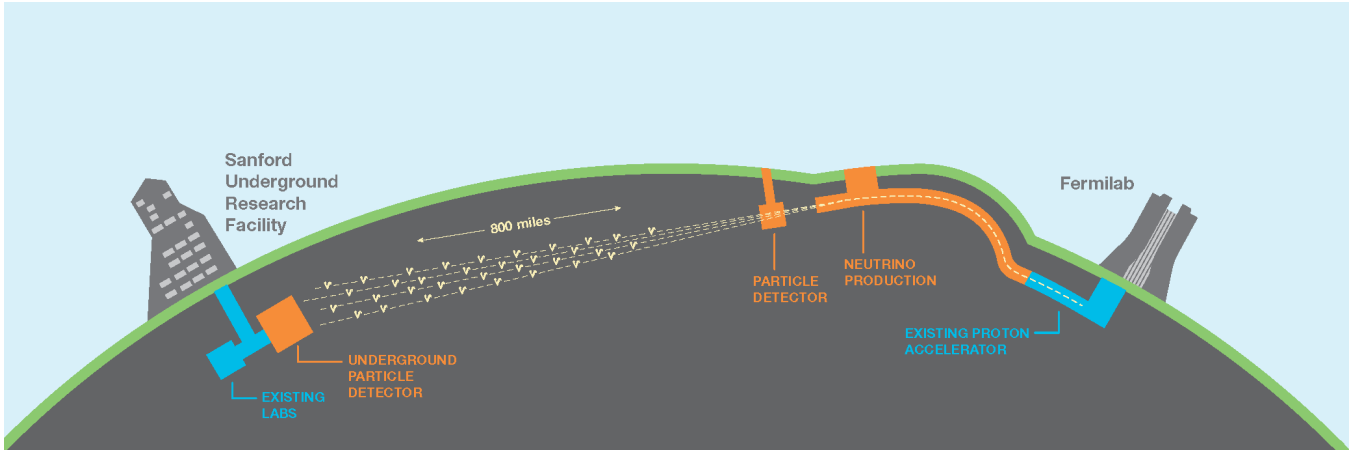


Beam Optimization TF Update

Laura Fields and Alfons Weber

Fermilab

Science & Technology Facilities Council
Rutherford Appleton Laboratory

UNIVERSITY OF OXFORD

DUNE

Outline

- Milestones
- Reminder of Status as of Oct 2016
- Recent Progress
  - New Mechanical Model
  - Comparison to CDR Optimized Beam
  - Comparison to Reference Beam
  - High-z Target Study
- Response to LBNC recommendations
- Conclusion

Major Milestones

Task	Task (Description)	Priority	Start Date	Duration (Months)	FTE %	Type Sci or Eng	
1	Identify engineering constraints on Optimization	H	Q4 2015	1	0.30	S/E	✓
2	Modify simulation to accommodate engineering constraints	H	Q4 2015	1	0.50	S	✓
3	Run Optimization	H	Q4 2015	9	1.00	S	✓
4	Implement parameterized parabolic horn option	M	Q4 2015	1	0.50	S	✓
5	Study alternate physics metrics in optimized designs	M	Q2 2016	3	0.25	S	✓
6	Study impact of high-z downstream target	M	Q1 2016	3	0.25	S	✓
7	Cost-benefit analysis of He vs H_20 cooling	M	Q1 2016	3	0.25	S/E	✓
8	Estimate basic cost implications of optimized designs	H	Q1 2016	6	0.20	S/E	✓
9	Develop realistic design from idealized optimized designs	H	Q4 2015	9	0.20	S/E	✓
10	Simulate realistic optimized design	H	Q1 2016	9	0.50	S	✓
11	Detailed sensitivity studies of optimized design	H	Q1 2016	9	0.20	S	✓
12	Estimate systematic uncertainties of optimized designs	M	Q2 2016	6	1.00	S	✓
13	conceptial design of He/N_2 filled facility	M	Q1 2016	6	0.50	E	✓
14	Cost-benefit analysis of He vs N_2 vs air	M	Q3 2016	3	0.50	E	✓
15	write draft report	H	Q4 2016	3	0.50	P	✓

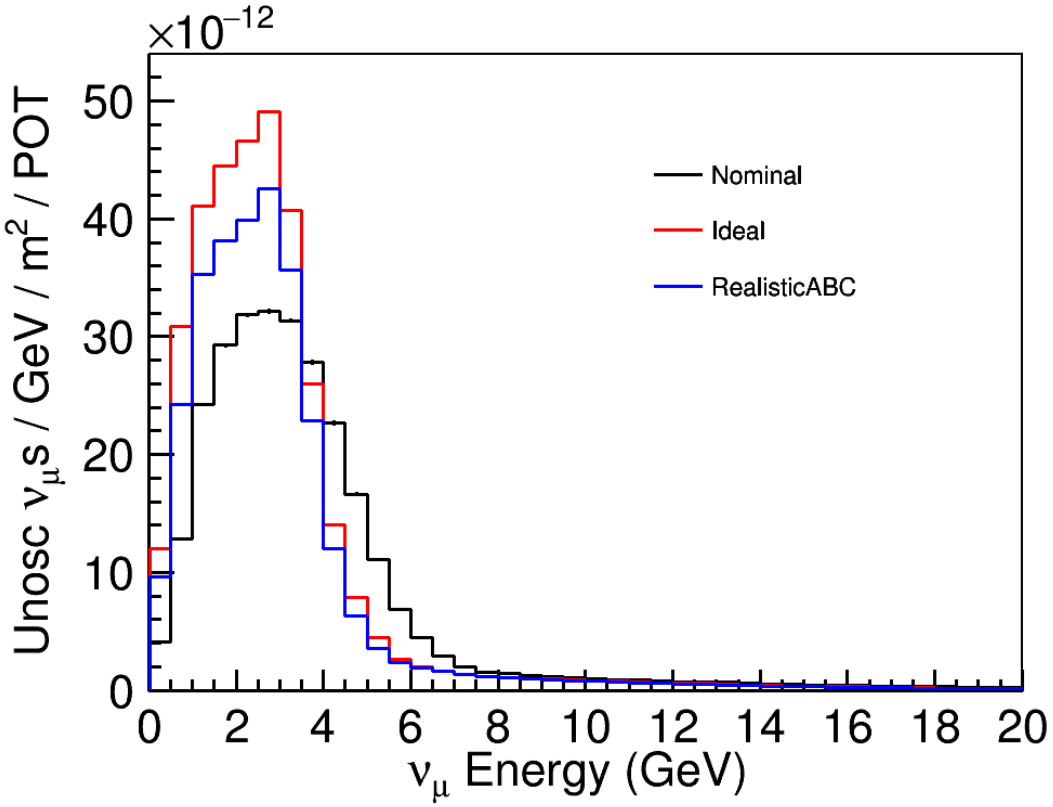
✓ Complete

✓ Moved to LBNF

Review of Status as of October

We simulated the mechanical model of beam design recommended in BOTF interim report:

- Flux loss from engineering changes was greater than expected

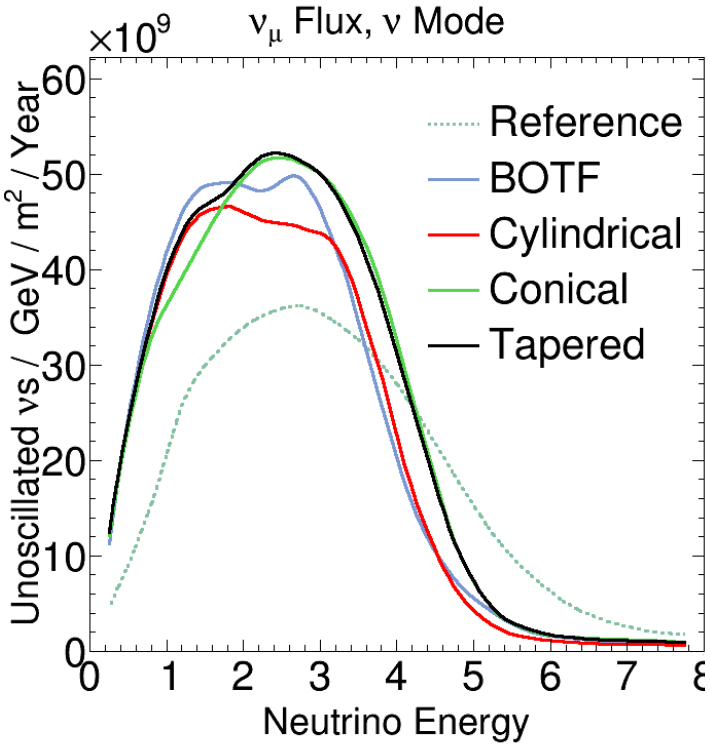


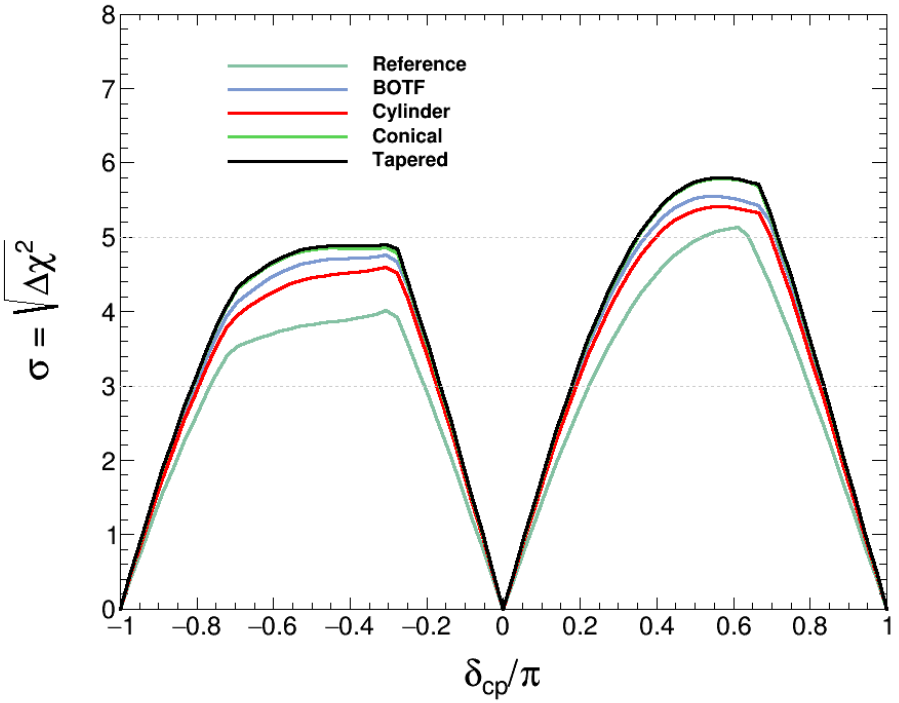
	0-2 GeV	2-5 GeV
Flux Loss	16.3%	13.6%

Review of Status as of October

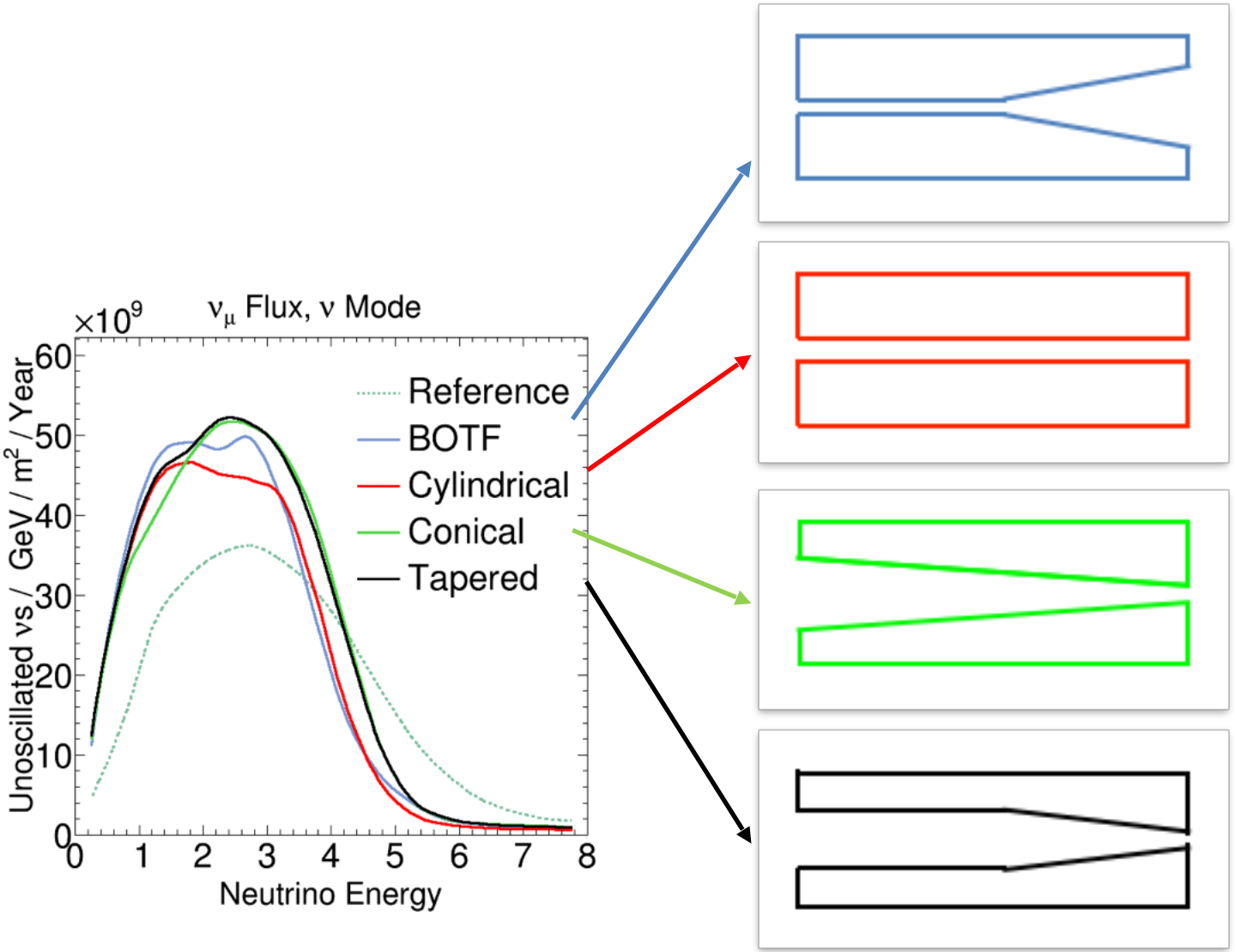
We also reported the results of the final round of multidimensional optimization

- This round considered a variety of shapes for horn A





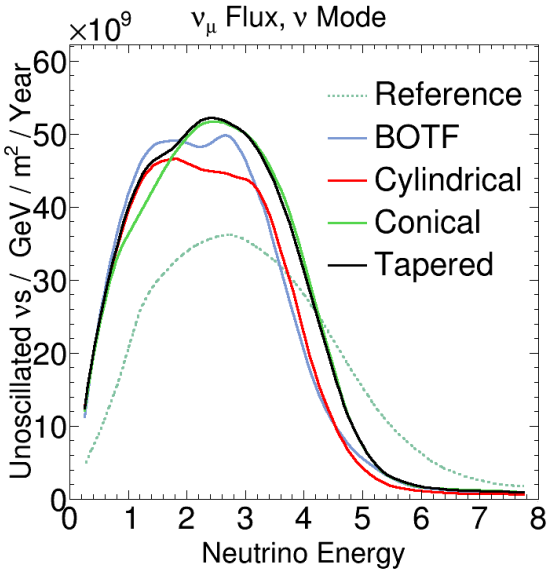
Review of Status as of October



Review of Status as of October

We reported that the "Tapered" Option was what we would be recommending in our final report:

- This configuration has the best CP sensitivity of any design we've identified so far
- Almost as good flux at low energy as flared horn option, and substantially better at high energy
- But, longer (3.9 m) second horn



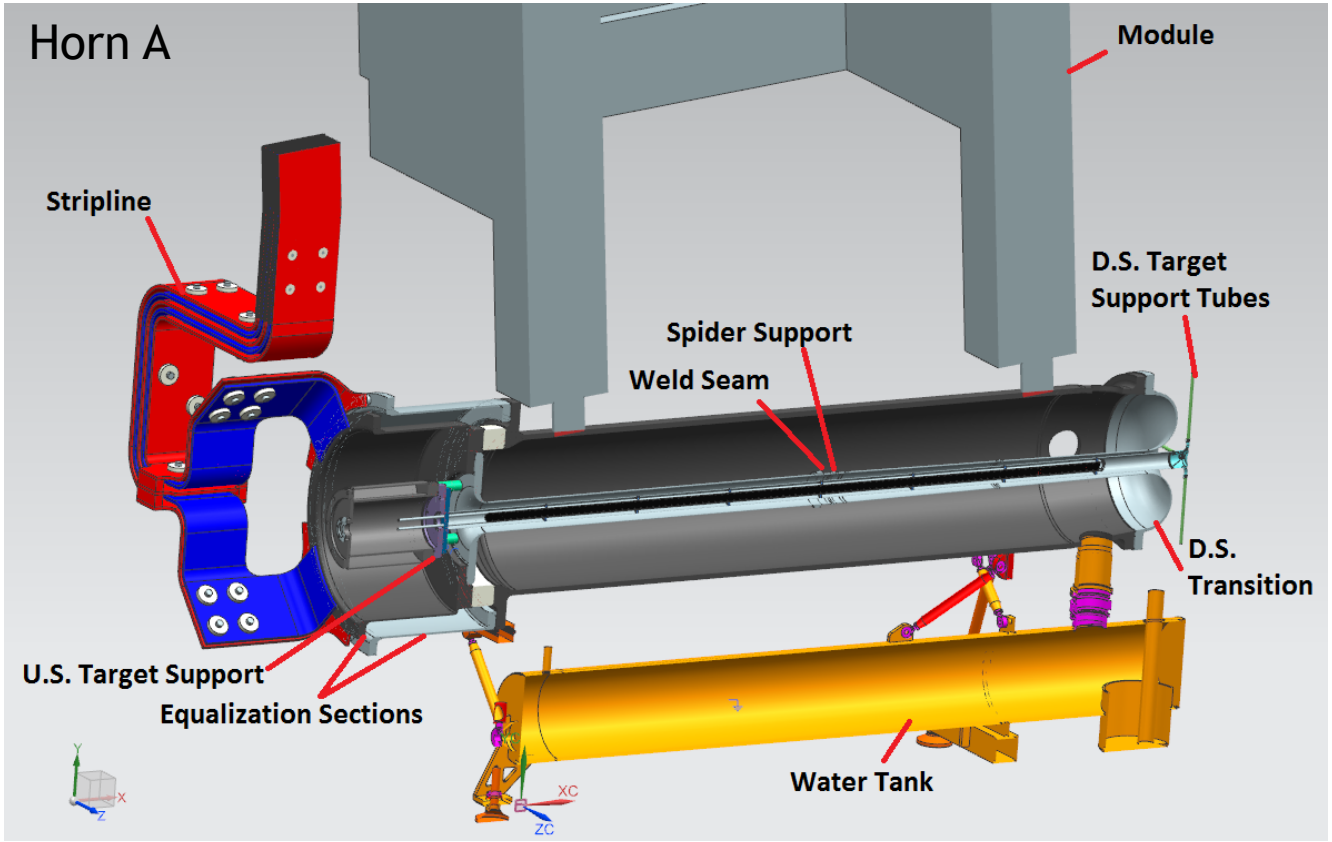
Review of Status as of October

We also presented a lot of other studies that are not discussed further here, but are discussed in BOTF final report:

- Decay pipe optimization
- Flux uncertainties in the reference and optimized beam
- Optimization of low energy and high energy flux
- Impact of magnetic field asymmetries on neutrino flux

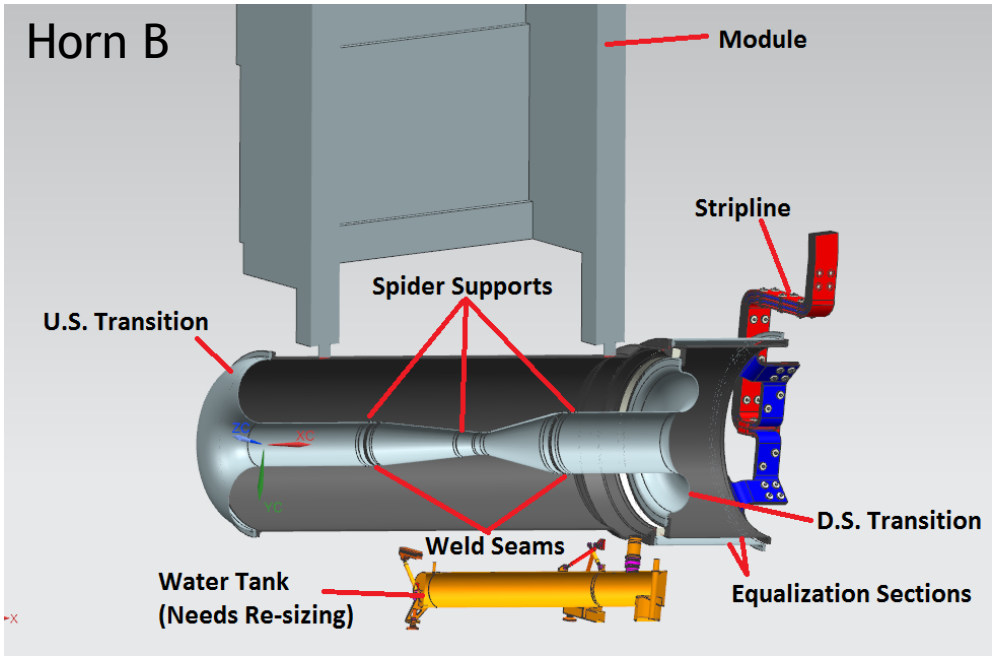
Recent Progress: New Mechanical Model

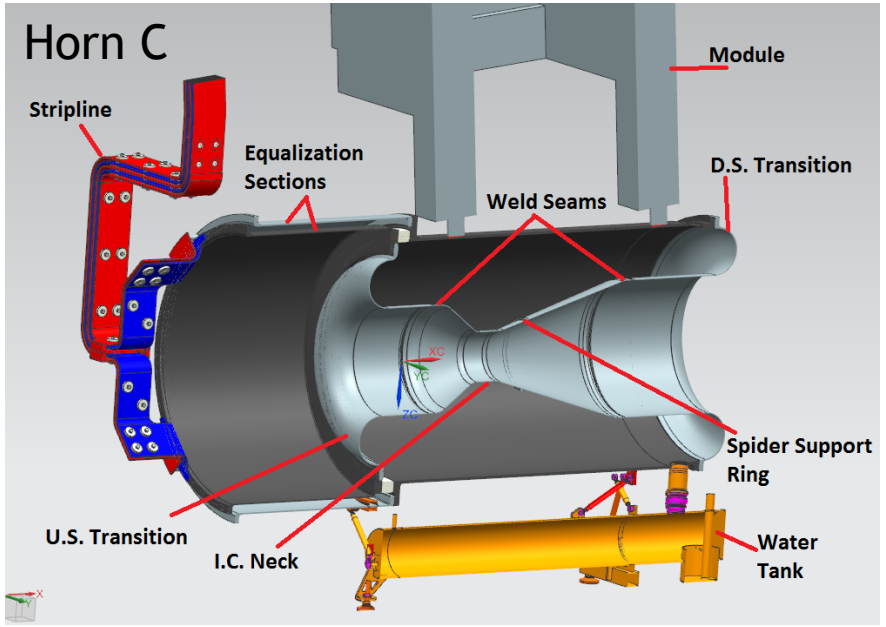
Cory Crowley (Fermilab) has developed a mechanical model of the final ("tapered" Horn A) design:



Recent Progress: New Mechanical Model

Cory Crowley (Fermilab) has developed a mechanical model of the final ("tapered" Horn A) design:

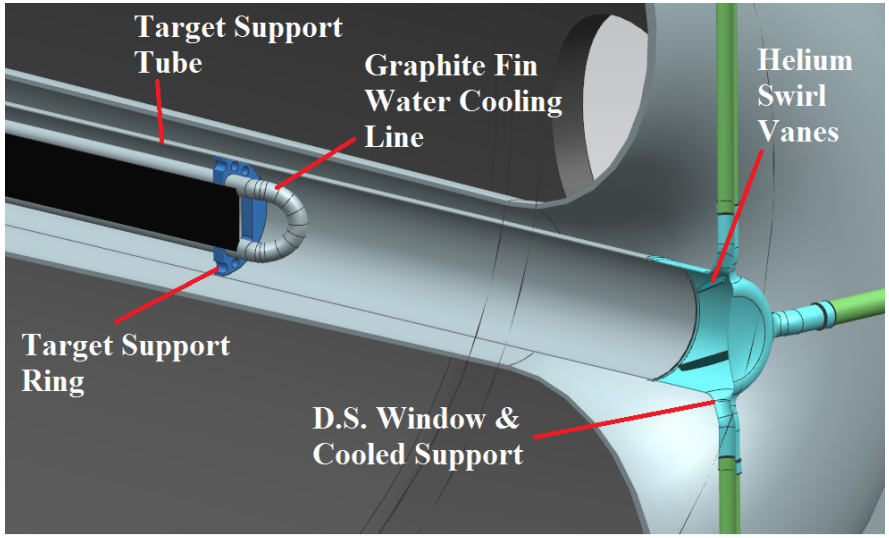


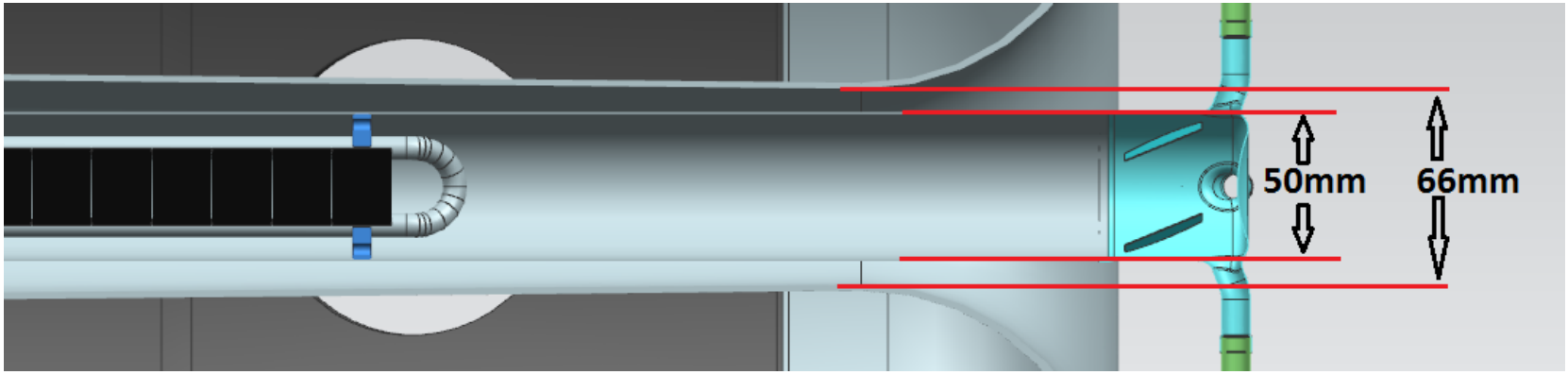


Recent Progress: New Mechanical Model

Cory Crowley (Fermilab) has developed a mechanical model of the final ("tapered" Horn A) design:

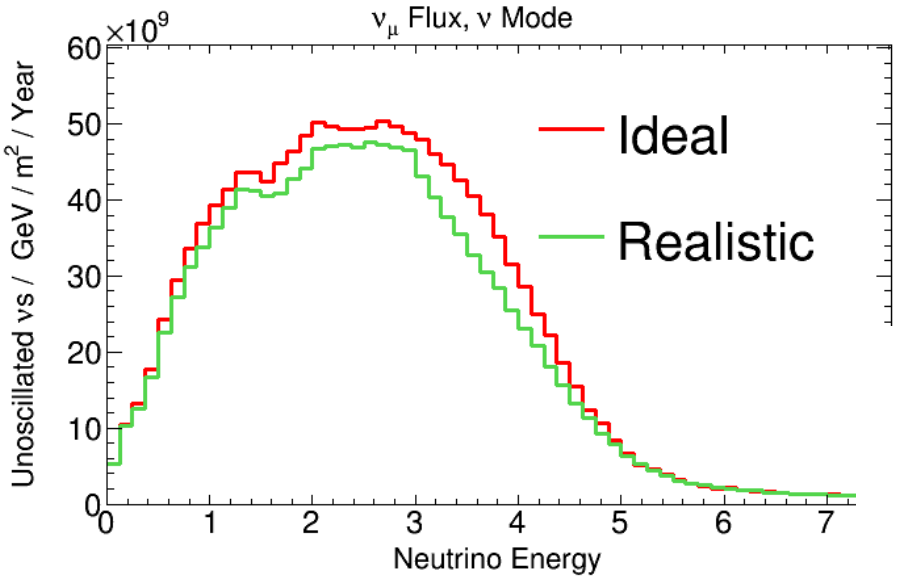
- **Downstream Target Mounting**
  - Target body & cooling lines are **held by support rings** inside grade 5 titanium tube.
  - **Helium flows** through support tube from upstream end for heat removal.
  - Significant **target design work is ongoing**

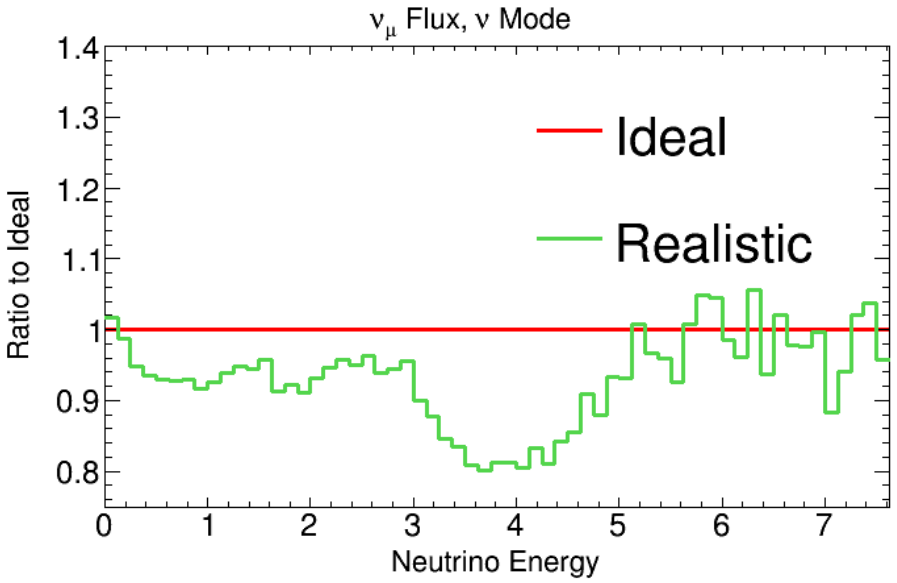




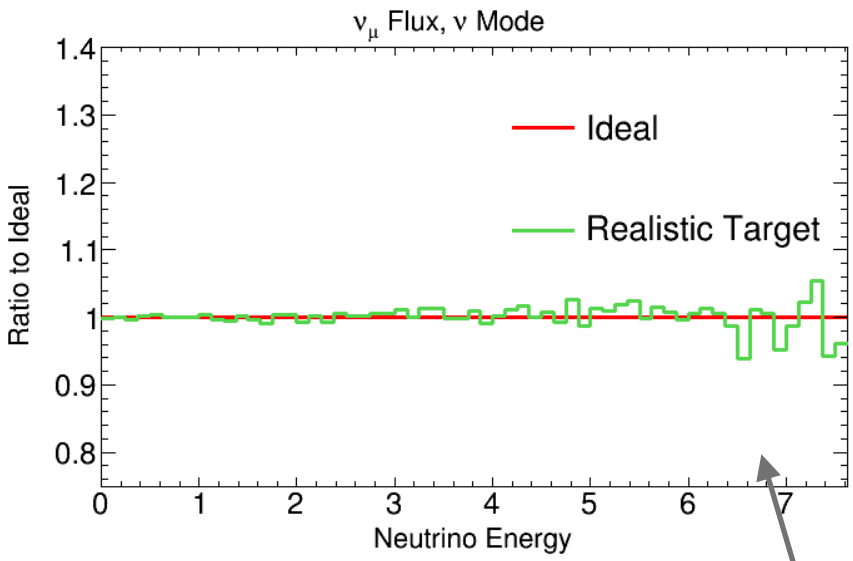
Recent Progress: New Mechanical Model

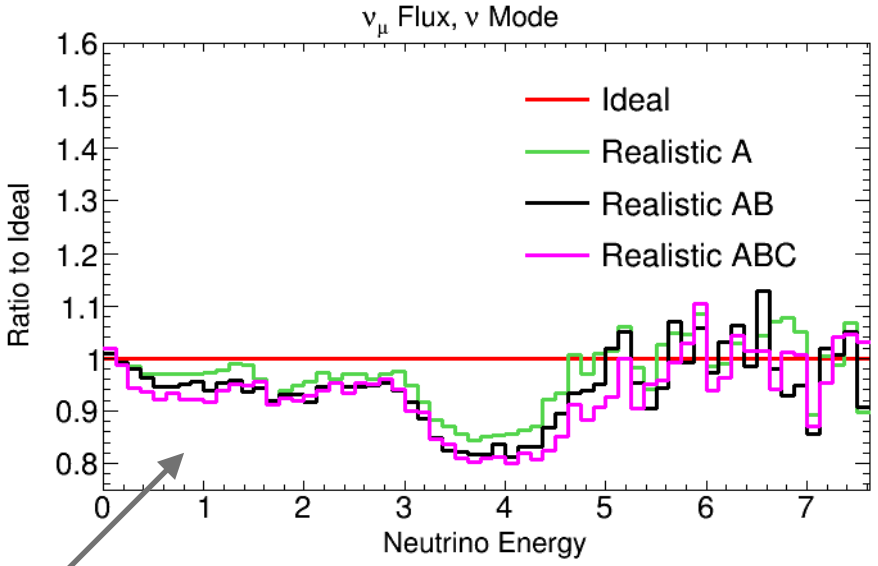
We have simulated the mechanical model and studied it's impact on flux:





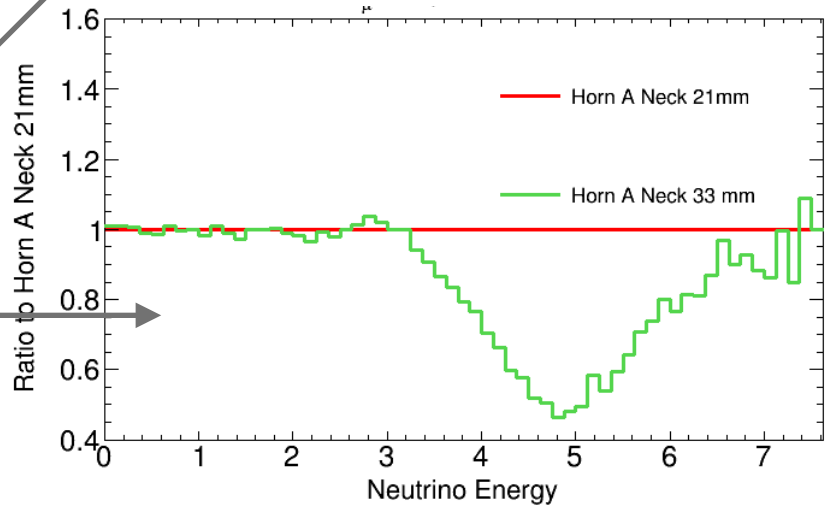
Recent Progress: New Mechanical Model





Flux changes dominated by changes to Horn A

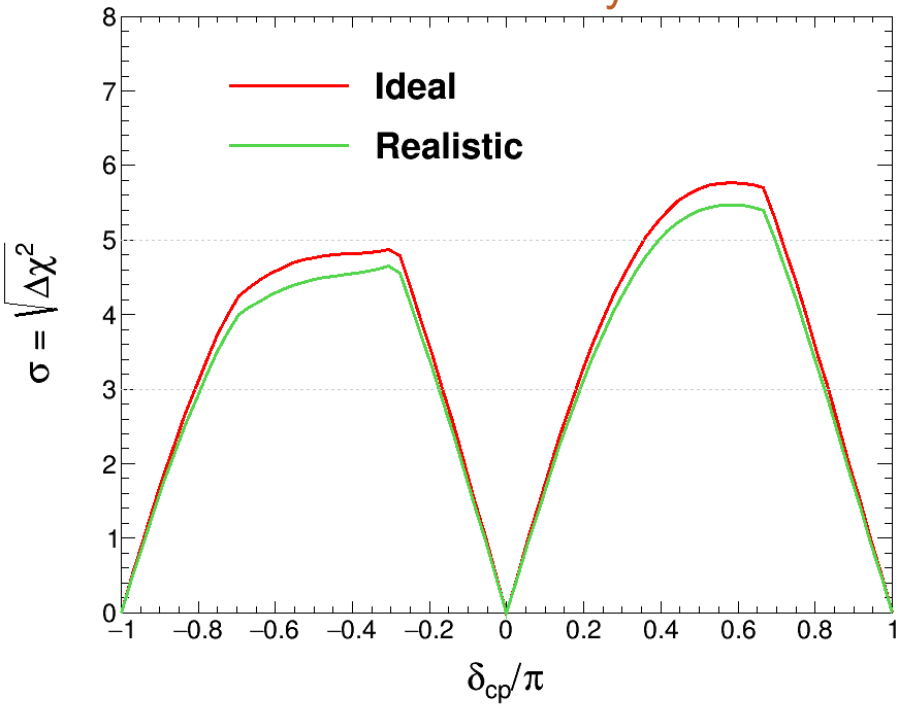
Dip at ~4 GeV dominated by decision to neck taper radius



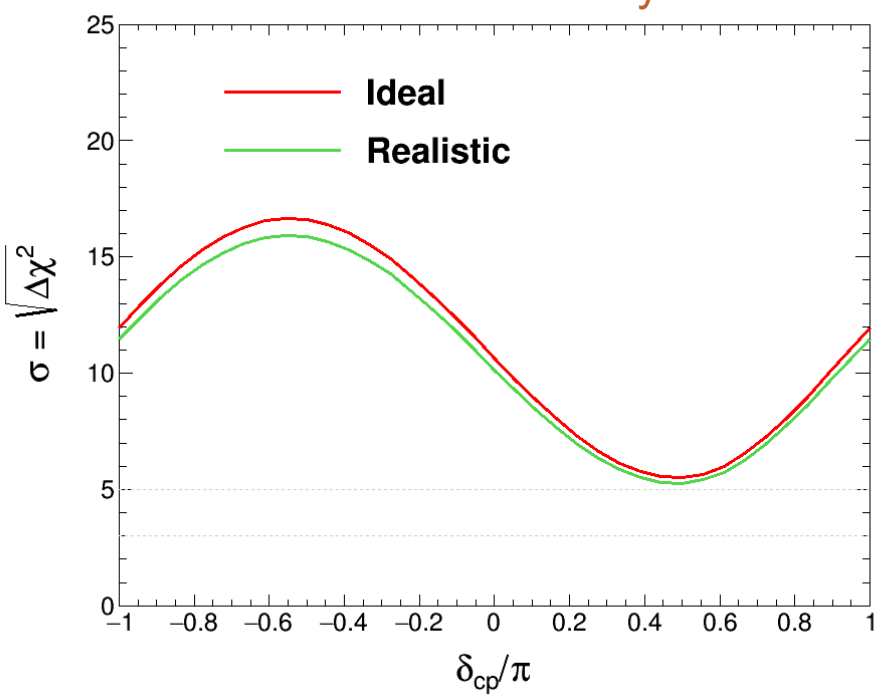
Recent Progress: New Mechanical Model

Physics Impact of All Engineering Changes:

CP Sensitivity



MH Sensitivity

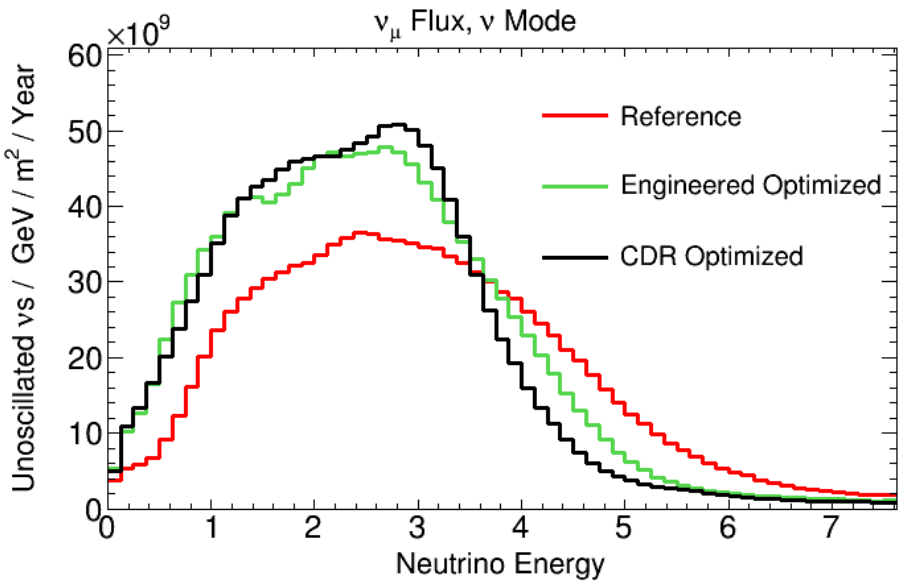


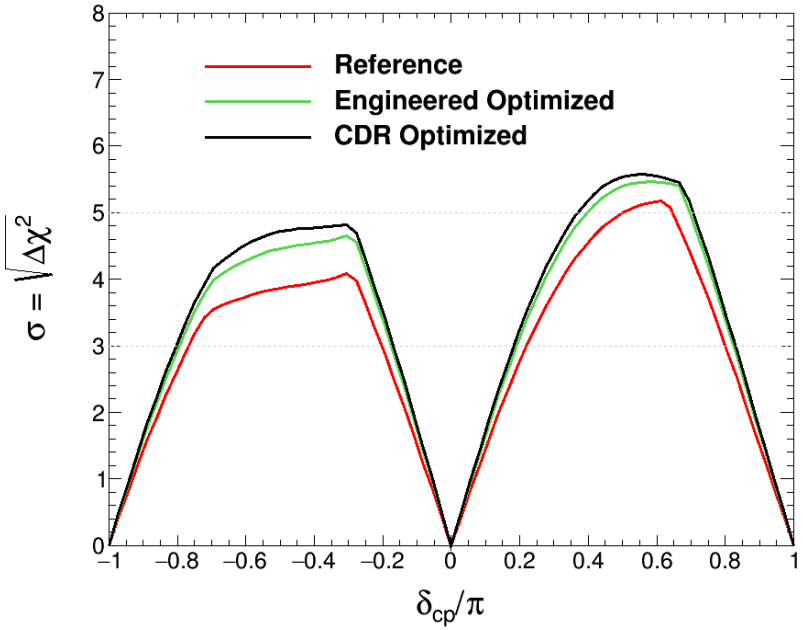
Sensitivities use CDR GLoBES setup and default parameters, and exposure of 300 kT MW years; CP sensitivity assumes a normal mass hierarchy

Recent Progress: Comparison to CDR Optimized

Comparing to the CDR Optimized design

CDR optimized design here is run with the latest version of G4LBNF (updated hadronic model), a 200 m decay pipe, and and a 120 GeV proton beam for an apples-to-apples comparison of focusing systems:



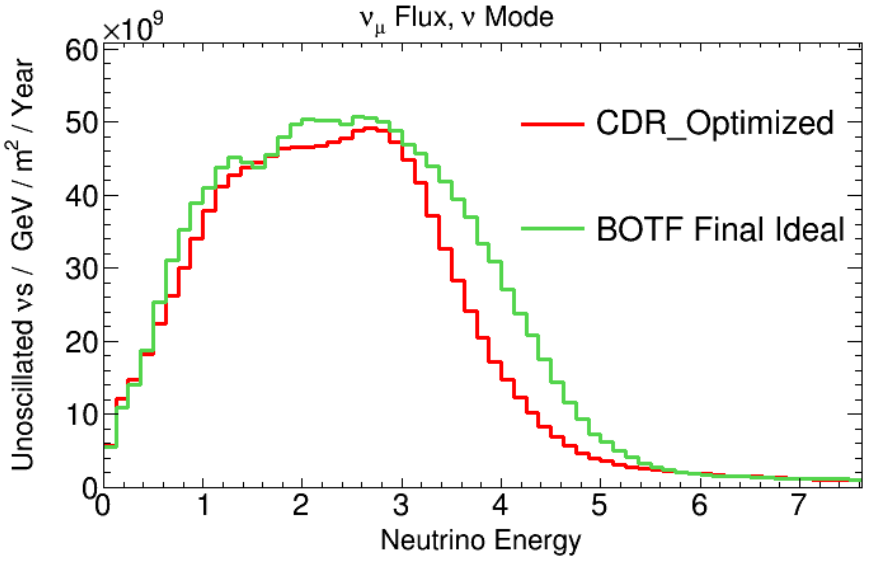


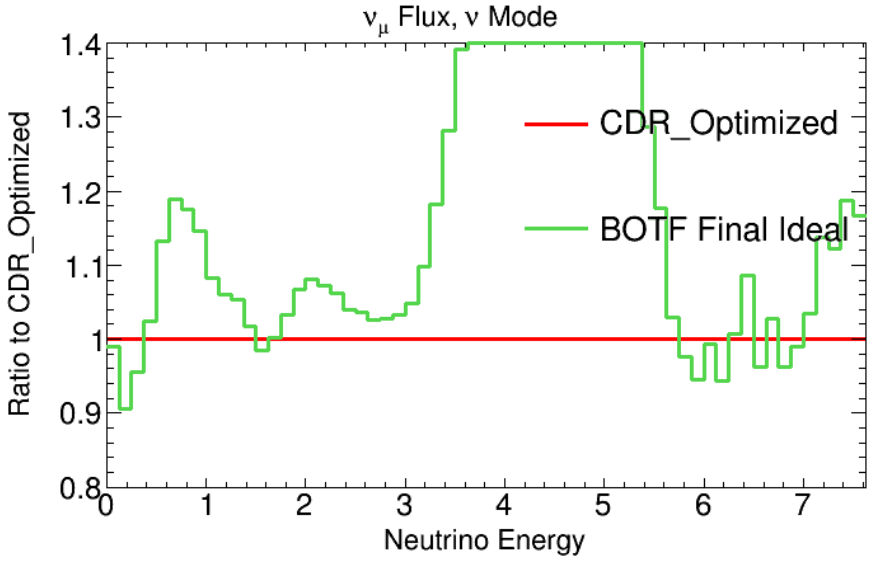
Some flux and sensitivity was lost compared to CDR optimized beam.

Recent Progress: Comparison to CDR Optimized

Comparing to the CDR Optimized design

CDR optimized design here is run with the latest version of G4LBNF (updated hadronic model), a 200 m decay pipe, and and a 120 GeV proton beam for an apples-to-apples comparison of focusing systems:

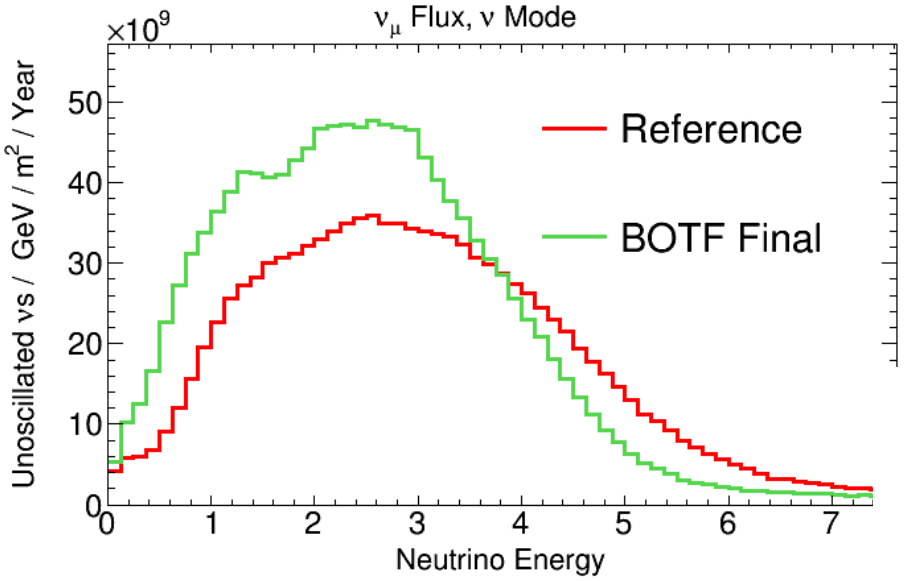


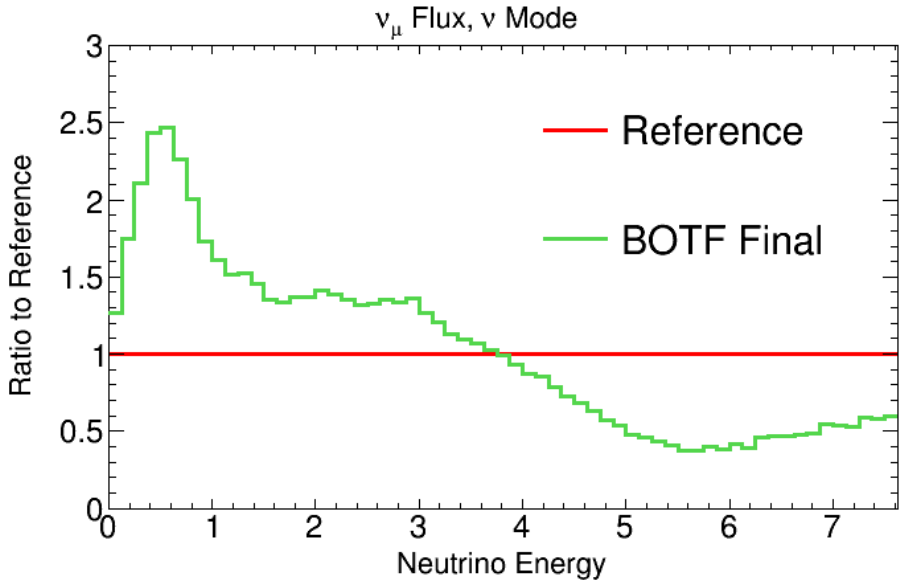


Further optimization after the CDR included tighter engineering constraints than was used in the CDR, but still managed to substantially improve flux, mitigating impact of the engineering changes

Recent Progress: Comparison to Reference

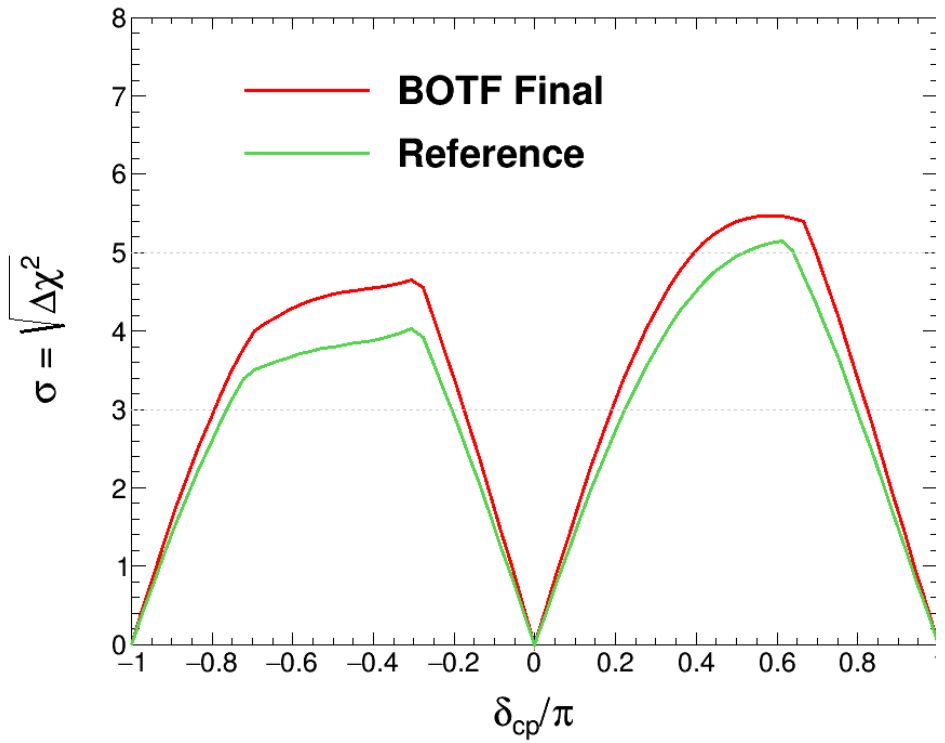
Comparison of final realistic beam with reference beam:

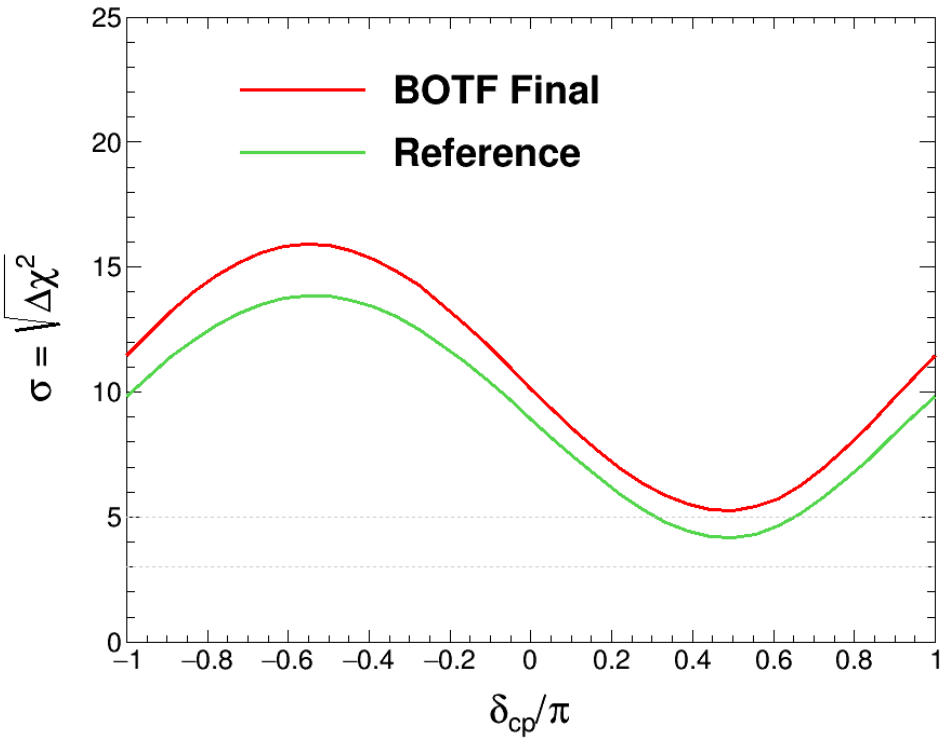




Recent Progress: Comparison to Reference

Comparison of final realistic beam with reference beam:



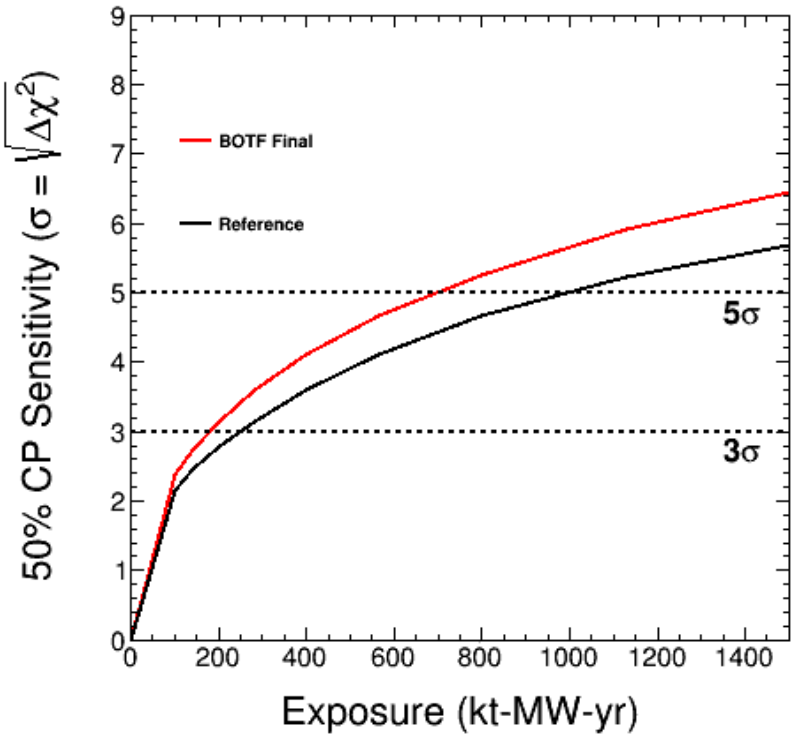


Sensitivities use CDR GLoBES setup and default parameters, and exposure of 300 kT MW years; CP sensitivity assumes a normal mass hierarchy

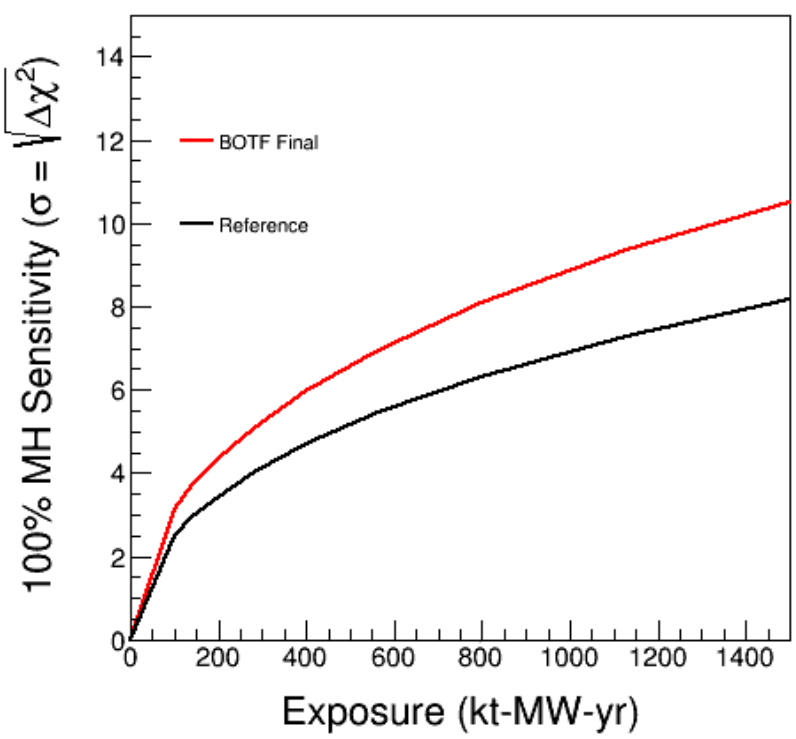
Recent Progress: Comparison to Reference

Comparison of final realistic beam with reference beam:

CP Sensitivity vs exposure



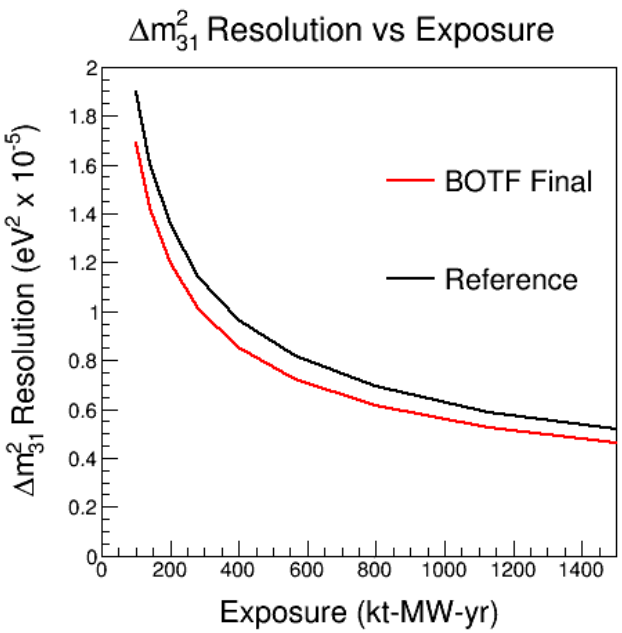
MH sensitivity vs exposure

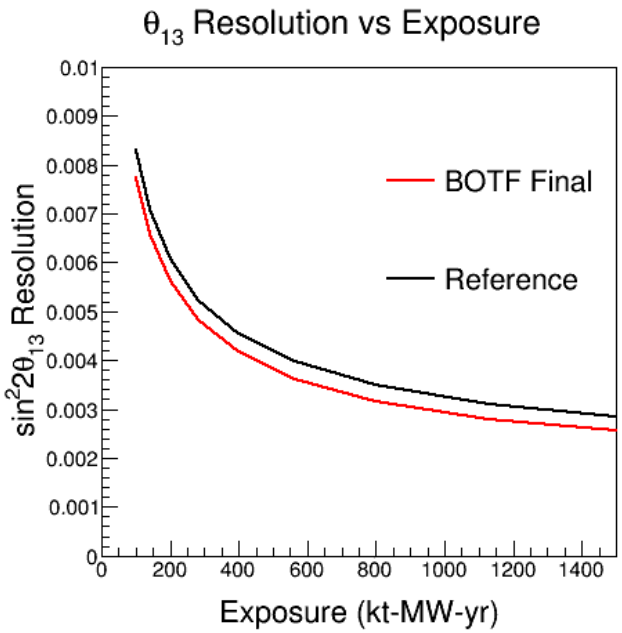


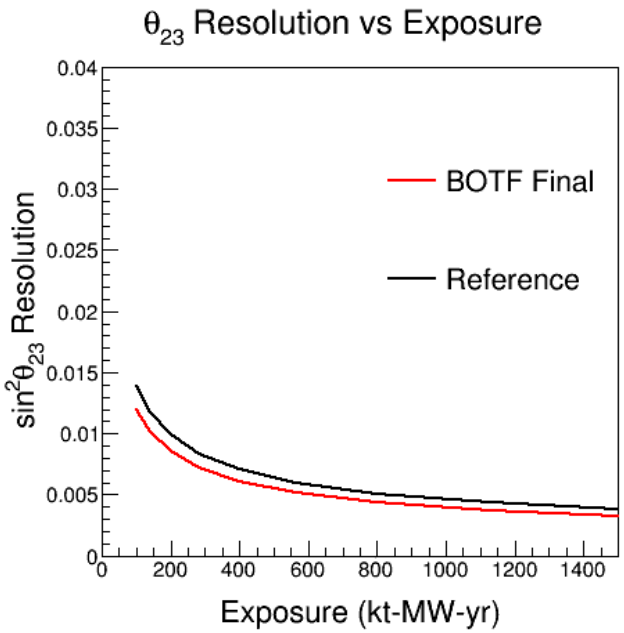
Sensitivities use CDR GLoBES setup and default parameters; CP sensitivity assumes a normal mass hierarchy

Recent Progress: Comparison to Reference

Comparison of final realistic beam with reference beam:



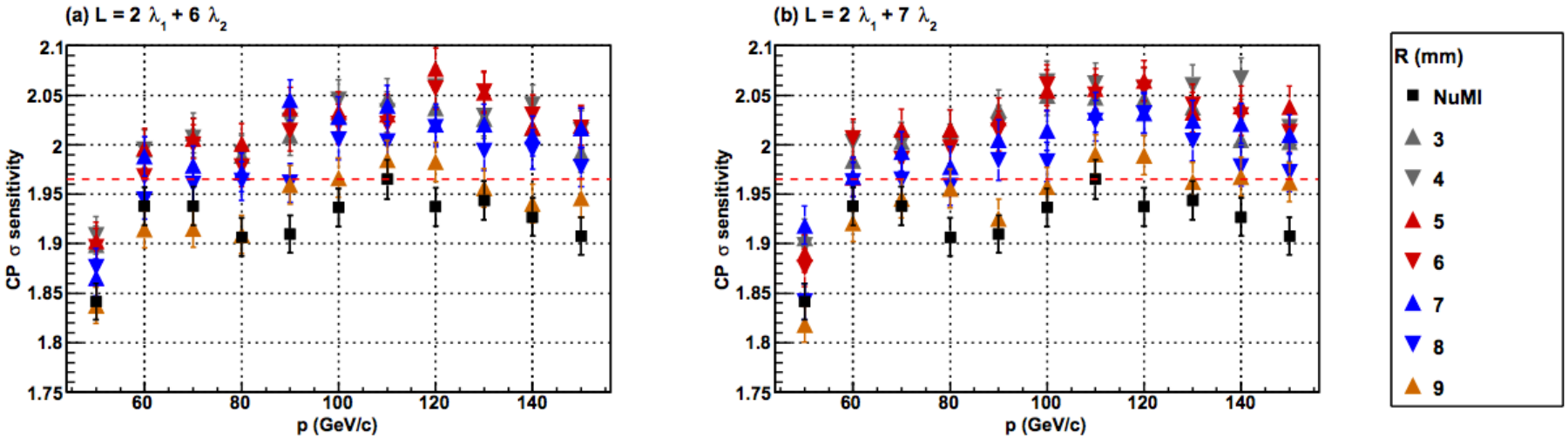




Sensitivities use CDR GLoBES setup and default parameters; CP sensitivity assumes a normal mass hierarchy

Recent Progress: High-Z Target

John Back (U. Warwick) has also studied high-Z targets options:

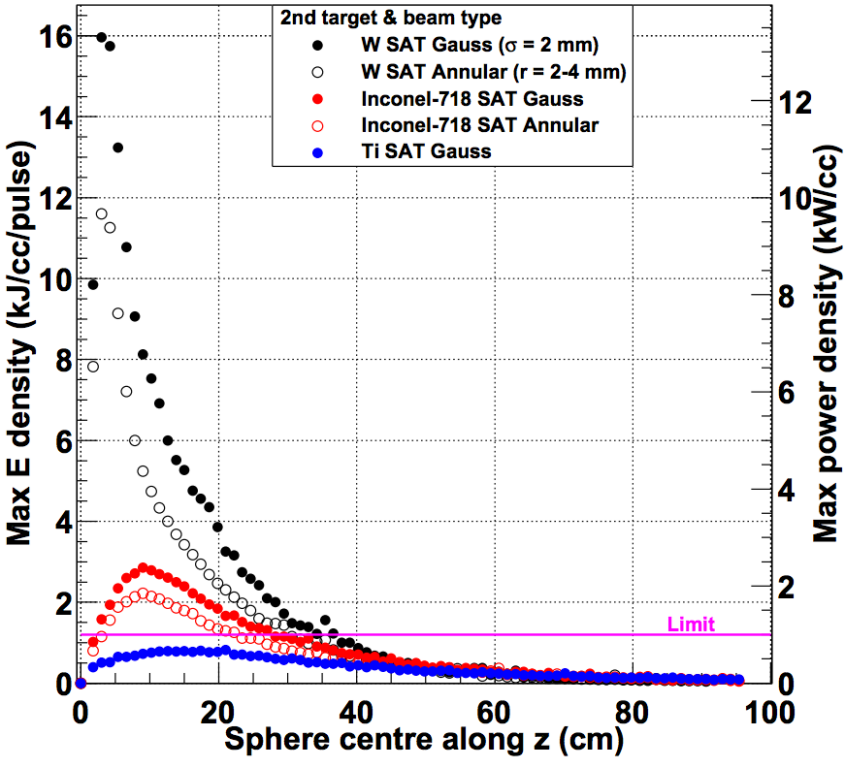


CP sensitivities assuming 2 interaction lengths of graphite cylinder followed by 6 (left) or 7 (right) interaction lengths of Tungsten spheres, compared to four interaction length carbon fin target (black squares)

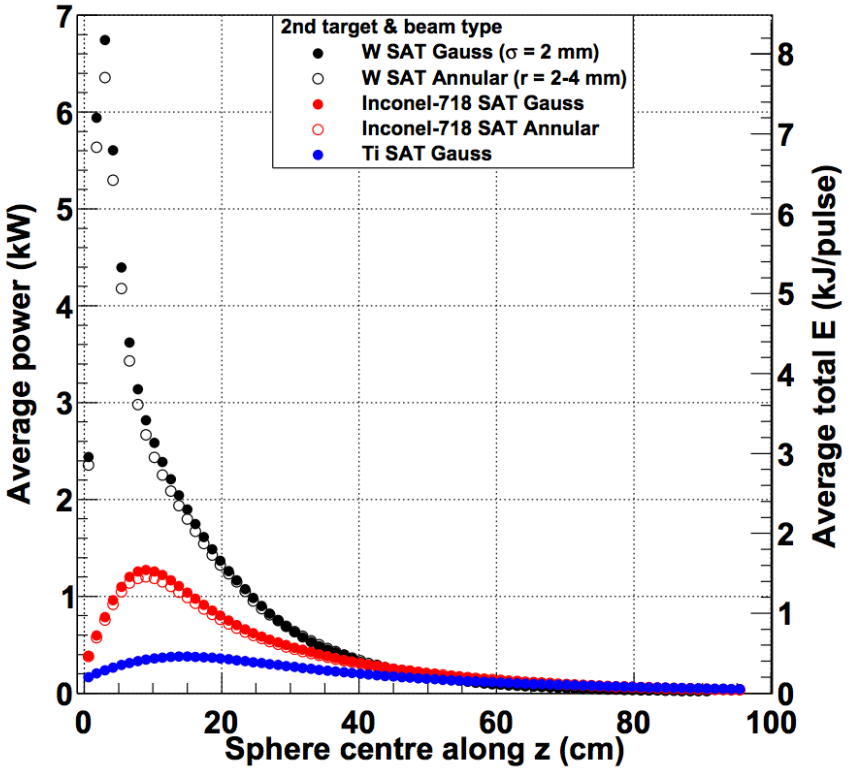
Small improvements in CP sensitivity are possible.

Recent Progress: High-Z Target

John Back (U. Warwick) has also studied high-Z targets options:



Peak energy density



Average power

But a energy depositions for a Tungsten target are much higher than can be feasibly cooled.

Recent Progress: High-Z Target

Conclusions of High-Z Target study

- Improvements in CP sensitivity are possible with a High-Z target, particular for Tungsten; Inconel and Titanium yields smaller gains.
- Energy depositions in high-z materials appears to be too high for Tungsten and Inconel
- Titanium yields more feasible energy depositions, but does not produce sufficient improvement in sensitivity to justify a lot of new design work
- The project is currently considering graphite fin and graphite cylinder target designs
  - The task force supports this; target decisions should primarily made based on engineering considerations, but should be checked to make sure they don't substantially degrade physics performance

Response to LBNC Recommendations

From October 2016 Review:

- "Complete the design. Submit the final report and proceed with engineering studies and cost estimate."

  On Going: *Design is complete; Final report is drafted (but not yet submitted); engineering studies and cost estimate are on-going by project*

Conclusions

- The BOTF has completed it's work
  - A draft of our final report has been written and will be provided to collaboration leadership by the end of this month
- We have recommended a design for the focusing horns that substantially improves flux and sensitivity to 3-flavor oscillation parameters
  - This design is being developed into a Conceptual Design by the project team
  - We recommend that this design be chosen for development of preliminary design
  - And that future design changes be checked to ensure they do not degrade flux/physics sensitivities

Conclusions

- Thank you for the opportunity to serve on the Beam Optimization Task Force and report to the LBNC over the past 18 months

- It has been a pleasure working with you

Backup

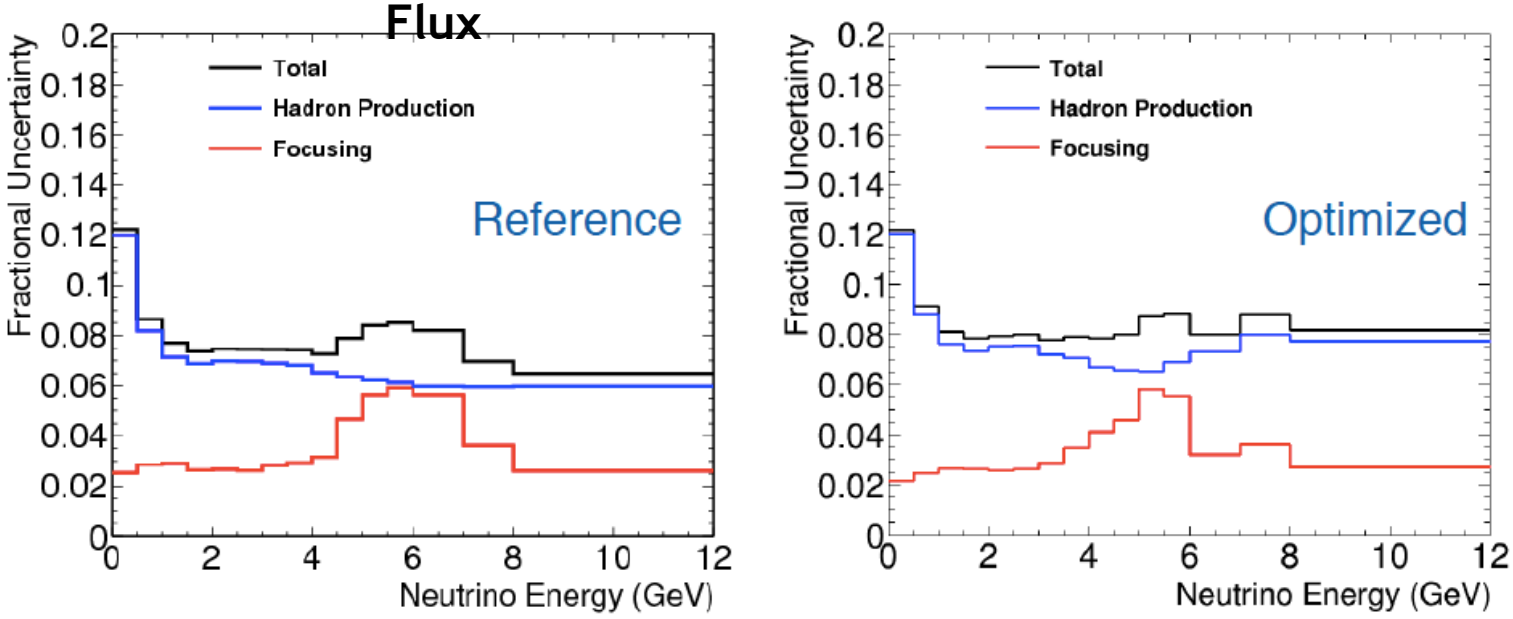
Charge

- The Purpose of the task force
  - Further develop the **physics-driven optimization of the beam line**, including the target, horn configuration (and decay pipe)
  - **Identify potential options** and develop a **first-order cost-benefit analysis**
  - Produce a **first report by July 2016** summarizing the findings; the report will go to the DUNE EC and EFIG, and a **final report will be delivered by December 2016**
- Our role
  - ensure that the required work is completed in a timely manner
  - Work closely with working groups
    - e.g. Accelerator & Beam Interface, Beam Simulations and Long-Baseline Physics
  - and LBNF Beamline team

Beam Systematics with Optimized Beam

- A **major concern** of the optimized beam has been that it may **increase systematic uncertainties** on the neutrino flux due to more **re-interactions** in long target
  - Complete assessment of uncertainties indicates **this is not a problem**

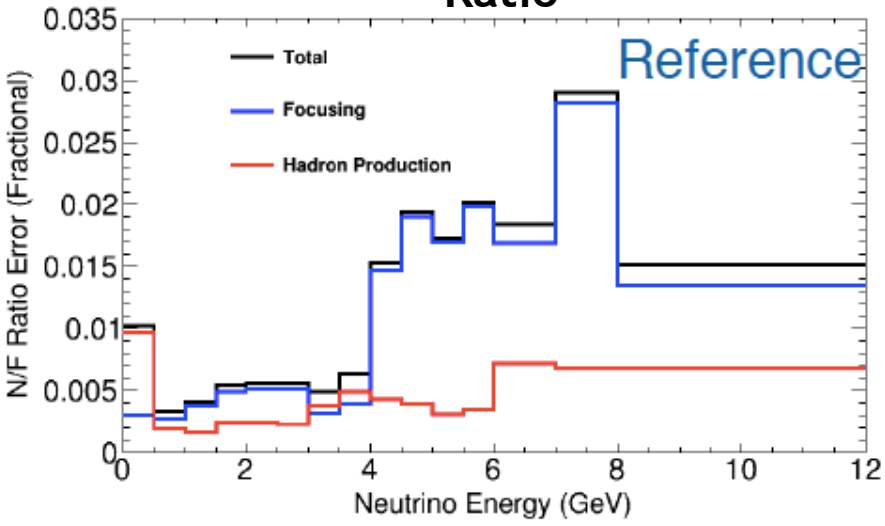
Uncertainties on the Neutrino Flux

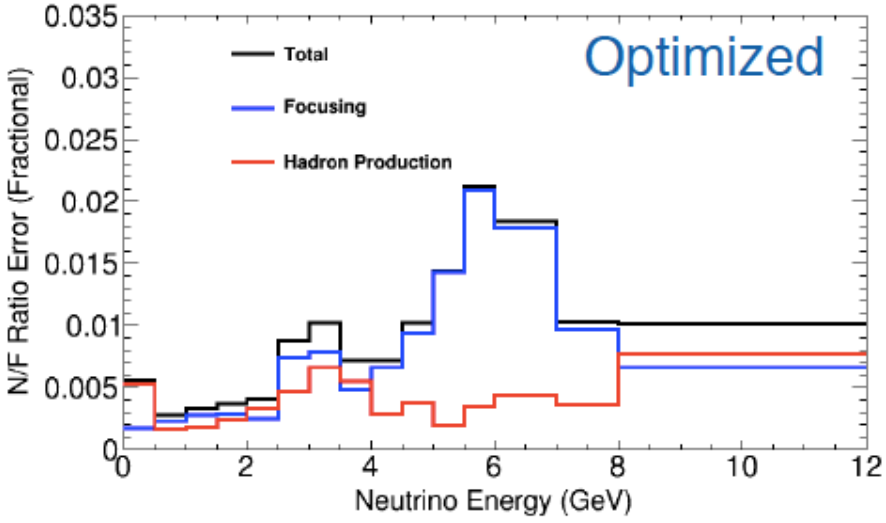


Beam Systematics with Optimized Beam

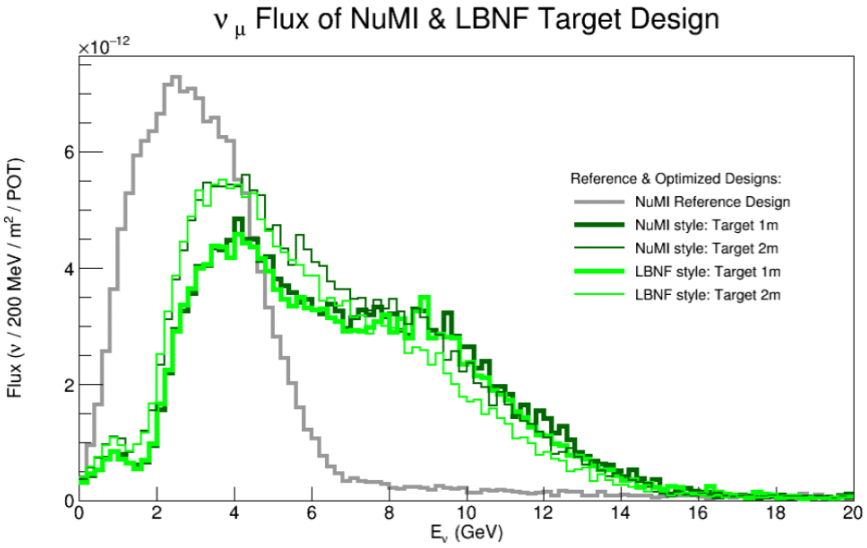
- A **major concern** of the optimized beam has been that it may **increase systematic uncertainties** on the neutrino flux due to more **re-interactions** in long target
  - Complete assessment of uncertainties indicates **this is not a problem**

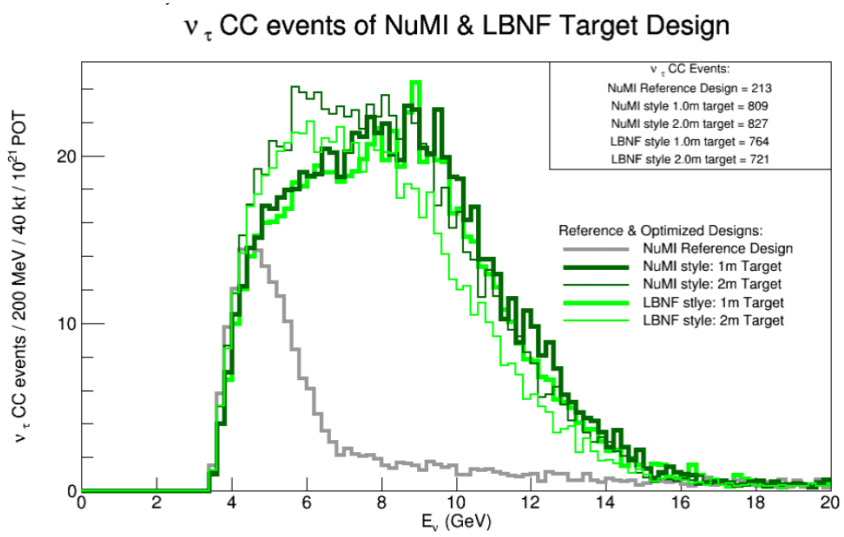
Uncertainties on the Near/Far Flux Ratio





High Energy Optimization





$\sigma_{\text{beam}} = \text{target width}/3$

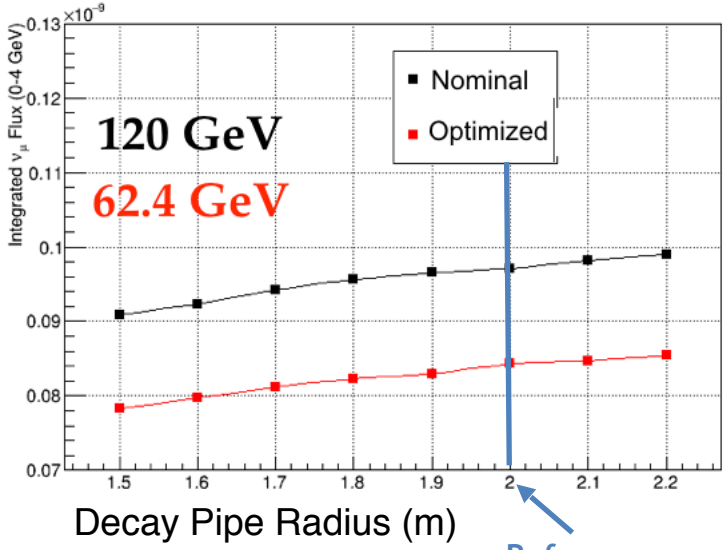
Decay Pipe Optimization

- The BOTF charge also mentioned the decay pipe:
  - Further develop the physics-driven optimization of the beam line, including the target, horn configuration and decay pipe
  - Identify potential options and develop a first-order cost-benefit analysis
  - Produce a first report by July 2016 summarizing the findings; the report will go to the DUNE EC and EFIG, and a final report will be delivered by March 2017.
- The current decay pipe size (~194 m by 2m) was chosen after careful consideration
  - We decided to confine our studies of decay pipe size to answering the question:
    - **Is the relationship between flux and decay pipe size substantially different with the optimized focusing system vs reference?**

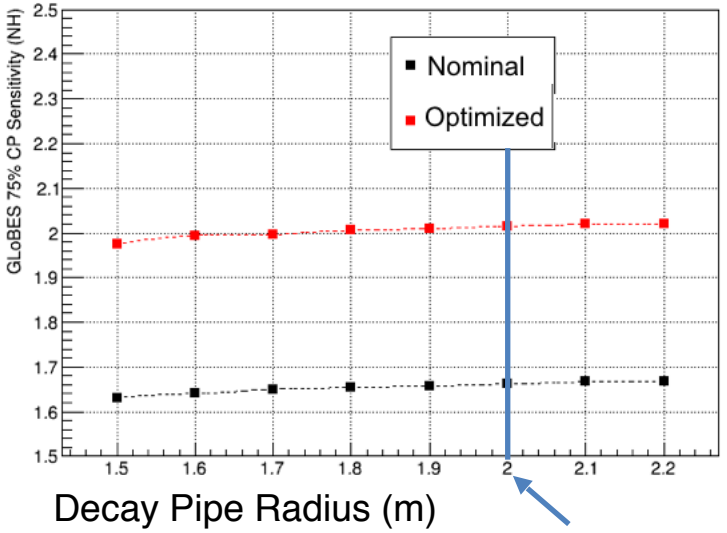
Decay Pipe Radius Optimization

- So we looked at flux per POT and sensitivity vs decay pipe radius for the two beam design options:

Flux per POT vs Decay Pipe Radius



Sensitivity vs Decay Pipe Radius

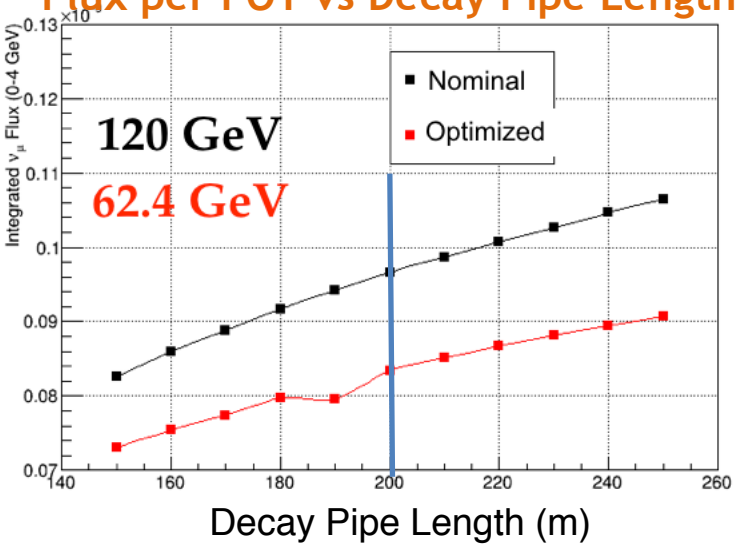


- Impact of decay pipe size on CP sensitivity is very similar in nominal and optimized beam

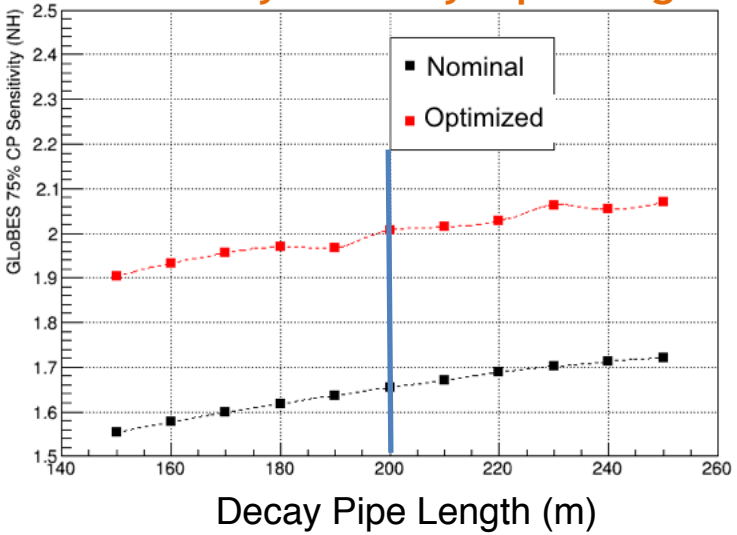
Decay Pipe Length Optimization

- These conclusions are very similar for decay pipe length:

Flux per POT vs Decay Pipe Length



Sensitivity vs Decay Pipe Length



- The Beam Optimization Task Force is recommending no change to the current decay pipe dimensions

Feedback form Previous LBNC Meetings

- Comments (extract)
  - Many of the beamline parameters have a wide range of values over which there is relatively little impact on the CP reach. Therefore the impact of varying such parameters on cost and risk may be more important considerations than CP reach. It is therefore important to move from physics optimization to the final engineering of the proposed solution as soon possible
  - Decisions concerning the cooling and the gas in the hall could have significant design and cost implications and would benefit from engineering study in the near term.
- Recommendation
  - DUNE management, working with Fermilab management and other possible sources of engineering resources, should work to identify a source for engineering personnel needed to progress work on costs and risks associated with beam facility design decisions.

Feedback form Previous LBNC Meetings

- Recommendation
  - Complete assessment of the recent narrow-band beam option by mid July