



Managed by Fermi Research Alliance, LLC for the U.S. Department of Energy Office of Science

The Long-Baseline Neutrino Facility

Jim Strait, LBNE Project Director

Open meeting for the scientific community to form LBNF

5 December 2014 (CERN)

12 December 2014 (Fermilab)

Outline

- Overview of the Fermilab Neutrino Program
- Increasing proton beam power: PIP and PIP-II
- The Facilities for a long-baseline experiment
 - The facilities team for LBNF
 - Neutrino Beamline
 - Sanford Underground Research Facility
 - Conventional Facilities at Fermilab and SURF
 - Cryogenic infrastructure
- Technically limited schedule
- Summary and Conclusions

Accelerator-Based Neutrino Program at Fermilab

Fermilab hosts an active, diverse, international accelerator-based neutrino program

- Two neutrino beams in operation and a third under design
- Four experiments currently taking data
- Three completed experiments analyzing data
- One experiment under construction
- Two experiments under design
- One proposal reviewed by the PAC and under consideration by Fermilab management
- Several experimental proposals submitted or in development
- Various R&D programs proposed or under way
- Supporting test beam program for detector development and calibration.

The Fermilab Neutrino Program Hosts Collaborators from across the globe:

Brazil, Canada, Chile, Czech Republic, Greece, India, Italy, Mexico, Peru, Poland, Russia, Switzerland, UK, US, ...

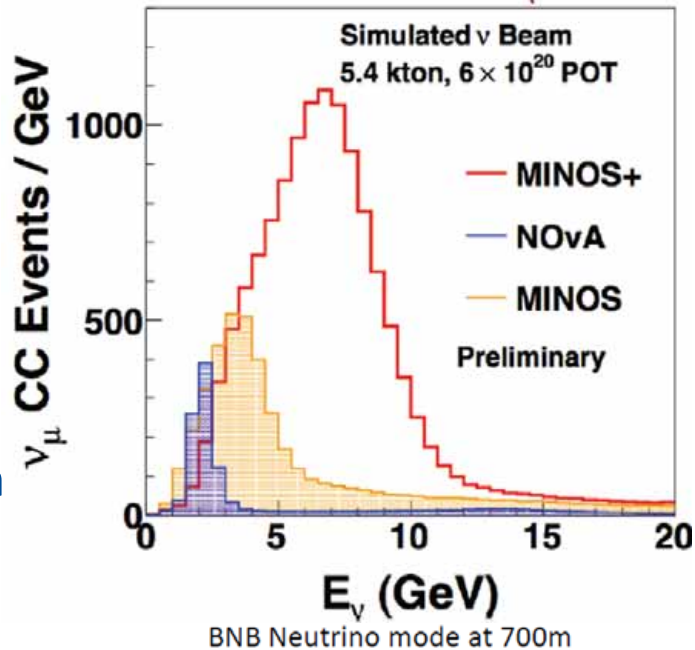
Fermilab Accelerator Complex



NuMI and Booster Beams

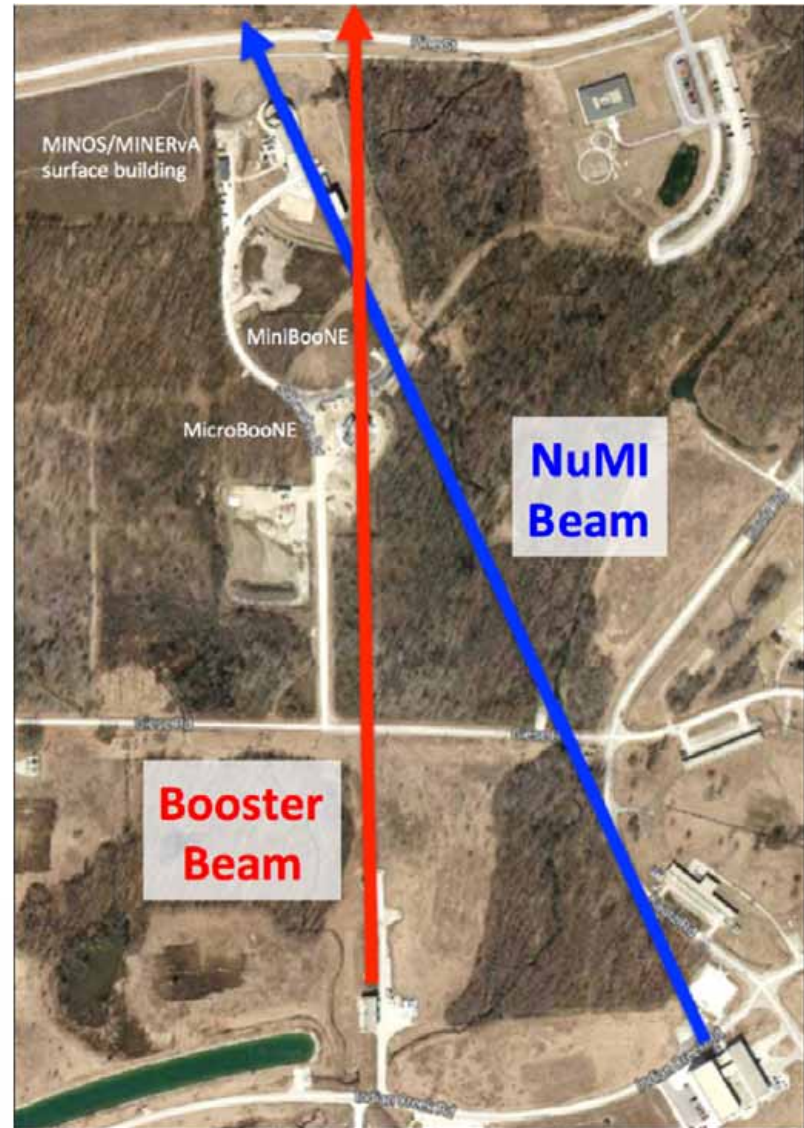
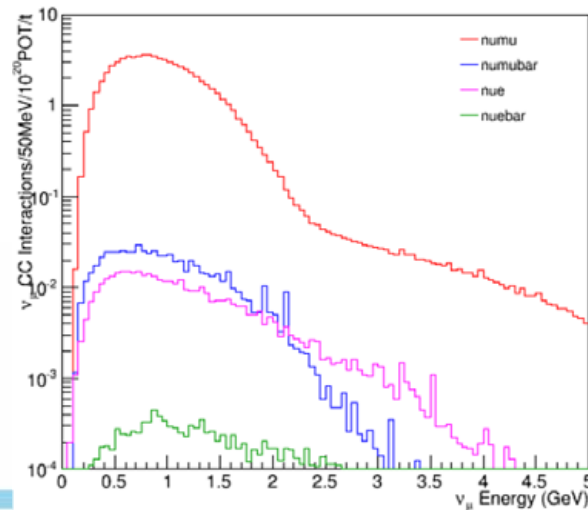
NuMI:

- tunable
1 GeV to
>10 GeV
- Near hall
at 1 km
- Far detectors
735 – 810 km



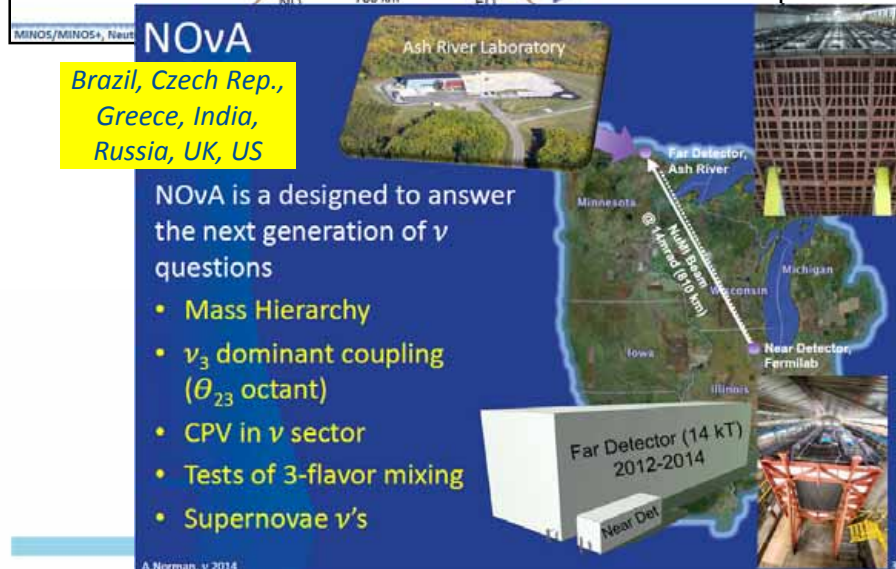
BNB:

- Low energy
0.1 – 1.5 GeV
- Focused on
short-baseline
oscillations and
cross sections

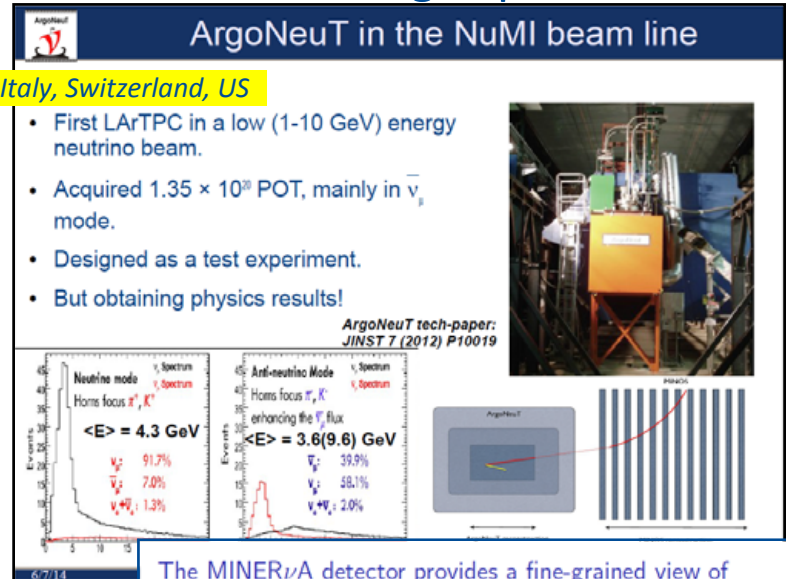


Experiments in the NuMI Beam

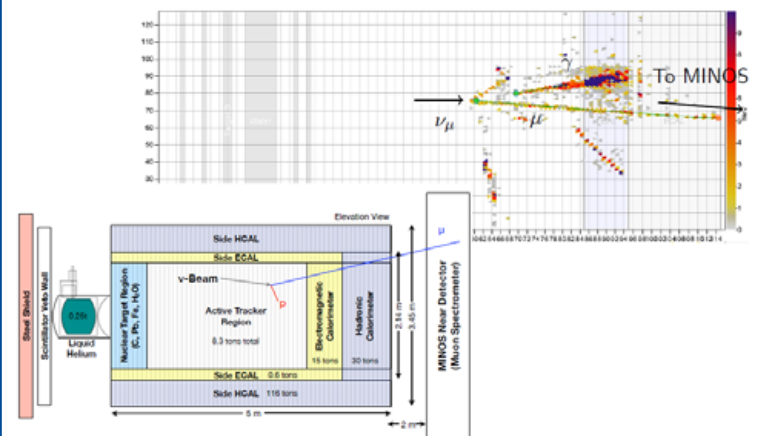
Long-baseline oscillation experiments



Neutrino scattering experiments



The MINERvA detector provides a fine-grained view of neutrino-nucleus interactions



Brazil, Chile, Mexico, Peru, Russia, Switzerland, US

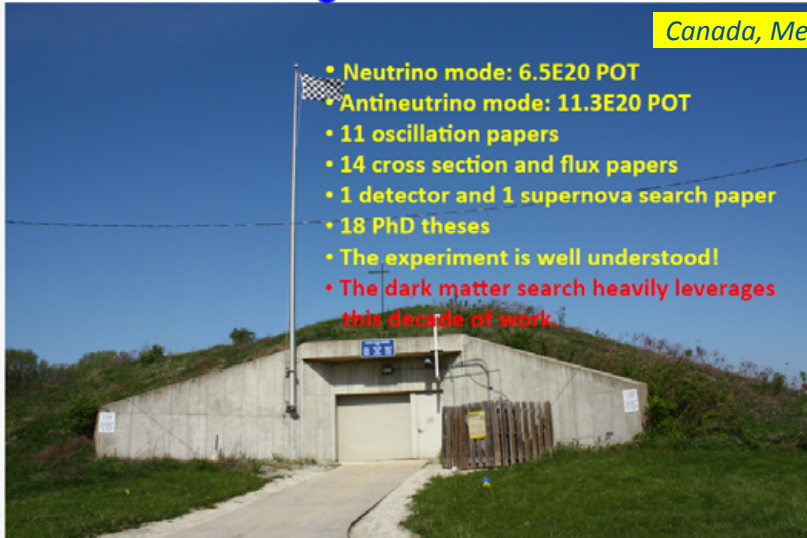
Experiments in the Booster Neutrino Beam

Testing short-baseline anomalies ... sterile neutrinos?

Ten Years of Successful MiniBooNE Running and Results!

Canada, Mexico, UK, US

- Neutrino mode: 6.5E20 POT
- Antineutrino mode: 11.3E20 POT
- 11 oscillation papers
- 14 cross section and flux papers
- 1 detector and 1 supernova search paper
- 18 PhD theses
- The experiment is well understood!
- The dark matter search heavily leverages this decade of work.



01/22/2014

MiniBooNE Run Request PAC 2014

12

MicroBooNE

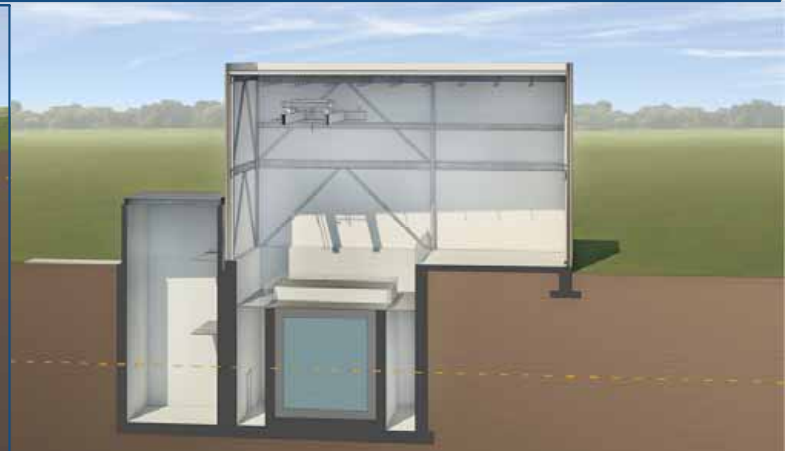
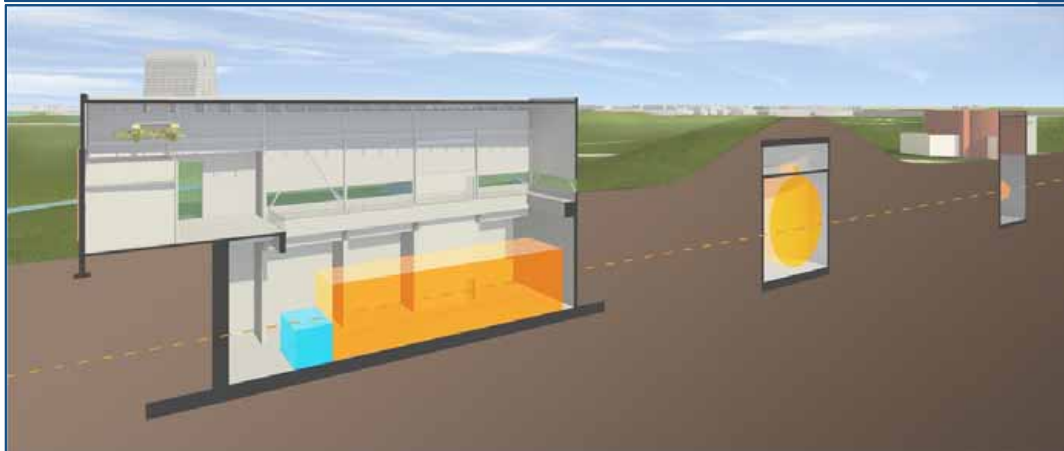


Switzerland, UK, US

Fermilab Short Baseline Neutrino (SBN) Program

- Utilize successful Booster Neutrino Beamline (BNB) developed for MiniBooNE
- In 2015 next phase: MicroBooNE (approved for 6.6E20 P.O.T.)
- In 2018: Three LAr-TPC detectors:
 - Near: New detector using LBNE technology @ 110m from BNB target *Switzerland, UK, US*
 - Middle: MicroBooNE @ 470m *Switzerland, UK, US*
 - Far: refurbished ICARUS detector moved from Gran Sasso, Italy @ 600m *Italy, Poland, Russia, Switzerland, US*
- Motivations
 - Science: precise study of ν anomalies from the MiniBooNE and LSND experiments. Search for Sterile ν 's
 - R&D: continued development of LAr-TPC technology for LBNF program
 - Build international partnerships for LBNF program

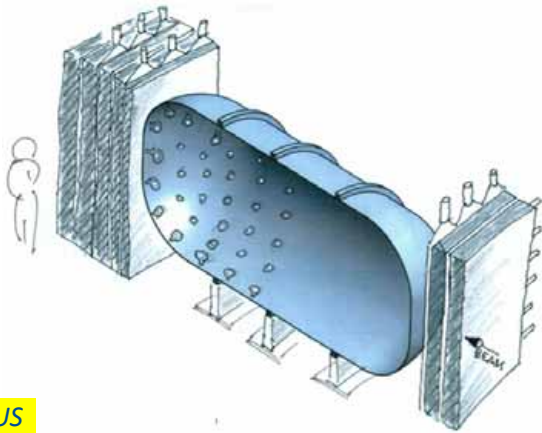
SBN Program Layout



SBN Program Development

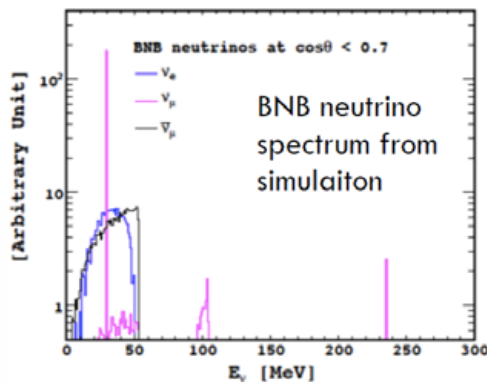
- International partnership of the three collaborations developing joint proposal for submission to January 2015 PAC meeting
 - More than 40 institutions from 5 countries including 4 DOE labs and CERN
 - Strong support from US DOE and NSF, INFN, and CERN. Additional support requests to CH NSF and UK STFC
- Very Fast timeline
 - 2014 – Proposal preparation initial design and logistics
 - 2014 – Civil construction start, near detector design, T600 refurbishing
 - 2016 – Civil construction complete, near detector construction, T600 refurbishing
 - 2017 – Detector installation
 - 2018 – Beam operations with all three detectors
- Support expected from US DOE, US NSF, INFN and CERN.

Additional Possible Experiments in the Booster Beam



UK, US

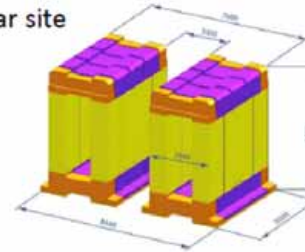
ANNIE: Measure ν -induced backgrounds relevant for large water detectors using an Optical Time Projection Chamber in BNB



Calibrate LAr TPC response to low-energy neutrinos with stopped pion beam

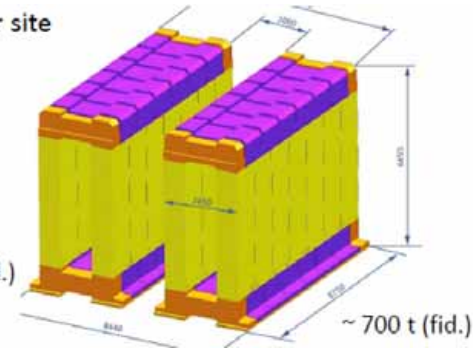
Croatia, Italy, Russia, Switzerland

Near site



~ 300 t (fid.)

Far site



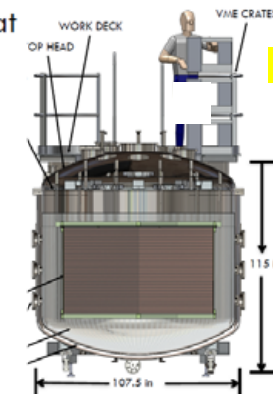
~ 700 t (fid.)

Short-baseline ν_μ -disappearance measurement in BNB (NESSiE)

space is available in and out of building at points A, B and C



CAPTAIN

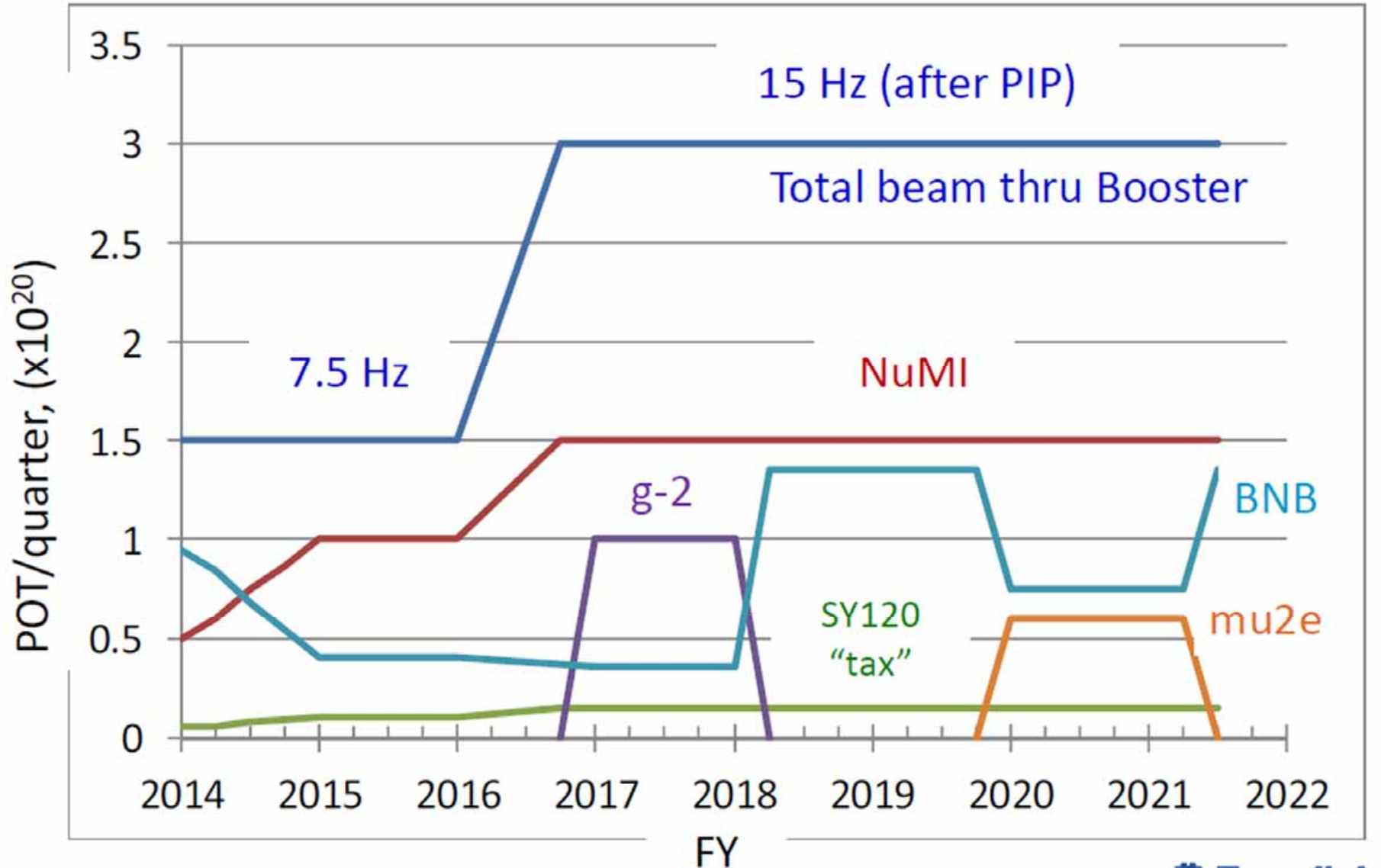


US

Increasing beam intensity

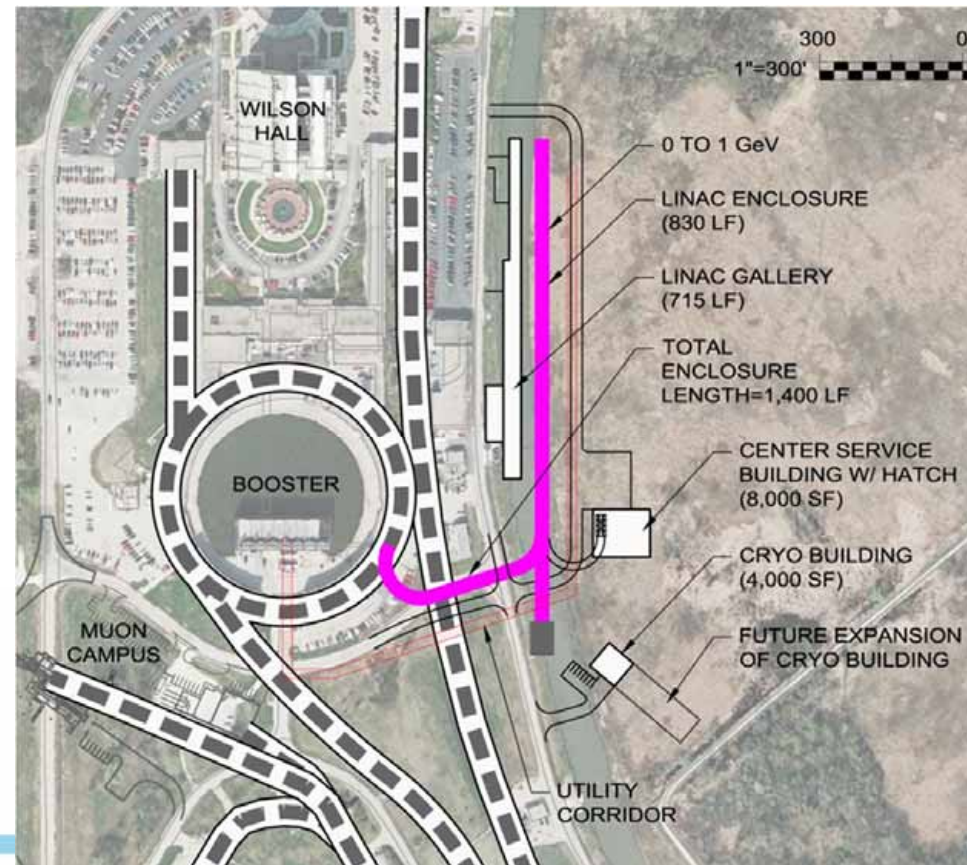
- Upgrades to the Main Injector and Recycler done as part of the NOvA construction will enable doubling the NuMI beam power to 700 kW
 - Convert Recycler to proton-stacking ring
 - Increase Main Injector ramp rate
 - ~10% increase in intensity per pulse
- Proton Improvement Plan (PIP) to increase proton flux from Booster to the Main Injector
 - Refurbish Booster RF system: 7.5 \rightarrow 15 Hz beam operation
 - Upgrades to Linac and Booster for higher reliability
- Combined upgrades will deliver 700 kW to NOvA and increase the intensity of the Booster Neutrino Beam.

Proton delivery scenario (approximate)



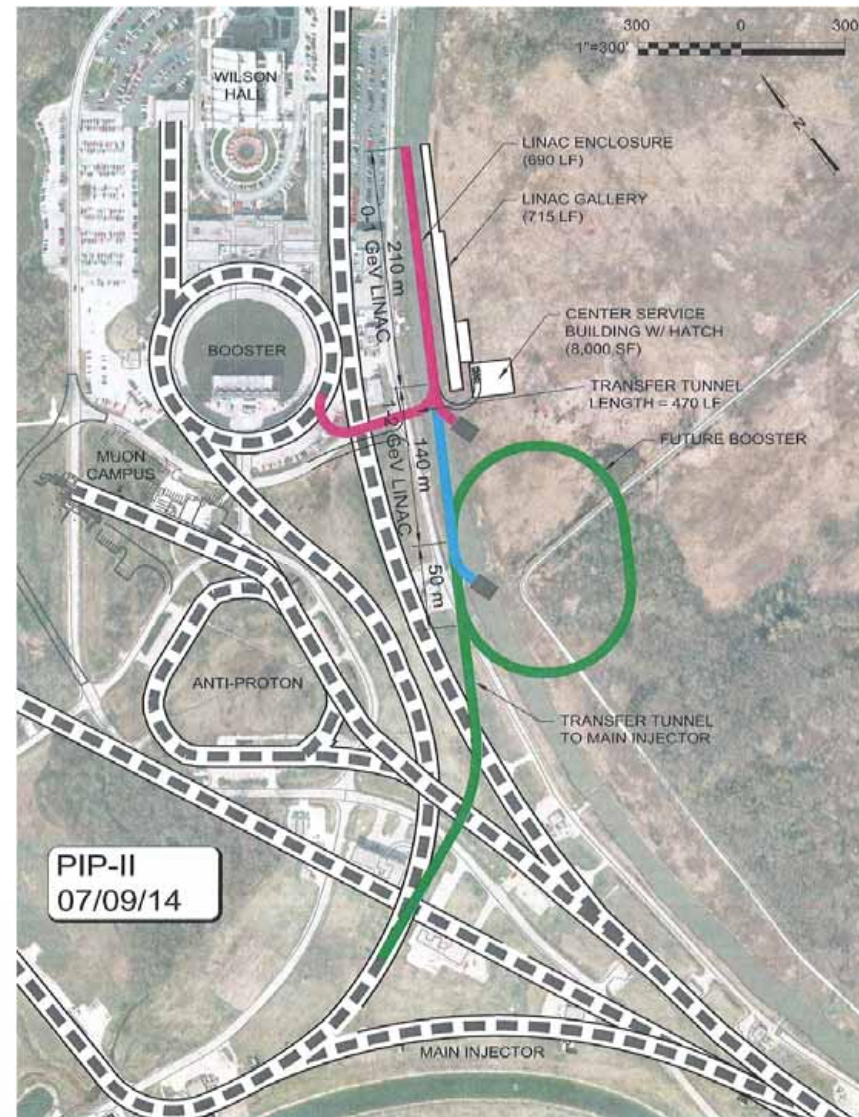
Proton Improvement Plan II (PIP-II)

- Goal is to increase Main Injector beam power to 1.2 MW.
 - Replace the existing 400 MeV linac with a new 800 MeV superconducting linac => 50% increase in Booster intensity.
 - Shorten Main Injector cycle time 1.33 → 1.2 sec.
- Build this concurrently with LBNF => 1.2 MW to LBNF from $t = 0$.
- This plan is based on well-developed SRF technology.
- Developing an international partnership for its construction
- Strong support from DOE and P5



Flexible Platform for the Future

- Future upgrade would provide > 2 MW to LBNF
- Flexibility for future experiments
 - 100's kW at 800 MeV
 - 100's kW at few GeV, depending on design of next upgrade
 - Example shown is for 2 GeV SRF linac + new Rapid Cycling Synchrotron



Long-Baseline Neutrino Facility

Fermilab is prepared to host a Long-Baseline Neutrino Facility. Working with international partners it will provide the infrastructure required to carry out a world-leading long-baseline neutrino oscillation experimental program.

The facilities will include:

- A neutrino beam capable of operating at 1.2 MW and upgradeable to at least 2.4 MW
- Far site infrastructure to house a massive LAr TPC far detector 1300 km from Fermilab at the Sanford Underground Research Facility,
- Near site infrastructure to house the near detector
- Major technical infrastructure such as cryostats and cryogenic systems for LAr TPC detector(s).

The LBNF Facilities Team

The work so far has been done mainly by the LBNE Project Team, already with significant international collaboration: *China, Finland, Japan, Switzerland, UK, US, ...*

- Beamline: Fermilab with collaborations with UTA, RAL, RADIATE Collaboration, CERN, US-Japan Task Force, IHEP/Beijing, and others.
- Conventional Facilities: Fermilab, SURF and contractors; collaboration initiated with LAGUNA-LBNO team
- Cryostat and cryogenic systems: Fermilab; collaboration initiated with CERN and with LAGUNA-LBNO team.

The LBNF team will be built on this foundation, with expanded collaboration as this becomes a truly international program.

- Expanded roles for existing partners
- Augmented by additional partners

The LBNF Facilities

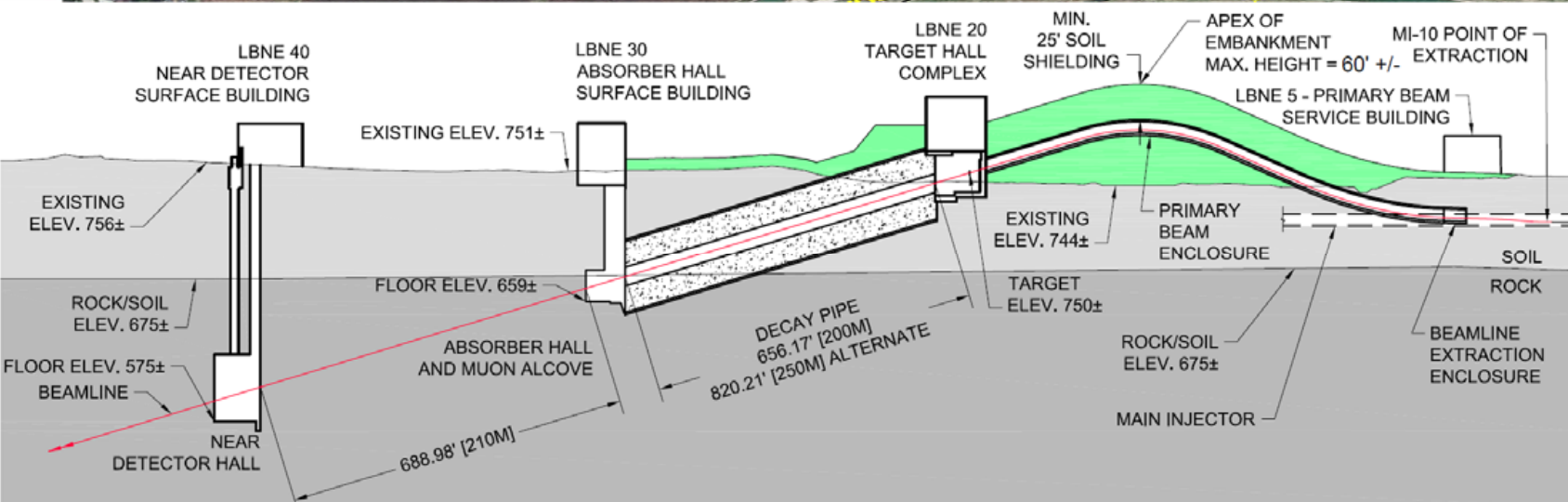
- The facilities team has been working with the scientific community to develop facilities to support the experimental program.
 - Has worked for many years with the LBNE Collaboration
Armenia, Brazil, Czech Rep., India, Italy, Japan, Russia, UK, US
 - During the past year, have expanded to also work with the LAGUNA-LBNO Collaboration
Bulgaria, Finland, France, Germany, Greece, Italy, Japan, Poland, Romania, Russia, Spain, Switzerland, Turkey, UK
- The LBNF facilities team will work with the new Collaboration, which will provide scientific and technical requirements for the LBNF experiment, to design and build the facilities that will enable a world-leading long-baseline program.
- The slides that follow summarize the current facility designs on which the new LBNF facility designs will build.

Beamline for a new Long-Baseline Neutrino Facility

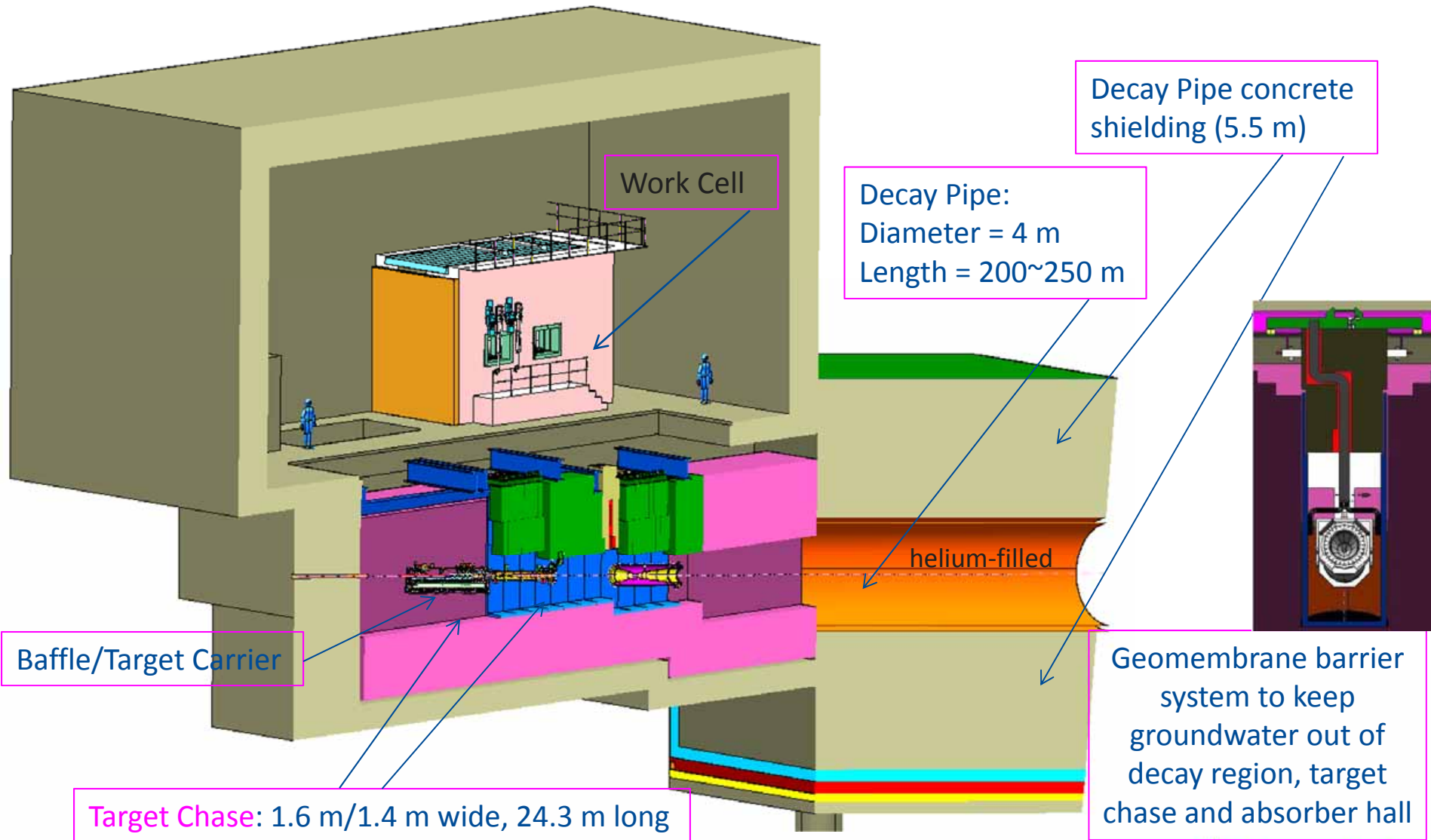
A design for a new neutrino beam at Fermilab is under development in the context of the LBNE Project, which will support the new Long-Baseline Neutrino Facility.

- Directed towards the Sanford Underground Research Facility (SURF) in Lead, South Dakota, 1300 km from Fermilab.
- Beam spectrum to cover 1st (2.4 GeV) and 2nd (0.8 GeV) oscillation maxima => Cover 0.5 ~ 5 GeV
- All systems designed for 1.2 MW initial proton beam power.
- Facility is upgradeable to ≥ 2.4 MW proton beam power.

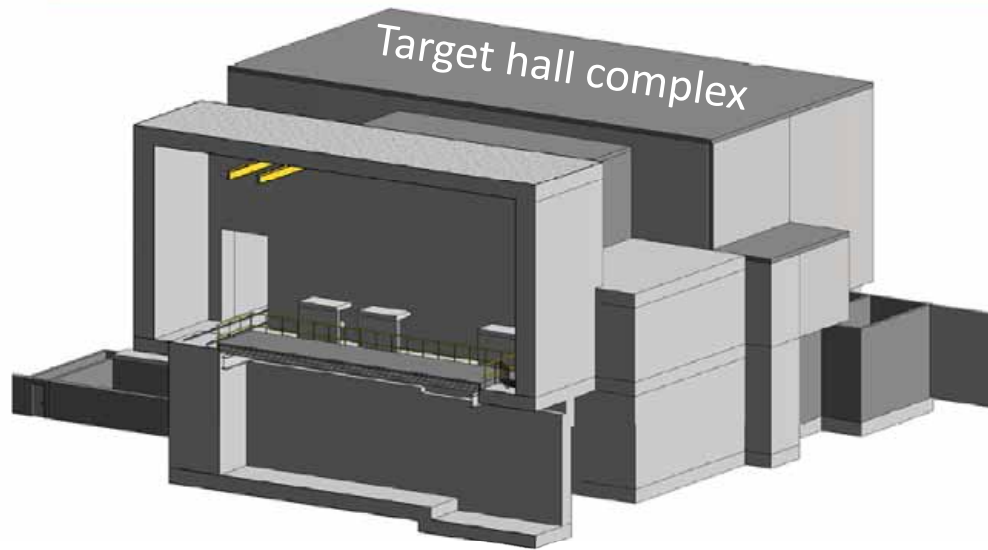
Beamline for a new Long-Baseline Neutrino Facility



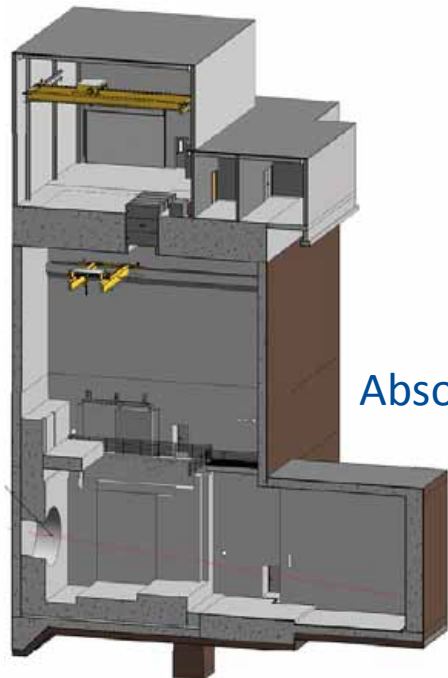
Target Hall and Decay Pipe Layout



Conventional Facilities Designs



Absorber hall



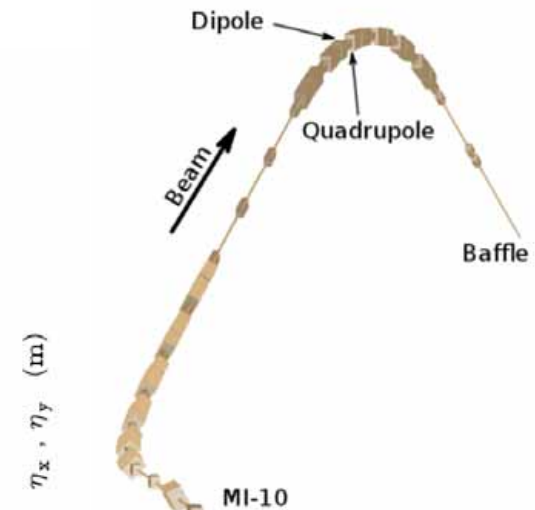
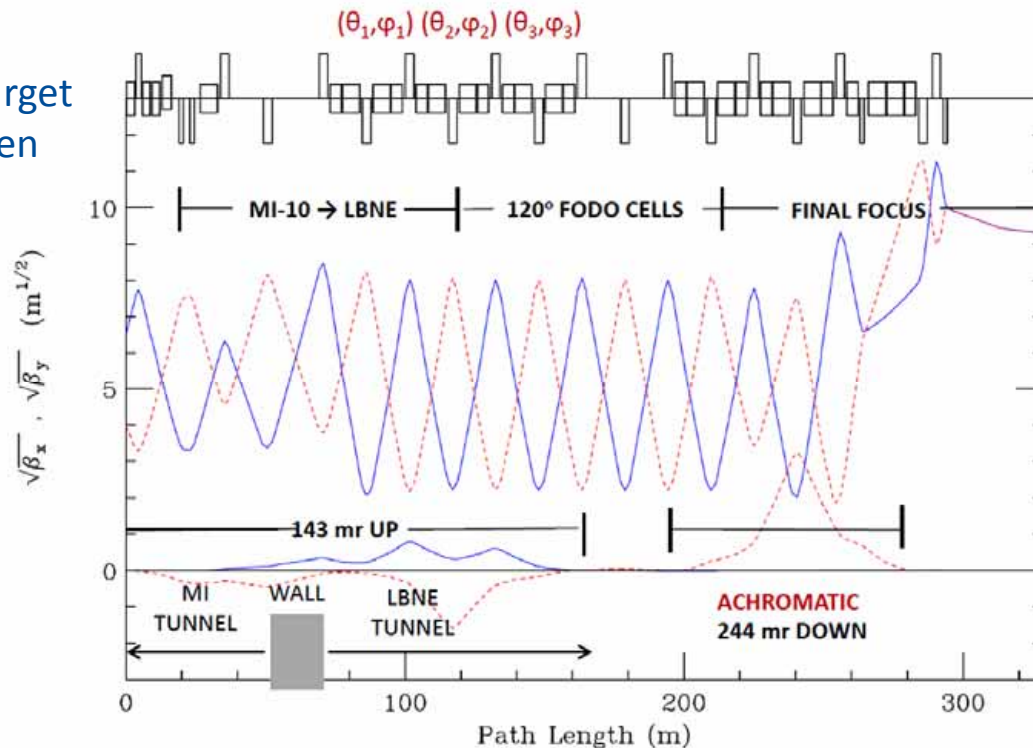
Near Detector Hall and Surface Building



Primary Beam and Lattice Functions

- The LBNF Primary Beam will transport 60 - 120 GeV protons from MI-10 to the LBNF target to create a neutrino beam. The beam lattice points to 79 conventional magnets (25 dipoles, 21 quadrupoles, 23 correctors, 6 kickers, 3 Lambertsons and 1 C magnet).

Beam size at target
tunable between
1.0-4.0 mm



STRUCT/MARS simulations have shown that highest beam loss rate takes place right at the apex of beamline

Horizontal (solid) and vertical (dashed) lattice functions of the LBNF transfer line

The final focus is tuned for $\sigma_x = \sigma_y = 1.50$ mm at 120 GeV/c with $\beta^* = 86.33$ m and nominal MI beam parameters $\epsilon_{99} = 30\pi$ μm & $\Delta p_{99}/p = 11 \times 10^{-4}$

Components inside the target chase

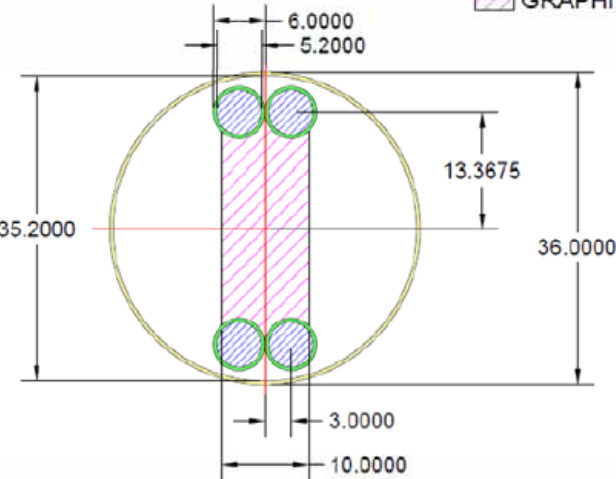
Baffle

47 graphite target segments, each 2 cm long

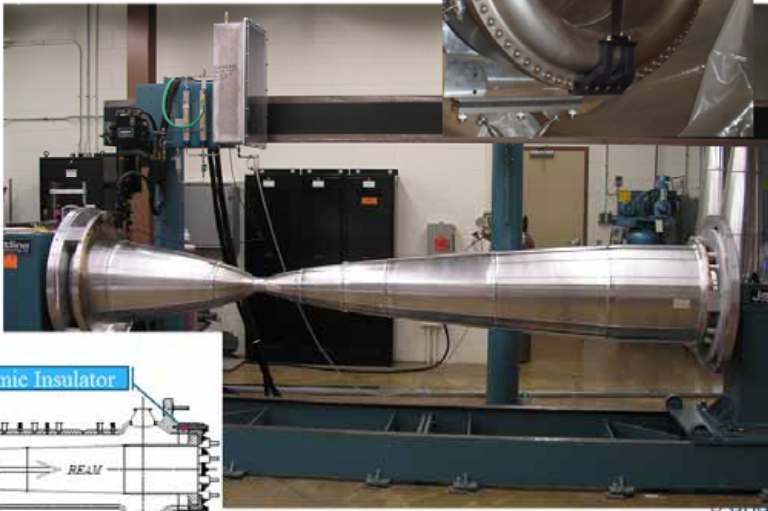


Target cross section

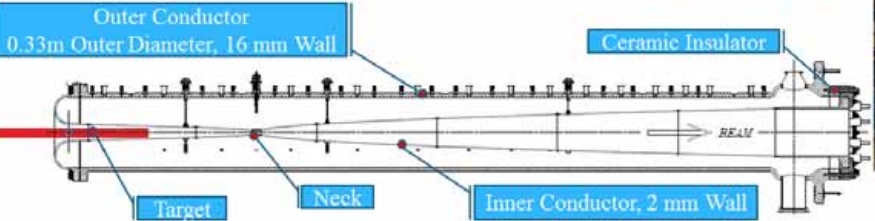
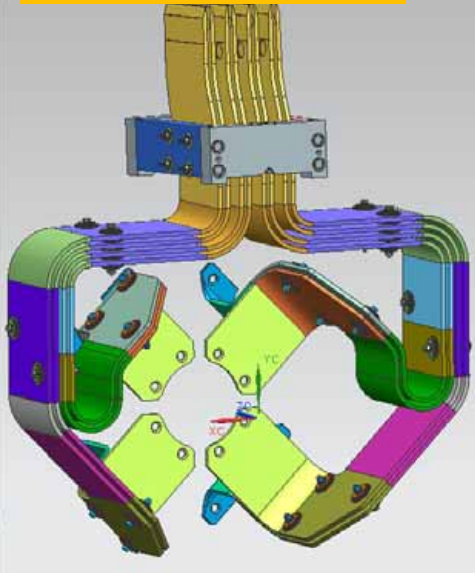
- BERYLLIUM
- TITANIUM
- WATER
- GRAPHITE, 1.78 G/CC



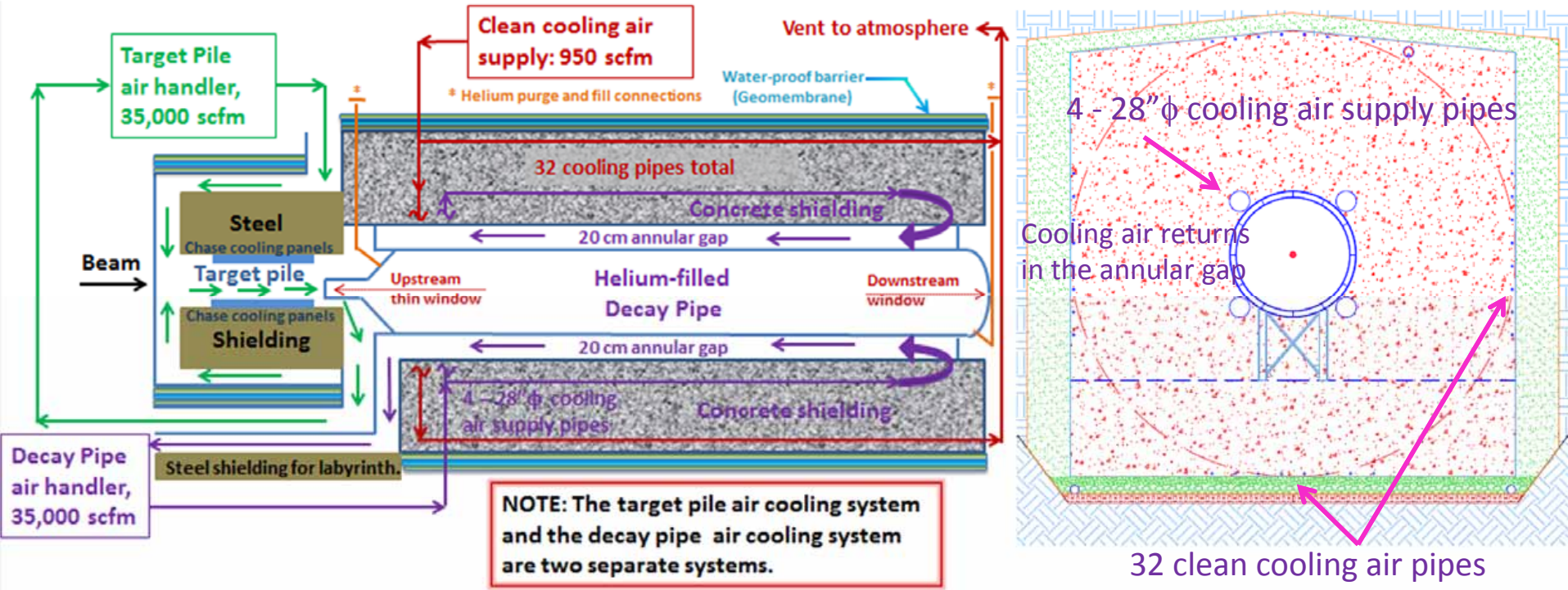
Horn



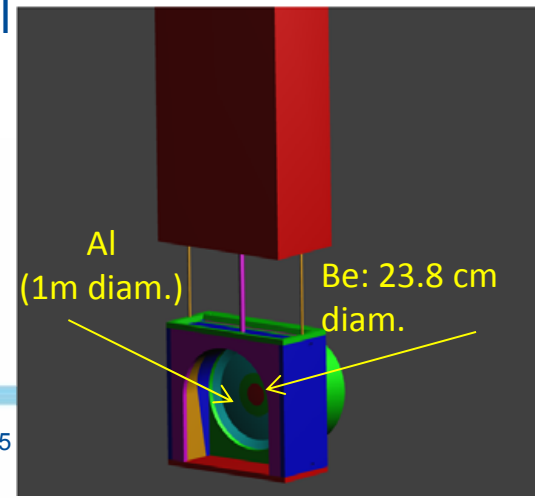
Horn Stripline



Helium-filled/Air-cooled Decay Pipe



- Concentric Decay Pipe. Both pipes are ½" thick carbon steel
- Decay pipe cooling air supply flows in four, 28" diam. pipes and the annular gap is the return path
- The helium-filled decay pipe requires that a replaceable, thin, metallic window be added on the upstream end of the decay pipe

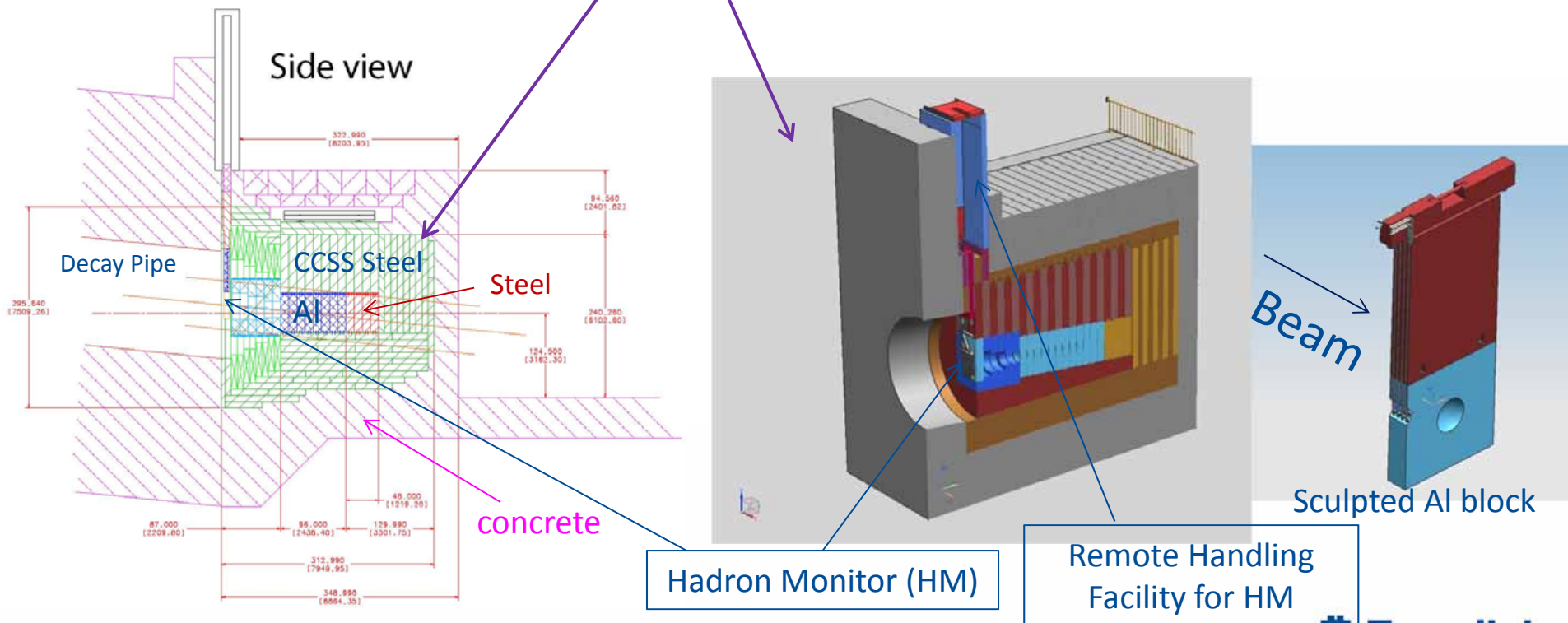


Absorber Complex – Longitudinal Section

The Absorber is designed for 2.4 MW

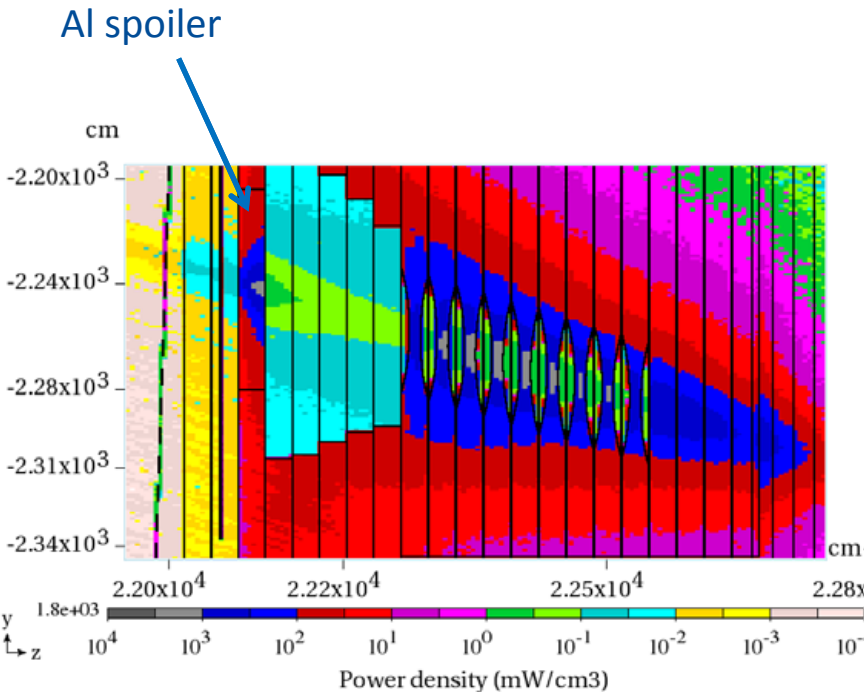
A specially designed pile of aluminum, steel and concrete blocks, some of them water cooled which must contain the energy of the particles that exit the Decay Pipe.

Thermal, structural, mechanical engineering development in progress



Absorber Design/MARS Simulations (2.4 MW)

9 sculpted Al blocks and 4 solid Al blocks in the core

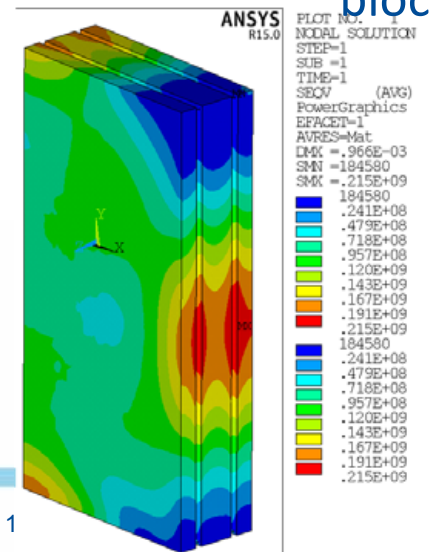
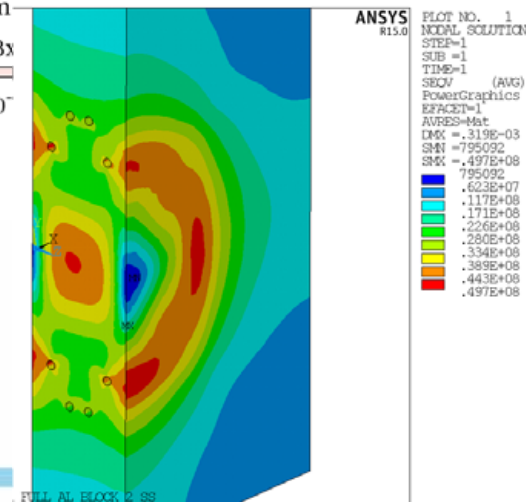
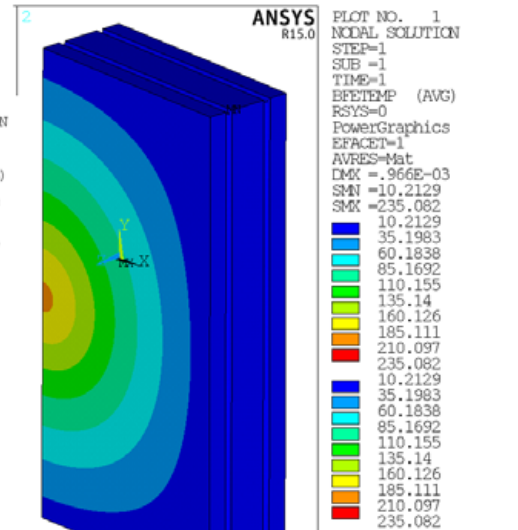
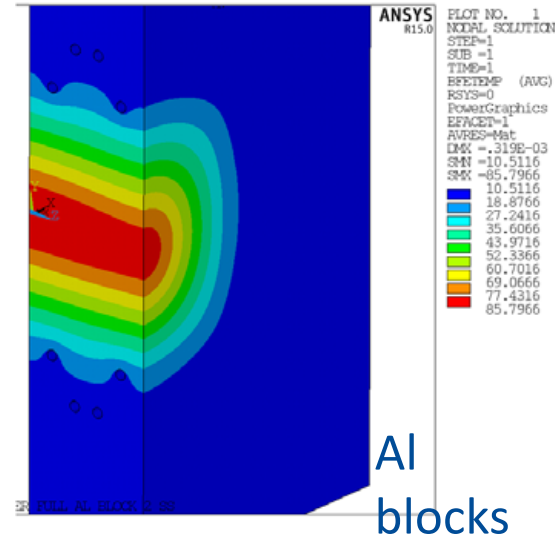


Max Temp Al: 86°C

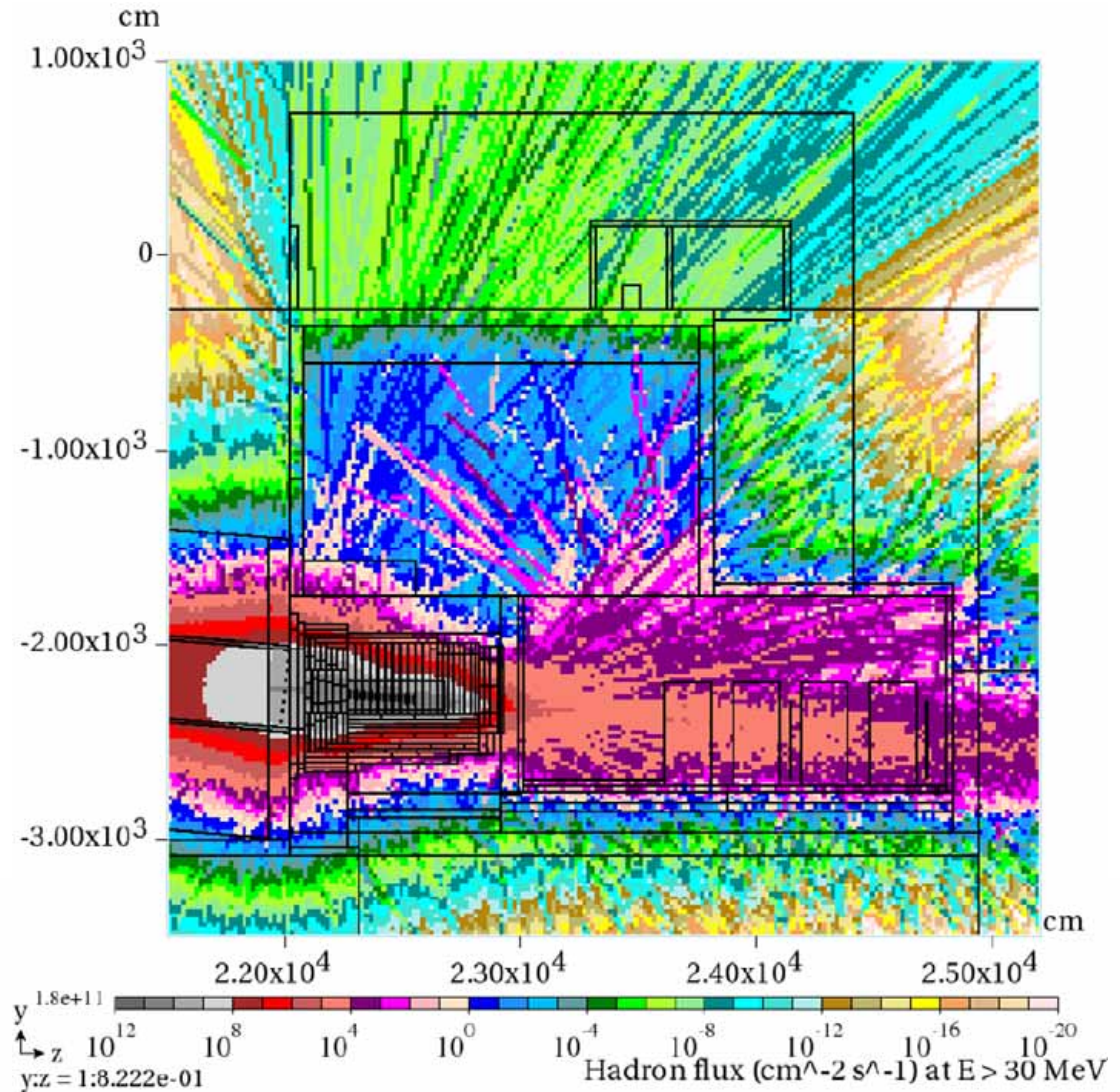
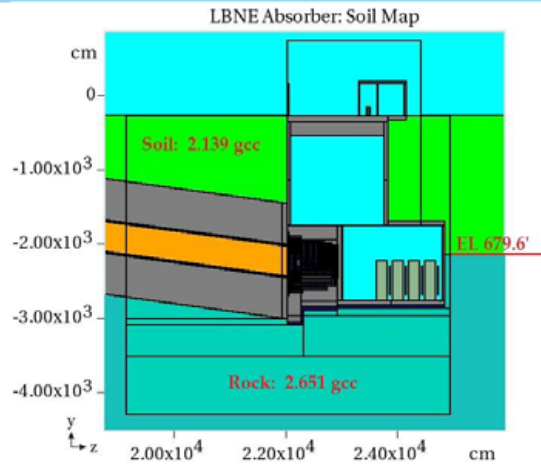
Max VM stress Al: 50 MPa at water line

Max Temp steel: 235°C

Max VM stress Al: 215 MPa

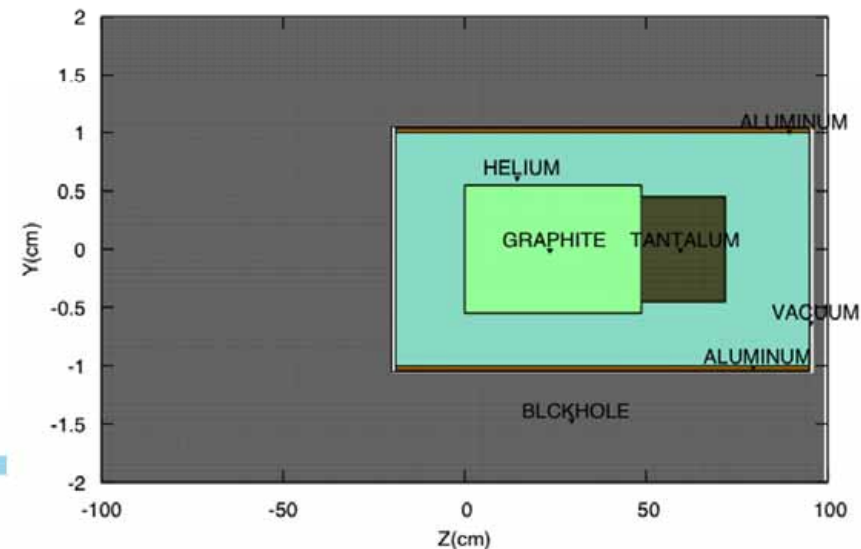
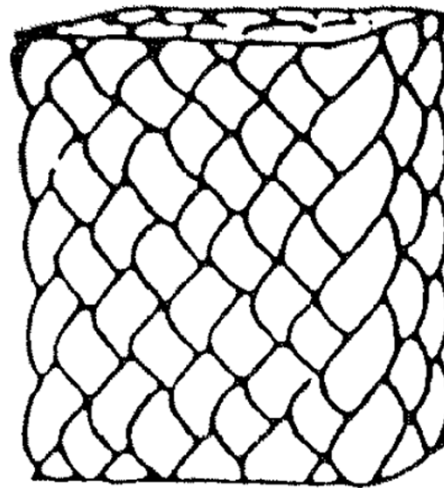
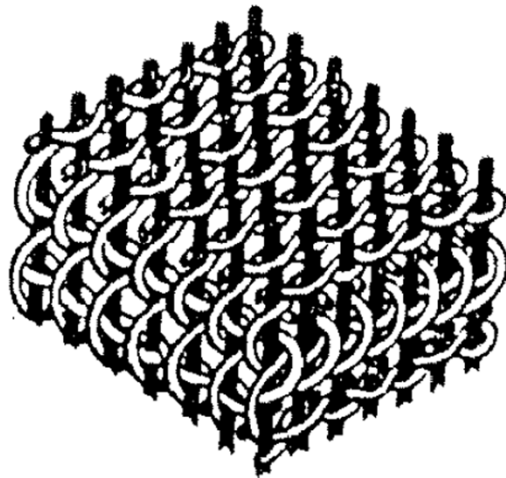
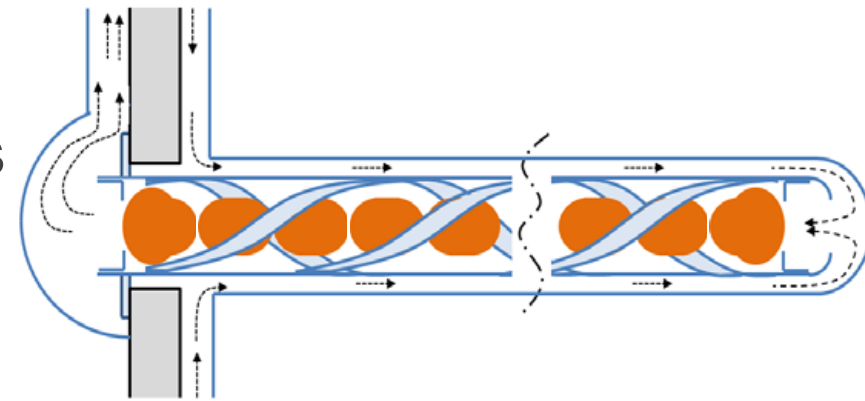
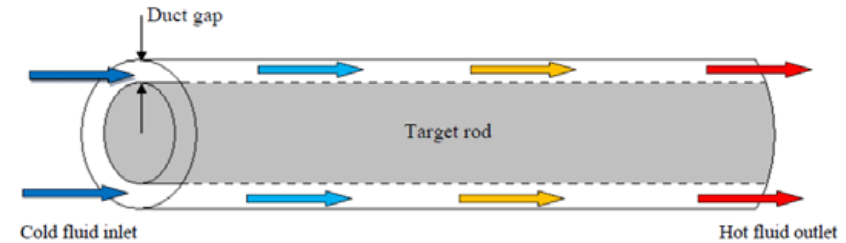


Hadron Flux ($\text{cm}^{-2} \text{s}^{-1}$) at $E > 30 \text{ MeV}$ (2.4 MW)

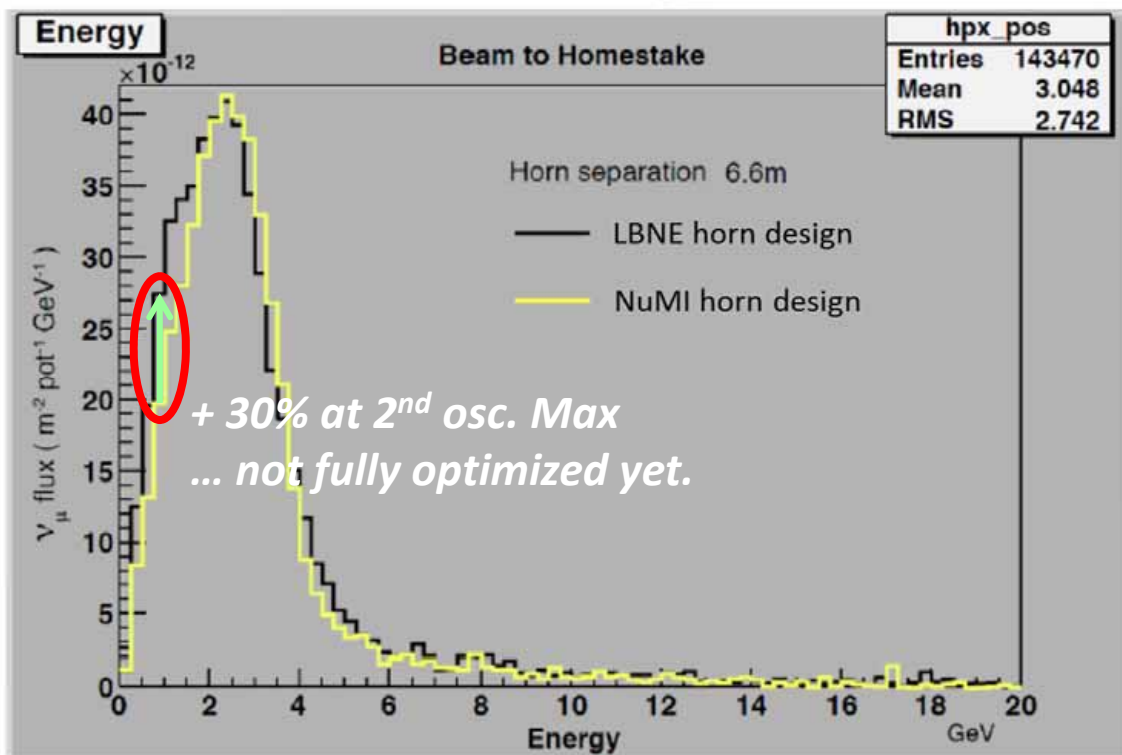
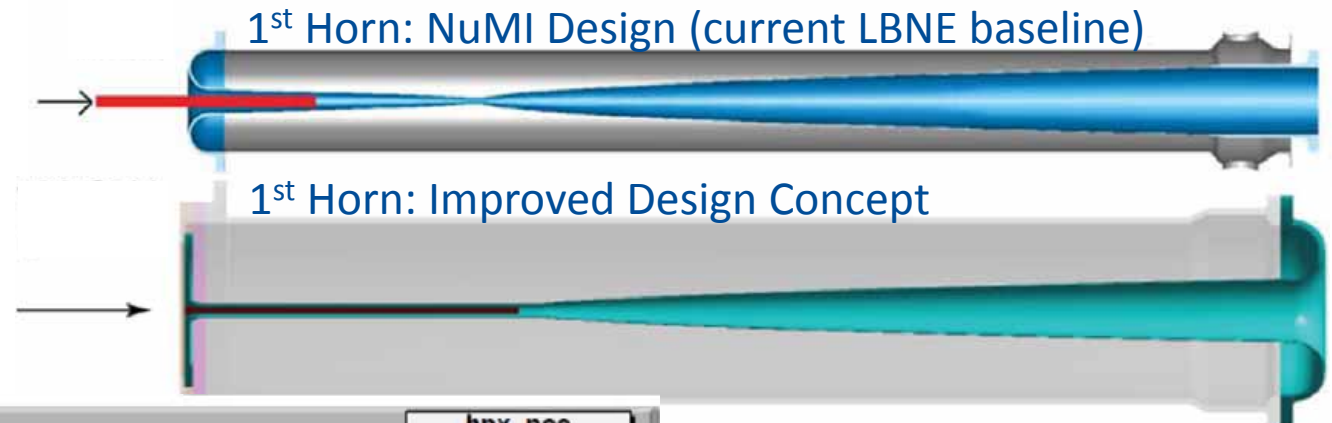


Novel Target Designs

- High heat-flux coolants
 - Elimination of water
- Composite targets
- Segmentation
- Robust materials and assemblies



Improved Focusing for Second Oscillation Maximum



Significant improvements are possible and needed, which collaborators could bring into the design of the LBNF beam design.

CN2PY ν -beam optimisation

► Beam target and focusing system optimization using Genetic Algorithm

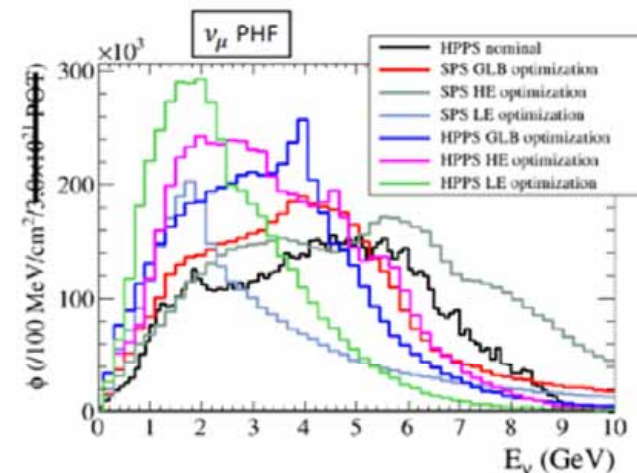
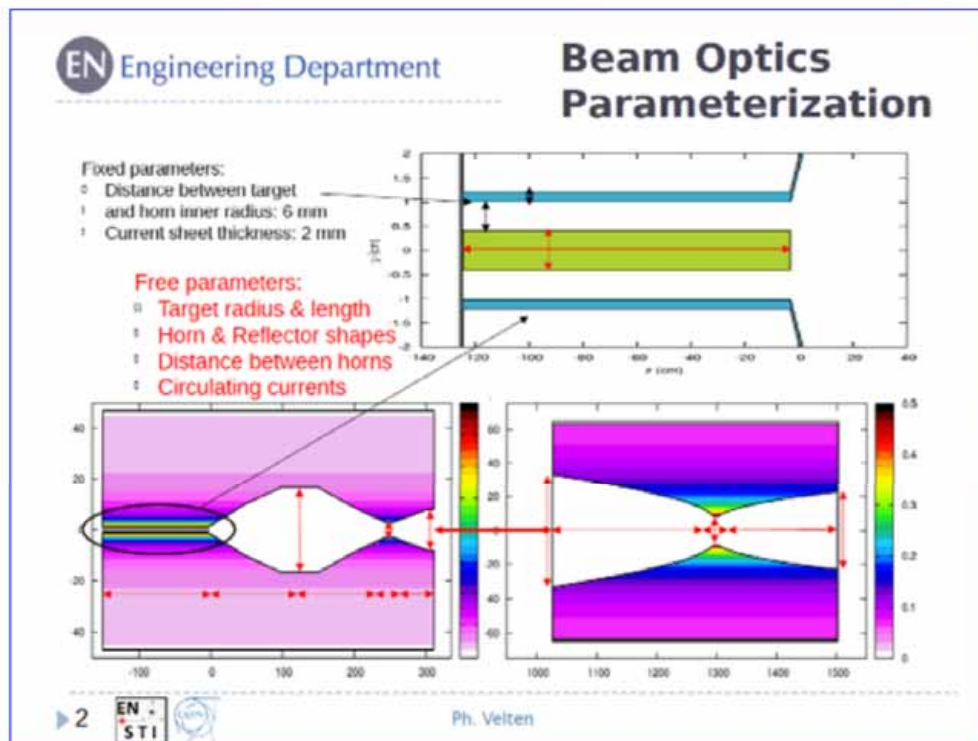
- Multi-variable analysis of horn/reflector parameters

- Optimization:

- use **GLOBES** to maximize the δ_{CP} sensitivity at the FD

- **HE-optimization**: maximum yield of ν -s in the range [1-10] GeV

- **LE-optimization**: maximum yield of ν -s in the range [1-2] GeV



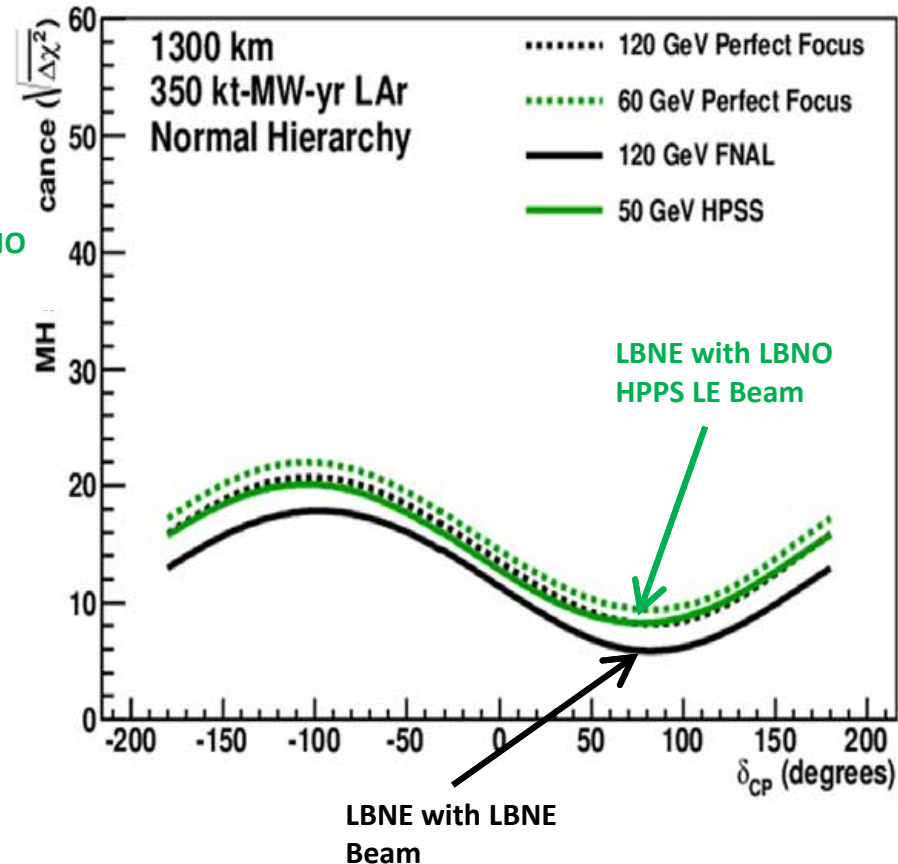
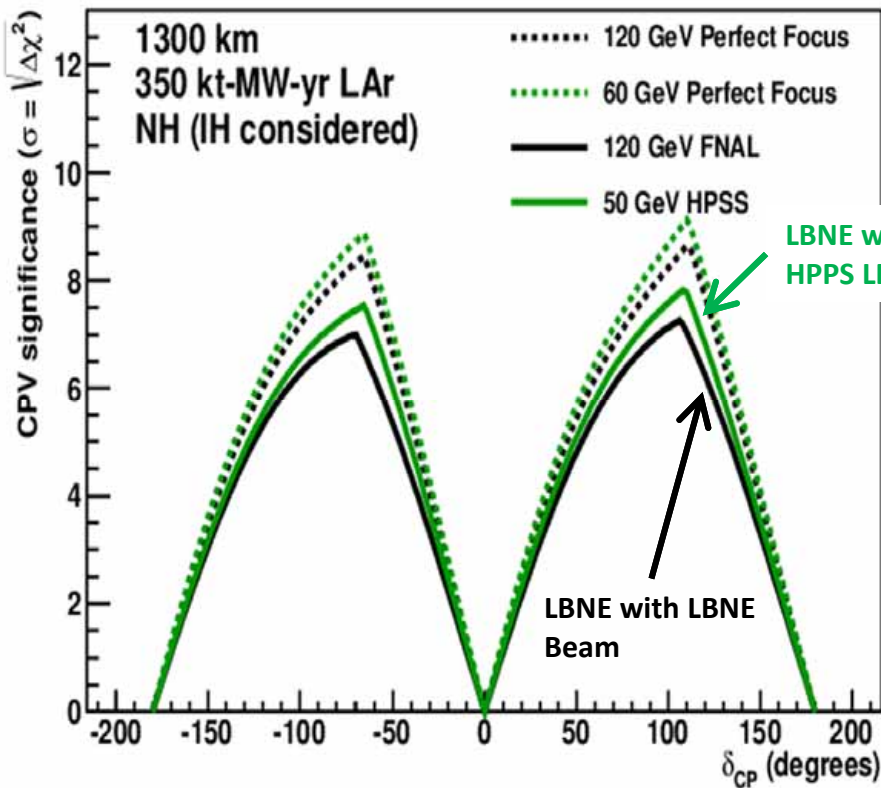
POT normalization for SPS: 3.75E+20

POT normalization for HPPS: 3.0E+21

► New optimization for CDR, using additional engineering constraints:

- R_{min} horn ~ 27 mm
- Same relative position horn/reflector for 400/50 GeV beams
- Target length < 1.3 m

Apply LBNO-design low-energy beam (HPPS LE) to LBNE



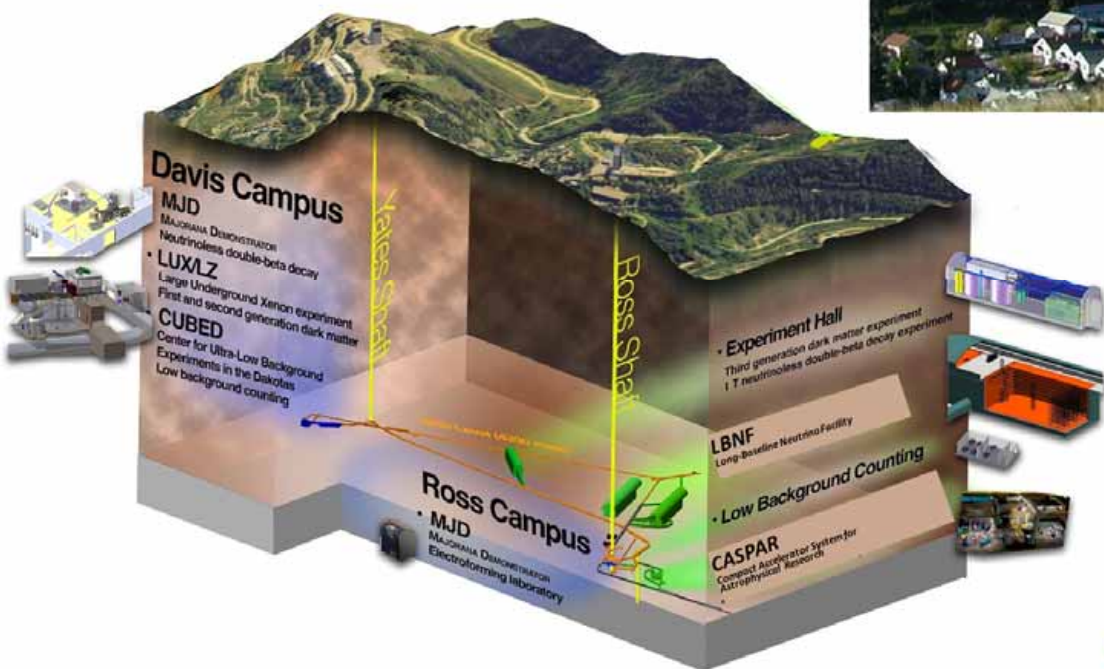
- Application of HPPS LE beam spectrum to LBNF baseline
 - modestly improves CP violation reach
 - improves minimum $\Delta\chi^2$ by $\sim x2$ for MH

Sanford Underground Research Facility

Experimental facility operated by the State of South Dakota.

Current experiments:

- LUX (dark matter)
- Majorana ($0\nu\beta\beta$)
- Several smaller experiments



Future home of:

- LZ (G2 dark matter experiment)
- CASPAR (Compact Accelerator System for Astrophysical Research)
- LBNF

Sanford Underground Research Facility

Entrance to Davis Campus



Majorana Demonstrator ($0\nu\beta\beta$)



- Experimental Facilities at 4300 mwe
- Two vertical access shafts for safety
- Shaft refurbishment in process and has reached the 2000 foot level
- Total investment in underground infrastructure is >\$100M
- Facility donated to the State of South Dakota for science in perpetuity

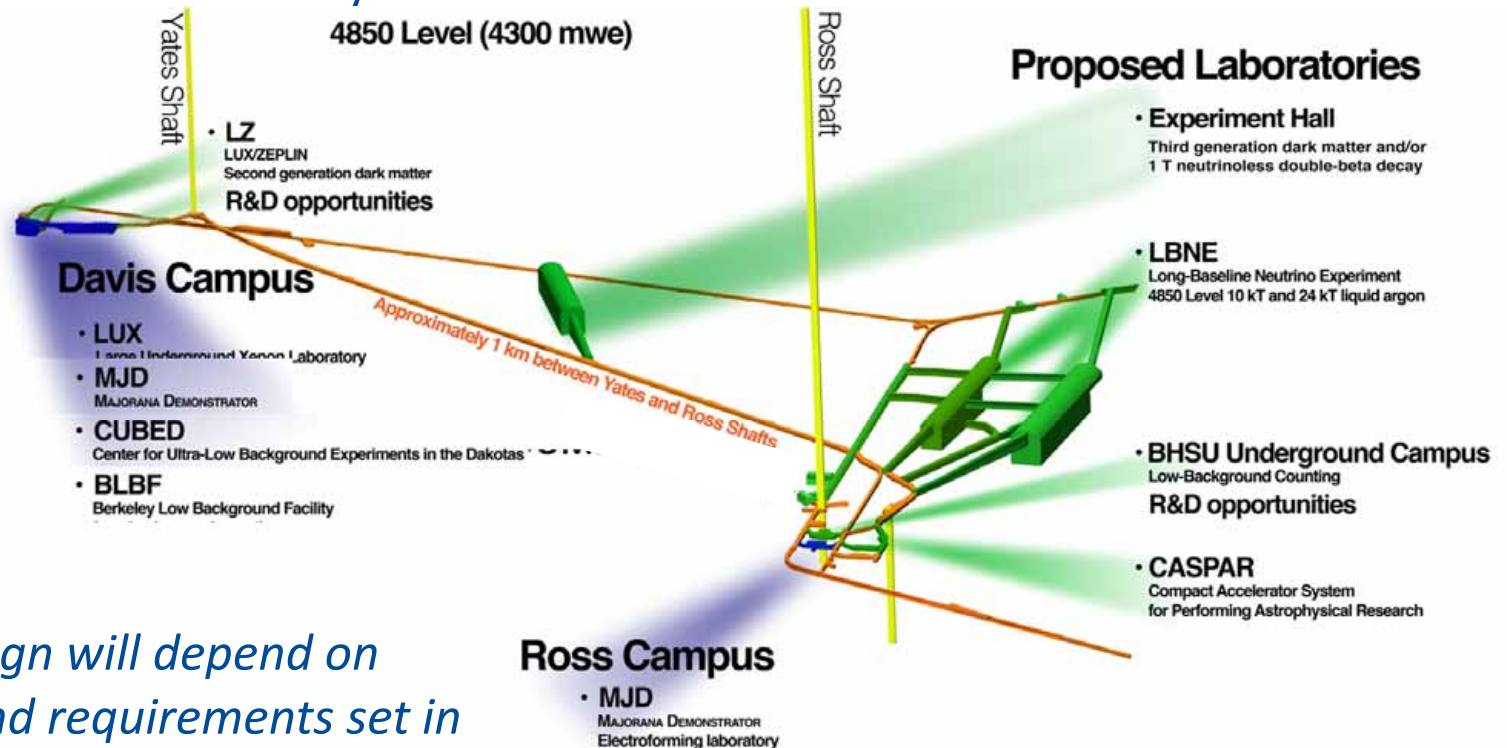
LUX (dark matter)



Planned Location of LBNF Cavern(s)

Current reference* design:

- Rectangular caverns for rock-supported cryostats
- 2 caverns: 10 kt + 24 kt fiducial mass sizes
- 10 kt cavern fully outfitted and detector-ready
- 24 kt cavern excavated only



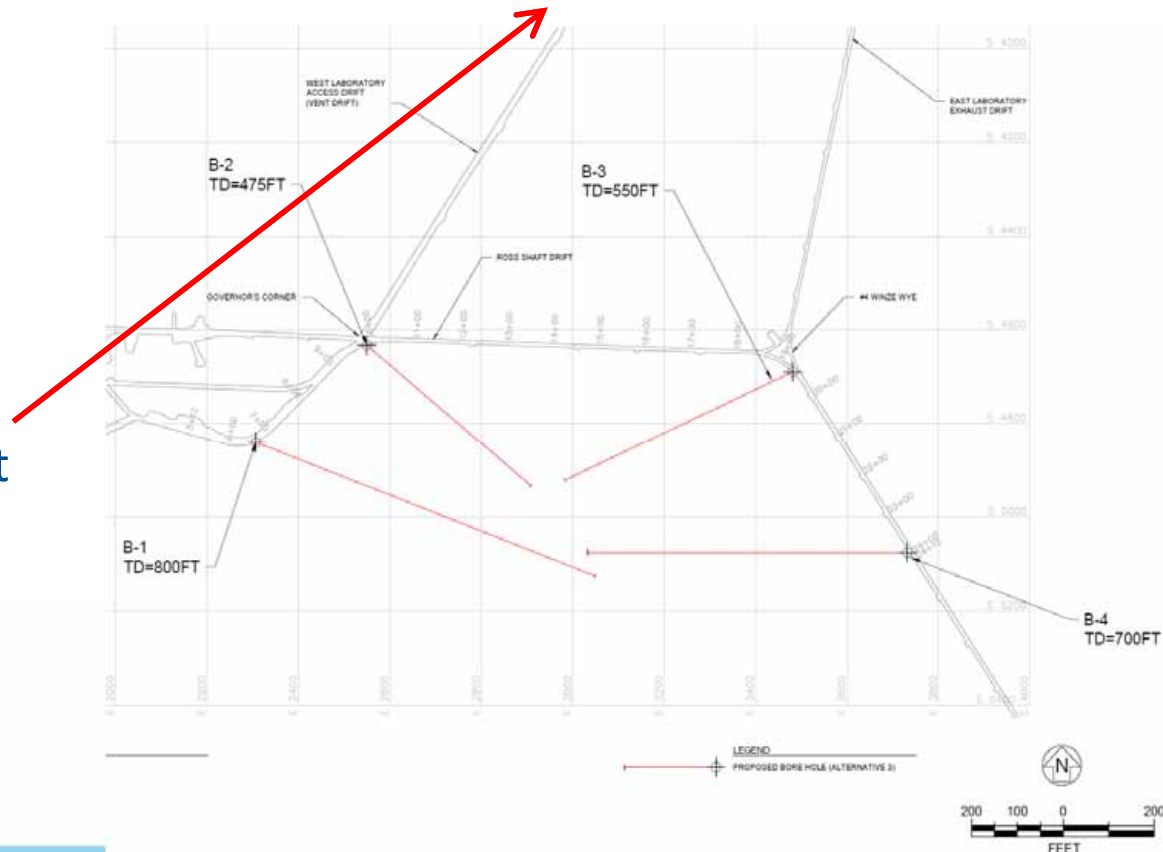
* Actual design will depend on strategy and requirements set in discussion with Science Collaboration

Geotechnical Investigation Program



A geotechnical exploration program at the 4850L has been completed to explore the rock mass south of the south access drift. Analysis of geotechnical data is on-going to determine maximum span and preferred cavern geometry.

Area near Yates shaft extensively studied for WCD option.



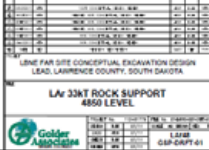
NOT FOR CONSTRUCTION



PHASE 3

FRASE 2
SOLUÇÕES

ELABORATE **USE**



LENE FAR SITE CONCEPTUAL EXCAVATION DESIGN
LEAD, LAWRENCE COUNTY, SOUTH DAKOTA

LAr 33kT DETECTOR CAVERN
EXCAVATION SEQUENCE

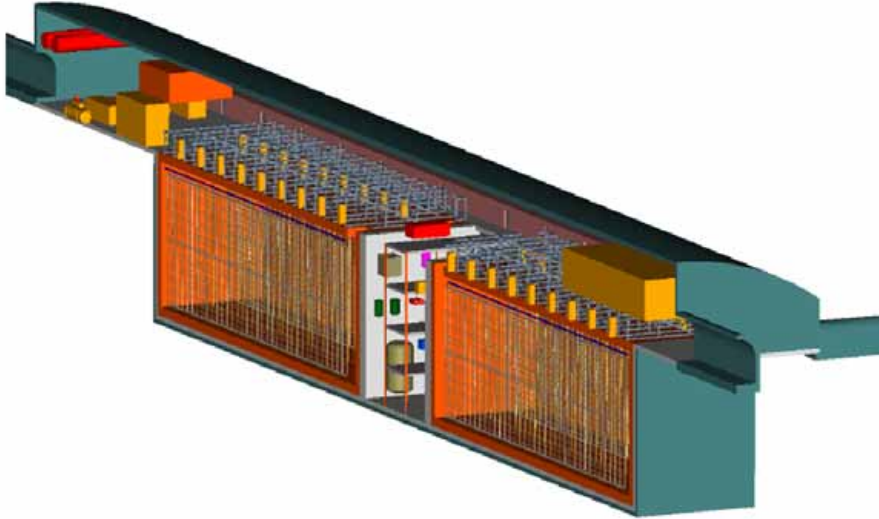
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1000	1000	1000	1000

Golden Associates <small>Quality Investments</small>	1-800-455-4555	40%	100%	Live! DECS-6
	1-800-771-1111	20%	100%	
	1-800-444-4444	10%	100%	

Rectangular vs. Cylindrical Cryostat

LBNE Design:

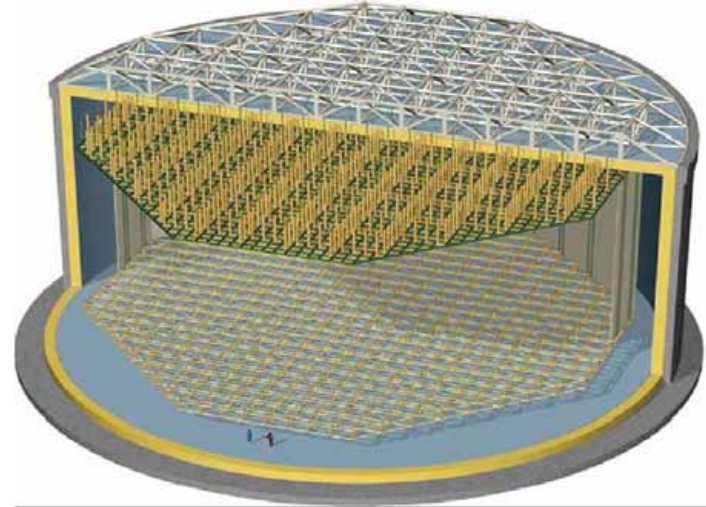
Rectangular, rock-supported cryostat



- Current reference design
- Rectangular geometry makes maximum use of excavated volume
- Rectangular geometry requires rock support

LBNO Design:

Cylindrical, free-standing cryostat

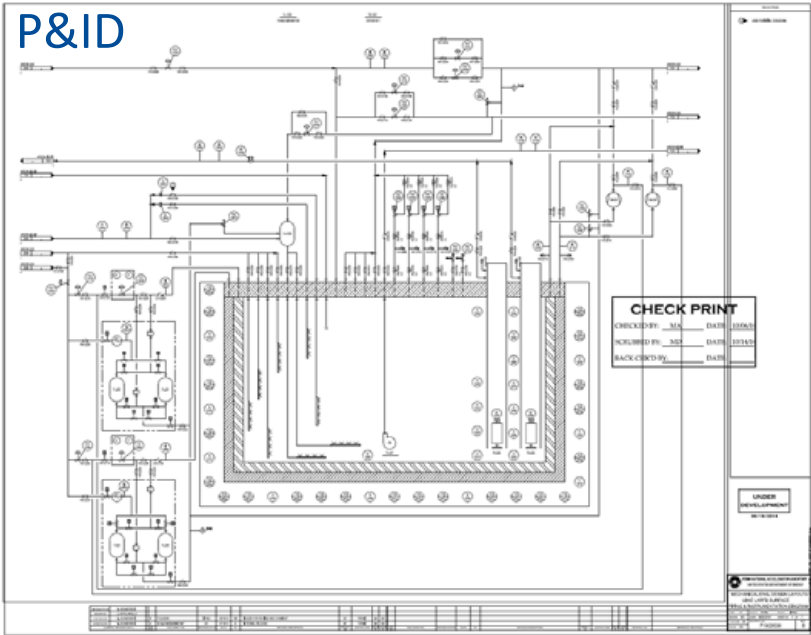
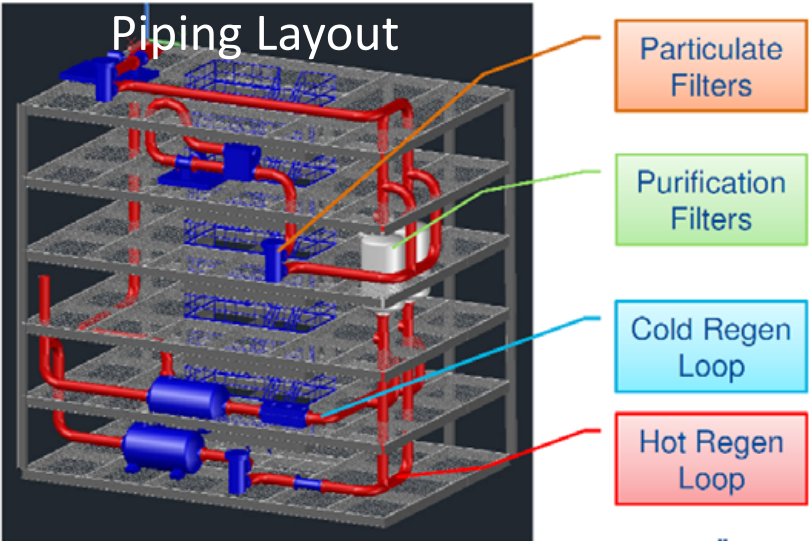
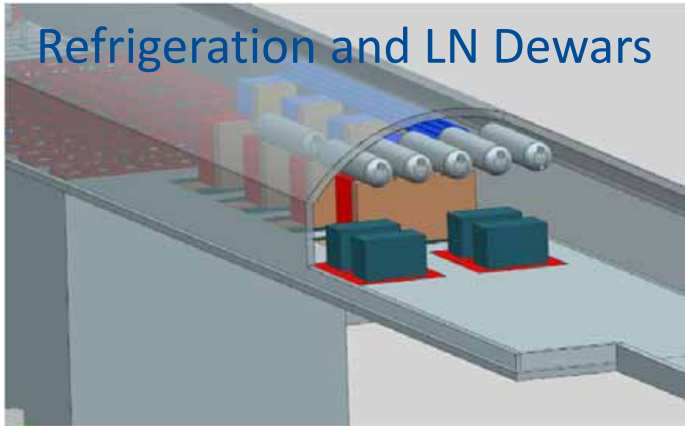
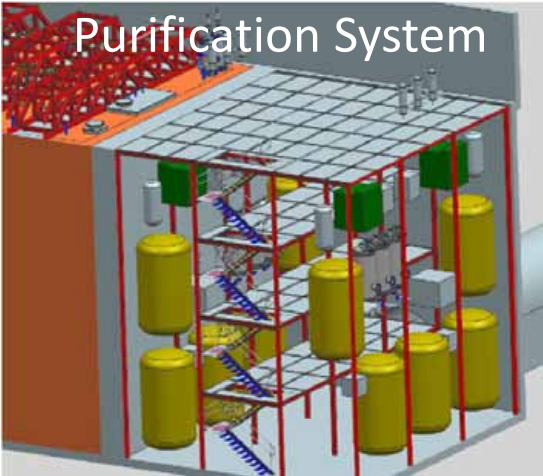


3D Tank & Detector Model Screen Shot (courtesy ETH Zürich)

- Follows industry standard design and construction methods
- Requires larger span cavern, similar to LBNE WCD design

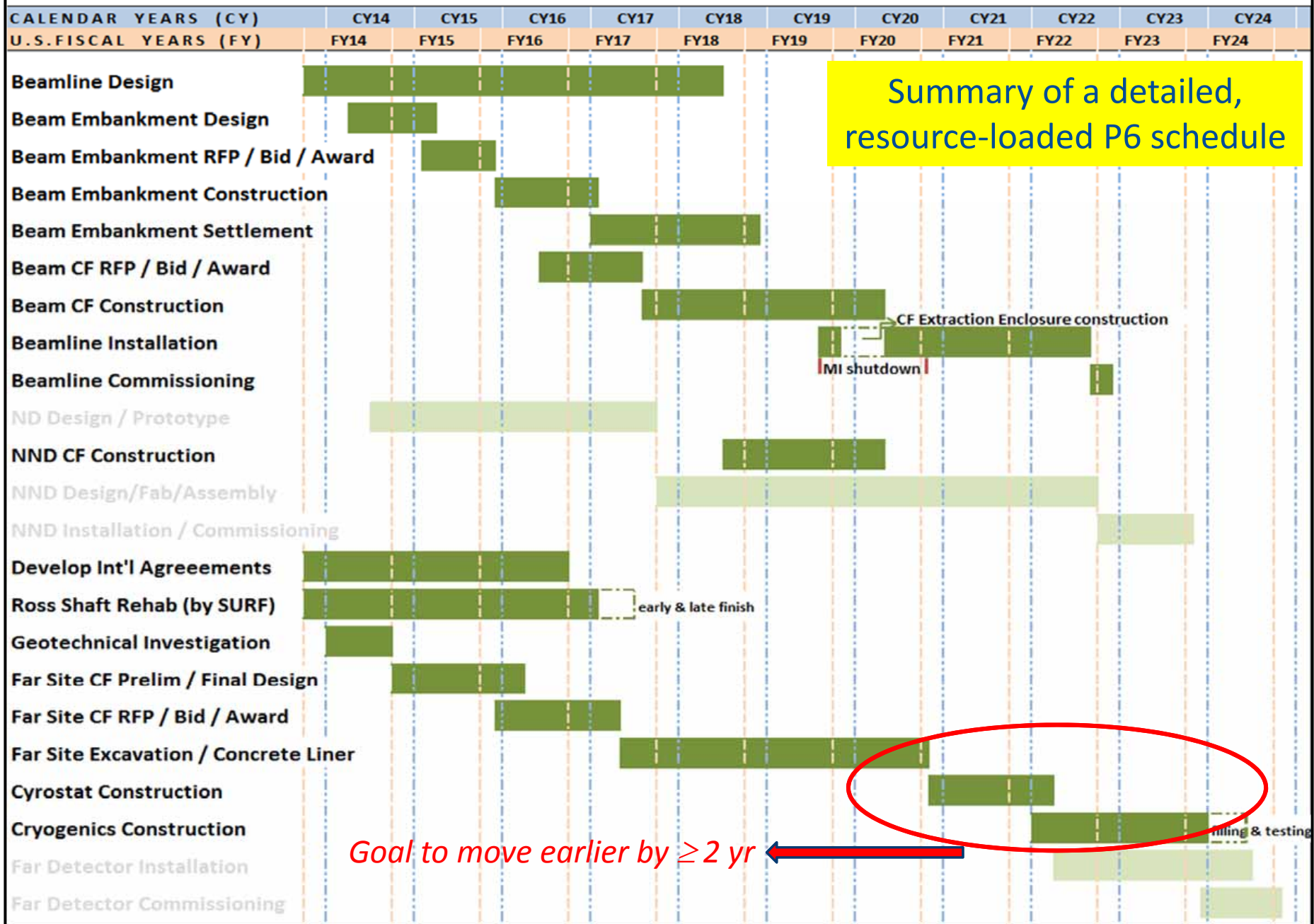
Joint LBNE – LBNO evaluation launched

Cryogenic System Design



Potential Technically-Limited Schedule for International LBNF

19 Sep 2014



Summary and Conclusions

- Fermilab hosts an active, diverse international accelerator-based neutrino program.
- Fermilab has a record of delivering high-intensity proton beams with high reliability and long running time for neutrino physics.
- On-going upgrades will increase the Main Injector beam power to 700 kW over the next ~2 years.
- PIP-II will further increase the beam power to 1.2 MW and provide a platform for future beam power >2 MW.
- Fermilab is prepared to host LBNF and work with international and U.S. partners to provide:
 - A high-intensity, broad-band neutrino beam
 - Conventional facilities for the LBNF detectors at SURF and Fermilab
 - Major technical infrastructure for the LBNF detectors