Liquid Argon R&D in the US

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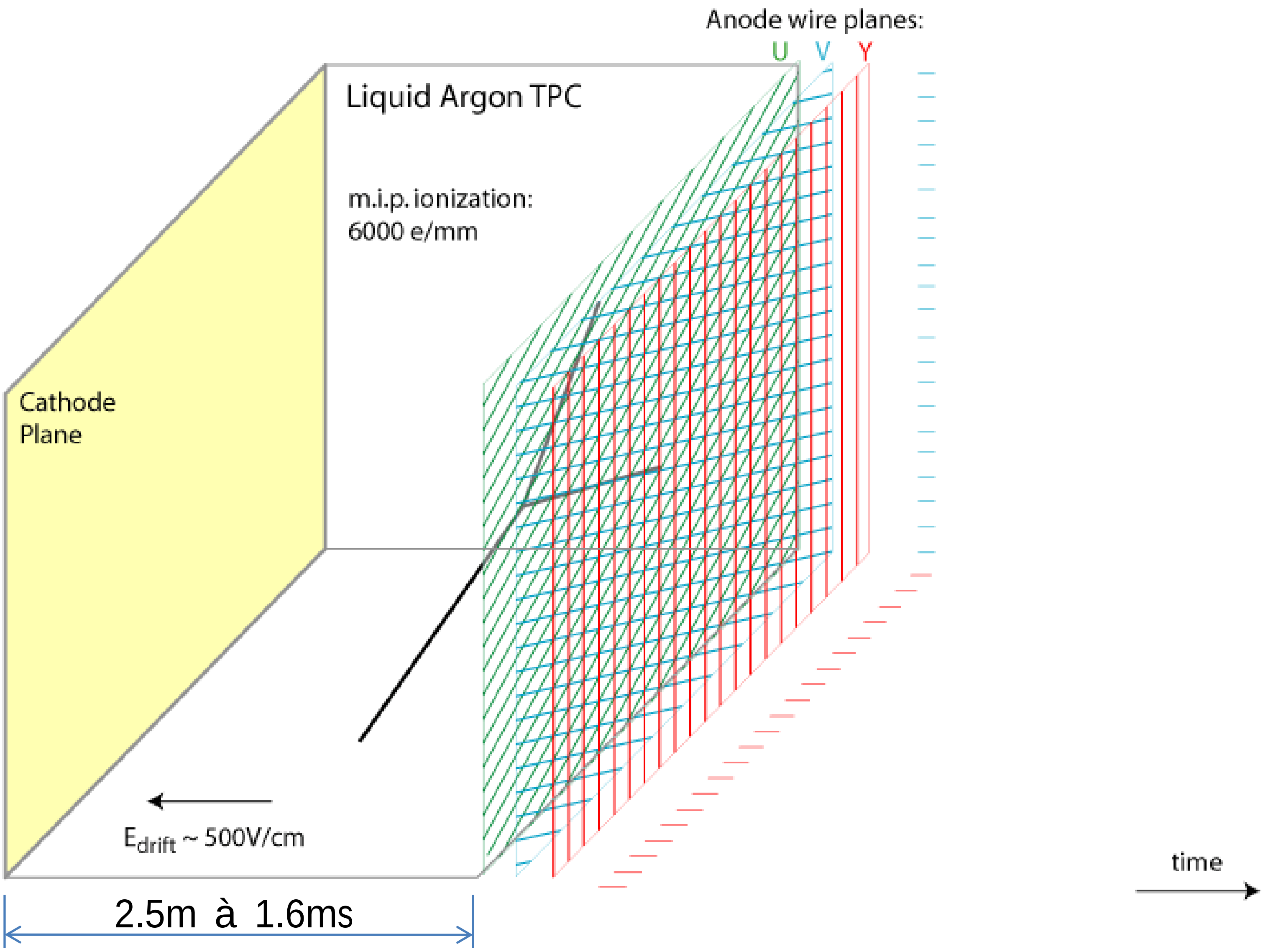
Fermilab

Outline

- LAr TPC Basics
- The Integrated R&D Plan
- The Short Term Goal (LBNE – LAr20)
- Argon purity
- On-wire electronics
- LAr TPC operation
- Summary



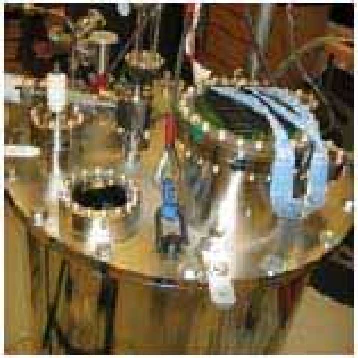
Need extremely good LAr purity, low convective flow

Liquid-Argon Time Projection Chambers

Status of R&D Program in the US Leading to LAr20

The first TPCs in the United States:

Yale TPC



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

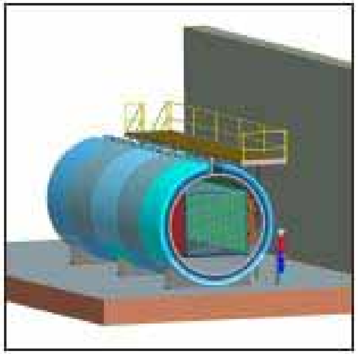
Bo

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

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

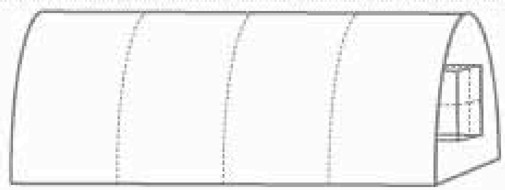
MicroBooNE

Construction begins 2010
Physics: Investigate low-energy neutrino interactions

0.1 kton

4x50x

LAr TPC for LBNE

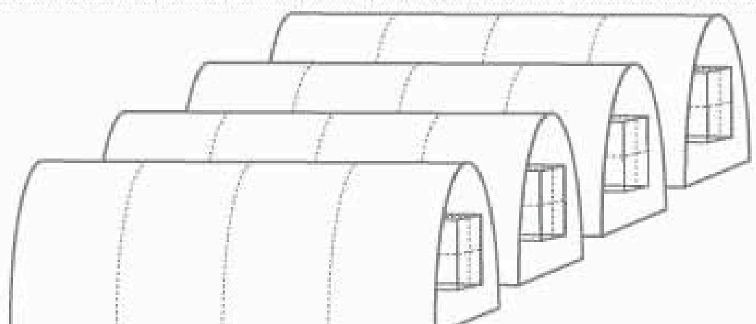


R&D in progress
Physics: Measure neutrino oscillations at 1,000+ km

LAr20

20 kton

Final goal



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

N x 20 kton


DUSEL
Lead, SD
South Dakota
North Dakota
Minnesota
Wisconsin
Michigan
Ontario
L = 1290 km
Milwaukee
Chicago
Fermilab
Iowa
Illinois
Missouri
Image NASA
© 2008 Tele Atlas
Image © 2008 TerraMetrics
© 2008 Europa Technologies
Google
Pointer 43°03'56.44" N 95°10'42.53" W Streaming 100%
Eye alt 1108.62 km

LBNE - Long Baseline Neutrino Experiment

$950M on 1 slide

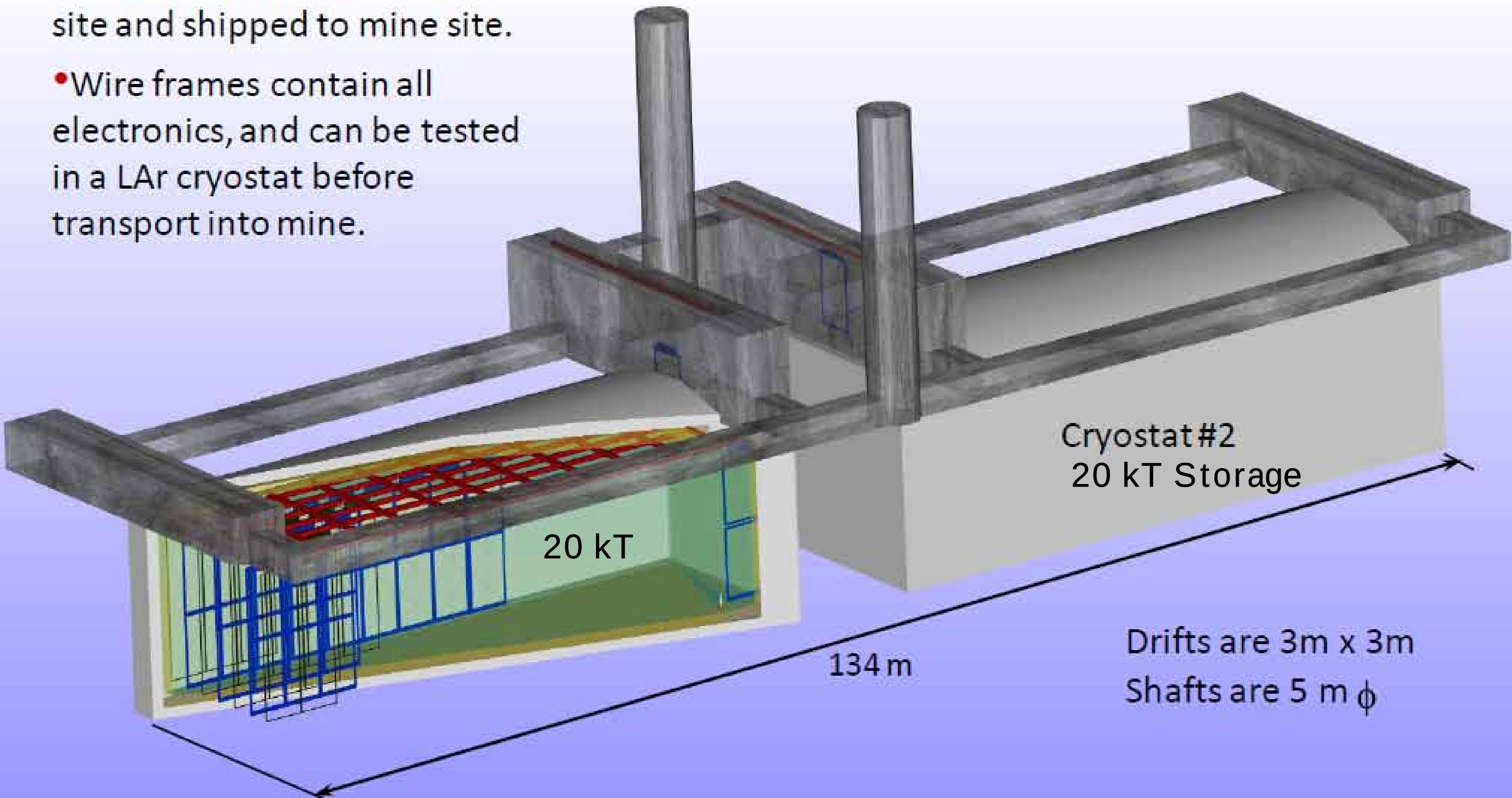
- 10 year project
- CD-0 granted in mid January
- CD-0 Scope
  - 700kW proton beam (upgrade path to 2MW)
  - Neutrino beam (0.5 – 4 GeV)
  - Near detector
  - 1000+km baseline
  - 2 x 100kton Water Cherenkov Equivalent far detectors, for instance
    - 100kton WC
    - 16.7 kton LAr TPC à LAr20
- CD-1 review December 2010

Is this technology ready?
Is it cost competitive, safe?

LAr20 Reference Design 3a

Cryostat #1 cut open to show assembly; drifts and shafts are transparent

- Cathode and wire frames can be manufactured at a remote site and shipped to mine site.
- Wire frames contain all electronics, and can be tested in a LAr cryostat before transport into mine.

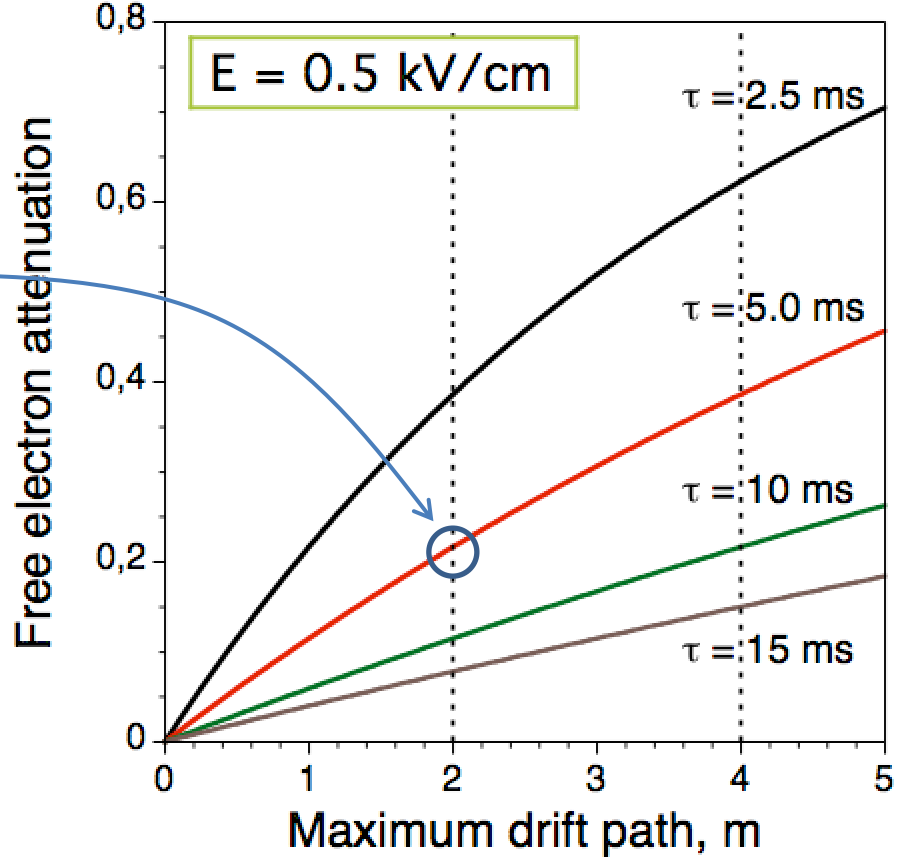


Main Challenges for Massive LAr TPCs

- **LAr Purity in large industrial vessels**
  - Materials qualification à Materials Test Stand
  - Purification techniques for non-evacuable vessels à LAPD
- **Large scale low-noise, low-power readout (~500k channels)**
  - On-Wire (cold) electronics and signal multiplexing à LAr20 R&D
- **Underground issues: safety à LAr20**
  - **No cryostat penetrations in the liquid**
- **Cost à LAr20**

Purity Requirement

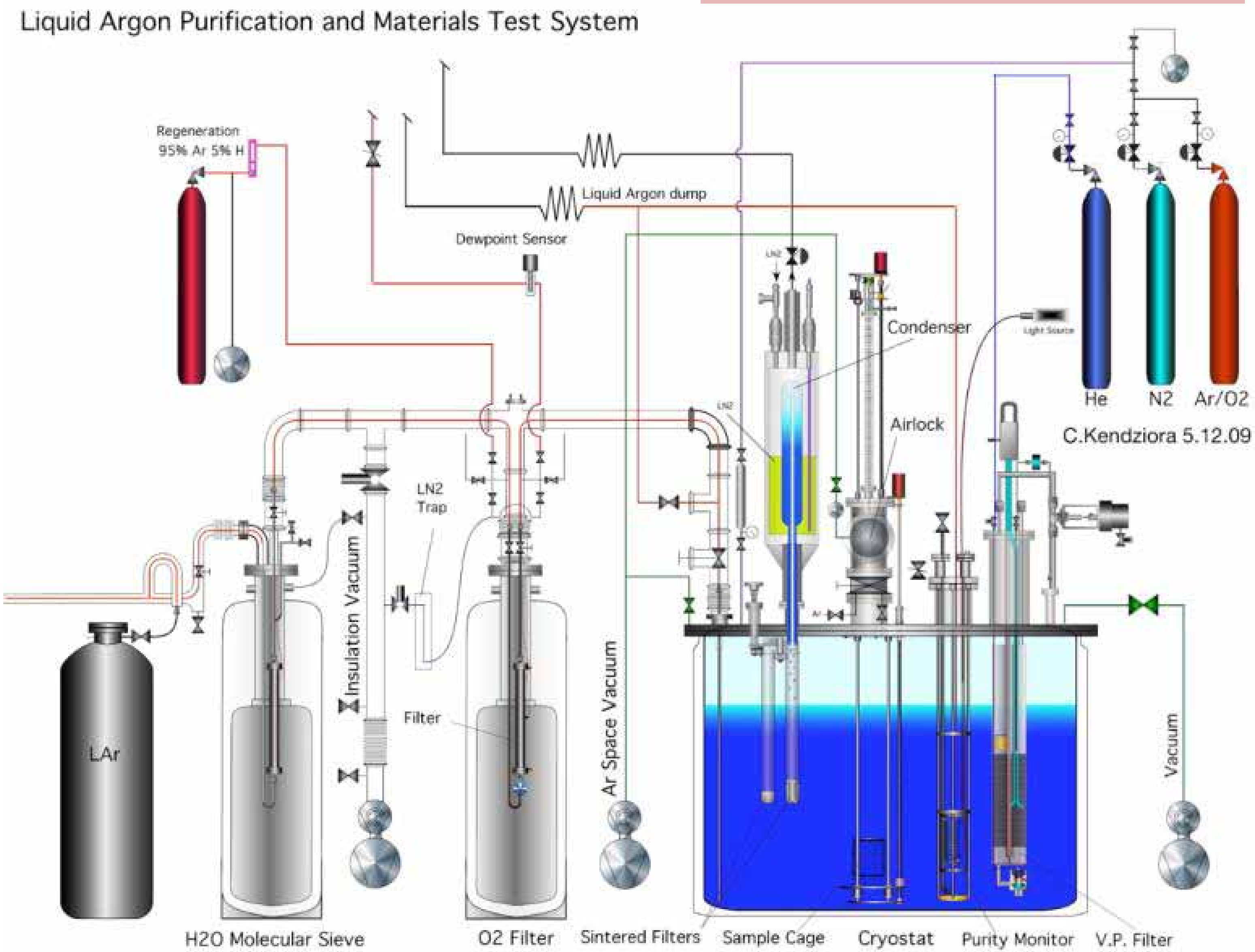
- Electro-negative contaminants
  - O_2 & water
- If 20% signal loss is OK for 2m drift
  - Need 5 ms electron lifetime ~60 ppt O_2 contamination
  - LAr supply typical 1 ppm
- N_2 < 1 ppm for light collection



Test Stands (Bo & Luke)

Stephen Pordes (FNAL)

Pordes, Kendziora, Tope (FNAL)



Materials Test Stand Features

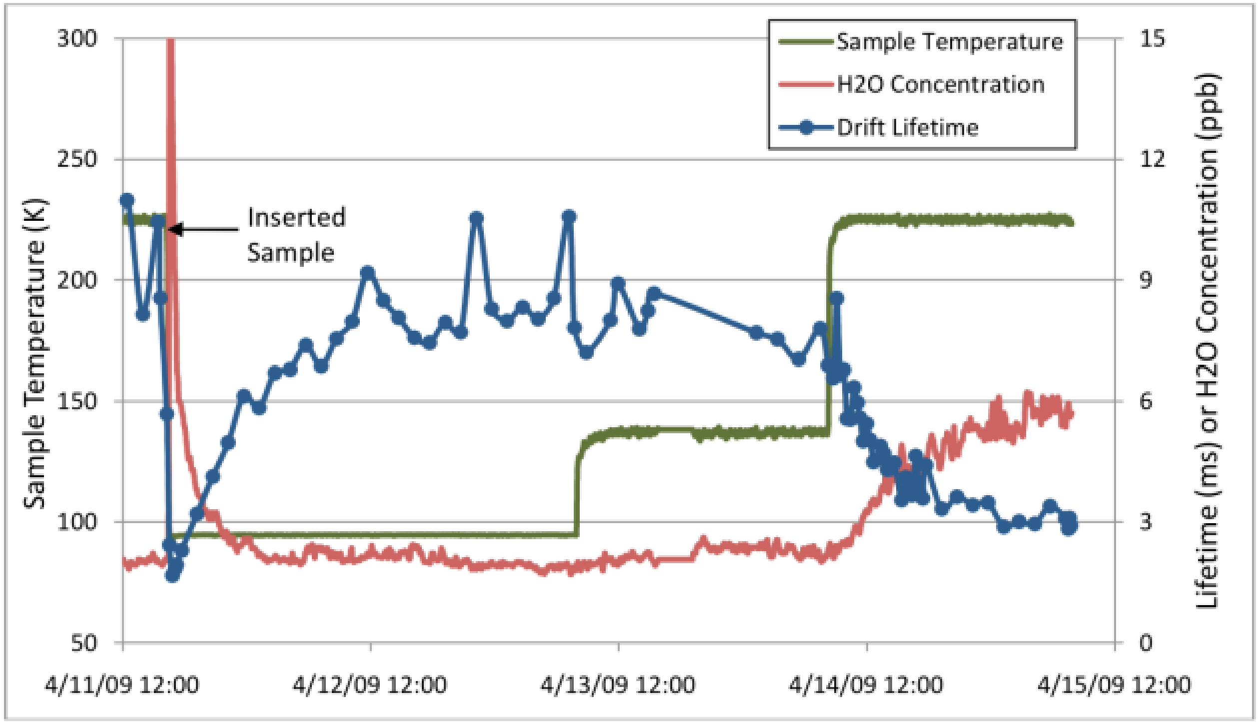
- Can insert materials into known clean argon
- Can insert materials after purging only or after pumping on them.
- Can position materials into liquid and into ullage with range of temperatures
- Can insert known amounts of contaminant gases
- LN2 condenser can maintain liquid for long studies (weeks)
- Internal filter-pump can remove contamination introduced by materials – 2hr cycle
- Sample points at Argon Source, after single-pass filters, in cryostat gas and liquid

Summary of Results

Material	Sample Surface Area (cm^2)	Effect of Material on Electron Drift Lifetime (LT)			Comments
		94 K liquid	≈120 K vapor	≈225 K Vapor	
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 endpoint for uBooNE	225	None	None	None	Sample was evacuated in airlock prior to testing
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.

Water Effects

FR-4 based circuit board – from Argon lock *with purging only*



Significant change in H20 reading and significant reduction in lifetime

Water is the dominant contaminant, not O_2, for lifetimes of 5 – 10 msec
Not a contaminant if the materials containing it are maintained at ~100K

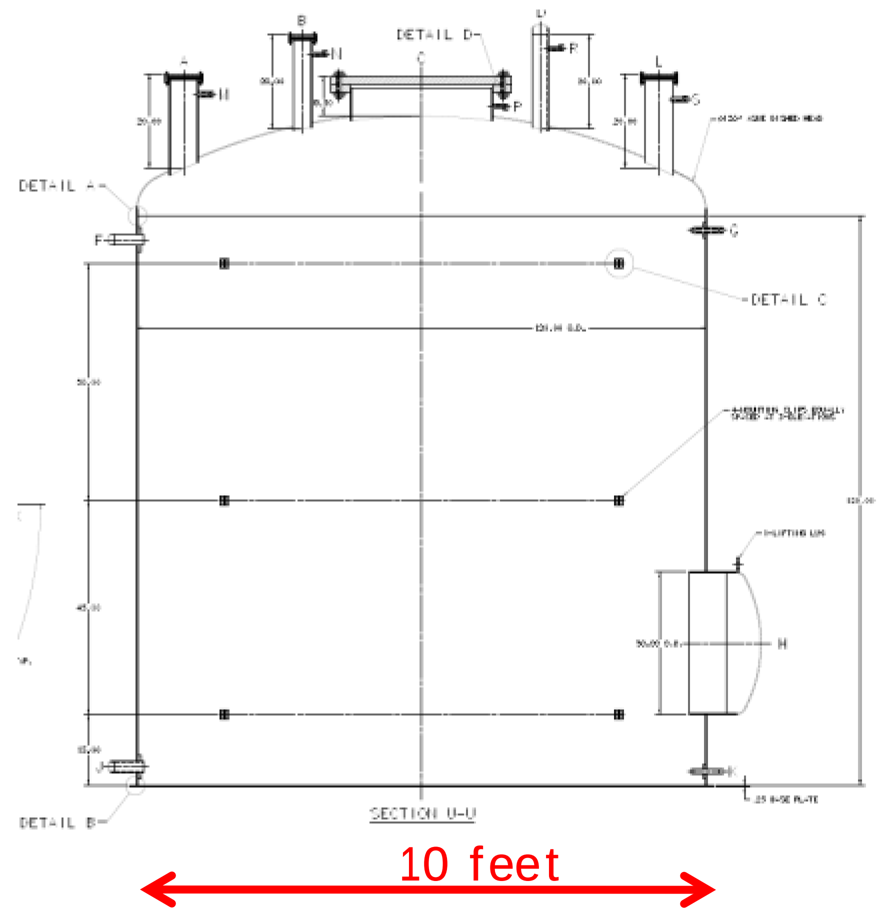
Purification in a Massive LAr TPC

- Contaminants are in the vapor
  - Remove gas from top of cryostat continuously
- Removal rate proportional to the partial pressure difference of the water concentration in materials and the surrounding atmosphere
  - Hot dry argon gas should be as effective as evacuation in removing water (and O_2)
- Liquid Argon Purity Demonstrator (LAPD) will test this concept

LAPD

Brian Rebel, Rob Plunkett (FNAL)

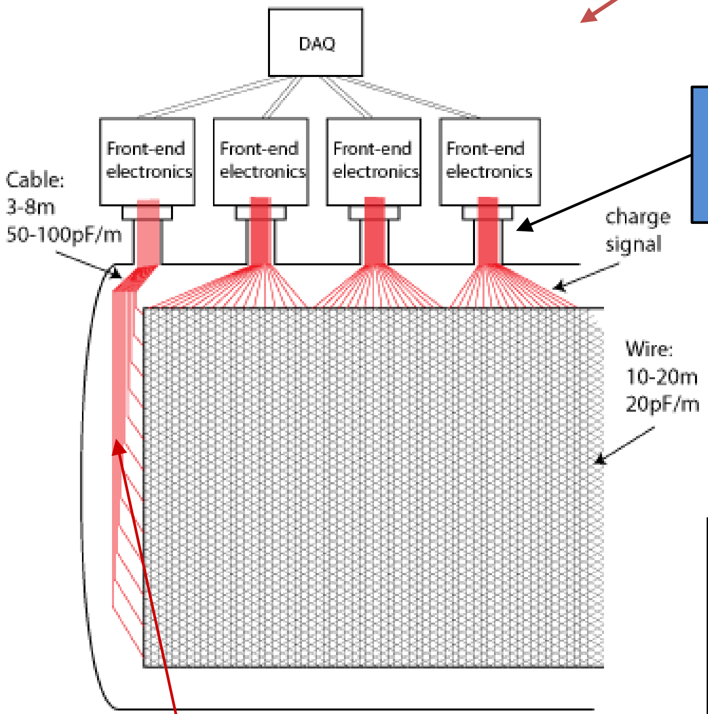
- Commercial SS tank & cryo system
- Steps
  - Remove air w gaseous argon (GAr) piston
  - Flush w GAr
    - 2.6 volumes à 100 ppm
  - Heat to 50°C
  - Recirculate GAr through purification system
  - Cool-down and fill w LAr
  - Check purity
- Results in Fall 2010



Cold Electronics

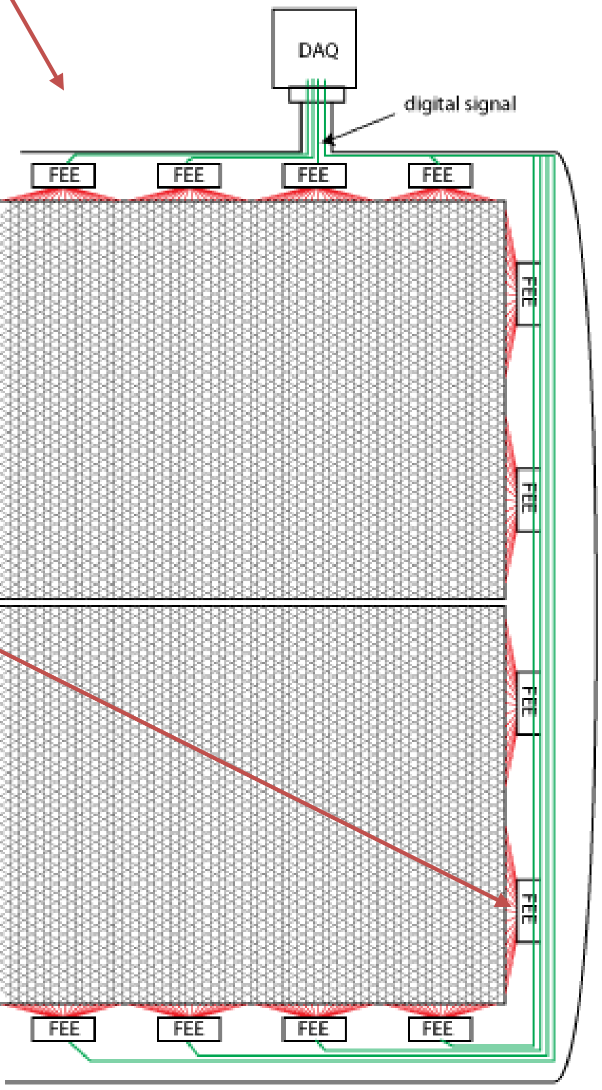
- Large detector (20m x 20m) à long cables to warm preamplifiers à high noise à cold electronics
- Minimize cables à on-wire amplification, digitization, zero suppression & multiplexing à cold ASIC
- Work by Radeka, Rescia (BNL), Yarema, Deptuch (FNAL), Edmunds (MSU)
  – Collaboration with Cressler (Georgia Tech)

Cryostat Design: "Warm" vs "On-Wire" Electronics



Cables outgas in warm GAr

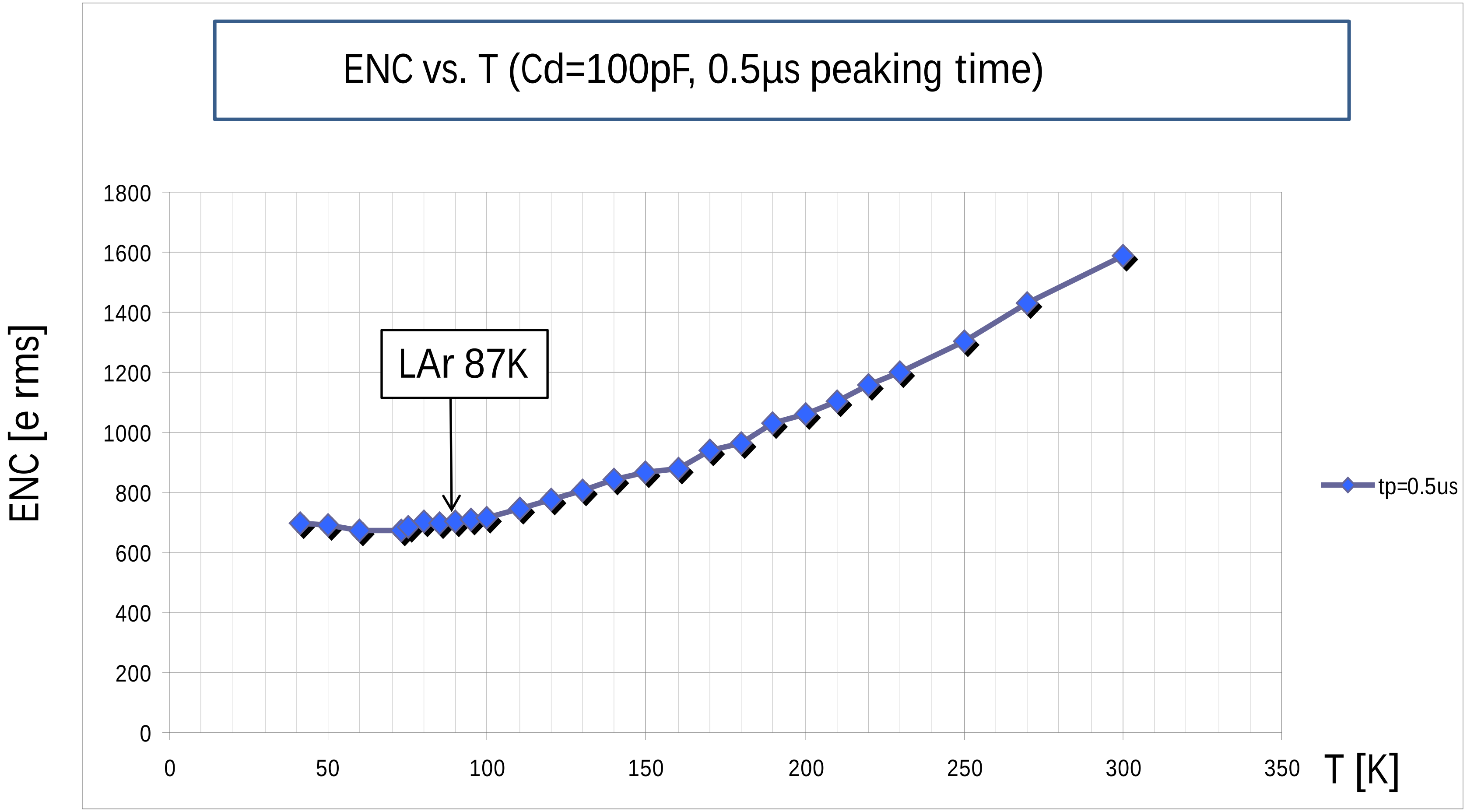
Signal cable lengths increasing to >10-20 meters for detector fiducial volume > 1kton resulting in high capacitance and high noise



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

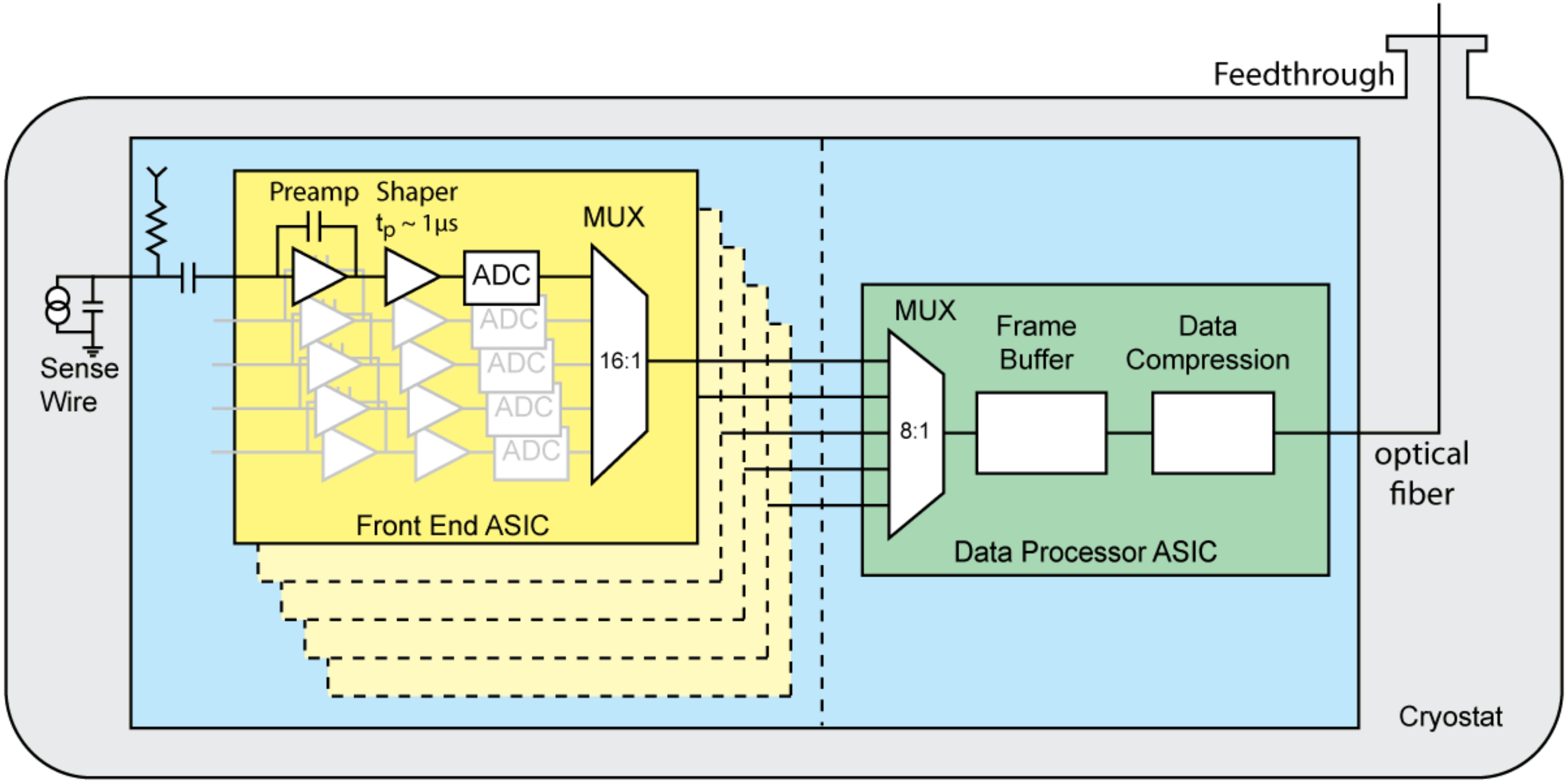
Noise *vs* T in CMOS: *Preliminary Test Result*

Existing ASIC, not designed for LAr



CMOS in LAr has less than half the noise as that at room temperature

LAr20 Electronics



Cost = $3.5M design & prototyping + $4/channel (including ASICs, boards, feedthroughs)

ArgoNeuT: Collaboration

6 Institutions,
20 collaborators

F. Cavanna
University of L'Aquila

B. Baller, C. James, G. Rameika, B. Rebel
Fermi National Accelerator Laboratory

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

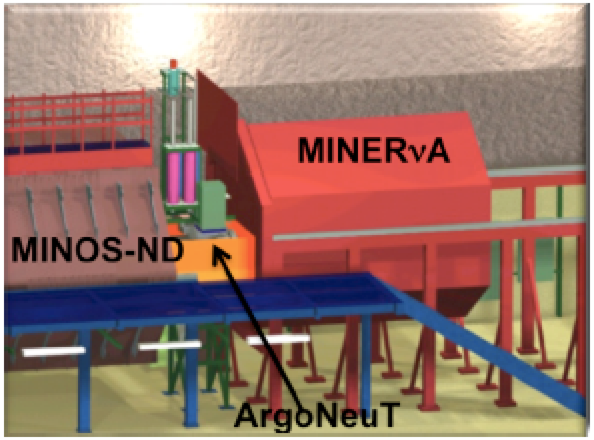
C. Bromberg, D. Edmunds, P. Laurens, B. Page
Michigan State University

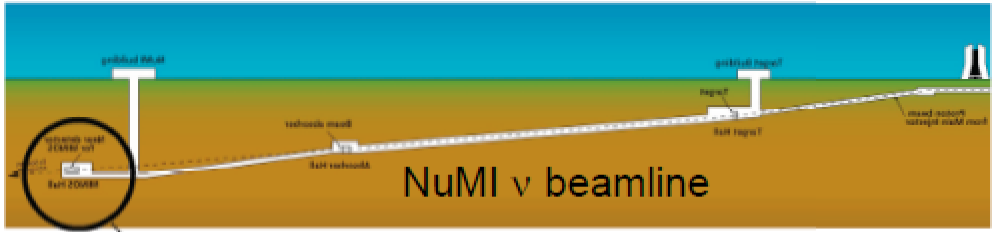
S. Kopp, K. Lang
The University of Texas at Austin

C. Anderson, B. Fleming, S. Linden, K. Partyka, M. Soderberg*, J. Spitz
Yale University

* = *Spokesperson*

ArgoNeuT

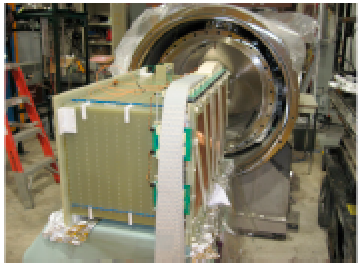




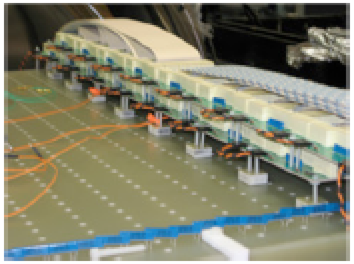
ND hall

- ArgoNeuT sandwiched between MINOS ND and MINERVA (*Under Construction/Commissioning*)

TPC Insertion into cryostat



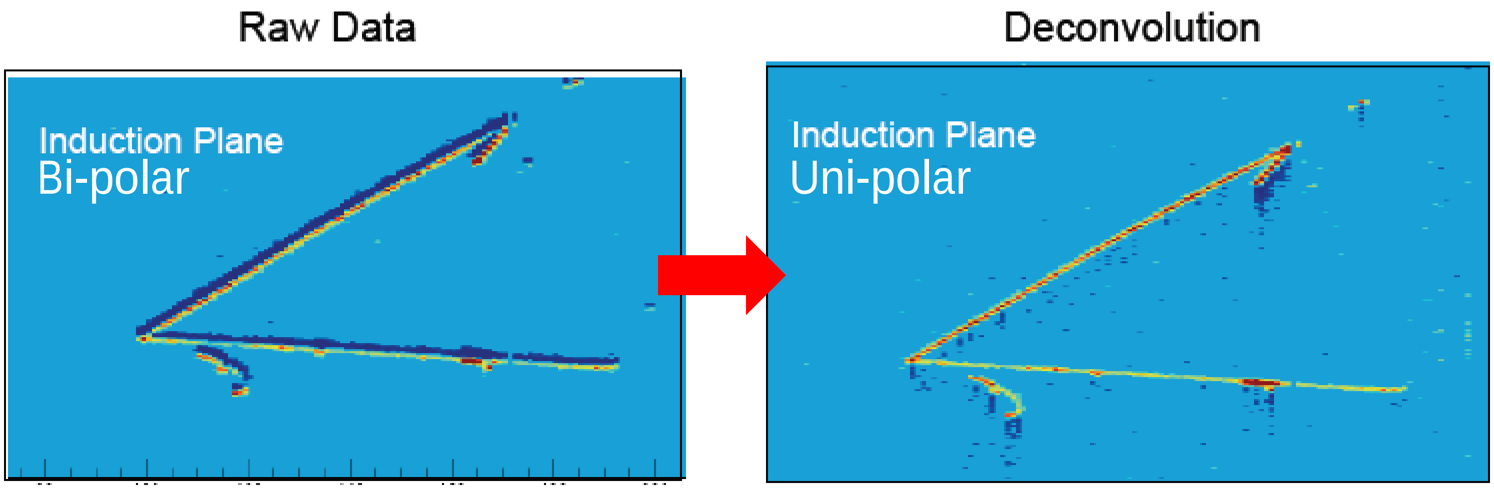
Bias Voltage Distribution plug-in Cards w/*R&C*



- 1/4-ton TPC, 3 wire planes, 2 readout planes (wires ± 30° wrt vertical)
- 4 mm pitch, 4 mm plane separation, 240 wires/plane
- Cryo-cooler driven purification system, ~ 500 μs e^- lifetime (PM)
- Bias voltage distribution/decoupling caps in the LAr

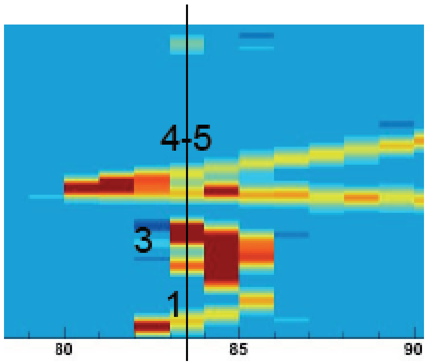
ArgoNeuT Data

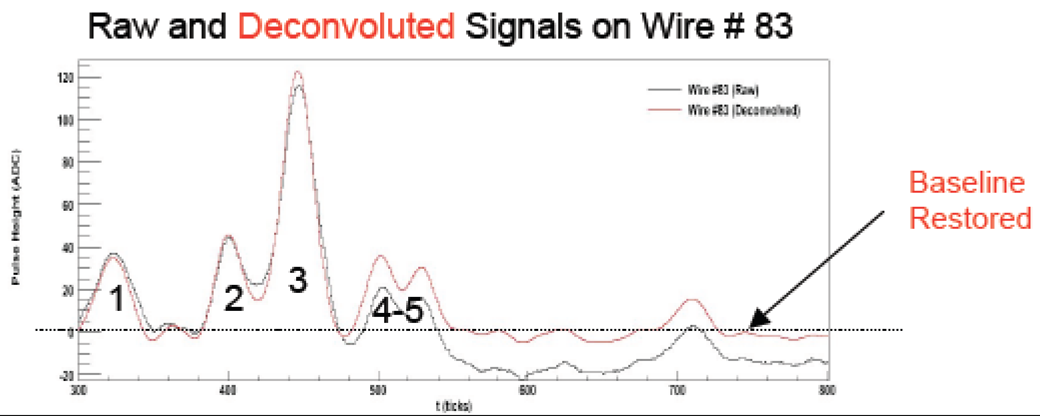
- Prepare for digital signal processing
  - Diffusion much less than inter-plane spacing
  - Find average pulse/wire with “flat” muon tracks (no delta-rays)
- Use FFT to perform deconvolution of raw data
  - Chose FFT filter parameters for hit finding & best signal to noise
  - Removes baseline issues
  - Produces unipolar induction signals with good ionization information



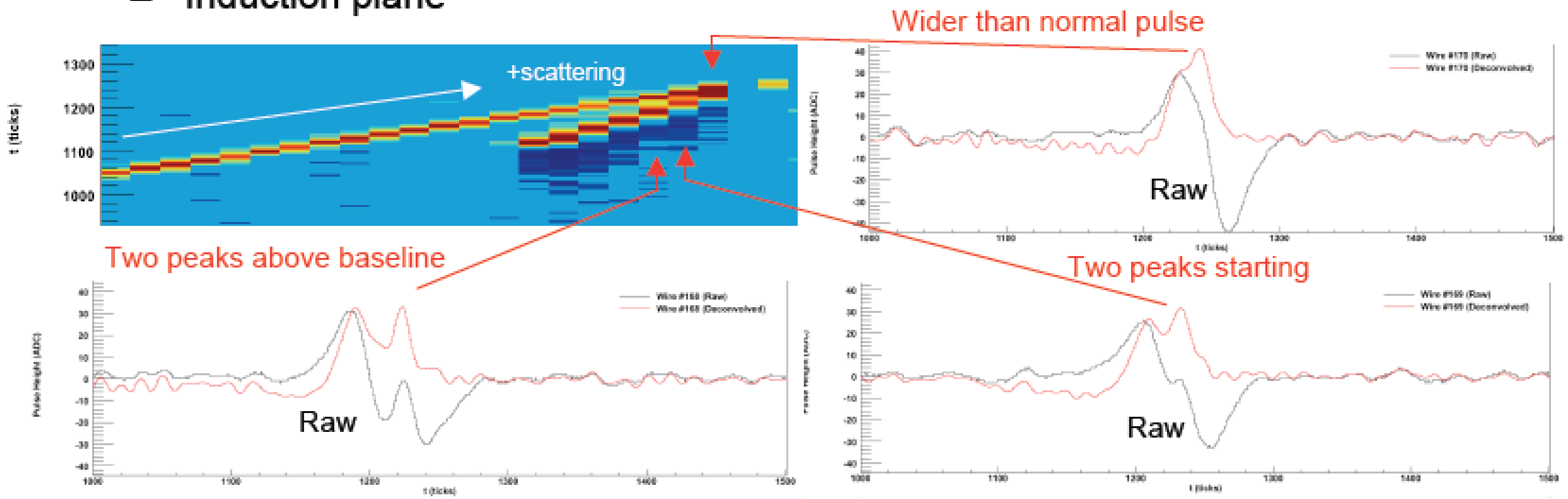
ArgoNeuT Hit Finding LArSOFT

- Define hits as signals above threshold (typically using 5 counts)
  - Collection plane



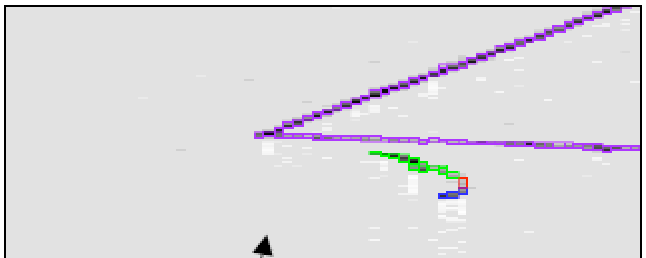


  - Induction plane



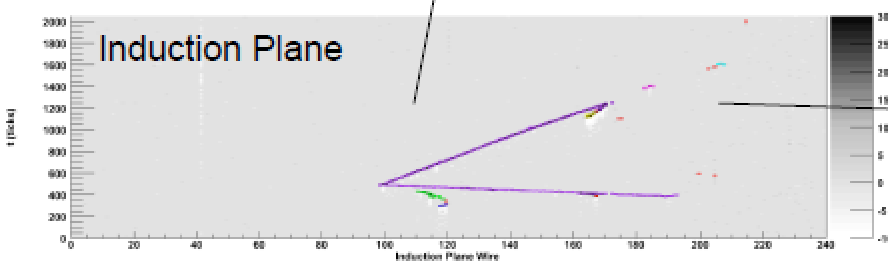
ArgoNeuT Hits to Clusters

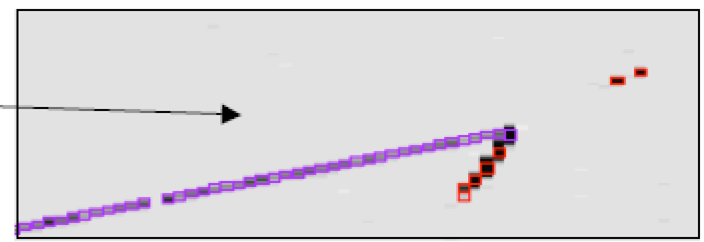
- DBSCAN: Density Based Spatial Clustering - Applications with Noise
  - Algorithm uses distance of a hit to neighboring hits, minimum # hits in cluster
  - Gray scale hit display: using colors for clusters



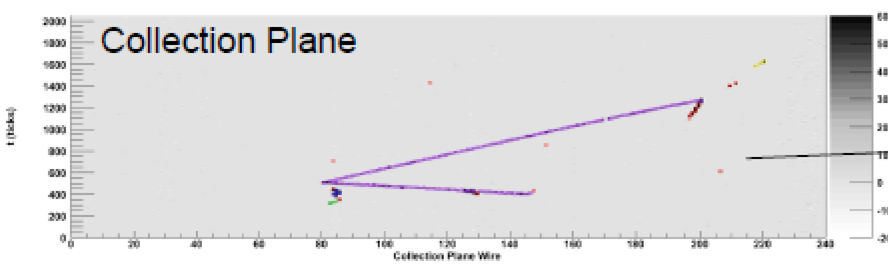
Violet cluster includes both primary vertex tracks

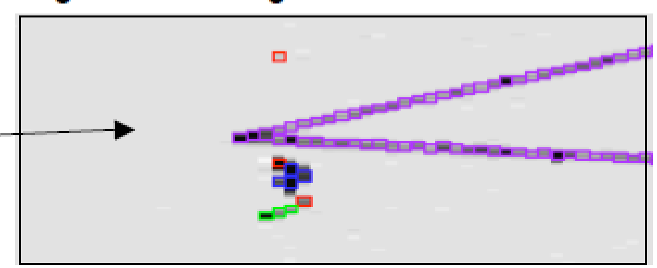
Red hits not in clusters





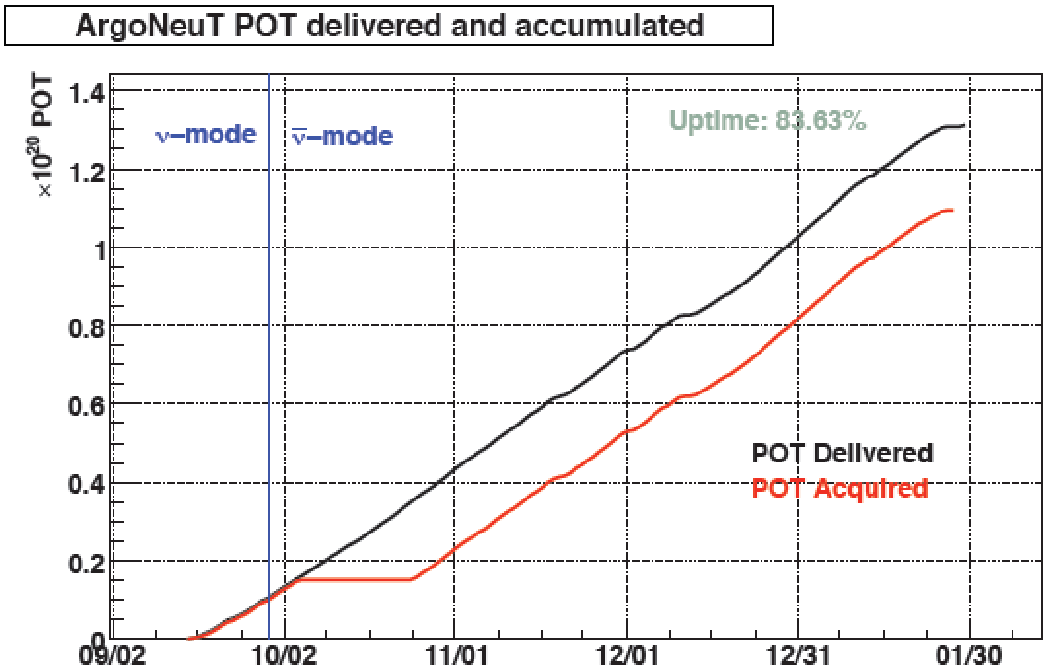
Algorithm having trouble with wide hits





ArgoNeuT Physics

- ArgoNeuT should acquire ~1.4E20 Protons On Target (P.O.T.) by the end of its run, mostly in anti-neutrino mode.
- This data is being used to develop techniques for reconstructing events in 3D.
- Proving dE/dx effectiveness using data will be an important result.
- We also expect to obtain cross-section measurements (most notably CC Quasi-Elastic) for the first time in a LAr experiment!



Event Type	# in 180 days (1.4×10^{20} POT)
ν_μ CC	28800
$\overline{\nu_\mu}$ CC	2520
ν_e CC	540
NC	9720

Neutrino Mode

Event Type	# in 180 days (1.4×10^{20} POT)
ν_μ CC	9026
$\overline{\nu_\mu}$ CC	8111
ν_e CC	175
NC	5933

AntiNeutrino Mode

Summary

- Integrated R&D Plan developed, reviewed & submitted to DOE
- Materials Test Stand
  - Water is the culprit
- LAPD will confirm this result this summer
- Cryogenic ASIC's obviate many problems w LArTPC's
  - Minimize cables, outgassing, design constraints
- ArgoNeuT analysis of neutrino data
  - World first
- Aggressive schedule to build LAr20
  - Liquid argon technology risks well understood and manageable