FNAL experience with thin beam windows

Issue is:

- Survival of window in high power proton beam

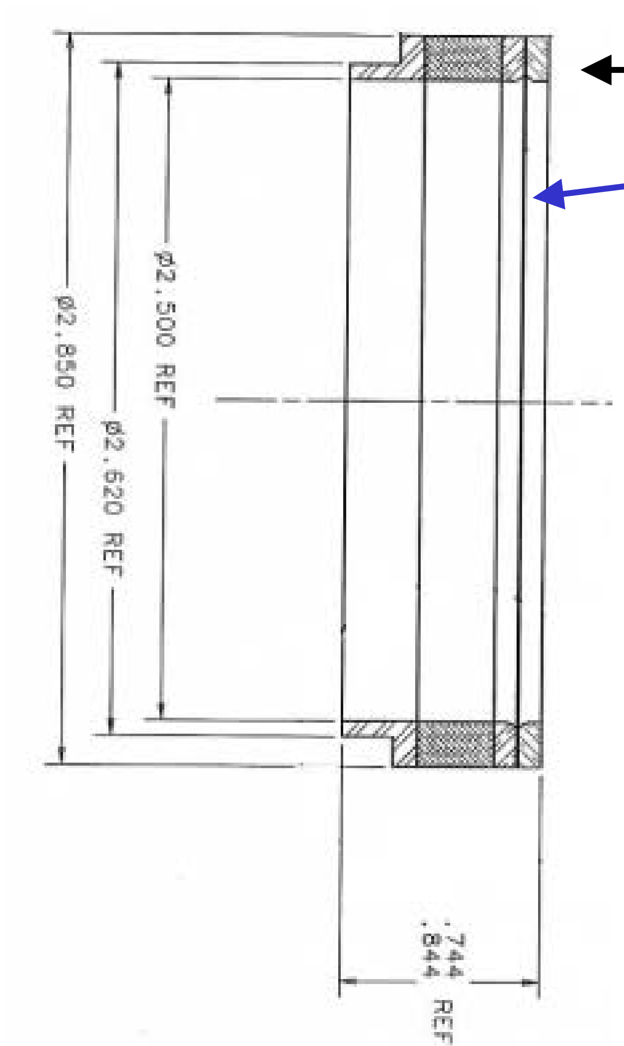
Windows described in this talk:

- FNAL Anti-proton production target station experience –
  Information provided by Patrick Hurh and James Morgan

- NuMI prototype-target test window experience

- NuMI Decay Pipe Window calculations

Titanium window
on proton beamline for pbar production



← Tri-clad transition ring and weld backup ring

← 1.5 mil thick Titanium grade 2 foil

Run I era:
- beam sigma of 0.4 mm
- 3E12 protons per 1.6 μsec pulse

failure every year or two

Run II era: (~1 – 2 E18 protons/month)
- beam sigma 0.3 mm on window
- increasing from 4E12 to 5.25E12 per pulse

failures at 3 months, 1 month, 2 weeks

Titanium window
on proton beamline for pbar production

Failure mode:

- Develop vacuum leak (~ 10-7 torr litre /sec)
- See no signs of cracks on the Ti window under a microscope
- See some oxidation (similar to picture later in talk)

Failure mechanism not known, but have a supposition

- failure is earlier than probably expected from radiation damage
- peak temperatures are above "alpha/beta transus" , so high temperature and rapid cooling could be inducing micro-structural changes, decreasing ductility, making titanium brittle

Ti window was replaced with Be window last year

Beryllium window

on proton beamline for pbar production

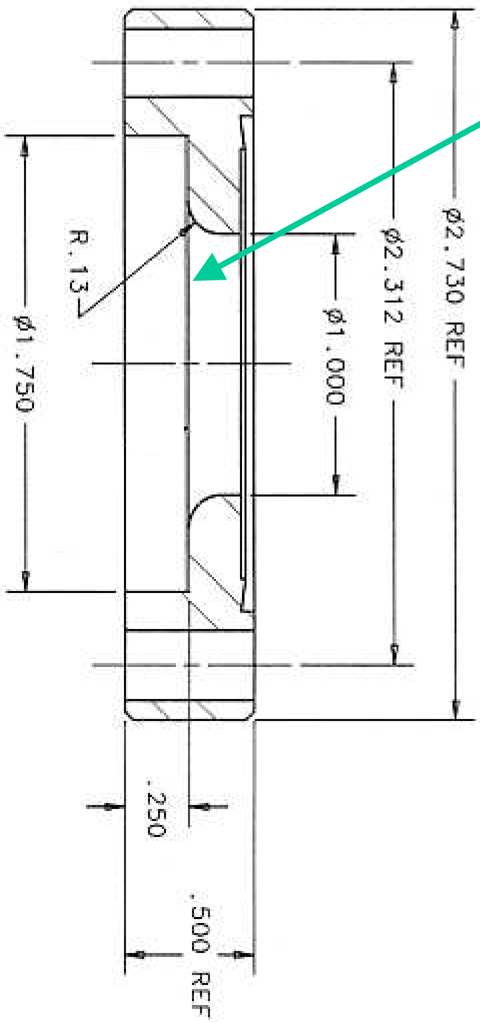
in beam for about a year now
0.3 mm RMS spot size
~5e12 protons/pulse

accumulated about 1.7E19 protons
with no failures

can see spot where beam heating
has caused oxidation

having to clean-up mixed waste
(after a wrench-meets-window
incident NOT at pbar) induced
installation of a catcher
(pair of Ti windows with air break
where spot size is 4 mm)
which would limit spread of
Be contamination upstream
in case of catastrophic window failure

Beryllium Window
beamline window versus pbar SEM



10 mil thick Be foil in beamline window

Be window used on pbar target SEM is even better test

- has held vacuum longer (for about 7 years)
- with spot size about half that listed for Ti window

(recently about 5e12 at ~0.2 mm rms spot size)

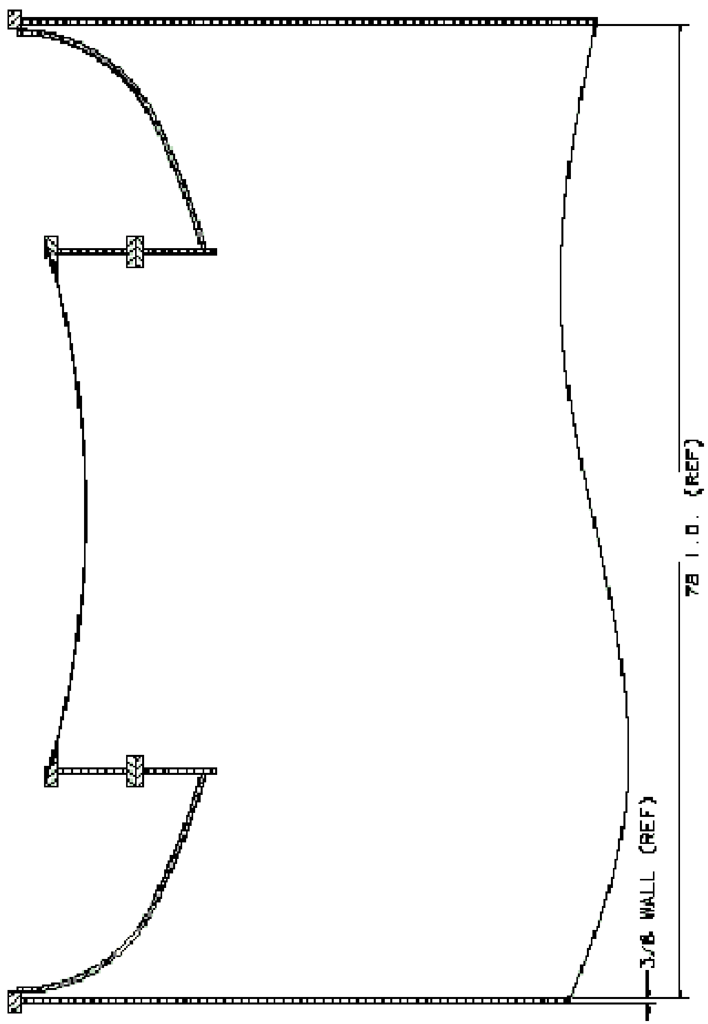
NuMI Prototype Target Test target can Beryllium window

During the NuMI target prototype test, an even more intense spot was generated for a short period of time

- 10^{13} protons/ 10 μsec pulse
- 0.21 mm x 0.16 mm spot size

No visible damage to beryllium window
(however target was not run at a high vacuum, only a few milli-torr, so a small leak could have gone unnoticed)

NuMI Upstream Decay Pipe Window



Steel at large radius

Transition ring

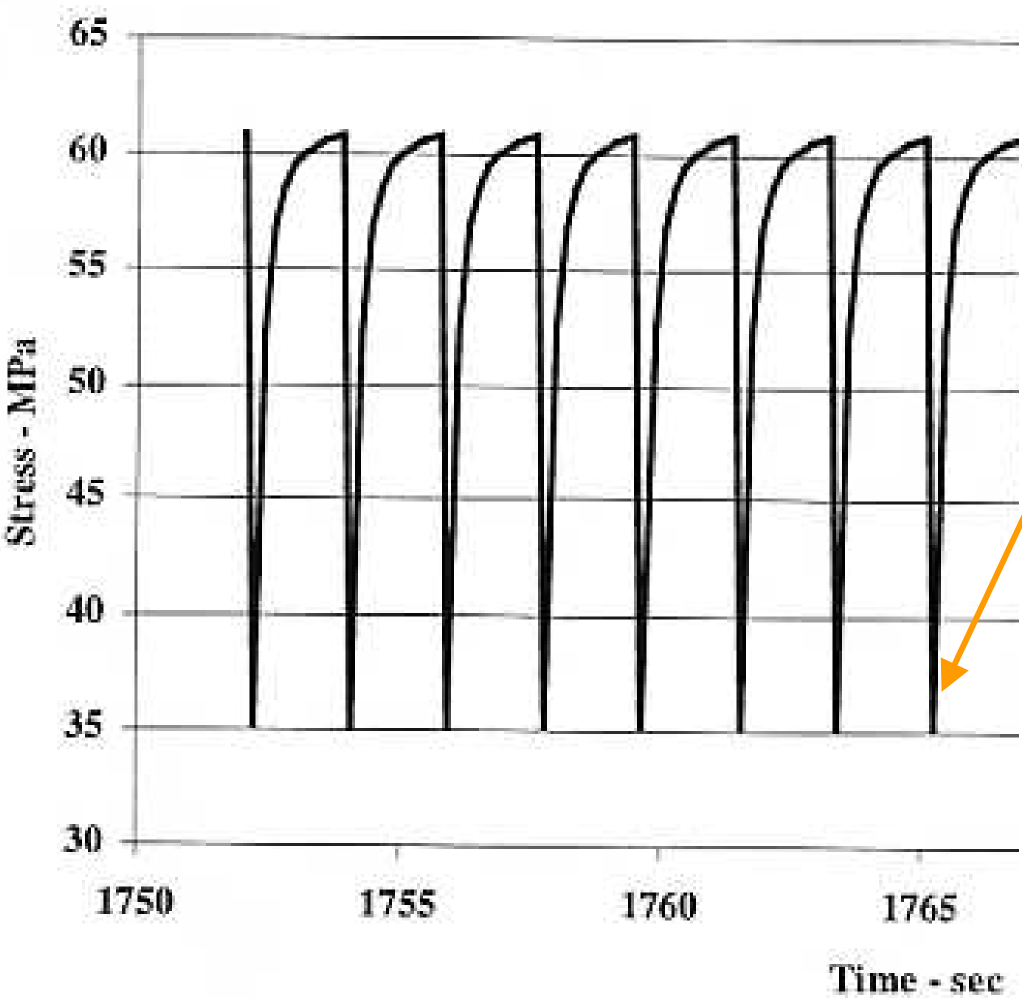
Aluminum thin window
1/16” thick 6061-T6 Al

46 m after target

(Downstream window is ¼” steel)

Decay Pipe Window

(accident condition –beam misses target)



Accident condition:

$4x10^{13}$ proton/spill

~2.5 mm RMS beam spot

Air pressure pre-stresses vacuum window

Beam heating temporarily reduces stress at center of window

Normal running condition:

~$4x10^{12}$ proton/spill through target

~11 mm RMS beam spot at window

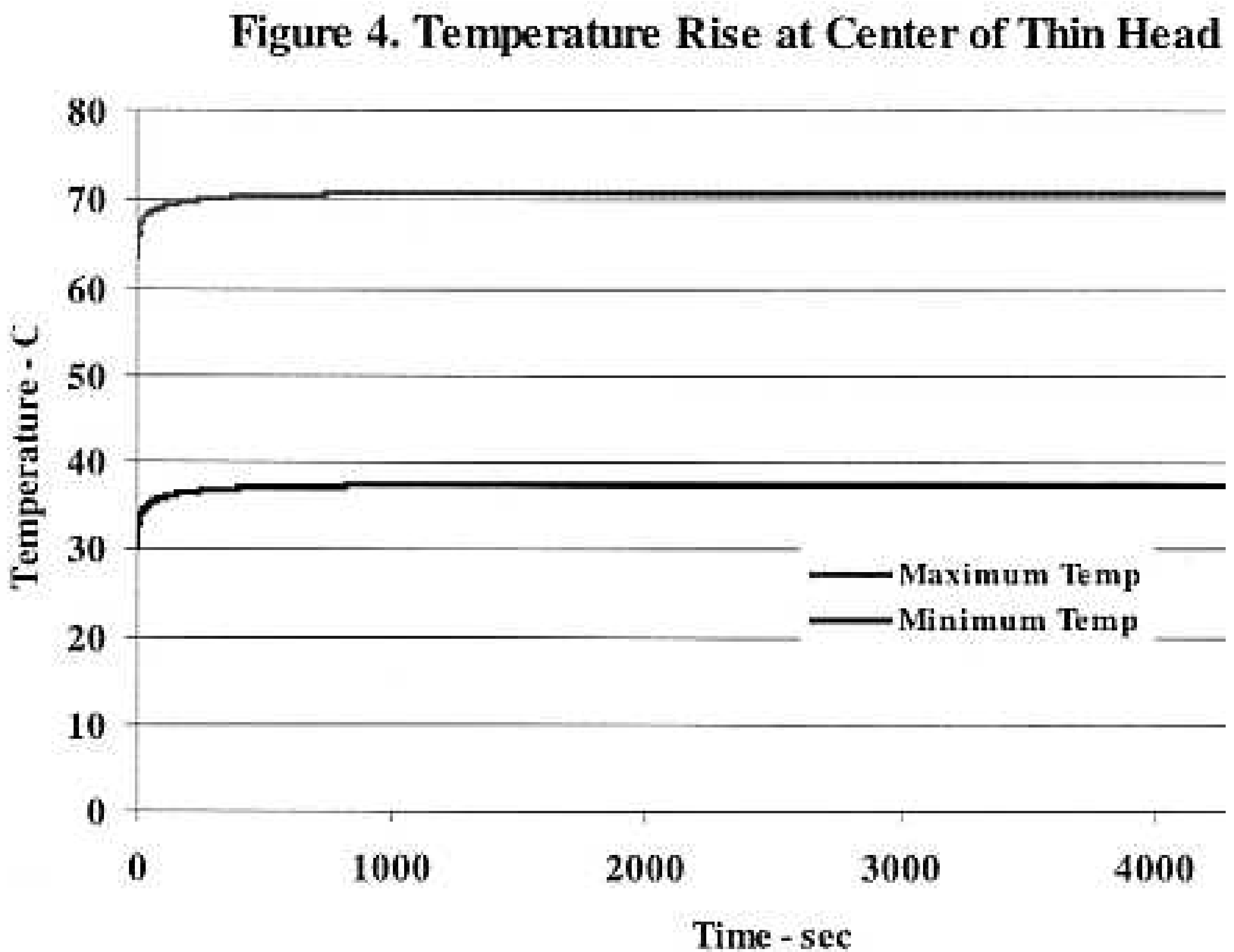
Expect radiation damage at

~ $4x10^{19}$ proton/mm^2

~ one century of running

Decay Pipe Window

(accident condition –beam misses target)



Temperature rise after many beam cycles is small

(1 pulse / 1.87 seconds)

Conclusions

Performance of Beryllium windows is adequate for NuMI near the target,
(4e13 protons/pulse at 1 mm rms spot size) while Titanium would not be

The ES&H aspect of Beryllium has to be dealt with during design
(plan for containment and/or clean-up considered)

Aluminum appears adequate for the decay pipe window,
where beam conditions are not as harsh