LH2 Absorber Window R & D Program

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Muon Collaboration meeting

BNL

April 28, 2004

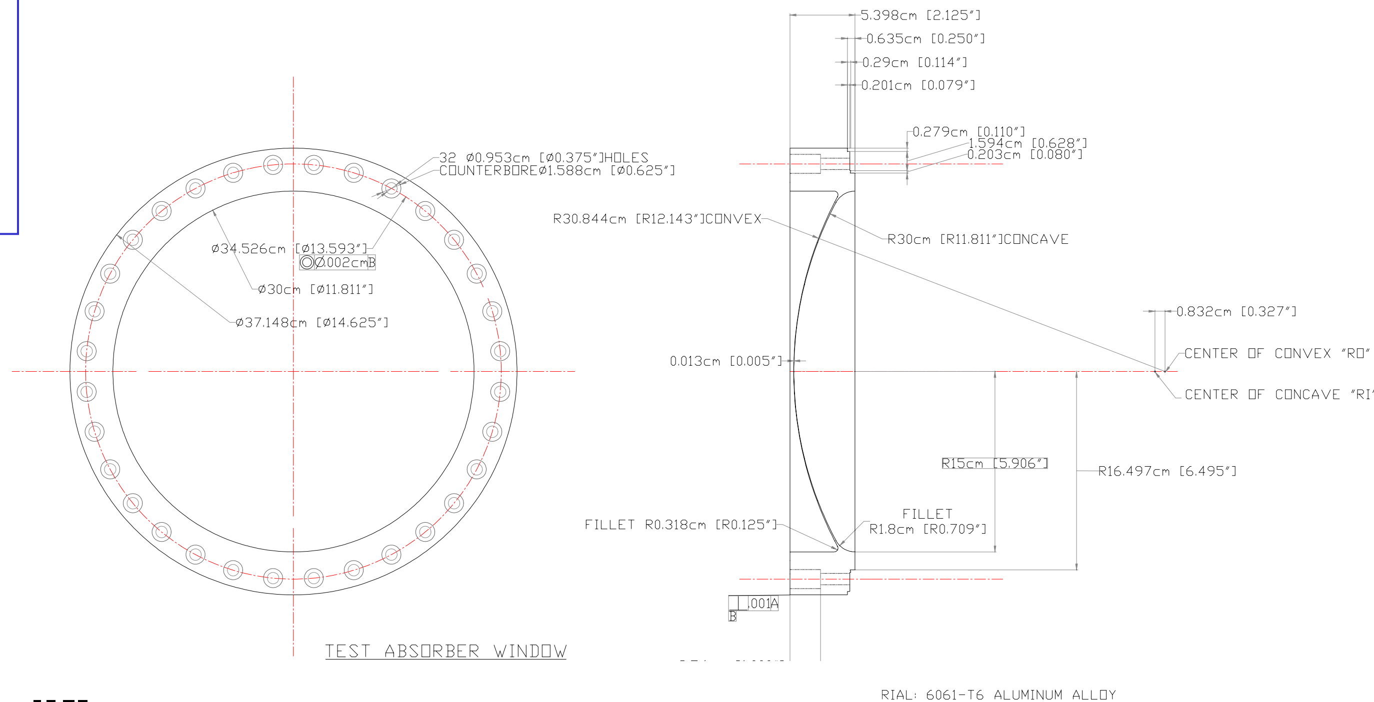
Topics

- Review
  - Window design and test history
  - FNAL test requirements

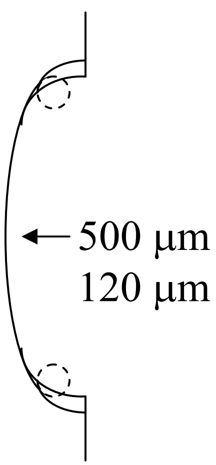
- Current program
  - FEA (finite element analysis) motivation and development
  - MICE cooling channel windows
  - Window test upgrades
  - Plans

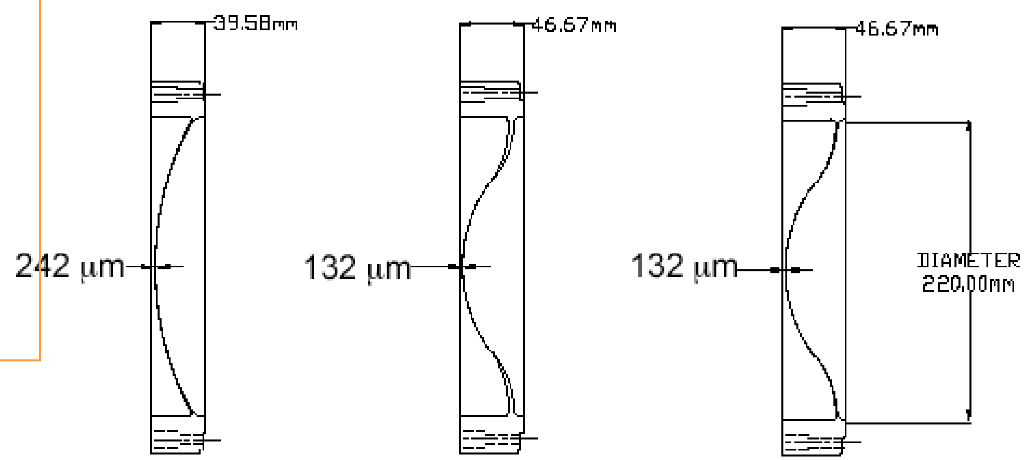
Thin Windows Design

Tapered thickness from window edges can further reduce the minimum window thickness near beam:



Originally..

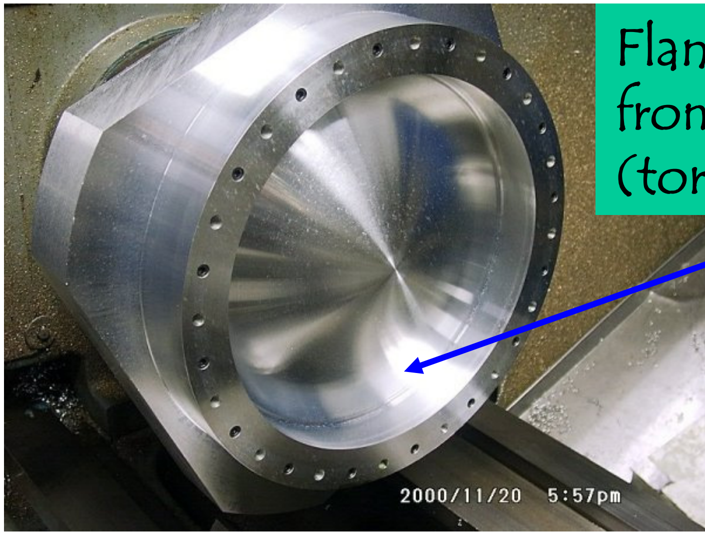




Progression of window profiles: torispherical (1) "tapered" (2) and "bellows" (3 & 4)

Window manufacture (U of Miss)

Flange/window unit machined from aluminum piece (torispherical 30 cm diam)

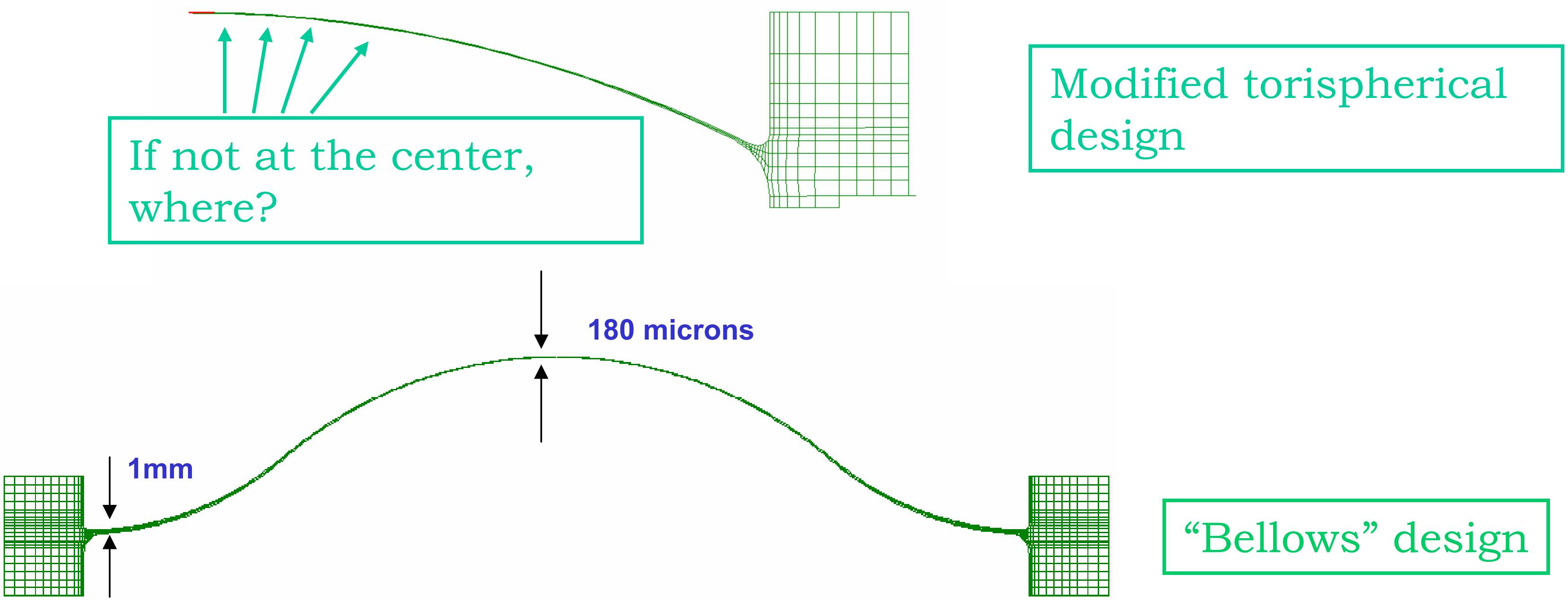


Backplane for window pressure tests

Backplane with connections, and with window attached

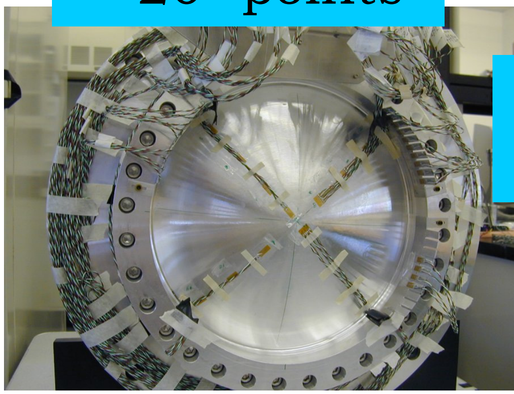
Measuring the "thinnest" thickness

1. Want to design thinnest window that can be confirmed as **safe**
2. Different radii of curvature on either side of window
3. Machined sides possibly not concentric
4. **What is the critical measurement?**

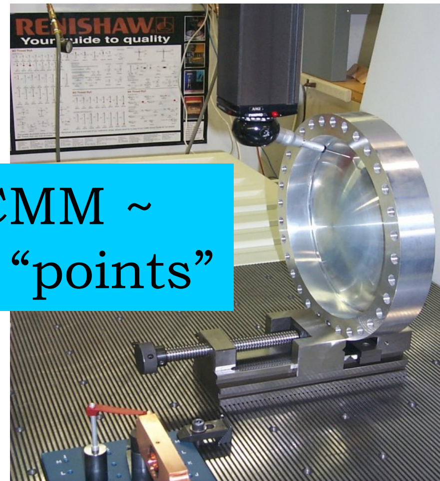


Photogrammetric measurements

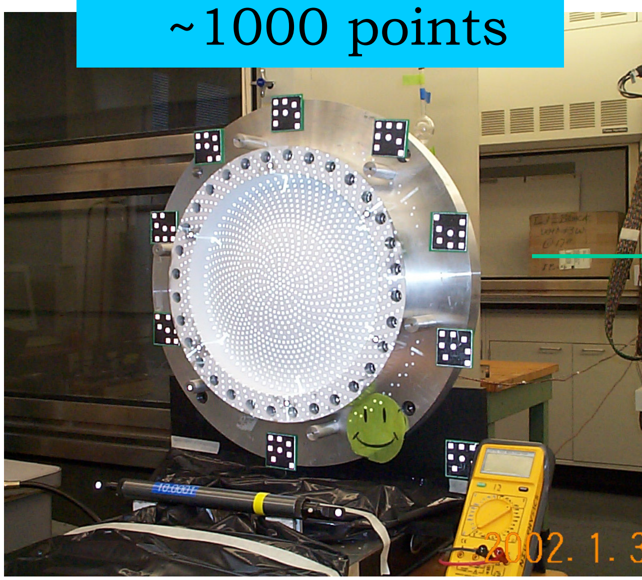
Strain gages
~ 20 "points"



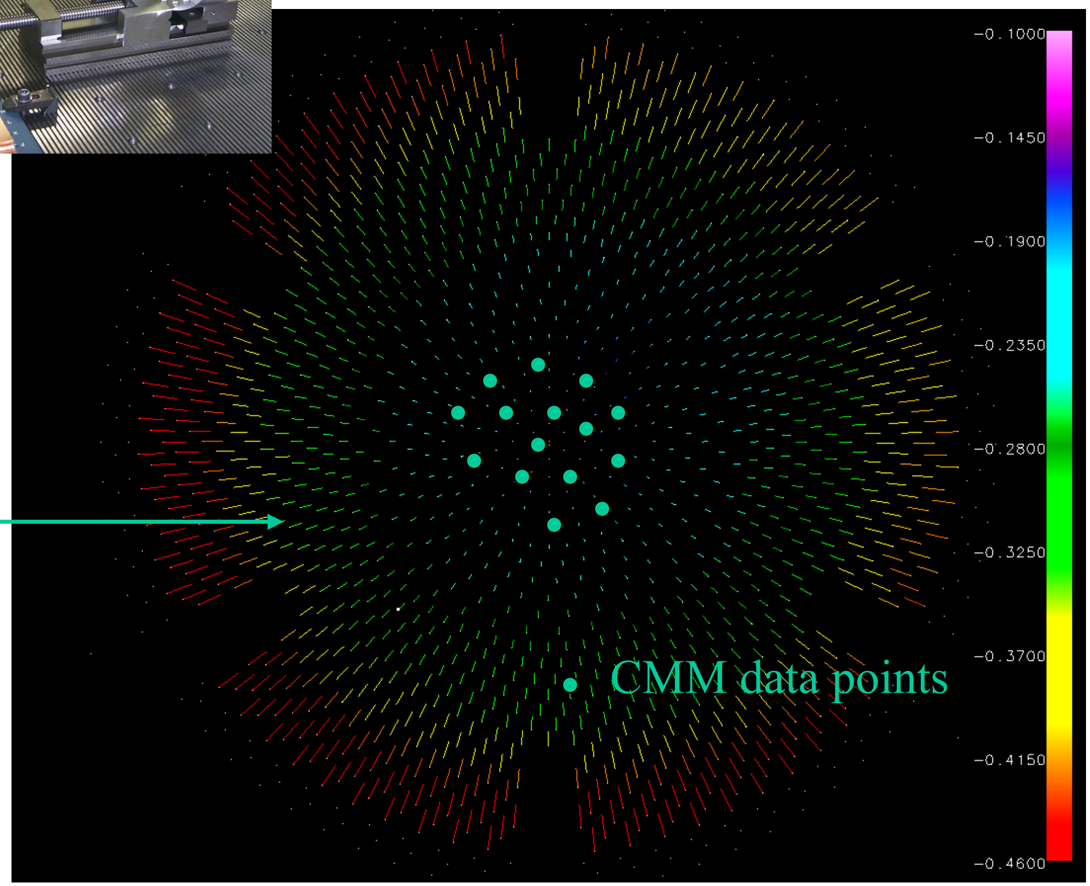
CMM ~
30 "points"



Photogrammetry
~1000 points

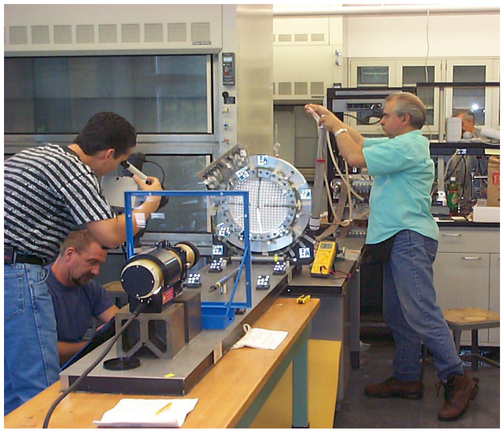


Can use global fits, more accurate predictions

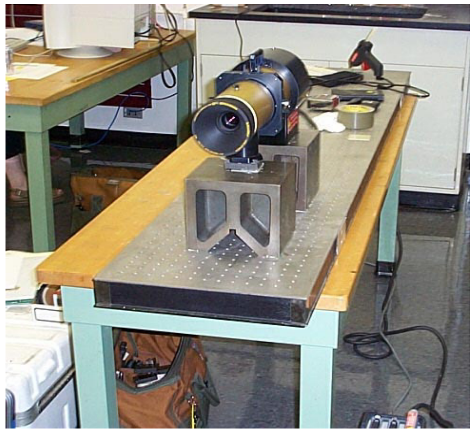


Elements of Photogrammetry

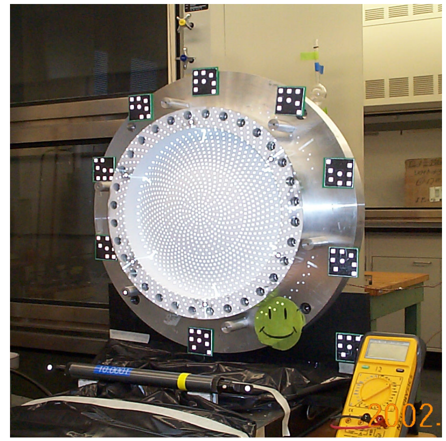
Photogrammetry set-up



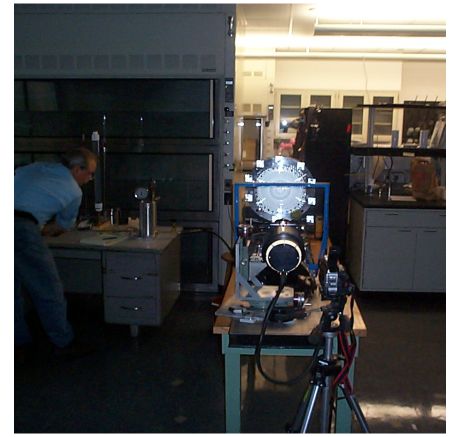
Pro-spot projector



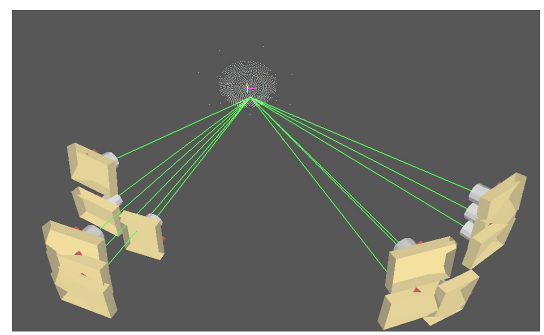
Targets



Projecting targets



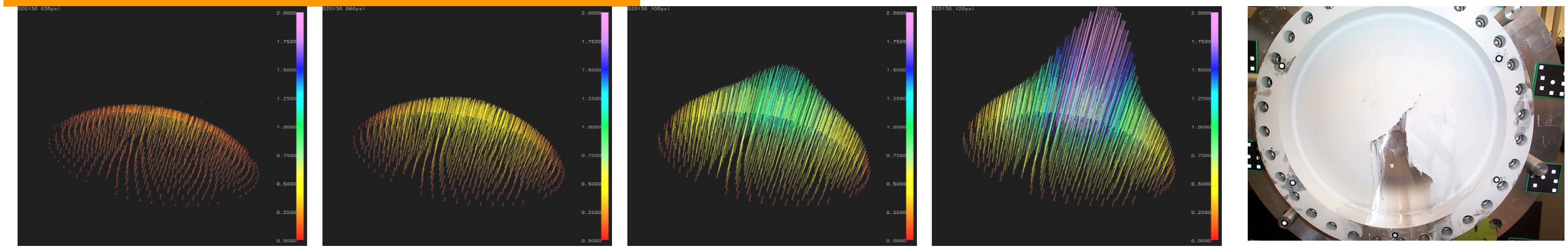
1. Contact vs. non-contact measurements (projected light dots)
2. “Several” vs. ~ thousand point measurements (using parallax)
3. Serial vs. parallel measurements (processor inside camera)
4. Larger vs. smaller equipment
5. Better fit to spherical cap.
6. Precision measurement of real space points



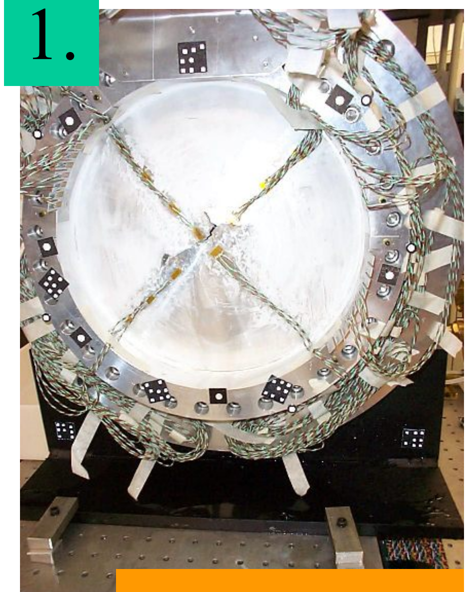
Photogrammetry is the choice for shape and pressure measurements

Rupture tests

photogrammetry measurements



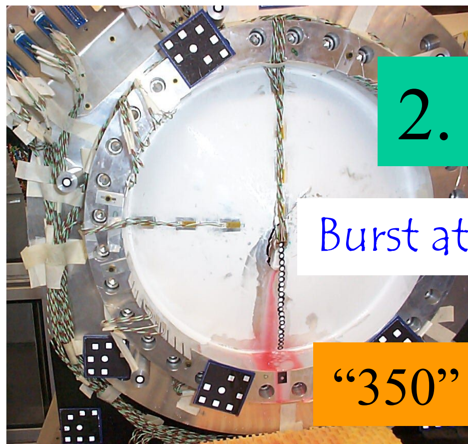
1.



130 μ window

Leaking appeared at 31 psi
..outright rupture at 44 psi!

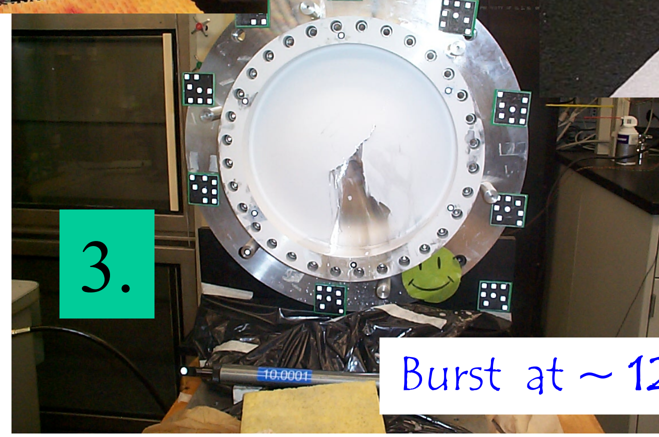
2.



Burst at ~ 120 psi

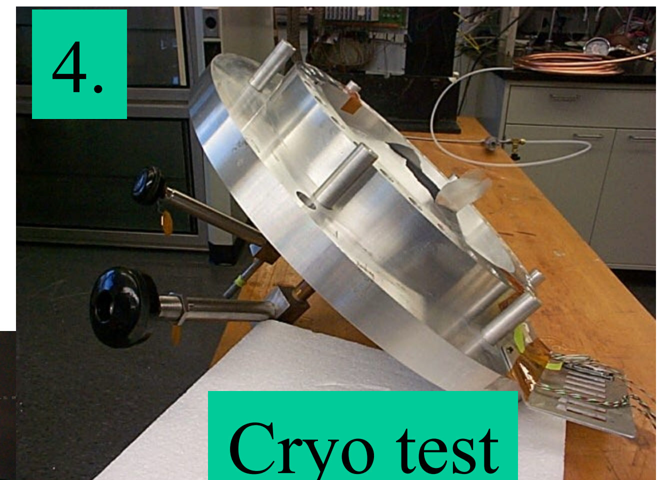
"350" μ windows

3.



Burst at ~ 120 psi

4.



Cryo test

Burst at ~ 152 psi

FNAL Absorber window test results

- Performance measurement (photogrammetry)
  1. Room temp test: pressurize to burst ~ 4 X MAWP (25 psi)
  2. Cryo test:
     a) pressure to below elastic limit to confirm consistency with FEA results
     b) pressure to burst (cryo temp – LN2) ~ 5 X MAWP

from ASME: UG 101 II.C.3.b.(i)

Window #	Test temp.	FEA results		Test results	
		Minimum window thickness (mm)	Rupture pressure (psi)	Window thickness from CMM (mm)	Measured rupture pressure (psi)
1	293K	0.13	48	0.114	42
2	293K	0.33	117	0.33	119
3	293K	0.345	123	0.345	120
4	80K	0.33	156	0.33*	152

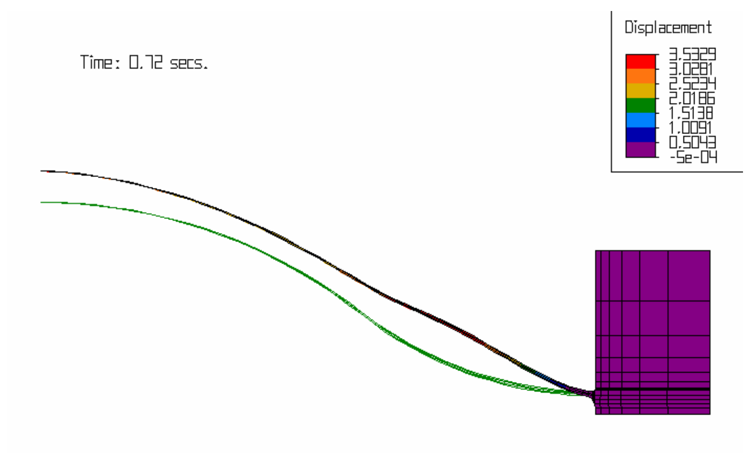
Discrepancies between photogrammetry and FEA predictions are < 5%

FNAL Vacuum Windows

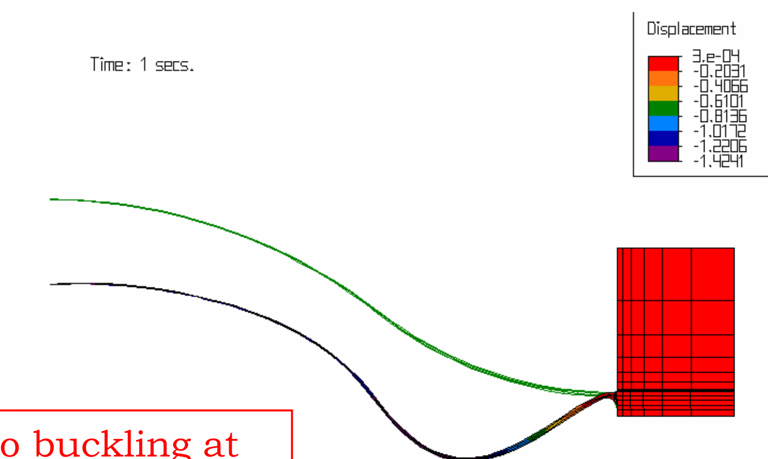
FNAL Requirements:

1. Burst test 5 vacuum windows at room temp. to demonstrate a burst pressure of at least 75 psid for all samples. (pressure exerted on interior side of vacuum volume).
2. Non-destructive tests at room temperature:
   a. External pressure to 25 psid to demonstrate no failures: no creeping, yielding, elastic collapse/buckling or rupture
   b. Other absorber vacuum jacket testing to ensure its integrity

Vacuum “bellows” window (34 cm diam):



Internal pressure: burst at 83 psi

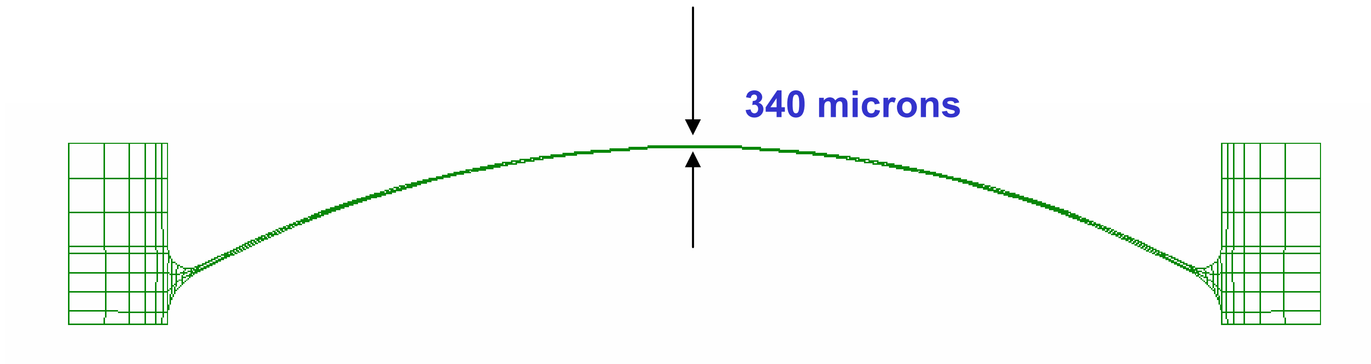


No buckling at 1st yield (34 psi)

Finite Element model

The FEA model set up to simulate the displacement and stress distribution on the torispherical window design…

- Step loading the window with internal pressure until ultimate tensile stress is reached – numerical definition of rupture



Design must follows the rules set out in Division 1 of ASME VIII Pressure Vessel Design Code, or other similar international standard, **except** when

- The thickness of the window is non-uniform;
- The shape of the window is non-standard

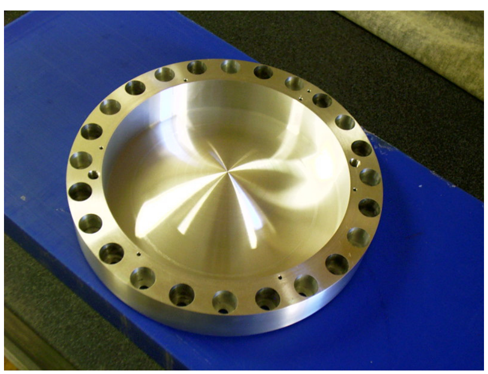
Under Division 2 of the ASME VIII, the above justifies use of a FEA.

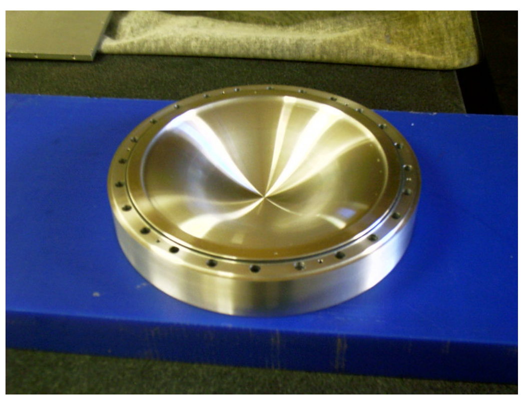
Progress since last MUTAC review

- New bellows window arrived to FNAL
- New testing area set up at FNAL (both pressure and shape measurements)
- Upgraded the camera software
- Upgrades to projector:
  - Improved scanning system…
  - Lens has adjustable iris to reduce the number of saturated dots… able to tune the intensity of the light
  - New masks to accommodate the 21 cm window geometry
- Test of absorber bellows windows (FNAL reqs.)
- Vaporization deposition of optical coating
- Modification to test set-up for “external” pressurization
- MICE safety review (LBNL, Dec. 2003) - for windows, relied heavily on Mucool R & D
- MICE window designs refined and safety-optimized

Learning to manufacture new window

First window (above)!
Second window (below)



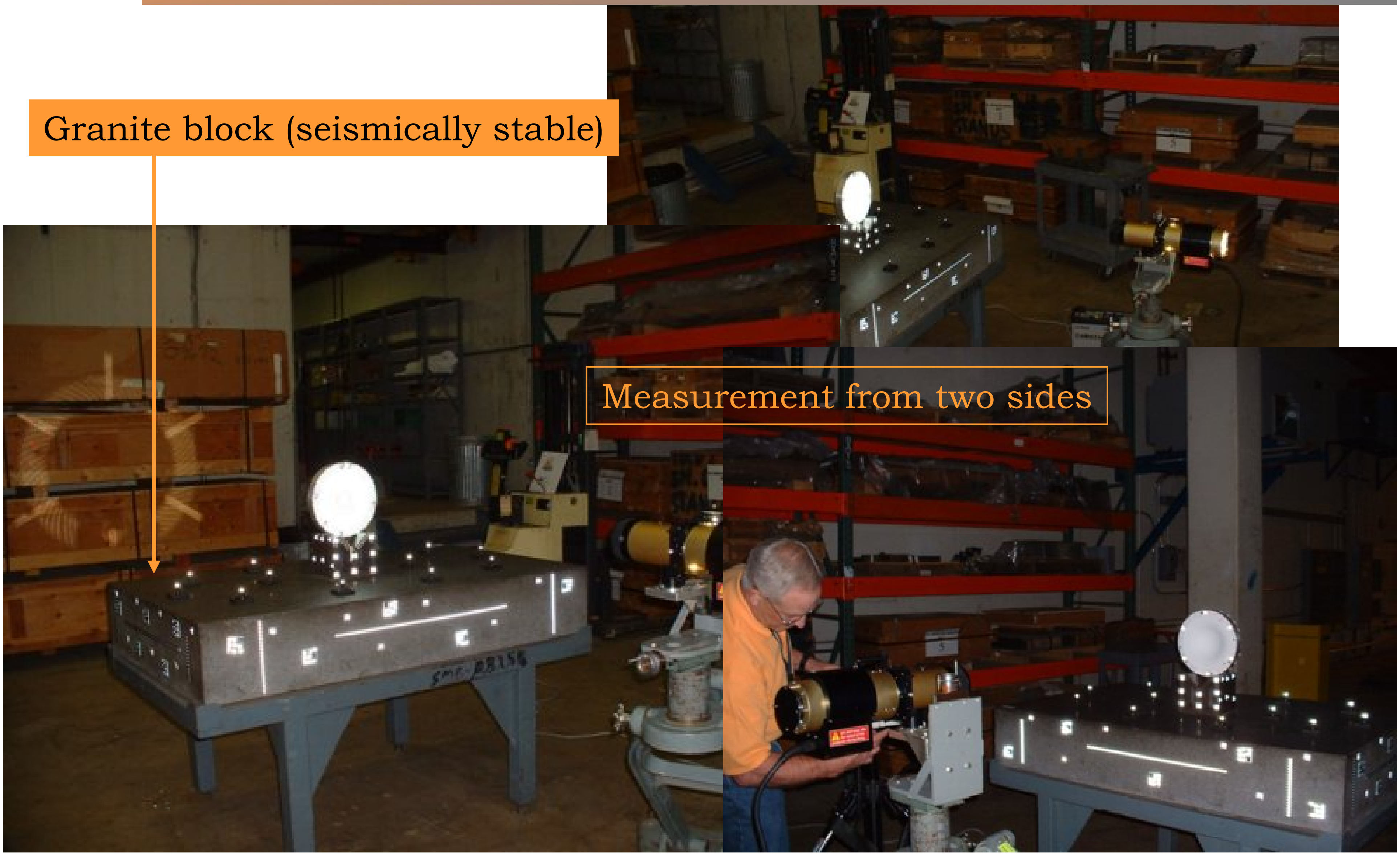


"Bellows" Window

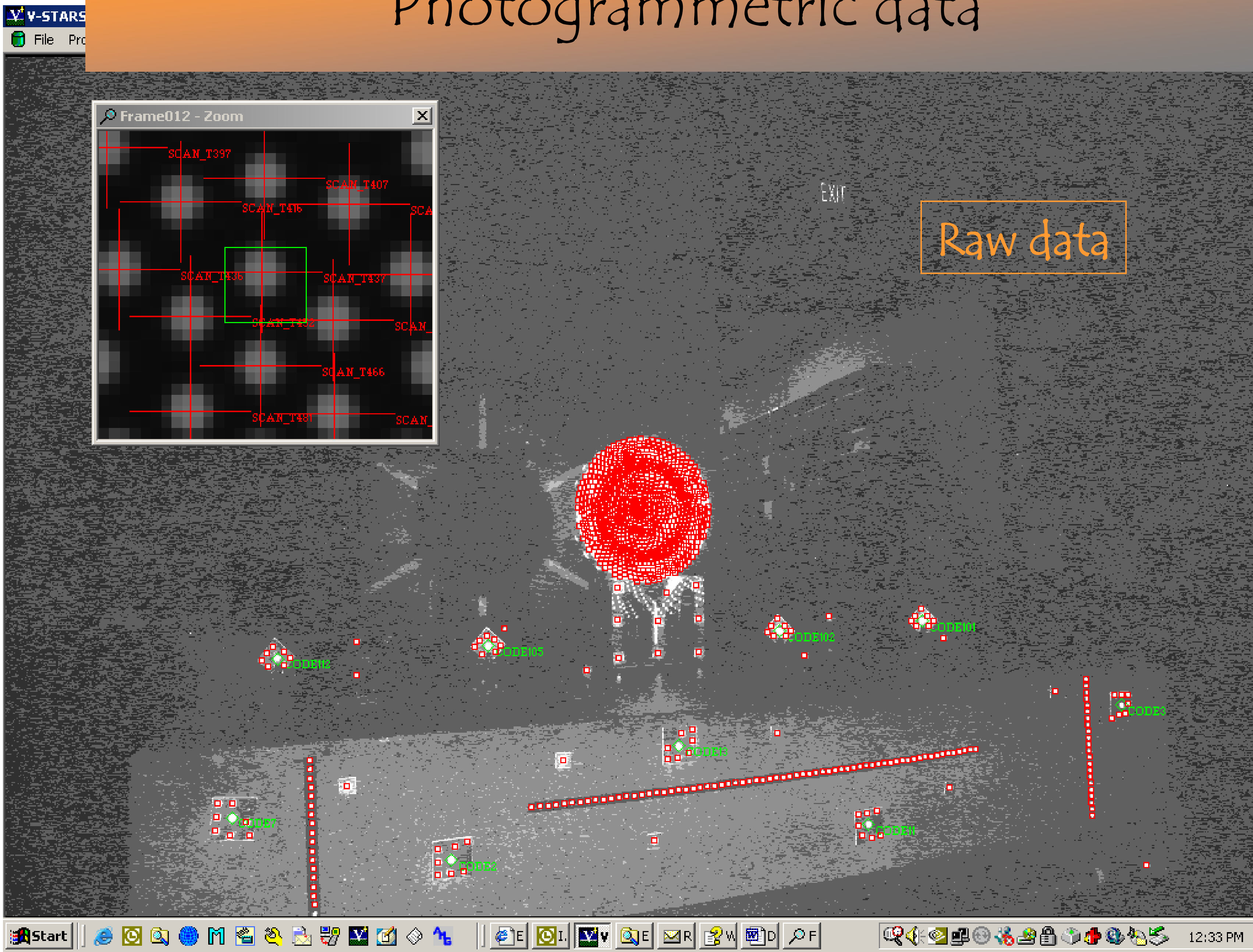
(FNAL/Oxford)

Current Photogrammetic Test Setup (FNAL)

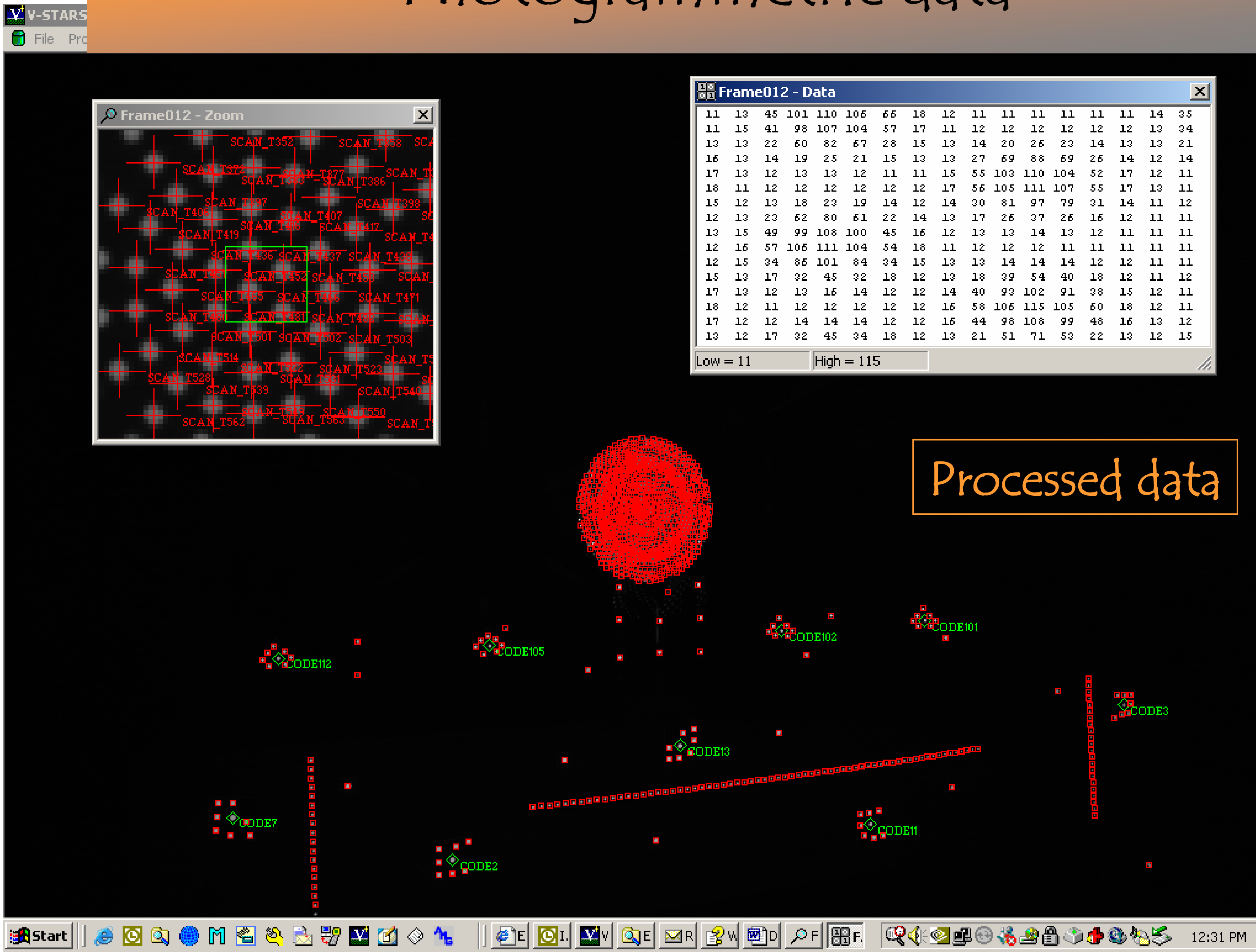
Granite block (seismically stable)



Photogrammetric data



Photogrammetric data



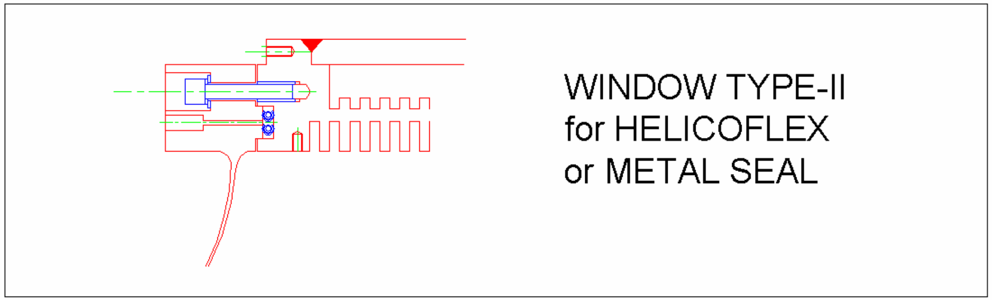
MICE Safety Review for Windows

- Mucool manufacture and testing procedures deemed safe
- RAL window pressure test requirements (Absorber and Vacuum):

Test Pressure	Test temperature	# of tests required	Remarks
96 psi (4 x design P)	@ 293K	3	Test to rupture. Windows to subject to thermal cycling before the test
> 96 psi (5 X design P)	@ 77K	1 or 2	Test to rupture. If shrapnel is evident, one further test will be needed. The additional test will have the safety mesh fitted to verify that shrapnel doesn't reach the safety window.
25 psi	Room temp	1	Test for buckling (external)

design P = 24 psid

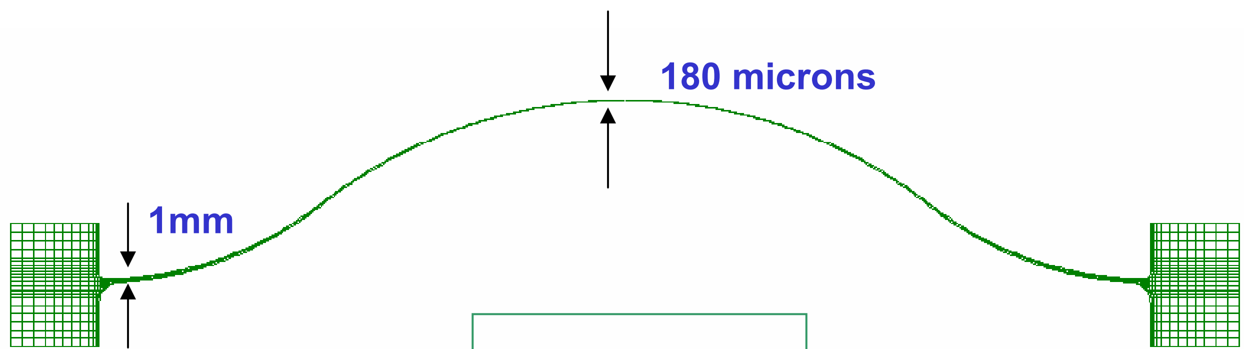
- Window attachment:
  - different seals
  - bolted vs. welded seal



FEA results on current bellows window design

The current window design has a double curvature to ensure that the thinnest part is membrane stress dominate

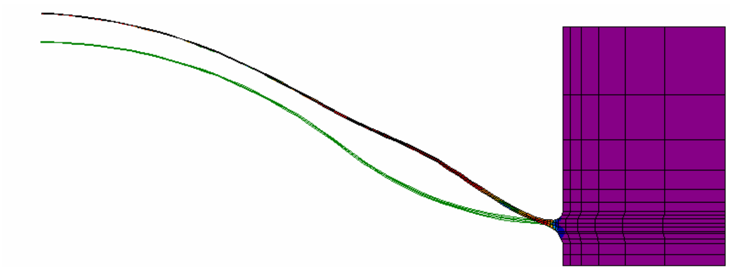
Here is the FEA model on the Absorber window. (Note that in the MICE experiment both the Absorber and the Safety windows now have the same pressure load requirements!)



30 cm diam.

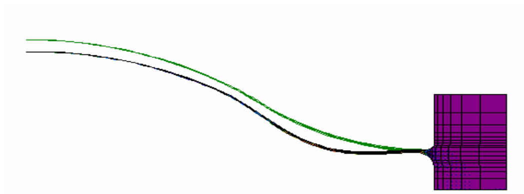
MICE window FEA

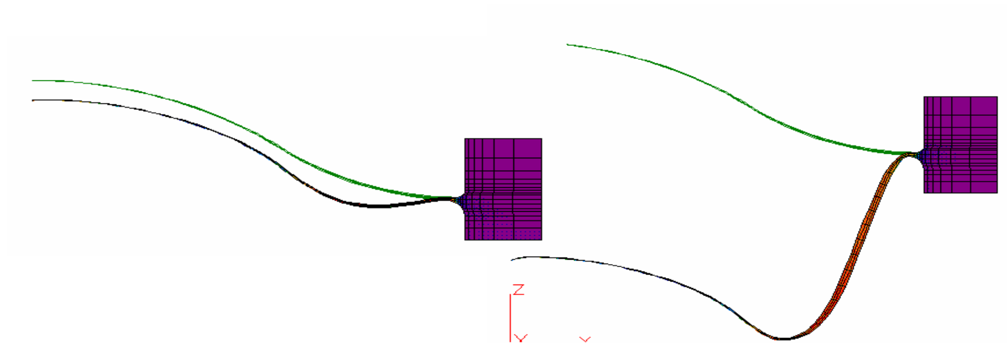
The same FEA was applied to all the window shapes radii that were developed subsequently…



Behaviour of window under an incremental **internal** pressure until burst

Behaviour of Window under incremental **external** load…





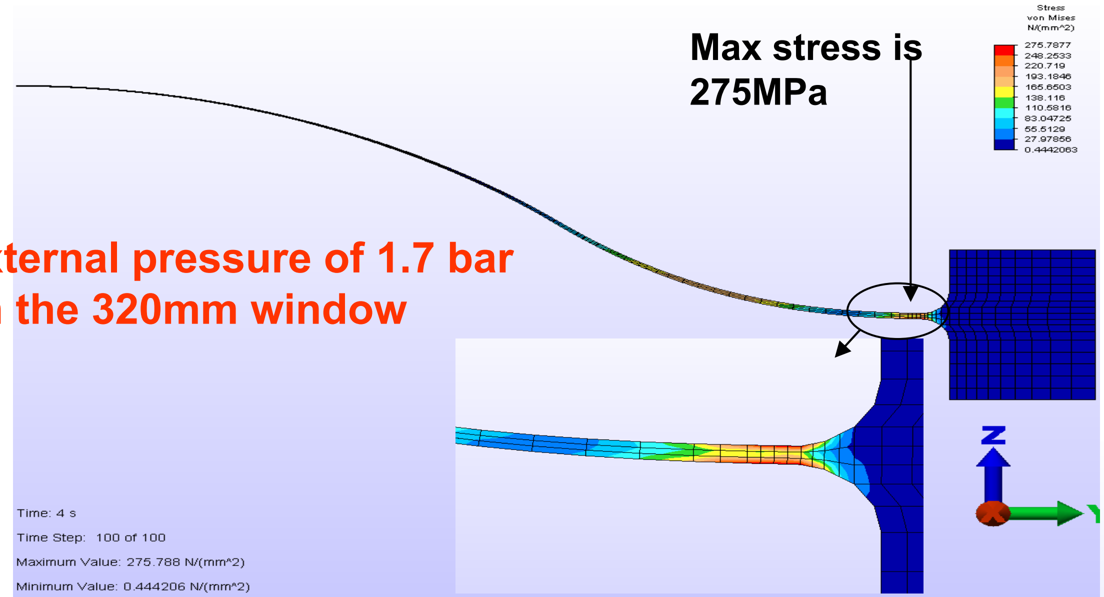
Looking for the development of the first yield stress

Finding the first sign of buckling development

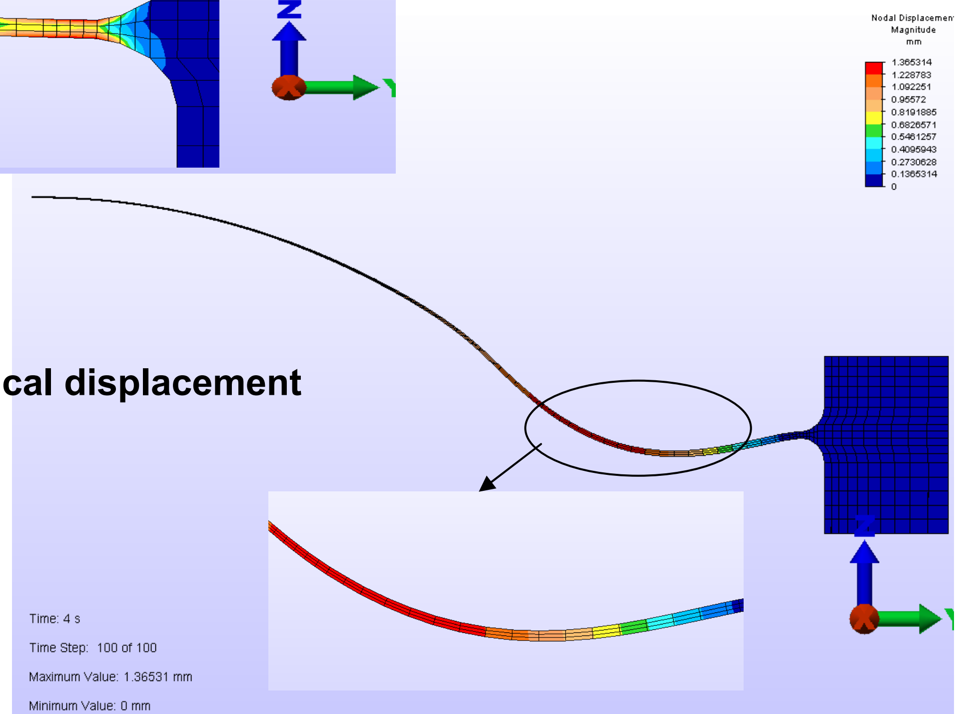
MICE window FEA studies (con't)

External pressure of 1.7 bar on the 320mm window

Max stress is 275MPa



Max displacement is 1.36mm, mainly vertical displacement



Bellows window design features

Finite element analysis results:

Window Type`	MICE Req. Burst Pressure	FEA calc. Burst Pressure	MICE Req. Buckling Pressure	FEA calc. Buckling Pressure
Absorber (30 cm diam)	96 psid	105 psid	25 psid	26 psid
Safety (32 cm diam)	96 psid	105 psid	25 psid	26 psid

Further observations from the FEA results are:

- Stresses in the crown of the window are mainly membrane stresses;
- Stresses at the outer edge of the window are predominantly bending stress
- Previous window design (torispherical) has peak stresses at the window crown area;
- Peak stress is now shifted to the edge of the window which is a lot thicker than the crown region.
- This indicates a strong tendency of a leak before a break
- We will be in a position to compare our FEA results with test data.

Current Goals

- Determination of a satisfactory shape measurement algorithm
- Streamlining the test procedures
- Finalization of external pressurization test setup
- Determination of certification for the real (not test!) cooling channel windows
- Completed tests of Mucool absorber and vacuum windows and MICE window

Concluding remarks

- Both software and testing methods are maturing
- Have standardized requirements for Mucool and MICE experiments
- Mucool window approach has passed MICE safety review
- FEA analyses developed for absorber windows now used in other aspects of cooling channel designs (i.e. RF windows)

Safety Strength requirements

The ASME design code stipulates the following stress limits:

- Primary membrane stress, the lower of S_m < 2/3 of yield or ¼ UTS
- Primary bending stress $S_b = 1.5\ S_m$

The MAWP exceeds these limits, but because of the the non-standard design, ASME allows certification based on **burst tests:**

Section UG-101-m-2a suggests that the burst pressure P_b should be

$P_b = 5 \times P \times S_t/S_w$ where **P** is the **maximum working pressure** and S_t is the minimum tensile stress at test temp and S_w is the minimum tensile stress at working temperature

The S value for 6061 T6 material is 310 MPa at room temperature and 415 MPa at working temp.

→ $P_b = 5 \times 310\ /\ 415 \times P\ = 5 \times 0.76\ P\ = 4xP$

Hence a burst pressure of **4 times the working pressure when** tested at room temperature will meet the requirement of section UG -101 in Div. 1 of ASME VIII