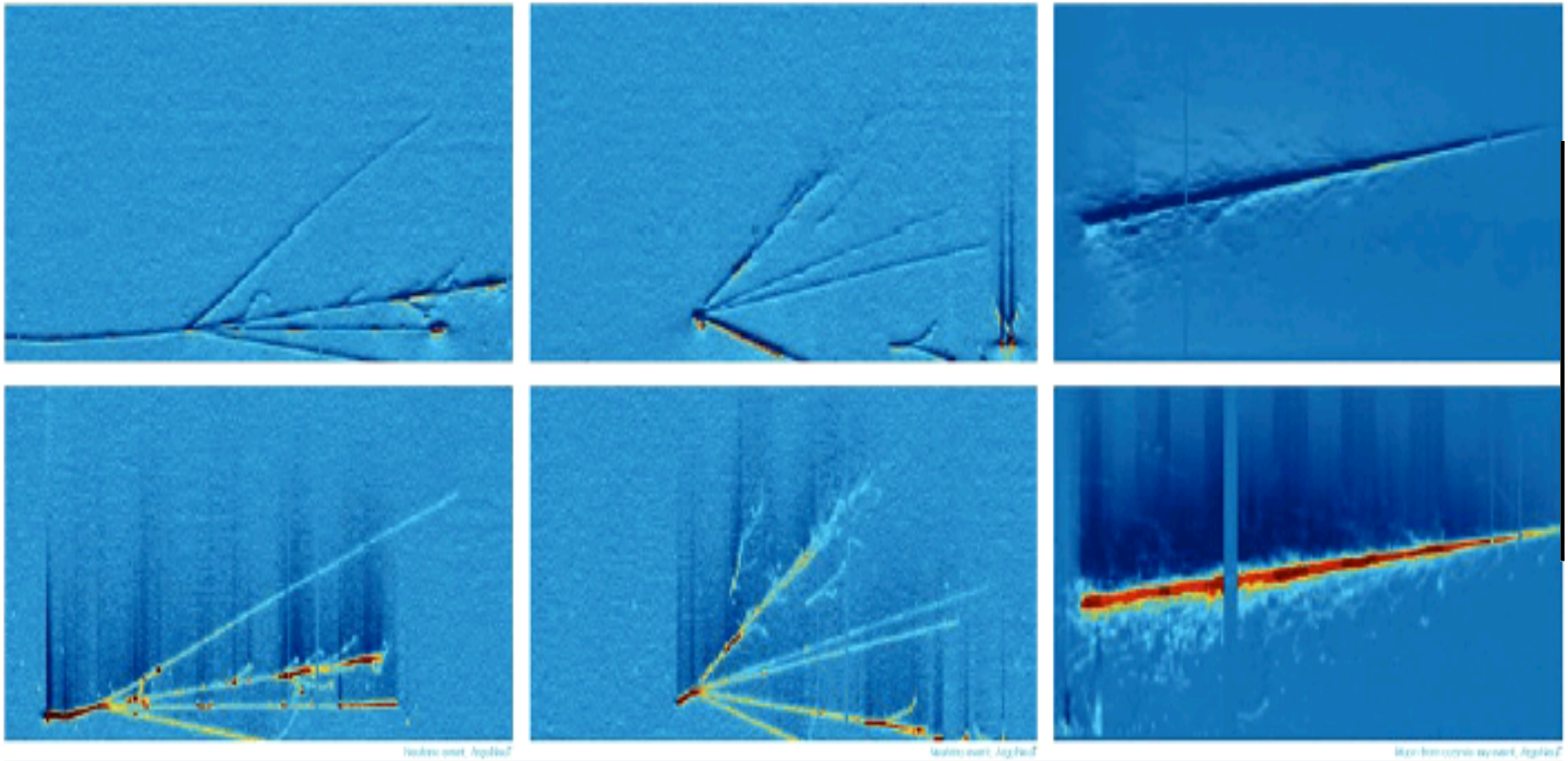


Recent results from the ArgoNeuT experiment

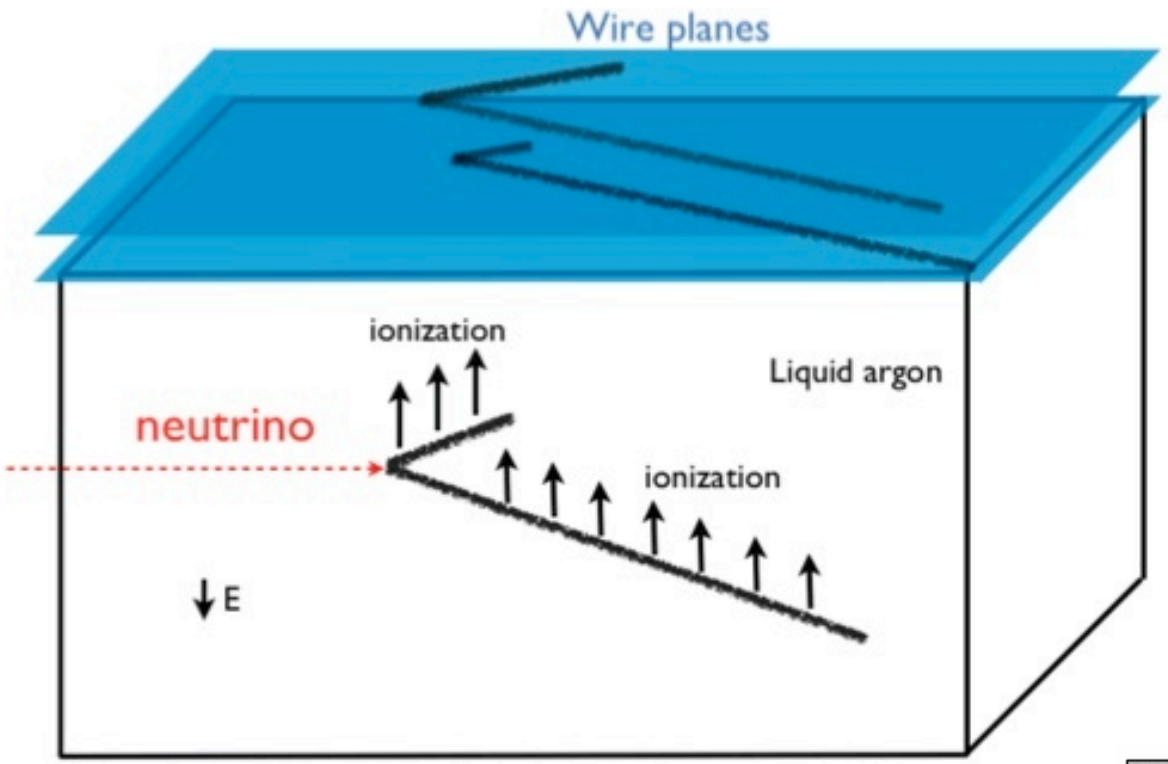
Roxanne Guenette
Yale University

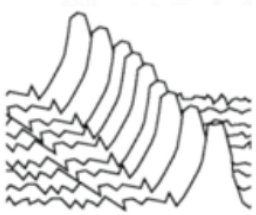
CIPANP Conference
May 30th 2012

Outline

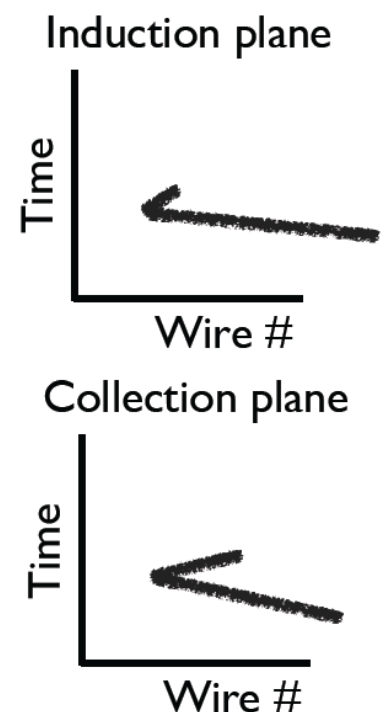
- Overview of the LAr TPC concept
- Description of the ArgoNeuT experiment
- Event reconstruction techniques
- First physics result: CC-inclusive measurement
- New developments in ArgoNeuT analysis
- LArTPC calibration in test beam with ArgoNeuT
- Conclusions

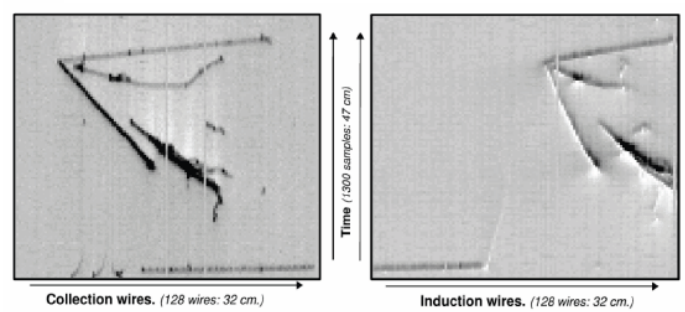
LAr TPC concept





Wire pulses in time give the drift coordinate of the track





ICARUS 50 L in WANF neutrino beam

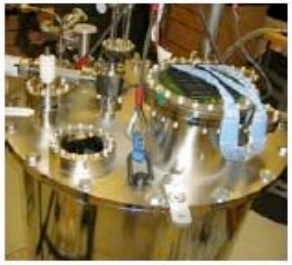
ArgoNeuT

Liquid-Argon Time Projection Chambers

Status of R&D Program in the US

The first TPCs in the United States:

Yale TPC



Location: Yale University
Active volume: 0.00002 kton
Year of first tracks: 2007

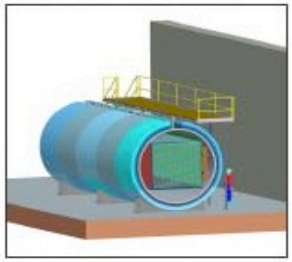
Bo

Location: Fermilab
Active volume: 0.00002 kton
Year of first tracks: 2008

ArgoNeuT

Location: Fermilab
Active volume: 0.0003 kton
Year of first tracks: 2008
First neutrinos: June 2009

MicroBooNE



Location: Fermilab
Active volume: 0.1 kton
Start of construction: 2010

Test stands to improve liquid-argon technology:

Luke

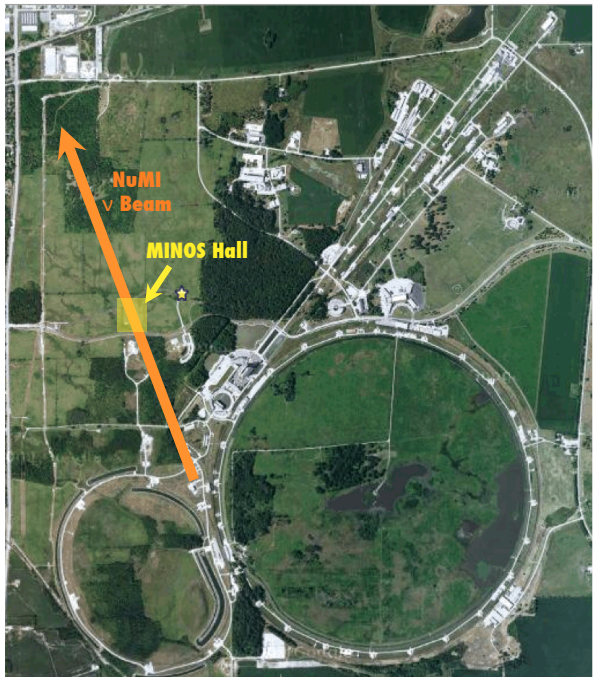
Location: Fermilab
Purpose: materials test station
Operational: since 2008

LAPD

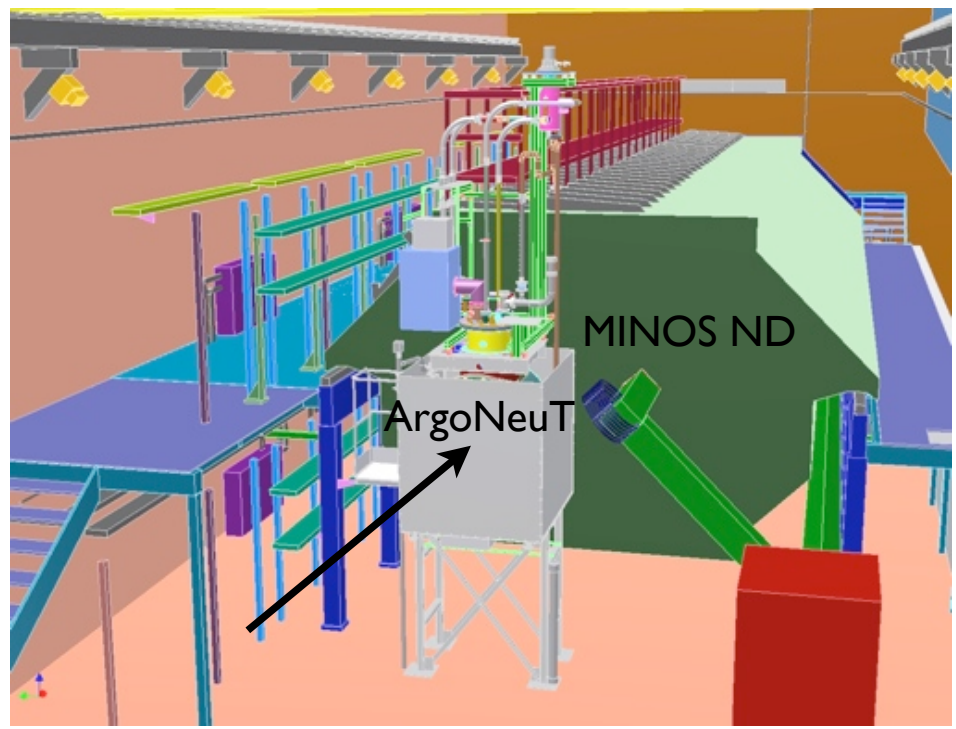
Location: Fermilab
Purpose: LAr purity demo
Operational: 2010

ArgoNeuT detector

- 175 liter (active) LAr TPC
- Detector was designed and assembled in 2007-2008
- Moved underground in the NuMI beam at FNAL in early 2009
- Data taking in ν / $\bar{\nu}$ mode from September 2009 to February 2010

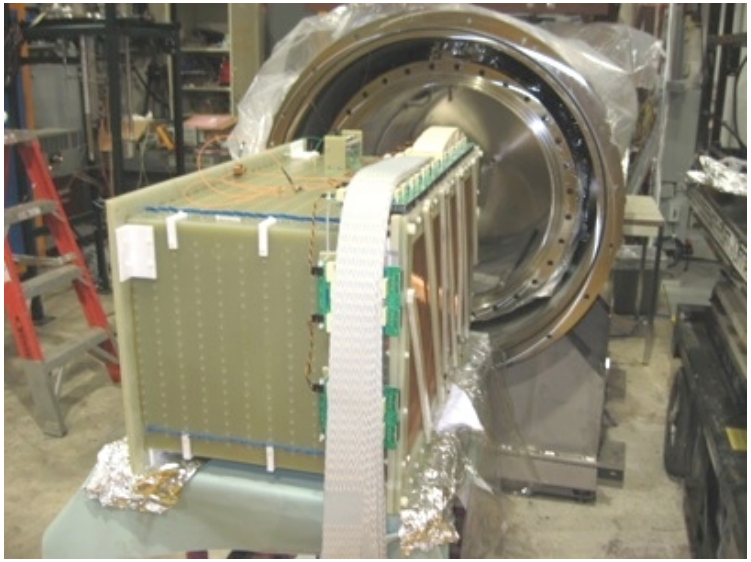


Fermilab, NuMI beam line

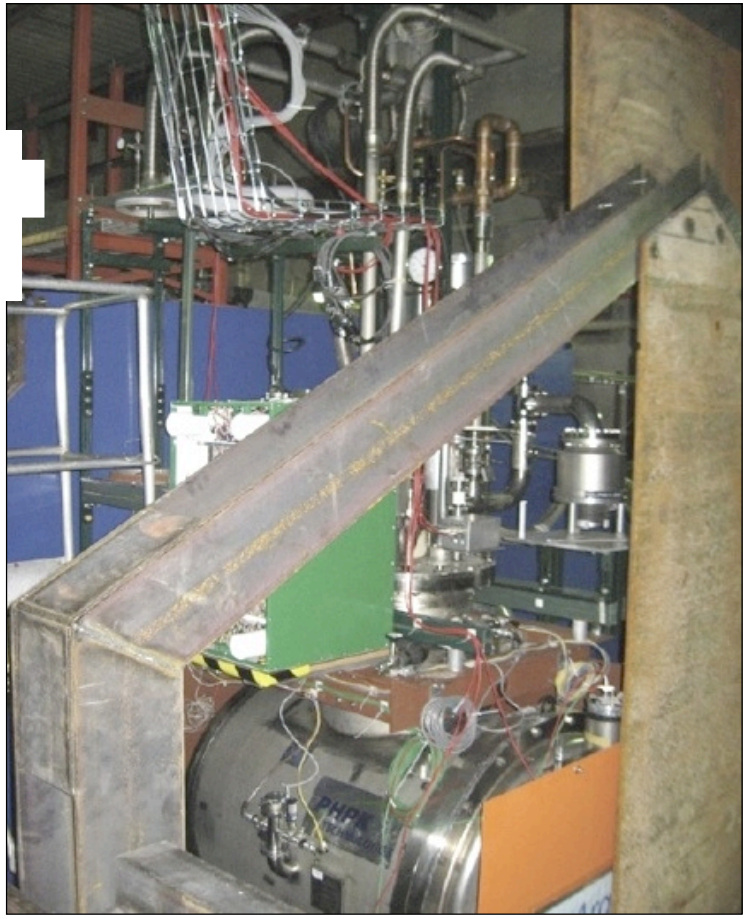


ArgoNeuT

Cryostat Volume	500 Liters
TPC Volume	175 Liters
# Electronic Channels	480
Wire Pitch	4 mm
Electronics Style (Temperature)	JFET (293 K)
Max. Drift Length (Time)	0.5m (330μs)
Light Collection	None



The TPC, about to enter the inner cryostat



The fully-instrumented detector in the beamline

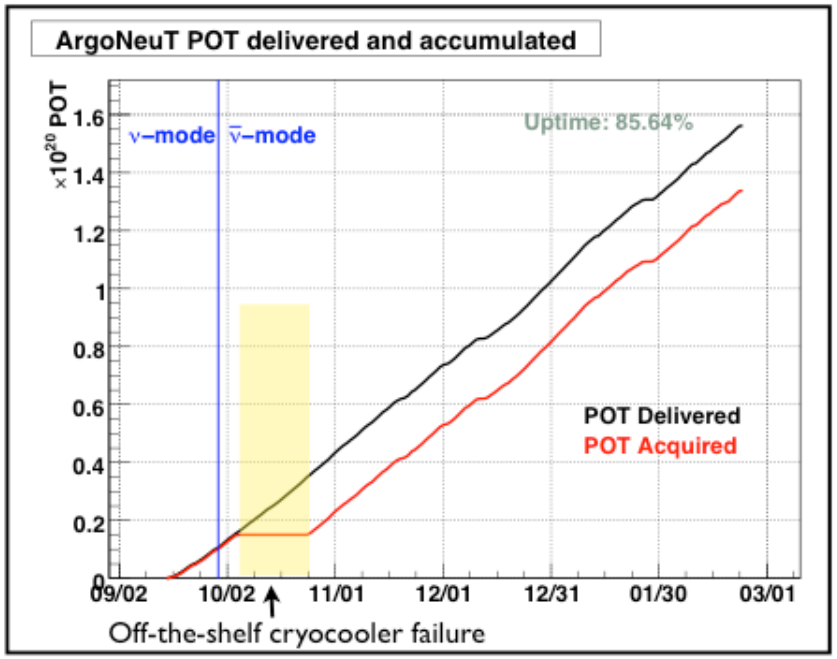
ArgoNeuT goals

- Development goal:
  - R&D project for the LArTPC plan in the US

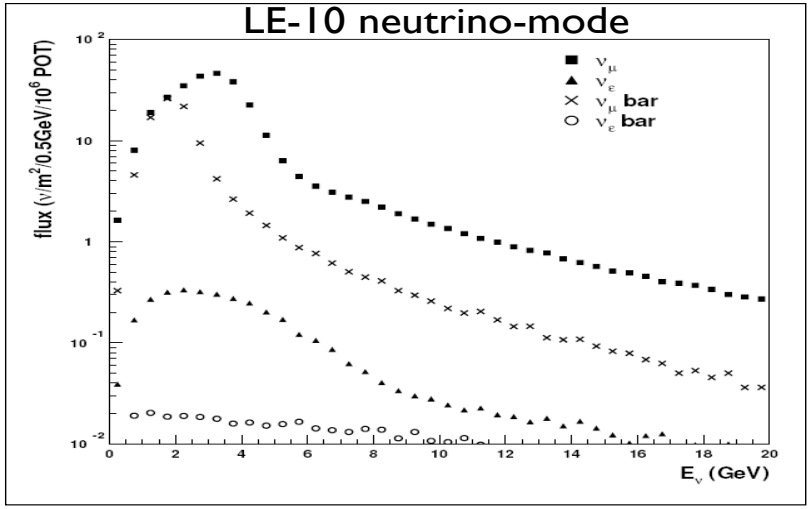
- Physics goals:
  - Measure charged-current cross-sections in the 1-5 GeV range with high sensitivity to the products of **FSI**
  - Demonstrate dE/dx particle separation (e.g. e/ γ) capabilities of LArTPCs
  - Develop automated reconstruction techniques to be used for all LArTPC experiments

ArgoNeuT data taking

- NuMI beam in LE configuration
- Stable, shift-free operation for over 5 months!



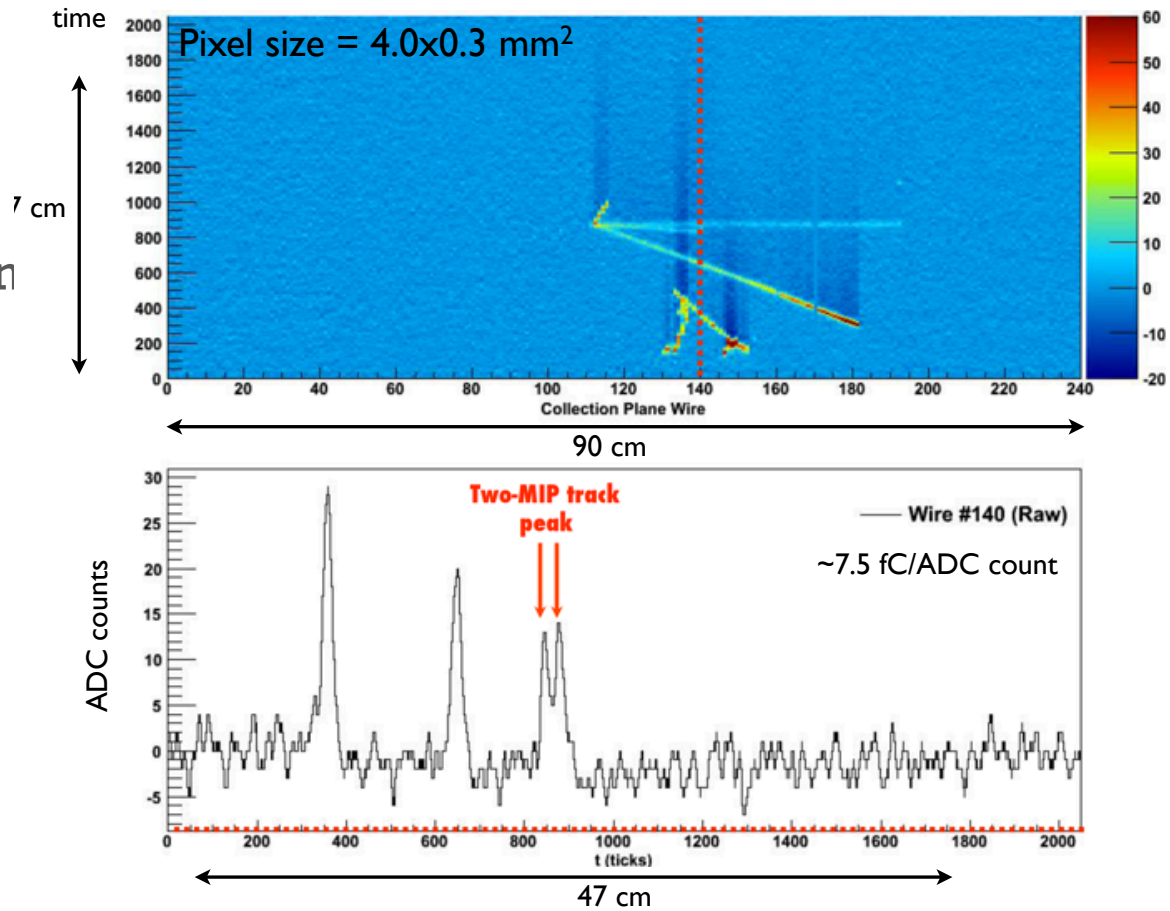
2 weeks in neutrino-mode, 4.5 months in anti-neutrino-mode



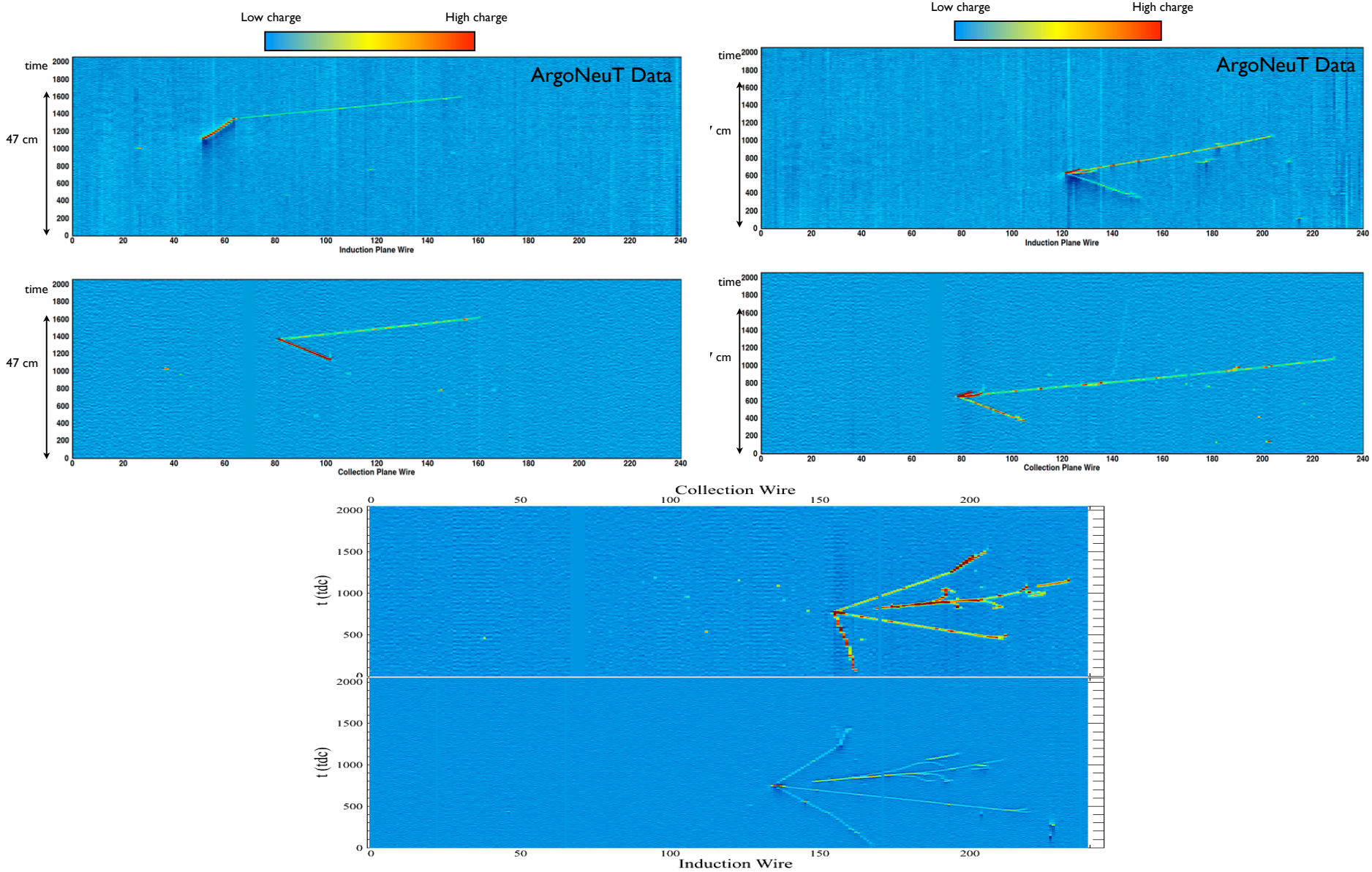
Reaction	#events in AV (~1.35E20 POT)
ν_μ CC	~6600
$\overline{\nu}_\mu$ CC	~4900
ν_μ CCQE	~600
ν_e CC	~130

ArgoNeuT data: Events

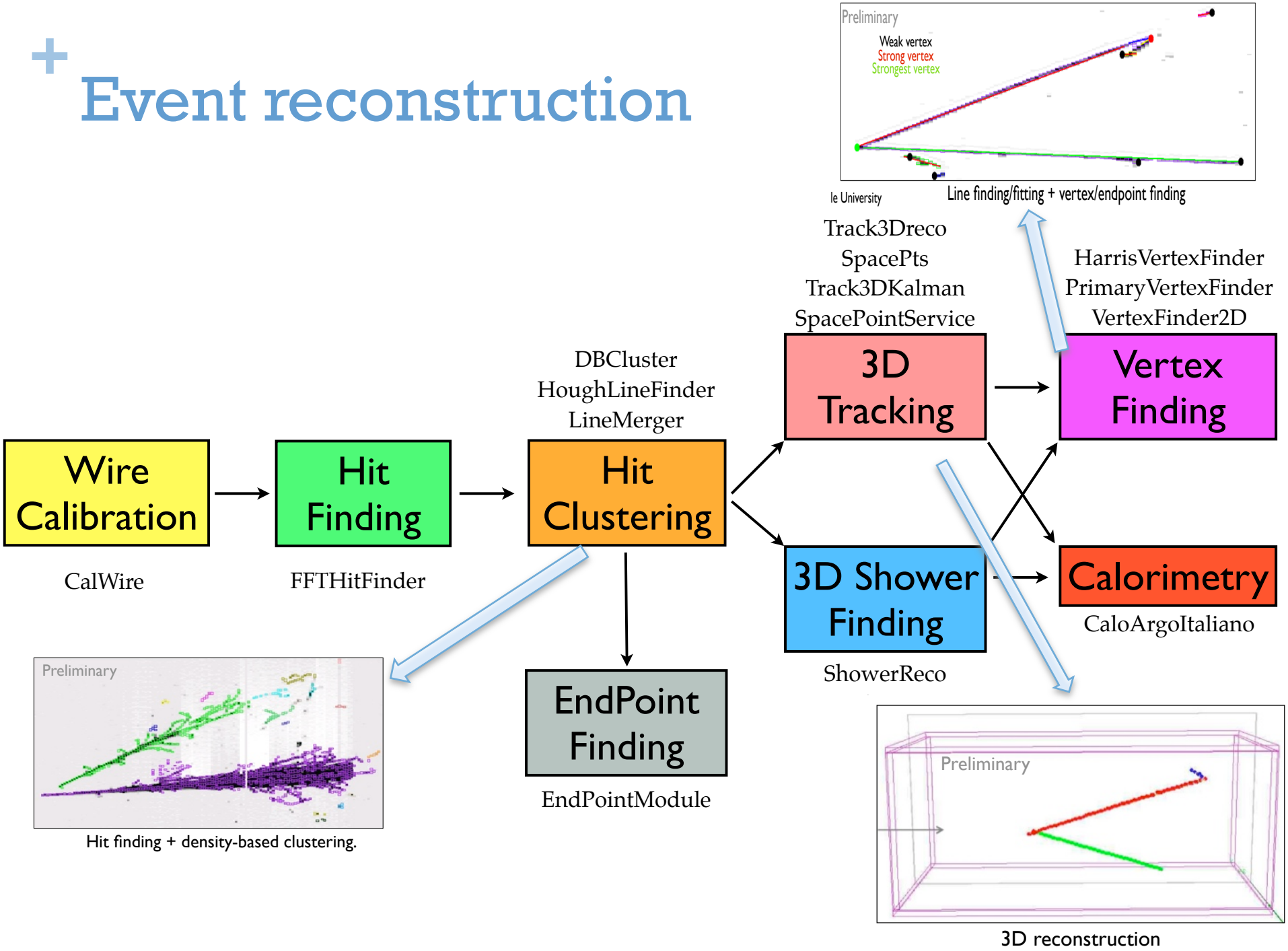
- The color scale represents the energy deposited along the track
- The wire pulse can be seen in the wire view



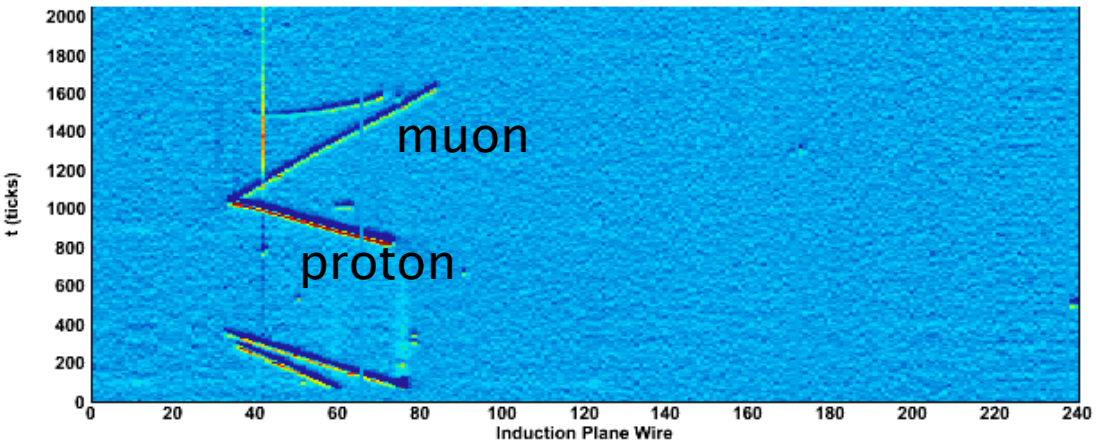
ArgoNeuT events

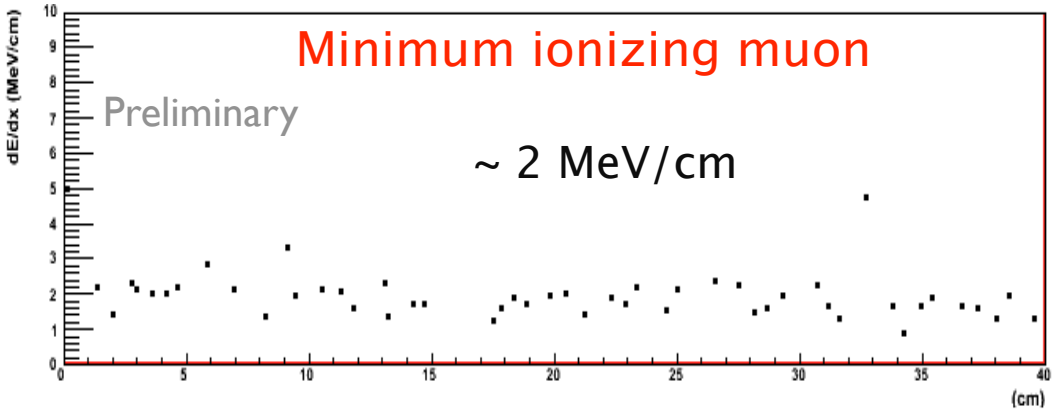


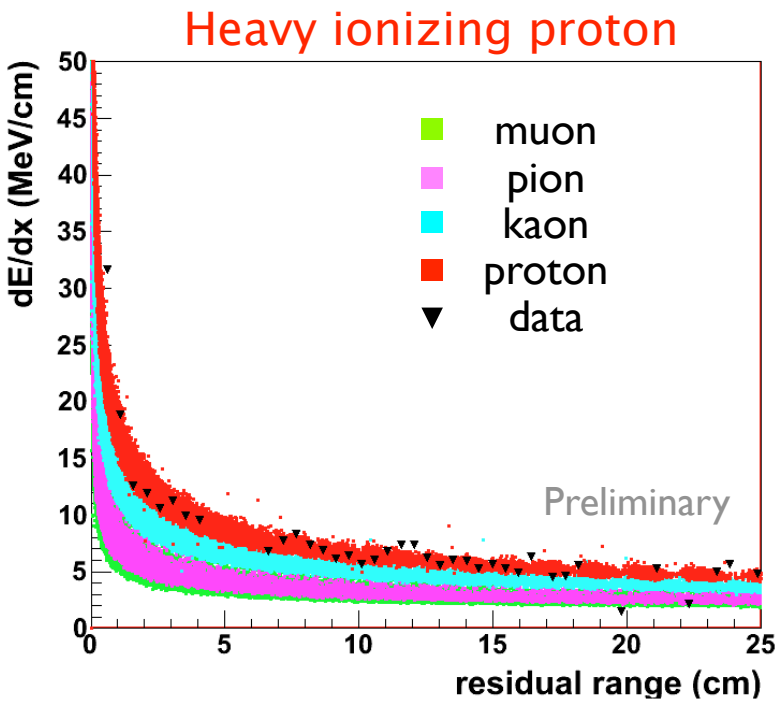
Event reconstruction



Calorimetry







Cross-section measurements with ArgoNeuT

- Address CCQE cross-section tension between NOMAD and MiniBooNE (FSI?)
- First natural measurement is the CC-inclusive cross section since it is minimally sensitive to FSIs and to the exclusive channel definitions
- Subsequent ArgoNeuT exclusive channel cross-section measurements can be compared to the inclusive one to perhaps disentangle the effects of FSI and nuclear modeling from actual neutrino-nucleus interactions (e.g. SciBooNE for CC and NC coherent pion production cross sections)

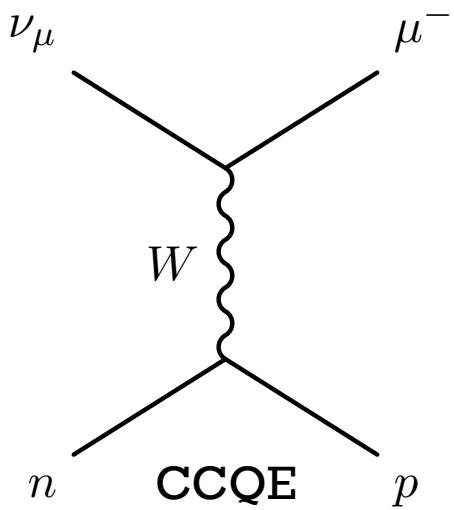
Measuring CC-inclusive XSec

- Data acquired in neutrino mode (8.5 x 10^{18}POT) have been analyzed
- Ideally, the double cross section would be reported

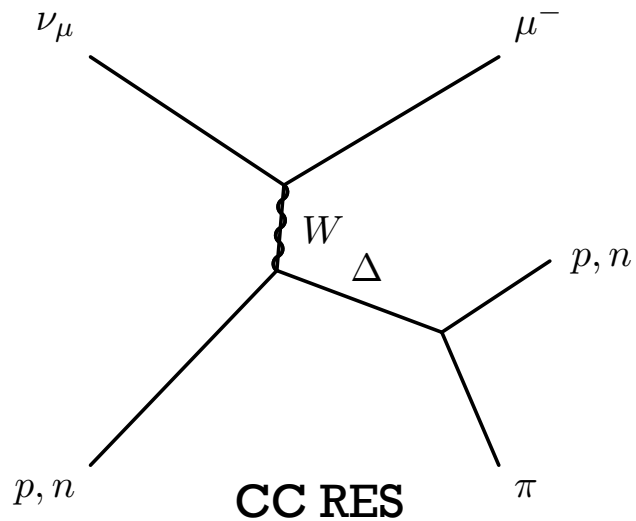
$$\frac{d\sigma}{d\vartheta_{\mu} dp_{\mu}}$$

- However, it requires very high statistics in order to populate the two dimensional bins in (θ ,p) space and the neutrino mode do not have enough statistics
- The double cross section will be measured for anti-neutrino mode data

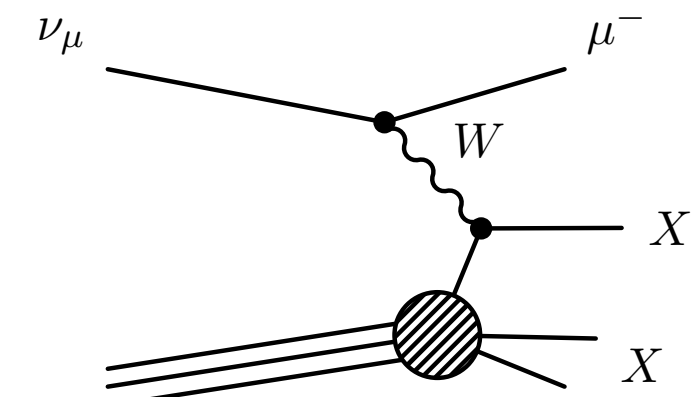
Measuring CC-inclusive XSec



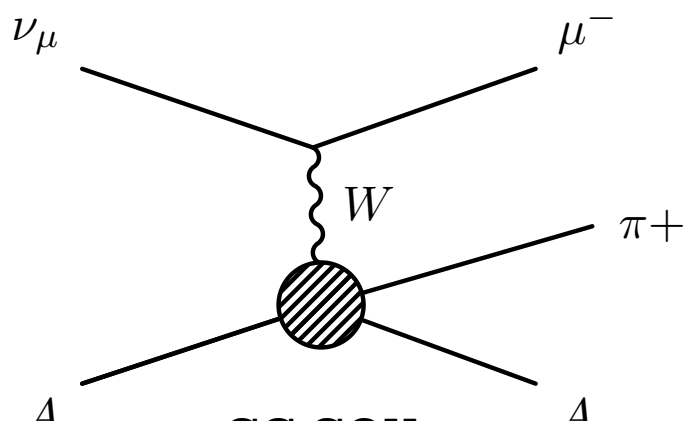
CCQE



CC RES

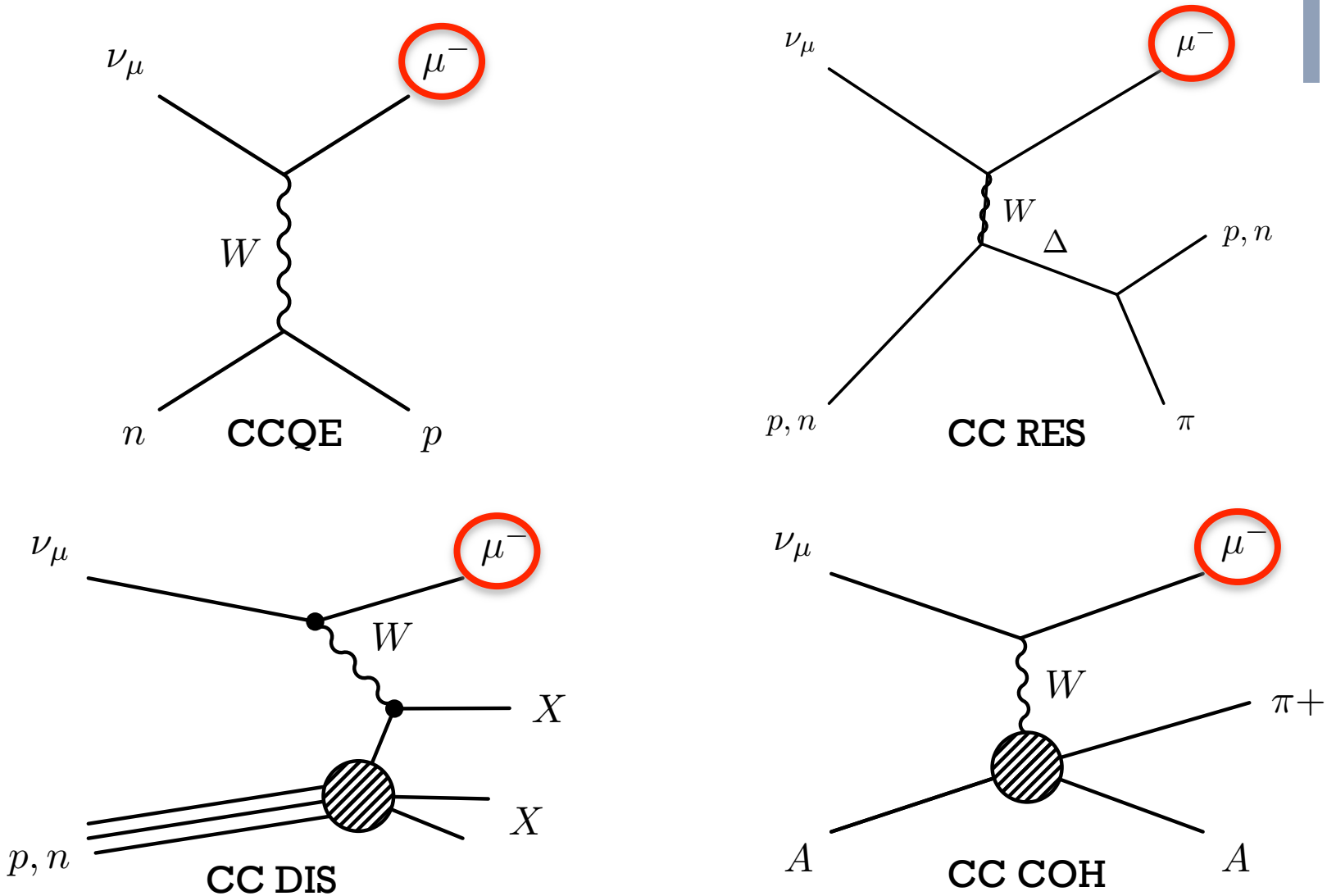


CC DIS



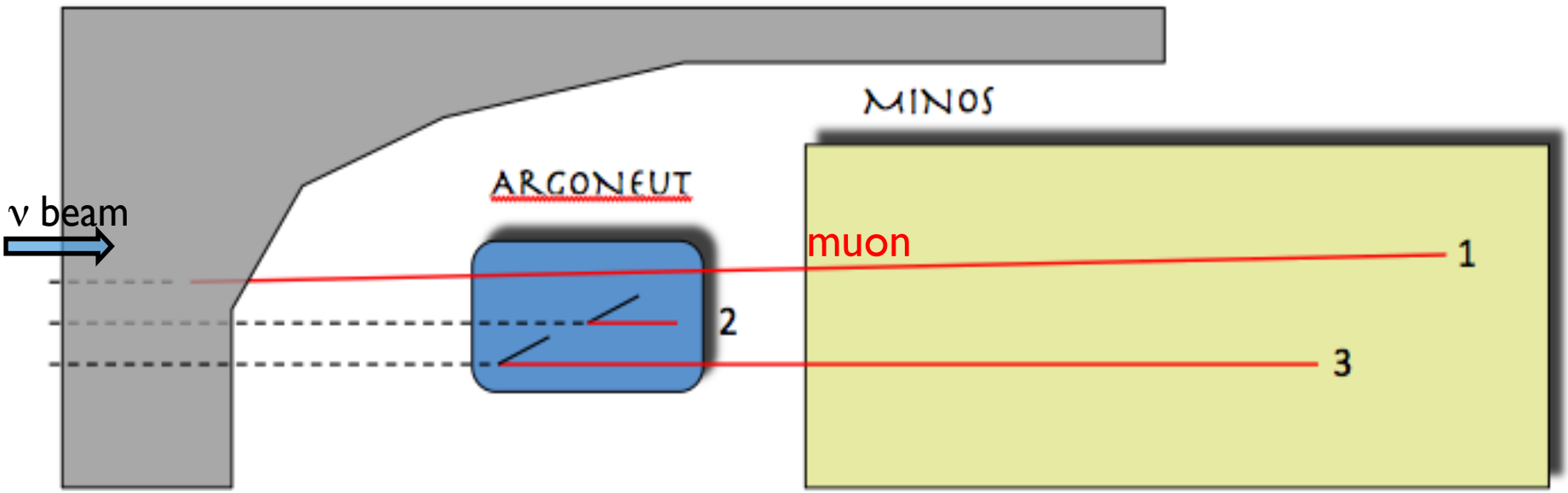
CC COH

Measuring CC-inclusive XSec



CC interactions

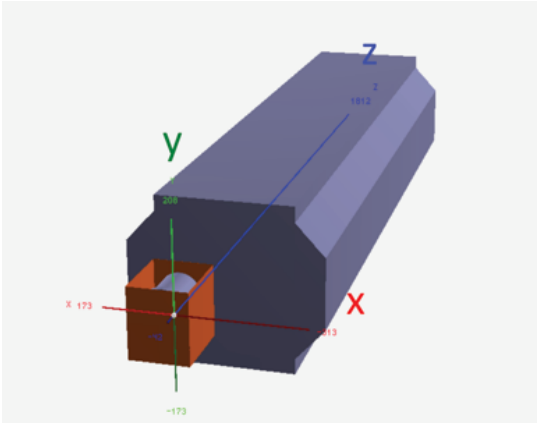
- The key is the μ^-
- Most muons escape ArgoNeuT
- Need MINOS near detector

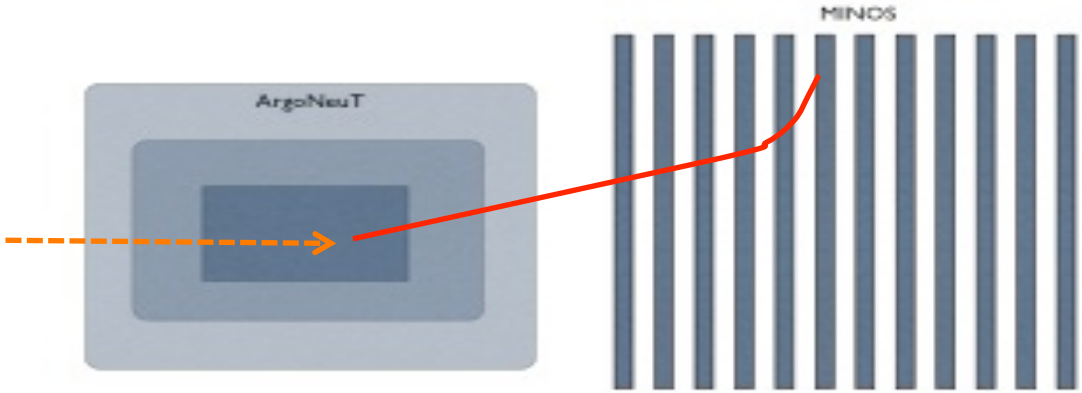


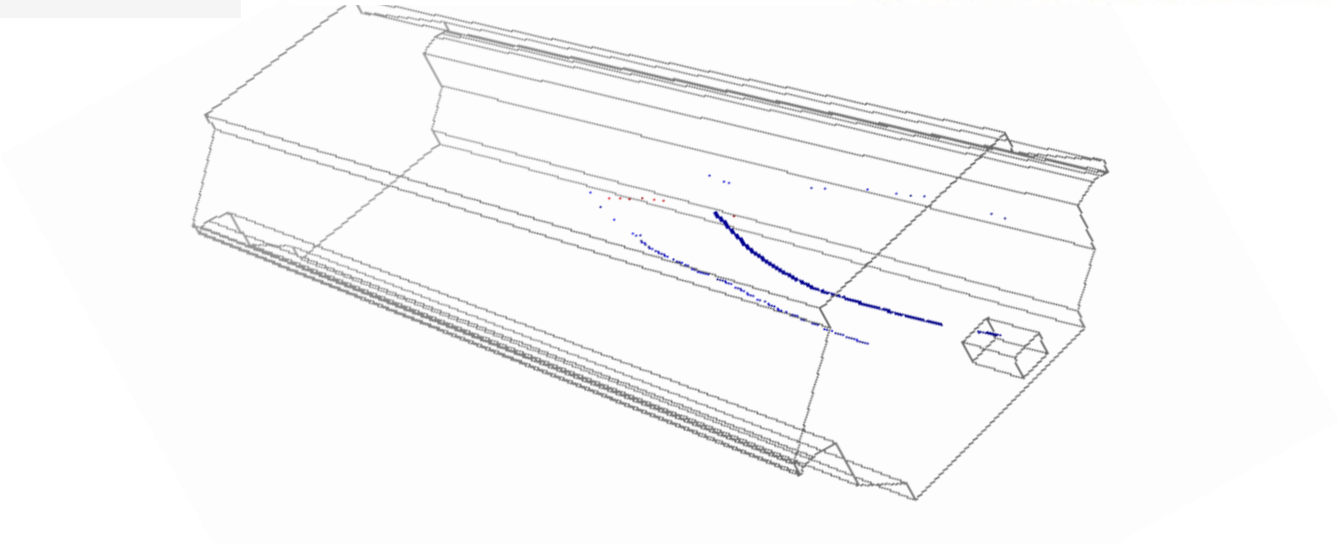
We gratefully acknowledge the cooperation of the MINOS collaboration in providing their data for use in this analysis

On the trace of muons

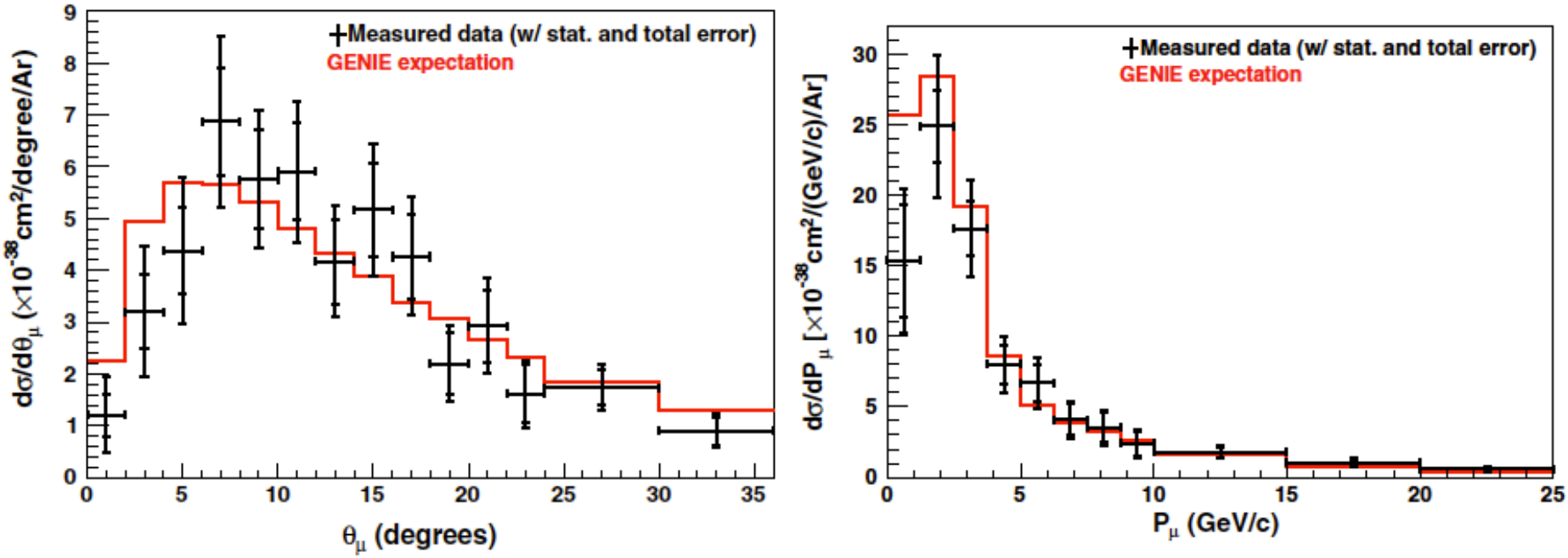
- Events are reconstructed in ArgoNeuT
- They are then matched to muons in MINOS







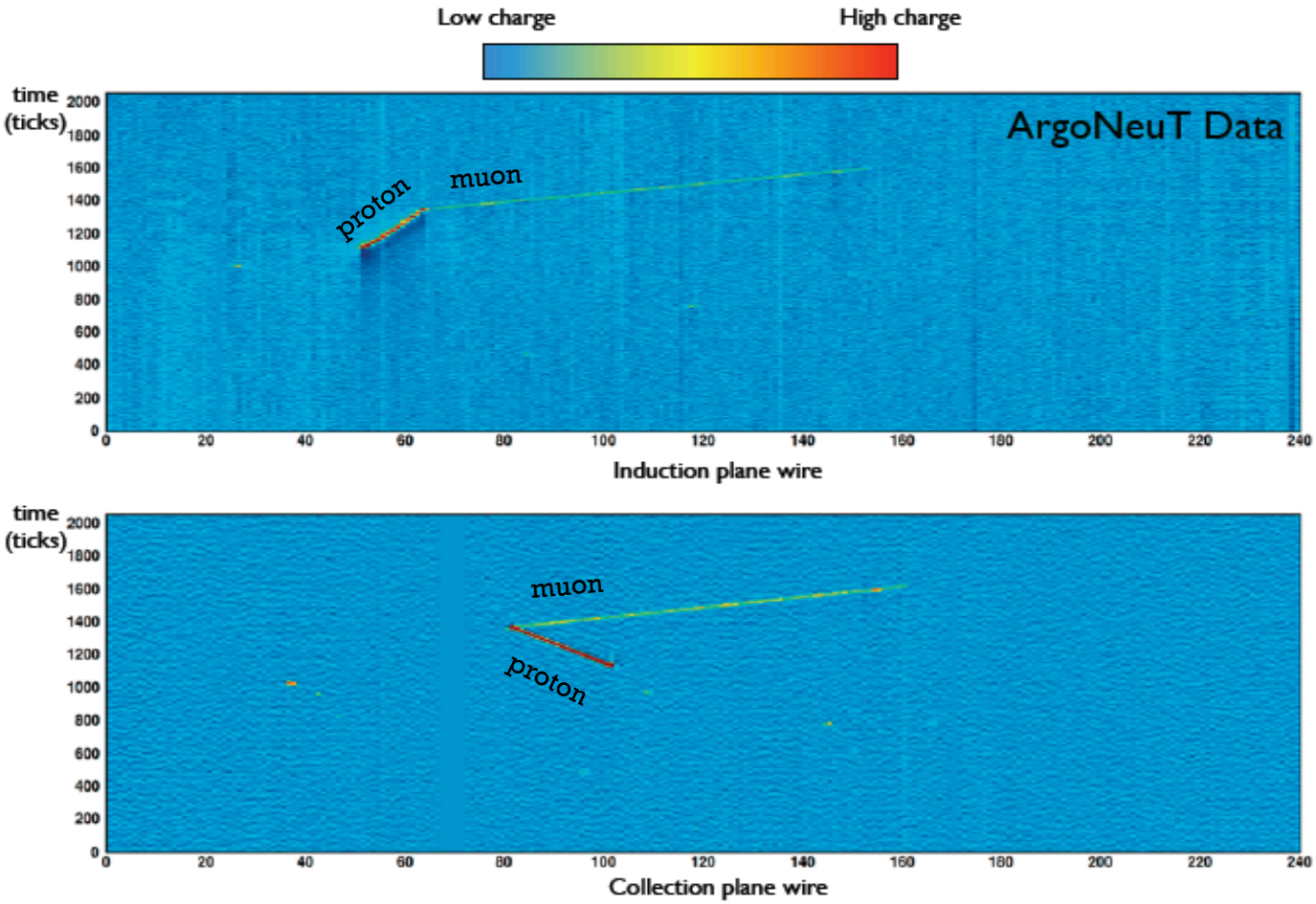
Measurement!



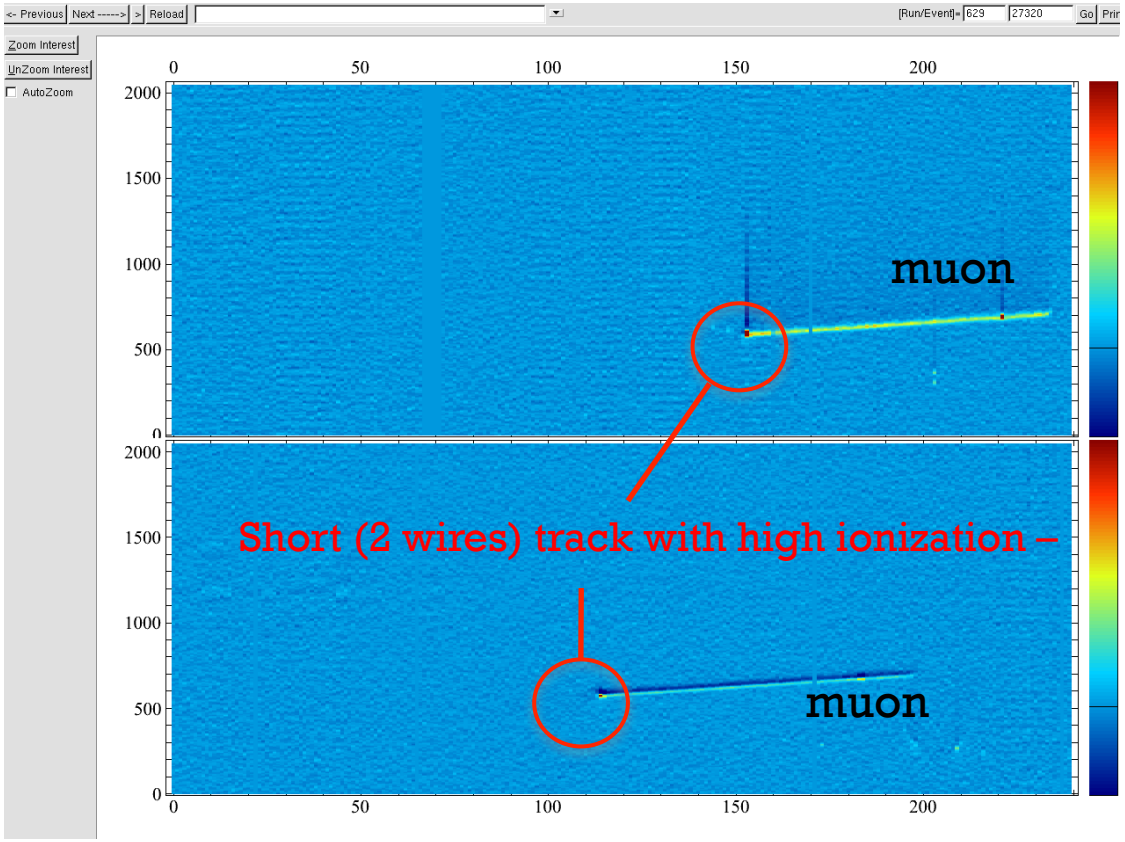
Aderson C. et al., PRL 108, 2012

Progress in other types of analyses

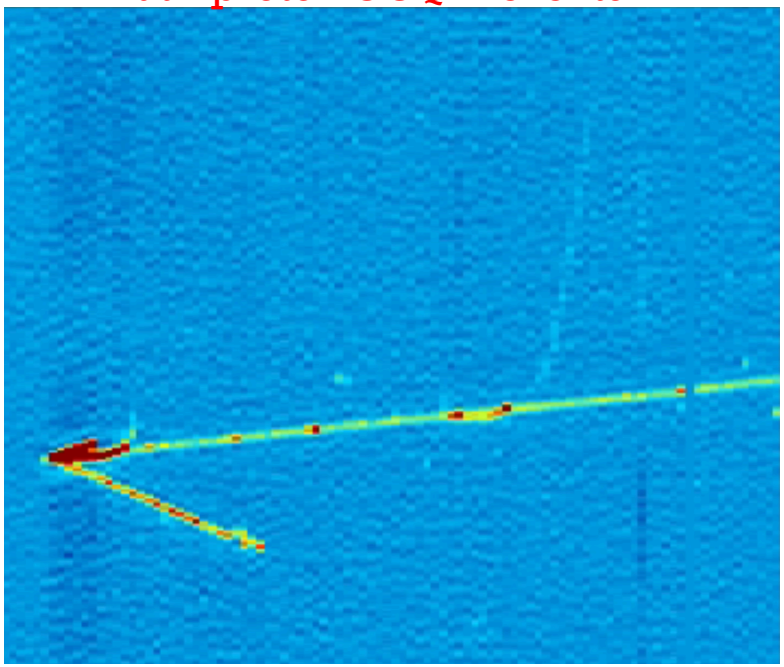
- **CCQE** analysis ($\nu_\mu + n \rightarrow \mu + p$)



CCQE analysis



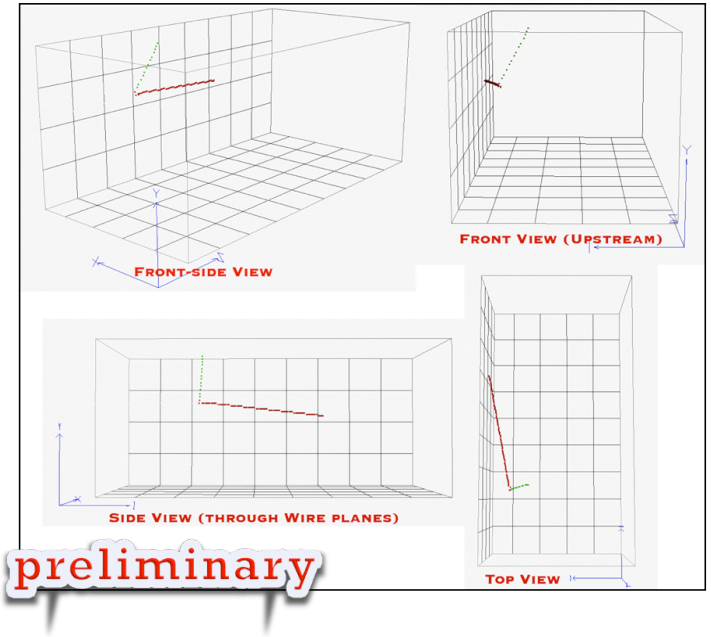
Mutli-proton CCQE events



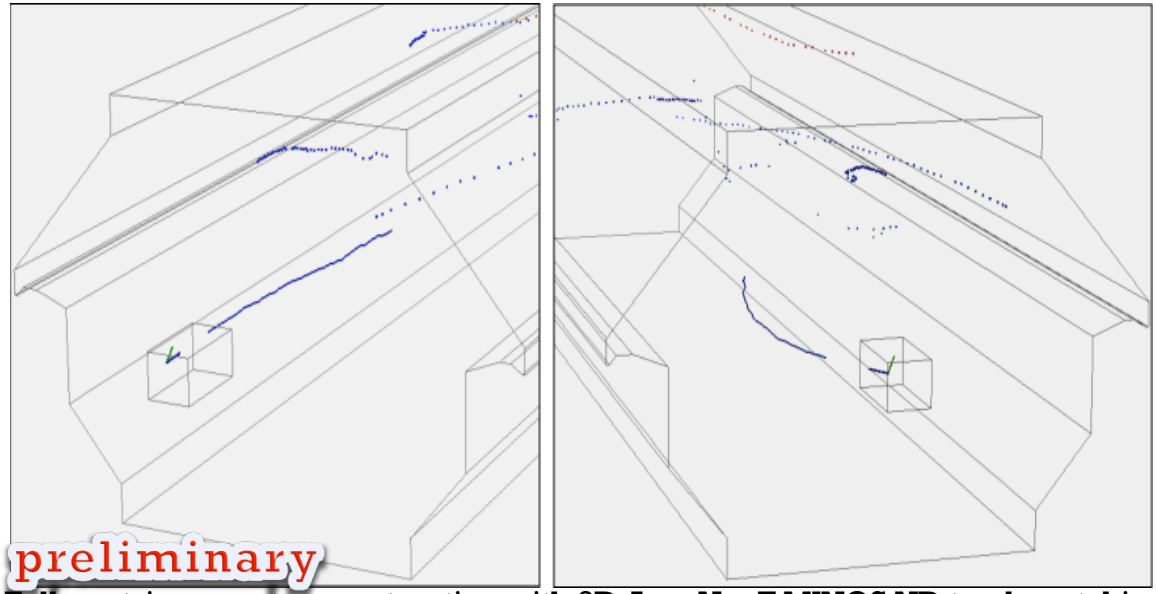
CCQE reconstruction

We gratefully acknowledge the cooperation of the MINOS collaboration in providing their data for use in this analysis

Neutrino event reconstructed in 3D space



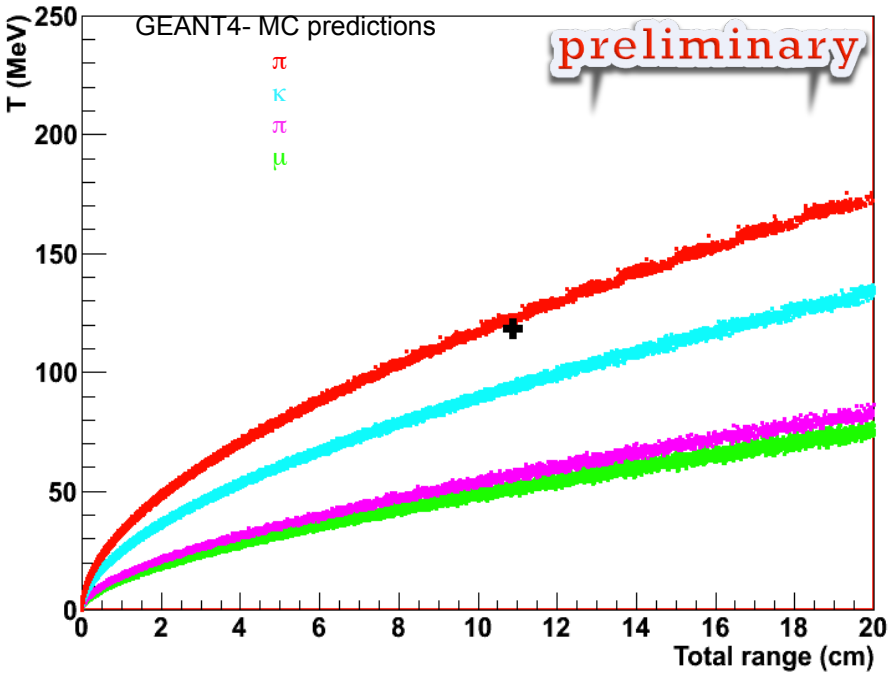
μ- escaping ArgoNeuT (and reaching MINOS-ND downstream)



Full neutrino event reconstruction with 3D ArgoNeuT-MINOS ND track matching

Muon (ArgoNeut+MINOS reconstruction): p=2.85 GeV/c

CCQE reconstruction



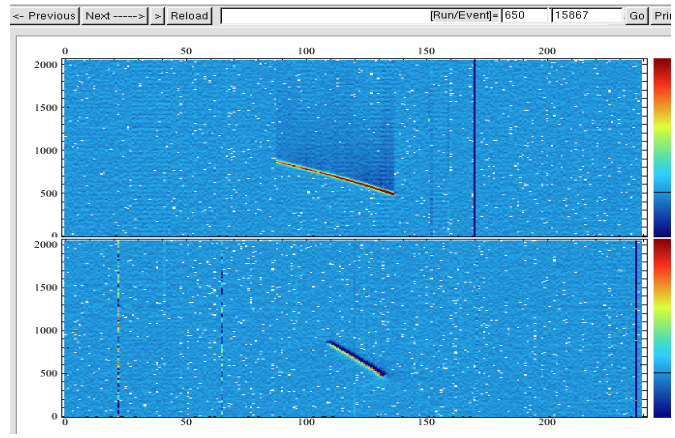
Proton (ArgoNeuT reconstruction):
track length= 10.88 cm,
T=118 MeV, p=0.485 GeV/c

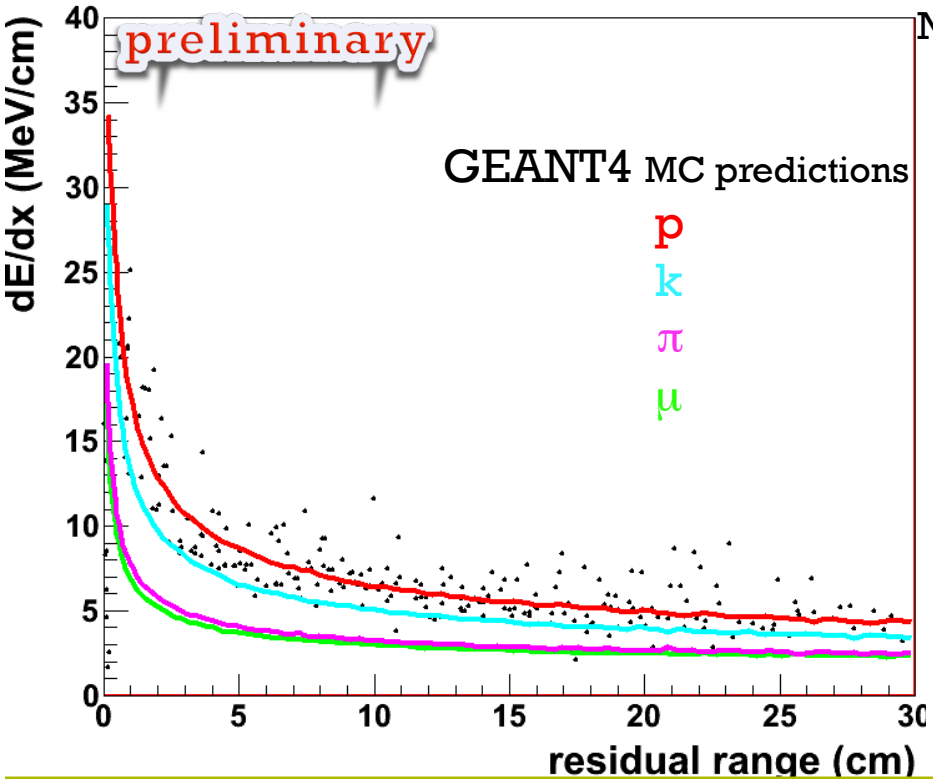
$$E_\nu = p_\mu \cos\theta_\mu + p_h \cos\theta_h$$

Reconstructed Neutrino Energy= 3.1 GeV

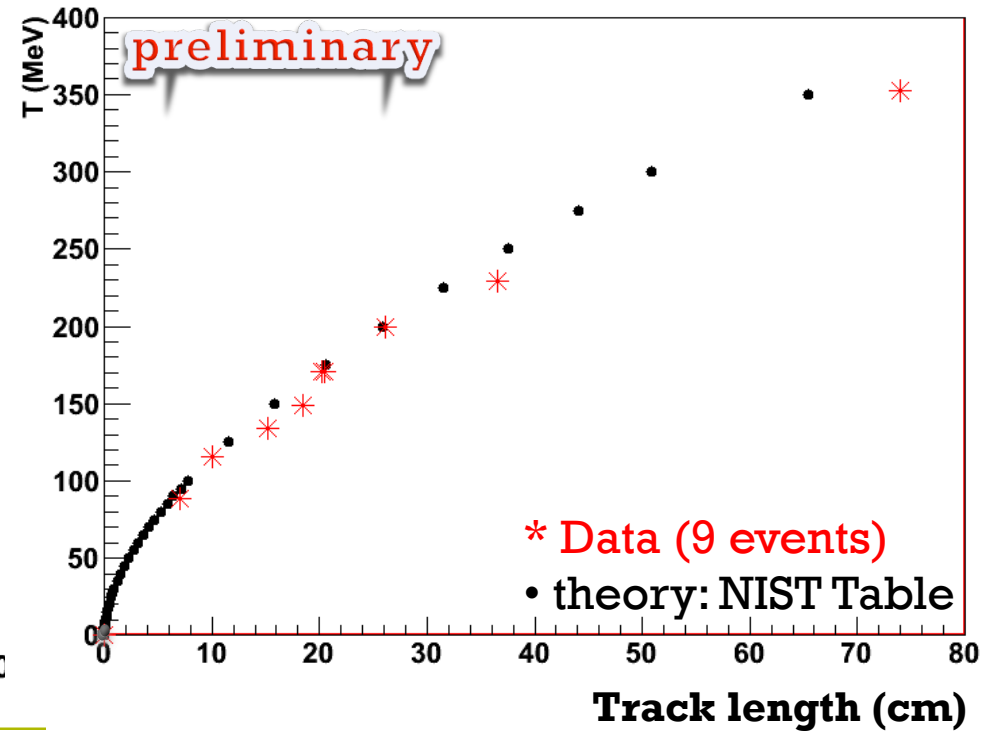
More on proton reconstruction:

- REAL data!
- Measurement of dE/dx along the track, of the kinetic energy deposited and of the track length





NIST predictions (**Stopping-Power and Range Tables**)

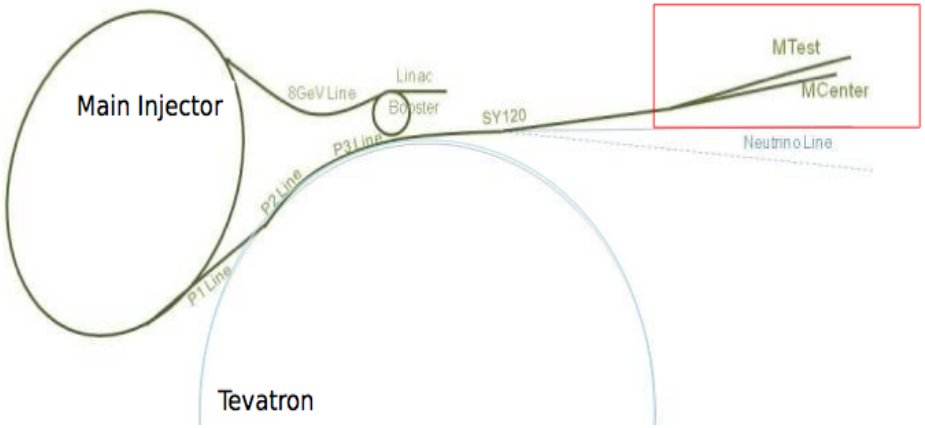


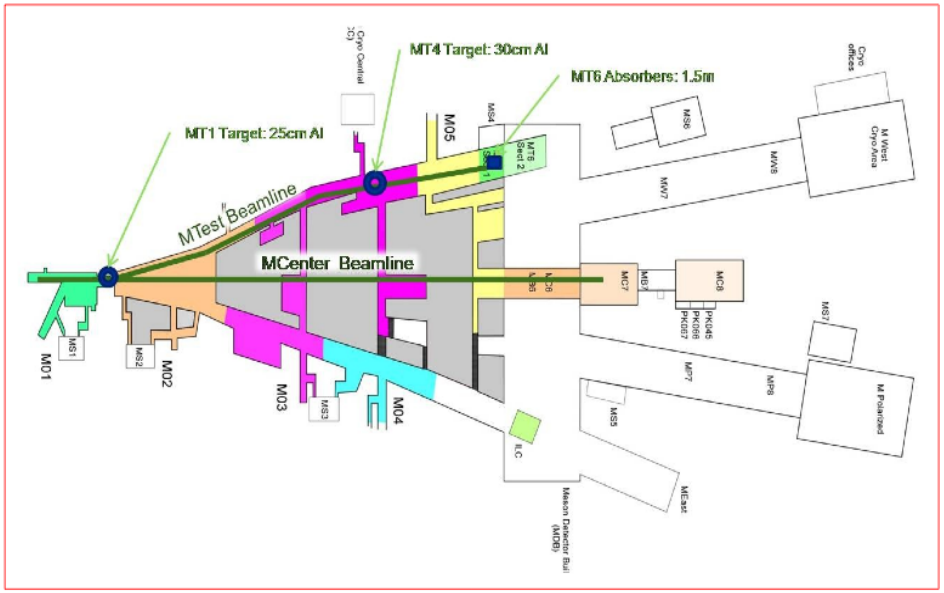
Using ArgoNeut to calibrate LArTPCs

- New detectors (eg trackers, calorimeters) are usually *calibrated* (before physics application)
- Calibration can be done if you know input particles (type and energy) ➠ test-beam
- Single track reconstruction: ”calibration” = charge to energy conversion (i.e. determination of the charge recombination factors)
- e to γ separation [for CCQE ($\nu_e \rightarrow e$) vs NC ($\pi^0 \rightarrow \gamma\ \gamma$)
- μ to π separation (based on *dE/dx - if possible*) [for CCQE vs NC-RES separation]
- kaon identification and *dE/dx* [for p-decay search]

Test Beam at FNAL

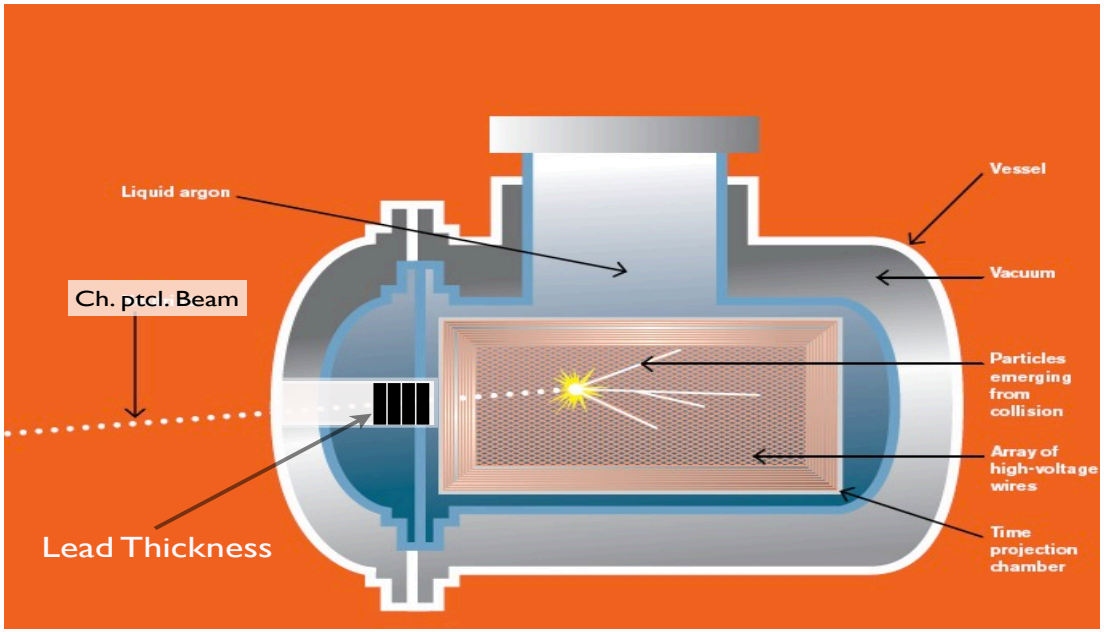
- Different types of beam with PID
- Now shutdown
- Presumed restart: Spring 2013





Using ArgoNeuT…

- Proposal has been submitted to put ArgoNeuT in Test Beam
- Redesign front flange (minimize material upstream of active volume)
- PMTs (2 HQE)
- Possible scintillator paddles
- DAQ/electronics upgrade (future)
- Magnet (future)

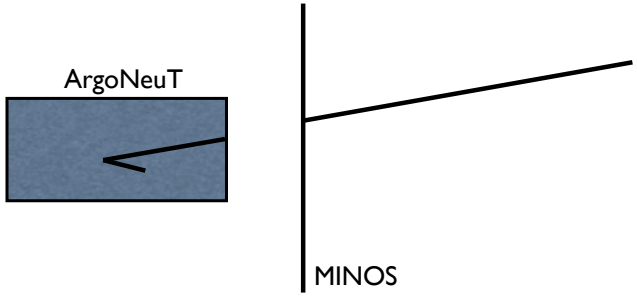


Conclusions

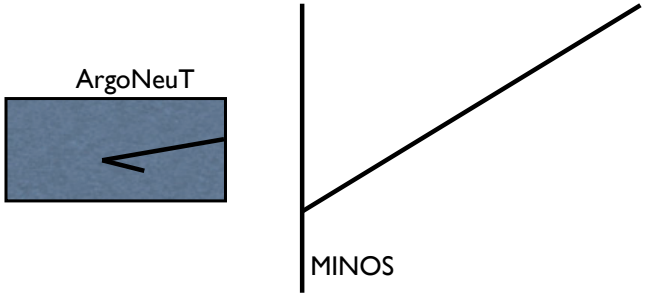
- The 2 weeks of neutrino data have been analyzed to make a CC-inclusive measurement
- First CC-inclusive differential cross section measurement
- Full reconstruction software operational
- The anti-neutrino mode data are under analysis with higher (~15x) statistics for CC-inclusive double differential cross section
- Exclusive channel analyses are underway (ex: CCQE)
- FSI studies
- Considering using ArgoNeuT for LArTPC calibration

Backup slides

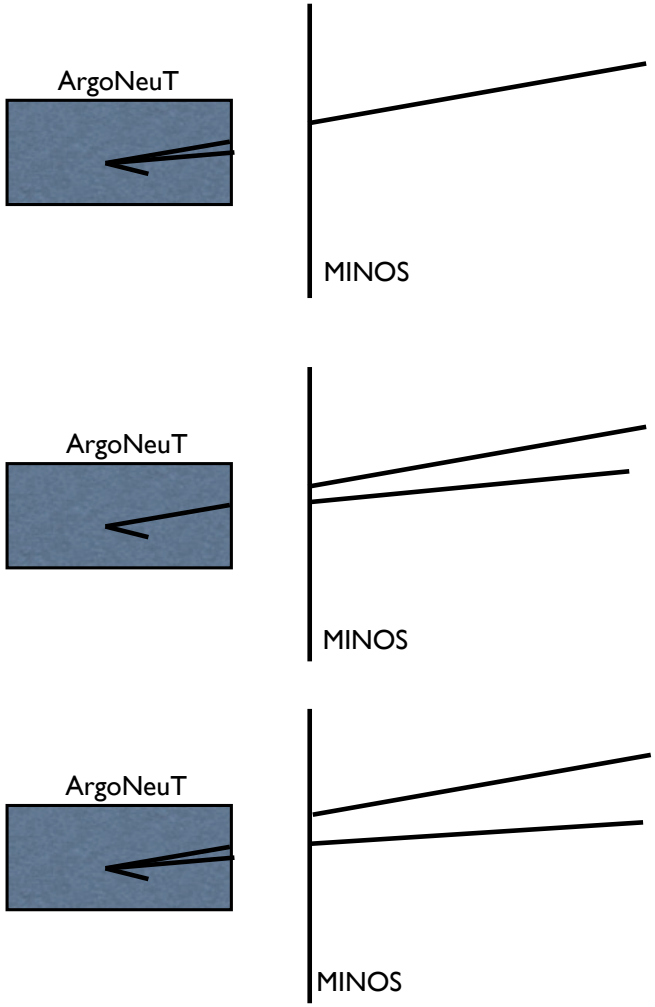
On the trace of muons



Match



No Match



Multiple Matches

Josh Spitz, PhD Thesis 2011

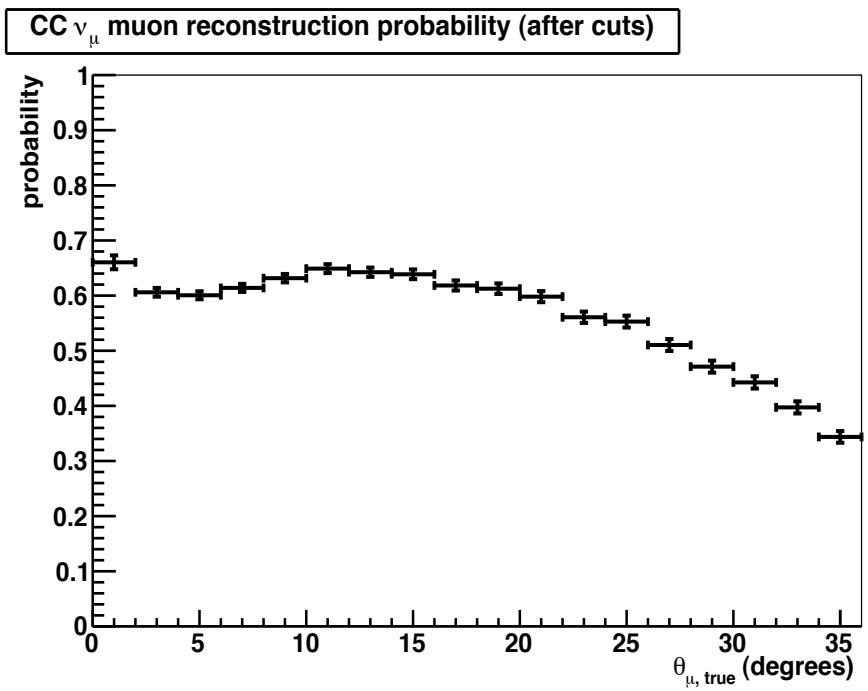
Background contamination

- NC neutrino-induced track originating in ArgoNeuT can be matched with through-going muon MINOS track
- The charge of a wrong-sign neutrino event's muon originating in ArgoNeuT can be reconstructed as negatively charged
- A pion from NC event originating in ArgoNeuT can be matched with a muon that enters MINOS
- A through-going muon that enters ArgoNeuT and is reconstructed by MINOS

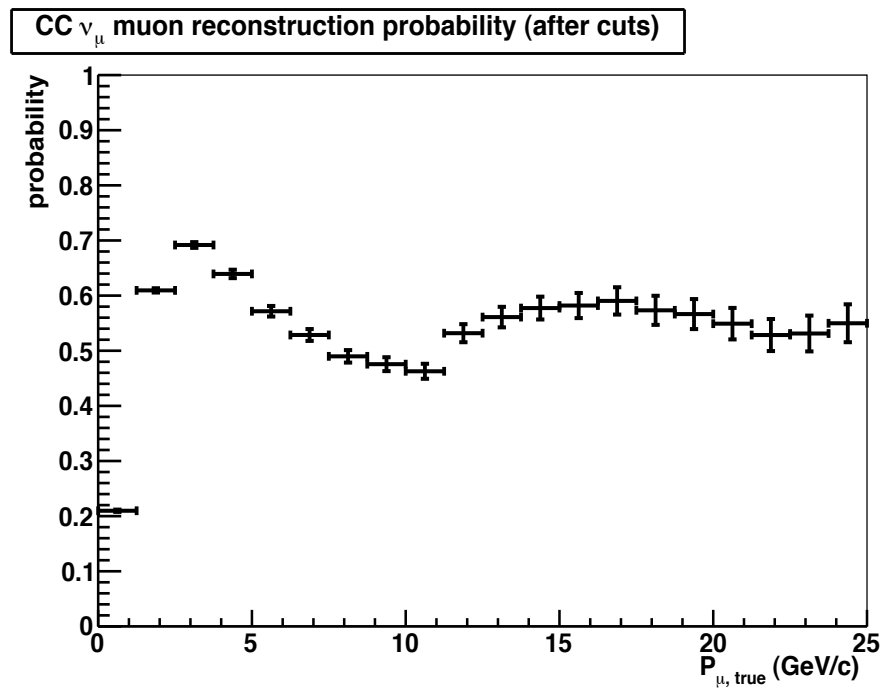
Signal (CC ν_μ) reconstruction probability	51.3%
Signal (CC ν_μ) purity	95.5%
NC/WS background contamination	2.1%
TG muon background contamination	1.2%
NC match w/ TG muon background contamination	1.1%

Reconstructing CC events

$$\text{Total reco. probability} = \frac{\#\ \text{of completely reconstructed CC}\ \nu_\mu\ \text{events in FV}}{\#\ \text{of CC}\ \nu_\mu\ \text{events in FV}}$$

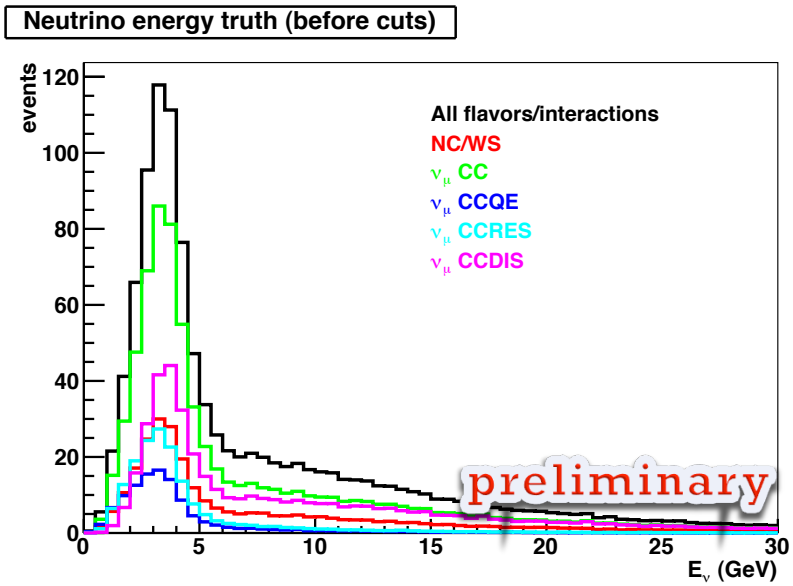


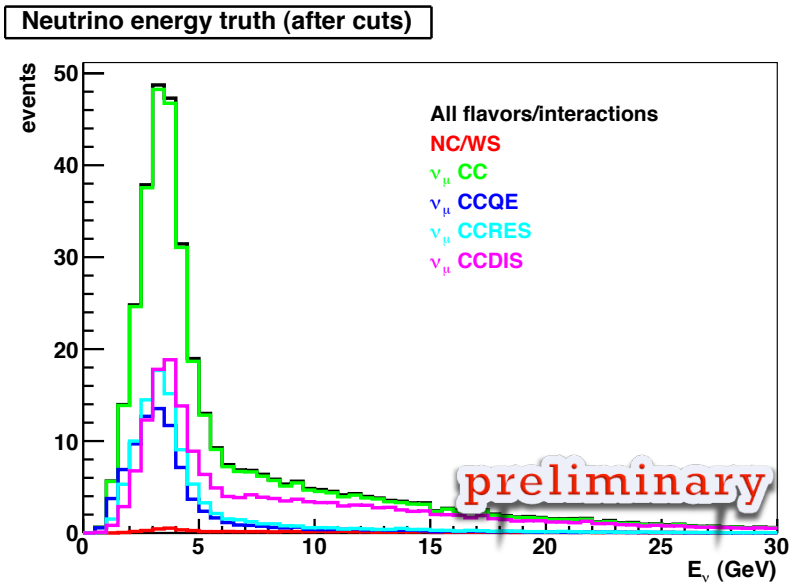
Josh Spitz, PhD Thesis 2011



Josh Spitz, PhD Thesis 2011

True energy distributions





Josh Spitz, PhD Thesis 2011

Test Beam at FNAL

- **Secondary Beam**
- Low Energy Pion Mode: 1 - 32 GeV
- Muon mode: The best rates are given in the Low E Pion Mode at 32 GeV -at 300,000 particles per spill, you should get several thousand muons per spill, over an area of 1 square meter.
- **Tertiary Beam**
- 400 MeV - Low E pion modes