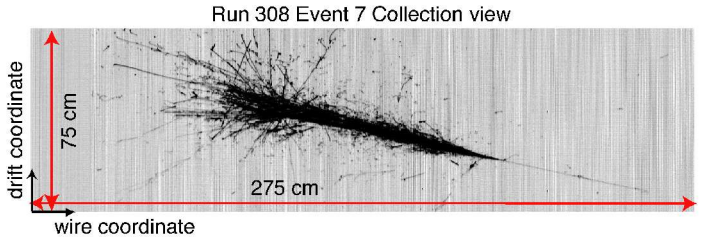
B.T.Fleming
uDiG workshop
October 17, 2008

Liquid Argon Summary

- Physics reach for LarTPCs addressed in this workshop
- Path to using this technology
- LArTPC baseline detector plans for DUSEL

Why consider Liquid Argon TPCs.....

Liquid Argon TPC detectors for neutrino physics and nucleon decay



Unique Detectors
⇒ precision measurements in neutrino physics
⇒ appear scalable to large volumes

- Neutrino oscillation physics: significantly more sensitive than WC detectors. (translates into smaller volumes for same physics reach) (Mark Dierckxsens)
  ν_e appearance is difficult. Need powerful LAr detectors.....
- Proton decay searches (Ed Kearns)
  - sensitive to $p \rightarrow \nu k$
  - Extend sensitivity beyond SK limits with detectors larger than 5kton
- Supernova and solar neutrinos (Josh Klein)

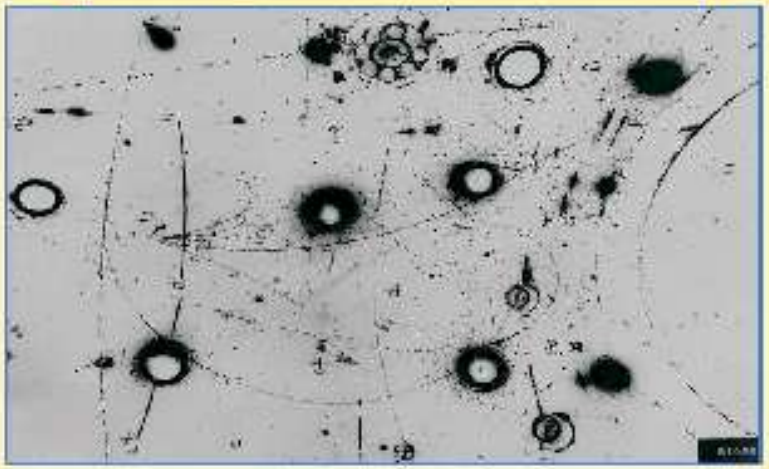
Detector sensitivity and simulation...

A. Rubbia (Sept. 2005)

Why 2km LAr TPC? (1)

- **Fully active, homogeneous, high-resolution device** ⇒ high statistics neutrino interaction studies with bubble chamber accuracy .

Gargamelle bubble chamber



bubble diameter ≈3mm

Capable of 1-event discovery…

Real event in ICARUS



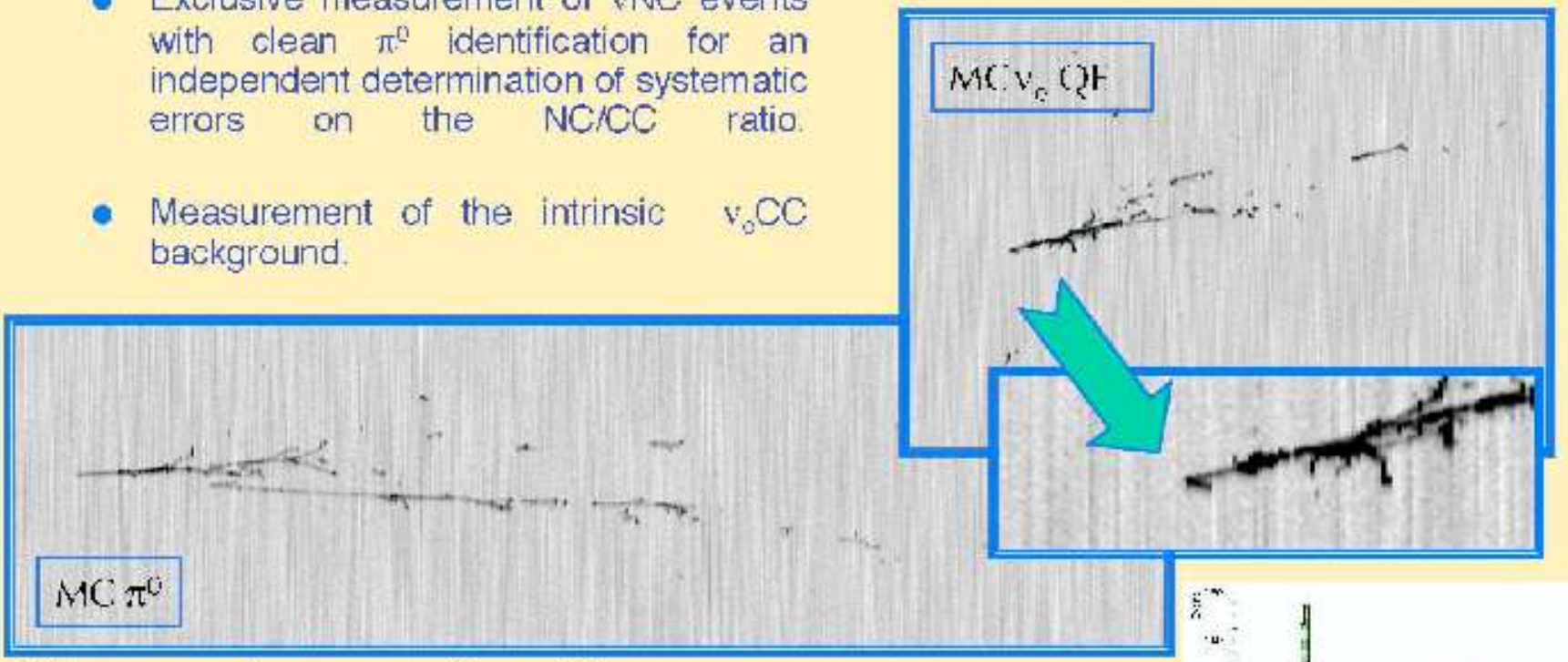
High granularity: Sampling = 0.02 X_0
"bubble" size ≈3×3×0.4 mm³

Kirk McDonald

A. Rubbia (Sept. 2005)

Why 2km LAr TPC? (3)

- Exclusive measurement of νNC events with clean π^0 identification for an independent determination of systematic errors on the NC/CC ratio.
- Measurement of the intrinsic ν_eCC background.



When vertex known, combine with probability to convert within 1 cm:

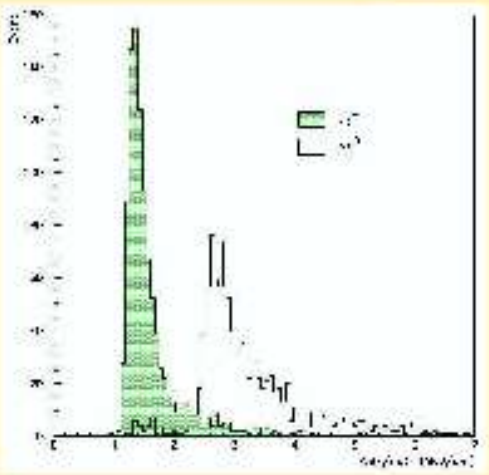
$\Rightarrow$ 5.4%

Combined, aim at:

$\Rightarrow$ 0.2% π^0 efficiency by imaging for 90% electron efficiency

dE/dx cut efficiency:

Energy (GeV)	π^0 efficiency (%)	$< dE/dx >_{cut}$ (MeV/cm)
0.25	6.5	2.13
0.5	5.5	2.19
1	3.7	2.21
2	2.7	2.10



Kirk McDonald

A. Curioni (Aug. 2006)

$\nu_e n \rightarrow p e^- X$ Efficiency ~ 90%

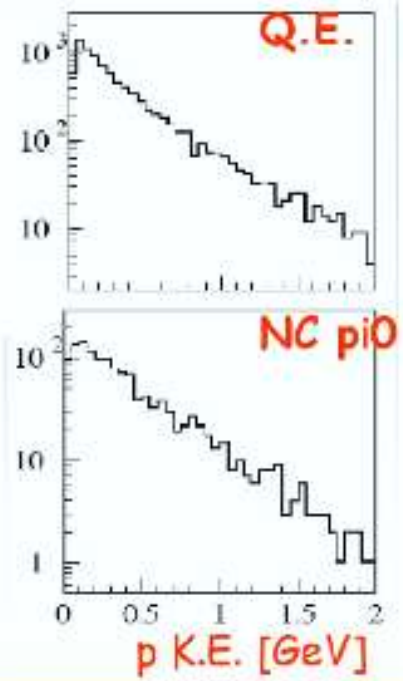
Require E_{proton} > 50 MeV).

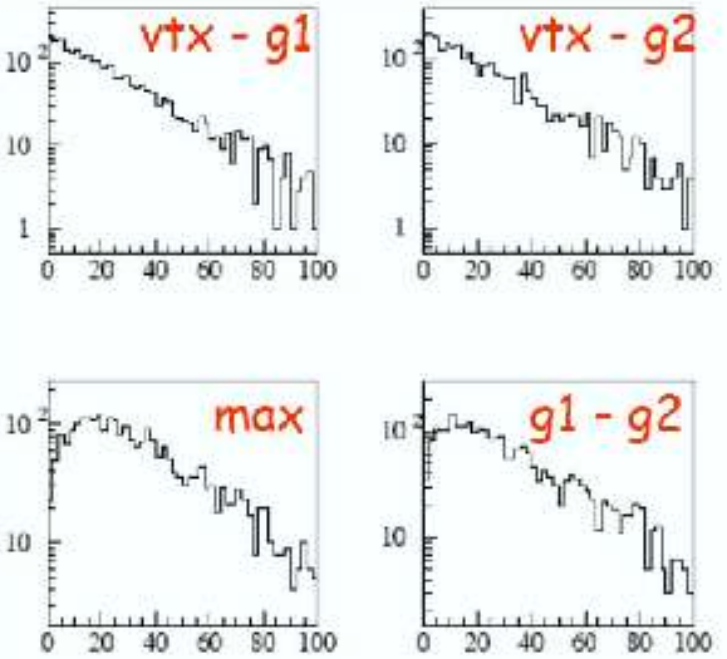
Rejection of $\nu_\mu n(p) \rightarrow n(p)\pi^0 X$ ~ 200:1

Reject whenever one or both γ more than 2 cm from primary vertex (100:1)

Require E_{proton} > 50 MeV (2:1)

[Predictions similar to those of Rubbia group.]





Kirk McDonald

Visual Scan of 450 Monte Carlo Events (2005)

Estimation of Signal Efficiency and Background Rejection for a Liquid Argon Detector in the NuMI Off-Axis Beam

H. Gallagher, B. Bowler, S. Cangotena, A. Hall, W. A. Mann, J. Schneps, A. Para, J. Weiner

May 25, 2005

Abstract

In this note we describe a small study carried out at Tufts University to evaluate the signal efficiency and background rejection capabilities of liquid argon detectors for sub-dominant $\nu_\mu \to \nu_e$ search in the NuMI beam. The analysis is based on a blind scan of 450 events.

		N	pass	ϵ	η
NC		290	4	-	73±31
signal ν_e	CC	32	26	0.81±0.07	-
Beam ν_e	CC	24	14	0.58⊥0.10	-
	NC	8	0	-	/
Beam $\overline{\nu}_e$	CC	13	10	0.77 ⊥ 0.09	-
	NC	19	0	-	/
ν_μ	CC	32	0	-	/
ν_μ	CC	32	1	-	/

$\varepsilon = 81 \pm 7$ % for ν_e appearance.

Rejection factor = 73 ± 31 for neutral current events with a π^0.



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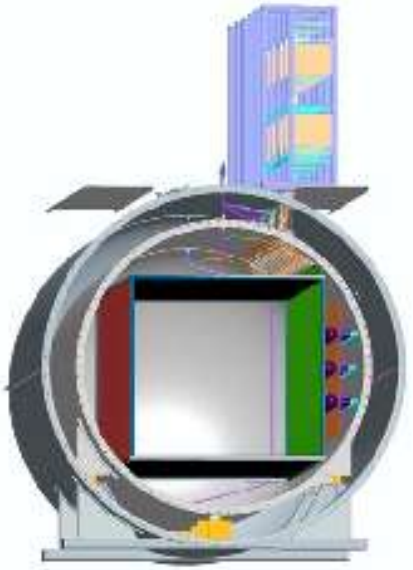
Present and Future Opportunities for Software Development

LAr TPC Hardware R&D Projects:

- Argoneut
- BO

Physics Experiments with LAr TPCs:

- ICARUS
- microBooNE
- T2K 2km Near Detector



LAr TPC event reconstruction is likely beyond the scope of an R&D project.

US effort will likely focus on the microBooNE experiment at Fermilab.

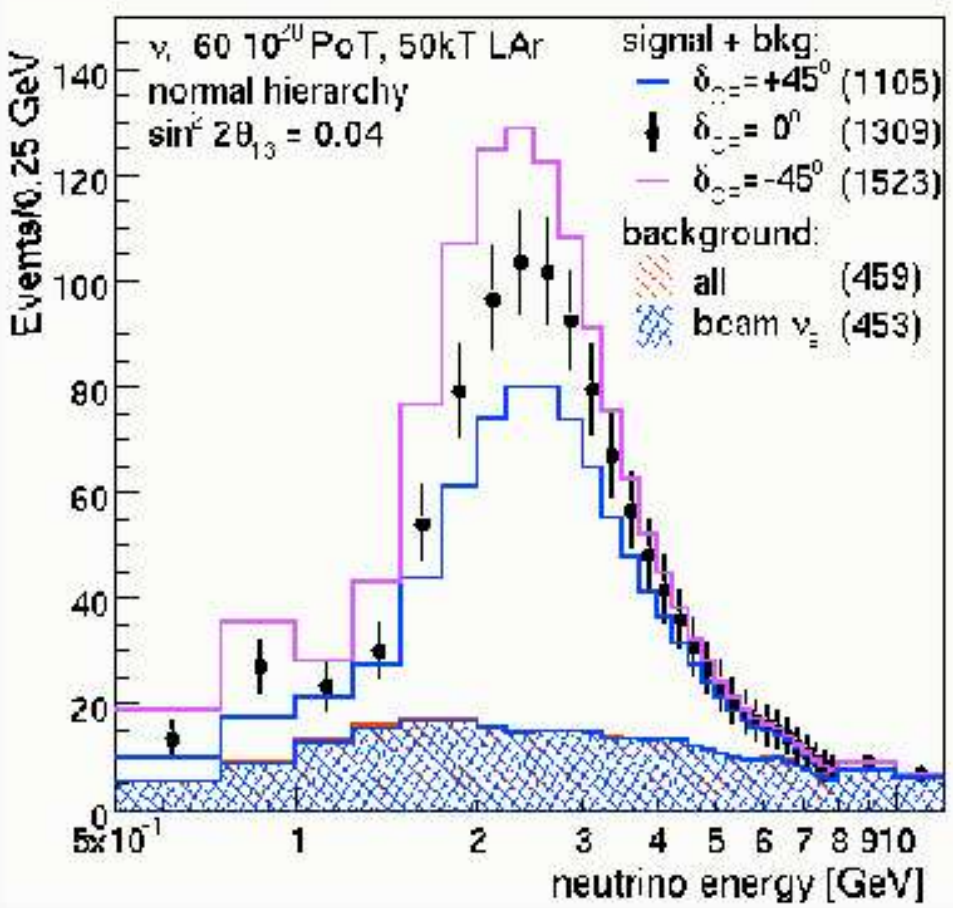
The challenge is significant: no bubble chamber event reconstruction was every fully automated.

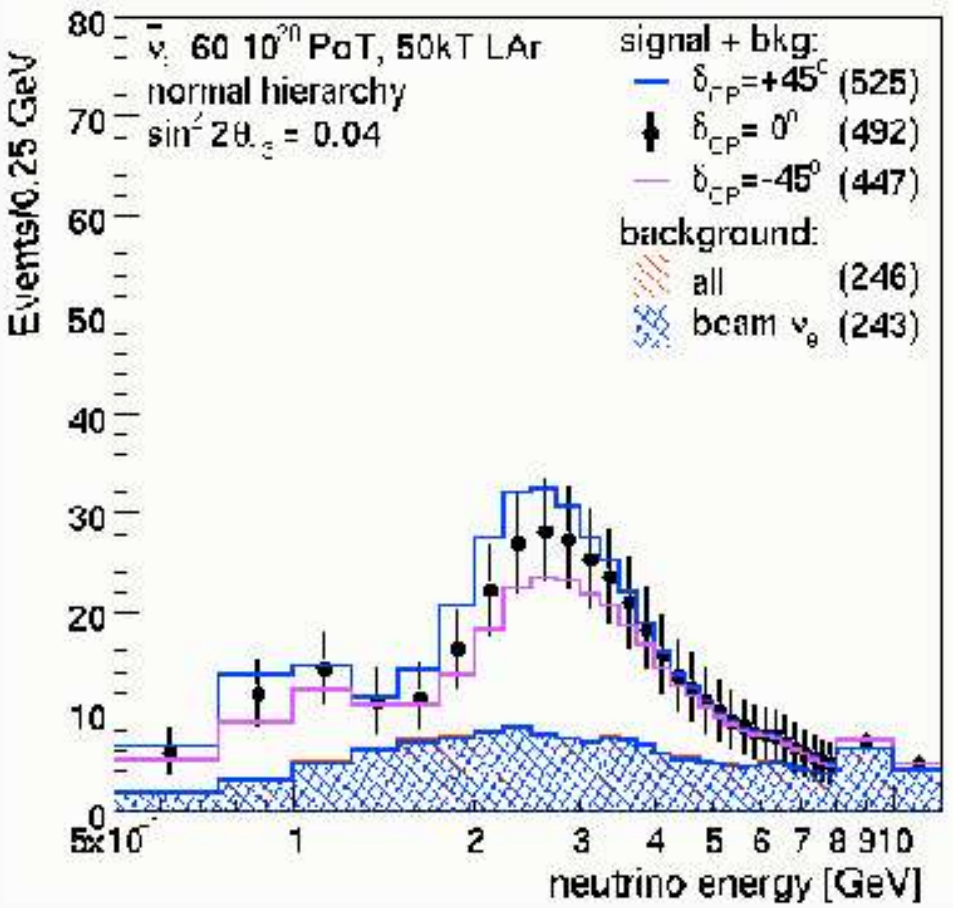
- 3 Independent studies show ν_e eff: 80-90%
- excellent pi0 rejection
- significant work to do but drive to do so is here

Kirk McDonald

Spectra – Liquid Argon

How do these sensitvities translate into physics reach?





2.4MW beam, $\sin^2\theta_{13}$=0.04, normal hierarchy

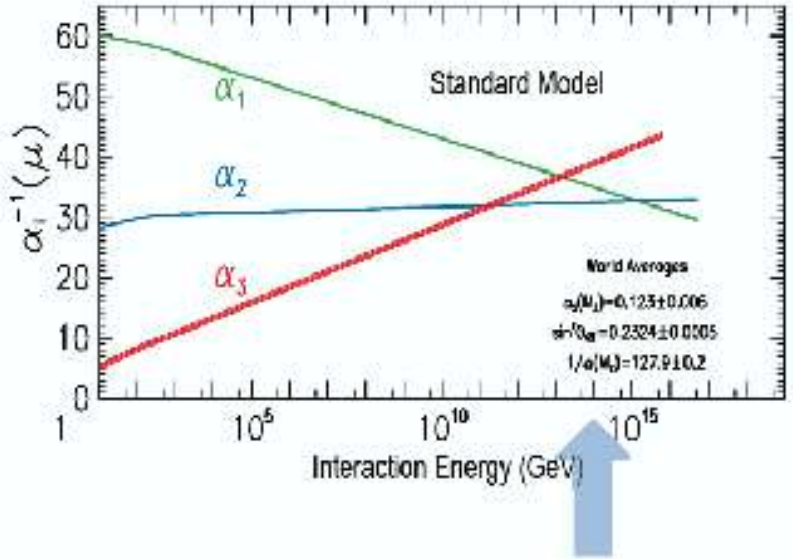
Different Exposures

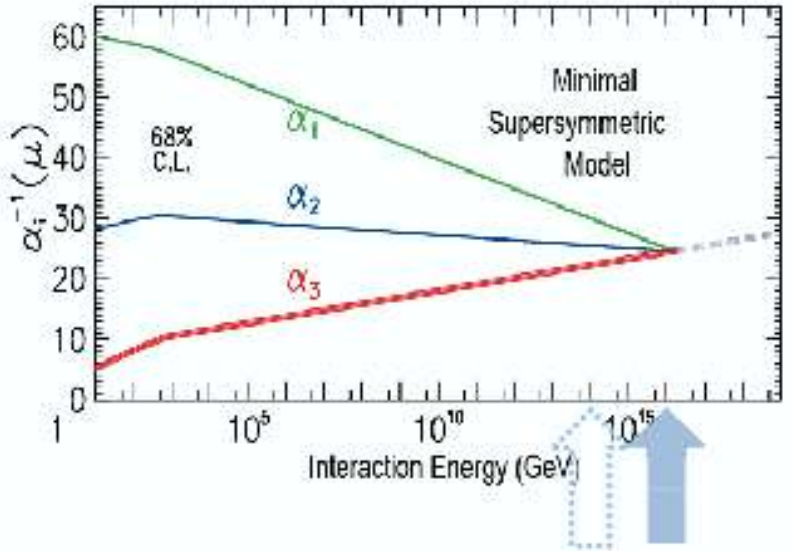


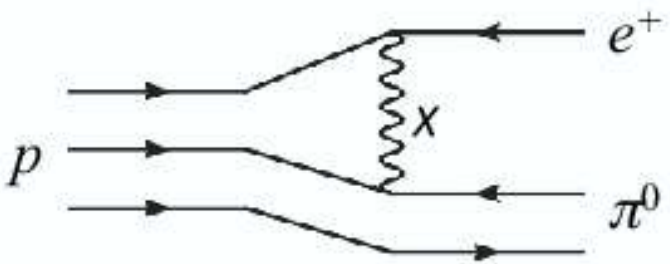
		$\sin^2 2\theta_{13} \neq 0$ 3σ, all δ_{cp}	sign(Δm^2_{31}) 3σ, all δ_{cp}	CPV 3σ, 50% δ_{cp}
Water Cherenkov	300kt, 1.2MW	0.008	0.018	0.030
	300kt, 2.4MW	0.006	0.012	0.015
	600kt, 2.4MW	0.004	0.010	0.008
Liquid Argon	50kt, 1.2MW	0.007	0.014	0.018
	50kt, 2.4MW	0.005	0.011	0.010
	100kt, 2.4MW	0.003	0.008	0.003

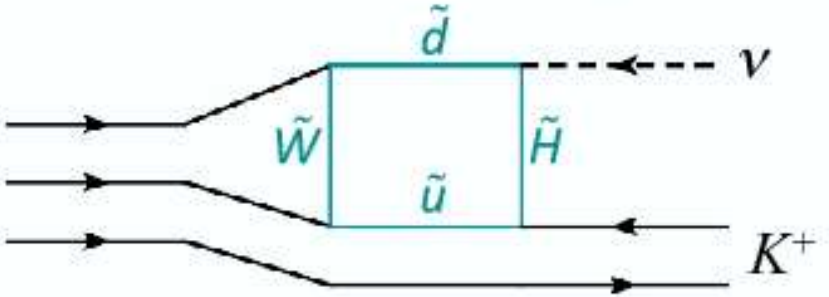
Need ~6x smaller LAr to obtain similar sensitivities to WCh
Small NC bkg contamination will affect LAr, in particular CPV

Unification of Running Coupling Constants





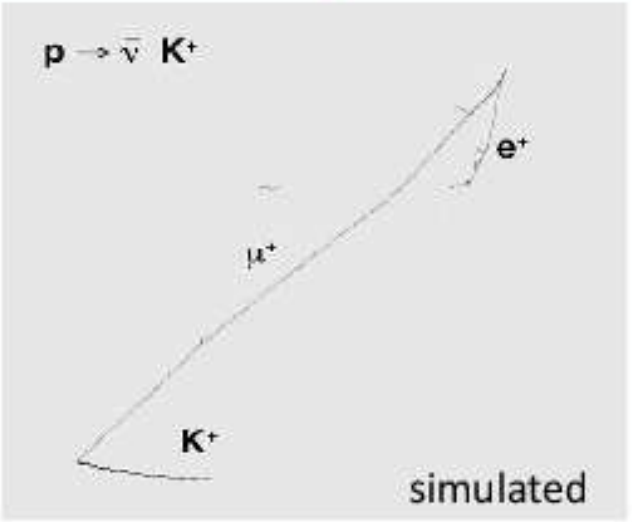


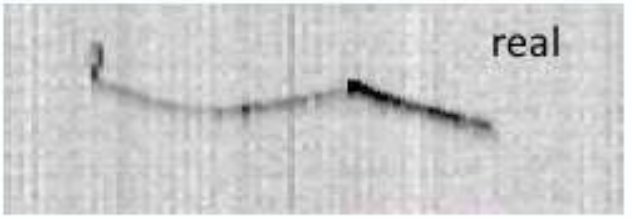


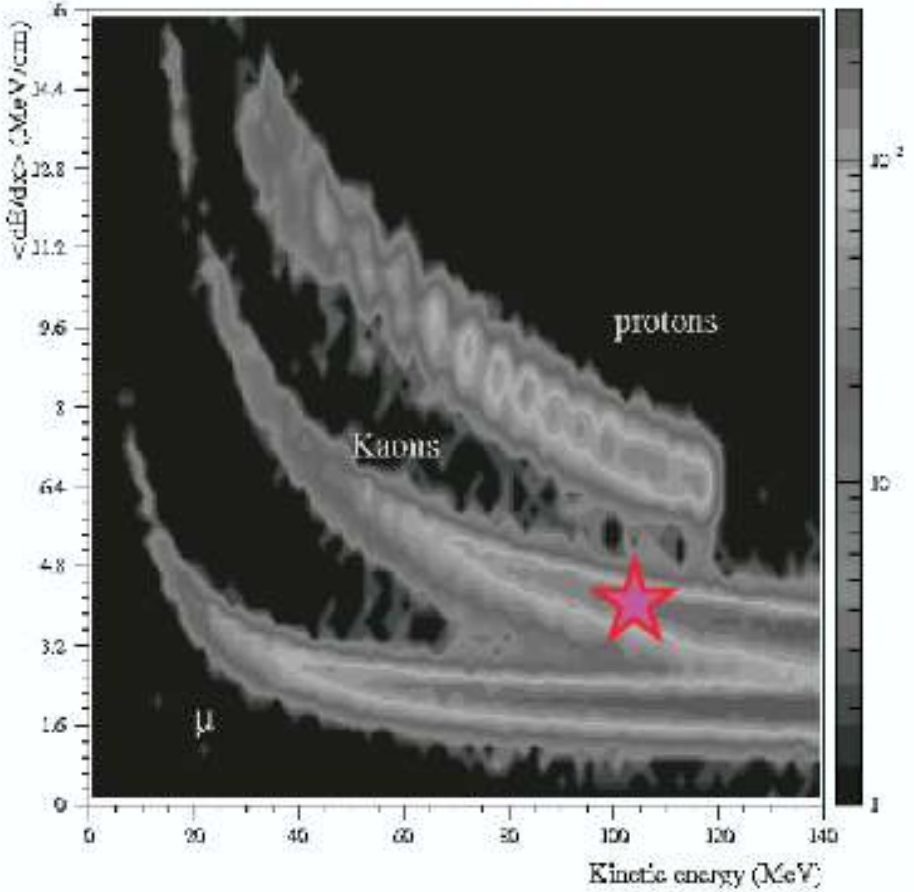
$\tau/B = 4.5 \times 10^{29\pm1.7}$years SU(5)
$\tau/B > 8.4 \times 10^{33}$years SK I + II

$\tau/B = 10^{29-35}$years SUSY
$\tau/B > 2.3 \times 10^{32}$years SK I

Liquid Argon's Killer App

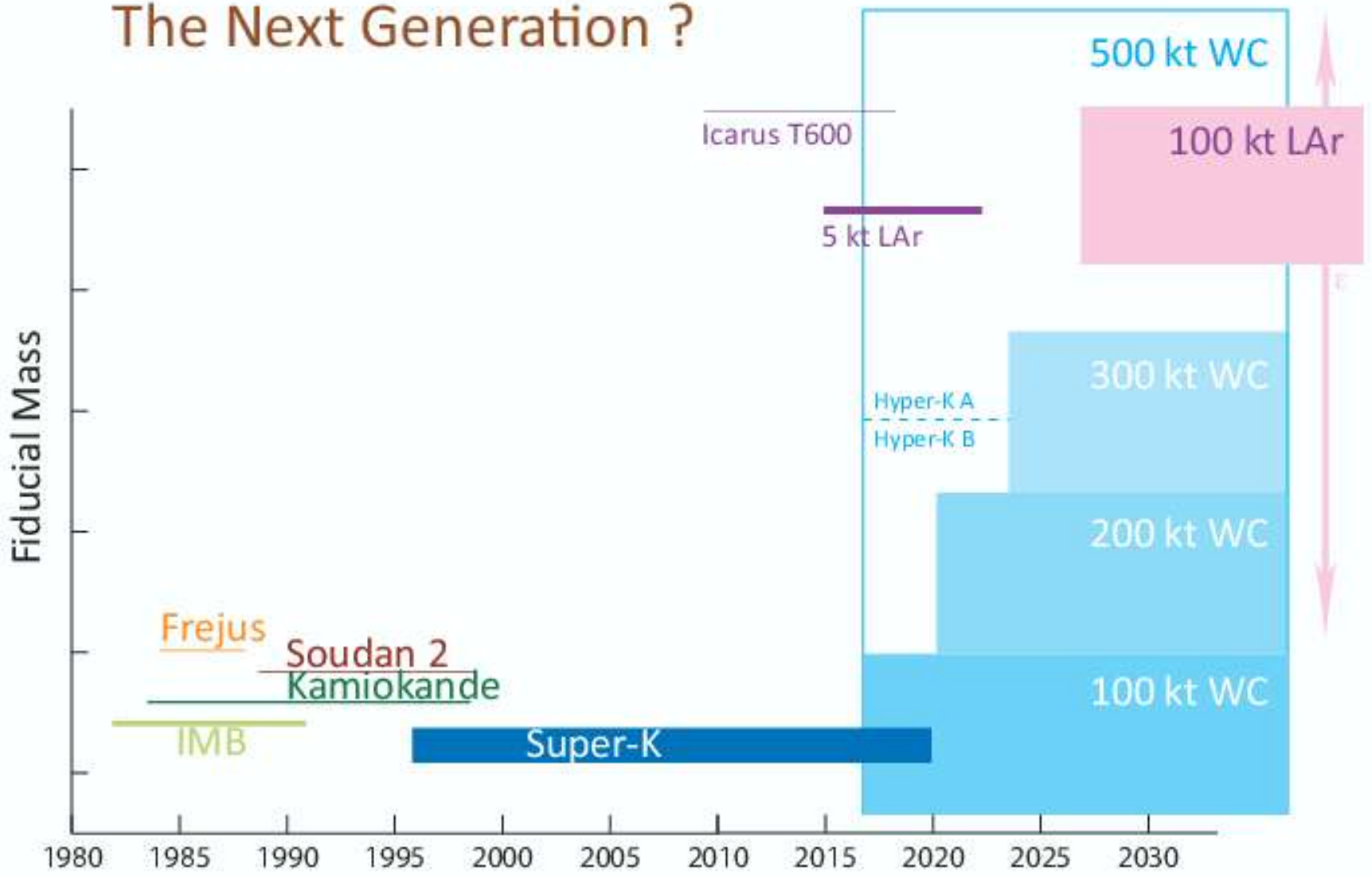






Cuts	(p3) $p \to K^+ \bar{\nu}$	ν_e CC	$\bar{\nu}_e$ CC	ν_μ CC	$\bar{\nu}_\mu$ CC	ν NC	$\bar{\nu}$ NC
One kaon	96.8%	308	36	871	146	282	77
No other charged tracks, no π^0	96.8%	0	0	0	0	57	9
$E_{vis} < 0.8$ GeV	96.8%	0	0	0	0	1	0

The Next Generation ?



Water Cherenkov	Liquid Argon
The GOOD: Cheap mass Energetic EM showers, muons; μ decay Mature, time-tested technique $e^+\pi^0$	**The GOOD:** High resolution and detail Charged Particle dE/dx Exciting "new" technology $K^+\nu$
NOT SO good: Sub-threshold charged particles Mature technique is boring	**NOT SO good:** Unknowns: cost, feasibility, operation, safety
Questions for the next generation: PMT coverage (40% - 20% - 5%?) Can we reduce per channel cost? Details, details, details...	**Questions:** Design paths (wires, GEMs, vacuum etc.) When will we see a detector operate for a year? Is 100 kton realistic?

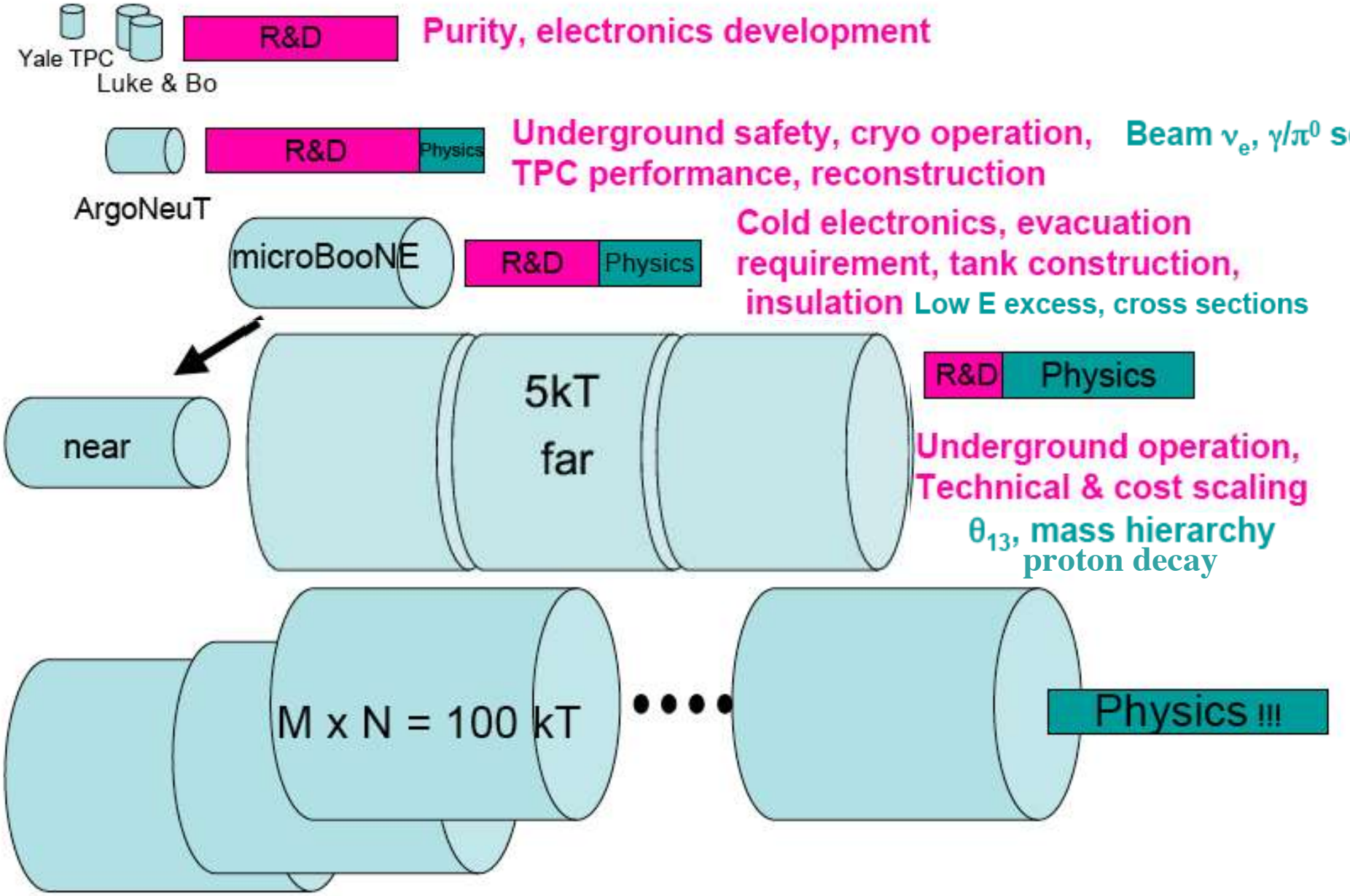
Challenges for large detectors...

- Seeing that they work! (Continous operation of a detector for a year)
- Low Noise Electronics and signal multiplexing
- Light detection for Triggering
- Purification Issues: large, industrial vessels
- Physics Development: Interactions on argon, simulation, reconstruction, data reduction
- TPC design: Wire plane structure
- Vessel Design: materials, insulation, feedthroughs
- Vessel location and Installation
- Underground construction, operation, and safety

Need a staged program for LArTPC detectors

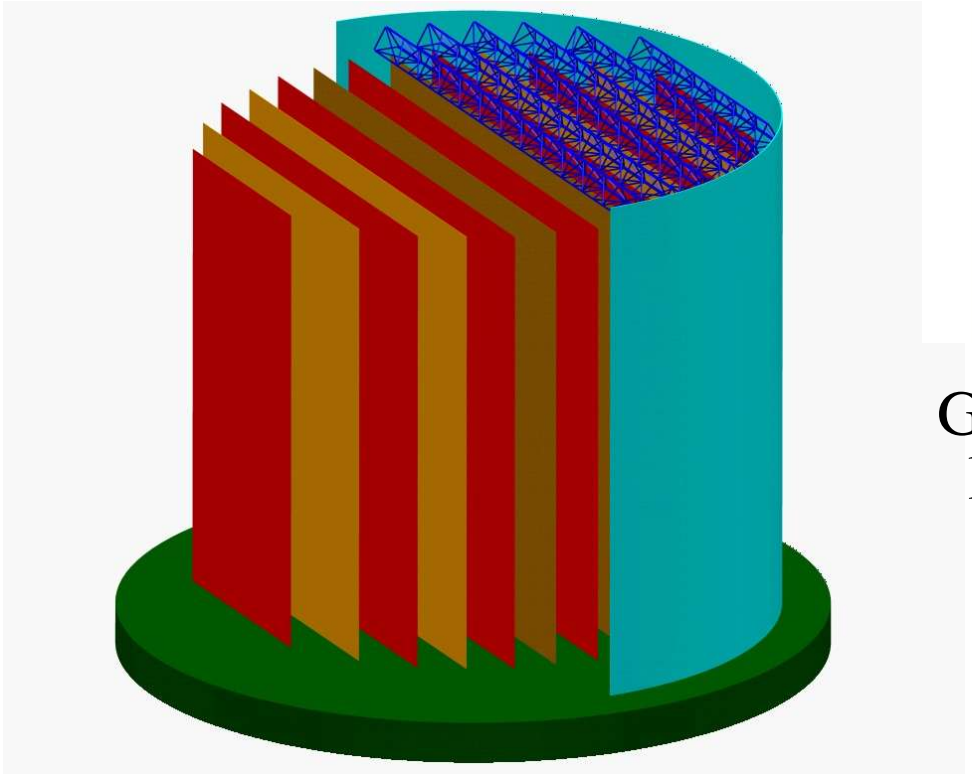
- address R&D questions at the relevant scale
- Move from R&D to physics goals
- Appropriate steps in size and cost

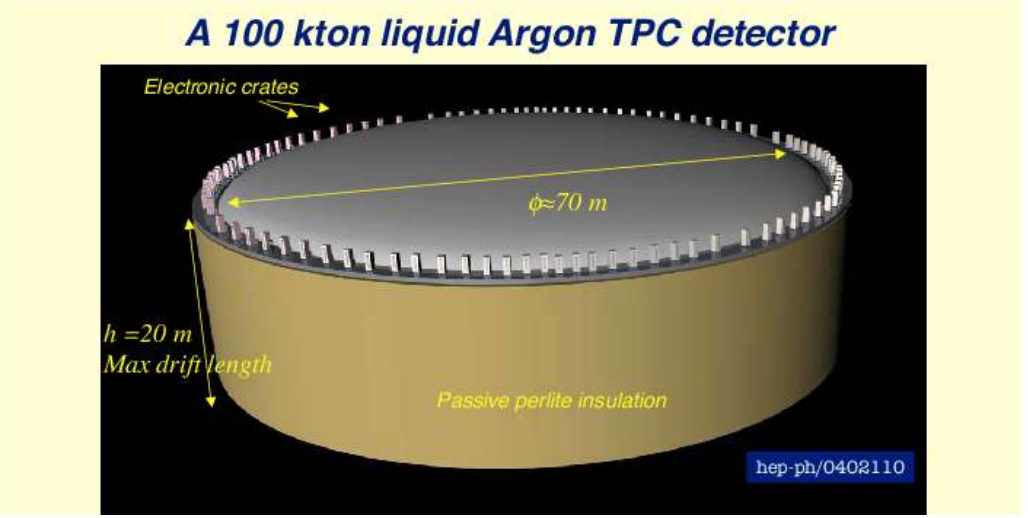
Evolution of the Liquid Argon Physics Program in the US



Possible designs for massive detectors:

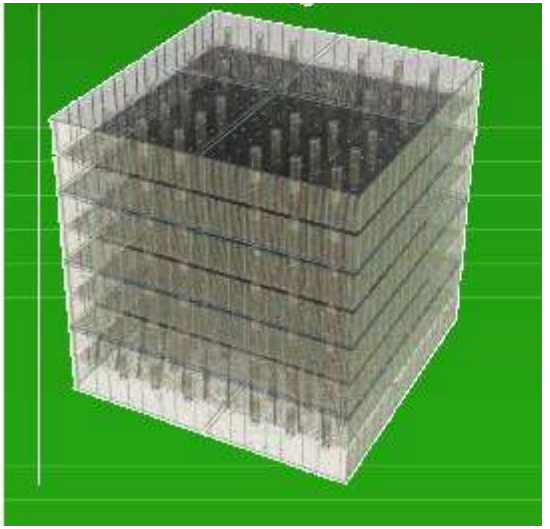
LArTPC: Modularized drift regions in one large (10-50kton) tank (un-evacuated)



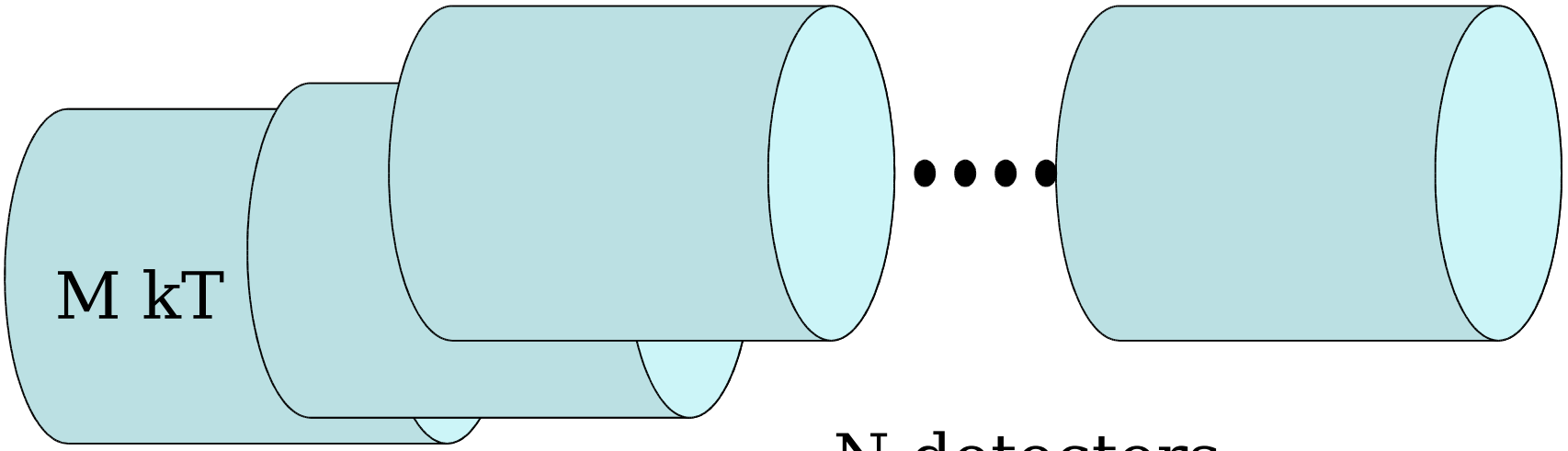


GLACIER: Combination of charge and light collection, single large drift area

LAANDD:
single module
cubic
evacuated vessel



Modularized Option



M x N = 100

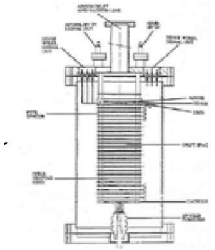
100 > M > 5

1 < N < 20

Optimize M & N against cost, schedule, technical feasibility, and safety

Similar evolution in European program

Test Stands →

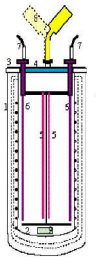


24 cm drift wires chamber

1987: First LAr TPC. Proof of principle. Measurements of TPC performances.

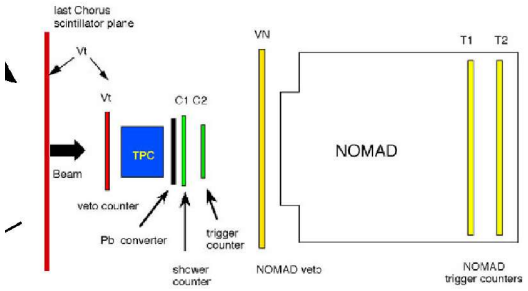
3 ton prototype

1991-1995: First demonstration of the LAr TPC on large masses. Measurement of the TPC performances. TMG doping.



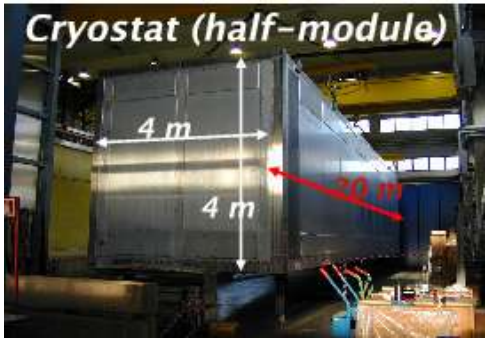


Seeing neutrino Interactions →



50 litres prototype
1.4 m drift chamber

1997-1999: Neutrino beam events measurements. Readout electronics optimization. MLPB development and study. 1.4 m drift test.

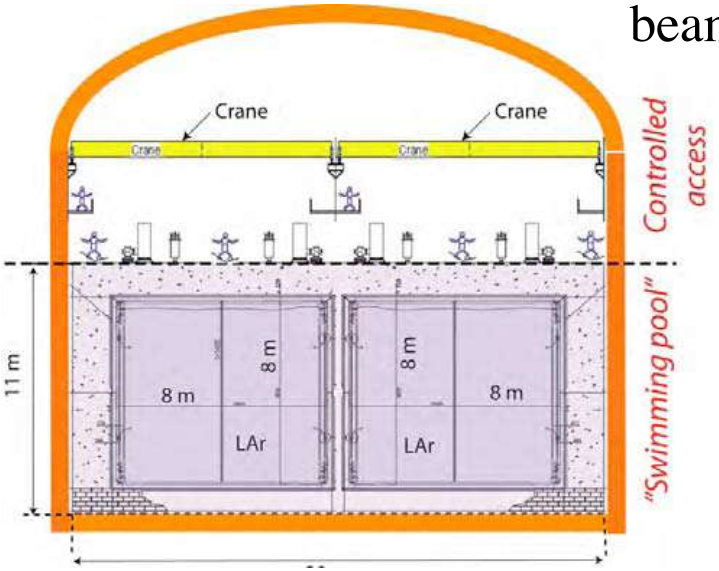


T600: data in '08
~2000 evts/yr, 17 GeV CNGS beam

Towards massive detectors →

SLICE:
slice of MODULAr
- 600 ton LArTPC
- low energy ν interactions
- prototype for MODULAr

similar program to MicroBooNE



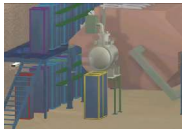
MODULAr:
5kton modules

Evolution of the Liquid Argon Physics Program

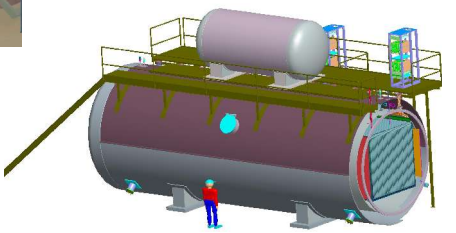




Yale TPC
Luke & Bo
R&D
Program underway

ArgoNeuT
R&D
Physics
Spring 2008



microBooNE
R&D
Physics
Data : 2011

near
5kT
far
R&D
Physics
Data : ~2015-2016

M x N = 100 kT
Physics !!!
Data 20??

R&D

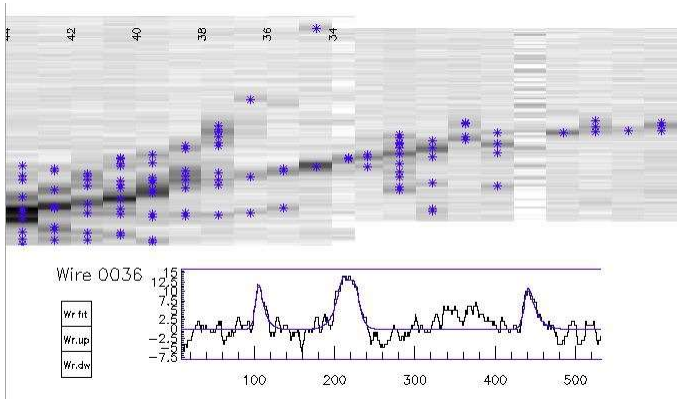
Test stands

-developing electronics components
-developing filtering techniques
  -Testing materials in Argon
  -Gaseous argon purge for purification
-developing Light Collection techniques
-technology transfer

Good as “bench top” tests, but there are scale limitations....



TPC at Yale



First tracks in US, April 2007

Materials Test Stand
Electronics Test Stand
at Fermilab



5m long drift test

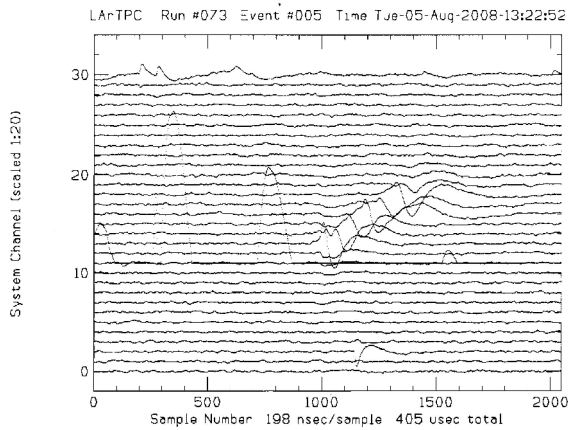


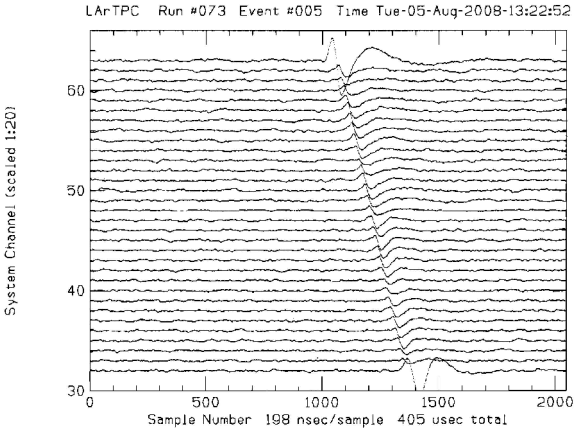
R&D

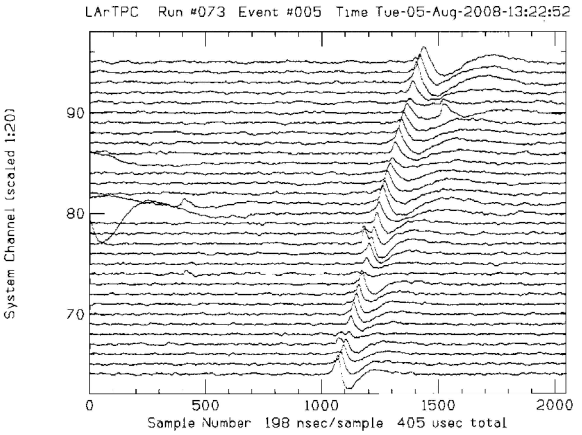
Bo Electronics Test Stand







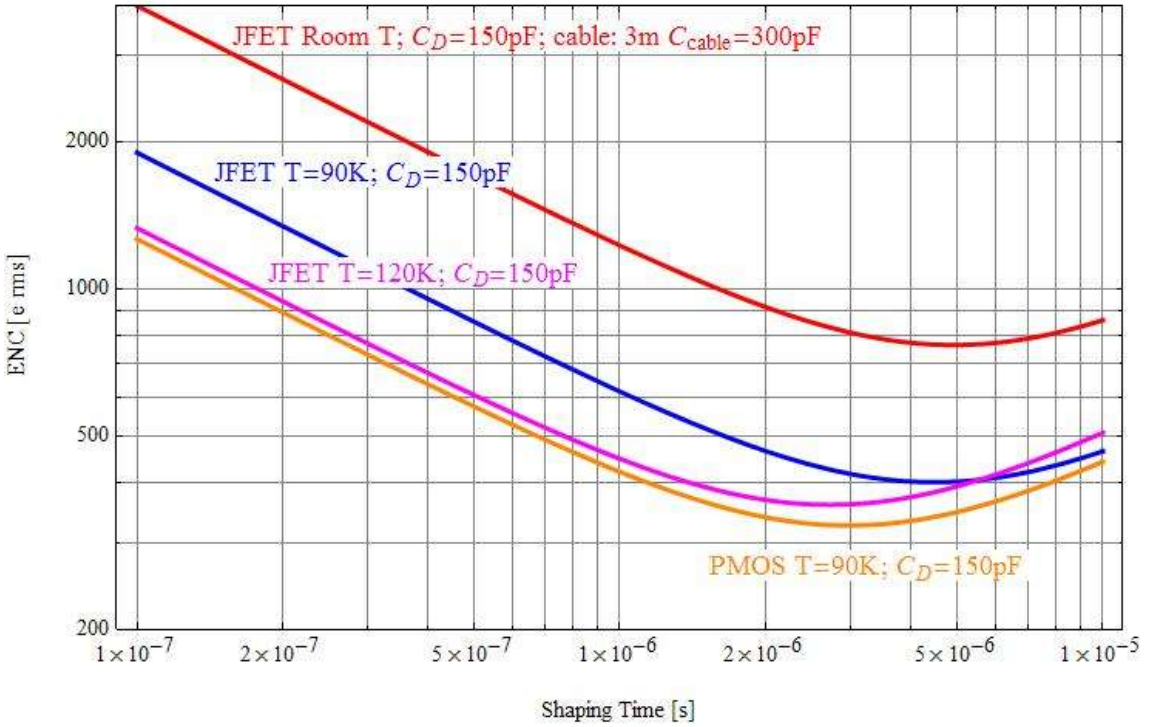




Warm electronics developed at MSU/FNAL

First tracks seen in early August

Cold Readout Electronics development at BNL



- To maximize S/N and have flexibility in detector geometry
- Factor of at least 3 better than at room temperature

Combine what is learned with JFET hybrids in GAr in MicroBooNE (very similar S/N to CMOS) with development of CMOS technology in LAr

- Develop Readout architecture → multiplexing at cryogenic temperatures to handle ~million channels of very large detectors

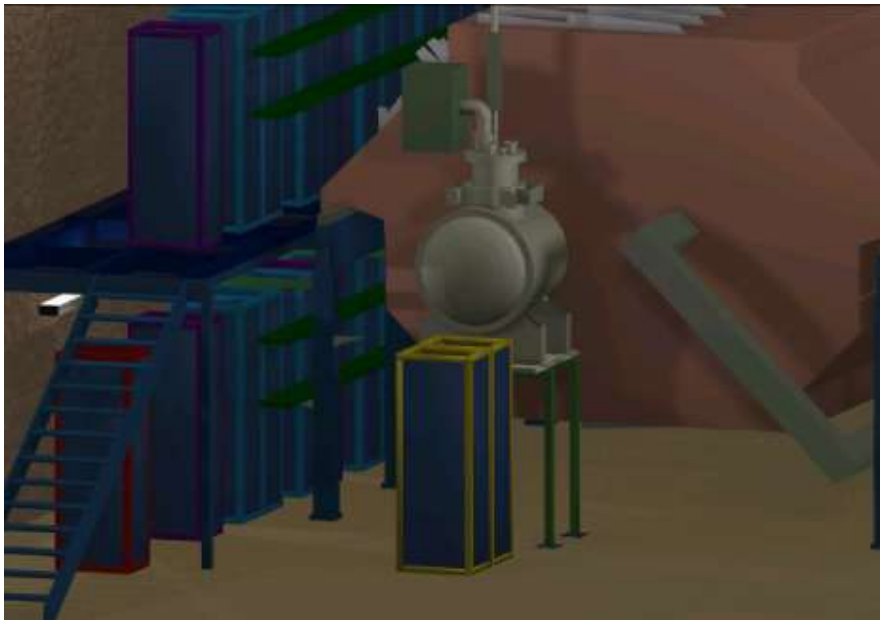
R&D | Physics

ArgoNeuT (2008)

Joint NSF/DOE project

0.3 ton active volume

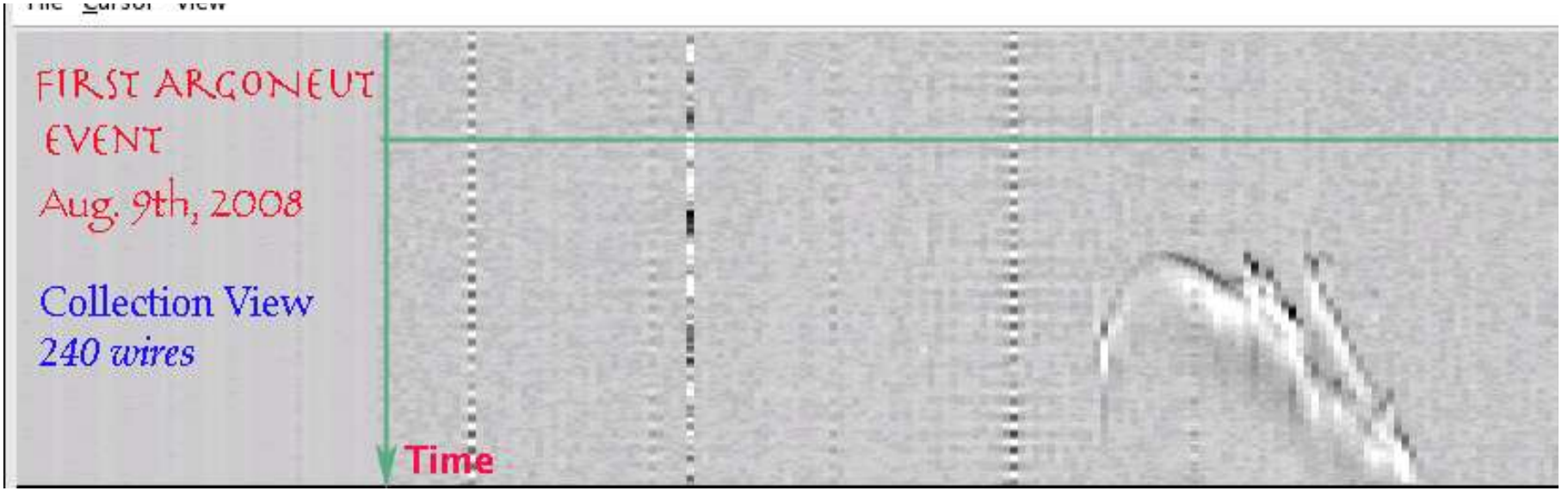
0.5 x 0.5 x 1.0 m^3 TPC; 500 channels



Located in NuMI near hall using MINOS near detector as a muon catcher

- See neutrino interactions (~150 evts/day)
- Long term running conditions
- Underground issues

ArgoNeuT fill with LAr for first time on August 4th. First cosmic tracks seen on August 9th!



R&D | Physics

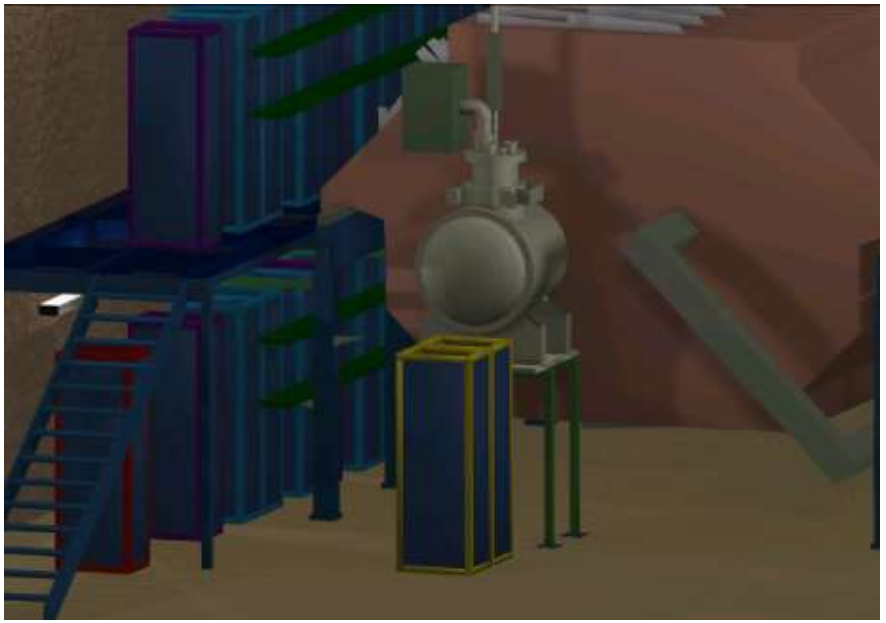
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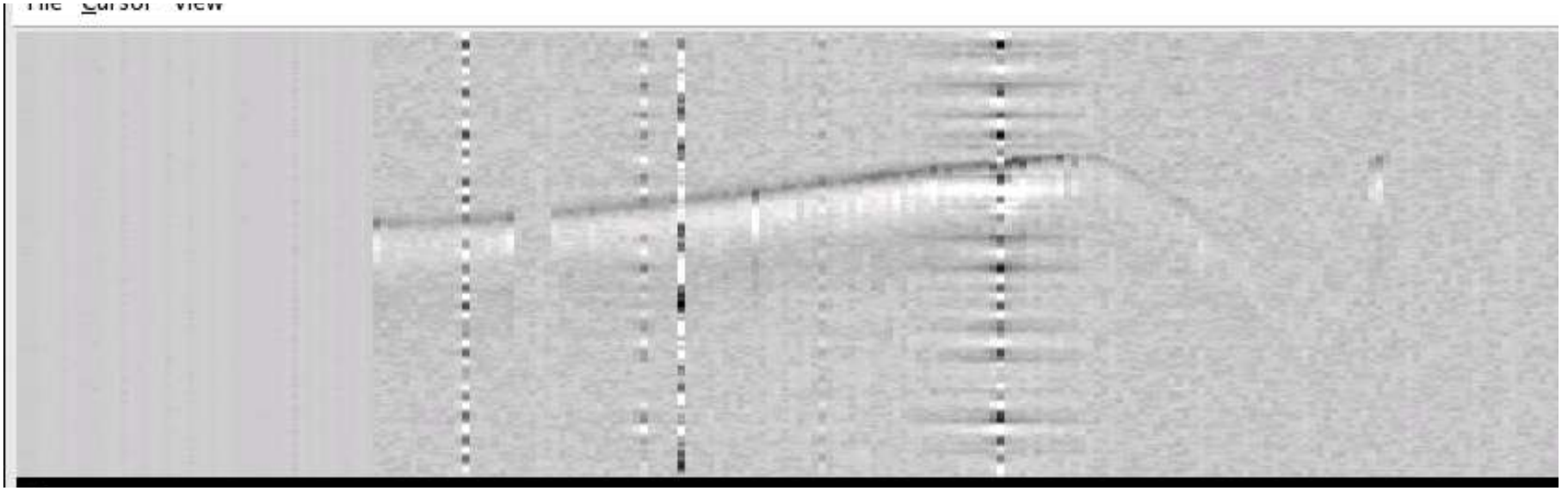
0.5 x 0.5 x 1.0 m^3 TPC; 500 channels

- See neutrino interactions (~150 evts/day)
- Long term running conditions
- Underground issues



Located in NuMI near hall using MINOS near detector as a muon catcher

Crossing muon track



R&D | Physics

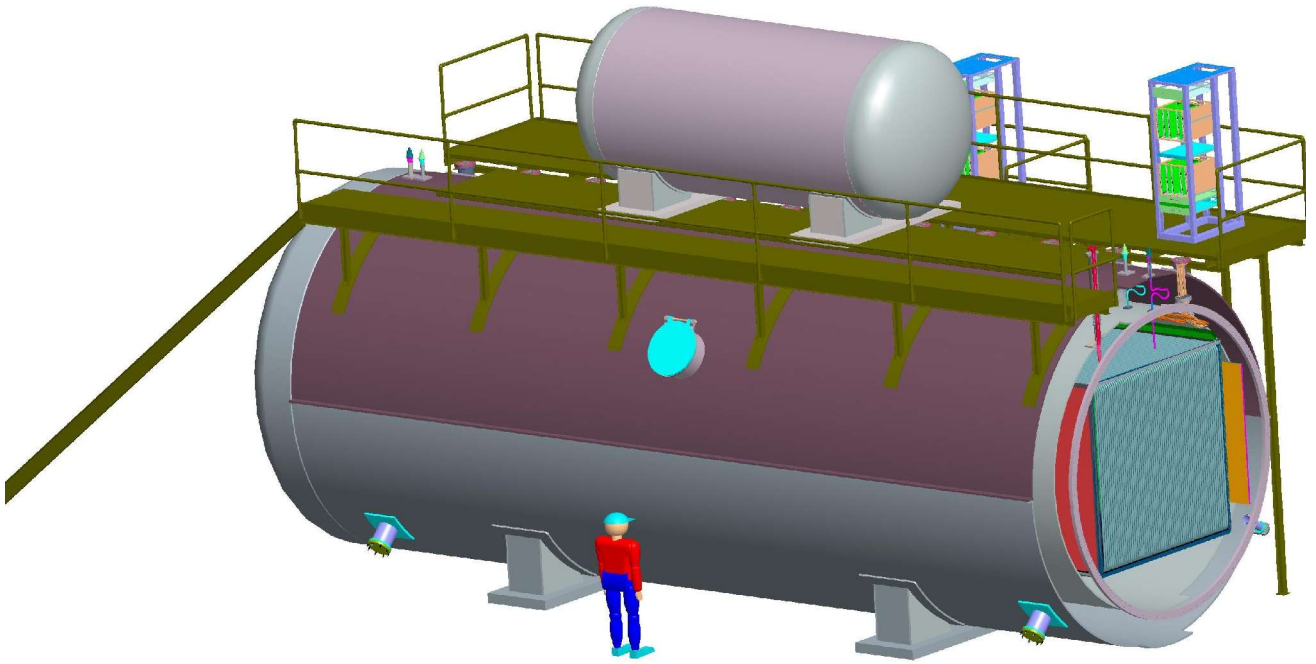
MicroBooNE: Full scale experiment physics results with a LArTPC detector

- Purity in a non-evacuated vessel
- Full systems test of low noise electronics
- Light Detection: data reduction, triggering
- Physics Development
  - See fully contained n interactions
  - Simulation, reconstruction, analysis
  - Study surface running issues (cosmics)
- TPC and Vessel Design
- Value engineering

- Low energy neutrino interactions
  - Resolve MiniBooNE low energy excess
  - Measure neutrino cross sections
  - Measure kinematics for PD signals

Collect:

- BNB: 100K ν events
- NuMI: 60K ν events



Received Stage 1 Approval in June

In design/prototyping stage

DOE/NSF project (NSF MRI this year)

DUSEL Baseline detector plan: 5+(25) ktons

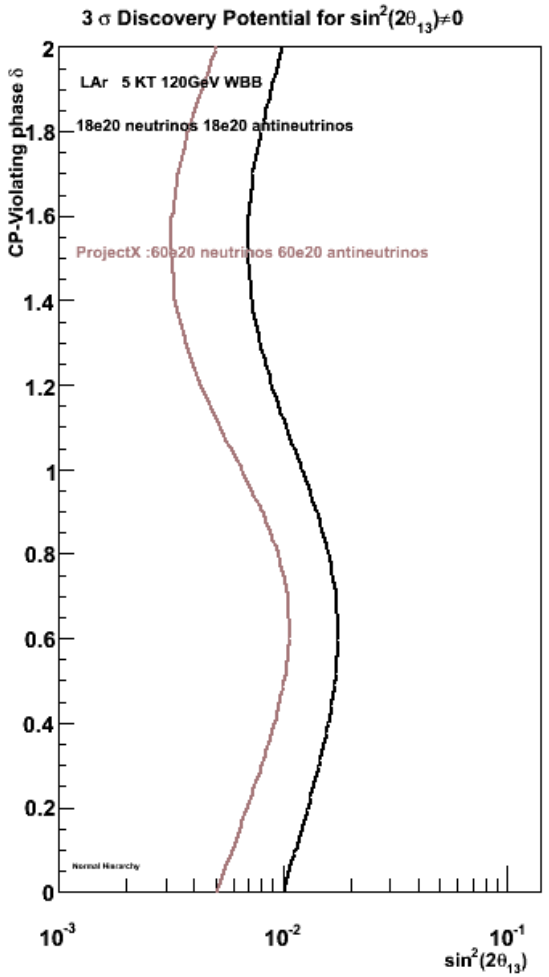
First step is 5 kton

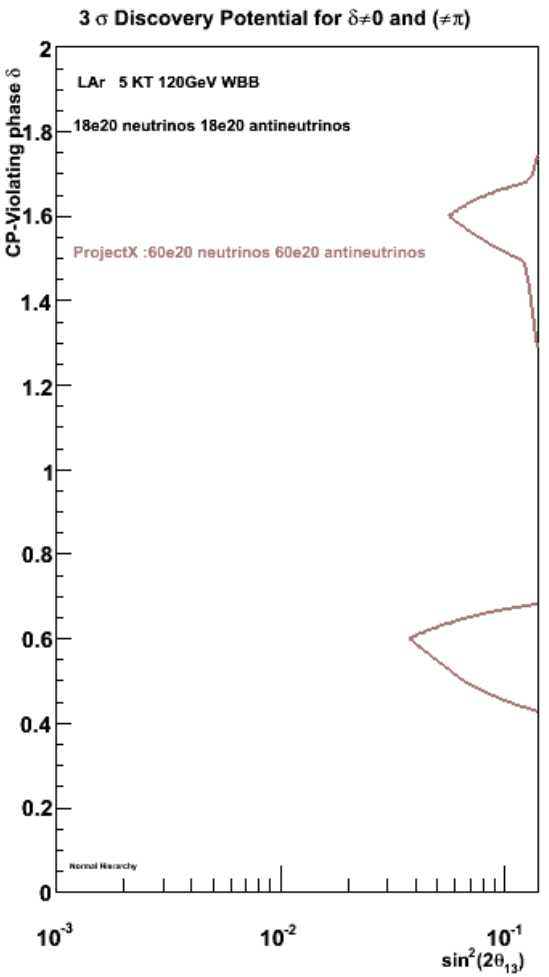
- good step in scale, cost, and physics

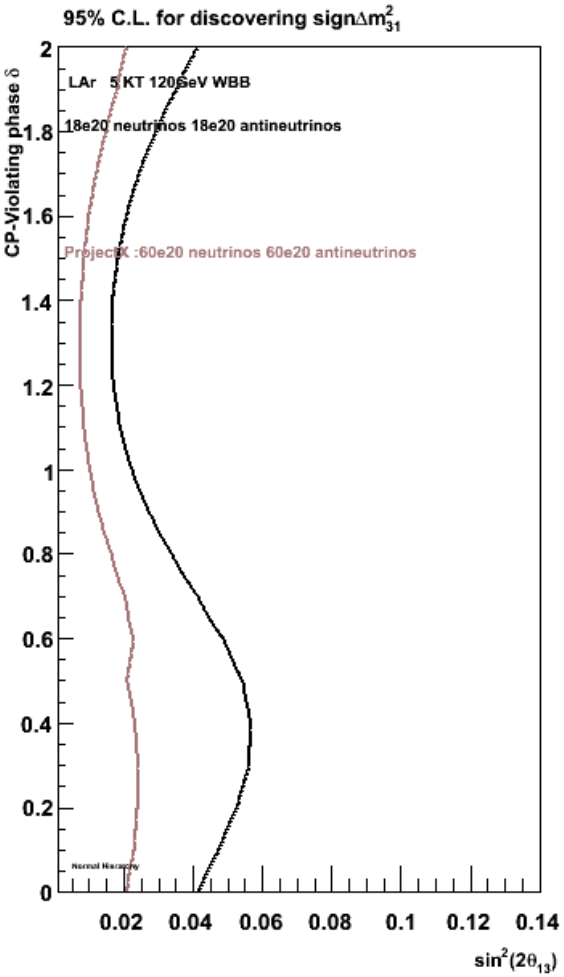
Next step is ~25ktons although design would be driven by what we learn in the next few steps: (ie: can we live without evacuatable vessels..)

Steps beyond this in ~30kton modules: Significant physics gain as you add more modules

Physics reach of 5ktons







N. Saoulidou

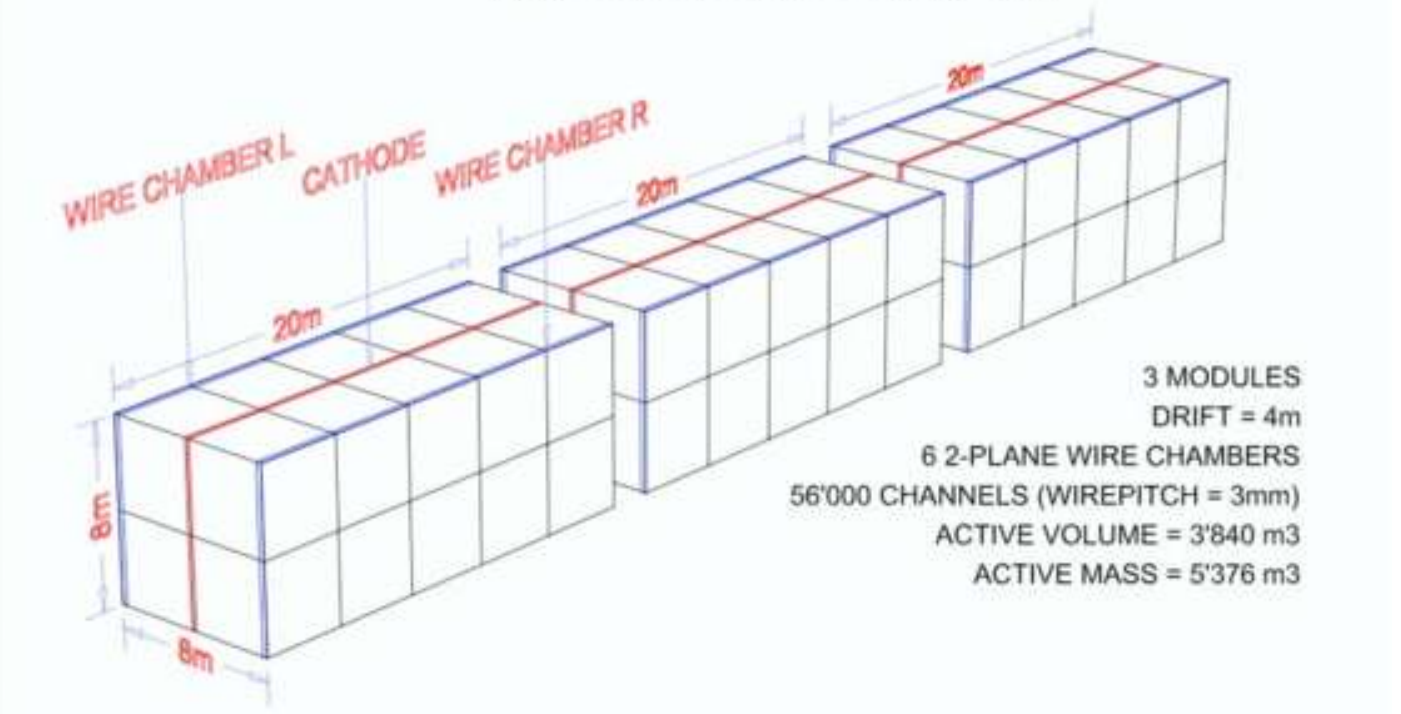
$p \rightarrow K^{+}\nu$



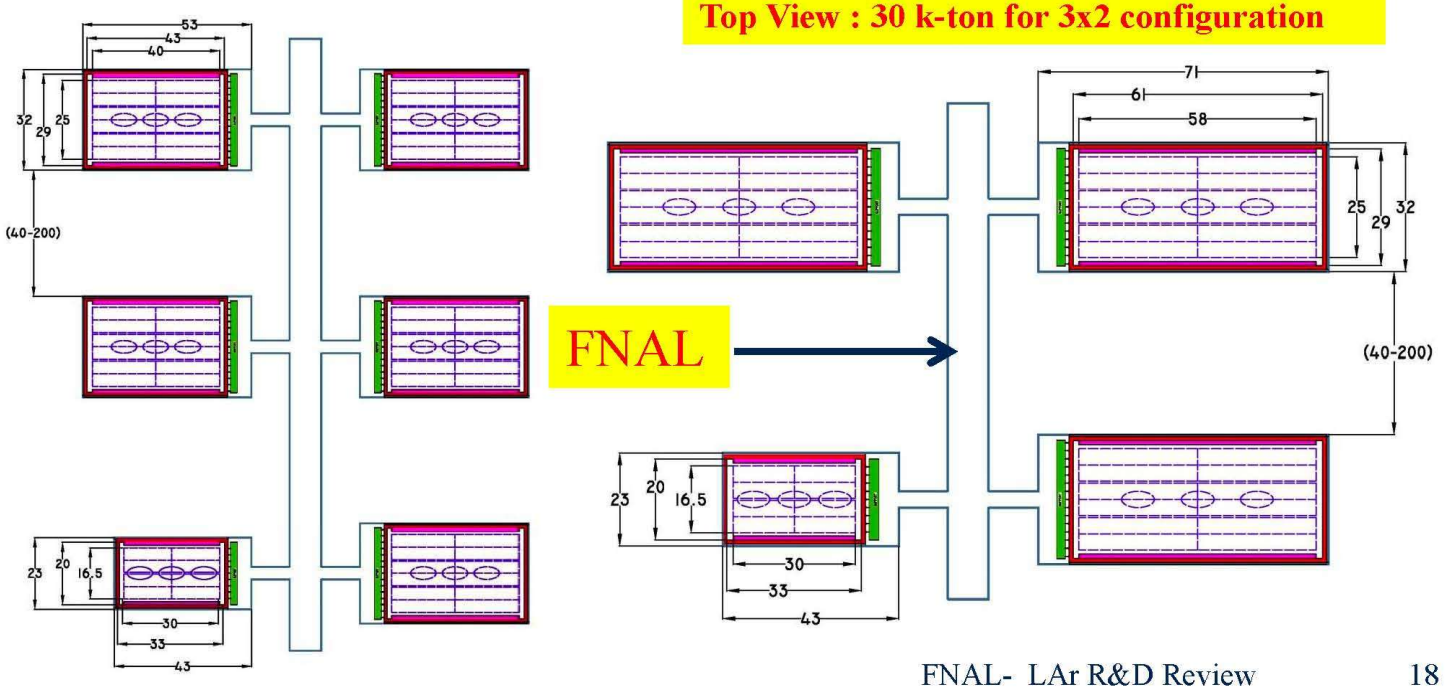
WC efficiency = 0.14
BG = 1.2 evts/100 kty
Nobs = Nbg

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

5kton LAAND Modular Concept (D. Cline, F. Sergiampietri)



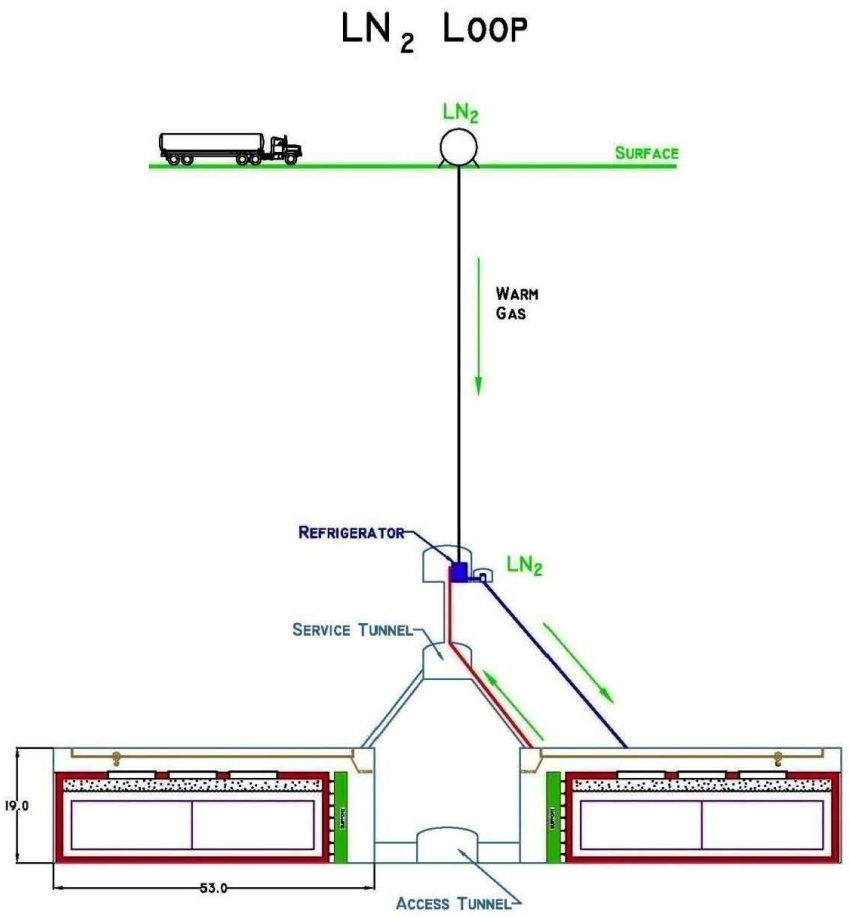
Top View : 30 k-ton for 3x2 configuration

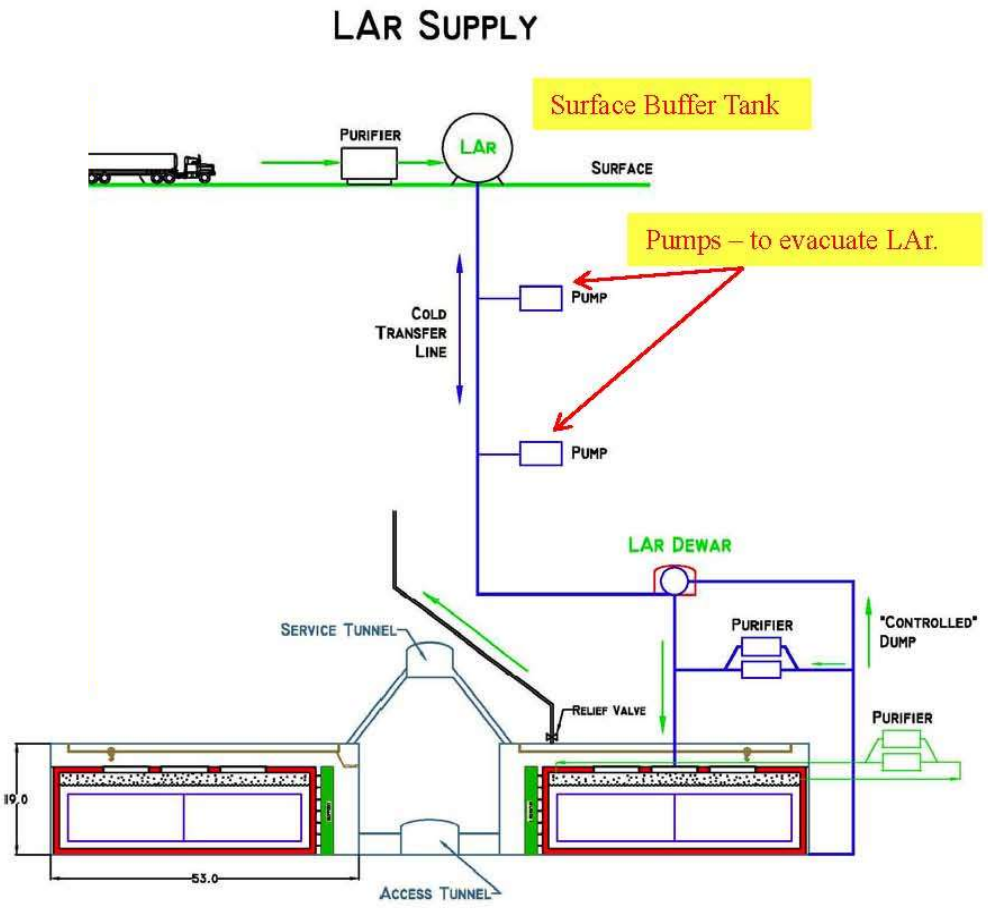


Microboone like concept: modularized detectors

5kton + larger modules in various possible configurations..

Initial Concepts for Cryogenics Underground





FNAL- LAr R&D Review

General underground siting issues:

LAr loss: 0_2 content, reduction of temperature

Mitigation:

- Design: Use best cryo-techniques to minimize leaks
- Egress/Shelter: In cavern and from cavern

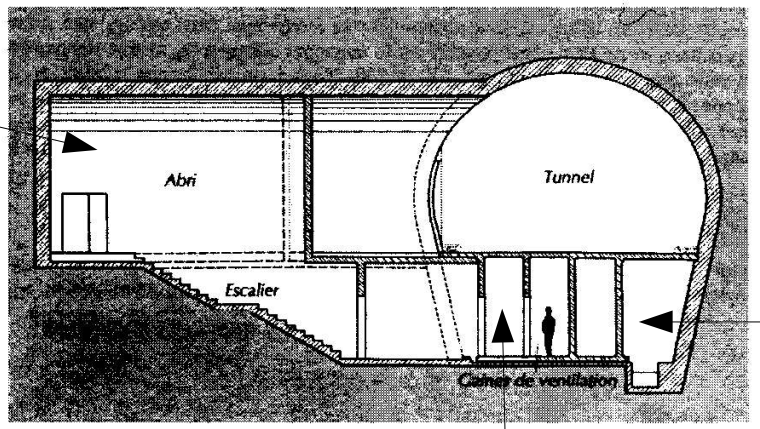


Experience from LNGS industry on bulk transport and storage

Mont-Blanc Safety upgrade

Refuge Shelter with fresh air

Ventilation ducts



Smoke extraction

- Ventilation: Dedicated exhaust shaft
- Freeze/thaw damage: placement and insulation

Conclusions

LarTPCs are an exciting “new” technology to couple with world class neutrino program at DUSEL

Path towards large detectors is underway with significant progress recently but much more to do...

Interest in LAr at DUSEL is continuing to grow

Next steps – S4 proposal and development of baseline detector plan for CD-1