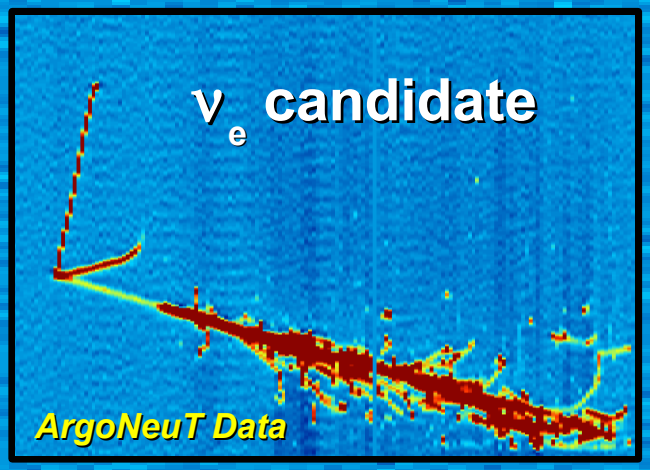
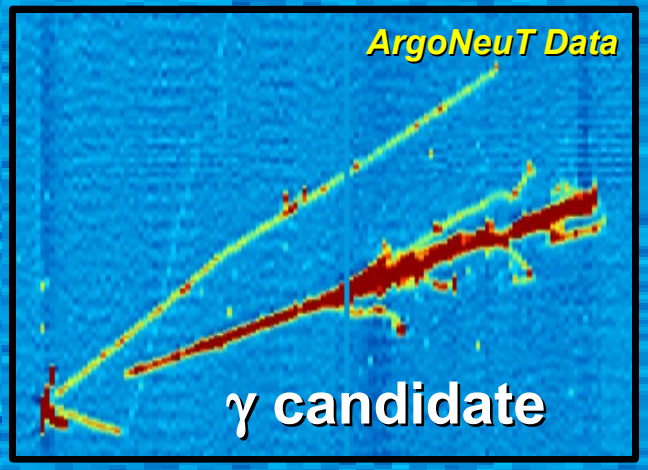
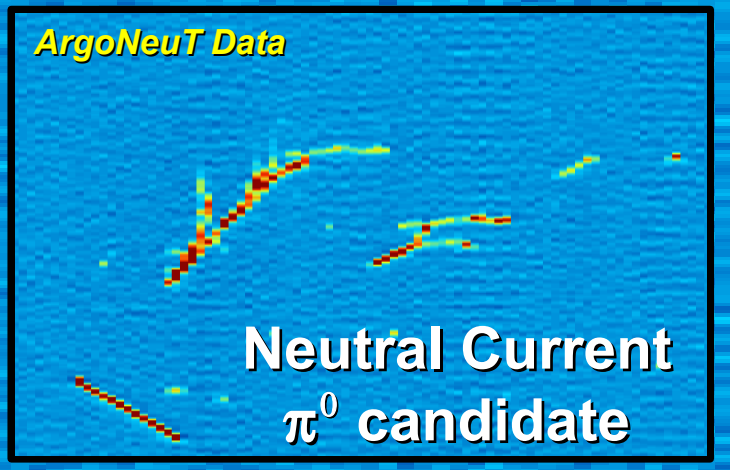
Future prospects of electron/photon separation & Neutral Current π^0 measurements with Liquid Argon TPCs and other methods







Jonathan Asaadi
Syracuse University

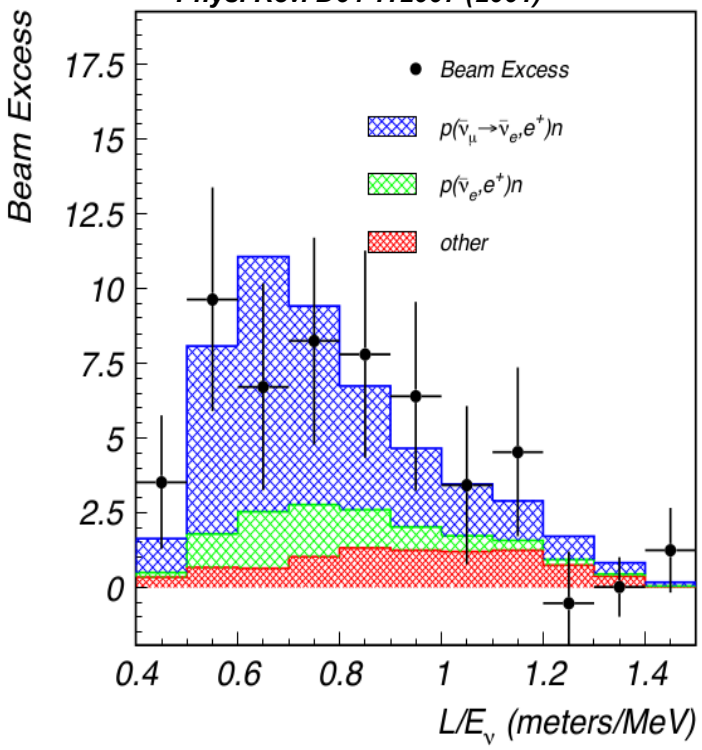
NuInt14

Overview

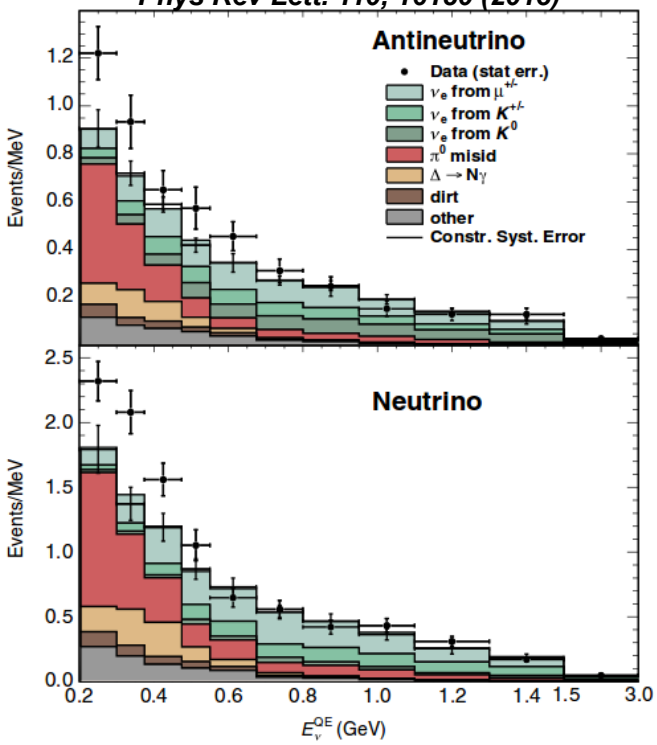
- **Importance of e/γ identification**
  - Electron (ν_e) signals
    - Oscillations
    - Supernova Neutrinos
  - Photon signals
    - Neutral Current Production
    - Axion Searches
    - Background to oscillation
- **Liquid Argon e/γ identification**
  - ICARUS
  - ArgoNeuT
  - MicroBooNE
- **ArgoNeuT Neutral Current π^0 analysis**
- **Going forward**

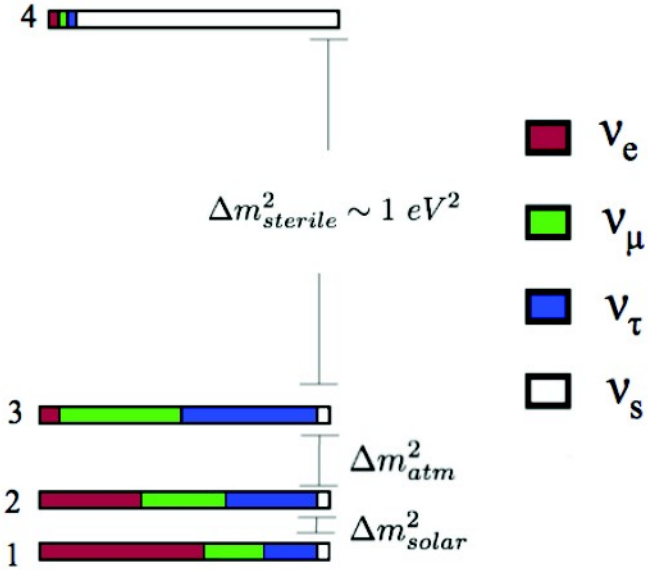
Importance of e/γ identification: Electron (ν_e) signals

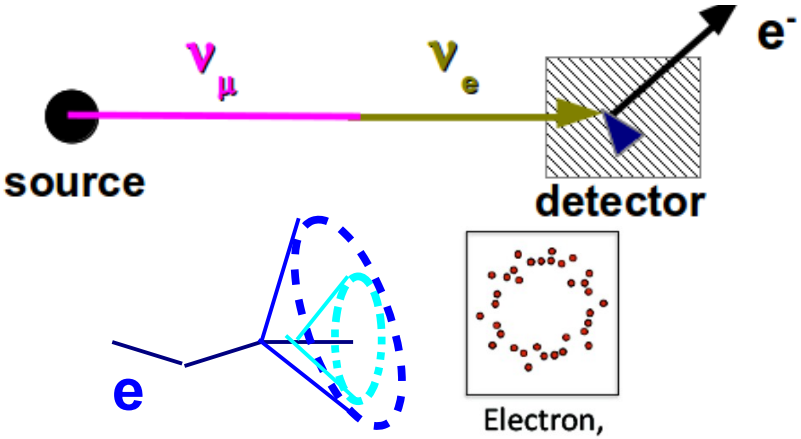
Phys. Rev. D64 112007 (2001)



Phys Rev Lett. 110, 16180 (2013)







Both used cherenkov detection techniques to identify ν_e events

Depending on which side you may sit we either

- Have need a better understanding of our backgrounds for short-baseline in ν_e appearance searches

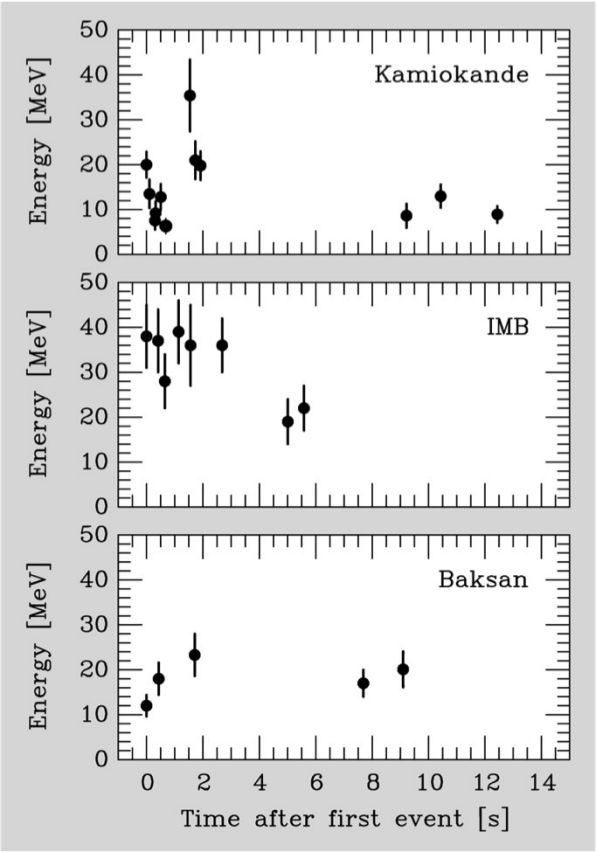
- Have evidence for new physics!

Importance of e/γ identification: Electron (ν_e) signals

Supernova Neutrinos

Most of the neutrinos coming from the "neutronization" during the supernova ($p+e^- \rightarrow n + \nu_e$)

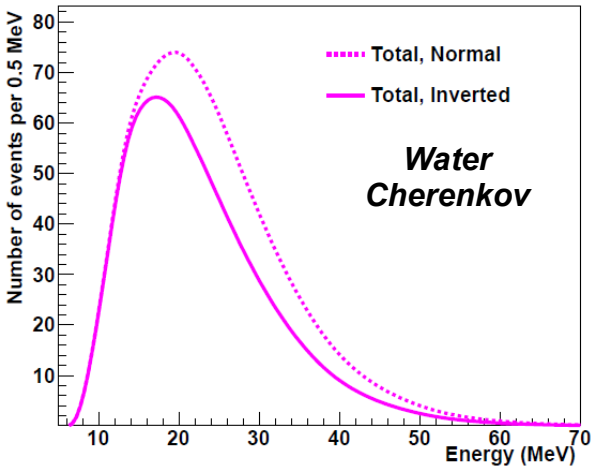
SN1987a

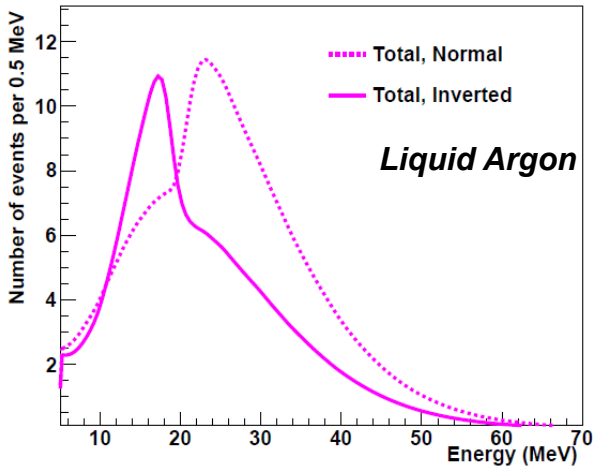


We can learn an enormous amount from supernova neutrinos

- Requires low energy reconstruction (~5 MeV) of electrons in your detector
- Requires an understanding of ν_e interactions on your detector medium to extract the astrophysics
- Requires you to be lucky and ready!

arXiv:1307.7335



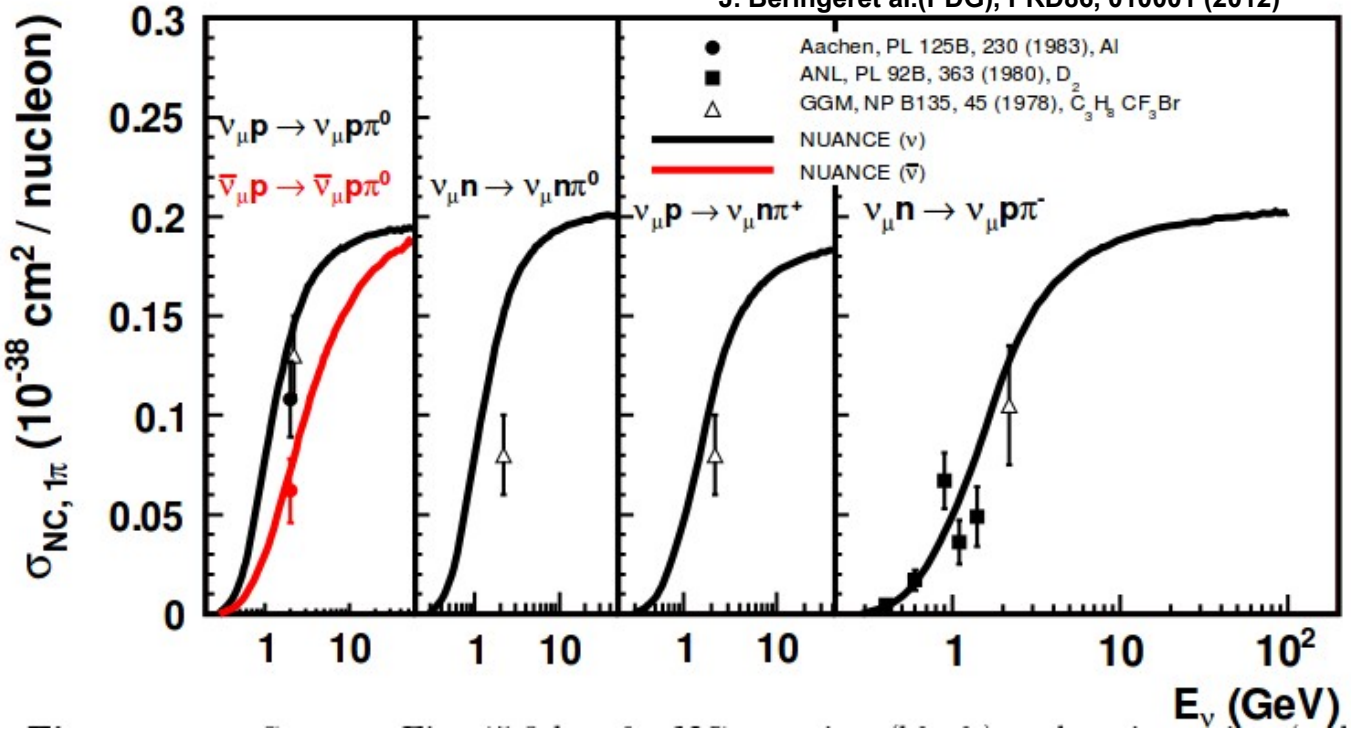


Importance of e/γ identification: Photon signals

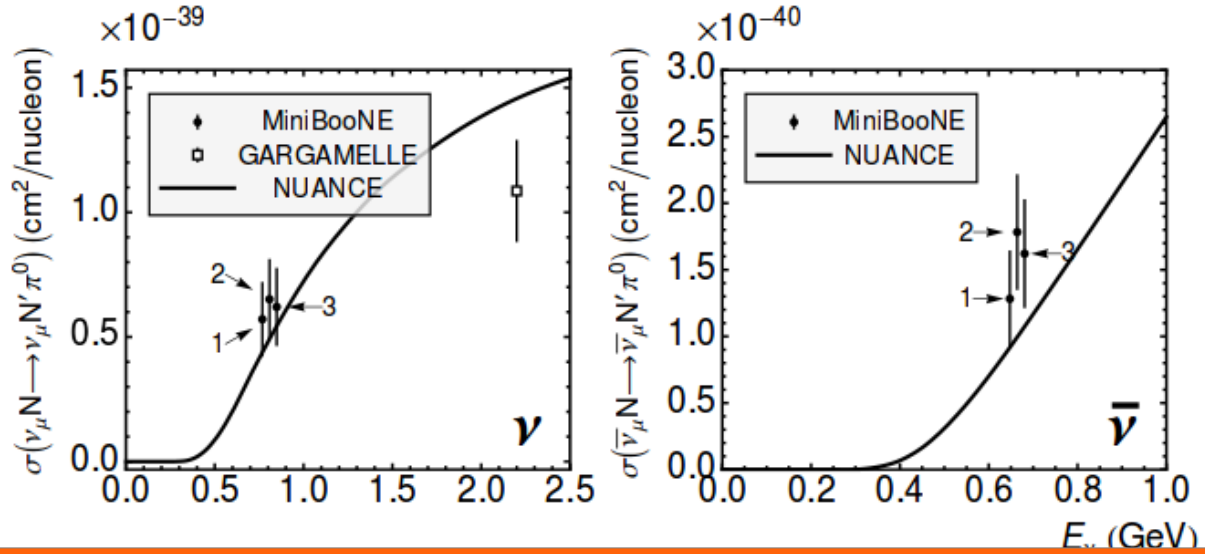
Neutral Current π^0 is both a sparsely measured cross-section as well as being an important background to oscillation analysis.

At the heart of both of these points is understanding photon identification

J. Beringeret al.(PDG), PRD86, 010001 (2012)

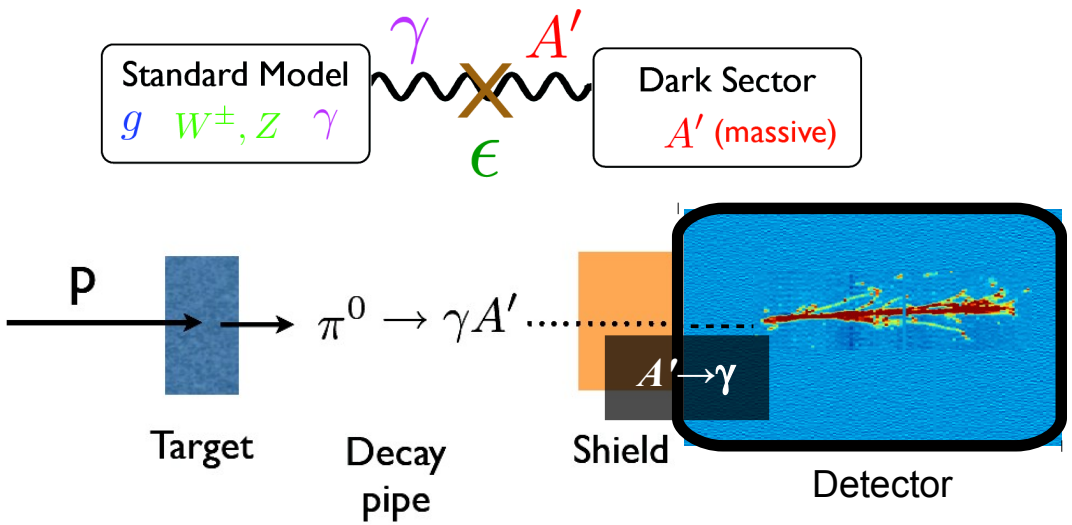


A. Aguilar-Arevaloet al., Phys. Lett.B664, 41 (2010)



Lots of interesting ways to get Single Photon (γ) signals

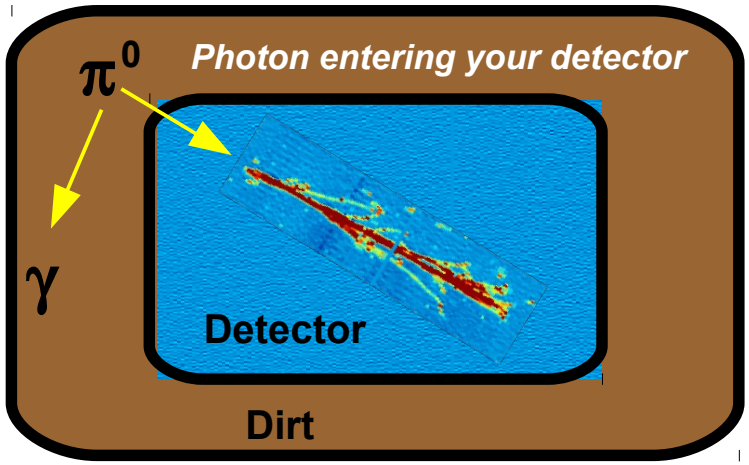
R. Essig Snowmass 2013

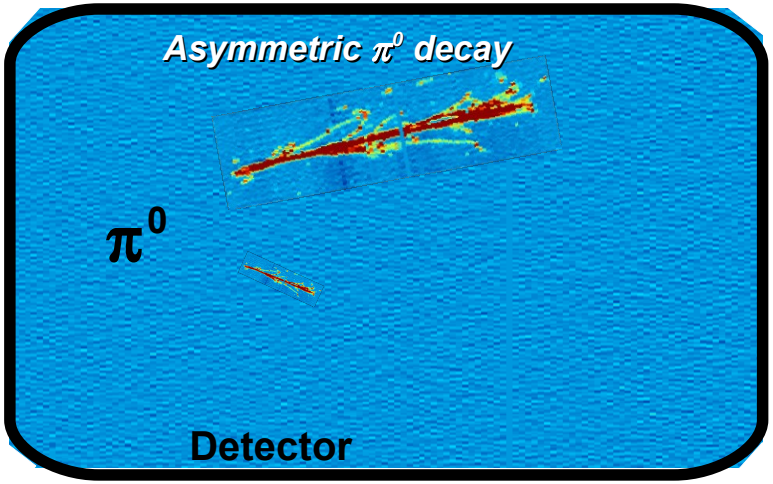


for low A′ masses, can also get

$A' \leftrightarrow \gamma$ "oscillation" (like ν's)

Could be signal

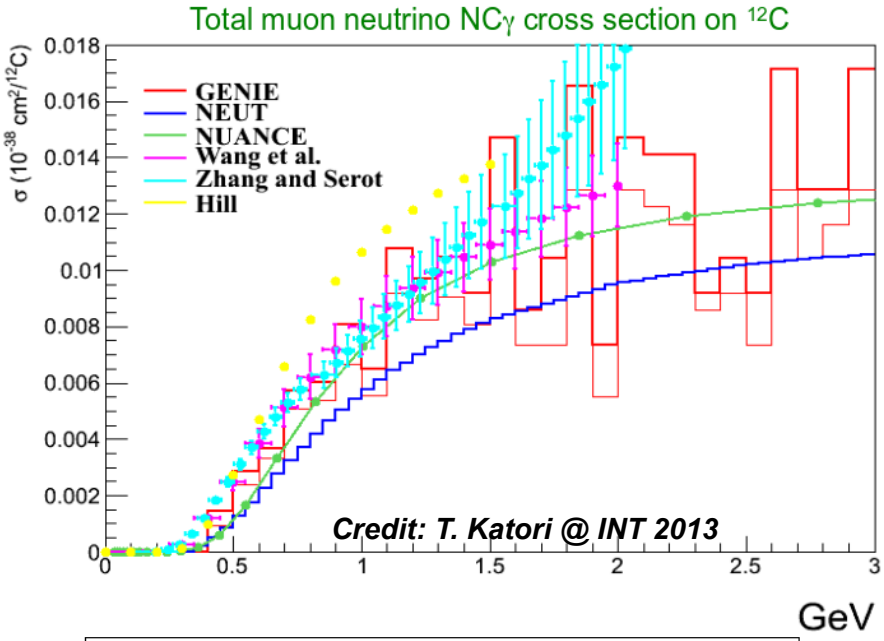


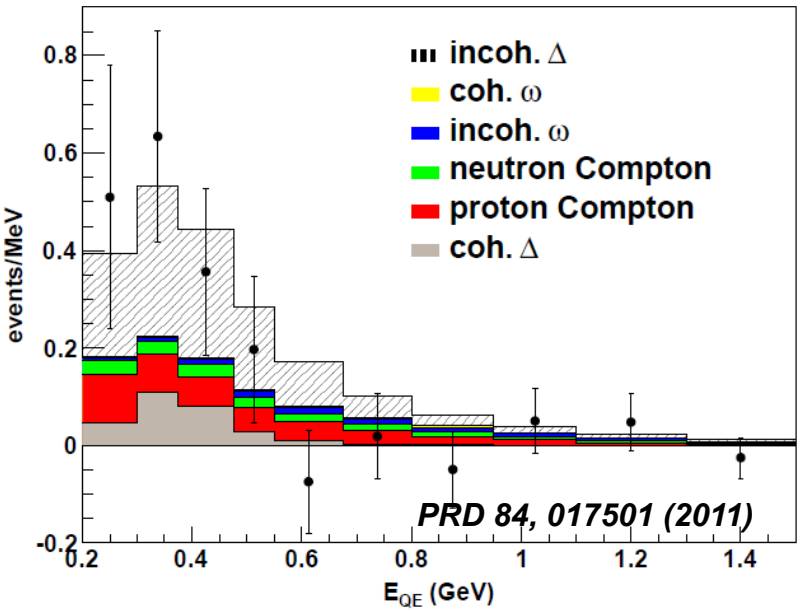


Could be background

Importance of e/γ identification: Photon signals

Photons (γ) also a background for oscillation physics

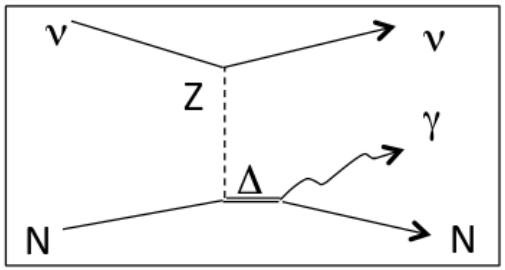




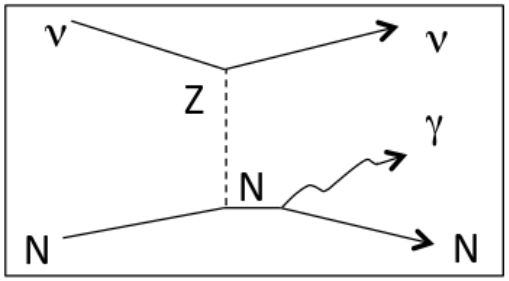
Depending on your model, single photon processes can greatly effect your oscillation results

Credit: T. Katori @ INT 2013

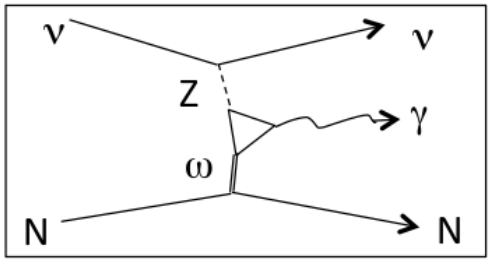
radiative Δ-decay



generalized Compton scattering



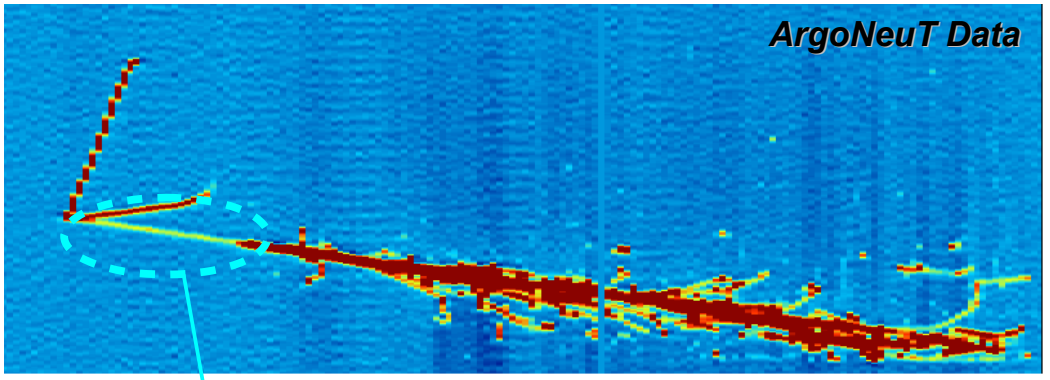
anomaly mediated triangle diagram

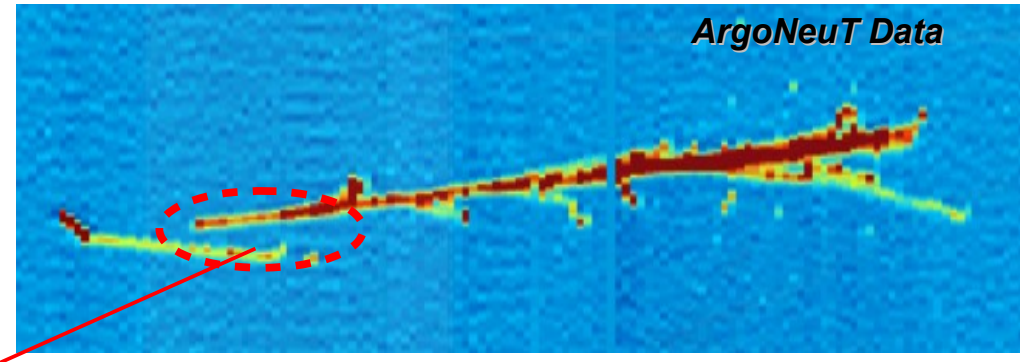


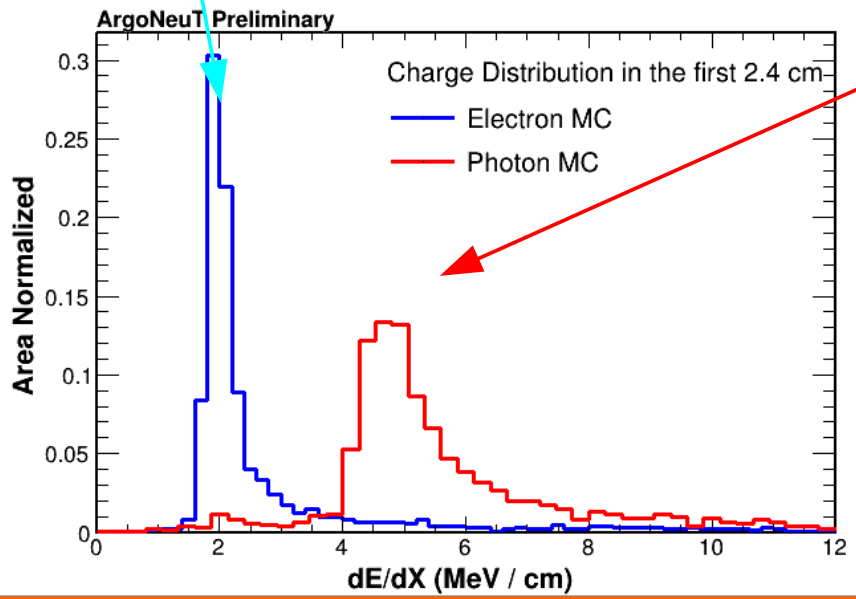
Poorly understood (possibly) background

Liquid Argon e/γ identification

LArTPC's utilize the fine grain resolution of the detector to distinguish electron's (minimum ionizing) from photons ($\gamma \rightarrow e^+e^-$) by analyzing the charge distribution at the beginning of the shower

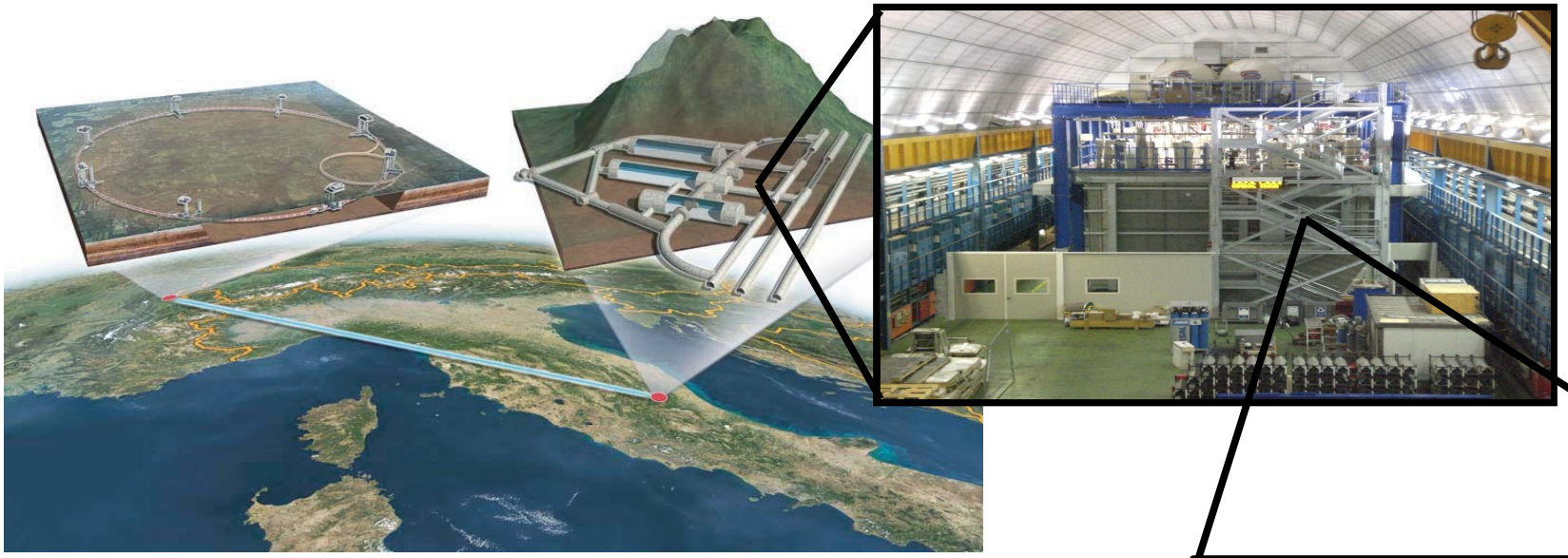




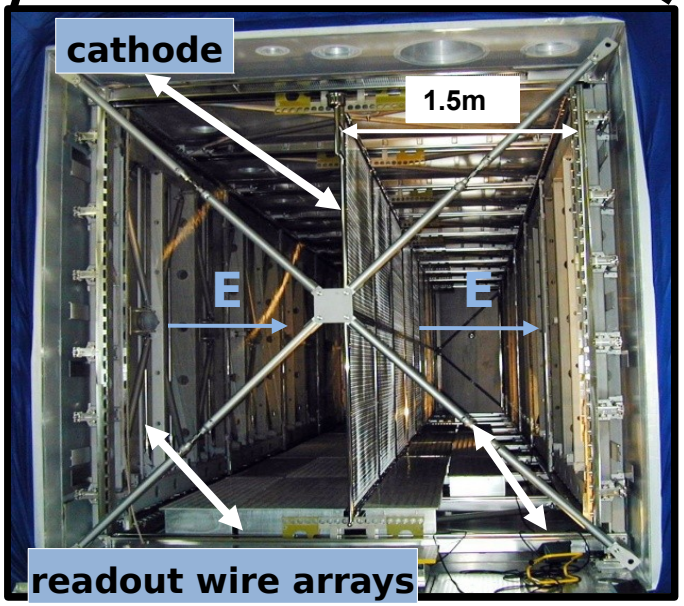


Possible to make this distinction based on both topological information (gap between vertex, shower profile, etc...) and dE/dX information of the shower itself

ICARUS LArTPC was the pioneer in this technology

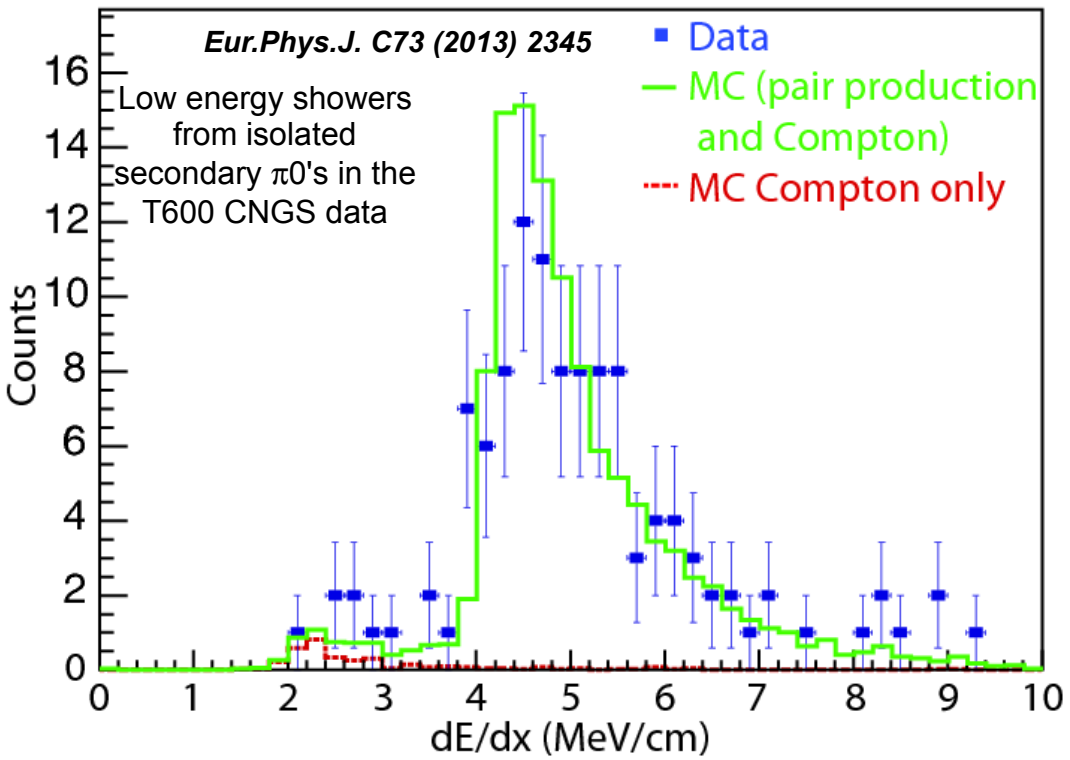


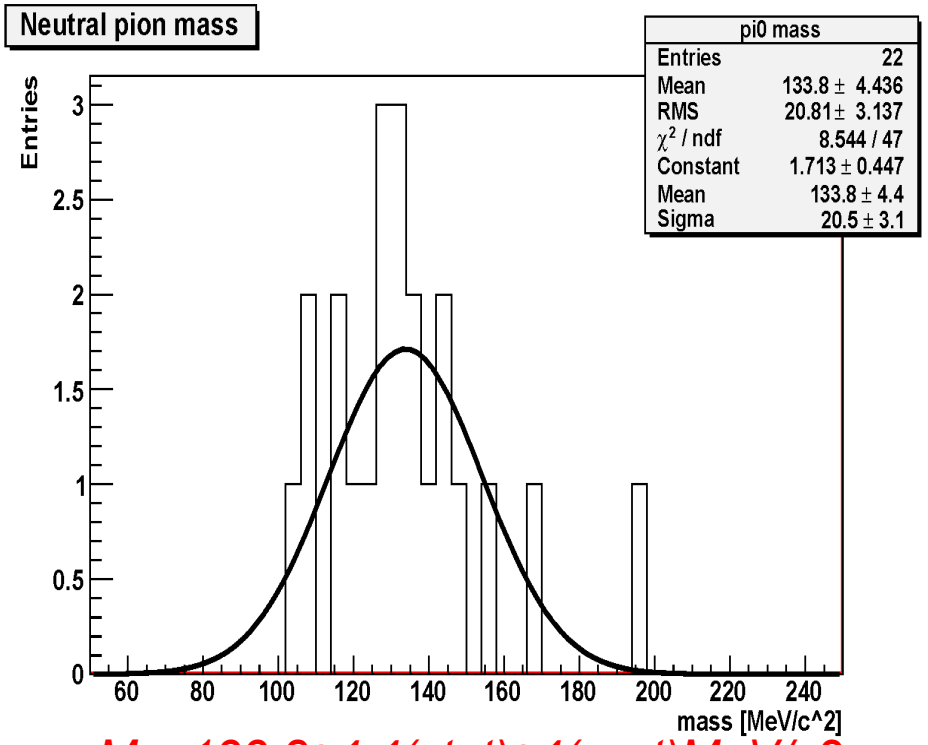
Cryostat Volume	~ 600 Tons
TPC Volume	476 Tons
# Electronic Channels	~54,000
Wire Pitch	3 mm
Max. Drift Length	1.5 m
Light Collection	74 8” PMT's
Beam	CNGS



D. Gibin “ICARUS Status and Plans” NNN13

ICARUS e/γ identification
(Photon Identification)

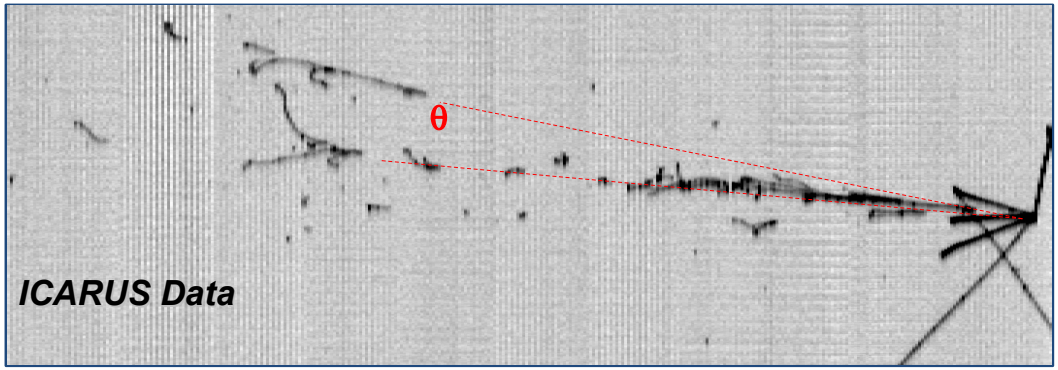




$M_{\gamma\gamma}$ = 133.8±4.4(stat)±4(syst)MeV/c2

D. Gibin "ICARUS Status and Plans" NNN13

D. Gibin "ICARUS Status and Plans" NNN13



π^0 reconstruction:

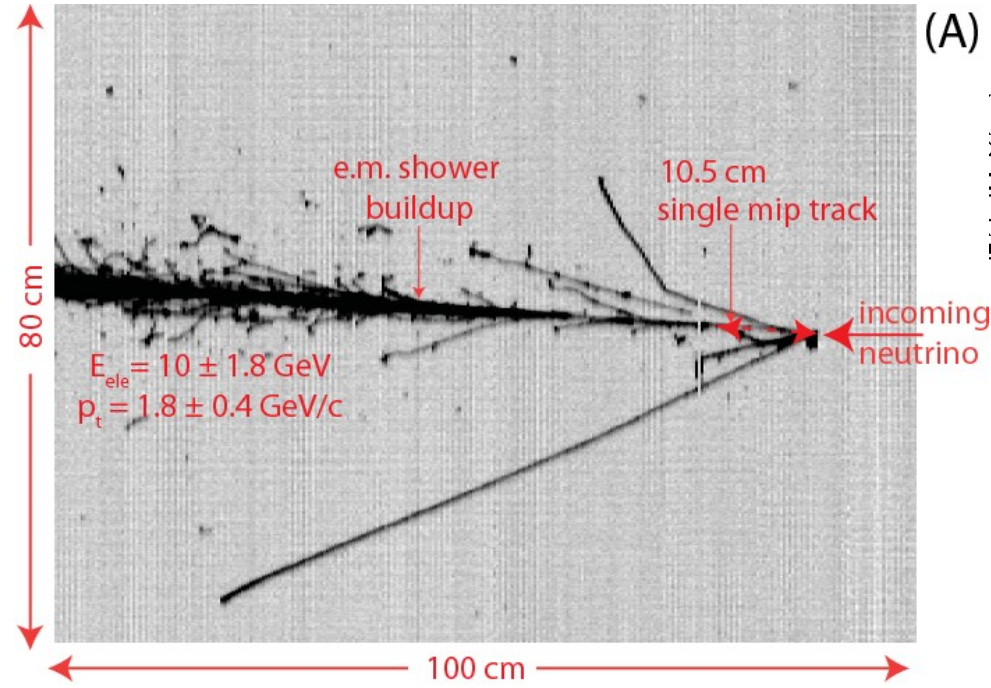
$p_{\pi 0} = 912 \pm 26$ MeV/c

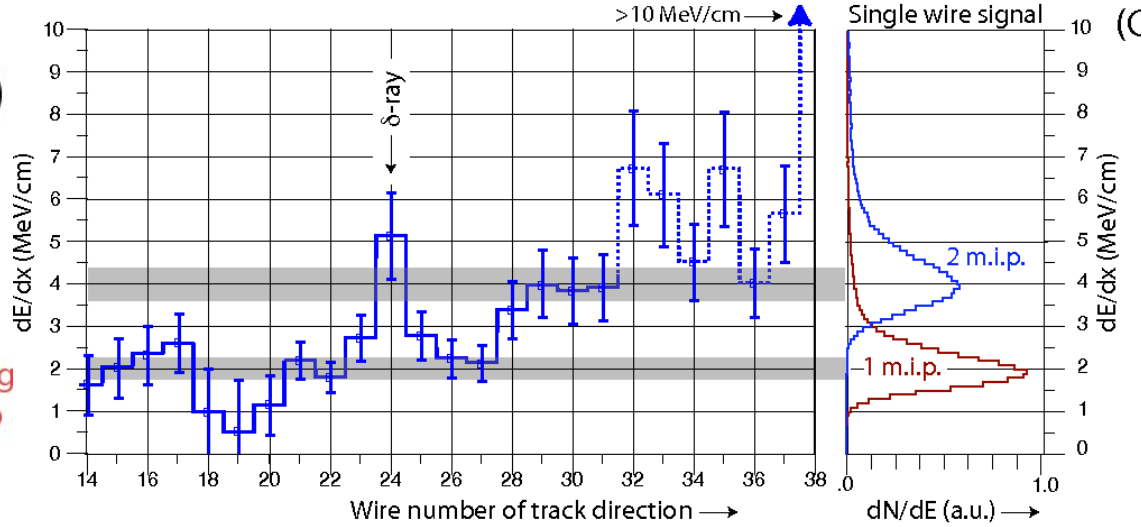
$M_{\pi 0} = 127 \pm 19$ MeV/c²

$\theta = 28.0 \pm 2.5º$

ICARSU e/γ identification
(Electron Identification)

Eur.Phys.J. C73 (2013) 2345

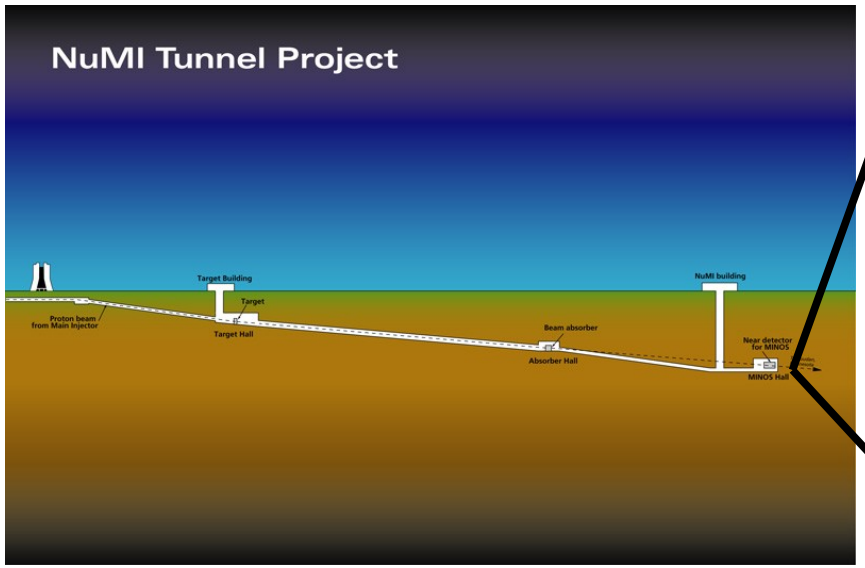


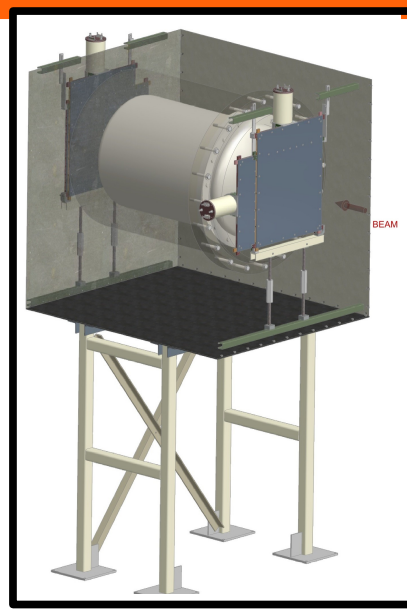


Identification of $\nu_\mu \rightarrow \nu_e$ candidate events in the CNGS beam used for a search for the "LSND anomaly"

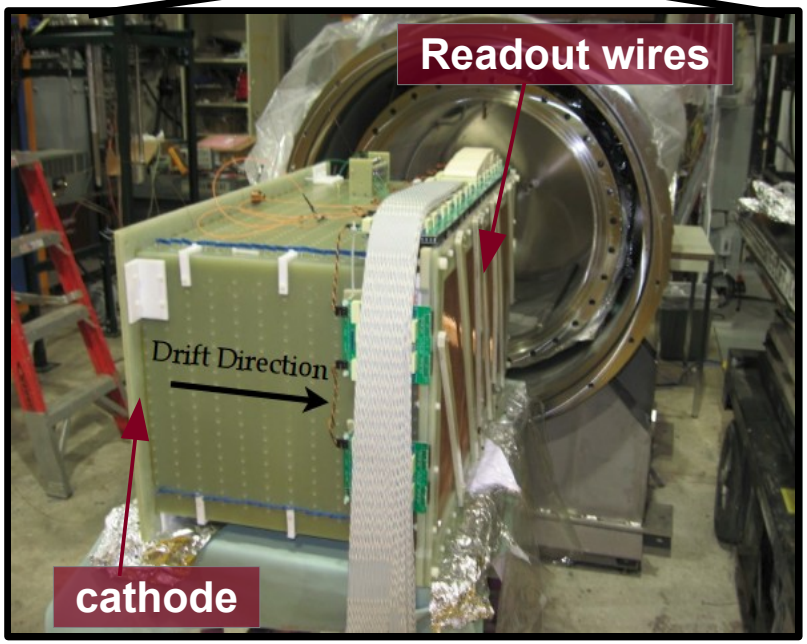
Eur.Phys.J. C73 (2013) 2345

ArgoNeuT LArTPC is pushing forward this effort





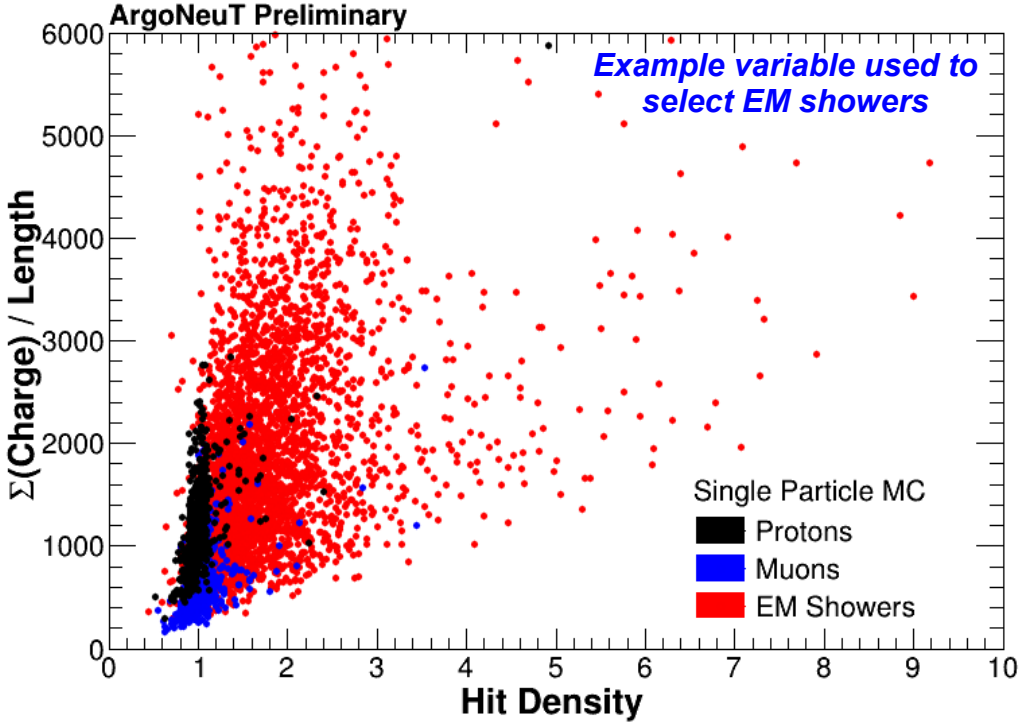
Cryostat Volume	0.76 Tons
TPC Volume	0.26 Tons
# Electronic Channels	480
Wire Pitch	4 mm
Max. Drift Length	0.47 m
Light Collection	None
Beam	NuMI

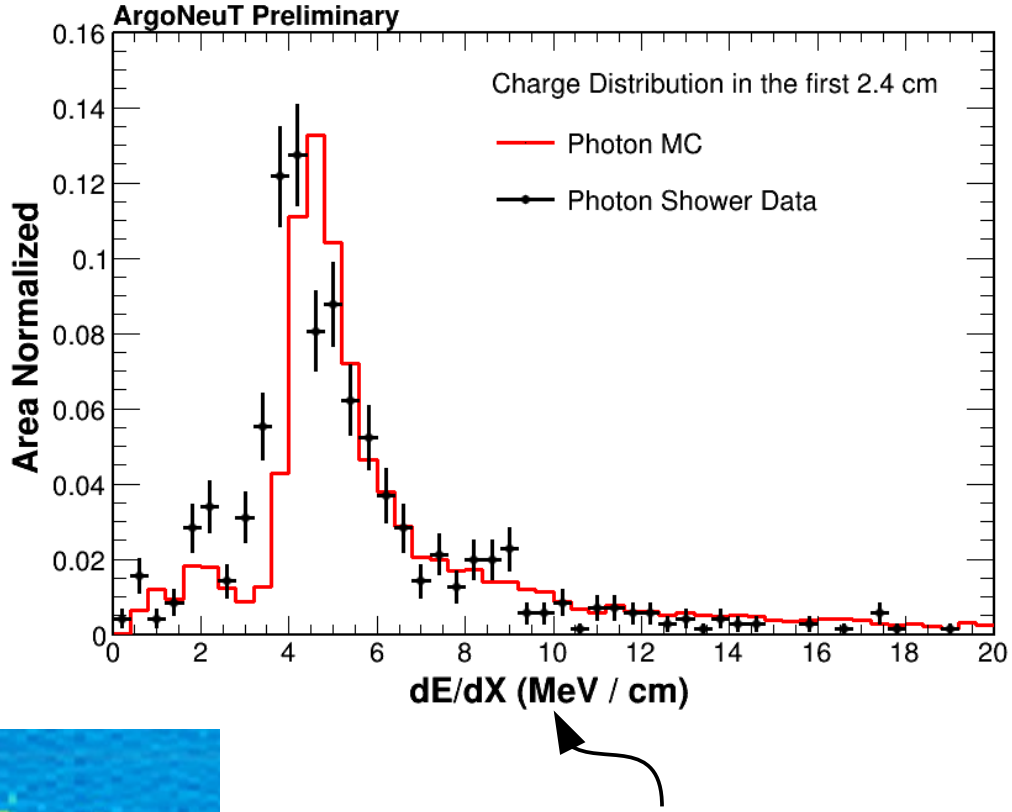


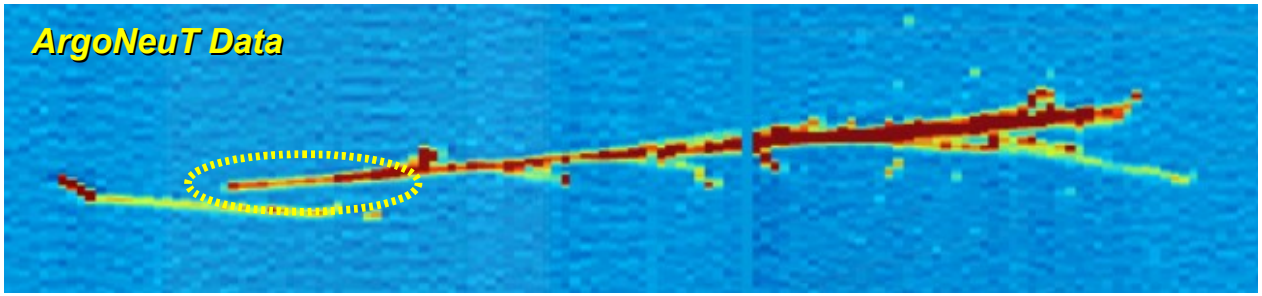
ArgoNeuT e/γ identification

(Photon Identification)

Utilizing topological information to select shower candidates in a ***fully-automated*** *way*







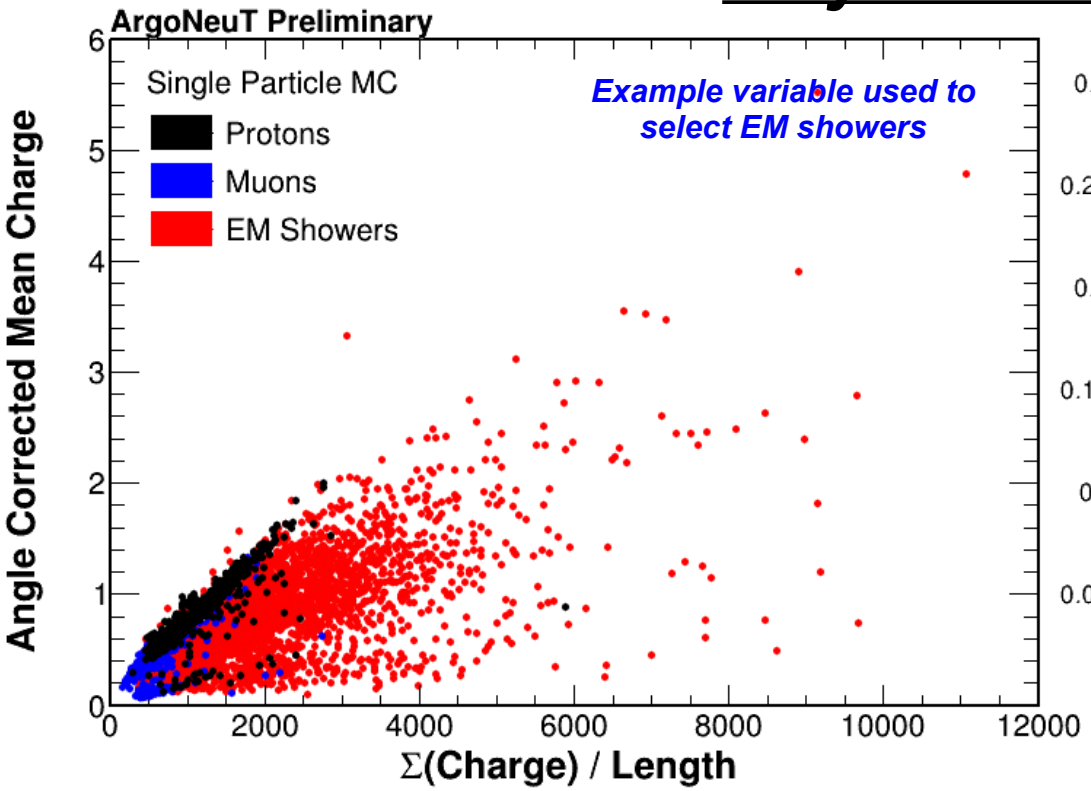
Then reconstruct the characteristic of the shower

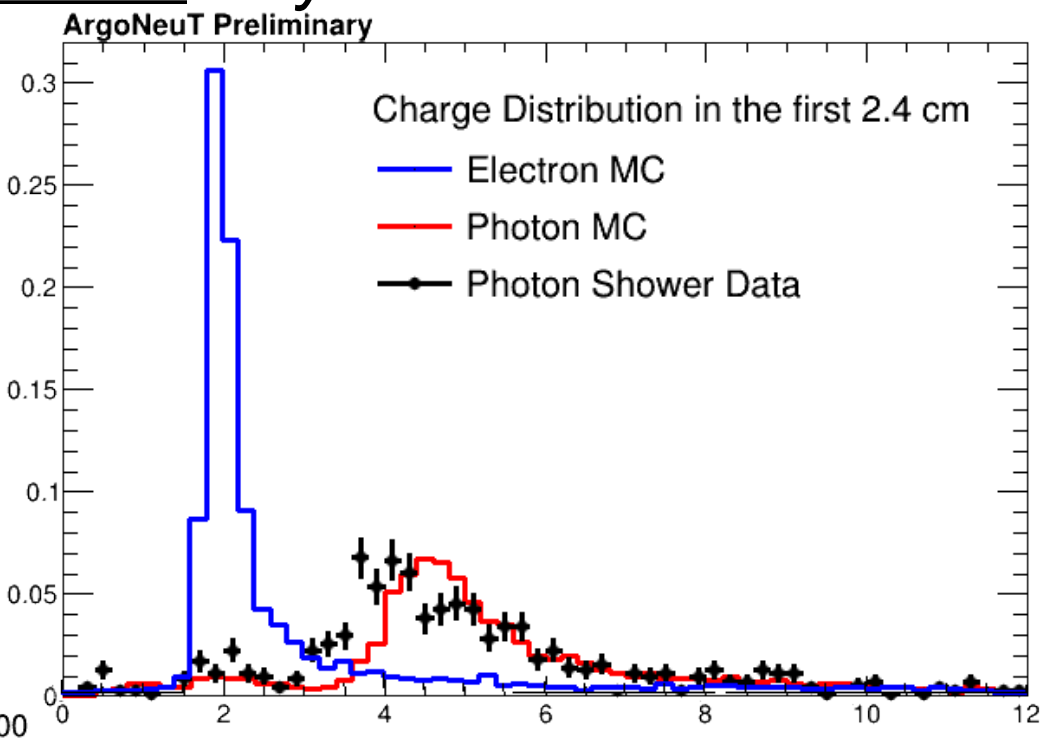
*Talks @ NuINT14 from ****

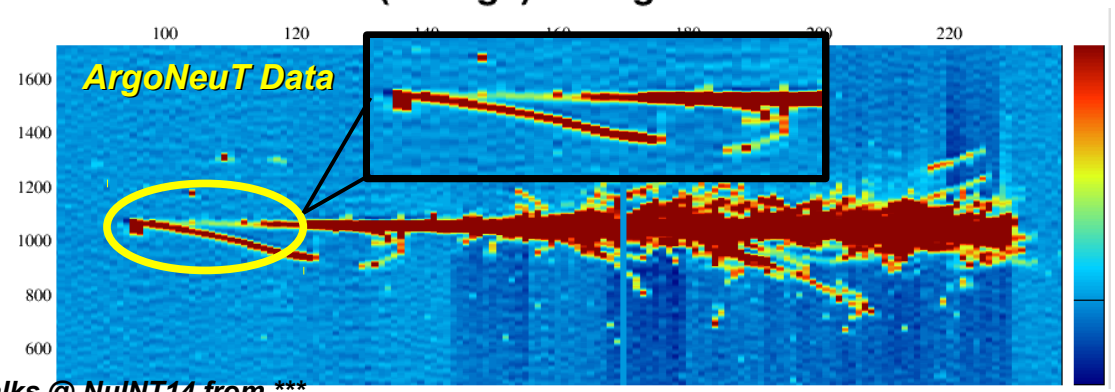
ArgoNeuT e/γ identification

(Electron Identification)

Utilizing topological information to select shower candidates in a ***fully-automated*** *way*





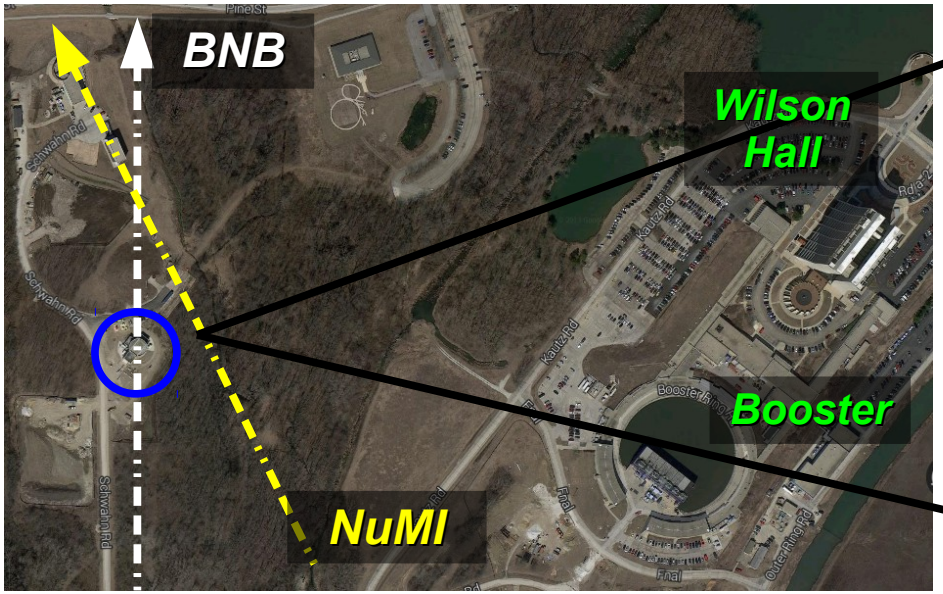


*Talks @ NuINT14 from ****

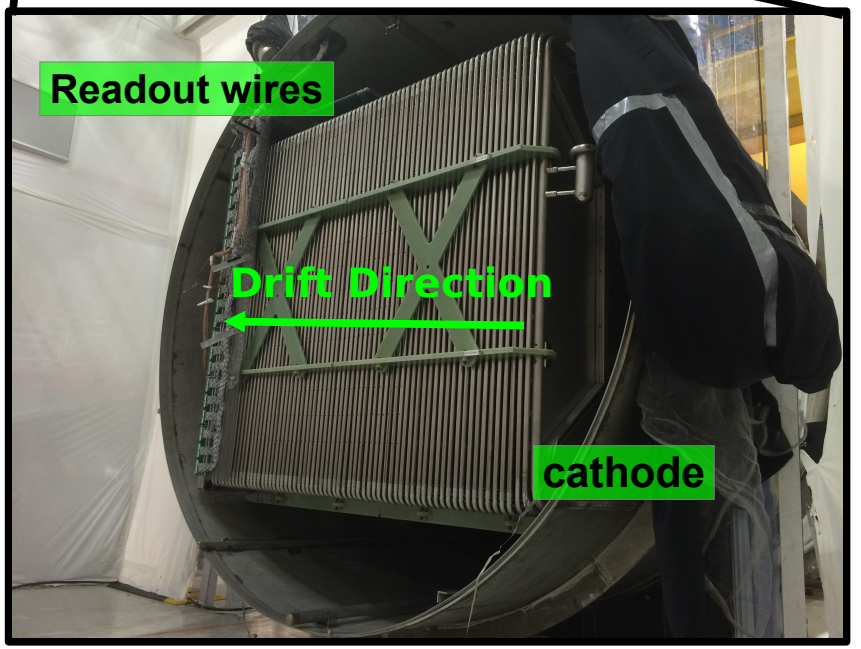
ArgoNeuT's first electron data will be shown at Neutrino 2014

See A. Szlec's talk @ Neutrino!!!

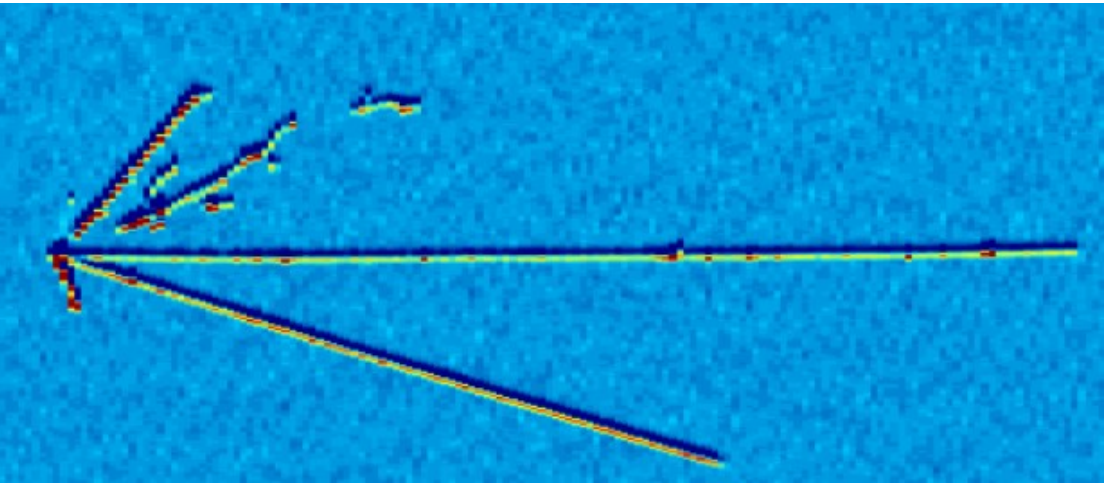
MicroBooNE LArTPC is the next generation experiment



Cryostat Volume	170 Tons
TPC Volume	80 Tons
# Electronic Channels	8256
Wire Pitch	3 mm
Max. Drift Length	2.5 m
Light Collection	32 8” PMT's
Beam	BNB / NuMI



MicroBooNE e/γ identification



MicroBooNE sits at a lower energy neutrino beam

→ Lower energy showers

→ Cluster and EM-shower identification will require additional tools

First step:

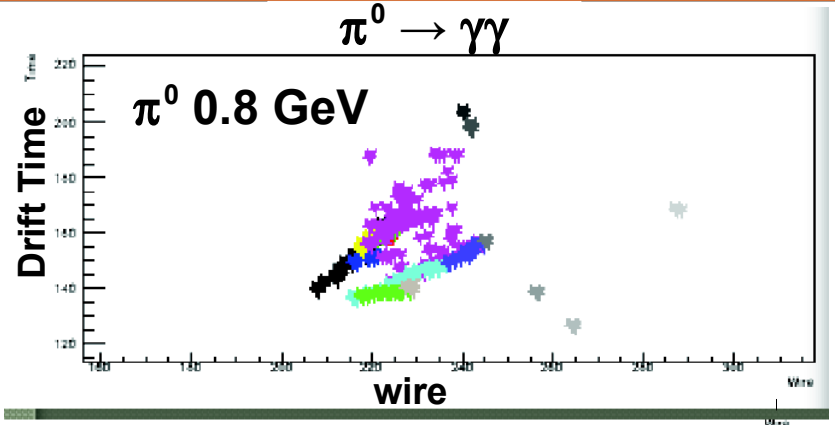
Identify likely “shower-like” or “track-like” clusters

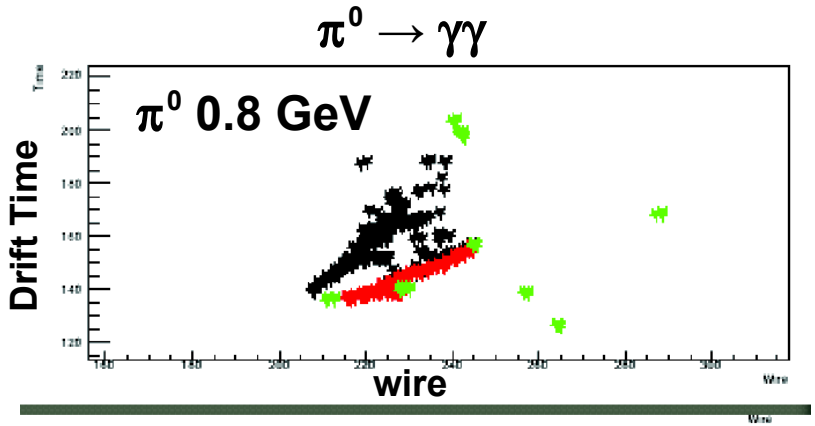
Good News:

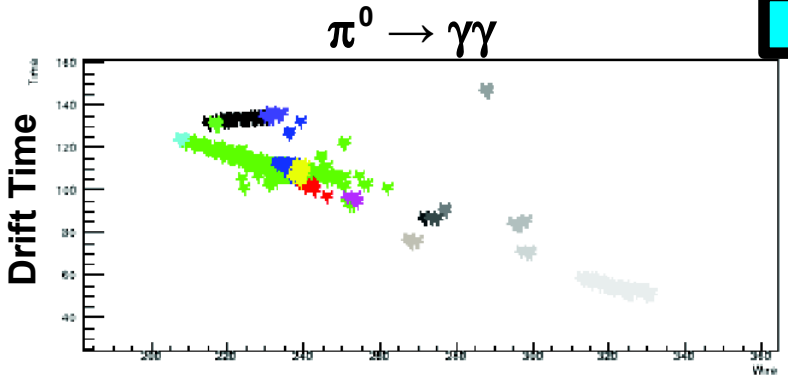
Build on the tools developed in ArgoNeuT!

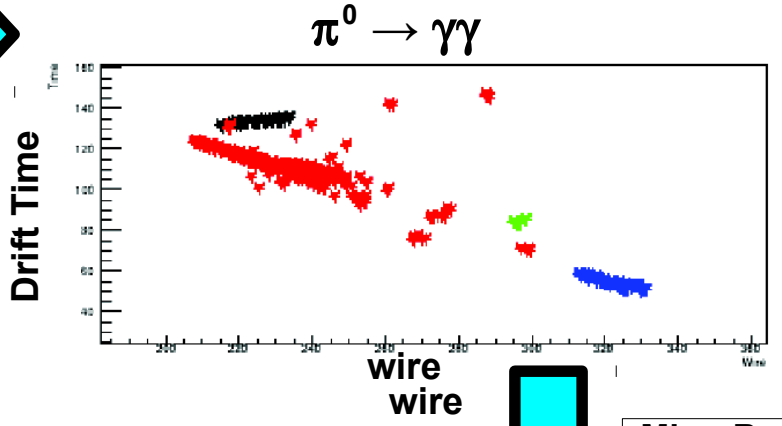
Next, decide if the “shower-like” cluster needs additional reconstruction to correctly associate all the charge together

MicroBooNE e/γ identification

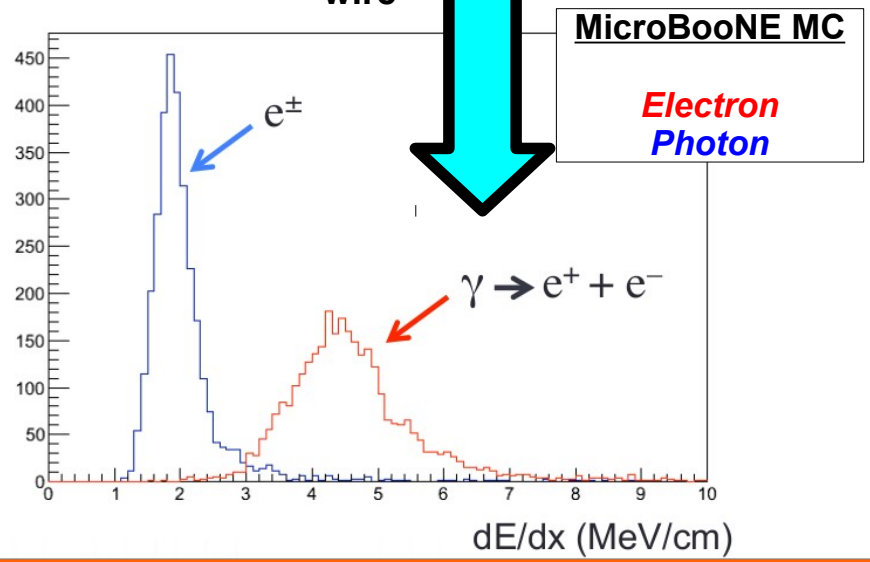








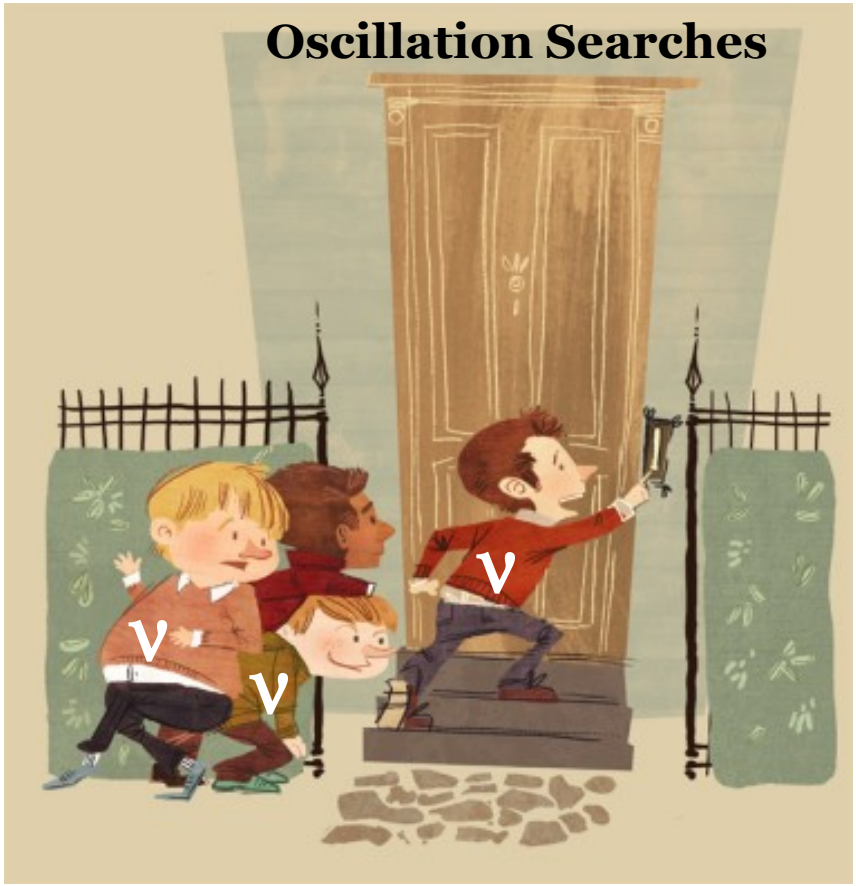
MicroBooNE is well on its way to developing **fully automated** shower reconstruction to provide electron and photon identification for this next generation liquid argon TPC



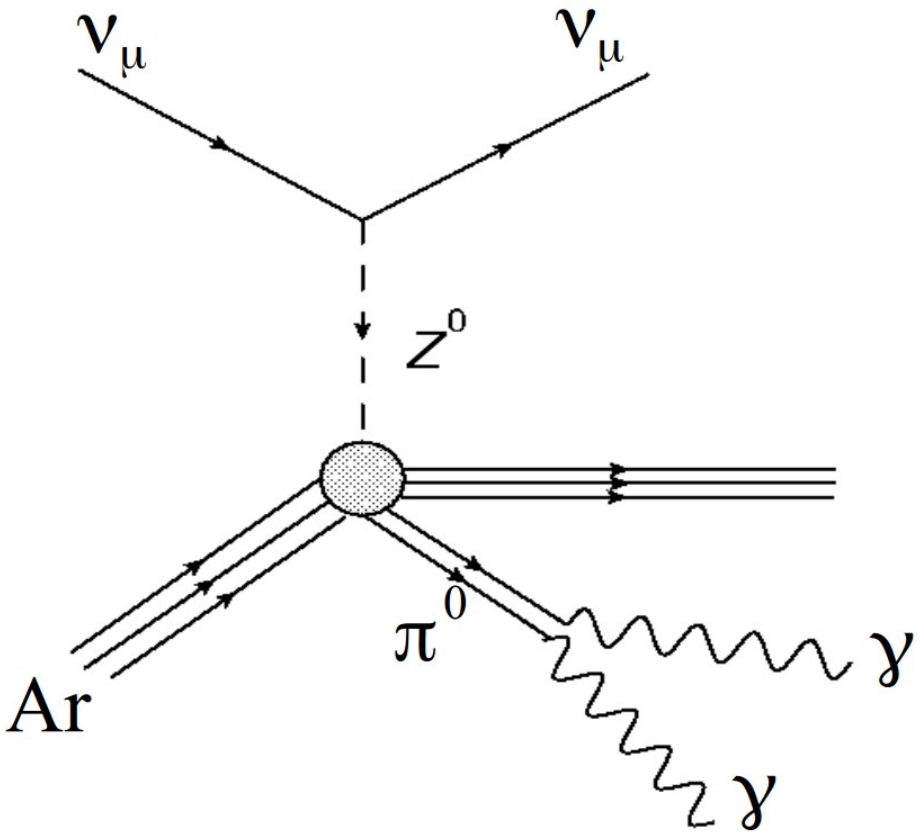
Neutral Current π^0 in ArgoNeuT

"...sometimes, the neutrino opts to play ding-dong-ditch instead, depositing a fraction of its energy in the detector before speeding away. This is called a neutral current event, and, in many cases, it is the bane of the modern neutrino physicist's existence...."

– Symmetry Magazine, May 06th 2014



Neutral Current π^0 in ArgoNeuT



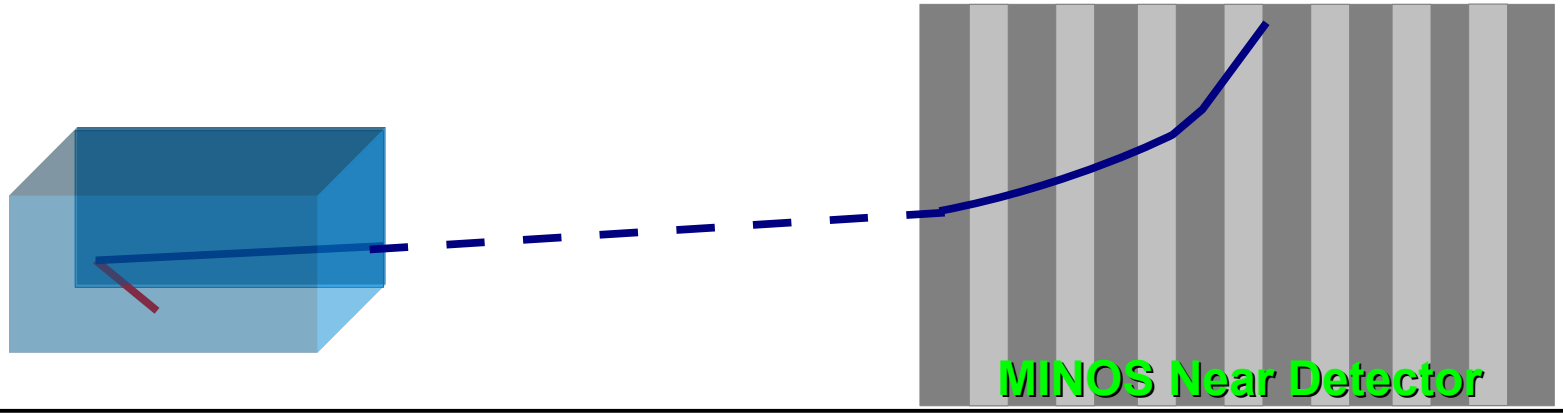
Important channel for oscillation searches and cross-section measurements.

→ Particularly insidious background for ν_e appearance searches

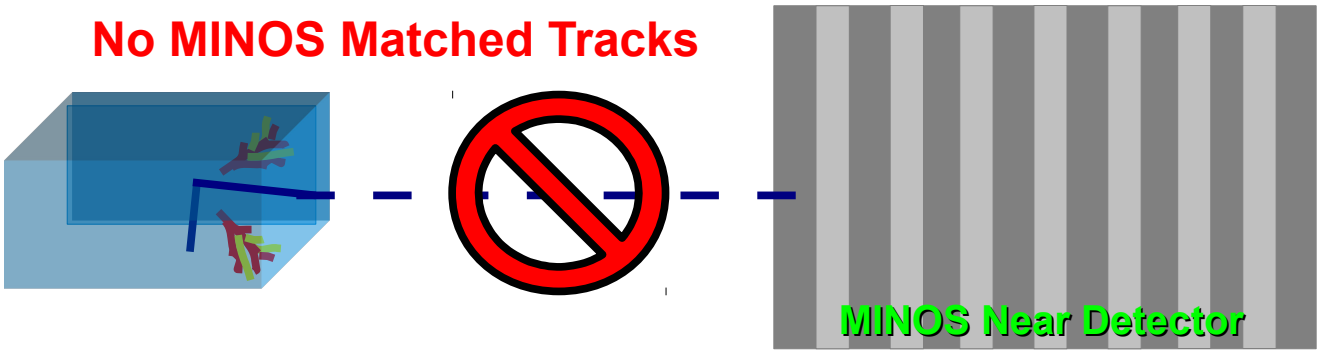
→ Despite the small volume and limited statistics in ArgoNeuT we want to begin to explore the capabilities of analyzing this channel in LAr

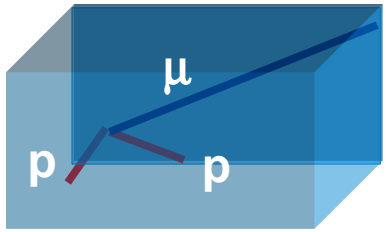
Neutral Current π^0 in ArgoNeuT

The "prototypical" charged current analysis from ArgoNeuT looks for a muon track inside the TPC that is matched to a track in the MINOS near detector



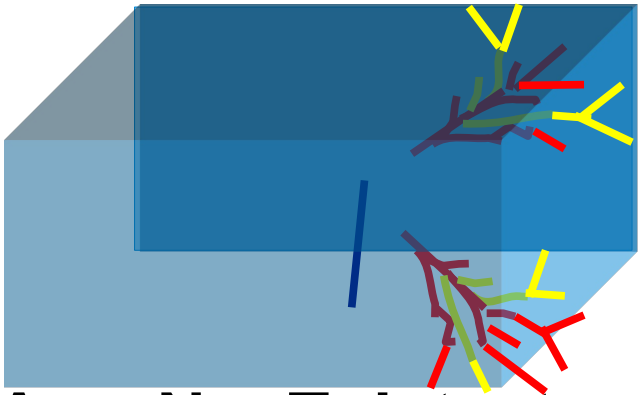
For the neutral current analysis we explicitly require that there is <u>no track</u> originating from the ArgoNeuT TPC that can be matched to the MINOS near detector <u>nor any evidence of a muon track near a vertex</u>

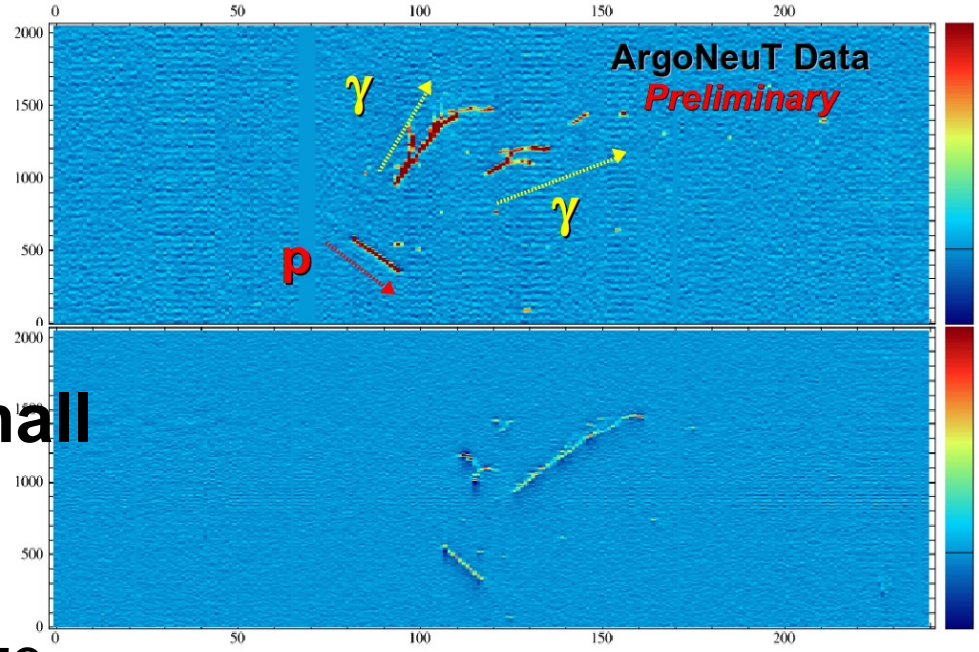




No Muon identified at a vertex

Neutral Current π^0 in ArgoNeuT





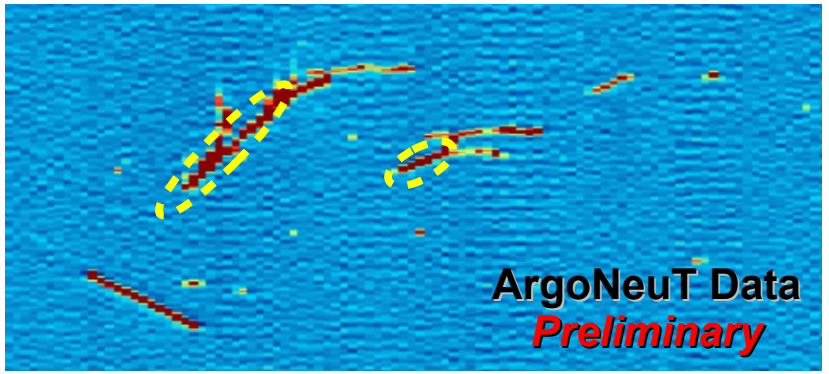
The ArgoNeuT detector is too small to see the full photon showers produced from π^0's

→ However, we are exploring how to utilize this data and identify NC π^0 production

Radiation length (X_0) in LAr ~ 14 cm

Utilizing the tracking power of LArTPC's

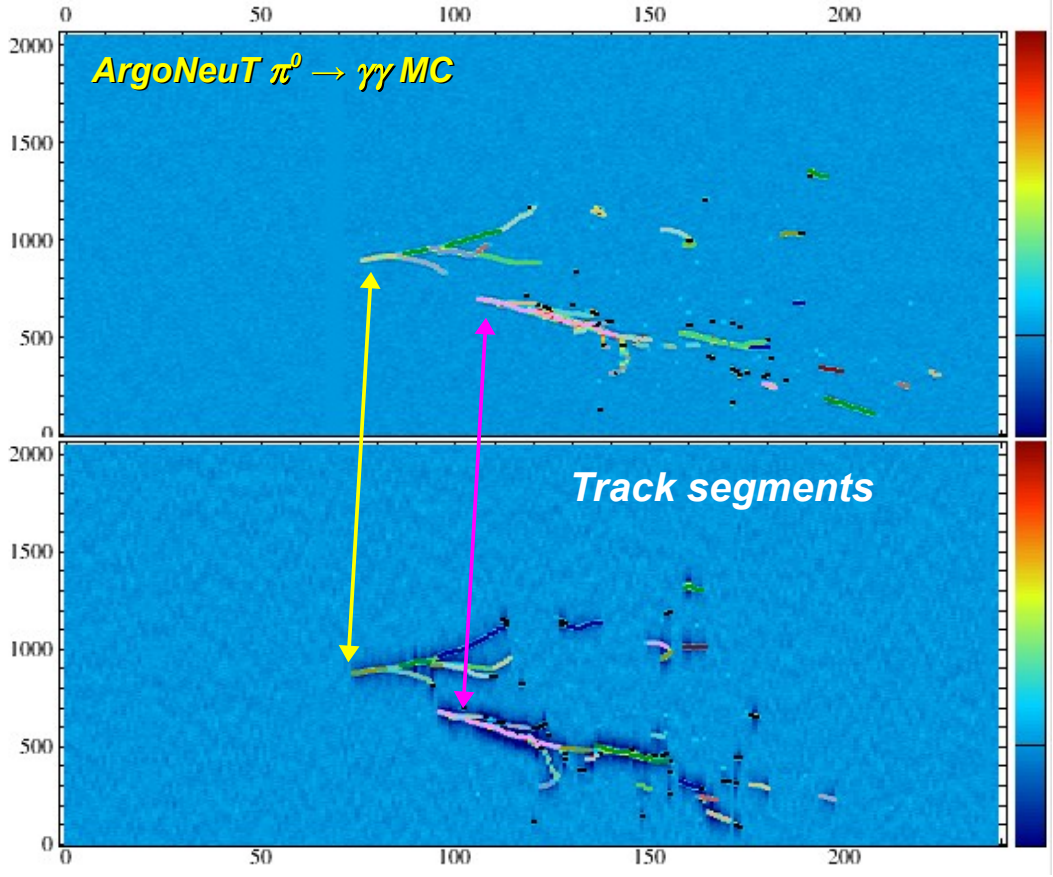
Break the EM-showers into smaller "track-like" segments and reconstruct the shower's "track-segments" to identify them as photons



Neutral Current π^0 in ArgoNeuT

Candidate neutral current π^0 events should have **two highly ionizing "track-segments" consistent with dE/dX profile for a photon pointed back to a common point**

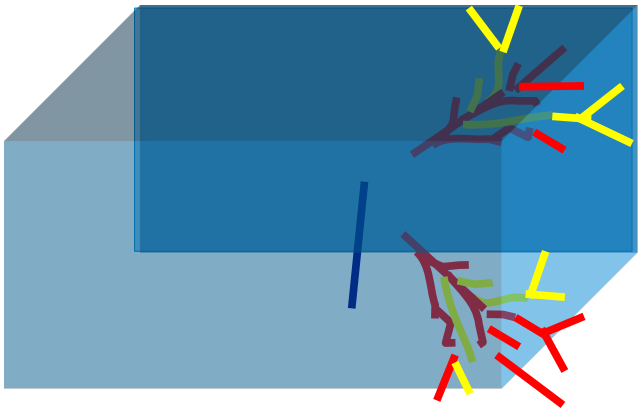
Reconstruction of photon "track-segments" done using fully automated reconstruction



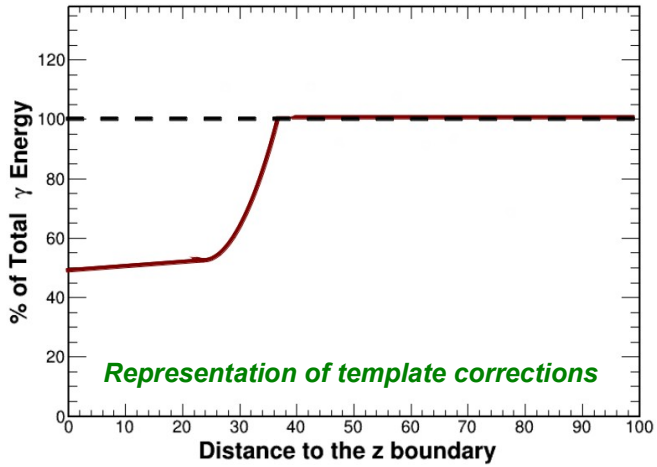
$\gamma \rightarrow e^+e^-$ candidate track segment requirement

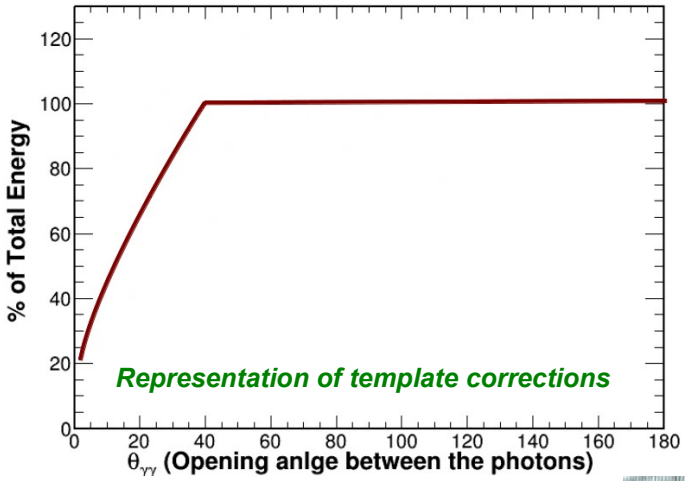
- Greater than 75% of the hits must have a dE/dX > 3.5 MeV/cm ***(not minimum ionizing)***
- Track pairs spatially separated ***(looking for photon candidate)***
- Track particle ID not consistent with proton, muon, pion hypothesis ***(not minimum ionizing)***

Neutral Current π^0 in ArgoNeuT



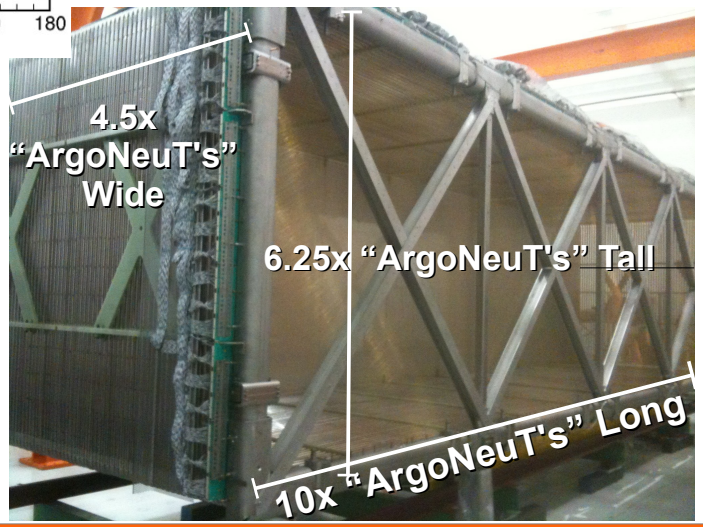
- Since the ArgoNeuT detector is too small to contain the majority of photon showers from π^0's we develop a MC based set of energy corrections based on the topology of the event





Example topological corrections applied to the reconstructed energy of the photons

- Worth noting that for larger LArTPC (e.g. MicroBooNE) these sort of correction will be less necessary due to the increased containment of electromagnetic showers



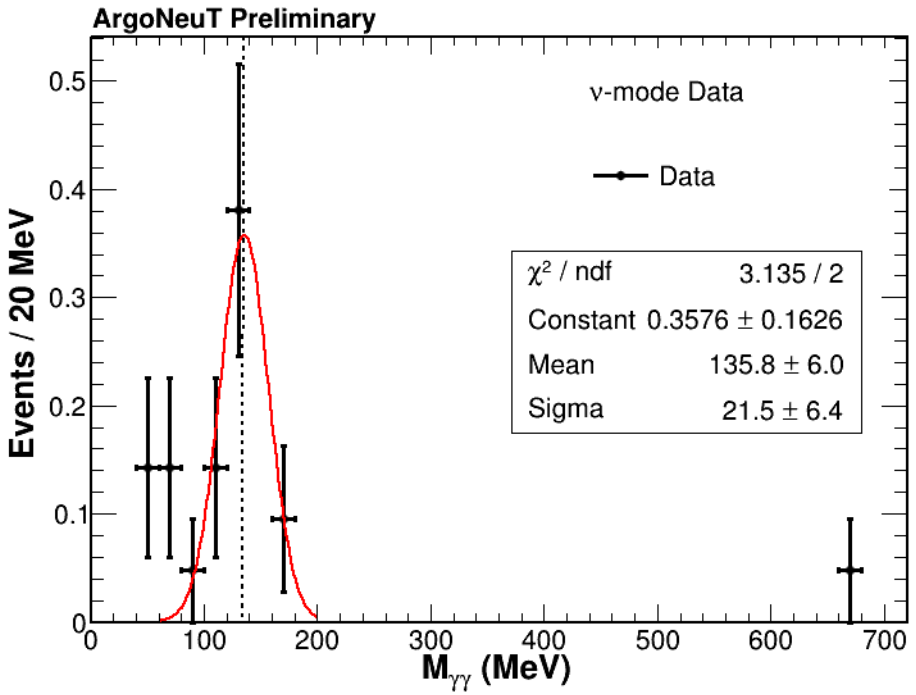
Neutral Current π^0 in ArgoNeuT

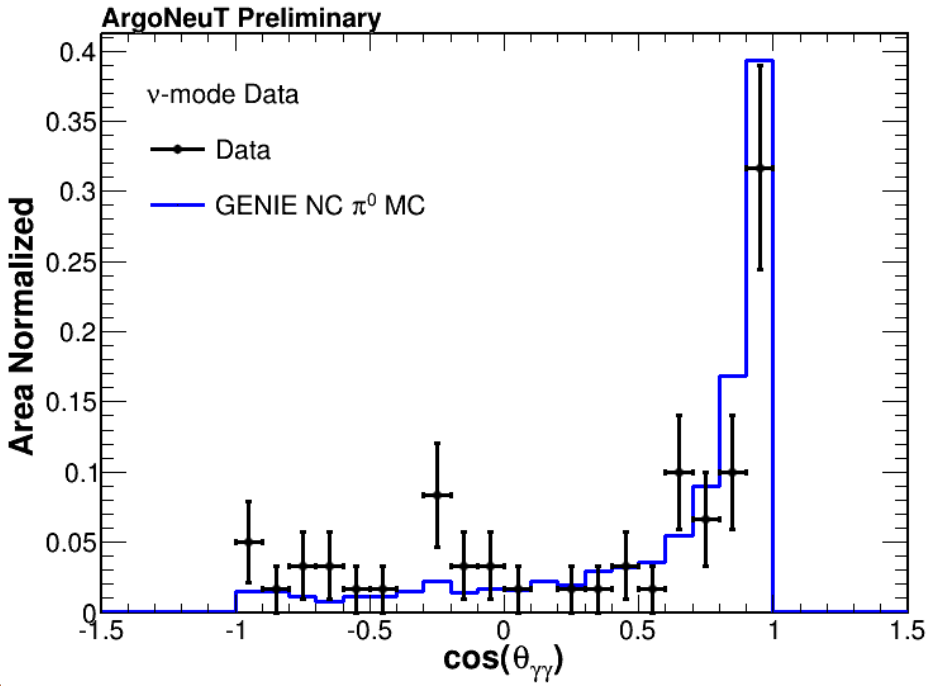
Reconstruct the photon showers in the candidate events

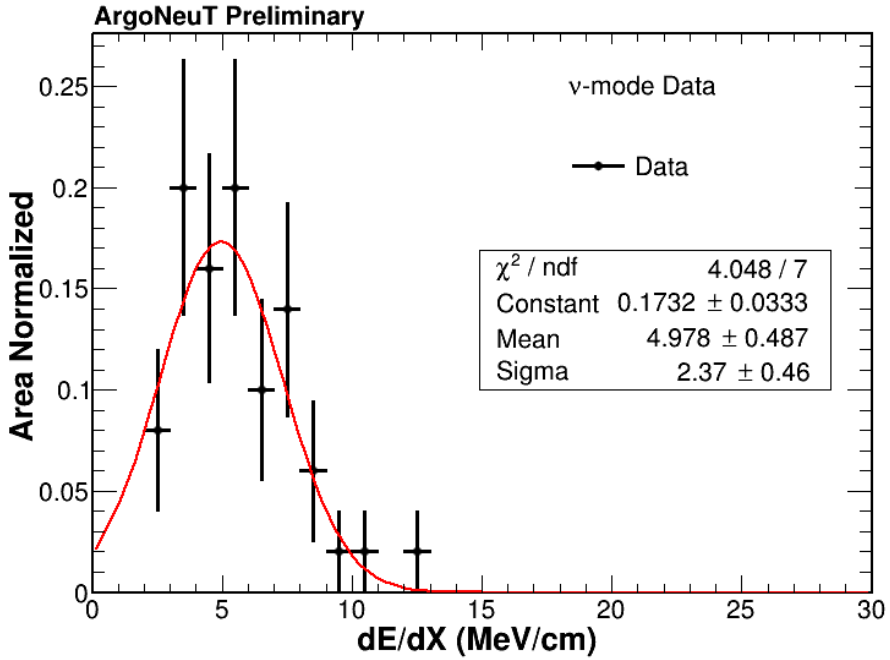
$M_{\gamma\gamma}$ ~ 135 +/- 21 MeV (stat. error only)

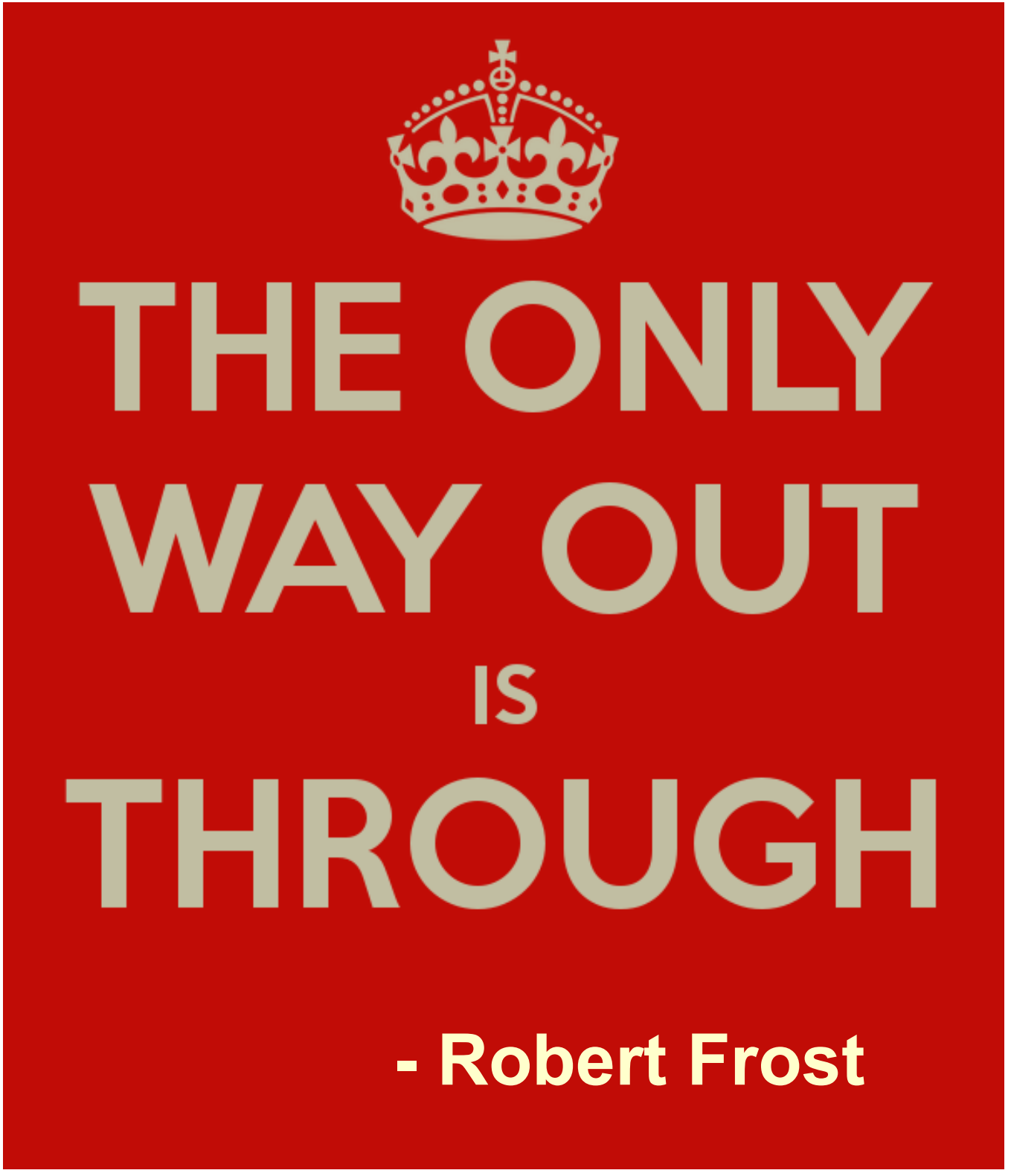
⟶ Work continuing to refine the energy corrections and analyze the full data set

Represents 1/8th of the total data





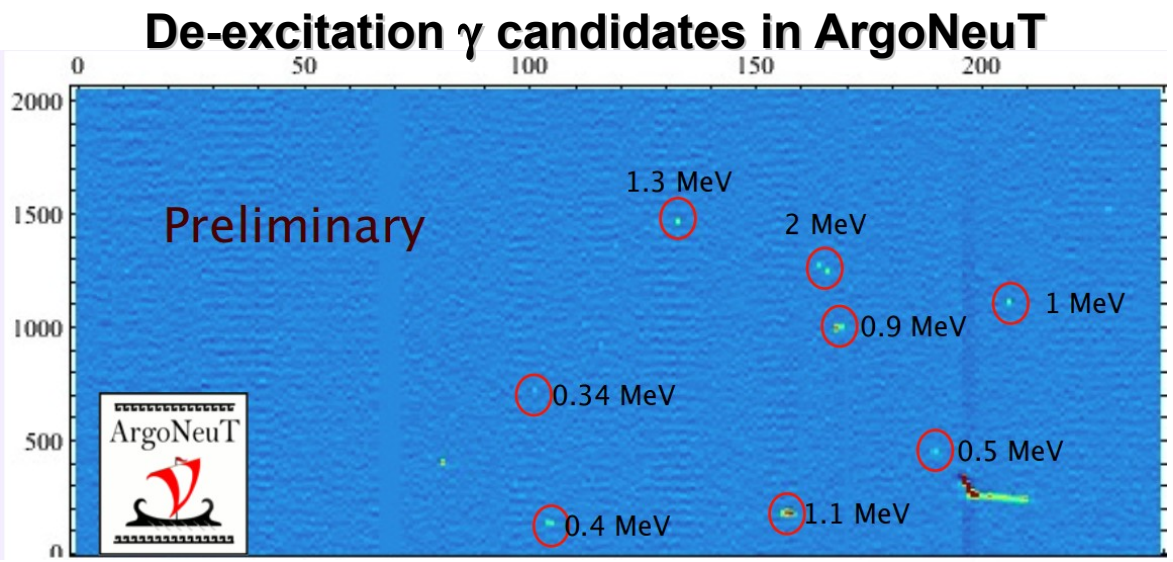


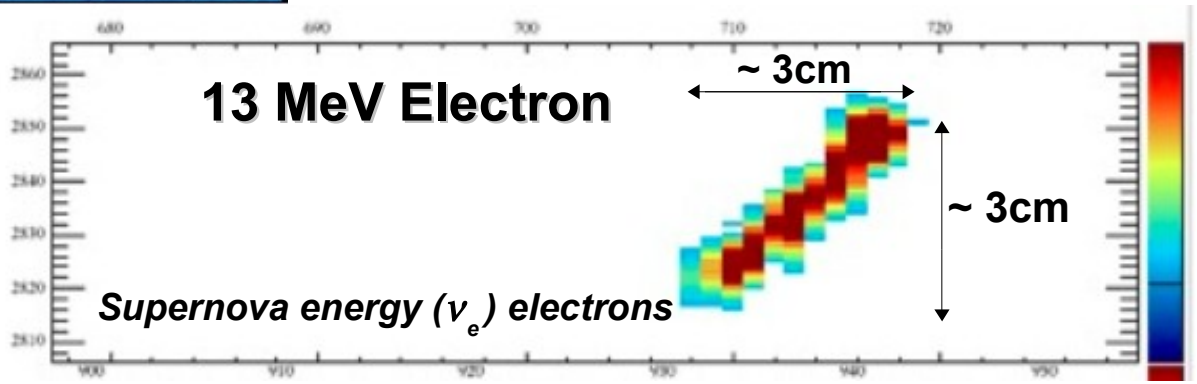


When thinking about the future I start with an American poet

...but to be fair he was published in England before he was recognized in the U.S.

Going forward



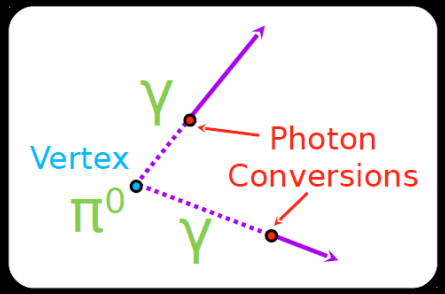


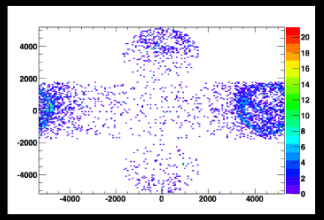
Low energy electrons and photons produced at MicroBooNE will present new challenges to LArTPC's that ***will be overcome*** to examine to explore low energy cross-sections and oscillation results

Going forward

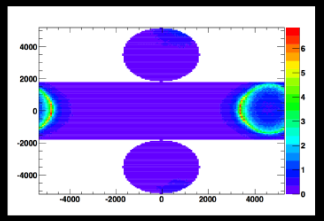
Event Selections Improvements

- Old π^0 cut: 2nd ring finder + π^0 mass
- New π^0 cut: Add fitter
  - Forces fits to π^0 and e^- hypotheses
  - Fits 12 parameters
    - Vertex (4)
    - Direction (2x2)
    - Momenta (2)
    - Conversion distances (2)

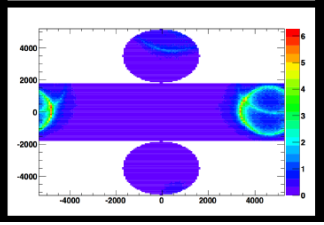




Measured Charge



Predicted Charge: Single Ring (e-like) fit

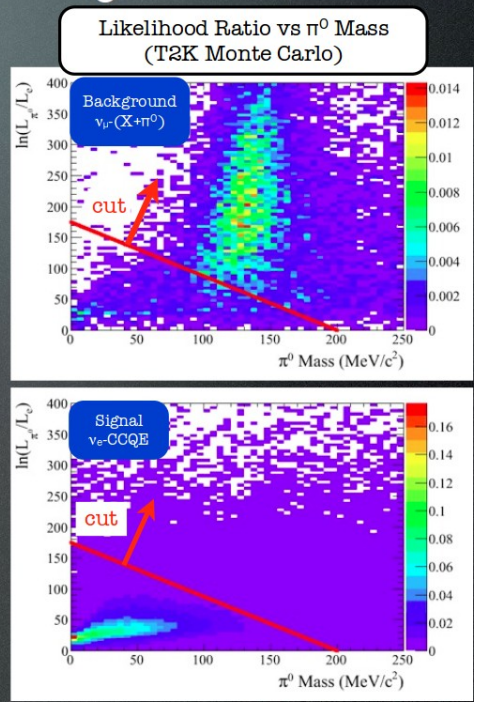


Predicted Charge: Two Ring (π^0-like) fit

20

Enhanced π^0 Rejection

- fiTQun can also use the best-fit **likelihood ratio** to distinguish e^- from π^0
- 2D cut **removes 70% of the remaining π^0 background** allowed by APFit for the same signal efficiency
  - Beam ν_e background does not change significantly
- Total background is reduced by 27%
  - 6.36 events → 4.64 events (for full Run 1-4 dataset)



Slides from T2K Presentation @ NNN13

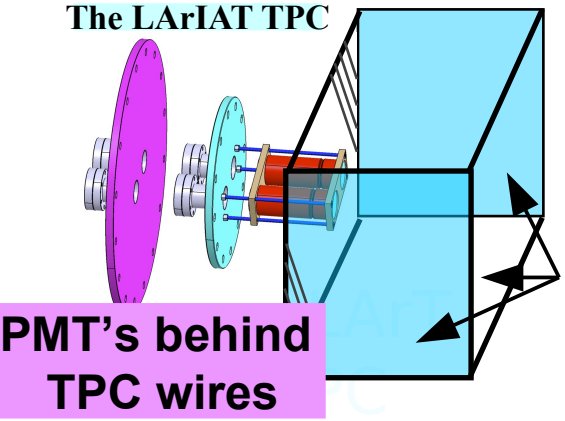
You should go talk to Michael Wilking (Fermilab Fantasy Football reigning Champion) about this...

Careful not to mention ν-Prisim though or you'll end up buying a very large water detector :-)

Revisiting and enhancing our reconstruction techniques can greatly improve our sensitivities and our background rejection

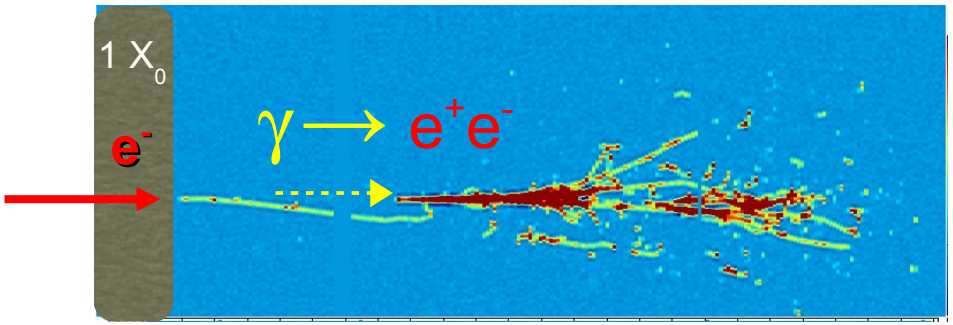
Going forward

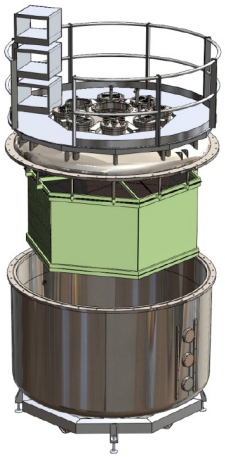
- A robust test beam program (LArIAT, CAPTAIN, LBNO-DEMO) will go a long way to helping us understand e/γ interactions in LAr



Two cryogenic PMTS

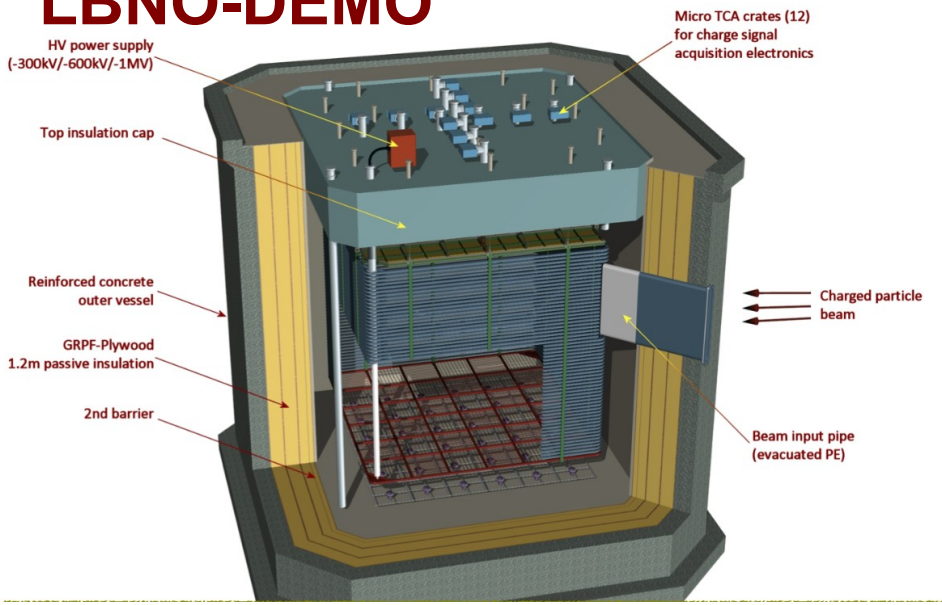
Wavelength shifting reflector foil lining the TPC





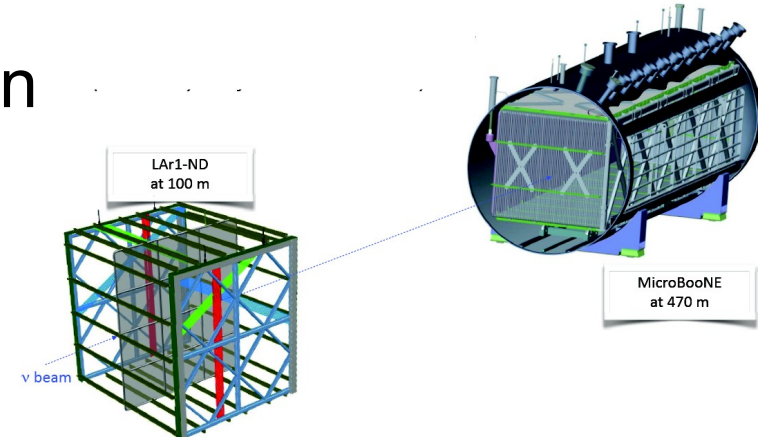
CAPTAIN

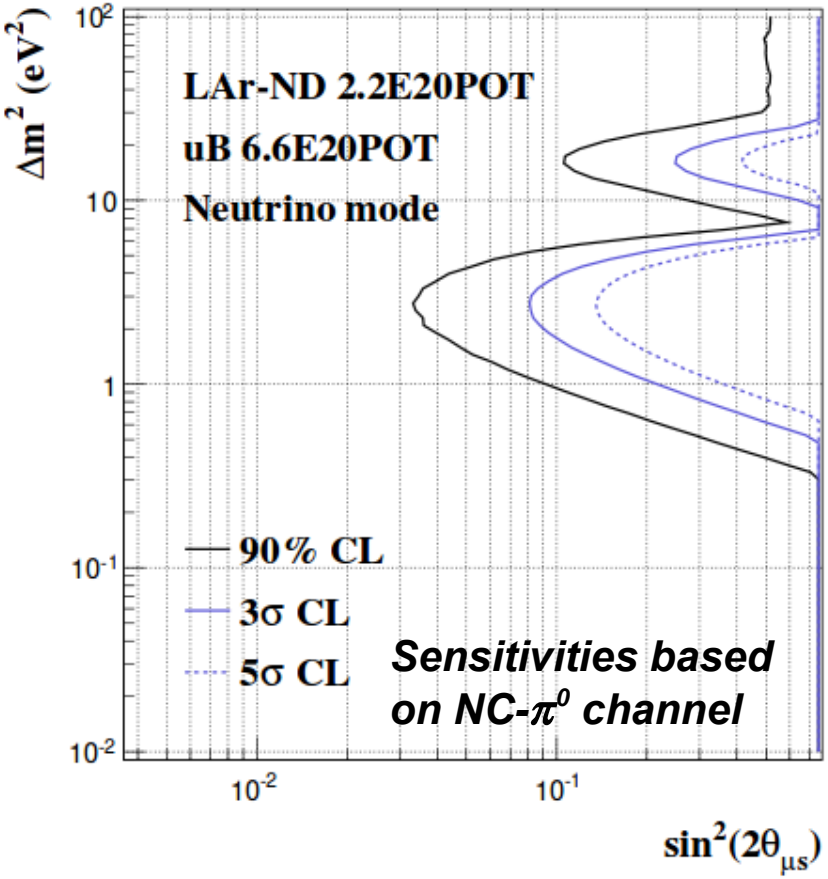
LBNO-DEMO



Going forward

- **NC-π^0 + (n)proton(s) measurement using near/far detectors w/ LAr1-ND & MicroBooNE may be a decisive way to search for sterile neutrinos in a short baseline**
  - Will require excellent π^0 reconstruction
    - This requires top-notch e/γ identification





MicroBooNE

Process	# of Events in 6.6 E20 POT
NC-π^0 + (n)proton(s)	~6,000

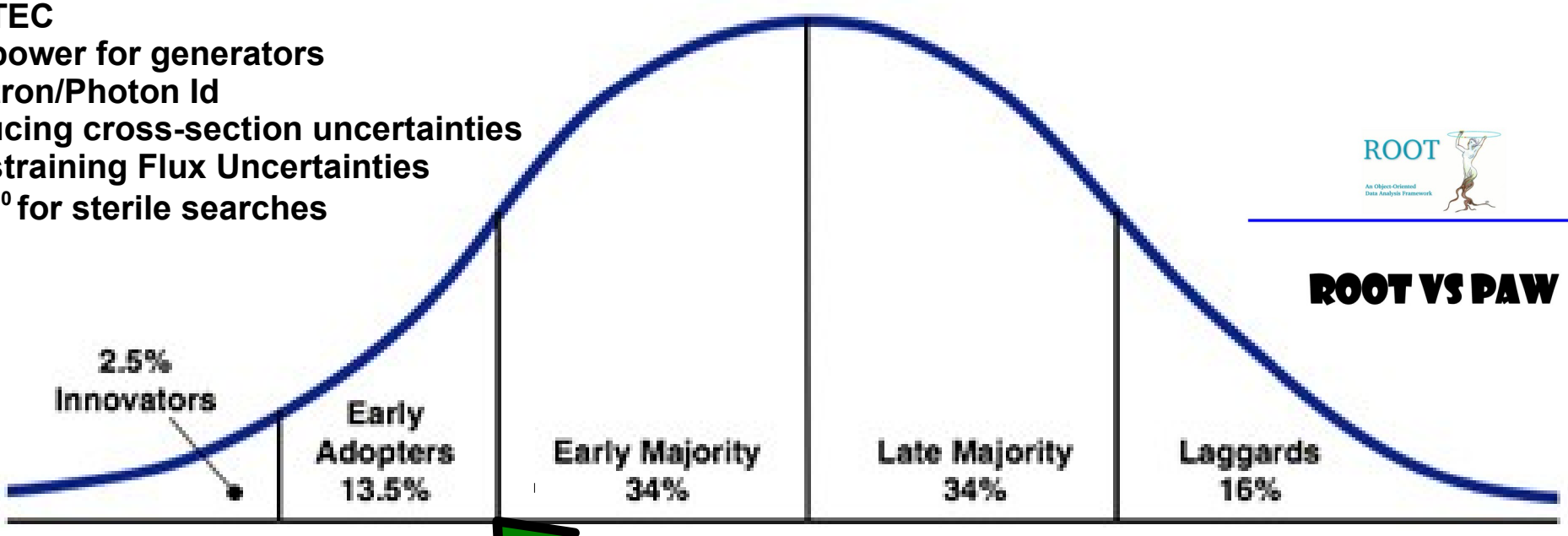
LAr1-ND

Process	# of Events in 2.2 E20 POT
NC-π^0 + (n)proton(s)	~54,000

Taken from LAr1-ND proposal to Fermilab PAC
http://www.fnal.gov/directorate/program_planning/Jan2014PACPublic/LAr1ND_Proposal.pdf

Closing thoughts

NuSTEC
Manpower for generators
Electron/Photon Id
Reducing cross-section uncertainties
Constraining Flux Uncertainties
NC-π^0 for sterile searches
….



ROOT

An Object-Oriented Data Analysis Framework

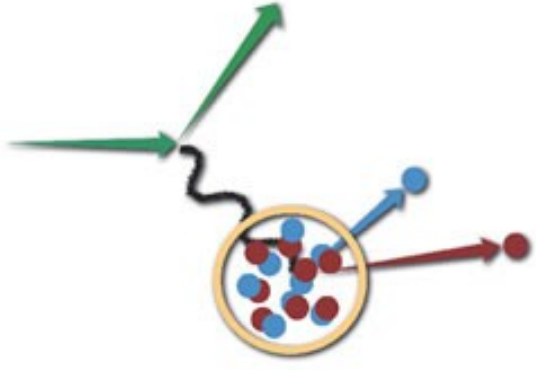
ROOT VS PAW

IOP Institute of Physics

NuInt14

9th International Workshop on Neutrino-Nucleus Interactions in the Few-GeV Region

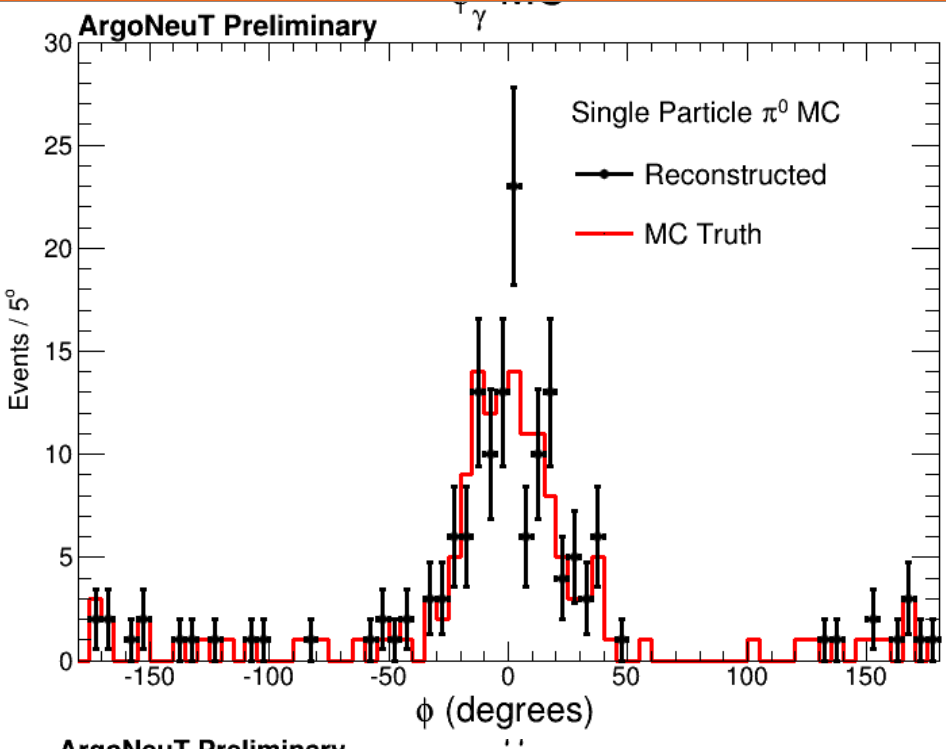
19–24 May 2014, Selsdon Park Hotel, Surrey, UK

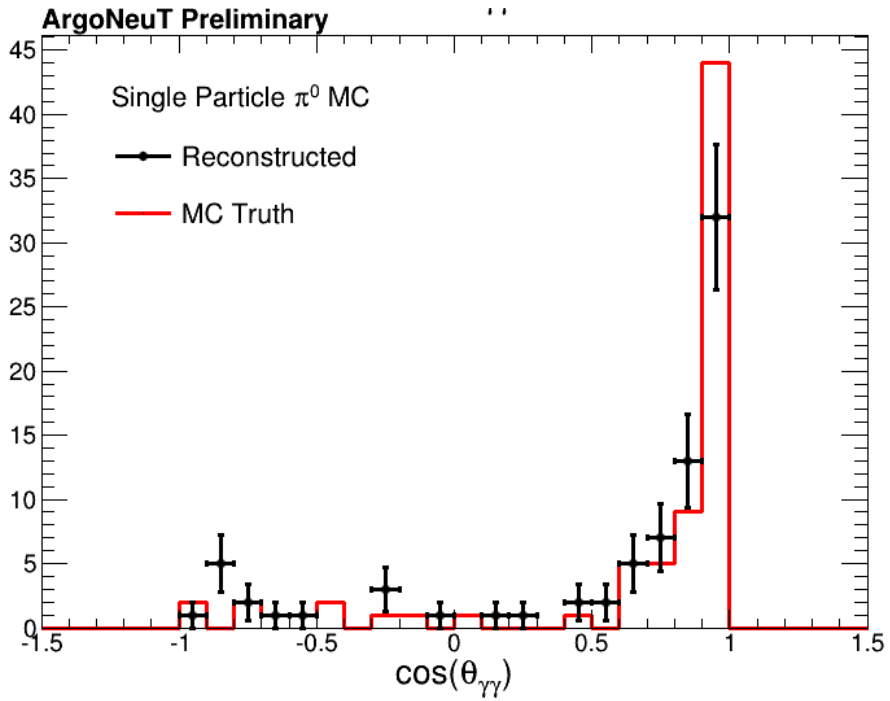


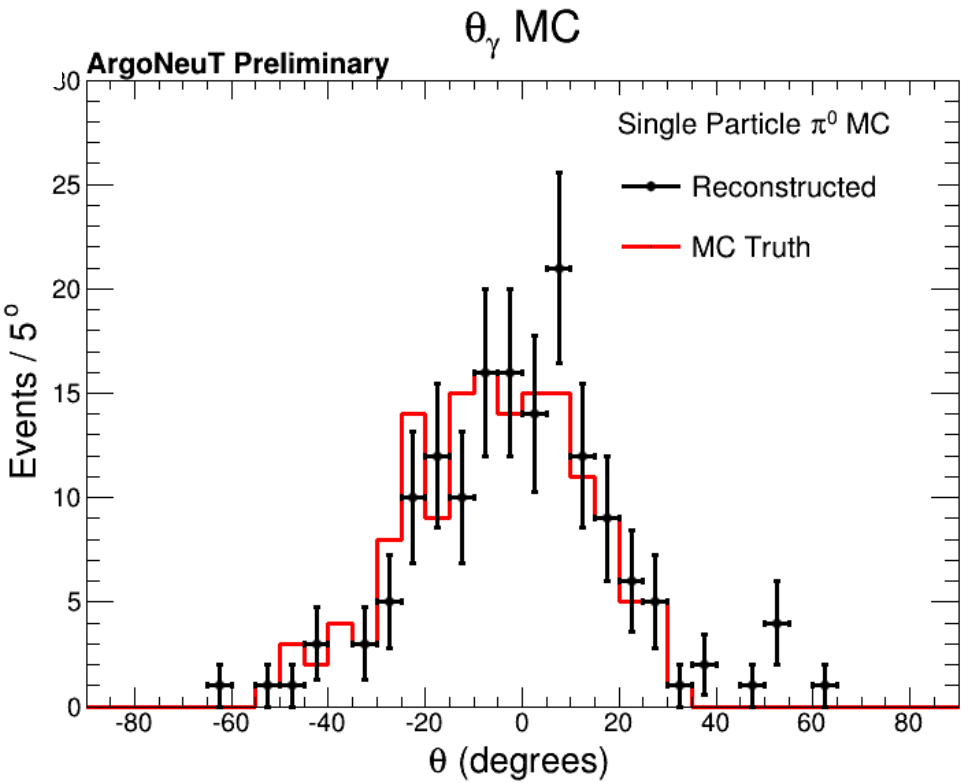

Thank you for your attention
Thank you for a wonderful conference

Backup Slides

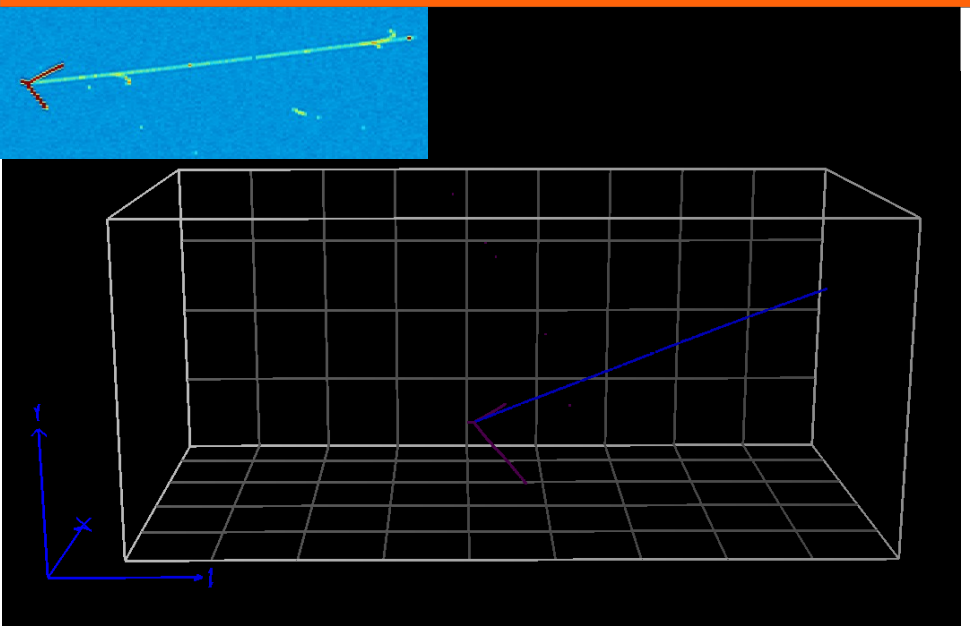
Neutral Current π^0 in ArgoNeuT





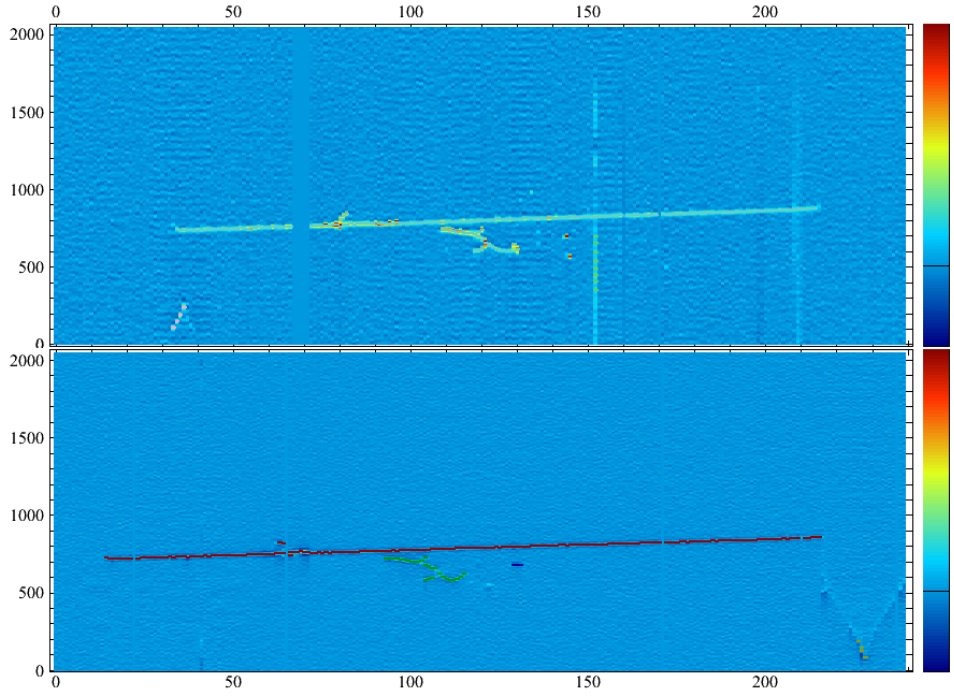


Neutral Current π^0 in ArgoNeuT

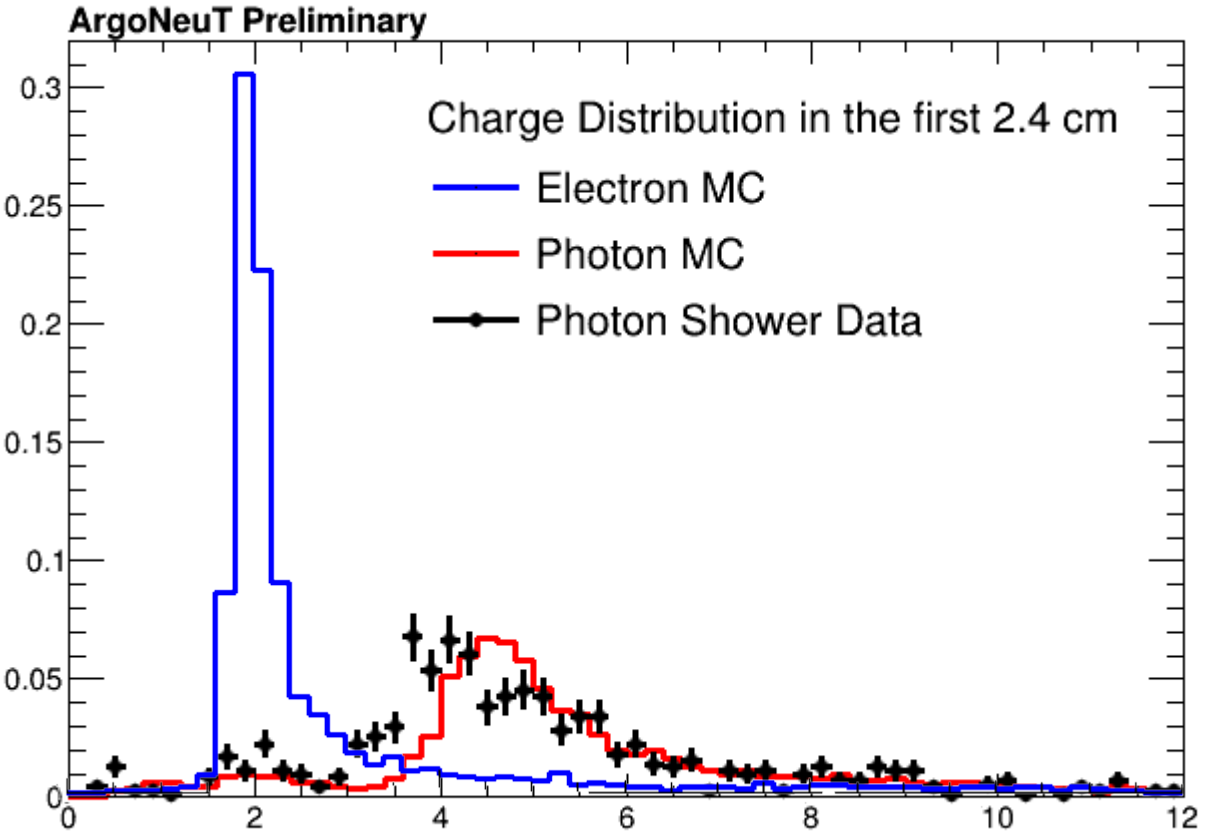


We can utilize the tracking and calorimetry information to further veto potential charged current backgrounds that aren't matched to MINOS

Here we look for two or more tracks that point back to a common point (+/- 5cm) and have a dE/dX consistent with being a muon + proton/$\pi^{+/-}$



We also look for through going muons from the beam that enter at a boundary but aren't matched to MINOS.


ArgoNeuT Preliminary
Charge Distribution in the first 2.4 cm
Electron MC
Photon MC
Photon Shower Data
0.3
0.25
0.2
0.15
0.1
0.05
0
0
2
4
6
8
10
12