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Mary Anne Cummings

MUTAC Review

LBL

April 26, 2005

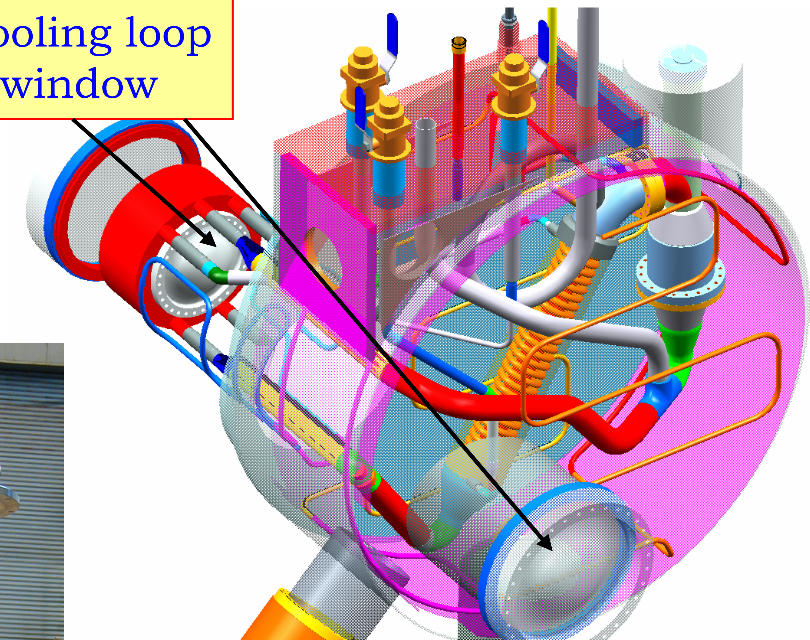
Wrslfv

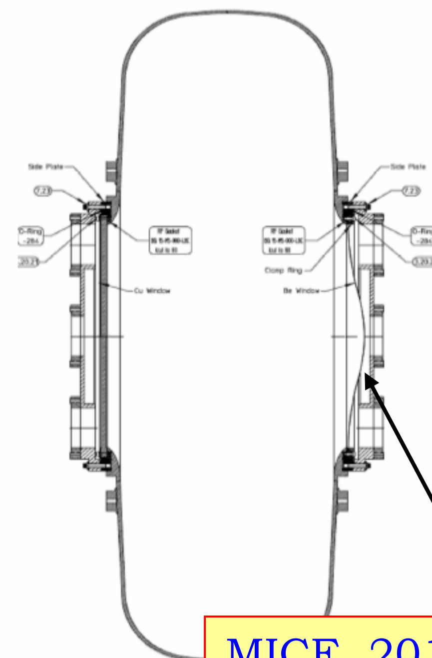
- Review
  - Window design and test history
  - FNAL test requirements

- Current program
  - FEA (finite element analysis)
  - MICE cooling channel windows
  - New window tests – and improvements
  - Comments

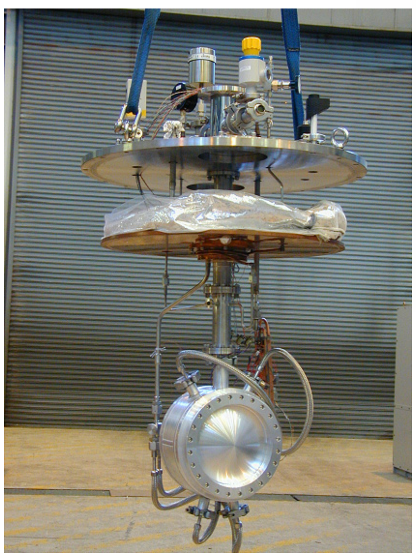
- Absorbers, Vacuum and RF windows

Forced-Flow Absorber with external cooling loop And secondary window



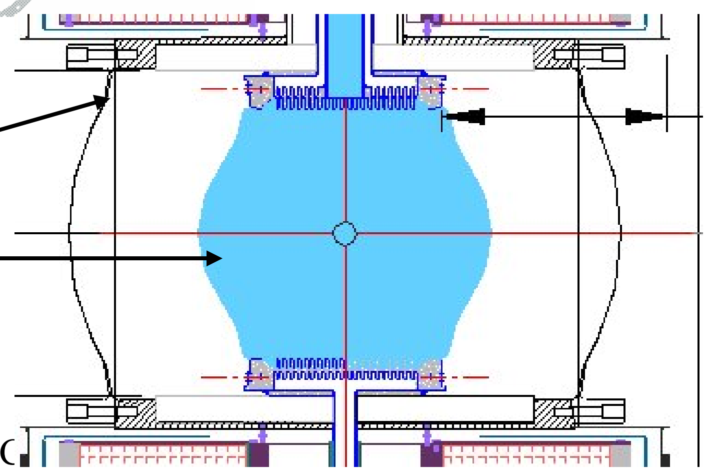


MICE 201 MHz RF (Be window)



KEK Convection Absorber at MTA

MICE Convection Absorber in AFC module (and containment)



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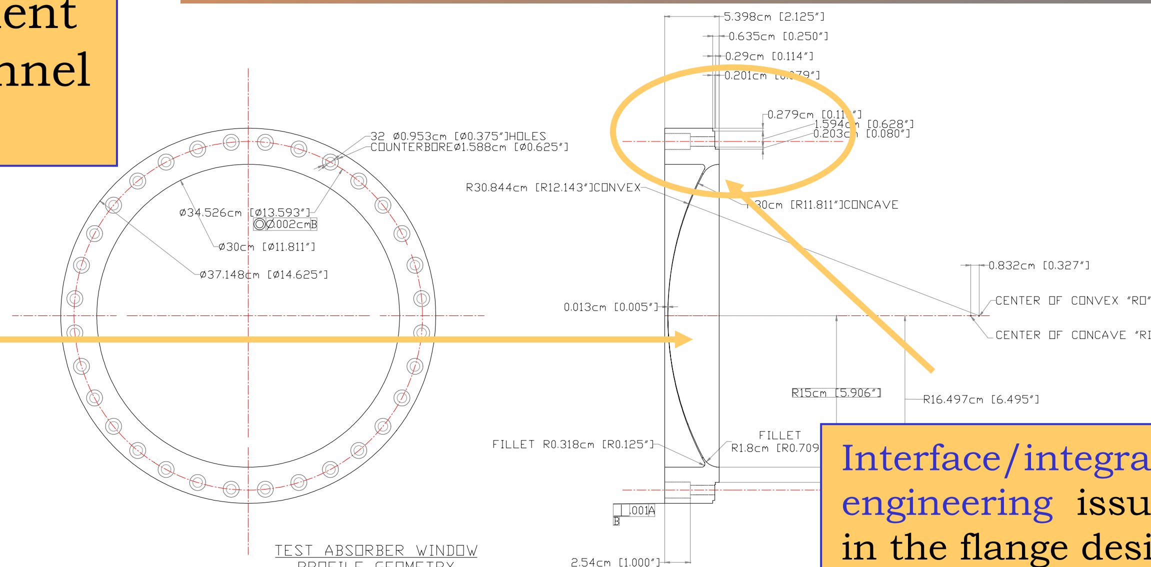
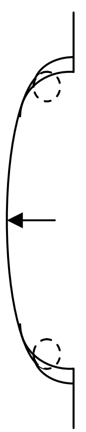
Window design independent of particular cooling channel configuration

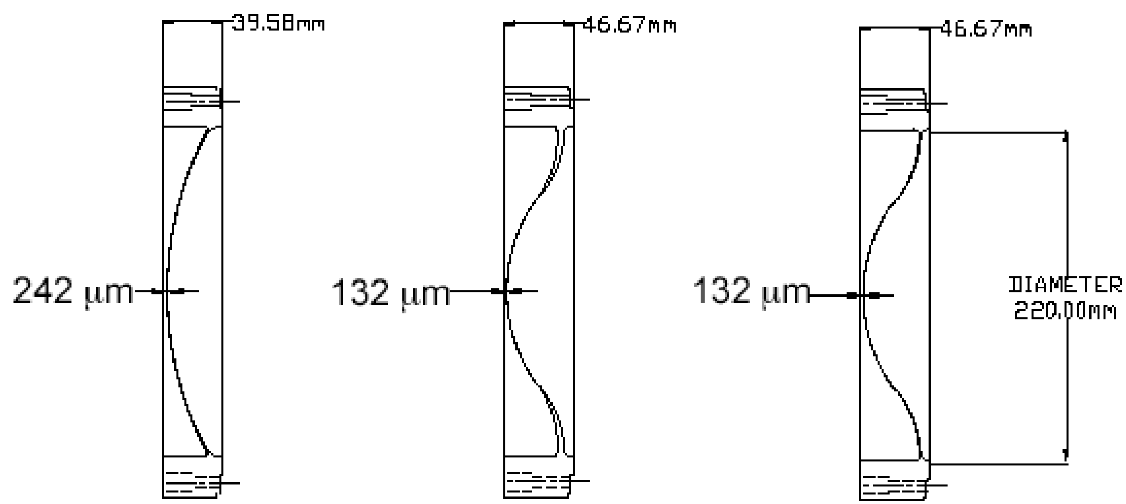
Cooling and safety issues are in the window profile



Interface/integration engineering issues are in the flange design

Originally..





Modified torispherical
FNAL, Cummings

Tapered torispherical
Black, Cummings

"Bellows"
Lau, Black

"Thinned Bellows"
Lau, Black, Yang

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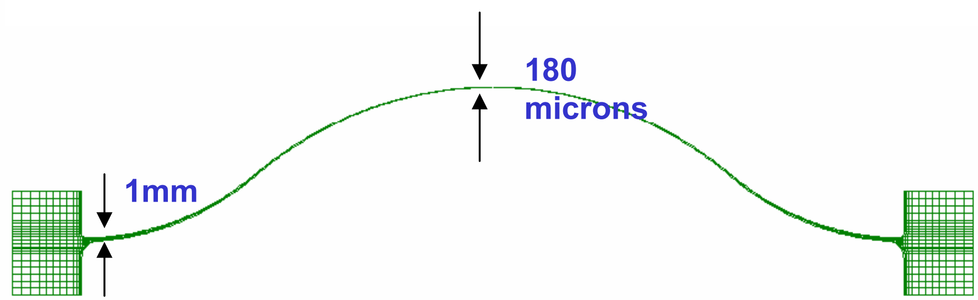
- **ASME vessel design definitions:**
  - Design by Rule:
    - Based on maximum Stress Theory
    - Standard shapes, equations
  - Design by Analysis — Must do destructive tests!
    - Based on maximum Shear Stress
    - Use FEA to determine MAWP for non-standard windows

1. Want windows 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?**

If not at the center, where?



FNAL Requirements:

Vacuum

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

Absorber

1. Room temp test: pressurize to burst ~ 4 X MAWP (25 psi at FNAL)
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)

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- Mucool manufacture and measuring 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 Pressure = 24 psid MAWP FNAL = 25 psid -

Effectively, the same for MICE and MuCool

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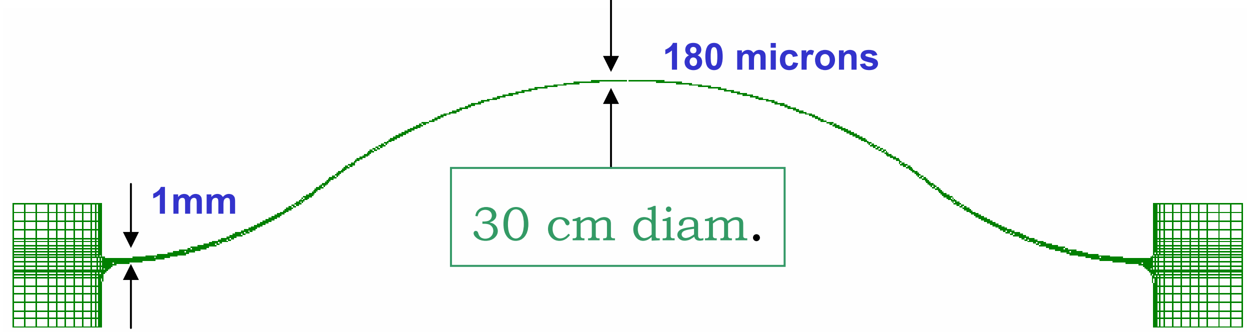
The current window design has a double curvature to ensure that the thinnest part is membrane stress dominate



The current window FEA analyses show that the shape scales can use same analysis for different diameters of same profile!

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

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

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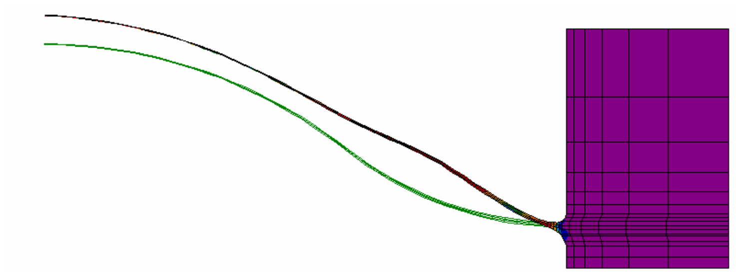
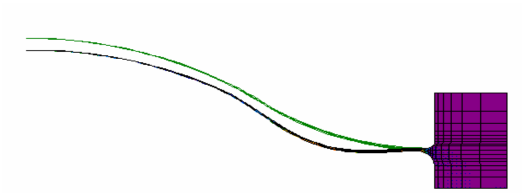
The same FEA was applied to all the window shapes that were developed subsequently…

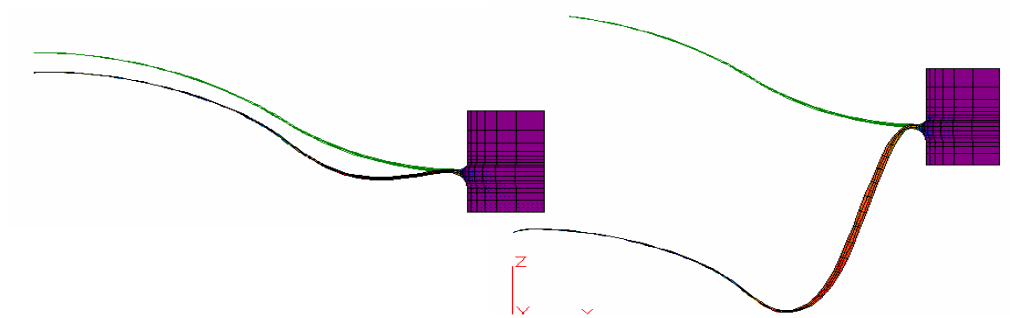


Behavior of window under an incremental **internal** pressure until burst

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



Looking for the development of the first yield stress



Finding the first sign of buckling development

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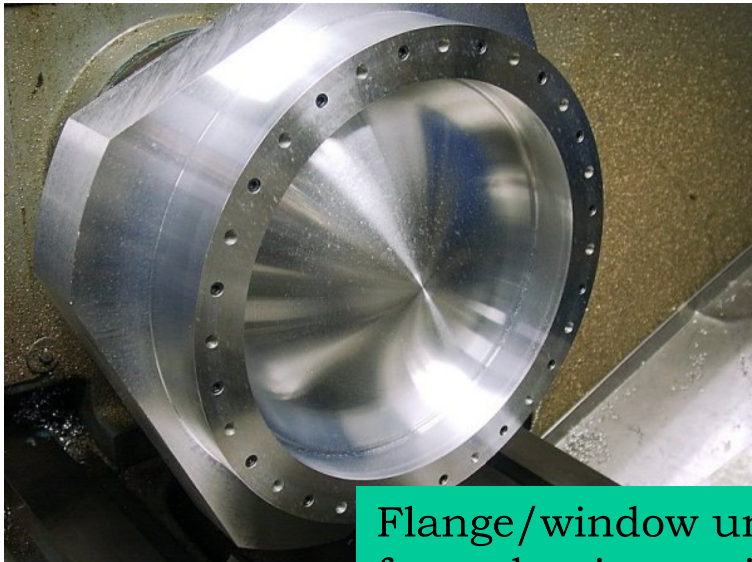
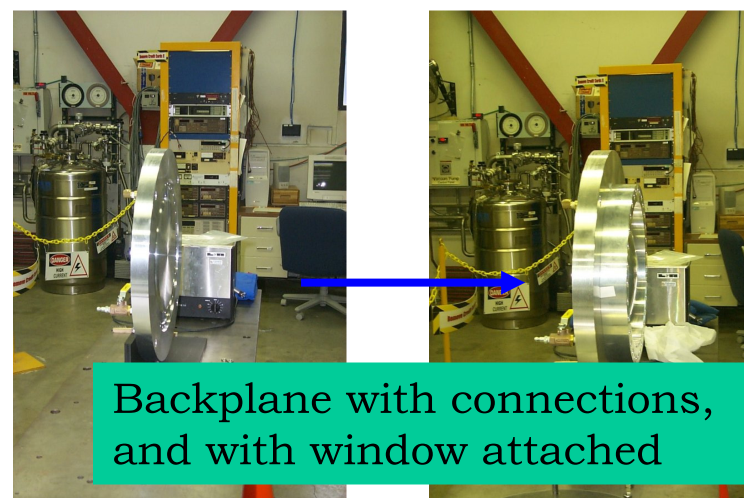


Flange/window unit machined from aluminum piece (torispherical 30 cm diam)

Backplane for window pressure tests



Backplane with connections, and with window attached

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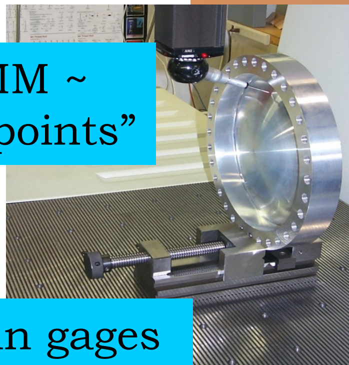
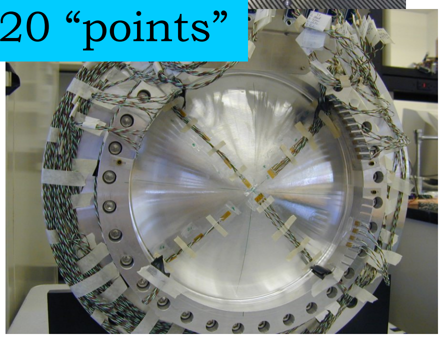
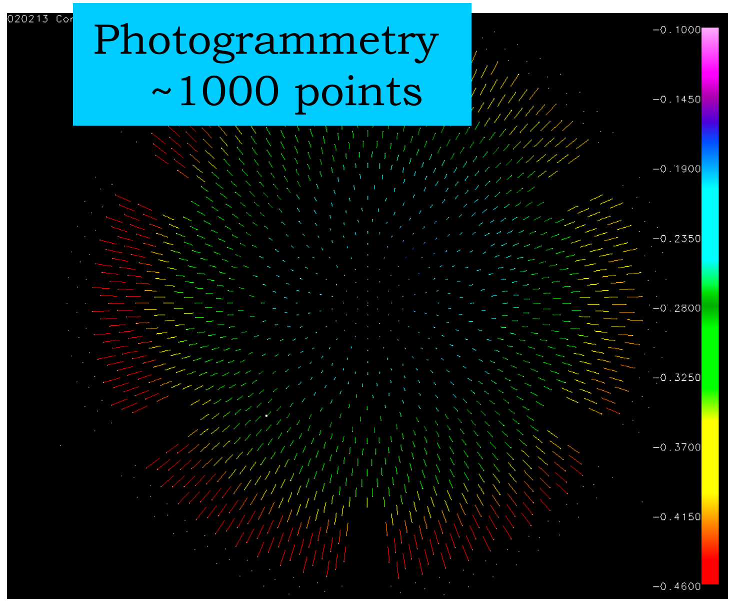
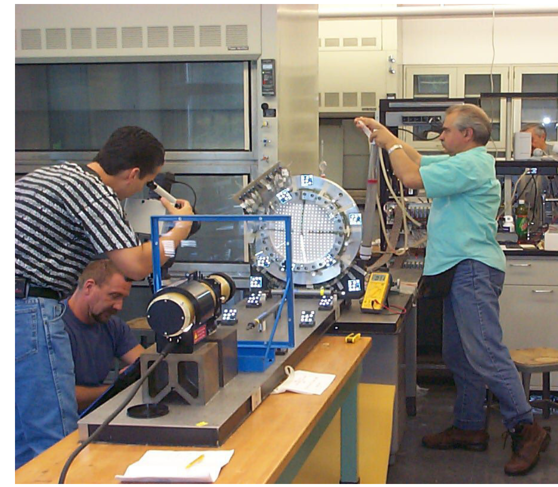


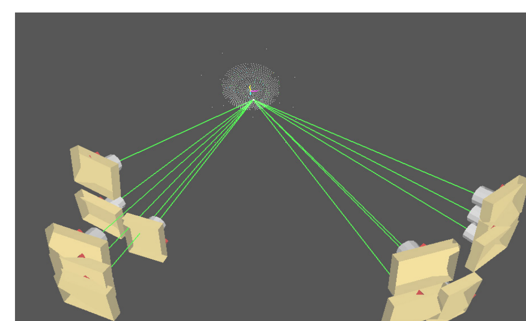




Photogrammetry set-up



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. Can do measurements and performance tests
5. Better fit to spherical cap.
6. Precision measurement of real space points



Photogrammetry is the choice for shape and pressure measurements

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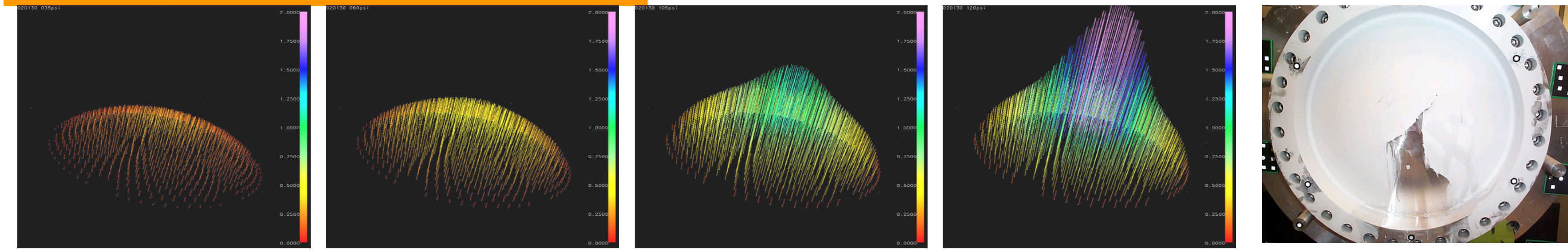
photogrammetry measurements



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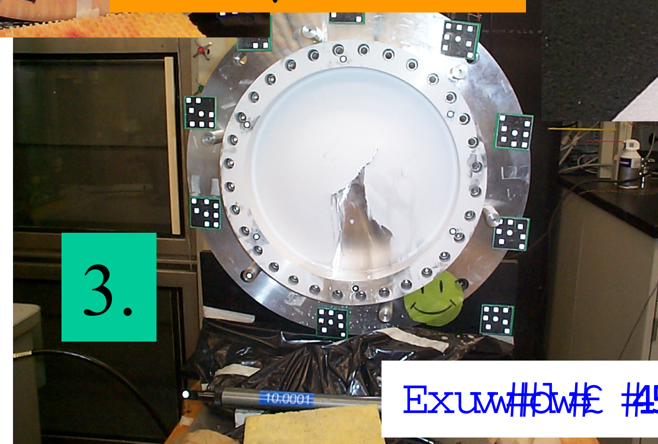
“350” μ windows



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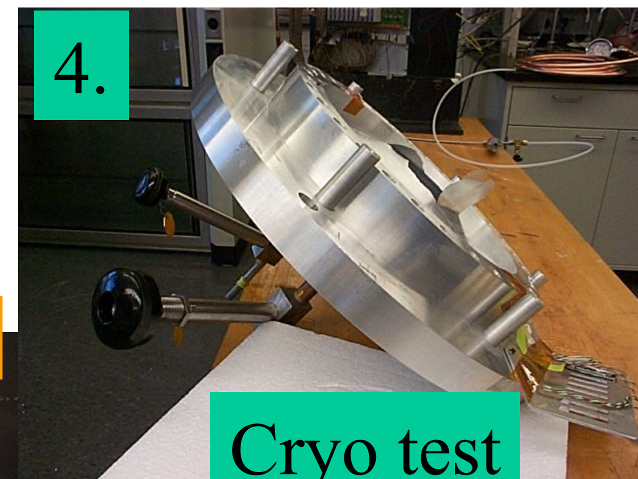

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1rxwuljkw#uxswxuh#dw#77#svl$

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- Performance measurement on **torispherical** windows
  - Discrepancies between photogrammetry and FEA predictions are < 5%
  - Room temperature and crygogenic tests validated design

- Performance measurement on the 21 cm **“bellows”** window

  Tests:
  - Measured at 190 μm .. Designed for 132 μm
  - Leaked at seal in first pressure test (design improved)
  - Burst at 144 psid.. (predicted burst at 104 psid)

  Corrections:
  - Revised FEA calculations … and ~144 is predicted
  - Optical coatings determined to be major source of measurement error

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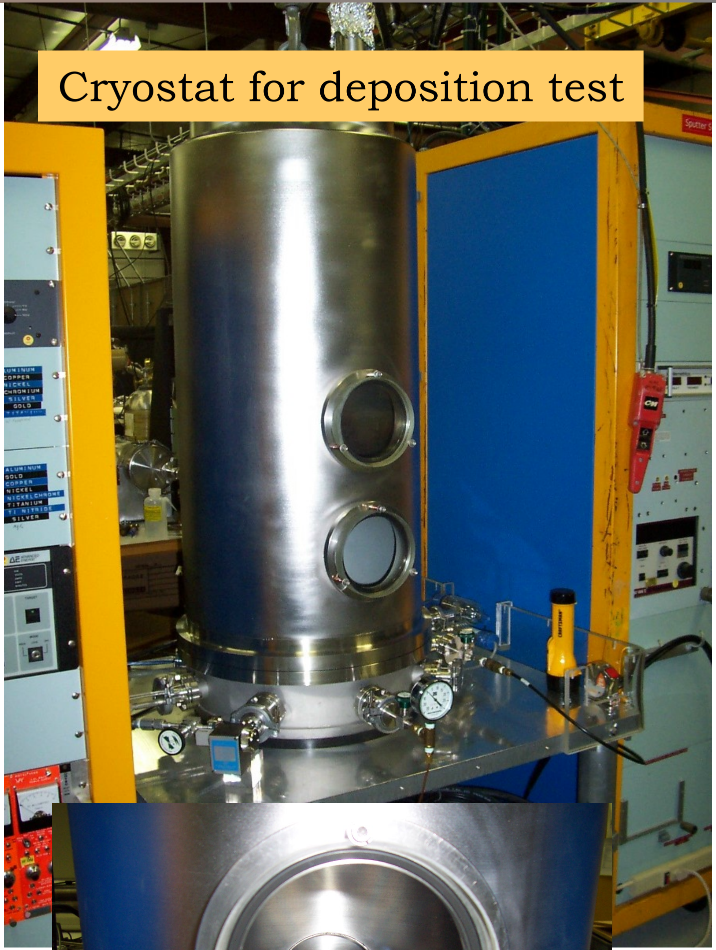
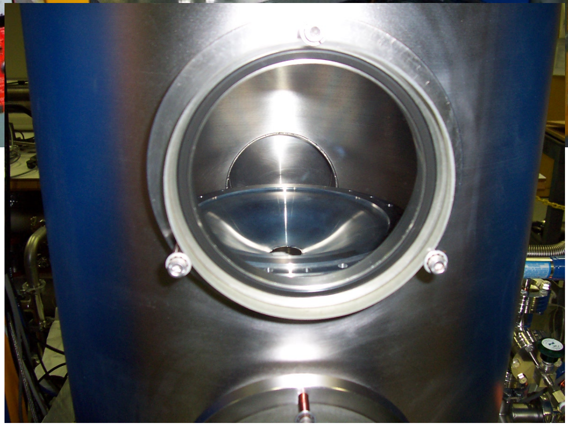
- Vapor deposition:
  - Set-up and experts at FNAL
  - Safety review completed
  - Working to achieve proper TiO_2 uniform coating < 2 μm

Alternatives:

- Chemical process for deposition
  - Simpler technology
  - Need to demonstrate on aluminum
- No coatings:
  - Test photogrammetry, other CMM methods can give sufficient results



Cryostat for deposition test



Broken window in deposition test

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- So far, we have looked at the window safety from a single source of loading only, i.e. the pressure load.
- Other possible loads considered, but not rigorously analysed. These include:
  - Thermal load caused, possibly, by the uneven temperature distribution of the liquid hydrogen during operation
  - Stress from beam deposition – (pizeo-electric instrumentation)
  - Thermal cycling – fatigue tests
- Still need to study the high stresses at the edge of the new window
- Other alloys are still under consideration (i.e., Al Li alloys, Albemet)
- Window instrumentation is still planned

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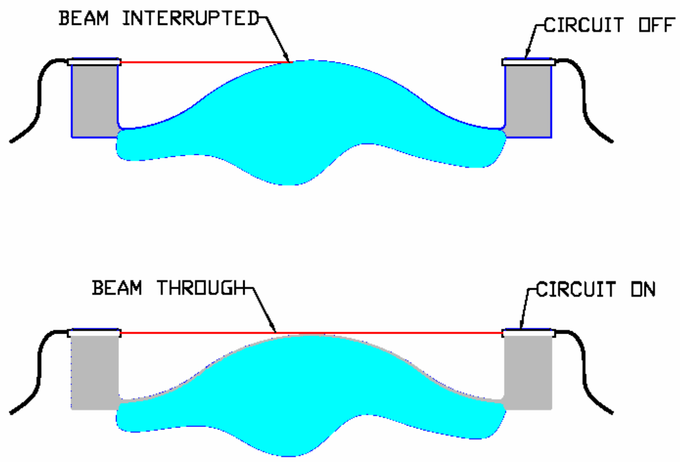
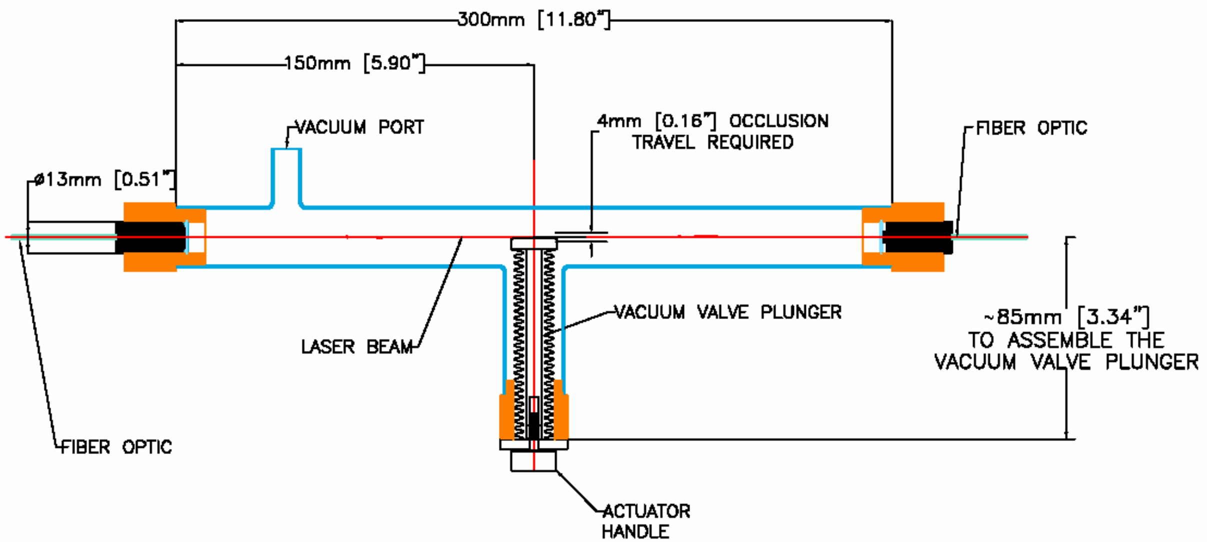
- Can be used as a threshold for occlusion or clearance



- Baumer electronics laser distance sensor is one candidate
- Test set-up at NIU:



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- New manufacturing of bellows windows (just started)
- Optical coating (thickness control)
  - Vapor deposition
  - Chemical deposition
  - Tests for uncoated
- Upgrades to projector and new camera. Optical table obtained for dedicated destructive tests.
- Plans are maturing for vacuum tests

Frqfoxglqj#Uhpdunv

- ICAR funding loss has hurt this program
- Do not want "institutional" knowledge to disappear.
- Absolutely need to go through a complete testing cycle for the new window, to continue progress.
- Have a dedicated window test area at FNAL, and can accommodate all Mucool and MICE window tests.
- Takes good advantage of expertise at FNAL
- If new window source is established, will expedite tests and certifications.
- Can have possible beam test of thin window on LH2
- Good program for students

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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.

➔ $P_b = 5 \times 310\ /\ 415 \times P\ = 5 \times 0.76\ P\ = 4 \text{x} P$

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