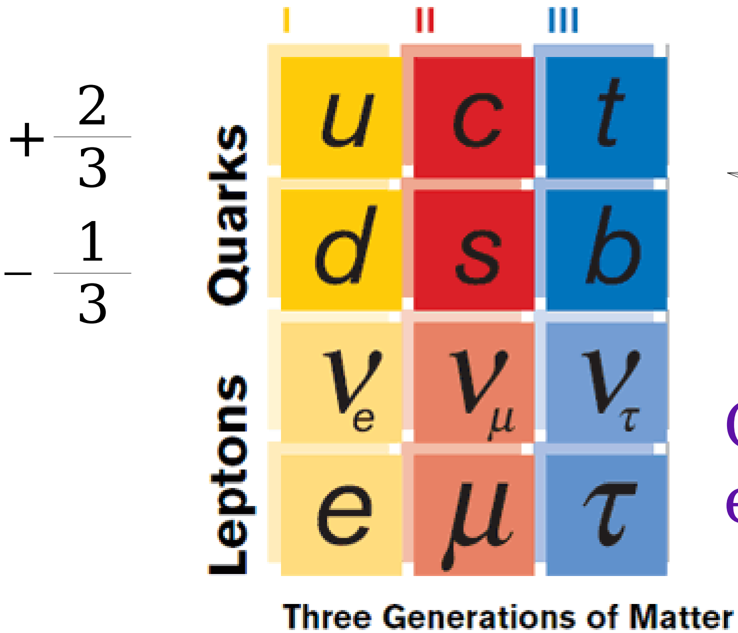
B.T.Fleming
LBL Seminar
March 17, 2009

The US Liquid Argon Time Projection Chamber program: Leading to DUSEL

- Exciting time in Neutrino Physics
- Liquid Argon TPCs for Long Baseline νs
- R&D program to get there!

The Standard Model



Quarks interact electromagnetically, strongly, weakly

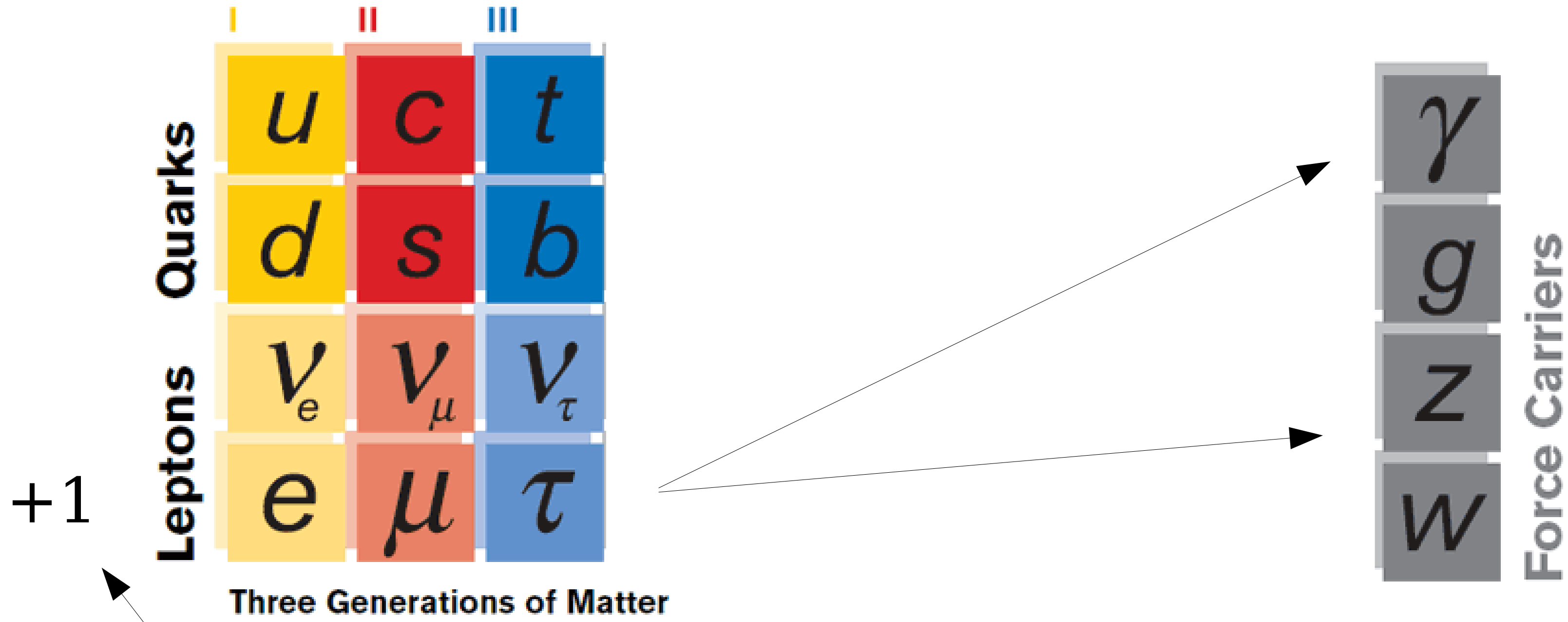
Quark masses range from ~1 MeV to 170 GeV

Quarks mix between their flavors

The CKM Matrix

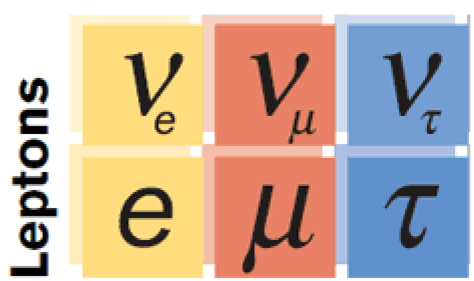
$$\begin{bmatrix} d' \\ s' \\ b' \end{bmatrix} = \begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix} \begin{bmatrix} d \\ s \\ b \end{bmatrix}$$

The Standard Model



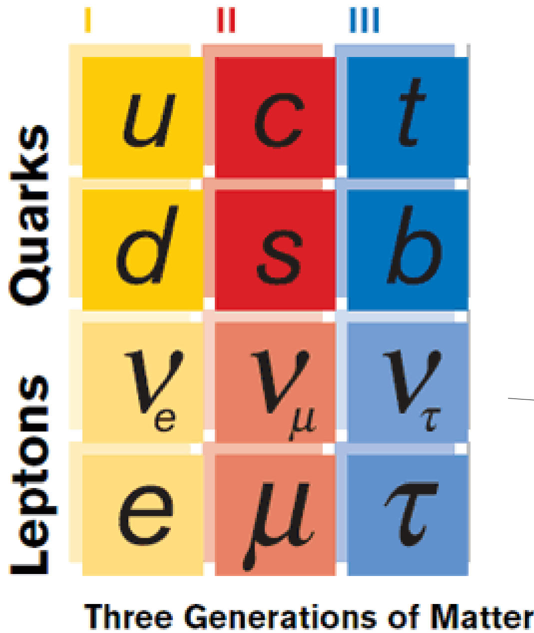
Charged leptons interact electromagnetically and weakly

Charged leptons range in mass from 0.5 MeV to 1.7 GeV



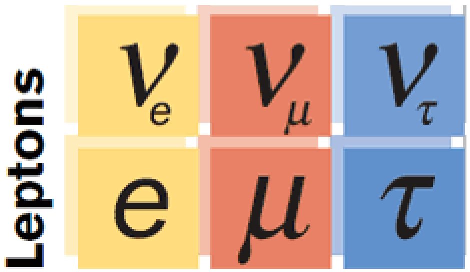
paired in doublets with neutrinos

Neutrinos in the Standard Model



Weakly
interacting
only

By comparison, we know relatively little about the neutrinos....



paired in doublets
with electrons
no charge
Only recently
– ***they have mass!***

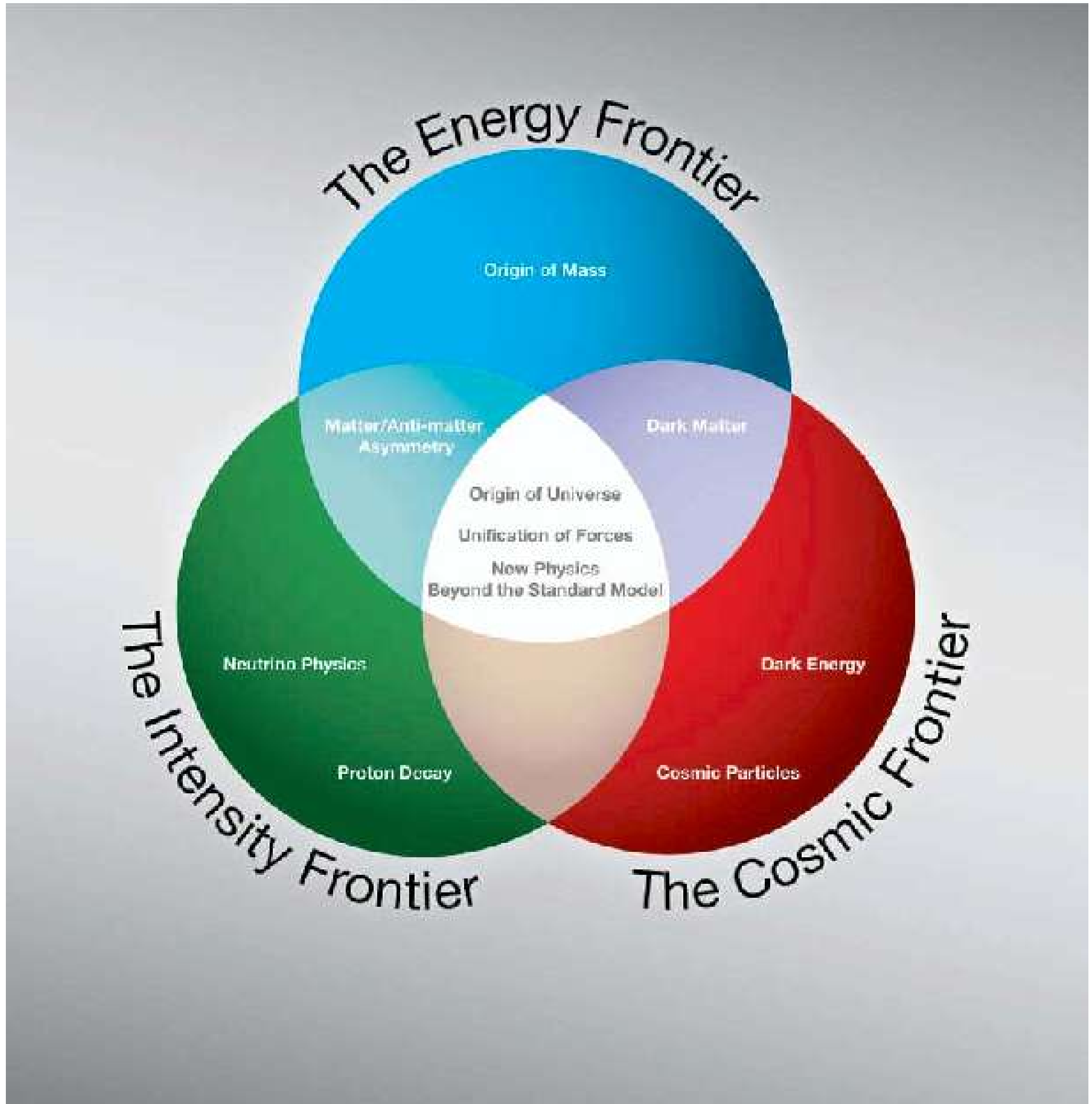
Addressing the question of neutrino mass has opened up new questions in neutrino physics at the forefront of particle physics today

The Neutrino Matrix
The APS Neutrino Study, 2004:

- Neutrinos and the New Paradigm
- Neutrinos and the Unexpected
- Neutrinos and the Cosmos

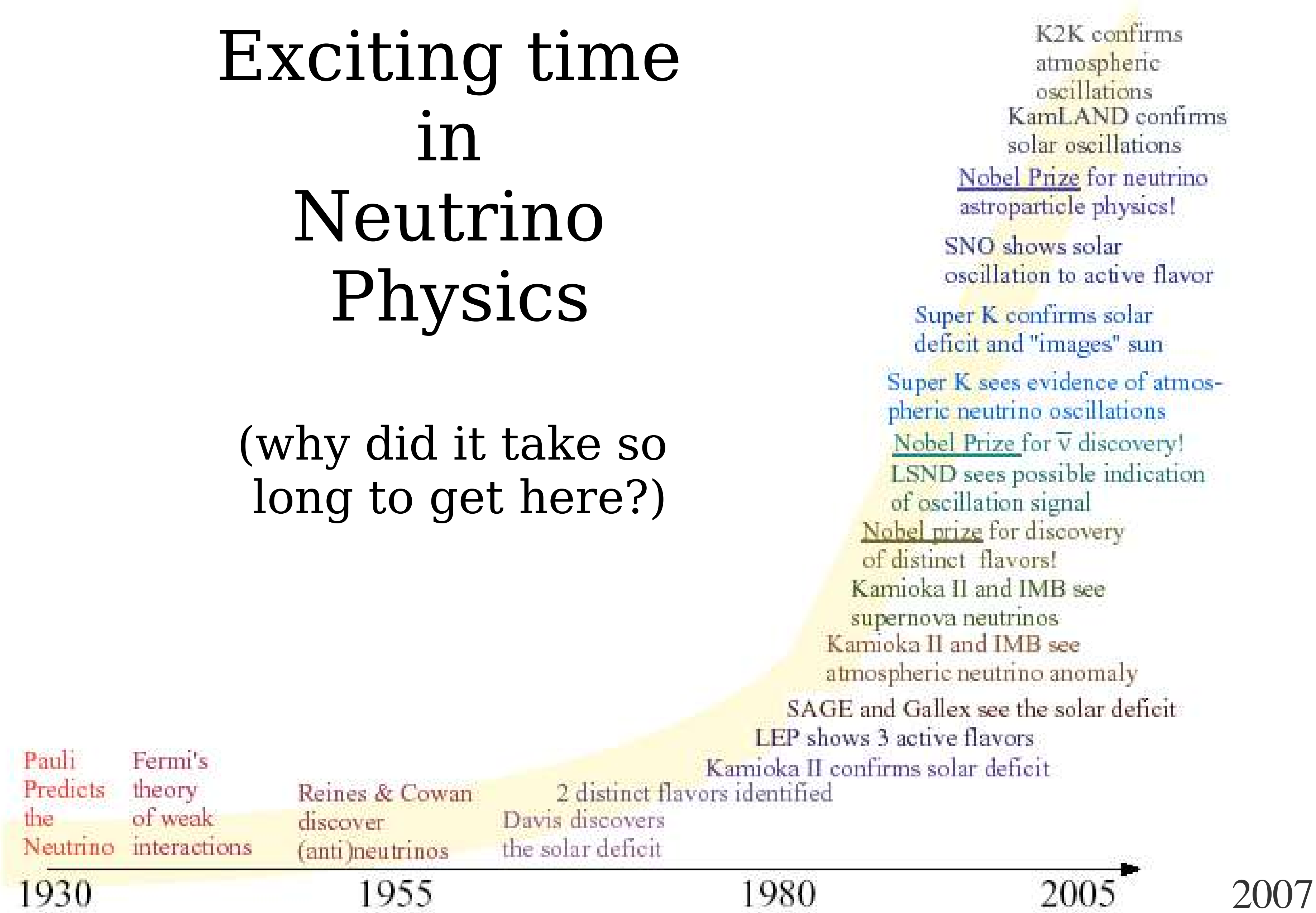
Exciting time in neutrino physics… ~5 years later the particle physics community is poised to develop experiments to address these goals!

Recommendations from the Report of the P5 Panel for particle physics, May 29, 2008

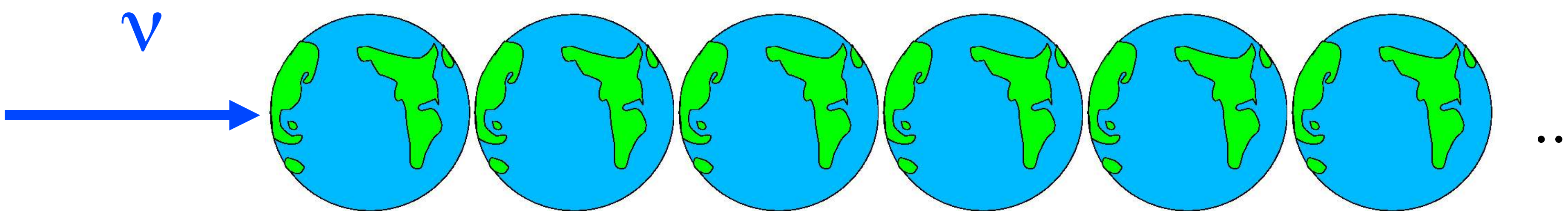


Exciting time in Neutrino Physics

(why did it take so long to get here?)



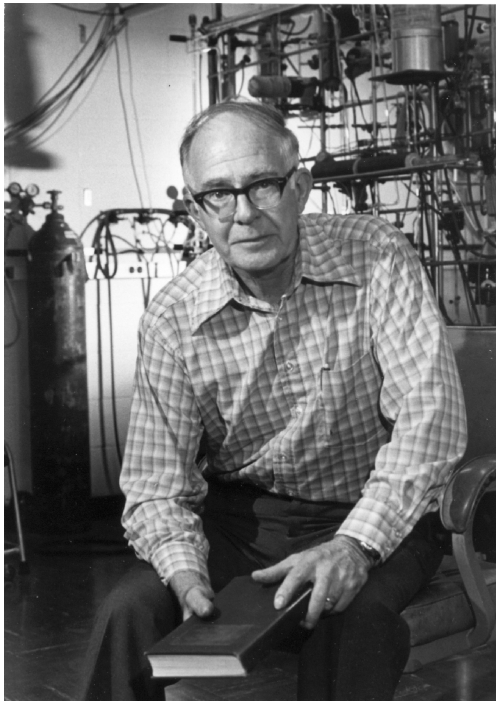
the weak force is weak!
neutrinos interact
100,000,000,000
times less often than quarks



A neutrino has a good chance of traveling through
200 earths before interacting at all

2002 Nobel prize in physics:

"for pioneering contributions to astrophysics,
in particular for the detection of cosmic neutrinos"

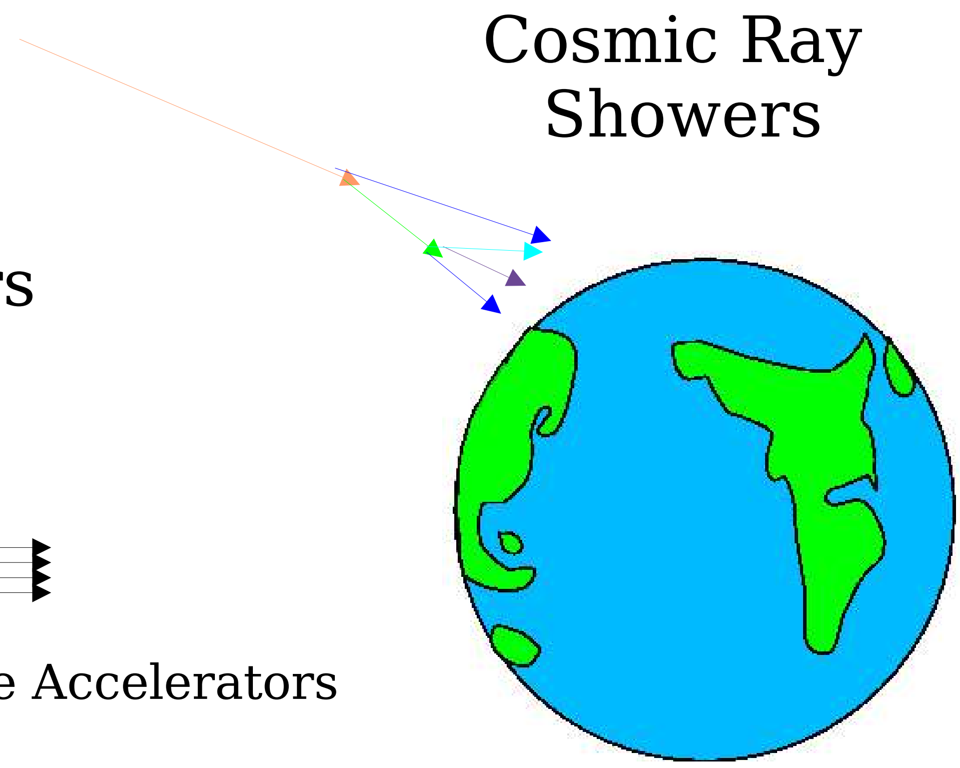


Ray Davis:
Homestake
Experiment

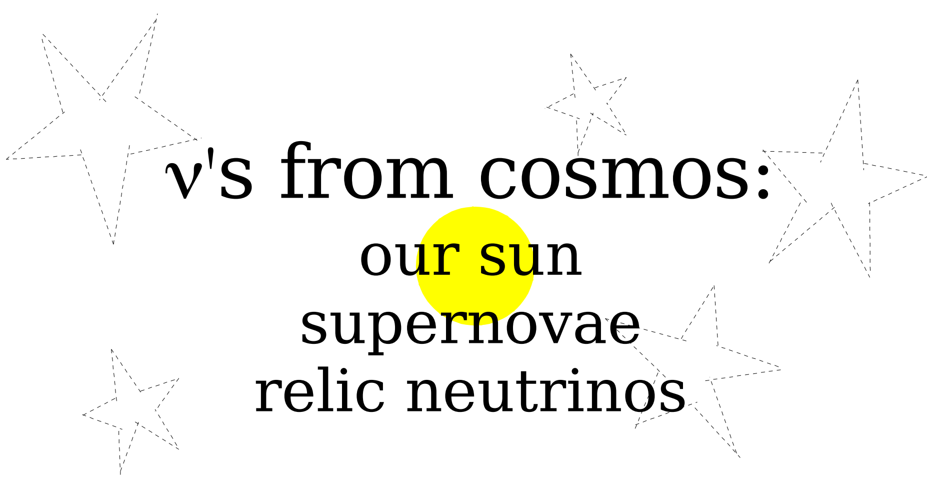
Masatoshi Koshiba:
Kamioka Observatory

To see neutrino interactions, you need:

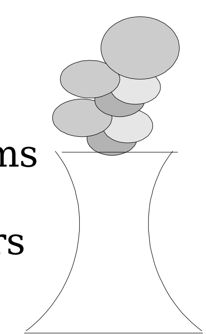
1) **lots of neutrinos**
2) lots of detector
3) fine-grained
   or specialized detectors
4) some combination
   of the above



Neutrino Beams made from Particle Accelerators



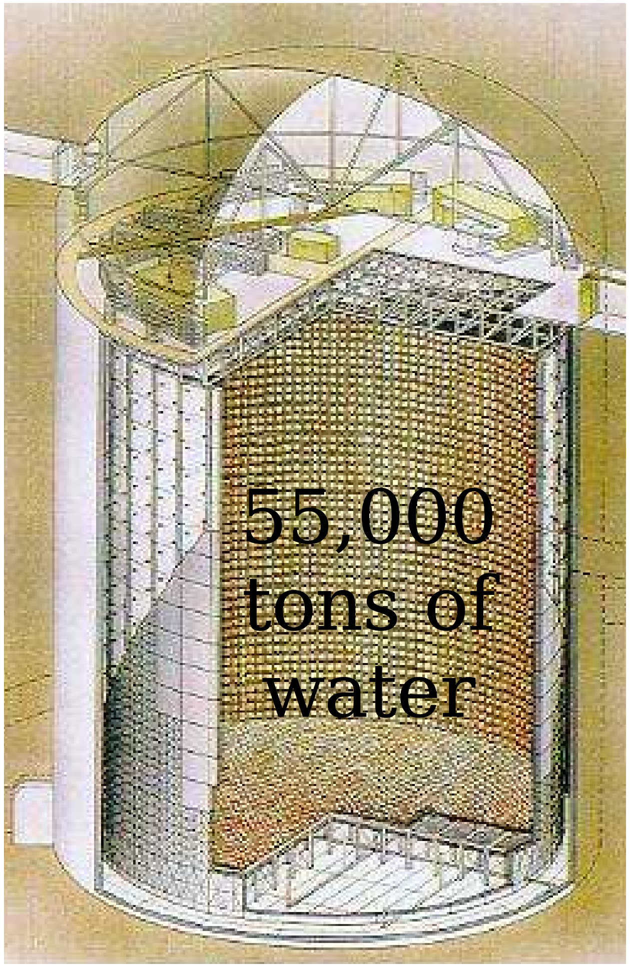
Neutrino Beams
made
from Reactors



To see neutrino interactions, you need:

1) lots of neutrinos
2) **lots of detector**
3) fine-grained
   or specialized detectors
4) some combination
   of the above

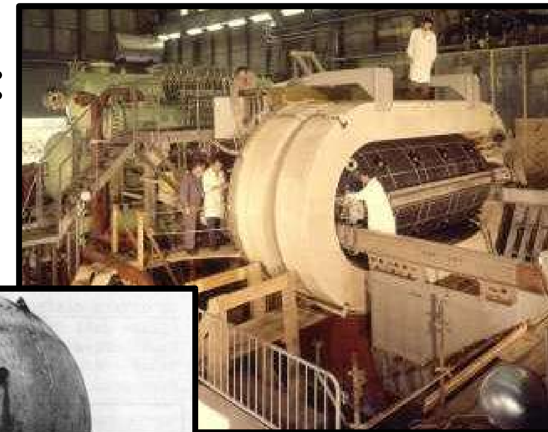
Super-K

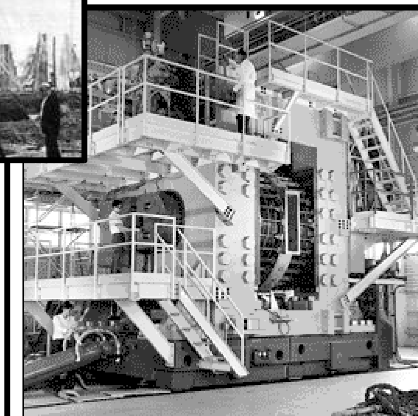


MINOS far detector
5.4 ktons of steel to STOP
neutrinos

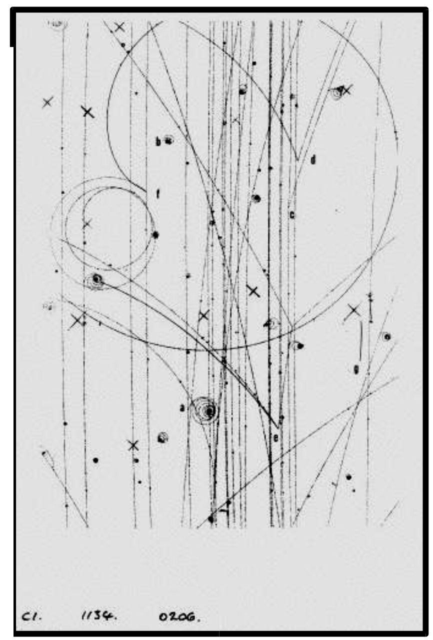
To see neutrino interactions, you need:

1) lots of neutrinos
2) lots of detector
3) **fine-grained**
   or specialized detectors
4) some combination
   of the above

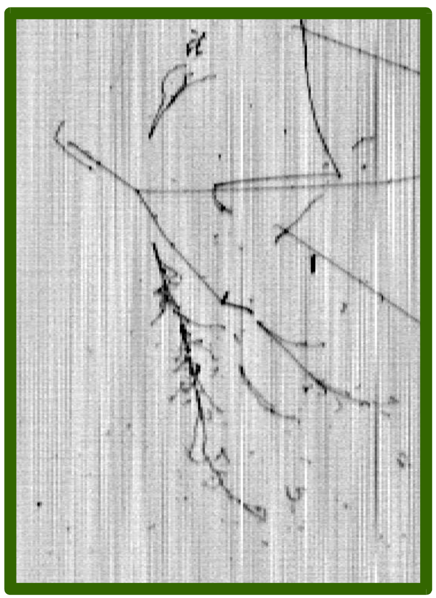


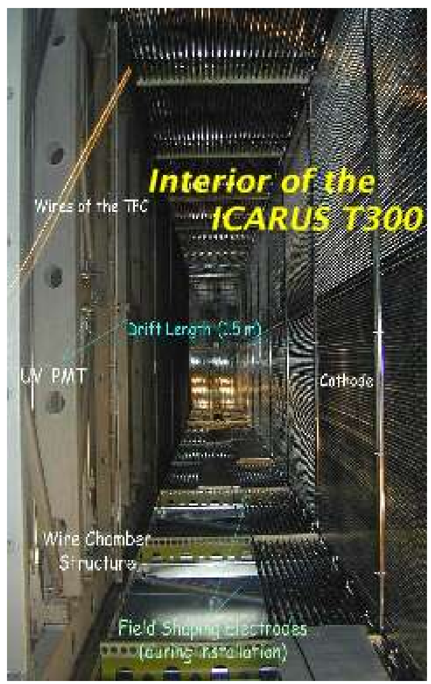


The 80-inch Bubble Chamber



Bubble chambers: limited size....

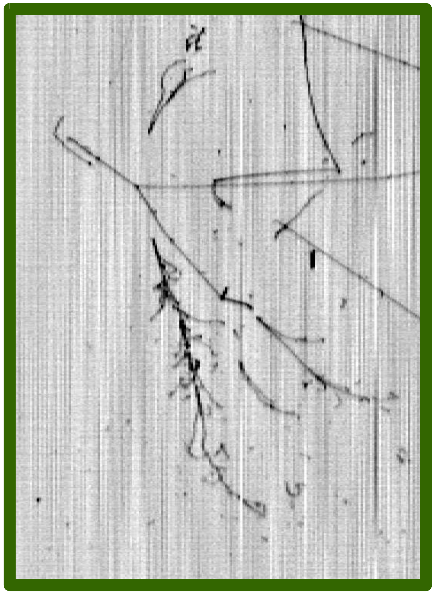




Liquid Argon
time projection chambers

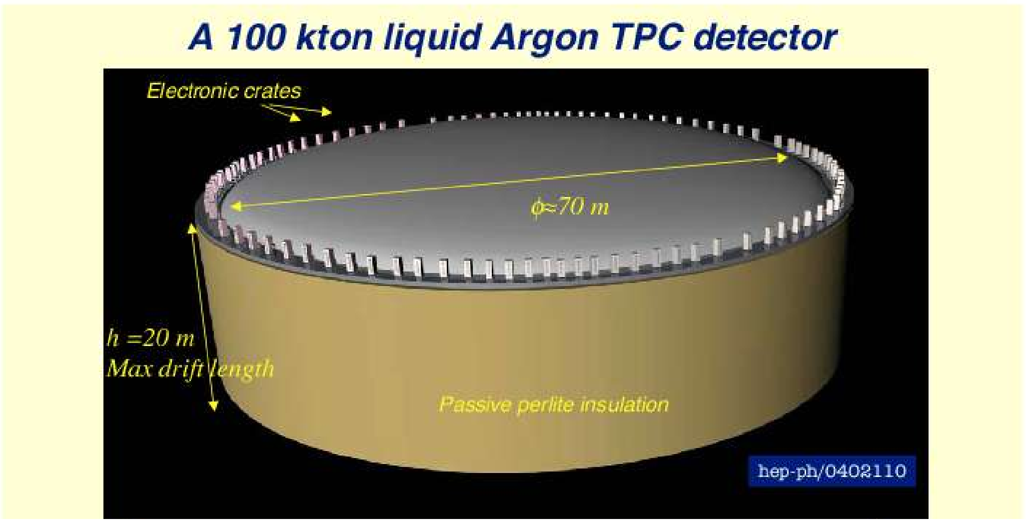
To see neutrino interactions, you need:

1) lots of neutrinos
2) lots of detector
3) **fine-grained**
   or specialized detectors
4) some combination
   of the above

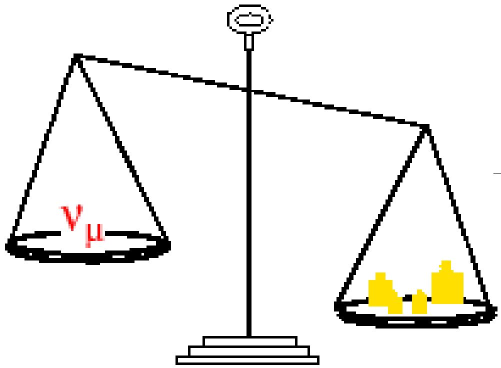


Liquid Argon
time projection chambers

Very intense
neutrino beam



Very massive, fine-grained detector!



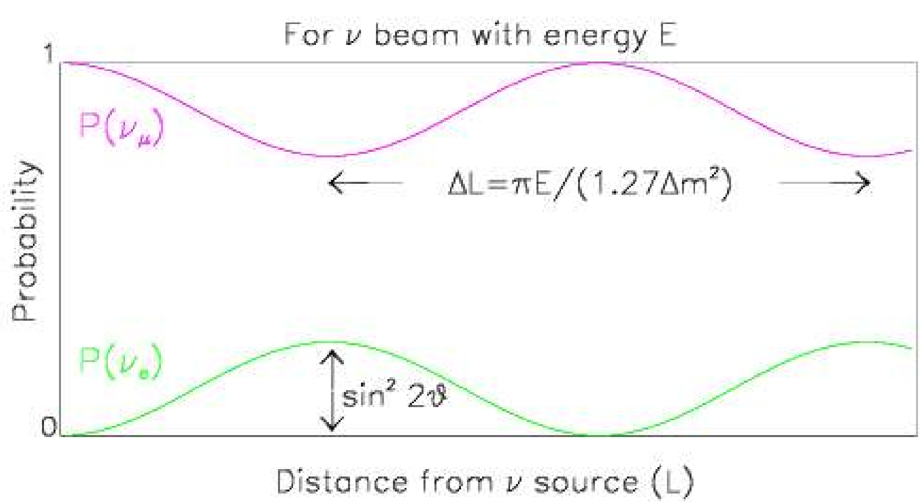
→ Does not yet work to measure mass in the usual way….. neutrinos are too small!

What other behavior is associated with mass?
A quantum mechanical effect called
Neutrino Oscillations

$\nu_\mu \longrightarrow \nu_e$

The Probability for Oscillations...

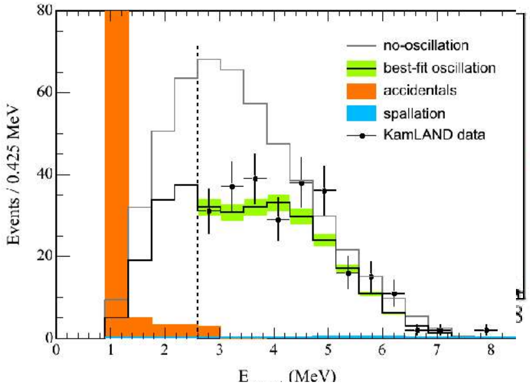
$$P_{osc} = \sin^2 2\theta \sin^2(1.27 \Delta m^2 L/E)$$



ν_μ disappearance

ν_e appearance

Oscillation Landscape

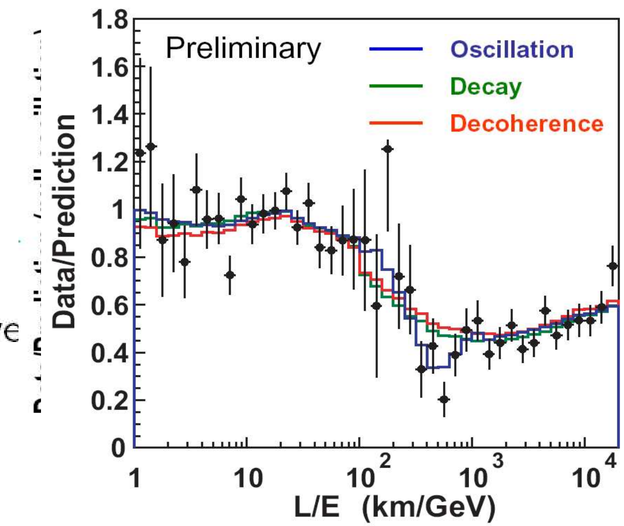


Solar Neutrino Oscillations

- Deficit of ν_e observed from Sun
  Cl (Homestake), H_2O ((Super-)K), Ga (GALLEX, SAGE)
- Confirmation at SNO and KamLAND (reactor $\bar{\nu}_e$)

Atmospheric Neutrino Oscillations

- Zenith angle-dependent deficit of ν_μ:
  Kamioka, Super-Kamiokande, Soudan, MACRO
- Confirmed by accelerator exp K2K; MINOS will be definitive



The CP Violation Parameter

Three Neutrino Mixing Matrix:

$$U = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{pmatrix}$$

$$= \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

From Atmospheric and Long Baseline Disappearance Measurements

From Reactor Disappearance Measurements

From Long Baseline Appearance Measurements

From Solar Neutrino Measurements

Chooz limit is
$\sin^2 2\theta_{13} \sim 0.1$

The CP Violation Parameter

Three Neutrino Mixing Matrix:

$$U = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{pmatrix}$$

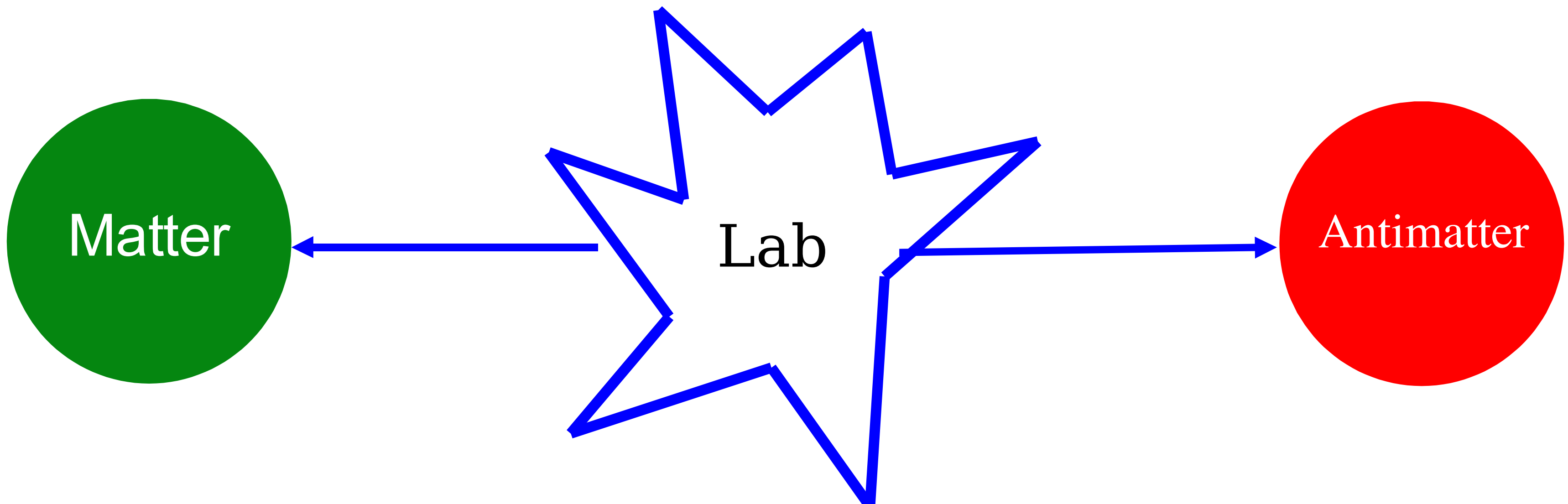
$$= \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

From Long Baseline Appearance Measurements

Goal is to be sensitive to

- Final unknown mixing angle, θ_{13}
- the CP violating phase, δ
- the effects of matter on the different neutrino species

In the laboratory, when we produce matter, we can do so only by producing an equal amount of anti-matter



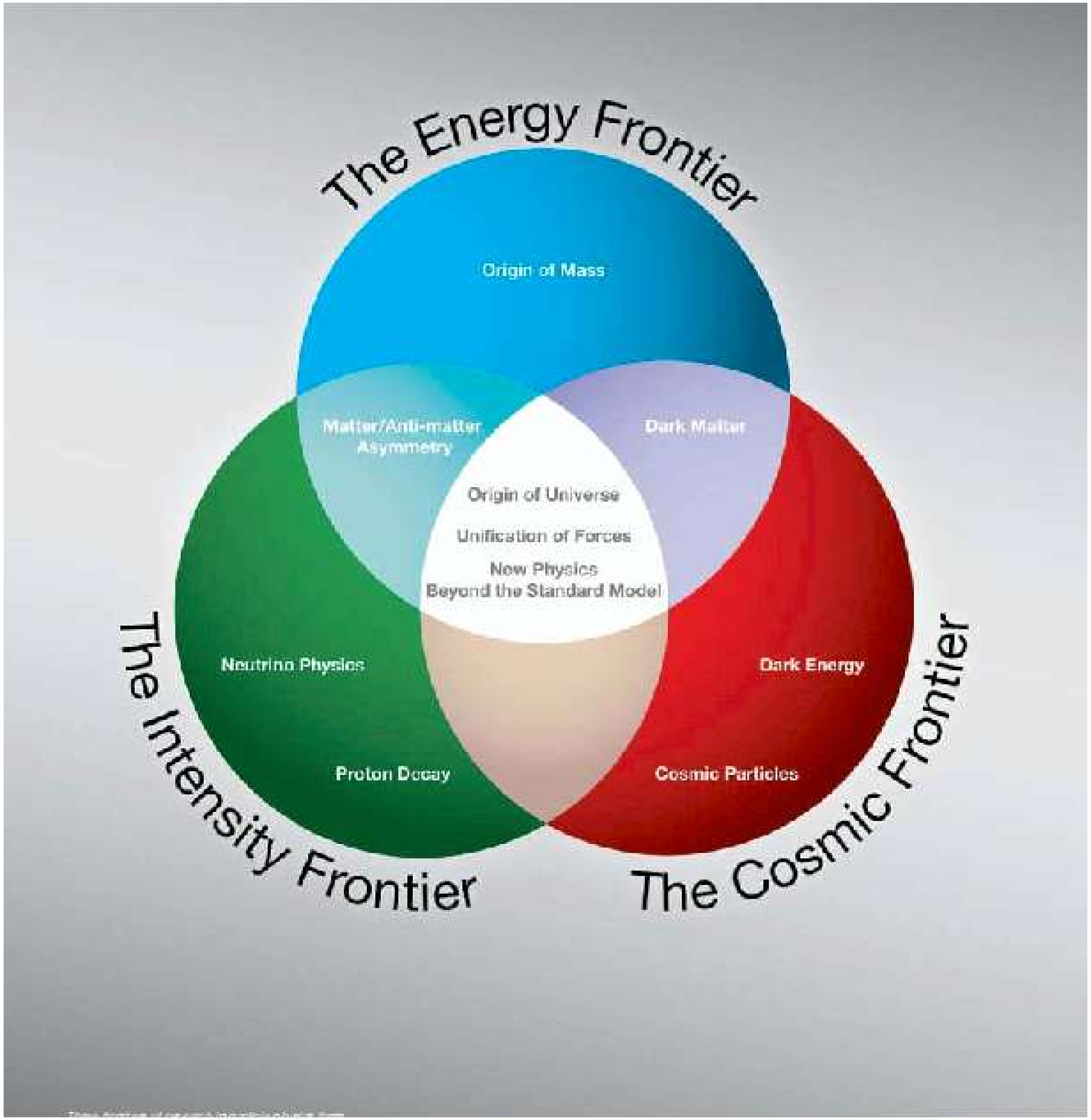
In the universe we observe more matter than anti-matter (thankfully!)

What asymmetry in the Early Universe could have given rise to this?

Not enough of an asymmetry (CP Violation) between QUARKS and ANTI-QUARKS

Could this asymmetry have arisen from the neutrino sector?
(Are Neutrinos the Reason We Exist?)

Recommendations from the Report of the P5 Panel for particle physics, May 29, 2008



Recommendations from the Report of the P5 Panel to HEPAP, May 29, 2008

At the Intensity Frontier:

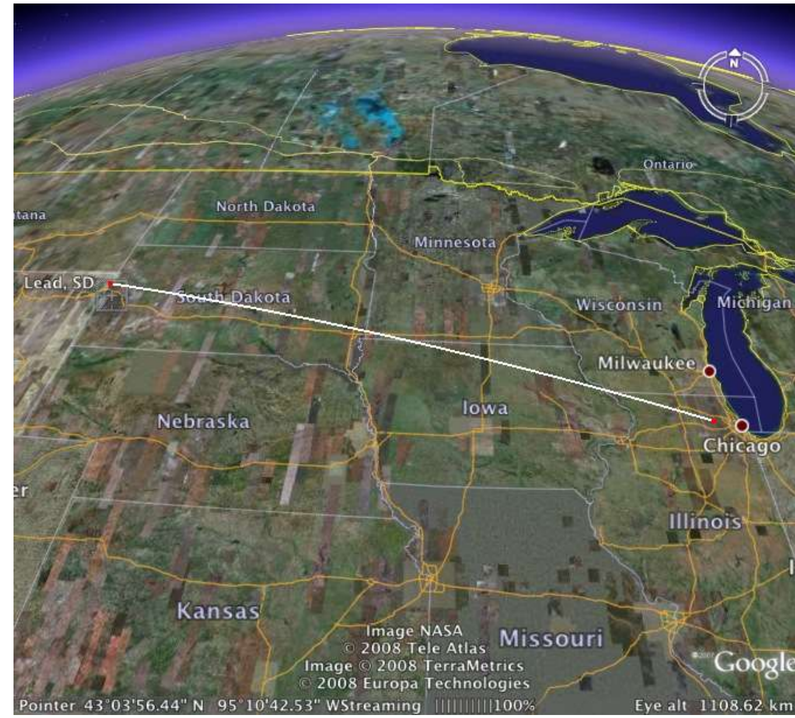
The panel recommends a world-class neutrino program as a core component of the US program, with the long-term vision of a large detector in the proposed DUSEL laboratory and a high-intensity neutrino source at Fermilab

Long Baseline Neutrino Oscillation Physics: CP Violation in the neutrino sector
Neutrinos and the New Paradigm

The panel recommends proceeding now with an R&D program to design a multi-megawatt proton source at Fermilab and a neutrino beamline to DUSEL and recommends carrying out R&D in the technology for a large detector at DUSEL.

The panel recommends support for a vigorous R&D program on liquid argon detectors and water Cerenkov detectors in any funding scenario considered by the panel. The panel recommends designing the detector in a fashion that allows an evolving capability to measure neutrino oscillations and to search for proton decays and supernovae neutrinos.

Long baseline neutrino program:
Shoot Intense neutrino and anti-neutrino beams from Fermi National Accelerator Laboratory
to a
Deep Underground Science and Engineering Laboratory.
DUSEL in Lead, SD



L = 1300 km (more matter effect in the oscillations)

Oscillation maximum at higher energies

Broad band beam can cover

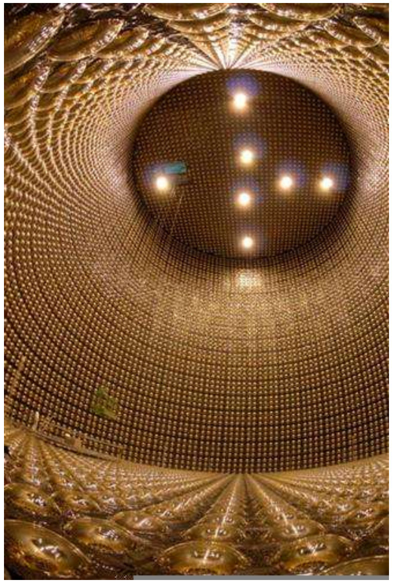
1st and 2nd maximum

Look for CP Violation in the Neutrino Sector

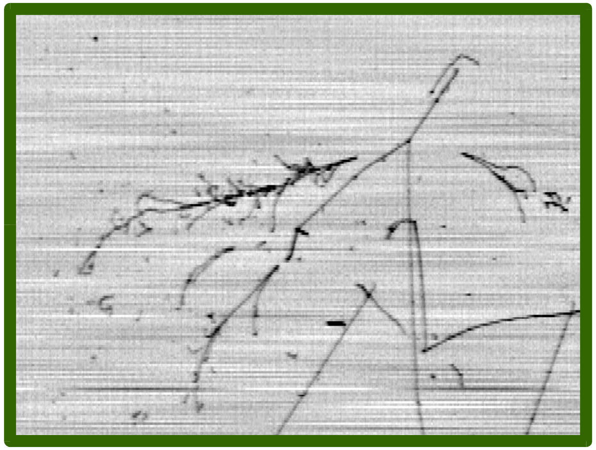
Massive detectors for long baseline program

Options under consideration:
50-100 kt LAr, 300 kton WC,
or some combination of the two technologies

Water Cerenkov
Imaging detectors



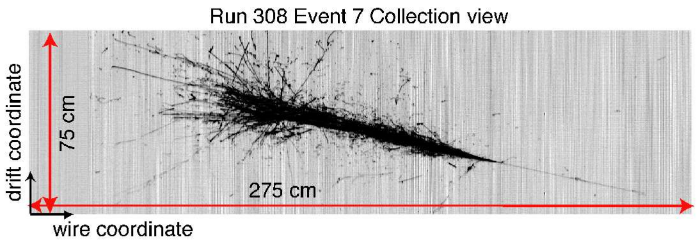
Liquid Argon TPCs



Siting deep underground shields the experiments from cosmic ray showers

Why consider Liquid Argon TPCs.....

Liquid Argon TPC detectors for neutrino physics and nucleon decay

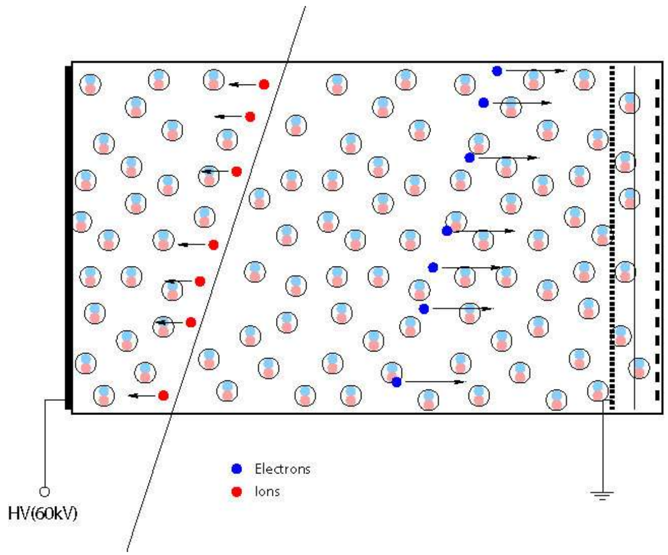


Unique Detectors
⇒ precision measurements in neutrino physics
⇒ appear scalable to large volumes

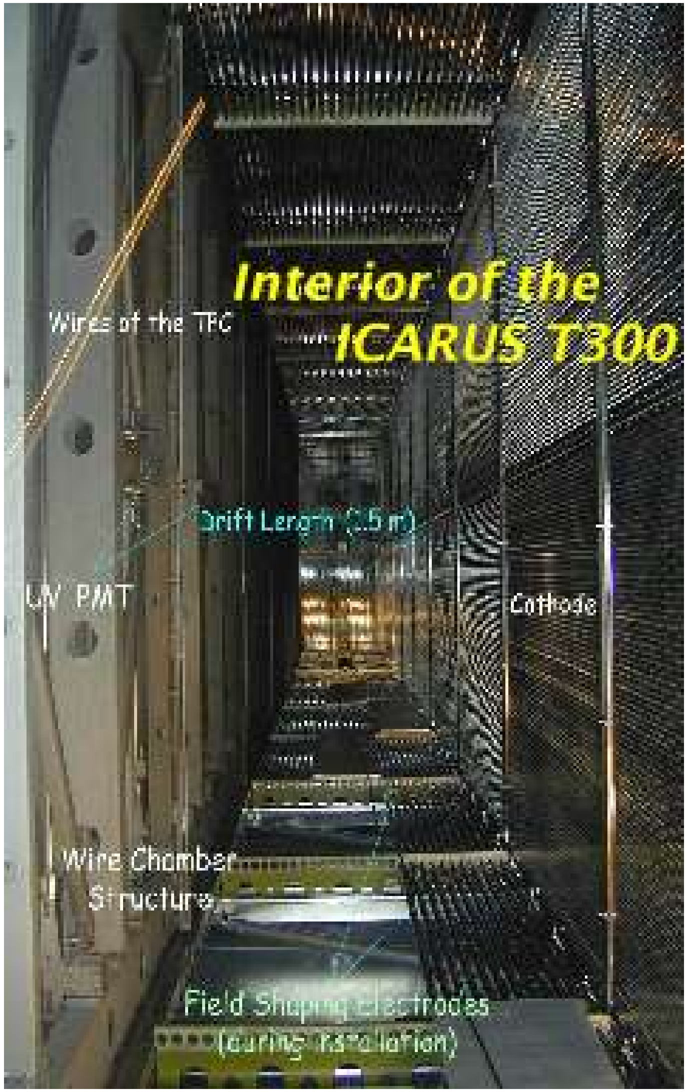
- Neutrino oscillation physics: significantly more sensitive than WC detectors.
  (~6 times more sensitive than WC technology
  translates into smaller volumes for same physics reach)
  background reduction in ν_e is difficult. Need powerful LAr detectors.....
- Proton decay searches
  - sensitive to $p \rightarrow \nu\, k$
  - Extend sensitivity beyond SK limits with detectors 5kton and larger
- Supernova and solar neutrinos

Liquid Argon TPCs:

passing charged particles
ionize Argon:
55,000 electrons/cm

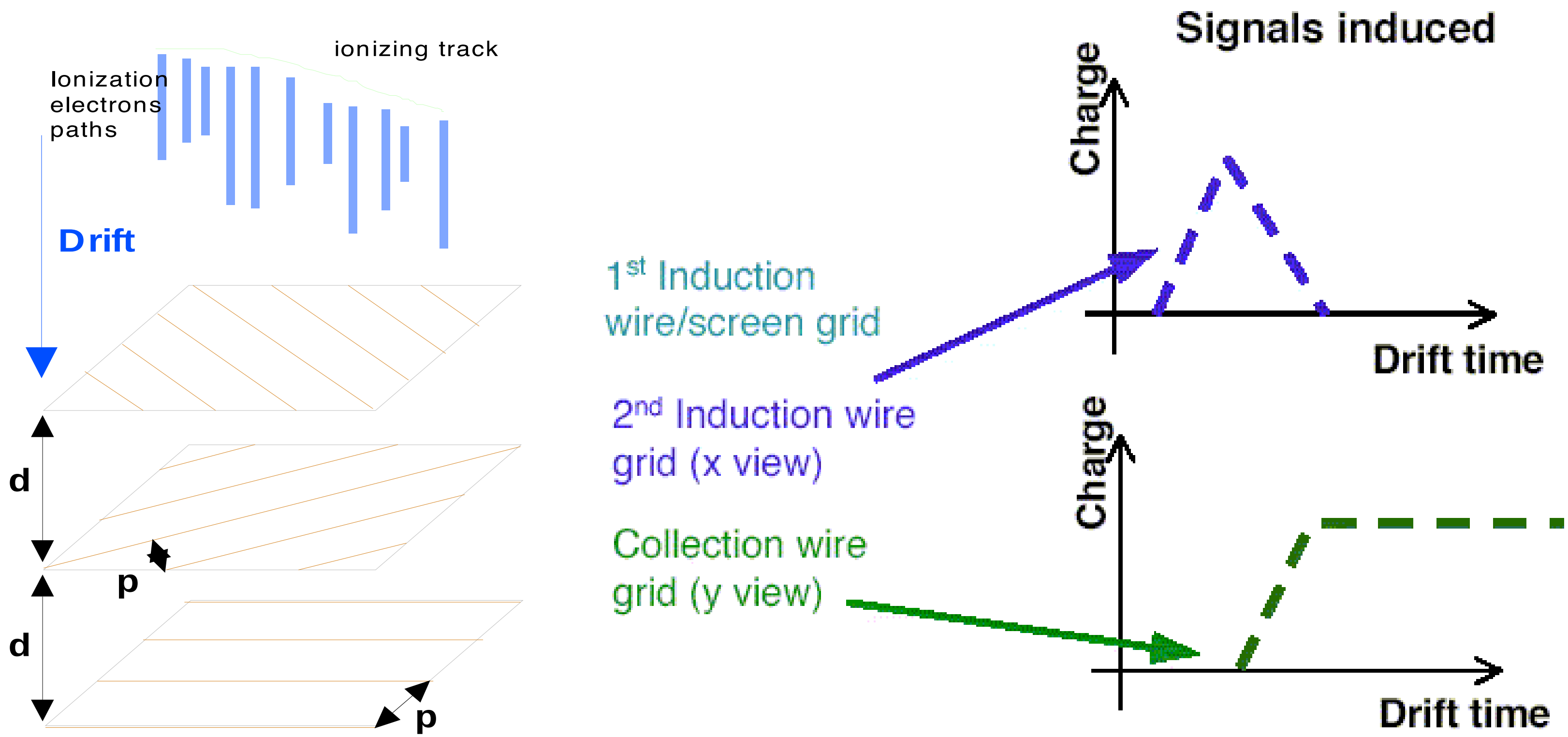


Drift ionization electrons
over meters of pure
liquid argon to readout
planes to image track



Detector technology pioneered by the
ICARUS experiment over last 25 years

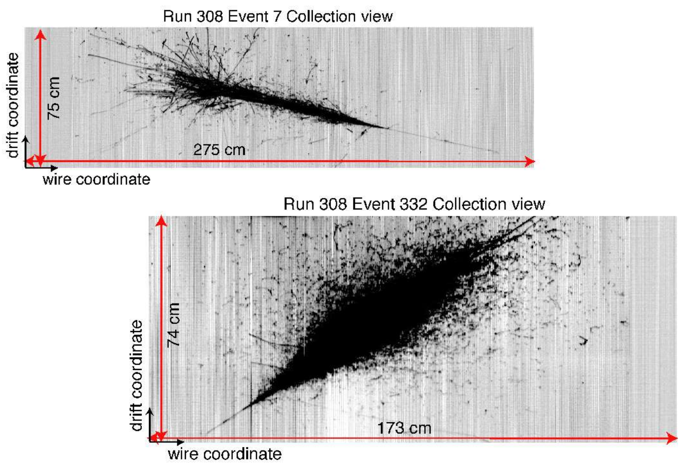
Liquid Argon TPC Readout

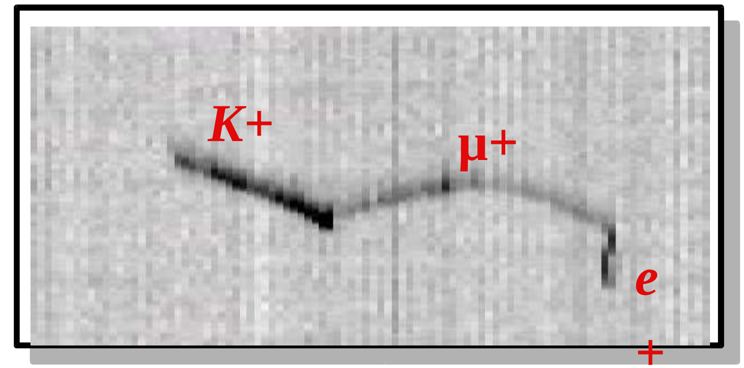


Combination of induction and collection planes both image the event and record energy deposited (dE/dx)

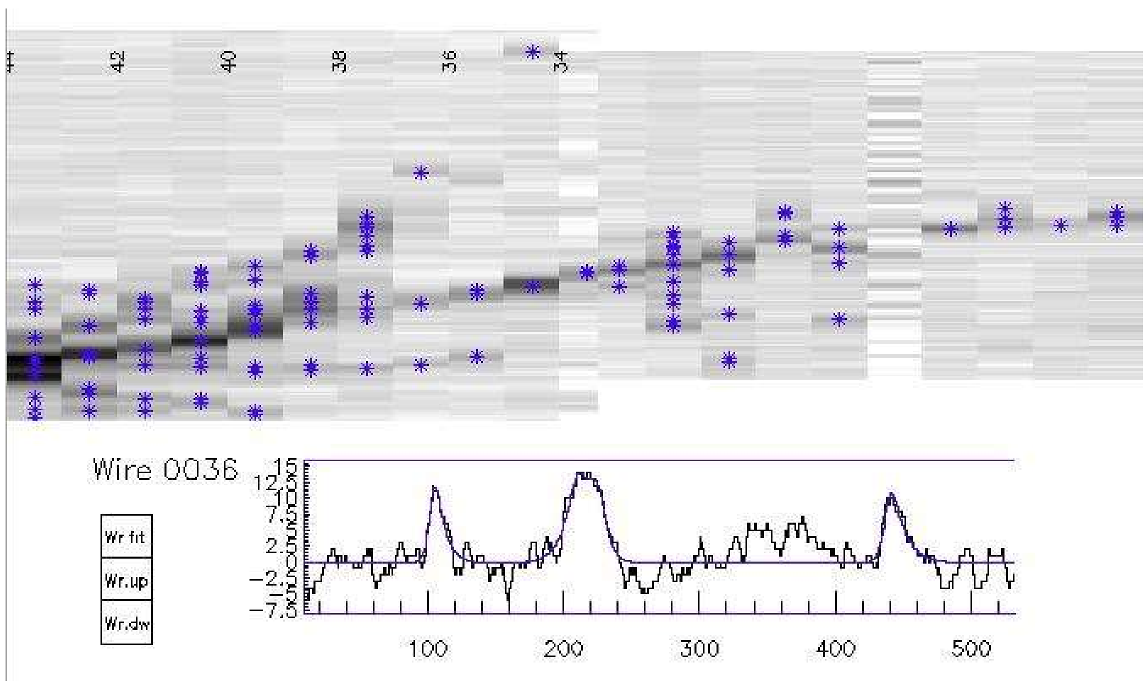
No amplification of signals in the Liquid Argon
- need low noise electronics to achieve good signal to noise

Particles in LArTPCs





T300 data from ICARUS test run 2001



Hadronic shower from Yale TPC run, April 2007

Achieve 80-90% efficiency for electron neutrino interactions

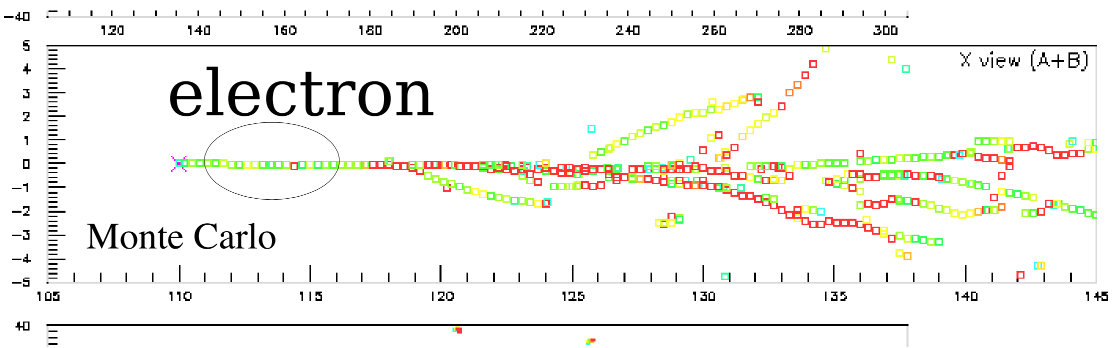
→ *Use topology to differentiate event classes*

LArTPCs image events *and collect charge*

Separates electrons from backgrounds with γs

→ do e/γ separation via dE/dx

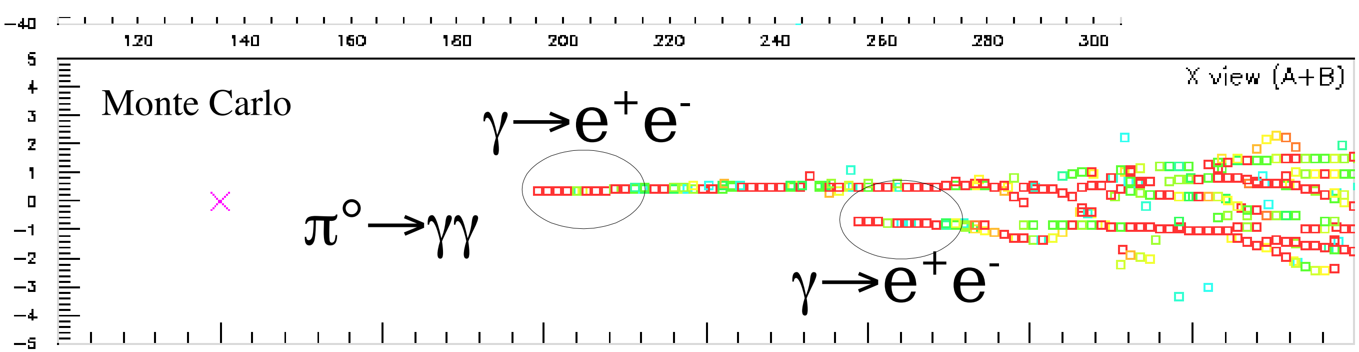
look in first couple cm of track before shower begins



Where electrons deposit

1 MIP = green

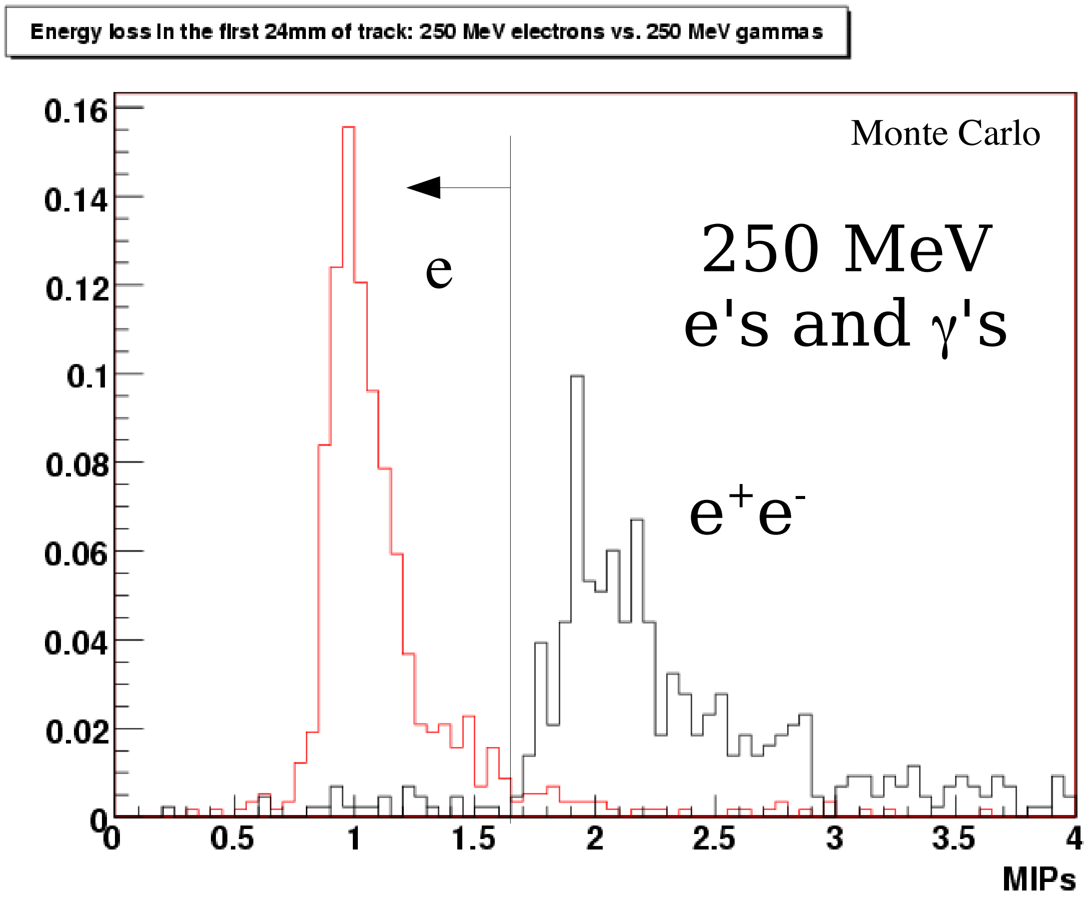
(MIP = minimum ionizing particle)



$\gamma \rightarrow e^+e^-$ deposit

2 MIPs = red

GEANT4 Monte Carlo Simulation



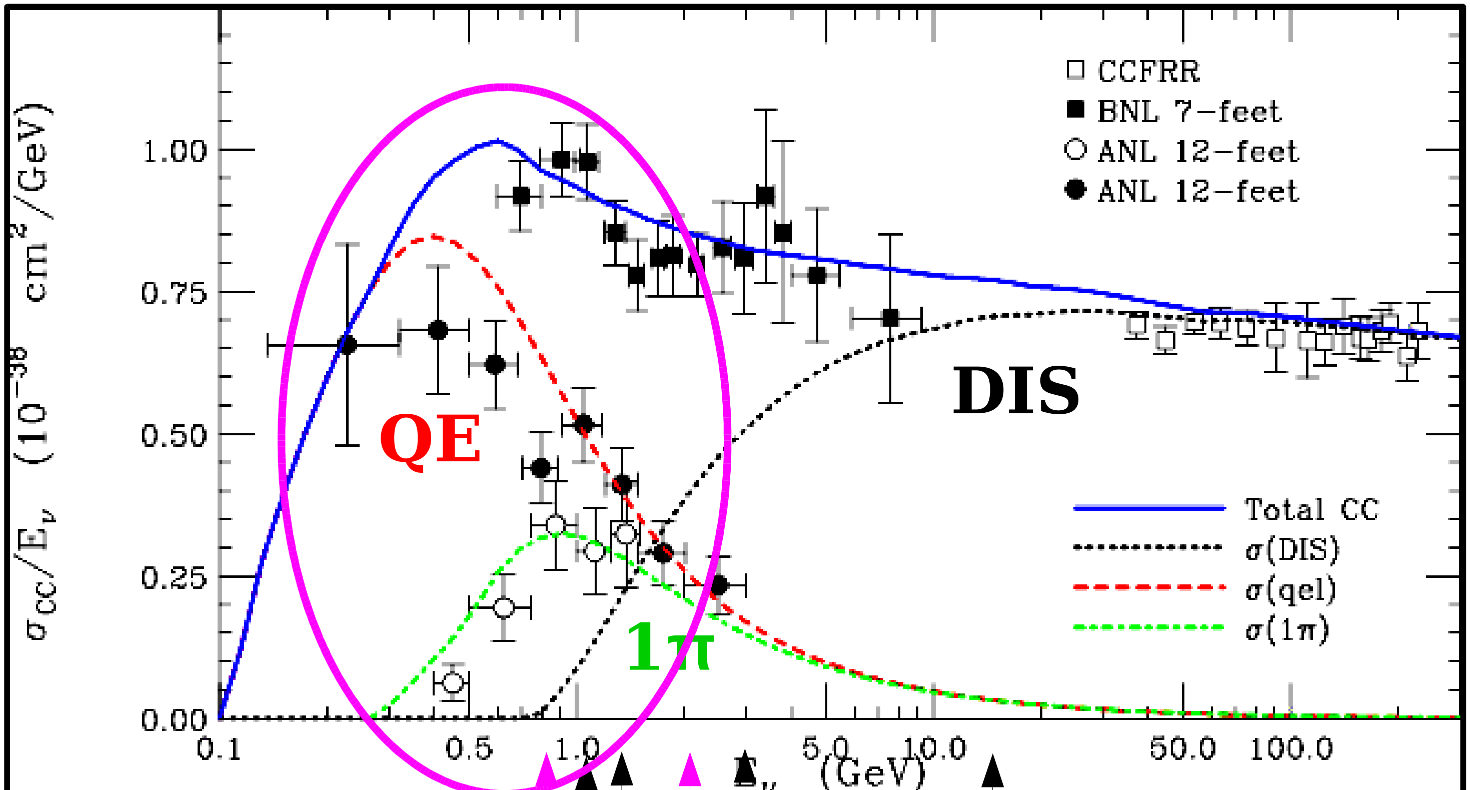
MIP deposition in first 2.4 cm of track

For electron efficiency of 80%

γ contamination is <5%

Similar studies report 90% electron efficiency for 6.5% γ contamination

Need fine-grained detectors and
e/γ separation to understand this rich energy regime!



MiniBooNE
SciBooNE
BNB

T2K

K2K

NOvA:
NuMI
off-axis

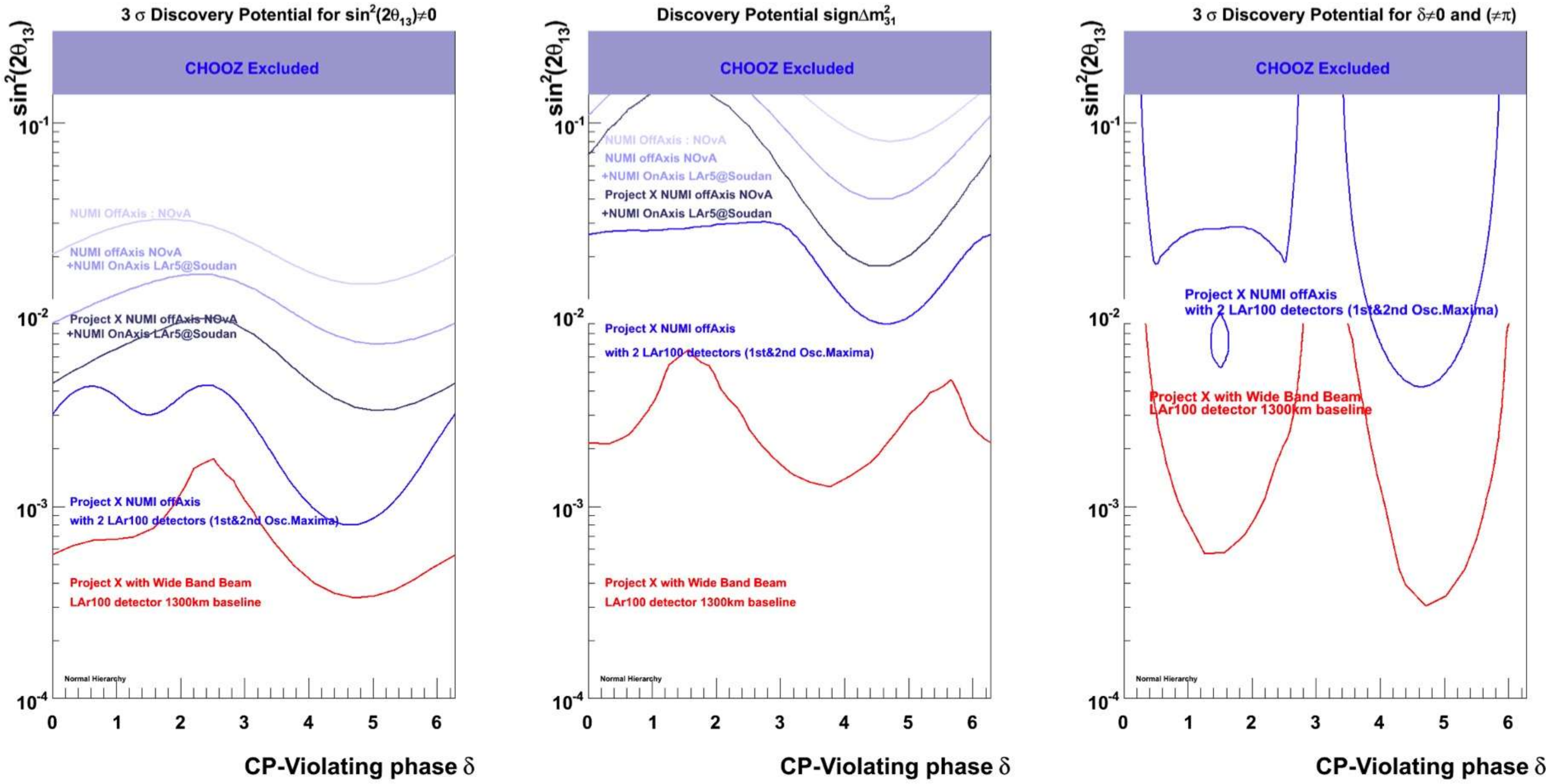
MINOS
MINERvA
NuMI
on-axis

CNGS
T600

FNAL to DUSEL

Key for
future ν
experiments!

100 kton fiducial volume gives impressive physics reach for CP Violation search and proton decay



N. Saoulidou

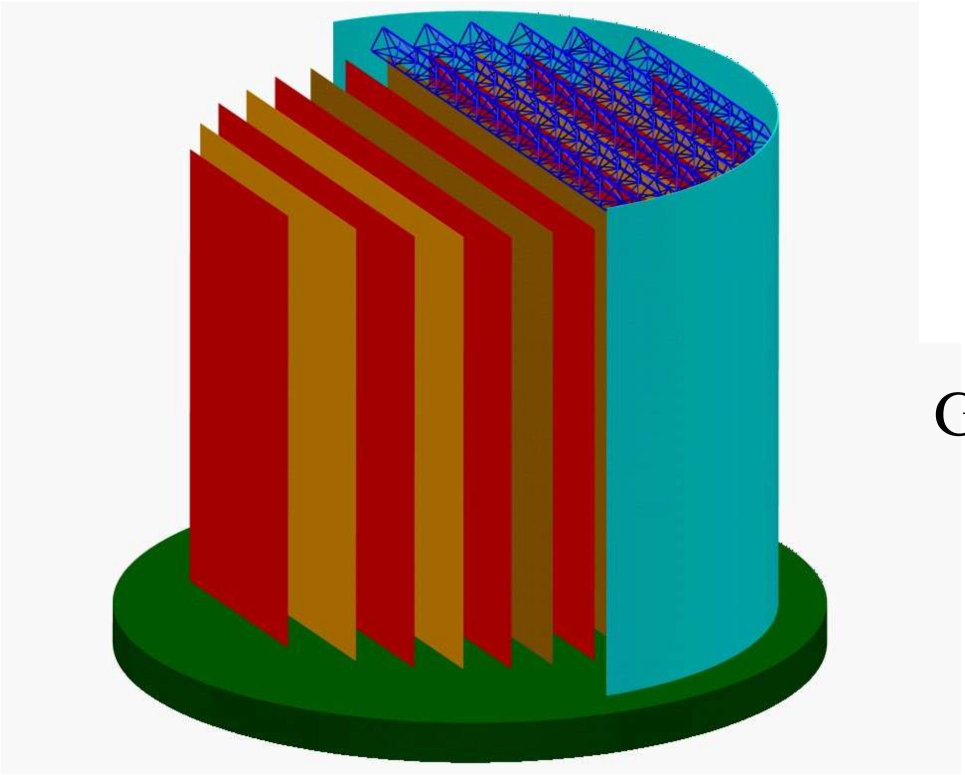
$p \rightarrow K^{+}\nu$

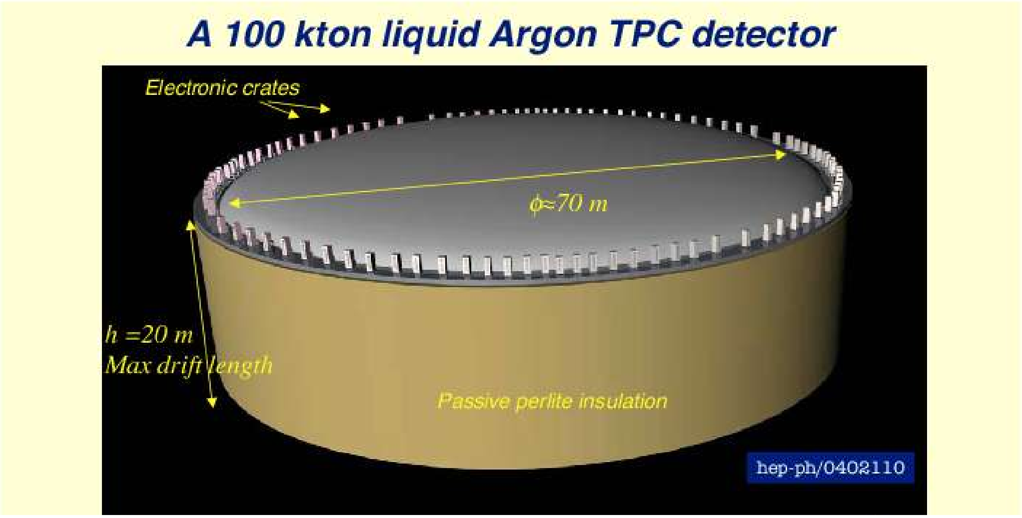
WC efficiency = 0.14
BG = 1.2 evts/100 kty
Nobs = Nbg

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

Possible designs for massive detectors:

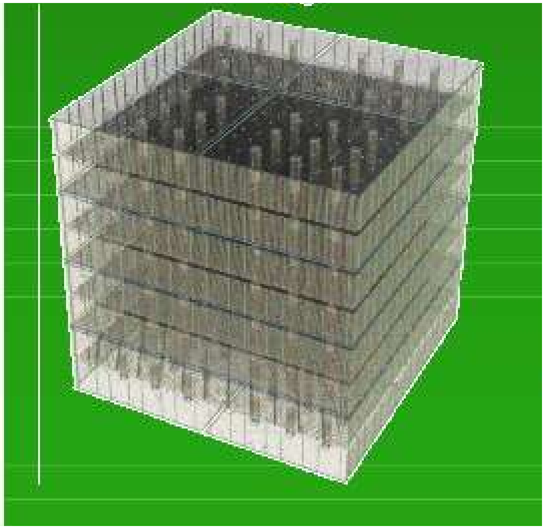
LArTPC: Modularized drift regions in one large (10-50kton) tank (un-evacuated)



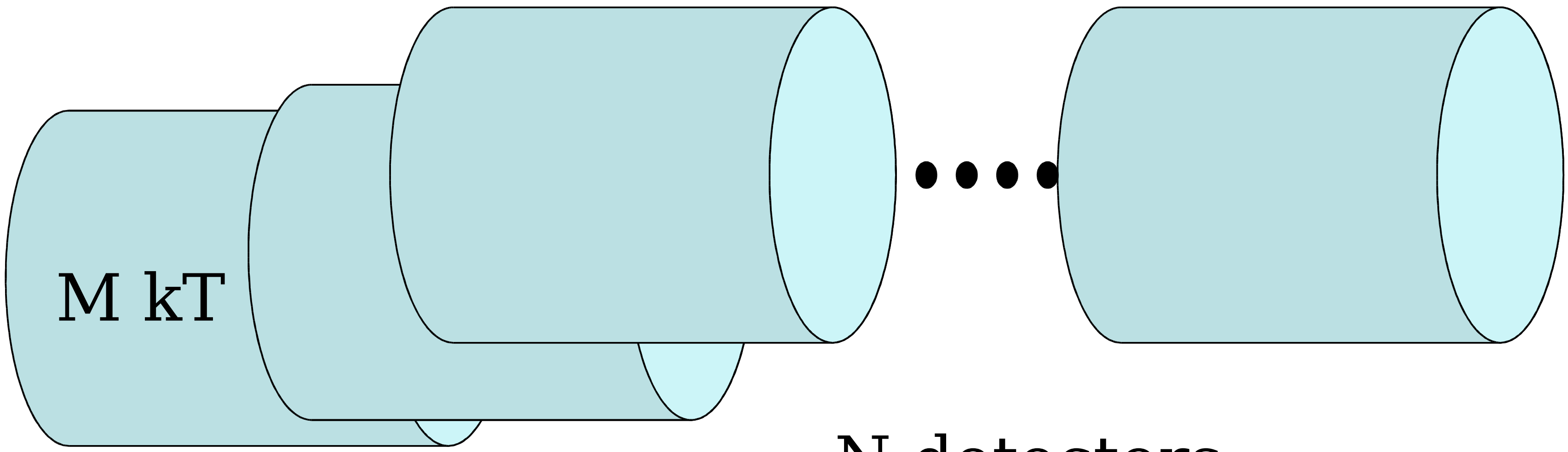


GLACIER: Combination of charge and light collection, single large drift area

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

Main challenges for massive LArTPCs

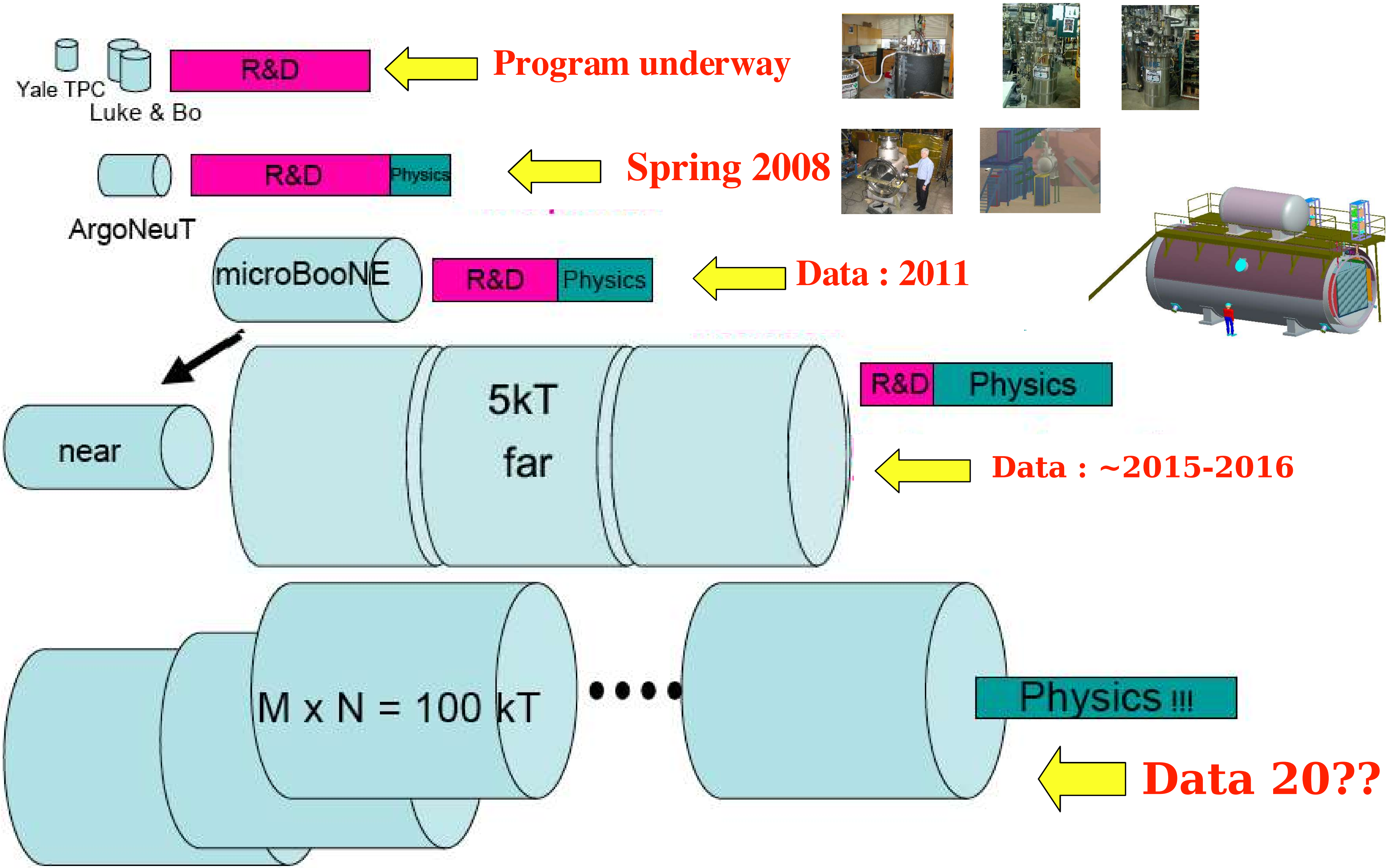
- **Purification Issues: large, industrial vessels**
  - Test stand measurements
  - Purification techniques for non-evacuatable vessels
  - Purity in full scale experiment
- **Cold, Low Noise Electronics and signal multiplexing**
  - Test stand measurements
  - Plan for R&D towards cold electronics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

Working to address these within DUSEL WGs

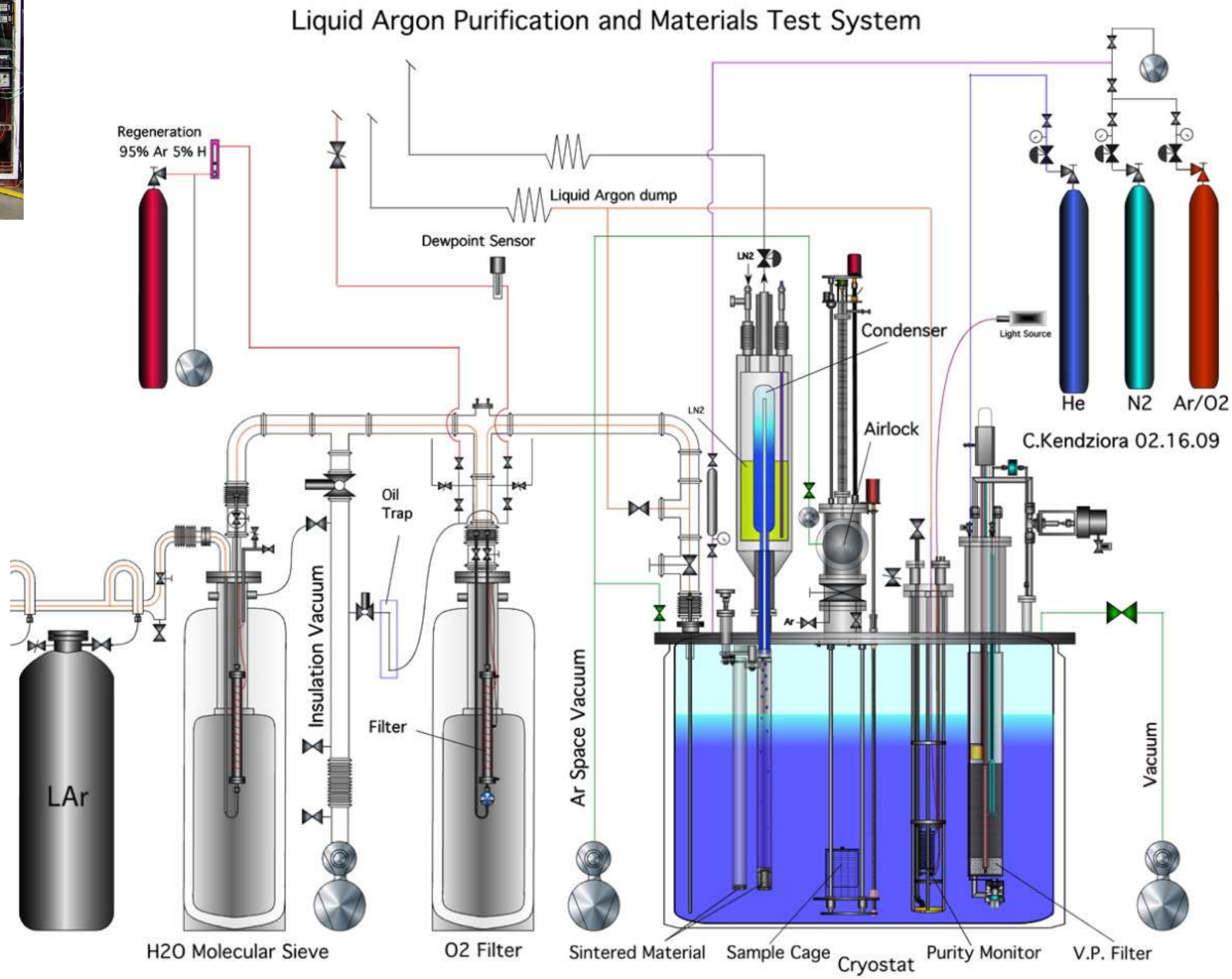
US program to address these is moving along rapidly!
Ongoing R&D and plans for what more needs to be done....

Collaborations are growing and getting organized
→ building teams to do this work....

Liquid Argon TPC R&D program in the US



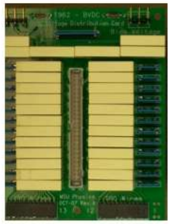
Fermilab Materials Purity Test Stand



System to study the impact of different materials on purity and effectiveness of different purification techniques

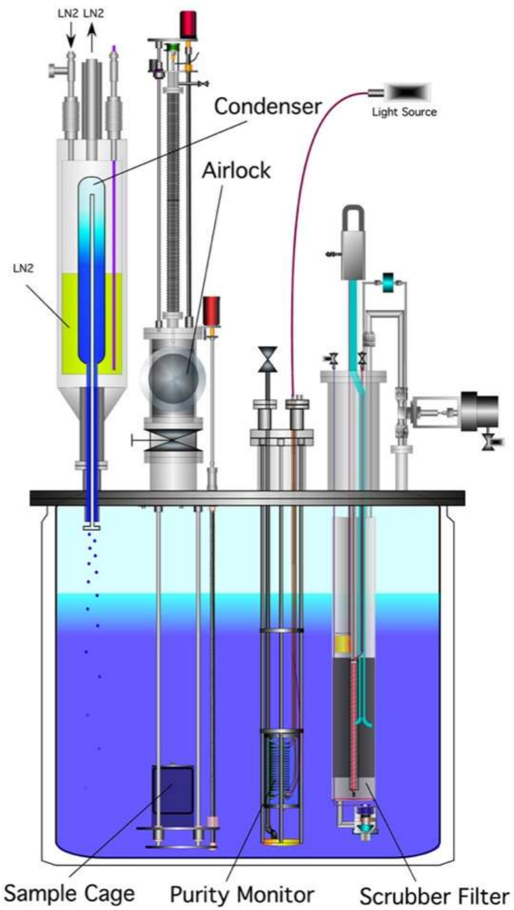
System is running and taking data using different filtering techniques and with samples of materials to be used in detectors

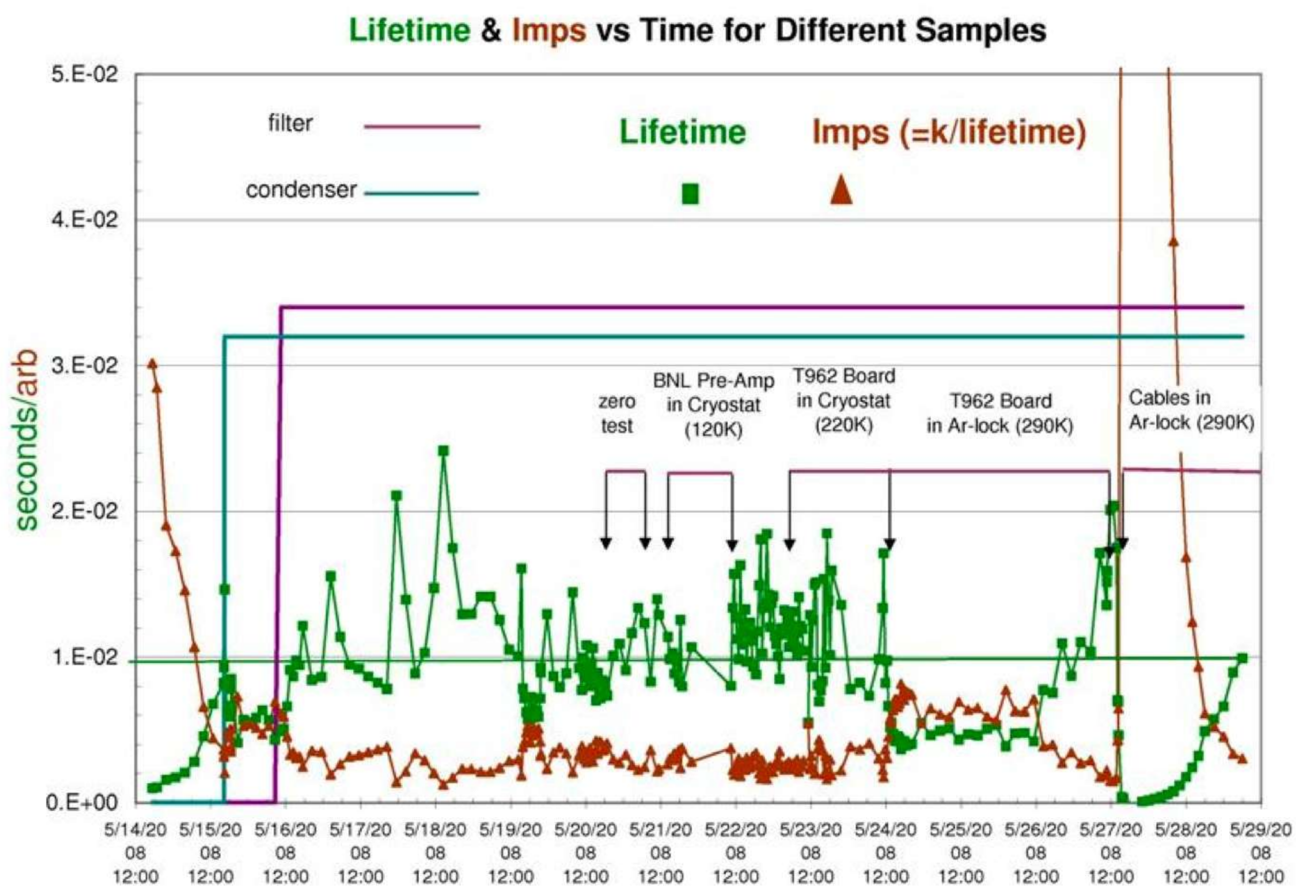

BNL 4-ch Amp


ArgoNeuT Bias Board


Cables/Cable-Tie Bundle

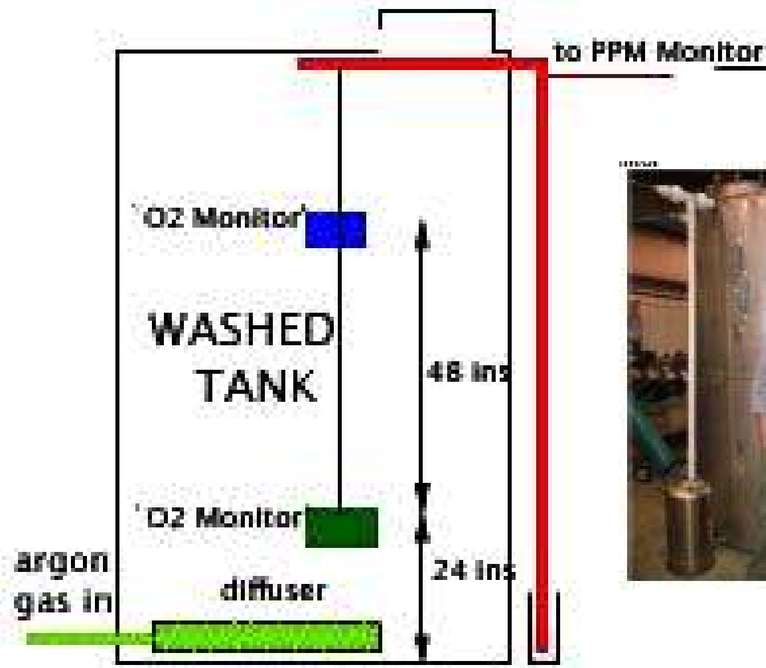
Measurements with the Materials Test System



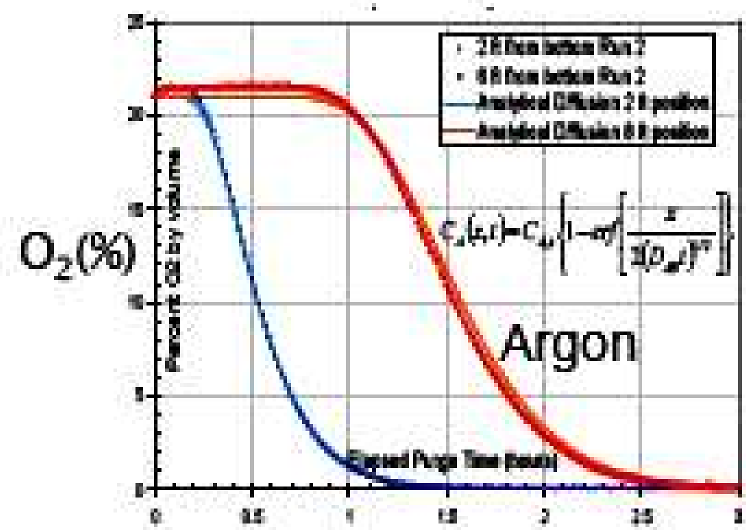


Achieving purity in an un-evacuatable vessel

- Test stand at FNAL
- 20 ton purity demonstrator
- MicroBooNE R&D program



Oxygen content vs. time



2.6 volume changes to reach 100 ppm O_2

- Flush tank with clean Argon gas
- Monitor level of O2 in tank as it is flushed

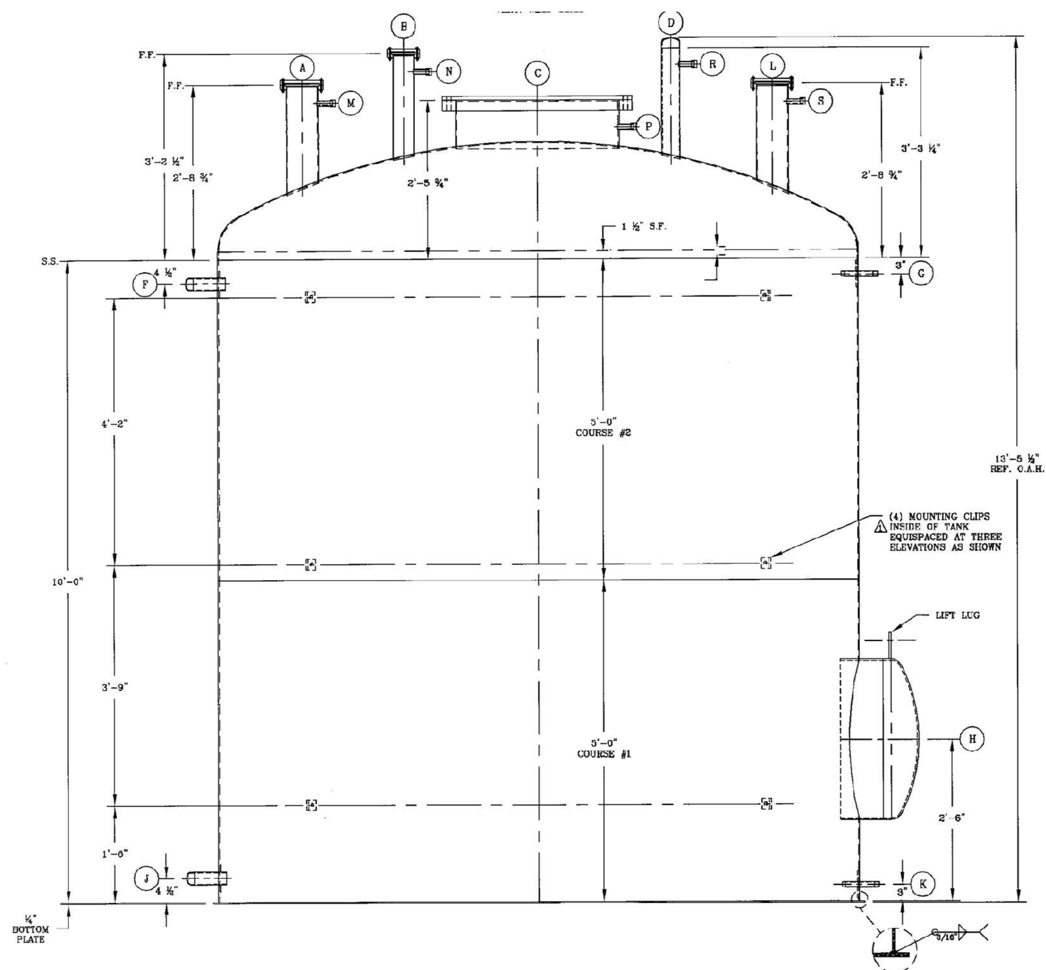
Achieve purity in un-evacuatable commercially built tank

- Clean with gas purge then liquid as getter
- Fill and purify in gas and liquid phases
- Achieve 10ms lifetimes (<0.1 ppb impurities)

20ton purity demonstrator

smallest tank built using industrial techniques

Test underway: tank is being procured...



R&D | Physics

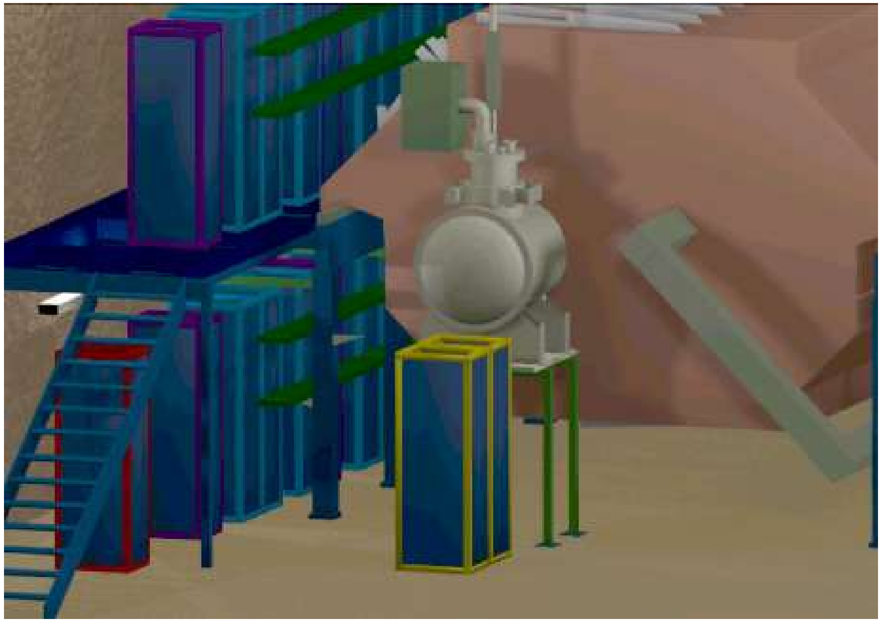
ArgoNeuT

Joint NSF/DOE project

0.3 ton active volume

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

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



University of L'Aquila
F. Cavanna

Fermilab
B. Baller, C. James, G. Rameika, B. Rebel

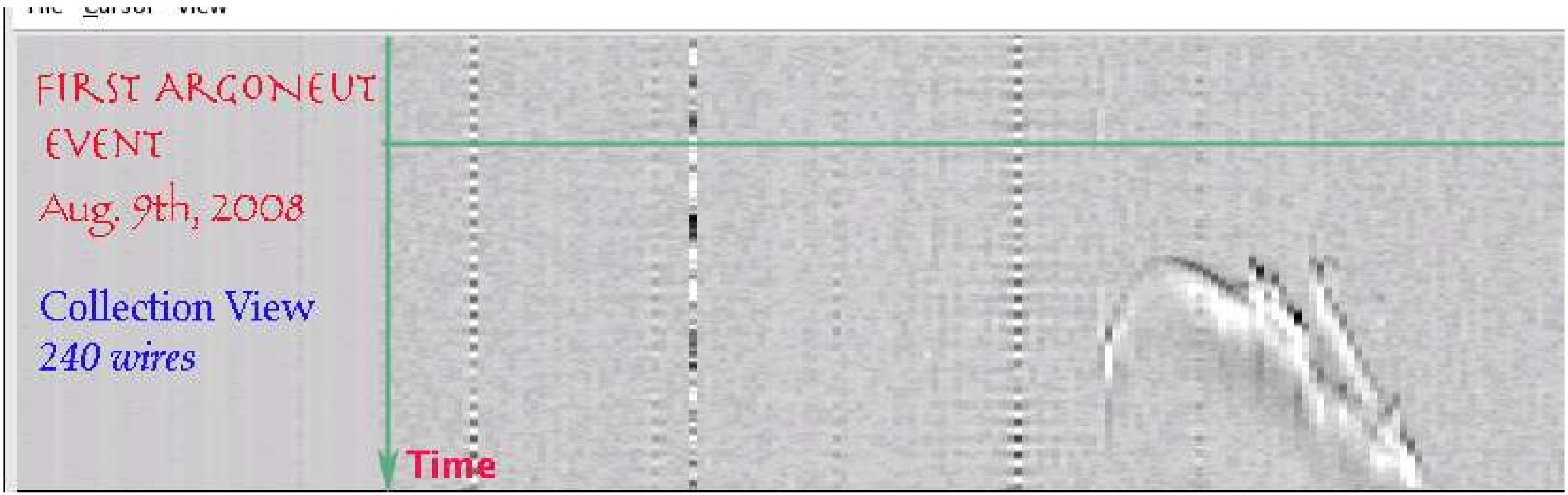
Gran Sasso National Lab
M. Antonello, R. Dimaggio, O. Palamara

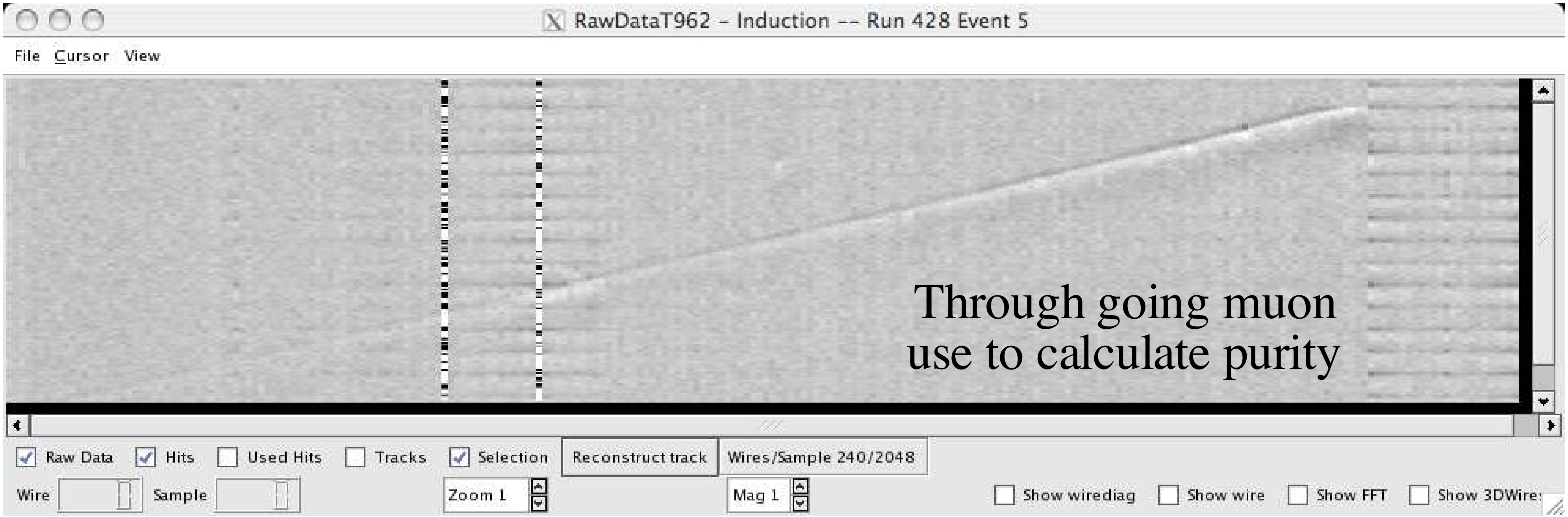
C. Bromberg, D. Edmunds, B. Page
Michigan State University

S. Kopp, K. Lang
University of Texas at Austin

Yale University
C. Anderson, B. Fleming*, S. Linden, M. Soderberg, J. Spitz
*=spokesperson

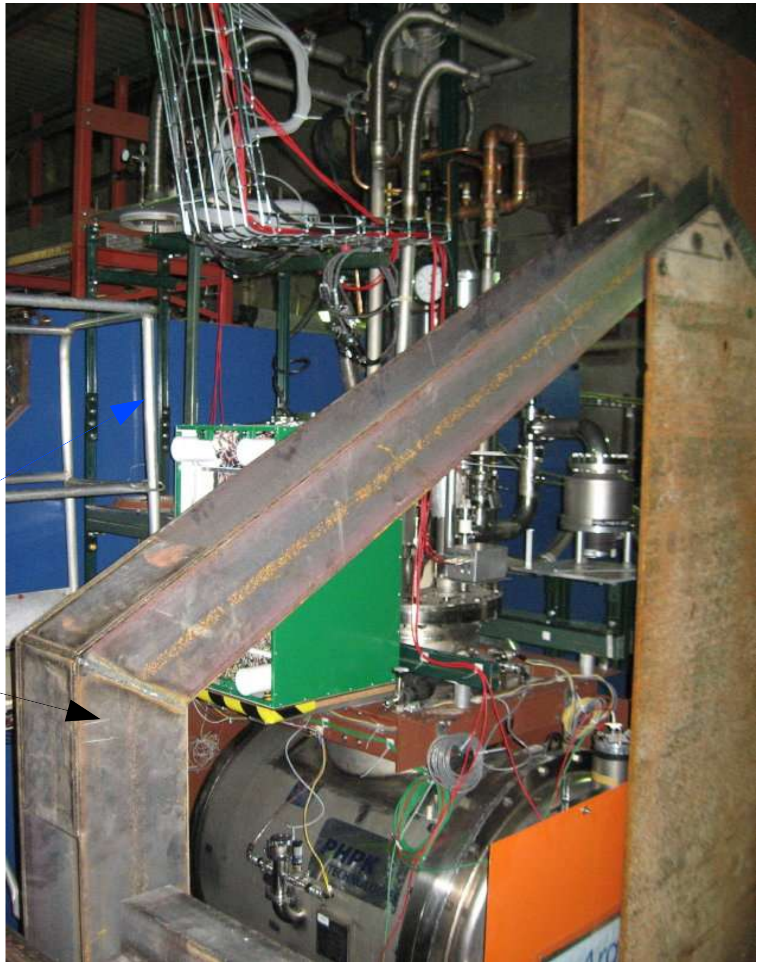
ArgoNeuT commissioned with LAr for first time on August 4th, 2008. First cosmic tracks seen on August 9th!





ArgoNeuT installation underground in January

ArgoNeuT being lowered down the NuMI shaft



Wedged in between MINOS near detector and MINERvA

Will fill and start data taking soon

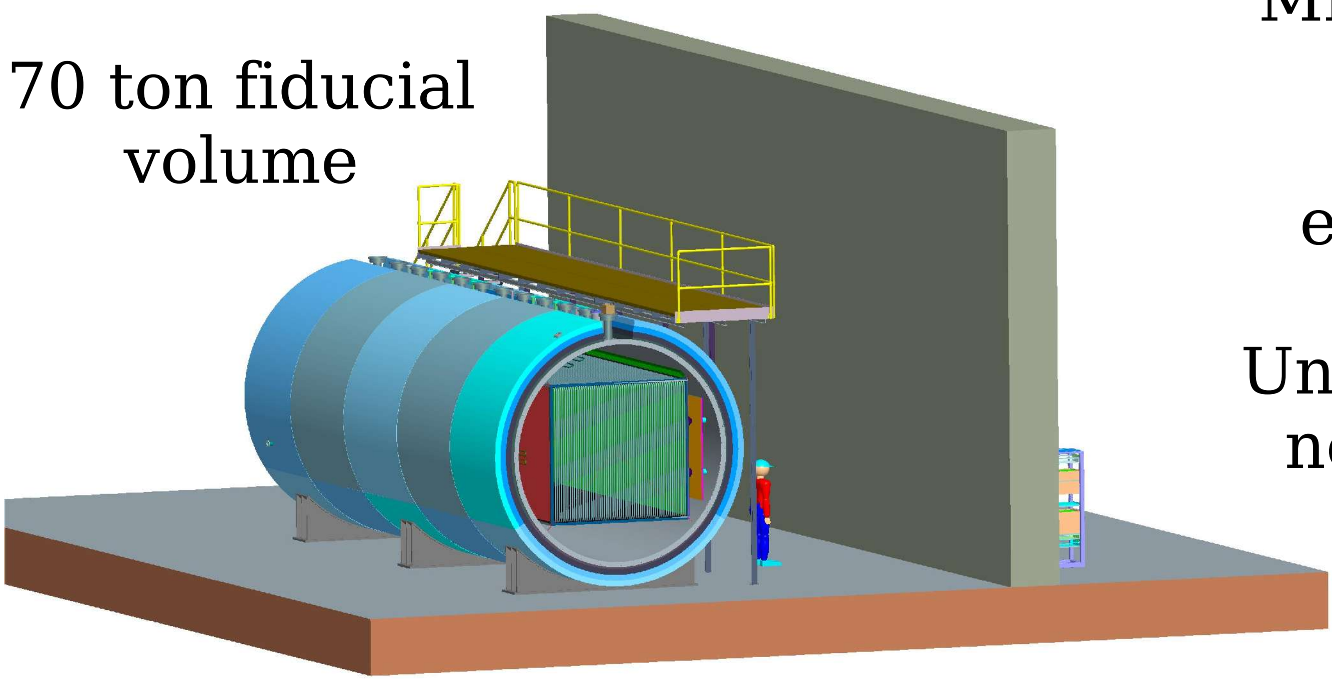
R&D | Physics

MicroBooNE: Full scale experiment
R&D towards DUSEL scale detector

- **Purity in a non-evacuated vessel**
- Full systems test of **low noise electronics**
- **Physics Development**
  - See fully contained ν interactions
  - Simulation, reconstruction, analysis
- **TPC Design**

Running detector and physics analysis of real data provides the best way to understand detector strengths and shortcomings

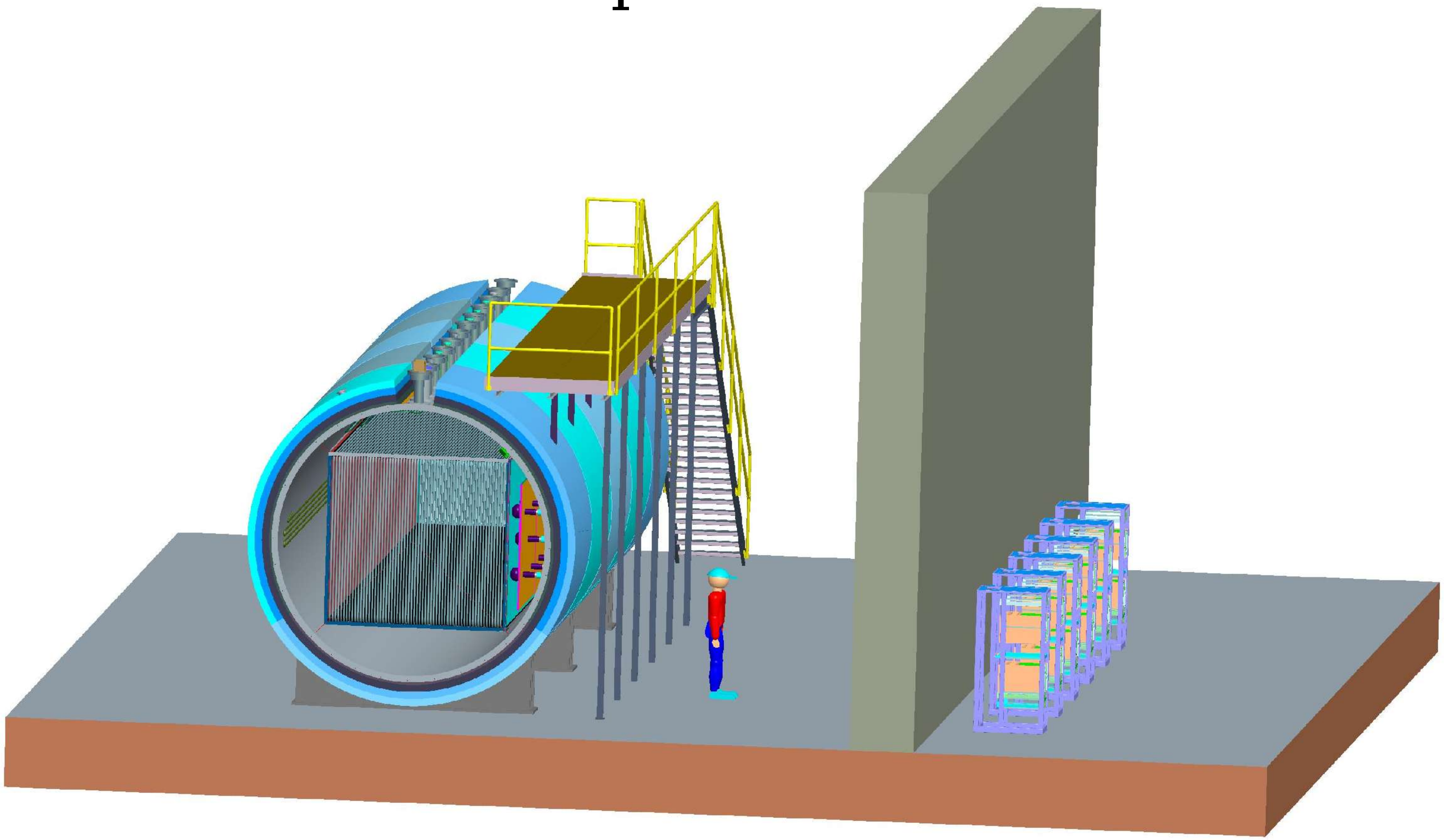
70 ton fiducial volume



MicroBooNE's physics case highlights the need for excellent detectors!

Understand low energy neutrino phenomena
MiniBooNE low energy excess!

MicroBooNE purification program: Achieve purity without evacuation in full physics scale experiment



MicroBooNE Purge test: 6 week program to precede physics run

- 10 volume changes of GAr to reduce O_2 concentrations to 10 ppm
- Recirculate filtered gas or introduce small amount of LAr as getter and continue purification for ~1 month
- Introduce filtered LAr and test for purity

Cold Electronics Development

Need for Pre-amplification and multiplexing in LAr
- S/N requirements (need to limit capacitance to electrodes only)
- Geometry – must readout on the sides of the TPC (in LAr)
- Signal feedthroughs: must multiplex to avoid ~1M channels of readout (messy, heat leaks, ...)

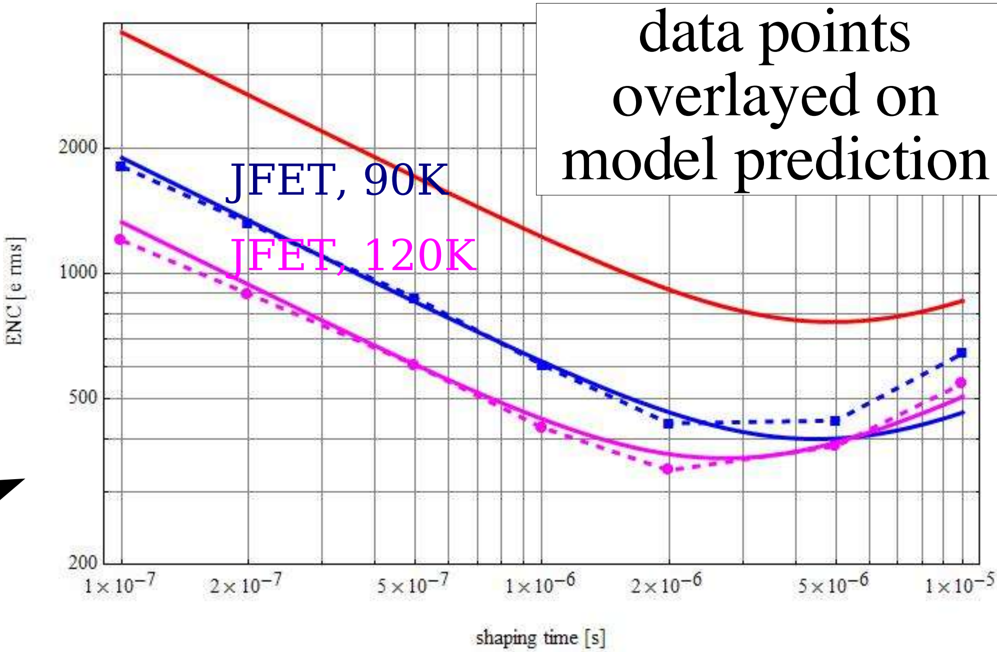
Some experience in electronics in LAr but more needed for DUSEL scale detectors…

MicroBooNE readout electronics design

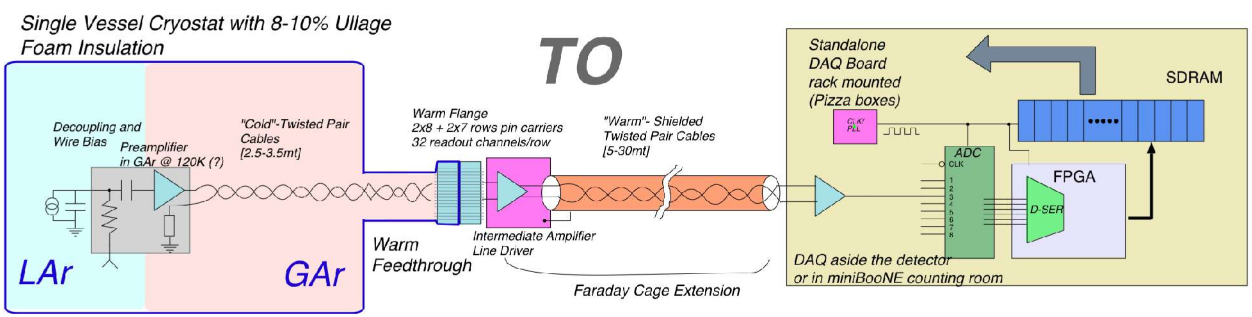
One step towards fully cold electronics....

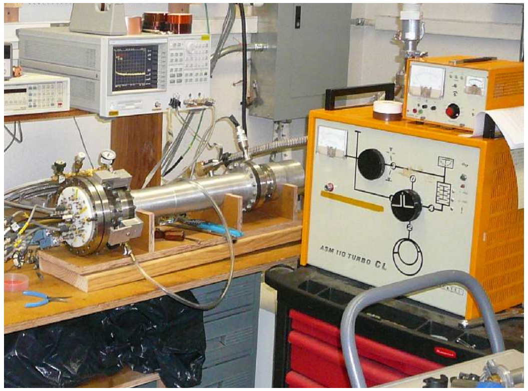
JFET in GAr ullage:
- low noise at 1-2 μs shaping
- Study S/N levels expected in next generation LArTPCs

data points overlayed on model prediction



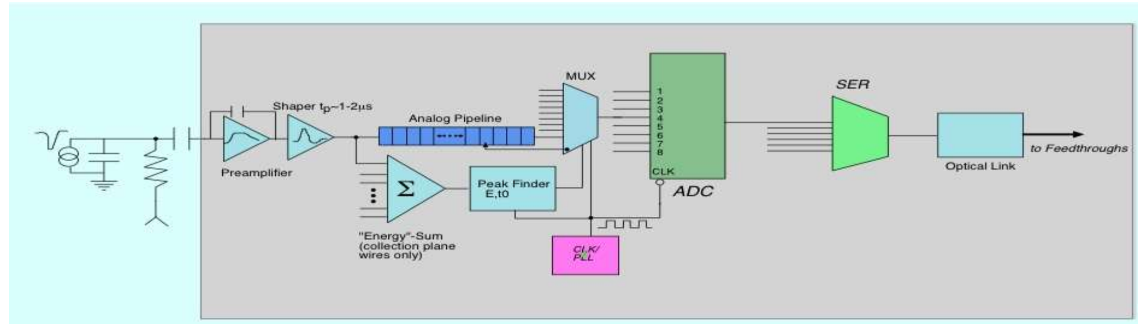
Bench tests of JFET hybrid at Brookhaven: room temp, 90K, 120K





Plan for developing CMOS technology for DUSEL detectors

Fully integrated ASIC with CMOS technology



Preliminary schematic of front-end

1. Investigate technologies and develop models for cryogenic operations

6 months: up to end of 2008

2. Characterize analog & mixed-signals ASIC already developed towards cryogenic operations:

3 months

3. Select Technology and develop test structures and sub-circuit (analog and digital): 2-3 fabs

18 months: beg 2009 / mid 2010

4. Develop readout architecture (charge amplification in current-mode, processing, sampling, storage, multiplexing….)

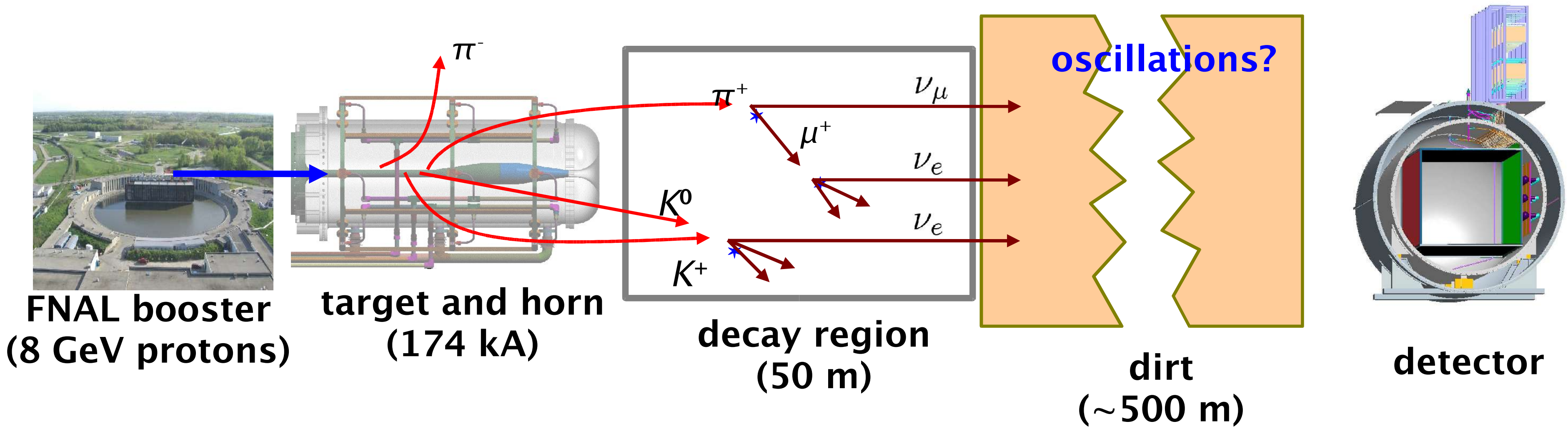
3 months

5. Develop ASIC (might be in functional blocks: low-noise, low-power analog, mixed signal readout): 2-3 fabs

24 months: mid 2010 / mid 2012

MicroBooNE: Liquid Argon Time Projection Chamber

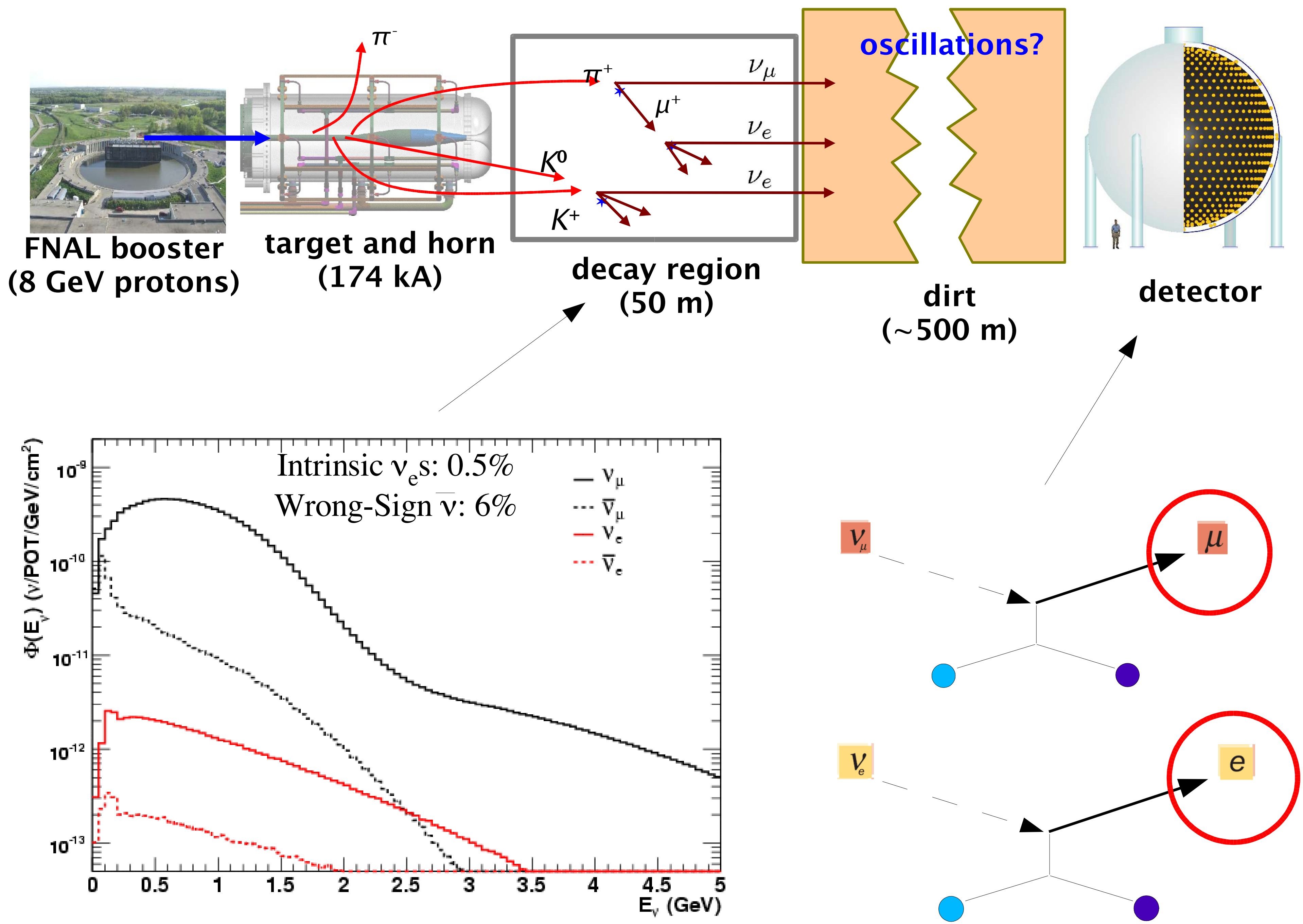
70 ton fiducial volume LArTPC to be exposed to the Booster Neutrino beam and NuMI Neutrino Beams at Fermilab



Look for low energy neutrino phenomena

- MiniBooNE low energy excess
- Low energy neutrino cross sections
- R&D for LArTPCs

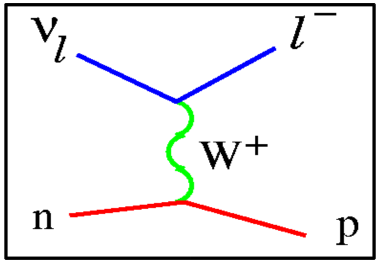
Approved by FNAL July 2007
NSF MRI 2007



FNAL booster
(8 GeV protons)
target and horn
(174 kA)
decay region
(50 m)
dirt
(~500 m)
detector
oscillations?
π^-
π^+
μ^+
K^0
K^+
ν_μ
ν_e
ν_e
Intrinsic ν_es: 0.5%
Wrong-Sign $\bar{\nu}$: 6%
ν_μ
$\bar{\nu}_\mu$
ν_e
$\bar{\nu}_e$
$\Phi(E_\nu)$ (ν/POT/GeV/cm^2)
E_ν (GeV)
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
ν_μ
μ
ν_e
e

Almost pure muon neutrino beam (0.5% intrinsic electron neutrinos). Looking for electron neutrino appearance in this muon neutrino beam.

Muons: Produced in most CC events.

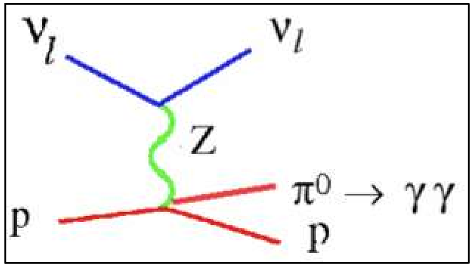


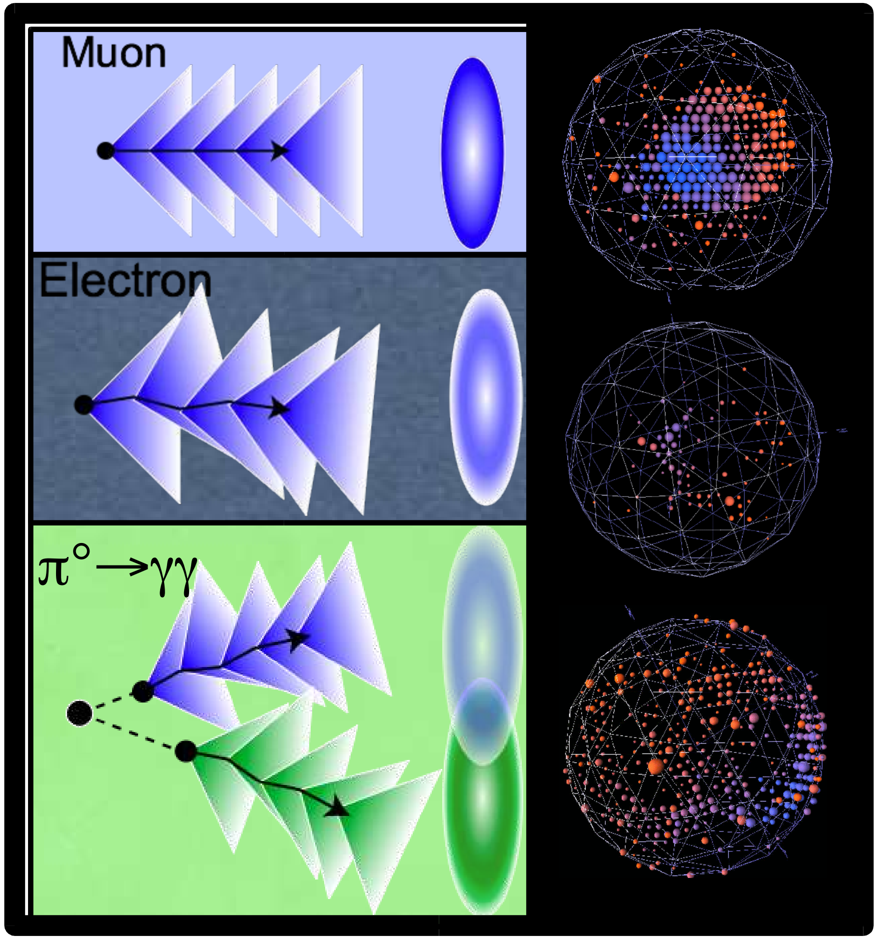
Electrons:

Tag for $\nu_\mu \rightarrow \nu_e$ CCQE signal.

π^0s:

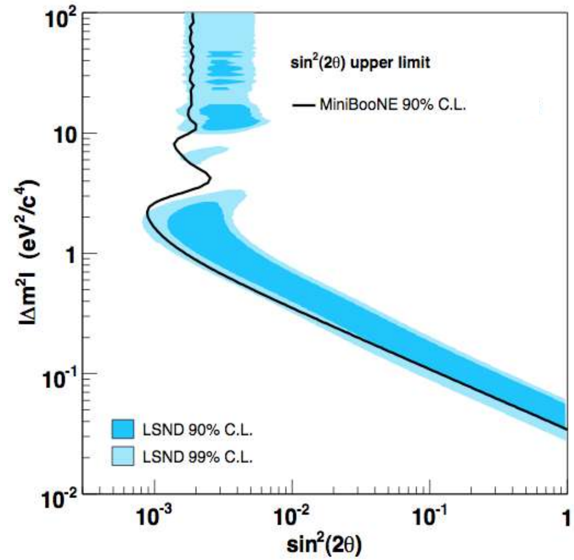
Can form a background if one photon is weak or exits tank.





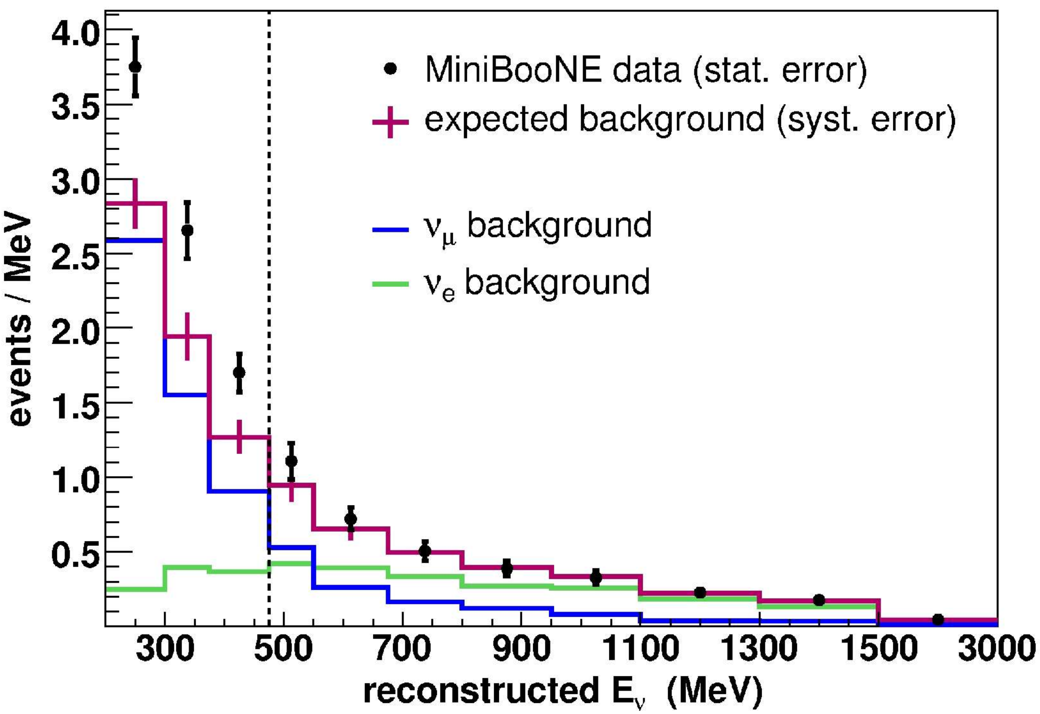
Backgrounds come from intrinsic ν_es and mis-identified ν_μs

MiniBooNE Results
Data consistent with background in $475<E_\nu^{QE}<3000$ MeV analysis region



Incompatible with the LSND experiment at 98% CL.

Excess below this not well understood



reconstructed neutrino energy bin (MeV)	200-300	300-475
total bkgnd	284±25	274±21
ν_e intrinsic	26	67
ν_μ induced	258	207
NC π^0	115	76
NC $\Delta \rightarrow N\gamma$	20	51
Dirt	99	50
other	24	30
data	375±19	369±19
	2.5σ	3.7σ

MiniBooNE spent ~1 year to understand the low energy region and continues to see a >3 sigma excess.....

Some effects added to excess, some removed excess...

- Improved treatment of π flux errors
- Improved π^0/radiative Δ analysis
- Additional hadronic processes in cross section model
- Additional cuts to remove dirt events
- New data (0.83E20 pot in neutrino mode during SciBooNE run)

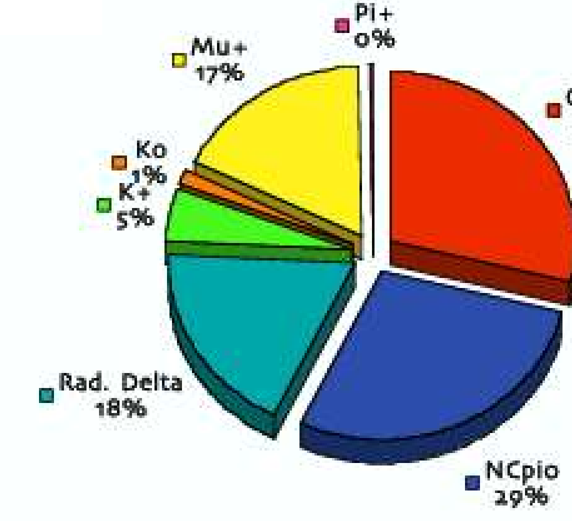
Final Results

reconstructed neutrino energy bin (MeV)	200-300	300-475
total bkgnd	186.8±26.0	228.3±24.5
ν_e intrinsic	18.8	61.7
ν_μ induced	168	166.6
NC π^0	103.5	77.8
NC $\Delta \rightarrow N\gamma$	19.5	47.5
Dirt	11.5	12.3
other	33.5	29
data	232	312
	1.7 σ	3.4 σ

MicroBooNE's LArTPC detection technique extremely powerful

MiniBooNE low E backgrounds

- e/γ separation capability removes ν_μ induced single γ backgrounds
- electron neutrino efficiency: ~x2 better than MiniBooNE
- sensitivity at low energies (down to tens of MeV compared to 200 MeV on MiniBooNE)



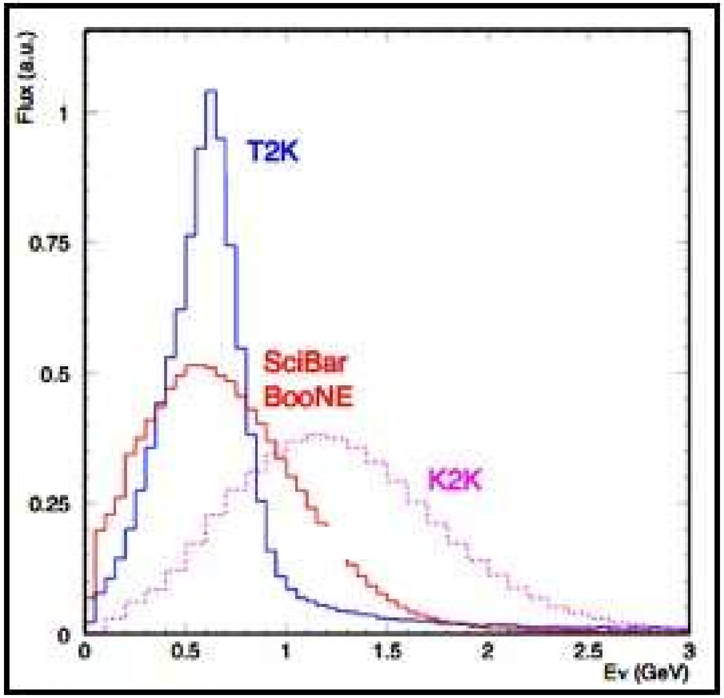
Translates to 5σ sensitivity if excess is ν_es

3σ if excess is γs

Inability to identify excess as ν_es or γs illustrates the need for the best detectors for ν_e appearance physics

→ the strength of the LAr detection technique

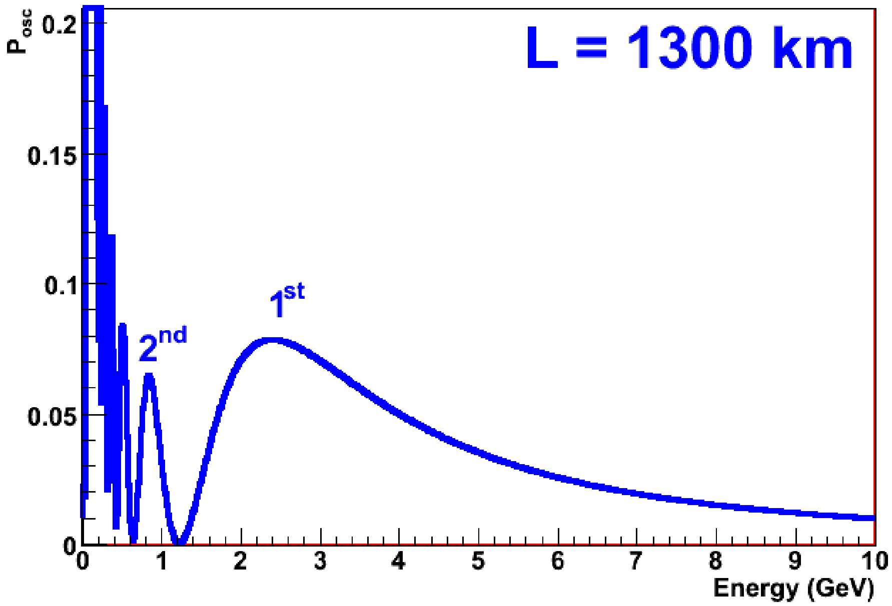
Impact on Broader program
Regardless of interpretation, excess must be understood for next generation ν_e appearance measurements.



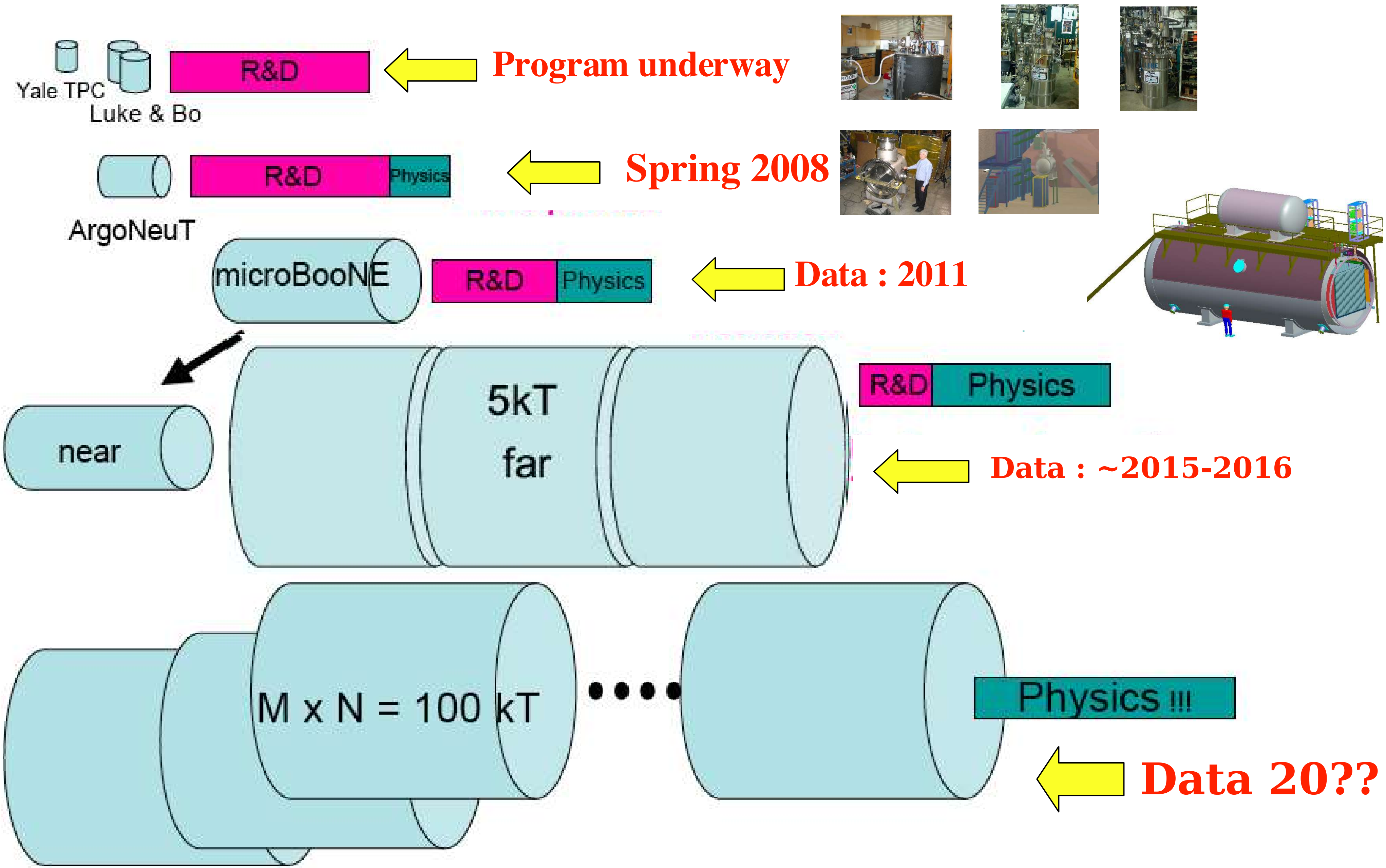
T2K experiment:

- Similar energy spectrum
- Cerenkov detection technique
- <1% oscillation probability
- excess would be a background of ~100 events at >100 MeV

DUSEL Long Baseline Program:
Low energy excess in region of 2^{nd} oscillation maxima



Liquid Argon TPC R&D program in the US

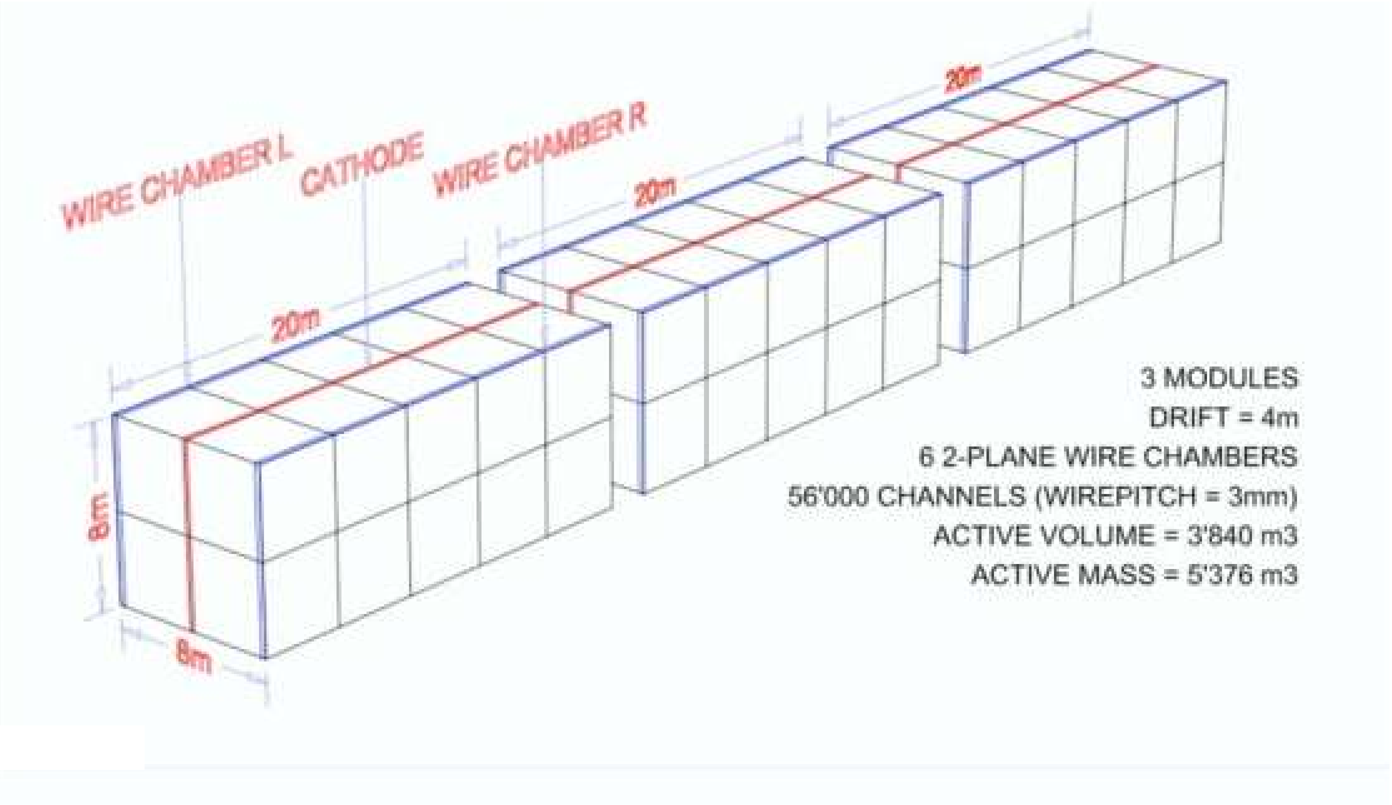


Next step beyond MicroBooNE, 5ktons at DUSEL

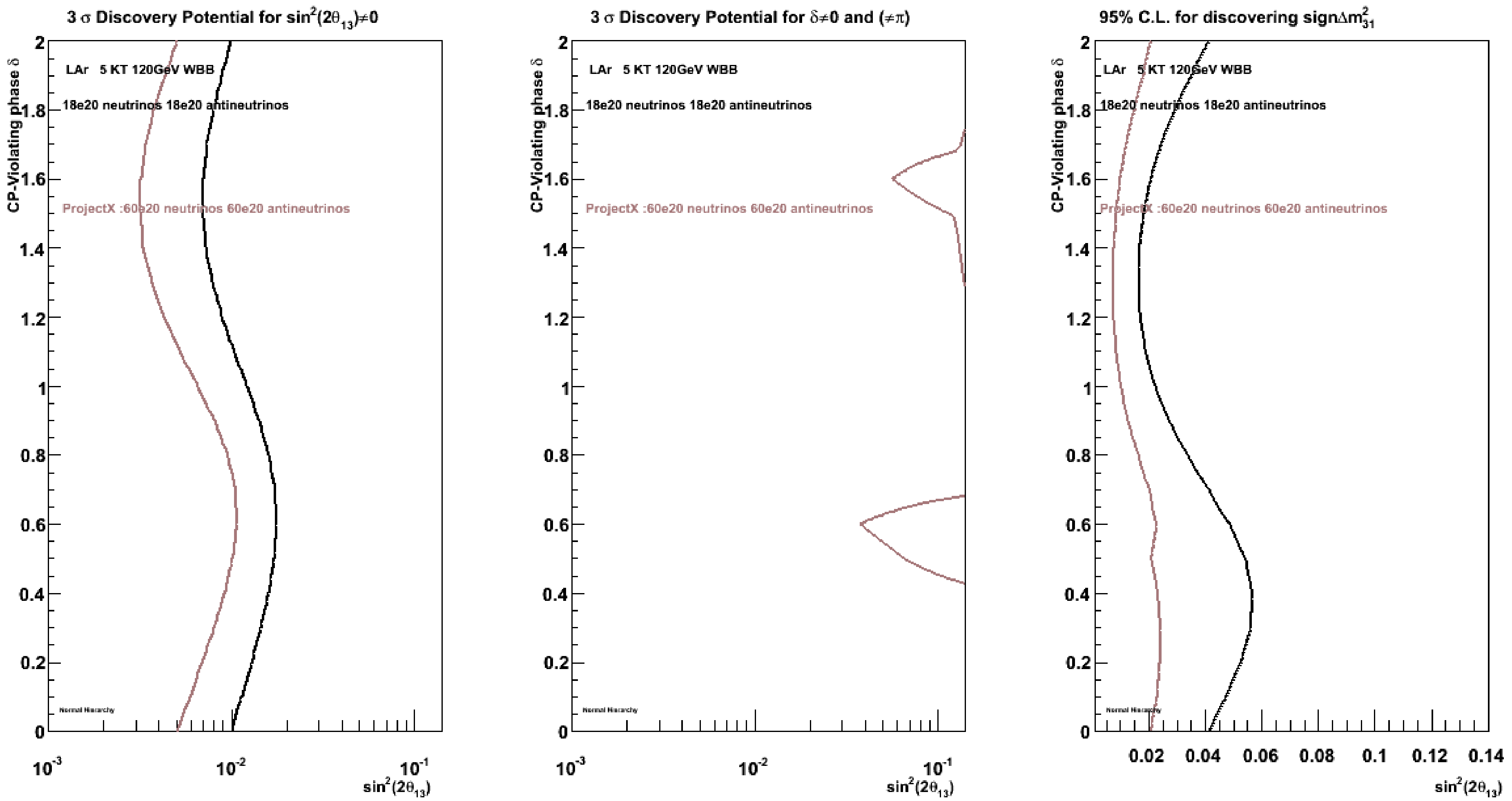
Why 5kton?

- Good physics reach
- sized well for ISE at DUSEL – get started soon!
- Appropriate step in size beyond MicroBooNE technically a reasonable step.....

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



Physics reach of 5ktons



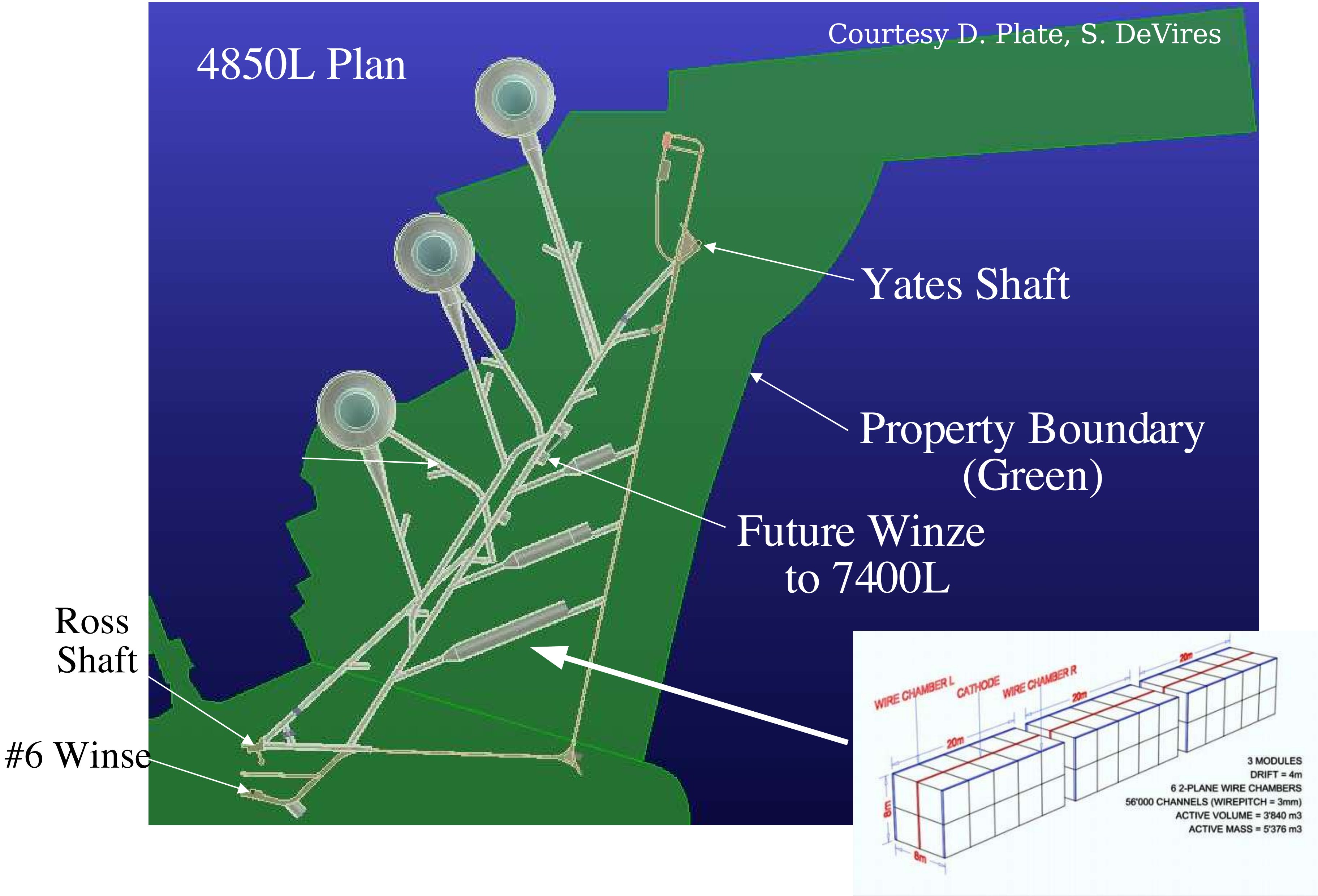
N. Saoulidou

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

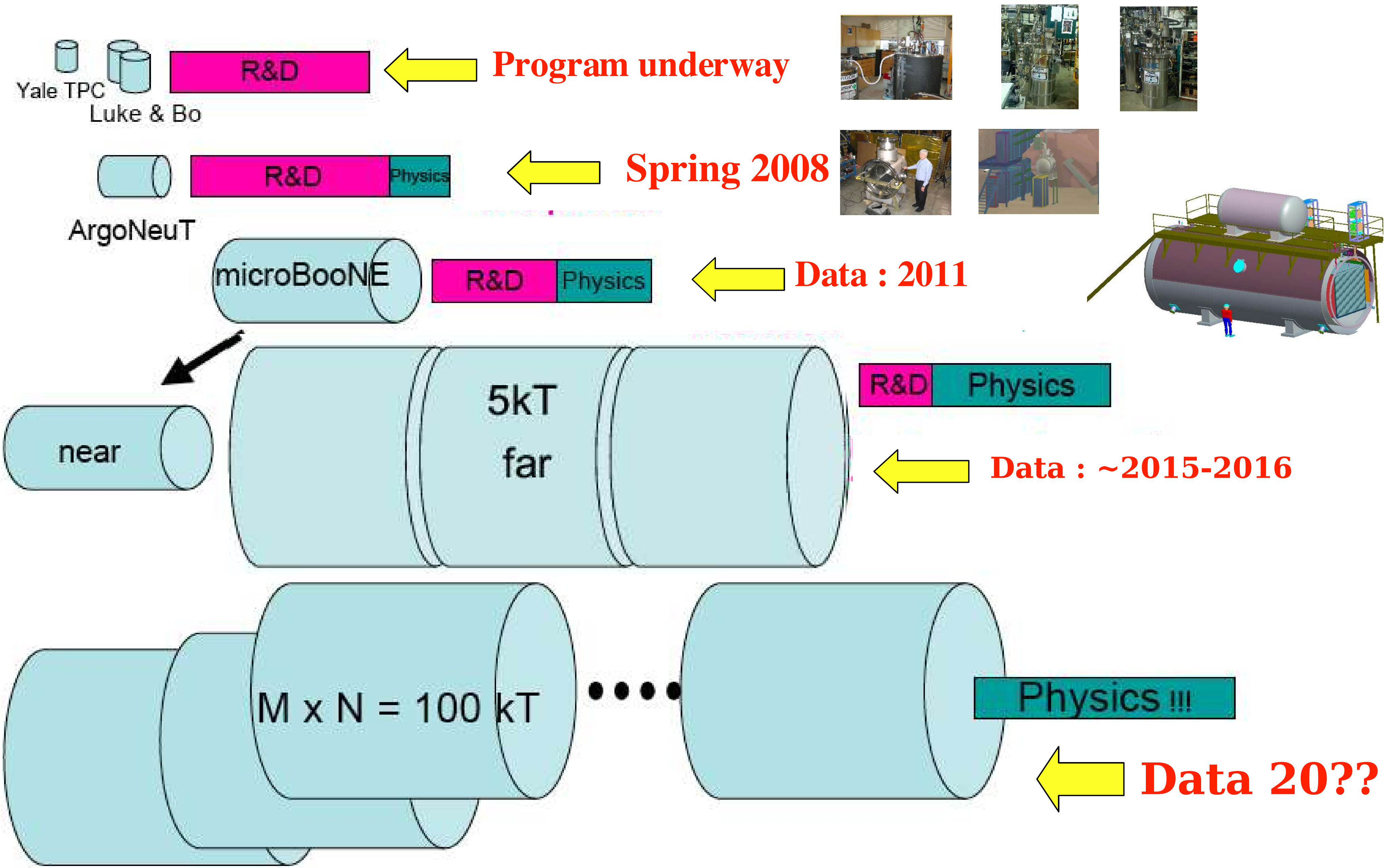
WC efficiency = 0.14
BG = 1.2 evts/100 kty
Nobs = Nbg

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

Underground caverns for DUSEL experiments
5kton fits in the largest of the caverns planned for the ISE



Liquid Argon TPC R&D program in the US

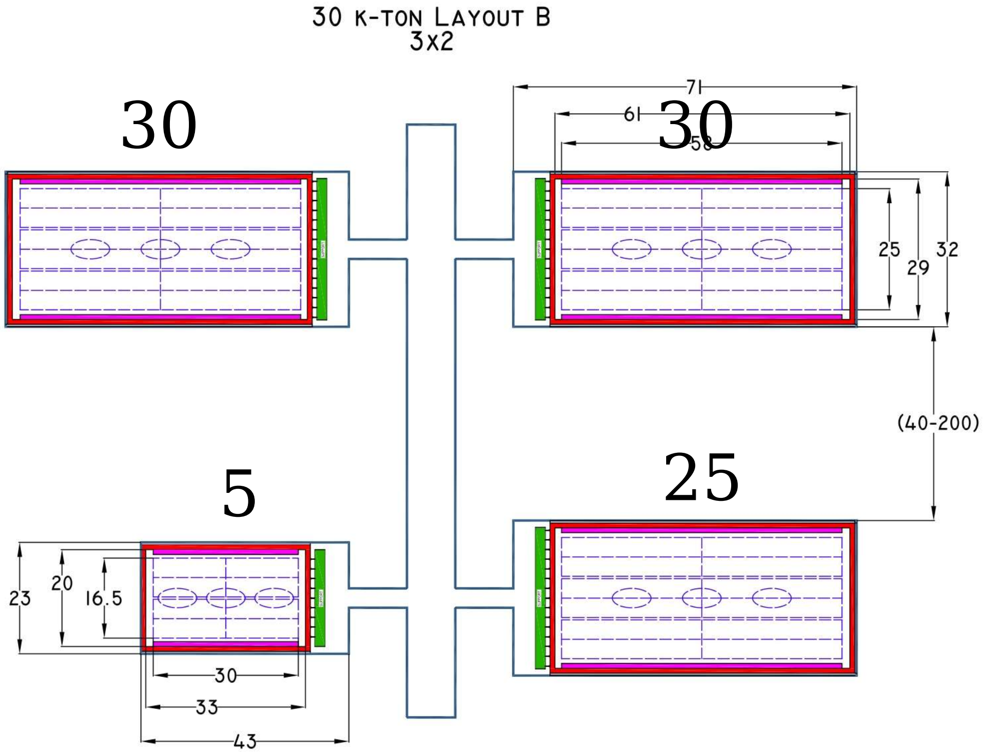


Over the last year, a plan has emerged from within the LAr community:

DUSEL LAr baseline plan for total detector mass of 90ktons comprised of smaller detector modules

5+25ktons
+ 30kton
+ 30kton

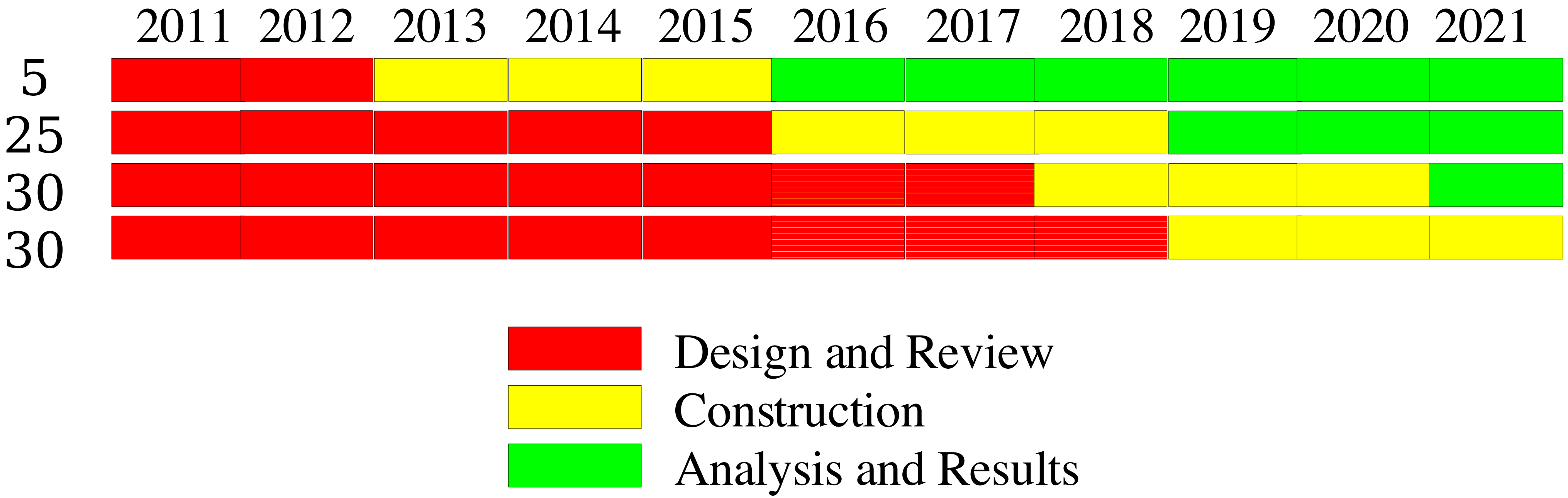
90ktons total



sited at 4850 ft level (see depth document)

Why modularized detector?

- Allows for first physics results early on
- Flexibility in construction and costs over time



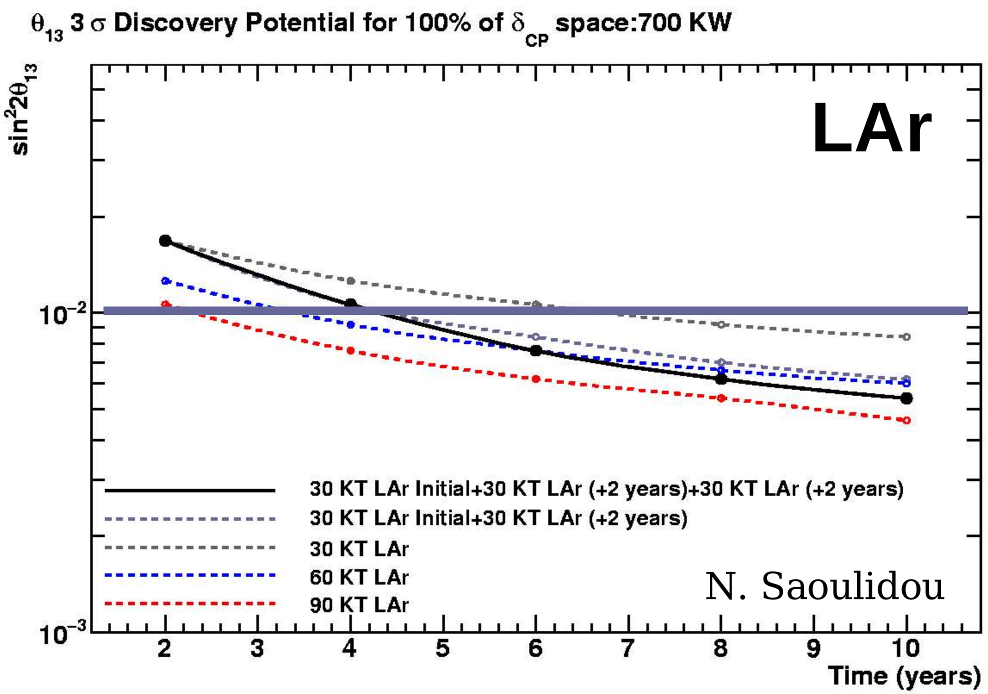
- Easier to protect against purity and safety problems
- Avoids some of the construction and cost issues of very large caverns
- Physics reach is nearly the same!

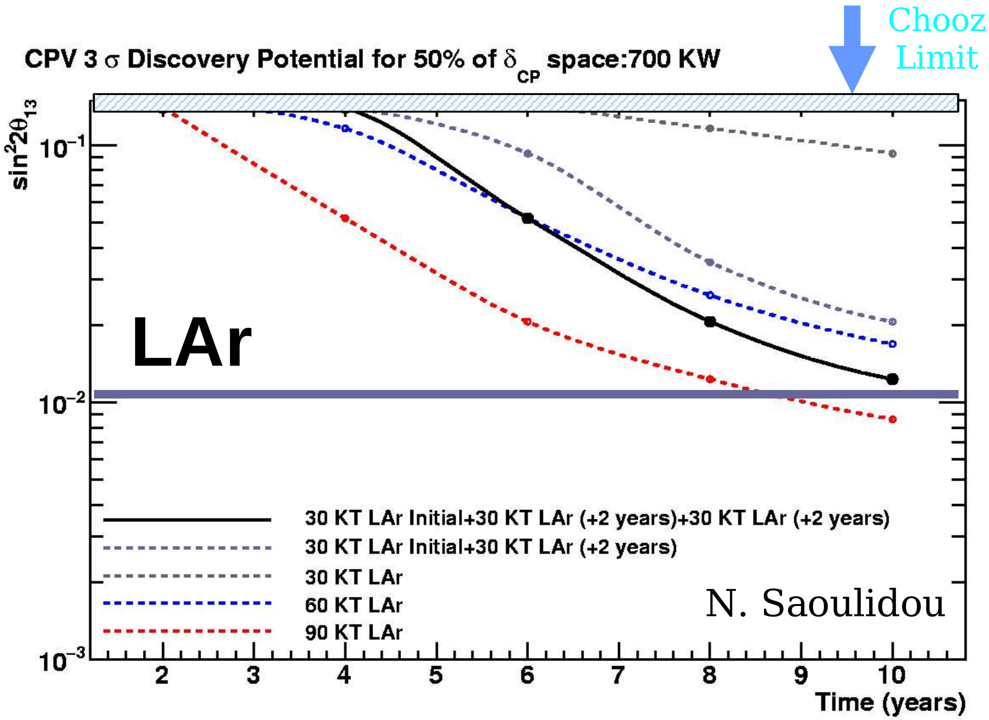
Sensitivities vs Time for LAr Detector: 700 kW beam

Add 30kton detector modules every 2 years for a total of 3 modules

θ_{13} Discovery Potential for all values of δ_{cp} (100%)

CPV Discovery Potential for 50% of δ_{cp}





No significant reach is gained when starting from Day 1 with the total Detector Mass, compared to adding Modules every 2 years.

For CPV Discovery, LAr is sensitive beginning with running of first 30kton module

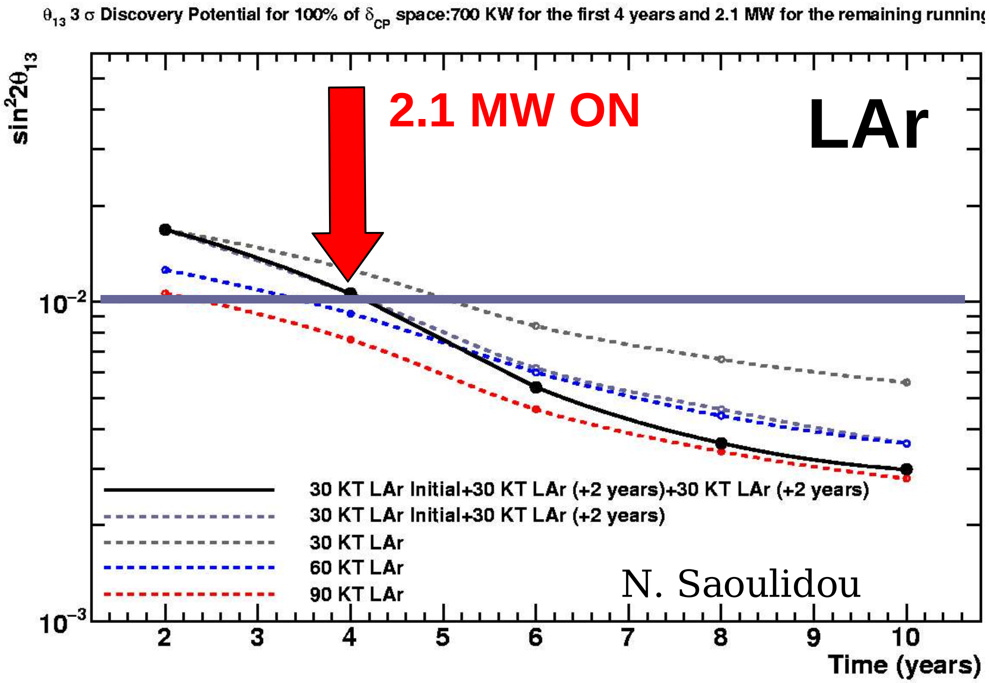
The WC – LAr mass equivalence is 1 – 6 (optimistic) to 1 –3 (very pessimistic)

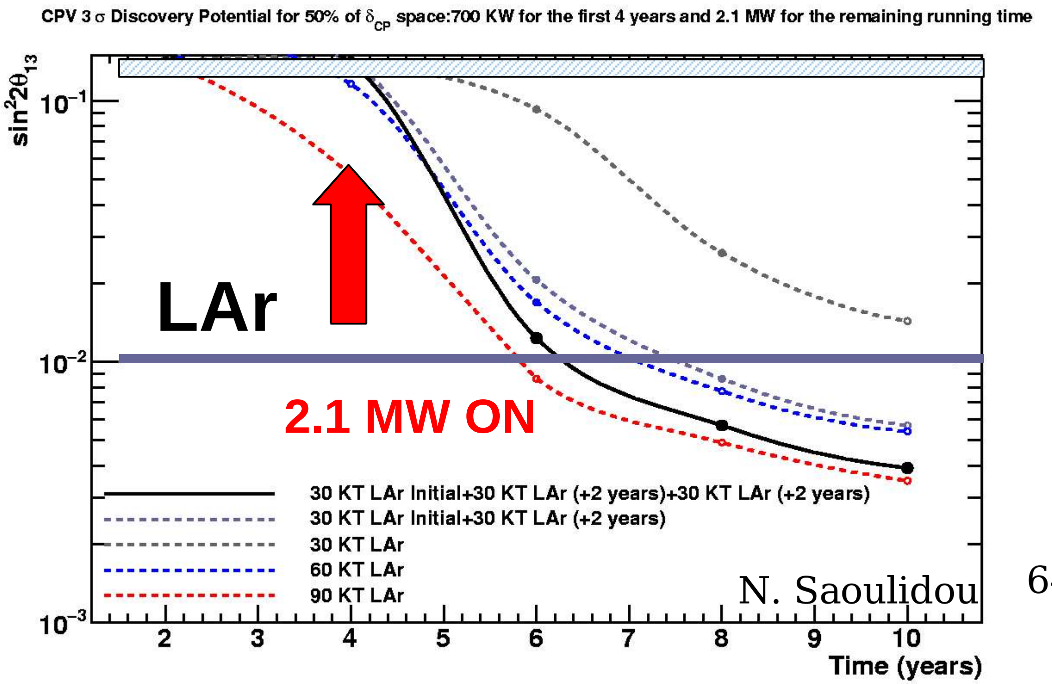
Sensitivities vs Time for LAr Detector: 700kW for first 2 years and 2.1MW for 6 years beyond this...

Add 30kton detector modules every 2 years for a total of 3 modules

θ_{13} Discovery Potential for all values of δ_{cp} (100%)

CPV Discovery Potential for 50% of δ_{cp}

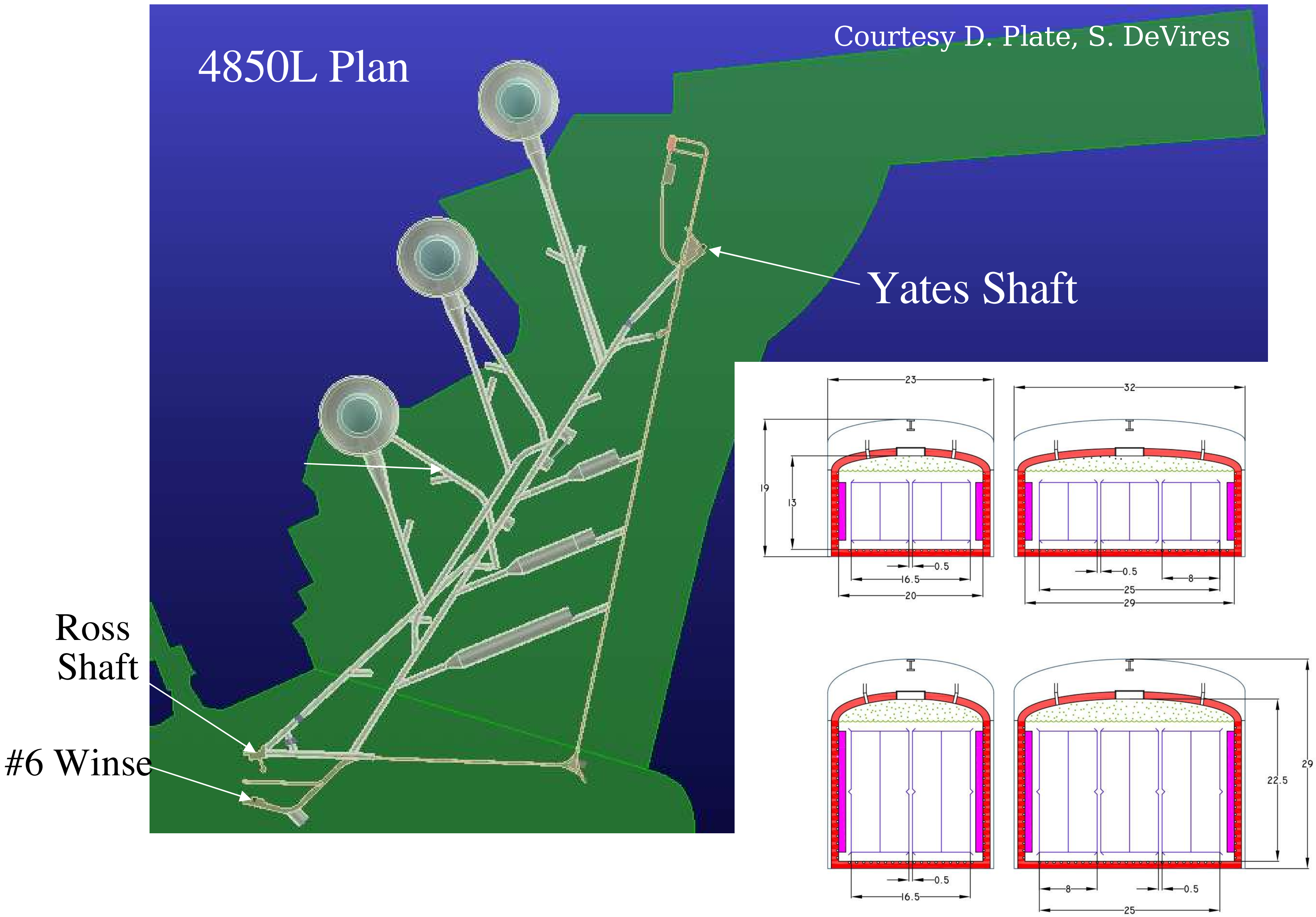




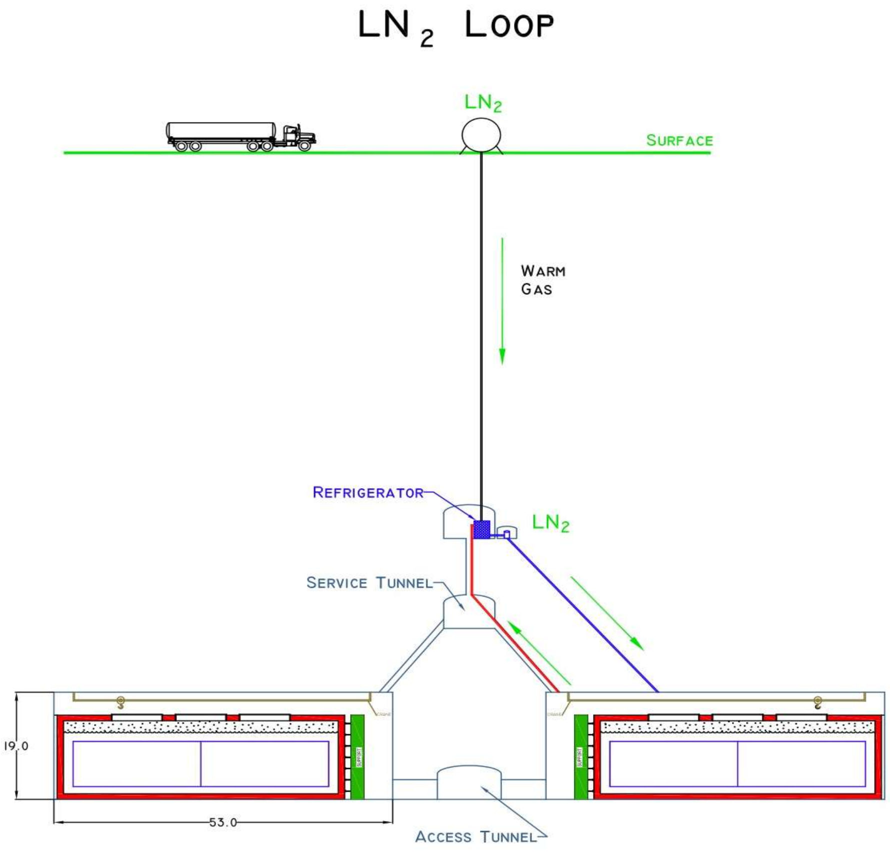
Of course, reach improved with 2.1MW beam!

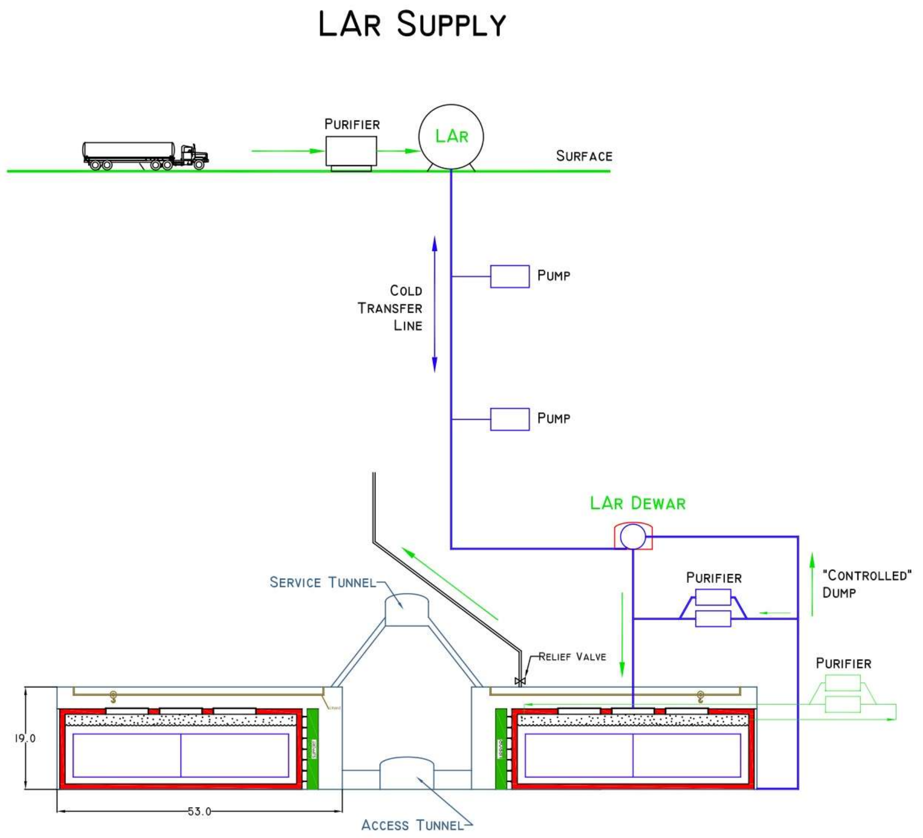
The WC – LAr mass equivalence is 1 – 6 (optimistic) to 1 –3 (very pessimistic)

Further excavation for modules beyond the 5kton needed



Initial Concepts for Cryogenics Underground





Underground Safety issues:

LAr loss: 0_2 content, reduction of temperature

Mitigation:

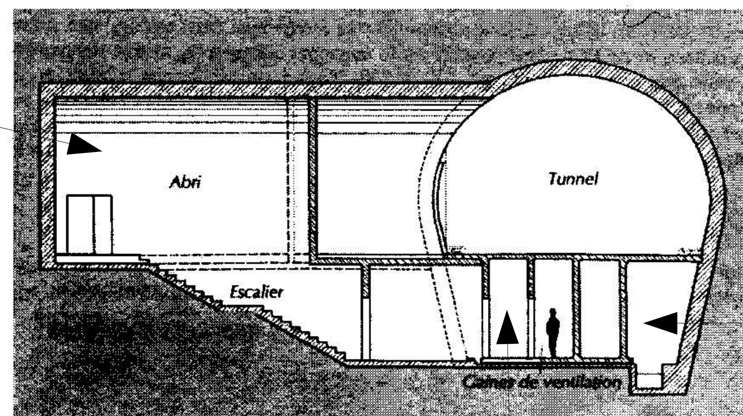
- Design: Use best cryo-techniques to minimize leaks
- Egress/Shelter: In cavern and from cavern

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

A lot underway, still a lot to do.....

Interest level in LAr program is growing rapidly in US!

- Test stand program: FNAL, BNL, and universities
- MicroBooNE: nearly doubled in size to 50+ scientiests since approval in July 2008
- LAr subgroup of LB to DUSEL collaboration
  - Rapidly growing collaboration list
  - Organizing into collaboration structure, for example...

S4 proposal to the NSF to fund R&D related to underground siting at DUSEL! →

Group Conveners :
Physics Reach: Niki Saoulidou
Cryostat and Cryogenics: Jon Urheim
TPC/PMT/HV: Bo Yu, Hanguo Wang
Electronics: Francesco Lanni

Team of people to push this effort is strong and expanding!
Growing support for the effort is needed to stay on an aggressive timescale...

Exciting time in neutrino physics!

R&D program that leads to Baseline plan
for 90ktons of LAr at DUSEL
Gives impressive reach in physics!

While massive LArTPC detectors seemed far off a few years ago – progress in US has proceeded very rapidly...
still lots of R&D to do but on a timescale that is do-able for DUSEL physics

5kton is a great way to start the program!
Fits in the caverns for the ISE
physics early on....