The LBNF Beamline

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Science & Technology Facilities Council
Rutherford Appleton Laboratory

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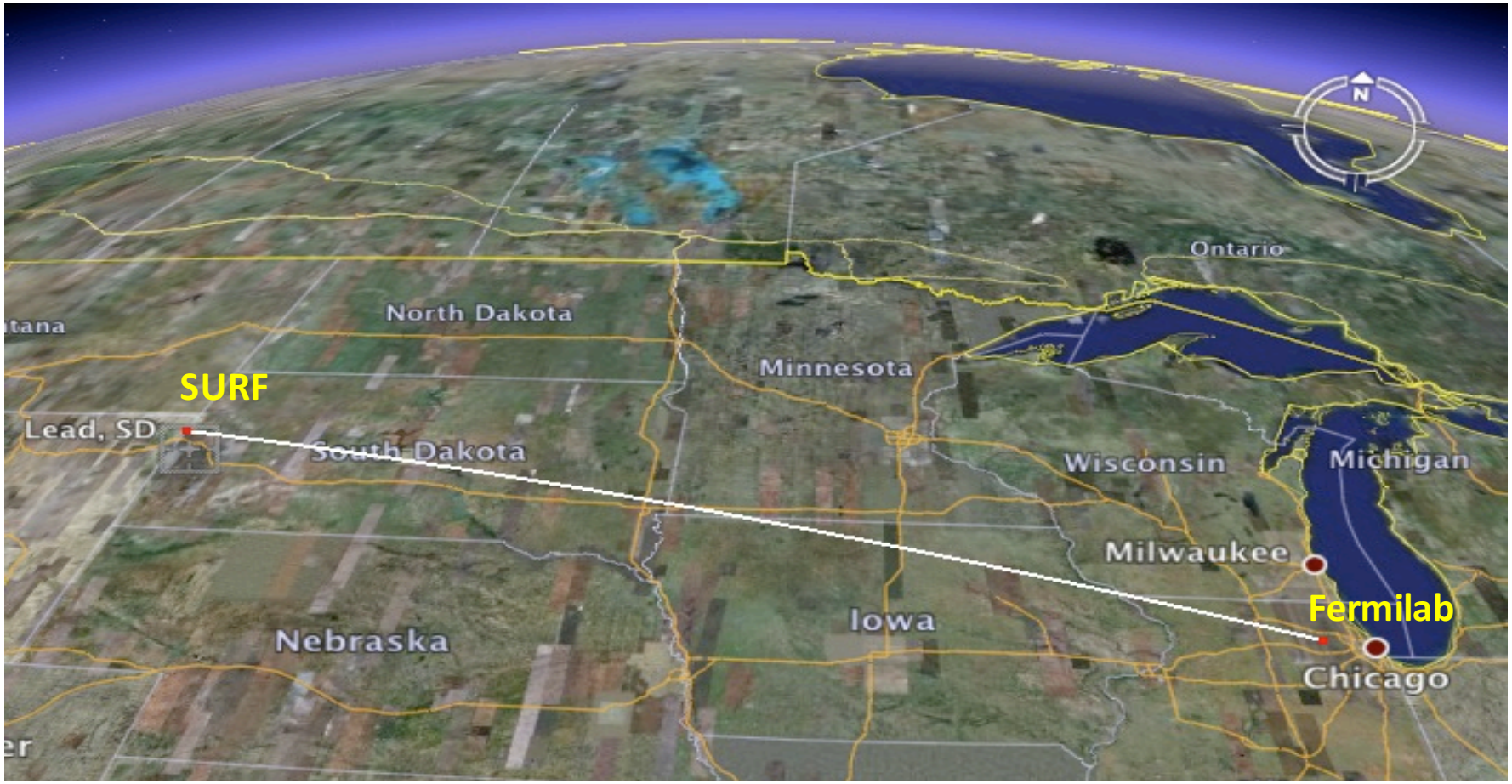
LBNF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Ontario
North Dakota
Minnesota
SURF
Lead, SD
South Dakota
Wisconsin
Michigan
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Fermilab
Iowa
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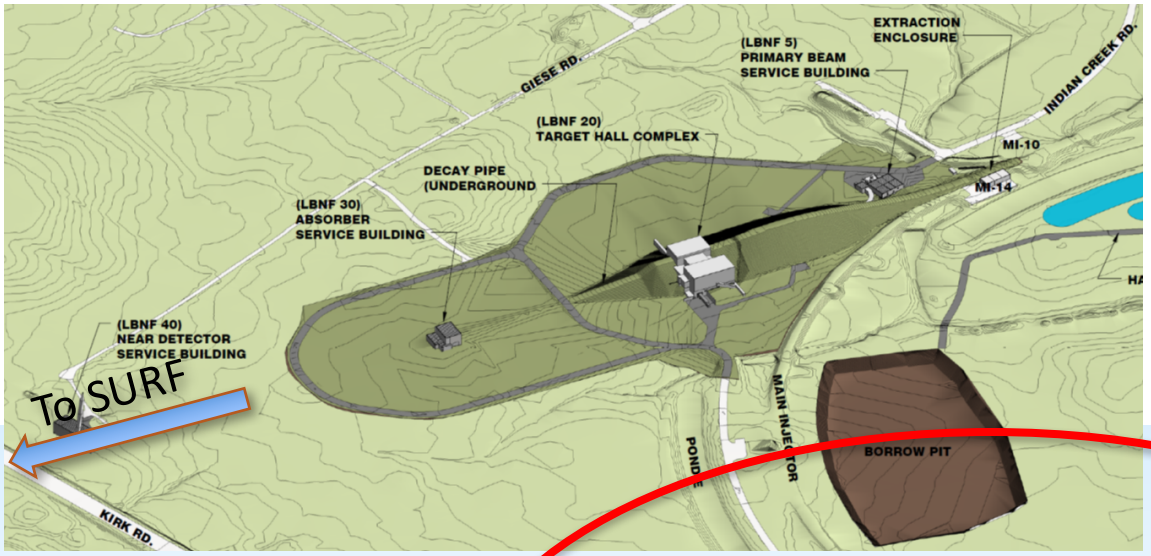
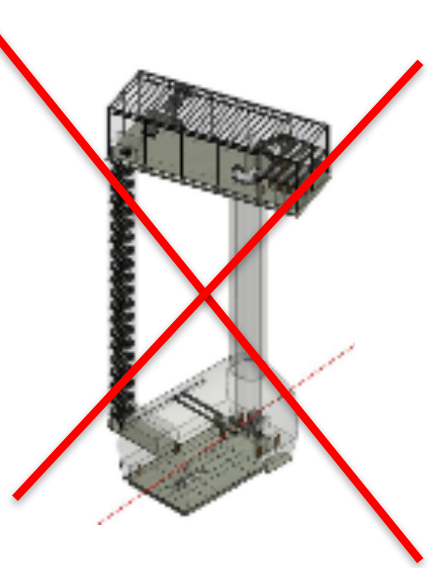
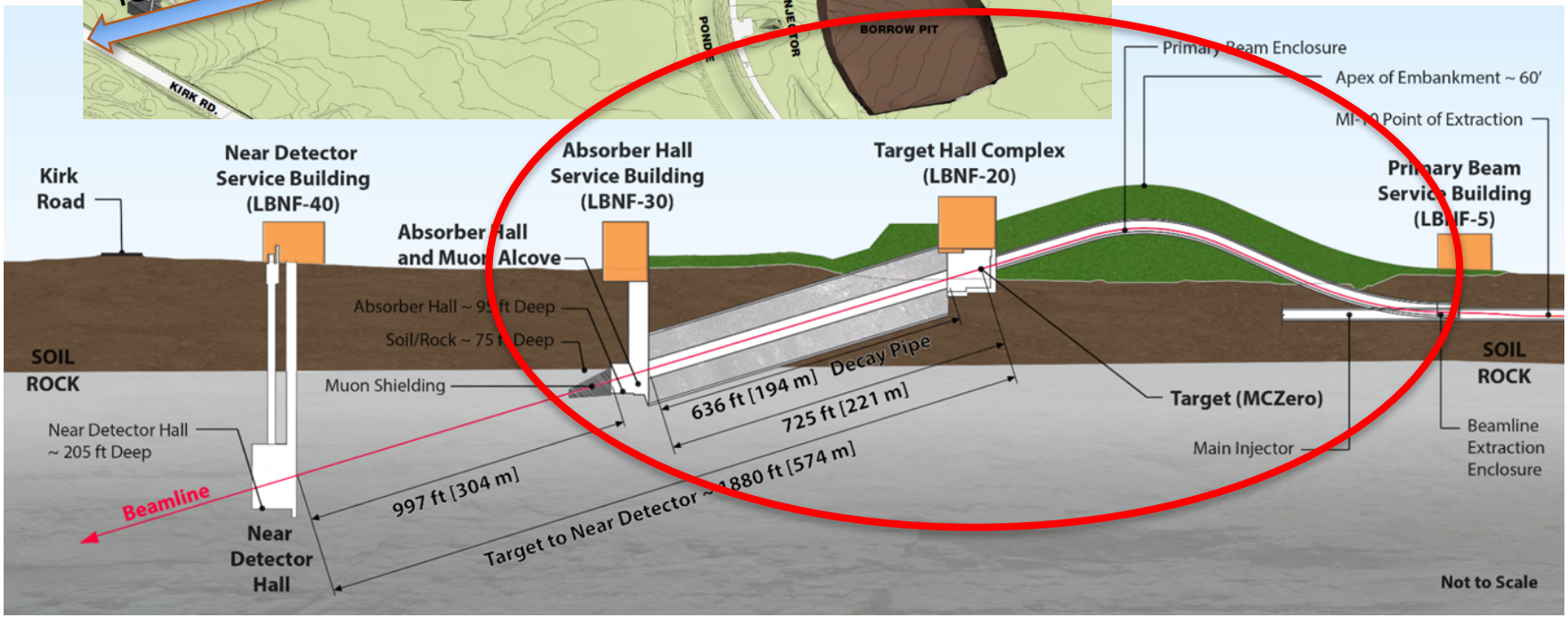
Chicago

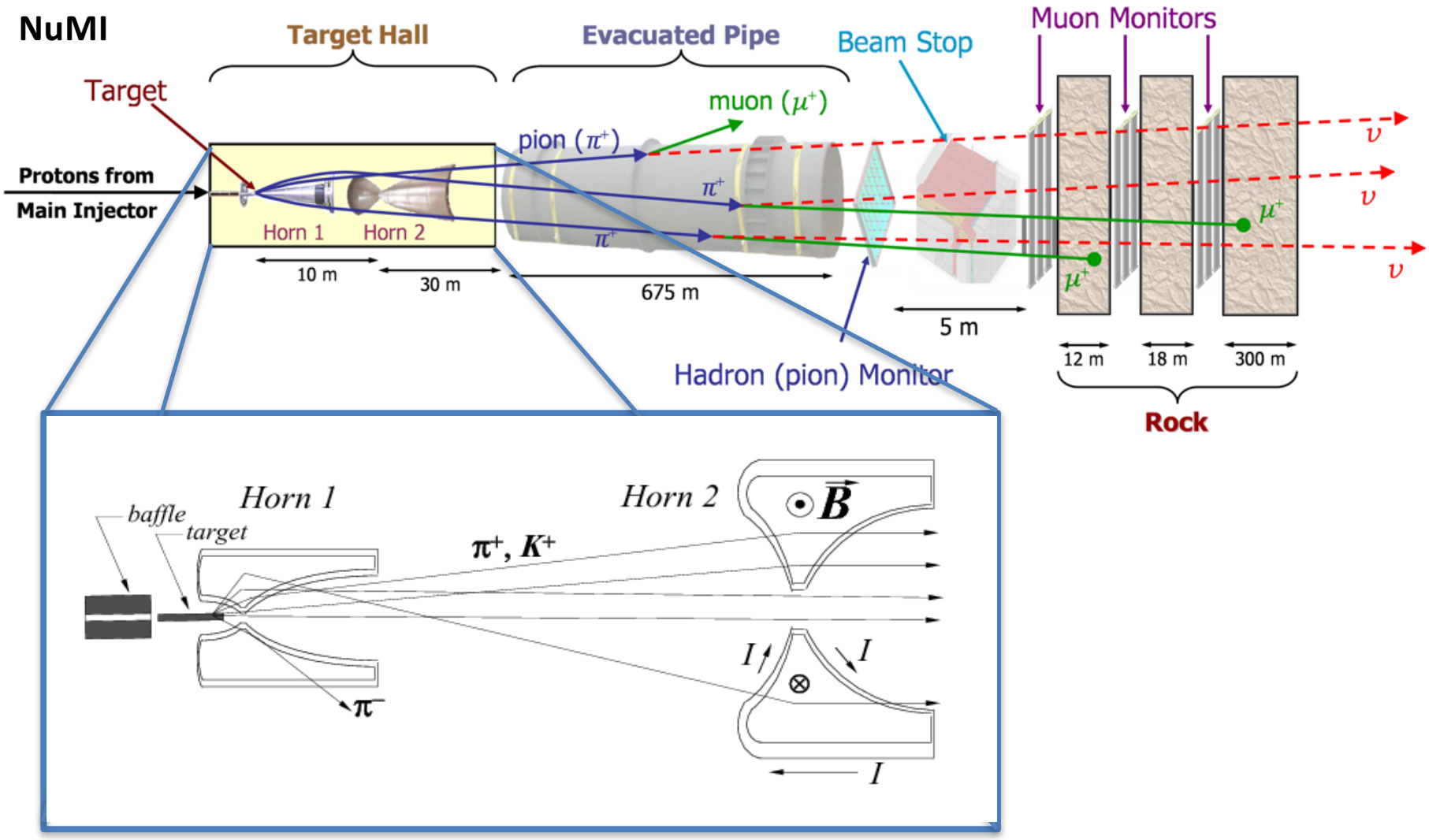
The Near Facilities





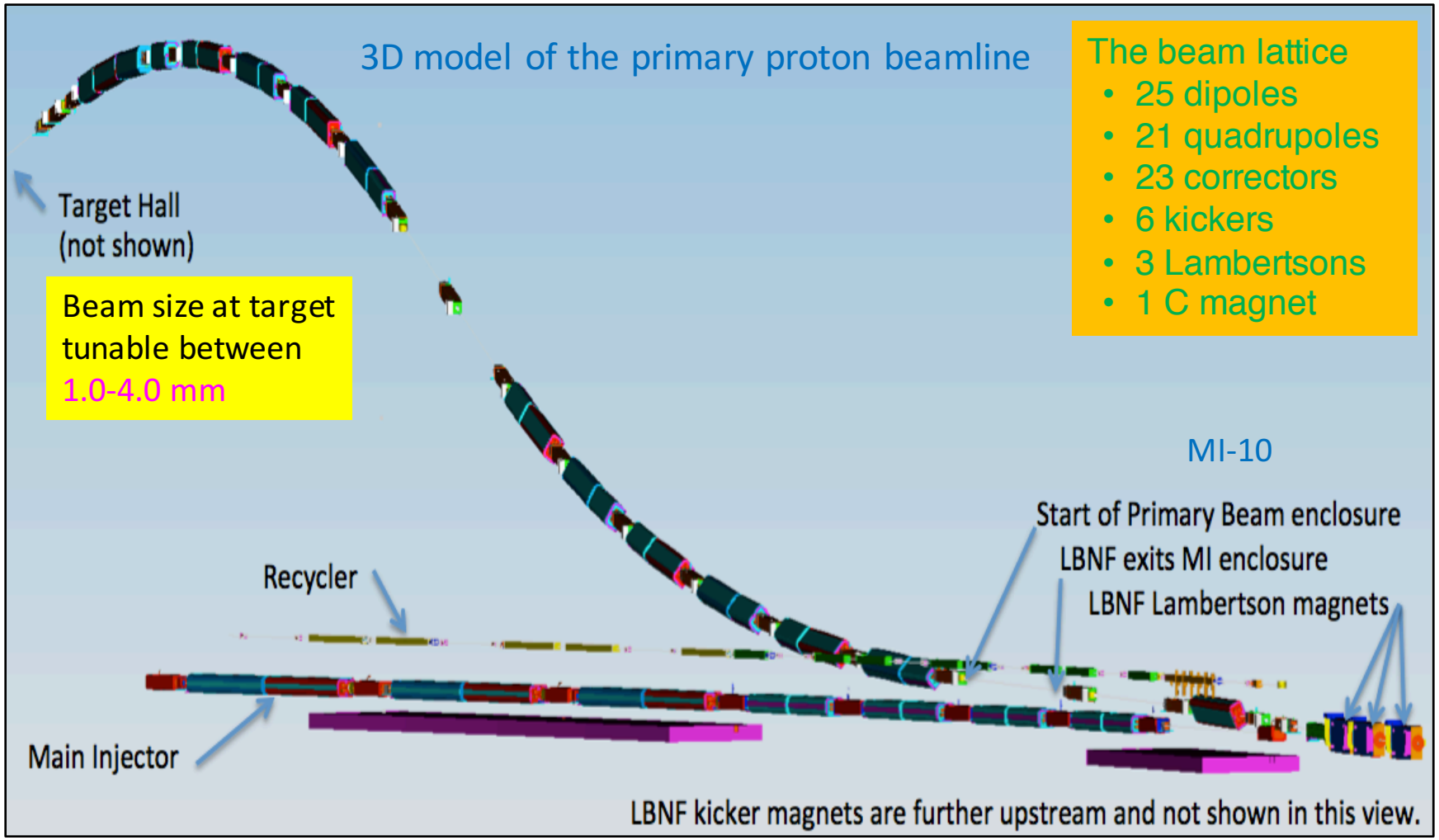


How to make a neutrino beam



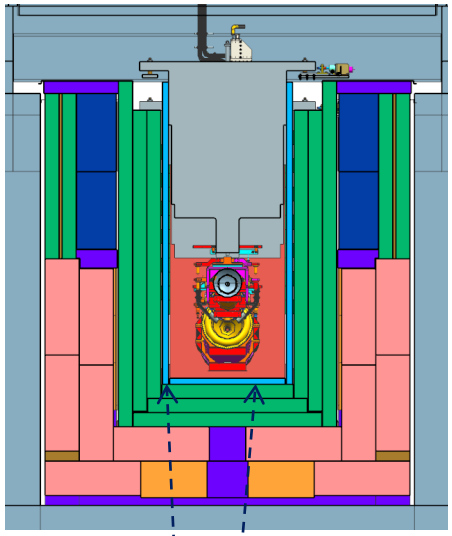
Primary Beam Line

Protons/cycle @60-120 GeV
1.2 MW era: 7.5×10^{13}
2.4 MW era: $(1.5\text{-}2.0) \times 10^{14}$
0.7 – 1.2 sec rep. rate

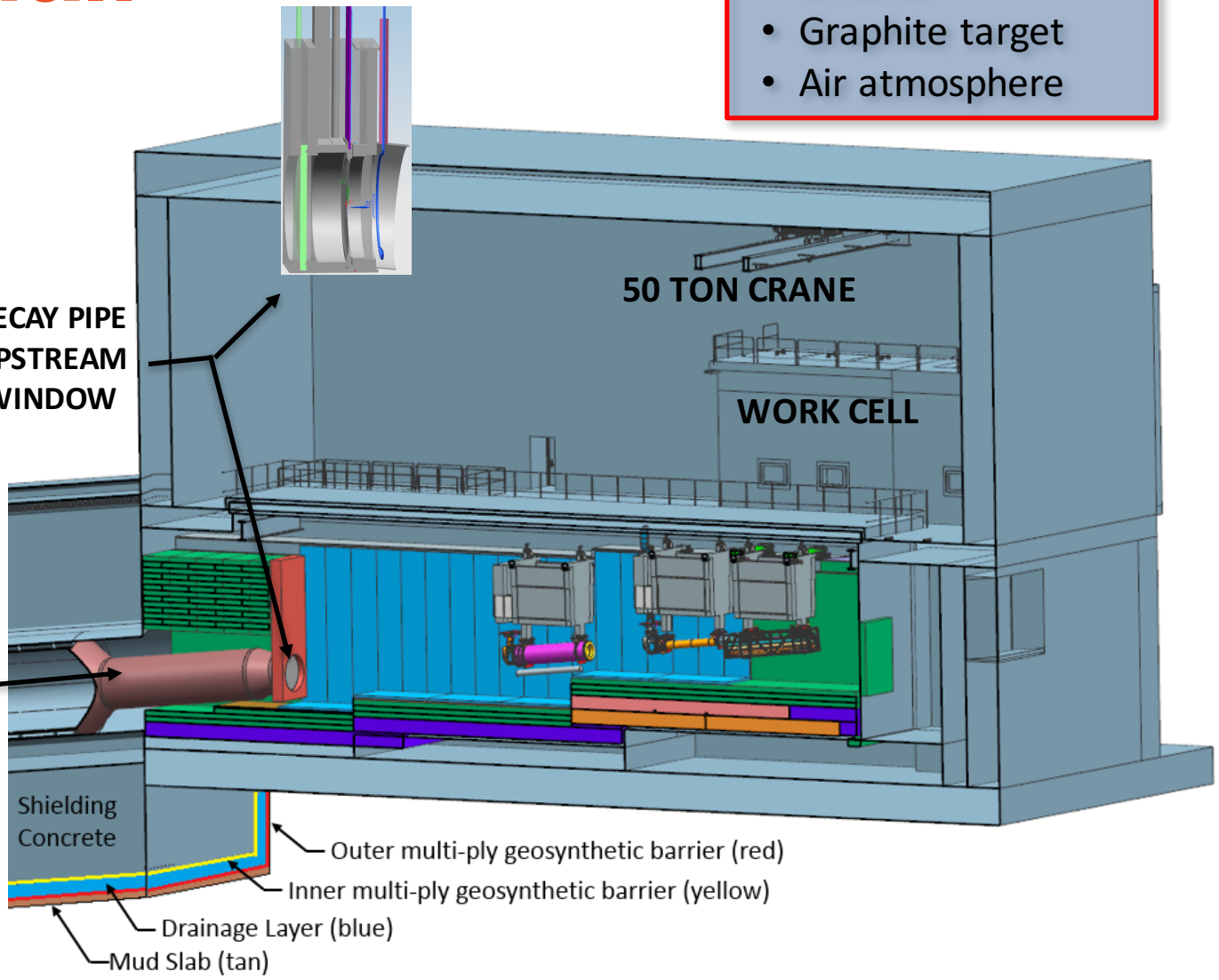


Target Hall

Here
- 2 horns
- Graphite target
- Air atmosphere



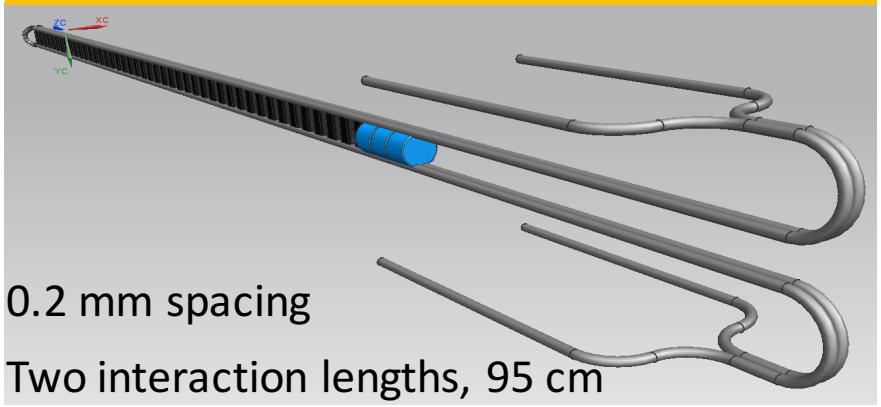
Cooling panels



Design principle
- flexibility
- 2.4 MW (when needed)

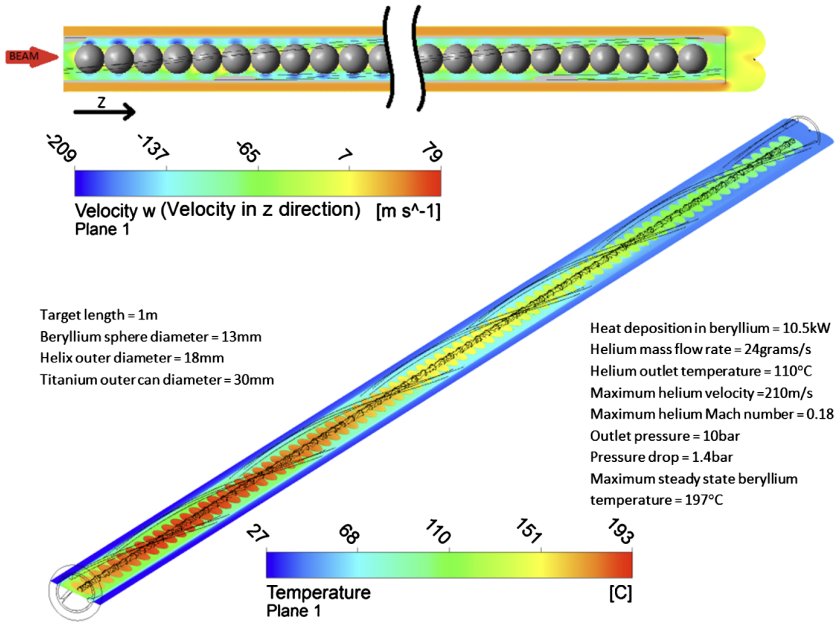
Target and Horns

47 graphite segments, each 2 cm long



0.2 mm spacing

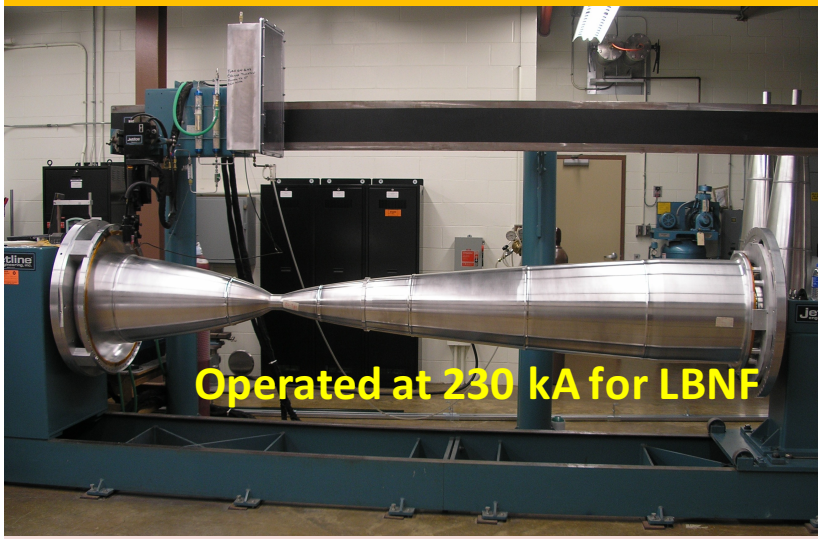
Two interaction lengths, 95 cm



NuMI-like (low energy) target and horns with modest modifications

Strong R&D program in place

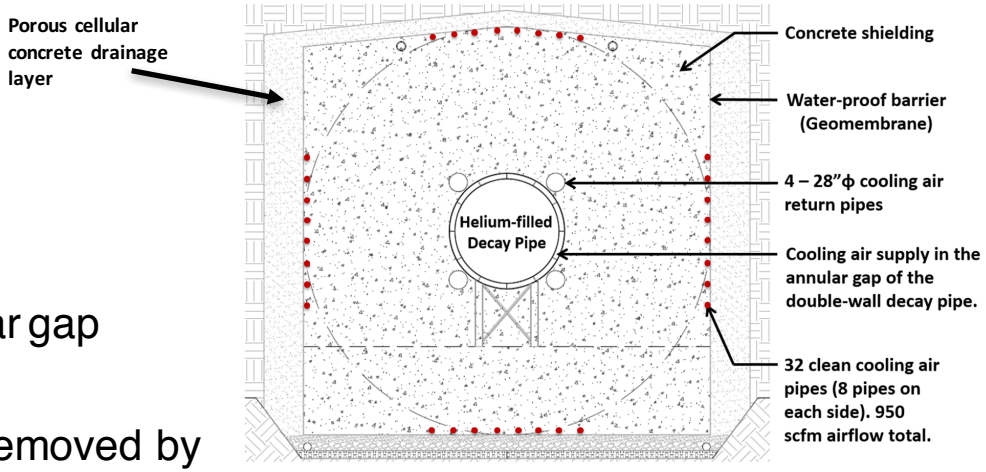
Inner Conductor of NuMI Horn

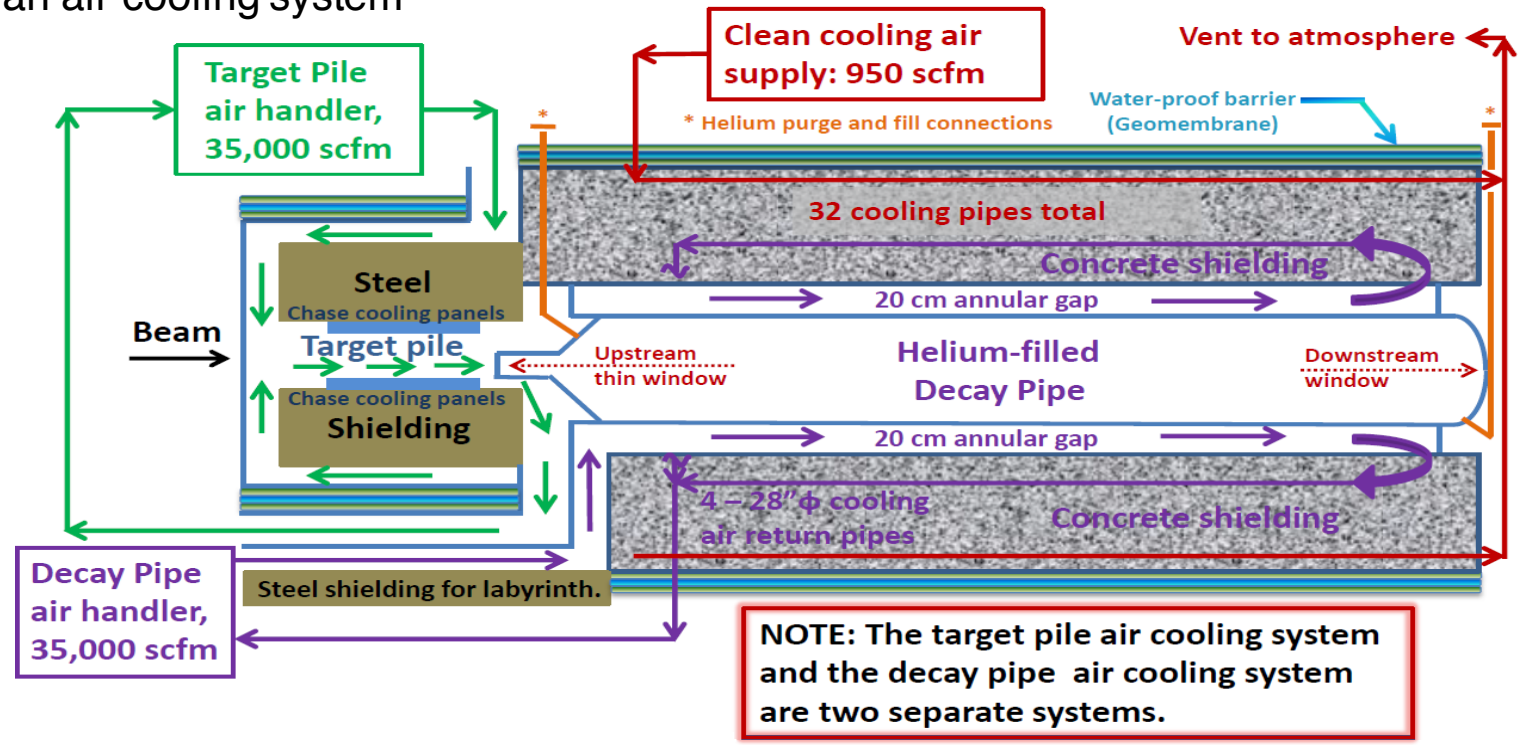


New Horn power supply needed to reduce the pulse width to 0.8 ms.

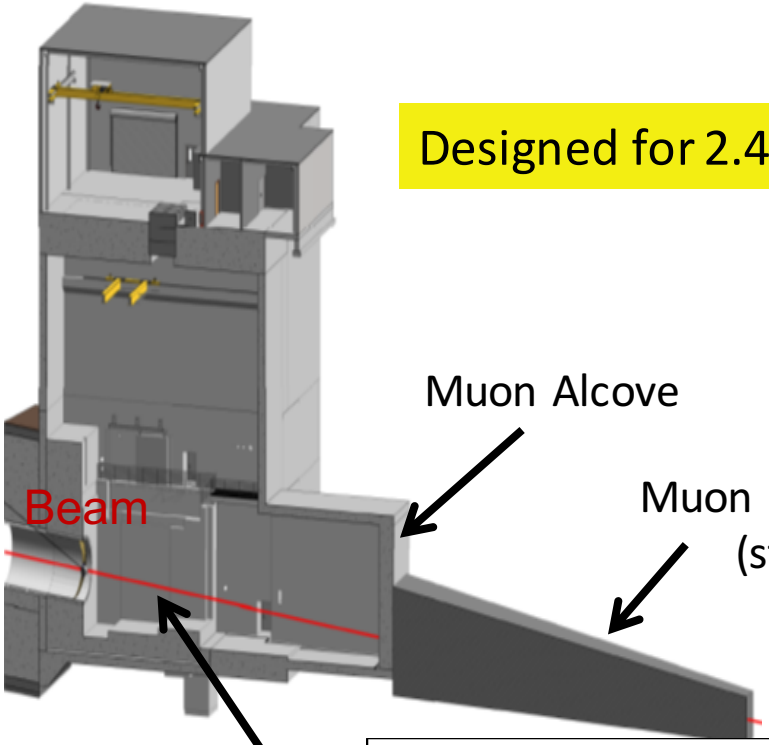
Decay Pipe

- 194 m long, 4 m inside diameter
- Helium filled
- double-wall decay pipe, 20 cm annular gap
- 5.6 m thick concrete shielding
- It collects ~30% of the beam power, removed by an air cooling system





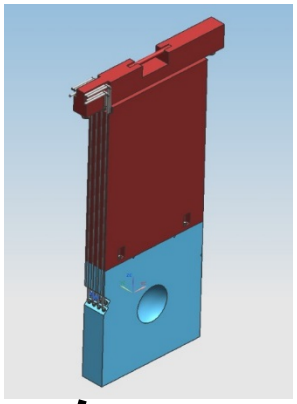
Hadron Absorber Hall



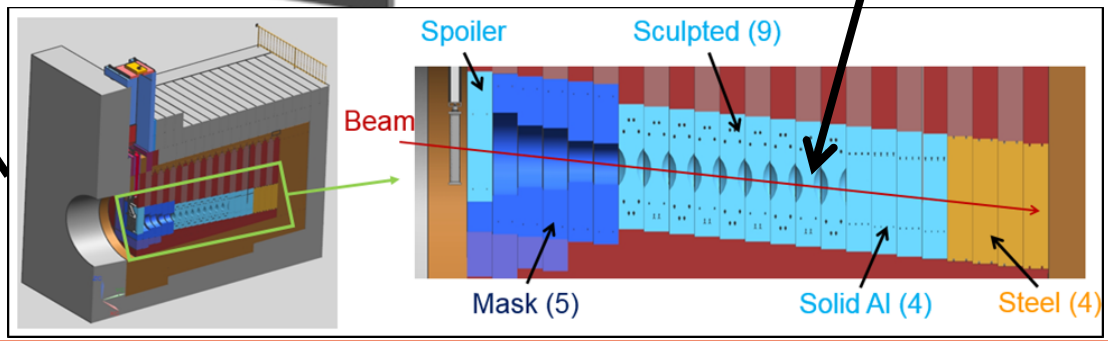
Designed for 2.4 MW

Cooling
- Core: water
- Shielding: forced air

Modular design



Core blocks replaceable
(each 1 ft thick)

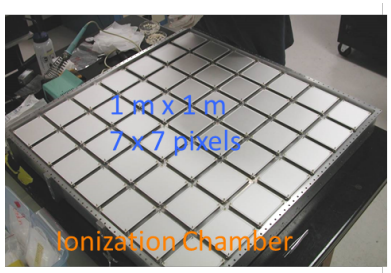


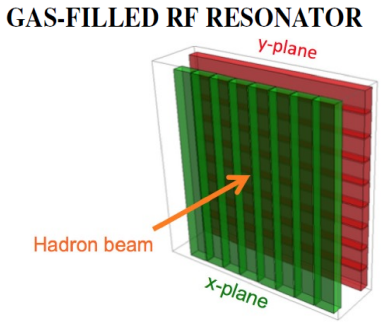
Instrumentation

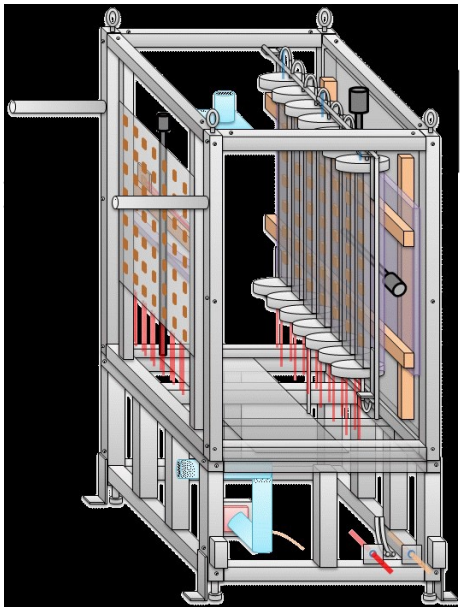
- Beam instrumentation is essential safety and physics

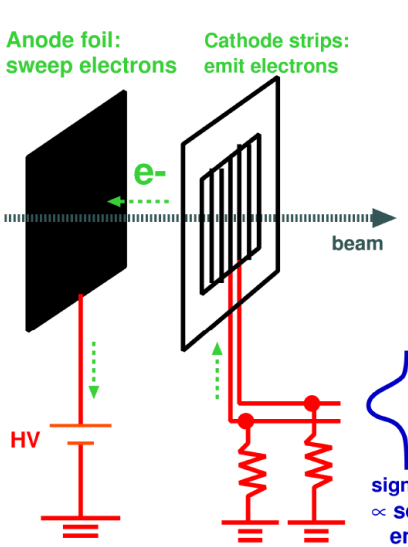
- Target/Absorber
  - Hadron/muon Monitor
  - Info 2nd beam alignment ➔horns & target

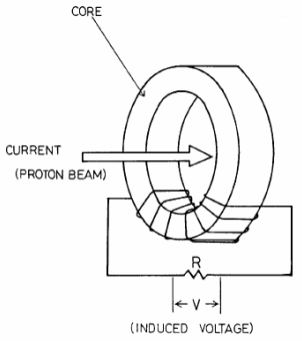
- Primary Beamline
  - Beam Position/Profile Monitor
  - Current Monitor

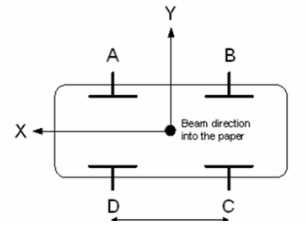










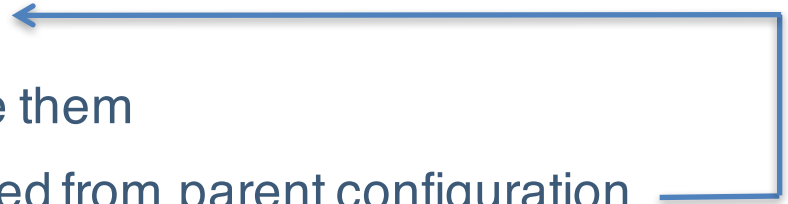


Neutrino Production System

- Original (CDR, CD1R)
  - 2 horns (NuMI-like)
  - 1 m target
    - Graphite fins
  - Target chase atmosphere
    - Air as default
  - Hadron Absorber
    - Sculptured core blocks
- Optimised (under study for CD2)
  - 3 horns (new design)
  - ~2 m target
    - Graphite fins or rod
    - Beryllium spheres
  - Target chase atmosphere
    - N_2 or He or air
  - Hadron Absorber
    - simplified

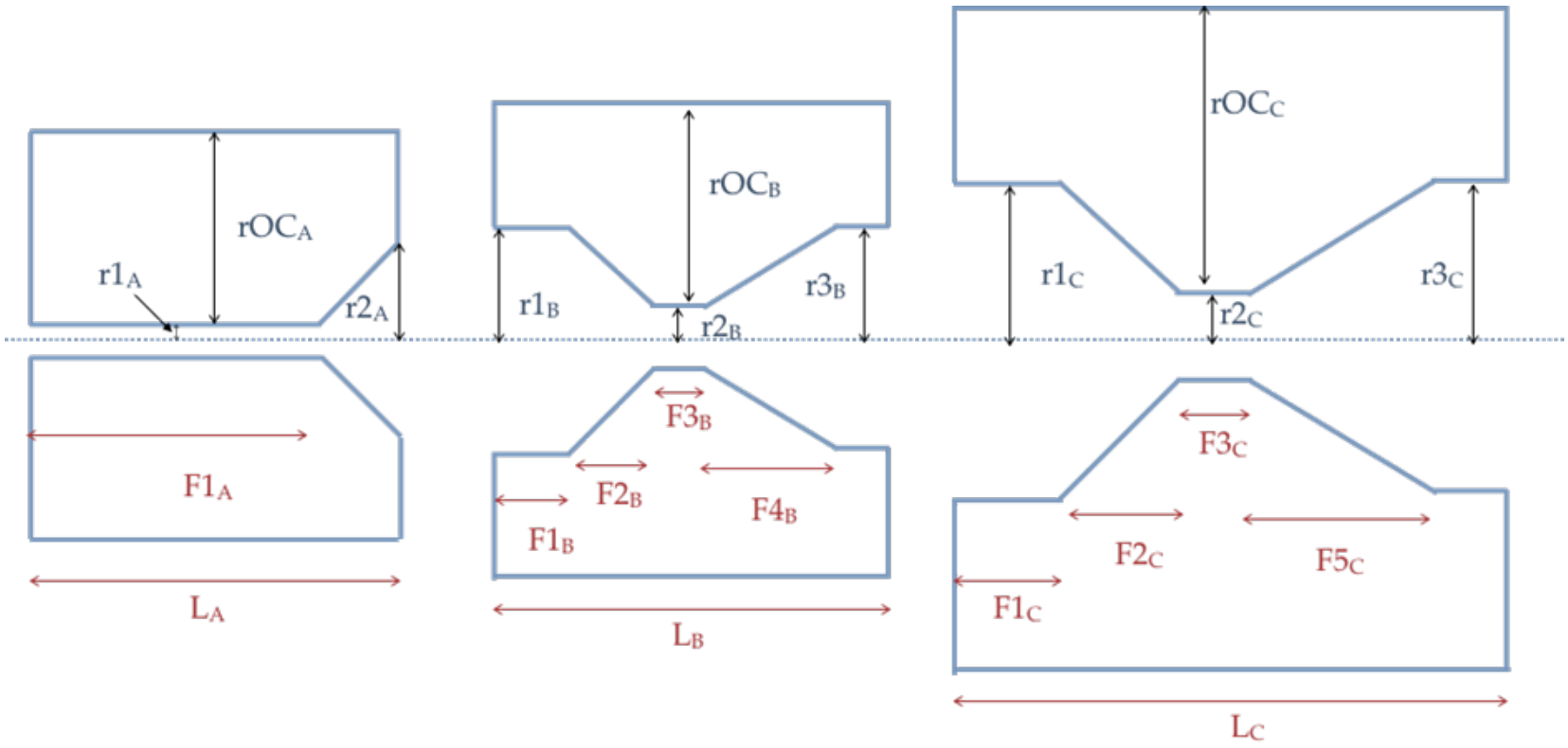
Beam Optimisation

- Neutrino flux and spectrum and detector define physics reach
  - Optimize neutrino flux for the physics
- Handles
  - Proton beam power and energy
  - Target material and shape
  - Focussing elements (horns)
  - ~~Decay volume~~
- Use genetic algorithm to optimize CP-sensitivity
  - Choose parameters at random
  - Evaluate fitness (CP-sensitivity)
  - Pick best configurations and mate them
  - Generate new configuration derived from parent configuration

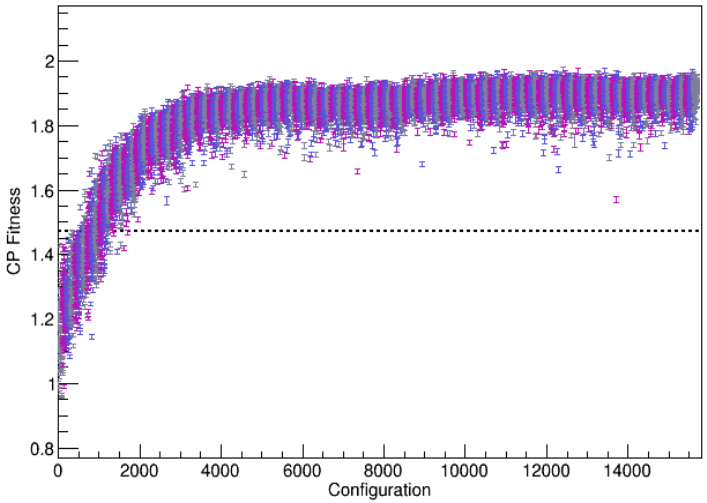


Horn Parameters

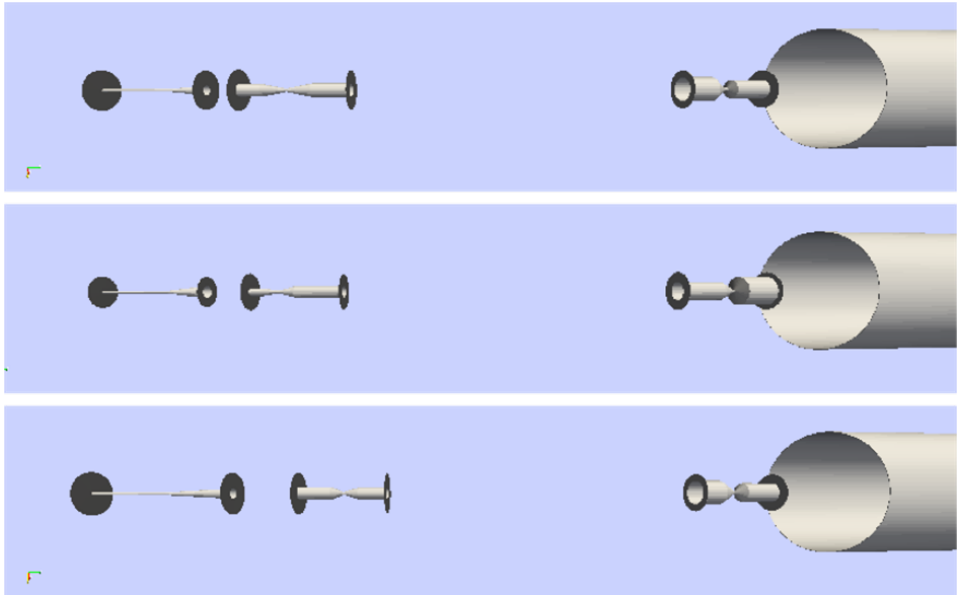
Optimisation with 3 horn system



Beam Optimization (preliminary)



Best fitness: 1.97
Compared to 1.47 reference

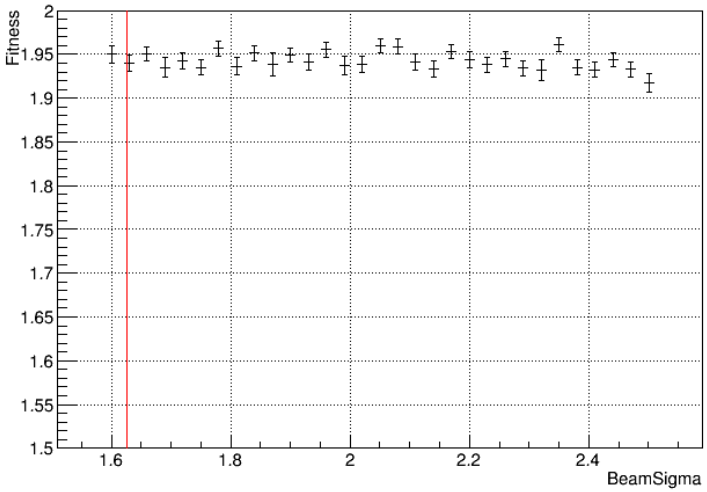


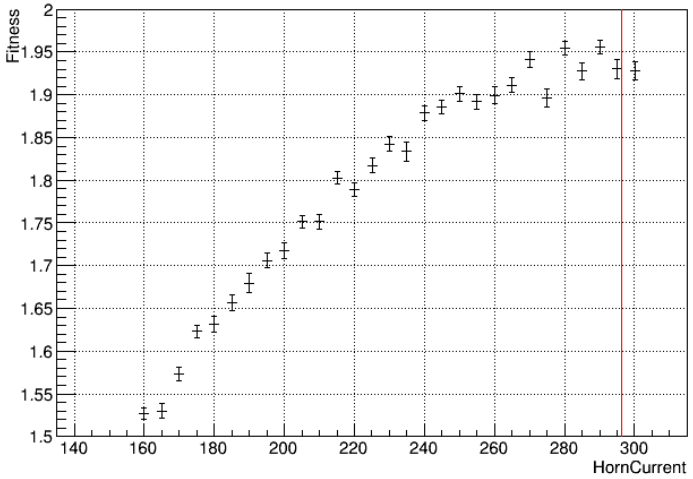
- CP Fitness: fraction of 3σ CP coverage
- Significant number of iterations
  - Each with O(100k) events

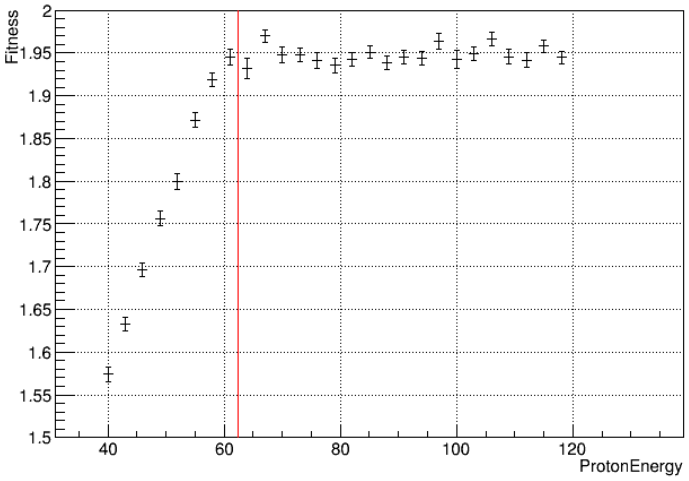
Optimization Result

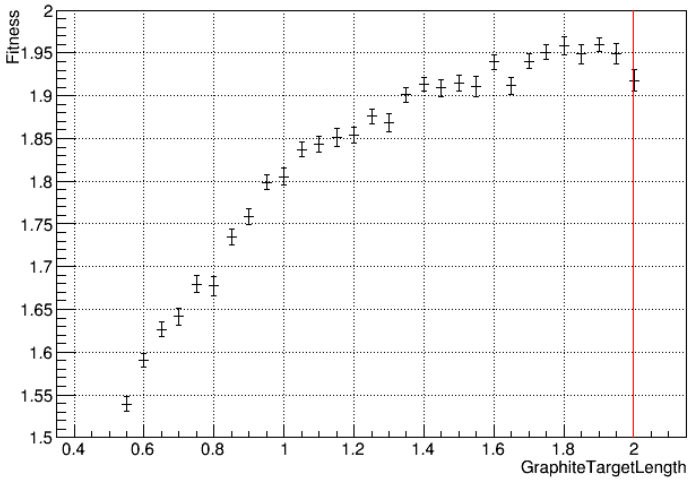
Parameter	Lower Lim	Upper Lim	Unit	Early Optimum	Final Optimum
Horn A: L_A	1000	4500	mm	2612	2815
Horn A: $F1_A$	1	99	%	81	65
Horn A: $r1_A$	20	50	mm	38	34
Horn A: $r2_A$	20	200	mm	109	145
Horn A rOC_A	200	650	mm	563	630
Horn B: L_B	2000	4500	mm	2361	3229
Horn B: $F1_B$	0	100	%	29	20
Horn B: $F2_B$	0	100	%	18	21
Horn B: $F3_B$	0	100	%	1	1
Horn B: $F4_B$	0	100	%	20	22
Horn B: $R1_B$	50	200	mm	163	191
Horn B: $R2_B$	20	50	mm	48	47
Horn B: $R3_B$	50	200	mm	189	204
Horn B: ROC_B	200	650	mm	628	630
HornB: Z position	2000	17000	mm	4269	3637
Horn C: L_C	2000	4500	mm	2723	2816
Horn C: $F1_C$	0	100	%	45	36
Horn C: $F2_C$	0	100	%	13	16
Horn C: $F3_C$	0	100	%	1	3
Horn C: $F4_C$	0	100	%	16	5
Horn C: $R1_C$	50	550	mm	365	398
Horn C: $R2_C$	20	50	mm	49	45
Horn C: $R3_C$	50	550	mm	277	310
Horn C: ROC_C	550	650	mm	637	643
Horn C: Z Position	4000	19000	mm	17440	17478
Target Length	0.5	2.0	m	2.0	2.00
Beam spot size	1.6	2.5	mm	1.68	1.62
Target Fin Width	9	15	mm	12.6	13.4
Proton Energy	60	120	GeV	64	62
Horn Current	150	300	kA	298	296

Parameter Scan



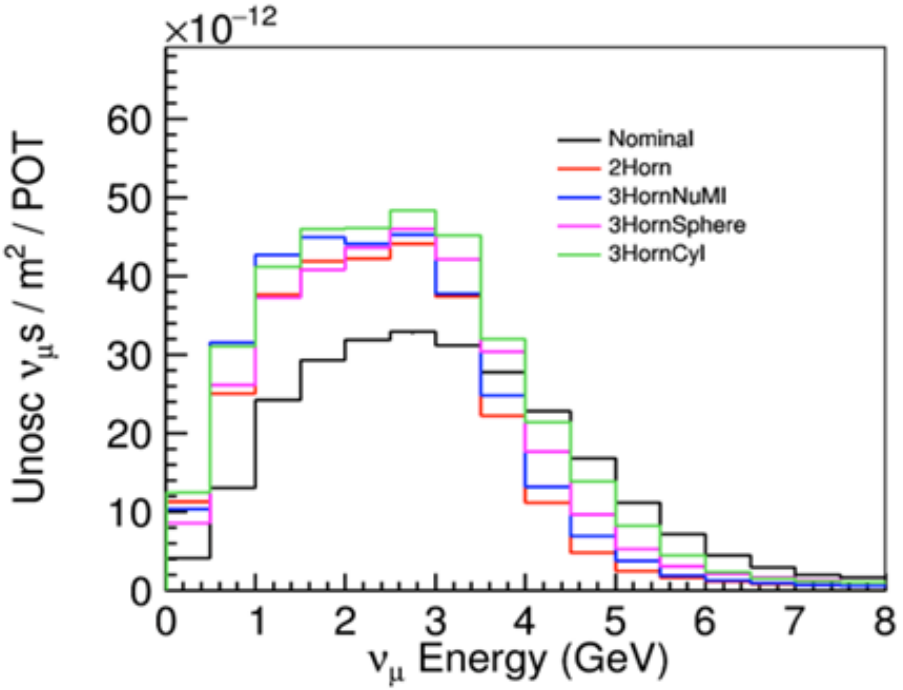


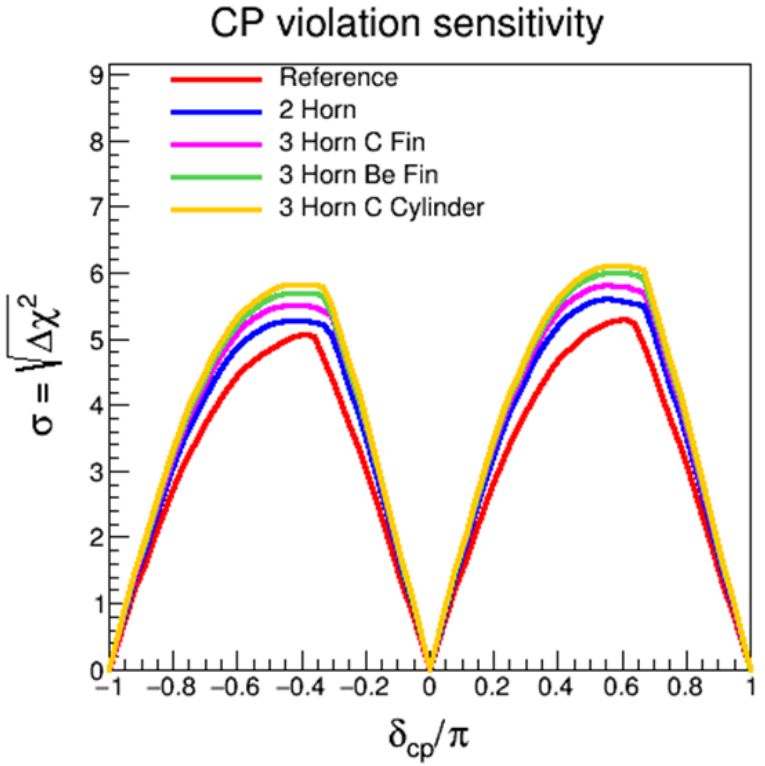




Conclusion

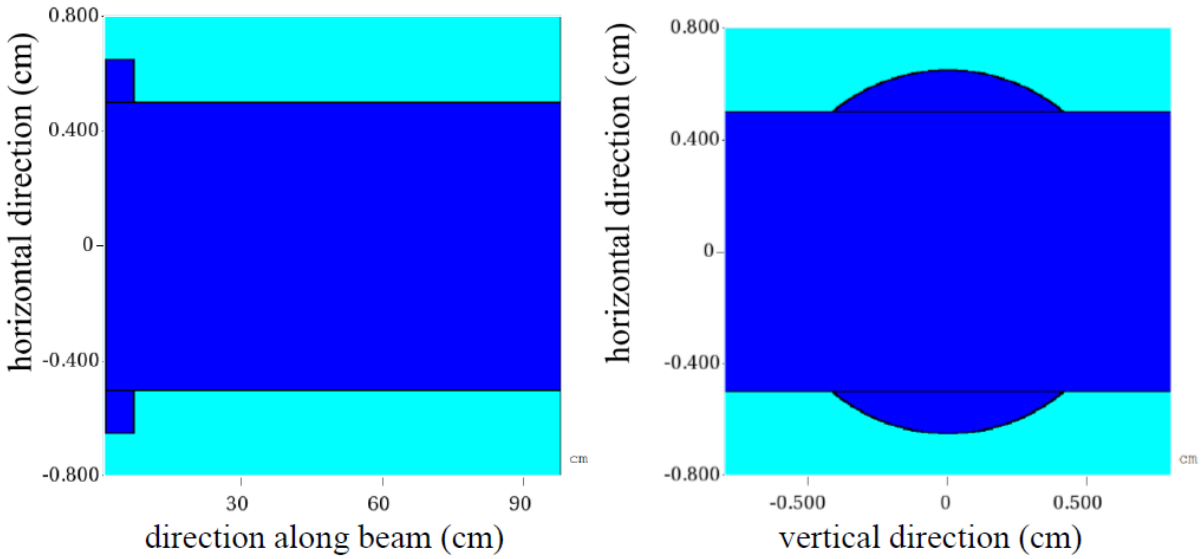
- Flux can be substantially improved
- 3 horns, long target
- Largely independent of target details



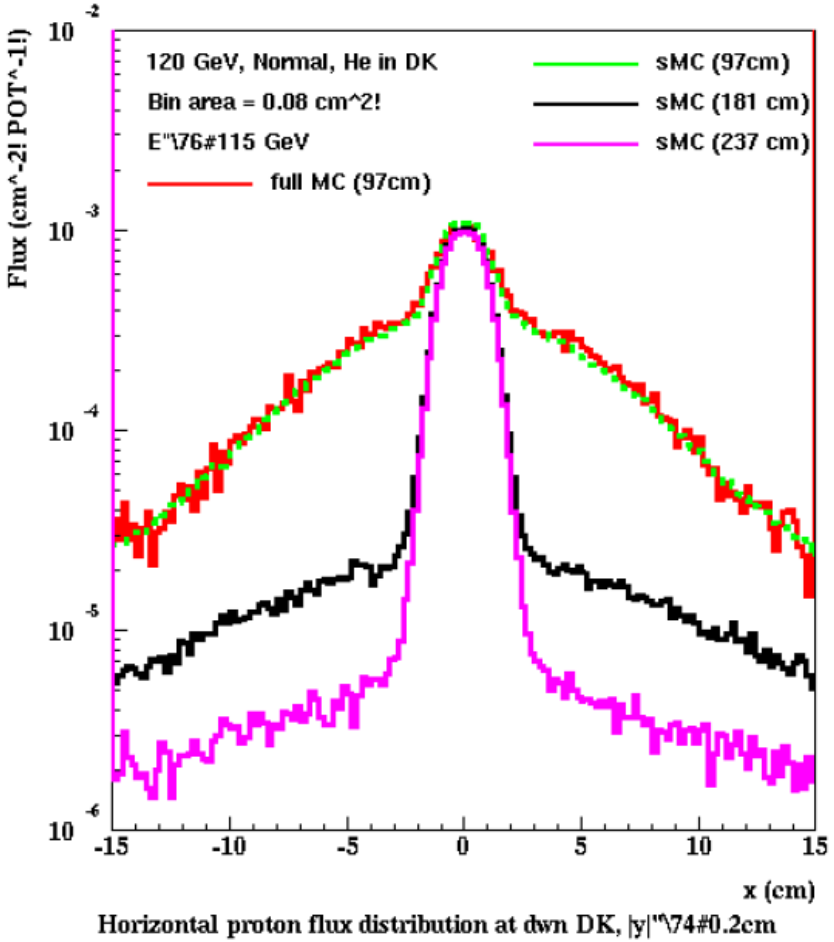


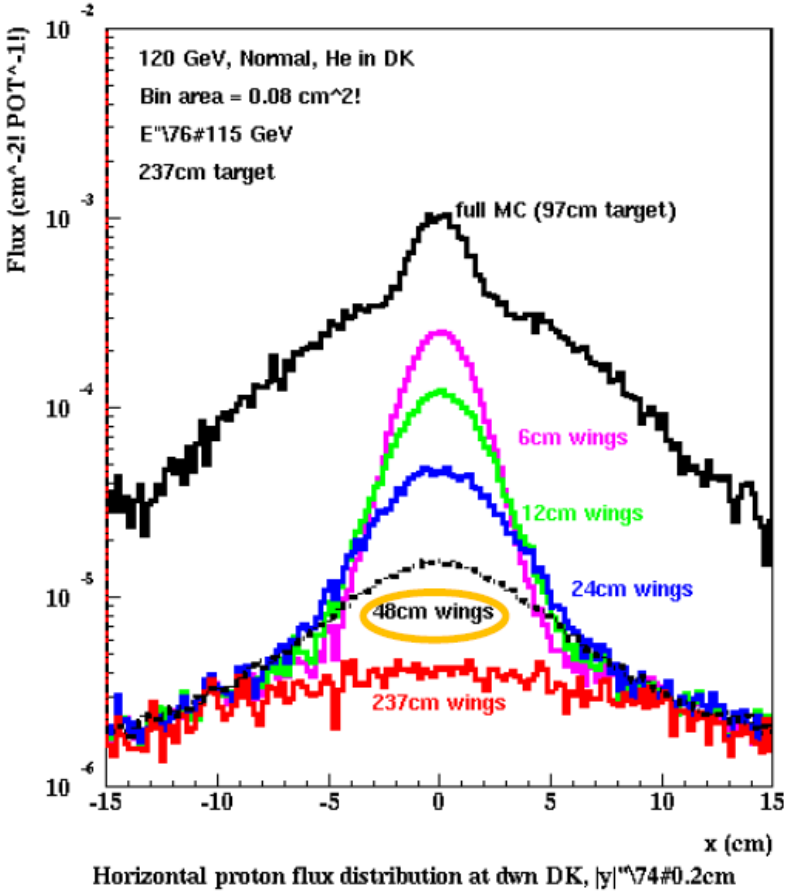
Target & Hadron Absorber

- Hadron Absorber and Target design are closely coupled
  - Larger target length
    - More protons interact ➔ lower peripheral energy deposition
  - Larger target radius
    - More beam “halo” protons interact ➔ lower central energy deposition



Particle Flux at Absorber

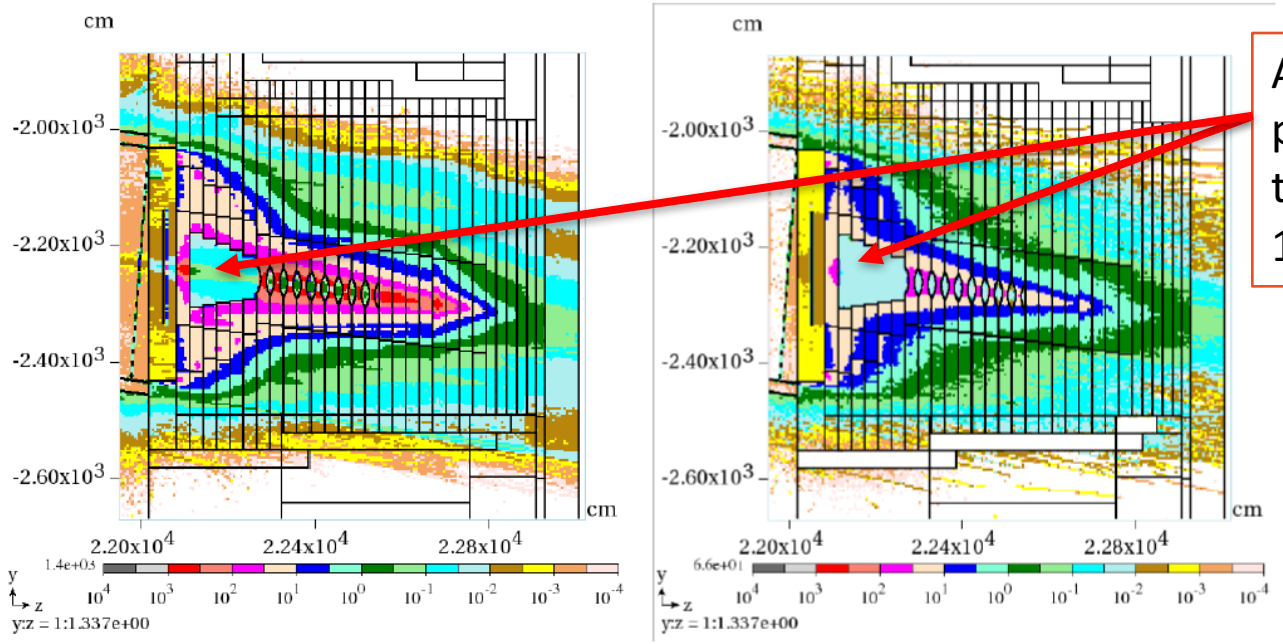




Hadron Absorber Energy Dep.

2 horns, short target

3 horns, long target, wings



Additional neutrino production target/decay volume 1% ND neutrinos

- Peak energy deposition reduced by factor 10-20
- Simplified absorber design
- Also reduced muon flux after absorber
  - Reduced radiological impact

Simulations

- Simulation are an important tool to design the LBNF facility
- Beam optimisation
  - Define the optimal placement, shape and form of components
  - GEANT4 based toolset available
  - FLUKA under development
- Energy depositions
  - Need to understand cooling requirements
  - Based around MARS (could be GEANT or FLUKA)
- Radiological impacts
  - High radiation environment, need to understand where radiation is produced and how to deal with activation

Opportunities for Collaboration

- non-DOE contribution essential
- Ample opportunities depending on interest and capabilities
  - Design, R&D, eventual construction
- Examples
  - Primary beam
    - Dipole and corrector magnets, PS, beam monitors, …
  - Neutrino beam
    - Target, instrumentation, hadron/muon monitor, shielding, cooling, horns, horn PS, remote handling, support modules, beam windows, absorber, …
  - Infrastructure
    - hot cell, cooling, atmosphere, …
  - Simulations
    - Energy depositions, radiological implications, beam optimisation

Summary

- LBNF beamline
  - Highest power (neutrino) beam world wide
- Variety of important tasks
  - Simulation, engineering, production
  - Scope from k$ to several M$
  - Something for everybody
  - You have an idea how to contribute or take a lead?
    - Almost anything can be accommodated
- Critical to success of LBNF/DUNE
  - Physics ~ flux * detector

The End

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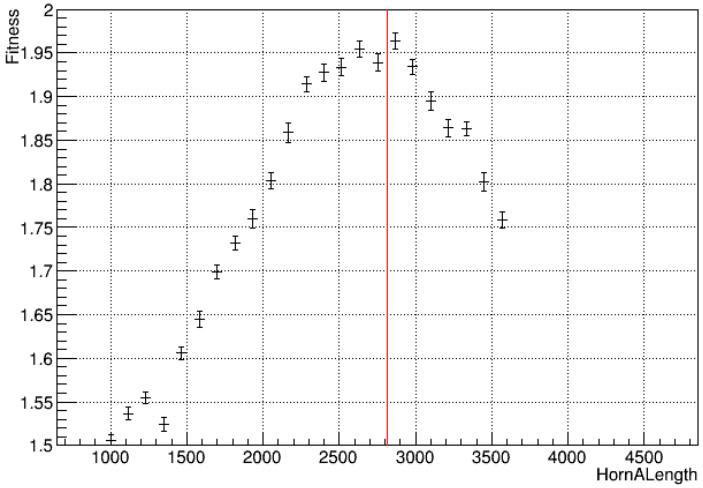
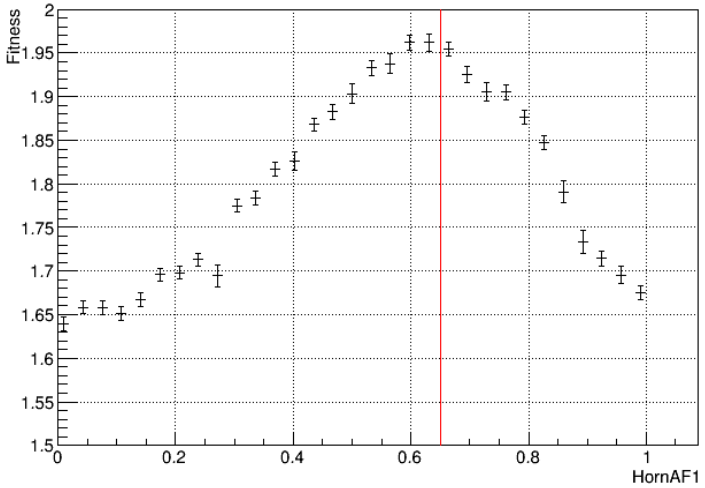
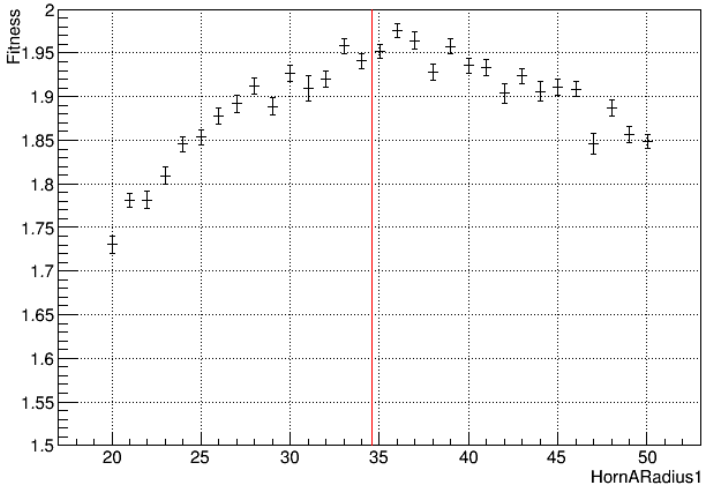
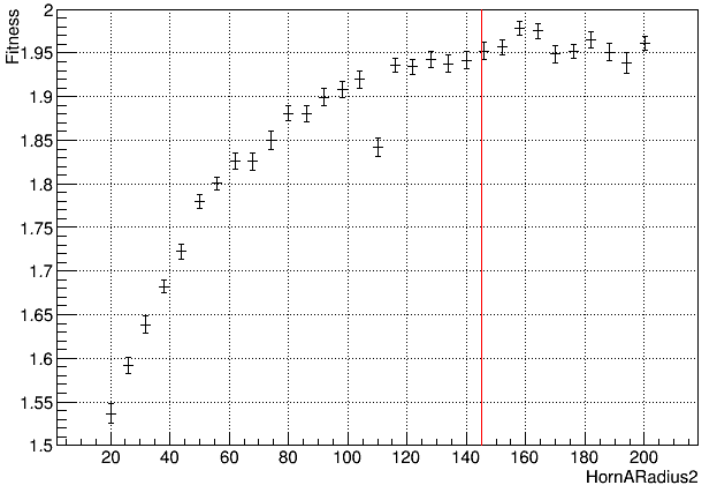
NuMI-style Parameter Scan

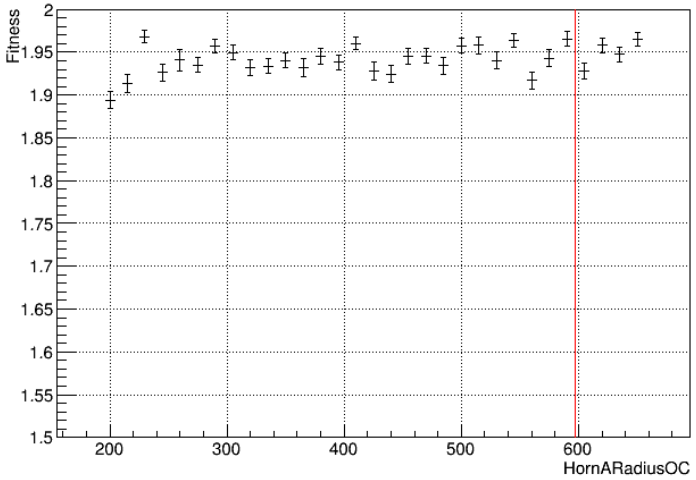


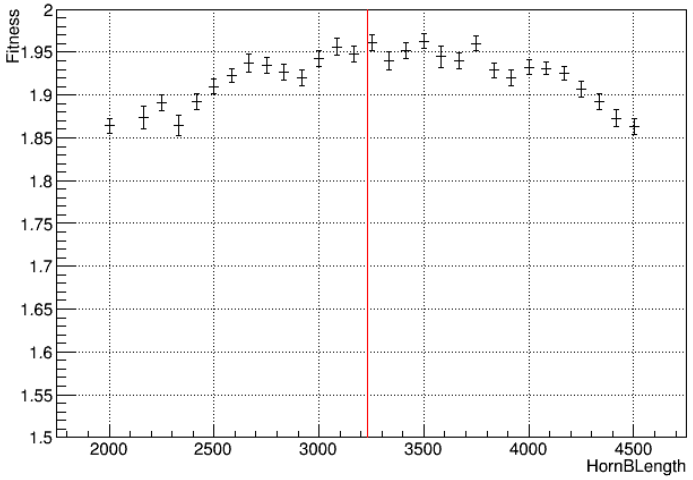


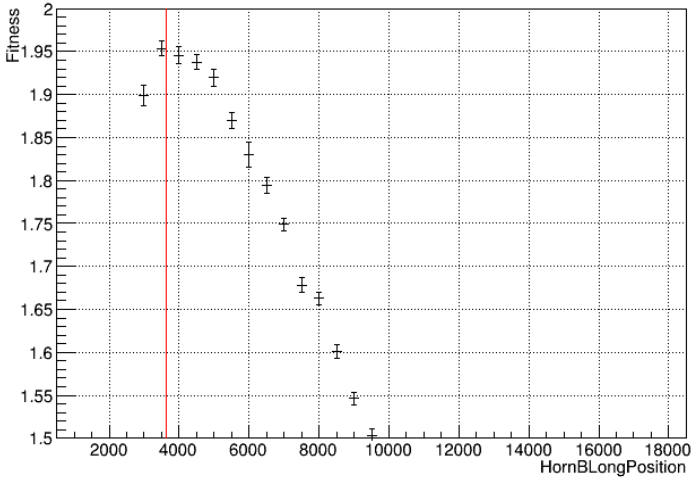


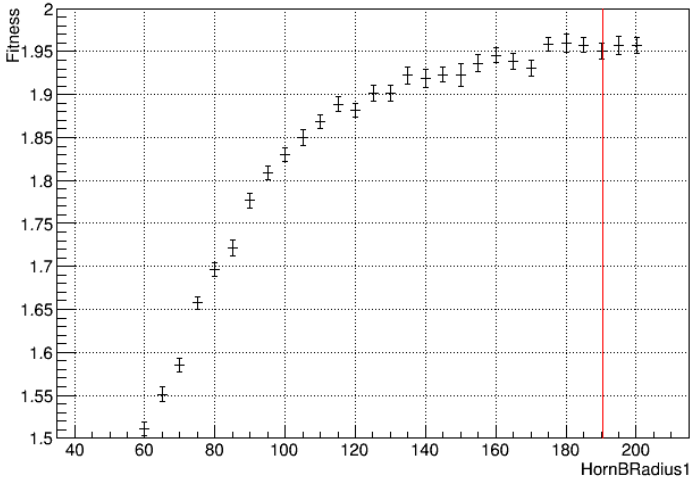


NuMI-style Parameter Scan









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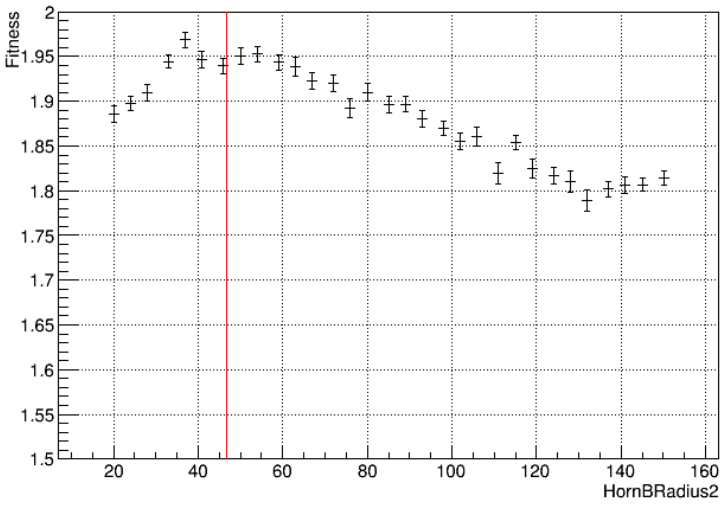
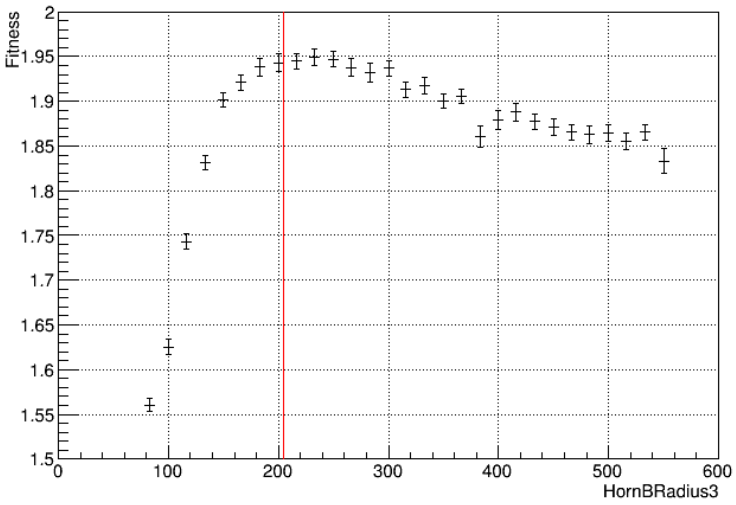
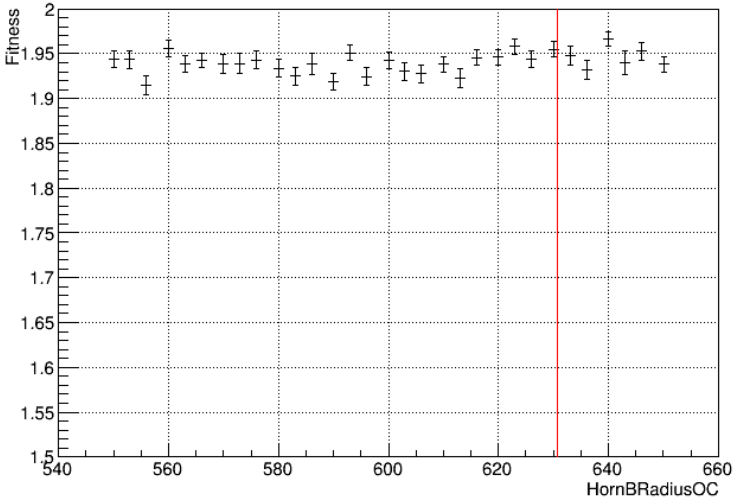
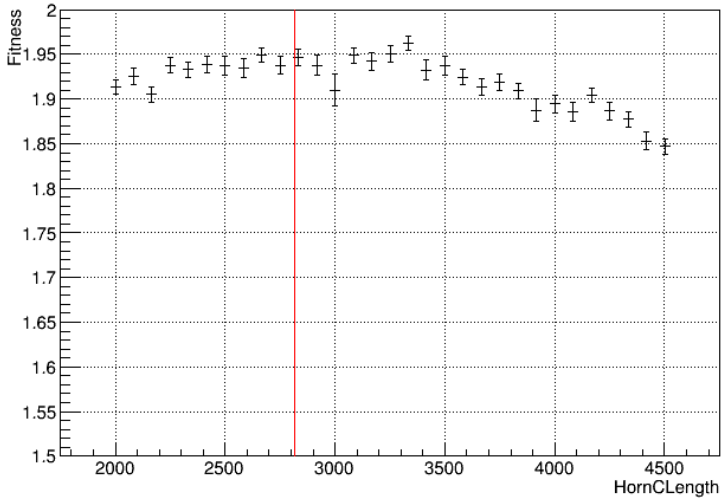
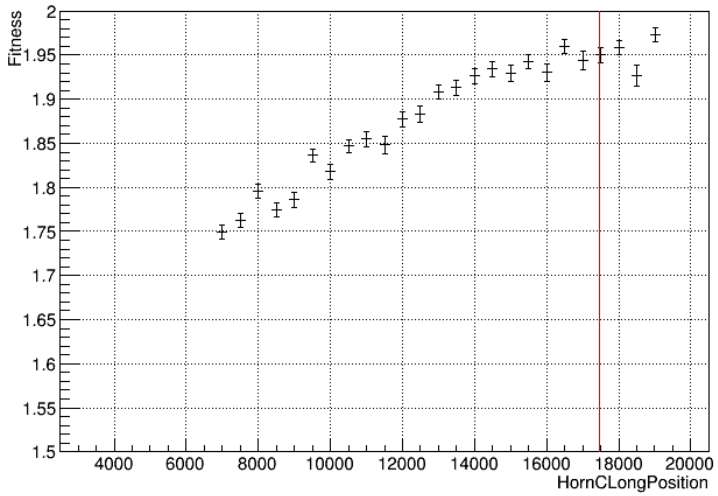


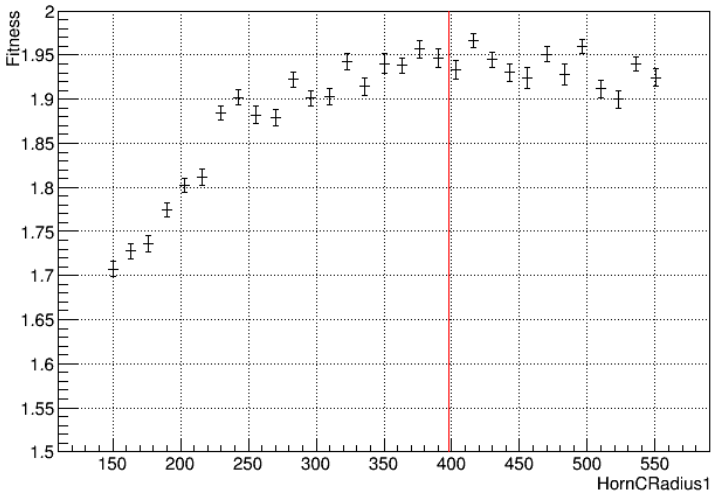


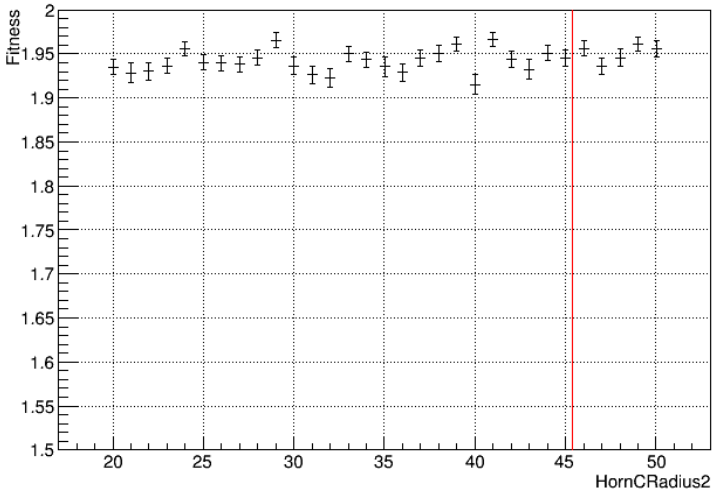


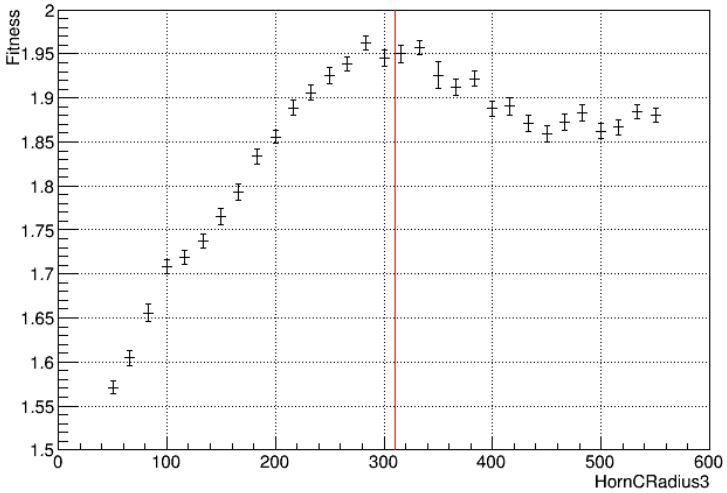


NuMI-style Parameter Scan









NuMI-style Parameter Scan