

# MicroBooNE

C. Mariani

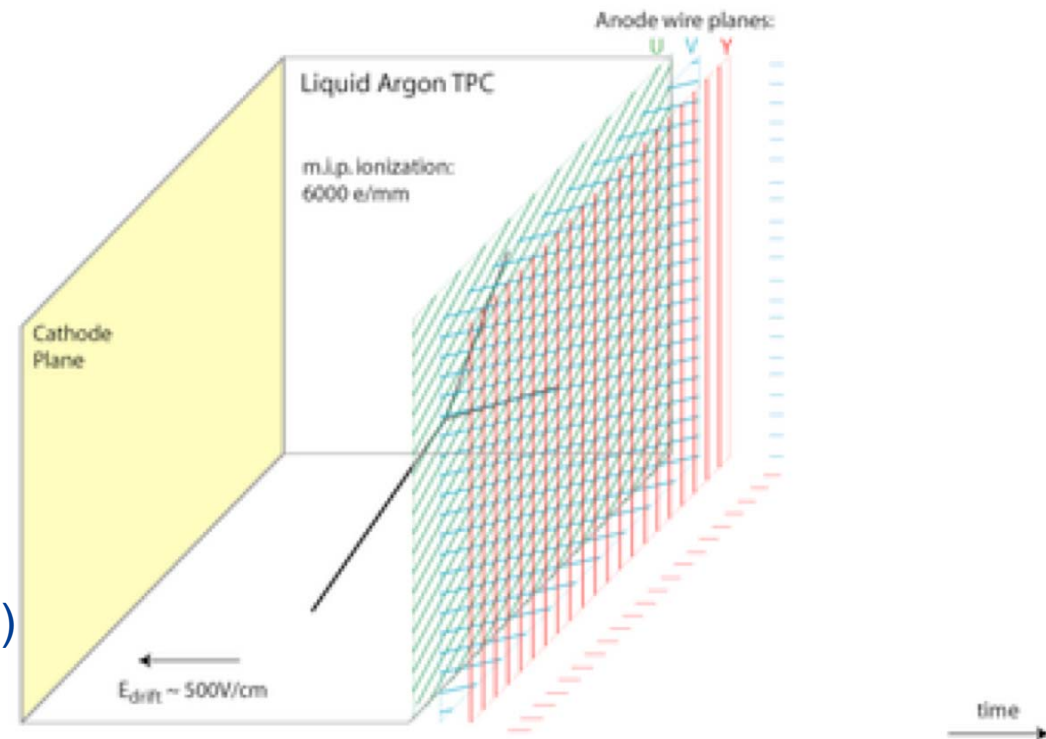
Columbia University



- Motivation to have a liquid argon detector (LArTPC):
  - physics;
  - R&D challenges;
- MicroBooNE:
  - physics goal;
  - detector overview;
  - location and neutrino beam;
  - Argon: physical - optical properties;
  - cryogenics;
  - electronics and readout;
  - simulation;
  - ArgoNeuT
- Future of LArTPC - DUSEL

# Why LAr TPC detectors

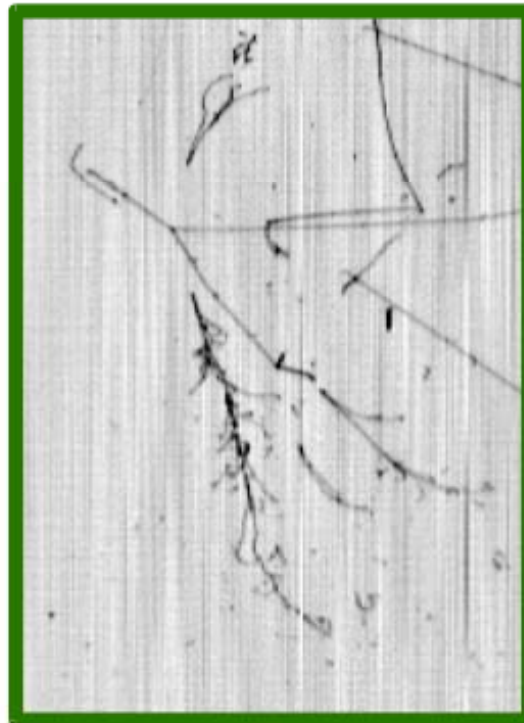
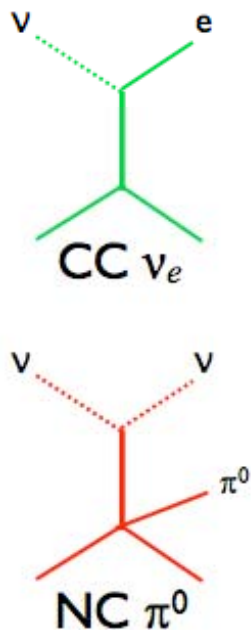
- Unique detectors, true “electronic” bubble-chambers.
- High precision measurements combined in one technology :
  - Tracking and Imaging (voxel size limited by diffusion)
  - Precision Calorimetry
  - Particle Identification (dE/dx meas. on the collection wire plane)



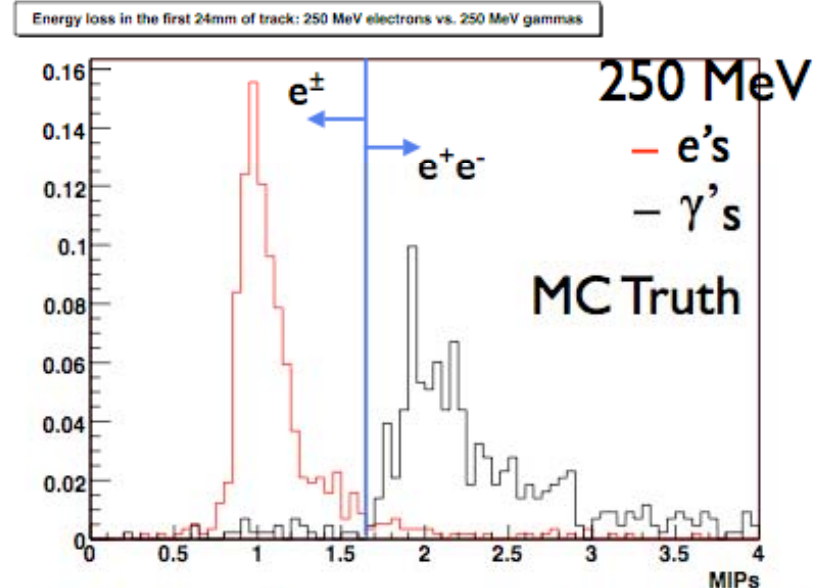
# Why LAr TPC detectors (cont'd)

$e/\gamma$  separation  $\rightarrow$  superior background rejection

- Particle identification comes from  $dE/dx$  measured along track.
- Small wire pitch and fast sampling allow for very fine-grained imaging.
- $\nu_e$  appearance: Excellent signal (CC  $\nu_e$ ) efficiency and background (NC  $\pi^0$ ) rejection
- Topological cuts will also improve signal/background separation



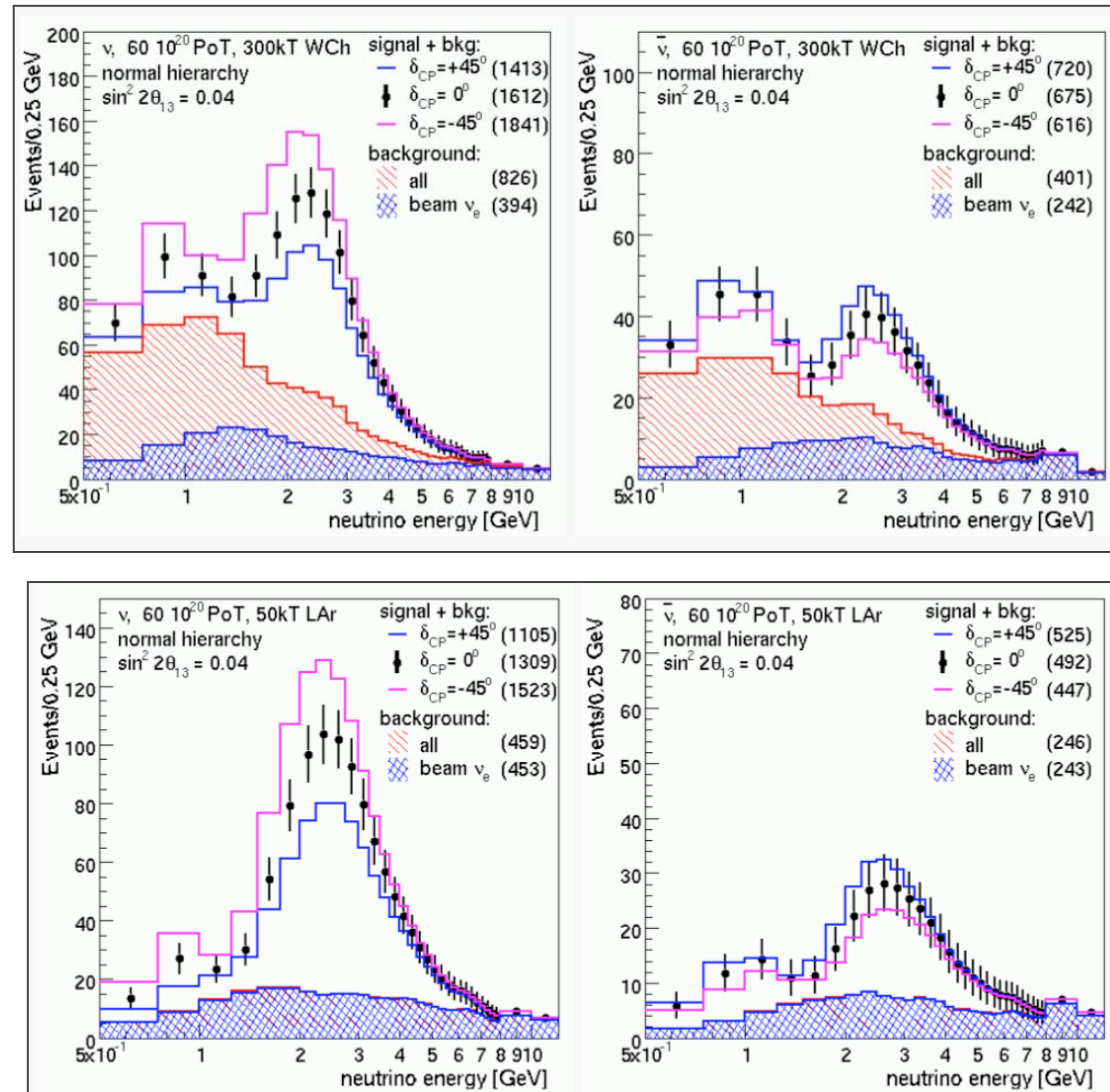
ICARUS Event



$dE/dx$  for electrons and gammas in first 2.4 cm of track

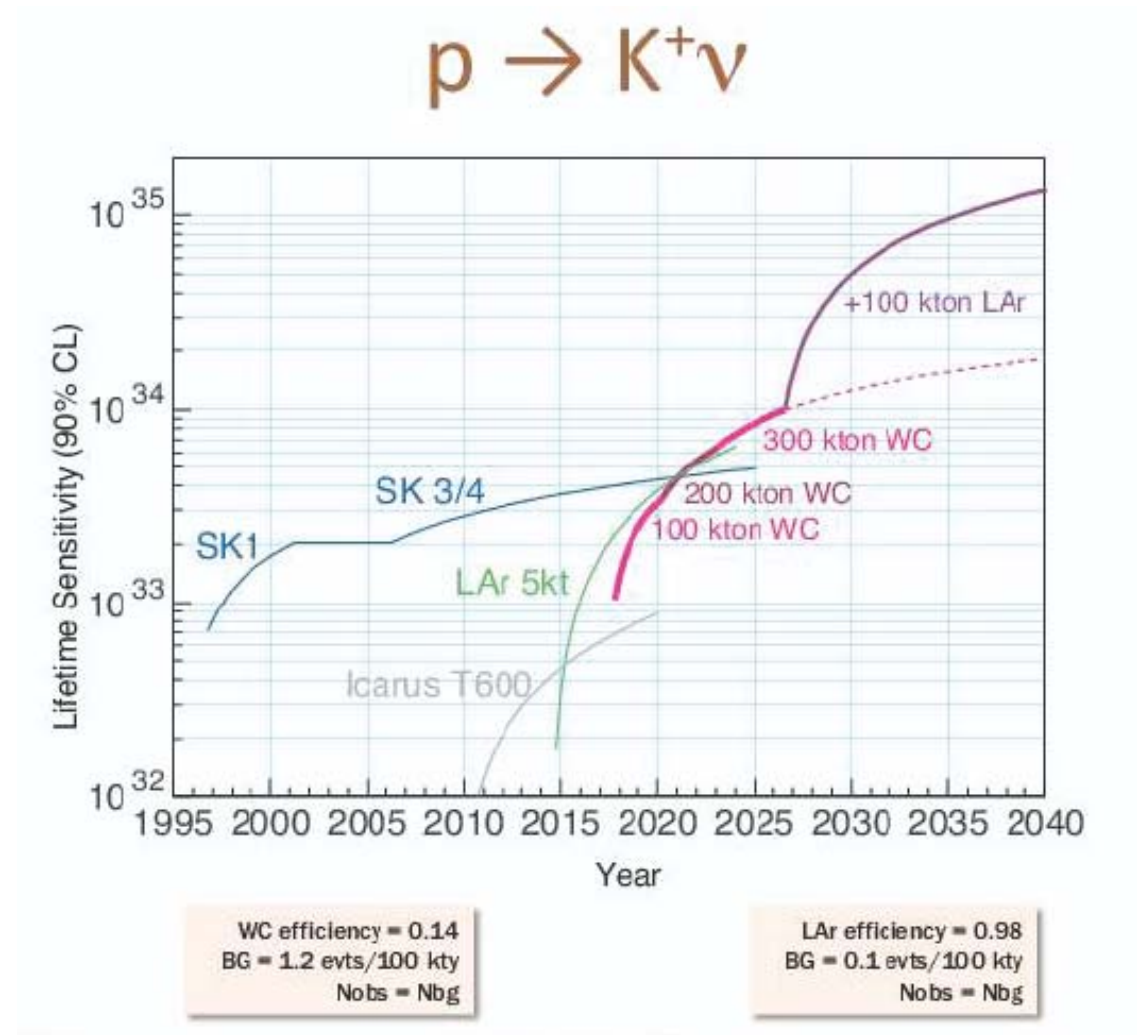
# Why LAr TPC detectors (cont'd)

- Neutrino oscillation physics:
- Significantly more sensitive ( $\sim x6$ ) than WC detectors (i.e. smaller volumes for same physics reach)
- More powerful background reduction  $\nu_e$



# Why LAr TPC detectors (cont'd)

- Proton decay search:
- Sensitive to other decay channels (e.g.  $p \rightarrow \nu K$ )
- Extend sensitivity beyond SK limits with  $>5\text{kton}$  detectors



Key issue is *feasibility of scaling in size*

- reaching the fundamental limits in terms of the signal-to-noise
- technological limits in terms of the readout complexity and cost

Indeed many technical challenges (several are entangled ...)

- **Cryogenic Vessels:**
  - Design, material, insulation, non-evacuatable
- **Underground Detector Integration:**
  - Safety, installation, cryogenics service location, costing...
- **LAr Purification:**
  - Purification techniques for large, non-evacuatable vessels, materials
  - Purity of LAr in full scale detectors/Max. drift achievable
- **Readout:**
  - **TPC configuration**
  - **Electronics**

# MicroBooNE: collaboration

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## Brookhaven Lab

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Veljko Radeka  
Sergio Rescia  
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Mike Shaevitz  
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Rich Schmitt  
Dave Schmitz  
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Qing He

## St. Mary's

Paul Nienaber

## University of California, Los Angeles

Hanguo Wang

## University of Cincinnati

Randy Johnson

## University of Texas at Austin

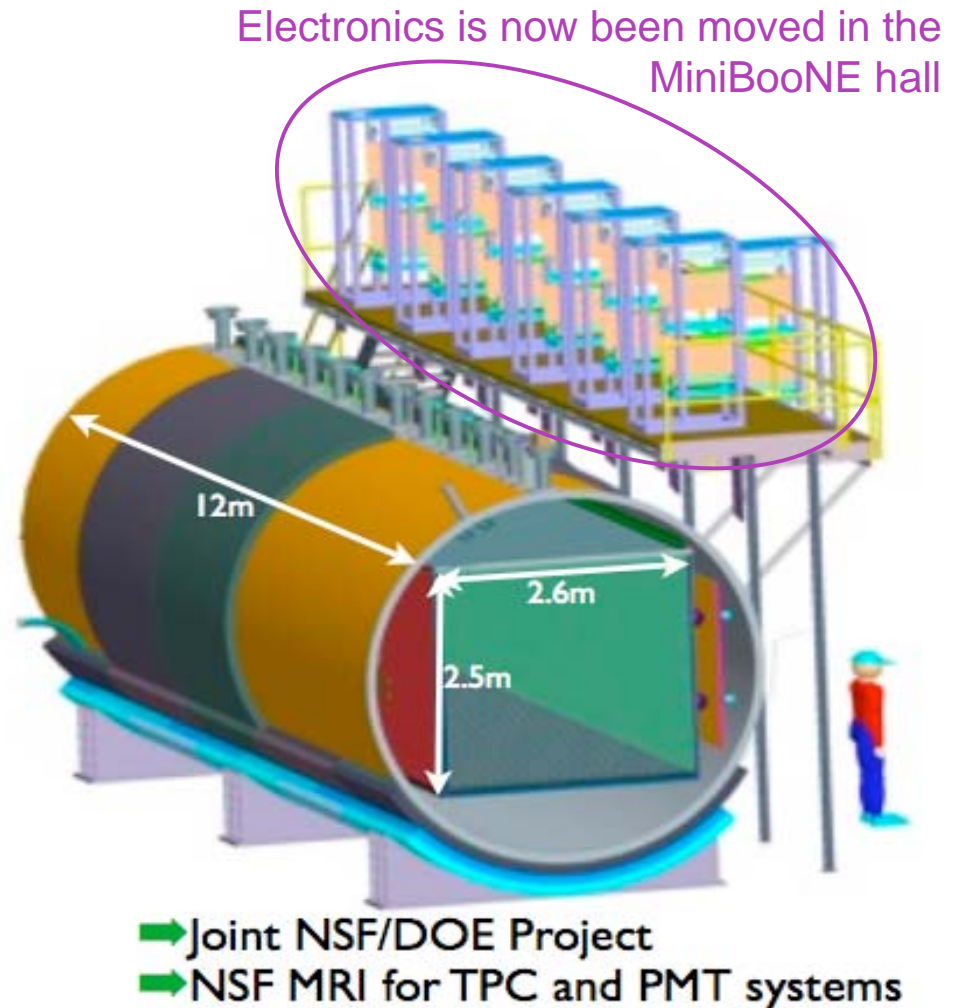
Sacha Kopp  
Karol Lang

## Yale

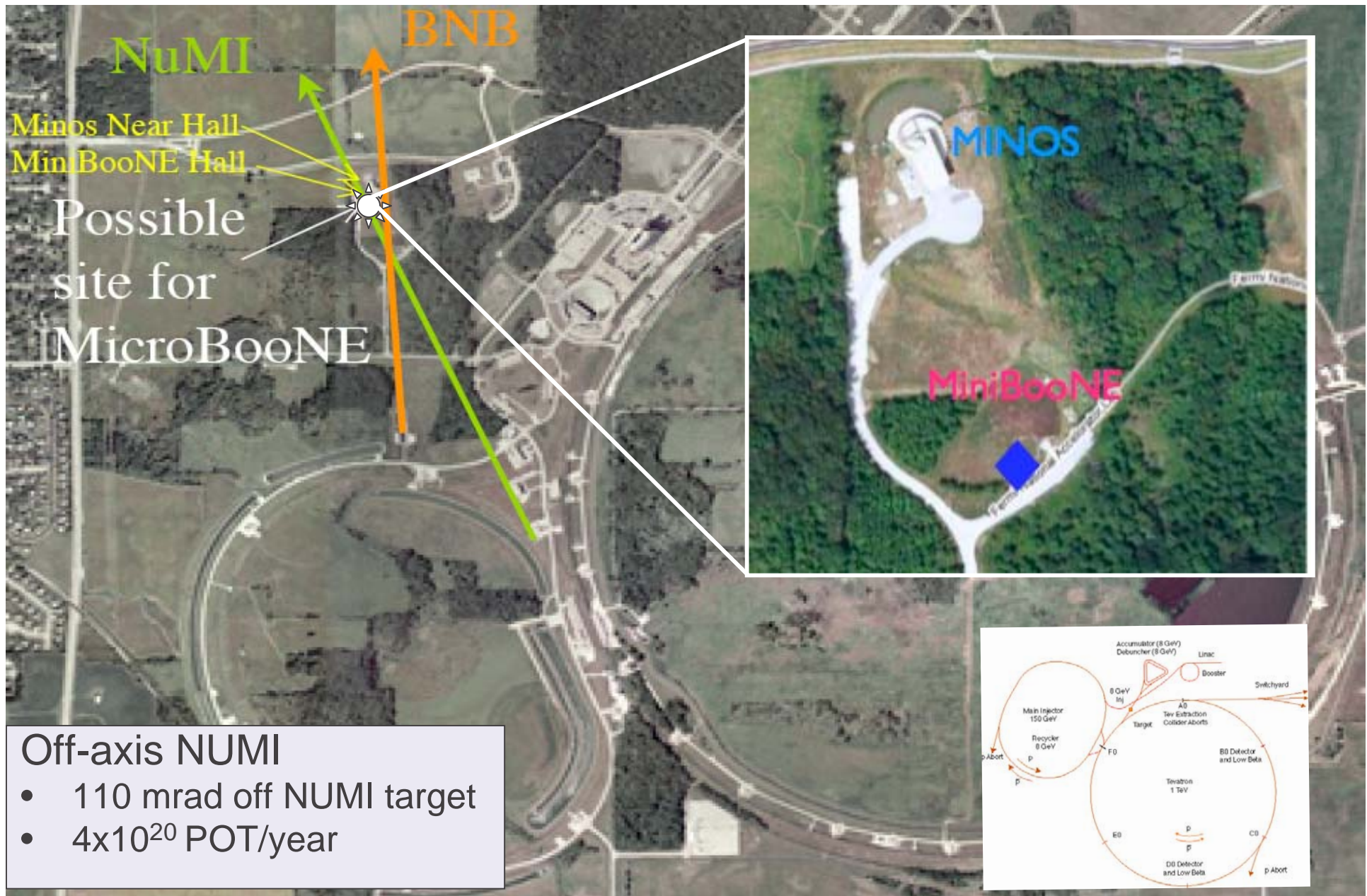
Colin Anderson  
Bonnie T. Fleming  
Steve Linden  
Mitch Soderberg  
Josh Spitz

# MicroBooNE: detector overview

- Cryostat (170 Tons LAr) as a large as can be built commercially and trucked to site;
- TPC parameters:
  - 70 Ton fiducial volume (depends on analysis definition)
  - 2.6 m drift @ 500V/cm → 1.6ms drift time
  - ~10.000 channels (using cold preamplifier)
  - 3 Readout planes ( $\pm 60^\circ$  Induction, vertical Collection planes)
- ~30 PMT for triggering;
- Purification/Recirculation system



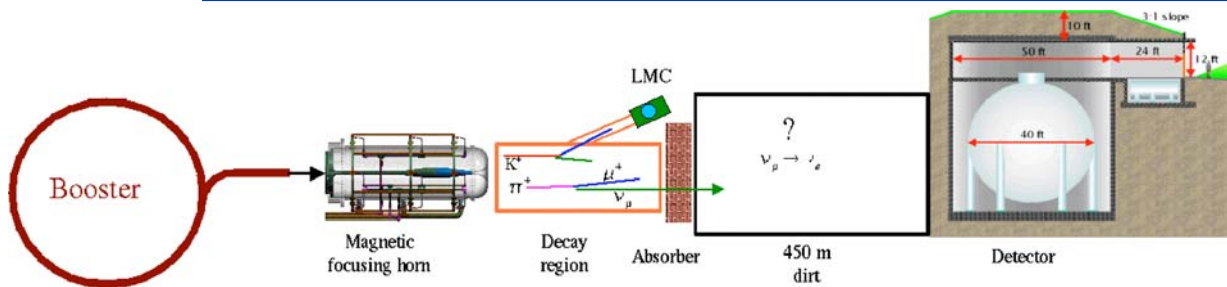
# MicroBooNE: location



## Off-axis NUMI

- 110 mrad off NUMI target
- $4 \times 10^{20}$  POT/year

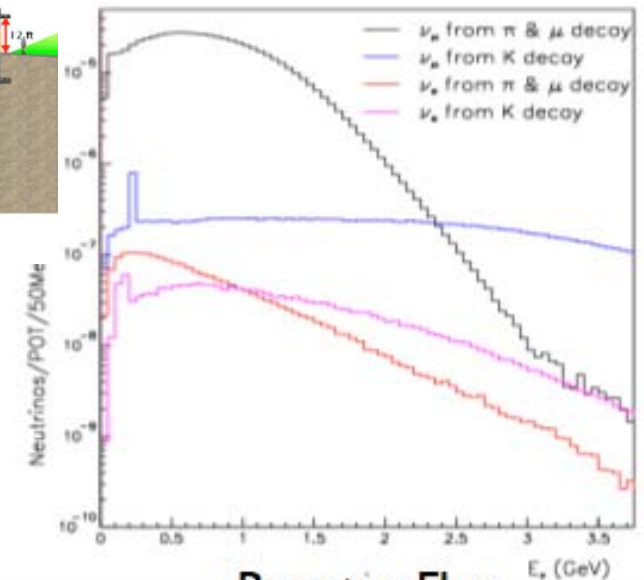
# MicroBooNE: beam



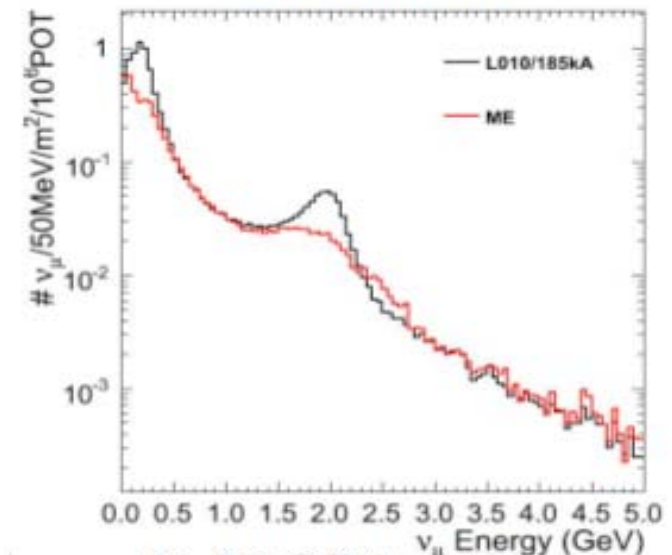
- On-axis BNB
- 8 GeV protons on Be target
  - Focusing horn:  $\pi^+$ ,  $K^+$
  - Decay channel 50mt
  - 450mt dirt
  - $2-3 \times 10^{20}$  POT/year
  - 3-2 years running ( $6 \times 10^{20}$  POT)

	BNB	NuMI
Total Events	145k	60k
$\nu_\mu$ CCQE	68k	25k
NC $\pi^0$	8k	3k
$\nu_e$ CCQE	0.4k	1.2k
POT	$6 \times 10^{20}$	$8 \times 10^{20}$

Expected Event Rates for MicroBooNE.



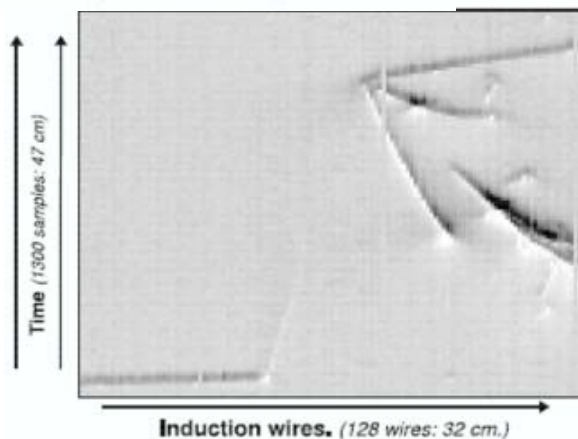
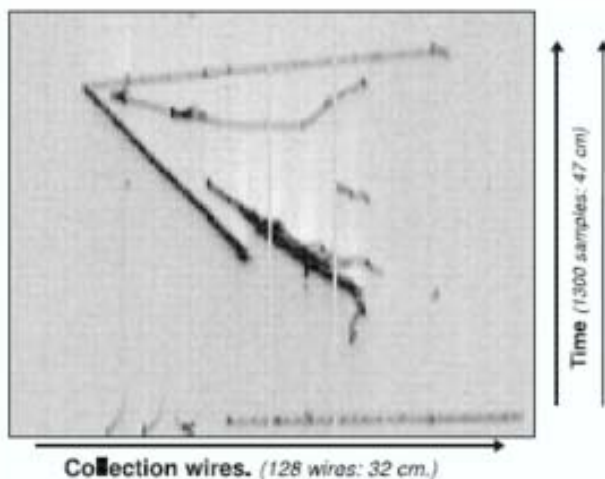
Booster Flux



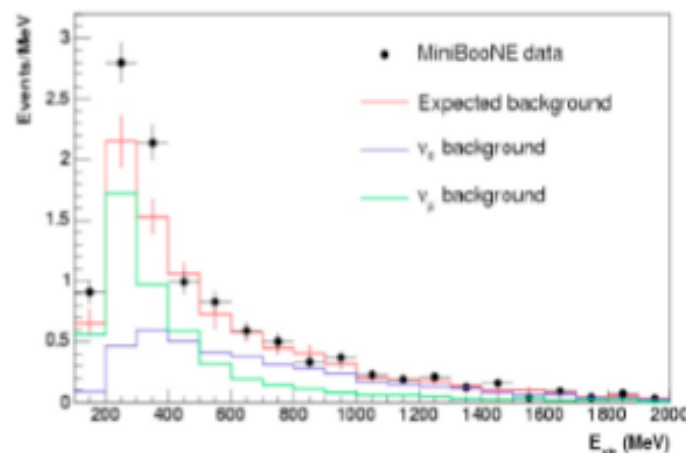
NuMI Off-Axis Flux

# MicroBooNE: physics goal

- Address the MiniBooNE low energy excess
- Utilize electron/gamma tag (using dE/dX information).



MiniBooNE Result Excess  
200-300MeV:  $45.2 \pm 26.0$  events  
300-475MeV:  $83.7 \pm 24.5$  events



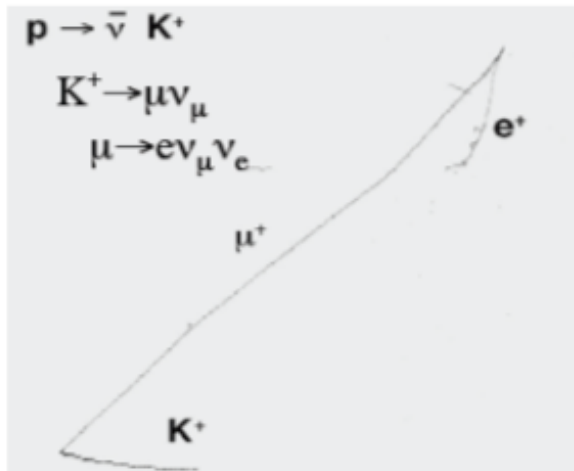
MicroBooNE will have  $5\sigma$  significance  
for electron-like excess,  $3.3\sigma$  for  
photon-like excess.

Refs:

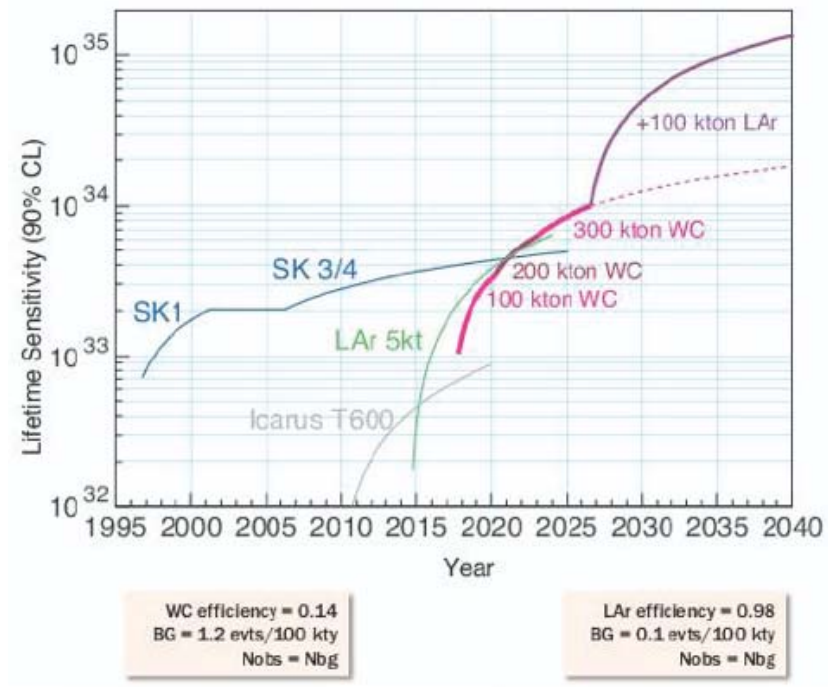
1.) *Unexplained Excess of Electron-Like Events From a 1-GeV Neutrino Beam* MiniBooNE Collaboration, Phys. Rev. Lett. 102, 101802 (2009)

# MicroBooNE: physics goal (cont'd)

- Low Energy Cross-Section Measurements (CCQE, NC  $\pi^0$ ,  $\Delta \rightarrow N\gamma$ , Photonuclear, ...)
- Use small (~500) sample of Kaons to develop PID for future proton-decay searches.
- Continue development of automated reconstruction.



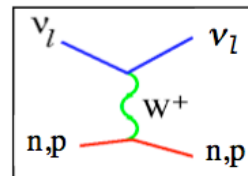
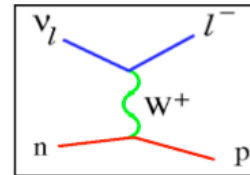
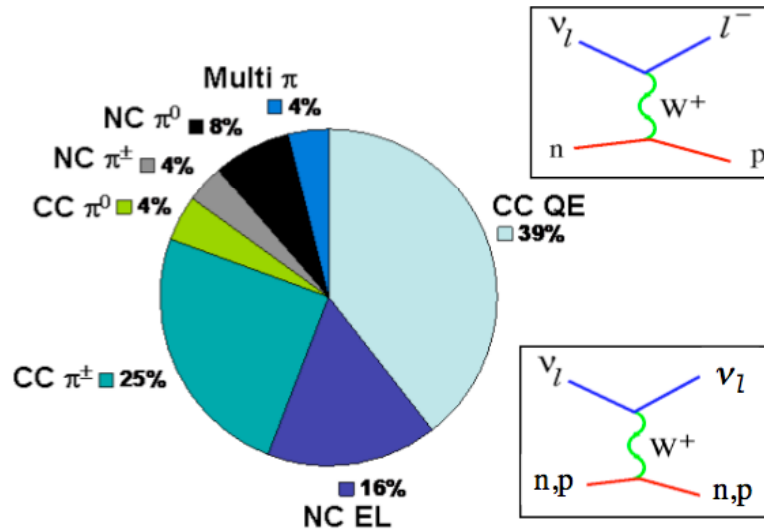
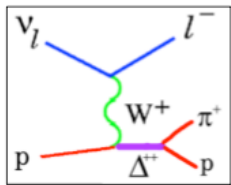
ICARUS Simulation



# MicroBooNE: cross-section and $M_A$

1. intellectually interesting
2. drives the precision of many of our other measurements
3. valuable for future LArTPC detectors

Subtopics for the BNB beam:

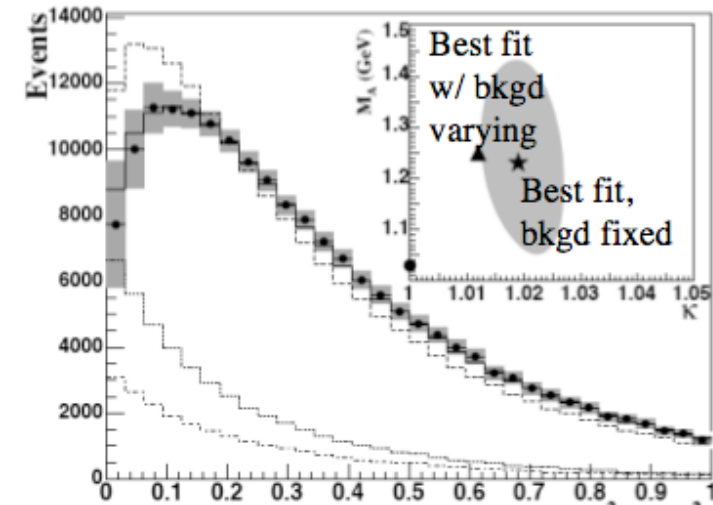


(note we can also use the NuMI beam)

Improve the  $Q^2$  resolution ( $Q^2=2ME_{\text{vis}}$ ):

plan is to have an energy threshold of  $E_{\text{vis}}=10$  MeV, this means a  $Q^2_{\text{min}} \sim 0.02$ , that can be reached only if we have a very good capability to study n/p separation vs. energy

Model describes MB CCQE  $\nu_\mu$  data well  
what about uB data?



From  $Q^2$  fits to MB  $\nu_\mu$  CCQE data:

$M_A^{\text{eff}}$  -- effective axial mass  
 $\kappa$  -- Pauli Blocking parameter

From electron scattering data:

$E_b$  -- binding energy  
 $p_f$  -- Fermi momentum

# MicroBooNE: exotic physics

## •Supernova capability

- ▶ Data will be buffered for  $\sim 1$  hour...in case there is a supernova notification received.
- ▶ Several modes of detection:
  - Elastic Scattering:  $\nu + e^- \rightarrow \nu + e^-$ 
    - ▶ Sensitive to all neutrino species
  - Absorption (CC):  $\nu_e + {}^{40}\text{Ar} \rightarrow e^- + {}^{40}\text{K}^*$ ,  $\nu_e + {}^{40}\text{Ar} \rightarrow e^+ + {}^{40}\text{Cl}^*$ 
    - ▶ Search for charged particle in final-state.
    - ▶ Also identified via photon from de-excitation of K/Cl atom.
  - NC:  $\nu + {}^{40}\text{Ar} \rightarrow \nu + {}^{40}\text{Ar}^*$ 
    - ▶ Sensitive to all neutrino species
    - ▶ Identified via photon from de-excitation of argon atom.
- ▶ Studies of low-E threshold for PMTs are getting started.

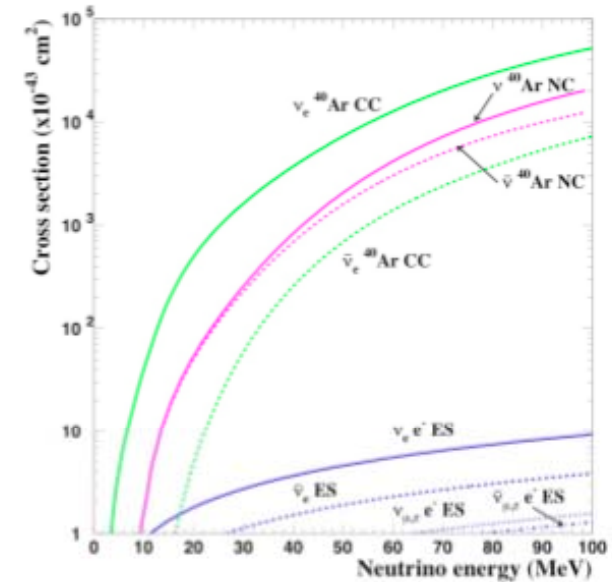


Figure 3: Neutrino cross sections relevant to the supernovae detection with a liquid Argon TPC detector.

### Refs:

- 1.) *Supernova Neutrino Detection in a liquid Argon TPC*, A. Bueno, I. Gil-Botella, A. Rubbia, hep-ph/0307222
- 2.) *Oscillation effects on supernova neutrino rates and spectra and detection of the shock breakout in a liquid Argon TPC*, I. Gil-Botella, A. Rubbia, hep-ph/0307244
- 3.) *Decoupling supernova and neutrino oscillation physics with LAr TPC detectors*, I. Gil-Botella, A. Rubbia, hep-ph/0404151
- 4.) *Supernova relic neutrinos in liquid argon detectors*, A. G. Cocco et al, JCAP12(2004)002

# MicroBooNE: NC elastic events

The physics of NC elastic events

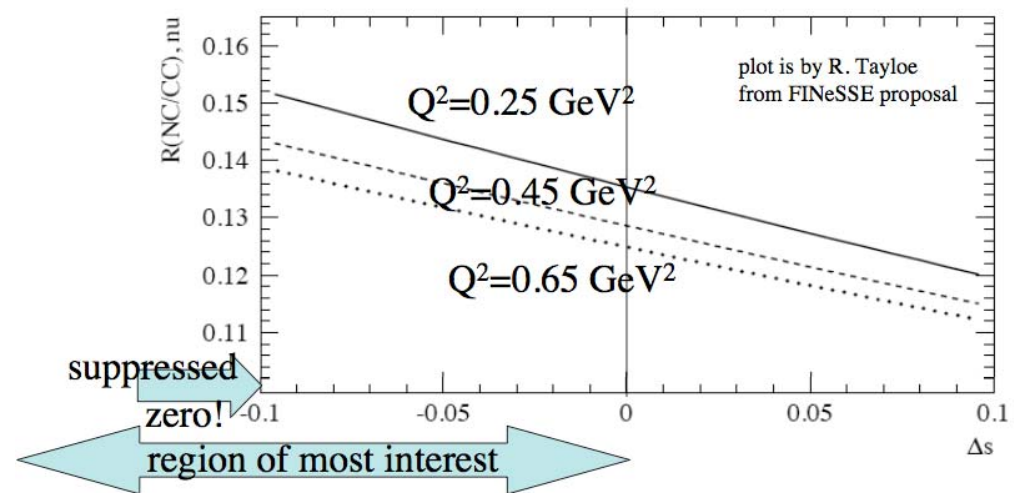
$$R_{NC/CC} = \frac{\sigma(\nu p \rightarrow \nu p)}{\sigma(\nu n \rightarrow \mu^- p)}$$

is sensitive to  $\Delta s$  -- the fraction of the spin of the proton carried by the strange quarks

Interesting because...

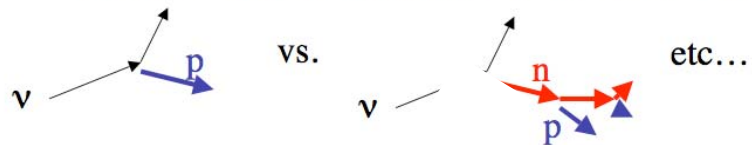
- We do not understand proton spin!
- Input for spin-dependent WIMP searches
- Gives useful information on final states for modeling events in LAr

$$R_{NC/CC} = \frac{\sigma(\nu p \rightarrow \nu p)}{\sigma(\nu n \rightarrow \mu^- p)}$$



Global fit by Bass, Rev. Mod. Physics:  $\Delta s = -0.10 \pm 0.04$   
and by Filippone, hep-ph/0101224.:  $\Delta s = -0.14 \pm 0.03$

First reason why this is hard to measure:  
neutron vs proton separation is difficult in most detectors



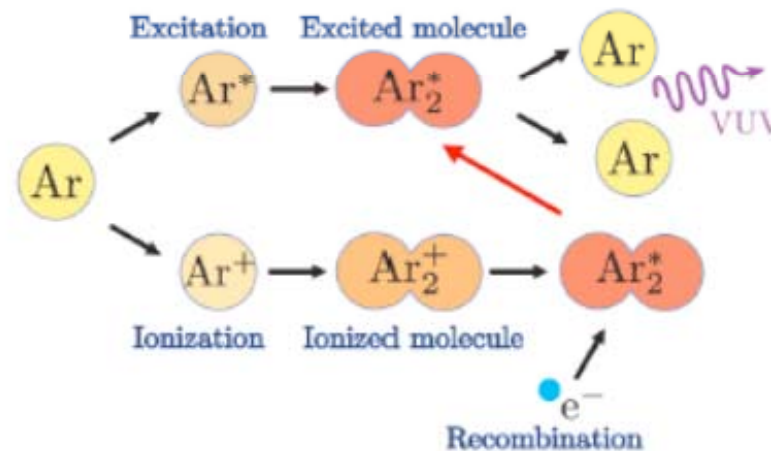
# MicroBooNE: Liquid Argon

- Ionization and scintillation light can be used for detection. Ionization electrons can drift over long distances in these liquids;
- Excellent dielectric properties allow these liquids to accommodate very high voltages;
- Argon is relatively cheap and easy to obtain (1% of atmosphere).

	He	Ne	Ar	Kr	Xe	Water
Boiling Point [K] @ 1atm	4.2	27.1	87.3	120.0	165.0	373
Density [g/cm <sup>3</sup> ]	0.125	1.2	1.4	2.4	3.0	1
Radiation Length [cm]	755.2	24.0	14.0	4.9	2.8	36.1
dE/dx [MeV/cm]	0.24	1.4	2.1	3.0	3.8	1.9
Scintillation [ $\gamma$ /MeV]	19,000	30,000	40,000	25,000	42,000	
Scintillation $\lambda$ [nm]	80	78	128	150	175	

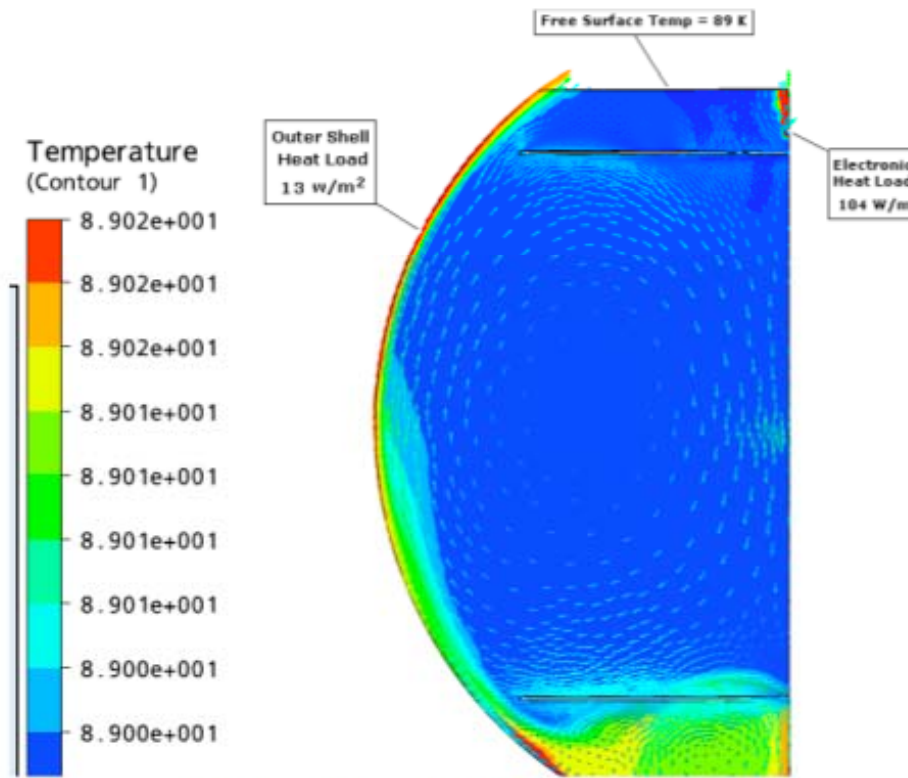
# MicroBooNE: Ar - optical properties

- Argon is an excellent scintillator.
- 128nm light (need to wavelength shift to collect...)
- De-excitation and recombination processes following the passage of ionizing particles in liquid Argon produce prompt scintillation radiation.

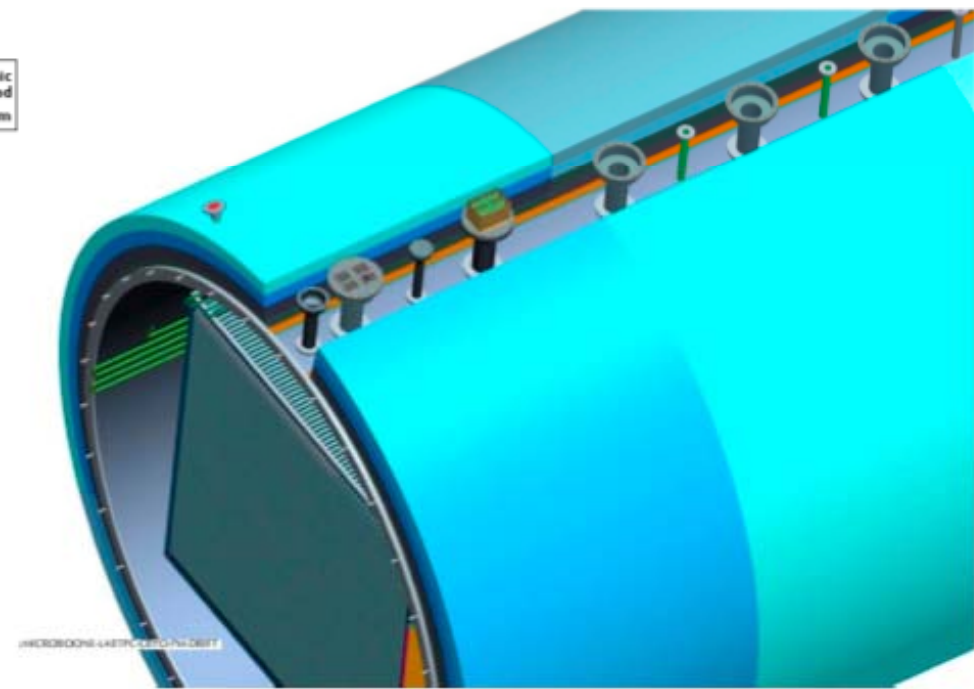


# MicroBooNE: cryogenics

- Preliminary studies have been performed to understand thermal load of system.
- ~16 inches (~40 cm) glass foam insulation
- 3.4kW total load ( $13\text{W}/\text{m}^2$ )
- Temp. gradient  $\ll 0.1\text{K}$  - crucial to reducing track distortions (drift velocity  $\sim T$ ).
- Services and detector integration are being designed.



Temperature distribution



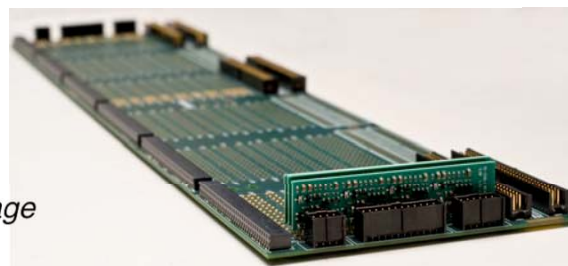
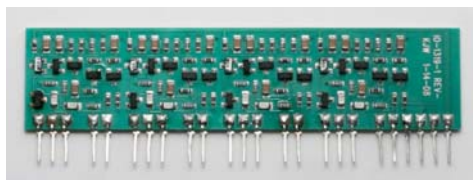
Detailed view of insulation/feedthroughs

# MicroBooNE: Readout Electronics

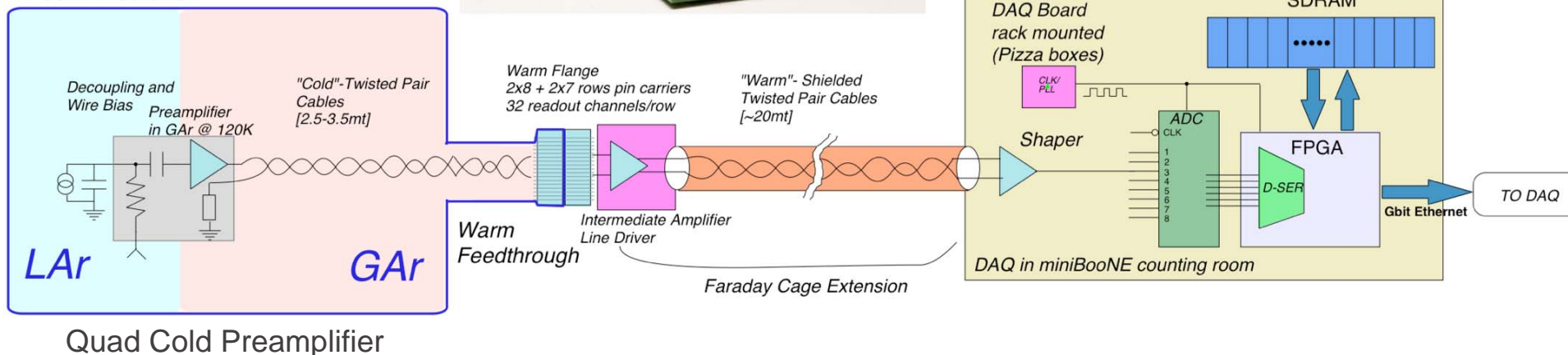
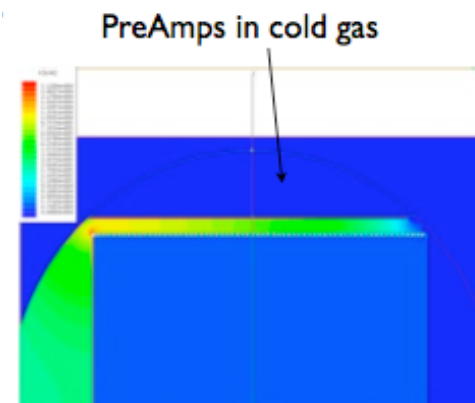
- Preamps within the cryogenics. Why? Because it reduces wire lengths between wires and preamps, thus reducing noise. Also in the cold the noise is smaller;
- Transition to the outside: line drivers on the cryostat, within a Faraday cage;
- 20m of cables and then Shapers near MiniBooNE electronics;
- ADC's
- Readout and DAQ.

JFET discrete preamplifier

Cold Preamp. Motherboard



Single Vessel Cryostat with 8-10% Ullage Foam Insulation

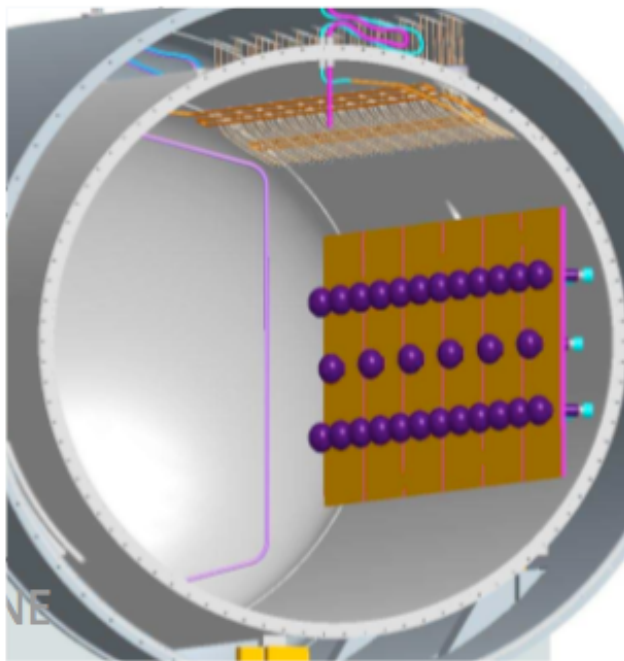


# MicroBooNE: Cryo. Electronics setup



# MicroBooNE: collecting light

- ~30 PMTs to aid in  $t_0$  determination and help reduce data load
  - ▶ *i.e.* - require coincidence of beam spill and light signal in PMTs
- Most likely will use tubes from Hamamatsu
- Coat tubes with wavelength shifter (TPB = tetraphenyl-butadiene) to allow collection of VUV light.
- Design work on all PMT details ongoing.



30 PMTs facing TPC

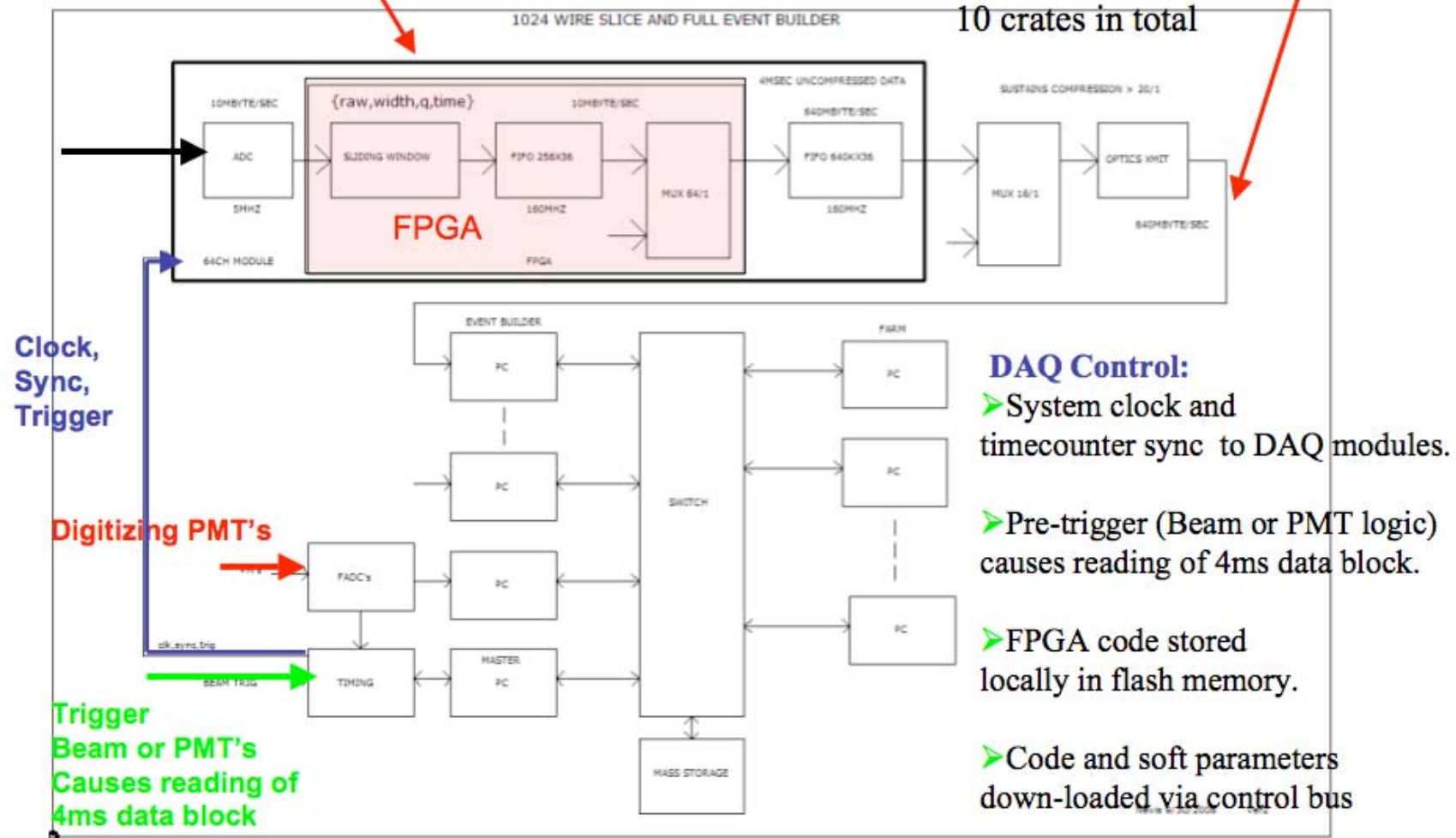


8" PMT

# MicroBooNE: DAQ and readout

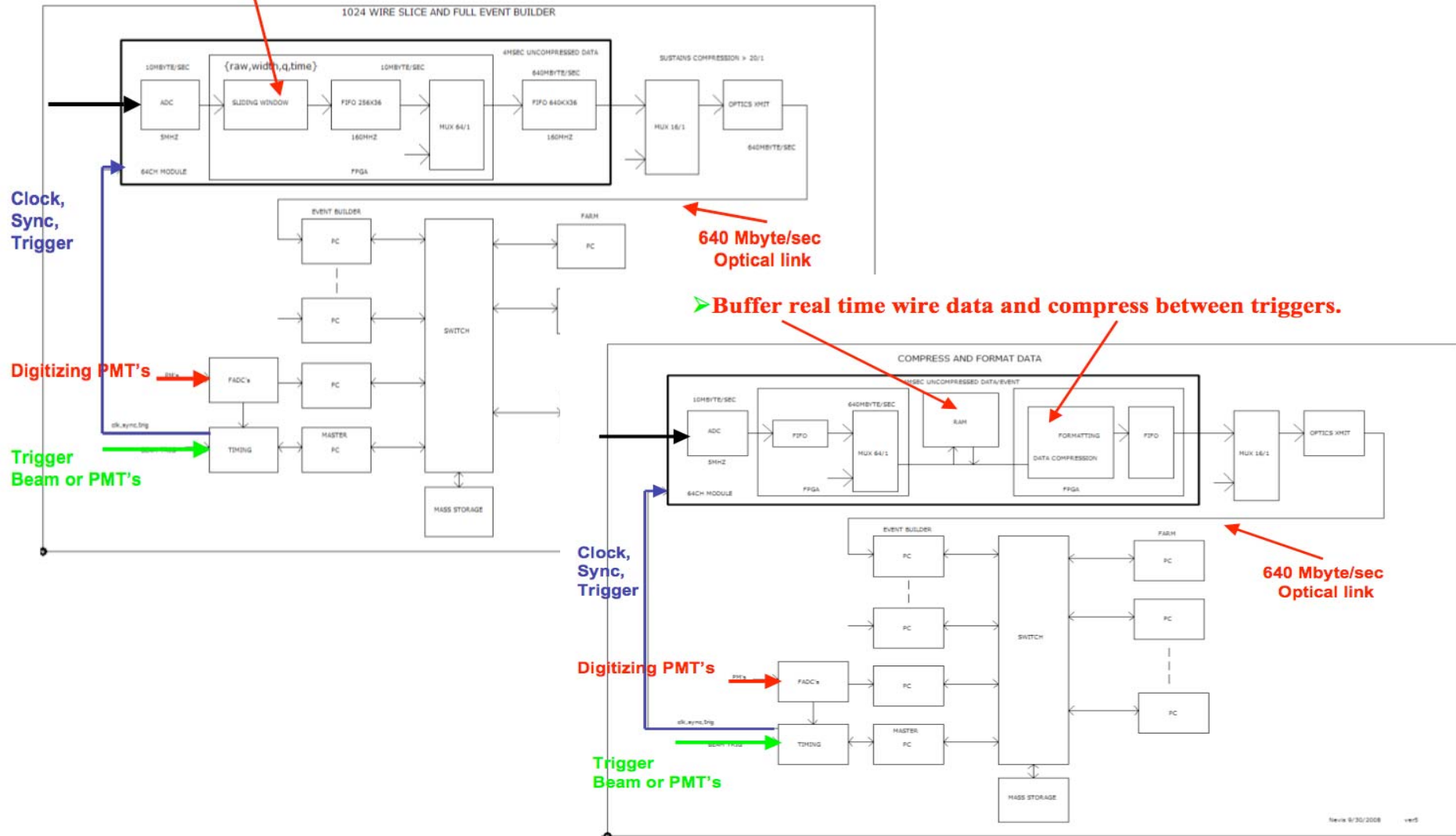
DAQ Module: **64** Shaper-ADC channels with compression and buffering.

DAQ Crate: **16** DAQ Modules and 640 Mbyt/sec optical link to a PC.

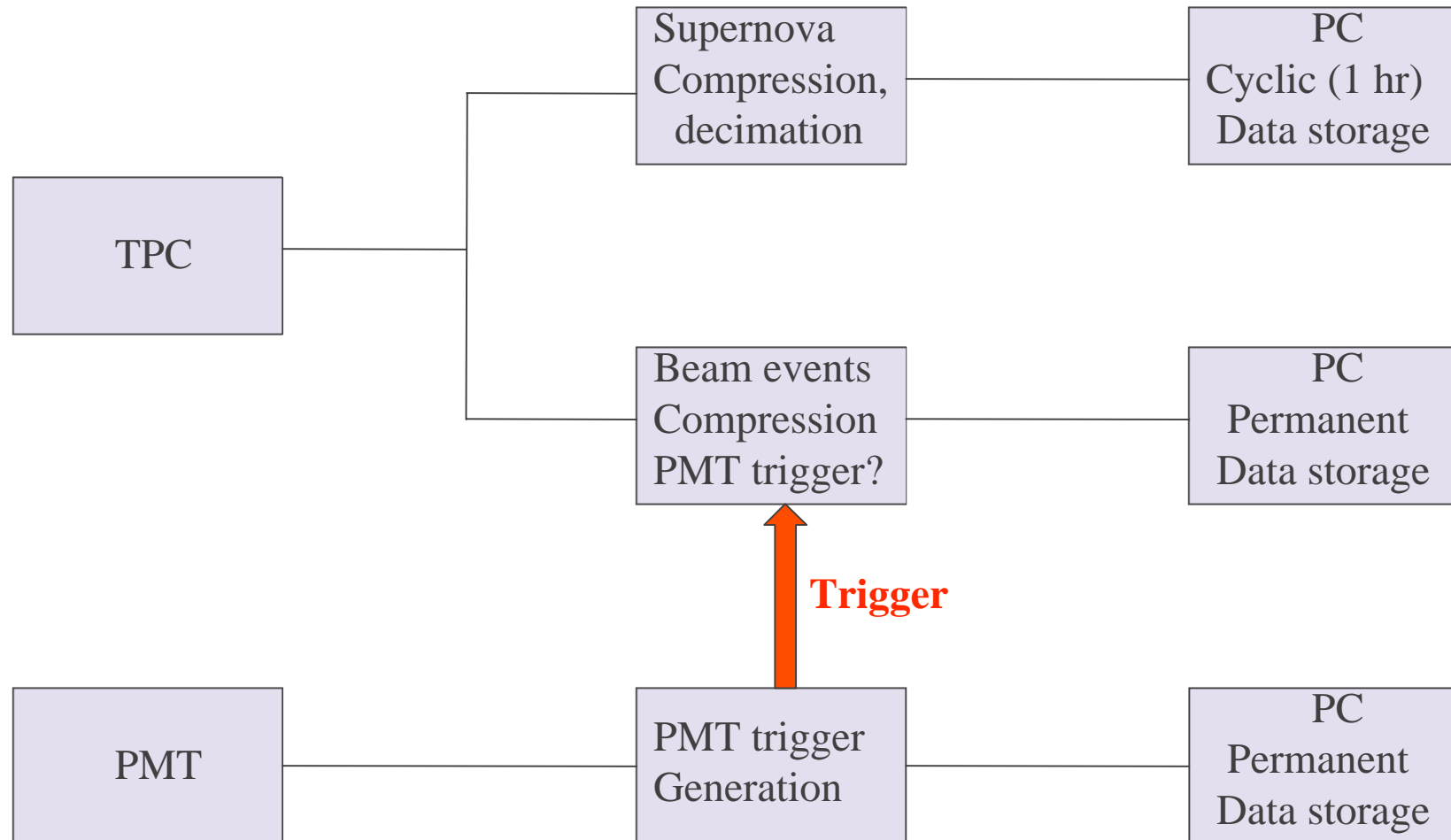


# MicroBooNE: DAQ and readout (cont'd)

➤ Baseline suppress raw wire data in real time before buffering.



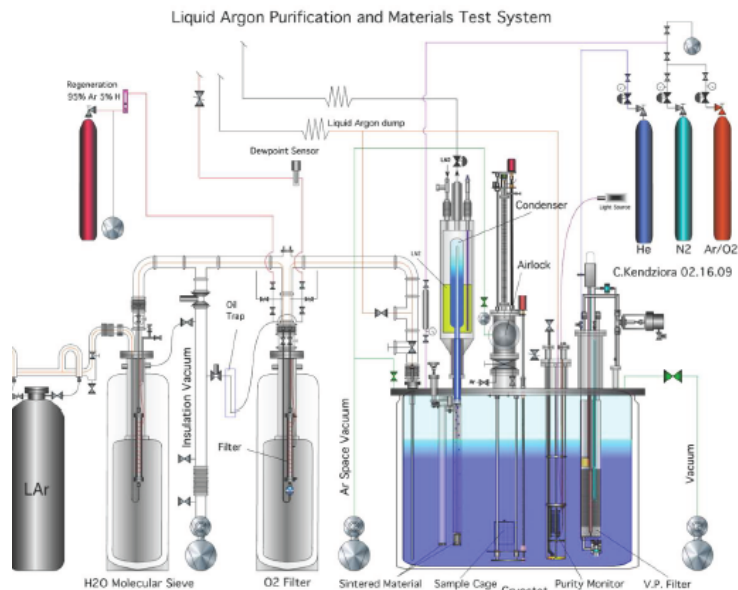
# MicroBooNE: DAQ and readout (cont'd)



# MicroBooNE: Material Purity Test@FNAL



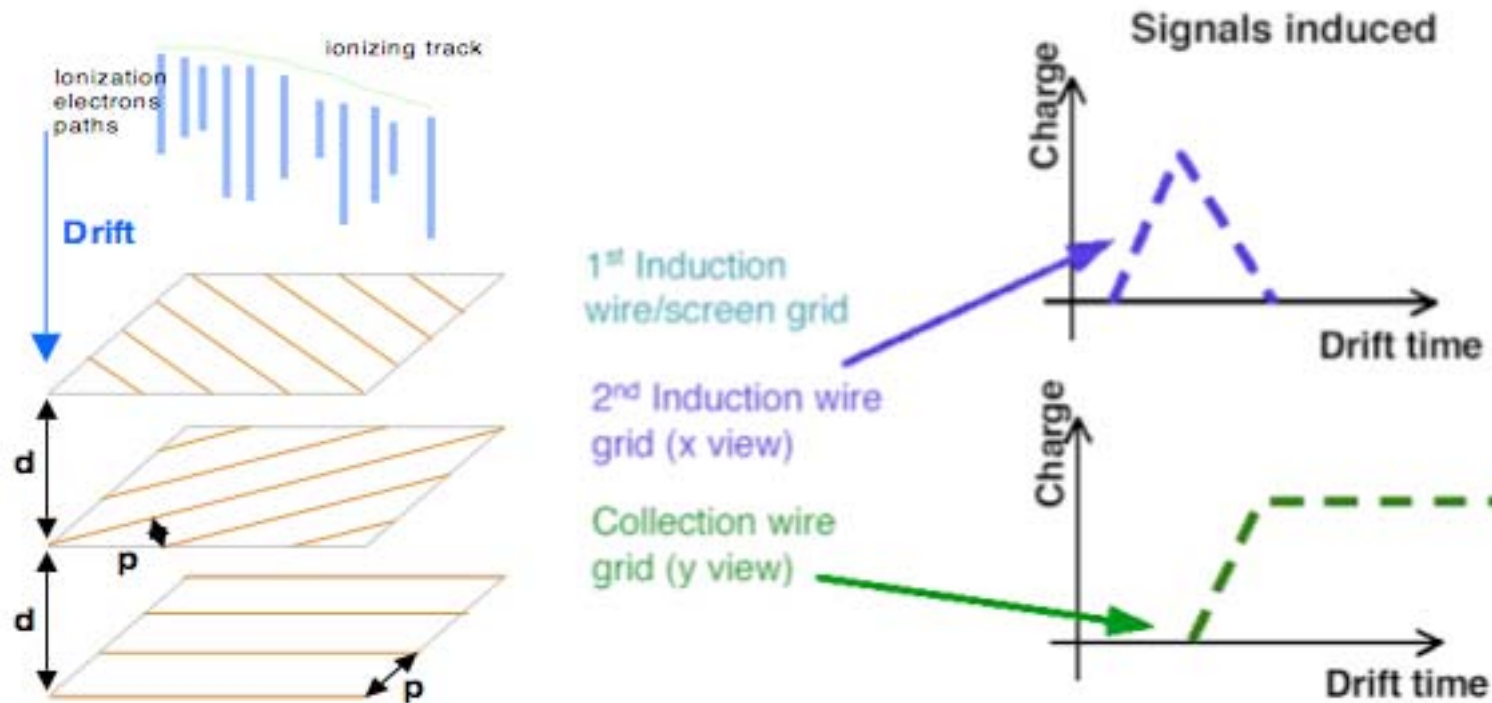
- System to study the impact of materials on purity and effectiveness of different purification techniques
  - Readout components tested...



Lifetime & Imps vs Time for Different Samples



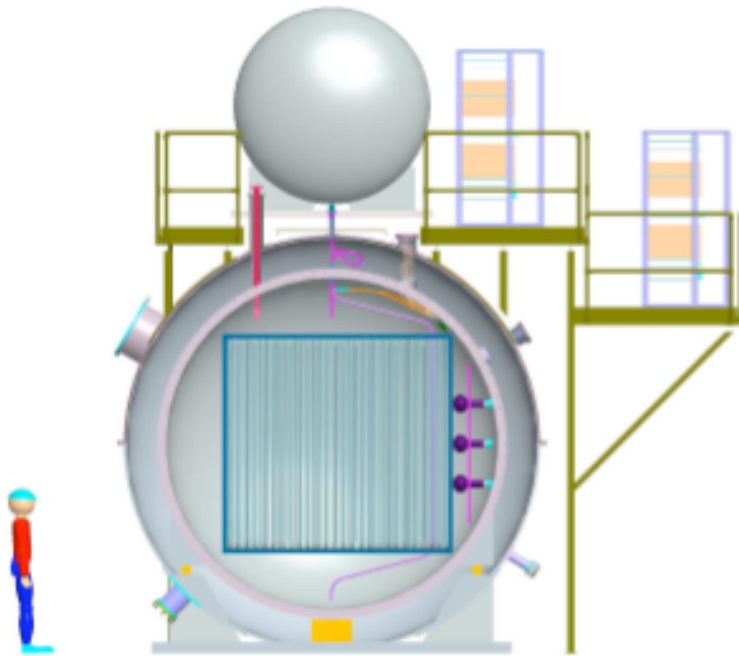
# MicroBooNE: TPC



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

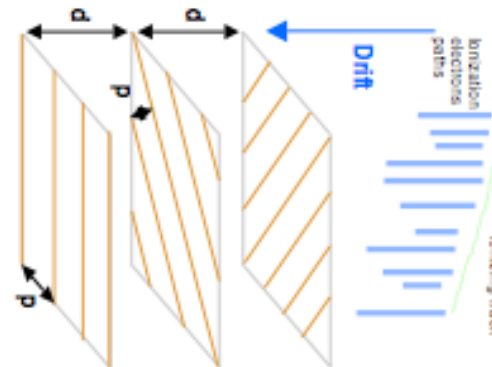
No amplification of signals in the Liquid Argon  
-need low noise electronics to achieve good signal to noise

# MicroBooNE: TPC



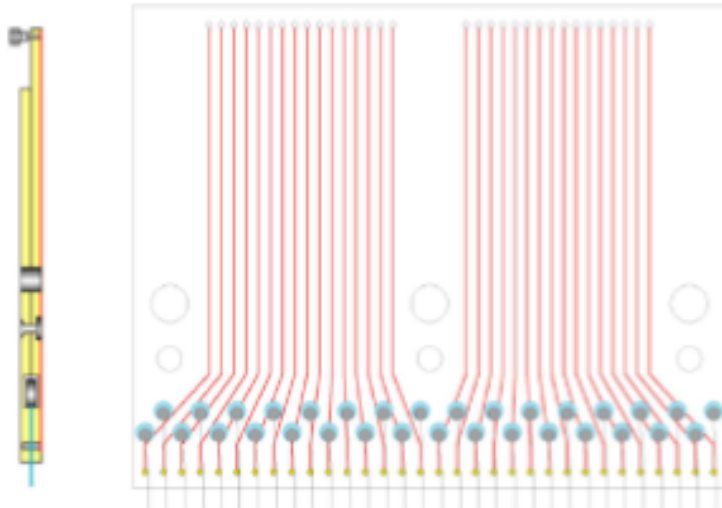
## Signal electrodes

- 2 induction planes at  $\pm 60^\circ$
- 1 vertical collection plane
- electrodes: 150 mm gold plated SS



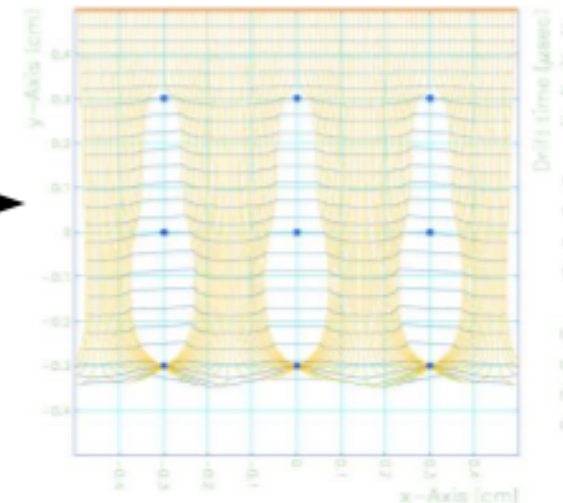
3mm wire pitch  
Planes biased at  
: -204V, 0V, 400V

Total of ~10k  
channels



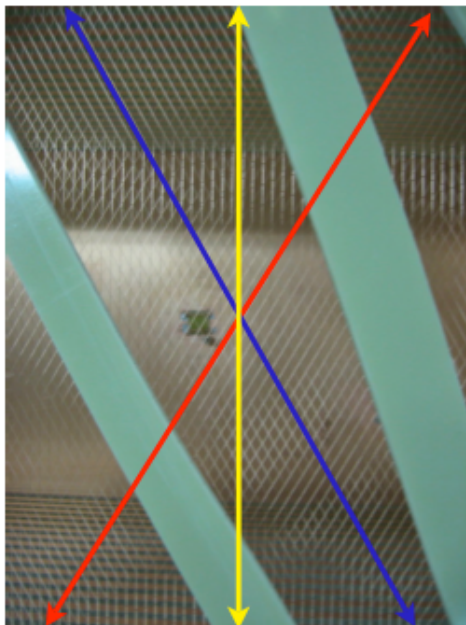
Ionization electron  
drift lines for a  
uniform track  
(Garfield-9) →

Wire holder guides  
wires to pre-amp  
and connections ←



# MicroBooNE: wire planes

- TPC wireplanes act as an electrostatic grid.
- Biasing planes properly allows them to be transparent to drifting electrons.
- Transparency is a function of wire geometry and fields around each plane.
  - ▶ **Transparency + Multiple planes allow complimentary position measurements of same particle.**
- Optimize wire/plane pitch to increase resolution, but keep S/N high.



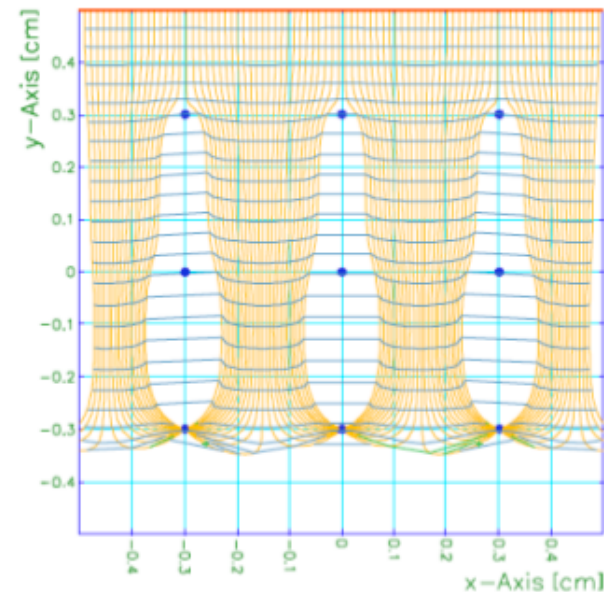
Wire Orientations

$$\frac{E_2}{E_1} \geq \frac{1 + \rho}{1 - \rho}$$

100% Transparency  
Condition:

$$\rho = \frac{2\pi r}{d}$$

$r$  = wire radius  
 $d$  = wire pitch



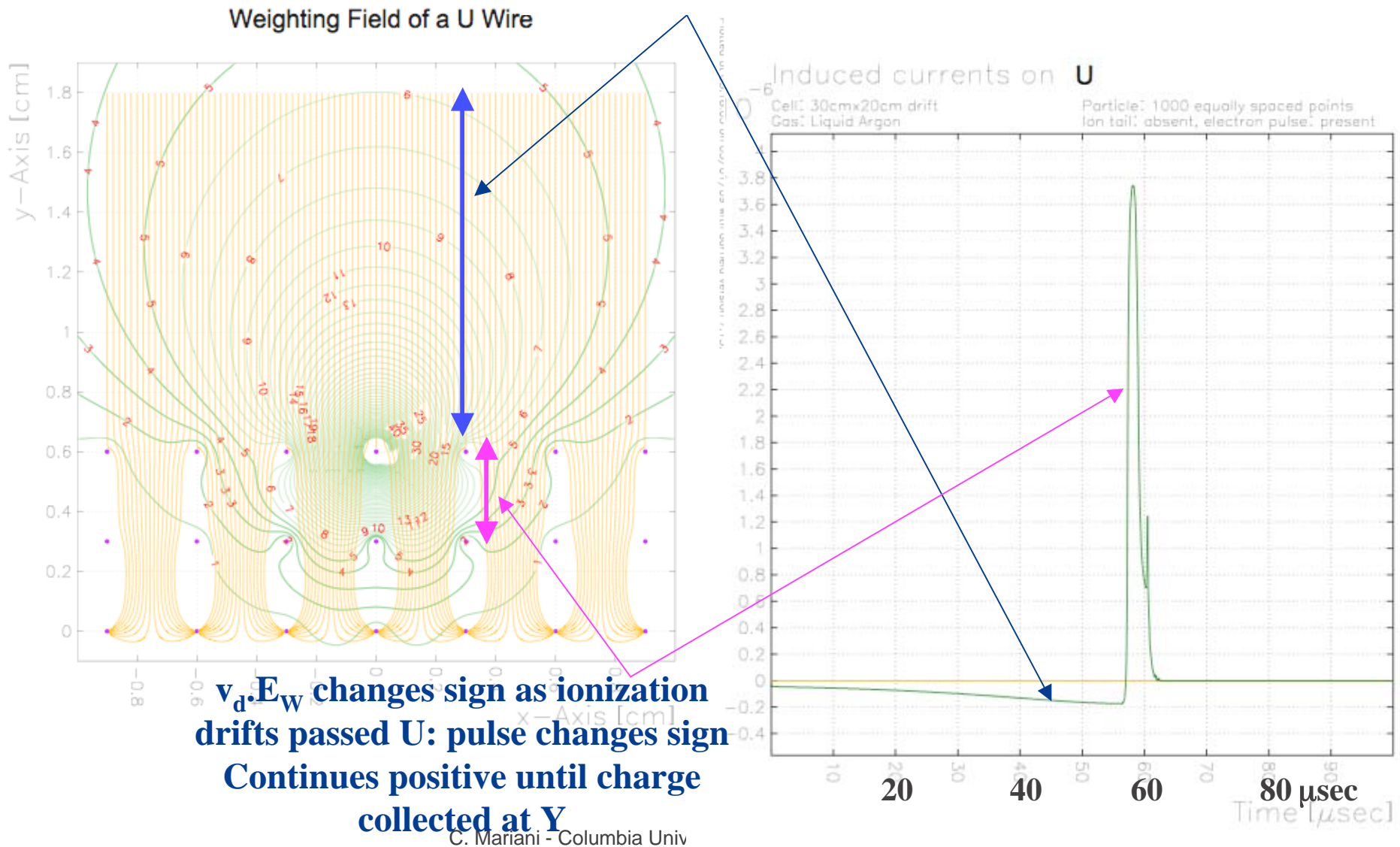
Garfield Simulation

Refs:

1.) *Design of Grid Ionization Chambers*, O. Bunemann, T.E. Cranshaw, and J.A. Harvey; *Canadian Journal of Research*, 27, 191-206, (1949)

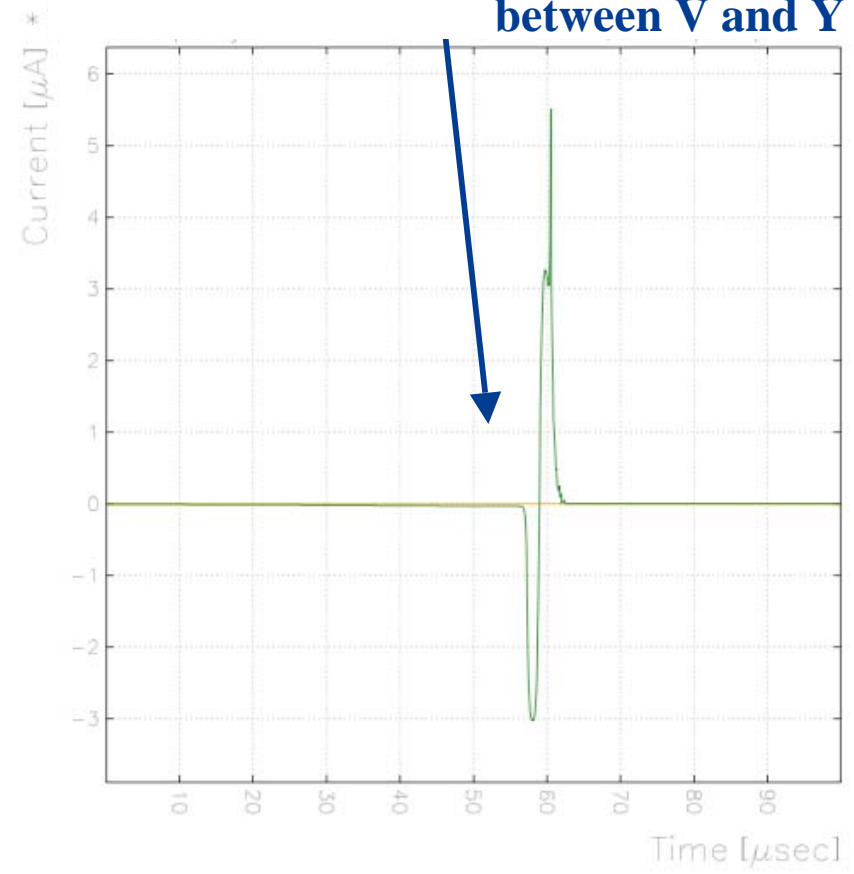
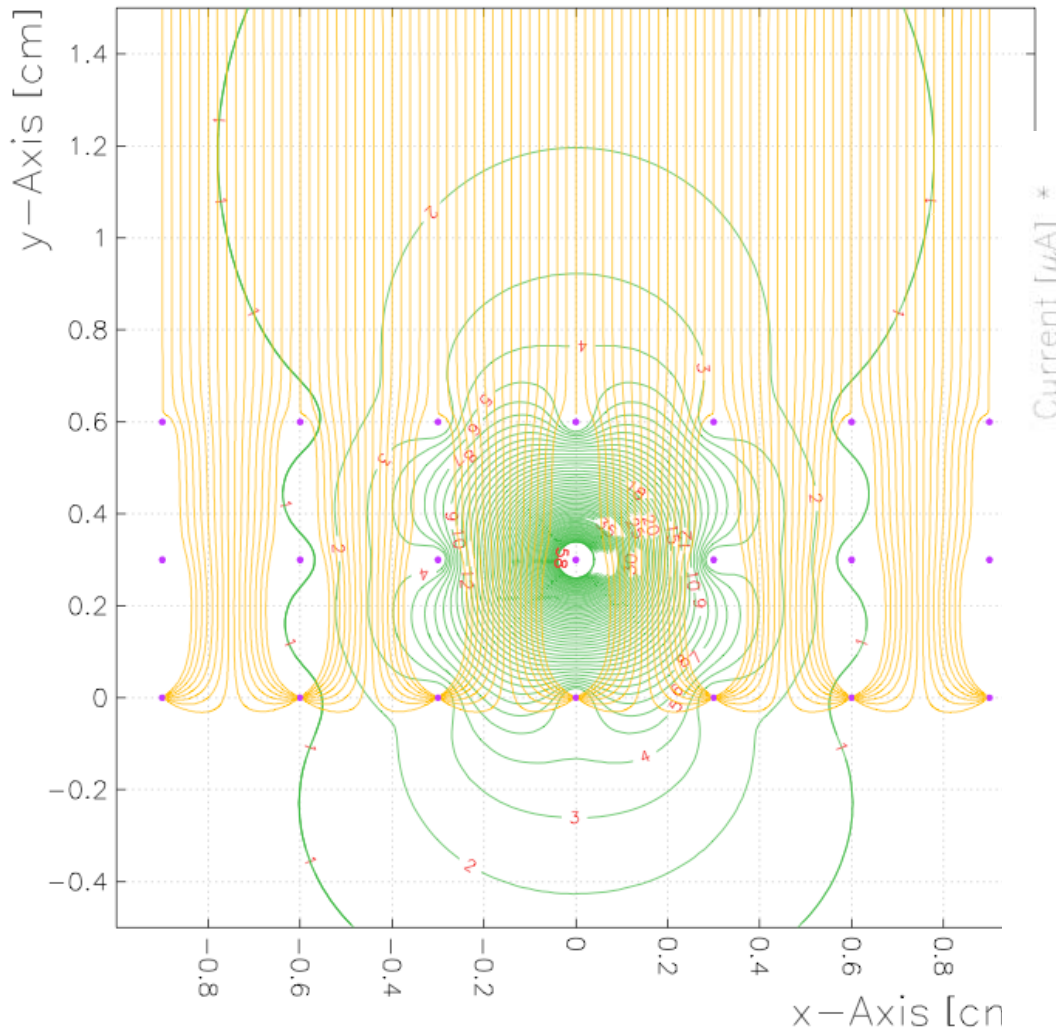
# MicroBooNE: wire planes - U

Long negative pulse seen on U until charge drifts passed U:



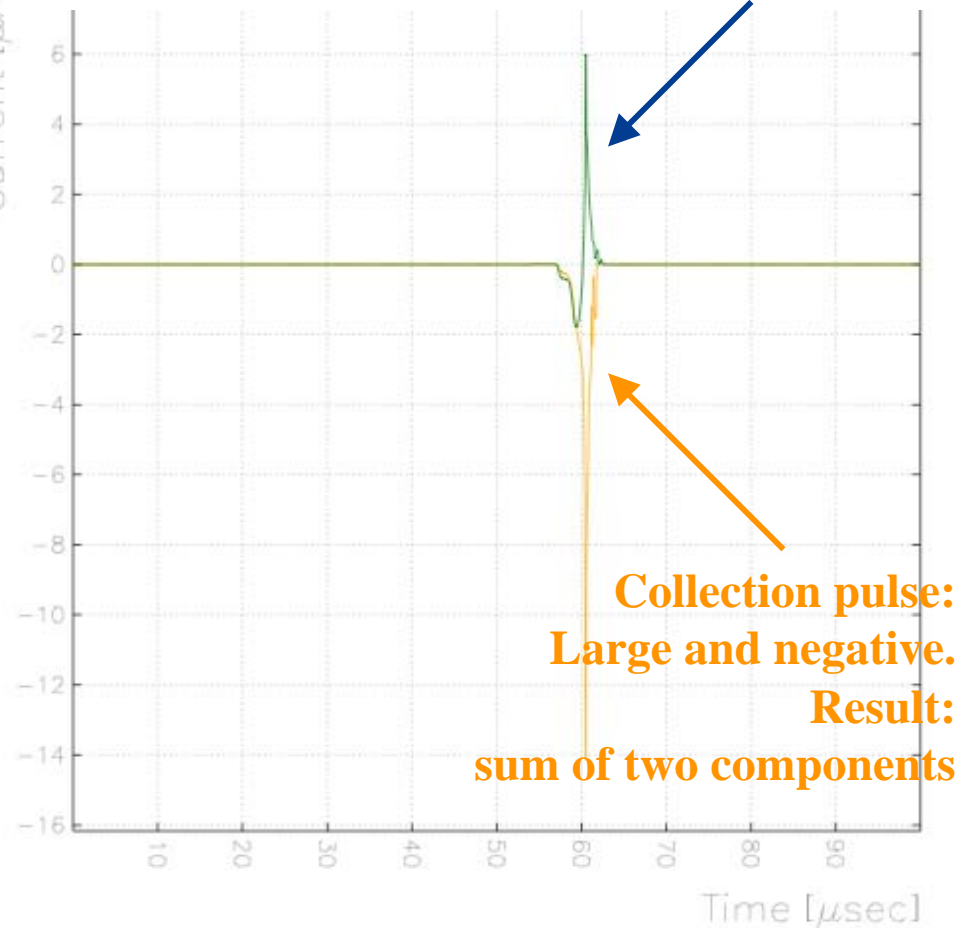
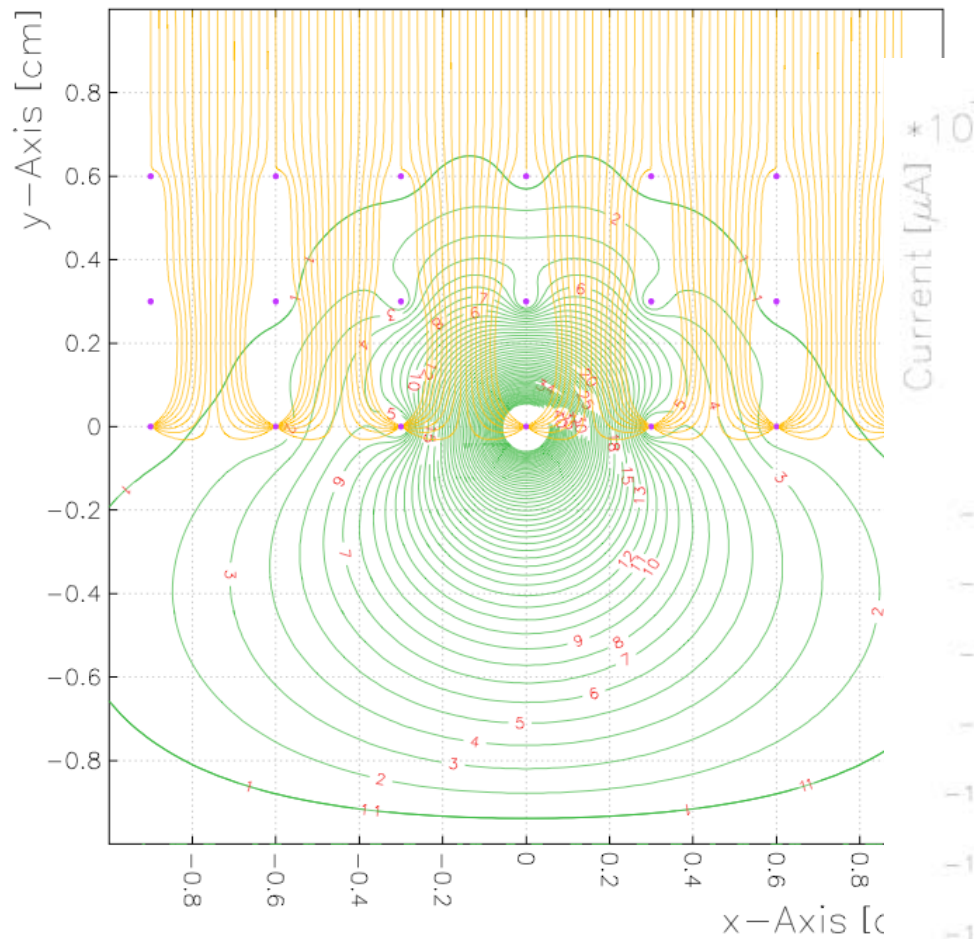
# MicroBooNE: wire planes - V

Not much charge seen on V until  
charge drifts passed U.  
Negative pulse while the charge drifts  
between U and V  
Positive pulse while ionization drifts  
between V and Y



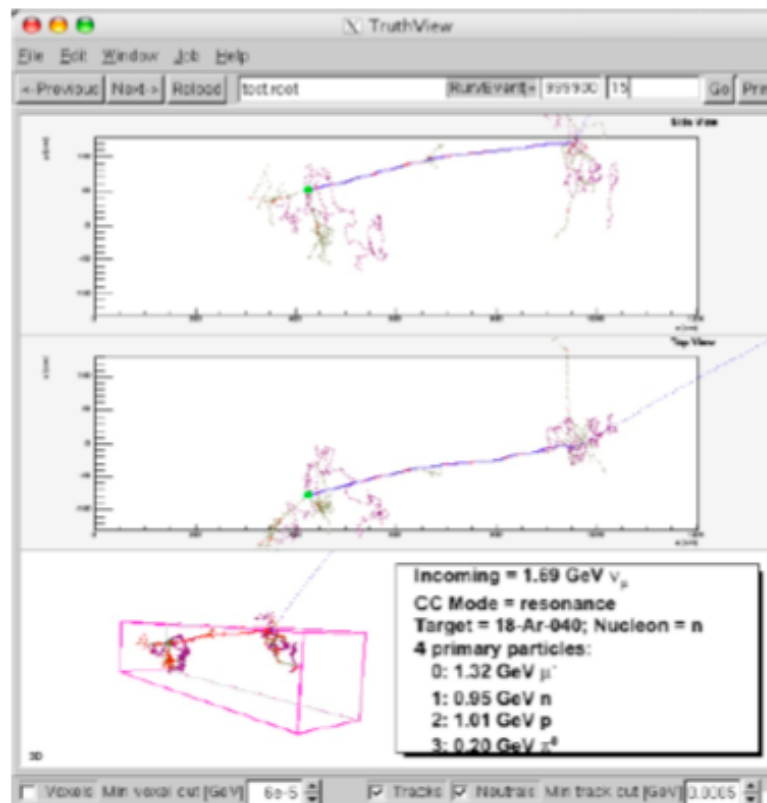
# MicroBooNE: wire planes - Y

**Induced pulse:**  
starts when ionization crosses U plane,  
increases when it crosses V  
**Goes positive when**  
**ionization reaches nearby wires**



# MicroBooNE: simulation

- Joint effort among ArgoNeuT/MicroBooNE/LAr5 proponents to develop simulation/reconstruction software.
  - ▶ Common tools, with different detector geometry plugged in.
- Utilizing FMVVK code environment for this work.
- Creating a brand new GEANT4 simulation for LArTPCs
- Already have interfaced generators (GENIE/Nuance/etc...) with simulation.
- Computing needs of LArTPCs (data and MC) will be vast, so we're thinking of this as well.



# MicroBooNE now: ArgoNeuT

R&D

Physics

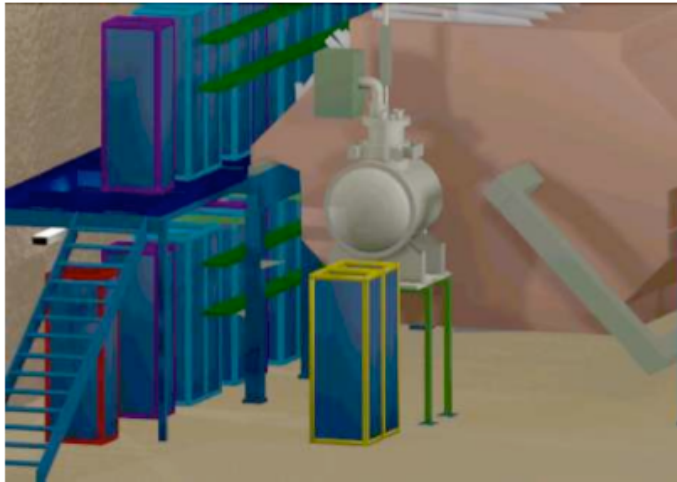
## ArgoNeuT

Joint NSF/DOE project

0.3 ton active volume

0.5 x 0.5 x 1.0 m<sup>3</sup> TPC; 500 channels

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



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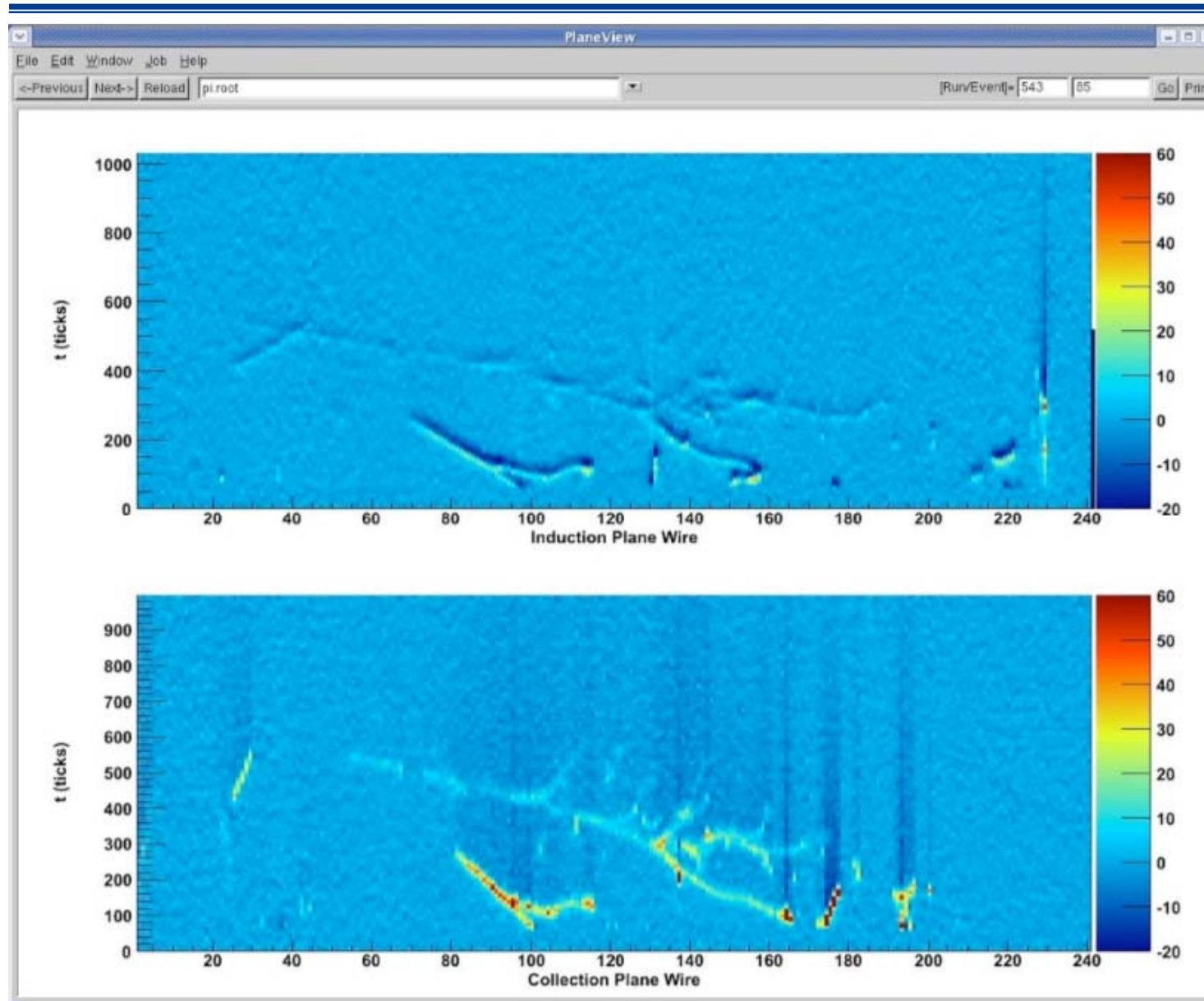
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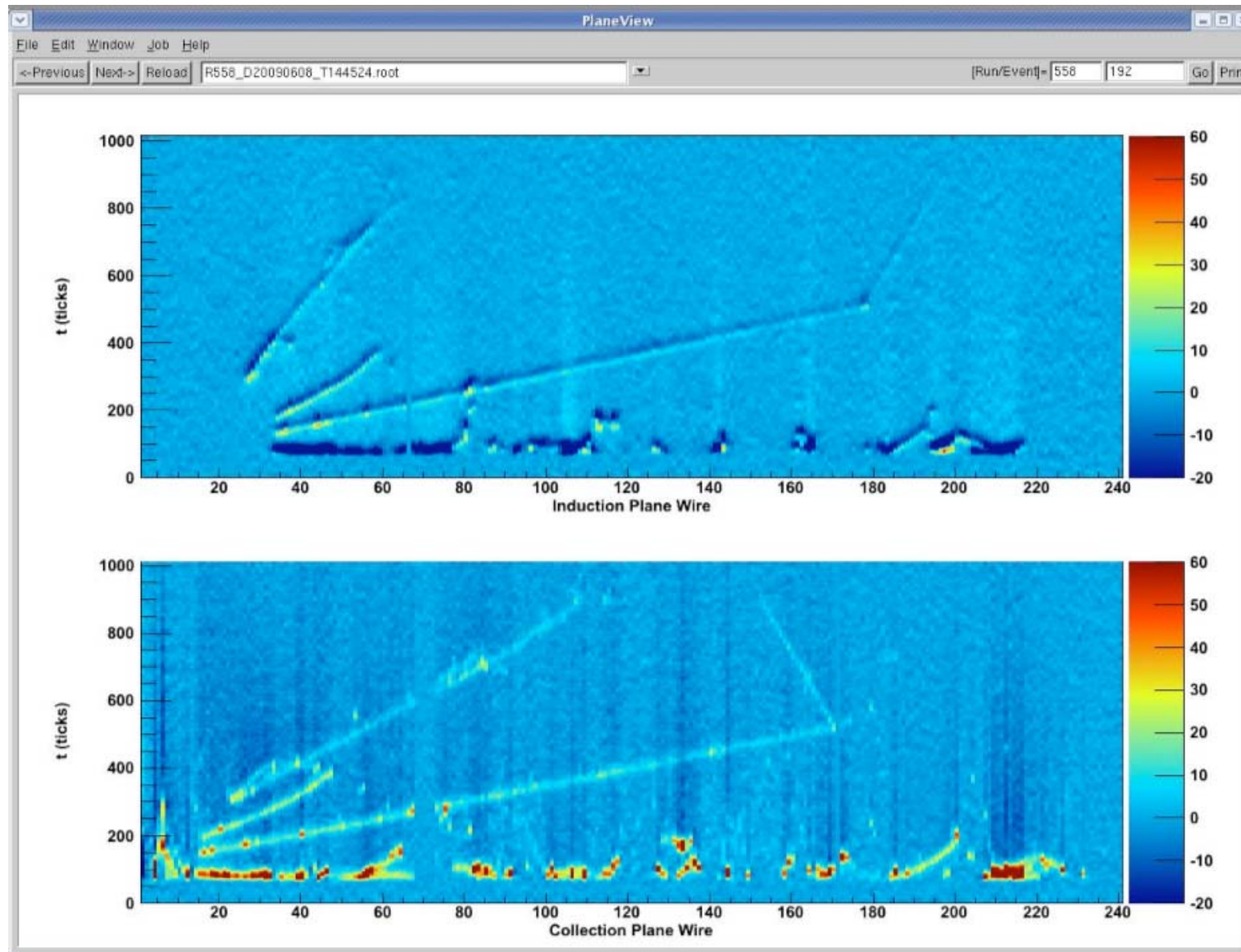
C. Anderson, B. Fleming\*, S. Linden, M. Soderberg, J. Spitz

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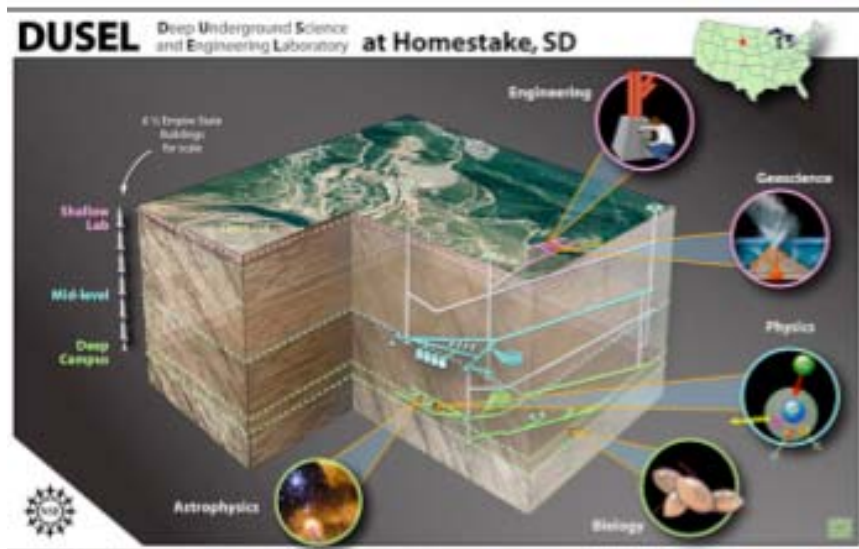
# MicroBooNE now: ArgoNeuT



# MicroBooNE now: ArgoNeuT



# R&D Roadmap in the U.S.



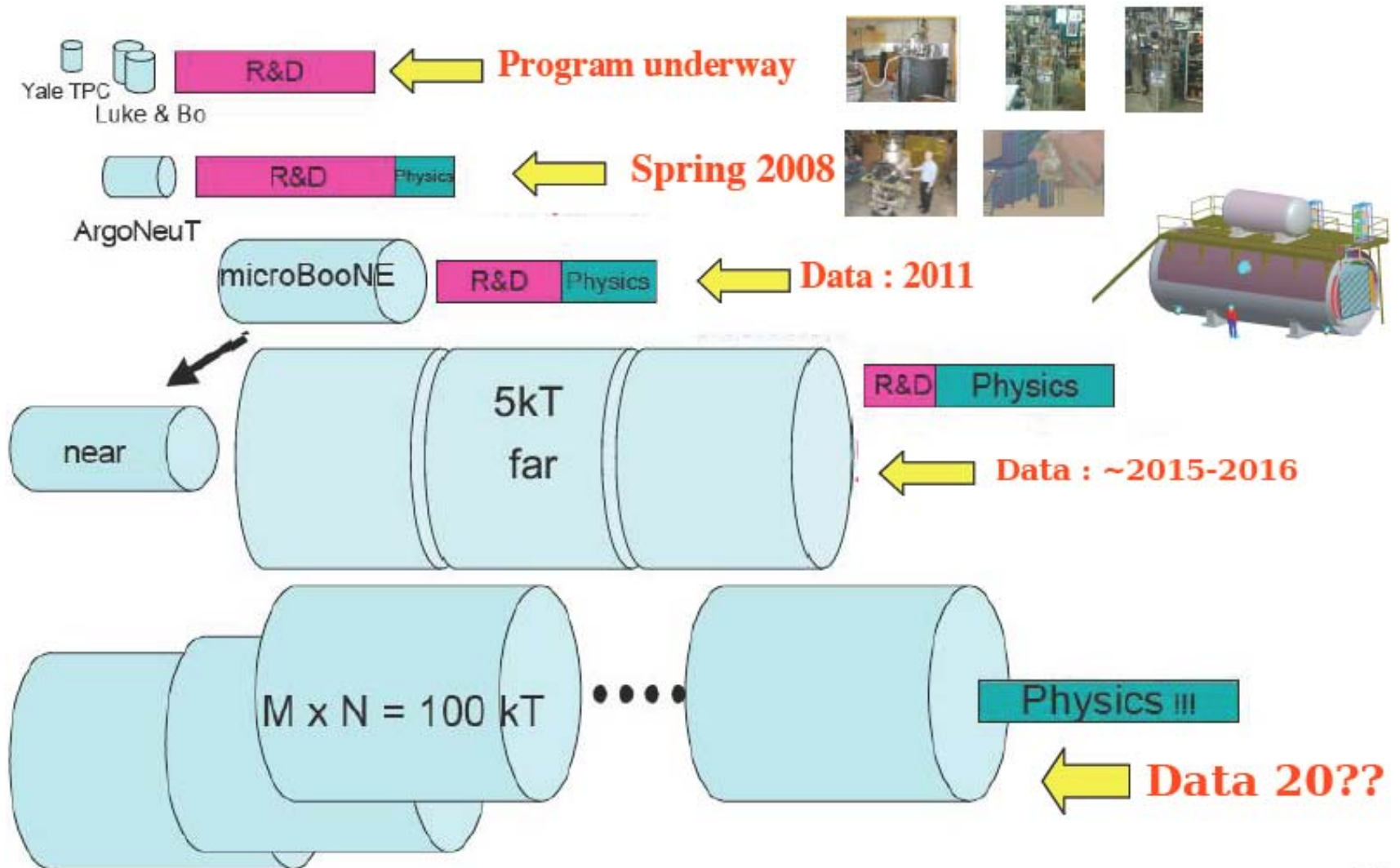
- The ultimate goal is to make LAr a viable option for massive detectors
- Very large detectors needed for next generation neutrino oscillation experiments and proton decay
- Oscillation experiment will be a major component of DUSEL
- Will allow us to measure CP violation in the neutrino sector, see 1st and 2nd oscillation maxima

# Challenges for a large detector

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- Low noise electronics and multiplexing
- Triggering from light detection
- Achieving sufficient purification in a large volume
- Designing the vessels - materials, insulation, feed throughs
- Safe underground operation
- Understanding the cross-sections on LAr
- Developing simulations, reconstruction software
- Proving they can work, and demonstrating continuous operation for long periods of time

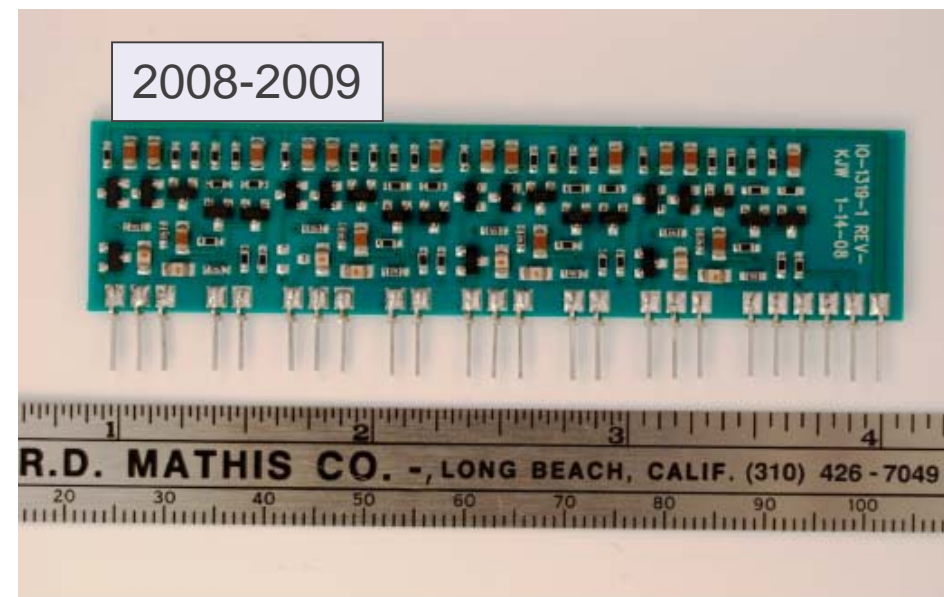
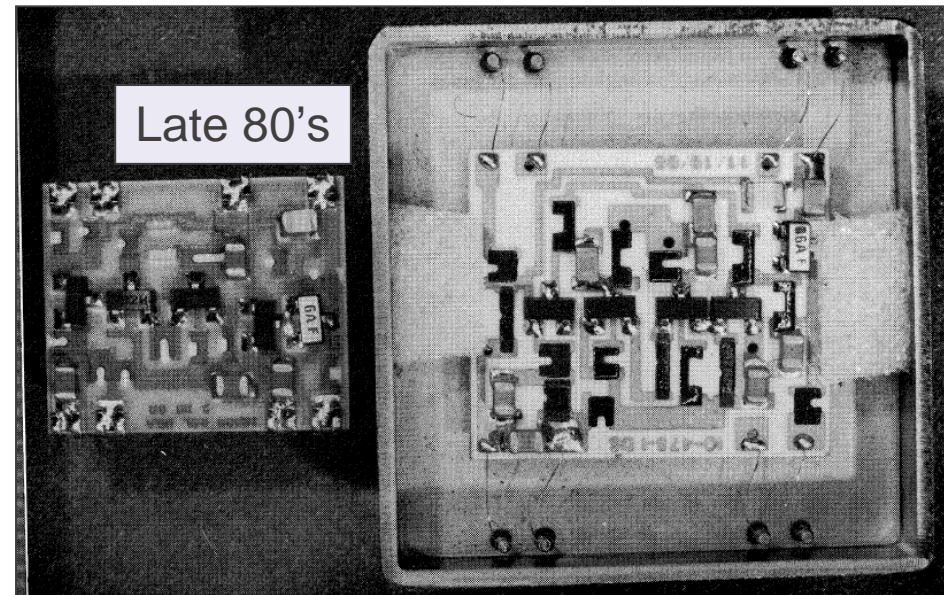
# Outlook



# Backup Slides

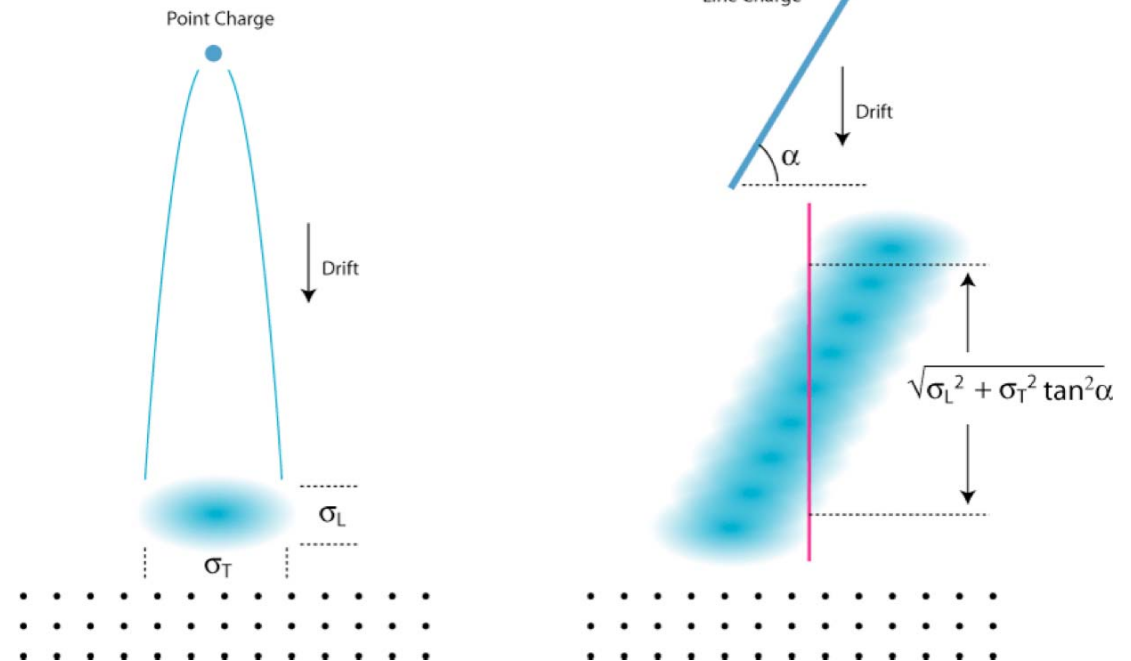
# MicroBooNE: Cryogenic Front-End

- Technology mature and available as of today
  - Reliability issues requires a careful choice of component and high-reliability assembly
  - Ceramic hybrid with co-fired traces and surface mount components properly tested
- Several years of experience
- Helios-NA34:
  - 576 preamplifiers
  - Operations: 4 years, multiple cool-downs
  - Failure: 1
- NA48:
  - Preamplifiers in LAr: 13,000
  - Operated at very high voltage
  - Failures: ~50 because of a HV accident in 1998. Negligible failures after that
  - Always kept at cryogenic temperature



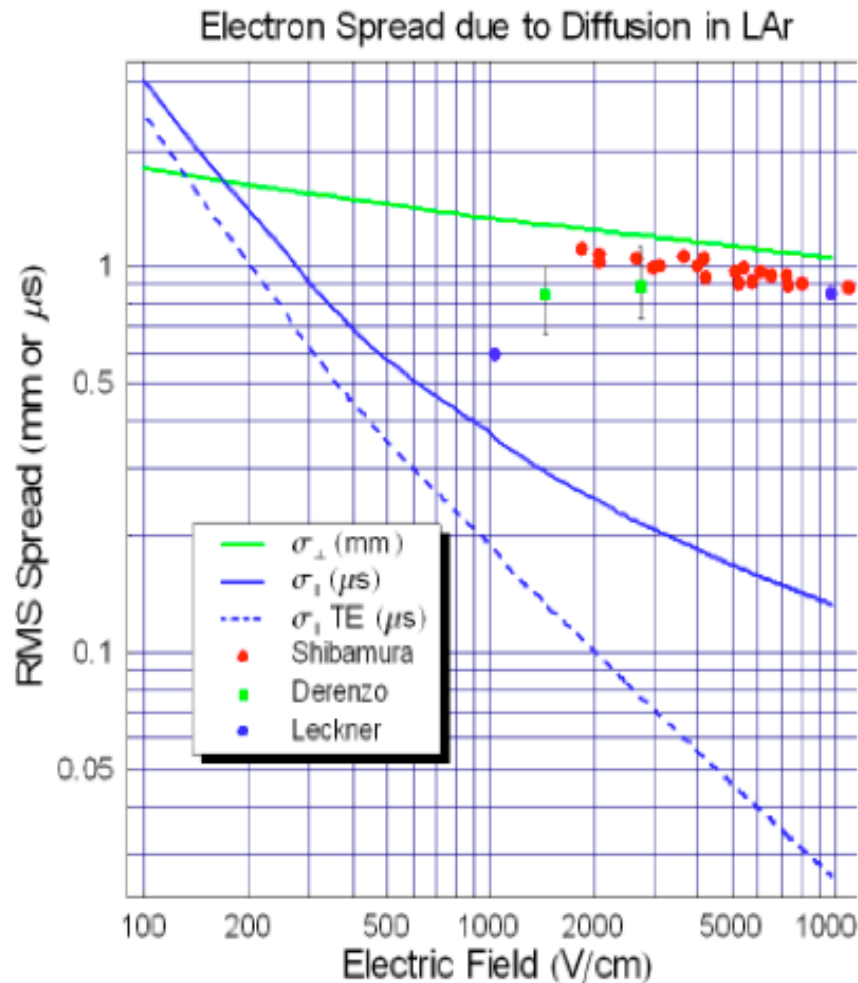
# MicroBooNE: Detector Optimization

- For example diffusion constants in LAr have great impact on the performance of the detector, and **need to be measured soon (both tranv. and long.)**:
  - TPC parameters, such as wire pitch, wire plane spacing, and maximum drift length
  - Electronics parameters, such as dynamic range, shaping time, sampling frequency, bandwidth



The effective rms spread in time is determined by  $\sigma_T \tan \alpha$  at large track angles

# Effects of diffusion in LAr



$$\sigma = \sqrt{\frac{2Dz}{v}} = \sqrt{\frac{2\varepsilon z}{E}}$$

$v_D = 1.54 \text{ mm}/\mu\text{s}$ ,  $D_{\perp} = 16.3 \text{ cm}^2/\text{s}$ , and  $D_{\parallel} = 6.2$

RMS electron swarm sizes after drift for a field of

Distance (m)	$\sigma_{\perp}$ (mm)	$\sigma_{\parallel}$ ( $\mu\text{s}$ )	$\sigma_{\parallel} T$
0.25	0.73	0.29	0.1
0.50	1.03	0.41	0.2
0.75	1.26	0.50	0.3
1.00	1.46	0.58	0.3
1.25	1.63	0.65	0.4
1.50	1.78	0.71	0.4
1.75	1.93	0.77	0.4
2.00	2.06	0.82	0.5
2.25	2.18	0.87	0.5
2.50	2.30	0.92	0.5