Recent Results from ArgoNeuT and Status of MicroBooNE

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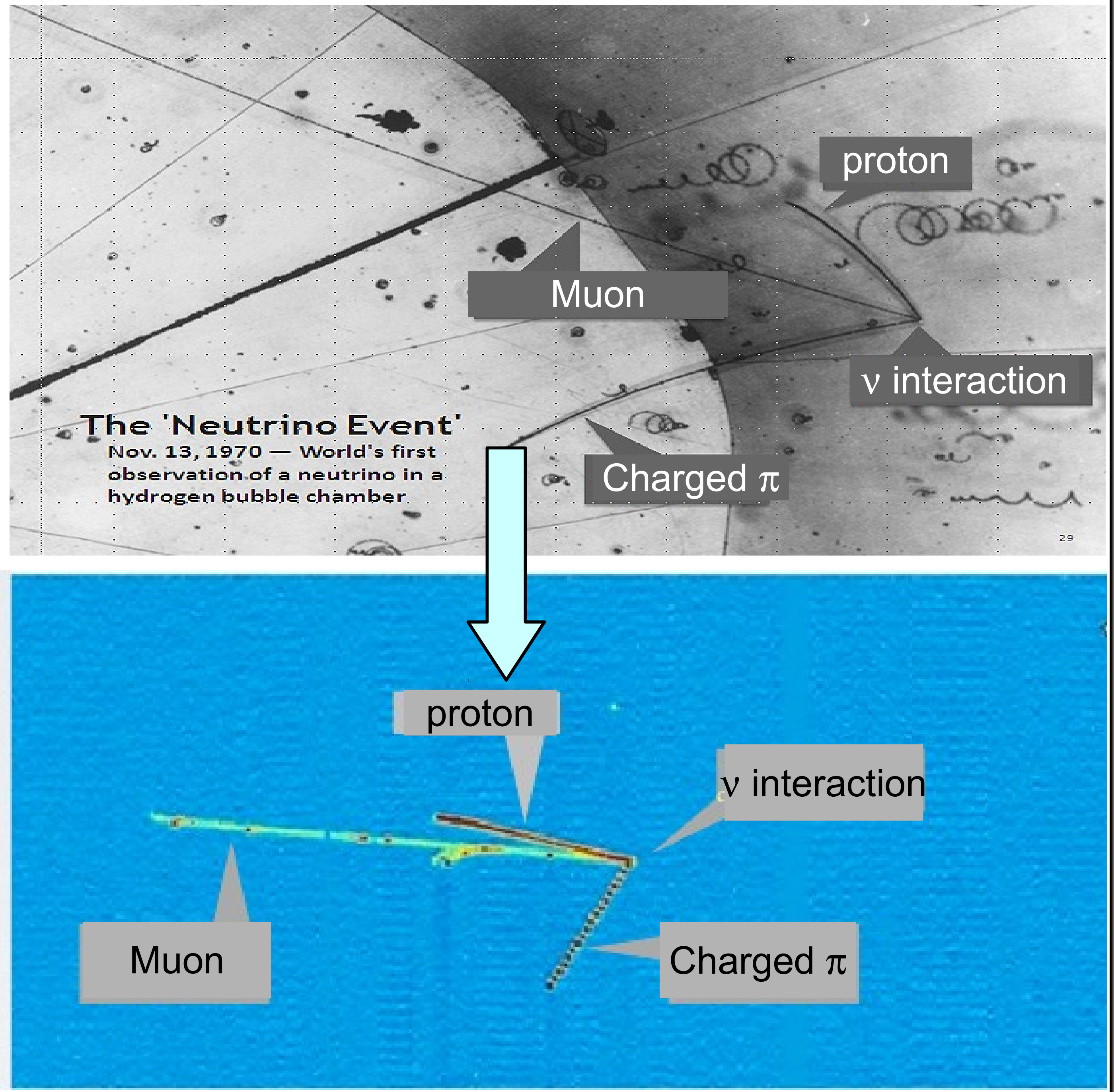
(on behalf of the ArgoNeuT and MicroBooNE collaborations)
Yale University

Why Liquid Argon?

- 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.

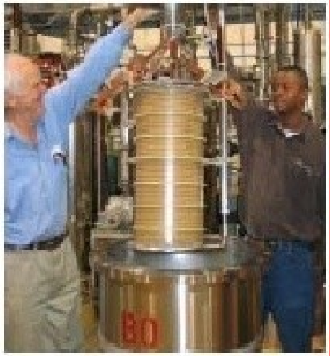


US based LAr R&D program

Yale TPC

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

Bo



Location: Fermilab
Active volume: 0.02 ton
operational 2008

ArgoNeuT

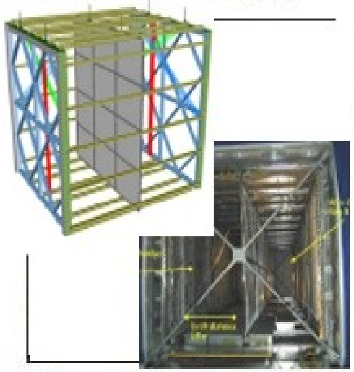
Location: Fermilab
Active volume: 0.3 ton
operational: 2008
First neutrinos: June 2009

MicroBooNE

Location Fermilab
Active volume: 0.1 kton
Operational: 2014

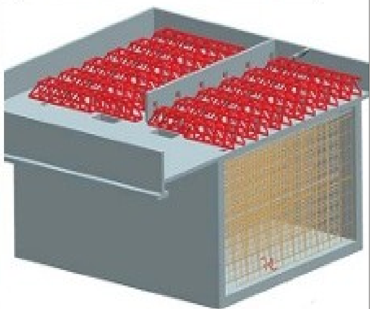
This talk

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

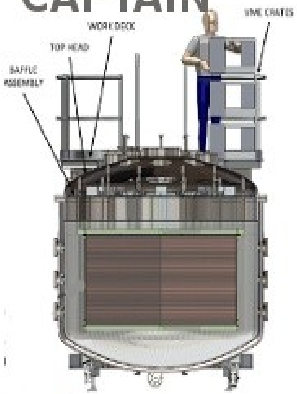
LAPD

Location: Fermilab
Purpose: LAr purity demo
Operational: 2011

LArIAT

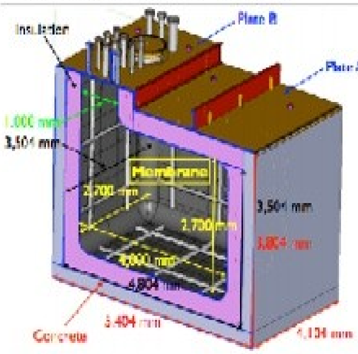
Location: Fermilab
Purpose: LArTPC calibration
Operational: 2014 (phase 1)

CAPTAIN



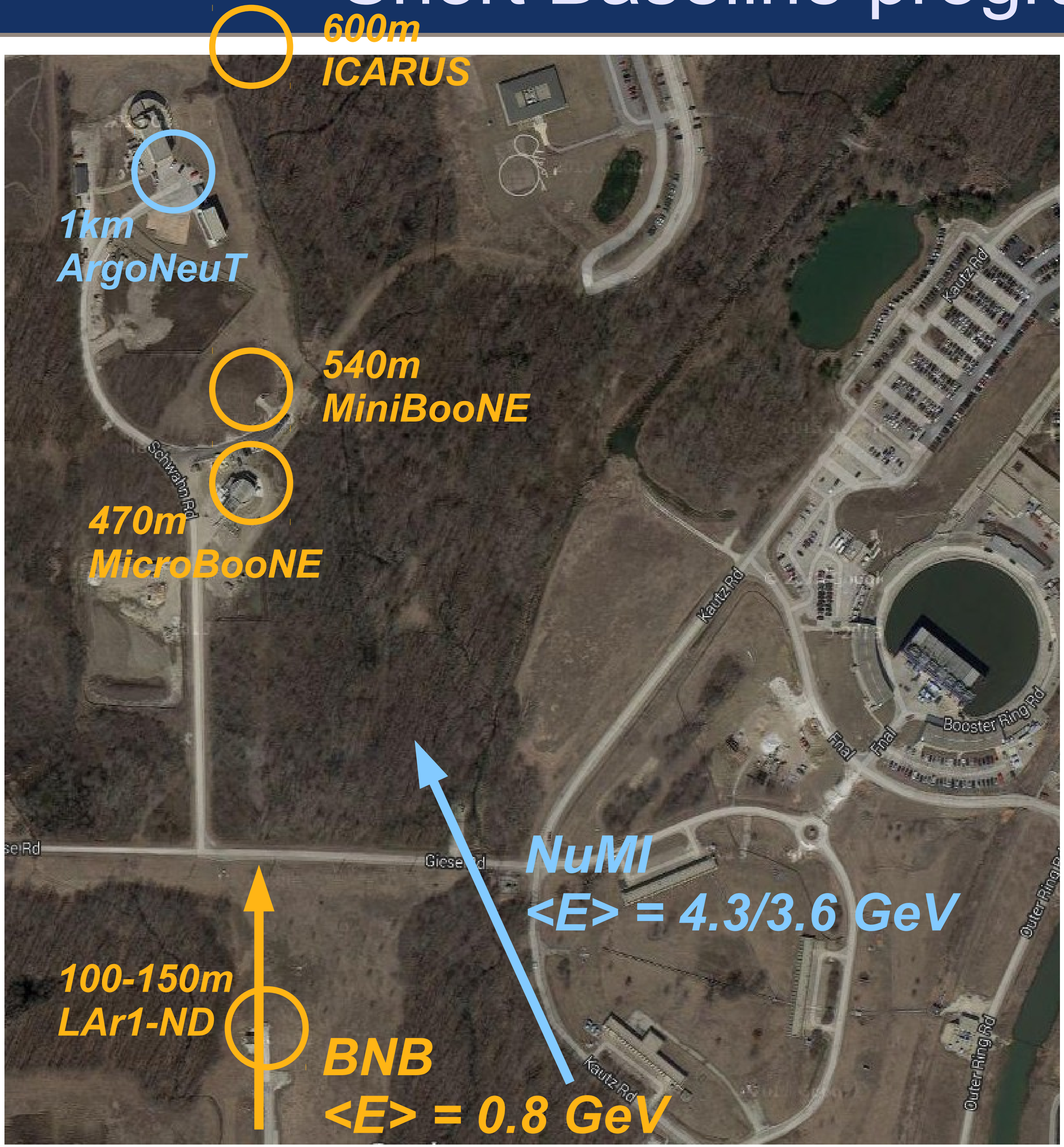
Location: LANL
Purpose: LArTPC calibration
Operational: 2014

LBNE 35 Ton



Location: Fermilab
Purpose: purity demo
Operational: 2013

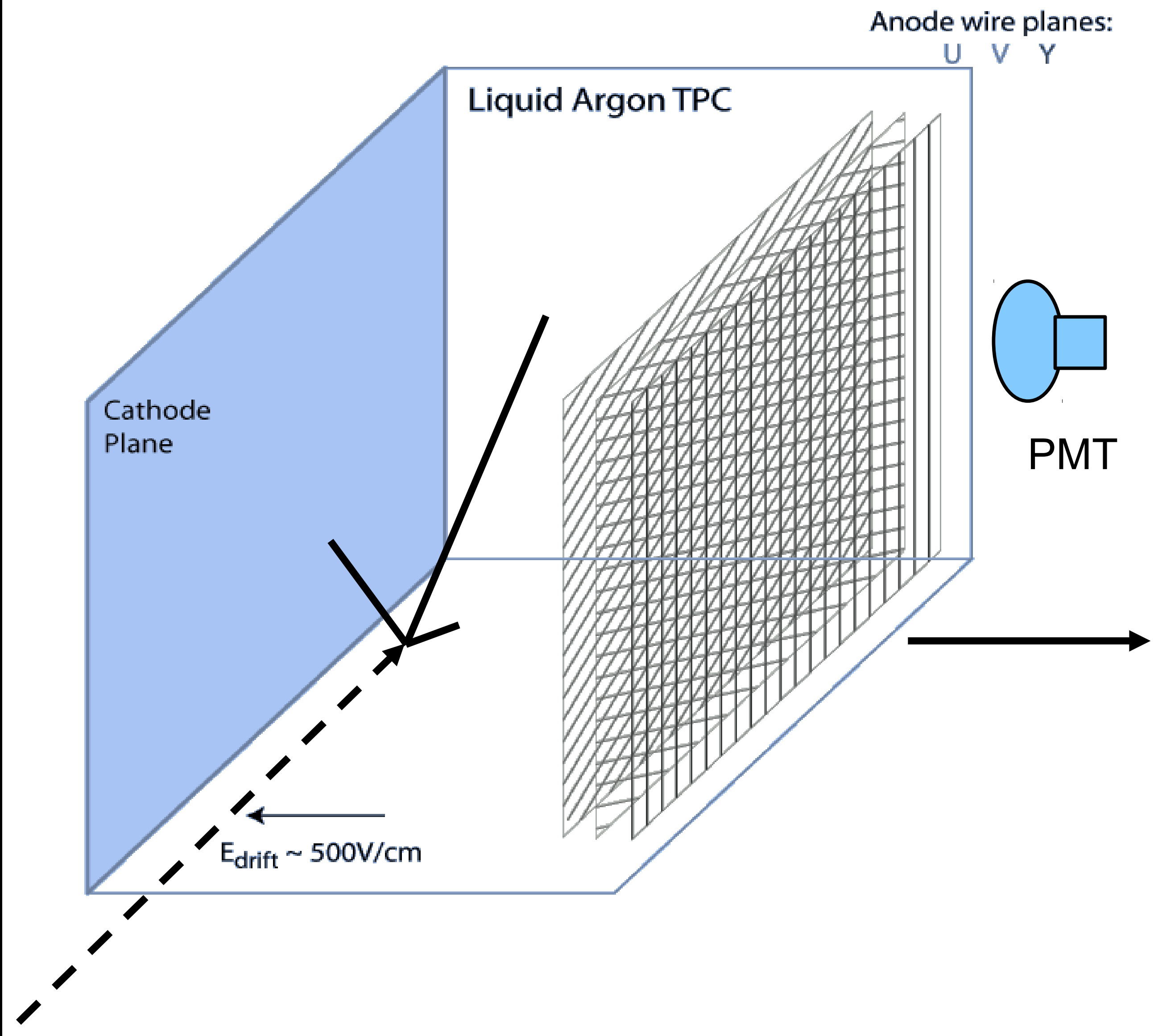
Short Baseline program at FNAL

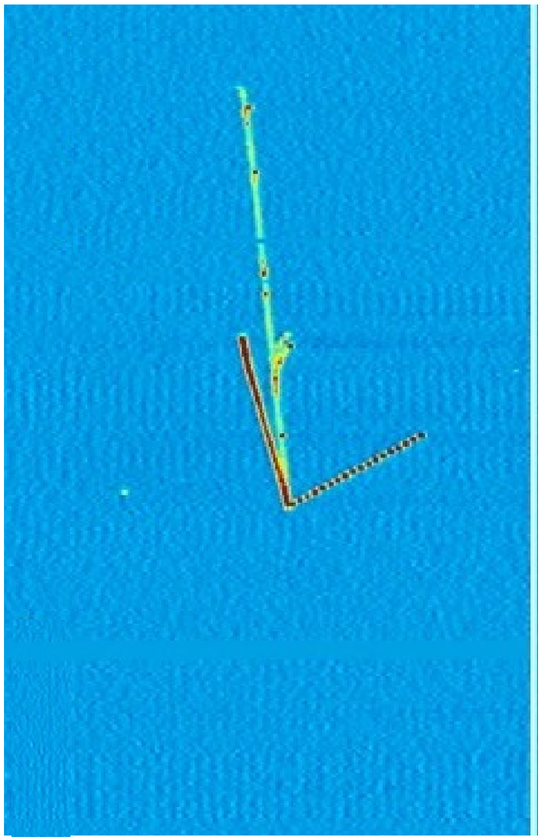


Exciting, precision physics at short baselines (for more see J. Spitz's talk in this session).

Develop the technology by putting the detectors in neutrino beams.

LArTPC Operation

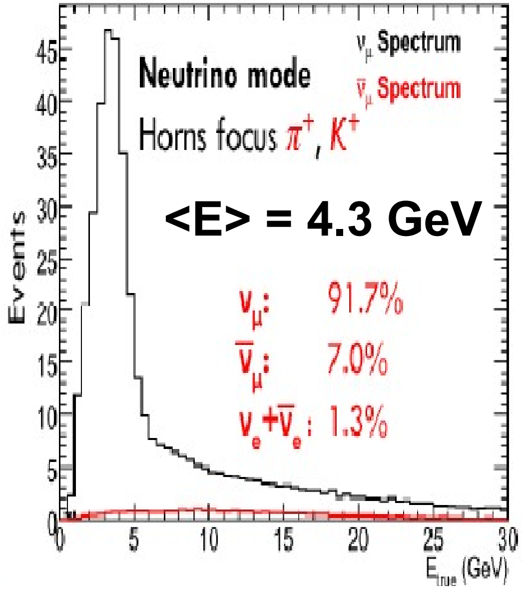


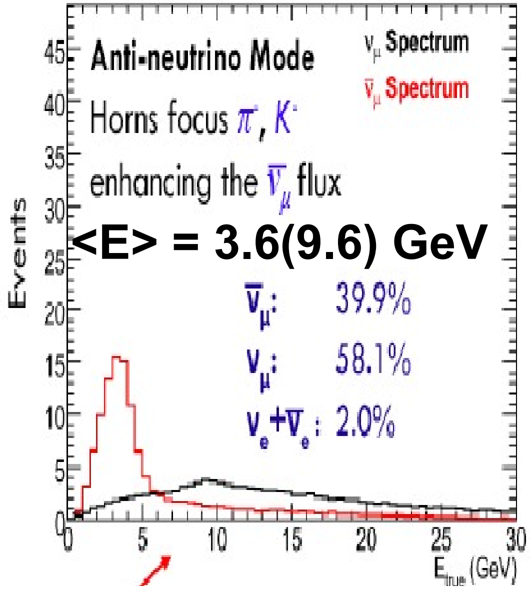


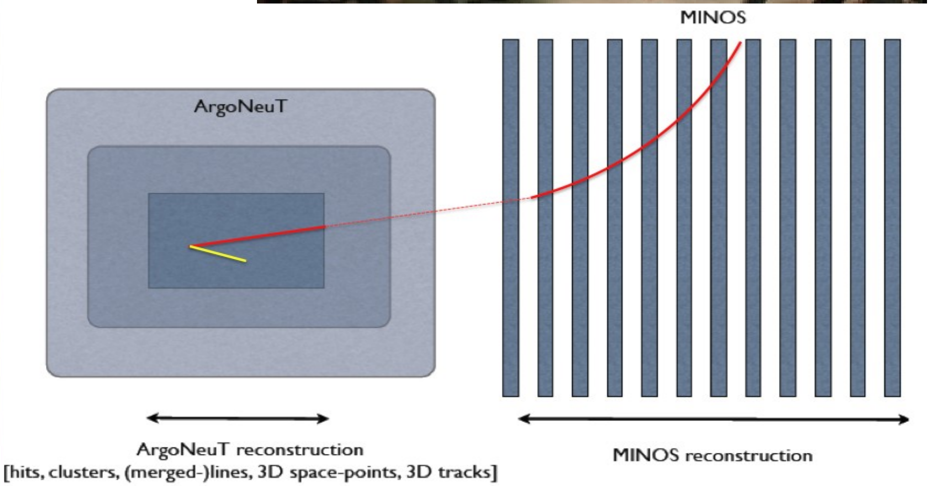
ArgoNeuT in the NuMI beam line

- 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!

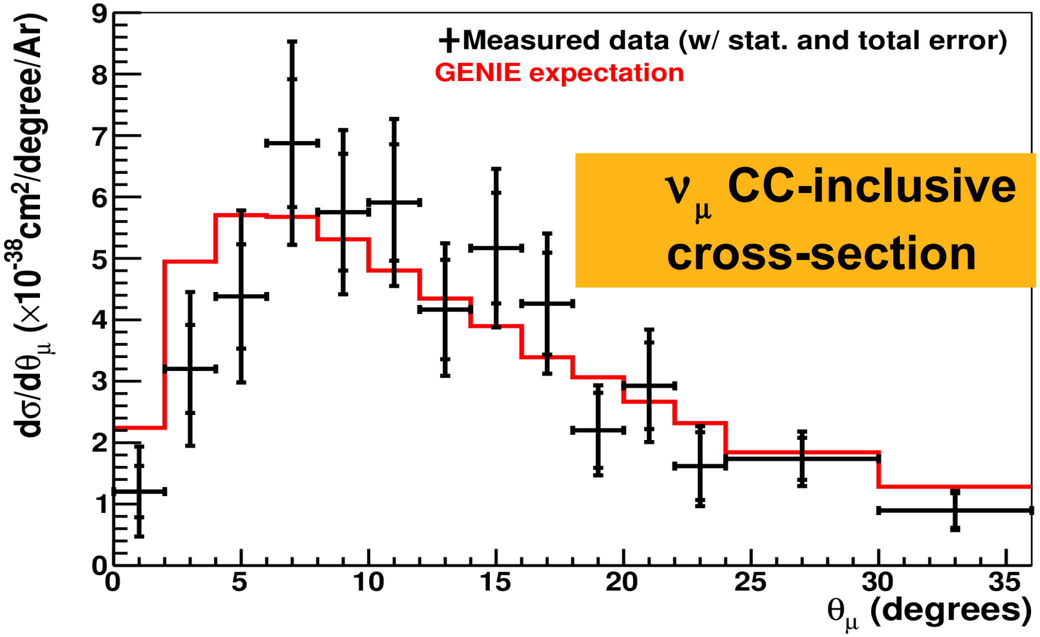
ArgoNeuT tech-paper: JINST 7 (2012) P10019





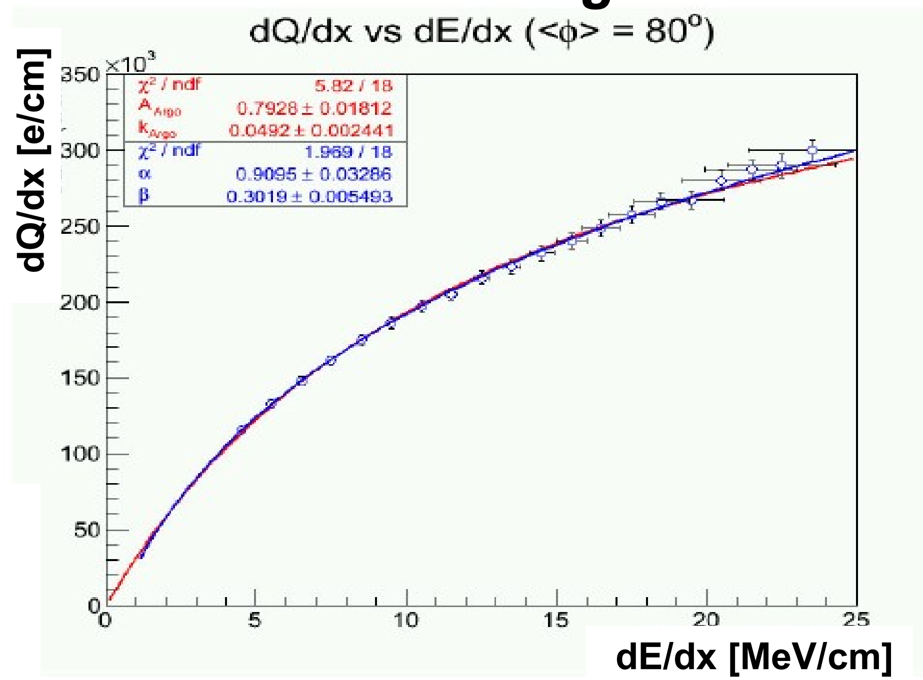


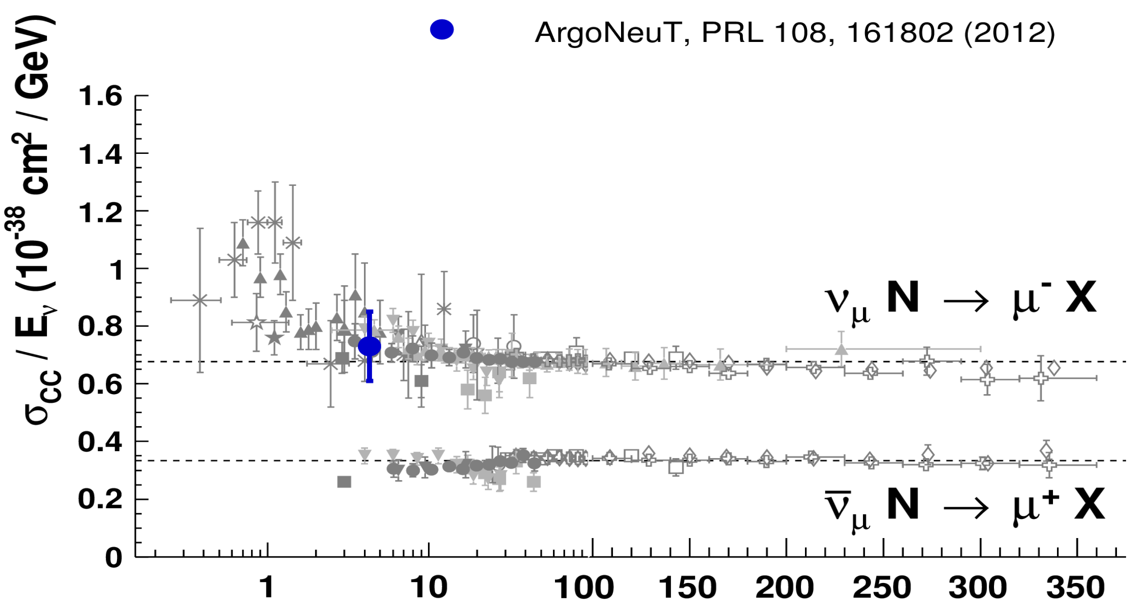
ν_μ Charged Current Inclusive



ν_μ CC-inclusive cross-section

Neutrino mode:
2 weeks of data taking





C. Anderson et al., PRL 108, 2012

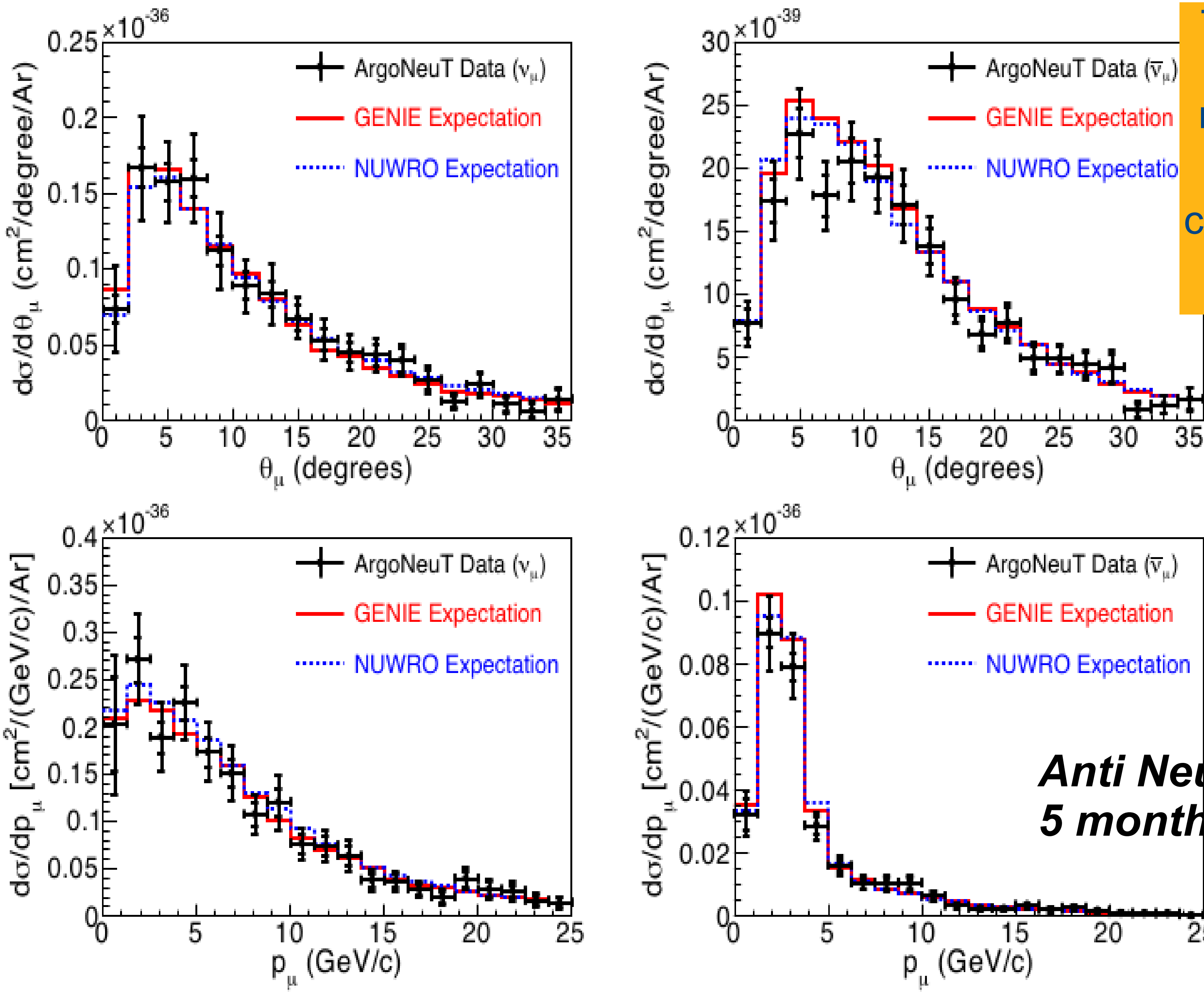
Charge recombination with stopping protons

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

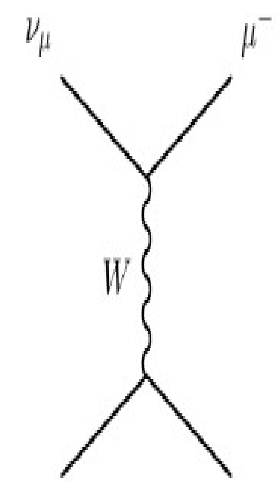
Calorimetry with through-going muons

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

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



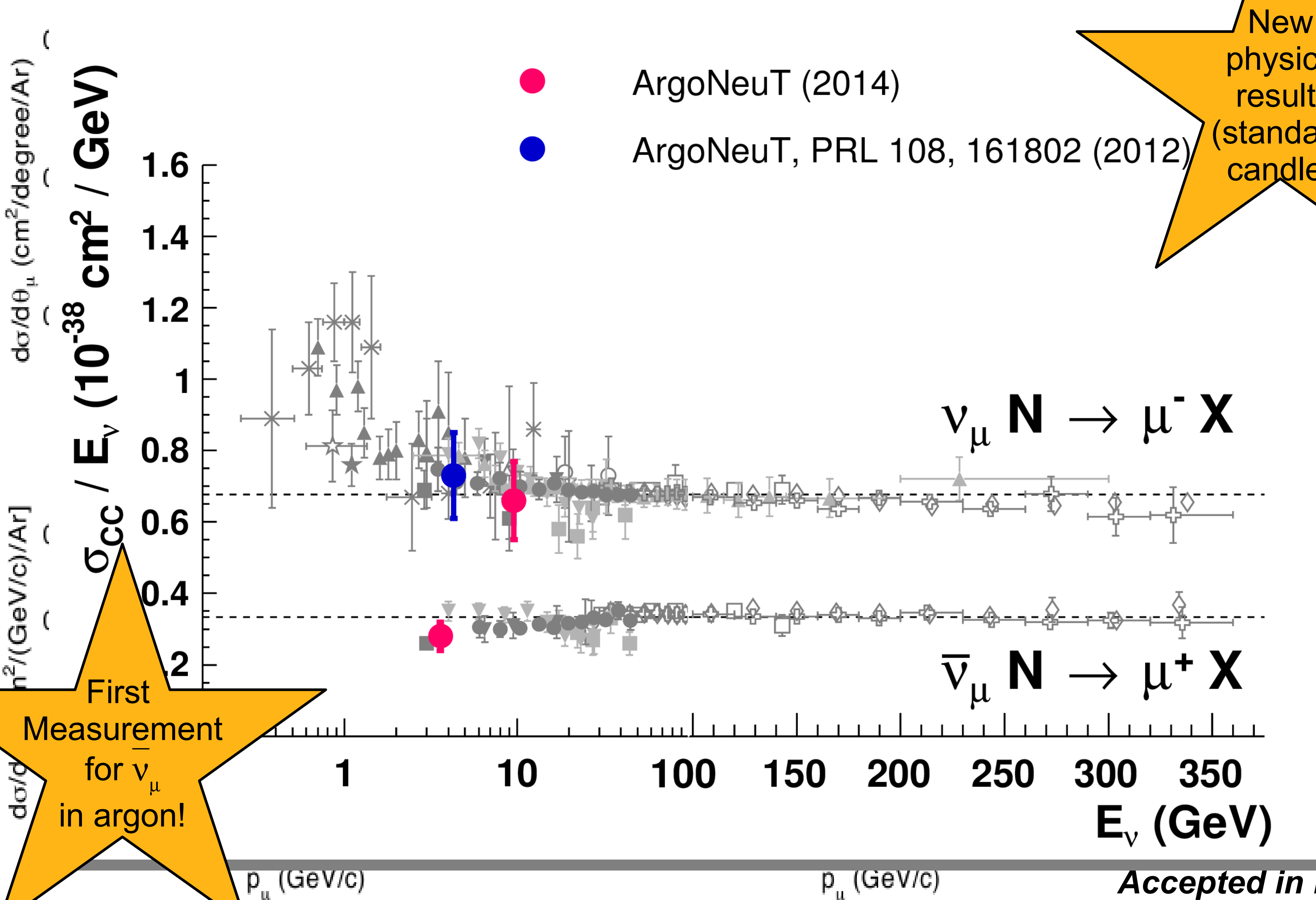
The composition of the beam allows measuring both the $\bar{\nu}_\mu$ and ν_μ components. Charge from MINOS.



Anti Neutrino mode:
5 months of data taking

ArXiv:1404.4809
Accepted in PRD

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



New physics result (standard candle)

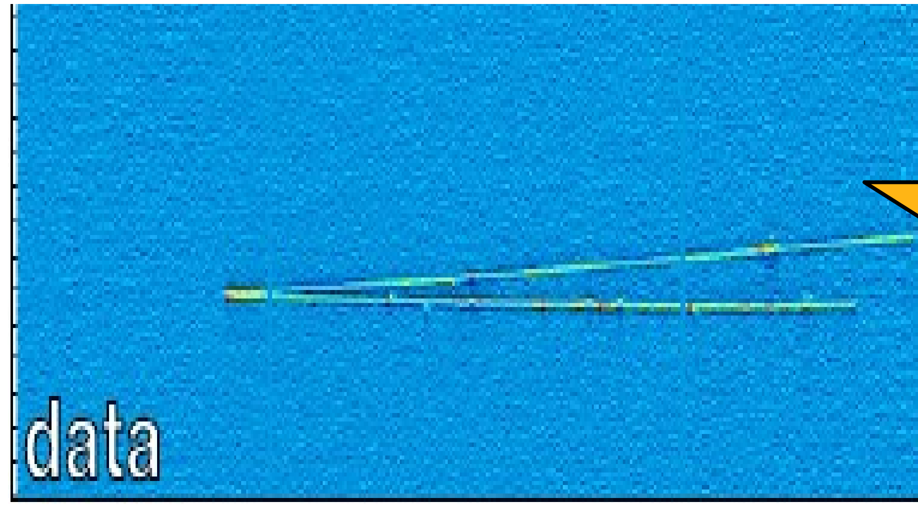
First Measurement for $\bar{\nu}_\mu$ in argon!

Accepted in PRD

Coherent Pion Production

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

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

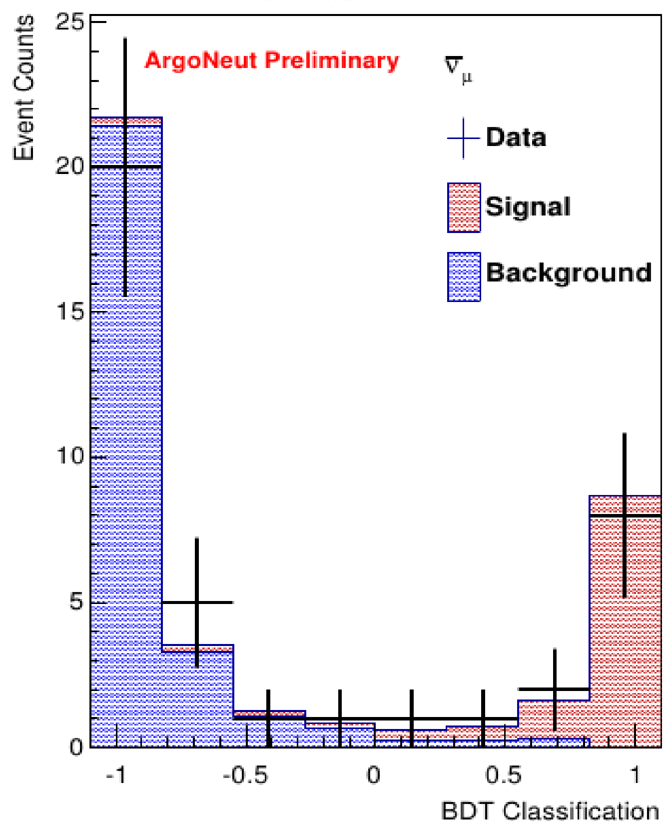


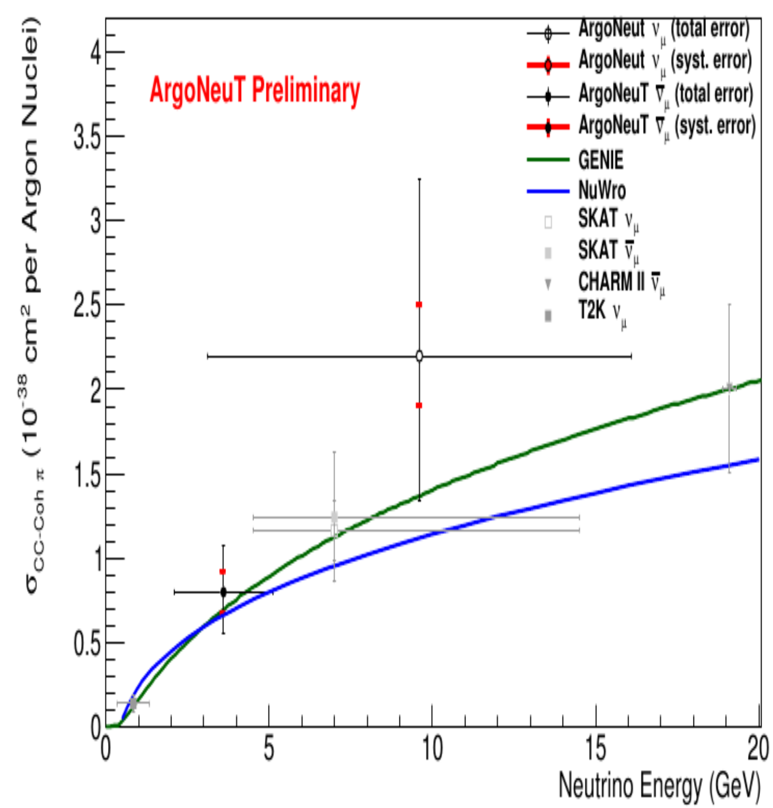
New physics result!

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.



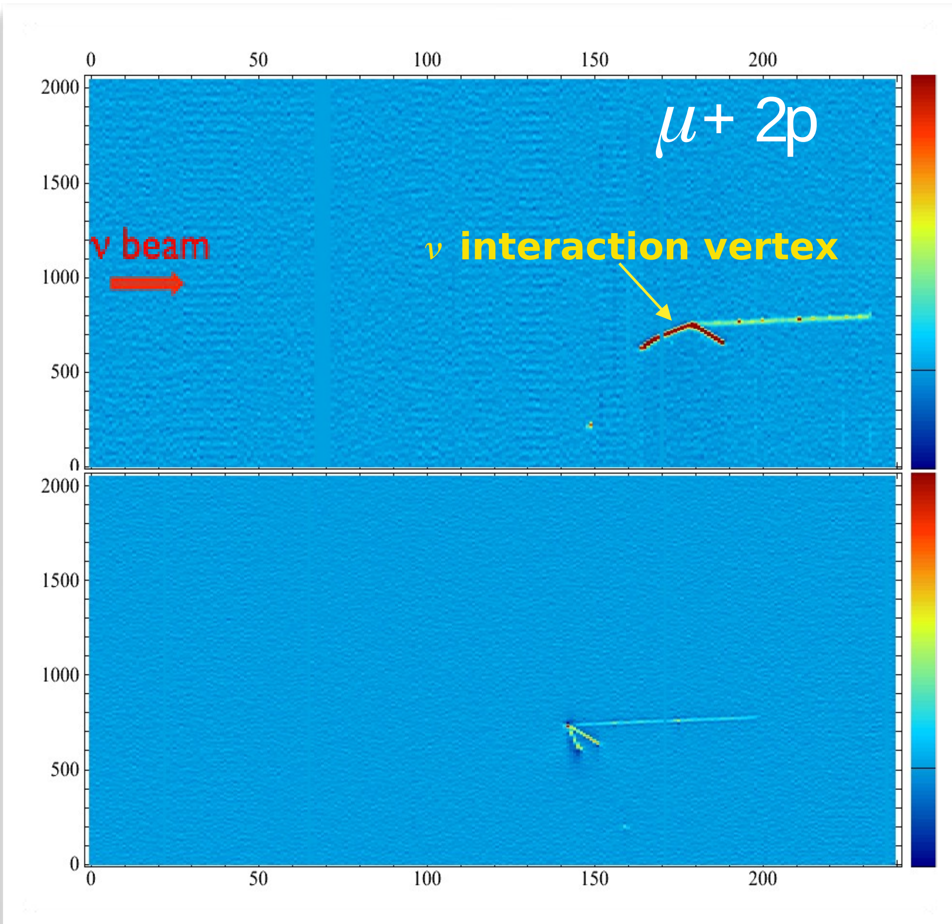


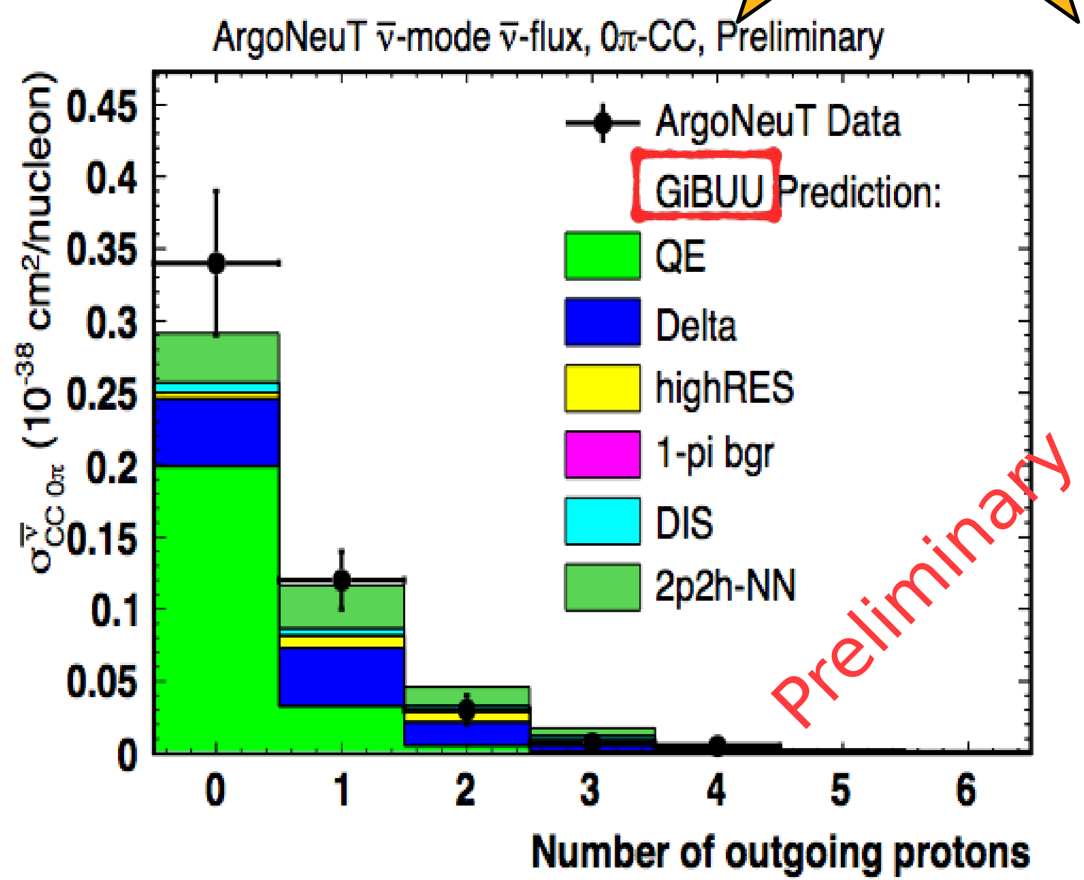
Also, recent results from Minerva and T2K.

Observing proton multiplicities

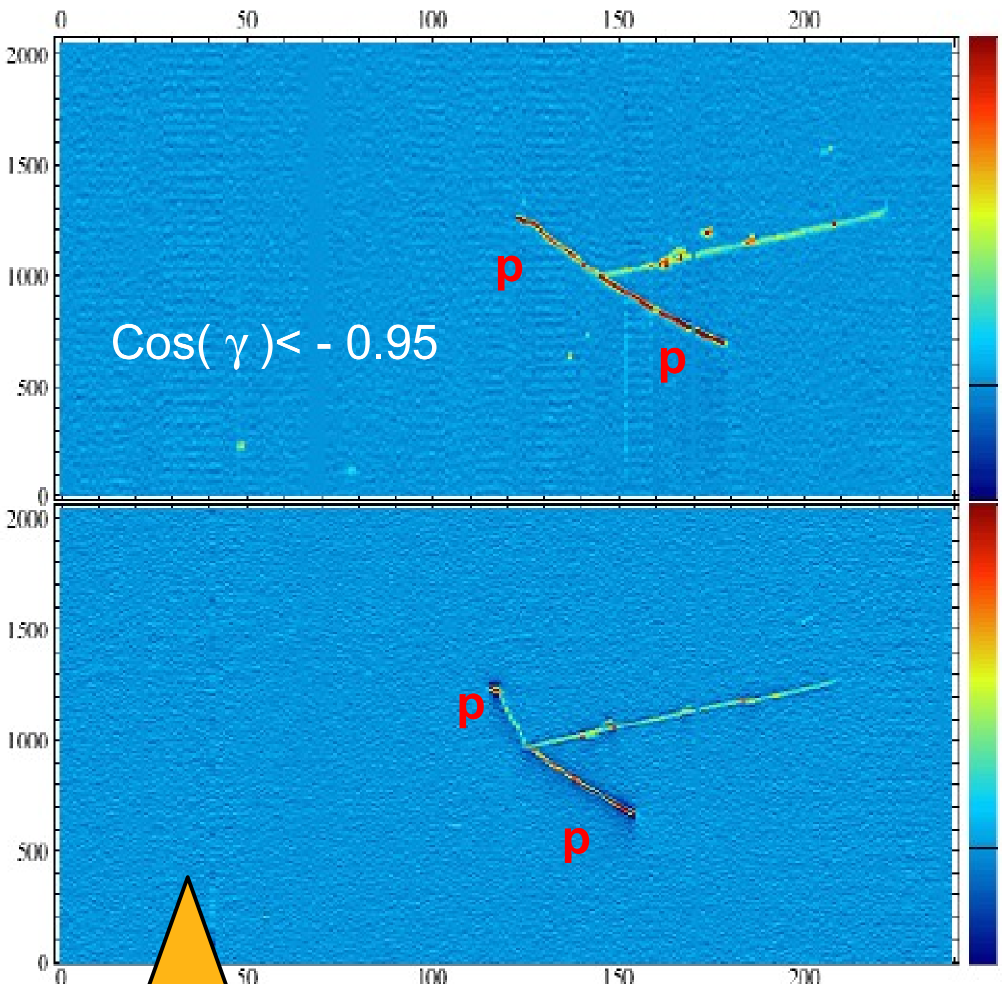
- The granularity of the LArTPC allows seeing actual final state topologies.
- Measuring cross sections as a function of proton multiplicity.

New, LArTPC enabled, physics result!

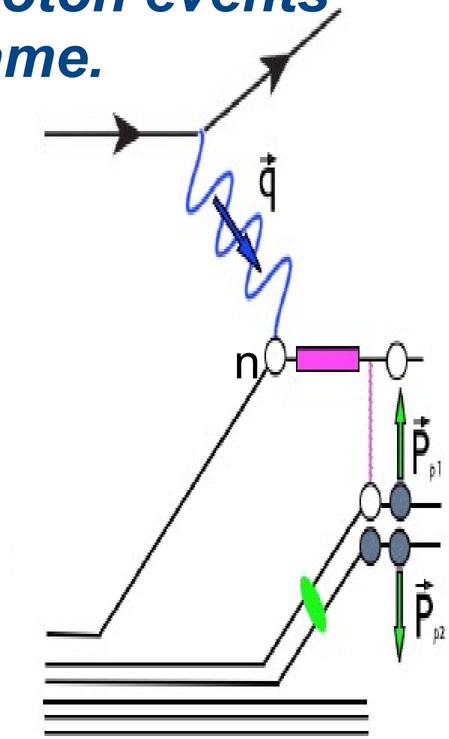




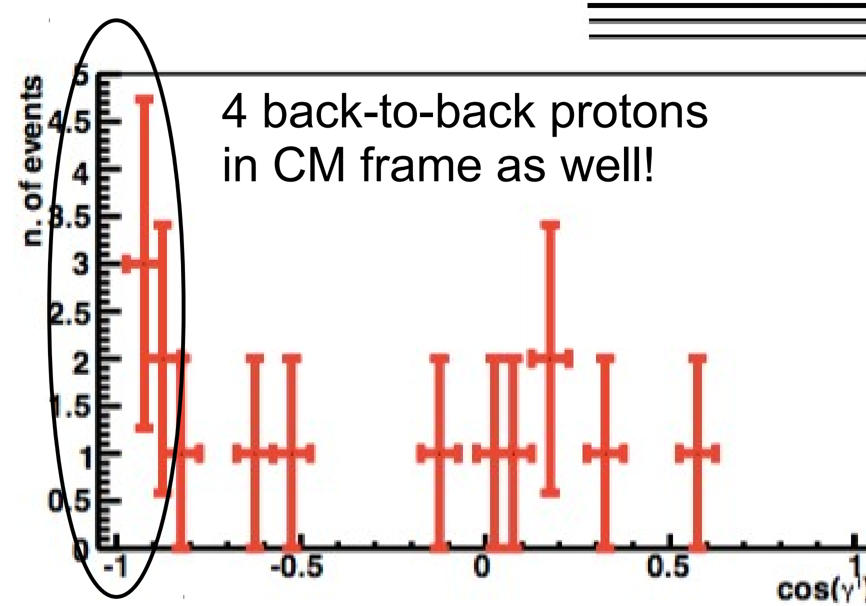
Back-to-Back Protons



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!

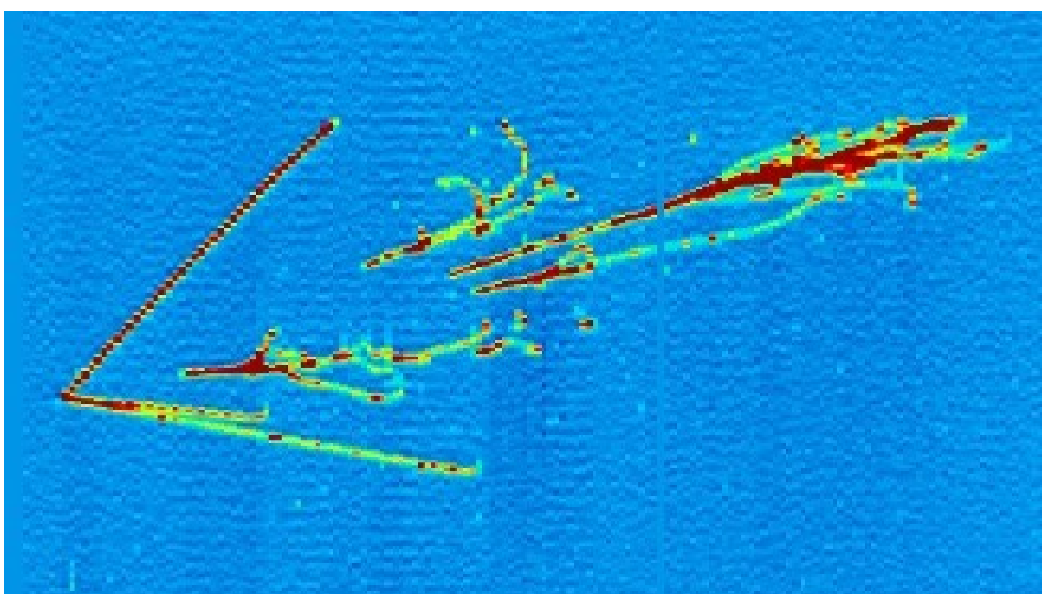
We can see nuclear effects!

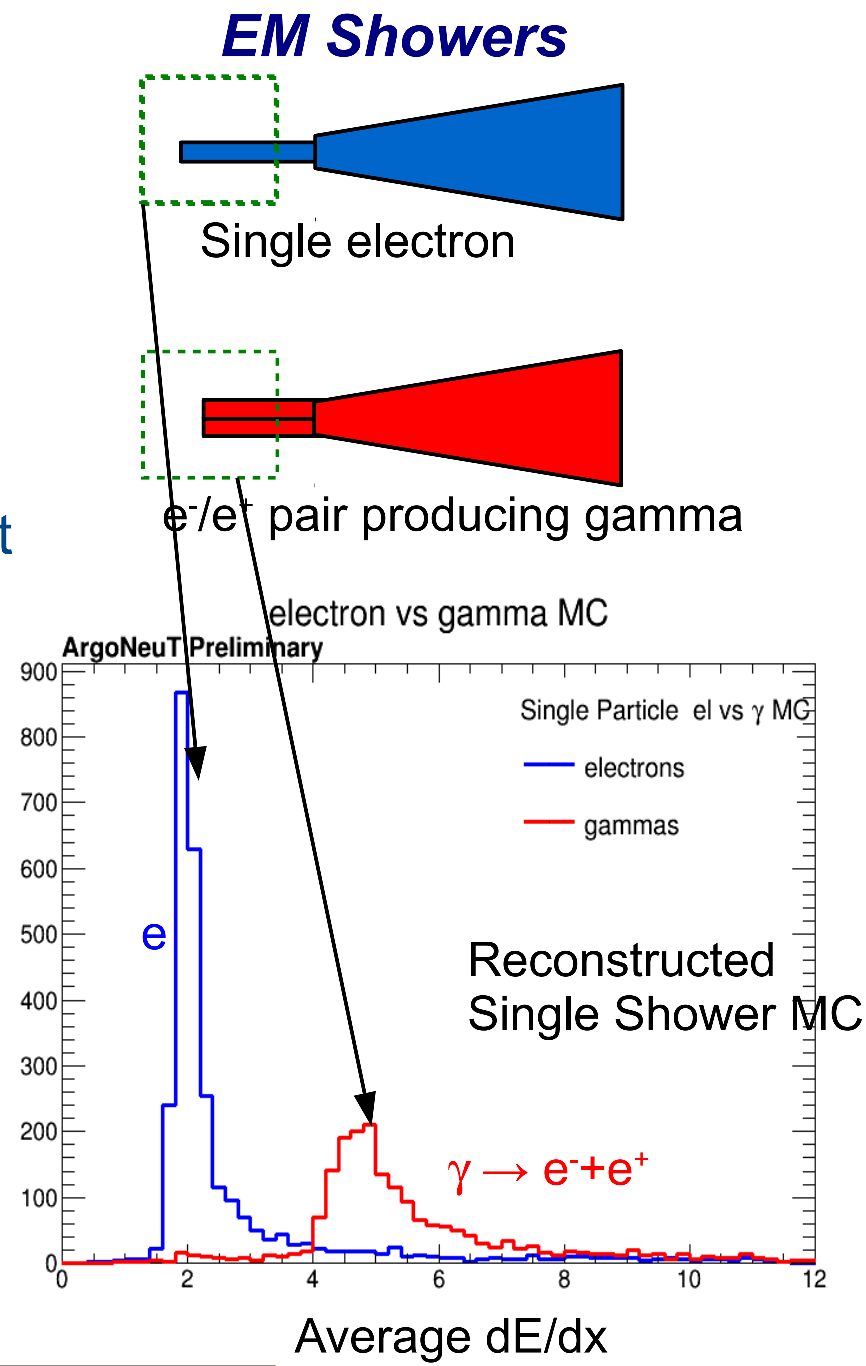
ArXiv:1405.4261

Submitted to PRD

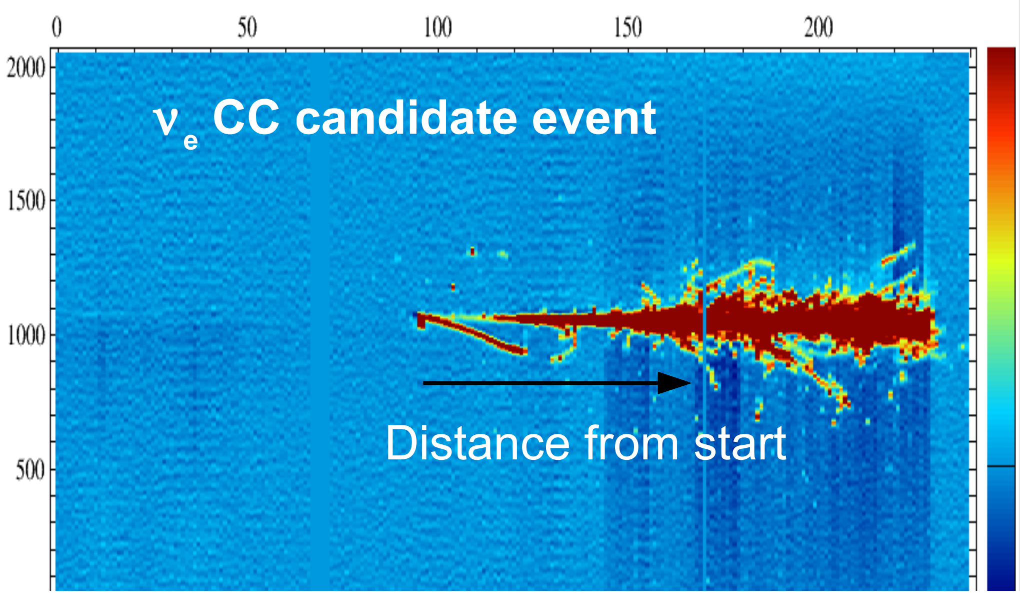
Electron/gamma separation

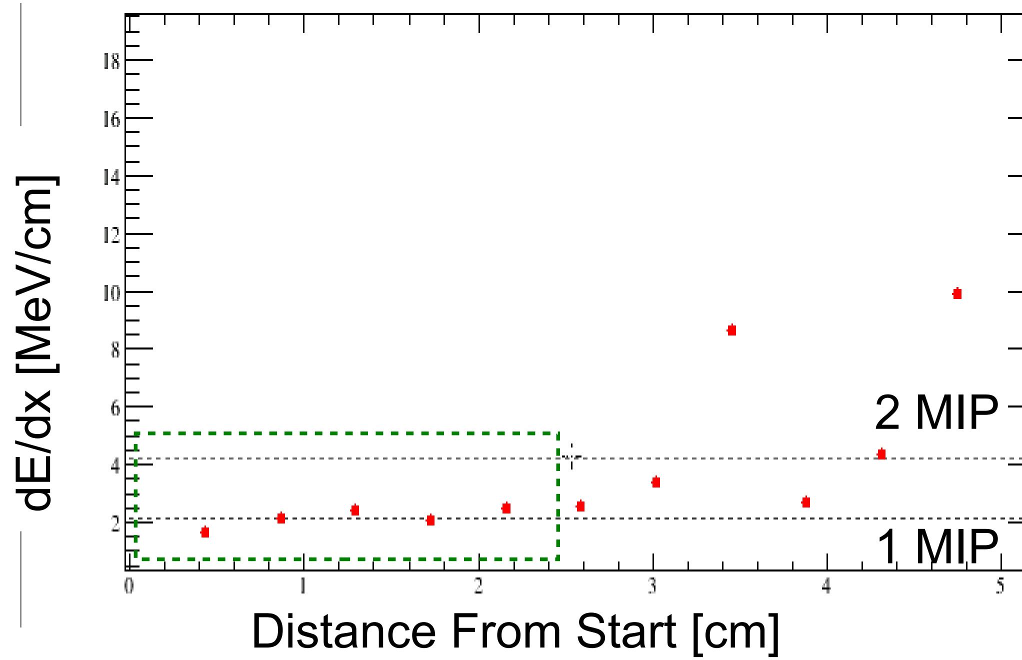
- An EM shower that starts after a gap from the vertex is always background (especially if you can see two of them).
- Even if the gap is very small all is not lost.
  - We can reconstruct the charge at the start of the shower - “dE/dx discrimination”.

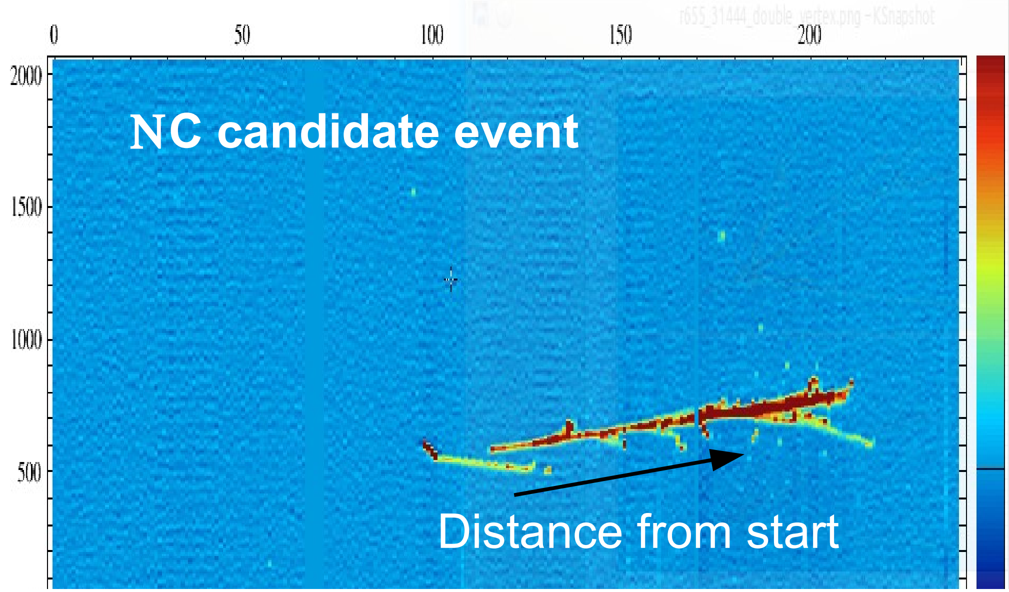


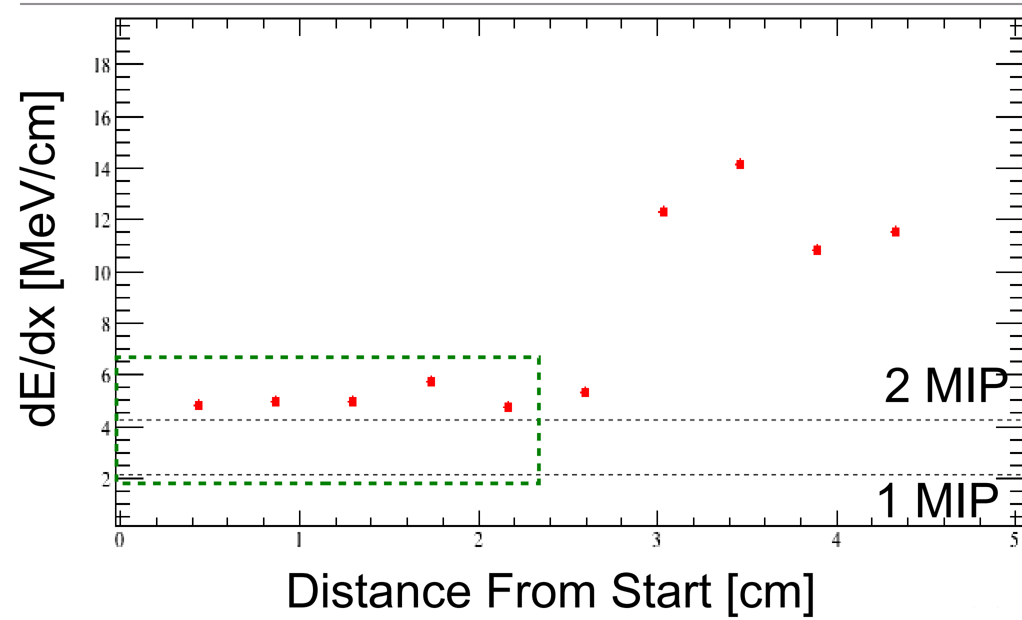


Example events





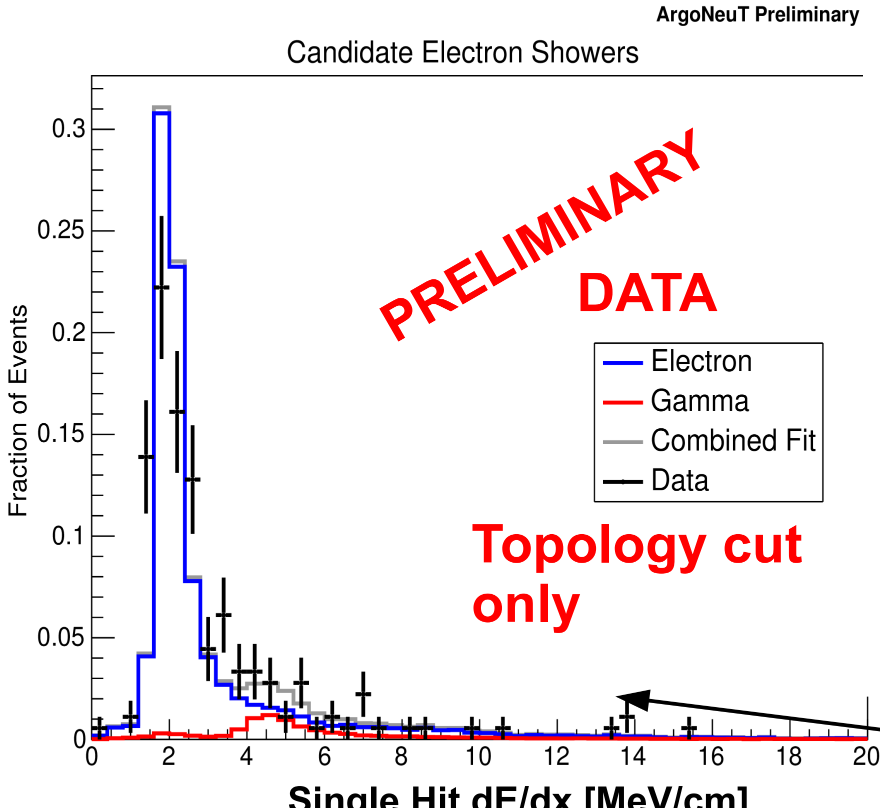




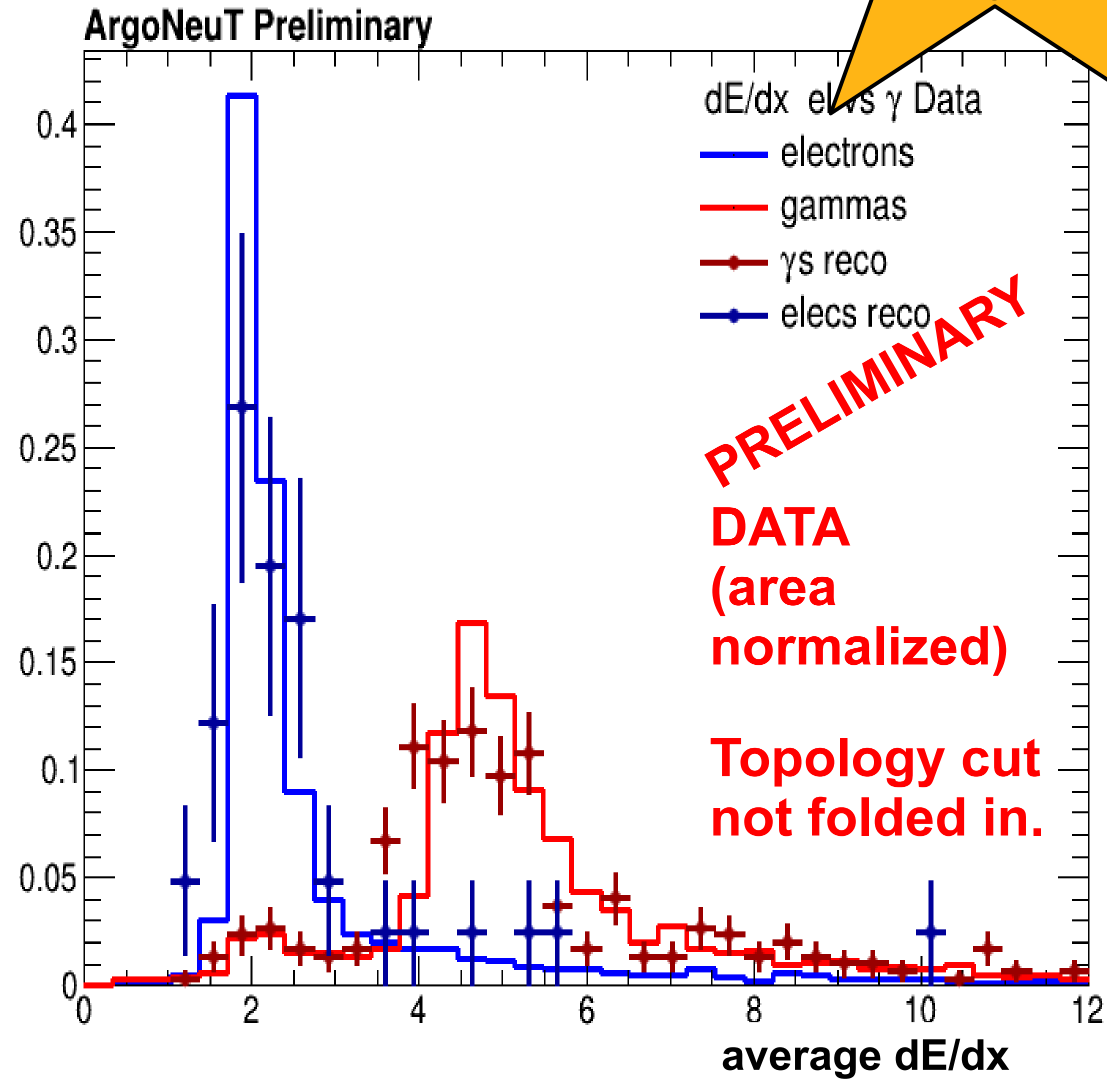
Data-Based dE/dx plot

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.*

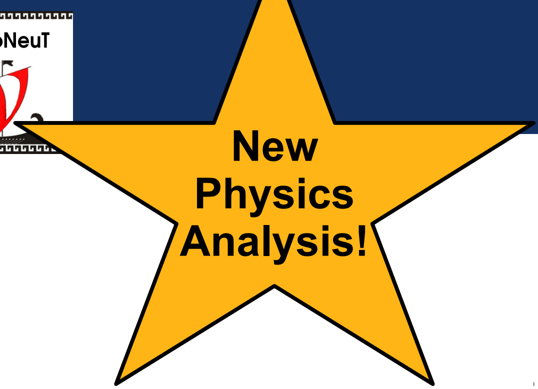


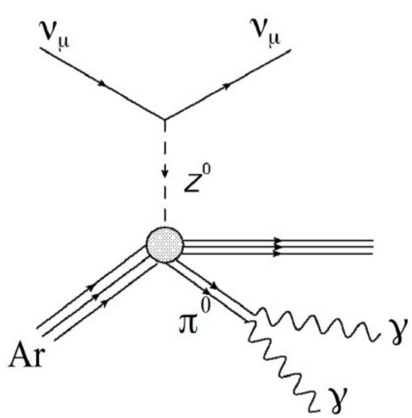
Electron/single gamma separation

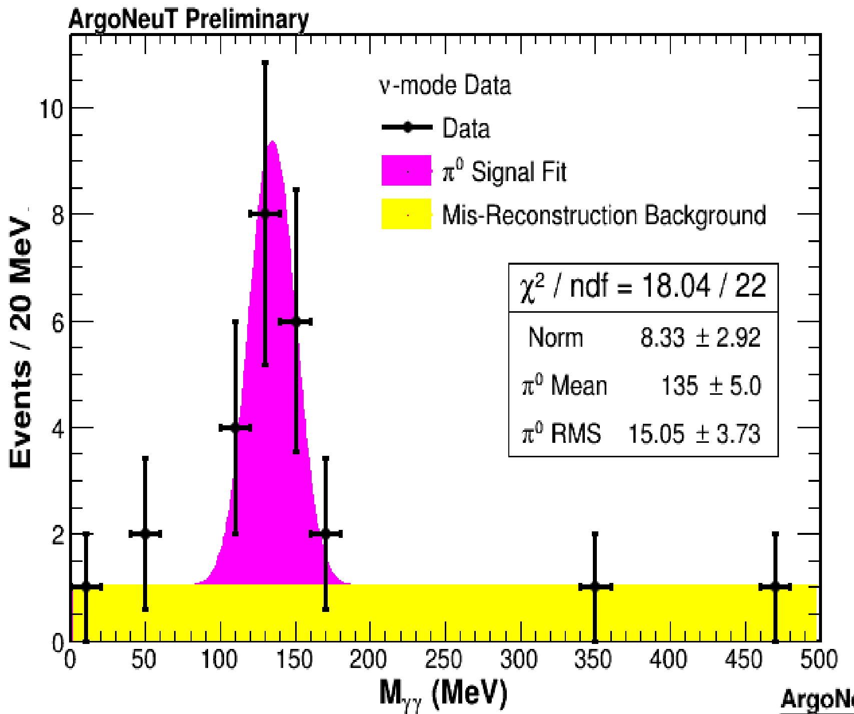


Landau-like distribution of electron event single hit charge depositions.

NC π^0 Study

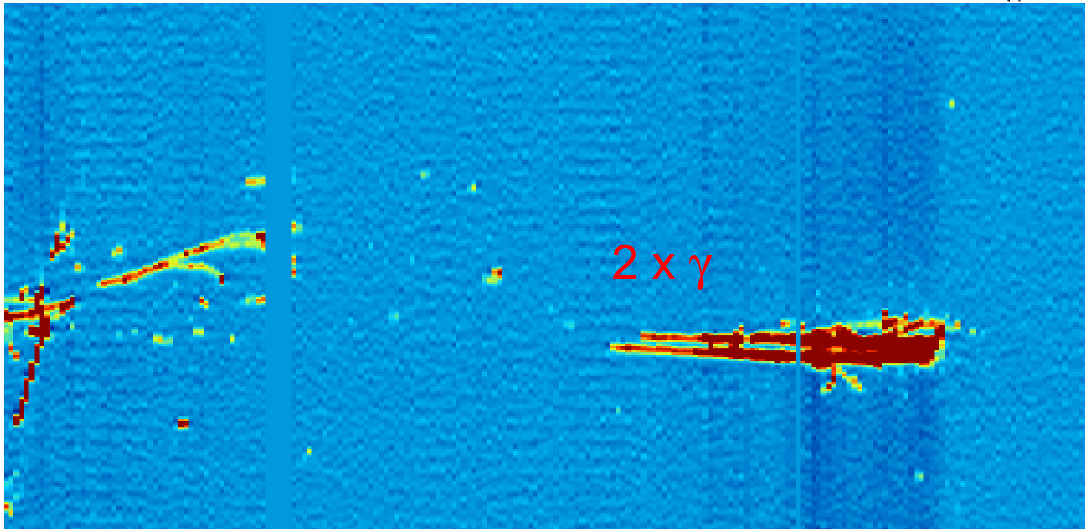


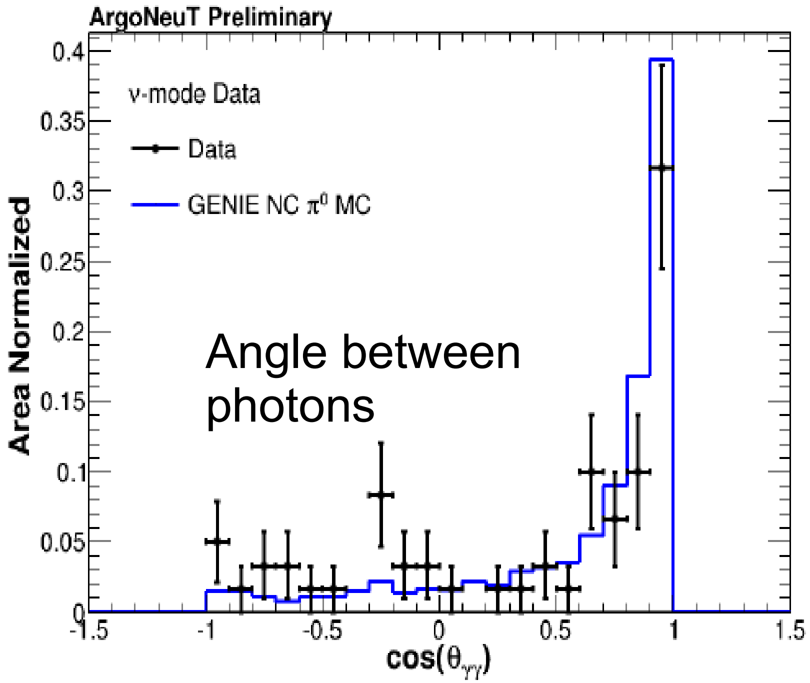




ArgoNeuT is too small to contain the majority of photon showers from π^0's.

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





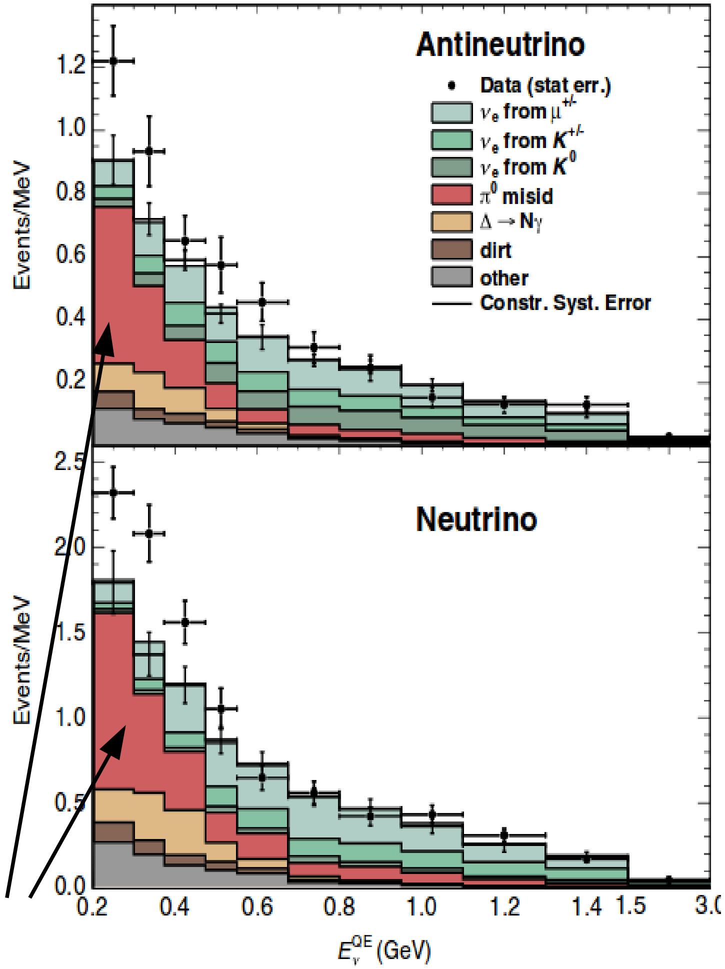
Work continuing to refine the energy corrections and analyze the full data set

MicroBooNE

MicroBooNE and the Short Baseline Anomalies

- MicroBooNE will determine the nature of the MiniBooNE low energy excess by running on the same beam.

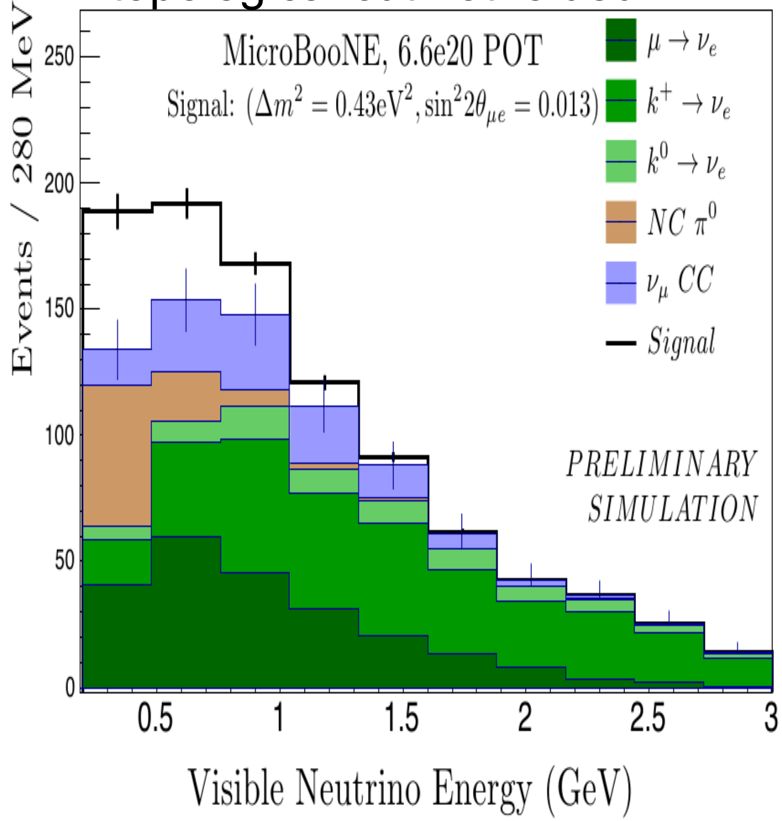
- The granularity and dE/dx separation will allow differentiating between photons and electrons.



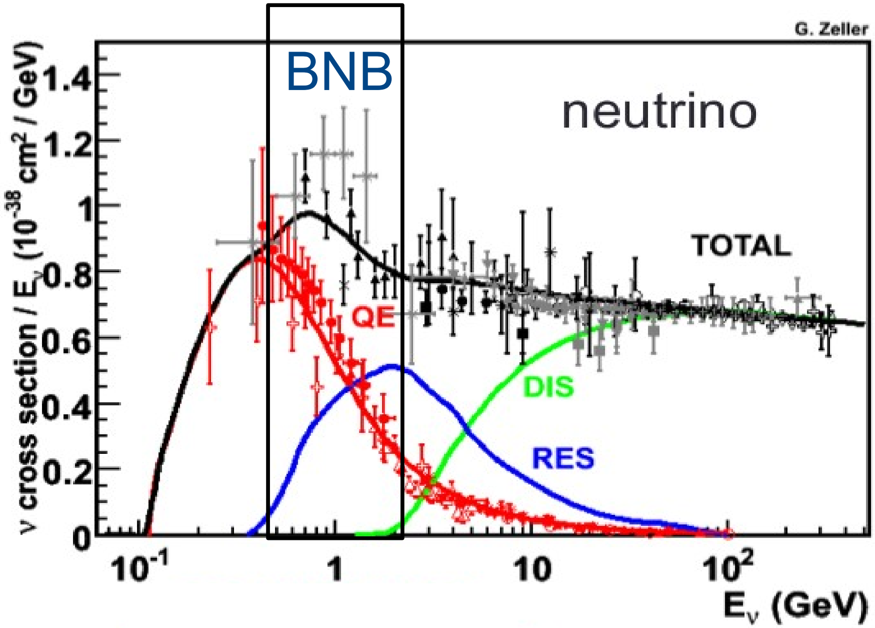
NC π^0 background!

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

topological cut not folded in



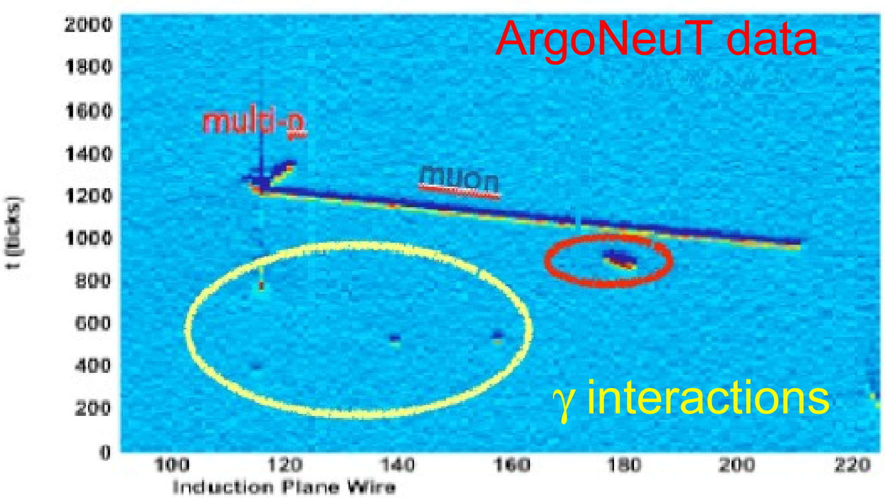
Cross – section and physics R&D



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

Cross-section physics

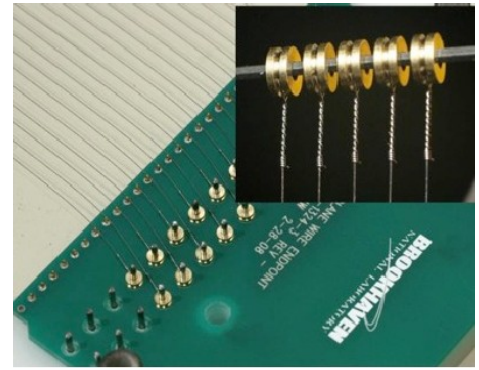
•***Future LAr detectors can be competitive in proton decay studies and complementary in SN detection.*** ***(see K. Scholberg's and B. Wilson's talks, Wed)***

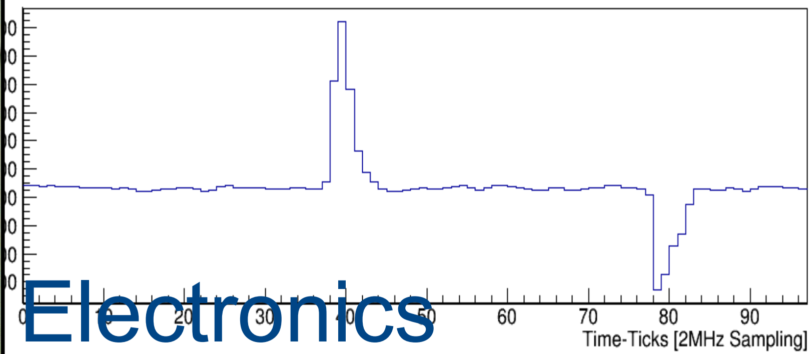


•MicroBooNE will be able to quantify potential backgrounds and test reconstruction methods for nucleon decay and see SN neutrinos.

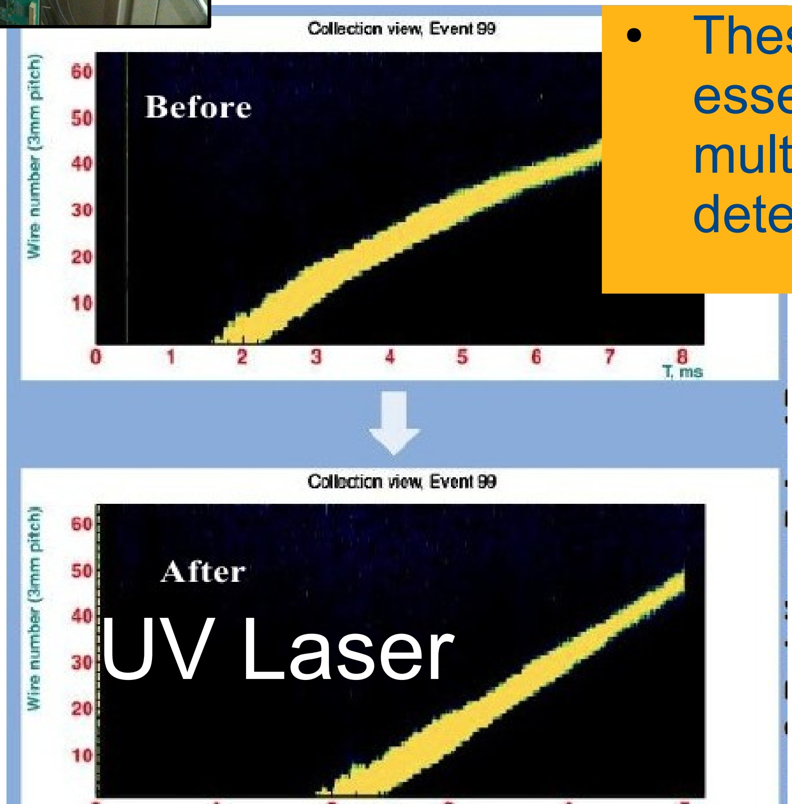
Physics R&D

TPC wires + PMTs





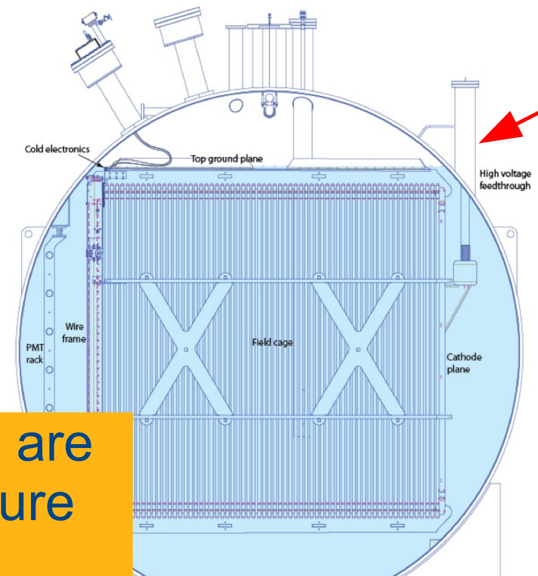
Cold Electronics



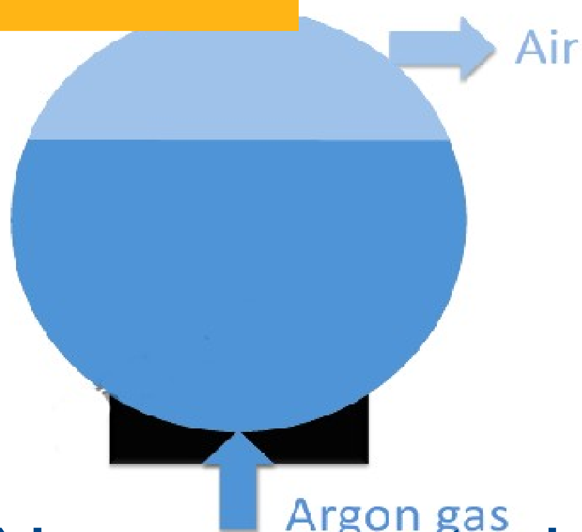
UV Laser

A. Ereditato et al. ArXiv: 1304.6961

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



High voltage



Non evacuated vessel

TPC push-in: Fri, 20th Dec, 2013

Cryostat welding Tue, 20th May, 2014

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!

Conclusions

- There is a vibrant LAr neutrino program at FNAL.
- First time LArTPC cross-section results are shown at Neutrino.
- We are laying the foundation of the long term vision of multi-kTon LAr neutrino detectors.

Thank You!

Brookhaven Lab
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- Veljko Radeka
- Sergio Rescia
- Andres Ruga
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- Gabriel Collin
- Janet Conrad
- Christina Ignarra
- Ben Jones
- Jarrett Moon
- Matt Toups
- Taritree Wongjirad
- Joshua Spitz

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- Dan Edmunds
- Brian Page

MicroBooNE and **ArgoNeuT** collaborations

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- 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

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

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- Jonathan Asaadi
- Jessica Esquivel
- Mitch Soderberg (*)

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

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- Igor Kreslo
- Michele Weber
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- Thomas Strauss

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- Ornella Palamara

Virginia Tech
- Mindy Jen
- Leonidas Kalousis
- Camillo Mariani

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

Posters you should have seen:

118 44 Liquid Argon Time Projection Chambers: MicroBooNE and Future Prospects for Neutrino Oscillation Physics. - A. Hackenburg

374 48 Measuring particle momenta via Multiple Coulomb Scattering with the MicroBooNE Time Projection Chamber. - L. Kalousis

184 45 PMT Triggering and Readout for the MicroBooNE Experiment. - D. Kaleko

185 46 Readout Electronics for the Time Projection Chamber in the Microboone Experiment. - D. Caratelli.

208 47 Muon Neutrino Disappearance with MicroBooNE and LAr1-ND, - J. Zennamo

375 54 Electron Neutrino Appearance with Multiple LArTPCS on the Booster Neutrino Beam. - C. Adams

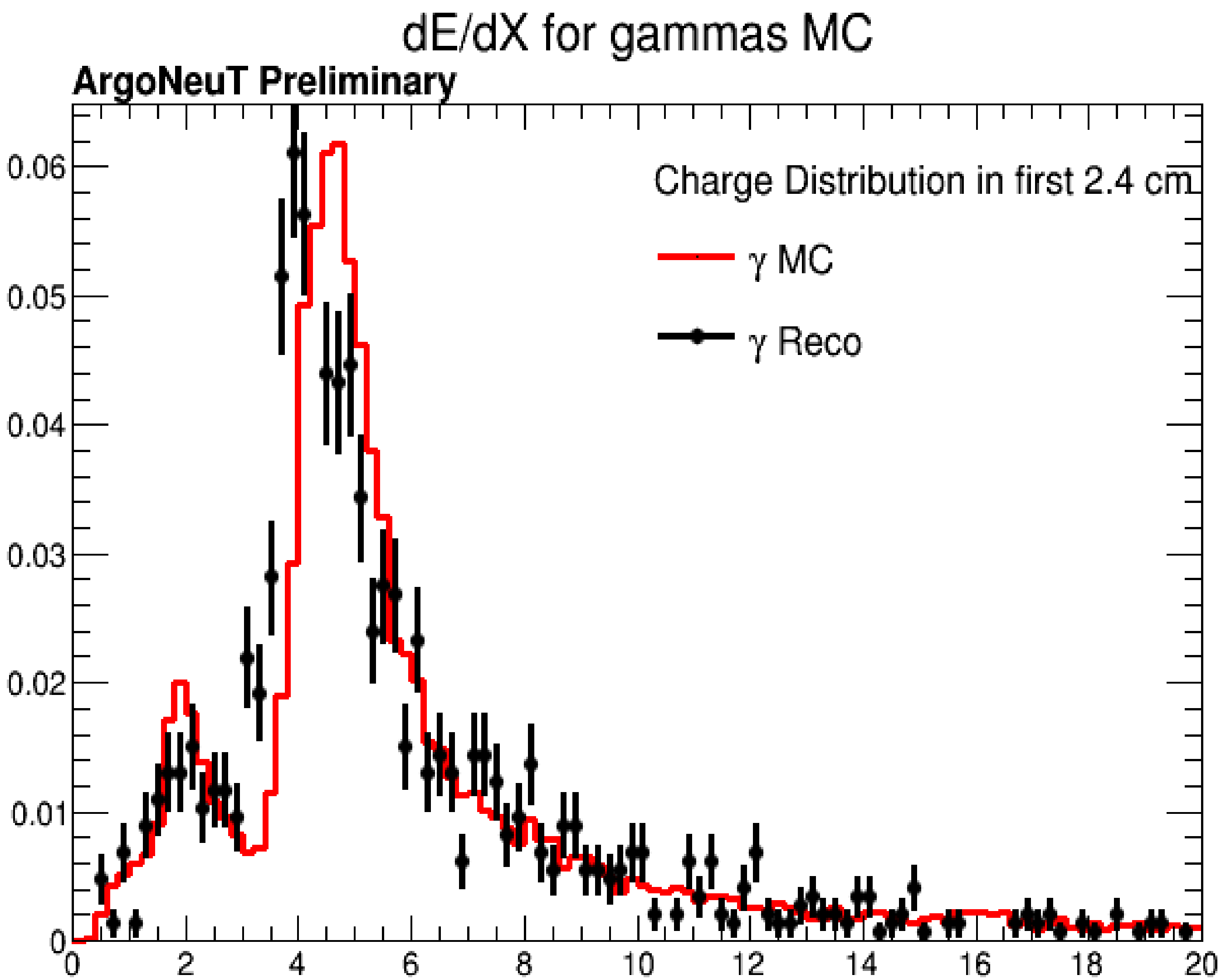
199 51 Investigating Surge Protection Devices to Protect Against Transient Over-voltages in Liquid Argon Time Projection Chambers. - J. Asaadi.

229 52 Liquid Argon Scintillation Studies with the Bo Test Stand. - B. Jones.

197 24 Argon spectral function implementation for LBNE/MicroBooNE. - C-M. Jen

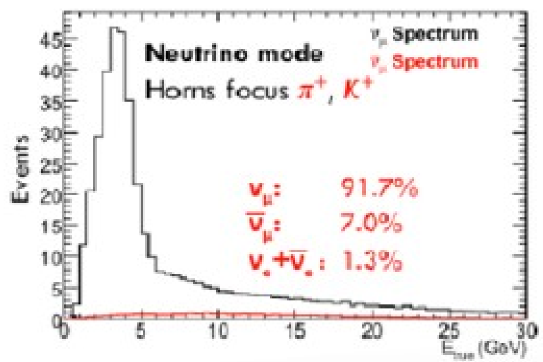
117 49 LArIAT. - J. St. John.

209 50 Light readout system tests and simulations on the way towards light - augmented calorimteric reconstruction and PID in LArIAT. - P. Kryczyński.

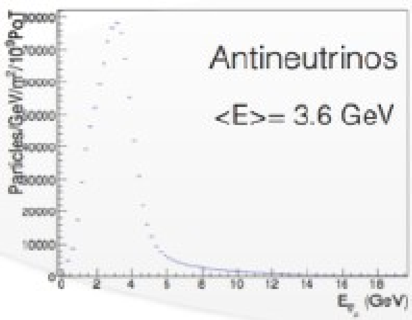

dE/dX for gammas MC
ArgoNeuT Preliminary
Charge Distribution in first 2.4 cm
γ MC
γ Reco
0.06
0.05
0.04
0.03
0.02
0.01
0
0
2
4
6
8
10
12
14
16
18
20

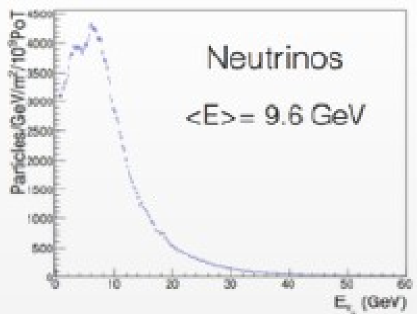
Fluxes

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** $\overline{\nu}_\mu$'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

NuInt14, London

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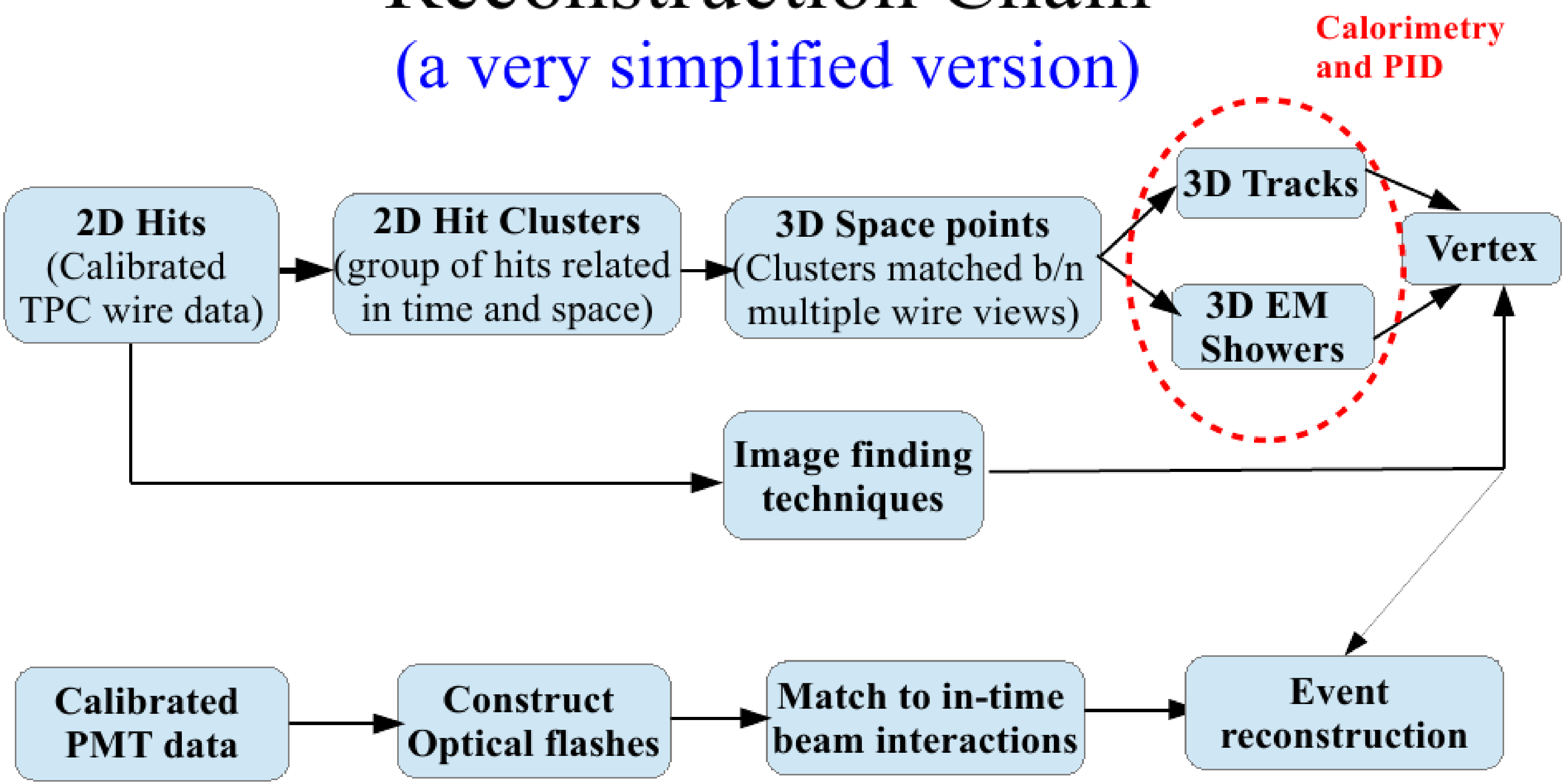
Reconstruction Chain
(a very simplified version)

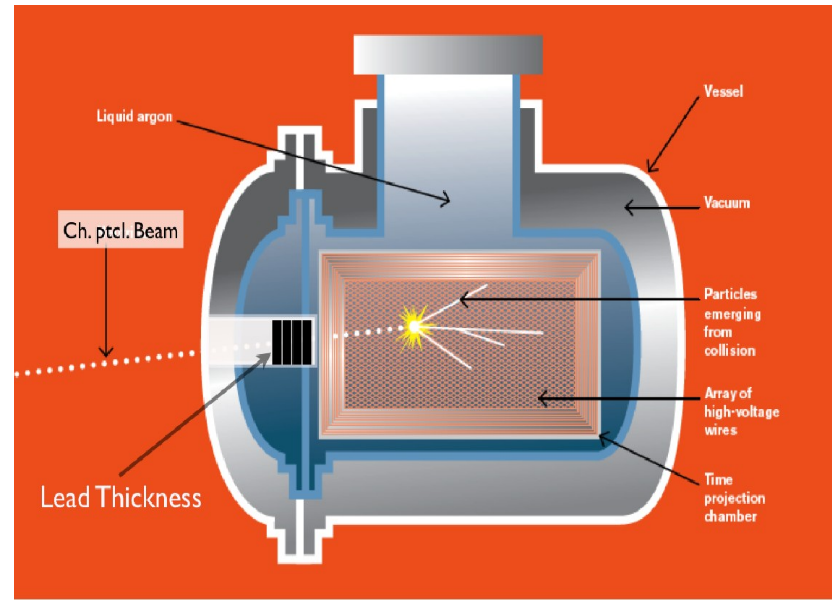


Process		No. Events
	ν_μ Events (By Final State Topology)	
CC Inclusive		88,098
CC 0 π	$\nu_\mu N \rightarrow \mu + Np$	56,580
	· $\nu_\mu N \rightarrow \mu + 0\mathrm{p}$	12,680
	· $\nu_\mu N \rightarrow \mu + 1\mathrm{p}$	31,670
	· $\nu_\mu N \rightarrow \mu + 2\mathrm{p}$	5,803
	· $\nu_\mu N \rightarrow \mu + \geq 3\mathrm{p}$	6,427
CC 1 $\pi^{\pm}$	$\nu_\mu N \rightarrow \mu + \mathrm{nucleons} + 1\pi^{\pm}$	21,887
CC $\geq 2\pi^{\pm}$	$\nu_\mu N \rightarrow \mu + \mathrm{nucleons} + \geq 2\pi^{\pm}$	1,953
CC $\geq 1\pi^0$	$\nu_\mu N \rightarrow \mathrm{nucleons} + \geq 1\pi^0$	9,678
NC Inclusive		33,000
NC 0 π	$\nu_\mu N \rightarrow \mathrm{nucleons}$	21,509
NC 1 $\pi^{\pm}$	$\nu_\mu N \rightarrow \mathrm{nucleons} + 1\pi^{\pm}$	4,886
NC $\geq 2\pi^{\pm}$	$\nu_\mu N \rightarrow \mathrm{nucleons} + \geq 2\pi^{\pm}$	635
NC $\geq 1\pi^0$	$\nu_\mu N \rightarrow \mathrm{nucleons} + \geq 1\pi^0$	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	$\nu_\mu n \rightarrow \mu^- \mathrm{p}$	48,626
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

ArgoNeuT becomes LArIAT

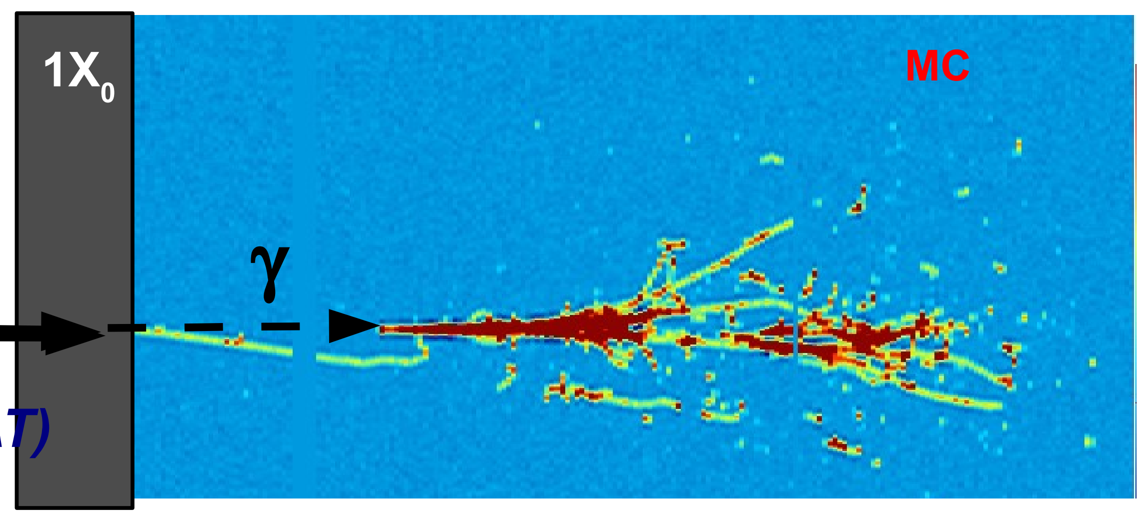
LArIAT by running in an instrumented charged particle beam line will allow us to tag electrons, providing a clean sample of events (and higher statistics).



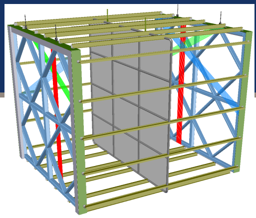
Electrons are found in tertiary beam. Photons generated via brehmsstrahlung in $1X_0$ pre-shower disk.

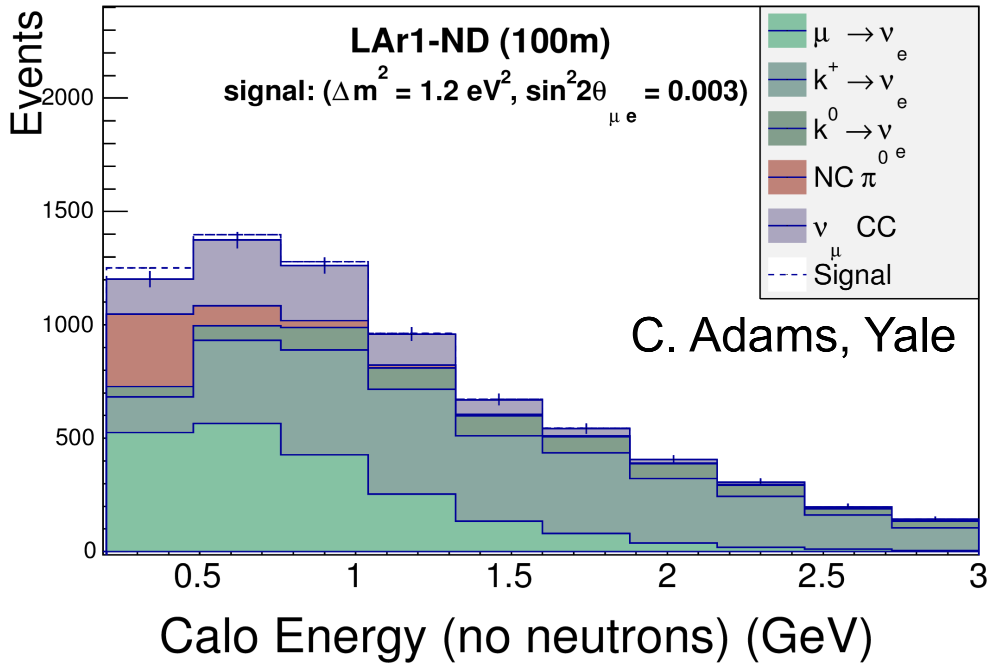
Do not need shower containment

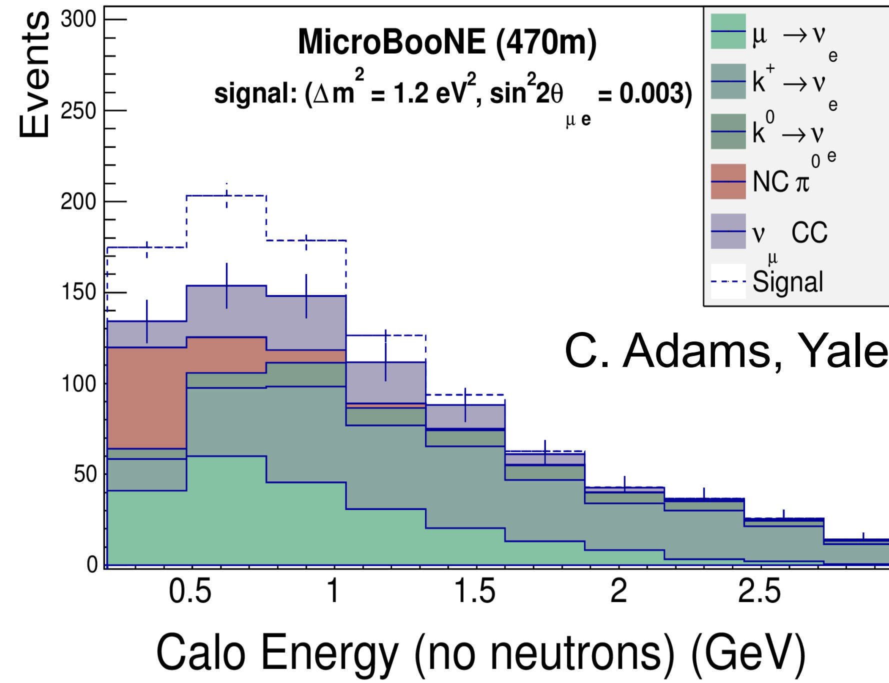
(This is only a small part of the Physics we will measure with LArIAT)



LAr1-ND, or MicroBooNE with a Near Detector



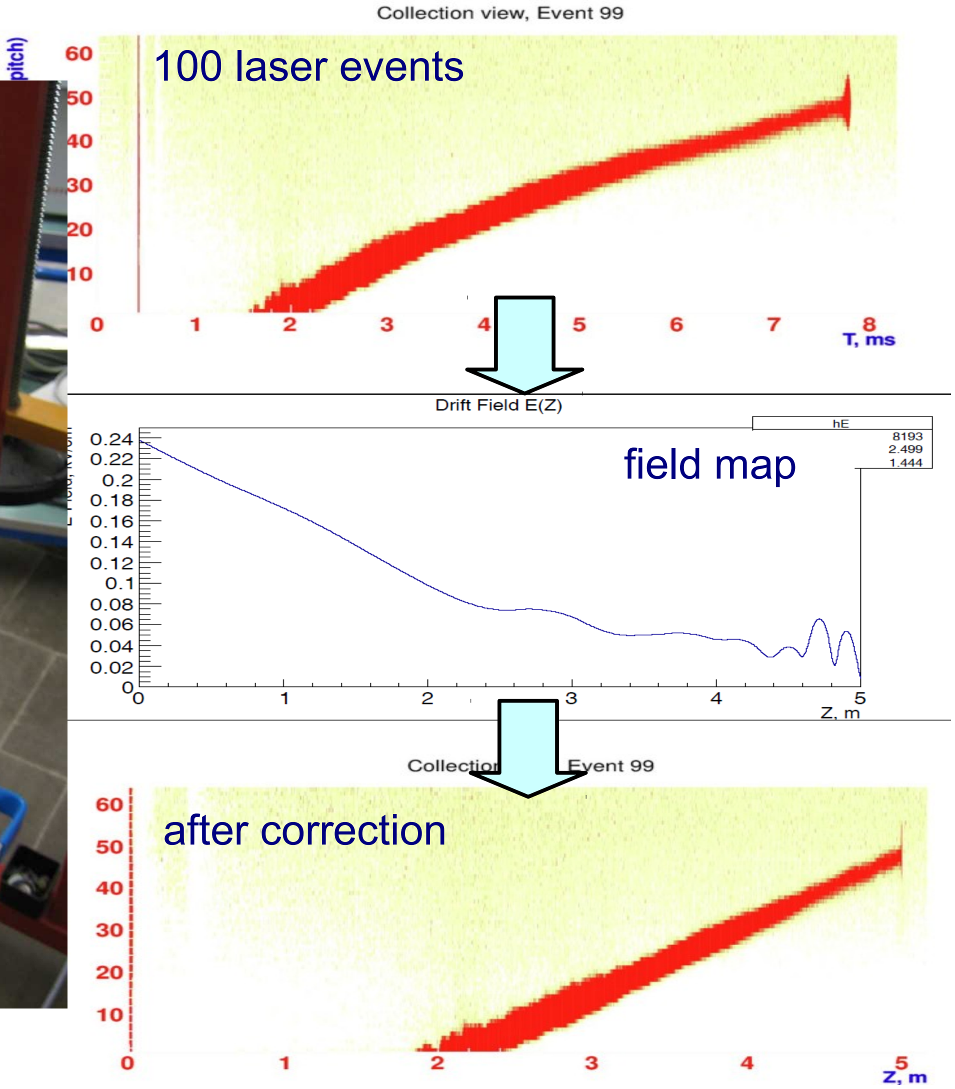




- A near detector, LAr1-ND sited in the existing SciBooNE hall can determine whether the MiniBooNE excess in neutrino mode is due to oscillation.
- Due to its proximity to the target hall, it is sufficient for it to run for one year to amass statistics much bigger than MicroBooNE
- To explain the excess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

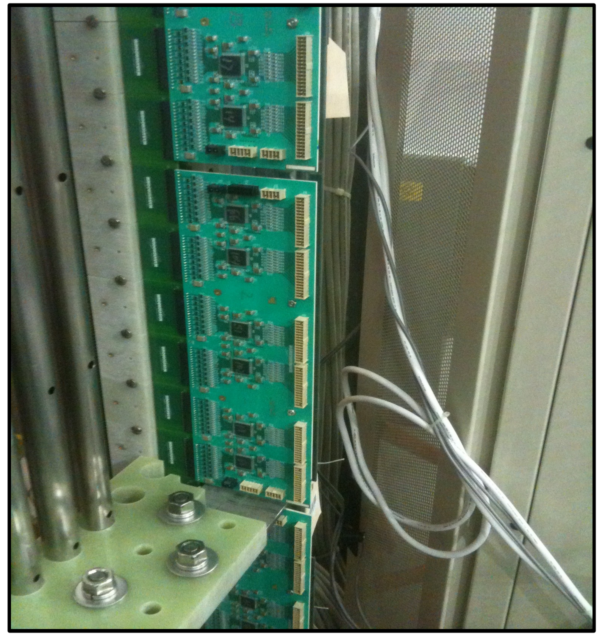
	ArgoNeuT	MicroBooNE
Detector:	LArTPC	LArTPC
Neutrinos:	SBN: NuMI $\langle E_\nu \rangle = 4.3$ GeV	SBN: Booster $\langle E_\nu \rangle = 0.8$ GeV
Location:	FNAL	FNAL
Size:	40x45x90cm 0.23 tons Active	230x256x1034cm 87 tons Active
Wires:	2 planes - 4 mm pitch	3 planes - 3mm pitch
Electronics:	Warm	Cold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

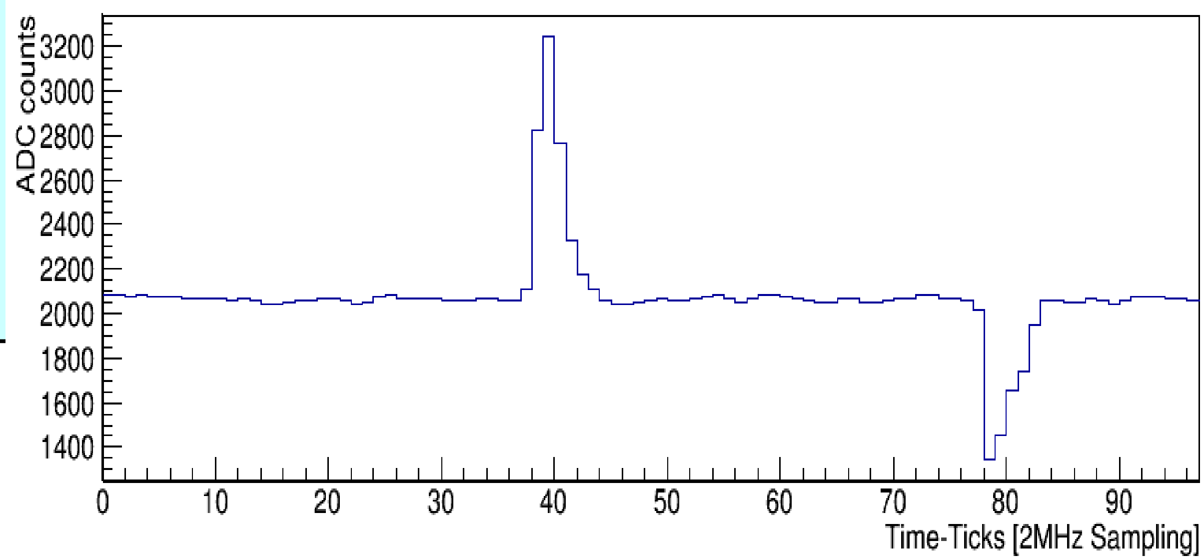
Cold Electronics

- 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.