Recent Results from ArgoNeuT and Status of MicroBooNE

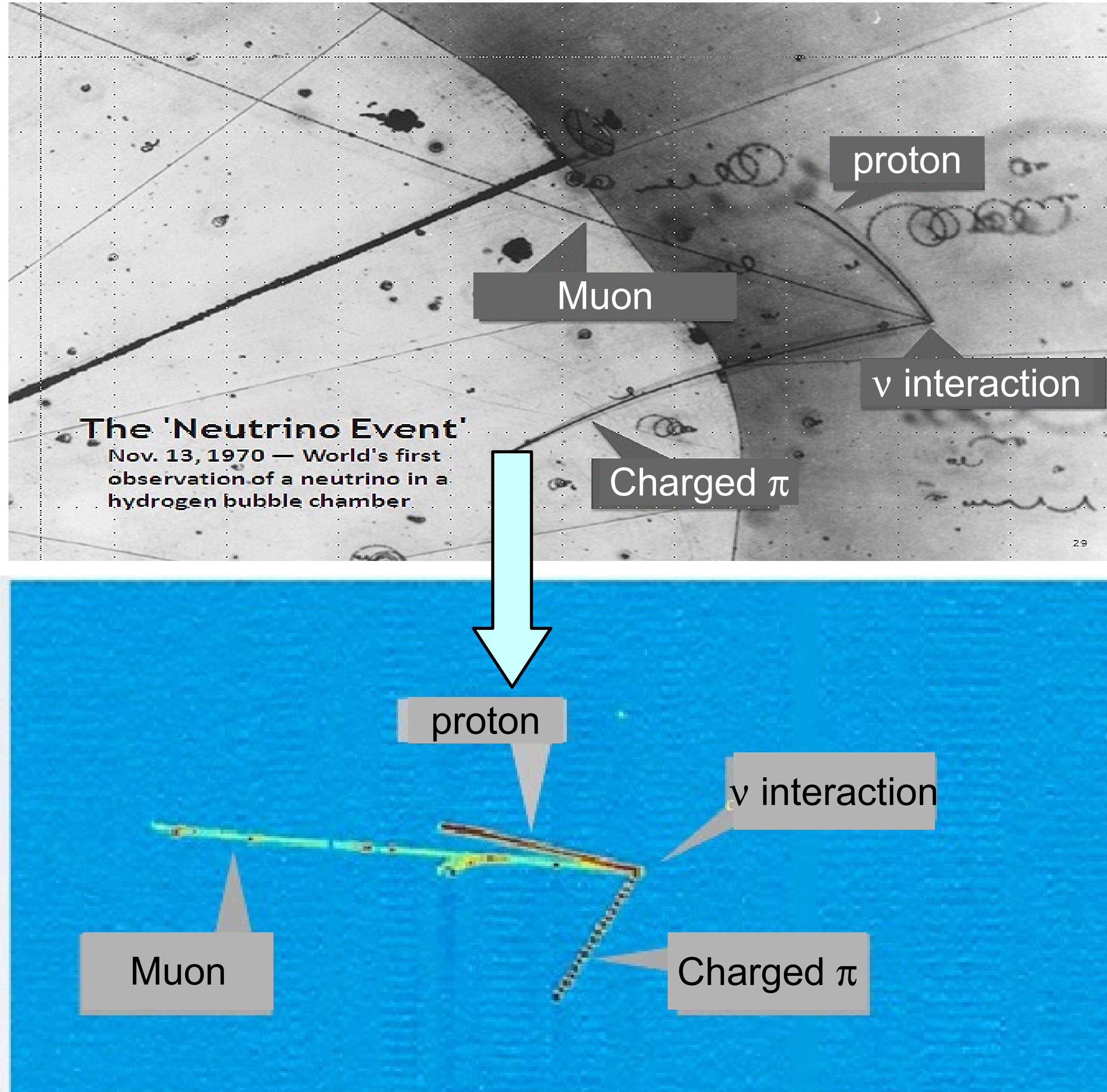
Andrzej Szelc

(on behalf of the ArgoNeuT and MicroBooNE collaborations)

Yale University

Why Liquid Argon?

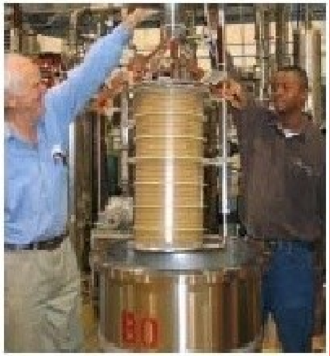
- Do I really need to explain in the home of liquid argon technology?
- Bubble chamber quality of data with added full calorimetry.
- Can produce physics results with a “table-top” size experiment:
  - Benchmark - “standard candle” results.
  - Physics enabled by LAr capabilities.
  - Development towards future large detectors.



US based LAr R&D program

Yale TPC


Location: Yale University
Active volume: 0.002 ton
operational: 2007

Bo


Location: Fermilab
Active volume: 0.02 ton
operational 2008

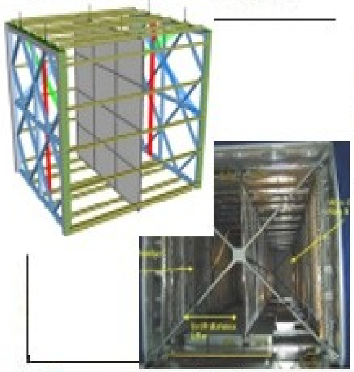
ArgoNeuT


Location: Fermilab
Active volume: 0.3 ton
operational: 2008
First neutrinos: June 2009

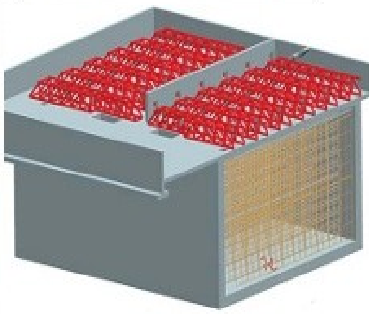
MicroBooNE


Location Fermilab
Active volume: 0.1 kton
Operational: 2014

This talk

SBN @ FNAL


Location: Fermilab
Active volume: 0.05 + 0.6 kton
Construction start: 2017

LBNE


Location: Homestake
Active volume: 35 kton
Construction start 202?

Luke

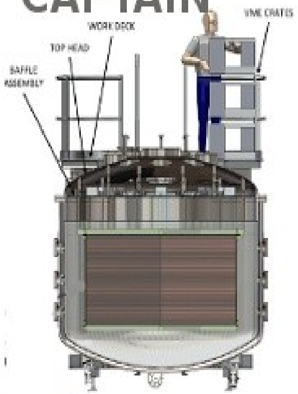

Location: Fermilab
Purpose: materials test st
Operational: since 2008

LAPD

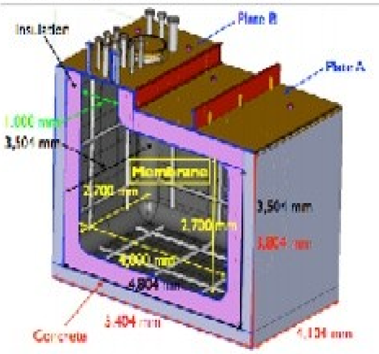

Location: Fermilab
Purpose: LAr purity demo
Operational: 2011

LArIAT


Location: Fermilab
Purpose: LArTPC calibration
Operational: 2014 (phase 1)

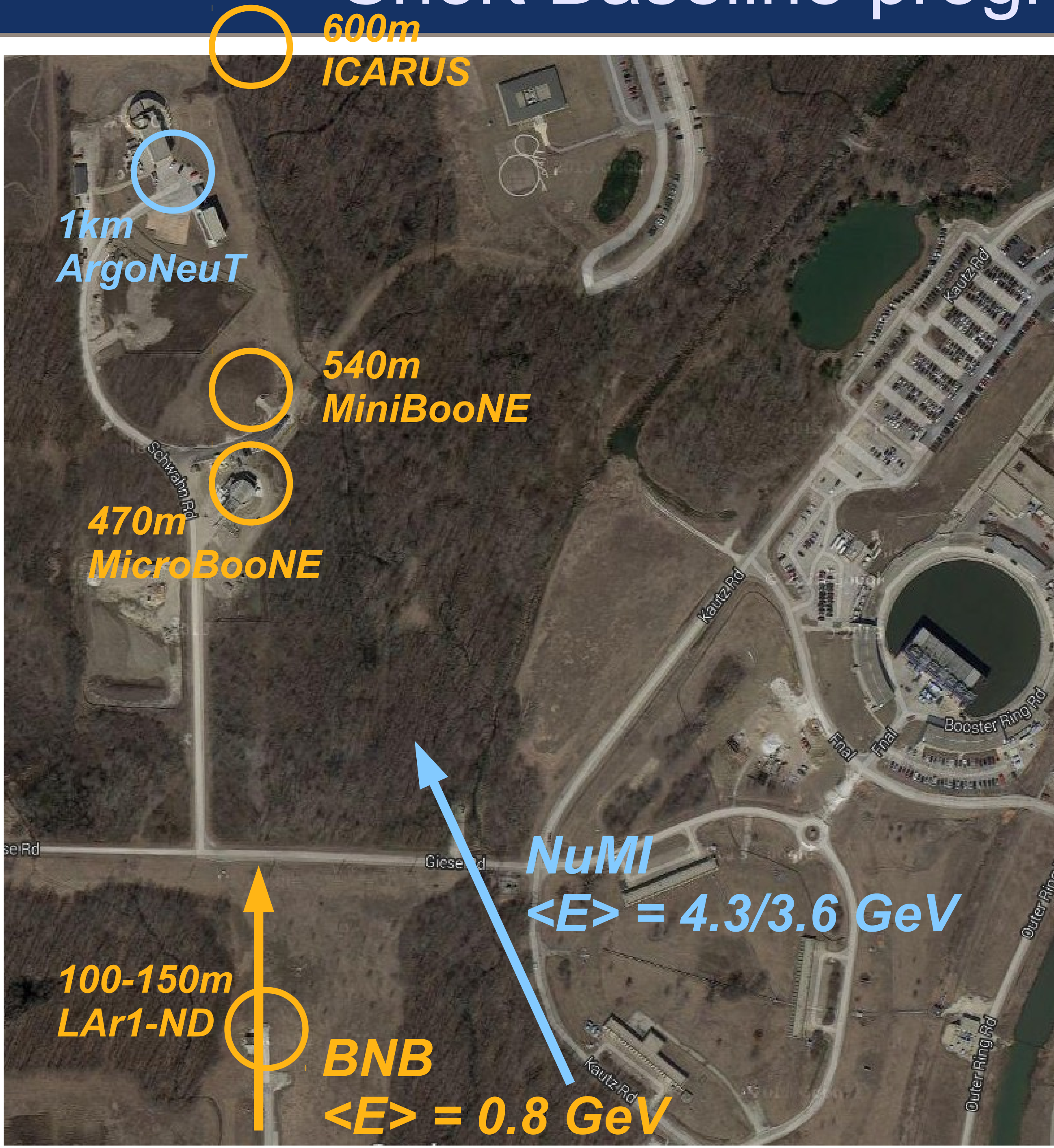
CAPTAIN


Location: LANL
Purpose: LArTPC calibration
Operational: 2014

LBNE 35 Ton


Location: Fermilab
Purpose: purity demo
Operational: 2013

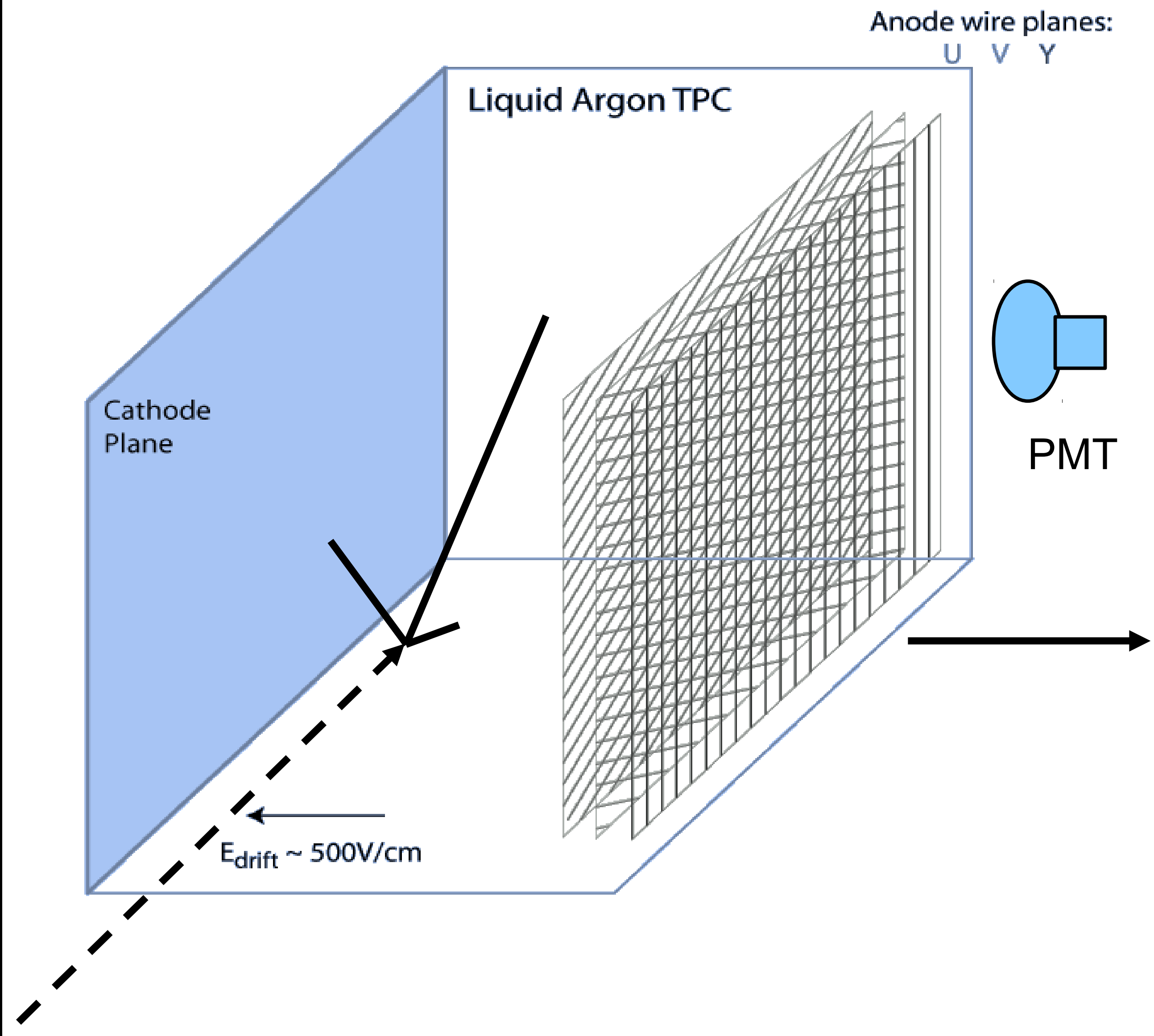
Short Baseline program at FNAL

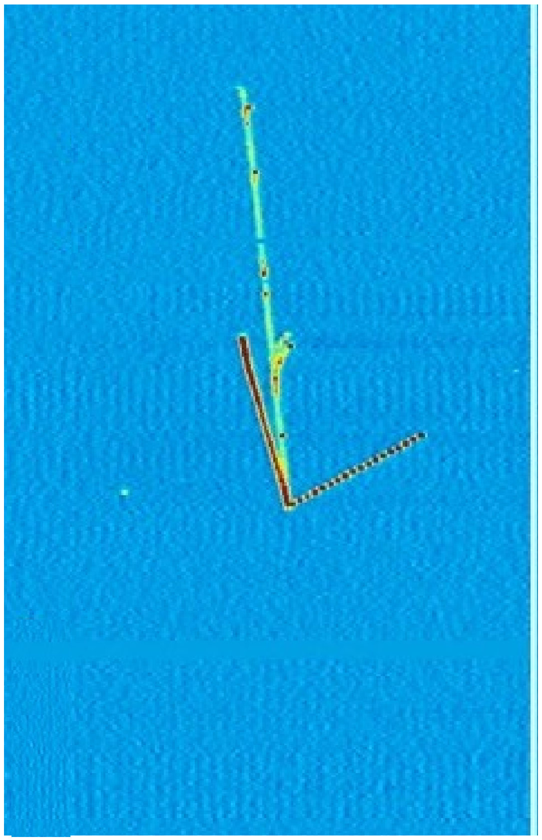


Exciting, precision physics at short baselines.

Develop the technology by putting the detectors in neutrino beams.

LArTPC Operation

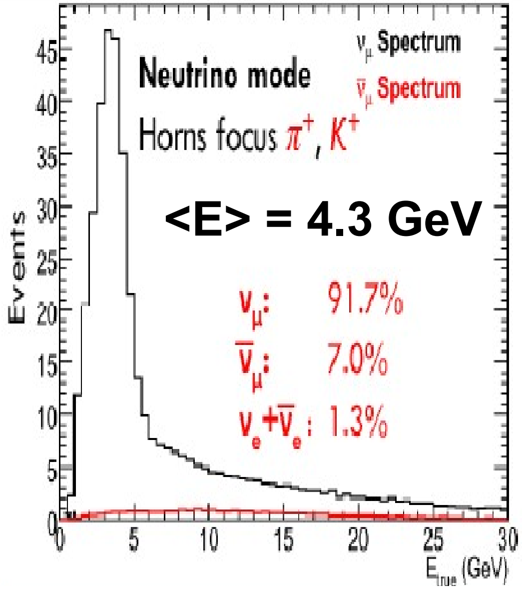


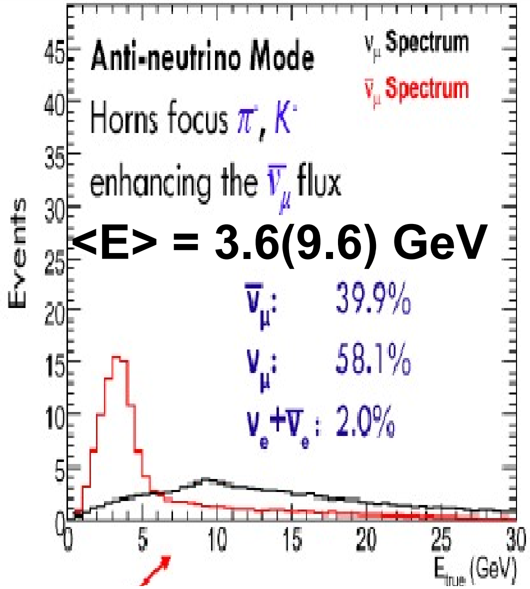


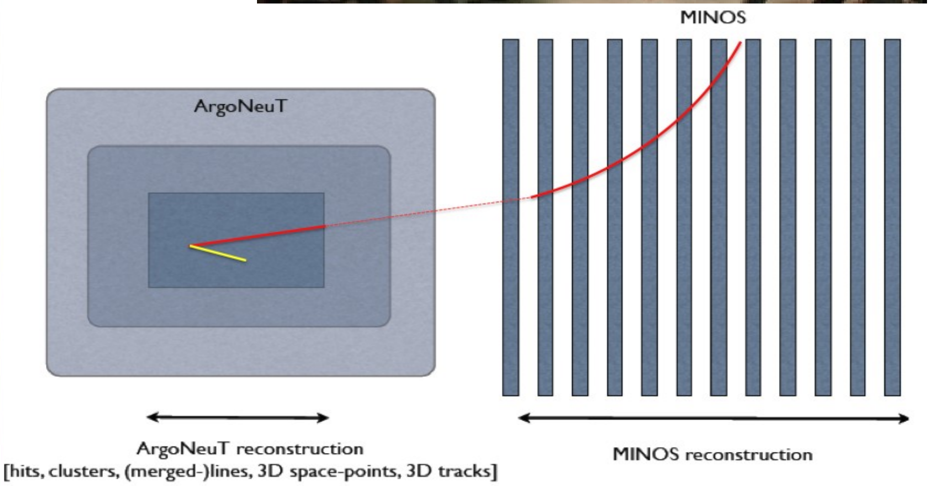
ArgoNeuT in the NuMI beam line

- First LArTPC in a low (1-10 GeV) energy neutrino beam.
- Acquired 1.35 × 10^{20} POT, mainly in $\bar{\nu}_\mu$ mode.
- Designed as a test experiment.
- But obtaining physics results!

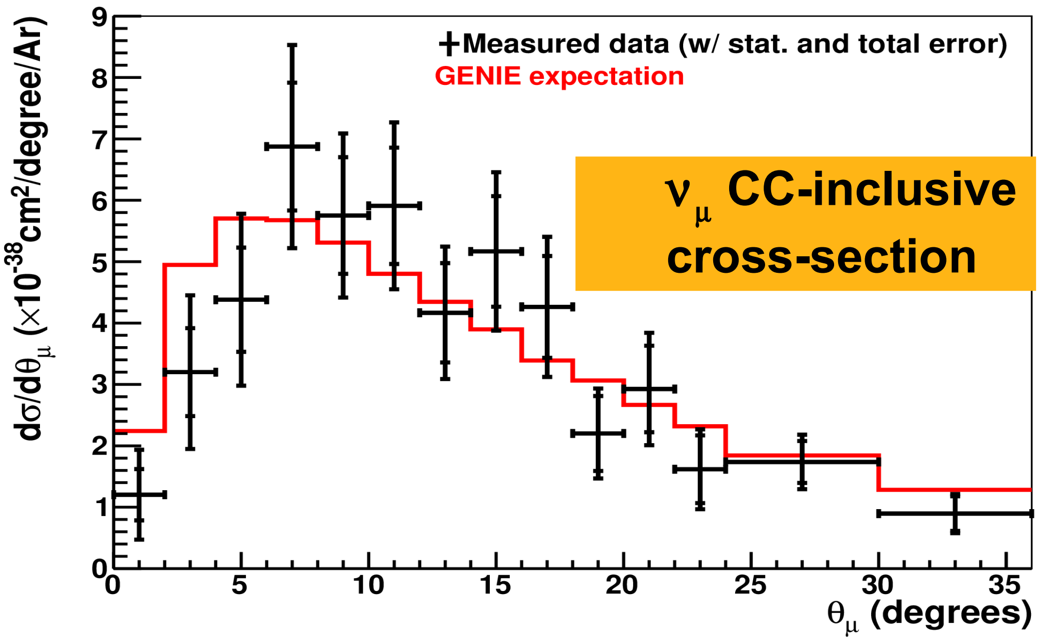
ArgoNeuT tech-paper: JINST 7 (2012) P10019





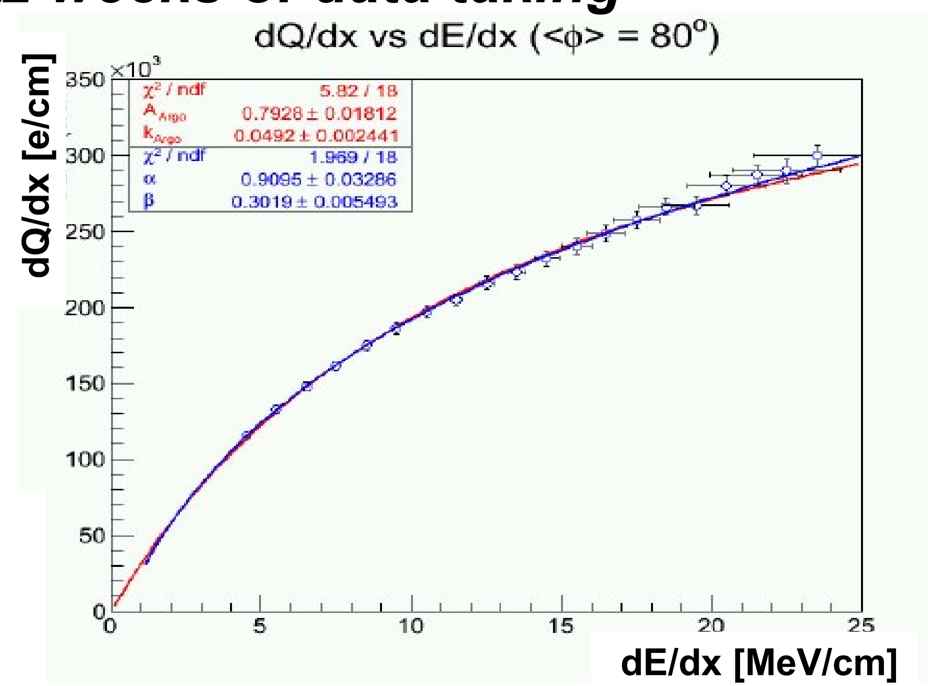


ν_μ Charged Current Inclusive



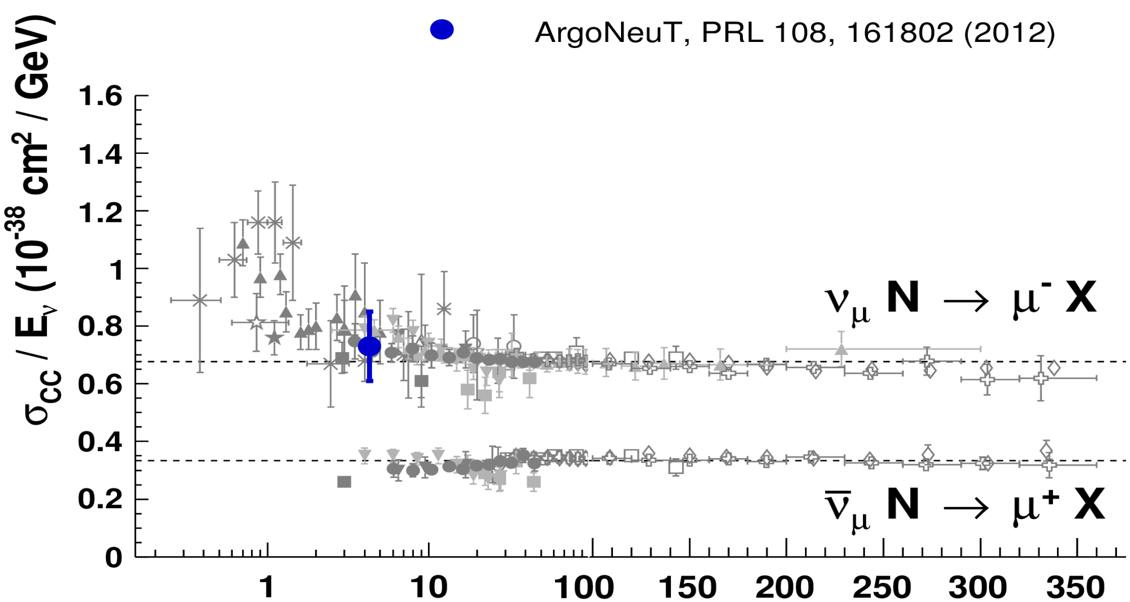
ν_μ CC-inclusive cross-section

Neutrino mode: 2 weeks of data taking



Charge recombination with stopping protons

R. Acciarri et al. ,2013 JINST 8 P08005 arXiv:1306.1712

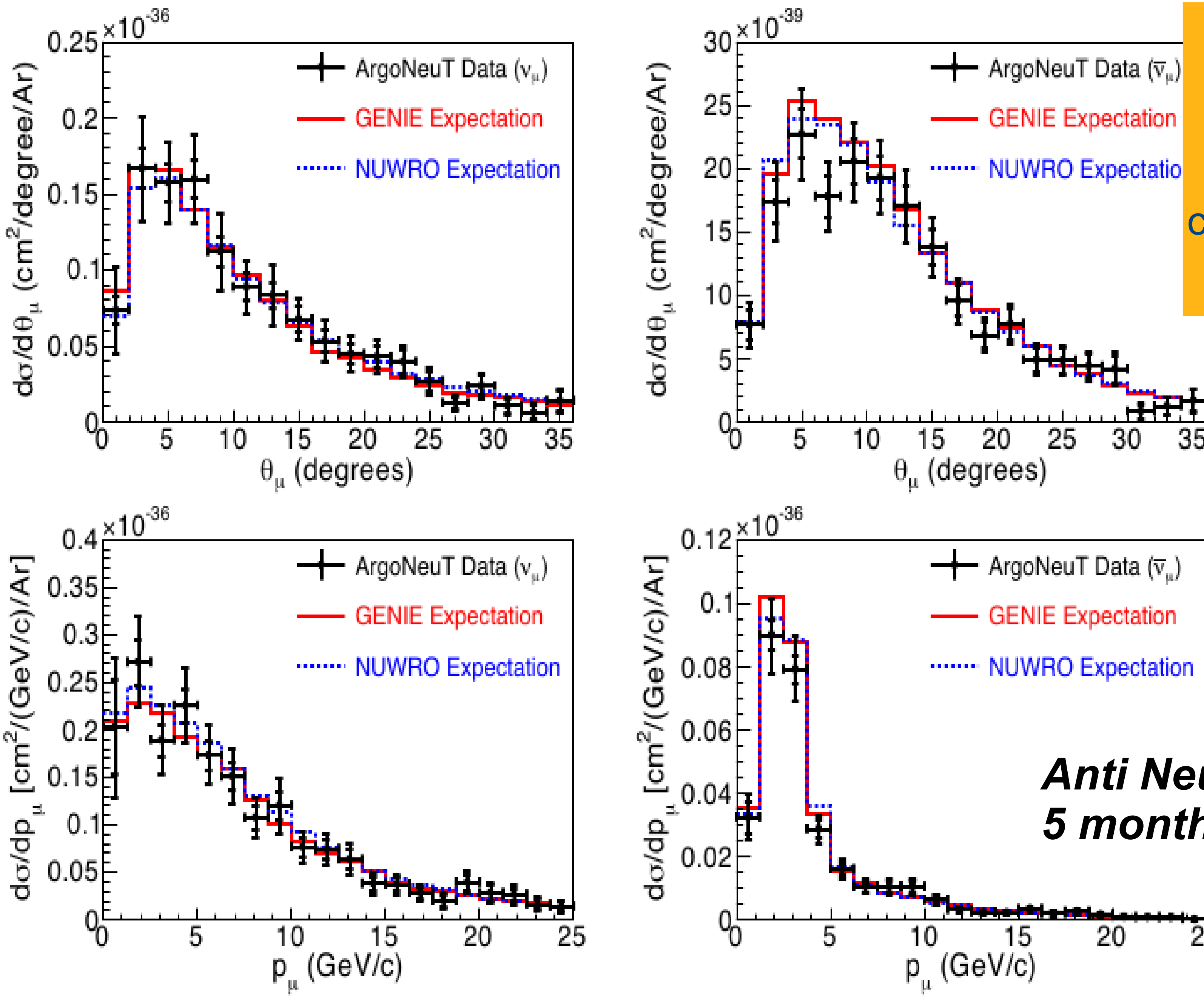


C. Anderson et al., PRL 108, 2012

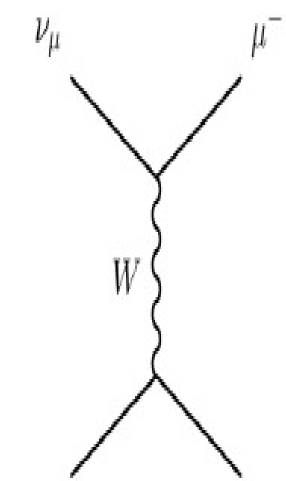
Calorimetry with through-going muons

C.Anderson et al., 2012 JINST 7 P10020; arxiv.org:1205.6702

CC Inclusive in $\bar{\nu}_\mu$ mode



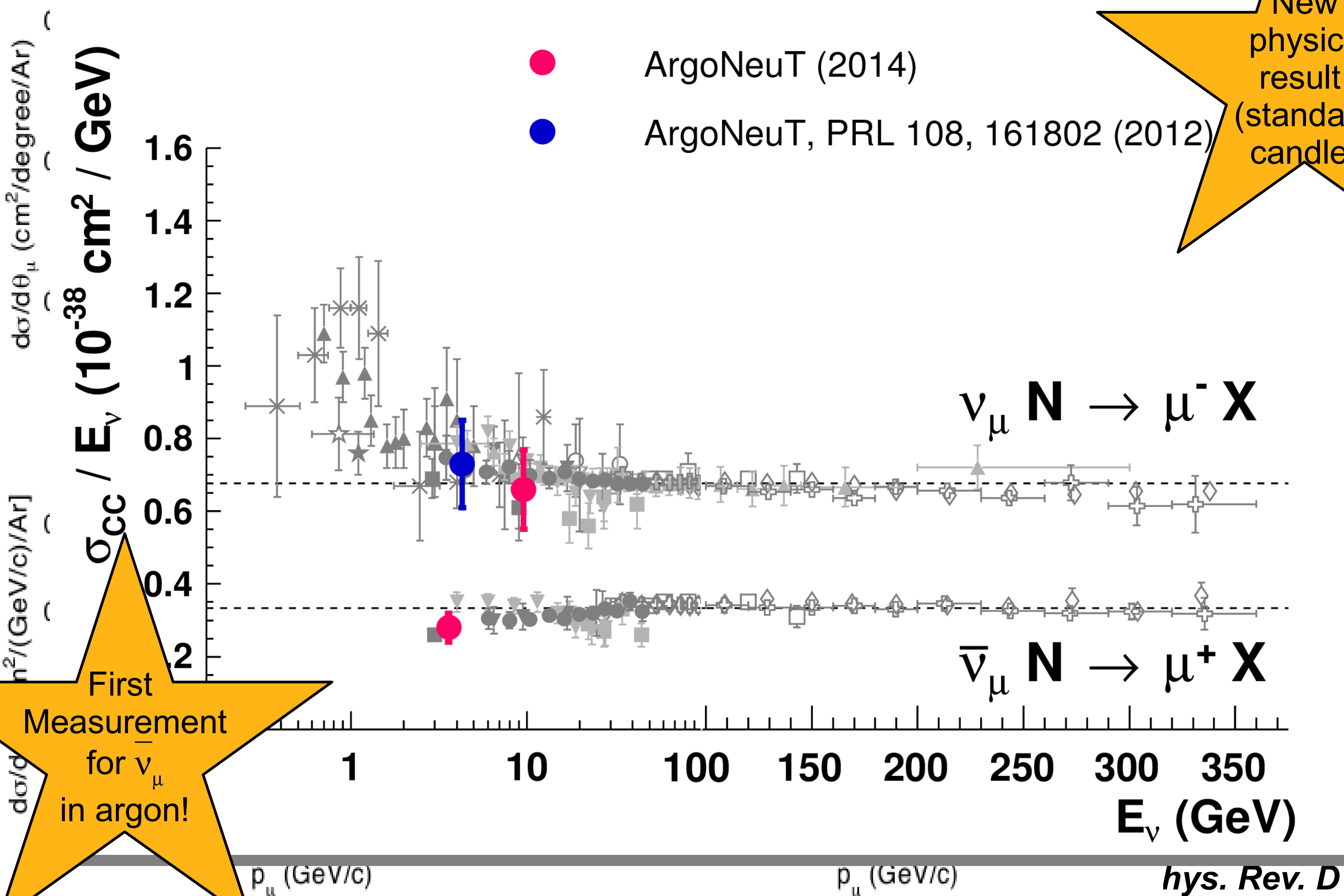
The composition of the beam allows measuring both the $\bar{\nu}_\mu$ and ν_μ components. Charge from MINOS.



Anti Neutrino mode: 5 months of data taking

ArXiv:1404.4809 Phys. Rev. D 89, 112003 (2014)

CC Inclusive in $\bar{\nu}_\mu$ mode



New physics result (standard candle)

First Measurement for $\bar{\nu}_\mu$ in argon!

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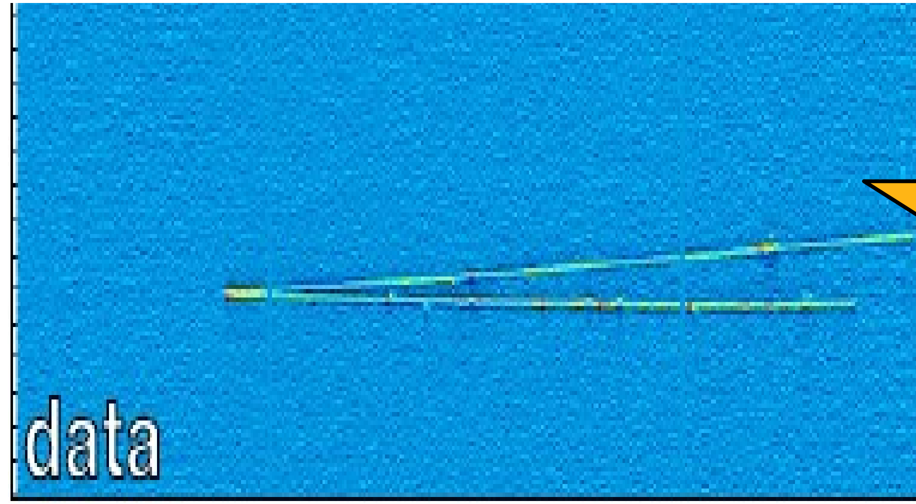
...09

...hys. Rev. D 89, ...112003 (2014)

Coherent Pion Production

$$\nu_\mu + A_{g.s.} \rightarrow \mu^- + \pi^+ + A_{g.s.}$$

$$\bar{\nu}_\mu + A_{g.s.} \rightarrow \mu^+ + \pi^- + A_{g.s.}$$

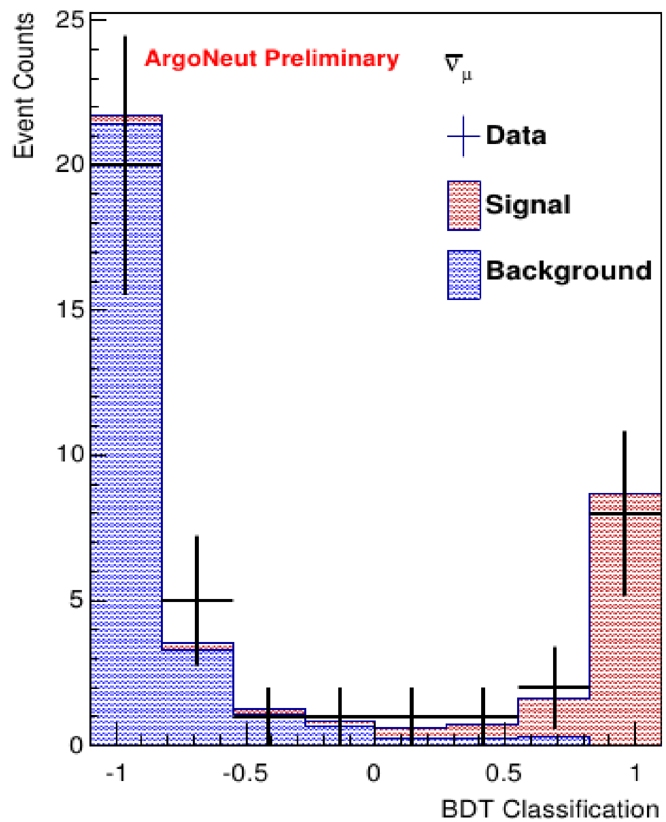


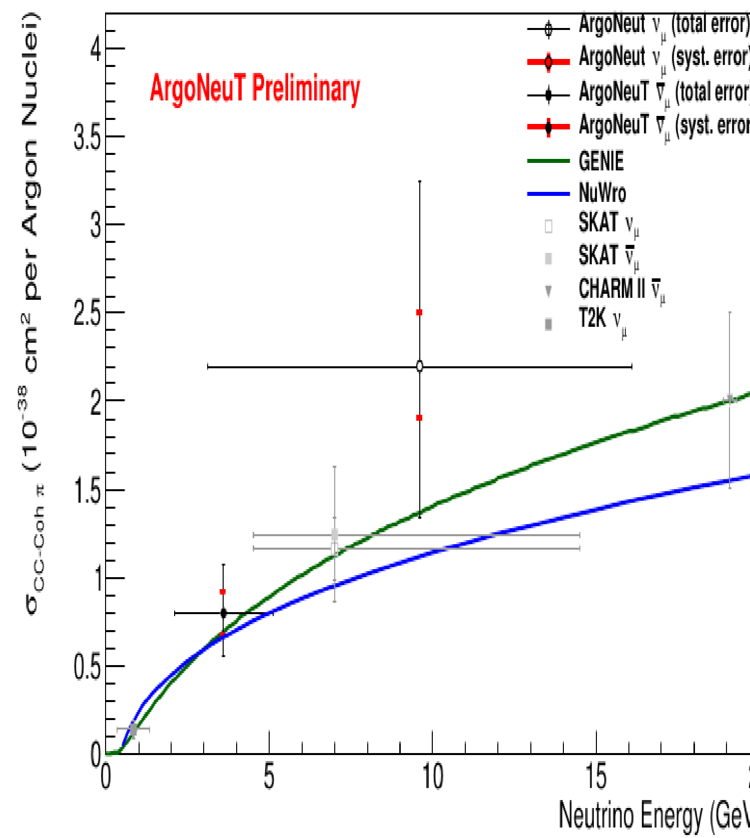
New physics result!

Most pions are not contained so not possible to use Q^2 or t as discrimination.

MC used to build a binned background and signal expectation for a BDT response (based on kinematic variables).

This is then fit to the data.



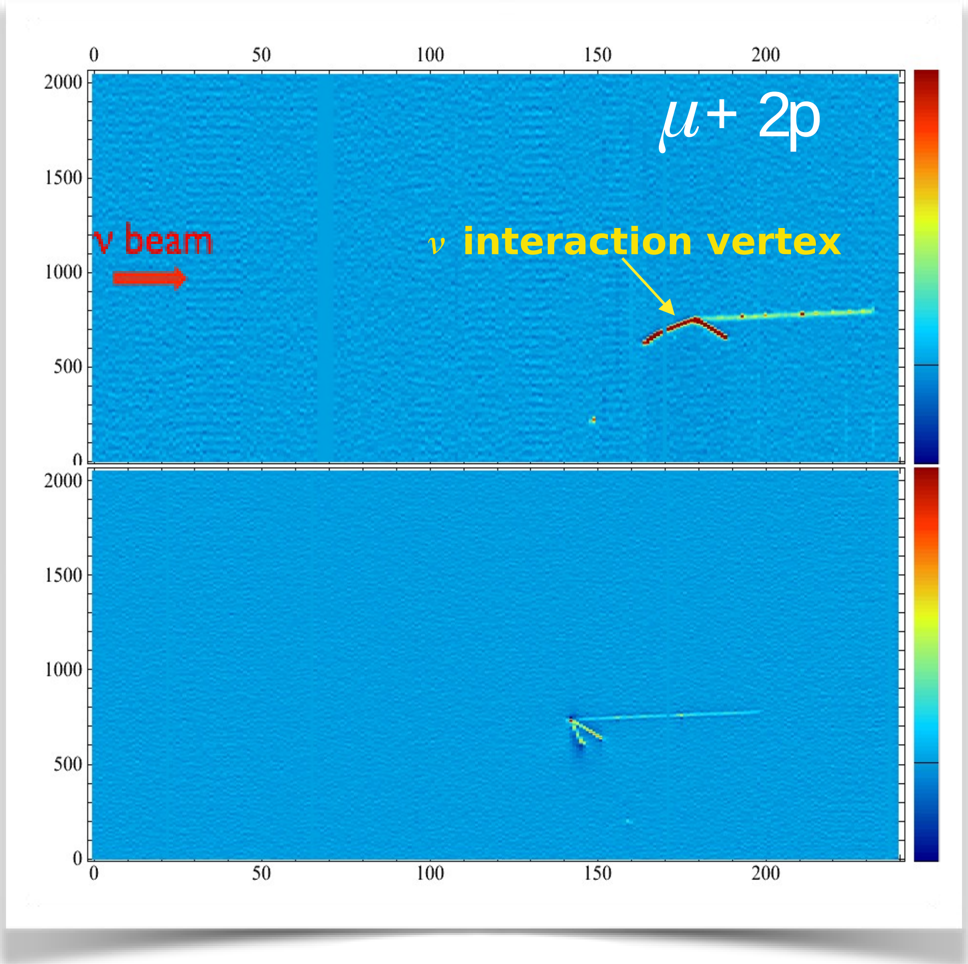


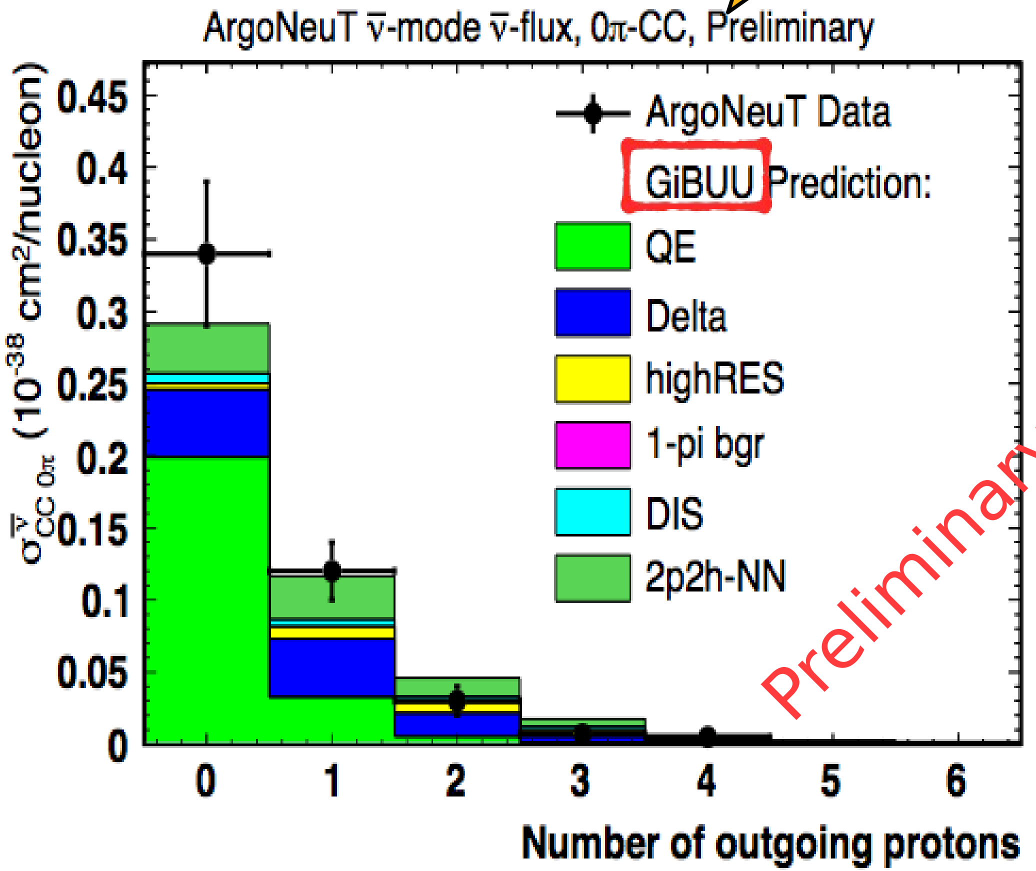
Also, recent results from Minerva and T2K.

Observing proton multiplicities

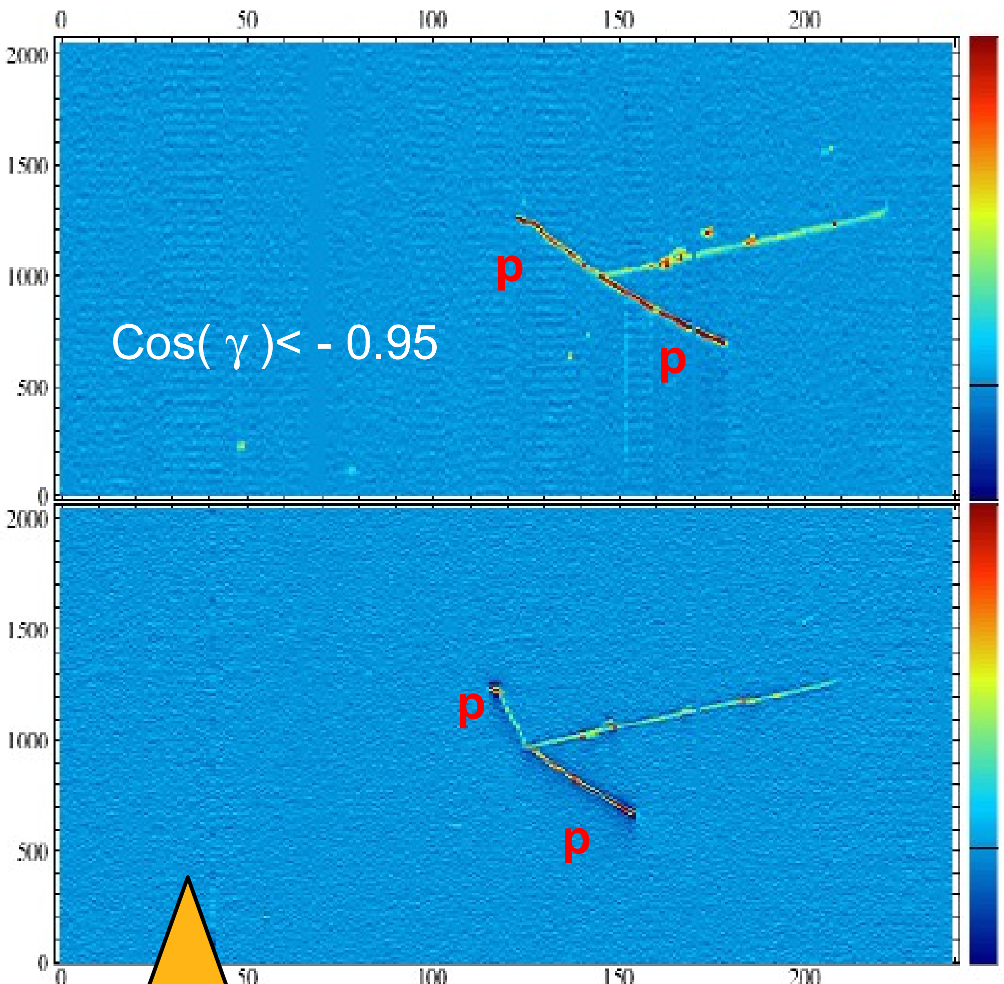
- The granularity of the LArTPC allows seeing actual final state topologies.
- Measuring cross sections as a function of proton multiplicity.

New, LArTPC enabled, physics result!

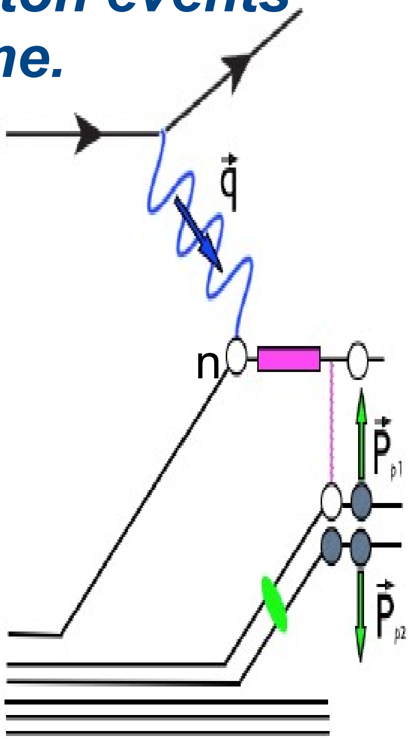




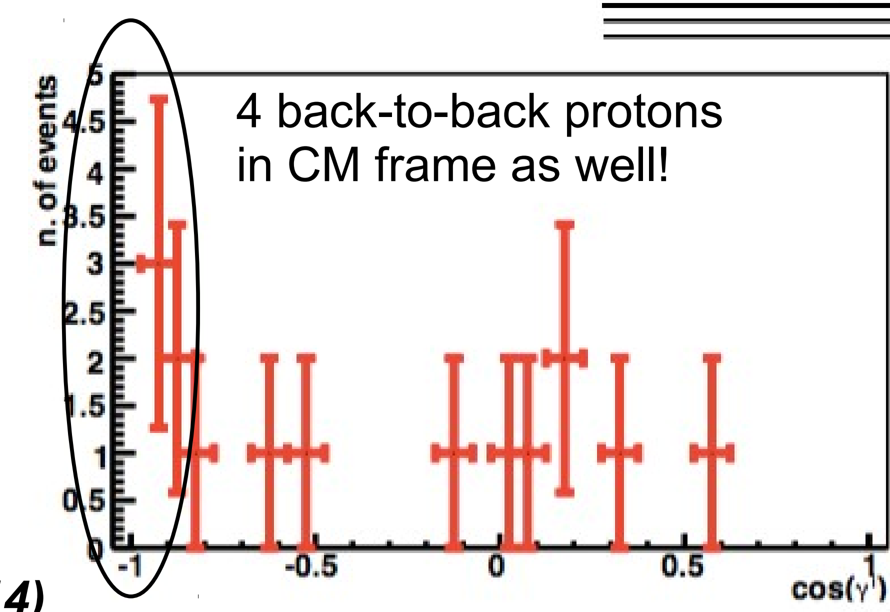
Back-to-Back Protons



4 back-to-back 2-proton events observed in Lab frame.



Possible mechanism is CC RES pionless reactions involving pre-existing SRC np pairs.



New, LArTPC enabled, physics result!

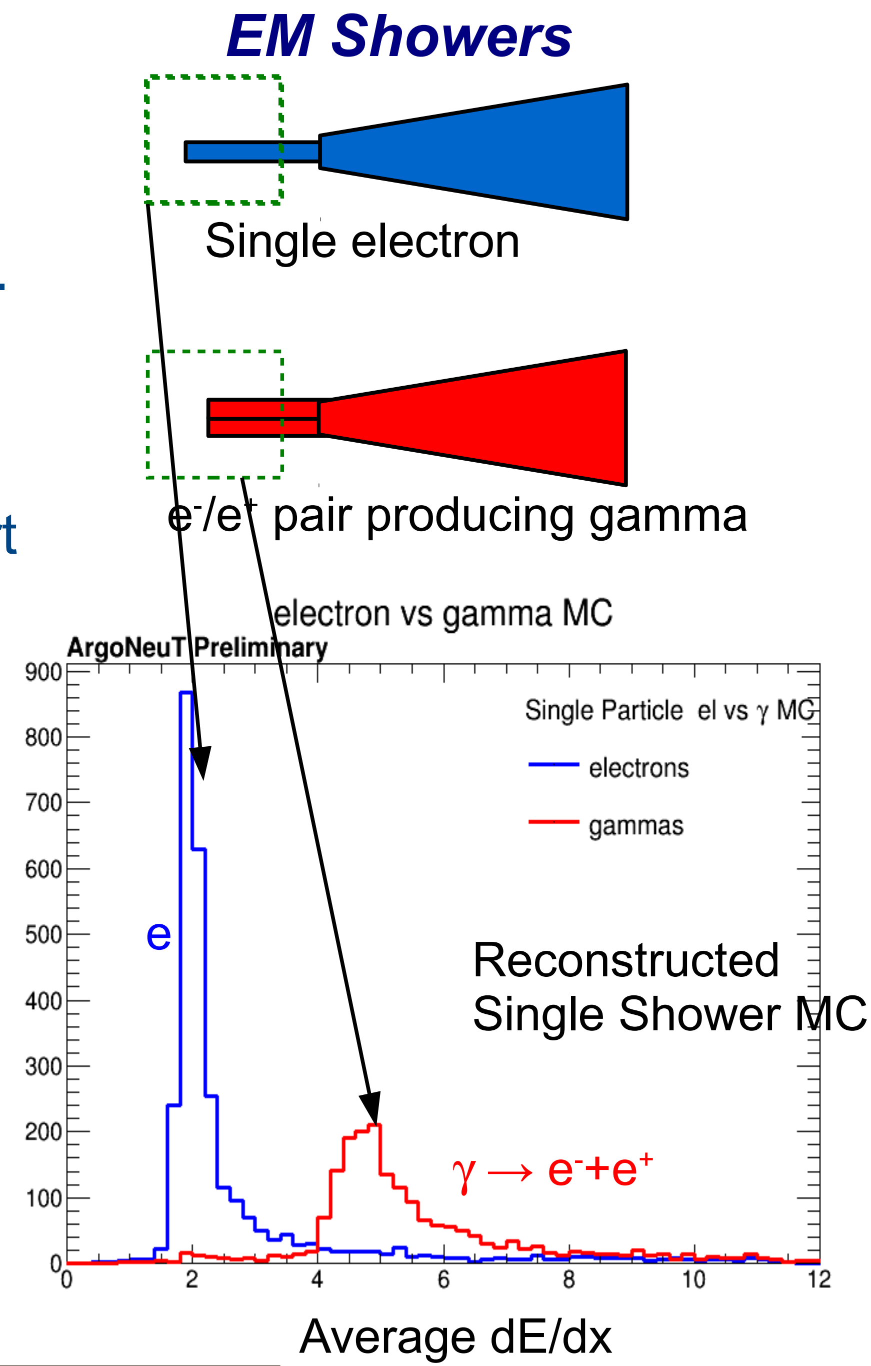
We can see nuclear effects!

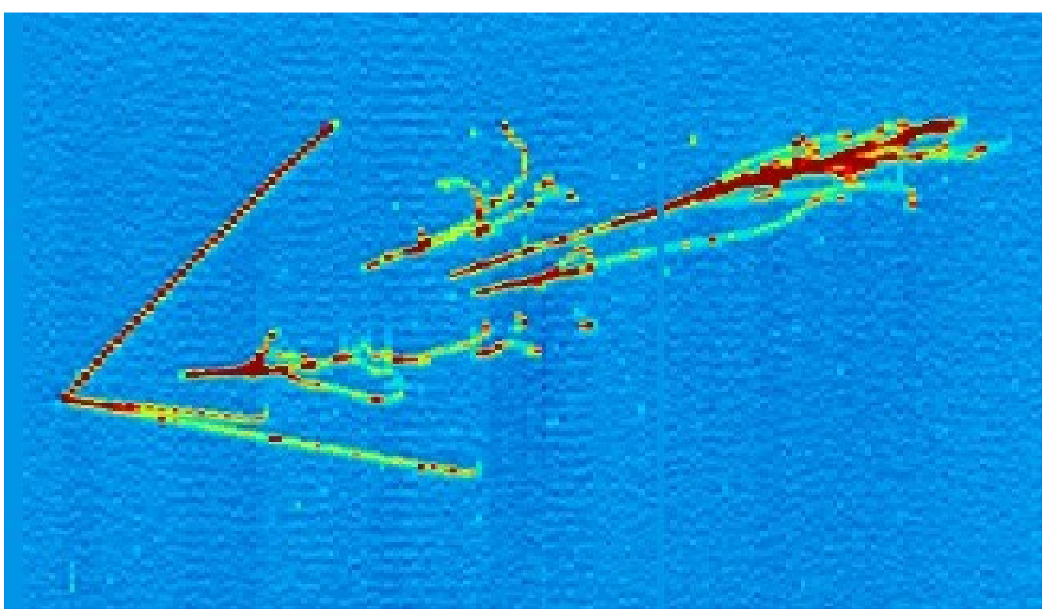
ArXiv:1405.4261

Phys. Rev. D 90, 012008 (2014)

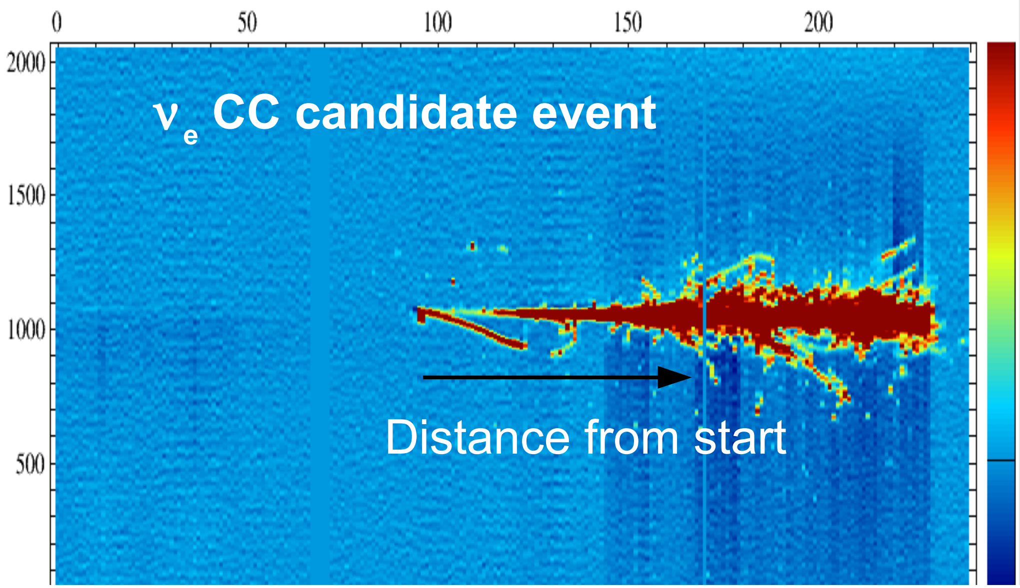
Electron/gamma separation

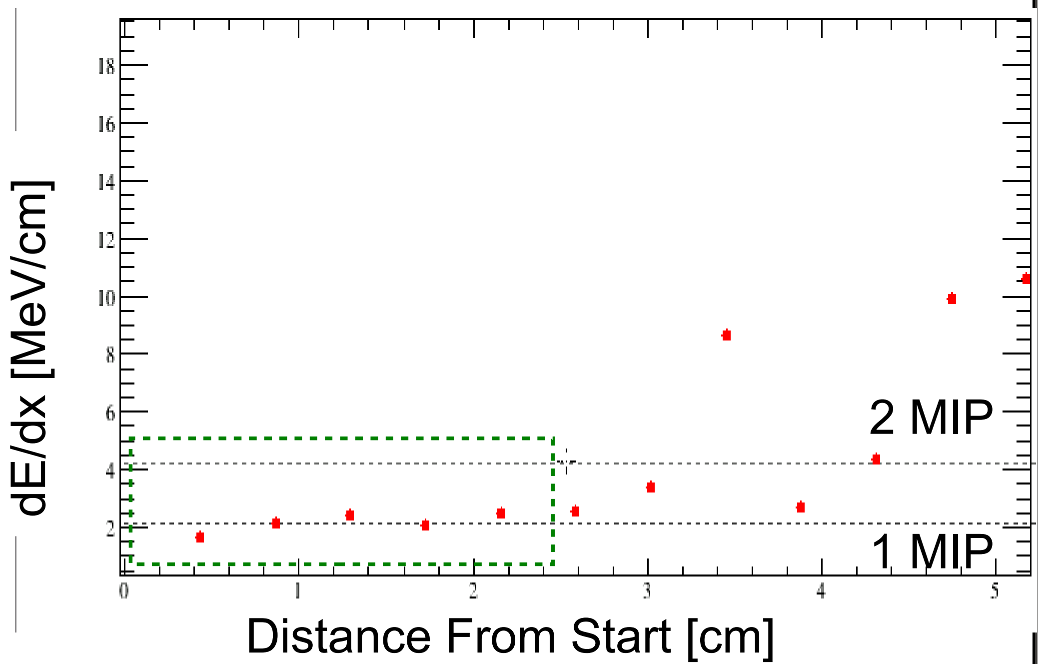
- An EM shower that starts after a gap from the vertex is always background (especially if you can see two of them).
- Even if the gap is very small all is not lost.
  - We can reconstruct the charge at the start of the shower - “dE/dx discrimination”.

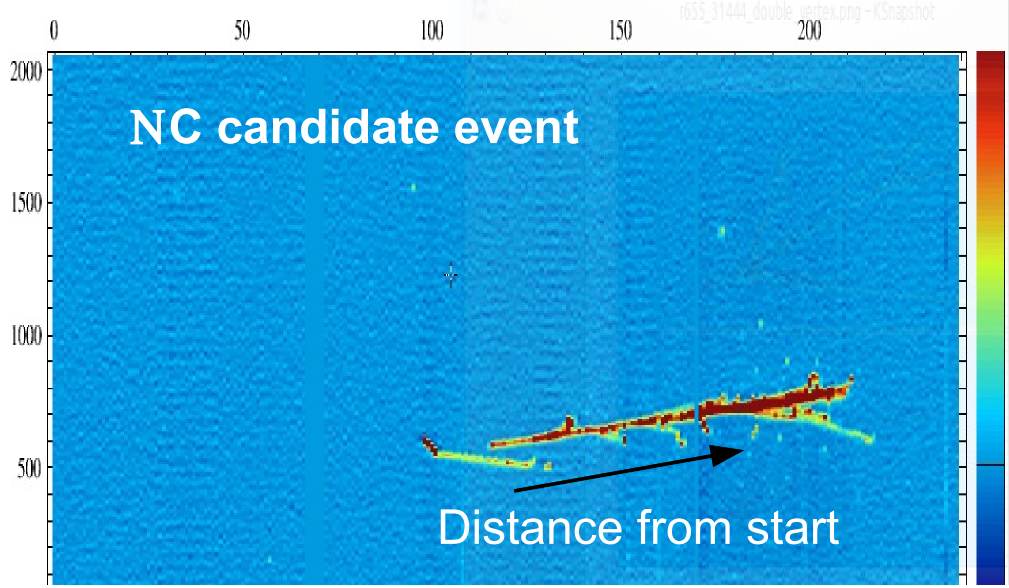


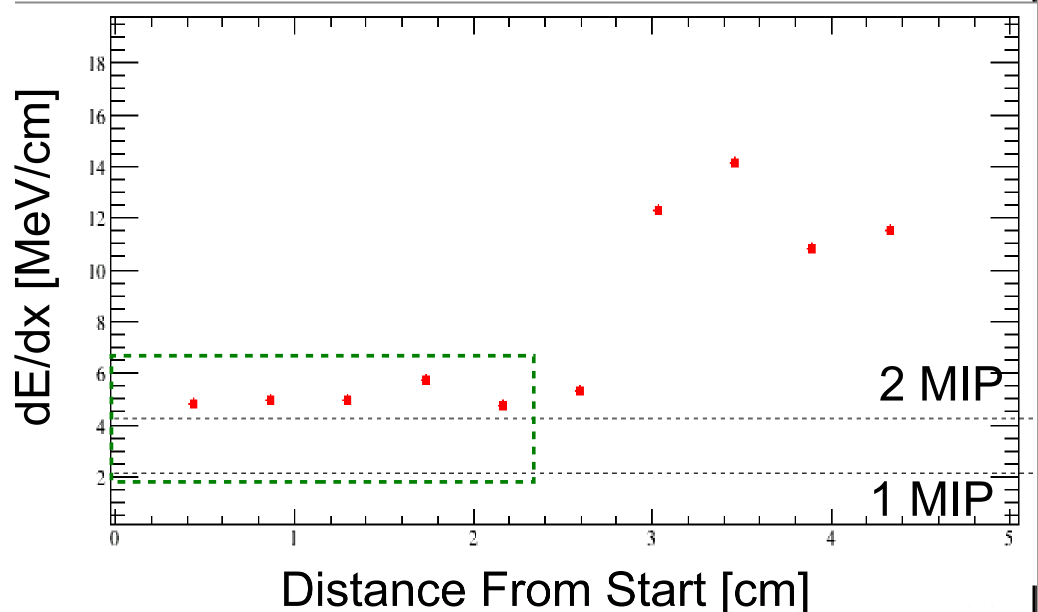


Example events





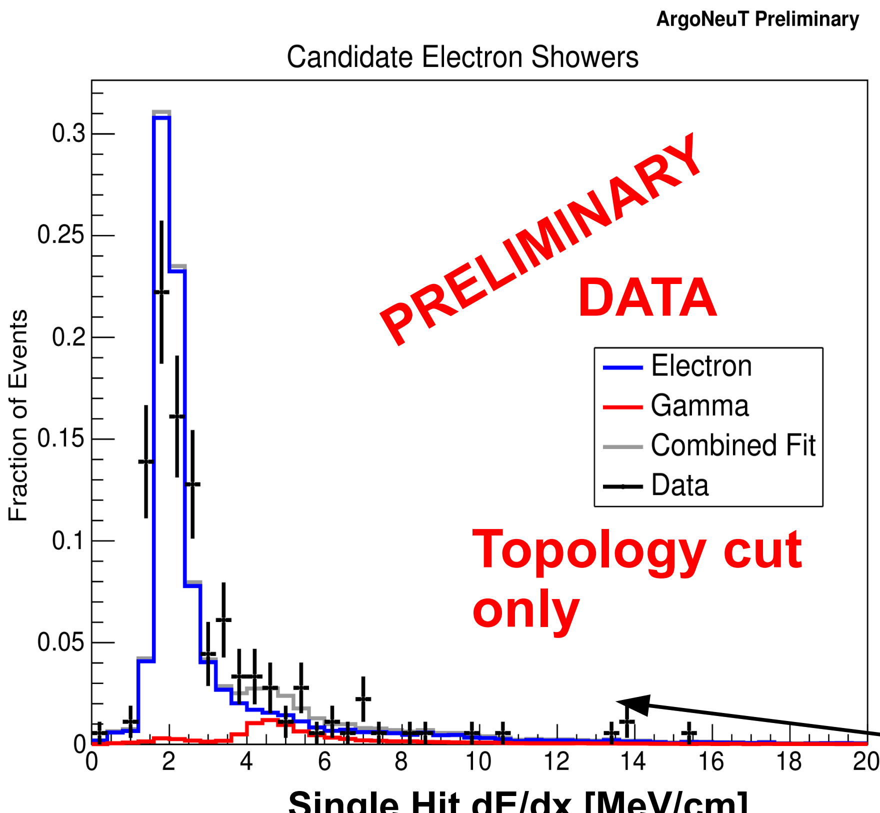




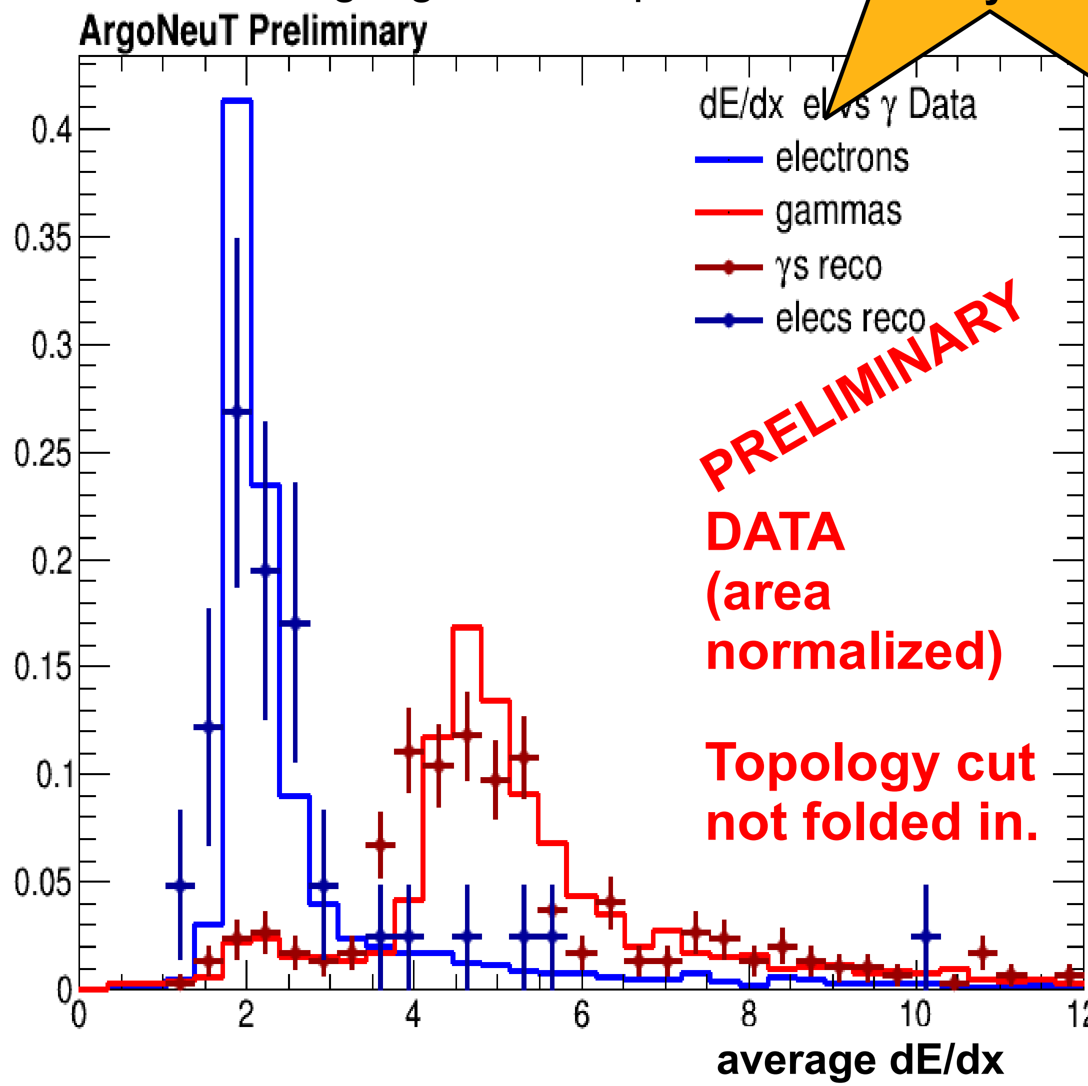
Data-Based dE/dx plot

New, LArTPC enabled, physics analysis!

- *Gammas defined as EM showers detached from visible vertex.*
- *Electrons defined as EM showers with visible vertex activity and no gap.*
- *Electron events require no track matched to MINOS muon.*



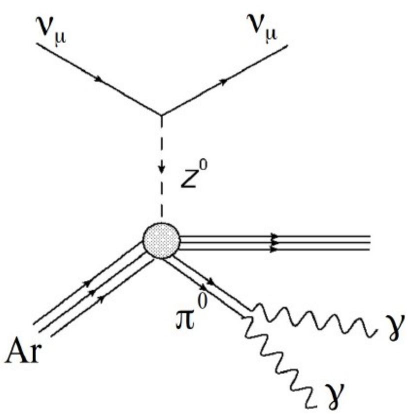
Electron/single gamma separation

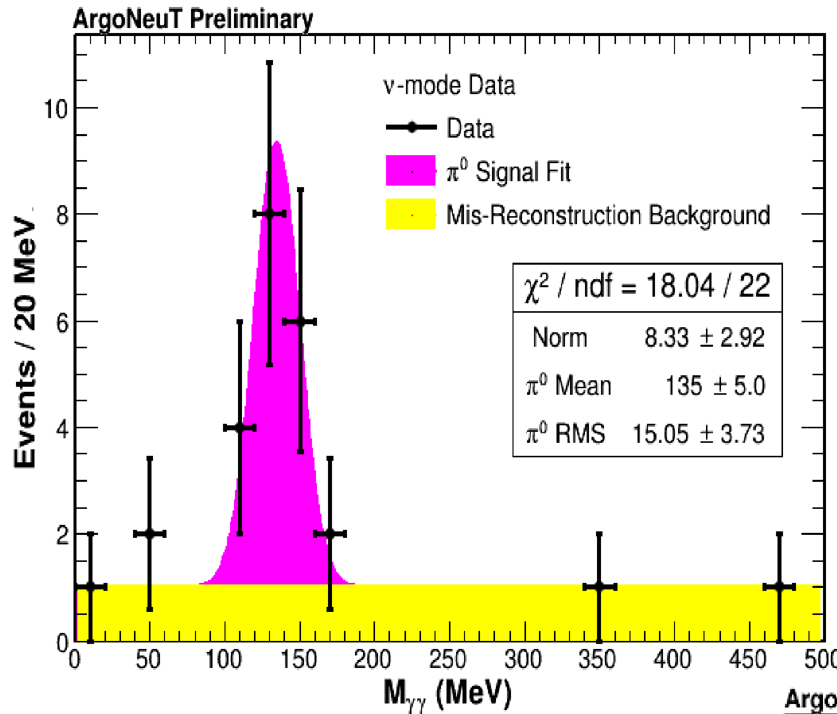


Landau-like distribution of electron event single hit charge depositions.

NC π^0 Study

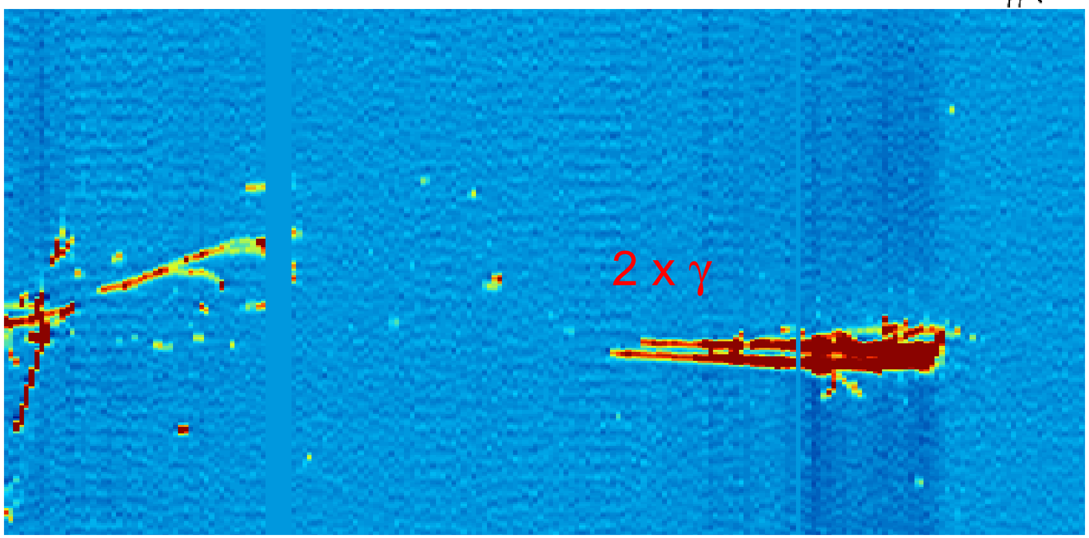
New Physics Analysis!



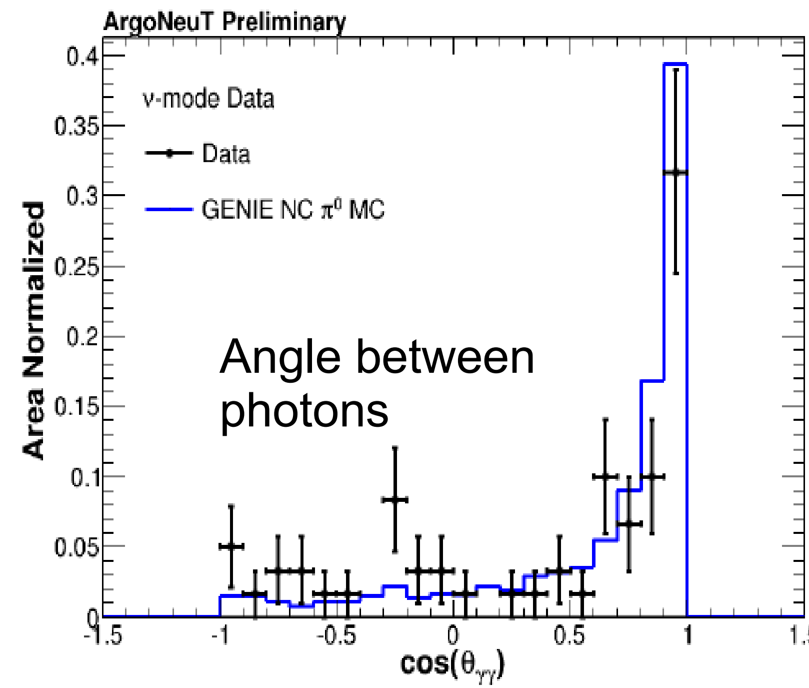


ArgoNeuT is too small to contain the majority of photon showers from π^0's.

An MC based set of energy corrections based on event topology is needed.



Work continuing to refine the energy corrections and analyze the full data set

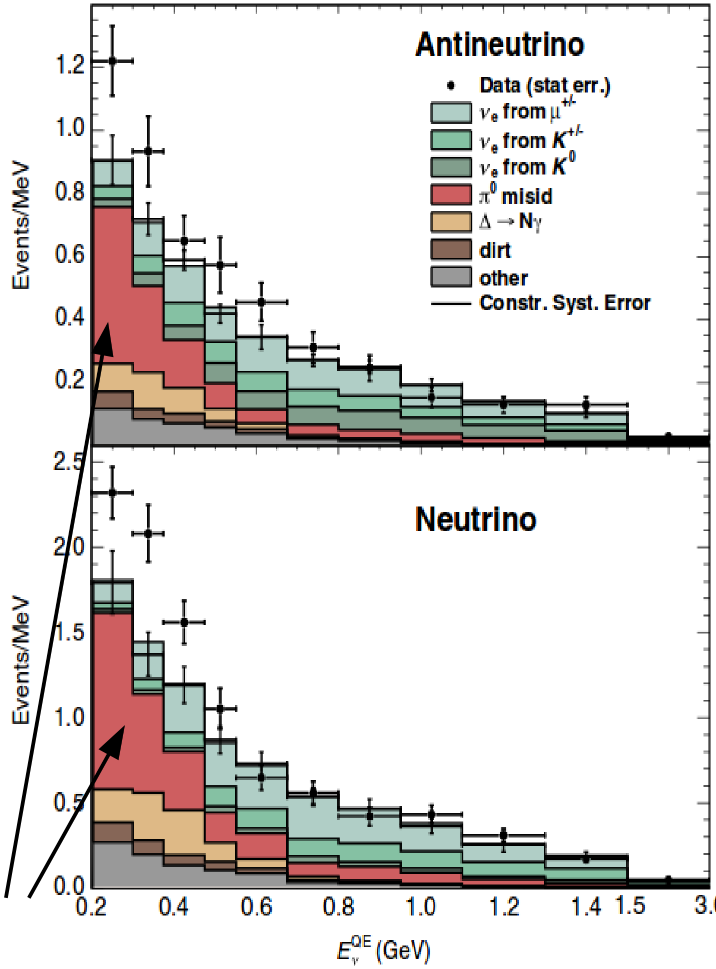


Angle between photons

MicroBooNE

MicroBooNE and the Short Baseline Anomalies

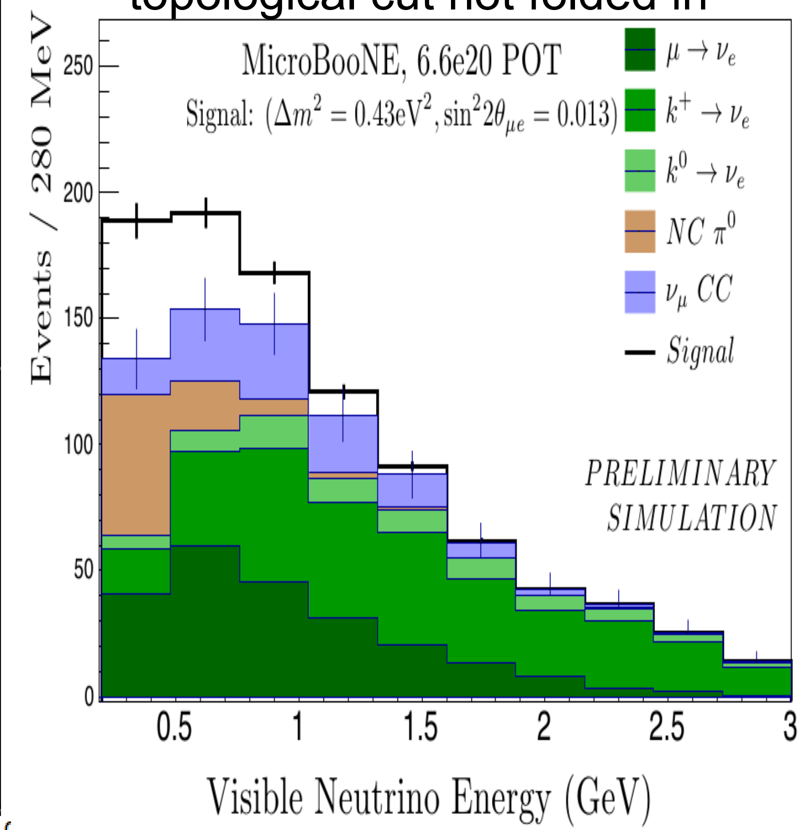
- MicroBooNE will determine the nature of the MiniBooNE low energy excess by running on the same beam.
- The granularity and dE/dx separation will allow differentiating between photons and electrons.



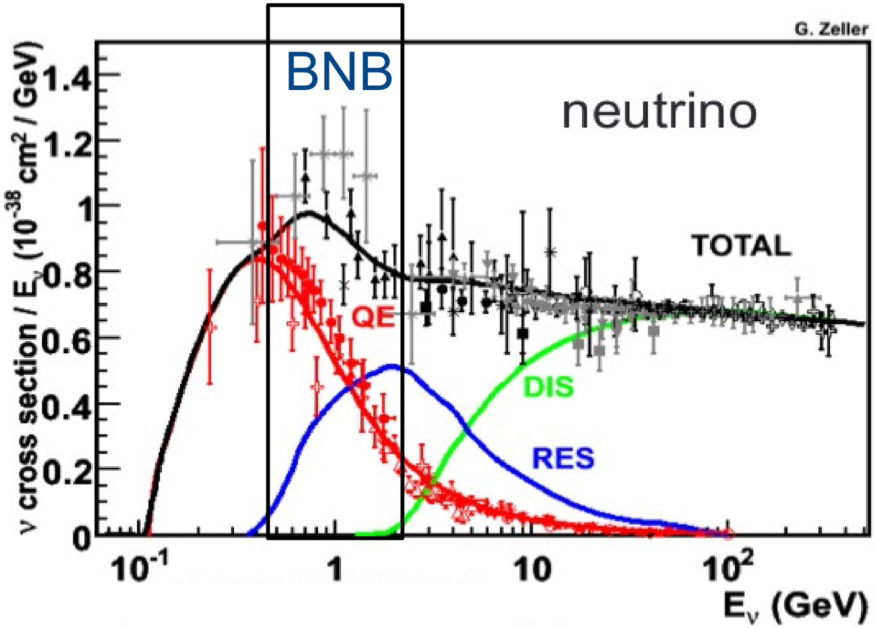
NC π^0 background!

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

topological cut not folded in



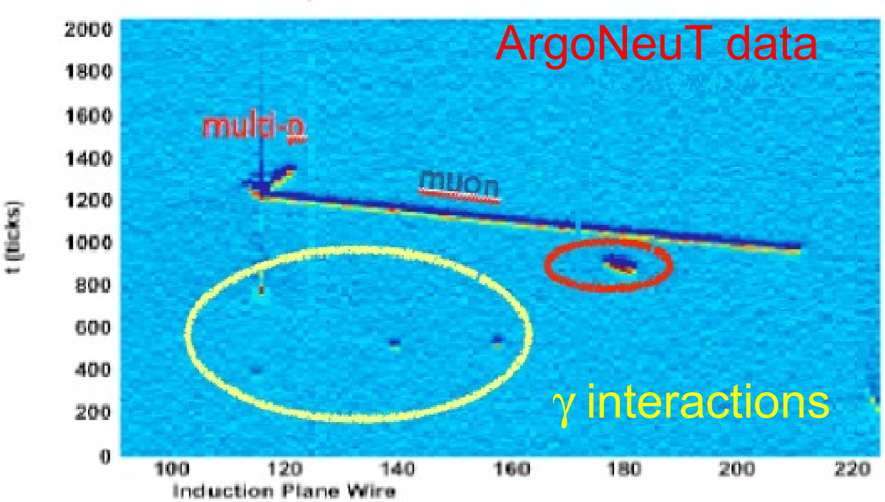
Cross – section and physics R&D



- (~1GeV) Energy range very interesting in terms of cross-sections.

Cross-section physics

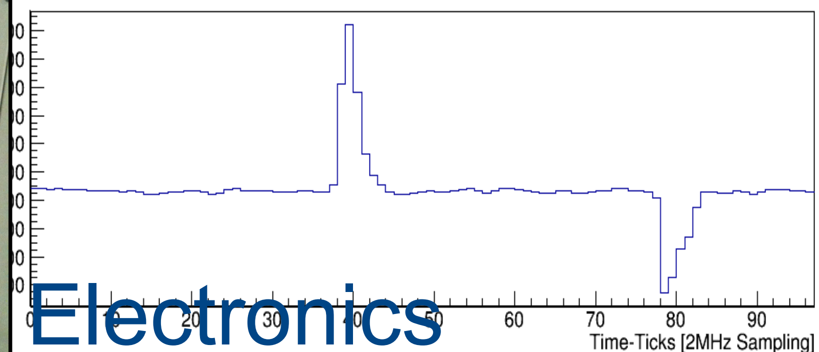
•***Future LAr detectors can be competitive in proton decay studies and complementary in SN detection.***



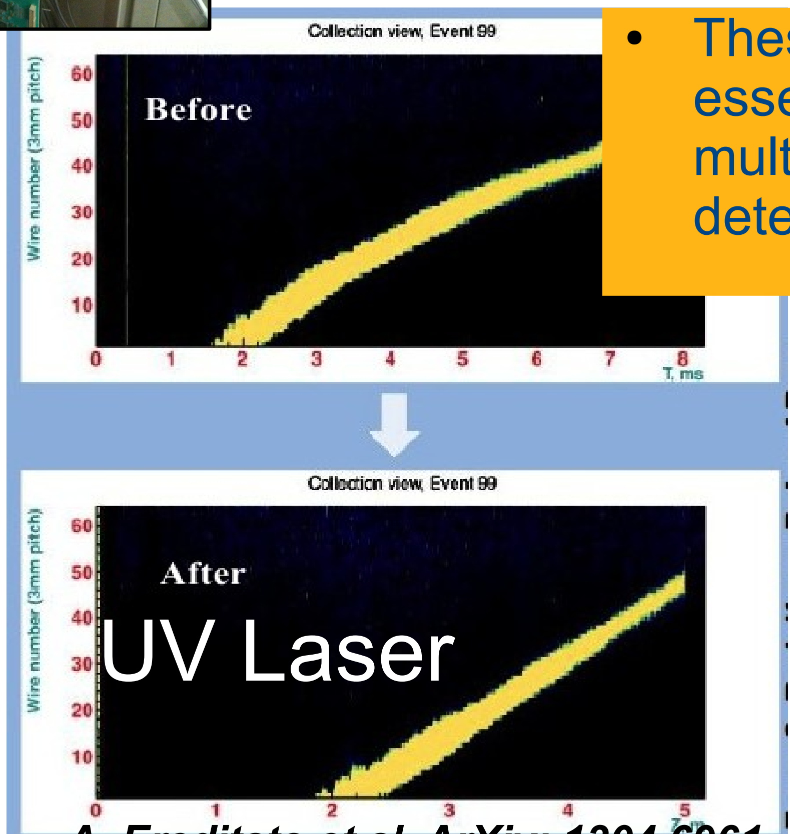
•MicroBooNE will be able to quantify potential backgrounds and test reconstruction methods for nucleon decay and see SN neutrinos.

Physics R&D

LArTPC Technology R&D in MicroBooNE



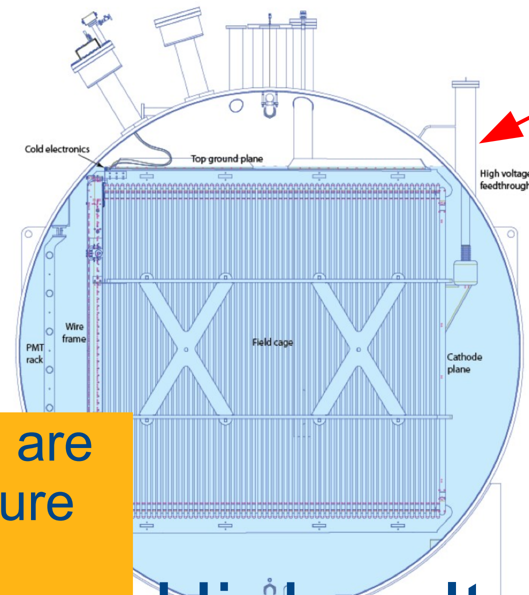
Cold Electronics



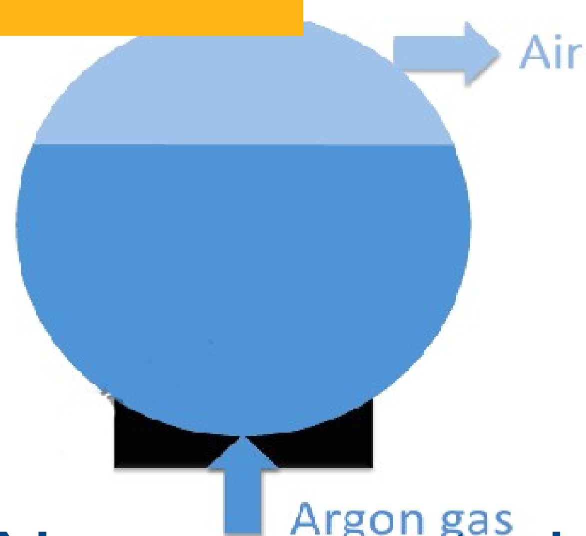
UV Laser

A. Ereditato et al. ArXiv: 1304.6961

- These components are essential for the future multi-kTon LArTPC detectors!



High voltage



Non evacuated vessel

Installation Milestones

TPC push-in, Dec 2013

Cryostat welding,
May 2014

Since then:

- **Insulation completed.**
- **Cabling completed.**
- **Starting electronics test.**
- **Cool down to start next month.**

Conclusions

- There is a vibrant LAr neutrino program at FNAL.
- Exciting results from ArgoNeuT and more will come from MicroBooNE soon.
- We are laying the foundation of the long term vision of multi-kTon LAr neutrino detectors.

Thank You!

Brookhaven Lab
Mary Bishai
Hucheng Chen
Kai Chen
Susan Duffin
Jason Farell
Francesco Lanni
Yichen Li
David Lissauer
George Mahler
Don Makowiecki
Joseph Mead
Veljko Radeka
Sergio Rescia
Andres Ruga
Jack Sondericker
Craig Thorn
Bo Yu
Chao Zhang

University of Cambridge
Andy Blake
John Marshall
Mark Thomson

University of Chicago
Will Foreman
Johnny Ho
David Schmitz
Joseph Zennamo

University of Cincinnati
Ryan Grosso
Jason St. John
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Columbia University
Nancy Bishop
Leslie Camilleri
David Caratelli
Cheng-Yi Chi
Jennet Dickinson
Georgia Karagiorgi
David Kaleko
Bill Seligman
Mike Shaevitz
Bill Sippach
Kathleen Tatum
Kazuhiro Terao
Bill Willis

Fermilab
Roberto Acciarri
Bruce Baller
Dixon Bogert
Ben Carls
Michael Cooke
Herb Greenlee
Cat James
Eric James
Hans Jostlein
Mike Kirby
Sarah Lockwitz
Byron Lundberg
Alberto Marchionni
Stephen Pordes
Jennifer Raaf
Gina Rameika
Brian Rebel
Anne Schukraft
Steve Wolbers
Tingjun Yang
Sam Zeller (*)

Kansas State University
Tim Bolton
Saima Farooq
Sowjanya Gollapinni
Glenn Horton-Smith
David McKee

Los Alamos National Laboratory
Gerry Garvey
Jackie Gonzales
Wes Ketchum
Bill Louis
Geoff Mills
Zarko Pavlovic
Richard Van de Water
Kevin Yarritu

Massachusetts Institute of Technology
William Barletta
Len Bugel
Gabriel Collin
Janet Conrad
Christina Ignarra
Ben Jones
Jarrett Moon
Matt Toups
Taritree Wongjirad
Joshua Spitz

Michigan State University
Carl Bromberg
Dan Edmunds
Brian Page

New Mexico State University
Alistair McLean
Tia Miceli
Vassili Papavassiliou
Stephen Pate
Katherine Woodruff

Otterbein University
Nathaniel Tagg

University of Oxford
Giles Barr
Matt Bass
Roxanne Guenette

University of Pittsburgh
Steve Dytman
Donna Naples
Vittorio Paolone

Princeton University
Kirk McDonald
Bill Sands

Saint Mary's University of Minnesota
Paul Nienaber

SLAC
Mark Convery
Brandon Eberly
Matt Graham
David Muller
Yun Tse Tsai

Syracuse University
Jonathan Asaadi
Jessica Esquivel
Mitch Soderberg (*)

University of Texas at Austin
Son Cao
Doug Davis
Junting Huang
Karol Lang
Rashid Mehdiyev

Laboratory for High Energy Physics, University of Bern, Switzerland
Antonio Ereditato
Igor Kreslo
Michele Weber
Christoph Rudolf von Rohr
Thomas Strauss

Istituto Nazionale di Fisica Nucleare, Italy
Flavio Cavanna
Ornella Palamara

Virginia Tech
Mindy Jen
Leonidas Kalousis
Camillo Mariani

Yale University
Corey Adams
Eric Church
Bonnie T. Fleming (*)
Ellen Klein
Elena Gramellini
Ariana Hackenburg
Elizabeth Himwich
Ornella Palamara
Flavio Cavanna
Brooke Russell
Kinga Partyka
Andrzej Szelc

MicroBooNE and **ArgoNeuT** collaborations

Ford
Illinois
P25 6480



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 - Driving Nu Physics
Fermilab


SKYJACK


MicroBooNE - Driving Nu Physics
Fermilab

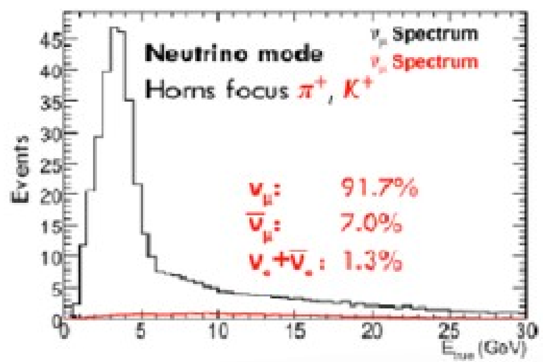
Near Future – the move to LArTF

- The building is ready.
- After final tests of all subsystems the Cryostat will move to the detector hall (week of june 23rd).

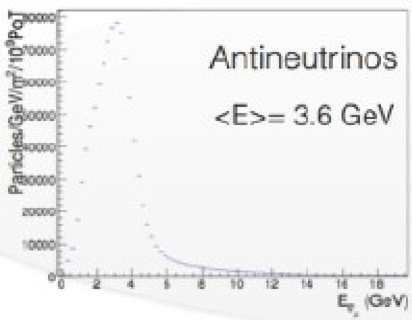
- Need to apply insulating foam and test all subsystems.
- 1-2 months for gas purge and cooling.
  - will start in the Fall!

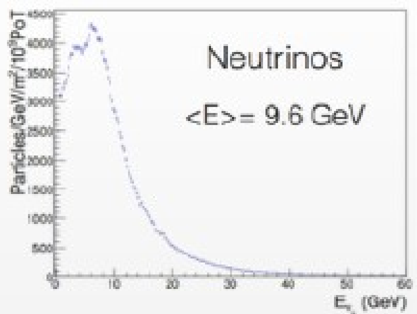
Fluxes

0.085e20 POT



1.2e20 POT





- ArgoNeuT took data over 5 months during 2009-2010.
- **Previous** Inclusive Charged-Current (CC) cross section results based on ν_μ's in the **neutrino beam**: PRL 108 (2012) 161802.
- **New** results are based on ν_μ's **and** $\bar{\nu}_\mu$'s in the **anti-neutrino** beam

We use so-called SKZP MINOS flux: NuMI flux simulation plus FLUKA, tuned from NA49 data and Minos ND data and a +/- 11% flat systematic error.

Event Classification

Multivariate method: Boosted Decision Tree[1] (BDT)

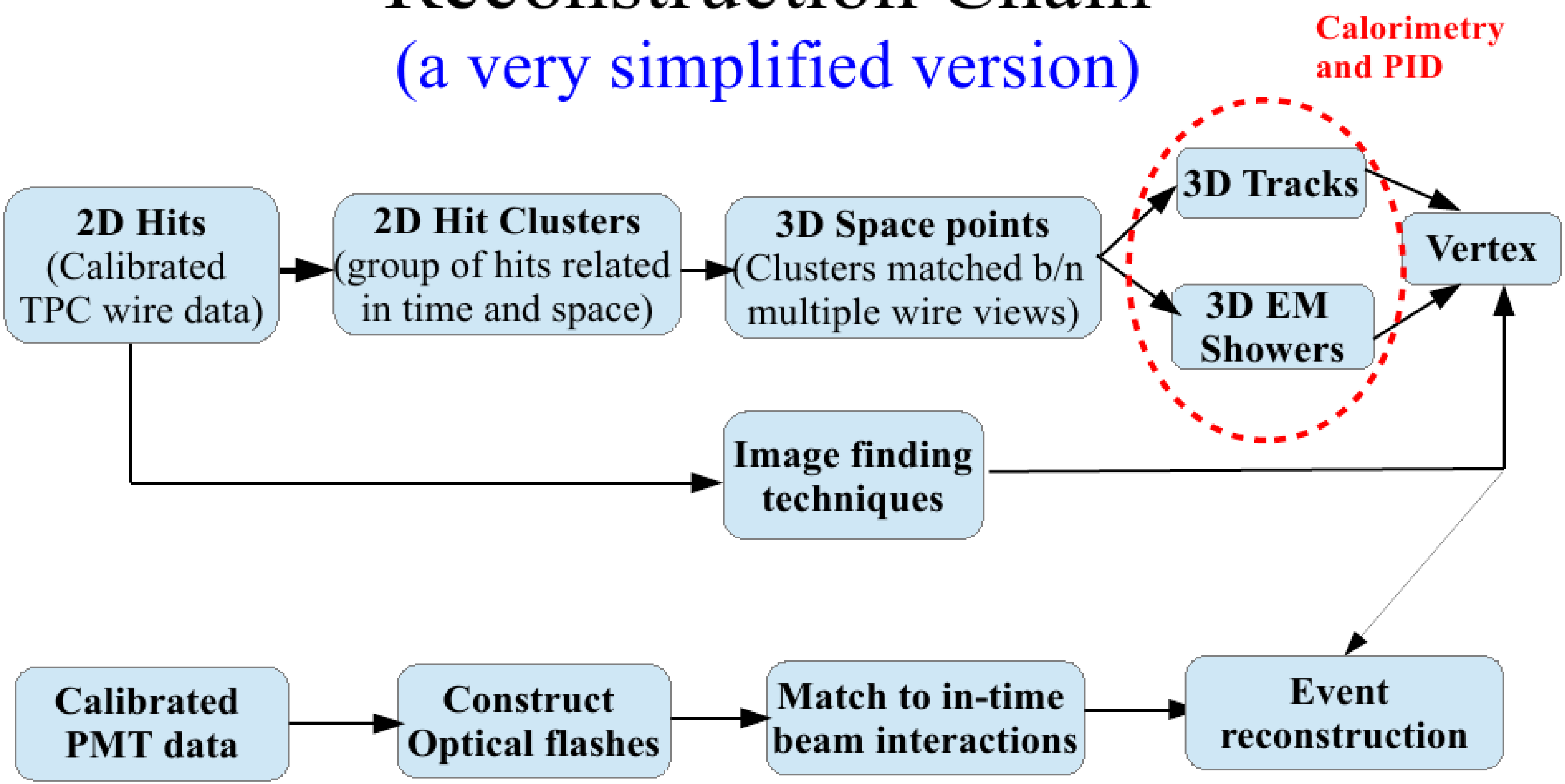
Inputs:

- θ_π: the angle of the π track.
- θ_μ: the angle of the μ track.
- $\Delta\theta$: the opening angle between the two tracks.
- K_π: the kinetic energy of the π based on calorimetry.
- $\left\langle \frac{dE}{dx} \right\rangle_\mu$: the average stopping power of the first third of the μ track.
- P_μ: the μ momentum.

ArgoNeuT

Reconstruction Chain

(a very simplified version)

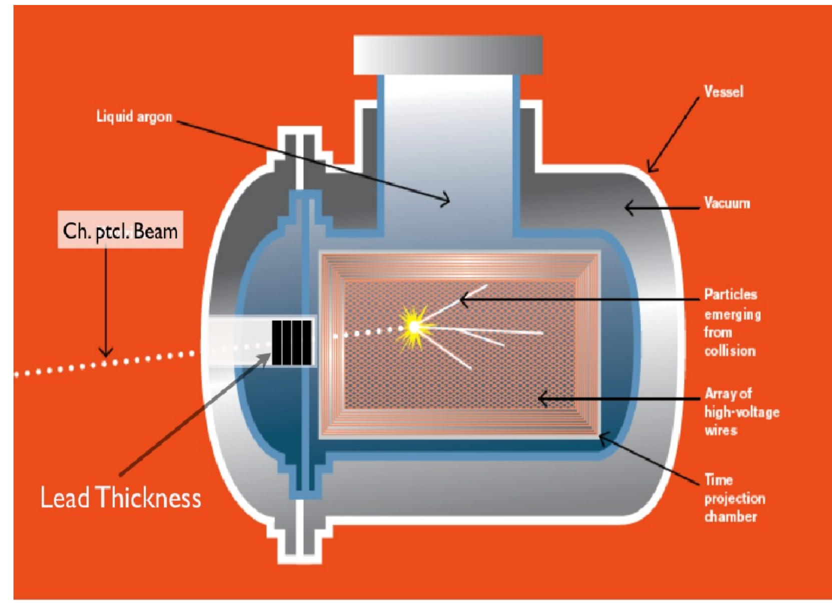


Process		No. Events
	ν_μ *Events (By Final State Topology)*	
CC Inclusive		88,098
CC 0 π	$\nu_\mu N \to \mu + Np$	56,580
	· $\nu_\mu N \to \mu + 0\mathrm{p}$	12,680
	· $\nu_\mu N \to \mu + 1\mathrm{p}$	31,670
	· $\nu_\mu N \to \mu + 2\mathrm{p}$	5,803
	· $\nu_\mu N \to \mu + \geq 3\mathrm{p}$	6,427
CC 1 $\pi^\pm$	$\nu_\mu N \to \mu + \mathrm{nucleons} + 1\pi^\pm$	21,887
CC $\geq 2\pi^\pm$	$\nu_\mu N \to \mu + \mathrm{nucleons} + \geq 2\pi^\pm$	1,953
CC $\geq 1\pi^0$	$\nu_\mu N \to \mathrm{nucleons} + \geq 1\pi^0$	9,678
NC Inclusive		33,000
NC 0 π	$\nu_\mu N \to \mathrm{nucleons}$	21,509
NC 1 $\pi^\pm$	$\nu_\mu N \to \mathrm{nucleons} + 1\pi^\pm$	4,886
NC $\geq 2\pi^\pm$	$\nu_\mu N \to \mathrm{nucleons} + \geq 2\pi^\pm$	635
NC $\geq 1\pi^0$	$\nu_\mu N \to \mathrm{nucleons} + \geq 1\pi^0$	6,657
	ν_e *Events*	
CC Inclusive		567
NC Inclusive		207
Total ν_μ and ν_e Events		121,099

	ν_μ *Events (By Physical Process)*	
CC QE	$\nu_\mu n \to \mu^- \mathrm{p}$	48,626
CC RES	$\nu_\mu N \to \mu^- N$	26,852
CC DIS	$\nu_\mu N \to \mu^- X$	10,527
CC Coherent	$\nu_\mu Ar \to \mu Ar + \pi$	376

ArgoNeuT becomes LArIAT

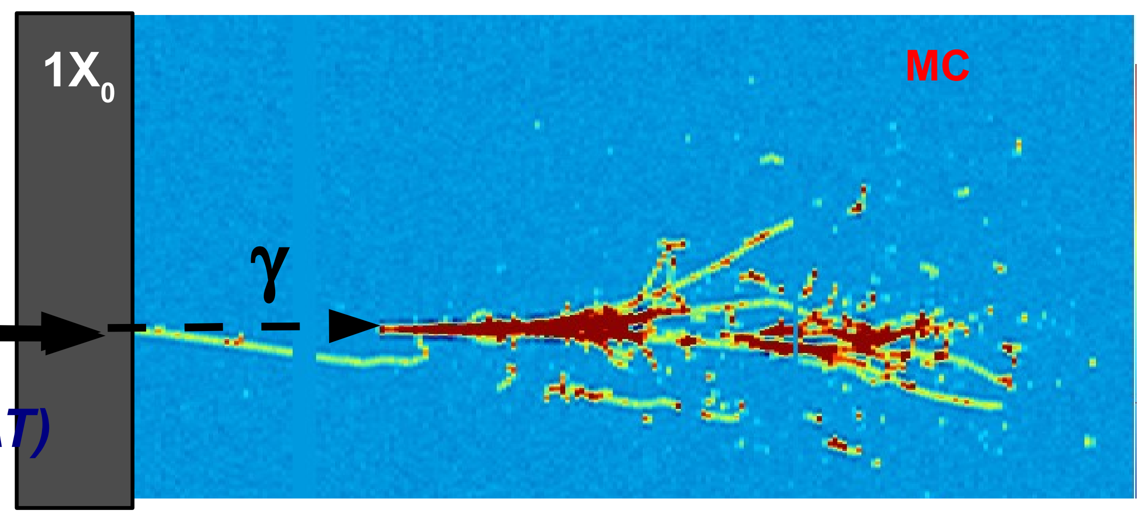
LArIAT by running in an instrumented charged particle beam line will allow us to tag electrons, providing a clean sample of events (and higher statistics).



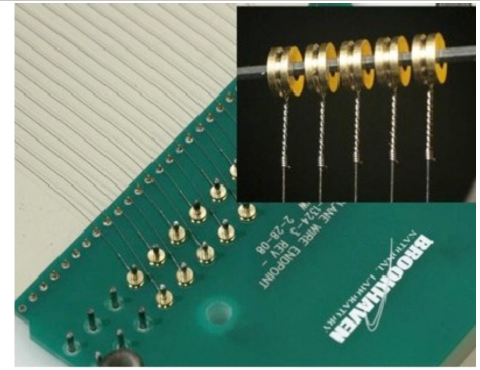
Electrons are found in tertiary beam. Photons generated via brehmsstrahlung in $1X_0$ pre-shower disk.

Do not need shower containment

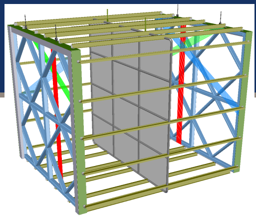
(This is only a small part of the Physics we will measure with LArIAT)

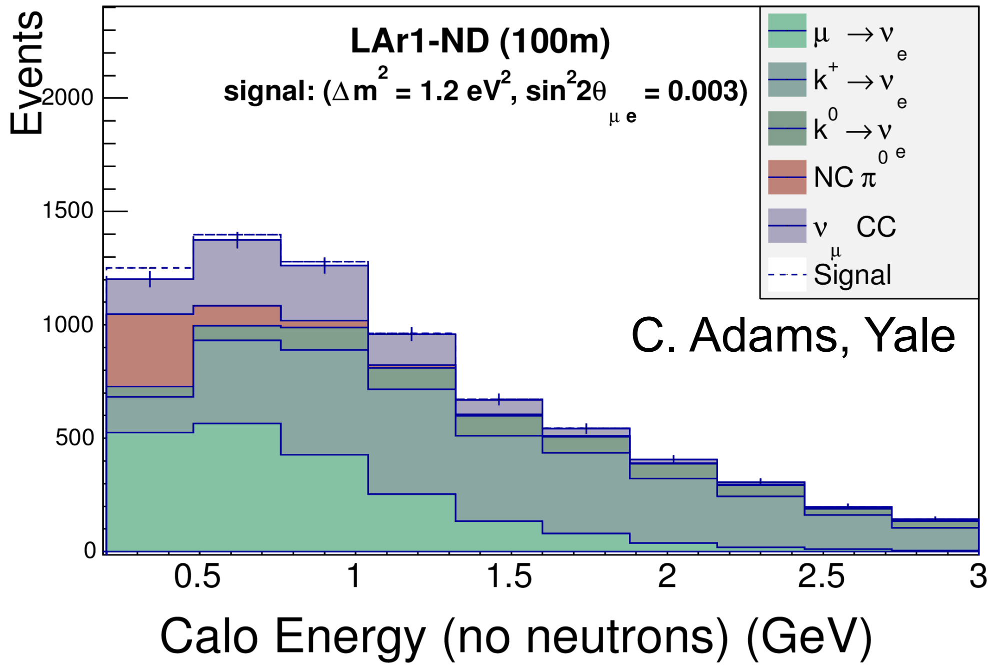


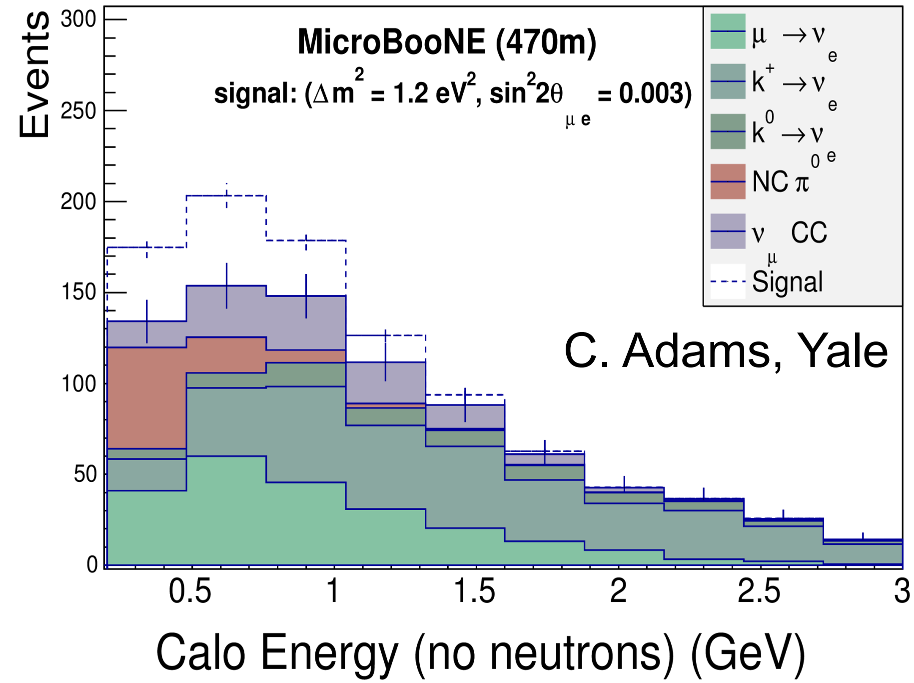
TPC wires + PMTs



LAr1-ND, or MicroBooNE with a Near Detector



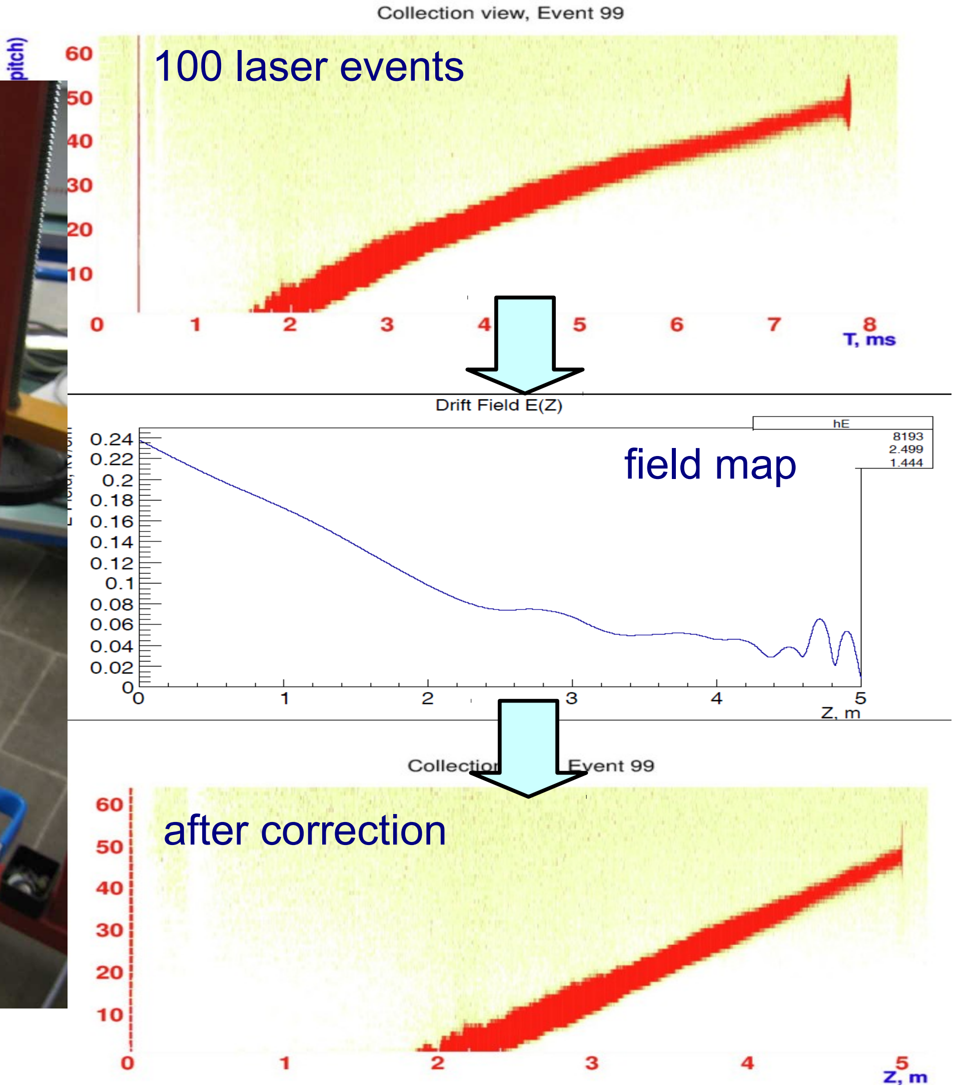




- A near detector, LAr1-ND sited in the existing SciBooNE hall can determine whether the MiniBooNE excess in neutrino mode is due to oscillation.
- Due to its proximity to the target hall, it is sufficient for it to run for one year to amass statistics much bigger than MicroBooNE
- To explain the excess in the anti-neutrino mode an additional far detector is necessary.

UV Laser

- UV Laser being installed to use for calibration.
- Allows mapping potential field distortions with a “track” guaranteed to be straight - muons can undergo multiple scattering.
- Laser goes in via optical feedthrough.
- Internal mirror allows remote change of angle.



ArgoNeuT and MicroBooNE

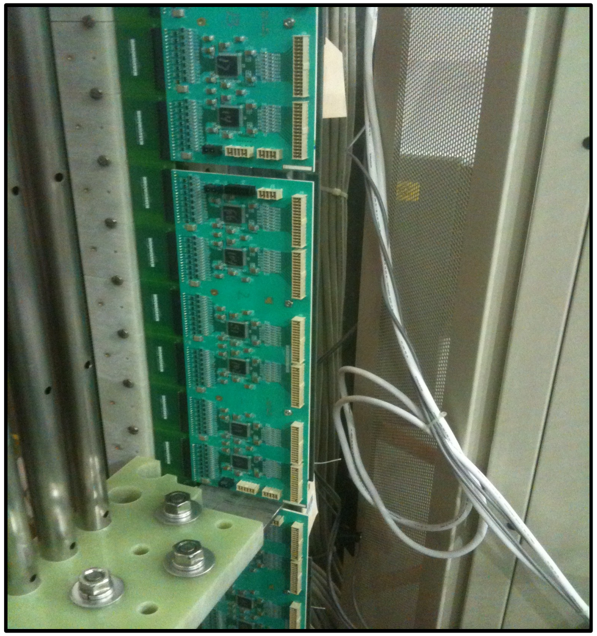
	ArgoNeuT	MicroBooNE
Detector:	LArTPC	LArTPC
Neutrinos:	SBN: NuMI $\langle E_\nu \rangle$ = 4.3 GeV	SBN: Booster $\langle E_\nu \rangle$ = 0.8 GeV
Location:	FNAL	FNAL
Size:	40x45x90cm 0.23 tons Active	230x256x1034cm 87 tons Active
Wires:	2 planes - 4 mm pitch	3 planes - 3mm pitch
Electronics:	Warm	Cold
Light Readout:	**None**	**32 8" PMTs**
Timeline:	Finished	About to take data

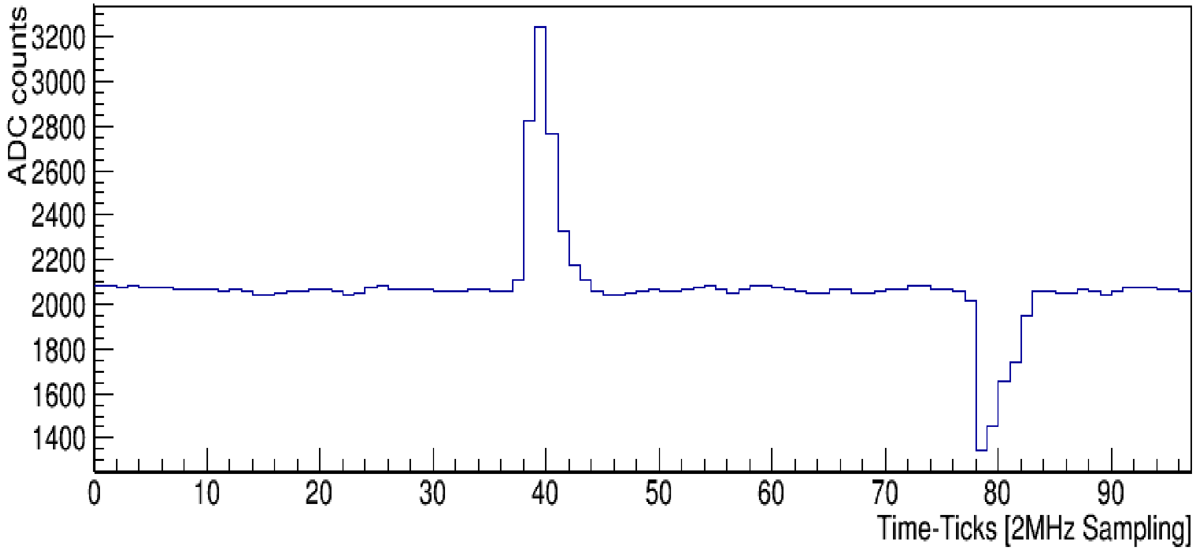
Cold Electronics

- Cold electronics are the same as those to be used in LBNE.
- Lower noise, and allows driving the signal longer distances (important for future large detectors).

- Motherboards installed on the wire carrier boards.

- All channels tested, one feed-through at a time.





Photomultipliers

- Liquid argon produces scintillation light (40k photons/MeV).
- It is in the VUV range, so need a wavelength shifter to see it in PMTs.
- Using acrylic plates coated with TPB.