LBNF Target
Conceptual Design Selection

Chris Densham (STFC Rutherford Appleton Laboratory)

On behalf of combined UK and Fermilab

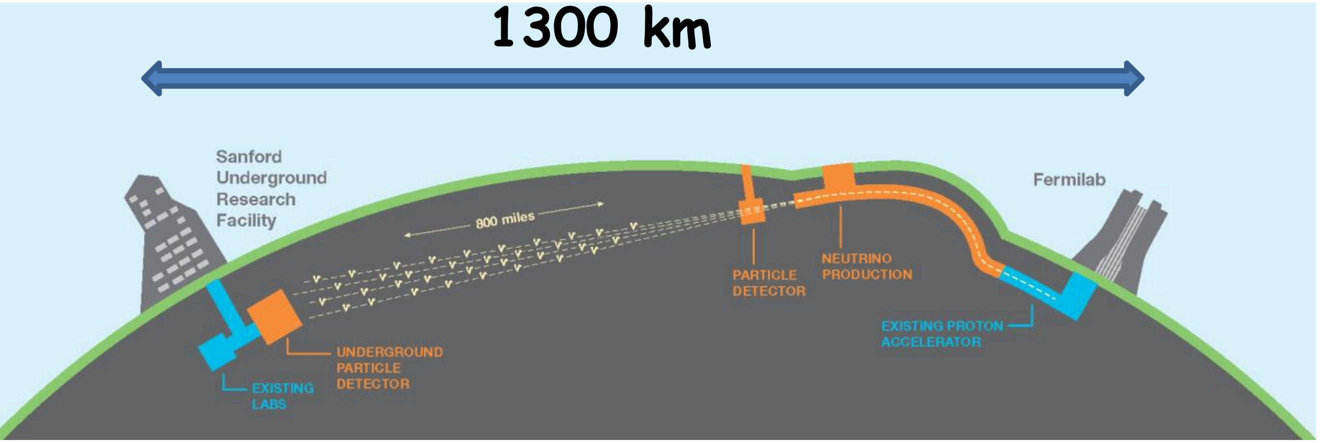
LBNF Project team

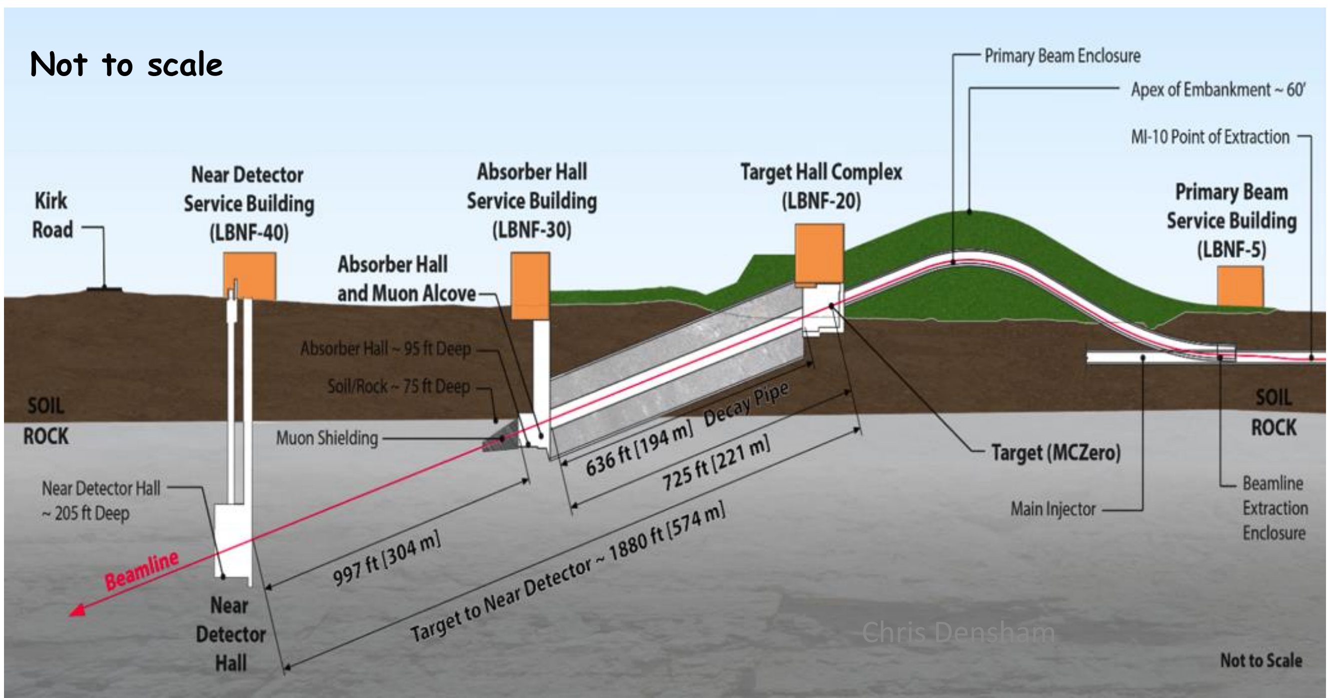
with physics plots c/o John Back (Warwick University)

DEEP UNDERGROUND NEUTRINO EXPERIMENT

Science & Technology Facilities Council
Rutherford Appleton Laboratory

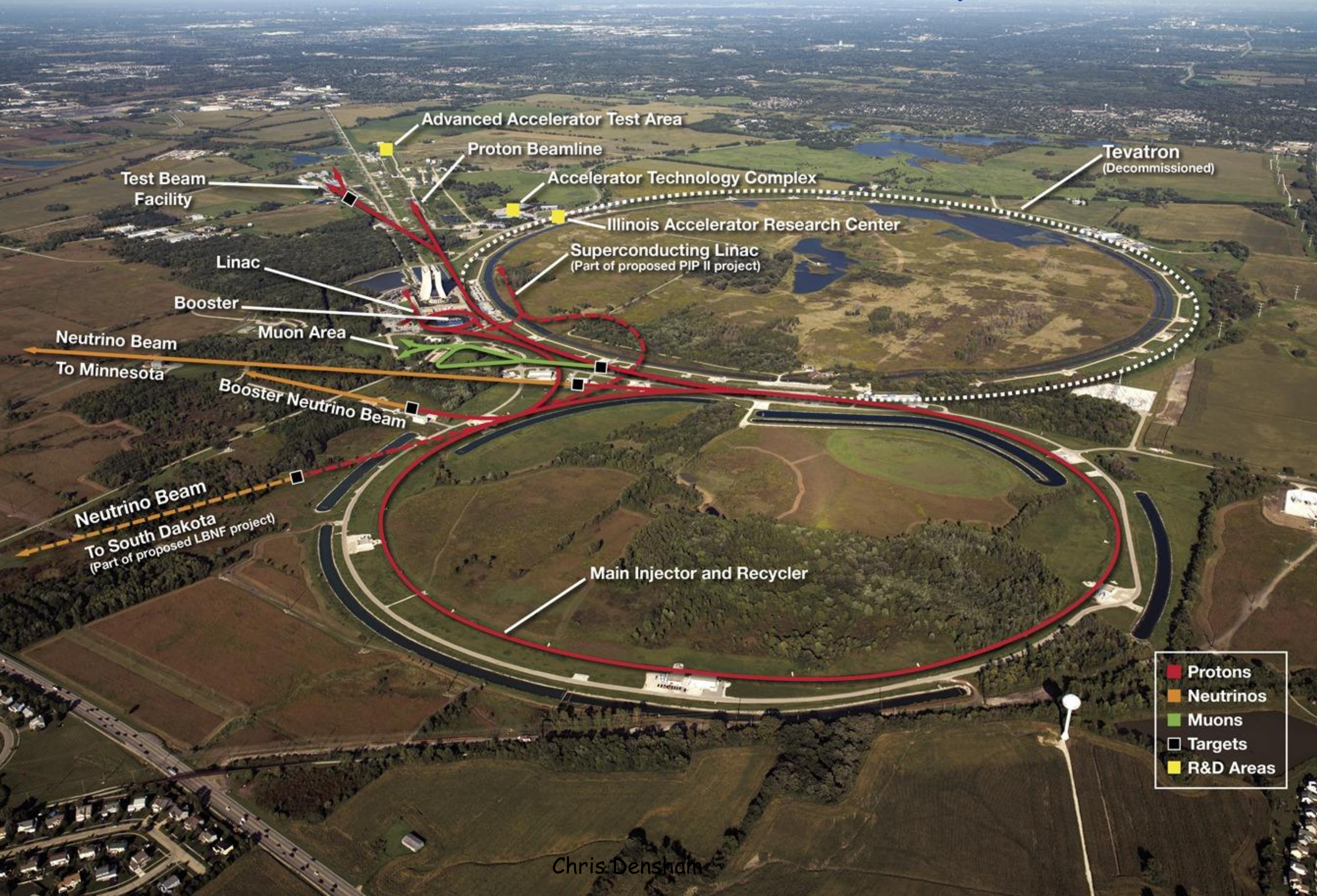
The LBNF/DUNE Beamline



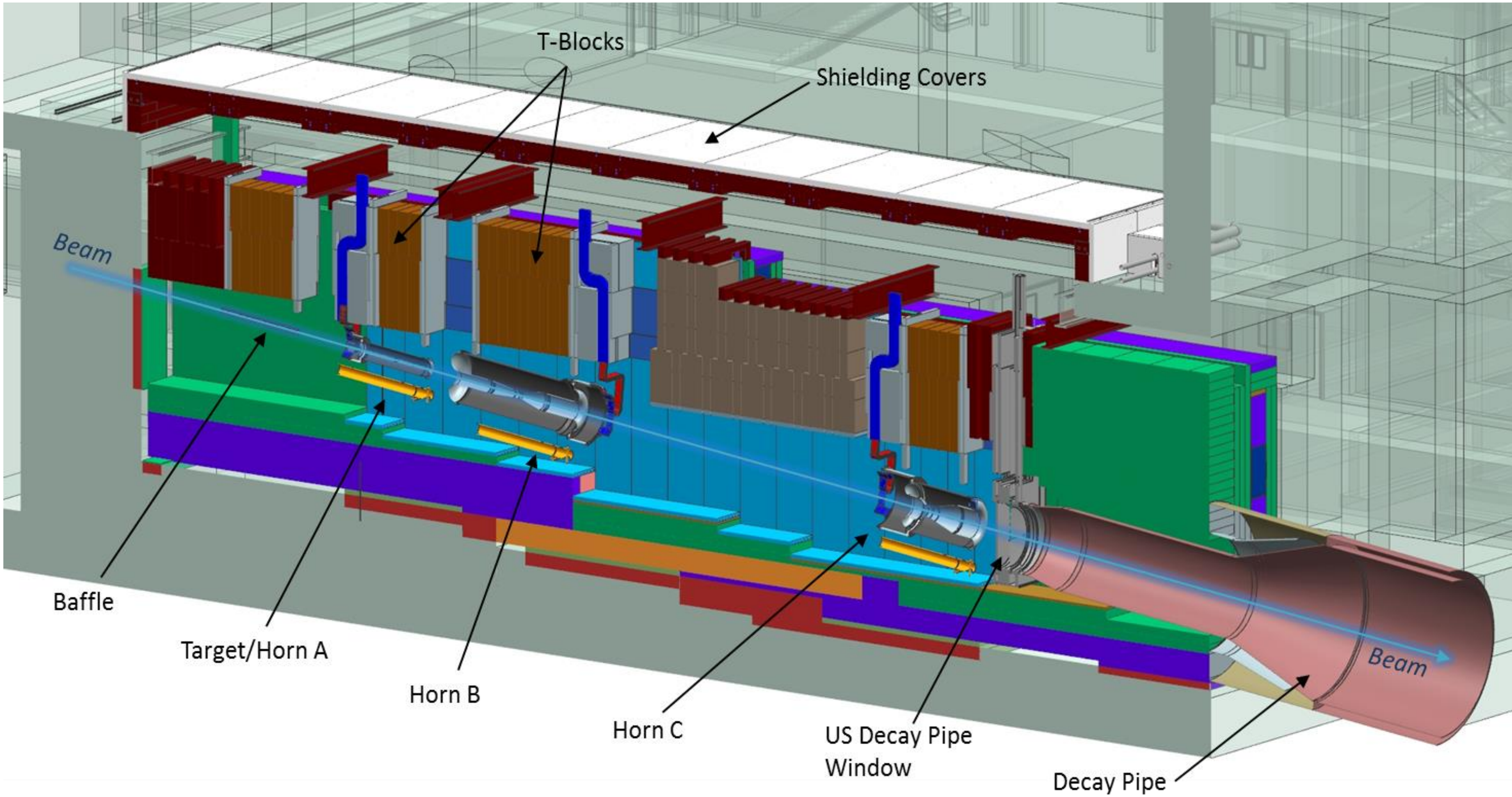


- On-axis, wide-band neutrino beam
- Primary proton beam 60 -120 GeV extracted from Main Injector
- Initial beam power 1.2 MW (PIPII)
- Upgradeable to 2.4 MW (PIPIII)

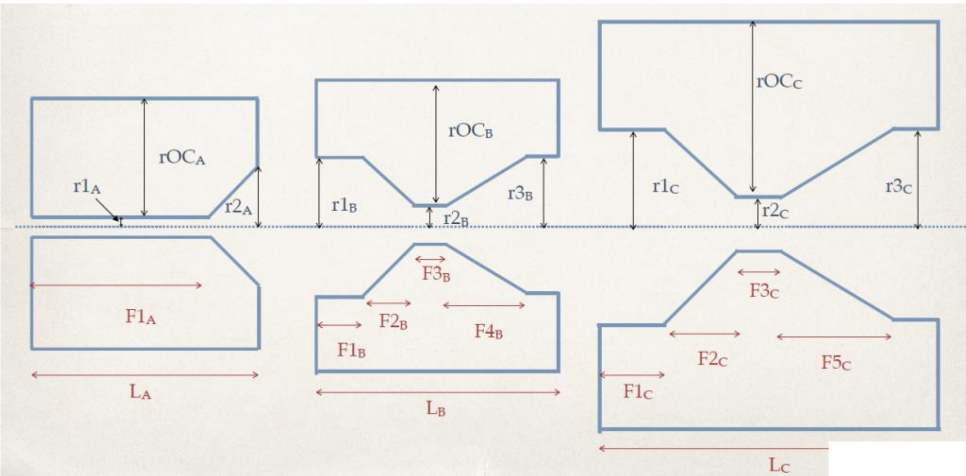
Fermilab Accelerator Complex



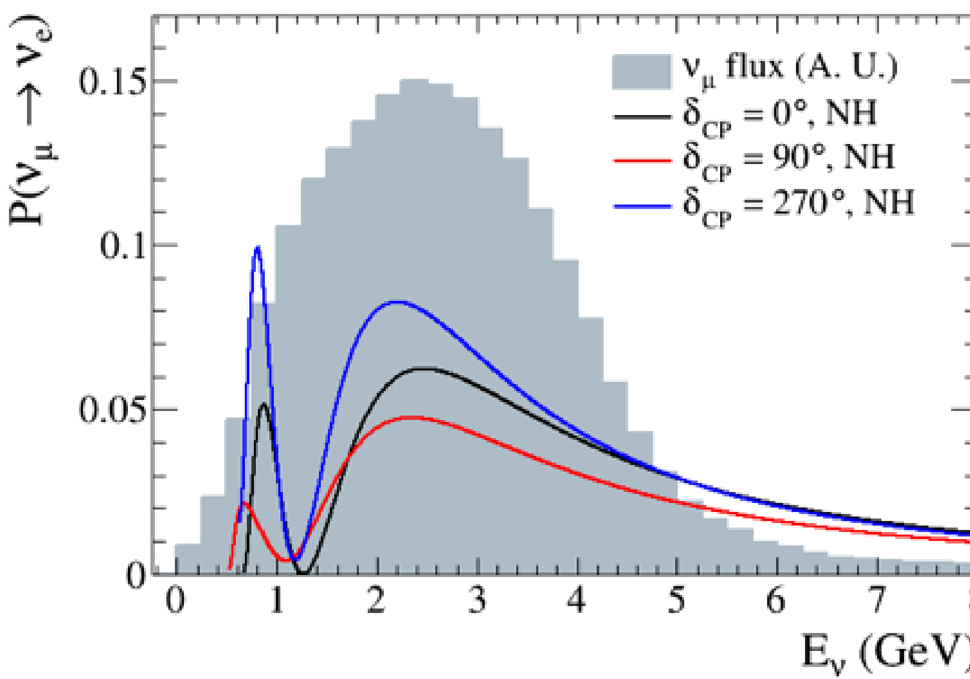
LBNF target station



Optimisation of LBNF/DUNE target & horn

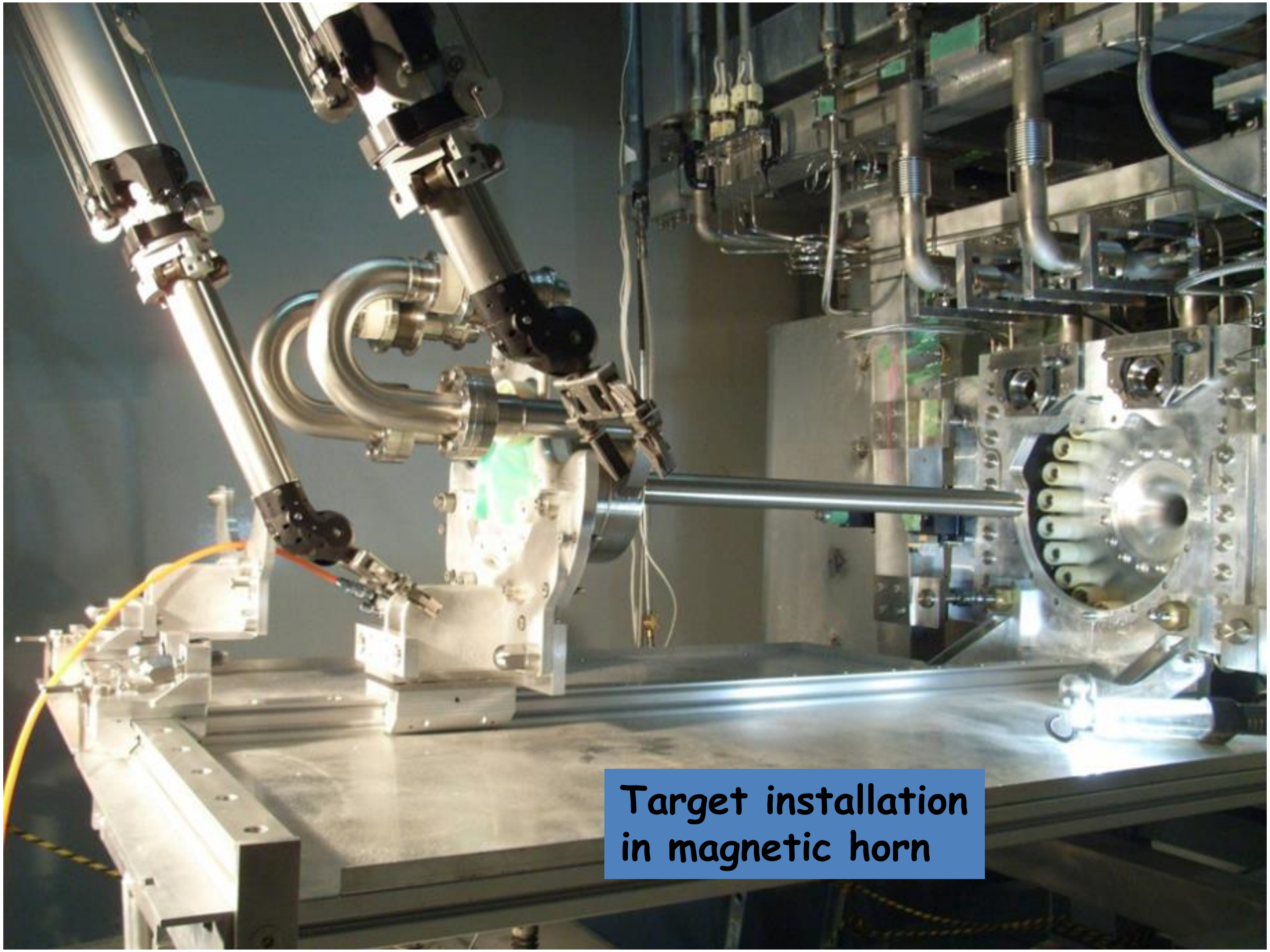


- Wide-band neutrino beam
- Genetic algorithm used to optimise horn & target geometry (Laura Fields)



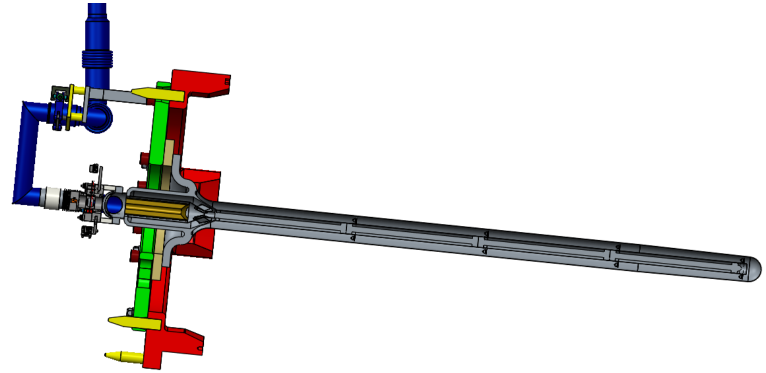
DEEP UNDERGROUND NEUTRINO EXPERIMENT

Our starting point: Helium Cooled T2K Target

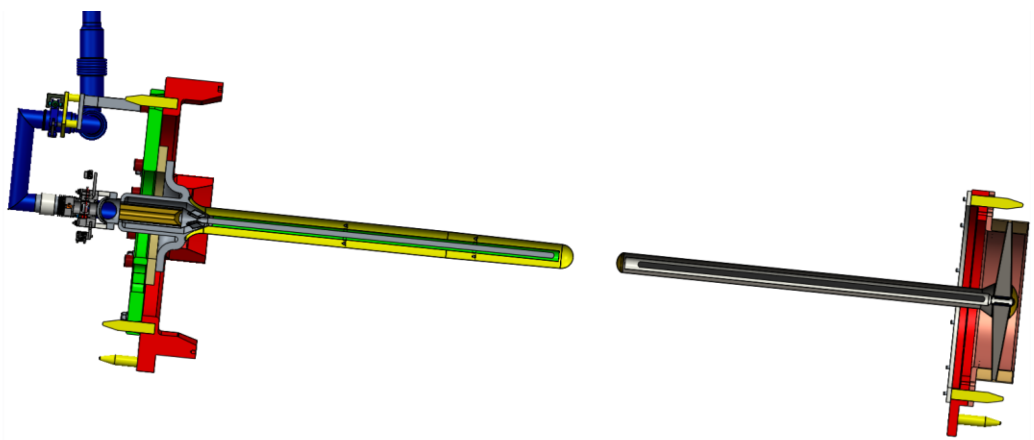


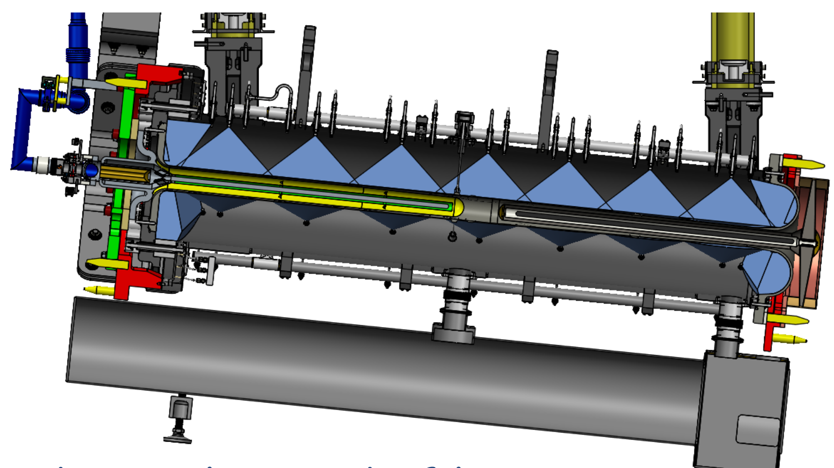
Helium cooled target concepts considered

1: Single 2.2m long target with remote-docking downstream support



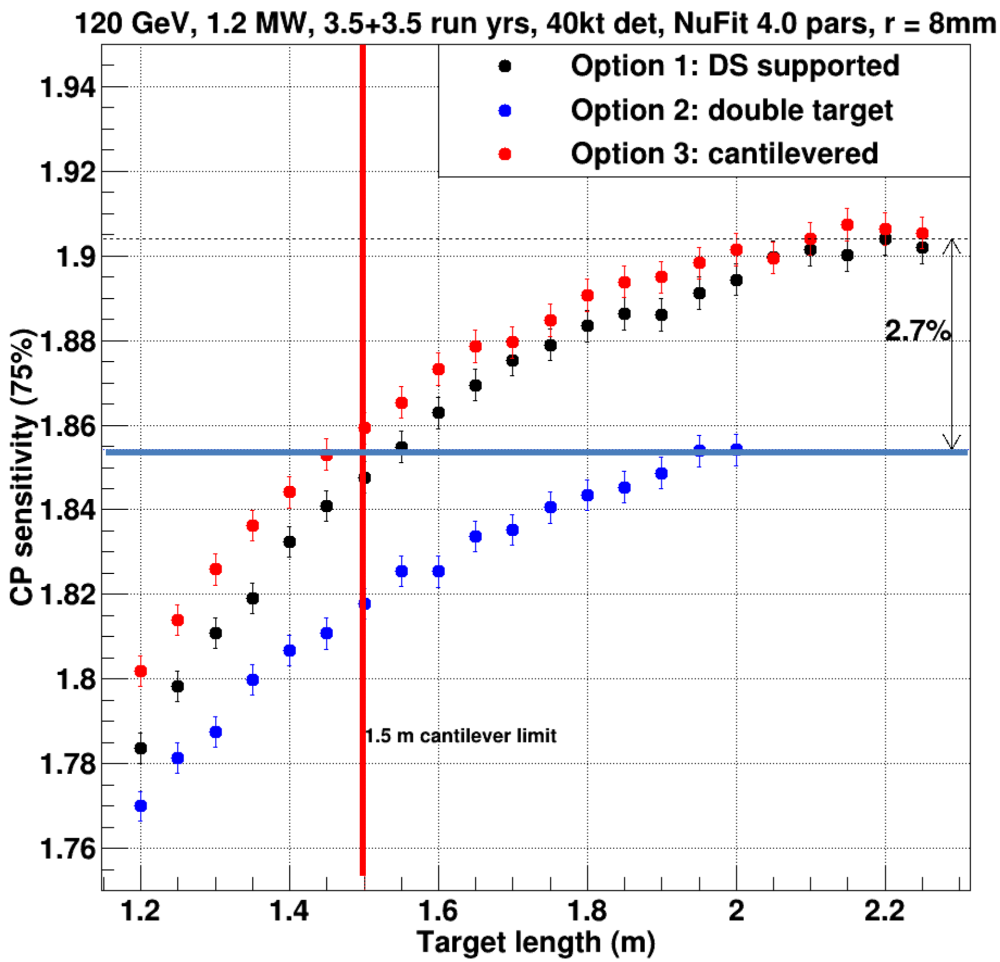
3: Single intermediate length (c.1.5 m or 'As Long As Realistically Achieveable') cantilever target





2: Two ~1m long cantilever targets, one inserted at either end of horn

Comparison of CP sensitivity for 3 options considered (all r = 8 mm, σ = r/3

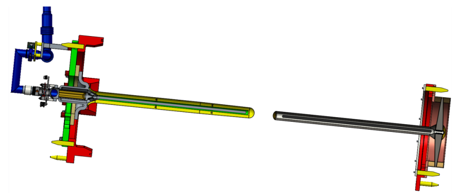
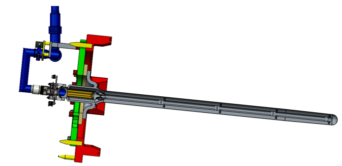


- Option 1: offers best physics performance at c.2.2 m length
- Option 2: Simple cantilever gives best performance for a given length (but may be limited to c.1.5 m)
- Option3: Double 1 m targets offer same performance as single 1.5 m cantilever

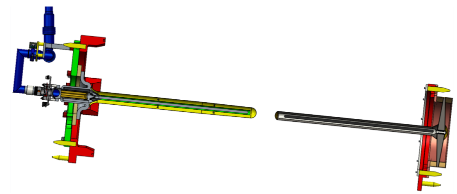
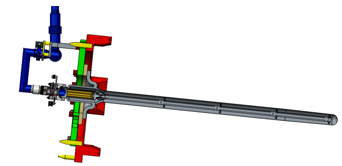
Particle Production Target 'Optimum' Performance

- $\lambda_{overall} = \lambda_{physics} \times \lambda_{reliability}$, *where* $\lambda_{reliability} = fn(I,\sigma,L\ldots)$
- For CP sensitivity – small target *r* & beam *σ* is favoured
- For target lifetime – bigger *σ, r* is better.
  - Lower power density – lower temperatures, lower stresses
  - Lower radiation damage rate
  - Lower amplitude 'violin' modes (and lower stresses)
- For CP sensitivity – long target (c.2m, 4λ) is better
- For max lifetime – short and *simple* target is better
- For **integrated** optimum performance, need to take both *instantaneous* performance and *reliability* into account
  - E.g. How to achieve best physics performance possible for a target lifetime of a minimum of 1 year?
- **Concept selection meeting considered these issues 24-26 July 2019 at Fermilab**

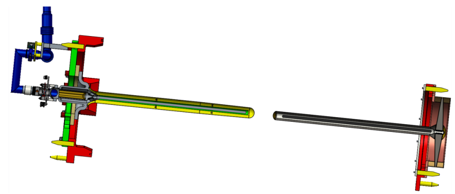
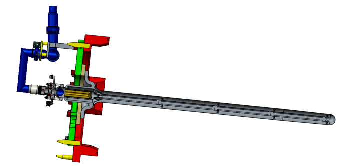
Key Design and Manufacturing Issues

	 **Option 1:1x2m long**	 **Option 2: 2x1m long**	 **Option 3: intermediate cantilever**
Complexity of horn Interface	Interfaces at both US and DS of horn, plus self interface! Needs Helium services routing to DS end.	Interfaces at both US and DS of horn. Needs Helium services routing to DS end.	Interface to horn US end only
Departure from Proven Technology	Departure from T2K in terms of length / segmentation and Self docking interface.	Closest to two-interaction length T2K target	Departure from T2K in terms of length / segmentation
Design Challenges	DS support design for radial stiffness + longitudinal compliance, requires prototyping.	DS support/manifold design w.r.t. pressure stress and thermal distortion.	Pushing for longest feasible length (re: deflection, violin modes)
Manufacturing Challenges	DS support manufacture is complex. Manufacture of long thin-walled titanium tube to tight dimensional tolerances.	US target most similar to T2K. DS low-mass manifold manufacture is complex.	Manufacture of long thin-walled titanium tube to tight dimensional tolerances.
Cost	Relatively high cost of manufacture and outstanding design tasks	Relatively high cost of manufacture and outstanding design tasks	Relatively low cost of manufacture and outstanding design tasks

Key Operation Issues

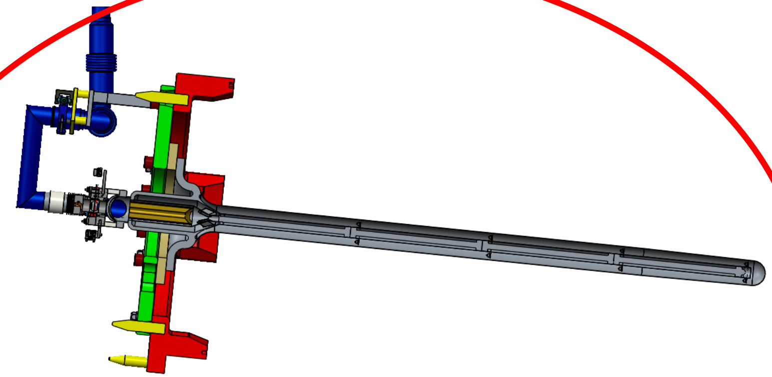
	 **Option 1:1x2m long**	 **Option 2: 2x1m long**	 **Option 3: intermediate cantilever**
Spare Production	Intermediate cost Build two in parallel?	Highest cost Build four (2 US + 2 DS) in parallel?	Lowest cost Build two in parallel?
Thermal Management	Highest heat load, single target cooling loop. Also need to cool DS support.	High heat load but divided between two cooling loops	Lowest total heat load
Mechanical loads	DS prop required to keep self-weight deflection and natural frequency in check	Most "robust" structure as measured by natural frequency and self-weight deflection	Inherently pushing at the limits on cantilever length
Complexity / number of failure points	High complexity due to cooled downstream mount	High complexity due to additional downstream target system	Low Complexity / number of components
Alignment Issues	Relies on DS support for target placement precision	Perceived difficulties with beam based alignment	Single object to align but largest self-weight deflection

Key Remote Maintenance Issues

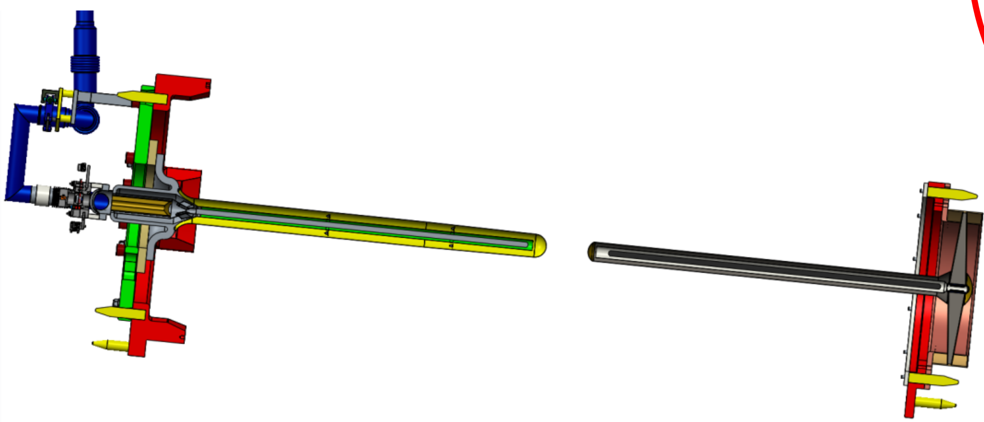
	 **Option 1:1x2m long**	 **Option 2: 2x1m long**	 **Option 3: intermediate cantilever**
Time estimate for planned target exchange	3 weeks	2 weeks	1 week
Risk / complexity	High (number of operations)	High (number of operations)	Medium (number of operations)
Work Cell Interfaces	Two sets of exchange tooling with mechanical/services interface	Two sets of exchange tooling with mechanical/services interface	One exchanger tool
Manipulator operations	Ergonomics compromised when module rotated. Long-reach manipulators.	Ergonomics compromised when module rotated	Can optimise reach/view for the single required configuration
Crane operations	Two module rotations, including re-configuration of supports etc	One module rotation, including re-configuration of supports etc	All work achieved with single module configuration

Helium cooled target concept selection

1: Single 2.2m long target with remote-docking downstream support

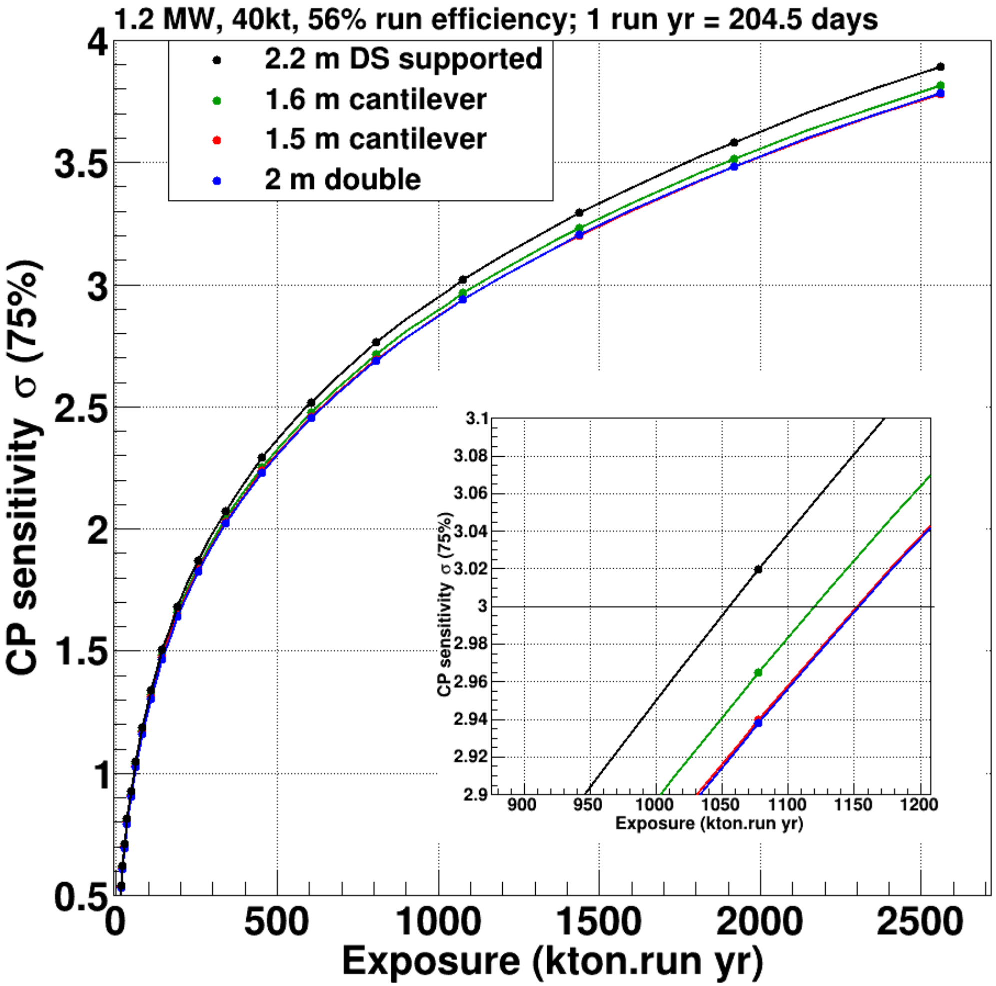


3: Single intermediate length (c.1.5 m or 'As Long As Realistically Achieveable') cantilever target



2: Two ~1m long cantilever targets, one inserted at either end of horn

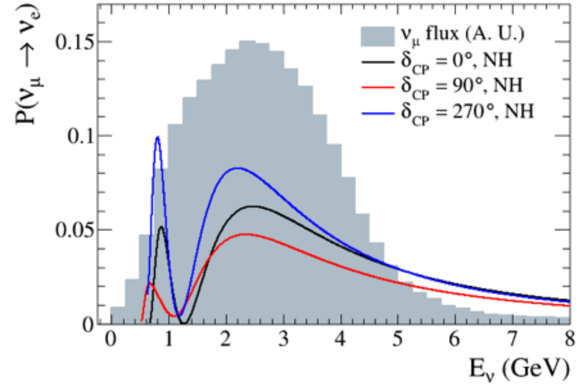
Integrated performance optimisation

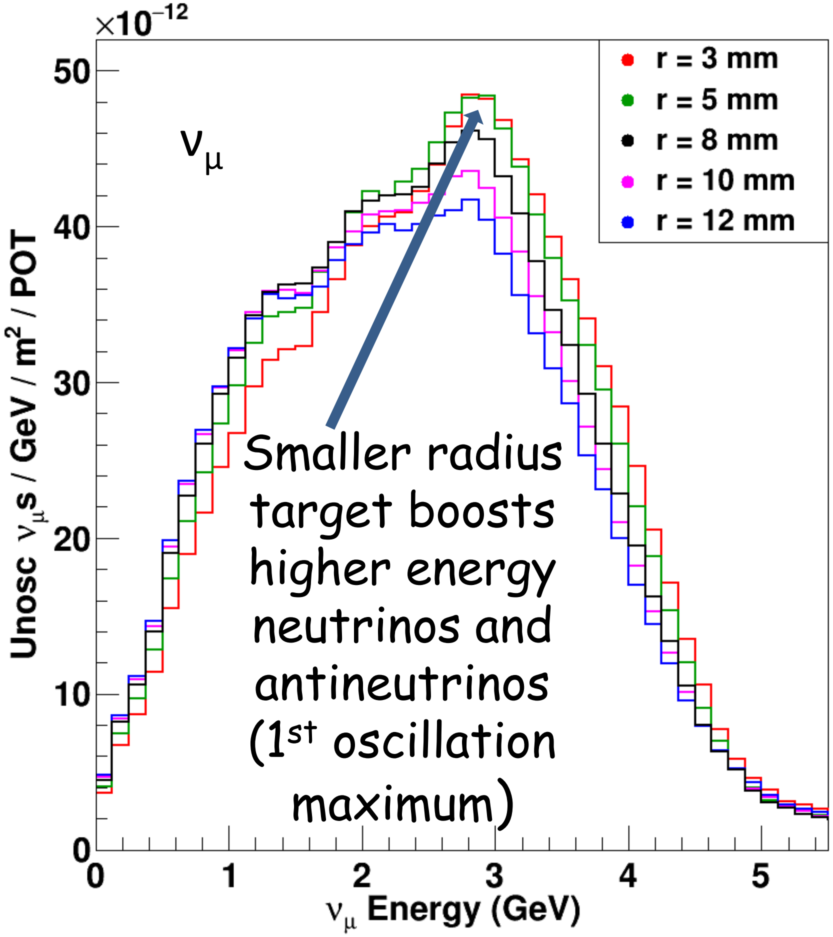


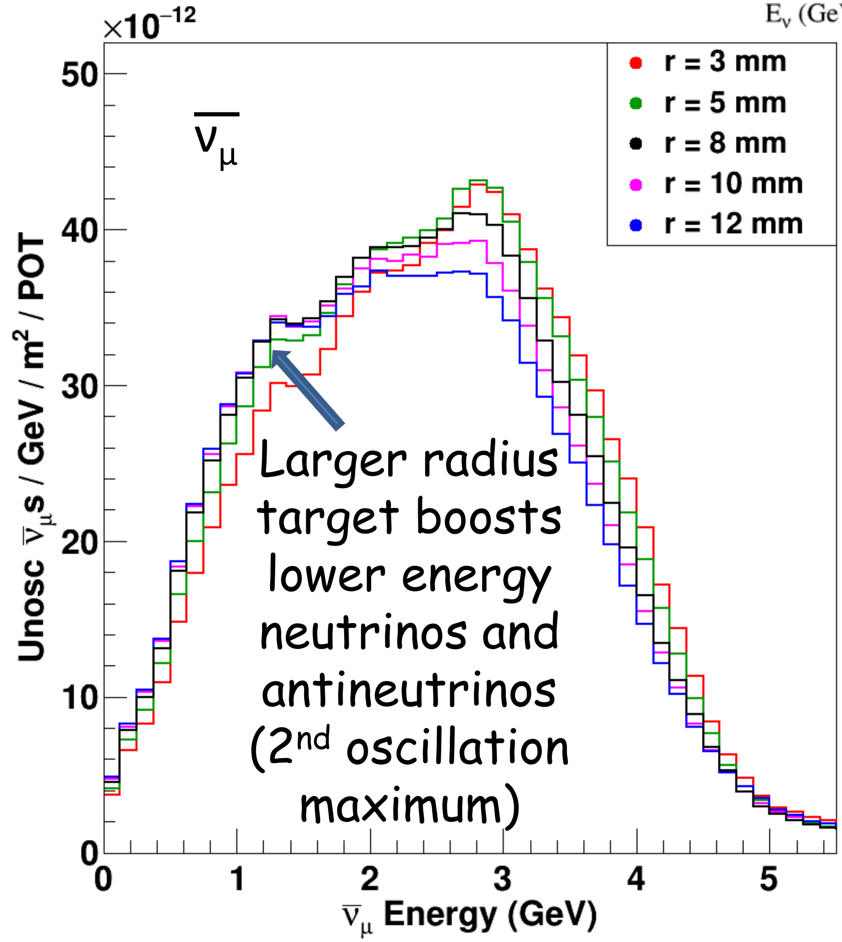
To achieve same 3σ exposure for ΔCP sensitivity as 2.2 m long target:

- 1.5 m cantilever *or* double target need to run extra 19 days/year
- 1.6 m cantilever needs to run extra 13 days/year
- **Conceptual Design Review Decision (last week): c.1.5 m cantilever will deliver better integrated performance**
- Ultimate objective: 'As Long As Realistically Achievable' cantilever target

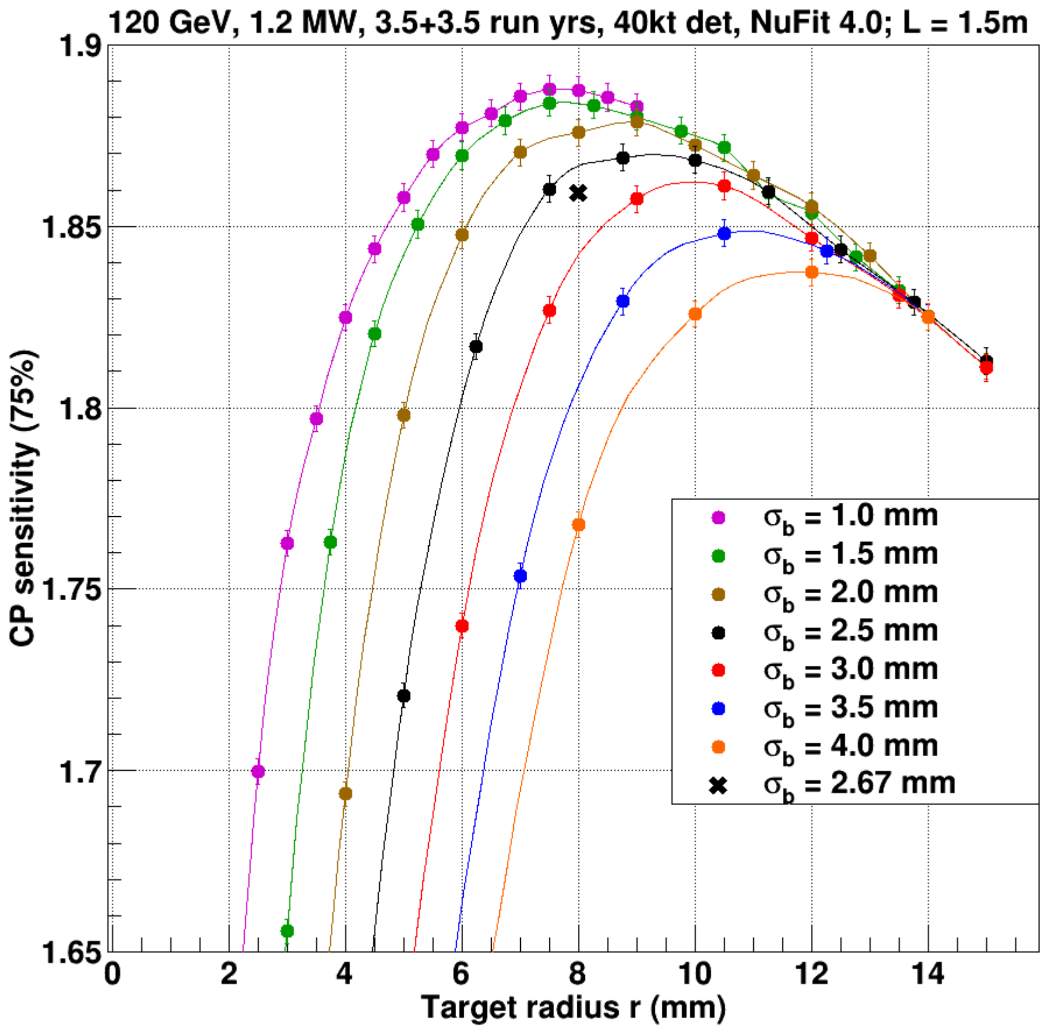
Neutrino flux for range of radii of 1.5 m long target







CPV sensitivity for 1.5 m cantilever target vs target & beam rms radius



- Comprehensive study of physics performance for range of beam and target radii
- Need to compromise between physics and engineering performance
- Some scope to improve ΔCP sensitivity for given beam rms radius

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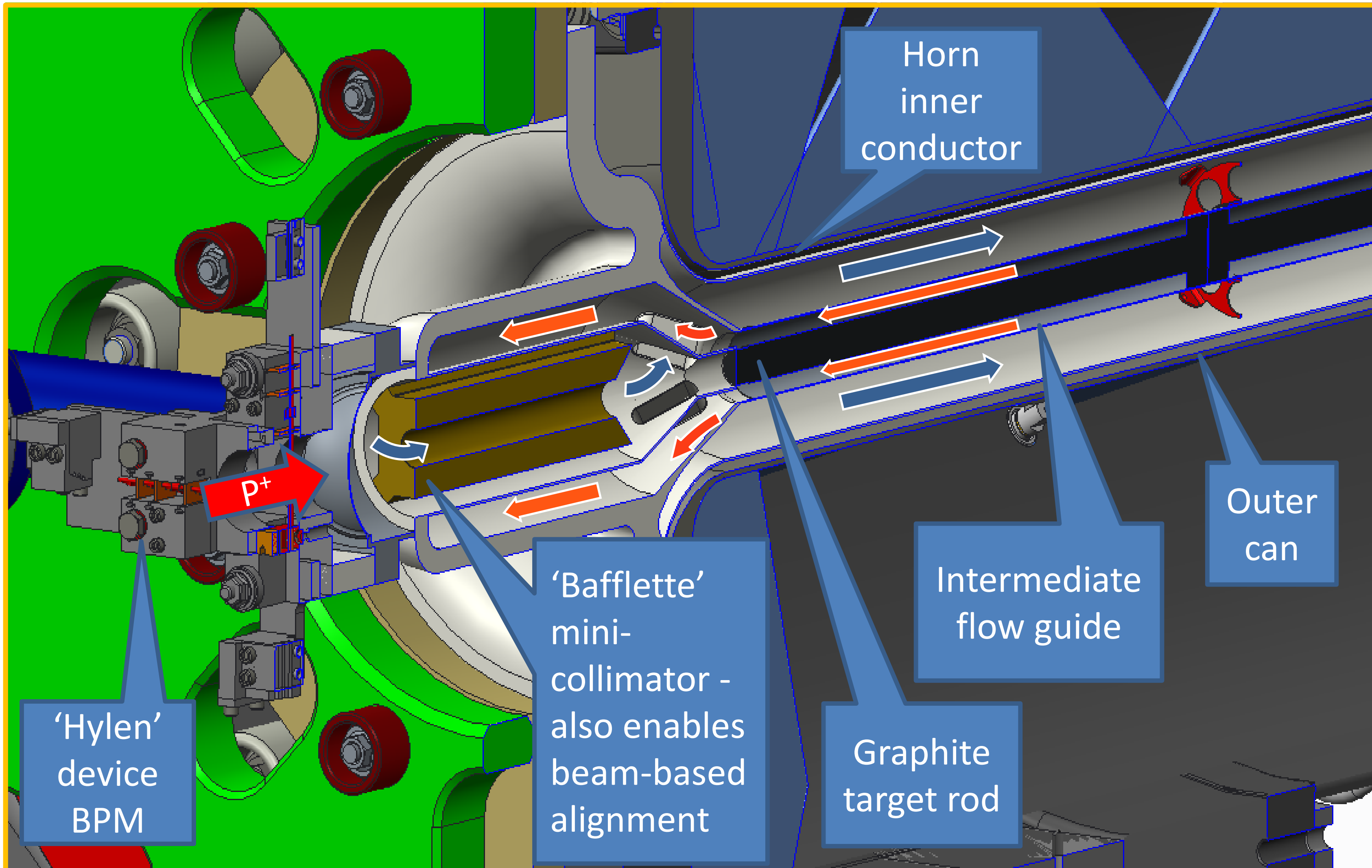
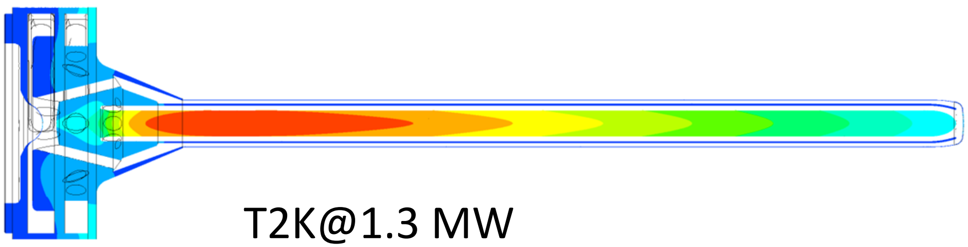
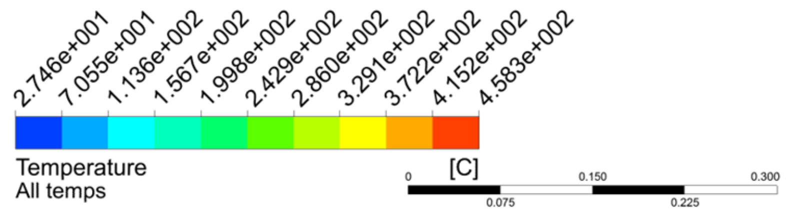
LBNF helium cooled target conceptual design



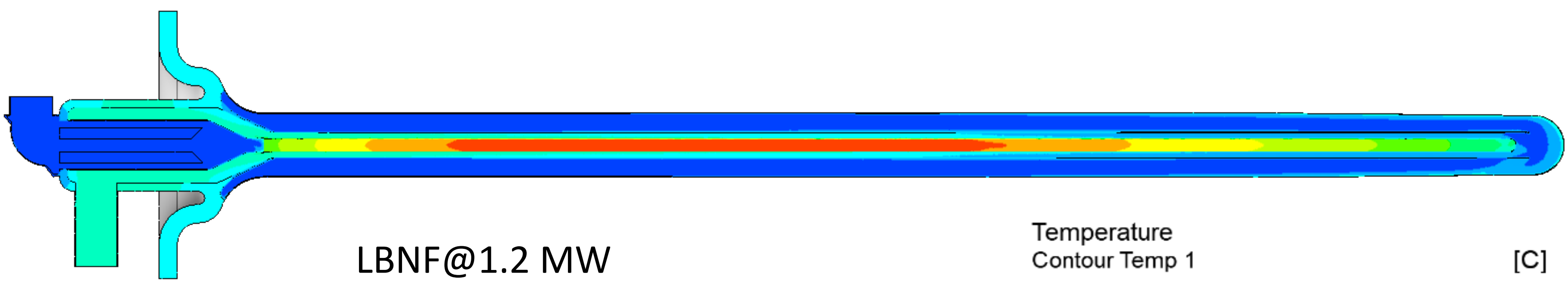
LBNF conceptual design compared with current 'state-of-the-art'



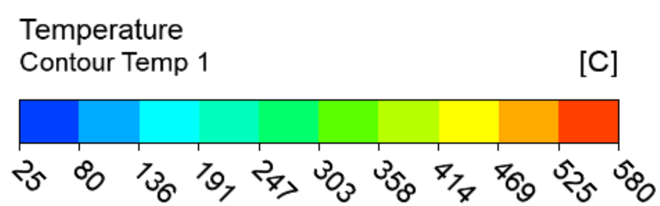
T2K@1.3 MW



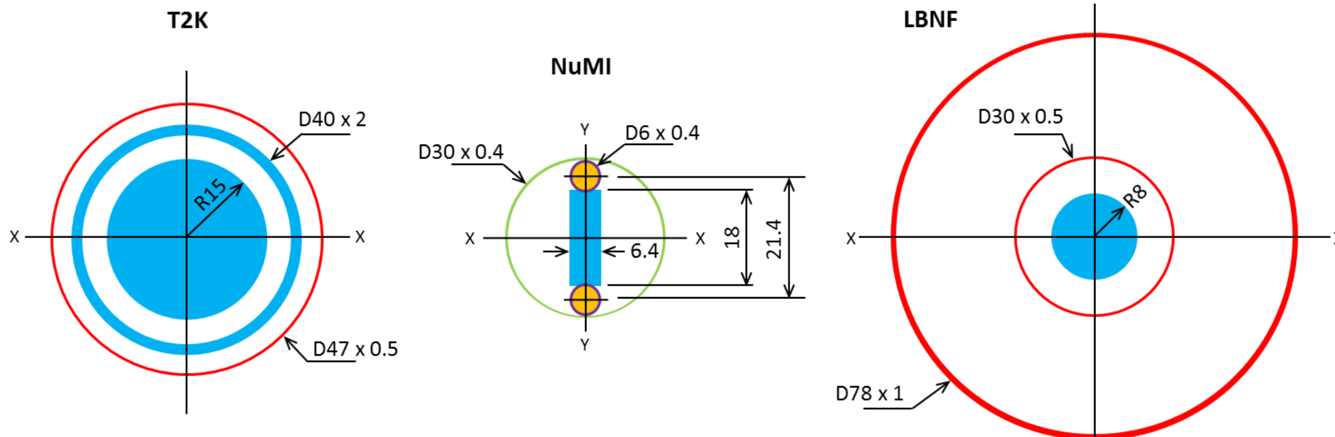
NB current experience up to 500 kW



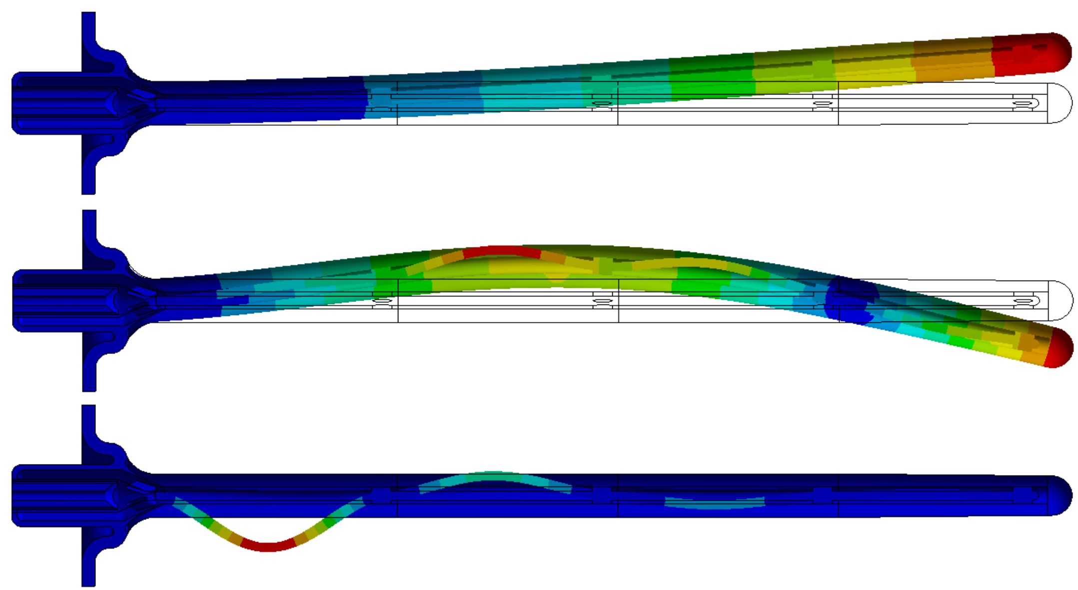
LBNF@1.2 MW



Dynamic stability as an indicator of 'robustness' (high frequency →low amplitude)

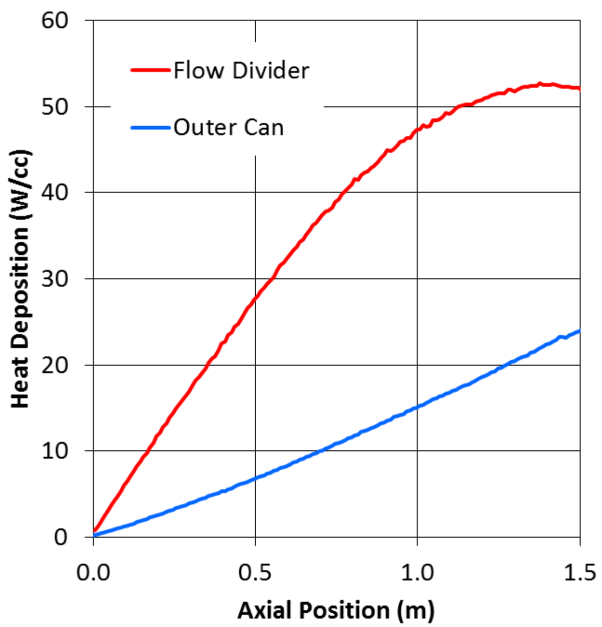


First 3 natural frequency modes:



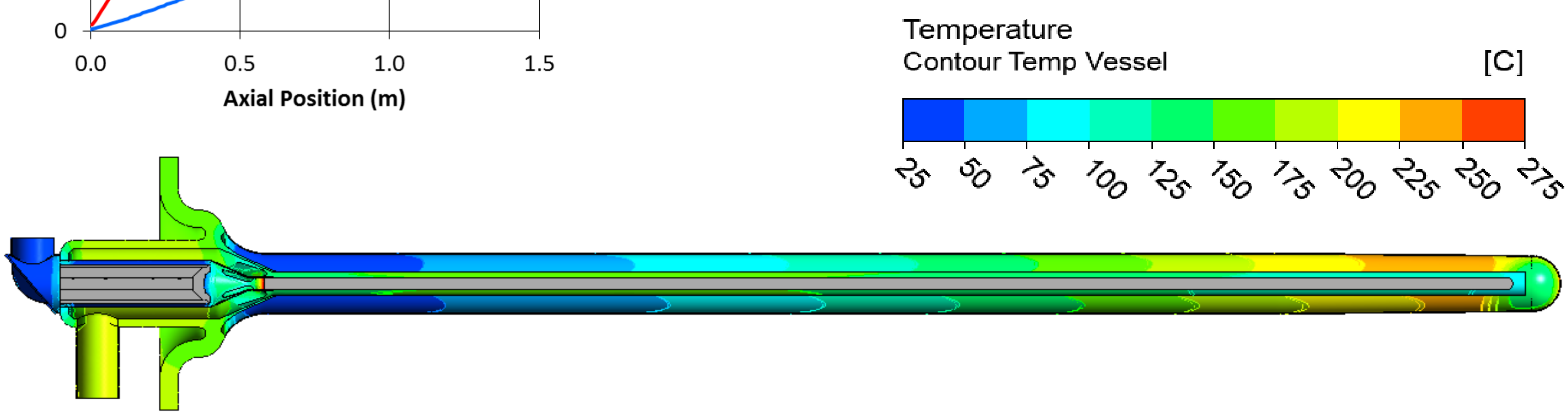
		LBNF	NuMI	T2K
Deflection under gravity (mm)		0.79	≈0.9	≈0.5
Natural Freq (Hz) for mode:	**1**	**22**	**14 (Horizontal)**	**28**
	2	135		
	3	228		

Design development



Heat loads in tubes

- Heat load in outer can and flow divider increases towards downstream end
- Need to increase heat transfer along length
- E.g. taper outer tube to accelerate flow along length?



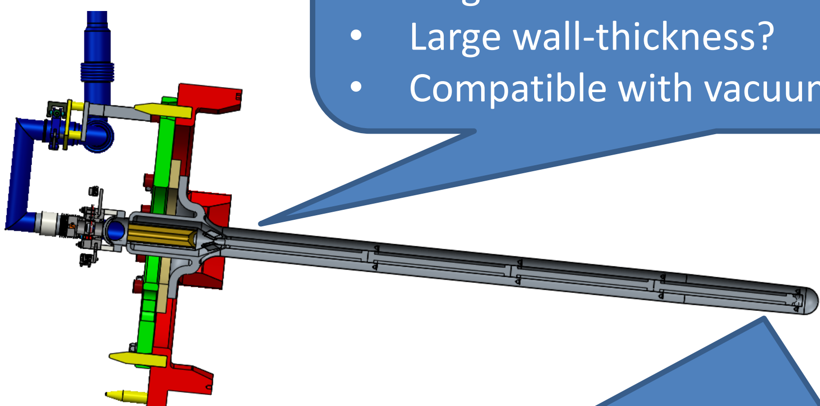
How can we maximise target length?

- Factors point towards a tapered (cone shaped) outer container
  - potentially good for mechanics, thermal management, and physics!
- Plenty of scope to optimise present design

Upstream part of Cantilever

Bending moment → High, Volumetric heating → Low

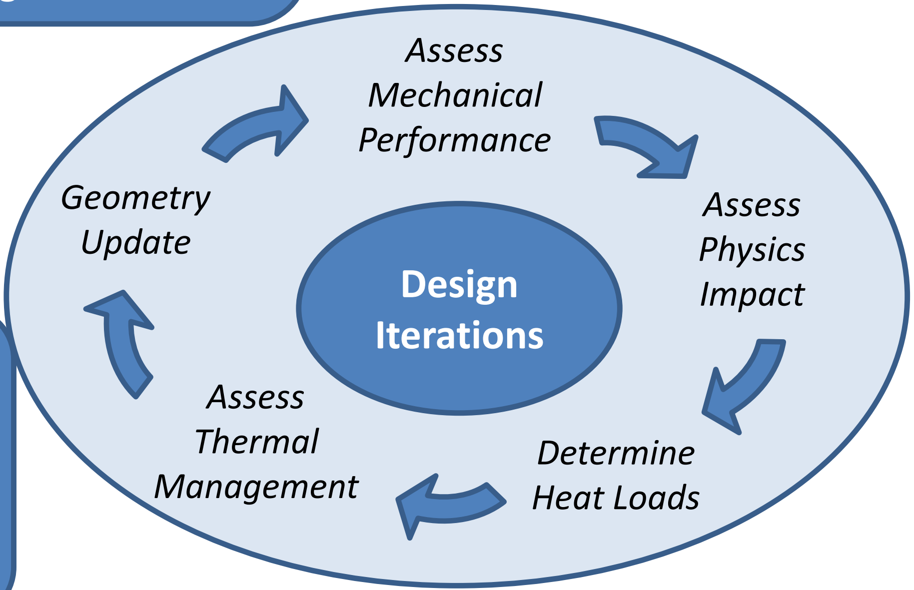
- Large tube diameter?
- Large wall-thickness?
- Compatible with vacuum buckling resistance ✓



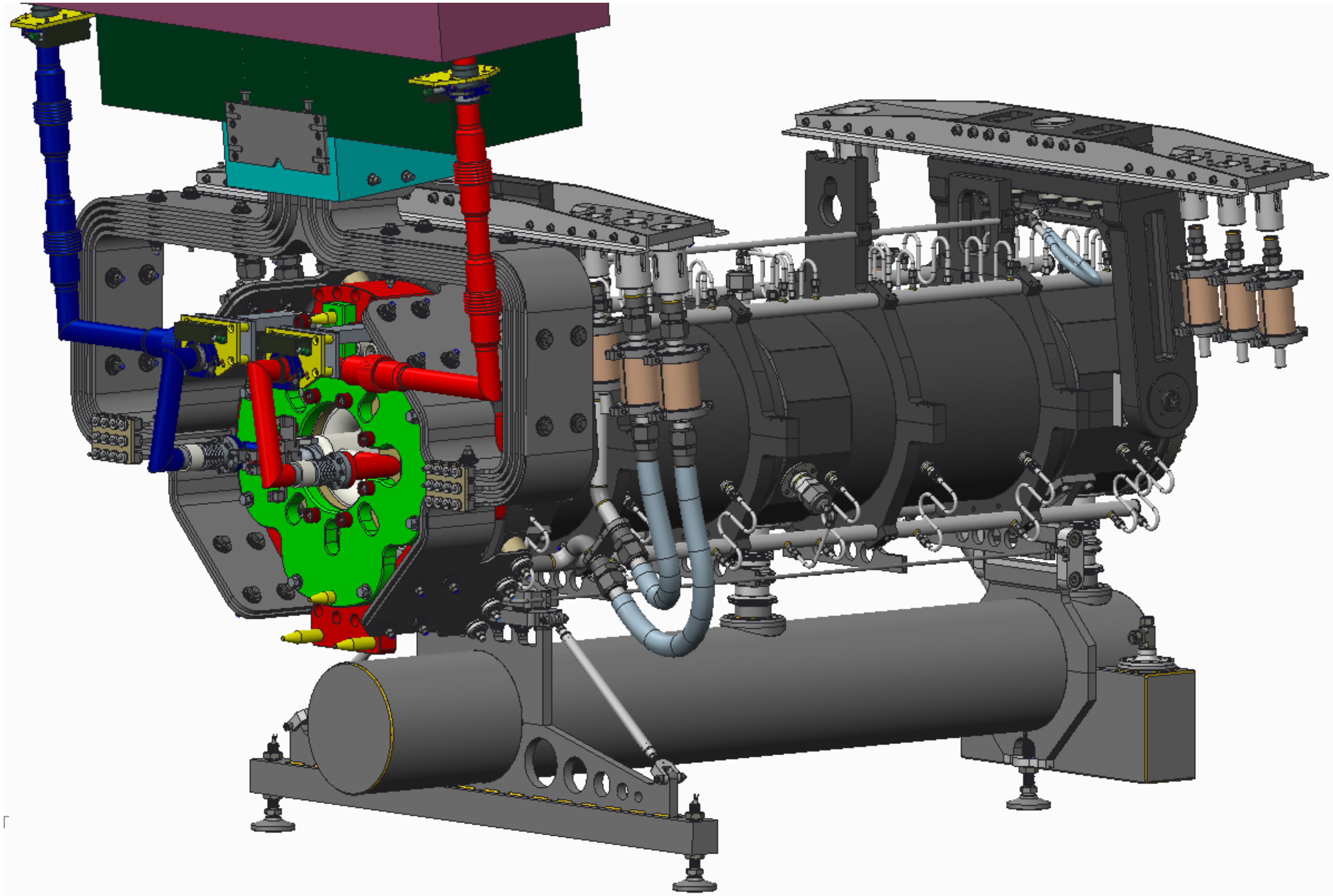
Downstream part of Cantilever

Bending moment → Low , Volumetric heating → High

- Small tube diameter?
- Small wall-thickness?
- Compatible with vacuum buckling resistance ✓



Cantilever target integrated with Horn



LBNF Target: summary

1. **Preliminary selection:** conceptual design of a ~ 1.5 m long helium cooled cantilever graphite target
2. **First:** consider feedback from Conceptual Design Review (held last week) and inform LBNF/DUNE Collaboration (starting with this talk…)
3. **Next:** Develop preliminary design: iterative process of design, physics & engineering analysis, feature prototyping etc
4. **Future:** construct 1st full prototype ~1.5 m long target (ideally will be a viable backup)
5. **Further ahead:** R&D towards construction of first operational 'As Long As Realistically Achievable Cantilever Target' (c.1.5 – 1.8 m long)