Hydrodynamic expansion experiments on ETA

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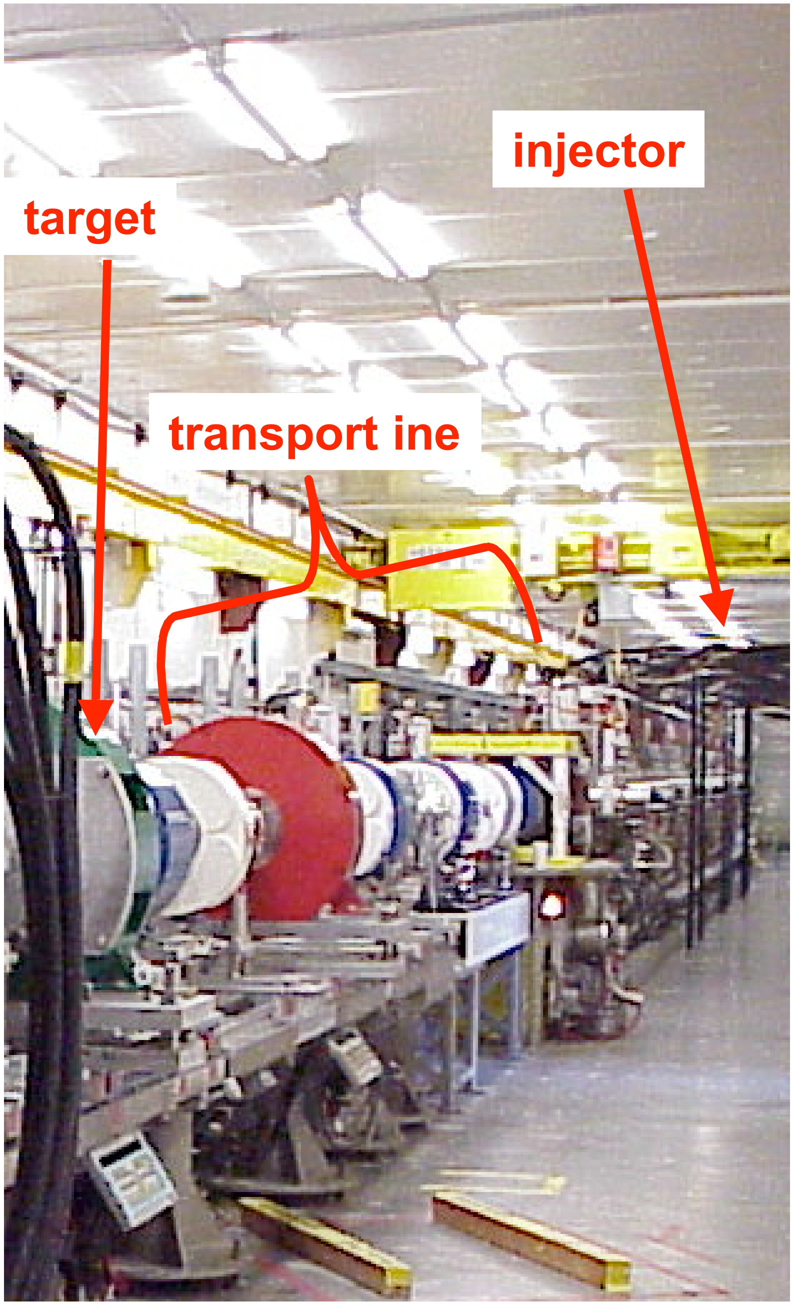
February 22, 2006

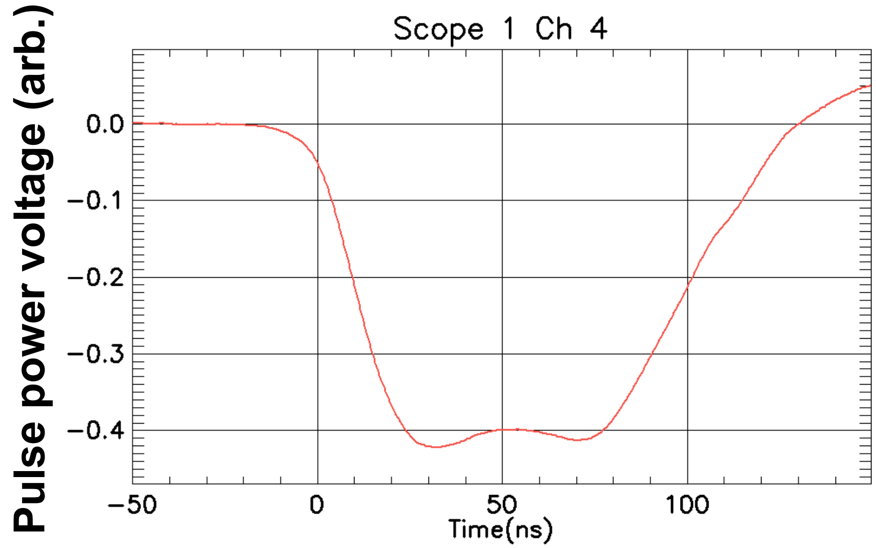
This work was performed under the auspices of the U.S. Department of Energy by University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

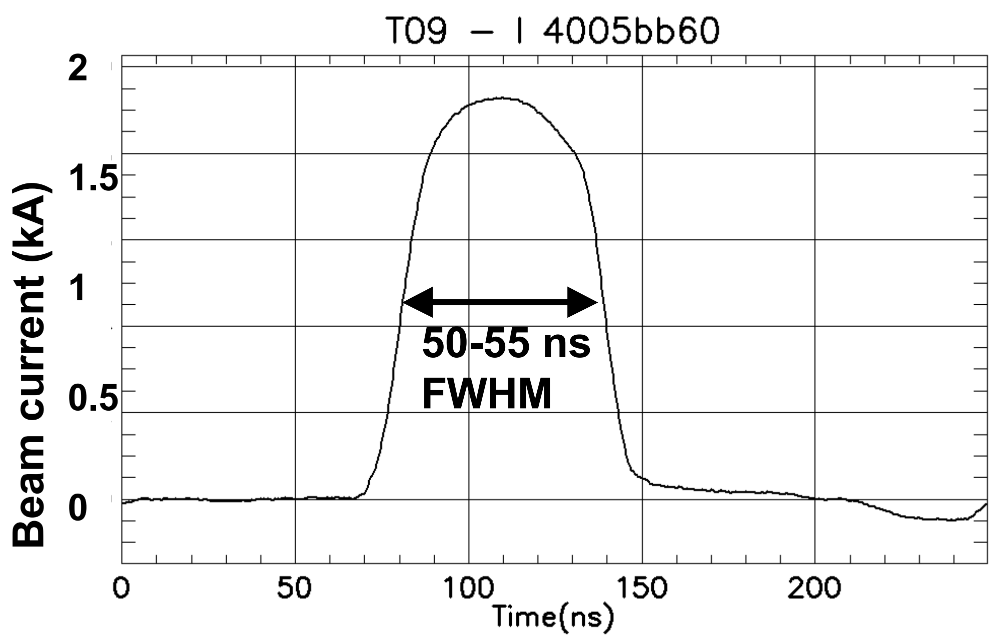
outline

- **ETA description**
- **Hydrodynamic calculations**
  - **T peak up to few eV, P peak (~300 kBar, dP/dz~10’s of Mbar/cm)**
  - **C_s transit effects (expansion during heating)**
- **X-ray Backlighter eXperiment (XBX) @ ETA**
- **XBX results - some agreement with model, and some remaining discrepancies**
- **Other diagnostic ideas**

ETA is a 5-6 MeV, 2 kA, 50 ns, 1 Hz induction LINAC

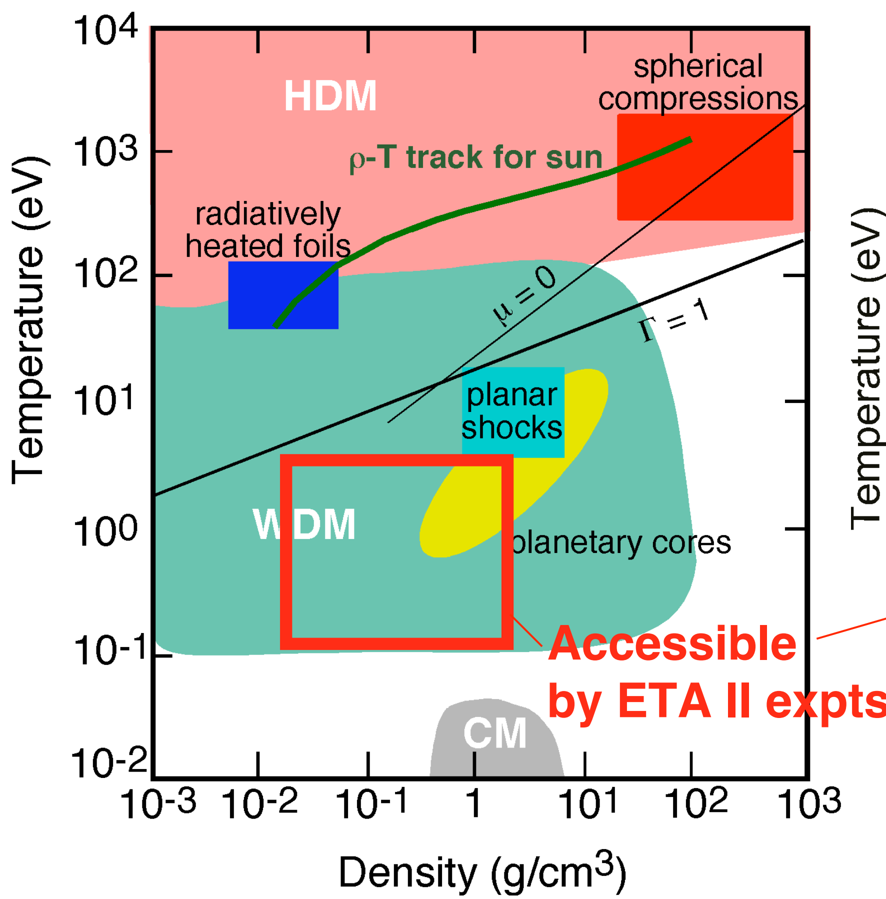




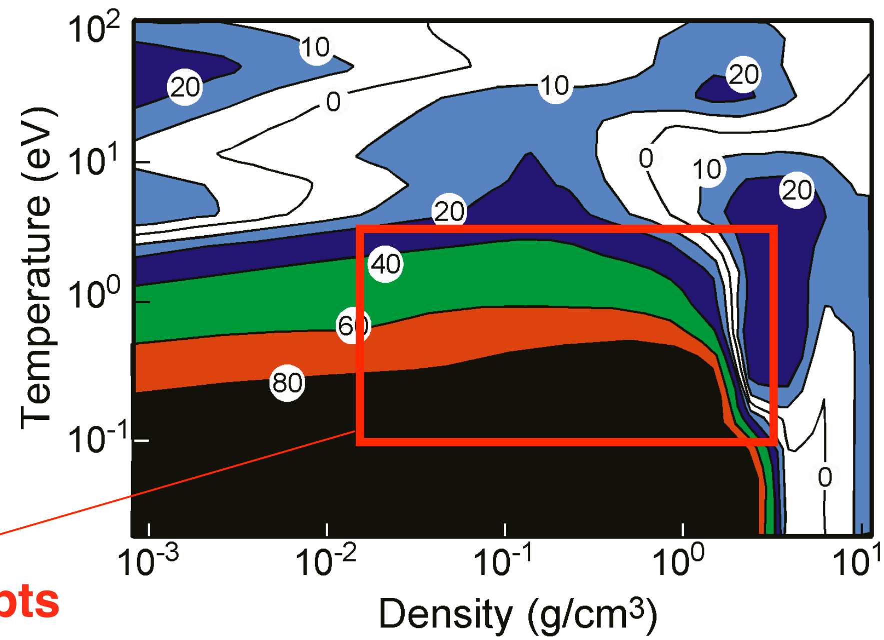


ETA can heat solid density targets to a few eV, where EOS's are least certain

Hydrogen phase diagram



Contours of difference in pressure for two different commonly used Equations of State for Aluminum



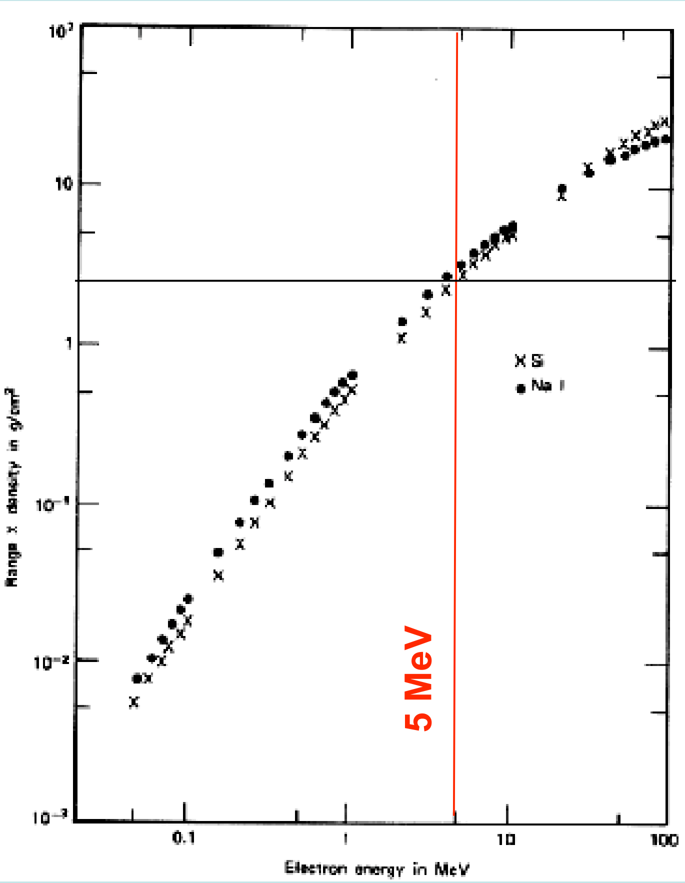
WDM is interesting (more difficult) because it is neither a classical plasma, nor is it solid state condensed matter physics.

Figures courtesy Richard Lee, LLNL.
Captions stolen from John Barnard, LLNL.

Macroscopically thick samples are heated: dE/dx per atom is nearly constant through mm thick targets

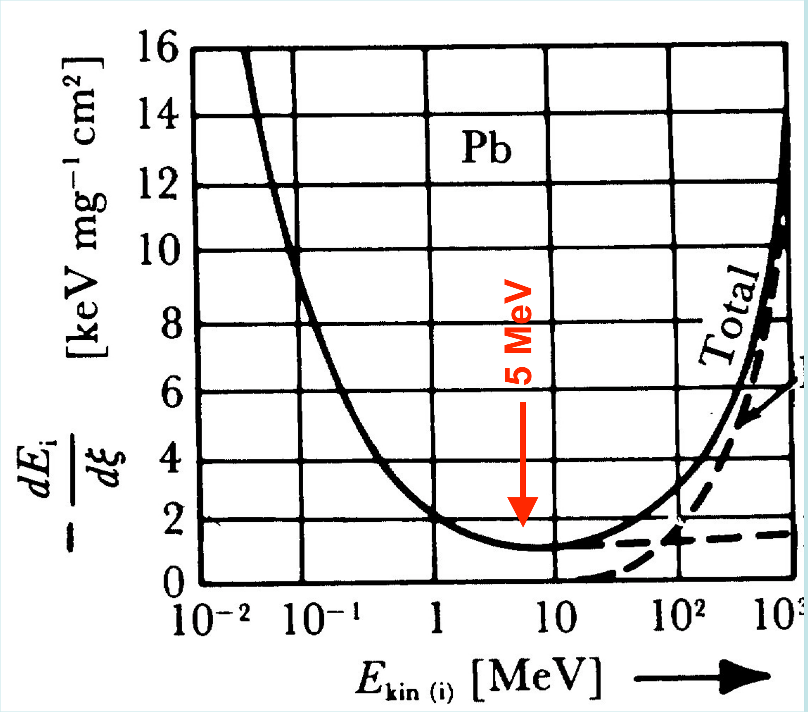
Range in Al is ~ 1 cm

--> uniform heating of 1st mm



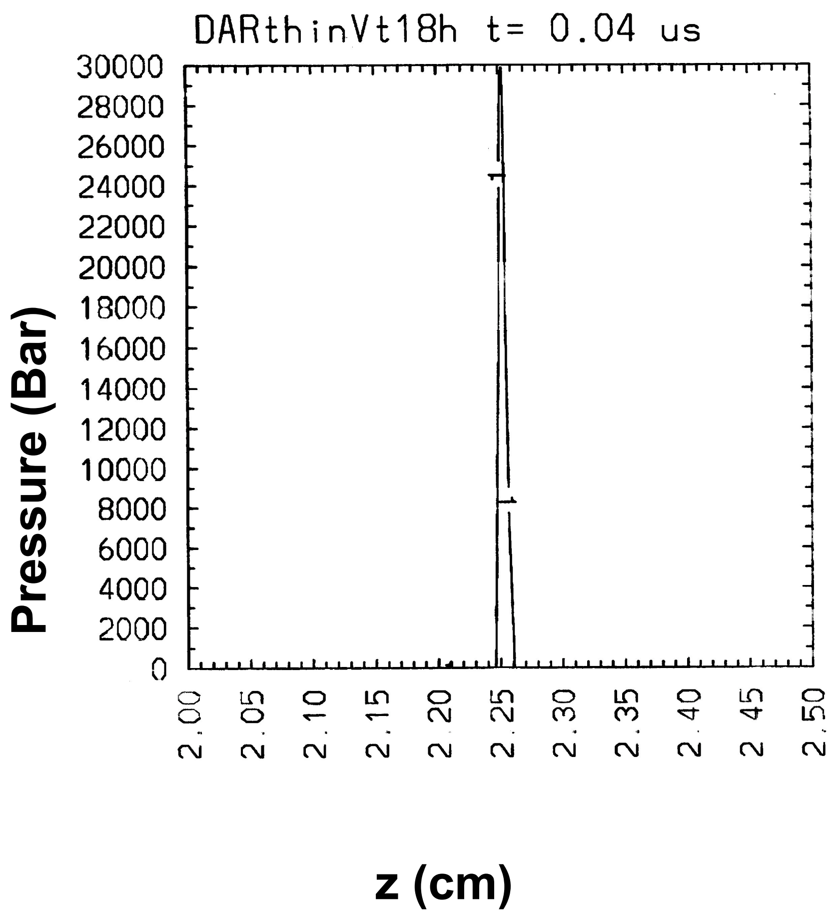
Even for Pb, ~100 µm thick foil can be heated with little axial variation

dE/dx~1.4 MeV/mm

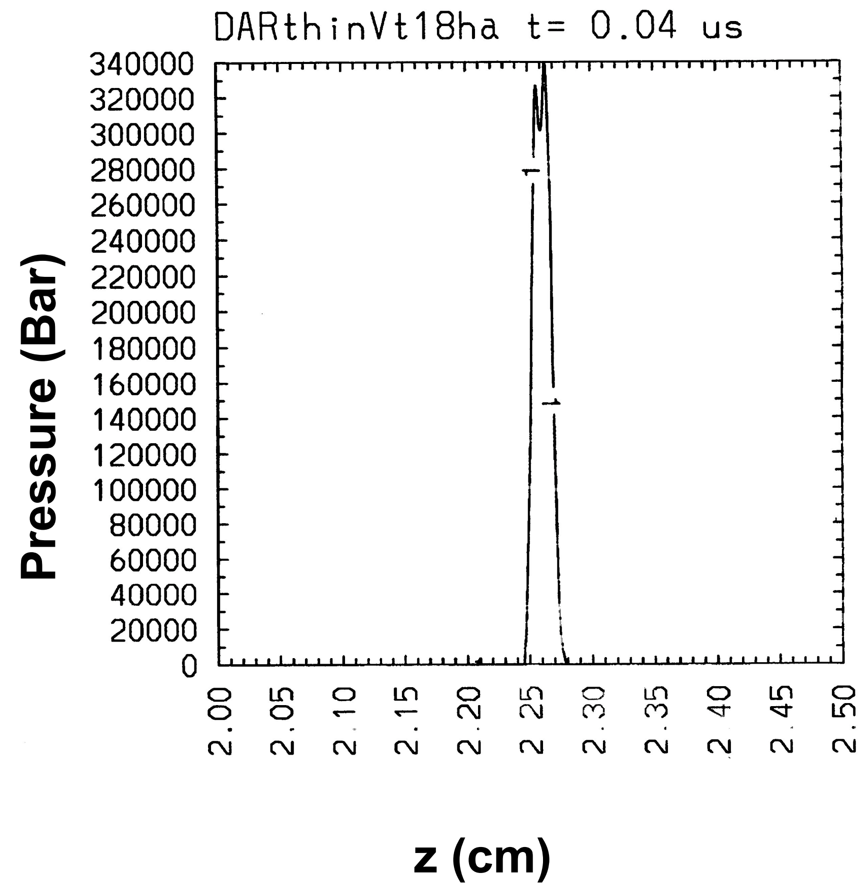


Pressure in Ta targets at end of beam heating increases with foil thickness

Foil thickness = 30 µm



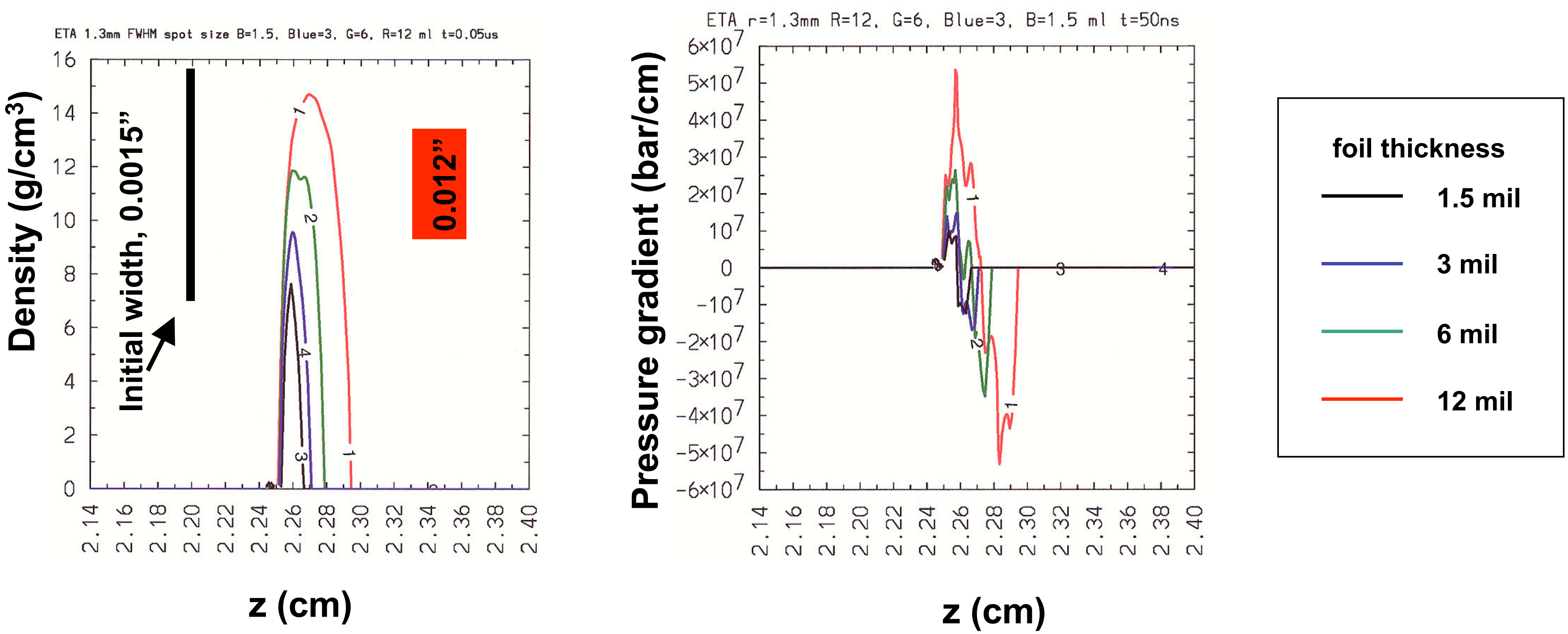
Foil thickness = 200 µm



Hydrodynamic simulations from Darwin Ho, LLNL

For thicker foils, it takes longer for the rarefaction wave to decompress the density at the center and this results in higher pressure gradient

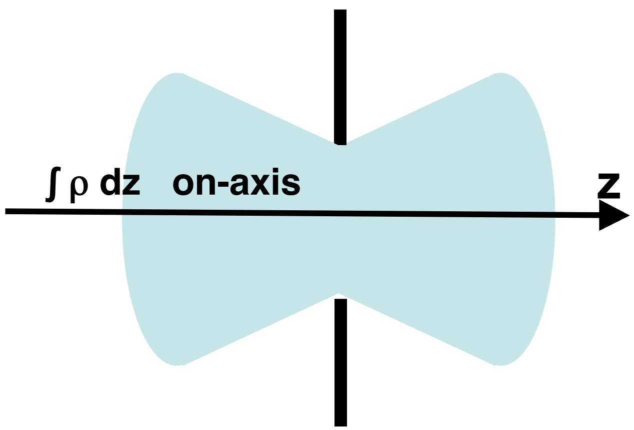
t = 50 ns

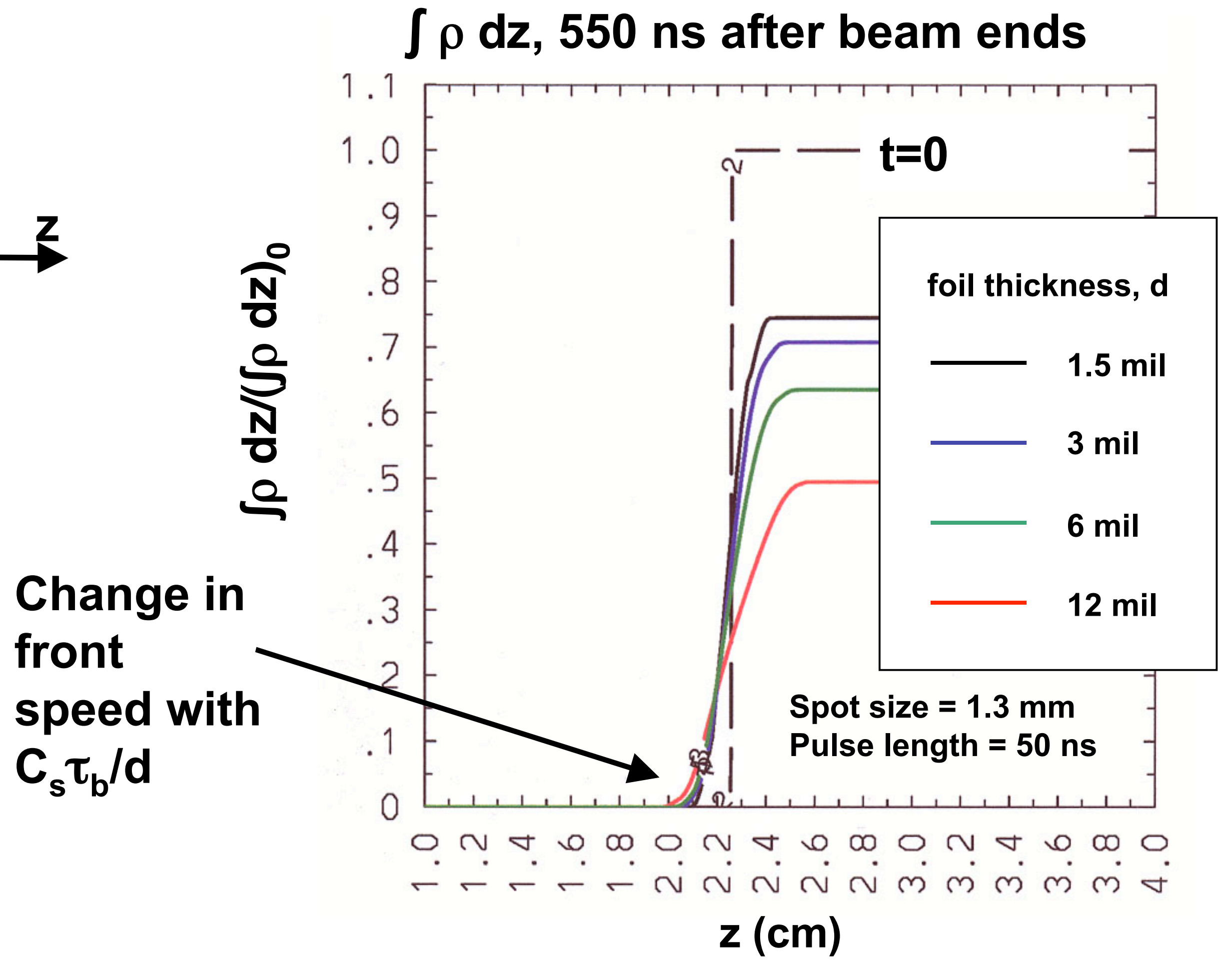


Hydrodynamic simulations from Darwin Ho, LLNL

A possible diagnostic for C_s might be the expansion speed variation with foil thickness

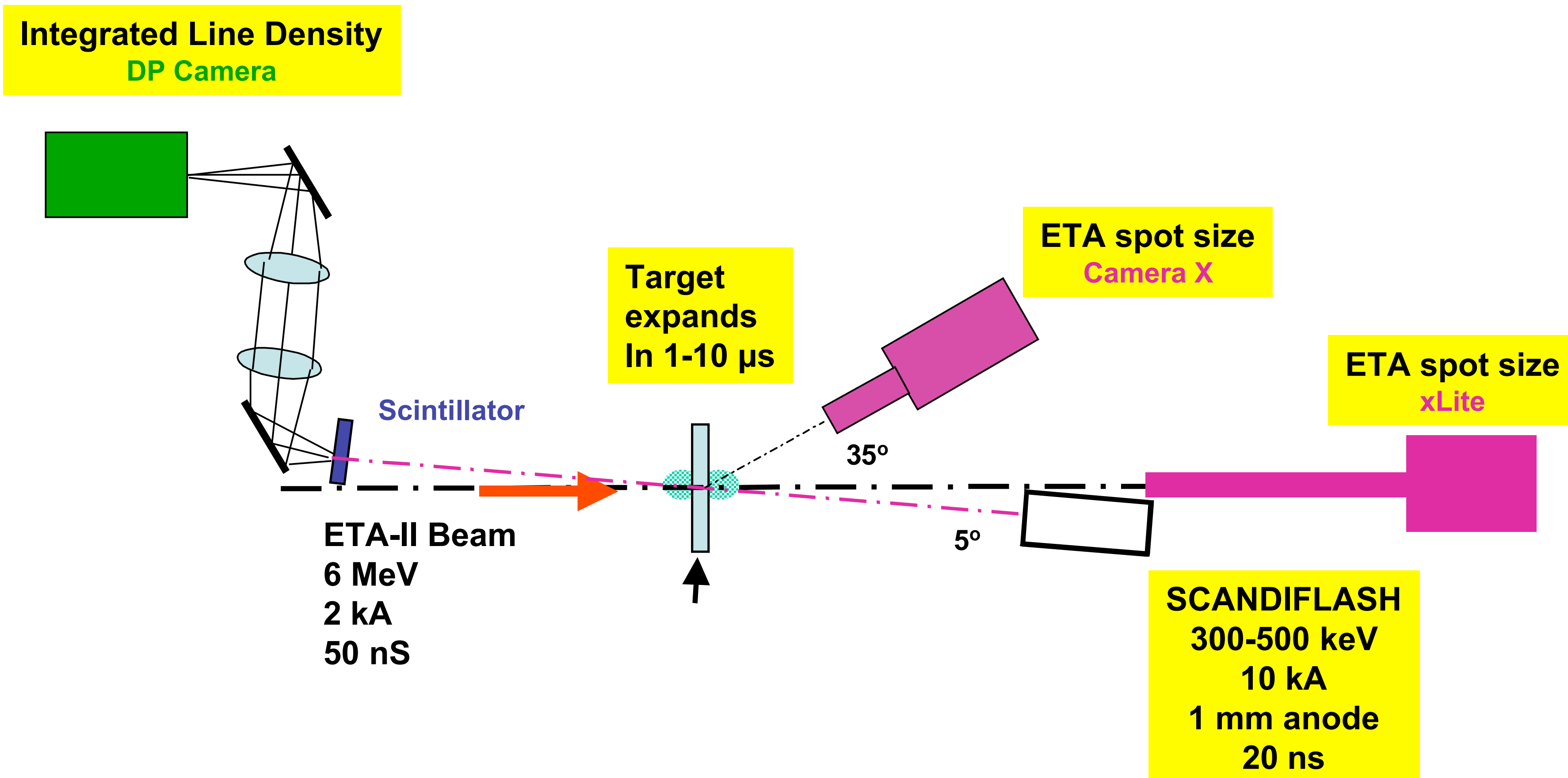
note that line density is also influenced by geometry changes.





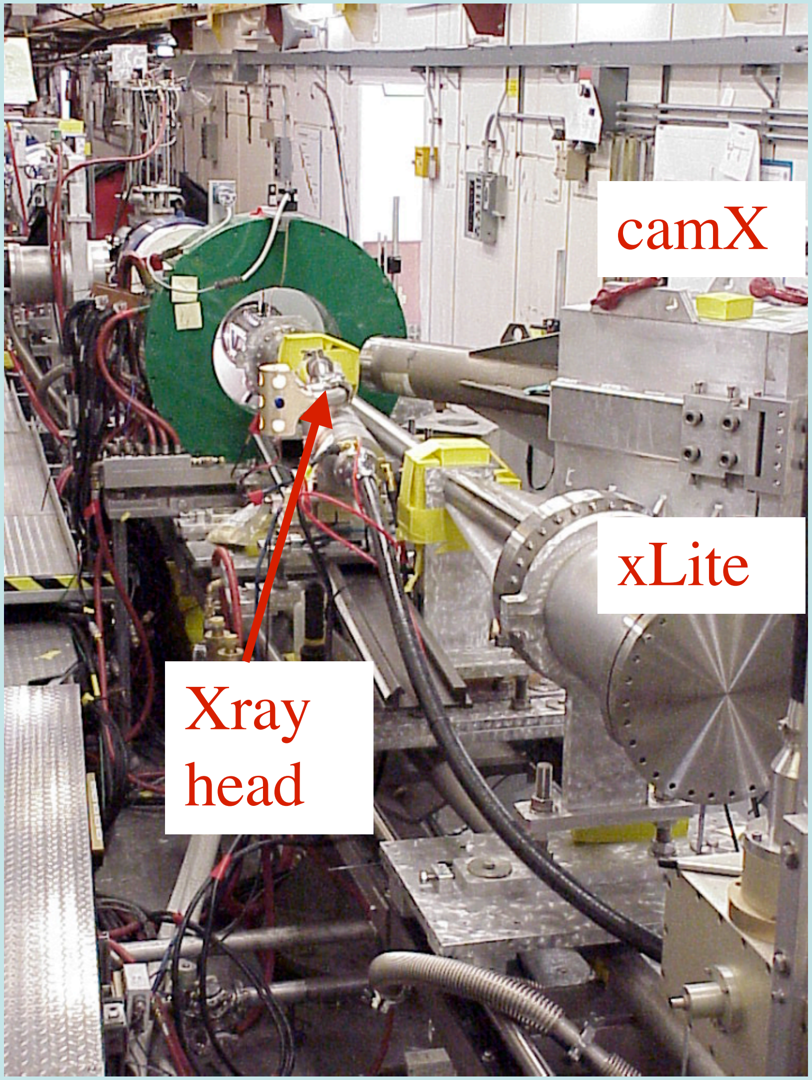
Hydrodynamic simulations from Darwin Ho, LLNL

Axial line density was measured 5° off axis to measure the target expansion

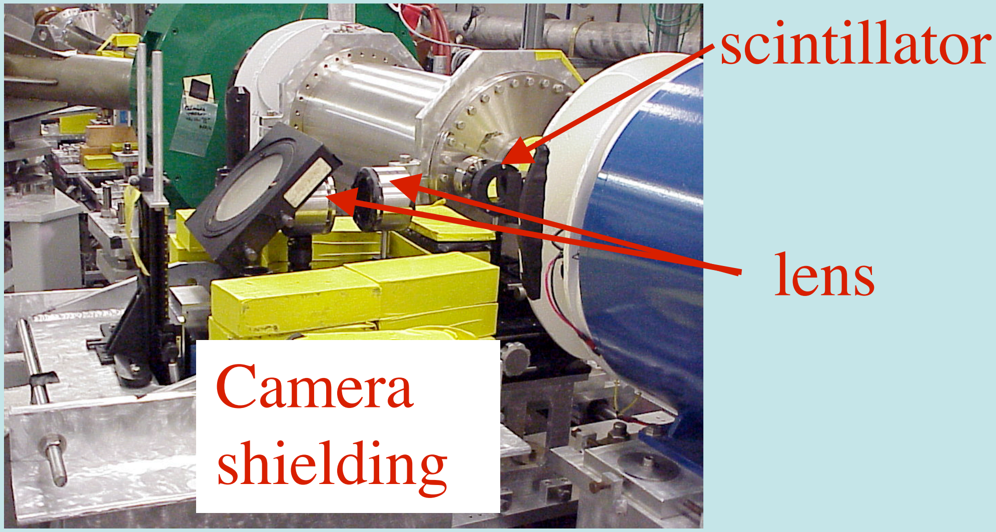


Hydrodynamic foil expansion experiments at ETA

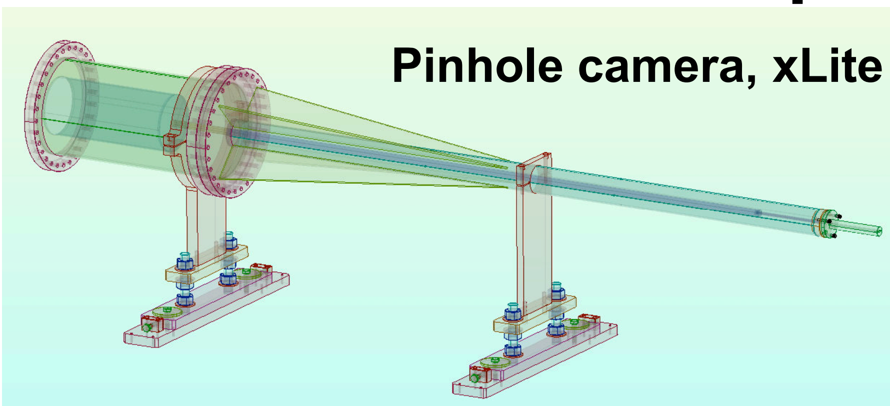
Backlighter source and beam spot diagnostics

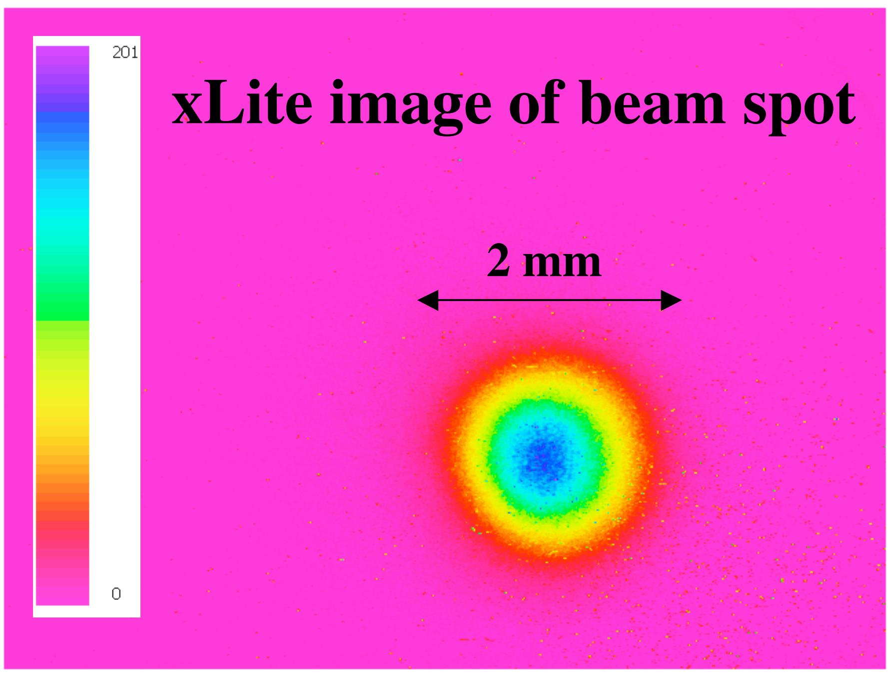


Transmitted x-ray detector



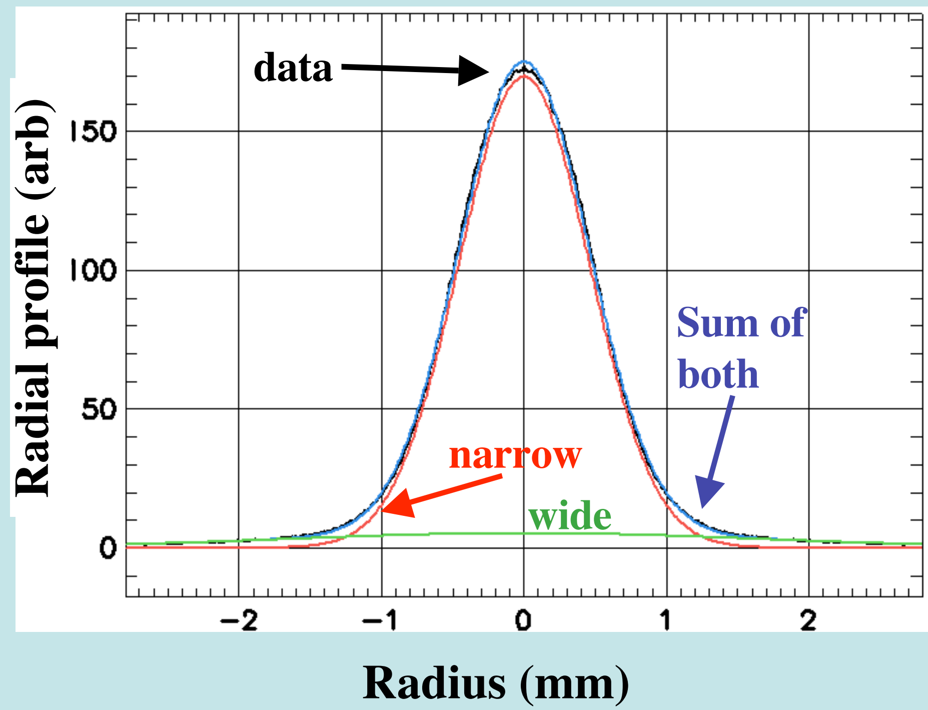
The time integrated spot size of ETA typically follows a bi-Gaussian profile





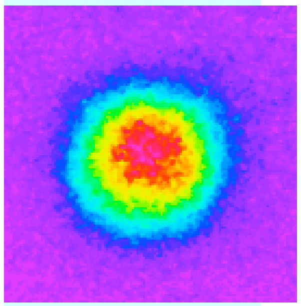
2220xl07.tif - False Color

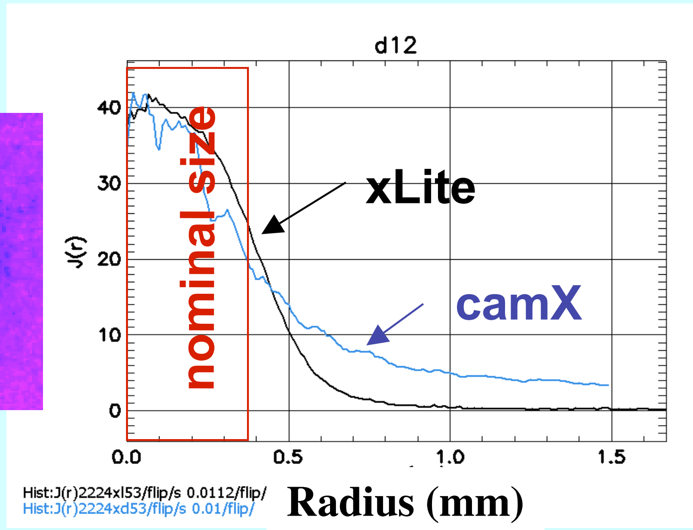
Radial beam profile is nearly Gaussian, ~20% of the beam in a wider Gaussian



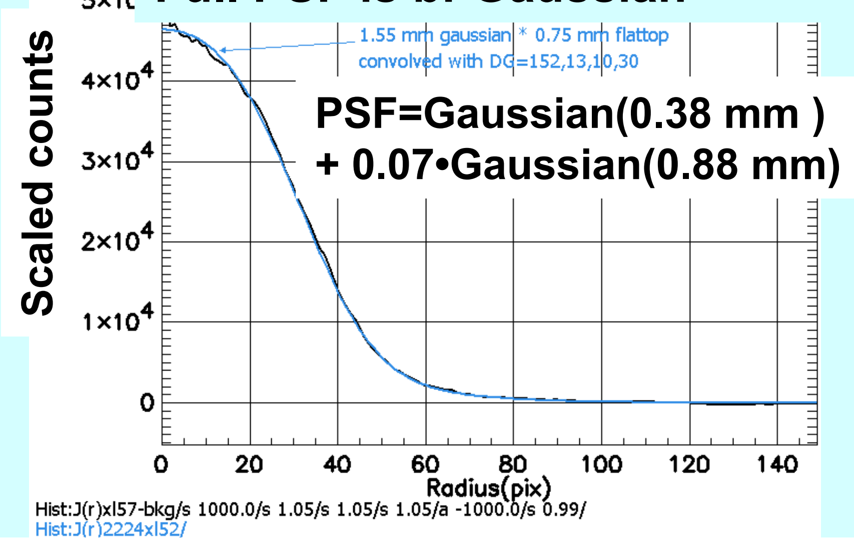
Accurate spatial profile measurement requires subtraction in quadrature from the Gaussian FWHM to account for point spread function of the pinhole camera

Deduce PSF from 0.75 mm target

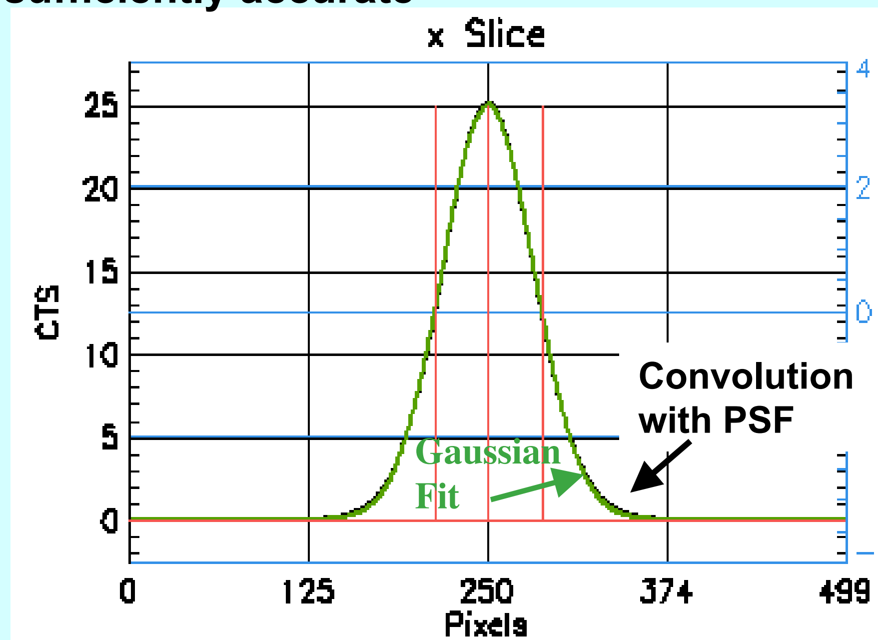




Full PSF is bi-Gaussian



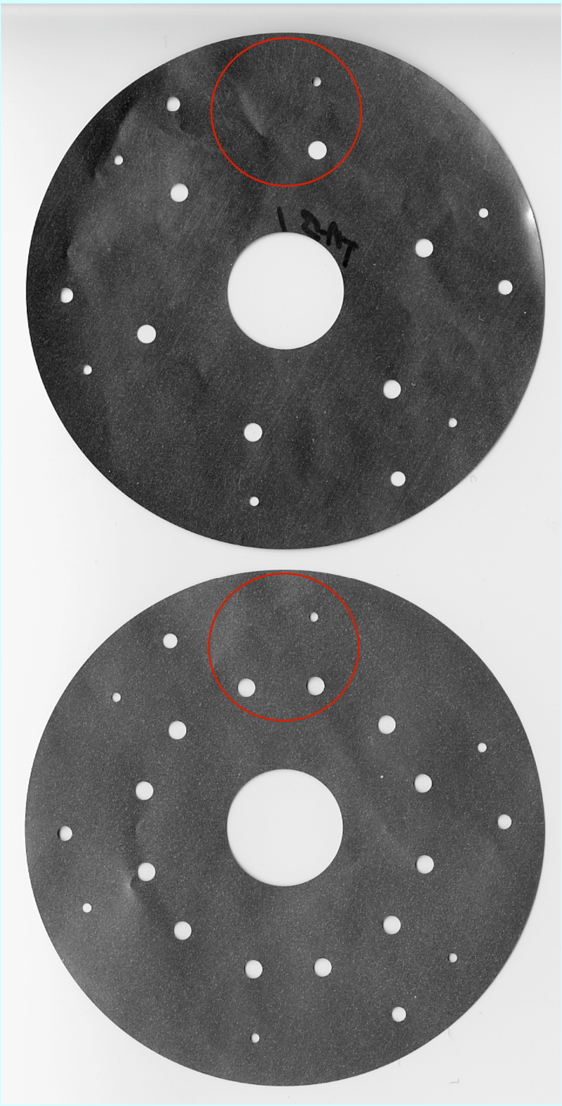
Deconvolution with single Gaussian(0.45 mm FWHM) by subtraction in quadrature is sufficiently accurate

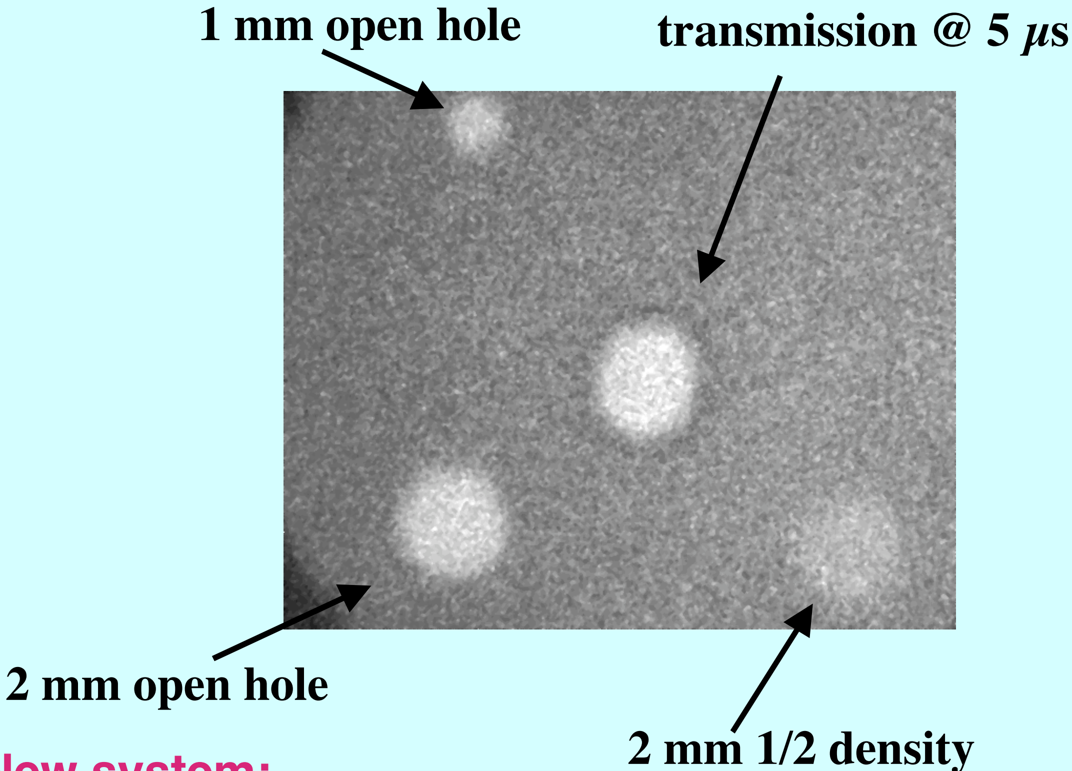


1. subtract ~0.45 mm in quadrature
2. For double gaussian, subtract from each
3. For our profiles, no significant wing addition beyond gaussian

Target foils are built with structure for shot calibration of backlighter resolution and spectral effects

2 Ta layers



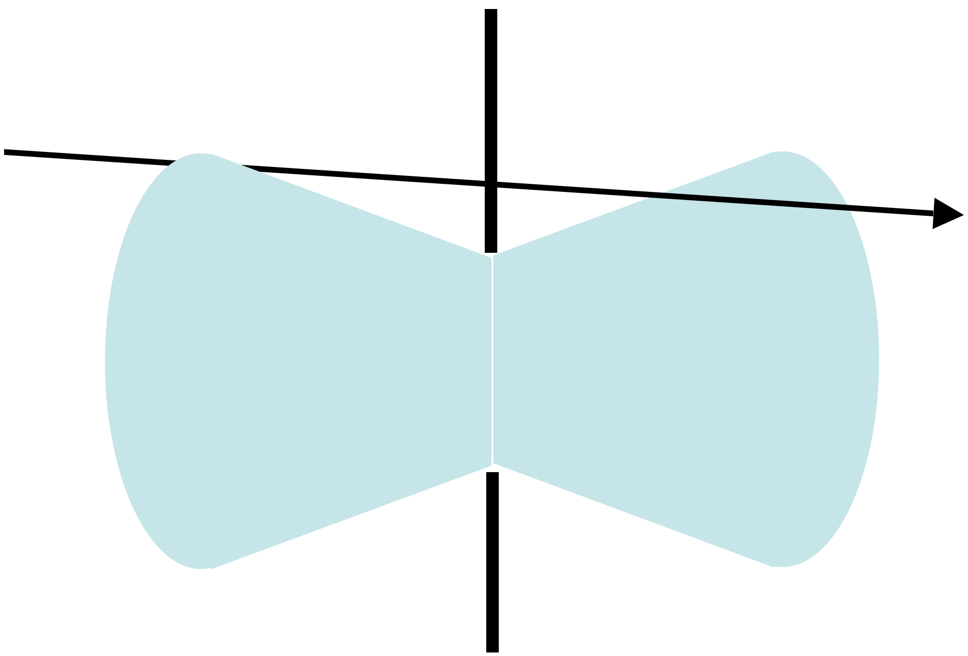


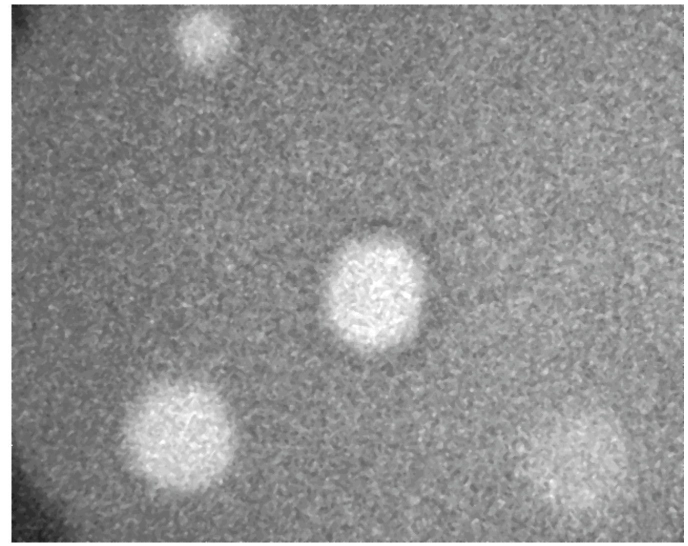
New system:

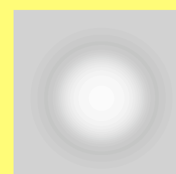
1. 1 mm source size
2. Improved relay optics
3. Optimized scintillator for resolution and contrast
4. Modified spectrum for improved contrast
5. 3 point calibration on every shot

The “moat” is caused by the overlap of the radial expansion with areas of the foil that have not expanded

This xray travels through the cold solid target as well as the edge of the plume, and is absorbed more strongly than by the cold target alone



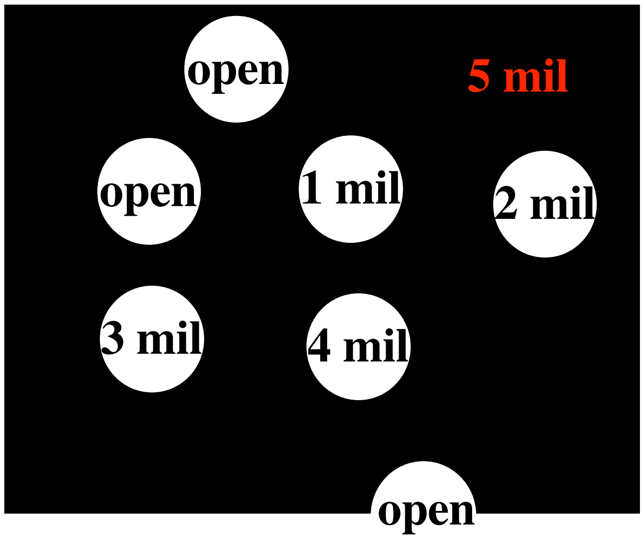




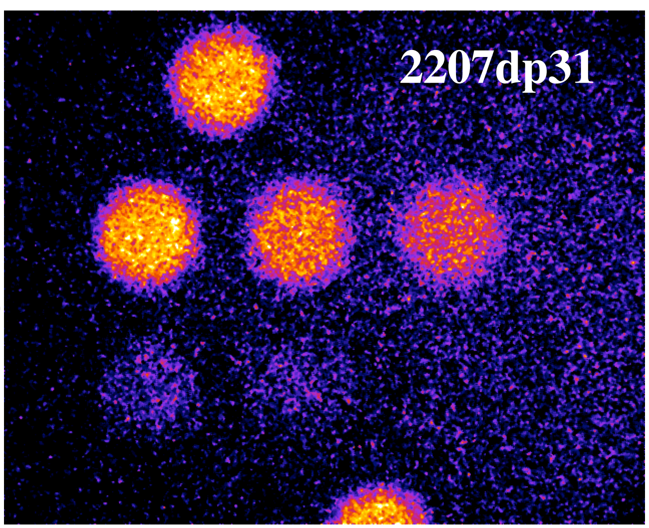
Hydrodynamic simulation convolved with 0.5 mm resolution

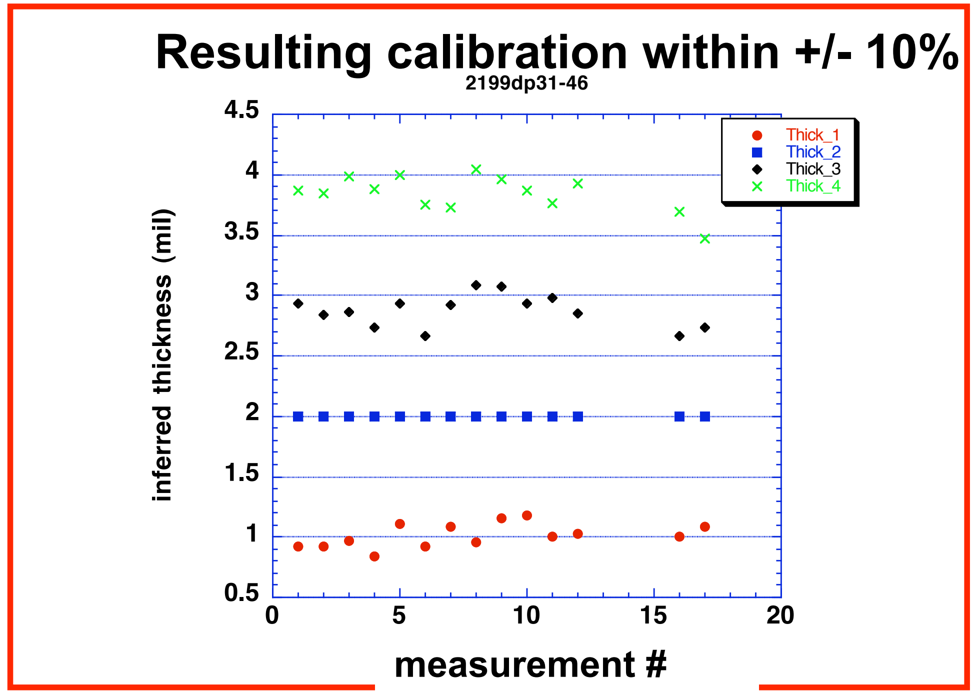
+/-10% accuracy using 3 point calibration -verified with step-wedge

Step-wedge

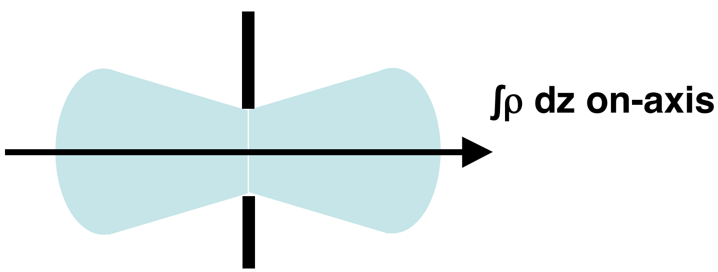


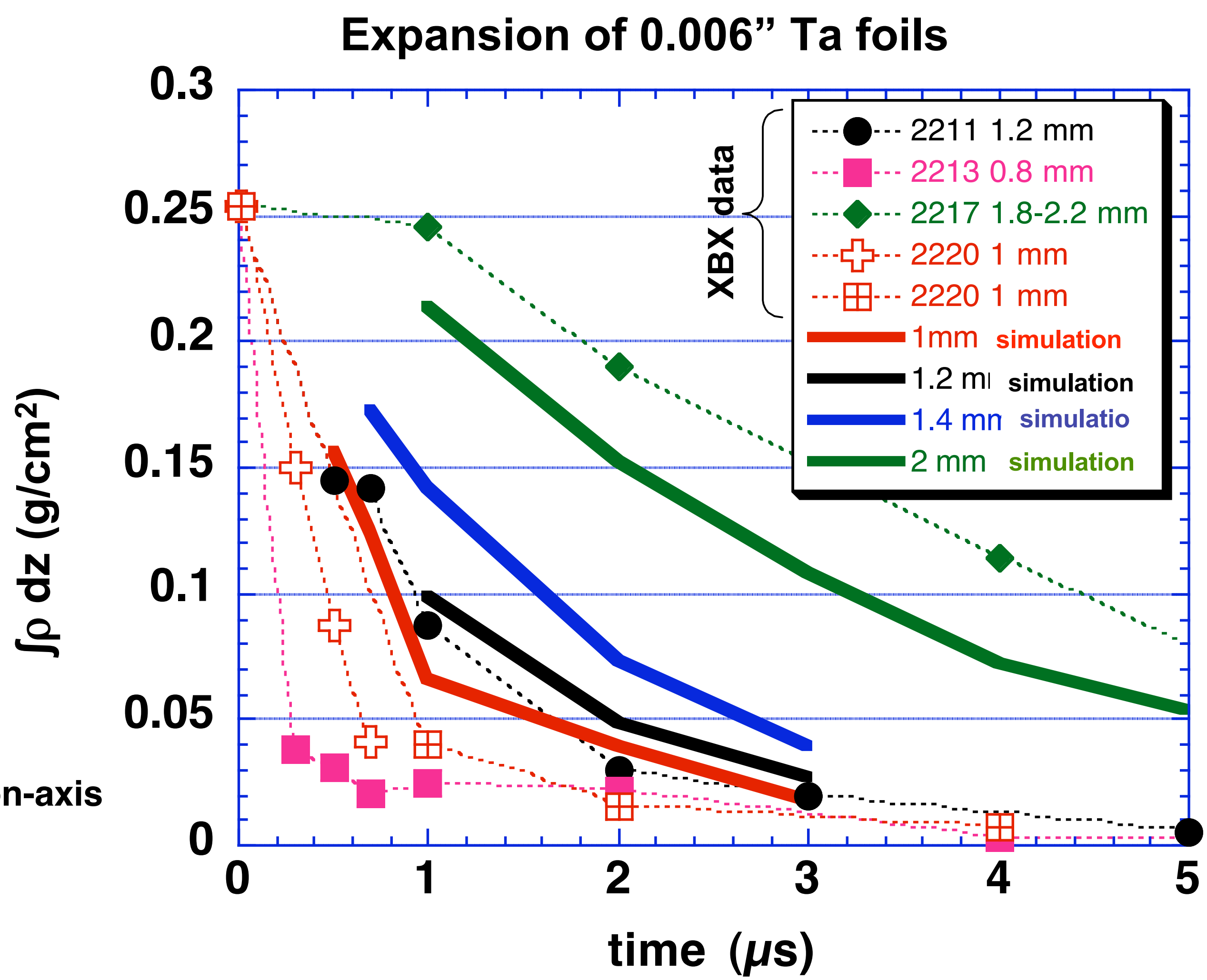
Transmission radiograph





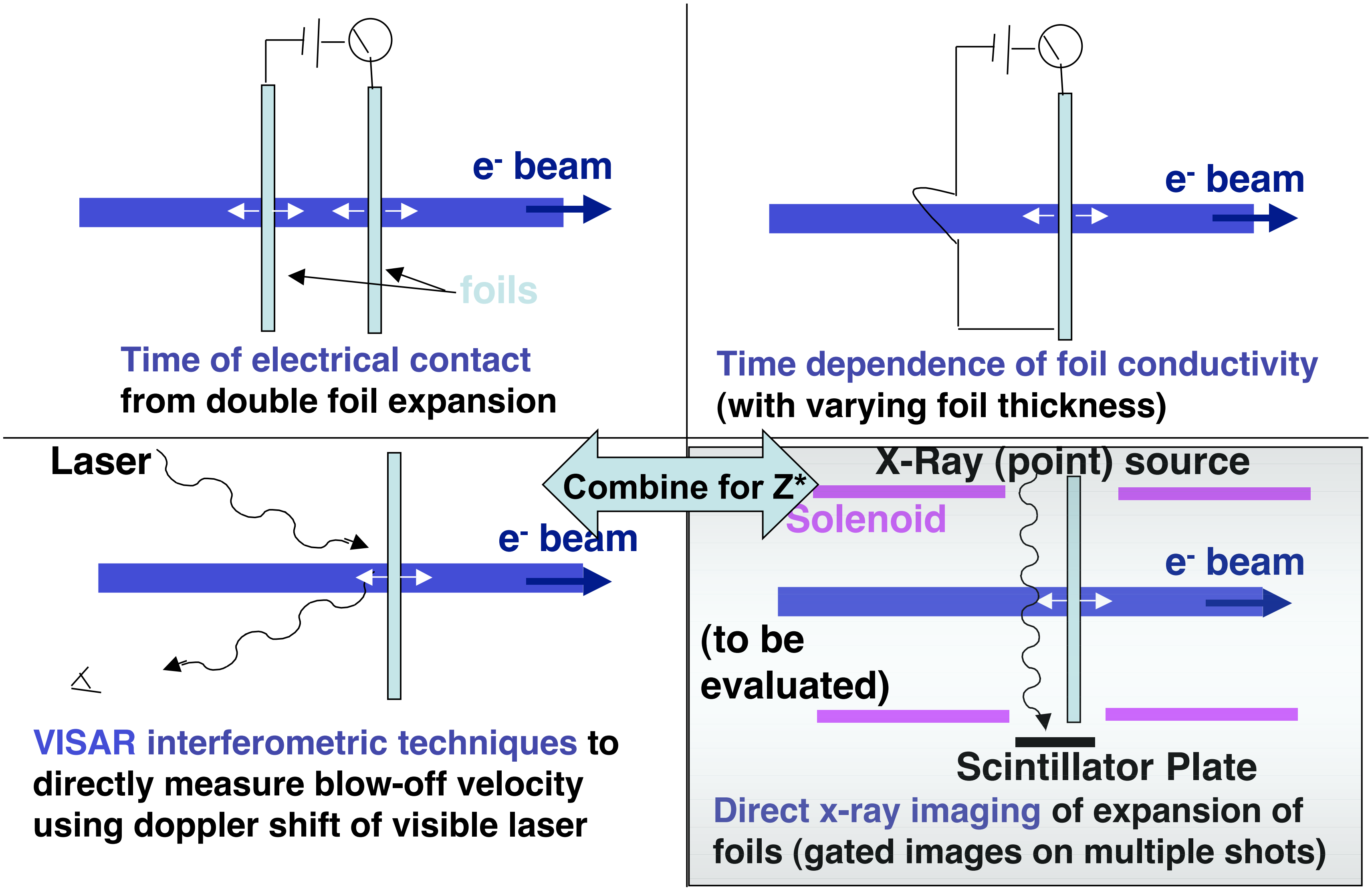
Some agreement with hydrodynamic simulations, but model has less spot size dependence than data. Does this suggest EOS lacks sufficient energy dependence?





Hydrodynamic simulations from Darwin Ho, LLNL

Other possibilities for EOS related measurements?



Time of electrical contact from double foil expansion

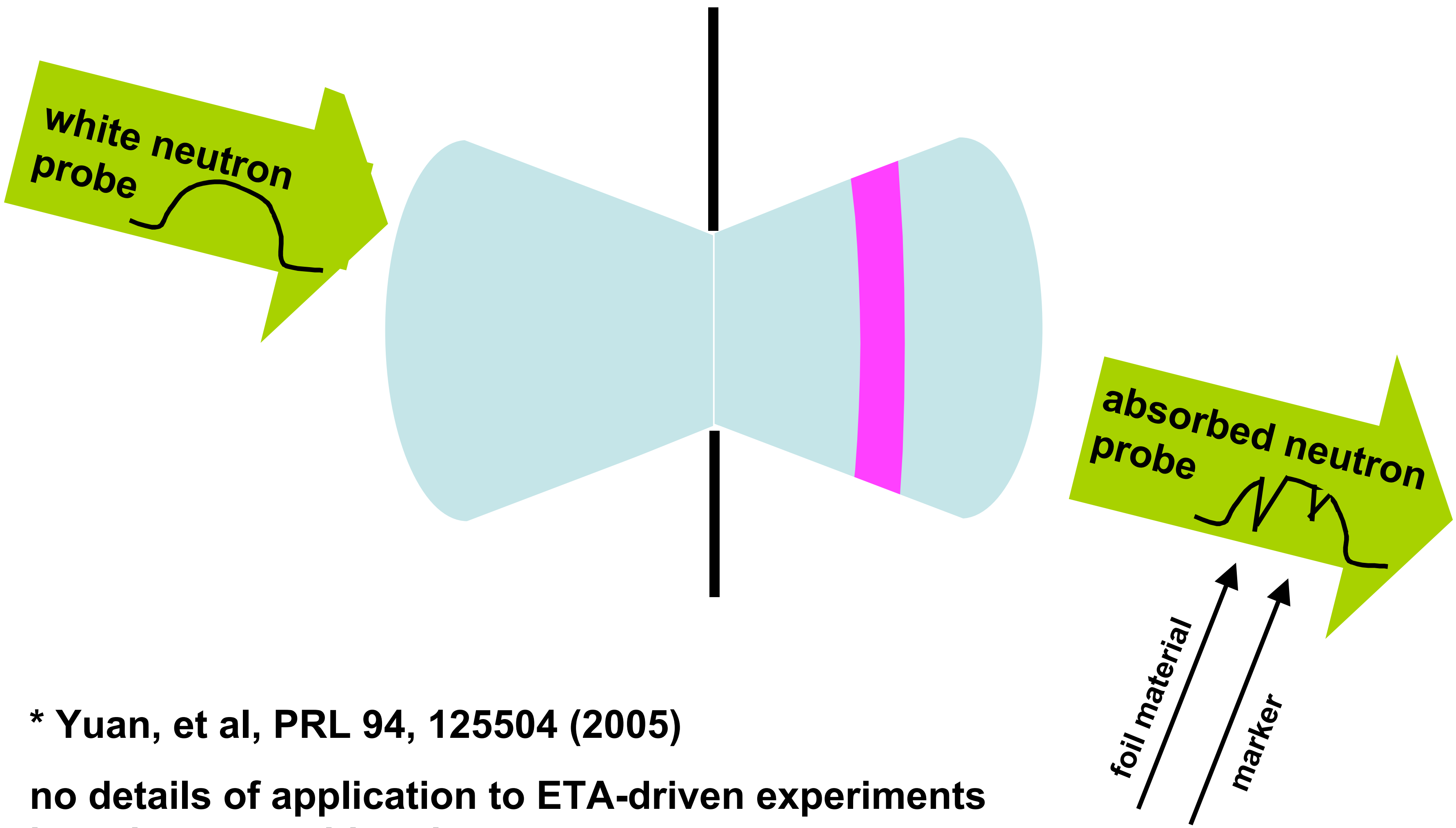
Time dependence of foil conductivity (with varying foil thickness)

VISAR interferometric techniques to directly measure blow-off velocity using doppler shift of visible laser

Direct x-ray imaging of expansion of foils (gated images on multiple shots)

Courtesy John Barnard, LLNL

Neutron probe* to observe properties of bulk material



* Yuan, et al, PRL 94, 125504 (2005)

no details of application to ETA-driven experiments have been considered yet

summary

- Electron beams such as ETA can heat macroscopic samples to WDM conditions
- Initial state is complicated by expansion during 50 ns heating
- Challenge is to find a diagnostic that samples the bulk EOS properties (temperature, pressure, sound speed, ionization state) of the macroscopic sample. Neutron probe of marker layers?
- … or alternately to measure expansion rates for a variety of energy densities for comparison with predictions by rival EOS tables. Samples multiple paths through EOS, as if mapping the vegetation on a hillside by releasing a bowling ball from different positions and measuring the resulting speeds…