated electron beam diode [1,2]

Diode current well modeled by critical current formulation:

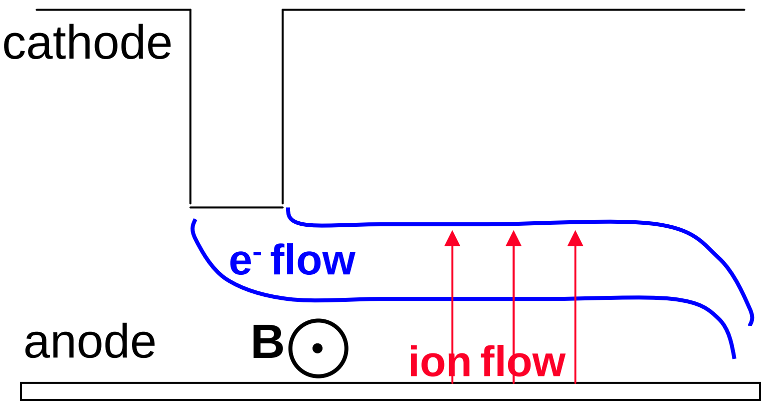
$$I = \alpha I_{crit}, \qquad 2.0 < \alpha < 2.6$$

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

Large self-magnetic fields (20 tesla) confine electrons to anode-rod tip and which circulate through the rod.

Diode current ~120 kA (at 6-7 MeV) focused onto 2.5 mm diameter anode rod.

rod-pinch diode geometry



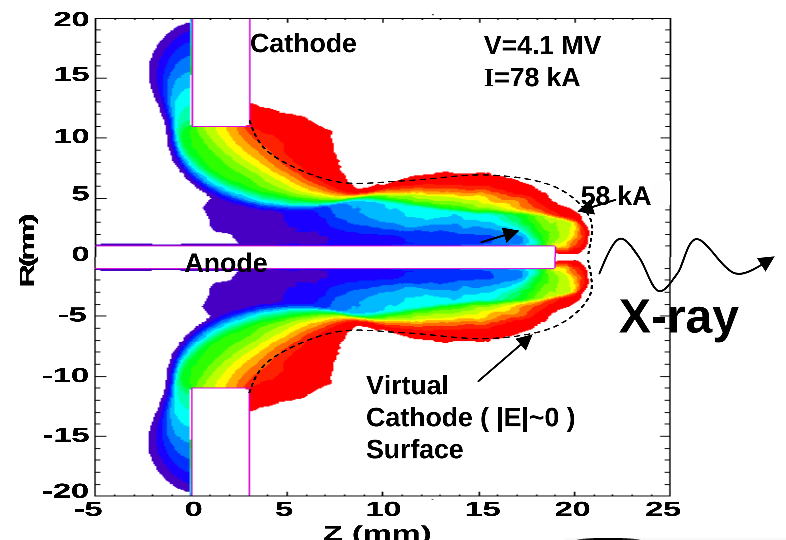


Fig. courtesy of S. Swanekamp, NRL

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

Experiments are fielded on the RITS-6 Accelerator

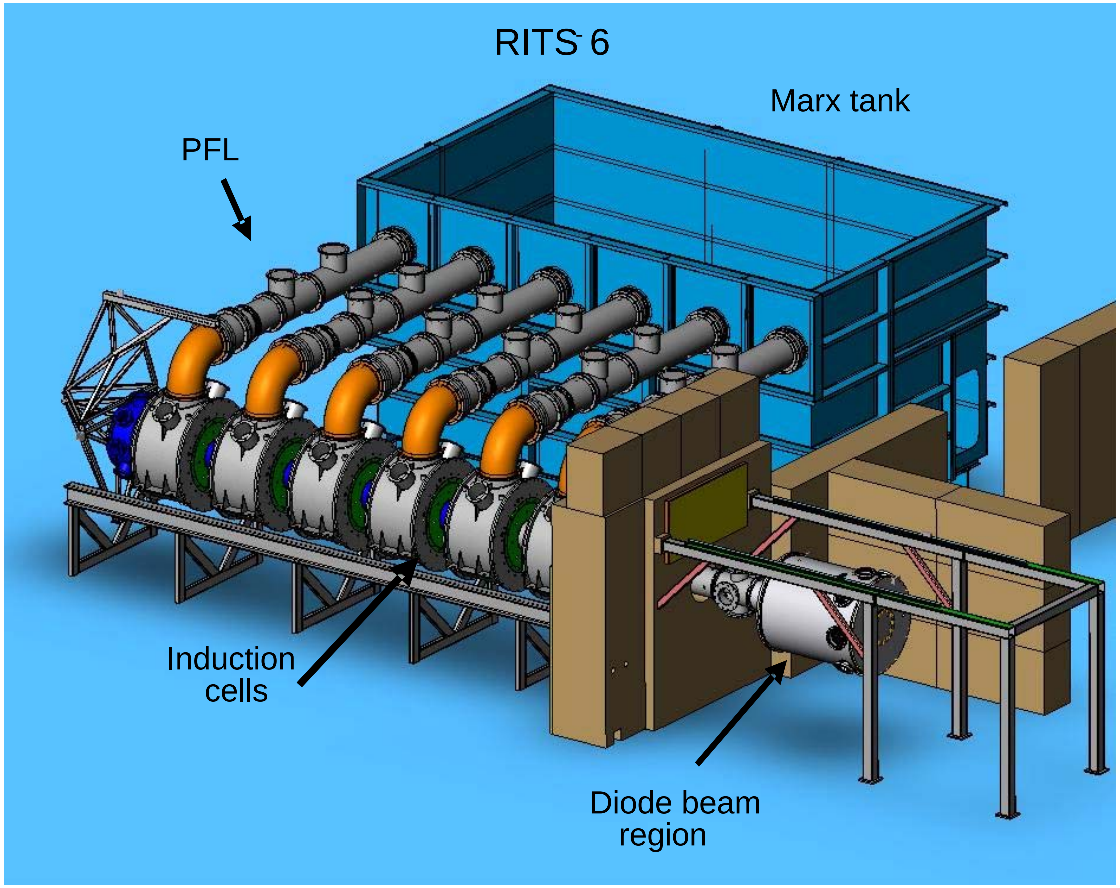
RITS is an Induction Voltage Adder (IVA) accelerator: 1 TW pulsed power generator, 70 ns pulse-length.

Accelerator operating parameters:

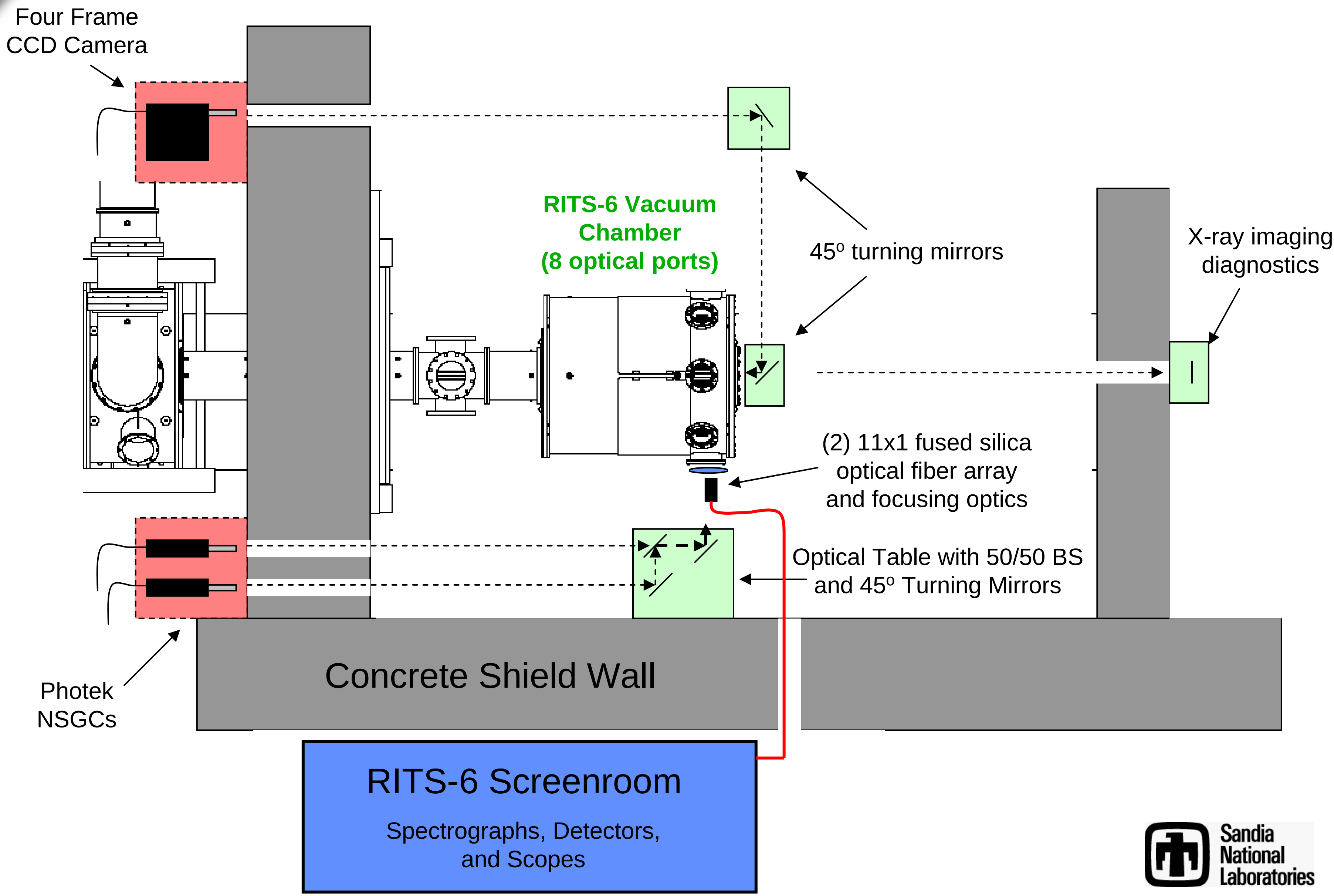
- 4.5-11 MV voltage
- 110-200 kA current

Drives high power electron-beam diodes for intense beam physics application.

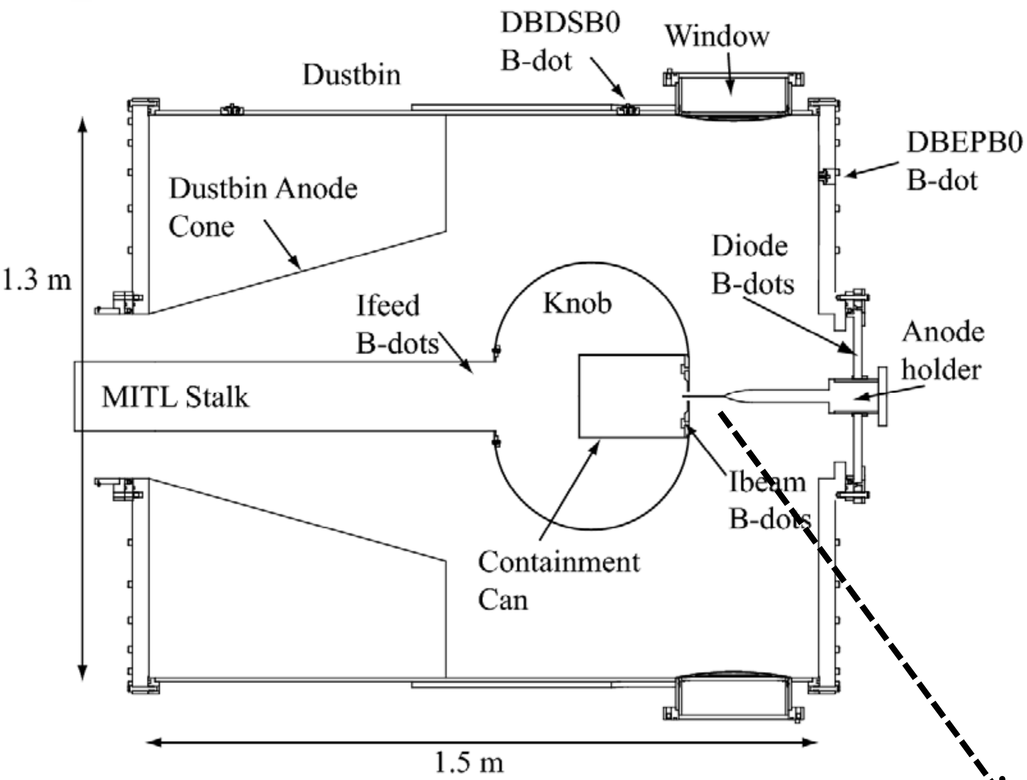
Rod-pinch diode experiments are fielded in negative polarity



Optical Diagnostic Setup on RITS-6

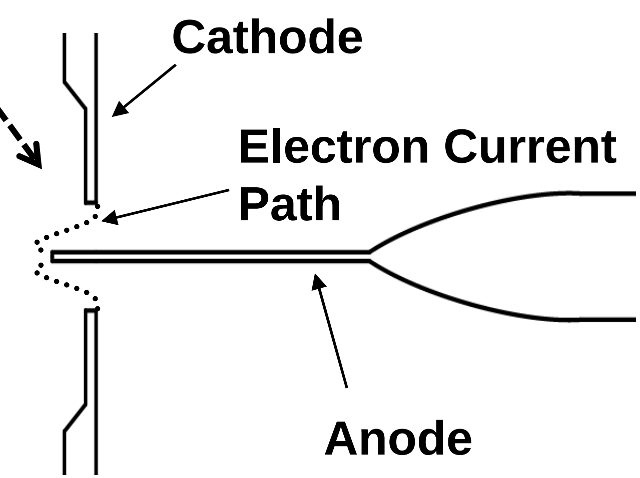


Experimental Diode Setup



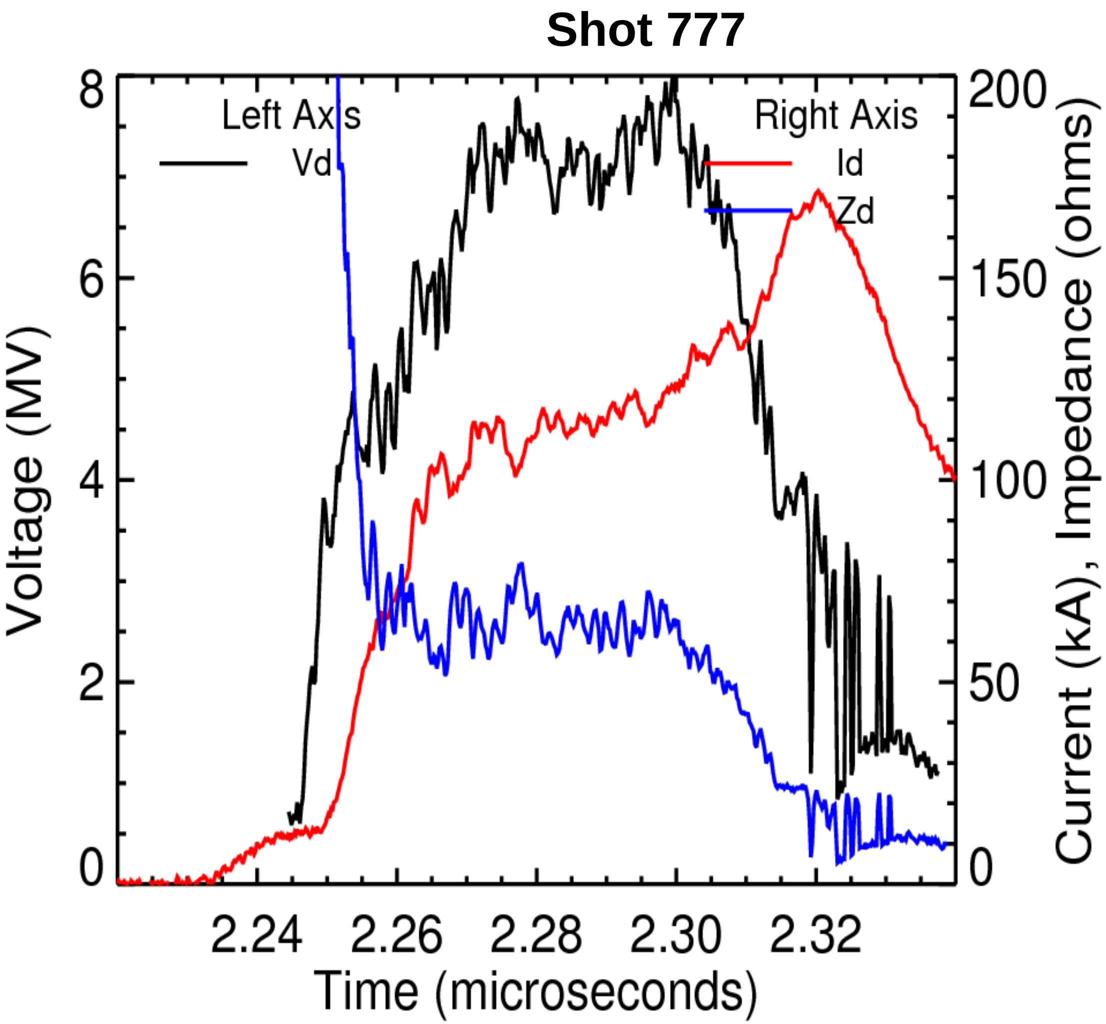
Diode Region

Anode rod is composed of a hollow Al tube with a W or Au converter placed at the tip



The beam deposit > 42 kJ on the anode target in 50 ns.

Typical diode e-beam paramete
- 120 kA
- 7 MeV
- 60 Ohm
- 45 ns FWHM pulse



Energy density is ~ 2 MJ/cm³ on target.

Optical and X-ray imaging confirm that e-beam attaches to the tip of rod on the high Z (W) converter

Converter target diameter 0.24 cm
length 0.4cm.

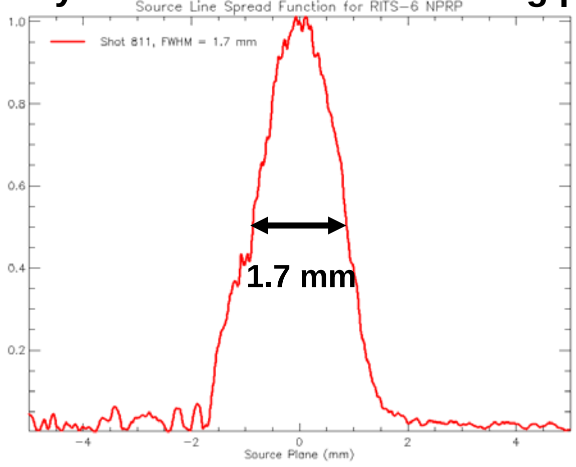
Power density on target ~ 42 TW/cm³

Electrical energy deposited in target is > 40 kJ.

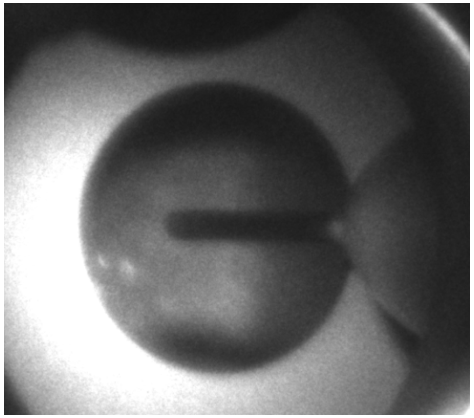
Energy per unit mass > 0.1 MJ/g

Little to no expansion of rod during power pulse, target remains near solid.

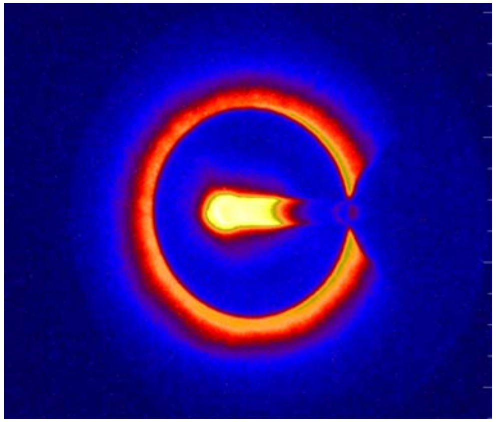
X-ray source distribution during pulse



Before Shot



Post Shot



Optical images from CCD framing camera (20 ns gate)

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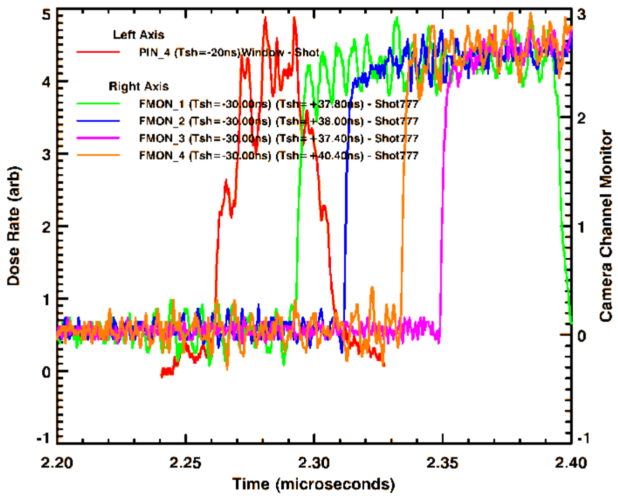
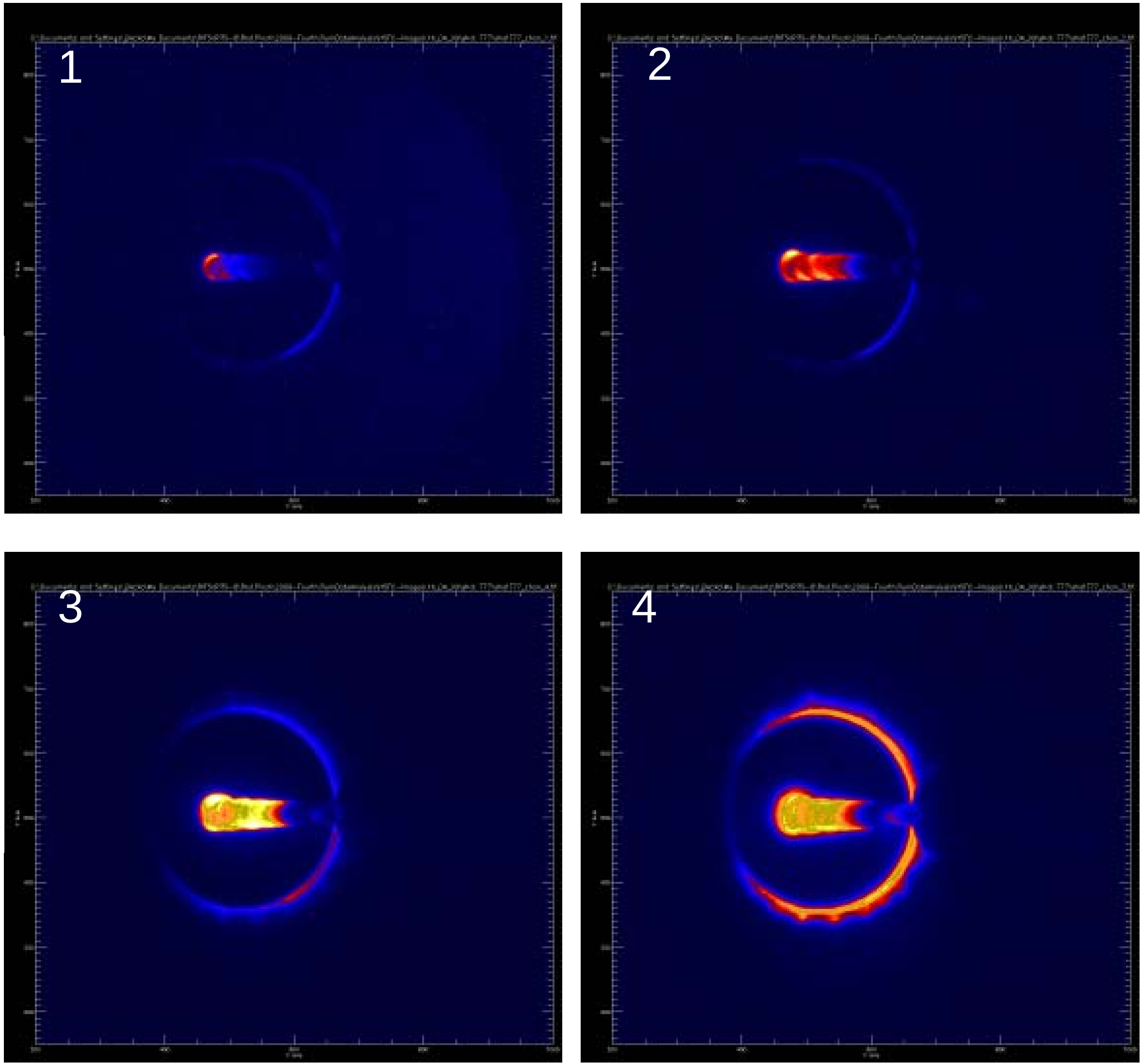
Optical framing images show expanding plasma after power pulse ends.

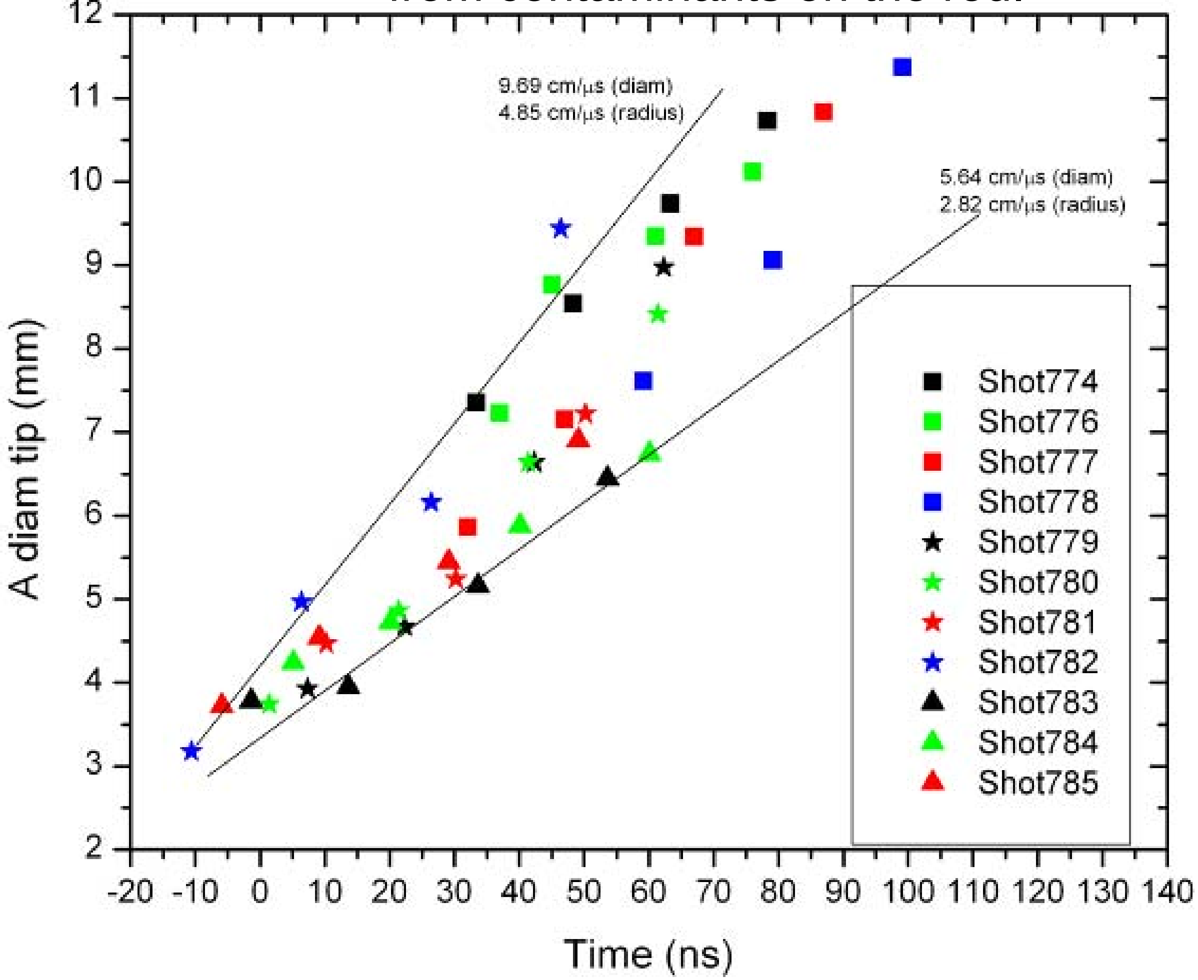
Channel	Delay	Gate	Gain
1	35	3	40%
2	50	3	40%
3	70	3	40%
4	90	3	40%





Anode plasma expansion velocities ~ 2-4 cm/μs

The visible light is probably from expanding Hydrogen plasma from contaminants on the rod.



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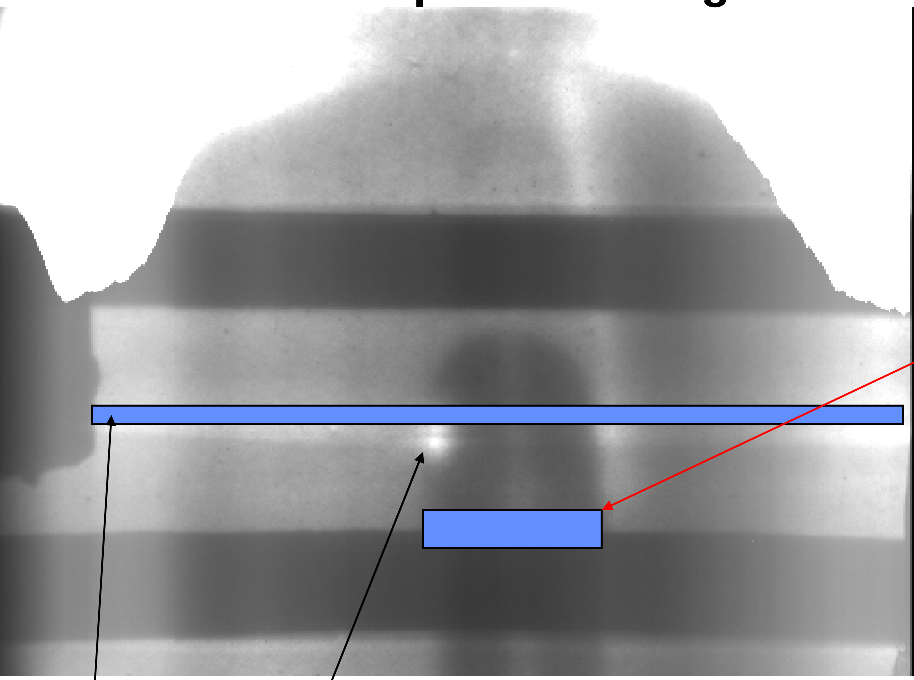
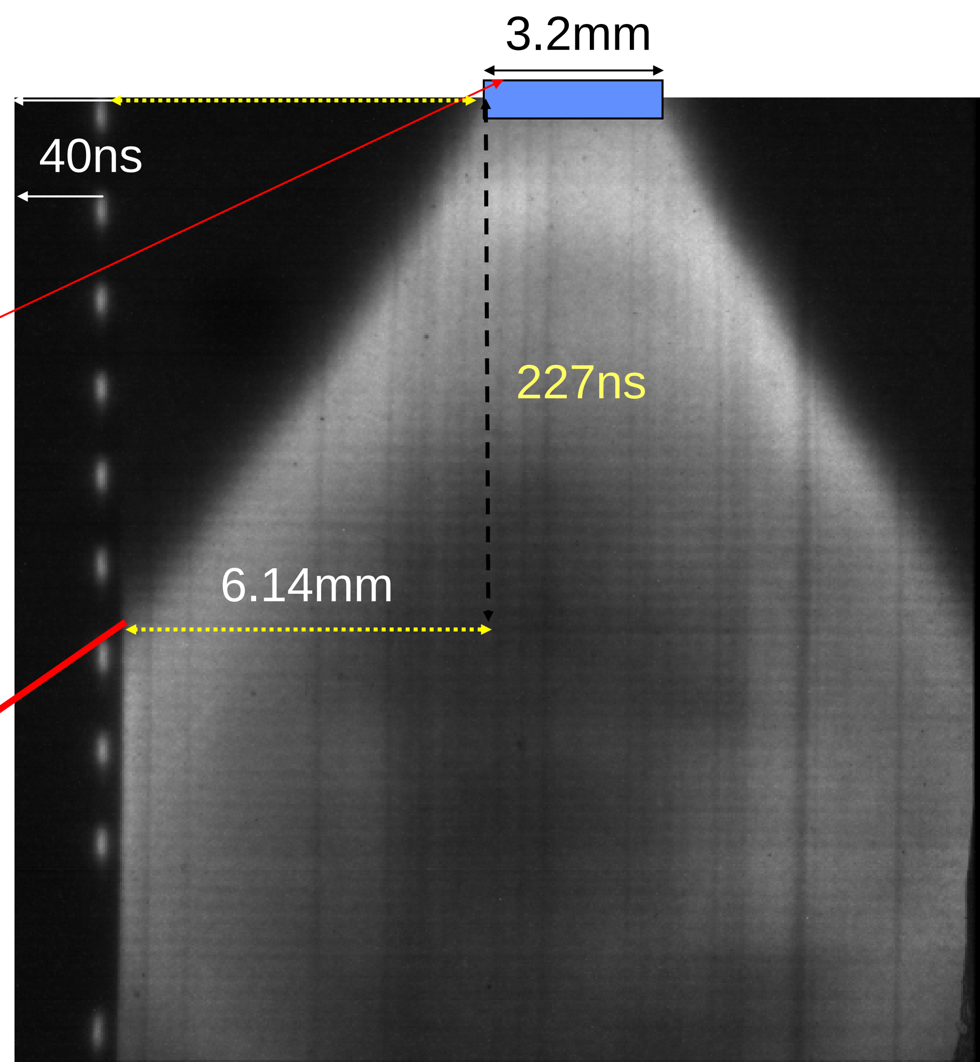
Streaked camera images also suggest ~ 2-4 cm/μs plasma expansion

Static pre-shot image

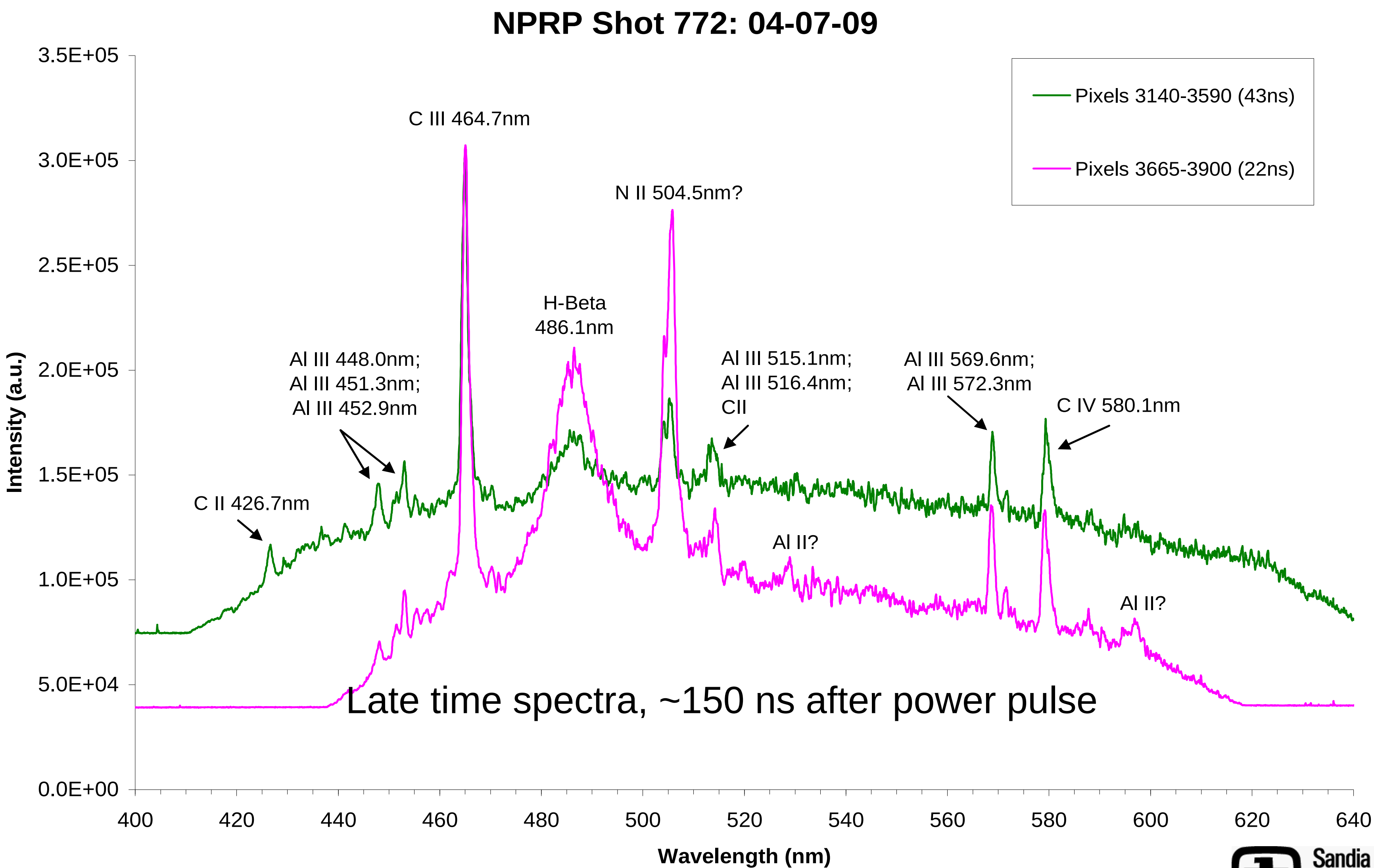


Streaked camera image



Implies electron temperatures of T_e ~ 4.5 eV for H plasma

Gated spectroscopy measure a predominant H-C plasma early in time and Al plasma later in time



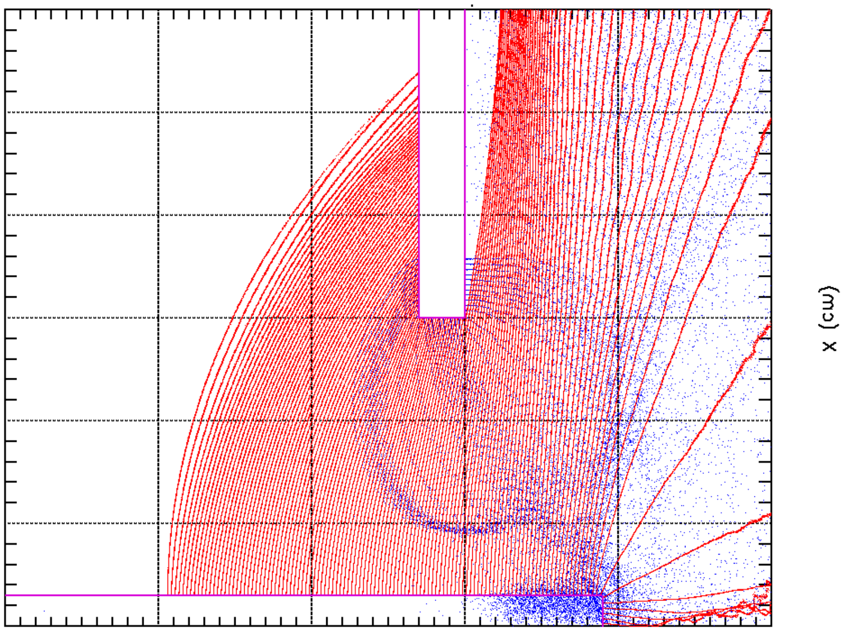
Coupled Monte-Carlo/Particle-in-cell* simulations demonstrate electron reflexing through the Rod tip

As ions (red) are emitted from the anode, the electrons (blue) pinch to the tip of the anode rod.

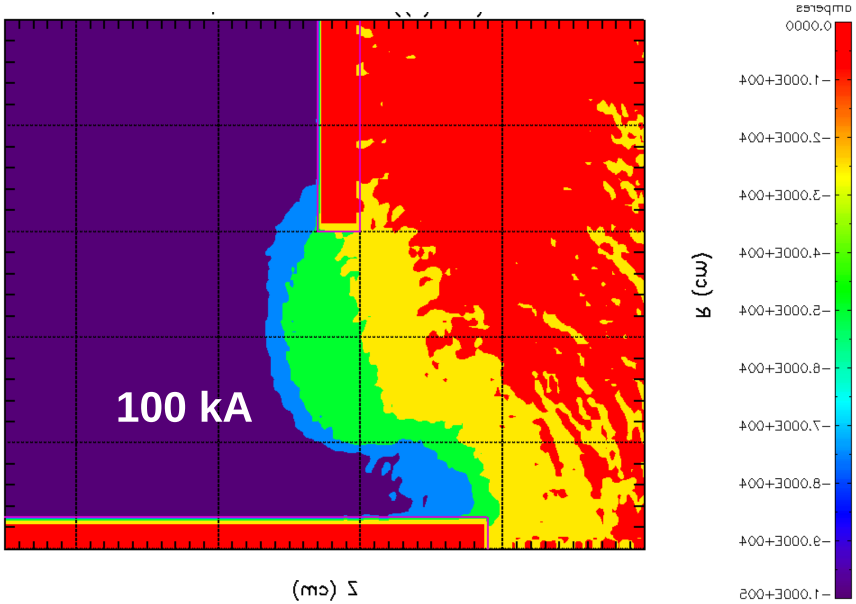
Electrons reflex through the range-thin anode

The majority of the electron current attaches to the tip of the anode

Particle configuration space



Current contours

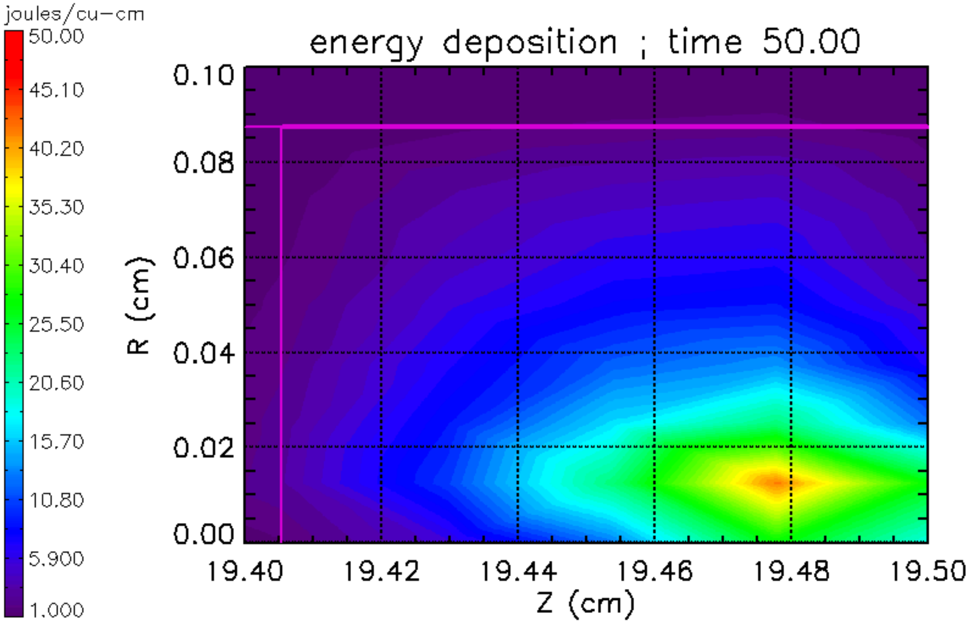


* D.V. Rose, D. R. Welch, B.V.Oliver et al. JAP, **91**, 3328 (2002)

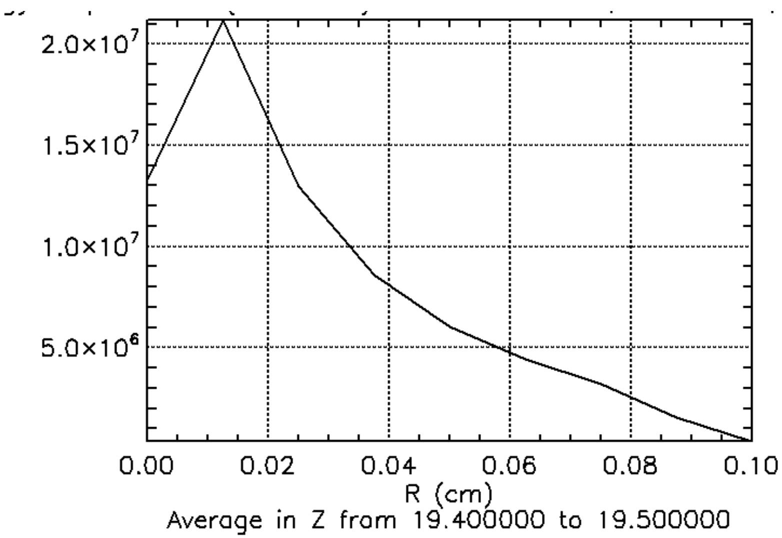
Simulations suggest up to > 10 MJ/cm³ Energy deposition in W plug

Assuming 1eV Temp per 3 eV deposition, 19 g/cm³ density, D=10⁷ J/cm³, T = 200 eV in the core region.

Translates to > 1 eV/nucleon



energy deposition in W target



Axially averaged energy deposition in W target

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Conclusions

The rod-pinch diode at 6-7 MeV endpoint energies is capable of coupling in excess of 2MJ/cm^3 onto large (10 mm^3, >0.1 g) targets.

Electron reflexing through the rod should make for a regions which are fairly uniform for diagnostic purposes.

Coupled Monte-Carlo PIC simulations suggest the possibility of creating energy densities in excess of 10 MJ/cm^3 near the axis of the pinch.

Time-resolved emission and absorption images of relevant materials (eg. Al or Au), in conjunction with x-ray diagnostics (hard and soft) will be used in the future to determine densities. Capability includes 250 micron spatial and <1ns temporal resolutions.

High resolution pyrometry/spectrometry will be used to determine blackbody surface temperatures which may be used to infer bulk material temperatures.