BNL E951 BEAM WINDOW EXPERIENCE

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OVERVIEW of E951 Experimental Studies

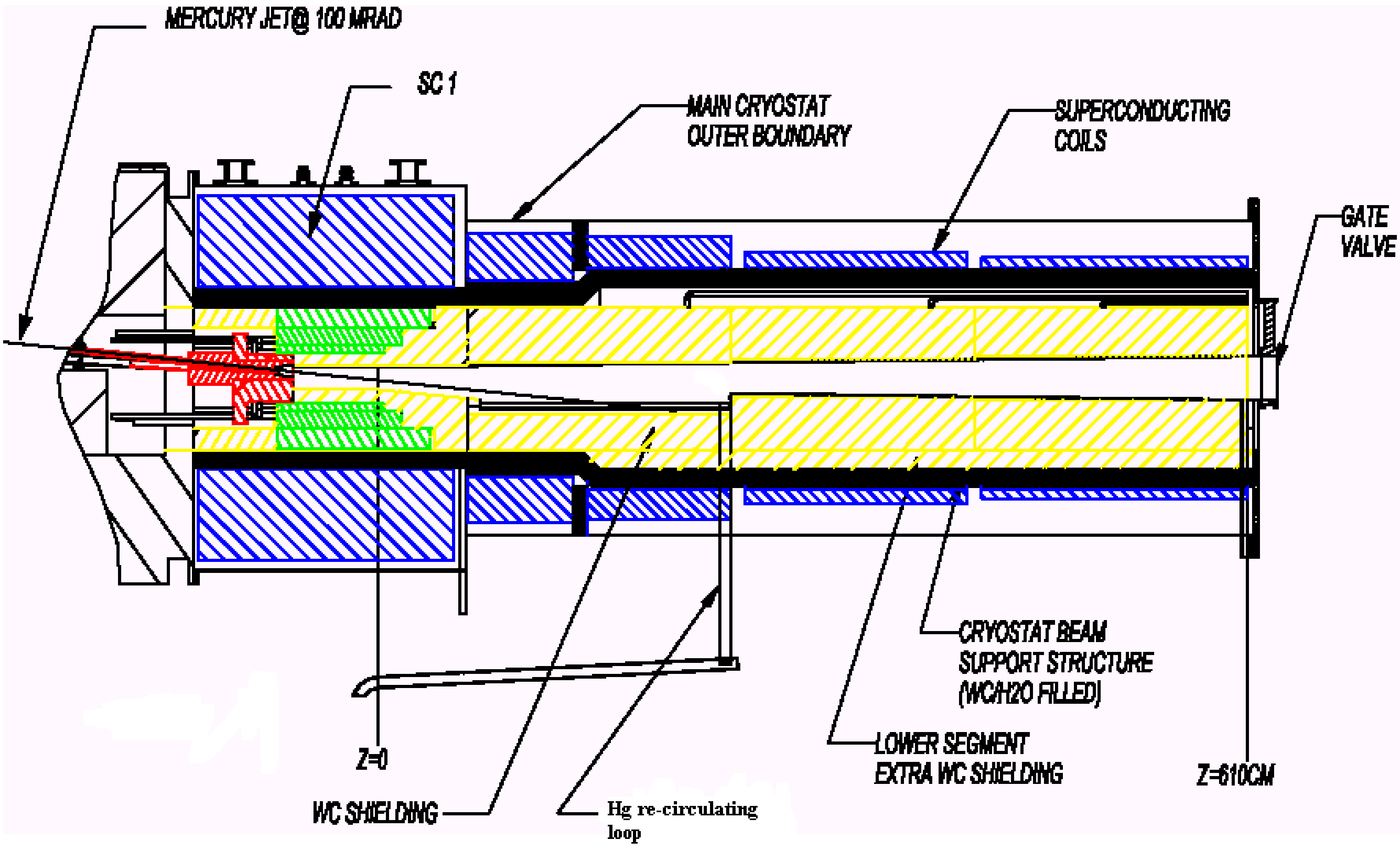
WHY Beam Studies ?

Simulation Studies

Benchmark Studies

Assessment

Liquid Jet Target Configuration for Neutrino Factory



Background

All studies suggest that, to push frontier in proton drivers to an order higher than the existing ones, one must maximize the yield at the source

Proton drivers with beam power up to 4 MW could become reality

Challenge in finding suitable materials that will withstand intense heating, shock waves and radiation damage

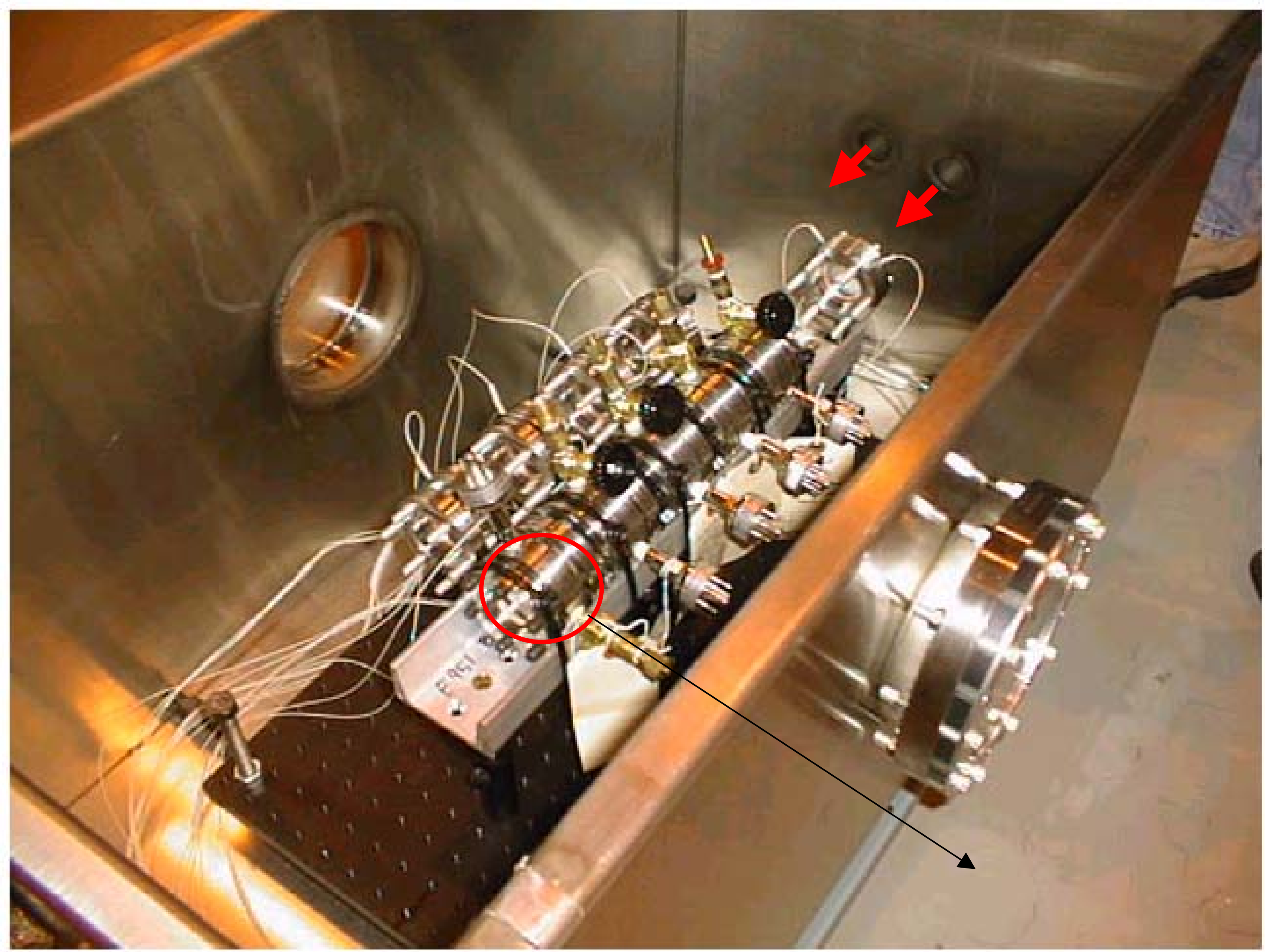
Experience suggests that without R&D surprises have a way of coming back

Study Goals

- **Find best possible materials that can be used as beam windows under extreme conditions**
- **Experiment with selected materials, measure responses**
- **Validate prediction models against measurements to gain confidence in predicting material response and/or failure at anticipated extreme conditions**

E951 WINDOW TEST Station Set-Up

Fiber-optic Strain Gauges & Double window vacuum monitoring



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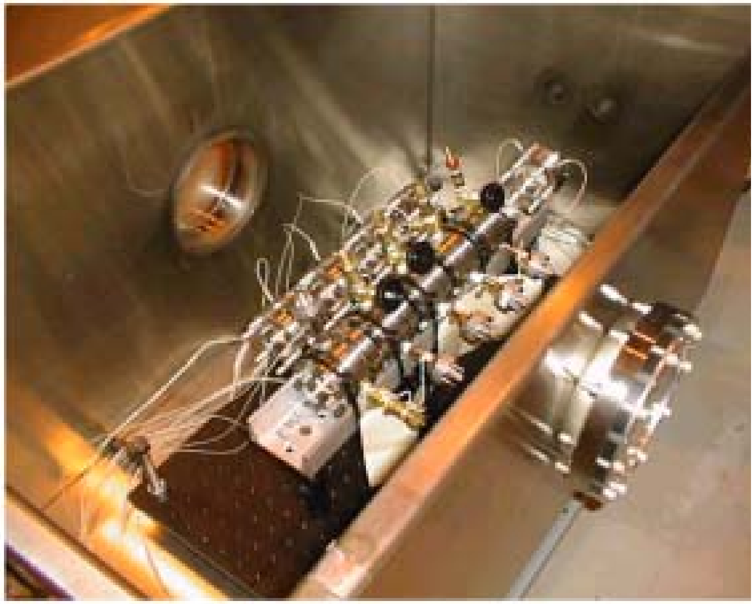
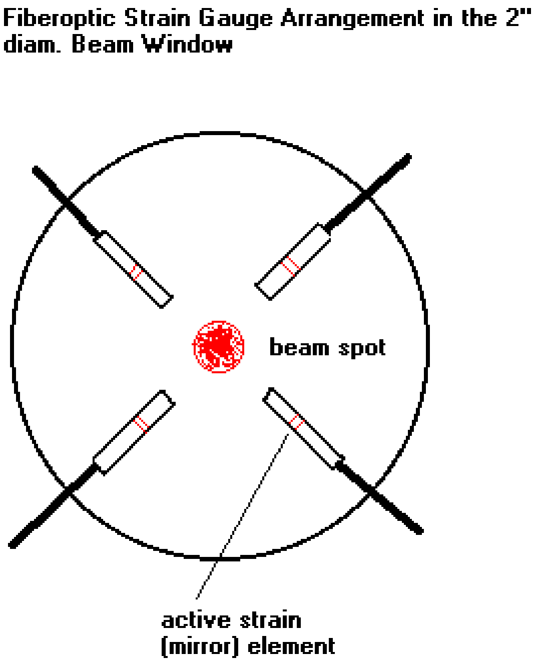
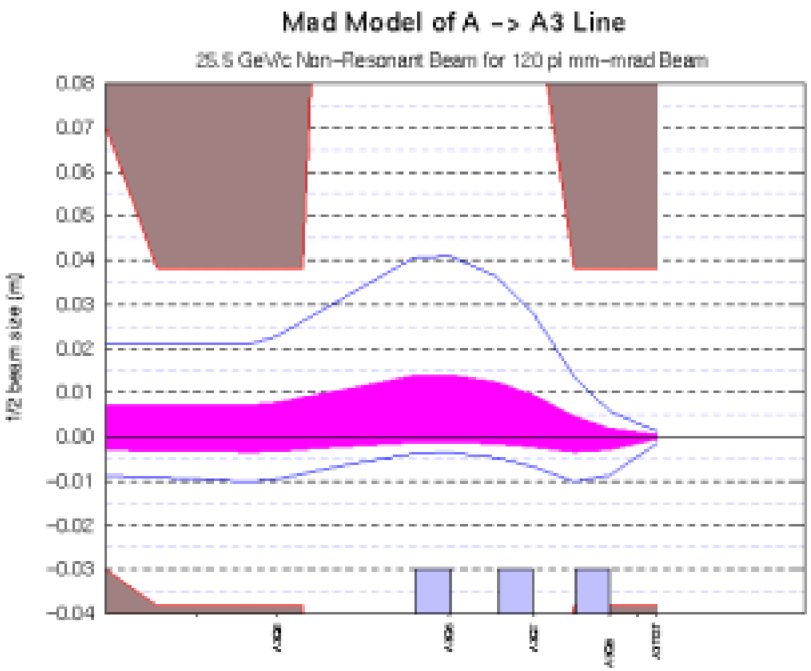
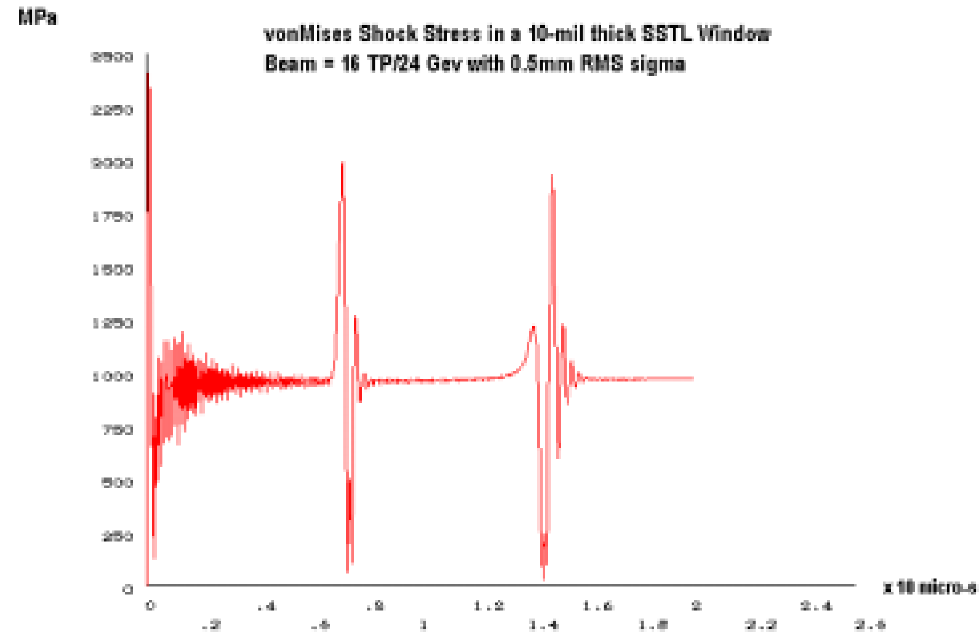




What Triggered the Window Experimental Effort





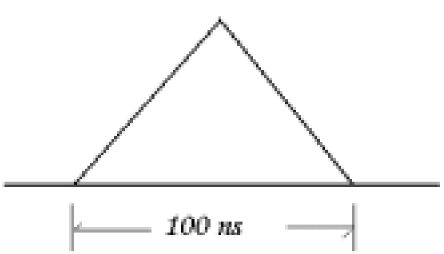
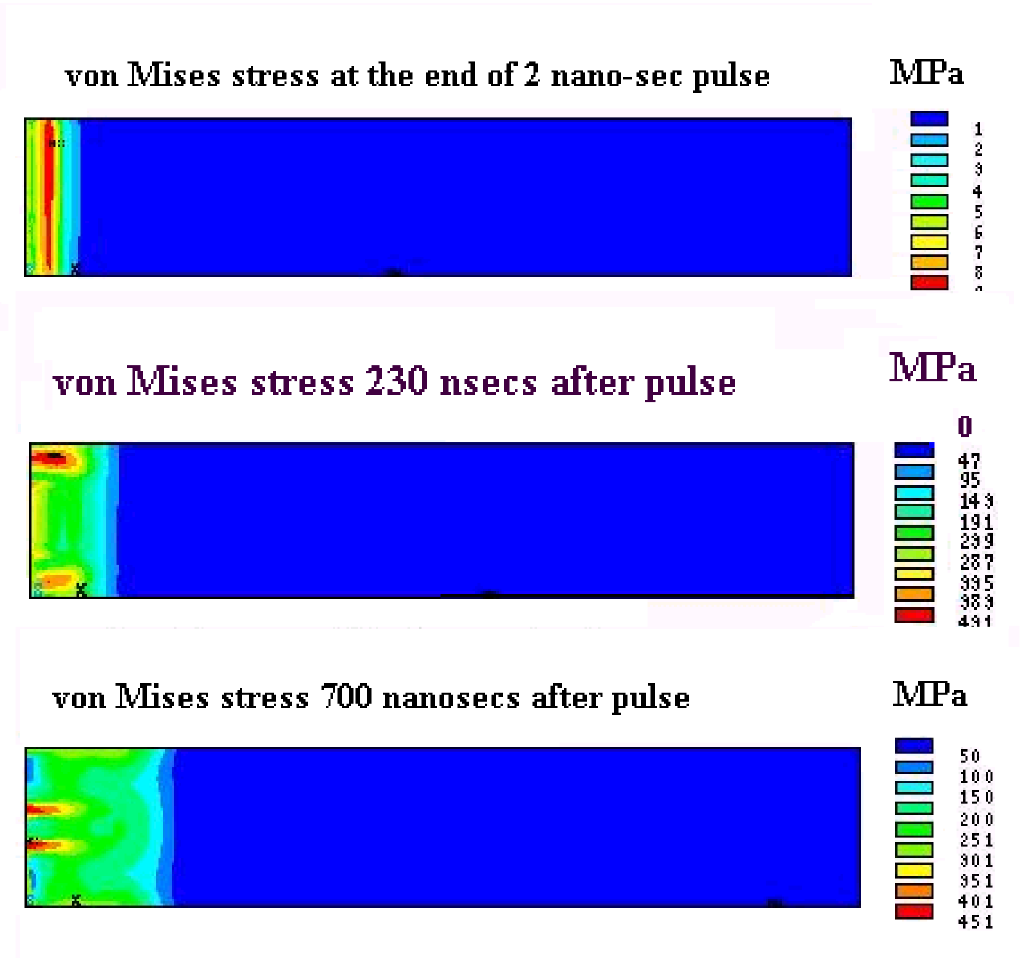


Figure above depicts the tight beam spot requirement (0.5 x 0.5 mm rms) for target experiment at AGS

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)

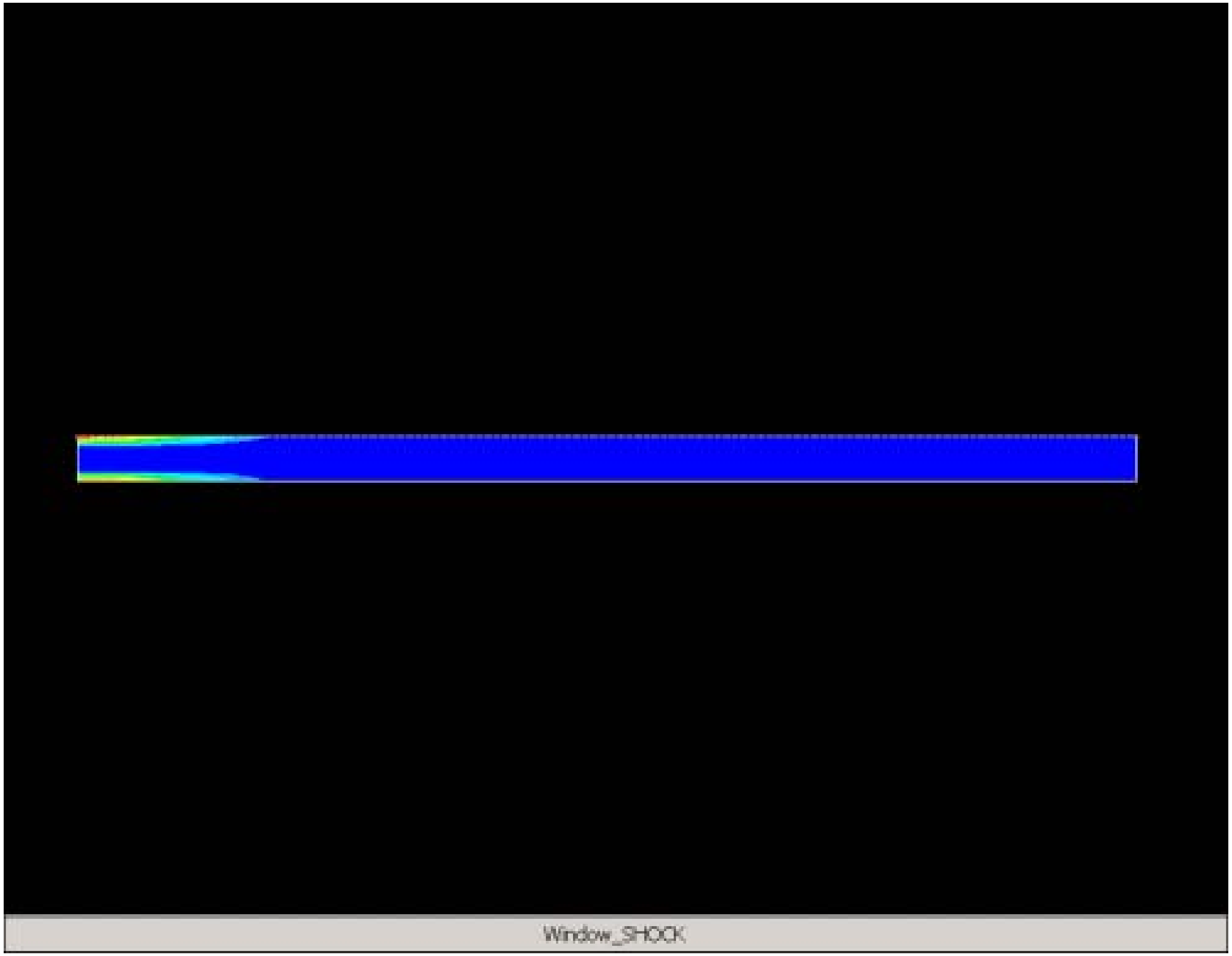
Figure (right) depicts prediction of vonMises stress in a stainless steel window for the above conditions. Initial shock stress is ~ 3 x yield strength of material !!

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

Mechanism of induced shock stress in windows

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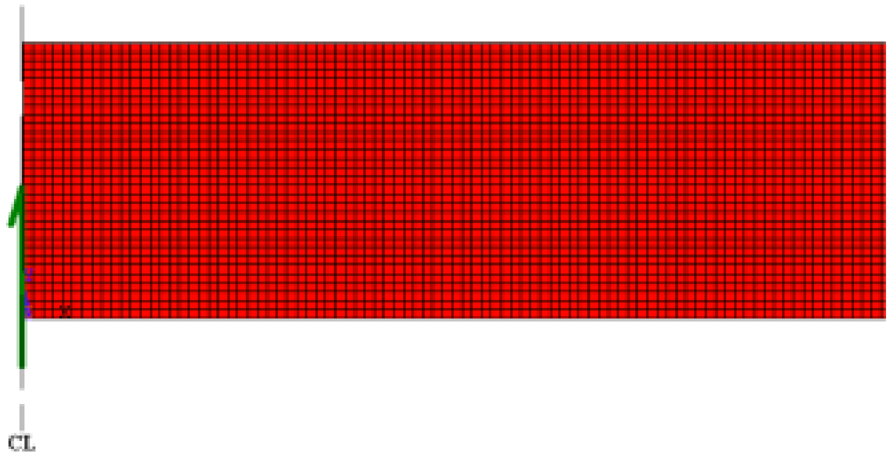
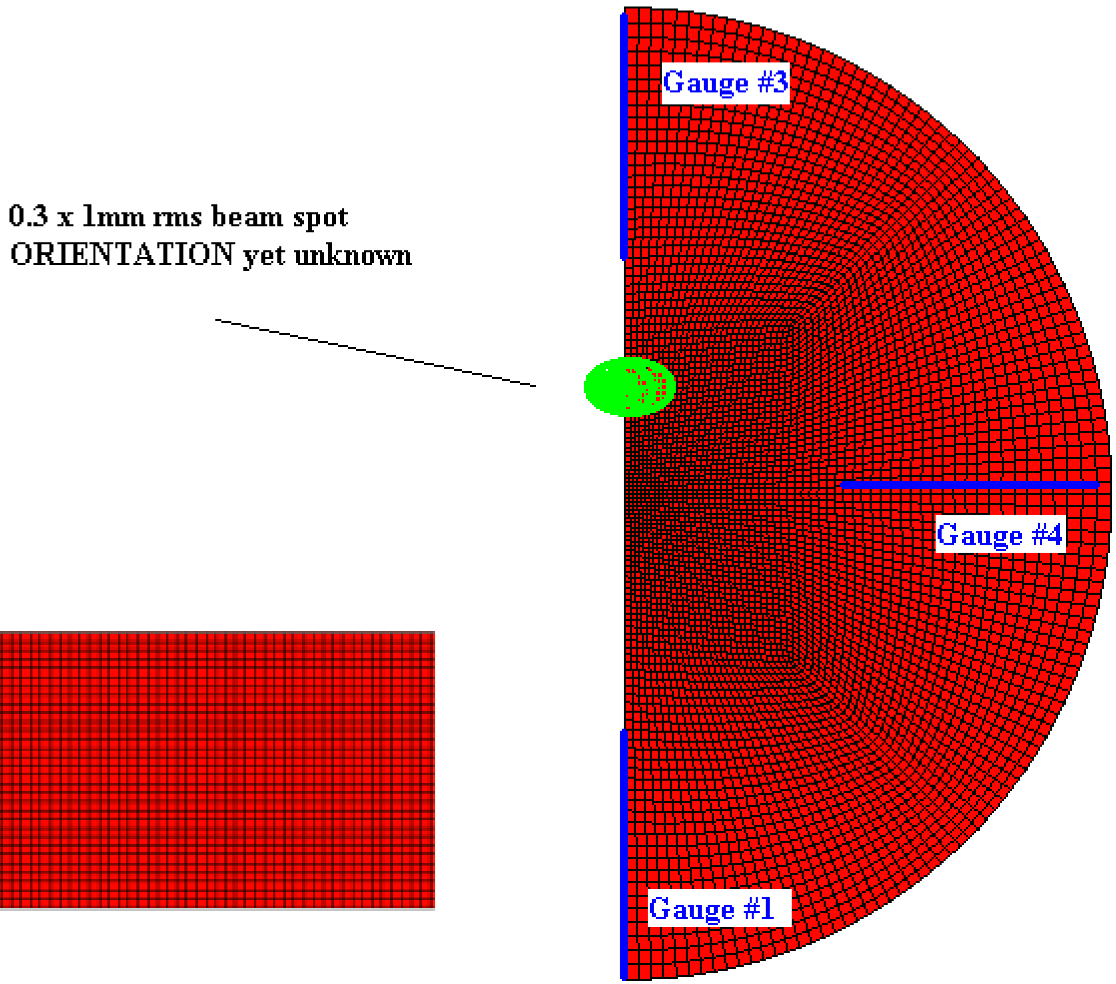
Window_shock2

Issues and Material Matrix selection

- FAST proton beam interacting with window and depositing energy in small spot inducing shock waves
- Based on a 24 GeV/16 TP/0.5 mm rms beam MOST materials could fail with a single pulse
- Though thin, failure in window governed by through-thickness response
- **Sound speed - material thickness** & **pulse structure** critical elements
- Material search combined with analytical predictions led to the following materials for testing
  - Inconel 718 (1mm and 6mm thickness to study the effect)
  - Havar
  - Titanium Alloy (highest expectation of survivability)
  - Aluminum
- Aluminum (3000 series) selected as the one that COULD fail under realistic expectations of AGS beam during E951 (~ 8 TP and 1mm rms)

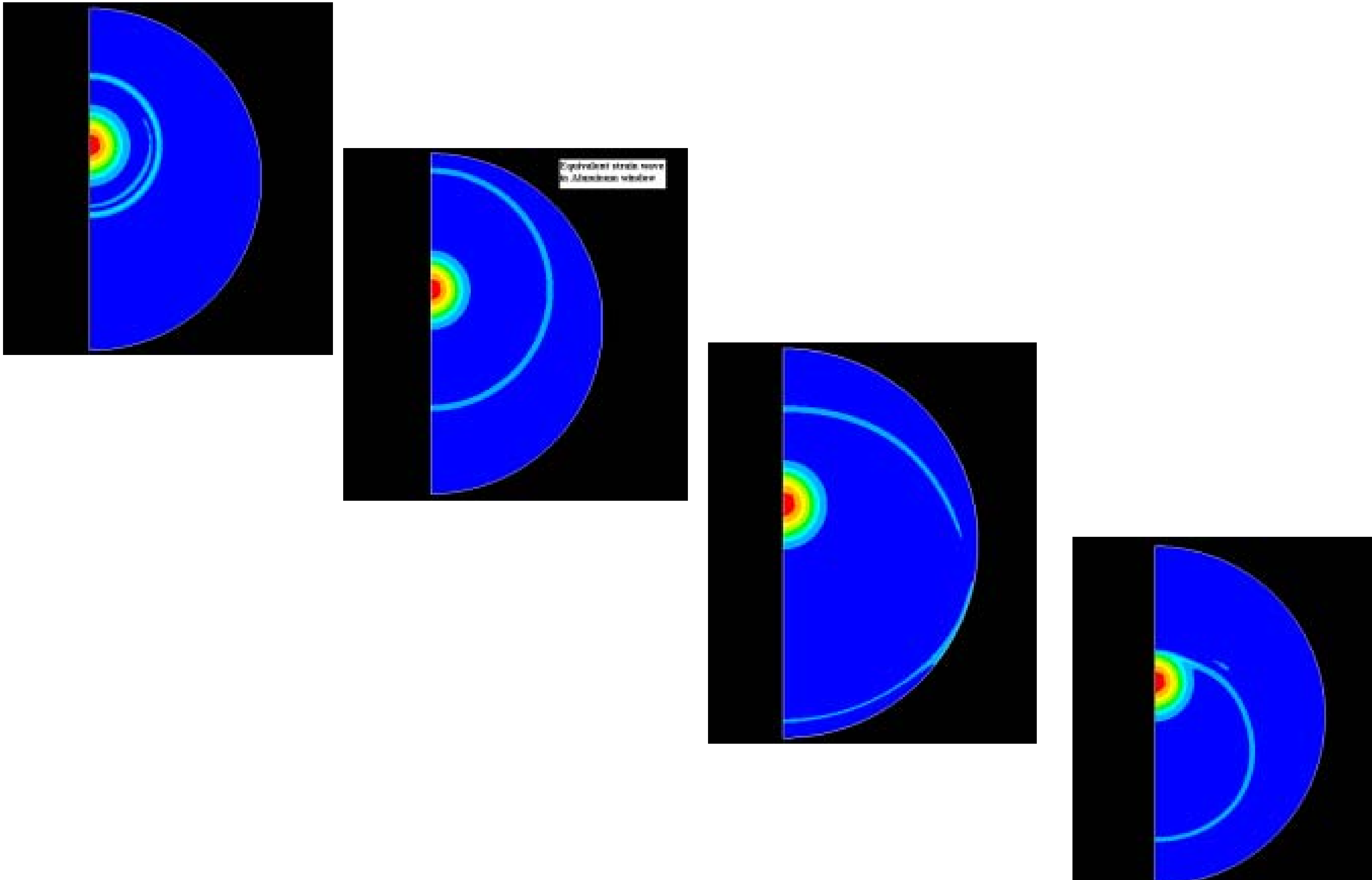
Finite Element Models to Capture the Dynamic Response of Windows



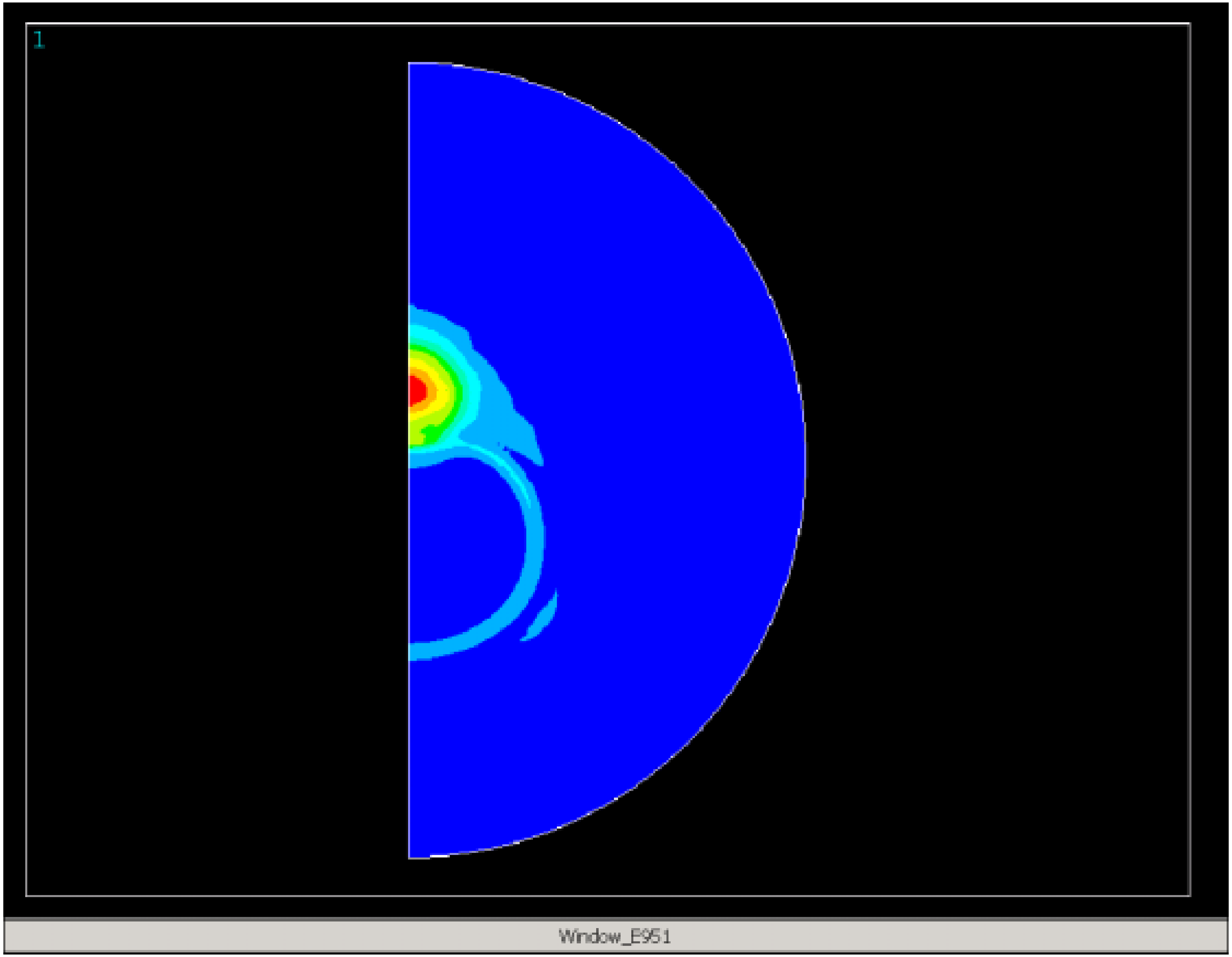


Aluminum Window Strain Waves

(beam spot ~ 0.3 x 1mm)

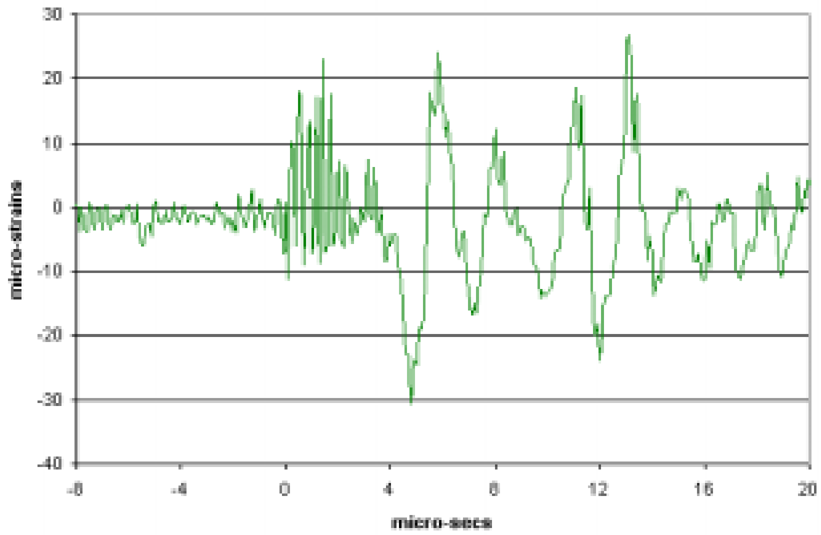


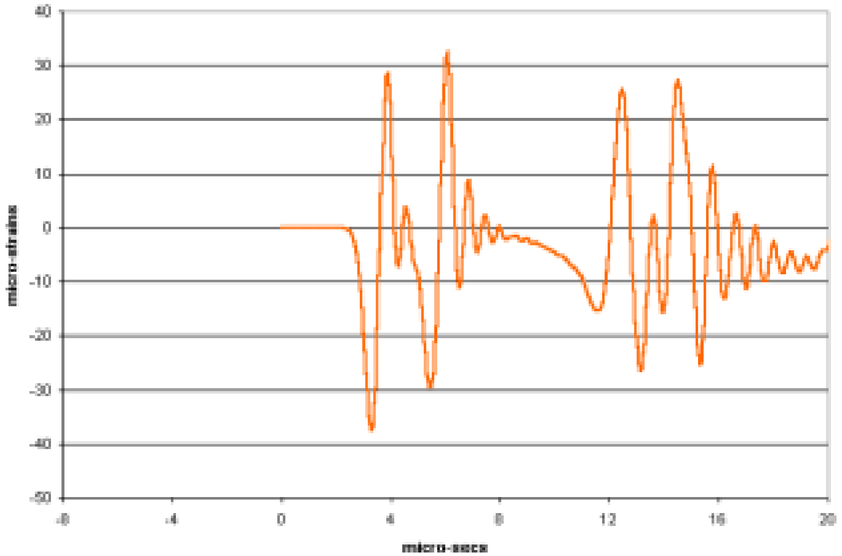
Aluminum Window Strain Wave Simulation



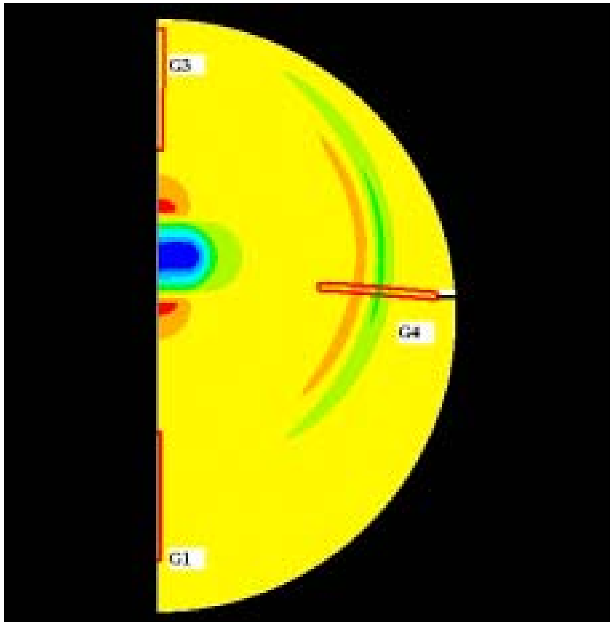
Aluminum Window Strain Data

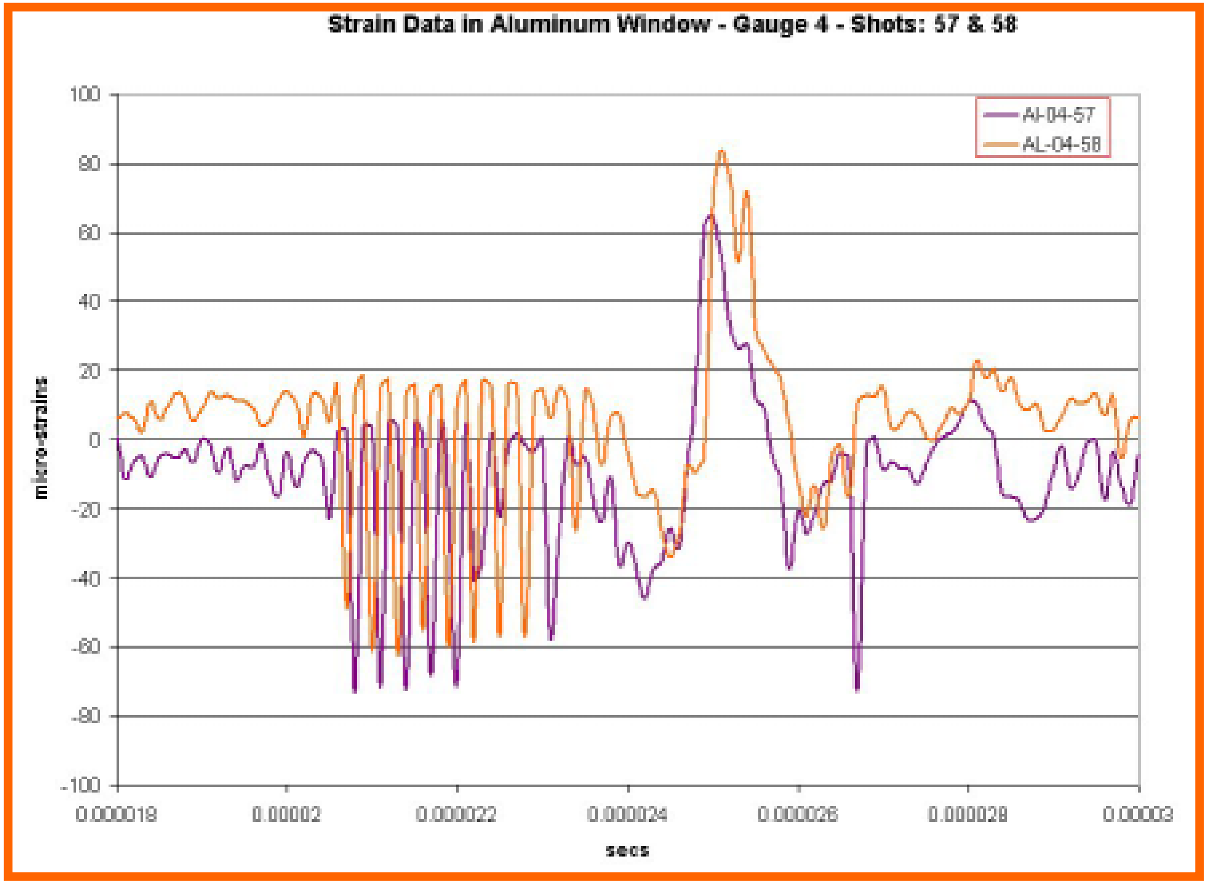
Experimental data vs. prediction using the new beam spot (0.3 x 1mm)



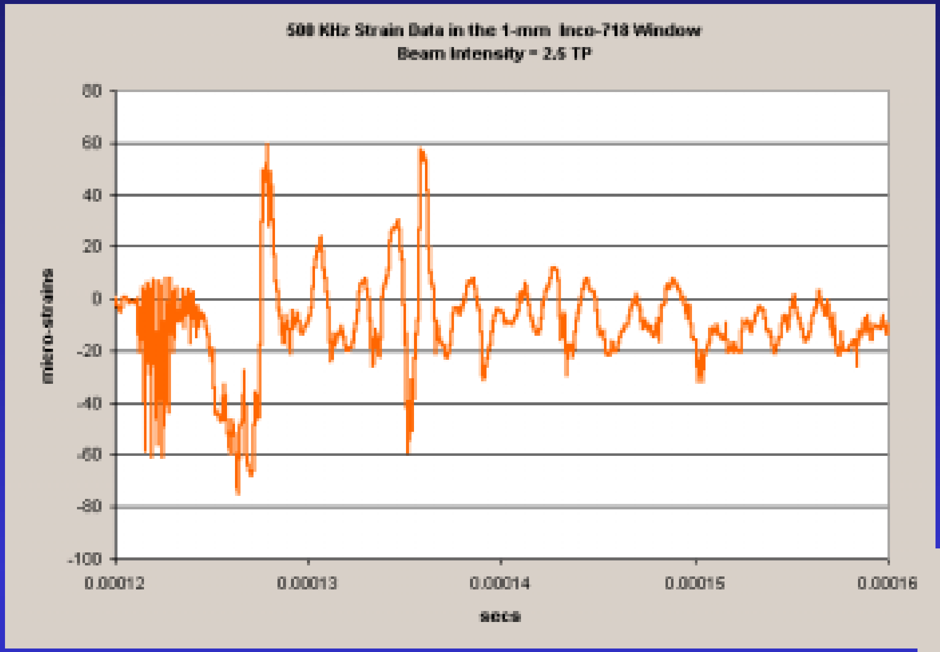


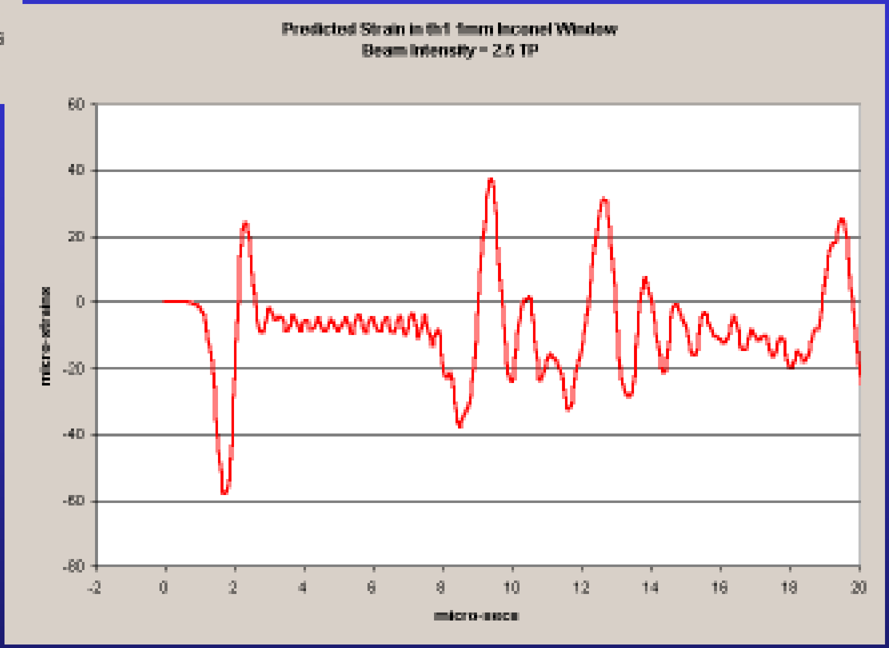
Recorded Aluminum Window Strain Data in back-to-back pulses



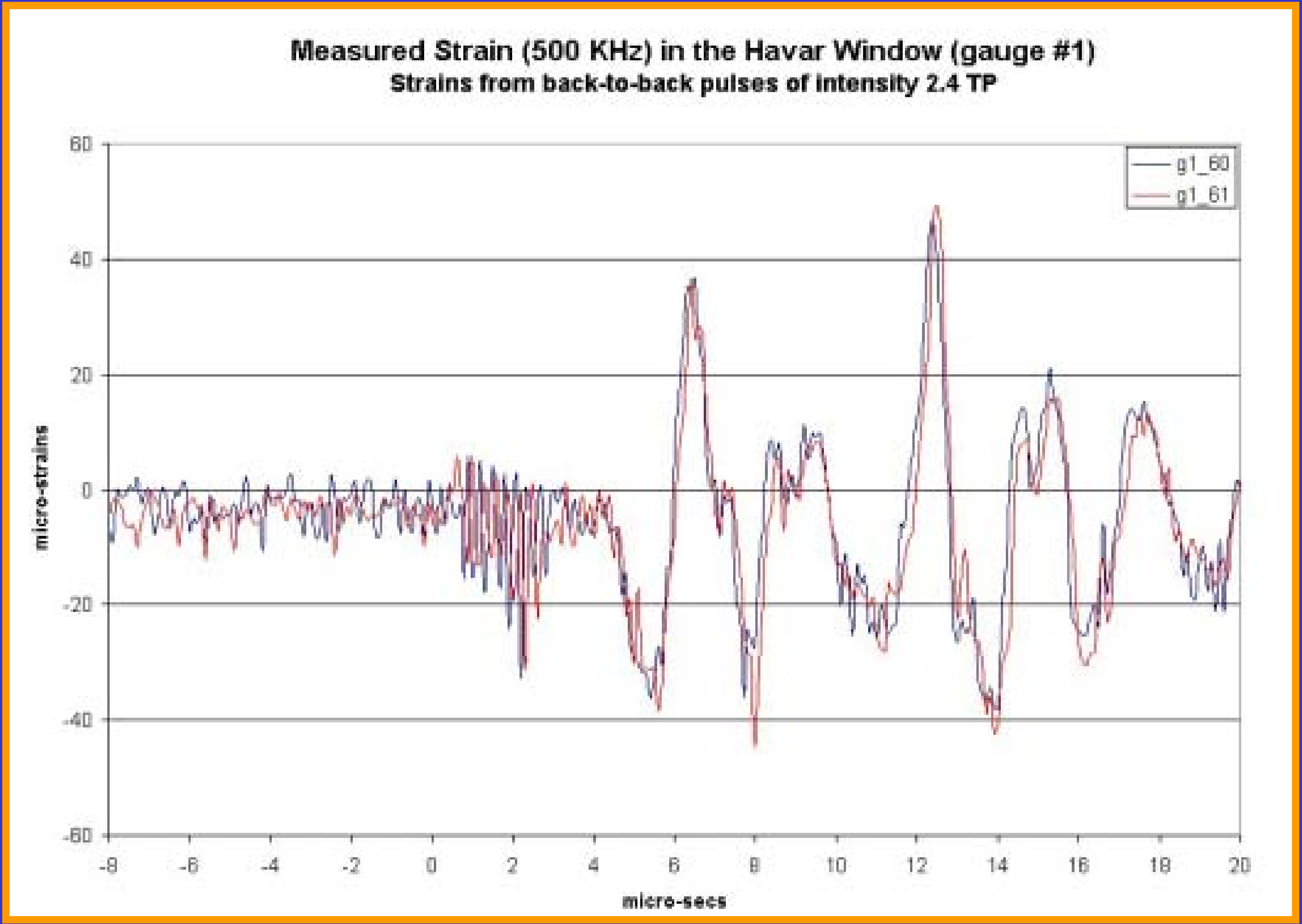


Measured and predicted strains in the 1mm thick Inconel-718

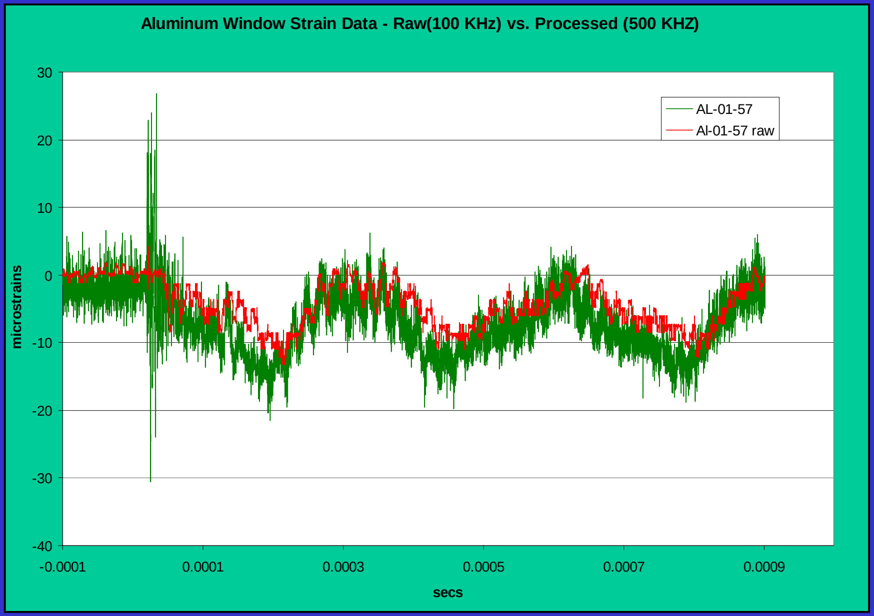




RECORDED strains in the Havar Window (back-to-back pulses)



Data Acquisition Considerations



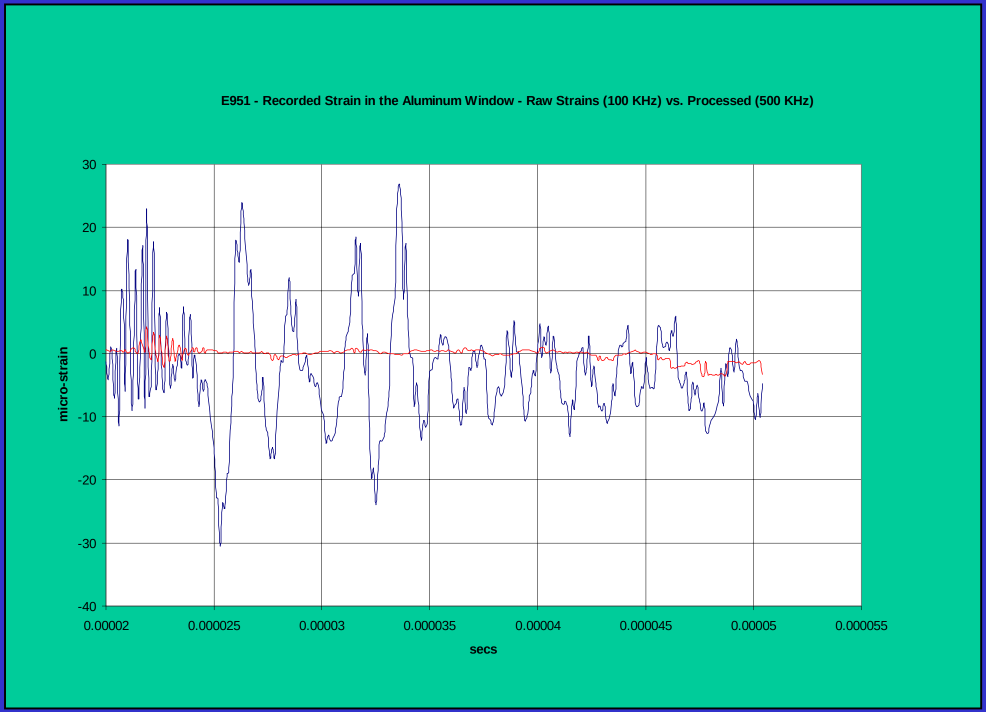
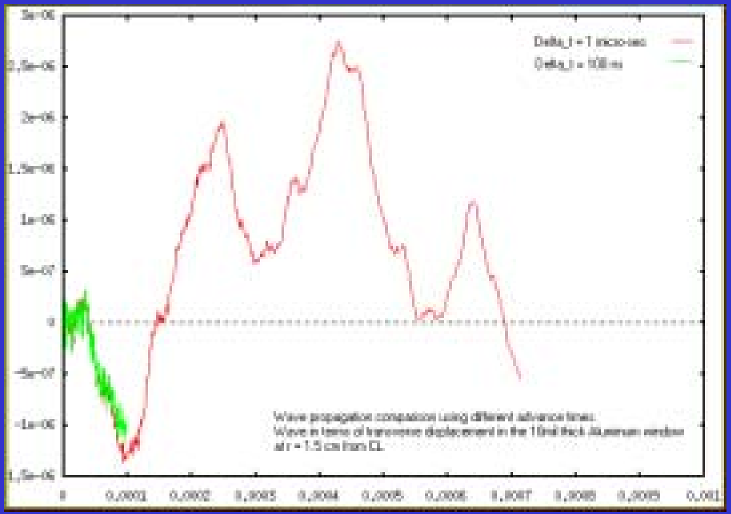
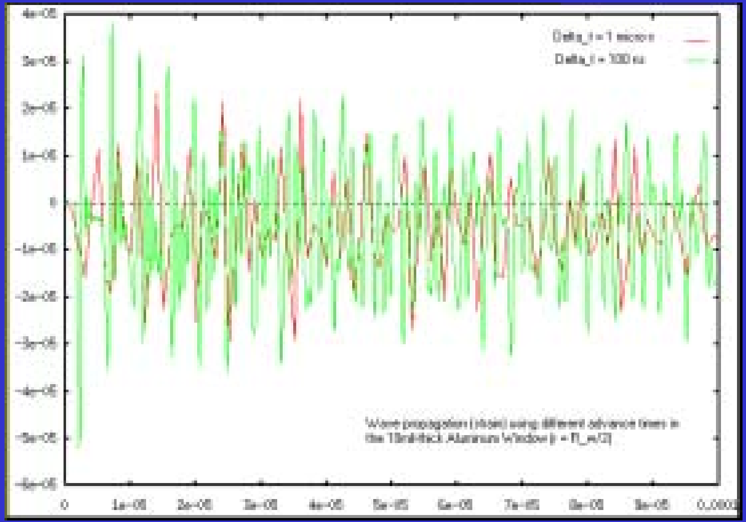
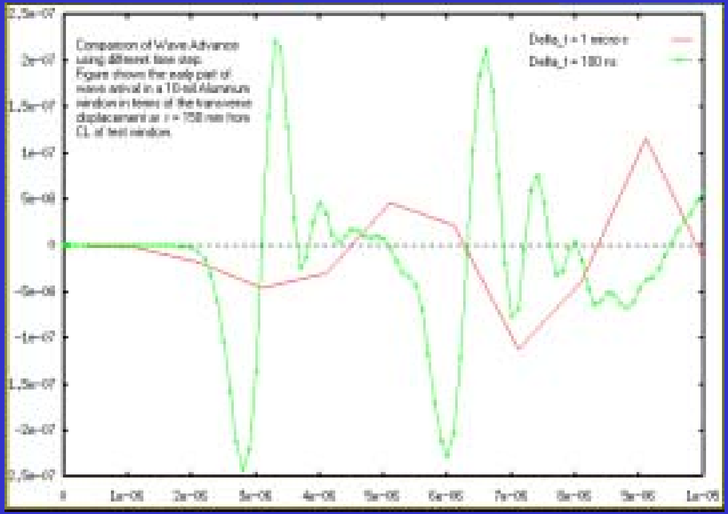


Illustration of sampling rate on data prediction







BNL E951 Window Study Assessment

- **Examination of the actual windows revealed that beam spot was tighter than originally thought (~ 0.3mm x 0.8mm)**
- **Therefore, energy density same order as one expected for 16 TP 0.5mm RMS**
- **Orientation of elliptical spot and offset KEY parameters for PHASE II of benchmarking exercise**
- **ANSWERS to some of the QUESTIONS:**
- **There was no loss of vacuum in any of the double windows, indicating that no FAILURE has occurred !!**
- **The utilized model also predicts that no window material (given the intensity achieved < 2.7 TP and the pulse length ~ 100 ns base) would approach yield**
- **BUT failure means different things to different people !!!**

SUMMARY

- Based on close examination of activation in the E951 windows beam spot size was smaller than originally estimated leading to desired energy densities

- Materials are more resilient than we give them credit for !!!

- Irradiation may have more to do with life limit

- There is need to go thinner in beam window applications => thus new materials must be tested