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DPF2006-JPS2006
November 1st, 2006

Liquid Argon Detectors for Long Baseline Neutrino Oscillation Physics

Big unknowns in neutrino physics:
$\sin^2 2\theta_{13}$, sign($\Delta m_{23}{}^2$), δ, **and LSND**?

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

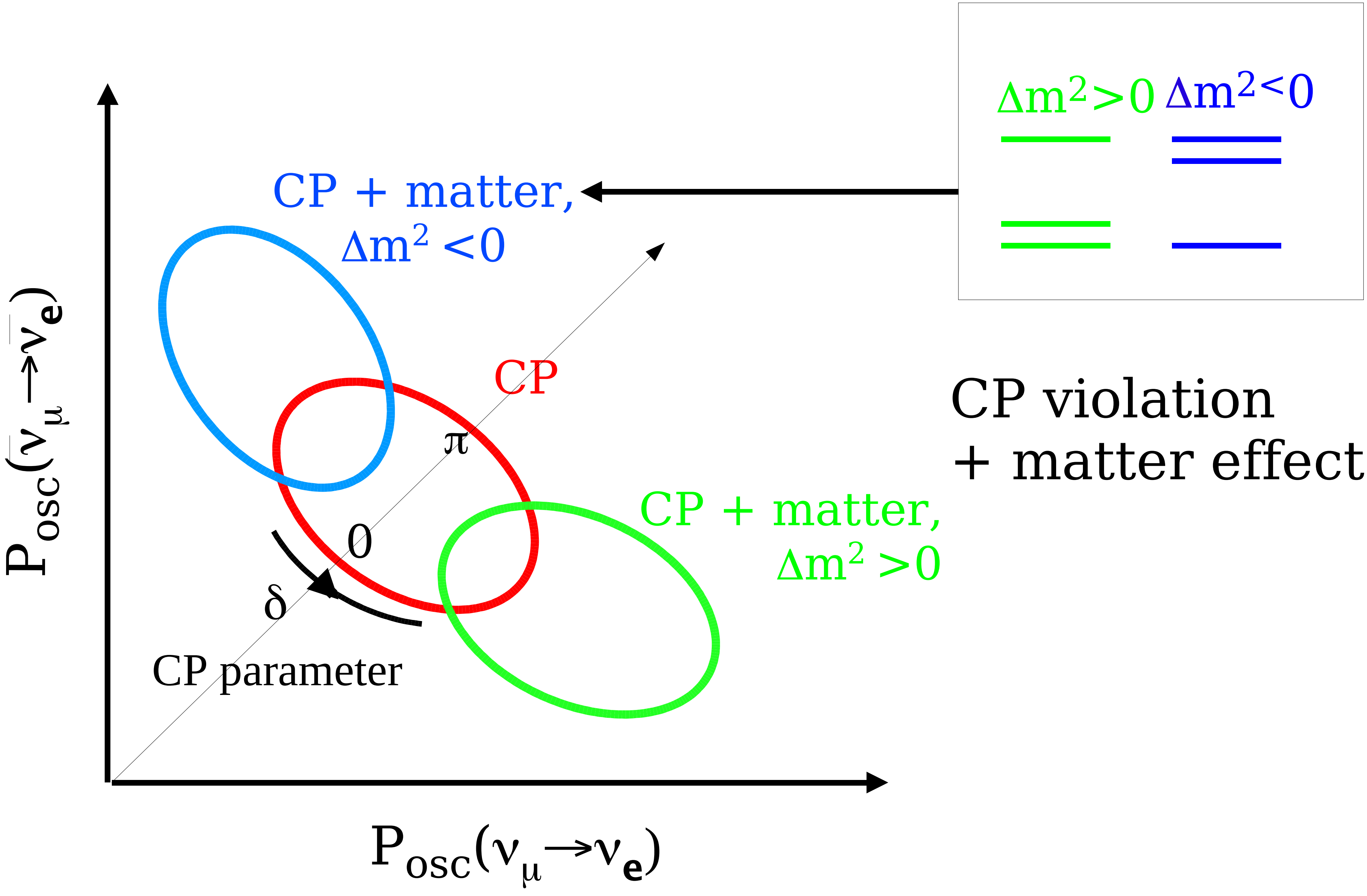
From Long Baseline Appearance Measurements

From Solar Neutrino Measurements

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

Long Baseline measurements probe δ and θ_{13}

As well as the mass hierarchy....

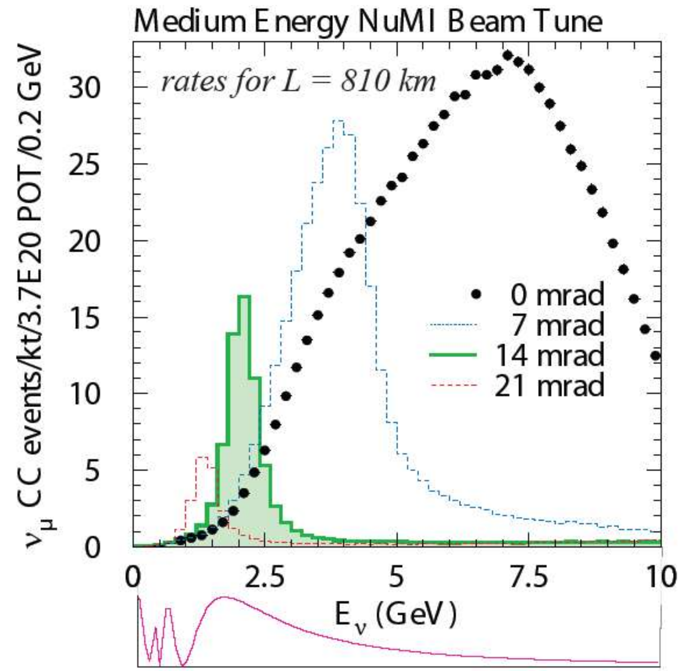


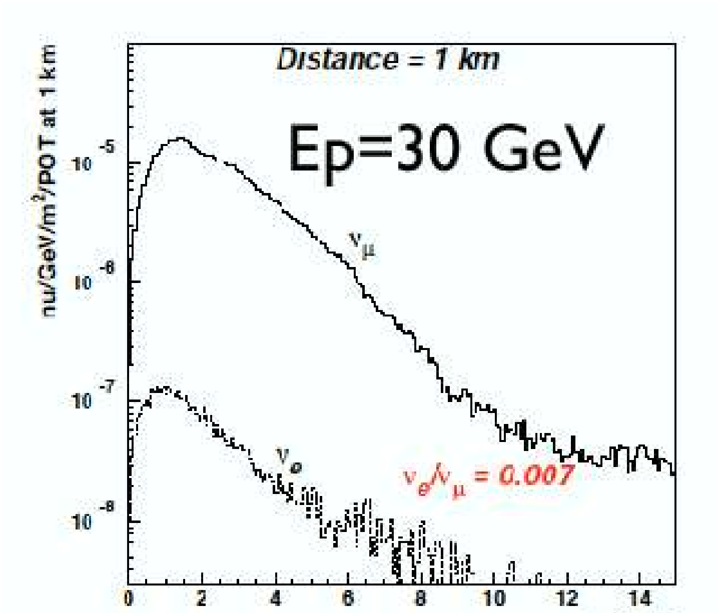
CP violation
+ matter effects

Two approaches to $\nu_\mu \rightarrow \nu_e$ long baseline searches

Off axis beams:
NOvA and T2K

Beyond NOvA (NuMI Off-Axis)
T2KK

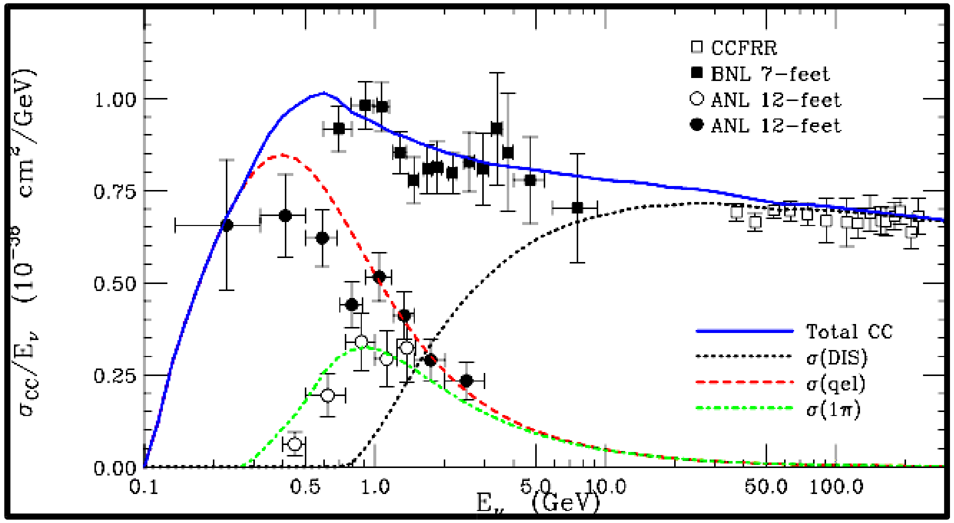




Wide Band, on axis beams:
Fermilab to DUSEL

Both span the 0.5-5GeV neutrino energy range

For both: need ***intense*** beams, and excellent detectors.....



Detector requirements:

- maximize ν_e efficiency
- minimize backgrounds from misIDs
  primarily NC $\pi°$ interactions

- Water Cerenkov
- Liquid Scintillator
- Liquid Argon TPCs

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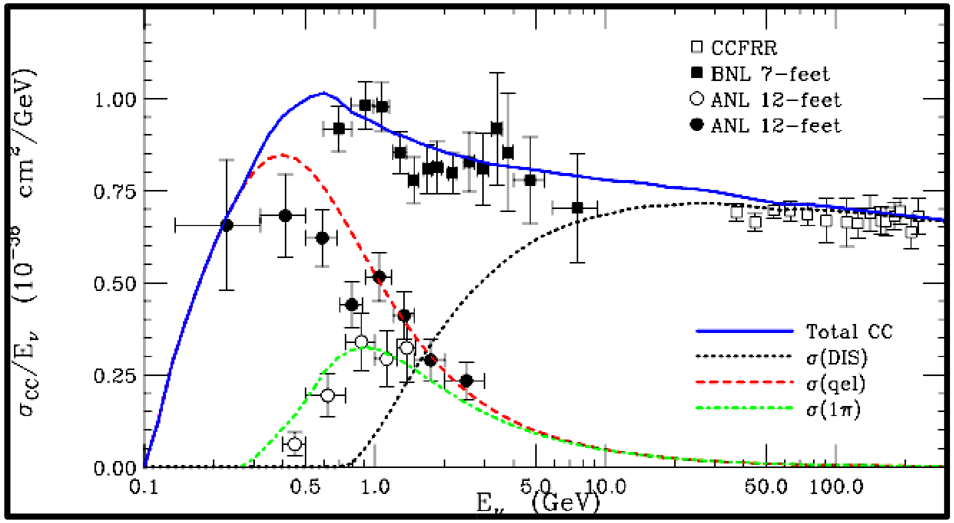

Detector requirements:

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- Water Cerenkov
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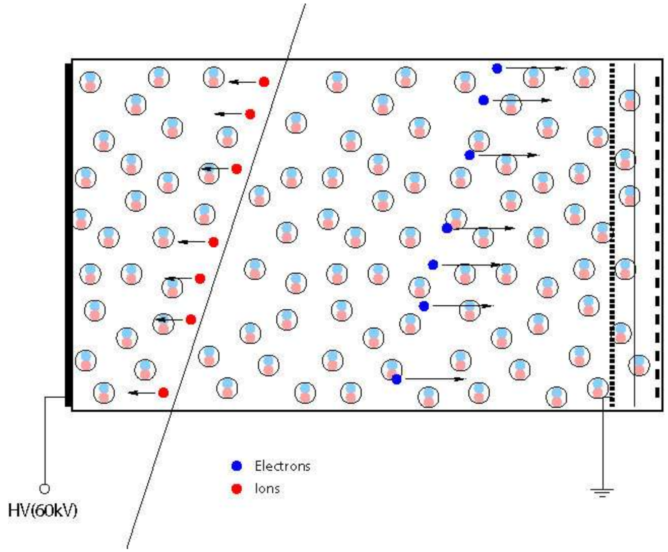
- Liquid Argon TPCs

LArTPCs by far have:

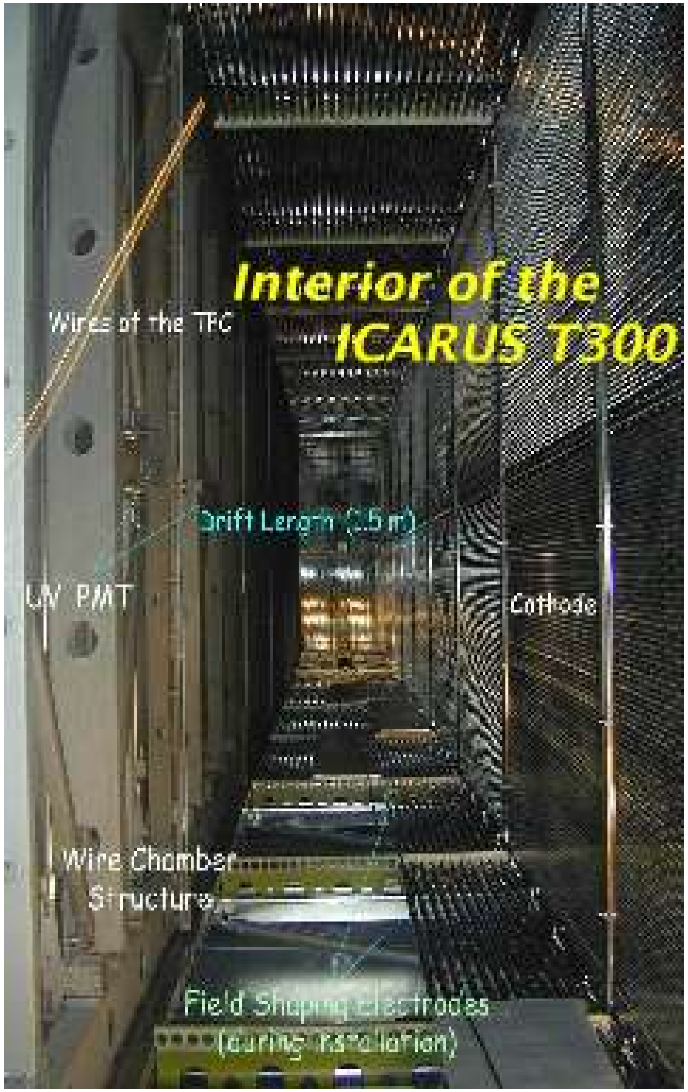
- *best ν_e efficiency : 80-90%*
- *neutral current π° rejection: <0.5%*
- *site detector at or near surface*

Liquid Argon TPCs:

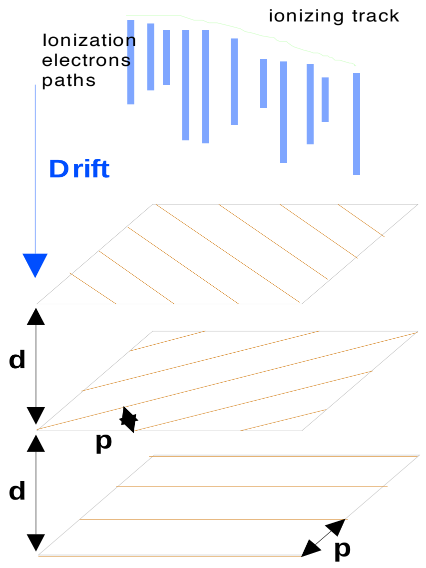
passing charged particles produce
55,000 electrons/cm



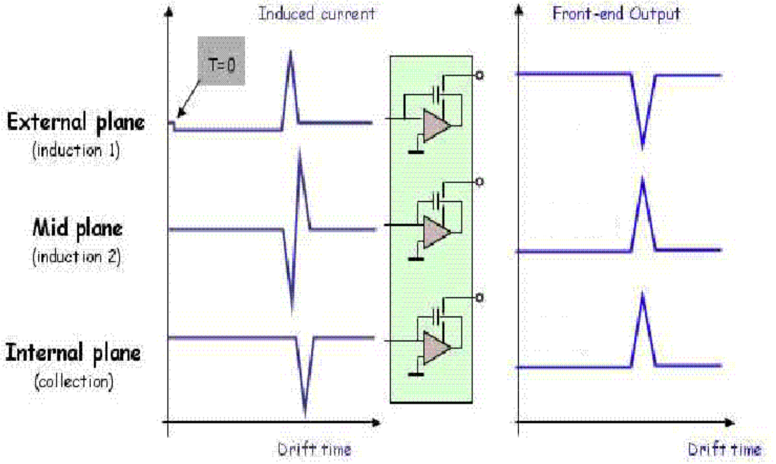
Drift ionization electrons over meters of pure liquid argon to collection planes to image track

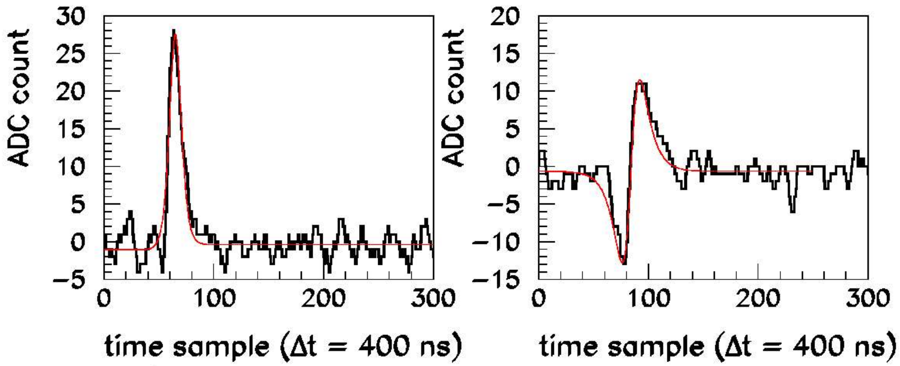


Signals on wire chamber planes



Arrange E fields and wire spacing for total transparency for induction planes. Final plane collects charge

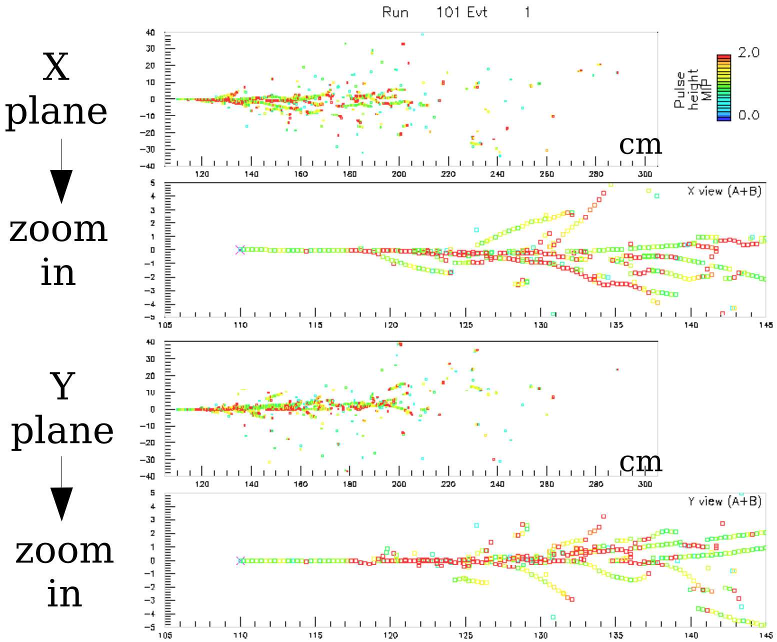




ICARUS TM/2001-09

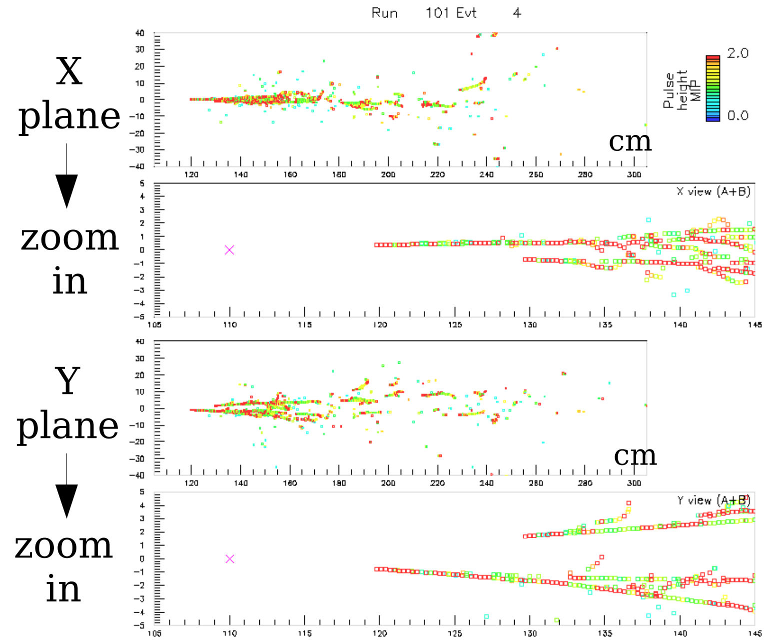
How does this translate into ν_e efficiency and π° rejection?

Dot indicates hit
color indicates collected charge
green=1 mip, red=2 mips



Electrons

Single track (mip scale) starting from a single vertex



π^0

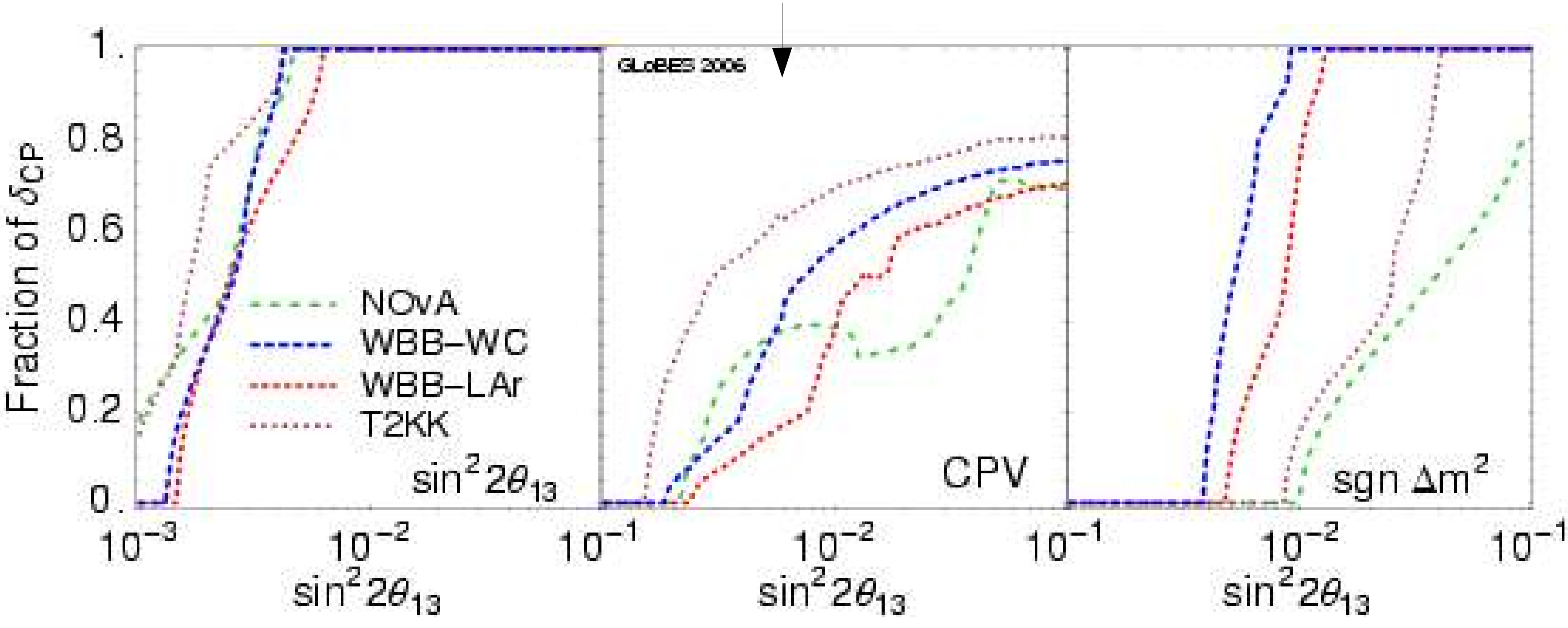
Multiple secondary tracks can be traced back to the same primary vertex

Each track is two electrons – 2 mip scale per hit

Use both topology and dE/dx to identify interactions

Signal efficiency and background rejection make these detectors ~x3 more sensitive to long baseline physics

See Parke et al. hep-ph/0505202 and more recently, Barger et al. hep-ph/0610301



"NOvA" = 100kton LAr detector at 1st osc. max
"WBB" = Wide band beam from FNAL to DUSEL
T2KK = Beam from JPARC to Kamioka and Korea

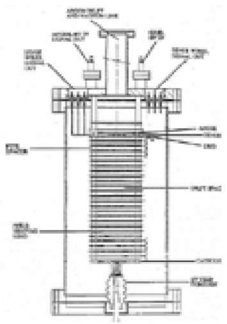
"WC": 300 kton Water Cerenkov Detector
"LAr": 100kton Liquid Argon TPC

These are great detectors, but even with excellent efficiencies they must be very large

↓

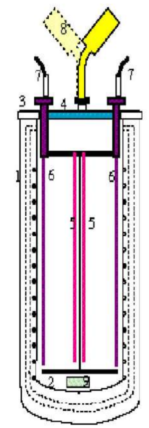
Can we build them?

Technical Feasibility:
History of prototype work on ICARUS



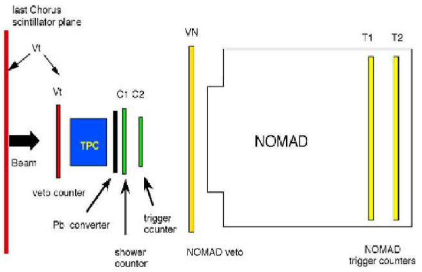
24 cm drift
wires chamber

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.



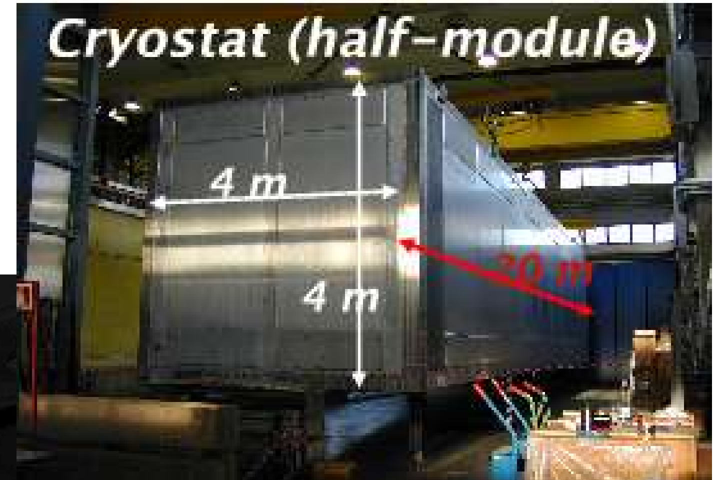
50 litres prototype
1.4 m drift chamber

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

10 m^3 industrial prototype

1999-2000: Test of final industrial solutions for the wire chamber mechanics and readout electronics.

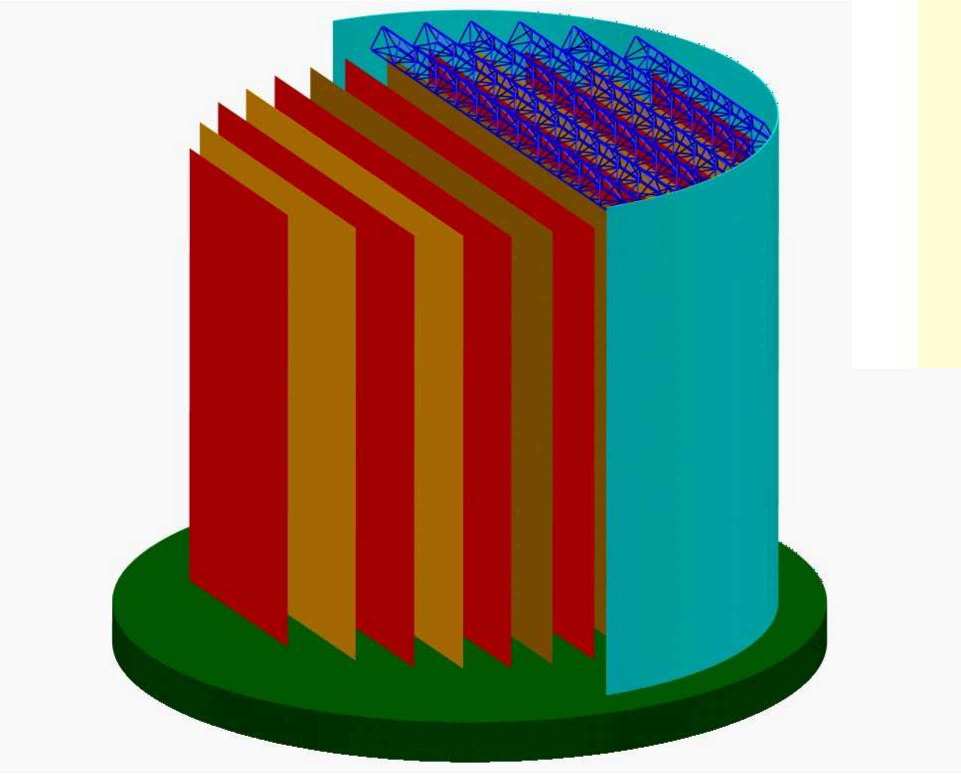
The success of the ICARUS T600

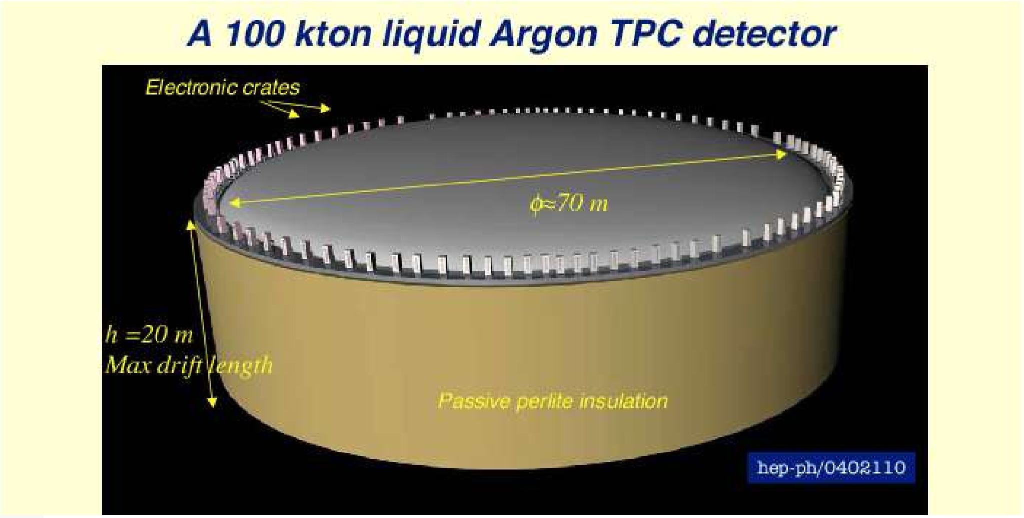


tested above ground in Pavia in 2001
now below ground in Gran Sasso

Several design ideas in moving beyond T600 to very massive detectors

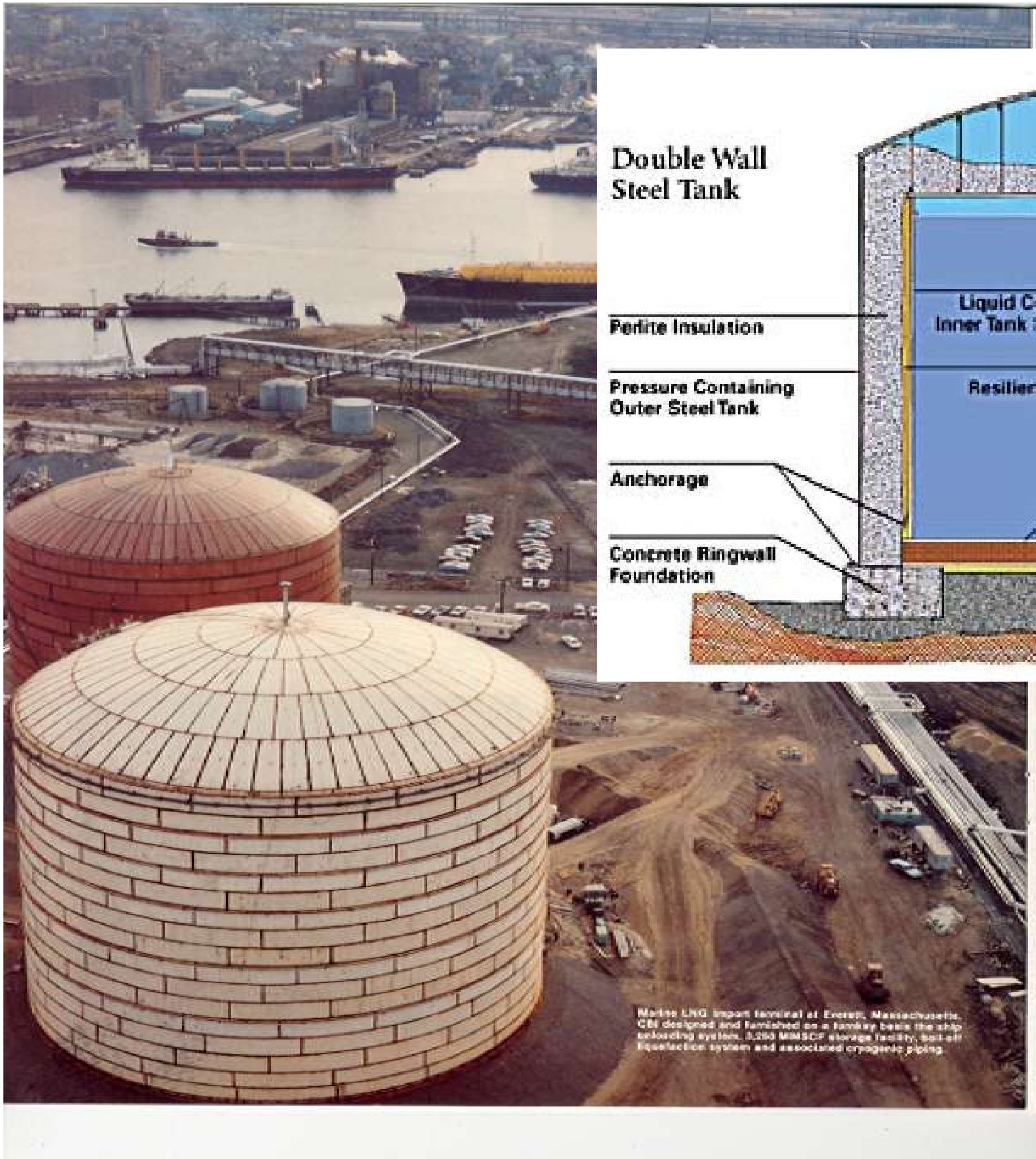
LArTPC: Modularized drift regions in one large (10-50kton) tank

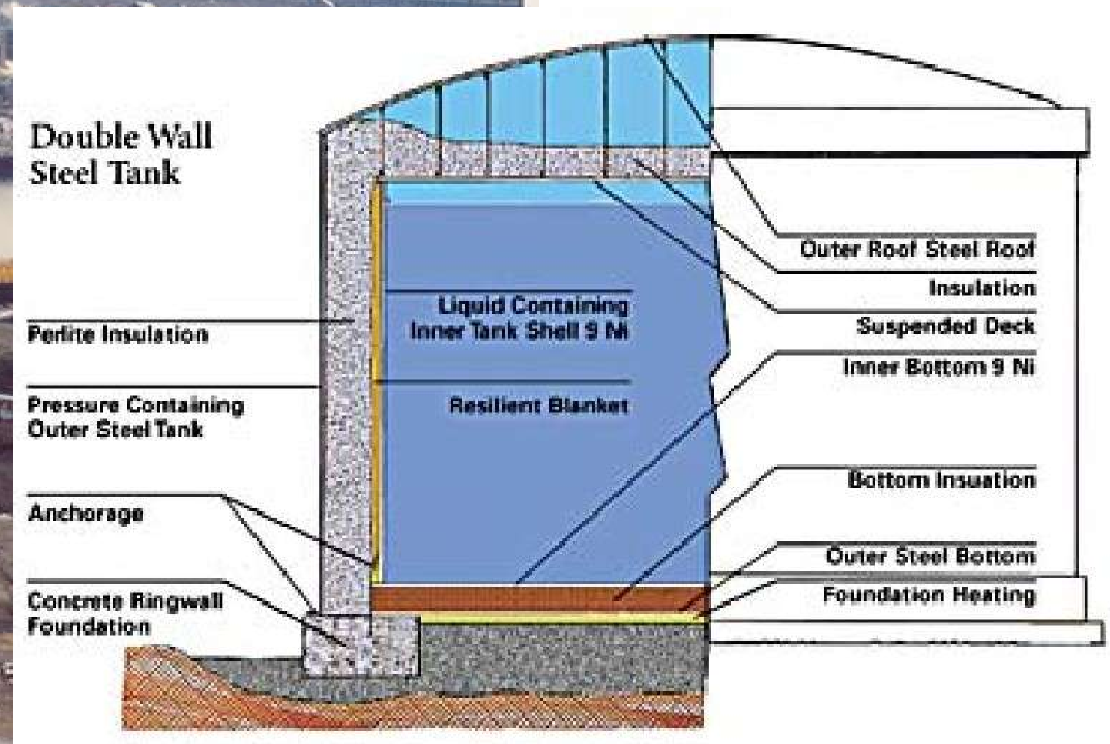




GLACIER: Combination of charge and light collection, single large drift area

LAANDD: modularized evacuated vessels



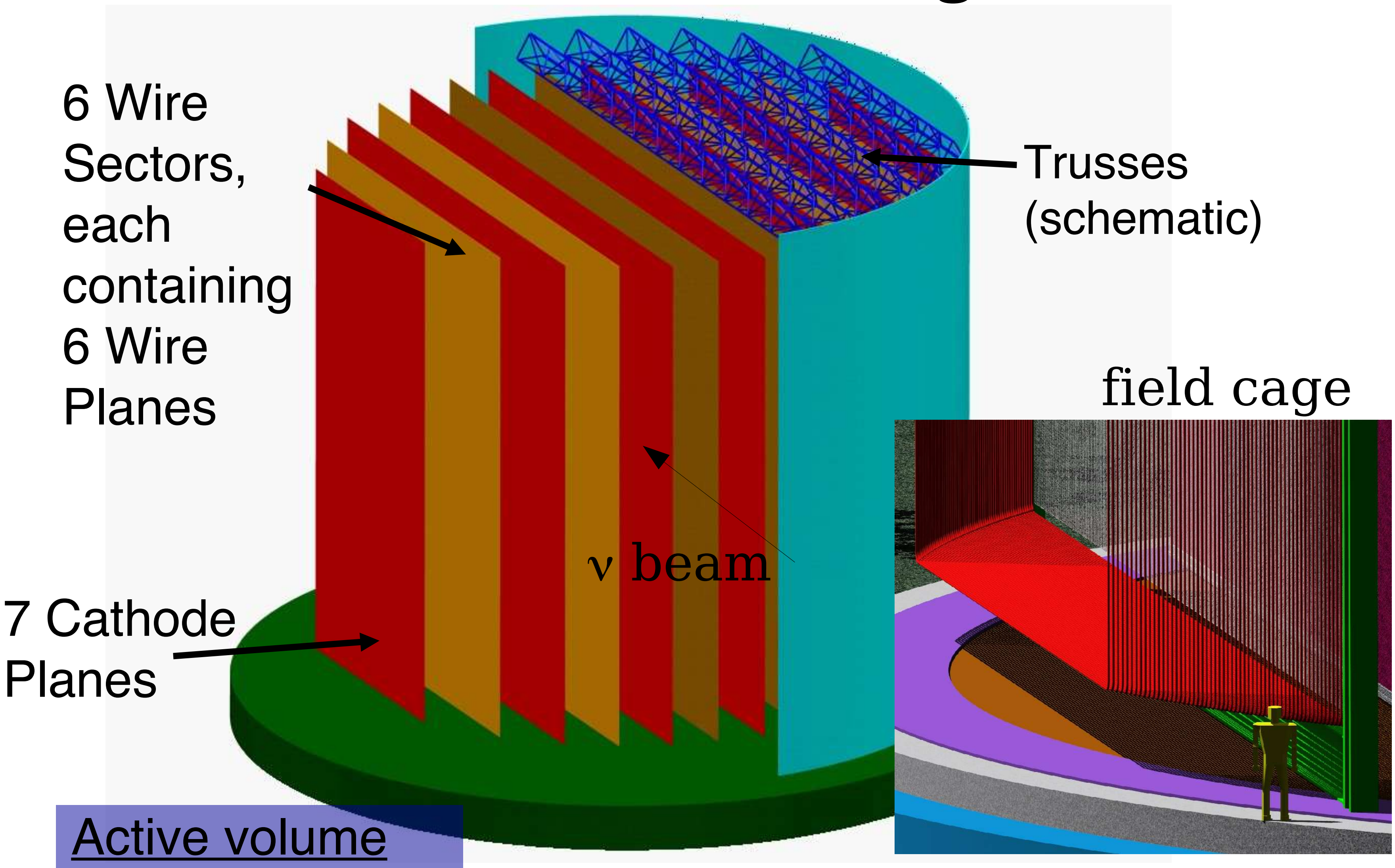


Many large LNG tanks in service

Excellent safety record

Last failure in 1940 understood

LArTPC: Modularized drift regions inside tank



Active volume
Diameter: 40m
Height: 30m

Scalable → 15-50 kTons
4 - 6 wire planes

Challenges for massive “ multi-drift region” detector

Purity:

3 m drift in LAr

purification - starting from atmosphere (cannot evacuate detector tank)

- effect of tank walls & non-clean-room assembly process

Wire-planes:

long wires *- mechanical robustness, tensioning, assembly, breakage/failure*

Signal processing:

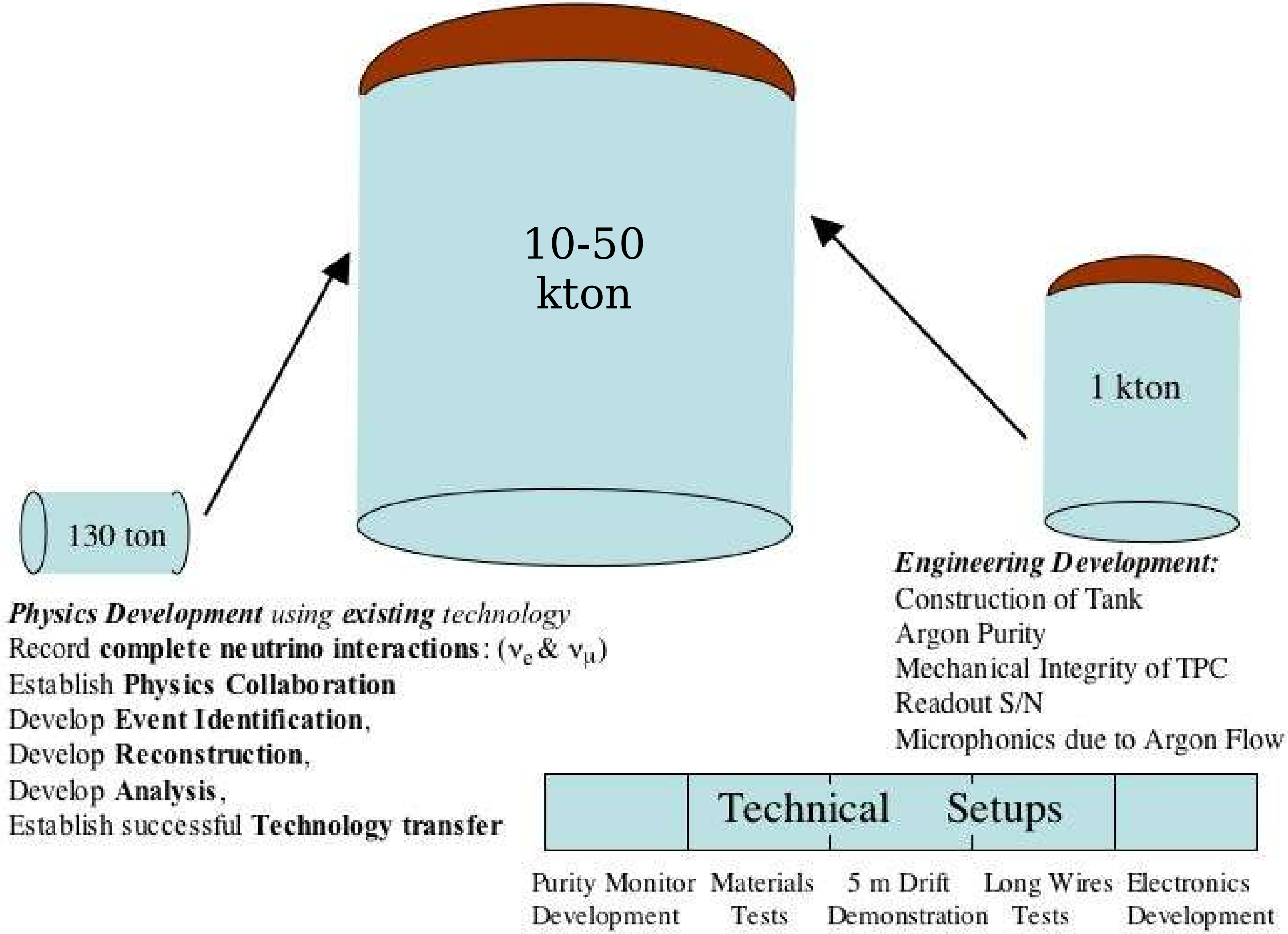
electronics *- noise due to long wire and connection cables (large capacitance)*

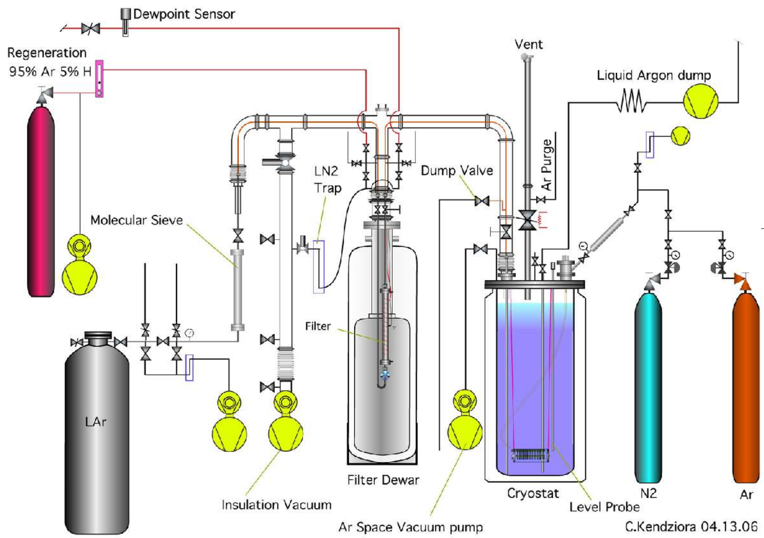
surface detector - data-rates,

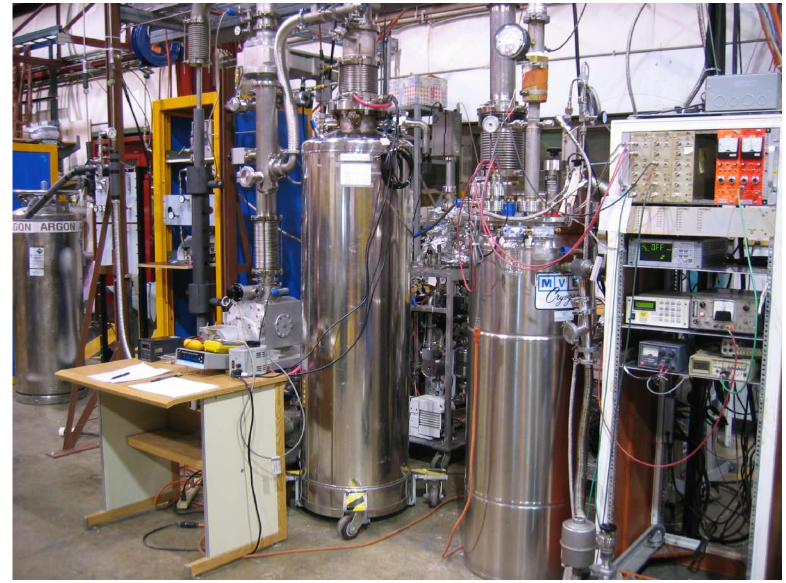
- automated cosmic ray rejection

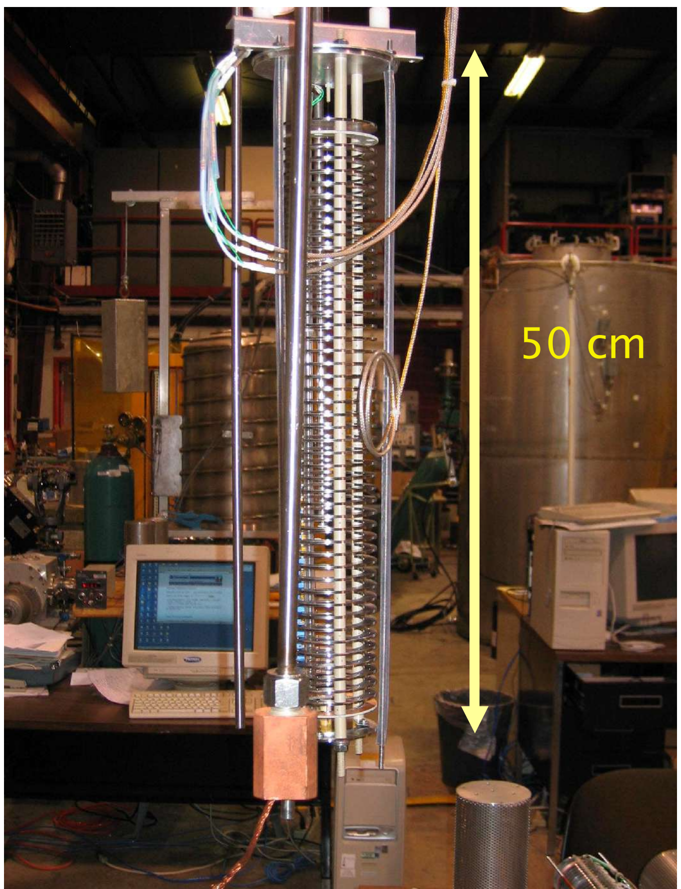
- automated event recognition and reconstruction

R&D path in scaling to 10-50 kton









Long drift test studies using Materials Test Stand at FNAL:

-Trigon filter, developed at FNAL

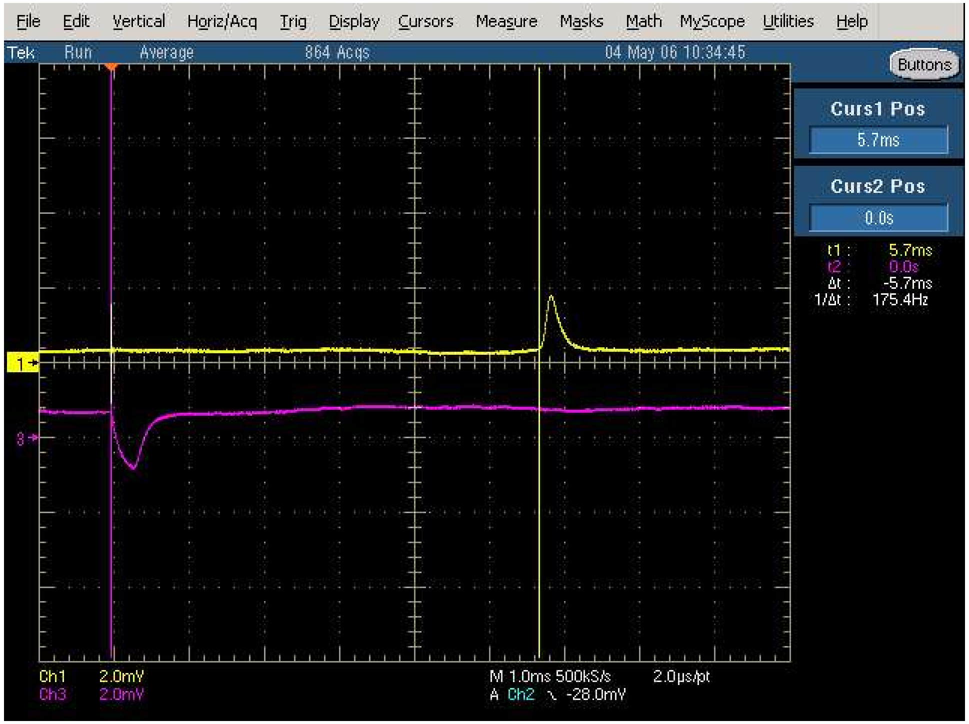
→ regenerated in line

-measure purity via ICARUS style purity monitor

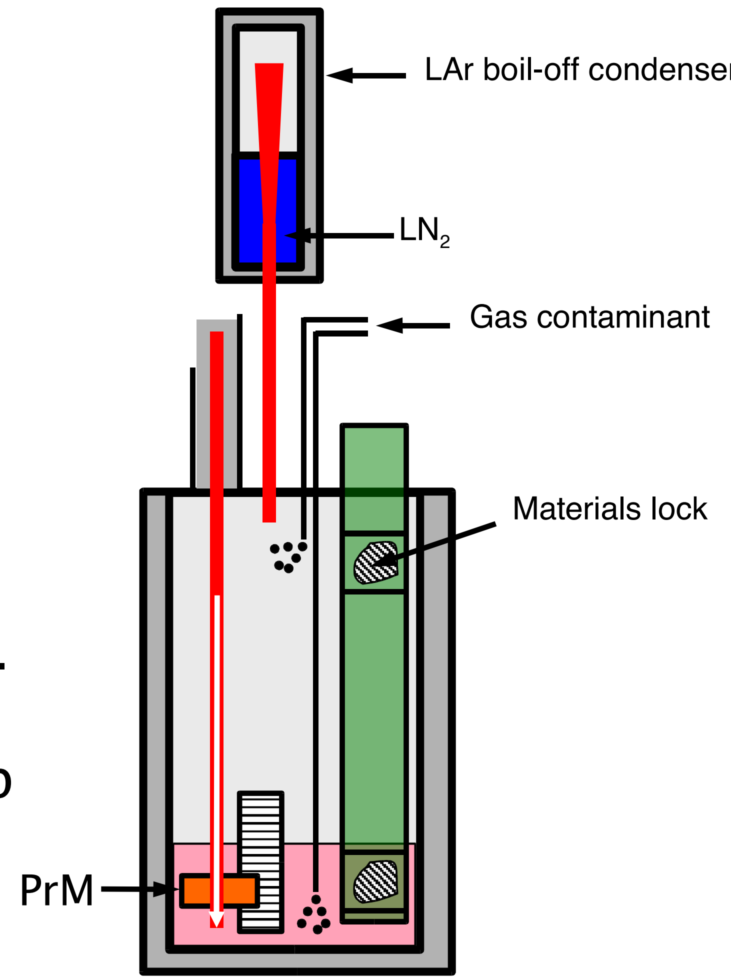
50 cm long drift

S. Pordes, FNAL

a 5.7 millisecond drift with the long PrM



Lifetime Measurements:
> 8ms lifetimes achieved.
Example here: 5.7ms drift



Next step:

Implement the Materials test station..
(new closed system cryostat)
Developing in-cryostat thermal pump

T. Tope

S. Pordes, FNAL

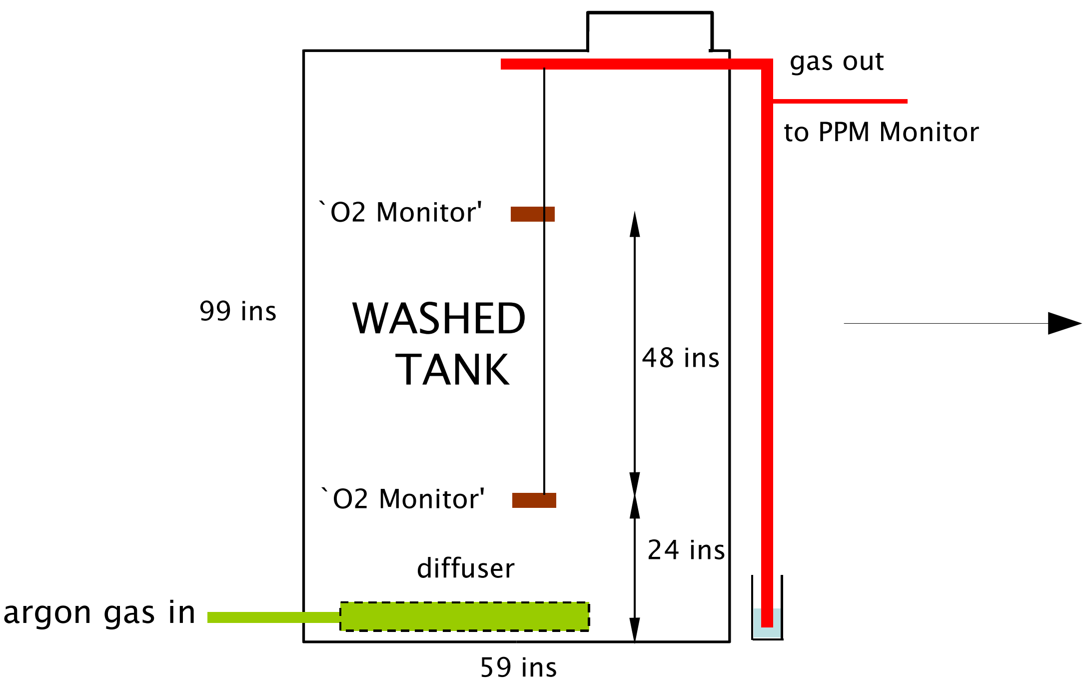
Purity in “industrial” vessel

Test of purging a volume from atmosphere:

insert Argon gas at bottom of tank over large area at low velocity;

the Argon introduced being heavier than air will act as a piston and drive the air out of the tank at the top;

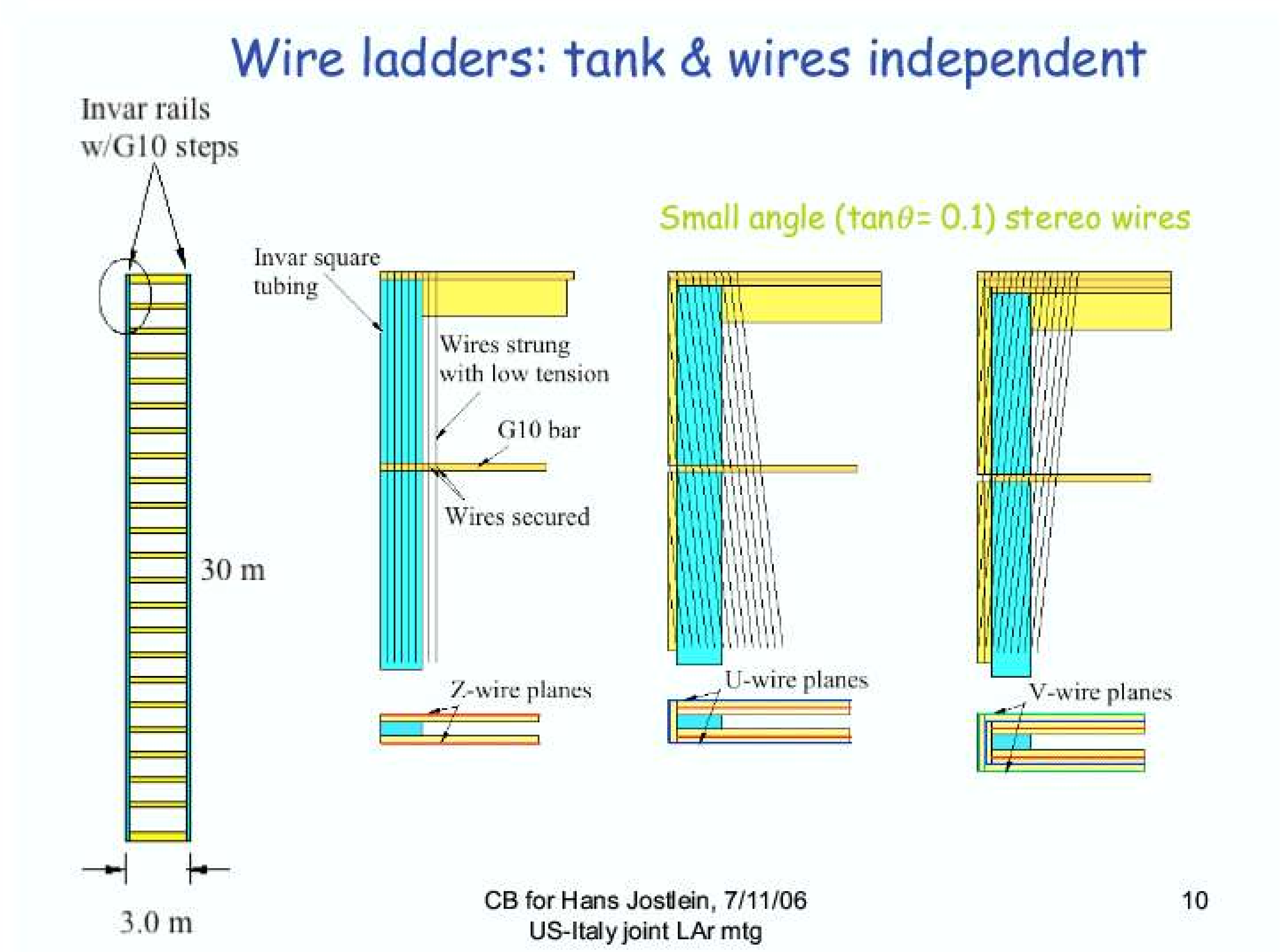
fewer volume changes than simple mixing model will achieve a given reduction in air concentration.



tank volume = 157 cf
tank cross section = 19 sf
flow rate ~ 73.2 cf/h (reading for air was 86 scfh)
climb rate ~ 3.8 f/h

S. Pordes, FNAL

Cellular design for detector wire planes

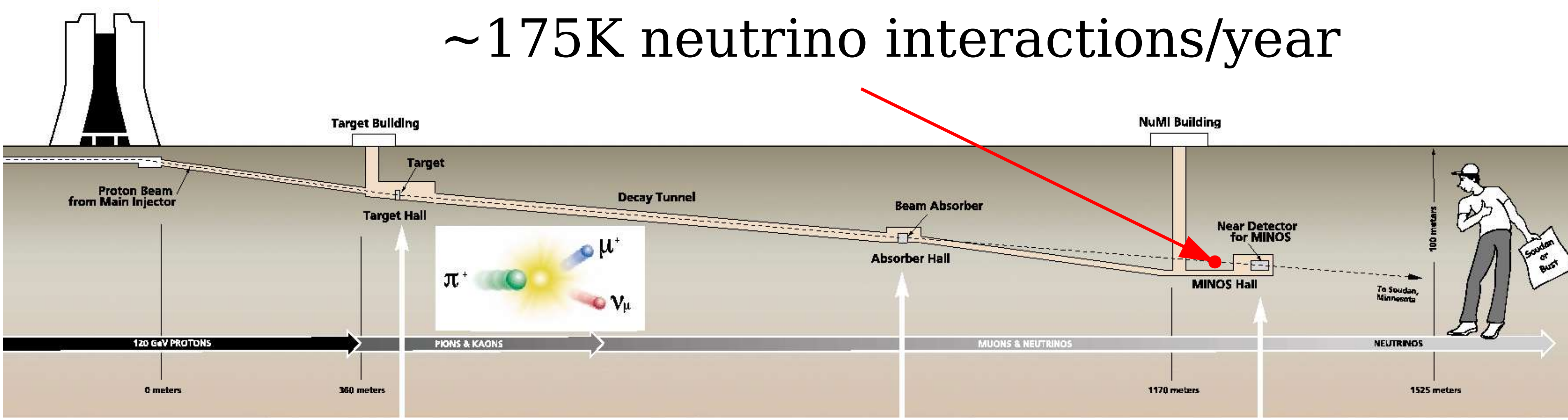


Seeing tracks:small TPC prototypes at Yale and FNAL

Yale Prototype TPC

Larger version of this
-> expose to NuMI beam

300 liter TPC (~175 liter active volume) exposed to on-axis NuMI beam:
~175K neutrino interactions/year



→ 5m drift TPC test program starting up at FNAL as well!

LArTPC's report to NuSAG*

www-lartpc.fnal.gov

Fermilab Note: **FN-0776-E**

A Large Liquid Argon Time Projection Chamber for Long-baseline, Off-Axis Neutrino Oscillation Physics with the NuMI Beam

Submission to NuSAG

September 15, 2005

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from NuSAG (Feb, 2006)

"A promising emergent technology for the detection of ne appearance is the Liquid Argon Time Projection Chamber."

One of top three recommendations for US accelerator program:
The US R&D program in Liquid Argon TPC's should be supported at a level that can establish if the technology is scalable to the 10-30 kiloton range. If workable, this technology will come into its own in the later phases of the long-baseline program.

Growing collaboration of Fermilab scientists, University groups (Michigan State, Princeton, Tufts, UCLA, Yale, York)

→ growing interest from INFN groups

Various considered options along the JPARC neutrino beam…
Korea > 100 kton
SK cavern ≈ 30 kton
2km ≈ 100 tons
280m ≈ 3 tons?
E137°30'
N39°
N37°
N35°
N33°
Tokyo
Kawasaki
Imperial Palace, Tokyo, Japan
Image © 2005 EarthSat
Google
A. Rubbia, Seoul, July 2006

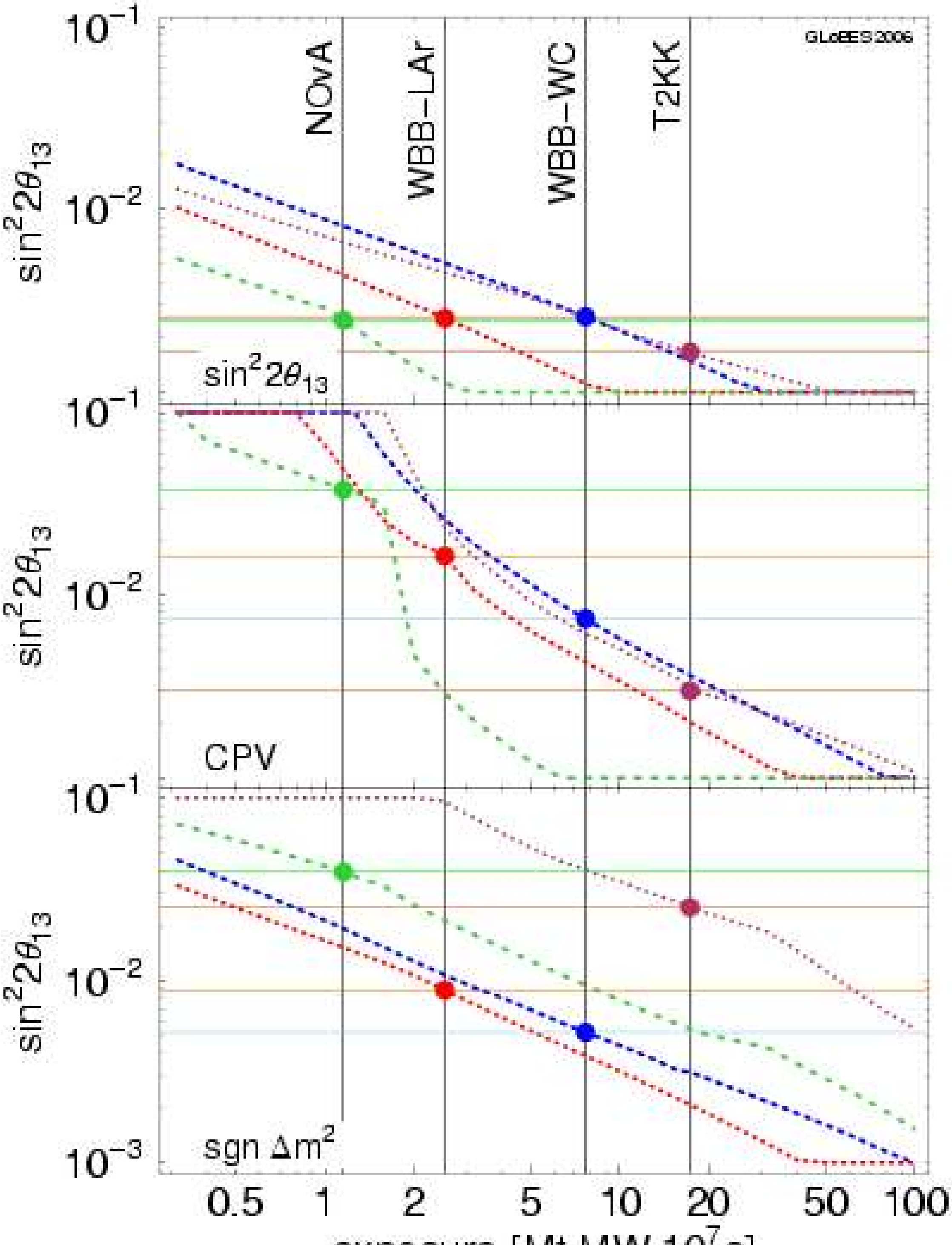
Summary

Liquid Argon TPCs are the best detectors for long baseline oscillation physics (as well as for nucleon decay, supernova detection....etc)

Challenging to construct on massive scales

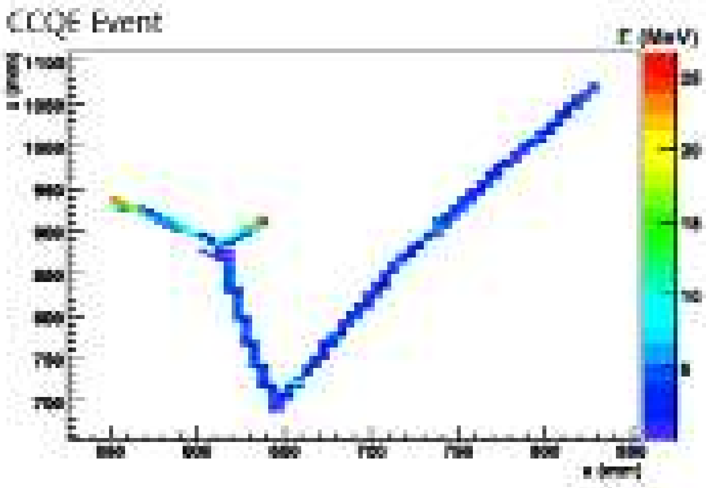
R&D program towards achieveing this both in the US, and in Europe and Japan

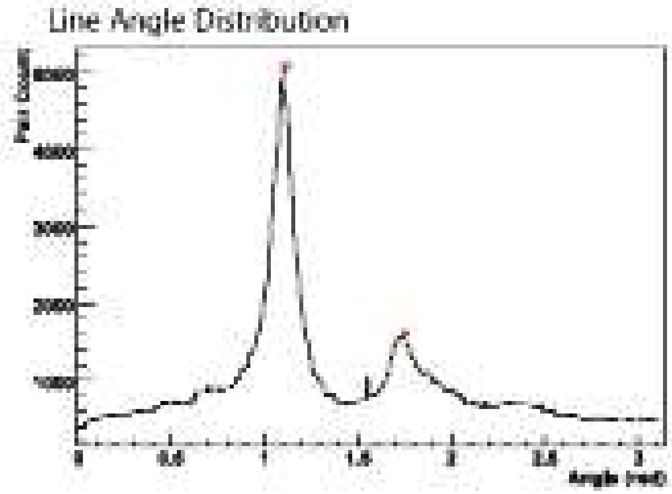
Growing interest in realizing these detectors!

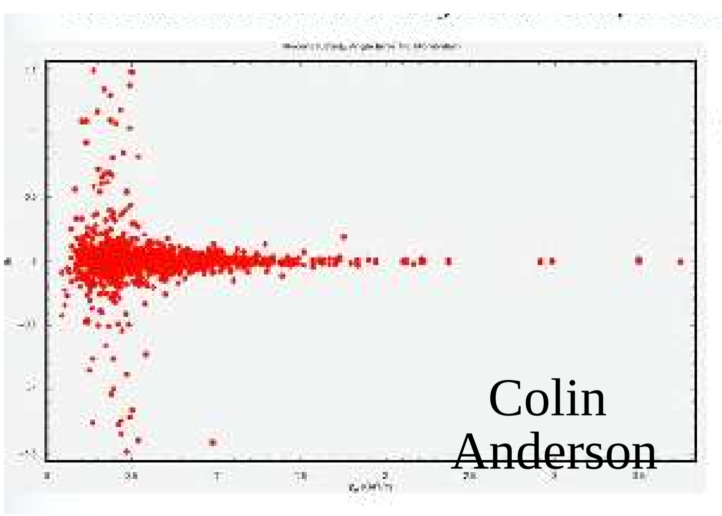


GLoBES 2006
NOvA
WBB–LAr
WBB–WC
T2KK
$\sin^2 2\theta_{13}$
CPV
sgn Δm^2
10^{-1}
10^{-2}
10^{-3}
0.5
1
2
5
10
20
50
100
exposure [Mt MW 10^7 s]

Physics R&D:
develop fully automated reconstruction....







Colin Anderson

Reconstruct primary and secondary vertex and muon track to within 2 deg.

work in progress