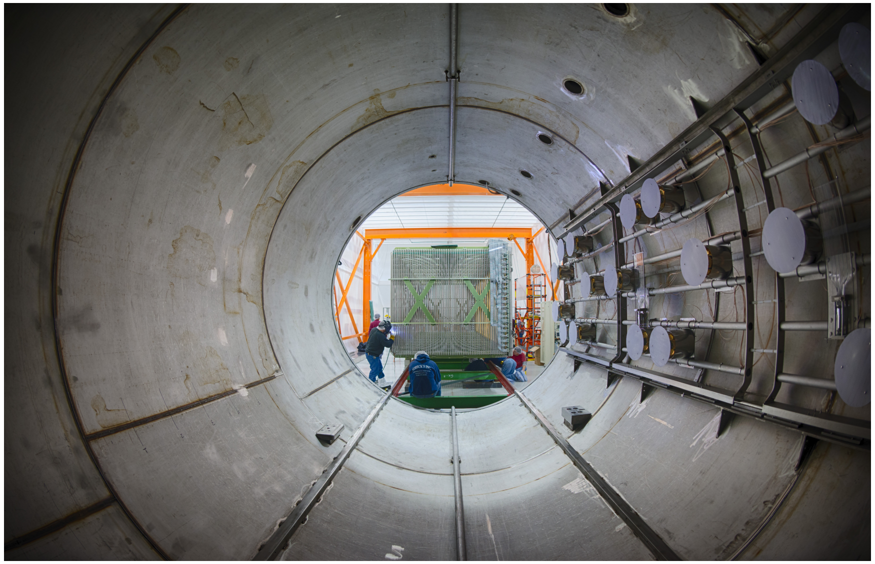
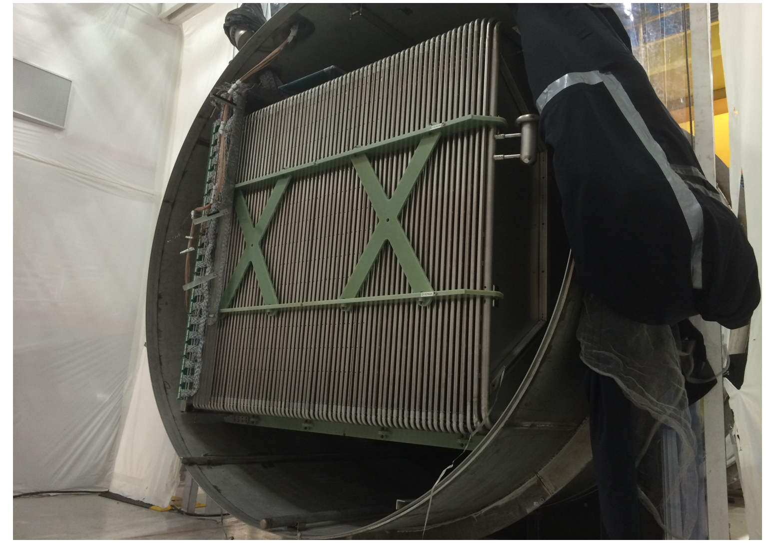
The MicroBooNE Experiment





Jonathan Asaadi
Syracuse University
On behalf of the MicroBooNE Collaboration

Outline

- Liquid Argon Time Projection Chambers (LArTPC)
- MicroBooNE
  - Motivation
  - Physics Goals
  - Detector Physics
- MicroBooNE's Current Status
- The Future Short & Long Baseline Neutrino Programs at Fermilab

LArTPC's

Liquid Argon is an excellent choice for neutrino detectors:

	He	Ne	Ar	Kr	Xe	Water
Boiling Point [K] @ 1atm	4.2	27.1	87.3	120.0	165.0	373
Density [g/cm^3]	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	

Note: 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!

→ Dense

40% more dense than water

→ Abundant

1% of the atmosphere

→ Ionizes easily

55,000 electrons / cm

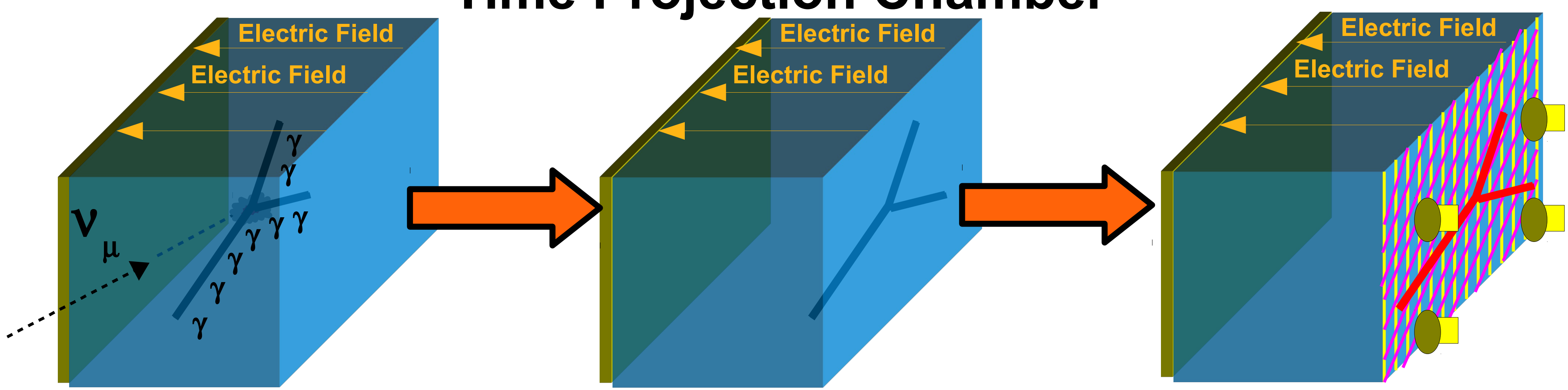
→ High electron lifetime

Greek name means "lazy"

→ Produces copious scintillation light

Transparent to light produced

Time Projection Chamber

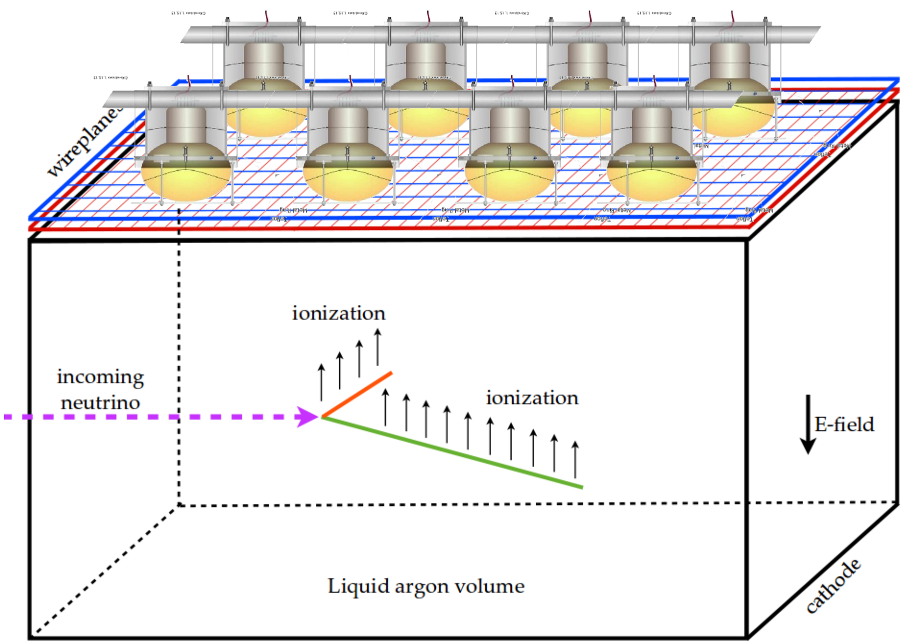


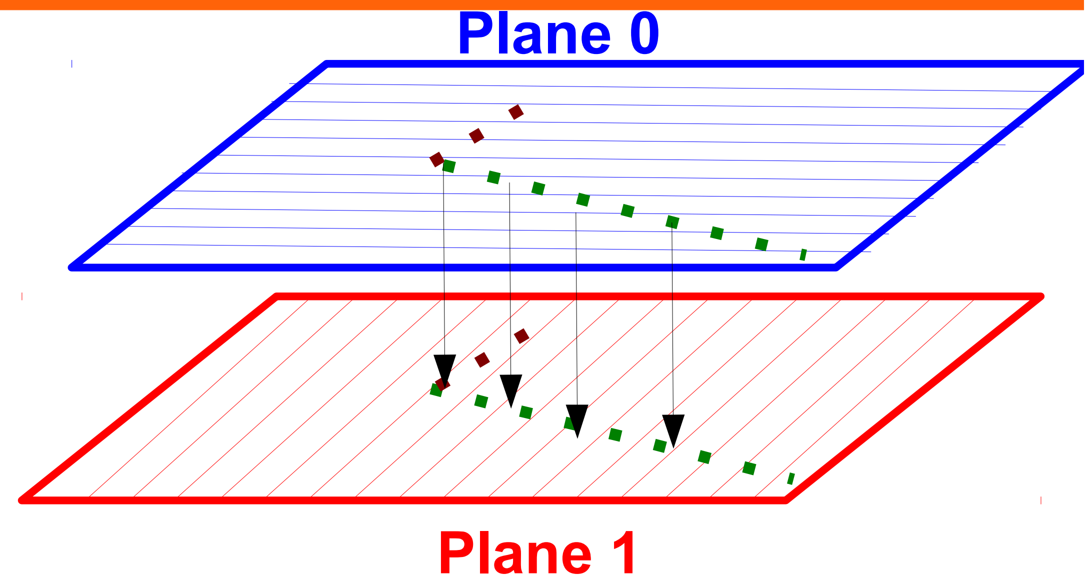
Neutrino interaction in LAr produces ionization and scintillation light

Drift the ionization charge in a uniform electric field

Read out charge and light produced using precision wires and PMT's

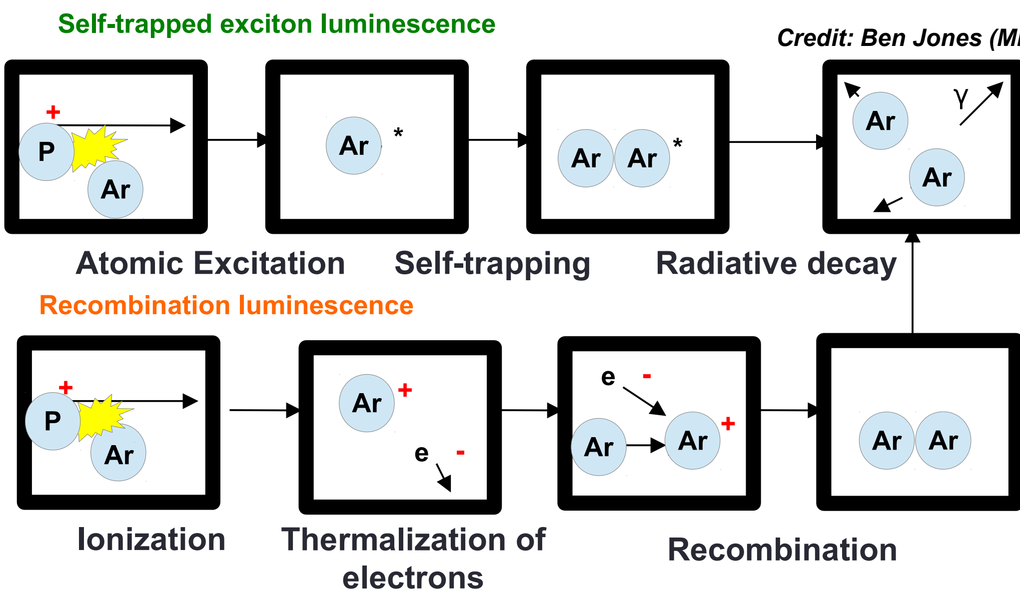
Using the charge for 3-d reconstruction



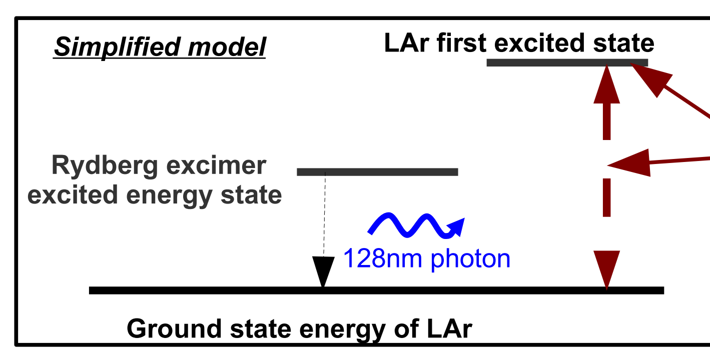


Matching charge locations across different angled wire planes allows for 3d reconstruction

Using the scintillation light to get the t-0



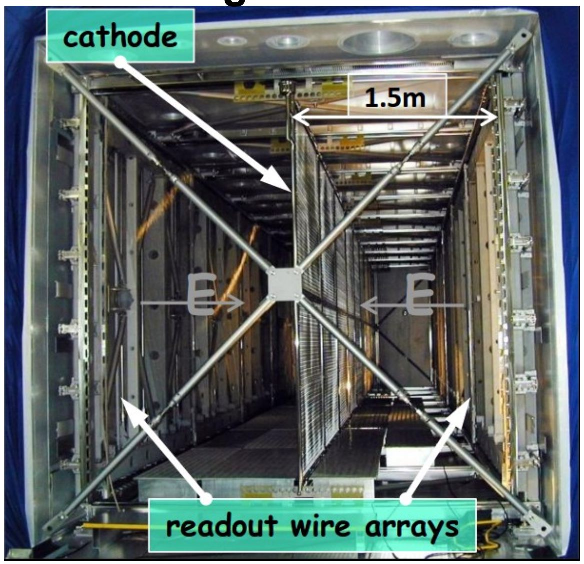
Credit: Ben Jones (MIT) for image



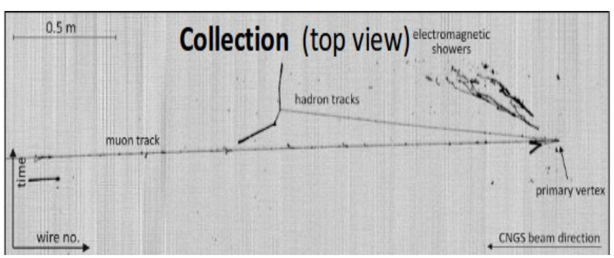
This difference between the energy levels is why LAr is transparent to the scintillation light it produces

Examples of LArTPC's

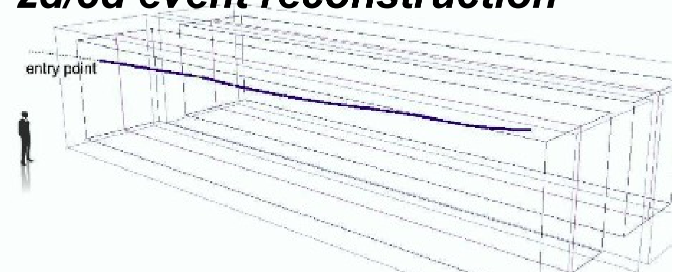
ICARUS @ CNGS
First Large LArTPC



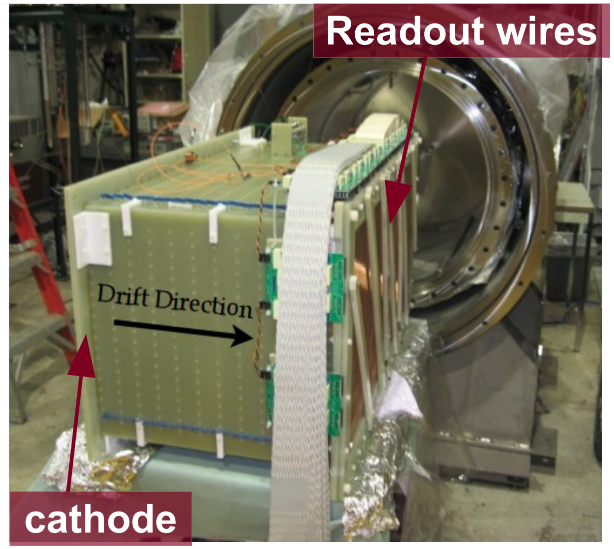
476 tons (active mass)
1.5 meter drift
53,000 wires (3mm pitch)



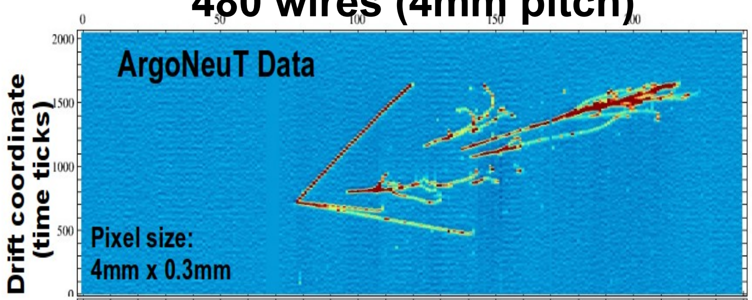
2d/3d event reconstruction



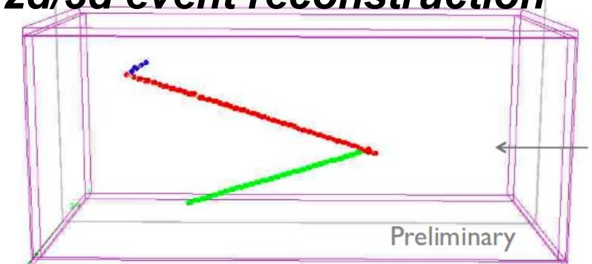
ArgoNeuT @ NuMI
First LArTPC in the U.S.



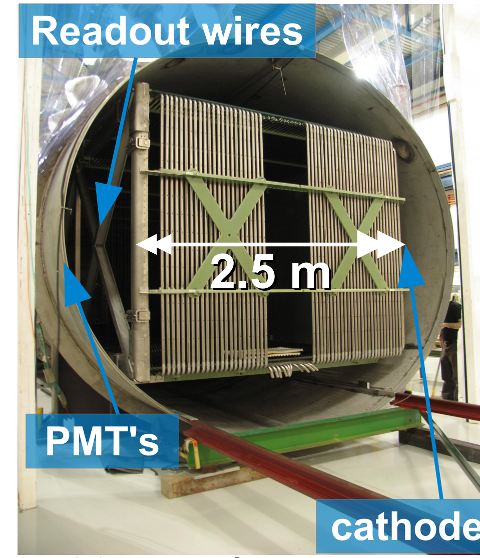
0.26 Tons (active mass)
0.47 meter drift
480 wires (4mm pitch)



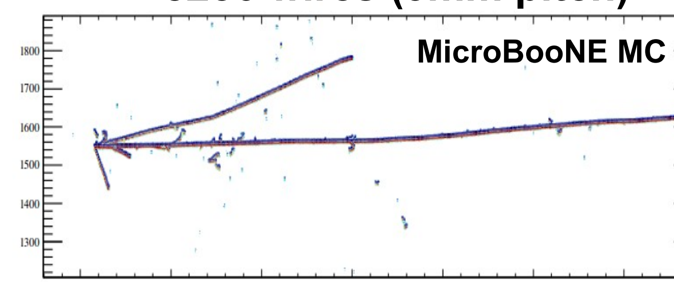
2d/3d event reconstruction



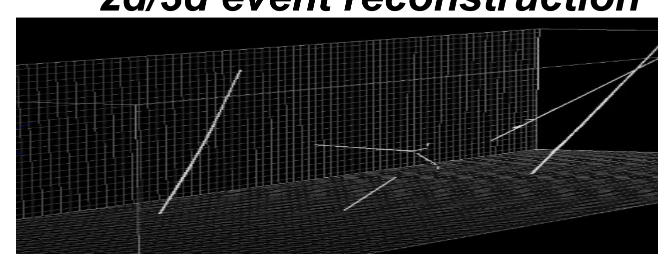
MicroBooNE @ BNB
First Large LArTPC in the U.S.



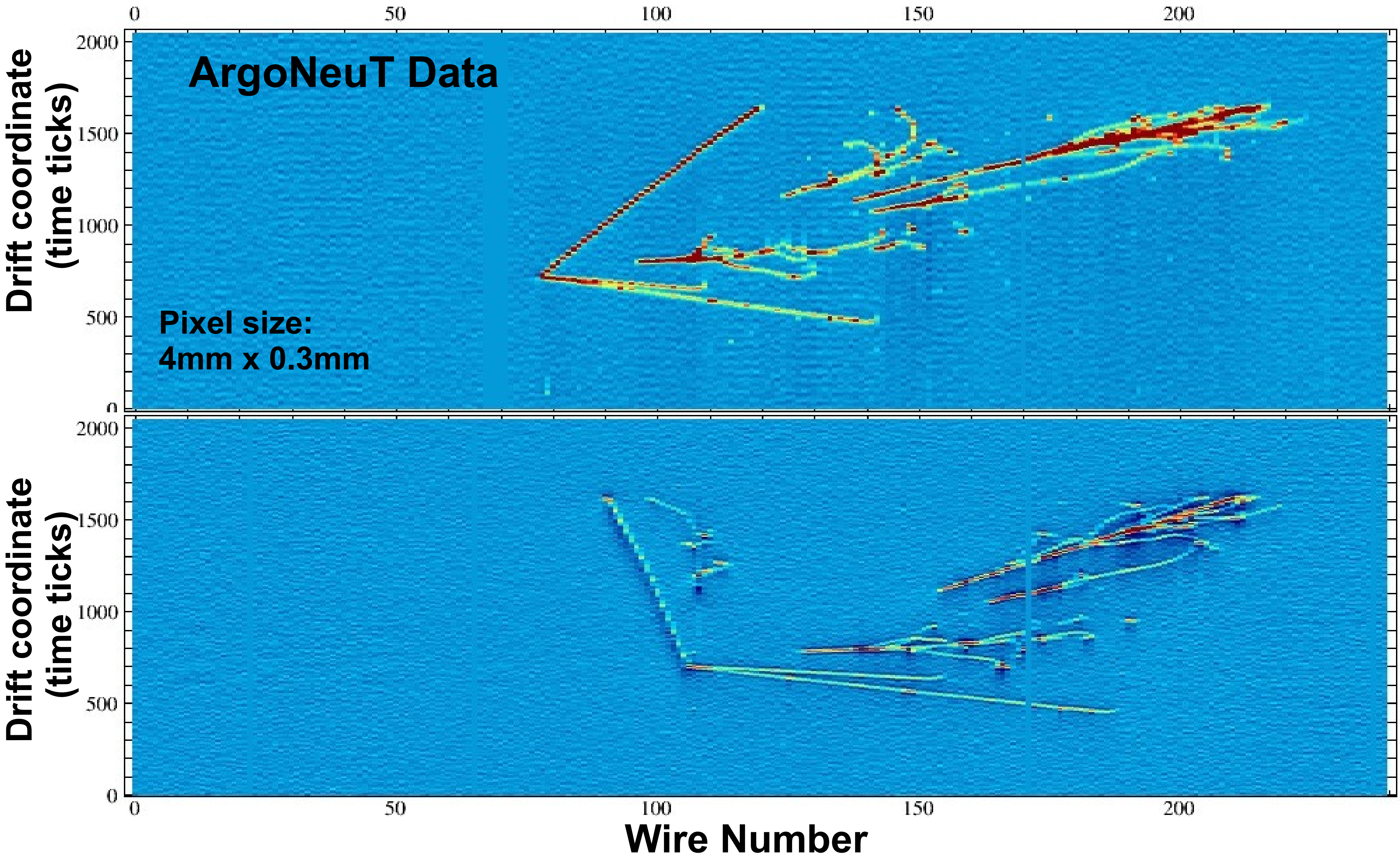
80 tons (active mass)
2.5 meter drift
8256 wires (3mm pitch)



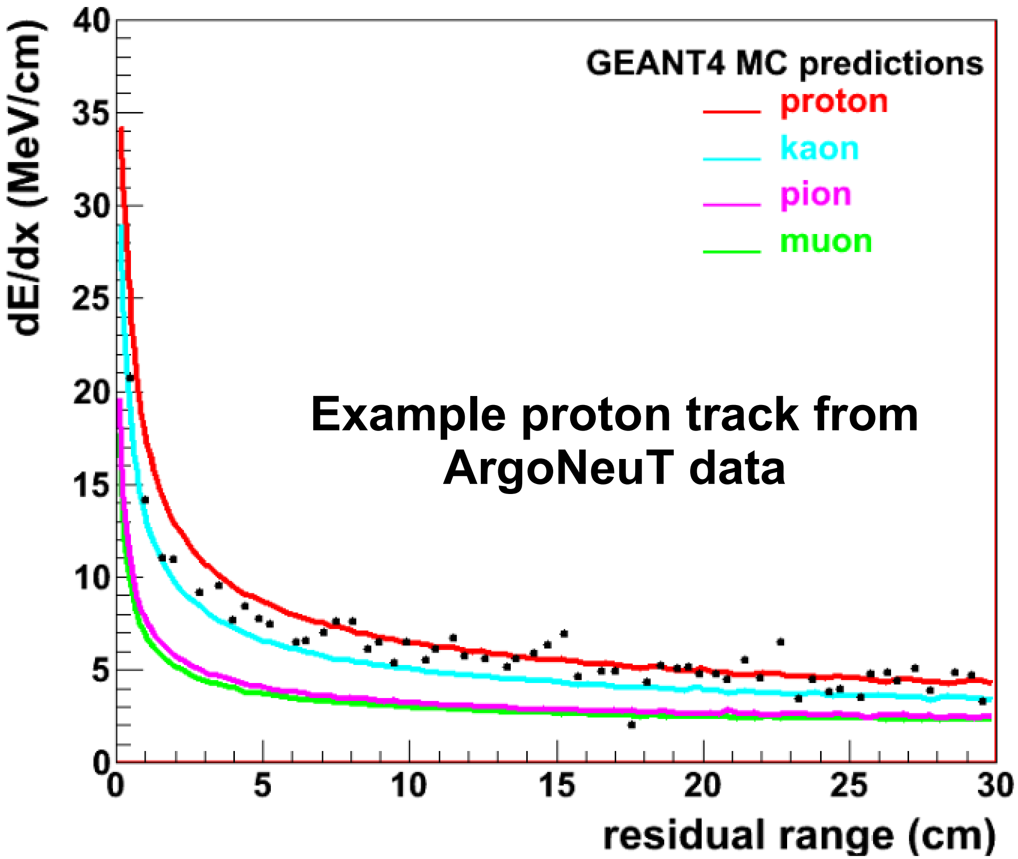
2d/3d event reconstruction

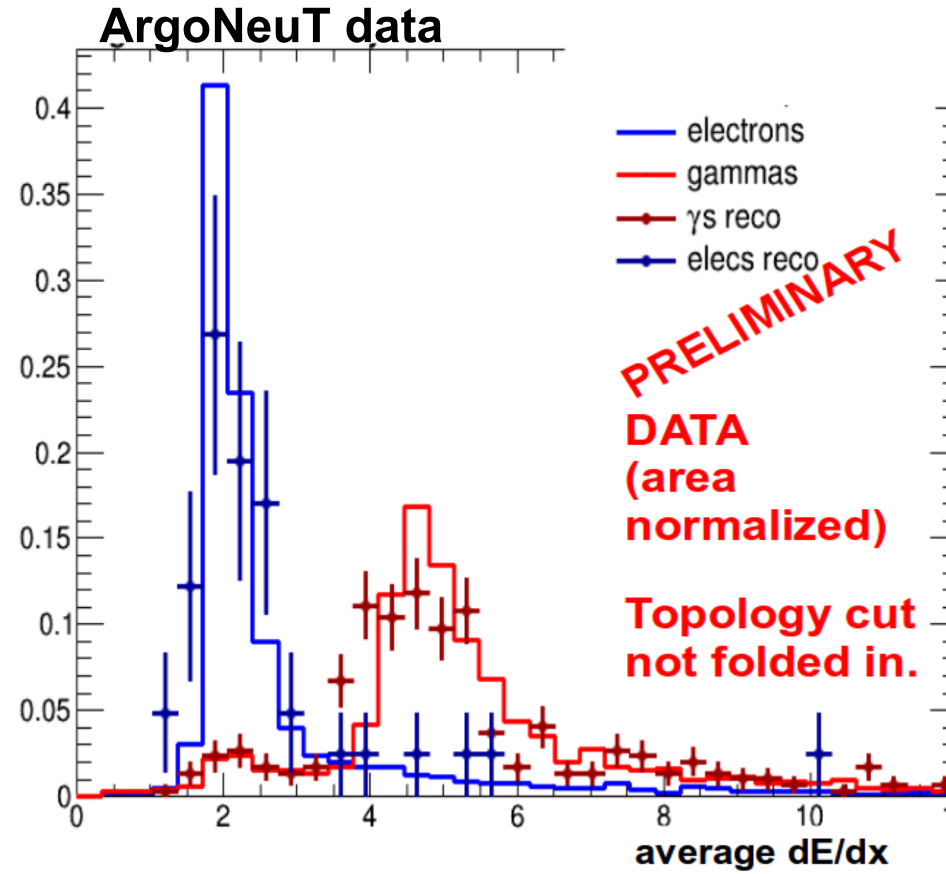


Liquid Argon Time Projection Chamber



Liquid Argon Time Projection Chamber

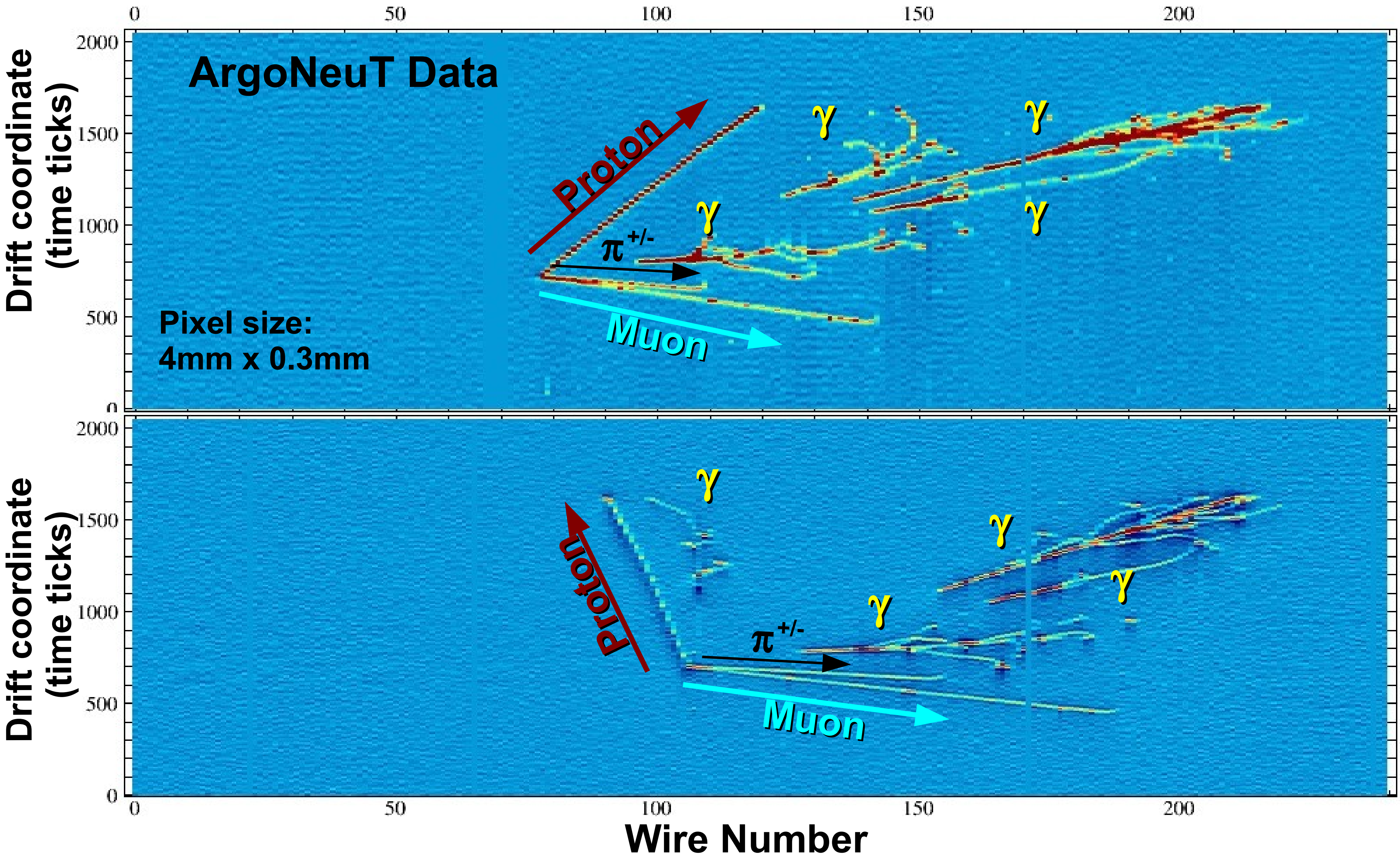




By analyzing the energy deposited along the track (dE/dX) as a function of distance along the track (range) you can perform particle identification (PID)

Analyzing the dE/dX for the start of an electromagnetic shower you can identify and separate photons from electrons

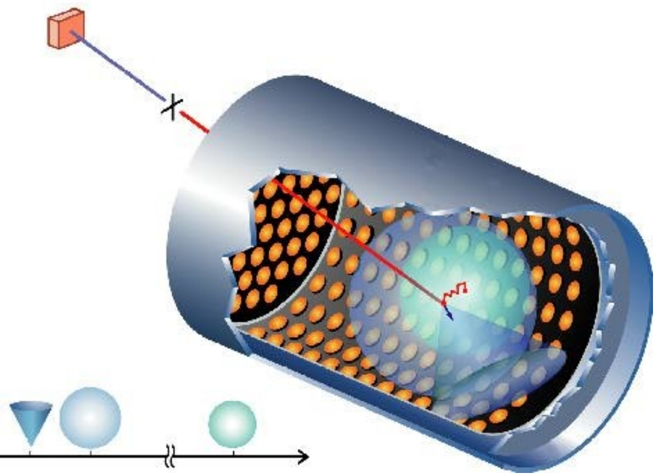
Liquid Argon Time Projection Chamber



Motivation for MicroBooNE

Driving ν (new) physics

MicroBooNE: Physics Motivation



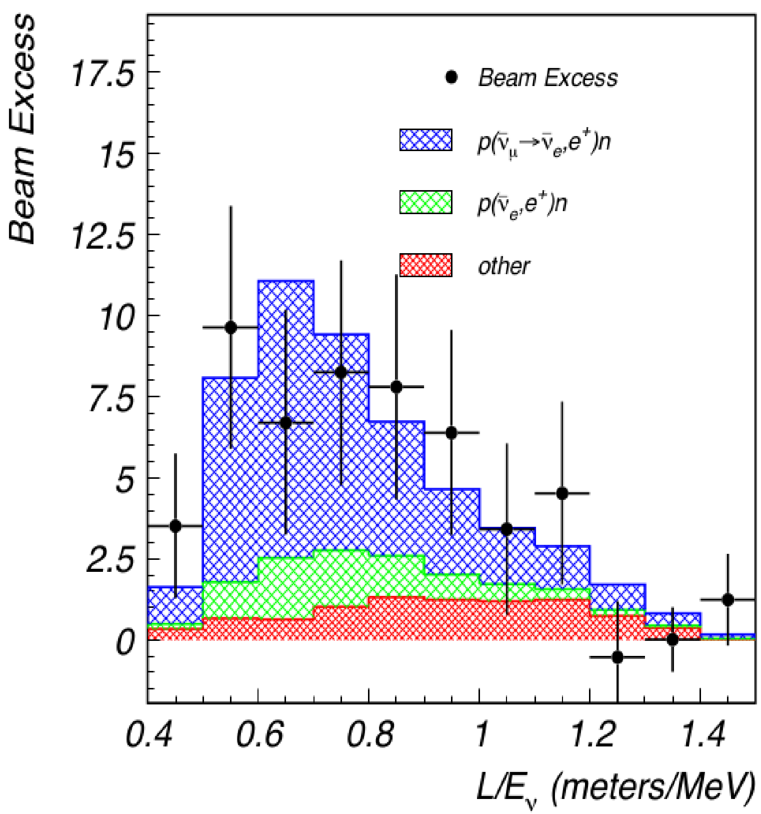
Liquid Scintillator Neutrino Detector (LSND) observes an excess of events (3.8σ above background) in $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ appearance search

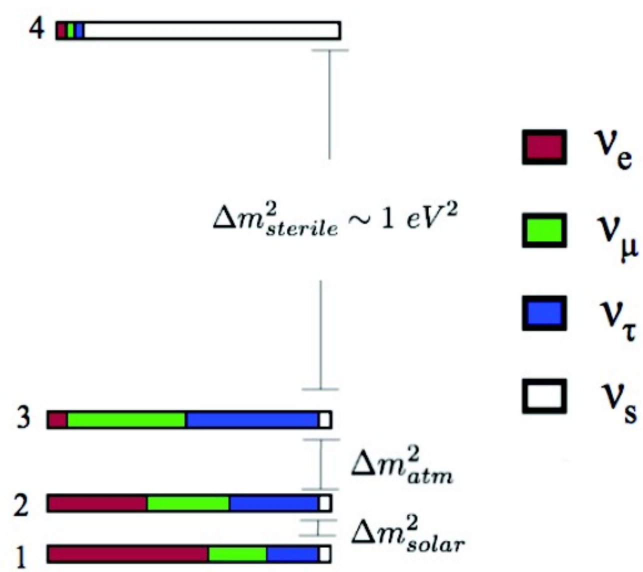
→ Much disputed result....

→ Could be evidence for new Physics? (Sterile Neutrinos)

→ Experimental setup defined L/E (this determines your oscillation probability)

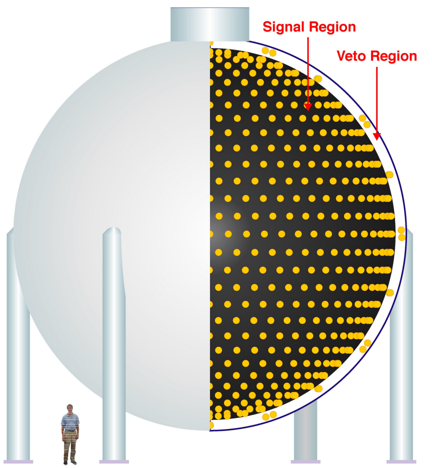
Phys. Rev. D64 112007 (2001)



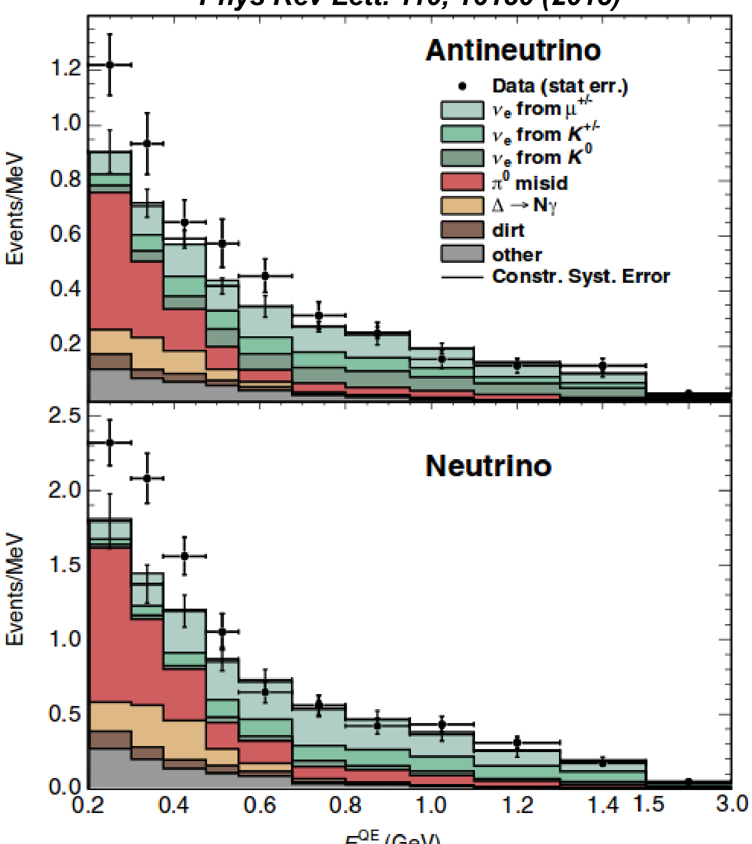


MicroBooNE: Physics Motivation

MiniBooNE Detector

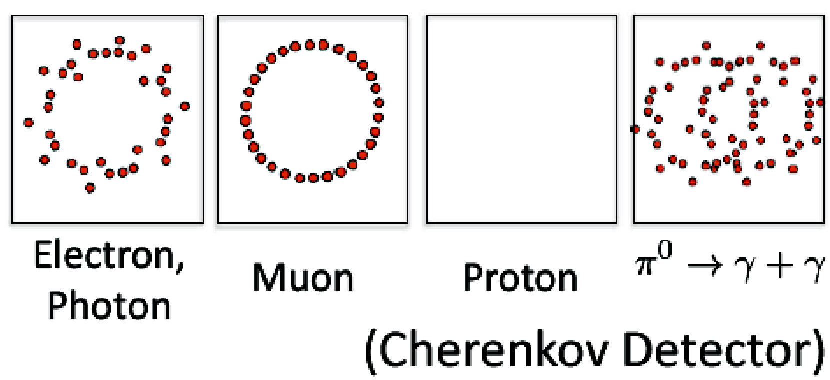


Phys Rev Lett. 110, 16180 (2013)



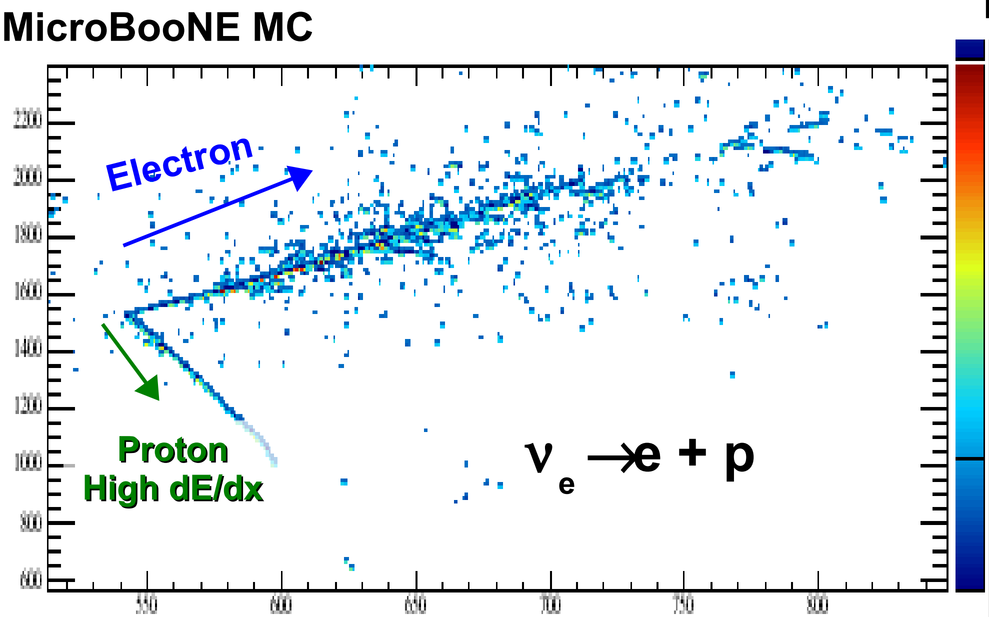
Mini-Booster Neutrino Experiment (MiniBooNE) at Fermilab ran at a similar L/E and saw a slightly different excess in $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ and $\nu_\mu \rightarrow \nu_e$ appearance search

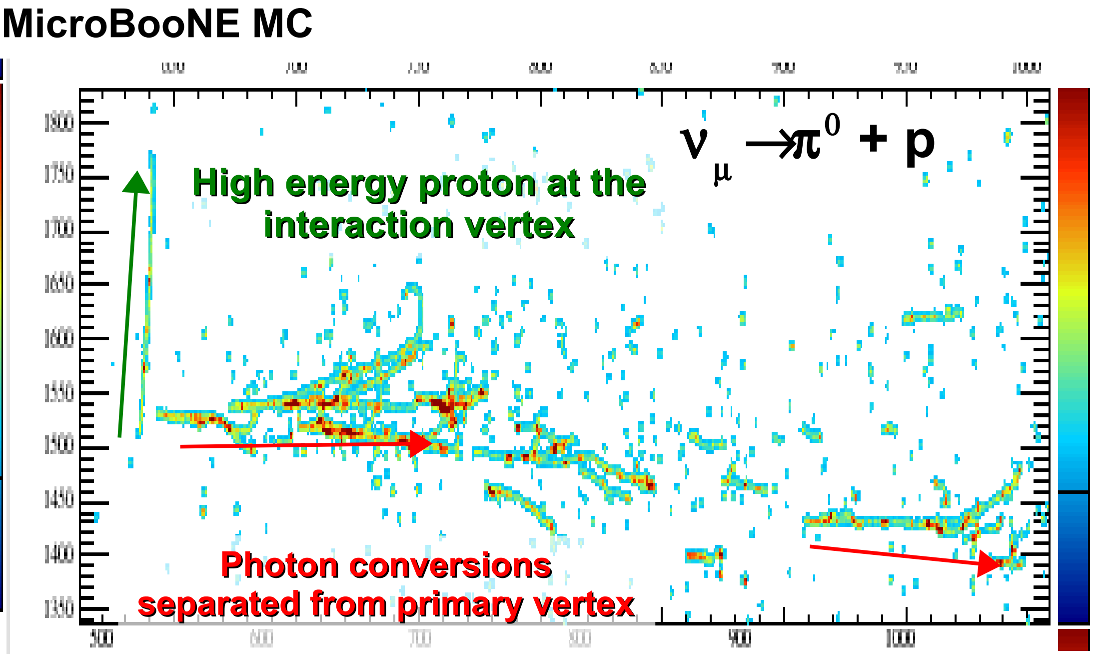
- **→ Effect dominates at low energy**
  - *Between 0.2 – 0.5 GeV*
- **→ Insidious backgrounds dominate**
  - → Can be *tough to distinguish $\pi^0 \rightarrow \gamma\gamma$ from e^- signature in a cherenkov detector*

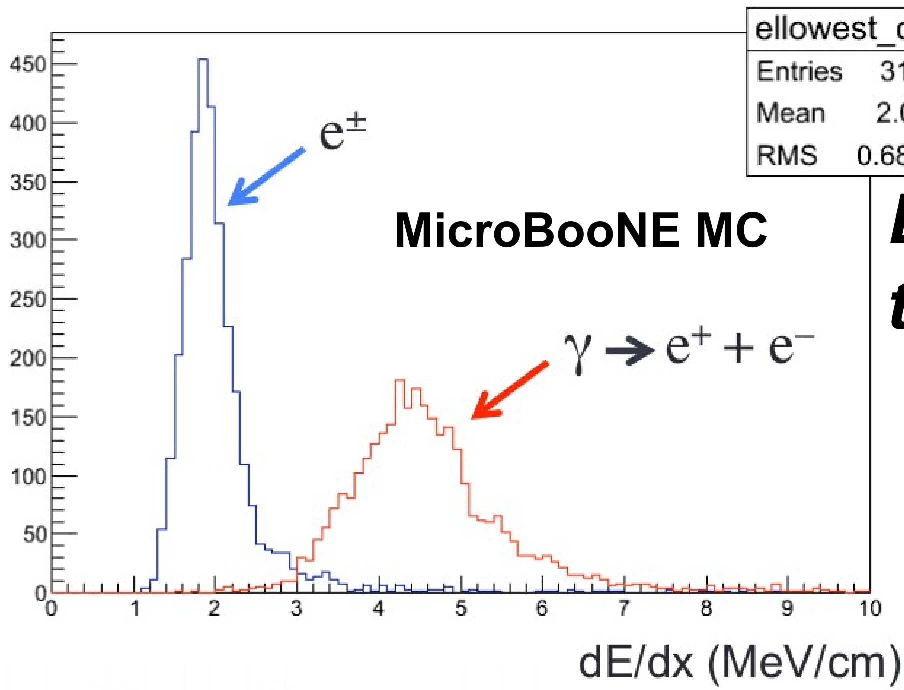


e/γ seperation is a specialty of LAr detectors!

MicroBooNE: Physics Motivation

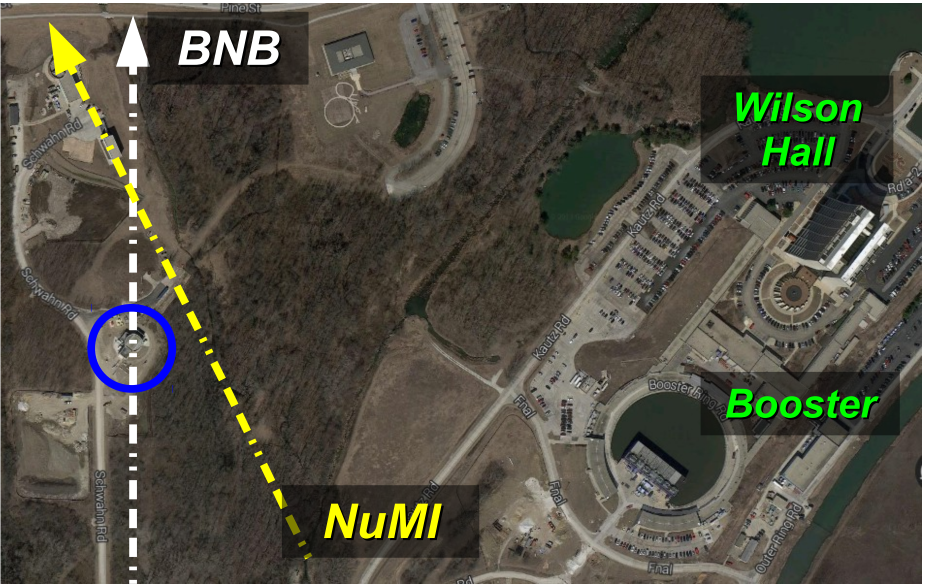






Liquid Argon TPC's offer the ability to distinguish background ($\pi^0 \rightarrow \gamma\gamma$) from signal ($\nu_e$ appearance) and address both of these anomalies

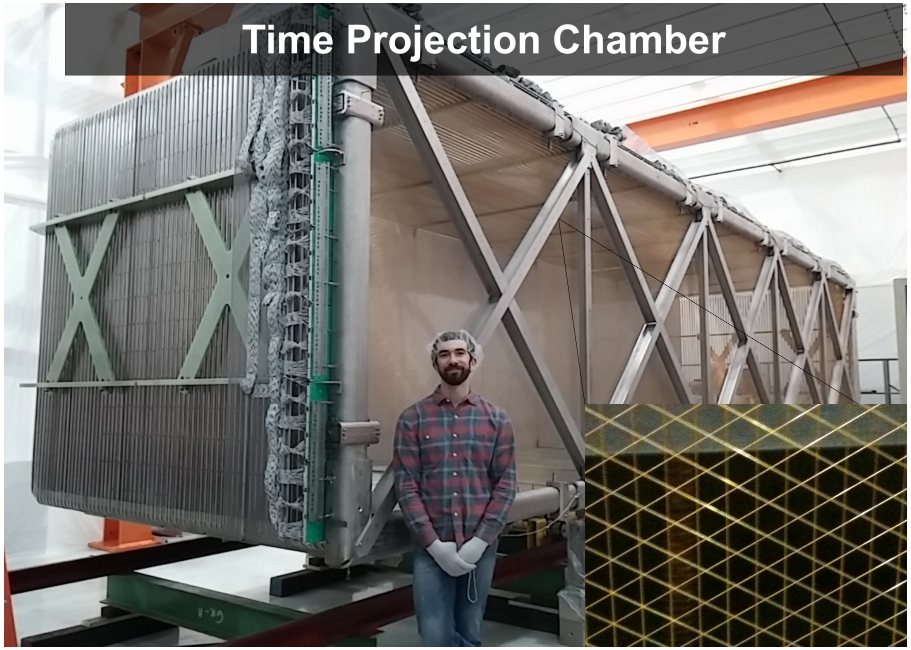
MicroBooNE: Overview

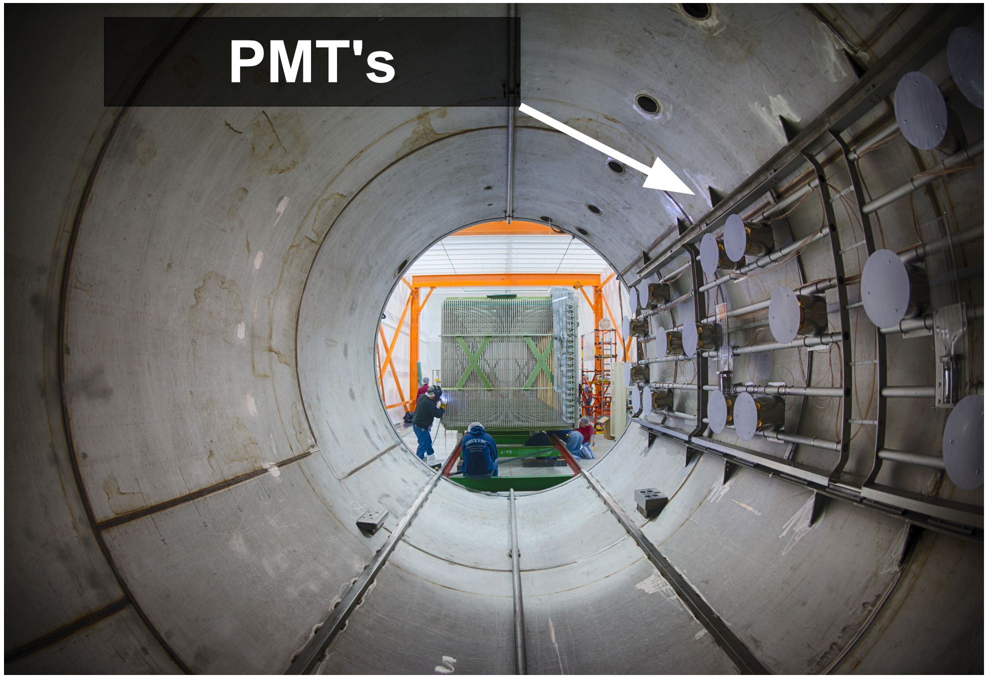


- **MicroBooNE is located at Fermilab's Liquid Argon Test Facility (LArTF)**
  - Will see the on-axis Booster Neutrino Beam (BNB)
    - **Nearly identical baseline as the MiniBooNE experiment**
    - Booster beam is created from 8 GeV protons on a beryllium target
      - Mean neutrino energy → < 1 GeV
  - Will also see off-axis Neutrinos from the Main Injector (NuMI) beam
    - **Provides an important cross-check**
    - NuMI beam created from 120 GeV protons on a carbon target
      - Mean neutrino energy → ~ 2-20 GeV
  - MicroBooNE will see both low and high energy neutrino interactions in the same detector

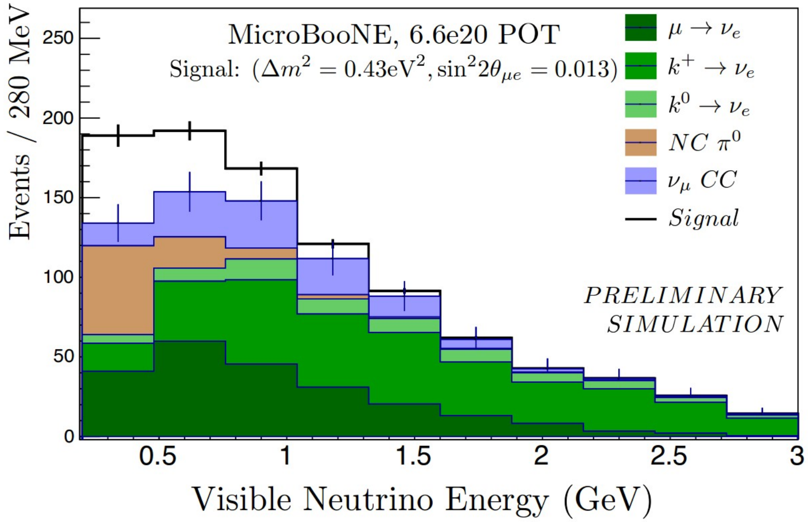
MicroBooNE: Overview

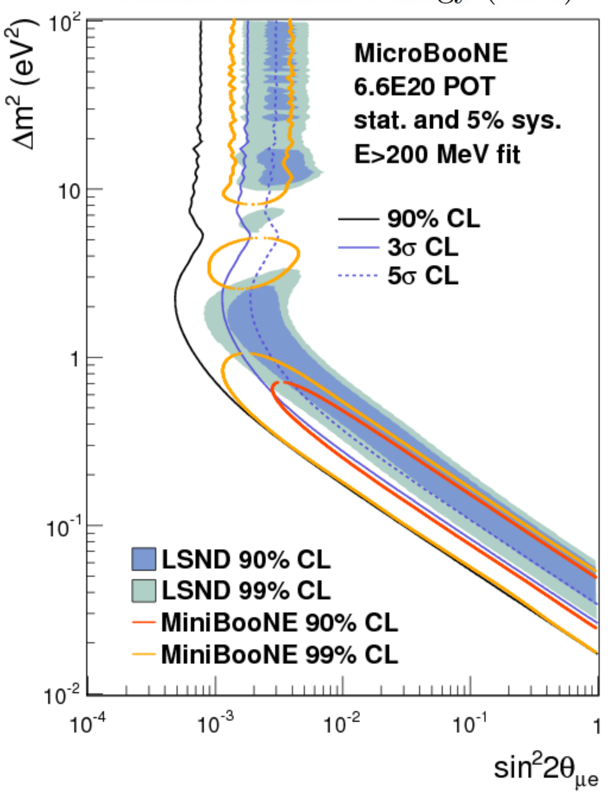
- **MicroBooNE is a 170 ton (total volume) LArTPC**
- **TPC Dimensions:**
  - 10.3 m long x 2.3 m tall x 2.5 m wide (drift distance)
  - 80 ton active mass
- **8256 wire channels**
  - 3456 Collection channels
    - Wires oriented w.r.t. the vertical
  - 4800 Induction channels
    - Wires oriented +/- 60^0
- **32 8" cryogenic PMT's**
  - Provides event t_0 as well as cosmic ray removal
- **UV Laser Calibration System**





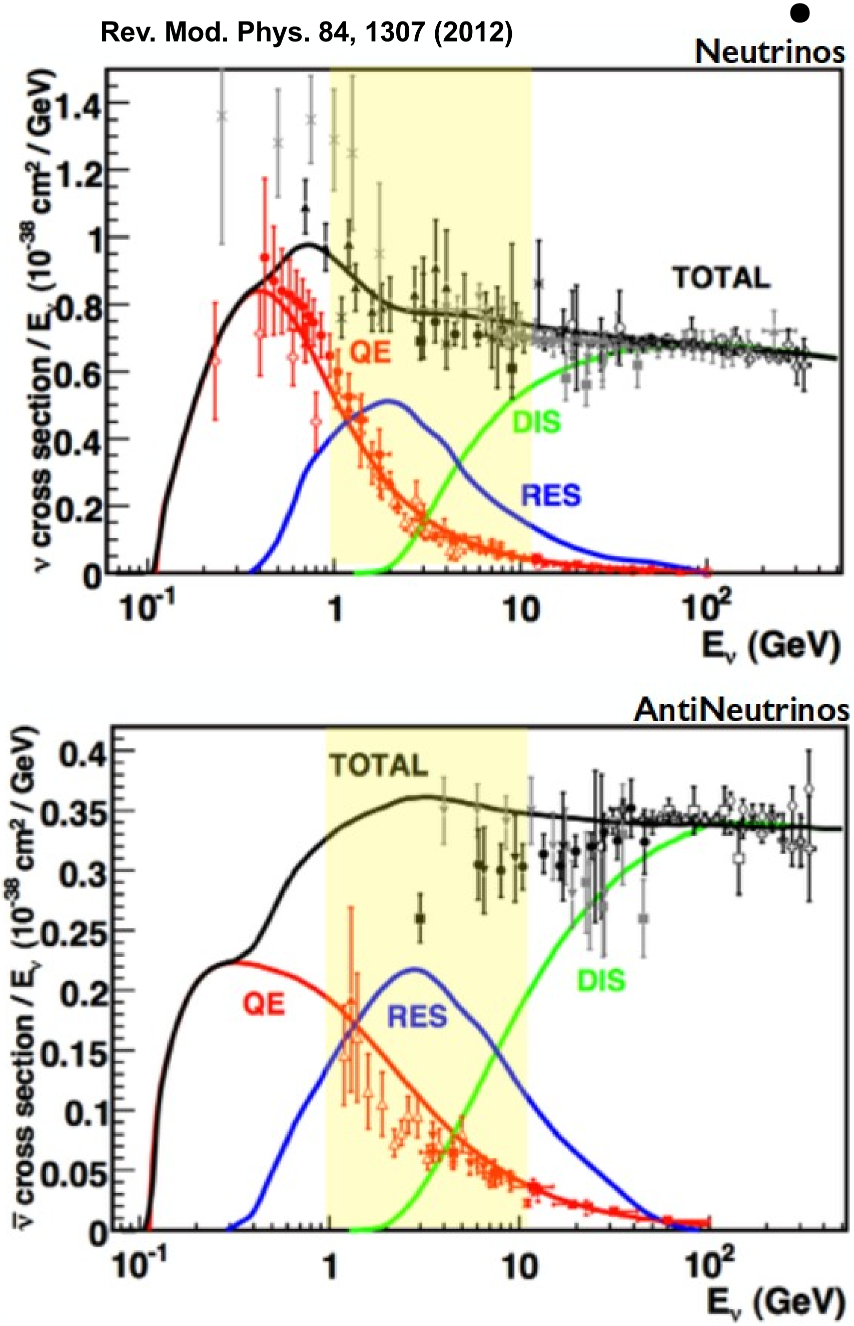
MicroBooNE: Physics Goals





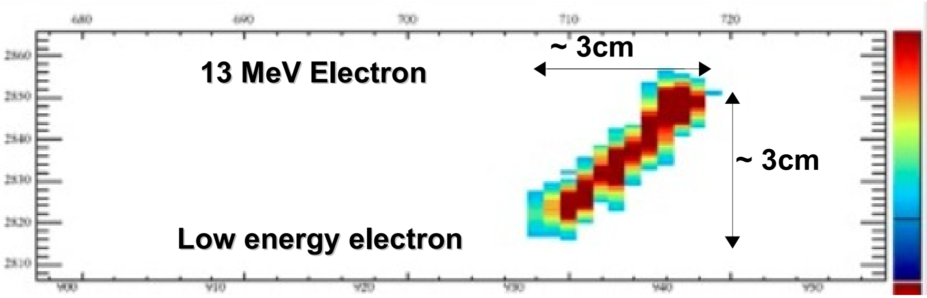
- **Oscillation Physics**
  - **MicroBooNE will directly address the low-energy excess of MiniBooNE**
    - Utilize its e/γ separation to determine if the signal is photon-like or electron like
  - **Regardless of if it is electron or photon like there is interesting physics to uncover!**
    - If it is electron-like than this is a compelling clue towards an oscillation signature
    - If it is photon like than there is a process that we are not including in our models
  - **MicroBooNE will ultimately weigh in on the LSND and MiniBooNE allowed regions**
    - *Assuming 60 tons fiducial volume, 80% reconstruction efficiency (assumed flat in energy), 3% sqrt{E} electromagnetic shower energy resolution, and statistical errors and 5% flat systematic uncertainty*

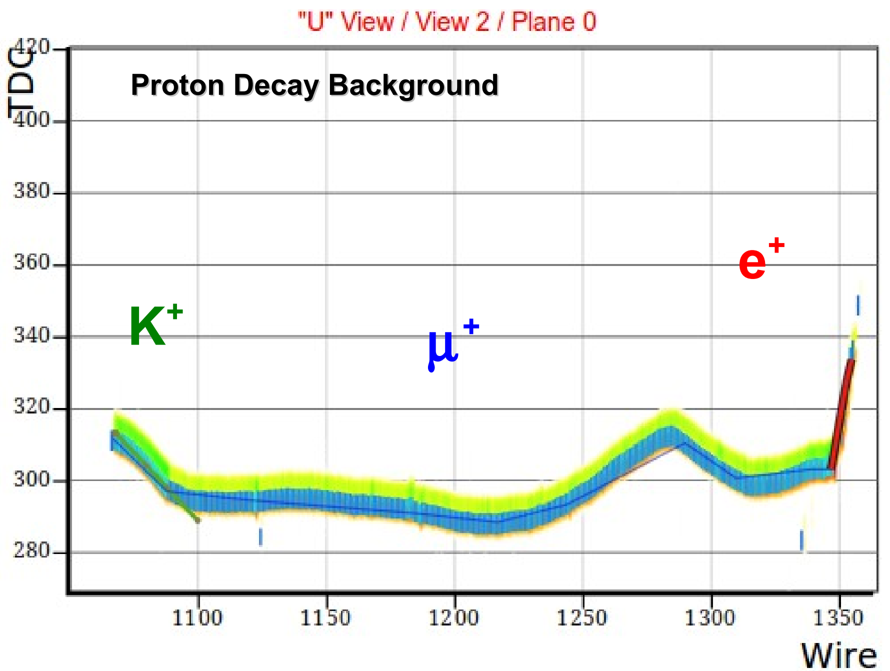
MicroBooNE: Physics Goals

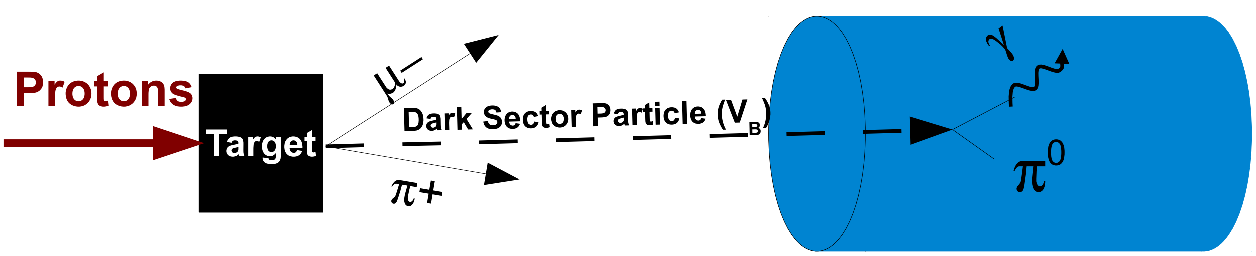


- **Cross-section physics**
  - The use of broad band beams in future long baseline experiments necessitates understanding the cross-sections over a wide range of energies
    - *Neutrino experiments that will search for CP-violation are operating in an energy-regime where several competing processes are active*
    - *MicroBooNE will be able to provide powerful insight*
  - Nuclear models of final state interactions (FSI) complicate the picture of the observed interaction
    - *LAr technology allows you to fully reconstruct the final state topology and understand FSI effects*
  - Understanding low energy cross-sections is crucial to many oscillation searches

MicroBooNE: Physics Motivation







Search for unique topologies

- **Astro/Particle & Exotica**
  - MicroBooNE will also provide a testing ground for many physics R&D subjects
    - **Supernova**
      - Low energy electron reconstruction
    - **Proton decay backgrounds**
      - Study Kaon decays as background to "golden" channel $p \rightarrow K^+ \nu_\mu$
    - **Searches for Beyond SM Signal's for Dark Matter**
      - Dark/Hidden Sector models for the production of Dark Matter at the neutrino targets may show up as unique topologies in MicroBooNE

MicroBooNE: Detector Physics



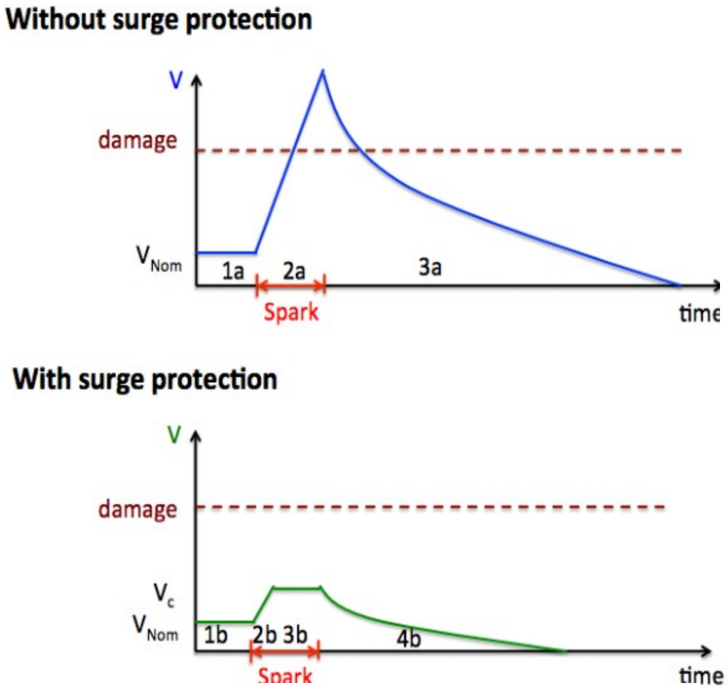
MicroBooNE has already started to contribute physics papers on the LArTPC detector technology

Related Publications by MicroBooNE Collaborators:

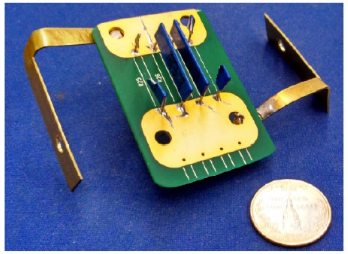
- L.F. Bagby *et al.*, "Breakdown Voltage of Metal Oxide Resistors in Liquid Argon", arXiv:1408.4013 [physics.ins-det]
- R. Acciarri *et al.*, "Liquid Argon Dielectric Breakdown Studies with the MicroBooNE Purification System", arXiv:1408.0264 [physics.ins-det]
- A. Ereditato *et al.*, "First Working Prototype of a Steerable UV Laser System for LAr TPC Calibrations", arXiv:1406.6400 [physics.ins-det]
- J. Asaadi *et al.*, "Testing of High Voltage Surge Protection Devices for Use in Liquid Argon TPC Detectors", arXiv:1406.5216 [physics.ins-det]
- M. Auger *et al.*, "A Method to Suppress Dielectric Breakdowns in Liquid Argon Ionization Detectors for Cathode to Ground Distances of Several Millimeters", arXiv:1406.3939 [physics-ins.det], JINST 9, P07023 (2014)
- A. Blatter *et al.*, "Experimental Study of Electric Breakdown in Liquid Argon at Centimeter Scale", arXiv:1401.6693 [physics.ins-det]
- T. Briese *et al.*, "Testing of Cryogenic Photomultiplier Tubes for the MicroBooNE Experiment", JINST 8, T07005 (2013)
- B.J.P. Jones *et al.*, "Photodegradation Mechanisms of Tetraphenyl Butadiene Coatings for Liquid Argon Detectors", JINST 8 P01013 (2013)
- B.J.P. Jones *et al.*, "A Measurement of the Absorption of Liquid Argon Scintillation Light by Dissolved Nitrogen at the Part-Per-Million Level", JINST 8 P07011 (2013)
- C.S. Chiu *et al.*, "Evironmental Effects on TPB Wavelength-Shifting Coatings", JINST 7, P07007 (2012)

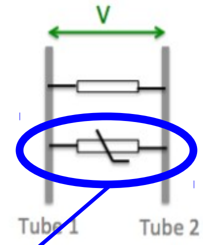
MicroBooNE: Detector Physics

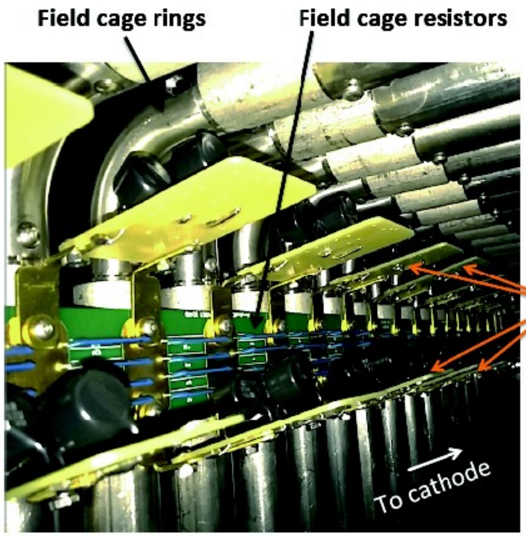
Use of Surge Arrestors to mitigate risk from high voltage breakdown



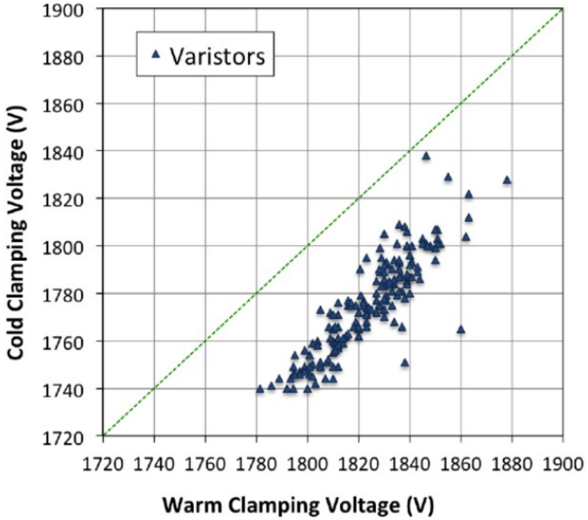
Typical failure mode:







Surge protection boards
(3 series varistors)



ArXiv:1406.5216 (Accepted by JINST August 2014)

Current Status


MicroBooNE TPC and Cryostat during installation


Cryostat being lowered into the detector hall

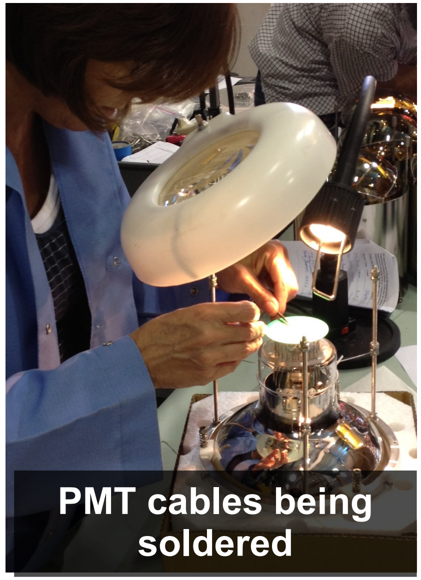
MICROBOONE

MicroBooNE is finishing construction now and will be operational in early 2015

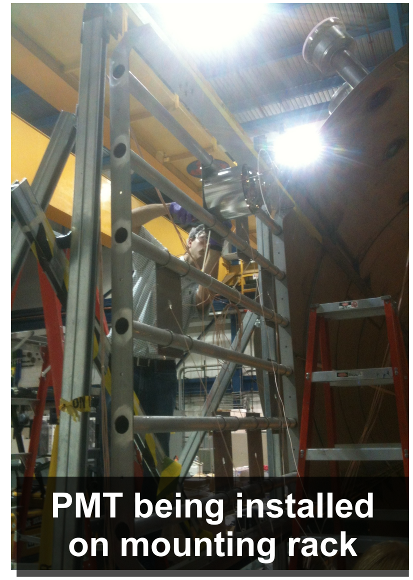
μB

Light Detection System

PMTs being prepared for installation

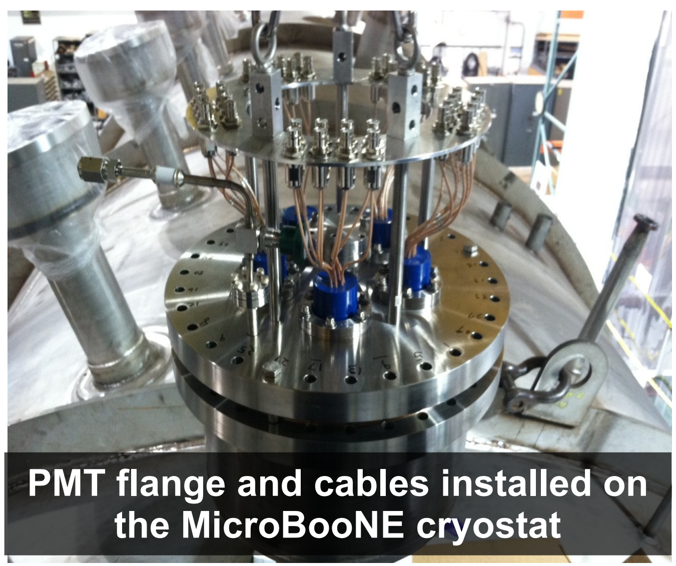


PMT cables being soldered



PMT being installed on mounting rack

The PMT Group



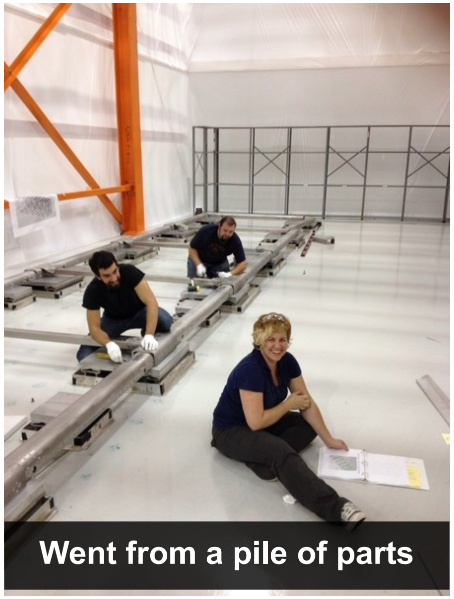
PMT flange and cables installed on the MicroBooNE cryostat

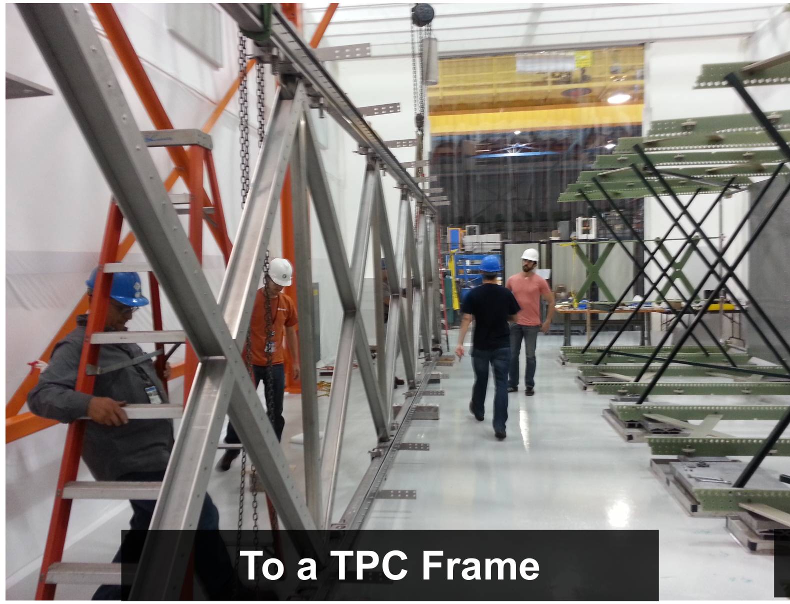
First rack installed

PMT's installed in MicroBooNE'a cryostat

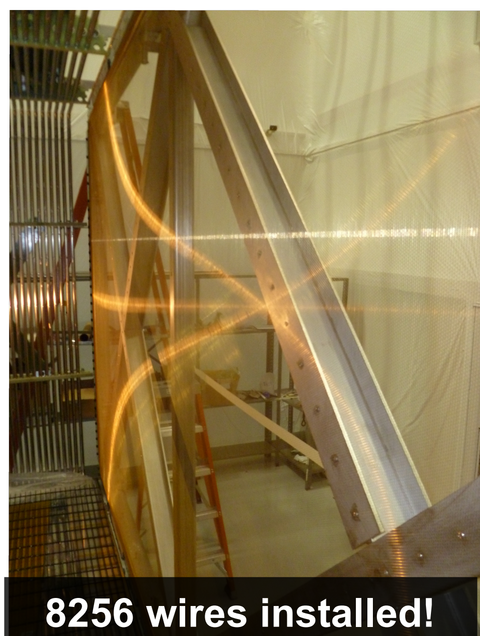
First complete subsystem installed in the cryostat!

Time Projection Chamber


Went from a pile of parts


To a TPC Frame


We then strung, installed and tensioned all the wires


8256 wires installed!


Completely instrumented TPC


Installed in the cryostat

Deploying MicroBooNE

Weld the end on

Load the detector onto a truck

Drive it across the lab

Pick it up

“Place” (we don't say drop) it in the detector hall

Cover it in foam

MicroBooNE as part of Fermilab's Future

Staged Multi-LArTPC Short-baseline Neutrino Program

Build on the existing infrastructure already present at Fermilab

Fully exploit the physics opportunity to address some of the important questions in neutrino physics

Build experience and perform detector R&D while working toward the long term goal the Long Baseline Neutrino Experiment

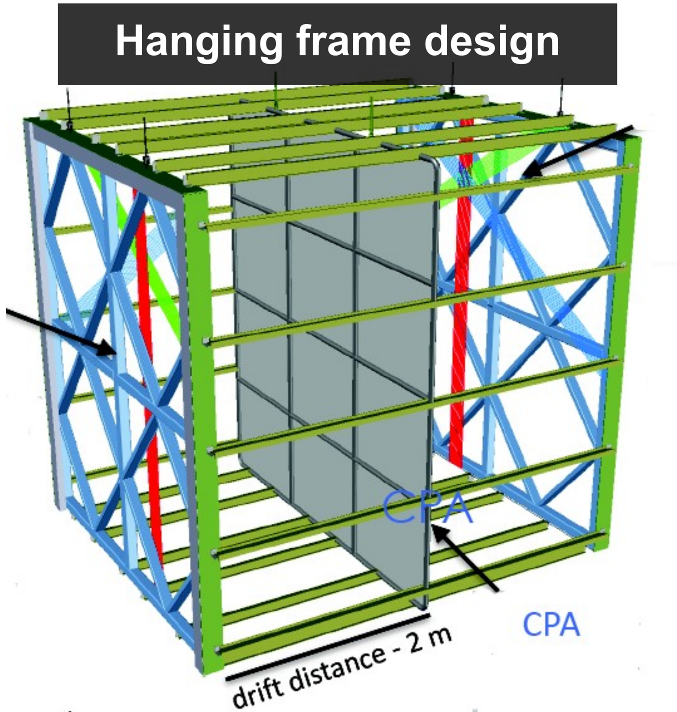
We are here

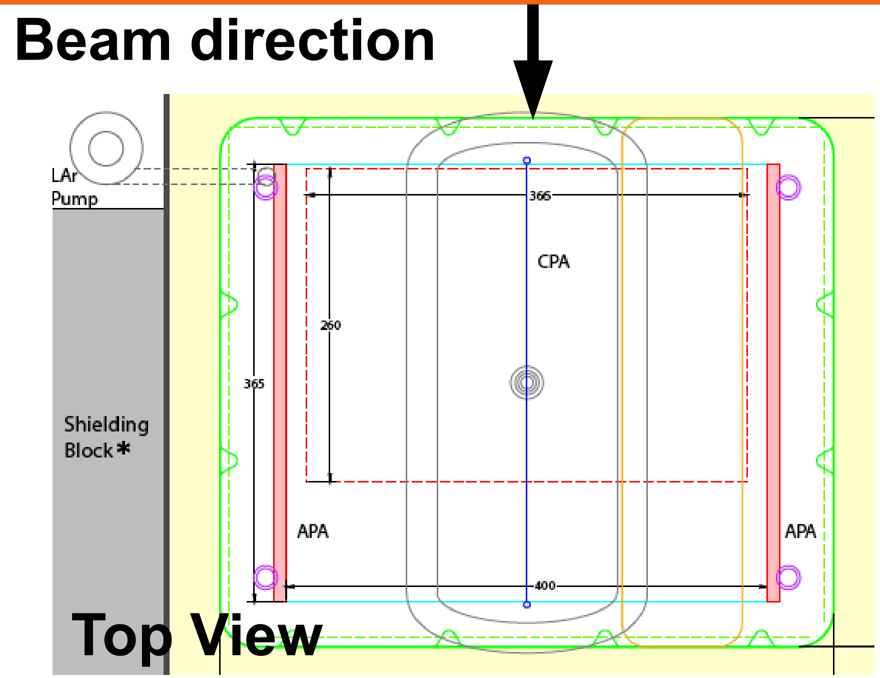
Phase 0: MicroBooNE
86 ton active volume TPC at length of 470m from the neutrino source

Phase 1: Near Detector
82 ton active volume TPC at length of 100m from the neutrino source

Phase 2: Far Detector
1000 ton active volume TPC at length of 700m from the neutrino source

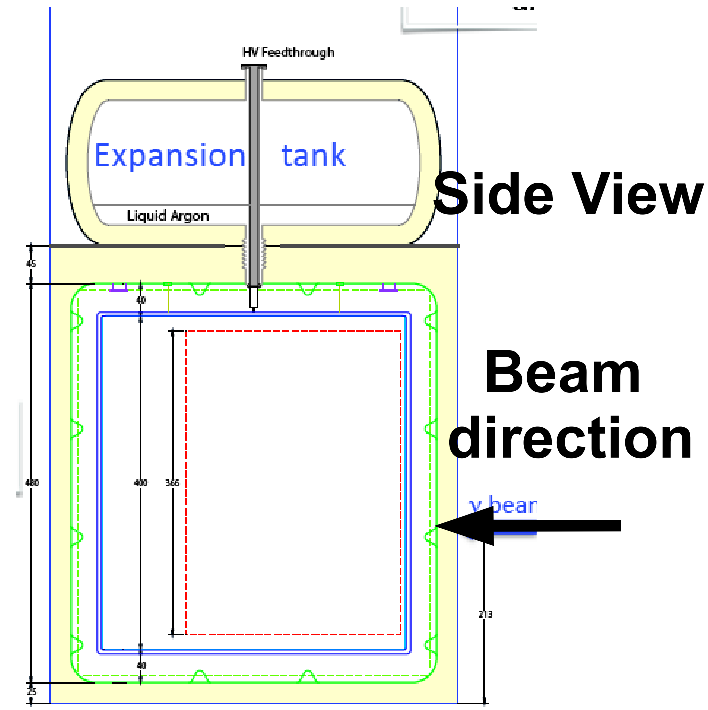
LAr1-Near Detector





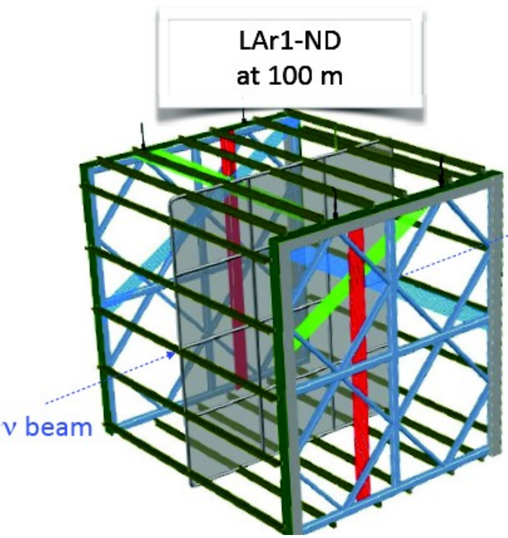
Run a 82 ton LArTPC detector near the existing SciBooNE hall ~100 meters from the target in conjunction with MicroBooNE

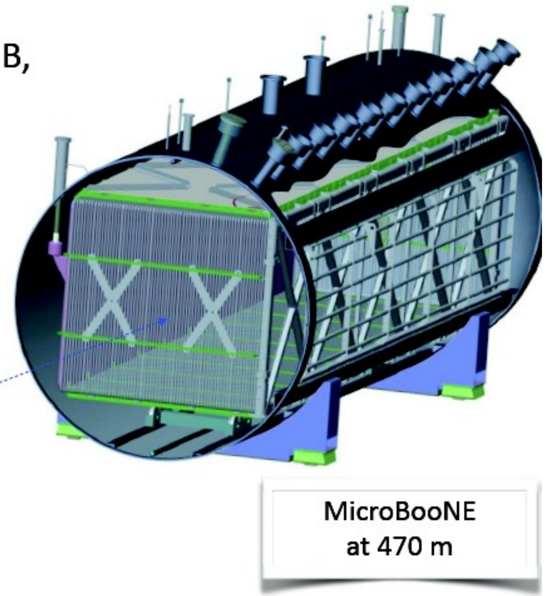
- → High statistics cross-sections
- → Near/Far configuration with LAr detectors
- → Utilize LBNE-like designs for TPC and Cryostat
- → Full electronics readout in the LAr

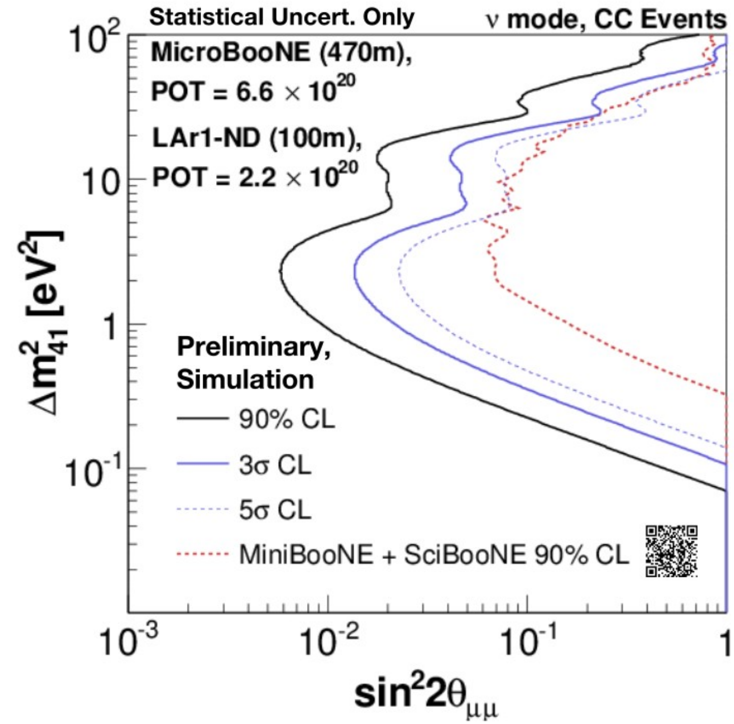


LAr1-Near Detector

A LArTPC Near Detector
(82 t active mass) in the SciBooNE hall,
to run in conjunction with MicroBooNE on the BNB,
for an exposure of 2.2×10^{20} POT
(in the last year of the MicroBooNE run)







Near detector opens up new physics not possible with MicroBooNE alone

- Improved sensitivity to MiniBooNE low energy excess
- ν_μ disappearance oscillation studies
- Neutral current disappearance
- Dark matter (axion) searches using beam off-target running

Conclusions

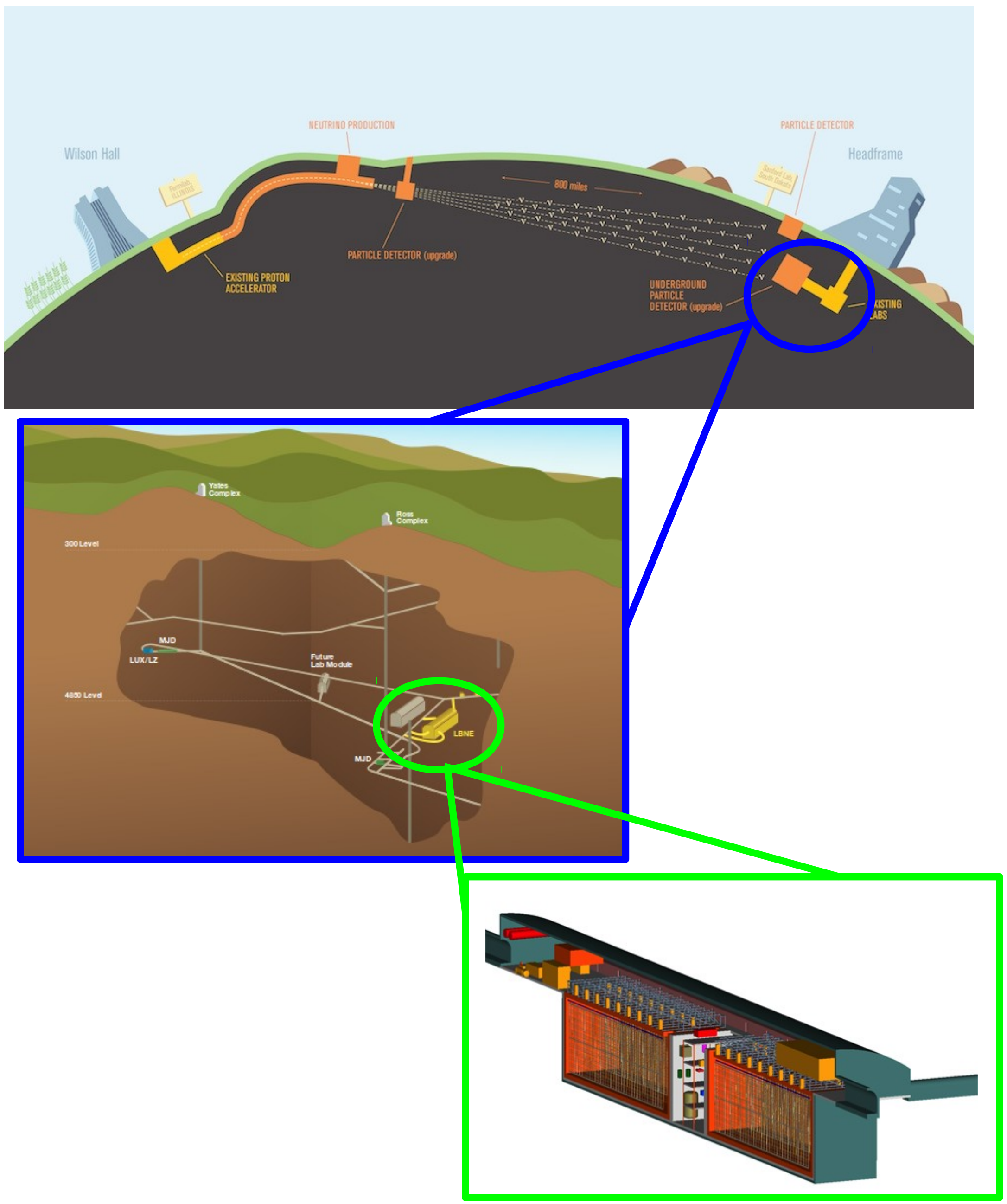
- LArTPC's are an exciting detector technology for use in precision neutrino physics measurements
- The MicroBooNE detector will address the LSND/MiniBooNE anomaly as well as push the envelope on the use of LArTPC's
- MicroBooNE is a center piece for the upcoming short-baseline neutrino program at Fermilab
- With the immanent turn on of MicroBooNE the coming months promise to be ***very exciting***

Thank you very much for your attention!

Back-up Slides

LBNE

Long Baseline Neutrino Experiment



- **Long Baseline Neutrino Experiment is the next major neutrino experiment proposed**
  - Build a large scale (34 kTon) LArTPC deep underground
  - Build it at a baseline that optimizes the oscillation parameters to probe CP violation and the mass hierarchy
  - Build it deep underground to maximize your sensitivity and allow you to do more physics
  - Shoot a powerful beam of neutrinos at it