



NuMI Horns Experience

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Horns were
put in
target hall
June 2004

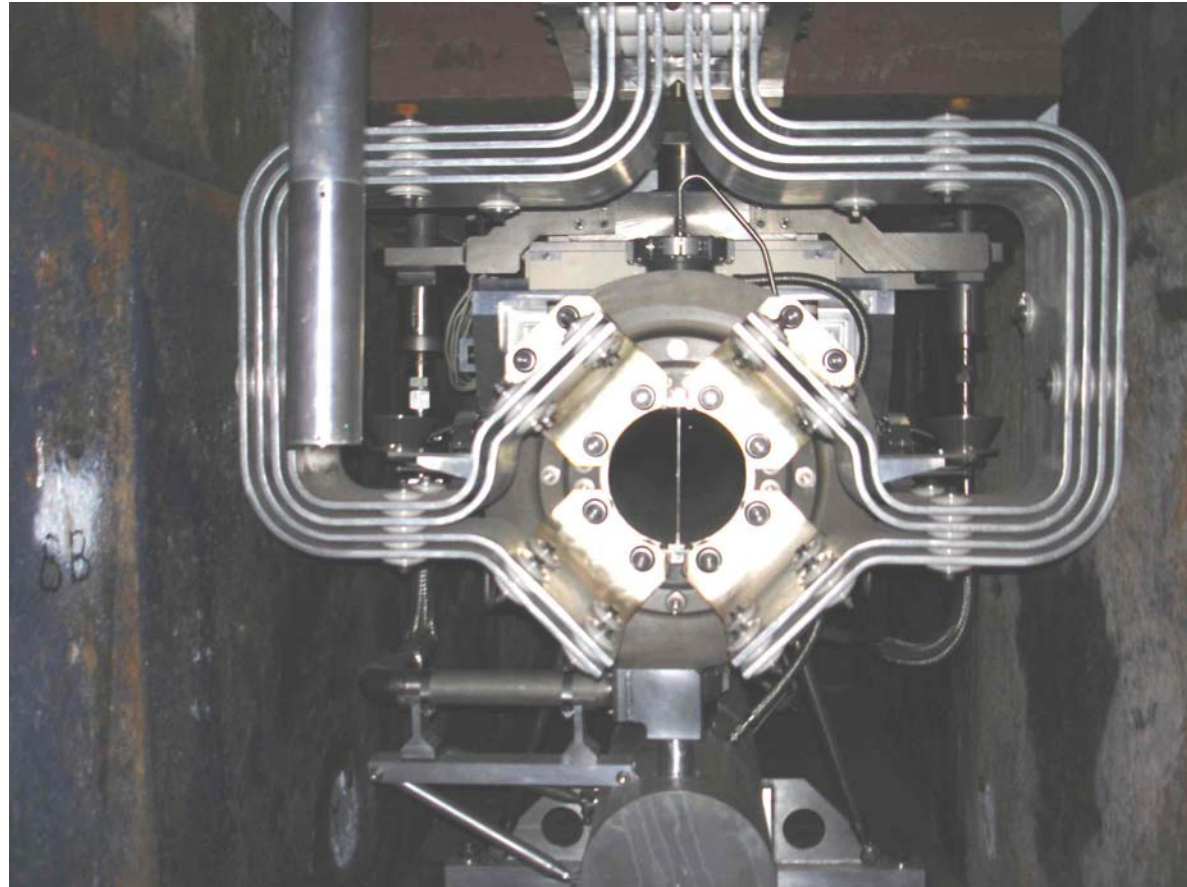
1st run with
beam
Jan. 2005

Accumulated:

9.2 Million
pulses

820 MW_{hr}
integrated beam power

Still running with first set of horns

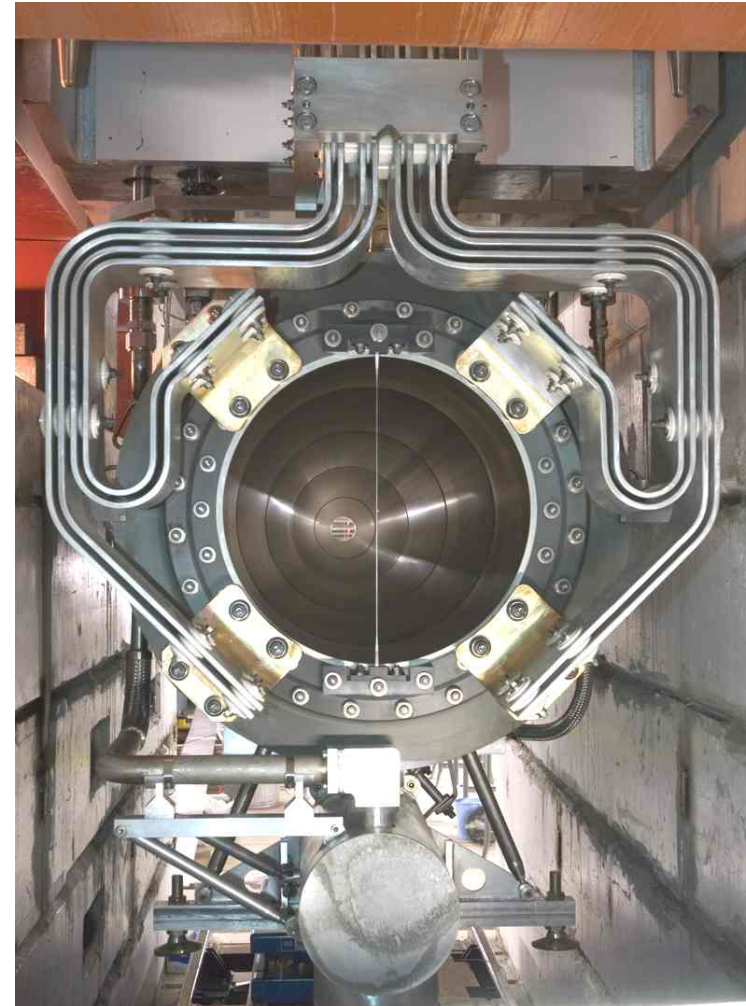




Horn system – 2 horns

(shown in work cell, hanging from support module)

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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





Horns connected in series with power supply by strip-line

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Peak current: 200 kA maximum
Pulse width: 2.3 m-sec half-sine wave
Repetition rate: 1.87 sec



Horn environment

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Horn inner and outer conductors are cooled via internal water spray.

We are running slow Argon gas purge through horns and water system.

Reduce corrosion, prevent buildup of flammable level of hydrogen.

Horn modules and strip-line are cooled with re-circulating air system,
which also cools baffle, target carrier, and shielding.

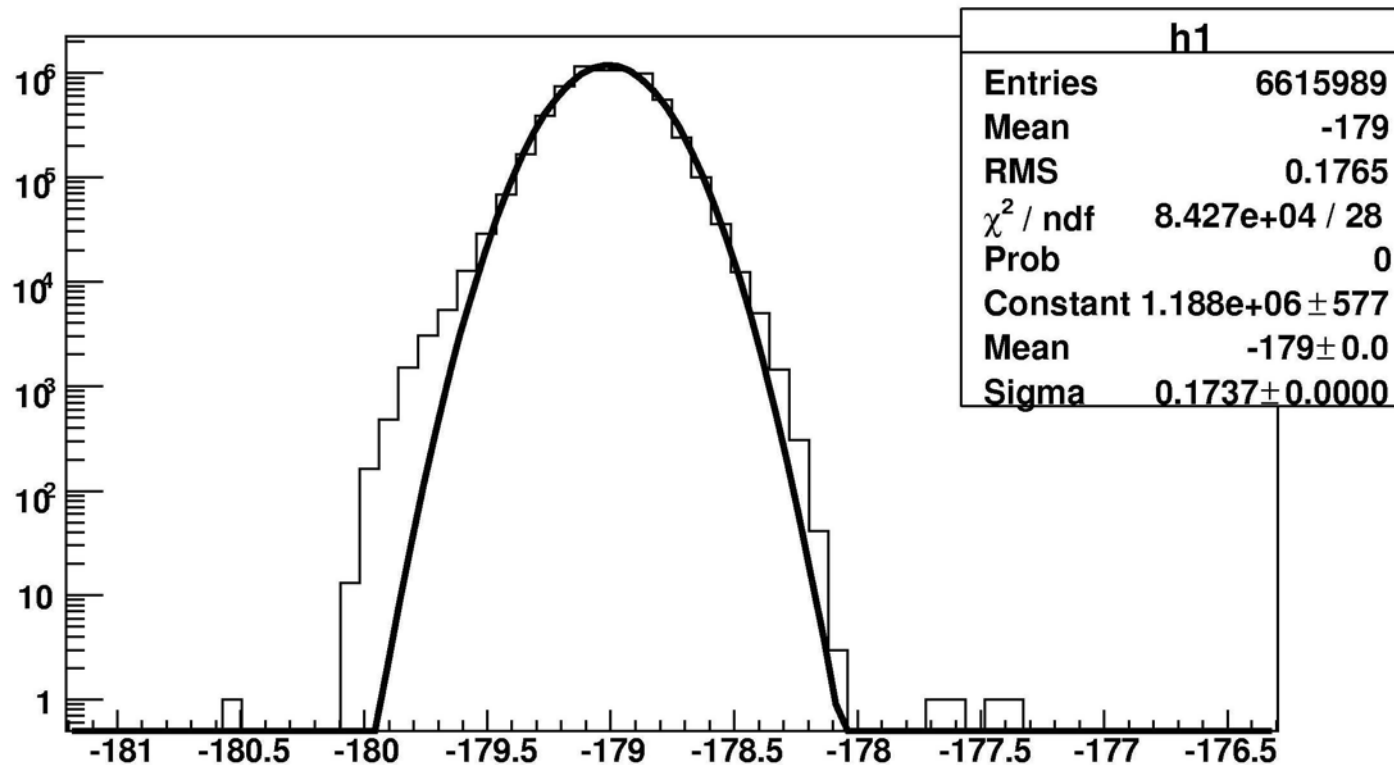
Air system keeps relative humidity down to 50% - 60%

Air exchange (leak) time constant is of order 45 minutes



NuMI Horn current

Horn Peak Current (uncorrected) during LE-10 running May, 2005 - Feb, 2006



Current stability is excellent, pulse-to-pulse RMS < 0.1 % (spec. 0.4%)

Horn field stability also shown by neutrino spectrum stability (see target talk)

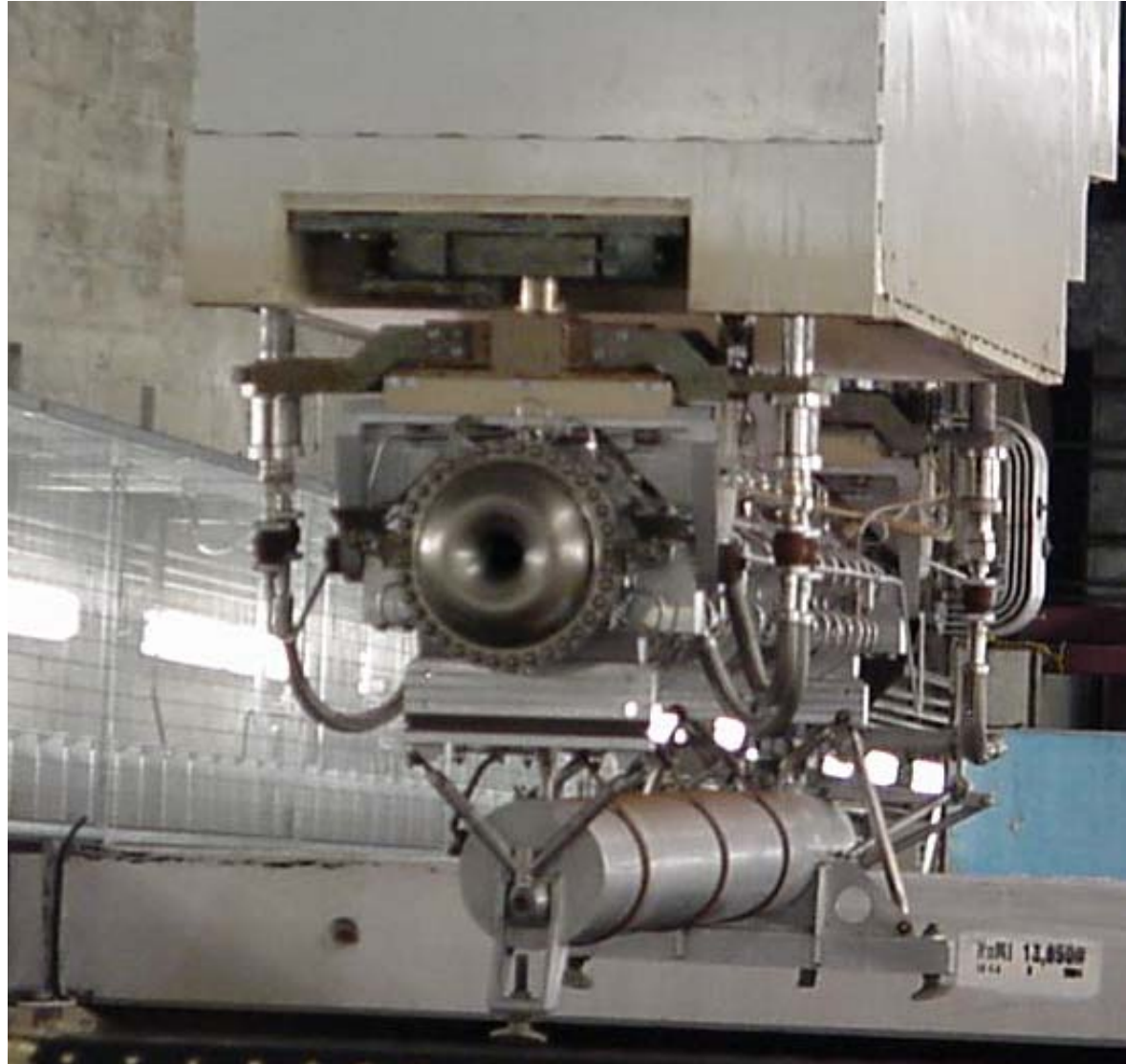


Problems ?

The most useful part of NBI is
to hear what DIDN'T work, so:

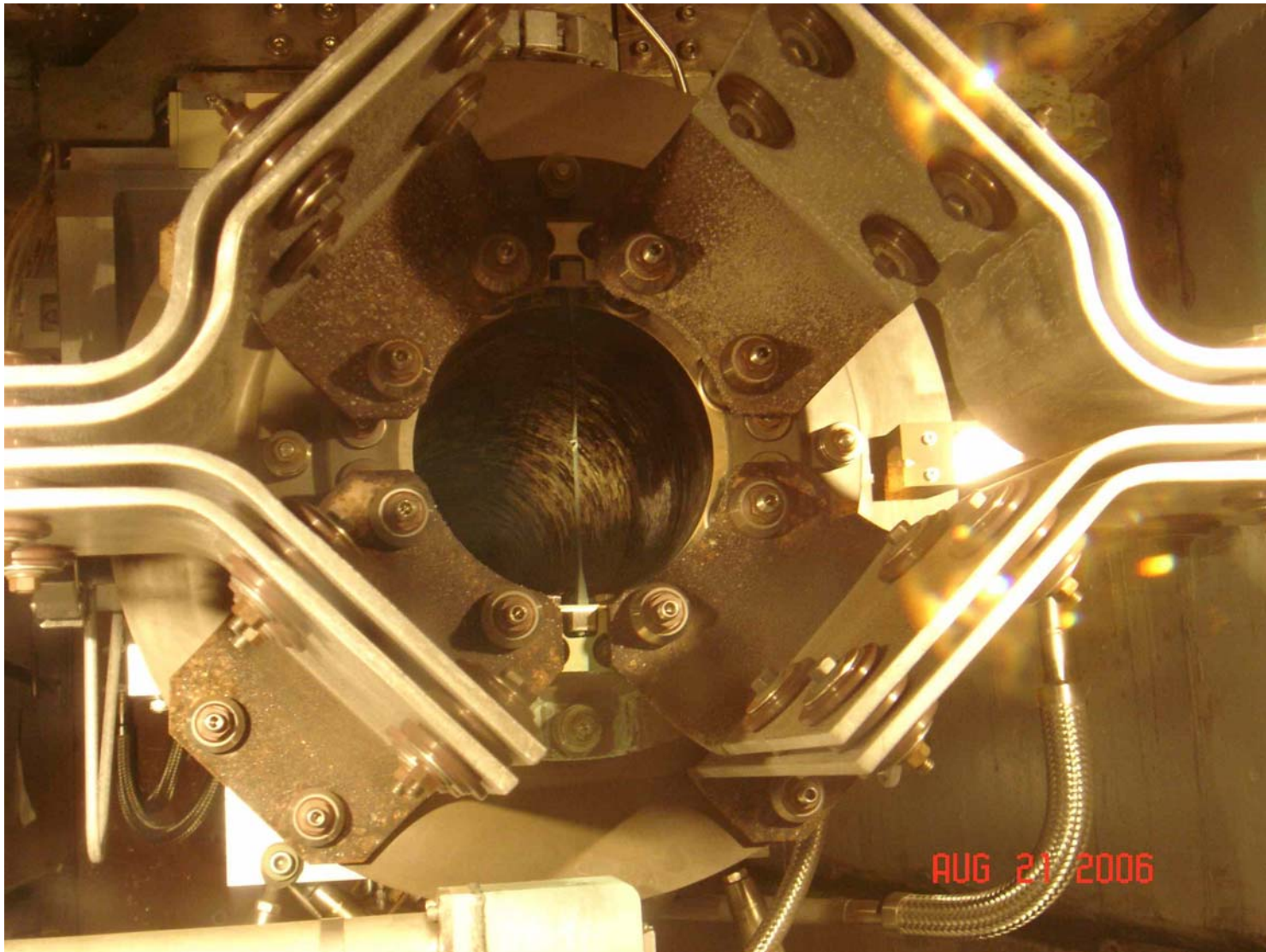


Horn 1, after a year of beam





Horn 1, after a year of beam





Use of ceramics in Horn

Where used	Material	Comment
Ring separating inner, outer conductors	Alumina, knife-edge seal	No indication of problem, no color change
Water spray line insulators	Alumina, braze joint	Two failures, suspect braze but need autopsy
Bdot coil magnetic field monitors	Ytria stabilized zirconia	No indication of problem, Bdots still operating
Inner conductor support spiders	Partially stabilized zirconia	No indication of problem, can't see them
Stripline insulators	Partially stabilized zirconia	No indication of problem, color change ivory > brown
Instrumentation cable insulation	Alumina ceramic fiber	No indication of problem, no color change

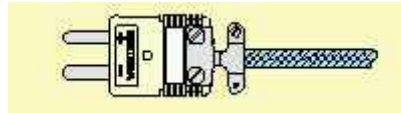


Use of metals

Where used	Material	Comment
Horn outer conductors, target rails	Anodized aluminum	Looks in excellent condition
Water lines, bolts, mechanical parts	Stainless steel	Looks in excellent condition
Fasteners	Titanium	Looks in excellent condition
Main module, T-block shield	Painted steel	Looks in very good condition
Carrier frame, Target casing	Aluminum	Looks OK, some surface degradation
Horn inner conductors	Nickel coated aluminum	End-cap looks good, Parabolic section looks bad
Module support, ceramic shell	Steel, invar	Corrodes
Alignment rails, gear boxes	Black oxide coated steel	Corrodes
Module tops, some shielding	Nickel coated steel	Large nickel flakes

Use of thermocouples

Used type J thermocouples
with ceramic connector for remote connection



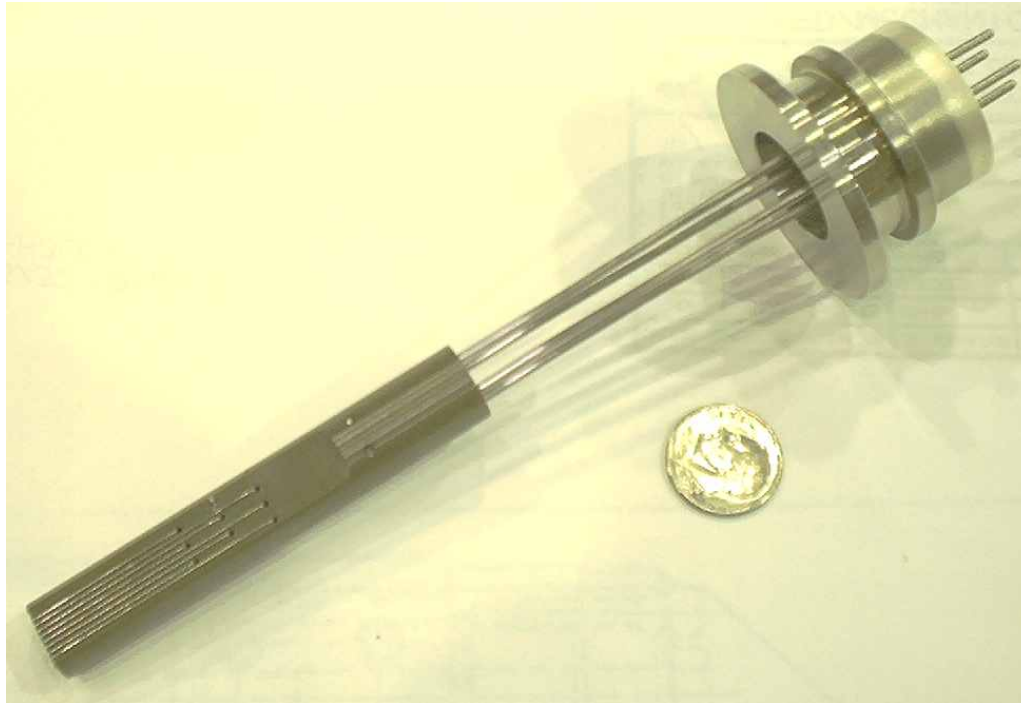
The iron pin on the connector corrodes
– need to look for something else





Bdot field monitoring coils inside horns

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The wet environment in the horns has been problematic for the un-insulated wiring.

After implementation of better coherent noise cancellation circuit,
the three b-dot coils on each horn run well enough to check field stability.
But would totally isolate these from water in future.



Inner Conductor Corrosion

Why is corrosion in general so bad ?

Ionized air produces ozone, nitric acid, ...

Note the water from dehumidifying the re-circulating air has PH of 2.6

Why does end bell of horn look great, and parabolic section horrible ?

Don't know, but...

End cap is in 18 mph wind

Parabolic section is relatively dead spot for air motion

Bad air may be building up in dead spot



Two horn water system leaks

Horn 2 in February 2006, Horn 1 in August 2006

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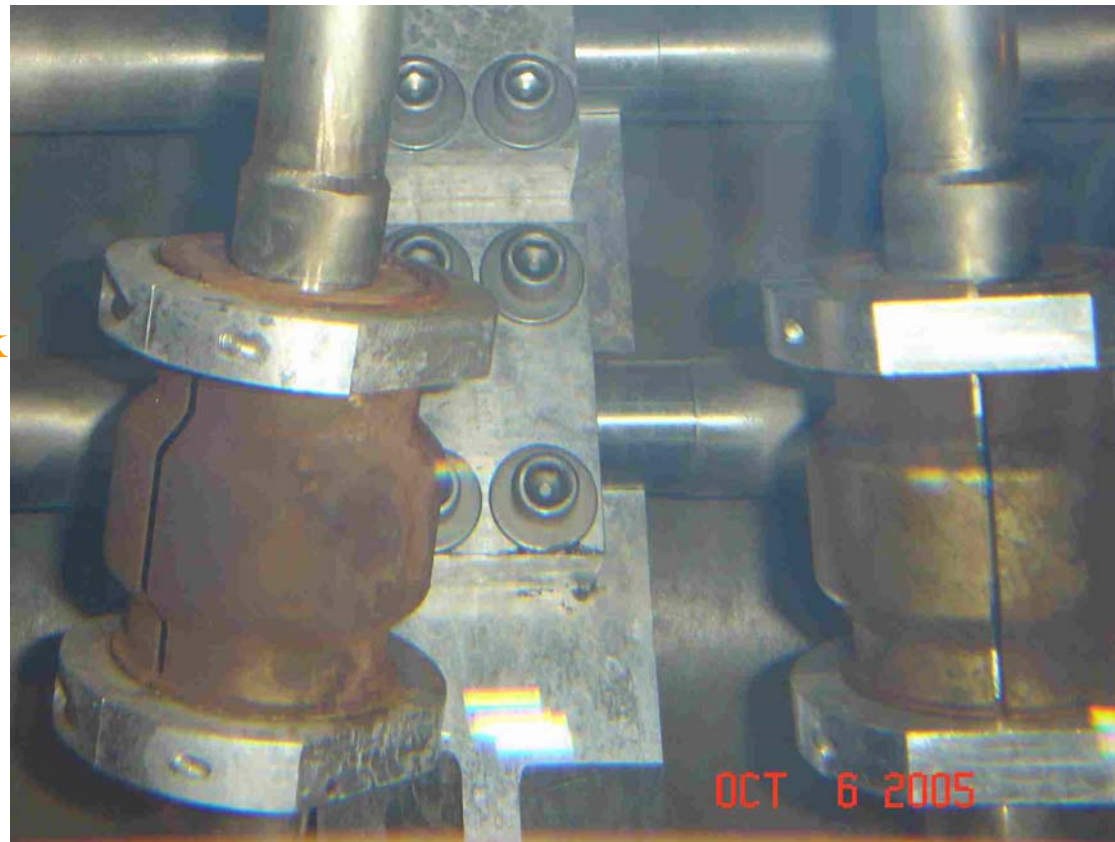
Have brazed ceramic electrical insulators on horn water lines
They are strain-relieved with invar+ceramic clam-shells

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

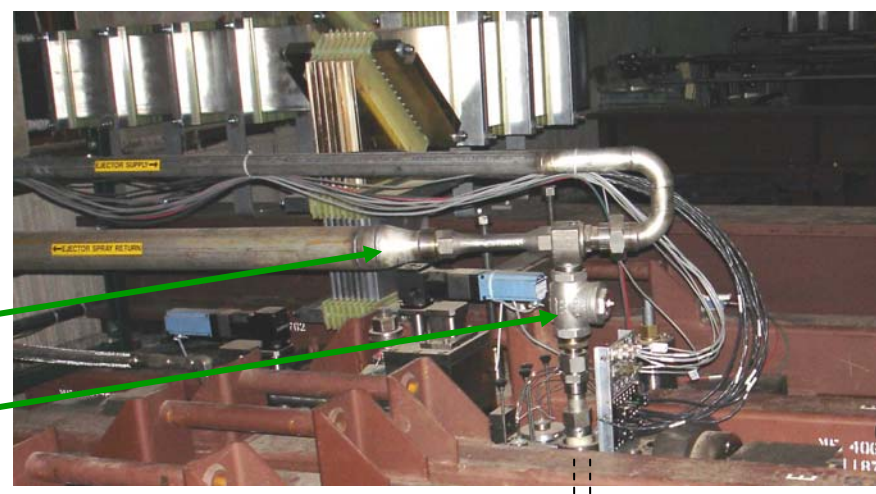
Both ceramic sections were
successfully replaced

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



Ejection pump
to suck up water

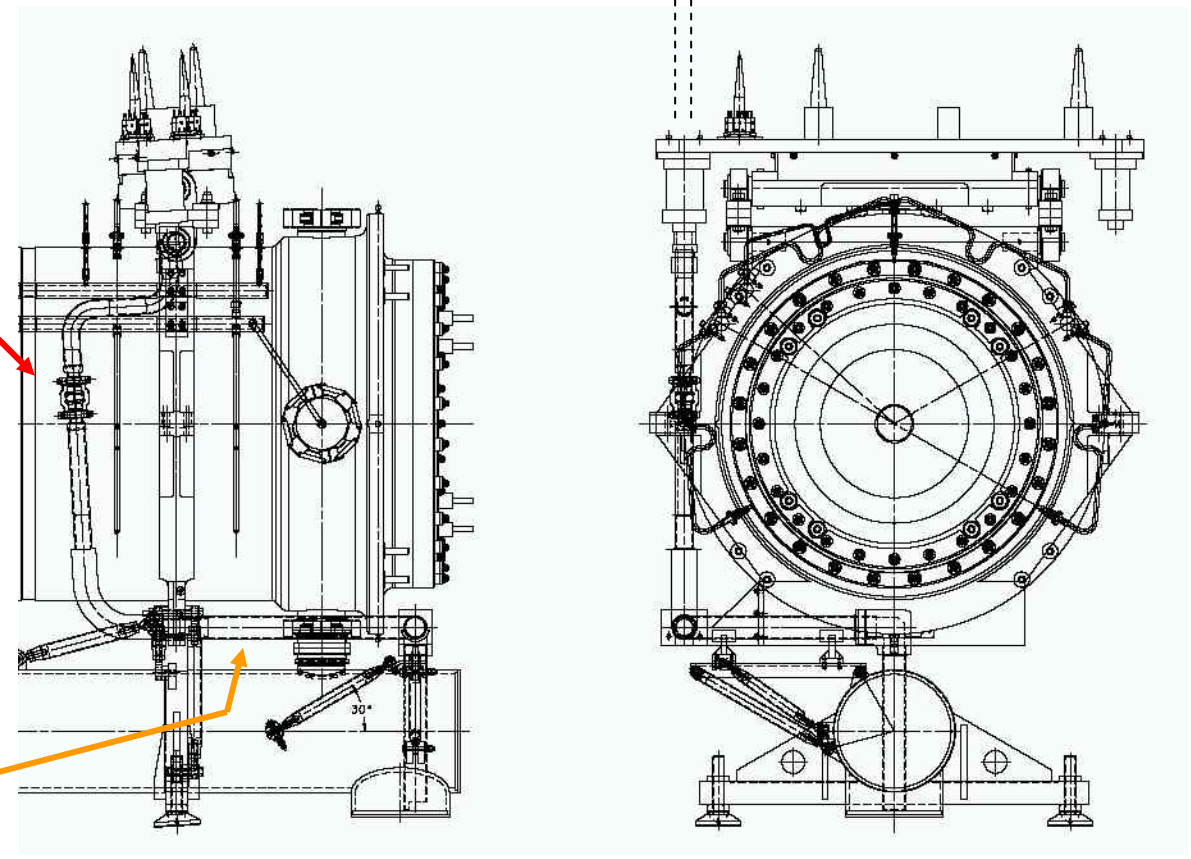
Check valve



Ceramic electrical insulation
*hole here in suction line
drawing in air
reducing water suction*

Water collection tank

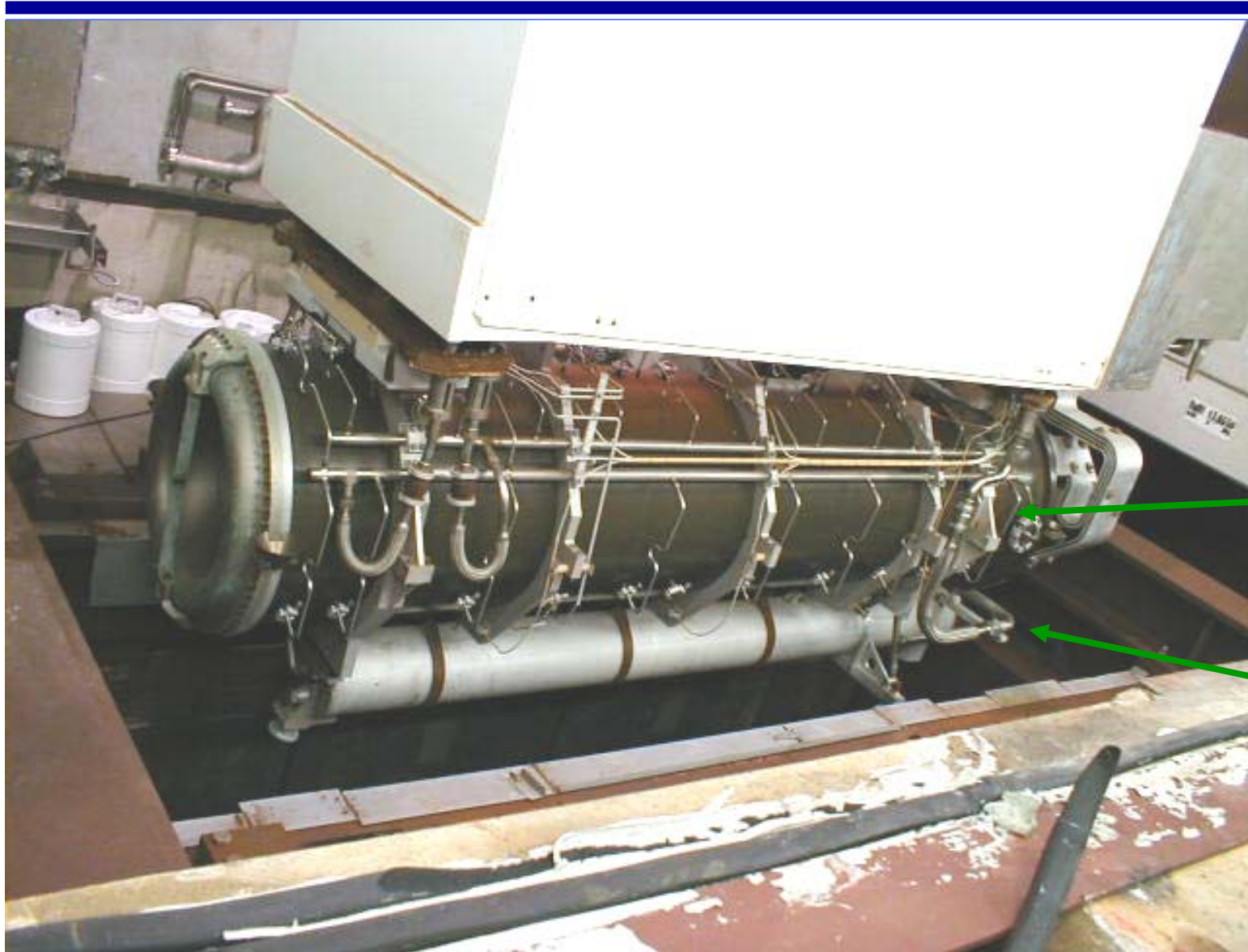
Cut suction line for repair





Horn 2 going back in shielding after suction line replacement

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New
ceramic

Water
suction
line

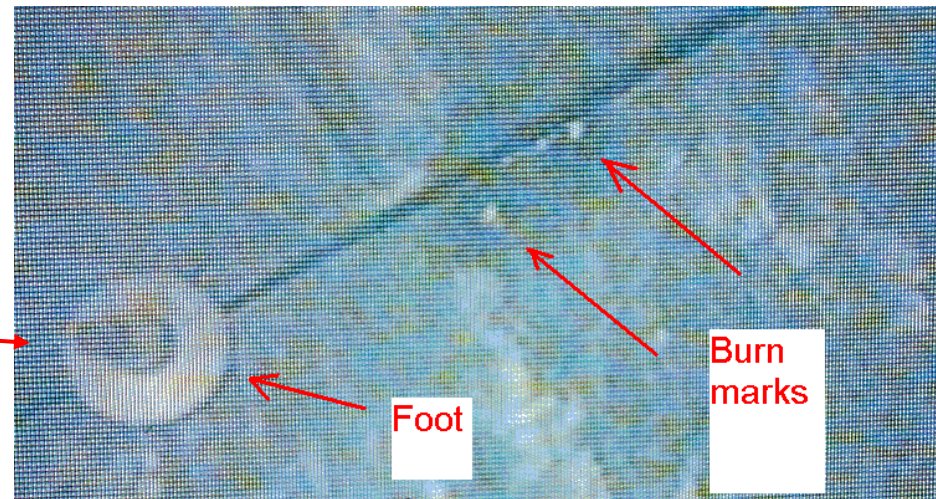
Horn 2 ground fault - - loose foot on horn



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



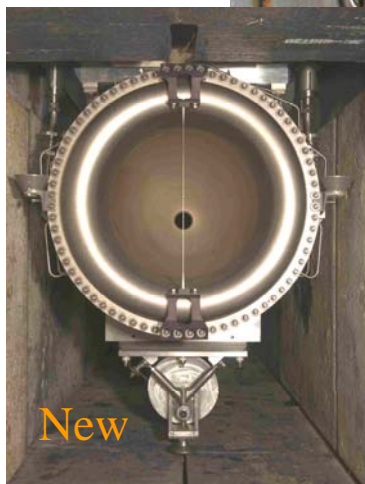
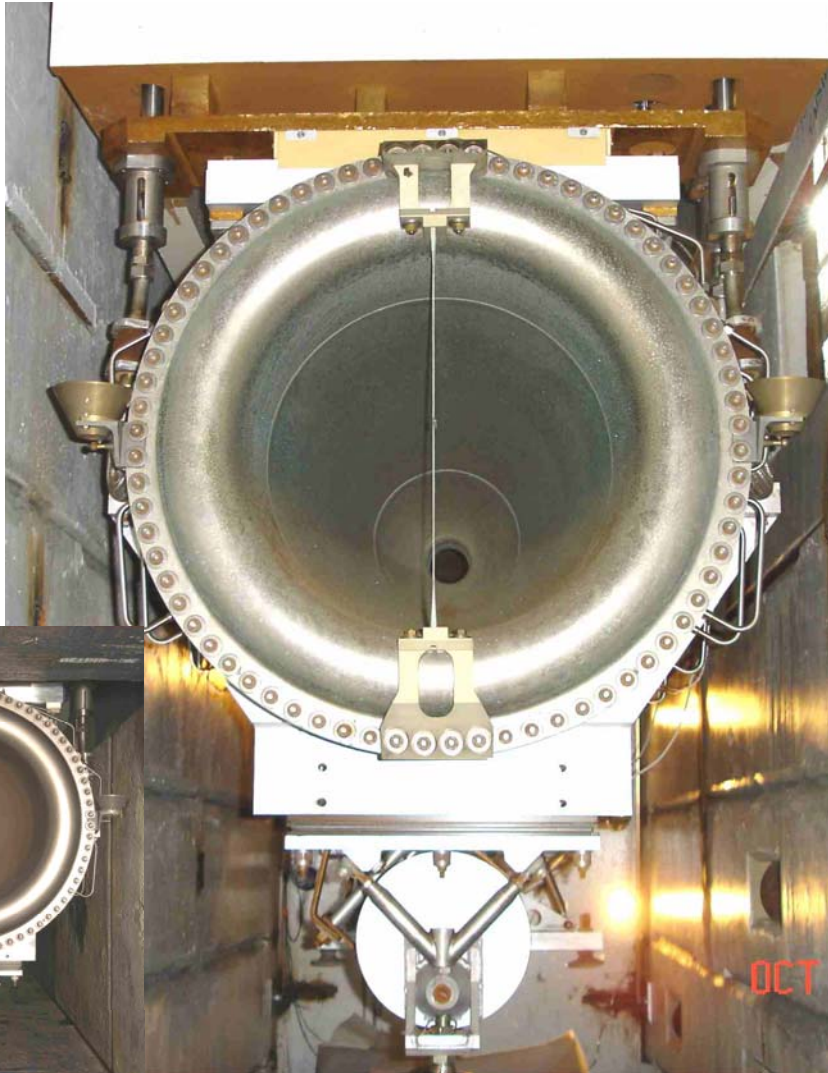


Visual inspection of horn 2

Oct 2005

(note, somewhat more green right now)

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Zirconia Ceramic changed color
- ivory to coffee

Alumina Ceramic unchanged

Nickel-coated aluminum inner
conductor shows slight discoloration
- bottom covered by rust dust

Al cross-hair - lots of surface corrosion

Anodized Al outer conductor is good

Stainless parts look OK

Other horn 2 feet corroded in place

No obvious problem spots

Strip-line block flake problem



Strip-line shielding block
is steel with nickel coating

Nickel is flaking off,
sometimes shorts stripline
but has always burned off
after 1 to a dozen pulses

We have rebuilt spare
strip-line block with
non-flaking technology
but haven't needed to
use it yet

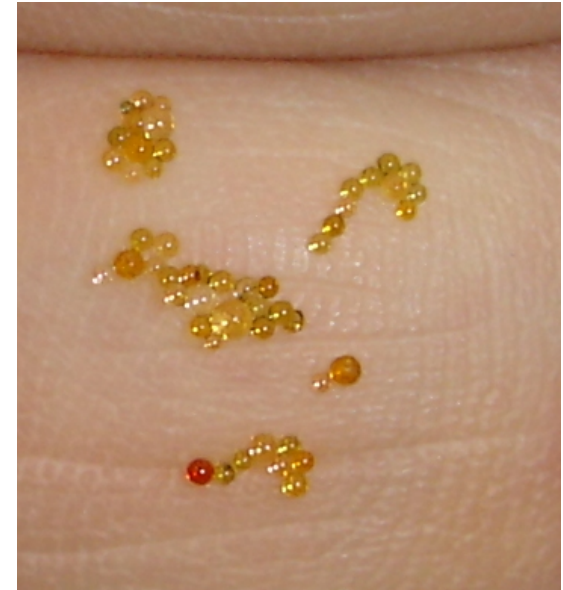


June 30, 2006, resin beads from deionization bottle clogged the water spray lines on Horn 1

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← Horn spray flowmeter with beads

New, uncontaminated beads →
Beads are ~ 20 mils diameter



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

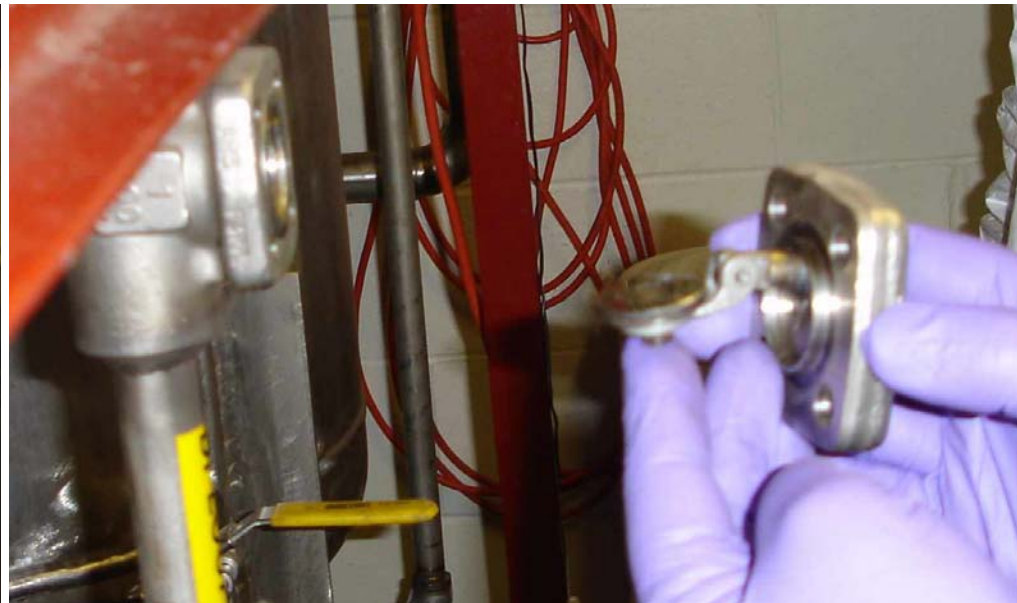
outer conductor nozzles round, 25 mils diameter (19 total)

plus two side-spray nozzles

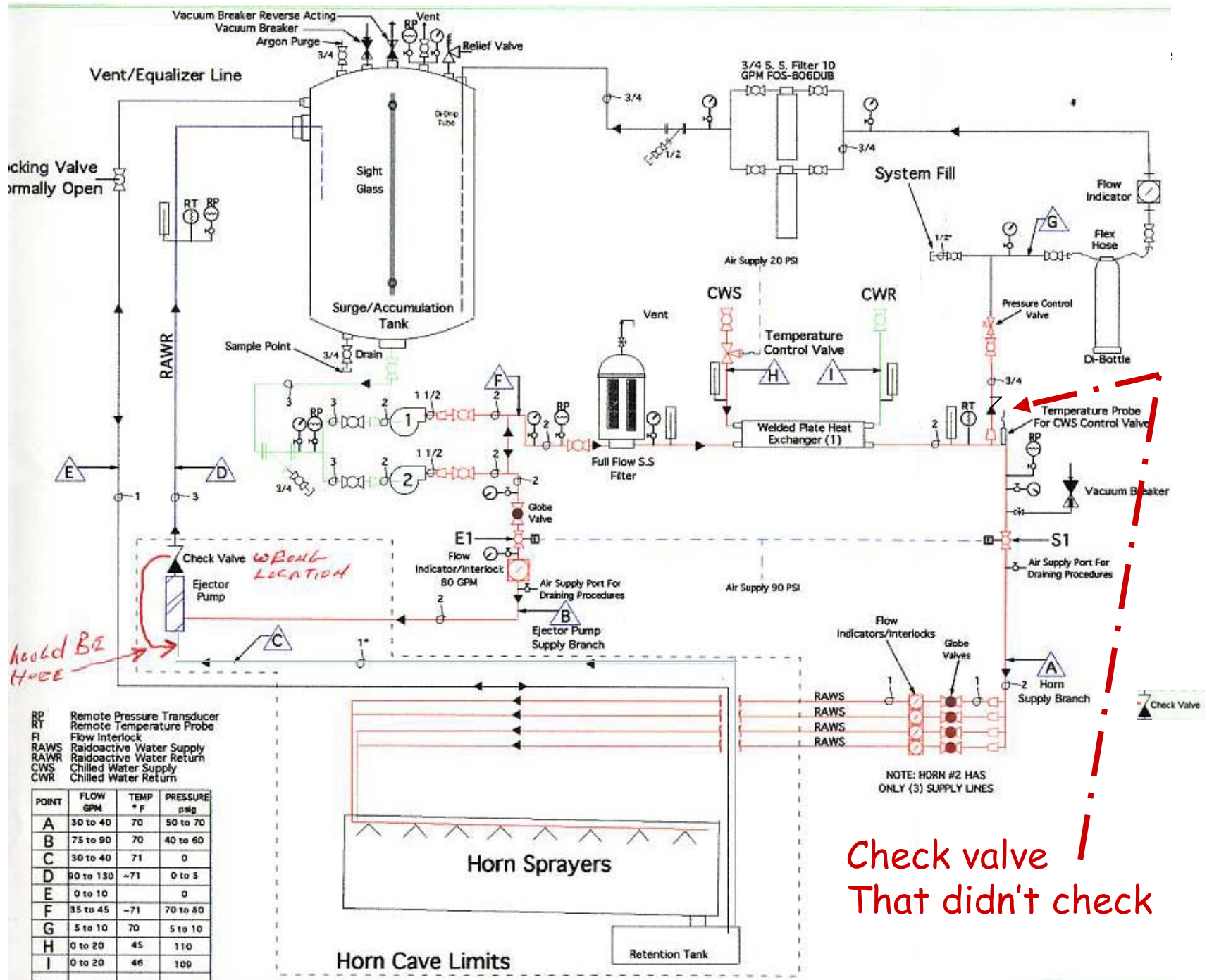


When water skid was turned off for maintenance,
beads floated backwards
through improperly mounted check valve

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The gravity un-assisted check valve



Cleaning
Out
Resin Beads

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

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Of course, many things worked

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Beam to horn timing was within spec. on first pulse, and totally stable over run.

Horn 1, Horn 2, and Target were aligned by survey on straight line, confirmed by beam scans using the horn “cross-hairs” beam alignment monitor. (The “cross-hairs” proved to be important).

Horn 1 motor drives worked as planned.

Remote water connections worked as planned.

Remote strip-line connection worked as planned.

The shielding and remote handling systems worked as planned.

This was a real 3D jig-saw puzzle.

The re-circulating air system balanced; measurements show reasonable flow through each of horn strip-line penetrations, around module walls, by target, around shielding pile outside walls, etc.

Measured vibration of horns hanging on modules was small.

Residual radiation was about as expected – important for repairs.



Conclusion

NuMI horn system has made it through 1st year of operation,
although some repairs have been necessary.

As described in the target talk,
the horn system produced the desired neutrino spectrum,
and the neutrino spectrum was also very stable over time !!!

We are learning on the job how to improve the hardware
- and look forward to lots more running !