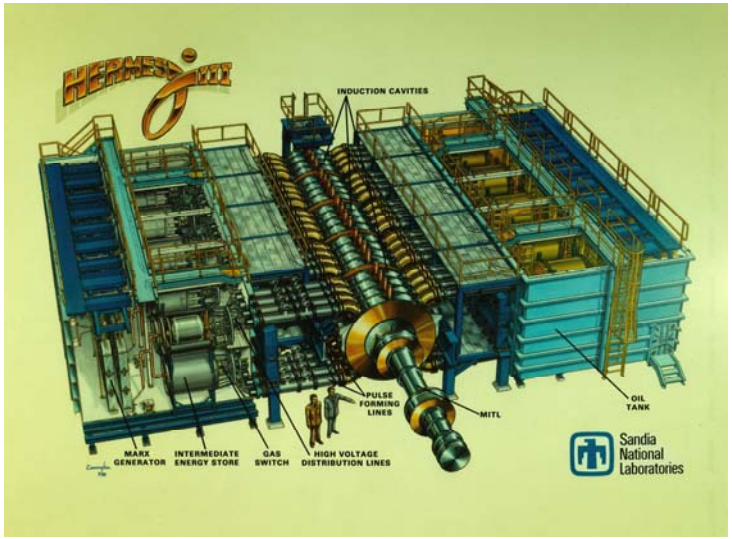
SAND2009-3810C

# Generation of Ion Beams in Positive Polarity on HERMES III Operated in a Long-Pulse Mode*

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**17th International Pulsed Power Conference (PPC 2009)**
**Washington, DC**
**June 28 - July 2, 2009**

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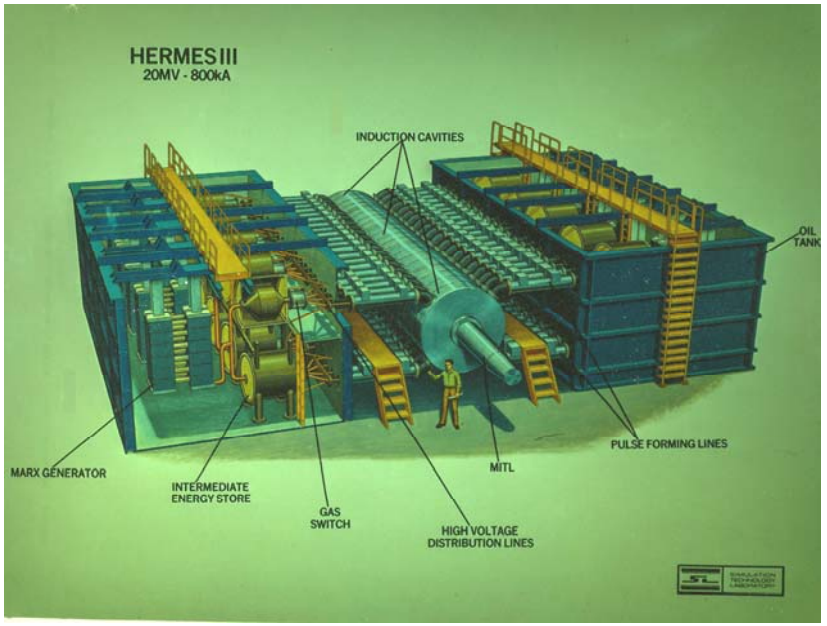
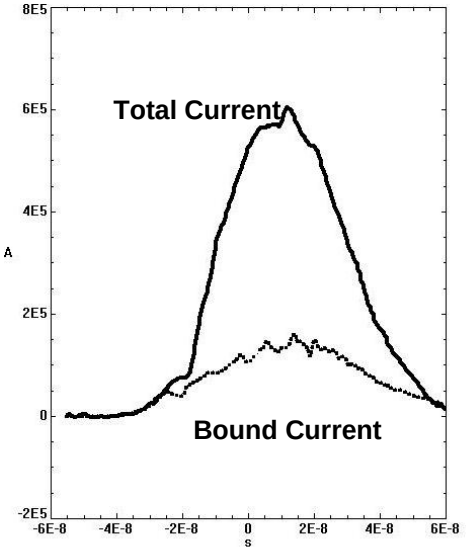
# Hermes III is the Test Bed for these experiments

- Hermes III - Inductive Voltage Adder architecture, 20 MV 700 kA 40 ns when operated in negative polarity normal pulse
- 20-stage IVA: significant vacuum current (Right) (Total minus Bound)
- Desired: Positive polarity (for beam extraction) w/o Cavity switching. Restricts to ~ 6 MV, produces 'layered flow' down MITL
- Desired: Simple ion diode geometry capable of small spot-size focusing. Chose Pinch Reflex Diode (PRD - NRL) to match to MITL flow
- NRL: Design of PRD, LSP modeling of current flow
- SNL: Experimental fielding, Diagnostic analysis
  - Bdot and Shunt current monitors
  - Rogowski net ion current monitor (gas cell)
  - Faraday cups
  - Nuclear Activation/Witness plates
- Power flow and diode characterization expected to be major issues

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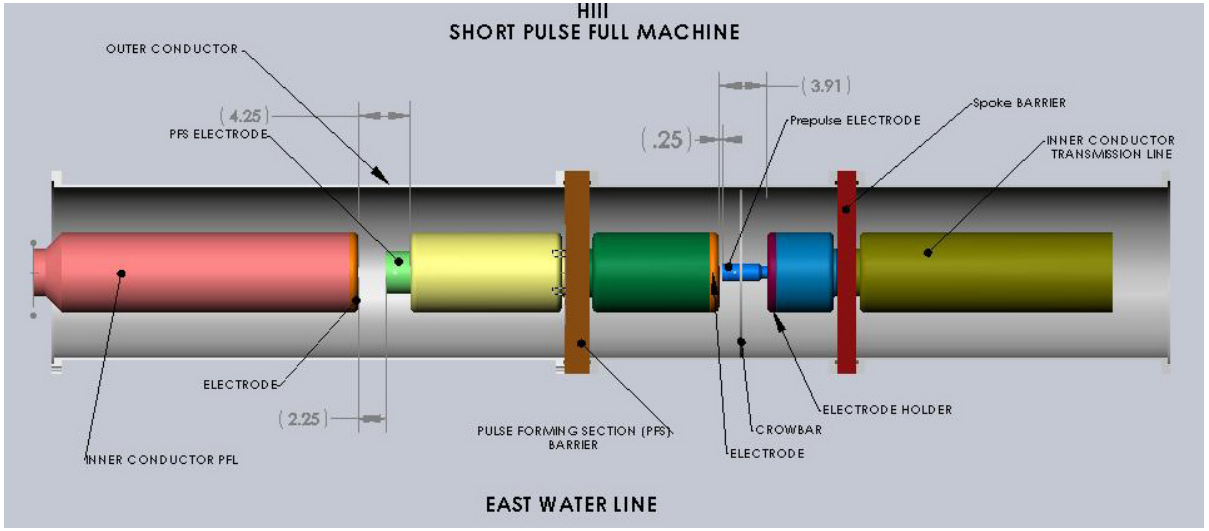
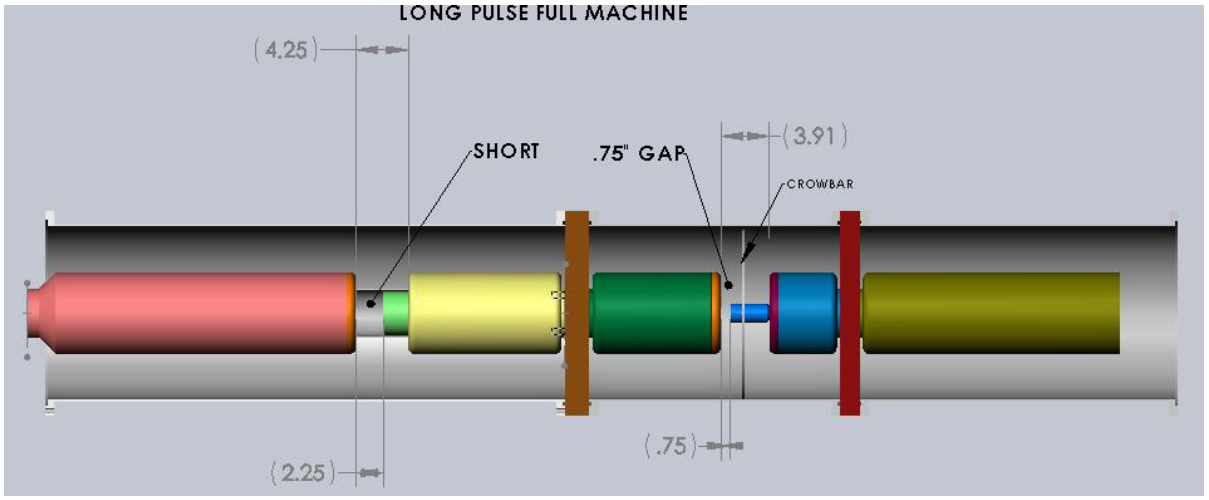
# Hermes III Long-Pulse Operation

## doubles power pulse width




- **(TOP) Short-Pulse Mode: 2.25 inch gap upstream of PFS Barrier, 0.25 inch self-break gap downstream**
- **(BOTTOM) Long-Pulse Mode: upstream gap shorted, 0.25 increases to 0.75 inch. Doubles capacitance and pulsewidth, halves output voltage for same charge**

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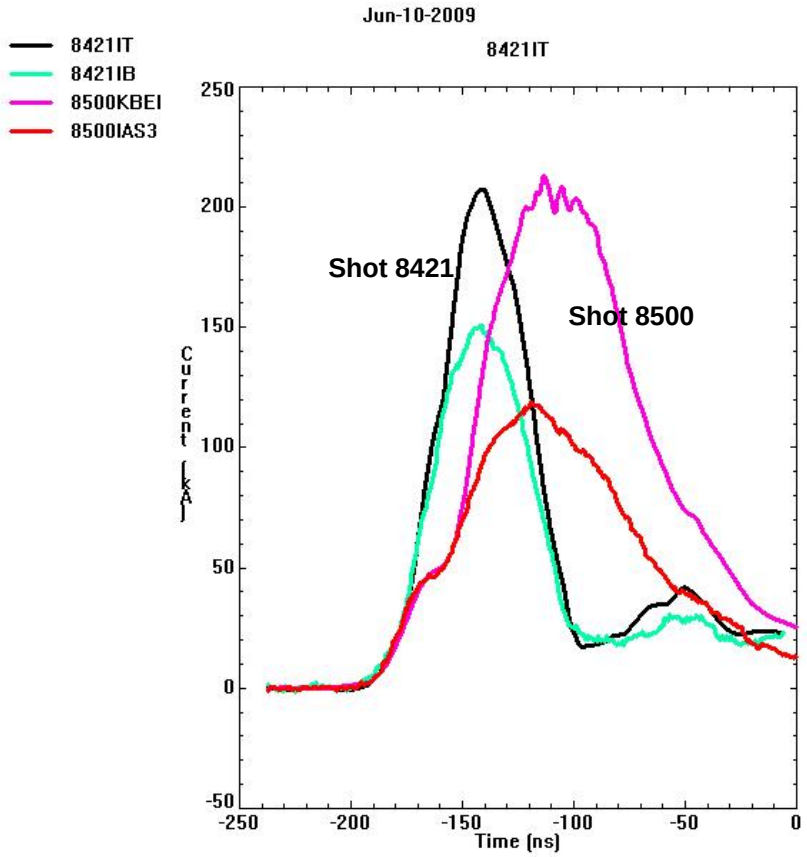
# Hermes III Long-Pulse Operation

# doubles power pulse width

- (RIGHT) Shot 8421 (Black-Turquoise) Total-Bound currents for short-pulse mode
- (Magenta-Red) Shot 8500 Long-pulse currents
- Slightly more vacuum flow on 8500

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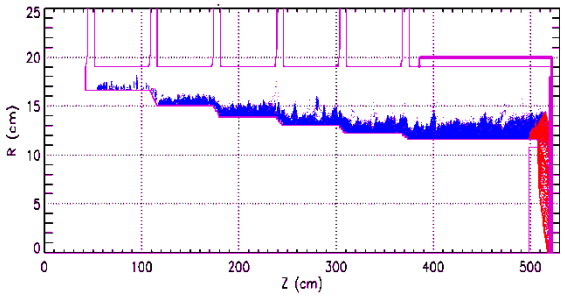
# Hermes Power Flow simulated with 5-stage LSP model. Demonstrates significant current flow difference +/- polarity

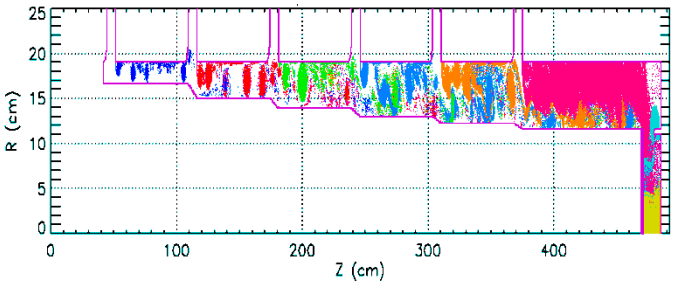
- Forward-going voltage waveform injected into each adder stage
- Pinch-reflex operates better in low-impedance, matching load-limited operating mode for best power flow
- Ion Efficiency predicted at ~ 20% since load still runs > 10 ohms
- Comparison with experiments at given A-K gap shows significant decrease in measured vs predicted current. Must multiply by 0.65 to get good agreement. Source of this implied loss is not known. Mercury (NRL), also IVA design, does not show this loss.

Ion Diode

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.




**NEGATIVE polarity**




**POSITIVE polarity**

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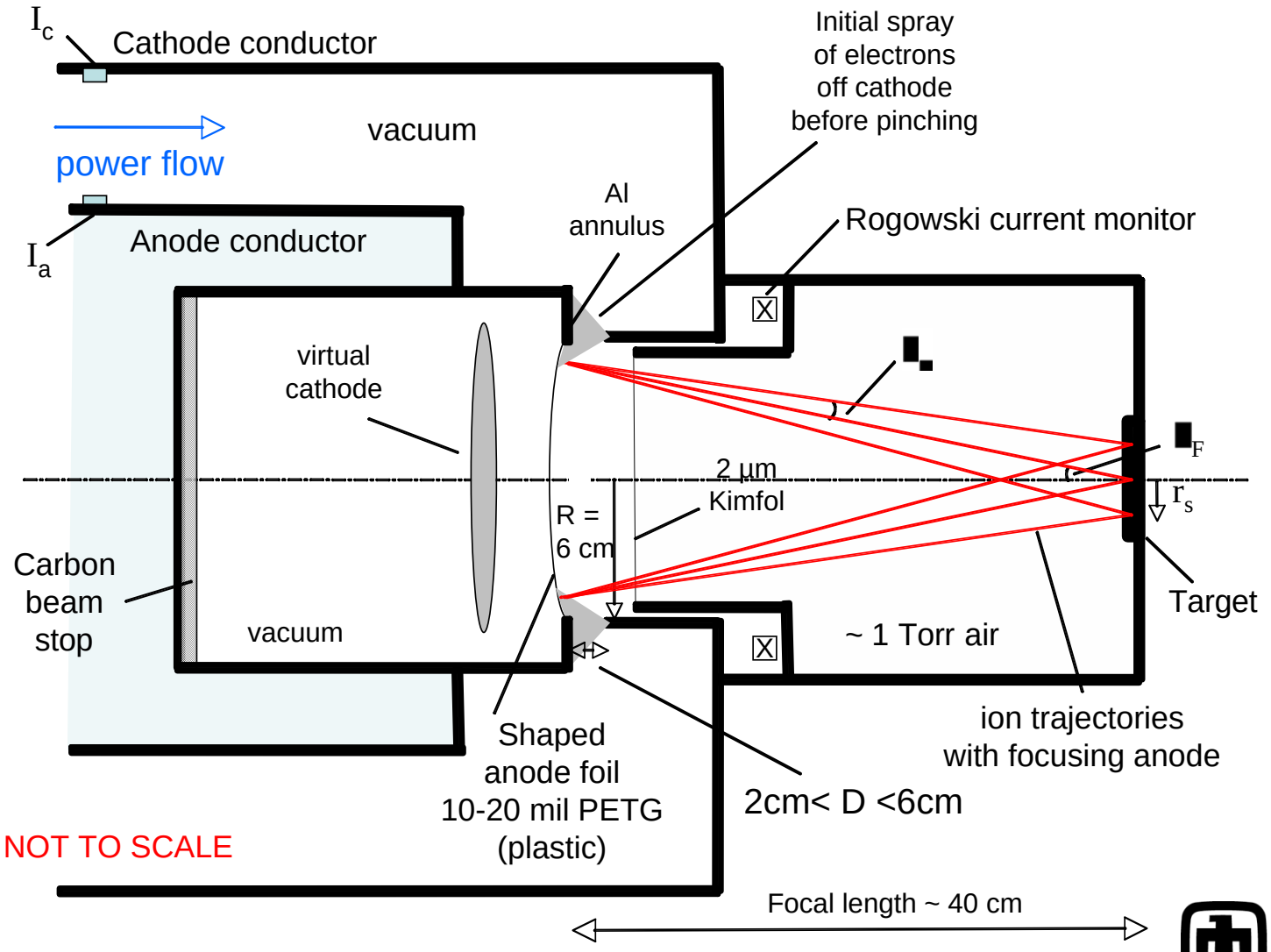
# Schematic view, initial 6 cm diode:
# Focusing geometry, gas cell, Rogowski for ion current

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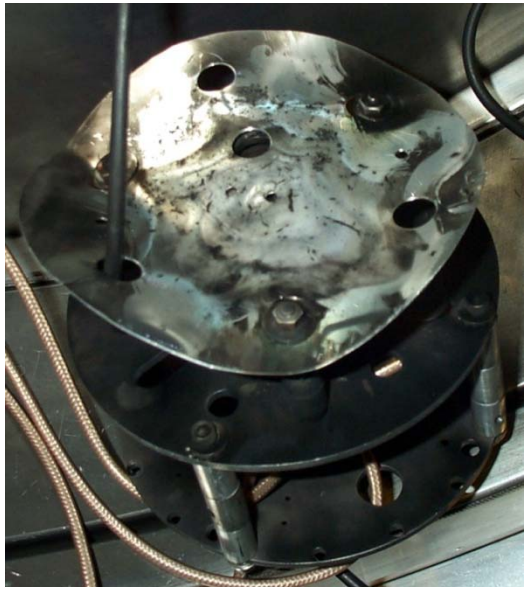
# Beam diagnostics:
# Rogowski, Fcups, Witness Plates, Nuclear Activation

- (TOP Photo): Array of proton activation samples in 'Peppershakers' set back from gas cell entrance (above)
- (BOTTOM LEFT photo): Peppershakers and Fcups mounted on stalks facing beam (top)
- (BOTTOM RIGHT photo): Al 1 mm 'Everbright' witness plate with thru holes for Fcups/peppershakers behind
- Activation diagnostics consistent with Fcup delivery at 1 μC/cm$^2$, but ambiguous with energy
- Proton Activation Reactions:
  - LiF with 2 MeV threshold for $^{7}Li(p,n)^{7}Be$
  - Ti with 4 MeV threshold for $^{47}Ti(p,n)^{47}V$
  - Ti with 5 MeV threshold for $^{48}Ti(p,n)^{48}V$

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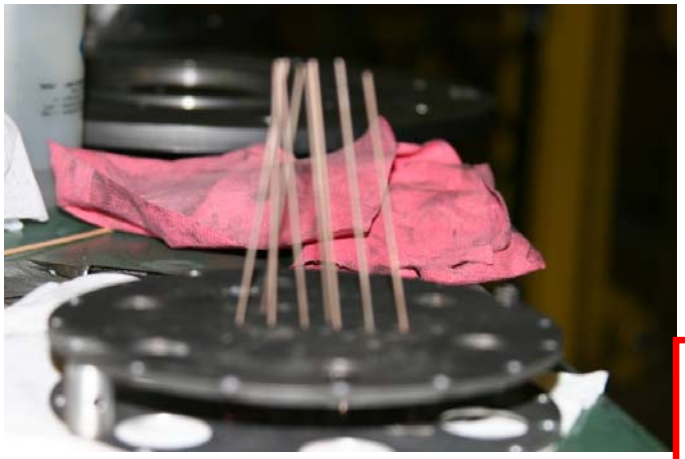
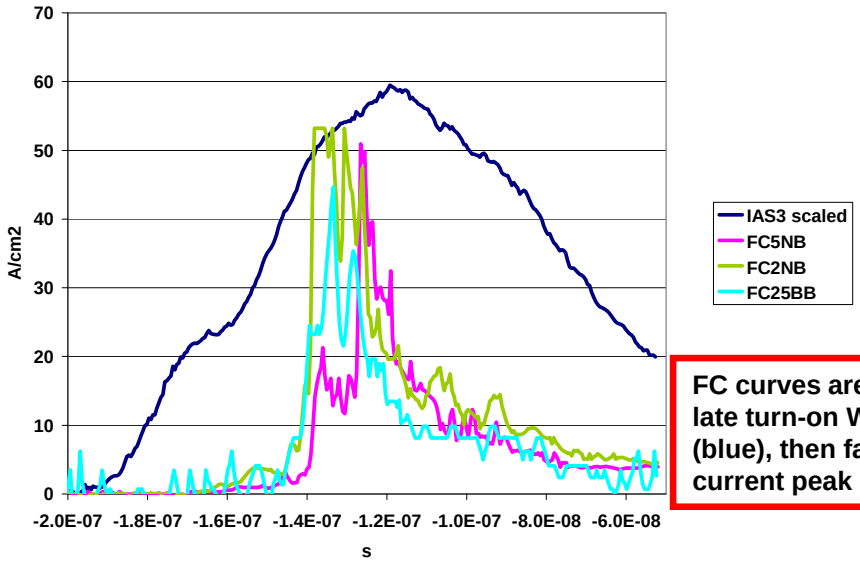
# Initial short-pulse 6 cm results: MITL current loss, De-focusing beam, ambiguous net ion current



Ray-traces of shadowbox spots show beam divergence from source (top) instead of focusing




FC curves are Fcups: note late turn-on WRT current (blue), then fall before current peak

- (LEFT Photo): From witness plate, infer diverging beam from just beyond anode
- (LEFT plot): Ion turn-on delay ($I_{total}$ to FCup break) substantial at 40 ns
- Fcup peaks, falls before $I_{total}$ peak: suggests source-limited behavior (these data taken with long-pulse)
- Maximum Fcup signals (max ~ 250 A/cm$^2$) inconsistent with ~ 40 kA Rogowski
- Rogowski at ~ 40 kA independent of A-K gap
- Interpretation: insufficient energy deposition in anode material to turn on. Can increase energy density by going to smaller-diameter anode.

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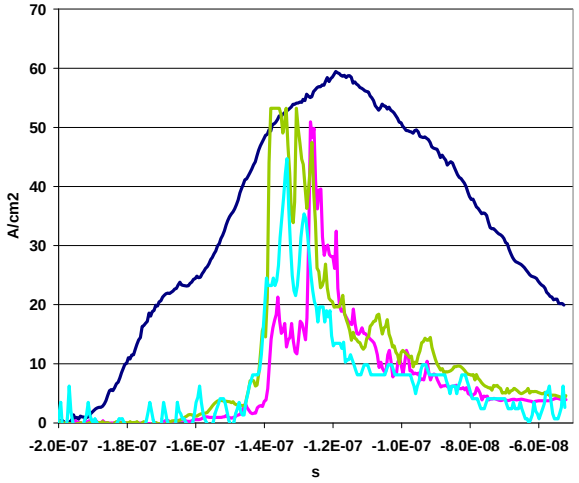
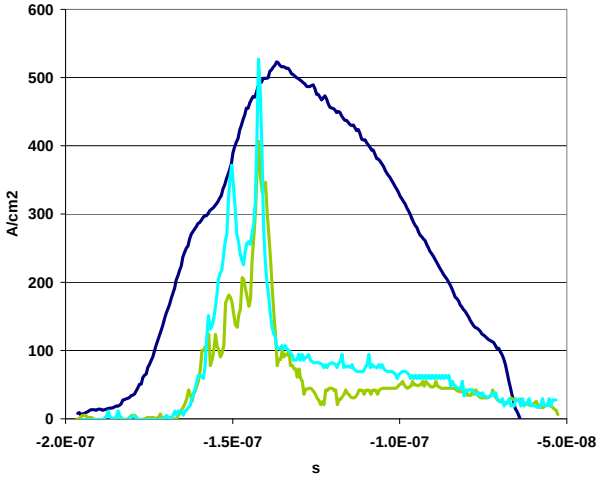
# Decrease in Anode size leads to faster beam turn-on









- (TOP Plot/Photo): 12 cm diameter anode
- (BOTTOM Plot/Photo): 6.35 cm diameter anode
- Delay time from Fcups drops from 40 to 20 ns
- Fcup maximum increases from 250 A/cm2 to 1 kA/cm$^2$, BUT only at beam center
- Source-limited behavior still evident
- Inferred total charge increases from ~ 1 μC/cm$^2$ to _ μC/cm$^2$ , still below _ μC/cm$^2$ goal

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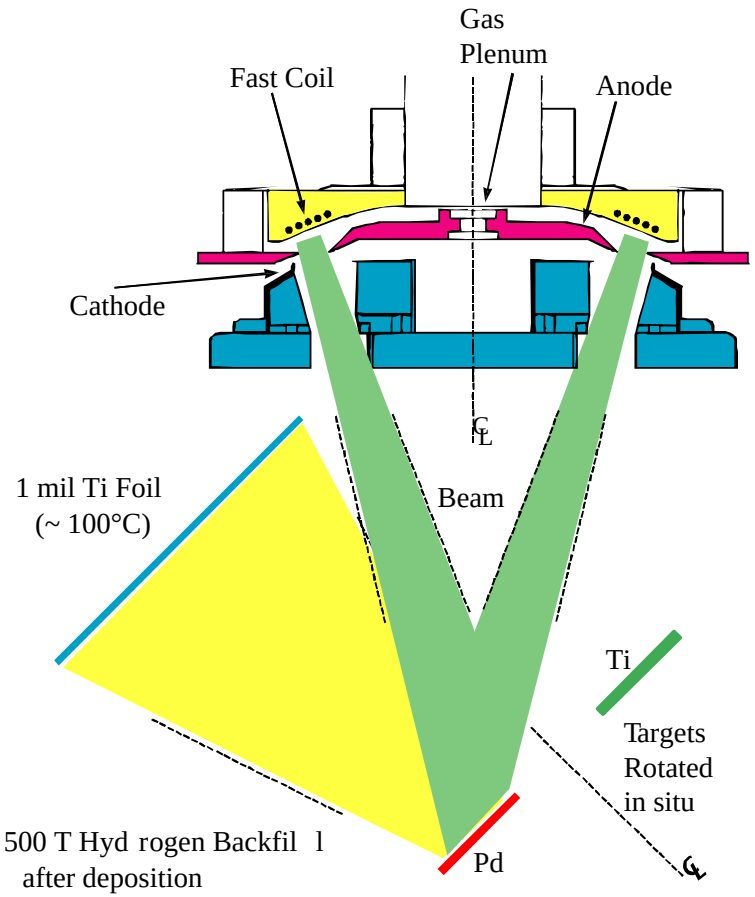
# A new Ti/Pd ion source is made by In-situ deposition from sequential targets using RHEPP-1




- **Prescription adapted from FZ Karlsruhe work***
- **An intense Nitrogen ion beam from RHEPP-1 is used to ablate alternating Ti and Pd targets**
- **First, ~ 150 nm (13 shots) Ti thickness deposited on 1 mil Ti foil substrate**
- **Then ~ 70 nm Pd (7 shots) Pd deposited over Ti to protect from oxidation**
- **Foil is kept heated at ~ 100° C during deposition**
- **Chamber then backfilled with ~ 500 T Hydrogen for 40 mins. H diffuses readily thru Pd, is absorbed by Ti.**
- **Separate heating pulser in German work not used here**
- *** H. Bluhm *et al*, *Formation of a Homogeneous Hydrogen Plasma Layer for the Production of Terawatt Ion Beams*, IEEE Trans. Plasma Sci. 21, 560 (1993).**

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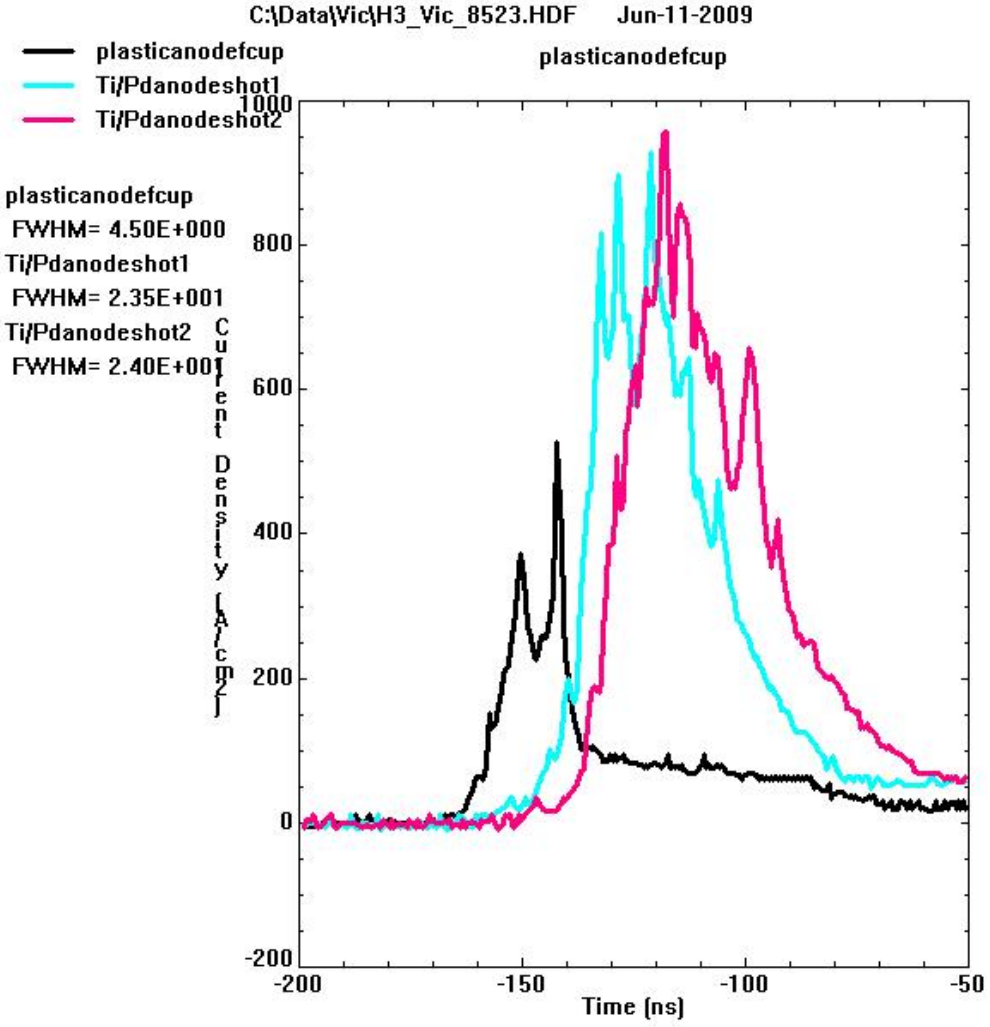
# Fcups show beam from Ti/Pd source produces more uniform beam, higher peak current, full power pulse width




- (RED-WHITE) Fcups from two Ti/Pd shots peak at 900-1000 A/cm$^2$ with full power pulse width
- (BLUE) PETG (plastic) anode turns on sooner, peaks lower and sooner
- Suspect Ti/Pd turn-on delay due to slower electron pinch - no plastic to flash over.
- A plastic collar around inner Ti/Pd foil may work better
- Charge delivery now up to _ μC/cm$^2$
- BUT, Fcup 2 cm from center only shows ~300 A/cm$^2$. Indication of 'pencil' ion beam on center, consistent with previous high-impedance PRD behavior (e.g. AURORA)
- Narrowness of beam propagation channel makes beam transport study difficult.

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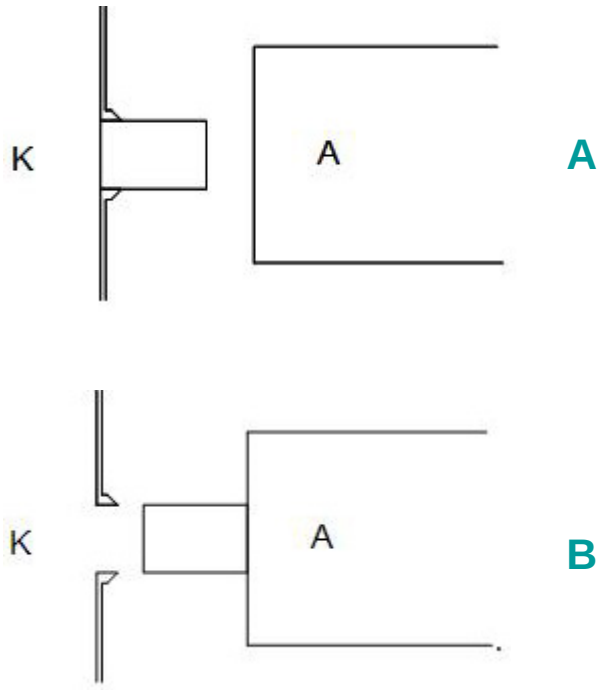
# Where we go from here




- Add SNL peppershakers and Fcups to Rogowski on Mercury ion diode experiments to cross-compare with Hermes data
- Field Ion Pinhole Camera with radiochromic film stack to measure local ion energy and total dose
- Implement Revised diode geometry (LEFT): A [OLD] to B [NEW]
  - Allows better access to full ion beam
  - Reduces energy losses to anode surround
- Confirm initial promise of enhanced ion current with Ti/Pd anode source
- Revised geometry B should help improve the slower turn-on of Ti/Pd source

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