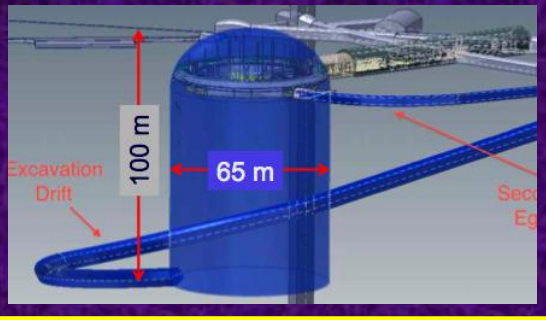

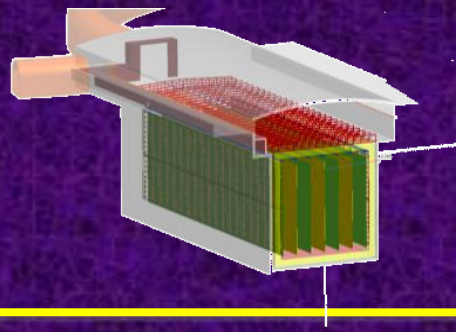

Status of the LBNE Long Baseline Neutrino Experiment

Jon Urheim, Indiana University
for the LBNE Science Collaboration

9 August 2011

Meeting of the Division of Particles and Fields of the American Physical Society

August 9-13, 2011

Brown University, Providence, Rhode Island

Goals for this Talk

- Introduce the LBNE Project:
  - Origins, Scope & Status
- Give snapshot of main features & development efforts:
  - Neutrino Beam Line & Near Detector
  - Water Cherenkov (WCD) Far Detector
  - Liquid Argon TPC (LAr) Far Detector
- Sample the physics menu
- Convey the vitality of LBNE current effort & future prospects

Disclaimer: "reference designs" described here evolving rapidly!

What is LBNE?

- LBNE = Long Baseline Neutrino Experiment
  - It is the name of the "Project" being proposed to U.S. funding agencies.
  - Its impetus was provided by the very influential 2008 P5 report.
  - LBNE represents the "next generation" of osc'n experiments following T2K & NOvA accelerator + Double Chooz, Daya Bay, & Reno reactor expts
- Nominally it involves:
  - A new intense wide-band neutrino beam line at FNAL.
  - A "Near Detector" facility located at the edge of the FNAL site
  - A "Far Detector" facility 1290 km away at "DUSEL" (Homestake mine in SD)
    - Liquid Argon TPC (24-51 kt) and/or Water Cherenkov (150-300 kt)
  - Much effort to keep overall Project cost as low as possible!!
- Timescale: Bulk of data-taking in the 2020's (!!)

LBNE Collaboration

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NGA: S. Malys, S. Usman

New Mexico: B. Becker, J. Mathews

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Oxford: G. Barr, J. DeJong, A. Weber

Pennsylvania: J. Klein, K. Lande, A. Mann, M. Newcomer, S. Seibert, R. vanBerg

Pittsburgh: D. Naples, V. Paolone

Princeton: Q. He, K. McDonald

Rensselaer: D. Kaminski, J. Napolitano, S. Salon, P. Stoler

Rochester: R. Bradford, K. McFarland

SDMST: X. Bai, R. Corey

SMU: T. Liu, J. Ye

South Carolina: H. Duyang, S. Mishra, R. Petti, C. Rosenfeld

South Dakota State: B. Bleakley, K. McTaggert

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Wisconsin: B. Balantekin, F. Feyzi, K. Heeger, A. Karle, R. Maruyama, D. Webber, C. Wendt

Yale: E. Church, B. Fleming, R. Guenette, K. Partyka, J. Spitz, A. Szelc

Primary Science Goals

Excerpt from Collaboration/Project statement (priority-ordered):

- Search for, and precision measurements of, the parameters that govern $\nu_\mu \rightarrow \nu_e$ oscillations. This includes measurement of the third mixing angle θ_{13}, …, and if it is large enough, measurement of the CP violating phase δ and determination of the mass ordering.
- Precision measurements of θ_{23} and $|\Delta m^2_{32}|$. (Is θ_{23} maximal?)
- Significant improvement in proton decay sensitivity.
- Detection of neutrinos from a local core-collapse supernova

The LBNE Beam Line

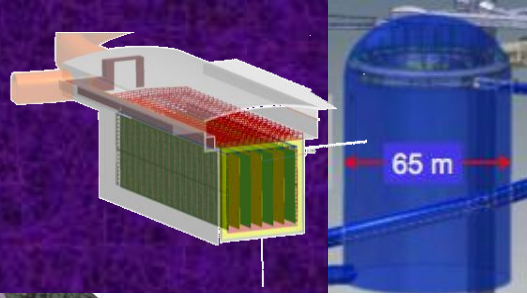
- Highlights:
  - Wide-band on-axis beam (0.5-5 GeV + HE tail)
  - Pitched down at 5.6^{o} (10% grade)
  - 700 kW beam line, upgradable to 2.3 MW
  - Builds on expertise gained with NuMI:
    - Focus on reliability, safety, finite lifetime of components, and need for remote handling & storage of spent components.

The Neutrino Beam Facility at Fermilab

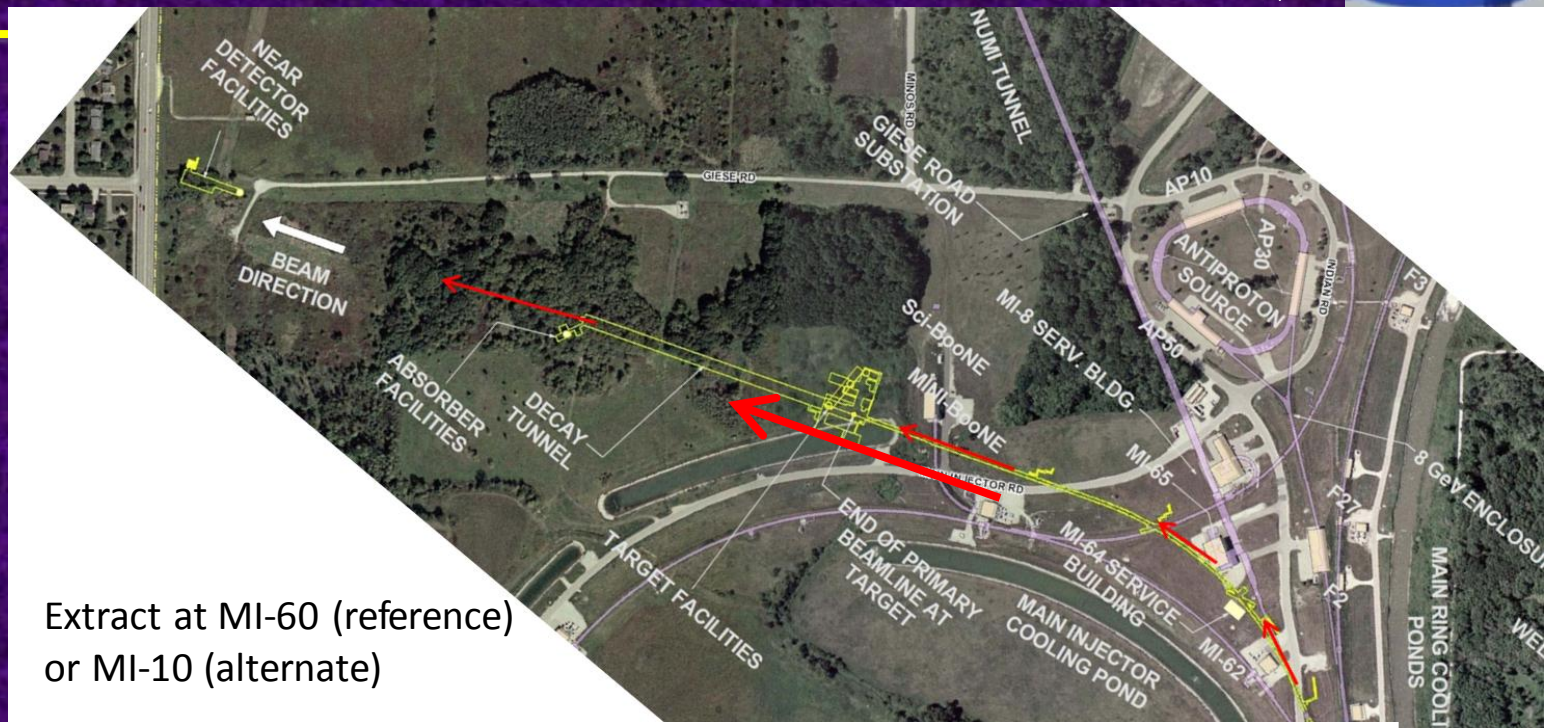
Start with a 700 kW beam, and then take profit of the significantly increased beam power (2.3 MW) available with Project X

Primary beam energy (protons from the Main Injector) from 60 to 120 GeV

Alternate Extraction & Transport Schemes

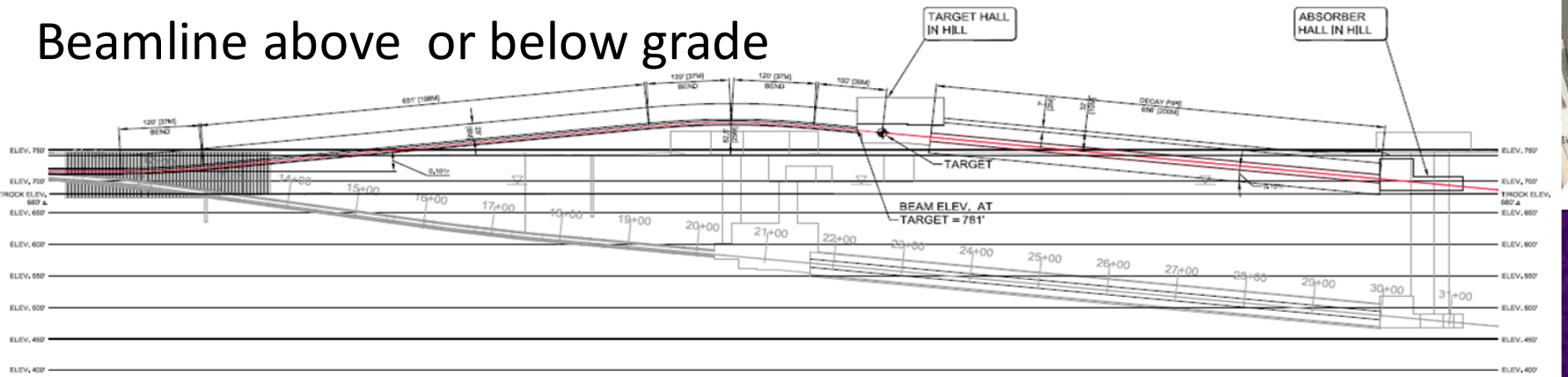


New beam line to Homestake: considerable civil construction costs; "above grade" beam extracted from MI-10 may be lowest cost option

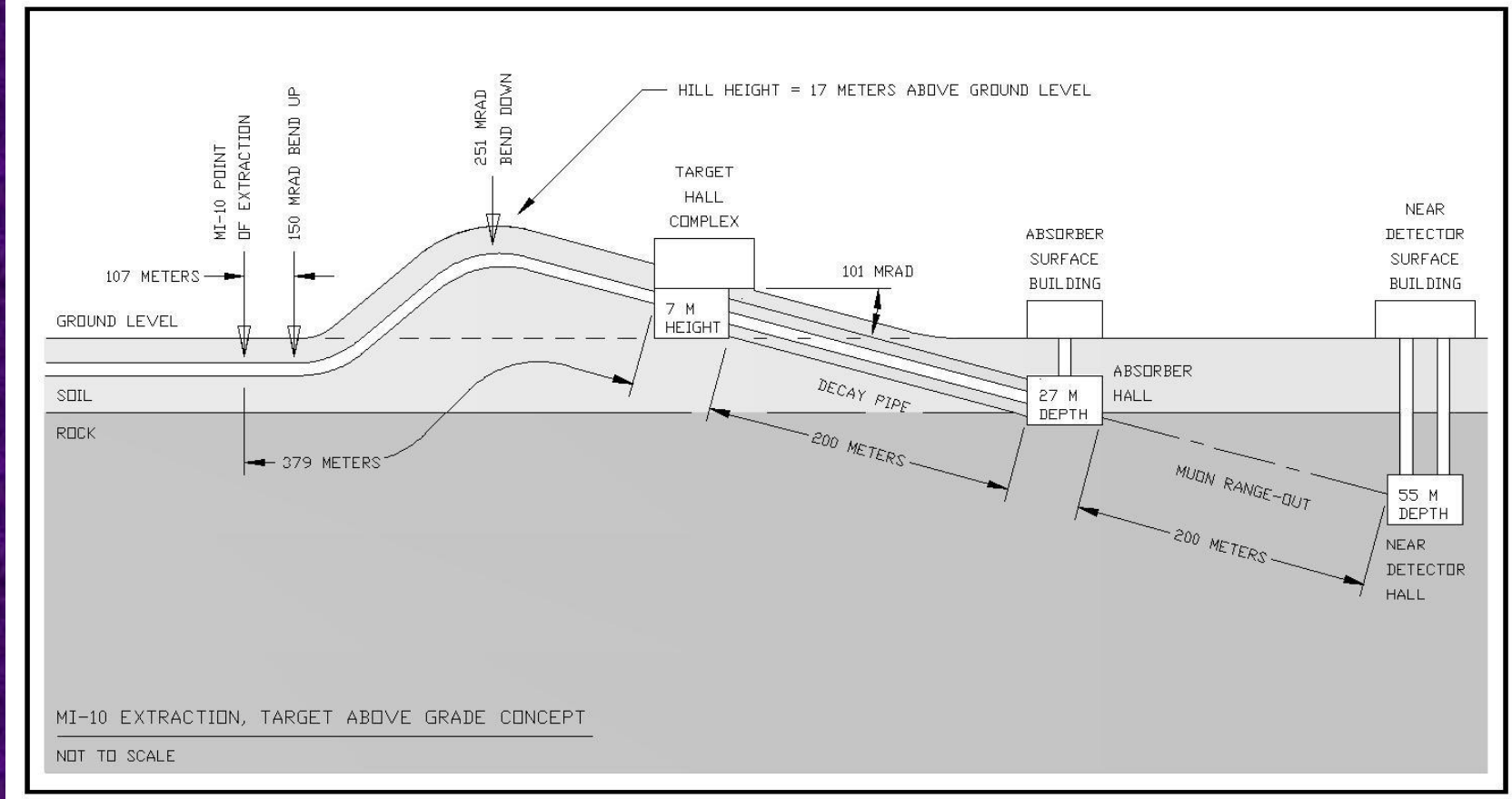


Extract at MI-60 (reference) or MI-10 (alternate)

Beamline above or below grade

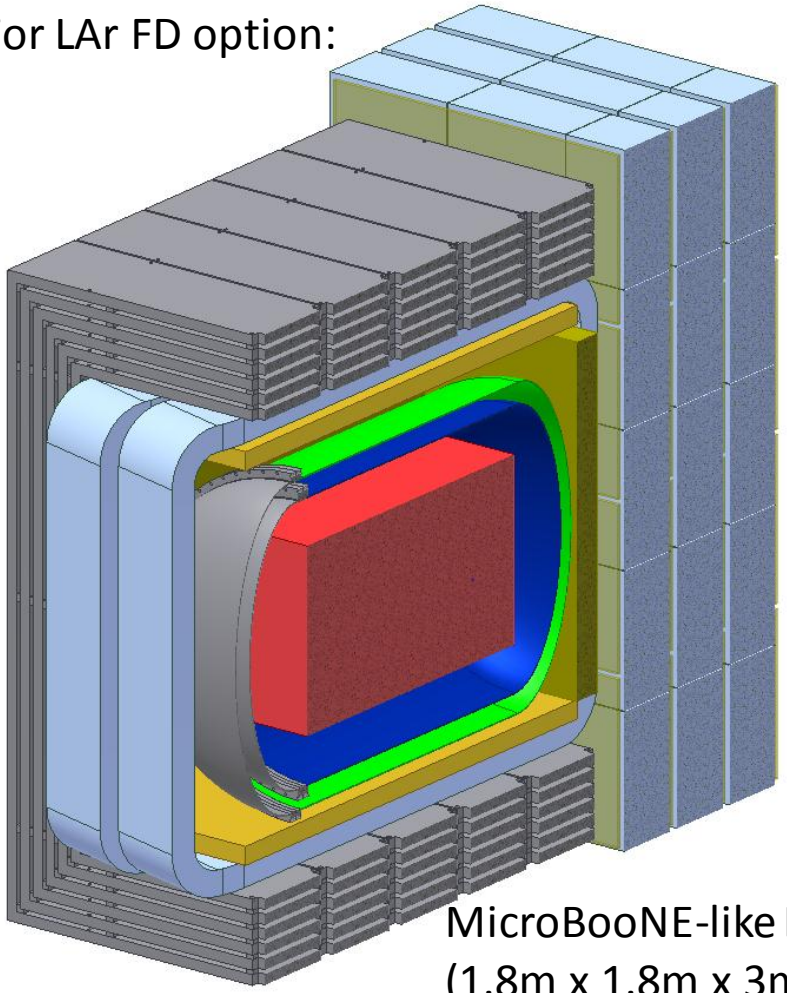


Above-grade concept



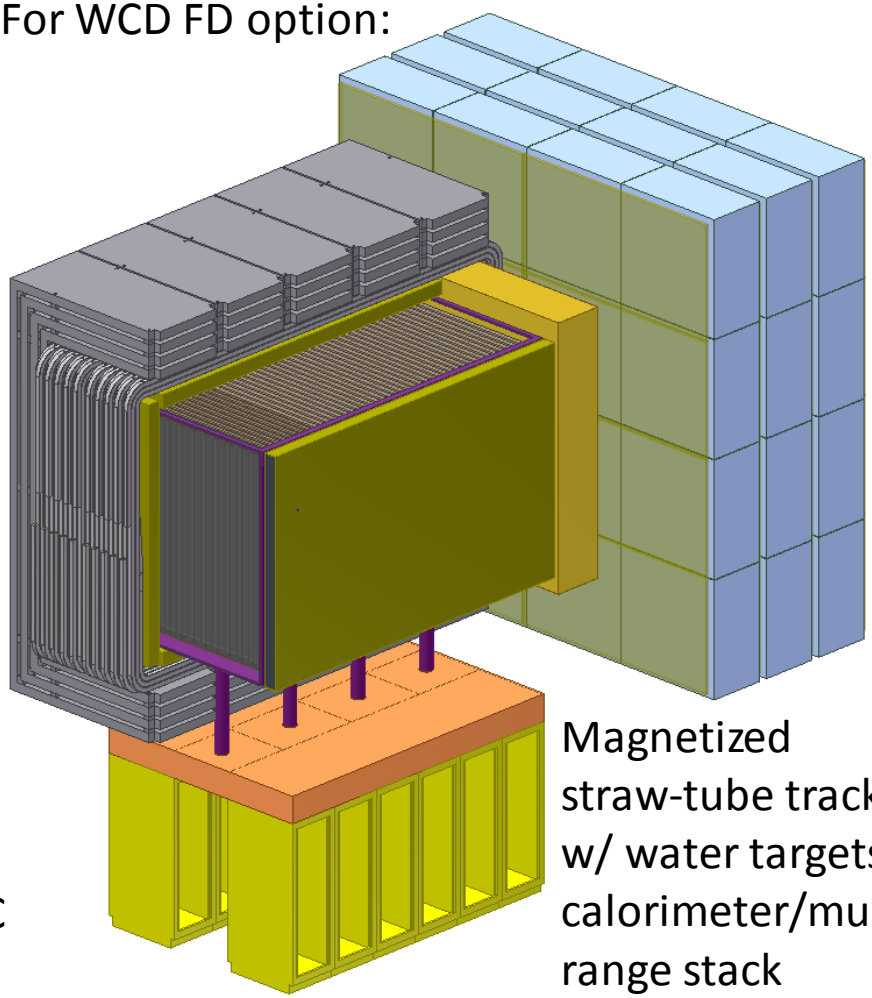
Near Detector Reference Configurations

For LAr FD option:



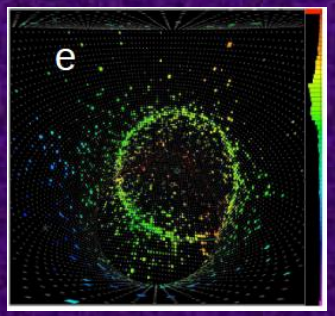
MicroBooNE-like LAr TPC
(1.8m x 1.8m x 3m)

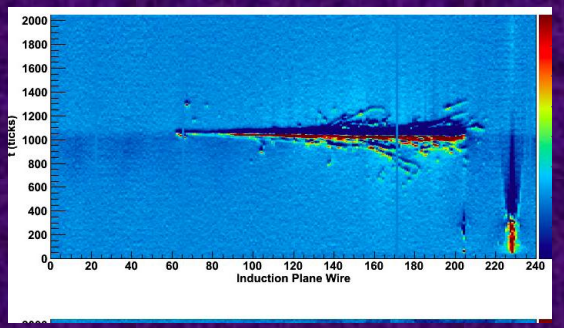
For WCD FD option:



Magnetized straw-tube tracker w/ water targets + calorimeter/muon range stack

Far Detector Options:





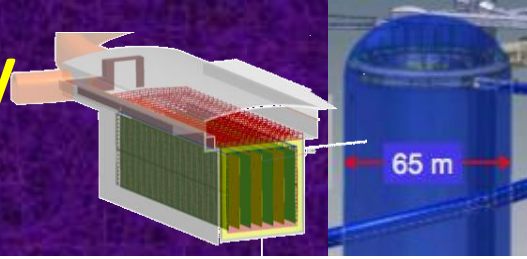
- 1 x 200-kt (fid.) Water Cherenkov Modules (WCD) ?
  - at 4850L of Homestake Mine
- 2 x 17-kt (fid.) Liquid Argon TPC Modules (LAr) ?
  - at 800L (reference design) or 4850L ??
- 1 x 150-kt WCD + 1 x 24-kt LAr ? (deemed too costly?)

The "WCD" Far Detector Module

- 200kt (fiducial) → active volume 63m (diam) x 77 m (high)
- Ref design: 29,000 x 12"-diameter HQE PMTs
  - w/ light collector system to increase coverage by 40%
  - Equivalent performance to SK-II
- Located at the DUSEL 4850' level (4290 mwe)
  - Cosmic muon rate ~ 0.1 Hz
  - Substantial cavern excavation project
- Builds on experience from SK and earlier detectors.

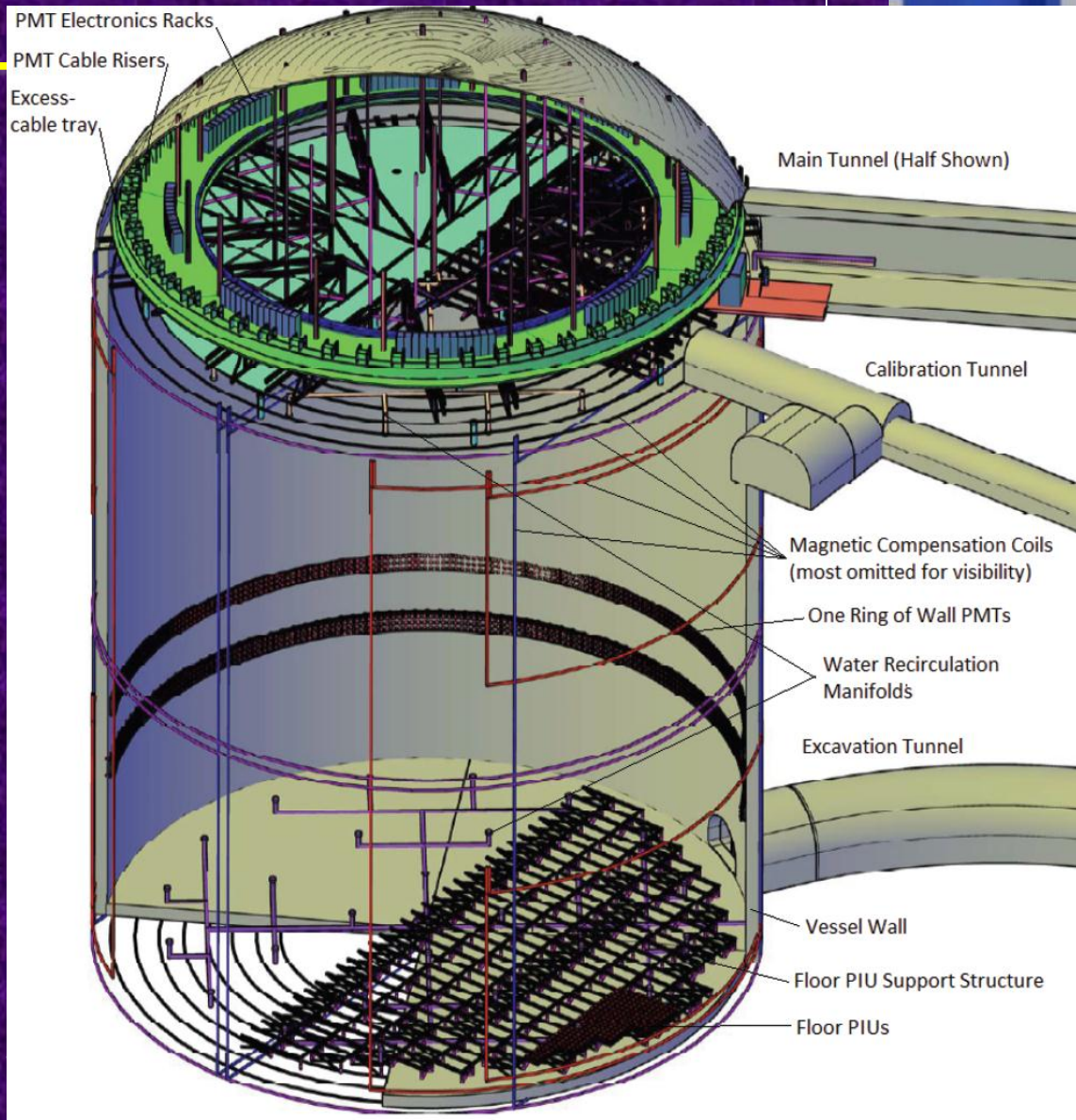
200 kt WCD campus: 4850' & 5060' Levels

200 kt Water Cherenkov Detector Module



Highly integrated design

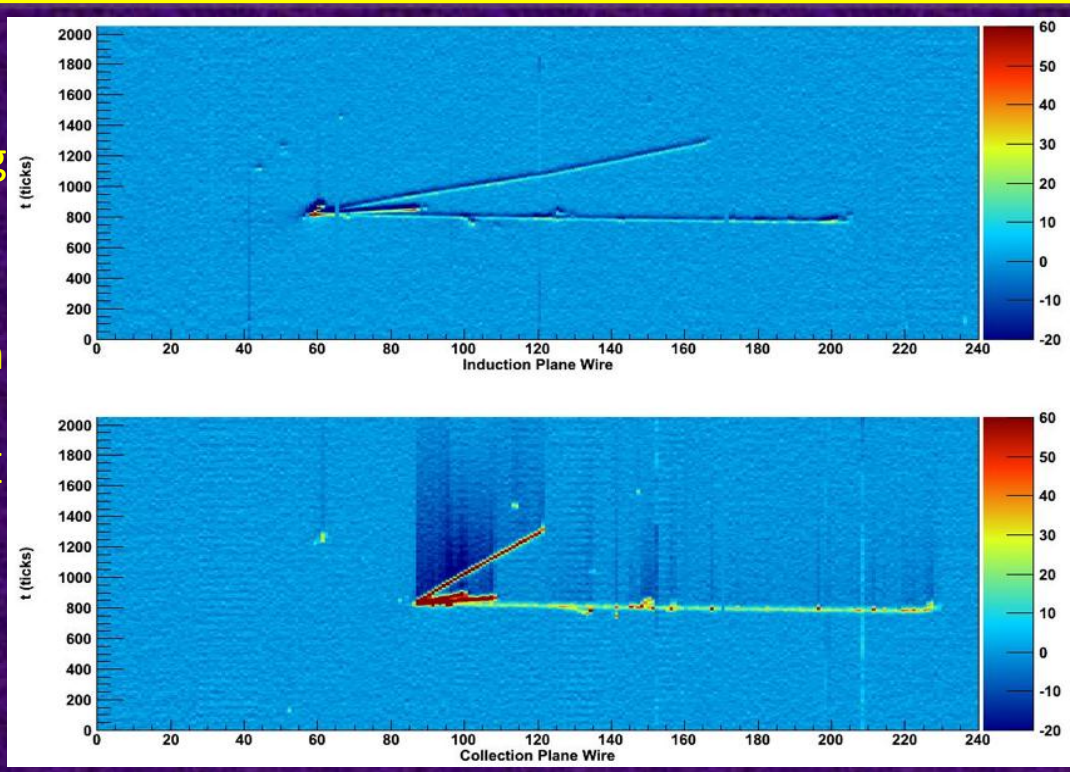
- Water containment/cavern interface
- Magnetic compensation coils
- PMT Installation Units
- Water recirculation manifolds
- Deck & electronics / PMT interface



The “LAr” Far Detector

LArTPC Development

- Much R&D over the years
  - ICARUS pioneered this, now taking data w/ T600 in LNGS
  - Vigorous U.S efforts over past 5+ years. ArgoNeuT providing data in the NuMI beam – w/ similar neutrino energy spectrum to LBNE
  - Other prototypes + MicroBooNE coming
- R&D now is mostly "D"
  - "R" on scintillation photon detection is ongoing
  - In other areas, mainly addressing implementation questions…

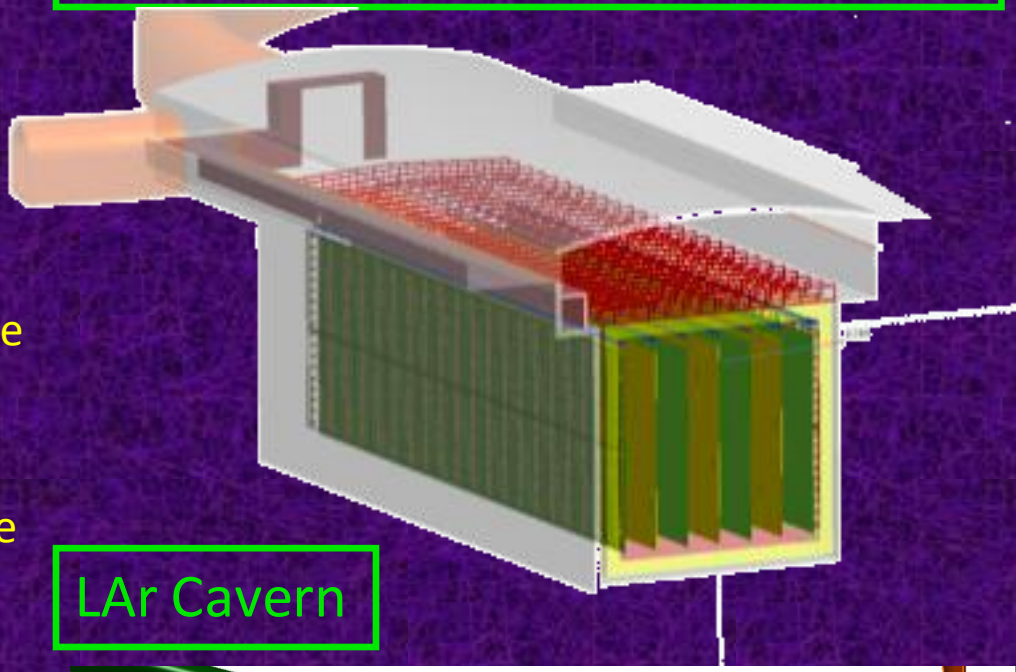


ν_μ CC event in ArgoNeuT

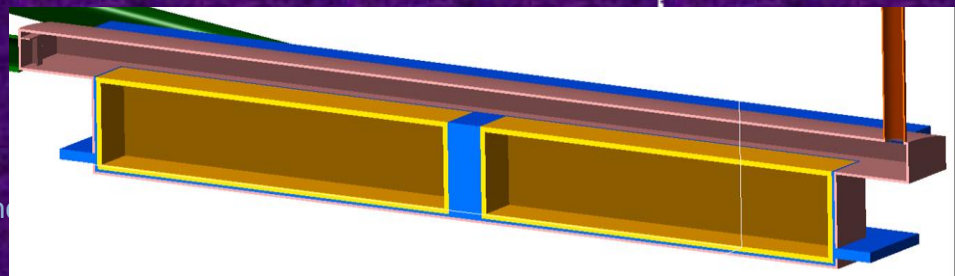
LArTPC Far Detector for LBNE

- We are proposing:
  - 42 kt (active) / 34 kt (fiducial) Far Detector: "LAr40"
  - Sited at 800L of Homestake mine
  - Two modules (cryostats) end-to-end in a single cavern
  - "Membrane" style cryostat w/ passive insulation; evacuable if need be
  - Modular TPC: Anode wire plane assemblies (APA's) and cathode plane assemblies (CPA's) hung from rails along cryostat roof.
  - CMOS electronics mounted on APA frames operating in LAr.

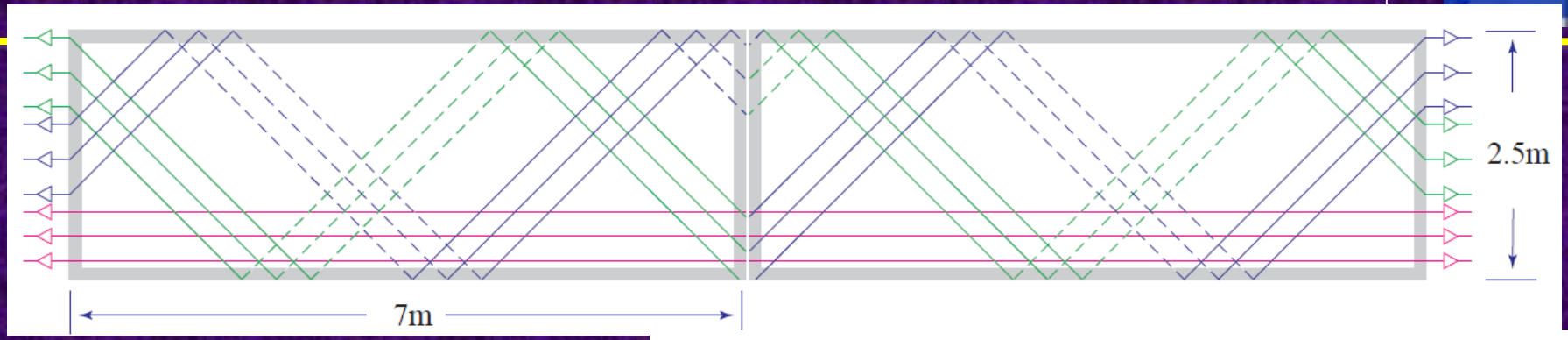
One of two 17kt fiducial LArTPC "modules" for LBNE



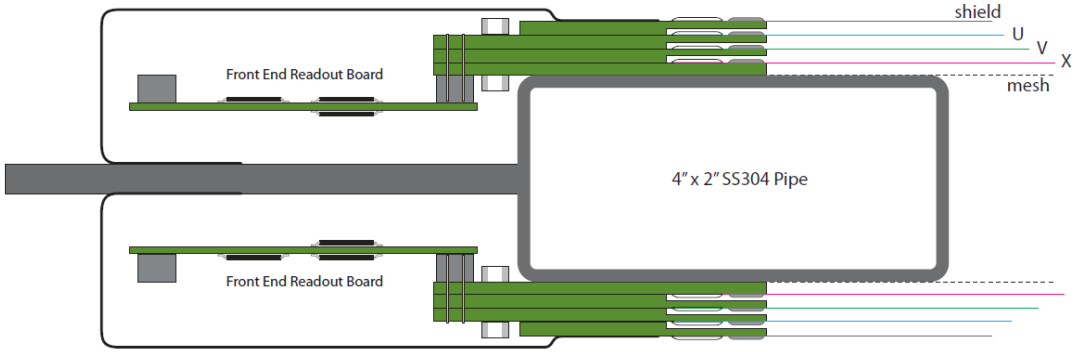
LAr Cavern



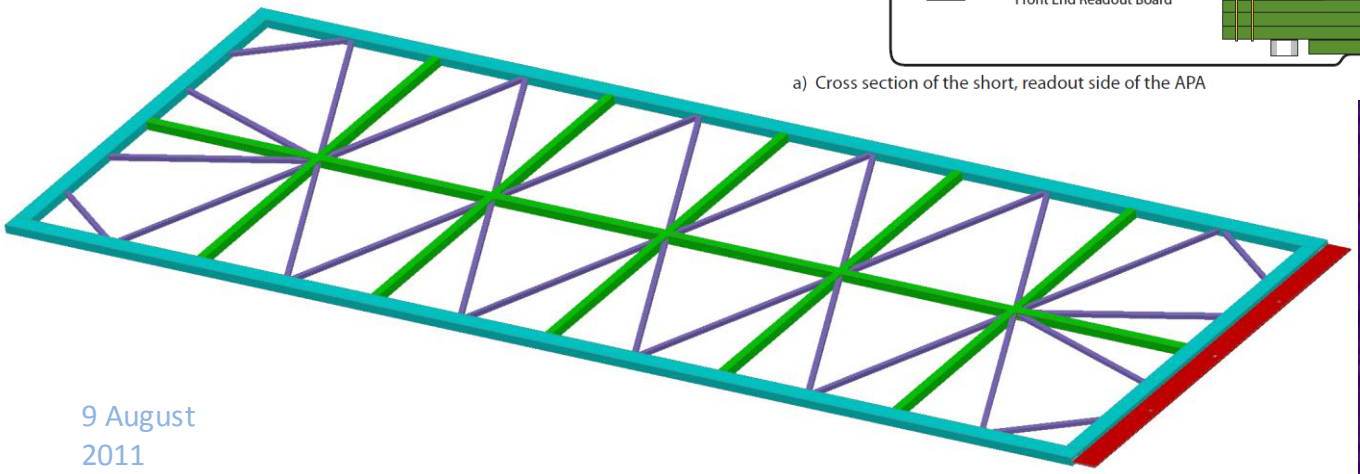
Anode Plane Assembly (APA)



7mx2.5m, stainless steel construction, 250kg
4 planes of wires @ 5mm pitch
2462 sense wires, 3470 wires total
Electronics on one end of the frame



a) Cross section of the short, readout side of the APA



Source: Bo Yu

TPC Assembly in the Cryostat

Shown:
Previous ref. design
168 APAs
224 CPAs
2.5 m max drift
3mm wire pitch

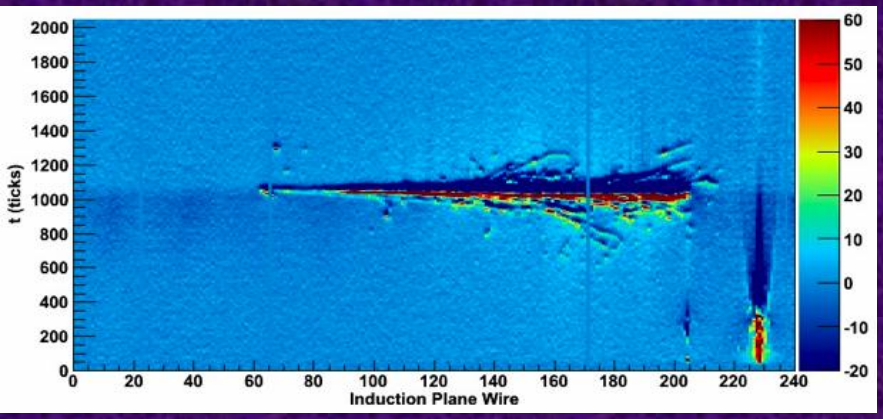
New ref. design:
108 APAs
3.7 m max drift
5mm wire pitch

Cost savings w/ minimal physics impact

Source: Bo Yu
9 August 2011

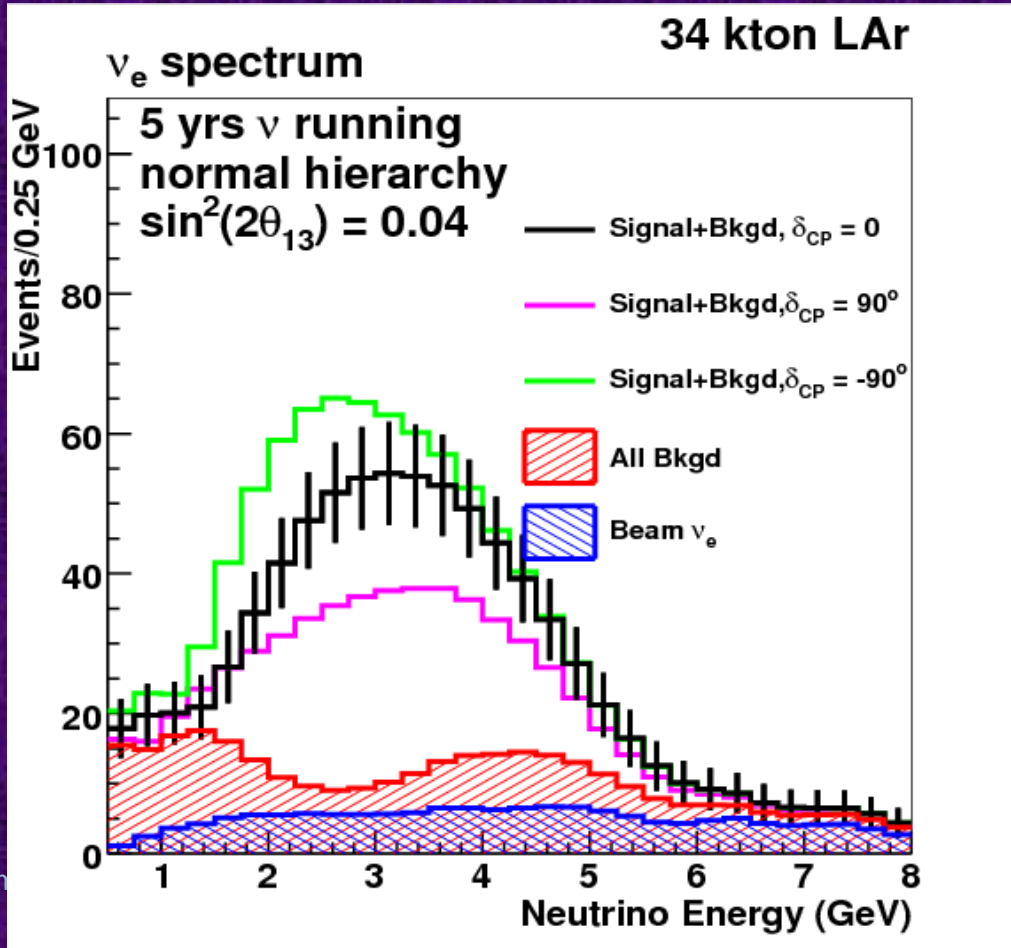
Sample of Physics Capabilities

Example: ν_e Appearance Physics

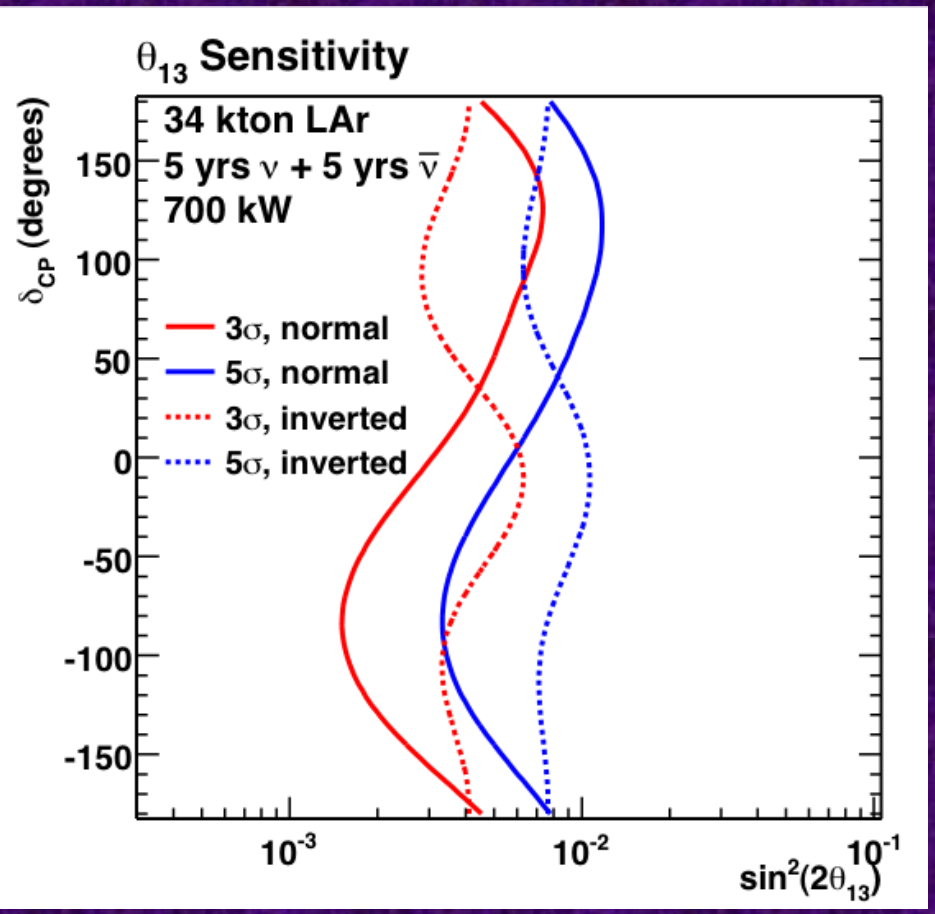


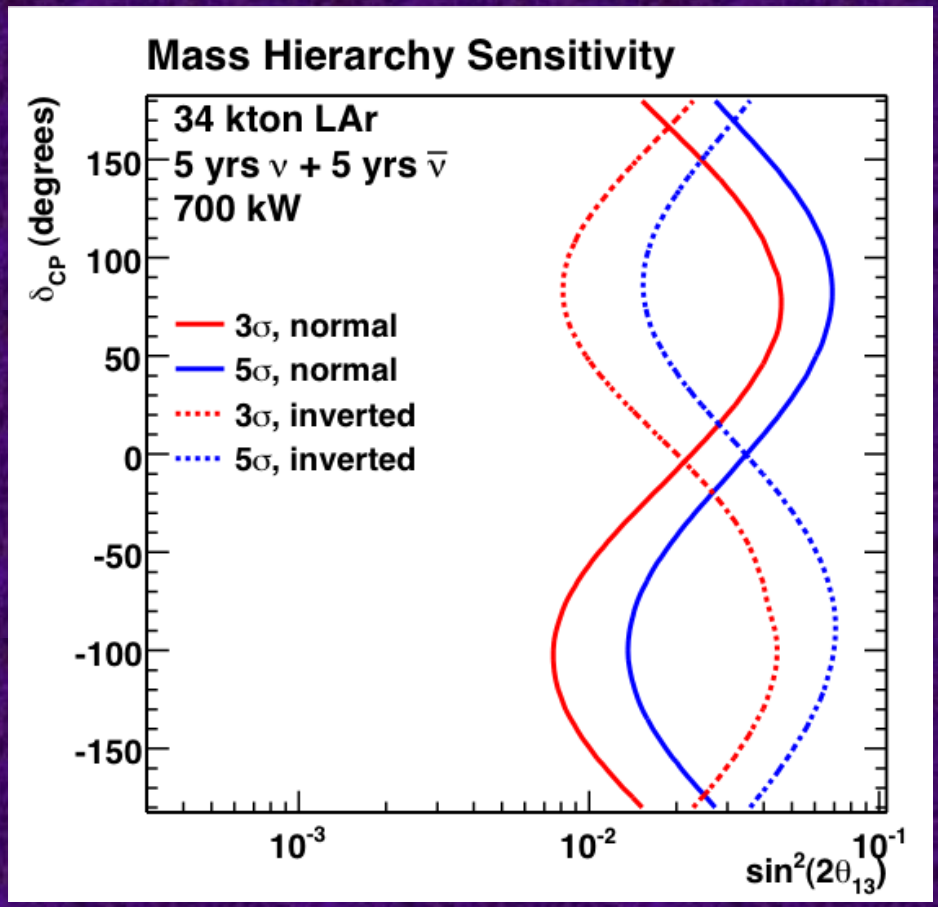
← Showering event in ArgoNeuT

- LAr: Inclusive selection of ν_e CC
  - Excellent energy resolution
  - Excellent NC background rejection.
- For WCD, similar sensitivity:
  - Larger target mass
  - Select quasi-elastics only



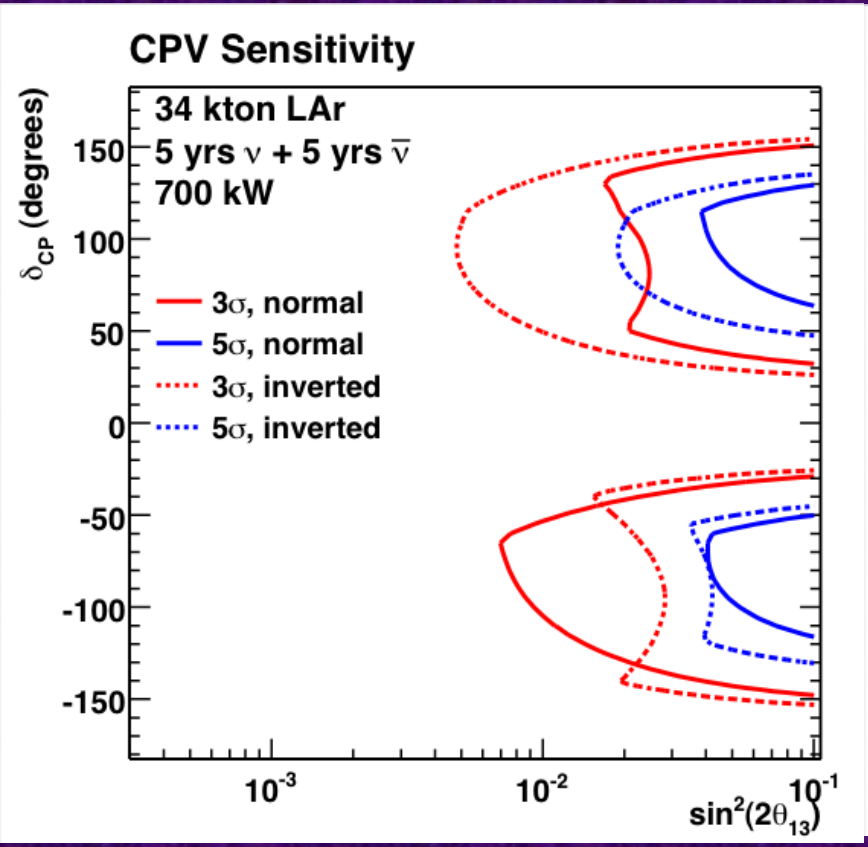
Sensitivity Estimates
(shown for LAr; WCD comparable)

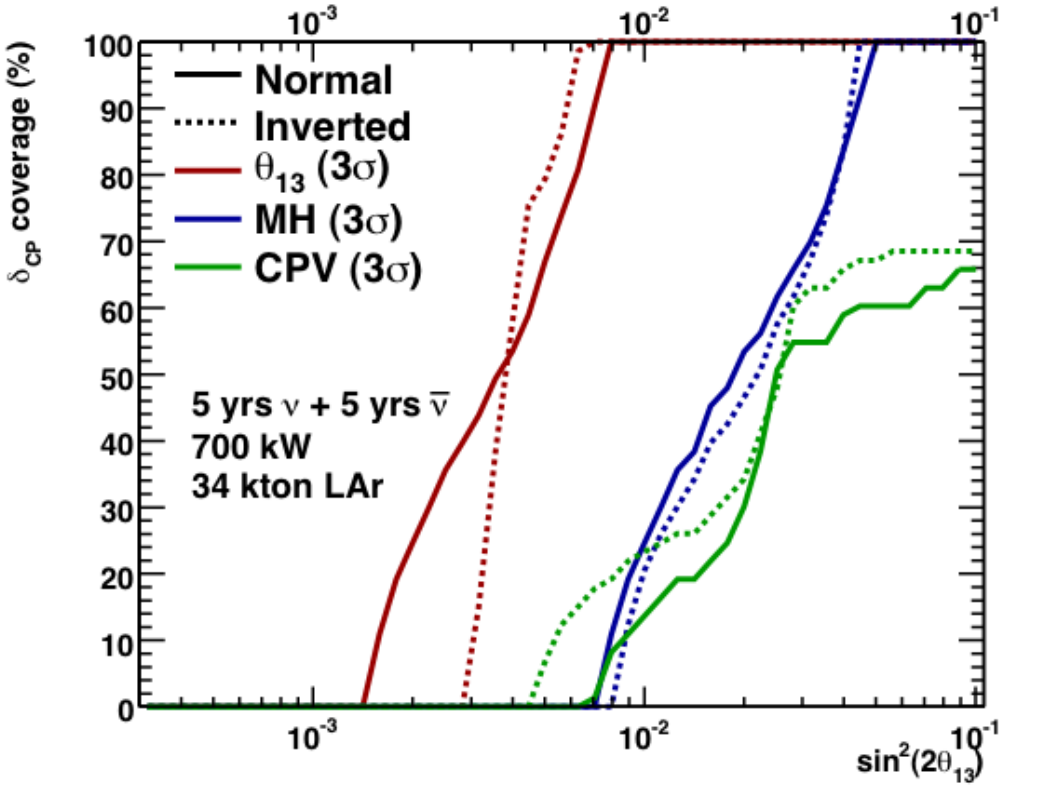




Plots by L. Whitehead, BNL

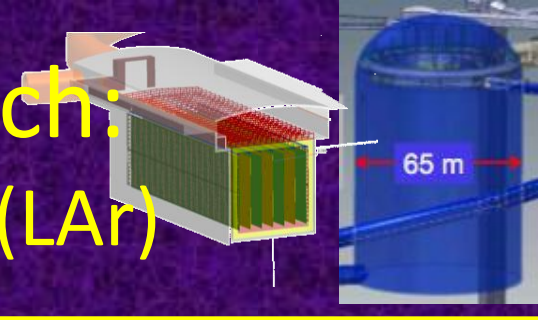
Sensitivity Calculations, cont'd.

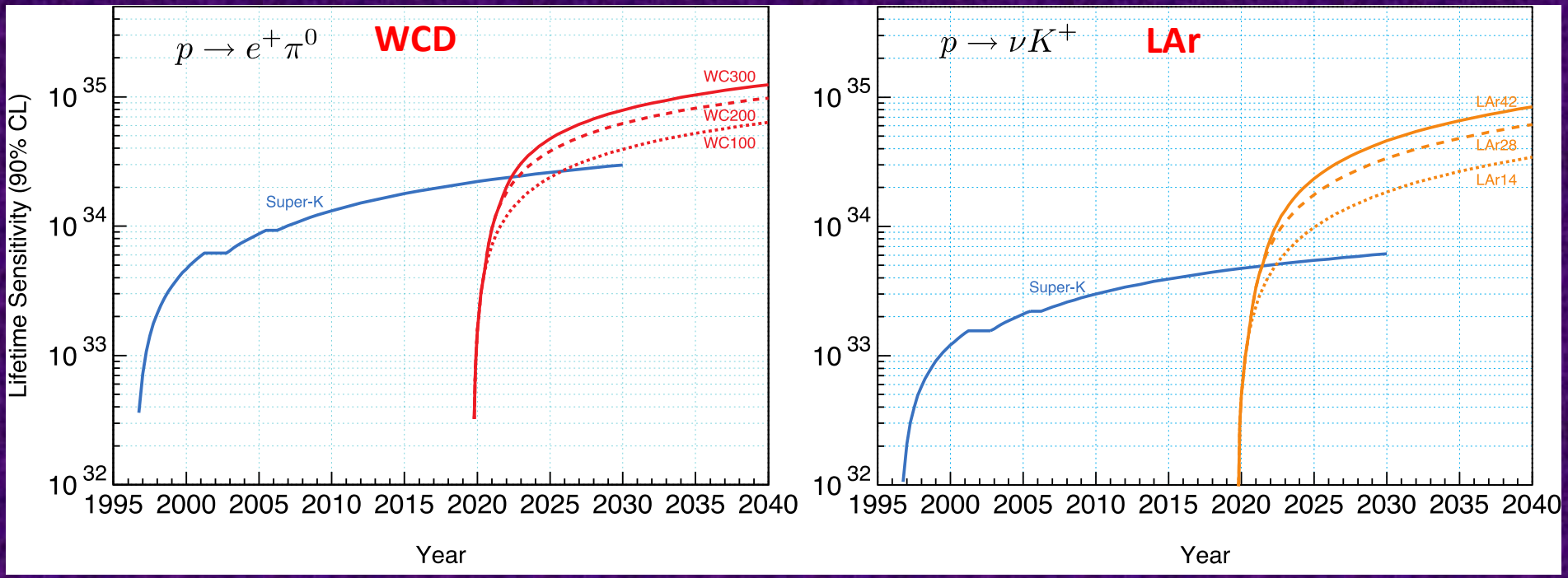




Plots by L. Whitehead, BNL

LBNE Proton Decay Reach: $p \rightarrow e^+\pi^\circ$ (WCD) & $p \rightarrow K^+\nu$ (LAr)





Status of LBNE

- LBNE is currently being supported as a DOE Project
  - CD-0 “Mission Need” has been approved
  - We are working toward CD-1:
    - >1000-page CDR from Fall ’10 now being revised
    - Possible FD technology decision this winter
  - reviews coming up (Lehman review for CD-1 in spring 2012 ?)
- NSF withdrawal of plans for construction/stewardship of DUSEL
  - Certainly has had some impact on the schedule described above!
  - We will hear soon about DOE plans for Homestake/underground science (maybe even here at DPF on Thursday?!)

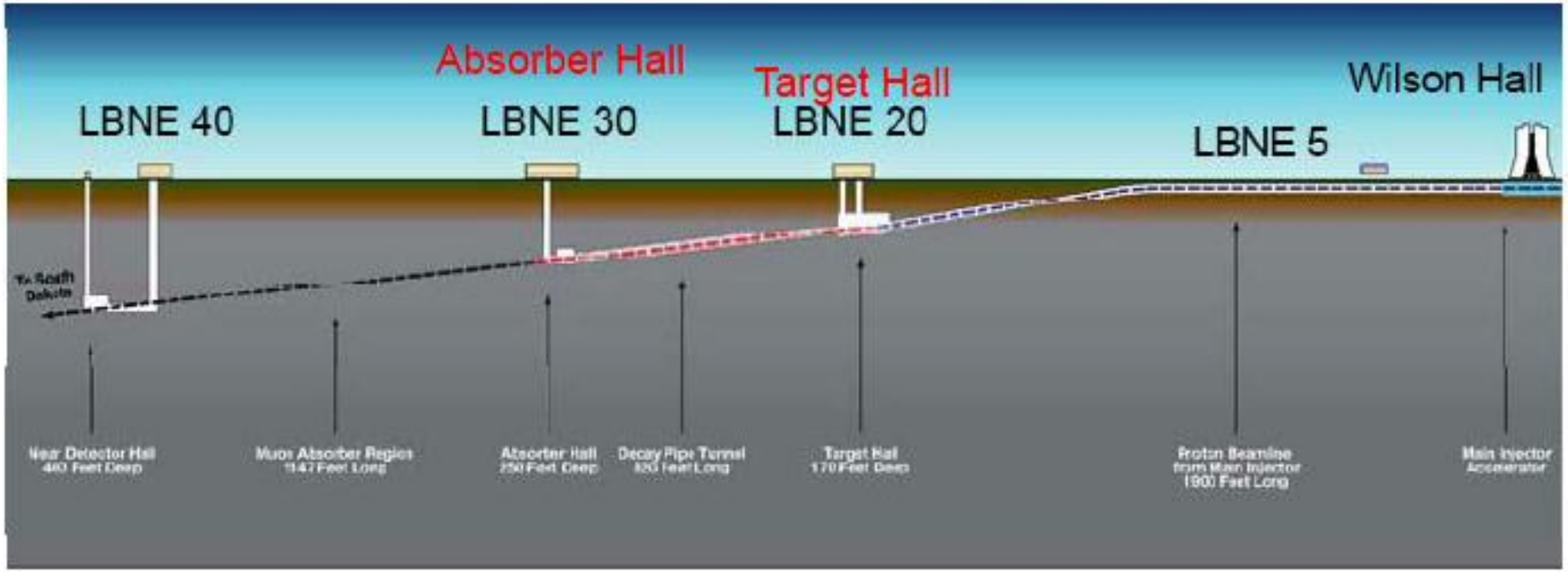
Summary

- Reference conceptual designs for LBNE beam and detectors are well advanced
  - Much engineering effort invested already
  - These systems appear technically feasible
- The physics arguments for realizing LBNE are strong
  - See, e.g., plenary talks by L. Everett & J. Raaf.
  - The case grows stronger in proportion to detector mass and beam power
- Many interesting challenges lie ahead
- Lots of room for new, creative ideas on all fronts

Backup Slides

Slide courtesy
G. Rameika

The Neutrino Beamline Facility



Primary Beam (magnets- 45 dipoles, 48 quadrupoles , 41 correctors-, magnet power supplies, LCW, vacuum, beam instrumentation, beam optics and beam loss calculations)

Neutrino Beam (window, baffle, target, 2 focusing horns, horn power supplies, decay pipe, absorber, RAW, tritium mitigation, target pile, remote handling, modeling, storage of radioactive components)

System Integration (controls, interlocks, alignment, installation infrastructure)

Beam Line Parameters

Compare w/ NuMI:

Design: 400 kW
Operating at: 300 kW

~ 3 x 10^{13} ppp
~ 2 sec cycle time

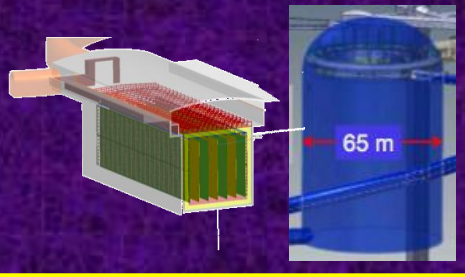
Beam Parameter	Value
Protons per cycle	4.9 x 10^{13}
Cycle time (120 GeV)	1.33 sec
Pulse duration	1.0 x 10^{-5} sec
Proton beam energy	60 to 120 GeV
Beam power at 120 GeV	708 kW
Operational efficiency	63%
Protons at target per year	7.3 x 10^{20}
Beam size at focus	1.5 mm
Beam divergence x,y	0.017 mrad

Primary Beam Line

- Requirements/Specifications:
  - Minimize Losses:
    - Extensive beam permit system w/ 250 parameters
    - Open extraction channel, large magnet apertures

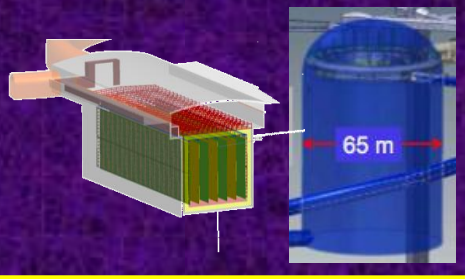
      (> 47mm x 120 mm for dipoles, 72 mm for quads) to accommodate varied beam conditions (beyond 500 π Main Injector dynamic aperture)
    - Strong focusing optics, automated beam pos'n control
    - Power supply regulation to few ppm.
    - Robust instrumentation.

Neutrino Beam Technical Components



Element	Parameter	Range	Reference design value
Target	material	graphite, Be	graphite
	diameter	0.5 to 1.6 cm	1.53 cm
	length	~2 interaction lengths	96.6cm
Focusing Horn 1	length	250 to 350 cm	300 cm
	current	180 to 300 kA	300 kA
Focusing Horn 2	length	300 to 400 cm	353 cm
	current	180 to 300 kA	300 kA
	distance from start of Horn 1	600 to 800 cm	660 cm
Decay Pipe	length	200 to 350 m	250 m
	radius	1.5 to 2 m	2 m
	atmosphere	Air, He, Vacuum	air STP
Near Detector Cavern	distance from target	Maximum, fits within site bdyboundary	700 m

Target and Horns



Target

- Nominally Graphite core
- Design for 700 kW target proceding at IHEP Protvino, upgradable to 2.3 kW
- Fully inserted into Horn 1, but can be removed w/ remote handling

Horns

- Horn 1 u/s: cylindrical
- Horn 1 d/s: parabolic
- Horn 2: parabolic
- Polarity under external control

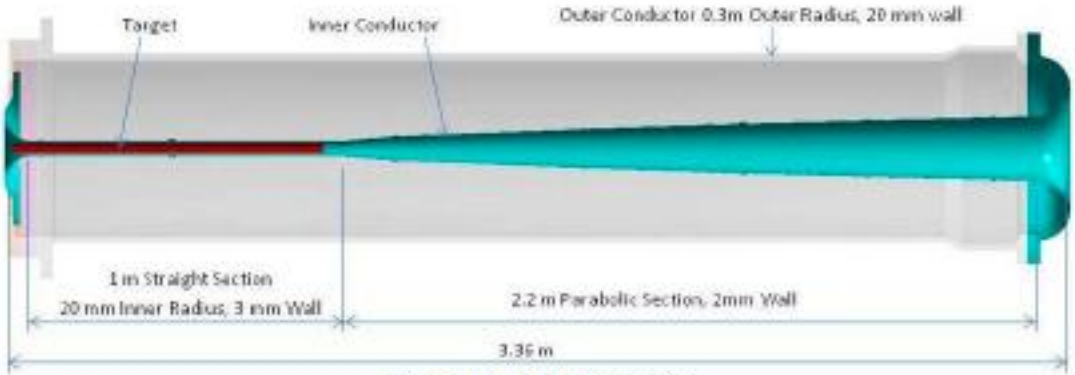


Figure 3-15: Horn 1 section

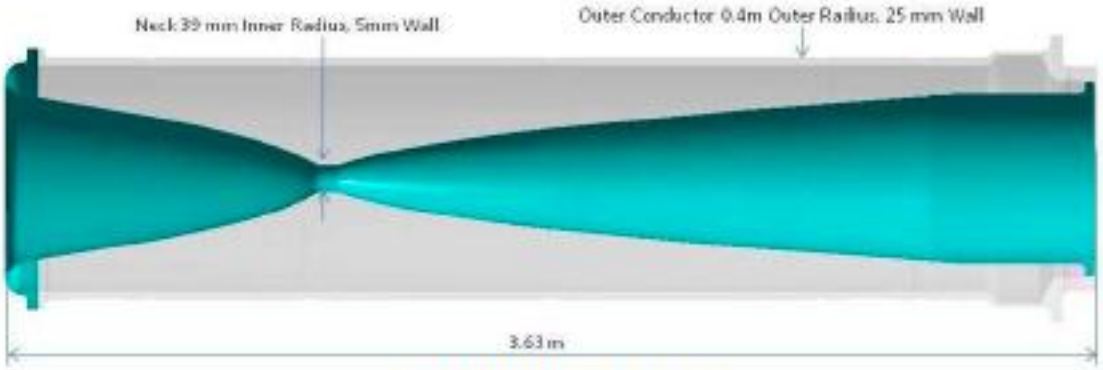
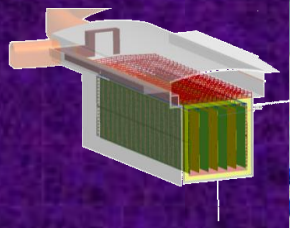
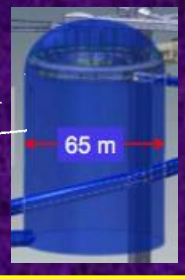
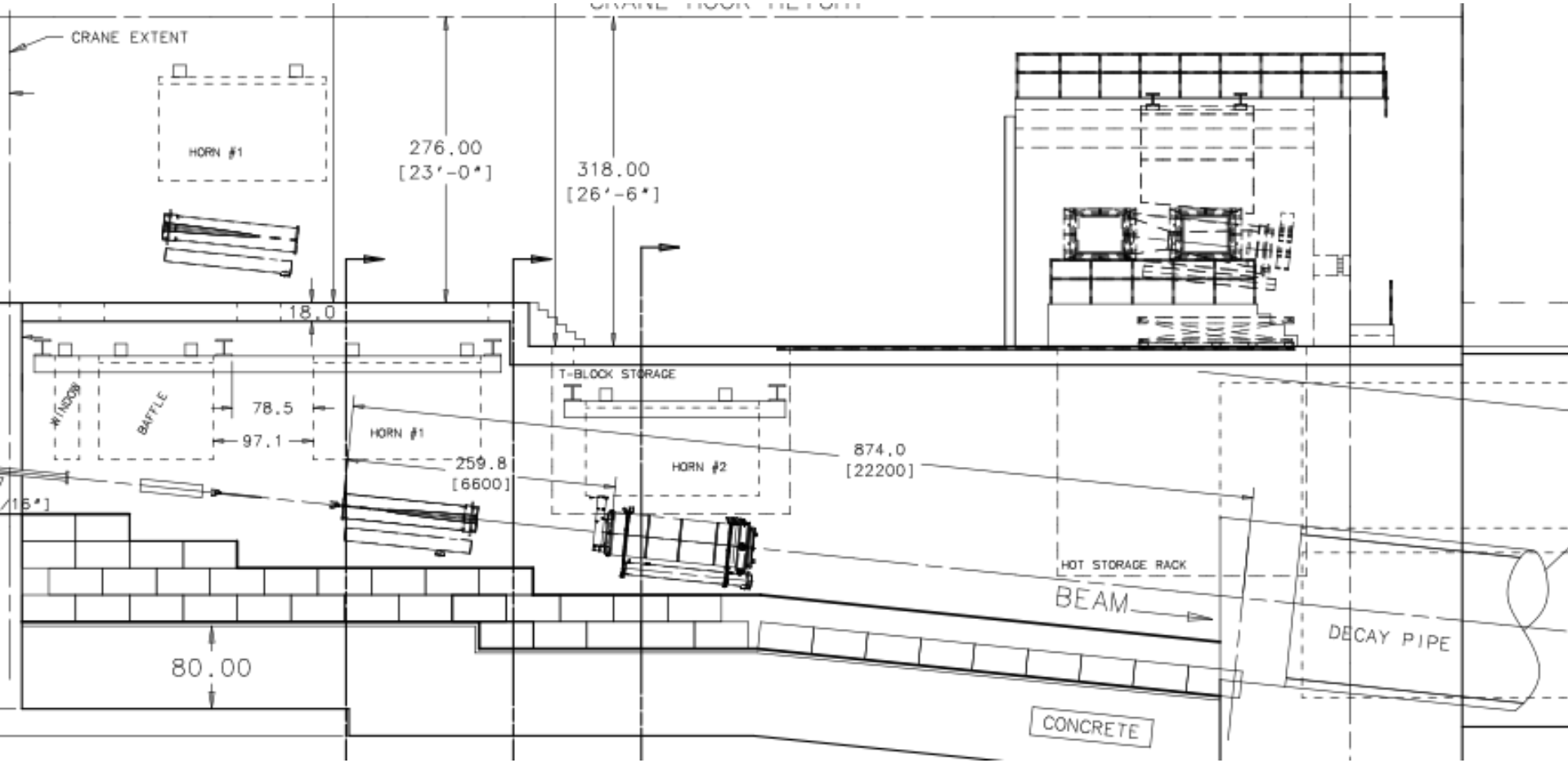


Figure 3-16: Horn 2 section

Target Hall Layout





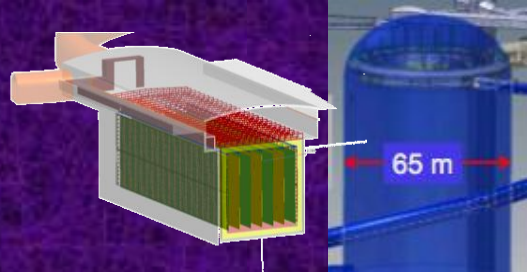


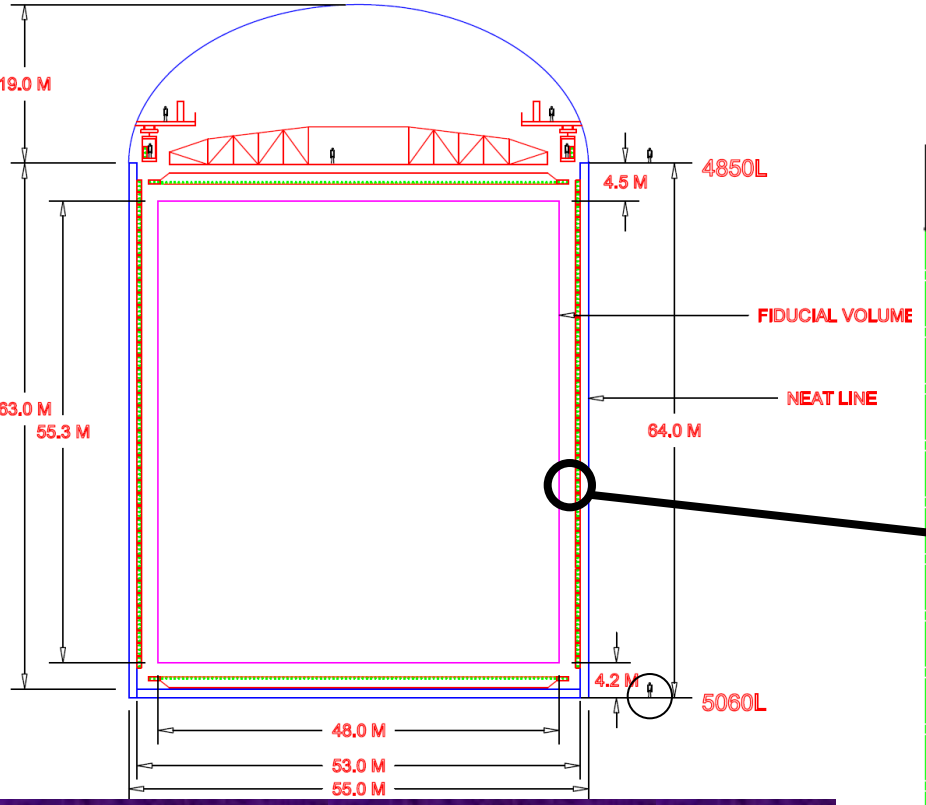
WCD Photodetector
(outdated specs, for 100kt module)

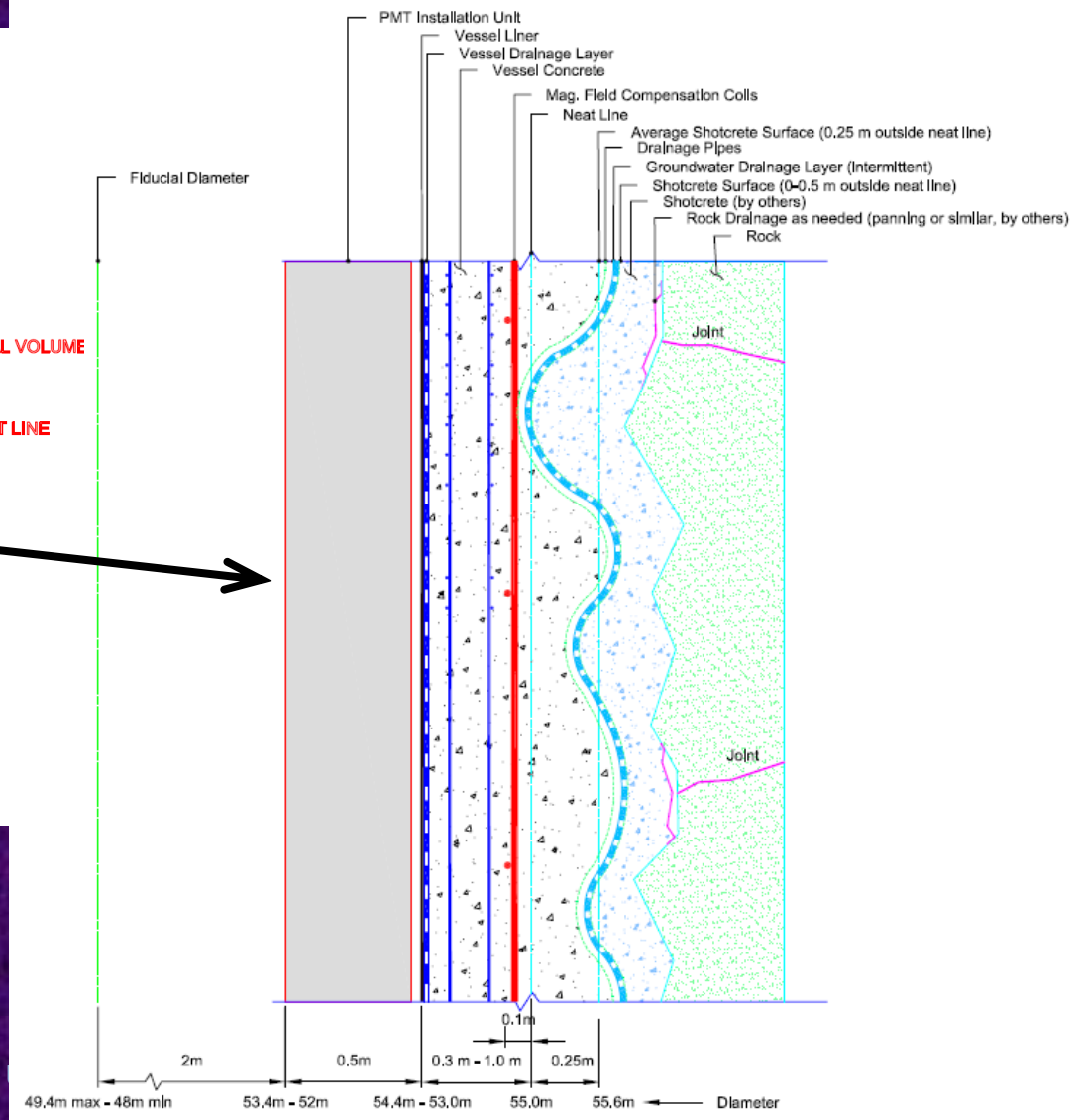
	LBNE	SNO	SuperK
Tube	10-12 inch	Ham-R1408	Ham-R3600
Dia (cm)	25-30 cm	20 cm	50 cm
Thickness (mm)	3-4 mm	2 mm	4 mm
Pressure (kPa)	580	215	380
Stress (Mpa)	12	5.3	12
Number	~50000	~9500	~ 11000

- Requirements and Specifications
  - Aim for 20% coverage, w/ Quantum Efficiency > 20%
  - Wavelength range 300 to 600 nm
  - Gain 10^7 @ < 2 kV, charge resolution 50%
  - Afterpulsing < 5%, pre-pulsing < 1%, dark rate 2500 Hz @ 13C
  - Long-term stability; Pressure resistance up to 700 kPa
- 50,000 Hamamatsu R7081 HQE version array meets requirements

Water Containment System







Vessel liner material:

- Polymeric sheet liner is a preferred option
- 3mm stainless steel (304) is in baseline for now, as polymeric materials are under study

WCD Water Circulation System

Fill Line From Surface

4850L

Outlet

PURIFICATION SYSTEM

Inlet

OUTER ZONE

INNER ZONE

PMTs

Lower Level Drift Elevation at 5060L

Pur. System Return

Pur. System Supply

Recirculation Pumps and Flow Configuration Valves

Flow from Top Manifold

Inner Zone Bottom Manifold Flow

Outer Zone Bottom Manifold Flow

Return manifold used during Vessel Fill

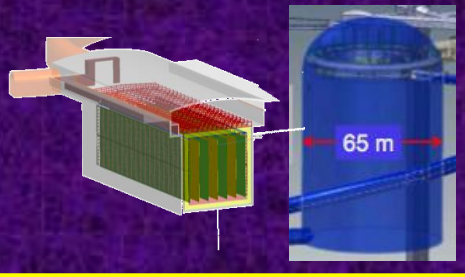
Drainage to DUSEL Facility Dewatering System

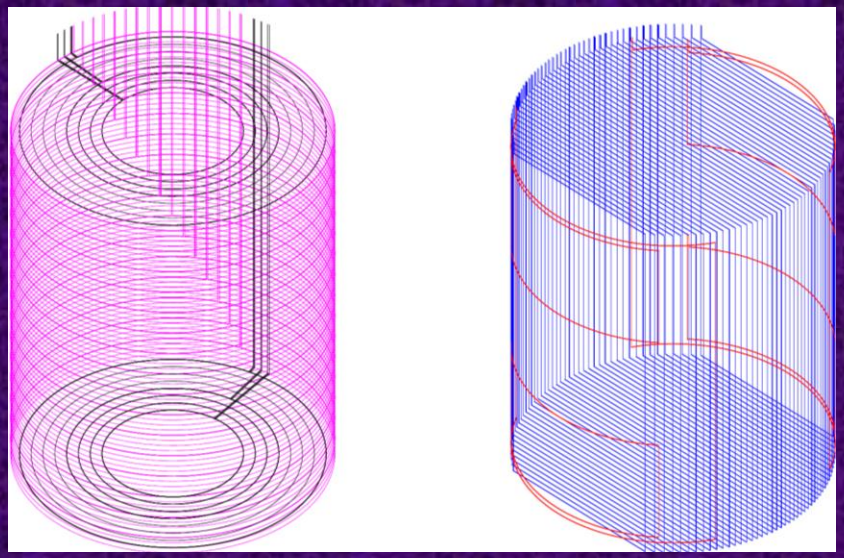
Detector Draining

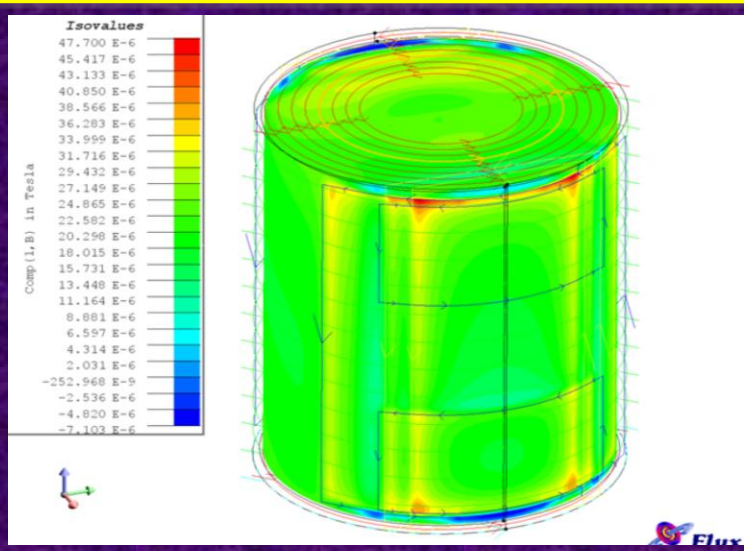
Drainage line for Vessel Leaks

Drainage line for Ground Water

Magnetic Compensation







Implementation:

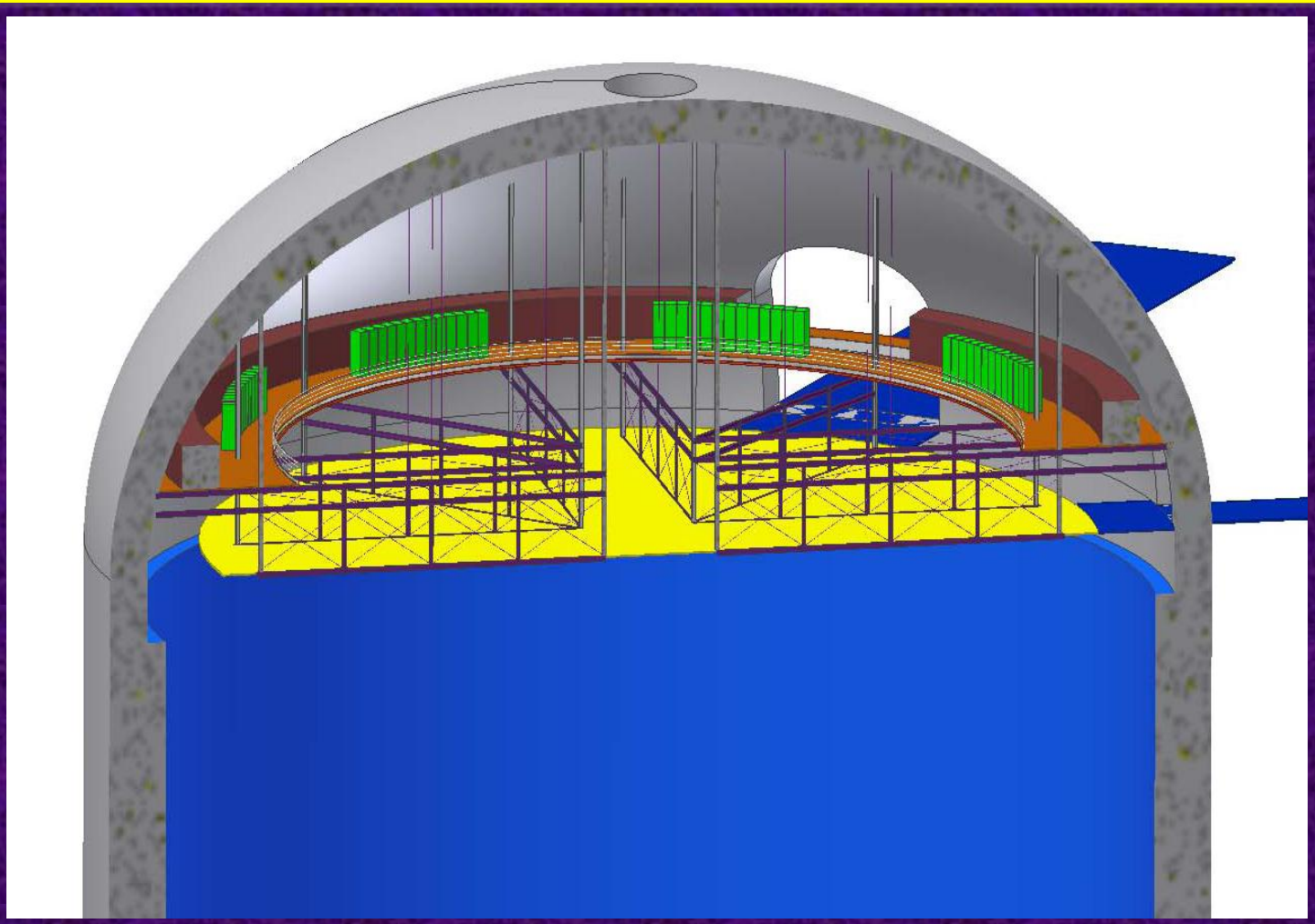
- Horizontal, vertical and saddle coils
- Conductor is copper in single or 4 strand cable
- All feed and power supplies on deck
- Coils buried between cavern rock and concrete vessel
- Proximity to PMTs may result in less than optimal compensation

Goal:

Less than 50 mG on at least 75% of all PMT positions
Less than 100 mG on at least 95%
Less than 150 mG everywhere

Slide courtesy F. Feyzi

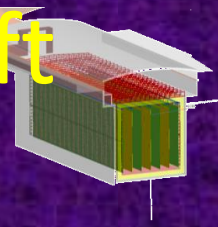
WCD Deck Configuration

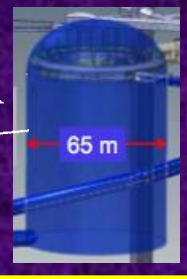


How to build a 20-kt scale LArTPC ?

0. Draw from previous experience – ICARUS
1. Need a large cavern deep enough to provide adequate shielding (most important for proton decay)
2. Need a vessel w/ low heat loss & no leaks
3. Need a cryogenics system to remove heat, re-liquefy boil-off, & achieve required argon purity
4. Need a simple, modular TPC structure
5. Need low-power, low-noise electronics
6. Need high-bandwidth readout & DAQ

Cavern: to be sited at 800-ft level, w/ drive-in access





Ramp From 300L to 800L

Yates Shaft

Kirk Portal

Existing 800 Level

Existing 300 Level

Utility Shafts To Surface

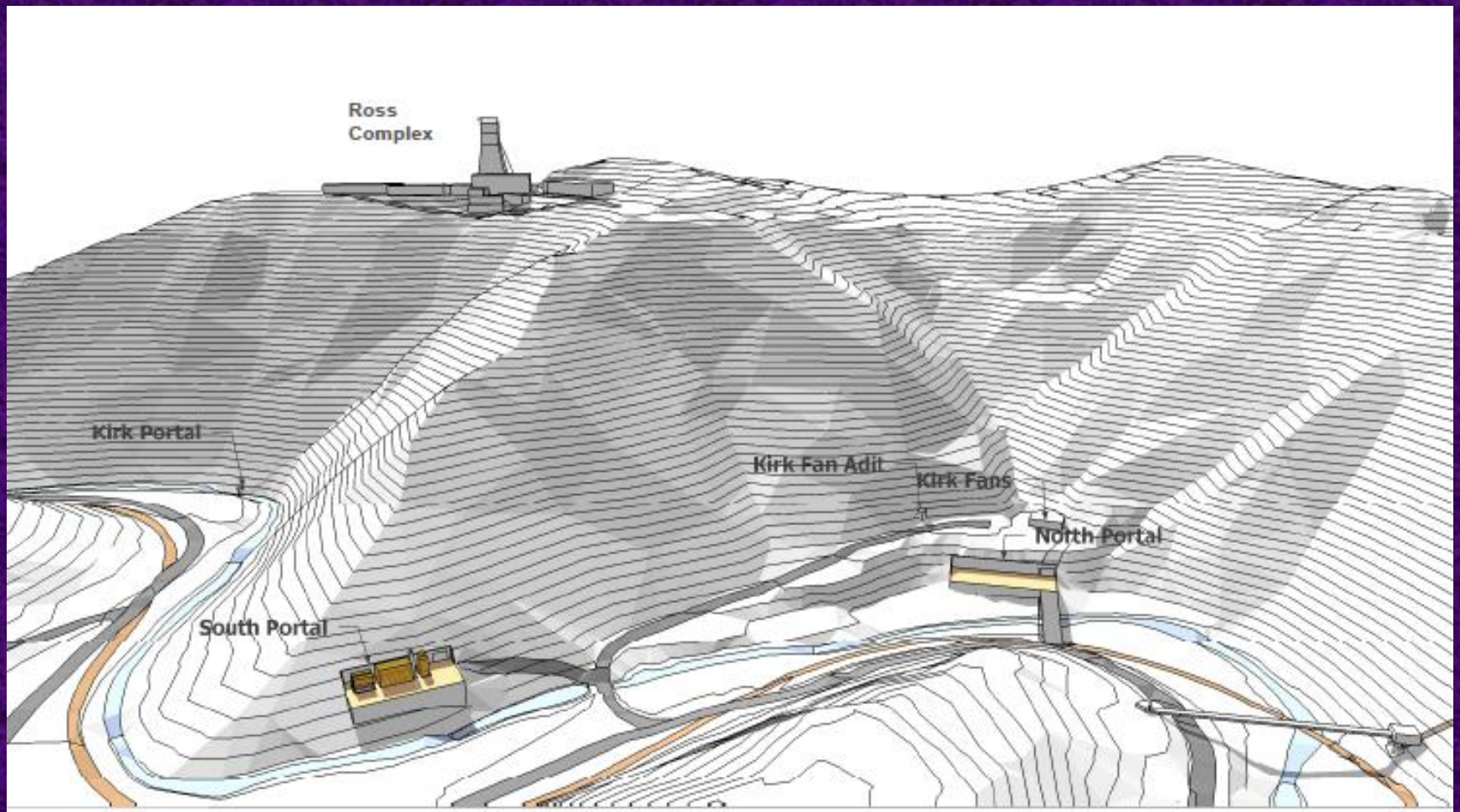
LArTPC Cavern 2

Ross Shaft

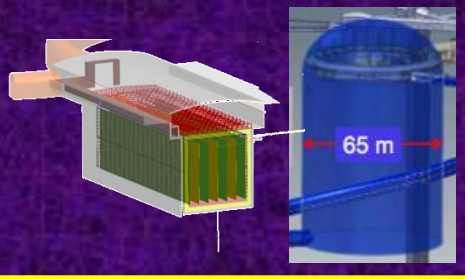
LArTPC Cavern 1

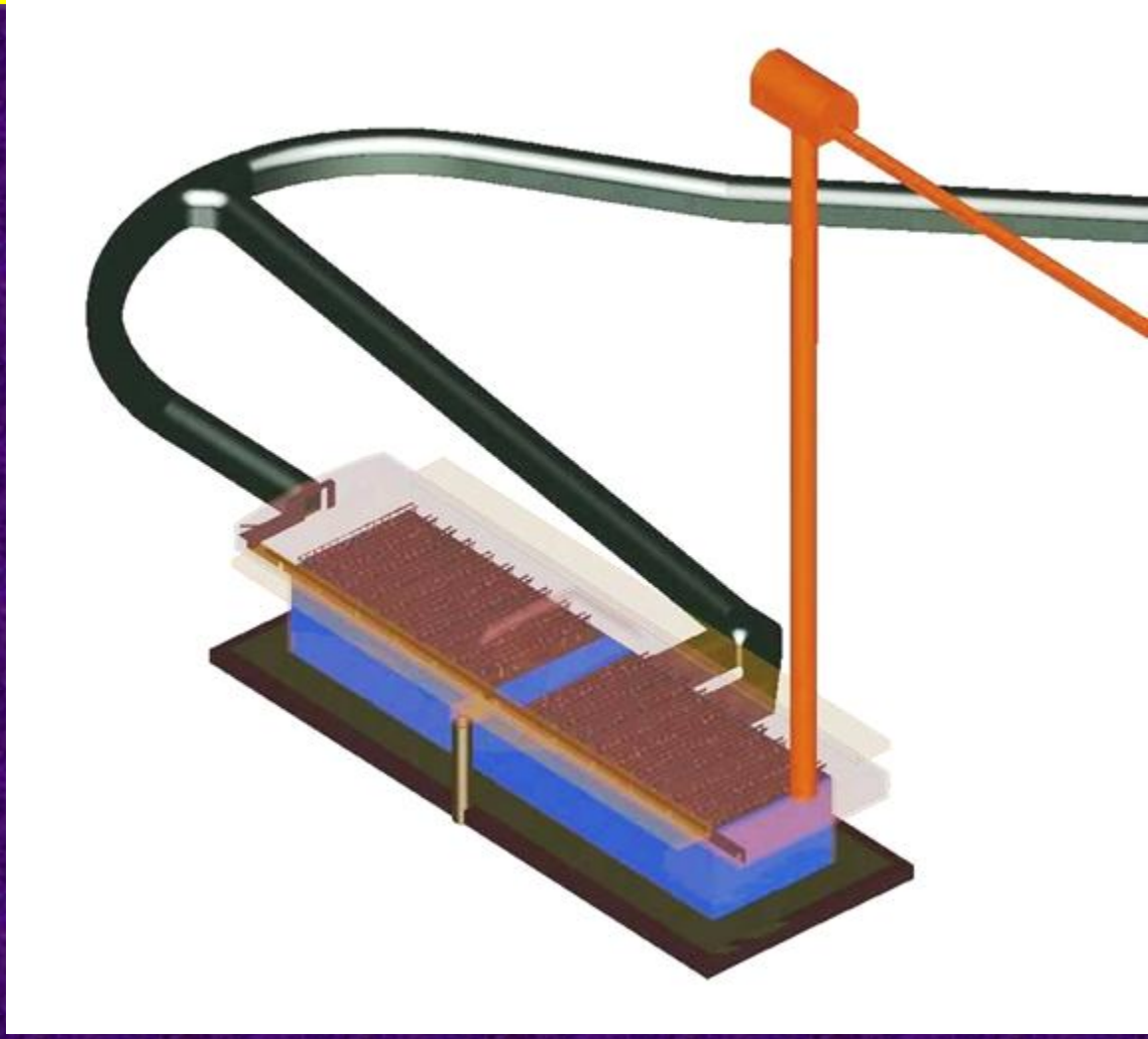
Note: New layout has 2x 20kt modules in a single cavern.

Access to 800L LAr Cavern via Kirk Portal @ 300L



Layout of the proposed cavern





Previous LAr20 Module Configuration (Fall 2010)

Key Elements:

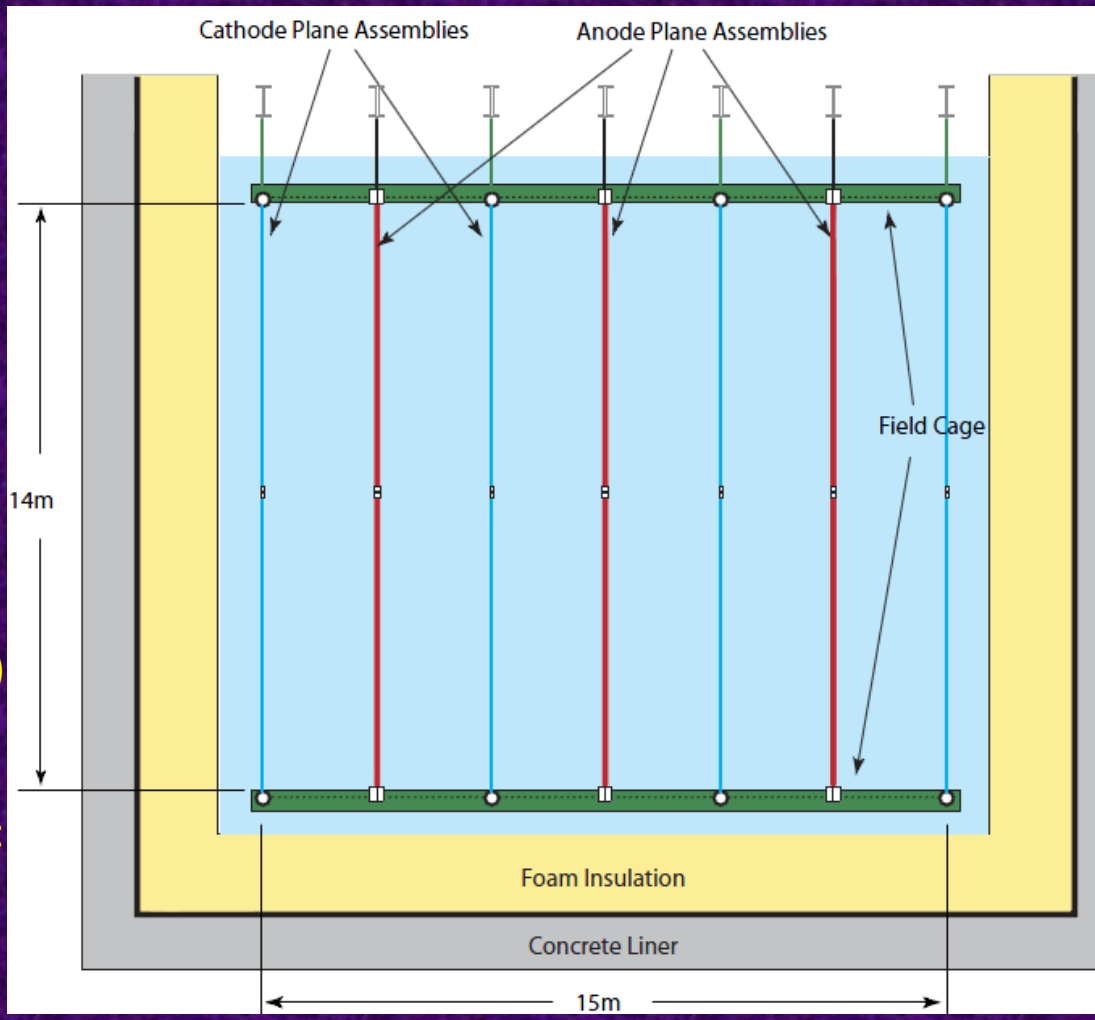
1) 16m x 15m x 74m of LAr in vessel:
   25 kt (total), 17 kt (fiducial)

2) 2.47 m maximum drift:
   123 kV on cathodes → 1.6 mm/μs
   max drift time 1.6 ms

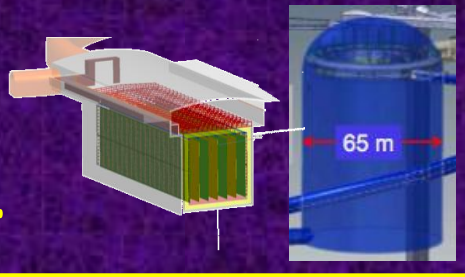
3) Aim for < 0.2 ppb O_2 contamination:
   ensures e lifetime > 1.4 ms

4) 3 R/O planes: vertical (coll.), +/- 45° (ind.)
   wire pitch 3.0 mm (Y) / 3.3 mm (U,V)

5) Segmented as "Anode Plane Assemblies":
   3840 readout wires per APA x 3 x 2 x 28
   = 645k channels, sampled @ 2 Msps



"Membrane Cryostat" inspired by LNG Tanker Ships…

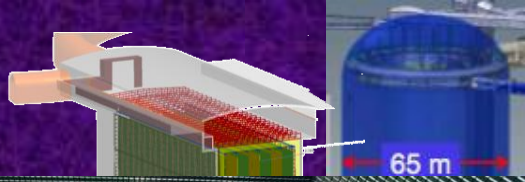


Membrane Cryostat for LNG ship tanker.
This tank is 35 m high x ~45 m wide, 40,000 m^3.
LAr20 will be 16 m high x 24 m wide X 49 m long = 19,000 m^3.

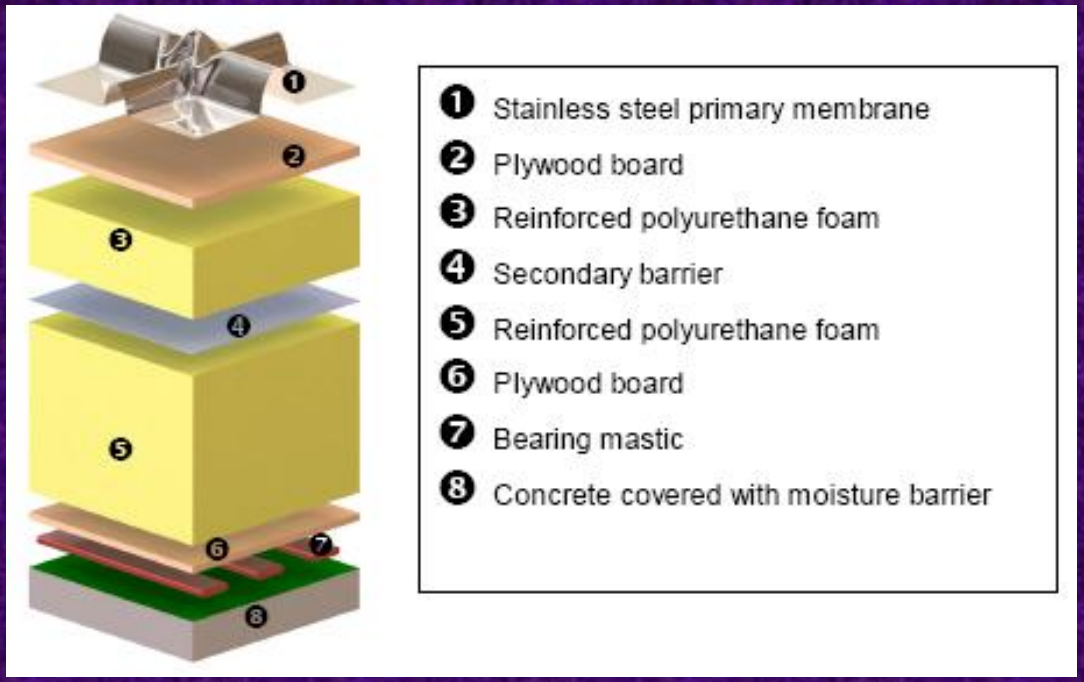
Person scale

Source: GTT & Russ Rucinski

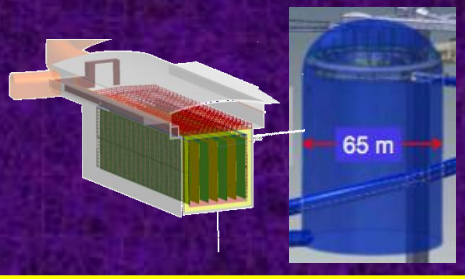
Cryostat



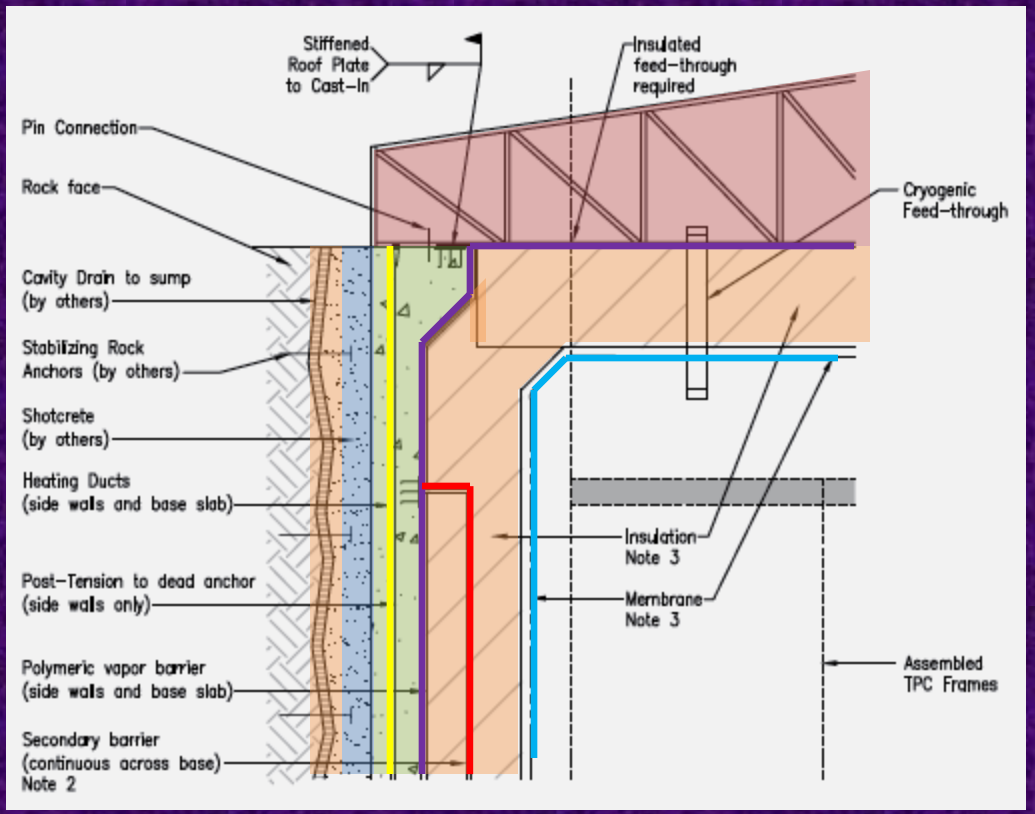
- GTT system
  - Onshore / floating LNG storage



Cryostat Structure/Insulation

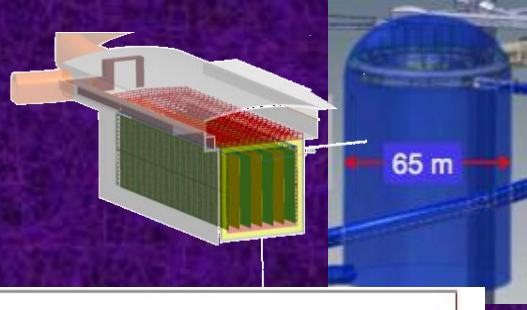


- Key Elements
  - Cavity drain
  - Shotcrete
  - Concrete liner
  - Steel roof
  - Heating system
  - Vapor barrier
  - Insulation
  - Secondary barrier
  - Primary membrane

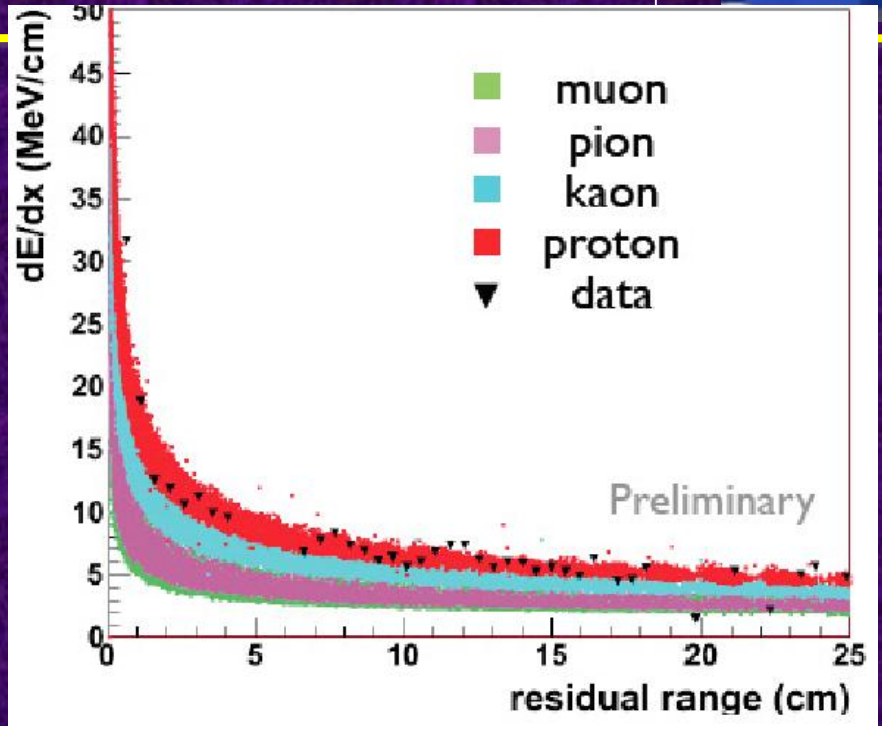


Source: ARUP

Example: Proton Decay: $K^+\nu$ Mode w/LAr



- Signatures:
  - dE/dx vs ($x_{range} - x$)
  - K to μ to e decay chain (e.g.)
  - Identification of multiple signatures main tool for background rejection
- Pernicious background:
  - HE cosmic rays interact outside detector generate K^0_L that enters & charge-exchanges
- Effc'y and backgrounds:
  - Estimated for Homestake 800L depth, based on Bueno et al., JHEP 0704, 041 (2007) [arXiv:hep-ph/0701101].



Mode	Liquid Argon Efficiency	Liquid Argon Background Rate (evts/100 kt-y)
$p \to e^+\pi^0$	45%	0.1
$p \to \nu K^+$	97%	0.1

  - Muon Veto and/or Photon Systems helpful here
  - Will study backgrounds w/ MicroBooNE & LAr1

Example: Proton Decay: $K^+\nu$ Mode w/LAr

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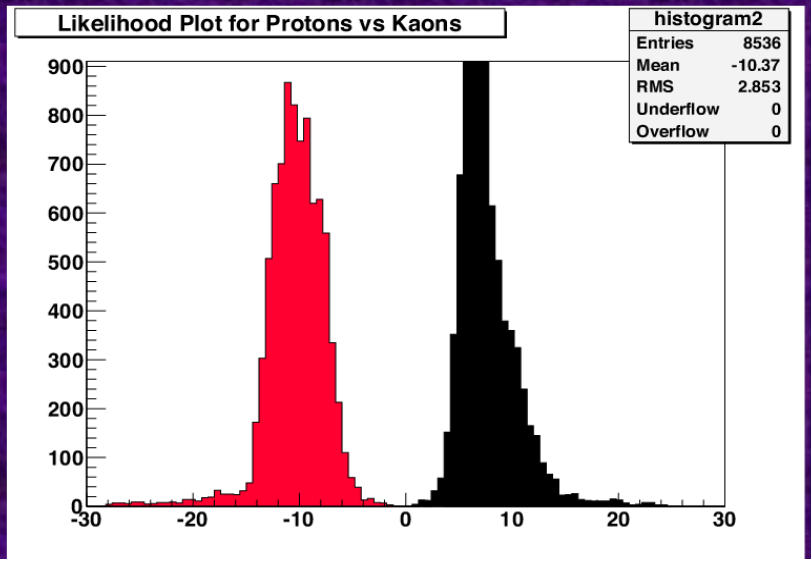
From LArSoft Simulation: K/p separat'n



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