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Voss Scientific

Development of the Hermes III Accelerator as a Short-Pulse Radiation Source*

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Abstract

The HERMES III accelerator[1,2] at Sandia National Laboratories generates a 19-MV, 700-kA electron beam which is being developed as a short pulse bremsstrahlung radiation source. A gas-filled drift cell has been employed previously to efficiently transport and temporally control the electron beam.[3] This concept is being revisited in order to generate a radiation pulse with a rise-time and width that is significantly reduced from the injected electron beam. Progress in the diode and gas cell development are presented.

1. J. A. Halbleib, T. W. L. Sanford and J. W. Poukey, “Radiation environment of HERMES III”, IEEE Trans. Nucl. Sci. 35, 1988, pp. 1282-1287.
2. J. J. Ramirez, *et a*l., “Performance of the HERMES-III gamma ray simulator”, in Proc. of the 7th International Pulsed Power Conference, vol. 1, 1989, pp. 26.
3. T. W. L. Sanford, “High-power electron-beam transport in long gas cells from 10-3 to 103 Torr nitrogen”, Phys. Plasmas 2, 1995, pp. 2539-2546.

Hermes III Accelerator

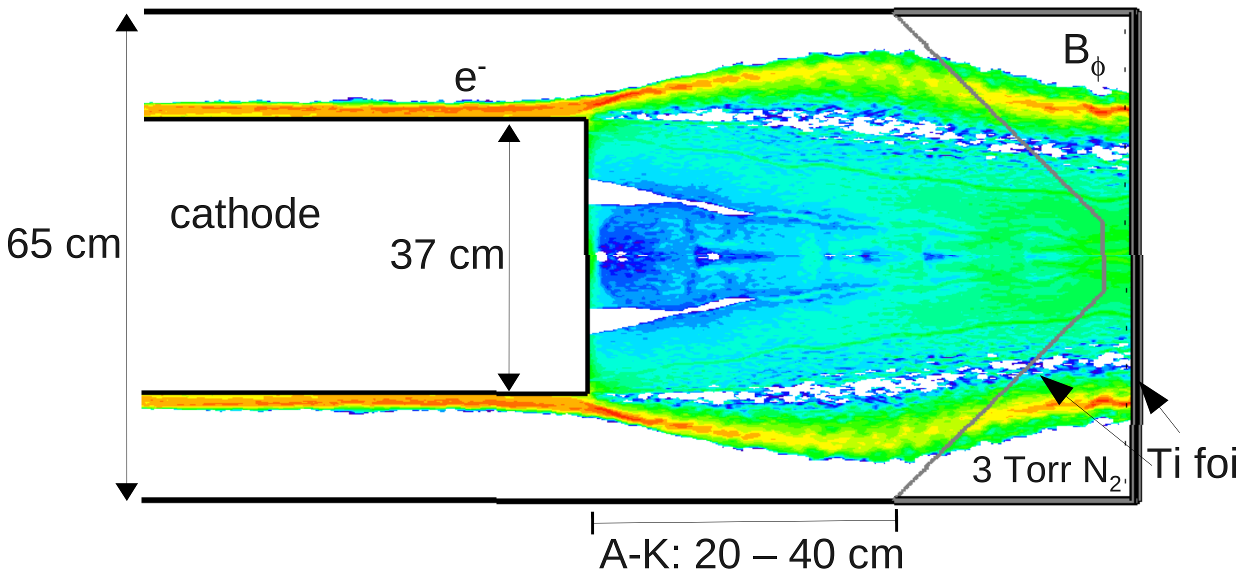
Hermes III operating parameters:
• IVA pulsed power accelerator
• 19 MeV, 700 kA electron beam
• 34±2 ns FWHM, 12 ns rise time (10 – 90%)

The goal:
A radiation pulse with 1 ns pulse rise and FWHM.

LSP simulations are used to aid in diode selection and design of the beam transport and pulse shortening technique.

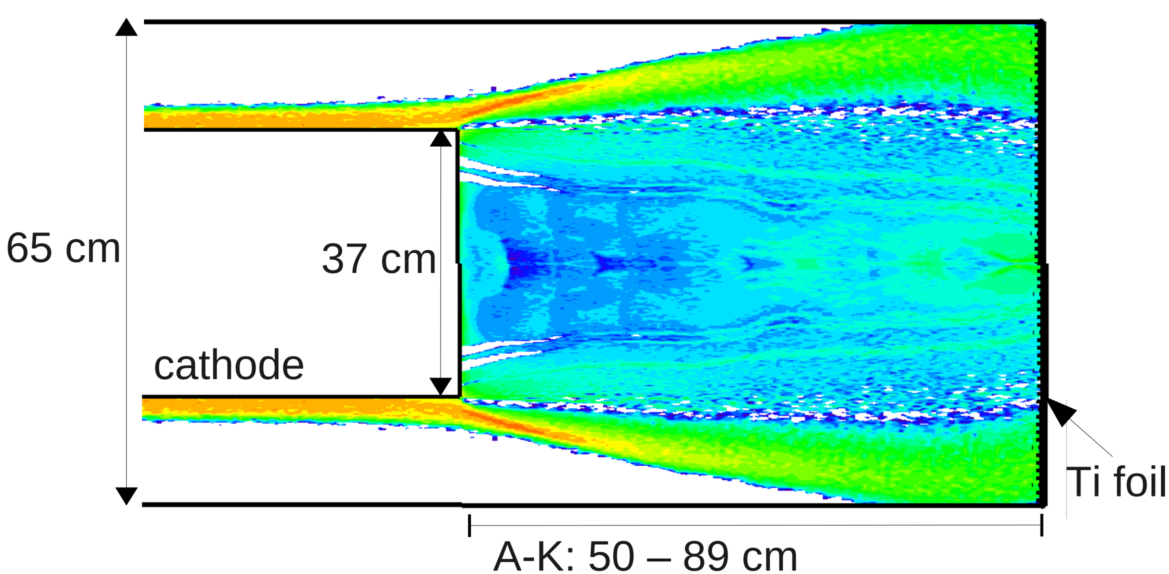
Diodes Fielded on Hermes III

compound-lens diode



- fielded in mid 90s
- a low-pressure gas cell with an external B_ϕ controls the beam angle of incidence
- the A-K gap controls the beam radius

solid-cathode diode



- fielded in 90s and this year
- the A-K gap is adjusted to control the beam angle of incidence and loss to the anode wall

Pulse compression via gas-cell transport

Electron beam transport in reduced-pressure gas cells has been employed to compress the pulse width and shorten the rise time. Previous work on Hermes III characterized the transport efficiency in N_2 gas from 10^{-3} to ~10^3 Torr.[1] The transport efficiency is a function of the rate of gas ionization, its conductivity, and any instabilities which arise. Two pressure regimes are considered for long-range transport:

1 – 100 mTorr

- semicollisionless ion focused regime[2]
- The leading edge of the pulse erodes while ionizing the gas.
- Plasma electrons are ejected from the beam path.
- The trailing portion of the pulse propagates in the residual ion space charge.
- At the conducting target, the self-repulsive electric field is canceled and the beam pinches.

1 – 100 Torr

- resistive collision dominated regime[3]
- The beam rapidly ionizes the gas with some front-edge erosion.
- Higher gas densities cause more significant collisional energy loss.
- Betatron oscillations occur.
- Instabilities may erode trailing portion of the pulse.
- previously used for long-range propagation rather than pulse compression

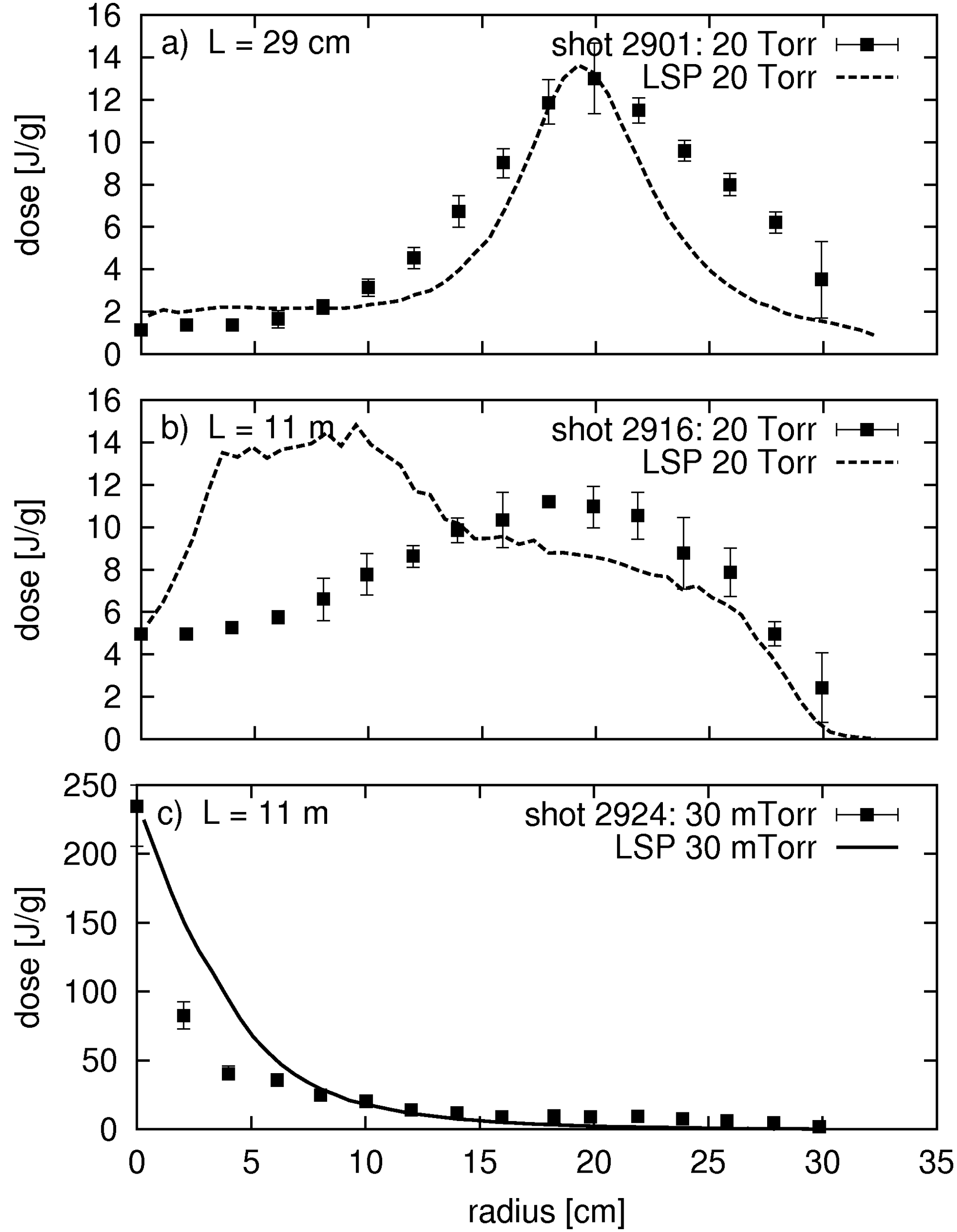
1. T. W. L. Sanford, Phys. Plasmas **2**, 2539 (1995).
2. H.L. Buchanan, Phys. Fluids **30**, 221 (1987).
3. R.B. Milller, *An Introduction to the Physics of Intense Charged Particle Beams* (Plenum, New York, 1982).

Hermes III compound-lens diode experiments: Benchmarking the code against data

Radiation dose radial profile

- A 50-cm AK diode is used to generate a 20-cm radius injected beam.
- 10 – 100 mTorr gas is modeled kinetically.
- 10 – 500 Torr gas is treated using a bulk conductivity model, with ionization and recombination rates from the LSP corona model.

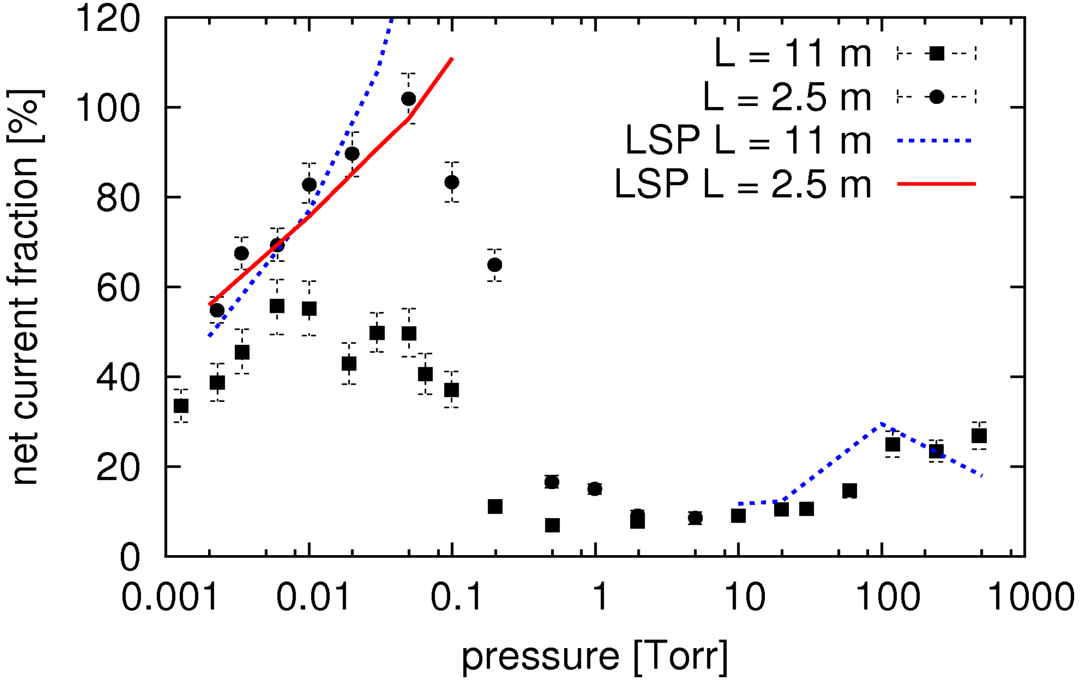
From Fig. 3, Phys. Plasmas **2** 2539 (1995)

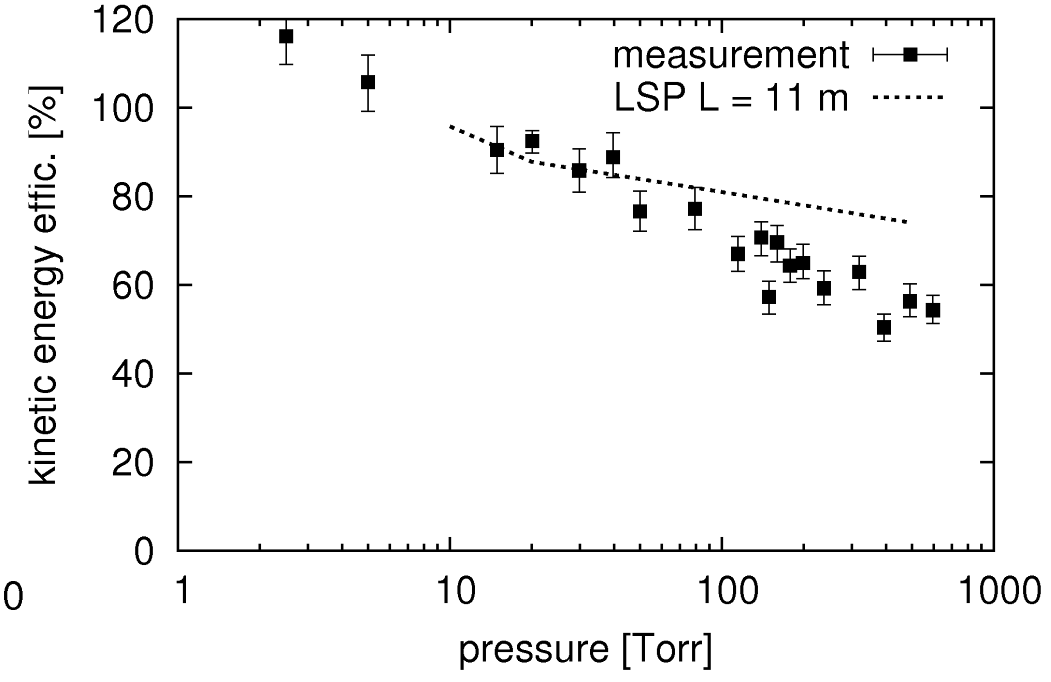


Hermes III compound-lens diode experiments: Benchmarking the code against data

Transport efficiency

from Figs. 8 and 12, Phys. Plasmas **2** 2539 (1995)





Proposed technique for pulse compression

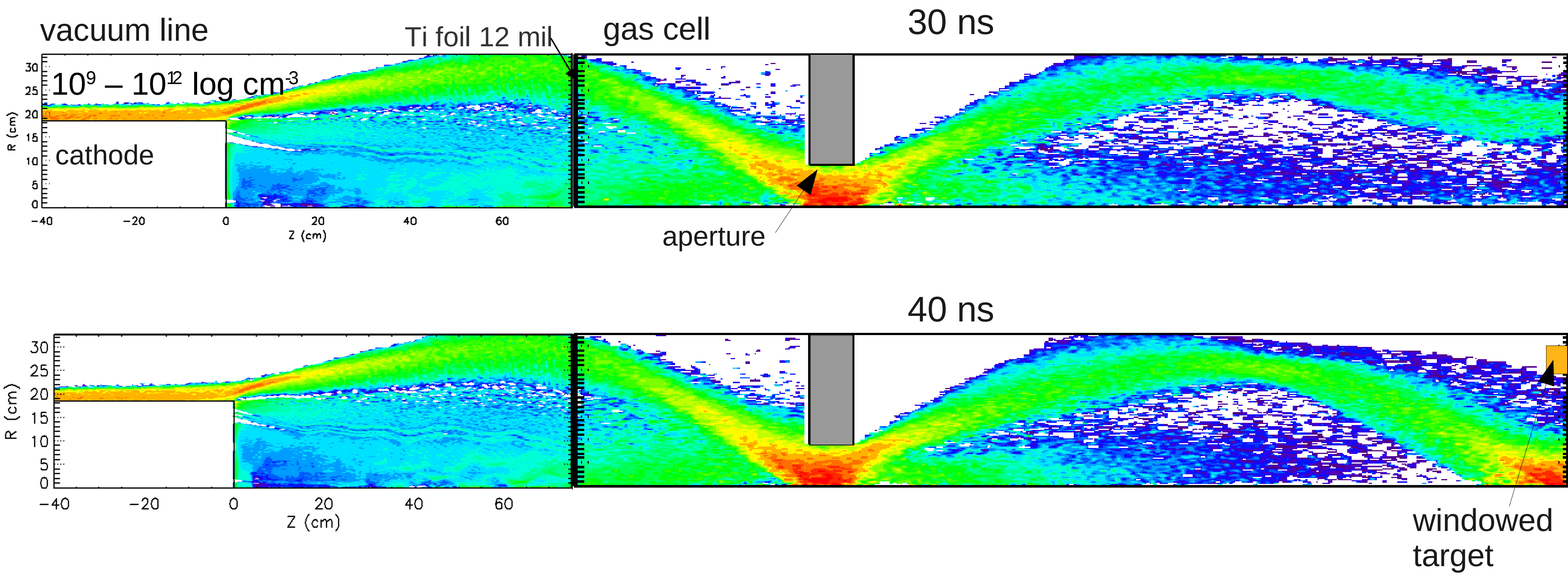
Previous technique:

- Recent experiments for 10 – 100 mTorr N_2 in a 6.2-m cell measured large oscillations in the radiation pulse.
- Simulations showed beam oscillations across the diode foil due to cyclic virtual cathode formation and discharge.
- The result was less efficient energy transport and no pulse compression.
- In addition, the beam at low pressures does not have a parameter with a significant temporal dependence which could be used to trim the pulse.

Proposed technique:

- At 10 – 500 Torr, the beam undergoes betatron oscillations in the cell.
- The wavelength varies in time as the gas ionizes, the beam front erodes, and the beam tail propagates through a more conductive channel. Taking advantage of this temporal behavior,
  1) Place an aperture at the $\lambda_\beta/4$ position to block the beam until it sweeps down to focus. This sharpens the pulse rise.
  2) Choose the gas pressure such that after this aperture, λ_β continues to decrease and the beam continues to sweep radially and axially.
  3) Window the target to capture only a portion of the radially sweeping beam. This shortens the FWHM.
- Use the easiest diode possible to achieve a large-radius, annular beam.

Proposed technique for pulse compression

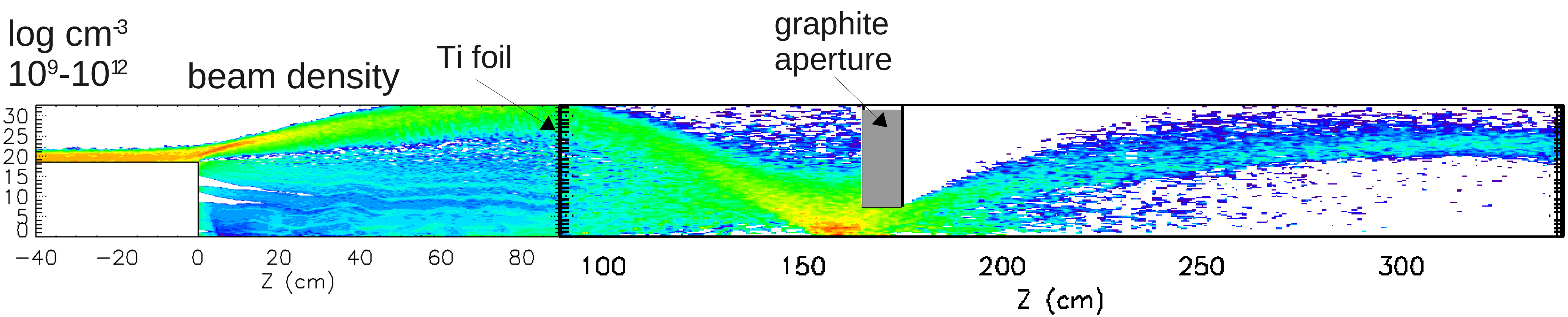


Cross sections of simulation geometry

Simulation of solid-cathode diode experiment from Feb. 2010

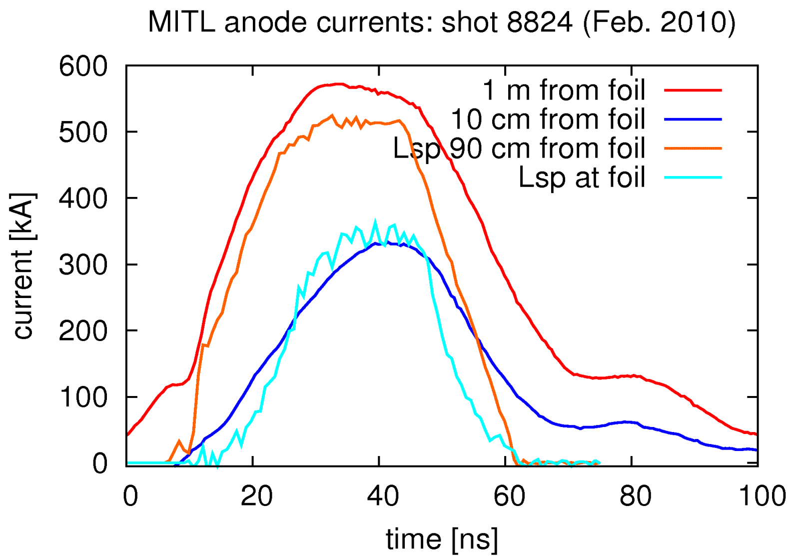
14.5 MV injected pulse
89-cm A-K gap

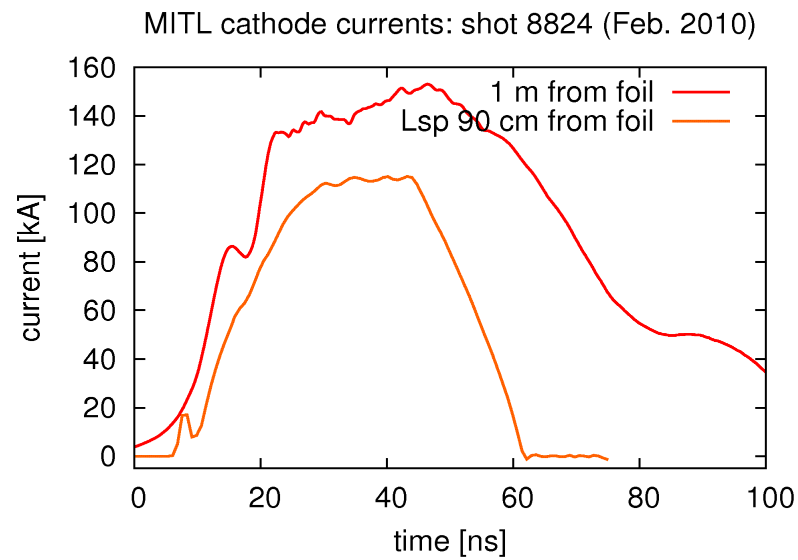
250 cm long gas cell at 100 Torr
Graphite beam block with 6-in diameter opening (7.6-cm radius)
The beam block is 76 cm downstream from the foil.



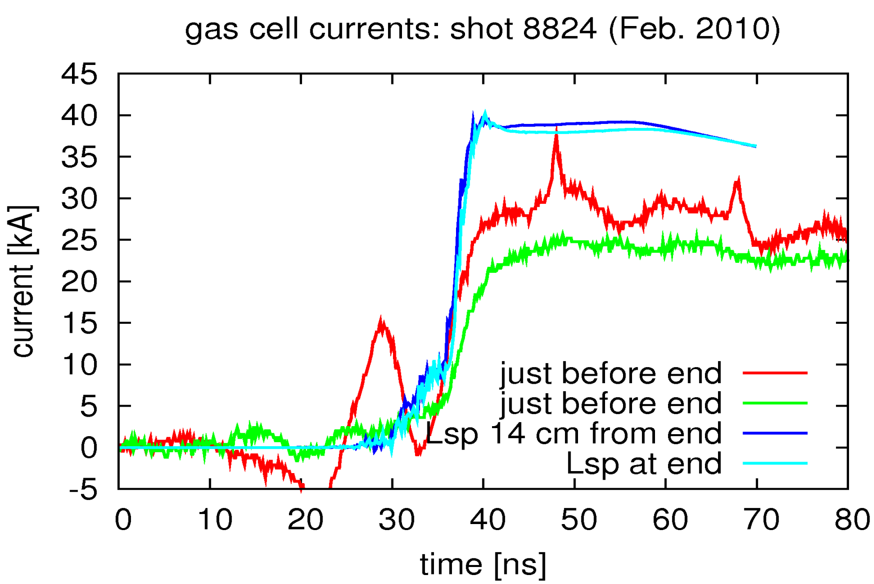
Note the beam block is not at $\lambda/4$.

Simulation of solid-cathode diode experiment from Feb. 2010





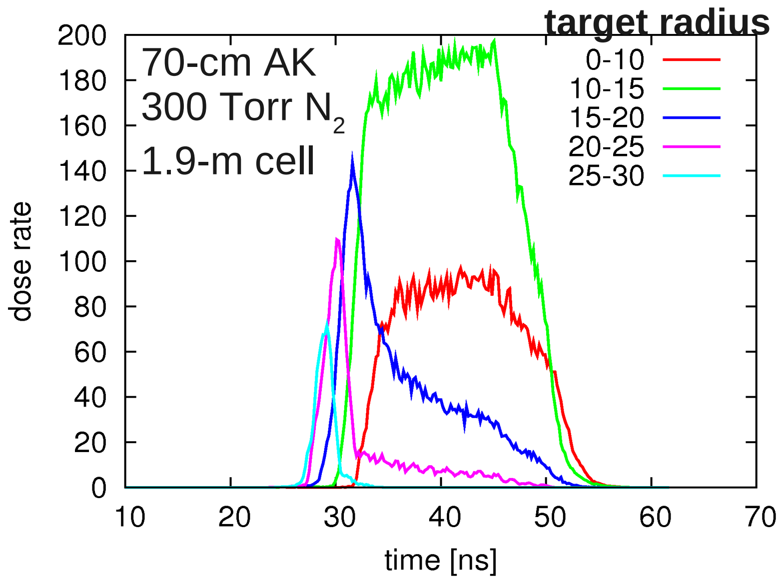
The measured anode currents are larger upstream than simulation, but more beam is lost to the anode wall before the foil. Still trying to understand disagreements in cathode current.

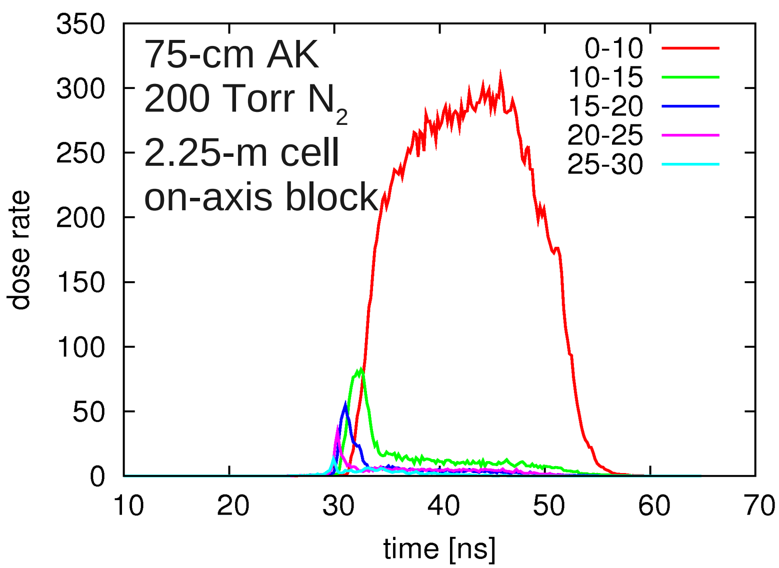


Simulated I_{net} in gas cell is high. We know that I_{net} and kinetic energy efficiencies are high from compound-lens comparisons. Possible additional causes include model parameters, incorrect beam injection angle, beam asymmetries and 3D instabilities.

Example pulse output with target window

Pulse-compression optimization is performed using the Hermes III accelerator energy from the last series of shots (14.5 MV). Two examples of radially windowed pulses. Note: sweep occurs during pulse rise, so shortened pulses do not have maximum dose rate.





target radius	peak dose	pulse width [ns]	pulse rise [ns]
20-25	109.52	2.312	2.361
25-30	71.52	1.913	1.623

target radius	peak dose	pulse width [ns]	pulse rise [ns]
10-15	82.31	2.254	1.200
15-20	54.65	1.349	0.781
20-25	34.19	0.660	0.636
25-30	13.03	0.534	1.535

Simulated dose rate is not calibrated.

Conclusions and Outlook

- Recent experiments for 10 – 100 mTorr N_2 in a 6.2-m cell measured large oscillations in the radiation pulse. Although rise-times were reduced through beam erosion, results did not show great promise for pulse compression.
- We propose to take advantage of the betatron oscillations in a 10 – 500 Torr N_2 cell for pulse compression.
- The design is still under development, subject to experimental verification of simulation parameters.
- Design parameters include:
  - diode A-K gap
  - gas species
  - gas pressure
  - cell length
  - aperture radius
  - target radius
- Tests have begun on Hermes III using a solid-cathode diode to achieve a large-radius, annular beam.