JPARC visit – T2K target hall

Tour of 50 GeV accelerator, hadron hall, T2K target hall/absorber/near detector

Had only short time with target hall experts, who are extremely busy getting ready to turn beam on to T2K target next month, but graciously took time out to show us the facility.

The timing of the trip was set by trying to get there before things became irradiated; knowing what things work well will come with a few years operating experience.

Note T2K permanent facilities (dump, shielding) designed for up to 4 MW, but replaceable items (collimator, window, target, horns) designed for 0.75 MW.

Will show
- Overview slides of beam-line "borrowed" from publicly available T2K talks
  Takashi Kobayashi, Chris Densham, Atsuko Ichikawa
- A few pictures we took
- Some comparisons to NuMI
- Some comments about what is transferable to DUSEL beam

(Accuracy warning: there is a reason hear-say is not admissible in court)

Some issues for LBNE (DUSEL beam)

? surface pit versus mining for target hall

- Containment of gas radio-isotopes
- Very large hook-height
- Shield blocks versus overhead dirt/rock
- Cheaper to have very large support rooms on surface ?

? inert gas in sealed target pile

Advantages:

- Reduces corrosion (e.g. NuMI nickel flakes)
- Reduces and contains short-lived radio-isotopes in gas
- Rome reduction in tritium (significant or not?)

Dis-advantages:

- No way to fix helium leak if there is a failure (?)
- Significantly raises the bar for interventions in target pile
- Need walls to withstand vacuum (?)
- Helium is not as good at standing off high voltage for horns

Some issues for LBNE (DUSEL beam)

? failure of crane during hot pick

- Pull component directly into coffin ?
- Side load so don't use crane, but rollers ?
- Put lots of redundancy on crane ?

? how to handle tritium

? inert gas around dump

? Monitoring beam

JPARC visit – T2K target hall

JPARC	DUSEL
short facility, 110 m target to dump	200 to 300 m DK

This and next bunch is borrowed slides

A T2K Roadmap – as of end of last year

	Day1 (up to Jul.2010)	Next Step	KEK Roadmap	Ultimate? [Not official any more]
Power(MW)	0.1	0.45	1.66	[3-4 MW]? [Original objective]
Energy(GeV)	30	30	30	[50]
Rep Cycle(sec)	3.5	3-2	1.92	
No. of Bunch	6	8	8	[8]
Particle/Bunch	1.2×10^{13}	$<4.1\times10^{13}$	8.3×10^{13}	
Particle/Ring	7.2×10^{13}	$<3.3\times10^{14}$	6.7×10^{14}	
LINAC(MeV)	181	181	400	
RCS	h=2	h=2 or 1	h=1	

After 2010, plan depends on financial situation

Target station

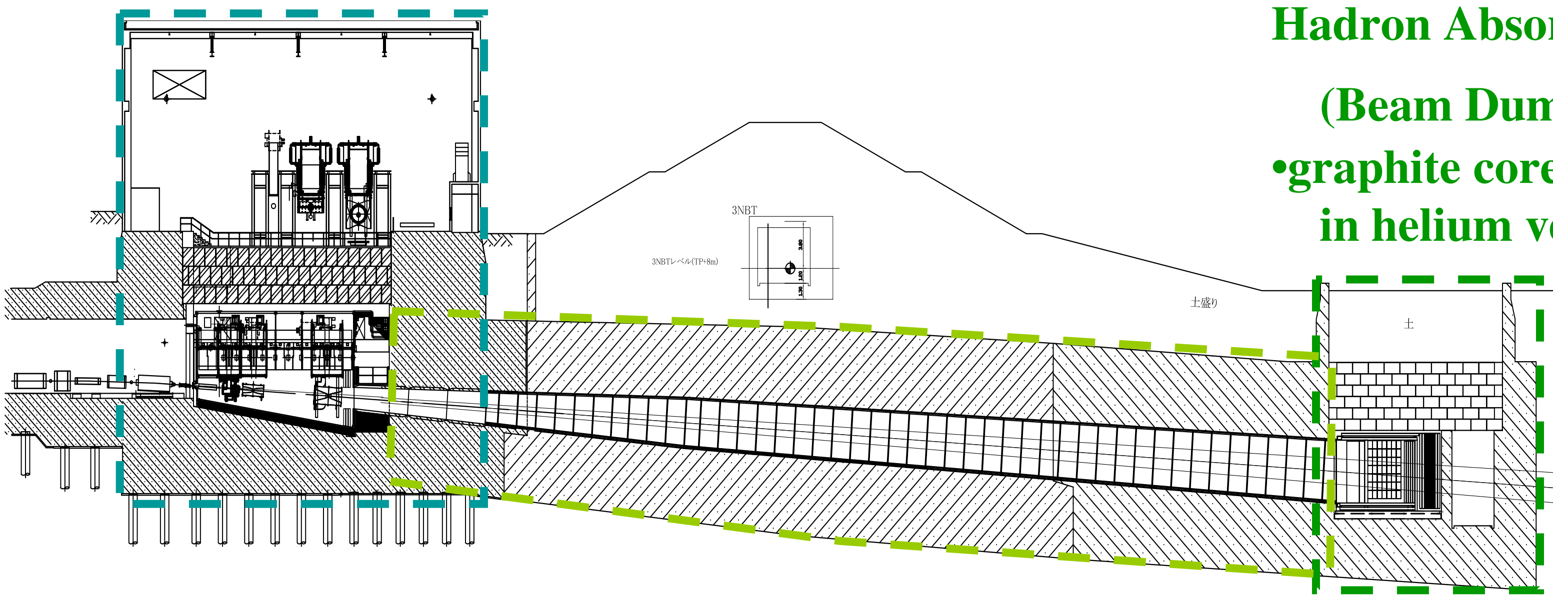
- **Target & horns in helium vessel**
- **Helium vessel and iron shields cooled by water**

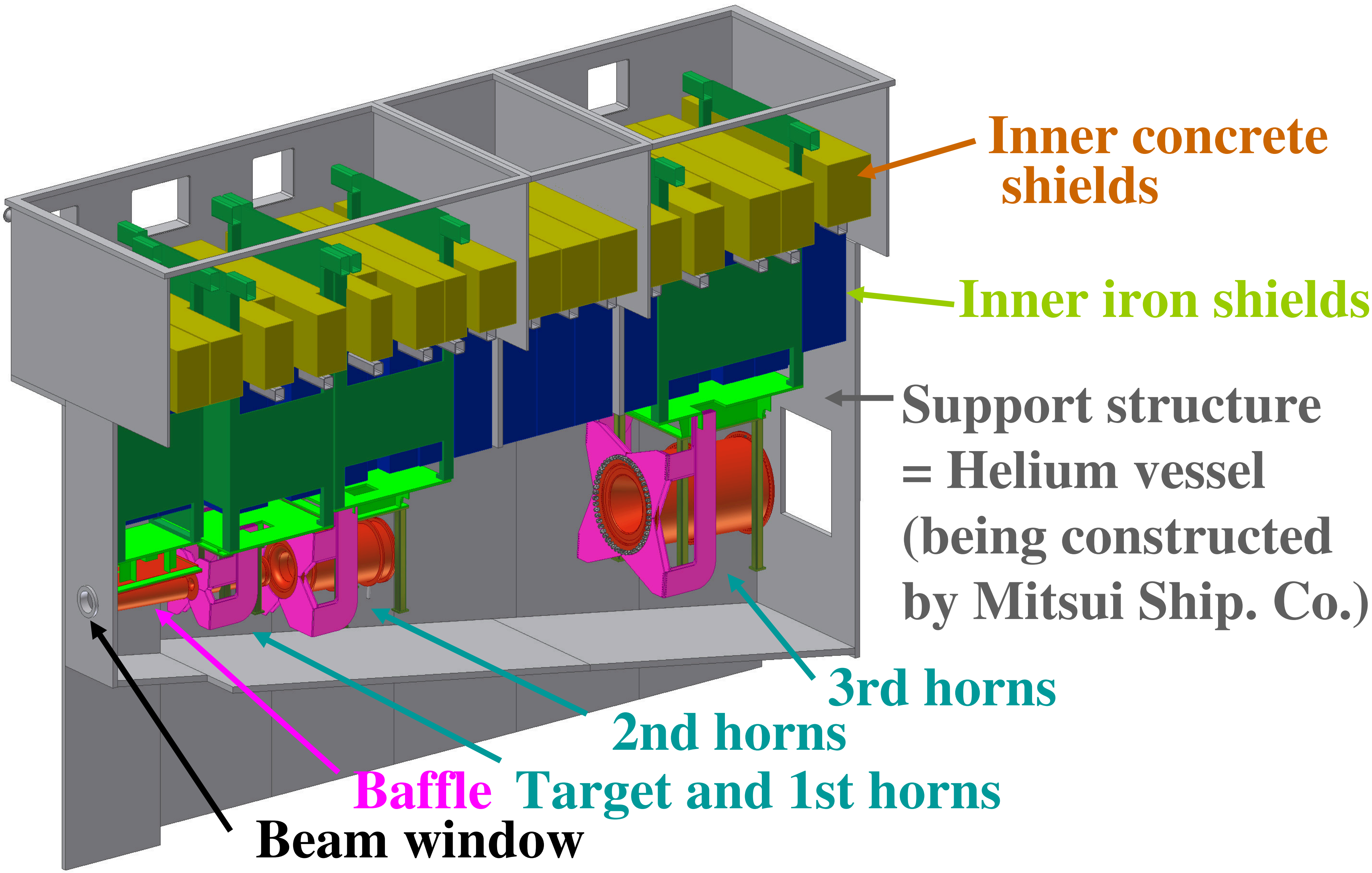
Decay Volume

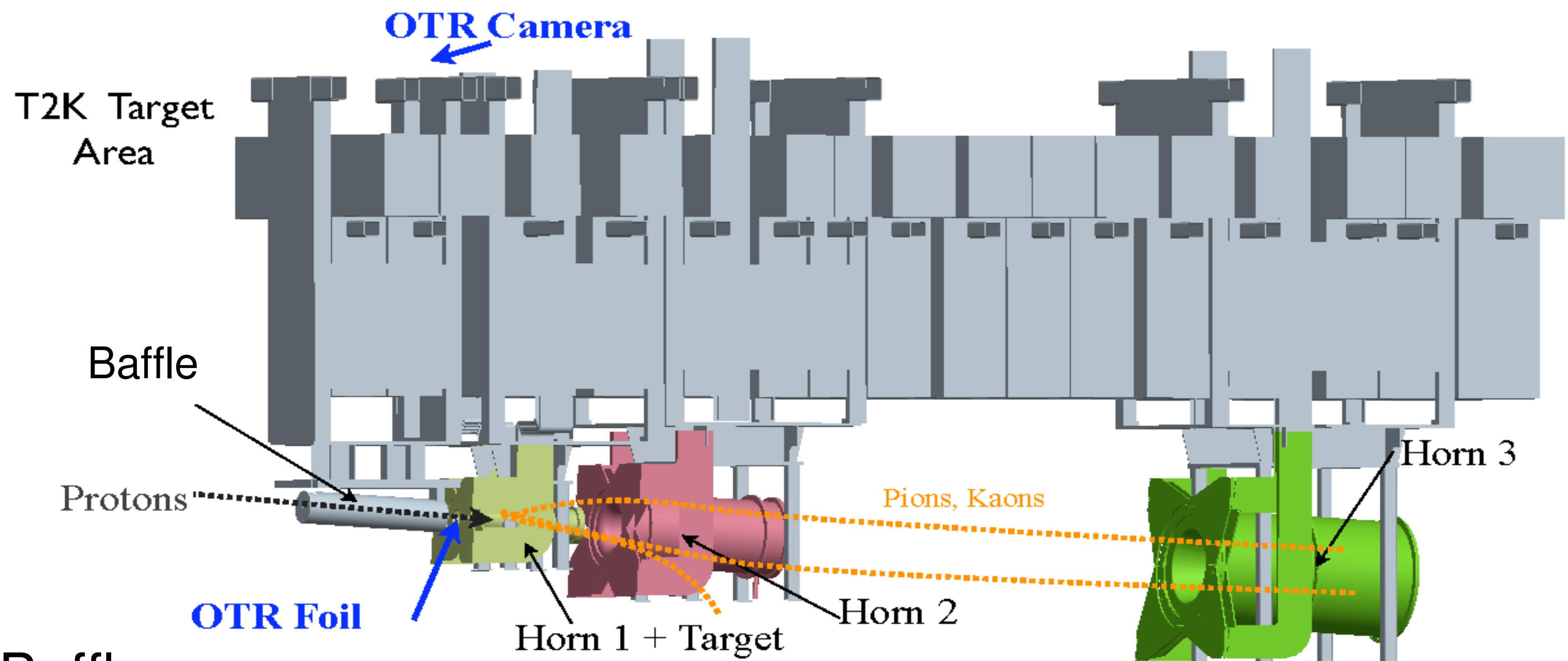
- **94m long helium vessel cooled by water**
- **6m thick concrete shield**

Hadron Absorber (Beam Dump)

- **graphite core in helium vessel**

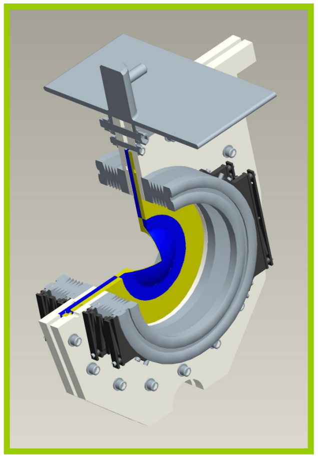


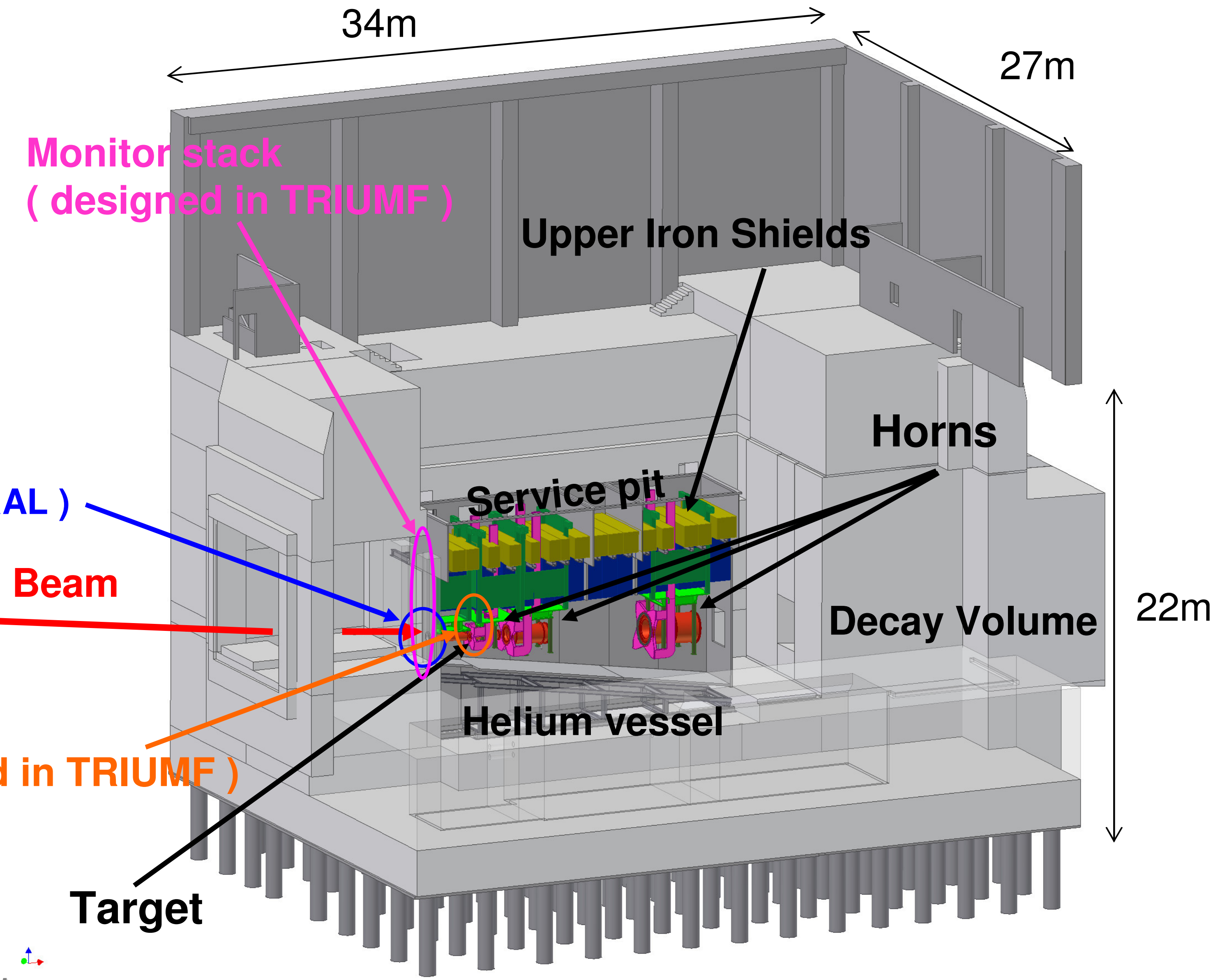

Inner concrete shields
Inner iron shields
Support structure = Helium vessel (being constructed by Mitsui Ship. Co.)
3rd horns
2nd horns
Baffle
Target and 1st horns
Beam window

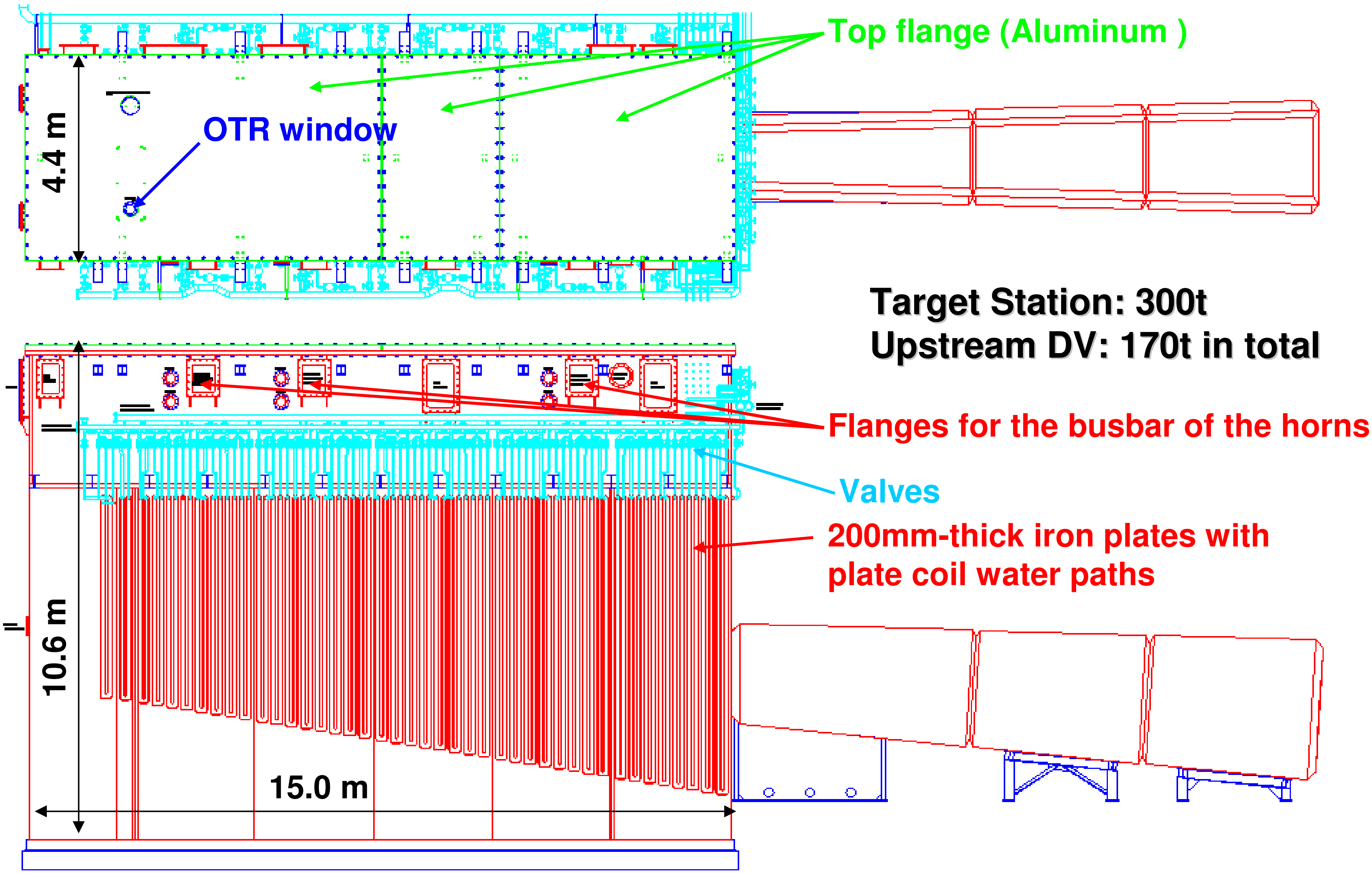


- Baffle
- 3 horns …. Hanged by support module.
- Target … installed in the 1st horn.
- OTR (Optical Transition Radiation monitor): attached to 1st horn

Target Station

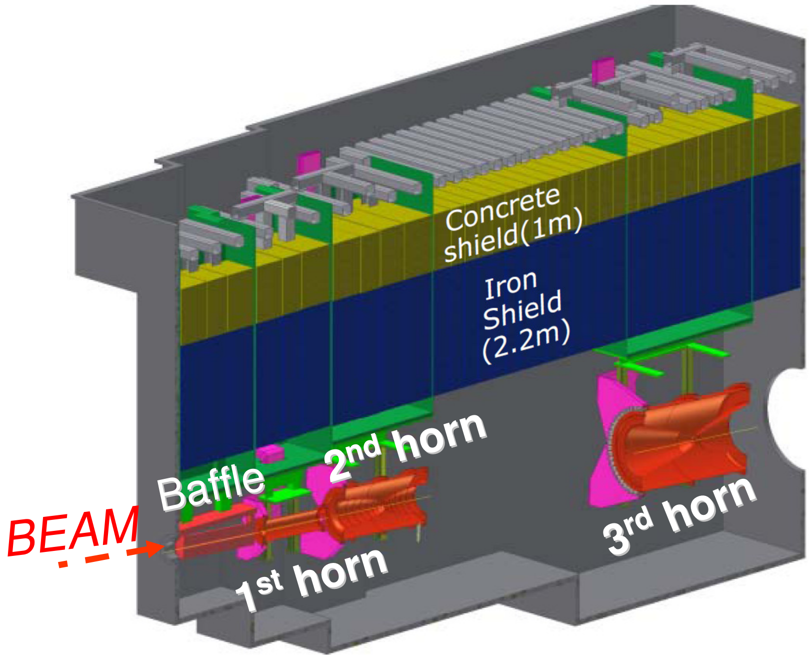


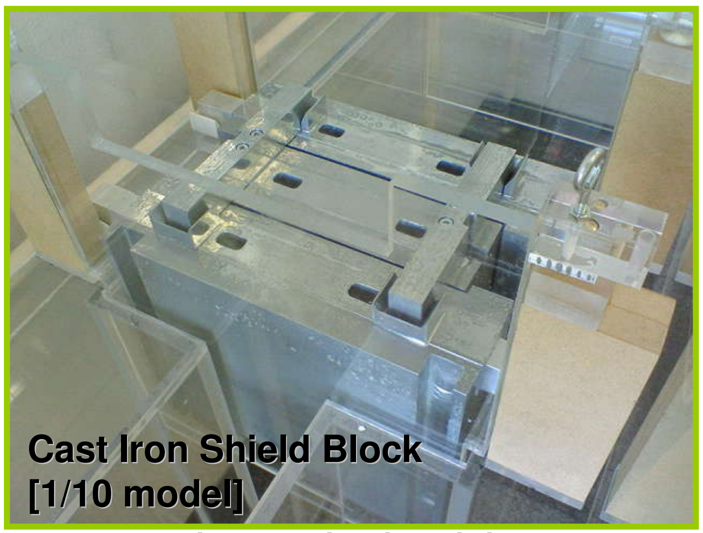


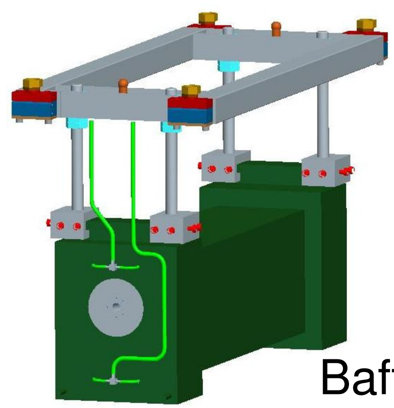


Target Station: 300t
Upstream DV: 170t in total

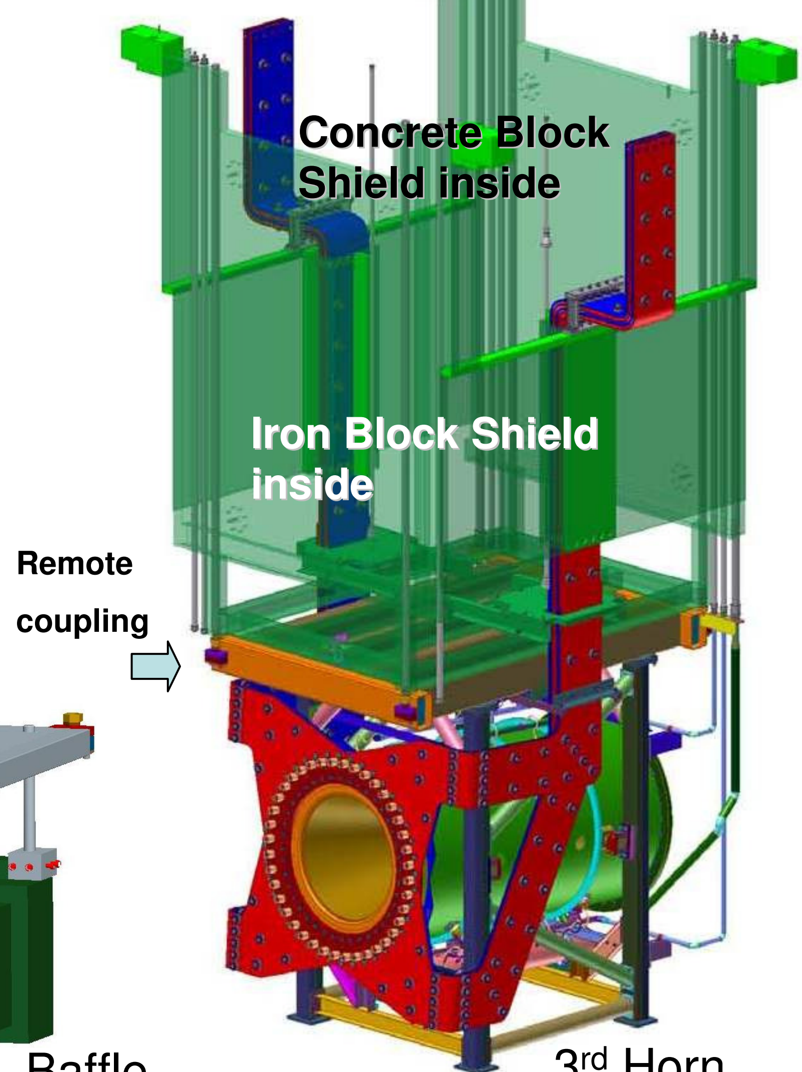
Horn & support module



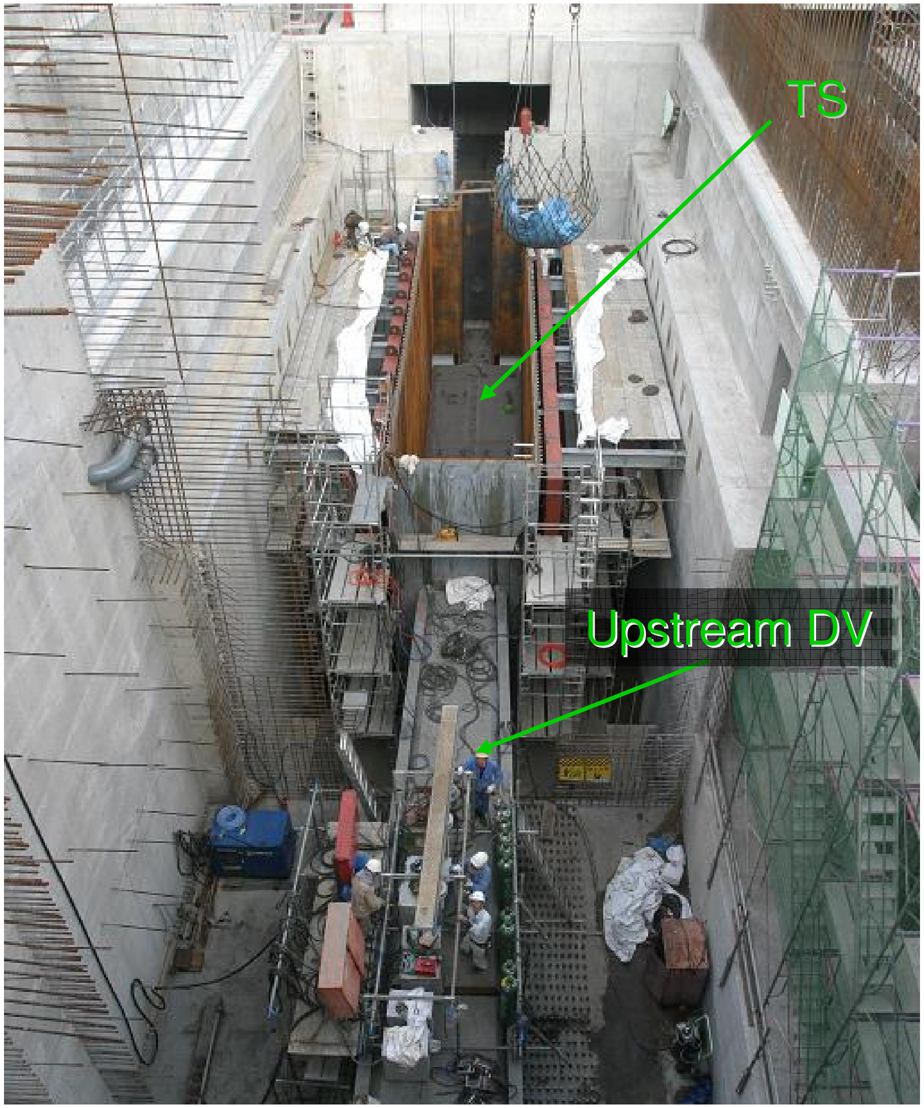


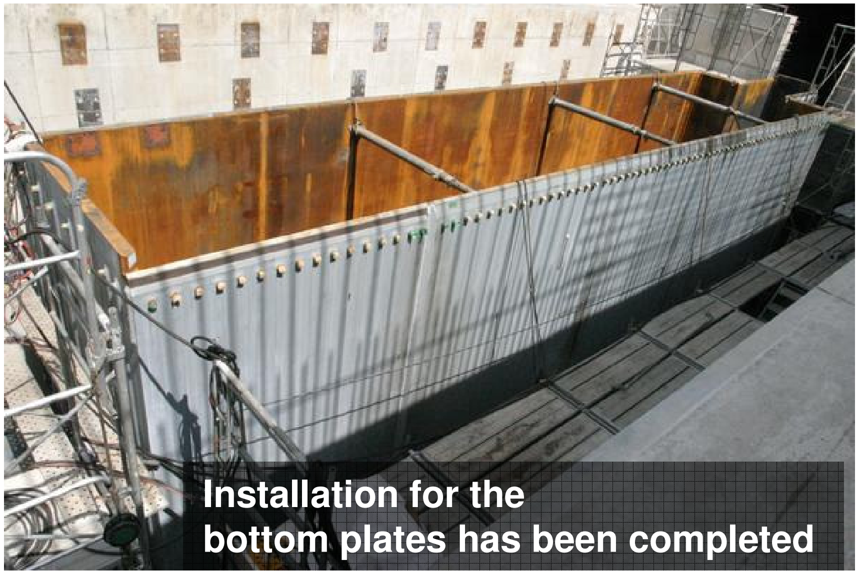


Horn Support Module

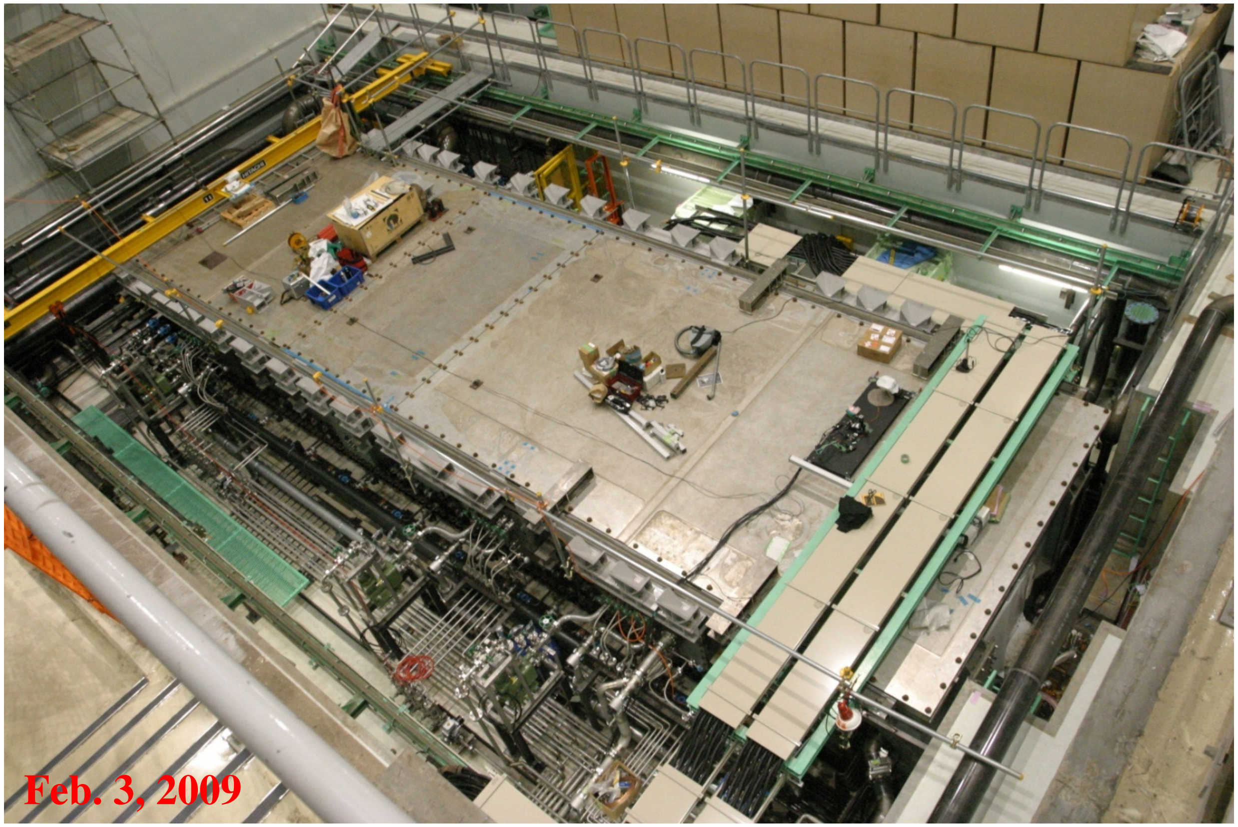


Helium Vessel Construction



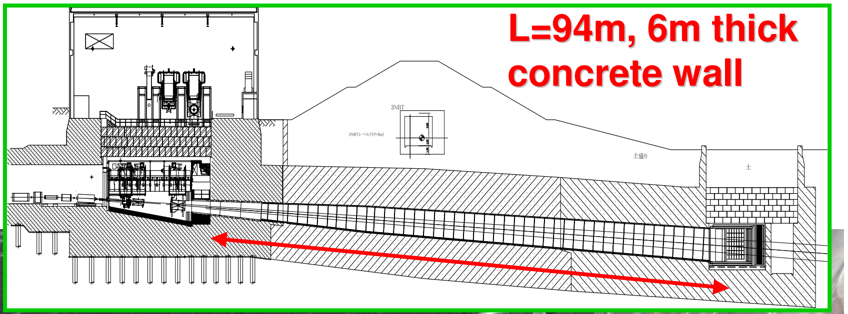


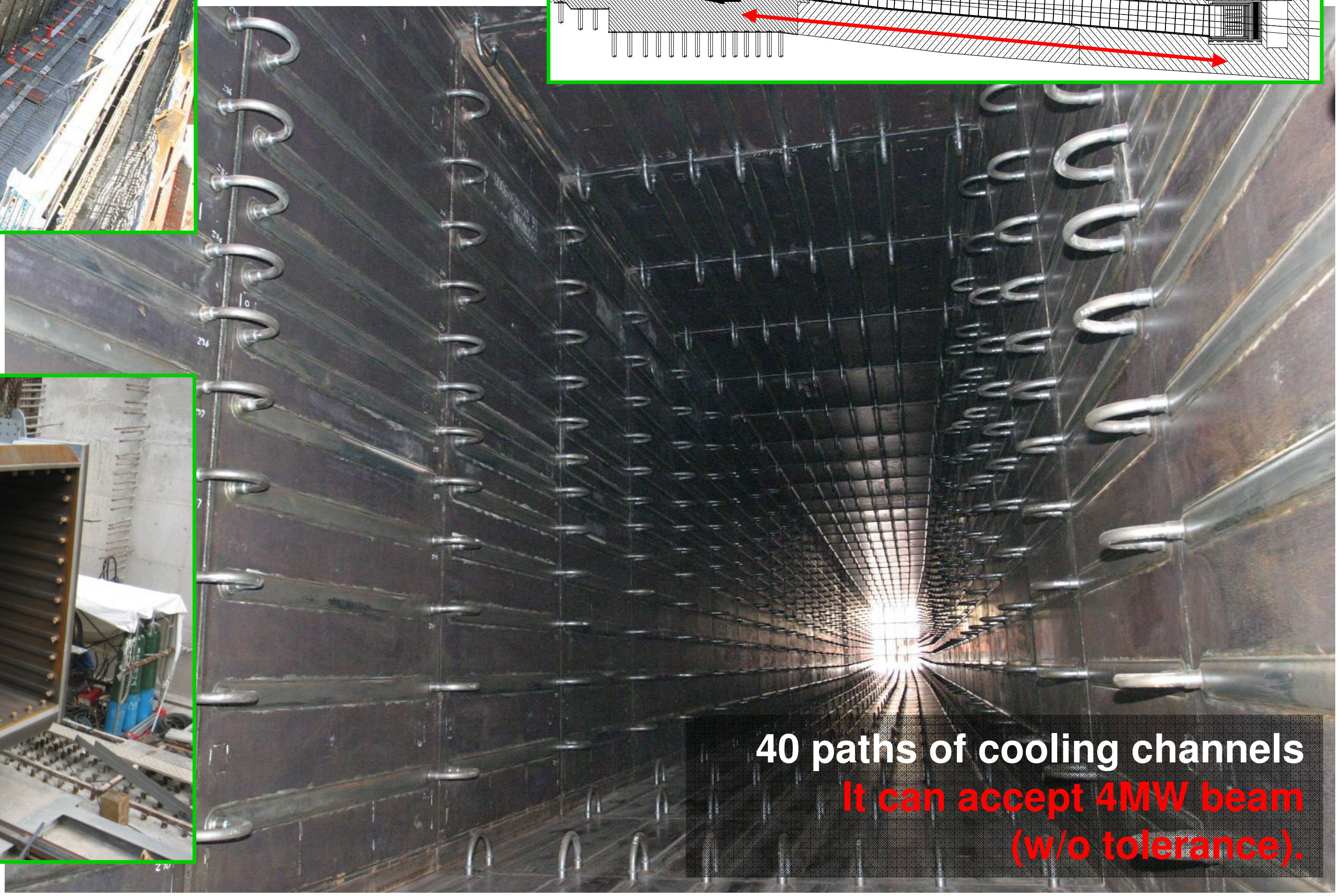
- **Installation is going on !**



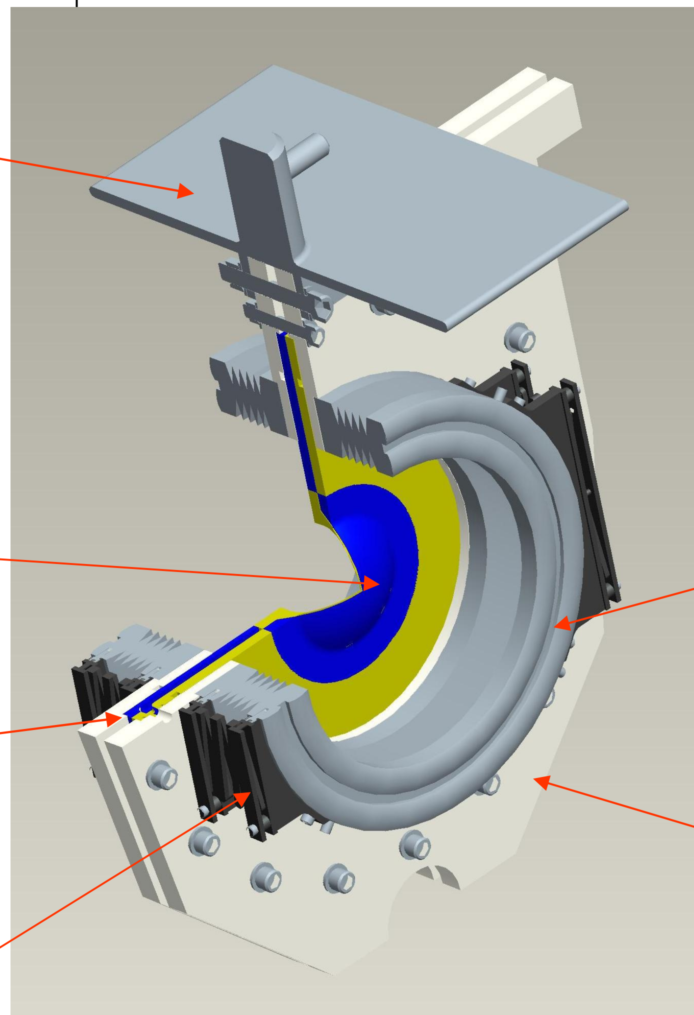
- **Vacuum test of He vessel finished on Feb. 18th.**
  - All TS+DV+BD connected to one BIG vessel (~3mx~5mx~100m=~1500m^3)
  - Evacuated down to 50 Pa by three pumps
  - **No leak found** after two repairs at the connection between DV-BD
- Ceiling concrete blocks will be installed from Mar. 9th to 16th.

Decay Volume

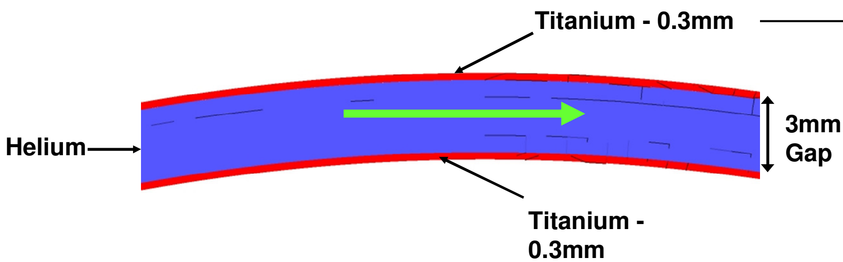




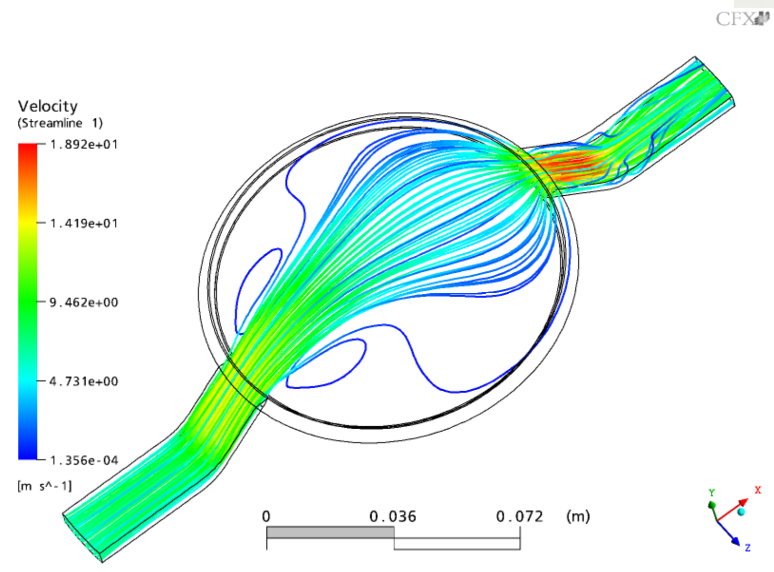
Beam Window


Top plate
Ti-6Al-4V Double
Beam window
Helium inlet
Pantograph mechanism
Pillow seal (mates
with mirror finished
flange on either side)
Support casing

Helium cooling of beam window



The finished window skins
(by RAL workshop):



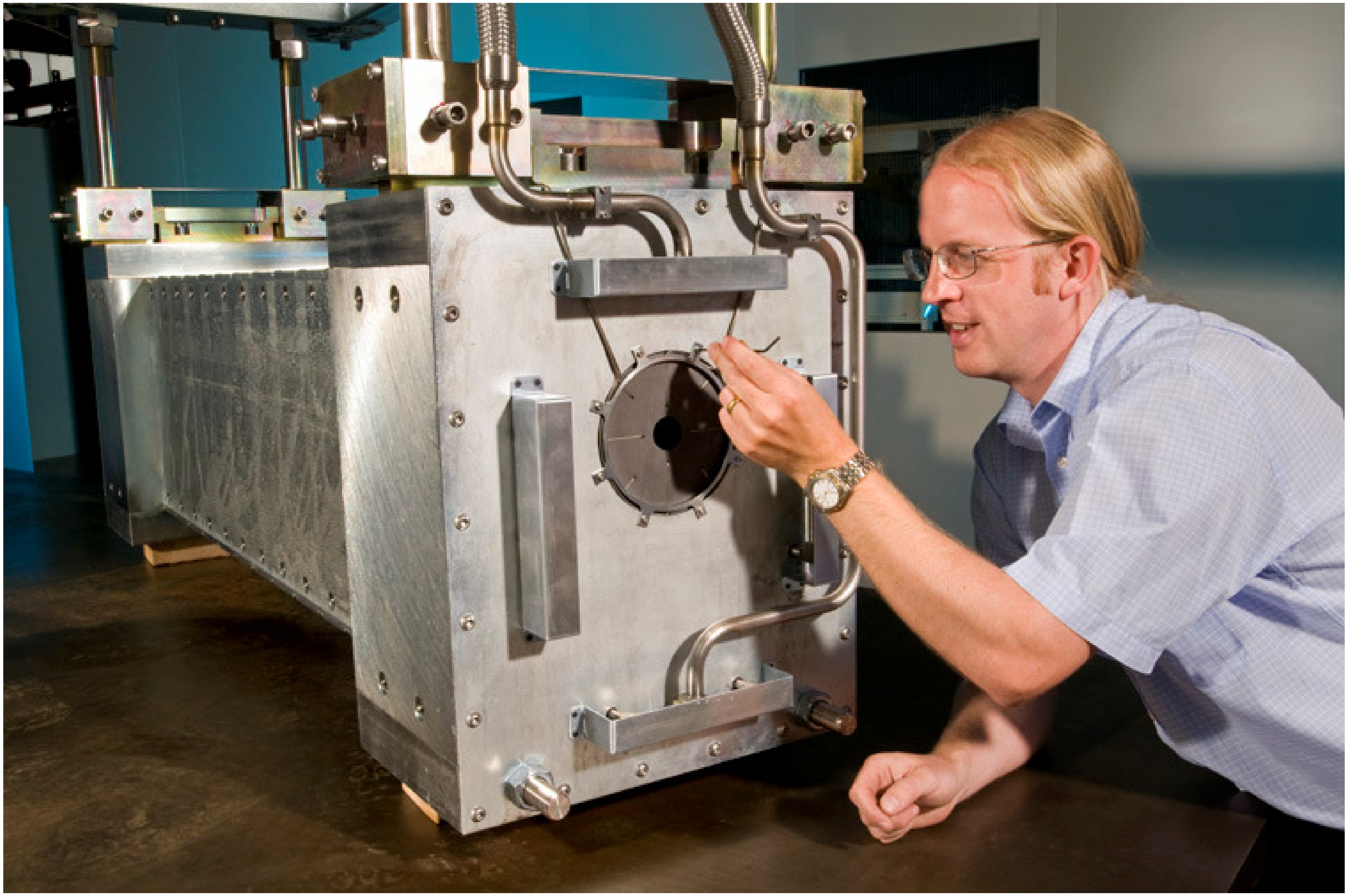
Helium velocity ≈ 5 m/s

Monitor stack and Window

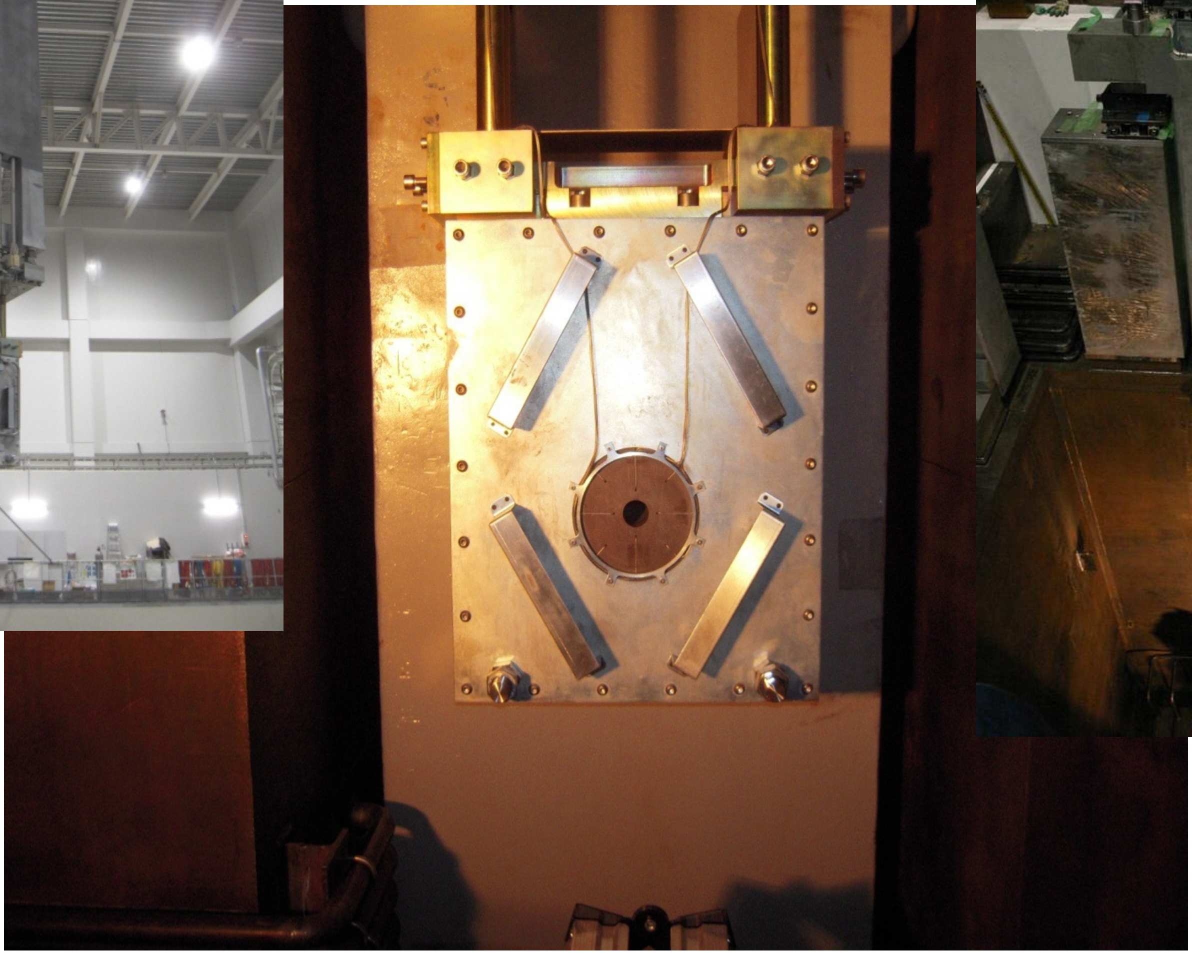
Monitor stack (TRIUMF) installed on Oct. 22nd.

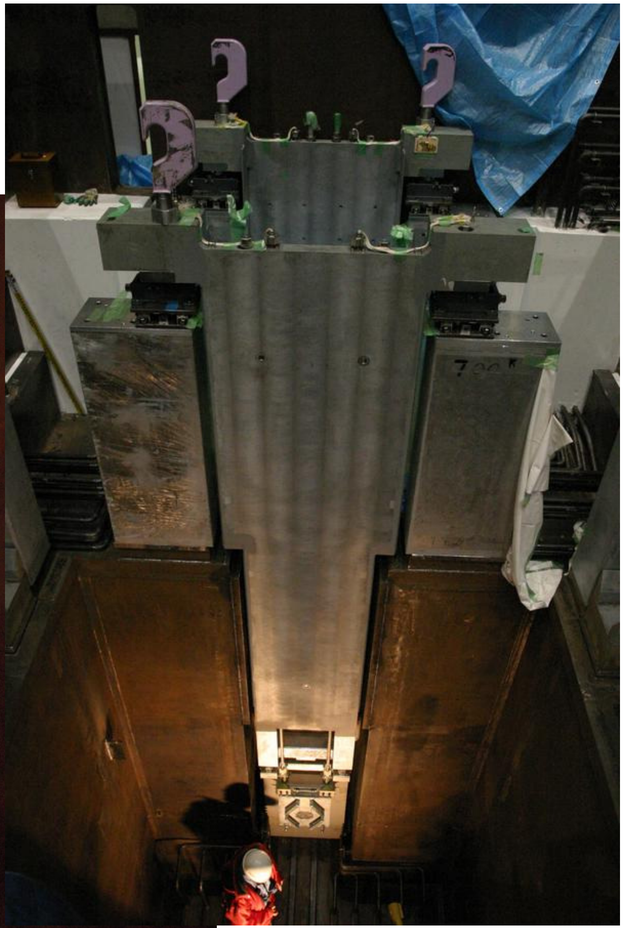
The beam window from RAL was installed on Oct. 23rd.

Collimator

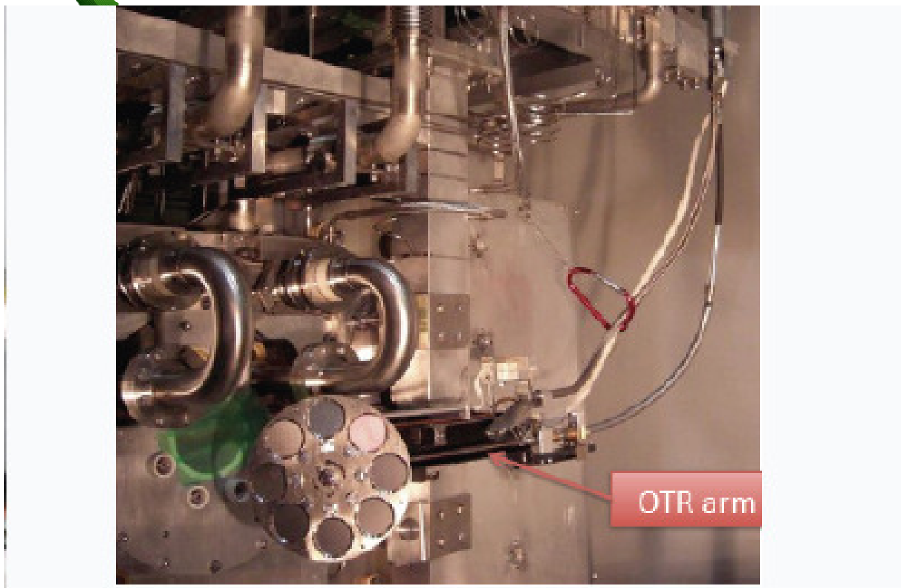


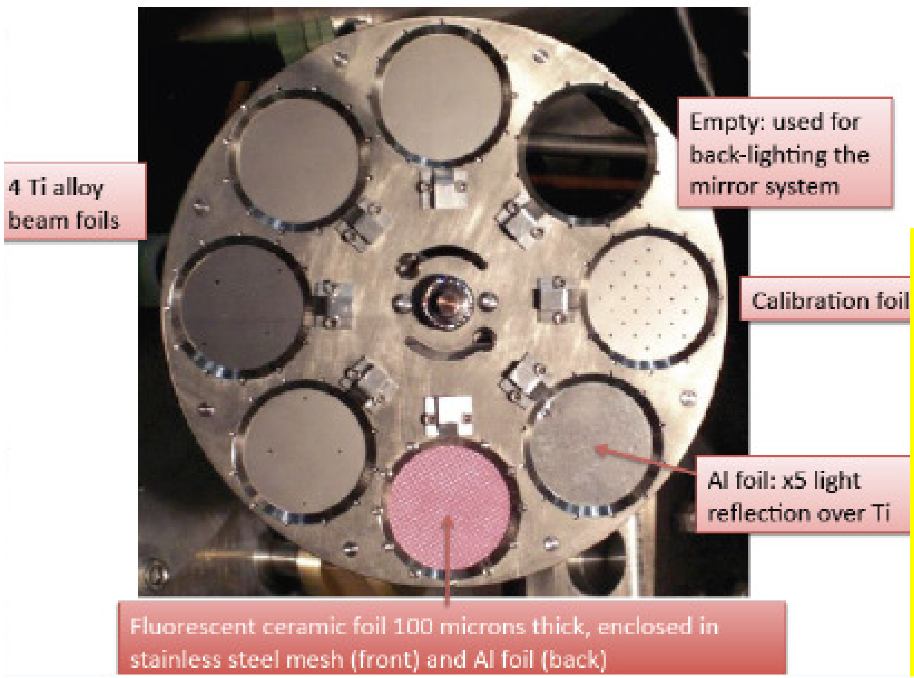
- Beam collimator in front of the 1st horn
- Designed & Build in UK
- Installation succeeded on Jan. 10th.



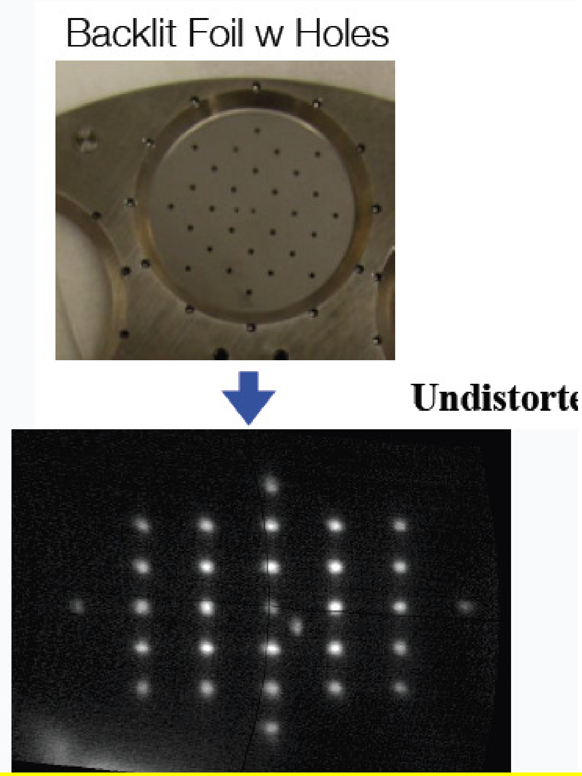


OTR (Canada)





Calibration image



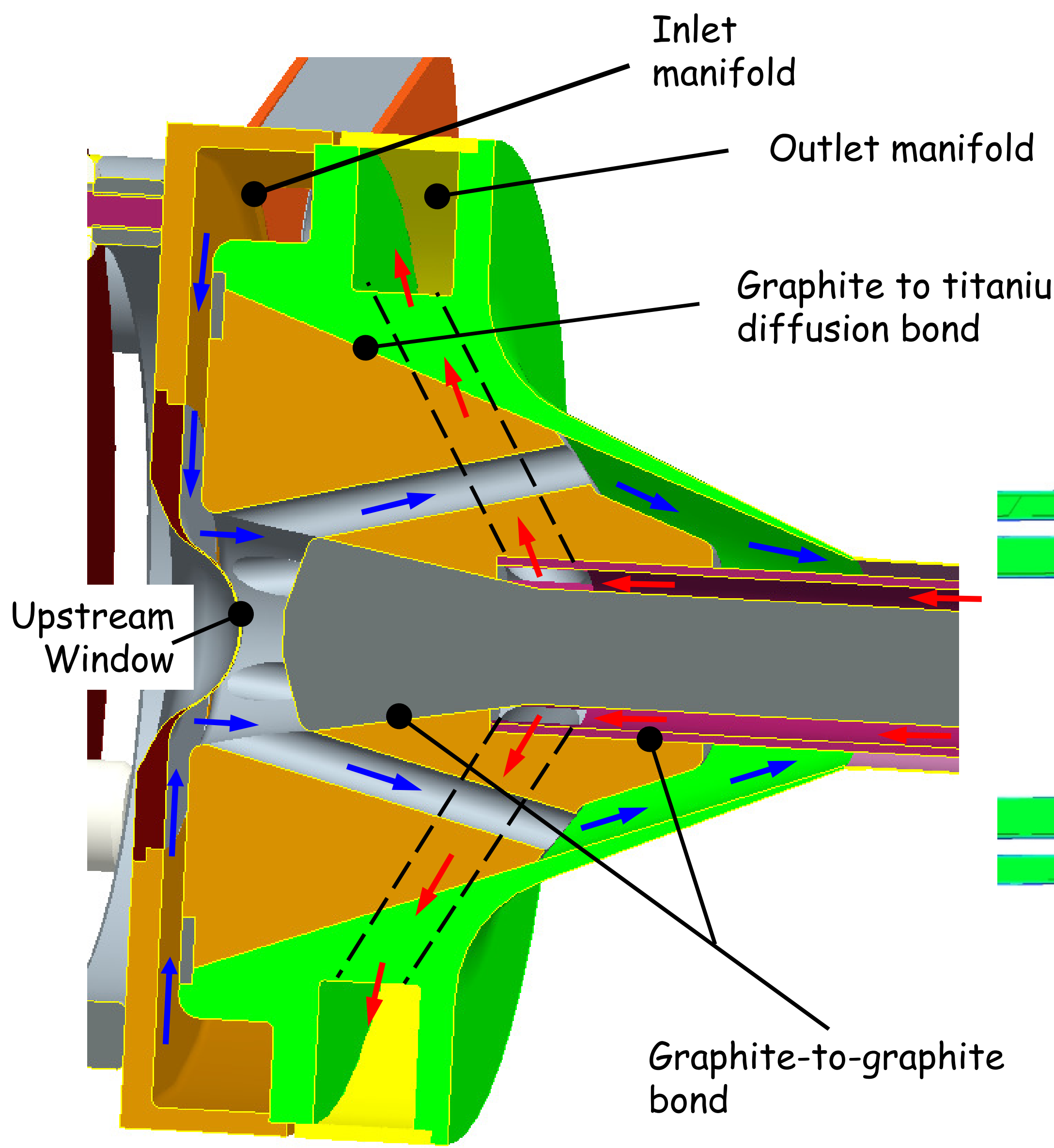
- Profile monitor just in front of target
- Foil structure is installed to 1st horn module.
- Optical path (Mirrors) is aligned and calibration image is obtained.
- Cabling, Installation of optical table on going

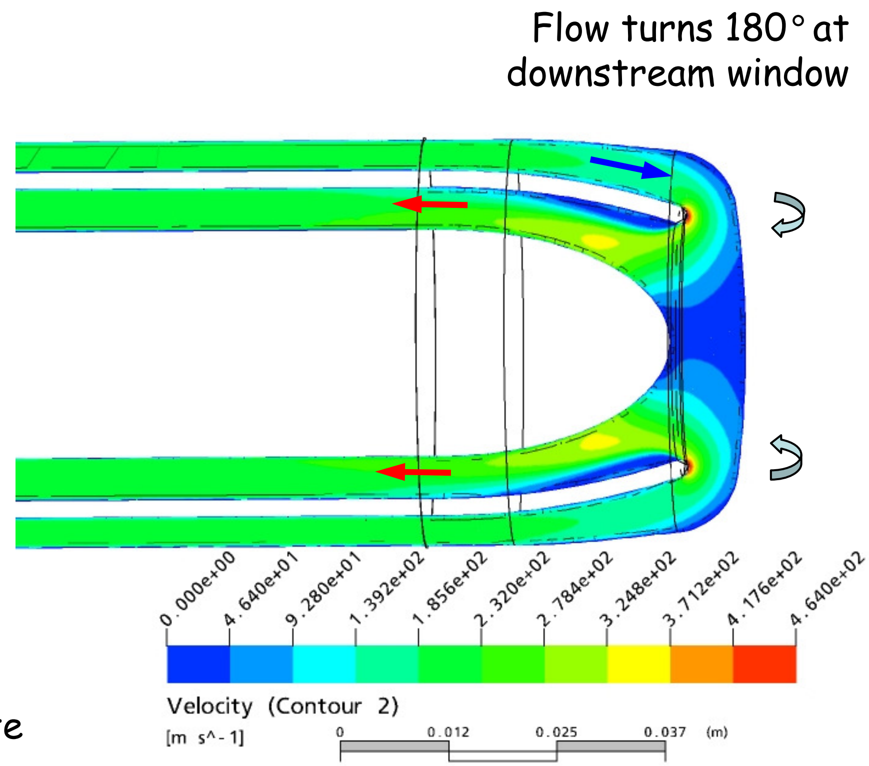
Target – (UK)

- Graphite rod, 900 mm (2 interaction lengths) long, 26 mm (c.2σ) diameter
- **c.20 kW (3%)** of **750 kW** Beam Power dissipated in target as heat
- Helium cooled (i)to avoid shock waves from liquid coolants e.g. water and (ii)to allow higher operating temperature
- Target rod completely encased in titanium to prevent oxidation of the graphite
- Helium cools both upstream and downstream titanium window first before cooling the target due to Ti-6Al-4V material temperature limits
- Pressure drop in the system should be kept to a minimum due to high flow rate required (max. 0.8 bar available for target at required flow rate of 32 g/s (30% safety margin))
- Target to be uniformly cooled (but kept above 400℃ to reduce radiation damage)
- It should be possible to remotely change the target in the first horn

Target Design:

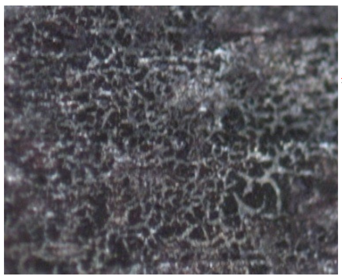
Helium cooling path



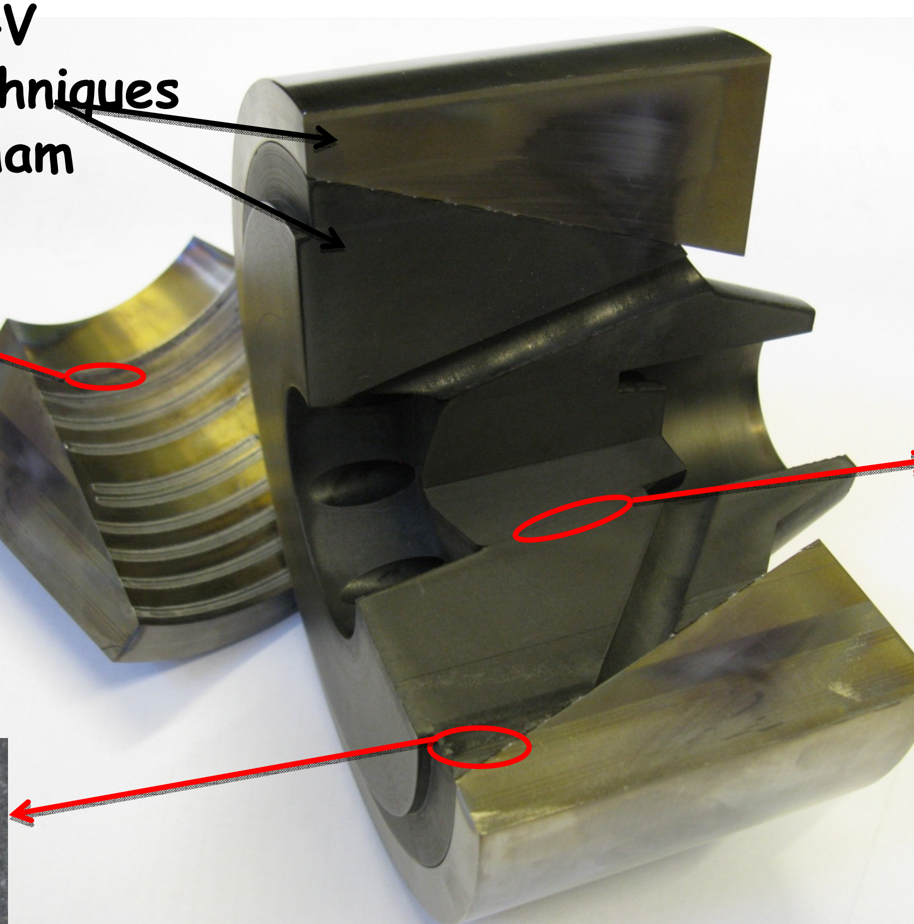


Diffusion Bond +
Graphite-Graphite bonding test

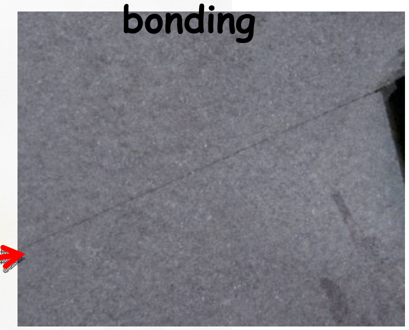
IG43 Graphite diffusion bonded into Ti-6Al-4V titanium, Special Techniques Group at UKAEA Culham

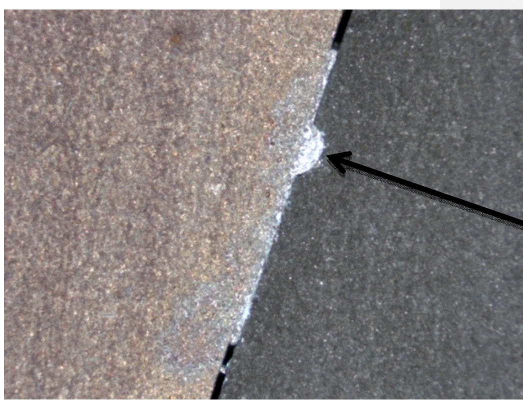


Graphite transfer to Aluminium



Graphite-Graphite bonding



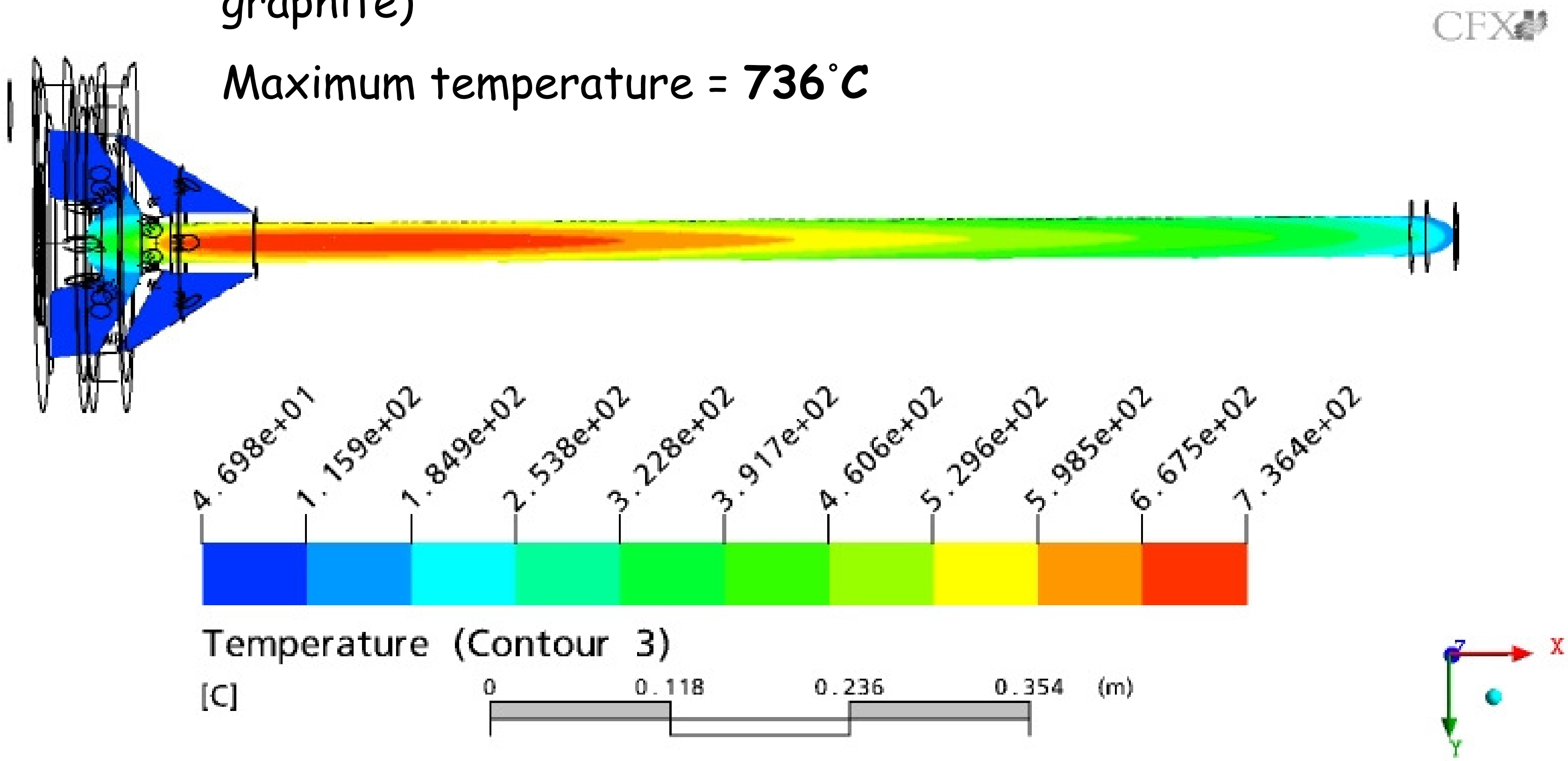


Aluminium intermediate layer, bonding temperature 550°C
Soft aluminium layer reduces residual thermal stresses in the graphite

30 GeV, 0.4735Hz, 750 kW beam

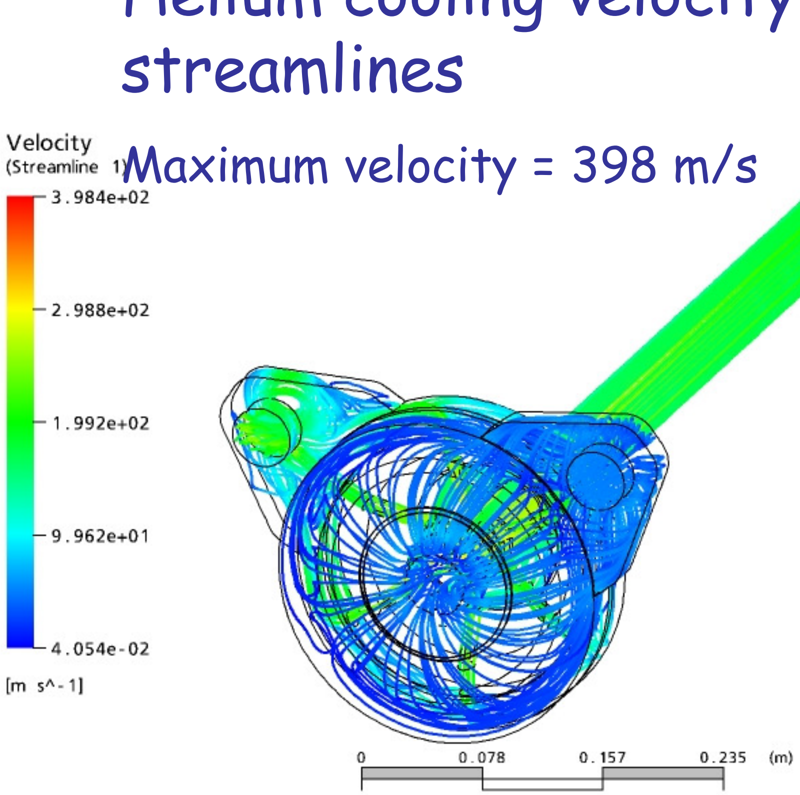
Radiation damaged graphite assumed (thermal conductivity 20 [W/m.K] at 1000K- approx 4 times lower than new graphite)

Maximum temperature = **736°C**



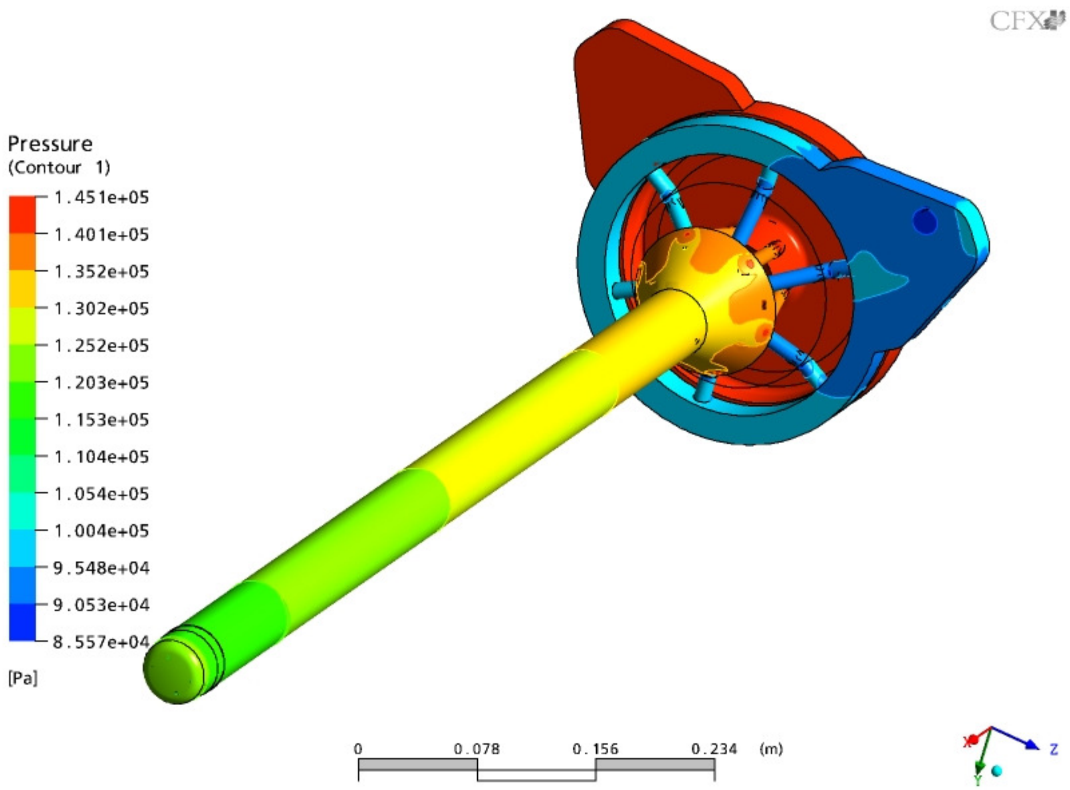
Helium cooling velocity streamlines

Maximum velocity = 398 m/s

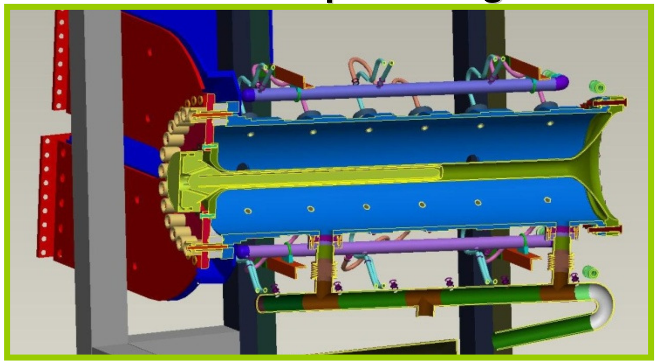


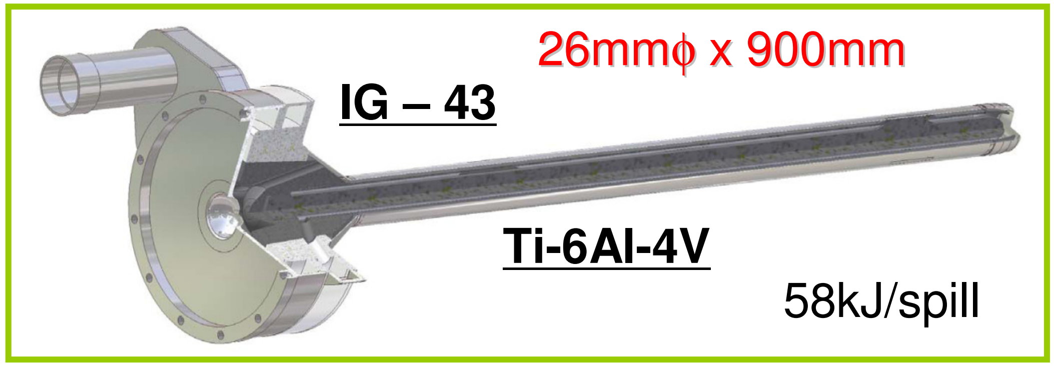
Pressures (gauge)

Pressure drop = 0.792 bar

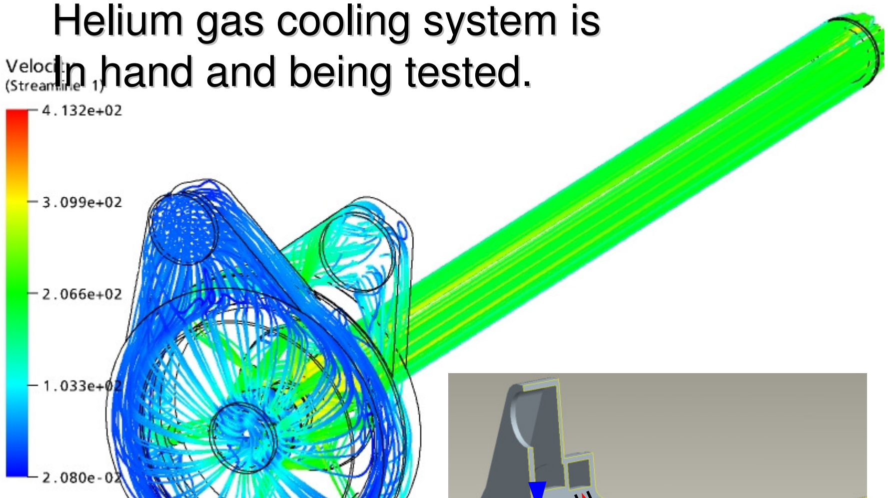


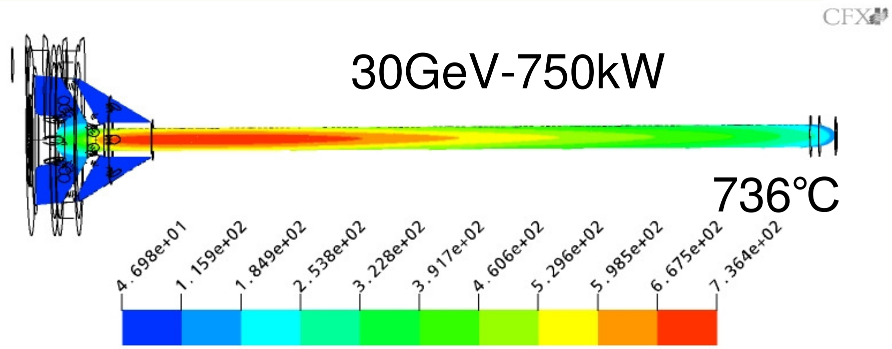
Helium-Cooled Graphite Target in the 1st Horn



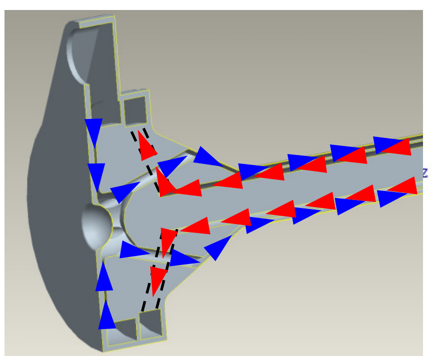


Helium gas cooling system is in hand and being tested.

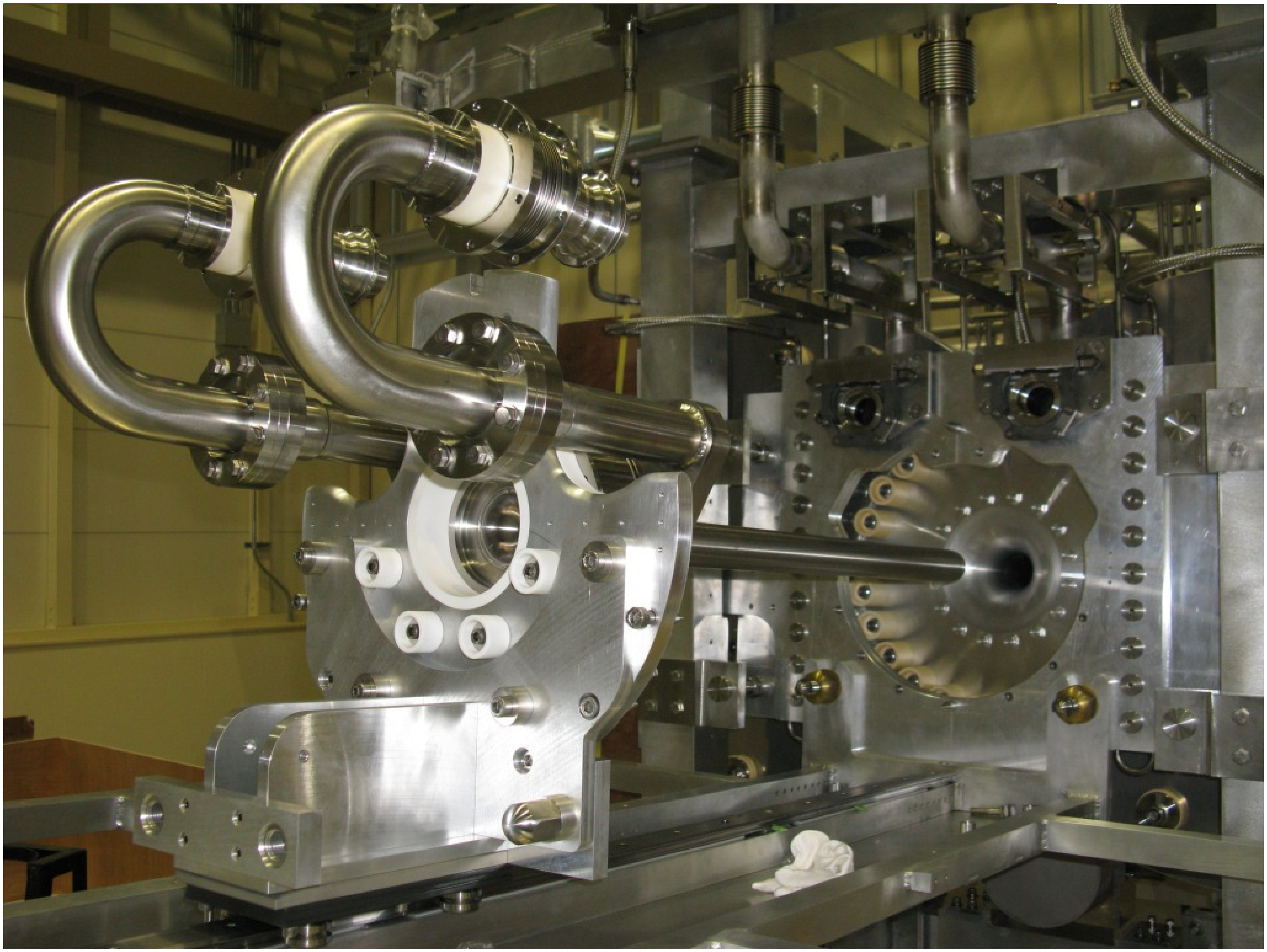




ΔT~200K ~7MPa(Tensile 27MPa)

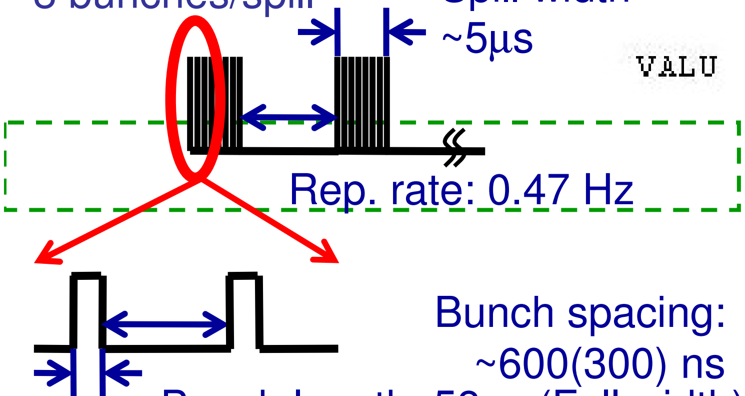


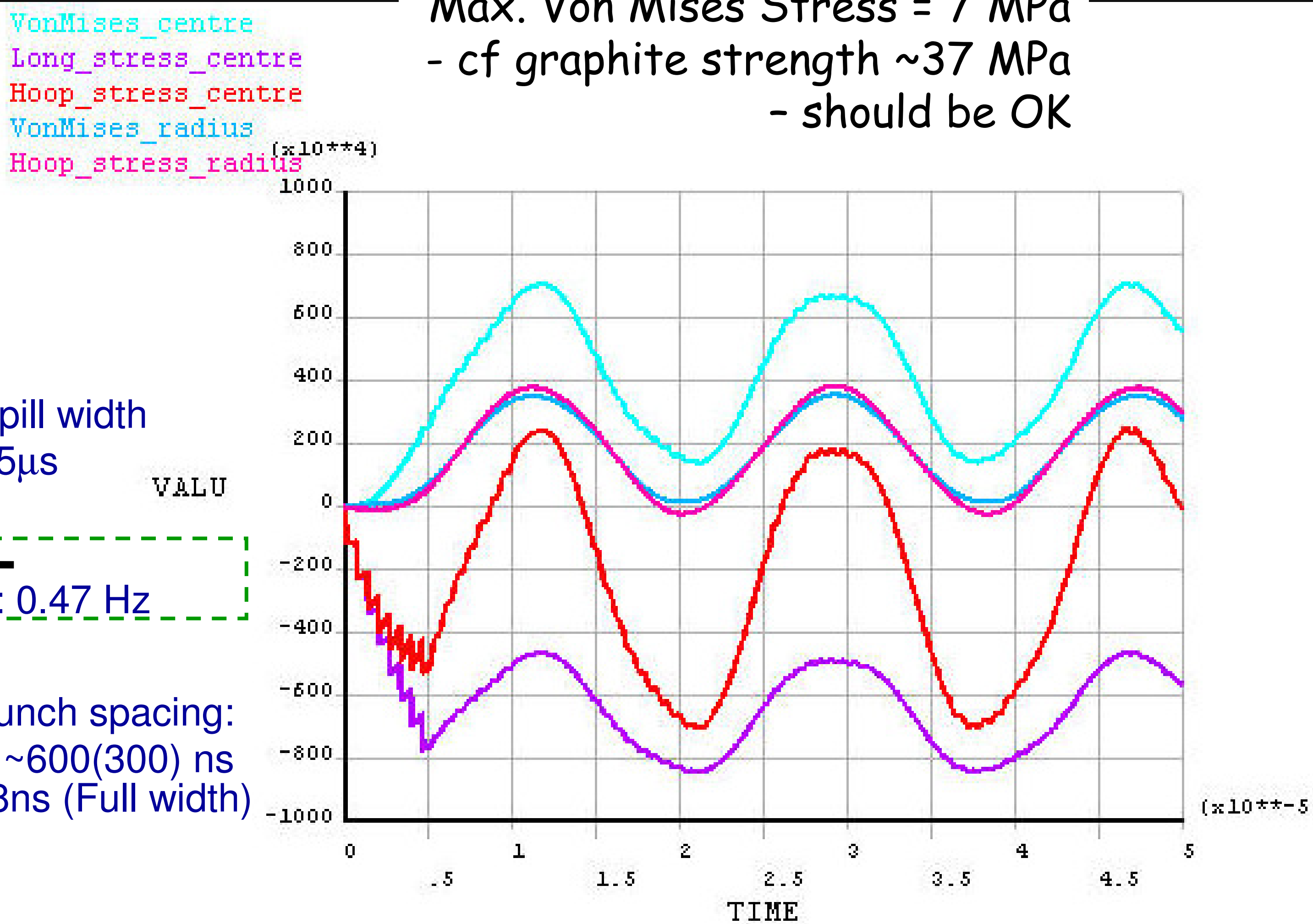
Full prototype to be delivered in Dec.



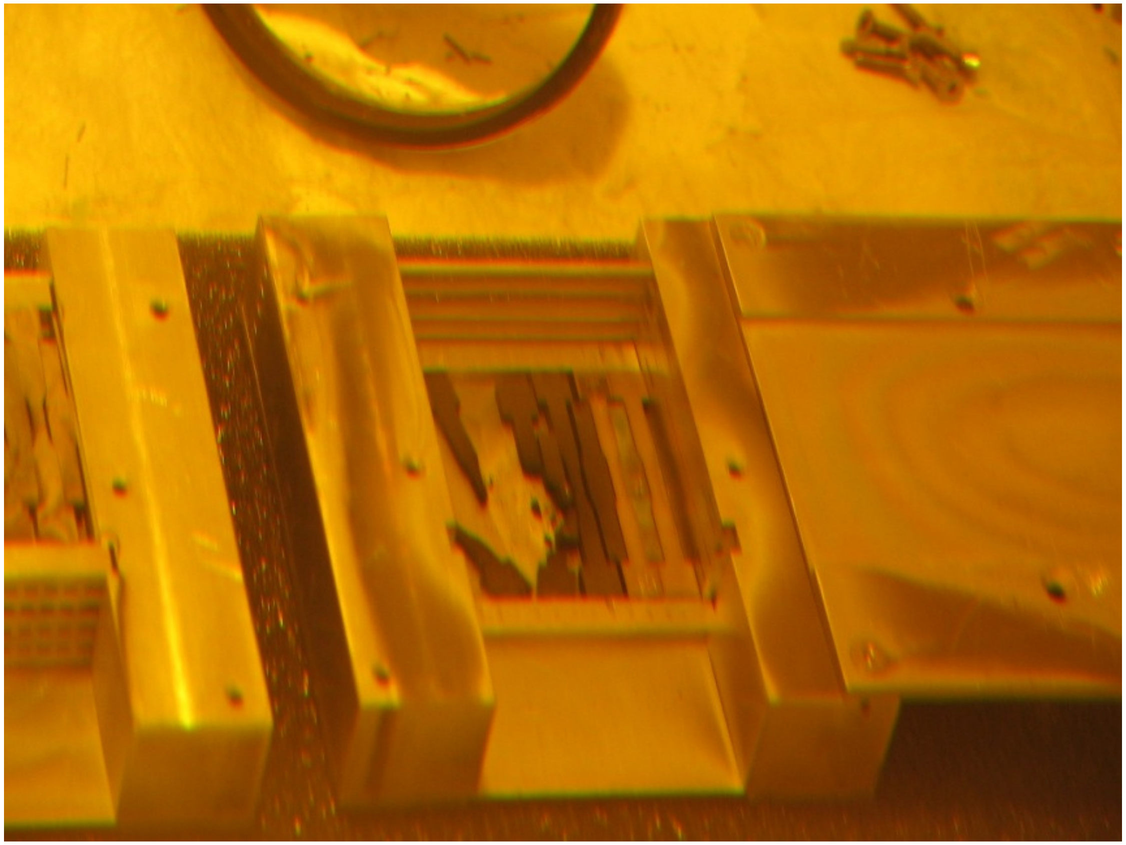
Pulsed beam induced thermal stress waves in target graphite

Max. Von Mises Stress = 7 MPa
- cf graphite strength ~37 MPa
– should be OK





Radiation Damage in IG43 Graphite - data from Nick Simos, BNL



200 MeV proton fluence

~10^21 p/cm2

c. 1 year operation in T2K

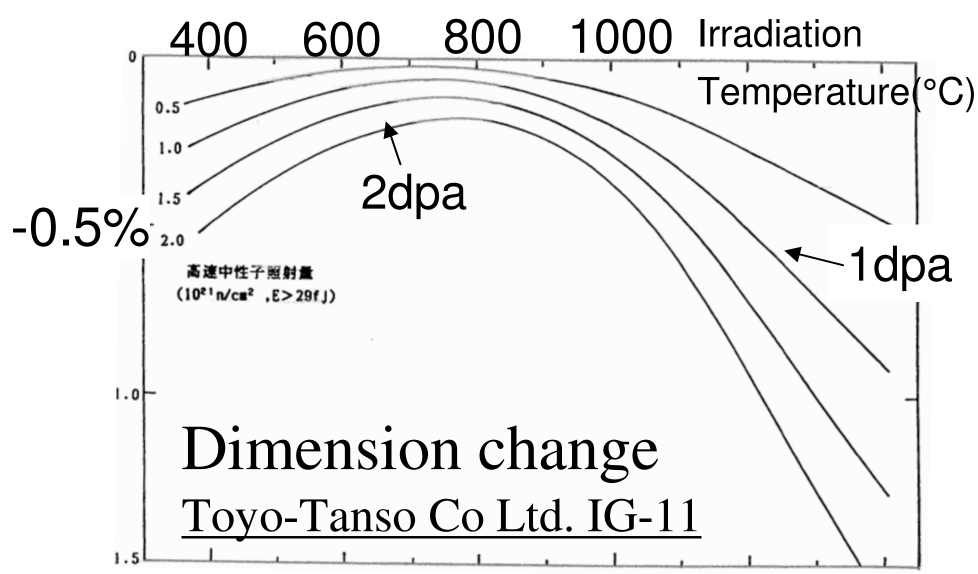
(phase 1, 750 kW)

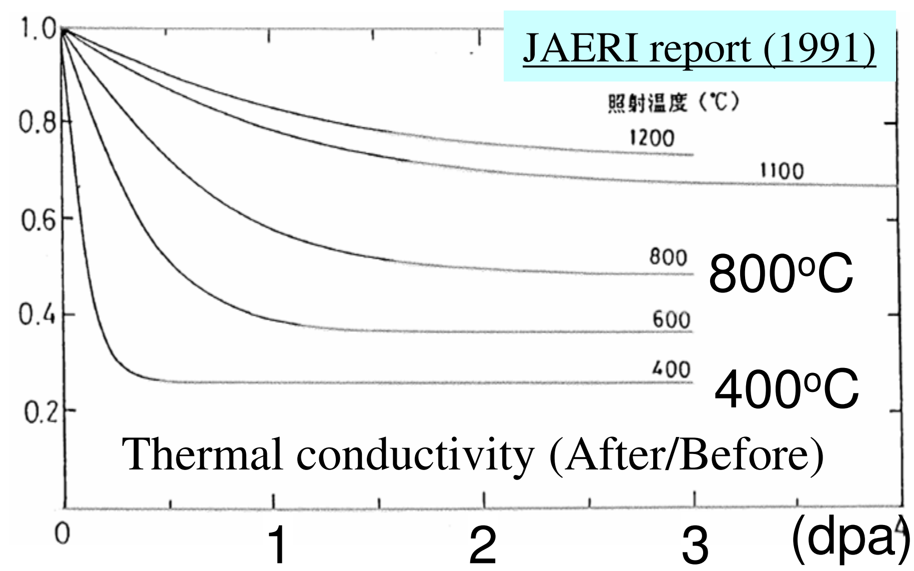
We don't expect targets to last long!

Targets can be changed within magnetic horn

Irradiation effects on Graphite

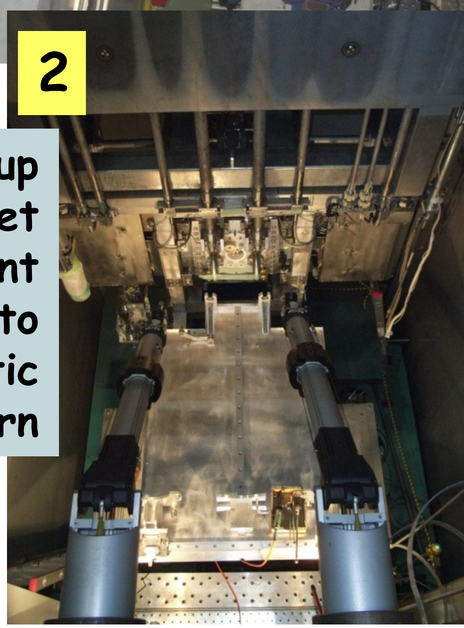
- **Expected radiation damage of the target**
  - The approximation formula used by NuMI target group : 0.25dpa/year
  - MARS simulation : 0.15~0.20 dpa/year
- **Dimension change** : shrinkage by **~5mm in length** in 5 years at maximum.
  ~75μm in radius
- **Degradation of thermal conductivity** … decreased by **97%** @ 200 °C
  70~80% @ 400 °C
- **Magnitude of the damage strongly depends on the irradiation temperature.**
  - It is better to keep the temperature of target around **400 ~ 800 °C**



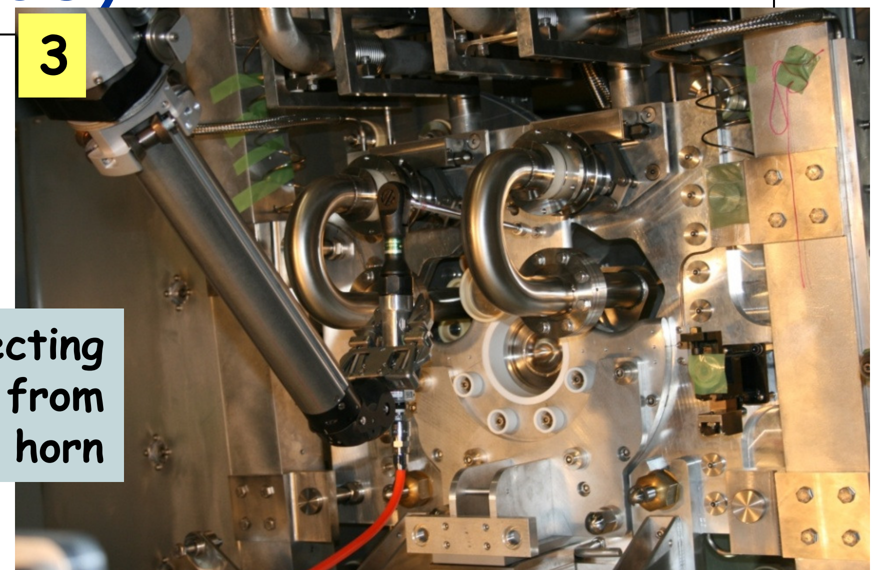


Target Remote Replacement Commissioning (Nov 2008)

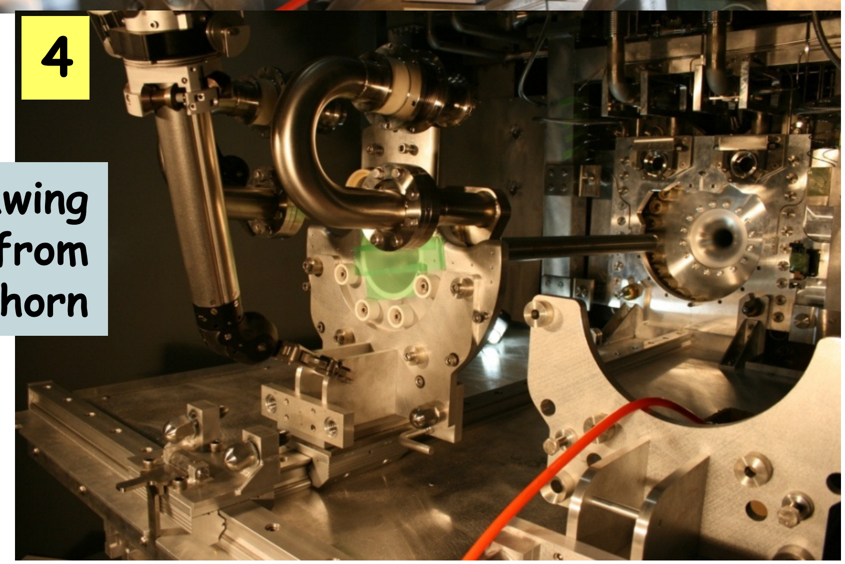
Installation of manipulators into hot cell



Offering up target replacement system to magnetic horn

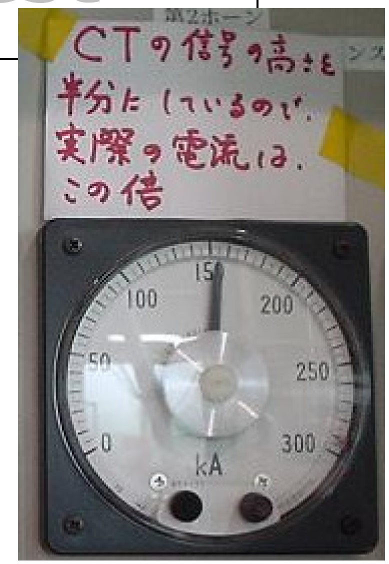


Disconnecting target from horn

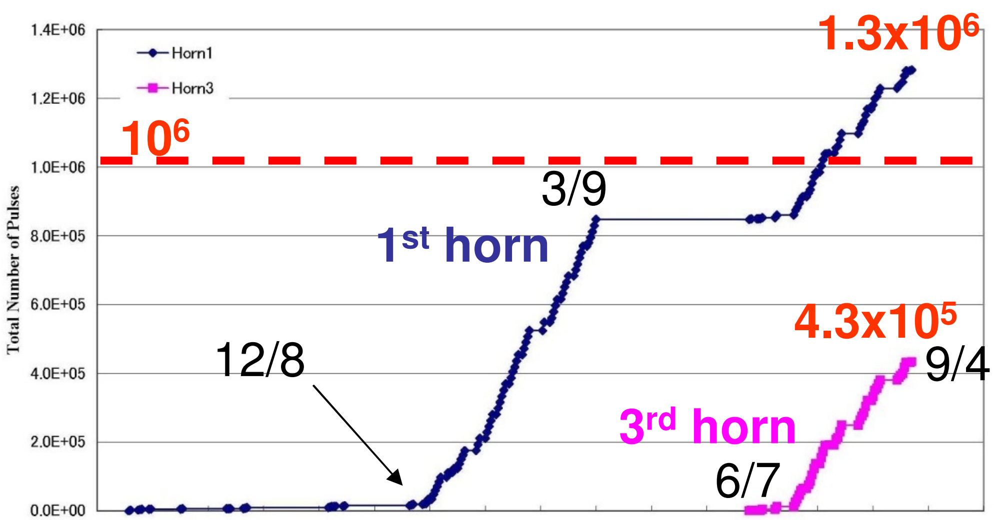


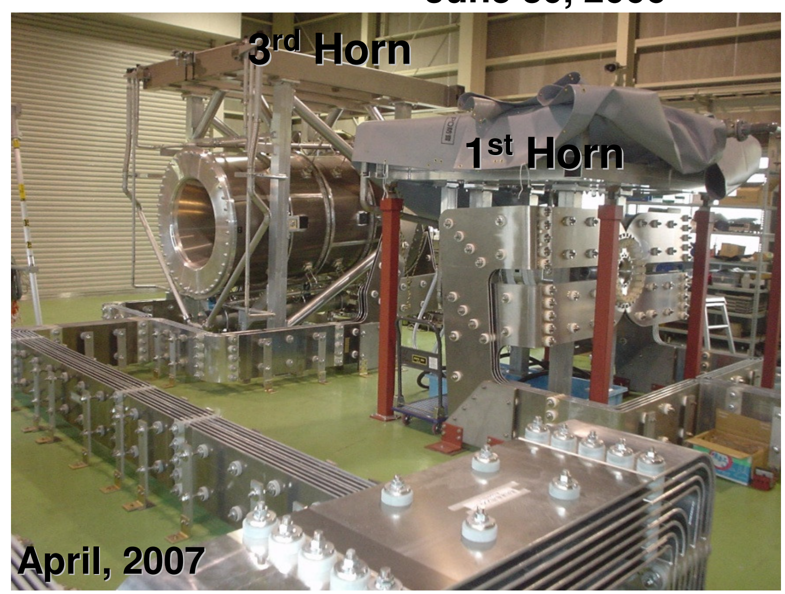
Withdrawing target from horn

1st / 3rd Horn Operation Test



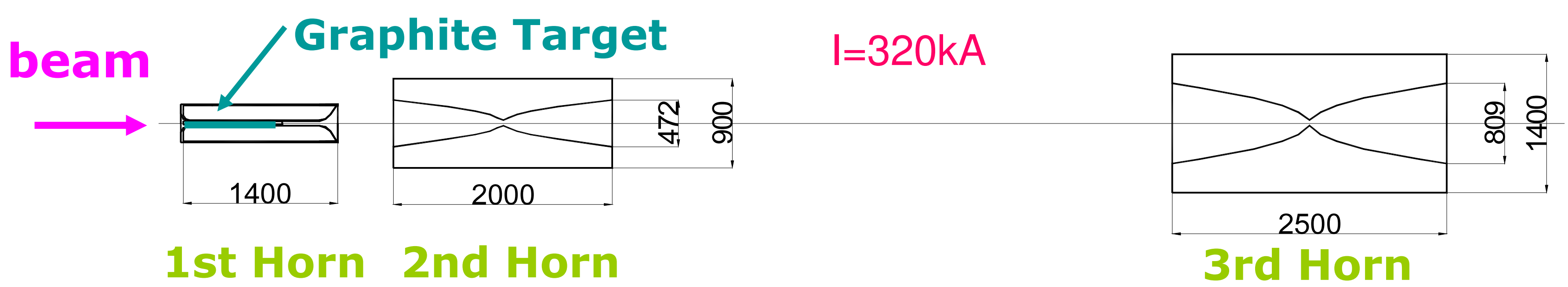
June 30, 2006



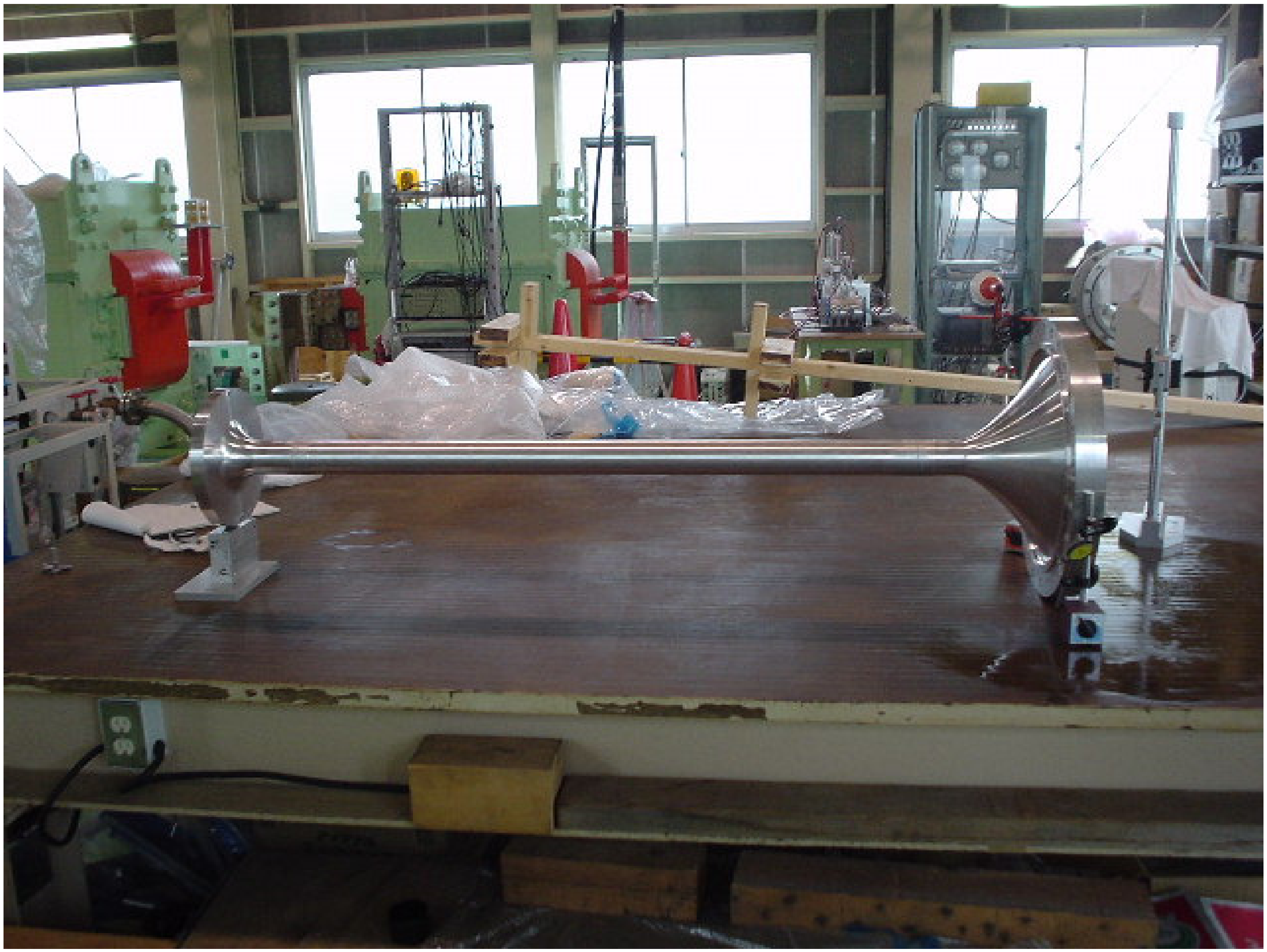


- 3rd horn test with support module: this fall
- 2nd horn fablication is in progress at U.S.

After consideration on the stress analysis, we decided to make inner-conductors w/ 3mm-thick aluminum.



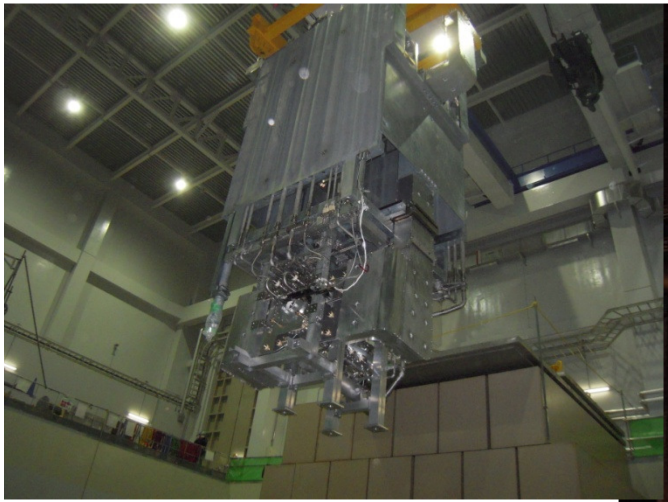
1st horn prototype

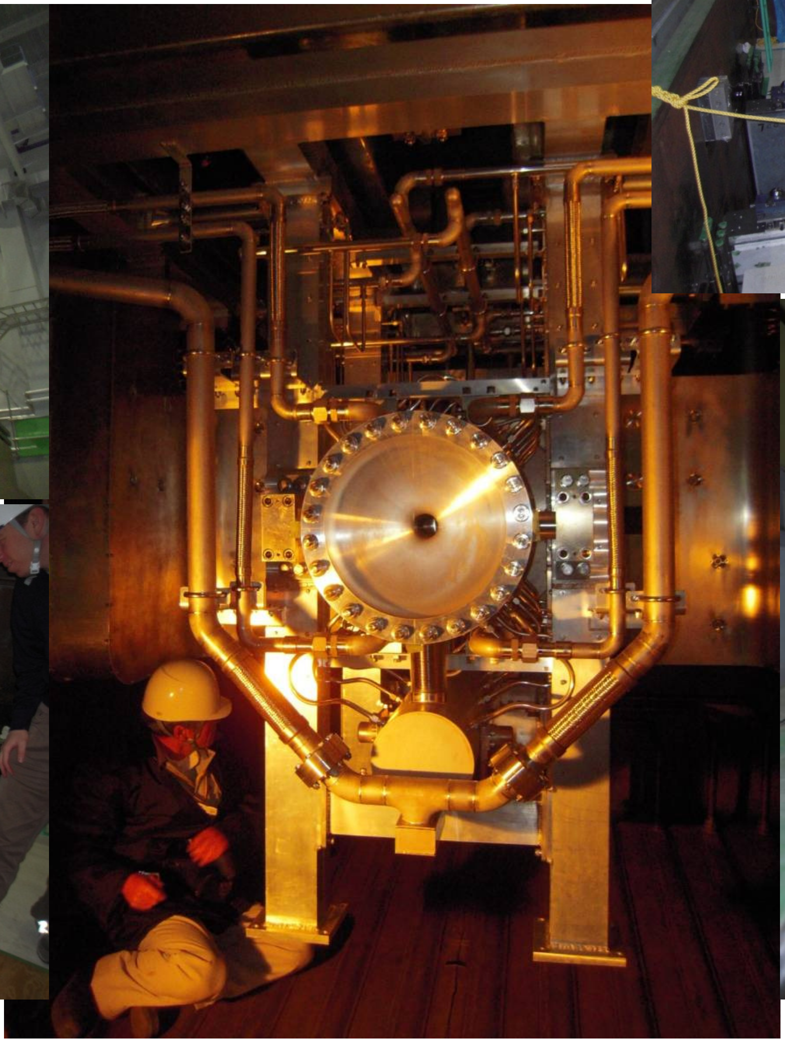


Assembled into the K2K outer-conductor.

Horn1 Installation

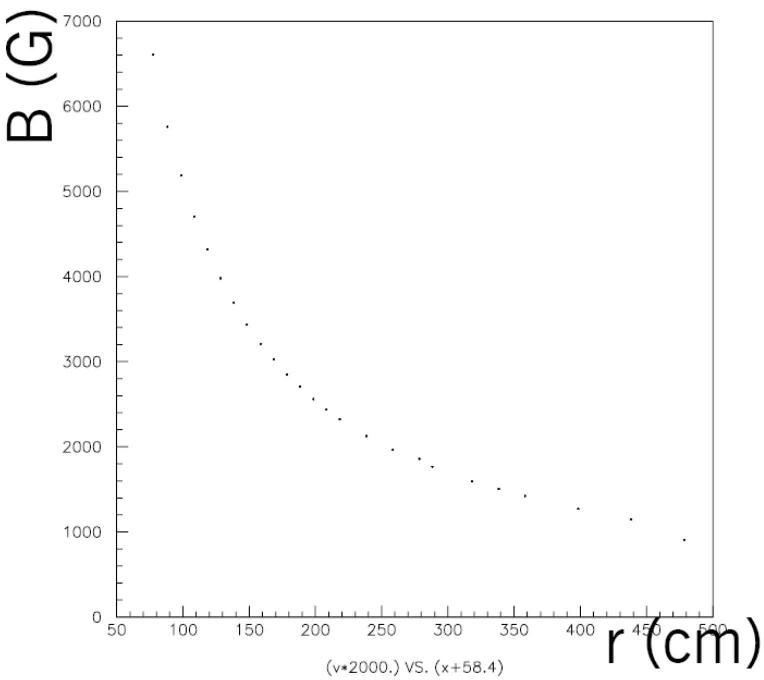
- Installation succeeded on Jan. 21st.
- Target/OTR attached also.





Horn2

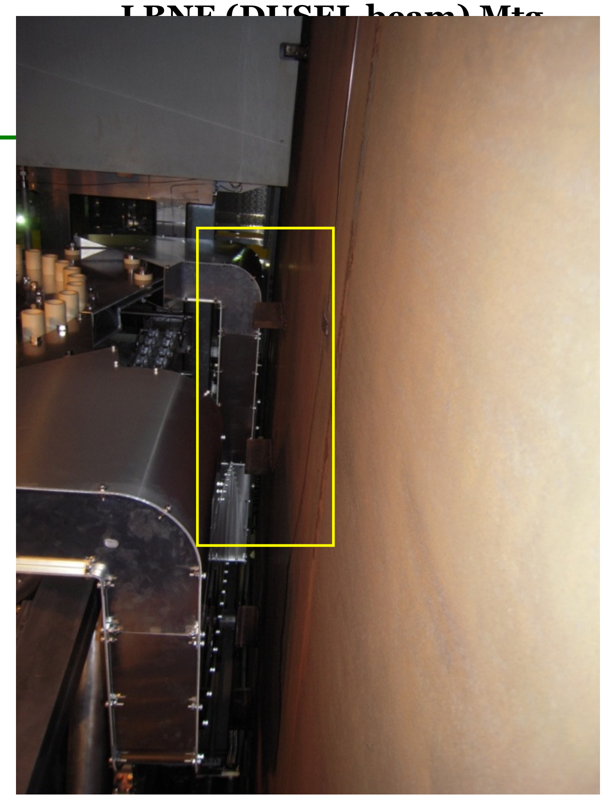
- US contribution
- Delivered to KEK at Mid. Jun.
- Test operation @ KEK (Tsukuba).
  - Mid. Aug ~ Early Oct.
  - ~ 230k pulses.
  - Distortion due to pulse is consistent with the expectation by FEM.
  - Measured magnetic field agrees with the design value in 1% level.

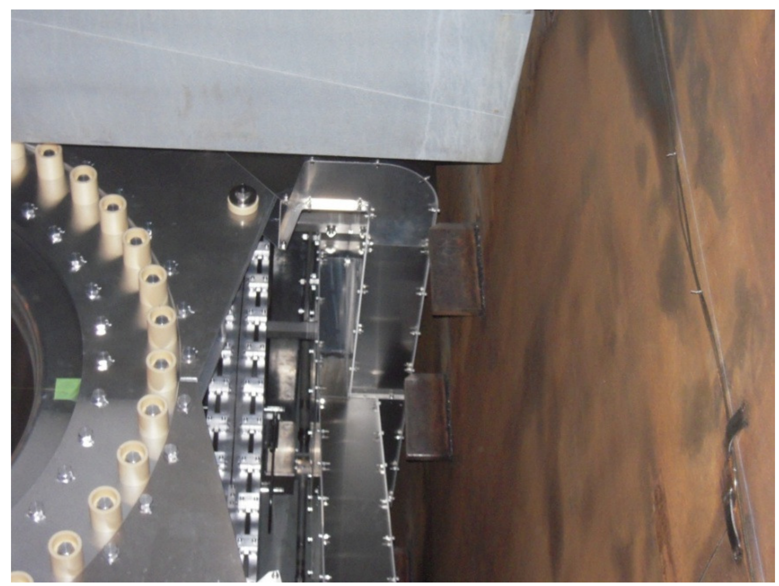


Structural interference is found during installation

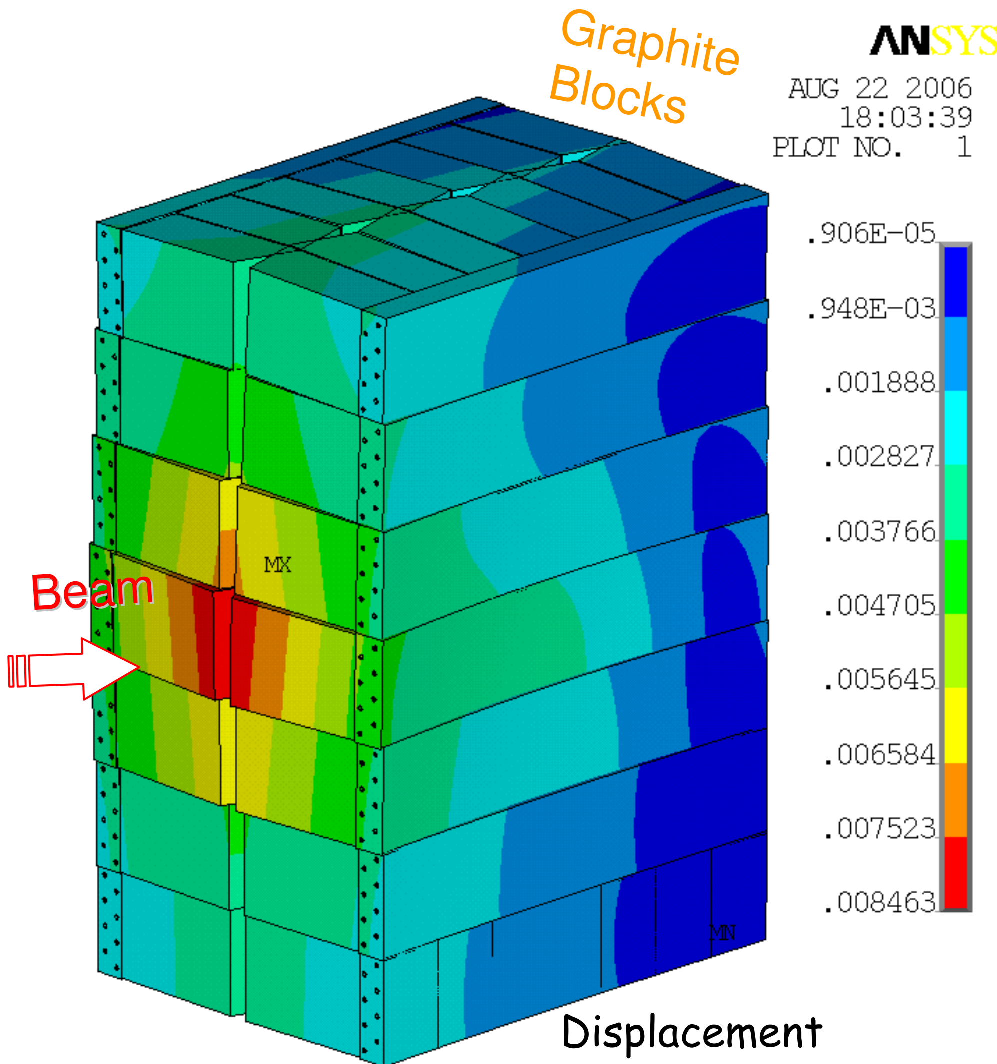
- Interferences between horn modules and He vessel found during Nov & Dec. 2008
  - Modification become necessary
  - ~ 2 months delay was foreseen
- In order not to delay April beam commissioning, **we decided to**
  - **Operate Target & 1st horn only in the April beam commissioning**
  - postpone installation of 2nd and 3rd horn after commissioning (June~Sept, 2009)
- Commissioning with full setup after summer shutdown
  - With high power beam environment

No impact on T2K overall schedule



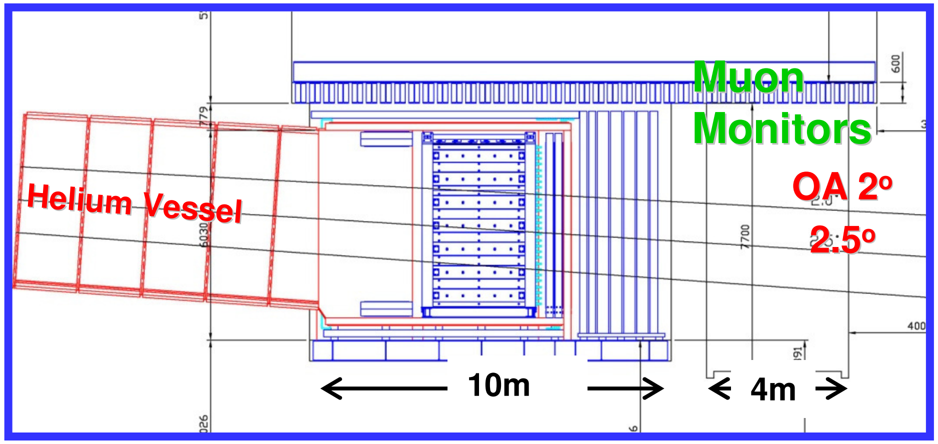


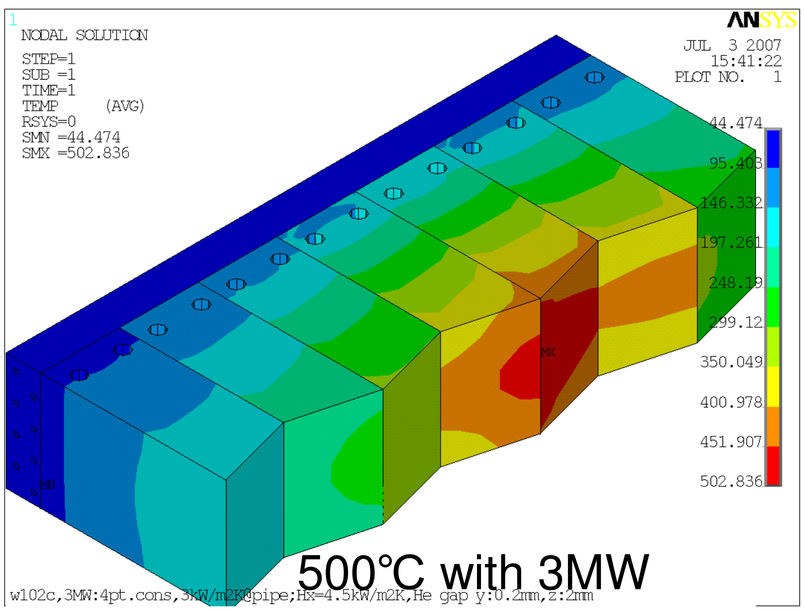
Dump



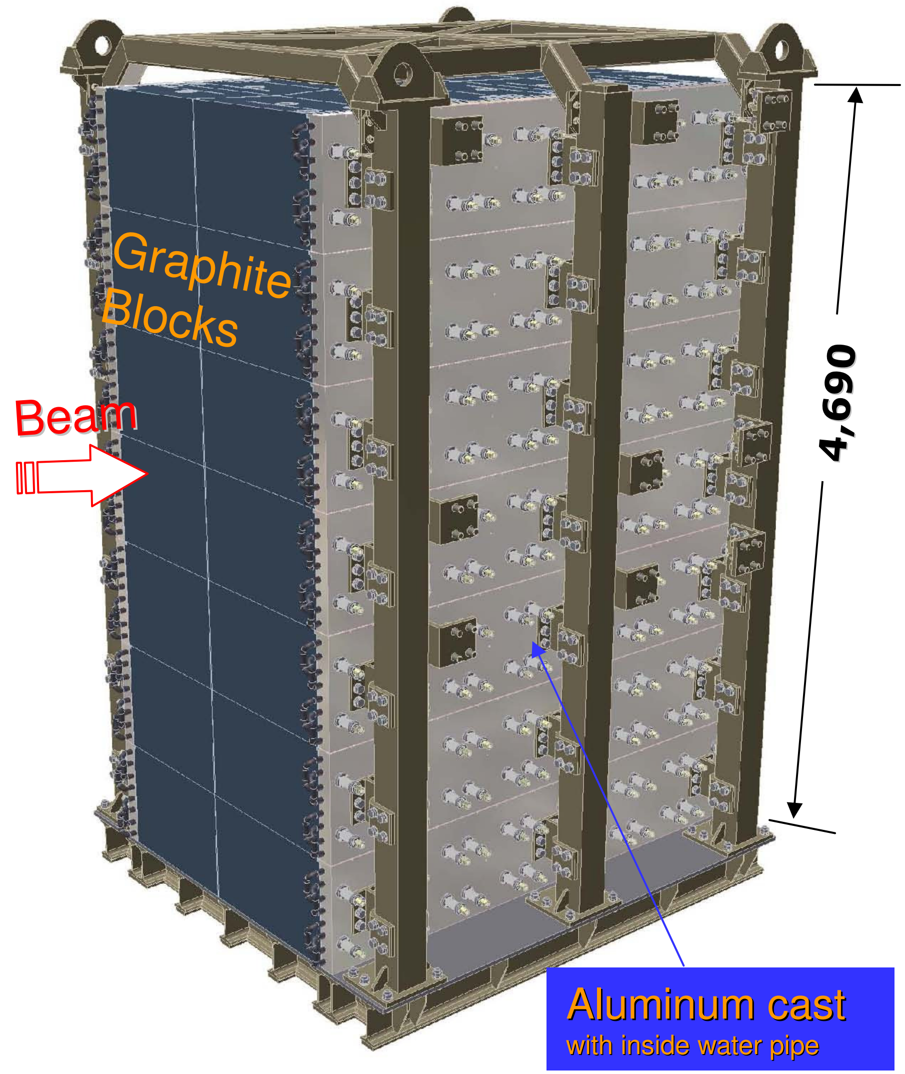
Displacement (max) = 8.5 mm at 4 MW

Beam Dump





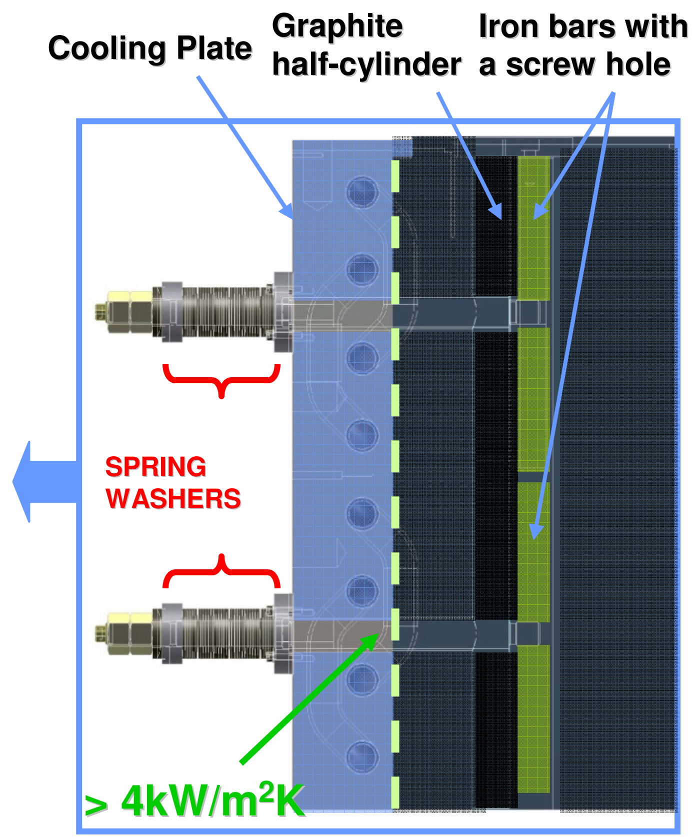
500°C with 3MW
[Assuming phase-I target]



- Design for the 2nd phase operation

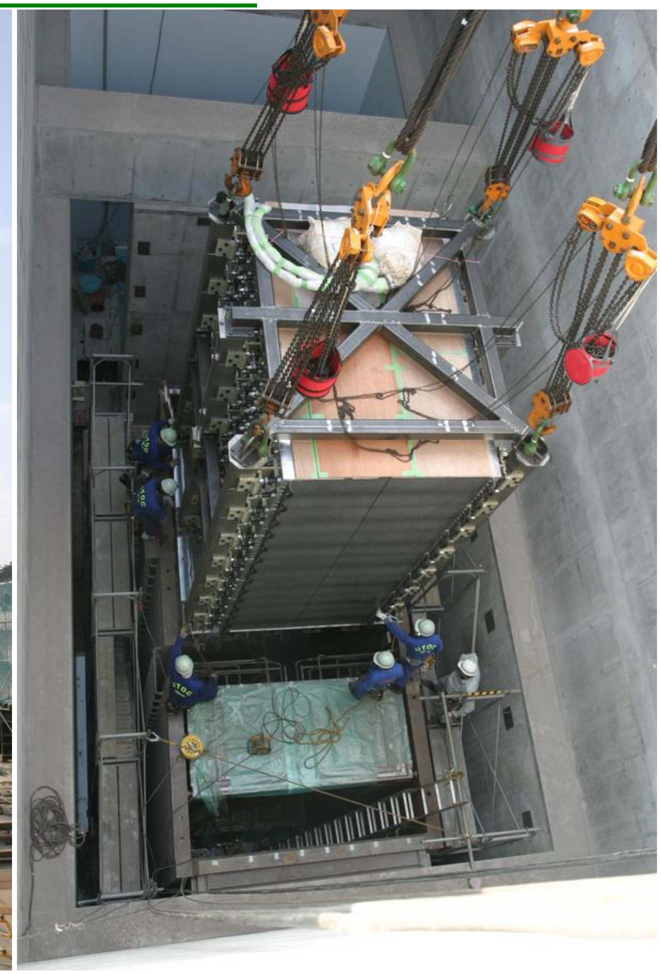
- Plumbing finished on Feb. 15th
- Installation of side/upper iron shields finished Feb. 12th
- Concrete ceiling is under construction and will be finished by Mar. 16th

Hadron Absorber Module



- A design with multiple spring washers was adopted, to control joint force between graphite blocks and an aluminum cast cooling plate
- Flatness of the cooling surface and the loading surface < 0.1 mm
  - Machine 7 graphite blocks at once

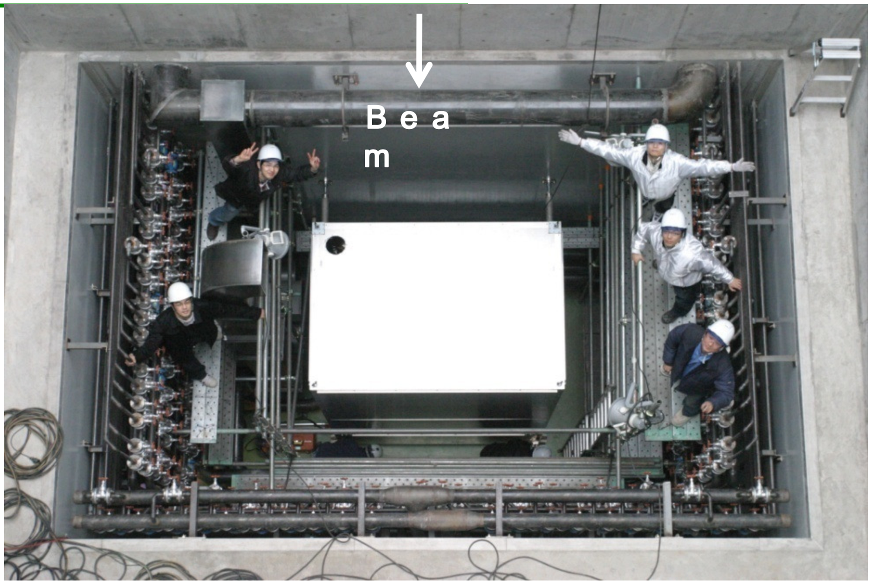
Beam Dump



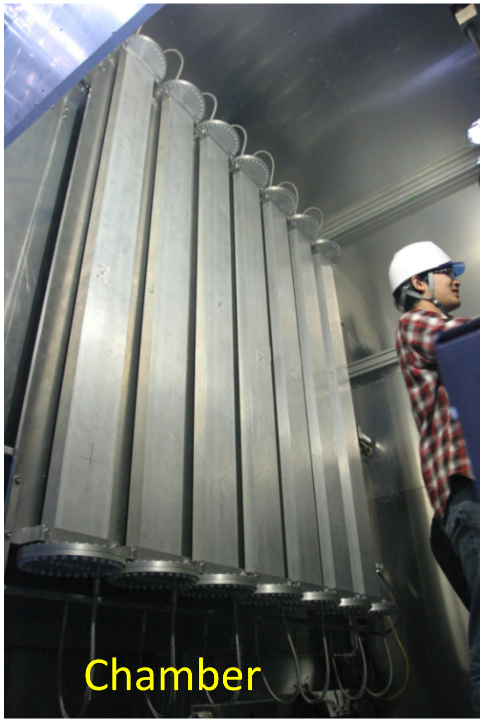
- Graphite core of BD was installed into the He vessel on Oct. 18th.

Muon monitor

Installed the support structure into the muon pit. (2/13)

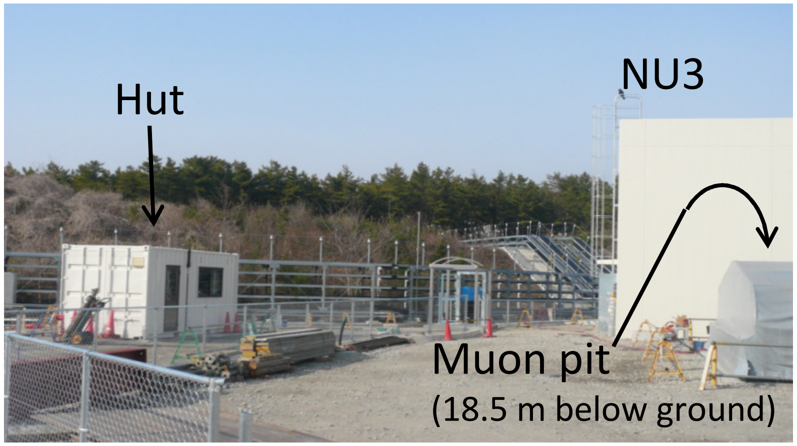


Installed all 7 ionization chambers and All of silicon PIN photodiodes.

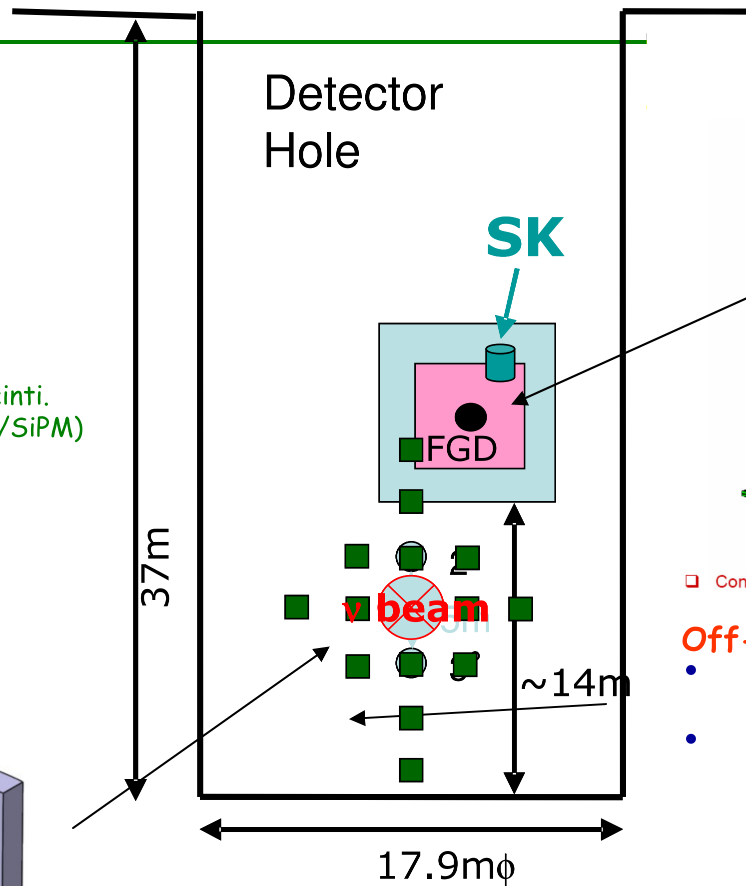


Achieved alignment precision of 1 mm.

- Readout electronics is installed in Hut.
- Cabling / gas-piping is also finished.
- Measured noise-level during MR operation is small enough. (±0.5mV)

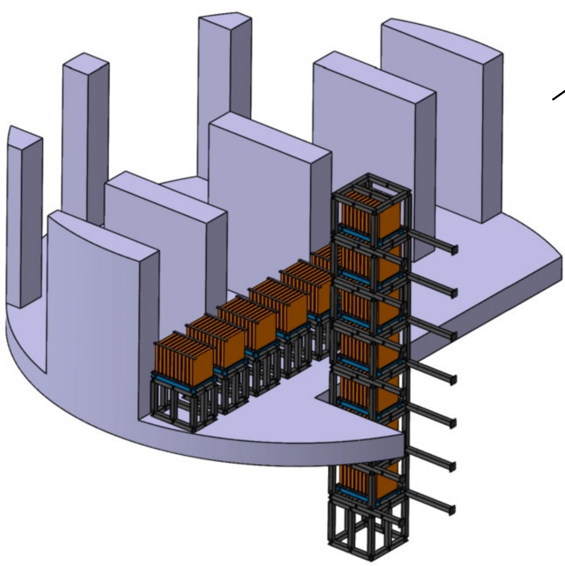


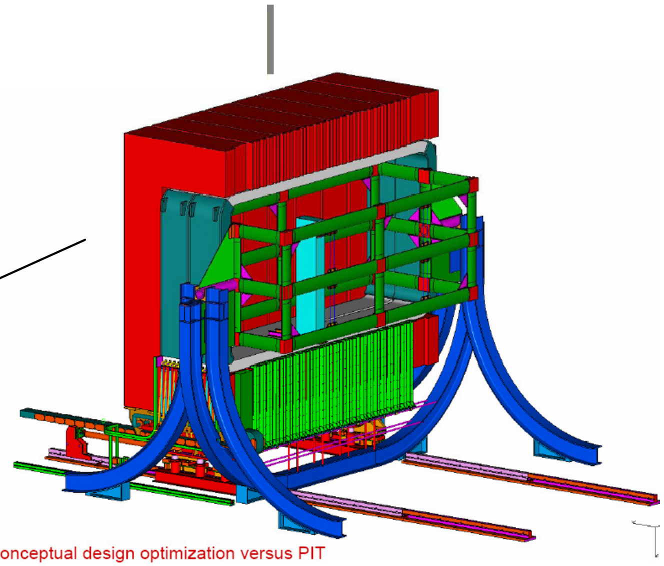
Near Neutrino Detectors @ 280m



On-axis neutrino moitor

- Monitor
  - Profile
  - Direction
  - Intensity (& Energy)
- Iron-Scintillator sandwich detector
  - 1mx1mx10cm Iron
  - 1.25cm thick extruded Scinti.
  - New Photo-Sensor (MPPC/SiPM)





❑ Conceptual design optimization versus PIT

Off-axis detector

- Measurement of ν flux and σ in the SK direction.
- Detector components.
  - UA1 magnet (0.2T)
  - TPC
  - Fine-Grained Scintillator detector (FGD)
  - Lead/Scintillator tracking detector for π^0
  - Electromagnetic Calorimeter
  - Muon Range Detector in mag
- Key technologies
  - Photo-sensor, Micromegas

Next up – my pictures and notes

Highlight:
- Remote connections
- Differences due to helium filled target pile
- Differences due to surface target hall

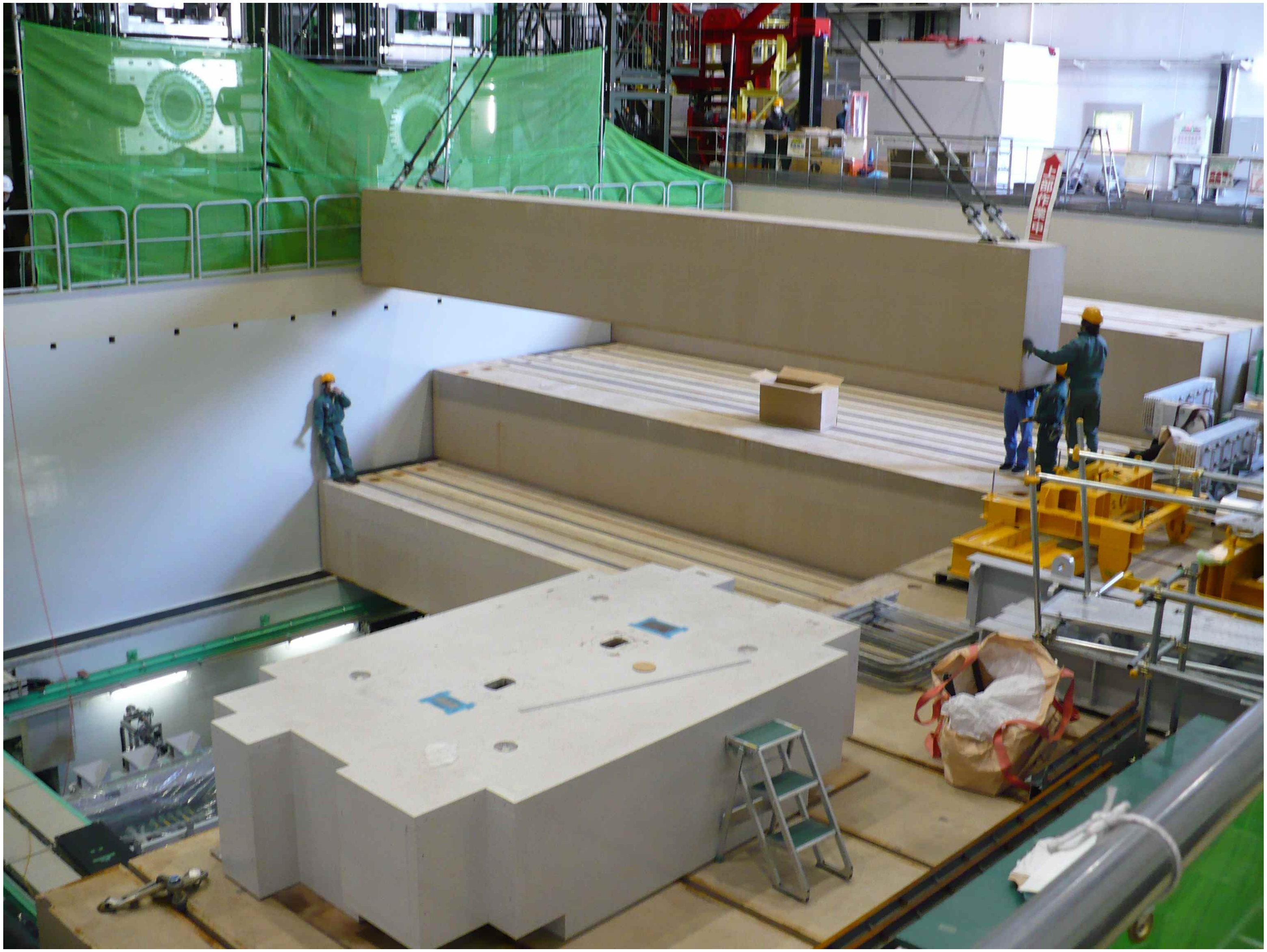
Underground – real elevators rather than cages !

WOW – look at those doors !

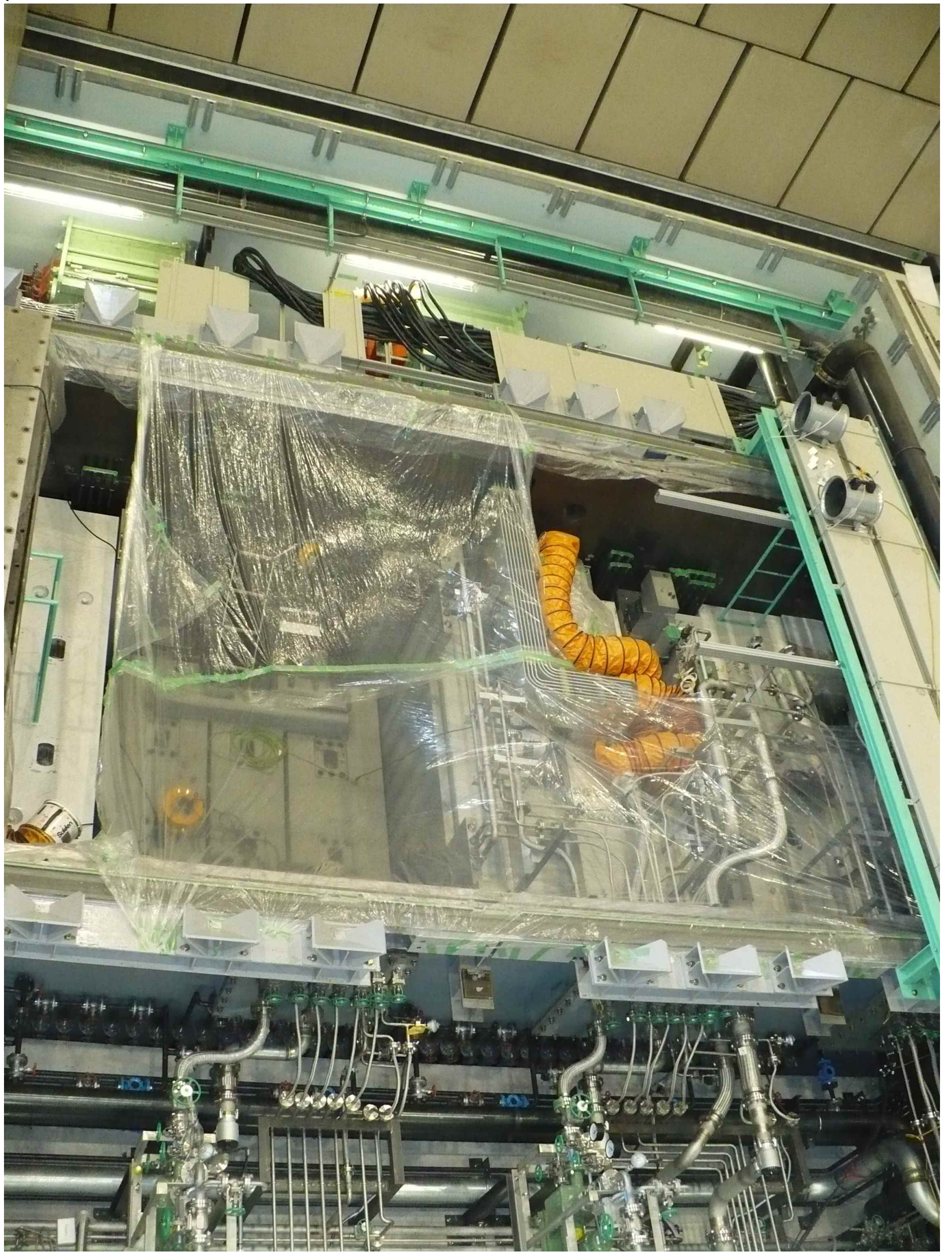
Buildings are 20 cm concrete equiv.
for shielding radio-activated H2O

(downside of surface bldg?)

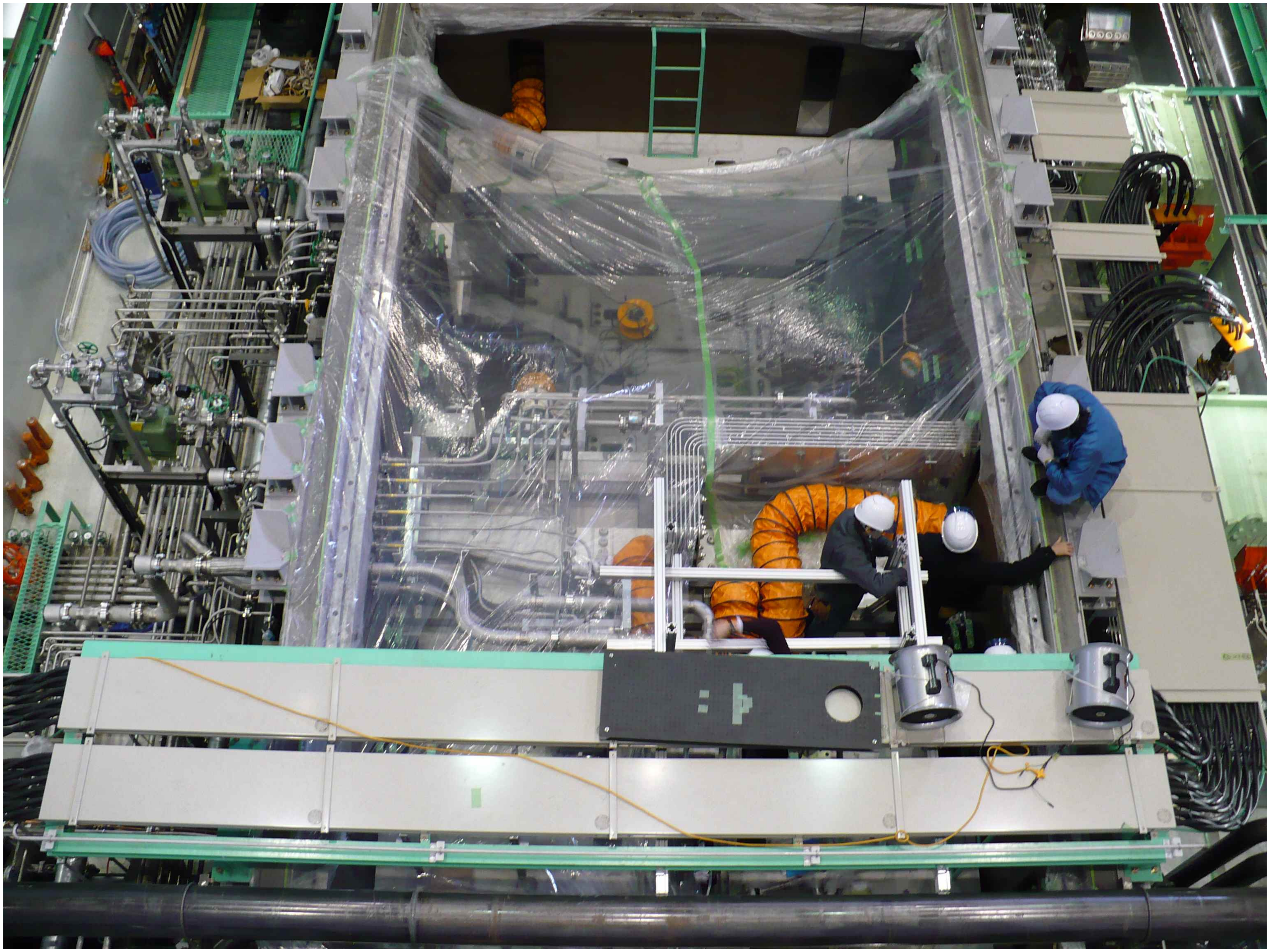
target pile top concrete shielding is massive
(surface bldg. equivalent of our rock/dirt cover, slows down repairs)



Half of T2K target pile (other half covered)



Half of T2K target pile



Pre-target to target hall transition

Pre-target beam magnets right up to target hall wall
(compare NuMI 10 m of straight section to define proton beam angle)

Wall is ~ ½ m of concrete, before target pile steel. (NuMI 6′ concrete)

T2K spec on beam angle is ~ 1 mr

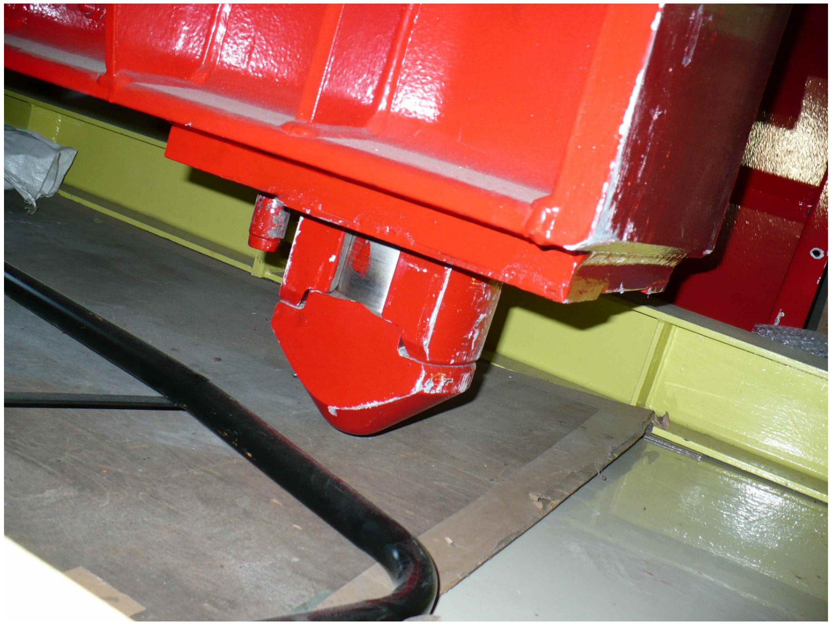
NuMI an order of magnitude tighter

Crane

Crane operator's control station has window to T-hall (to supplement cameras)

Main 40 T crane has duplicate motors in case of failure with hot item (not on smaller 15 T crane)

Lifting fixture



Commercial system where bottom part of pin rotates to lock into shielding block (believe this is normally used for shipping containers)

(NuMI used just a home-grown open hook system)

T2K target hall – horn/module test area

Horn drain tank, pump-out lines

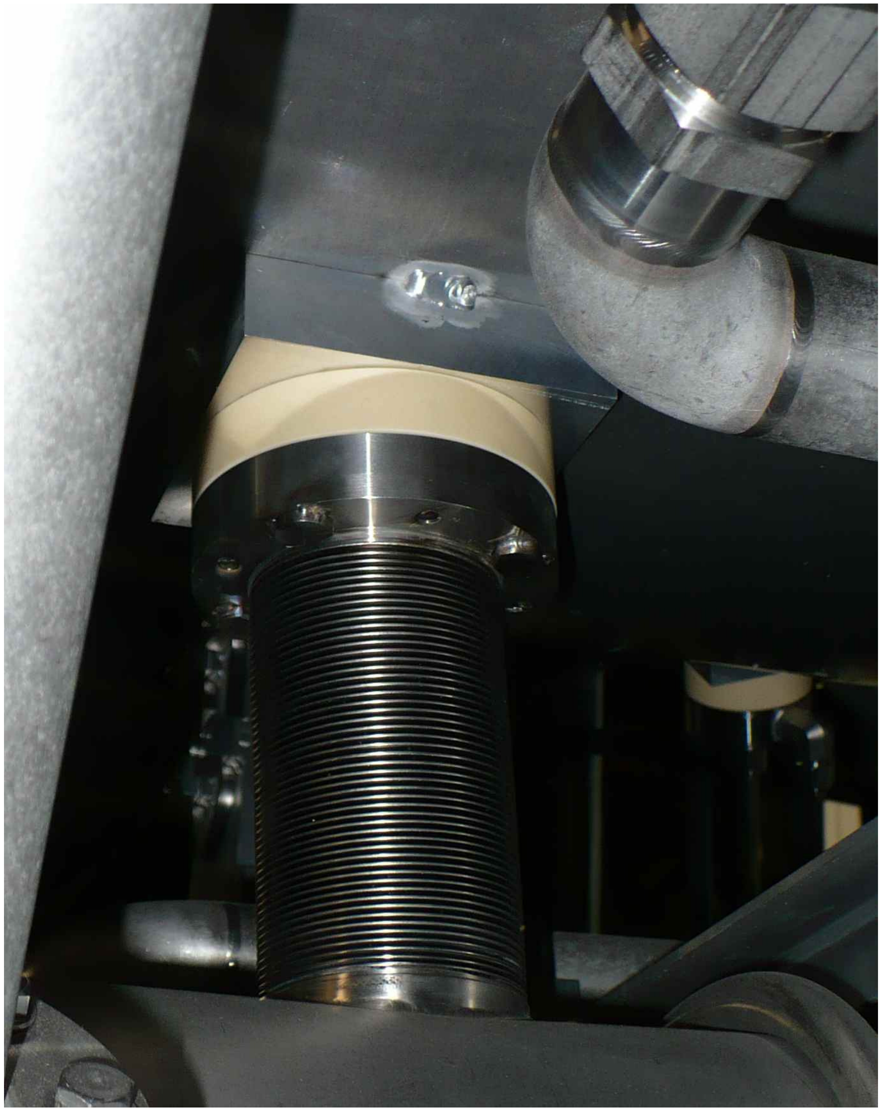
Like NUMI but
dual pump-out lines

Pump on top like NuMI

On edge of
operable height.
(Almost 9 m of lift
for water)

Pump-out was
problematic for NuMI,
so redundancy
sounds good

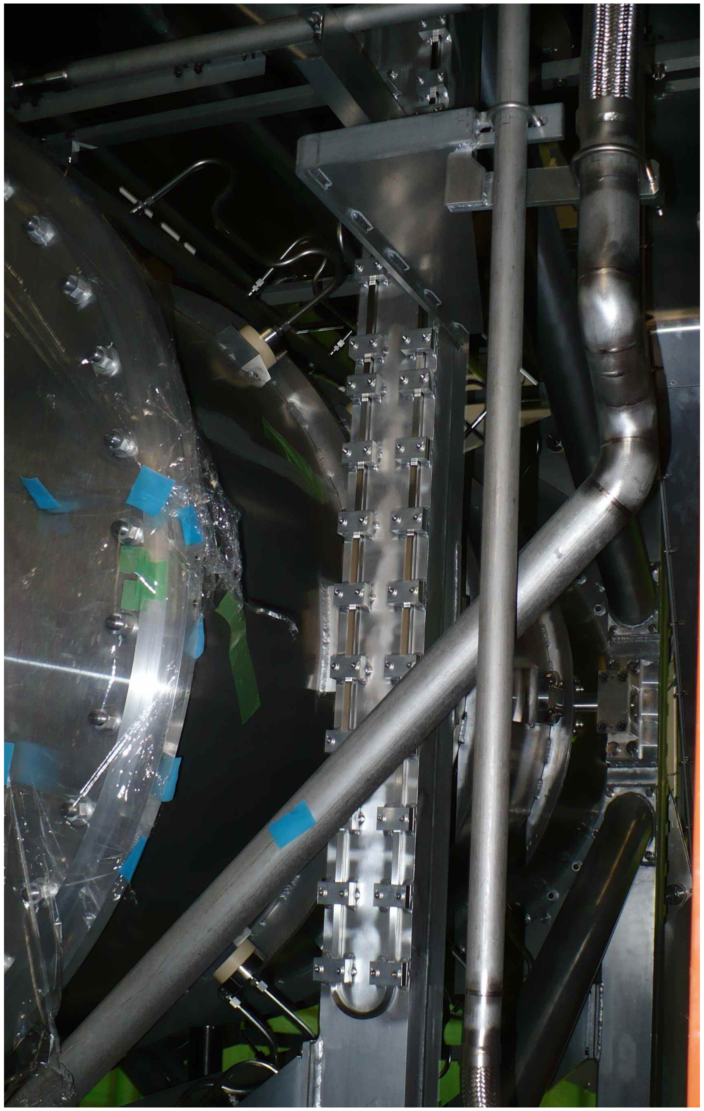
Horns – drain and electrical isolation



The NuMI horn electrical isolation is at the hanger above the horn, which we repaired several times.

Not sure this could be repaired, but CNGS did repair this seal on their horn 2 after a short period of running.

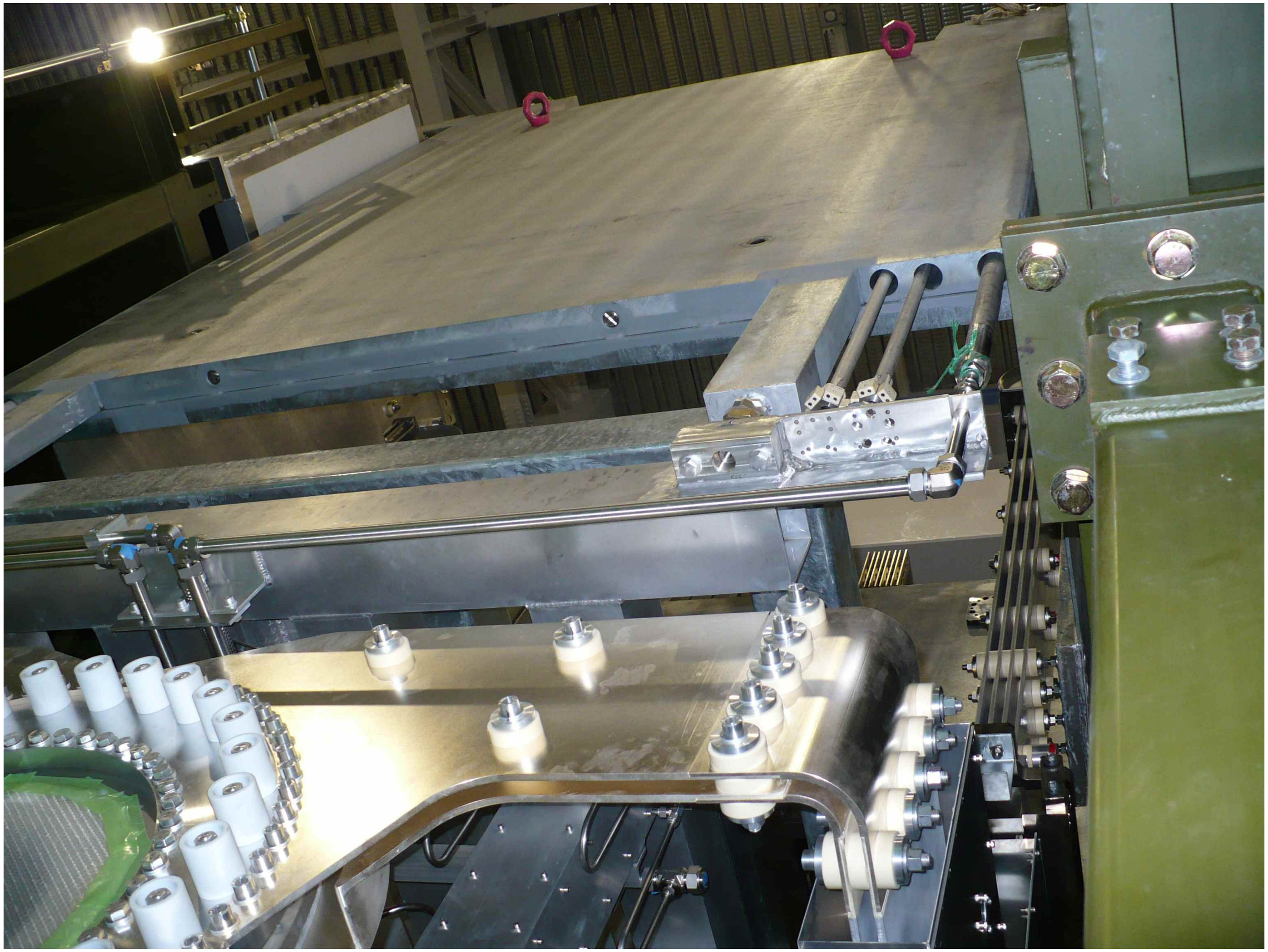
Horn support cooling



The horn support beams are water-cooled (U shaped loop)

(The water-cooled NuMI hanger for horn 1 was a source of a water leak, NuMI horn 2 did not need the cooling)

Horn hanging from module similar to NuMI



Remote water & instrumentation-line connections copied from NuMI.
Note strip-line sections clamped together (NuMI welded)

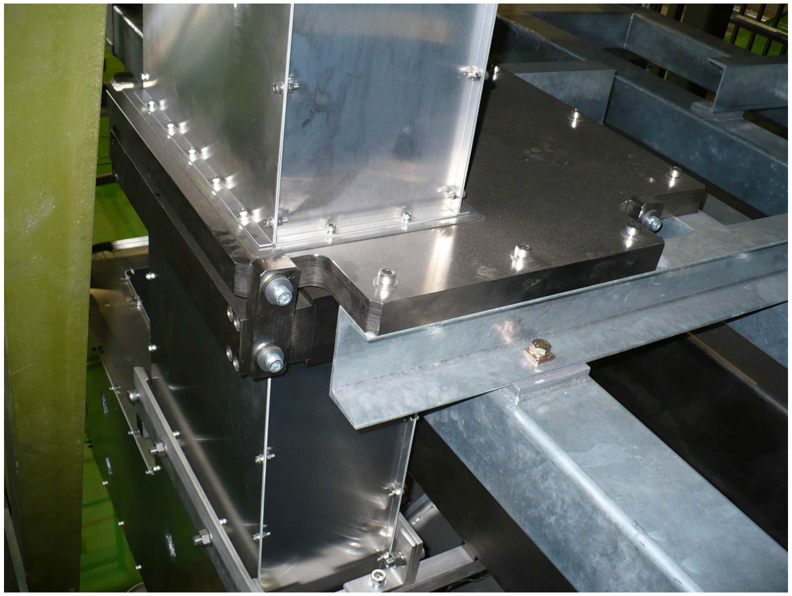
Horn water spray

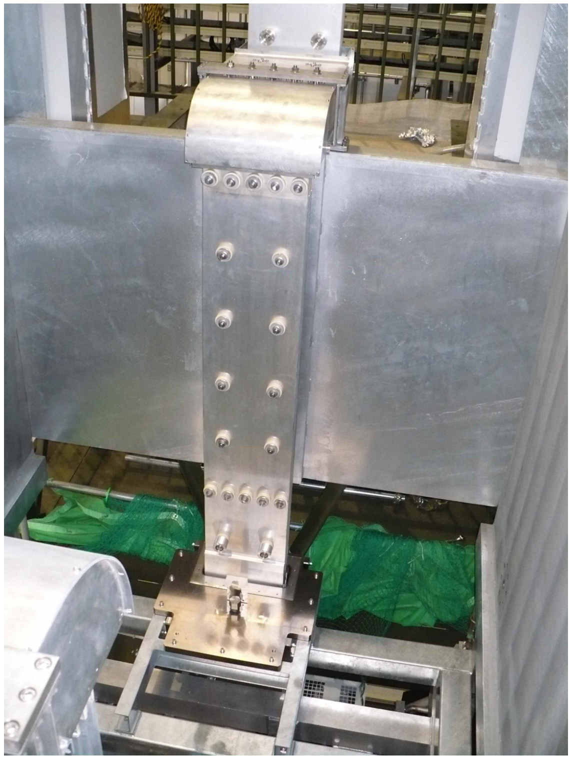
Water spray ports with electrical isolation and drains as per Mini-BOONE

Strip-line and remote clamp

Jog to remove line-of-sight

Duct flows helium to cool stripline

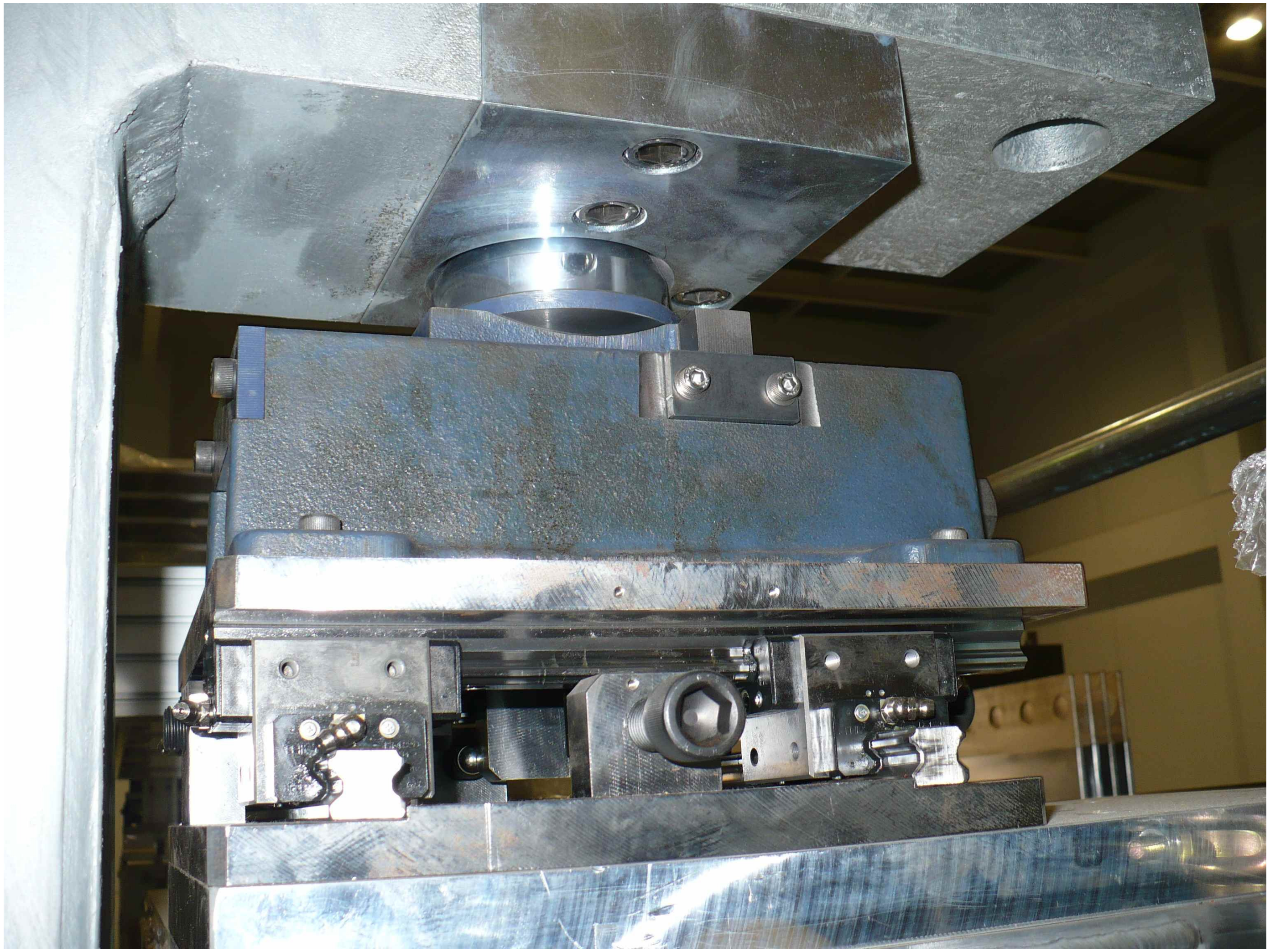




Strip-line remote clamp a la NUMI, but permanently fixed to module

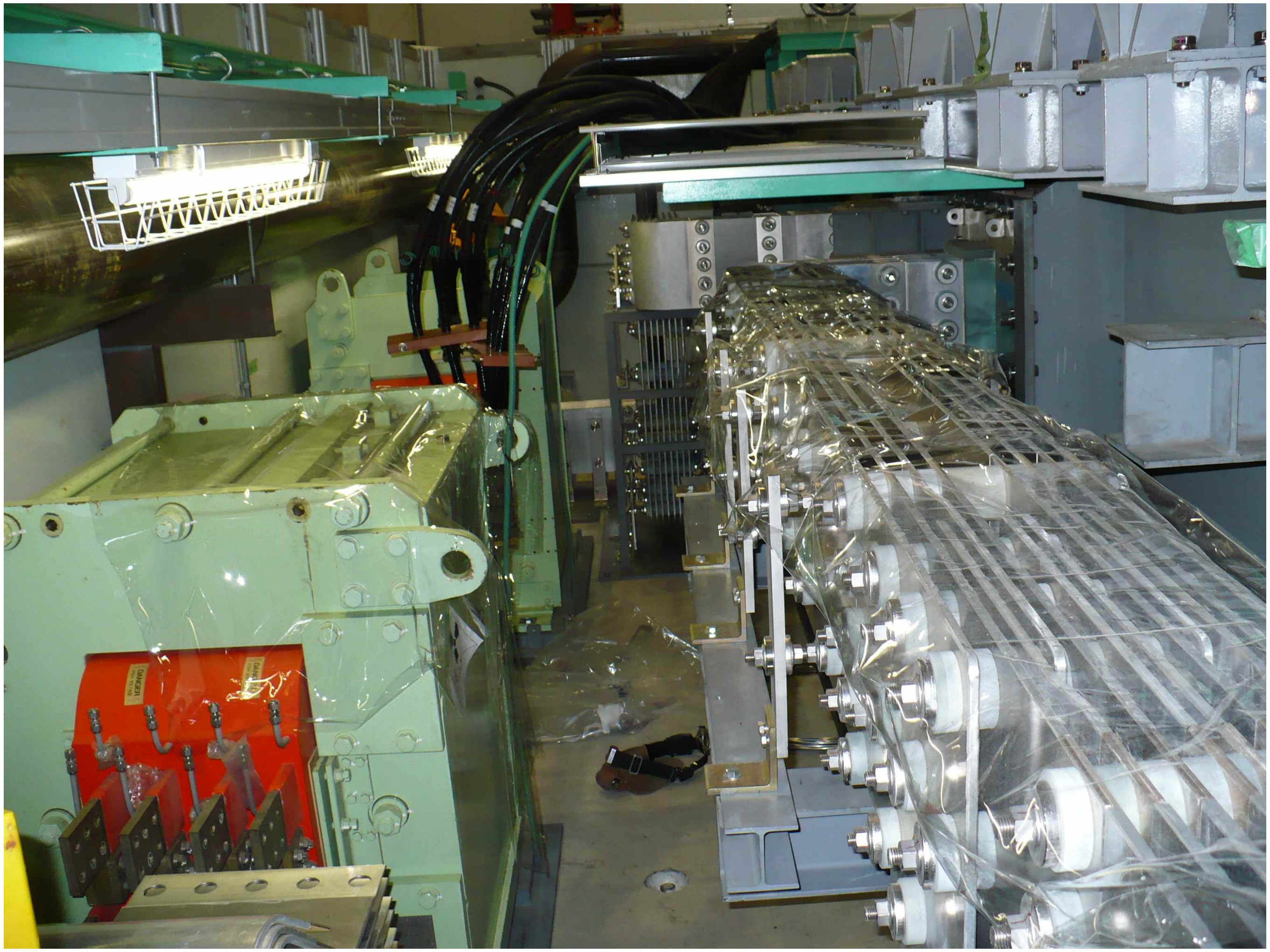
(NuMI strip-line block is replaceable; T2K helium may make this less risky)

Horn alignment via translation of entire module



NuMI has shafts through module for target, horn 1, but I would not repeat that, this makes more sense.

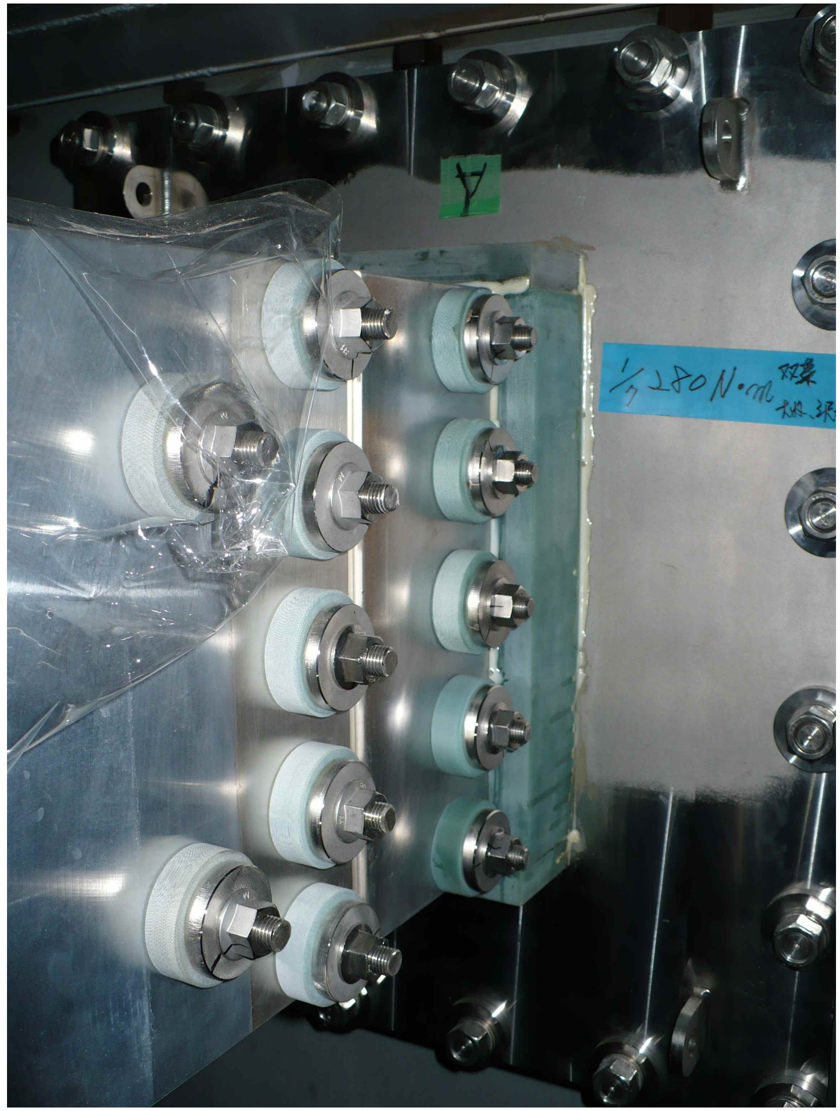
Transformers between power supply and horns



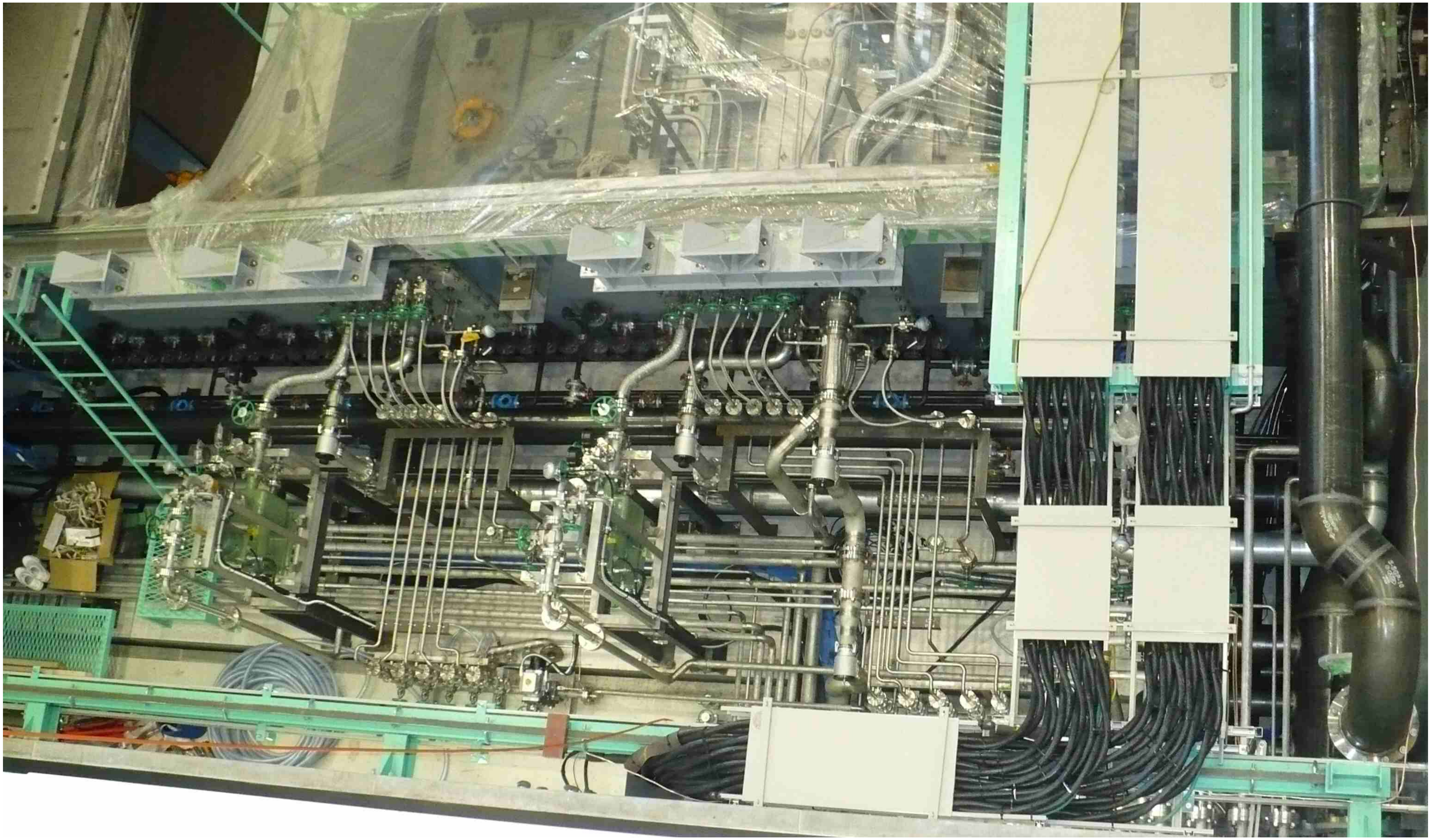
Horn 1 has separate transformer, Horns 2 and 3 are run in series.
Transformers are from K2K beam-line, mildly radioavtive.
(NuMI: No transformers, Horns 1 & 2 in series)

Strip-line penetration to helium volume

G10 electrical isolation
with epoxy gas seal



T2K target/horns water & helium penetrations

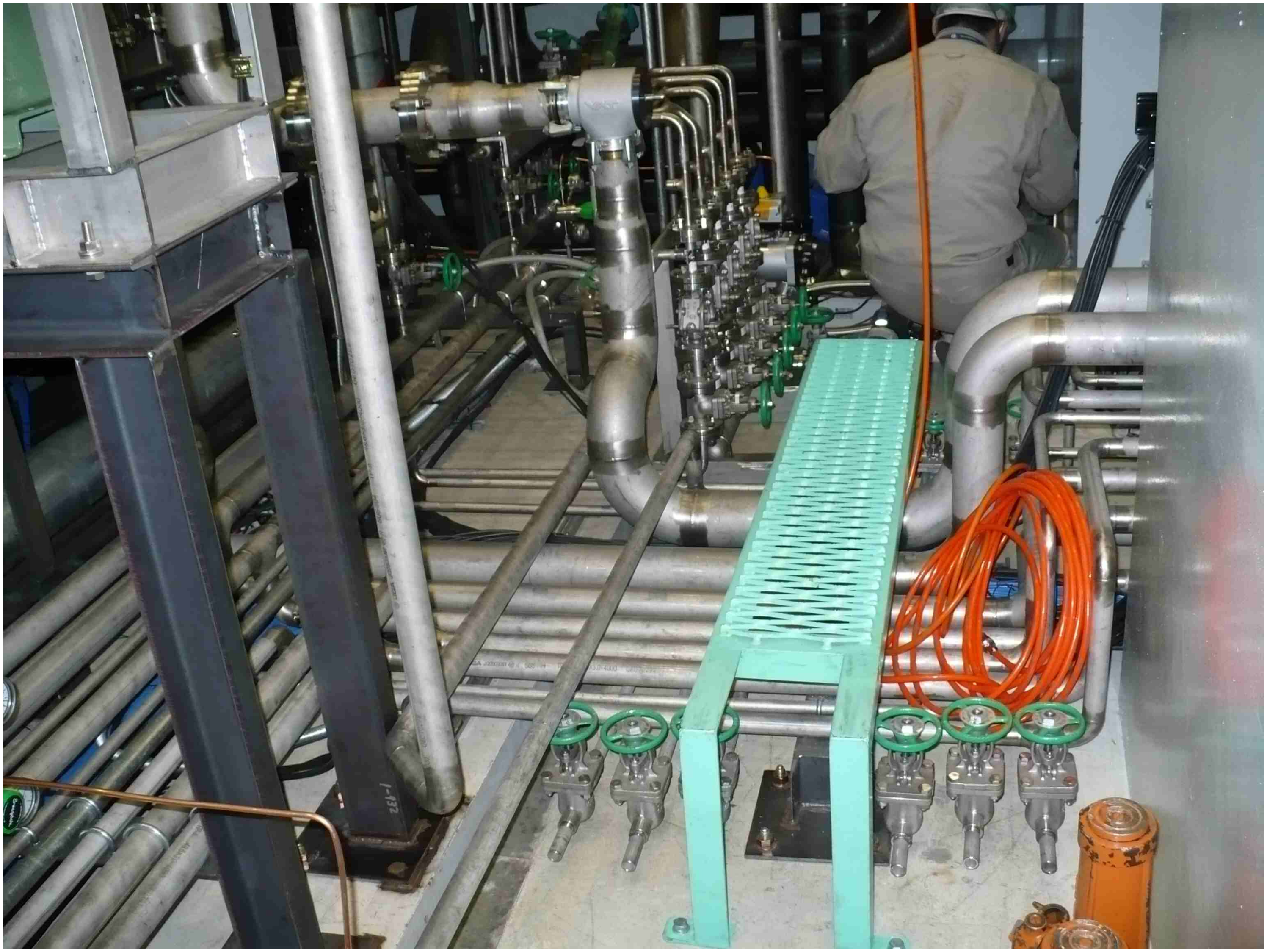


T2K target pile mechanical room (1/3)

Support room space extremely tight

Replacing anything big will be extremely hard

Walkway



Work-cell in T2K target hall

Helium Vessel

T2K Helium Vessel leak rate:

They re-welded two areas on target-pile to decay-volume transition, after which leak rate met specification, stated to be
10^-7 Pascal m^3/second (~ 10^-6 cm^3/second by my conversion but I don't see how one could measure to this level)

Evacuated to 50 Pascal (using 1 Atm = 10^5 pascal, reached 0.4 Torr, which is right around what the NuMI decay pipe ran at)

Compare helium vessel volume:
T2K: ~ 1500 m3
NuMI: ~ 2000 m3
DUSEL: ~ 3000 to 4000 m3 ?

At least for now, they will exhaust helium and fill with new helium when replacing target or horn.

No scrubbing system for now.
Sealed volume, not follow atm. pressure variations.
Note target pile evacuated before helium fill.

T2K beam-line comparison

T2K	NuMI	Comment
Titanium beam window with remotely operable seal	Beryllium beam window without remote seal	Our smaller spot size favors Beryllium. LBNE may want to copy remote seal.
Water cooled baffle (larger than NuMI, part of upstream shield wall)	Air cooled baffle	Air cooling gives one less water system to fail, provides larger temperature swing for beam-scraping monitoring
He cooled graphite target	H2O cooled graphite target	Target requires a lot of study

T2K beam-line comparison

T2K	NuMI	Comment
Tried stir-friction welding horns, but resorted to TIG for final inner conductor welds	Horns TIG welded. Already copying stir-friction welding for producing strip-lines	
No coating on horns	OC anodized, IC nickel-plated	T2K in helium, NuMI in corrosive air. LBNE in ??
Strip-line radial out from horn	Strip-line axial, then radial to allow for flexibility for thermal/alignment	At 700 kw, sufficient cooling of the axial stub is problematic for NuMI, under study
Ducts to carry cooling helium by strip-lines	Rely on general chase air-flow	Must improve NuMI design for LBNE

T2K beam-line comparison

T2K	NuMI	Comment
Horn remote water connection copied from NuMI	Compression fitting with nut turned by outer pipe welded to it	
Strip-line remote connection clamp copied from NuMI	Pressing plates to push strip-line prongs together	
Instrumentation remote connectors copied from NuMI	Ceramic-shell connectors guided in by daggers	
Horns hang from module, module is filled with shield blocks after installation, alignment is by moving whole module	Horns hang from module, module is filled with shield blocks after installation, horn 1 moves relative to module by motor-drive, horn 2 by moving whole module	NuMI can move horn 1 by re-aligning whole module at top, but involves shimming, is not easy. LBNE copy T2K?

T2K beam-line comparison

T2K	NuMI	Comment
Target chase, horns, decay volume, and absorber all in helium volume that can be evacuated	Decay volume is helium, target chase + horns + absorber are in air	*Helium advantages: reduced corrosion, don't need large volume for air to decay before release to atmosphere. Dis-advantages: making pressure-tight volume, extra time for target-pile intervention.*
Target pile + decay volume walls water-cooled	Target pile air-cooled, decay volume water-cooled	Air-cooled target pile sufficient for ANU 700 kw, but believe will need water-cooled inner shielding for LBNE
No decay-volume window (helium in both target pile and decay volume)	decay-volume upstream aluminum window not designed to be replaced	Could NuMI run with air in decay volume if window fails? Decay pipe upstream window should be replaceable or eliminated for LBNE

T2K beam-line comparison

T2K	NuMI	Comment
Surface building, several meters of top concrete shielding	Tunneled, uses the rock for final top-shielding, only 18" of top concrete shielding	LBNE target hall could be either tunneled or pit-mined. Pit-mined could be filled-over or open-to-surface. Consider crane hook-height, shielding, air migration in choices.
Crane has duplicate motors in case of failure with hot item on crane	Crane has standard set of motors	Could/should NuMI crane be upgraded ?
Primary beam instrumentation includes ion profile monitor	Has SEM profile monitor and OTR profile monitor only	Thinking about ion profile monitor as eventual upgrade ?
How is alignment done ?		

JPARC visit – T2K target hall notes

Extruded graphite at dump because cheaper
Carbon steel cooling pipe in cast aluminum pressing plates,
Trouble keeping flat as casting cooled
Surface tolerance 0.1 mm for good thermal contact

Deal with tritium exiting blue blocks?
-> they don't use blue blocks,
The JPARC hadron hall uses hundreds of blue blocks
Blue Block supplier Duratek changed to Energy Solutions,
ran out of U.S. radiated steel, now importing.
Capacity ~ 50 blocks / year, JPARC has them on order

NuMI order of magnitude without looking anything up ~ 400 blocks
~ 4,000 tons x $600 / ton = $2.4 million worth of steel
but we got it for ~ $0.1 million

JPARC visit – T2K target hall notes

Time for horn change-out? Months (up to six ?)
We did not have time to discuss their change-out procedure,
but the extensive top-shielding and the helium vessel certainly have impact

Repair strategy for helium vessel? …

JPARC visit – T2K target hall notes

320 kA, Horn 1 somewhere between 1 ms and 4 ms pulse,
some trouble with High Voltage

Alignment tolerances?
Horn 1 -> 1 mm, Horn 2 and 3 -> 3 mm (similar to NuMI/NOVA)

Instrumentation for targeting, horns?
OTR at target (note a single monitor can give X, Y
but not vertical and horizontal angles;
NuMI/Nova handles angles by scanning
baffle+target system, doesn't work for T2K/LBNE)

JPARC visit – T2K target hall notes

Horn construction:
Ceramic ring like NuMI but larger (special Japanese vendor)
no coatings

Monitoring for horn deterioration?

Asked about removing crane electronics -
they think level will be low enough not to have to.

Horn module about 15 ton, but use main crane on it
because of crane redundancy.

JPARC visit – T2K target hall notes

Fraction of running for neutrinos?
(130 days per year from a talk on web)
(Since May 1, 2005 NuMI has had beam for average of 262 days/year)

15x10^13/pulse proton beam 0.6 cm sigma beam spot
increase rep rate to compensate for 30 GeV vs 50 GeV
30 GeV 0.5 Hz 750 kw for forseeable future
1.6 km around ring for 9 bunch but 1 for kicker = 8 bunch
each bunch around 10 m long -> 30 ns, 5 microsecond spill
May increase to 18 (16?) bunches

JPARC visit – T2K target hall notes

T2K has no hadron monitor.

Muon monitor 10^8 particle/cm2
less than our hadron monitor (~2x10^9?),
but higher than our muon monitor

Some areas of JPARC have sunk ~ 1 inch
Piles were to be sunk 25 to 50 m to bedrock
below sand, but studies said 30 m in sand was OK.

Very clean - they put down plastic and plywood over
the epoxy coated floor so delivery trucks would not mar the surface.

Poured concrete over decay pipe and beam dump rather than shield blocks,
limits repair capability (done for budget reasons)
Beam dump is in helium volume.
Muon monitor is after helium volume.

JPARC visit – T2K target hall notes

DK collimator at end of target hall limits power to decay walls

For Access, where do shielding-blocks go?
did not get answer, may have to move outside.

Power spray: 1/3 target hall, 1/3 DK, 1/3 dump

Aluminum cover of target hall helium vessel
(two pieces, with port for OTR)
1.2cm thick decay iron
10 cm water-cooled steel helium vessel around horn
then steel shielding air cooled then concrete

Earthquake brace inside helium vessel interfered with
Strip-line on horn, delaying installation of horns 2 and 3,
they will modify strip-line by fall.

JPARC visit – T2K target hall notes

Patrick says shielding "T-Blocks" were zinc-clad steel

note target helium is separate system from vessel helium because vessel helium may not be pure enough to prevent oxidation of the target graphite

JPARC visit – T2K target hall notes

20 people limit in ND hall

Near Detector on-axis is deep because of 3.5 deg slope of beam
Want 1 mr accuracy -> 30 cm at ND 280 m on-axis monitor

"What have you learned that might not be obvious to us?
What worked well, what would you rather have done differently?"
"ask us after we have run"