T2K ND280 EM Calorimeter Performance and Lessons Learned

David Hadley

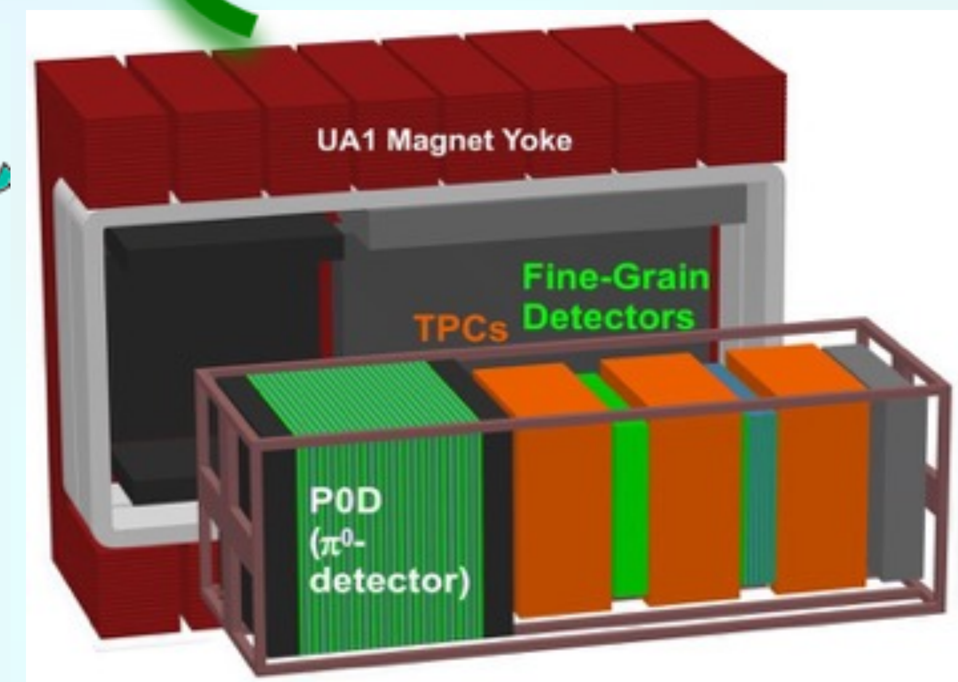
Outline

T2K and ND280 Experiments

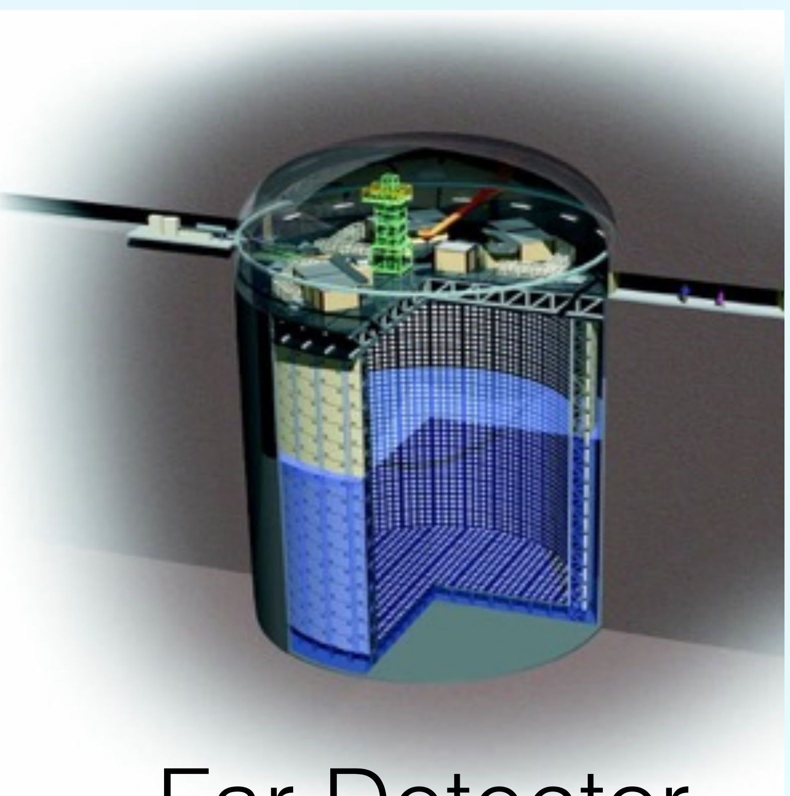
ND280 EM Calorimeter

EM Calorimeter usage and performance in current analysis

T2K



Near Detector (ND280)



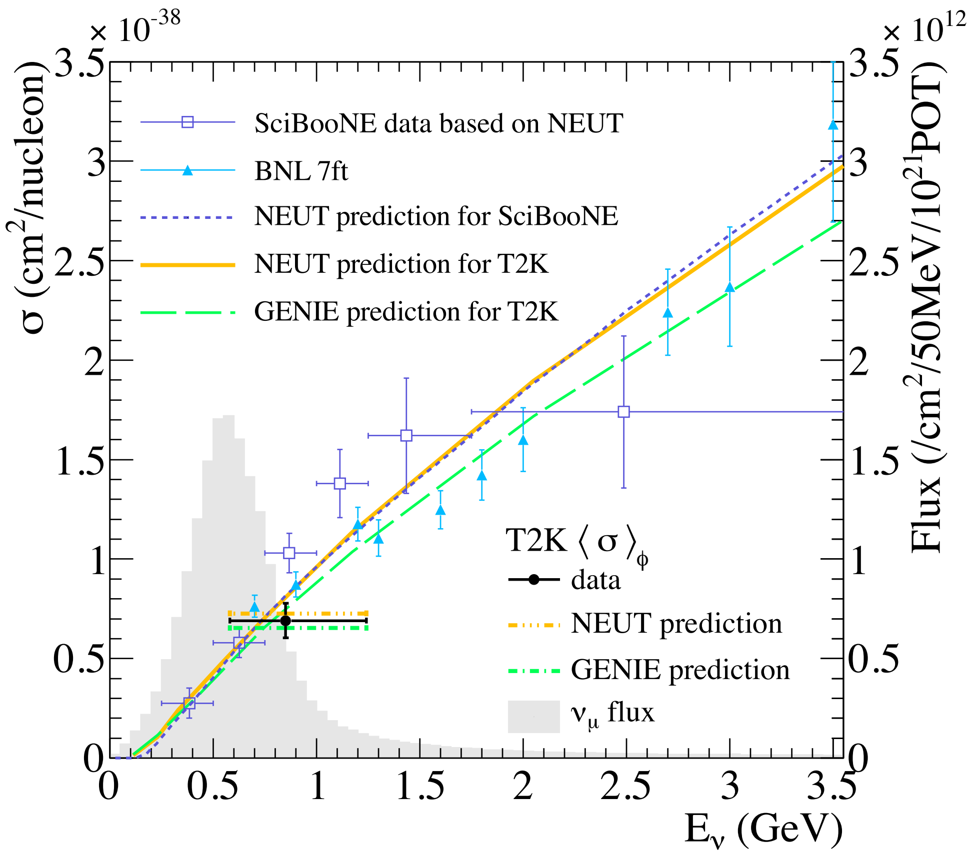
Far Detector
(Super-K)

1. Create intense beam of (anti-) muon neutrinos.
2. Measure neutrino interactions in near and far detector.
3. Compare rates.
4. Infer neutrino oscillation parameters.

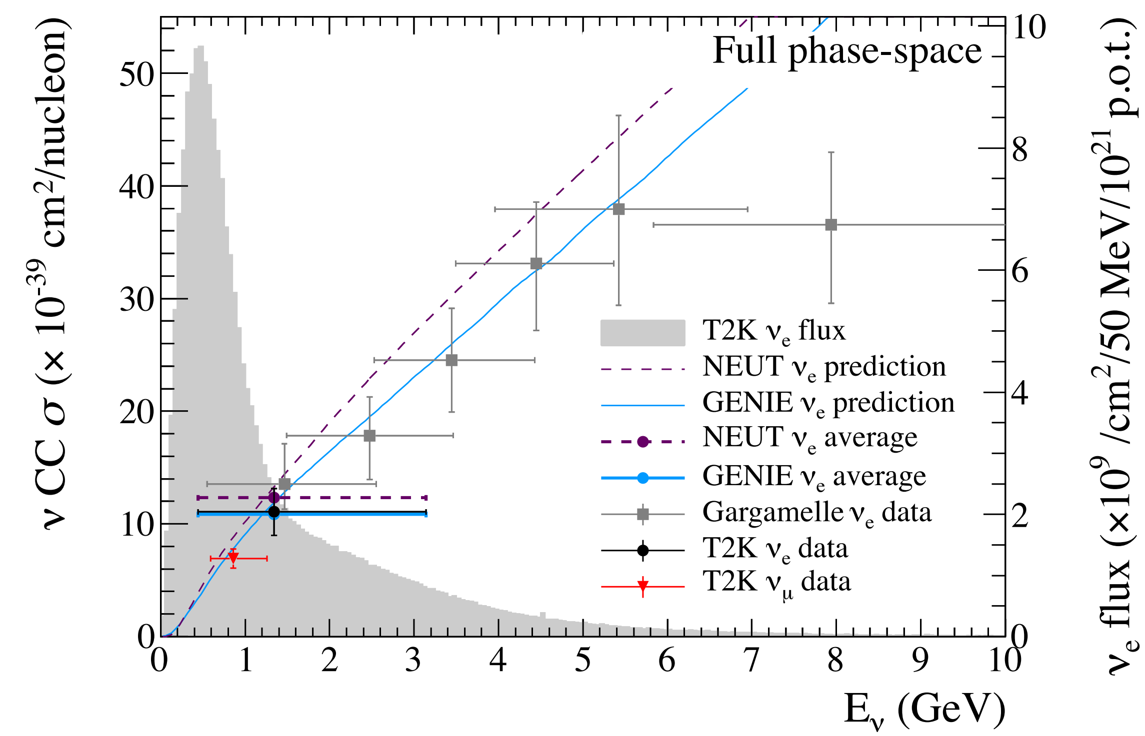
Also: study neutrino-nucleus interactions, exotics (eg steriles, NSI) ….

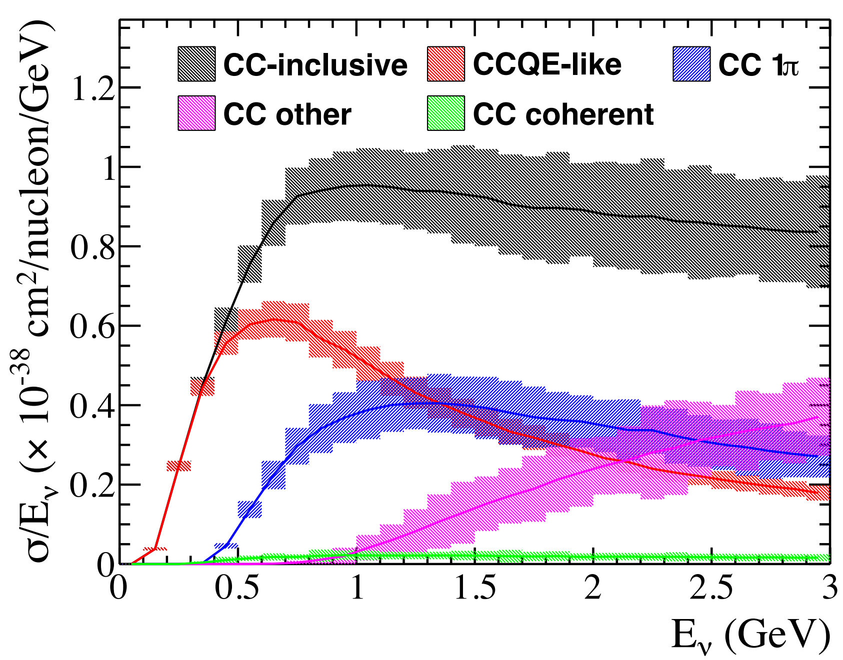
ND280 Flux

Phys. Rev. D 87, 092003 (2013)



Phys. Rev. Lett. 113, 241803 (2014)





In neutrino-mode

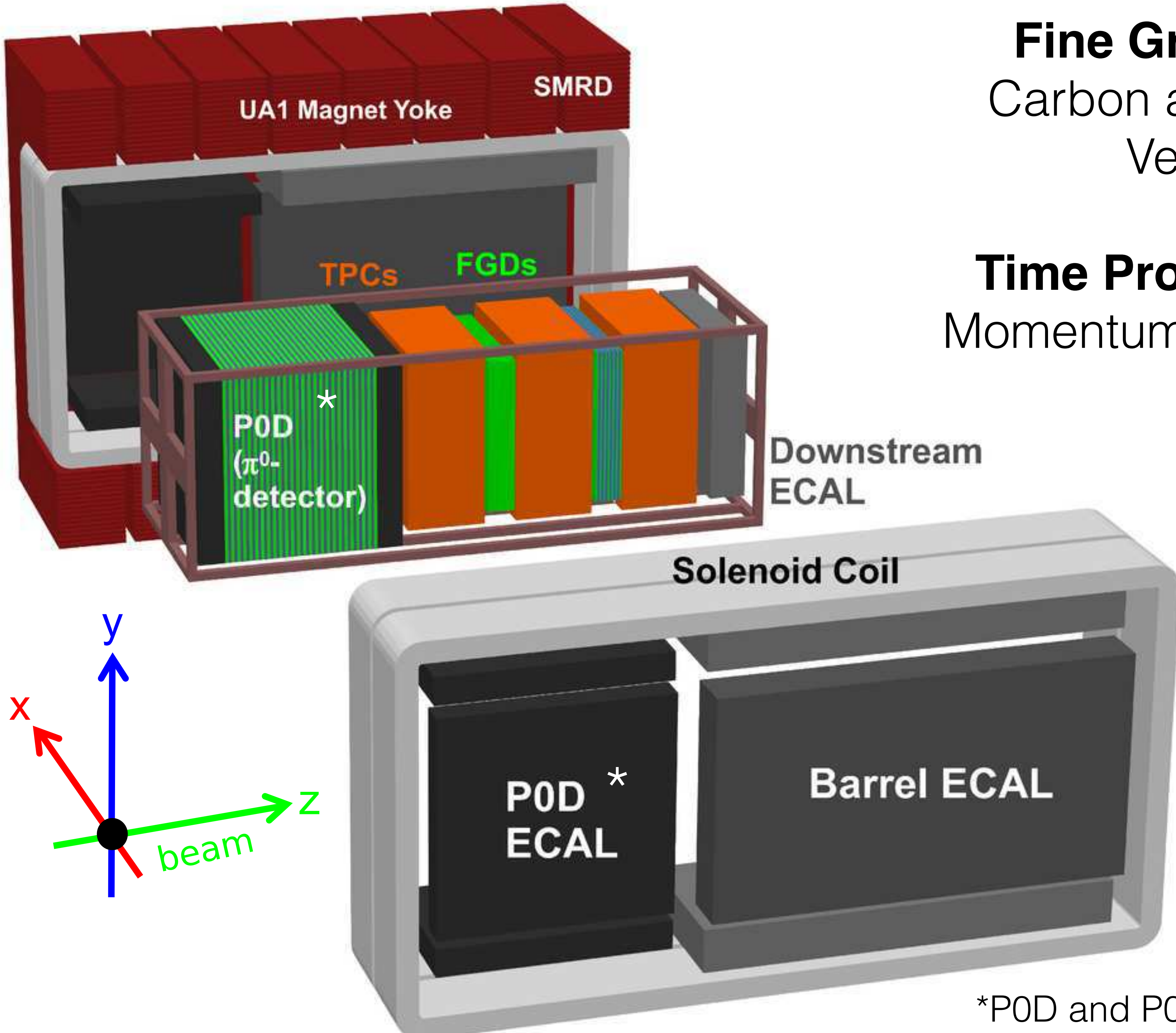
ν_μ : ⟨E⟩ = 0.85 GeV, (~90%)

ν_e : ⟨E⟩ = 1.3 GeV,(~1%)

Dominant Reaction: CCQE

Single Pion Production

ND280 Detector



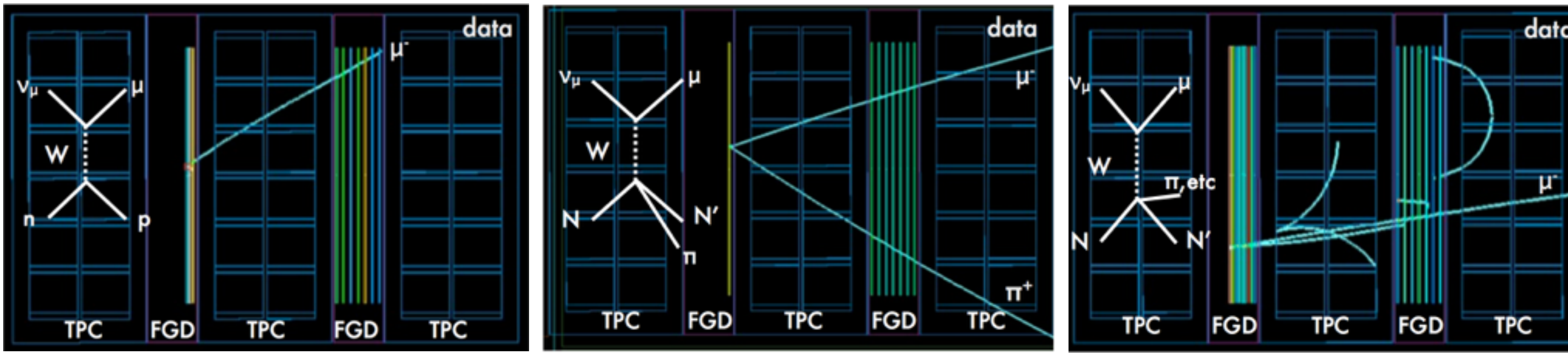
Fine Grained Detectors (FGD)
Carbon and Oxygen Target Mass,
Vertex reconstruction

Time Projection Chambers (TPC)
Momentum and Charge Measurement
Particle ID

EM Calorimeters
Neutral Particle Reconstruction
Additional PID and
energy measurement
Tag entering backgrounds

*P0D and P0D ECal detectors not be discussed here.
See arXiv:1111.5030 and arXiv:1308.3445 for information on these detectors.

ND280 Input to T2K Oscillation Analysis



ND280 data split based on reconstructed topology enhanced in different interaction types

Fit flux + interaction model and propagate to far detector

As statistics increase and analysis becomes more sophisticated incorporate more channels

ND280 ECal

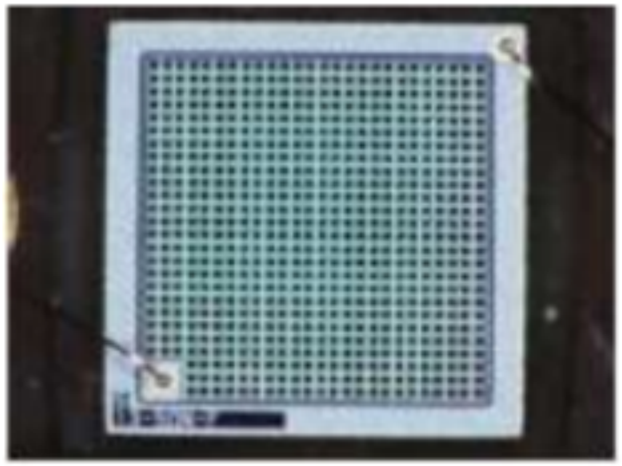
1 Downstream, 6 Barrel modules

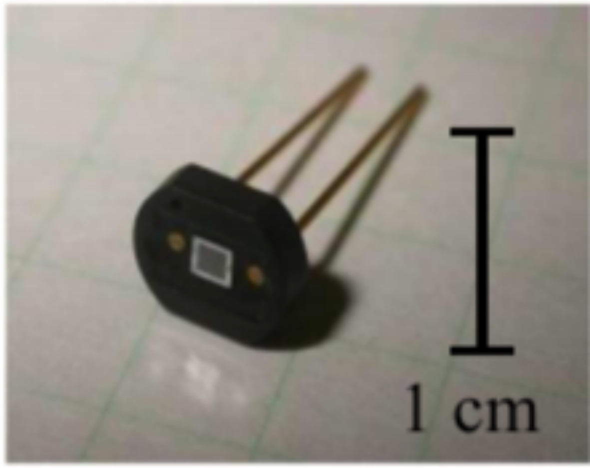
Sampling calorimeter
40 x 10 mm scintillating polystyrene bars sandwiched between 1.75 mm lead absorber layers
22,336 channels in total

Scintillation light carried by wavelength shifting fibres to multi-pixel photon counters (MPPCs)

Orthogonal even and odd layers allow 3D reconstruction

Hard constraint on detector size to fit inside pre-existing UA1 magnet
31 - 34 layers ~10 radiation lengths





JINST 8 P10019 (2013)
arXiv:1308.3445 [physics.ins-det]

ND280 ECal Reconstruction

Hit preparation

Calibration applied to MPPC hit charge and time
Bars with double ended readout are merged

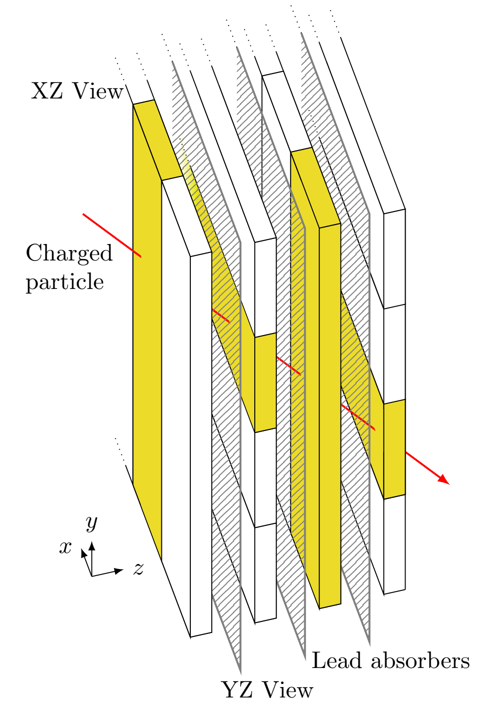
2D Clustering

Independent clustering in each of the 2D views

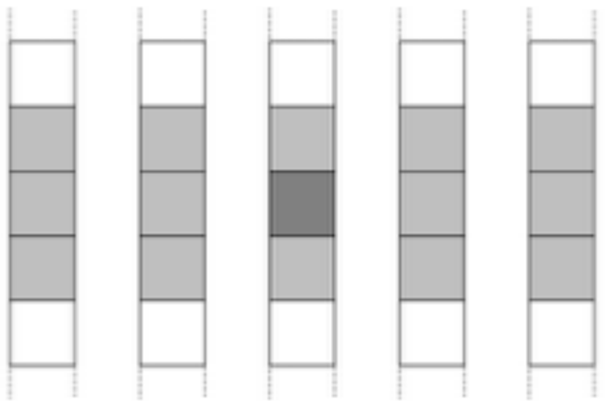
3D Matching

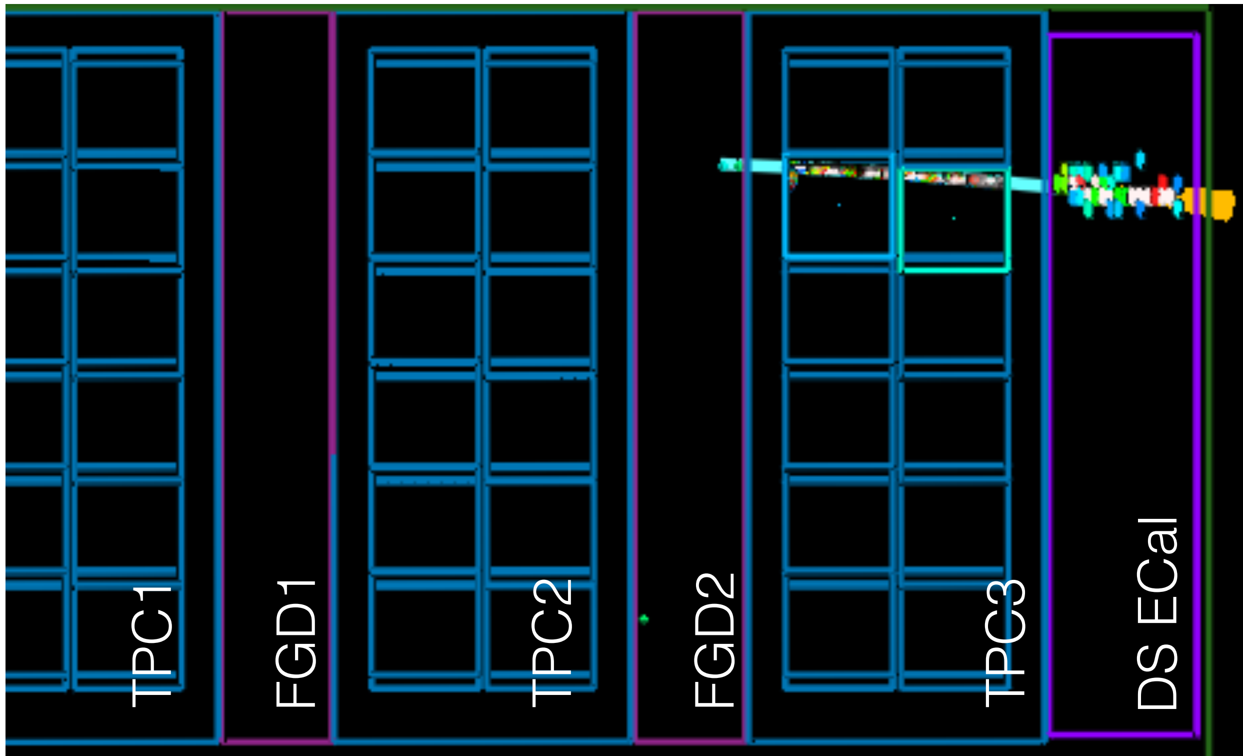
Likelihood-based matching of clusters between views to form 3D objects
Can be seeded with information from other detectors

Energy Reconstruction and Particle ID

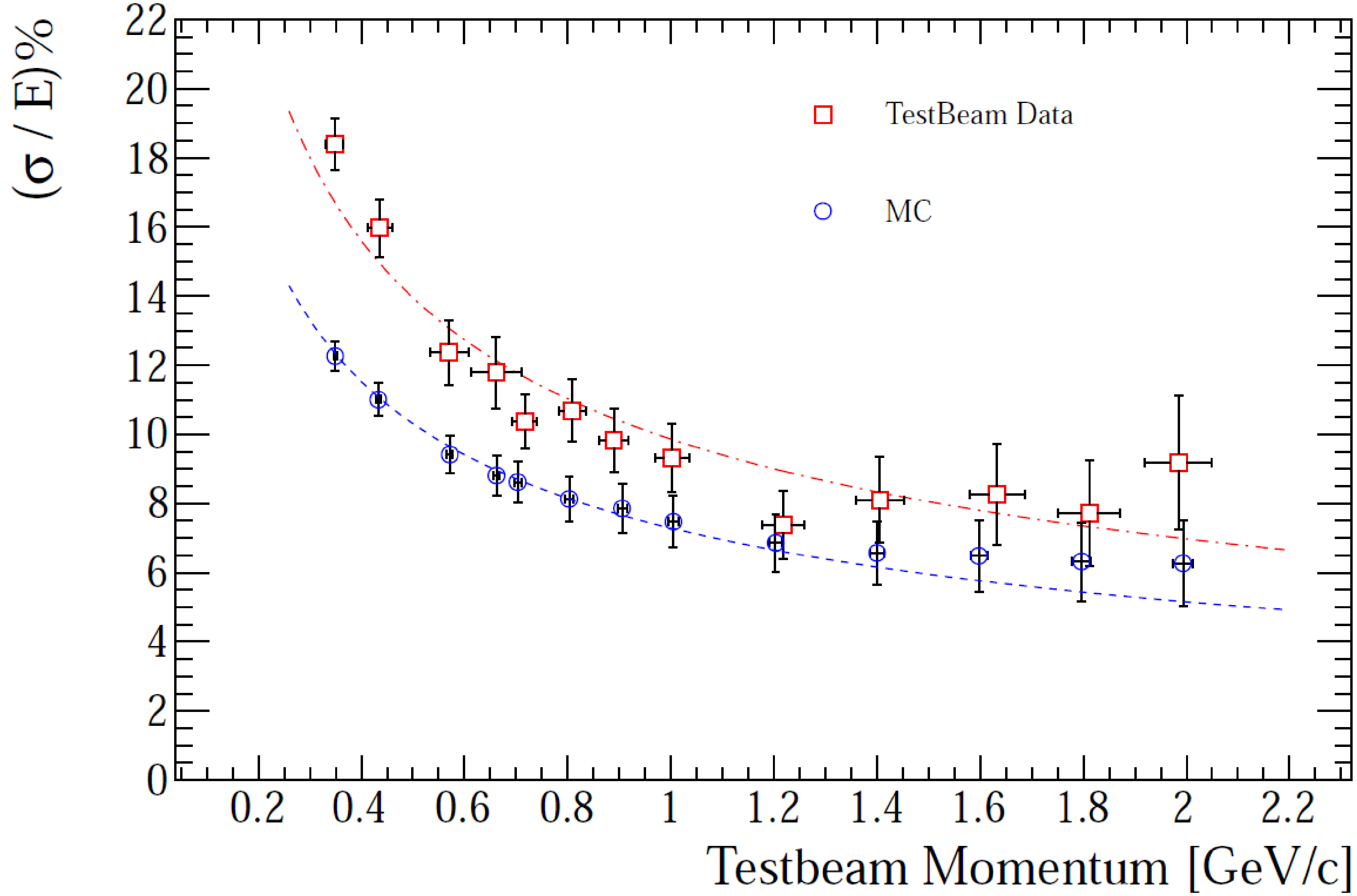


Orthogonal adjacent layers


2D view



Energy Reconstruction

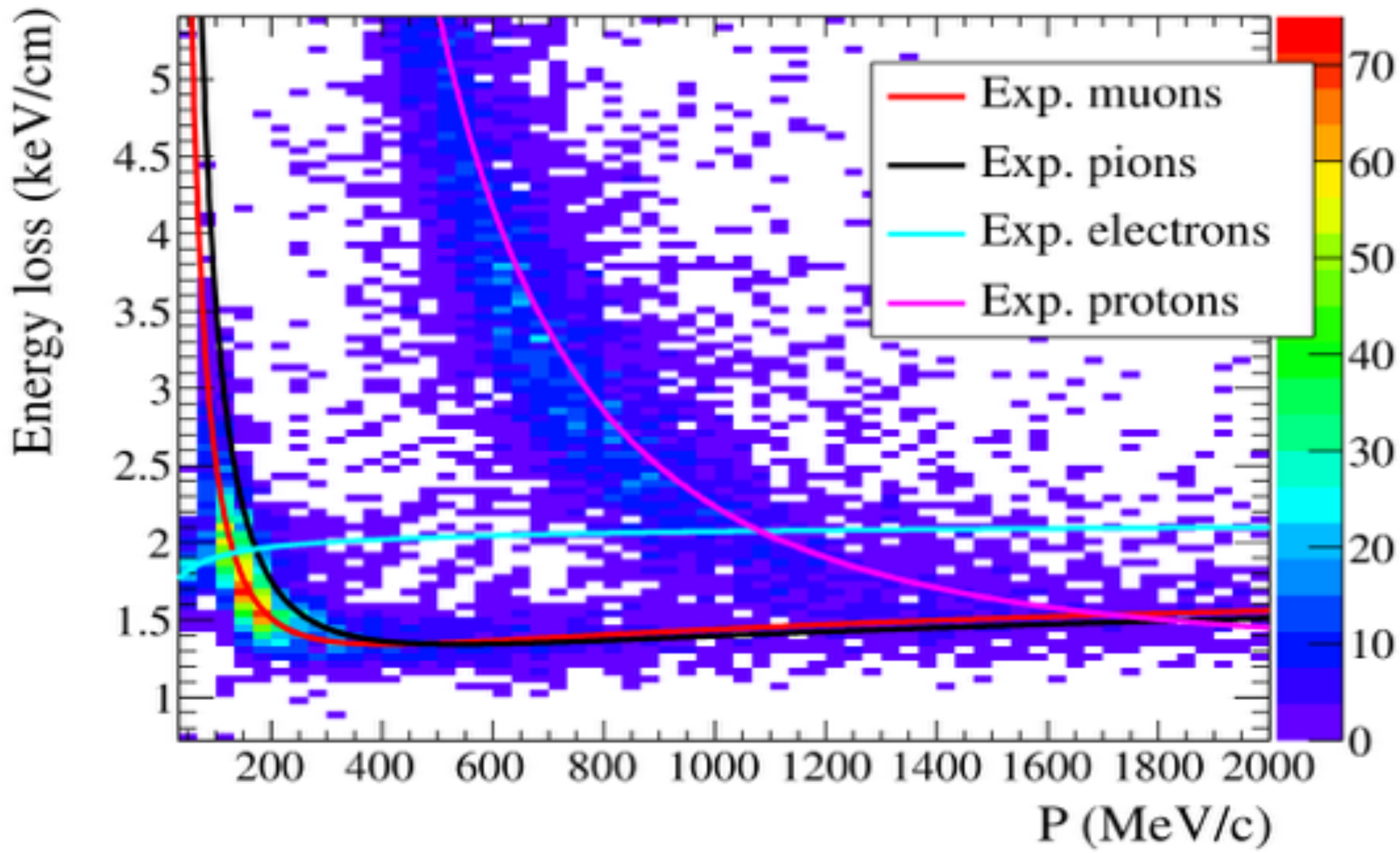


σ(E) ~ 8% at 1 GeV

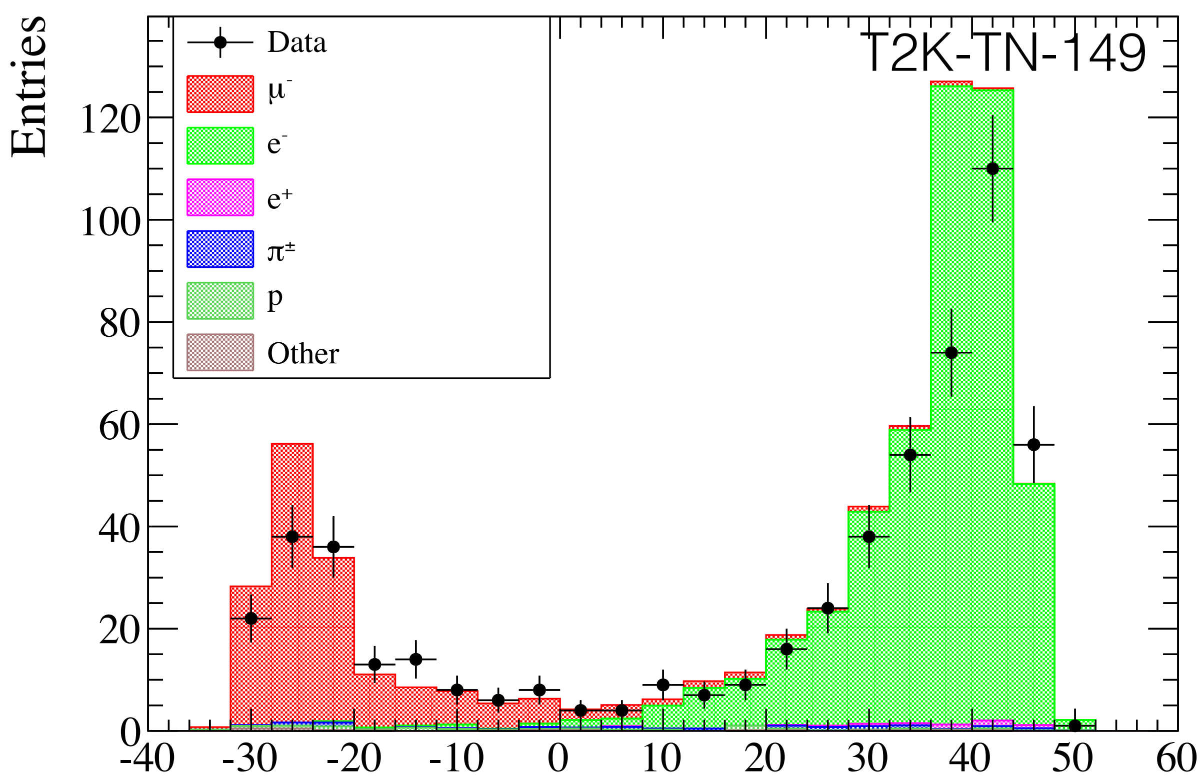
~ 10 X_0 to contain showers up to 3 GeV

Particle ID

TPC dE/dx PID



ECal PID Discriminator



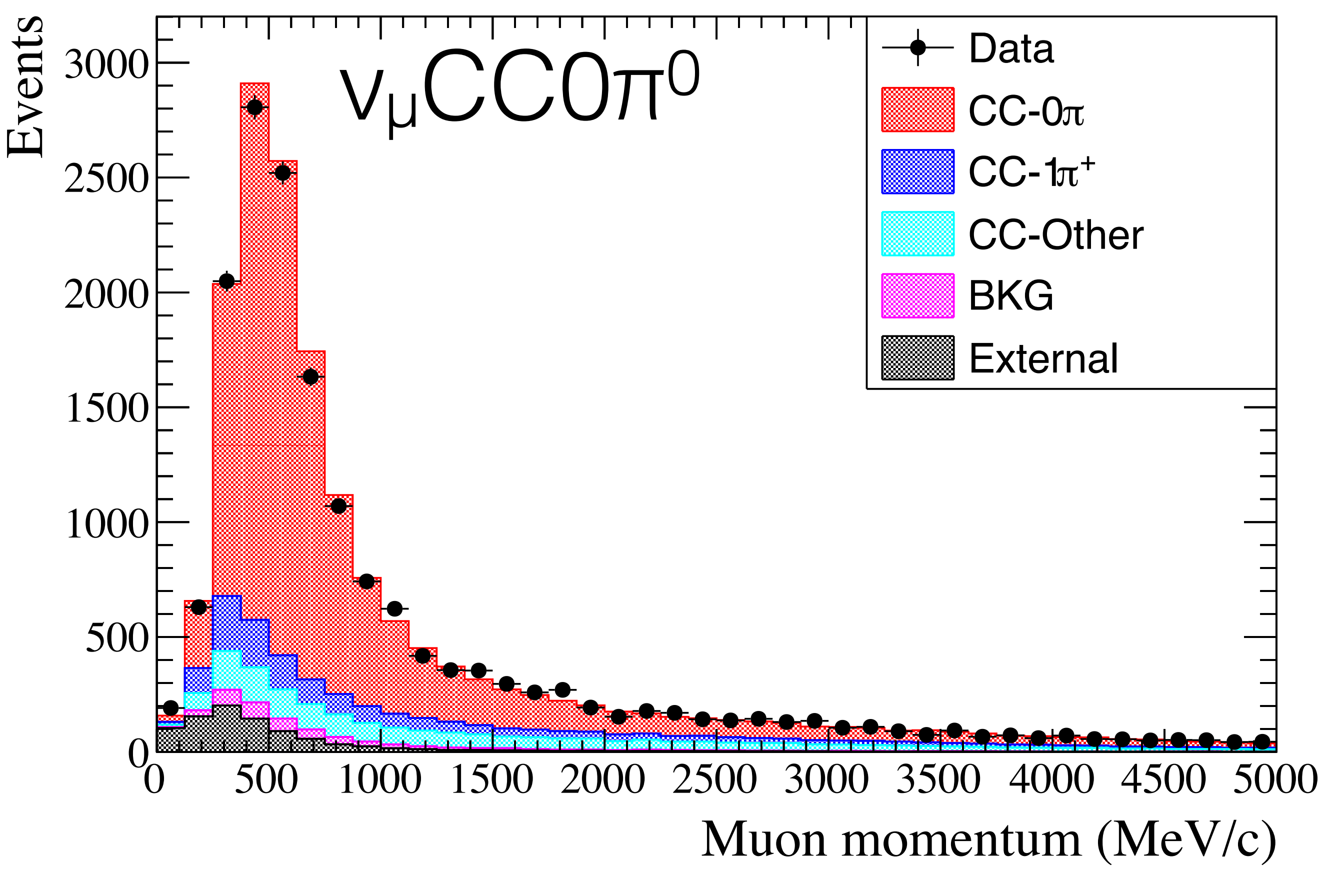
Track-like Shower-like

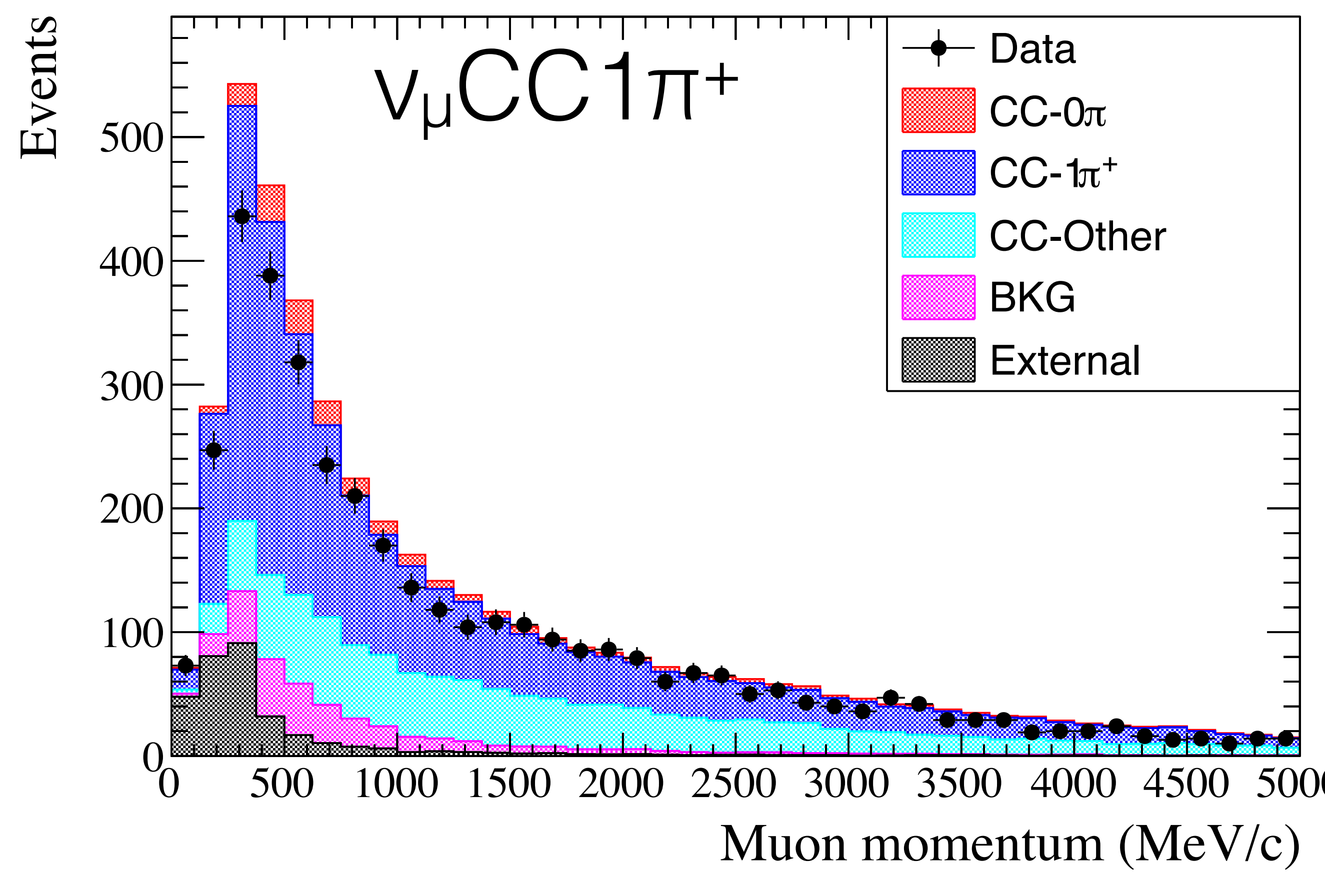
ECal provides independent particle identification

Important for momentum regions where the TPC dE/dx curves overlap

Also provides proton and pion tagging

Muon Analysis





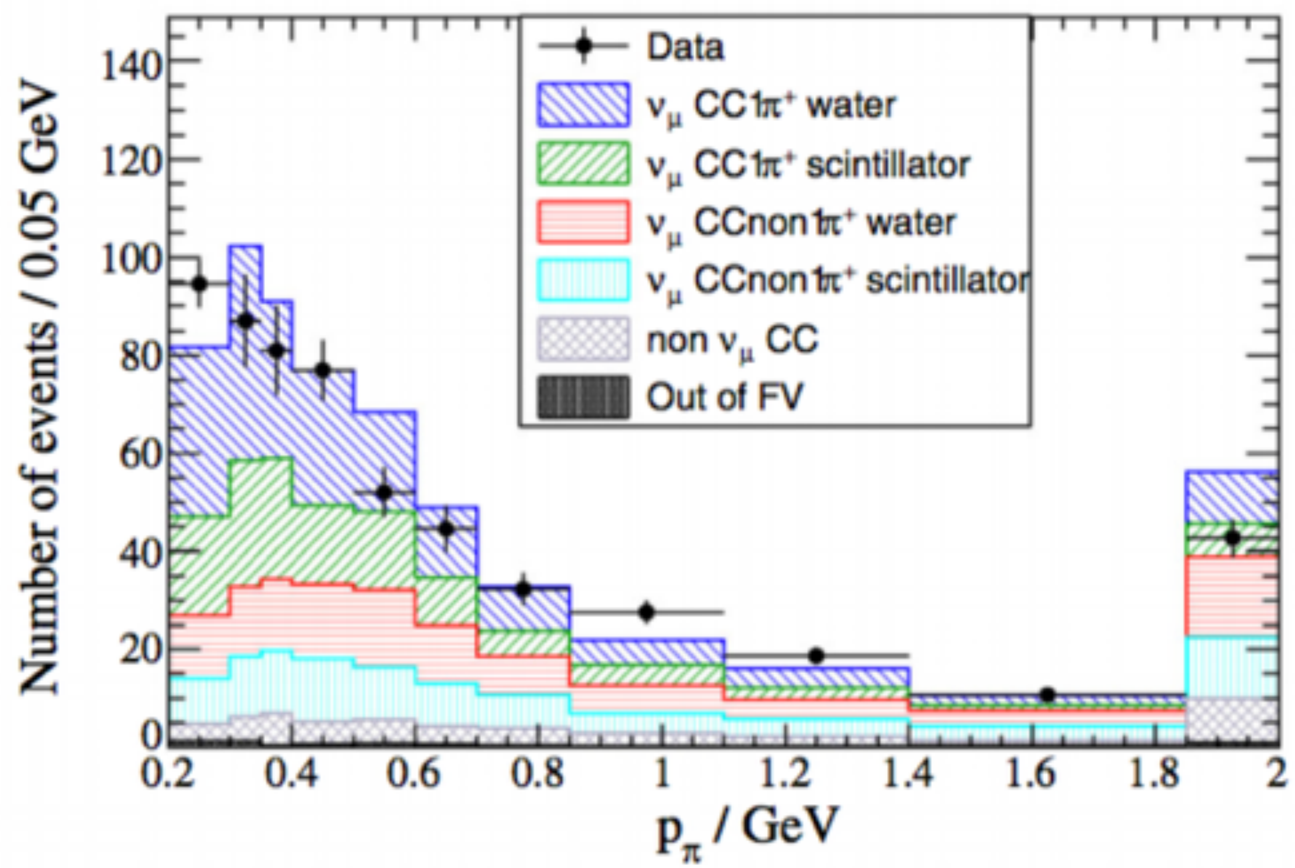
In standard muon analysis TPC+FGD work well enough ECal is currently not directly used

Used as an independent detector in some cases to construct control samples for systematics evaluation

Potential to veto π^0 (p) to improve purity of $\nu_\mu CC0\pi^0$ and $\bar{\nu}_\mu CC$

Muon Analysis

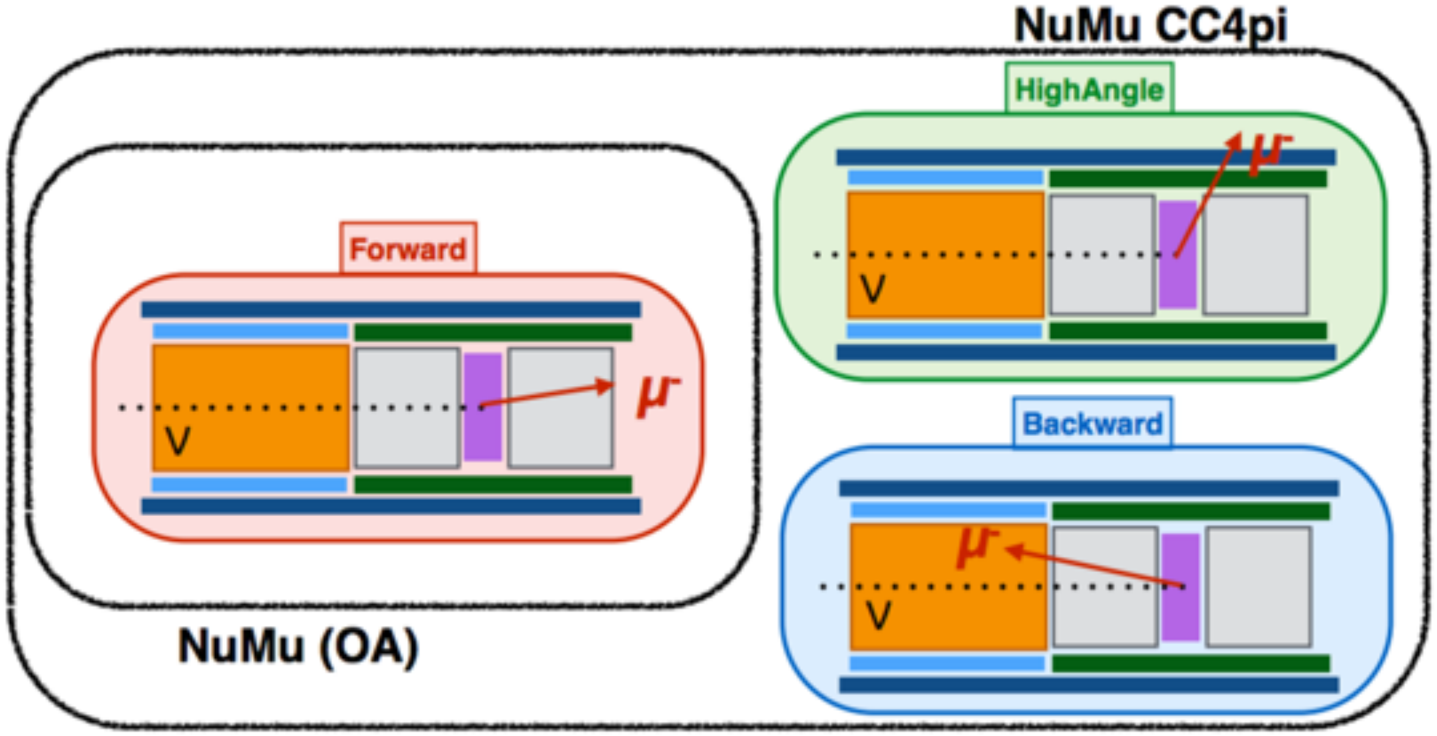
Phys. Rev. D 95, 012010 (2017)

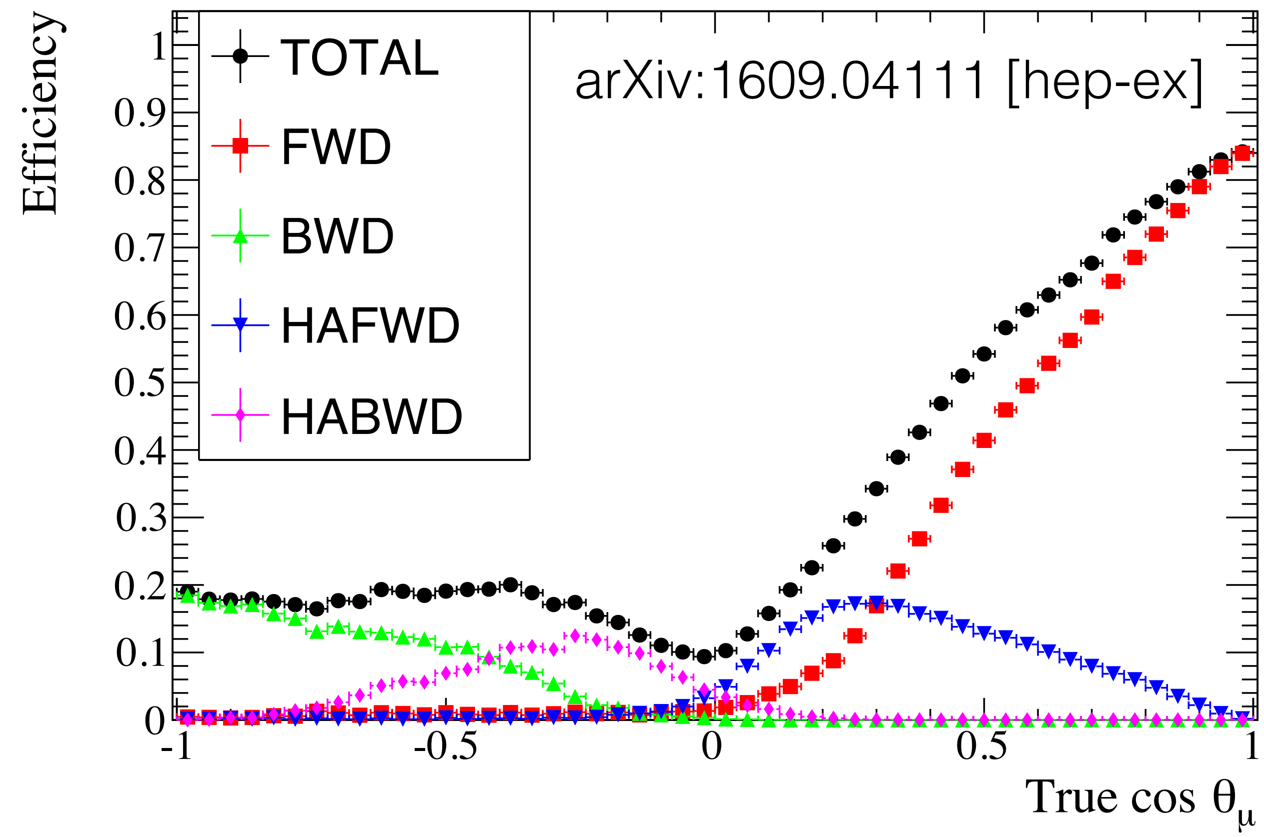


ECal π^0 veto used in recent CC1μ^-1π^+ cross section analysis

Signal Efficiency: 27% → 26%
Sample Purity: 45% → 52%

Muon Analysis





Super-K has 4π acceptance

Important to measure interactions at high angle in ND280

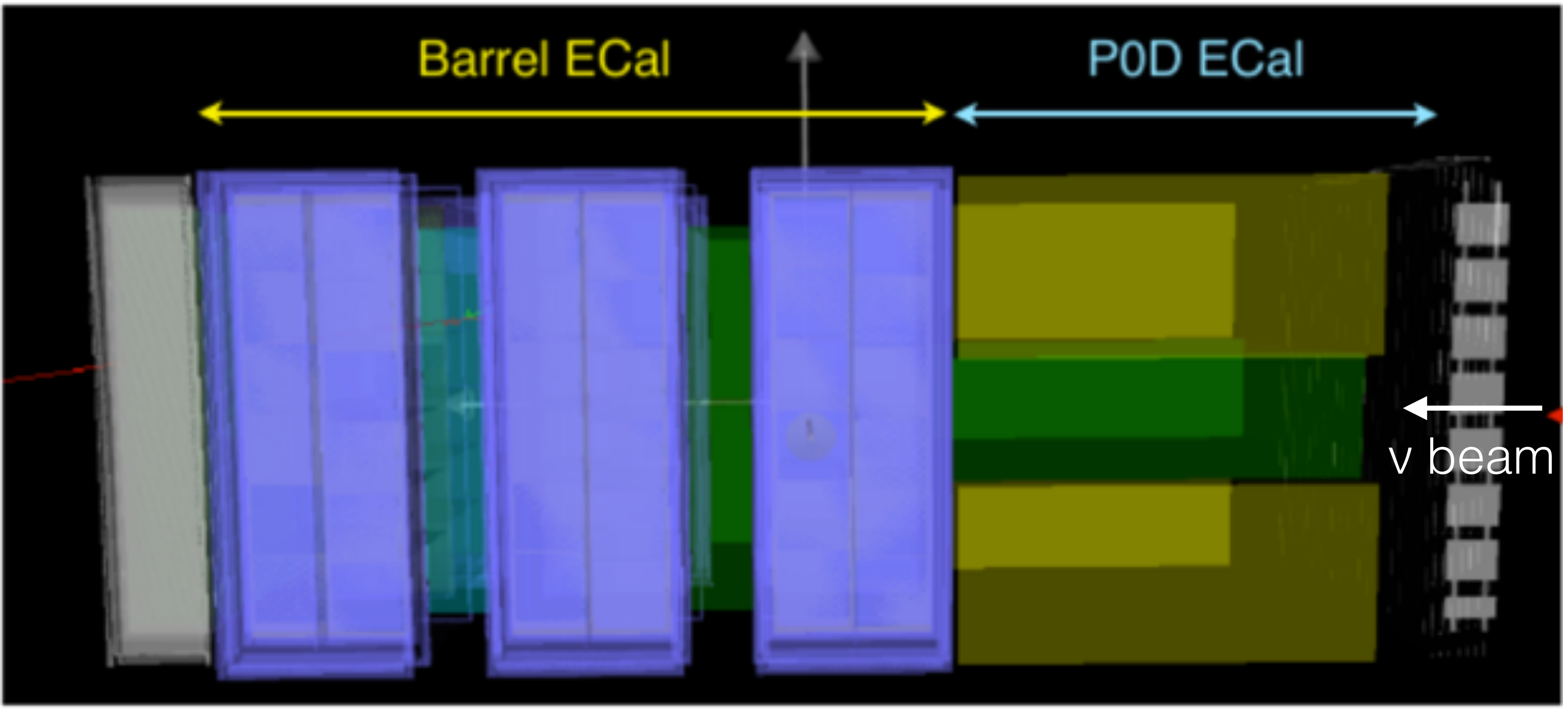
Short TPC tracks, Bad direction for orientation of FGD bars

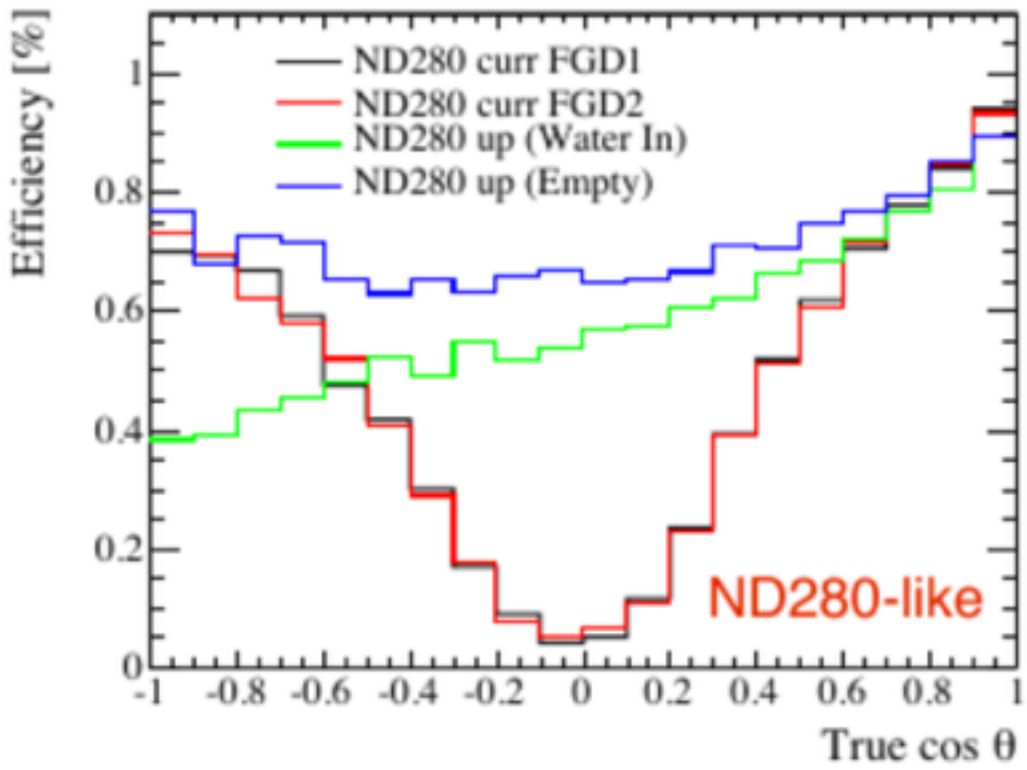
Orthogonal to Barrel ECal bar orientation

Use ECal reconstruction and PID

Momentum by range

Muon Analysis





M Zito, 3rd Workshop on Neutrino Near Detectors based on gas TPCs

Improving acceptance at high angles is one of the main motivations for planned upgrades to the ND280

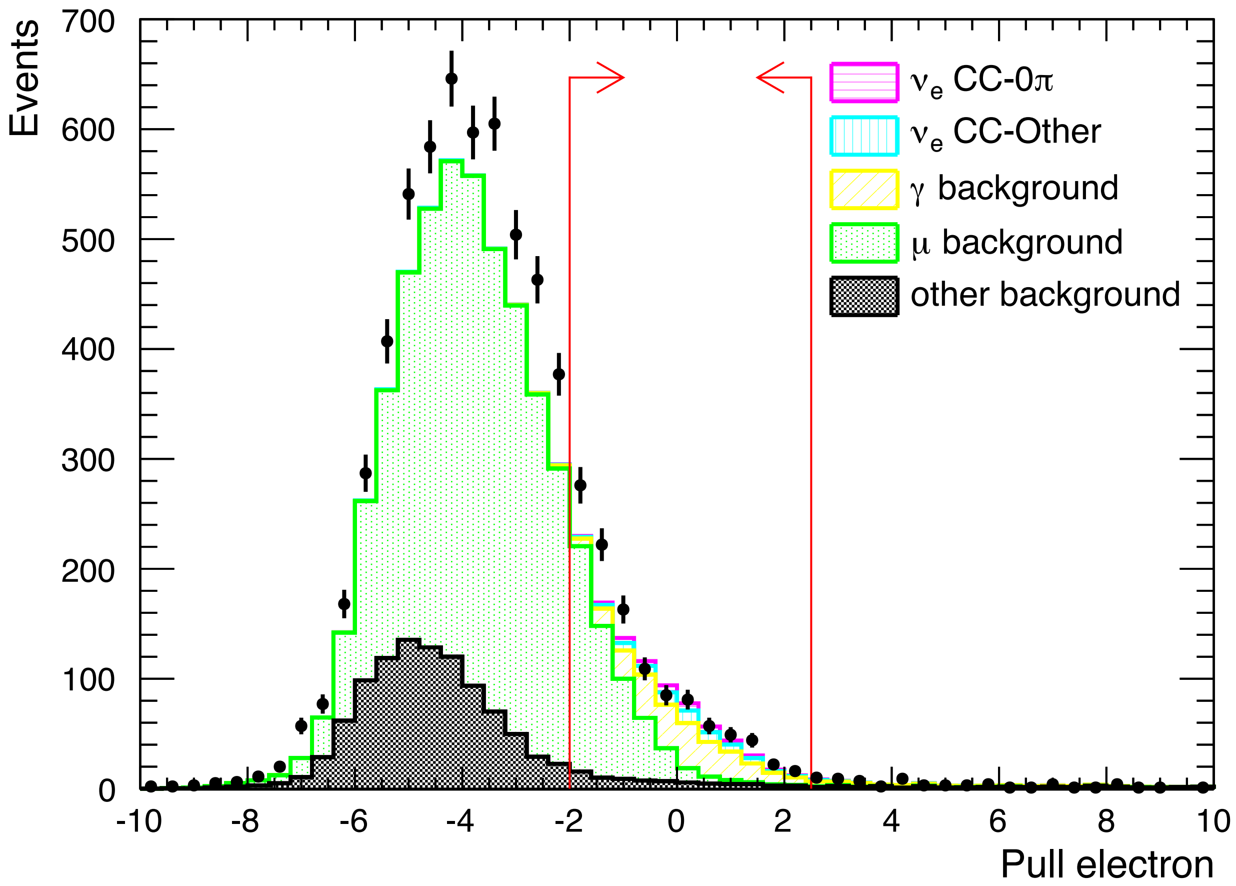
Electron Analysis

Important for ν_e appearance to measure intrinsic ν_e contamination in ν_μ beam

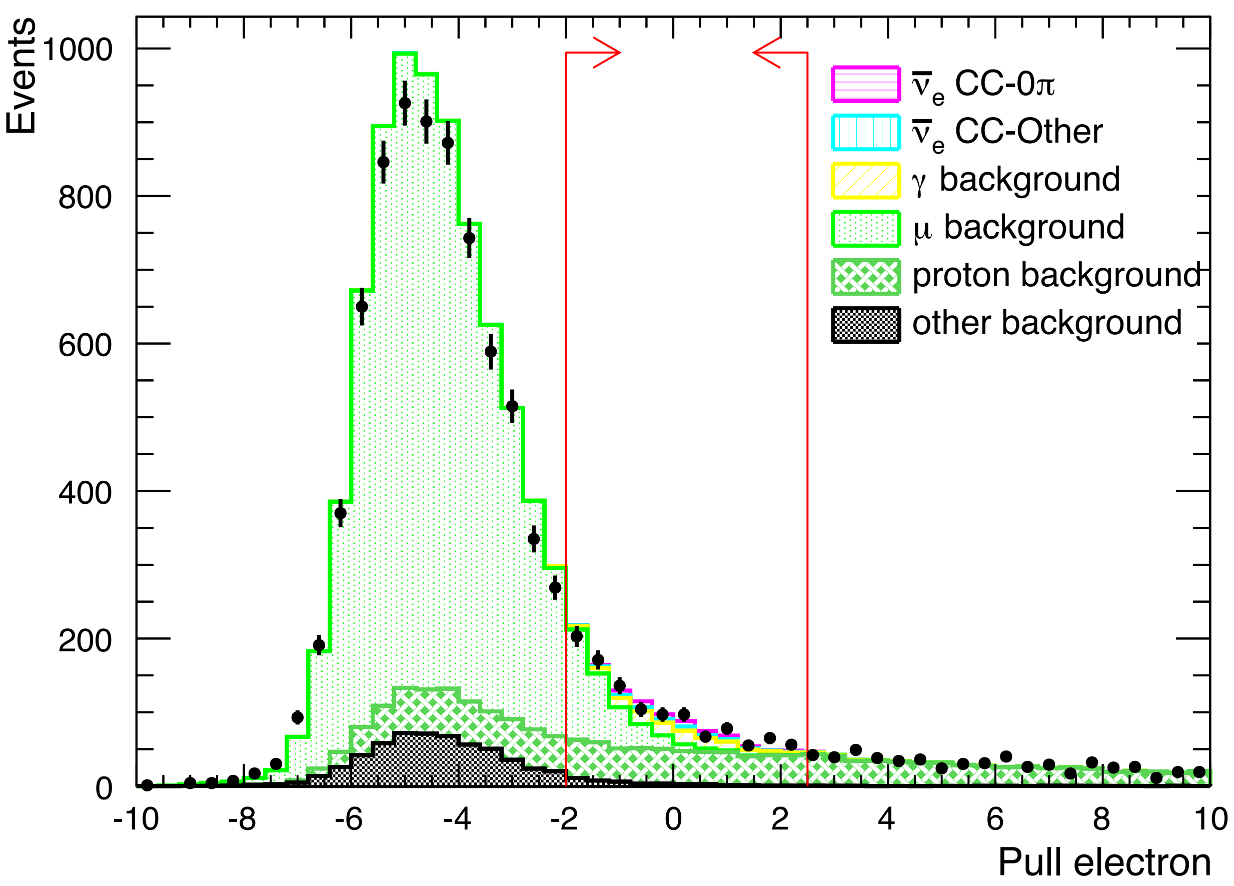
Large muon backgrounds

Large proton backgrounds in anti-neutrino analysis

ν_e TPC PID

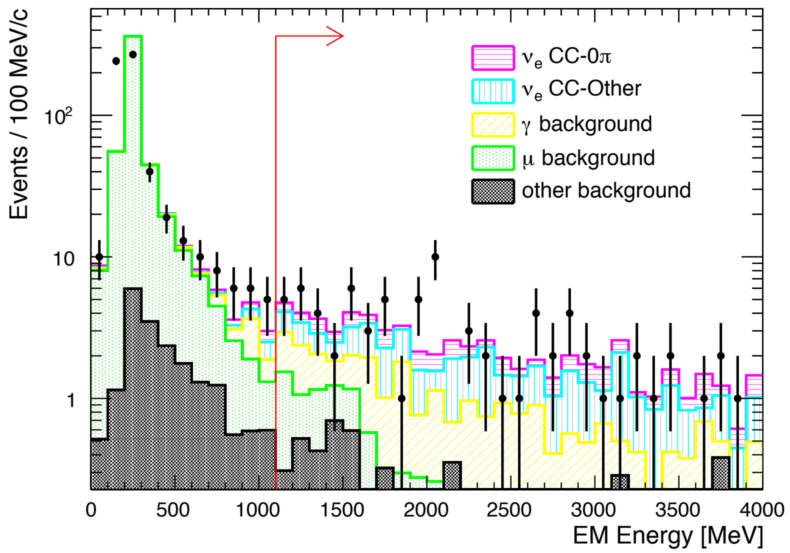


$\bar{\nu}_e$ TPC PID

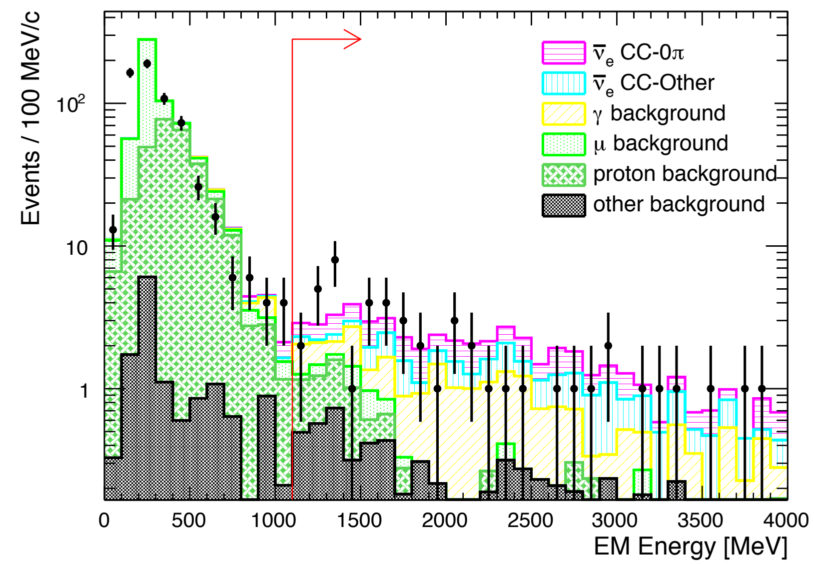


Electron Analysis

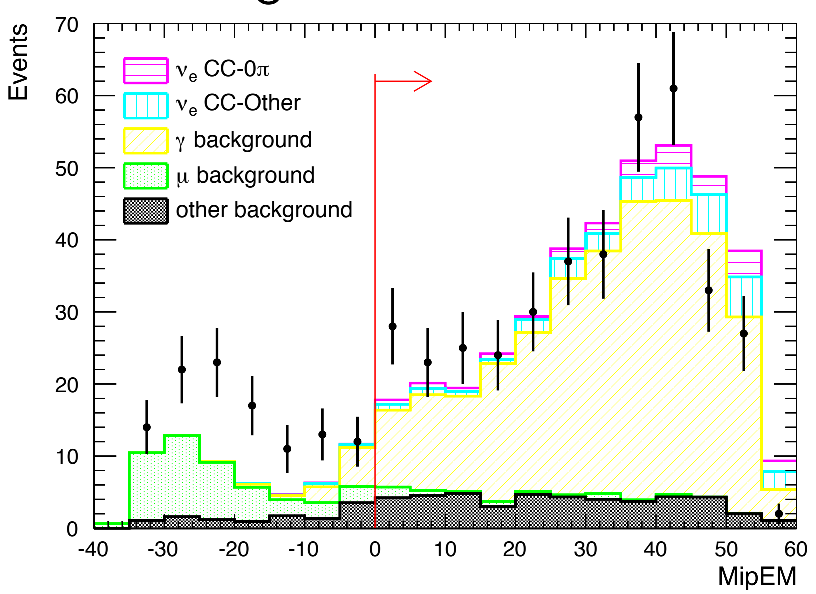
ν_e ECal Energy



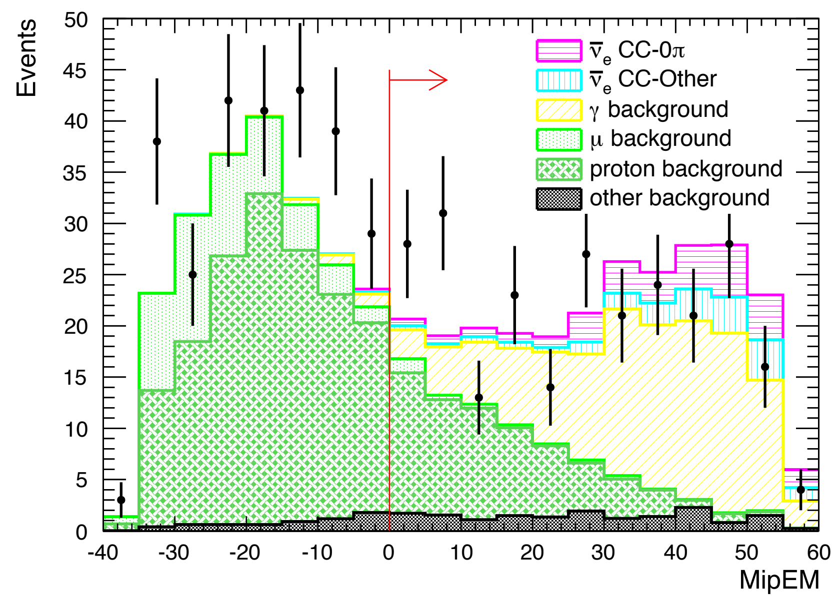
$\bar{\nu}_e$ ECal Energy



ν_e ECal PID



$\bar{\nu}_e$ ECal PID

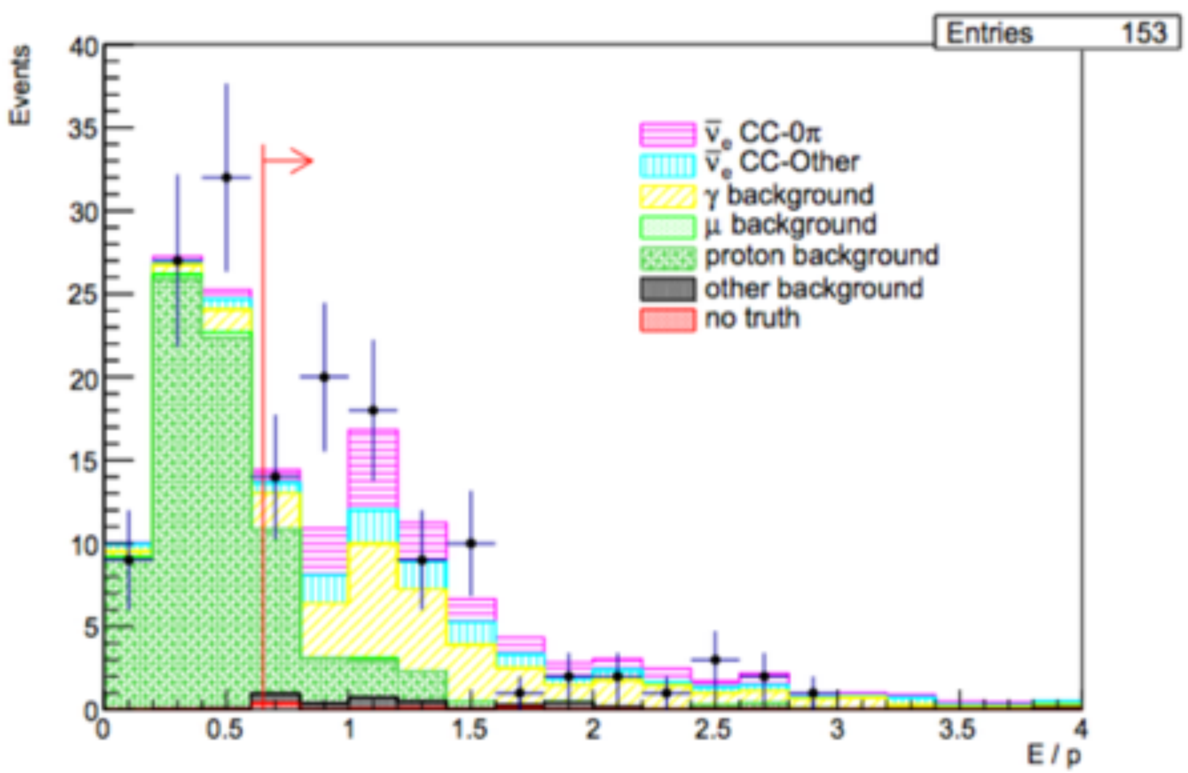


ECal provides additional PID information improving selection purity

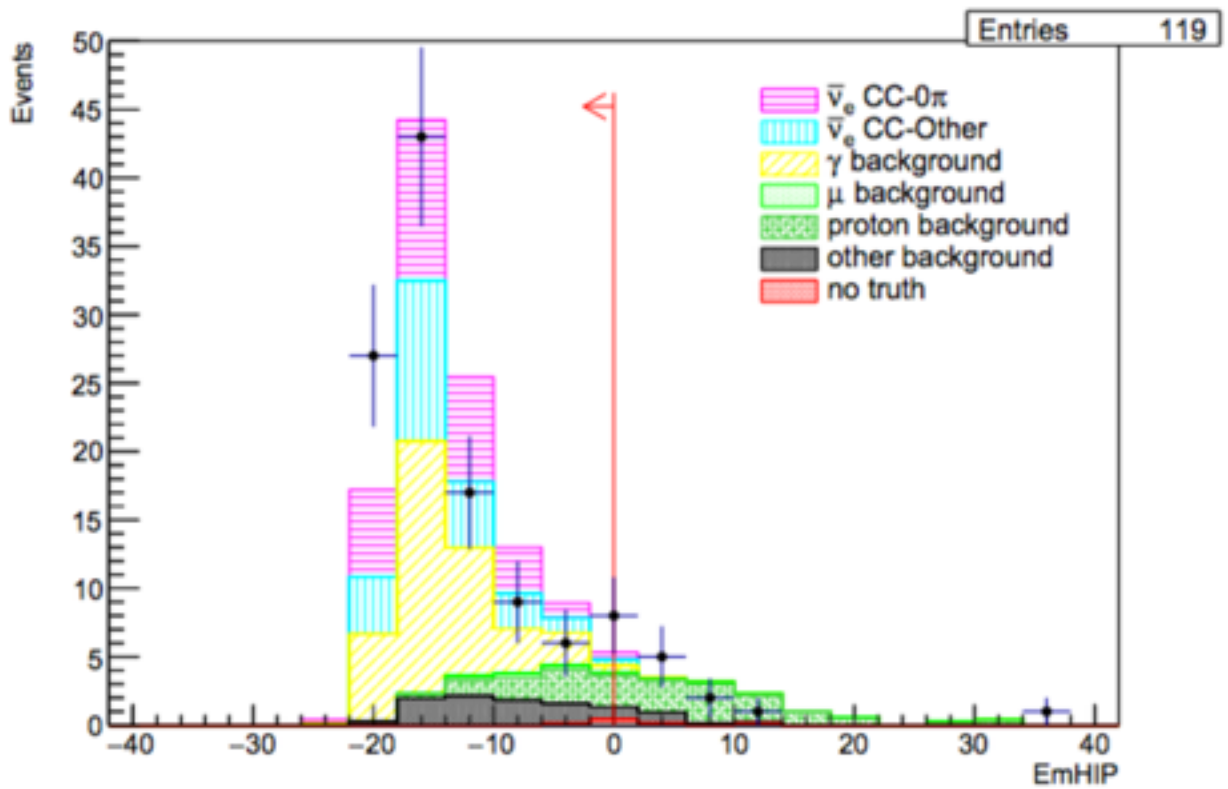
ECal veto entering backgrounds

Electron Analysis

$\bar{\nu}_e$ E / p



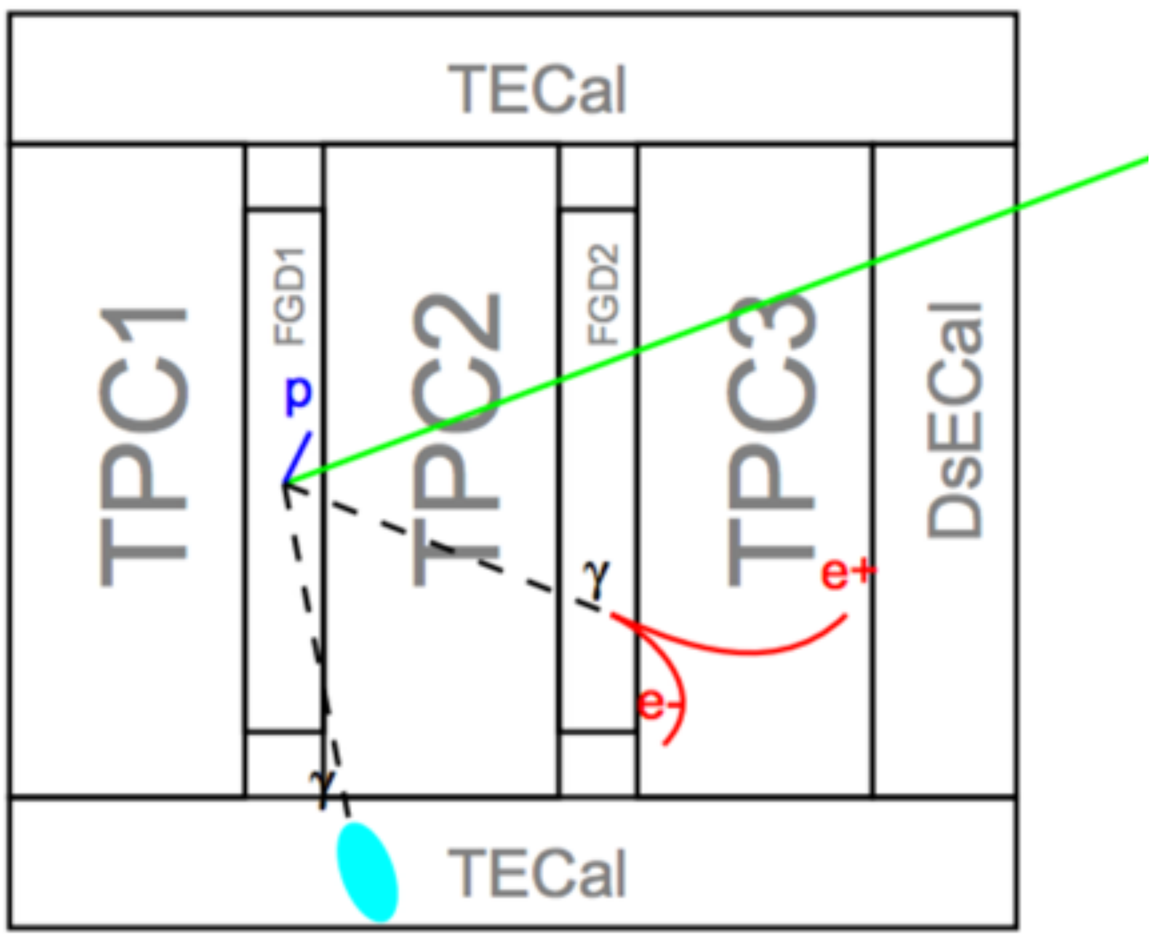
$\bar{\nu}_e$ ECal Proton PID



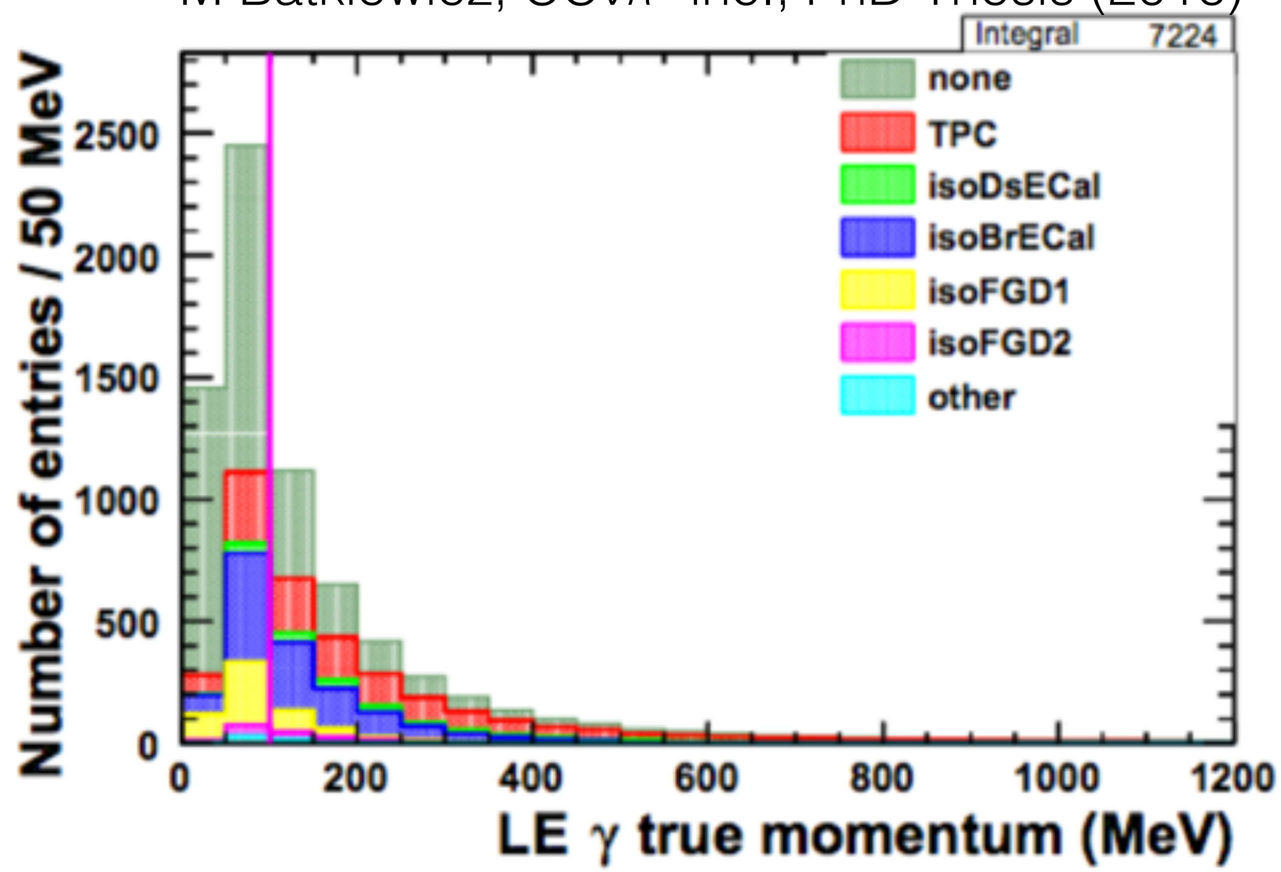
Extra PID cuts are applied in the $\bar{\nu}_e$ analysis to reduce the large proton background

π^0 Reconstruction

Multiple Tracker $\pi^0 \to \gamma\gamma$ analyses based on γ conversion location



M Batkiewicz, CC$\nu\pi^0$ inc., PhD Thesis (2016)



γ from π^0 can often be low energy
~24% both photons detected

Typically low efficiencies are achieved in ND280 π^0 measurements using ECal

π^0 Reconstruction

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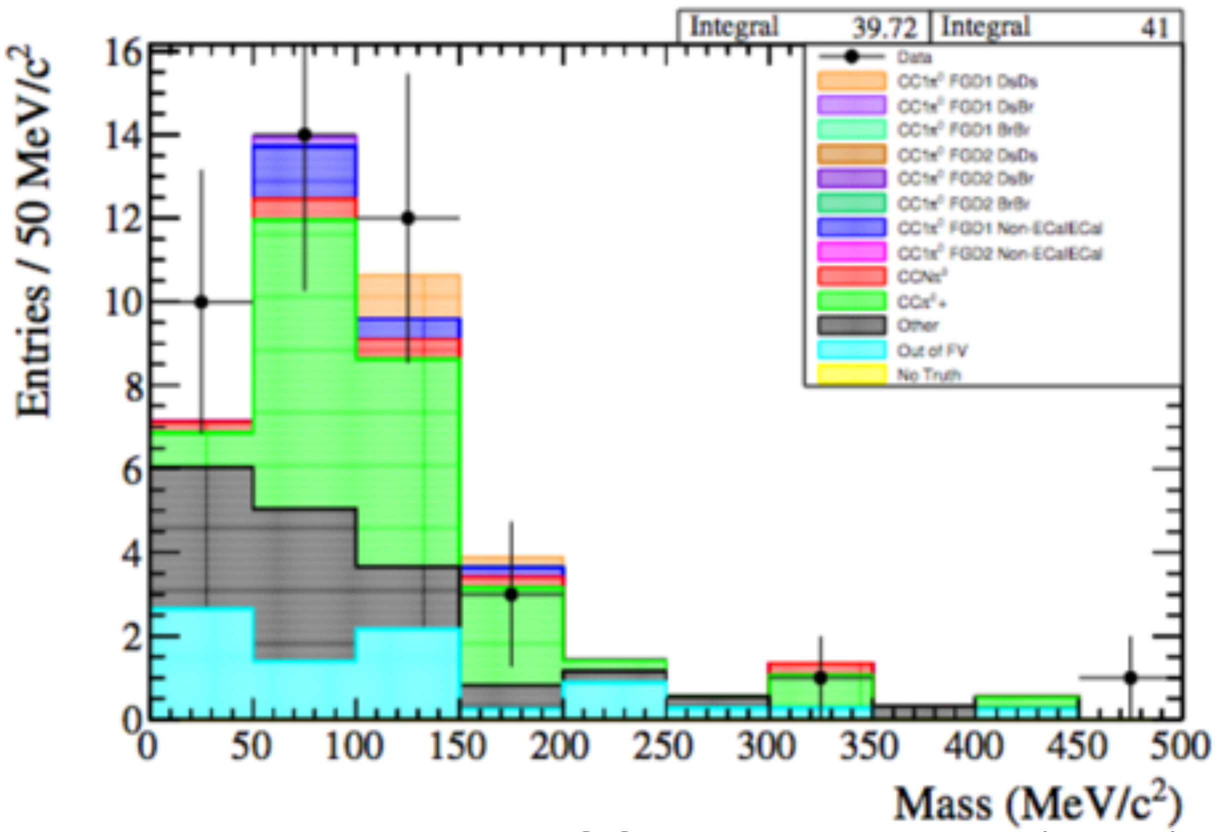


M Lawe, CC$\nu\pi^0$, PhD Thesis (2014)

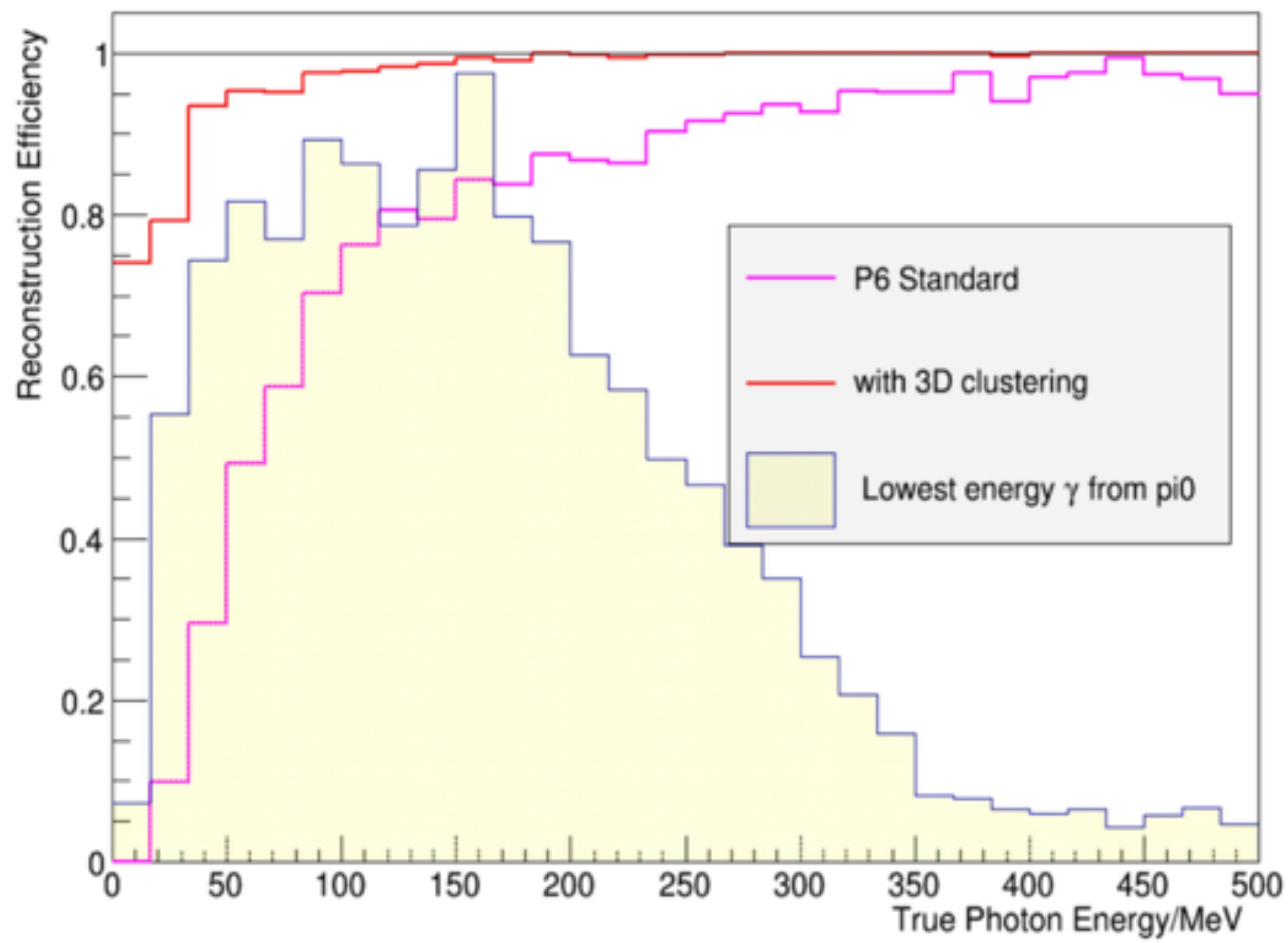
No.	ECal objects after cut:	real data	MC	data/MC ratio	signal reaction purity	prim. π^0 pur.	prim. π^0 eff.
1.	all isolated ECal objects	17625	15895	1.109	40.9%	31.7%	100%
2.	shower-like objects	9906	8936	1.108	49.0%	41.6%	73.7%
3.	electromagnetic energy $>$ 50 MeV	9532	8642	1.103	49.0%	41.5%	71.2%

M Batkiewicz, CC$\nu\pi^0$ inc., PhD Thesis (2016)

~40% the selected ECal objects from the primary π^0
Main backgrounds:
Pile-up
e/γ from secondary interactions

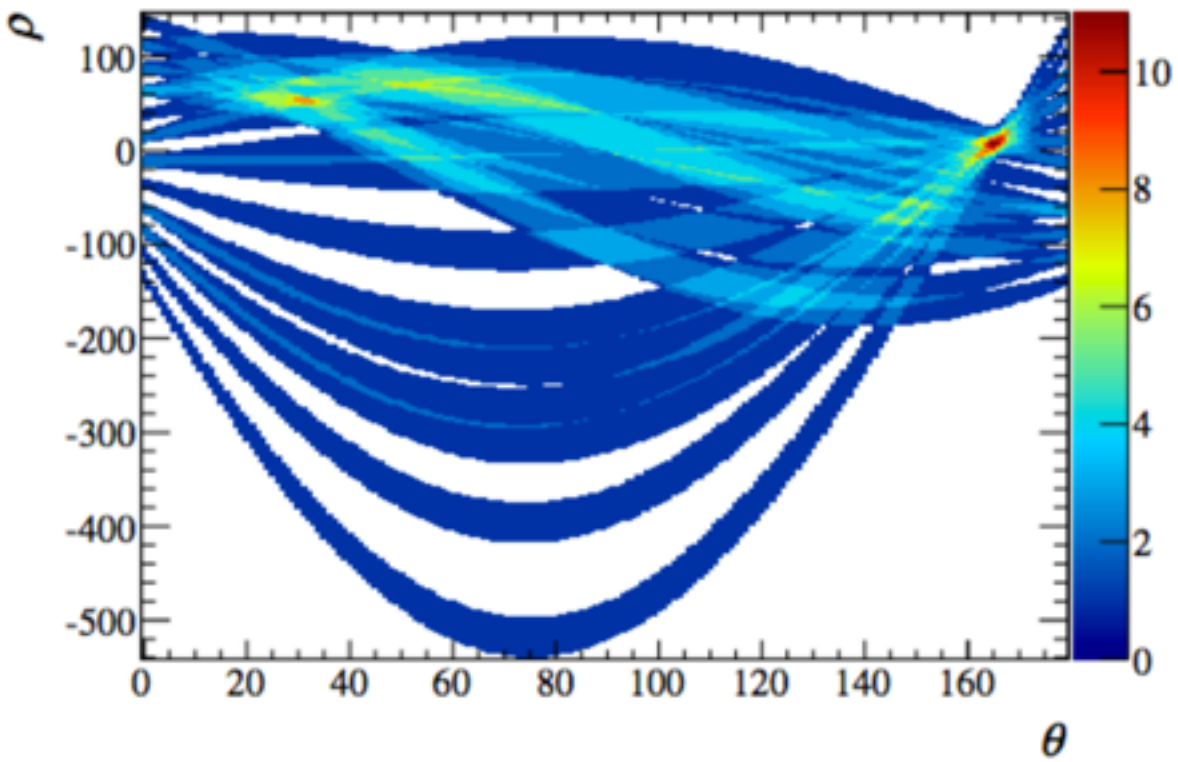
Even more difficult: NC π^0, exclusive final states π^0 kinematics

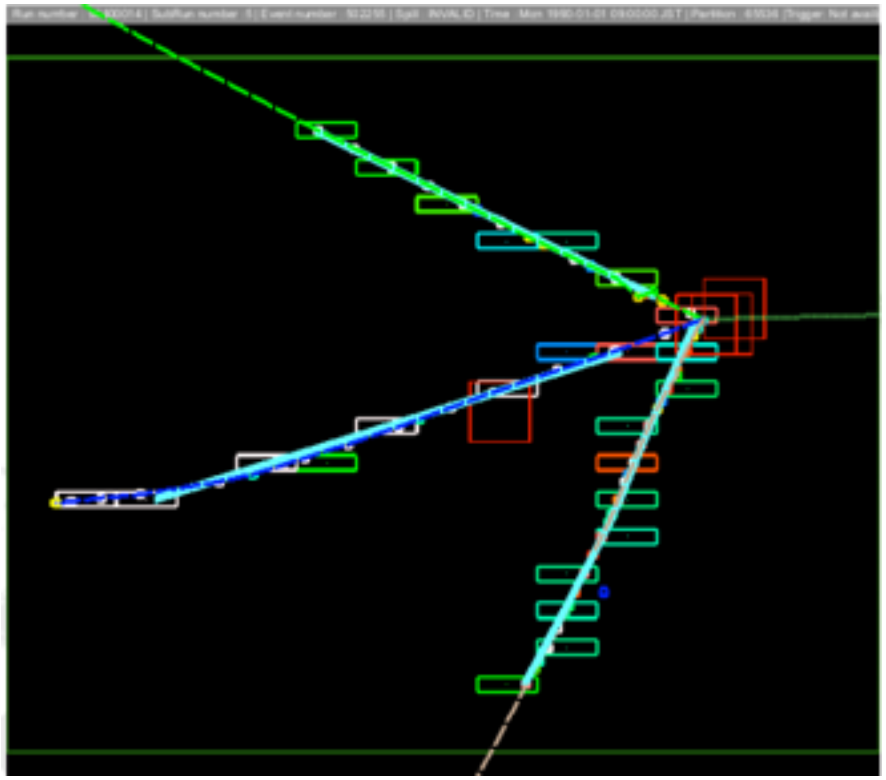
π^0 Reconstruction



On going efforts to improve reconstruction for better π^0 reconstruction

ECal as a Target





D Brailsford, PhD Thesis (2016)

ECal is largest active tracking detector in ND280

~ 40,000 kg target mass

Mostly lead

High event rates

Potential access to rare processes (eg $\nu+e^-$ elastic)?

Also a source for out-of-fiducial volume backgrounds for smaller mass inner detectors

Summary

ND280 ECal highly successful in reconstructing $e^{\pm}$ and μ for ν_e and ν_μ analyses

Provides useful PID and energy measurement
Tag entering backgrounds

Large target mass, viable vertex detector

Poor reconstruction of low energy γ makes π^0 reconstruction difficult
Expect improvements from on-going software development but π^0 reconstruction will likely always be difficult for this detector

T2K ND280 EM Calorimeter Performance and Lessons Learned

David Hadley

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Backup

ND280 ECal Properties

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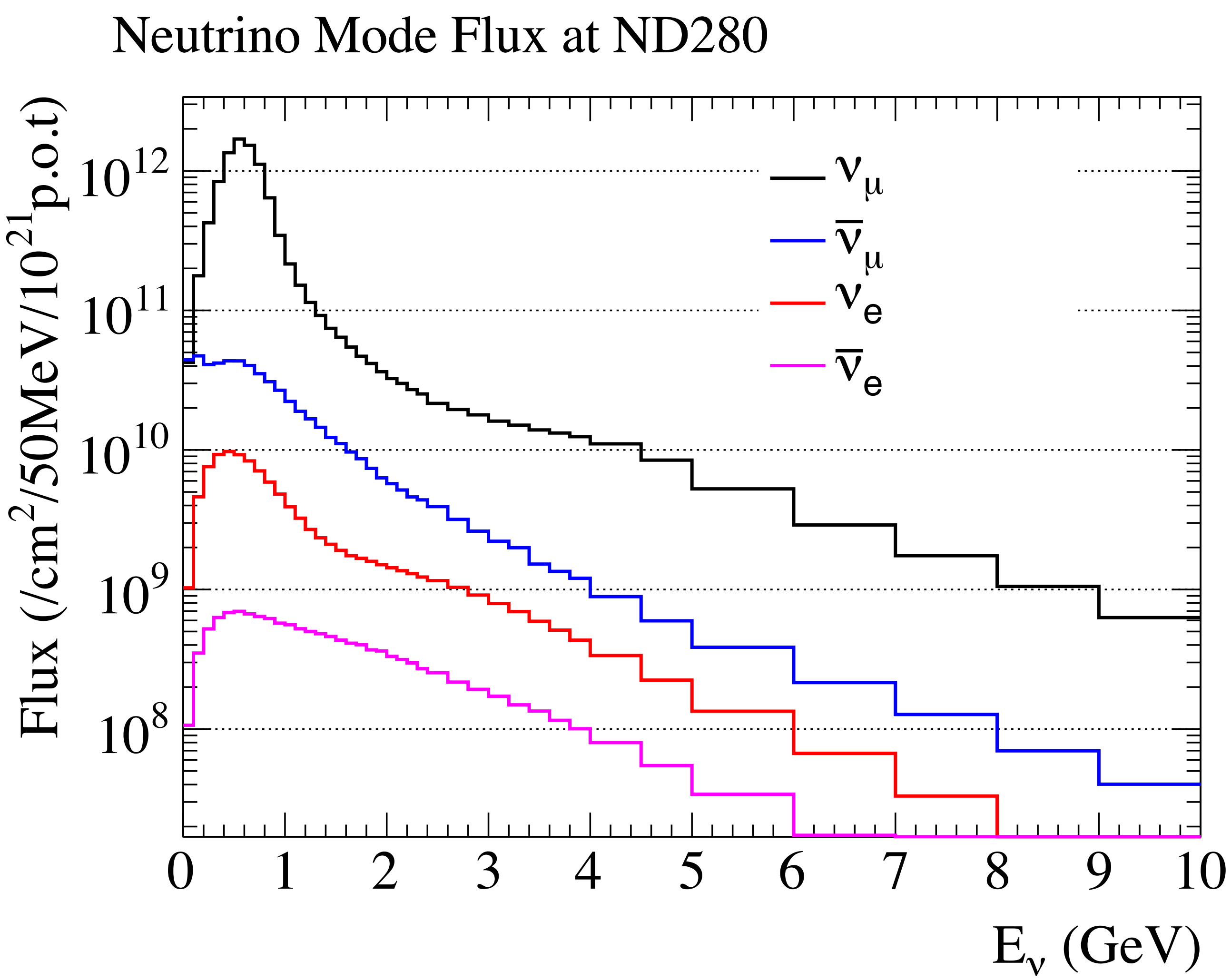
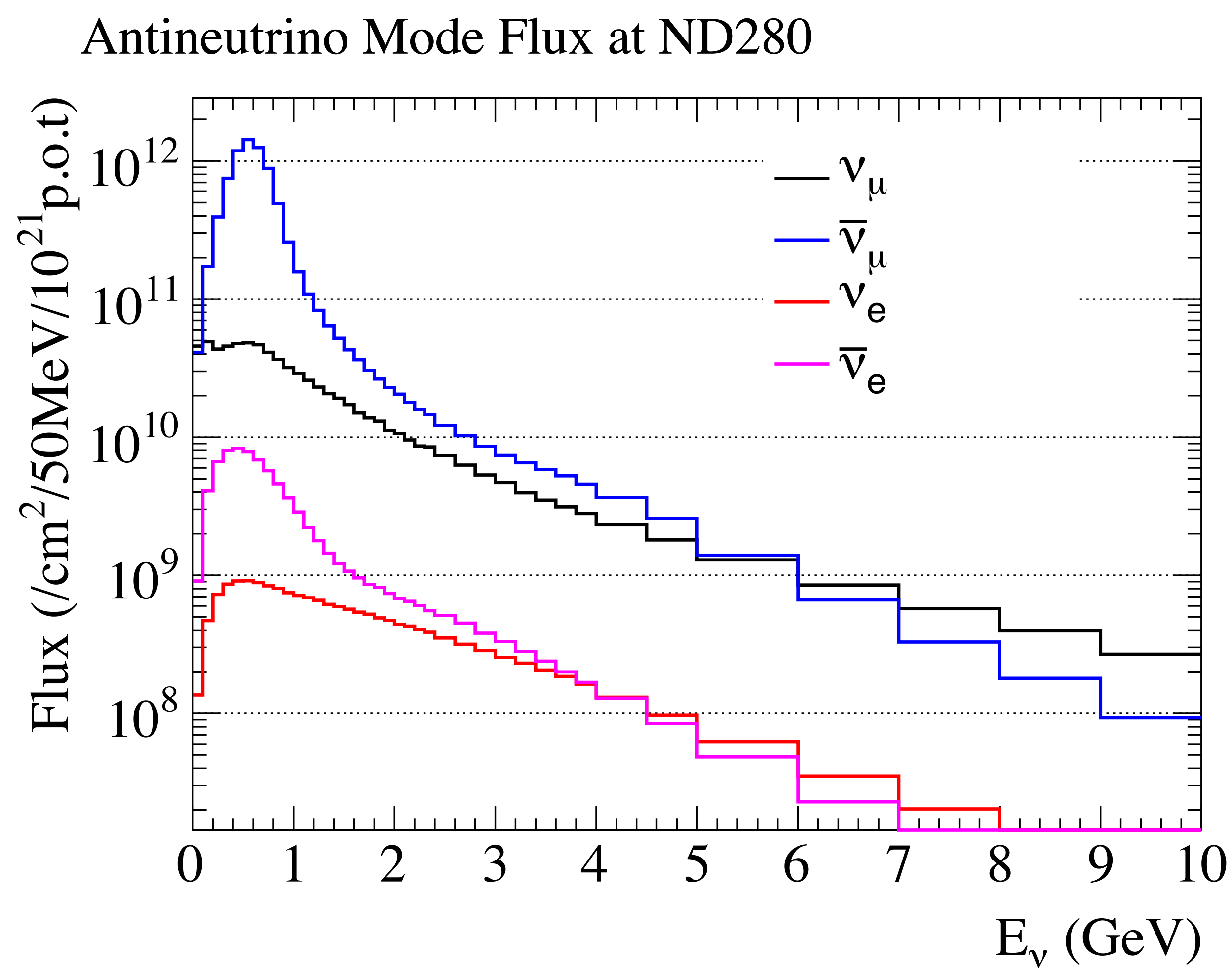
	DS-Ecal	Barrel ECal	P0D ECal
Length (mm) Width (mm) Depth (mm) Weight (kg)	2300 2300 500 6500	4140 1676 top/bottom 2500 side 462 8000 top/bottom 10000 side	2454 1584 top/bottom 2898 side 155 1500 top/bottom 3000 side
Num. of layers	34	31	6
Bar orientation	x/y	Longitudinal and Perpendicular	Longitudinal
Num. of bars	1700	2280 Longitudinal top/bottom 1710 Longitudinal sides 6144 Perp top/bottom 3072 Perp sides	912 Longitudinal top/bottom 828 Longitudinal sides
Bars per layer	50	38 Longitudinal top/bottom 57 Longitudinal side 96 Perp top/bottom/sides	38 Longitudinal top/bottom 69 Longitudinal sides
Bar length (mm)	2000	3840 Longitudinal 1520 Perp top/bottom 2280 Perp sides	2340 Longitudinal
Pb thickness (mm)	1.75	1.75	4.0

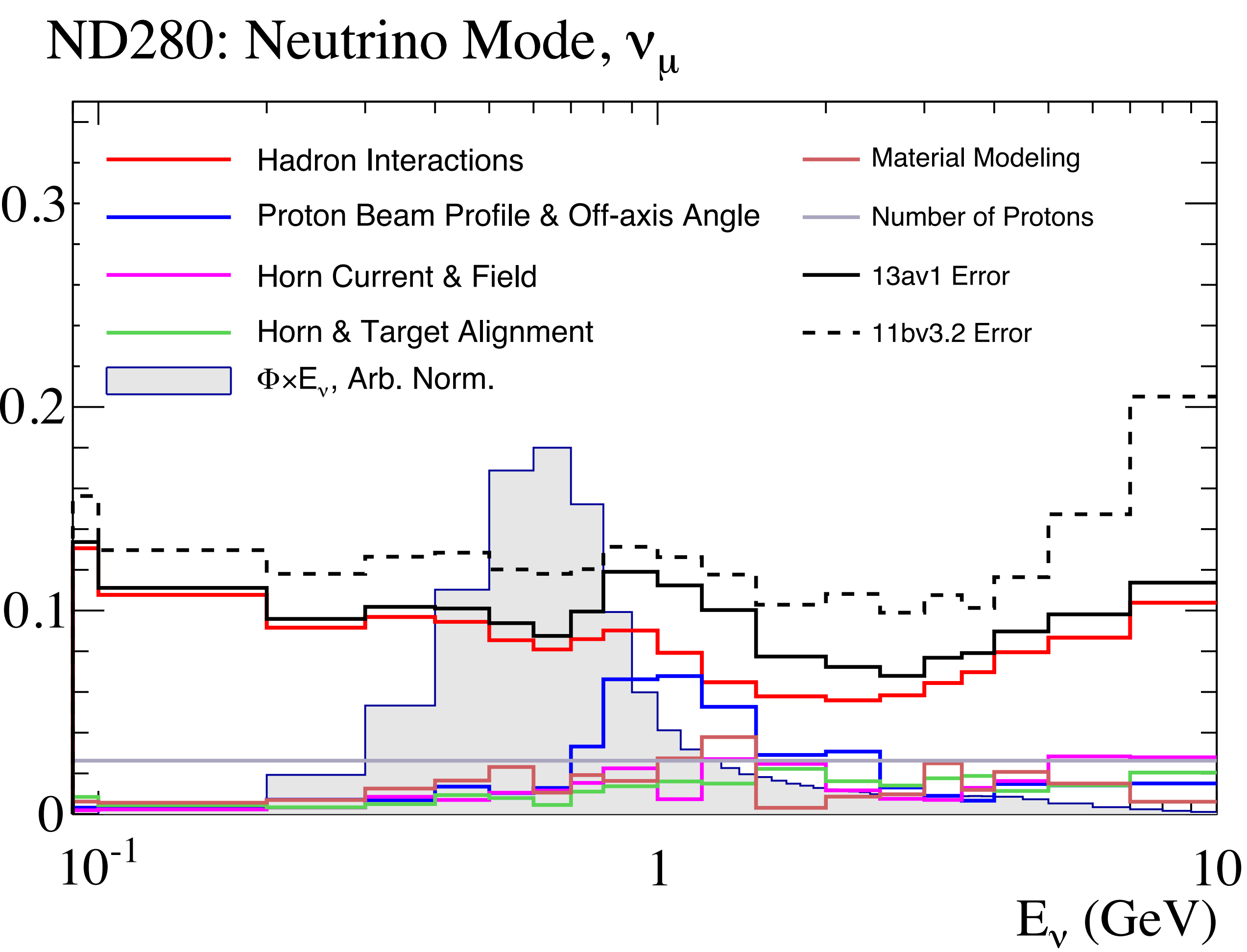
JINST 8 P10019 (2013), arXiv:1308.3445 [physics.ins-det]

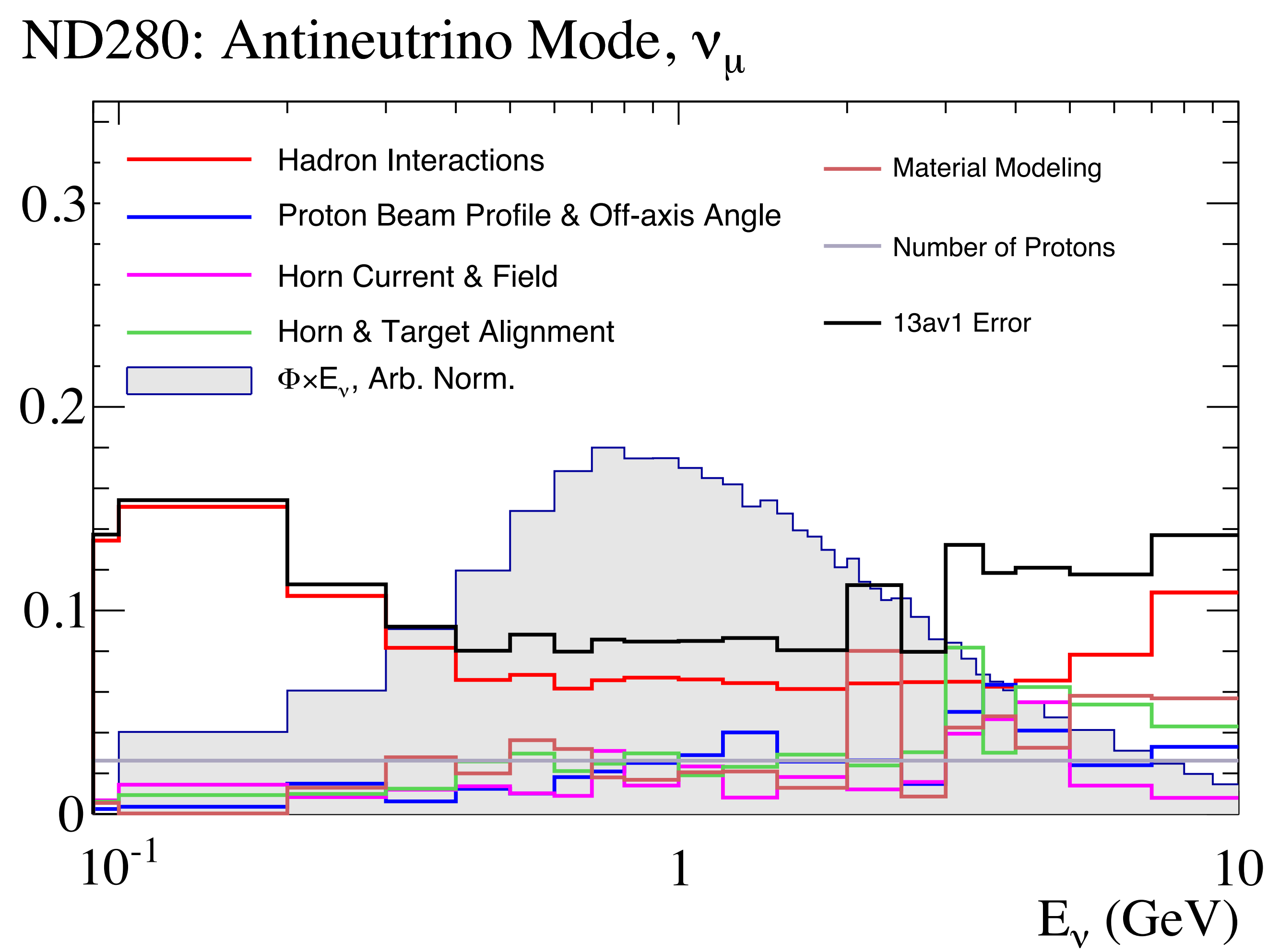
Flux at ND280



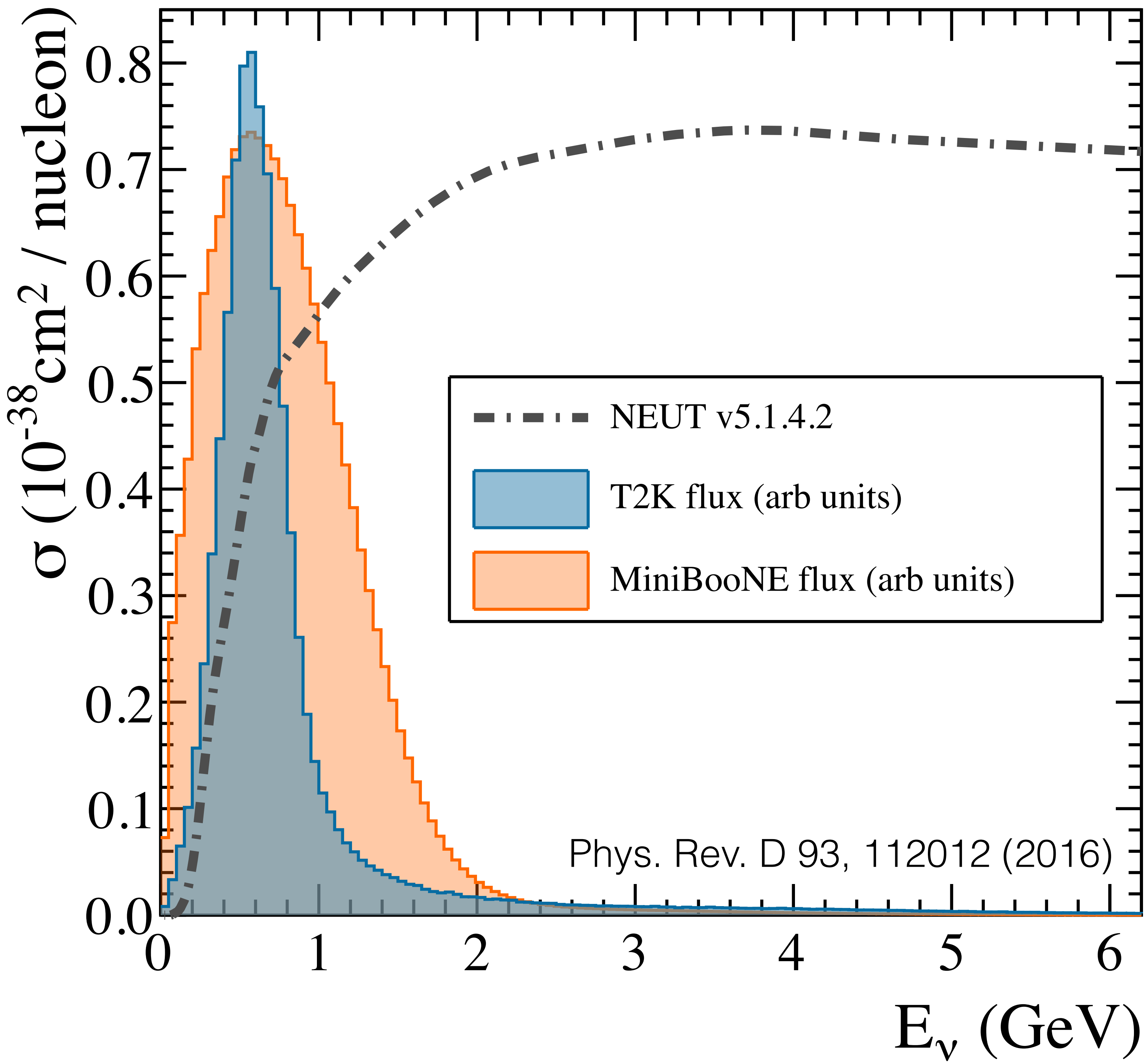


Flux at ND280

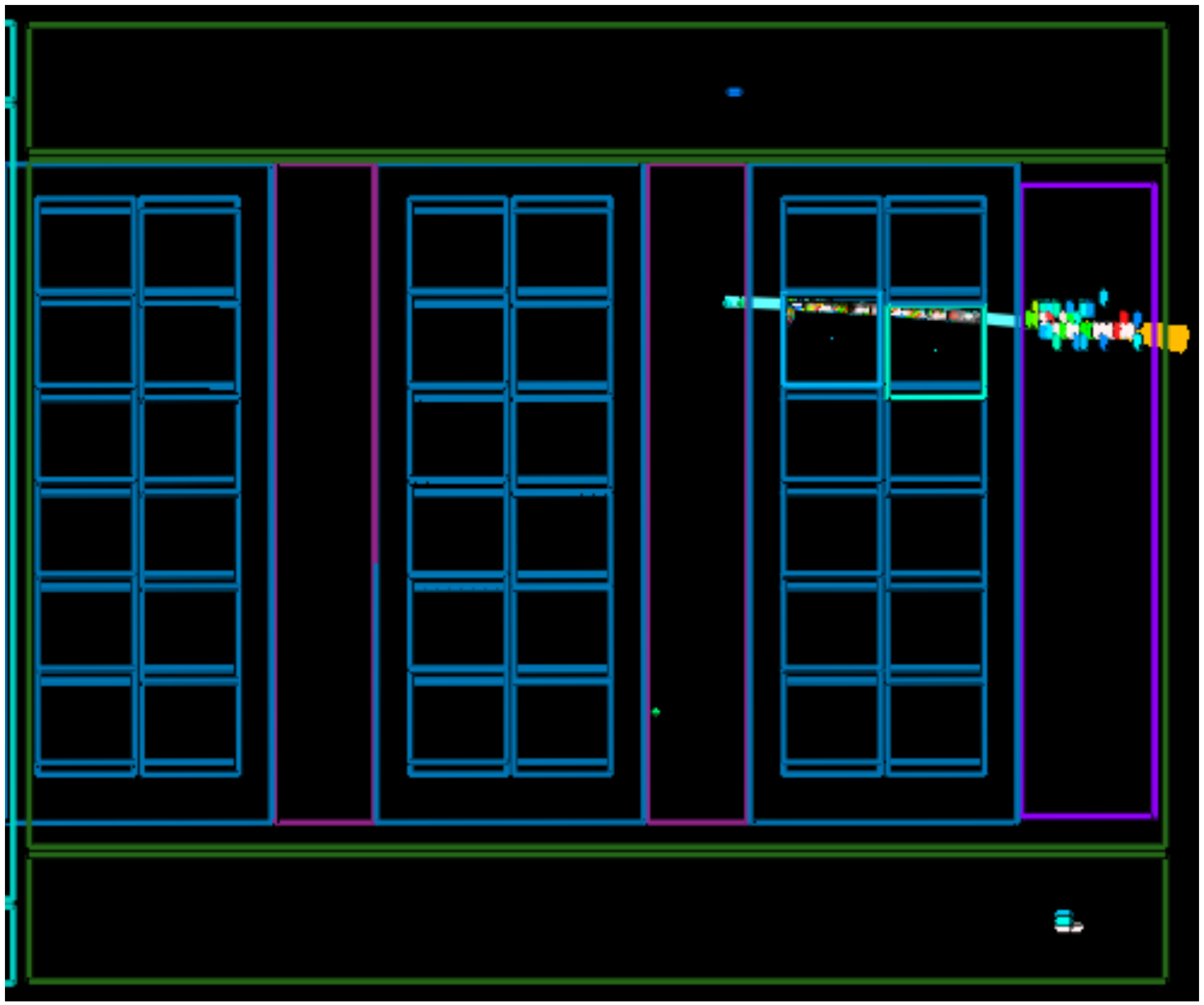




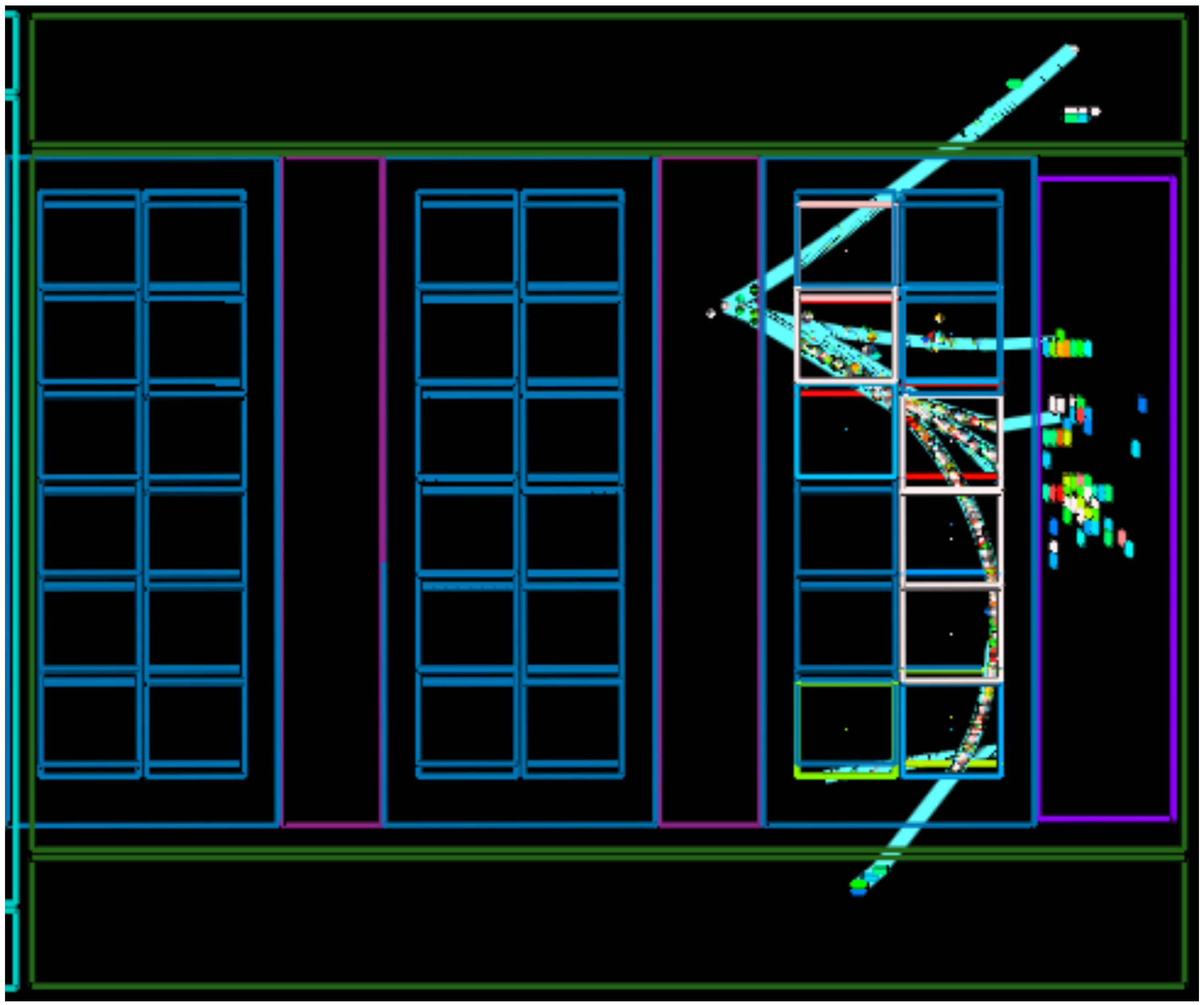
Flux and CC0π Cross Section



ν_e Event Displays

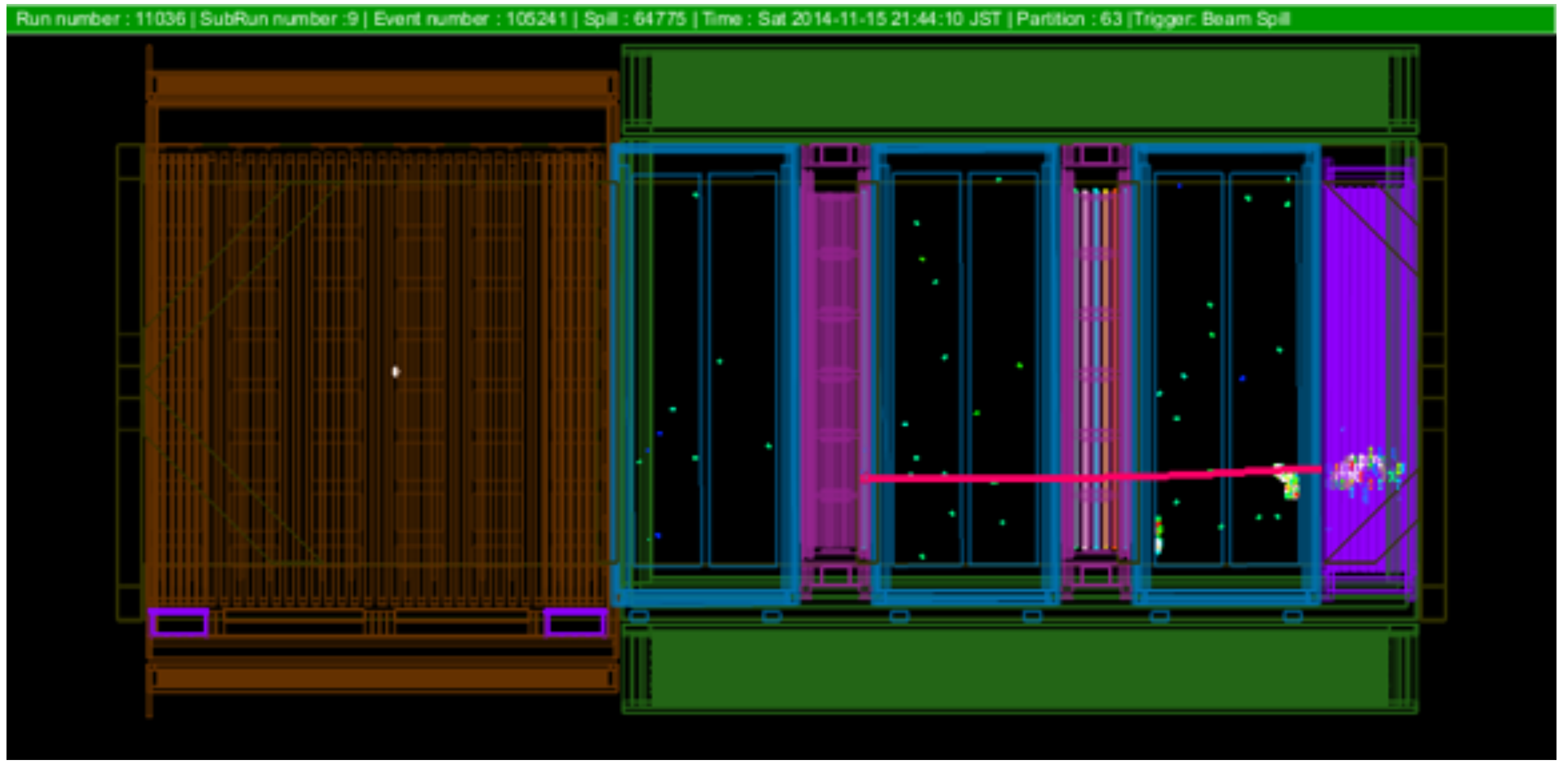


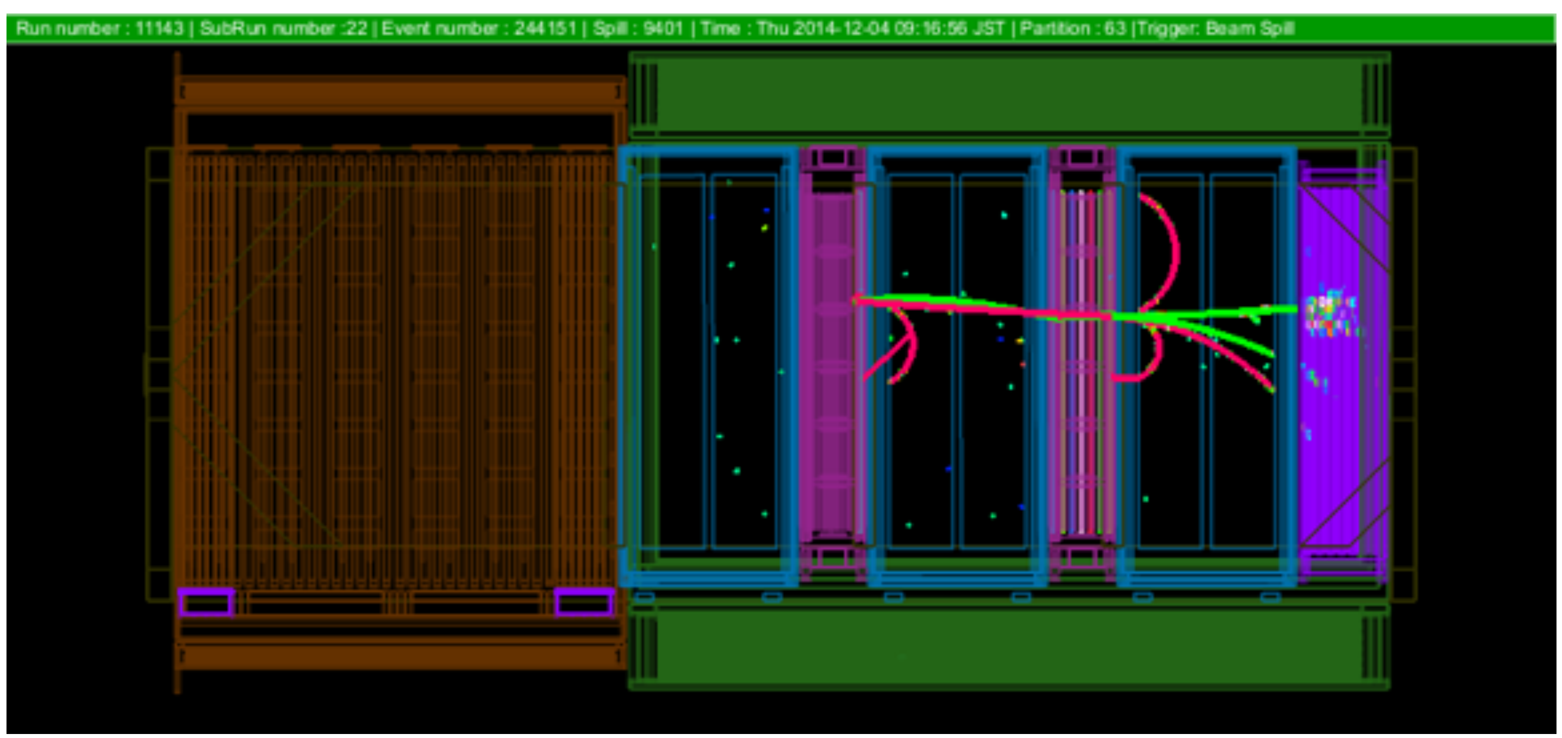
T2K-TN-149



T2K-TN-149

Anti-ν_e Event Displays





T2K-TN-282