7th Symposium on Large TPCs for Low-Energy Rare Event Detection
Paris, France, December 2014

The MicroBooNE experiment at FNAL

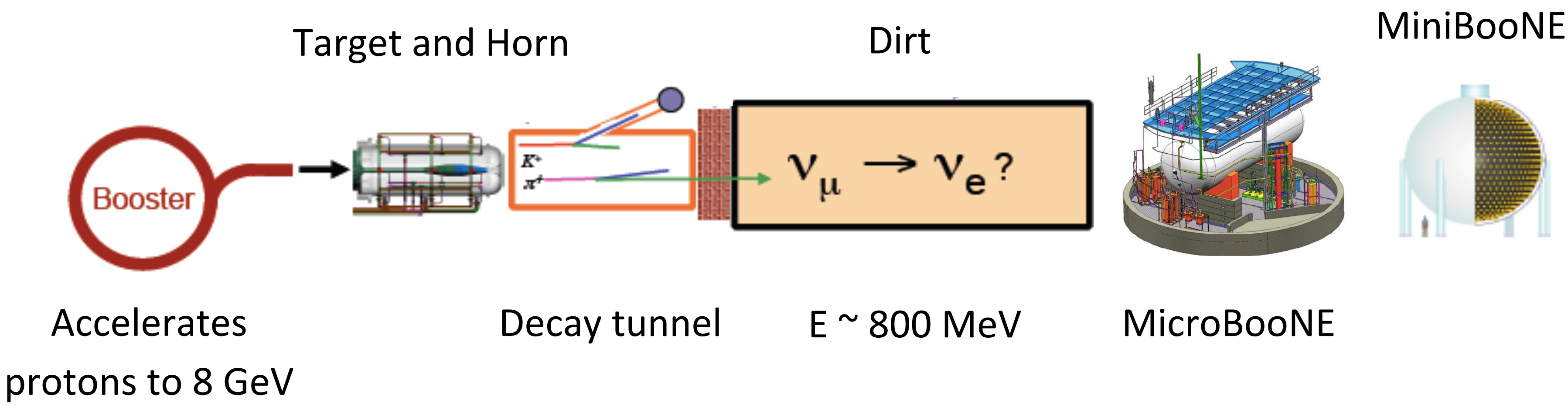
Leonidas N. Kalousis (Virginia Tech)
for the MicroBooNE collaboration

MicroBooNE

- MicroBooNE will be the largest ***Liquid Argon Time Projection Chamber*** (LArTPC) operating in the US.
  - *… and the second largest LArTPC in the world*
- Main motivation for designing and building MicroBooNE is the investigation of the low-energy electromagnetic excess seen by MiniBooNE.
- Additionally MicroBooNE will be able to:
  - *Perform cross-section measurements on argon*
  - *Study the background relevant to proton decay in LArTPCs*
  - *Detect neutrinos from supernova explosions*
  - *Further advance the LArTPC technology*
- And contribute to other, *more exotic*, searches …

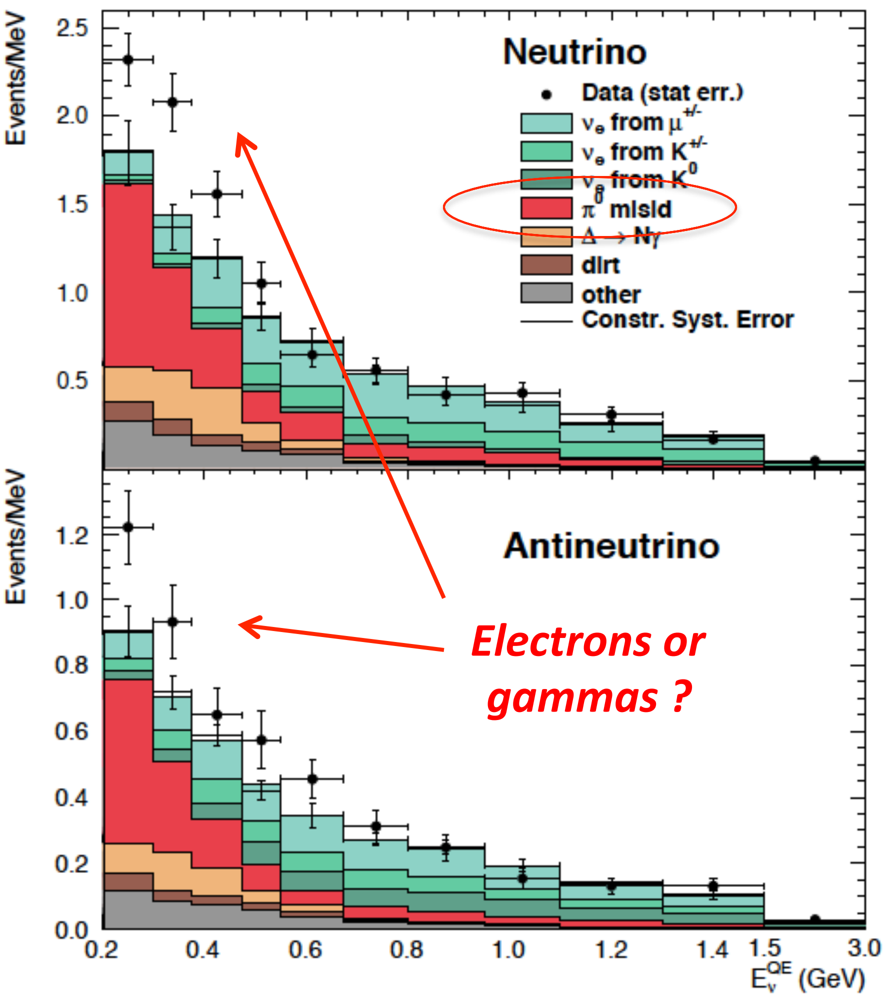
Experimental layout

- MicroBooNE (just like MiniBooNE) is now installed along the Booster Neutrino Beam (BNB) at Fermilab (FNAL).



- Placed in the *Liquid Argon Test Facility* (LArTF) at a distance of ~470 m from the beryllium target.
- It is expected to start data taking in 2015 and run for 2-3 years in the neutrino mode accumulating ~ 6.6 10^{20} POT.

The MiniBooNE puzzle



Phys. Rev. Lett. **110** (2013) 161801

$$\overset{(-)}{\nu}_\mu \longrightarrow \overset{(-)}{\nu}_e$$

Neutrino mode:

- Excess: 162.0 ± 47.8 (3.4σ)

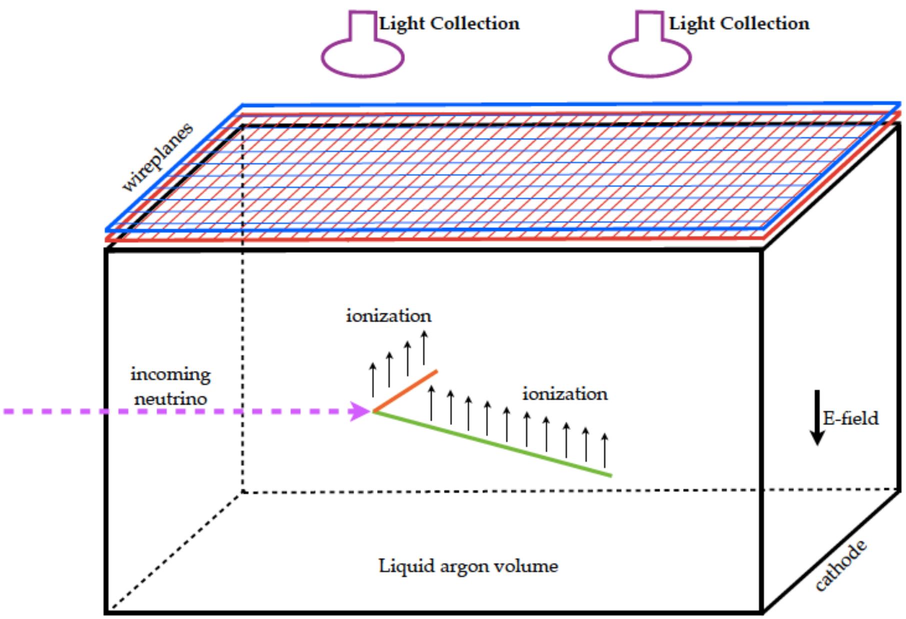
Antineutrino mode:

- Excess: 78.4 ± 28.5 (2.8σ)

Combined:

- Excess: 240.3 ± 34.5 ± 53.6
- 3.8σ statistical significance

Liquid Argon
Time Projection Chambers



Picture from M. Soderberg

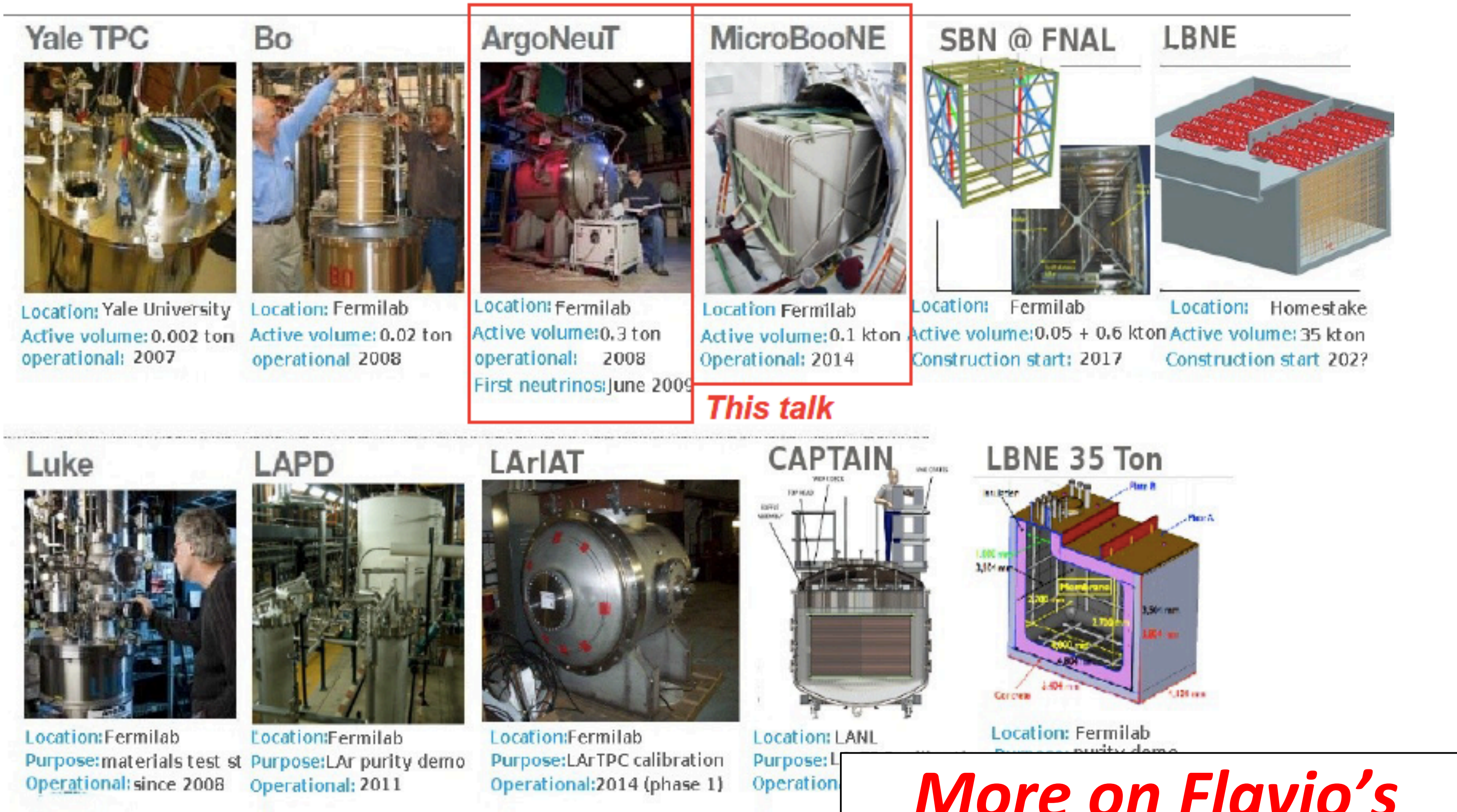
Incredible step in spatial resolution and calorimetry

<u>Why argon ?</u>

- Ionization charges drifted through macroscopic distances
- High scintillation yield
- Argon is rather cheap and abundant in nature
- Dense detectors can be made

- *Ionization electrons detected by a series of wire planes*
  – Particle identification and calorimetry
- *Scintillation light collected from a photomultiplier system*
  – Trigger and t_0 reconstruction

US based effort



More on Flavio's talk this Tuesday

Slide from A. Szelc, Neutrino 2014

The MicroBooNE LArTPC

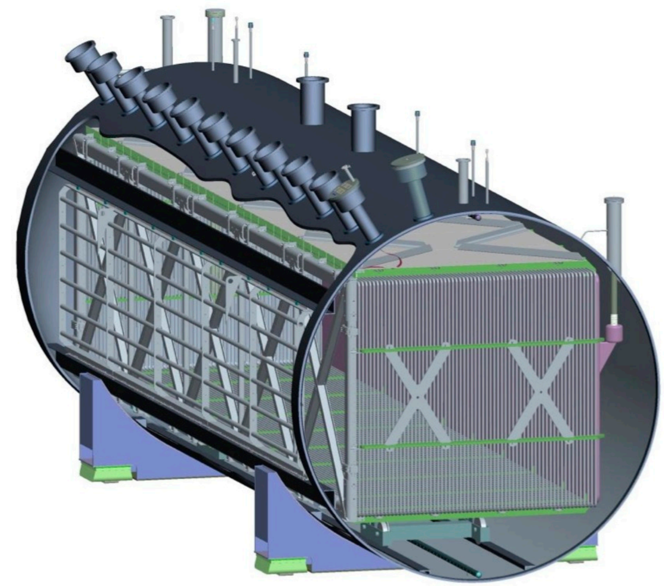
Time Projection Chamber:

- Three planes of wires at 3 mm pitch
  - One collection plane at 0° from vertical
  - Two inductions planes at ±60°
- 8256 channels totally
- 1.6 ms drift time (2.5 m drift length)

Optical system:

- 32 cryogenic photomultipliers (PMT)
- 4 light guide prototypes
- LED based light injection system

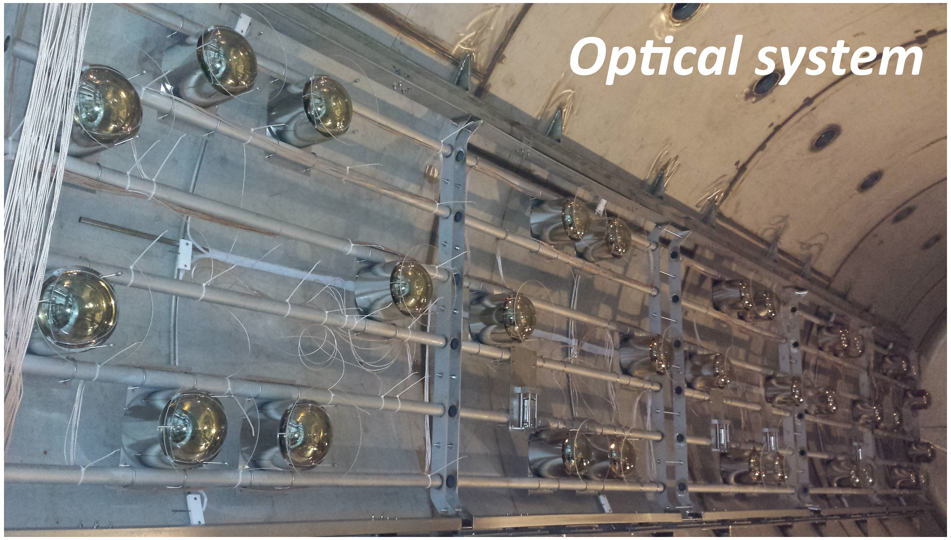
UV Laser calibration system

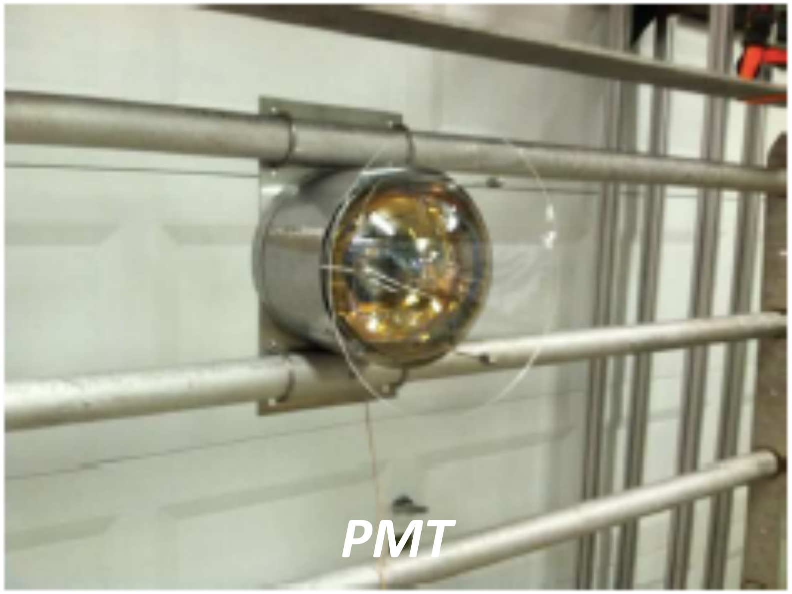


10.3 m × 2.3 m × 2.5 m
Uniform field of 500 V/cm
170 tons of purified LAr
(active volume ~80 tons)


Cryostat


Cryostat


Optical system

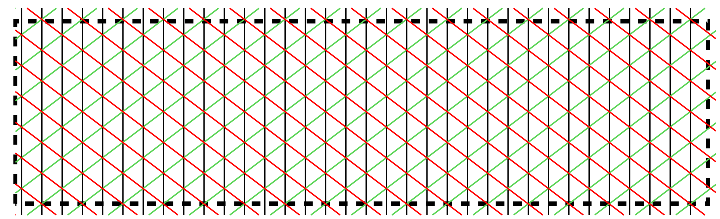

PMT

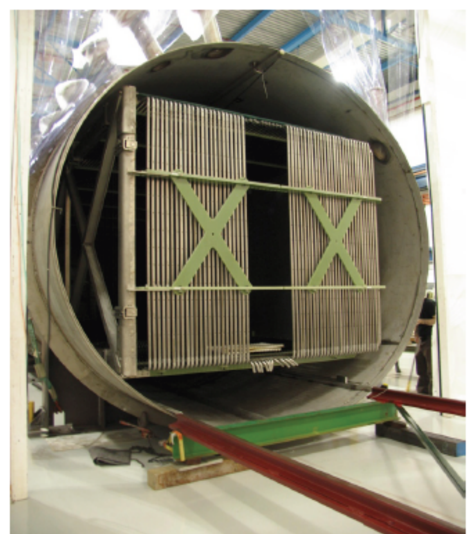
Time Projection Chamber

TPC pipes

Cathode
-128 kV

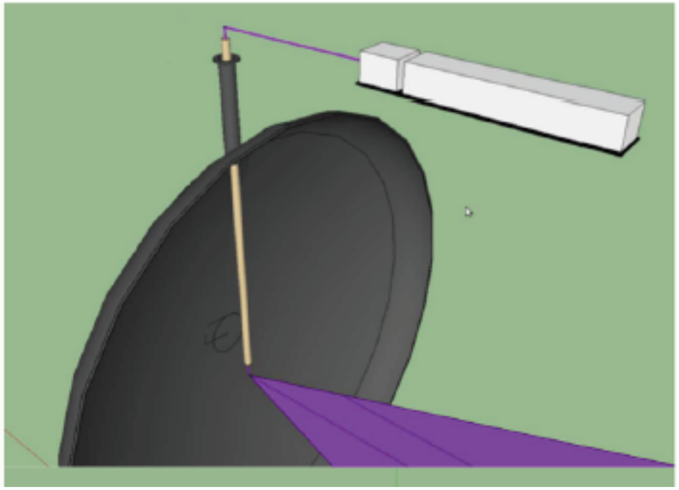
Three wire planes



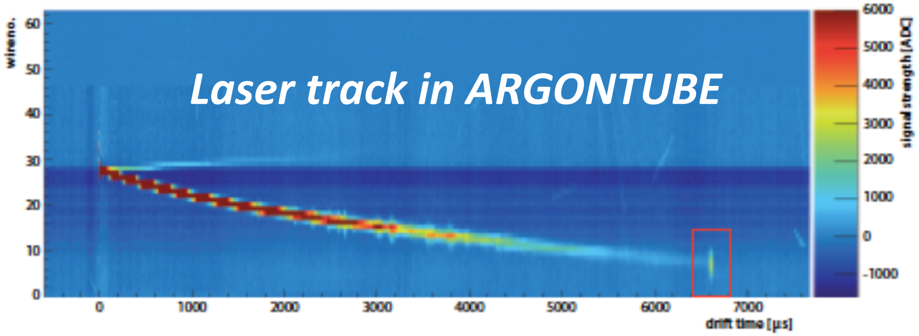


Laser calibration

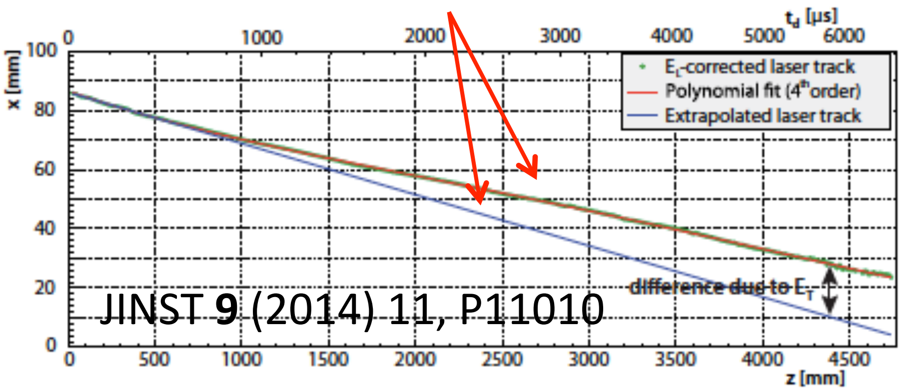
- Non-uniformities in the electric field can be well-understood and *calibrated out* using a UV laser
  - Accumulation of heavy positive ions
  - Inherent imperfections of the detector



Laser creates straight tracks



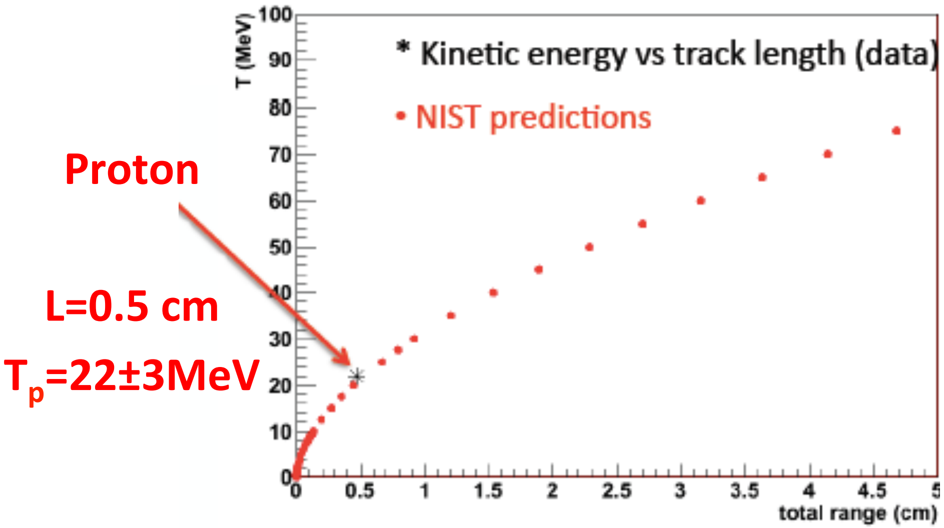
Deviation from straight line can be corrected

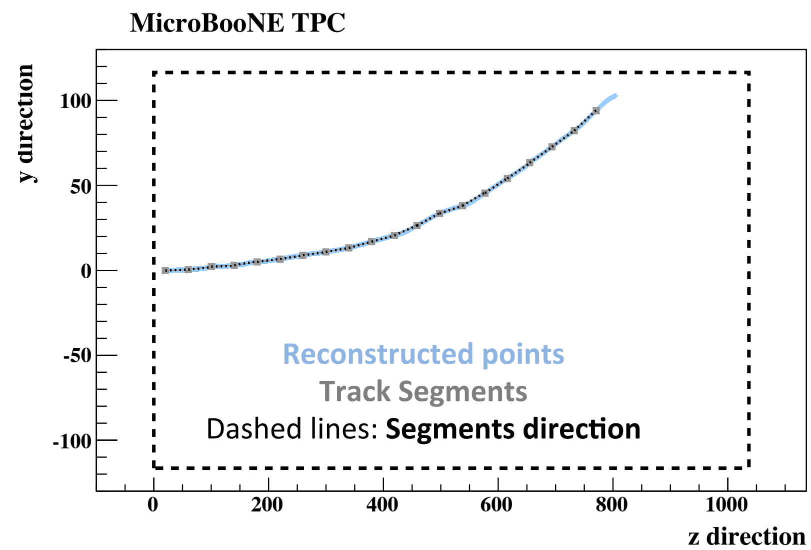


JINST **9** (2014) 11, P11010

Energy reconstruction

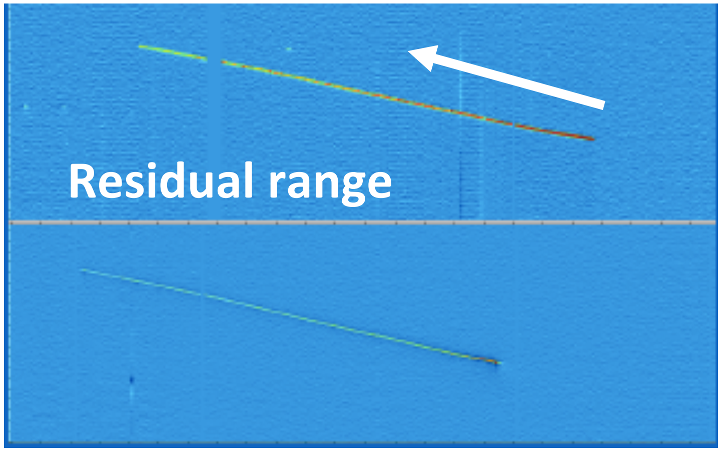
Calorimetry

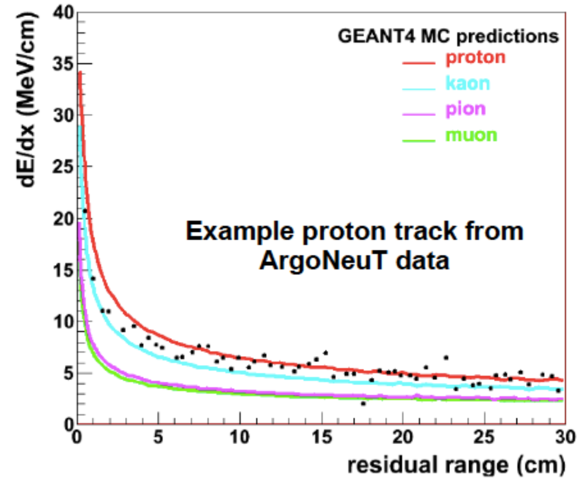


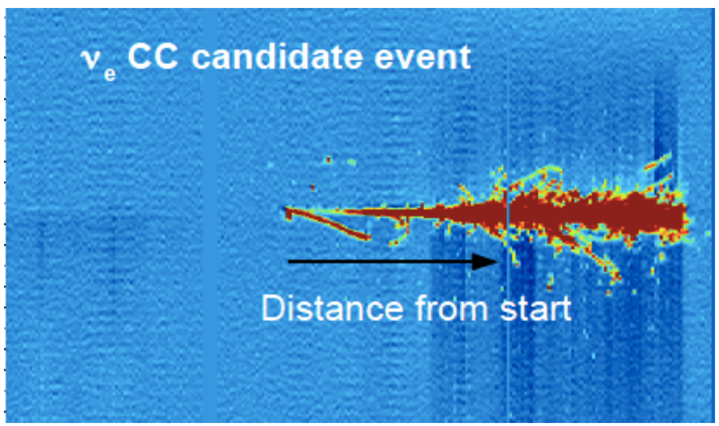


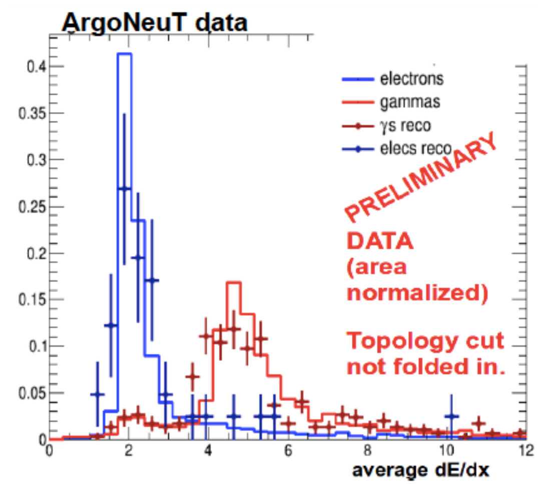
- Excellent energy resolution
  - ~ 1 - 2%/√E(GeV) for tracks
- ***Multiple Coulomb Scattering*** angular deflections can be used to infer the momentum (important for non-contained tracks)
  - ICARUS suggests a ~ 16% resolution (Neutrino 2014)

Particle identification









- *MicroBooNE can decisively answer the question whether the MiniBooNE excess is due to electrons or gammas*

Cross-section measurements

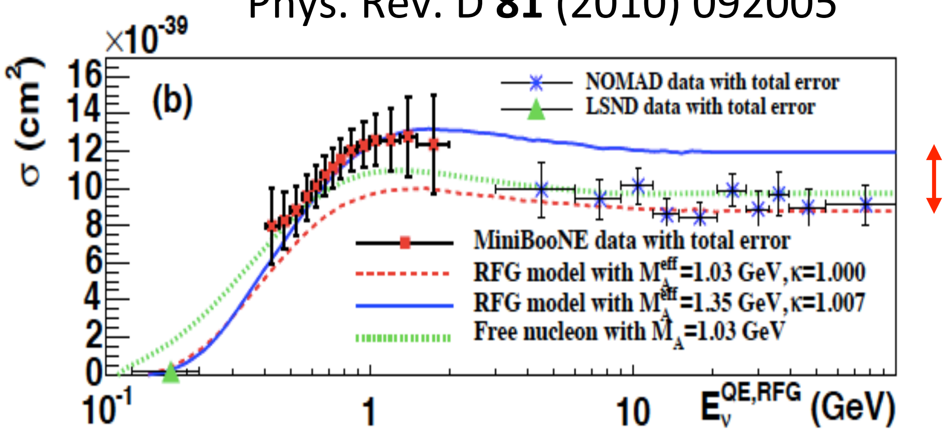
Ideal detector for cross-section measurements

- ✓ Good energy resolution
- ✓ Excellent tracking capabilities
- ✓ Robust particle identification

Process	Reaction	MicroBooNE 6.6 x 10^{20}POT
CC QE	$\nu_\mu n \rightarrow \mu^- p$	48,276
CC RES	$\nu_\mu N \rightarrow \mu^- N$	26,852
CC DIS	$\nu_\mu N \rightarrow \mu^- X$	10,527
CC Coherent	$\nu_\mu Ar \rightarrow \mu^- Ar + \pi$	376

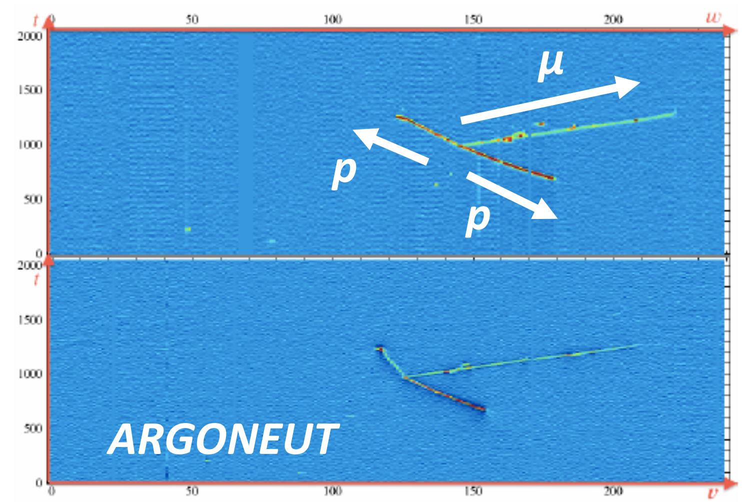
Preliminary

Phys. Rev. D **81** (2010) 092005



Intriguing deviation !!!

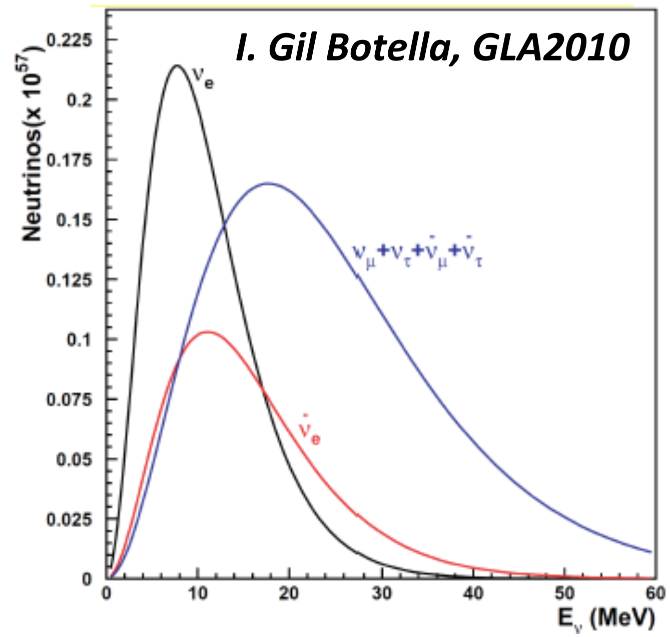
Multi-nucleon effects increase CCQE x-sec

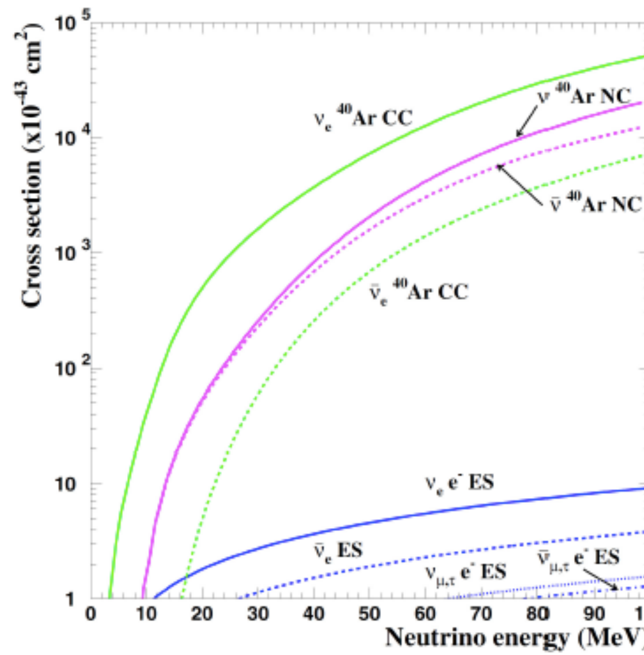


- ArgoNEUT has already published some very important results
  - MicroBooNE is expected to make further progress …

Supernova neutrinos

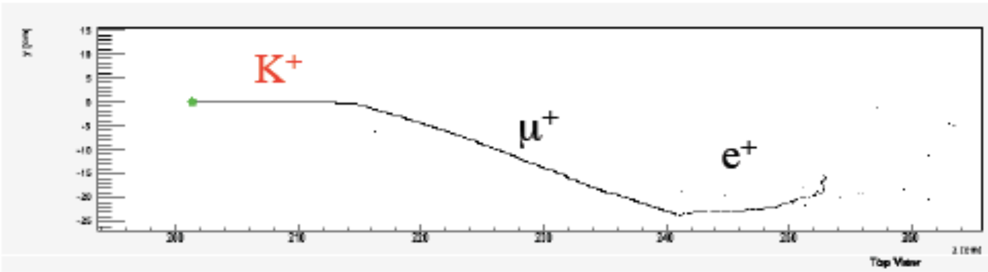
- A core-collapse supernova produces a burst of neutrinos of all flavors. First observed for SN1987A
  - Information on astrophysical phenomena
  - Physics of SN neutrinos very interesting
- Low energy neutrinos, MeV
- Detection channels:
  - $\nu_e + {}^{40}Ar \longrightarrow e^- + {}^{40}K\ ({}^{40}K^*)$
  - $\overline{\nu}_e + {}^{40}Ar \longrightarrow e^+ + {}^{40}Cl\ ({}^{40}Cl^*)$
  - $\nu_x + {}^{40}Ar \longrightarrow \nu_x + {}^{40}Ar\ ({}^{40}Ar^*)$
  - $\nu_x + e^- \longrightarrow \nu_x + e^-$
- Cannot trigger on these events
  - Data continuously stored in a cyclic buffer for ~ a few hours, waiting for a SNEWS alert





Background to proton decay

$$p^+ \longrightarrow K^+ + \bar{\nu}_\mu$$

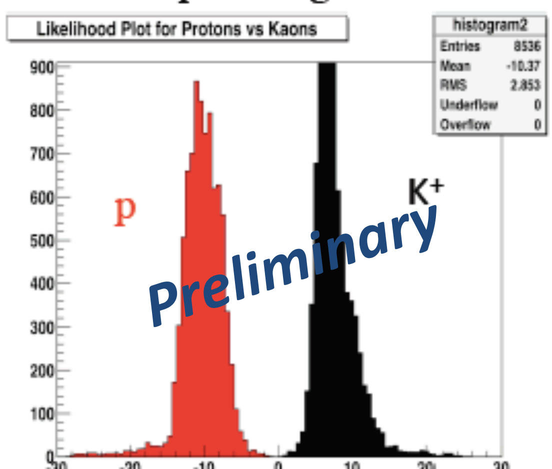


1. Identify K+

Example: Simulation Studies → Measurements

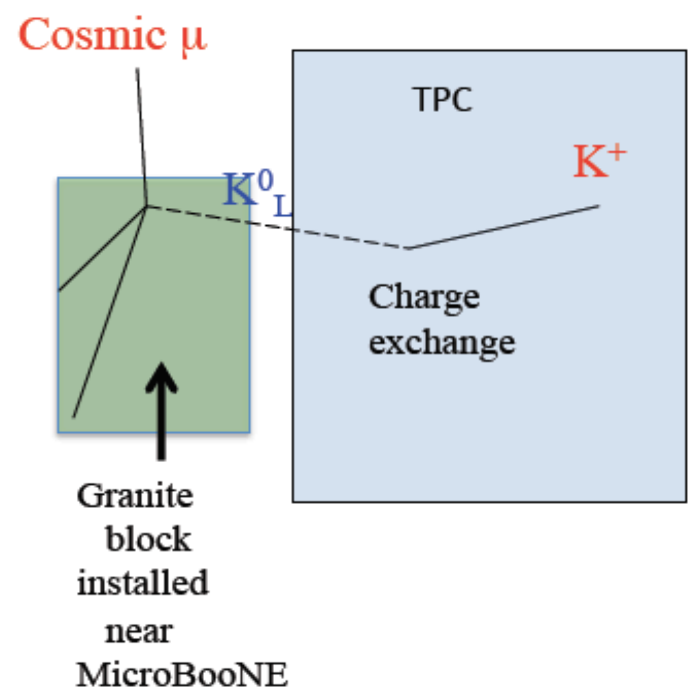
Separating 339 MeV/c K+

from protons of equal range: 15 cm



Likelihood: 4 dE/dx measurements along track

2. Measure background from cosmic rays



Calendar

ACCOMPLISHED STEPS:

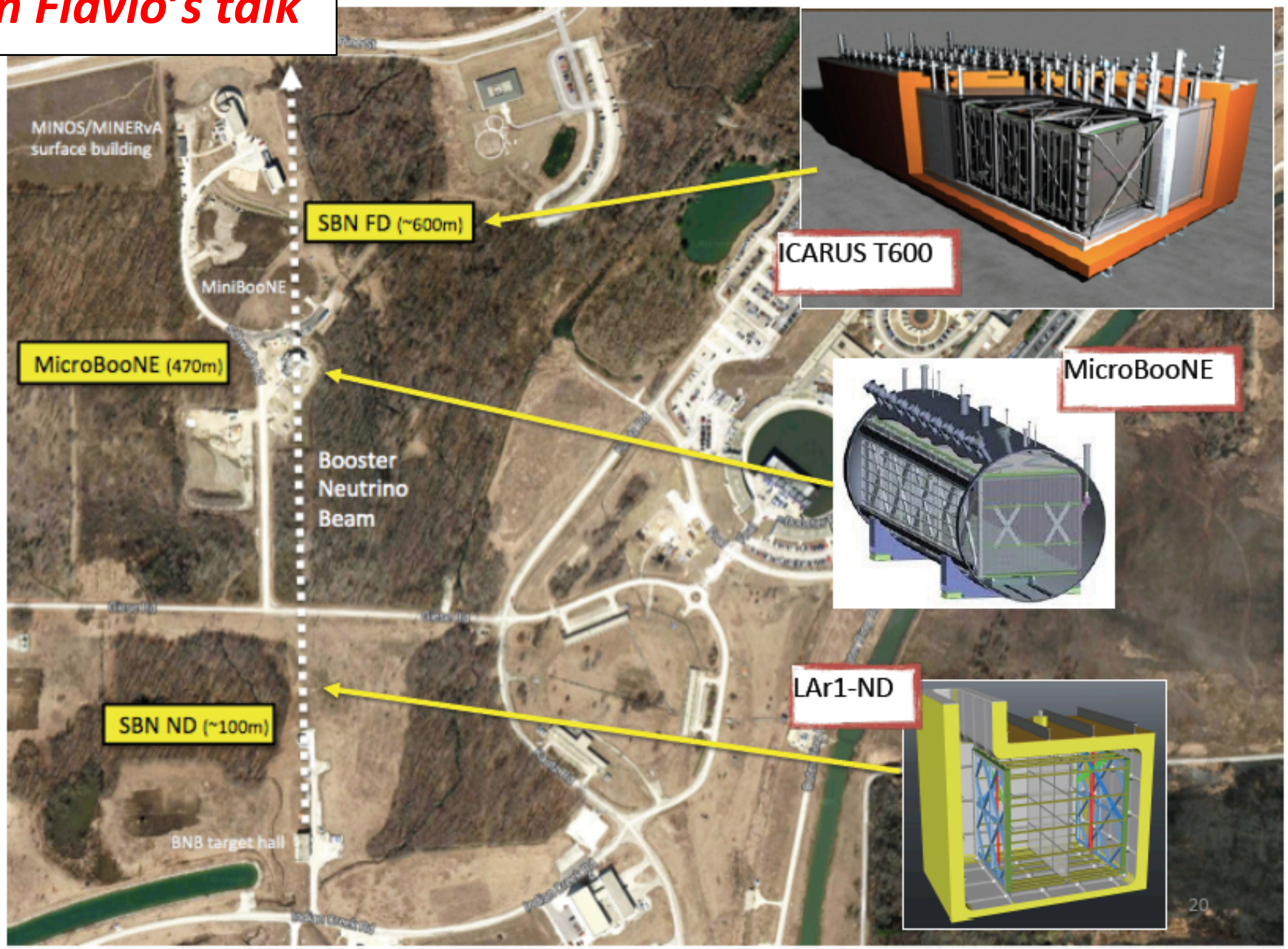
- The TPC has been constructed
- Cold electronics and wires installed
- TPC inserted in the cryostat, endcap welded and detector moved to LArTF
- Vessel insulated and platform and cables installed
- Racks installation and tests
- Cryogenics installation completed
- ***Passed with success the CD-4 review !***

TO BE DONE:

- Gas purge and cool down
- Filling with LAr and purification
- Ramp up High Voltage
- Detector commissioning

FNAL short-baseline program

More on Flavio's talk



Slide from A. Ereditato, NuFact 2014

Concluding remarks

- MicroBooNE will be a very beautiful and a multi-purpose detector … and presumably will deliver some equally wide and rich physics results !
  - Only possible due to the excellent capabilities of MicroBooNE detector
- MicroBooNE R&D includes:
  - *Electron drift at 2.5 m (HV, argon purity)*
  - *Design, manufacture and use of cold electronics*
  - *UV laser calibration*
  - *Fill without evacuating*
  - *Automatized reconstruction*
- Data taking is expected by spring 2015
- ***… until then stay tuned !***

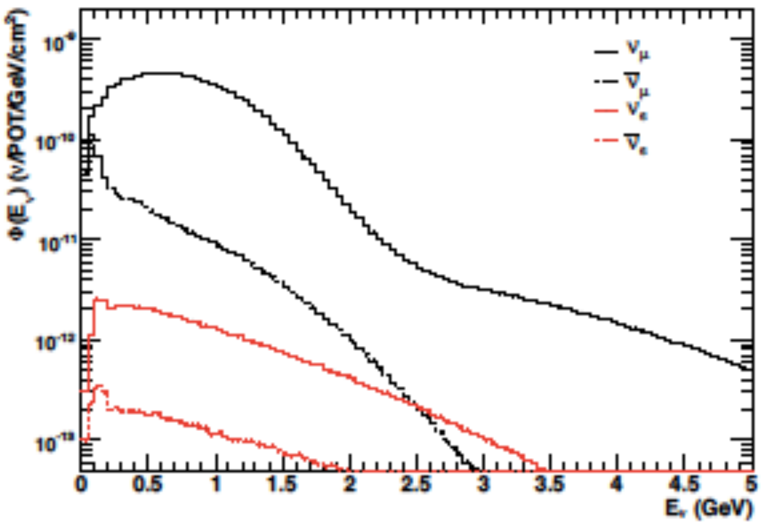
Thank you !

Leonidas
kalousis@vt.edu

SPARES

Booster Neutrino Beam

<E> ~0.8 GeV

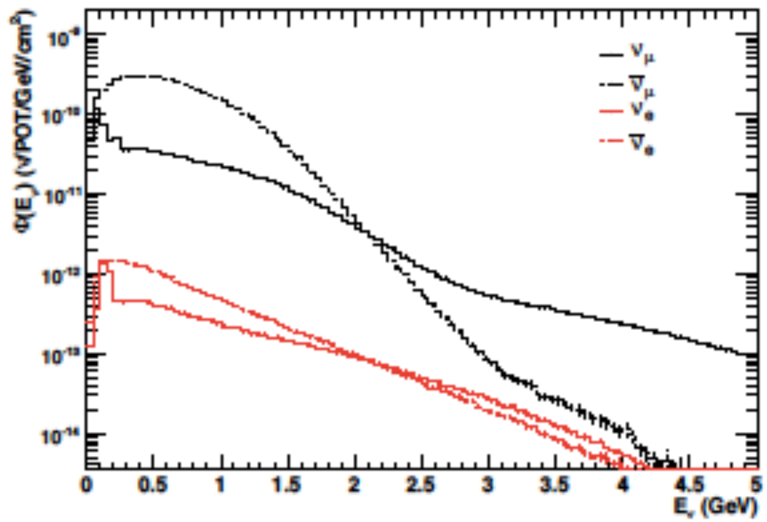


93.6% ν_μ

5.8% $\bar{\nu}_\mu$

0.6% $\nu_e + \bar{\nu}_e$

<E> ~0.6 GeV



15.7% ν_μ

83.7% $\bar{\nu}_\mu$

0.6% $\nu_e + \bar{\nu}_e$

Phys. Rev. D **79** (2009) 072002

BNB and NuMI beamlines

- Besides BNB MicroBooNE will also record neutrinos from the Main Injector beam (NuMI).

The MiniBooNE Detector

541 m downstream of target, 3 m overburden

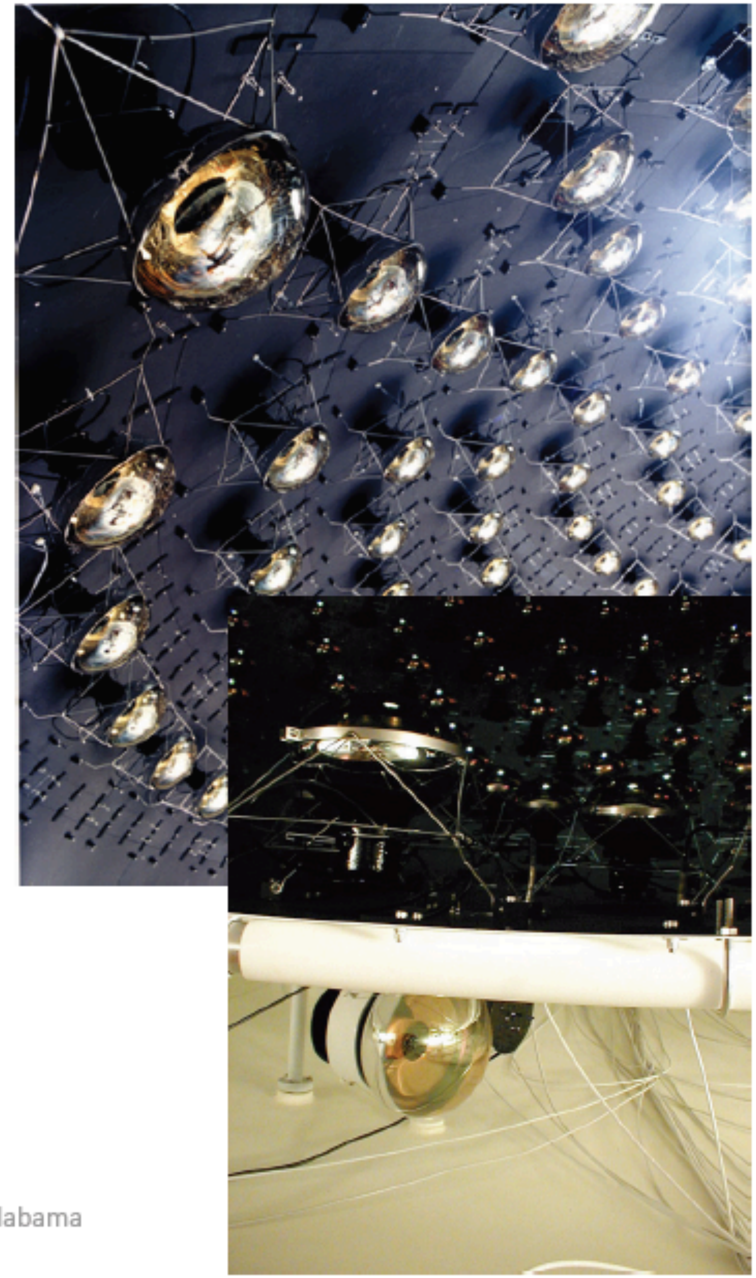
12.2-m diameter sphere (10 m fiducial volume)

800 tons pure mineral oil (CH_2), fiducial = 450 tons

1280 inner phototubes, 10% area (320 new, 960 old)

240 veto phototubes (old LSND)

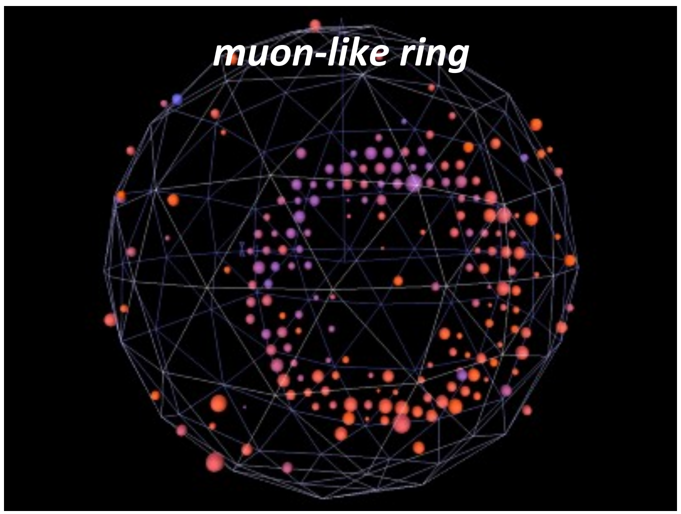
Simulated with a GEANT-3 Monte Carlo

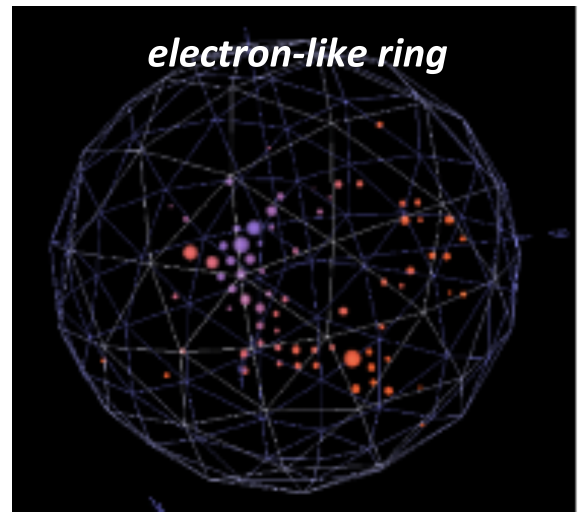


Slide from I. Stancu, FNP 2011

Cutting the Gordian Knot …

- MiniBooNE is a spherical cherenkov detector
  - 800 tons of mineral oil instrumented with 1280 phototubes





- Electrons and photons are indistinguishable
  - The same fuzzy rings in both cases
- MiniBooNE is blind to protons
  - Can multi-nucleon pairs bias the energy reconstruction ?

Cutting the Gordian Knot …

- MiniBooNE is a spherical cherenkov detector
  - 800 tons of mineral oil instrumented with 1280 phototubes

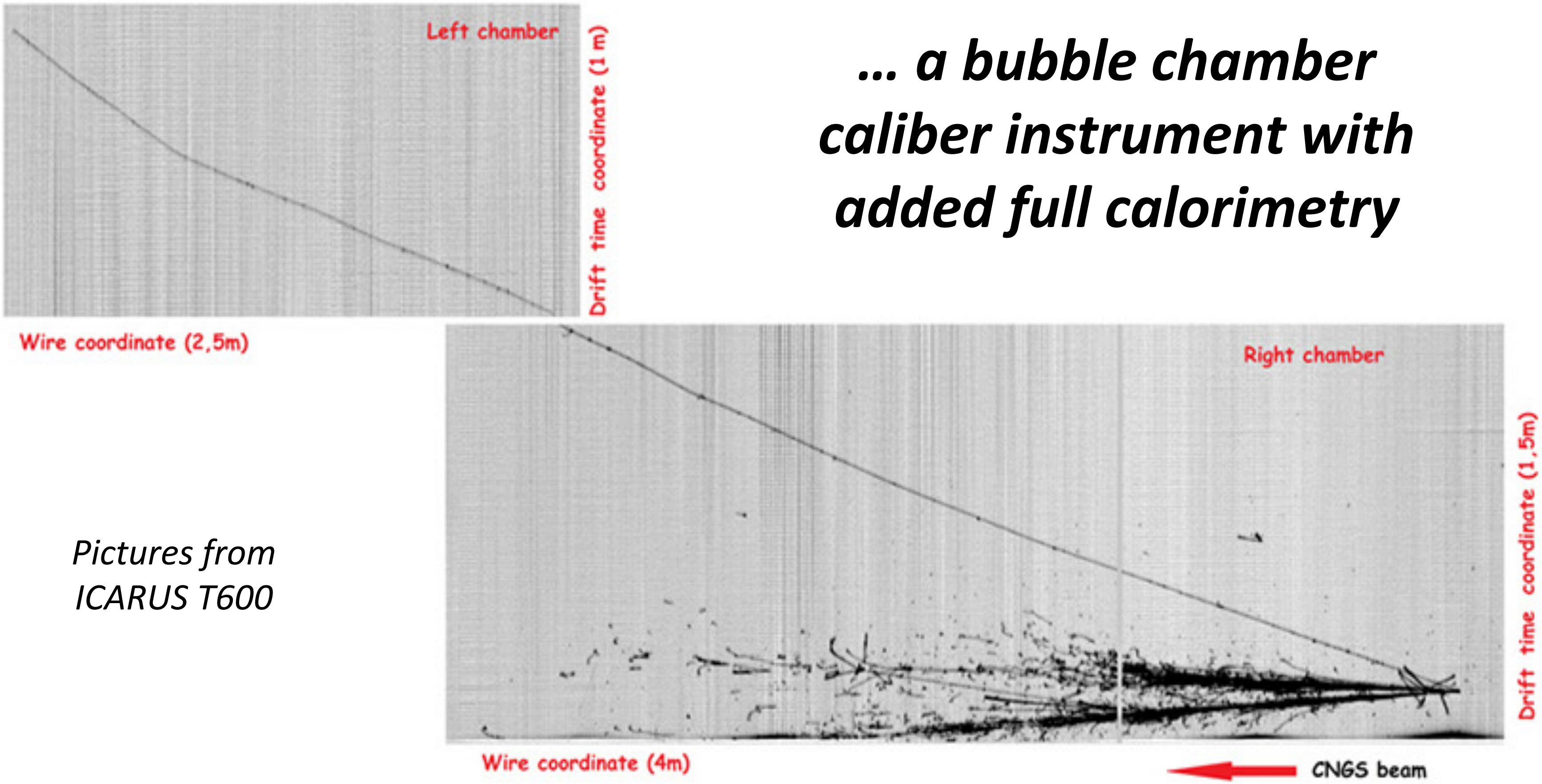
MicroBooNE is perfectly suited to resolve these questions !

- Electrons and photons are indistinguishable
  - The same fuzzy rings in both cases
- MiniBooNE is blind to protons
  - Can multi-nucleon pairs bias the energy reconstruction ?

Noble liquids

	He	Ne	Ar	Kr	Xe	Water
Boiling Point [K] @ 1atm	4.2	27.1	87.3	120.0	165.0	373
Density [g/cm³]	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 [γ /MeV]	19,000	30,000	40,000	25,000	42,000	
Scintillation λ [nm]	80	78	128	150	175	

… to quote J. Asaadi: this table was first produced by my boss Mitch Soderberg and if he had patented it he would have 10's of dollars because it shows up in every LAr talk I've ever seen!

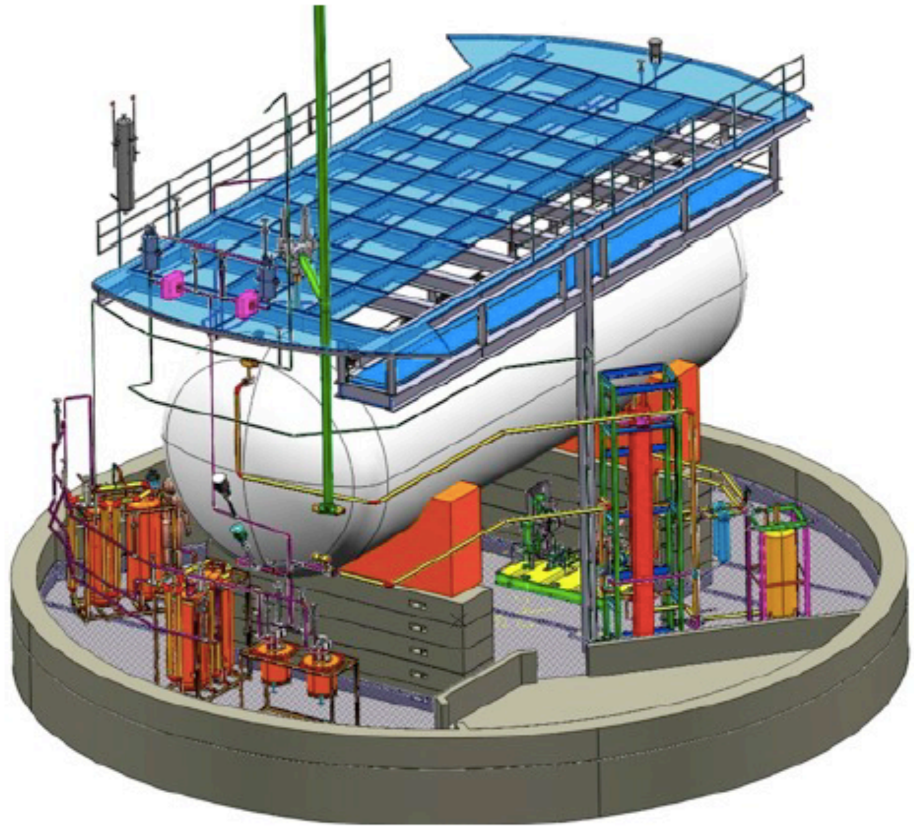


… a bubble chamber caliber instrument with added full calorimetry

Pictures from ICARUS T600

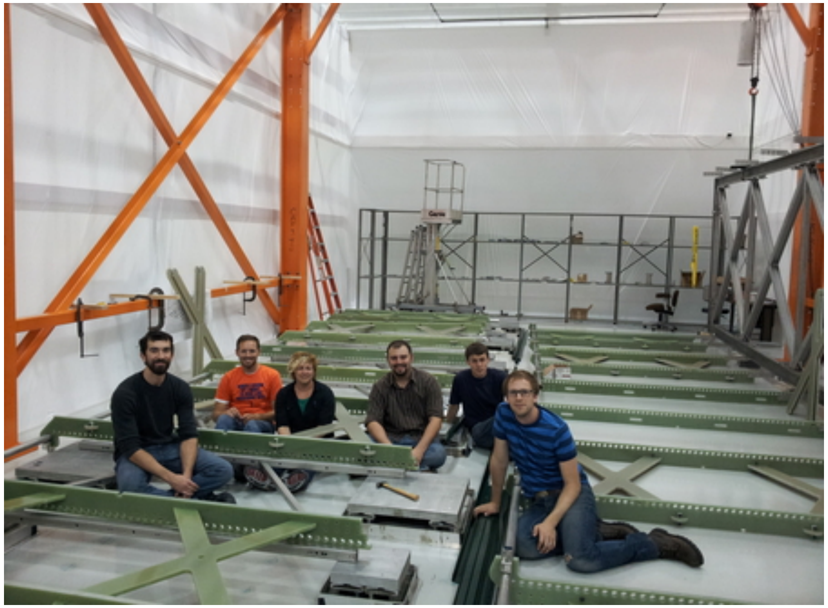
- LAr calorimeters proposed Willis and Radeka in 1974
- C. Rubbia, and others, introduce the LArTPC concept
  - ***Extensive R&D and effort leads to the ICARUS T600***
- By 2014, a great wealth of experimental proposals

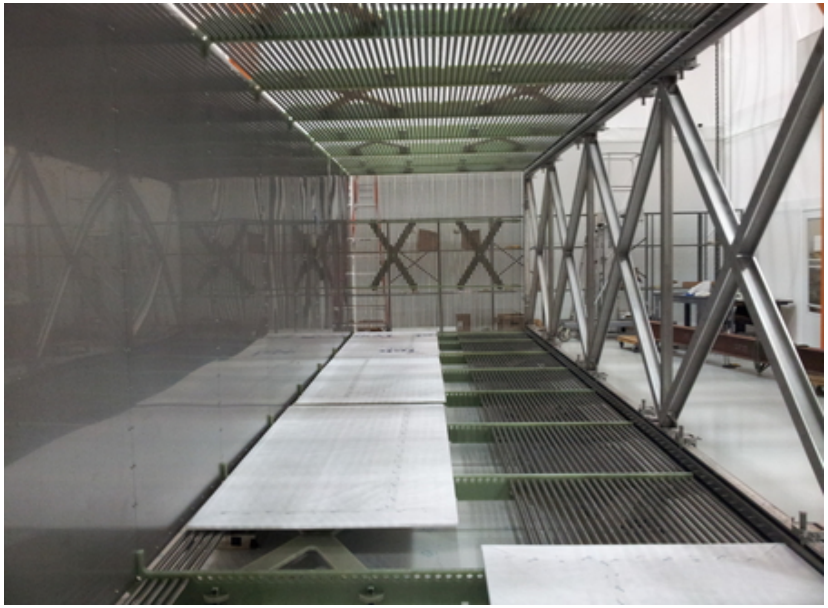
LArTF chronicles



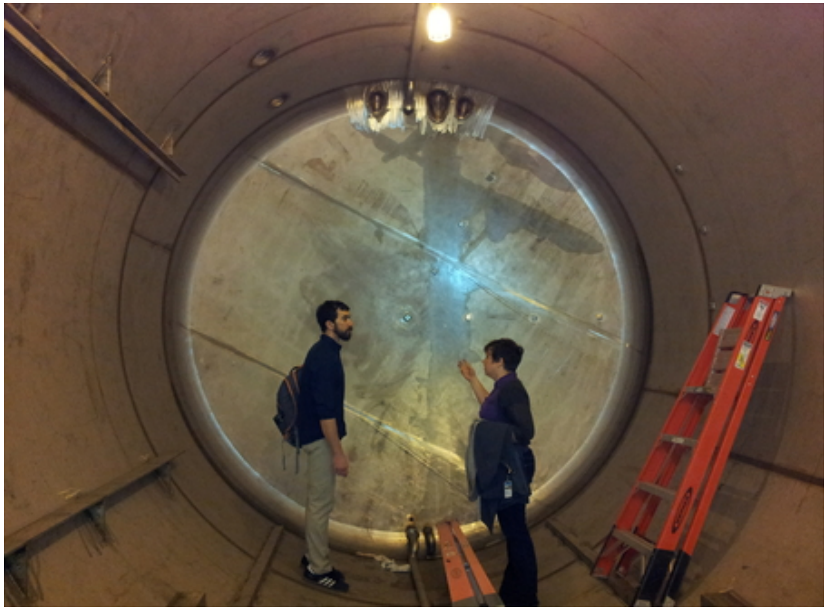
… may I present you MicroBooNE !

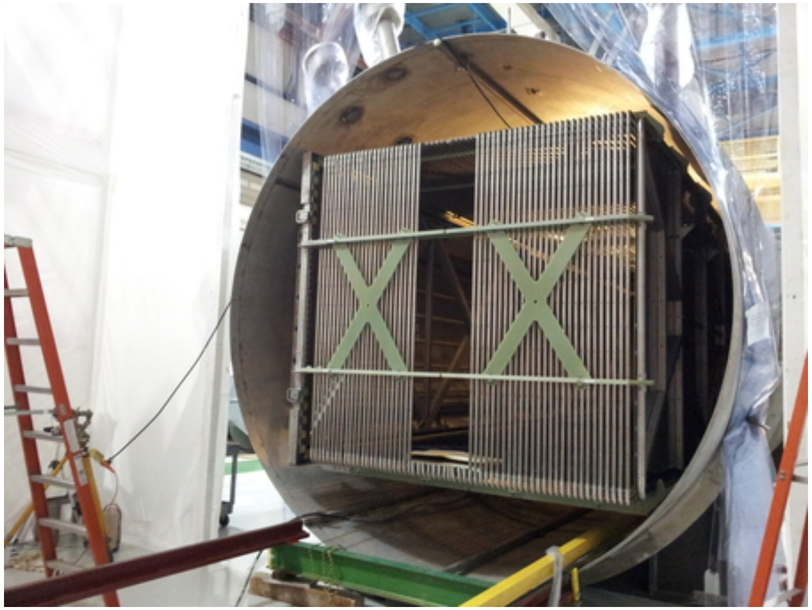
TPC cage construction



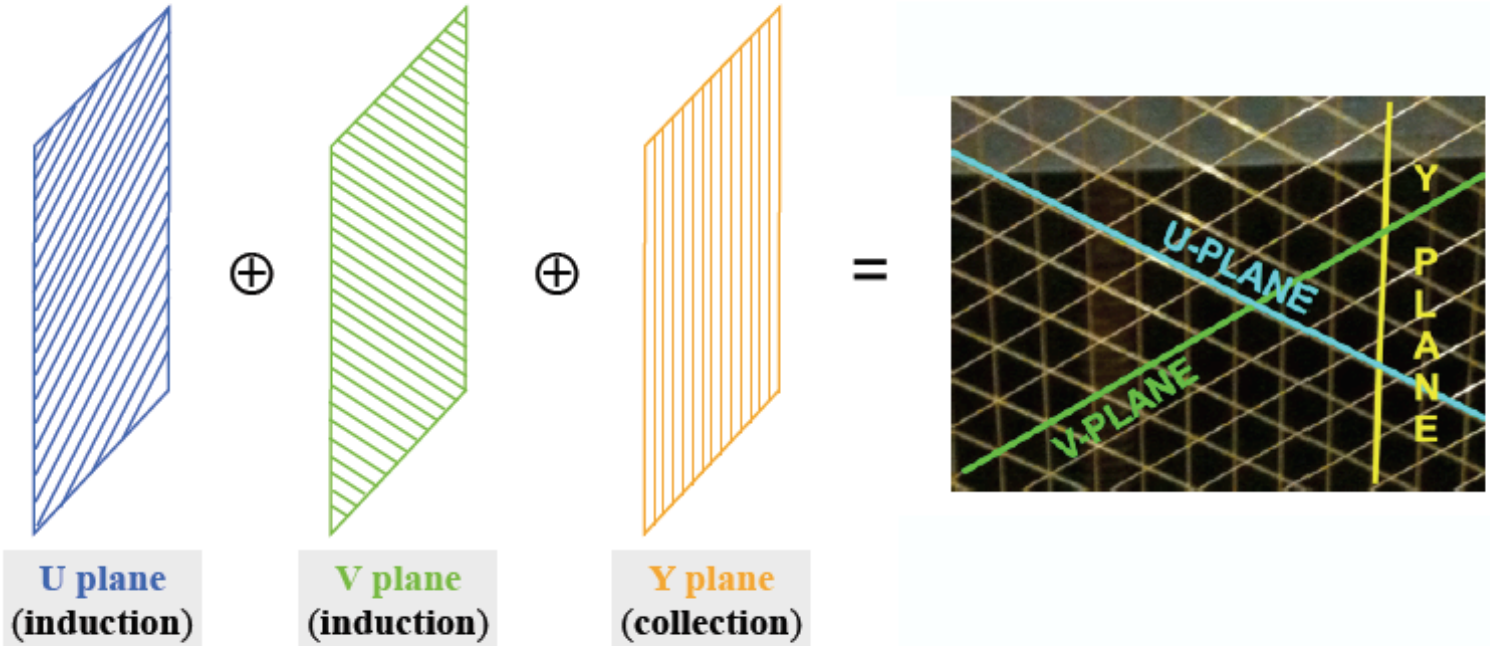



Arrival of the cryostat

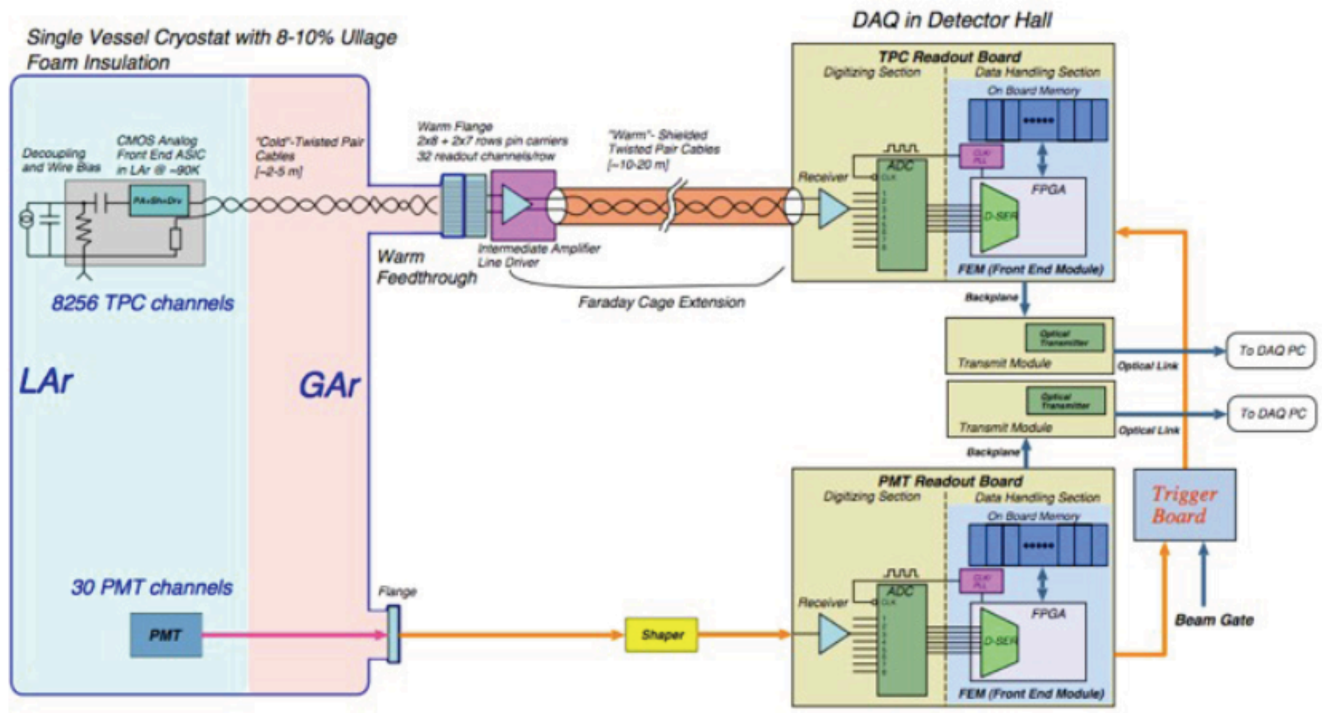




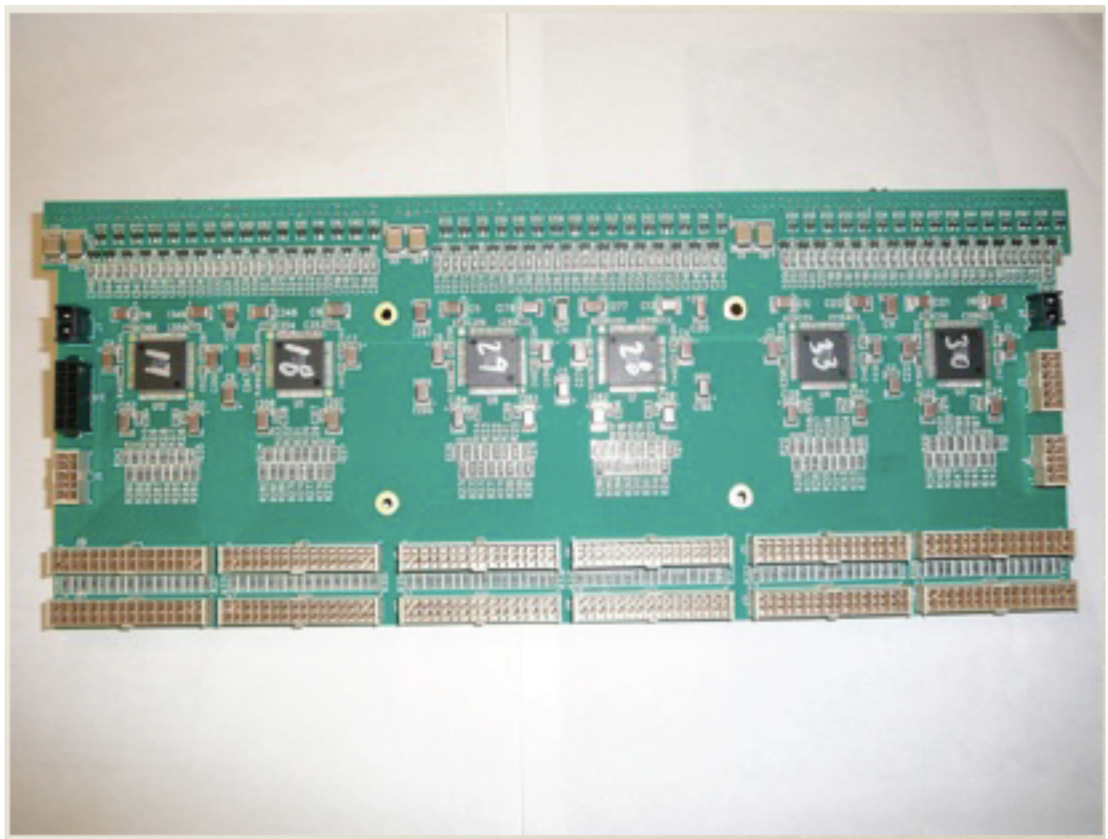
Wire planes


U plane
(induction)
V plane
(induction)
Y plane
(collection)
U-PLANE
V-PLANE
Y
PLANE

Electronics and Data Acquisition

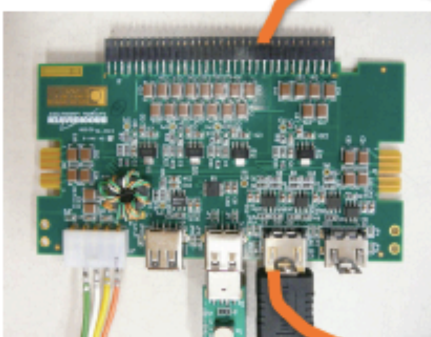


- Pre-amplifying CMOS ASIC in LAr at 87 K
  - Lower thermal noise; reduce capacitive noise and pickup
  - Radeka *et al*, J. Phys. Conf. Ser. **308** 012021

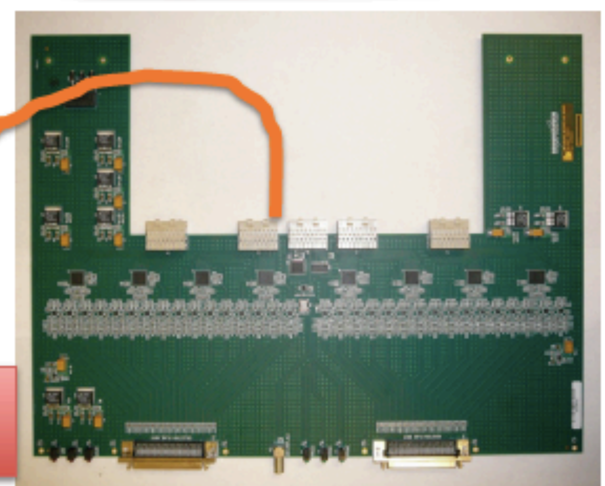


TPC Front End Electronics

- Pre-Amp CMOS ASIC in liquid at 87K
  - reduce capacitive noise and pickup and lower thermal noise
    V. Radeka et al, *J. Phys.: Conf. Ser.* **308** 012021
- Warm interface electronics
  - Intermediate amplifiers, service board



- Digitizing electronics
  - Receiver and ADC board

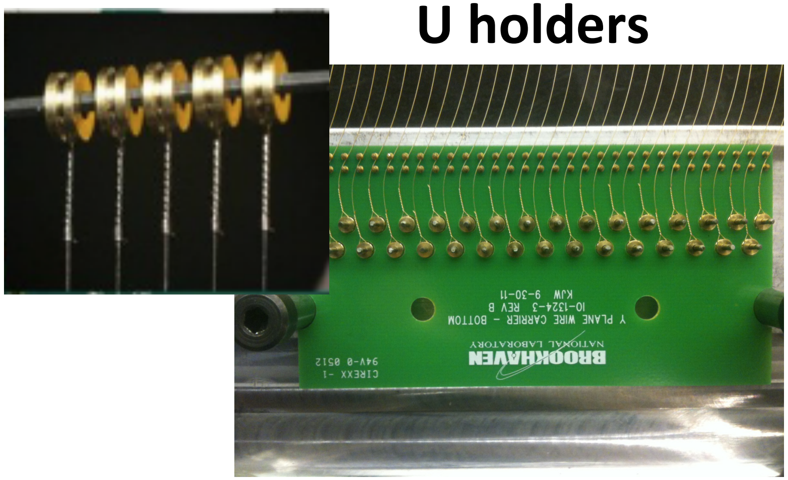


Slide from M. Weber

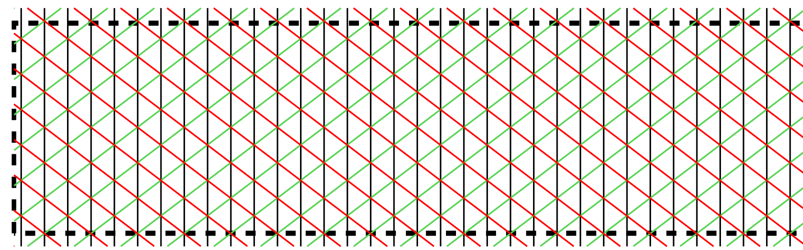
Time Projection Chamber (I)

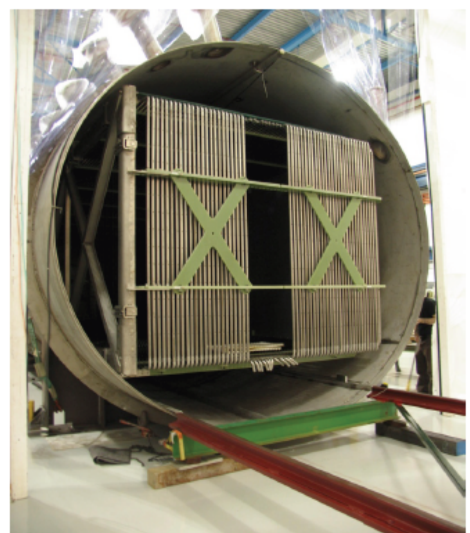
Time Projection Chamber (II)

U holders



Three wire planes, 3 mm

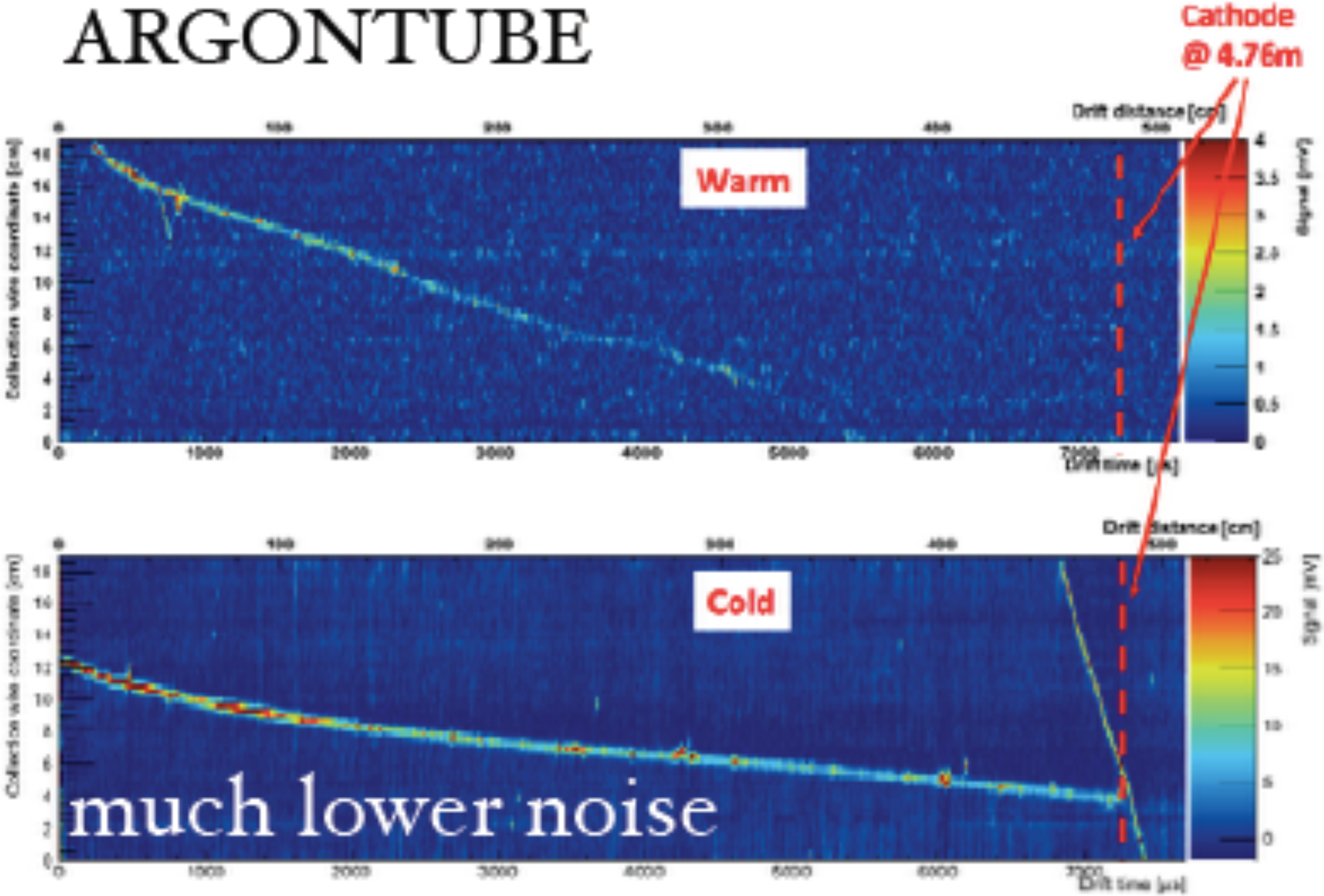





Varistors


Metallux HVR 969.23

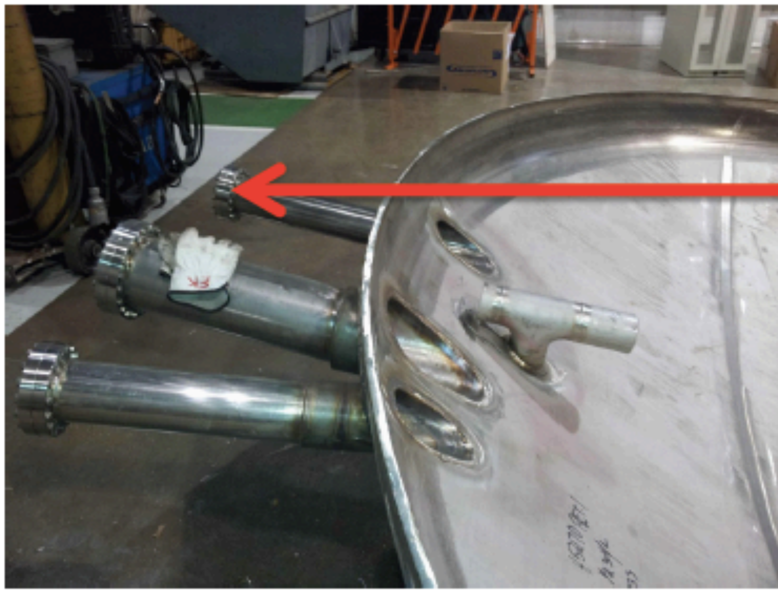
ARGONTUBE

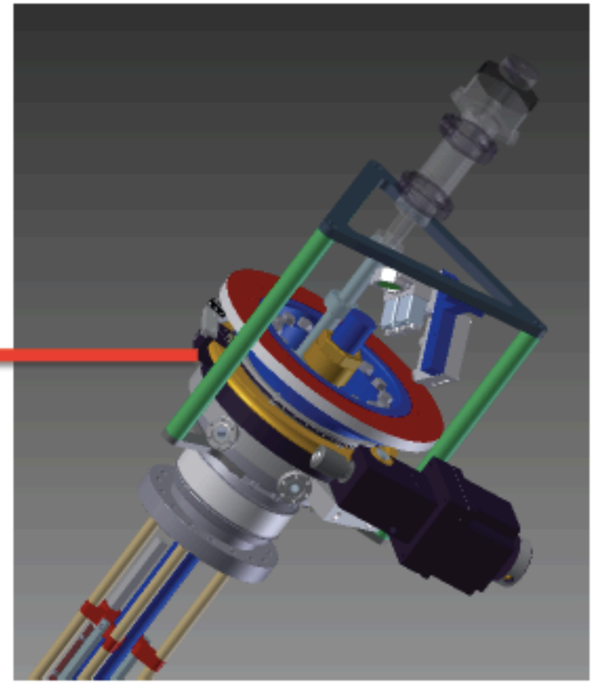

Cathode
@ 4.76m
Drift distance [cm]
Warm
Collection wire coordinate [cm]
Signal [mV]
Drift time [μs]
Drift distance [cm]
Cold
Collection wire coordinate [cm]
Signal [mV]
Drift time [μs]
much lower noise

arxiv.org/pdf/1408.6635v2.pdf

microboone

Remote controlled steered laser beam (mirrors)



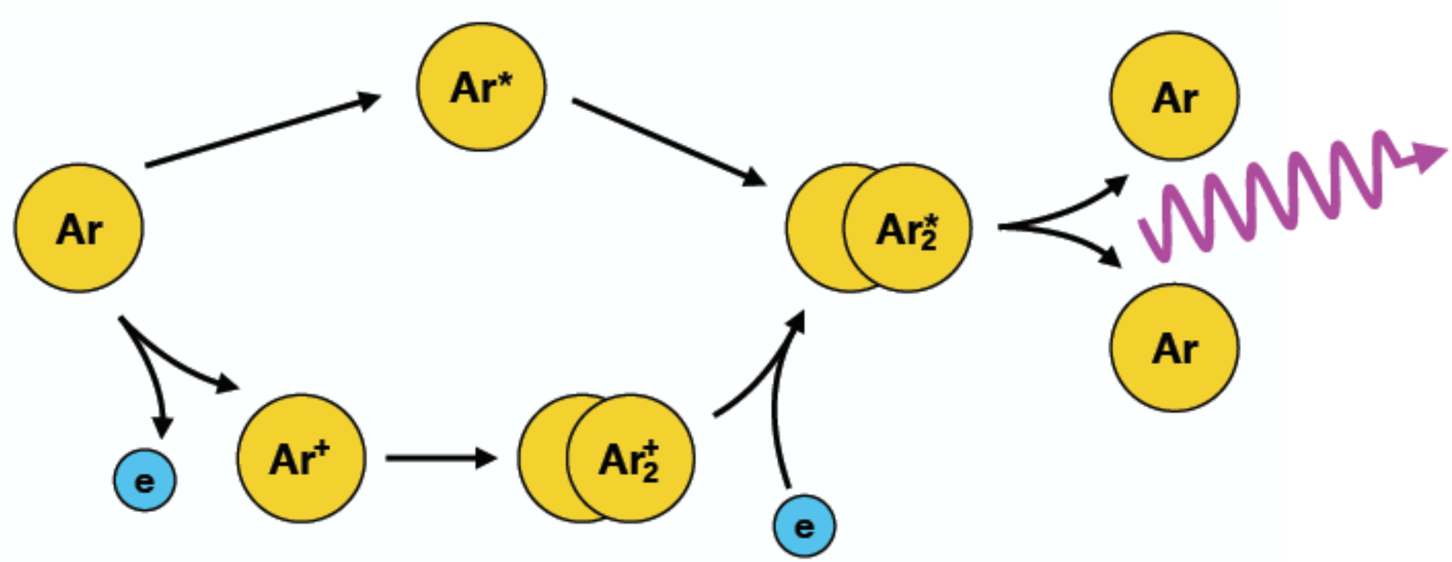


Slide from M. Weber

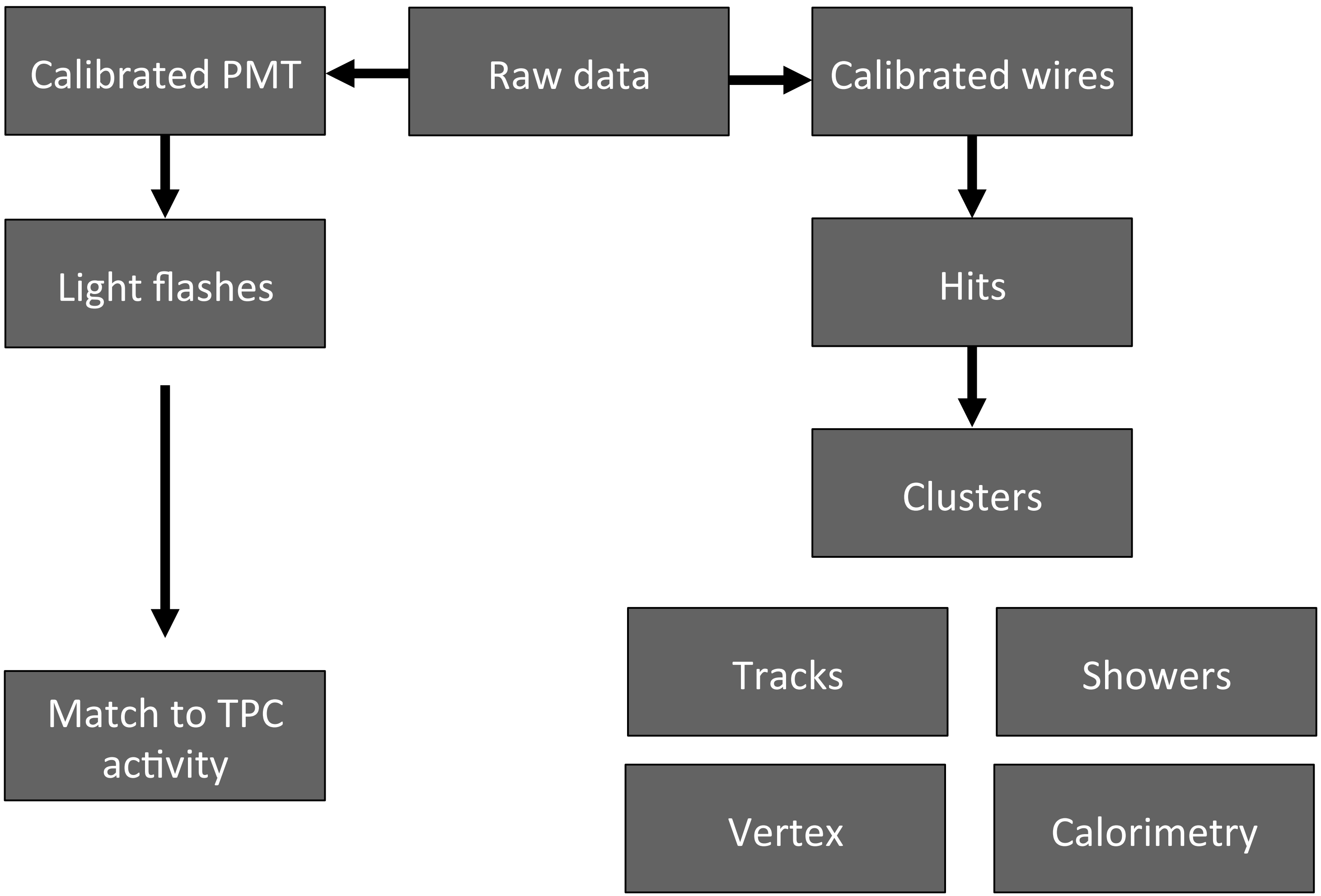
HV Feedthrough Test Fit

Slide from T. Yang, FNAL Users' meeting

LAr scintillation light

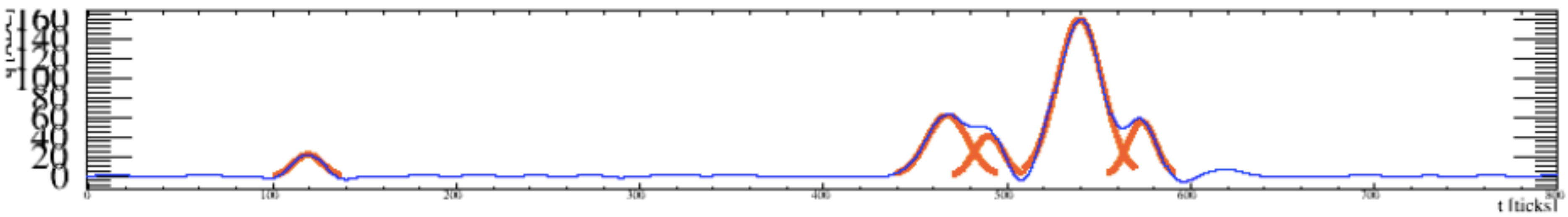


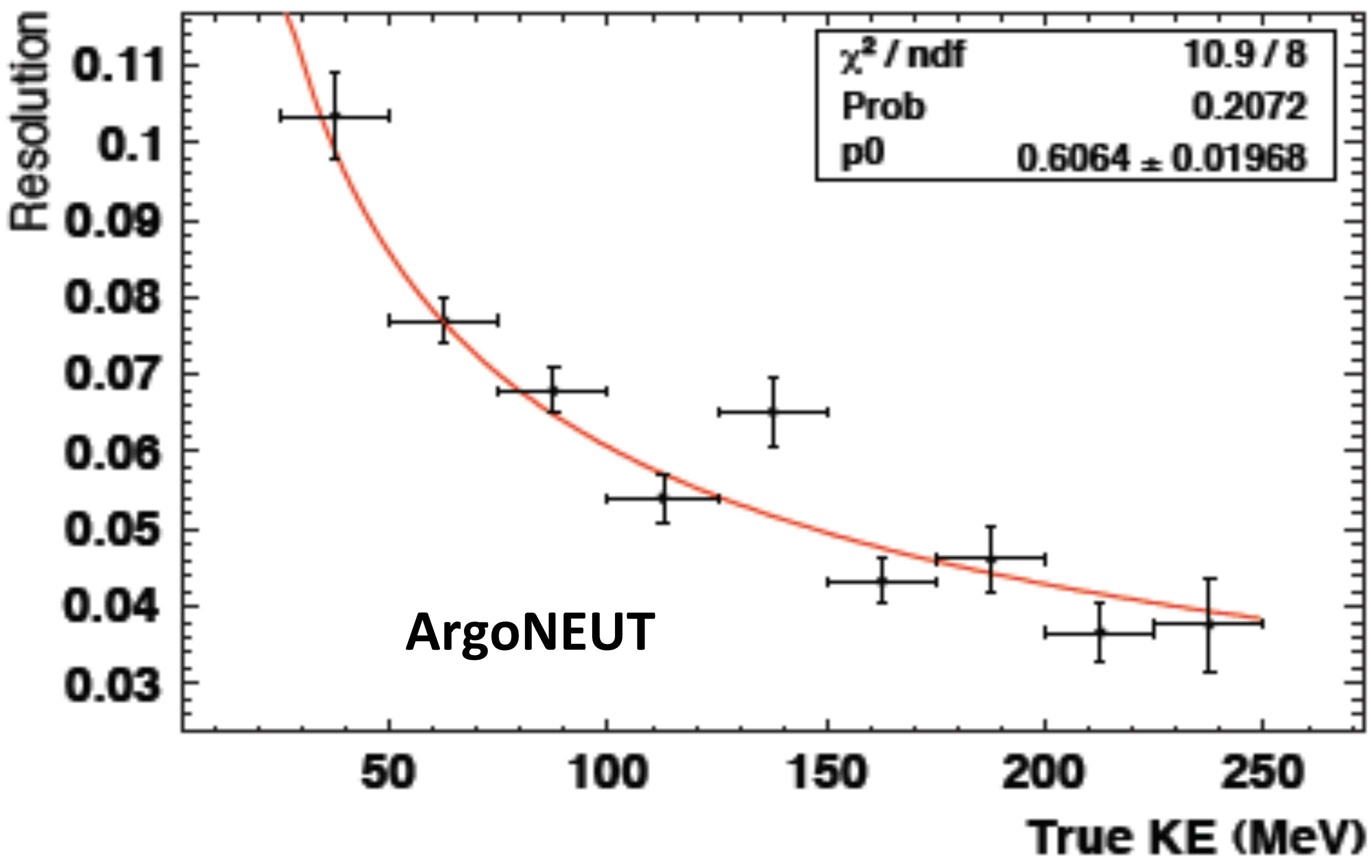
Event reconstruction



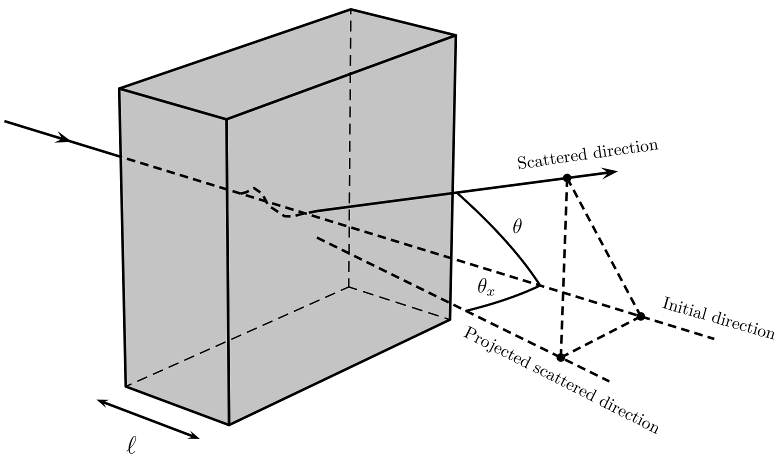
… an oversimplified diagram of the actual picture

Hits




Resolution
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
χ² / ndf 10.9 / 8
Prob 0.2072
p0 0.6064 ± 0.01968
ArgoNEUT
50
100
150
200
250
True KE (MeV)

Multiple Coulomb Scattering



Small angle deflections are governed by the so-called modified Highland formula

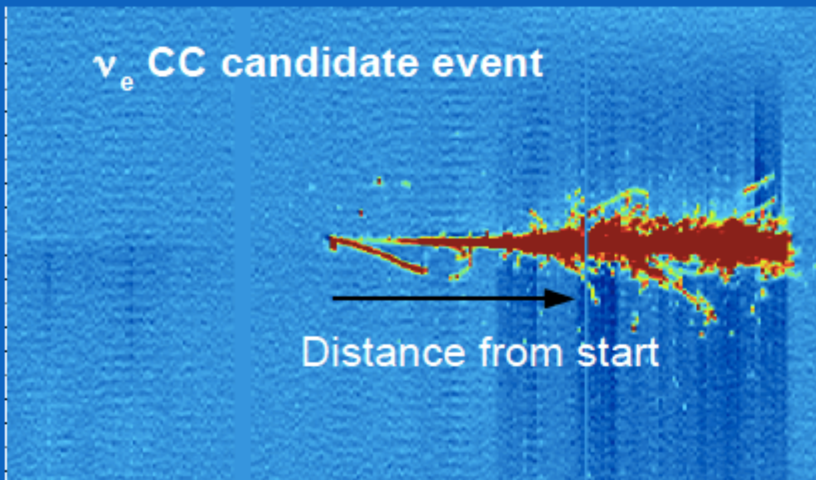
$$\theta_0 = \frac{13.6}{p\beta c}\sqrt{\frac{\ell}{X_0}}\left[\, 1 \,+\, 0.0038\, \ell n\left(\frac{\ell}{X_0}\right)\right]$$

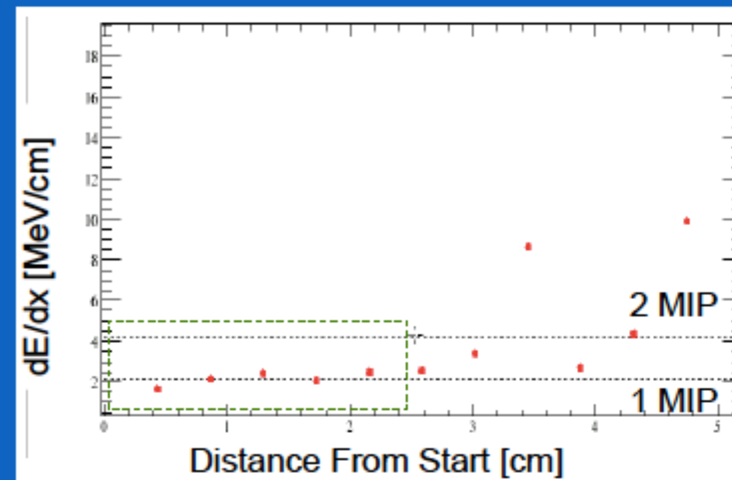
θ_0 : RMS of the $\Delta\theta$ distribution (mrad)
p : particle momentum (GeV/c)
\ell : material thickness
X_0 : radiation length

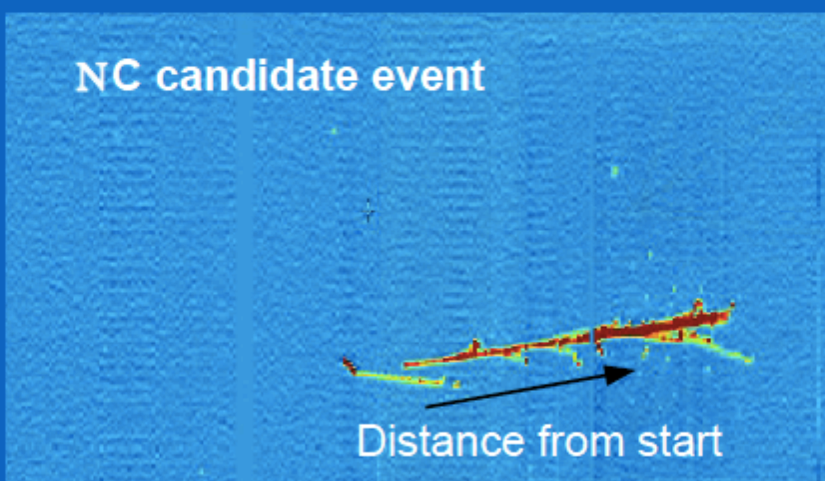
- The whole idea: use the projections of the angular deflections to get to the particle momentum
  - Can be done in precision tracking detectors

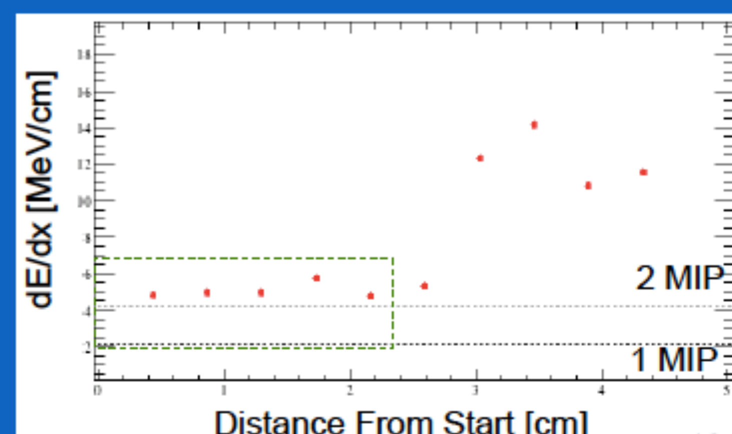
Particle Identification

- Some examples.









Refs:
1.)A. Szelc, Neutrino 2014

Slide from M. Soderberg, NuSTEC 2014

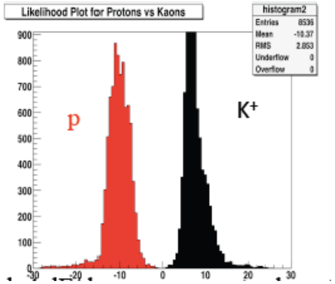
A multi-purpose instrument

- MicroBooNE will also record neutrinos from SN
  - A separate and continuous data stream

    $\nu_e + {}^{40}Ar \longrightarrow e^- + {}^{40}K\ ({}^{40}K^*)$, $\overline{\nu}_e + {}^{40}Ar \longrightarrow e^+ + {}^{40}Cl\ ({}^{40}Cl^*)$

    $\nu_x + {}^{40}Ar \longrightarrow \nu_x + {}^{40}Ar\ ({}^{40}Ar^*)$, $\nu_x + e^- \longrightarrow \nu_x + e^-$

- Study the background relevant to proton decay
  - Golden channels : $p^+ \longrightarrow K^+ + \overline{\nu}_\mu$
  - and neutron-antineutron oscillations
- Valuable R&D for more massive detectors



- Many other ideas on the table
  - Burst neutrinos
  - Direct dark matter searches
  - Measure the nucleon axial form factor to improve dark matter searches, *arxiv:1406.5204*

… eppur si muove


SAFETY FIRST