Neutrino Beam to DUSEL

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Accelerator Division - Fermilab

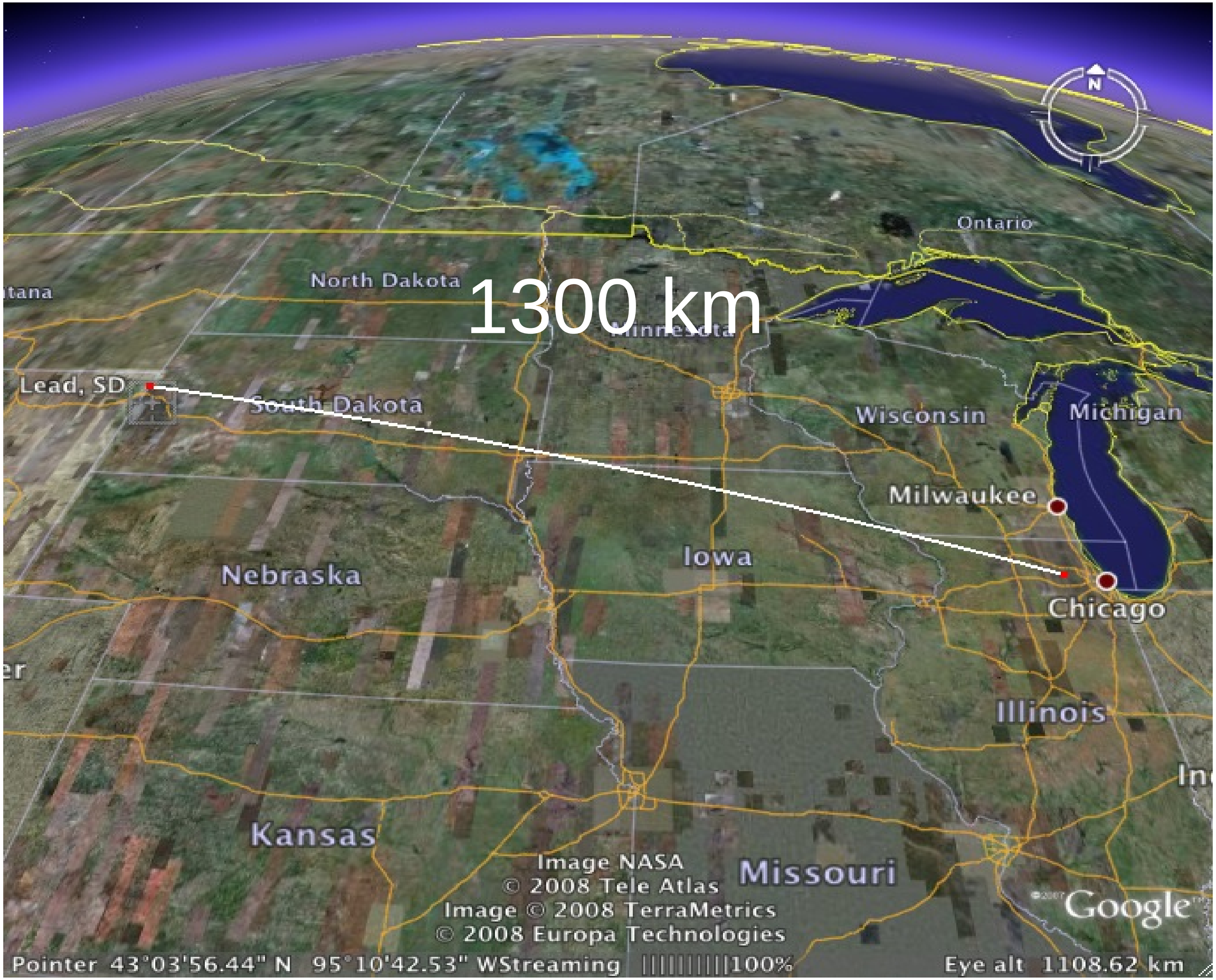
Project X Physics Workshop

November 9, 2009

Outline

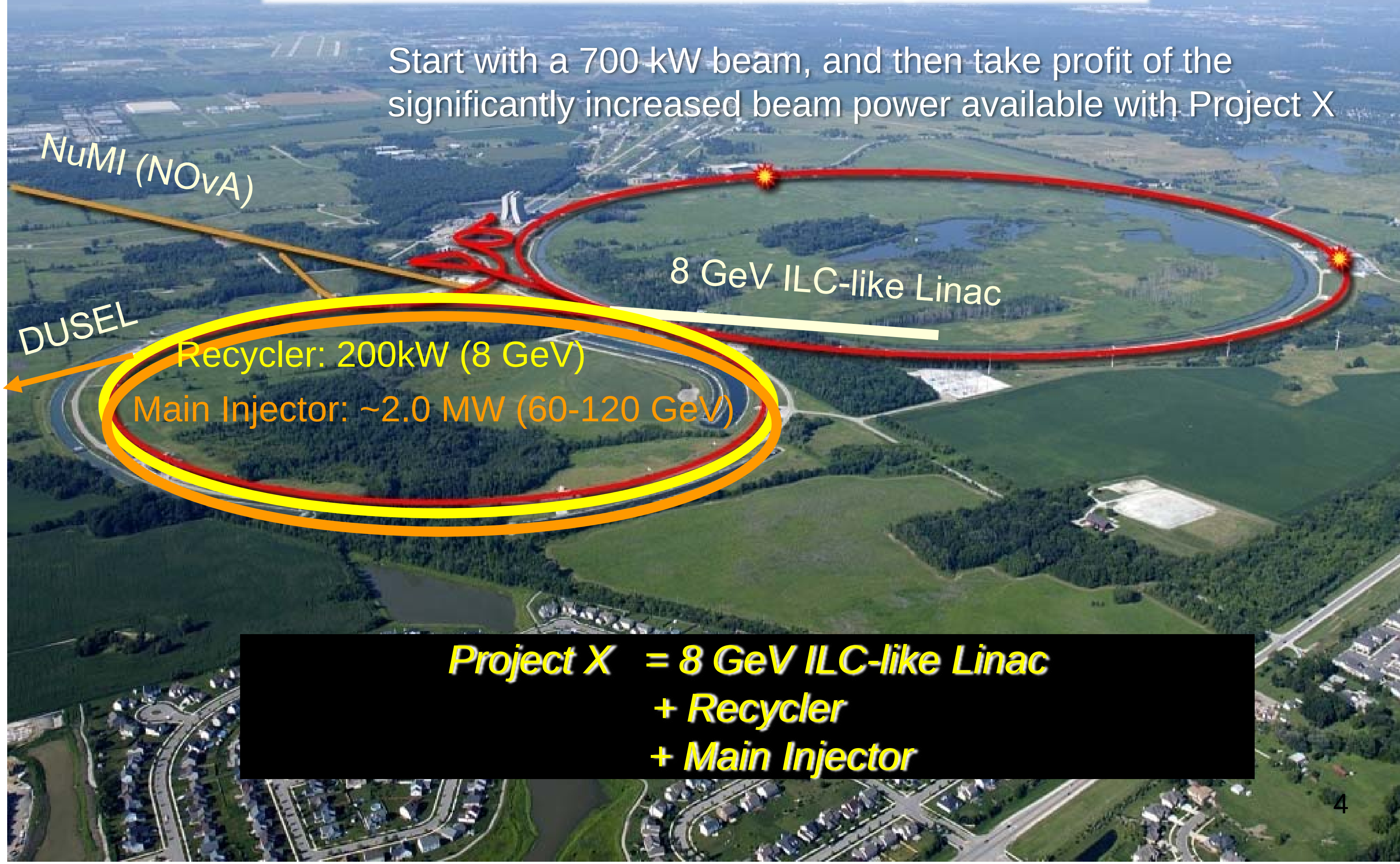
- Beam layout - Civil construction
- Primary Beam
- Neutrino Beam design requirements and layout
- Target R&D for a 2 MW Beam
- Conclusion

Long Baseline Neutrino Experiment



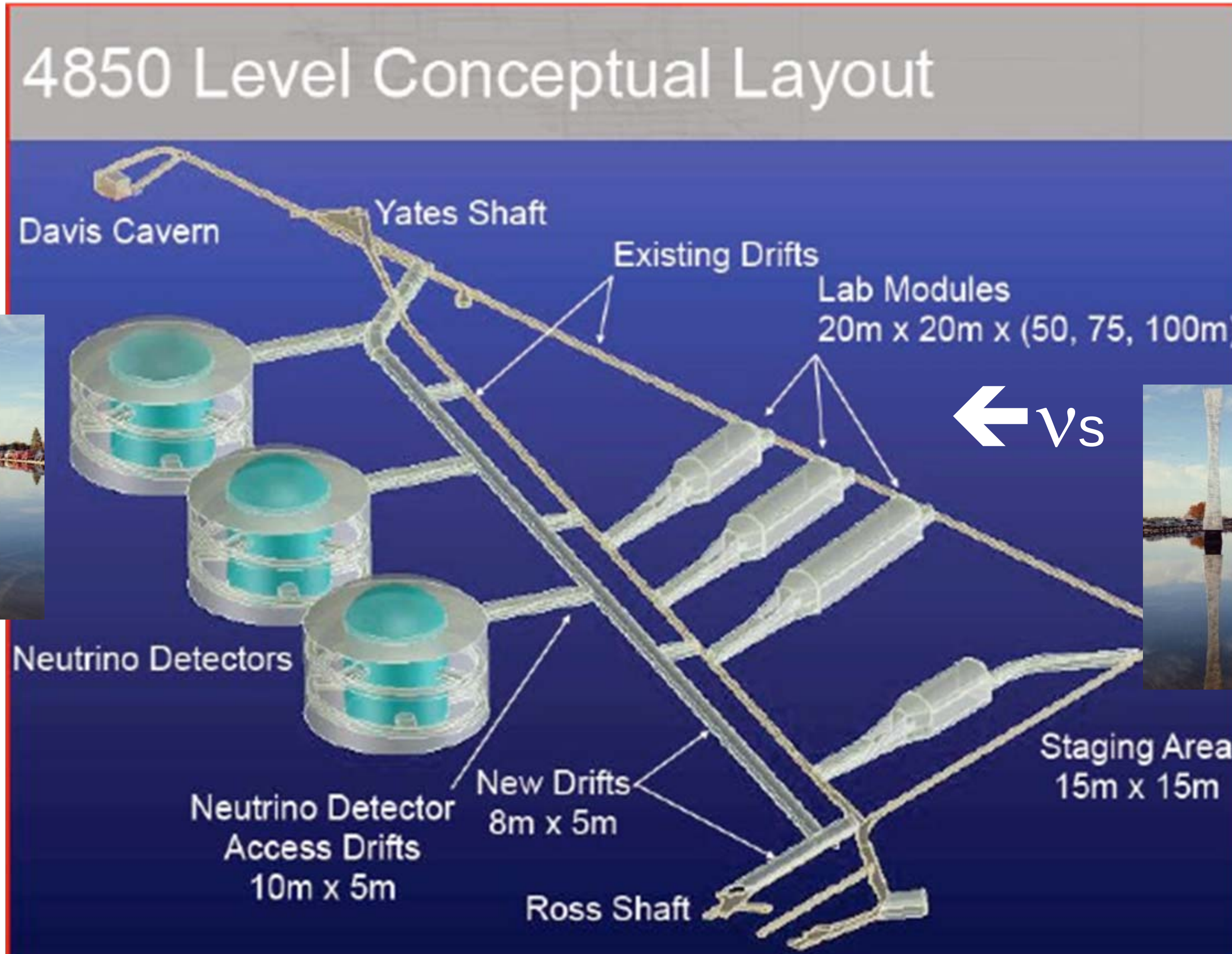
Fermilab vision :The Intensity Frontier with Project X:

Start with a 700 kW beam, and then take profit of the significantly increased beam power available with Project X



Project X = 8 GeV ILC-like Linac
+ Recycler
+ Main Injector

Deep Underground Science and Engineering Laboratory – Homestake



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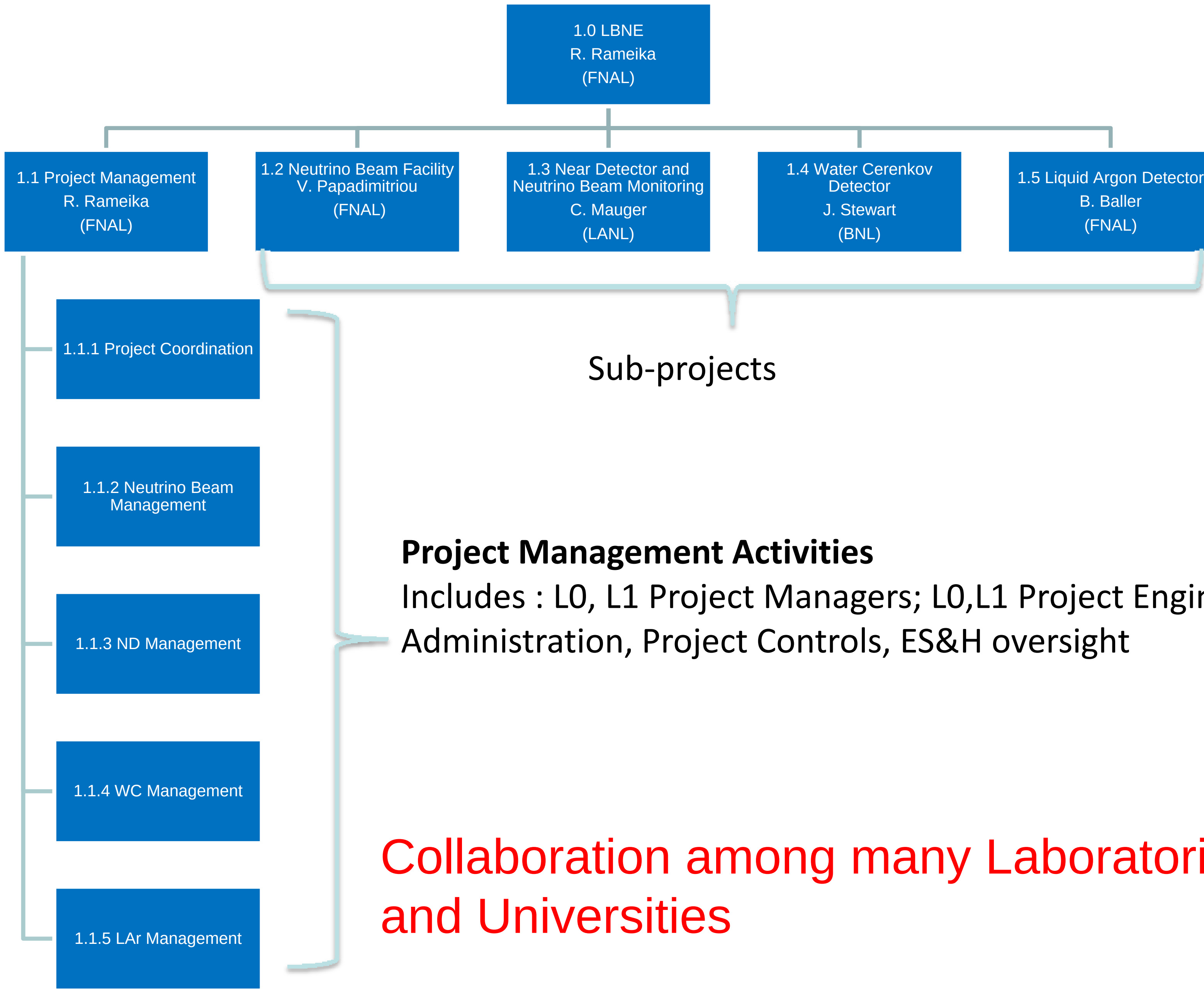
Project Organization

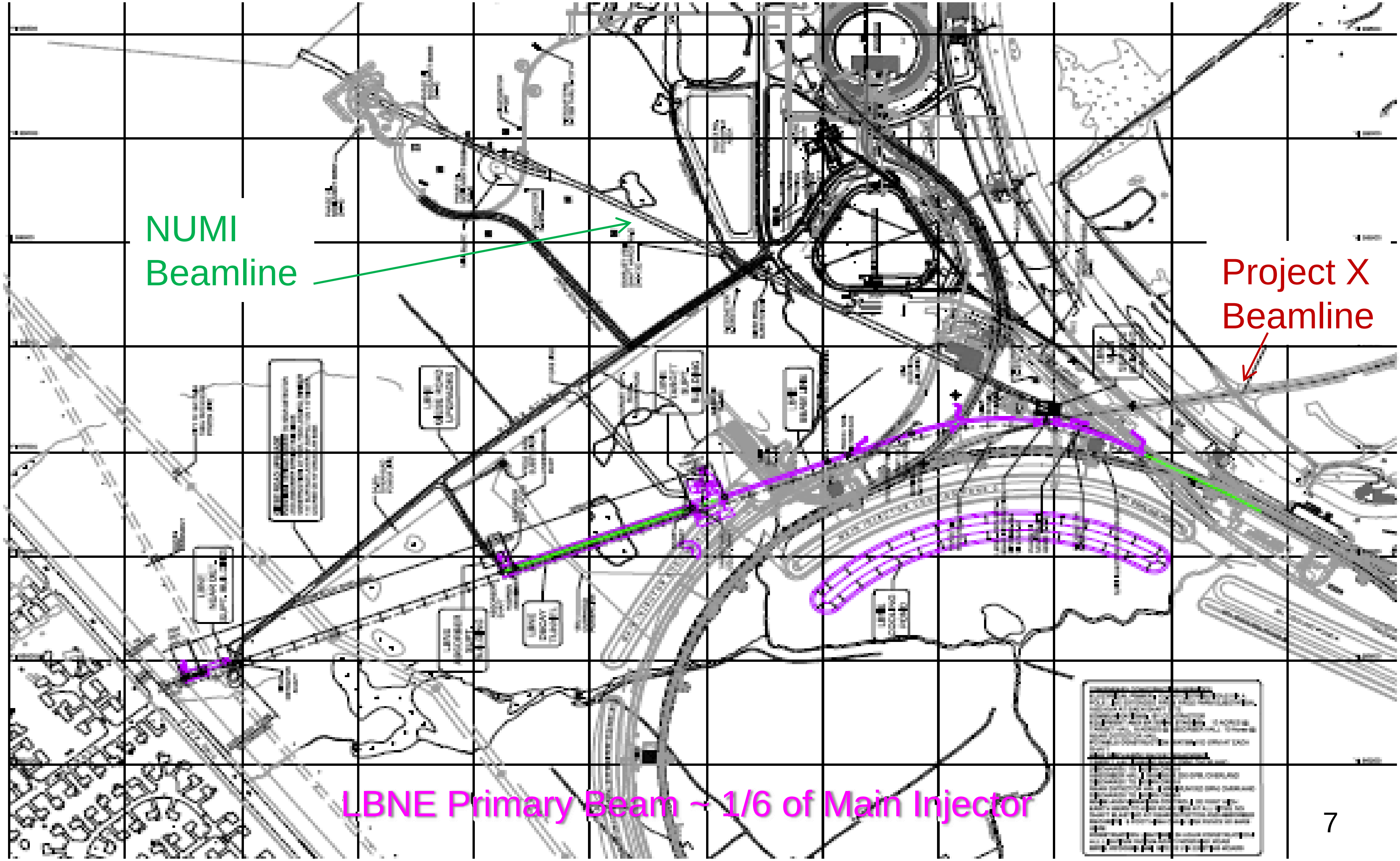


Project Management Activities

Includes : L0, L1 Project Managers; L0,L1 Project Engineers; Administration, Project Controls, ES&H oversight

Collaboration among many Laboratories and Universities

Site View - Fermilab



Civil Construction

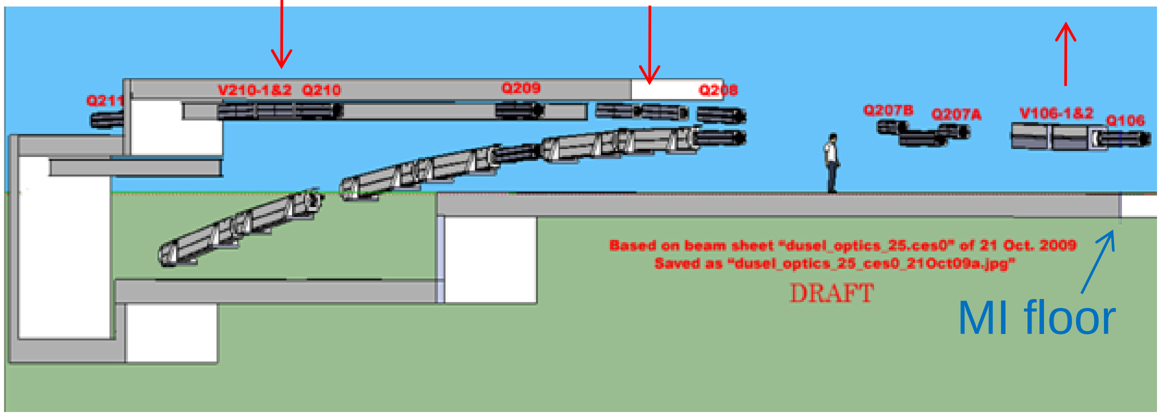
- Constructability Review of the LBNE mined Beamline and Near Detector underground facilities held at Fermilab in August 2009 and an Early Value Engineering Review in October 2009.

- No major geotechnical challenges or showstoppers were identified. The goal is to complete the field work this Fall/Winter.

- We are working with W.D. Wightman and company and with M.W.Zander on schedules for the completion and on preliminary cost estimates for the underground and the surface civil work, respectively.

Primary Beam – Beam Transport
Vertical and Horizontal bends

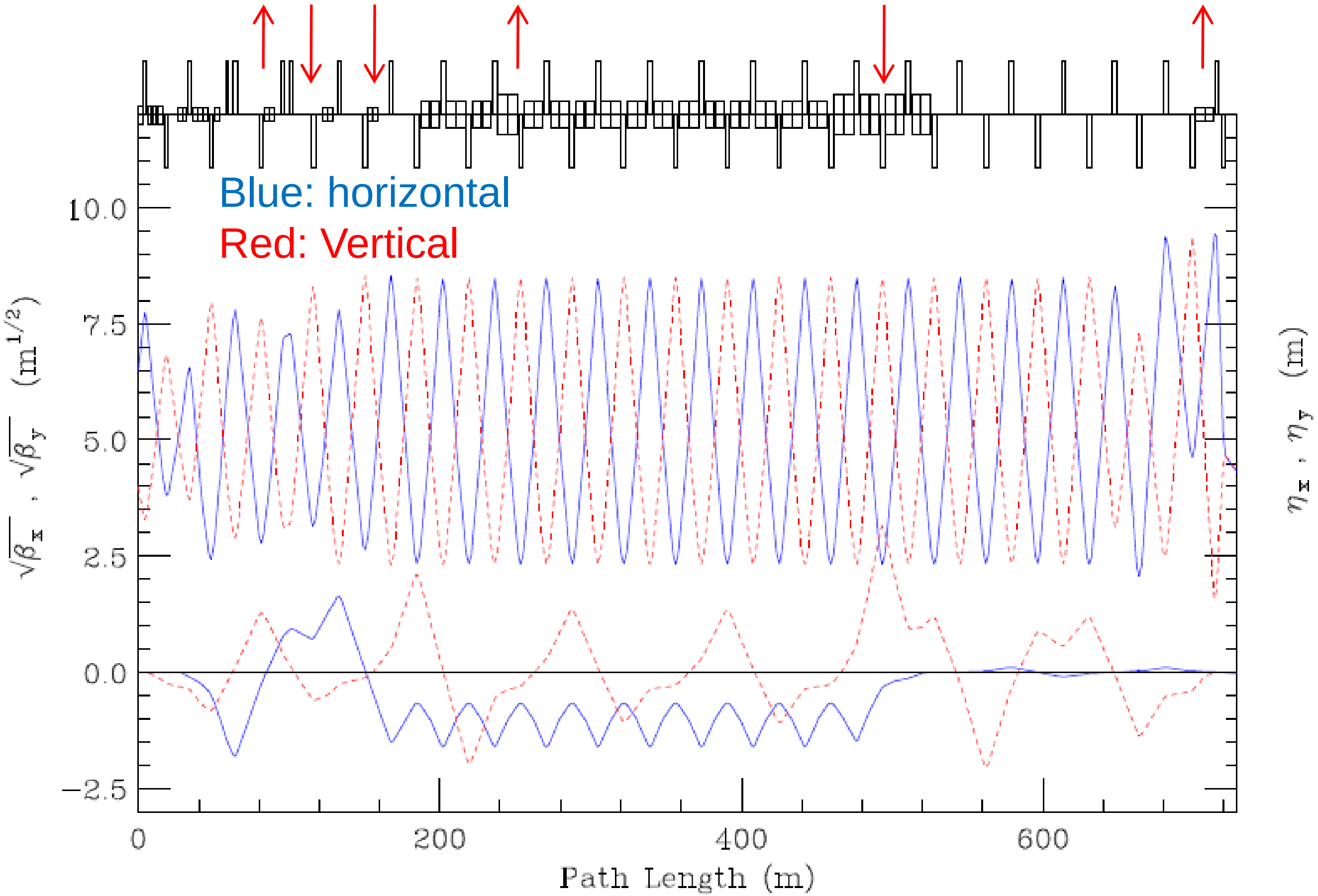
- Vertically up to get clear of NuMI line ~ 25 mrad
- Vertically down to be level just beneath the ceiling of the NuMI Stub ~ 25 mrad
- Vertically down heading for elevation same as the Main Injector ~ 25 mrad
- 48 degree horizontal bend to the west together with a vertical bend to remove the downslope
- Vertical down-bend to quickly traverse soil-rock interface ~ 150 mrad
- Vertical up-bend to set the angle pointing to DUSEL ~ 50 mrad



- ➢ Allow NUMI/MINERVA/NOvA running with LBNE
- ➢ Maximize distance between target and Near Detector

Neutrino Beam Facility – Beam Transport

J. Johnstone



120º FODO cells

Work in progress:

β_{max} = 72 m

$\eta_{x\ max}$ = 1.6 m

- Little rectangles : vertical bends
- Medium rectangles: horizontal bends
- Large rectangles: rolled dipoles
- Up and Down rectangles: quadrupoles (F&D respectively)

Needed:

~ 50 Dipoles

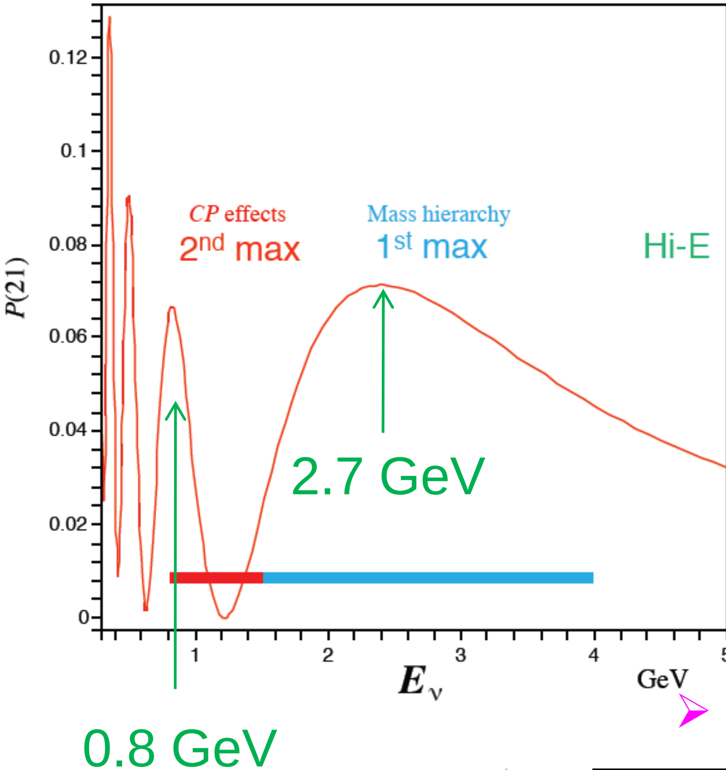
~ 45 Quadrupoles

~ 45 Correctors

Neutrino Beam Facility

Target Hall + Decay Pipe + Absorber + Near Detector Hall

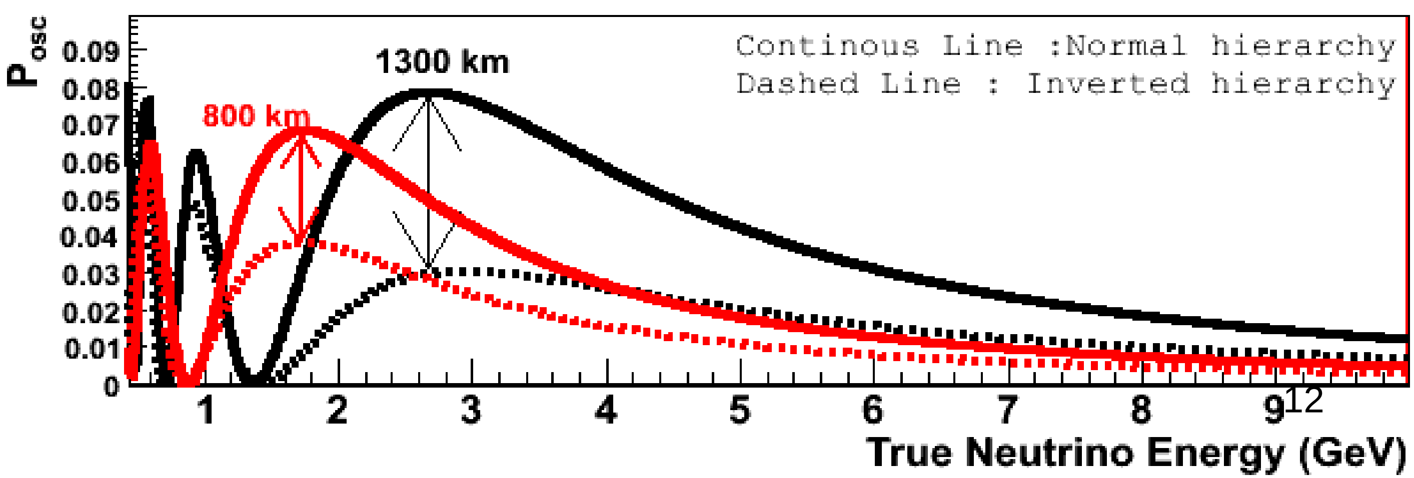
Beam Design Requirements



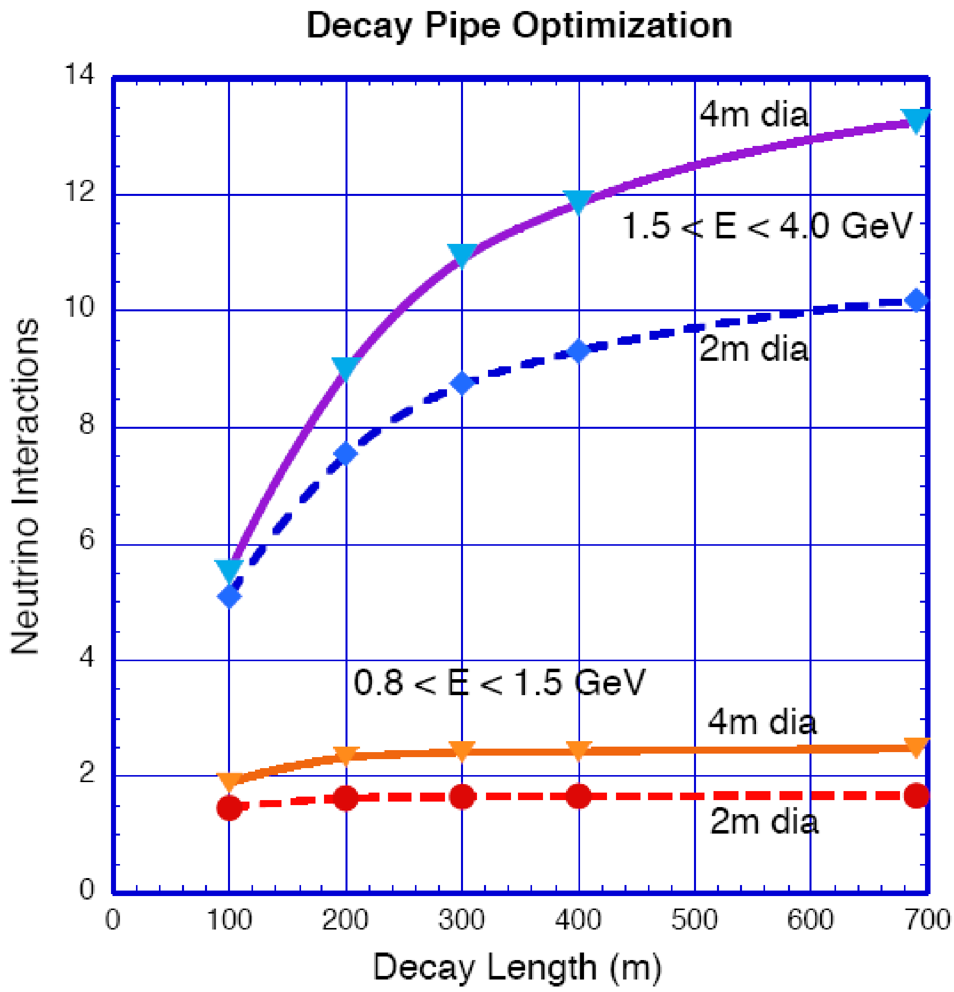
- Need a wide band beam to cover the 1st and 2nd oscillation maxima.

Normal mass hierarchy

- Energies above 10 GeV not very useful



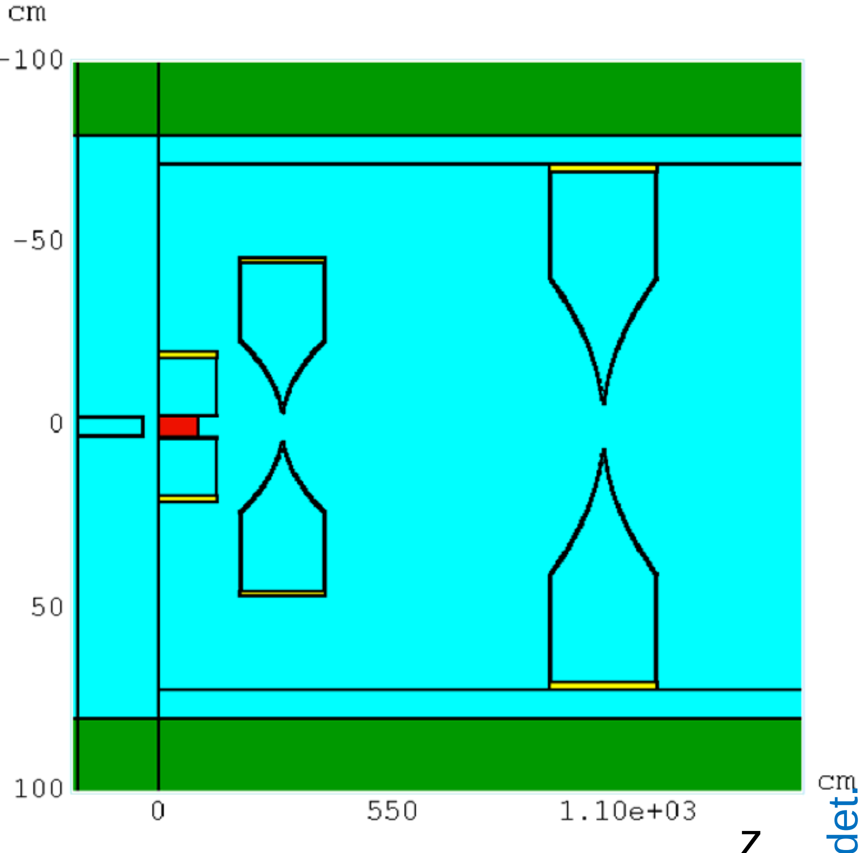
Decay Pipe Optimization



B. Lundberg

- Currently assuming: Decay region 250 m. length & 4 m. diameter and primary beam energy from 60 to 120 GeV

Optimizing the neutrino spectrum

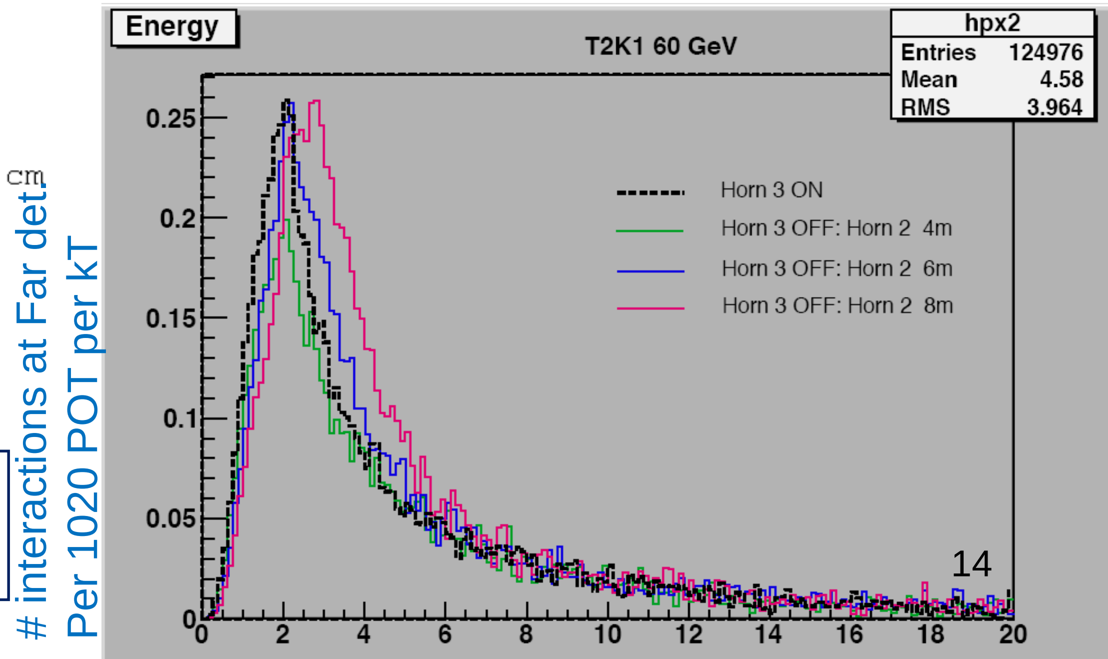


Target integrated into Horn 1
Assuming target radius of 0.9 cm

Reduce high energy tail and enchance low energies.

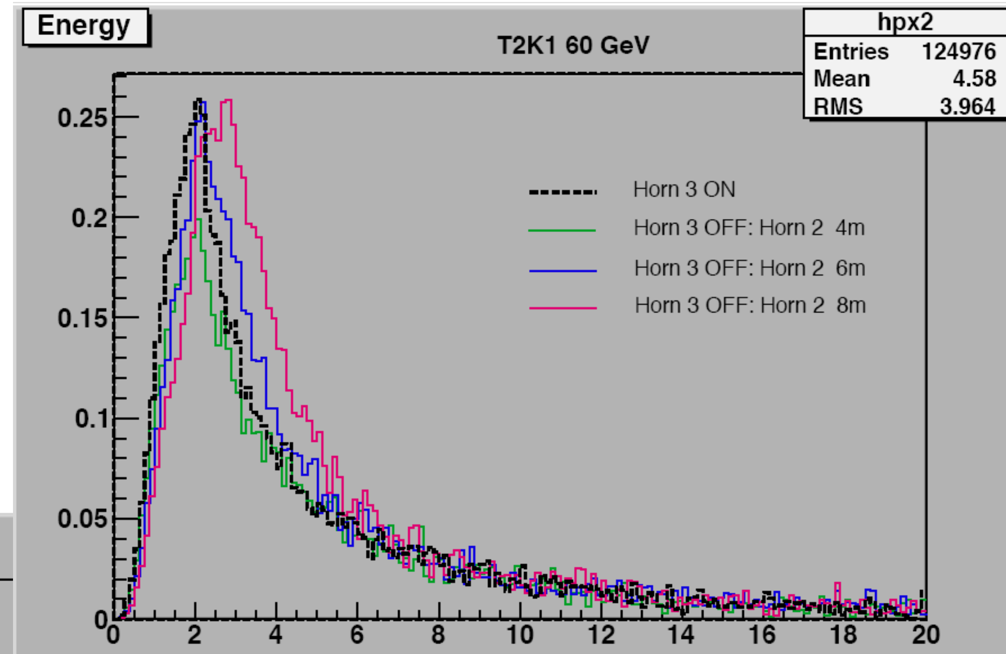
- Horn 1
  - Radius outer conductor:15 cm
  - Radius inner conductor: 1 cm
  - Length: 120 cm, z:0 cm
- Horn 2
  - Radius outer conductor: 45 cm
  - Length 200 cm, z: 290 cm
- Horn 3
  - Radius outer conductor: 70 cm
  - Length: 250 cm, z: 910 cm

Parabolic inner cond.



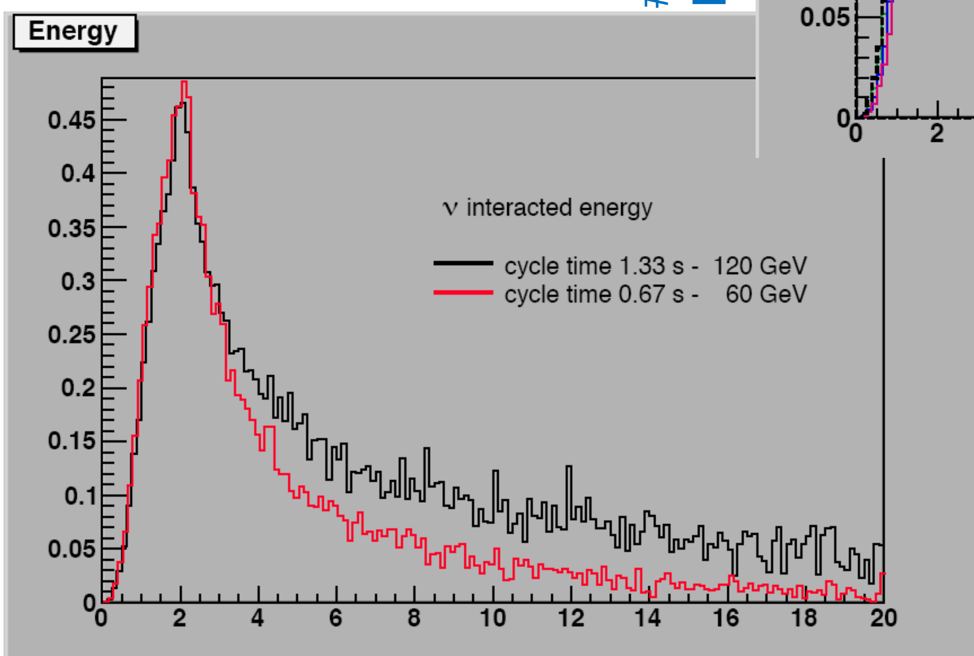
Optimizing the neutrino spectrum

B. Lundberg



interactions at Far det.
Per 1020 POT per kT

Energy



interactions at Far det.
Per 1020 POT per kT

Energy

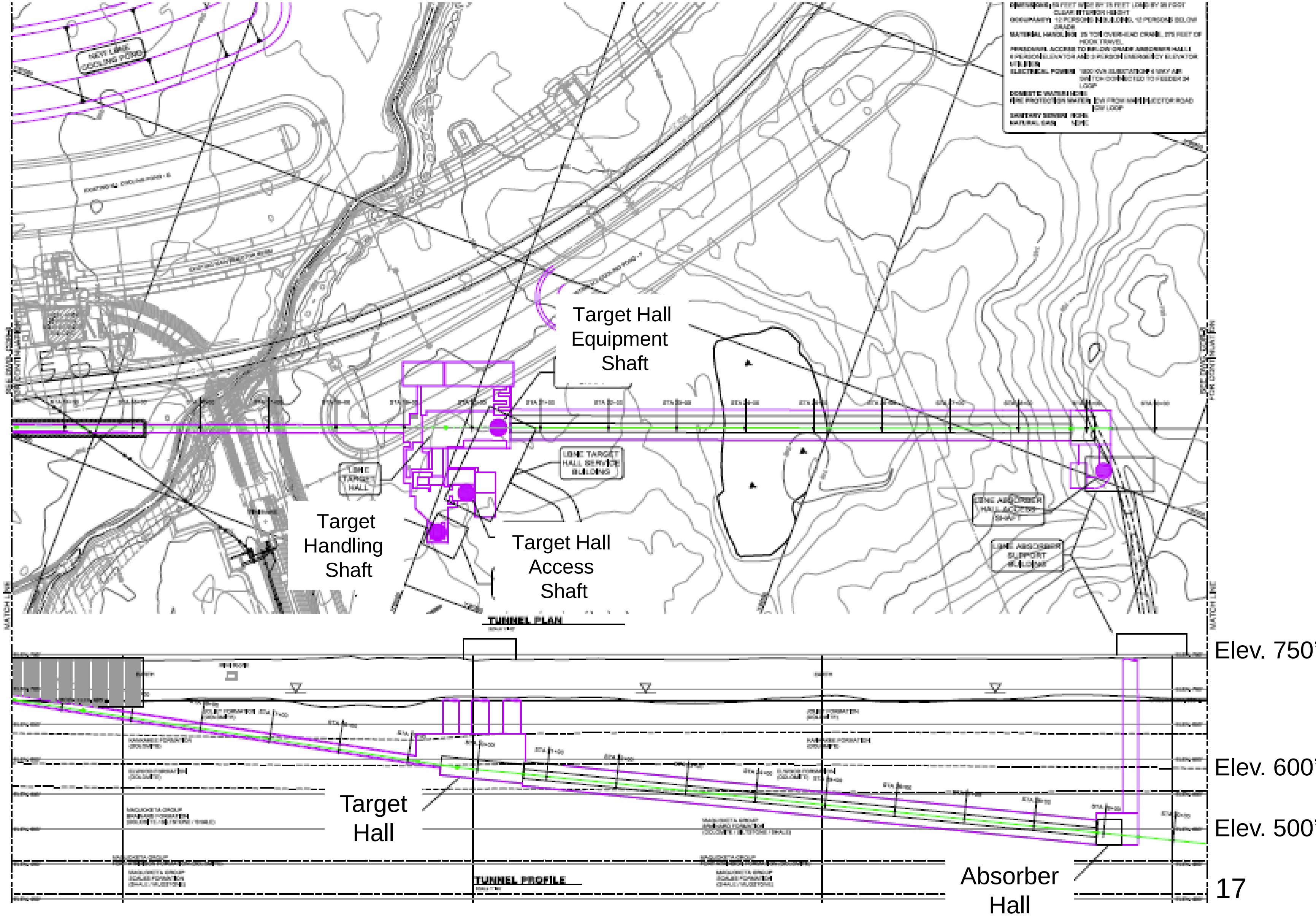
DOE guidance for the LBNE target

- Focus on designing a target for a 700 kW beam for the CDR

- Outline the R&D plan required to develop a target that can operate at higher (Project X) beam power (e.g. 2 MW)

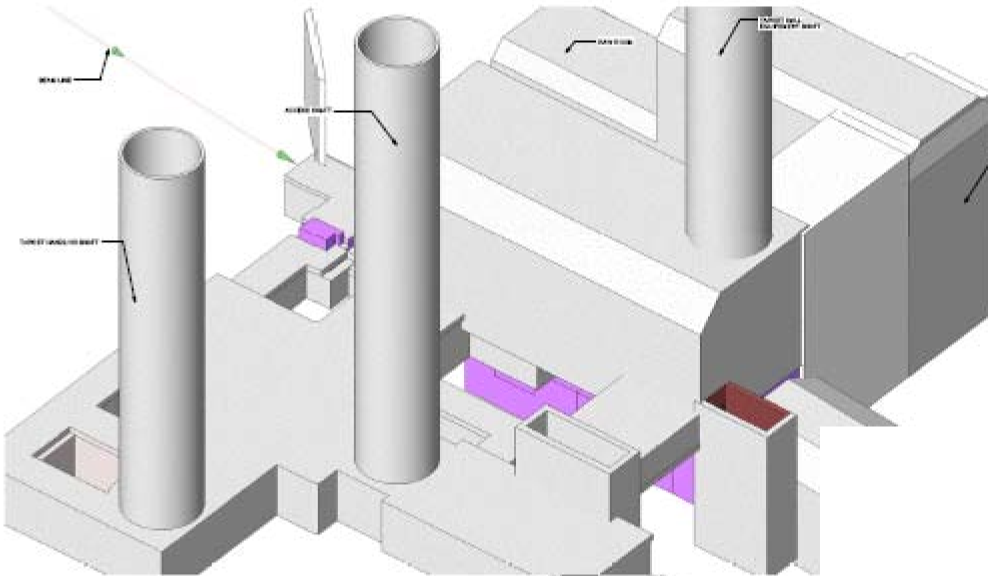
LBNE Neutrino Beam Facility

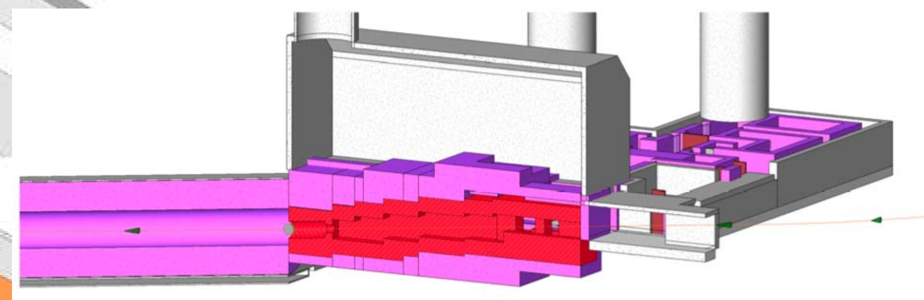
Target and Absorber Halls



Target Hall Isometric Views

Preparing for 2 MW





Shielding

Purple: Concrete

Red: Steel

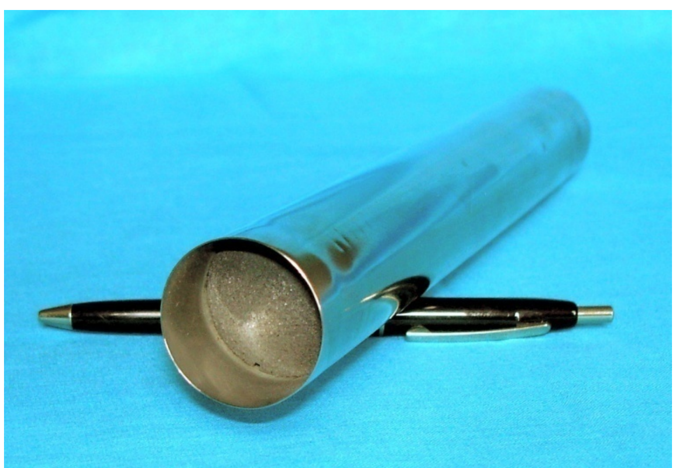
Note: Very early conceptual design stage (for civil construction estimating purposes)

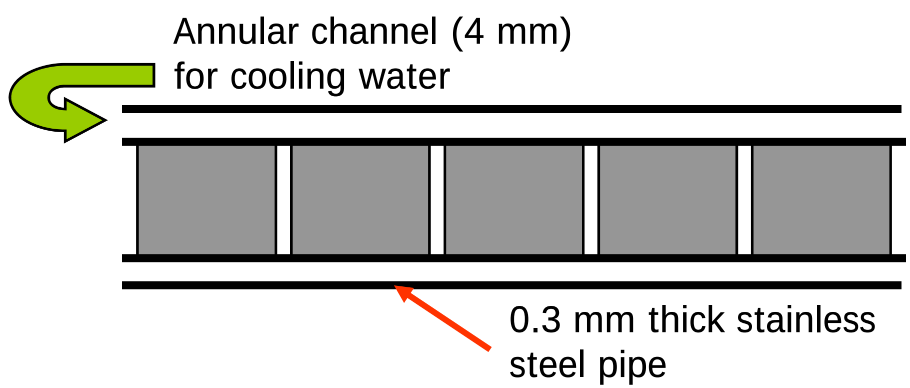
IHEP NUMI target study for a 2MW upgrade

From a 2005 study of graphite encapsulated in Al or steel sheath, with water cooling, graphite target stress and temperature were OK for 1.5e14 protons per pulse of a 2 MW beam.

Remaining issues were:

- Hydraulic shock in cooling water (150 atm.) *(suggested using heat pipe to solve)*
- Radiation damage lifetime *(est. at 1 year but not well known)*
- Windows + accident conditions

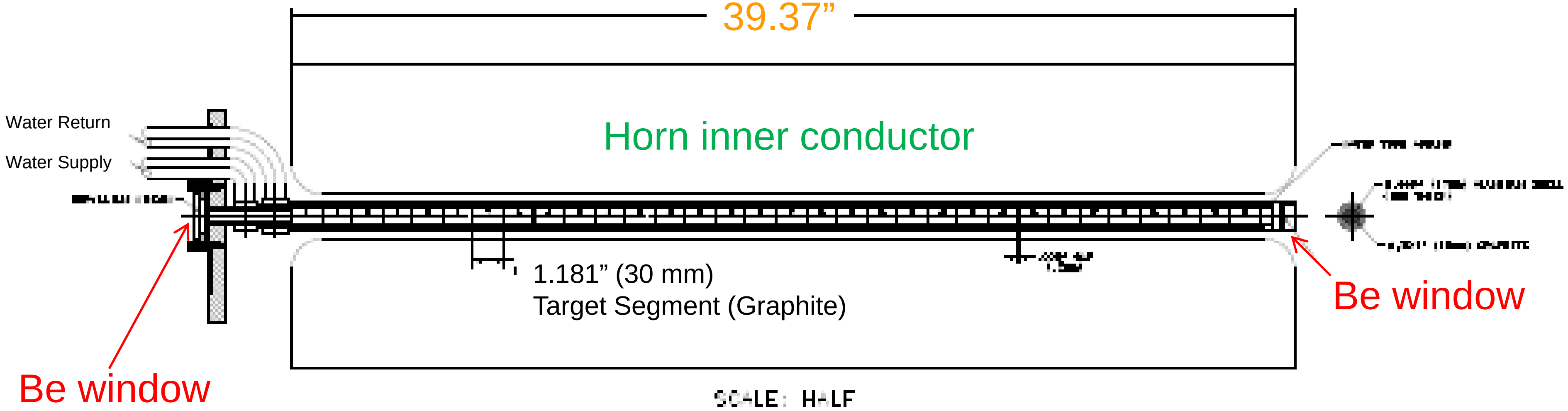




NUMI Target for 2 MW upgrades (IHEP, Protvino)

(NUMI-Note-Beam-1100
Design study of the NuMI Target for
2 MW upgrades IHEP,2005)

Draft design sketch of the LBNE 700 kW target system with a double-layer water system

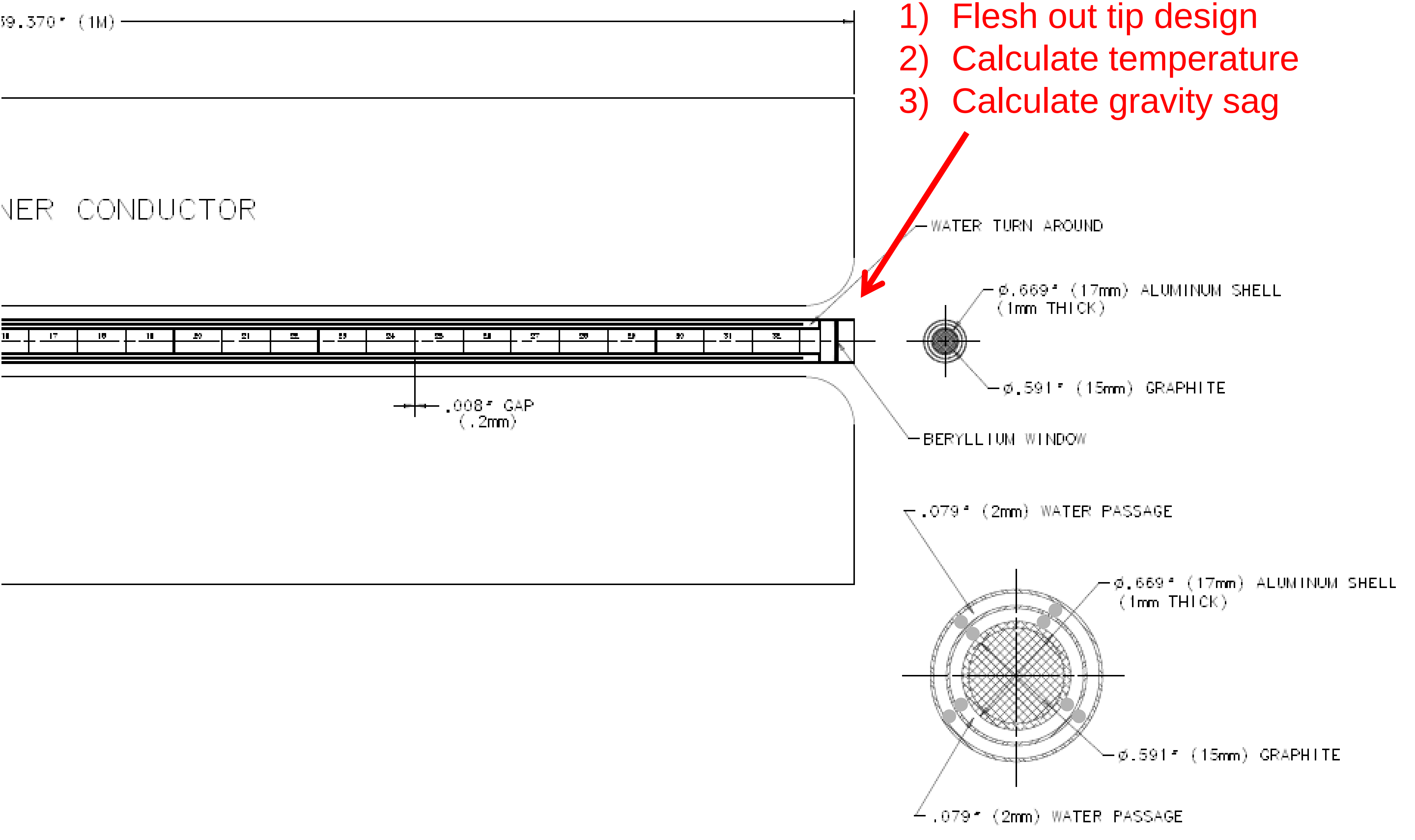


In the process of writing an Accord with IHEP, Protvino, Russia for the conceptual design of the LBNE 700 kW target.

Draft design sketch of the target system double-layer water system

IHEP tasks:

1) Flesh out tip design
2) Calculate temperature
3) Calculate gravity sag



Challenges for a 2 MW target

- Heat removal
- Radiation damage and how it affects the target lifetime
- Thermal shock (stress waves initiated by beam pulse)
- Oxidation
- Residual radiation
- Spatial constraints
- Optimization for neutrino flux (neutrino yield depends on target radius)
- Accident condition (mis-steered beam pulse)
- Keeping down-time (due to changing-out targets) low enough
- Keeping spare production rate sufficiently high

Issues to pay attention to:

- Selecting suitable target material (carbon/graphite/ Be/ AlBeMet/…) . Radiation damage changes the properties of materials.
- Cooling system (water, helium, 1 vs 2 phase, 2 phase (heat pipe vs bubbles), spray…)
- Beam window survivability (geometry, thickness, figuring out the minimum size of beam with which the window can survive,…)
- How to scale radiation damage (energy deposit, POT/cm^2, Displacement Per Atom -DPA, nuclear interactions, gas molecule production)?
- Is DPA transferable from neutrons to protons?
- Designing sufficient flexibility in the target Hall
- Developing remote handling capability
- Target/Horn configuration (mounting target to horn, integrating target into horn inner conductor, …)

Developing work packages and exploring collaborations: the steps ahead

❖ Evaluating the FNAL resources and established/considering collaborations with ANL, BNL, IHEP (Protvino, Russia), LANL, ORNL, RAL (UK) as well as Universities.

- ❖ Evaluating the technical merits and strengths of each Laboratory/Group and matching work packages.
- ❖ Considering cost issues.
- ❖ Maximizing the efficiency of the collaboration with other Laboratories within a broader context (collaborating in more than one technical projects, participation of the Laboratory in the scientific collaboration as well, etc.).
- ❖ Have to provide sufficient supervision and integration at the Fermilab site.

Developing work packages and exploring collaborations

- Analysis and simulation to investigate hydraulic shock in the cooling water (water hammer effect) – instantaneous pressure and temperature rise due to energy deposition (Contract for 4 weeks of engineering time at ANL).

- Radiation damage

  - Contract for 1 week of a material scientist time at ANL to review irradiation effects in graphite (correlate neutron irradiation with high energy proton irradiation?)

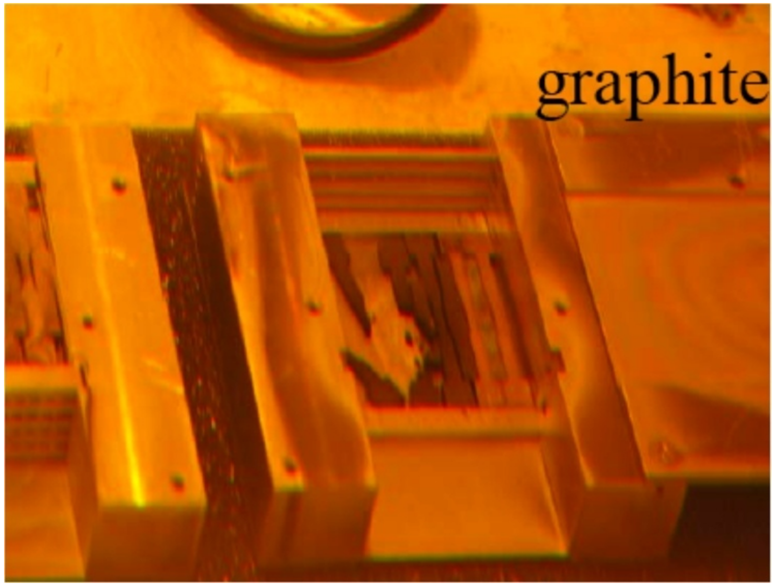
  - Planning irradiation tests and sample characterization at BLIP, BNL – aiming for a test in April 2010

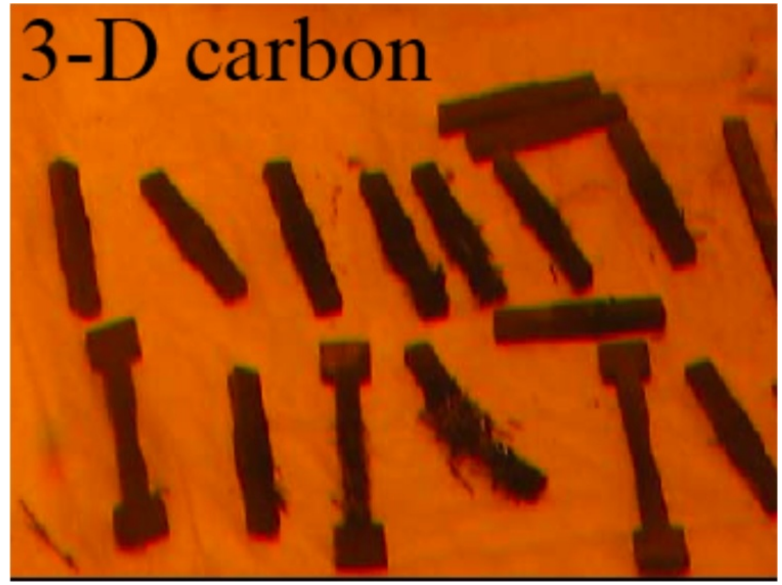
  - Contact established with ORNL as well

Radiation Damage

200 MeV proton fluence

~10^21 p/cm^2 at BLIP





- Atom displacement causes changes in material properties
- Not much literature on high energy proton irradiation of materials
- Lots of information on low energy neutron irradiation (nuclear reactors)

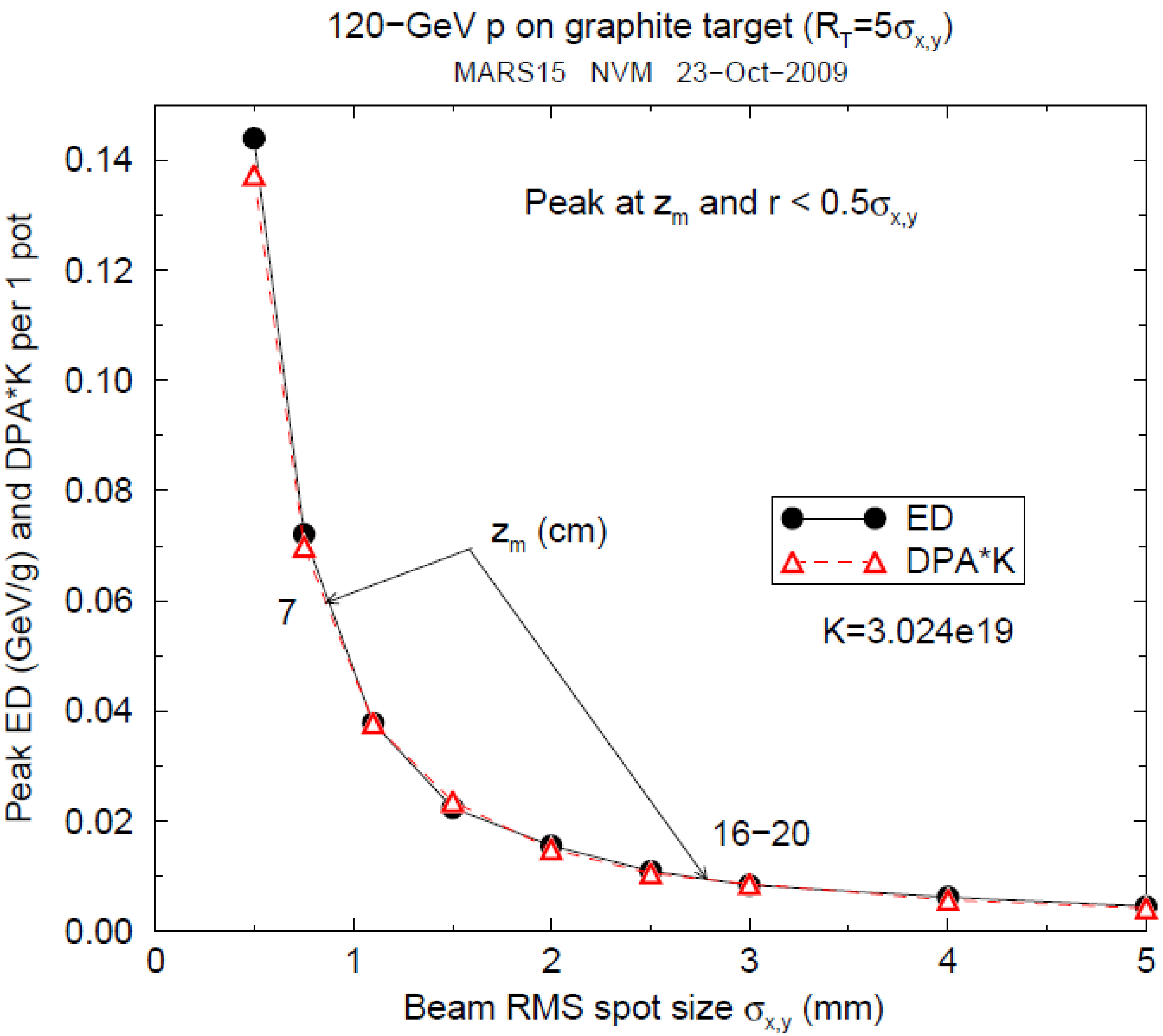
Pictures from N. Simos, BNL. Radiation damage studies for LHC.

DPA and Scaling DPA versus beam spot for extrapolating radiation damage

MARS15 simulations

Nikolai Mokhov

DPA/yr = 0.45 (NUMI) and ~ 1.5 (BLIP) for 4e20 p/yr and 1.124e22 p/yr, respectively.



Fall-off of peak DPA is about $R^{-1.5}$ in this range (not quite the R^{-2} of incident protons)

Thus increasing spot size from 1.1 mm (NuMI) to e.g. 1.75 mm may double the radiation damage lifetime.

But need to also consider other issues for spot size

Developing work packages and exploring collaborations

- Autopsy of 1st and 2nd NUMI target – tomography

  (exploring options at LANL and ORNL)

- Be thermal shock study to explore possibility of using a Be target (longer lifetime, elimination of beam windows, …)

  (In the process of writing and Accord with RAL group at UK)

- Initiated contact with IHEP on completing a 700 kW target design – 2005 study for NUMI target to withstand 2 MW. Cooling, beam window, etc.

- Need to establish contacts for the conceptual design of a replaceable beam window that can withstand 2 MW beam power.

Conclusion

- Fermilab, together with many other collaborating institutions, has significant responsibilities in carrying out an aggressive conceptual design phase for a Long Baseline Neutrino Experiment.
    - Awaiting CD-0 (DOE Mission Need)
    - Goal for CD-1 by end of 2010
- The 2 MW beam power from Project X is necessary in order to carry out the Long Baseline experiment on a realistic time scale.

Conclusion

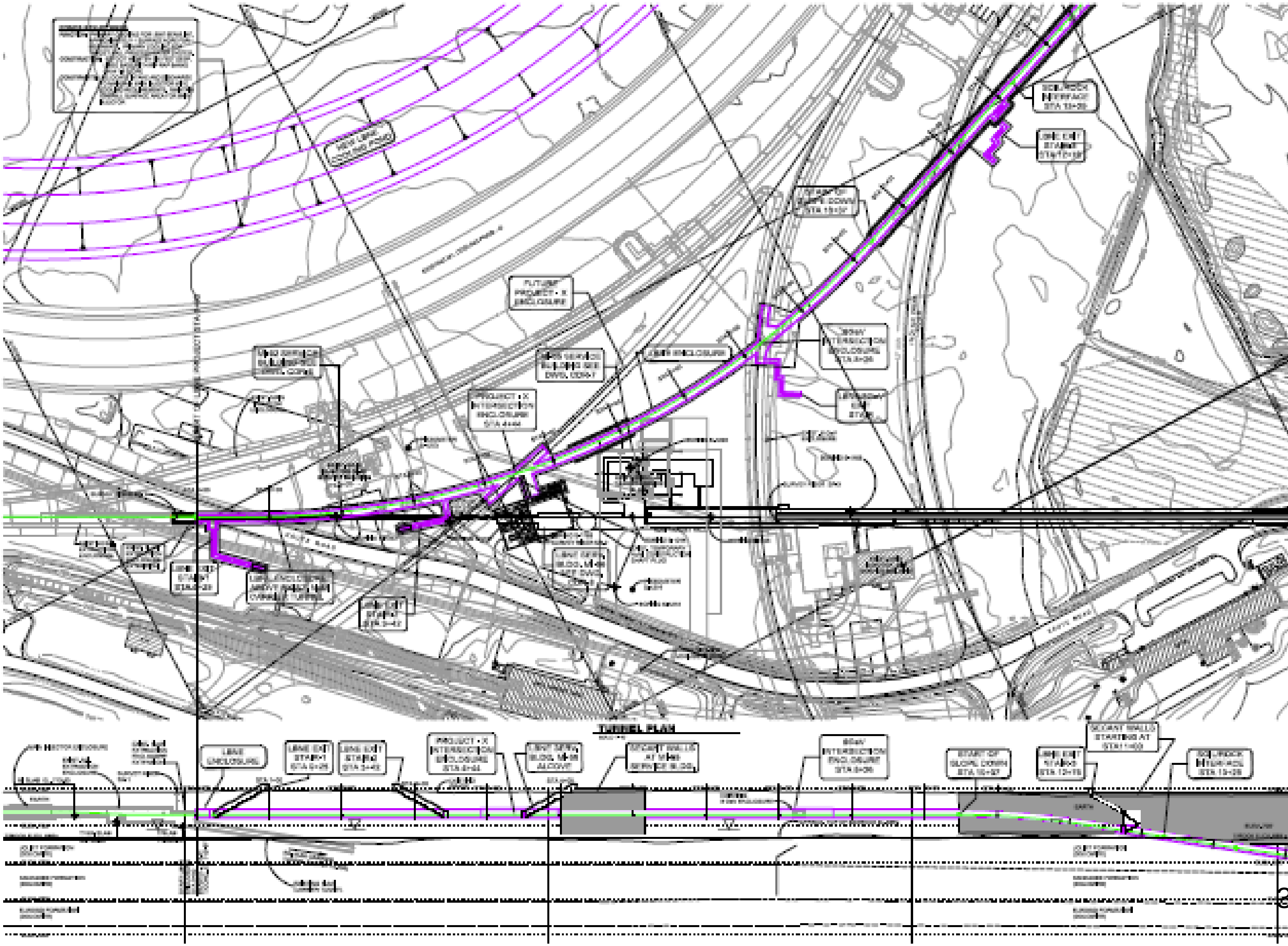
- On the Beam Facility site, the organization is in place, the WBS developed significantly, several people are on board.

- A lot of progress on civil construction issues (constructability review, preliminary cost estimate and schedule).

- Work in progress on the technical components in many fronts. In particular, developing work packages and exploring collaborations for target related work. Aiming for a 700 kW design sometime in the summer 2010 and doing R&D for a 2 MW target.

Backup

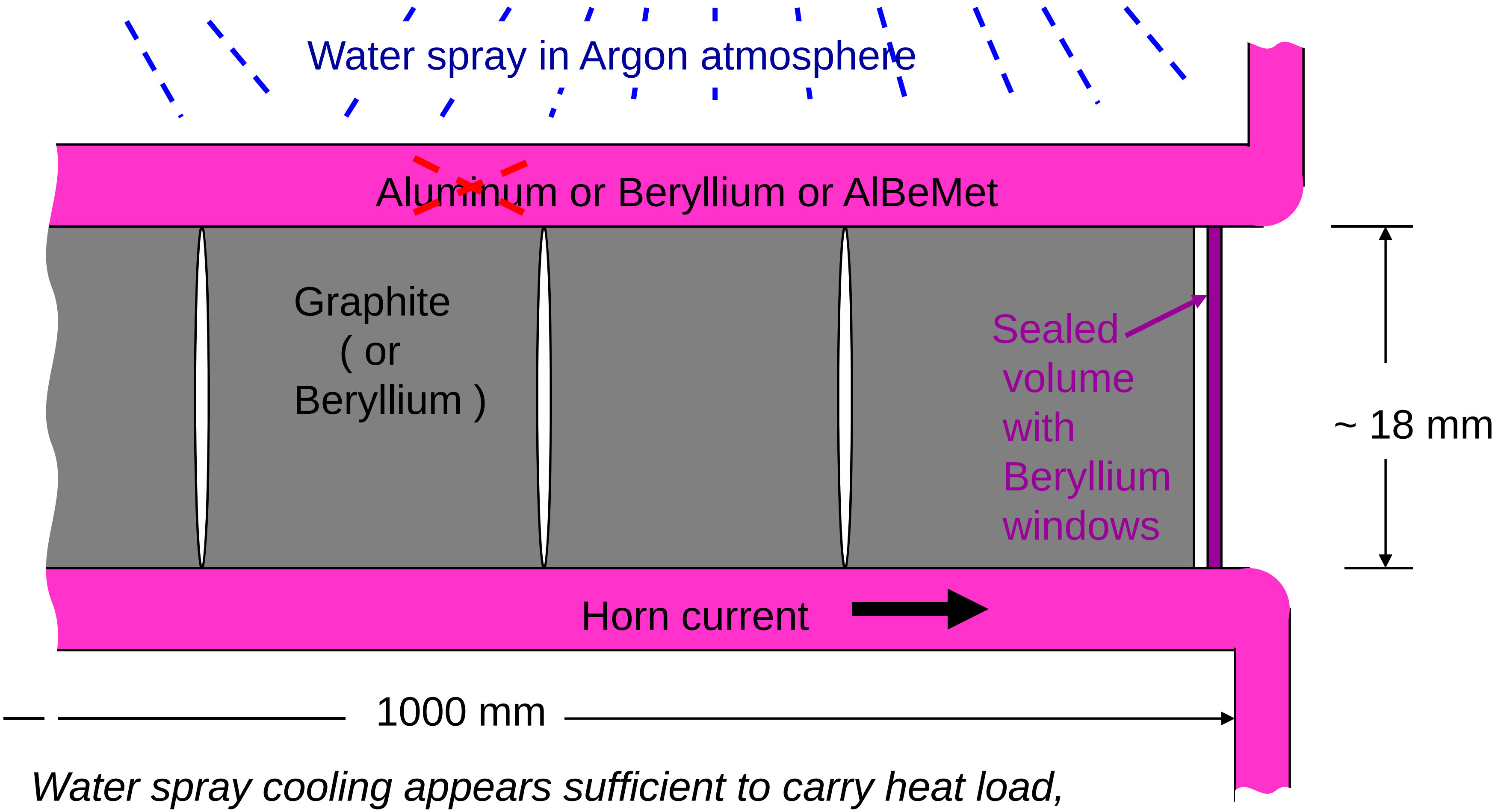
Site View - Fermilab



A concept of target encapsulated by horn inner conductor

- no hydraulic shock

J. Hylen



Water spray cooling appears sufficient to carry heat load, but beyond that an engineering study will be needed.