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Future Neutrino Targets

Chris Densham

Presenting work by High Power Targets Group
Rutherford Appleton Laboratory, UK
In collaboration with KEK (T2K) and Fermilab (LBNF)

LoI submitted to Snowmass

R&D for MW Pion Production Targets for Next Generation Long Baseline Neutrino Facilities

Abstract

The Long Baseline Neutrino Facility (LBNF) in the US and T2K/HyperK in Japan are both competing and complementary next generation neutrino facilities. In order to realise the potential offered by multi-MW proton drivers, both facilities need to develop efficient, robust and reliable production targets and associated beam windows. This LoI introduces the overlapping international collaborations that are being developed between physicists, engineers and materials scientists at accelerator, nuclear and university laboratories in order to develop the materials and technologies required to deliver optimum physics performance for these next generation facilities.

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Authors

C.J. Densham*, P. Loveridge, D.Wilcox, T.R. Davenne, M.D. Fitton, J. O'Dell, M.Parkin, E.Harvey-Fishenden, J. Bennett (STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, Oxfordshire, UK)

V. Kuksenko, S. Van Boxel, P. Earp (Materials Research Facility, Culham Laboratory, UK Atomic Energy Authority, Oxfordshire)

Y-L Chiu, B. Cai (School of Metallurgy and Materials, University of Birmingham, Edgbaston, Birmingham, UK)

D. Liu (University of Bristol, UK)

J.J. Back (University of Warwick, Coventry, UK)

P. Soler (Glasgow University, UK)

P.G. Hurh, F. Pellemoine, K. Ammigan, S. Bihar (Fermilab, US)

D. Senor (Pacific Northwest National Laboratory, US)

T. Ishida, T. Nakadaira, S. Makimura (KEK, Japan)

N. Nakazato (Muroran Institute of Technology, Japan)

RaDIATE collaboration

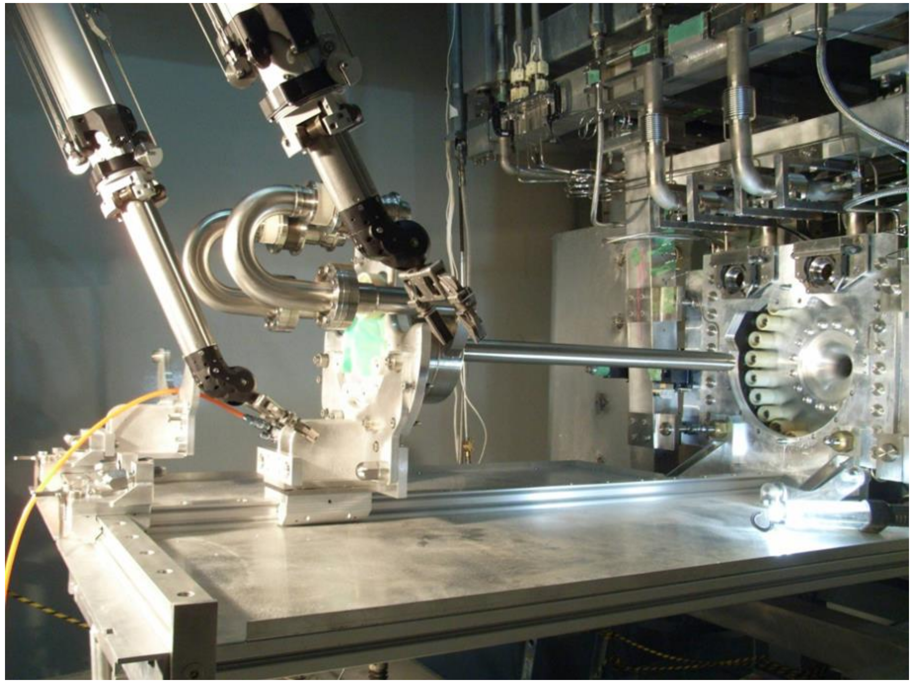
*chris.densham@stfc.ac.uk

(Dated: August 31st, 2020)

Part 1

- T2K target and upgrade for HyperK

T2K Target Installation into Magnetic Horn



- Targets successfully operated for 10 years up to 500 kW
- Integrated POT equivalent to 6 months operation at 1.3 MW
- Replaced once together with horn1 (no target failure to date)

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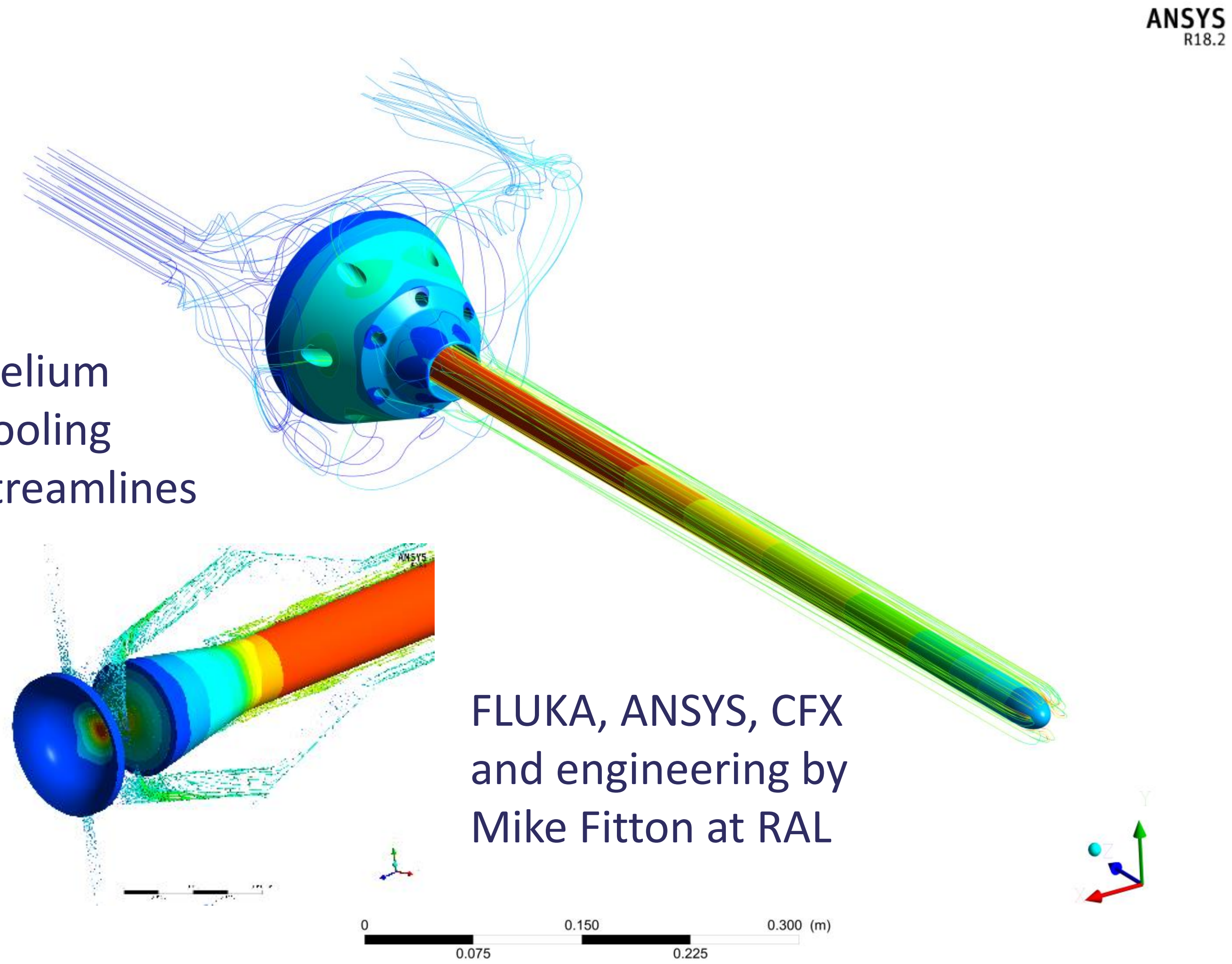
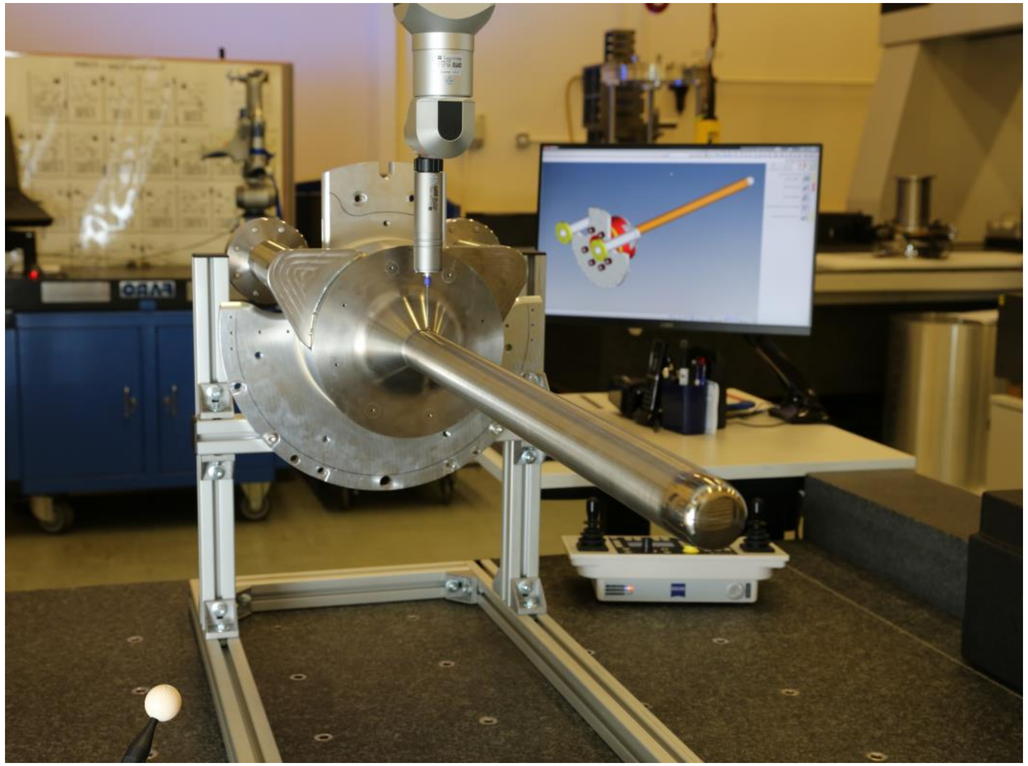
Current T2K target designed for 750 kW, operated at 500 kW



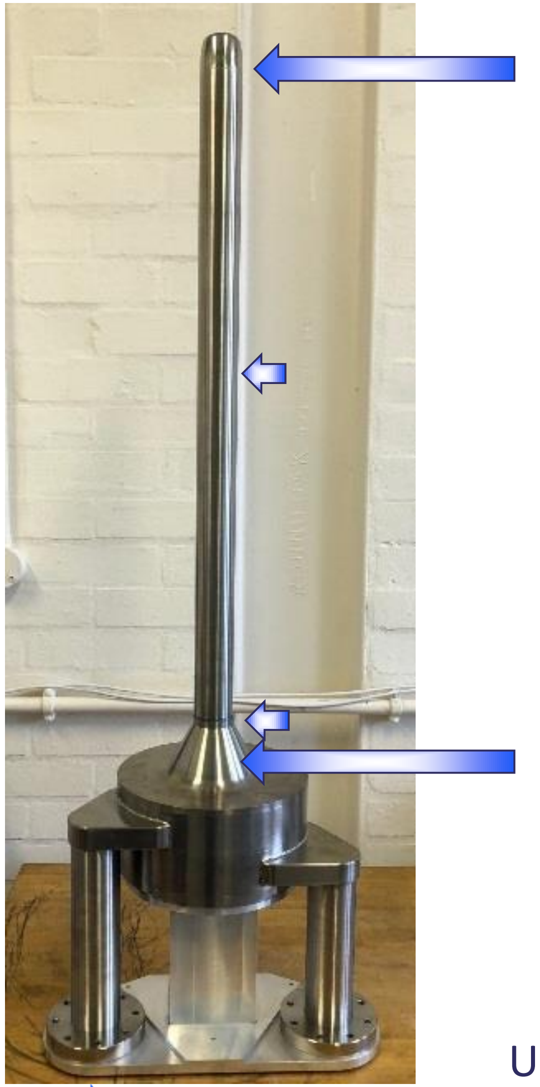
Helium cooling streamlines

FLUKA, ANSYS, CFX and engineering by Mike Fitton at RAL

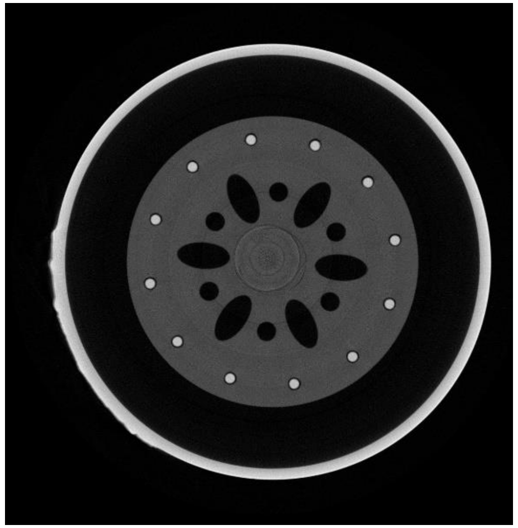


Survey of T2K target using Co-ordinate Measuring Machine (CMM) at RAL.

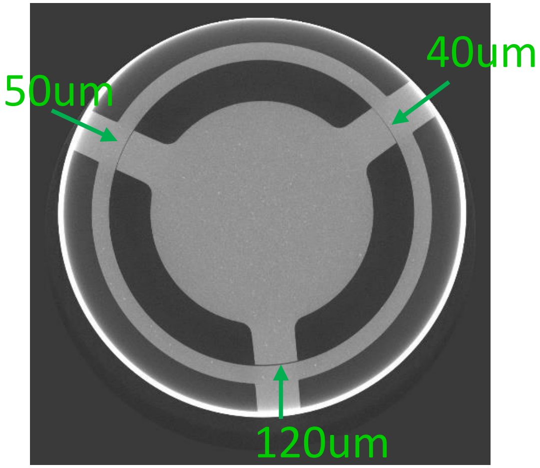
CT Scans of T2K (750 kW) target



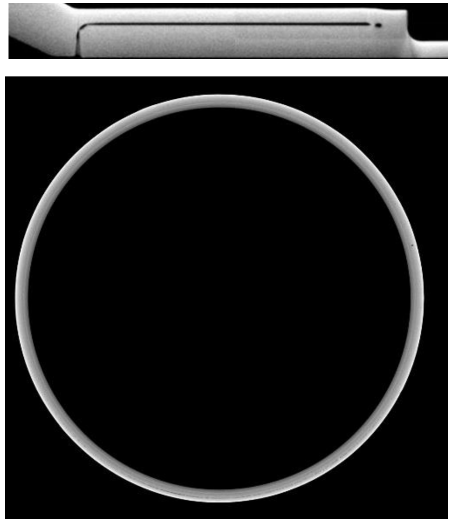
Downstream window



Upstream flow cross-over head



DS graphite spacer clearance to prevent thermal stress



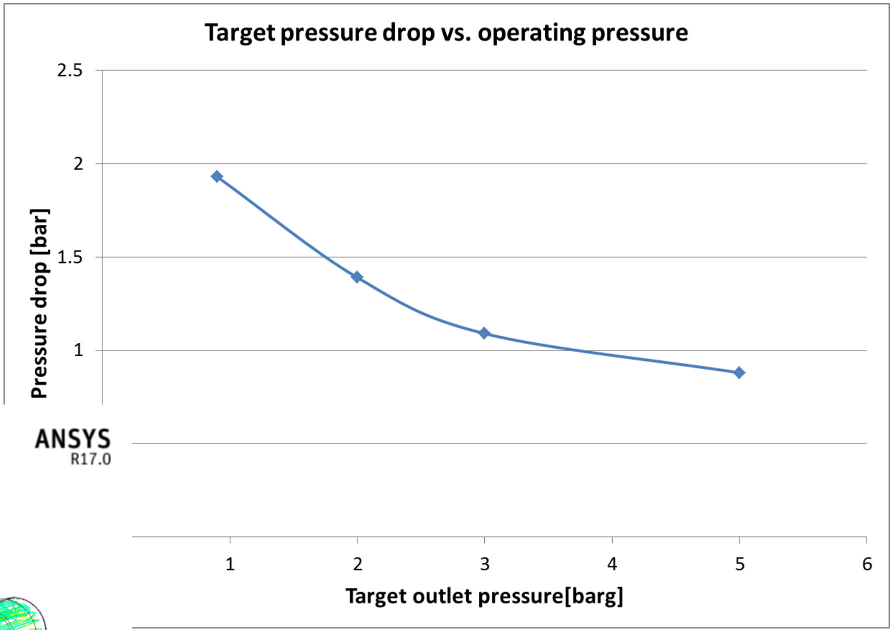
Ti tube base weld

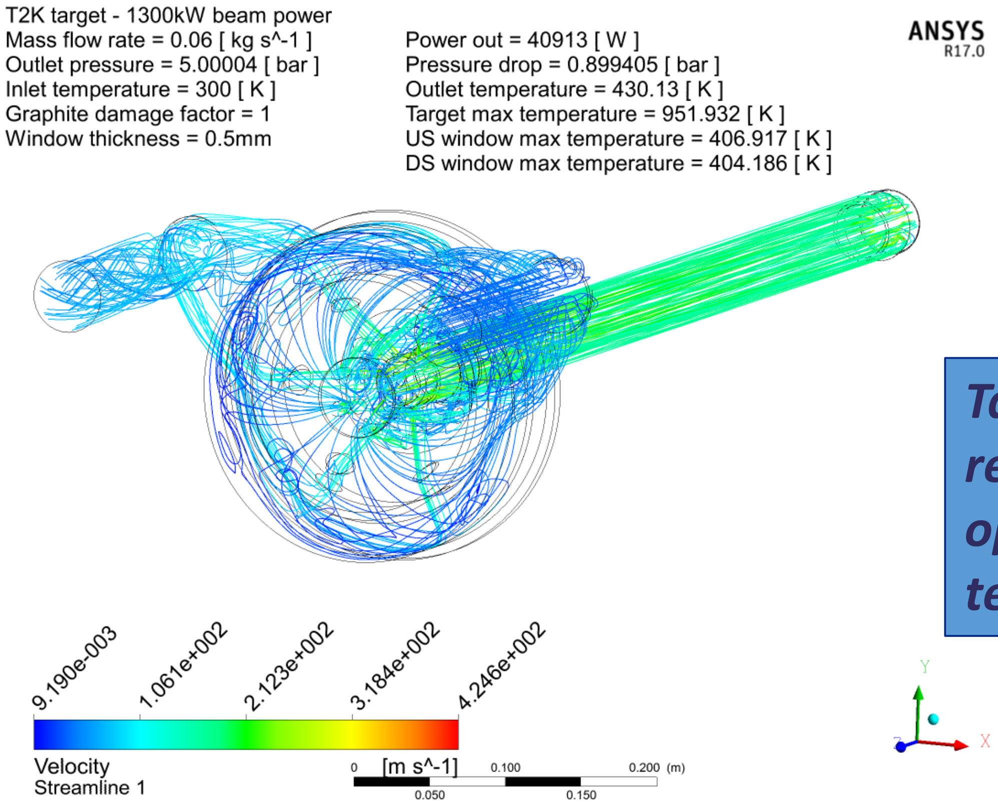
- ❑ Few small pores in graphite but no detectable cracks
- ❑ Welds good with only a few very small and isolated pores
  - ➢ Acceptable to NAS Class I
- ❑ Material thicknesses and clearances as expected

T2K target upgrade to 1.3 MW for HyperK era

- Current operational experience up to 500 kW
- Beam power 0.5→1.3MW increases integrated heat load on the target
- NB Cycle time 2.48s → 1.16s, same ppp so **no increase in thermal shock**
- Can't just increase flowrate:
  - Pressure drop
  - Helium velocity
- Need to increase operating pressure:
  - Allows higher mass flow rate without big increase in dP or velocities

- Increase operating pressure 1 → c. 5 bar
- Reduces pressure drop from 2 → 1 bar





Target components must be: re-designed/optimised for operation at 5 bar, and pressure tested at 7.5 bar

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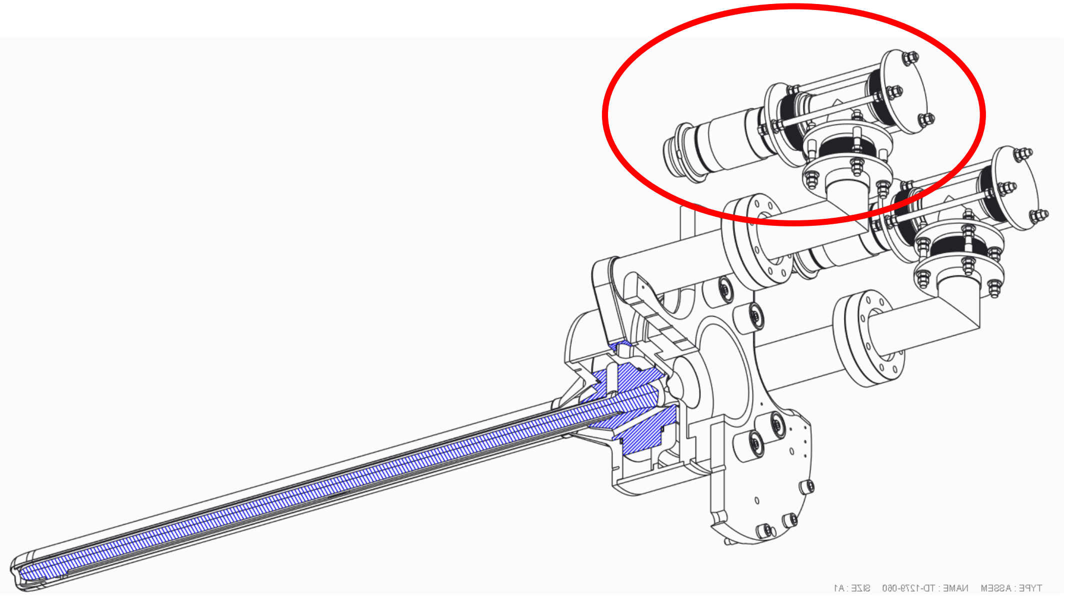
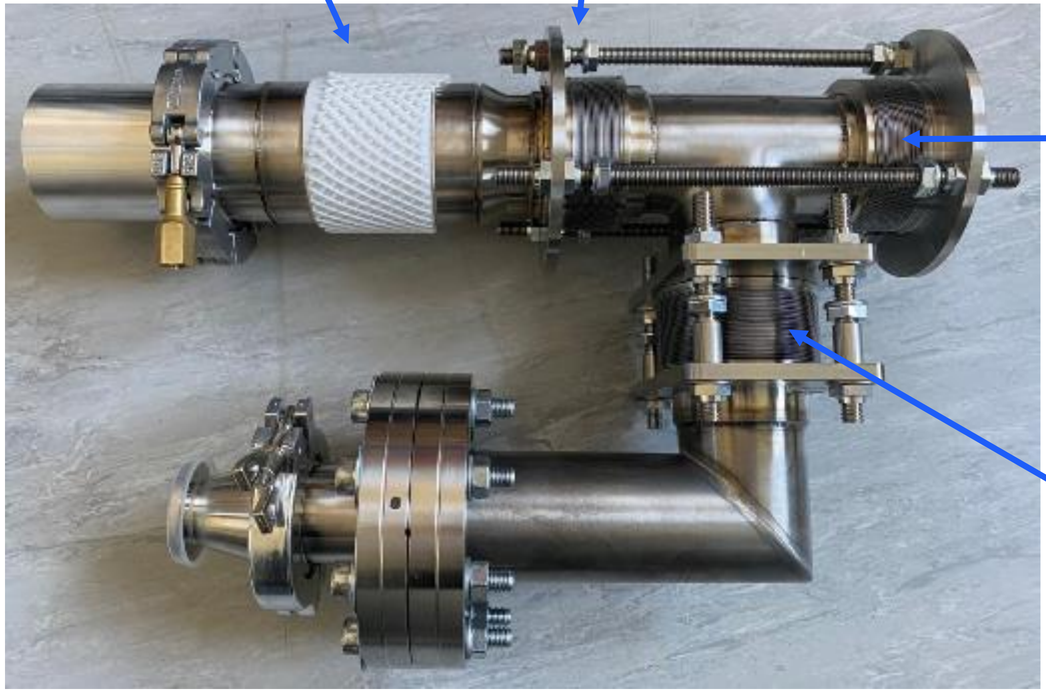
Target helium pipe R&D for 1.3 MW

- NB Most neutrino experiments have seen failures in ceramics on insulated coolant lines (CNGS, NuMI, T2K)
- 1st prototype of pressure balanced pipe successfully pressure tested at 8 bar





Ceramic isolator
Brazed ceramic electrically isolates the target from horn

Active bellows
Allows for compression of seals and thermal expansion (~0.2mm Y). Edge welded bellows minimise load on fragile ceramic.

Pressure balancing bellows
Connected to active bellows to create an opposite thrust force

Adjustment bellows
Corrects pipe position for Target and pipe fabrication errors and locks off in position

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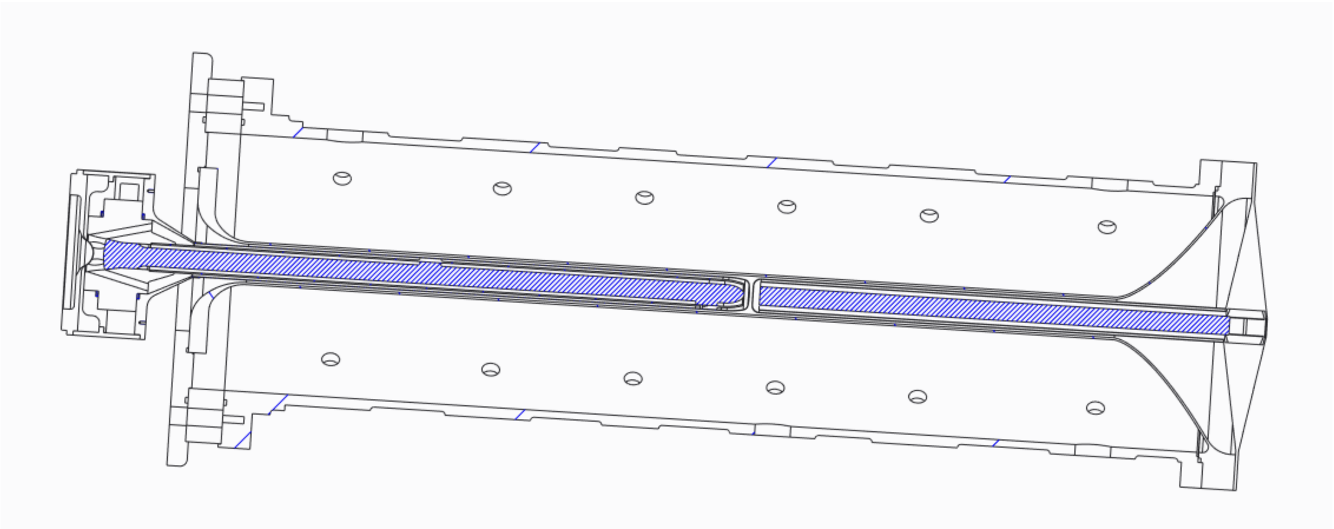
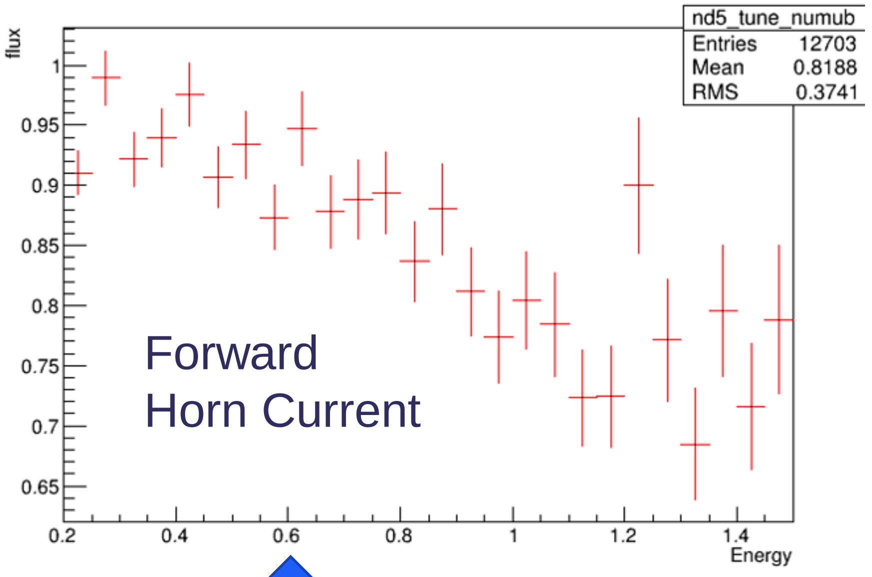
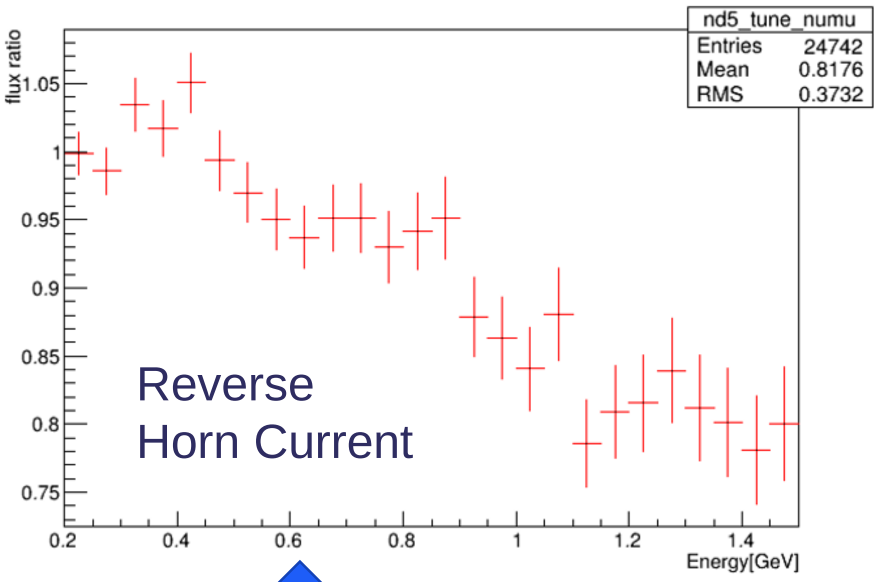
Target R&D for higher flux / reduced backgrounds



Simplified model of double target as input for physics studies

Ratio of wrong-sign contamination for a double graphite target compared to existing single target as a function of energy (in GeV)





University of Glasgow

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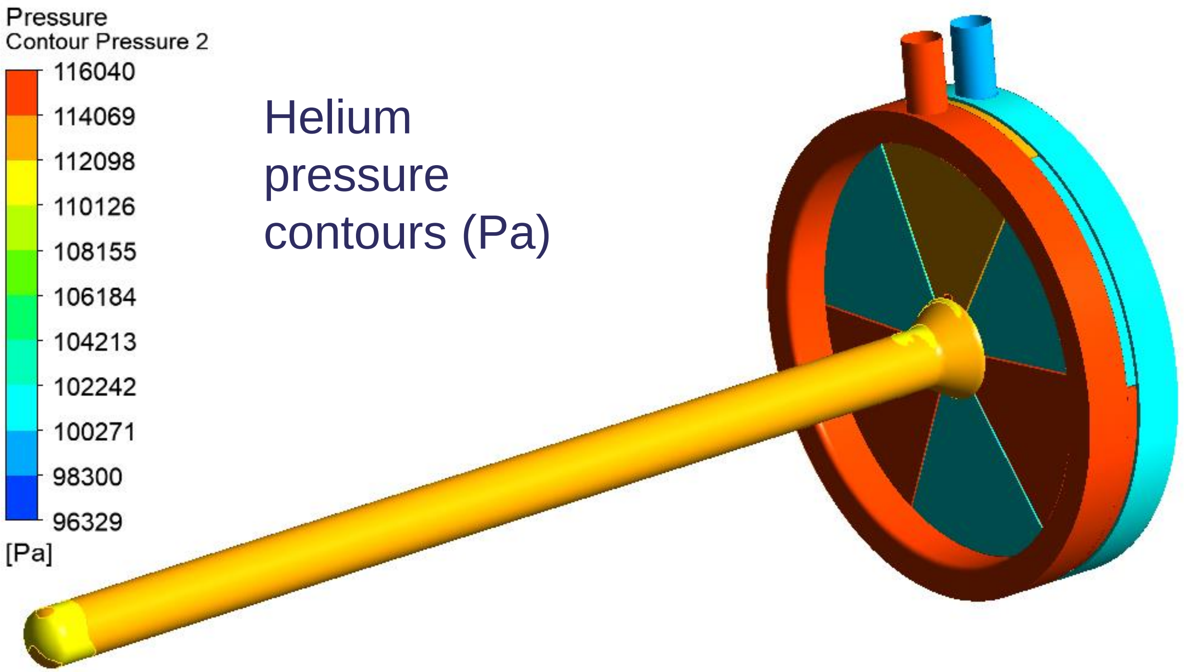
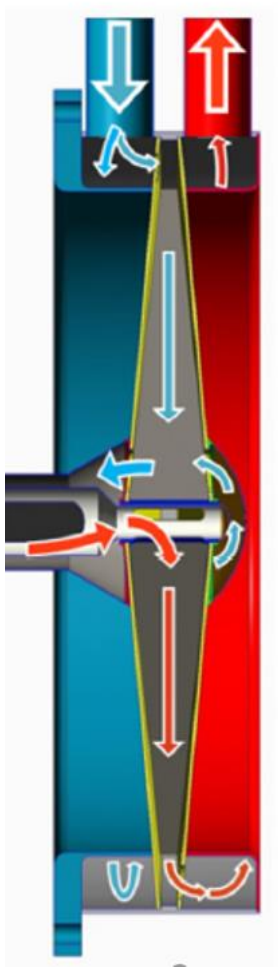
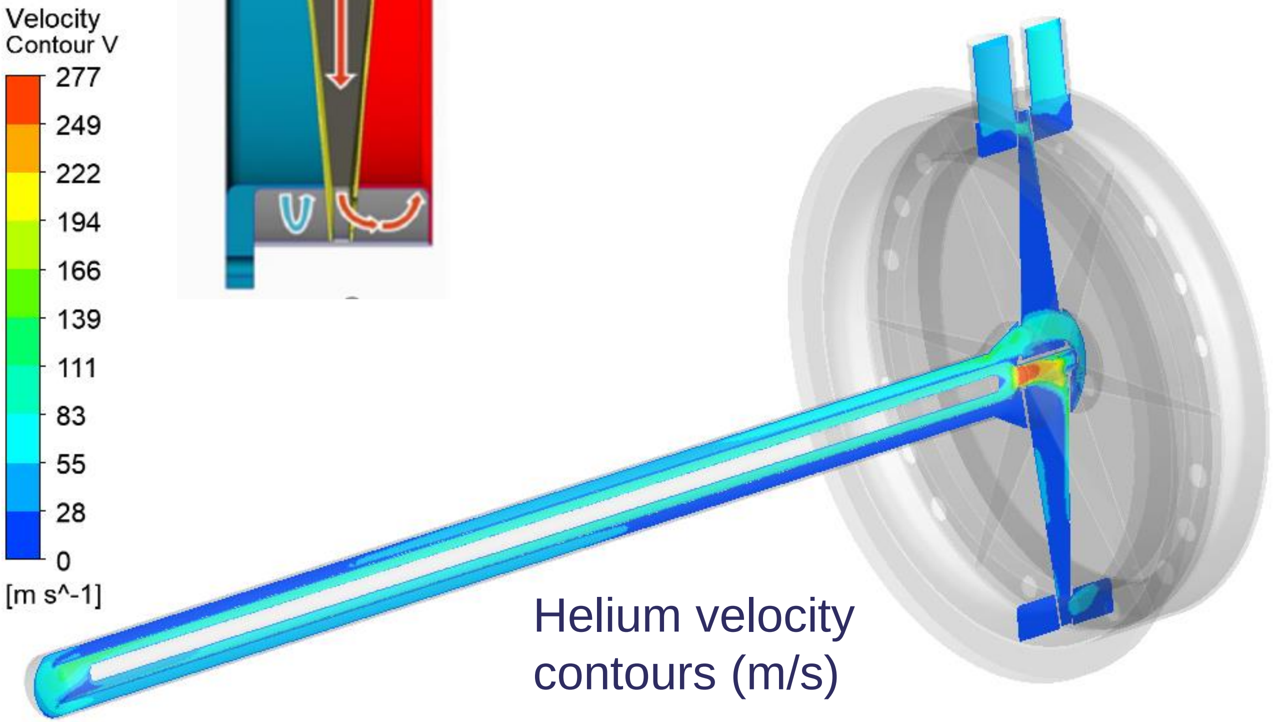
Potential downstream target conceptual design & CFD*



Helium pressure contours (Pa)





Helium velocity contours (m/s)

* CFD study by Dan Wilcox for LBNF option but also appropriate for T2K

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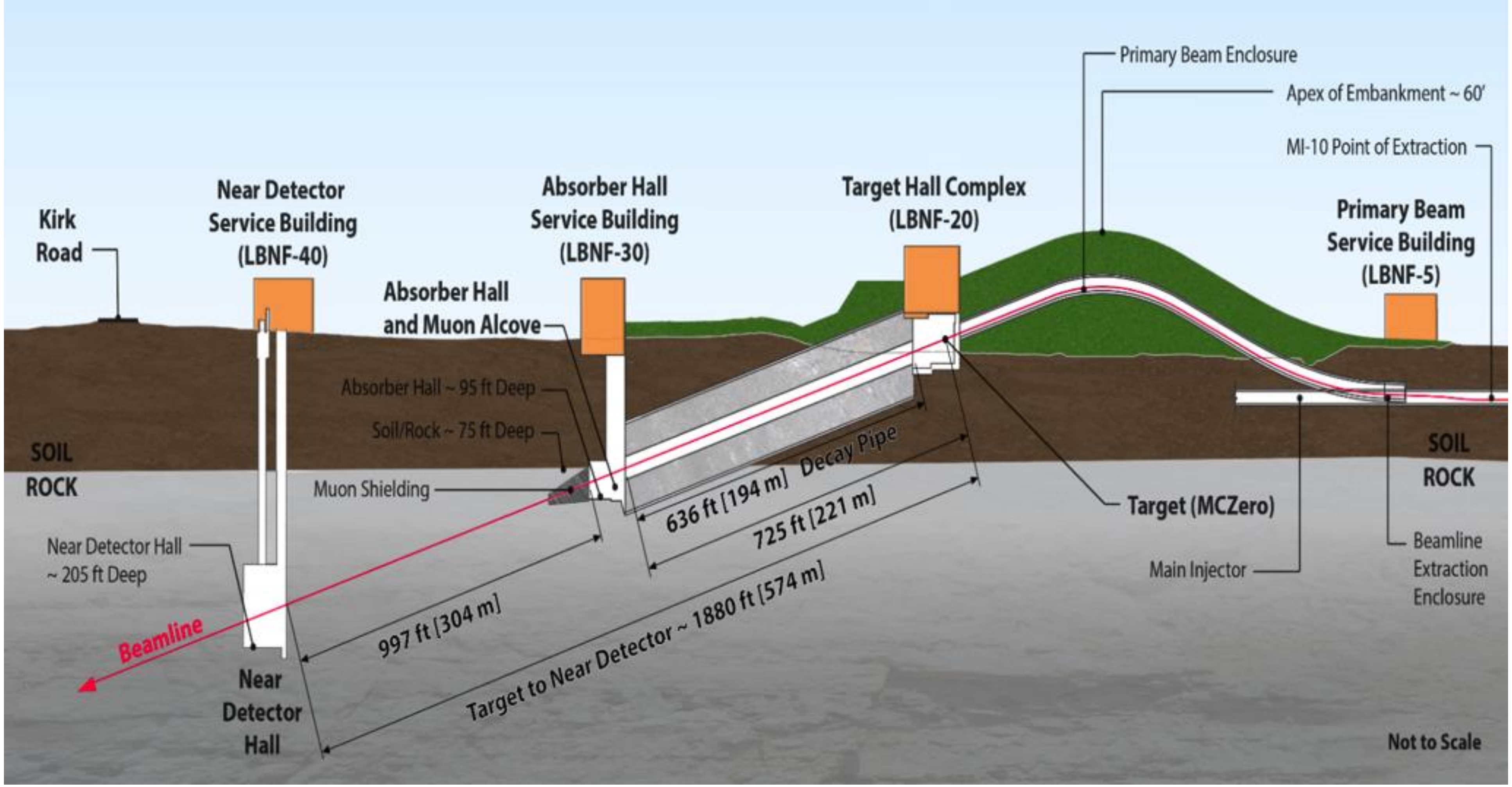
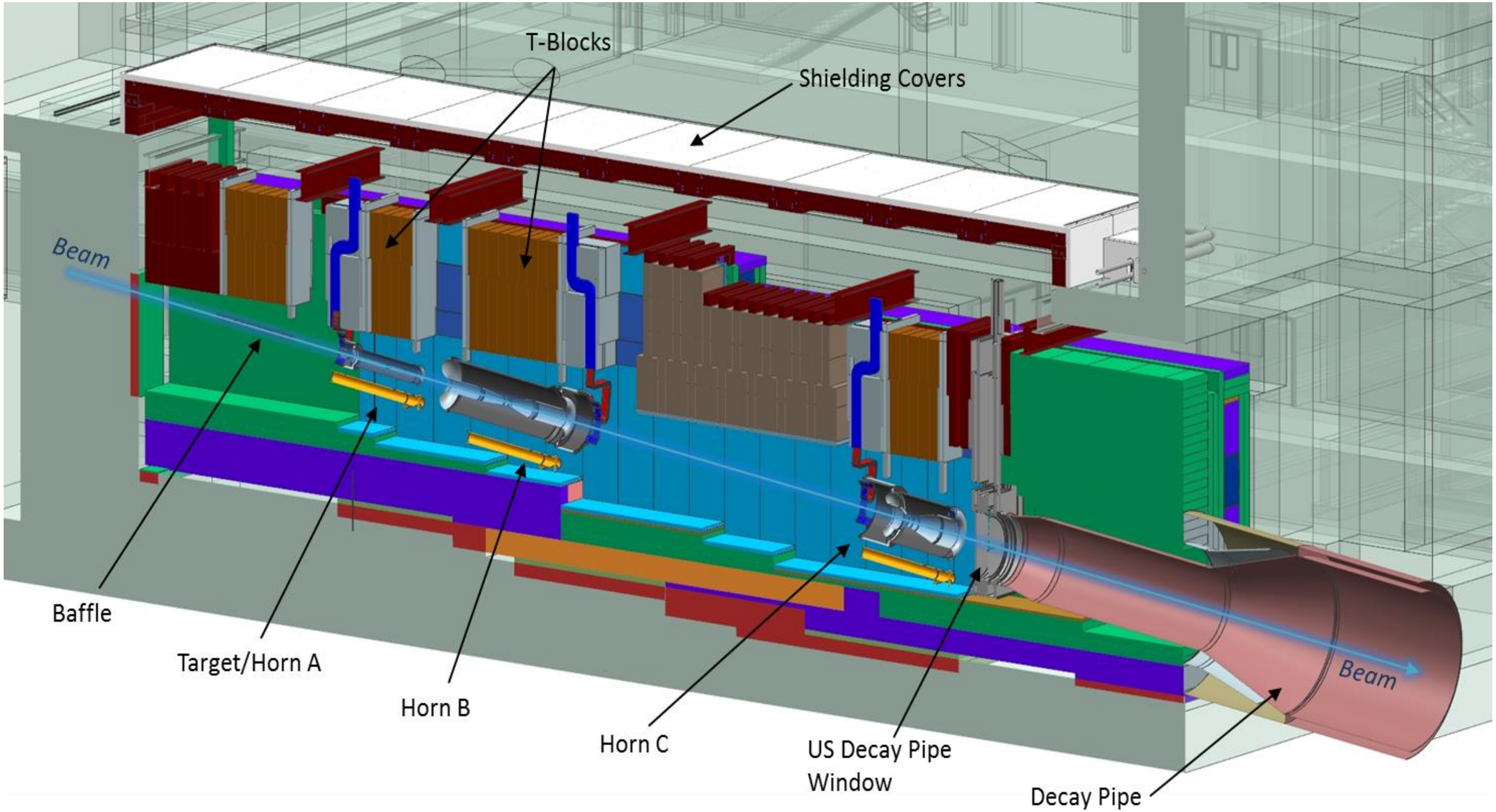
Part 2

- LBNF target for 1.2 MW operation

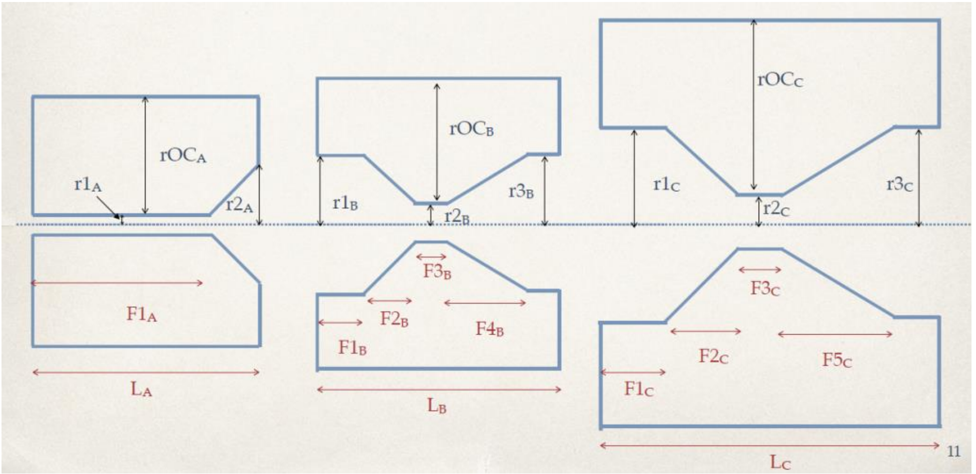
LBNF Secondary Beamline

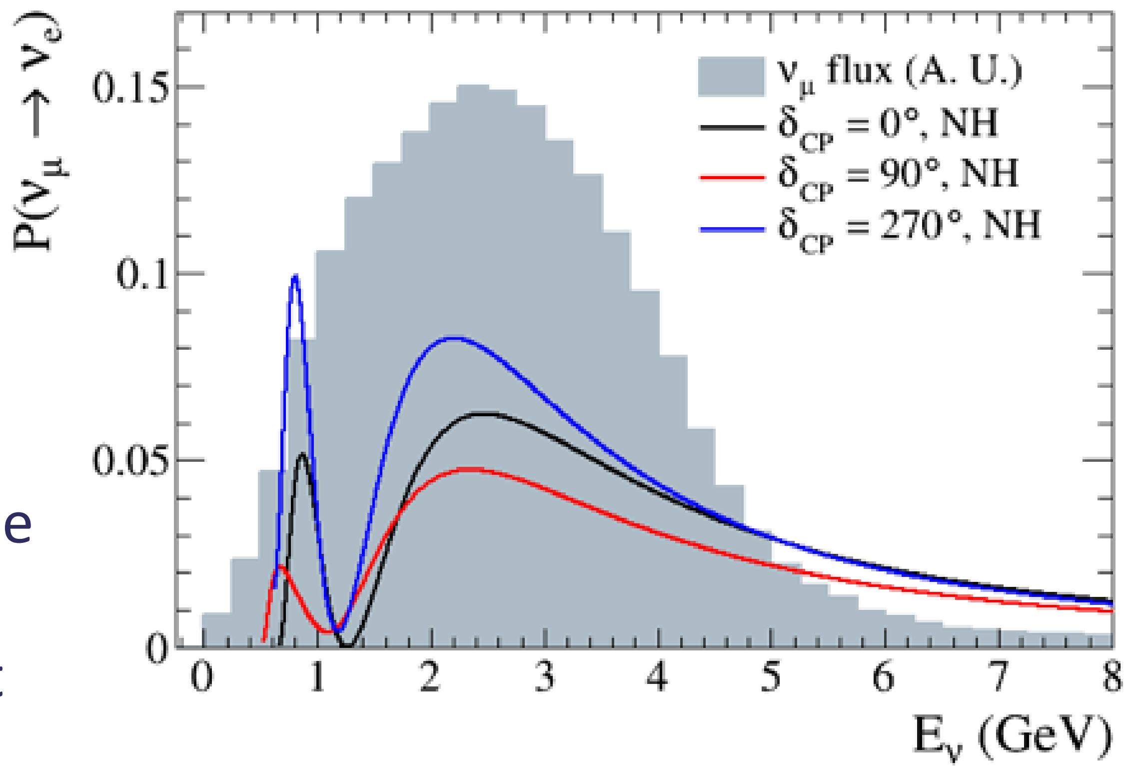


LBNF Target Station



Beam Optimisation (L. Fields)

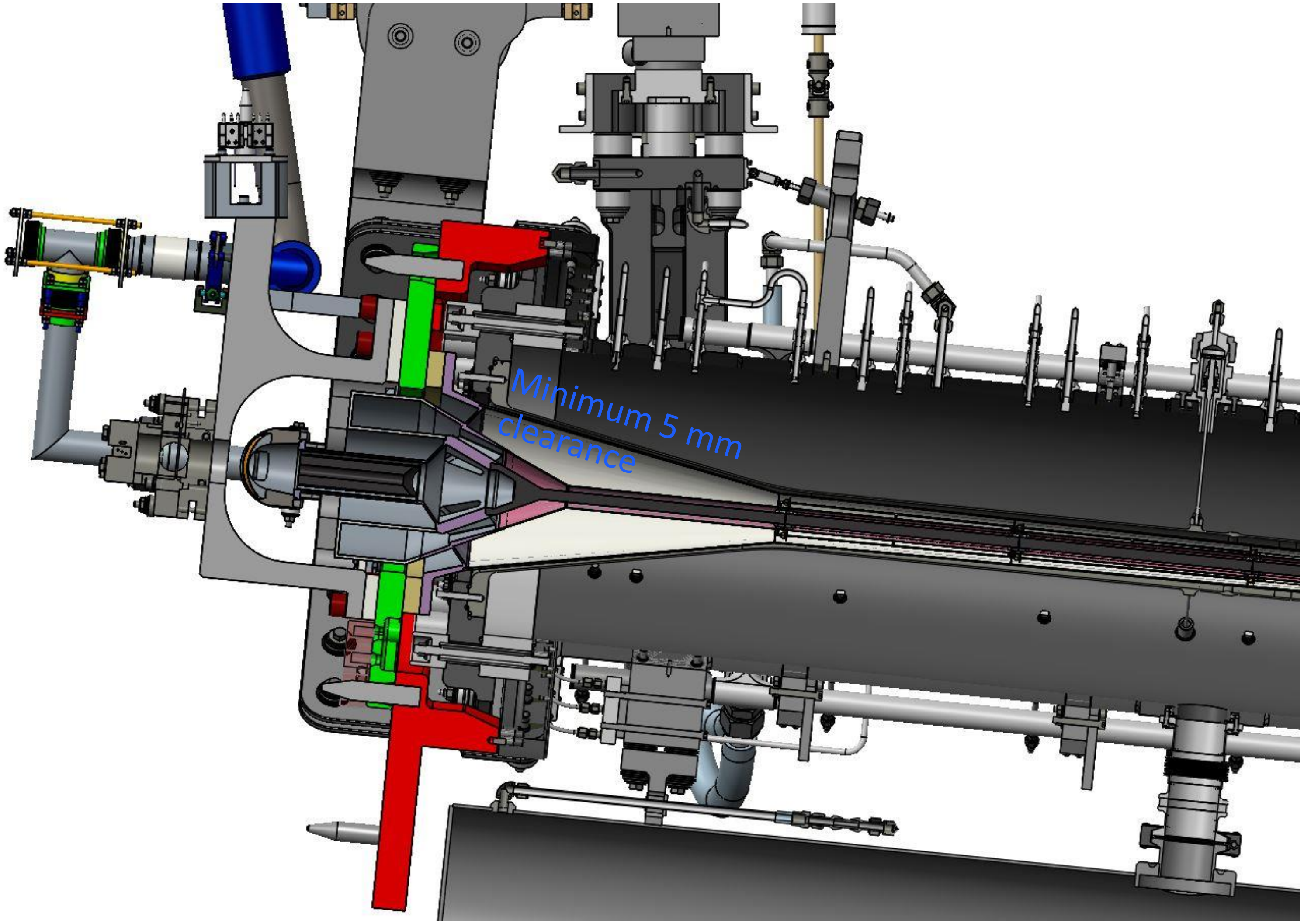




- 5 λ (interaction length) target found to be an approximate optimum
- c.2.2 m long – 2.5 x as long as T2K target
- Decision: 1st protoptype 1.5 m long
- 1st operating target up to 1.8 m long

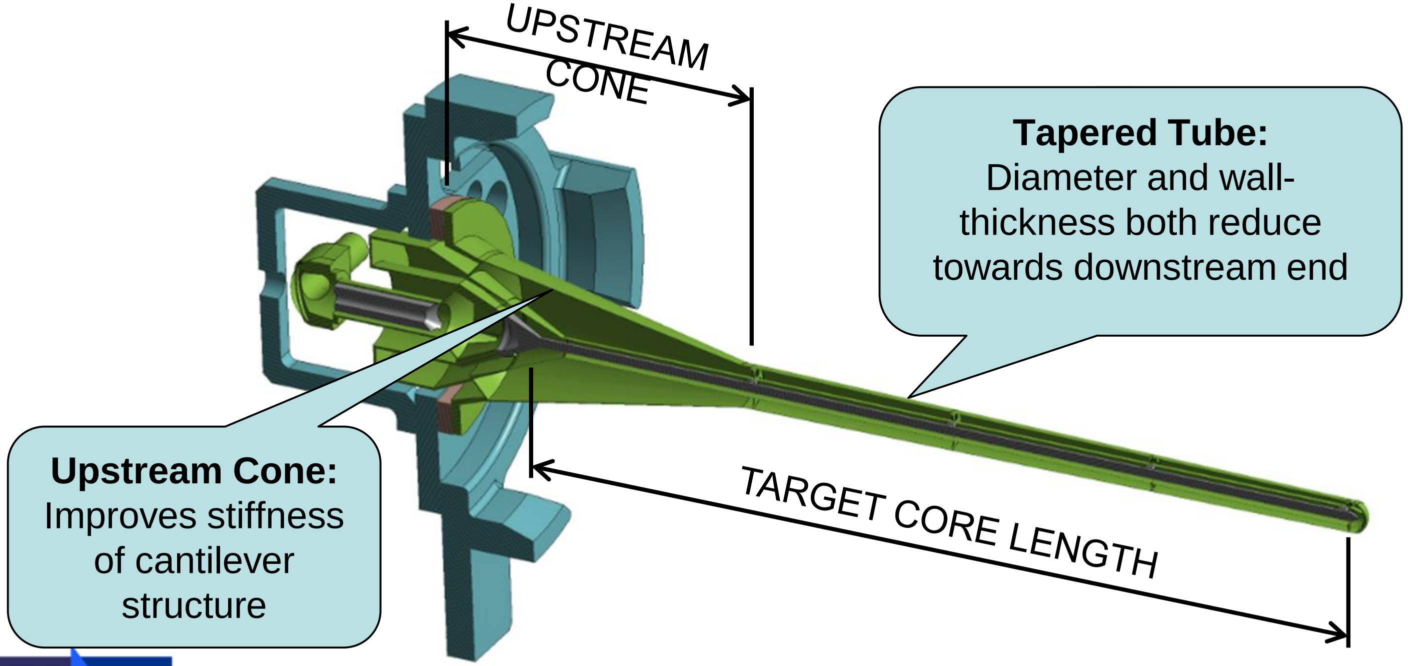
Target & horn assembly

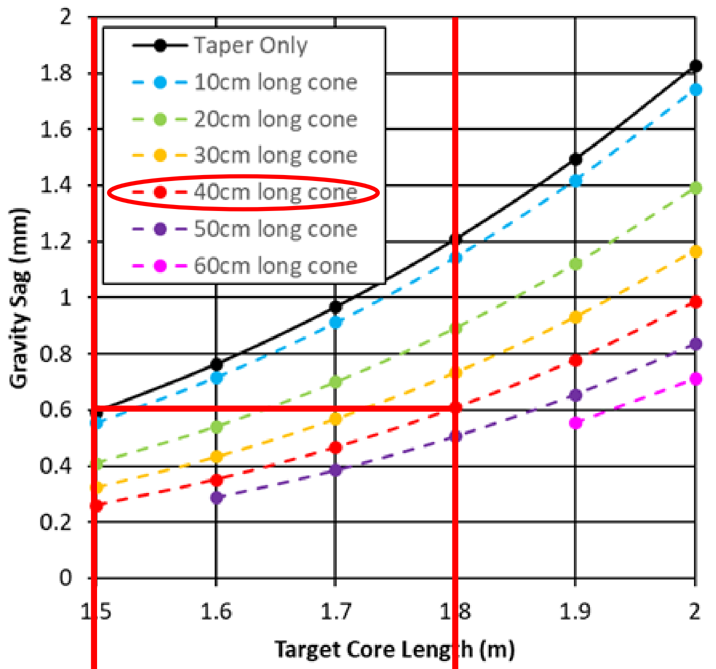
- Upstream horn inner conductor tapered to match upstream target cone
- Beam diagnostic features integrated into upstream target

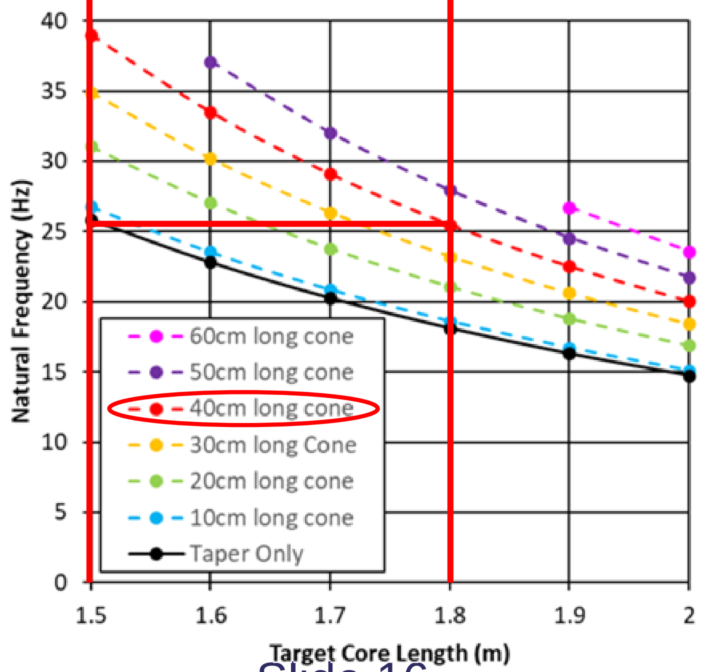


Path to extra target length

- Physics motivation to extend target from 1.5 m (baseline prototype) towards 1.8 m
- Upstream cone in addition to downstream tapered outer tube
- *But* reduces horn focusing efficiency







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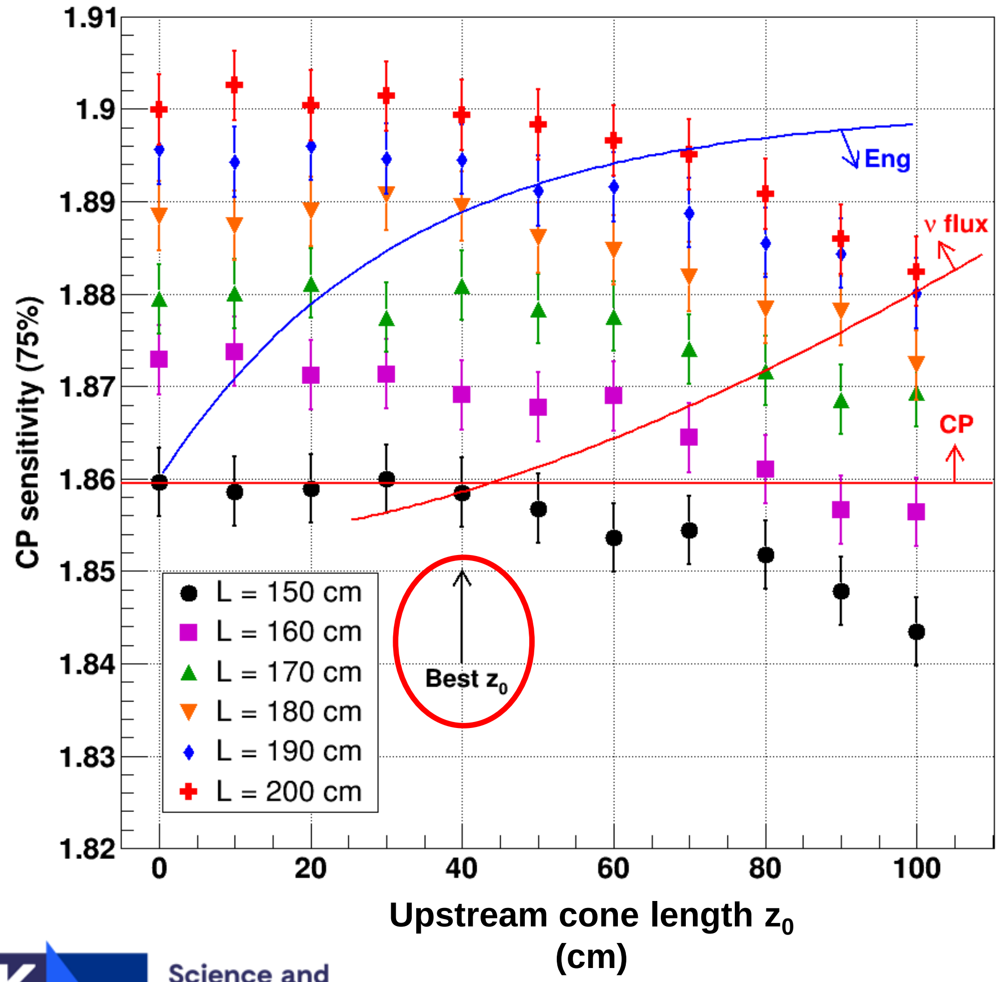
Combined physics/engineering optimization



Target core length L (cm)	Vessel cone min length z_0 (cm)	Extra time needed per run year (days)
150	0	19
160	17	13
170	28	11
180	**42**	**6**
190	56	5
200	73	4

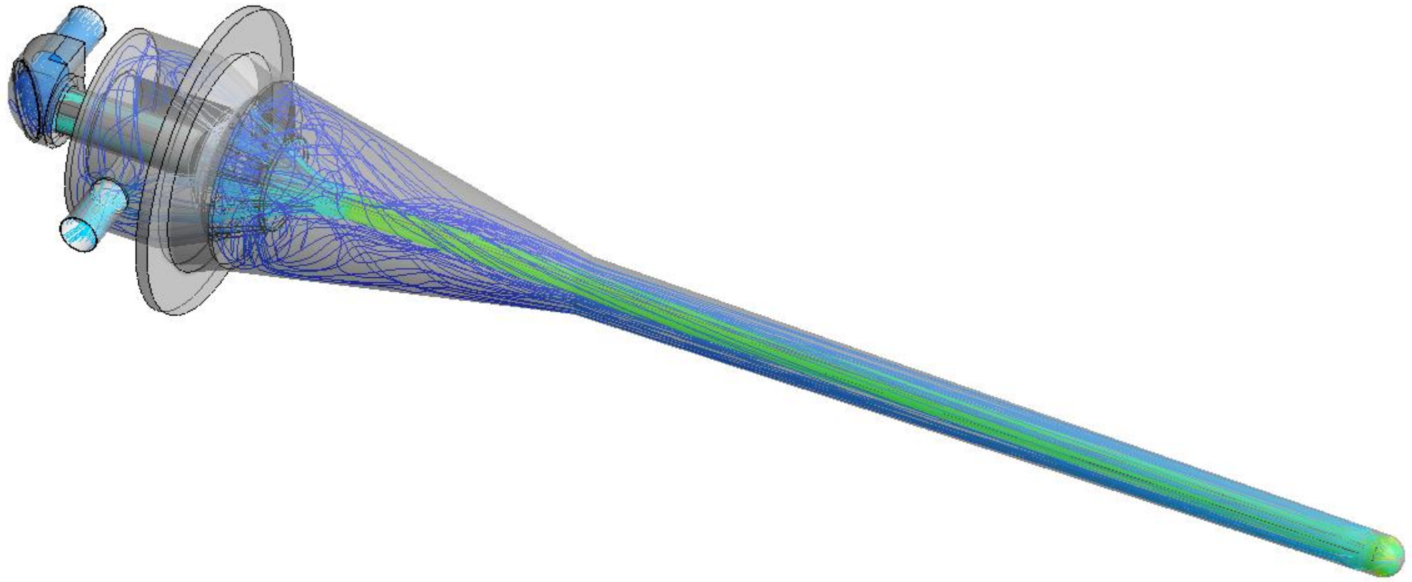
→ Cf 220 cm 'optimum' target

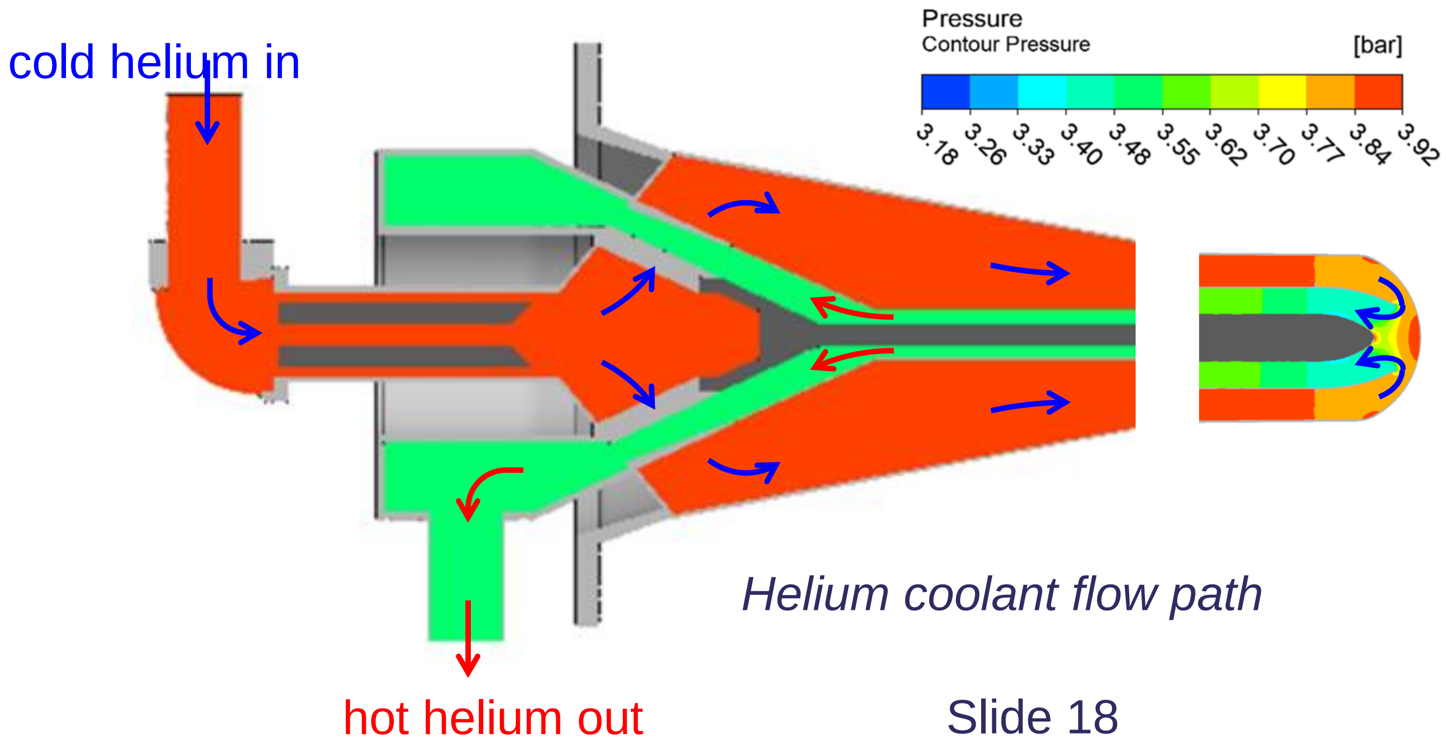
1st full prototype (L = 150 cm)

Aspiration (L = 180 cm)

Thermal Management

- Helium flow keeps beam windows and outer-vessel cool
- Graphite runs hot to “anneal out” radiation damage effects
- Development of T2K flow concept





Helium coolant flow path

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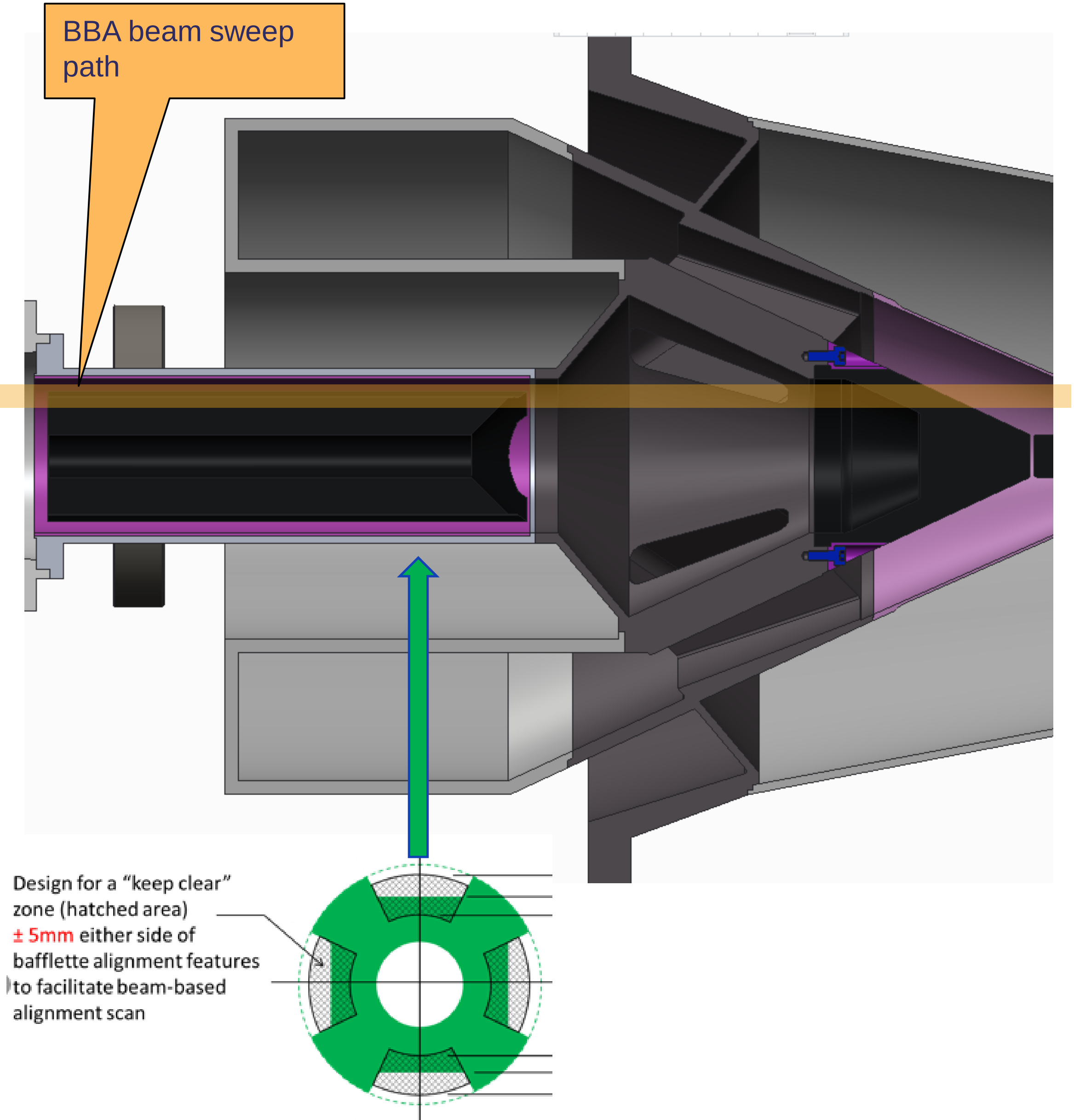
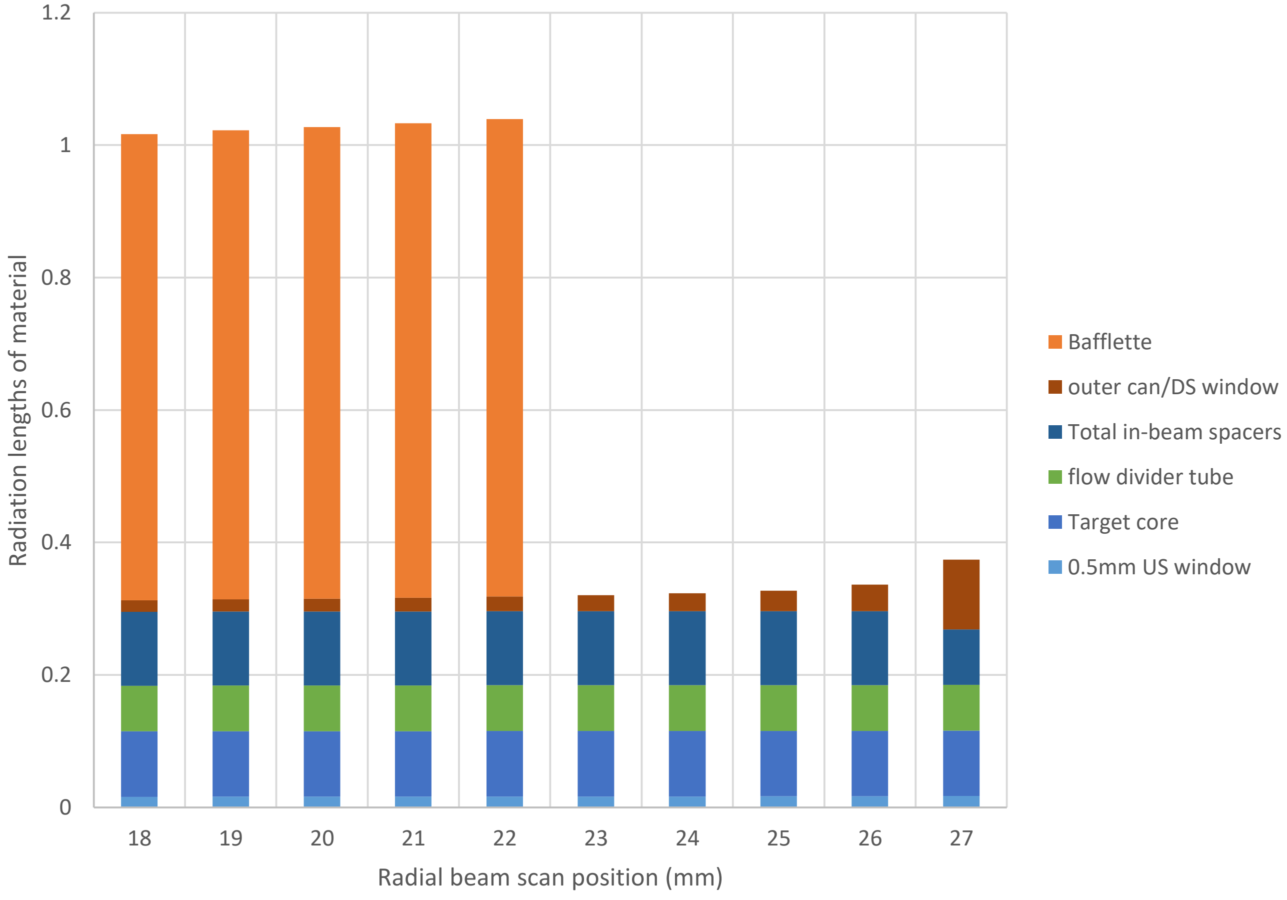
Design for Beam Based Alignment

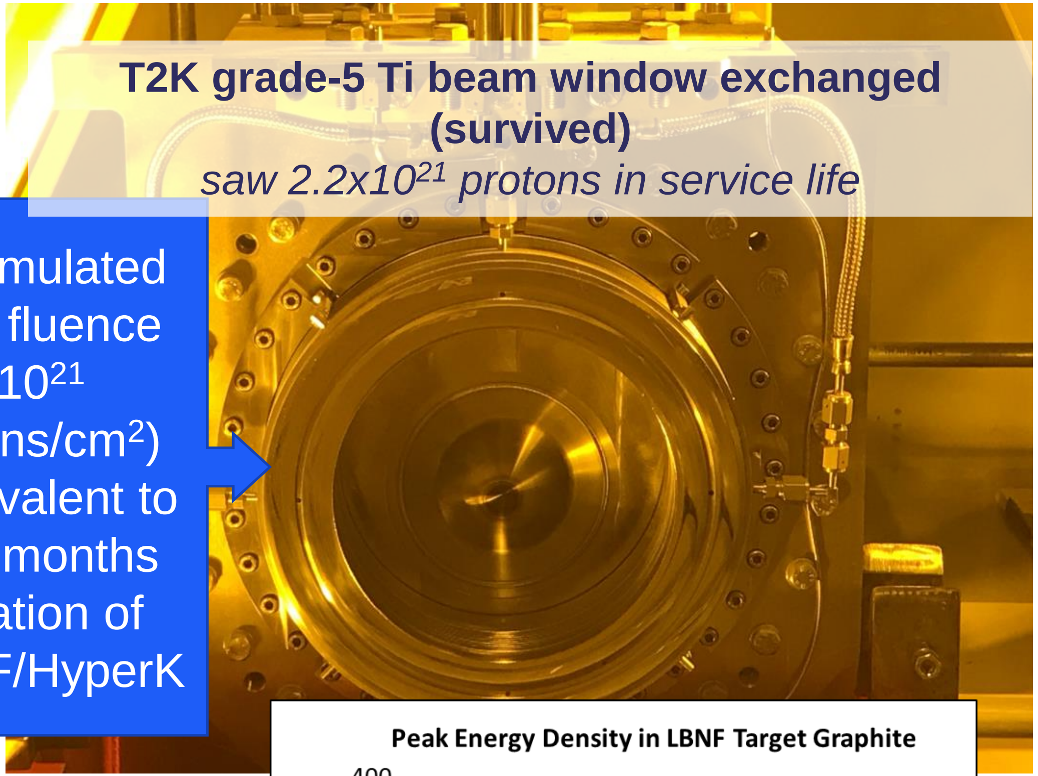


Plot of material radiation lengths through beam-based alignment scan on BBA feature +/- 5mm



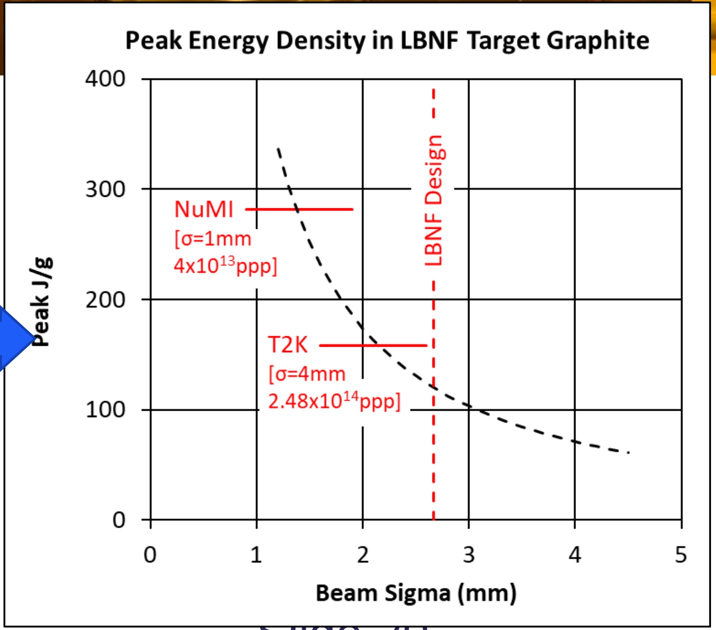
Radiation damage lifetime

- Target lifetime difficult to predict(!)
  - Operational data from T2K, NuMI
  - RaDIATE collaboration programme <https://radiate.fnal.gov>
- Titanium Beam Window
  - Reference: T2K window operation
- Graphite Core
  - Reference: T2K/NuMI operation
- Beam spot size is a key “handle” on severity of material impact
  - LBNF spot size @ target chosen as a compromise between material-survivability, thermal-management issues, and physics-drivers



Accumulated peak fluence (1.7x10^{21} protons/cm^2) (equivalent to c.six-months operation of LBNF/HyperK

Pulsed heat loads in graphite at T2K/LBNF lower than NuMI



Paper by RaDIATE collaboration

https://www.sciencedirect.com/science/article/pii/S0022311520310217

Points way towards more radiation tolerant alloys and grades

ELSEVIER

Journal of Nuclear Materials
Volume 541, 1 December 2020, 152413

Tensile behavior of dual-phase titanium alloys under high-intensity proton beam exposure: Radiation-induced omega phase transformation in Ti-6Al-4V

Taku Ishida [a, b], Eiichi Wakai [a, c], Shunsuke Makimura [a, b], Andrew M. Casella [d], Danny J. Edwards [d], Ramprashad Prabhakaran [d], David J. Senor [d], Kavin Ammigan [e], Sujit Bidhar [e], Patrick G. Hurh [e], Frederique Pellemoine [e], Christopher J. Densham [f], Michael D. Fitton [f], Joe M. Bennett [f], Dohyun Kim [g], Nikolaos Simos [g, 1], Masayuki Hagiwara [b], Naritoshi Kawamura [a, b] … Katsuya Yonehara [e]

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Fermilab

Pacific Northwest NATIONAL LABORATORY

BROOKHAVEN NATIONAL LABORATORY

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Finally: a more futuristic Snowmass Targetry SoI

A Flowing Granular Tungsten Pion Production Target for a Muon Collider at CERN

Abstract
The potential of pneumatically fluidized and flowing granular tungsten as a high-Z target technology for intense pulsed power accelerator applications such as a future muon collider (MC) at CERN is introduced. A muon collider has a combination of requirements that are well beyond the limit of any existing target technology. A high-Z target is required to be suspended within the bore of a high field solenoid and subject to the high pulsed power density of a multi-MW proton beam. Flowing granular tungsten pneumatically conveyed within a pipe is proposed as an alternative to the current baseline technology proposal of an open mercury jet. The status of off-line and on-line experimental research into such a technology is described, followed by an outline of a future program of work required to fully demonstrate its suitability for a muon collider or other facility with similarly demanding requirements.

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Authors

C.J. Densham*, P. Loveridge, D. Wilcox, T.R. Davenne, J. O'Dell, C. Rogers (STFC Rutherford

Appleton Laboratory, Harwell Campus, Didcot, Oxfordshire, UK)

J.J. Back (University of Warwick, Coventry, UK)

N. Charitonidis, I. Efthymiopoulos (CERN, Geneva, Switzerland)

D. Sprouster (BNL, US)

Muon Collider Collaboration

* chris.densham@stfc.ac.uk

(Dated: August 31st, 2020)

Any questions?

Chris Densham

Rutherford Appleton Laboratory, UK

NBI2021: 20-24 Sept, Oxfordshire, UK