Physics optimization of the LBNF target & horn system

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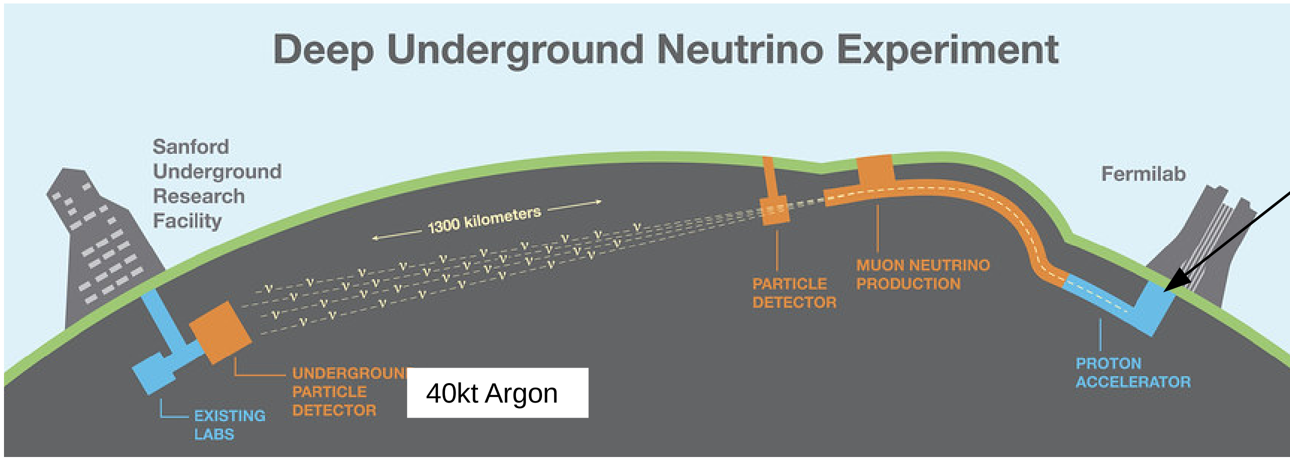
University of Warwick

on behalf of the DUNE collaboration

NBI 2022, 19-22 Sept 2022

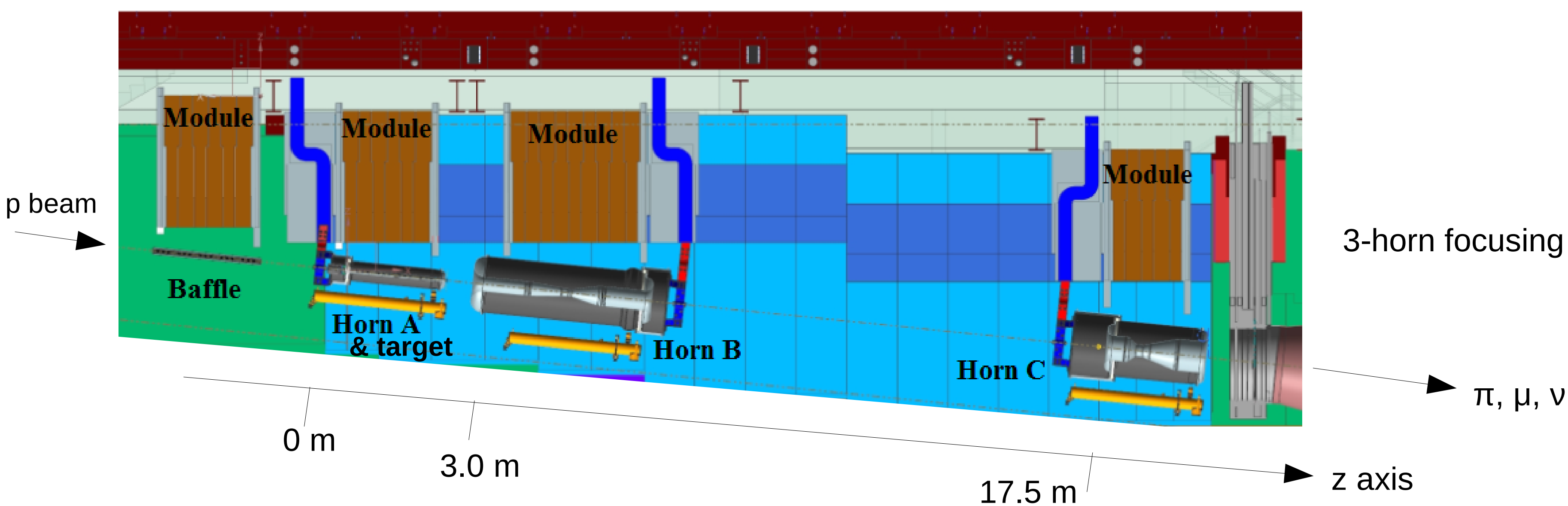
Introduction



Long-Baseline Neutrino Facility (LBNF): produces intense muon neutrino (ν_μ) beam for DUNE

DUNE: purpose is to measure neutrino matter-antimatter asymmetries (CP violation)
C = charge, P = parity

120 GeV proton beam collides with graphite target to produce $\pi \longrightarrow \mu \longrightarrow \nu_\mu$
Beam power = 1.2 MW (upgradable to 2.4 MW), Gaussian σ_{beam} = 2.67 mm



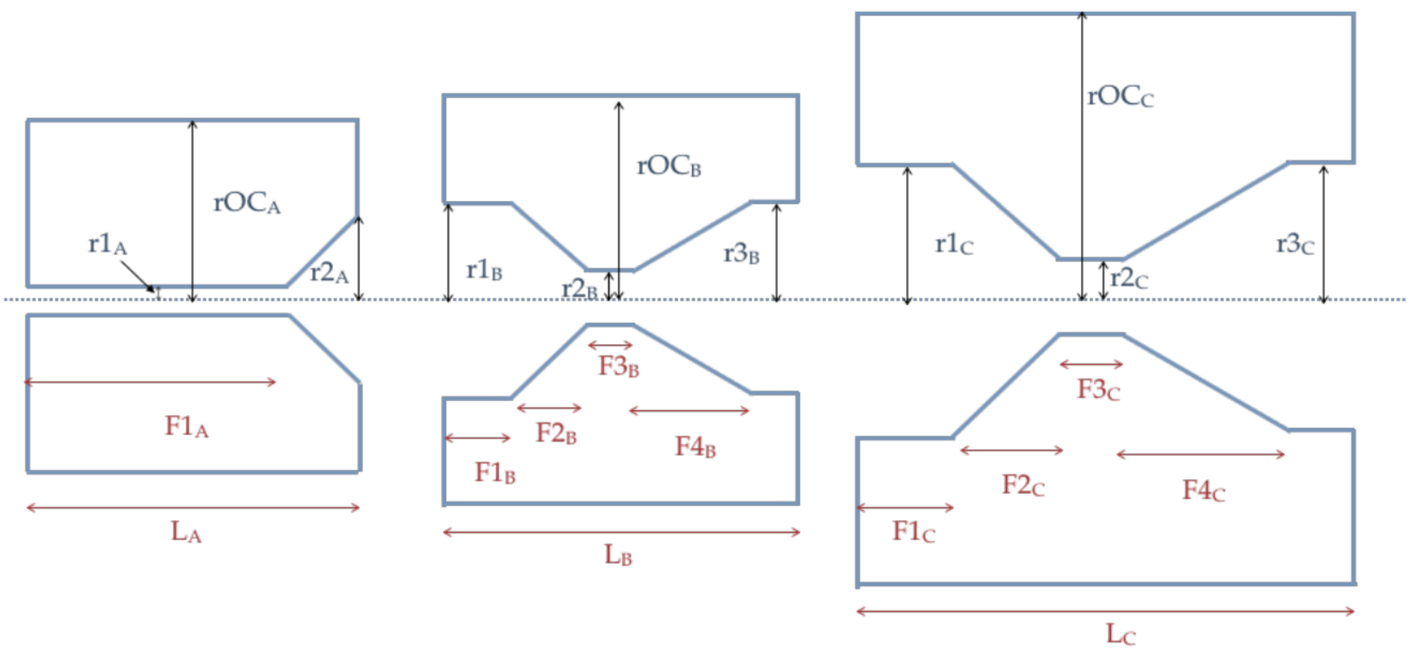
3-horn focusing system

Optimization of beamline for ν CP violation

Laura Fields

Genetic algorithm & **Geant 4** simulations: optimize geometry of **3-horn** π focusing system

Based on **NuMI 2-horn** beamline (3rd horn reduces individual horn lengths)
Target shape also optimized (graphite cylinder or graphite/beryllium fins)

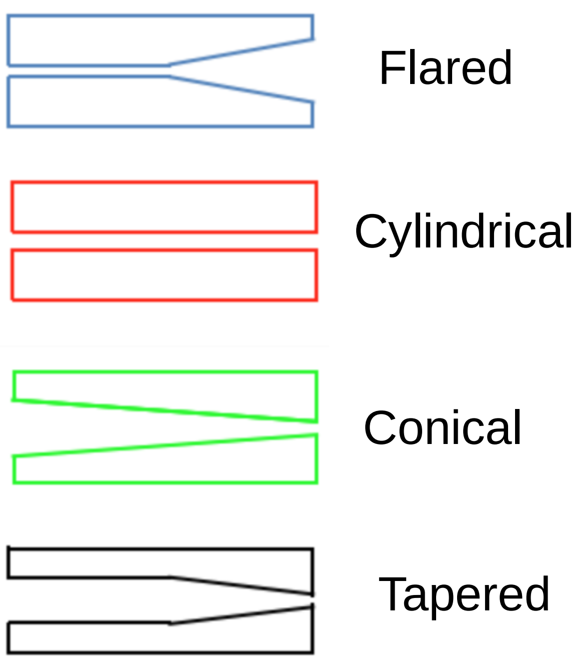


Horn A
(& target)

Horn B

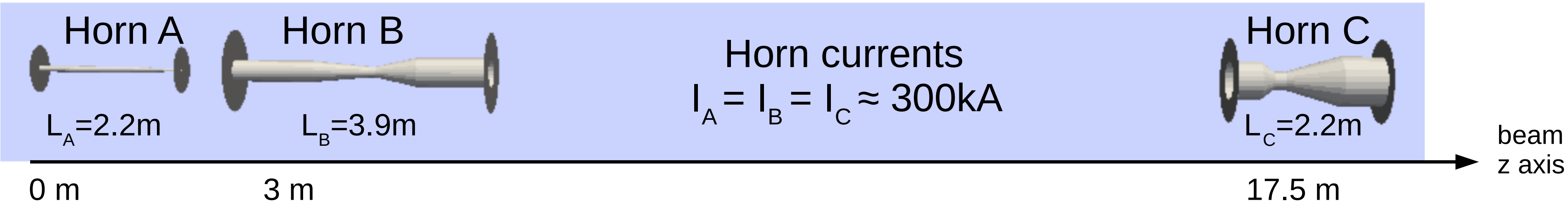
Horn C

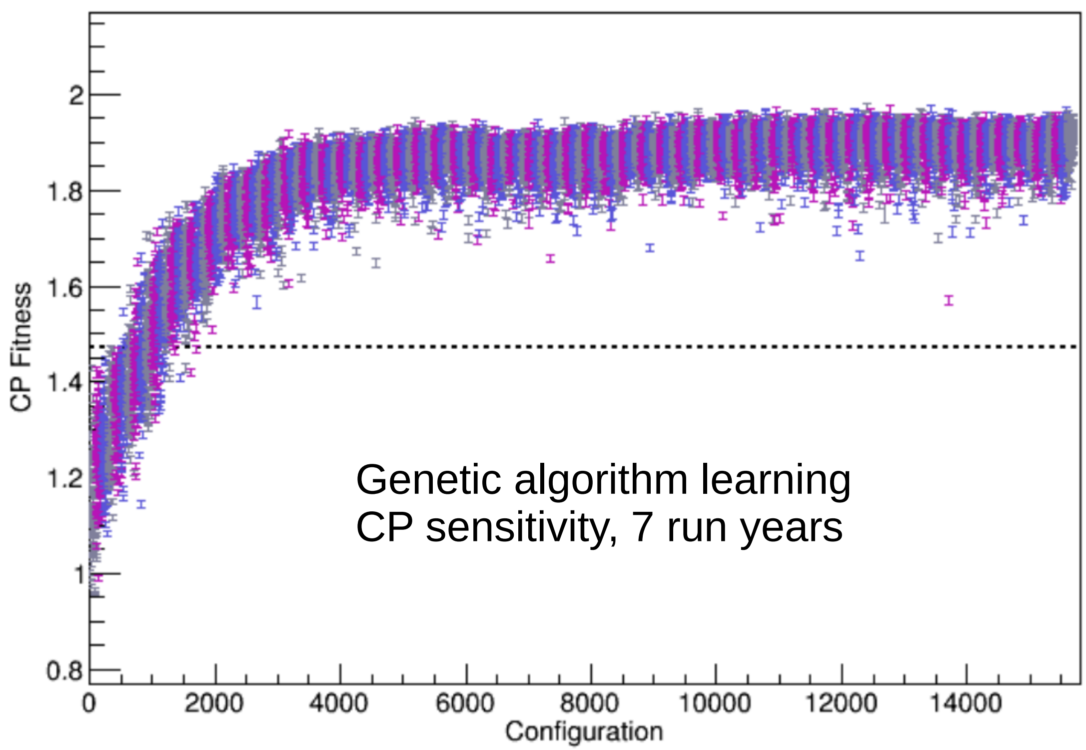
Horn Shapes

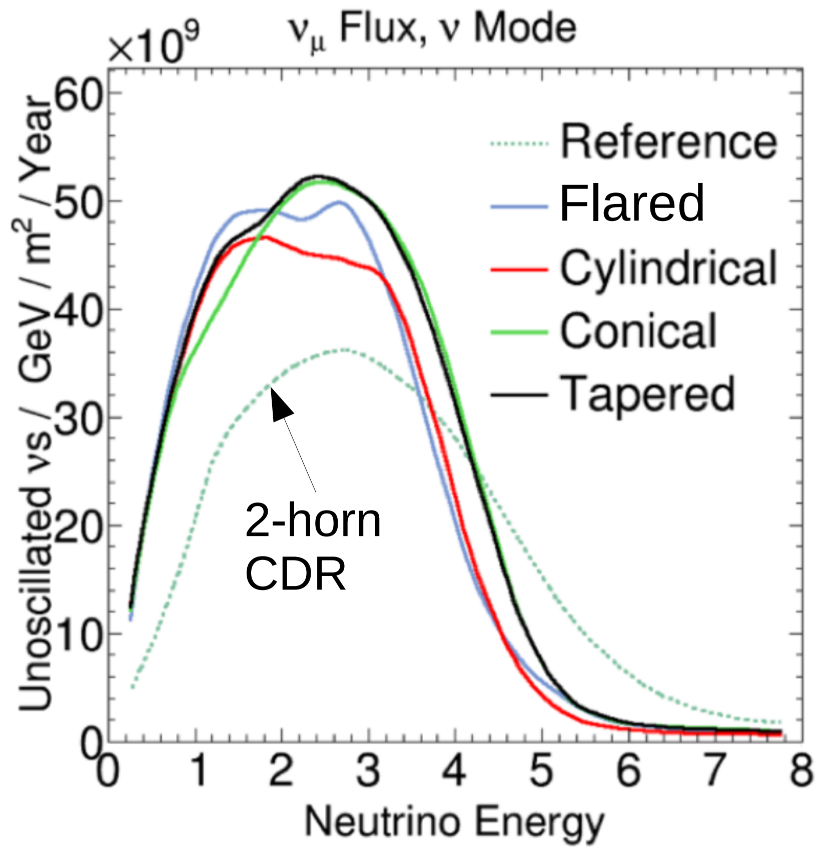


Target & 3-horn system optimization

Laura Fields







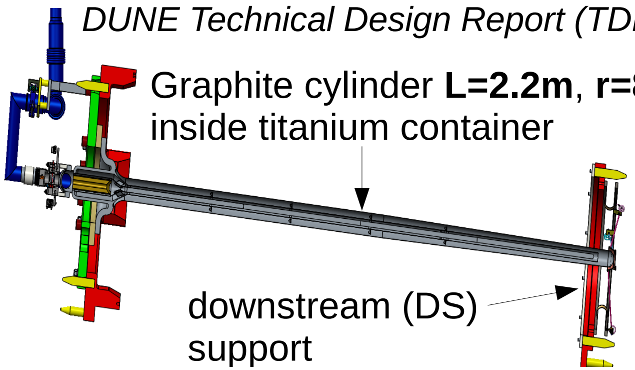
Tapered (TDR) vs **CDR** (2-horn) design: **30% increase** in signal ν flux (E_ν= 1 to 4 GeV)

Graphite target **L = 2 m (4 λ_{int})**, proton beam 1.2 MW, **120 GeV**, σ_{beam}= 2.67 mm

Conceptual Graphite Target Designs (RAL Target Group)

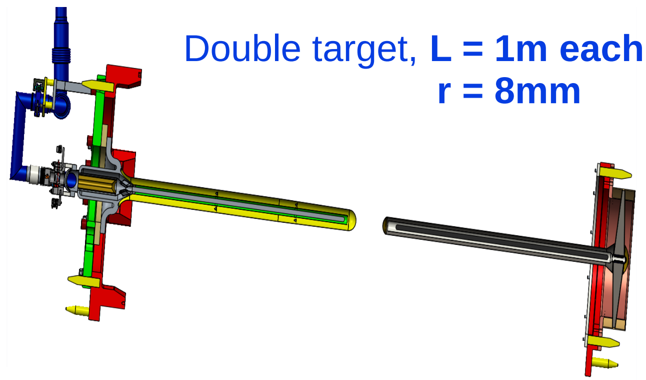
DUNE Technical Design Report (TDR)

Graphite cylinder **L=2.2m**, **r=8mm** inside titanium container

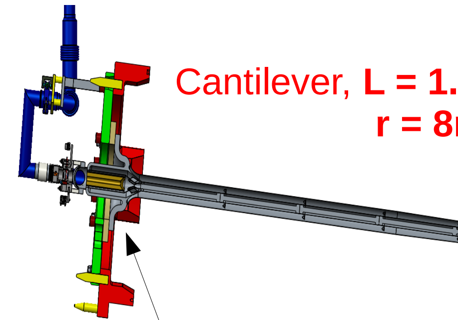


downstream (DS) support

Double target, **L = 1m each**
r = 8mm

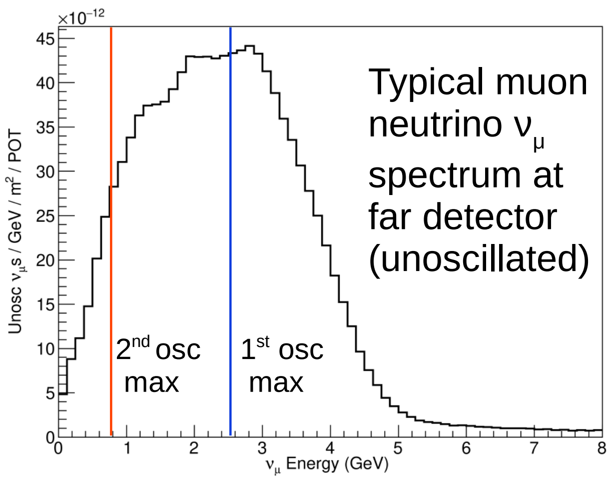


Cantilever, **L = 1.5m**
r = 8mm



upstream support

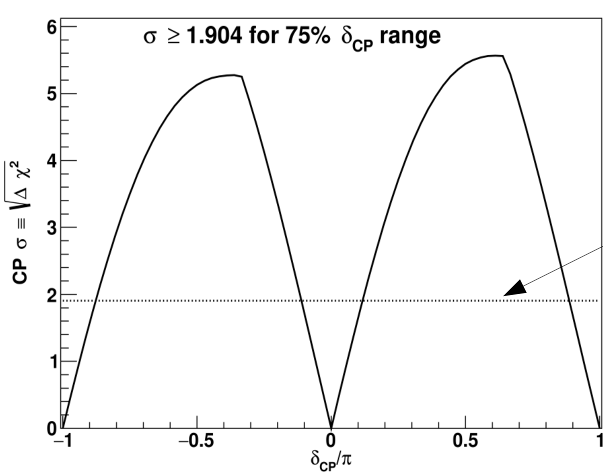
GEANT4 simulation



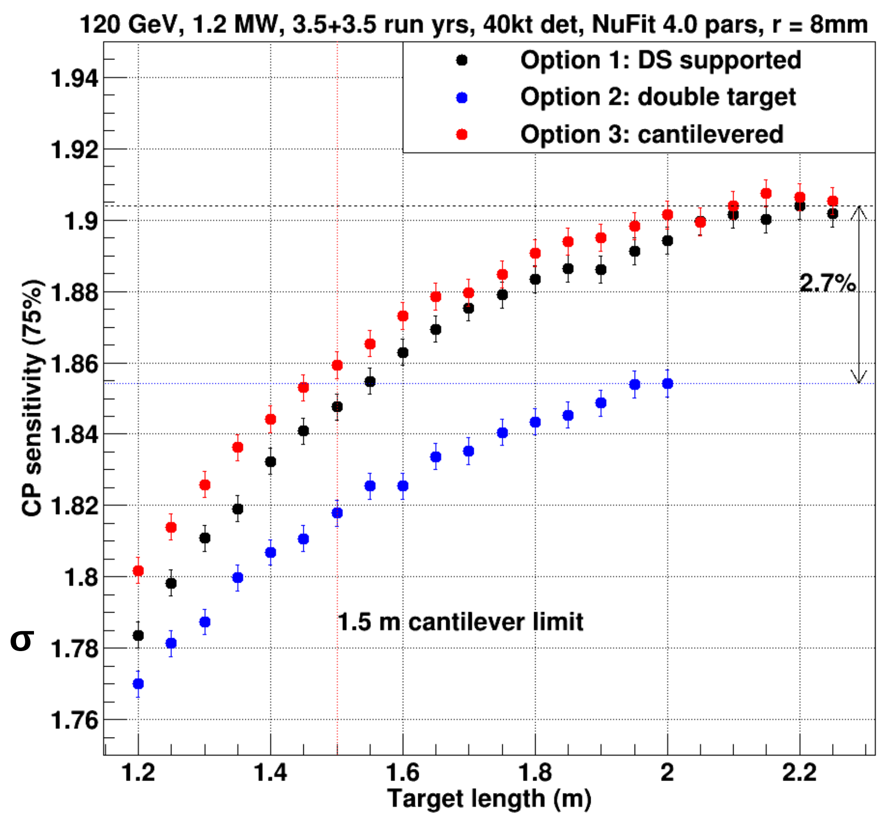
Typical muon neutrino ν_μ spectrum at far detector (unoscillated)

GLoBES software

NuFit 4.0 params

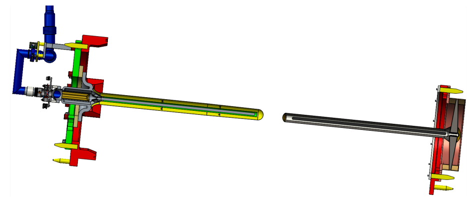
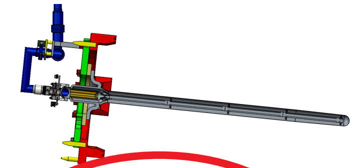


CP sensitivity σ covering 75% of neutrino oscillation phase δ_{CP}



Engineering & physics design review:
Cantilevered option chosen (since TDR)

Target Conceptual Design Review (July 2019, FNAL)

	 **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	High heat load. Unstable until supported.	High heat load but divided between 2 targets	Pushing at the limits on cantilever length.
Manufacturability	Difficult to make long tubes. DS support adds complexity.	2^{nd} 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, 2^{nd} 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.	2^{nd} target greatly increases cost and time.	Cheapest and fastest to produce.

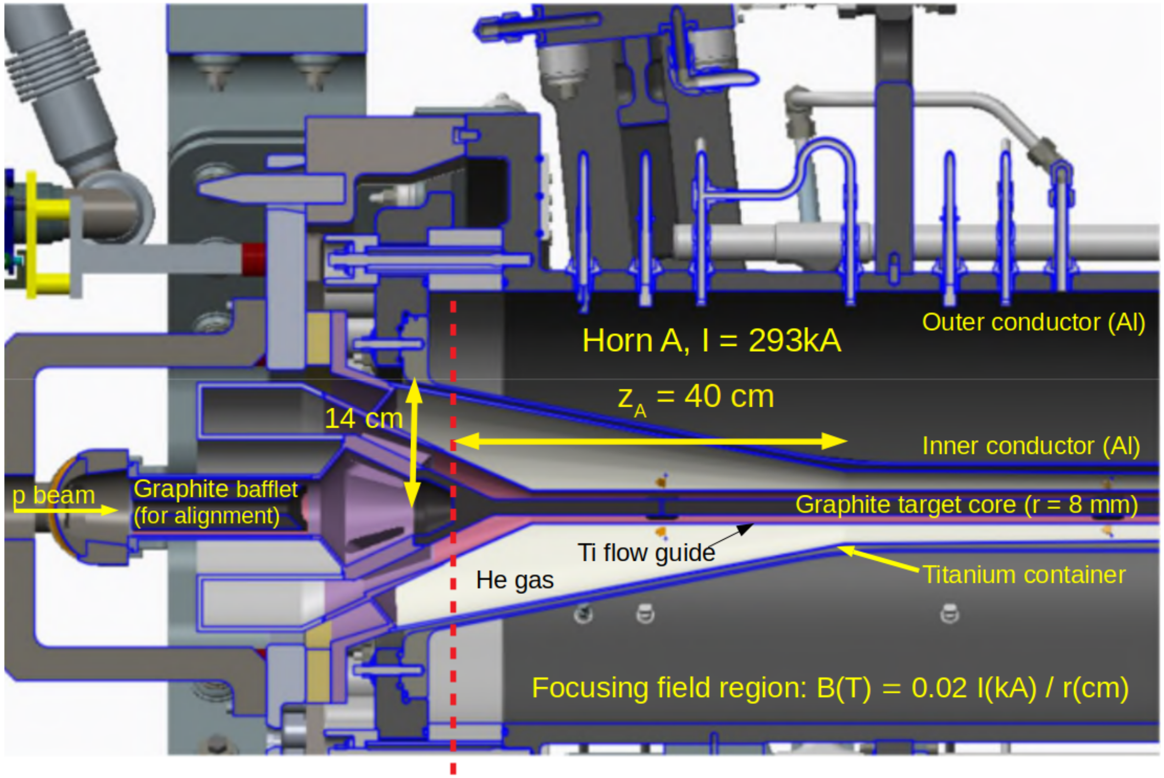
Target performance = physics x reliability

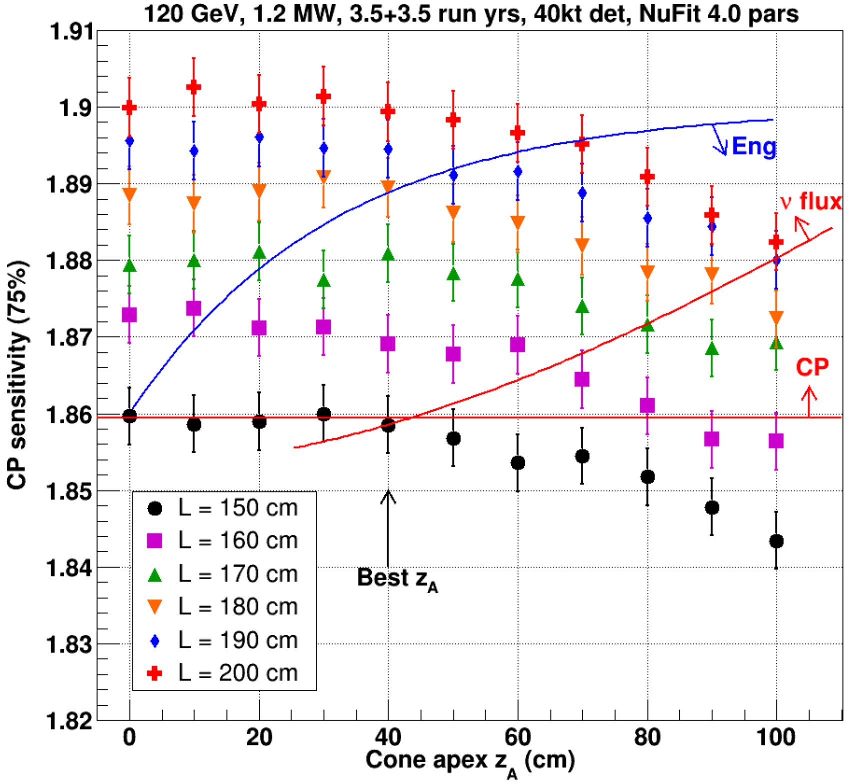
⇒Consensus to use **option 3: cantilever** with **L = 1.5 m** (prototype) up to **1.8 m** (goal)

Cantilever Design Optimization

Maximise target length: needs stronger upstream support ⇒ **cone** design

Courtesy RAL High Power Target Group





Layout of target inside 1st horn A

Engineering limits: minimum z_A

Physics limits: maximum z_A

Upstream horn A conductor **cone** (r = 14cm, h = 45cm)
⇒ space for wider (stiffer) titanium support for longer target

Max z_A= 40cm: L = 1.5 to 1.8 m

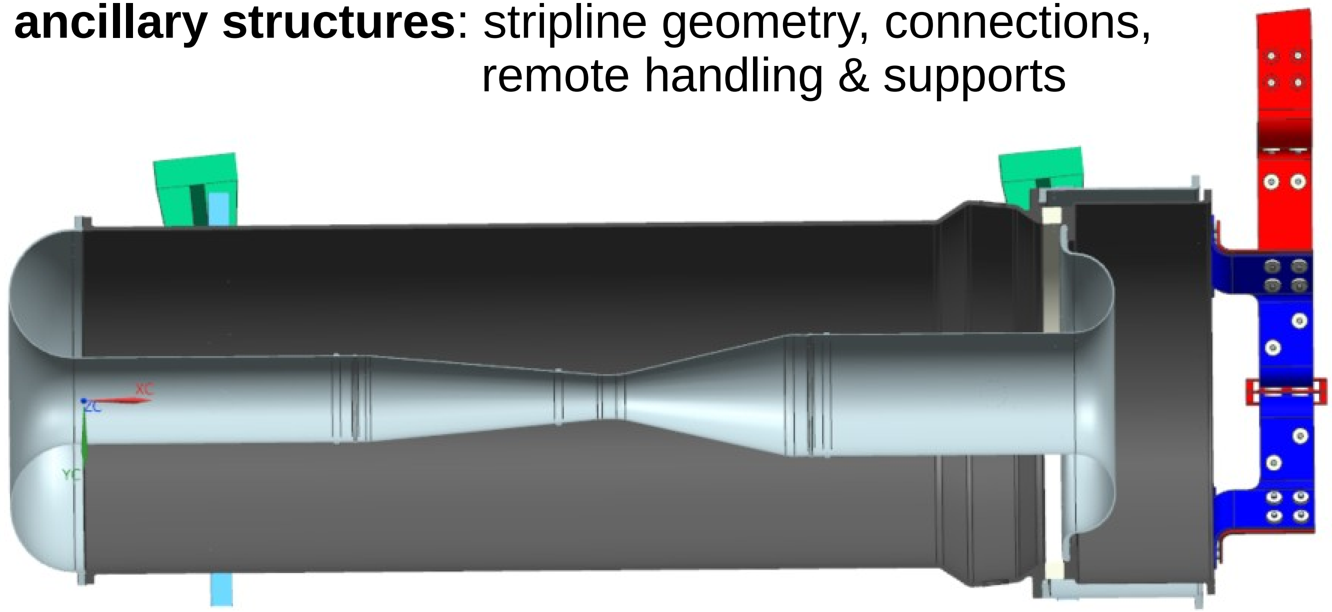
L = 3.1 to 3.8 λ_{int} (ρ=1.78 g cm^{-3})

Horn B (& C) Modifications

Cory Crowley

Reduce heating of current equalisation sections
Standardize ancillary structures: stripline geometry, connections, remote handling & supports

TDR
conceptual
engr. design
$r_{OC} = 63.4$ cm

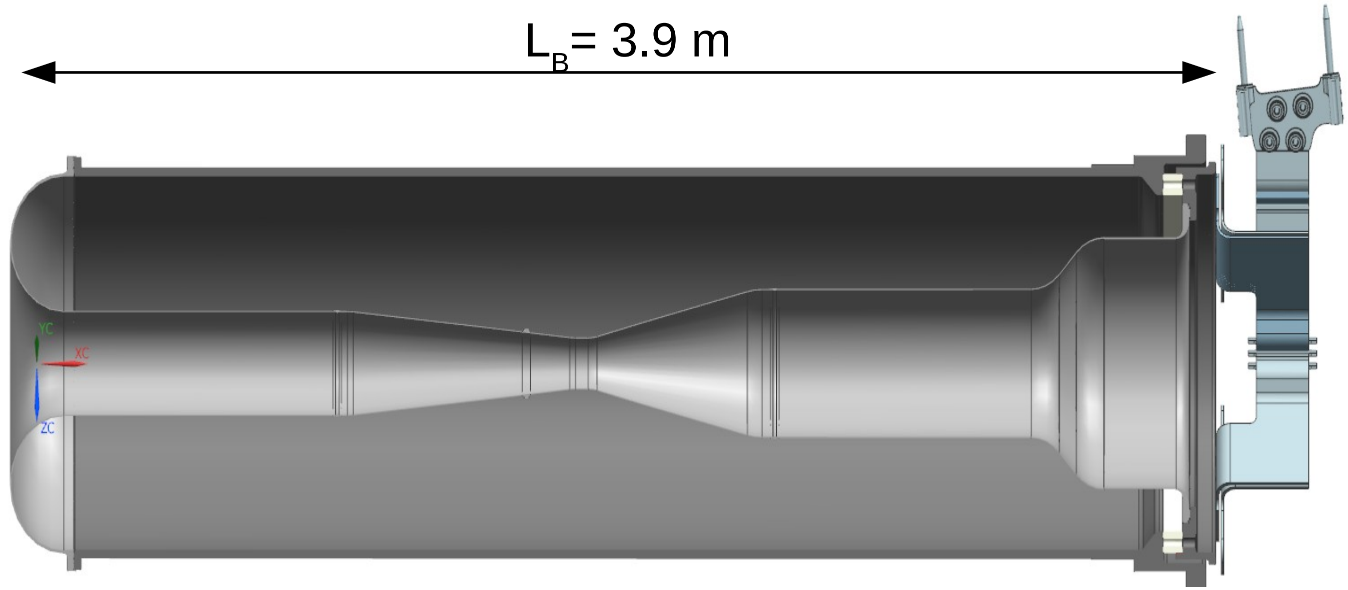


Striplines
not simulated

$L_B = 3.9$ m

$I_B = I_C = 300$kA

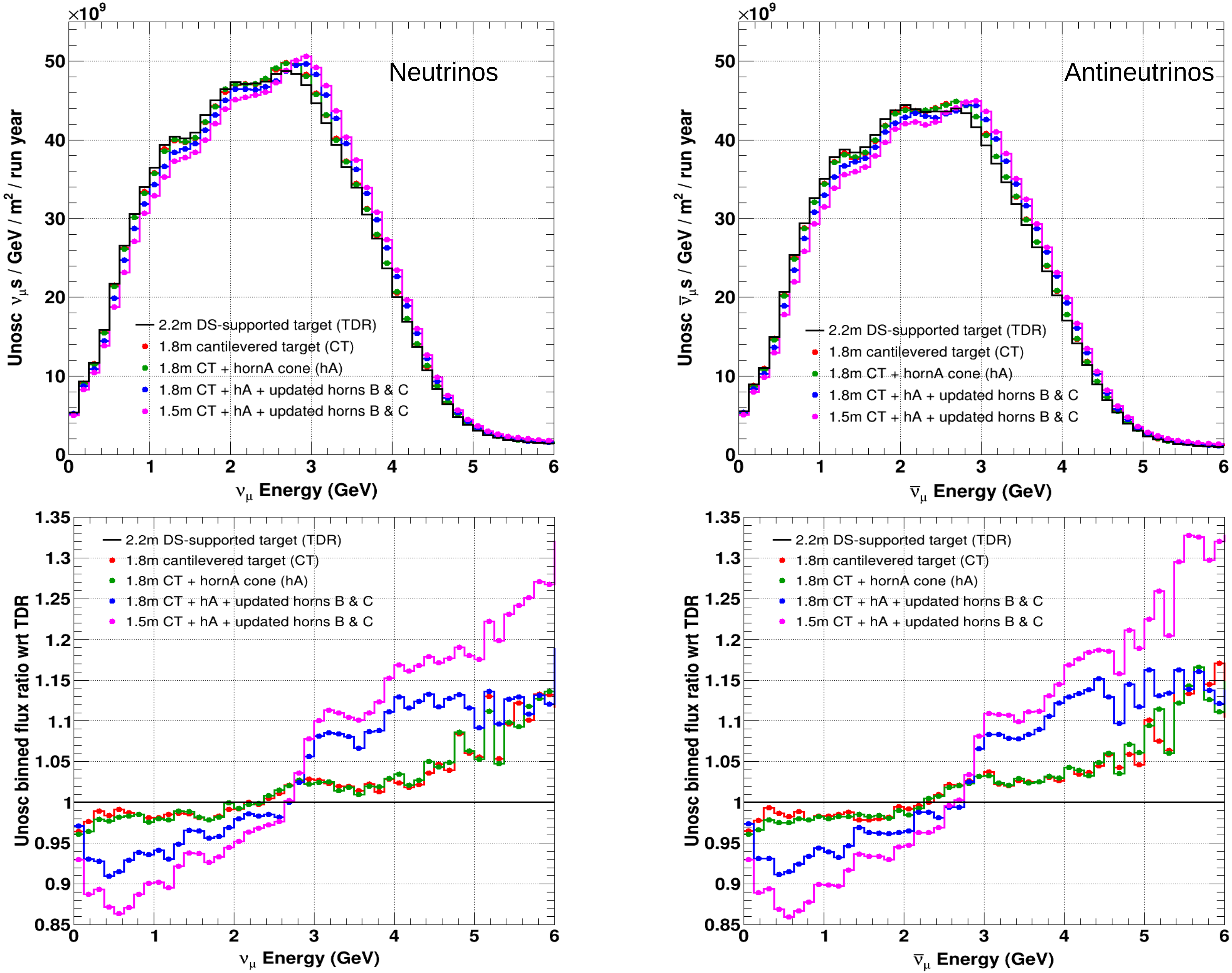
Current
standardized
engr. design
$r_{OC} = 60$ cm
maximum radius



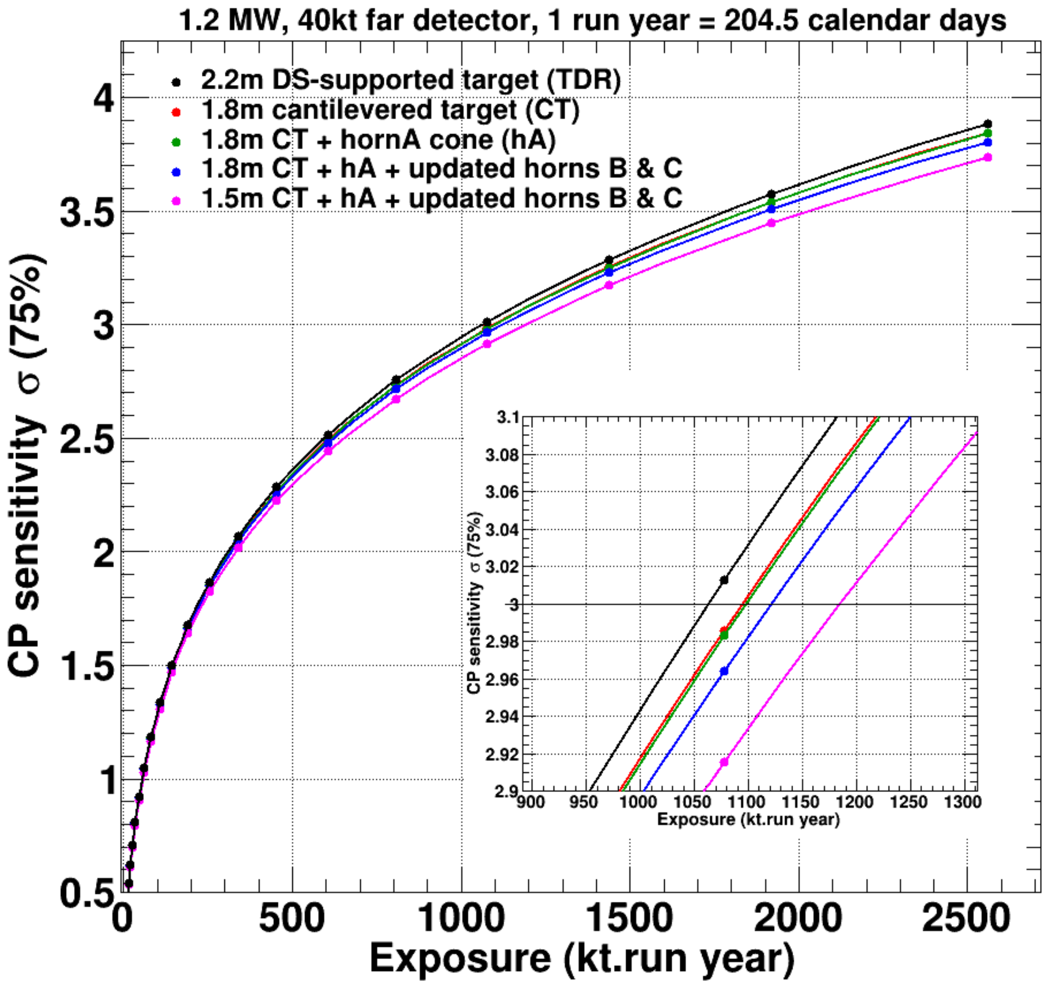
Striplines &
their **B** fields
included

Similar for Horn C, $L_C = 2.2$m (essentially a mirror image)

Signal ν flux changes since DUNE TDR



Projected target physics performance



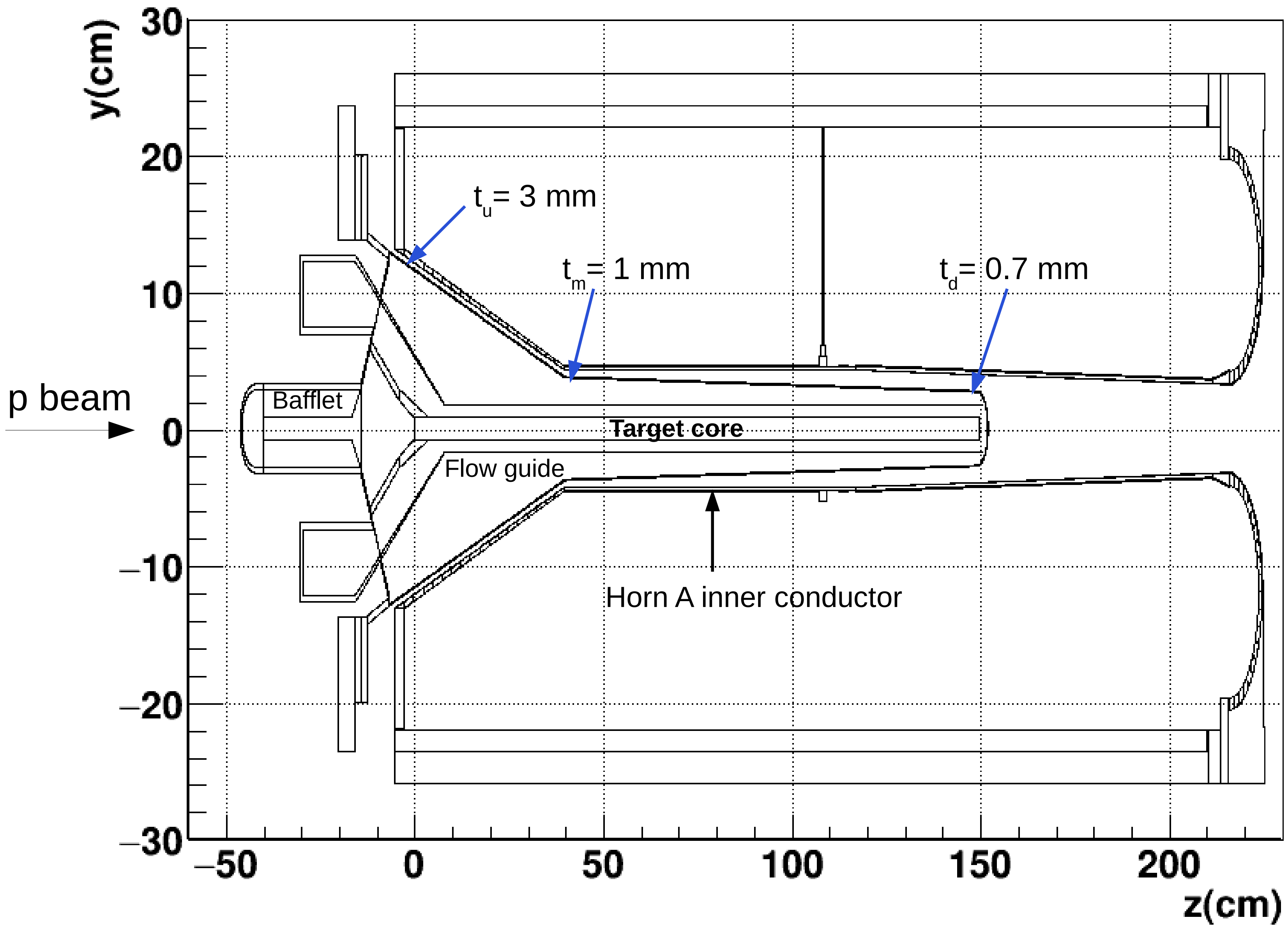
Approx **extra run time** needed to match TDR **CP σ sensitivity = 3**

Configuration	Extra time per run year (1 run year = 204.5 days)
2.2m target (TDR)	0 days (0 %)
1.8m cantilevered target (CT)	6 days (3 %)
1.8m CT + horn A cone (hA)	6 days (3 %)
1.8m CT + hA + updated horns B & C	**11 days (5 %)**
1.5m CT + hA + updated horns B & C	**23 days (11 %)**

Estimated **target exchange** times:
21 days for **TDR** target
7 days for **cantilevered** target

IPAC'21 poster **WEPAB212**
"Physics studies for the LBNF graphite target design"

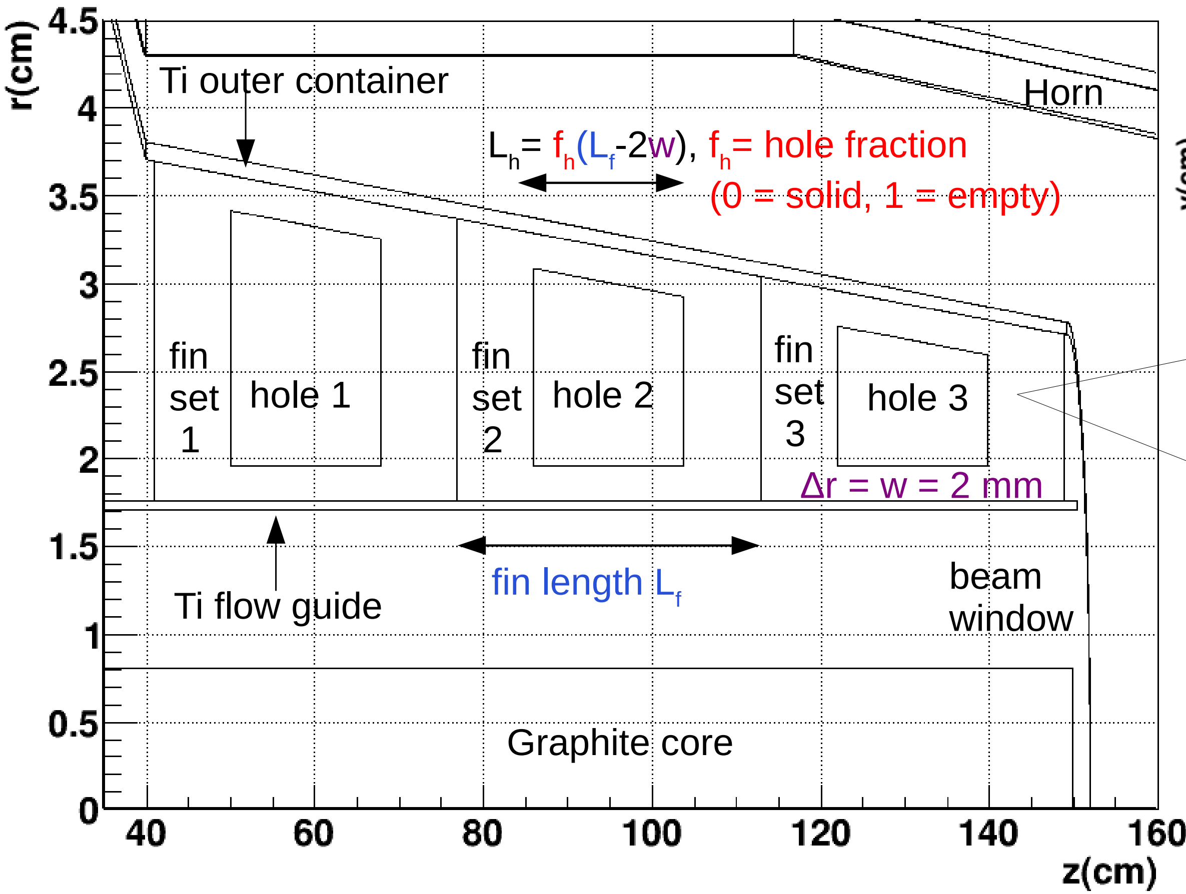
Target outer titanium container

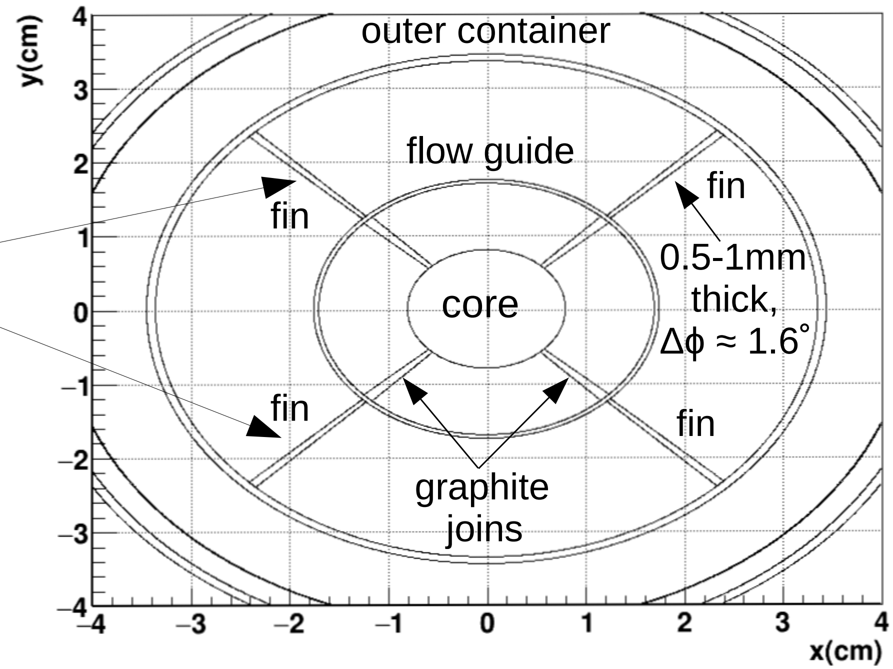


Tapered thickness: t_u= 3 mm, t_m = 1 mm & t_d = 0.7 mm

Minimum requirement to **prevent vacuum buckling**

Target titanium support fins

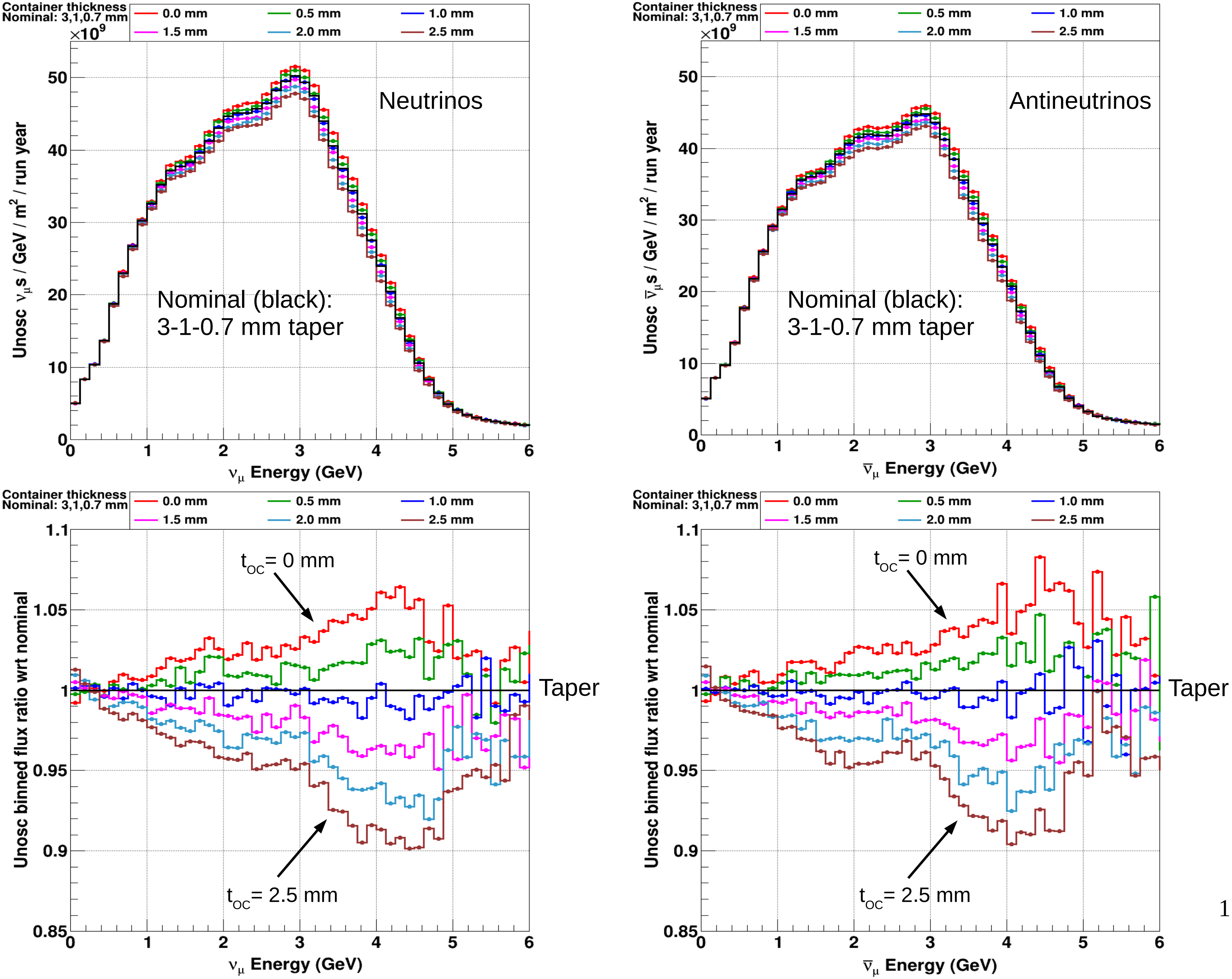




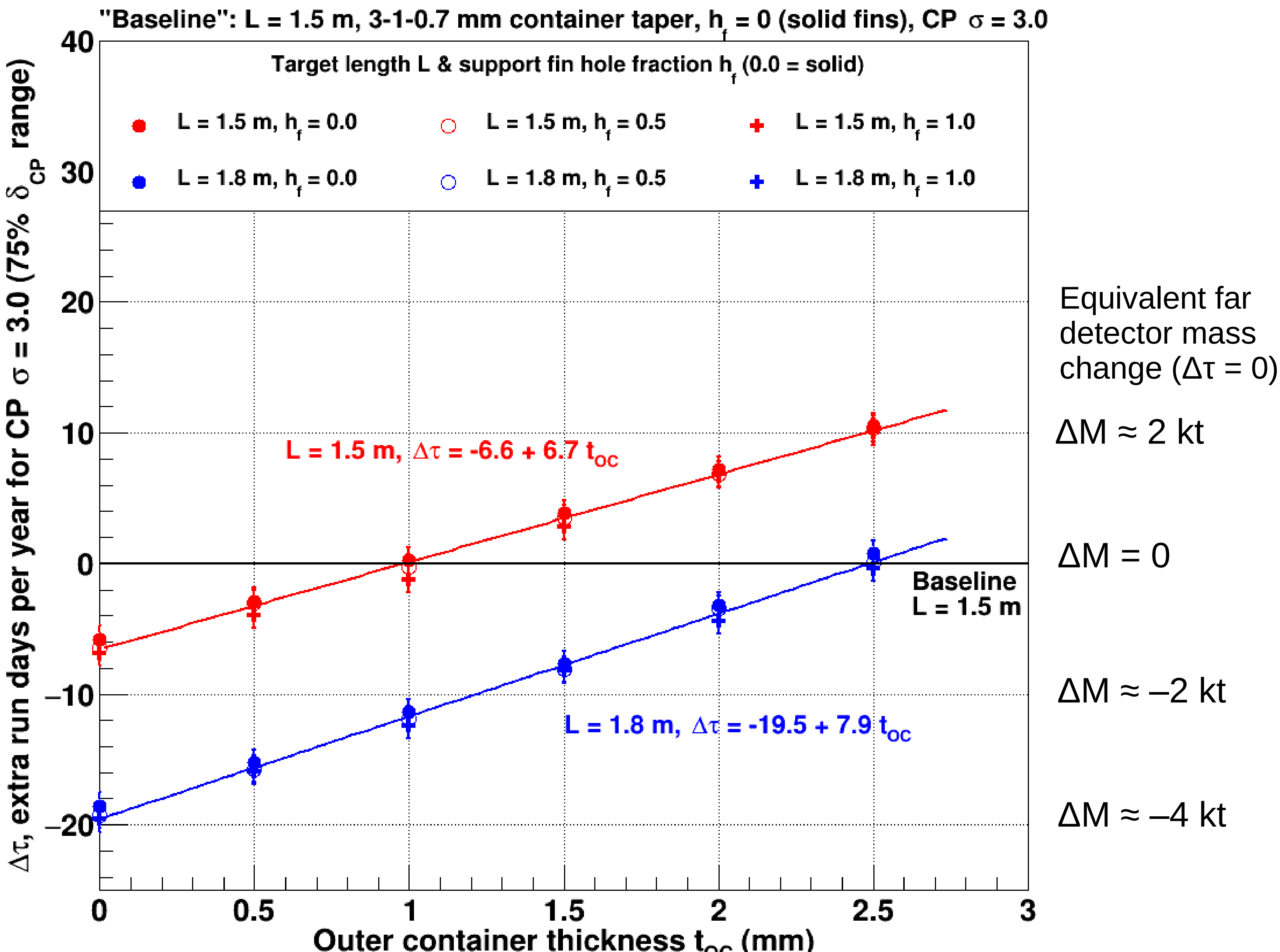
Thin Ti support fins at **±45** and **±135 degrees** along target length (from z = 40 cm)

Small effect on neutrino flux: only affects π trajectories close to these angles, slightly better to have holes (also good for cooling)

Signal ν flux for outer container thickness t_{OC} ($=t_u=t_m=t_d$): **L = 1.5 m, f_h = 0.5** (half solid fins)



Extra run days per year vs outer container thickness t_{OC}



$\Delta\tau$ extra days/yr = fractional exposure change x 204.5 days; same **40 kt** far detector mass, 1.2 MW

Summary

- LBNF 3-horn & target system
  - Optimized for neutrino CP violation physics for DUNE

- LBNF target: cantilevered graphite cylinder with He cooling
  - Design, prototyping & construction by RAL High Power Target Group
  - **L = 1.5 m** (prototype), **L = 1.8 m** (goal), r = 8 mm, σ_{beam}= r/3
  - Upstream cone support structure, target inside Horn A
  - Thin titanium support fins at ±45 & ±135 deg. along target length
  - Outer titanium container thickness: as small as possible
    - Engineered **3-1-0.7 mm taper** ≈ uniform 1 mm thickness

- Future plans: DUNE replica target for NA61
  - π production measurements to reduce ν physics uncertainties