# Aspects of Analysis of Z Machine Shock Wave Physics Experiments


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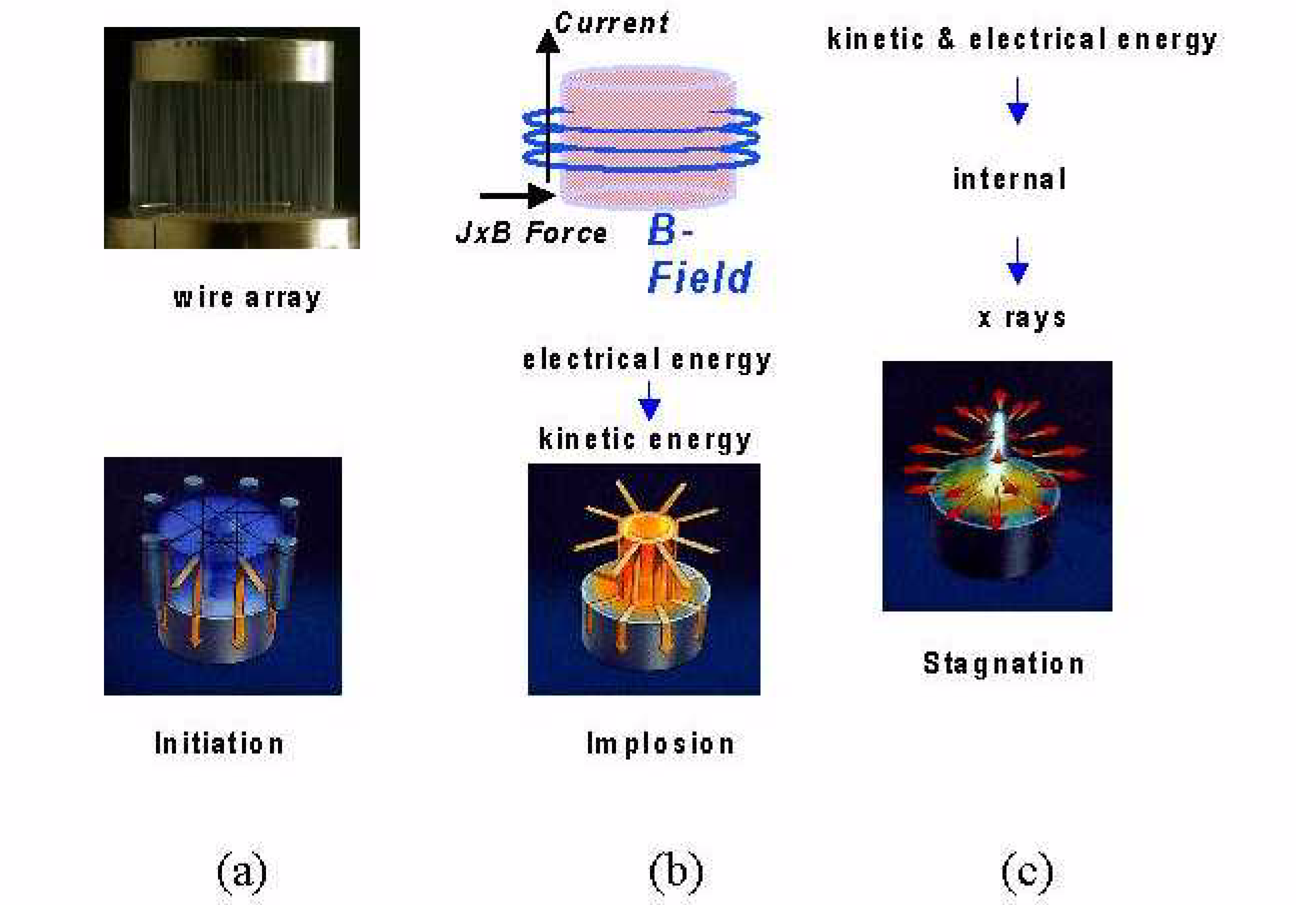
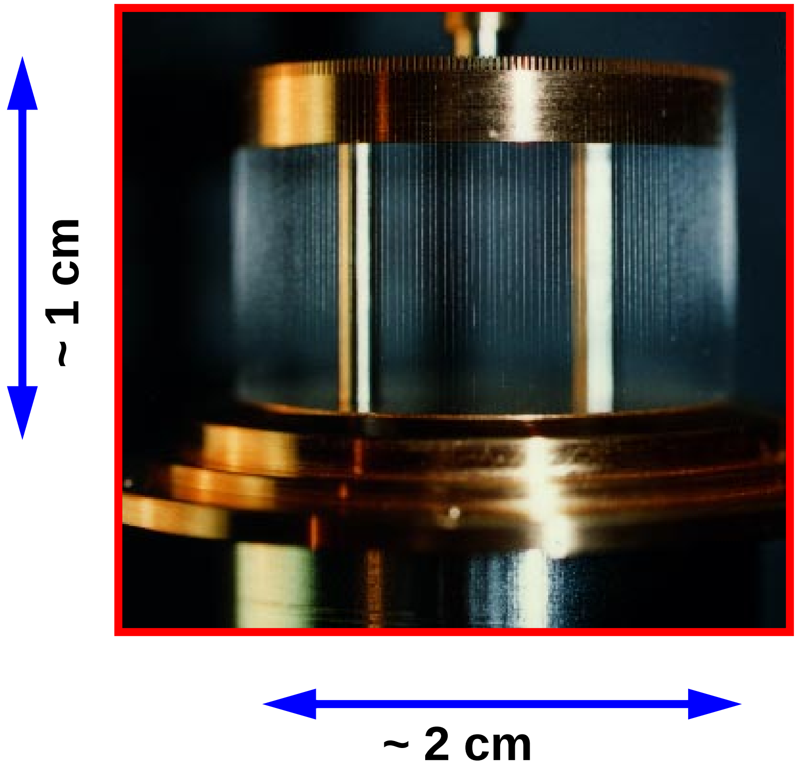
# The A-B-C's of fast Z-pinches:




**Z Machine - Fast switching (~100 ns) of ~ 11 MJ stored energy to produce ~ 20 MA currents; resulting X-ray pulse of ~ 2 MJ or more, in 5 - 10 ns (FWHM), with peak radiating power of 300 TW or more; temperatures of ~ 150 eV in a "*primary*" hohlraum.**

# Wire arrays are the key to the radiative output:




**300 tungsten wires, 11.4 μm individual diameter**

**~ 2 cm diameter, 1 cm axial length**

**~ 120 TW peak power for the Z189 and Z190 experiments**

**~ 140 eV peak radiation temperature in the primary hohlraum**

# Why pursue EOS experiments on the Z machine?

**Very high pressure shock waves can be generated.**

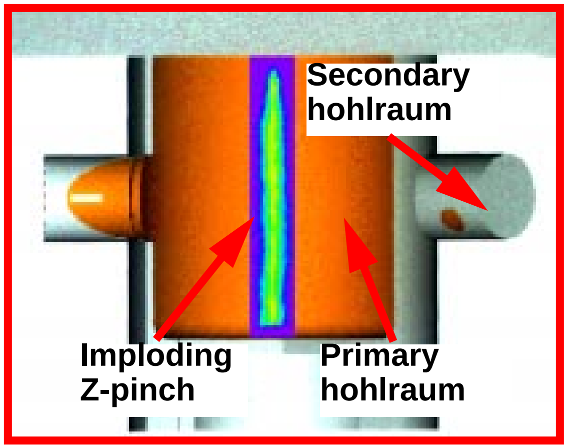
**There is a large amount of x-ray energy available:**

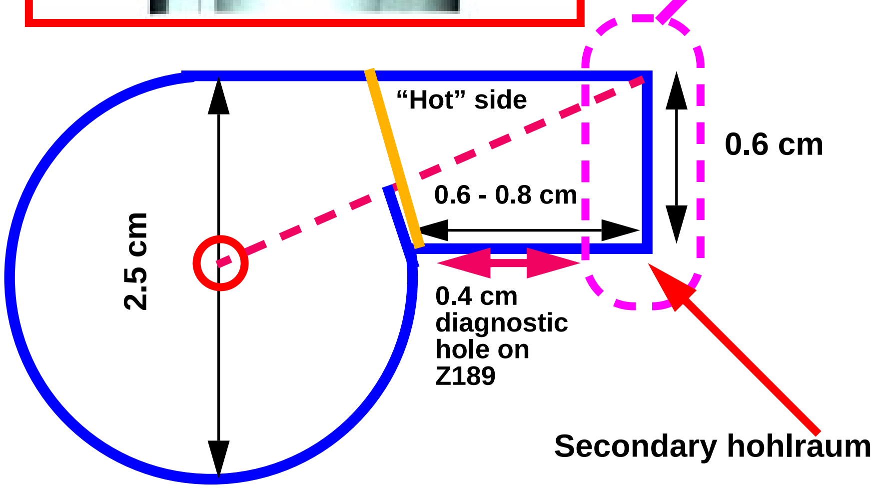
- **We can work with larger sample sizes, which eases diagnostic accuracy burdens**
- **There is the possibility of "staging" this energy creatively, for applications such as off-Hugoniot (isentropic) loading, and for launching flyer plates. We do this in a simple way through the use of "*secondary*" hohlraums.**

**Time-resolved diagnostics applicable to EOS measurements might have wider utility as complementary Z-pinch diagnostics.**

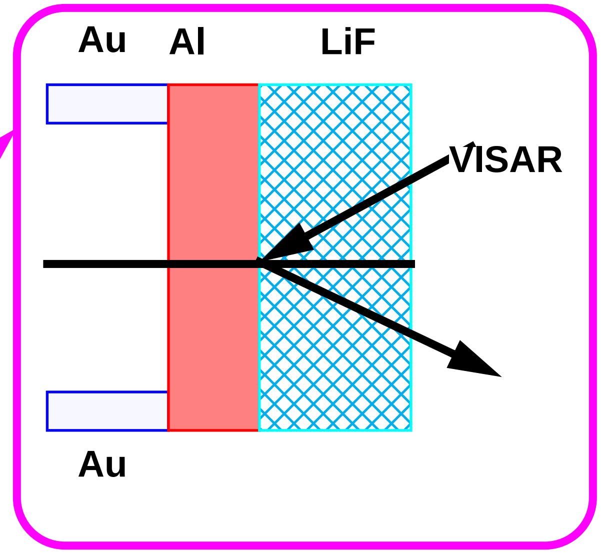
- **Of particular concern here is measurement of radiative drives**
- **Have also begun to evaluate these diagnostics to determine magnetic pressures in primary hohlraums**

# “Typical” EOS experiments are performed in “tangential” secondary hohlraums.




Axial view of primary hohlraum




Z189 - 0.6 cm; Z190 - 0.8 cm “cool” side

Two secondary hohlraums per experiment - VISAR and fibre-optic shock breakout measurements.

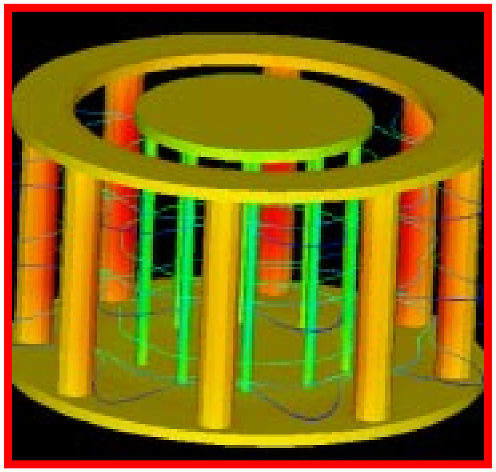
6.28 µm (Z189) and 1.83 µm (Z190) Parylene-N burnthroughs (leveraging work of Chrien, et al)

# We are using ALEGRA to suggest payloads and analyze experiments for the EOS program.

**ALEGRA is a 3-D multi-material finite element-based ALE code.**

**One intended application is to fundamental studies of Z-pinches and their applications:**

- **3-D parallel MHD**
- **3-D parallel multigroup diffusion**
- **Execution on ASCI hardware**

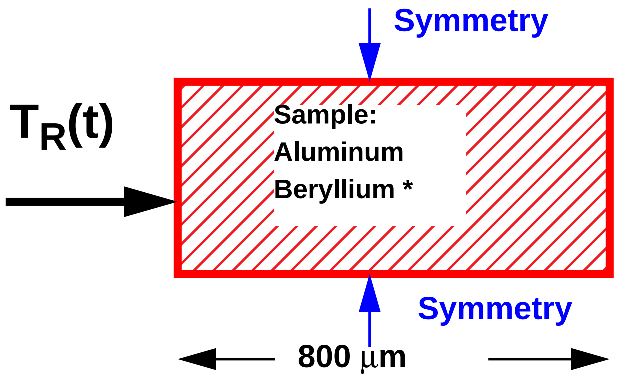


**The present calculations are performed using "1-D" hydro and the SPARTAN $SP_N$ rad-transport package (Morel and Hall, LANL). This combination of capabilities is called ASP (ALEGRA-SPARTAN). A multigroup diffusion package developed by Budge is also now being applied.**

**We are working to "validate" a physics package - radiation transport - which must become integral with the MHD at some point.**

# We are exploring simple payloads for simple development experiments using ALEGRA-SPARTAN.

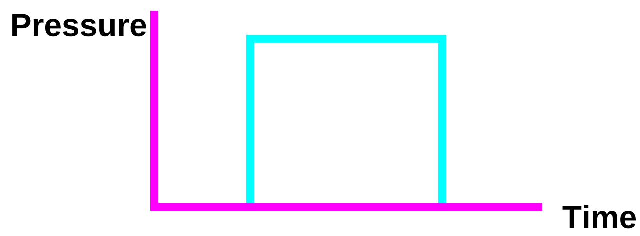
**Basic Geometry**




**Use Sesame EOS tables.**

**Opacities are calculated using an unclassified XSN model. Typically, we use 20 groups over the range 0.1 eV to 6.0 keV for such drives.**

## The ideal EOS pulse:




**Use of Hugoniot conditions requires steady wave:**

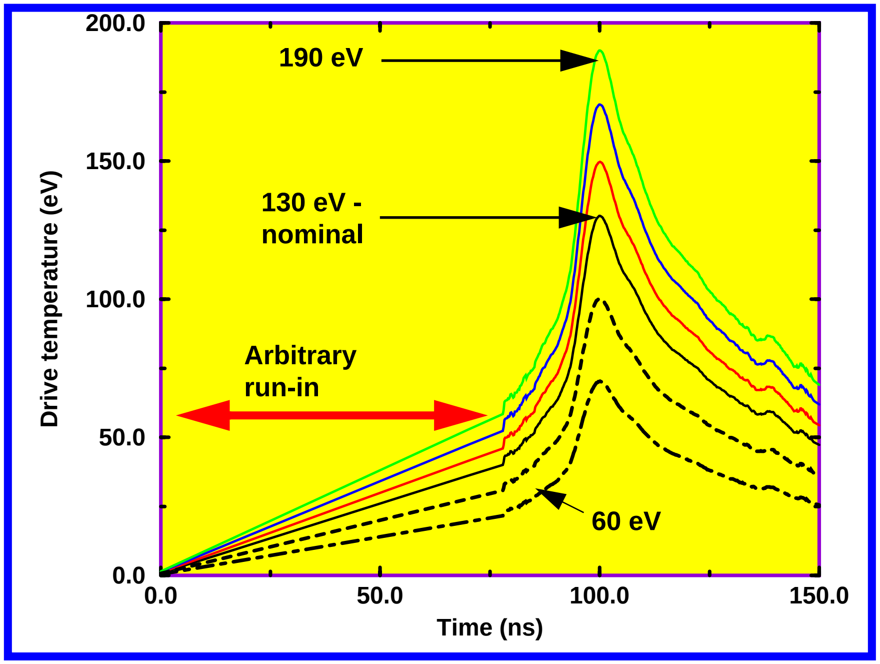
$$P = \rho_0 U_s u_p$$

$$\rho_0 U_s = \rho(U_s - u_p)$$

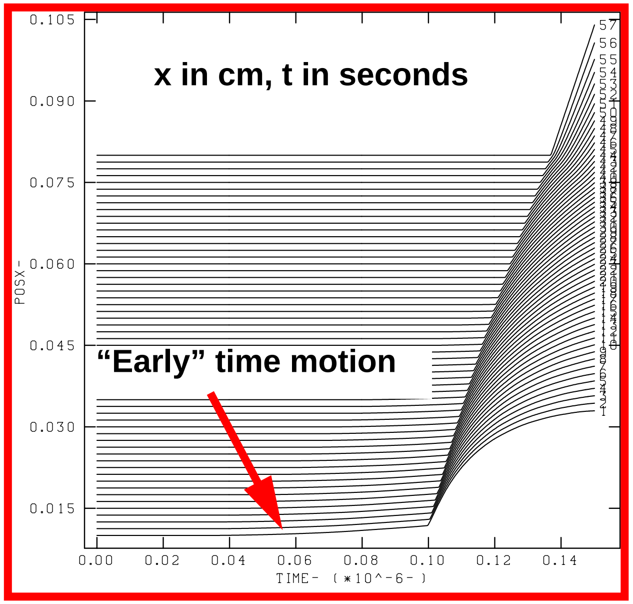
**Potential for "shaping" the pressure pulse via more complex payloads: Al/Be, CH/Be, more elaborate alternating impedance layers for plate launch.**

# We predict early time motion in the absence of burnthrough foils, although details of the "foot" of the drive may be difficult to measure.

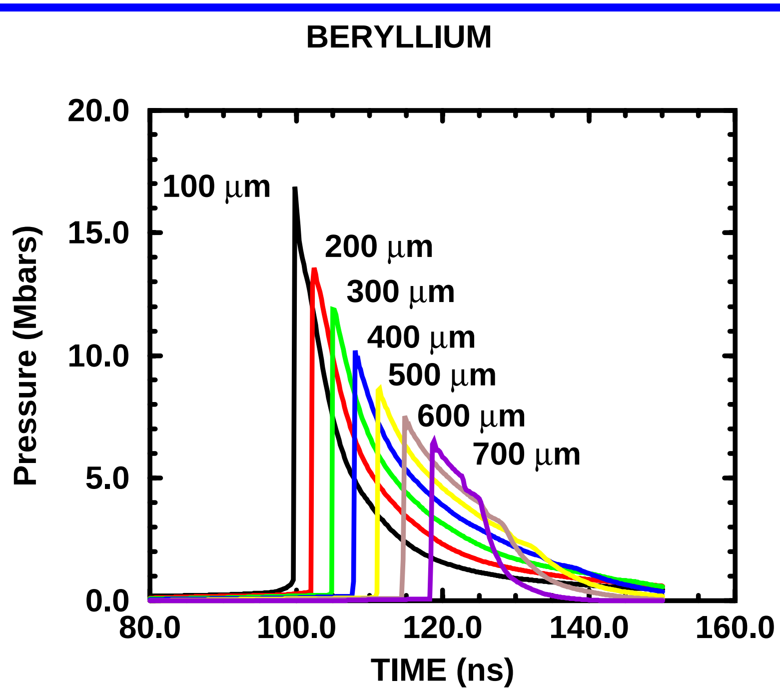
**The nominal source is based on shot Z91 primary hohlraum diagnostic, but the first 80 ns (below 30 eV) is simply guessed.**

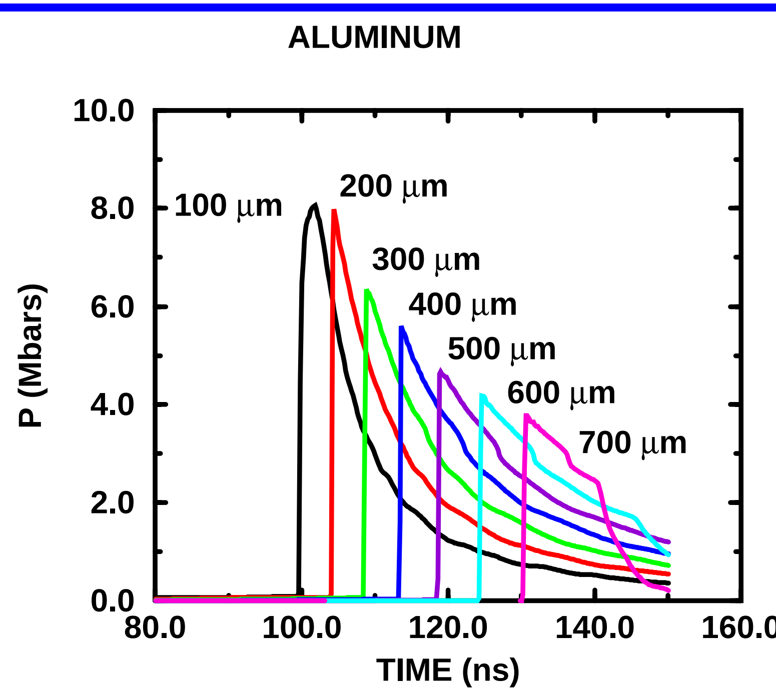



**x-t diagram for aluminum under the nominal drive.**



# Shock wave propagation for a nominal source (130 eV peak) in beryllium and aluminum (note the pressures).



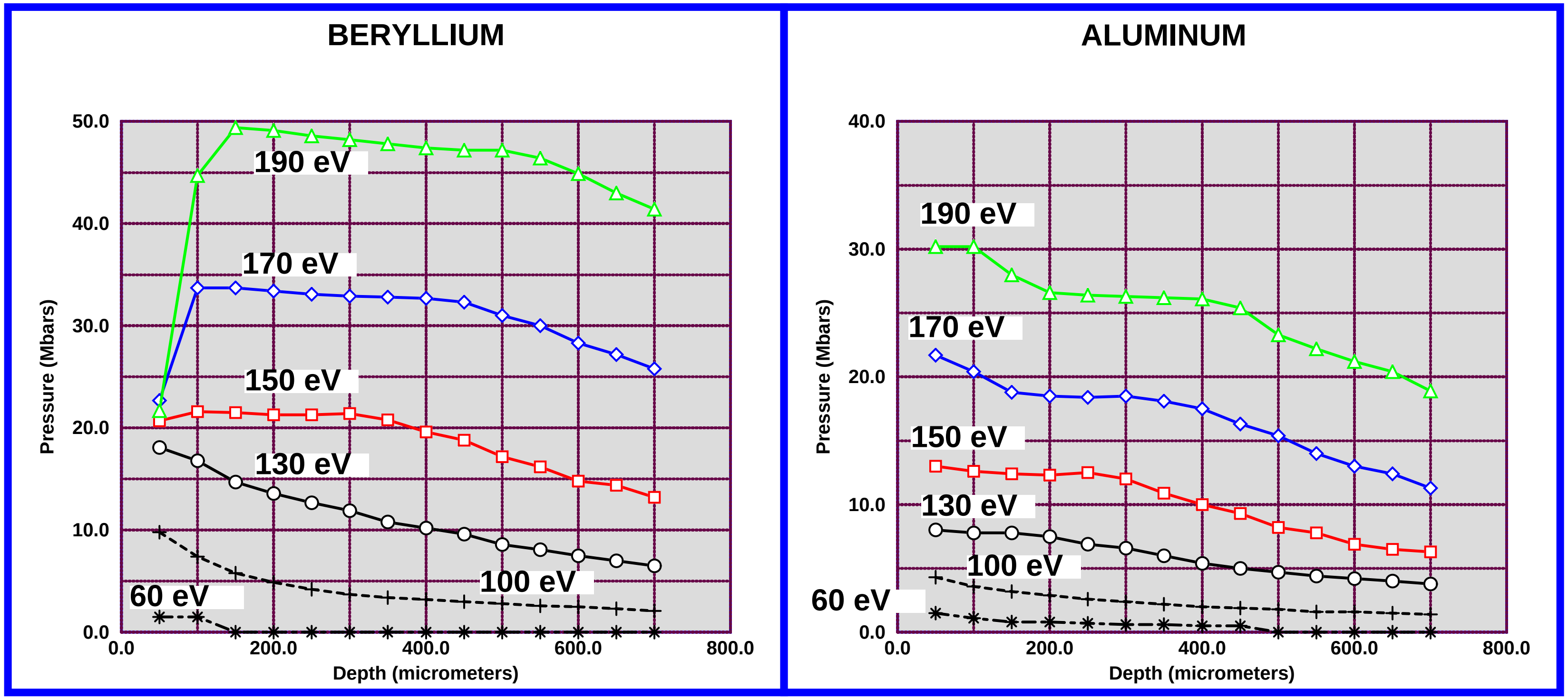

**SESAME #2022.**

**We know of no unclassified wedge or step data that gives us some feeling for whether or not these calculations are wrong or right.**

**SESAME #3715**

**We have one set of wedge shot data that provides some validation for our calculation of rad-hydro shocks in aluminum.**

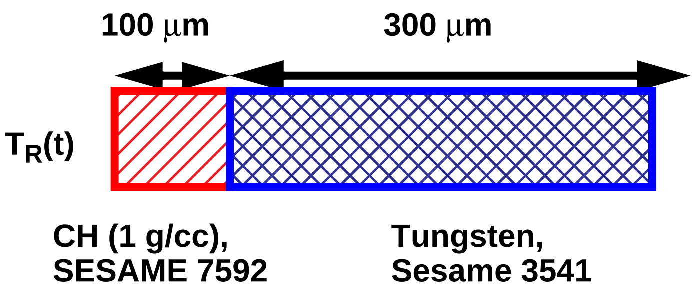
# Predicted peak pressures versus depth for the nominal drive allow fine tuning of the diagnostic.

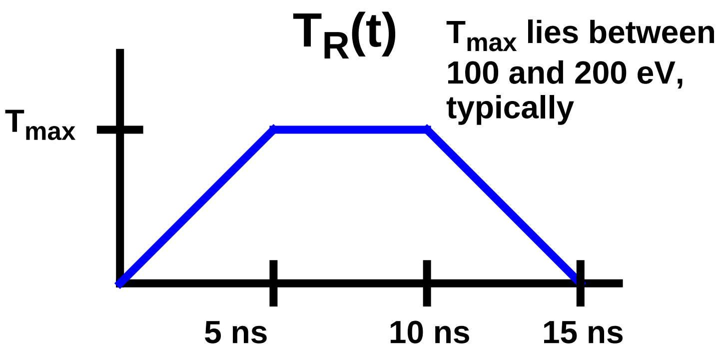



**We are most concerned with avoiding depths where attenuation is most extreme.**

**We also, of course, do not want to be stupid and perform a measurement in the ablation region without realizing it.**

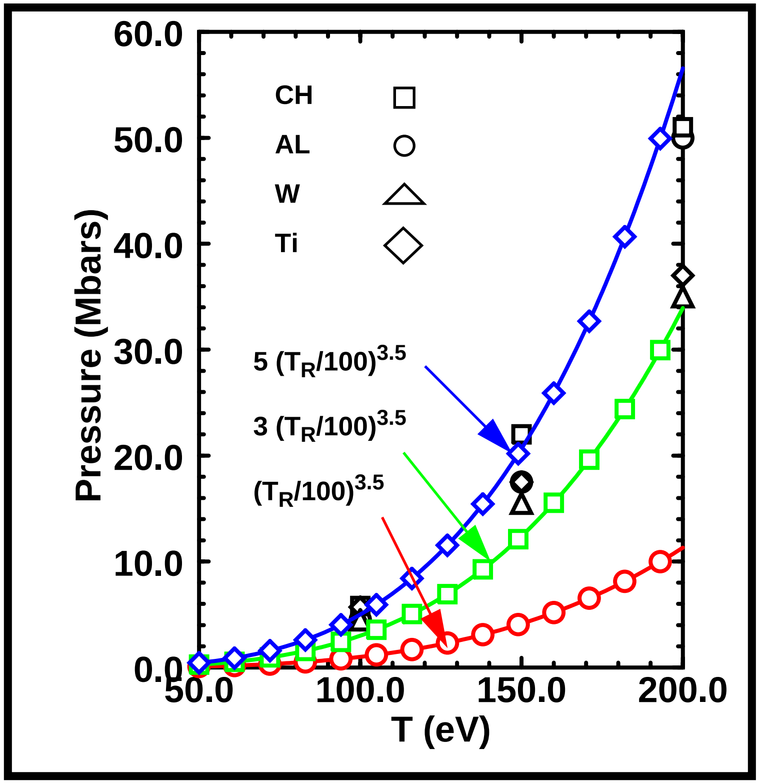
# One simple way to influence the pulse is to use ablators.



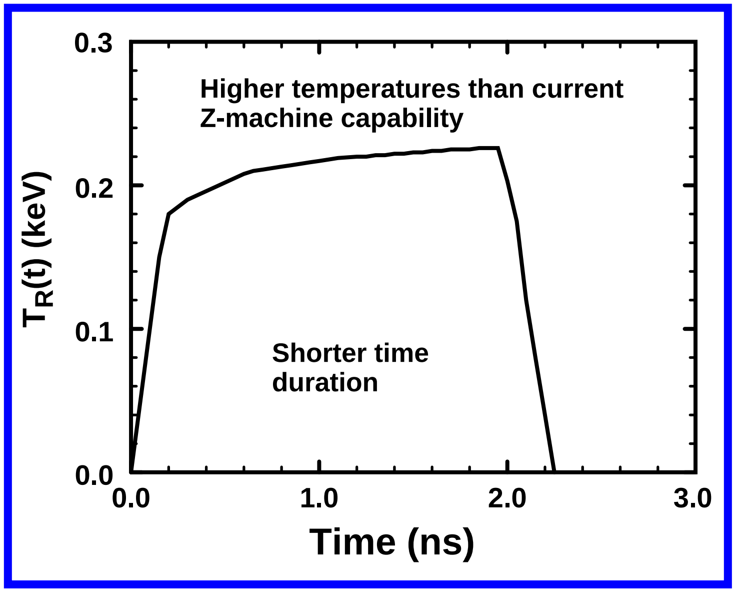



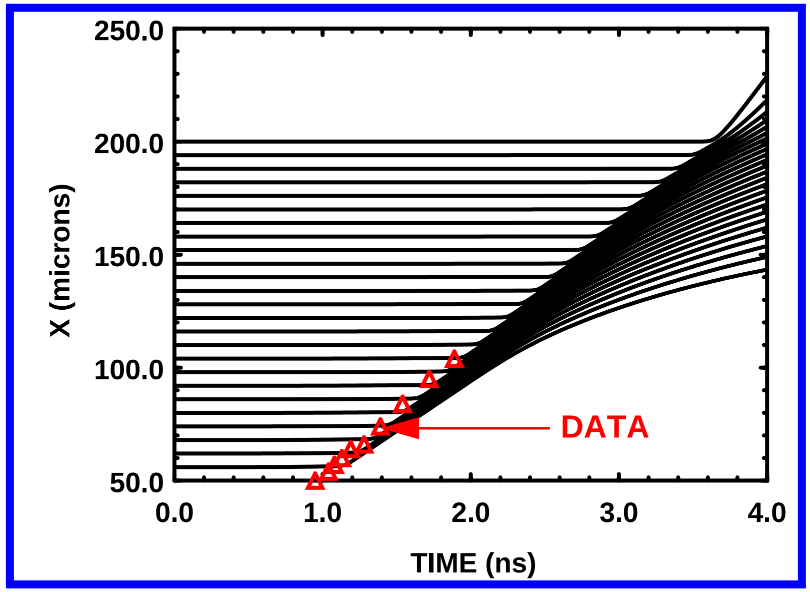

**ASP calculations of the pressure at the CH/W interface agree with Brand X.**

**ASP pressure scaling at high Z does not agree with Brand X.**



# We have some confidence in the application of ASP: NOVA wedge shot comparison.

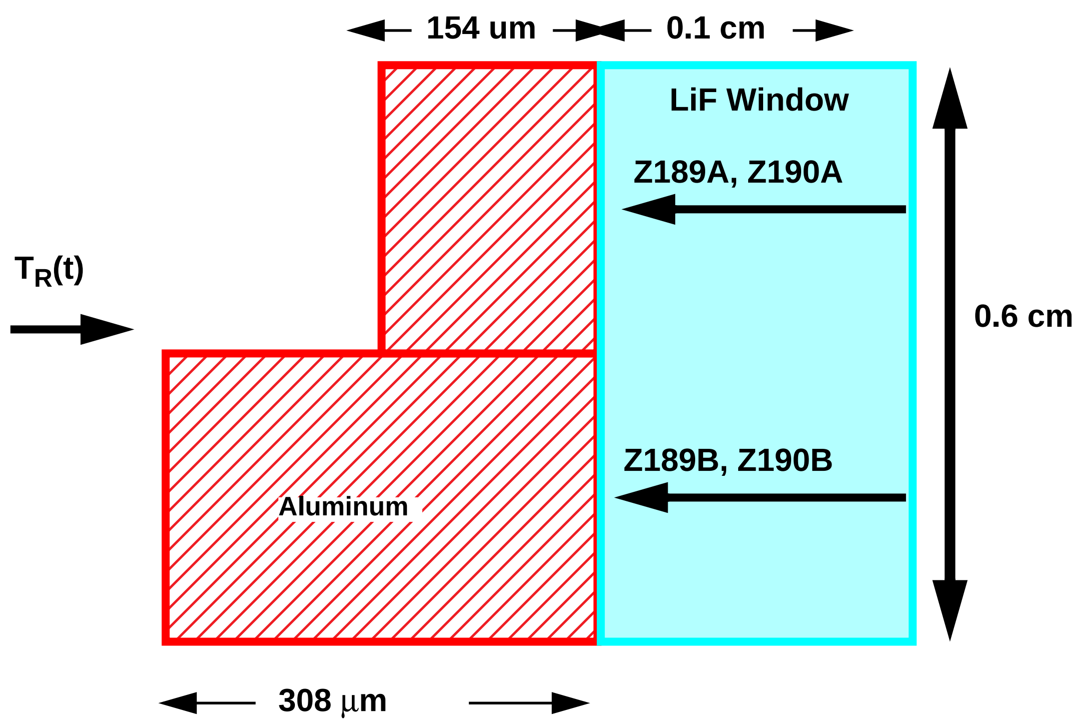


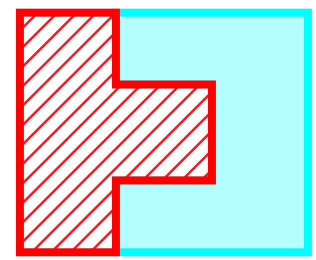

**See Lindl's review, Phys. Plasmas, 1995, Vol. 2, No. 11, 3933**

**We are not trying to do what this data was used for on NOVA, which was to contribute to a self-consistent prediction of the drive for a NOVA hohlraum.**

# Shots Z189 and Z190 were the first shock wave experiments on the Z machine that produced decent VISAR data.

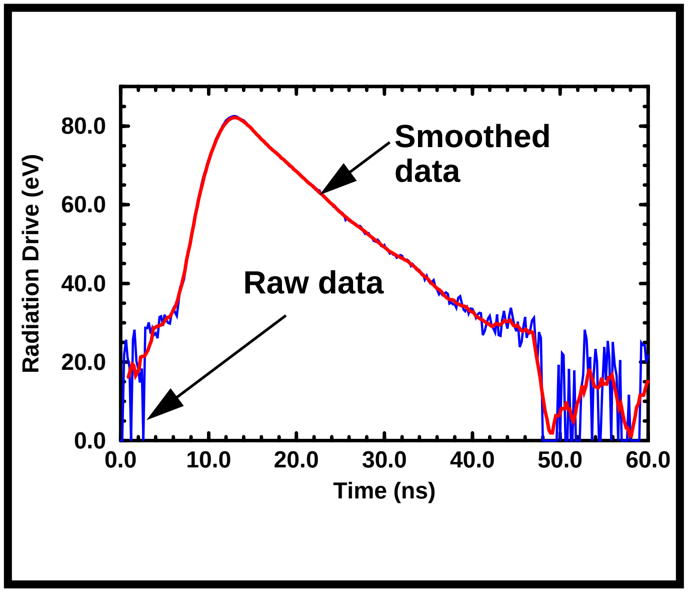



For these experiments, this is not an axisymmetric package. A sample such package is suggested below.

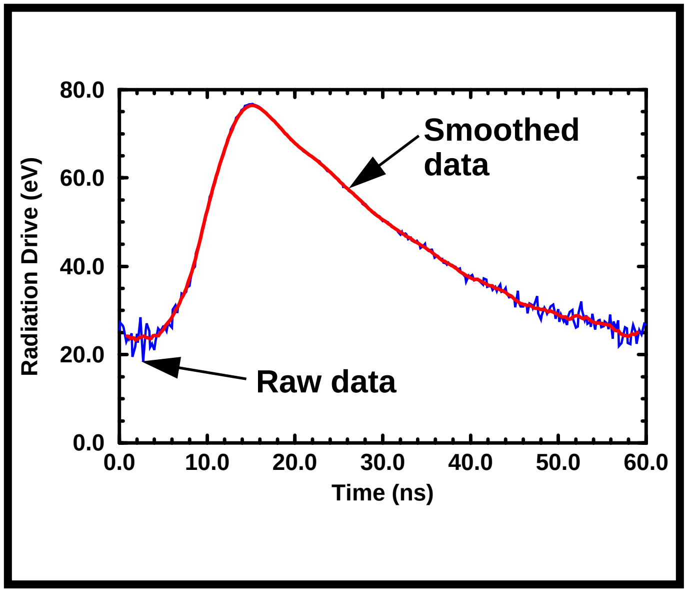


# The drive characterization is the greatest uncertainty in this analysis.

**Z189**

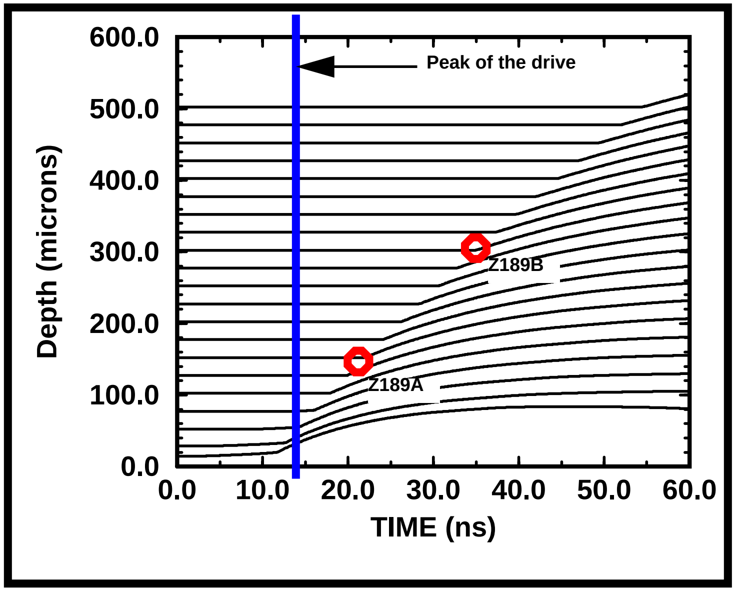



**Z190**

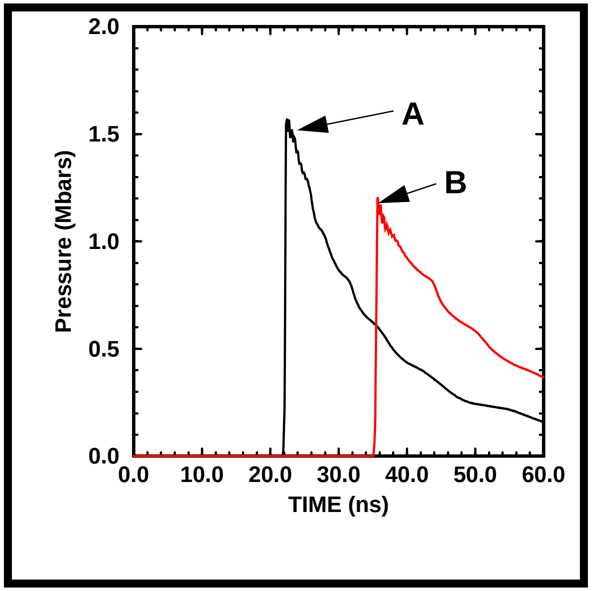



**The difference in peak drive temperatures can be accounted for simply by the increase in volume of the secondary hohlraum in shot Z190.**

# Z189 t-x diagram and diagnostic pressures:

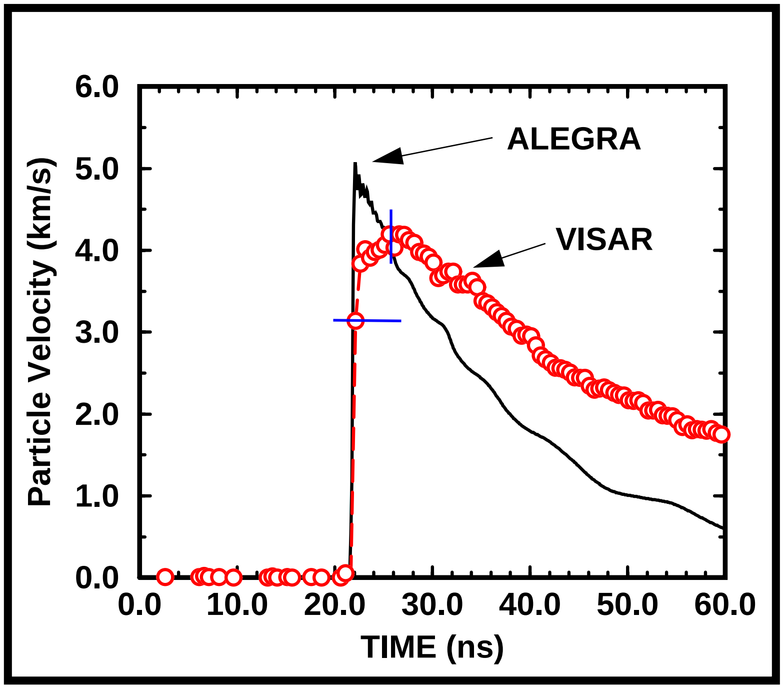


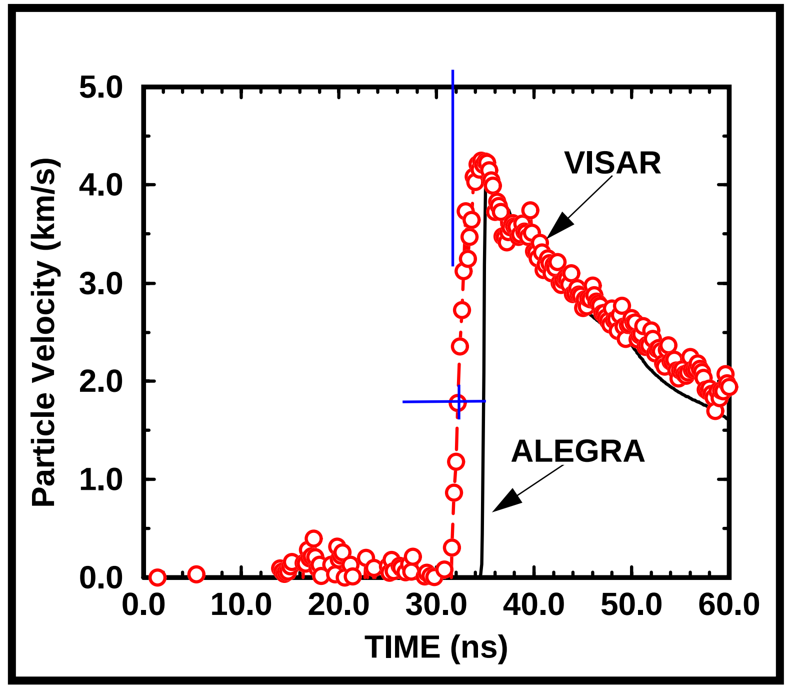

t-x diagram showing diagnostic locations.




Predicted pressures at diagnostic locations.

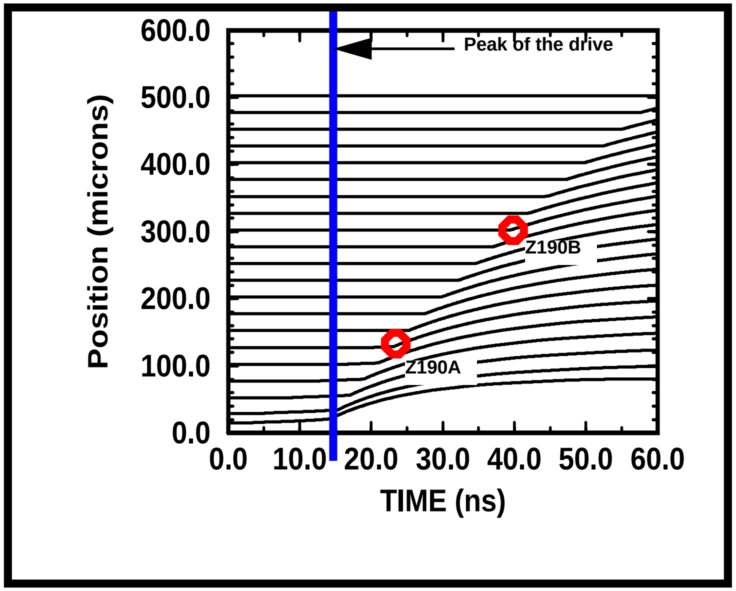
# Z189 calculation - experiment comparisons:

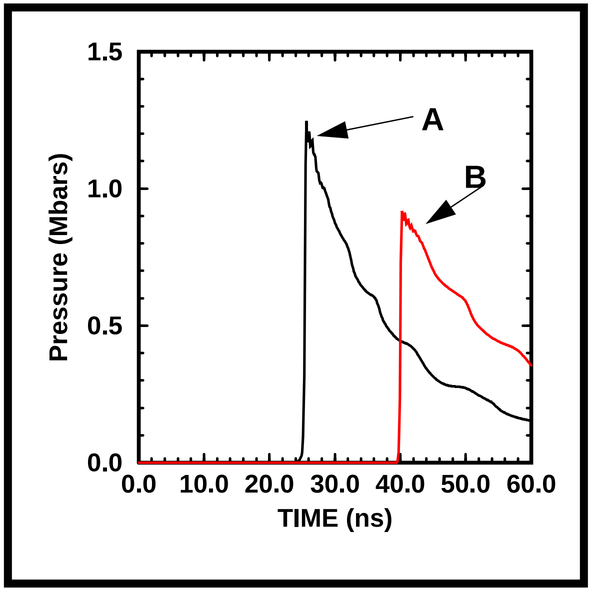



**Particle velocity non-peak error bars for Z189A are smaller than the symbols.**

# Z190 t-x diagram and diagnostic pressures:

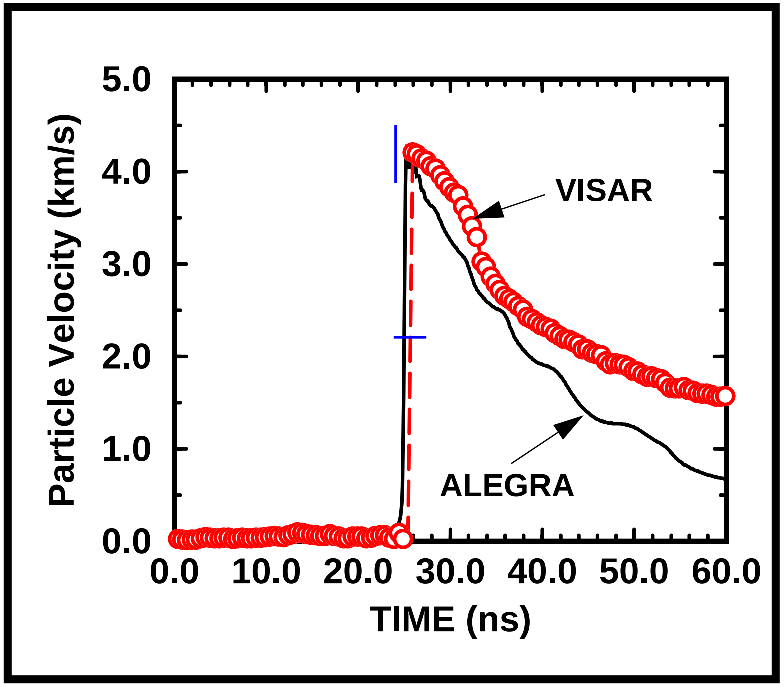


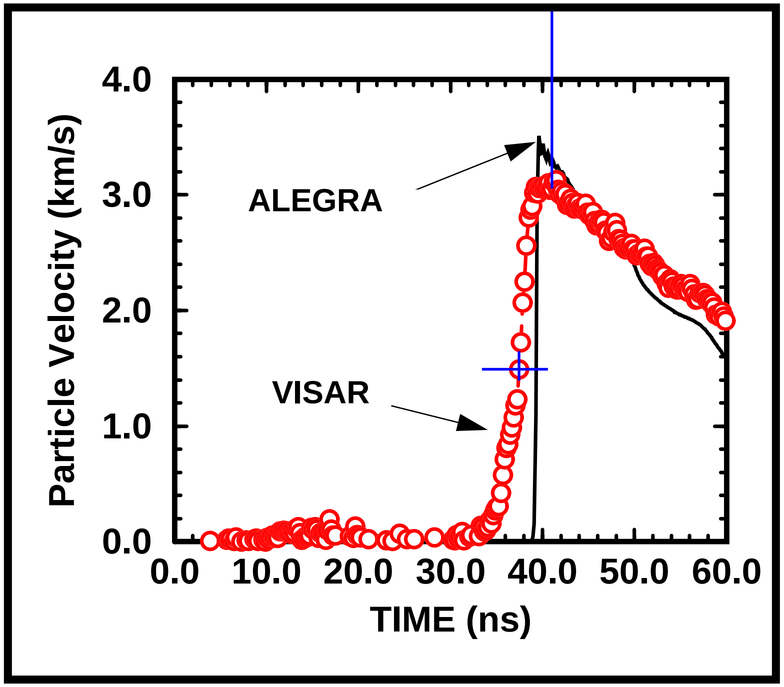




**t-x diagram showing diagnostic locations.**

**Predicted pressures at diagnostic locations.**

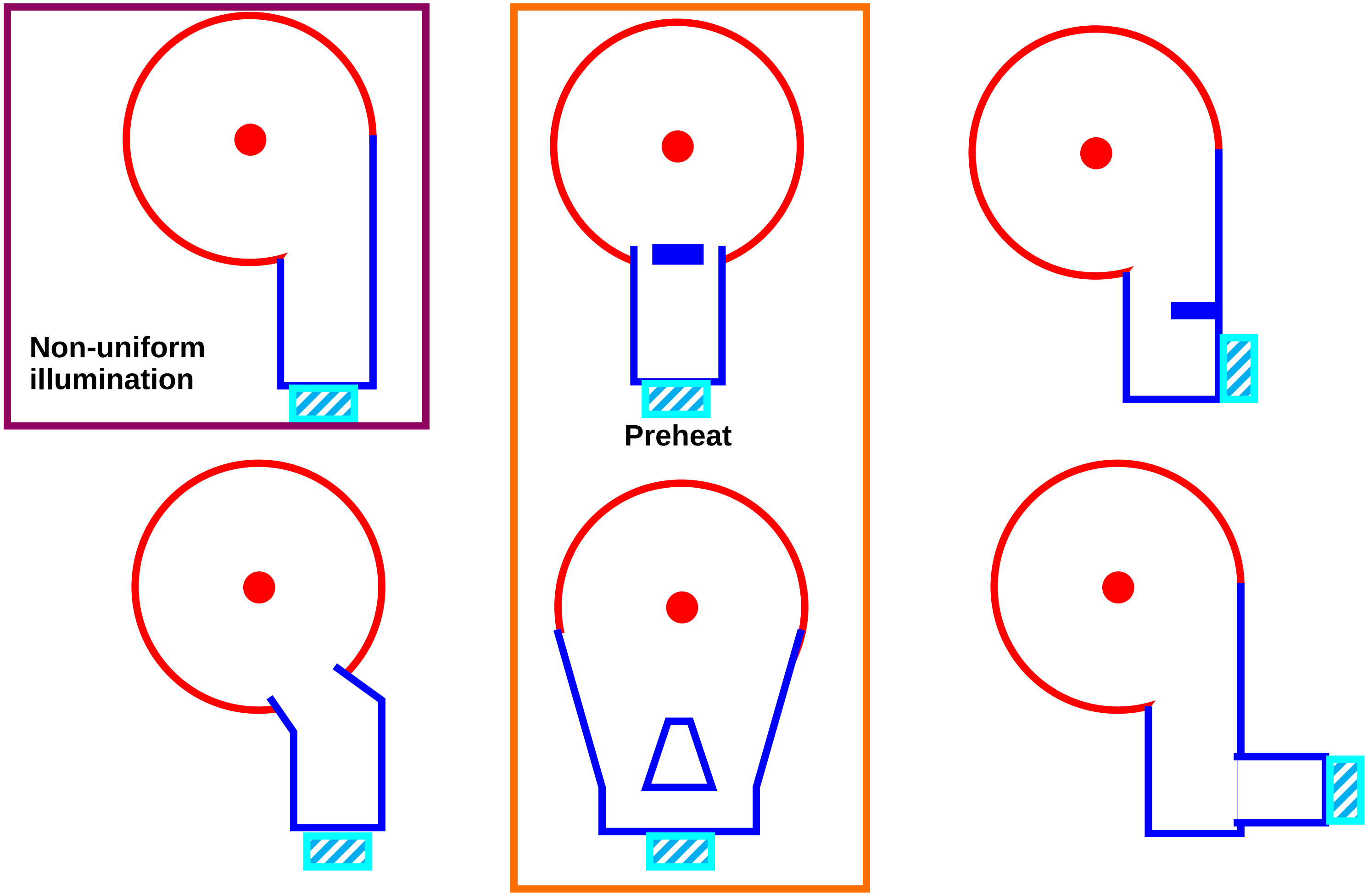
# Z190 calculation - experiment comparisons:




**Particle velocity non-peak error bars for Z189A are smaller than the symbols.**

# There are a lot of secondary hohlraum possibilities.




(a la M. Douglas)

# Where is this work going?

**First, start using the multi-group diffusion package (this is our path to 3-D, massively parallel rad-hydro).** ✓

**Second, get the VISAR diagnostic working effectively in the Z environment.** ✓

**Third, apply a more rational basis for secondary hohlraum design:**

- 3-D view factor plus simple energy/flux balance ✓
- LASNEX (?) for 2-D approximate hole closure calculations
- Would like to do 3-D hole closure calculations
- Worried about non-uniform illumination and the low-temperature run-in ✓

**Fourth, start gathering and using data:**

- Obvious EOS interest (Beryllium - July or August)
- Data for rad-hydro validation appropriate for Z machine work ✓
- Possibility of using VISAR data to diagnose the low temperature run-in

**Fifth, start thinking about "complex" pulse shaping for isentropic loading and launching flyer plates. (Jeff Lawrence)** ✓