Prospects for Making the First Neutrino Interaction Measurements on Argon at Low Energy with MicroBooNE

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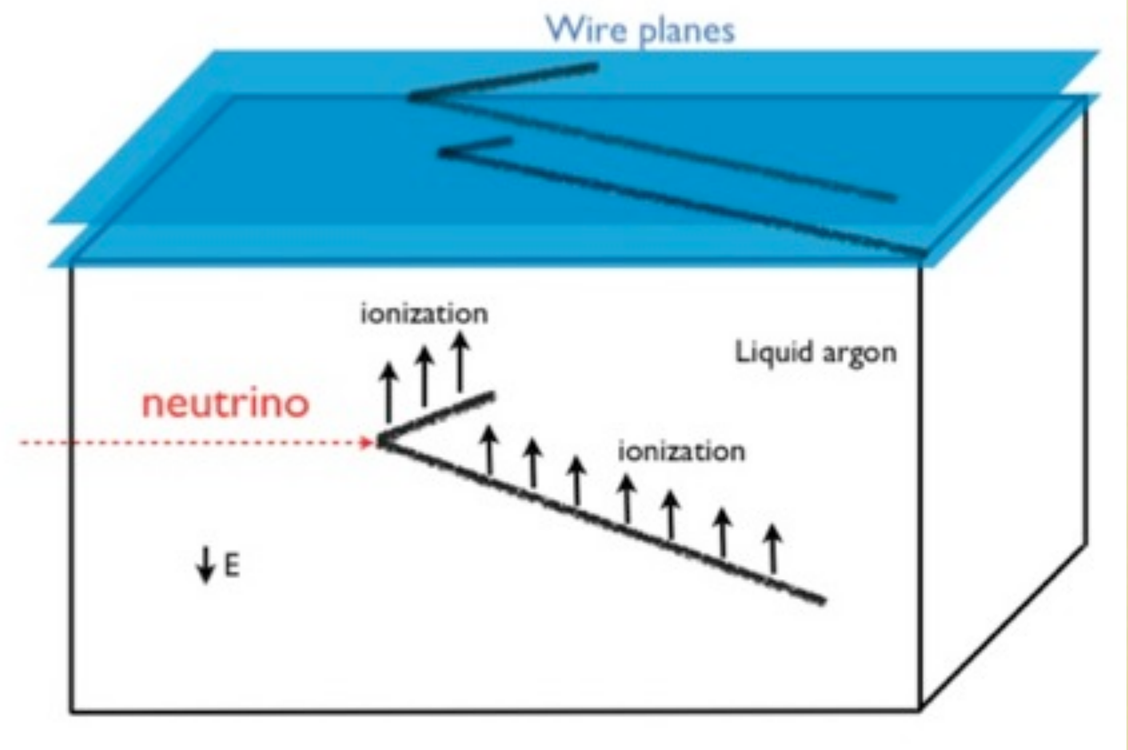
Why Neutrino Interactions On Argon at Low Energy?

LAr targets in the current generation of neutrino and dark matter experiments.

- Low energy (~1 GeV) neutrino interactions in LAr give physics signals (time projection chambers, scintillation) for ν physics
- Contributes understanding of nuclear effects, nucleon structure. Improves models used for more science.

LAr TPC Detector

- Ionization produced in neutrino interactions is drifted along E-field to highly segmented wireplanes.
- Timing of wire pulse information is combined with known drift speed to determine drift-direction coordinate.
- Calorimetry information is extracted from wire pulse characteristics.
- Copious scintillation light also available for collection and triggering.



Ref: *The Liquid-argon time projection chamber: a new concept for Neutrino Detector*, C. Rubbia, CERN-EP/77-08 (1977)

Choice of Argon

- Lots of ionization & scintillation light
- When purified (<0.1ppb), long ionization drift distances
- Excellent dielectric properties (very large voltages)
- Dense noble liquids - ν good target
- Relatively cheap (1% of atmosphere).
- Drawbacks?...no free protons...nuclear effects

	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
Interaction Length [cm]	568.4	82.22	85.77	61.80	58.29	83.33
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	

MicroBooNE Goals

Physics

- Investigate MiniBooNE low-E ν_e excess
- Measure low-energy cross sections and particle multiplicities on argon

LAr TPC R&D

- Cold, submerged preamplifiers
- High voltage system
- LAr recirculation & purification
- Long-drift reconstruction for $\boldsymbol{\nu}$-induced events

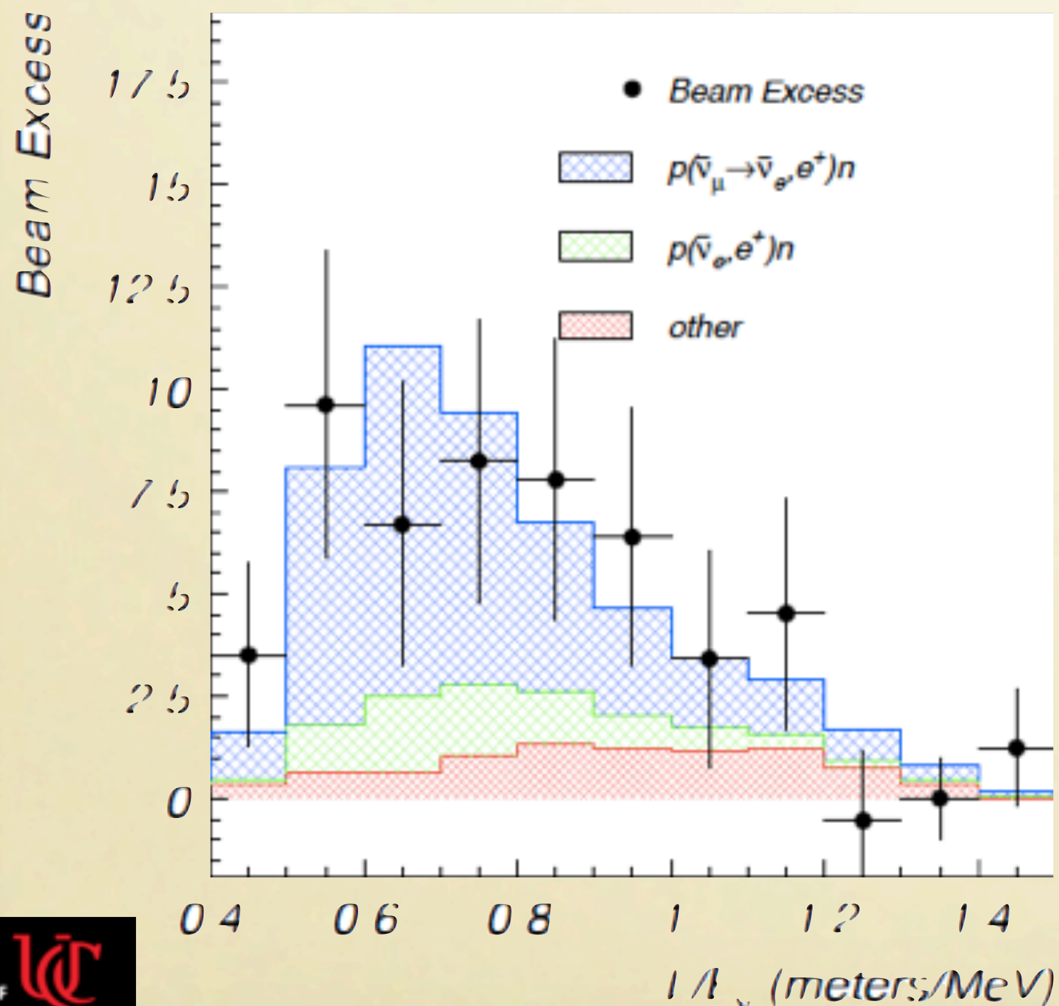
MicroBooNE: Context & Motivation

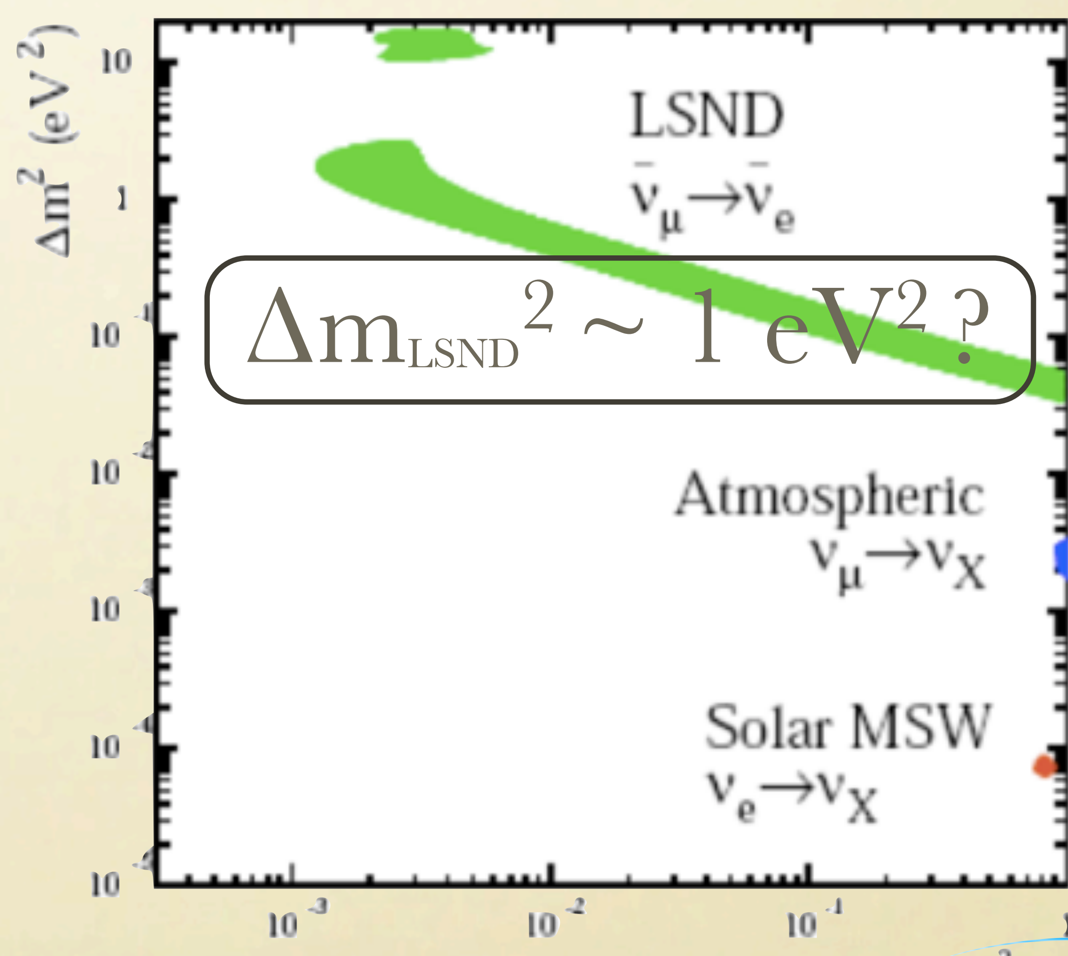
MiniBooNE investigated LSND result:

$(\nu_\mu \rightarrow \nu_e)$ consistent with $\Delta m^2 \sim 1 eV^2$.

$$P(\nu_\mu \rightarrow \nu_e) = \sin^2 2\theta \sin^2(1.27\, \Delta m^2\, L/E)$$

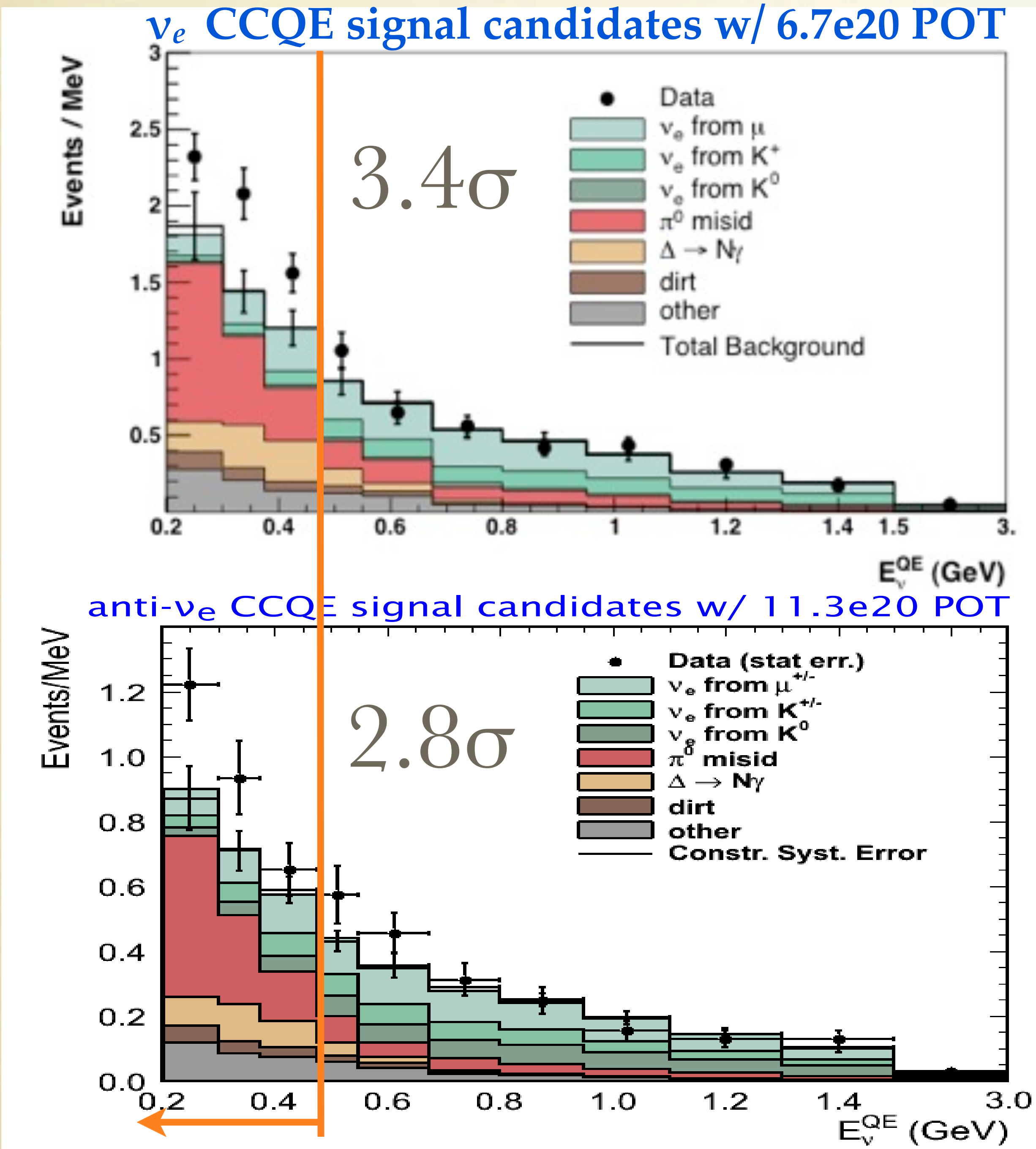
$\Delta m_{solar}^2 \sim 10^{-5}\, eV^2$ $\Delta m_{atm}^2 \sim 10^{-5}\, eV^2$





MiniBooNE: Context & Motivation

Observed 200-475 MeV excess in ν_e-type events



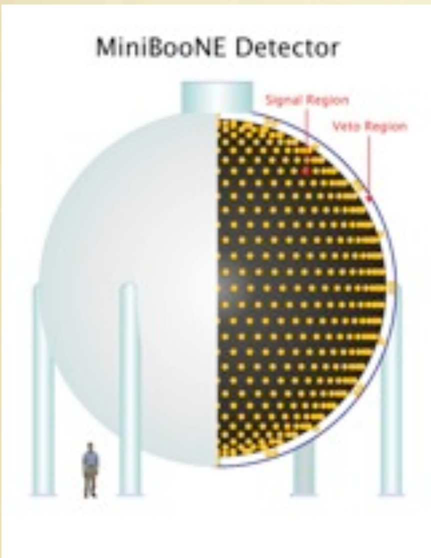
Similar L/E as LSND

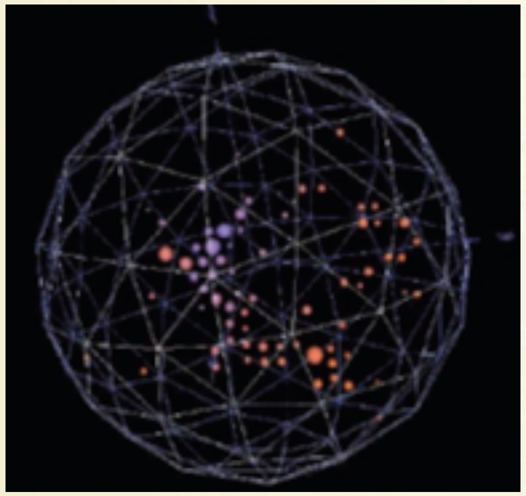
Allowed Δm^2, $\sin^2(2\theta)$ regions overlap with LSND

Also: Nature of low-E events?

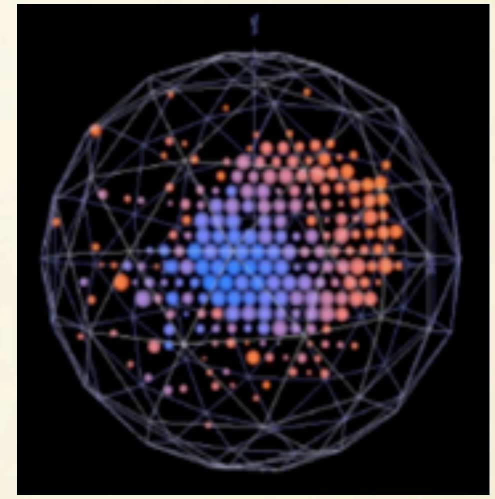
Aguilar-Arevalo et al.,
PRL 110, 161801 (2013); http://prl.aps.org/pdf/PRL/v110/i16/e161801)

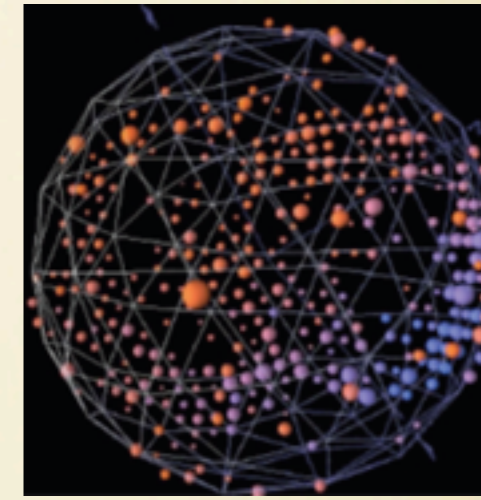
Detector Technology





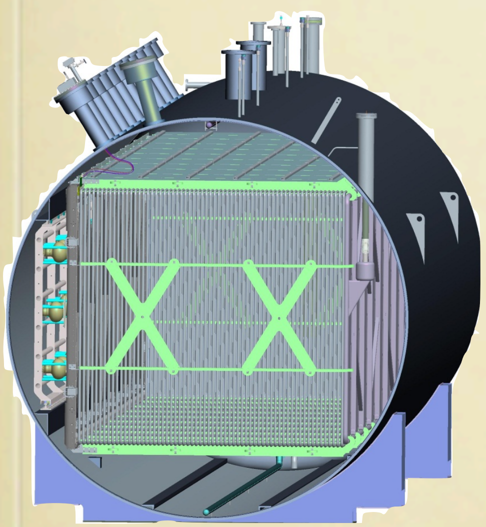
Some efficiency even below Cherenkov threshold *

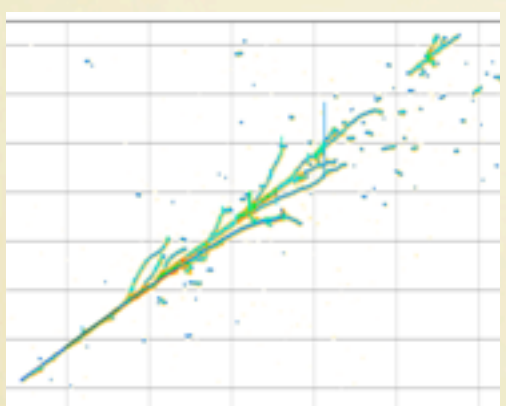


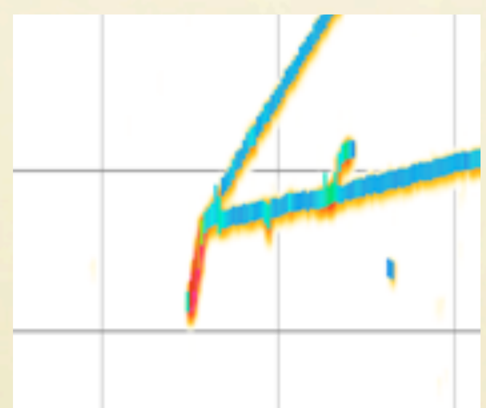


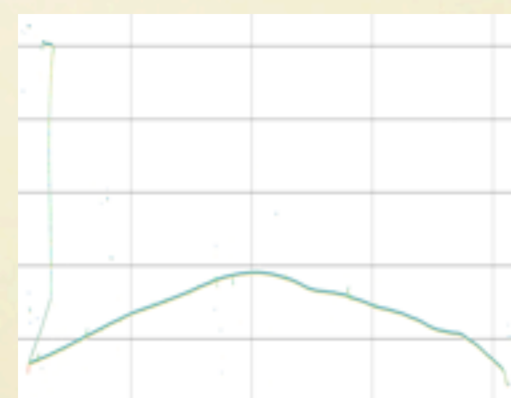
e/γ | p | μ | $\pi^{o} \rightarrow \gamma\gamma$

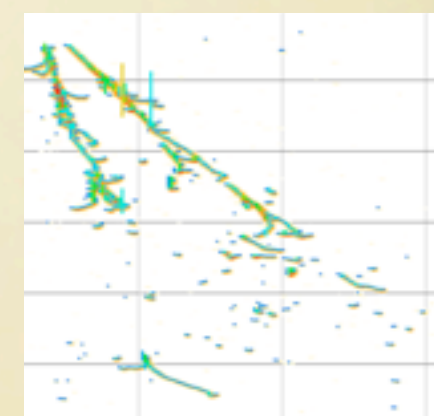
*http://arxiv.org/abs/1007.4730





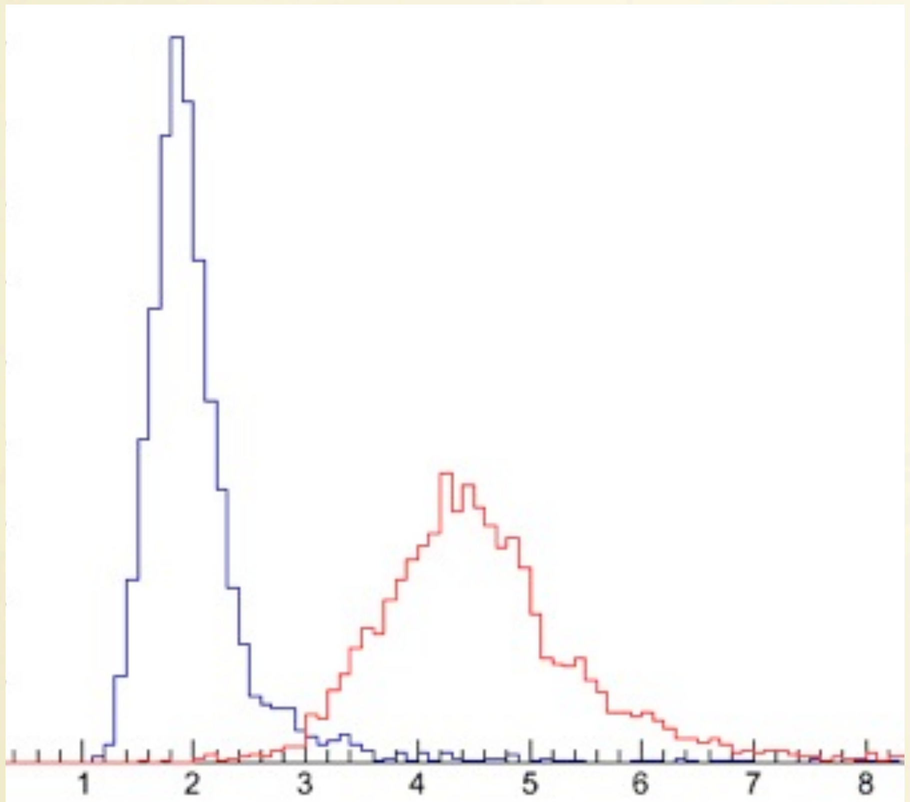






e/γ | p | μ | $\pi^{o} \rightarrow \gamma\gamma$

Detector Technology



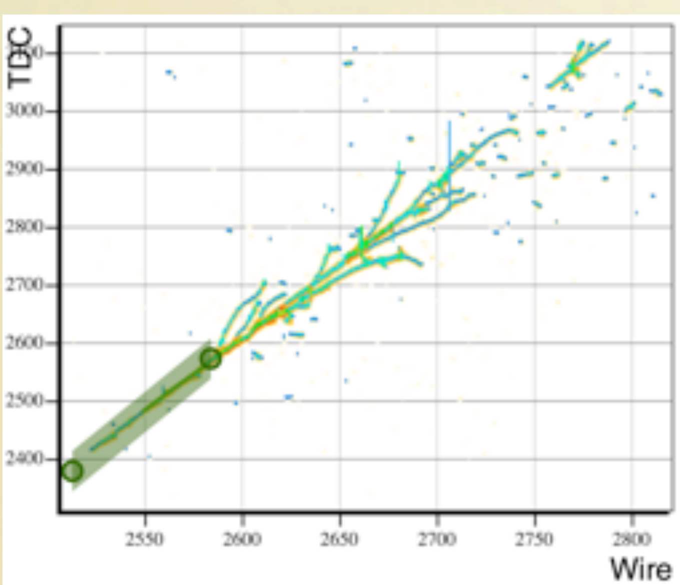
dE/dx at shower vertex distinguishes

e (1 MIP)

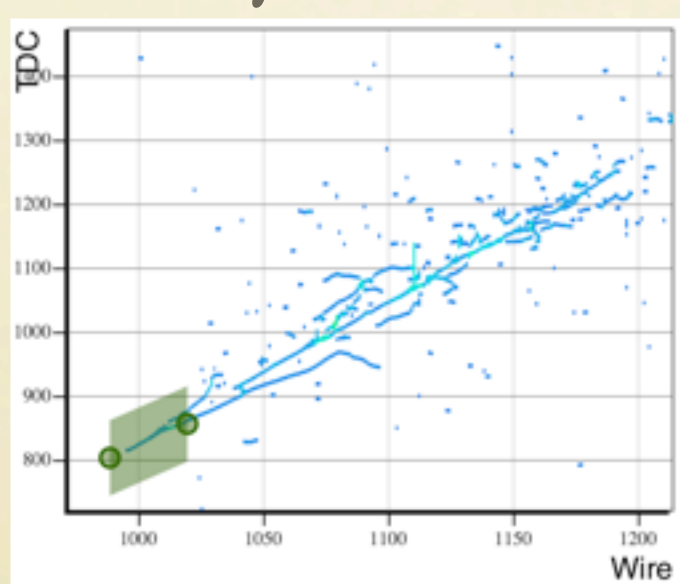
from

e^+e^- (2 MIPs)

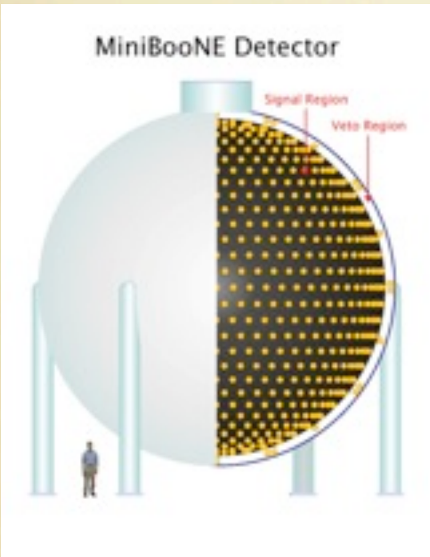
e

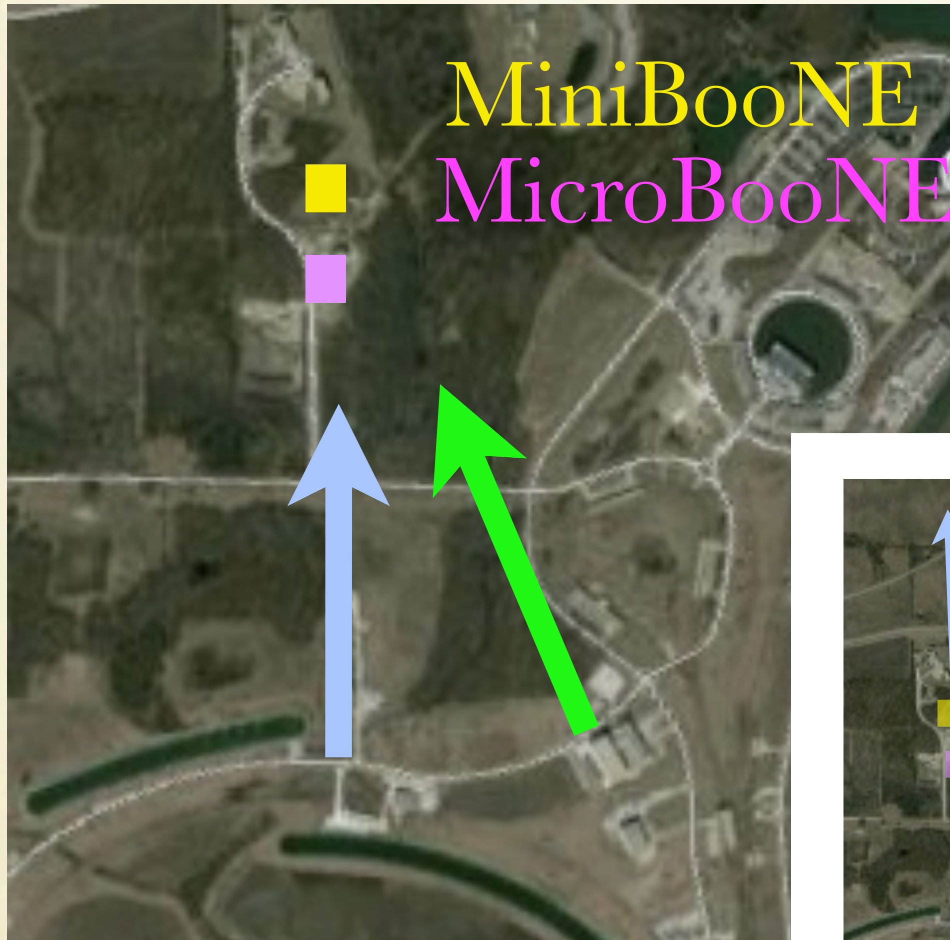


γ



MicroBooNE Baseline

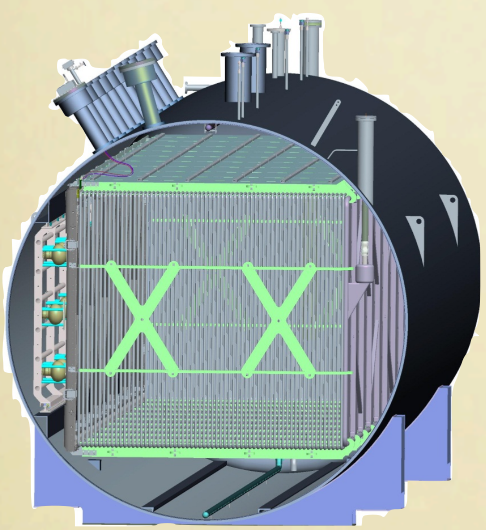




NuMI Beam
Booster ν Beam

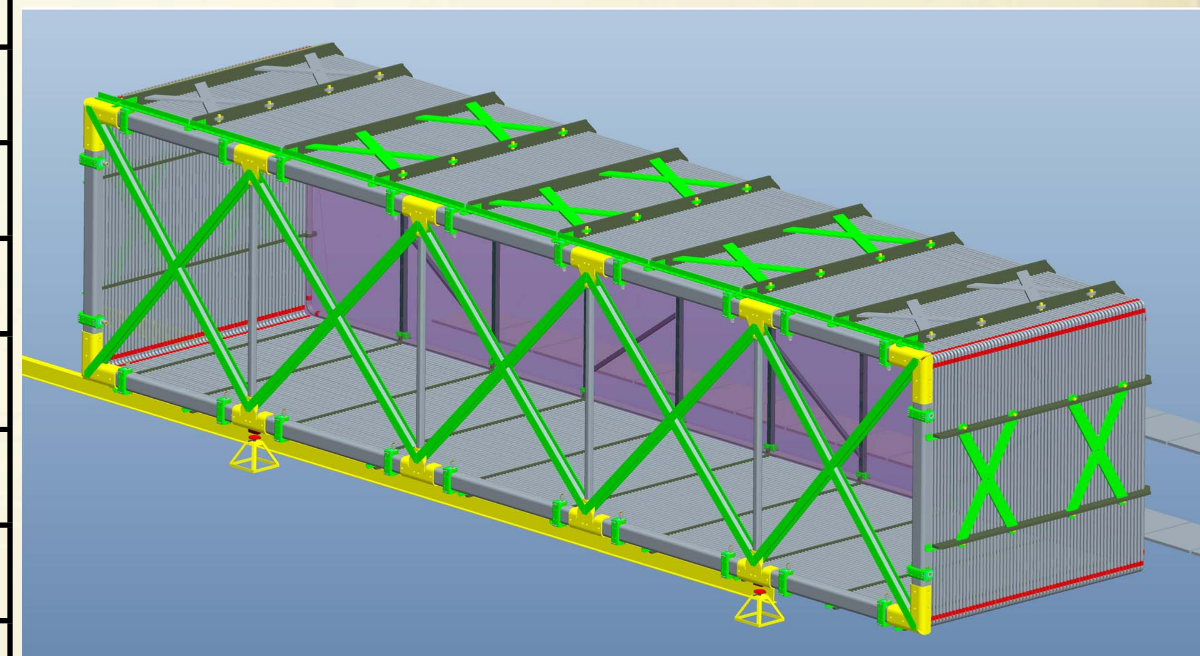
540 m

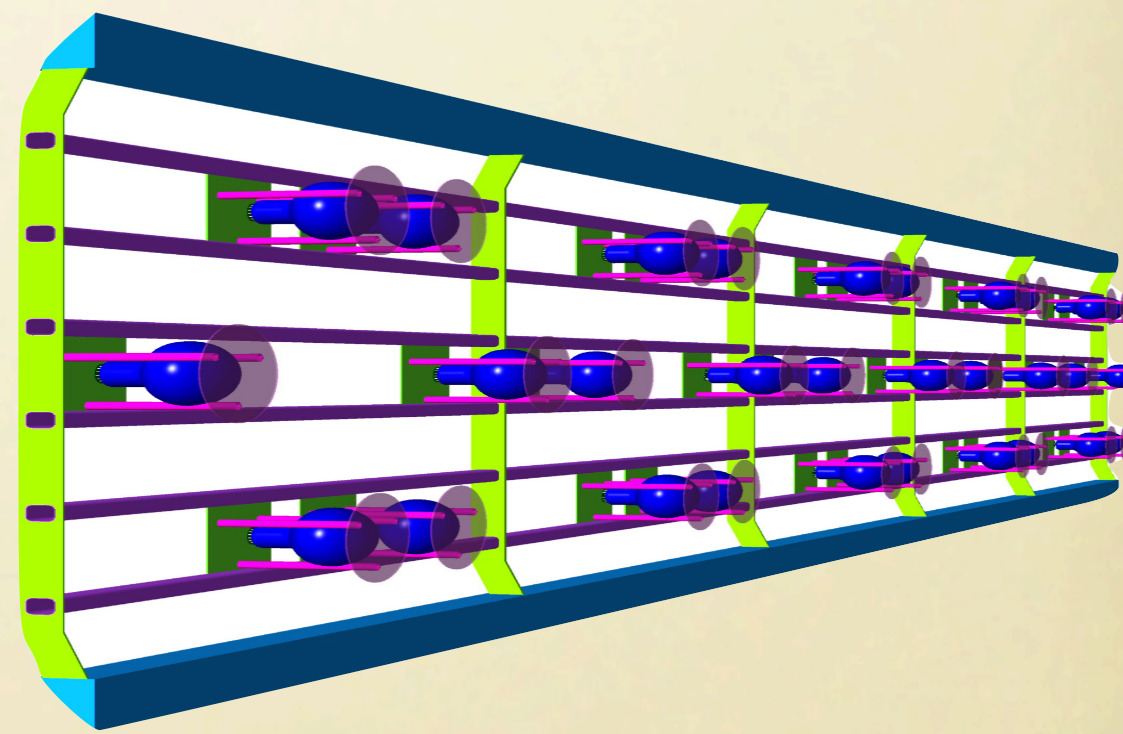
470 m



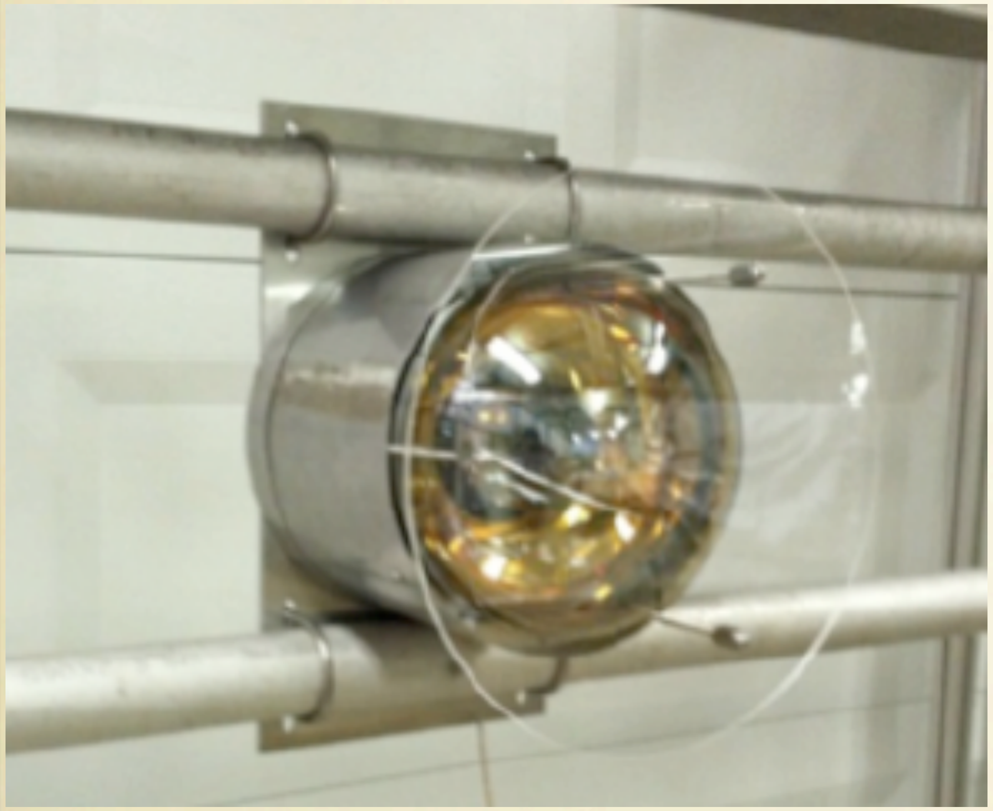
MicroBooNE: Stats

Cryostat Volume	170 Tons
TPC Volume (l x w x h)	89 Tons (10.4m x 2.5m x 2.3m)
# Electronic Channels	8256
Electronics Style (Temp.)	CMOS (87 K)
Wire Pitch (Plane Separation)	3 mm (3mm)
Max. Drift Length (Time)	2.5m (1.5ms)
Wire Properties	0.15mm diameter SS, Cu/Au plated
Light Collection	32 8" Hamamatsu PMTs





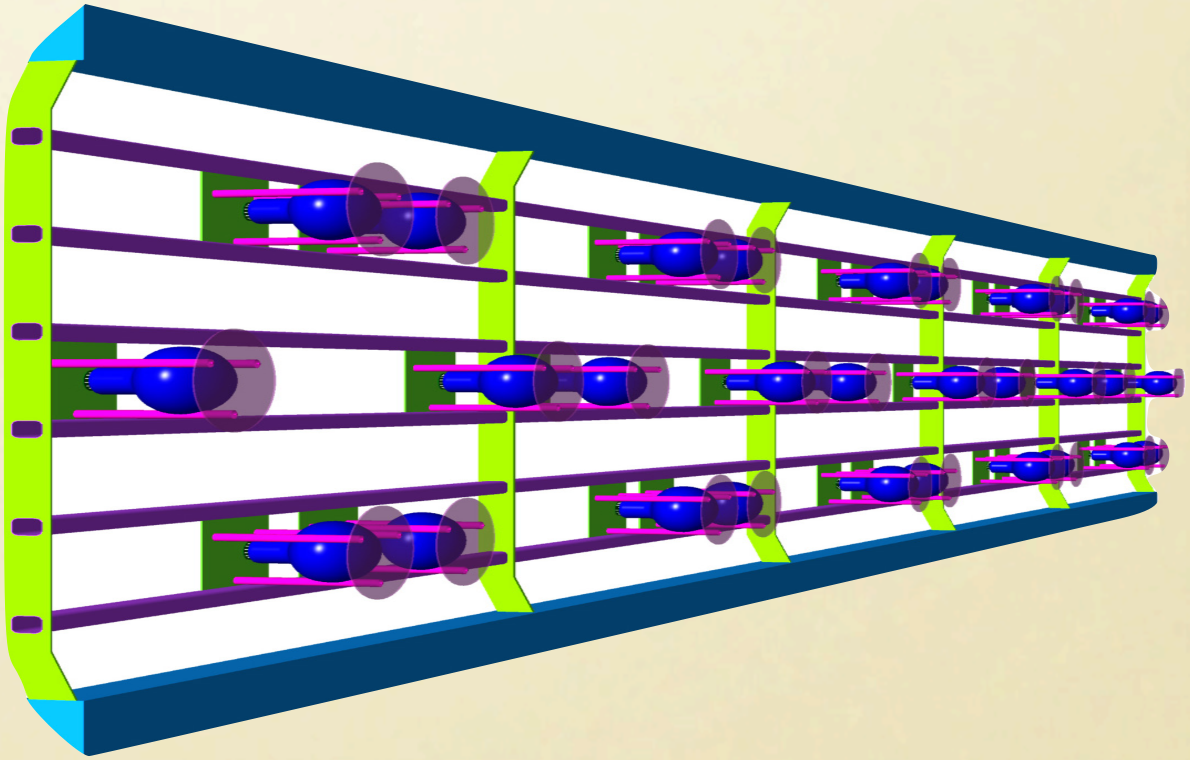
MicroBooNE PMTs



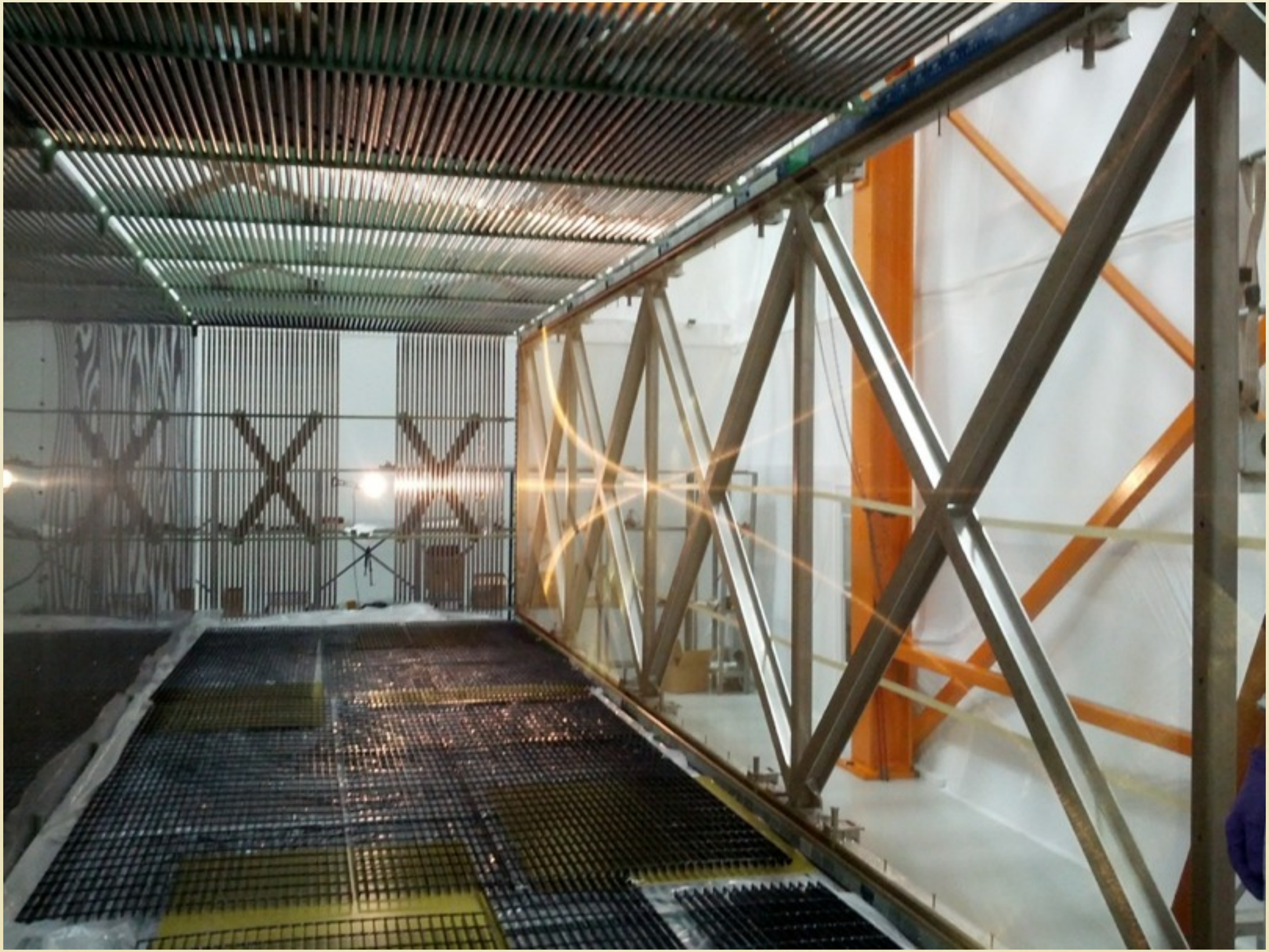
32 PMTs viewing LAr through TPB-coated, wavelength-shifting plates

LAr scintillation ~ 128 nm

More than triggering: Precise timing & important location information



MicroBooNE TPC



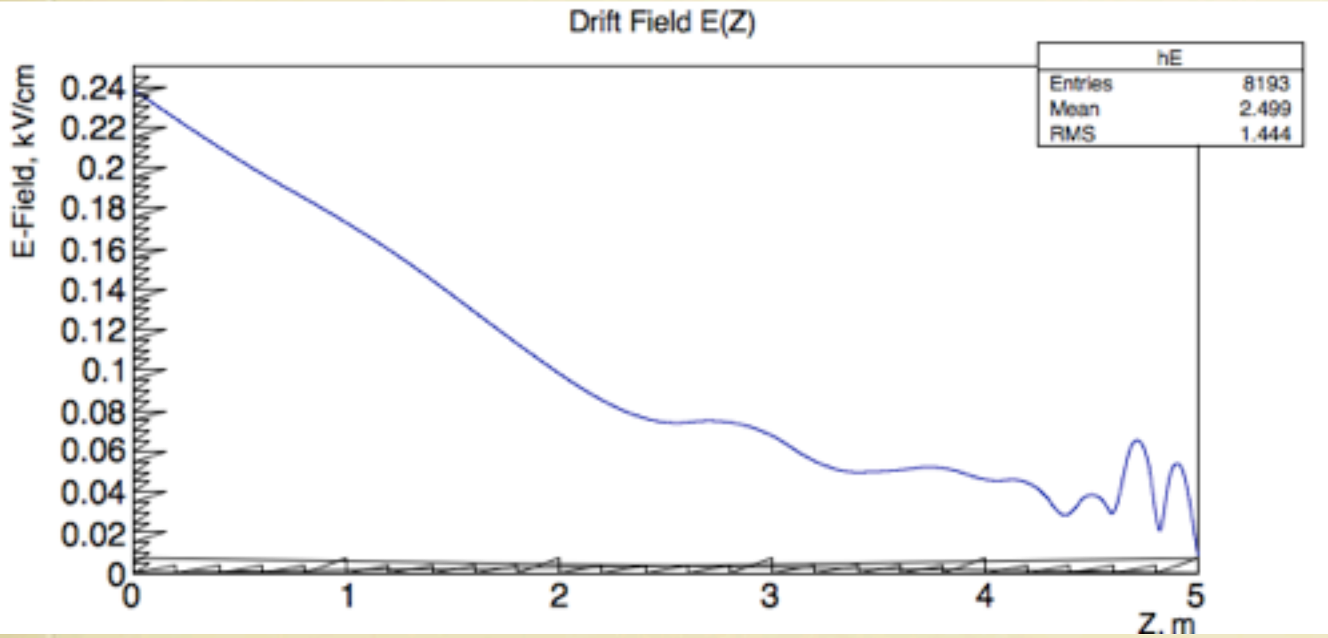
Laser Calibration

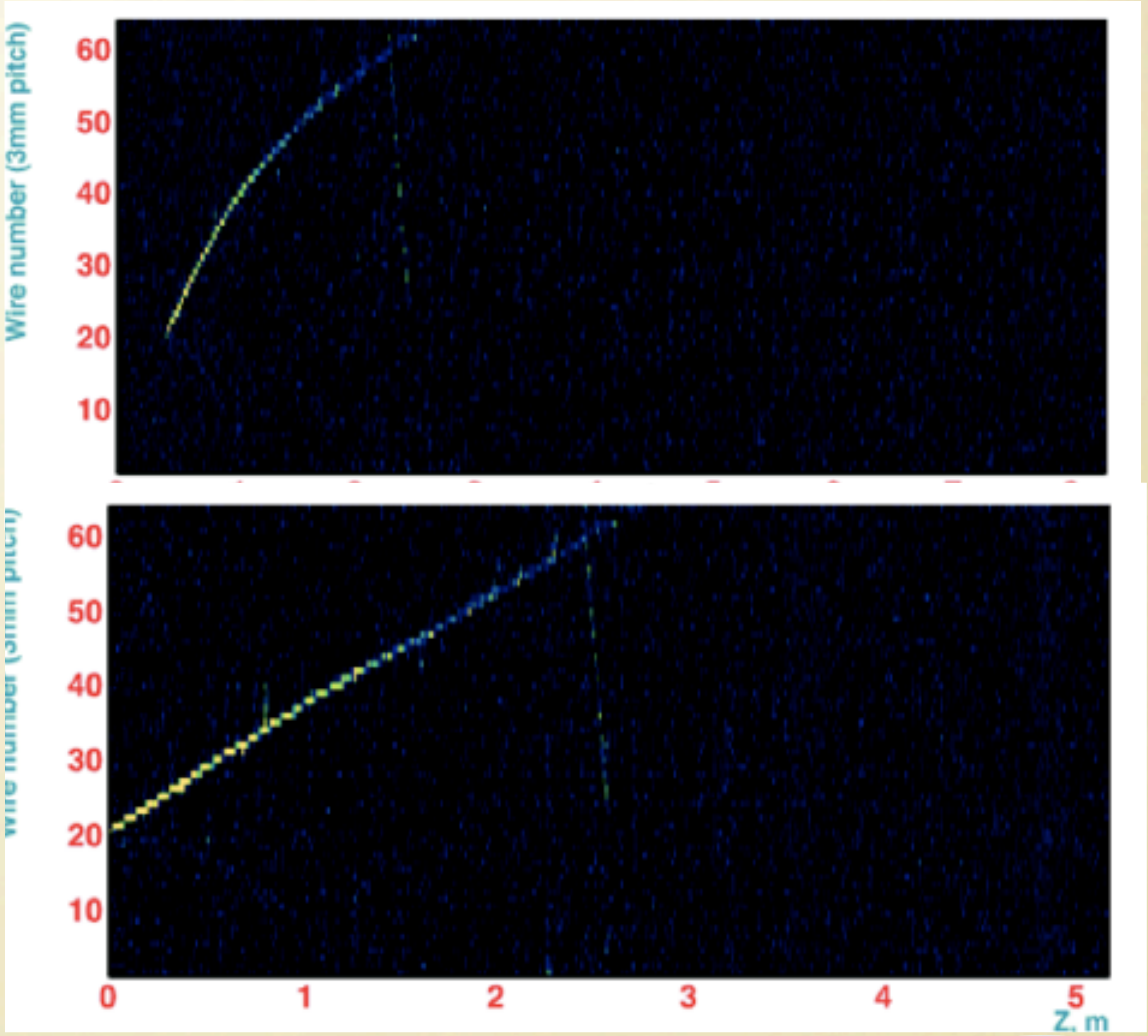
Nd:YAG (1064nm) ⇒ 266 nm wavelength

Perfectly straight ion tracks through the detector.

Calibrates the electric field

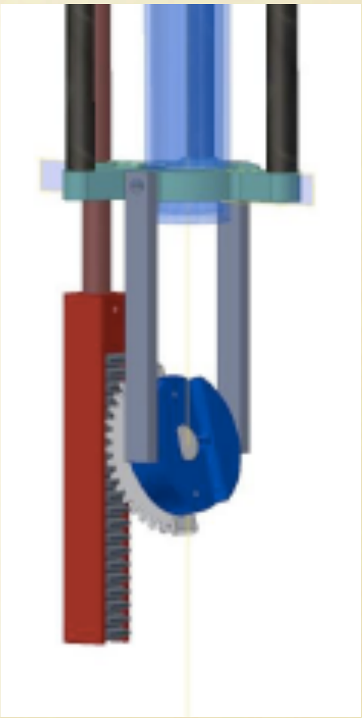
- 10 Hz max. pulse rate
- 60 mJ max
- 4-6 ns pulse width
- 0.5 mrad divergence



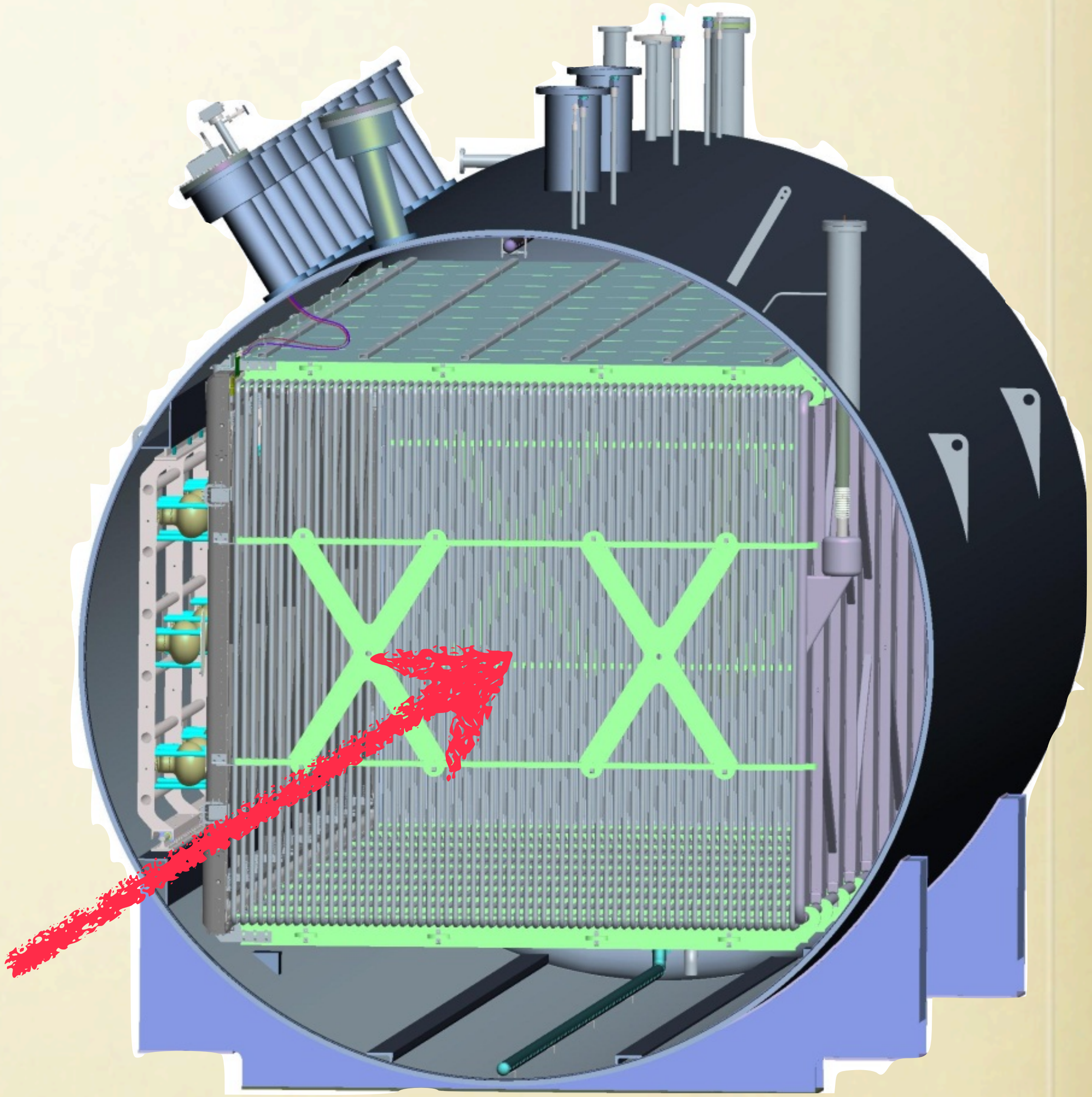


Laser Calibration

View from one laser port into TPC



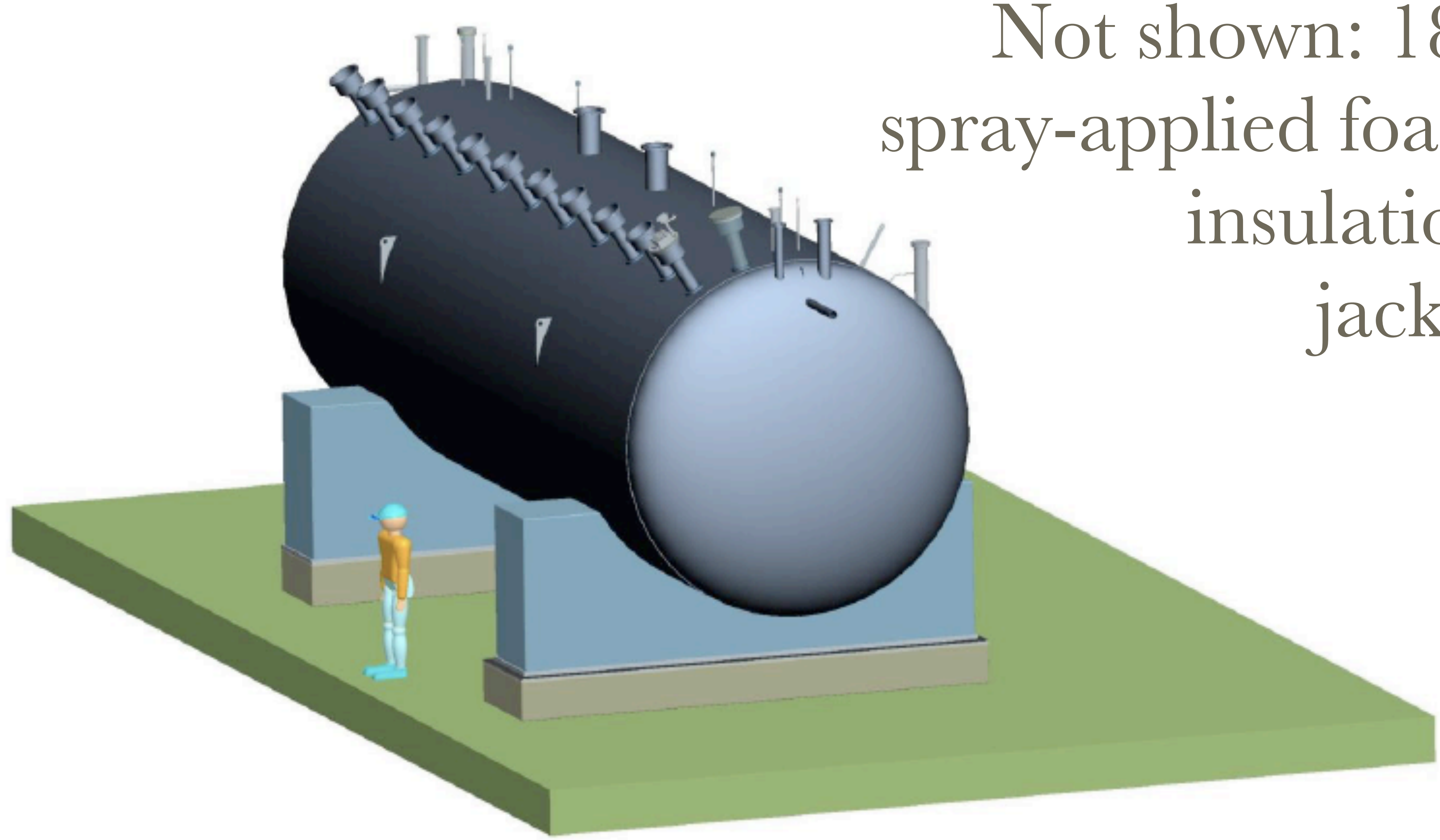
MicroBooNE Cryostat



MicroBooNE Integration

Assembled TPC test-fitted in cryo vessel with PMTs in place

Cryovessel Design & Support



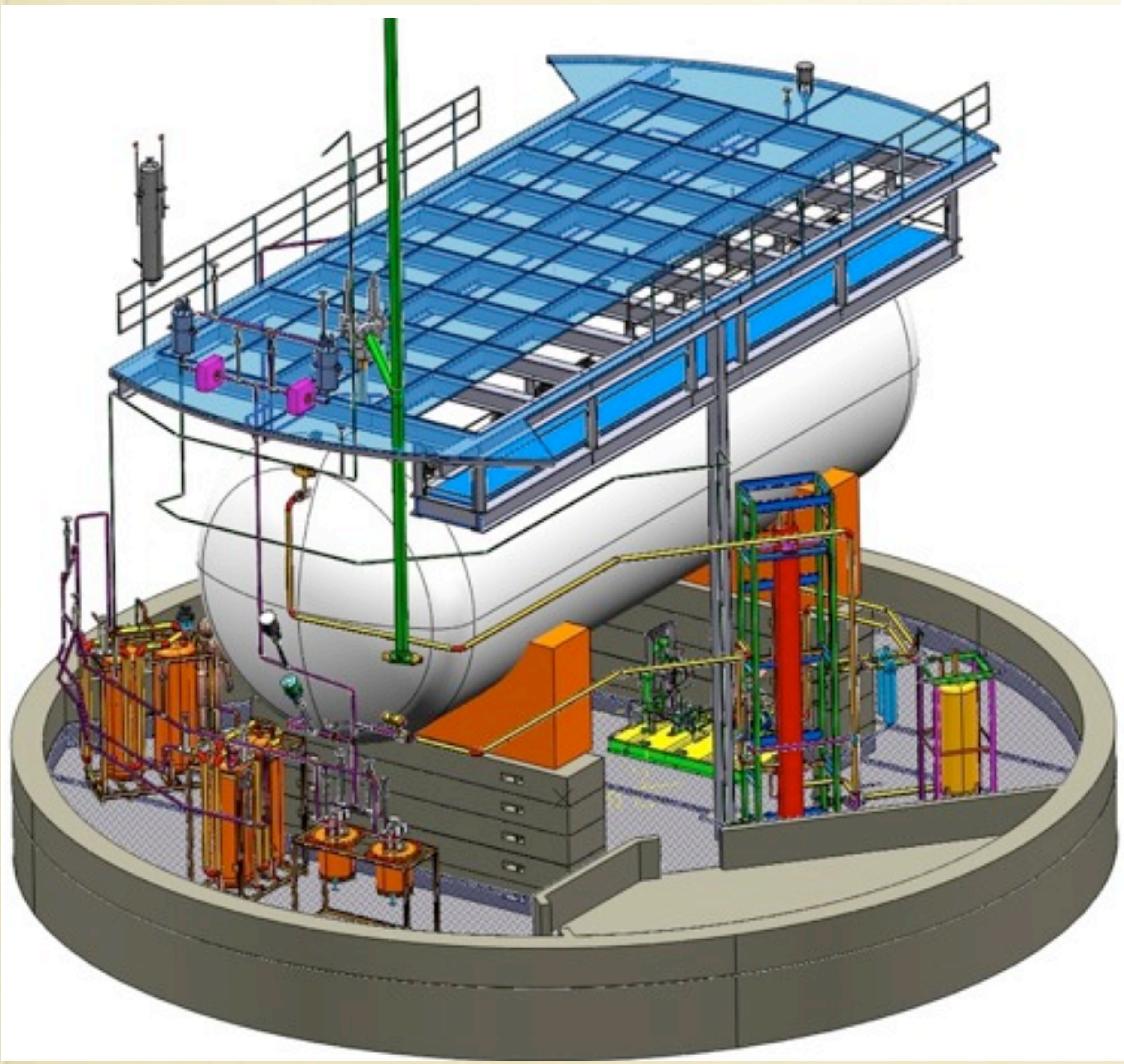
Not shown: 18" spray-applied foam insulation jacket

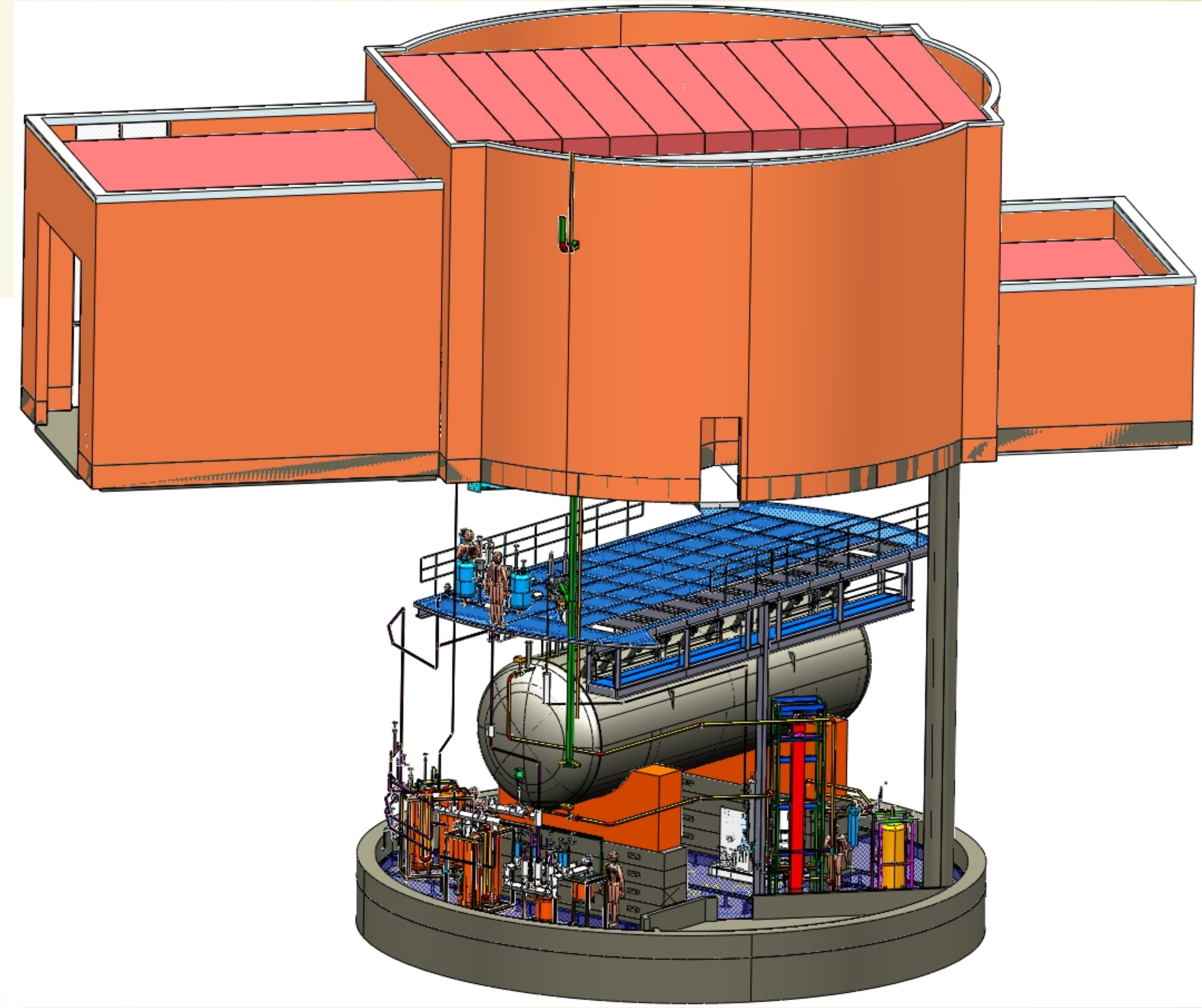
Cryovessel Design & Support

Custom-engineered foam cradle will support cryovessel

In place here at the LAr Testing Facility

LAr Testing Facility





MicroBooNE

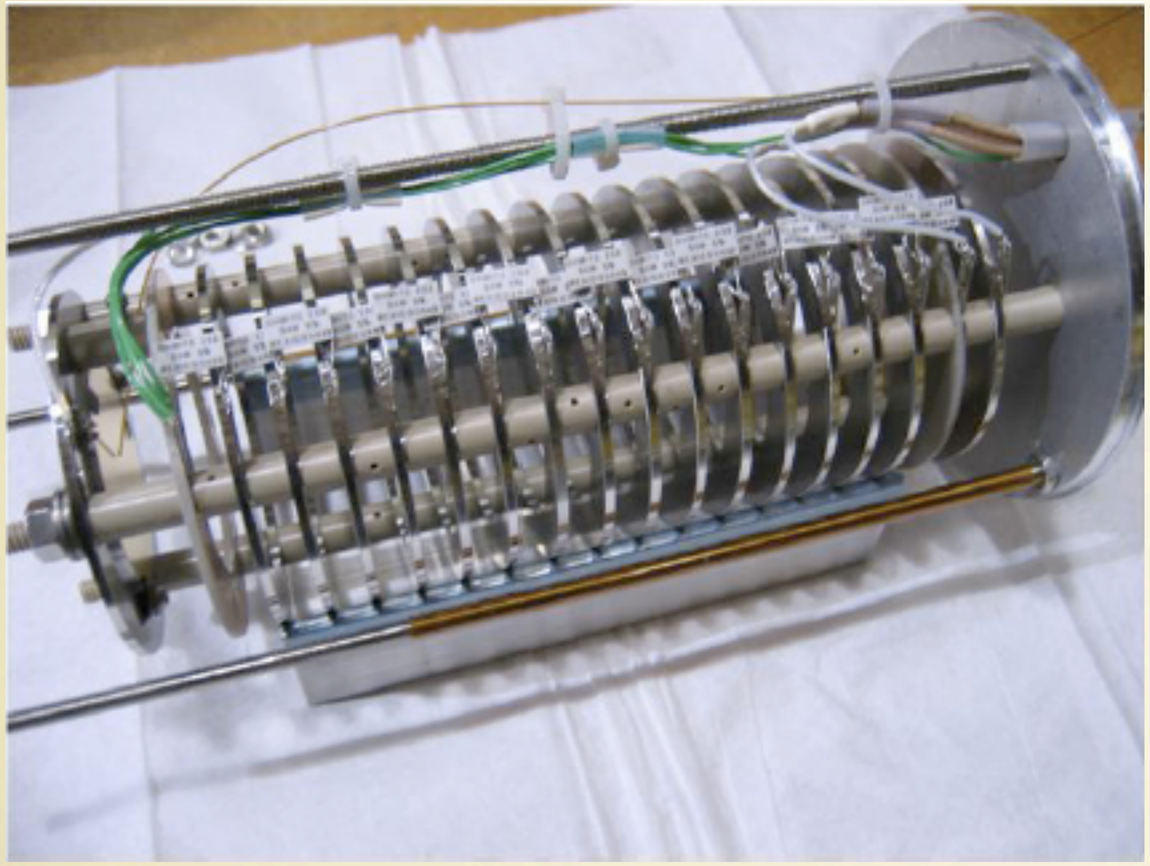
Completed facility looks just like the drawings!

Roof opens for crane to lower cryovessel into place.

University of Cincinnati

μBooNE

Filtered LAr Cryosystem



Purity monitors in vessel and LAr cryo recirculation system

A truck holds ~3500 gallons of LAr.
The cryostat: 38,000 gallons

Cross Section Measurements

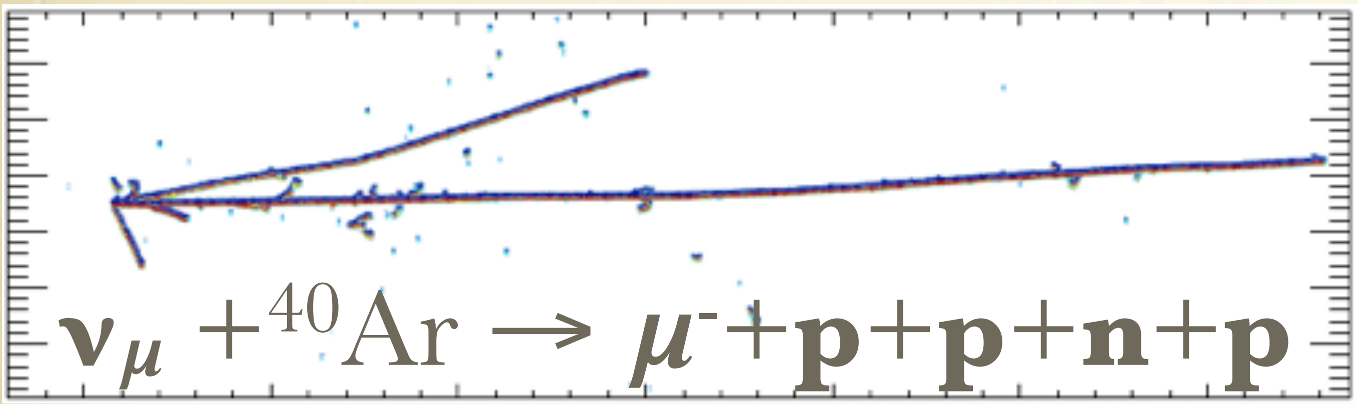
- Crucial inputs to oscillation measurements
- σ_ν historically not well known in the energy range we care about
- New measurements demonstrate importance of nuclear effects
  - MiniBooNE results a major driver here
  - MicroBooNE probes the same energy region with a more capable detector.
    - Superior resolution and PID
    - **p** reconstructable with kinetic energy as low as 20 MeV

After almost 10 years of FNAL Booster Neutrino Beam operation, flux is well characterized*. Positions MicroBooNE to make expeditious cross section measurements

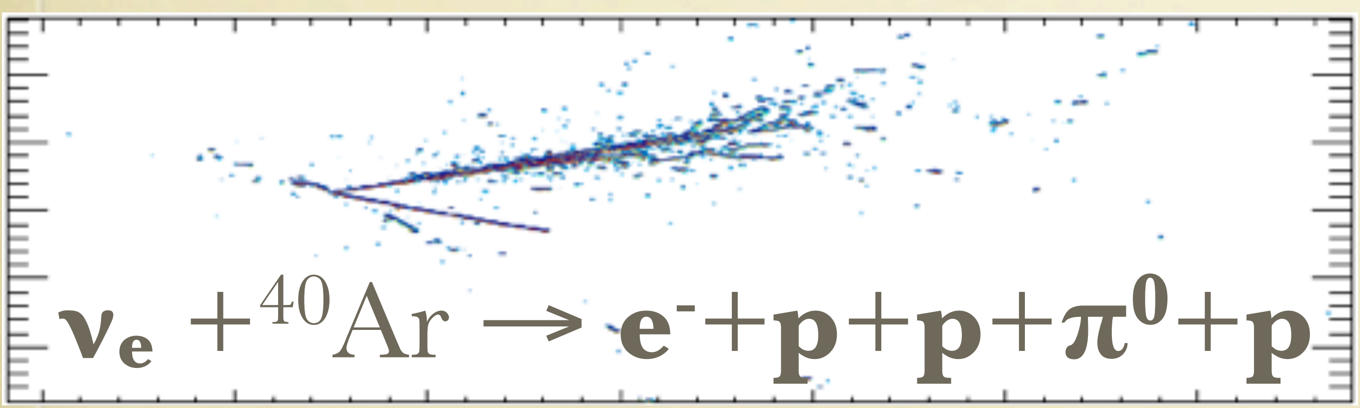
***Phys. Rev. D 79, 072002 (2009)**

Cross Section Measurements

Final-state interactions (pion absorption, charge exchange, re-scattering) very important to get right!



Simulated MicroBooNE data



arxiv.org/abs/1107.5112

production mode	formula	#evt ($\times 10^3$)
CC quasi-elastic	$\nu_\mu + n \to \mu^- + p$	66
NC elastic	$\nu_\mu + N \to \nu_\mu + N$	21
CC resonance π^+	$\nu_\mu + N \to \mu^- + N + \pi^+$	28
CC resonance π°	$\nu_\mu + n \to \mu^- + p + \pi^\circ$	7
NC resonance π°	$\nu_\mu + N \to \nu_\mu + N + \pi^\circ$	8
NC resonance $\pi^\pm$	$\nu_\mu + N \to \nu_\mu + N' + \pi^\pm$	3
CC DIS	$\nu_\mu + N \to \mu^- + X, W > 2$ GeV	1
NC DIS	$\nu_\mu + N \to \nu_\mu + X, W > 2$ GeV	0.5
CC coherent π°	$\nu_\mu + A \to \mu^- + A + \pi^+$	3
NC coherent $\pi^\pm$	$\nu_\mu + A \to \nu_\mu + A + \pi^\circ$	2
CC Kaon production	$\nu_\mu + N \to \mu^- + K + X$	~0.1
NC Kaon production	$\nu_\mu + N \to \nu_\mu + K + X$	<0.1
others		4
total		143

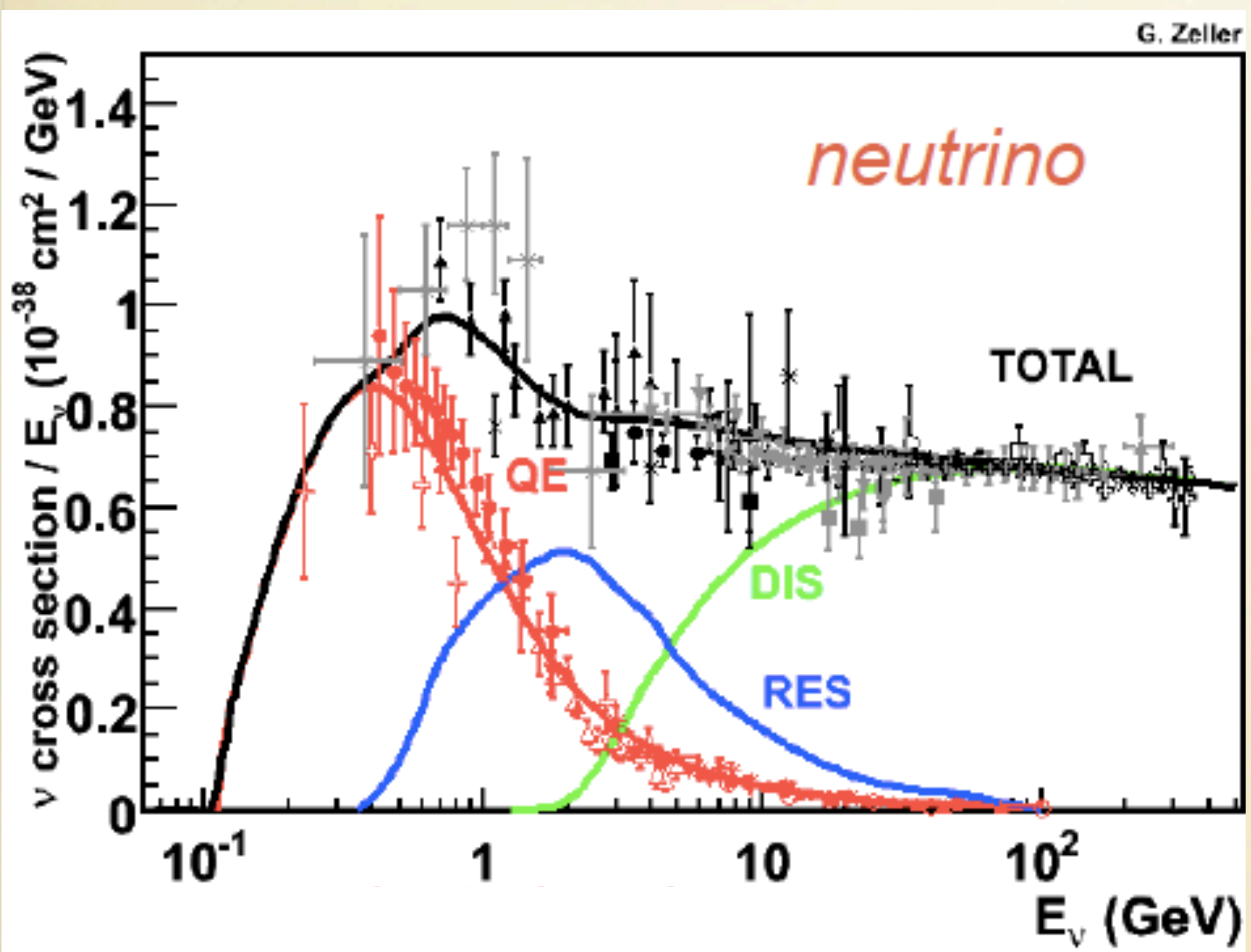
Estimated for 60-ton TPC
6.6E20 protons on tabrget

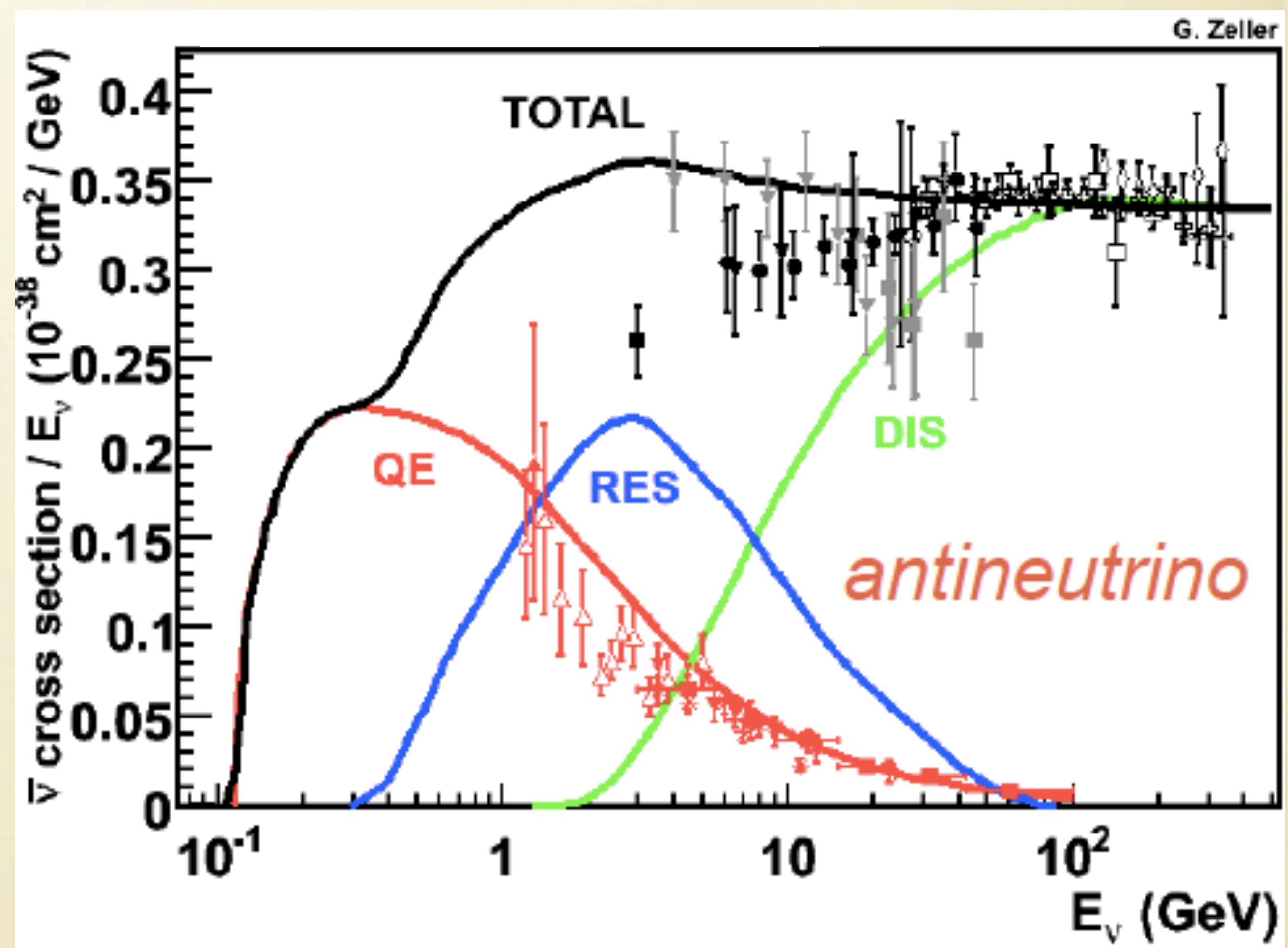
Cross Section Measurements

Multiple competing processes we need to understand in this region.

MicroBoone's ability to discriminate particle ID crucial to advancing this understanding.

Rev. Mod. Phys. 84, 13007 (2012)





Summary

On course to fill with LAr in early 2014

Use cosmics to demonstrate cold, submerged preamplifiers and long-drift reconstruction

Begin measuring low energy cross sections

With ~6.6 E 20 POT, expect to address MiniBooNE low-E excess (and a history of L/E ~ 1 measurements)

Look for results in the coming year!

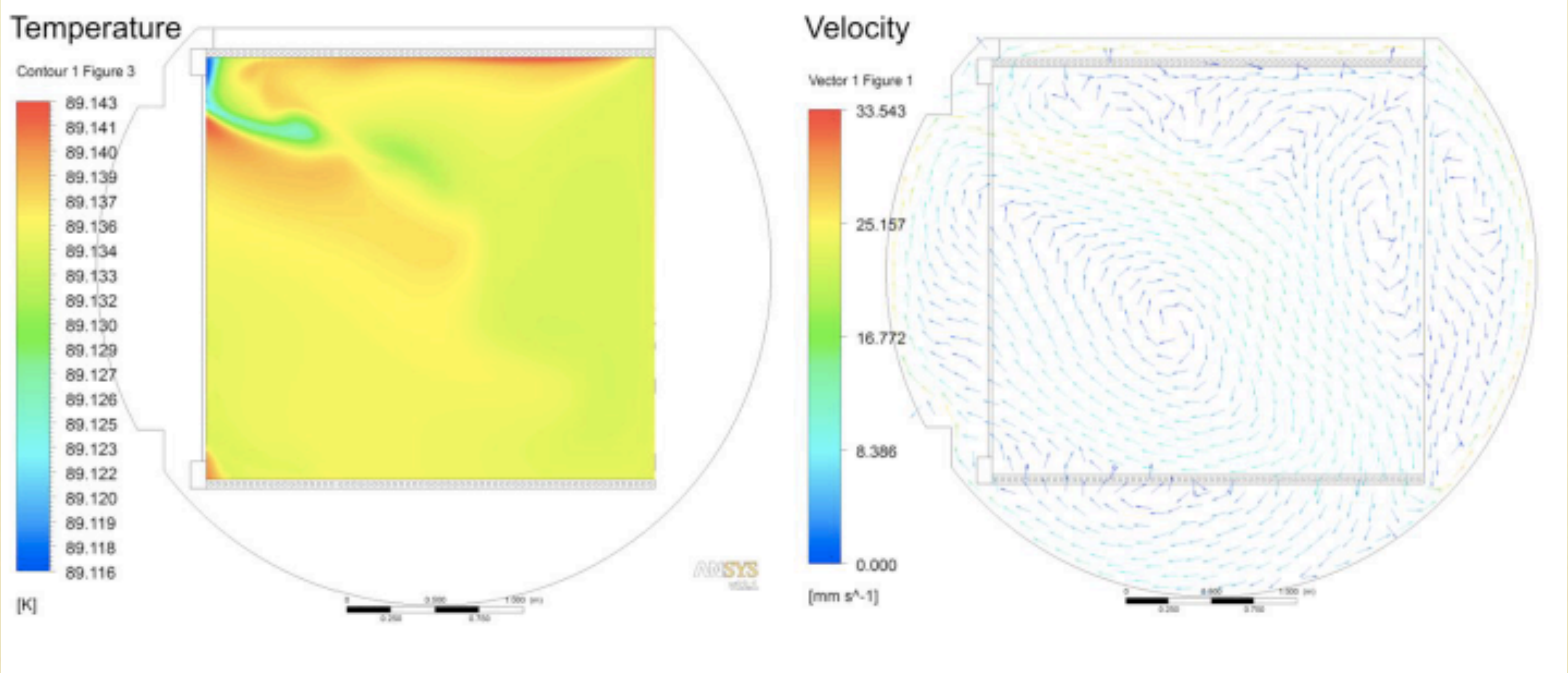
Thank You!

更多?

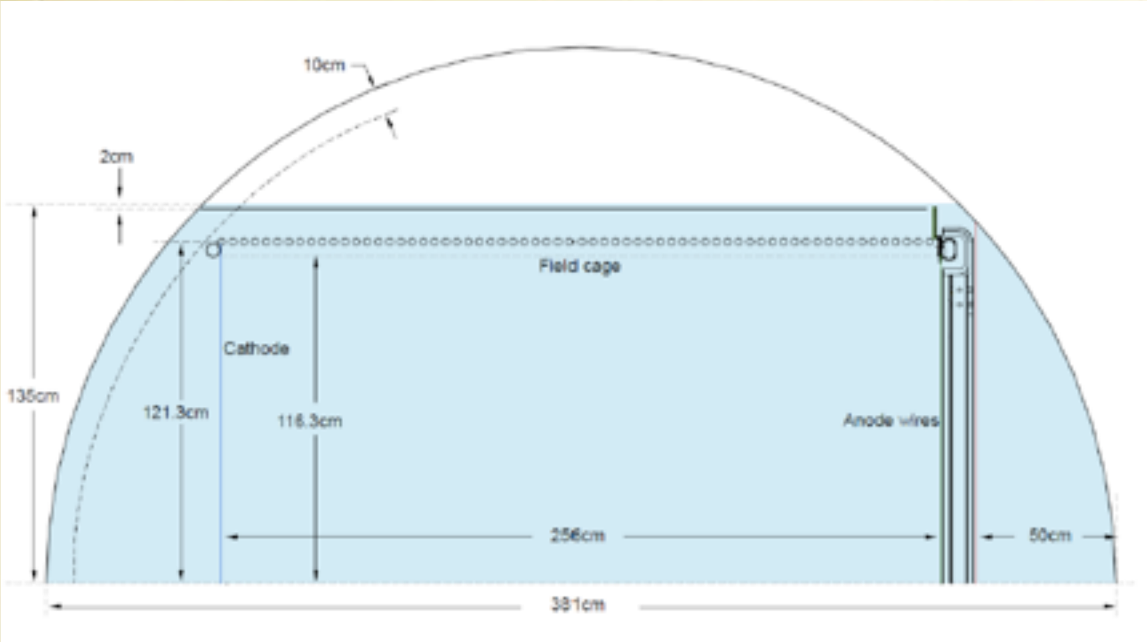
LAr Hydrodyanmics

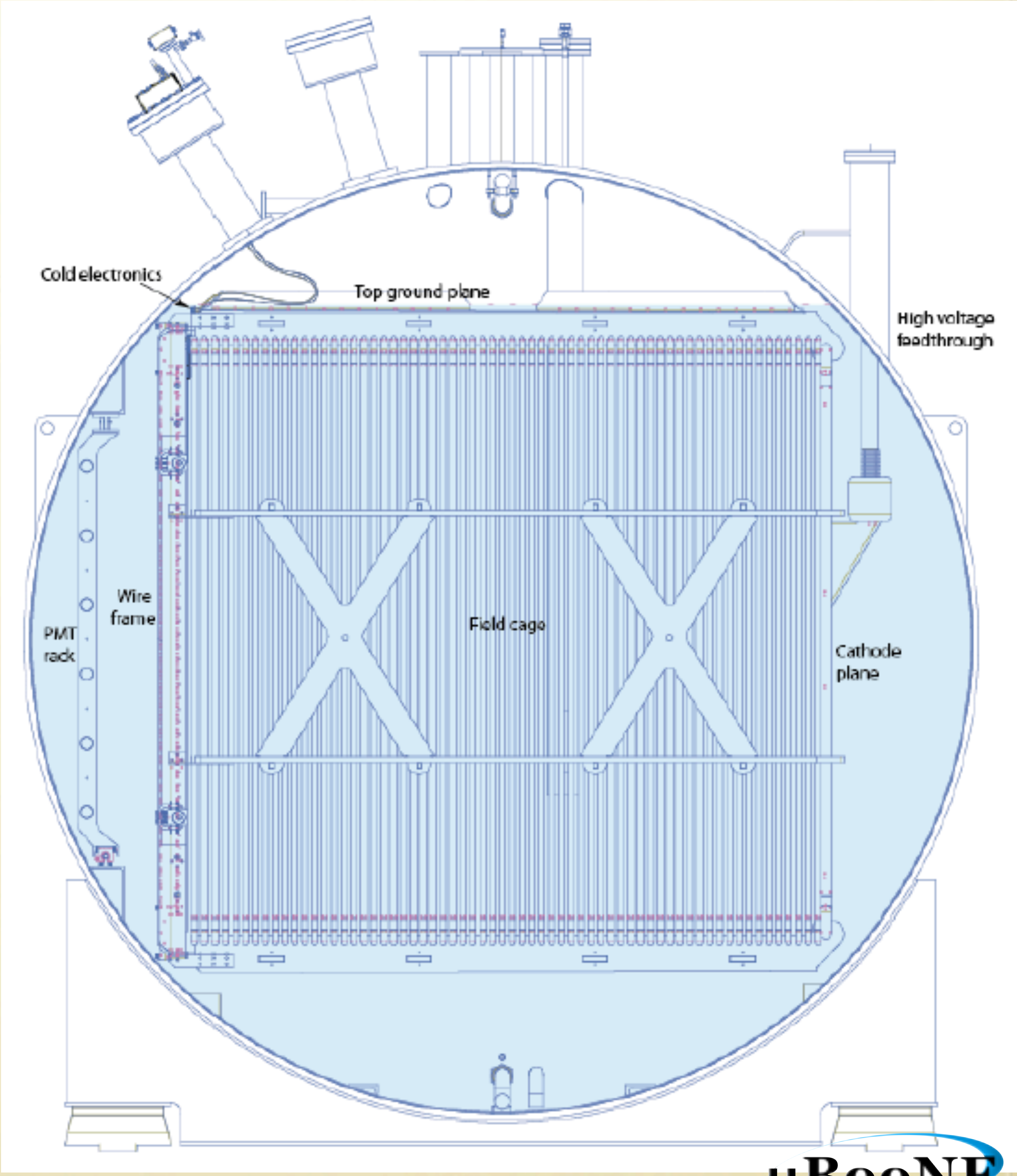
Flow affects temperature & purity variations

Important to know where Ar^+ may pool (cosmic and beam contributions)



Ullage





LAr purity affected by surfaces in the 'warm' gas region.

Laser Calibration

Multiphoton ionization

UNIVERSITÄT BERN
AEC ALBERT EINSTEIN CENTER FOR FUNDAMENTAL PHYSICS

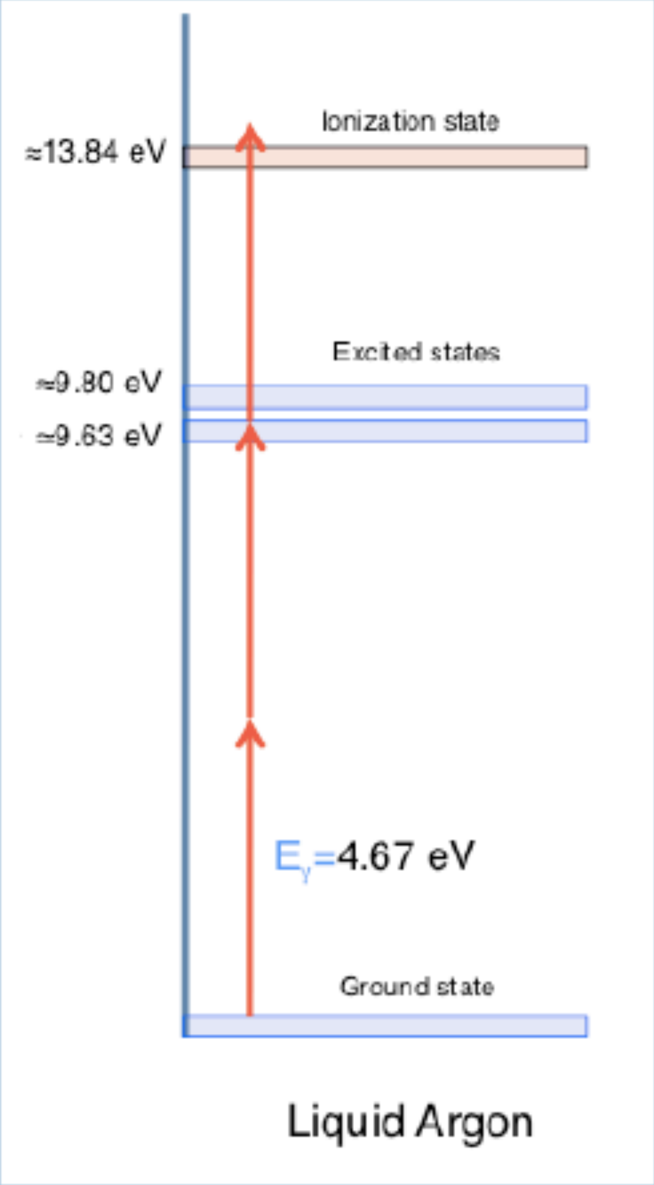
> λ = 266 nm correspond to E_γ = 4.67 eV
> For ionization ~14 eV are needed
> For non-resonant states the lifetime is given by

$$\tau_\gamma = \frac{\lambda}{2\pi c} = 1.4 \times 10^{-16} s$$

> For quasi-resonant states one has

$$\tau_\gamma \propto \frac{1}{\Delta E} = \frac{1}{(E_i - E_\gamma)}$$

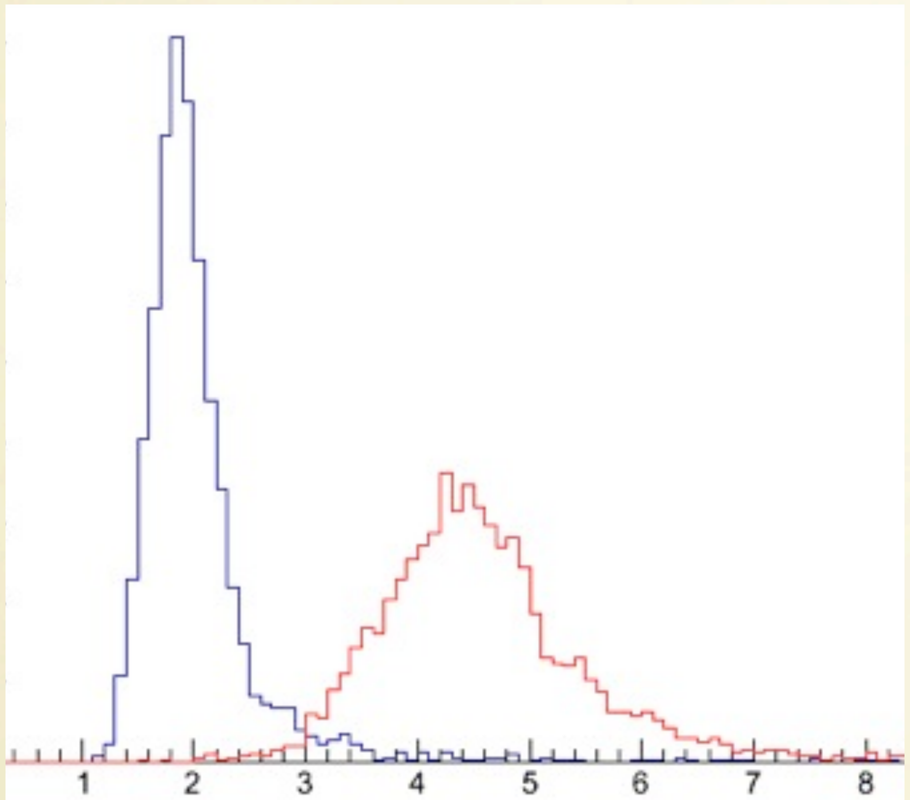
> The laser has to have enough intensity to allow a three-photon ionization



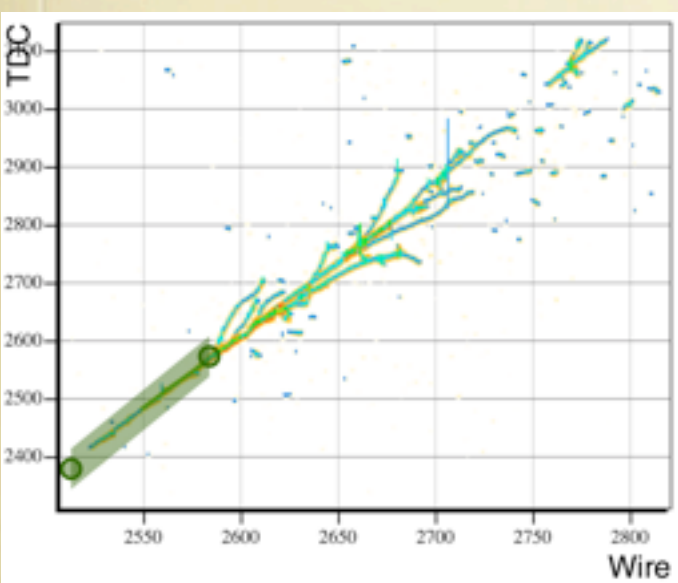
See also: B. Rossi et al. 2009 JINST **4** P07011
I. Badhrees et al. 2010 New J. Phys. **12** 113024

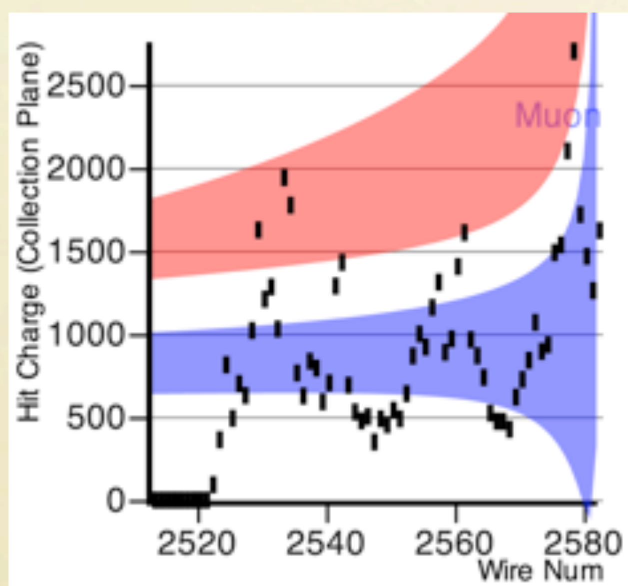
C. Rudolf von Rohr

Detector Technology

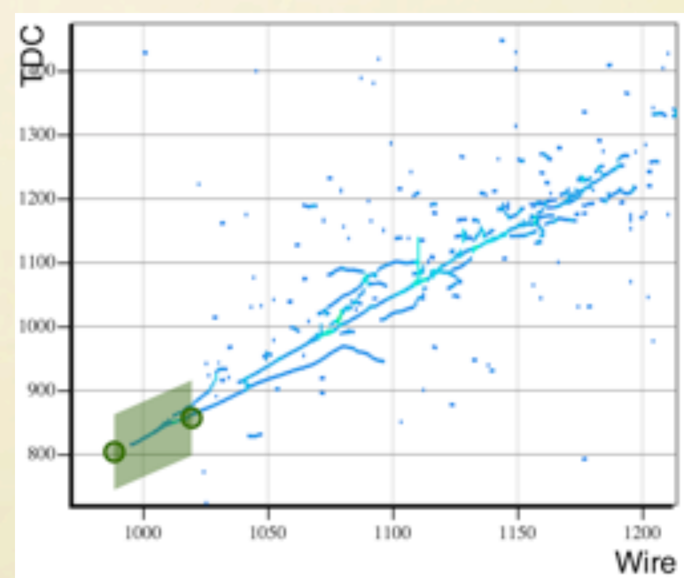


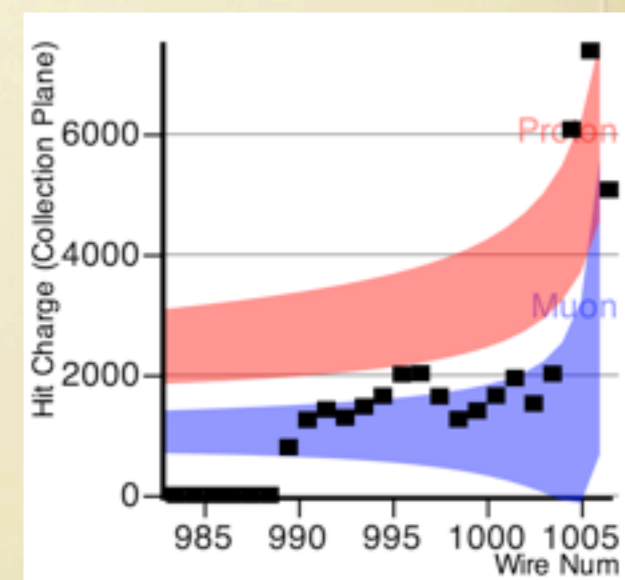
dE/dx at shower vertex distinguishes
e (1 MIP)
from
e^+e^- (2 MIPs)





e

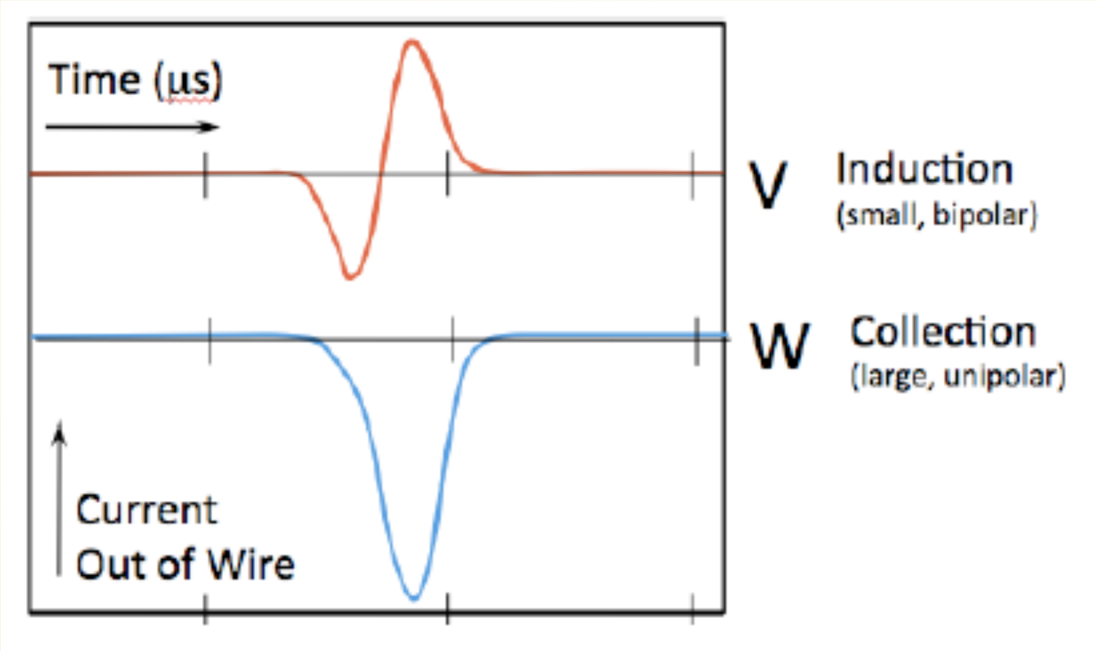




γ

MicroBooNE

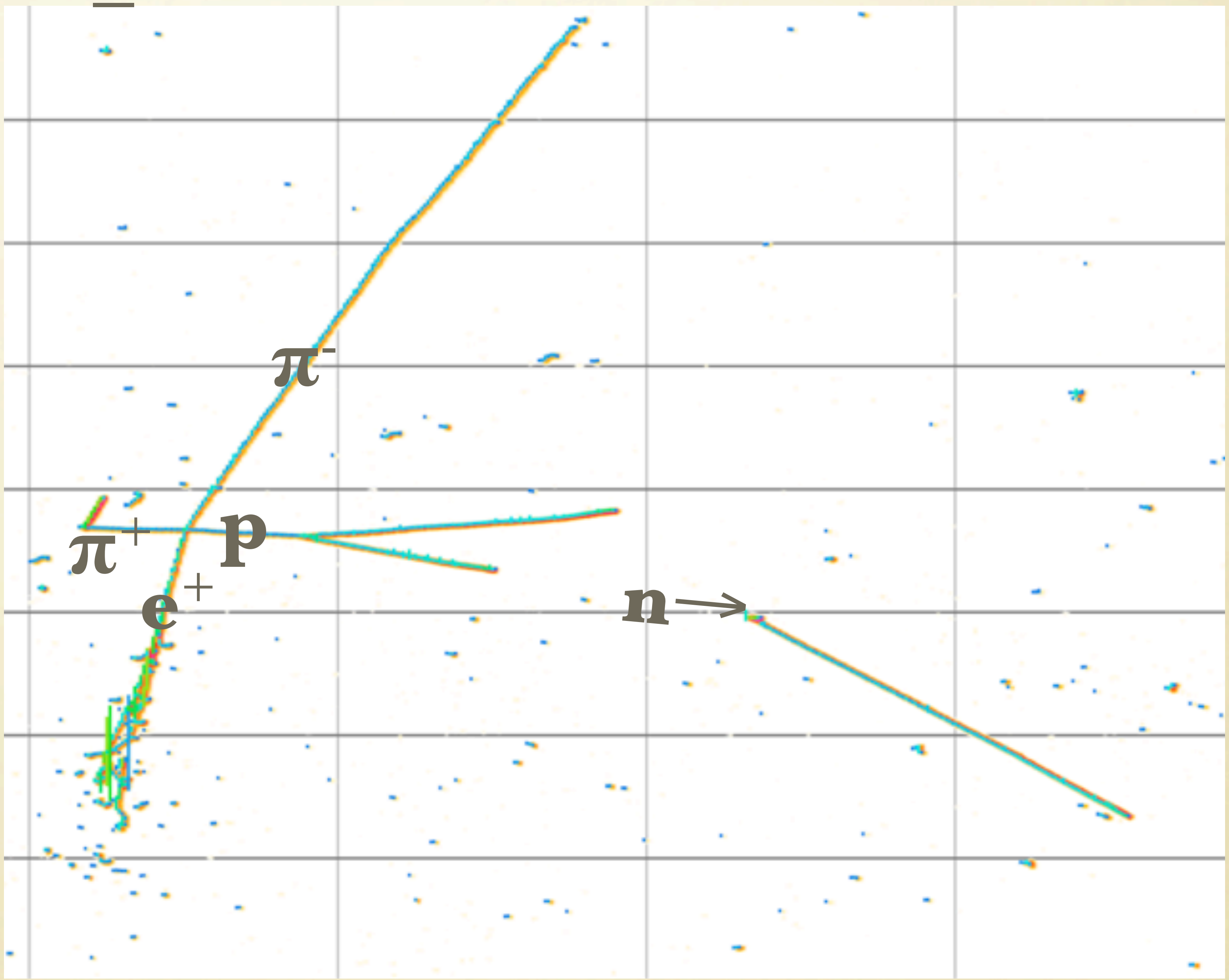
Induction and conduction channels have distinct time profiles in response to drifted charge.



MicroBooNE: Simulated Events

Resonant hadron production with some visible nuclear detritus

ν_e Ar → $\mathbf{e^+\pi^-\pi^+pn}$

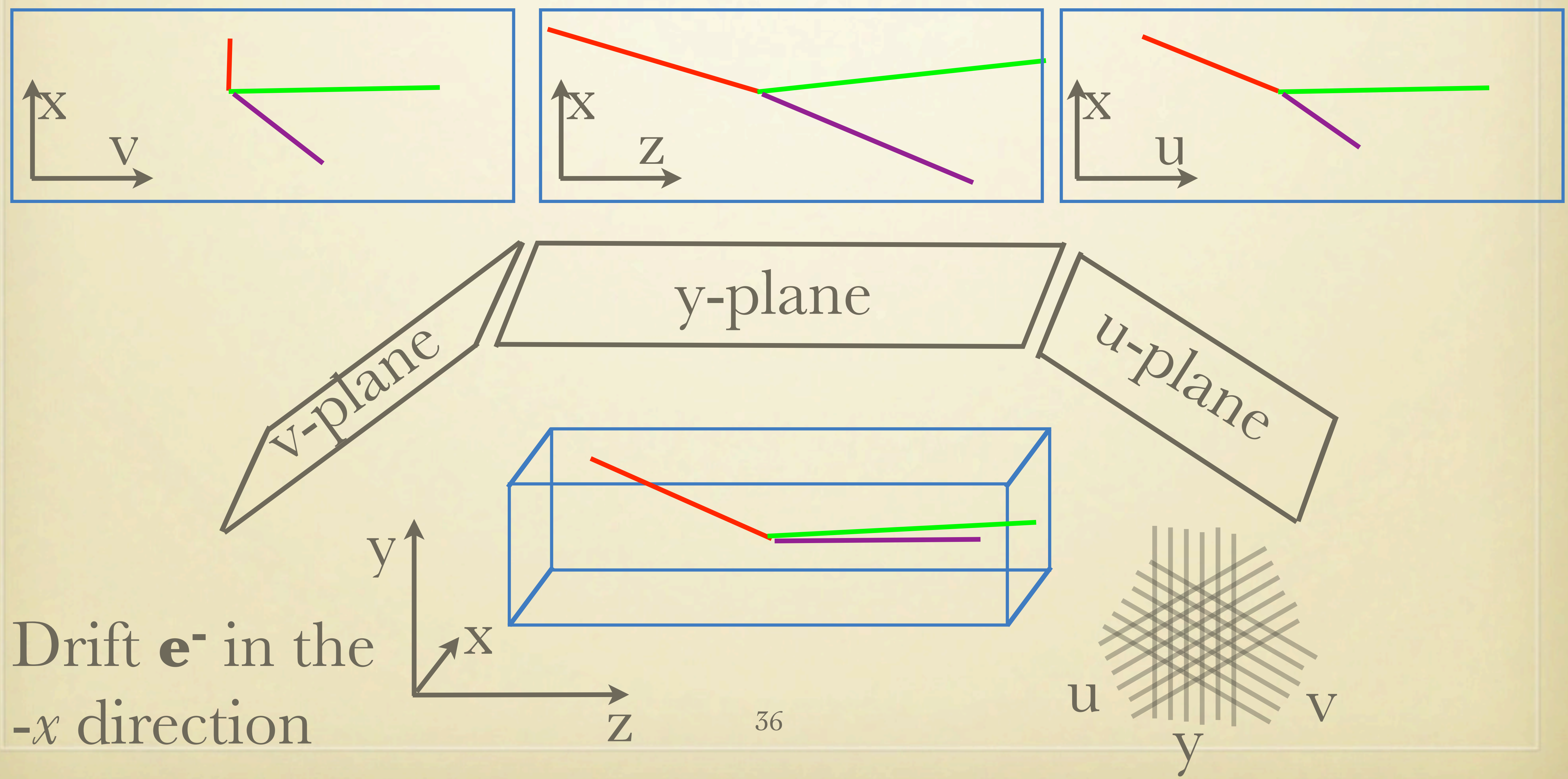


MicroBooNE: Projective Geometries

Drift direction x common to all 3 views

Projected angles and distances differ

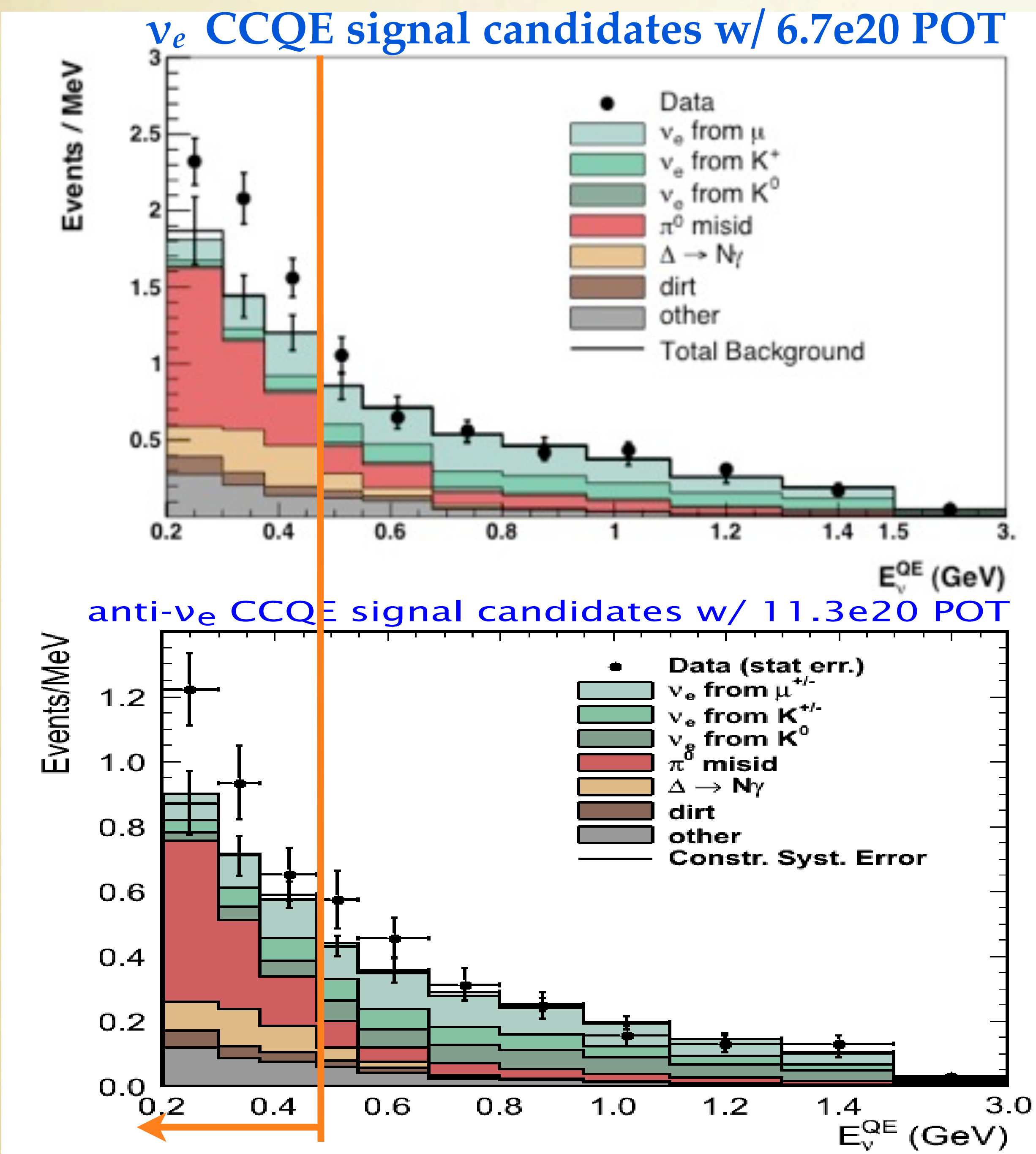
Makes 3D reconstruction possible



Drift **e⁻** in the -x direction

MiniBooNE: Context & Motivation

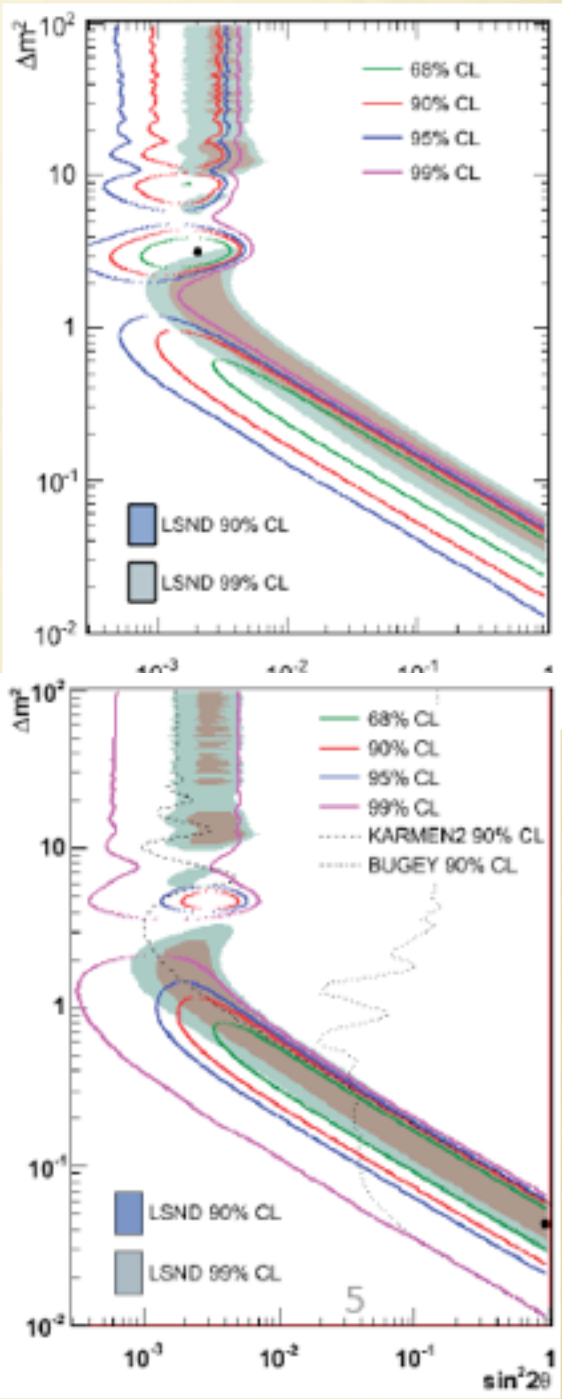
Observed 200-475 MeV excess in ν_e-type events



Similar L/E as LSND

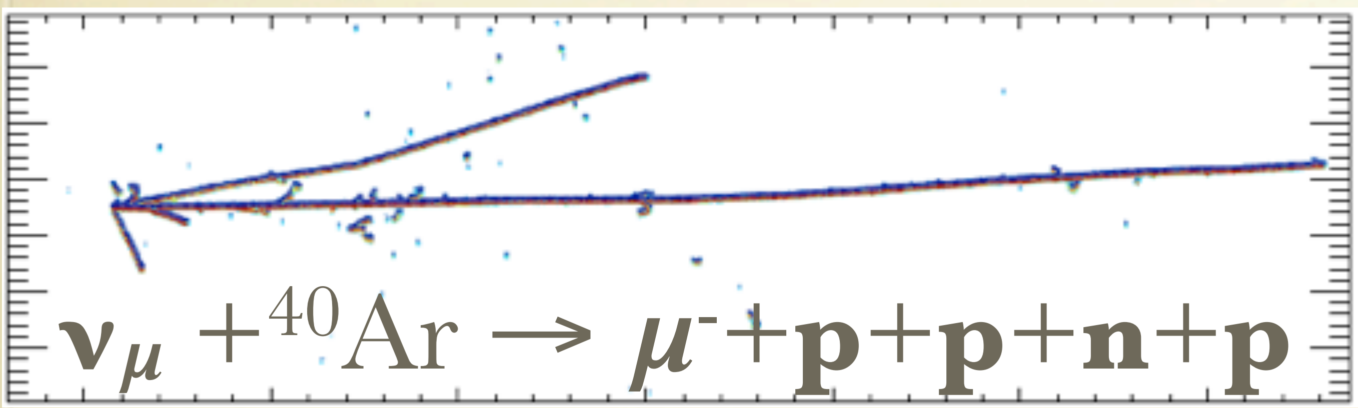
Allowed regions overlap with LSND

Also: nature of low-E events?

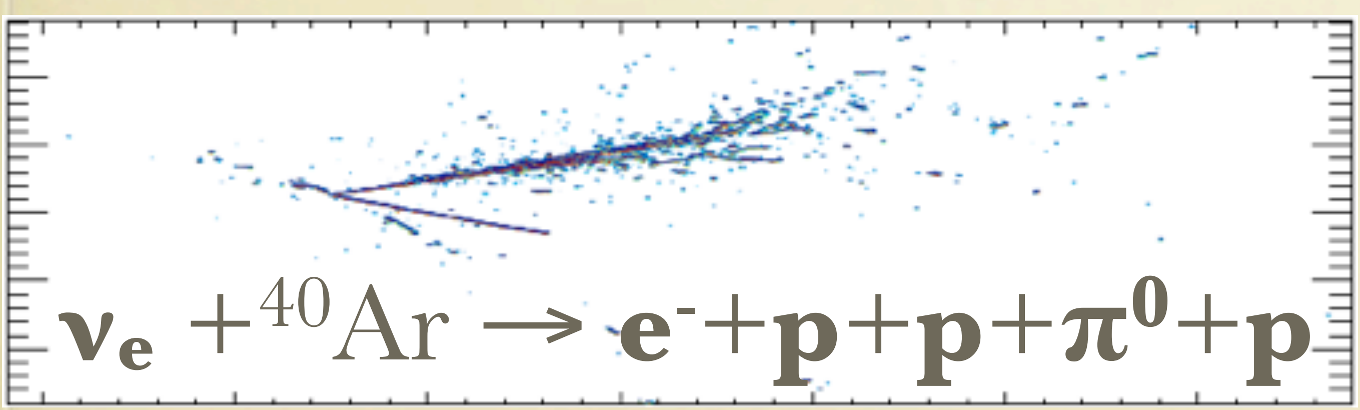


Cross Section Measurements

Final state interactions (pion absorption, charge exchange, re-scattering) very important to get right!



Simulated MicroBooNE data



TDR

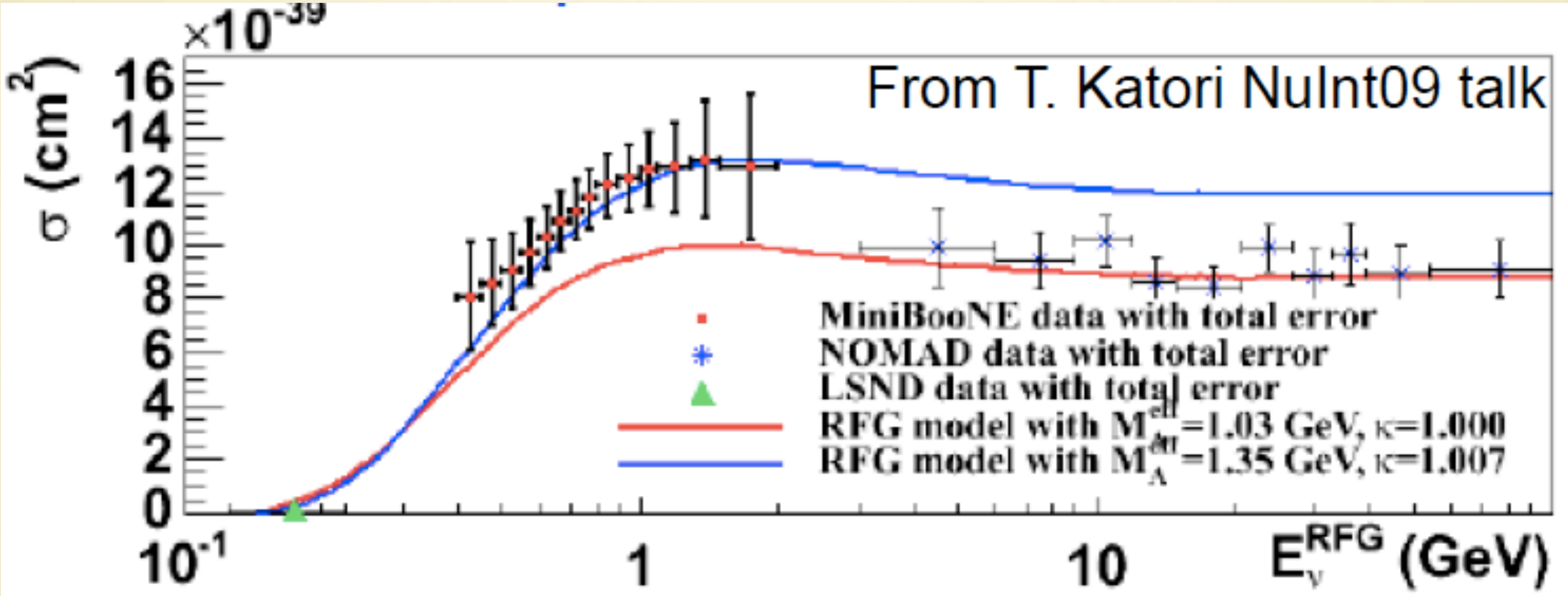
production mode	# events
CC QE ($\nu_\mu n \rightarrow \mu^- p$)	60,161
NC elastic ($\nu_\mu N \rightarrow \nu_\mu N$)	19,409
CC resonant π^+ ($\nu_\mu N \rightarrow \mu^- N \pi^+$)	25,149
CC resonant π^0 ($\nu_\mu n \rightarrow \mu^- p \pi^0$)	6,994
NC resonant π^0 ($\nu_\mu N \rightarrow \nu_\mu N \pi^0$)	7,388
NC resonant $\pi^\pm$ ($\nu_\mu N \rightarrow \nu_\mu N' \pi^\pm$)	4,796
CC DIS ($\nu_\mu N \rightarrow \mu^- X$, $W > 2$ GeV)	1,229
NC DIS ($\nu_\mu N \rightarrow \nu_\mu X$, $W > 2$ GeV)	456
NC coherent π^0 ($\nu_\mu A \rightarrow \nu_\mu A \pi^0$)	1,694
CC coherent π^+ ($\nu_\mu A \rightarrow \mu^- A \pi^+$)	2,626
NC kaon ($\nu_\mu N \rightarrow \nu_\mu K X$)	39
CC kaon ($\nu_\mu N \rightarrow \mu^- K X$)	117
other ν_μ	3,678
total ν_μ CC	98,849
total ν_μ NC+CC	133,580
ν_e QE	326
ν_e CC	657

Estimated for 60-ton TPC 6.6E20 protons on tabrget

Cross Section Measurements

Quasi-Elastic cross sections show some tension in RFG model, dipole form-factor approximation.

MicroBooNE can shed light on this, too, with an Ar target, tagging hadrons produced to improve available data.



MiniBooNE collaboration, PRD81(2010)092005