SNS Collimating System Design
Performance & Integration

N. Simos

Brookhaven National Laboratory

With input from

H. Ludewig

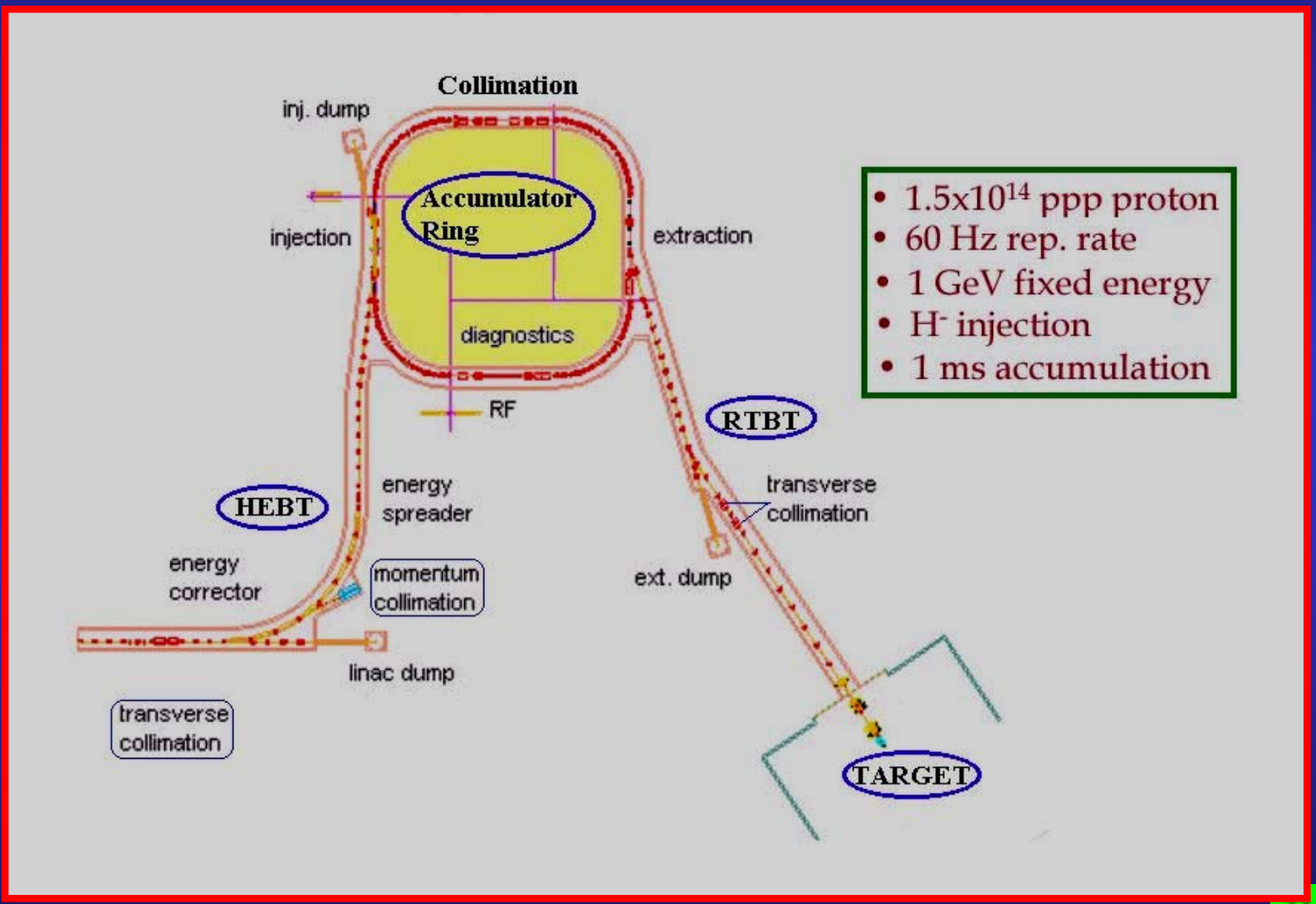
J. Brodowski

N. Catalan-Lasheras

D. Raparia

G. Murdoch

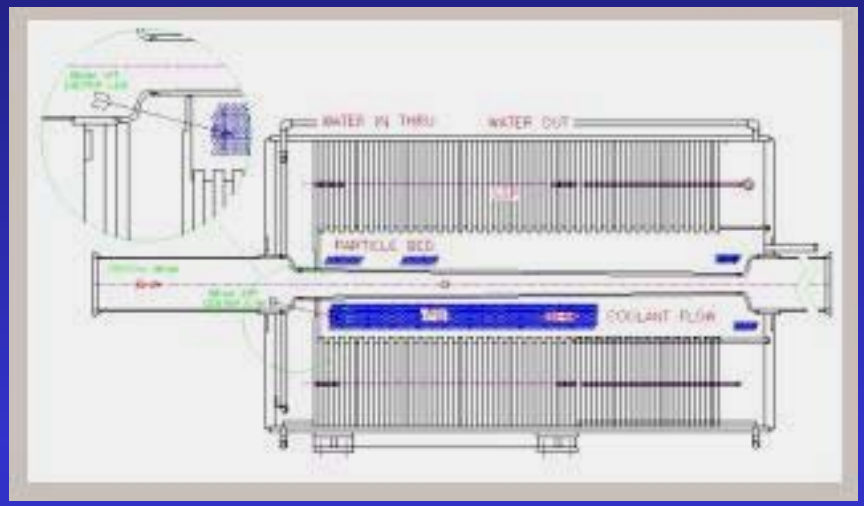
Collimation - GUIDELINES

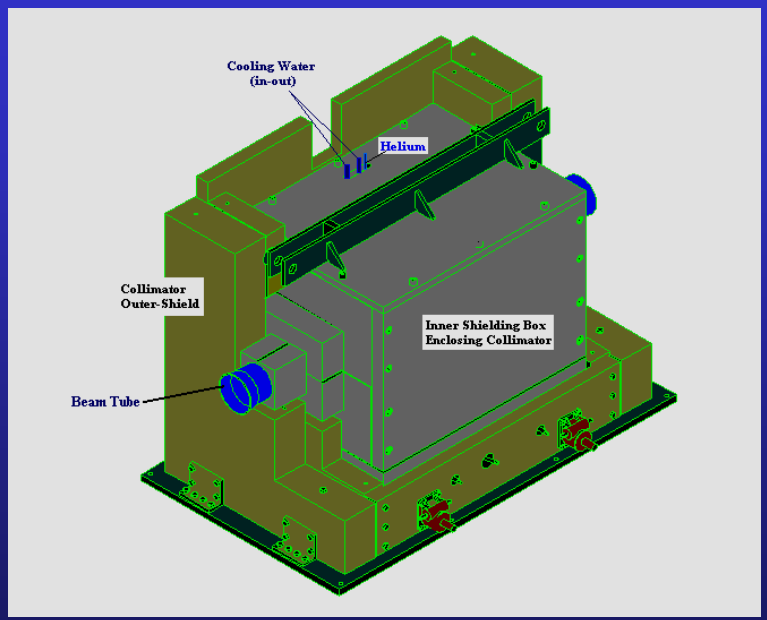


SNS Collimation – Philosophy/Goals

- Maintain 1 W/m beam loss
- Keep uncontrolled beam loss below 10e-4
- Beam loss primarily at collimators (efficiency > 90%)
- Minimize & contain secondary particles and/or isotopes within its space
- Shave-off halo surrounding "good beam"
  - approximately 0.1% of beam (or 2 kW of heat) under normal operating conditions
  - the closest to the "good beam" the better its functionality
  - beam spot evolves along length and so must beam tube

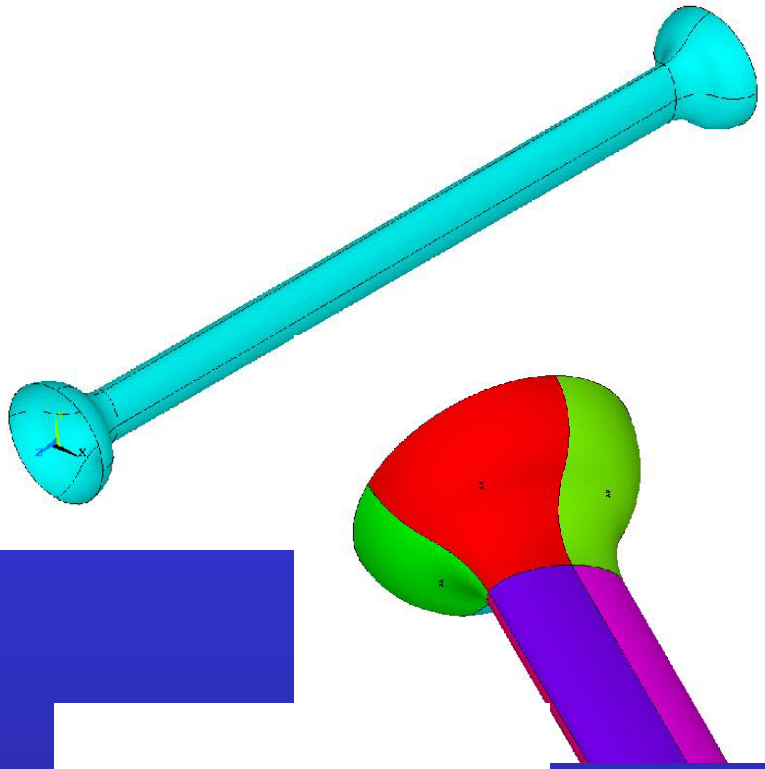
Collimation - APPROACH

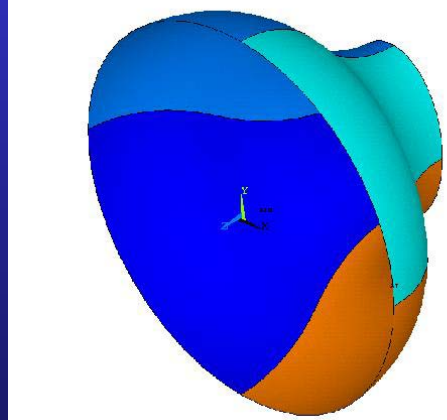




Layered Absorber Design

- elements in proton path progressively less transparent (beam tube material, borated water in original design, steel shot, high-density shield)
- protons stopped in the middle of the collimator (bulk of secondaries are generated there)
- SST shot (3/8 in. diam.) randomly packed provides for good heat transfer
- SST stacked disks surround shot and provide radial shielding
- two iron boxes (inner & outer) surround collimator body





Beam Tube Challenges

- **Impedance -** smooth transition requirement
- **Complex design of beam based on beam dynamics**
- **Beam tube material selection to satisfy key issues such as post-weld response, irradiation and life**

Concerns

- **tube failure with water ingress to vacuum chamber**
- **radiolytic decomposition of coolant possibly accelerated by the presence of boric acid**
- **no data/experience of borated water in a high energy neutron and proton environment (original design – NEW design implements borated aluminum upstream and downstream)**
- **data limited to reactor experience**

Available Accelerator Experience

- **LANSCE** windows - Inconel 718 cooled by light water
- **ISIS** Target - Tandalum cooled by light water
- **PSI** window - DIN 1.4926

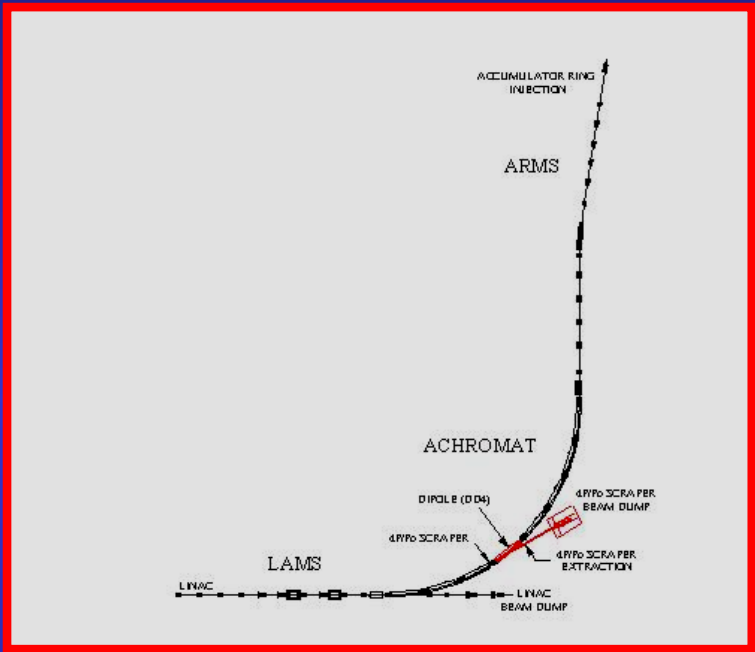
- **LANSCE & ISIS** targets operate at a current density of 10 $\mu A/cm^2$ - 15 $\mu A/cm^2$ and a total exposure of approx. 5 A-hrs
- New **LANSCE** window designed for a projected life of 4~5 yrs with peak current density of 15 $\mu A/cm^2$

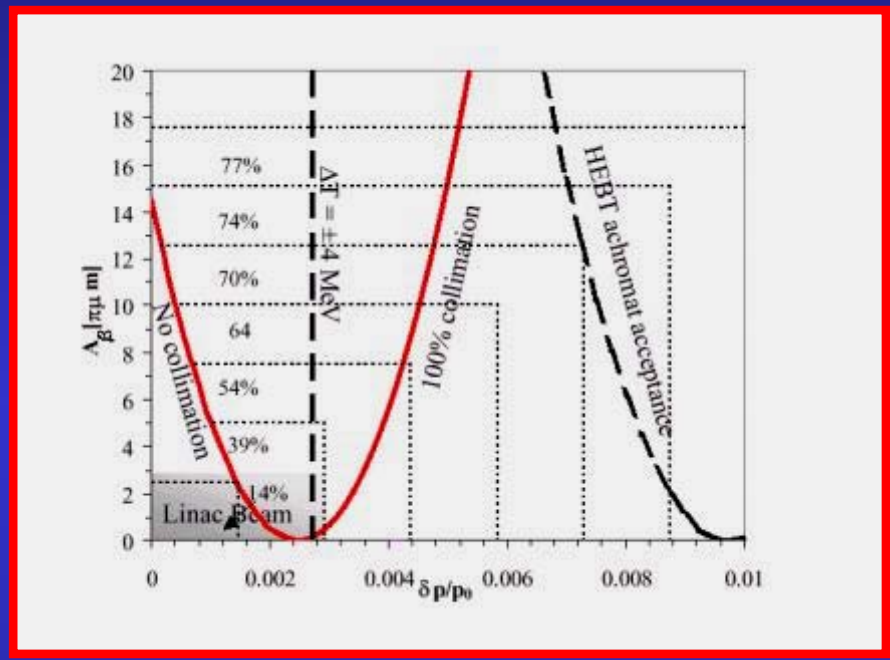
Useful Life Projections

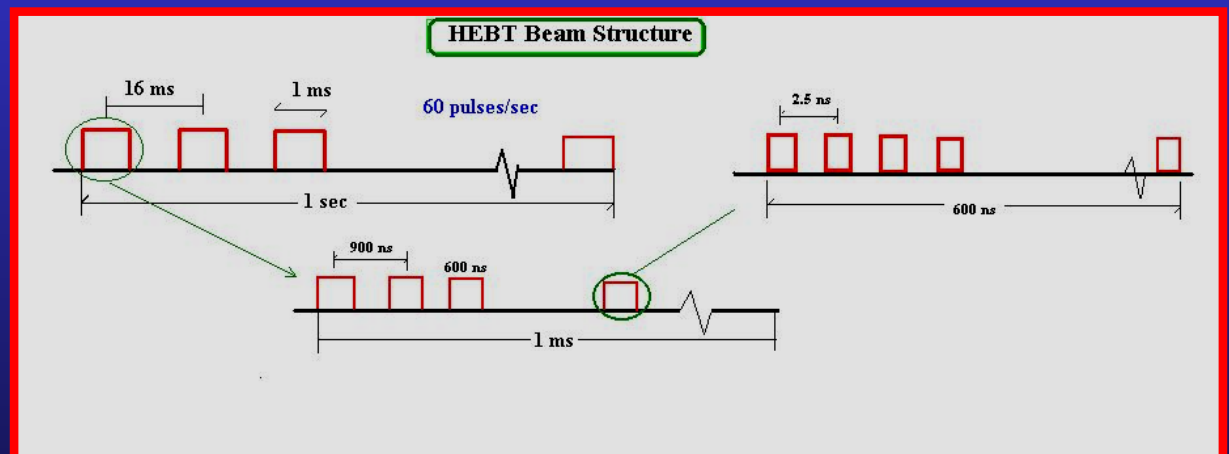
- For assumed halo ~0.3 cm beyond beam and beam diameter 4 cm, halo area = 4 cm^2
- Halo current (0.001 beam loss in halo) = 2μA
- Current density = 0.5 $\mu A/cm^2$
- Based on LANCE new window, design life ~ 100 yrs
- 100 yrs of continuous full power operation translates to ~ 2.0 A-hrs

Of course, if all goes according to plan …… (we know better by now !!)

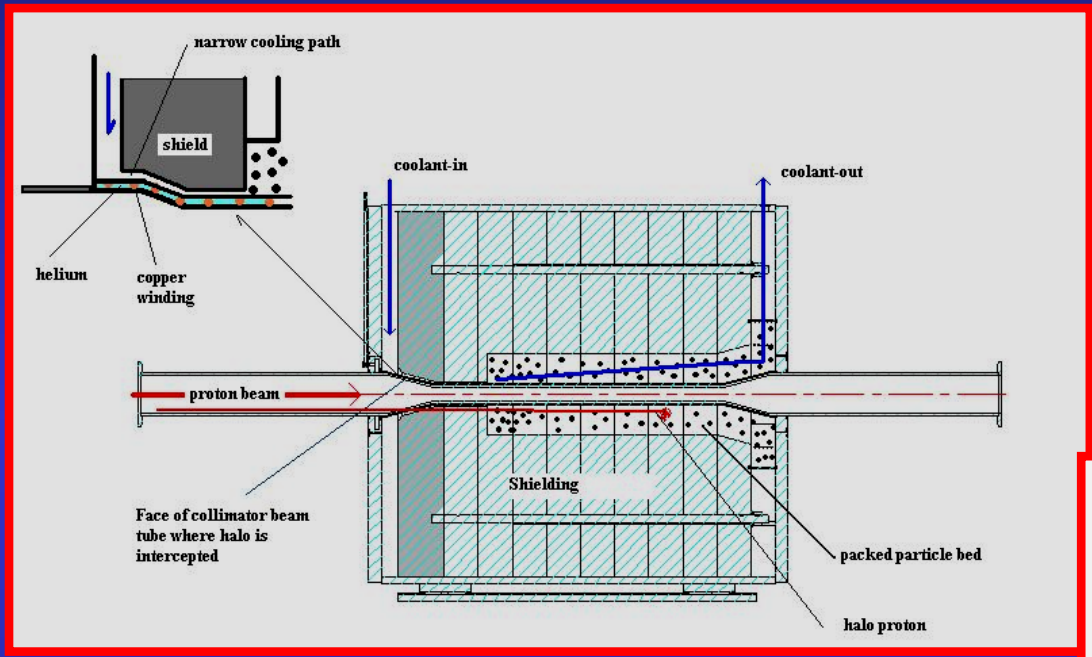
Collimation – HEBT (combination of charge exchange foils, stationary collimators and momentum absorber)

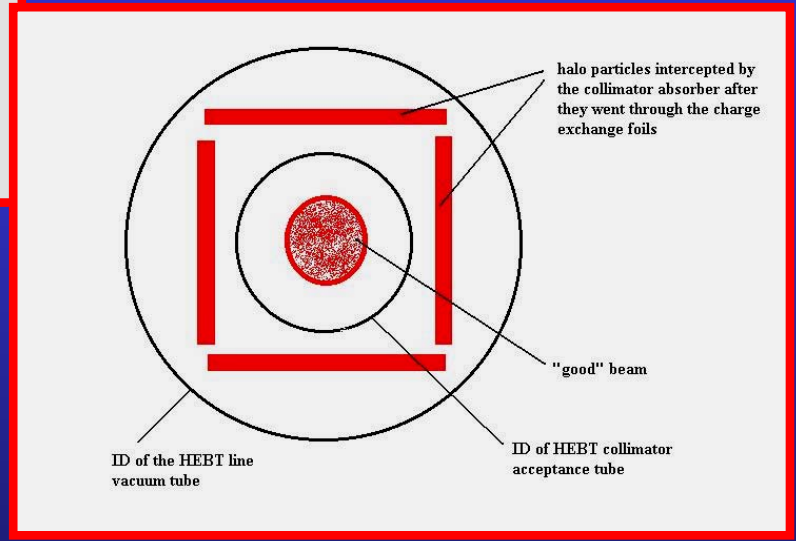




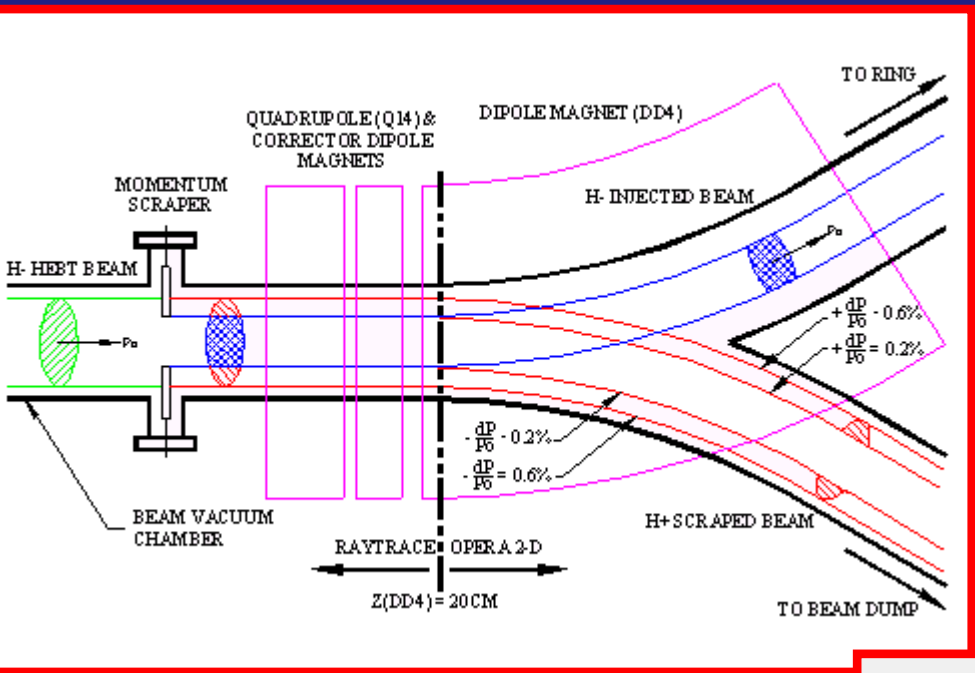


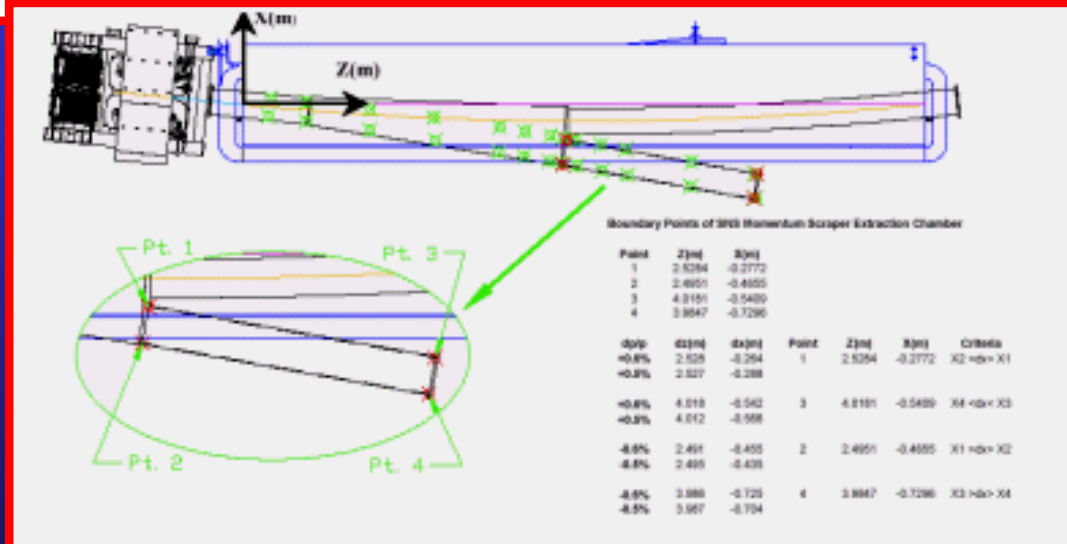
Collimation - HEBT



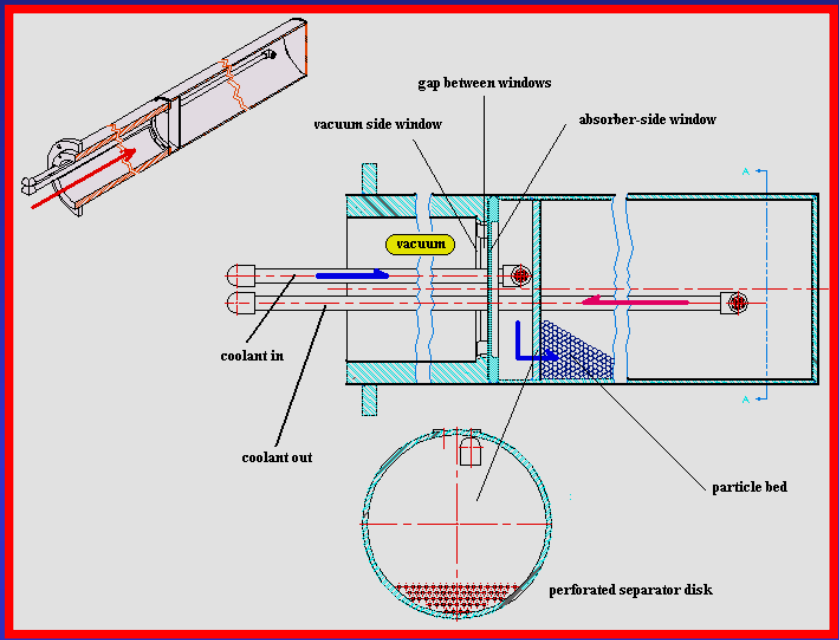


Collimation - HEBT



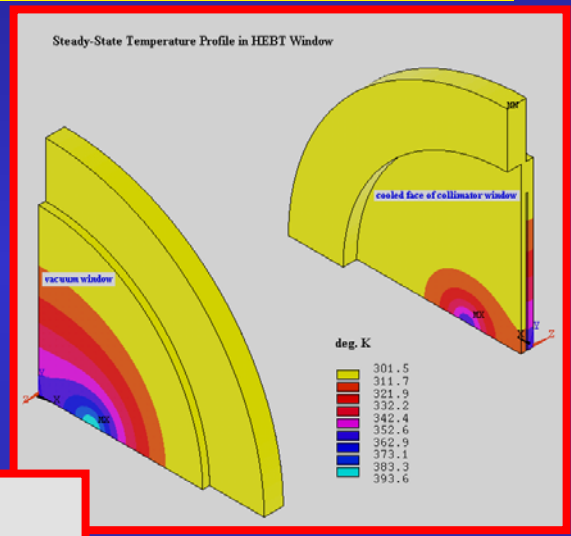


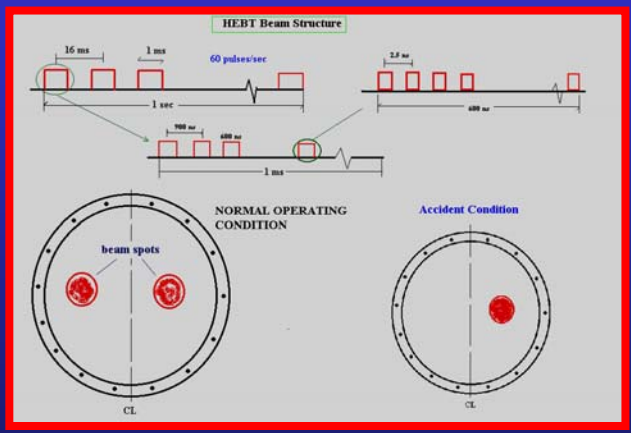
Momentum Collimation - HEBT

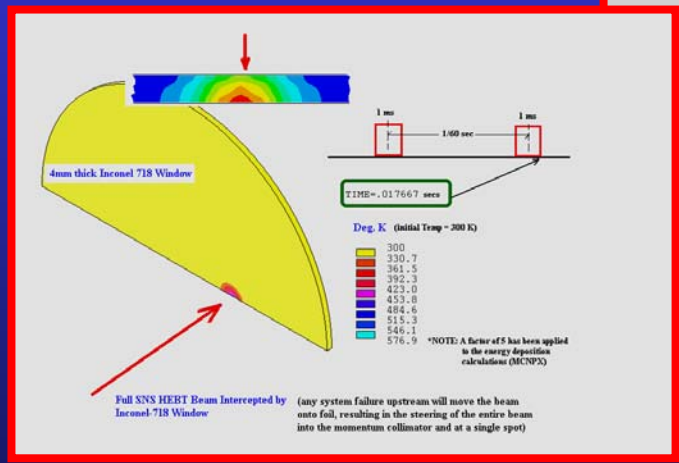


ISSUES:

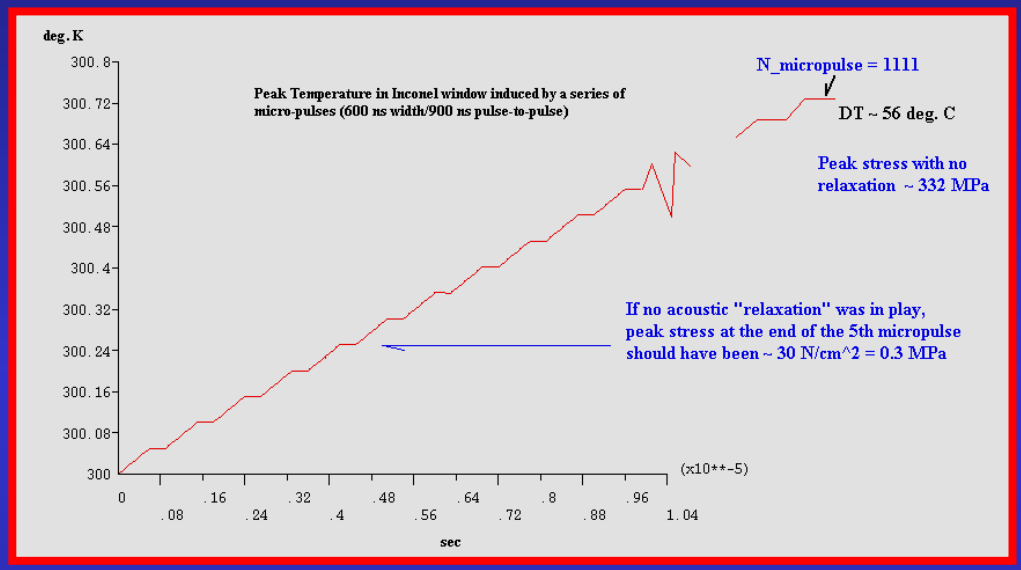
- FULL HEBT beam intercepted and diverted by Scrapers
- Accelerator tripped after two (2) 900ns-period pulses
- Shock thermal stress well within the elastic limits

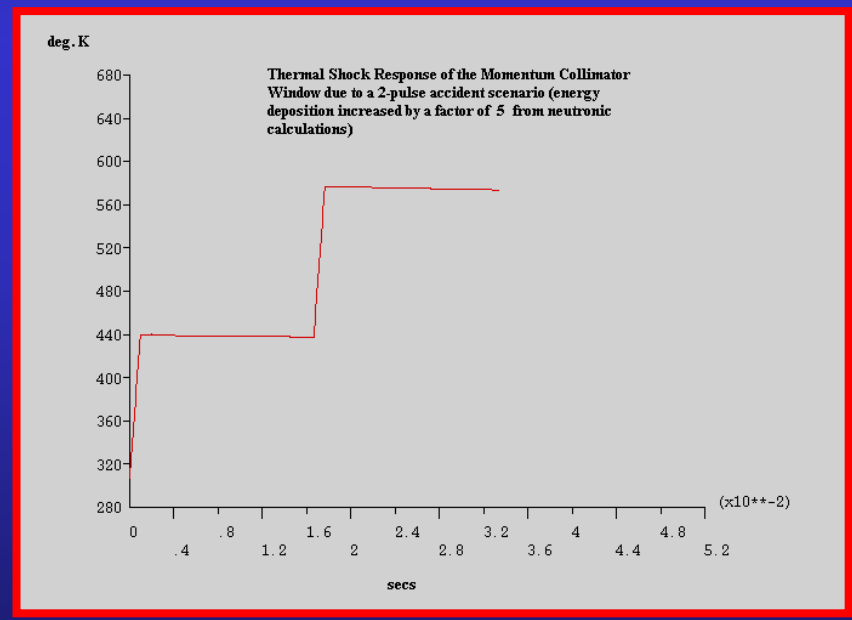






Momentum Collimation - HEBT





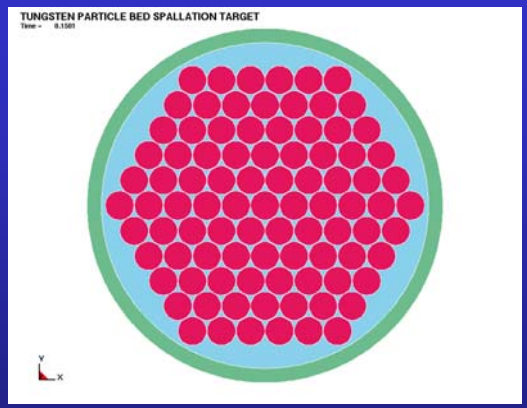
Use of Particle Bed Concept in SNS Collimation – Beam Stop

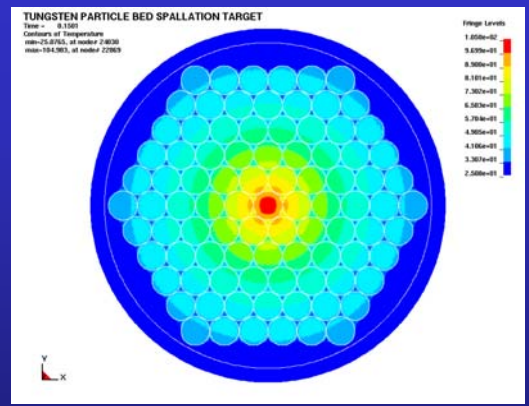
Cooled Particle Bed Around ALL Collimator Vacuum Tubes

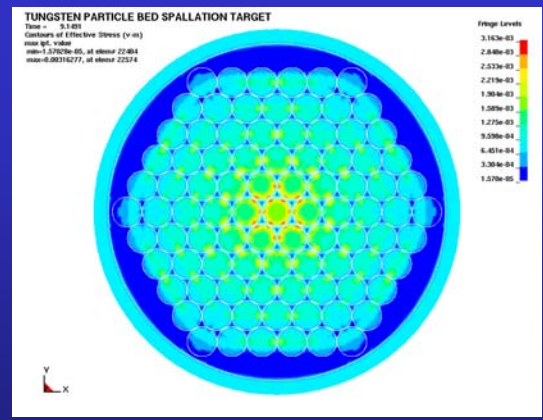
Particle Bed to Absorb Protons of Momentum Collimation in HEBT

PARTICLE BED vs. SOLID BEAM STOP/TARGET

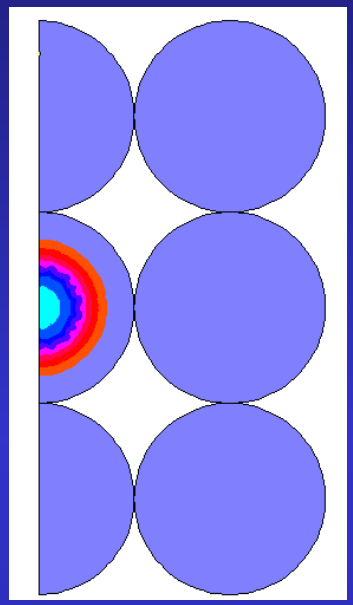
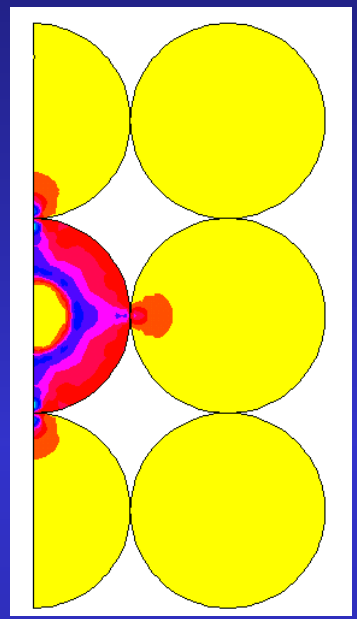
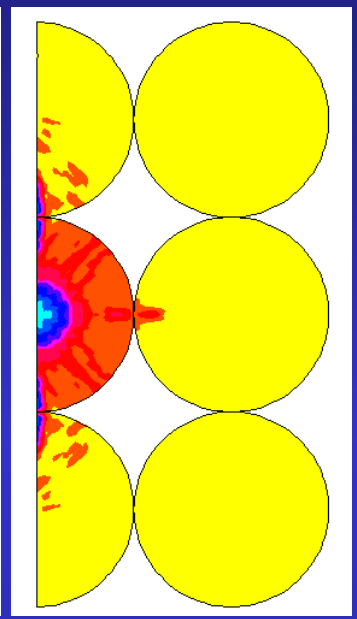
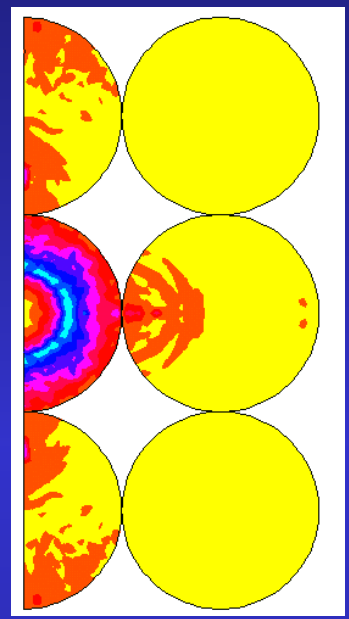
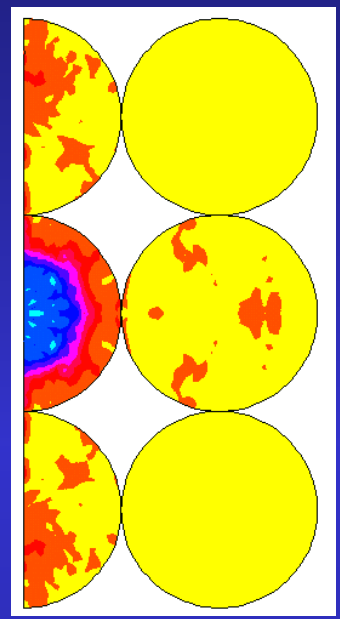
- More chance in particle bed to withstand undiluted beams
- Reduction in density may be made-up by cooling the bed with a liquid heavy metal
- A "smart" combination of particle-size and cooling agent can be found based on the impinging beam structure

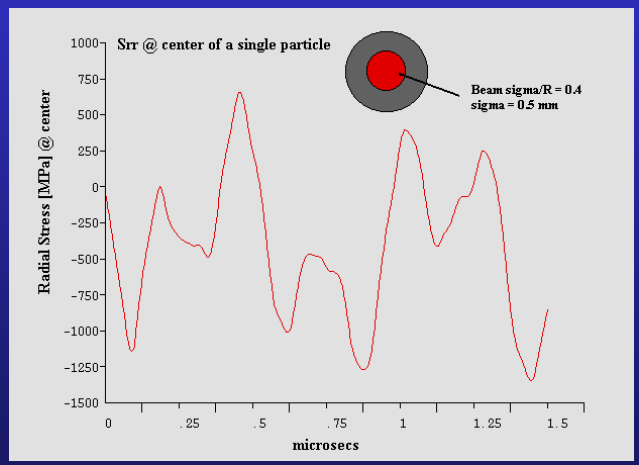


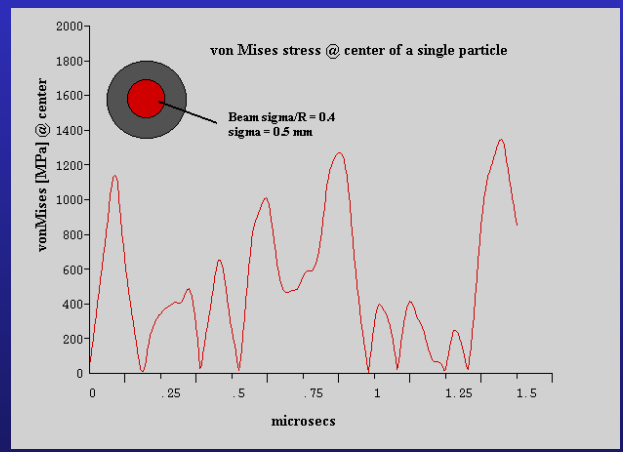




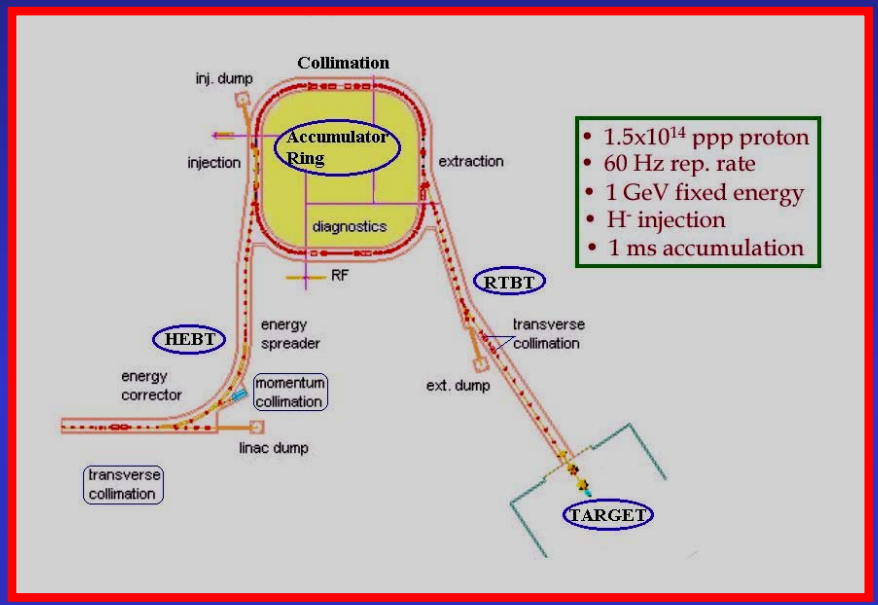
Particle Bed – Proton Beam Interaction

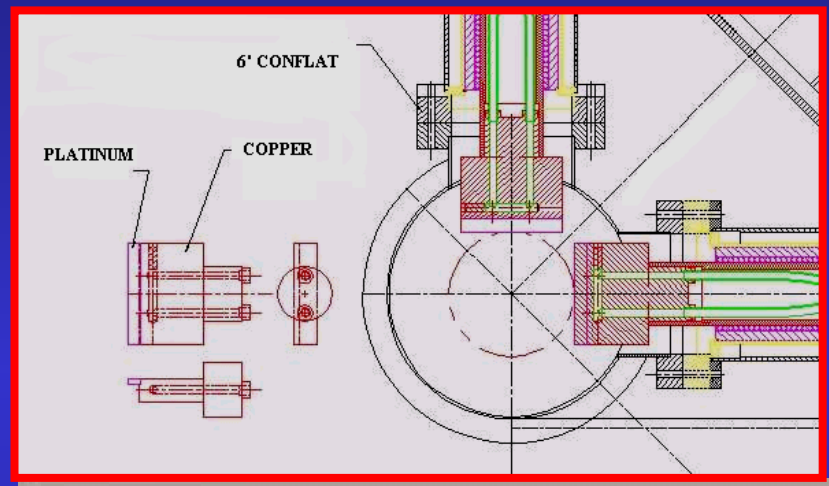






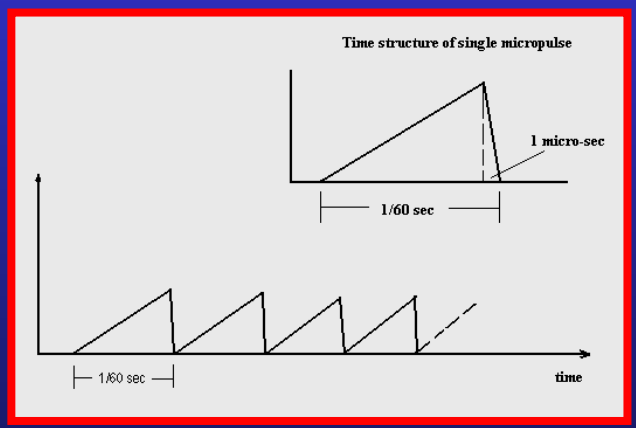


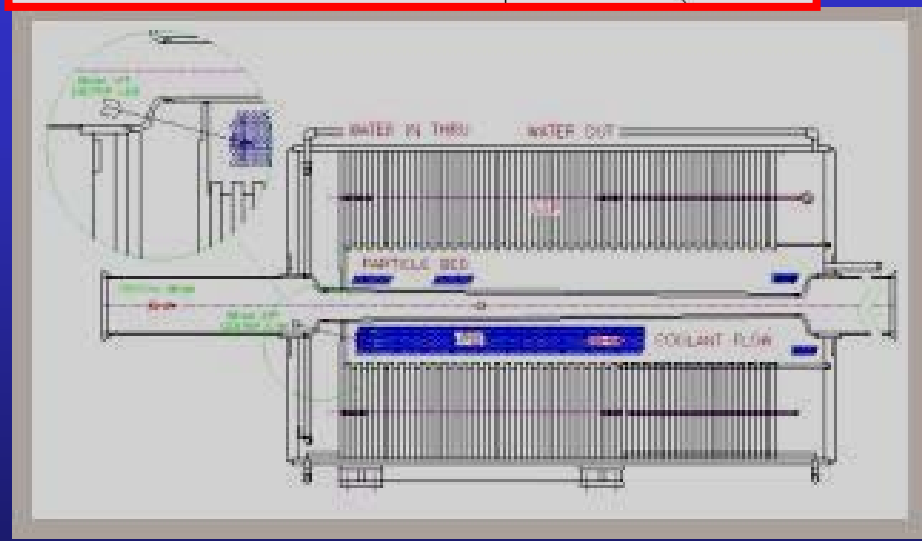


Collimation – RING
Movable & Stationary Collimators

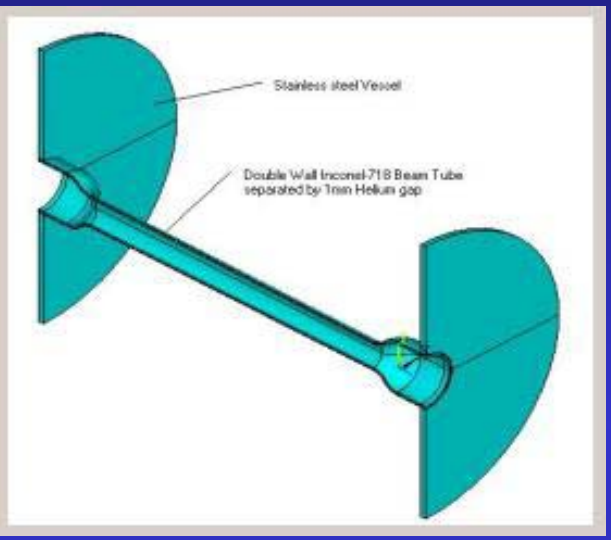


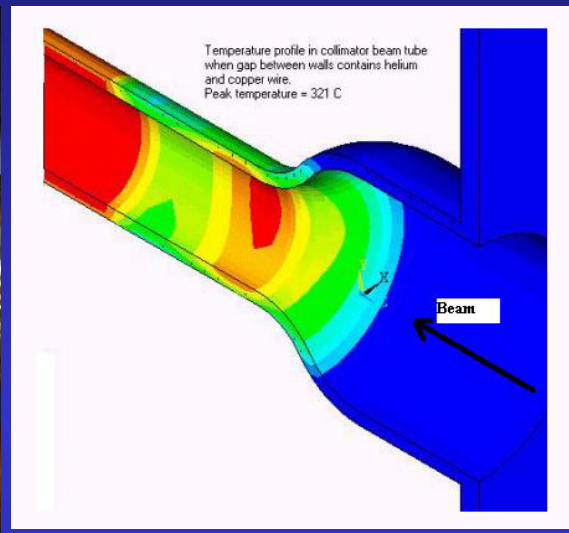


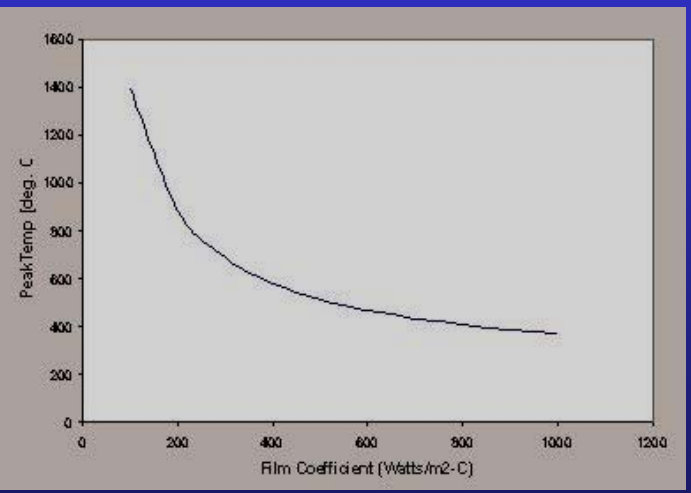


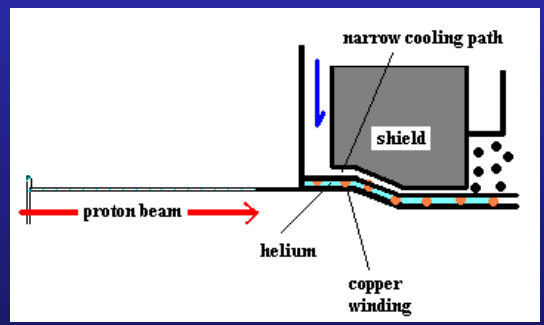


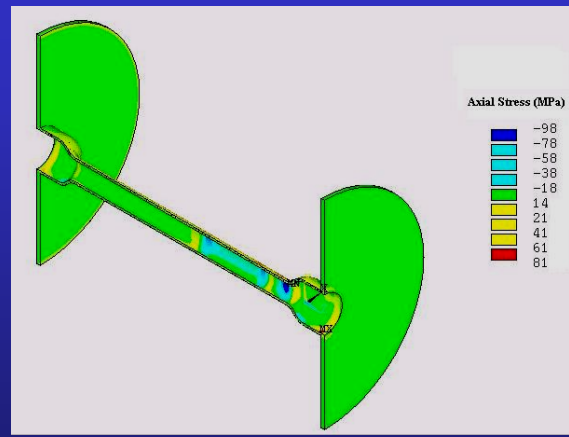
Collimation - RING



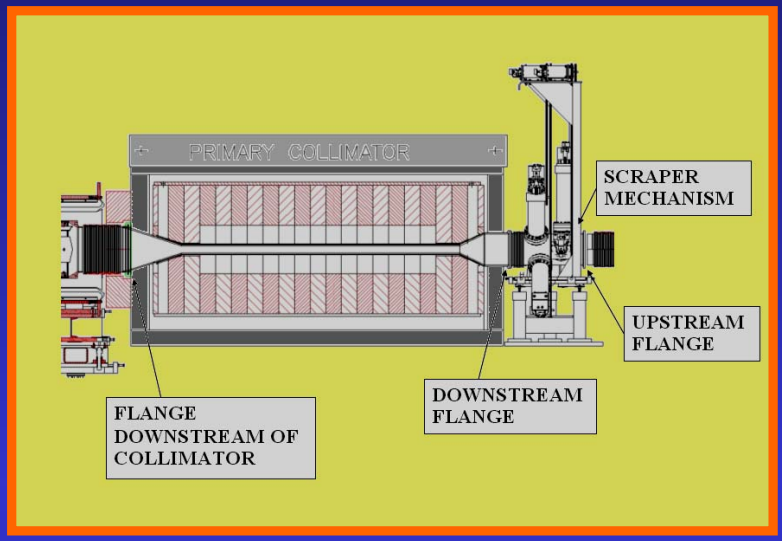


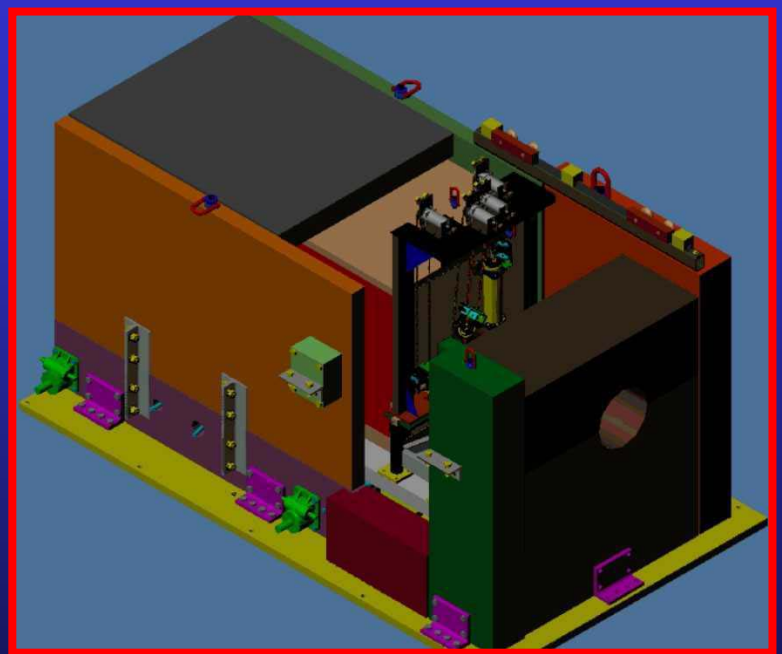


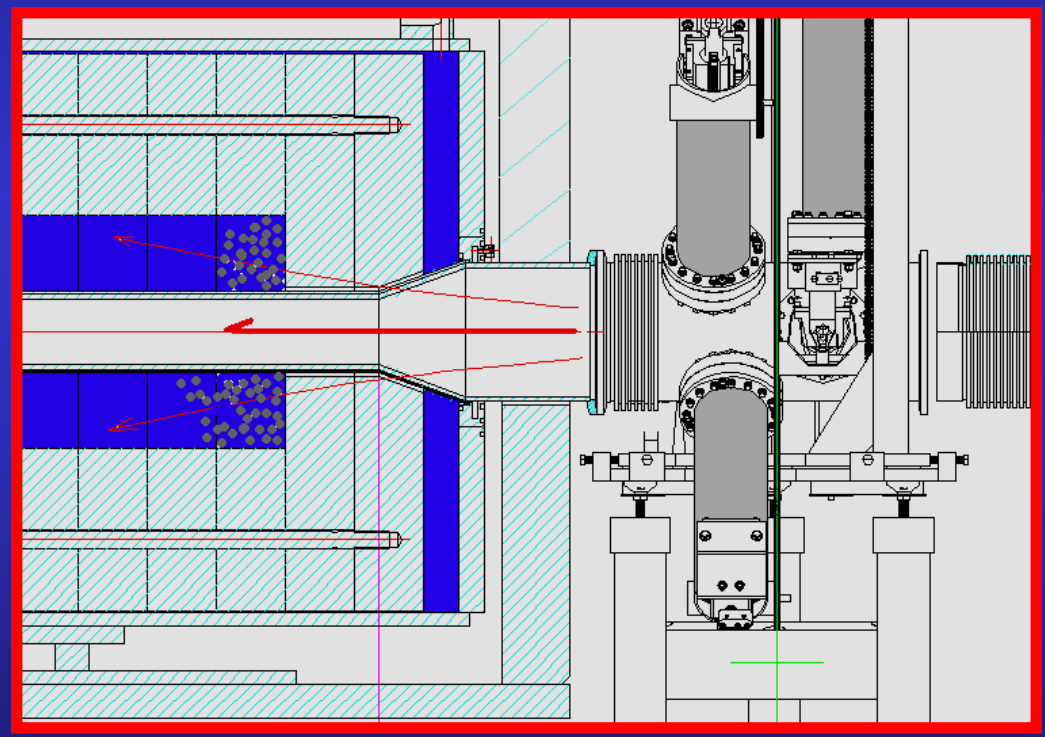




RING Collimation - Primary



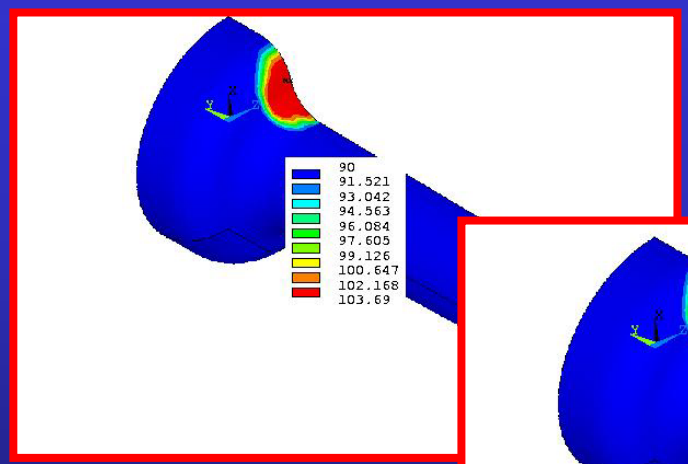


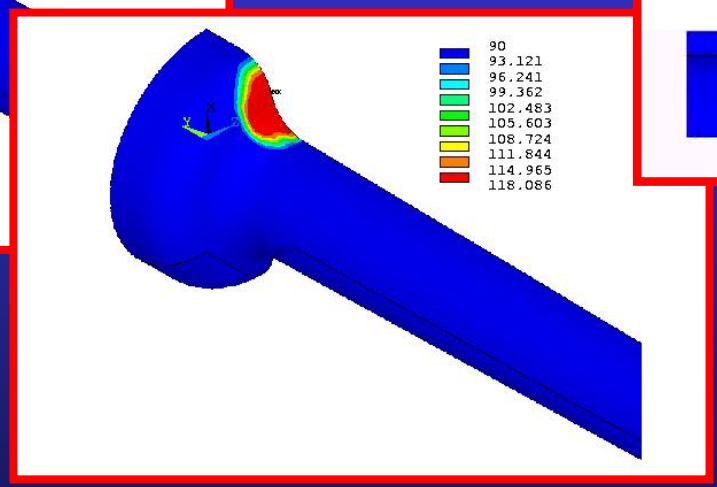


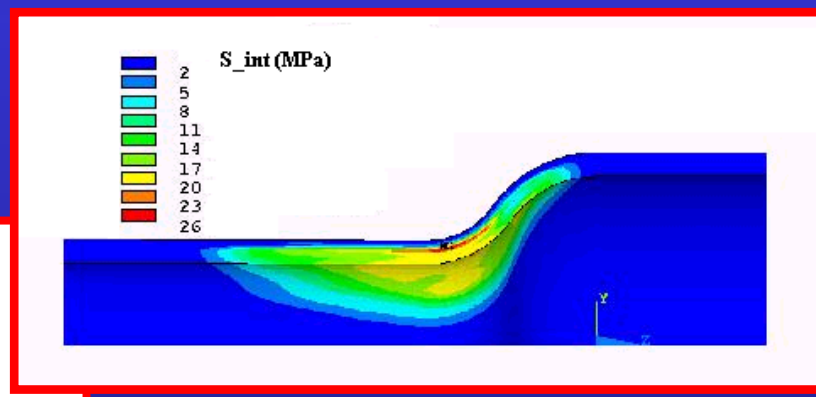
Collimation - RING

Accident Scenario – RING Collimator Issues

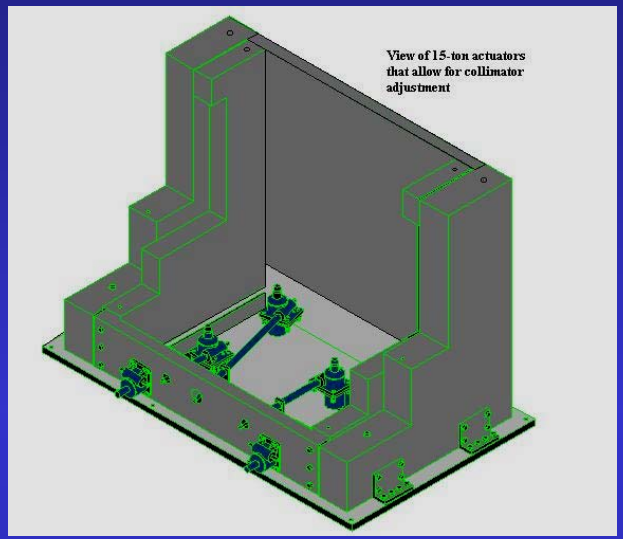
Magnet failure causing beam to stray onto movable collimator (scrapper)
Scrapper is in path of beam (rather than just halo) – Failure Potential ?
A good portion of beam is diverted onto the absorber through the double –wall beam tube
Potential for inner wall failure ?
Thermal fatigue (if diversion occurs frequently)
Breaching of vacuum space (He escape)/minimization of heat transfer path – Inner wall thermal response ?

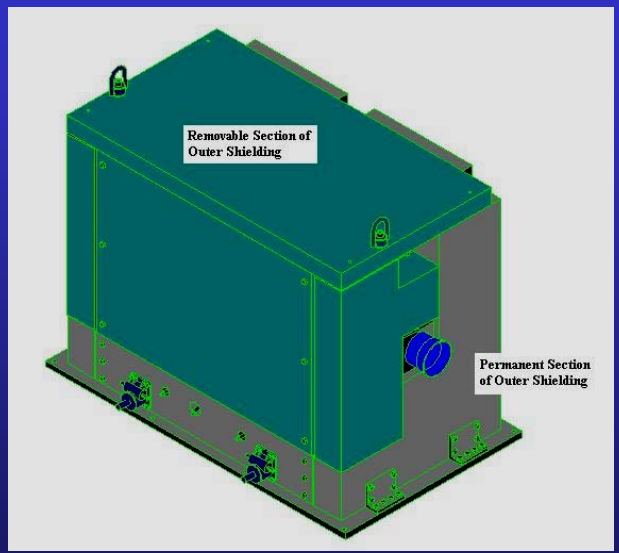


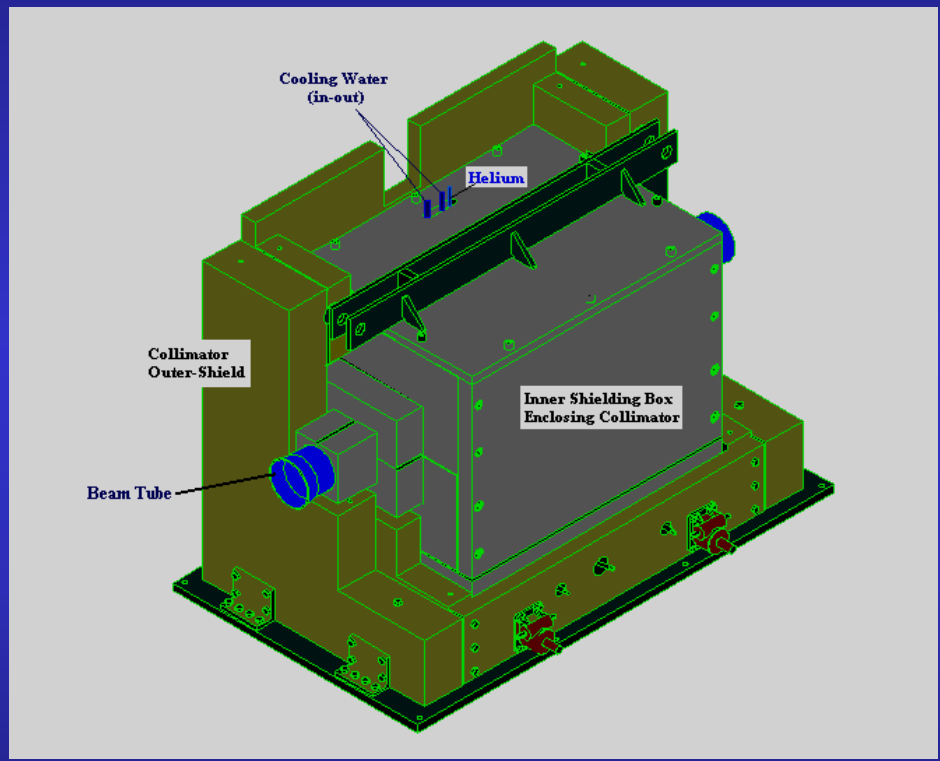




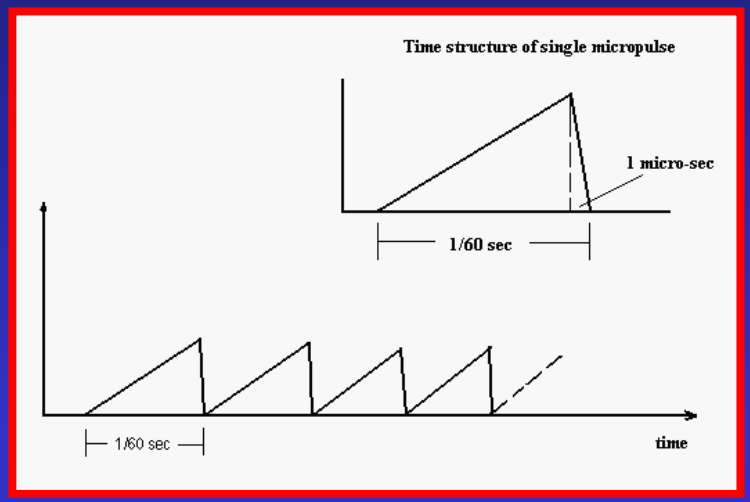
RING Collimation – Shielding Envelope

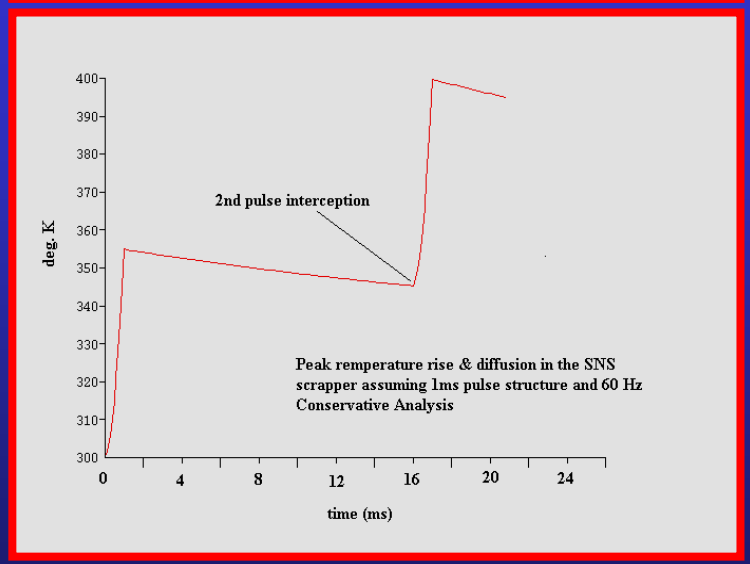


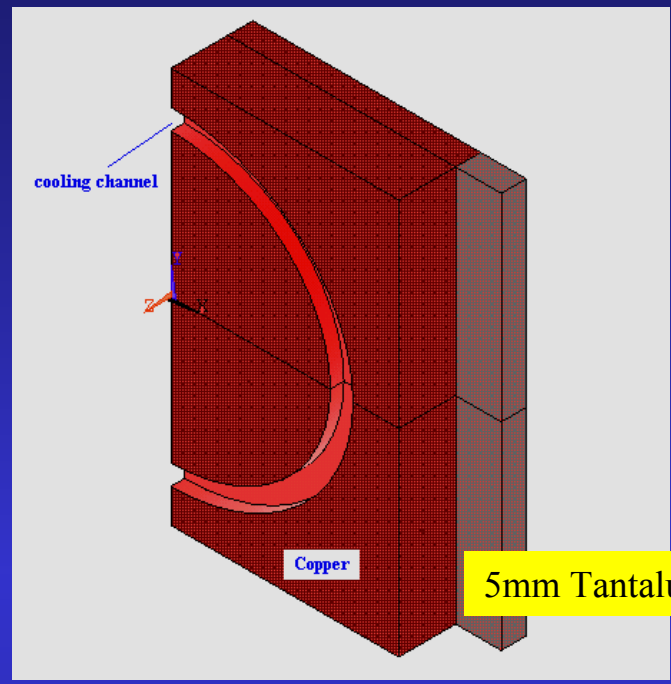


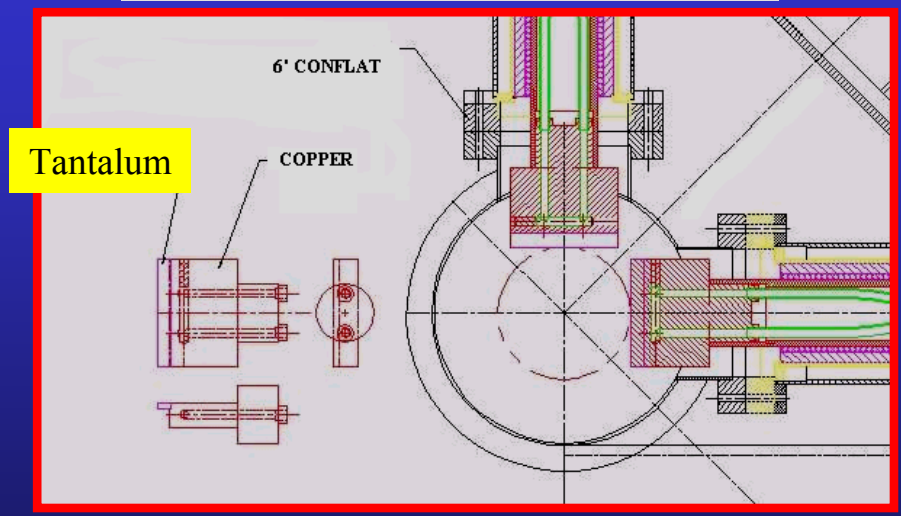


Movable Collimator - RING

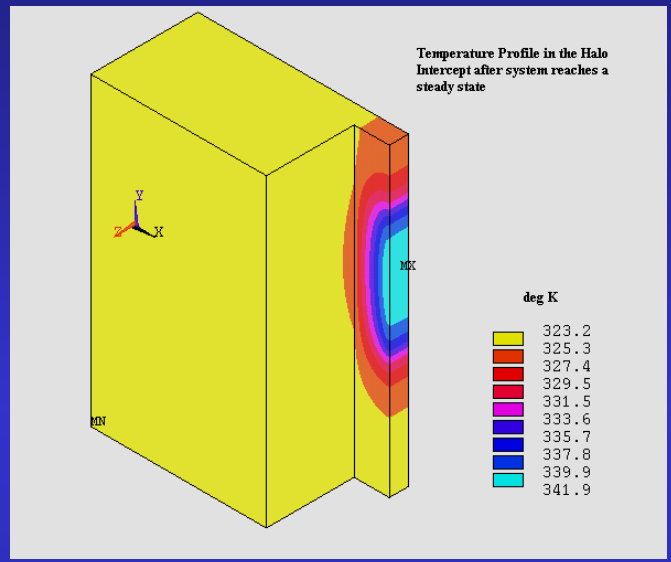


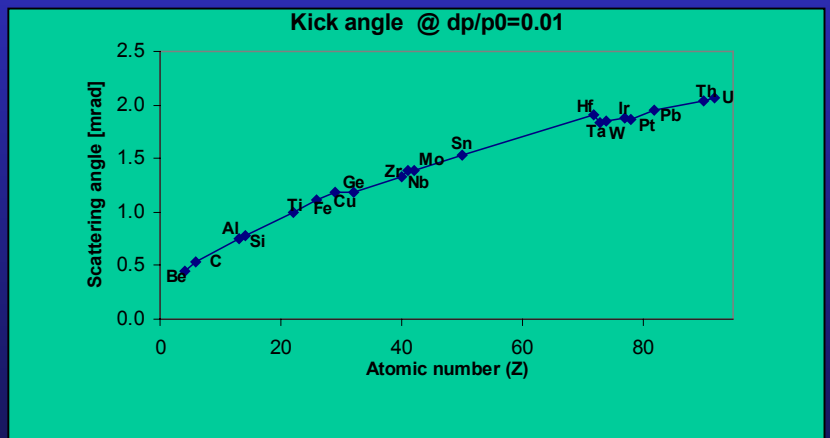


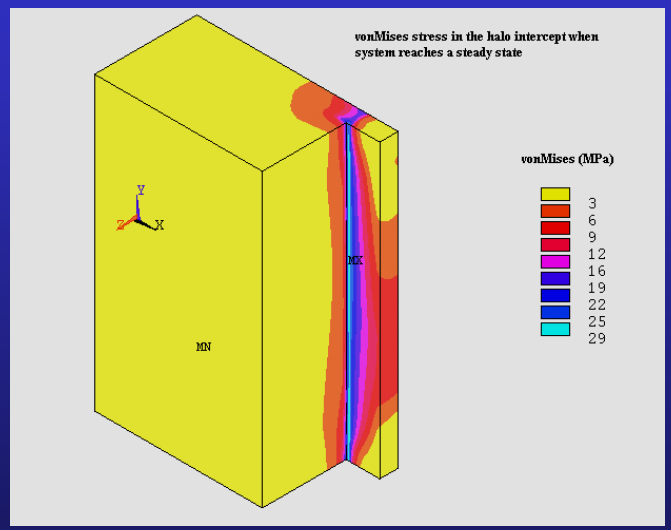




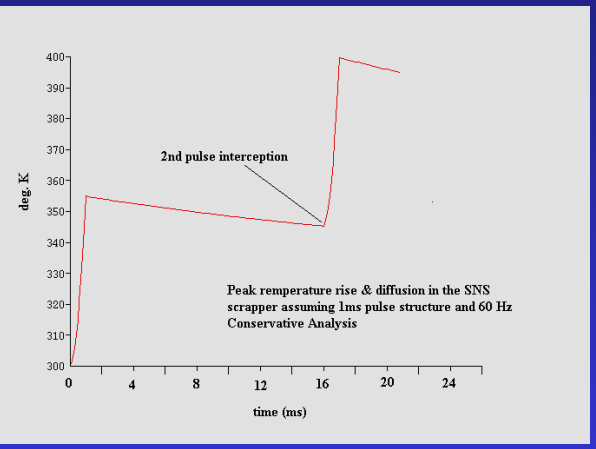
Collimation – RING – Movable Scrapers

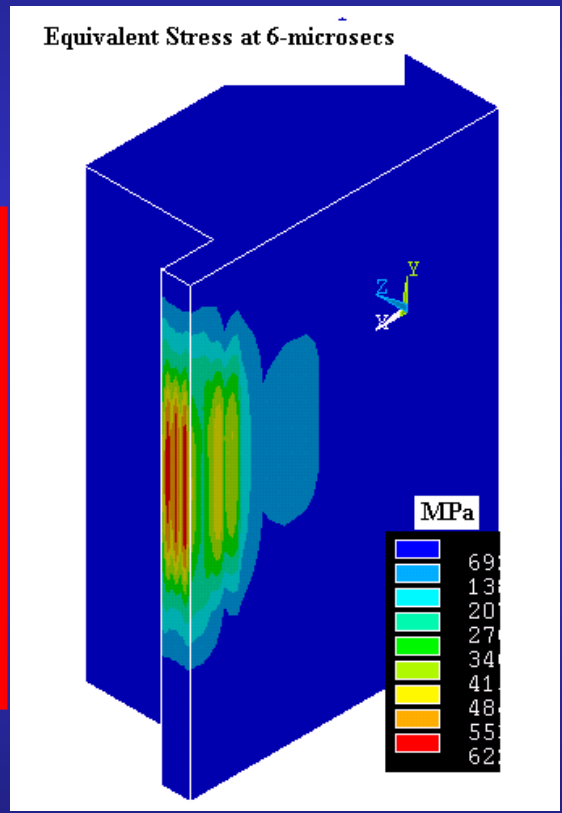


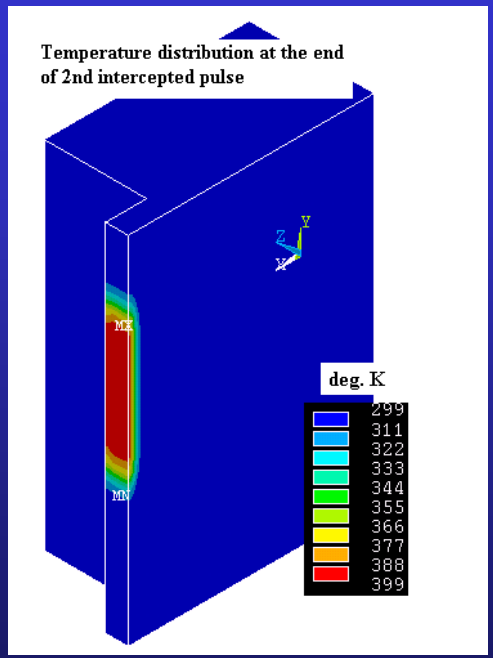




Collimation – RING – Movable Scrapers







Collimation - RTBT

Collimation - RTBT

RELEVANT STUDIES – Material Degradation
Inconel-718

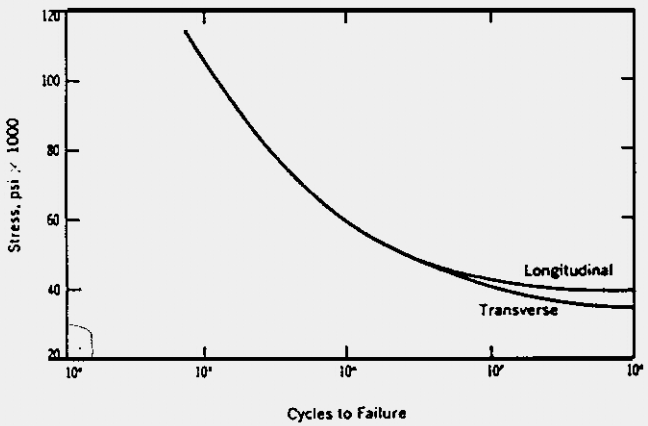
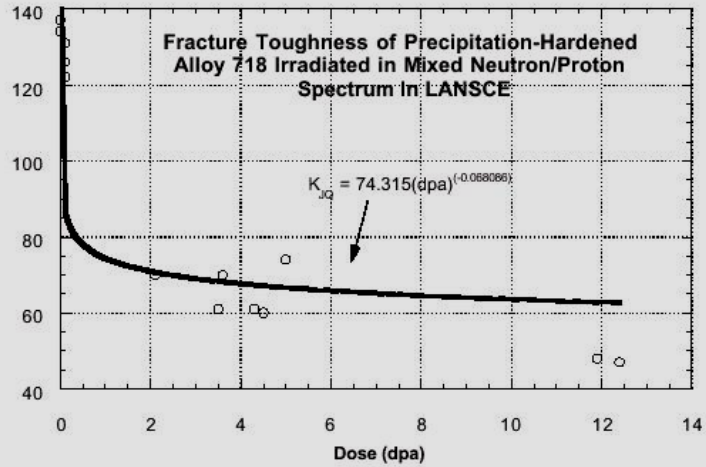


Figure 3—Room-temperature fatigue strength of 0.068-in. cold-rolled sheet annealed and aged in accordance with AMS 5596B (Krouse tests).

Table 30—High-Temperature Fatigue Strength of Hot-Rolled Bar (Annealed 1750°F/1 hr, A.C. and Aged)[a]

Test Temperature, °F	Fatigue Strength, psi			
	10^5 Cycles	10^6 Cycles	10^7 Cycles	10^8 Cycles
Room Temp.	132,000	101,000	92,000	90,000
600	115,000	110,000	110,000	110,000
1000	111,000	102,000	95,000	90,000
1200	100,000	94,000	88,000	72,000

[a] Rotating-beam tests. Average grain size, 0.0008 in. Aging—1325°F/8 hr, F.C. to 1150°F, held at 1150°F for total aging time of 18 hr.



Effects of irradiation on the fracture toughness of precipitation-hardened Alloy 718

RELEVANT STUDIES – Material Degradation Inconel-718

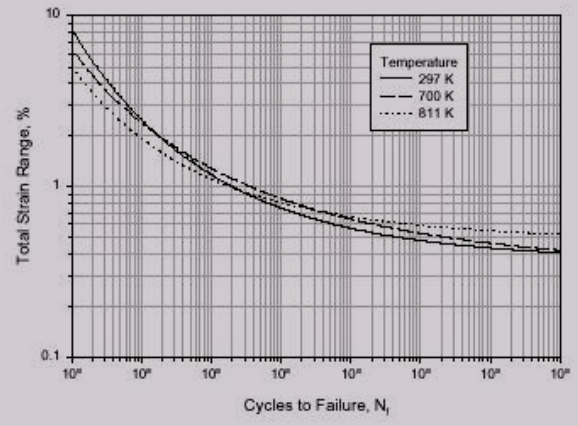
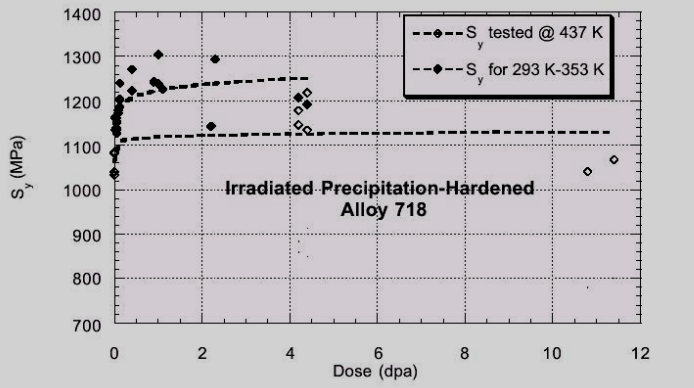
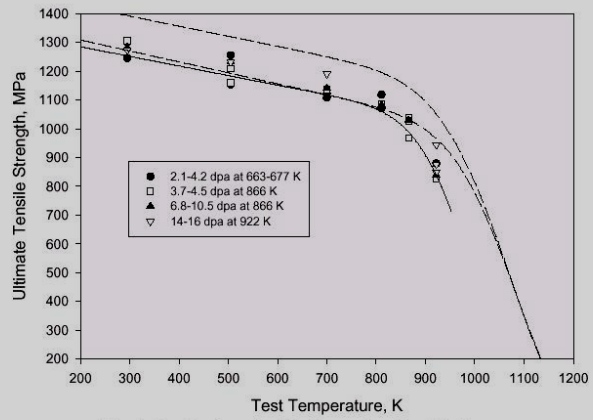


Figure 2-36. S-N curves for fatigue of Alloy 718 for temperatures of 297 K, 700 K, and 811 K.



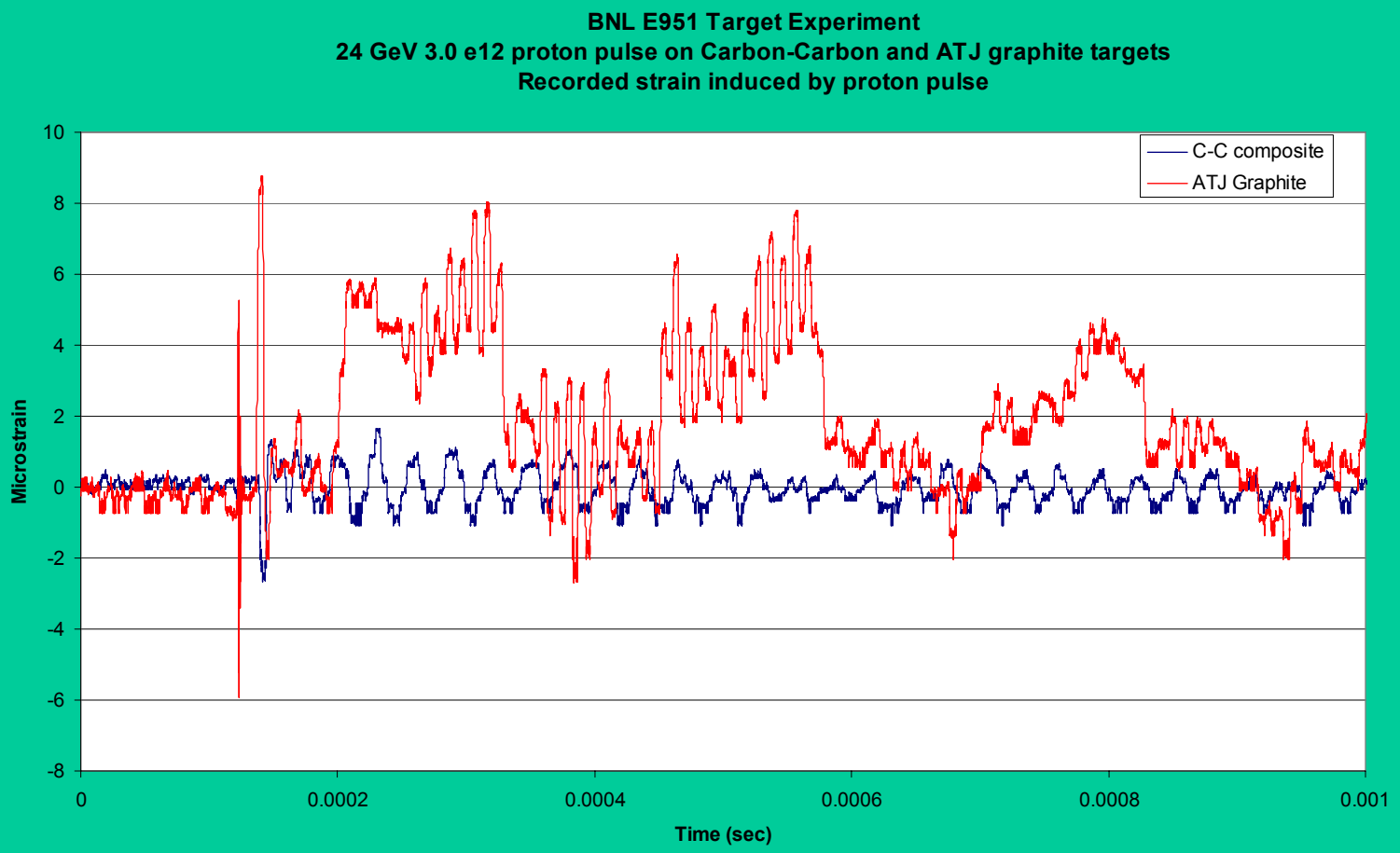
Effect of proton/neutron irradiation on the yield strength of Alloy 718PH



Ultimate tensile strength of fission neutron-irradiated Alloy 718PH as a function of test temperature. The dashed curves bound the range of S_U for unirradiated material; the solid curve is the lower bound for S_U in irradiated material

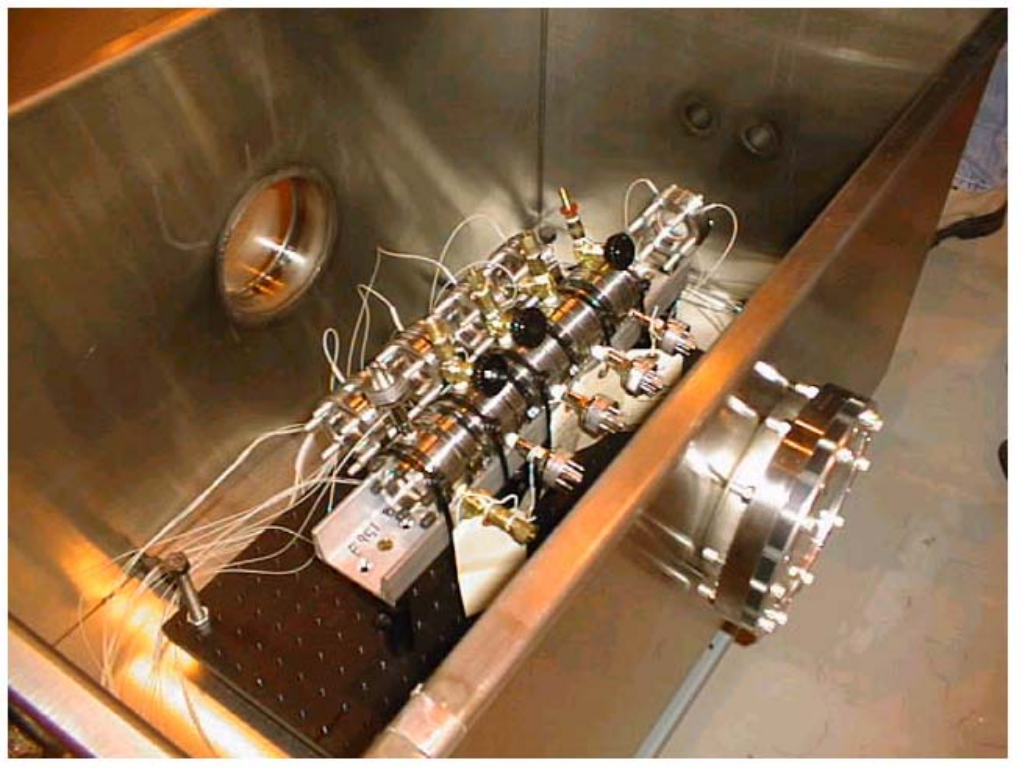
Strain Comparison: Graphite vs. Carbon-Carbon

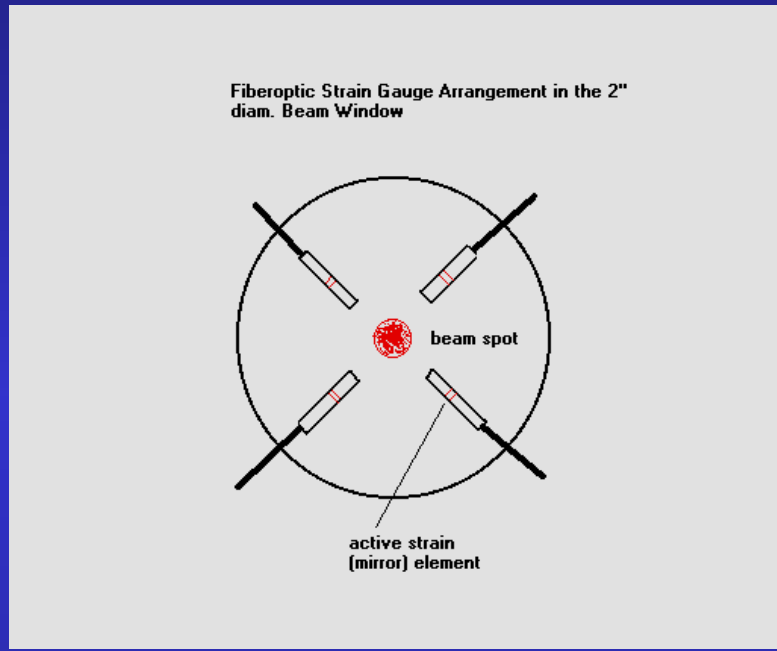
Carbon-Carbon Used in HEBT Charge Exchange Foils



E951 WINDOW TEST Station Set-Up

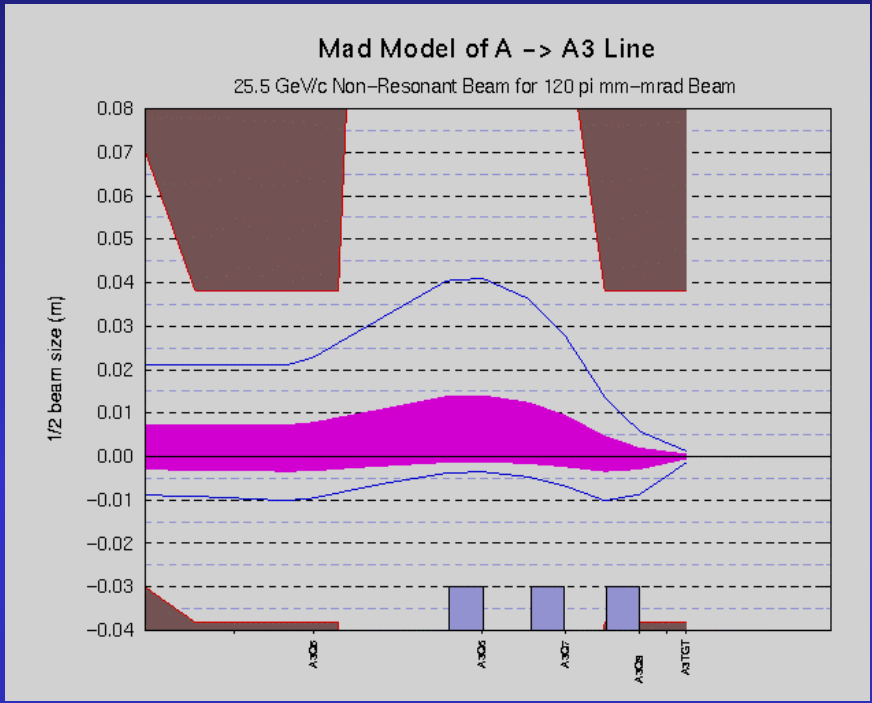
Fiber-optic Strain Gauges & Double window vacuum monitoring

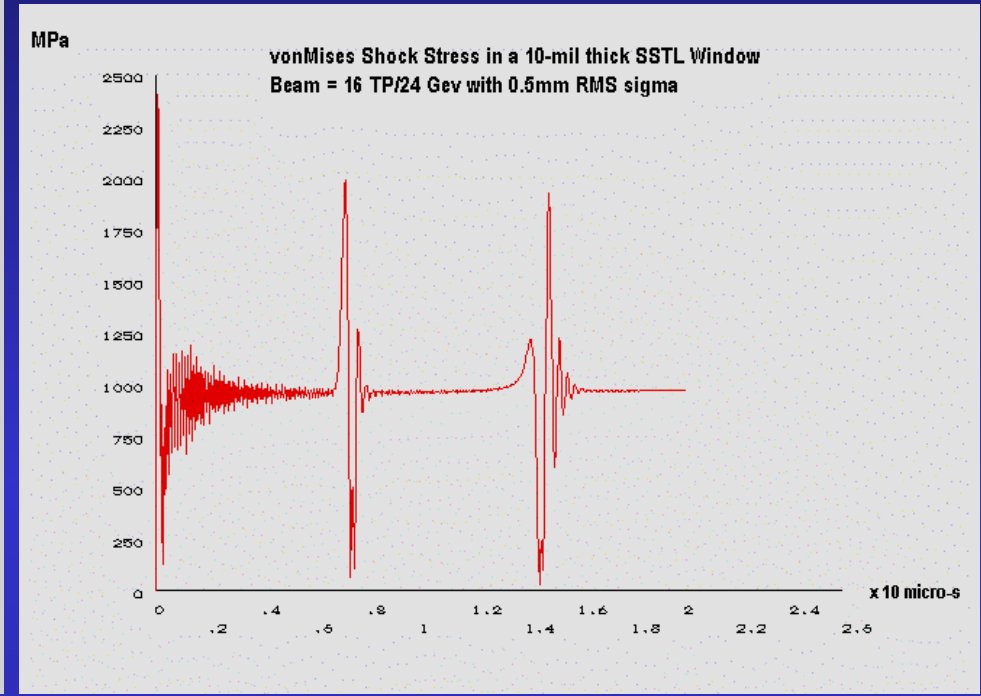




HALO-2003

What Triggered the Window Experimental Effort





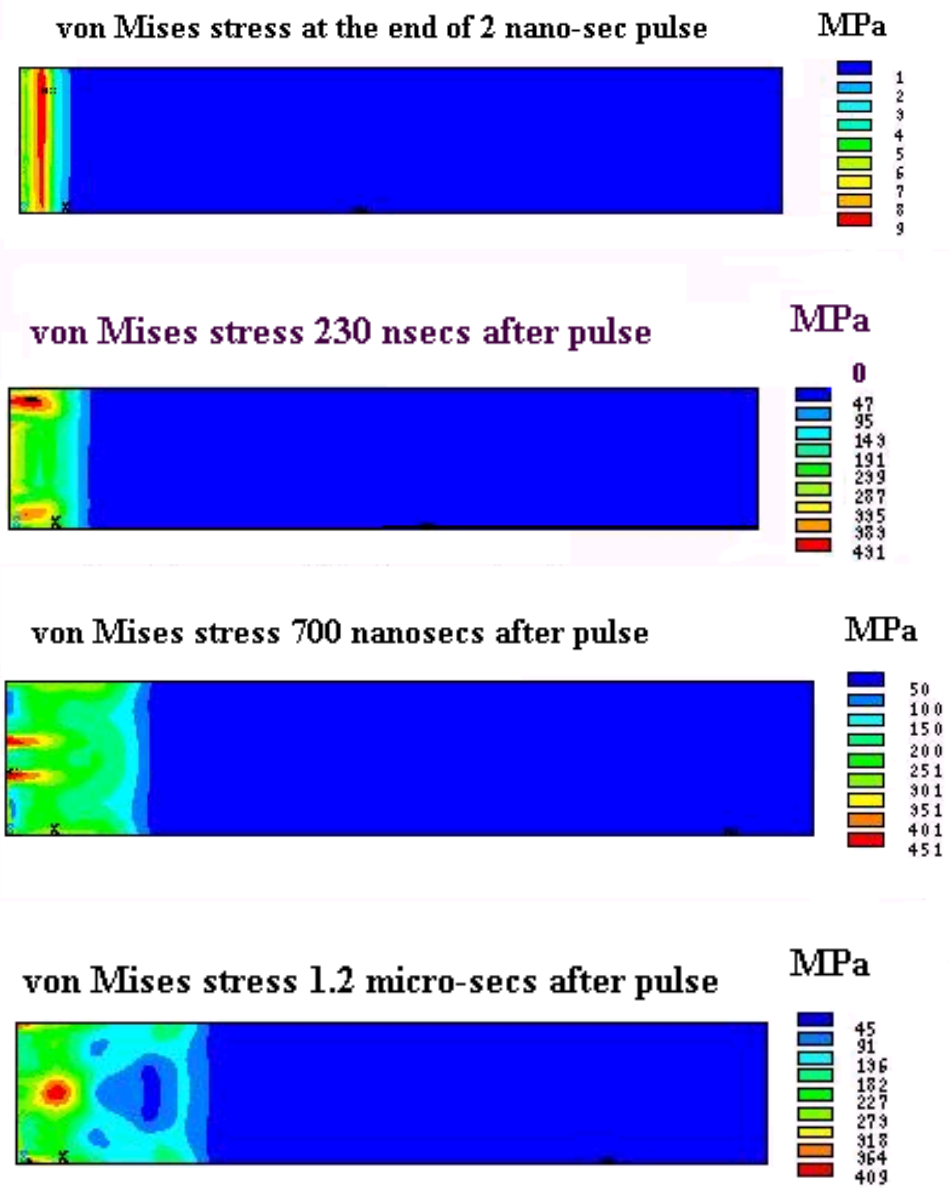
Beam spot requirement (0.5 x 0.5 mm rms) for target experiment at AGS

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 !!

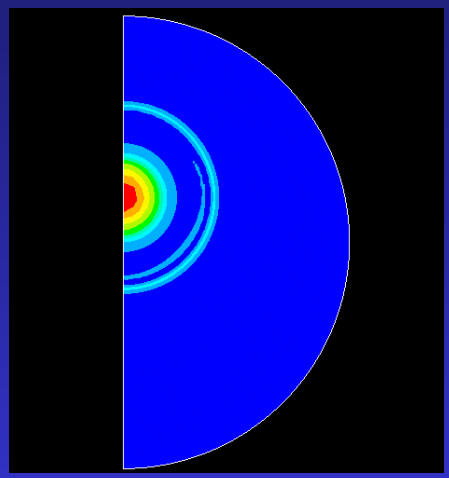
HALO-2003

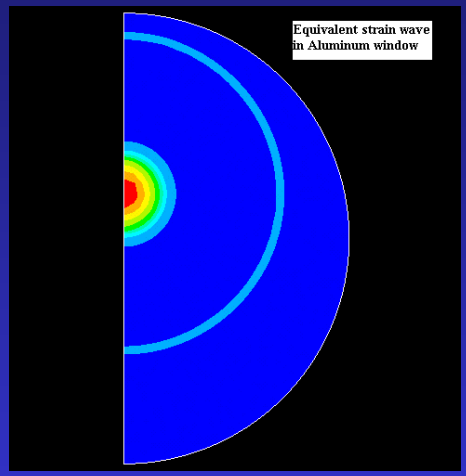
Mechanism of induced shock stress in windows

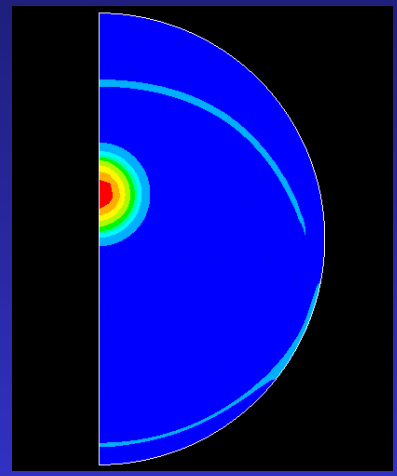


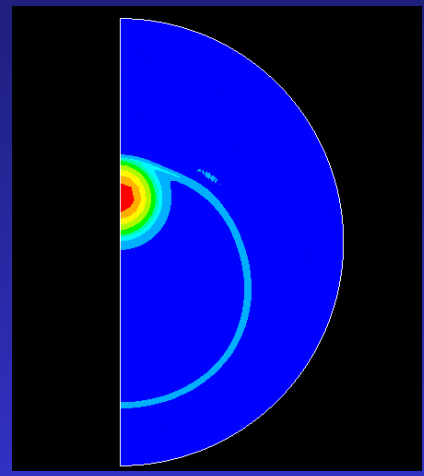
- No matter how thin the window is, the reverberation of stress between surfaces is the key issue
- vonMises stress amplitude depends on the spot size (initial compressive load amplitude), thickness of window, speed of sound and pulse shape
- the measurement of strain on the surface is to be used as 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

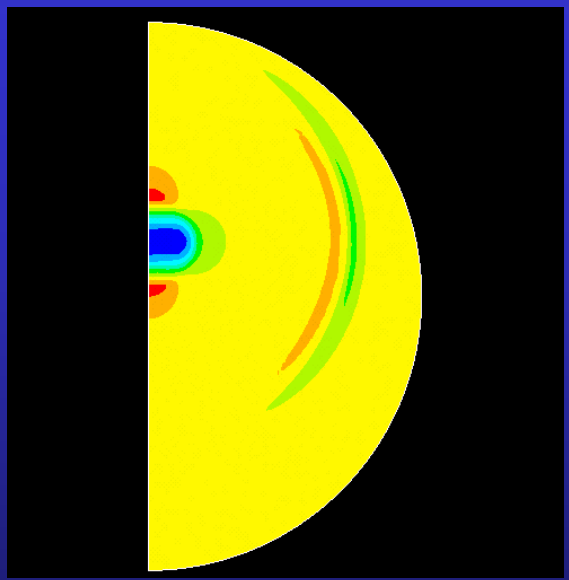
Simulation Beam Window Strain Waves

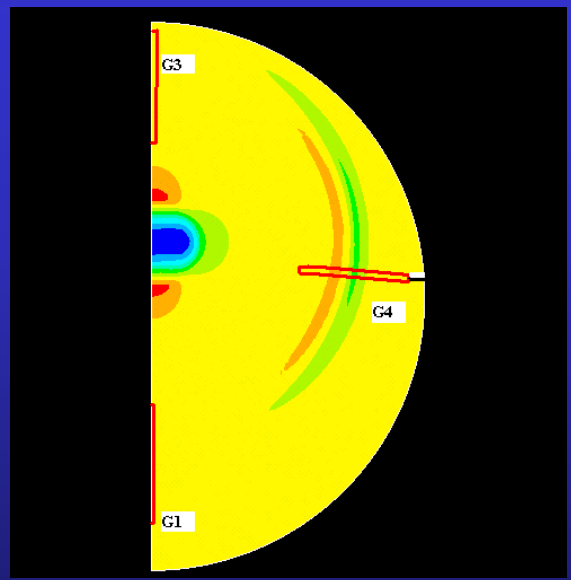


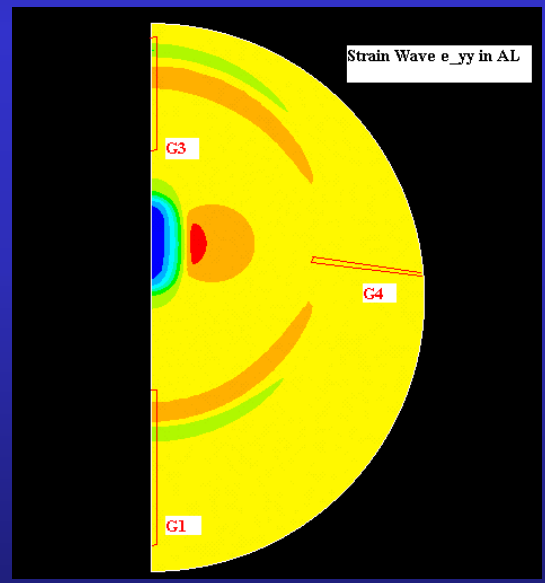






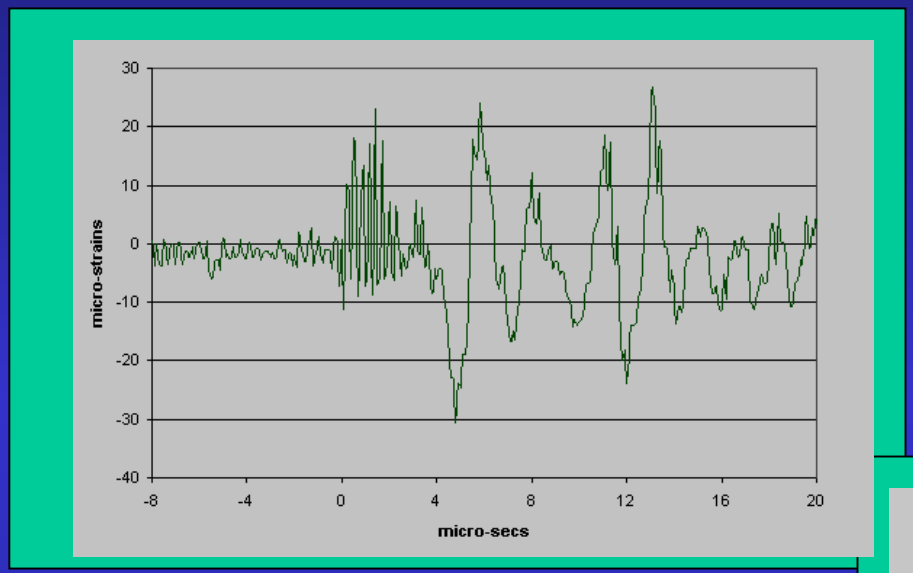


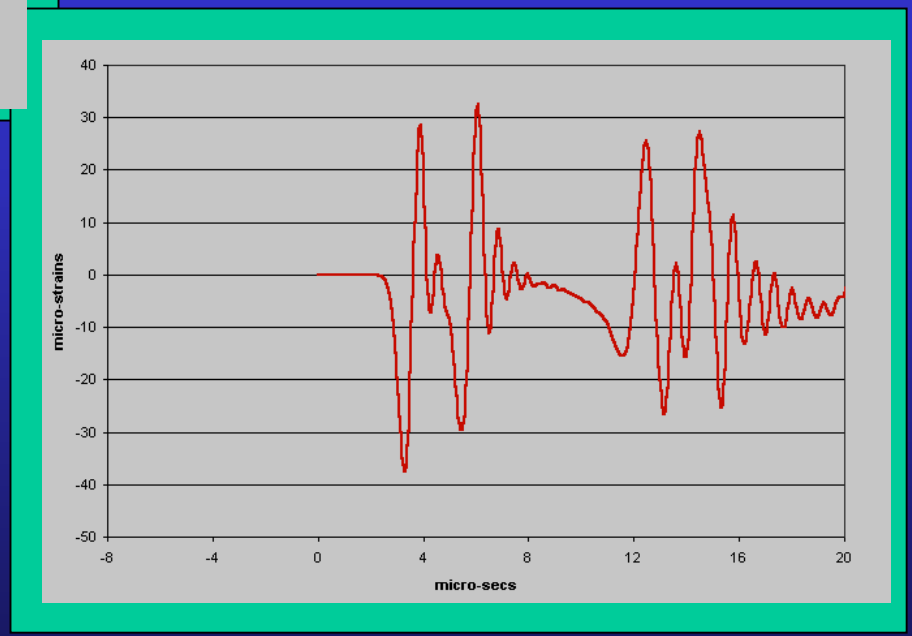




Aluminum Window Strain Data

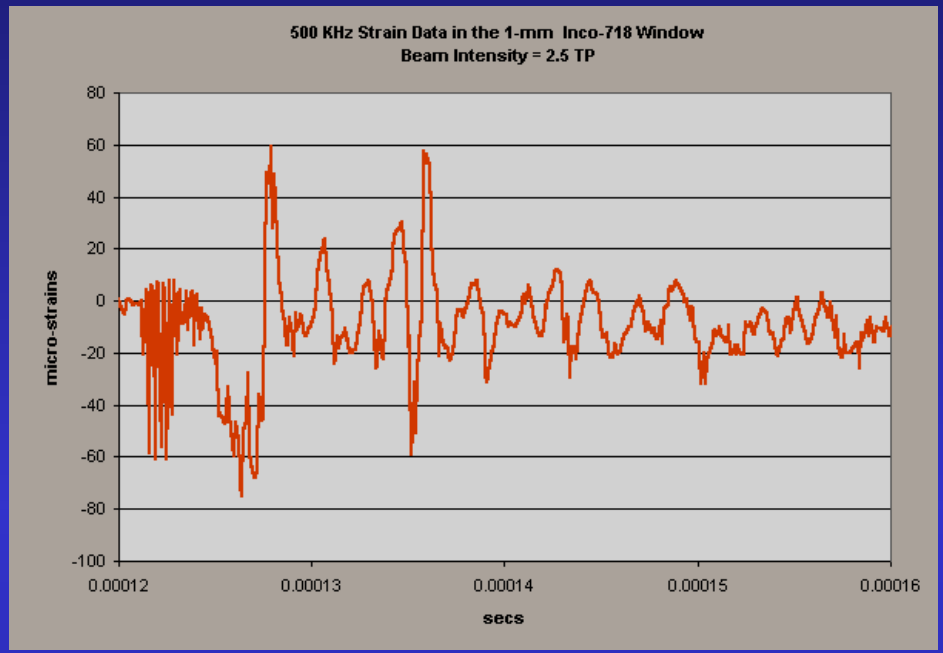
Experimental data vs. prediction using the new beam spot (0.3 x 1mm)

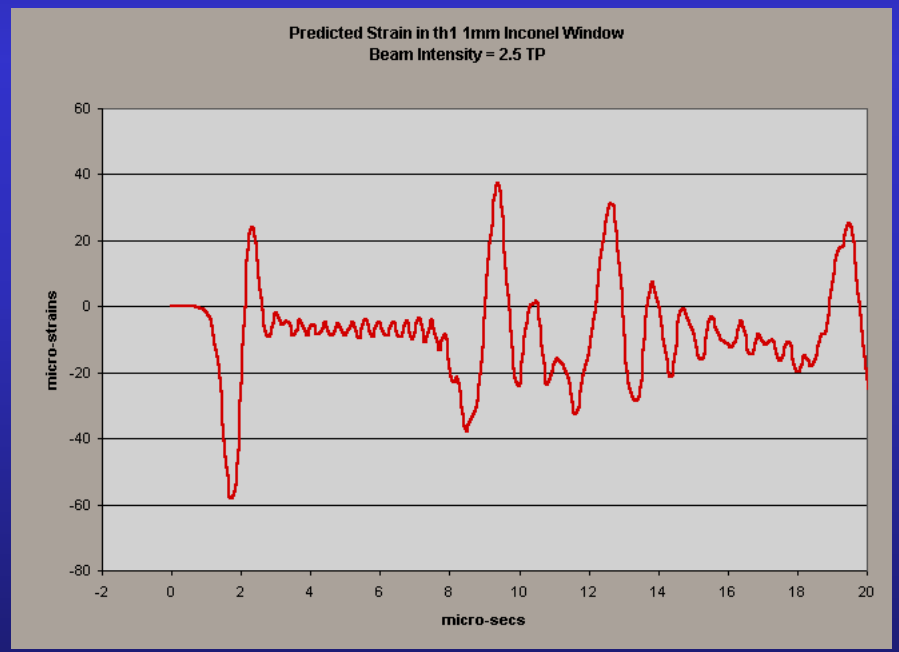




HALO-2003

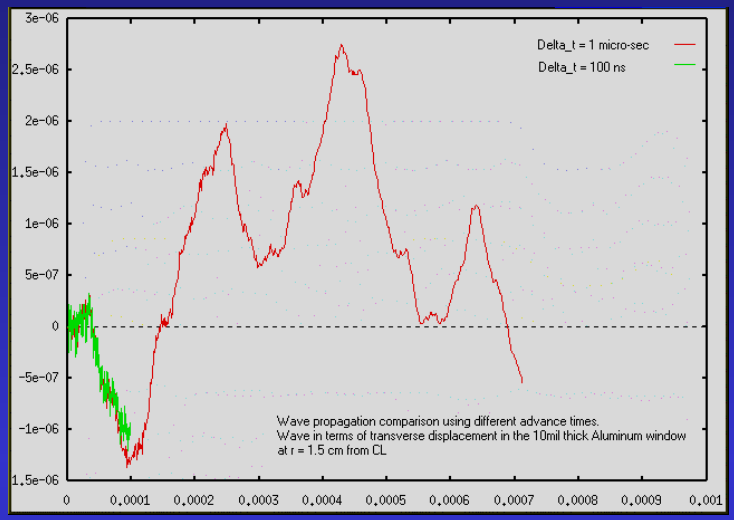
Measured and predicted strains in the 1mm thick Inconel

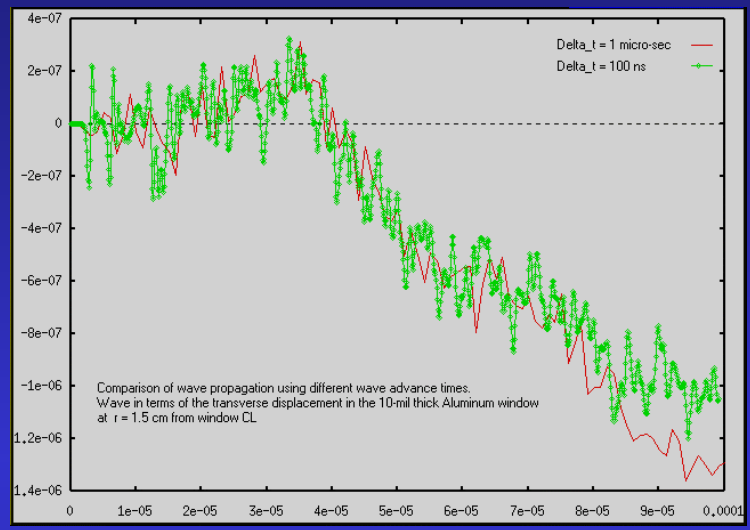


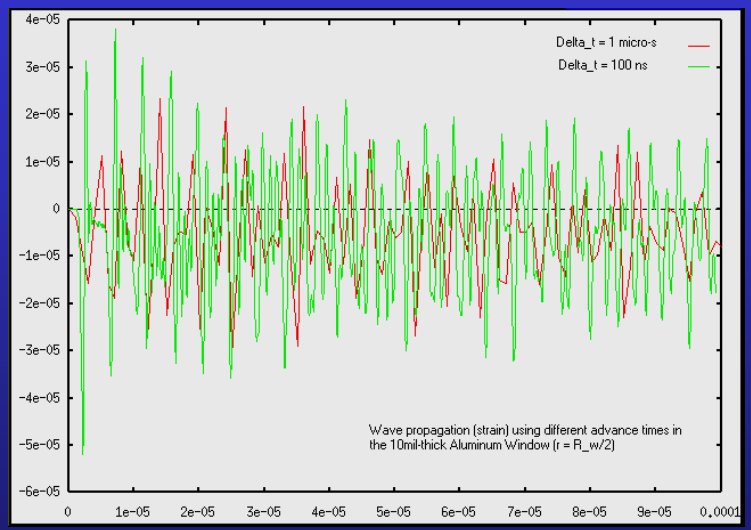


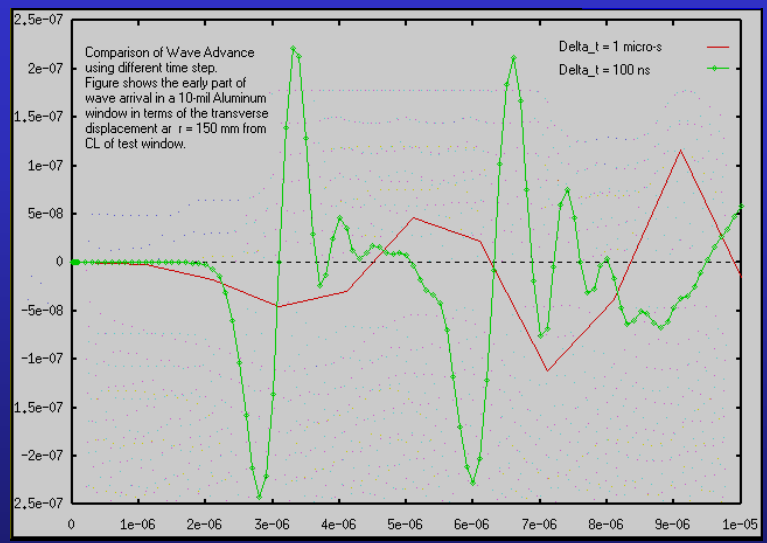
HALO-2003

Some Important Lessons Learned in Analyzing Beam/material Interaction

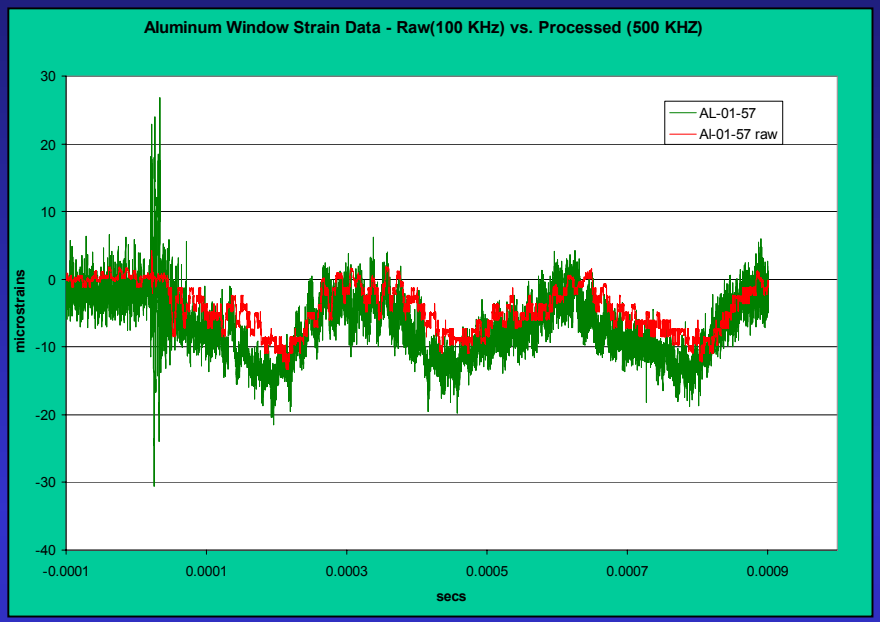


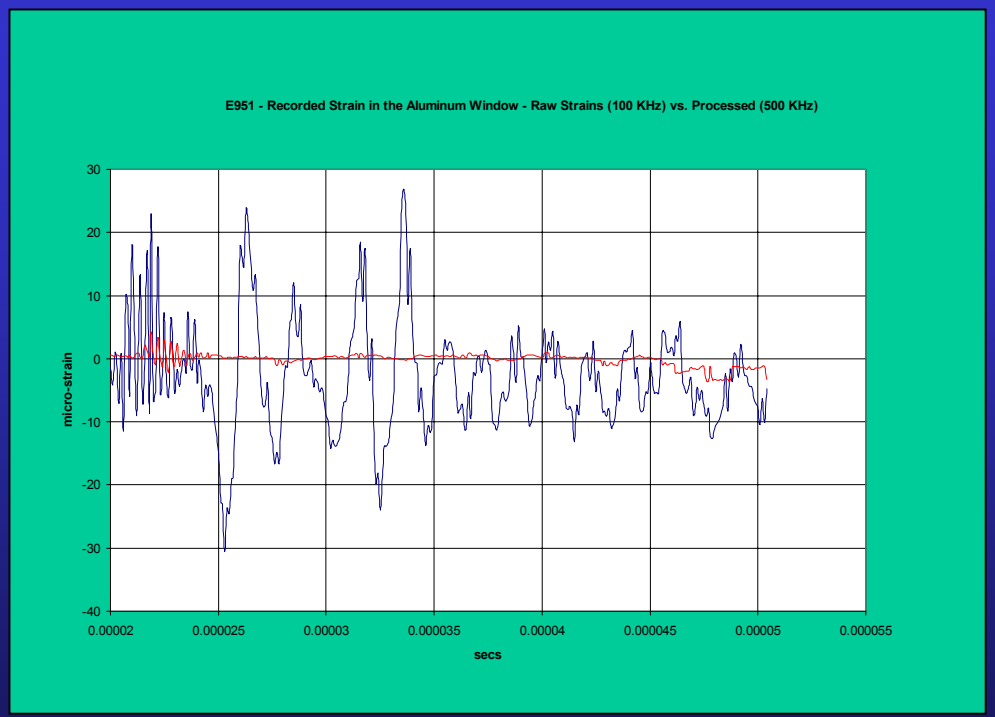






Lesson: You better have the resolution needed, or …





HALO-2003

SUMMARY

- SNS Collimator System Design Complete (almost)
- Collimators of HEBT, RTBT as well as secondary & tertiary in the RING are in fabrication stage (some already delivered)
- Installation will begin this summer (2003)
- From the design side, great effort has been made to address the worst case scenario over all key elements in the collimation system and we feel confident it will perform as designed. (it must, given that we have had more reviews I can remember !!!!)