# LBNF Beamline Status and Challenges

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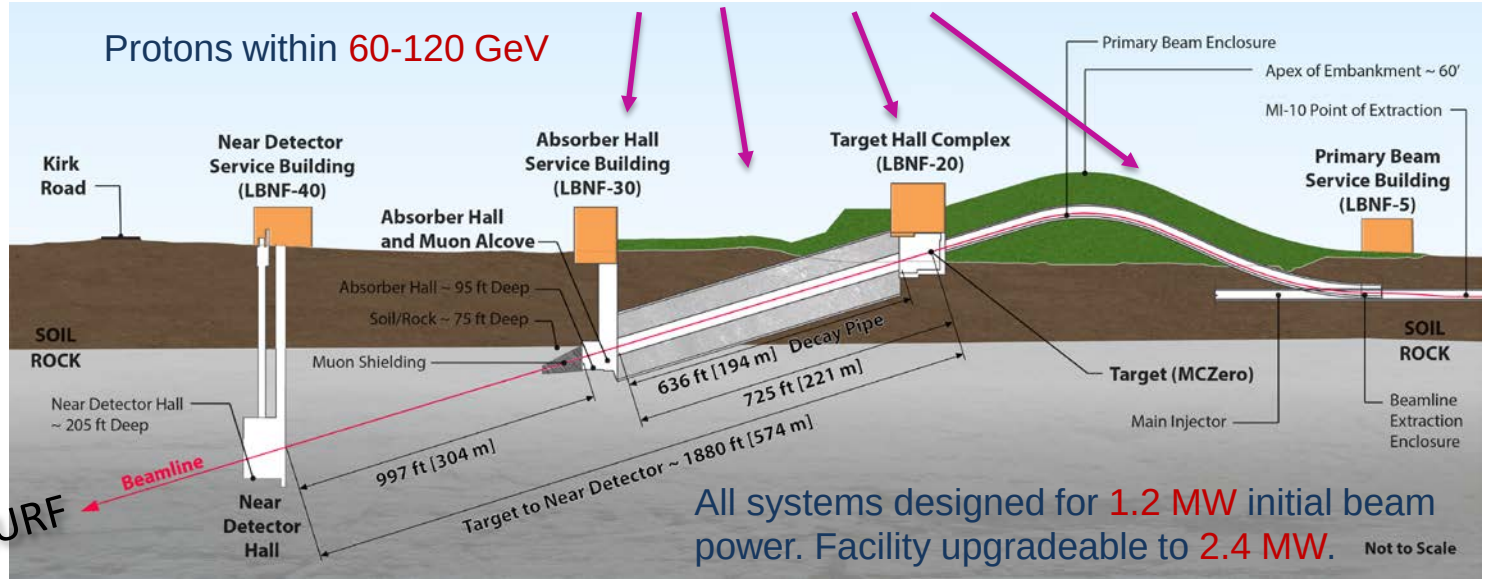
# Outline

- Beamline scope
- Recent technical progress
- Partners
- Schedule, milestones, resource requirements
- Challenges
- Conclusion

# Scope for Beamline Technical Components




- Primary Beam (beam optics, magnets, magnet power supplies, cooling, vacuum, beam instrumentation).
- Neutrino Beam (primary beam window, baffle, target, focusing horns, support modules, instrumentation, horn power supply, target shield pile, decay pipe cooling and windows, hadron absorber, RAW, remote handling, storage of radioactive components, muon systems).
- Beamline System Integration (controls, interlocks, alignment, installation infrastructure and coordination).
- Beamline Modeling and Radiation Physics & Protection; providing specs to Near Site Conv. Facilities.

# Recent history

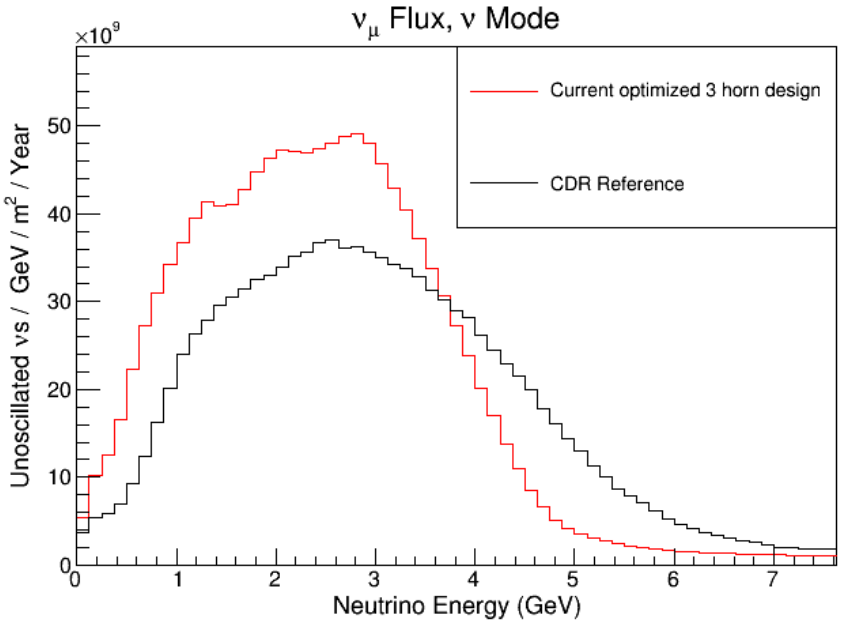
- Beamline Project effort significantly reduced in FY16 and FY17, right after CD-1R, due to reduced overall funding and emphasis on the far site.
- For past two years focused only on the neutrino beamline and on engaging partners:
  - Beam optimization effort for physics maximization
  - Conceptual design for optimized target & horns and impacted systems
  - Re-evaluation of activated air-releases and change of target chase atmosphere to $N_2$
  - Engineering design of $N_2$-filled target chase
  - Partner activities (IHEP/RAL)
- Just started ramping up in April 2017, since we were preparing to start preliminary design in FY18. This allowed for 1.5 year to develop preliminary design so that we could meet the stake on the ground for beam delivery by the end of 2026.

# Beam optimization effort - target and horns

- Have been optimizing target and horns for better physics, on the basis of sensitivity to CP violation.
- Encouragement by the CD-1R Review Committee (July 2015) to continue along these lines.

> Recommendation: Actively pursue further improvements to the target and horn layout with an overall goal of reducing the time to obtain first physics results.

The optimization leads to significantly more flux, a flatter spectrum in the energy range of interest and reduced high energy tail.

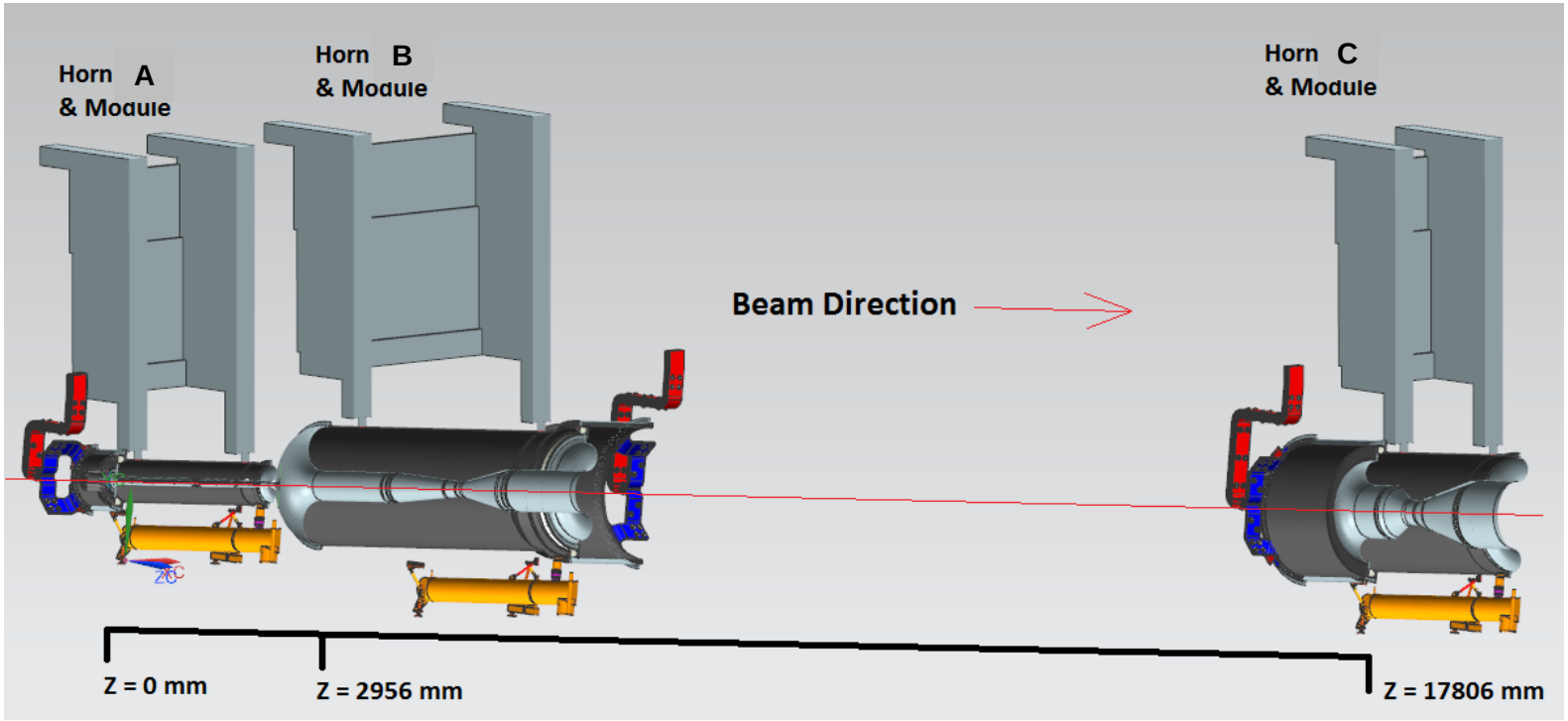


# Beamline recent design development activities

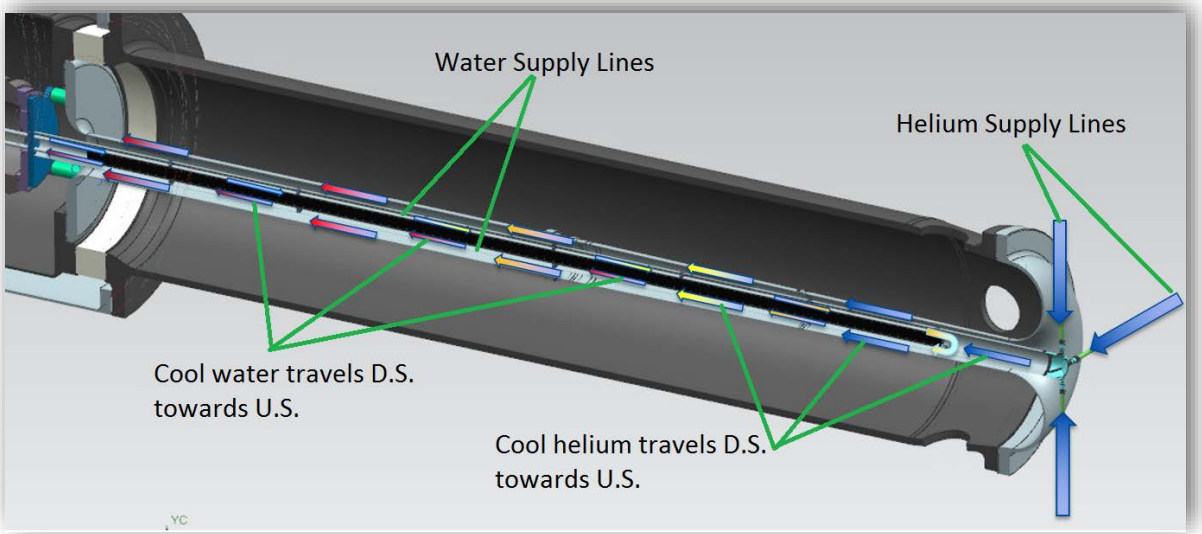
- Physics optimization requires:
  - 4 (instead of 2) interaction length target
  - 3 new (instead of 2 NuMI-like) magnetic horns
- Evaluating as well impacts of optimized designs on target/horn support structures, horn power supply, remote handling, target shield pile and decay pipe shielding and cooling, hadron absorber, muon shielding, conventional facilities.
  - MARS simulations indicate energy deposition relative to the reference design:
    - 30% more in the target shield pile and the target chase
    - 20% more in the decay channel
    - 50% less in the absorber.
- Decision on Beamline final conceptual design planned in the Fall of 2017.
- Decision could be full-scale optimized, partial implementation with provisions for full implementation, or reference design with provisions for full implementation, etc. (**factors: physics performance, radiological constraints, engineering feasibility, feasibility of staging, cost, schedule, and possible partner participation).**

# 1.2 MW Optimized Design for horns

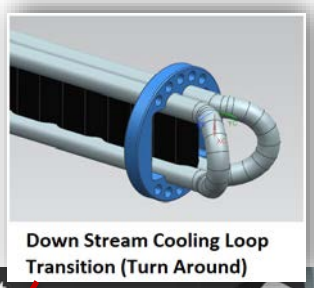
- All three optimized horn and horn stripline mechanical designs implemented into MARS. Energy depositions complete, FEA complete. Results look satisfactory.



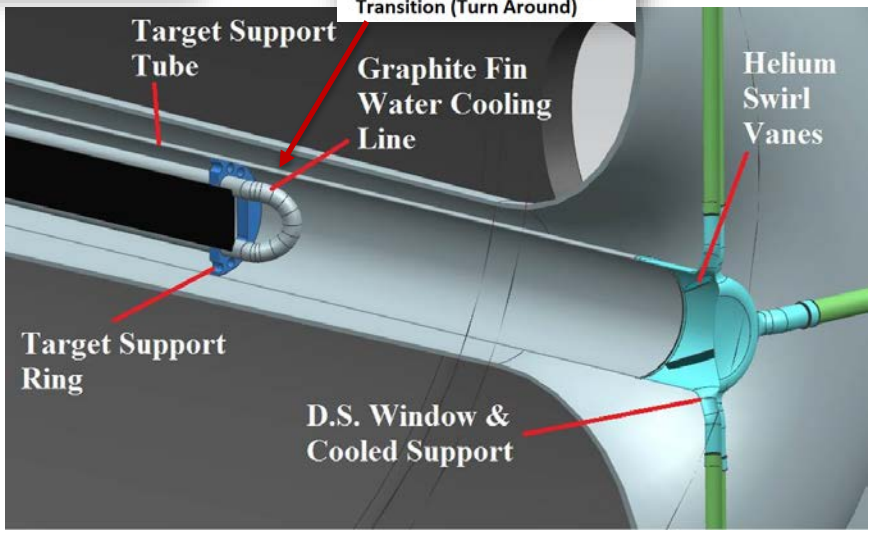
# 1.2 MW Optimized Design for target – water cooled




- First iteration optimized target design (2m long graphite fin target – 4λ)




- Cooling
  - Water cooled target
  - Downstream window and target support must be actively cooled with helium

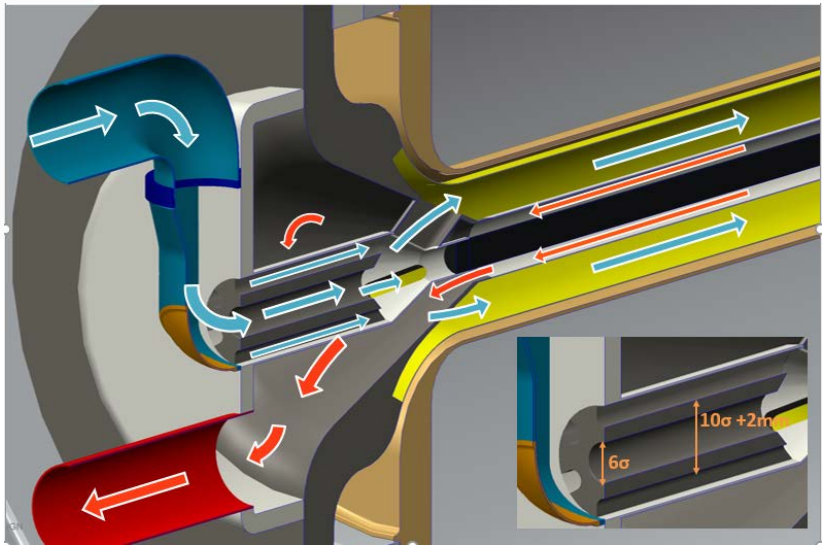



This is the target that was used in all MARS simulations so far

# 1.2 MW Optimized Design for target – helium cooled

Working with RAL
Expect report end of June 2017

- Second iteration optimized target design (2m long cylindrical, segmented graphite target – 4λ)

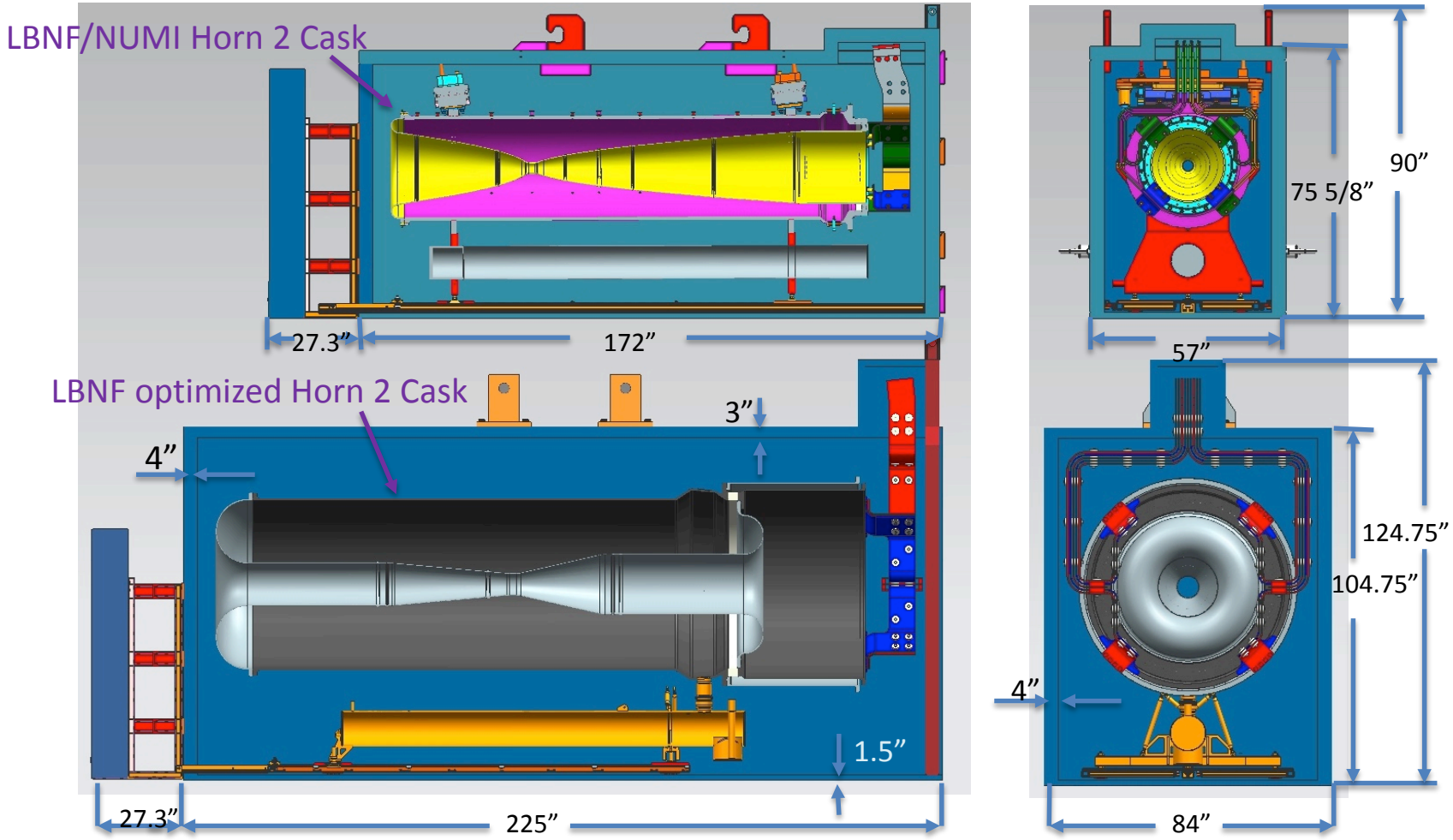



- Cooling
  - Fully helium-cooled

This is the target whose conceptual design we expect to have ready for August/September 2017 reviews

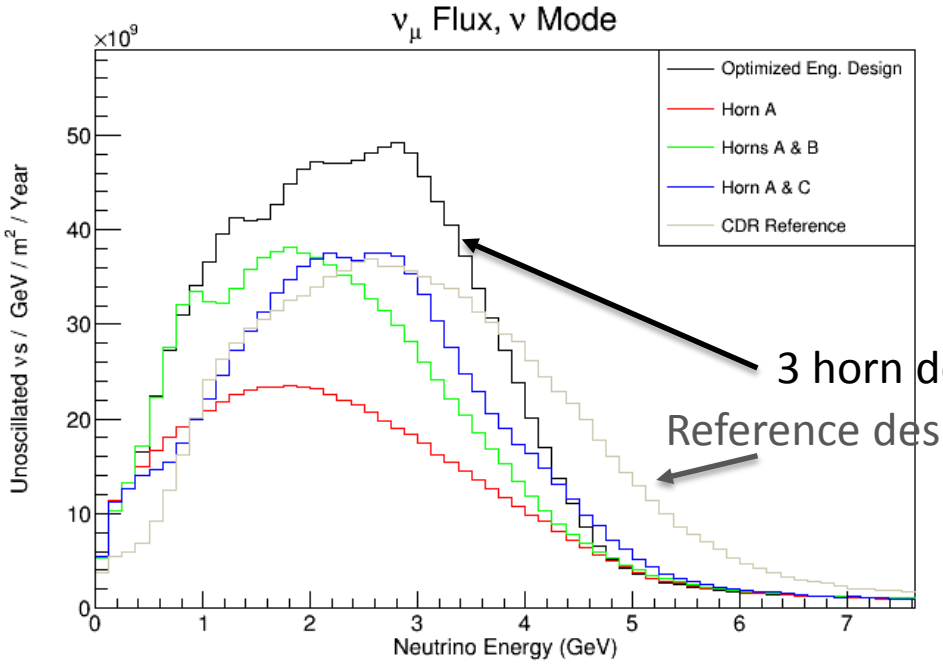
# Remote Handling - Horn Casks

The LBNF optimized Horn cask is 53” longer, 27” wider and 34.75” taller than the NUMI Horn cask. The NUMI cask with horn weight is 30 ton; the LBNF cask with horn weight is about 50 ton. (Increased crane capacity).



# Beam optimization – staging possibilities

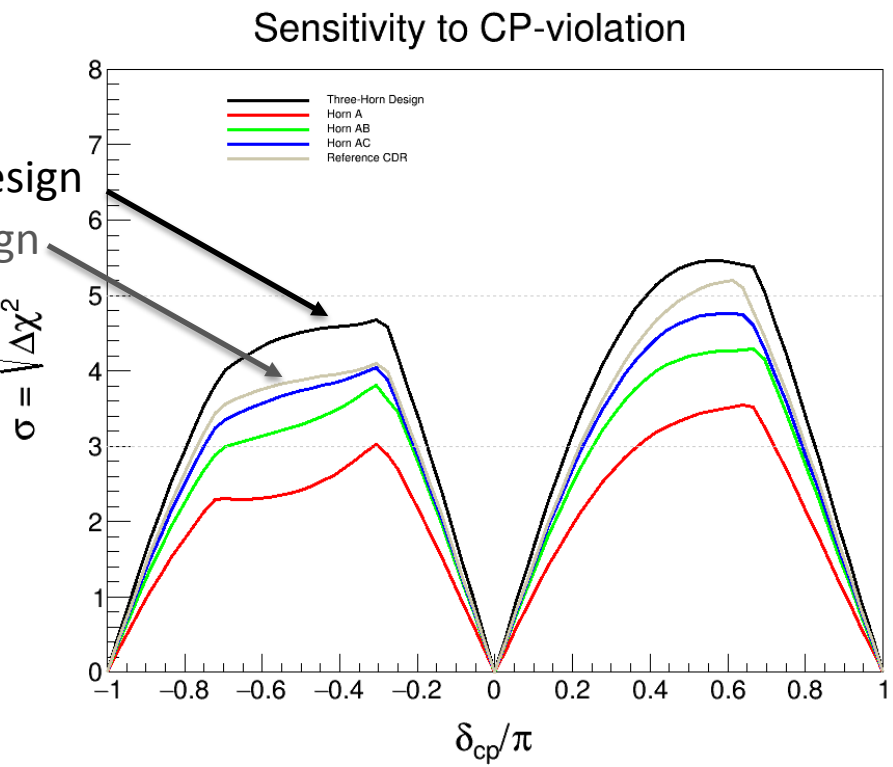
- Studying physics reach in different staging scenarios




3 horn design

Reference design

300 kT MW years exposure



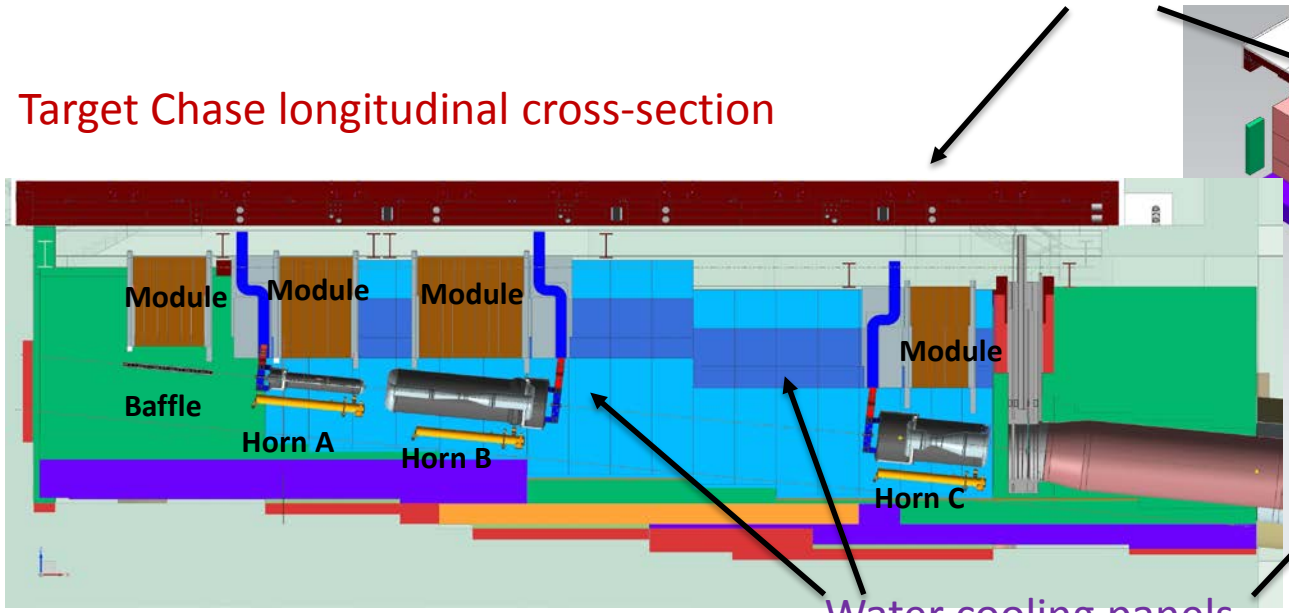

Similar spectra and sensitivities for Reference Design and for staged horn AC configuration

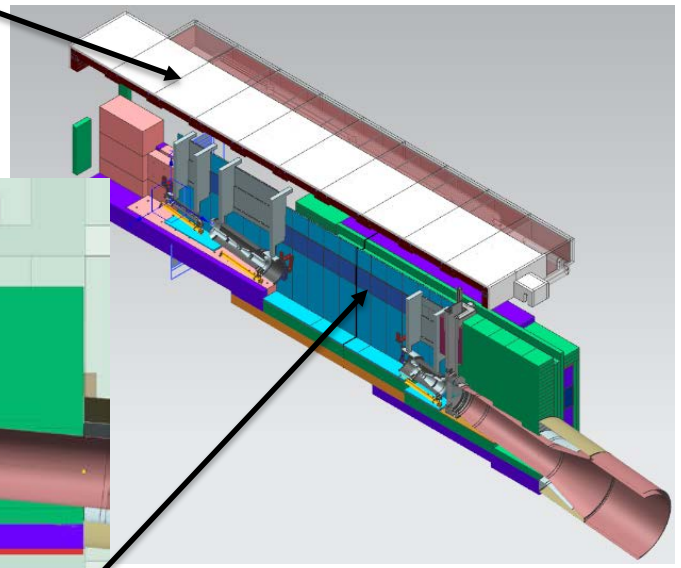
# Beamline recent design development activities

- Due to the required bigger target chase, changed from air to nitrogen atmosphere in the chase and for the decay pipe cooling in order to reduce the production of $^{41}$Ar and Ozone.
- This implies additional gas-tight liner in the target chase, leak-tight seals at chase cover plates & feed-throughs, revised Conventional Facilities/shielding/remote-handling configuration.

Removable hatch cover system

Target Chase longitudinal cross-section



Water cooling panels

# International Partners

IHEP/China (interested in spending M&S now):

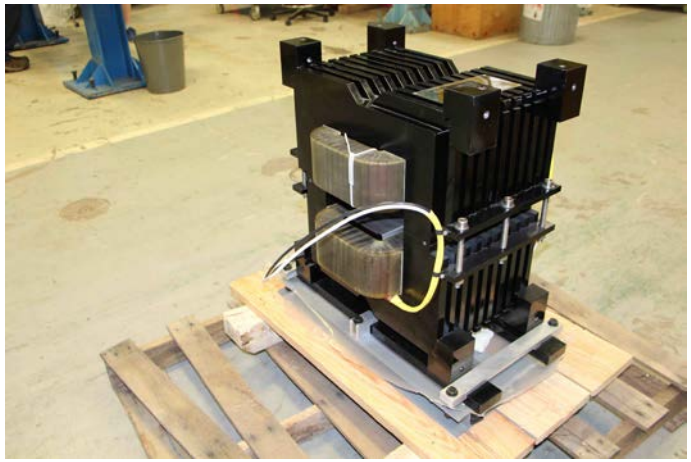
- Corrector magnets for primary beamline – prototype and 24 production magnets (advanced stage).
- Working on FEA for the decay pipe windows for the past 3 years. Recently received confirmation that IHEP is interested in prototyping the upstream decay pipe window, working with the Zhengzhou Research Institute. Preparing another SOW to be added to the existing I-CRADA.
- Discussions on a possible Hadron Monitor prototype.

RAL/UK (proposal submitted to STFC):

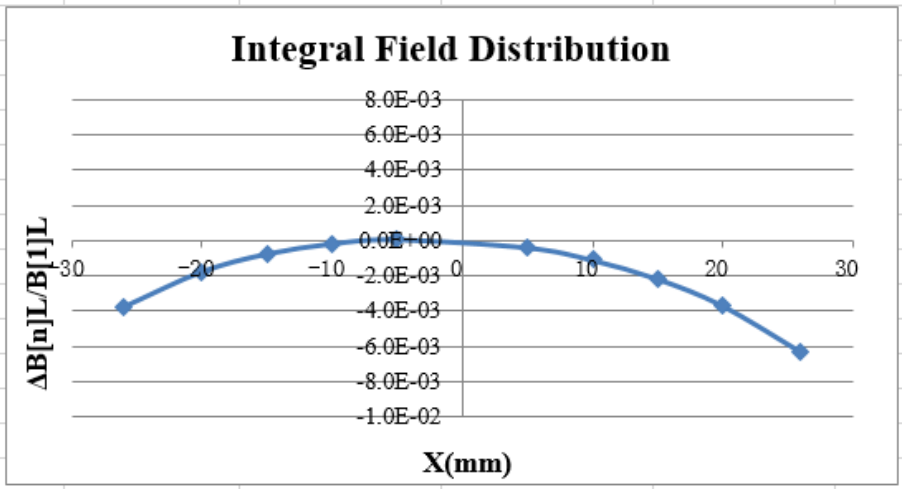
- Target R&D.
- Target.
- Possibly associated remote handling aspects or baffle.
- Decision on funding was expected in June 2017/now unclear.
- Bridge funding for the conceptual design of optimized target. SOW in place.

# International Partners – IHEP/China

- I-CRADA approved by DOE and Lab Directors in March 2017.
- Corrector magnet prototype (FNAL design) assembled and tested at IHEP. Results looked good.
- Prototype received at Fermilab on June 19, 2017 and under testing now.



Corrector magnet prototype
integral field measurement - rotating coil




| | |
|---|---|
| Maximum Magnet (Core) Length | 17.25 (12) in |
| Maximum cross-section | 24x24 in$^2$ |

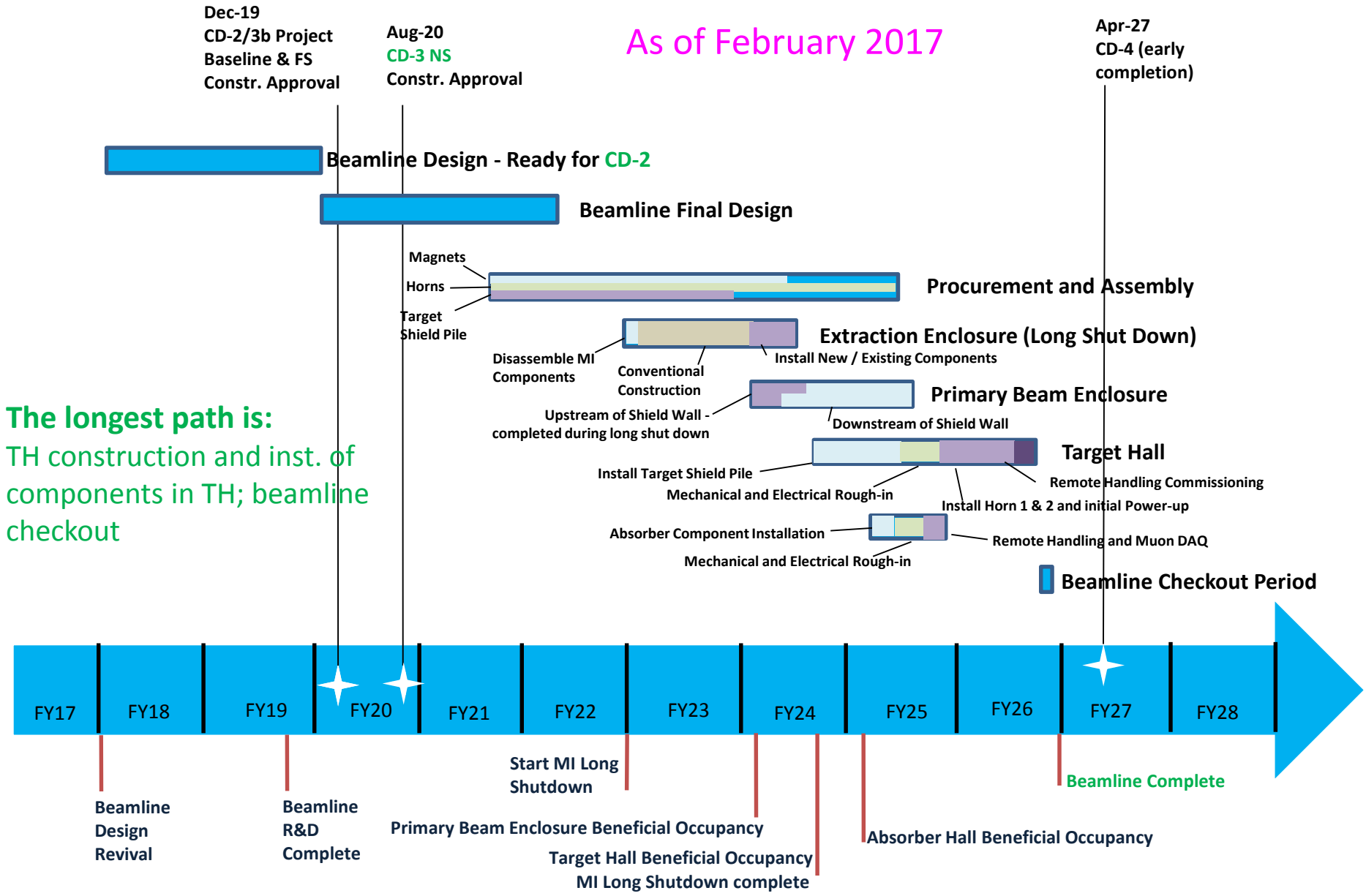
# Beamline collaboration opportunities

- Corrector magnets - IHEP/China
- Dipole magnets
- Quadrupole magnet power supplies
- Primary vacuum pumps

- Target (RAL interest)
- Target and Horn Instrumentation (including Hadron Monitor)
- Target/Baffle Support Module and Carrier
- Horn Support Modules
- Possibly one optimized Horn?
- Horn Power Supply
- Upstream decay pipe window (Interest by IHEP/China)
- Absorber core modules
- Target Chase cooling panels
- Target Chase leak tight covers
- Muon system construction (U. of Colorado and Drexel working on R&D now)

The optimized beam design opens up more opportunities for collaboration

# 131.01.03.03 Beamline Schedule Summary Overview

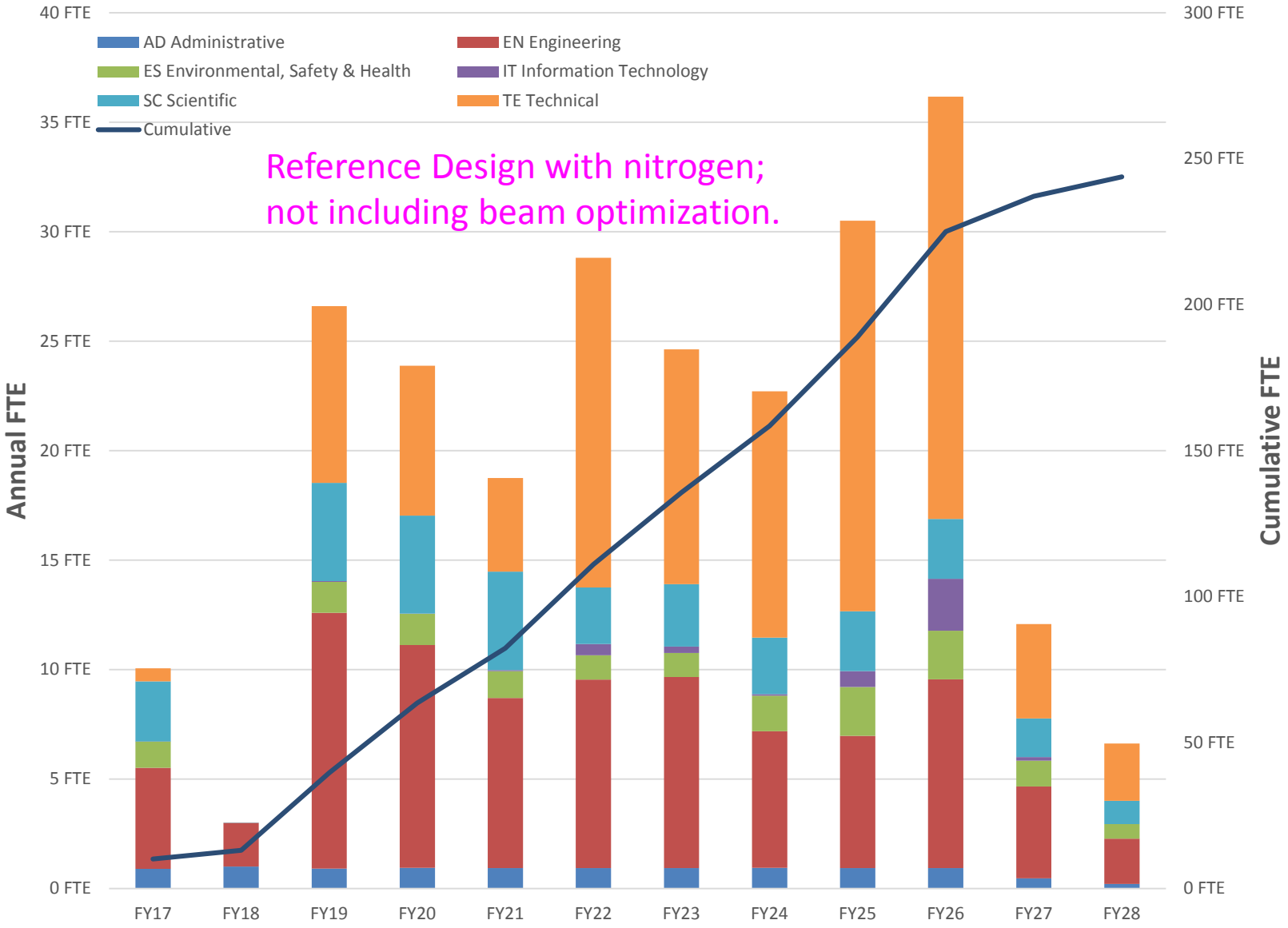


# Beamline Team's high level milestones as of Feb. 2017

- **Beamline ready for operations: September 2026**
- Beneficial occupancy of Target Hall complex: June 2024
- CD-3 approval: August 2020 (Construction starts)
- CD-2 approval: December 2019 (Baselining the entire project)
- Ready for CD-2 reviews: April 2019 (Preliminary design complete)
- **Preliminary design for the Beamline starts: October 2017**
- Decision on Beamline final conceptual design (EFIG evaluation and recommendation): September 2017
- Comprehensive technical design and cost internal and external reviews August 2017. LBNF Project Office review expected in early September 2017.

These milestones will shift according to funding availability

# Beamline DOE Labor Resource Profile



# Challenges

- 20-25% of the cost of the Beamline is expected to come from non-DOE partners (~ $35 M in BCWS not including optimization costs).
- The great majority of the non-DOE cost not covered at this point.
- Preliminary design cannot proceed unless partners identified; otherwise the default will be to use DOE Project funds.
  - 6 months in advance of such milestones discussion within the project

# Challenges

- Funding has been unstable for the Beamline requiring ramp-down and ramp-up which is inefficient and costly.
- In May we learned that the beamline effort basically has to pause in FY18.
- Unless budget restored, CD-2 and other milestones will be delayed.
- Recently informed that no scientific Intensity Frontier research effort will be supported for LBNF Beamline AD scientists in FY18. (Minimal MARS support).
- Engineering resources multi-tasking; missing; recruiting challenging when the project funding is unstable.
  - In January 2017 hired an E1 Mechanical Engineer in AD to concentrate on the LBNF Beamline
- The more we wait, the more new ideas come up requesting evaluation.

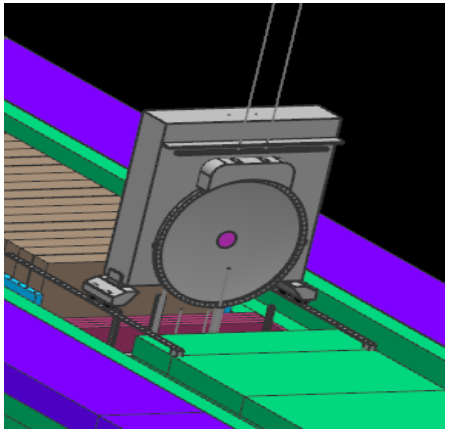
# Conclusion

- **Recent main accomplishments:**
  - With limited resources, the Beamline Team developed – and is currently costing – the conceptual engineering design of an optimized target, three horns and other impacted systems.
  - Decision taken on the optimized beamline in the Fall of 2017.
  - Decision on filling/cooling the target chase and cooling the decay pipe with nitrogen gas.
  - Conceptual design ready for a leak tight target chase to be filled with nitrogen.
  - Engaging partners. I-CRADA signed for corrector magnets with IHEP/China.
- **Several challenges that we need to overcome to be able to deliver beam to DUNE as soon as possible.**

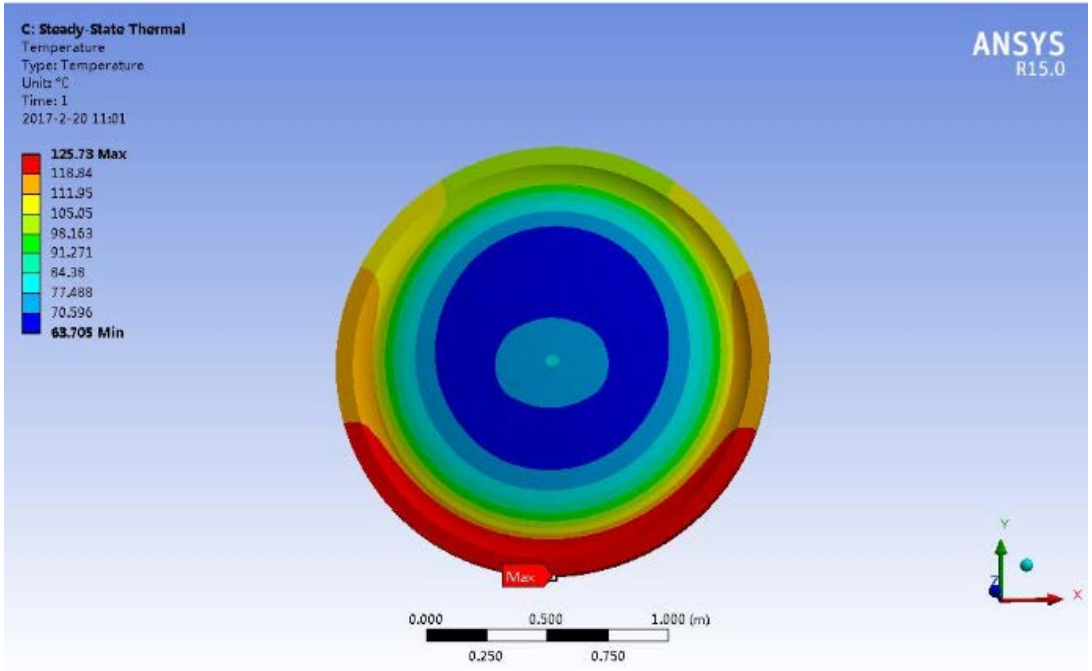
# Backup

# International Partners – IHEP/China

Upstream Decay Pipe Window: Diameter of 1.5 m. Made from Aluminum with a center portion (20 cm diameter) made from beryllium or AlBeMet



FEA analysis provides guidance for the design




Decay Pipe Window has a thick 50 mm outer ring.
We are studying its required size and potential cooling.

# Recent DOE IPR Review - Beamline overall impression

## February 28 – March 2, 2017

**Comments:**

- We were very impressed with the optimization and conceptual work done by the team. They have reached a very advanced stage for the conceptual work and all important aspects have been studied in detail. We were in particular impressed with the beam optimization task force work, the particle-matter simulation work for safety, radiation protection and beam optimization and the conceptual design work on the target chase with inert gas atmosphere.
- Conceptual design is progressing very well and that includes the new optimized design (target and three horns) and the design for target chase with inert gas atmosphere. **However, now is the time for decisions and the team needs to follow the set milestones to reach the required decisions so that technical reviews can start in July 2017.** If not, there will not be enough time for preliminary design to be ready for CD-2.

# Recent DOE IPR Review - Beamline overall impression

February 28 – March 2, 2017

**Recommendations**

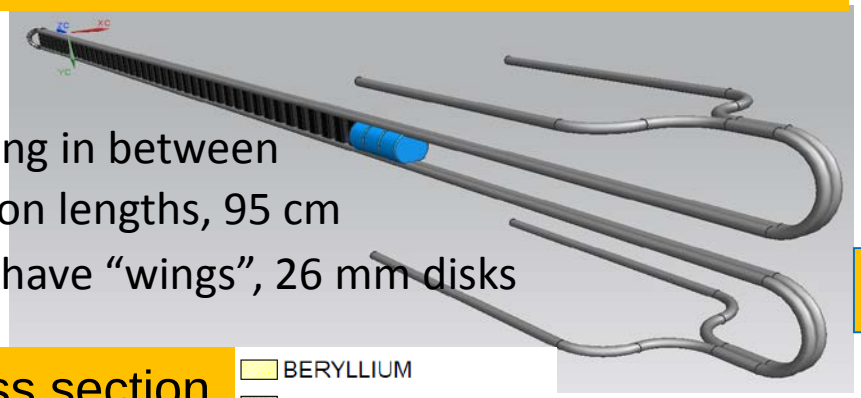
1. The project team should add all accelerator scientists to the project from FY 2018 onward.

2. The project and laboratory management must make required engineer and technical resources available for the beamline team by July, there is no margin to delay preliminary design any further.

3. The beamline team must make a firm plan, with milestones and reviews, with RAL on how to advance the new target concepts proposed by RAL and integrate into the design without perturbing the other decisions to be taken and the preliminary design work starting in October 2017.

# 1.2 MW Reference Design (CD-1R) target and horns

47 graphite target segments, each 2 cm long



0.2 mm spacing in between

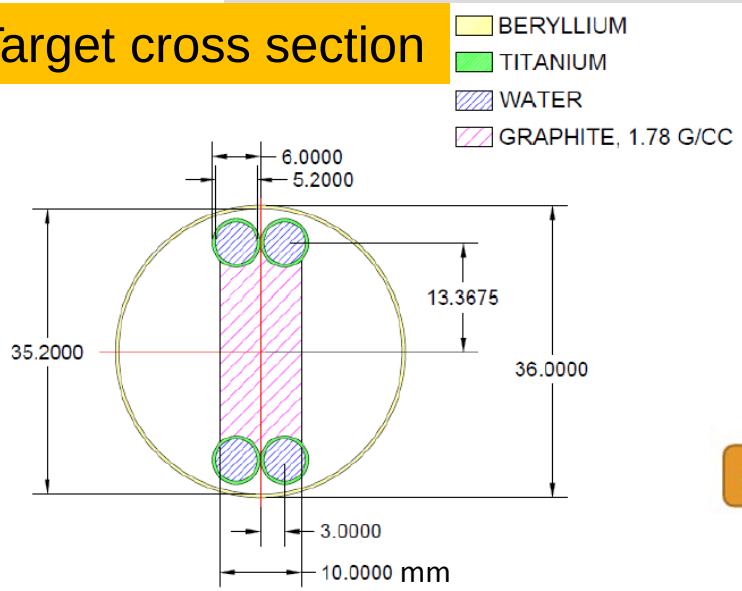
Two interaction lengths, 95 cm

First few fins have “wings”, 26 mm disks

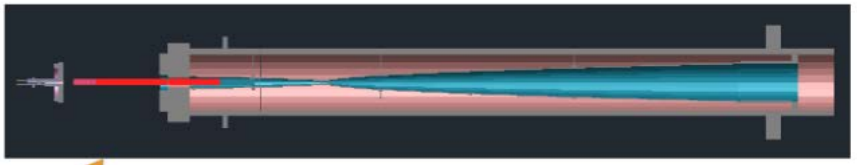
NuMI-like (low energy) with modest modifications target and (two) horns

Tunable neutrino energy spectrum

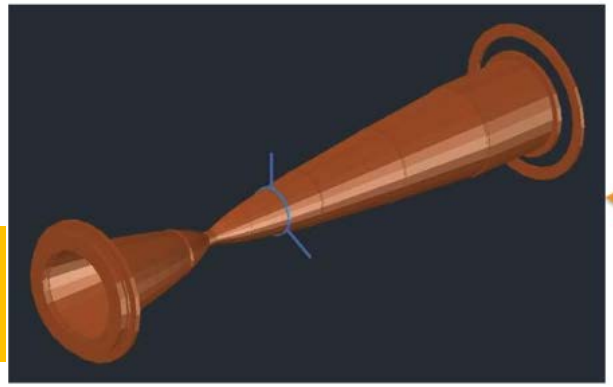
Target cross section




Operated at 230 kA for LBNF



Horn 1



Horn 2 (Inner Conductor)

New Horn power supply needed - reduced pulse width of 0.8 ms to reduce beam heating.

# Target Chase

- Shortly before the CD-1R review of July 2015, we implemented an enlarged Target Chase/Hall to be able to fit in different future designs that we were in the process of evaluating at the time of the review.

Two-horn, short-target Reference Design