Pressure Transients in the ILC Beam Dump

Tristan Davenne, Ottone Caretta, Chris Densham
(Rutherford Appleton Laboratory)
Rob Appleby (Manchester University)

LC-ABD Collaboration meeting
Birmingham University
17th April 08

Contents

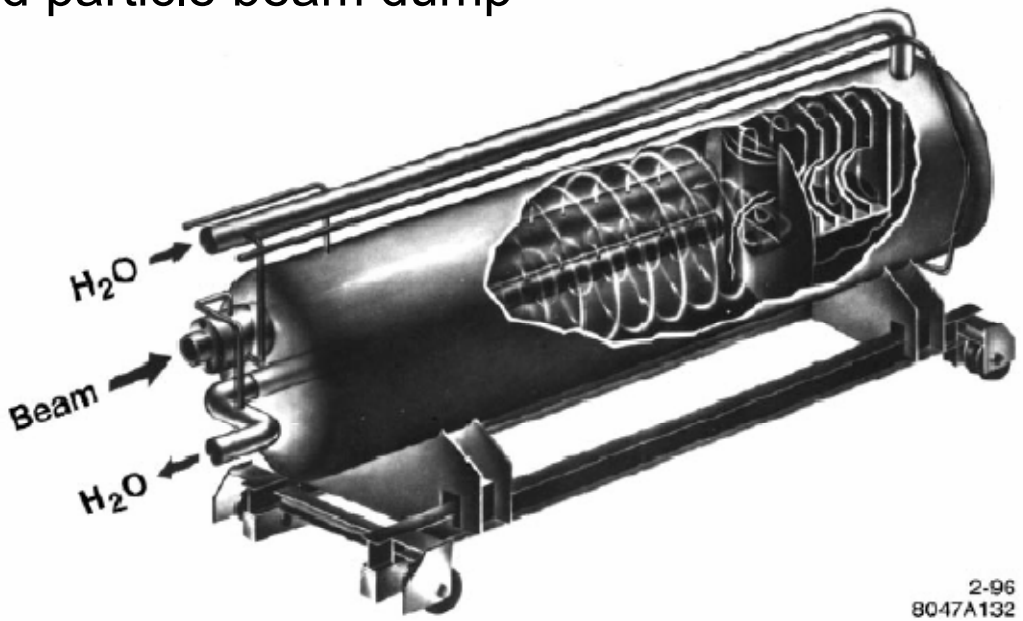
High Power Targets
www.STFC.ac.uk

Water beam dump
for the ILC 18MW charged particle beam dump

1966

SLAC installed two primary water beam dumps with 2.2MW power capacity (Walz *et al*)

Very successful, running at up to 800kW.



1996

Walz et al. Design concept proposed for a 10MW beam dump based on 1966 design.

2005

Walz et al. Beam dump dissipating up to 18MW of average power is feasible with absorption medium being water, questions remain about radiation damage to window.

Shmitz et al. Principally feasible, but inherent risks will make it difficult to “sell“ it as reliable, safe and robust, transient pressure in water sited as a problem. -1.6bar to 3.7bar.

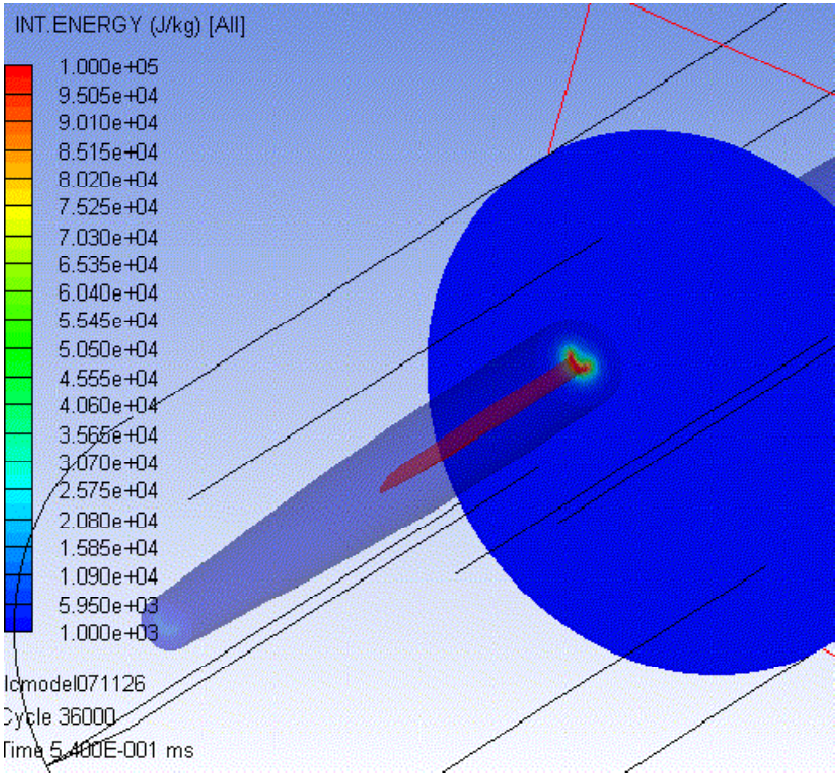
2007 Walz Vessel provides safety factor of 5 in terms of pressure;
hoop stress=6000psi, yield strength=30000psi. No comments on transient pressures.

ILC Beam Dump
-Inputs to Simulation

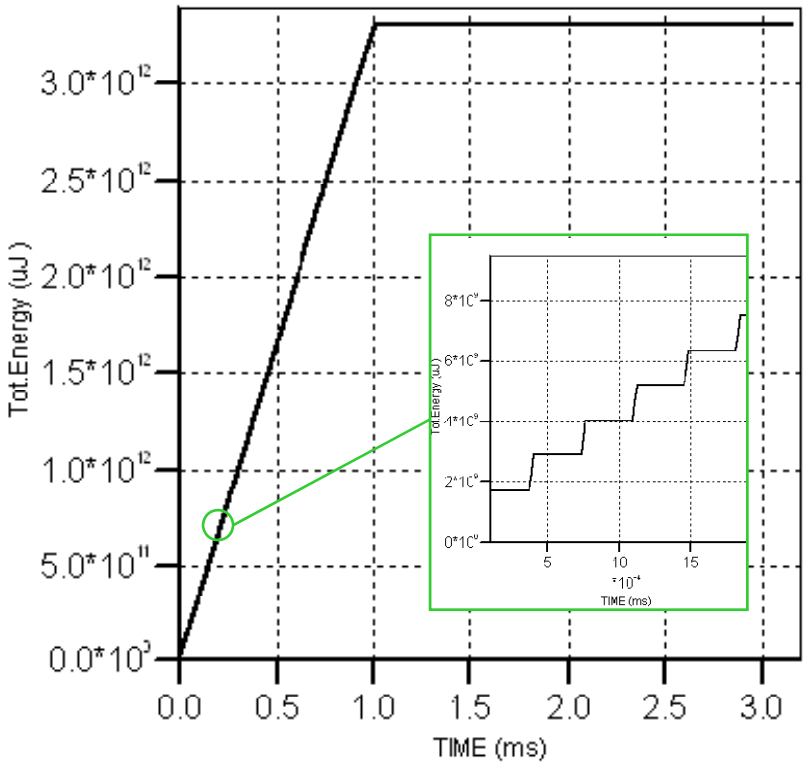
Inputs

- material – water (no gas contained in water)
- equation of state – single phase shock with tensile failure model set at 1bar
- domain size = 6m x 1.45m diameter
- boundary conditions = rigid tank walls
- duration of bunch = 30ns
- duration of interval between bunches = 330ns
- number of bunches in a bunch train = 2800bunches
- duration of a bunch train ~ 1ms
- energy deposited per bunch = ~1.19kJ
- energy deposited per bunch train = ~ 3.3MJ
- time averaged power deposition = 16.5MW
- number of electrons per bunch = 2e10
- beam energy = 500GeV
- Beam eccentricity = 300mm
- beam rastoring radius = 30mm
- beam rastoring speed = 6280rad/s

ILC Beam Dump
Energy Depositon

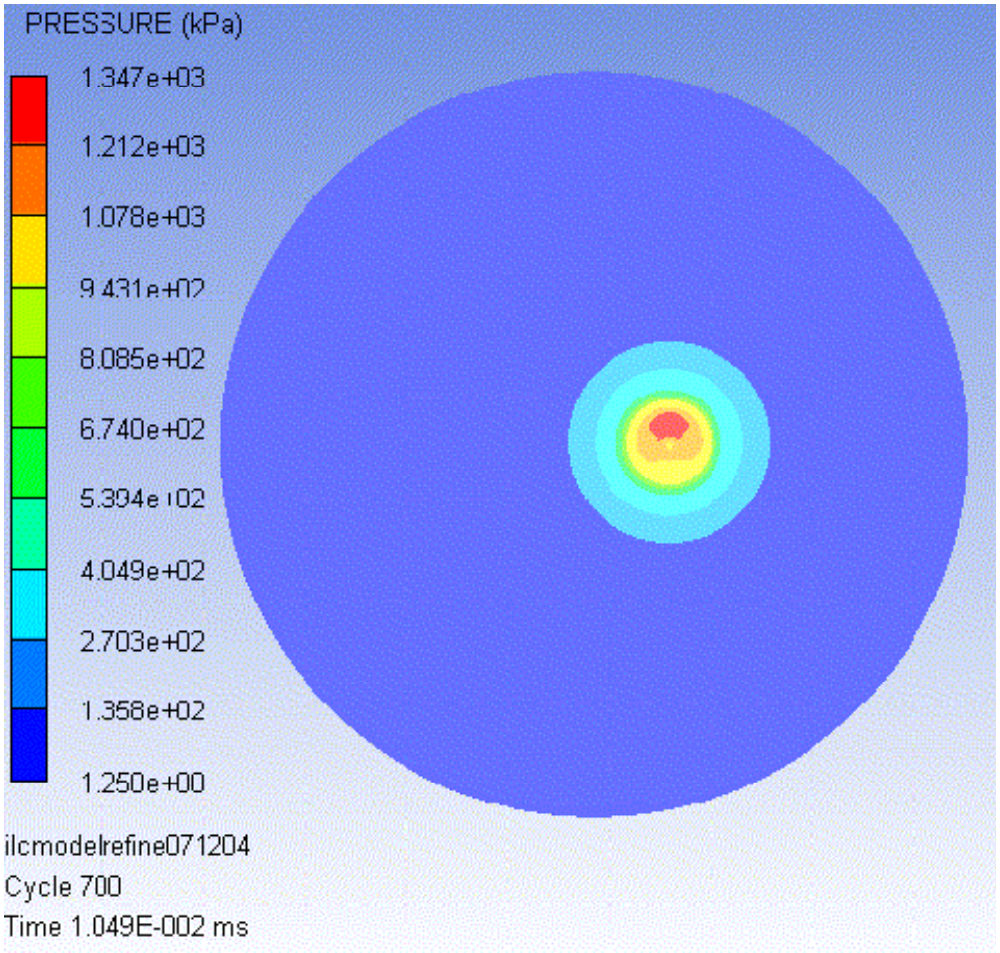


Contours of energy deposition



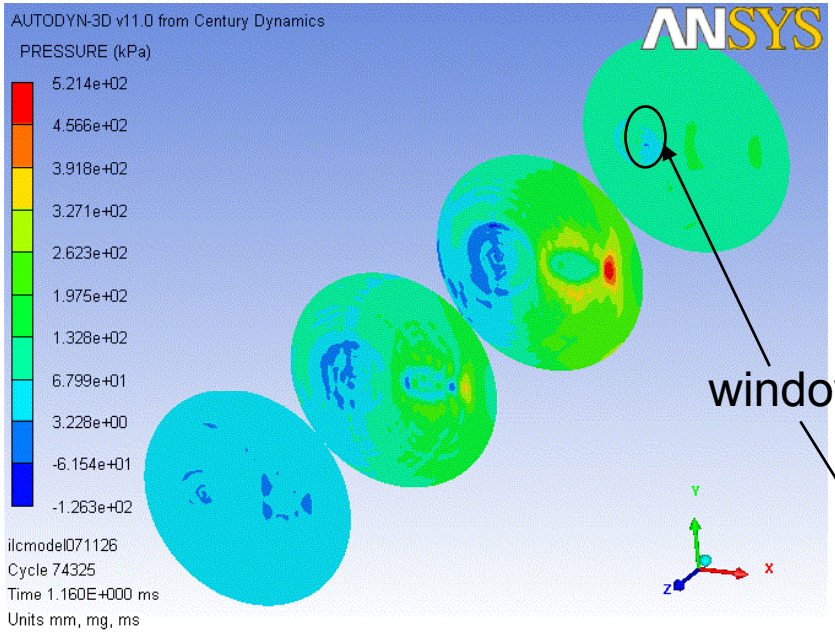
Total energy deposited

ILC Beam Dump
Peak Pressure



Refined mesh (2mmx2mm) around region of shower maximum indicates a peak pressure of ~13.5bar occuring after 0.01ms or about 28bunches

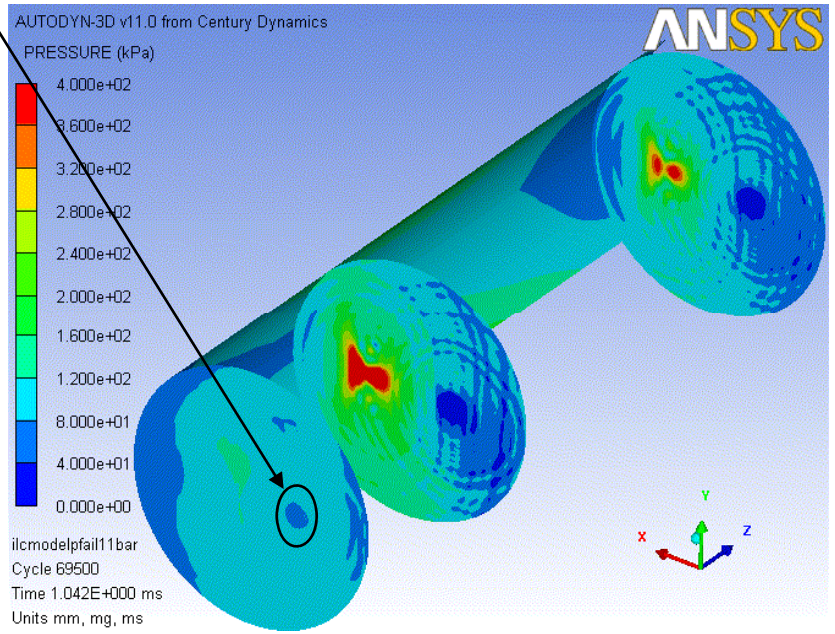
ILC Beam Dump
Pressure Field



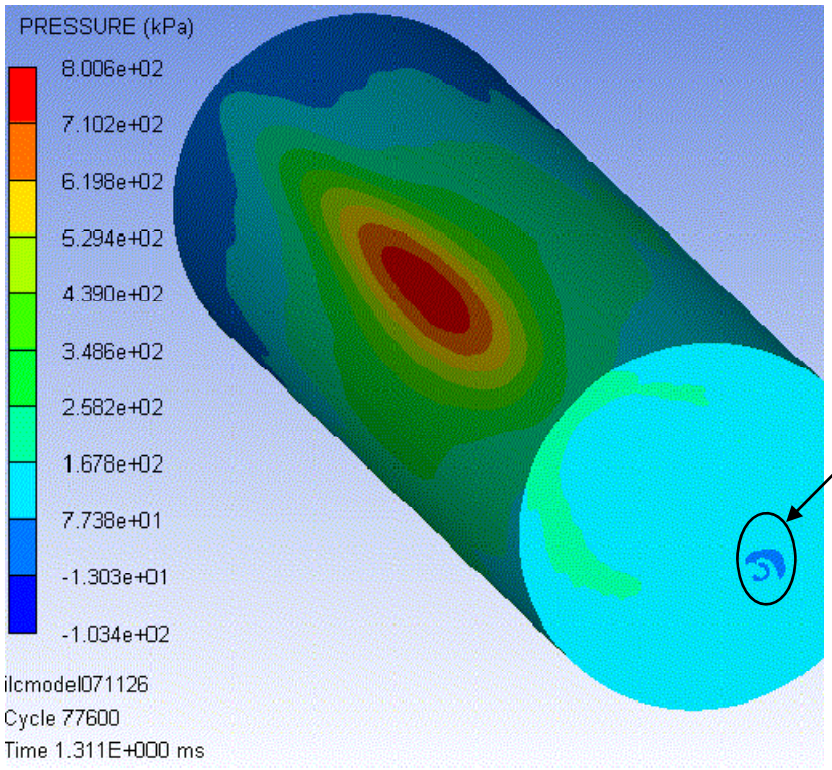
Pressure Contours on 4 sections along complete length of dump

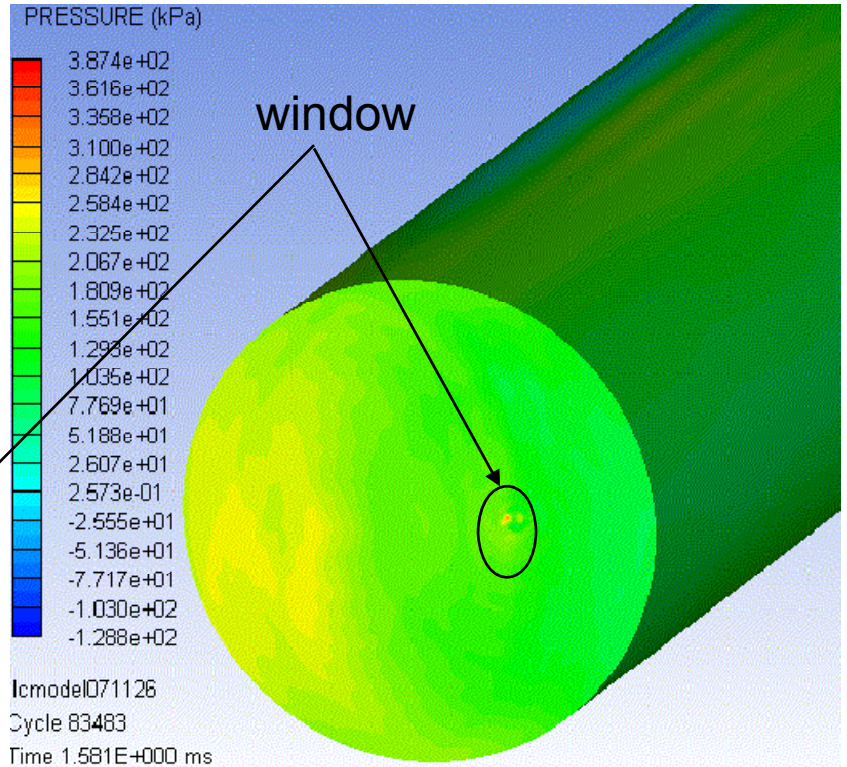
window

Pressure contours at window end of dump



ILC Beam Dump
Pressure on internal surfaces of beam dump

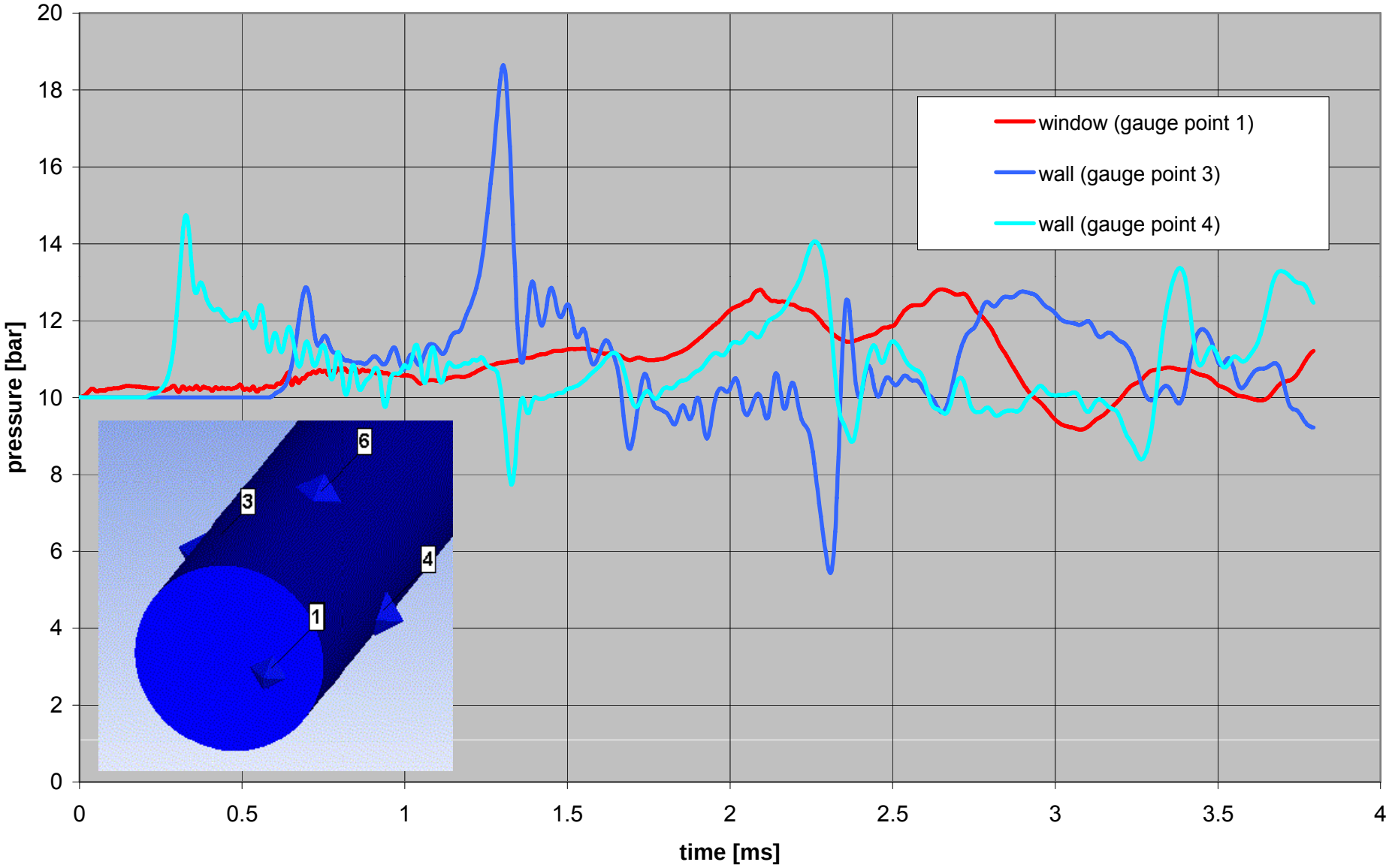




Pressure on dump wall reaching 8bar

Pressure at window reaching 4bar due to reflecting pressure waves after the bunch train is deposited.

ILC Beam Dump
Summary of predicted pressure transients

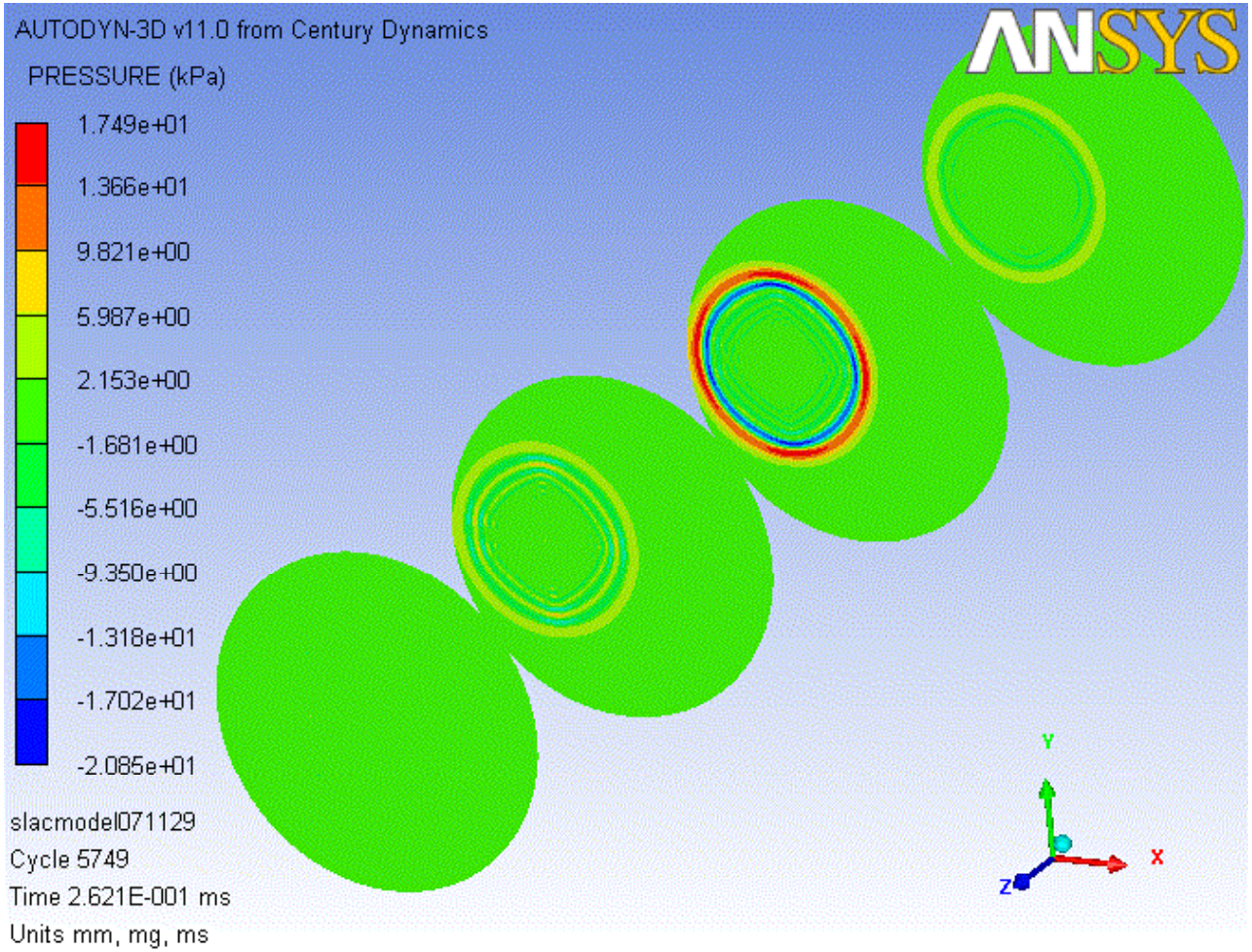


SLAC Beam Dump
-Inputs to Simulation

Inputs

- material – water (no gas contained in water)
- boundary conditions = rigid tank walls
- equation of state – single phase shock
- domain size = 6m x 1.45m diameter
- duration of bunch = 270ns
- duration of interval between bunches = 8.3ms
- energy deposited per bunch = 5.4kJ
- number of electrons per bunch = 5.5e11
- beam energy = 45GeV
- time averaged power deposition = 0.65MW
- Beam eccentricity = 300mm

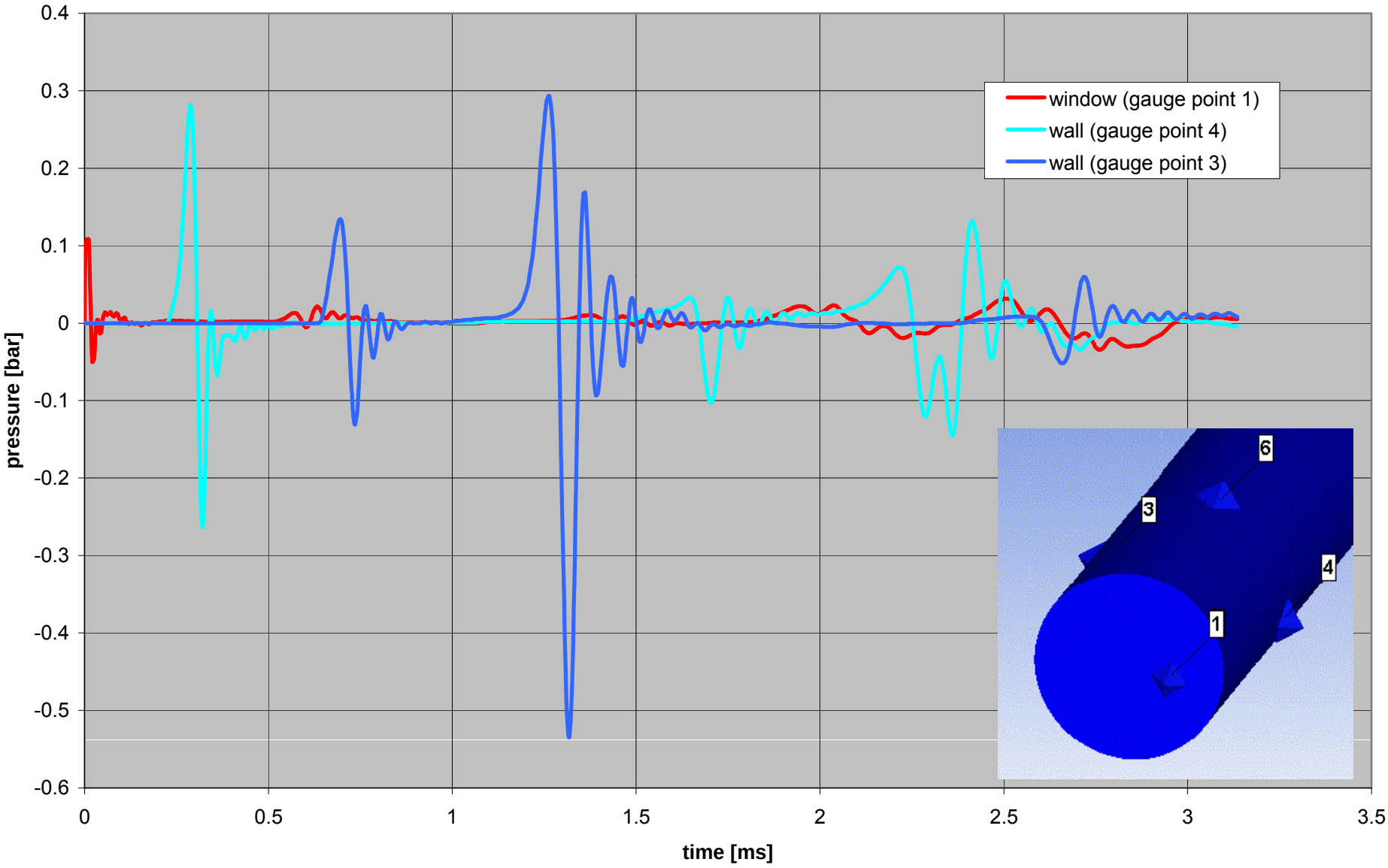
SLAC Beam Dump
-Pressure Field



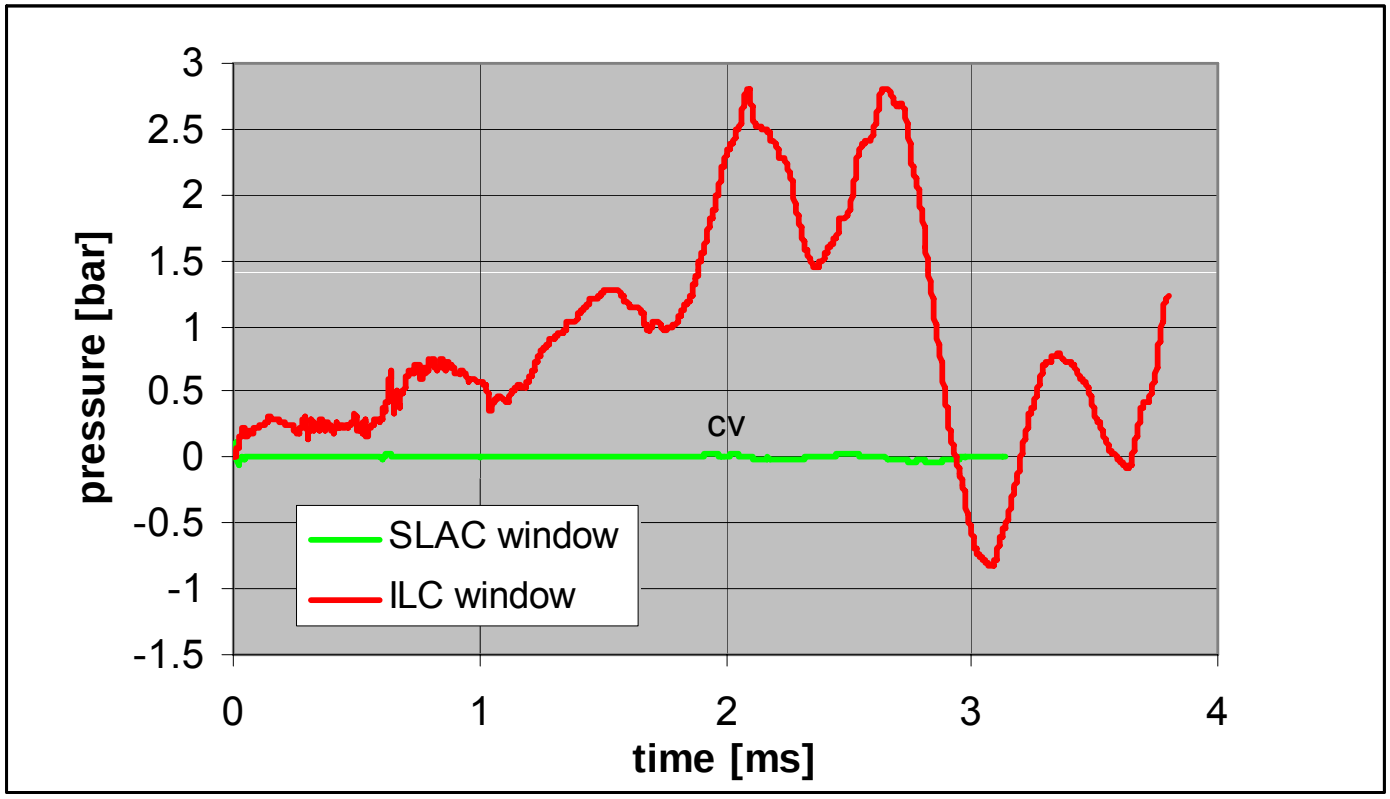
Pressure wave from a single bunch approaches tank wall at 0.17bar

Tensile pressure not large enough to induce cavitation and secondary shock waves

SLAC Beam Dump
Summary of predicted pressure transients



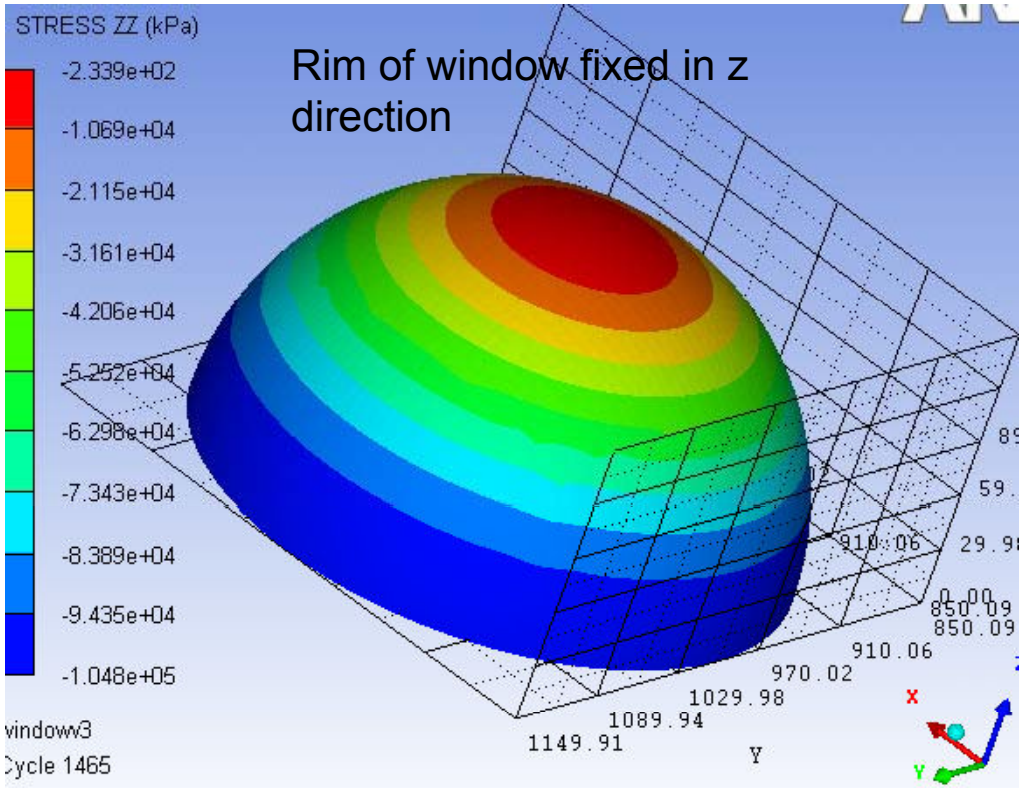
Comparison of transient window pressure for ILC and SLAC



Beam Dump window analysis
-Stress due to water pressure

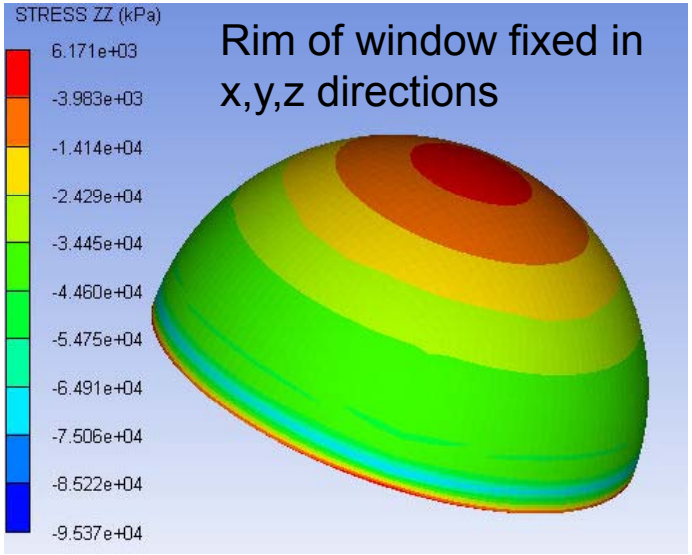
Proposed design :

300 mm diameter, 1mm thickness hemisphere made from titanium alloy, Ti6Al4V.



Peak compressive stress in window due to 14 bar water pressure = 105MPa

Mechanical Properties of Ti6Al4V
Yield Stress ~ 1000MPa
Fatigue Limit 100MPa → 600MPa (depending on damage)
Prevey et al



Water pressure alone doesn't seem to be a show stopper, consider mounting of window to avoid notching or scratching and stress concentrations due to attachment method.

Beam Dump window analysis
-Stress due to interaction with beam

Peak stress induced by direct interaction with beam = $E\alpha\Delta T$ (Sievers 1974)

- Youngs modulus, E=114GPa
- Thermal expansion coefficient $\alpha=12.43\times10^{-6}\ K^{-1}$
- Peak temperature rise in single bunch train - 3K
- Peak stress due to direct interaction with single bunch train = 4MPa
- Finite element simulation under way

Stress induced by time averaged differential thermal expansion in window

- depends on cooling efficiency of window
  - radial conduction through window
  - cooling by convection between water flow and window
- Further analysis required

Conclusions

- This Analysis has highlighted a potentially important risk factor to be considered when designing the beam dump window for the 18MW charged particle beam dump.

- The transient pressure rise above the static water pressure in the region of the beam dump window is calculated to be 4bar. This transient water pressure needs to be considered in conjunction with the static water pressure when calculated the stress on the window due to the water pressure. The window must also sustain average thermal stresses due to averaged differential thermal expansion in the window as well as transient thermal stresses resulting from interaction with the beam.

- A comparison calculation with the SLAC beam indicates that the SLAC beam dump window is exposed to transient water pressures an order of magnitude less than what is expected with the ILC beam.

- Analysis of the stresses experienced by the proposed ILC beam dump window design is continuing.

High Power Targets

www.STFC.ac.uk