Development of the T2K target for a 0.75 MW proton beam

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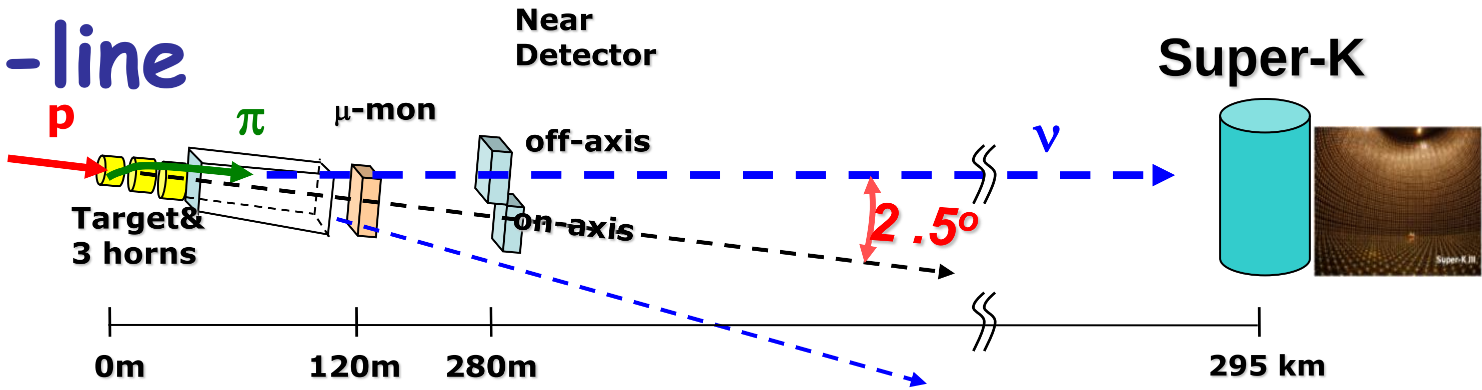
RAL/KEK/Kyoto Collaboration

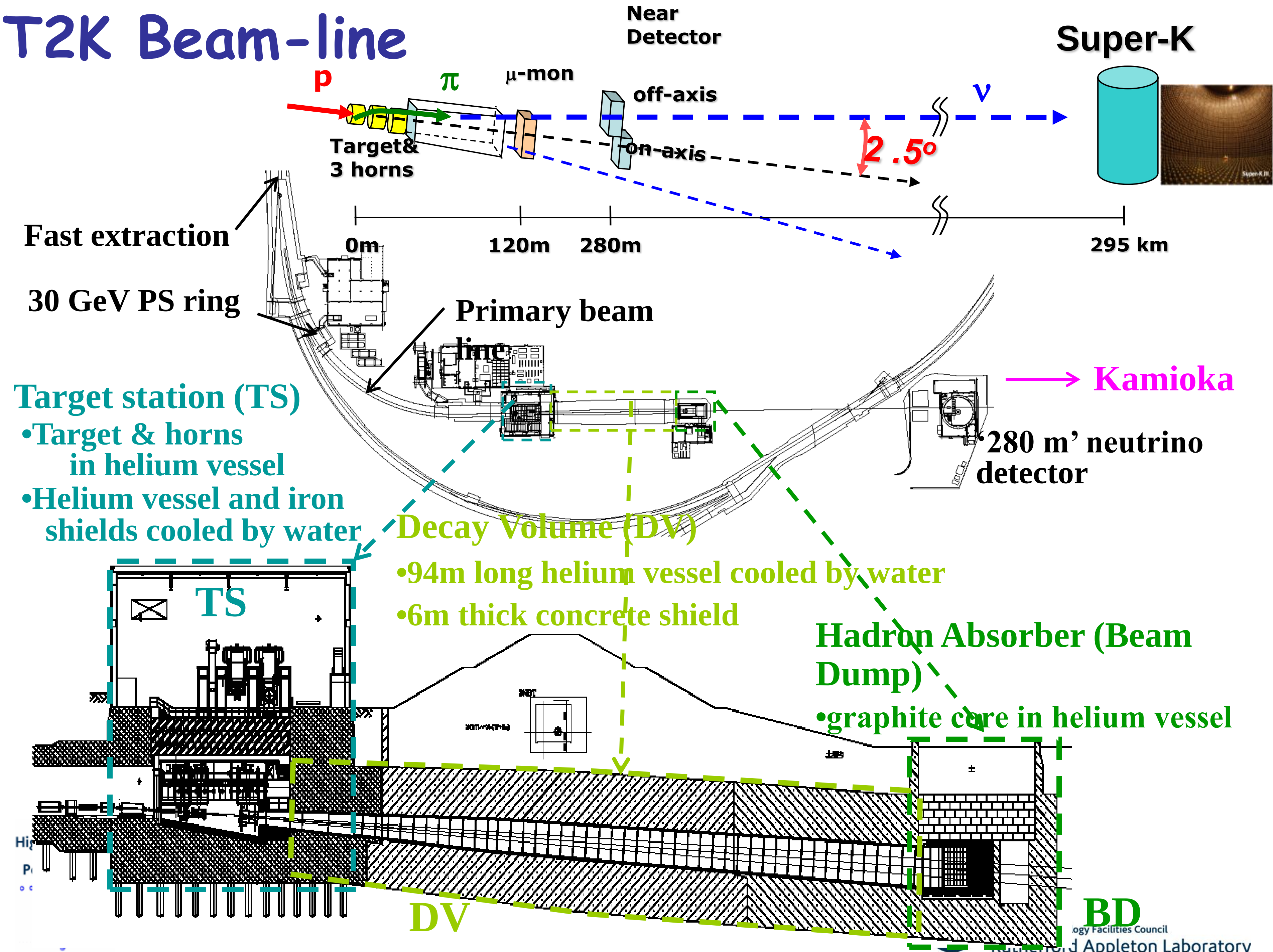
High Power Targets

Science & Technology Facilities Council
Rutherford Appleton Laboratory

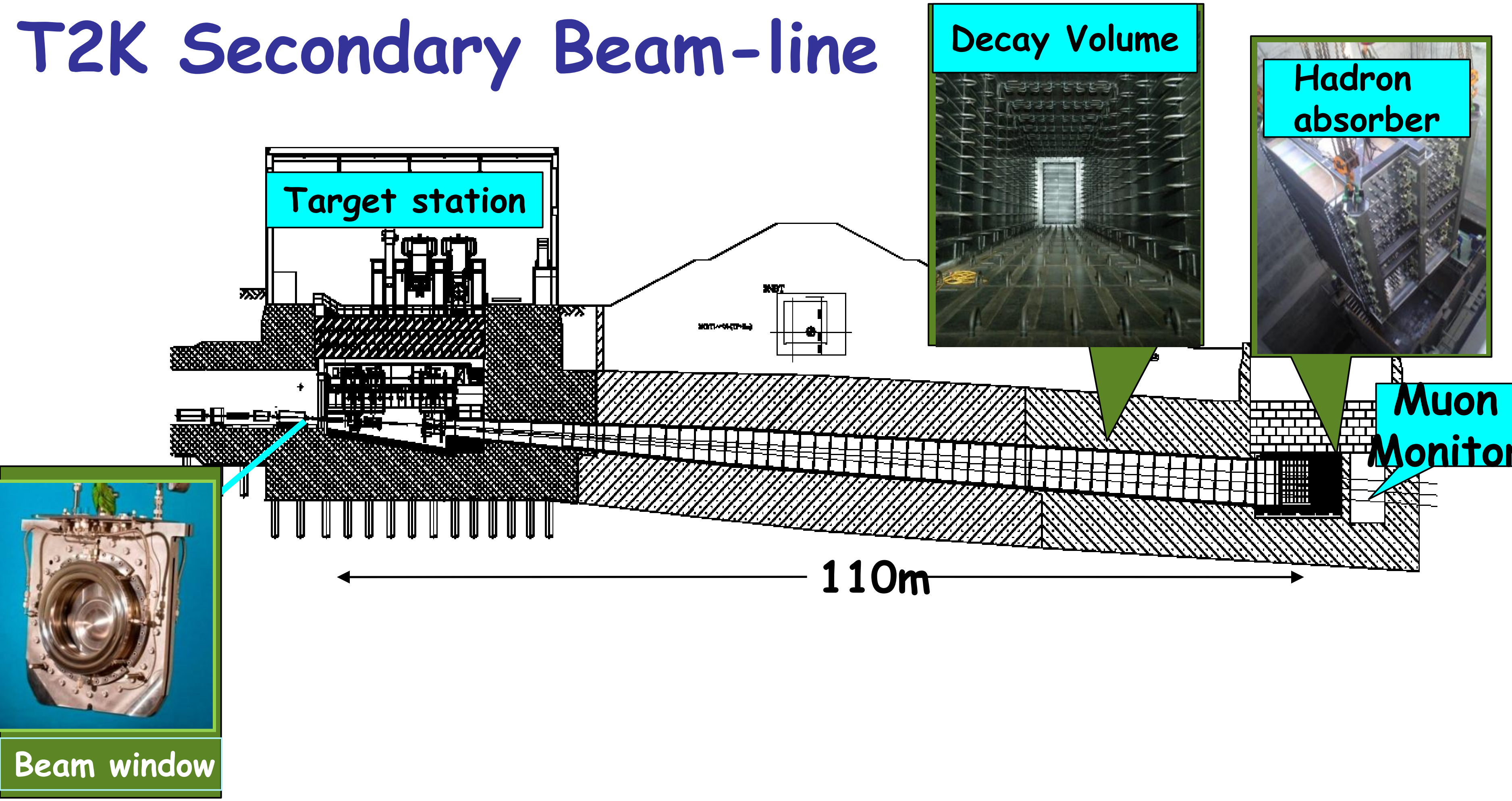
T2K Beam-line



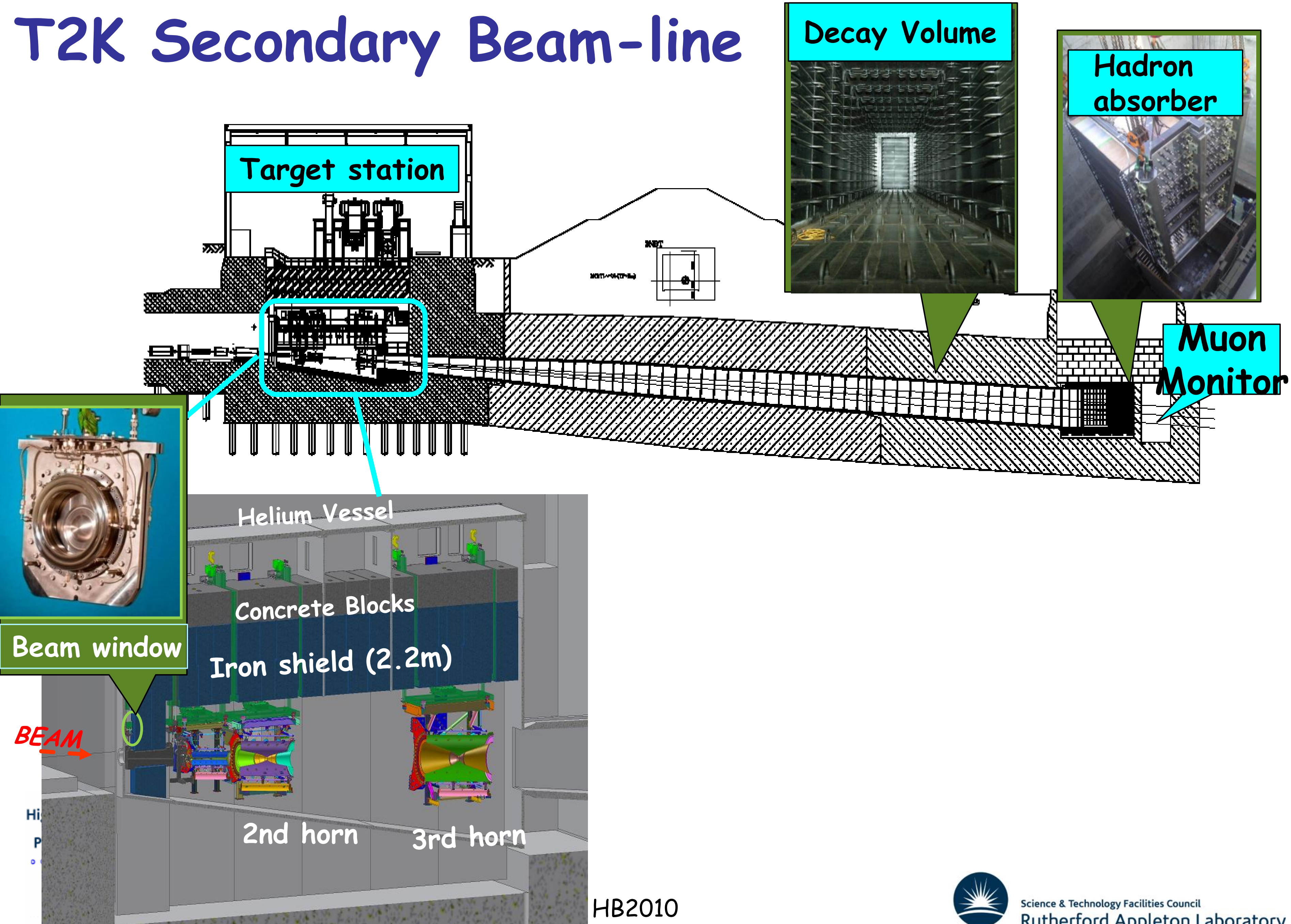
T2K Beam-line



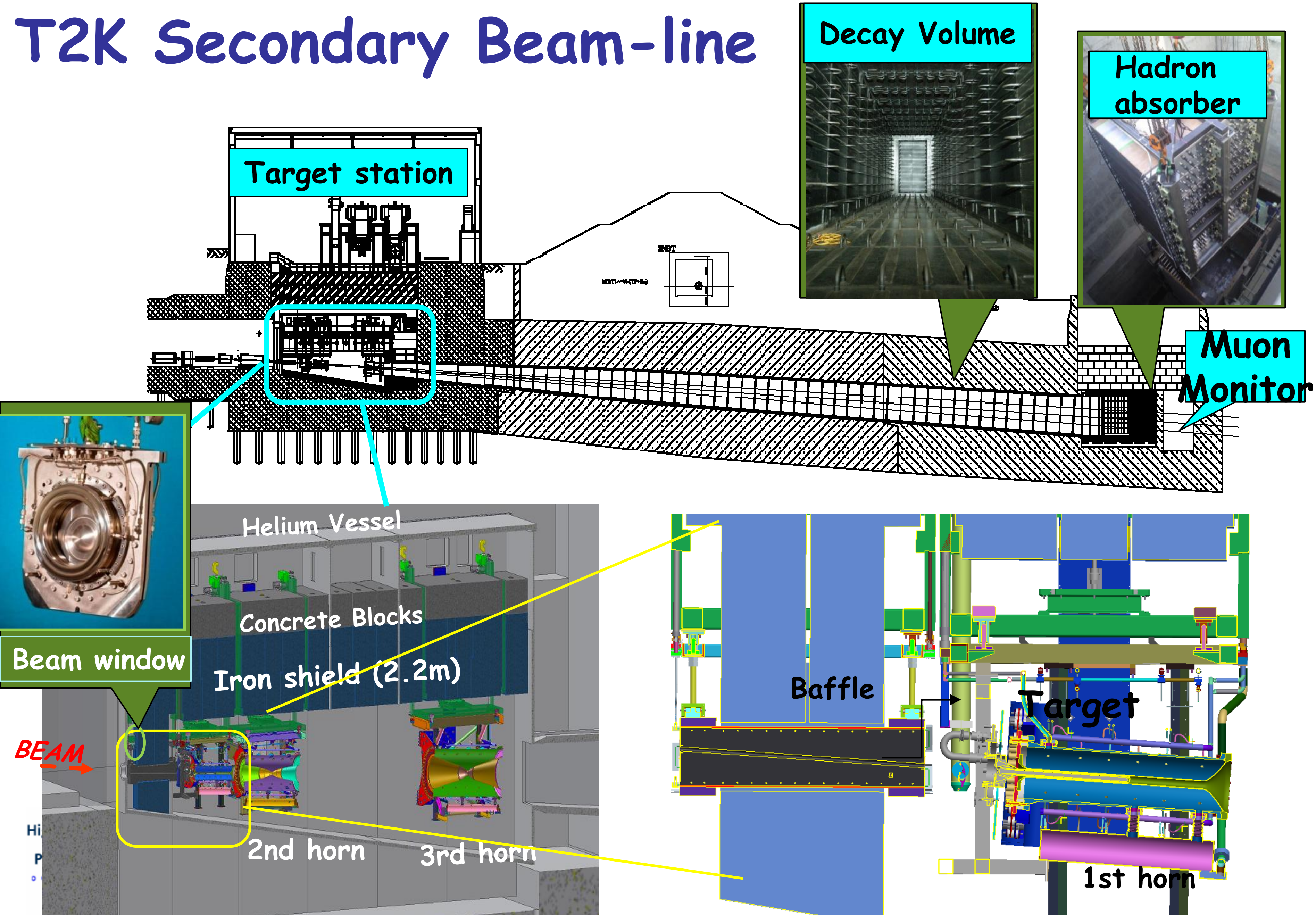
T2K Secondary Beam-line



T2K Secondary Beam-line



T2K Secondary Beam-line



Specified Beam Powers for T2K Secondary Beamline design – towards a Superbeam

- Start-up schedule date: 1st April 2009
  - Actual first beam 23 April (Not bad!)
- Components built for Phase I: 0.75 MW
  - Beam window
  - Baffle (collimator)
  - Target + 1st horn
- Phase II power: 1.66 MW
  - Road map anticipates within 5 years
- Components built for ultimate power: 3-4 MW
  - Target station
  - Decay volume
  - Hadron absorber (beam dump)

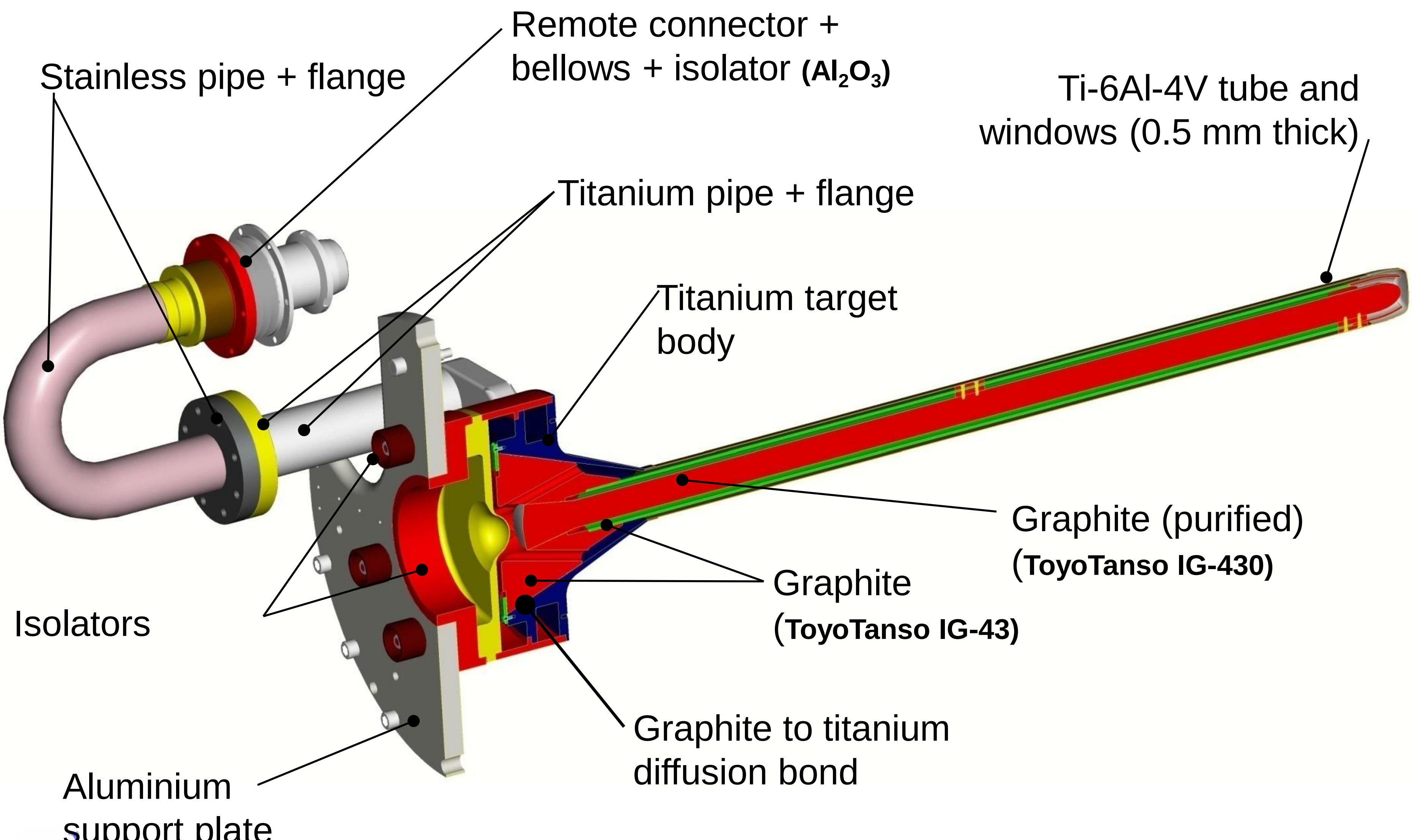
Design beam & target parameters for start-up (April 2009)

Proton beam kinetic energy	30 GeV
Average beam power	750 kW
Protons per pulse	3.3×10^{14}
Beam cycle	2.1 s
Pulse width	5 μs
Bunch structure	8 bunches
Bunch length / spacing	58 ns / 598 ns
Beam size at target (1σ)	4.2 mm
Target material	Graphite (Toyo Tanso IG430)
Target radius	13 mm
Target length	900 mm (c.2λ)
Heat load on target	23.4 kW
Peak temperature rise per beam pulse	200 K
Cooling medium	Helium (g), 32 g/s

Specification of Phase 1 Target Design

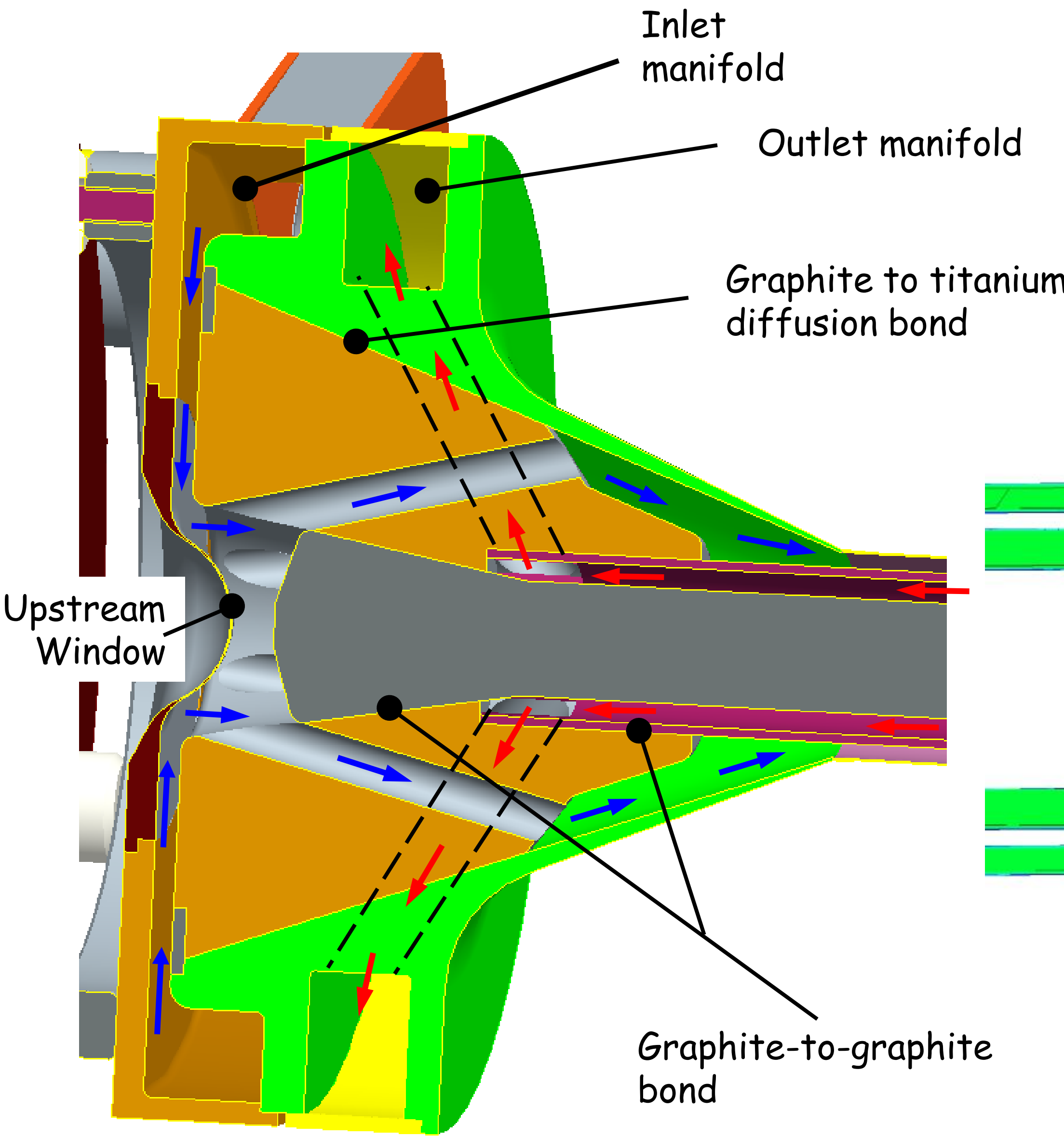
- Graphite rod, 900 mm (2 interaction lengths) long, 26 mm (c.3σ) diameter
- **c.20 kW (3%)** of **750 kW** Beam Power dissipated in target as heat
- Helium cooled (i) to avoid secondary particle induced pressure waves from liquid coolants e.g. water and (ii) to allow higher operating temperature (above 400 C to reduce radiation damage in graphite)
- 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))
- It should be possible to remotely change the target in the first horn
- Start-up date: April 2009

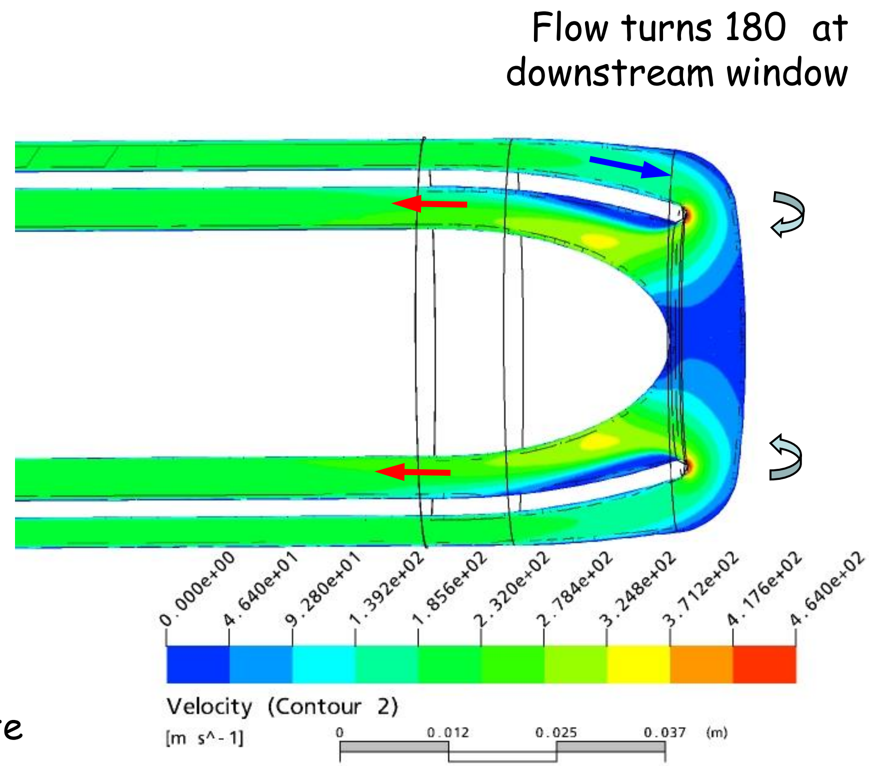
Target Mk 2.0 Design



Target Design:

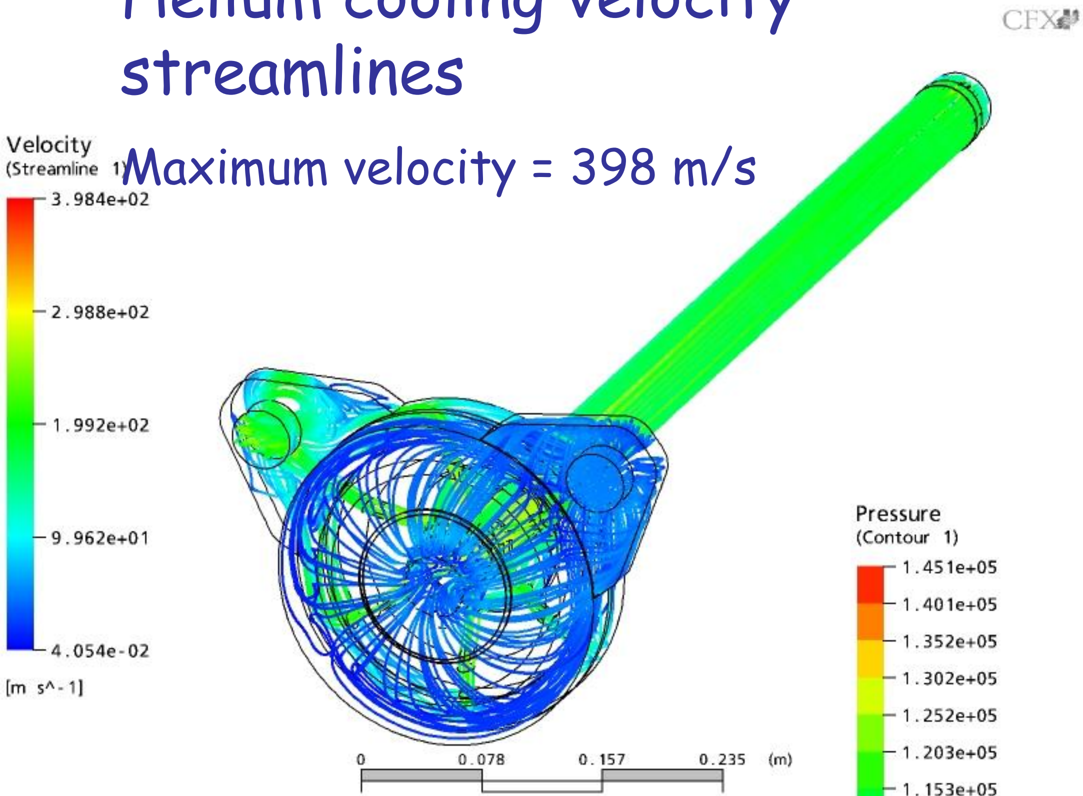
Helium cooling path





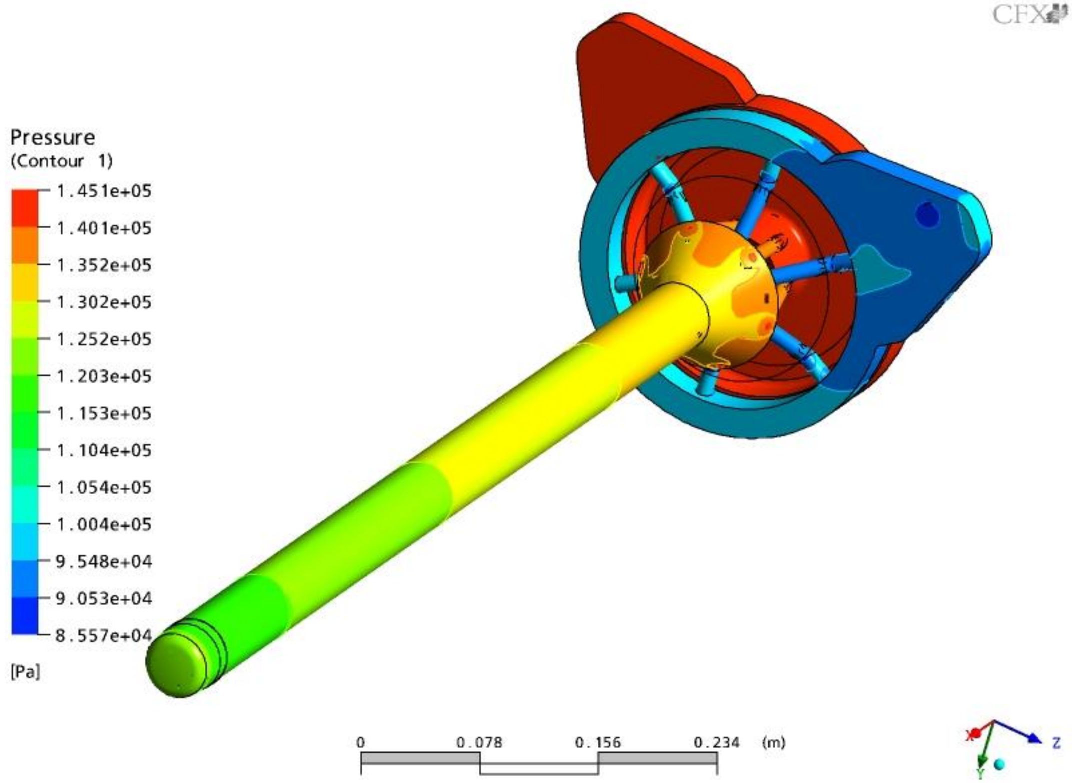
Helium cooling velocity streamlines

Maximum velocity = 398 m/s



Pressures (gauge)

Pressure drop = 0.792 bar

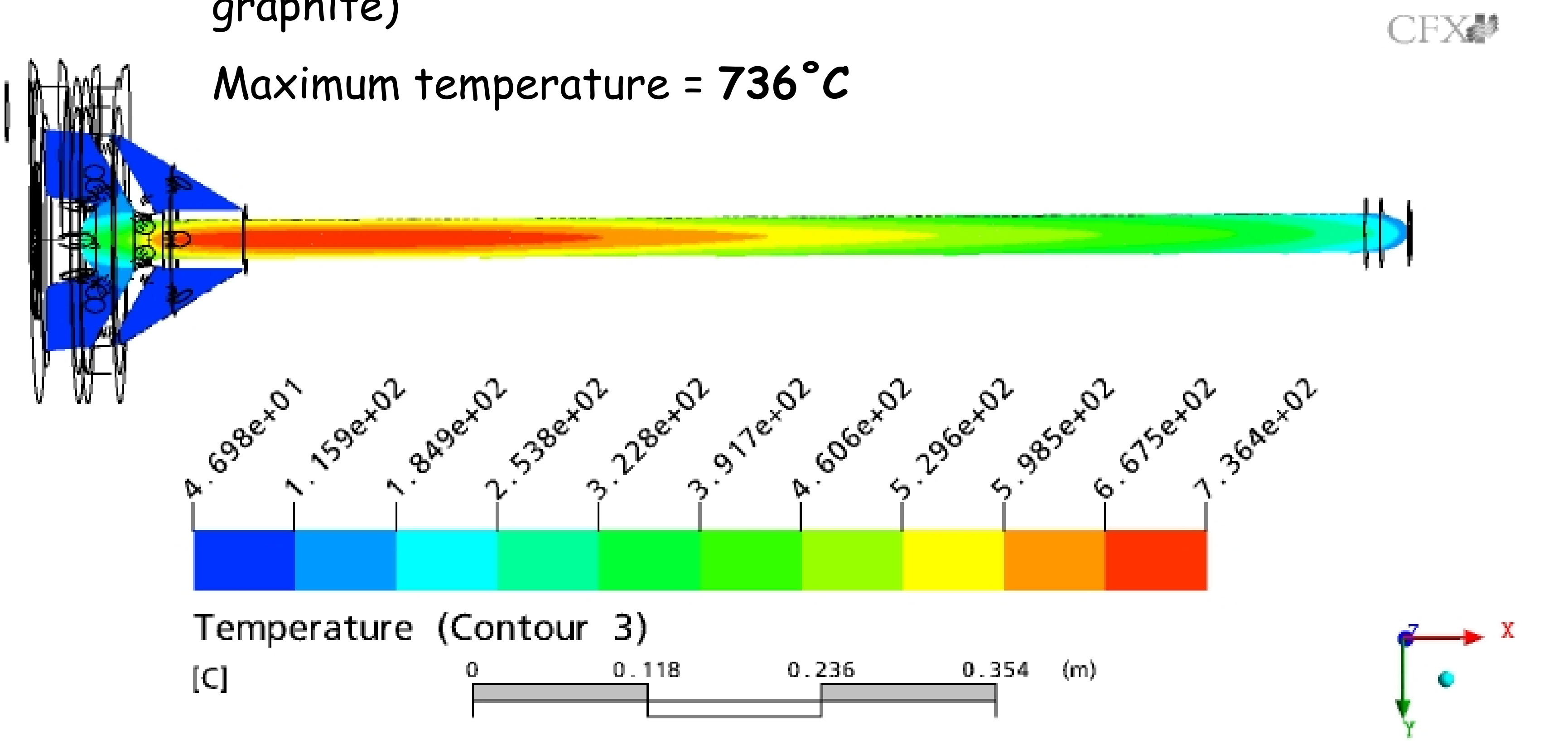


Steady state target temperature

30 GeV, 0.4735Hz, 750 kW beam

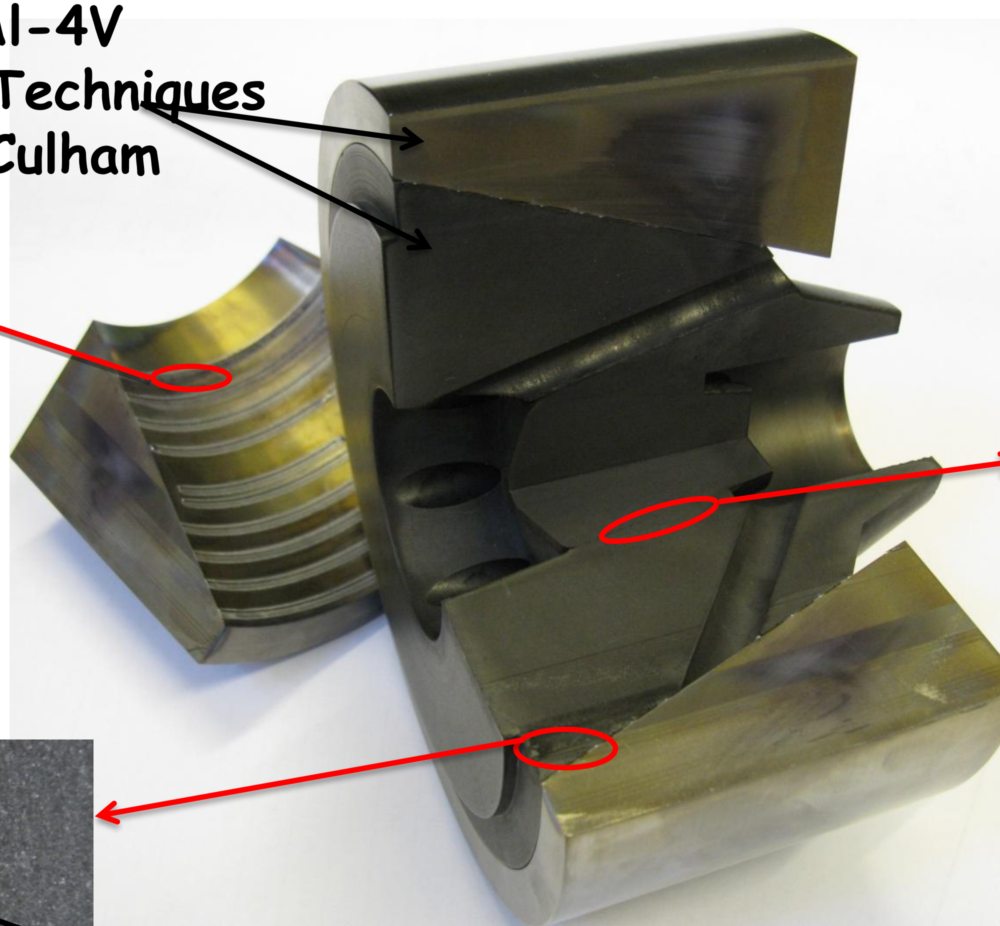
Radiation damaged graphite assumed (thermal conductivity 20 [W/m.K] at 1000K- approx 4 times lower than new graphite)

Maximum temperature = **736°C**

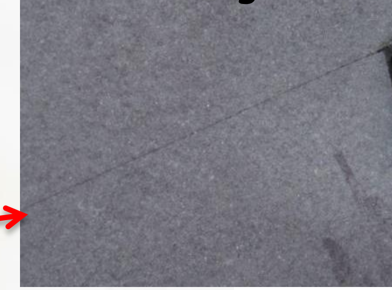


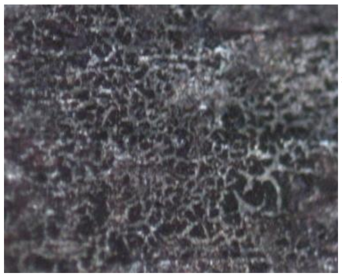
Diffusion Bond + Graphite-Graphite bonding test

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



Graphite-Graphite bonding

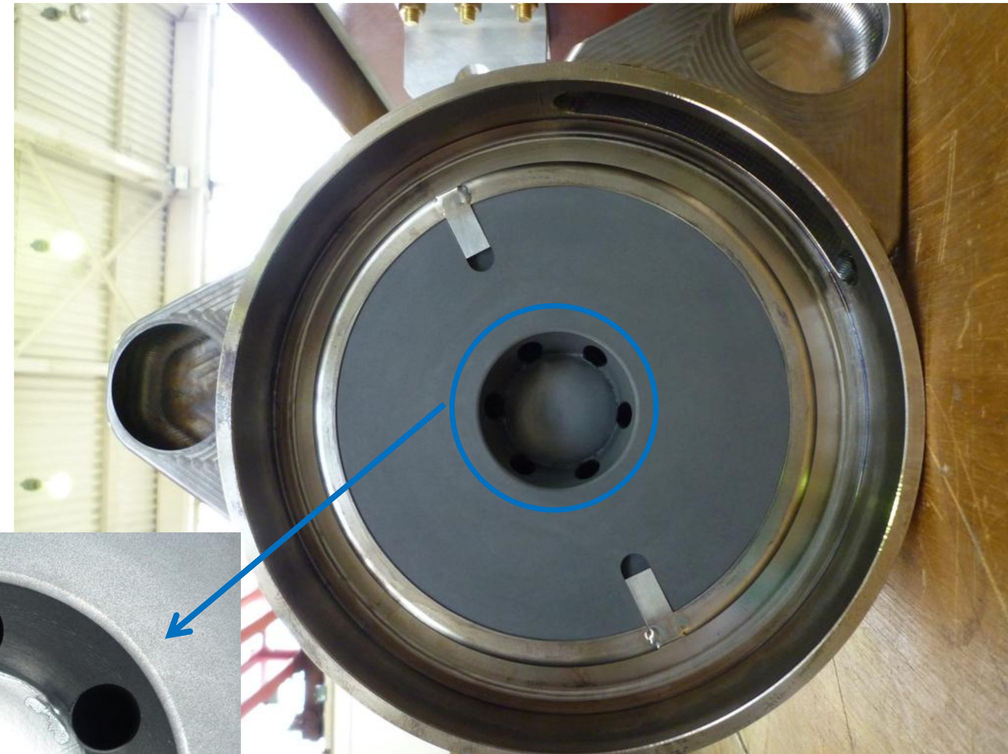


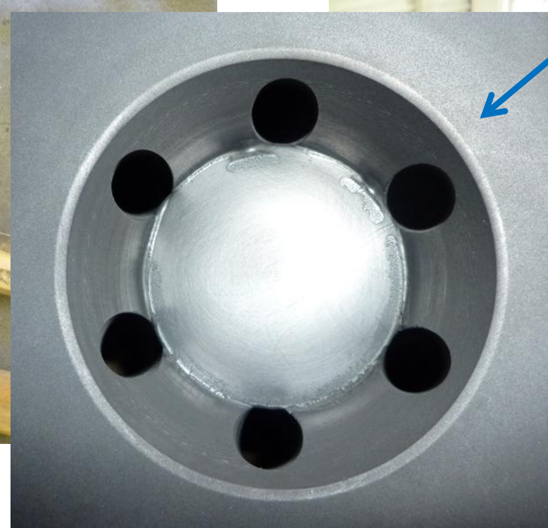


Graphite transfer to Aluminium

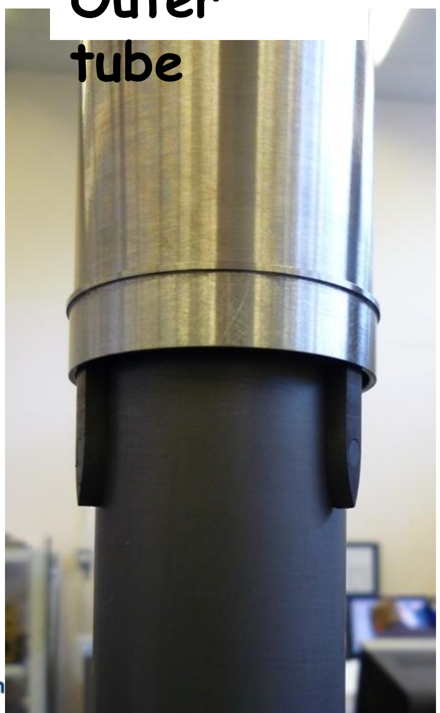
Aluminium intermediate layer, bonding temperature 550°C
Soft aluminium layer reduces residual thermal stresses in the graphite

All graphite components assembled and bonded in one operation

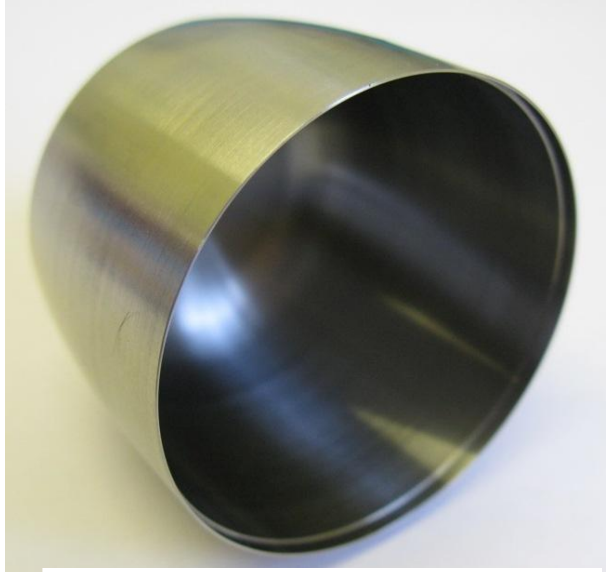




Final titanium components assembled and electron beam welded

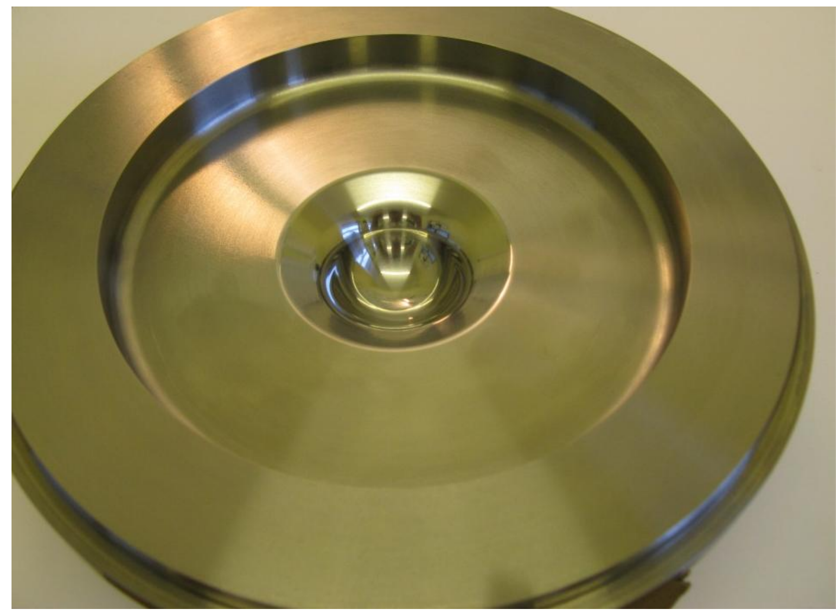


Outer tube



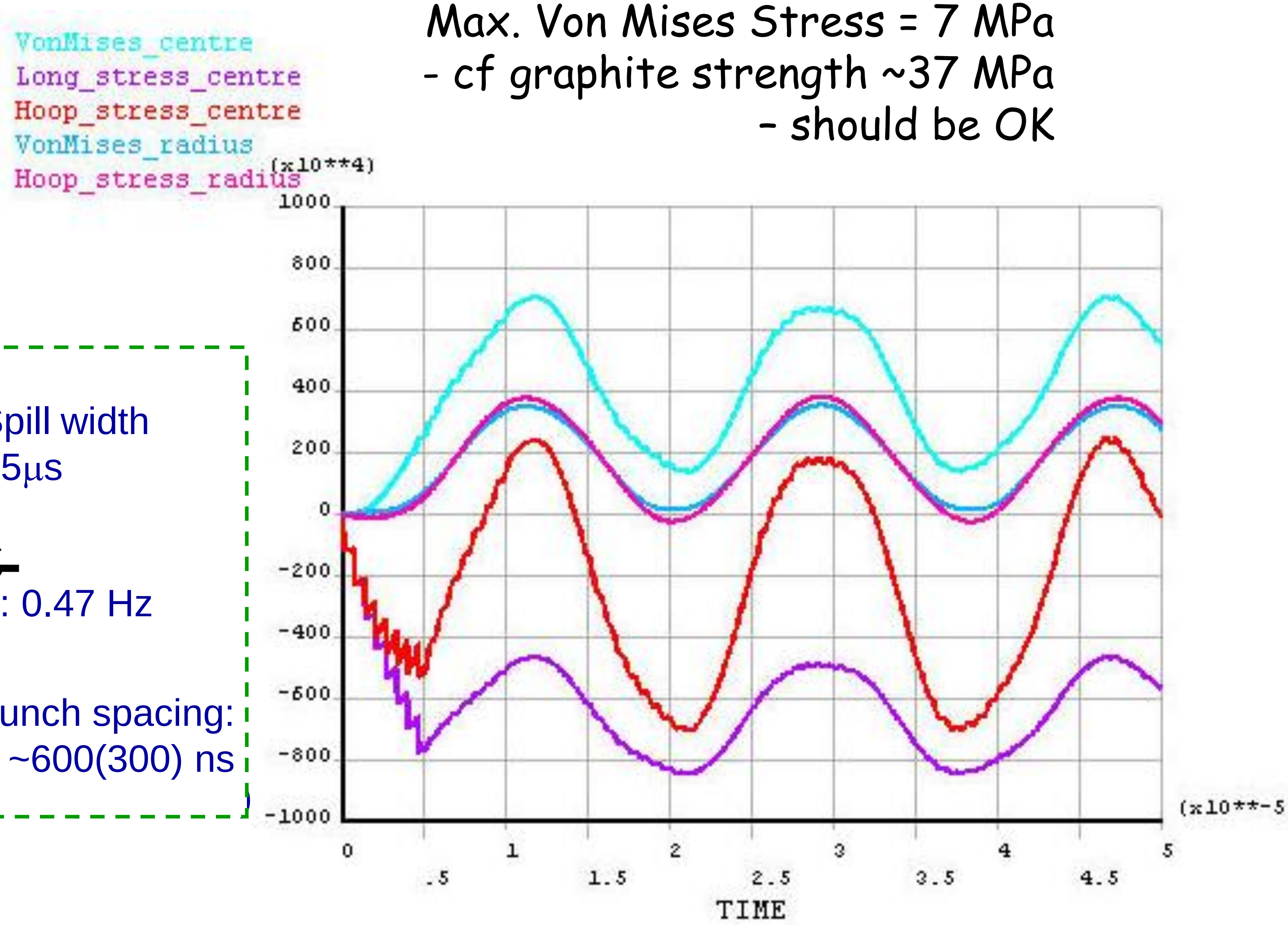
Downstream window

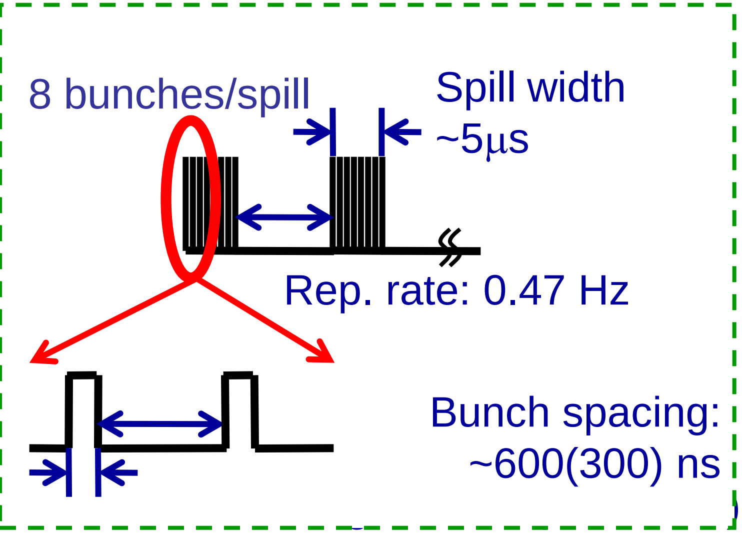
Upstream window



Pulsed beam induced thermal stress waves in graphite

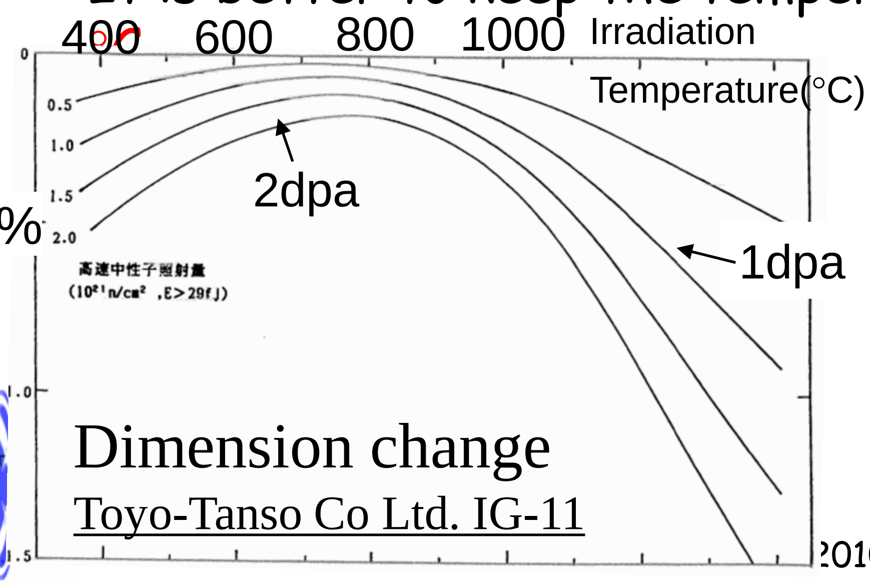
Max. Von Mises Stress = 7 MPa
- cf graphite strength ~37 MPa
- should be OK

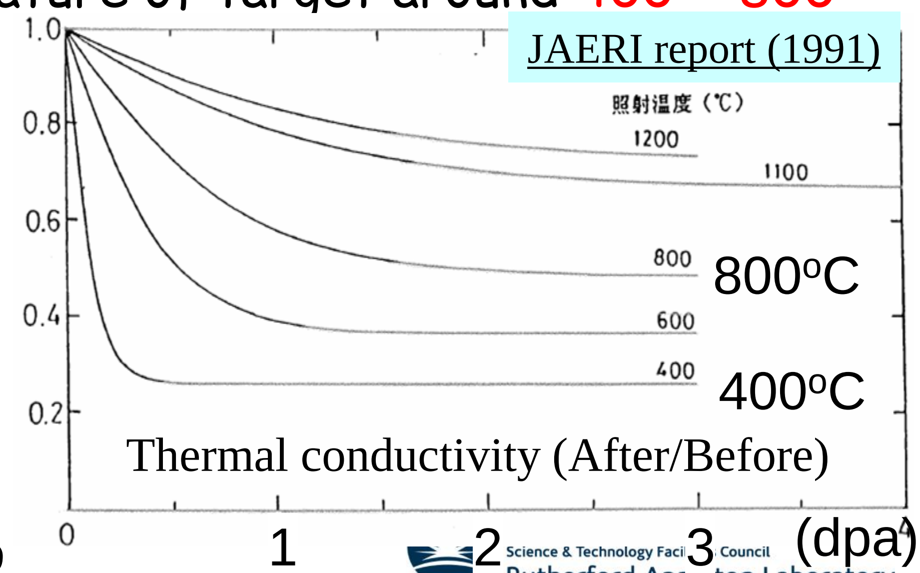




Irradiation effects on Graphite

- 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

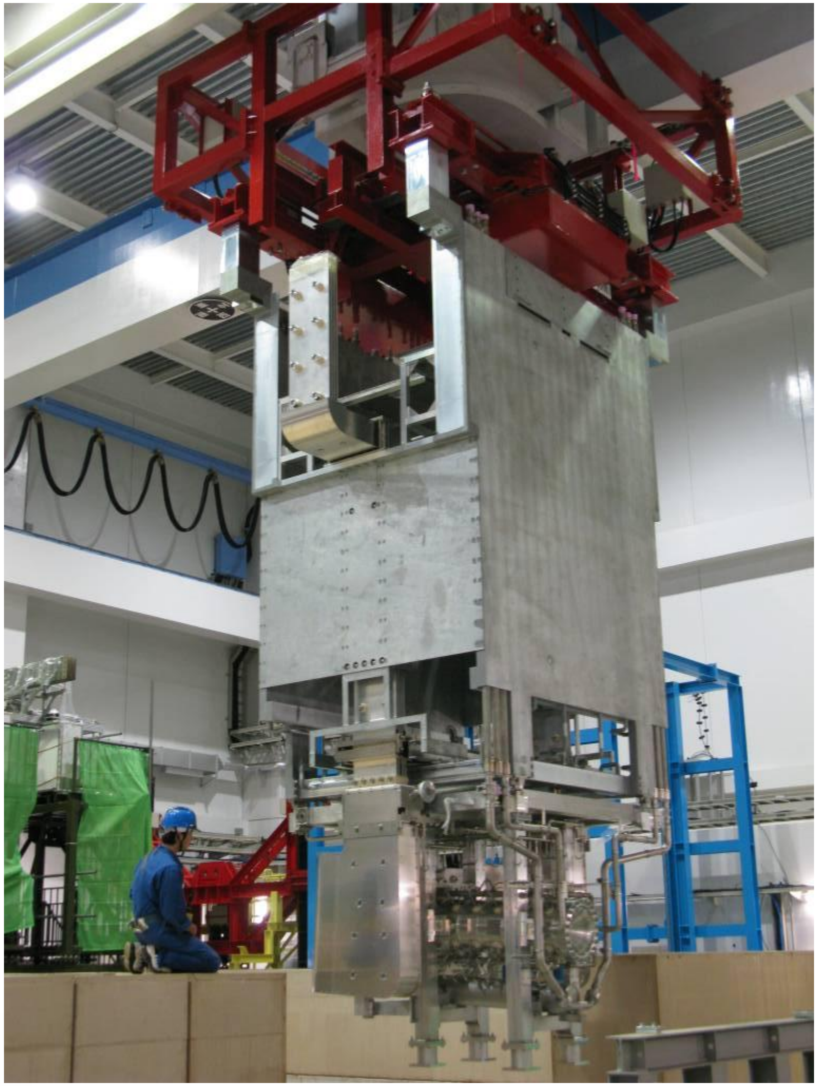


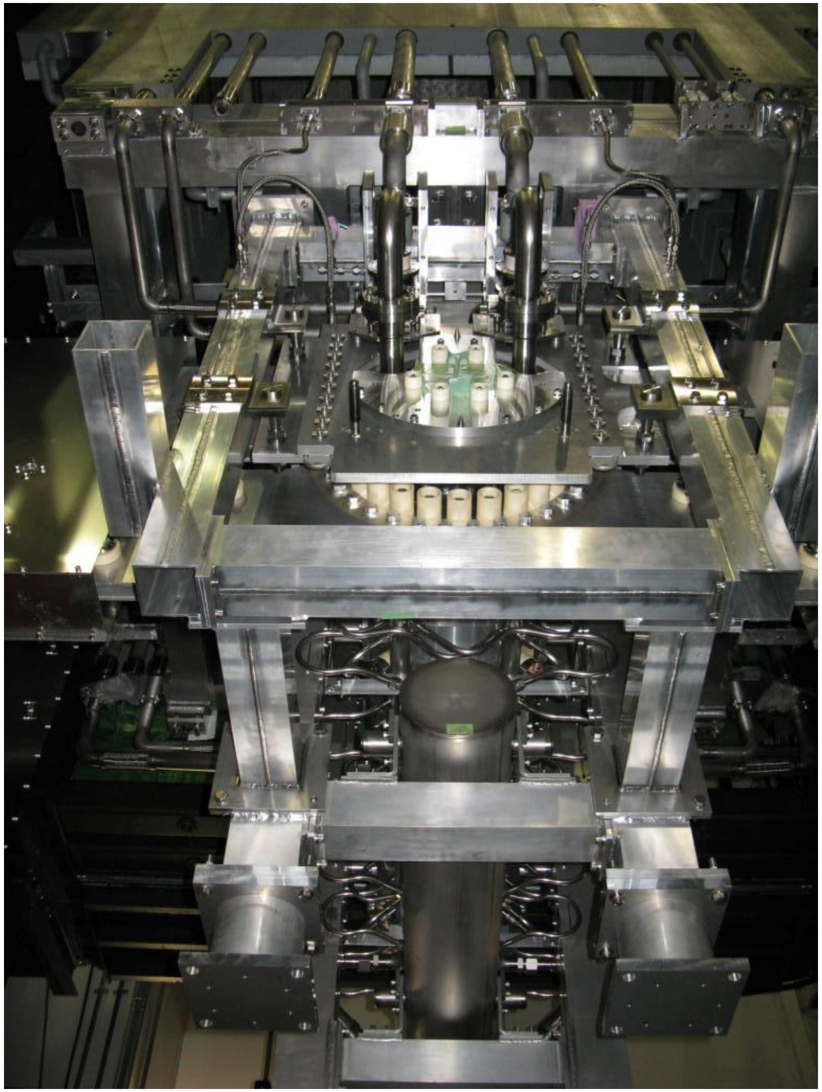


Target Remote Handling requirements

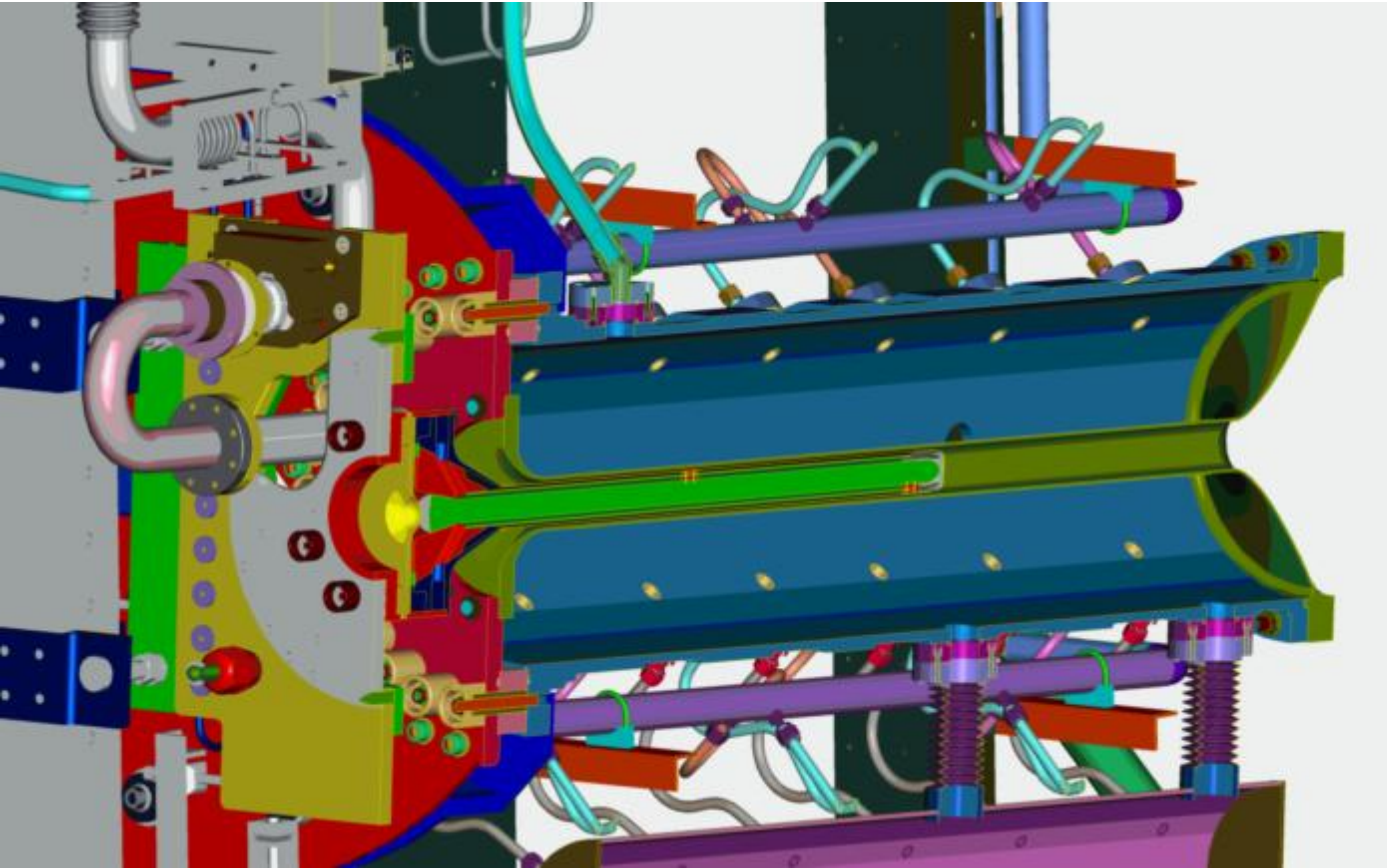
- Want to be able to replace a failed target and re-use Horn 1.
  - 1 month cool down required (at 750 kW operation)
  - Horn 1 with failed target to be lifted from beamline and installed in Remote Maintenance Area
  - Failed target to be removed, new target installed, and Horn 1 assembly re-installed in beamline.
  - Failed target to be placed inside disposal flask
- Many limitations within Remote Maintenance Area
  - Very limited space
  - No crane access – lift tables only
  - Horn can only be installed in RMA with reproducibility of ±10 mm but target needs to be installed within horn to accuracy of ≈0.1 mm.

Installing spare horn 1 in the hot cell (last month)

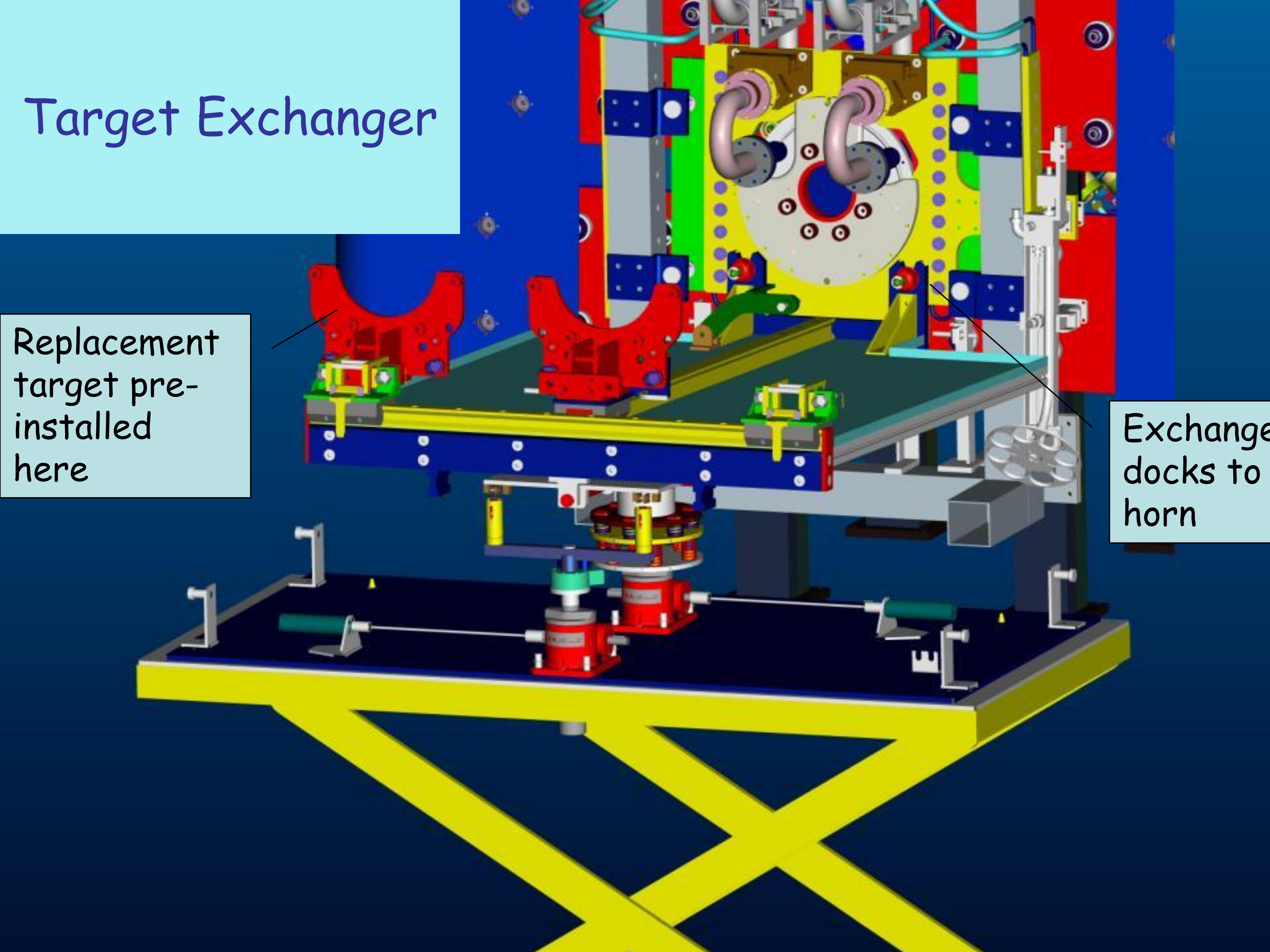


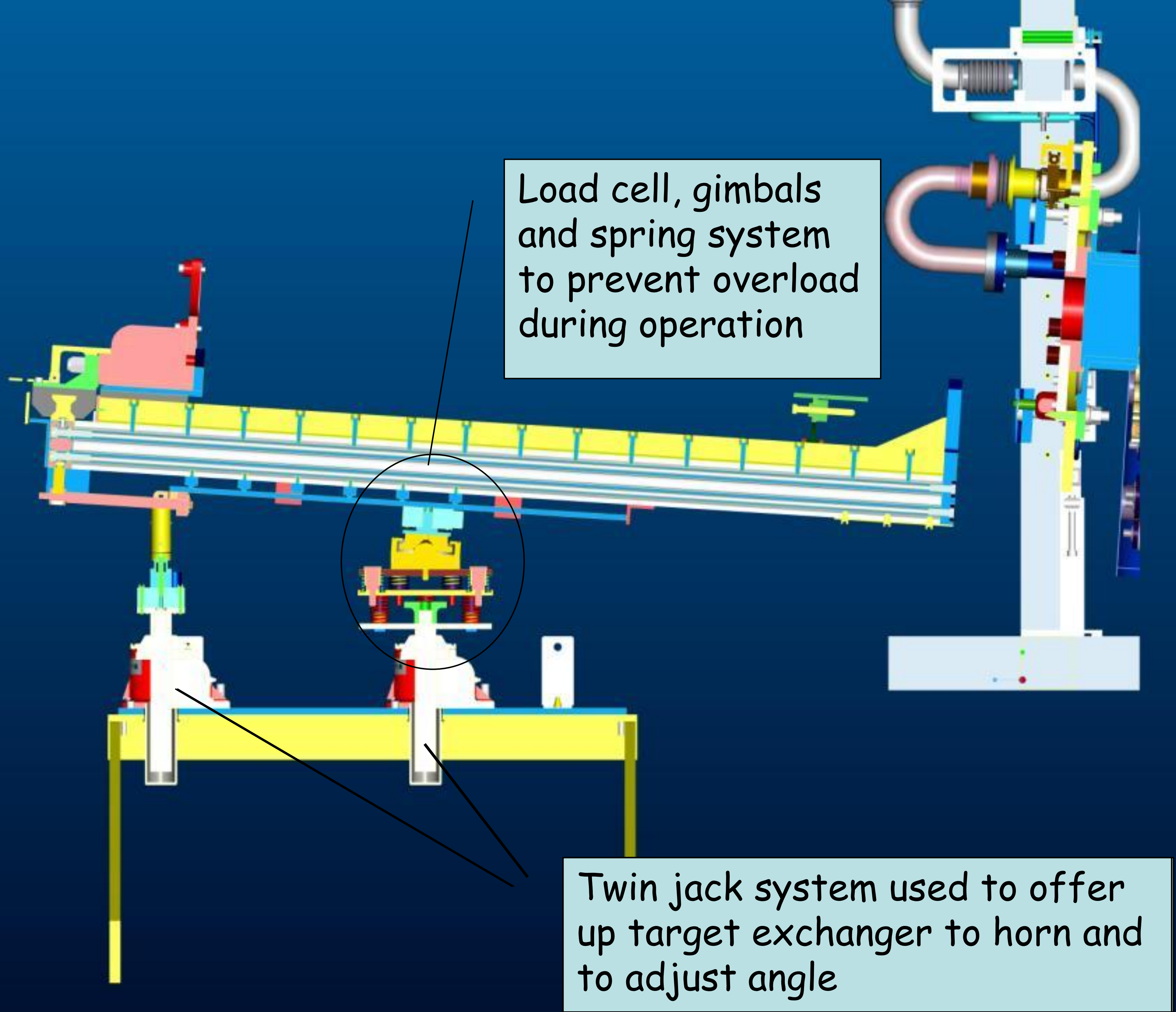


Model of Target installed in 1st magnetic horn

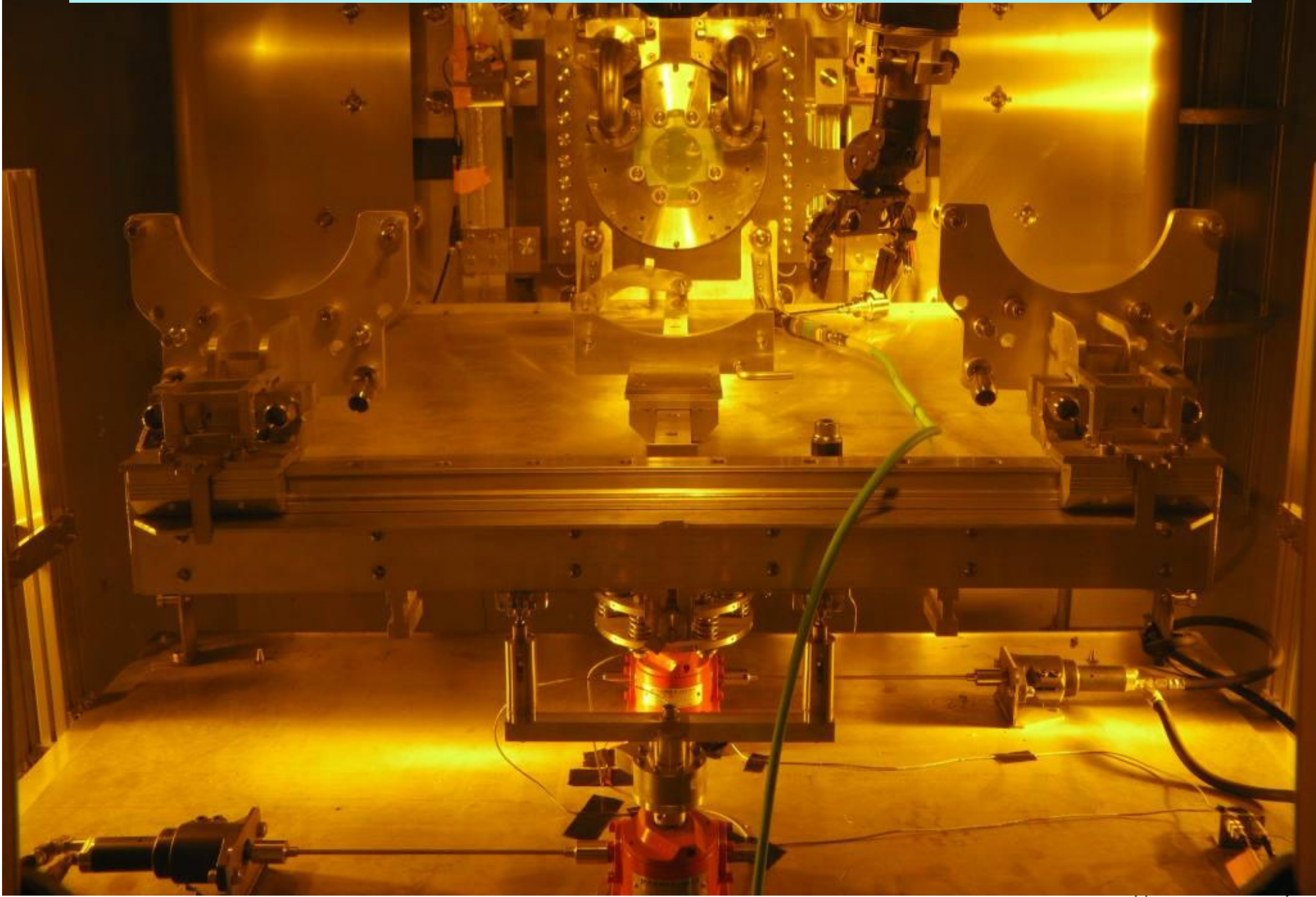


Target Exchanger

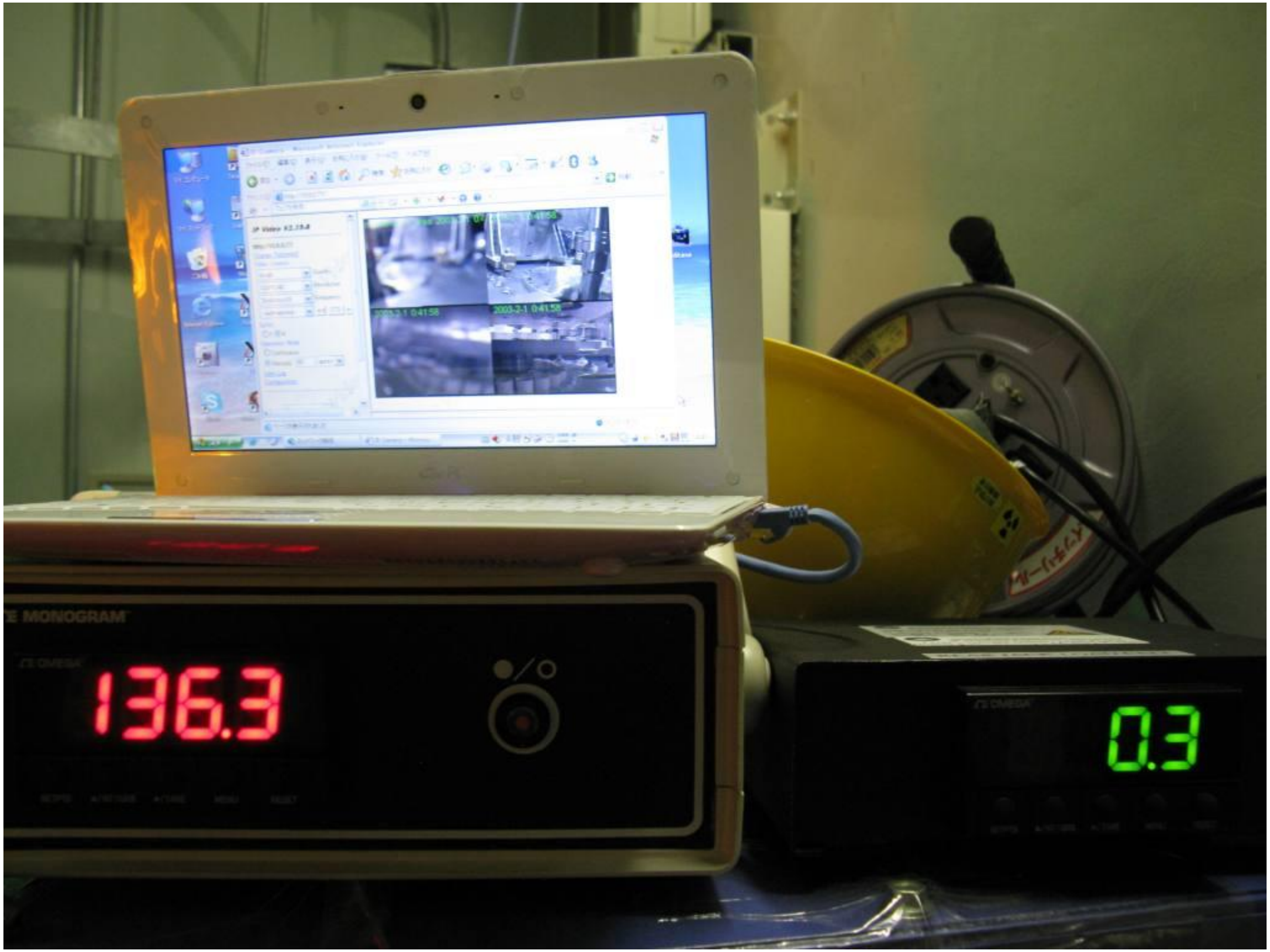



Load cell, gimbals and spring system to prevent overload during operation
Twin jack system used to offer up target exchanger to horn and to adjust angle

Final exchanger commissioning – Last month

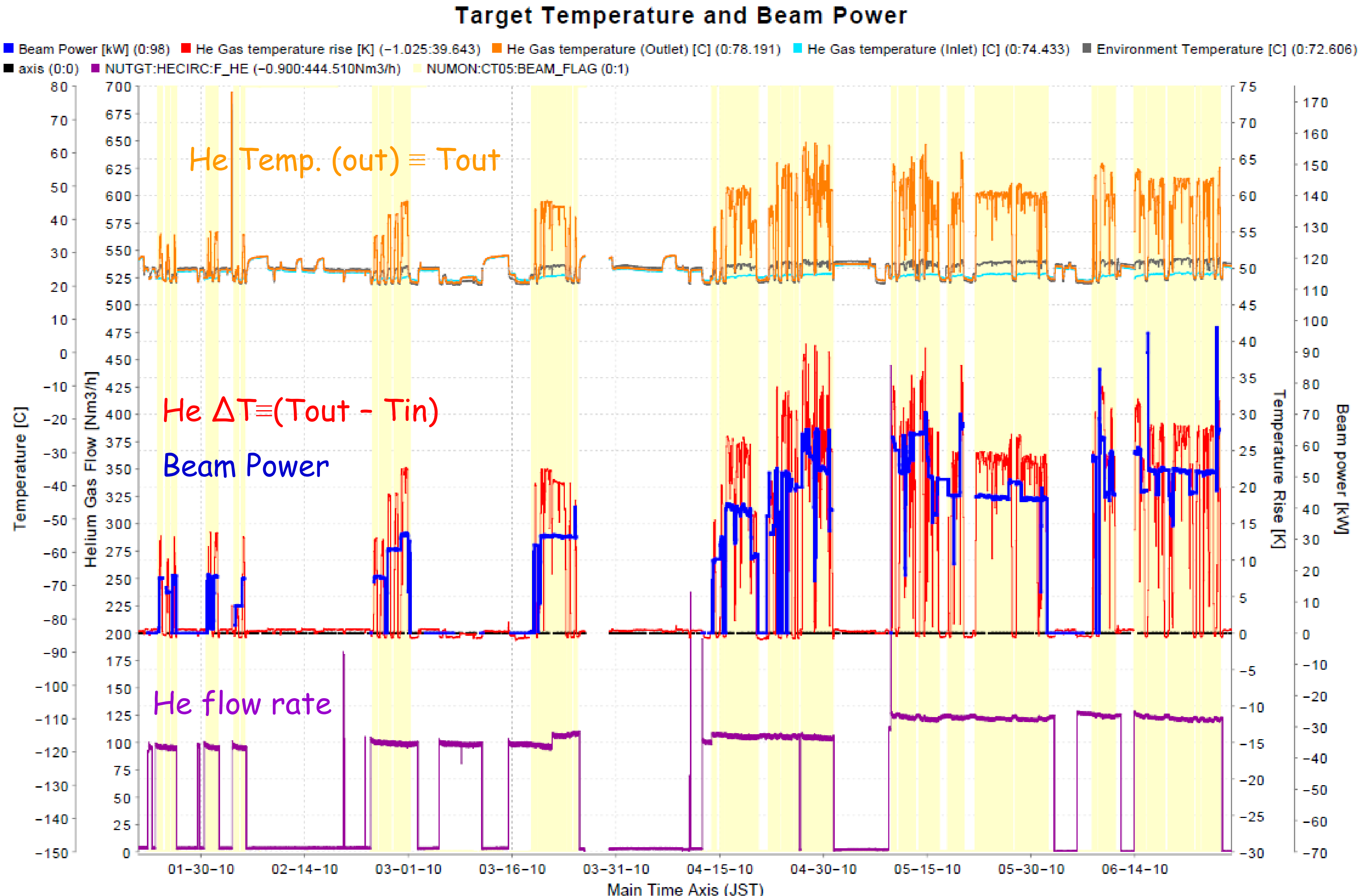


Load cell readouts from jacks crucial for docking exchanger to horn - more important than visual



Target Exchanger Commissioning

Experience from 1st physics run



T2K target status summary

- Start-up date of April 2009 achieved
- During 1st year of operation mk 1.0 target has run at 50 kW continuously and 100 kW short-term (few minutes)
- Upgrades to kicker magnet and target station should enable operation at up to 750 kW beam power
- Spare 1st horn and target now ready
- Possible to replace targets within 1st horn