# Suggestions for target selection criteria

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DEEP UNDERGROUND NEUTRINO EXPERIMENT

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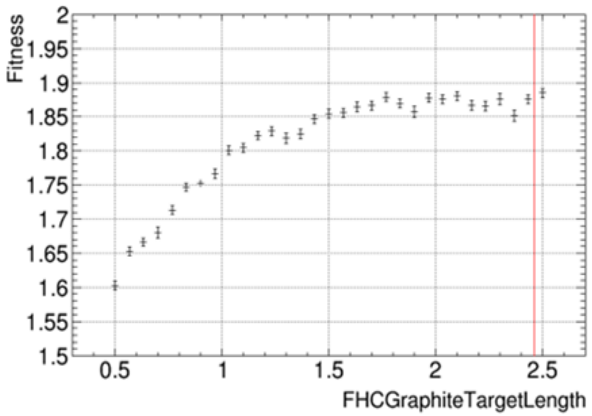
# Neutrino Target 'Optimum' Performance

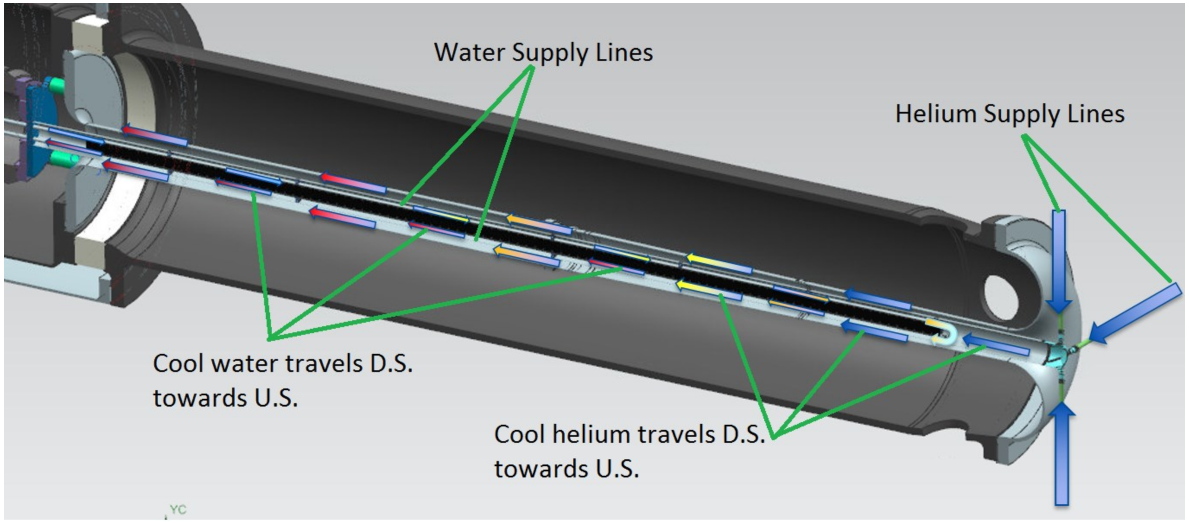
- To compare a particular design with a reference design:

  $\lambda_{overall} = \lambda_{physics} \times \lambda_{reliability}$ , where $\lambda_{reliability} = fn(I, \sigma, \ldots)$

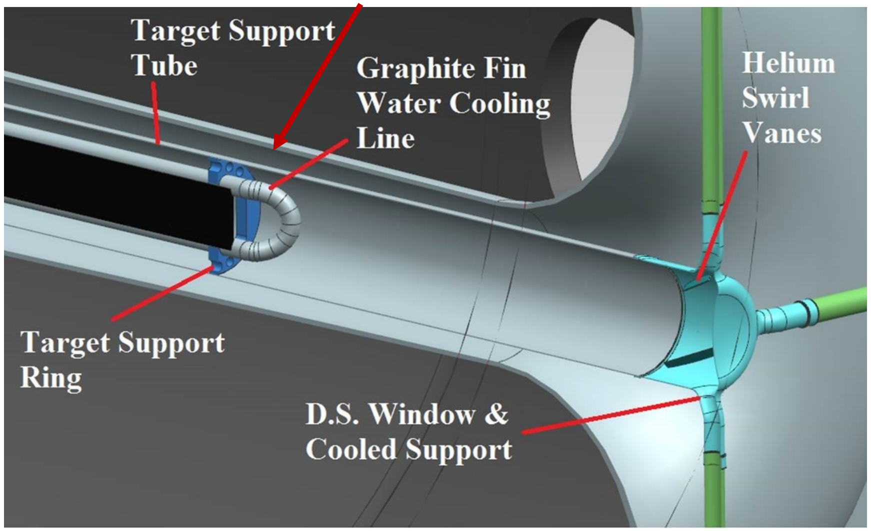
  λ is normalised to 1 for a reference design
- For neutrino flux – smaller beam & target is better
- For target lifetime – bigger is better.
  - Lower power density – lower temperatures, lower stresses
  - Lower radiation damage
  - Lower amplitude 'violin' modes (and lower stresses)
- For integrated neutrino flux, need to take many factors into account
  - E.g. How to achieve best physics performance possible for a target lifetime of a minimum of 1 year?
  - Answer will depend on Beam Power

# 1.2 MW Initial baseline 'NuMI/MINOS' style water cooled target

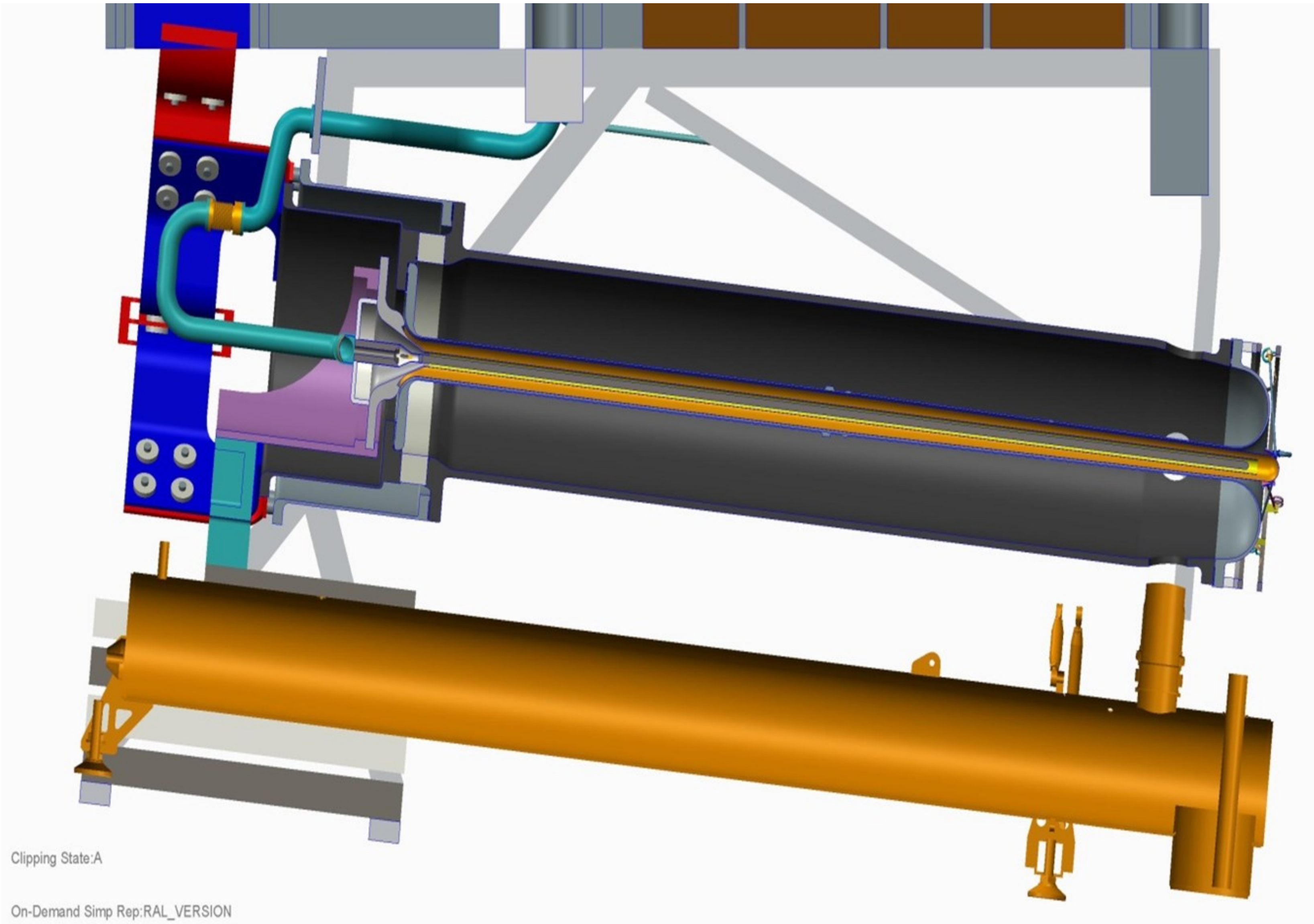



- First iteration optimized target design (2m long graphite fin target – 4$\lambda$)
- Water cooled target
- Downstream window and target support must be actively cooled with helium
- Target welded in (horn & target must be changed together)

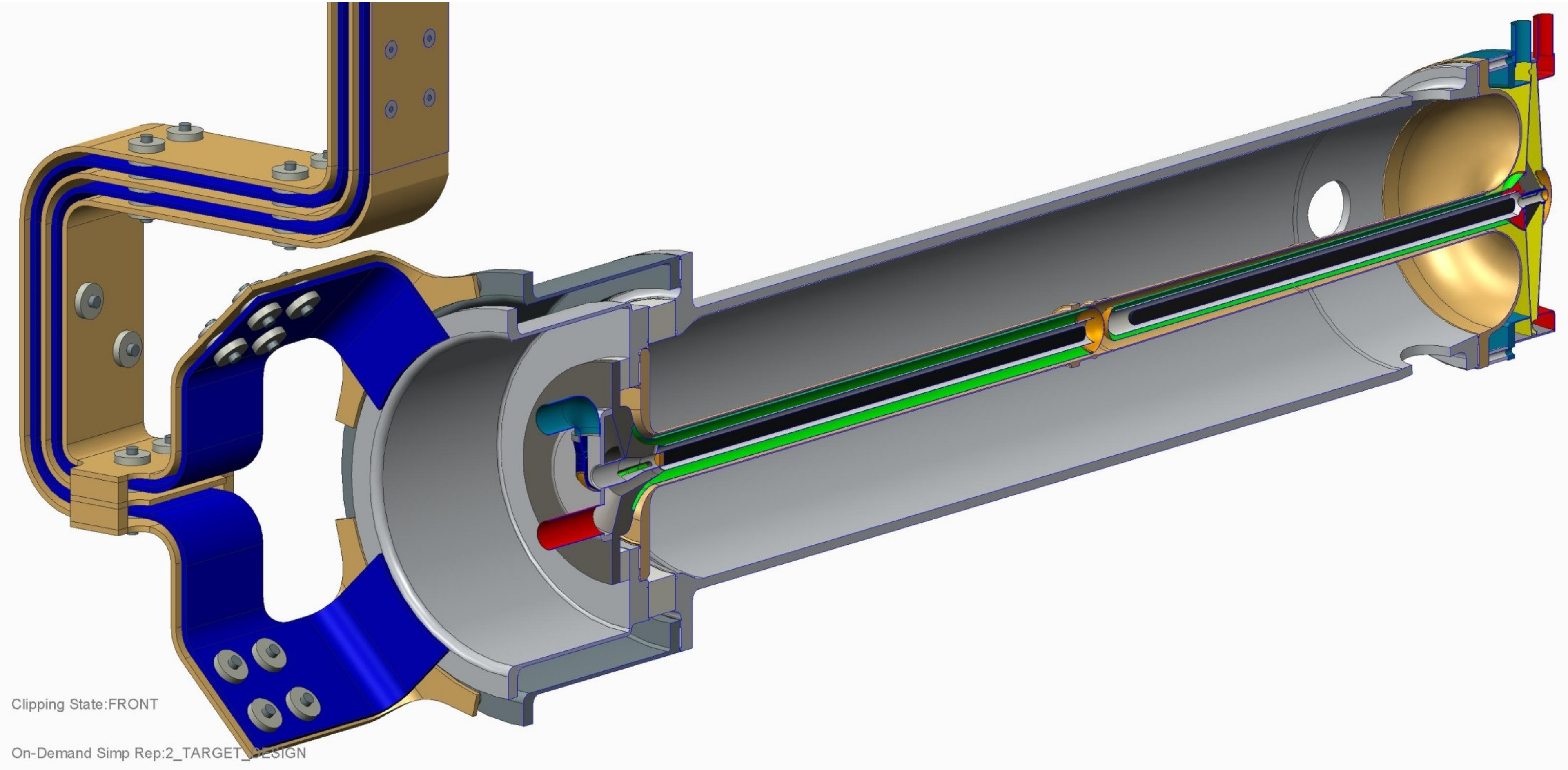


# 2m long cyl. target with downstream support



# 2 x 1m double target concept

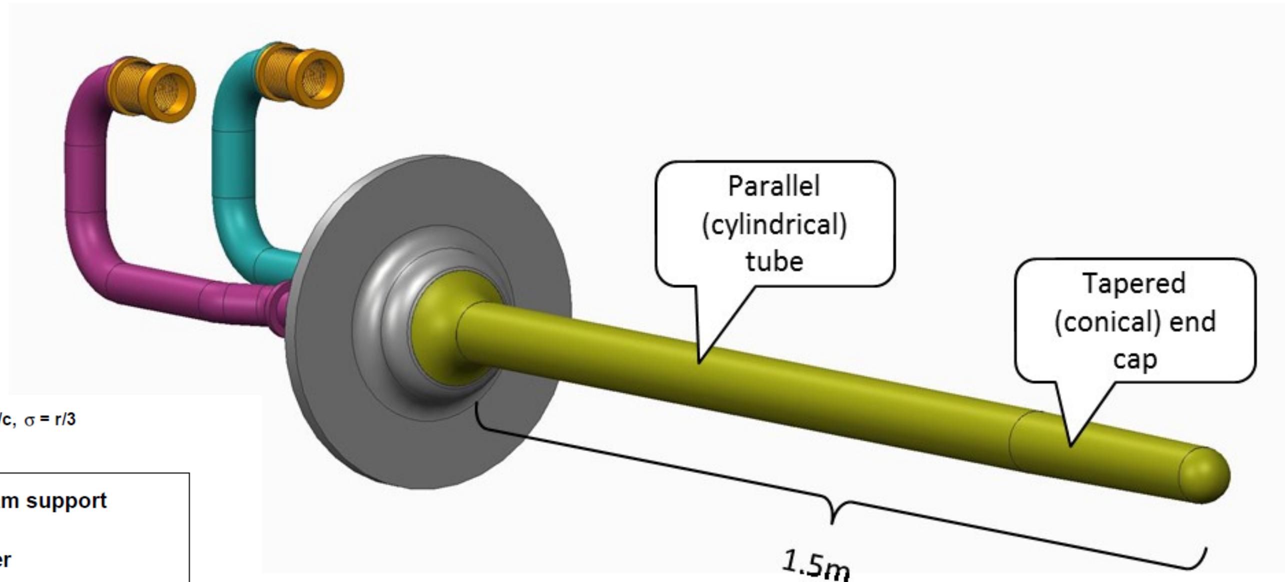
- Target cantilevered from each end of the horn
- Outer sheath of the DS target smaller in diameter than the US end due to the tapered shape of the horn.
- More options available for DS target optimisation

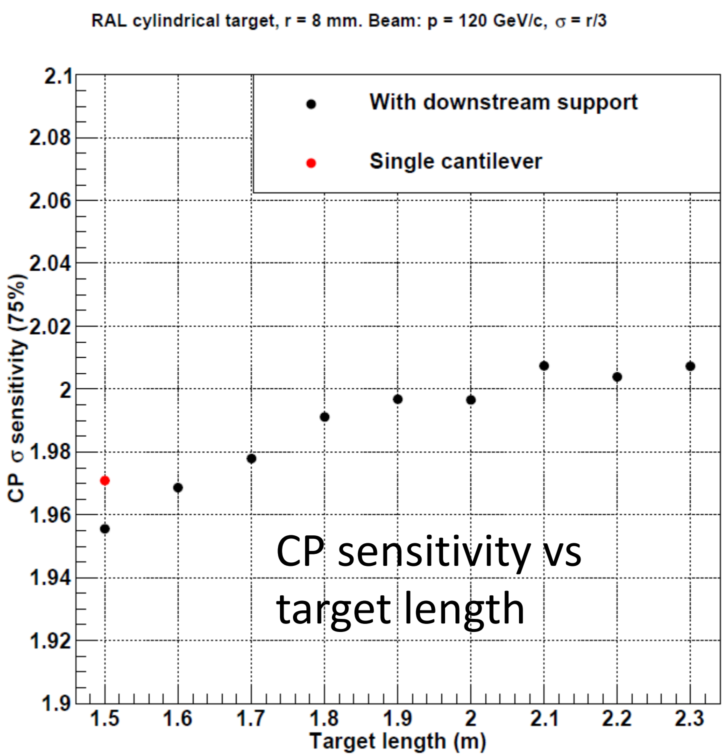


# Compromise – longest practicable T2K-like cantilever c.1.5m long

Risks with Option C:-

1. Manufacture of long target
2. Reliably coupling with down stream support




CP sensitivity vs target length

If the target is sufficiently short it could be supported as a simple cantilever with no downstream support

*A* c. 1.5m long cantilevered target appears potentially feasible

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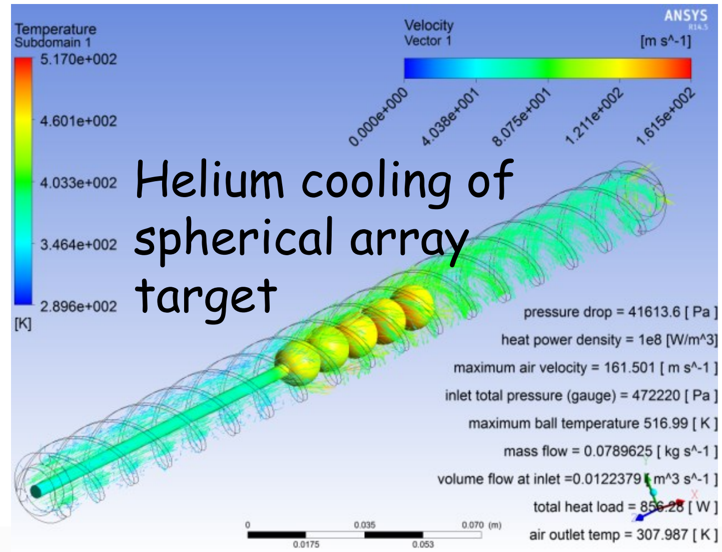
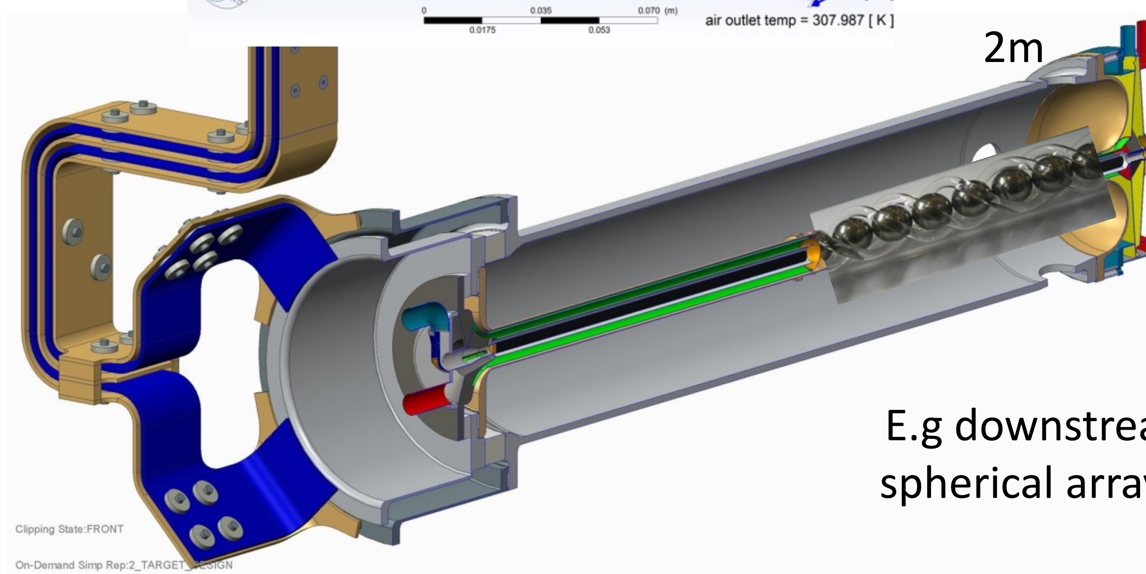
# Hybrid target ideas

E.g. possibility to incorporate Spherical Array Target (from our 2010 study)




Helium cooling of spherical array target

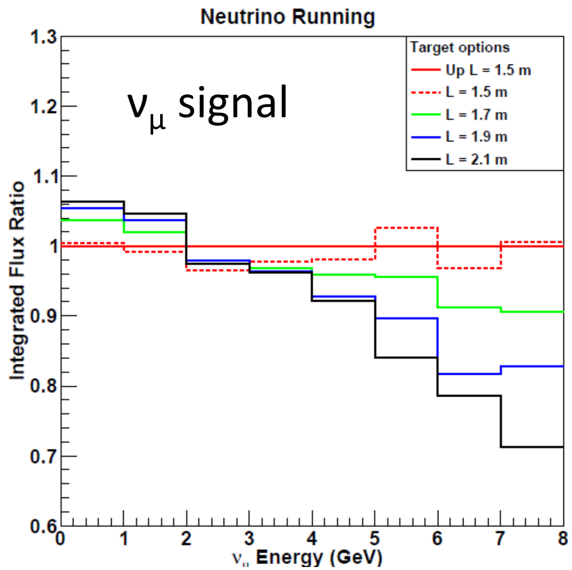
Induction furnace tests of packed bed

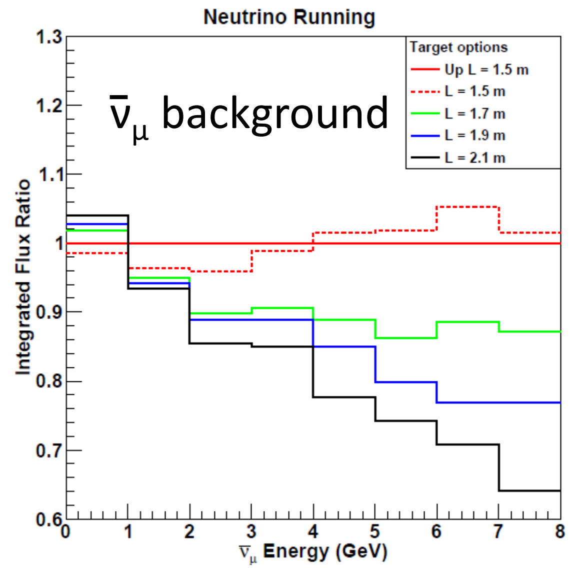


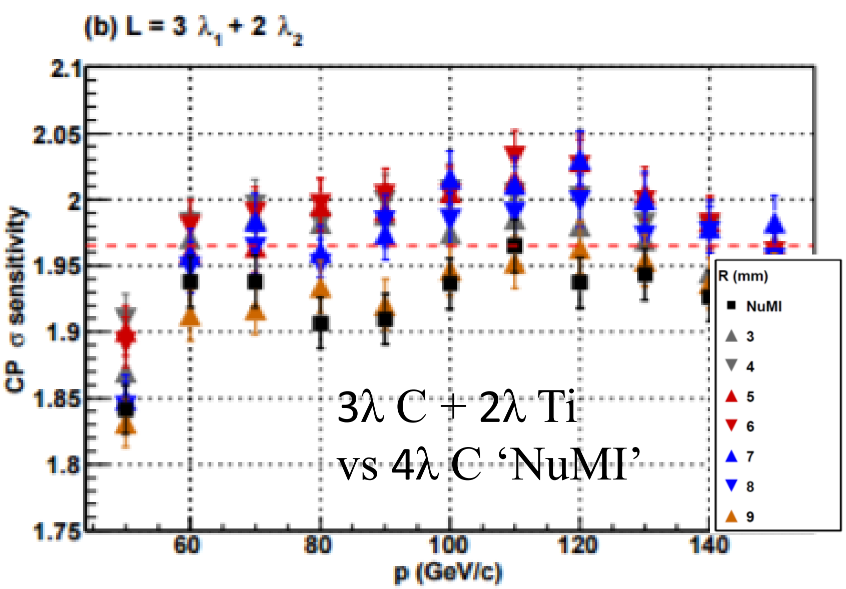

2m

E.g downstream spherical array –

# Instantaneous physics performance




Investigations of longer &/or higher-Z material combinations to:

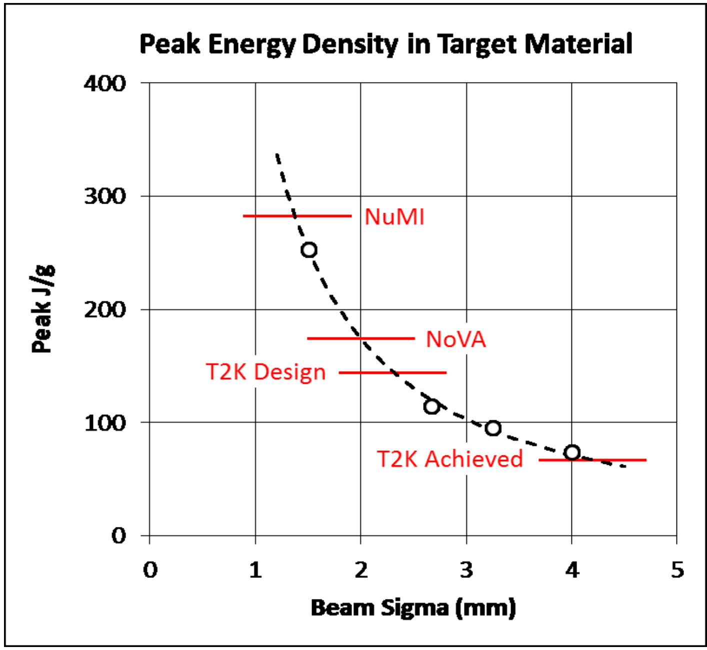
- increase 'right-sign' pion yield
- reduce on-axis 'wrong-sign' pions

*Are benefits worth risks?*

# Comparison of target heat loads: LBNF vs T2K, NuMI, NOvA

| | T2K (Design) | T2K (Achieved) | NuMI | NoVA | LBNF cylinder |
|---|---|---|---|---|---|
| Target Material | ToyoTanso IG-43 | ToyoTanso IG-43 | POCO ZXF-5Q | POCO ZXF-5Q | ToyoTanso IG-43 |
| Beam Energy [GeV] | 30 | 30 | 120 | 120 | 120 |
| Beam Power [kW] | 750 | 350 | 400 | 700 | 1200 |
| Beam Current [μA] | 25 | 12 | 3.3 | 5.8 | 10 |
| Protons per Pulse [-] | $3.3\times10^{14}$ | $1.8\times10^{14}$ | $4.0\times10^{13}$ | $4.9\times10^{13}$ | $7.5\times10^{13}$ |
| Cycle Time [s] | 2.1 | 2.5 | 1.9 | 1.3 | 1.2 |
| Beam Sigma [mm] | 4.2 | 4.2 | 1 | 1.3 | 2.7 |
| Peak Energy Density in target material [J/g] | 144 | 67 | 282 | 174 | 118 |
| Peak Proton Fluence on Front Face [μA/cm²] | 23 | 11 | 53 | 55 | 22 |

Total and pulsed heat loads lower than that seen on NoVA and NuMi and on T2K design

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# *Draft* target selection criteria

| LBNF target selection criteria | Weighting | | Weighting share | Candidate score | | | | | Weighted candidate score | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Fin/water | 1x2m cyl/He | 2x1m cyl/He | 1.5m cyl/He | Hybrid | Fin/water | 1x2m cyl/He | 2x1m cyl/He | 1.5m cyl/He | Hybrid |
| 1 Physics performance | **30** | Instantaneous physics performance | 40% | 90% | 90% | 90% | 70% | 100% | 10.8 | 10.8 | 10.8 | 8.4 | 12 |
| | | Upgradeability to 2.4 MW | 30% | | | | | | 0 | 0 | 0 | 0 | 0 |
| | | Flexibility re optimisation (materials, beam size etc) | 20% | | | | | | 0 | 0 | 0 | 0 | 0 |
| | | Compatibility with beam alignment (hadron vs muon?) | 10% | | | | | | 0 | 0 | 0 | 0 | 0 |
| 2 Engineering performance | **20** | Safety factor = f(stress, temperature) | 30% | | | | | | 0 | 0 | 0 | 0 | 0 |
| | | Lifetime, resilience to radiation damage | 30% | | | | | | 0 | 0 | 0 | 0 | 0 |
| | | Resilience to off-normal conditions | 20% | | | | | | 0 | 0 | 0 | 0 | 0 |
| | | Resilience to beam trips | 10% | | | | | | 0 | 0 | 0 | 0 | 0 |
| | | Potential for diagnostics | 10% | | | | | | 0 | 0 | 0 | 0 | 0 |
| 3 Impact on other systems | **10** | Impact on horn/stripline design | 10% | | | | | | 0 | 0 | 0 | 0 | 0 |
| | | Ease of integration with horn | 10% | | | | | | 0 | 0 | 0 | 0 | 0 |
| | | Ease/reliability of alignment with horn axis | 10% | | | | | | 0 | 0 | 0 | 0 | 0 |
| | | Impact on services/plant | 10% | | | | | | 0 | 0 | 0 | 0 | 0 |
| | | Ease of remote handling/disposal | 10% | | | | | | 0 | 0 | 0 | 0 | 0 |
| | | Impact on TS design | 10% | | | | | | 0 | 0 | 0 | 0 | 0 |
| | | Impact on absorber design | 40% | | | | | | 0 | 0 | 0 | 0 | 0 |
| 4 Cost | **10** | Cost & resource for design/prototyping | 20% | | | | | | 0 | 0 | 0 | 0 | 0 |
| | | Cost & resource for manufacture | 30% | | | | | | 0 | 0 | 0 | 0 | 0 |
| | | Cost of RH equipment | 20% | | | | | | 0 | 0 | 0 | 0 | 0 |
| | | Disposal cost | 30% | | | | | | 0 | 0 | 0 | 0 | 0 |
| 5 Schedule | **10** | Time to design | 30% | | | | | | 0 | 0 | 0 | 0 | 0 |
| | | Time to prototype | 20% | | | | | | 0 | 0 | 0 | 0 | 0 |
| | | Time to manufacture | 20% | | | | | | 0 | 0 | 0 | 0 | 0 |
| | | Schedule impact on other systems | 30% | | | | | | 0 | 0 | 0 | 0 | 0 |
| 6 Risk | **20** | Design complexity | 20% | | | | | | 0 | 0 | 0 | 0 | 0 |
| | | Ease of manufacture | 20% | | | | | | 0 | 0 | 0 | 0 | 0 |
| | | Remote handling complexity | 20% | | | | | | 0 | 0 | 0 | 0 | 0 |
| | | Departure from known technology | 10% | | | | | | 0 | 0 | 0 | 0 | 0 |
| | | Schedule risk | 10% | | | | | | 0 | 0 | 0 | 0 | 0 |
| | | ES&H / ALARA issues | 20% | | | | | | 0 | 0 | 0 | 0 | 0 |
| Totals | **100** | | | | | | | | 10.8 | 10.8 | 10.8 | 8.4 | 12 |