NuMI Target Hall Performance/Plans

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DOE Tevatron Operations Review

March 27, 2007

Outline

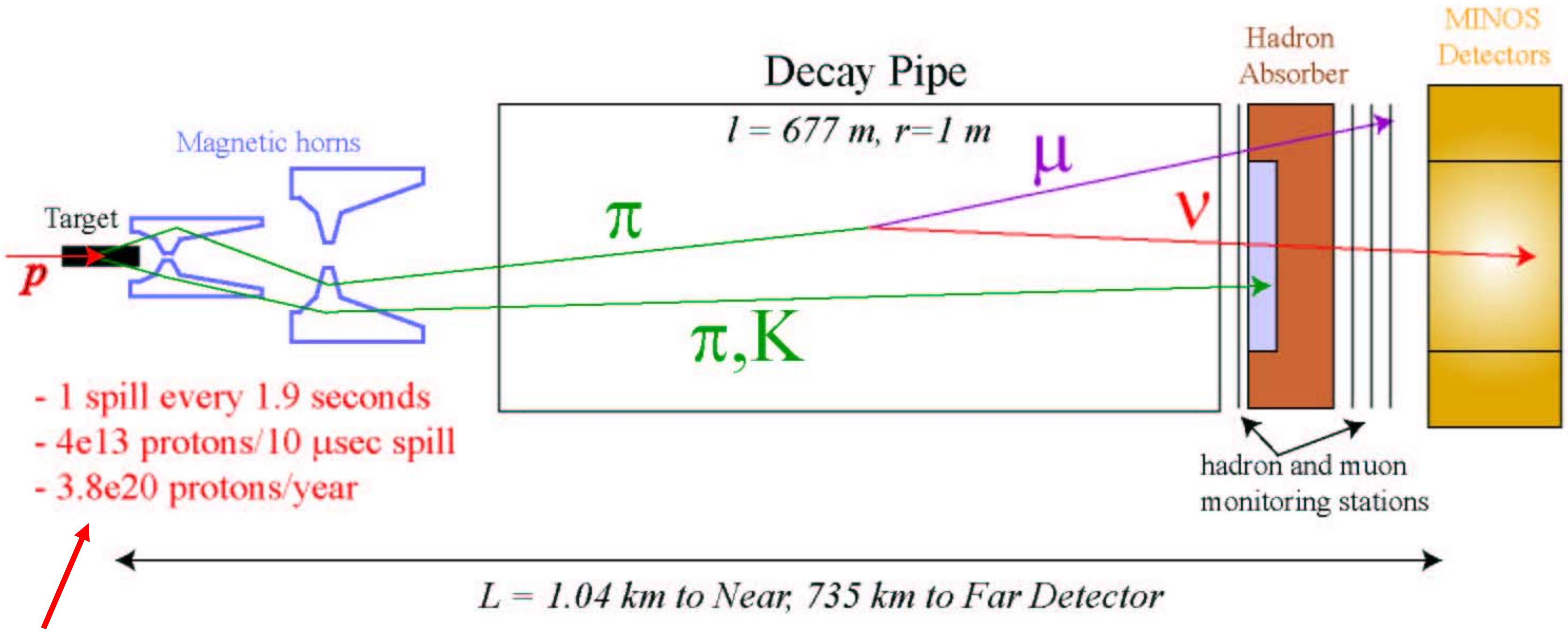
- Overview of target hall
  and target/horn experience
- Summary of problems causing 1 day or more downtime, and corrective actions underway
- (back-up slides describing individual problems)
- Spares status
- Plans for target with evolving beam conditions

How NuMI ν beam is produced

120 GeV/c protons strike graphite target

Magnetic horns focus charged mesons (pions and kaons)

Pions and kaons decay giving neutrinos



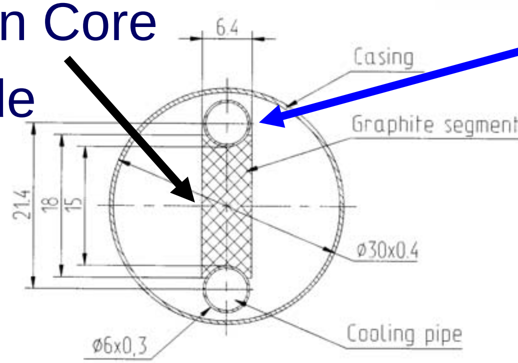
- 1 spill every 1.9 seconds
- 4e13 protons/10 μsec spill
- 3.8e20 protons/year

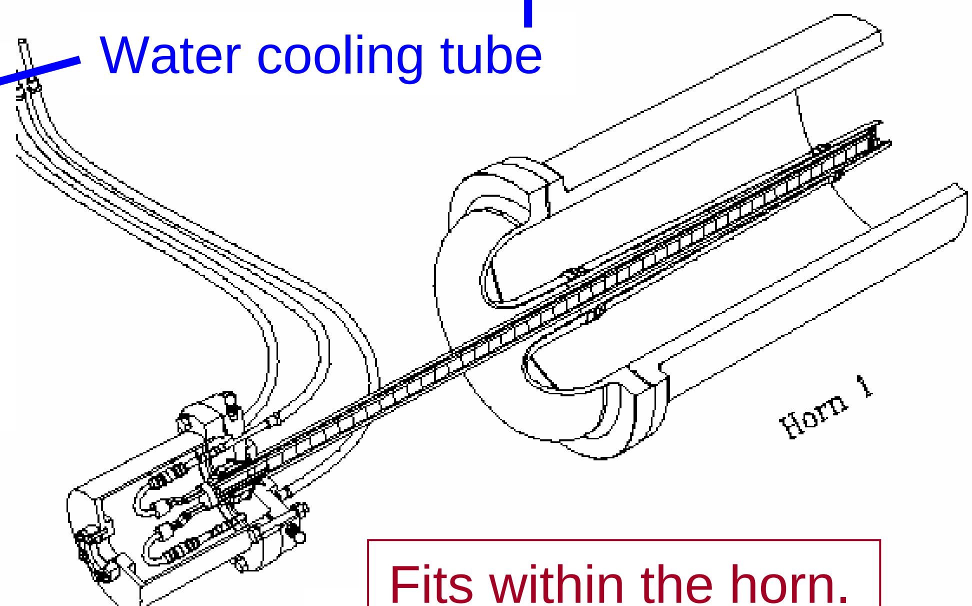
Design for 0.4 MW proton beam

Target for Low Energy Neutrino Spectrum

Graphite Fin Core
6.4 mm wide

Water cooling tube





Backing target out of horn produces neutrinos at higher energies

Fits within the horn.

Experience with the NuMI Target

1st Target took beam for over a year, 820 MWhr integrated beam power. Two problems:

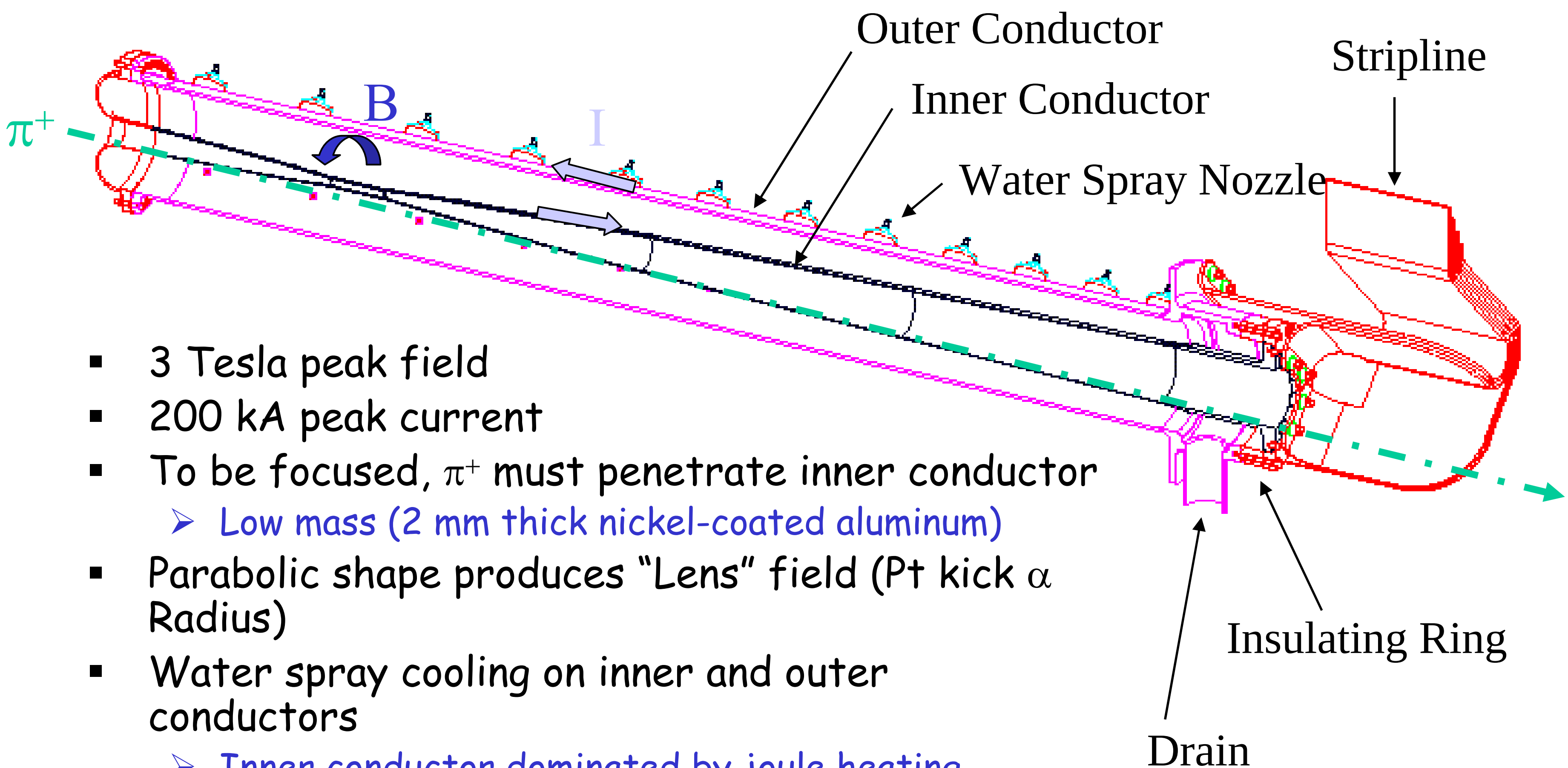
- water leak soon after turn-on; back-pressure with Helium to keep water out
- target motion drive shaft froze up after year of operation – stuck in H.E. focus

2nd Target is running (no leak)

	Max. Proton/spill	Max. Beam Power	Integrated Protons on Target
Target Design specification	40e12 p.p.p.	400 kW	370 e18 p.o.t. lifetime
1st target Before leak	25e12 p.p.p. *11e12 day before leak*	69 kW	0.7 e18 p.o.t.
1st target After leak	30e12 p.p.p.	270 kW	158 e18 p.o.t.
2nd target	40e12 p.p.p.	320 kW	105 e18 p.o.t.

Magnetic Horns

π focused by toroidal field between conductors



- 3 Tesla peak field
- 200 kA peak current
- To be focused, π^+ must penetrate inner conductor
  - Low mass (2 mm thick nickel-coated aluminum)
- Parabolic shape produces "Lens" field (Pt kick α Radius)
- Water spray cooling on inner and outer conductors
  - Inner conductor dominated by joule heating
  - Outer conductor dominated by beam heating
- 3 m long focusing region
  - Achieved ~ 0.1 mm radial tolerance after weld

Horn Inner conductors

Parabolic inner conductors:
- 3 Tesla max. magnetic field
- 3 m active length each horn

Inner conductors welded together at FNAL by lead engineer Kris Anderson

NuMI Horns Experience

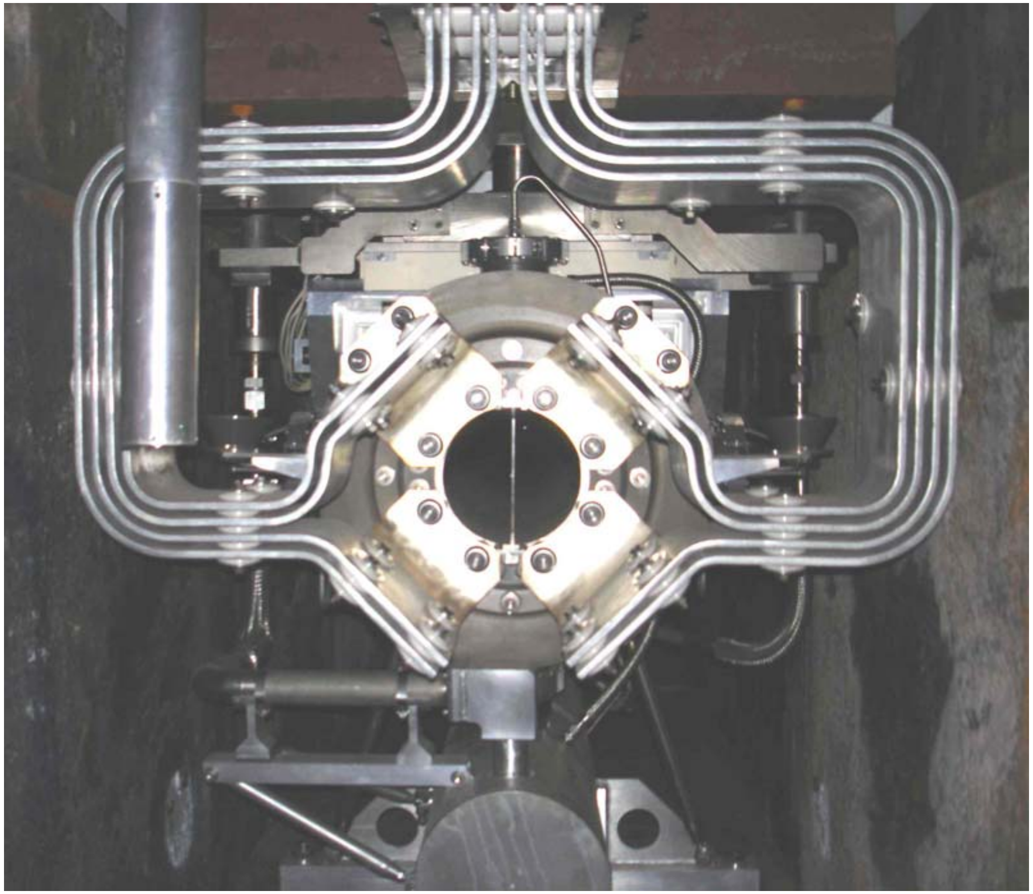
Horns in target hall
June 2004

1st run with beam
Jan. 2005

Accumulated:

15 Million pulses

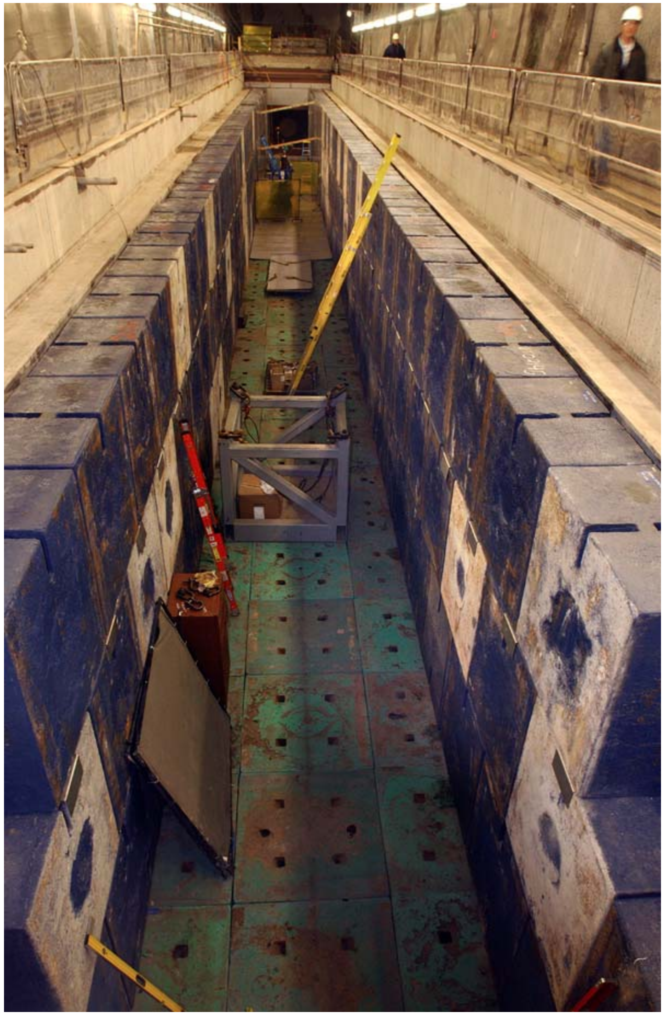
1,350 MWhr
integrated beam power



Still running with first set of horns

Target Hall during construction

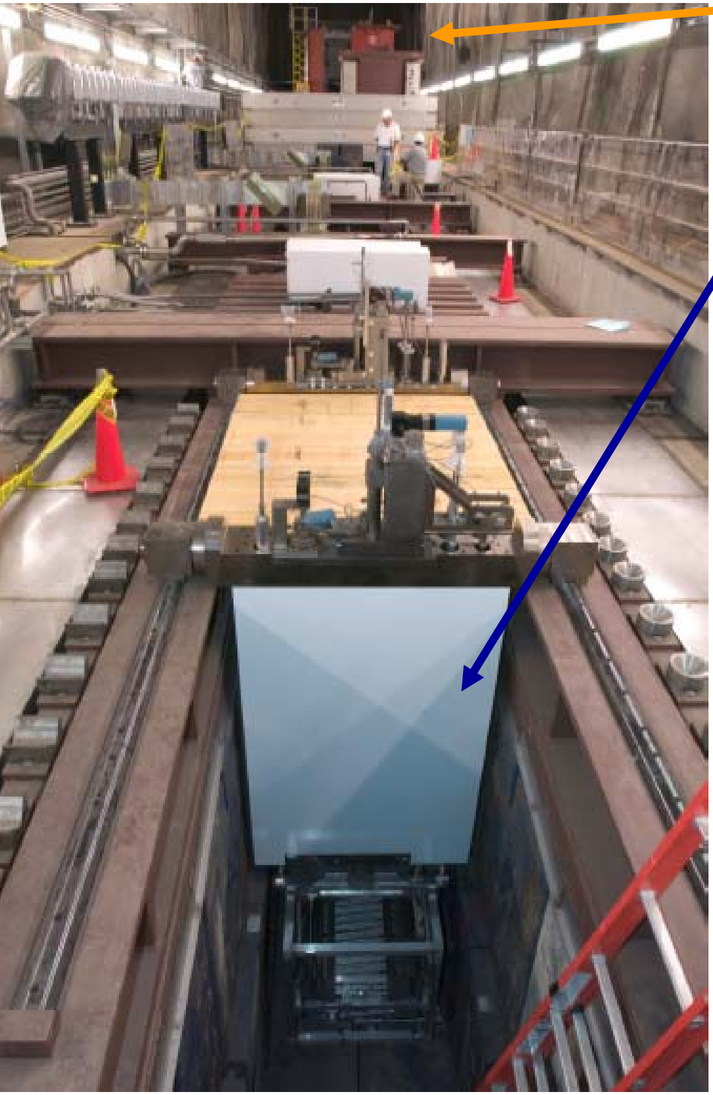
1/2 of the
8000 tons
of shielding
is installed



Work cell

Target module in beam-line

1st target being removed



NuMI work cell for radio-activated components

Shown during test-assembly above ground

Lead-glass windows (not shown)

Remote controlled door

Remotely installable top shielding

All NuMI target hall beam components and innermost shield layers are installed /removed remotely with crane and cameras

Crane includes remote hook rotation.

Steel shielding block being moved.

Big Picture of Maintenance

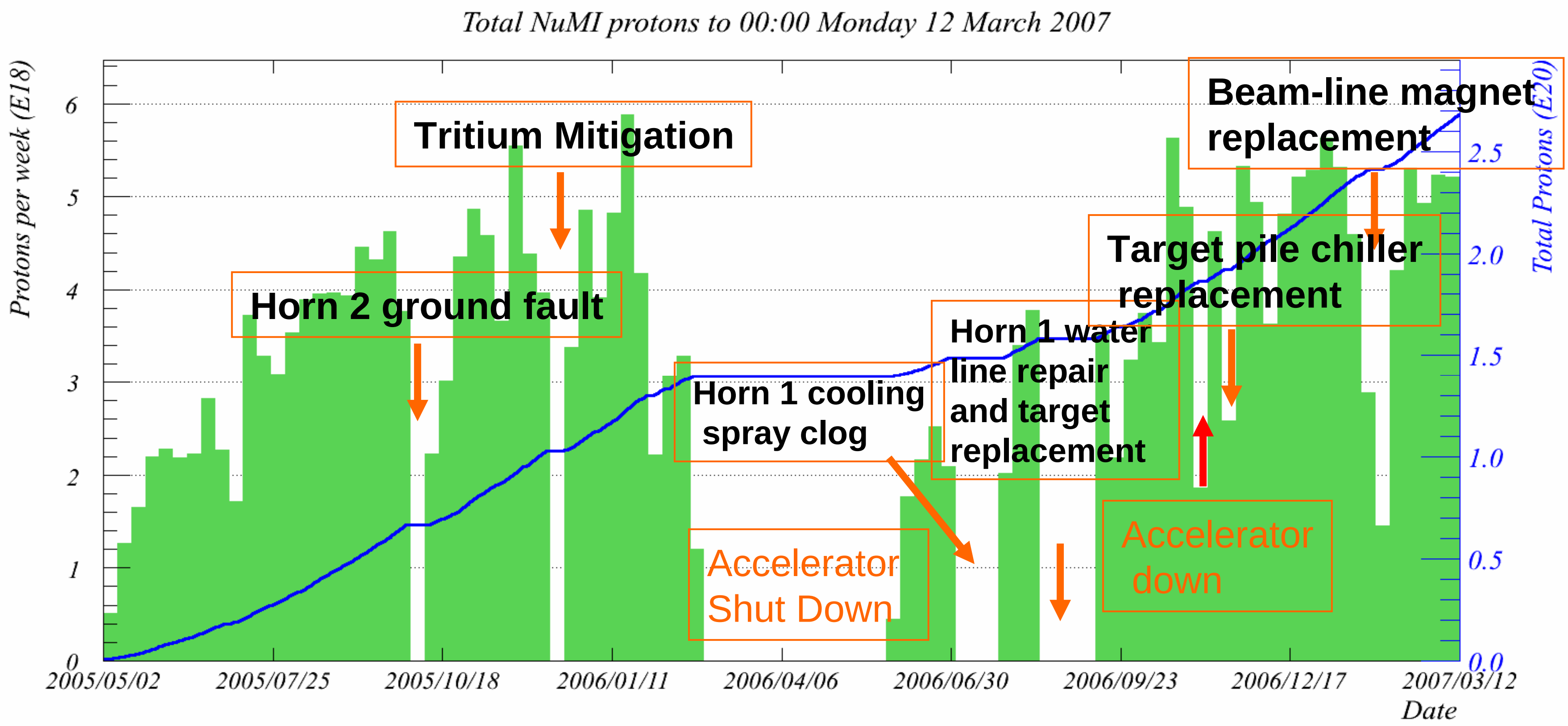
- NuMI target hall is a difficult system
  - High radiation forces remote handling
    - repairs take a long time
  - Target hall is nasty environment
    - E.g. humidity has PH of 2.6, very corrosive
    - Limited list of materials are rad-hard enough
  - Interventions are time-consuming
    - Access to components requires 1 shift just to put electronics back on target hall crane
    - Must un-stack, then re-seal shielding each access
    - Components are an order of magnitude larger than Pbar's

Achieving high up-time requires design of robust components

If you have no spare - you must repair !

- Biggest current concern:
  - Producing an adequate supply of spare horns
    - Usually replacement takes less time than repair

NuMI Performance - POT/week



Up (513) and down (83) days 5/1/05 – 3/22/07
86% / 74% efficiency excluding / including sched. shutdown

Days	Description (**non-recurring)		Long term corrective action
513	Up for beam		
95	Accelerator scheduled down		
25	Horn cooling spray clog **		Check valves, filters on skids
14	Horn water line repair		Eliminate braze on spares
14	Target motion frozen		Graphalloy bushing on spare
10	Horn ground fault		Pin feet, float modules
8	Tritium mitigation **		Condensate sys./dehumidifiers
6	Replace NuMI beam-line magnet		
4	Replace accelerator magnet		
2	Replace pile chiller compressor		New hot spare chiller unit

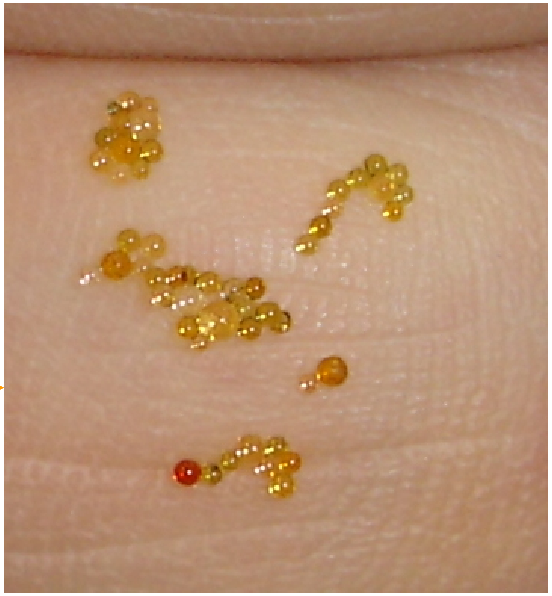
Other long term actions

- Corrosion protection
  - Improve dehumidification of target pile
    - Planned installation summer 2007
  - Selection of materials
    - E.g. stainless sheathing instead of nickel coating of shielding on remote electrical clamp for spares
- Accelerate production of spares
  - Batch process horns
    - Doing several at once is much more efficient
  - Engineer hired specifically for spare horn welding
  - Tech. assigned specifically to track parts

June 30, 2006, resin beads from deionization bottle clogged the water spray lines on Horn 1

Horn spray flowmeter with beads

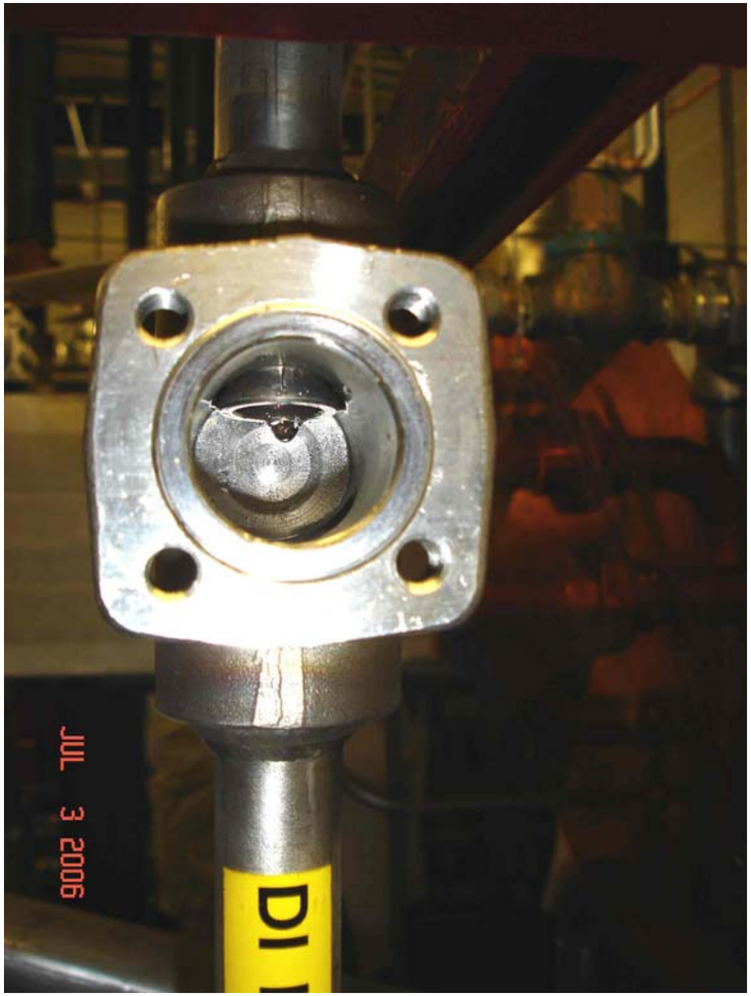
New, uncontaminated beads
Beads are ~ 20 mils diameter



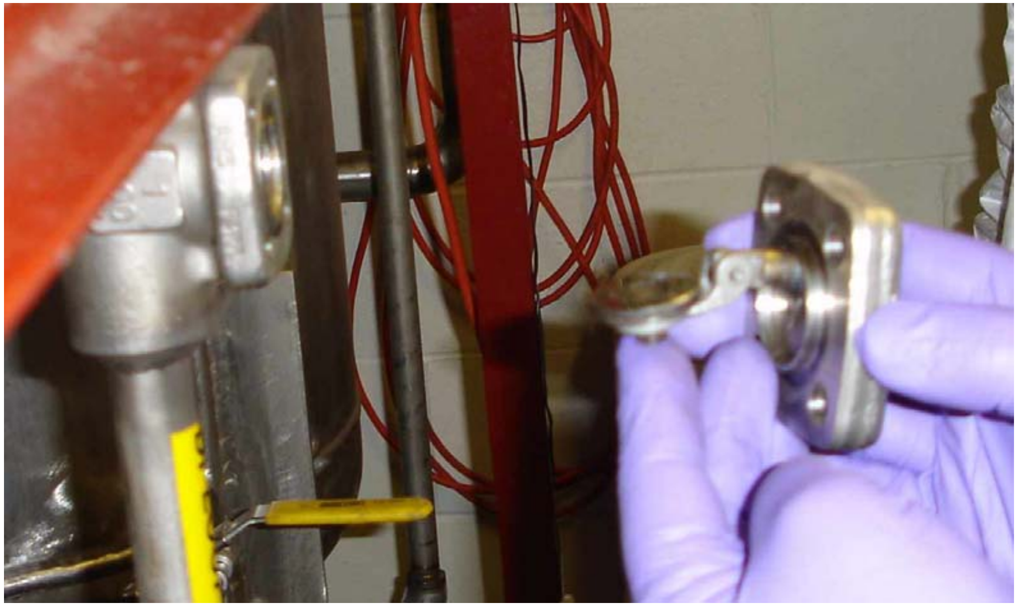
Horn nozzle for inner conductor is eliptical ~40 mils short direction (48 total)

outer conductor nozzles round, 25 mils diameter (19 total)

plus two side-spray nozzles



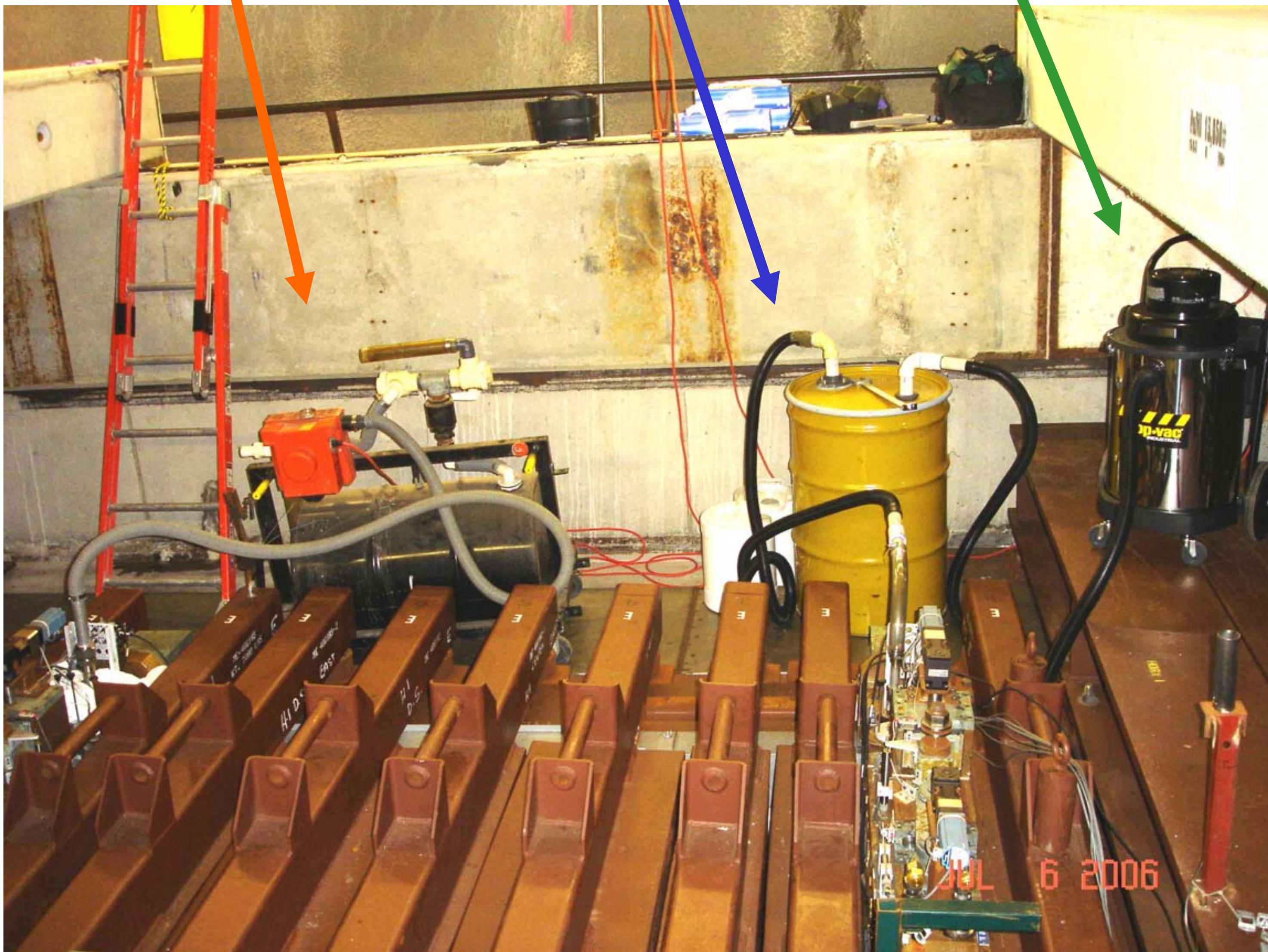
When water skid was turned off for maintenance,
beads floated backwards
through improperly mounted check valve



The gravity un-assisted check valve

Fan push, water-in-barrel filter, vacuum suck

Cleaning Out Resin Beads



Two horn water system leaks:
Horn 2 in February 2006, Horn 1 in August 2006

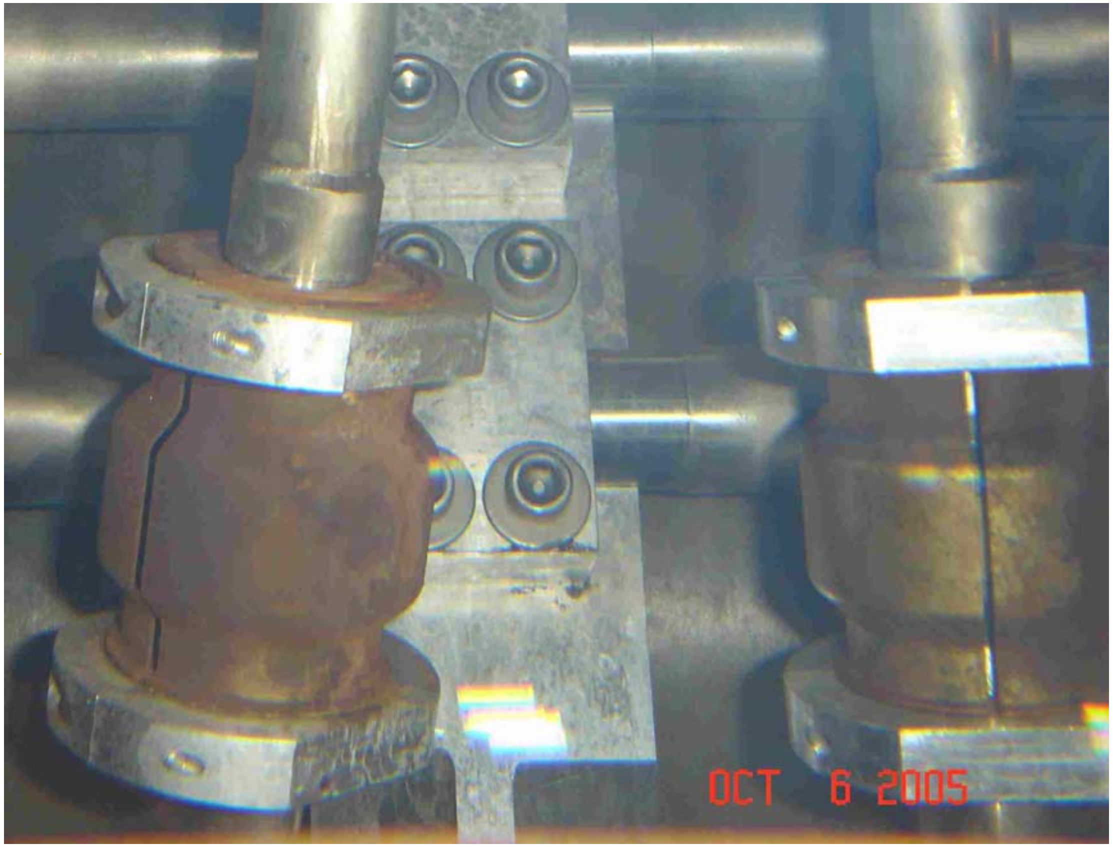
Have brazed ceramic electrical insulators on horn water lines
They are strain-relieved with invar+ceramic clam-shells

On horn 1, developed a 7gal/day water leak on line to spray header

On horn 2, leak on suction line drew air in, reducing amount of water ejector pump could remove from horn collection tank

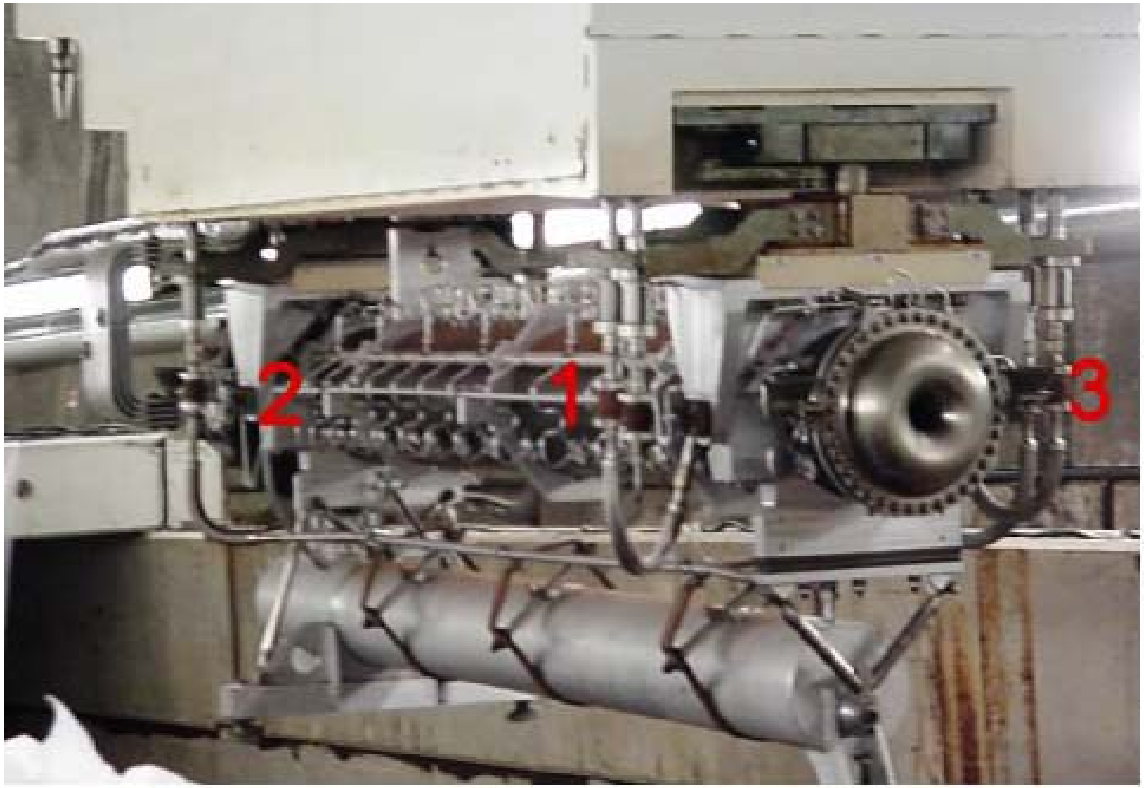
Both ceramic sections were successfully replaced

Speculate braze corrodes… planning to switch from brazed to a shrink-fit ceramic/steel connection for spare horns



High dose rates made Horn 1 ceramic replacement challenging

75 r/hr (0.75 Sv/hr) on contact
35 r/hr (0.35 Sv/hr) at 1 foot



Point	Doserate @ 1 foot (mr/hour)	Doserate On Contact (mr/hour)
1	35000	75000
2	40000	75000
3	35000	80000

Repair people got weekly dose limit in a few seconds

Shielding for Horn 1 ceramic repair job

Built an extension of the work-cell with window for work

(Horn is in work-cell, behind the door)

Mock-up and practice for repair

Plan, time, and practice, practice, practice repair

Needed to undo two Swagelok fittings, remove old section, insert new section, and tighten two fittings.

Time est: 2 min. of actual work in slot

Dose for this "2 min." job was 371 mr, (3.7 mSv) divided over ~10 people.

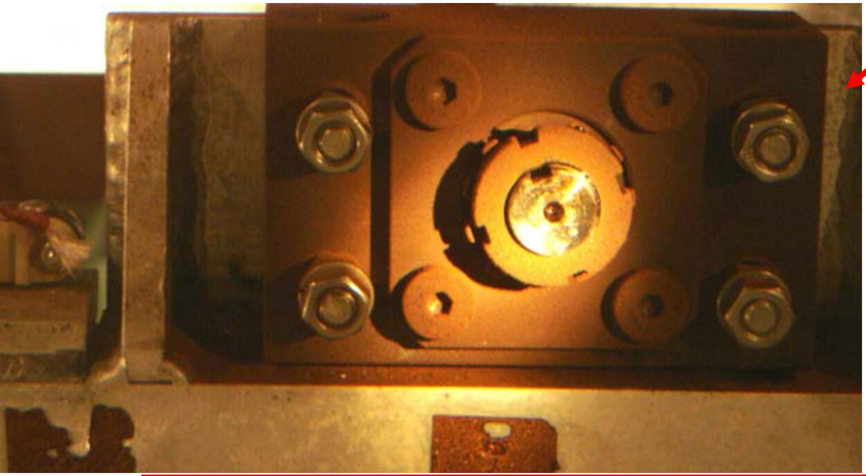
The rest of job is in much lower radiation field, but dose can be non-negligible due to time involved.

Frozen drive shaft on target motion system

After month-long test in High Energy position
drive shaft will not rotate to move target into Low Energy position

On target carrier #3, change to Graphalloy bushing

Old jammed pillow-block



On 2nd carrier -
Light lube
of nuclear grade
anti-seize compound

Horn 2 ground fault -- loose foot on horn

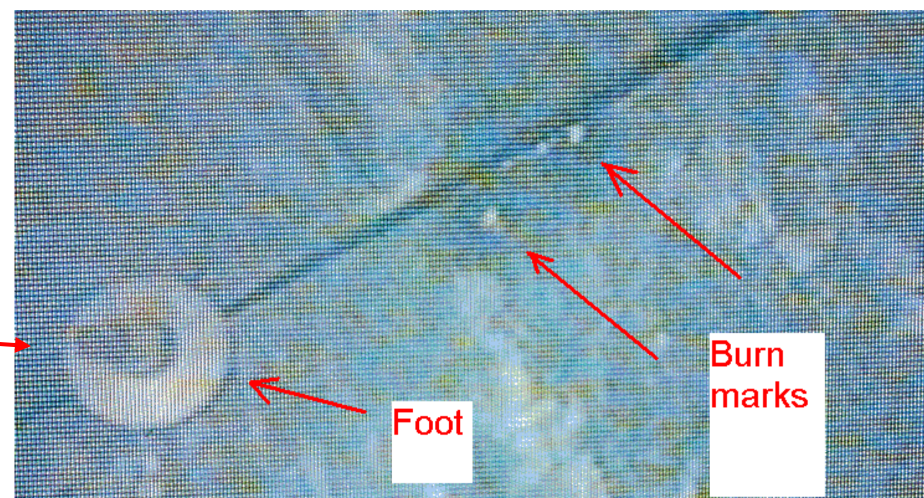
Horn 2 before beam

1.5 inch clearance foot to floor

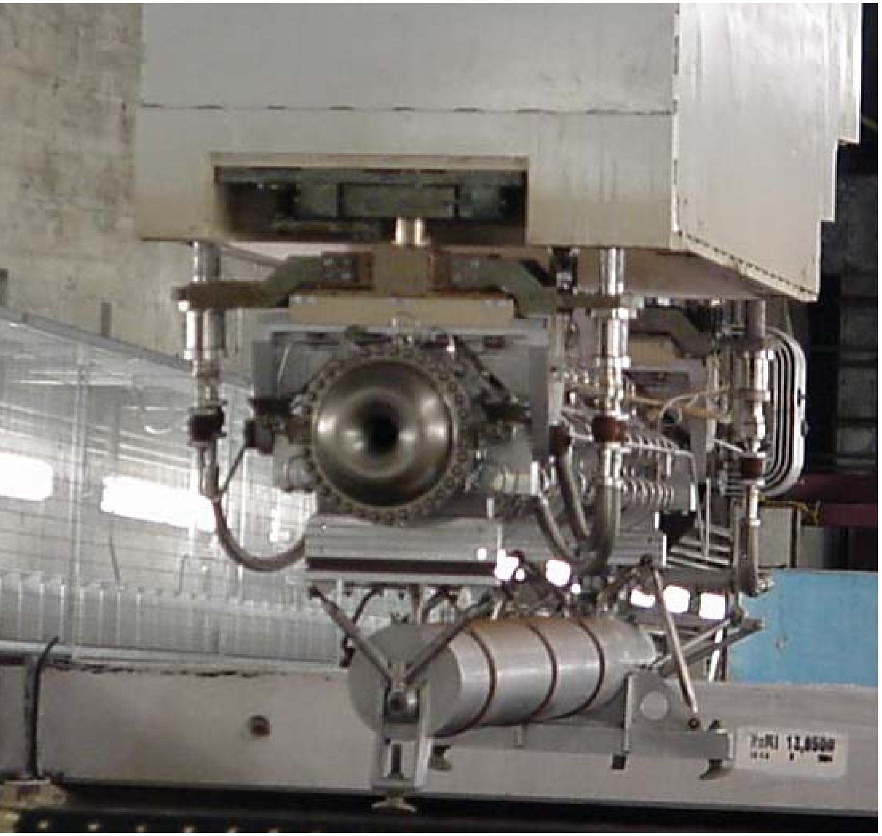
Owl shift Thurs. Sept. 29, 2005 intermittent horn trips.
Owl shift Sat. Oct. 1, hard ground fault of 1 ohm.

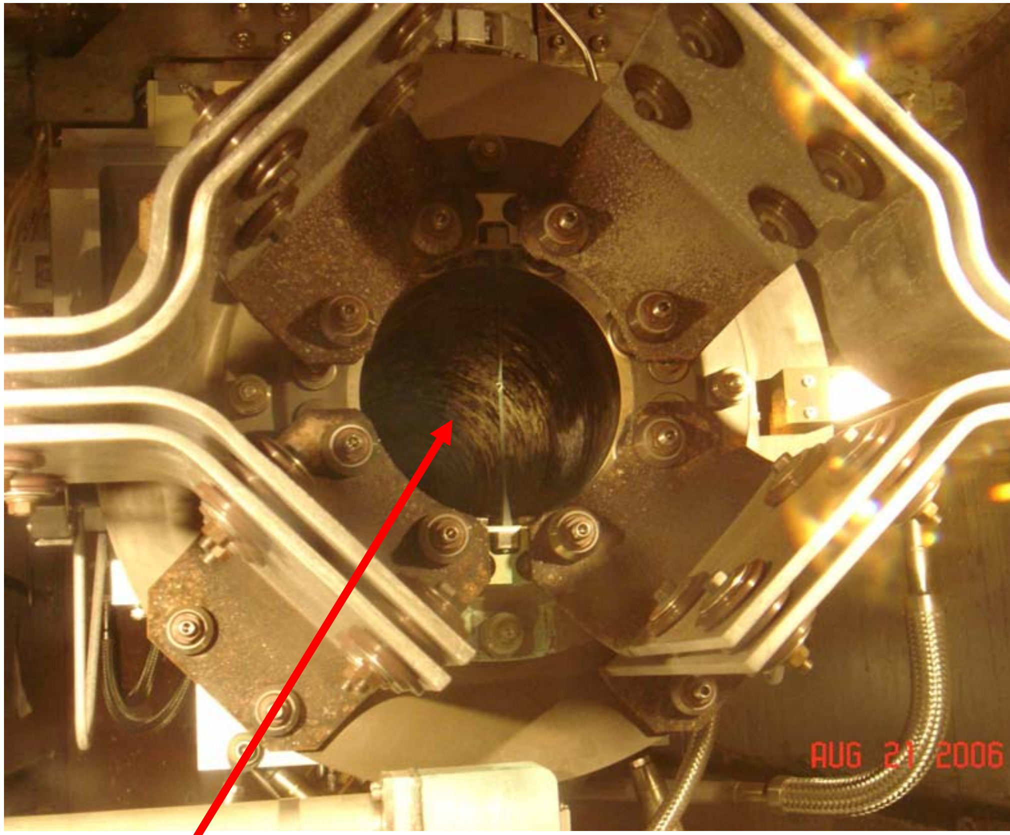
- *-removing stripline fingers Horn 2 + stripline block*
- *-when Horn 2 moved to work cell ground fault cleared*
- *-foot left behind in chase, nut had vibrated off*
- *-scorch marks seen under foot*

Moved old foot, installed new foot



Horn 1, after a year of beam





Horn is corroding – eventually will have to replace it

Spares Status - Horns and target

HORNS	PH1-00	PH1-01	PH1-02	PH1-03	PH1-04	PH1-05		PH2-01	PH2-02	PH2-03	PH2-04
in use	**proto**	**in use**						**in use**			
fiducialize (survey)											
instrumentation											
water tank, hangers											
test pulse			2/3								
stripline									silvered		
water lines etc											
I.C.+O.C assem											
O.C. silvered											
O.C. coated											
O.C. welds											
O.C. machined											
O.C. blanks											
I.C. silvered											
I.C. coated											
I.C. welds			7/7	3/7	3/7	3/7			6/6	5/6	
I.C. machined											5/7
I.C. blanks											
					700kW	700kW					700kW

TARGETS	NT-01	NT-02	NT-03	NT-04
in use	**stuck**	**in use**		
fiducialize (survey)	**in**			
instrumentation	**H.E.**			
hangers	**posn.**			
mount target + baffle				
fab carrier				
fiducialize target				
fab target + baffle				ordered

Color code
- Used
- Done
- In progress
- to do

Plan for target for evolving beam condition

Existing target was designed for 4.0e13 p/pulse, 400kW

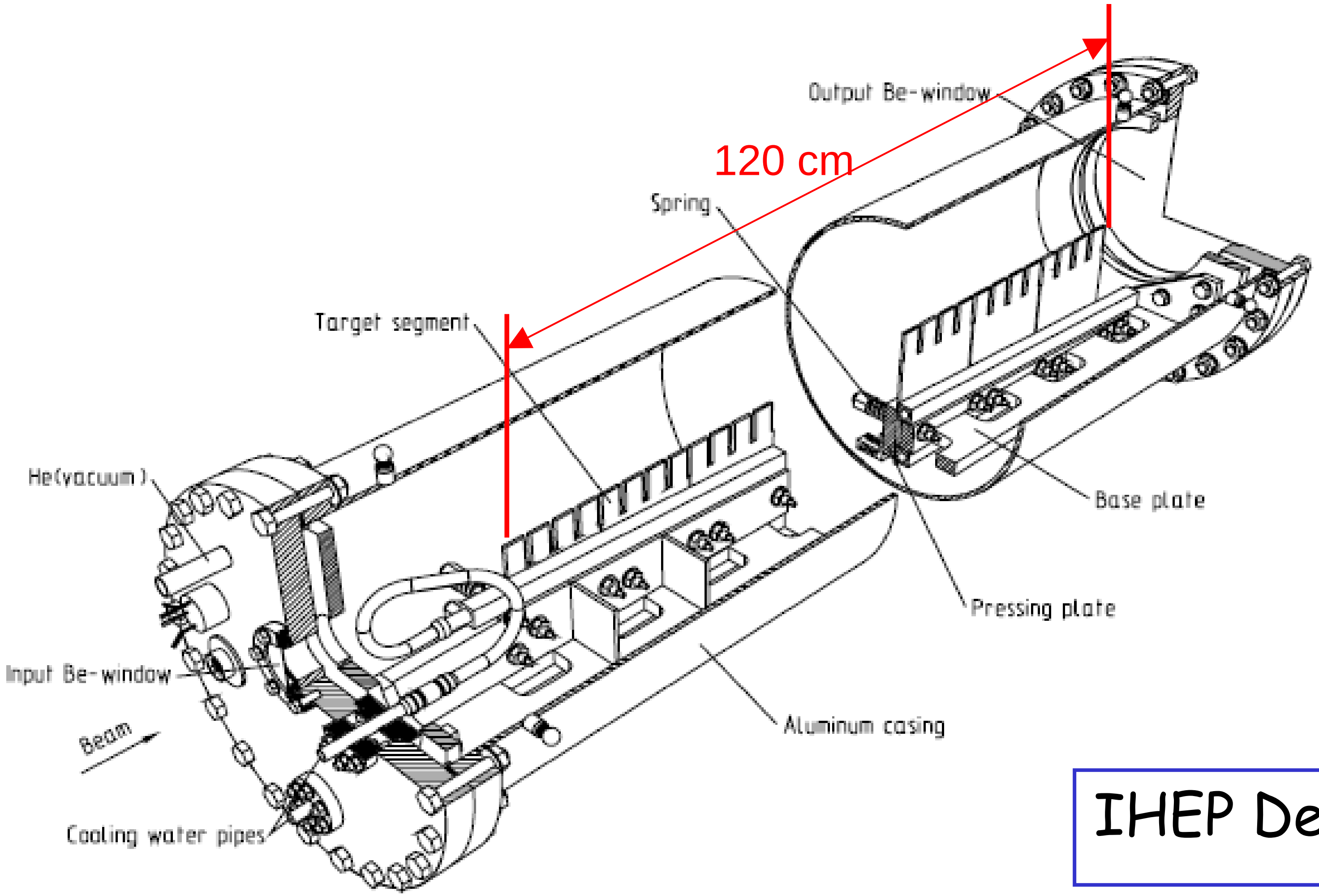
- After summer shutdown, slip-stacking may provide up to
  4.5e13- 4.8e13 p/pulse, 400 kW (when pbar source not running)
  - By increasing beam spot size to 1.2 mm RMS for 4.5e13, will have same stress as current 1.0 mm RMS for 4.0e13 on target
  - Have tested larger spot size, baffle scraping by beam still fine
  - Preliminary Monte Carlo indicates negligible impact on neutrino spectrum

Plan for target for evolving beam condition

For NOVA experiment (2011),
target no longer needs to fit in horn → M.E. target design

- With ANU sub-project, beam specification is
  4.9e13 p/pulse, 700 kW
  - By increasing beam spot size to 1.3 mm RMS, will have same stress as current 1.0 mm RMS for 4.0e13 on target
  - Moving water cooling further from beam-spot reduces water-hammer
  - Still work to do on window and outer casing cooling, but does not appear to be any show-stoppers

Medium Energy Target for NOVA running



IHEP Design

Plan for target for evolving beam condition

A possible next stage for beam after ANU is to re-use Accumulator Ring

Plan to use essentially same NOVA M.E. target design

- With Accumulator, beam specification could be
  8.3e13 p/pulse, 1200 kW
  - By increasing beam spot size to 1.5 mm RMS, would have calculated stress safety factor of x1.4 on graphite
  - Still work to do on window and outer casing cooling, but appears doable