UK contribution to LBNF/DUNE beam and target system

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Credit to P. Hurh (Fermilab) for previous contracts on LBNE, NuMI, NOvA

WARWICK
THE UNIVERSITY OF WARWICK

Science & Technology Facilities Council
Rutherford Appleton Laboratory

Objectives of proposed UK programme

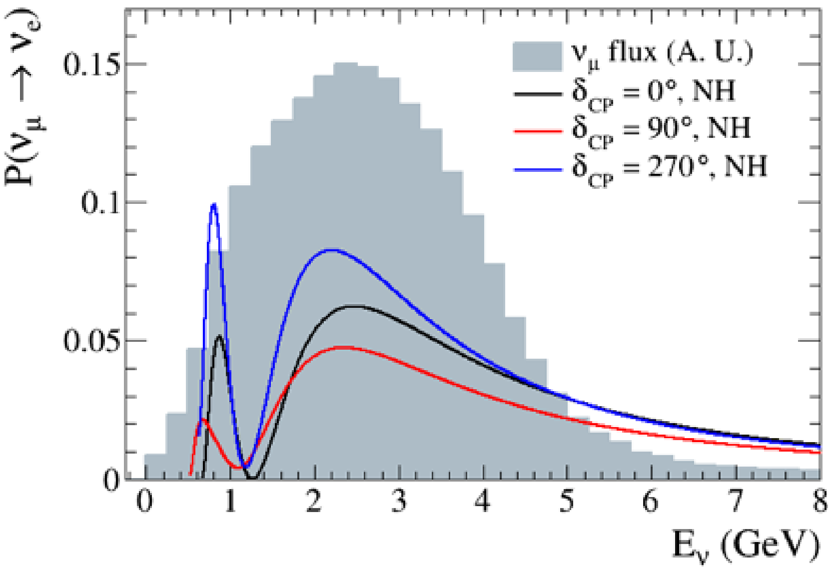
Collaborate with Fermilab and partners (e.g. ex-LBNO?) on **target and target station** design to:

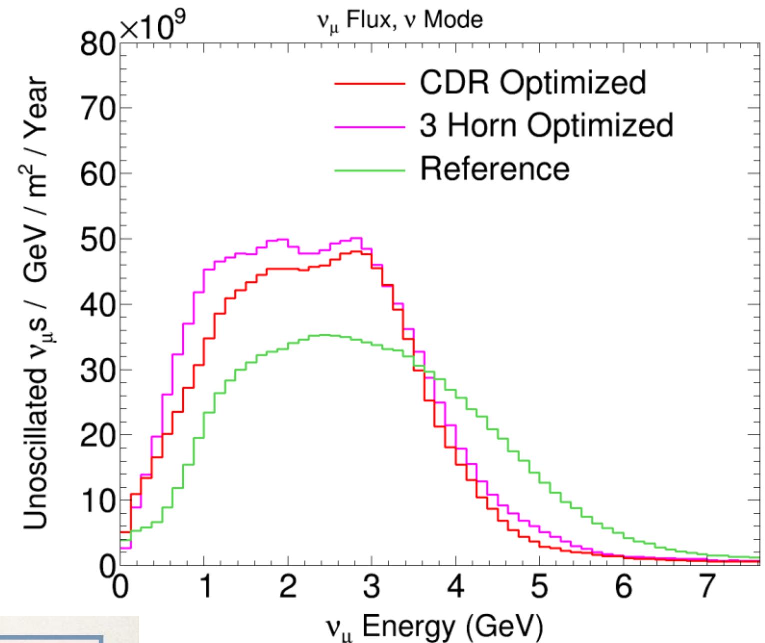
(i) realize the potential performance offered by the recent beam optimization work

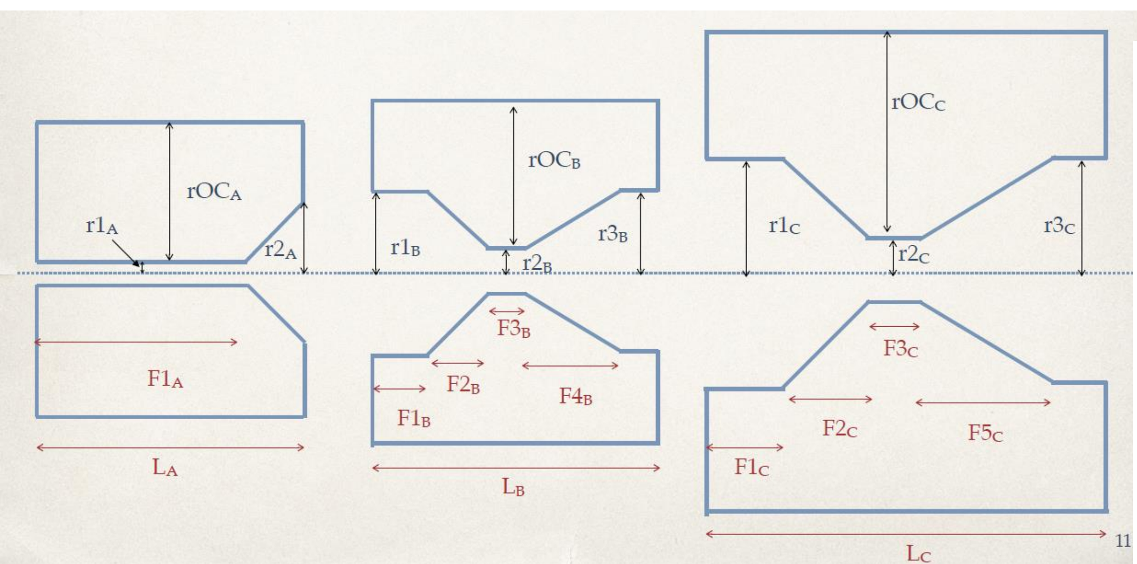
(ii) Exploit experience from NuMI and T2K to develop conceptual design of 2.4 MW target station – **limited upgradeability after operation**

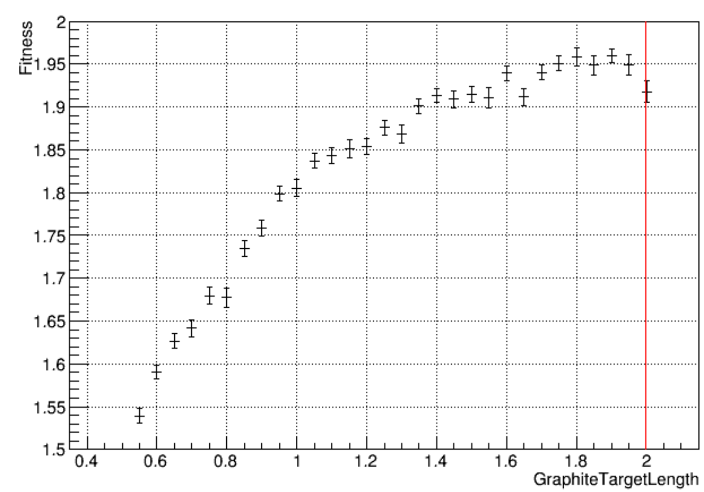
(iii) Prepare detailed and costed estimates for future in-kind hardware contributions

Results of optimisation (L. Fields)



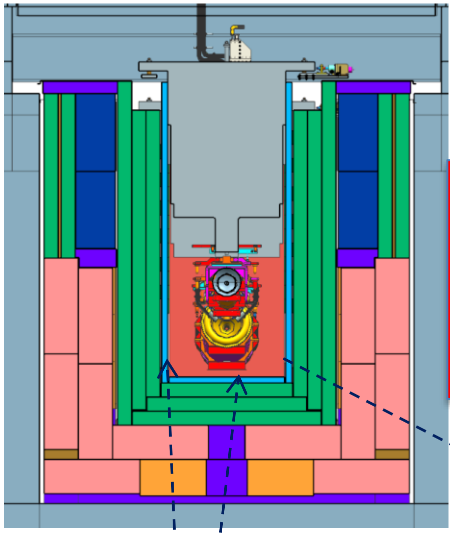


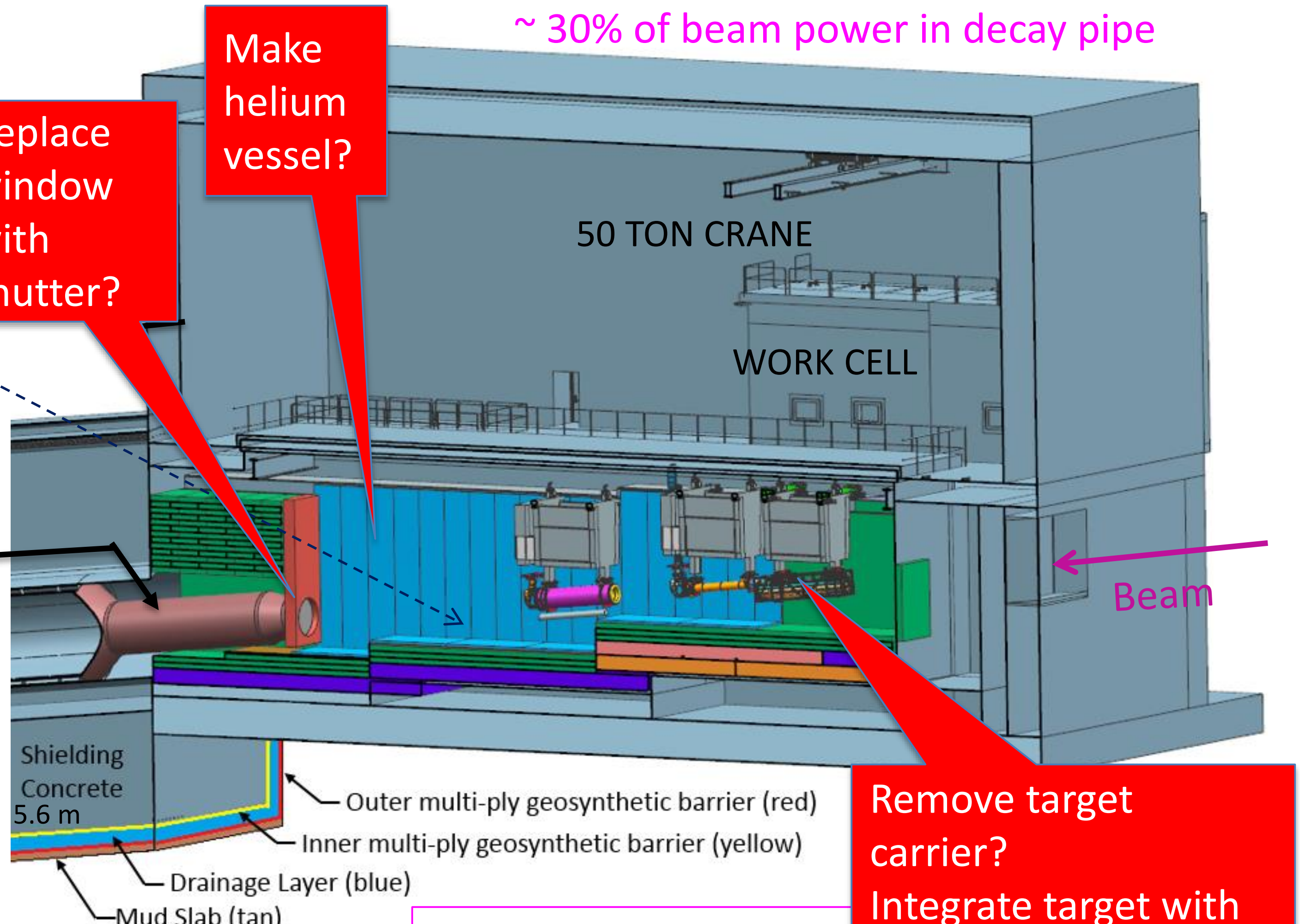




Thoughts on LBNF Target Hall/Decay Pipe Layout

~ 40% of beam power in target chase
~ 30% of beam power in decay pipe





Decay Pipe: 194 m long, 4 m in diameter, double – wall carbon steel, helium filled, air-cooled.
Helium cooled?

Target Chase: 2.2 m/2.0 m
air-filled and air & water-c… (cooling panels)

Possible shutter between helium filled Target Station & Decay Pipe

UHV vacuum system for LIGO featuring 44-inch diameter gate valves

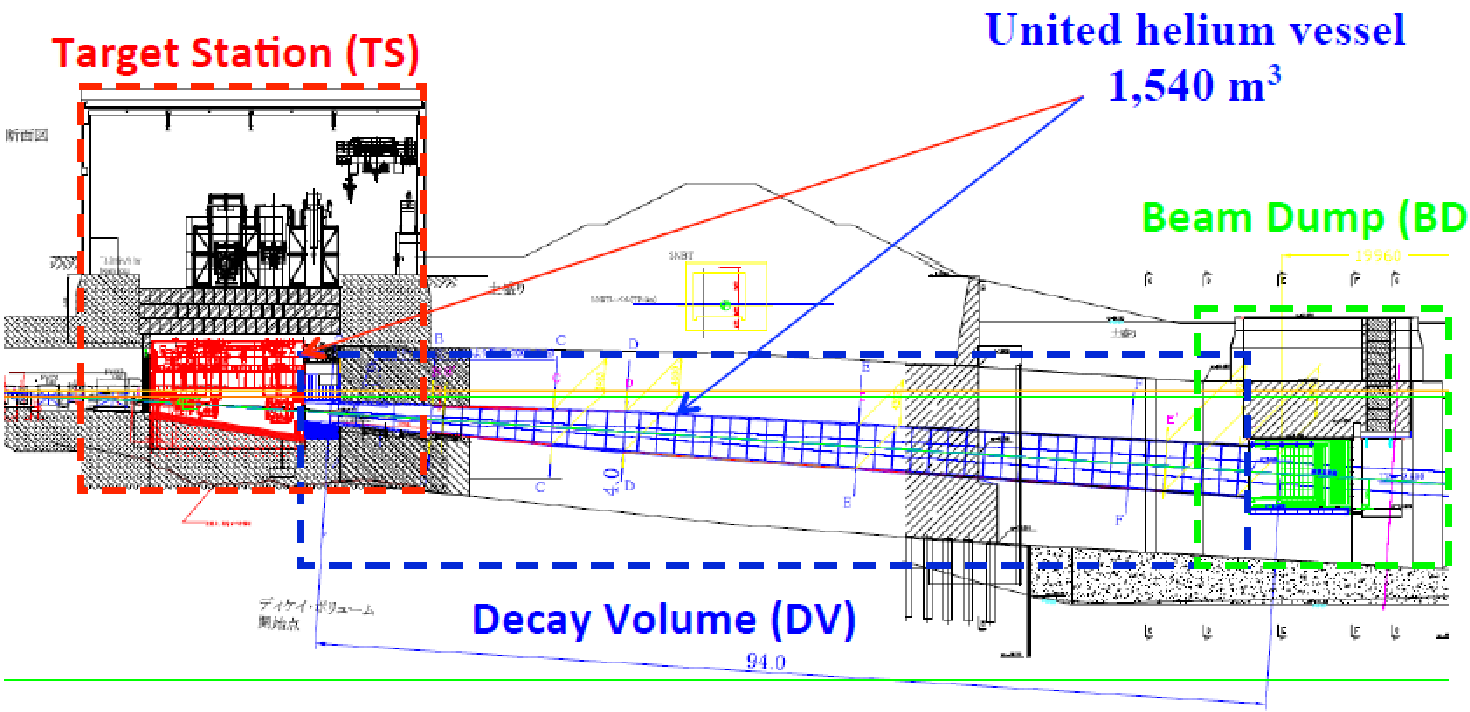
Potential candidate for shutter between target chase and decay pipe.

- Allows target station interventions without venting the decay pipe
- Target station in helium mitigates: (i) corrosion due to NO_x & ozone production (ii)radionuclide generation
- Eliminates window/particle interactions during operation
- Single helium plant for both decay pipe (*2400m³*) and target chase (*150m³*)

T.Nakadaira:

Overview of J-PARC neutrino facility: secondary beam-line

- Horn/Target is installed in Huge He vessel.
  - He vessel is designed to be evacuated.
  - Aiming to reduce NOx production.



T.Nakadaira:

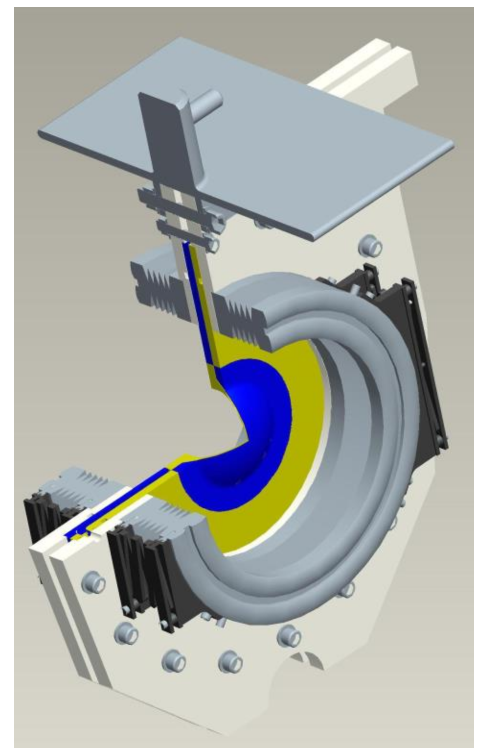
Disadvantage :

- At J-PARC neutrino facility, it takes time to start the horn maintenance work compared to FNAL NuMI.
  - For example, 2015 target maintenance,
    - Beam operation was stopped at 1st week of June. → The horn-1 was transported to the remote maintenance area at late September.
      - Considering the summer holidays, power outage due to annual maintenance, and non-related work, it takes about ~3 months.
    - Horn is re-installed in the beam-line at the 3rd week of Dec. and the beam-operation resumed at the end of Jan.
      - It takes about 1month and so. The He vessel evacuation + re-filling takes about 1week.

Want to combine advantages of helium filled Target Chase (T2K) with easy access in air (NuMI)

T2K Beam Window – prototype for LBNF?

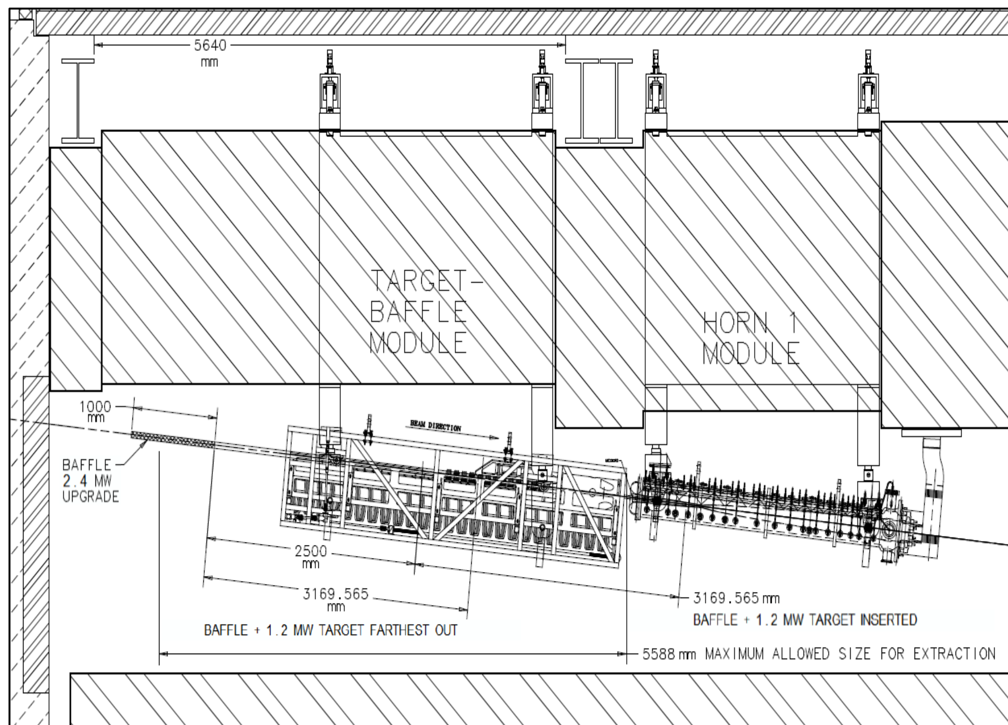
- Vacuum-to air beam window
- Utilises inflatable pillow seals
- T2K uses double skin of 0.3mm thick Ti-6Al-4V, cooled by He gas (0.8g/s)
- Peripherally cooled beryllium has good track record for NuMI/NOvA, good for LBNF



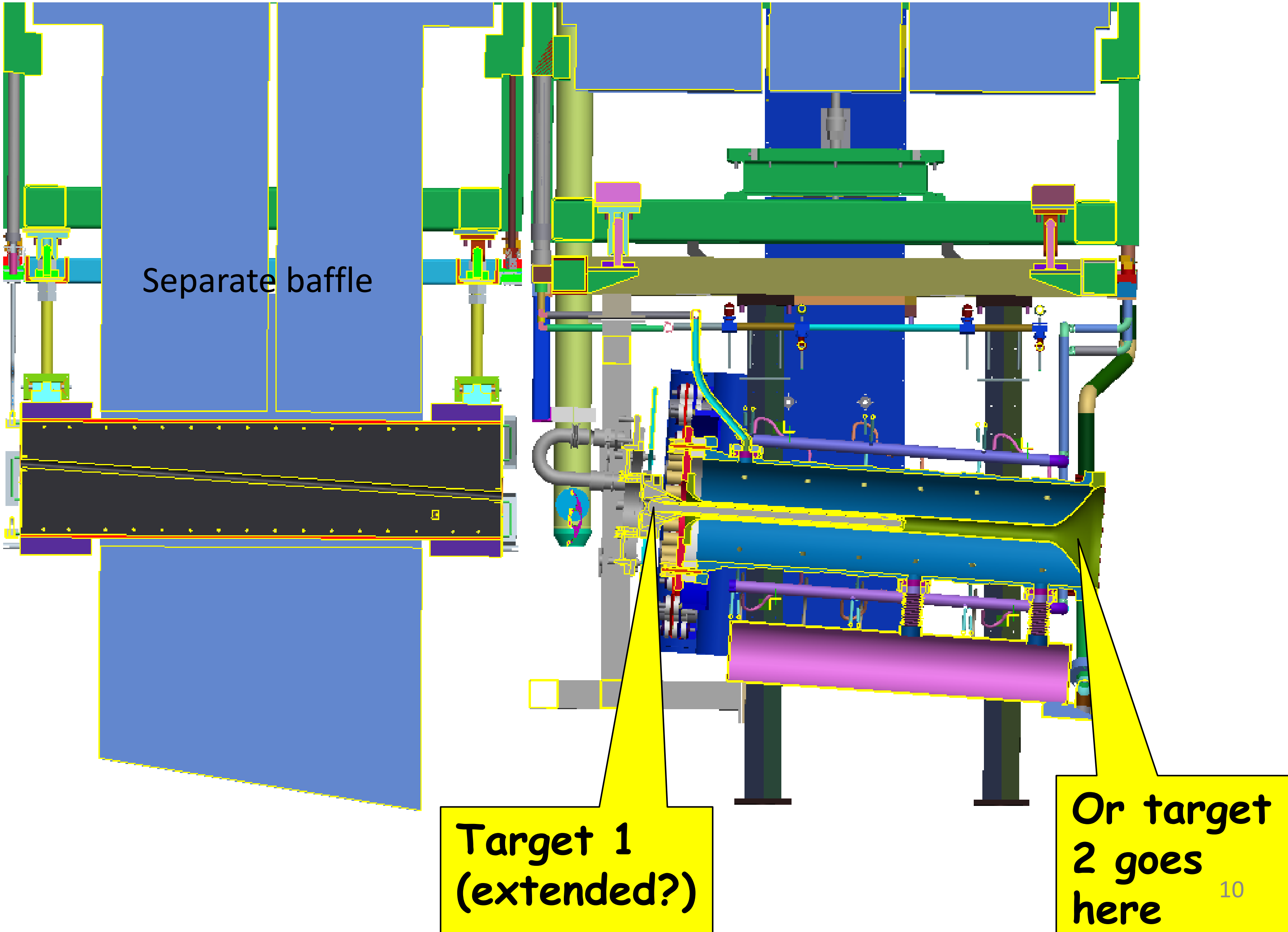
Target and Horn Integration - Current baseline in CDR (a la NuMI)

Proposal: **Eliminate target carrier**

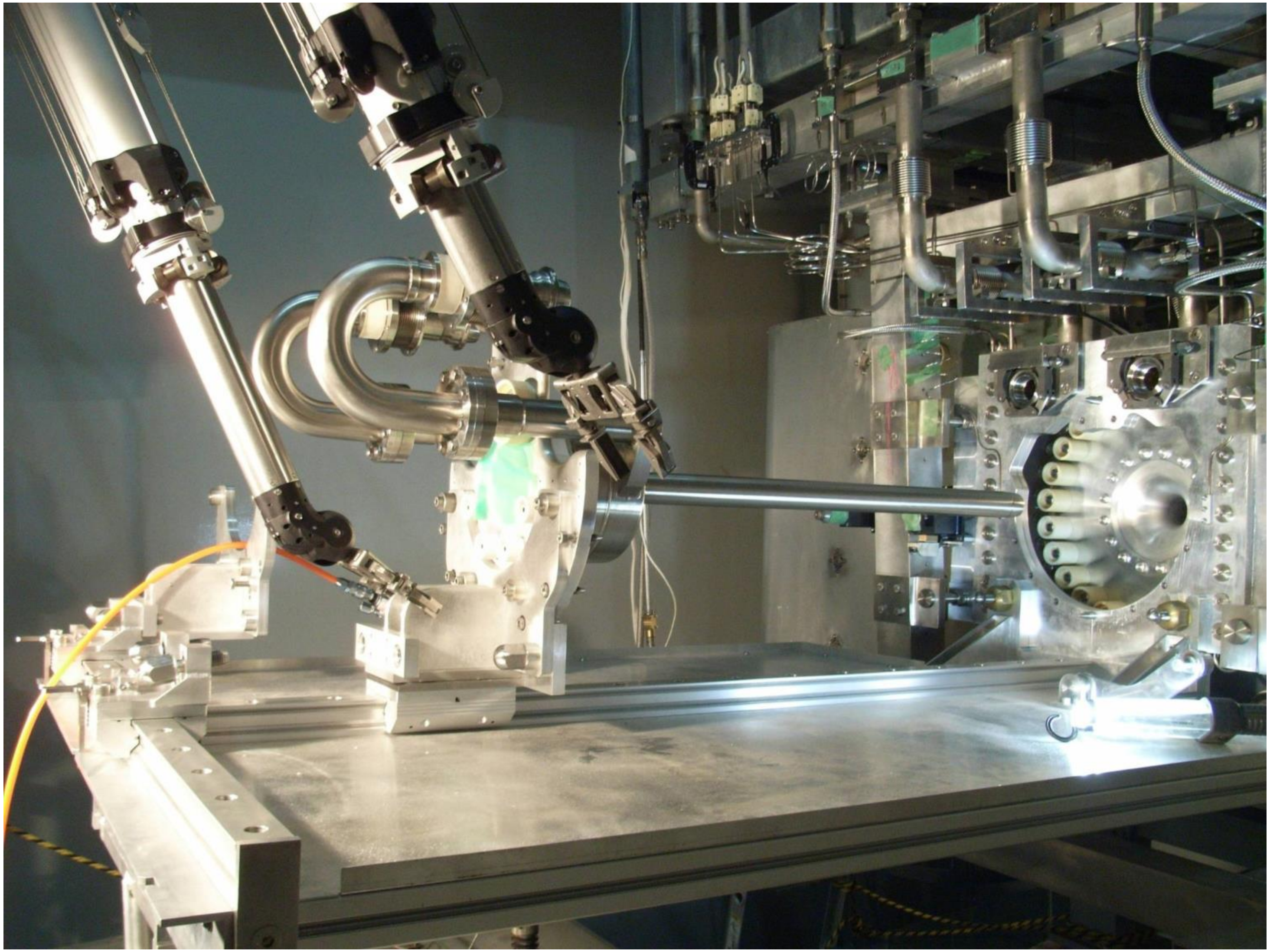
- Reduces cost
- Can make targets longer and chase shorter
- Install target(s) in separate hot cell



LBNF optimisation work → T2K layout

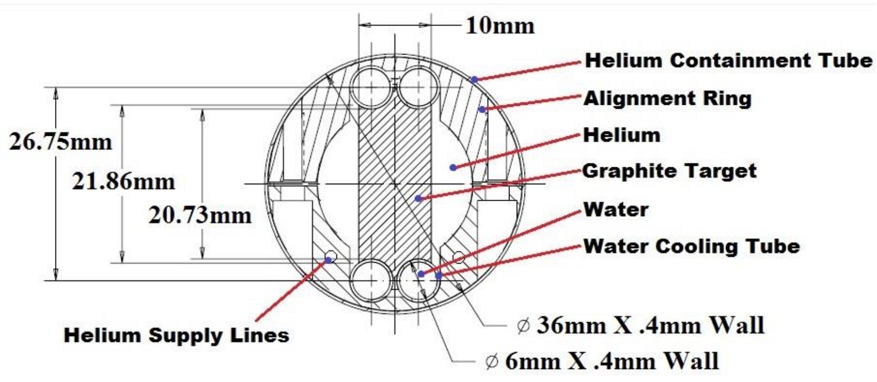


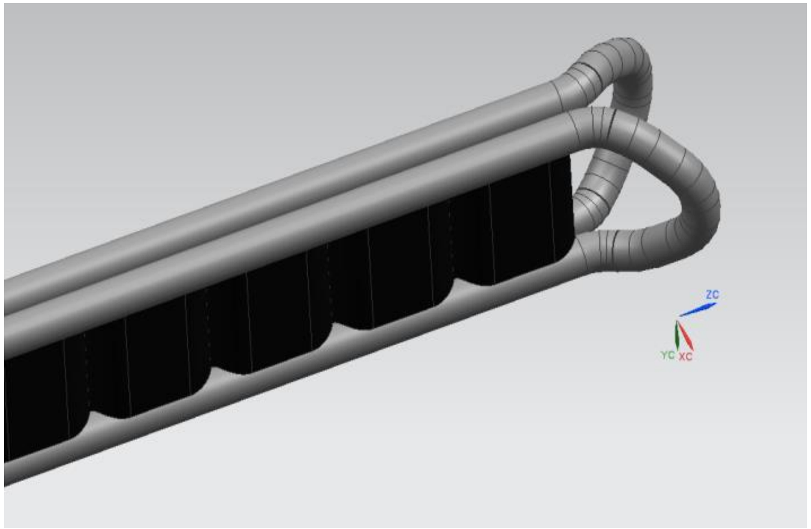
Prototype target exchange system?

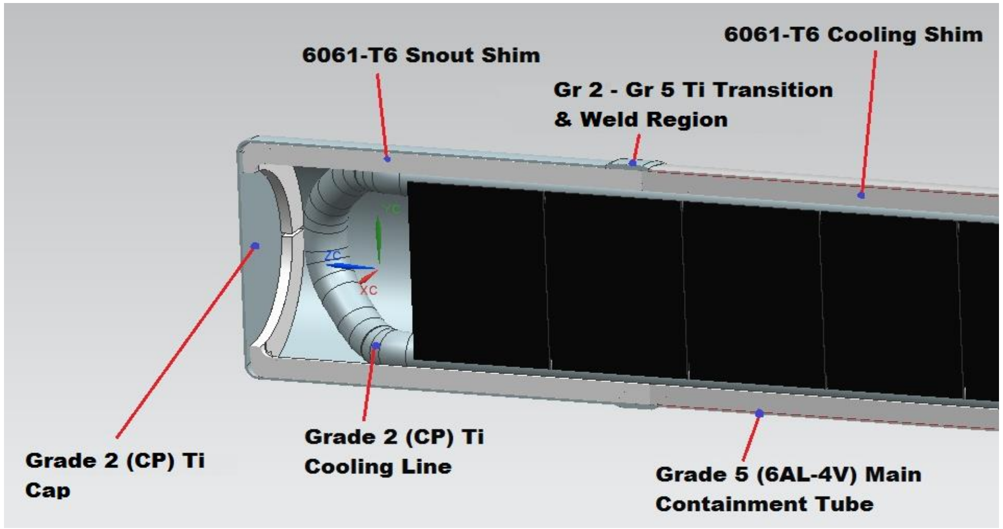


LBNF 1.2 MW Target Design - Target Core

- Fin width increase from 6.4mm to 10mm.
- Added helium cooling lines through alignment rings.
- Containment tube diameter increase from 30mm to 36mm.
- Twin 6mm OD X .4mm wall cooling lines for heat removal.



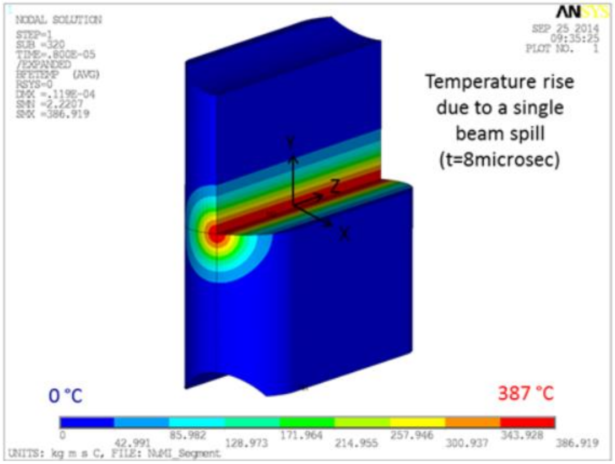


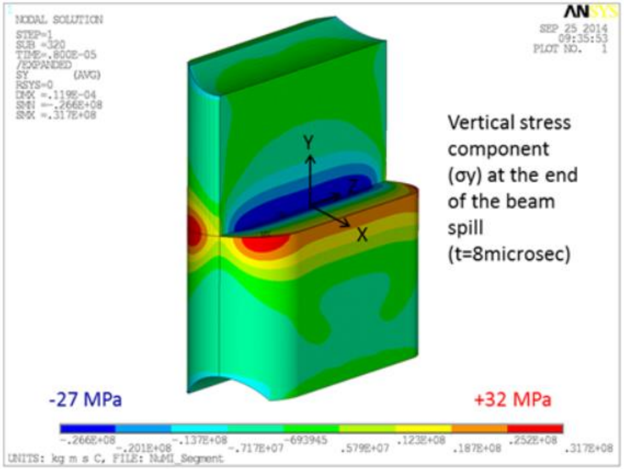


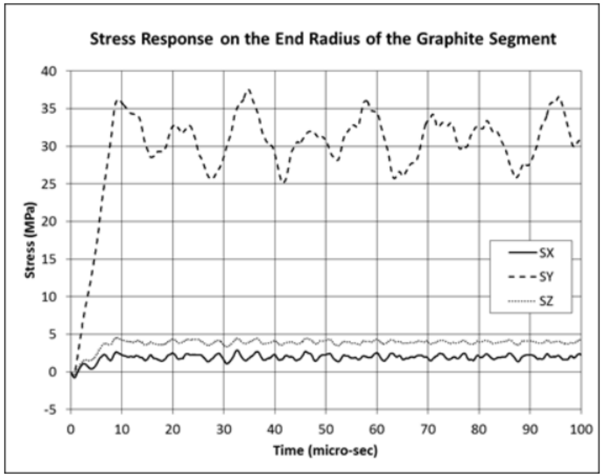
Fermilab

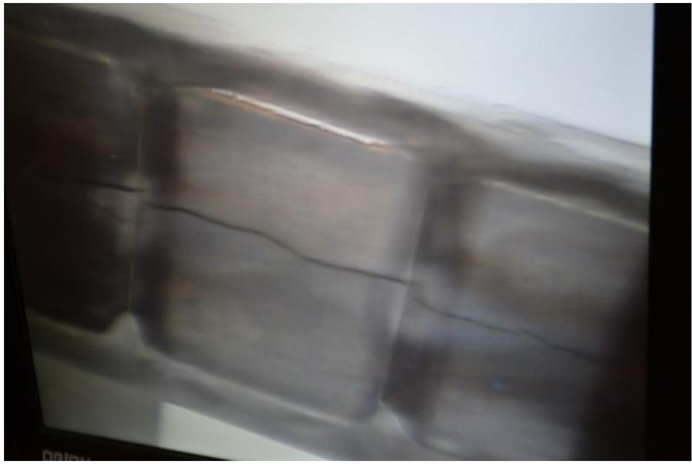
Issues with NUMI target → 1.2 MW baseline

- Water leaking from water cooling tubes (should be solved with Ti but NB water hammer)
- High beam induced cyclic stresses in graphite fins
- Graphite fins found to be cracked after post mortem
- Fin geometry limits beam spot size
- No current program for 2.4 MW operation



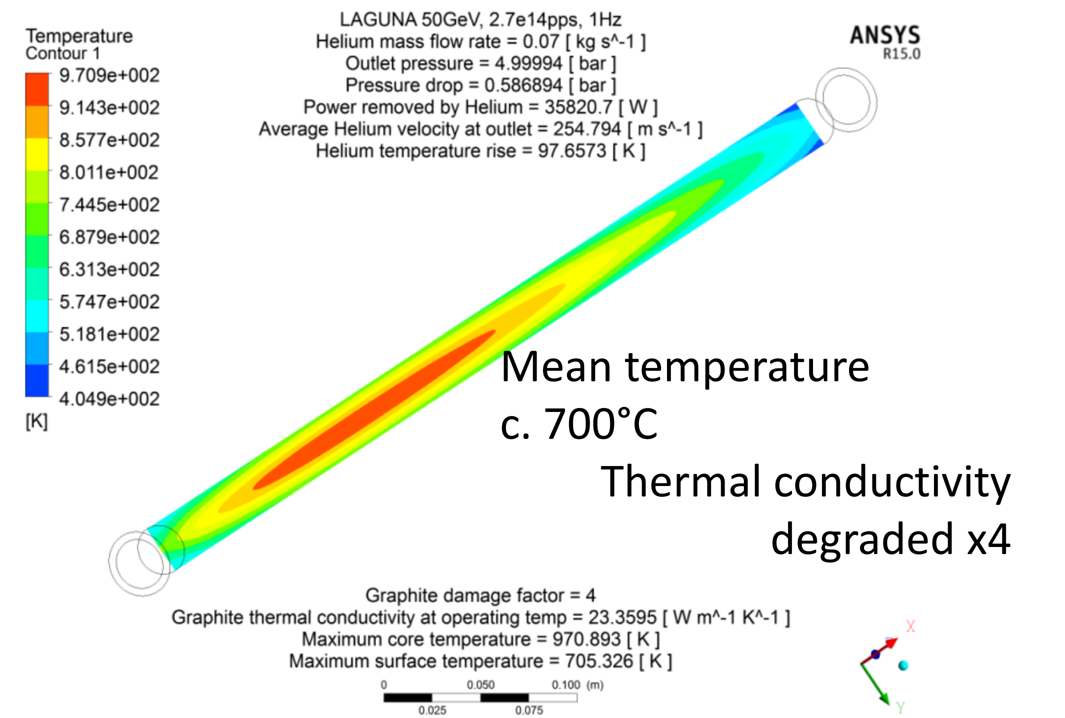


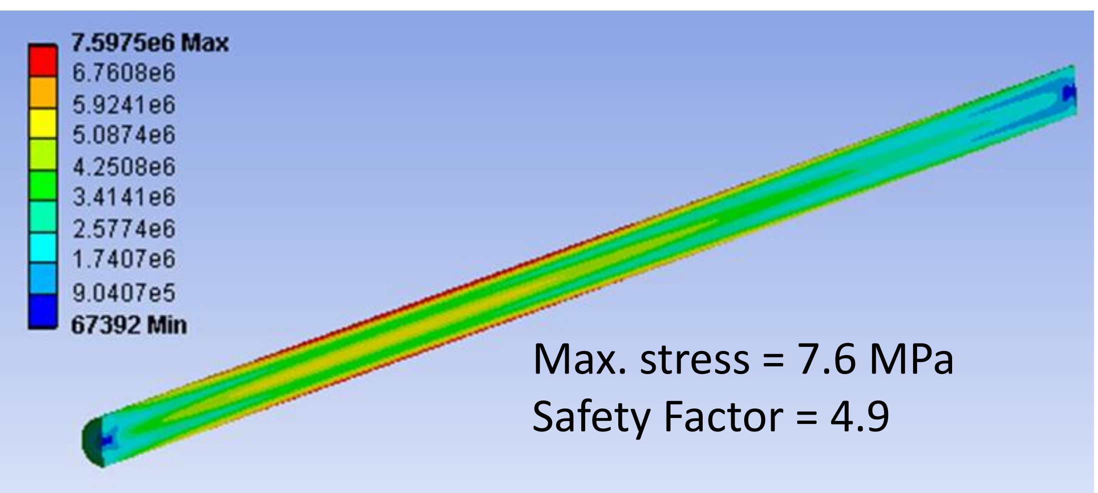




Autopsy of NT-03 (photo courtesy of V.Sidarov)

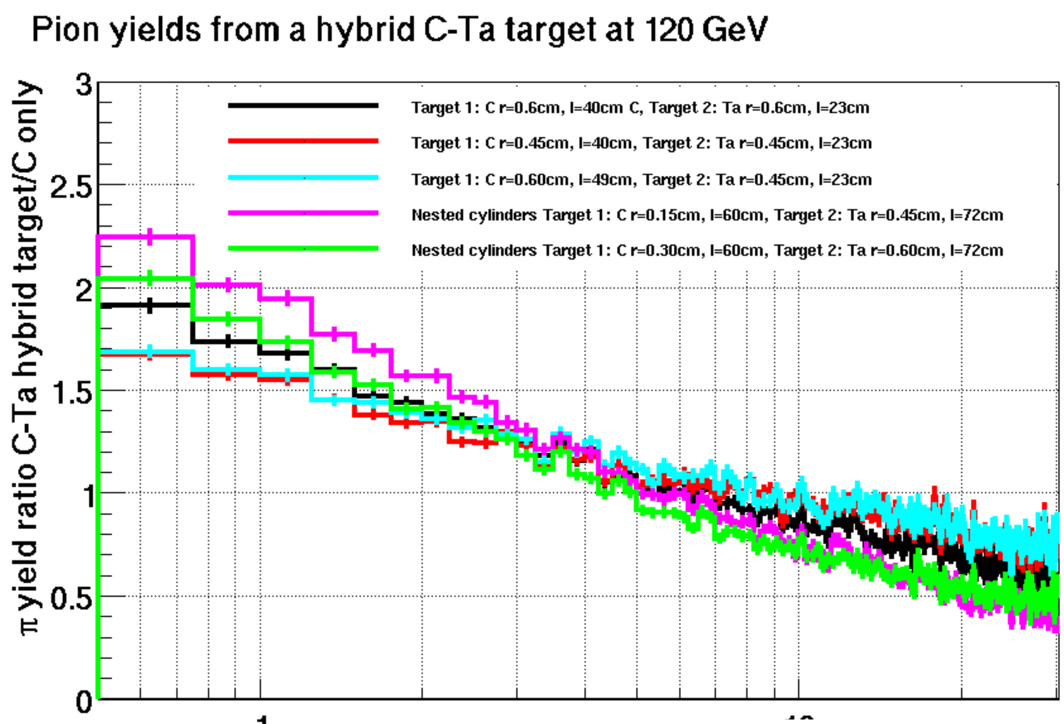
Helium cooled graphite rod





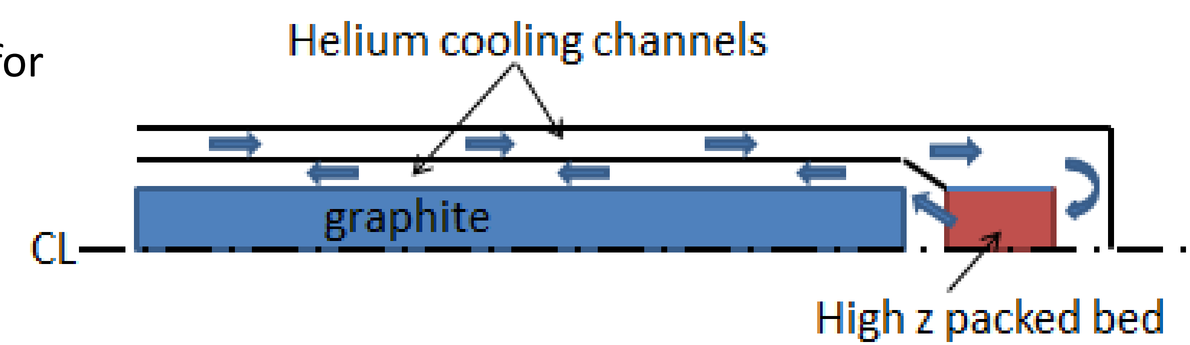
- LBNO study of rod for 50 GeV beam
- 36 kW in target at 2 MW
- Lower heat load for 120 GeV beam
- High temperature operation reduces radiation damage c.f water cooling
- Appears feasible – but what is expected lifetime?

High Z outer tube or downstream plug? (M. Bishai)

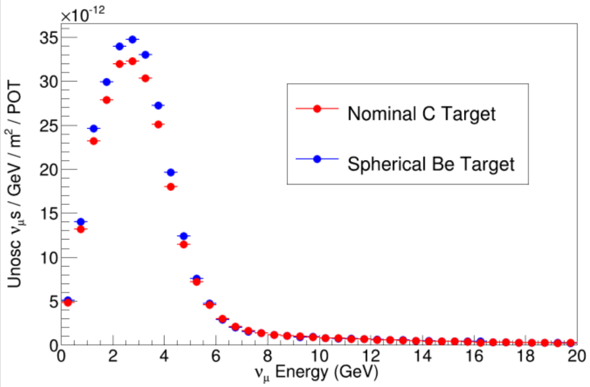


- High z plug downstream of the target and/or high z target outer tube
- Increase pion yield relative to a 2 interaction length graphite target.
- Graphite cylinder inside a High-Z tube gives best increase in yield

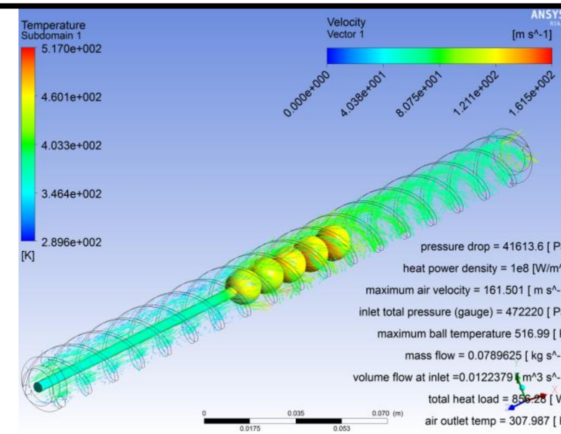
- Need to take study forward for new optimised horn system
- Need to study engineering implementation, materials selection etc
- Cost benefit analysis



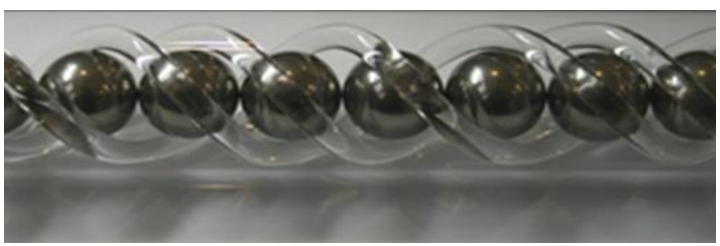
Alternative: Spherical Array Target – Be or graphite

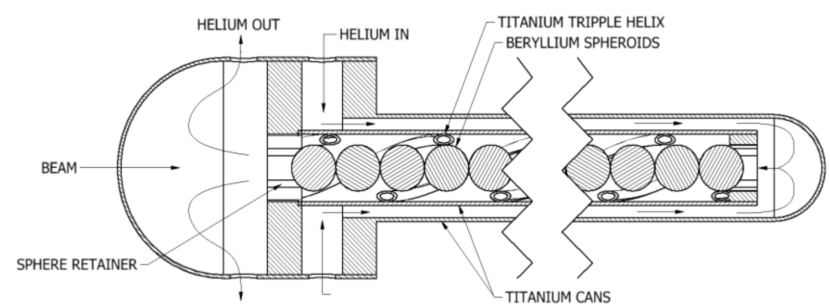


RAL/Warwick/Fermilab collaboration: physics optimisation and thermomechanical performance predictions



Prototype target testing





Close working relationship required between target development and the horn integration and overall target station design

Particle Production Target 'Optimum' Performance

1. Physics ~ *integrated* flux * detector mass
2. *Integrated* flux ~ lifetime ~ beam RMS radius
   - Radiation damage rate inversely proportional to maximum power density
   - Bigger beam = longer target lifetime
   - Need to compromise for optimum overall performance
3. Performance of finned (NuMI style) target vs cylindrical?
4. Performance of graphite vs beryllium
5. Optimum solution depends on beam power

Target technology for 2.4 MW?

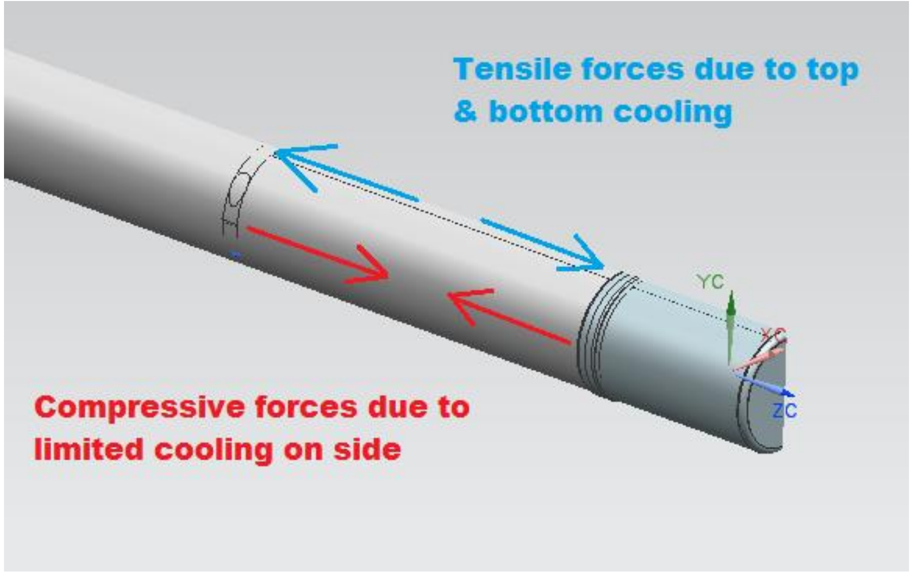
1. Material and cooling medium choice
   - Graphite
     - Excellent track record, obvious candidate
     - Best tolerance to radiation damage when operated at c.500 - 1000 C
     - Helium cooling favoured
   - Beryllium
     - May be more tolerant to radiation damage – jury still out (ref. RaDIATE program)
     - As for all metals, best properties at low temperatures
     - Water cooling most effective, but difficult to implement reliably
     - Helium cooled Spherical Array Target looks promising
   - Investigate higher-Z downstream plug Inconel, titanium (tungsten?)

Extra slides

Containment Tube / D.S. Window

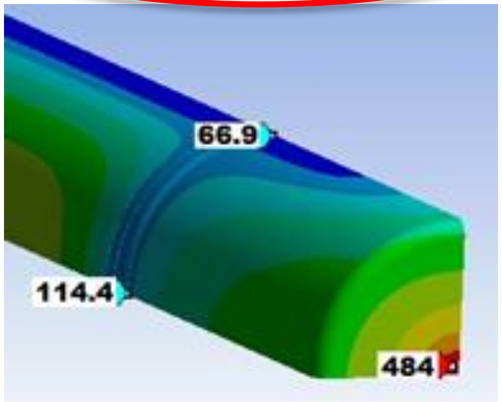
- Containment tube Summary

- Thermal stresses are unavoidable with this design due to symmetric, but non-uniform cooling.
- Alternate cooling methods add mass to target core & produce unacceptable beam heating in horn 1 I.C.
- Not a limiting factor of the design.

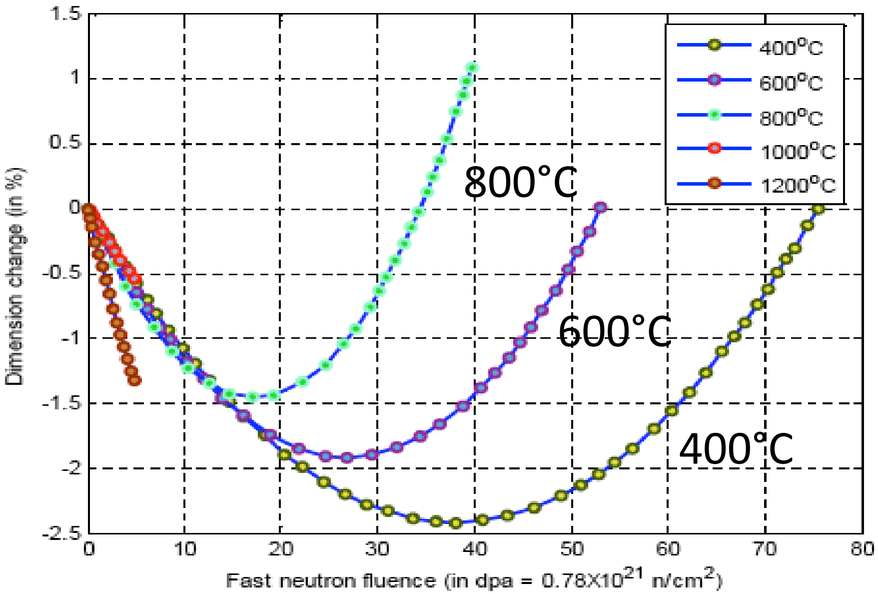


- Window / Cap Summary

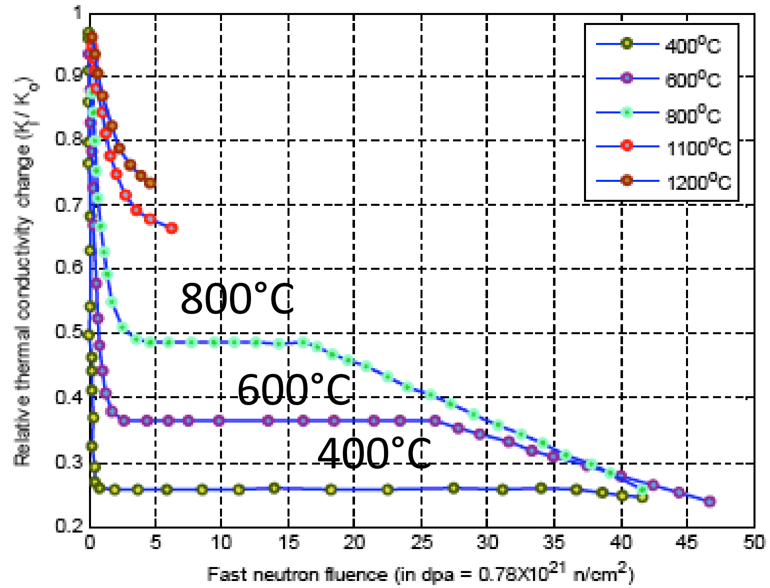
- Max steady state temp of ~400C & max transient temperature of ~480C at beam spot could be problematic.
- TiN / TiAlN / TiCrN coating with higher oxidation resistance would have to be utilized.



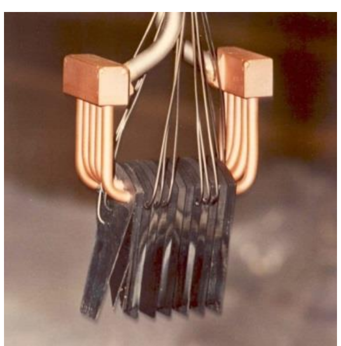
Radiation damage of graphite vs temperature



Dimensional change due to fast neutron irradiation damage on graphite IG110



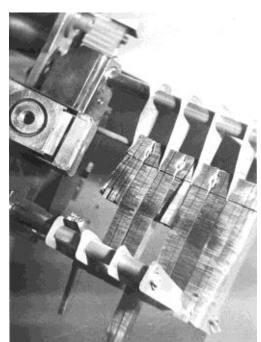
Degradation of thermal conductivity due to fast neutron irradiation damage on graphite IG110

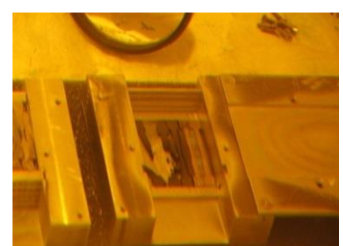


←LAMPF

PSI→

10^{22} p/cm^2

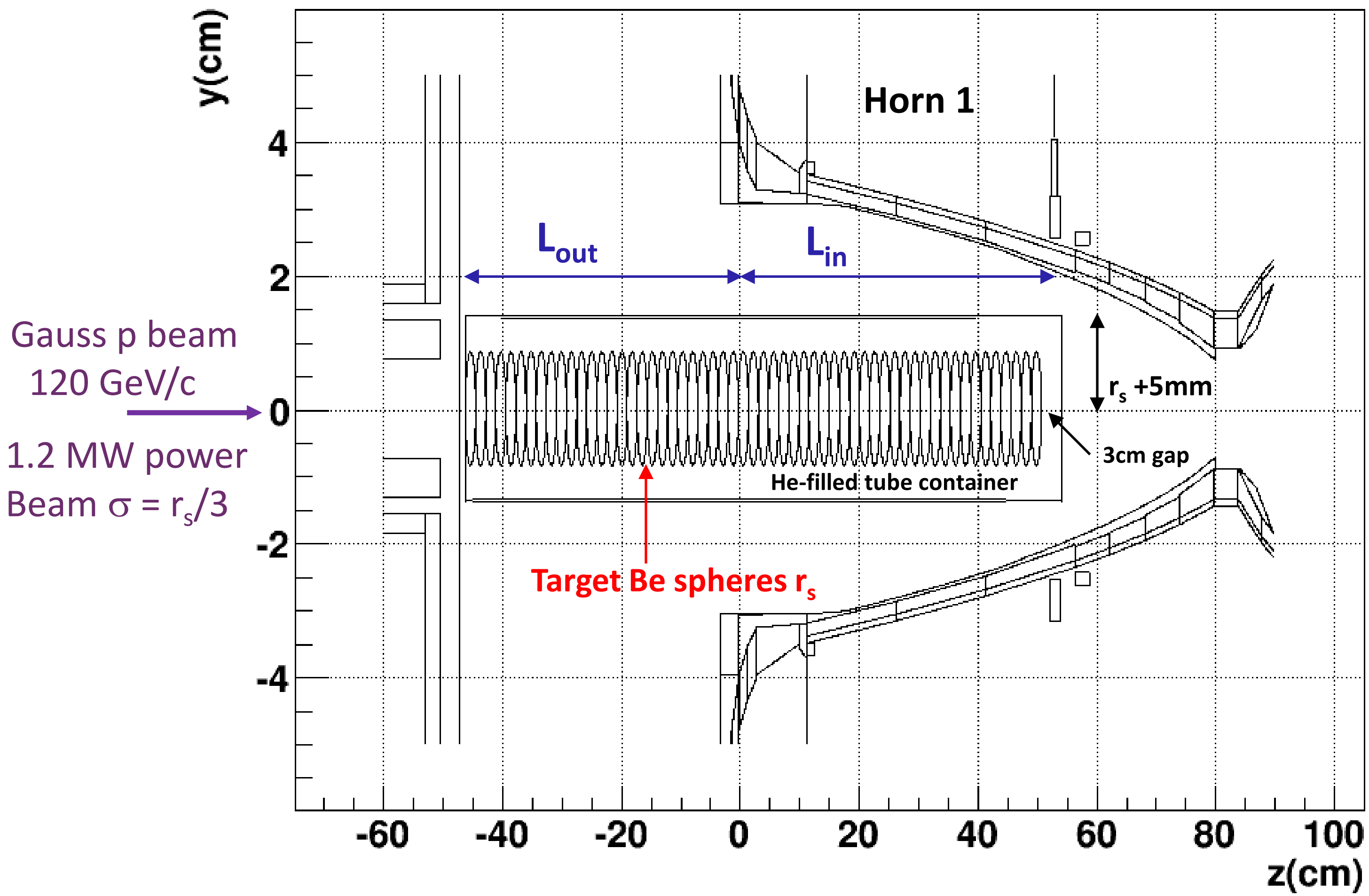




BNL tests (in water)

10^{22} p/cm^2

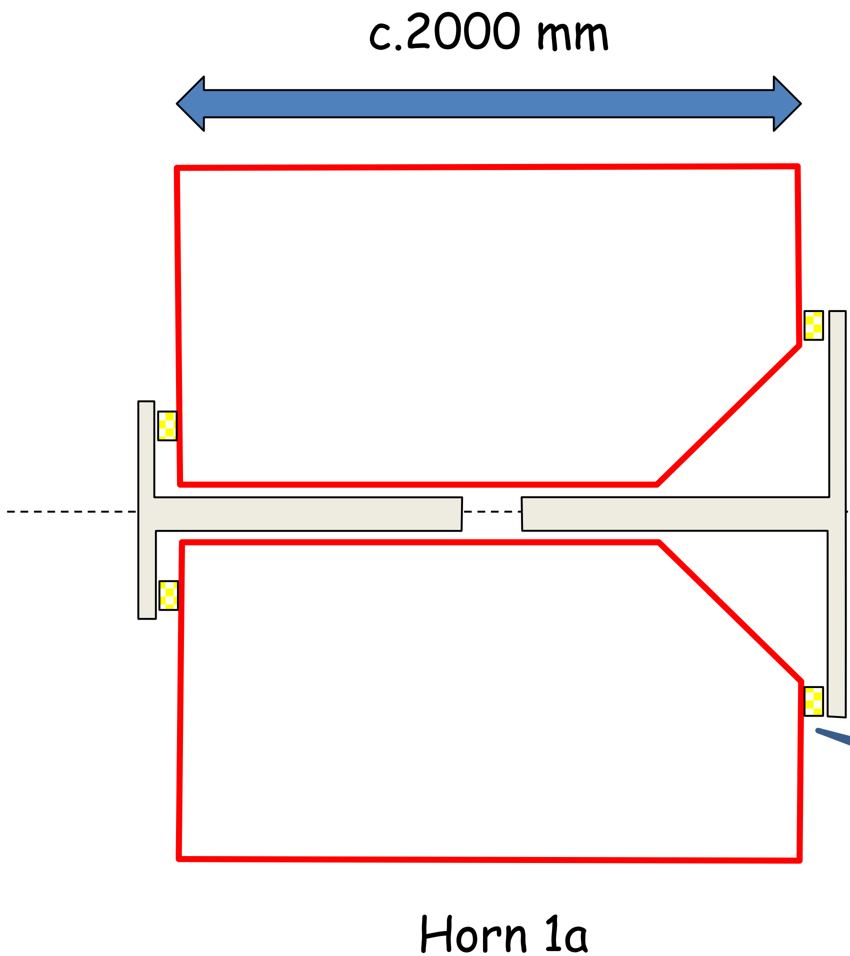
Geant4 (G4LBNE) SAT Reference Geometry



Engineering considerations: minimum feasible Be sphere radius $r_s \approx 6.5$ mm

Reminder: Nominal target is the T2K-style graphite L = 2λ cylinder

Target and Horn Integration
One idea: split target into two lengths



Upstream & downstream targets installed in Horn 1a

- Each target similar length to existing targets
- Heat load divided in 2 (solutions proposed)
- Can be cantilevered inside horn
- Targets supported from horn support structure

NB Ceramics at large enough radius to clear majority of particle shower