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PARAXIAL DIODE OPERATION ON RITS-6*

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Outline

I. Introduction
   A. RITS-6 accelerator
   B. Primary diagnostics
   C. Paraxial diode basic physics

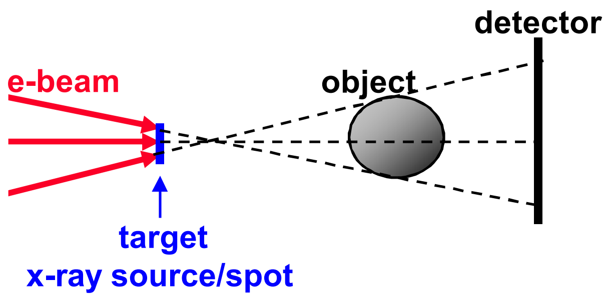
II. Experimental data

III. Comparison with simulations

IV. Conclusions

Pulsed electron-beam diodes are attractive flash x-ray radiography sources.

- **Primary Objective:** Focus an electron beam into a small spot, < 5 mm



Long term goal
2-mm spot, 1000+ Rads@1m

- We require extensive control of beam with **specific characteristics**:
  - Intense (~ 10 kA/cm^2)
  - Low emittance (~ 1 cm-rad)
  - High endpoint voltages (7 – 12 MV)

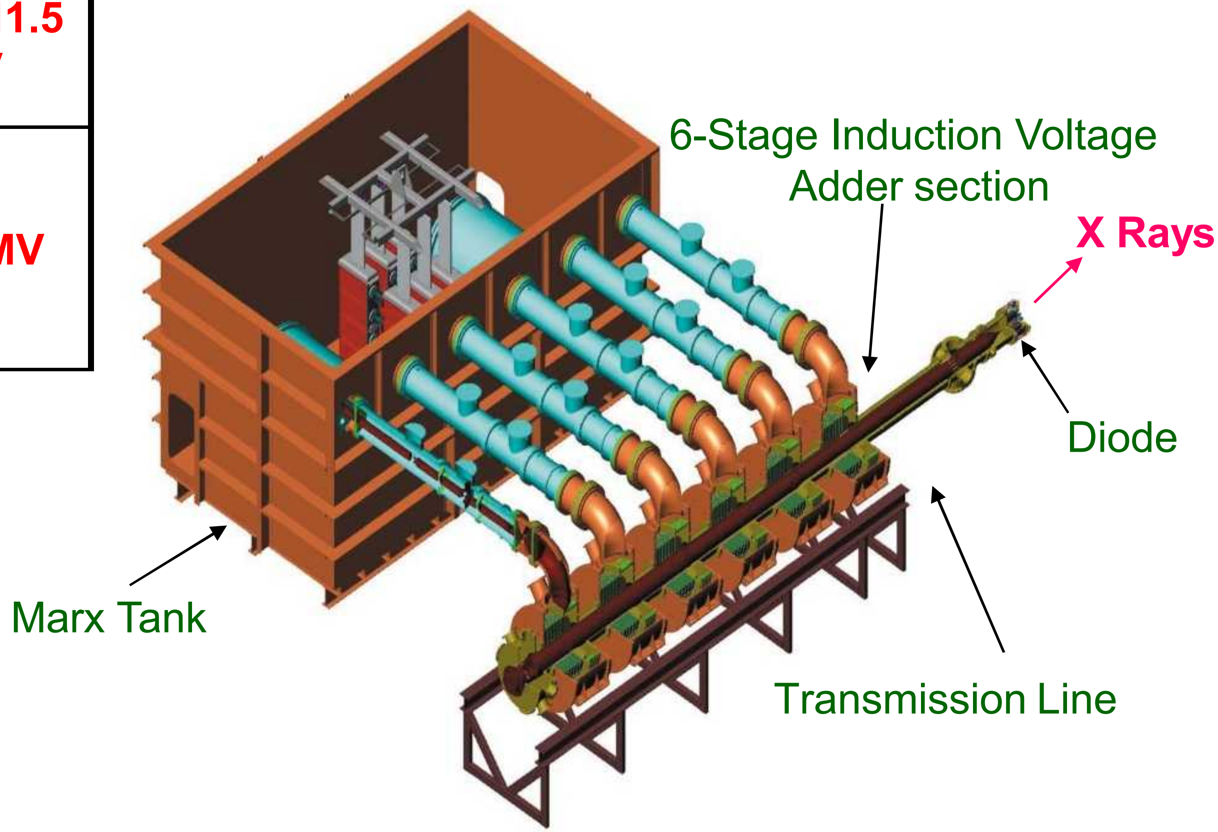
- **Time-integrated spot-size** is a key figure of merit for radiography.
  - *Spot size for paraxial diode > 5 mm → too large*

- We need to understand **time-dependent diode physics.**

The diode is fielded on Sandia's RITS-6 accelerator.

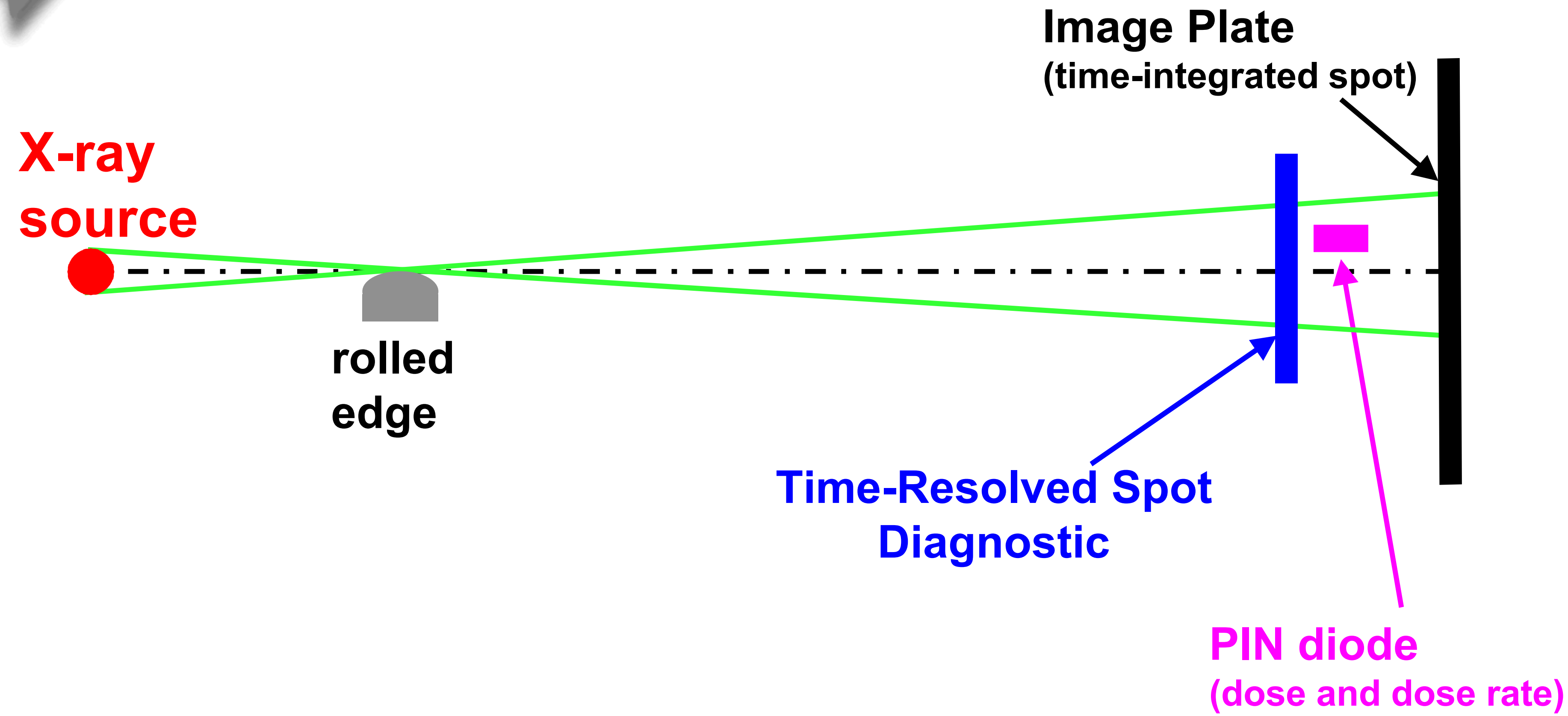
	Rise time	Voltage
Standard pulse	~ 15 ns	4.5 – 11.5 MV
Increased rise-time pulse	35 ns	9.0 MV

Radiographic Integrated Test Stand (RITS-6)



Pulse rise time affects beam formation and focusing.

Time-resolved measurements of the x-ray spot size are crucial for comparing with simulations.



Intercepting x rays with rolled edge yields information about source distribution.

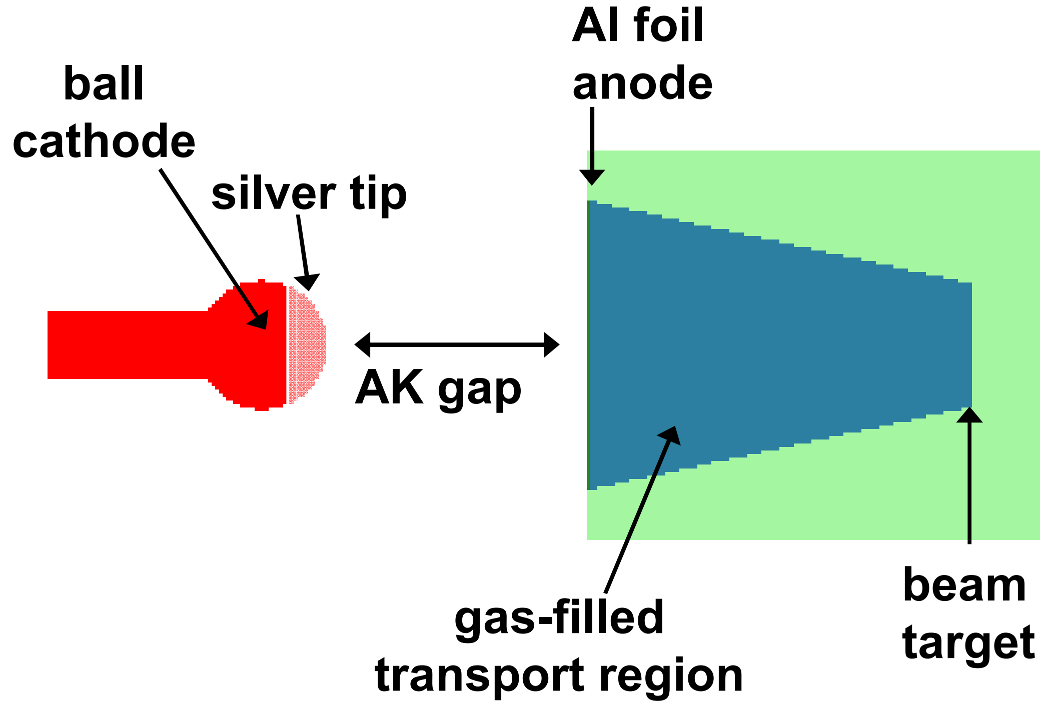
The paraxial diode utilizes a gas-filled transport cell to focus e-beam onto X-ray target.

Initial Paraxial Diode Model[1] includes the following diode physics.

Cathode
Low emittance
Limited emission area (silver tip)
Desire normal incidence at foil

AK gap
Space charge limited
Desire monopolar electron flow

Foil
Beam scatter, emittance growth



Gas-filled transport focusing cell
E-beam breaks down gas (~1 torr air)

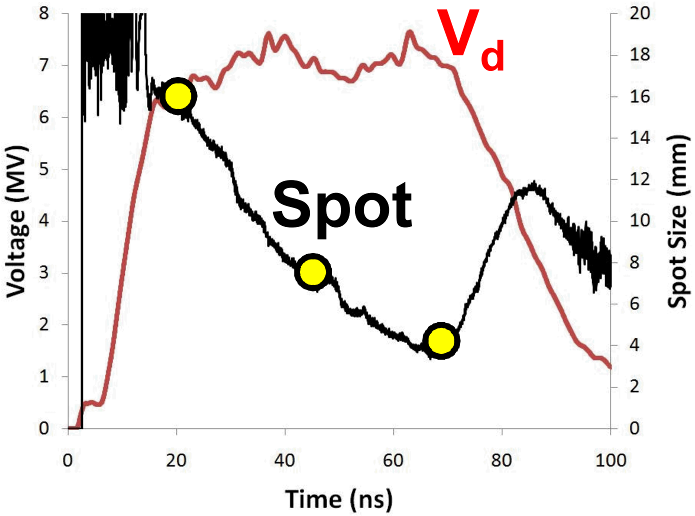
Simulations utilize IPROP gas-breakdown model in hybrid PIC/fluid code LSP[2]

[1] B.V. Oliver, *et al.*, IEEE Trans. Plasma Sci., 33, 704 (2005).
[2] LSP is a software product developed by ATK Mission Research, Albuquerque, NM 87110.

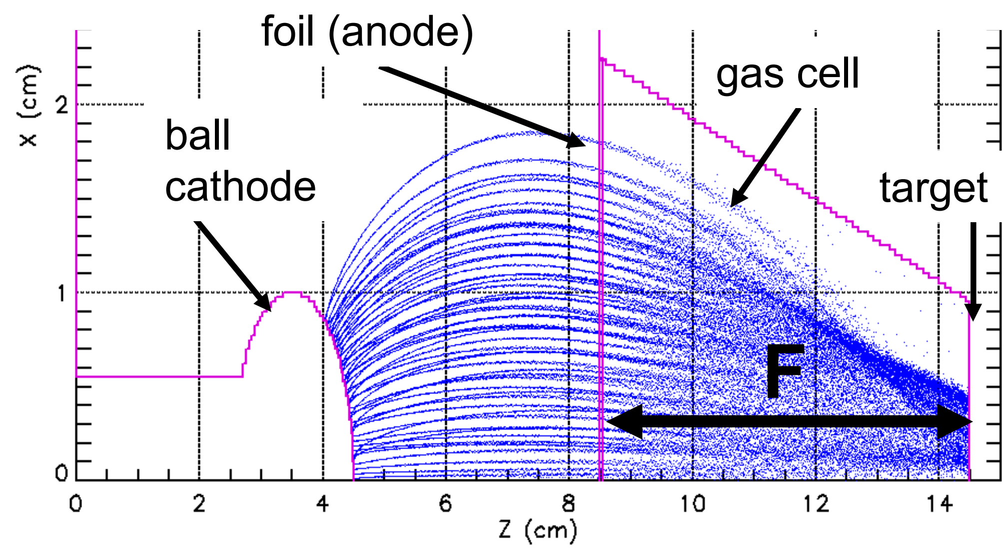
Initial Paraxial Diode Model

Beam focal position sweeps during pulse *aka "beam sweep".*

Simulation Predictions



Particle Plot from Lsp Simulation



Beam breaks down gas (~ 1 torr air), forming plasma

- Finite decay of plasma resistivity
- I_{net} increases
- Focal position (F) depends on I_{net}

$$I_{net} = I_b + I_{plasma\ return}$$

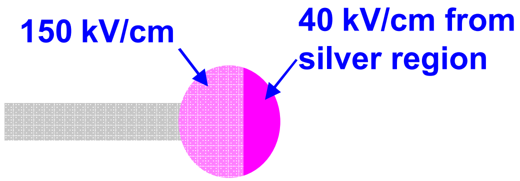
$$F \cong \frac{R}{2}\left(\frac{\pi I_A}{I_{net}}\right)^{1/2}$$

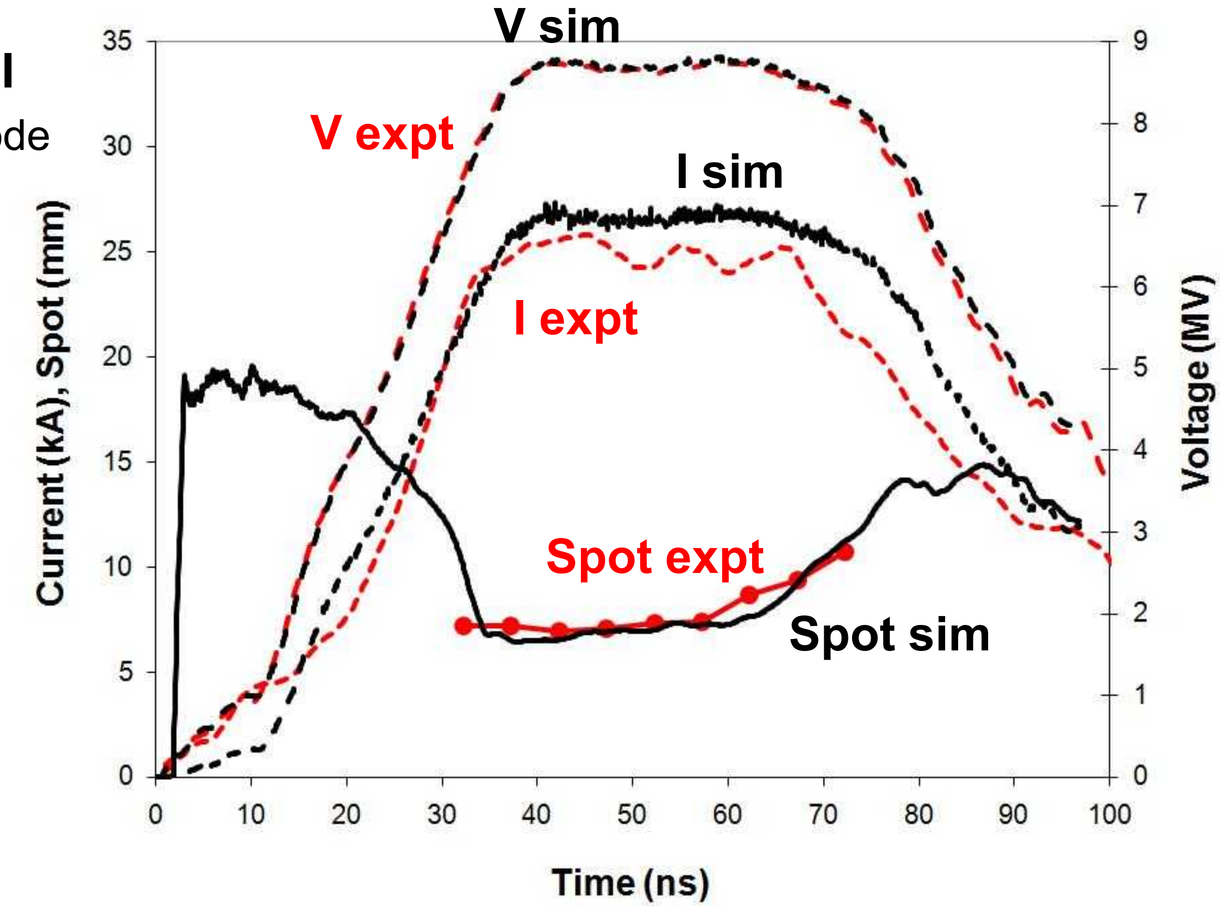
Primary contribution to large spot is due to beam sweep.

For slower rise times, spot behavior is well modeled using IPROP gas-breakdown model.

Modification to initial model

Allow emission from **entire** cathode

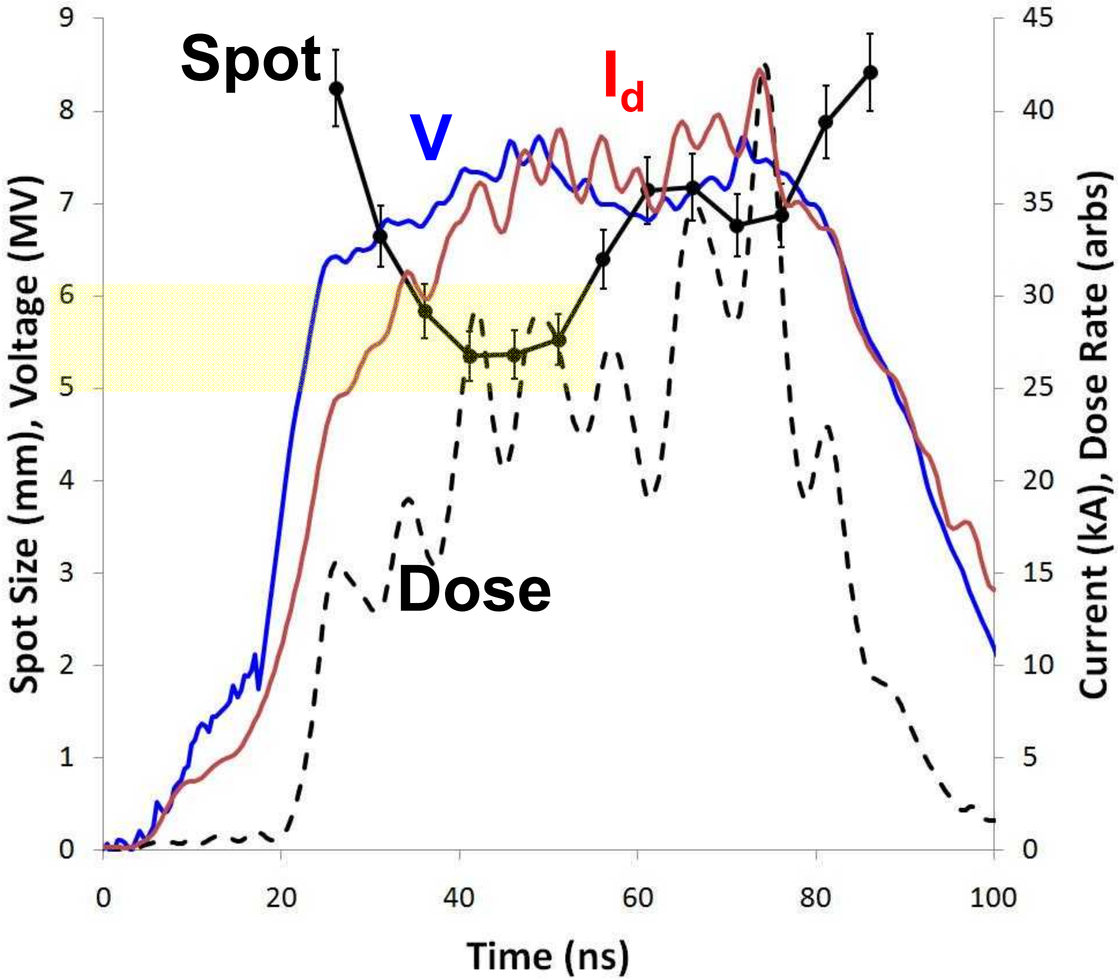




Though model is validated, emission from entire cathode ball is undesirable.

Cathode emission is more complex for faster rise-time pulse.

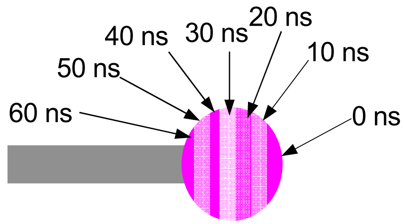
- Experiments with standard RITS pulse shape
  - ~ 15-ns rise-time pulse
  - Range of voltages studied: 4.5 -11.5 MV
- Observations:
  - Spots > 6 mm
  - Emission area increases gradually
  - Minimum spot ~ 5.3 cm



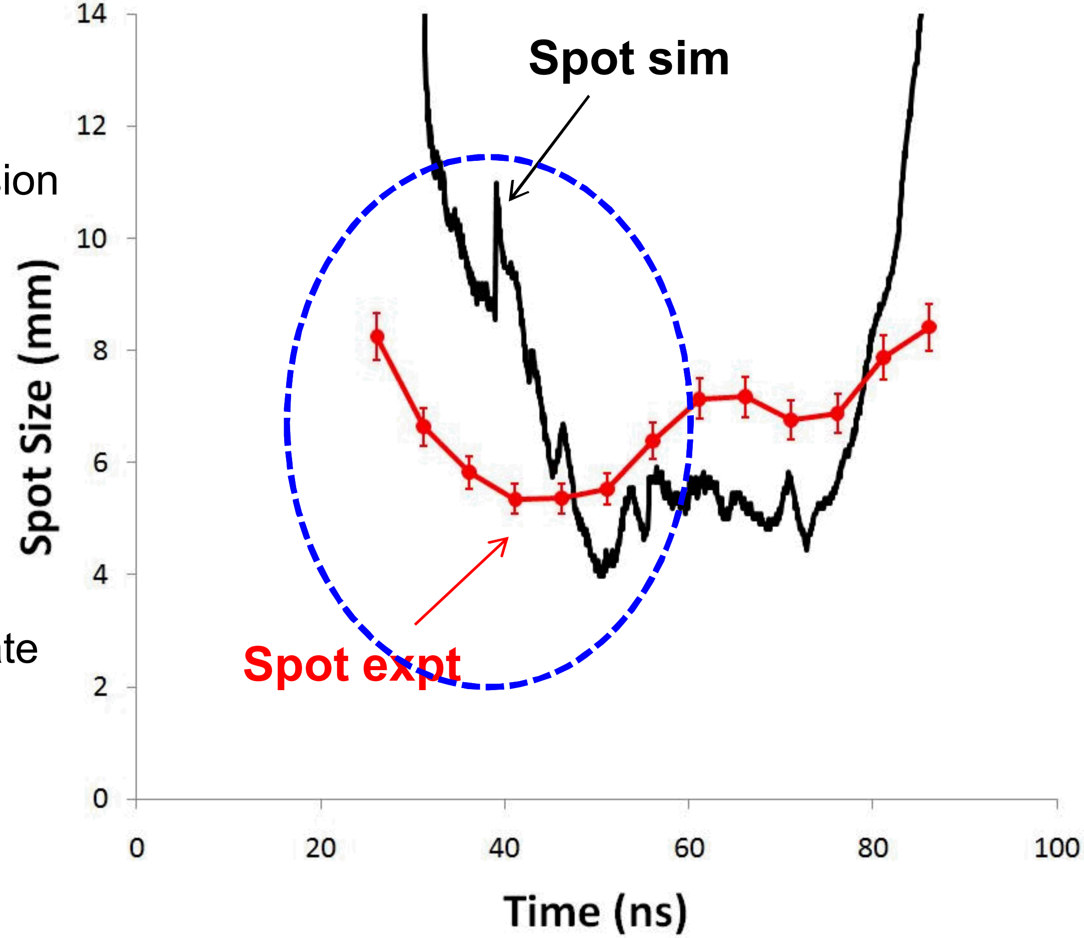
Images of cathode emission and beam profile indicate non-uniform emission.

Because of poor cathode emission characteristics, data do not compare with simulations.

- **Another modification to Initial Paraxial Diode Model**
  - Time-dependent cathode emission



- **Simulations vs. Data**
  - I and V compare well
  - Time-resolved spot and dose rate **do not** compare well



For shorter rise times, beam formation and gas-breakdown dynamics do not compare with ANY model.

Future work needs to first improve cathode emission characteristics.

- Time-integrated spot size for the paraxial diode is too large, > 5 mm, for future radiographic applications.

- New measurements of time-resolved spot size have been obtained on RITS-6 for different pulse rise times and peak voltages (4.5 – 11.5 MV).

  - **Long RITS-6 rise time, ~ 35 ns:**

    Spot behavior is consistent with gas breakdown model.

    Beam emits from larger area of cathode.

  - **Standard RITS-6 rise time, ~ 15 ns:**

    Spot sizes: 6-10 mm.

    So far, beam focusing is inconsistent with any modifications to initial paraxial diode model.

    Beam formation in vacuum is likely worse than desired

- Once beam is optimized, the next step is to mitigate beam sweep by utilizing a pre-ionized plasma in lieu of gas [3].

[3] D. R. Welch, *et al.*, Phys. Plasmas, **11**, 751 (2004).

Abstract

The paraxial diode is a relativistic electron-beam-driven diode that is being investigated as a potential x-
ray source for flash radiography. The diode typically employs a gas-filled transport cell (~1 torr air) t
o focus the beam onto a high-atomic-number target to generate x-rays. Two key objectives are to p
roduce a small x-ray spot size (< 5 mm) and high forward-directed dose (> 600 Rads@1m). Ultimat
ely, it appears the limitation in the diode is its large spot size (> 5 mm). Previous particle-in-cell (PI
C) simulations have shown that the primary limitation in spot size is due to beam sweep in which th
e finite decay of the plasma return current inside the gas cell causes the beam focal location to swe
ep axially away from the target during the timescale of the pulse. This leads to an increased time-in
tegrated spot size [1]. Paraxial diode experiments have been performed on the RITS-6 pulsed pow
er accelerator at Sandia National Laboratories at voltages 4.5 – 10.5 MV and with different rise-tim
es 5 - 30 ns. Measurements of dose, dose rate, time-integrated (and time-resolved) spot size, and
current are reported. These results are compared with the previous and newer models developed u
sing the hybrid PIC/fluid code LSP. Simulations consider temporal cathode emission evolution, ano
de ion emission, and kinetic and fluid gas-breakdown models for the range of operating parameters
on RITS-6. The potential for this diode to meet future requirements is evaluated.

1. B.V. Oliver, D. Short, G. Cooper, J. McLean and J. O'Malley, "Paraxial gas-cell focusing of relativistic electron beams for radiography", IEEE Trans. Plasma Sci., 33, 704 (2005).

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