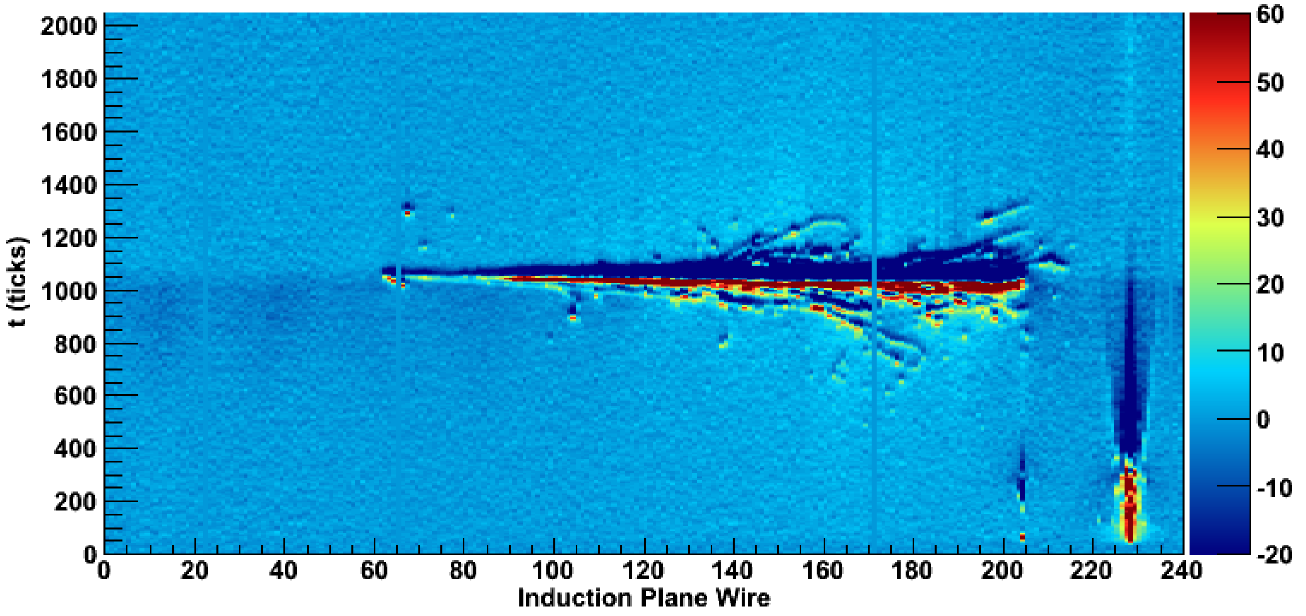
B.T.Fleming
October 2, 2009
Homestake Workshop

Liquid Argon TPC for LBNE

- LArTPC technique, sensitivity, and challenges
- Integrated plan to get to LBNE scale detectors
- Progress on designs for LBNE detectors

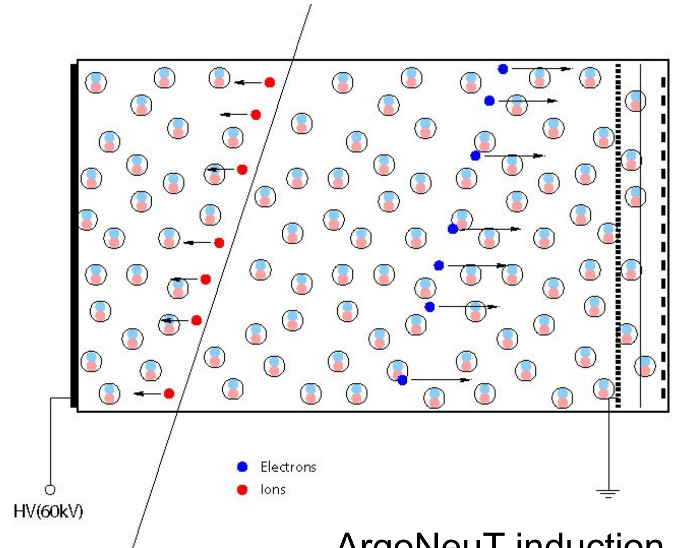


LArTPC technique

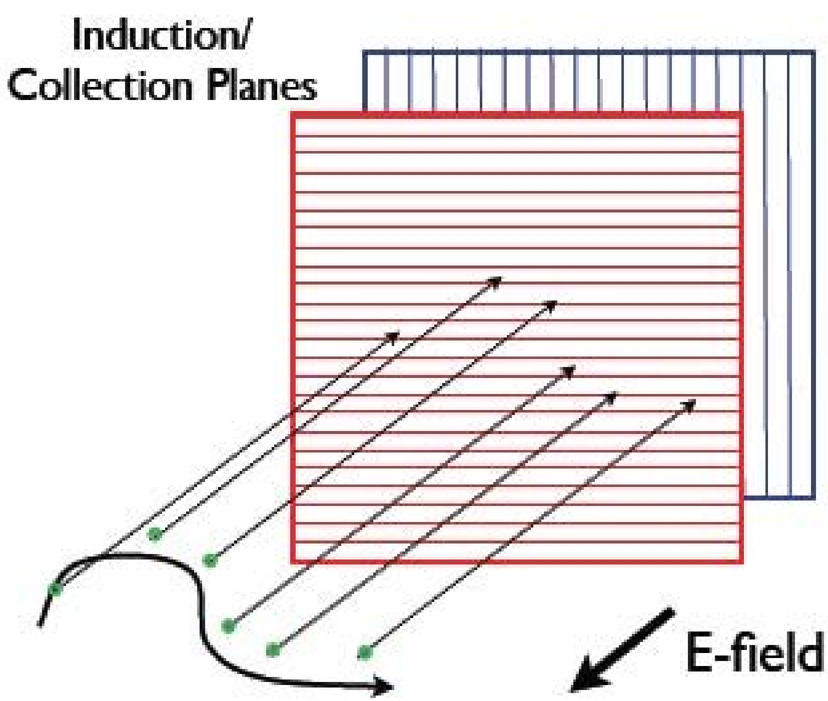
Passing charged particles ionize Argon – 55k ionization electrons/cm

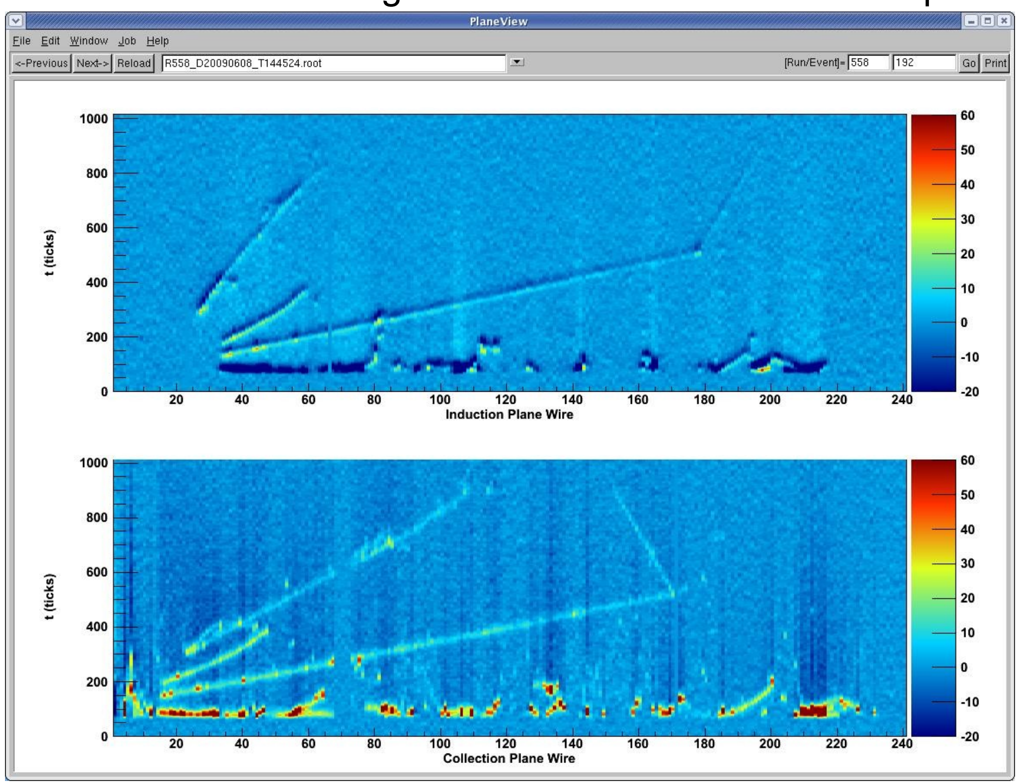
Electric field drifts electrons meters to wire chamber planes

Induction/Collection planes image charge, record dE/dx

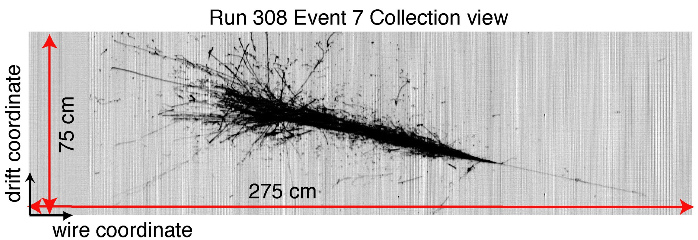


ArgoNeuT induction and collection planes





Detector Capability...



Unique Detectors

precision measurements in neutrino physics

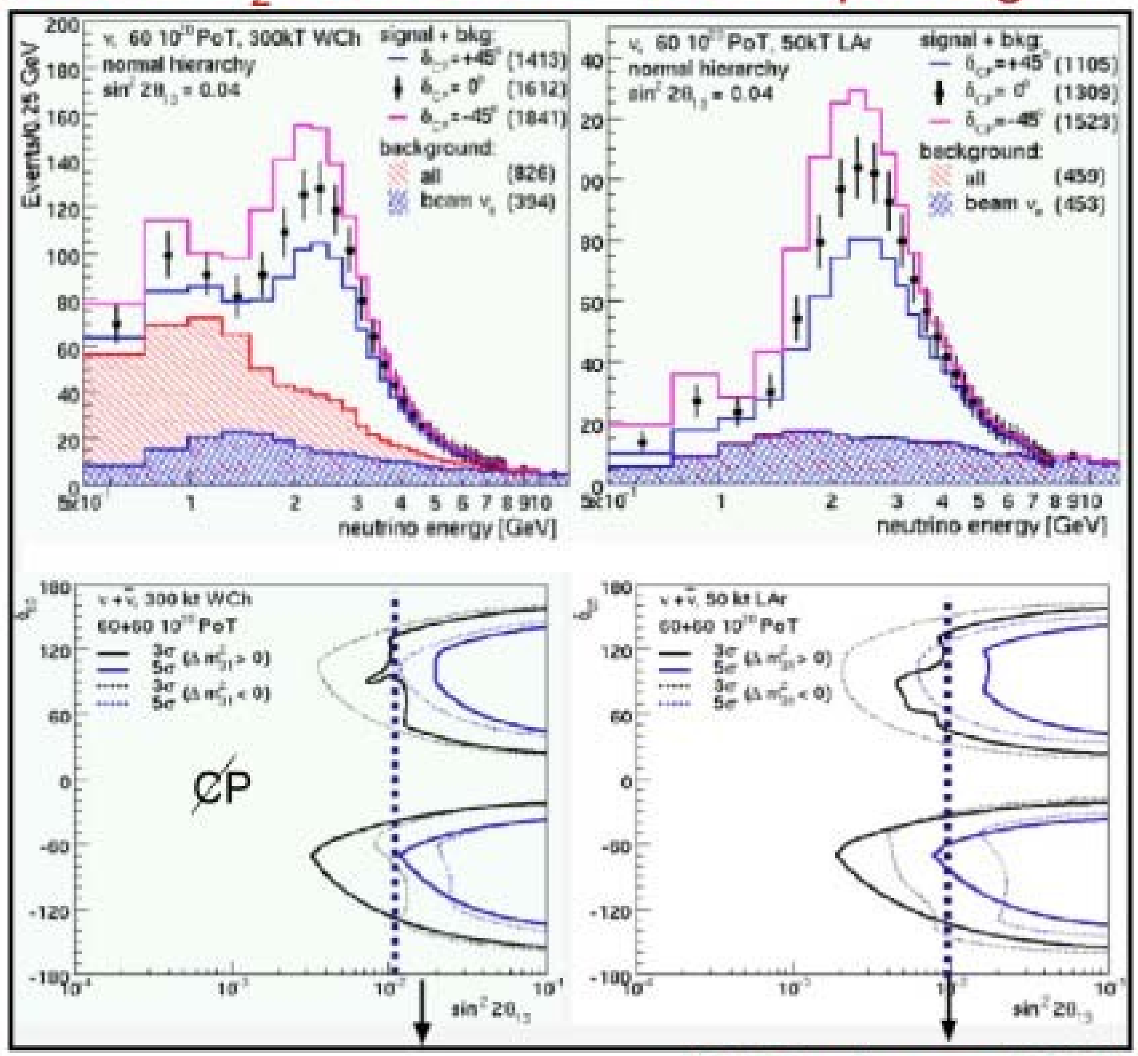
appear scalable to large volumes

- Neutrino oscillation physics: ~6 times more sensitive than WC technology
  translates into smaller volumes for same physics reach
- Proton decay searches
  - sensitive to p k
  - Extend sensitivity beyond SK limits with detectors larger than 5kton
- Supernova and solar neutrinos

Neutrino Oscillation Physics: 80-90% efficient for $_e$ detection, nearly eliminate backgrounds → from neutral current pion production

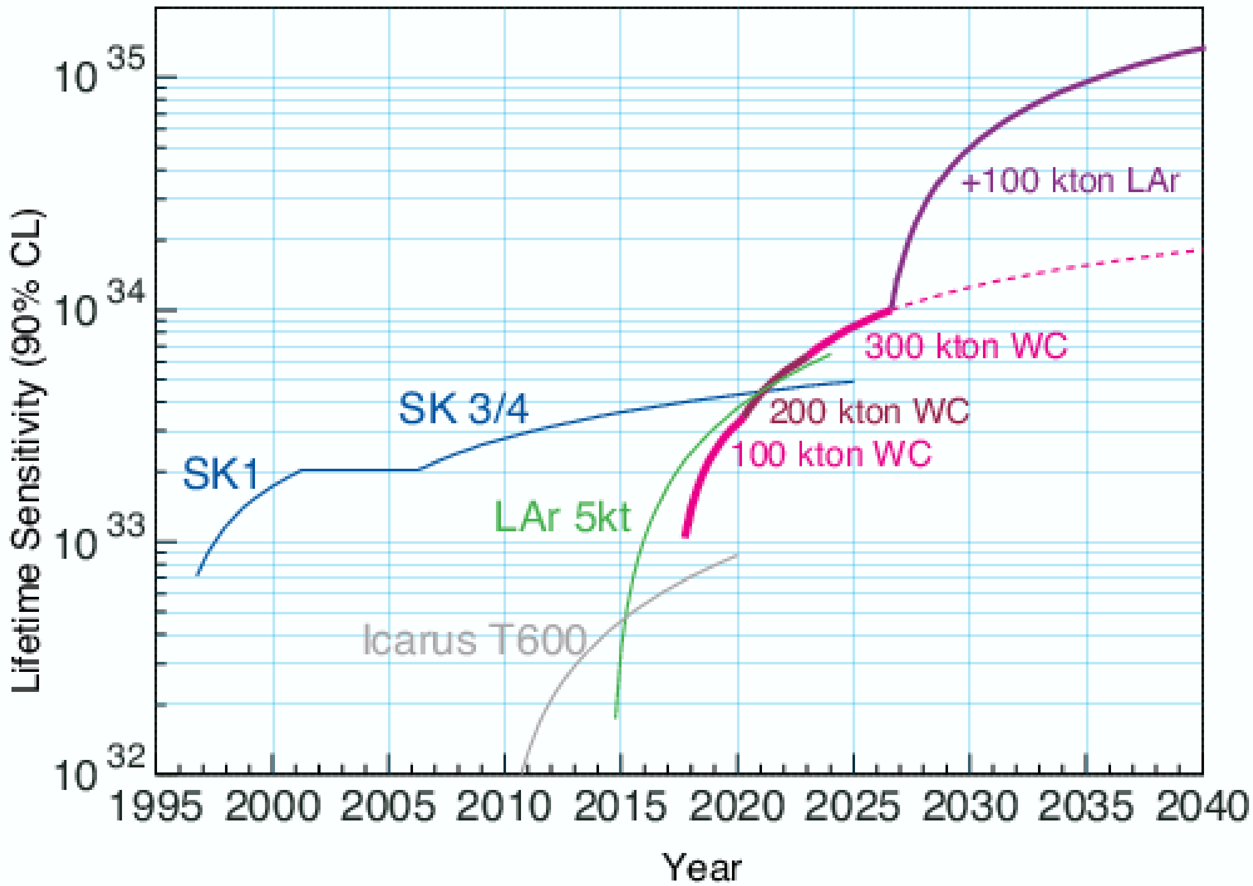
Translates into x6 reach in electron neutrino appearance searches and therefore CP Violation

300kT H_2O Cerenkov 50kT liquid argon



(M. Dierckxsens, 2008)

p → $K^+\nu$



WC efficiency = 0.14
BG = 1.2 evts/100 kty
Nobs = Nbg

LAr efficiency = 0.98
BG = 0.1 evts/100 kty
Nobs = Nbg

LArTPCs most sensitive to this decay mode

Supernova neutrino reactions in WC and LAr are sizable
and complementary in reaction type and signal shape

H_2O

$$\bar{\nu}_e + p \rightarrow n + e^+ \qquad (88\%/89\%)\,,$$
$$\nu_e + e^- \rightarrow \nu_e + e^- \qquad (1.5\%/1.5\%)\,,$$
$$\bar{\nu}_e + e^- \rightarrow \bar{\nu}_e + e^- \qquad (<1\%/<1\%)$$
$$\nu_x + e^- \rightarrow \nu_x + e^- \qquad (1\%/1\%)\,,$$
$$\nu_e + {}^{16}O \rightarrow e^- + {}^{16}F \qquad (2.5\%/<1\%)$$
$$\bar{\nu}_e + {}^{16}O \rightarrow e^+ + {}^{16}N \qquad (1.5\%/1\%)\,, an$$
$$\nu_x + {}^{16}O \rightarrow \nu_x + O^*/N^* + \gamma \; (5\%/6\%)\,,$$

LAr

$$\nu_e + {}^{40}\mathrm{Ar} \rightarrow {}^{40}\mathrm{K}^* + e^-$$
$$\bar{\nu}_e + {}^{40}\mathrm{Ar} \rightarrow {}^{40}\mathrm{Cl}^* + e^+$$
$$\nu_\alpha + {}^{40}\mathrm{Ar} \rightarrow {}^{40}\mathrm{Ar}^* + \nu_\alpha$$
$$\hookrightarrow {}^{40}\mathrm{Ar} + \gamma_1 + \ldots \gamma_n$$
$$\nu_e + e^- \rightarrow \nu_e + e^-$$
$$\bar{\nu}_e + e^- \rightarrow \bar{\nu}_e + e^-$$
$$\nu_x + e^- \rightarrow \nu_x + e^-$$

100 kt of LAr, SN @ 10 kpc

Interaction	Rates ($\times 10^4$)
ν_e CC (^{40}Ar, ^{40}K*)	2.5
ν_x NC (^{40}Ar*)	3.0
ν_x ES	0.1
anti–ν_e CC (^{40}Ar, ^{40}Cl*)	0.054

A. Bueno NP2008, via K.Scholberg

100 kt H_2O, SN@10 kpc

Interaction	Rates ($x10^4$)
$\bar{\nu}_e + p \rightarrow n + e^+$	2.3
$\nu + e \rightarrow \nu + e$	0.1
$\nu_x + {}^{16}O \rightarrow {}^{16}O + \nu_x$	0.05
$\nu_x + {}^{16}O \rightarrow {}^{16}F + e$	0.2

SuperNoVA relic searches also possible...

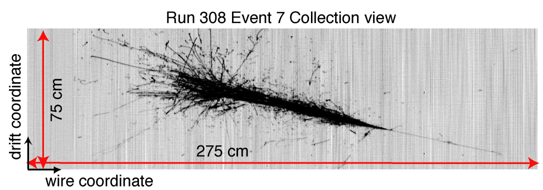
Main challenges for massive LArTPCs

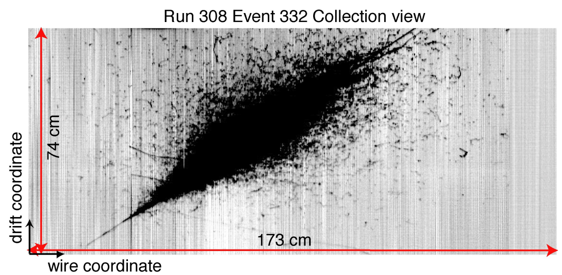
- **Purification Issues: large, industrial vessels**
  - Test stand measurements
  - Purification techniques for non-evacuatable vessels
  - Purity in full scale experiment
- **Cold, Low Noise Electronics and signal multiplexing**
  - Test stand measurements
  - Plan for R&D towards cold electronics
- **Vessels: design, materials, insulation**
  - Learn as we go in designing MicroBooNE
- **Vessel siting underground: safety, installation ...**
- **Understanding costs of these detectors**

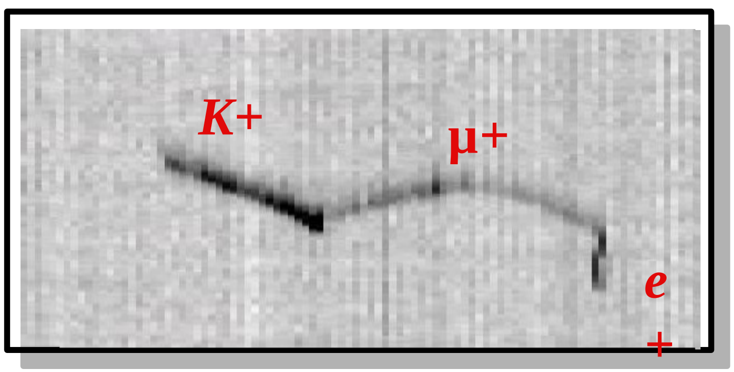
History of LarTPC development

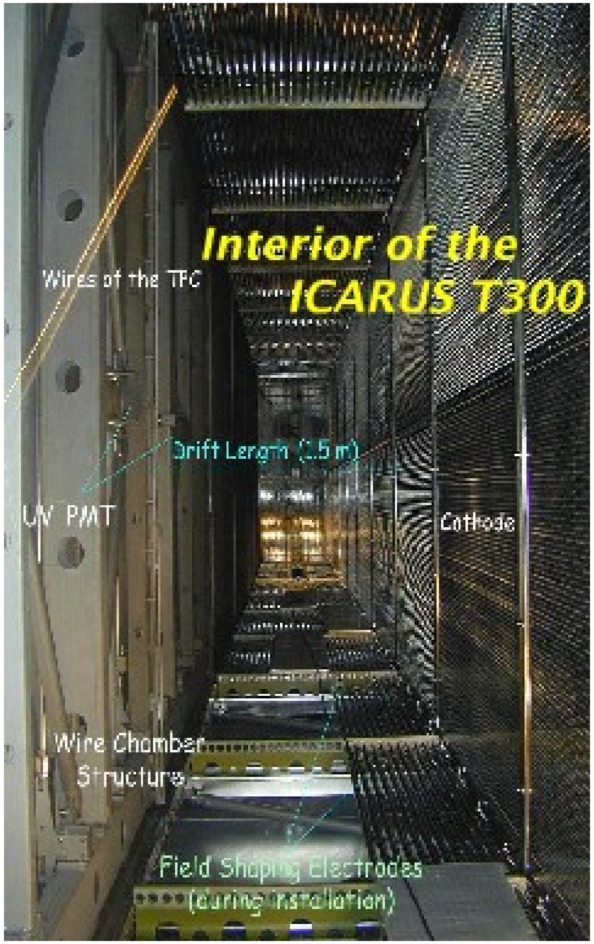
Early work by Chen, Radeka, Willis, and others in the US in the late 70s.

Early and continuing work by Rubbia and others within the ICARUS collaboration
Over the last 30+ years → first cosmic ray tracks in a large volume
T300 – 300 ton ICARUS surface test in Pavia in 2001



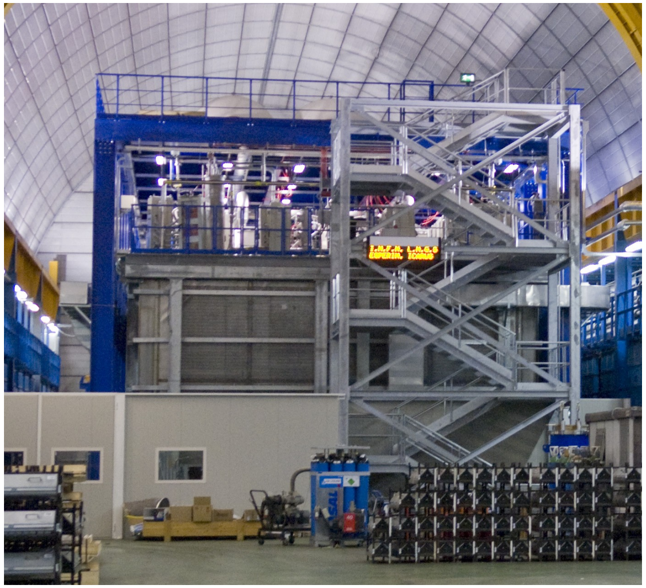


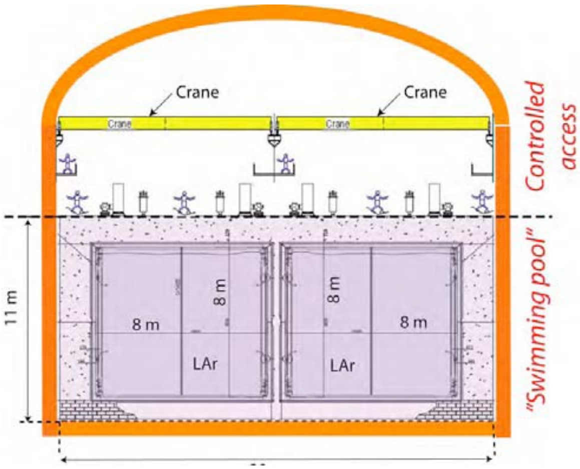


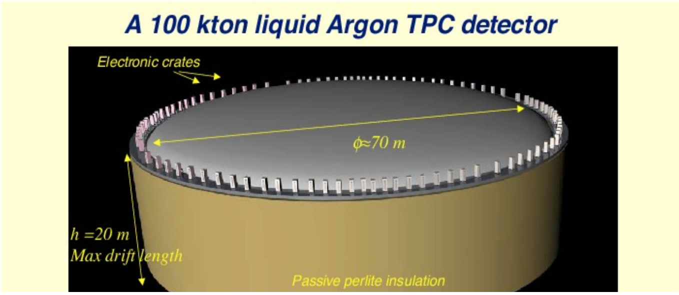


Current programs

ICARUS readying for beam in Gran Sasso, considering next-generation efforts: DoubleLAr, Modular...

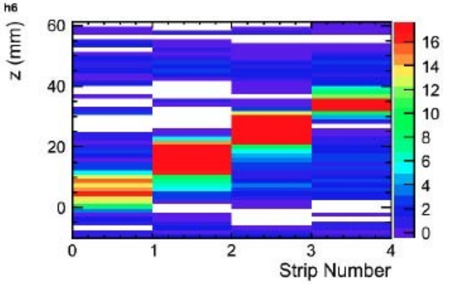


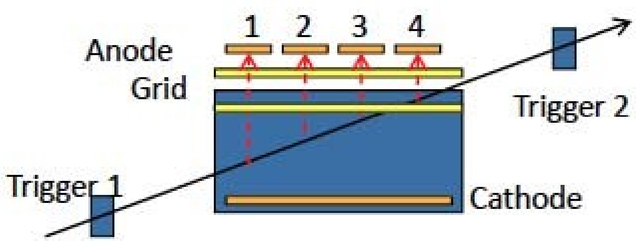




GLACIER effort in the LAGUNA collaboration in Europe:
GLACIER: Combination of charge and light collection, single large drift area

KEK-ETHZ collaboration to develop larger detectors for T2KK





While there are big challenges to scaling these detectors to Large sizes – worldwide interest in doing so.

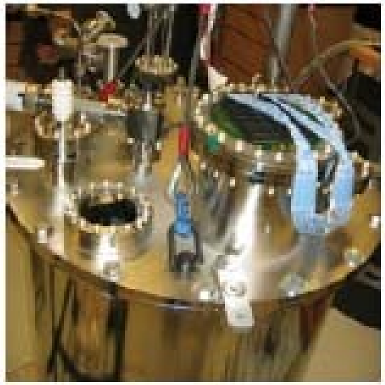
US Program →

Liquid-Argon Time Projection Chambers

Status of R&D Program in the US

TPCs in the United States:

Yale TPC



Location: Yale University
Active volume: 0.00002 kton
Year of first tracks: 2007

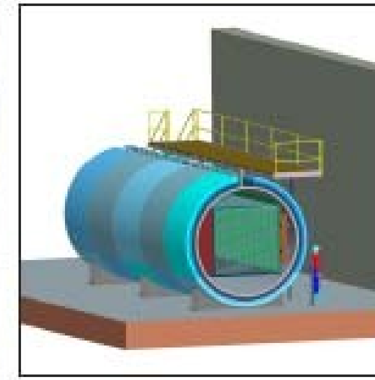
Bo

Location: Fermilab
Active volume: 0.00002 kton
Year of first tracks: 2008

ArgoNeuT

Location: Fermilab
Active volume: 0.0003 kton
Year of first tracks: 2008
First neutrinos: June 2009

MicroBooNE



Location: Fermilab
Active volume: 0.1 kton
Start of construction: 2010

Test stands to improve liquid-argon technology:

Luke

Location: Fermilab
Purpose: materials test station
Operational: since 2008

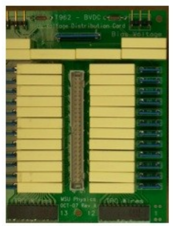
LAPD

Location: Fermilab
Purpose: LAr purity demo
Operational: 2010

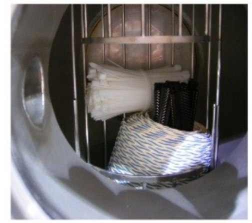
Luke: Materials Test Stand at FNAL
Test materials in Argon and purification techniques for clean LAr

Luke

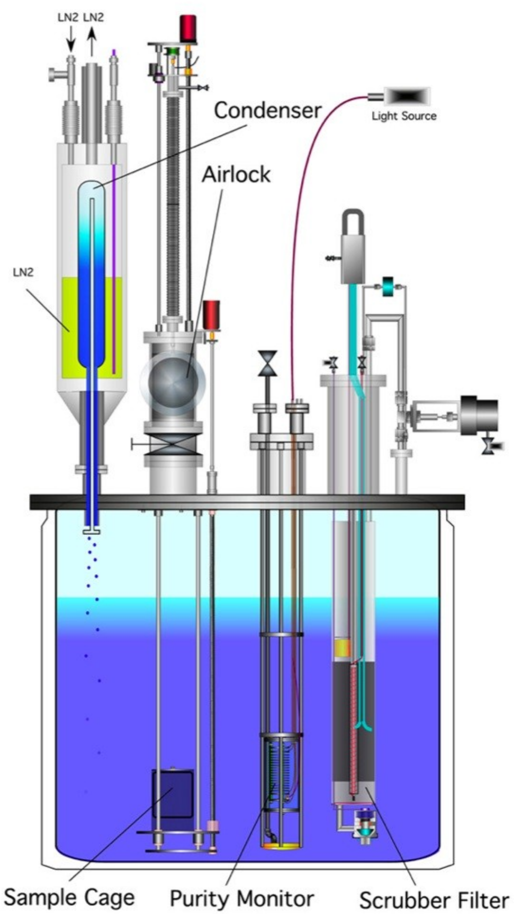
BNL 4-ch Amp

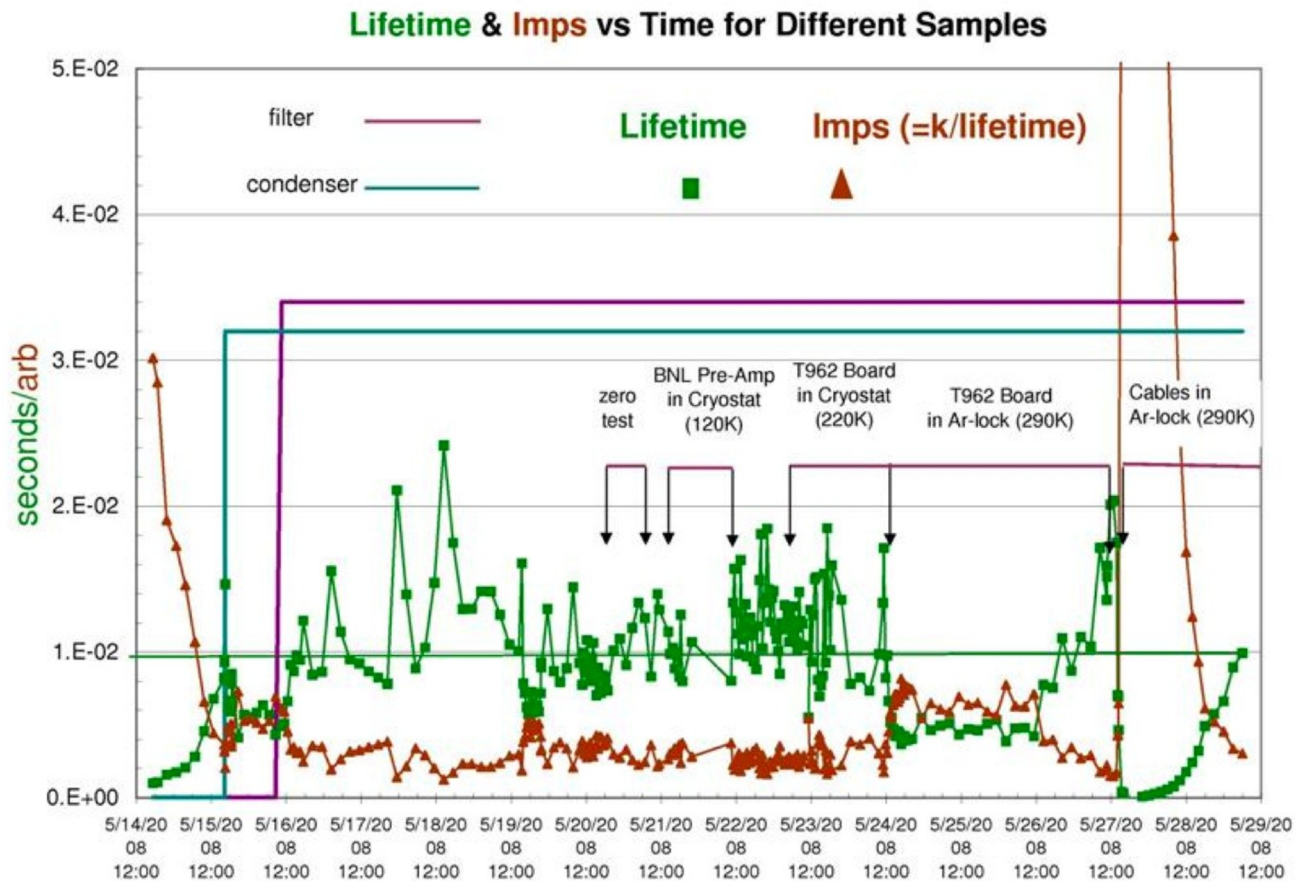


ArgoNeuT Bias Board



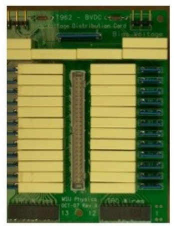
Cables/Cable-Tie Bundle

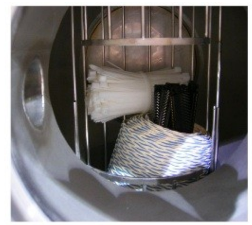


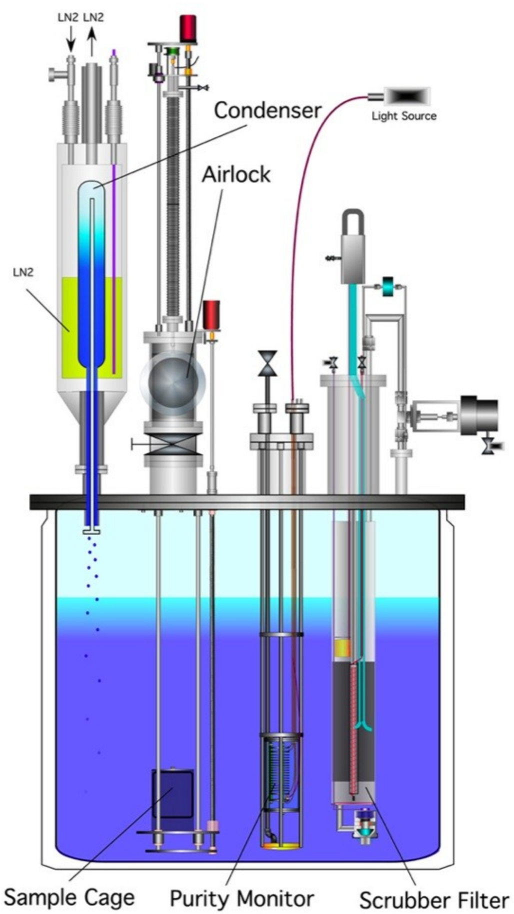


Luke: Materials Test Stand at FNAL
Test materials in Argon and purification techniques for clean LAr


BNL 4-ch Amp


ArgoNeuT Bias Board

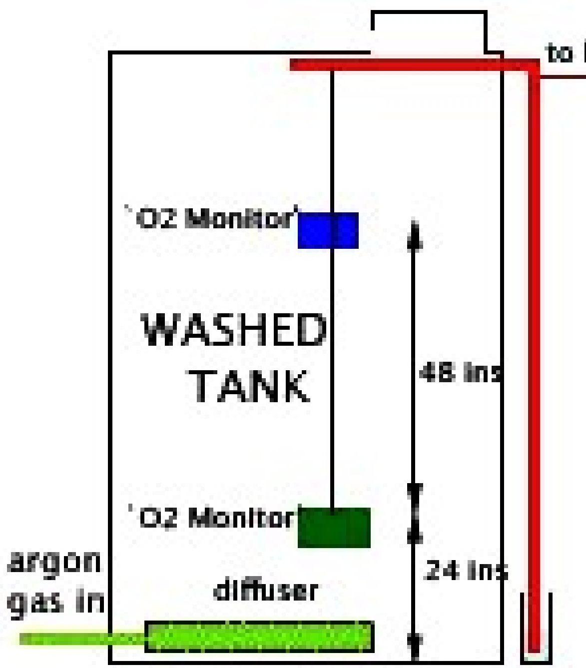

Cables/Cable-Tie Bundle



Material	Sample Surface Area (cm^2)	Effect of Material on Electron Drift Lifetime (LT): 94 K liquid	≈120 K vapor	≈225 K Vapor	Comments
Red-X Corona Dope[a]	100	None	None	LT Reduced from 8 to 1 ms; recovery observed.	H_2O concentration not monitored.
Deactivated Rosin Flux[b]	200	None	Not Tested	LT reduced from 8 to 1.5 ms recovery observed	H_2O concentration not monitored.
FR4	1000	None	Not Tested	LT reduced from 8 to <1 ms	Outgassed enough H_2O at 225 K to saturate sintered metal return.
Taconic[c]	600	None	Not Tested	LT reduced.	Sample outgases water at 225 K.
Hitachi BE 67G[d]	300	None	Not Tested	LT reduced; recovery observed	Sample outgases water at 225K; outgassing reduced over time.
TacPreg[e]	200	None	None	LT reduced; recovery observed	Sample outgases water at 225 K; outgassing reduced over time.
FR4, y-plane wire endpoint for uBooNE	225	None	None	LT reduced from 8 to 3 ms	Sample outgases water at 225 K.
FR4, y-plane wire cover for uBooNE	225	None	None	None	Sample was evacuated in airlock prior to testing
Devcon 5-min epoxy	100	None	None	LT reduced from 10 to 6 ms; some recovery observed	Sample outgases water at 225 K.

Achieve purity in an un-evacuable vessel

- Small test stands at FNAL
- 20 ton purity demonstrator: LAPD (underway)
- MicroBooNE R&D program



- Flush tank with clean Argon gas
- Monitor level of O_2 in tank as it is flushed
- 2.6 volume changes to reach 100ppm O_2

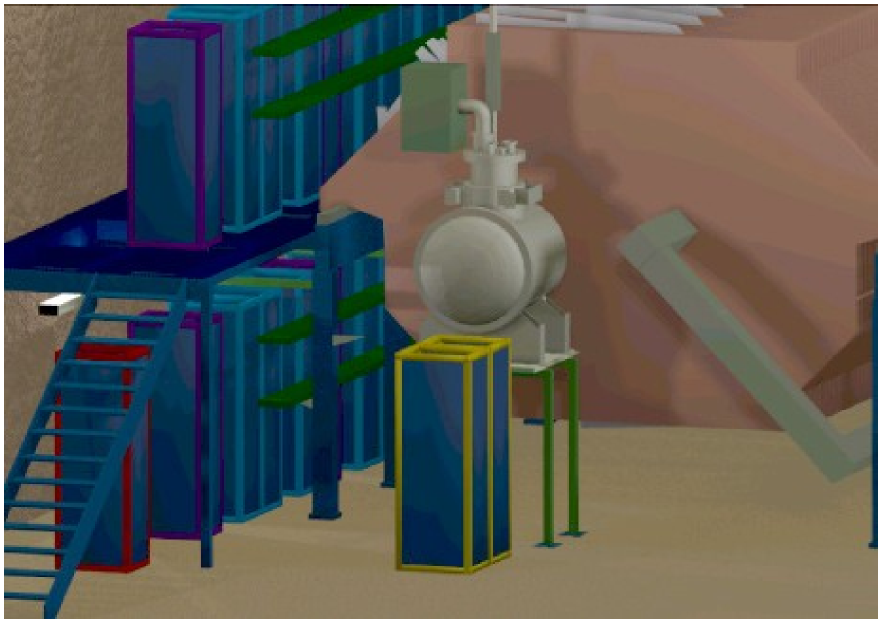
ArgoNeuT

Operational

Physics: Measure neutrino-argon cross sections

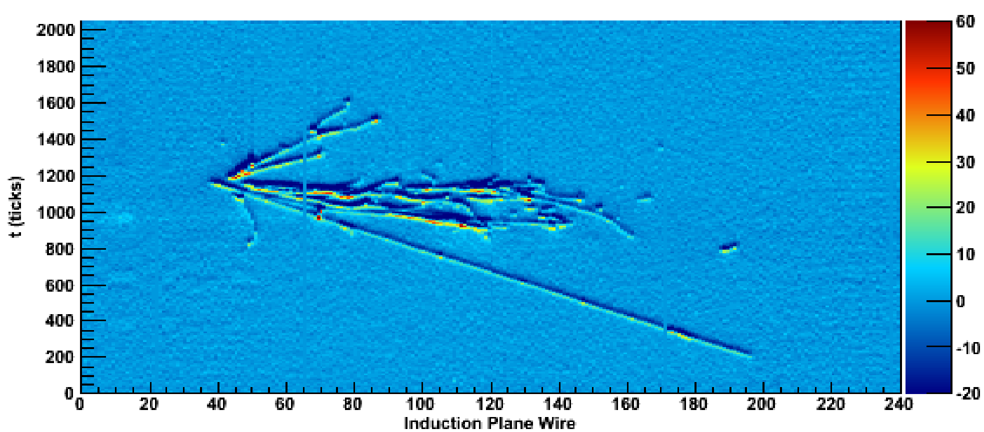
0.0003 kton

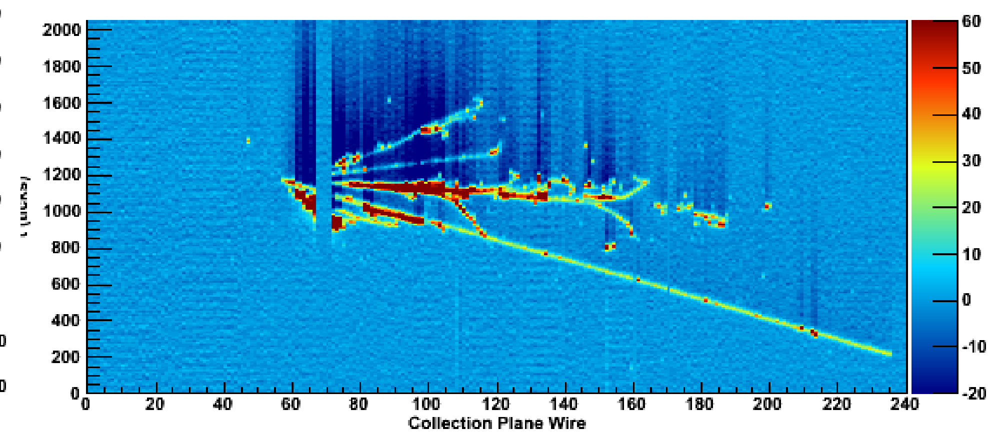
330x



0.3 ton TPC using MINOS to catch muons

Installation and Commissioning Underground





Data run began mid-September – expect ~20k neutrino and anti-neutrino events by March

MicroBooNE

Construction begins 2010

Physics: Investigate low-energy neutrino interactions

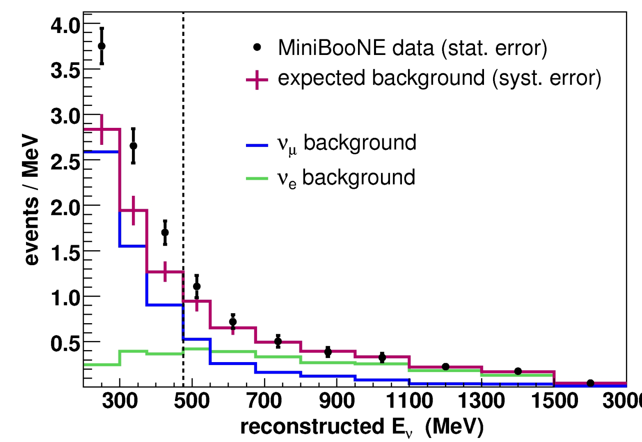
0.1 kton

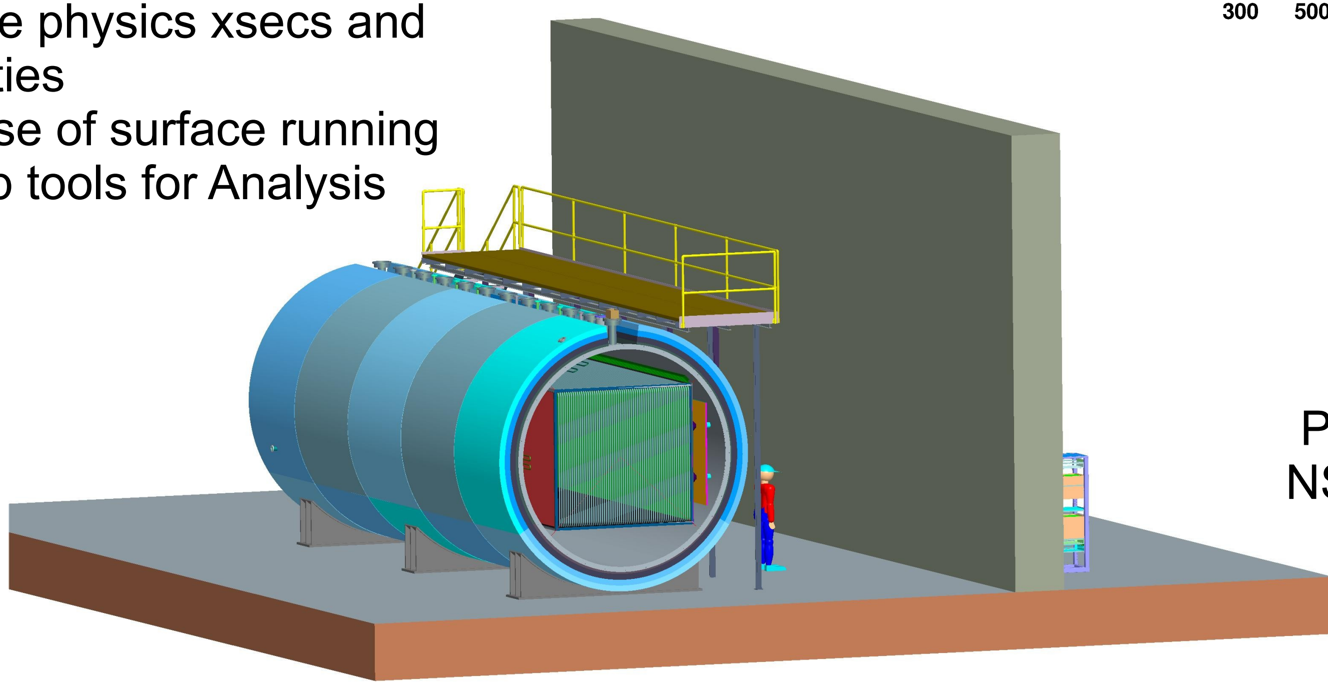
4 x 50x

MicroBooNE R&D
- Cold electronics
  - Implementation of cold electronics in Gar
  - Development and testing of cold electronics in Lar
- Purity: Test of Gar purge in large, fully instrumented vessel
- TPC design and wire stringing
- Data!
- Measure physics xsecs and sensitivities
- Test ease of surface running
- Develop tools for Analysis

Measure low energy neutrino Interactions:
- MiniBooNE low energy excess
- Suite of low energy cross section mmnts.

MicroBooNE Physics





Fermilab Stage 1 approval in 2008

CD-0 from DOE this week

Partial funding through NSF MRI and proposals (1.5M total)

Liquid-Argon Time Projection Chambers

Outlook of R&D Program in the US

Active Volume

Yale TPC & Bo

Yale TPC: Dismantled
Bo: Operational

0.00002 kton

15x

ArgoNeuT

Operational
Physics: Measure neutrino-argon cross sections

0.0003 kton

330x

MicroBooNE

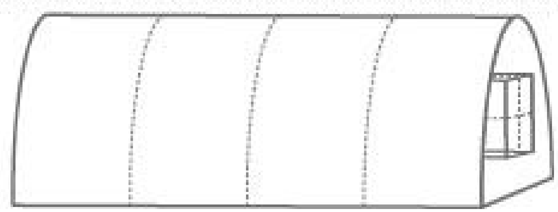
Construction begins 2010
Physics: Investigate low-energy neutrino interactions

0.1 kton

4 x 50x

LAr TPC for LBNE

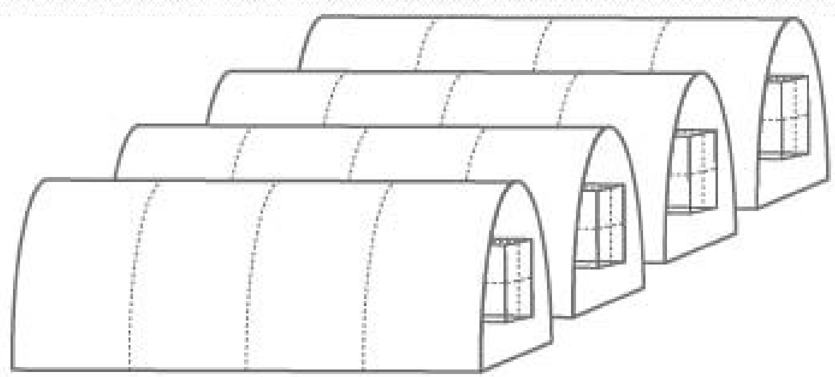
R&D in progress
Physics: Measure neutrino oscillations at 1,000+ km



20 kton

Final goal

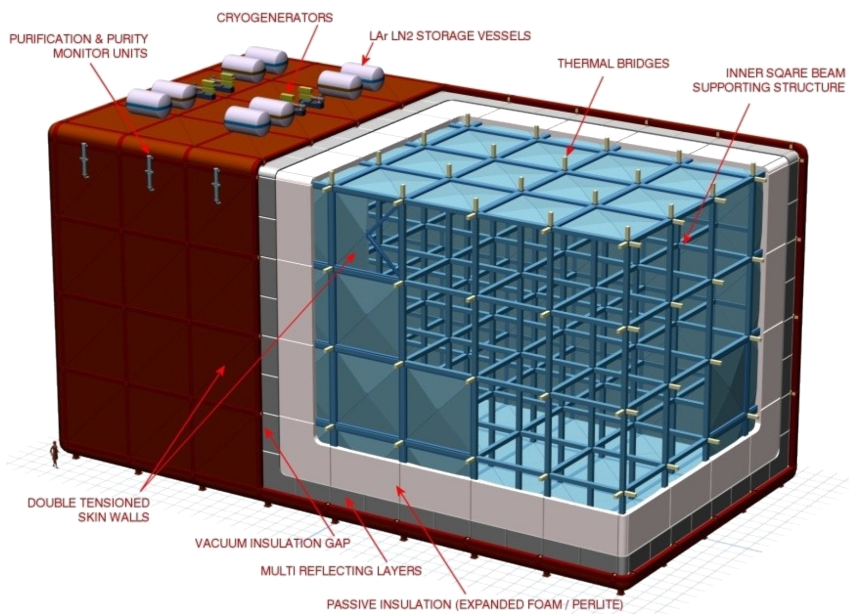
Replicate proven technology
Physics: Search for CP violation in neutrino sector

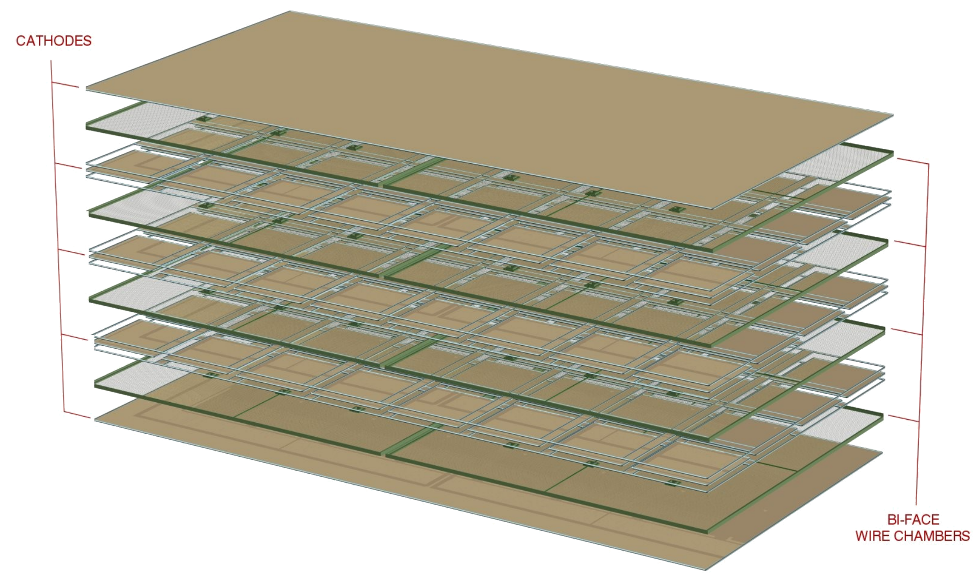


N x 20 kton

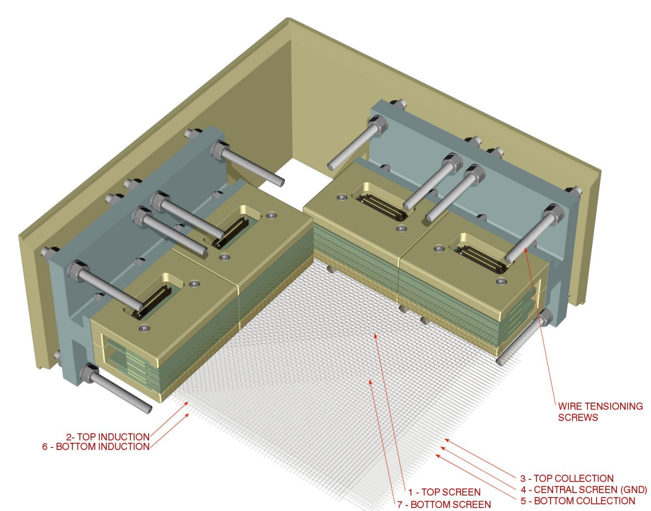
For DUSEL, developing conceptual designs for 3-6 x 20Kton modules

LANNDD 20kton concept





LANNDD 20kton concept
- 20m x 20m x 40m “box-car”
- **Free standing**
- **Evacuable vessel**
- **Vacuum insulated**



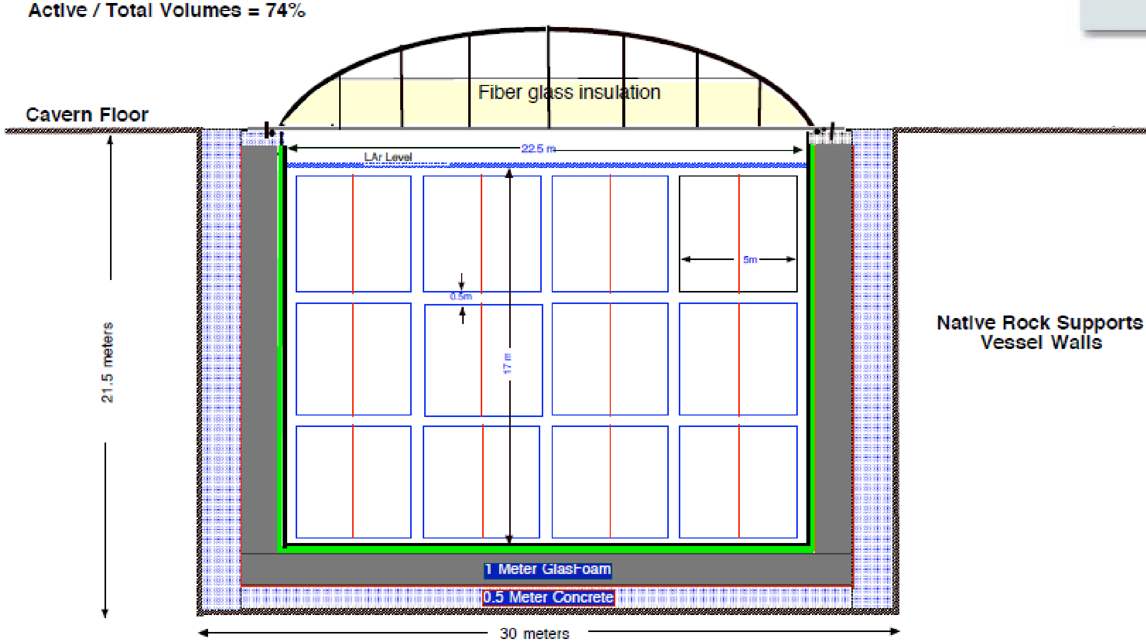
Membrane Cryostat:

- Externally supported by cavern walls
- Un-evauable
- Passive insulation

20 KT DUSEL LAr Detector, Model B - Preliminary Layout

John Sondericker

Shown - 48 dual TPC detector basic units
5m x 5m x 40m = 12,000 m^3, 16.8 kt active volume LAr
22.5m x 17m x 42.5m = 16,256m^3, 22.76 kt Total LAr volume
Active / Total Volumes = 74%

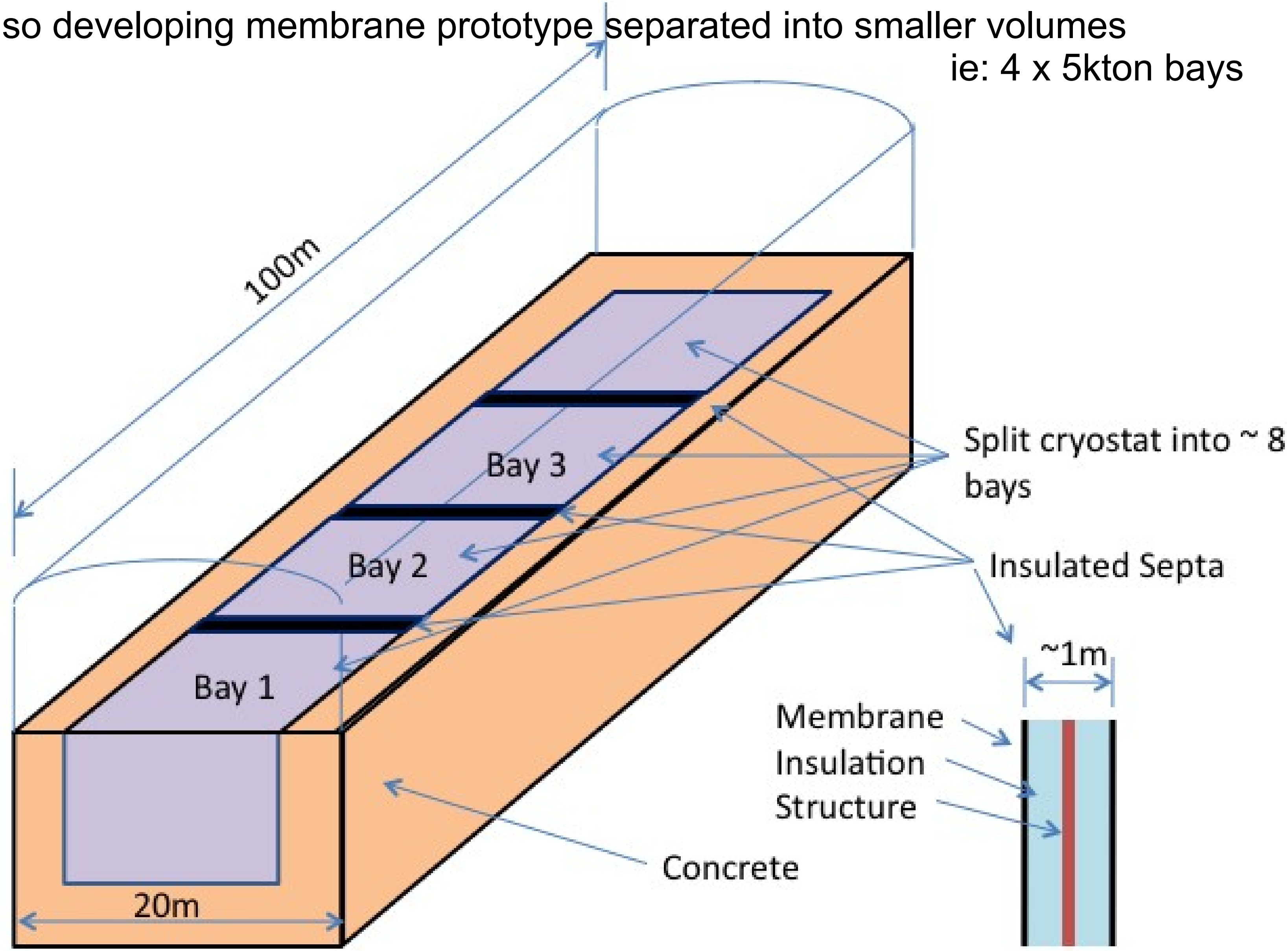


Inner containment vessel corrugated Stainless Steel or Invar, Inner wall dimensions are fixed.
Green is 3/4 inch plywood backing. Red is capping material for foamglas insulation.
Dark gray is 1 meter thickness of foam glass insulation which is also used as secondary containment of LAr.
Outer blue is reinforced concrete, 0.5 meter at base to support hydrostatic head and vessel pressure loads...
Vertical concrete fills gaps so that vessel walls are supported by native rtock.

Pilot underground cavern
For LNG storage:Daejeon, Korea

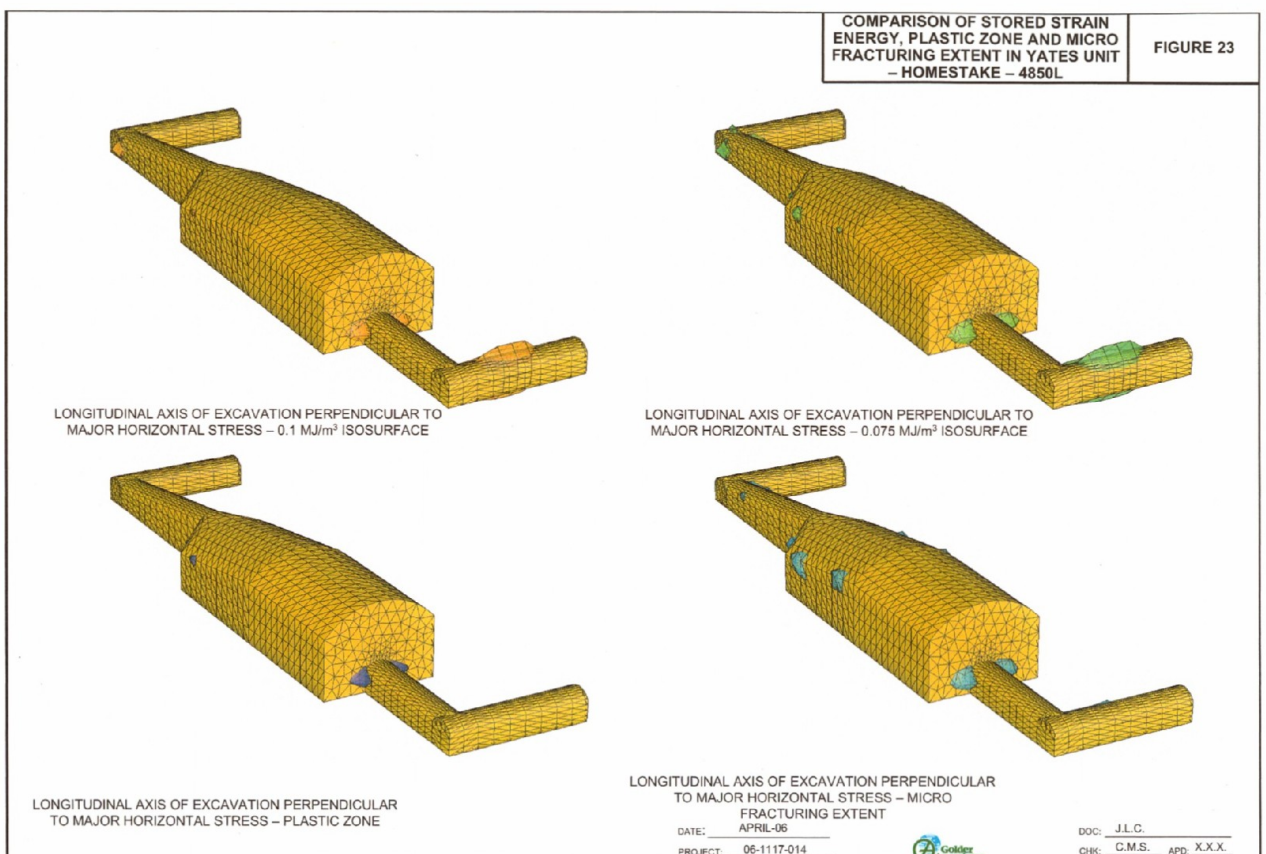
Geostock Prototype for LNG storage

Also developing membrane prototype separated into smaller volumes
ie: 4 x 5kton bays

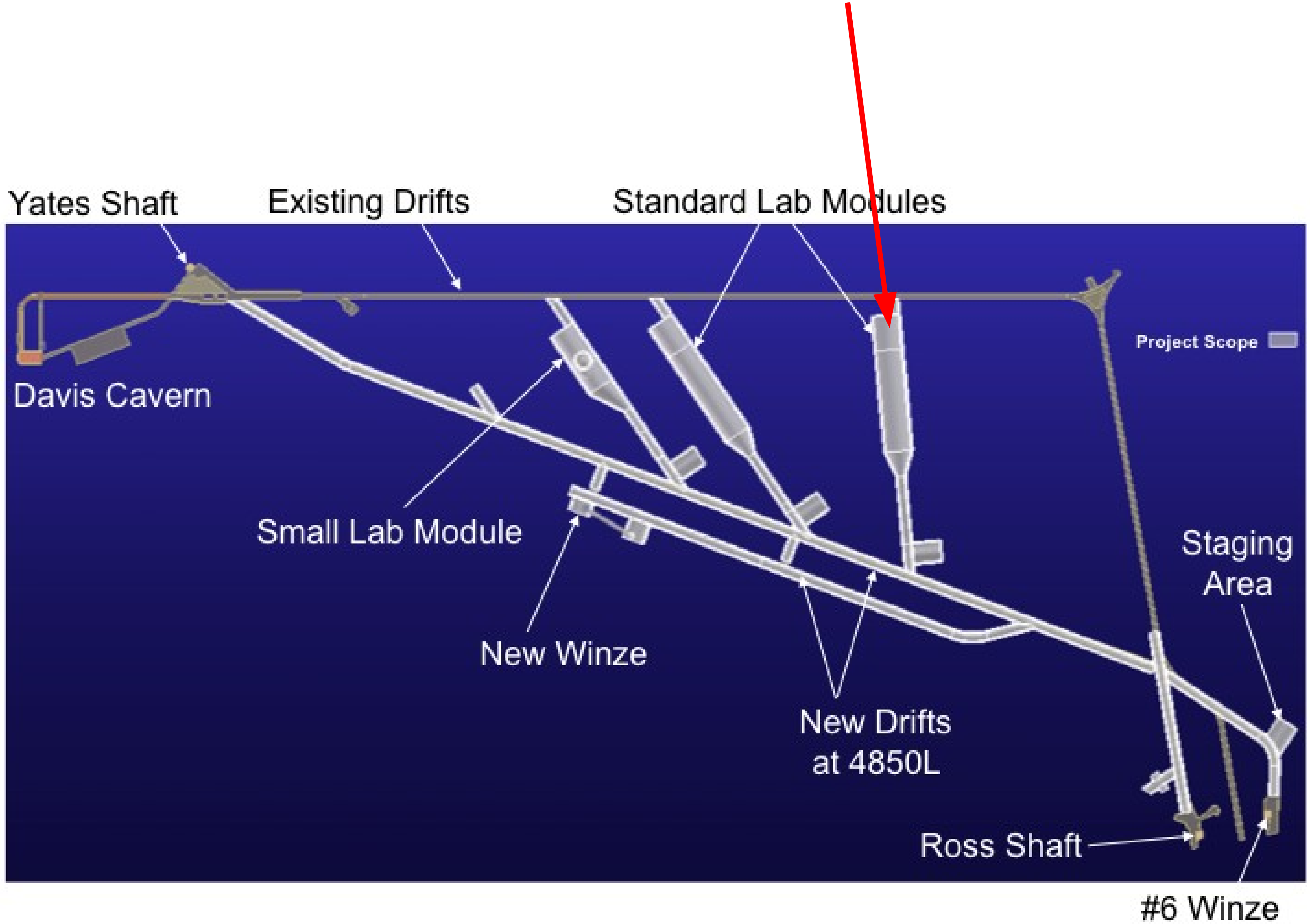


Cavern requirements

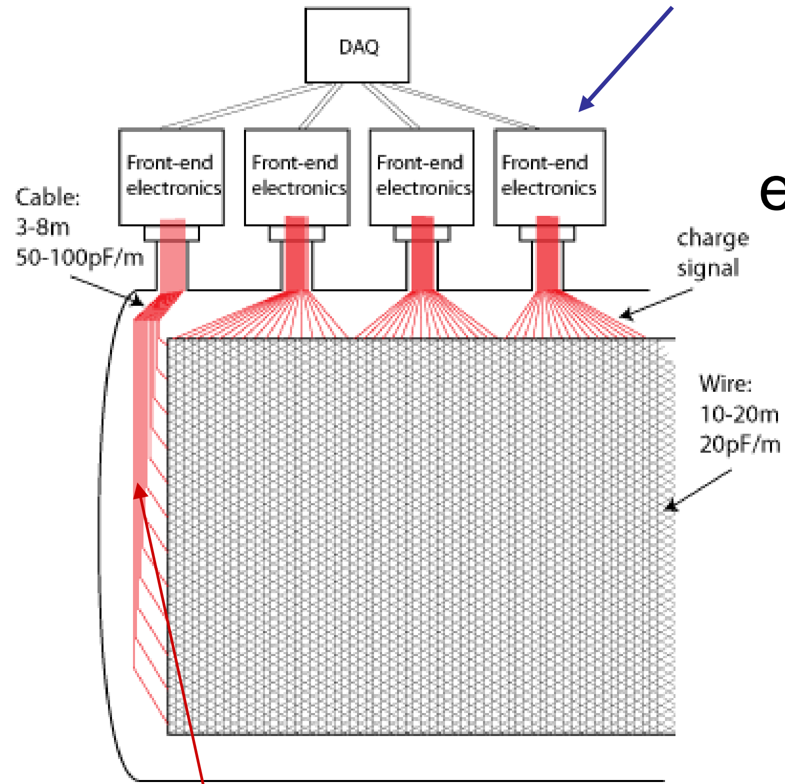
- Standard lab module 100m long houses detector
- 10m pit for secondary containment (standard)
- Environmental req. similar to FNAL lab space
- Assuming equivalence with FNAL design standards (ODH)



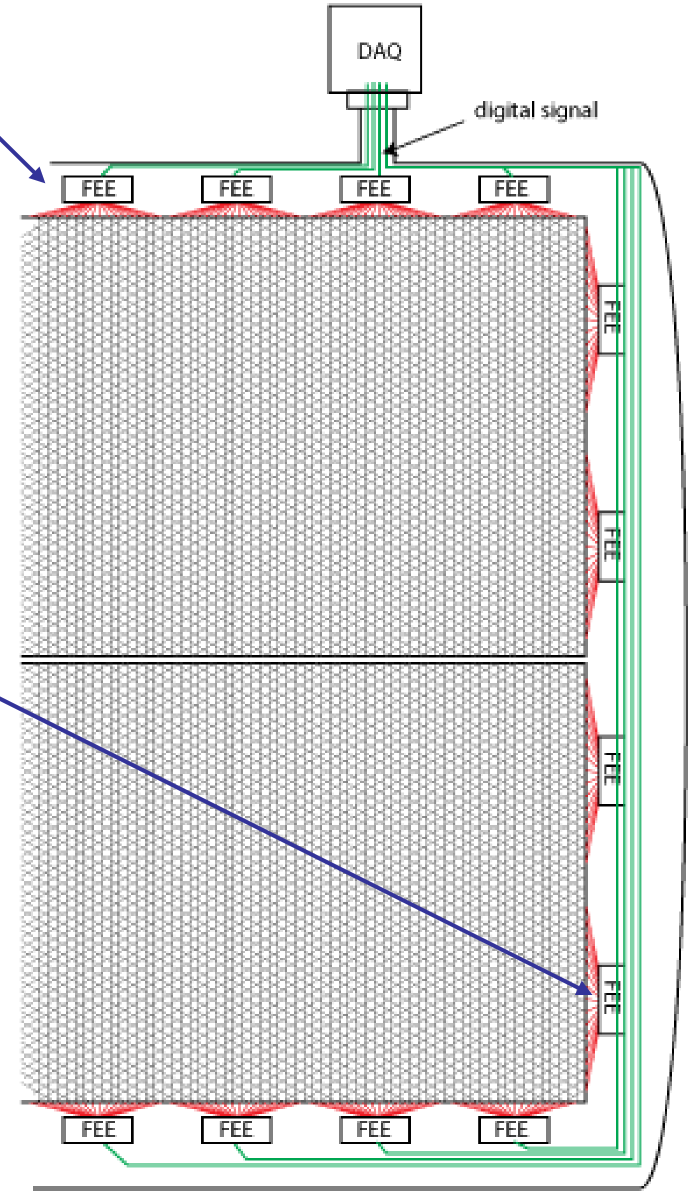
Lar20 in Standard Lab module aligned with beam from FNAL



Cryostat Design: "Warm" vs "Cold" Electronics



Electronics: Cold front end multiplexed inside the cryostat



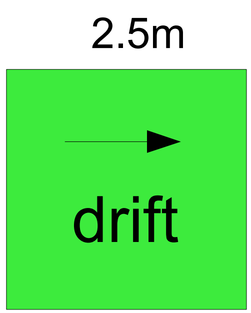
Signal cable lengths increasing to >10-20 meters for detector fiducial volume > 1kton resulting in high capacitance and high noise.

Cold electronics decouples the electrode and cryostat design from the readout design: *noise independent of the f ducial volume.*

Conceptual Design assumes cold electronics

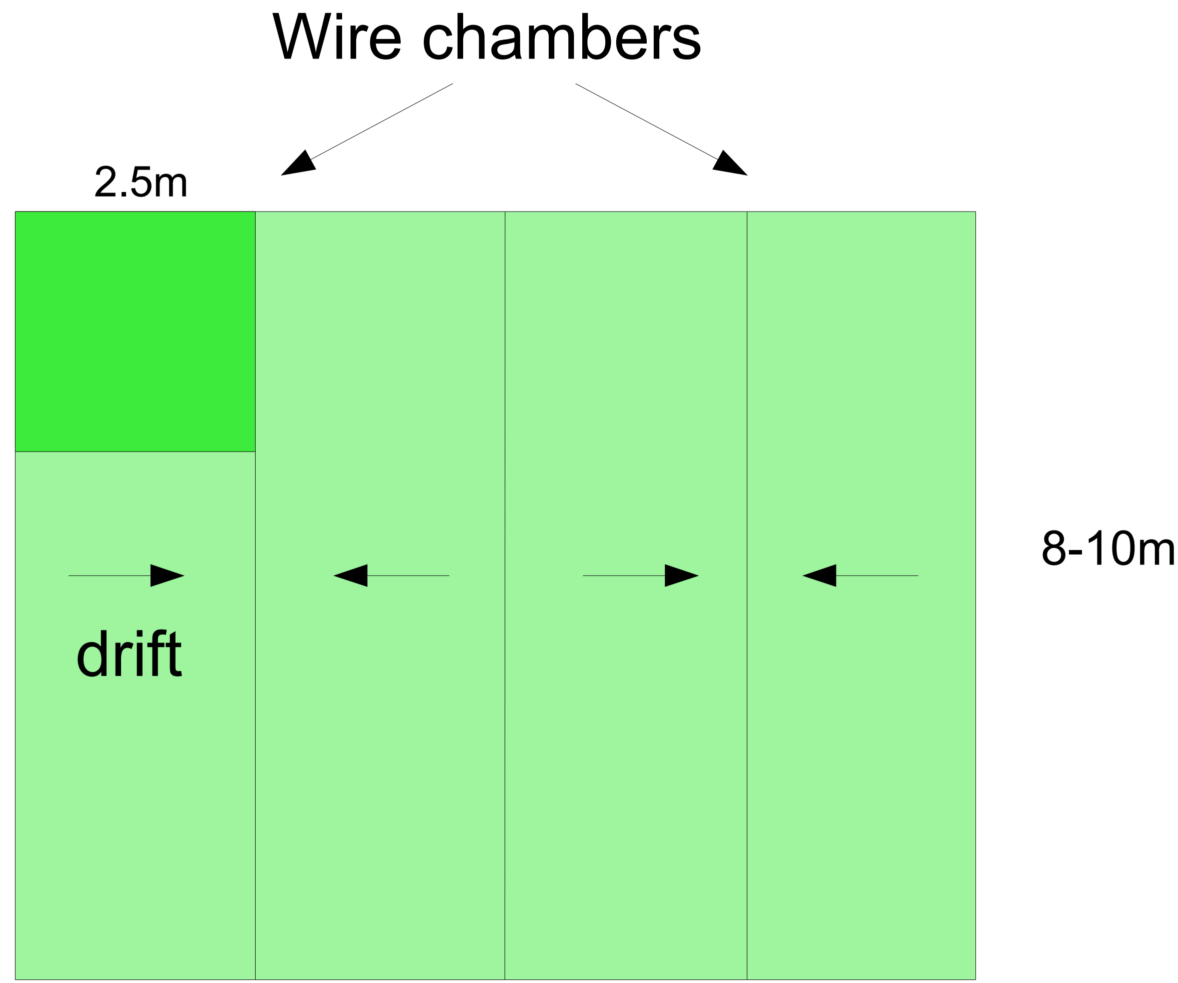
TPC design parameters: The same for both conceptual designs
for cryostats

- 2.5m drift
- 2-3 wire planes
- 3-5mm drift
- TPC design
- Wire stringing methods



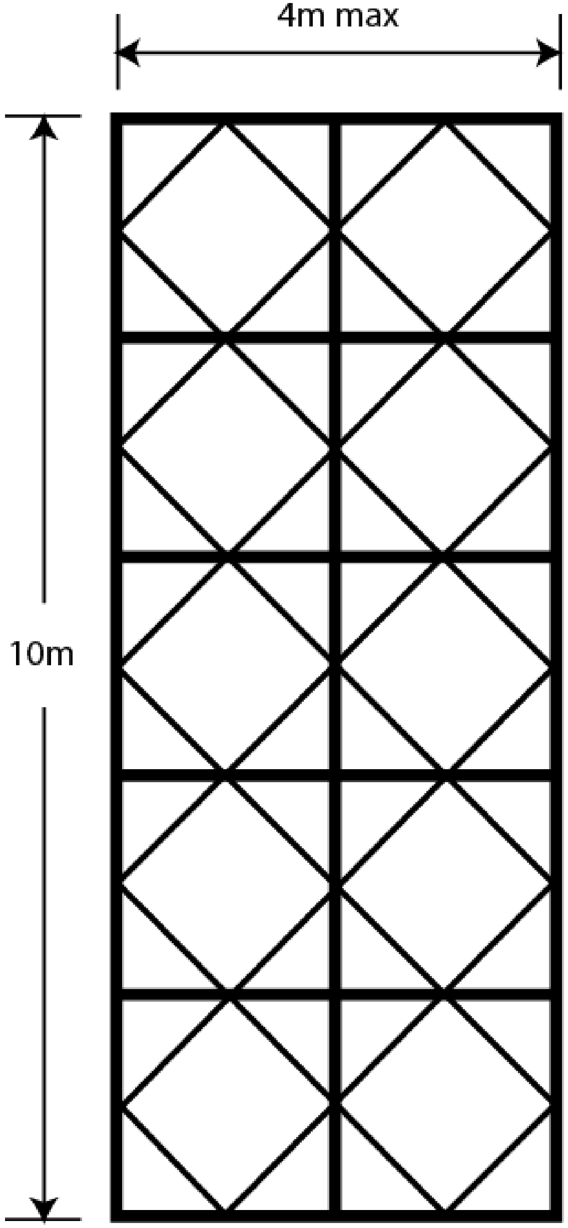
MicroBooNE

Build off
MicroBooNE
design



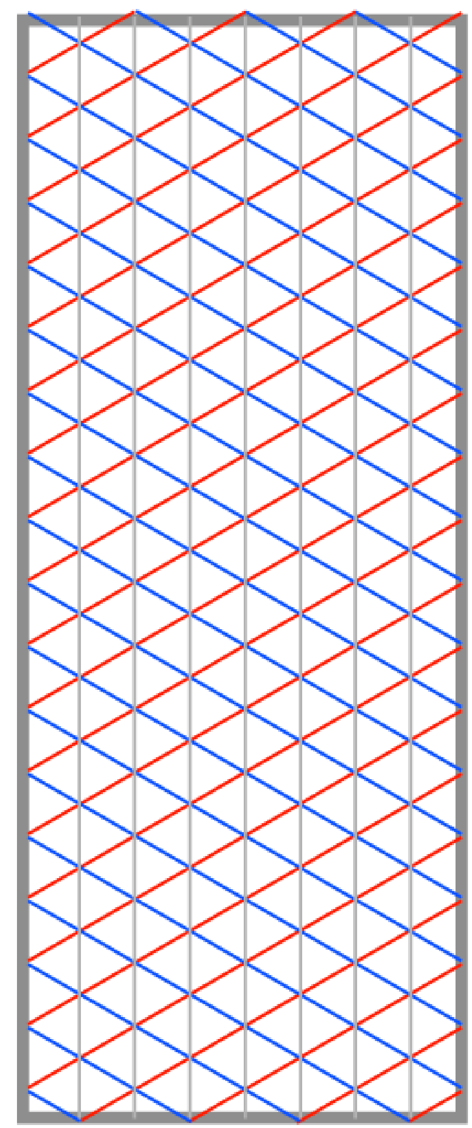
Cross section of
TPC at DUSEL

A Modular Wire Frame Design to Accommodate Cold Electronics



Wire Length:
Y: 10m
U: 4.6m
V: 4.6m

Number of Wires
@3mm pitch
Y: 1333
U: 3552
V: 3552
Total:
8437 each side



Status of developing conceptual design for CD-1

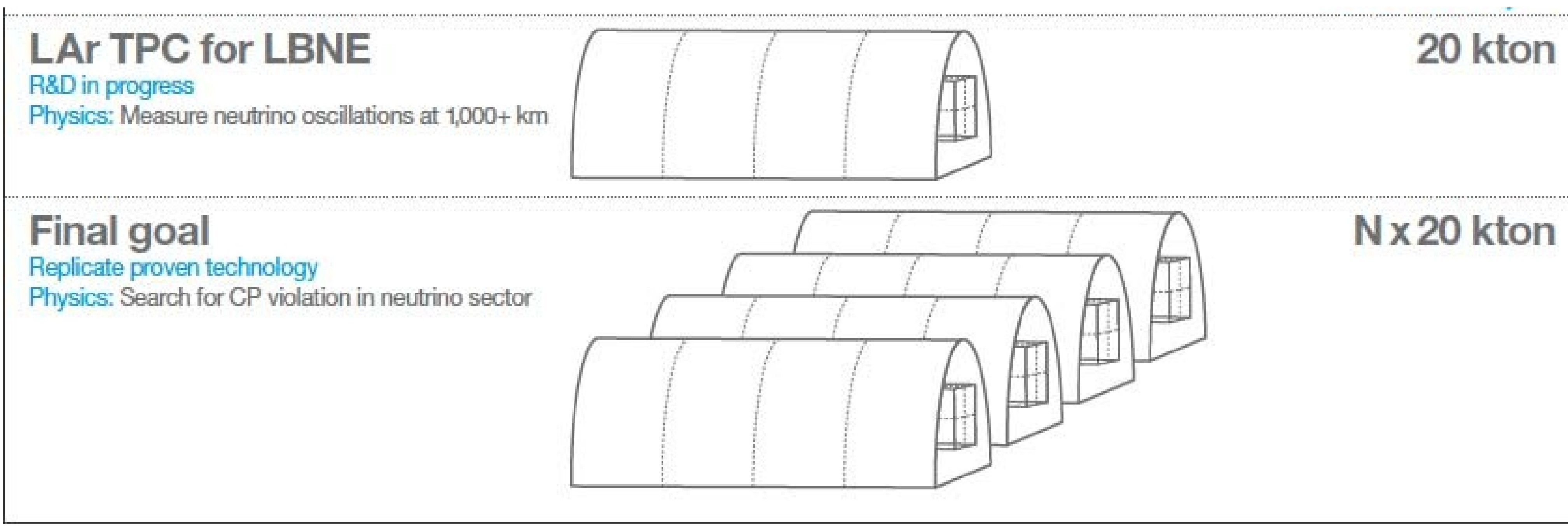
- Detector design parameters
  - 2.5m drift distance
  - Fiducial mass = 1/6 of 100kt Water Cherenkov   16.7kt (LAr20)
  - 2 - 3 wire planes, wire spacing = 3 - 5 mm
  - Cold electronics

- Engineering firms will provide conceptual designs for:
  - Cavern excavation
  - Modular & membrane style cryostats
  - Installation for both depth options: 300 ft and 4850 ft
  - Cryogenics plant above/below ground
  - Underground cryogen safety mitigation
  - **Contract negotiations underway**

Issues related to argon purity, TPC design, neutrino interactions:
Answered along the way with program scaling from small to large

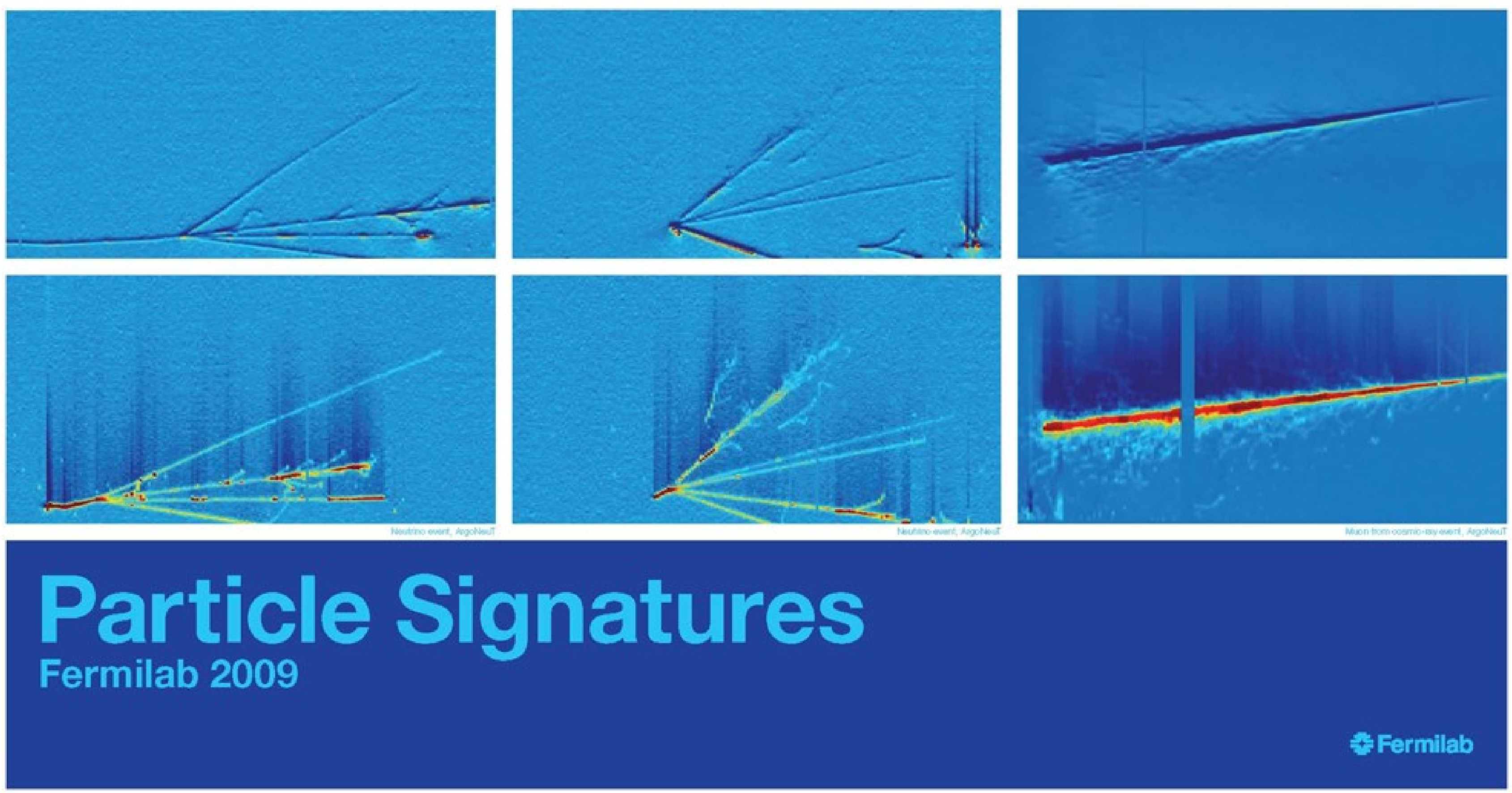
Brief Summary
Lots of progress towards conceptual design for Final goal:
LAr20 and beyond

Final goal: Detectors at DUSEL for broad physics program
Neutrino oscillations, Nucleon decay, Astrophysics



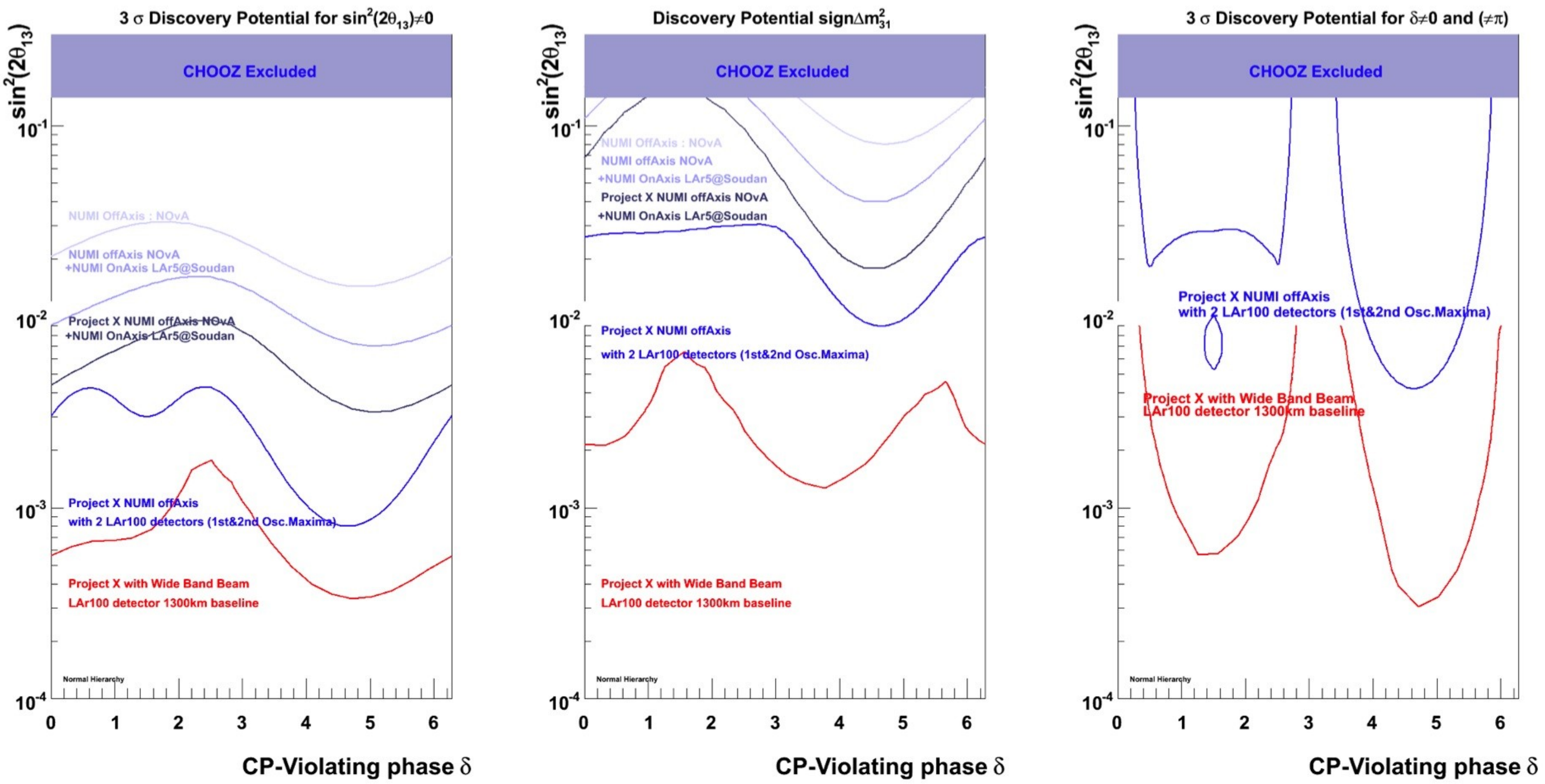
Continuing progress on test stands and experiments needed to develop LAr technology to get there

Poster given to Governor Rounds on his recent trip to Fermilab

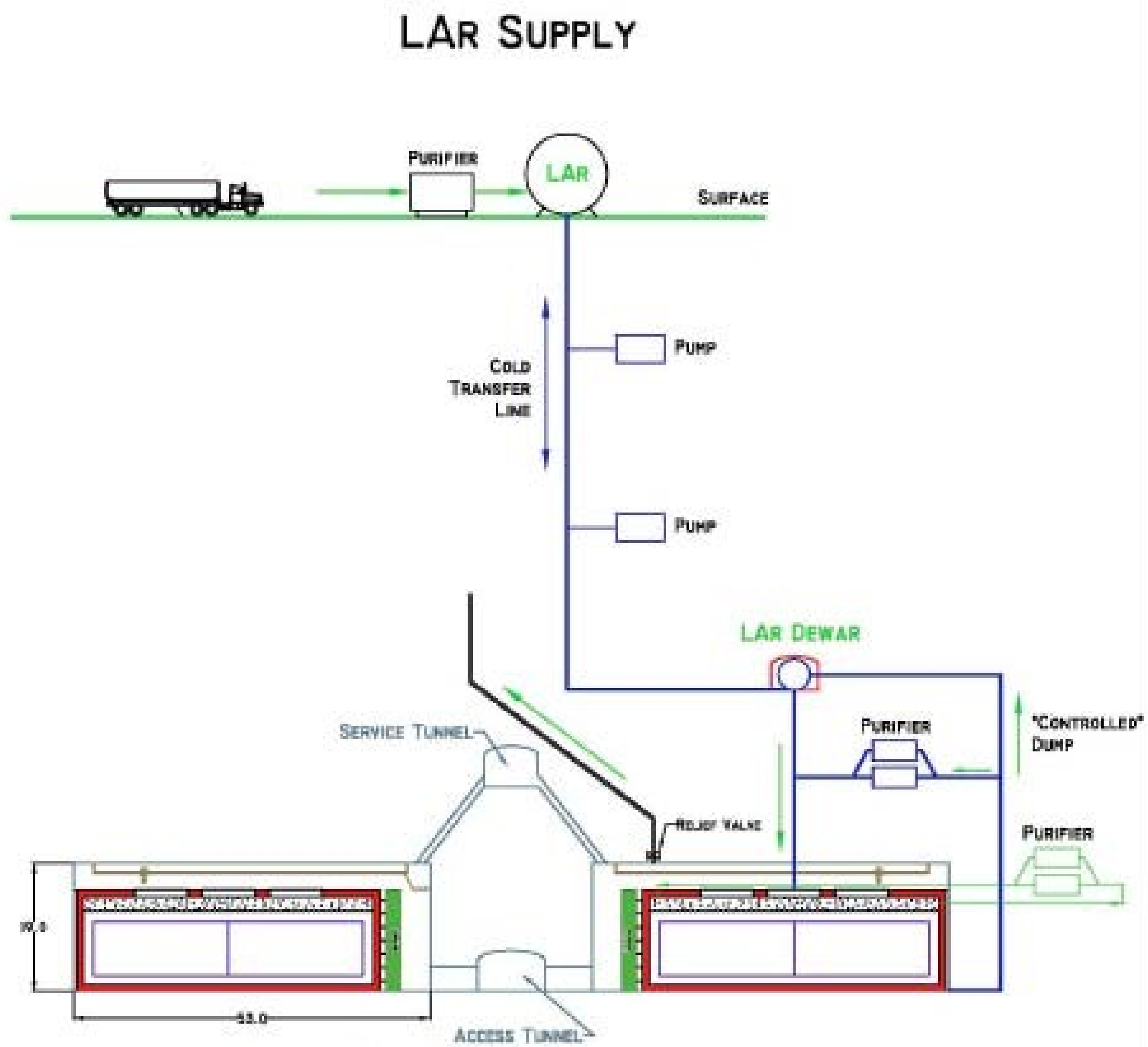


Backup Slides

Impressive physics reach for CP Violation search



Concept for supply of cryogenics underground: implementation that minimzies cost, safety risk, technical risks (ie: purity)



Example of cavern arrangement and liquid supply paths