Science & Technology Facilities Council

UK Research and Innovation

LBNF Target Design

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(High Power Targets Group, RAL)

on behalf of combined UK and Fermilab LBNF project team

NBI 2019, Fermilab

Outline

- Background
- Target concept selection
  - Physics performance
  - Engineering simulations
  - Optimal tradeoff
- Target selection result
- Design assurance
- Future work

Background

- The LBNF target will be an in-kind contribution from the UK's Science and Technology Facilities Council
  - Engineering: High Power Targets Group, RAL
  - Physics: John Back, Warwick University

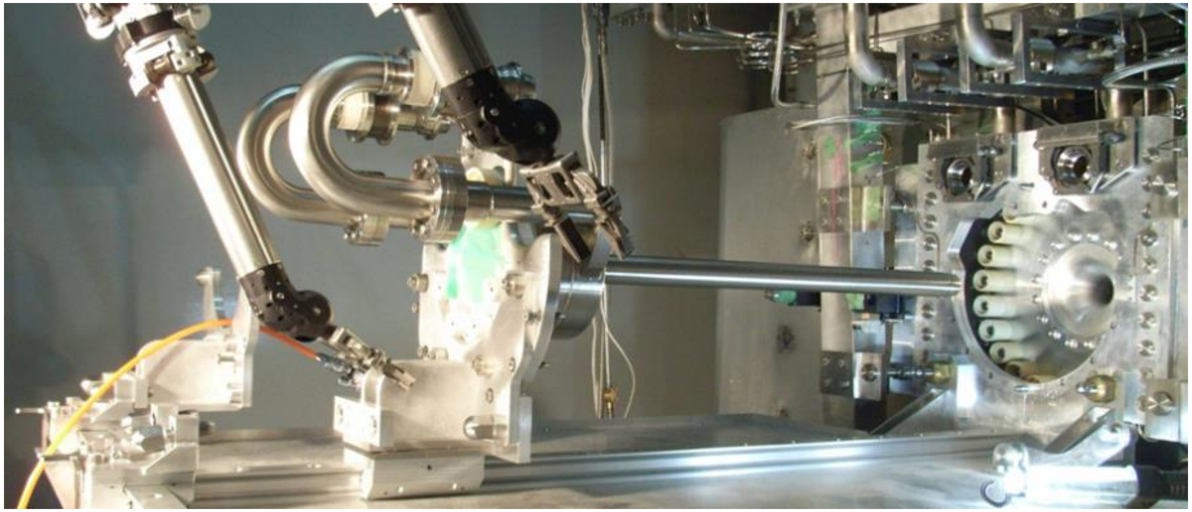
- 3 options originally proposed, 'Target Concept Selection' meeting held at Fermilab 23rd-25th July 2019

- The preferred option has been selected, and has passed conceptual design review on 21st August 2019

Target Concepts

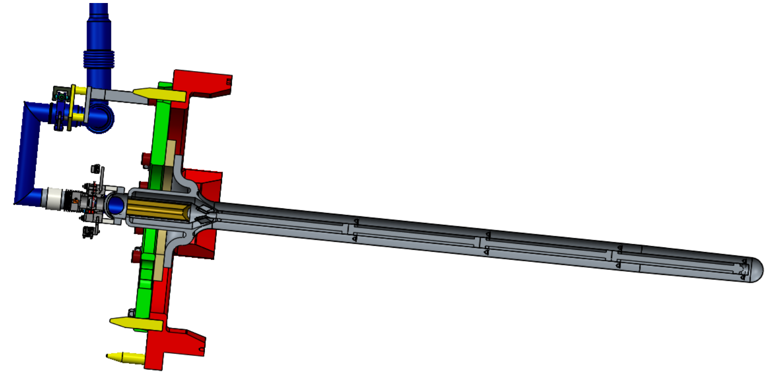
- Optimised physics design by Laura Fields indicates a long target (4λ, ≈2m) is preferred for maximum CP sensitivity

- 3 options developed based on experience from T2K (2λ, 1m)
  - Helium cooled, graphite core, titanium vessel and windows
  - No thermal shock in coolant, target runs hot to anneal radiation damage, low activation/corrosion

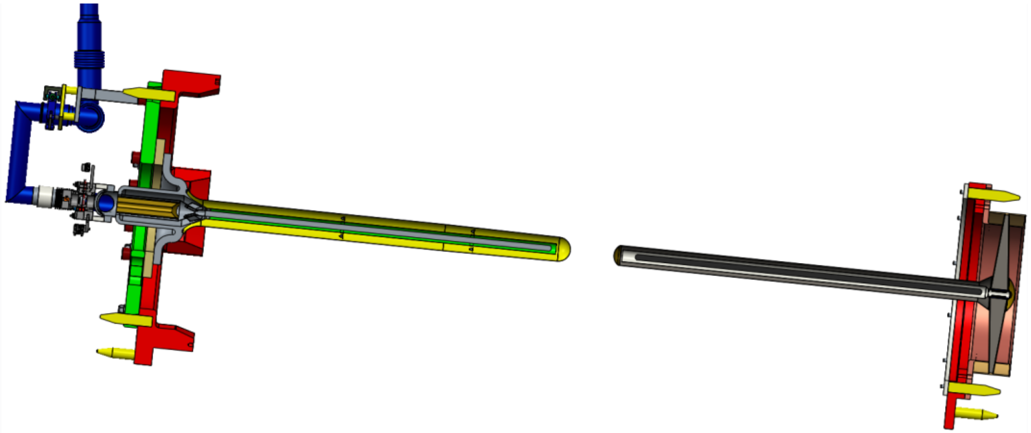


Target Concepts

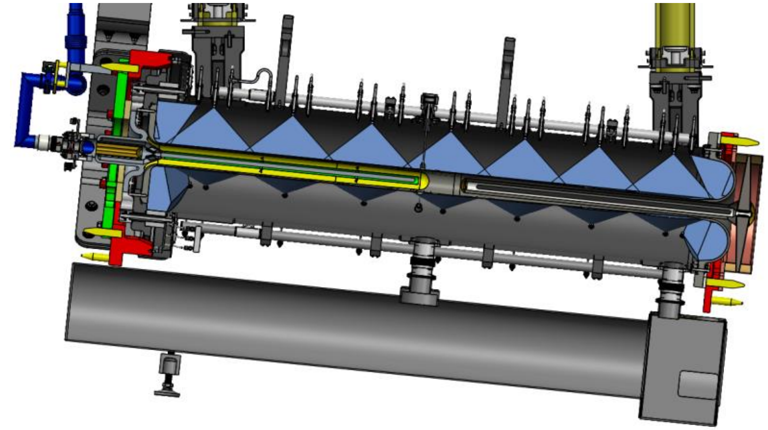
1: Single 2.2m long target with remote-docking downstream support



3: Single intermediate length (≈1.5m) cantilever target

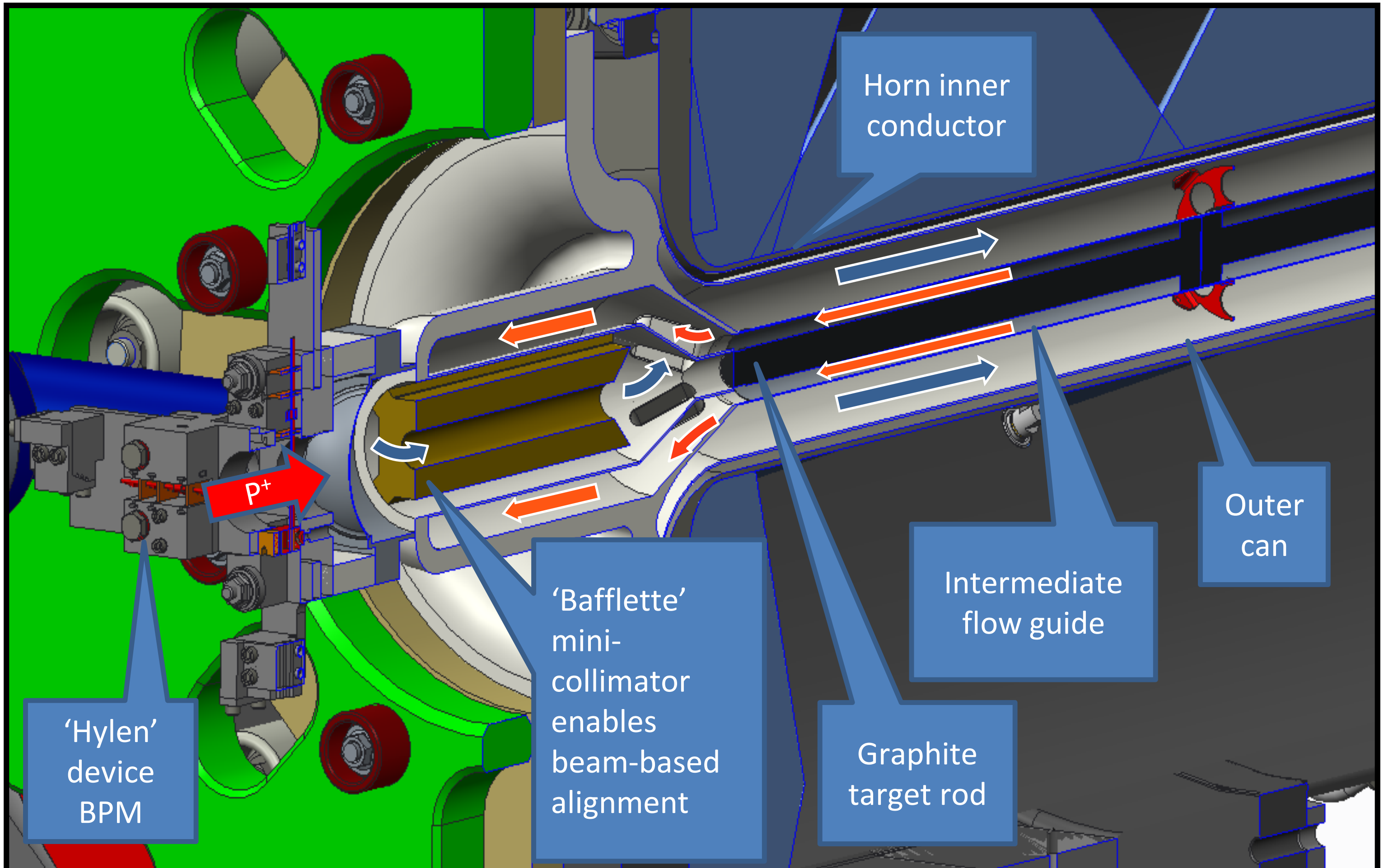


2: Two ≈1m long cantilever targets, one inserted at either end of horn

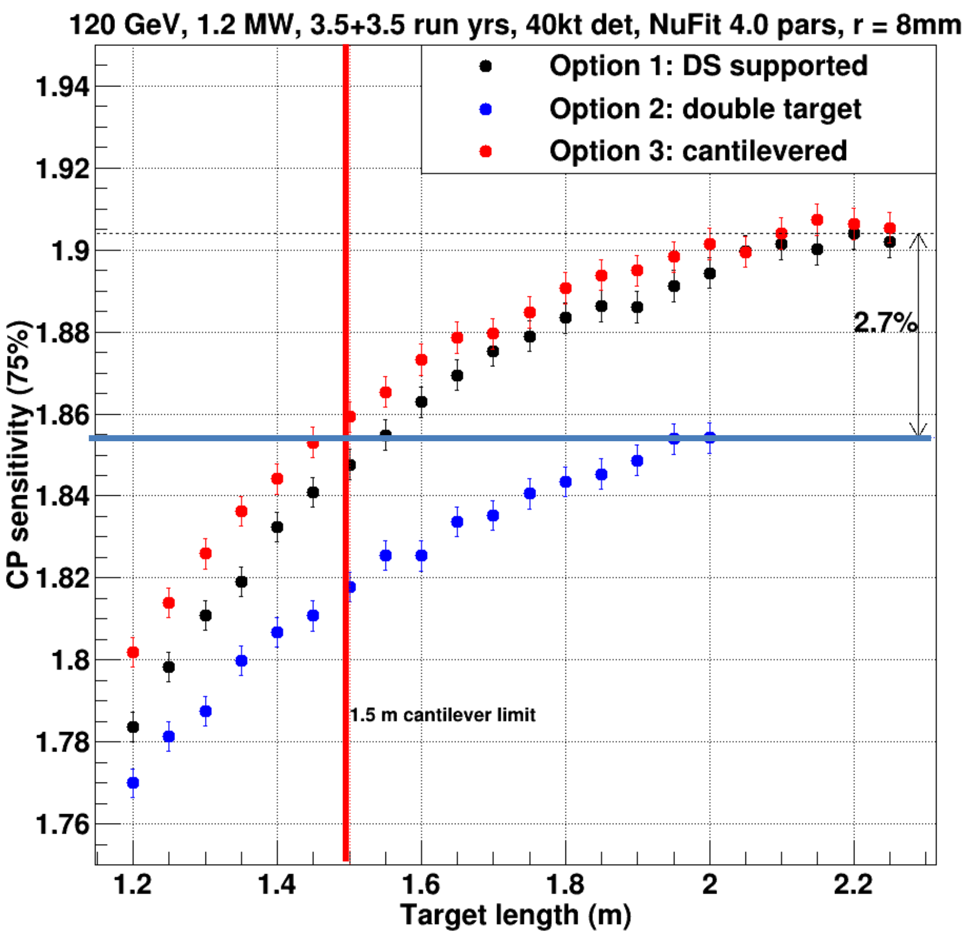


Target Concepts

- Upstream inlet geometry is the same in each case



Instantaneous Physics Performance



- Simple cantilever gives best performance for a given length (but the achievable length will be limited)
- DS supported target gives best performance for lengths where a simple cantilever is not possible
- Double 1m targets offer similar performance to a single 1.5 m cantilever

Plot courtesy of J. Back, Warwick University

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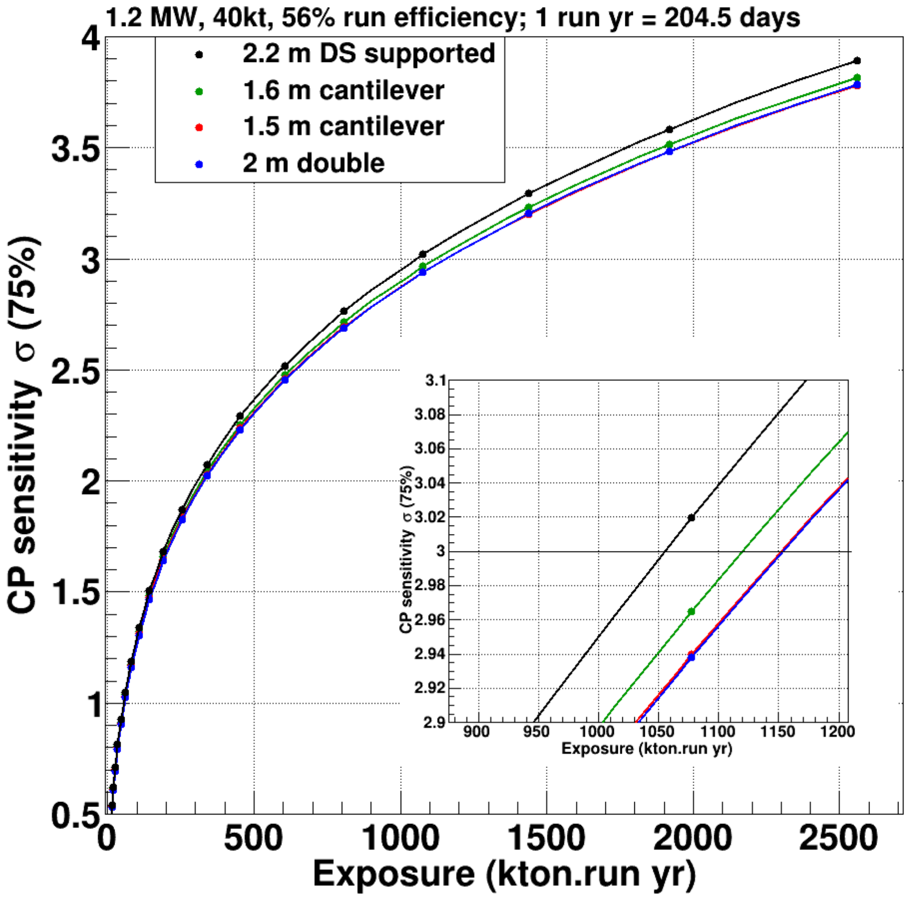
Instantaneous Physics Performance



- John Back calculated the extra number of days running per year required to achieve the same physics as a 2.2m target with downstream support

Required 3σ exposure increase:

Double Target 9.5% (19 days/run yr)

1.5m Cantilever 9.5% (19 days/run yr)

1.6m Cantilever 6.2% (13 days/run yr)

Plot courtesy of J. Back, Warwick University

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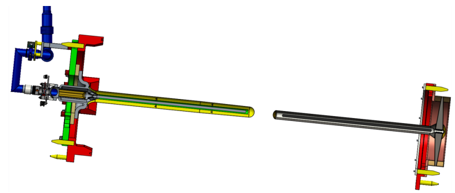
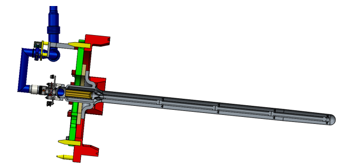
Target Concept Selection

- No engineering showstoppers for any of the options
  - Further work required to manage vessel temperatures
  - 1.5m cantilever looks achievable, 2.2m target will require a downstream support

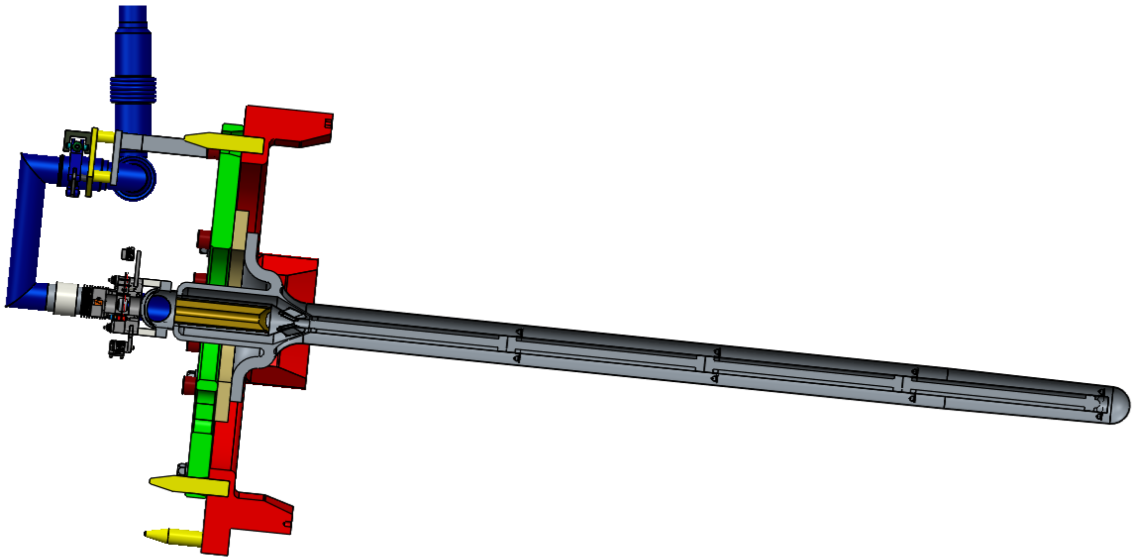
- Consensus on a preferred option was reached at a ‘Target Concept Selection’ meeting held at Fermilab
  - Included members of the engineering and physics teams

Performance = (instantaneous physics) x (facility uptime)

Target Concept Selection

	 **Option 1:1x2m long**	 **Option 2: 2x1m long**	 **Option 3: intermediate cantilever**
Instantaneous physics	Best instantaneous physics.	Needs an extra 19 days/yr to match option 1.	1.5m needs an extra 19 days/yr (13 days/yr at 1.6m).
Engineering performance	No showstoppers. High heat load. Unstable until supported.	No showstoppers. High heat load but divided between 2 targets	No showstoppers. Pushing at the limits on cantilever length.
Manufacturability	Difficult to make long tubes. DS support adds complexity.	2nd target low-mass manifold is complex.	Difficult to make long tubes.
Ease of remote maintenance	≈3 weeks exchange time, DS support adds time and risk.	≈2 weeks exchange time, 2nd target adds some time and risk.	≈1 week exchange time, lowest complexity and risk.
Cost and schedule impacts	DS support somewhat increases cost and time.	2nd target greatly increases cost and time.	Cheapest and fastest to produce.

Target Selection Result



- Single cantilever target selected to be taken forward
  - 1.5m has structural rigidity similar to proven T2K design
  - Future development will aim to increase the length further
  - 1.8m or more is best for physics (4 interaction lengths)

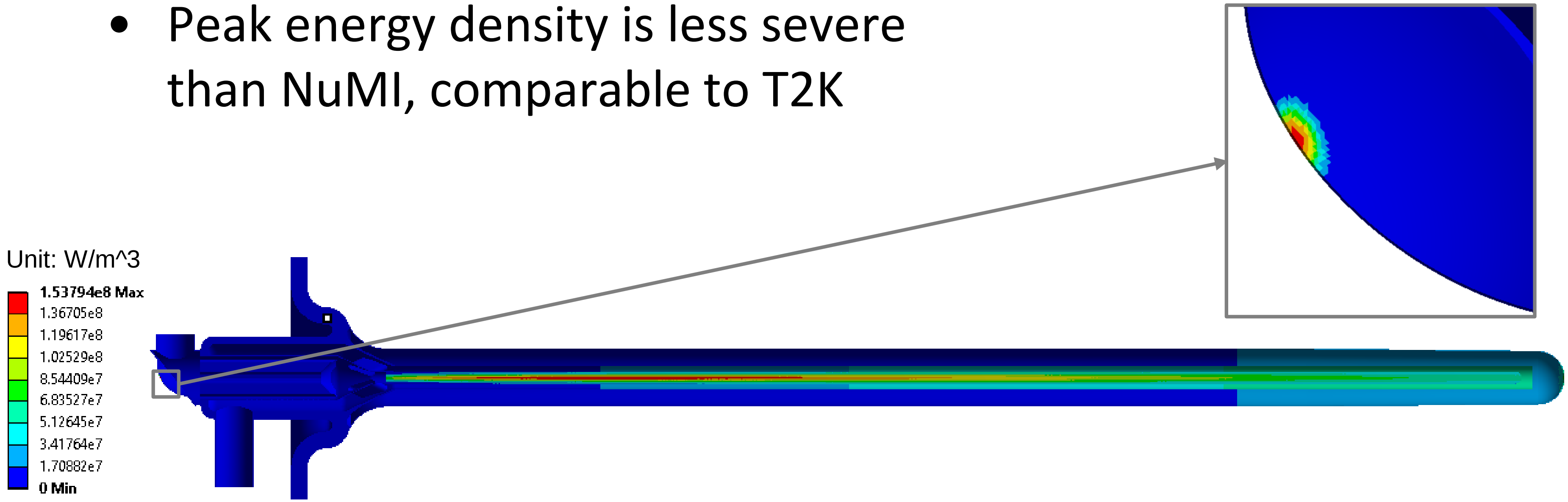
- Passed conceptual design review on 21st August 2019

Engineering – Heat Loads

	LBNF	NuMI	T2K	
	1x1.5m		Achieved*	Design**
Integrated Power (kW)	24	4.9	8.7	22
Peak Energy Density (J/g/pulse)	100	282	73	185
Peak ΔT per pulse in graphite (°C)	142	400	≈80	147

*Measured operational data at 485kW **750kW Design simulation, 3.3e14 ppp in MARS v15

- Peak energy density is less severe than NuMI, comparable to T2K

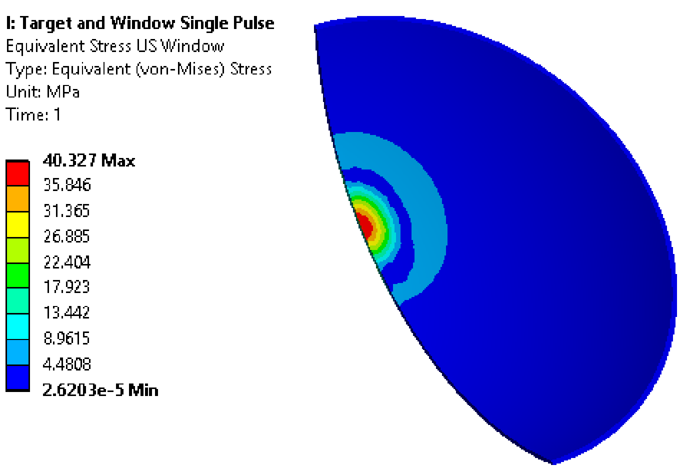


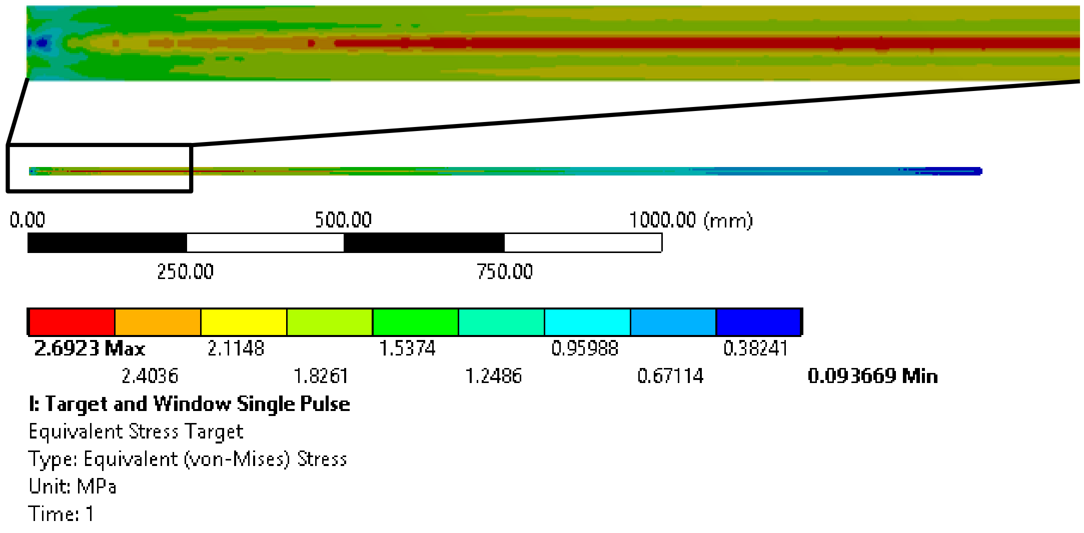
Engineering – Beam Induced Stress

- Peak occurs in the upstream window (Titanium) and the first 1m of upstream target (Graphite)

	Peak steady state stress (MPa)	Peak Δσ per pulse (MPa)	Tensile Strength (MPa)
Graphite	0.3	3	≈37
Titanium	29	40	≈898

Beam induced stress distributions after a single pulse:

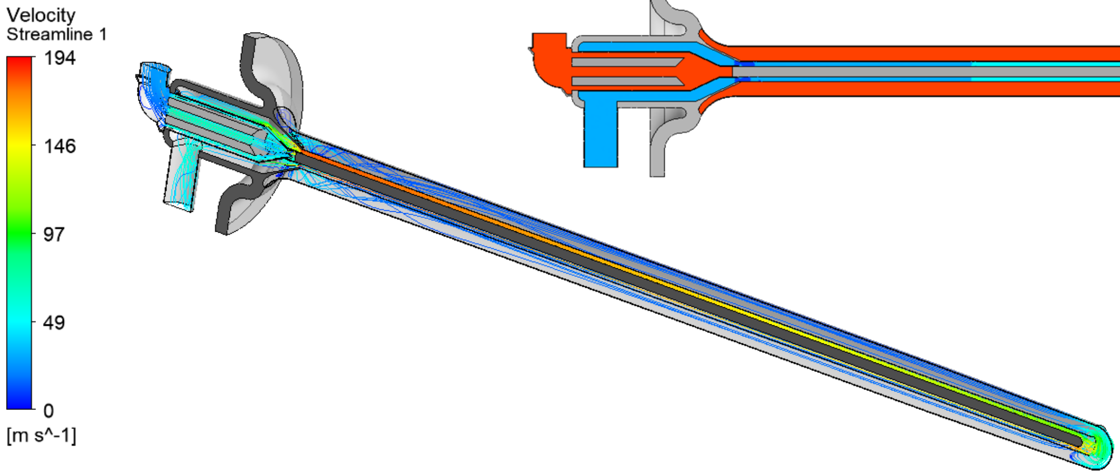


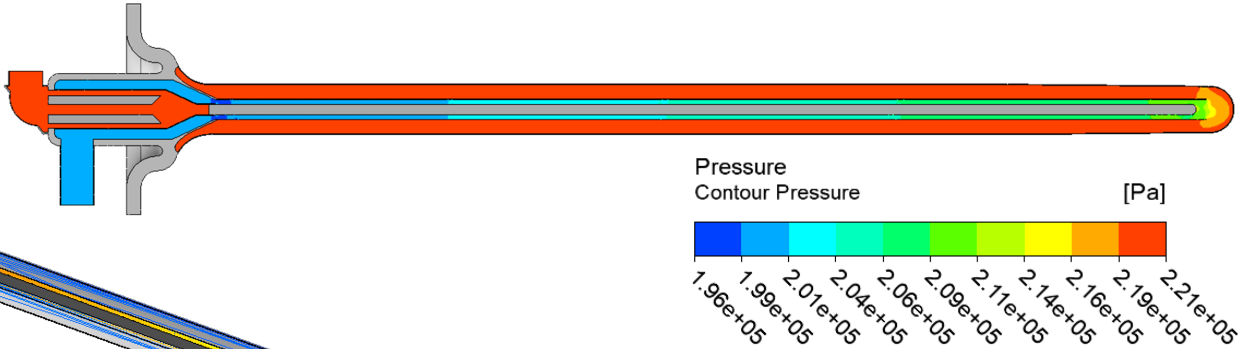


Engineering – Fluid Performance

- Flowrate chosen to keep outlet temperature below 200°C to protect return piping, bellows, isolators, etc

	LBNF	T2K
	1x1.5m	Design
Flowrate (g/s)	26	32
Pressure drop (bar)	0.21	0.73
Peak Mach number ( )	0.16	≈0.5

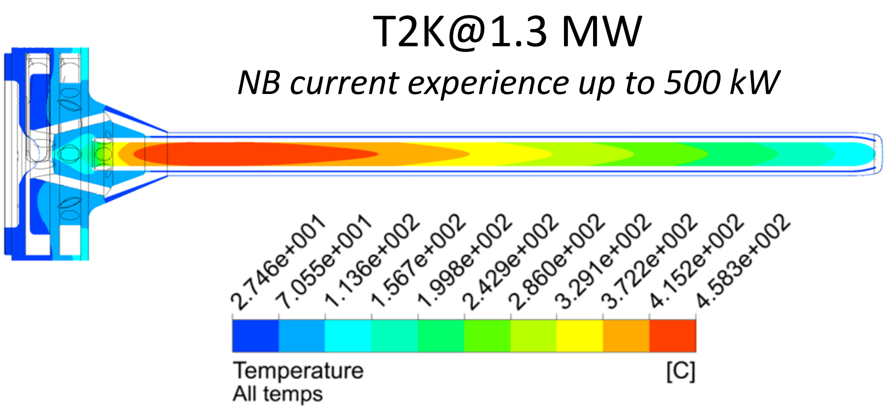


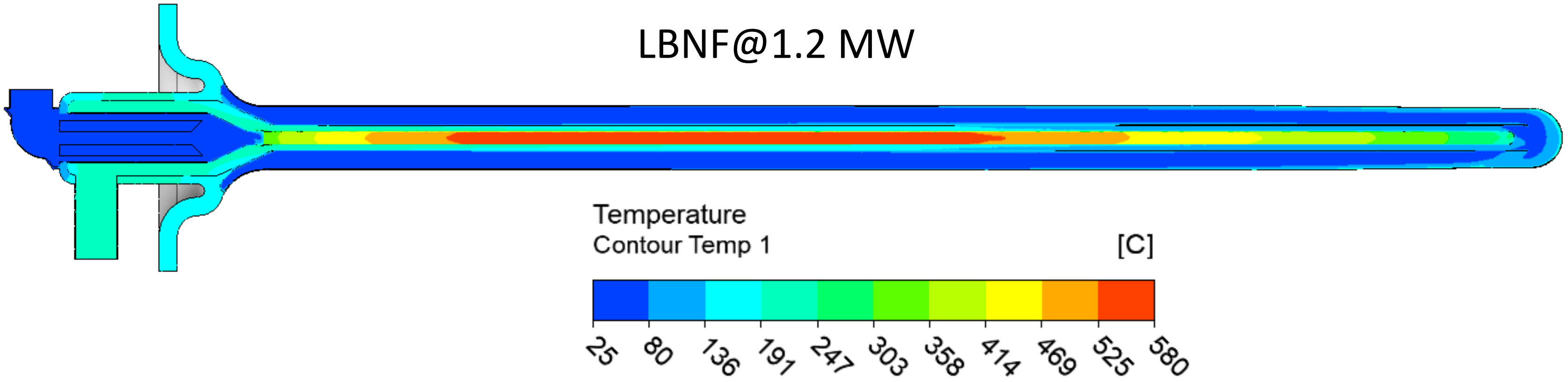


Engineering – Thermal

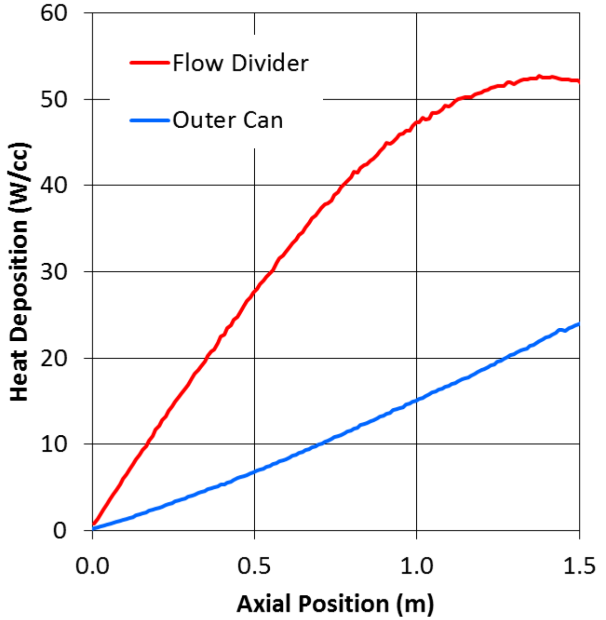
- Flowrate chosen to keep outlet temperature below 200°C

	LBNF
	1x1.5m
Flowrate (g/s)	26
Target Core	580
Outer Can	247
DS Window	264
Helium Outlet	199

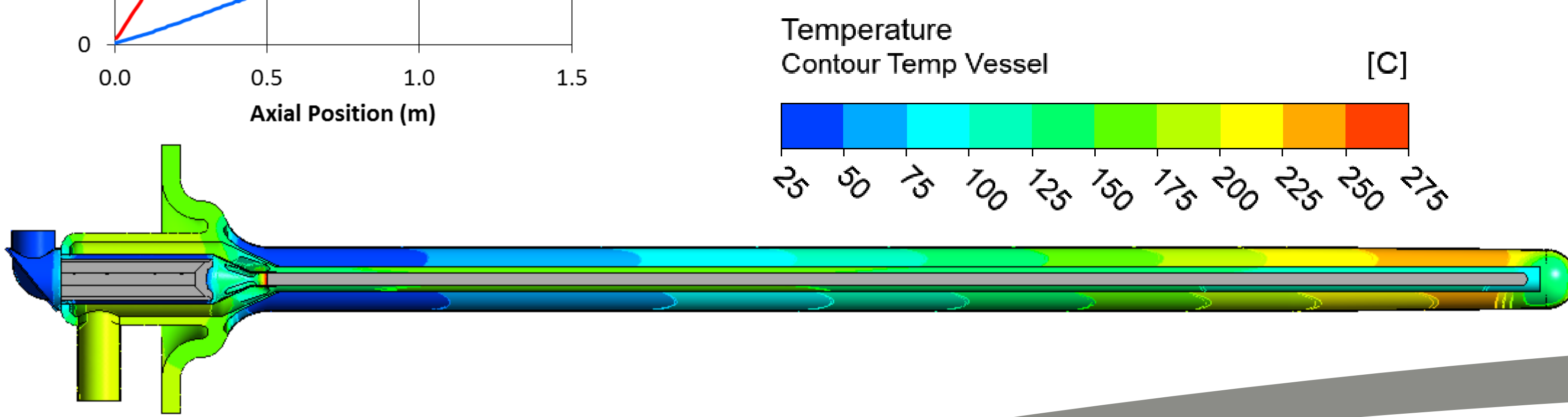




Engineering – Thermal

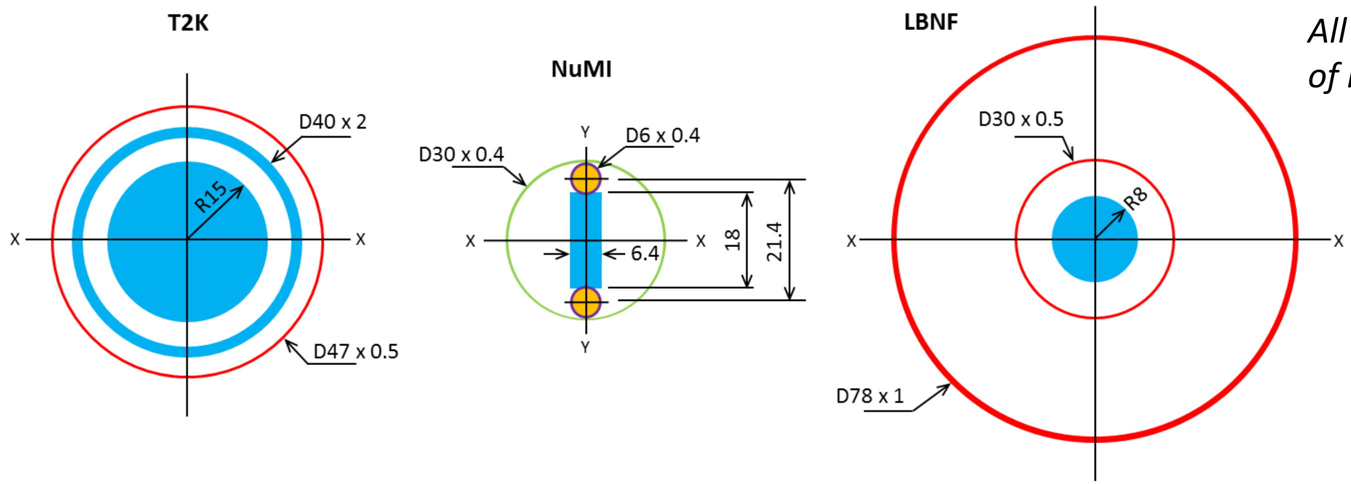


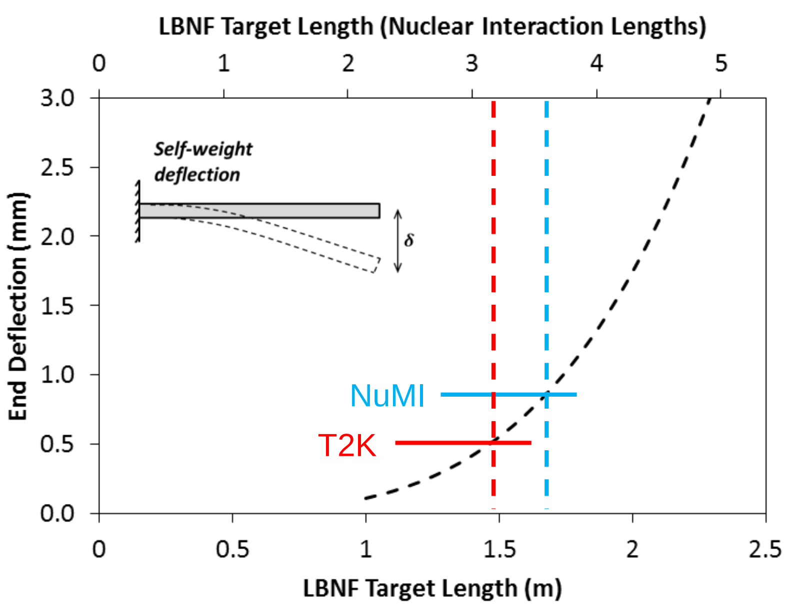
- Heat load in outer can and flow divider increases with target length
  - Needs further work to address, e.g. reduce vessel volume and/or increase flowrate

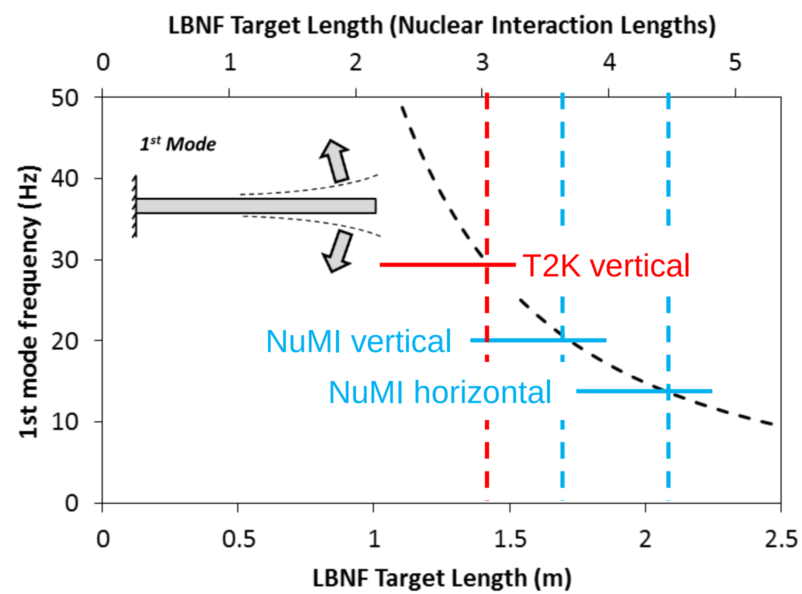


Engineering – Structural Rigidity

All images courtesy of P. Loveridge, RAL







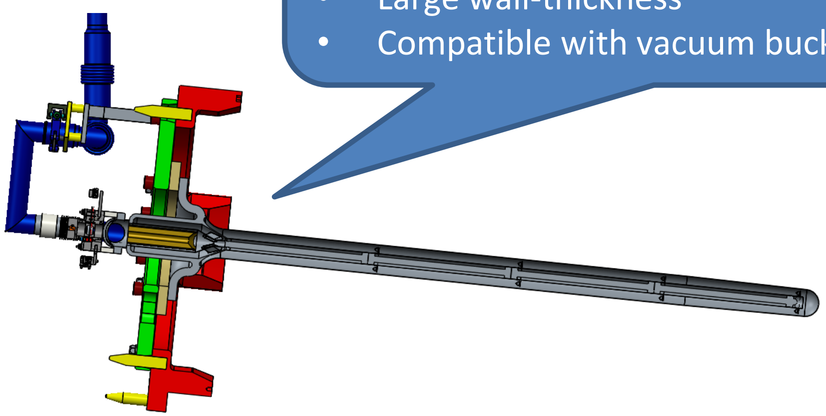
Increasing Target Length

- Factors point towards a tapered (conical) outer container
  - Potentially good for structural mechanics, thermal management, and physics!
  - But may be difficult to manufacture accurately
  - 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 ✓

Future Work

- Design and development of the ‘As Long As Reasonably Achievable’ cantilever target concept
  - Simulation and prototype manufacturing for tapered tubes
  - Detailed design and prototyping of upstream manifold
  - Further design assurance, off-normal cases, etc.

- Construct and deliver a ≈1.5m prototype, fit for use in-beam as a spare

- Construct and deliver an operational target, 1.5-1.8m long dependent on lessons learned from the prototype

Conclusions

- 3 preliminary target concepts were considered
- Single cantilever selected as the best combination of physics and reliability
  - Particularly if the length can be increased from 1.5 to ≈1.8m without compromising reliability
  - No engineering or manufacturing showstoppers found, but pushing the limits of cantilever length will be challenging
- Design work is ongoing, with feature prototyping due to start soon