Muon Collaboration

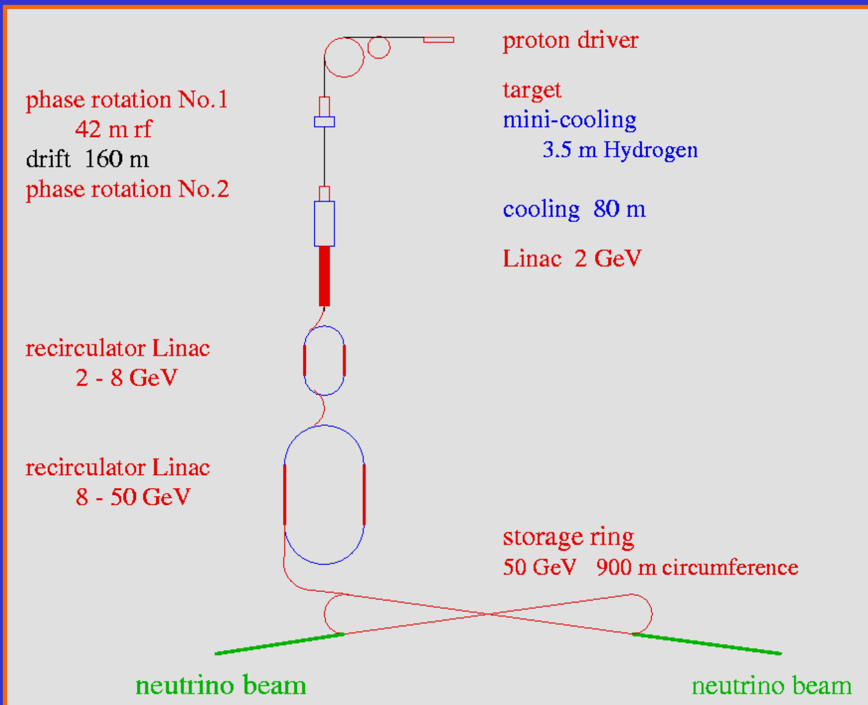
# Primary Target Systems for a Muon Collider / Neutrino Factory. What the experimental effort has taught us thus far


**N. Simos, H. Kirk, S. Kahn, P. Thieberger, R. Samyulak, BNL**

**A. Fabich, J. Lettry, CERN**

**K. McDonald, Princeton U.**

# Neutrino Factory Layout – Target Station Schematic



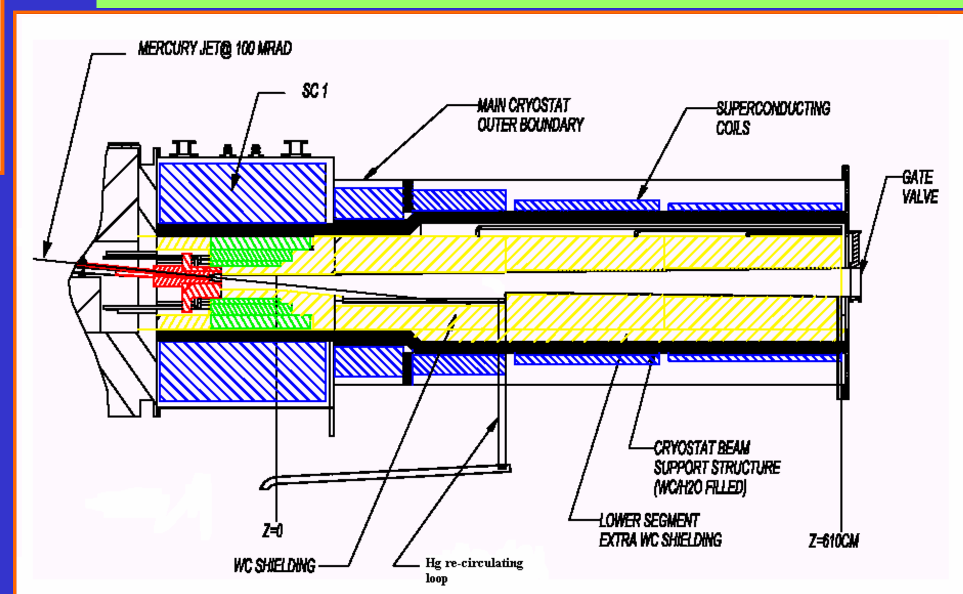

**High Z target options**

Liquid Hg Jet

solid (inconel, superInvar, vascomax)

**Low Z Targets (carbon-based)**

**ALL within a 20 Tesla Field Solenoid**



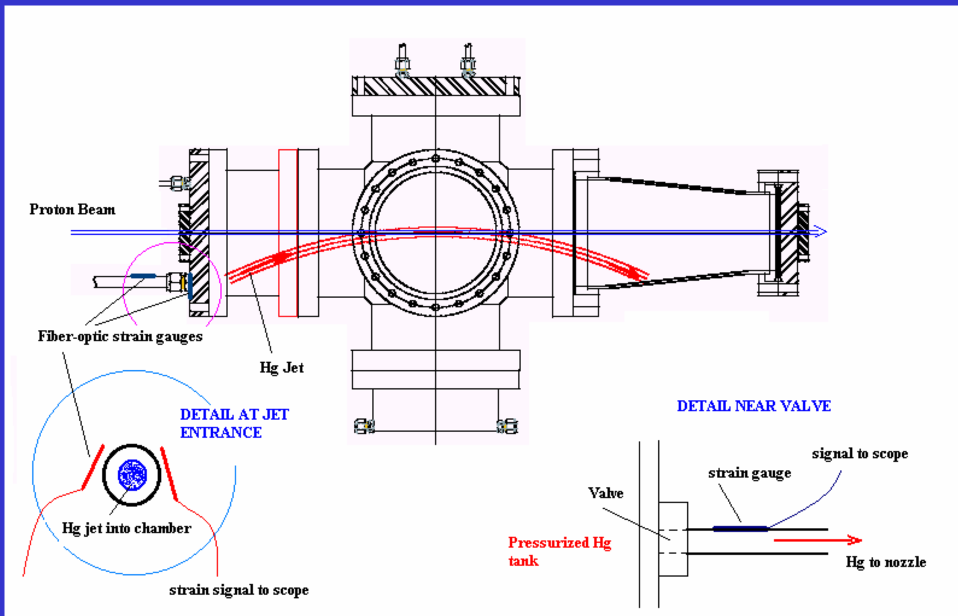
# Things we need answers for

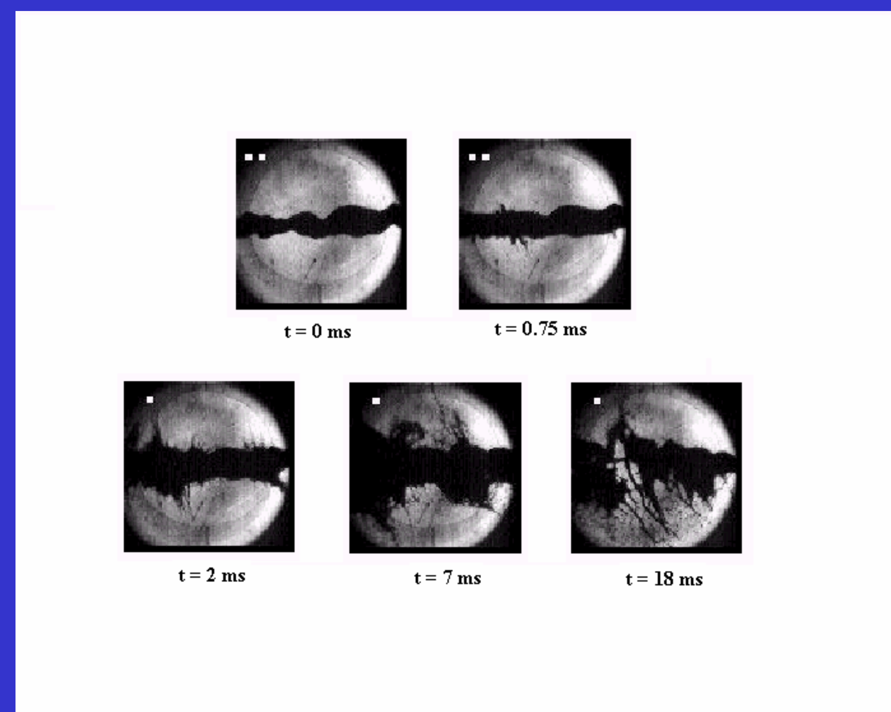
- **Hg jet target response to beam/magnetic field**
  - **ability to pass a train of micro-pulses before jet destructs**
  - **assessment of how violent jet destruction is**
  - **stability of jet entering 20 Tesla magnetic field**
- **Solid target survival chances (graphite, carbon-carbon, inconel, superInvar, etc.)**
- **Beam window survival – KEY issue since Hg is involved !!!**

**<u>IN THE PROCESS ……</u>**

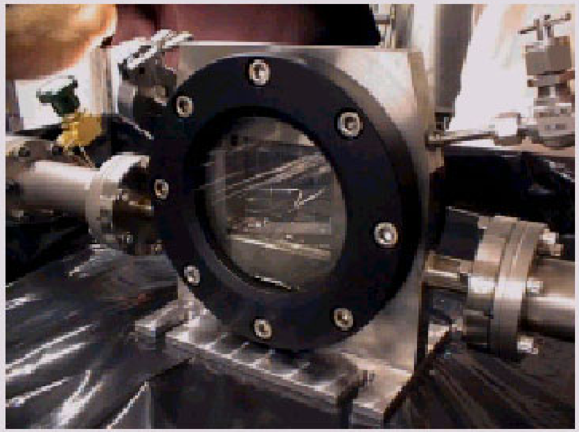
- **Push the AGS intensity to 16 TP and beam spot to 0.5 mm RMS sigma**
- **Experiment with and identify best candidate materials through measured responses**
- **Validate prediction models against measurements to gain confidence in predicting material response and/or failure at extreme conditions**
- **Finally, use experimental results to benchmark energy depositions predicted by the various Monte Carlo codes**

# Hg Jet Tests with no Magnetic Field

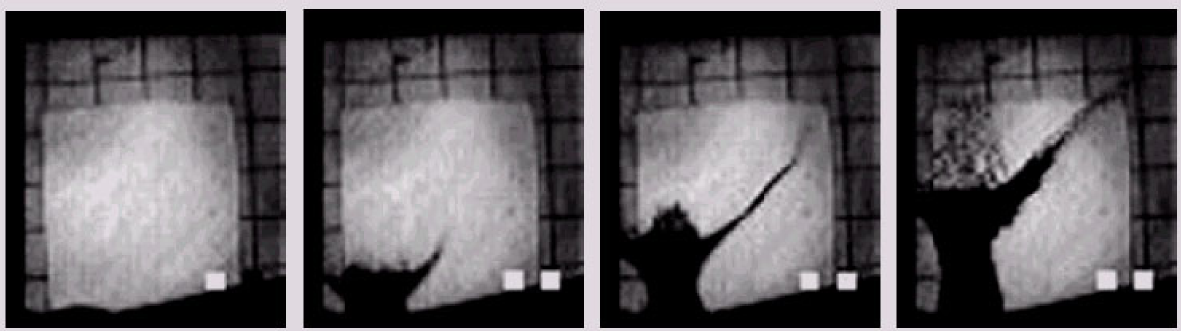


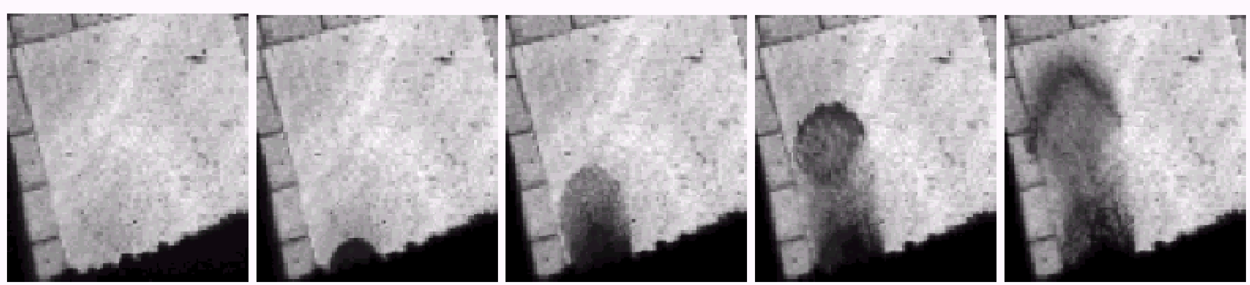



# CERN Hg Target

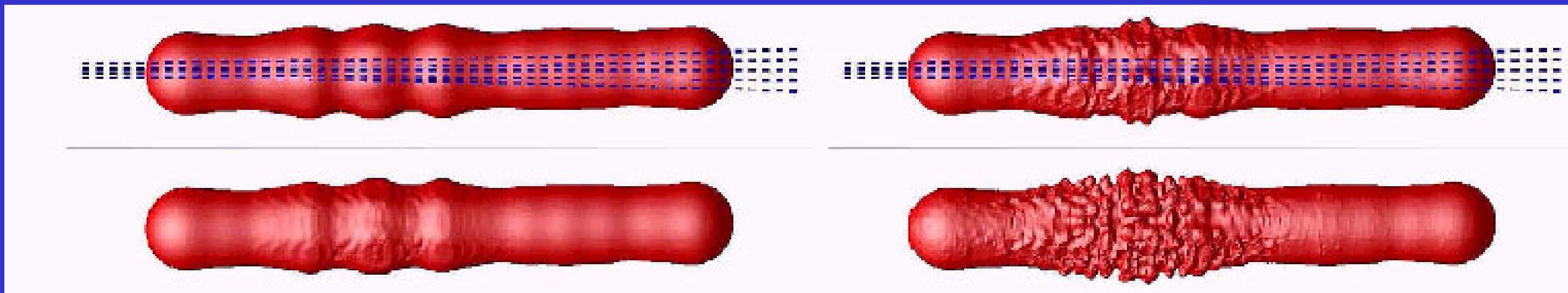


Exposures of 25 $\mu$s at
$t = 0, 0.5, 1.6, 3.4$ msec,
$\Rightarrow v_{\text{splash}} \approx 20 - 40$ m/s:

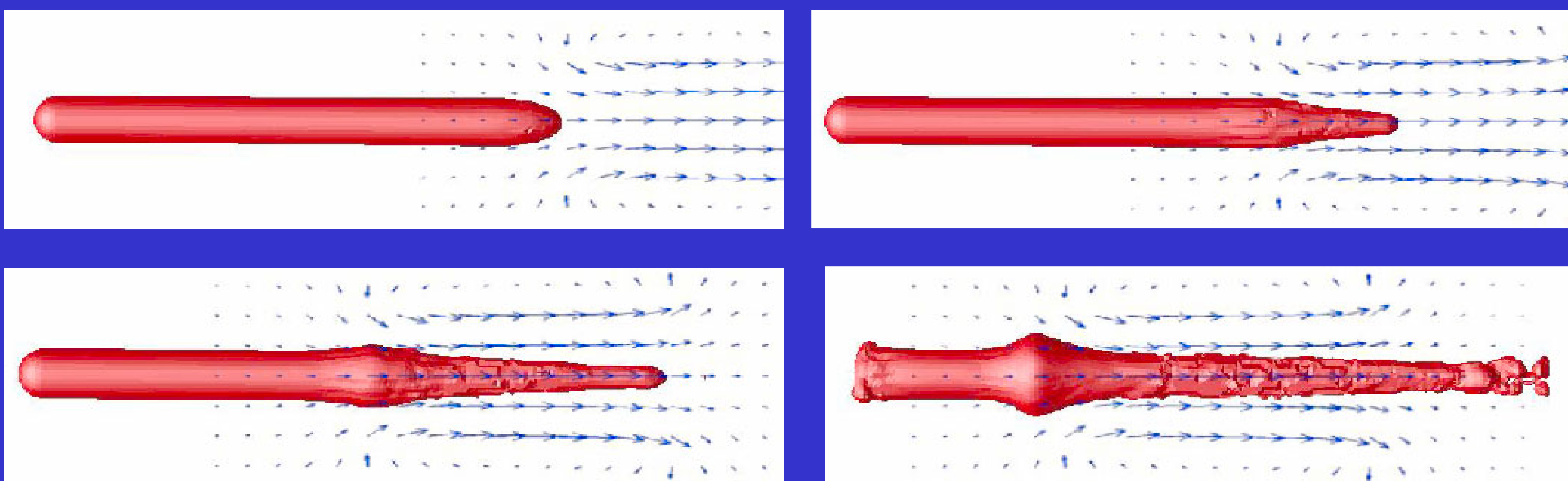




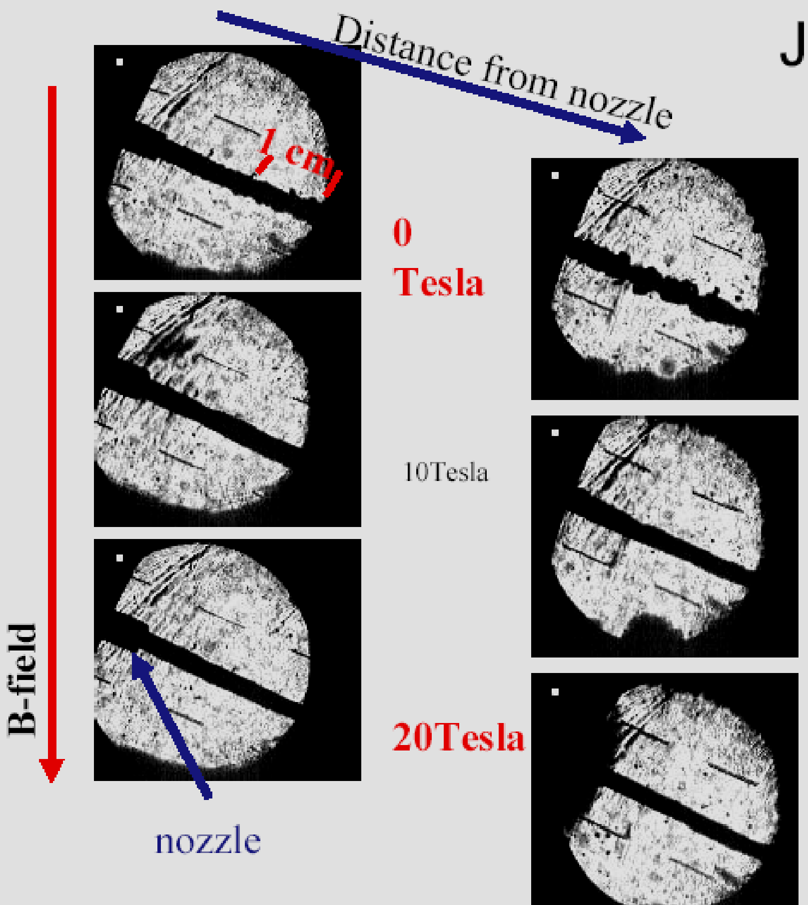
## Proton Beam – Hg Jet Interaction



## MHD Simulation



# CERN Hg Jet/Magnetic Field Study

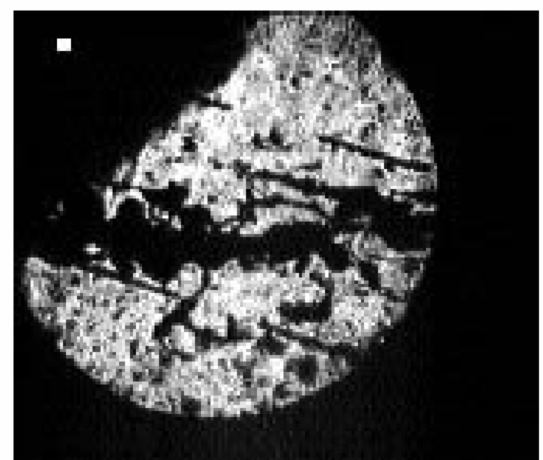



Jet traverses $B_{max}$

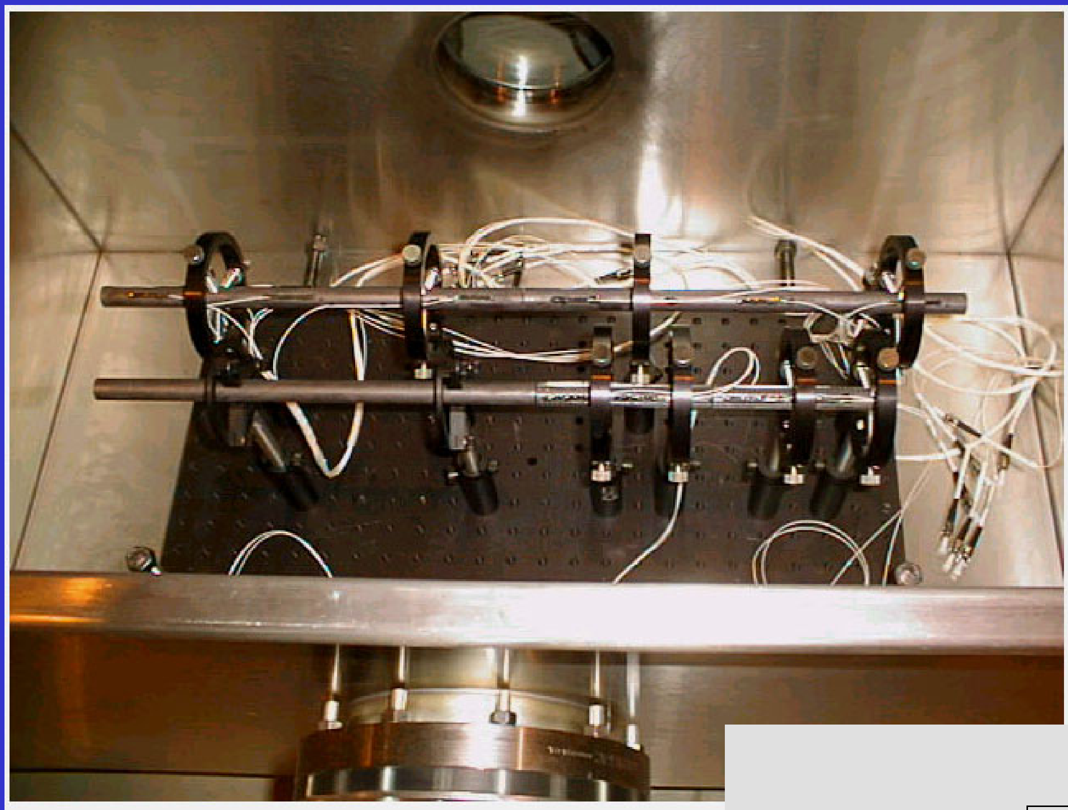
This **qualitative behaviour** can be observed **in all events.**

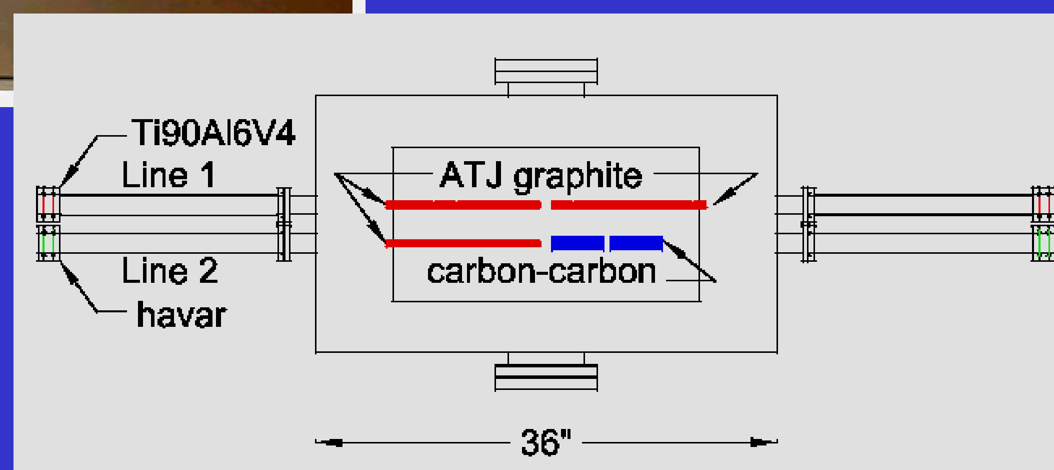
(court

Magnetic Field FAILED to stabilize a turbulent Jet

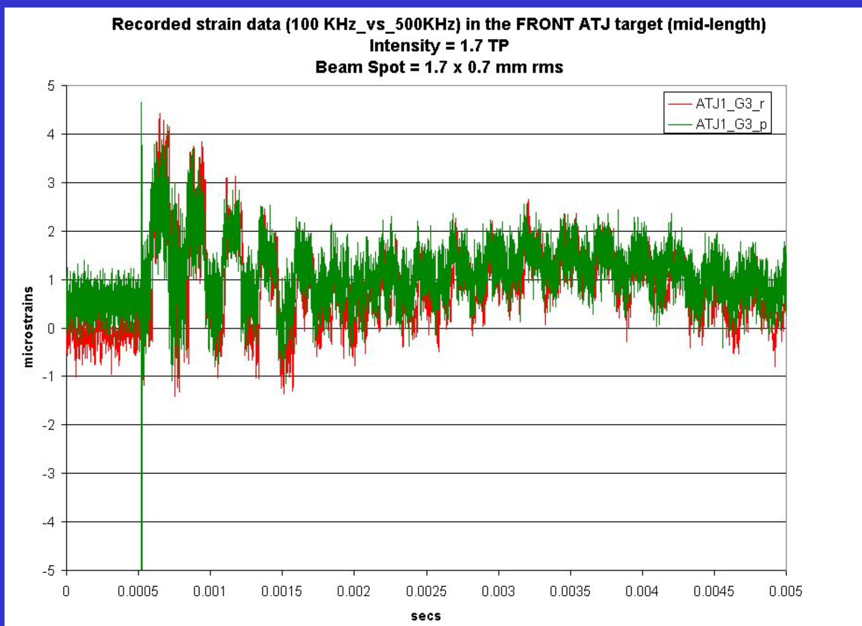


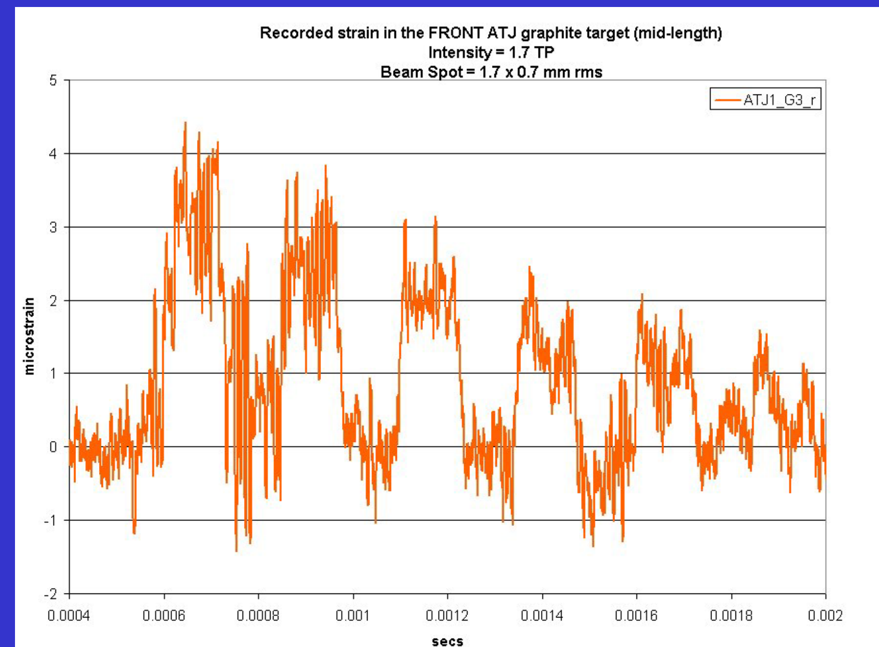
# E951Target Station Set-Up
# Graphite & Carbon-Carbon Targets





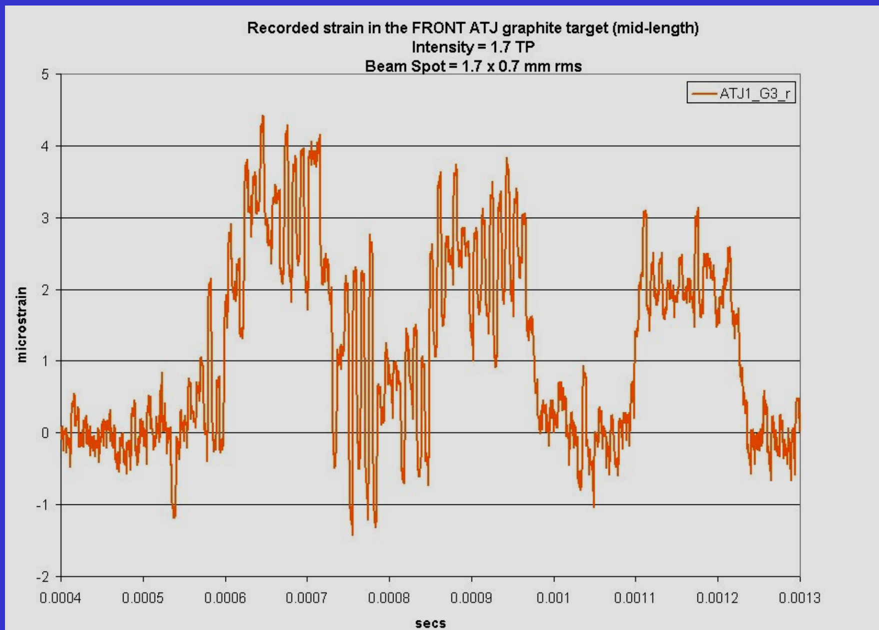
# ATJ Graphite Strain Data

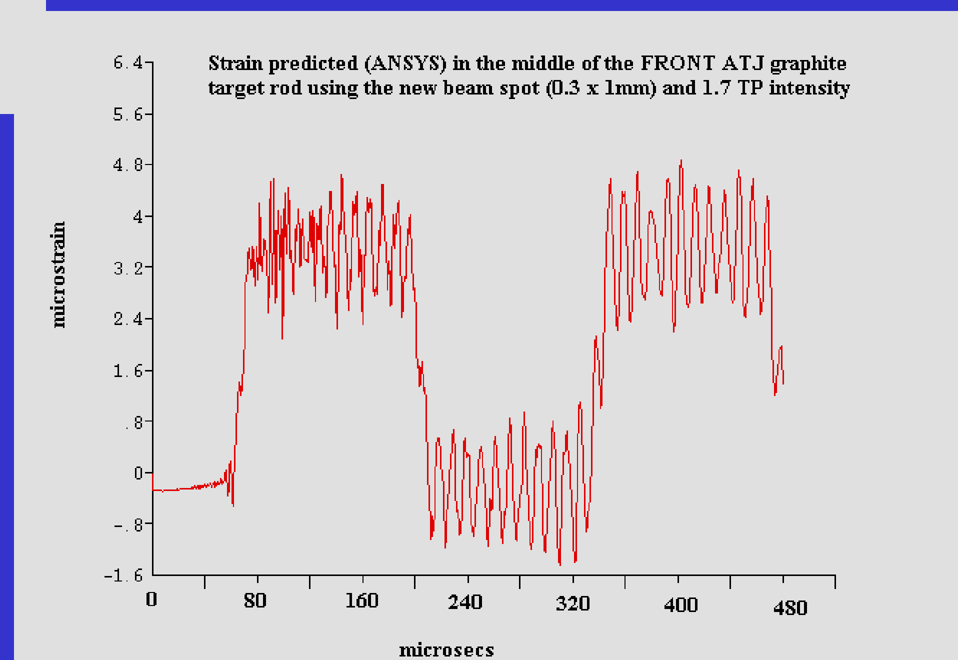


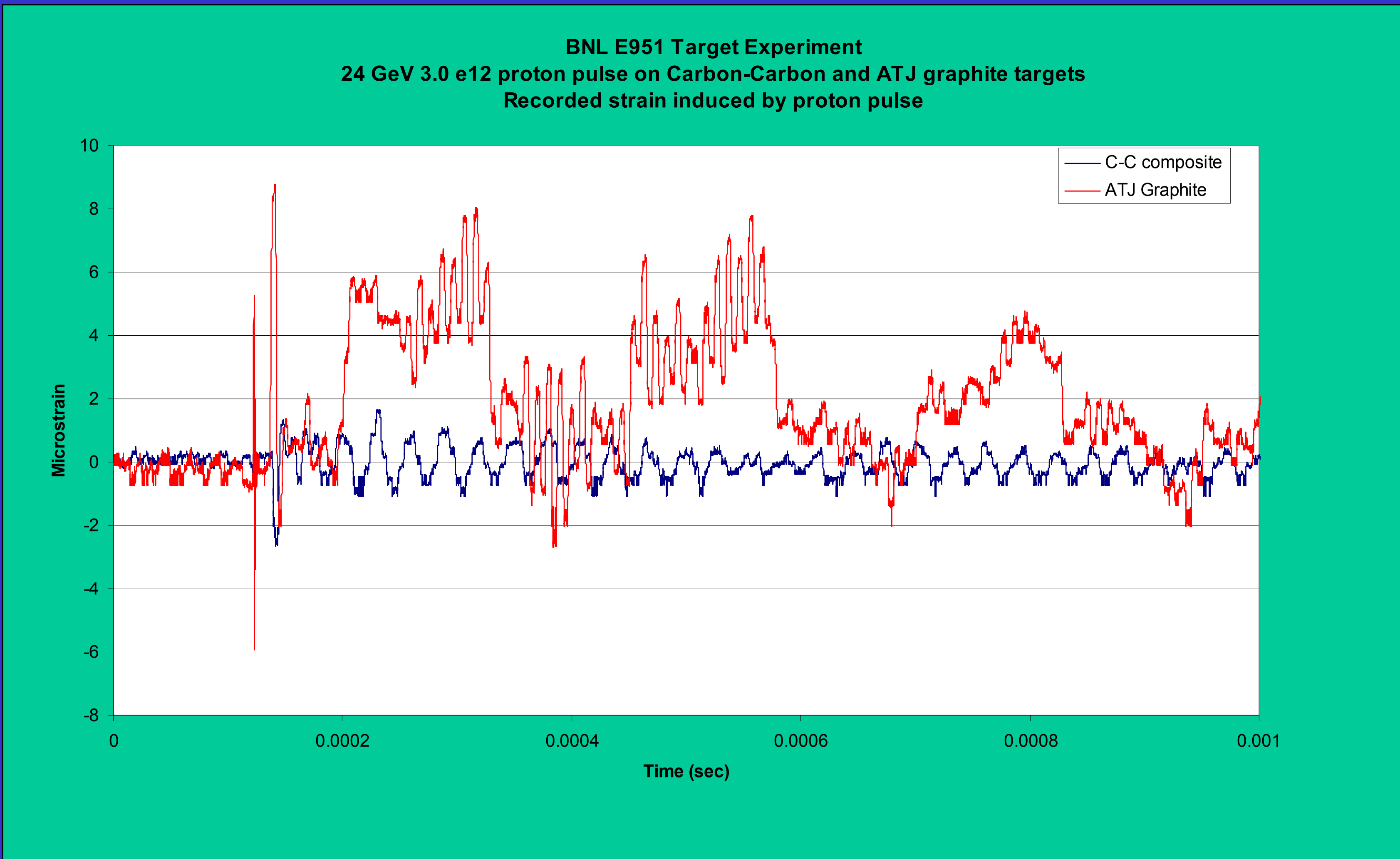
# ATJ Graphite Strain Comparison

## BASIS FOR HADRON CALCULATIONS BENCHMARKING



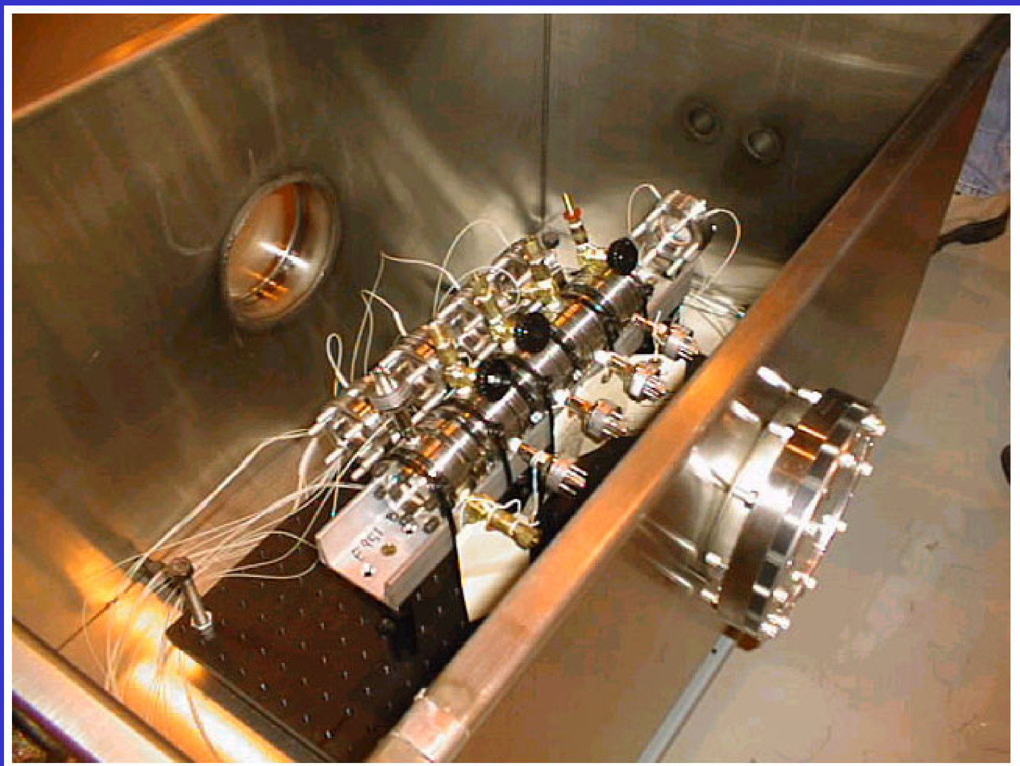



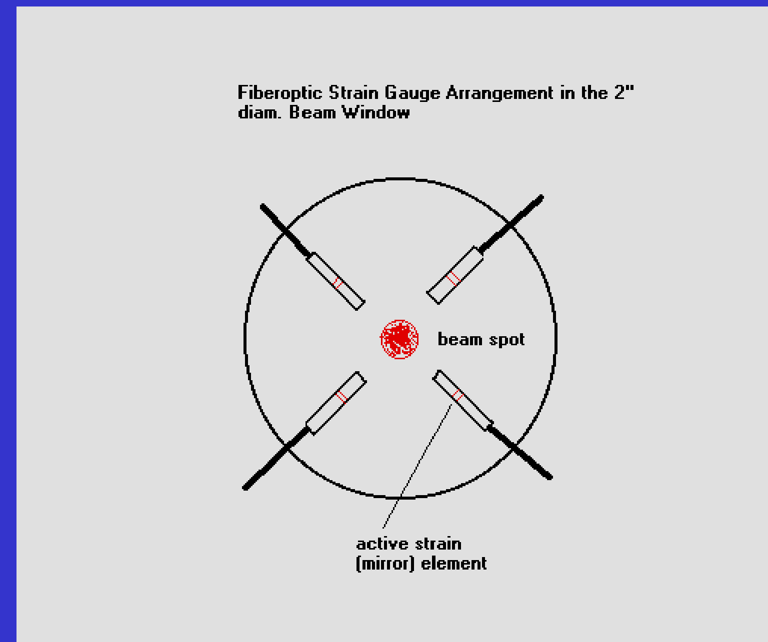
# Strain Comparison: Graphite vs. Carbon-Carbon



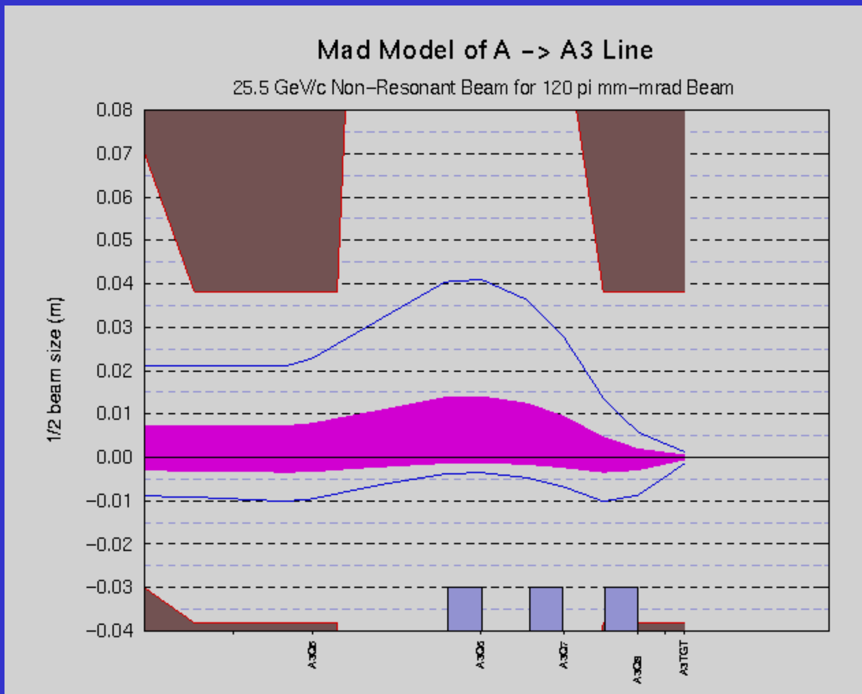
# E951 WINDOW TEST Station Set-Up

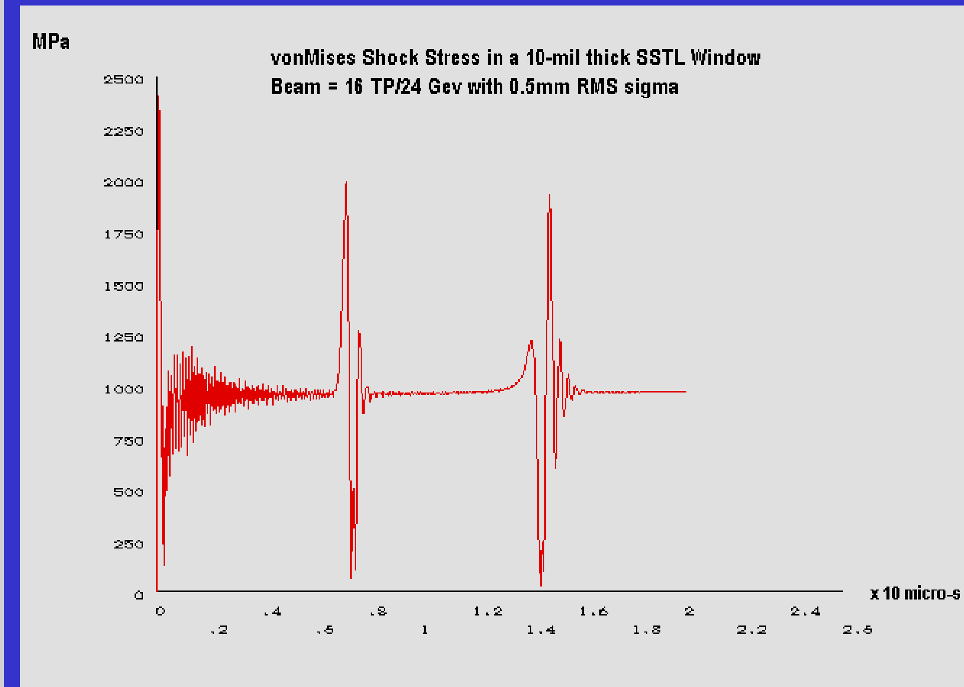
## Fiber-optic Strain Gauges & Double window vacuum monitoring



# What Triggered the Window Experimental Effort



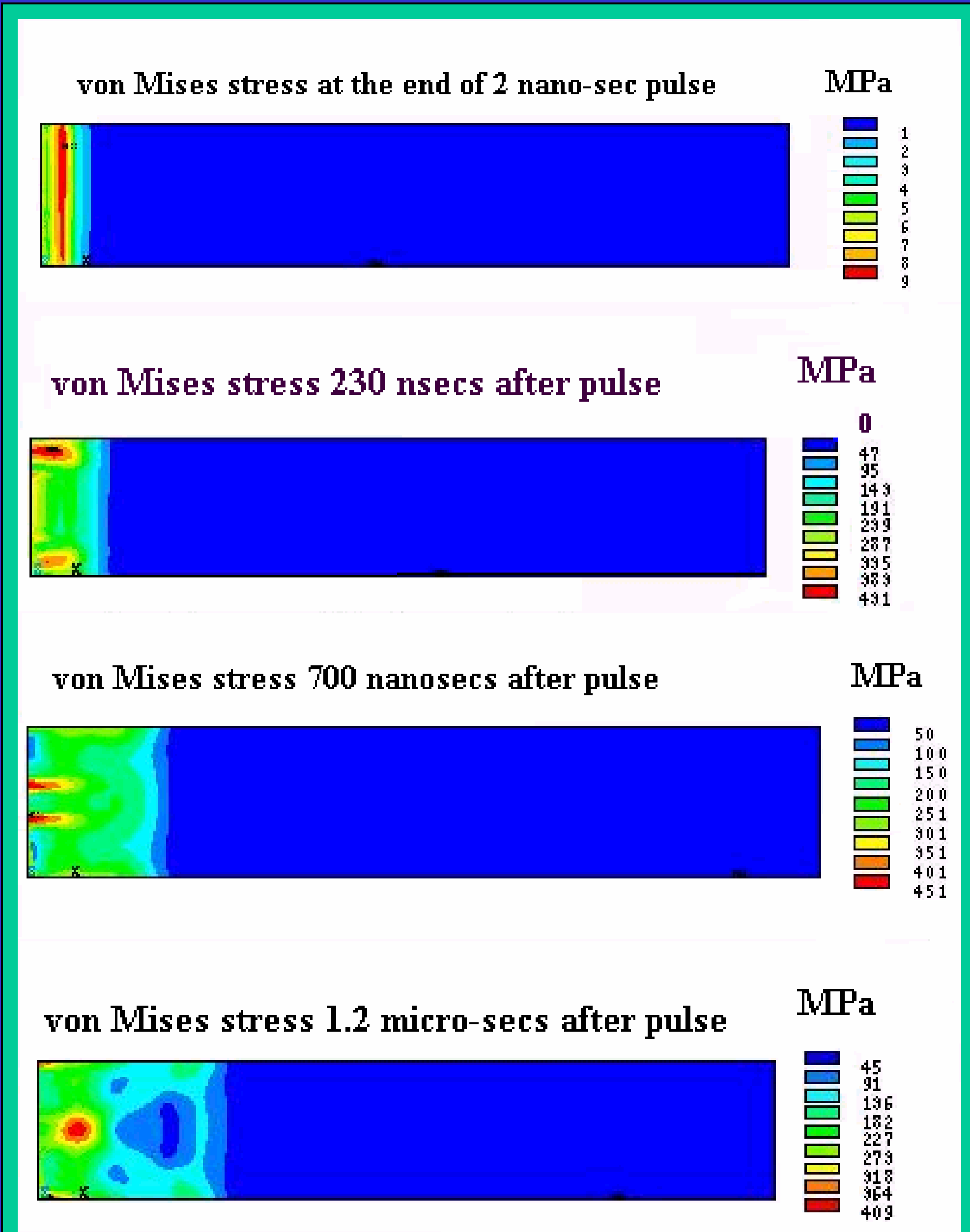




**Beam spot requirement (0.5 x 0.5 mm rms) for target experiment at AGS**

**Induced shock stress in a window structure by 16 TP intensity beam and the spot above will likely fail most materials in a single short pulse ( ~ 2 ns)**

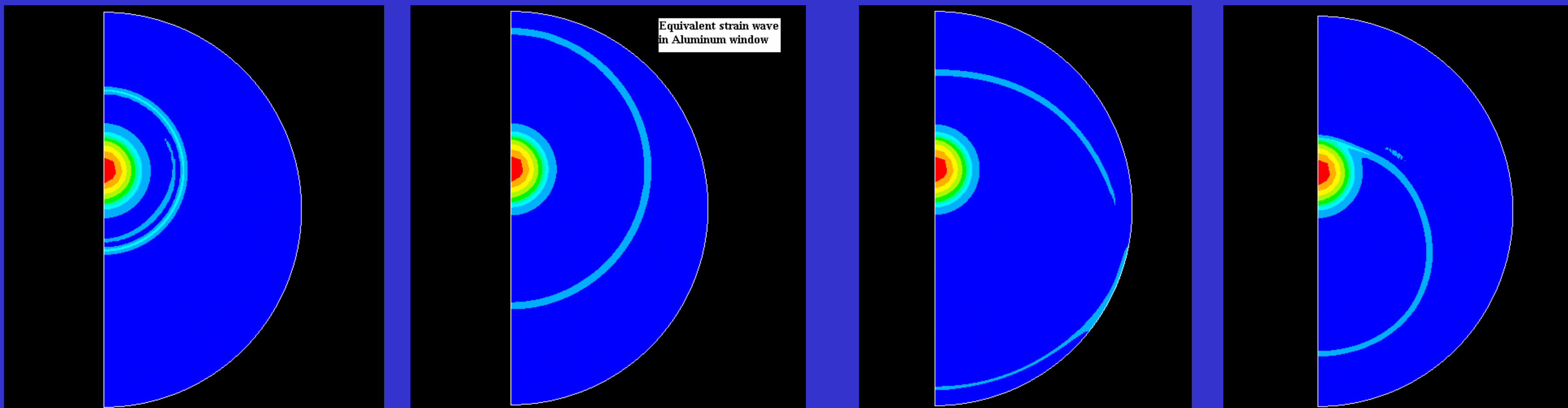
**Figure (right) depicts prediction of vonMises stress in a stainless steel window for the above conditions. Initial shock stress is ~ 3 x yield strength of material !!**

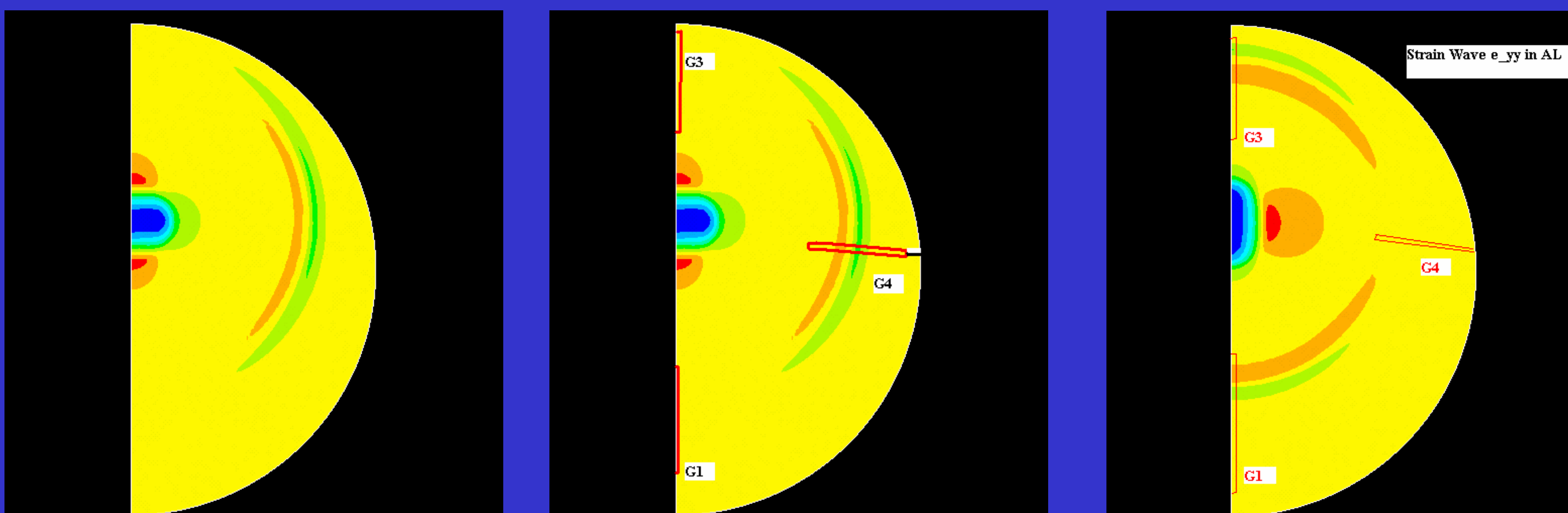
# Mechanism of induced shock stress in windows




- No matter how thin the window is, the reverberation of stress between surfaces is the key issue
- vonMises stress amplitude depends on the spot size (initial compressive load amplitude), thickness of window, speed of sound and pulse shape
- the measurement of strain on the surface is to be used as benchmark of the ability of the model to predict the stress field in the heated zone
- the radial response (stress/strain) and the ability of the pulse to relax depends on the spot size and the pulse structure
- smaller spot size does not necessarily mean larger response at a distance
- smaller spot size definitely means higher stress field in the vicinity of the heated zone

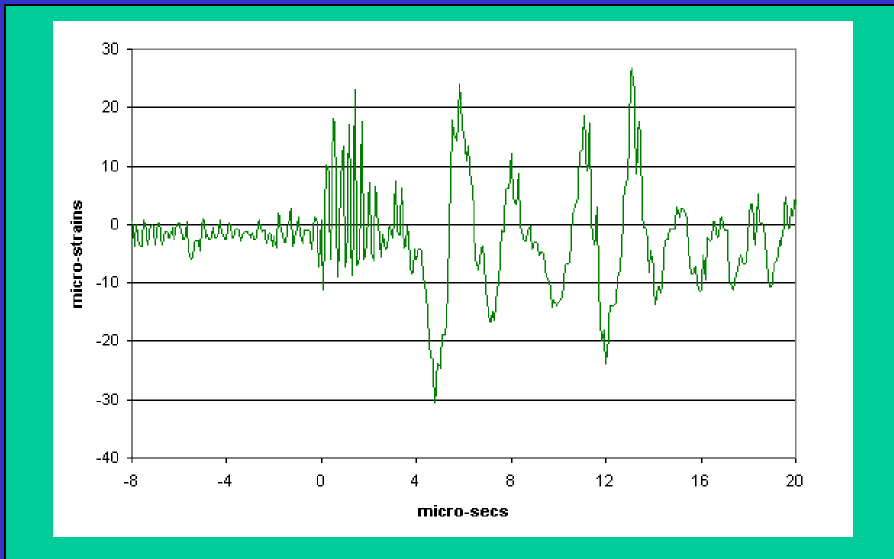
# Simulation Beam Window Strain Waves

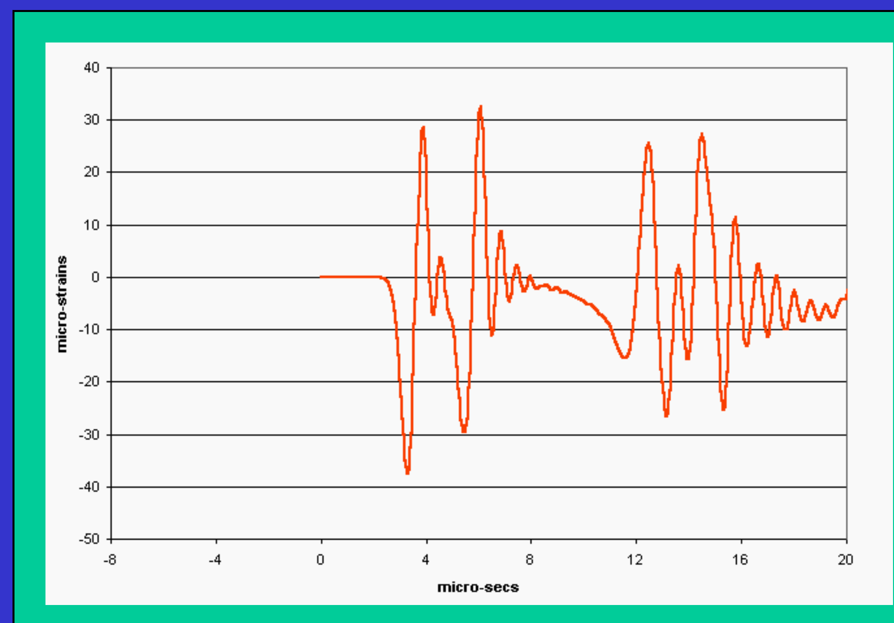


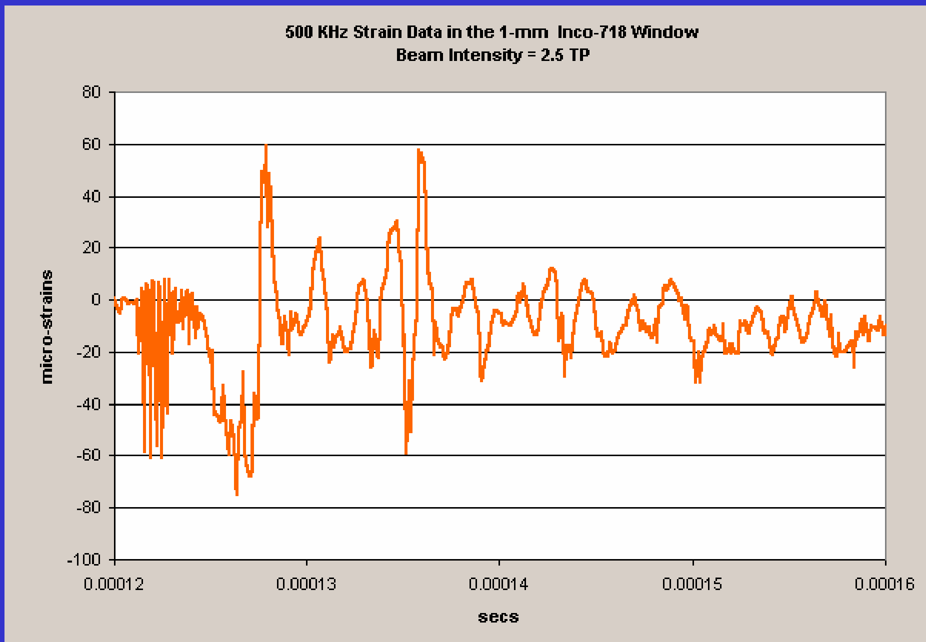
# Aluminum Window Strain Data

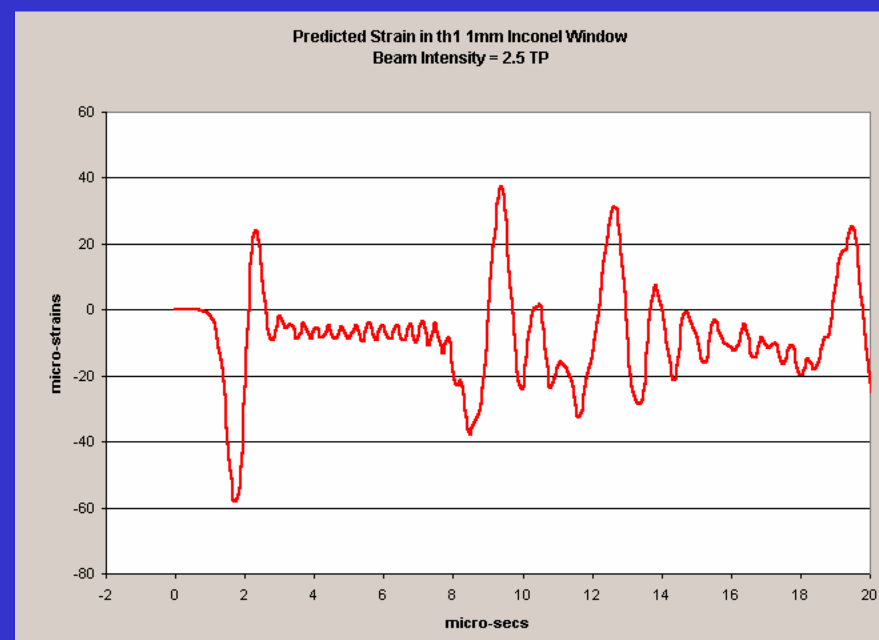
## Experimental data vs. prediction using the new beam spot (0.3 x 1mm)



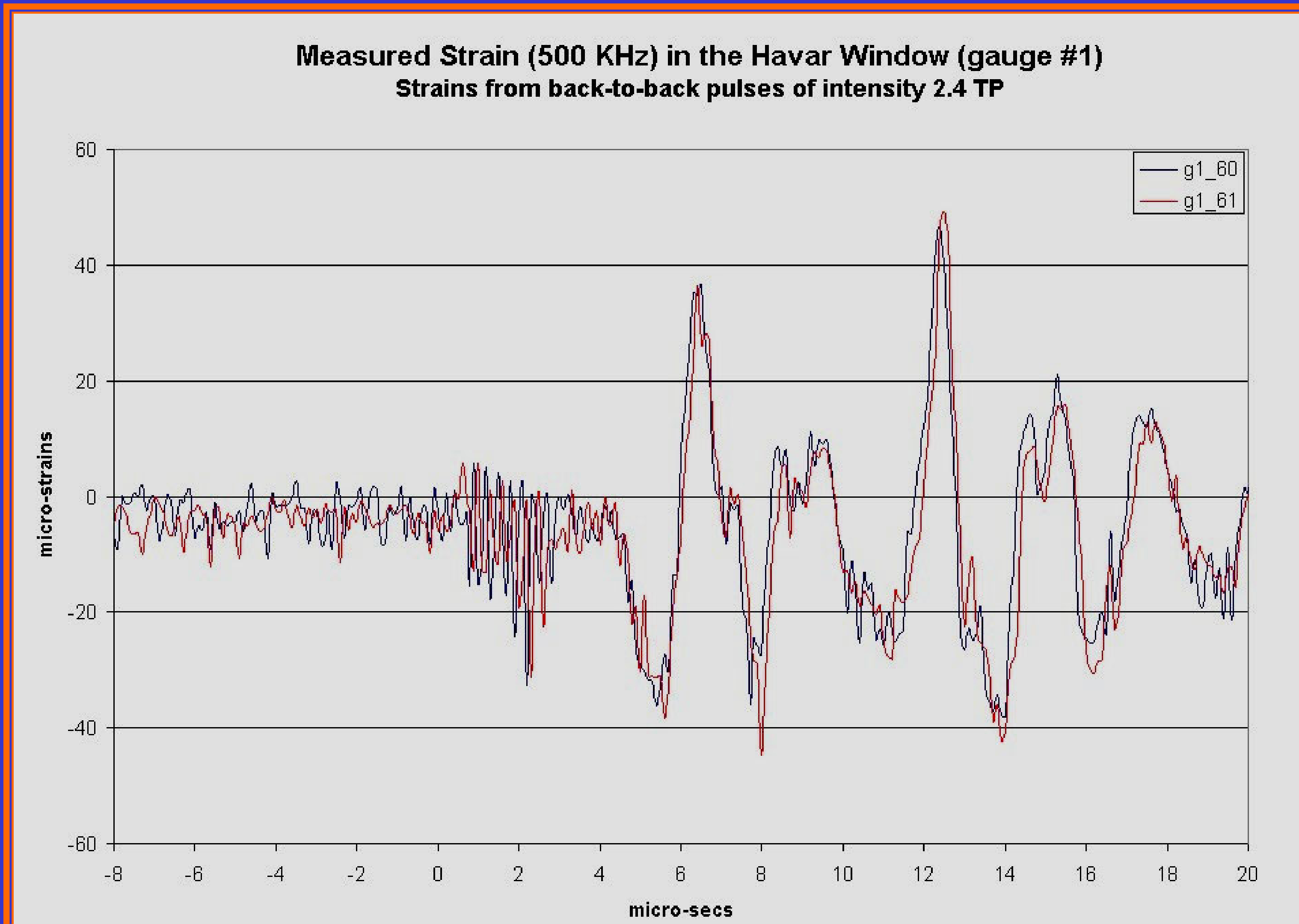



# Measured and predicted strains in the 1mm thick Inconel

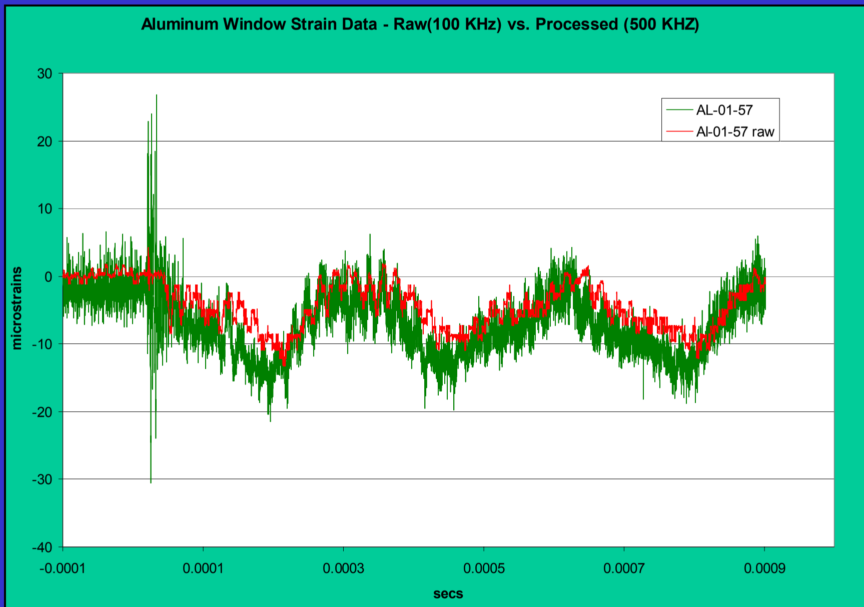


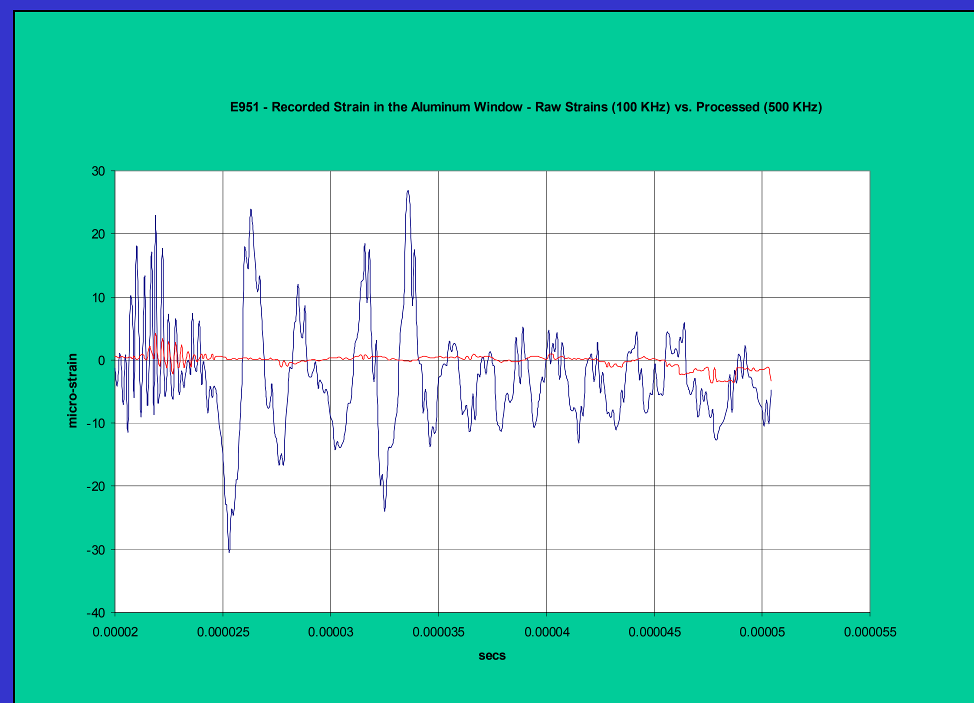



# RECORDED strains in the Havar Window

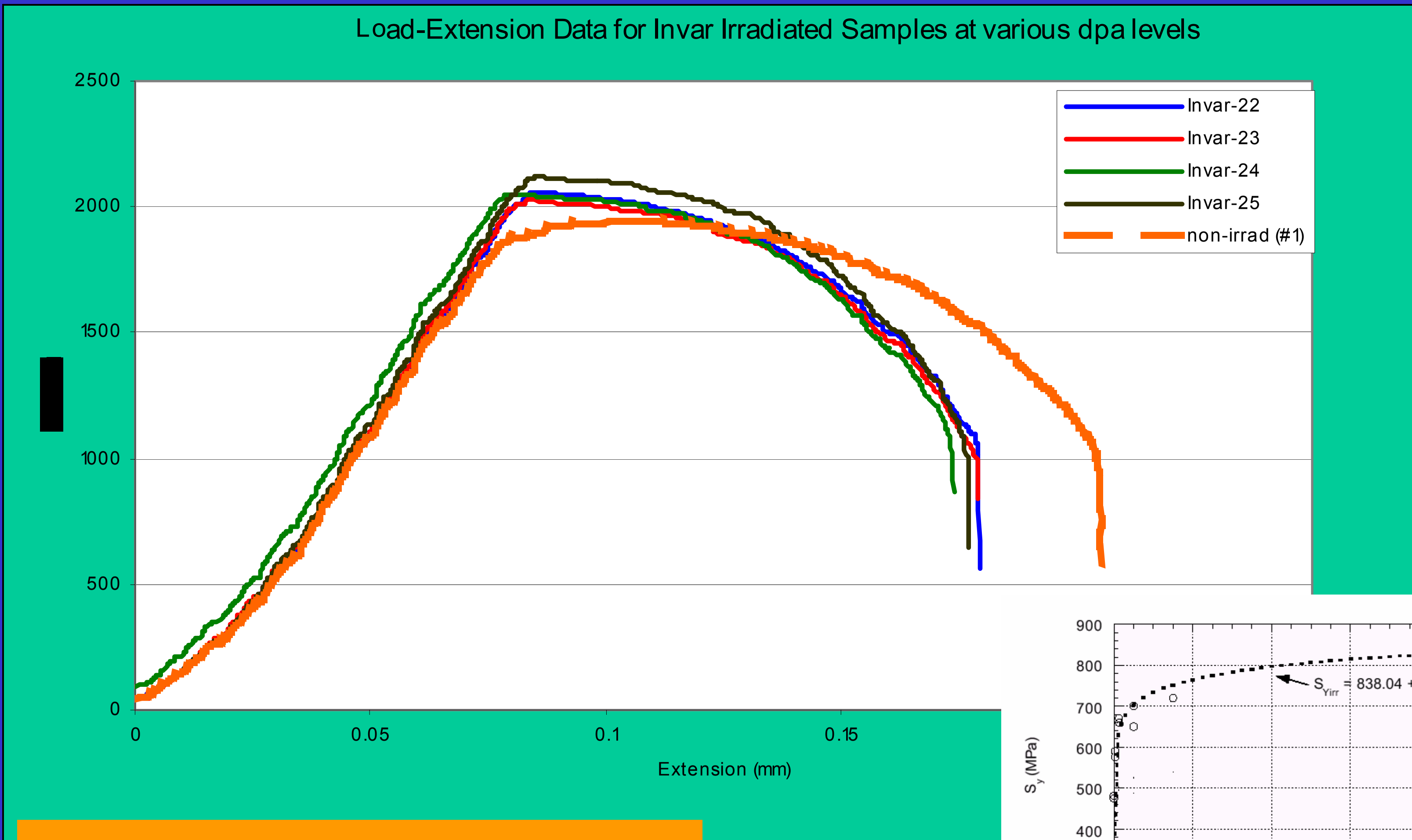


# **Lesson**: You better have the resolution needed, or …



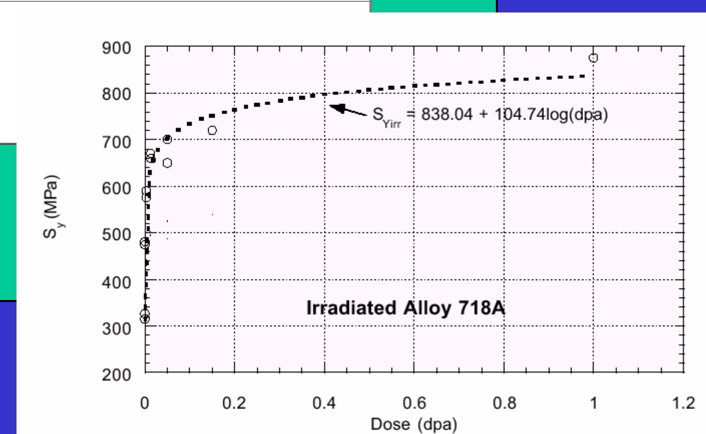



# Solid Target Option: Super-Invar Irradiation Study



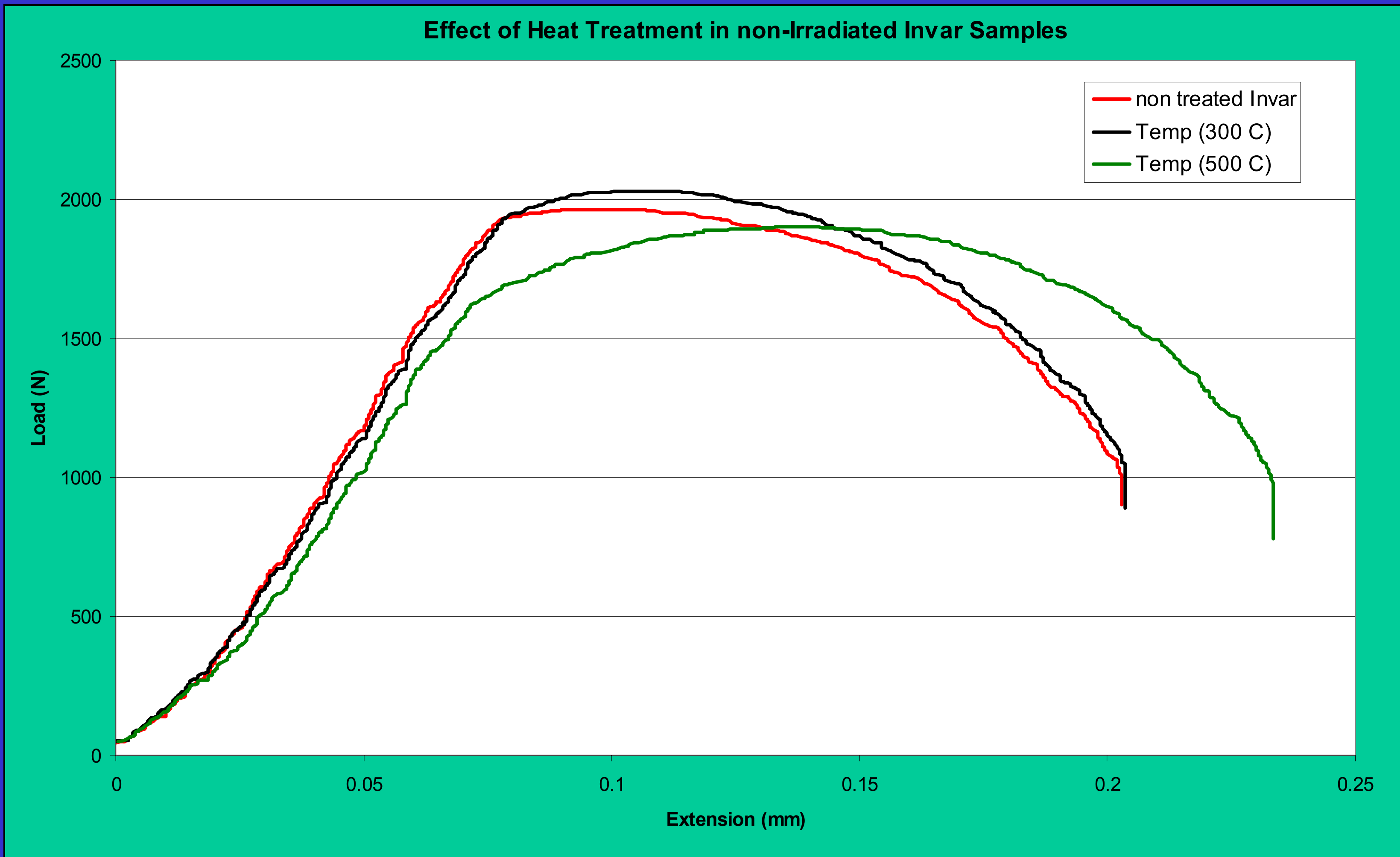

**WHY STUDY super Invar ?**

- High-Z with low CTE (0-150 °C)
- How is CTE affected by radiation?
- What happens to other important properties?



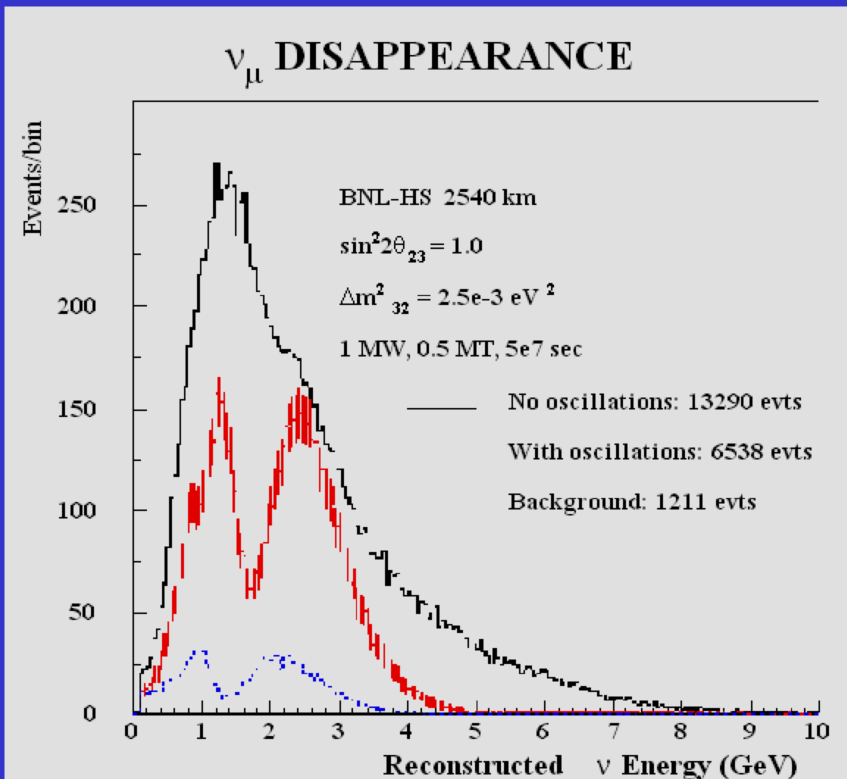

Effect of irradiation in HFIR on the room-temperature yield strength of Alloy 718A

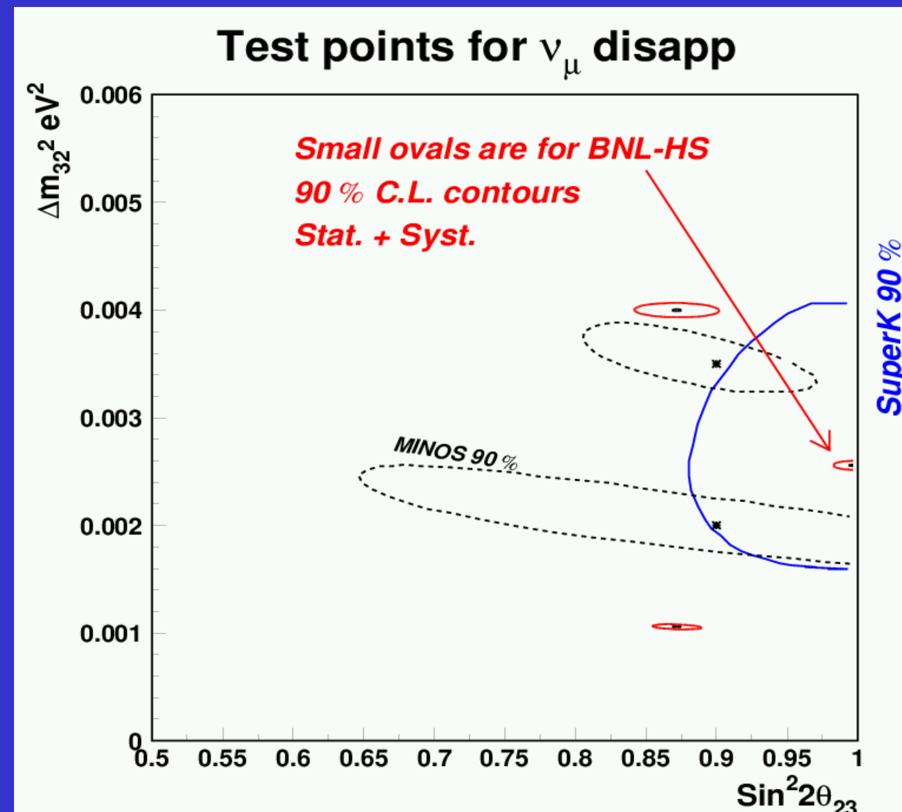
# Super-Invar Irradiation Study – Temperature Effects



# BNL Neutrino Superbeam Initiative

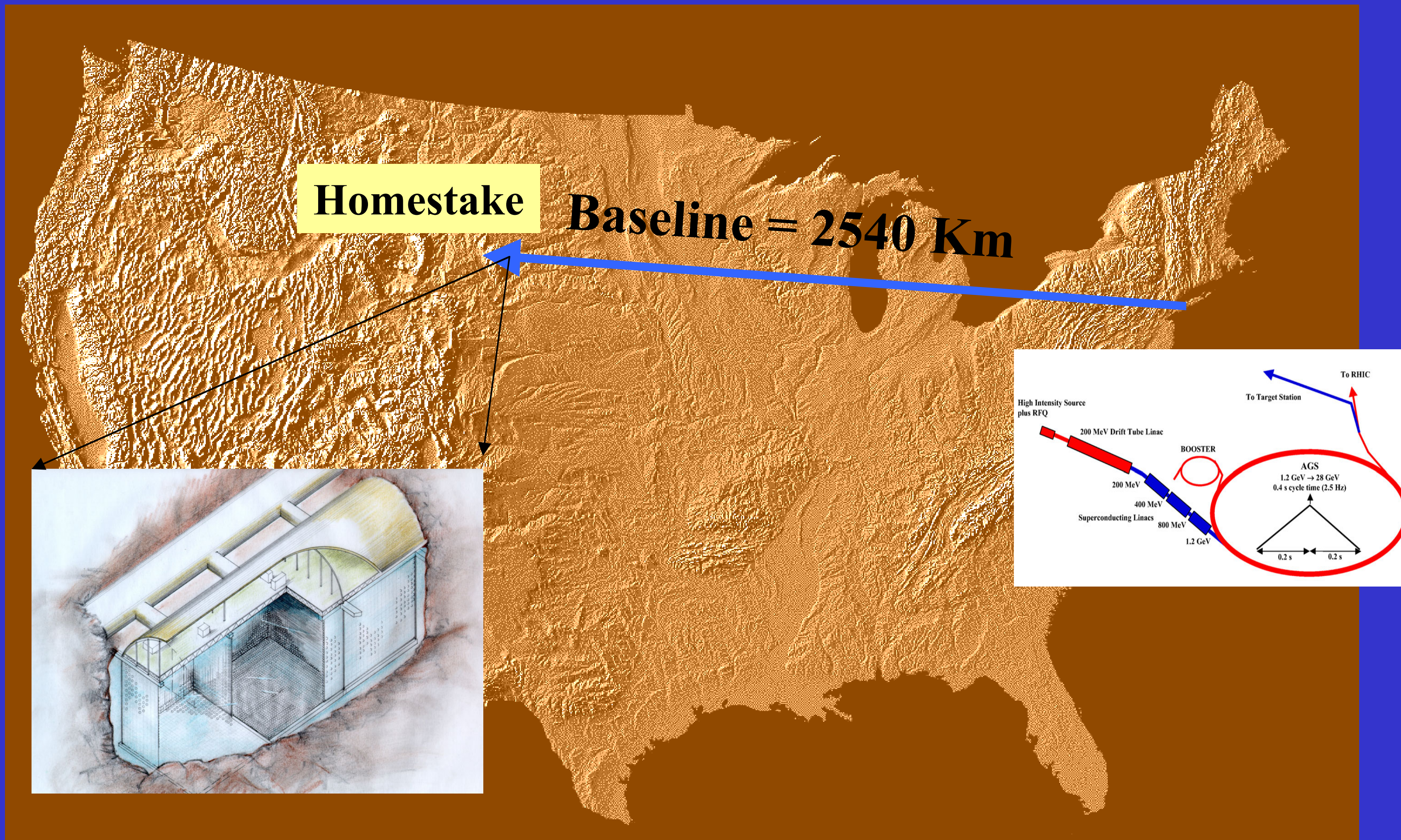
**Direct use of data collected thus far (targetry/windows/material irrad.)**




Ref: arXiv:hep-ph/0303081 v1 10 Mar 2003

# Neutrino SuperBeam Initiative



# SUMMARY

**In the course of E951 we were able to test in the 24 GeV beam:**

- **Hg jet target**
- **Solid targets and beam windows**
- **Performed irradiation studies on promising materials**
- **CERN collaborators concurrently are evaluating magnetic field effects**
- **Shock simulations on solid targets/windows and Hg jets (including MHD) have been performed and verified**

**LESSONS LEARNED……**

- **Materials are more resilient than we give them credit**
- **For low-Z targets in high-power machines CC composite appears to have an edge**
- **Hg jet destruction is a reality BUT time scales are there to pass train of pulses**
- **Projectile velocities confirmed to be acceptable**
- **Magnetic field helps stabilize laminar jets but not turbulent ones (not yet, anyway)**
- **Irradiation seems to affect key properties of potential target materials (on going evaluation)**
- **In performing these kind of experiments it is important to have the minimum required resolution, otherwise the primary effects are lost**

**A good portion of the work already done applicable to the BNL neutrino beam initiative**