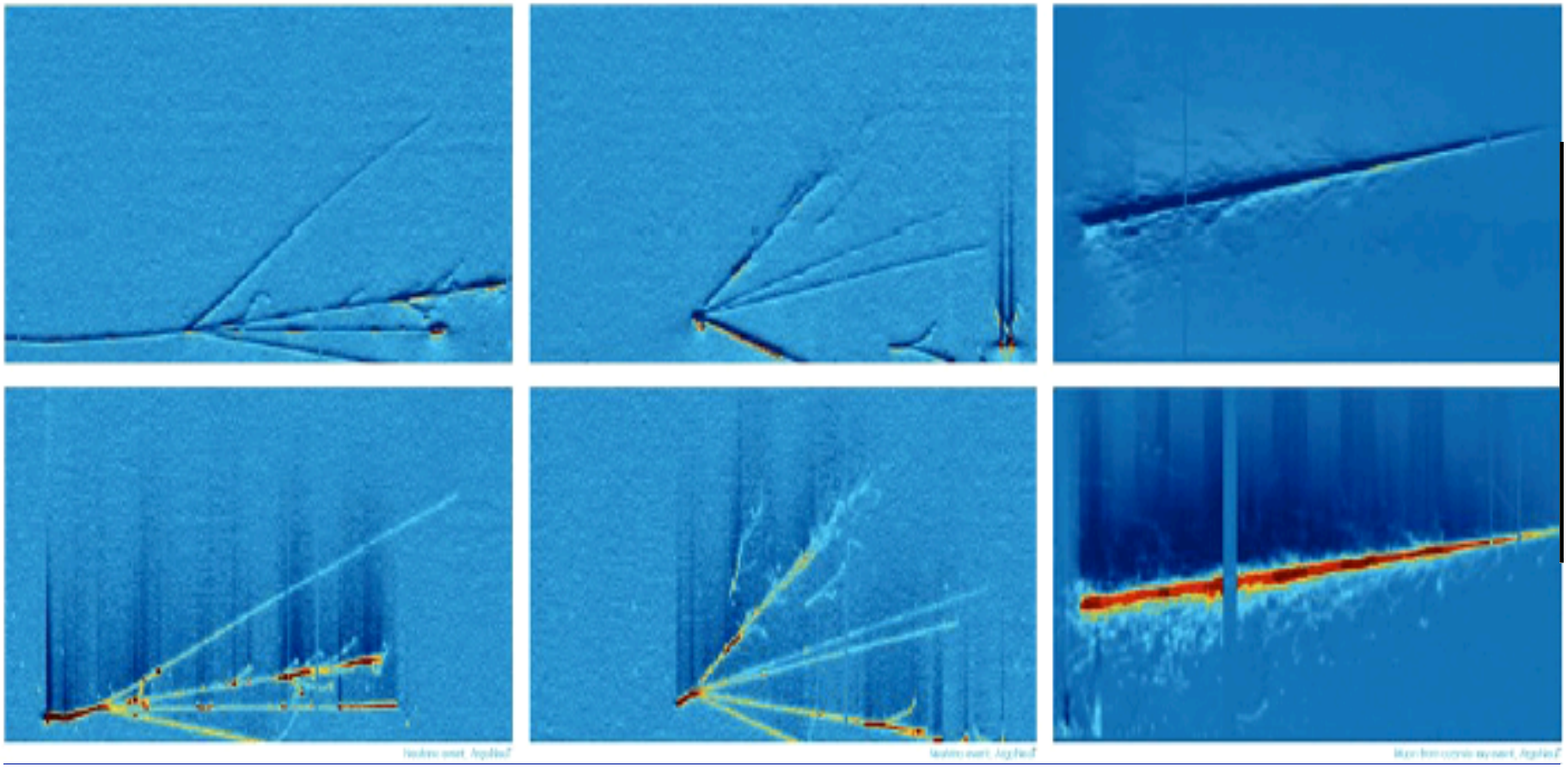


# The ArgoNeuT experiment

Roxanne Guenette
Yale University

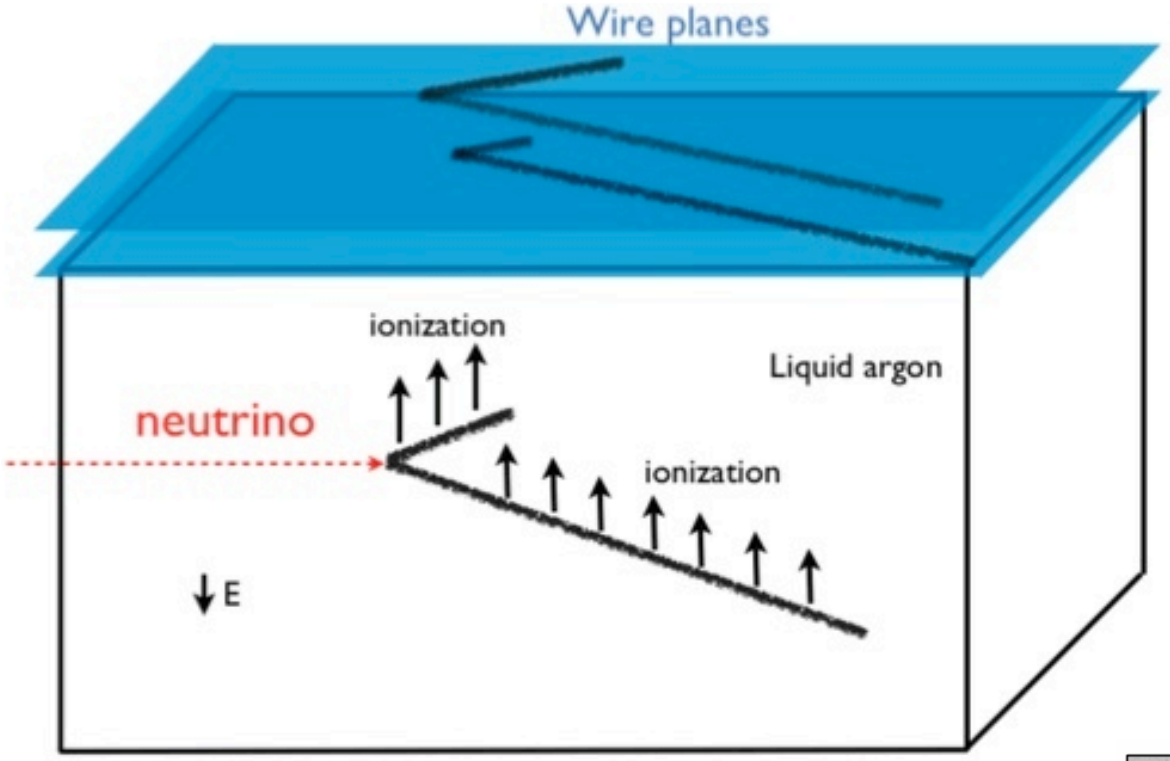
DPF Conference
August 12th 2011

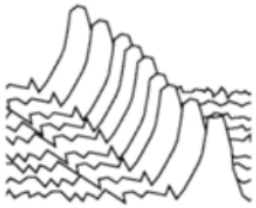
# Outline



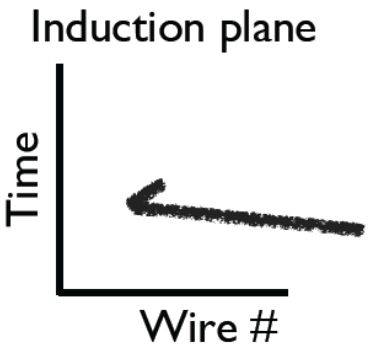

- Overview of the LAr TPC concept
- Description of the ArgoNeuT experiment
- Event reconstruction techniques
- CC-inclusive measurement
- Conclusions

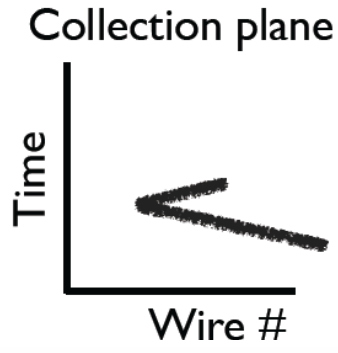
# LAr TPC concept

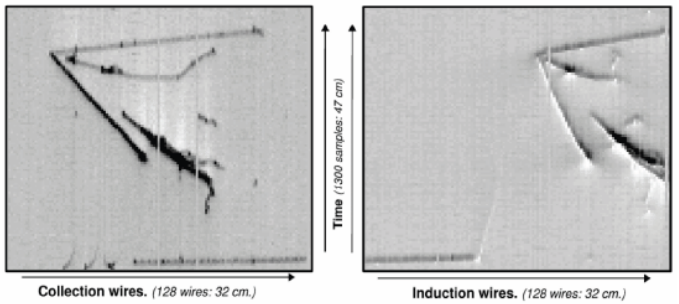


Wire pulses in time give the drift coordinate of the track




ICARUS 50 L in WANF neutrino beam

# Why Ar?

- Ar is a good target for neutrino (18 p, 22 n)
- Cheap and easy to obtain
- Good for large electric field
- Produces a lot of scintillation light as well as ionization
- Ionization can drift over large distance with high purity
- LArTPCs offer precise spatial resolution (mm scale) and good calorimetry
- LArTPCs allow excellent neutrino interaction characterization and superior background rejection

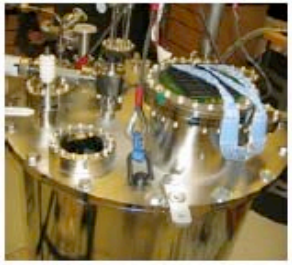
# ArgoNeuT

## 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

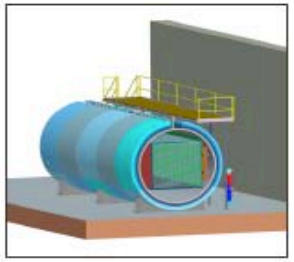
### Bo

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

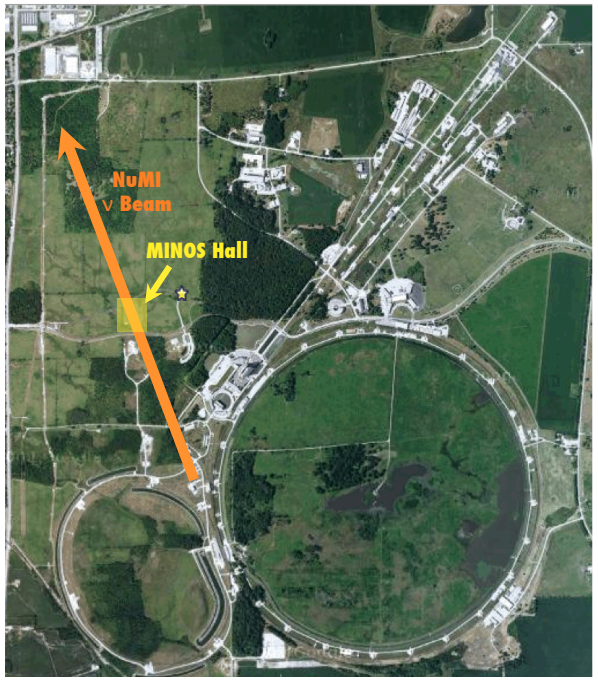
Location: Fermilab
Purpose: materials test station
Operational: since 2008

### LAPD

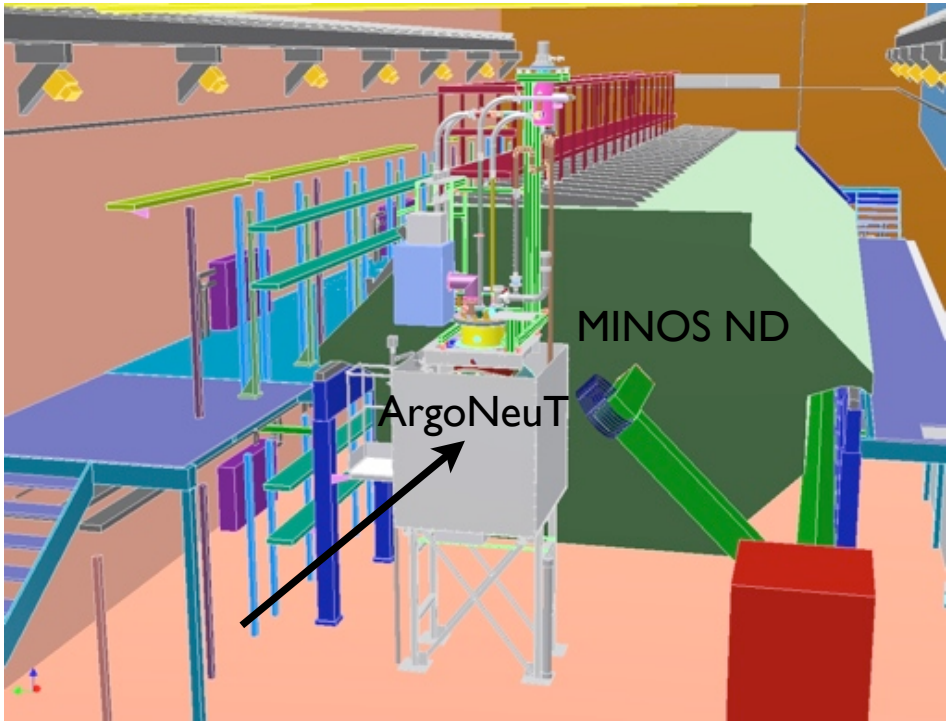
Location: Fermilab
Purpose: LAr purity demo
Operational: 2010

# 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 $\nu$ / $\overline{\nu}$ mode from September 2009 to February 2010

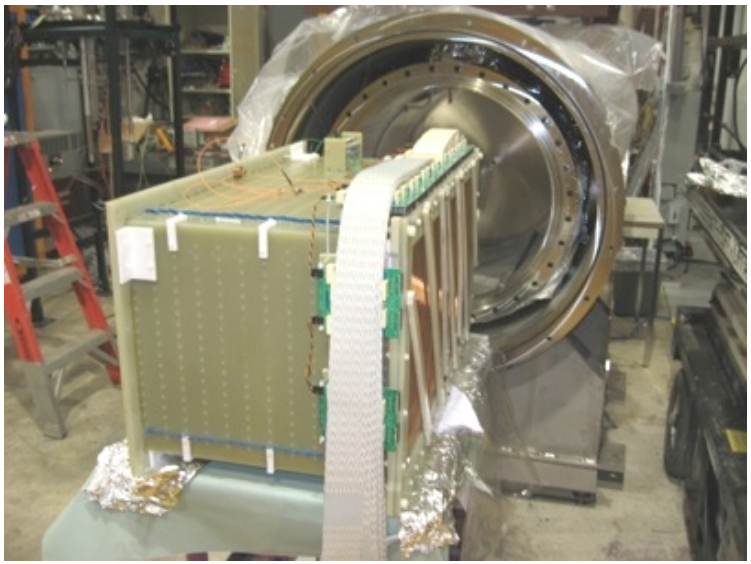



Fermilab, NuMI beam line

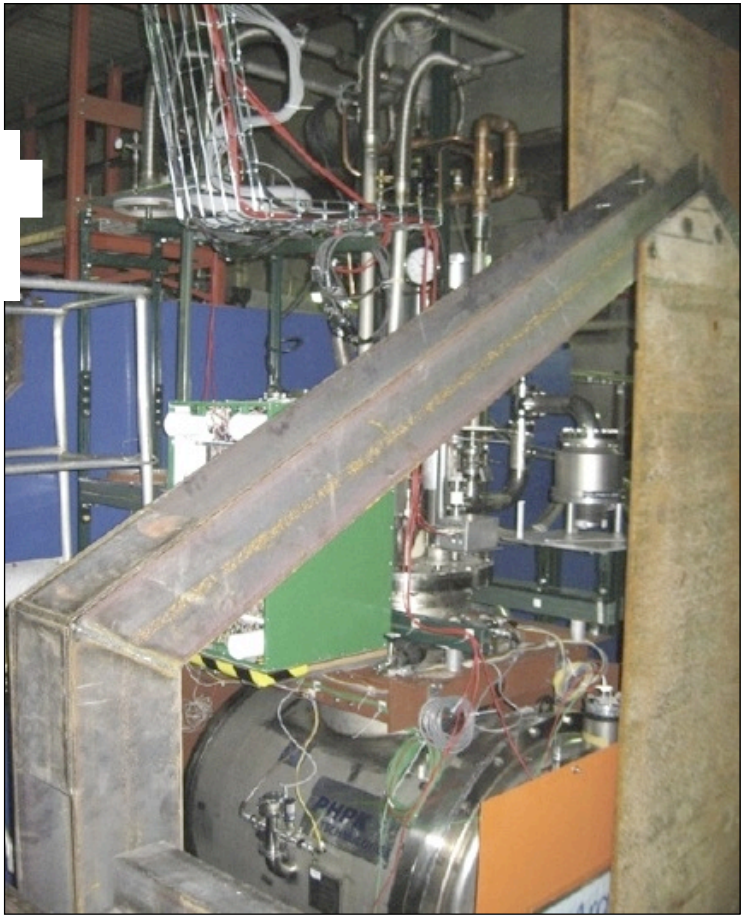


# ArgoNeuT

| | |
|---|---|
| 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



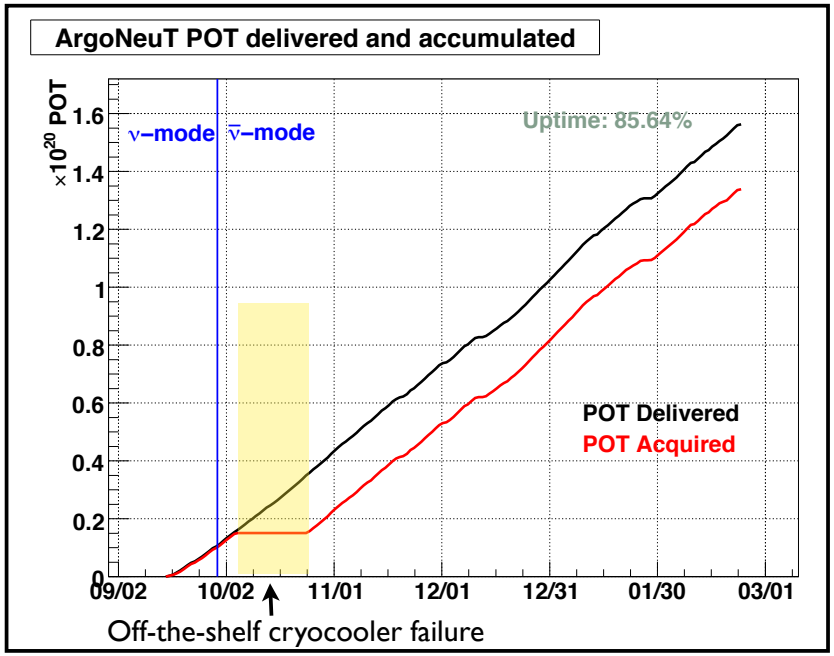
The fully-instrumented detector in the beamline

# ArgoNeuT goals

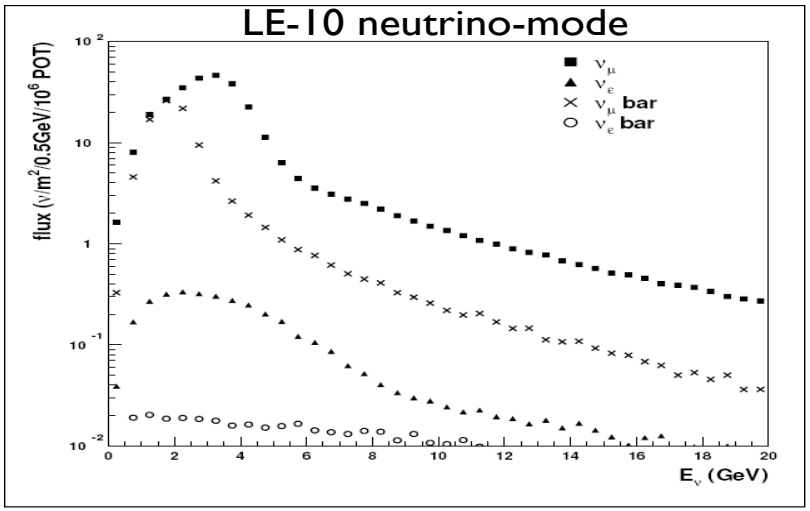
- Development goals:
  - R&D project for the LArTPC plan in the US
- Physics goals:
  - Measure charged-current cross-sections in the 1-5 GeV range with high sensitivity to the products of FSI
  - Demonstrate dE/dx particle separation (e.g. e/$\gamma$) capabilities of LArTPCs
  - Develop automated reconstruction techniques to be used for all LArTPC experiments

# ArgoNeuT data taking

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



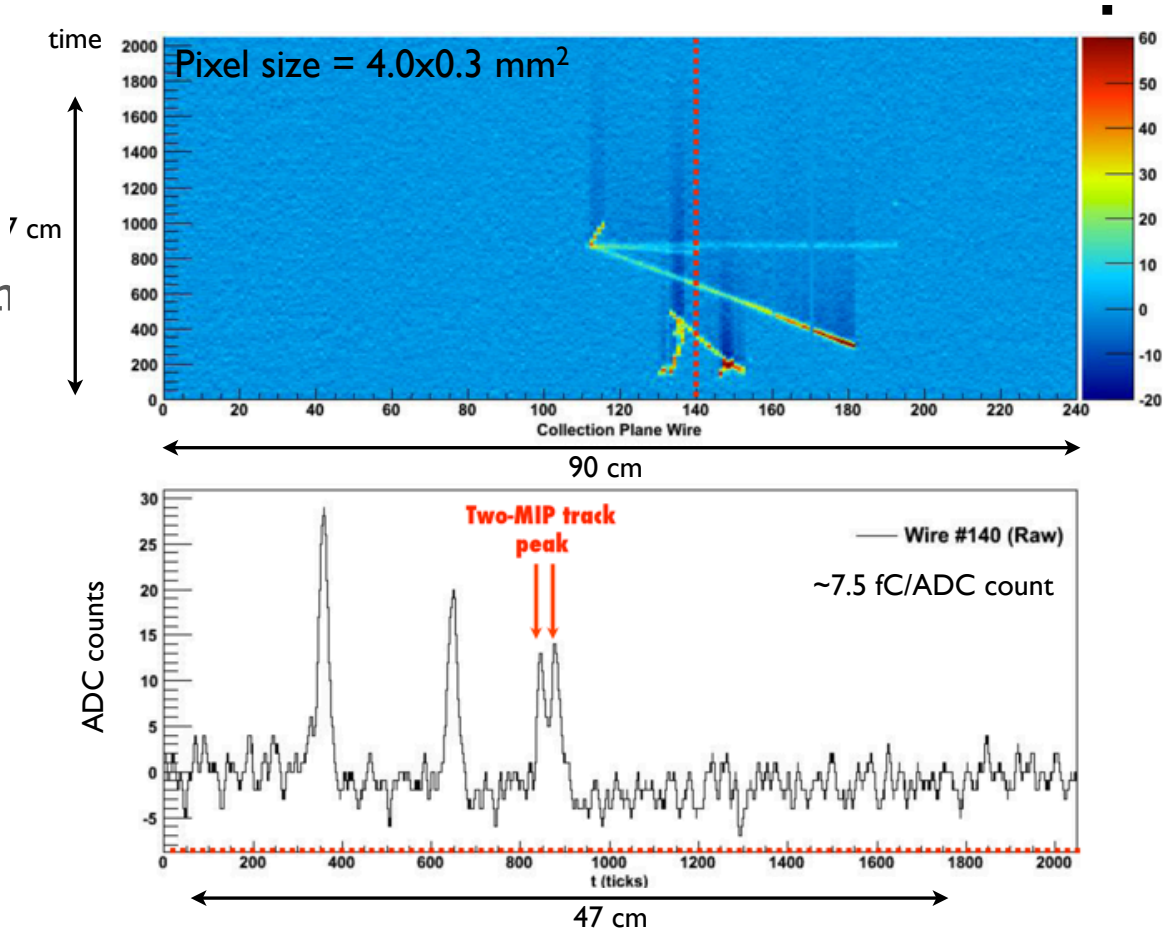

2 weeks in neutrino-mode, 4.5 months in anti-neutrino-mode



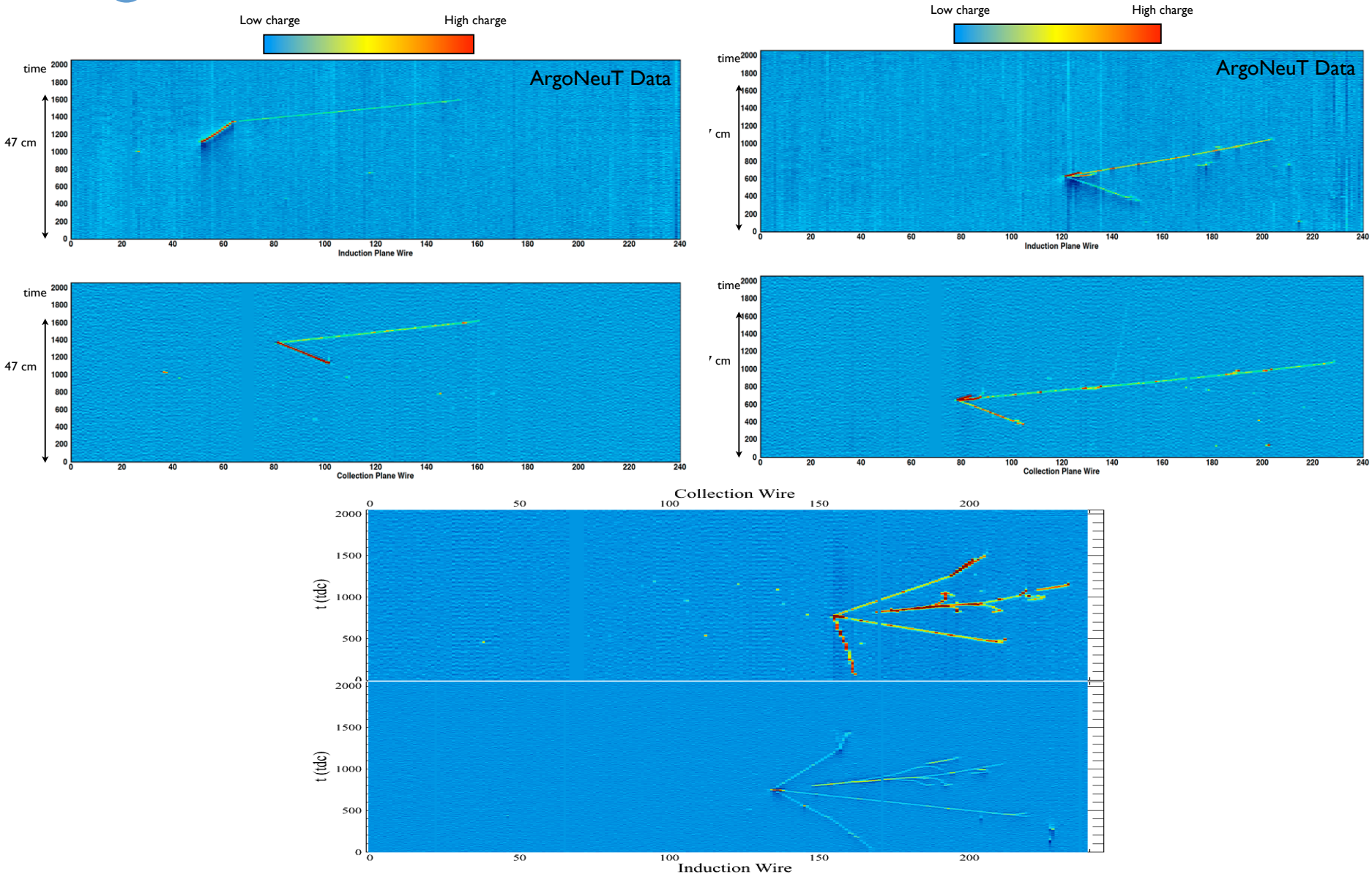

| Reaction | #events in AV (~1.35E20 POT) |
|---|---|
| $\nu_\mu$ CC | ~6600 |
| $\overline{\nu}_\mu$ CC | ~4900 |
| $\nu_\mu$ CCQE | ~600 |
| $\nu_e$ CC | ~130 |

# ArgoNeuT data: Events

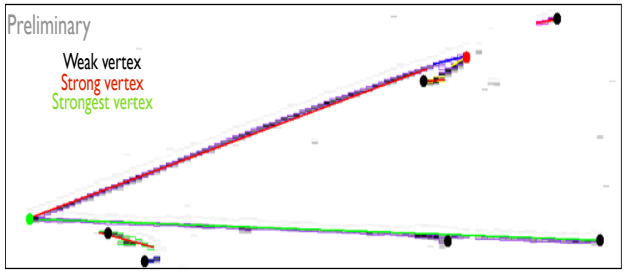
- The color scale represents the energy deposited along the track
- The wire pulse can be seen in the wire view



# AgoNeuT events



# Event reconstruction




Line finding/fitting + vertex/endpoint finding

Track3Dreco
SpacePts
Track3DKalman
SpacePointService

HarrisVertexFinder
PrimaryVertexFinder
VertexFinder2D

DBCluster
HoughLineFinder
LineMerger

Wire Calibration → Hit Finding → Hit Clustering → 3D Tracking → Vertex Finding

Hit Clustering → 3D Shower Finding → Calorimetry

CalWire

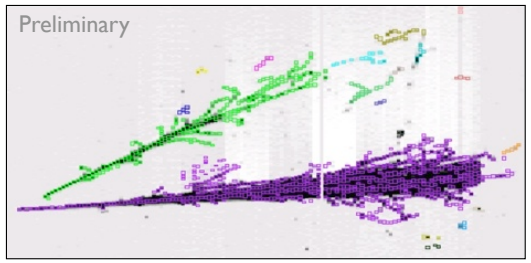
FFTHitFinder

CaloArgoItaliano

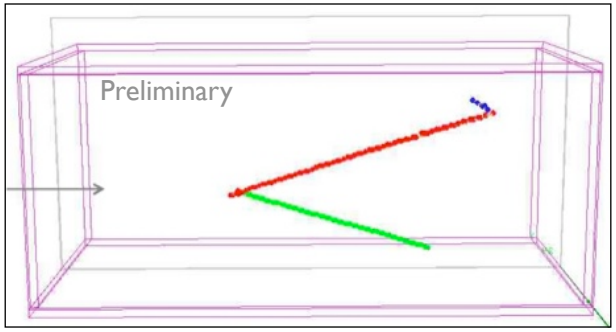
ShowerReco

Hit Clustering → EndPoint Finding

EndPointModule

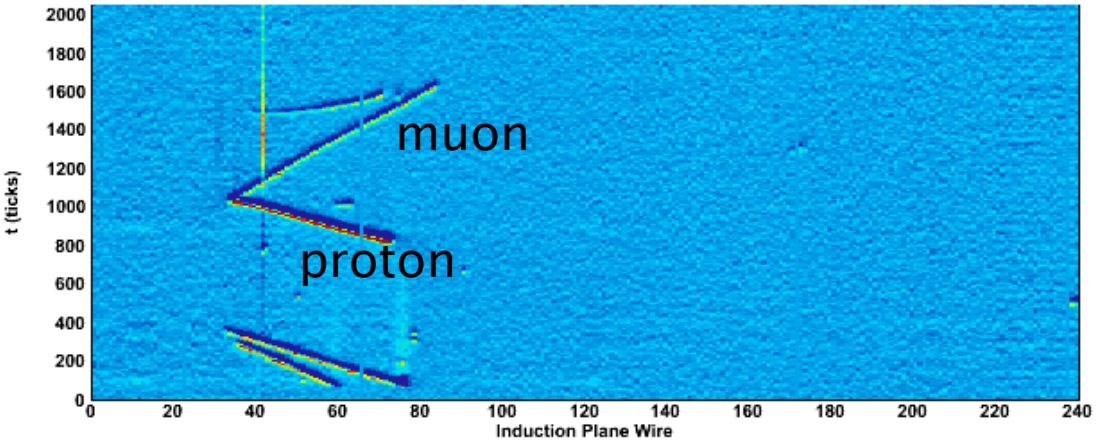


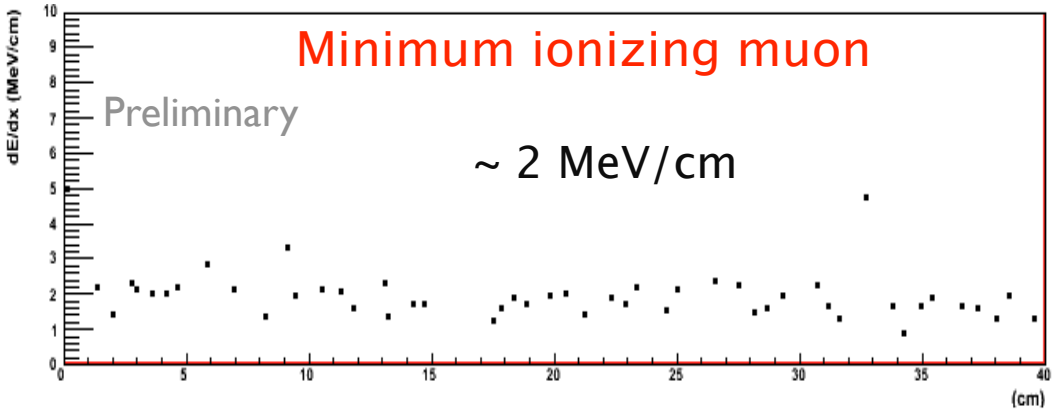

Hit finding + density-based clustering.

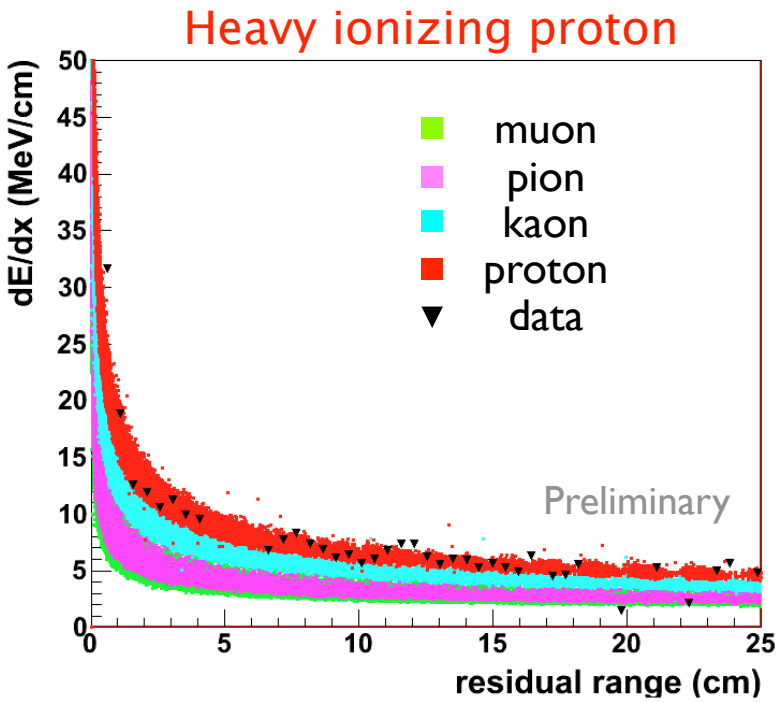



3D reconstruction

# 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)

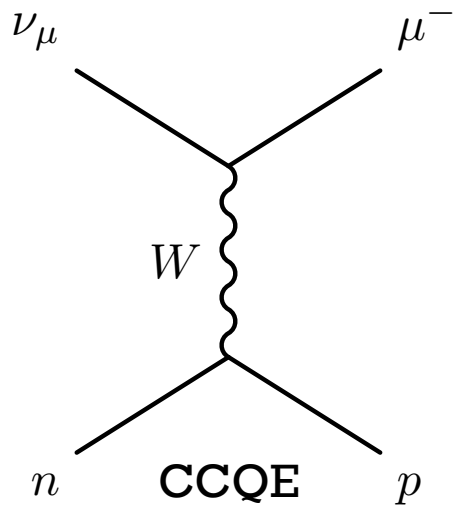
# Measuring CC-inclusive XSec

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

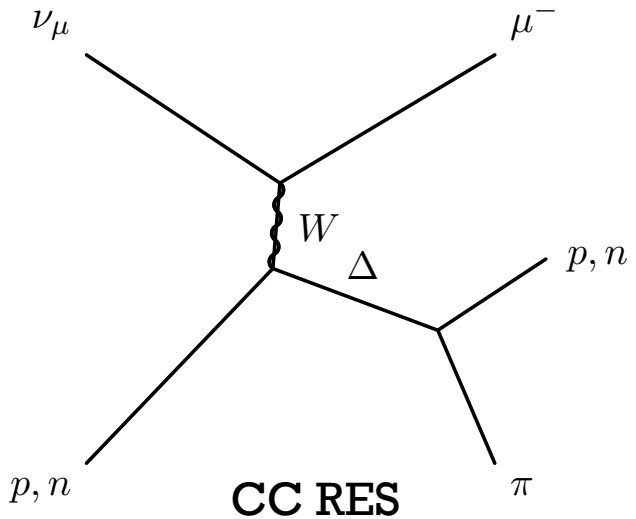
$$\frac{d\sigma}{d\vartheta_{\mu} dp_{\mu}}$$

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

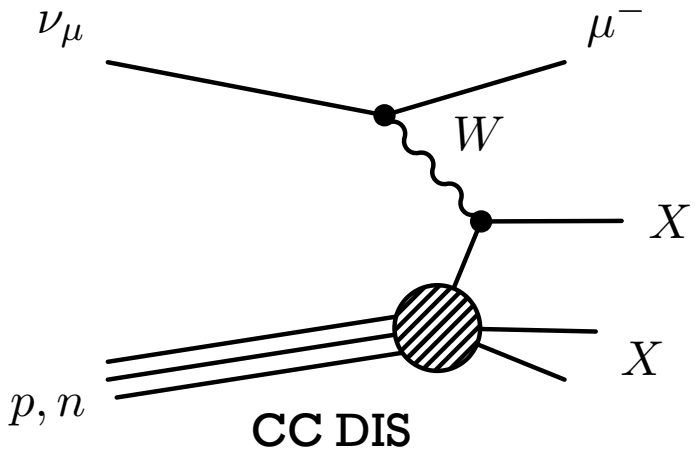
# Measuring CC-inclusive XSec



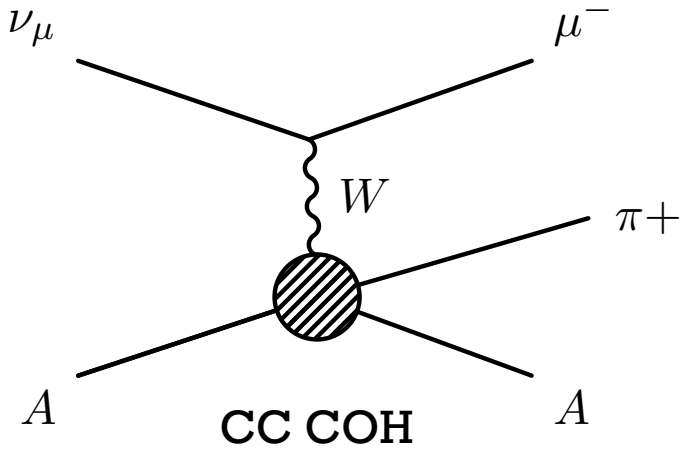

CCQE




CC RES

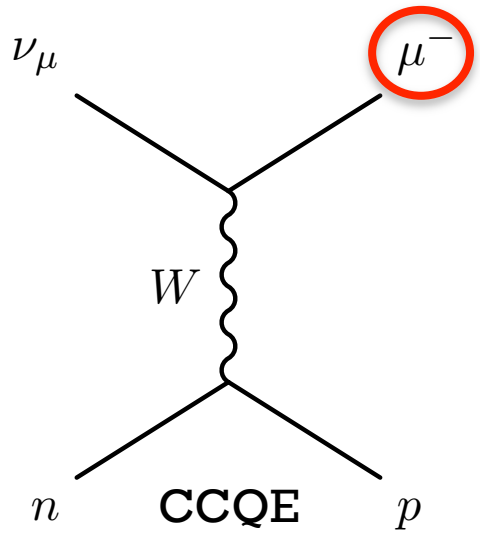



CC DIS

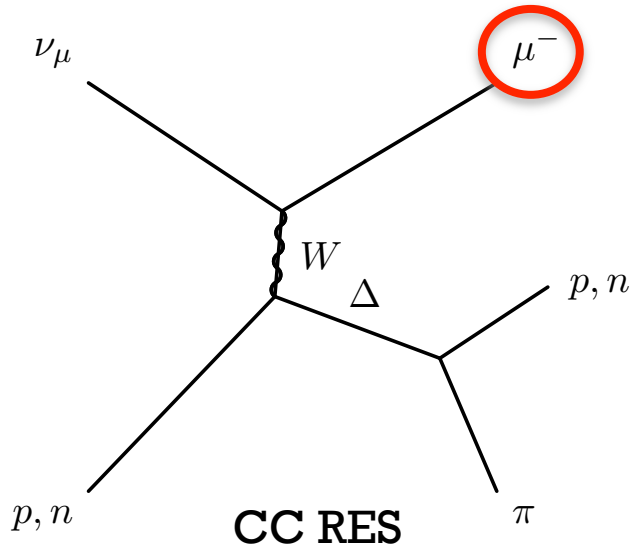



CC COH

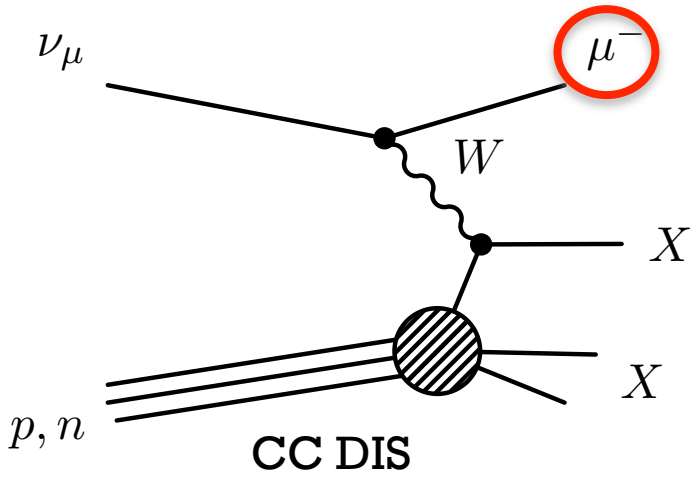
# Measuring CC-inclusive XSec



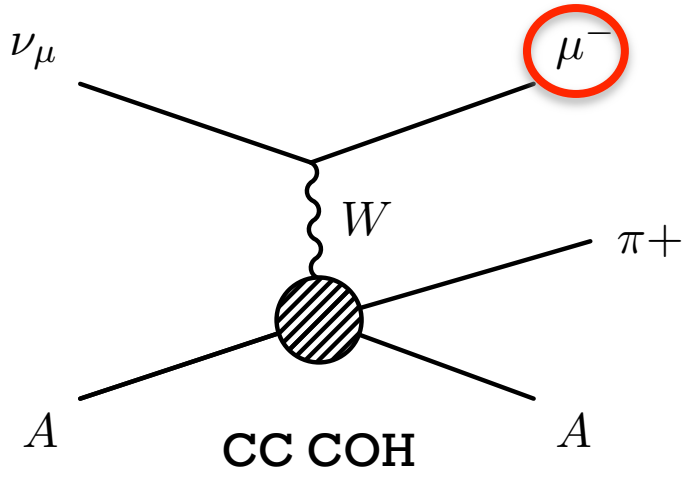

CCQE




CC RES



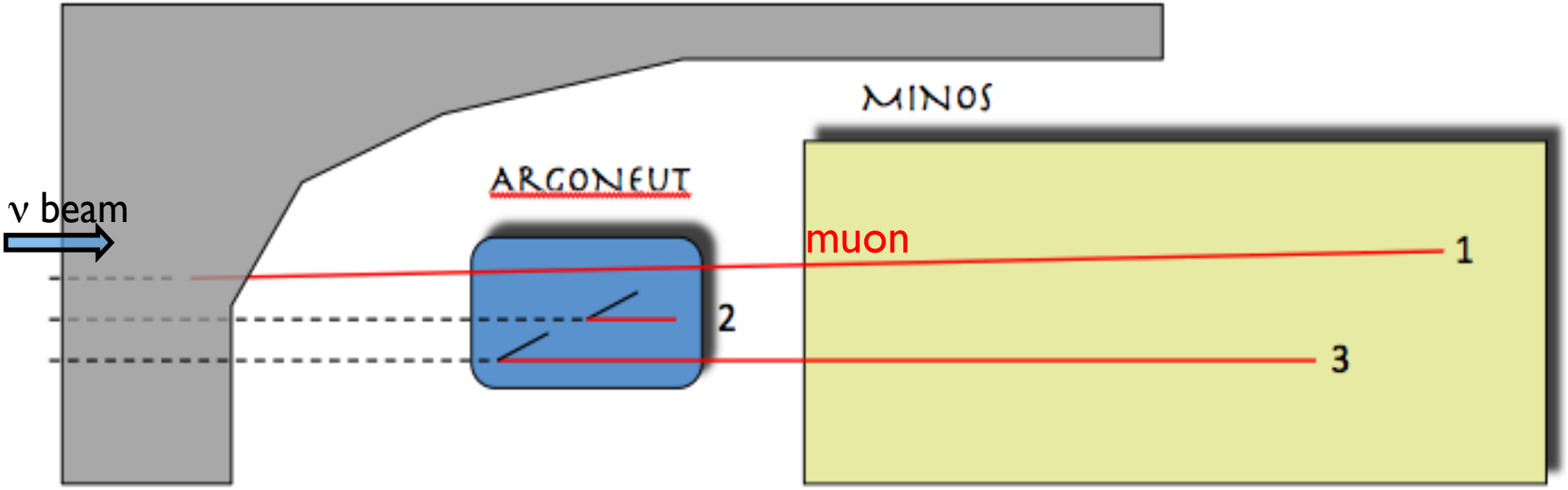

CC DIS




CC COH

# CC interactions

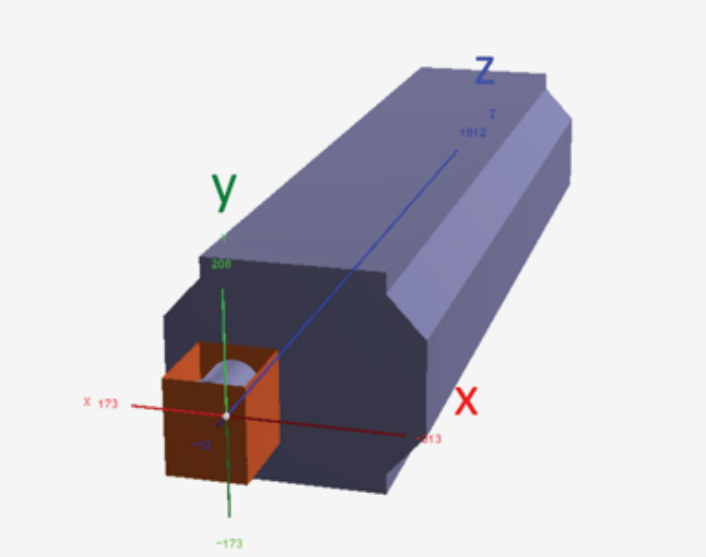
- The key is the $\mu^-$
- Most muons escape ArgoNeuT
- Need MINOS near detector

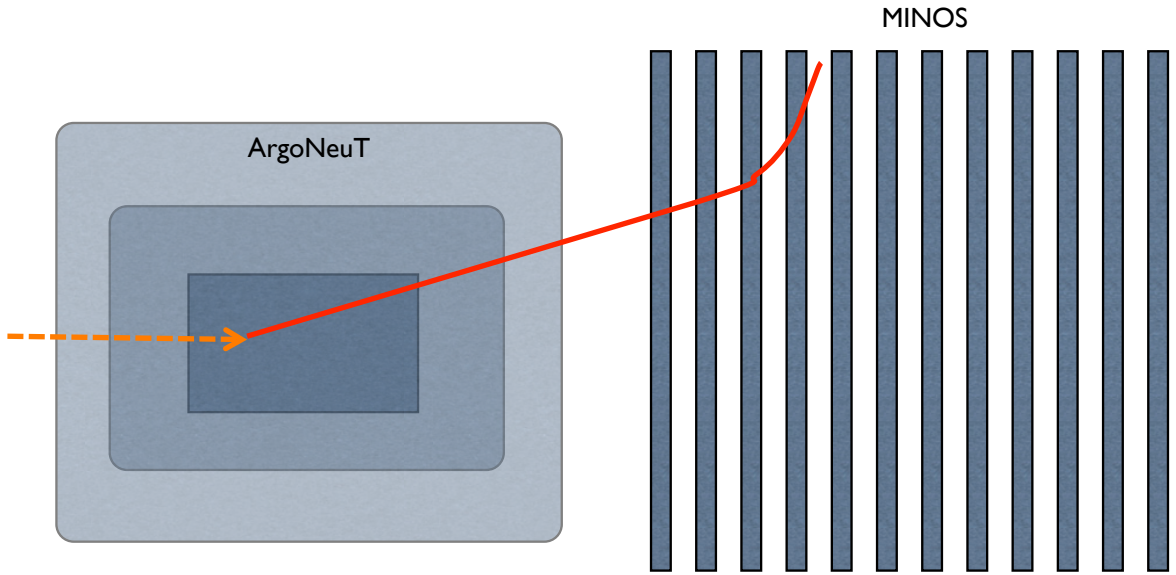



We gratefully acknowledge the cooperation of the MINOS collaboration in providing their data for use in this analysis

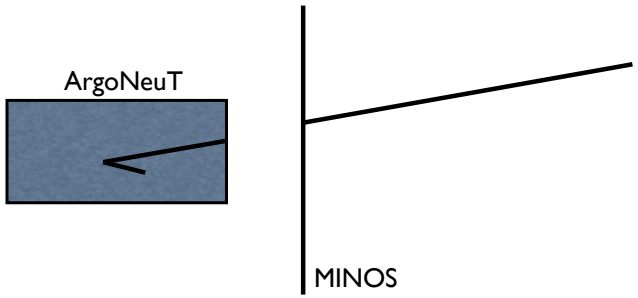
# On the trace of muons

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

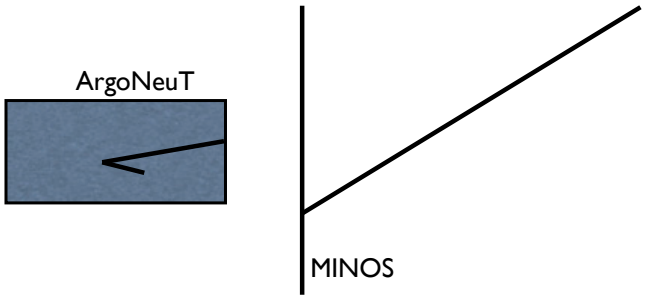


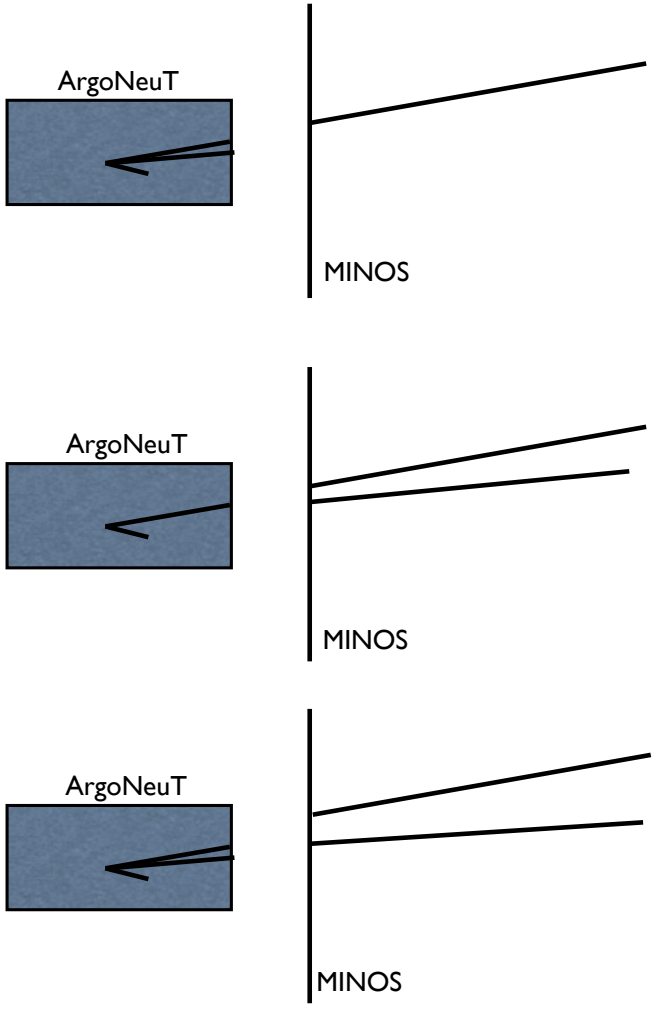
# On the trace of muons




Match




No Match




Multiple Matches

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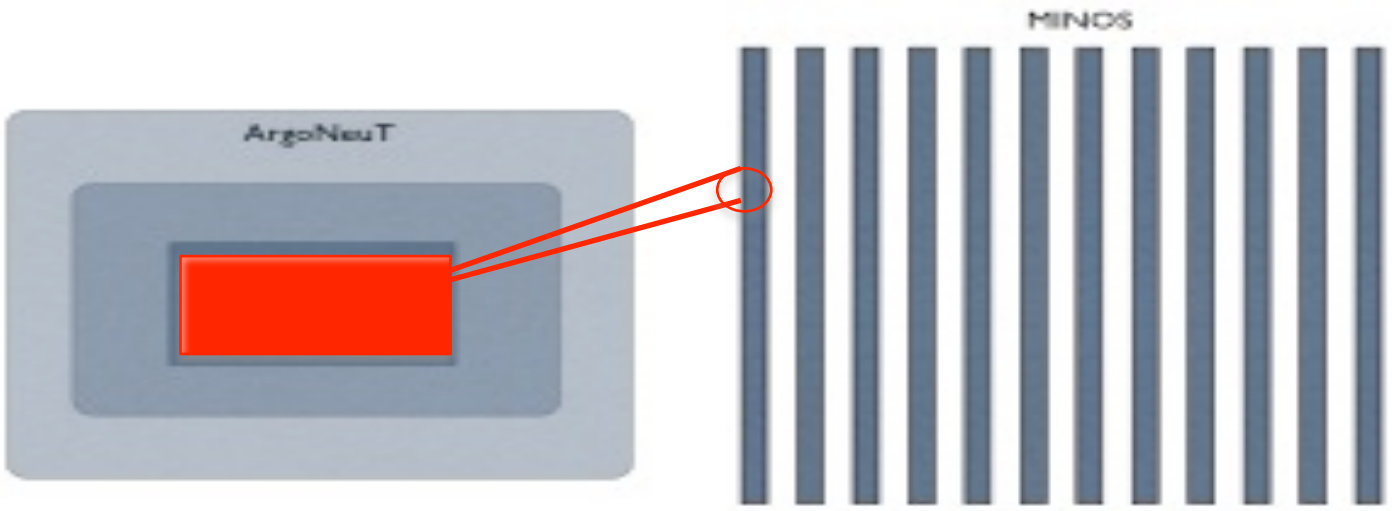
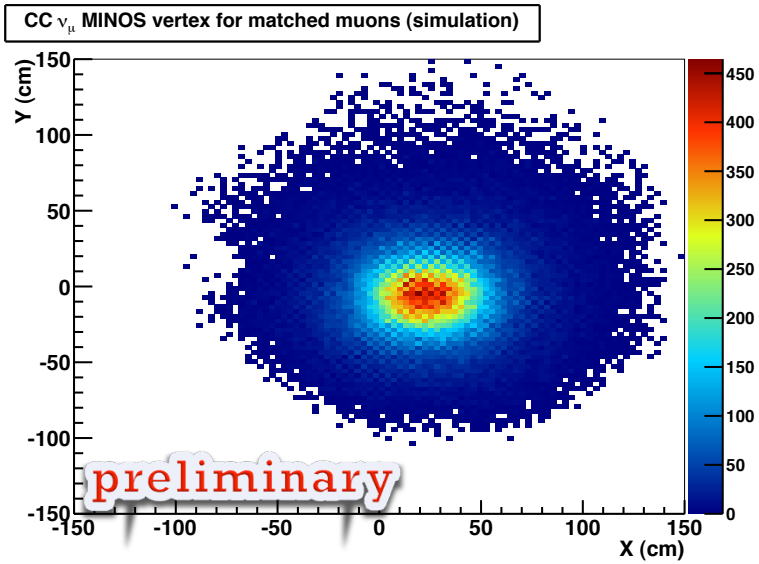
# Reconstructing CC events

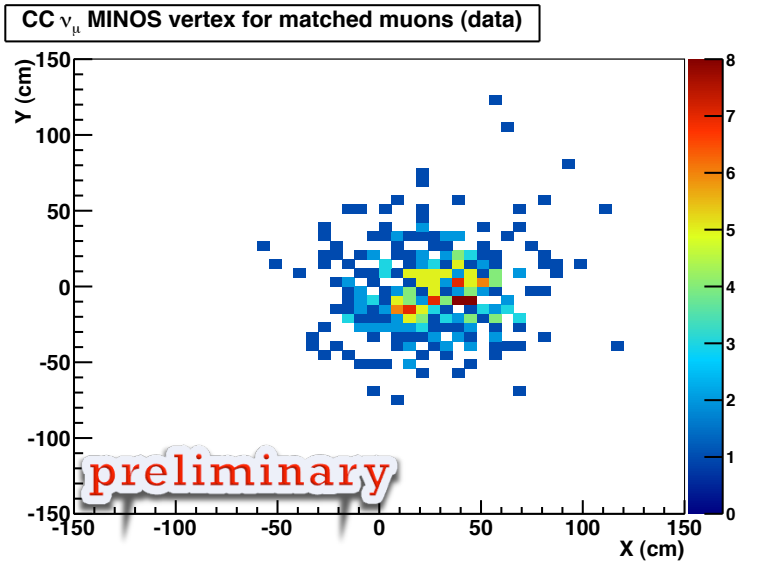
## Cuts are applied to select muons

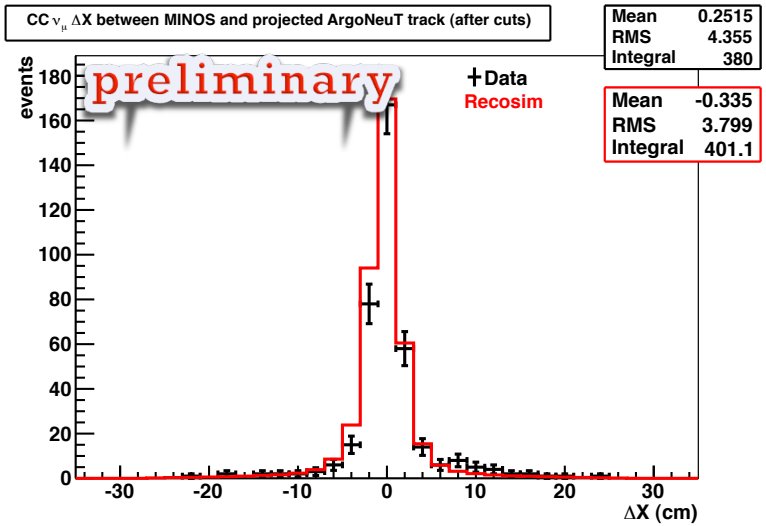
| | |
|---|---|
| Fiducial volume requirements | 3 cm $<$ X $<$ 44 cm (3 cm from boundaries)<br>-16 cm $<$ Y $<$ 16 cm (4 cm from boundaries)<br>6 cm $<$ Z $<$ 86 cm [6(4) cm from up(down)stream boundary] |
| Matching requirements | $\theta <$ 0.4 rad<br>$\Delta r <$ 27 cm |
| MINOS requirement | q $< 0$ |

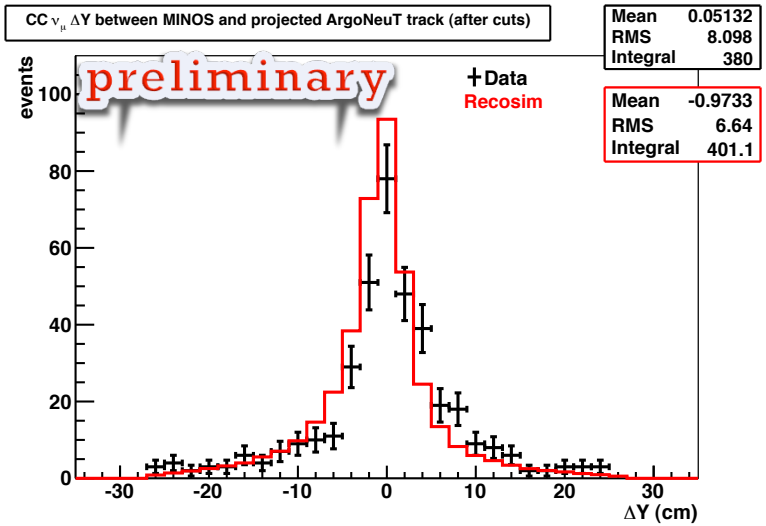


# Reconstructing CC events

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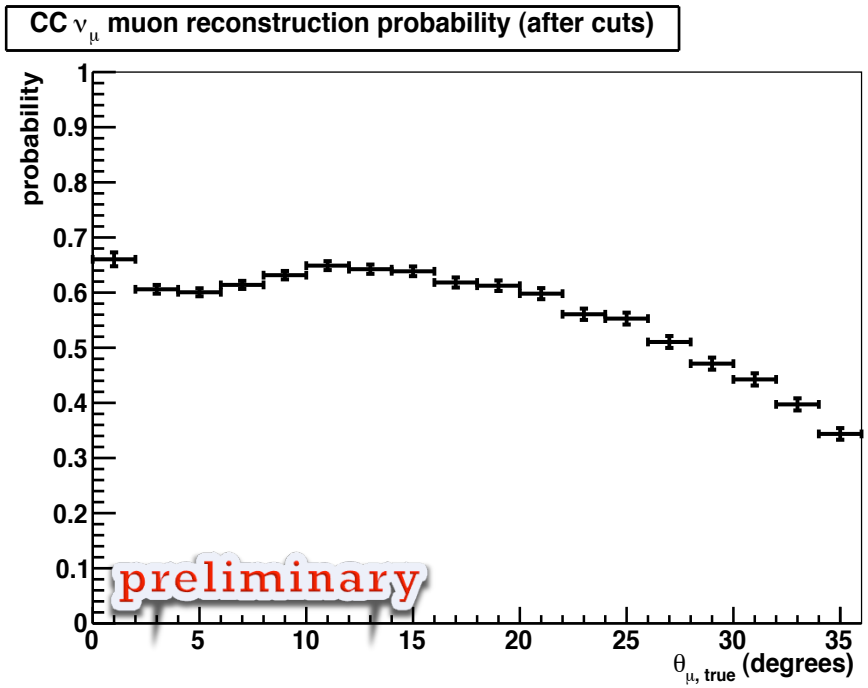
# Reconstructing CC events

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

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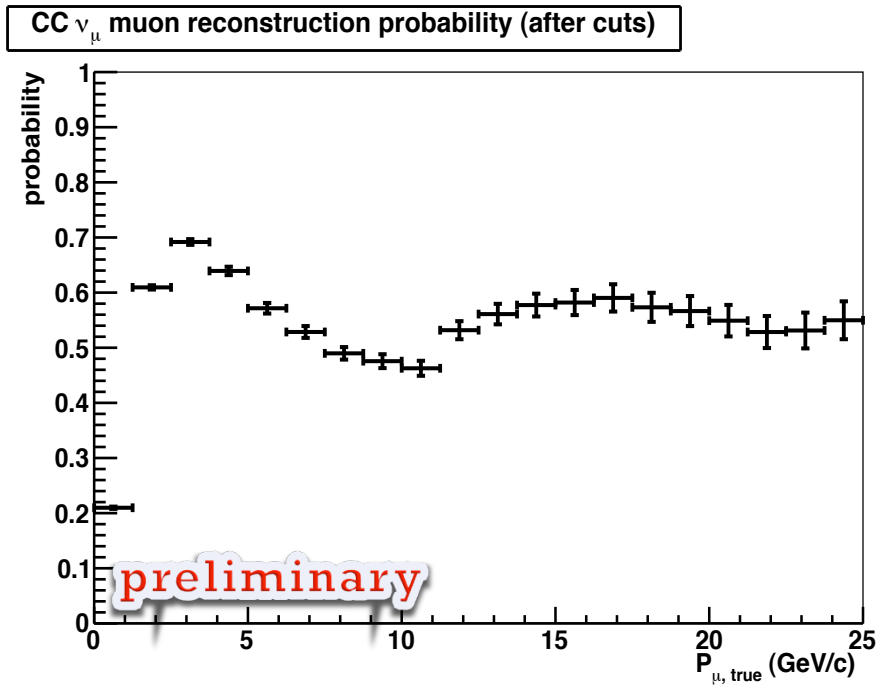


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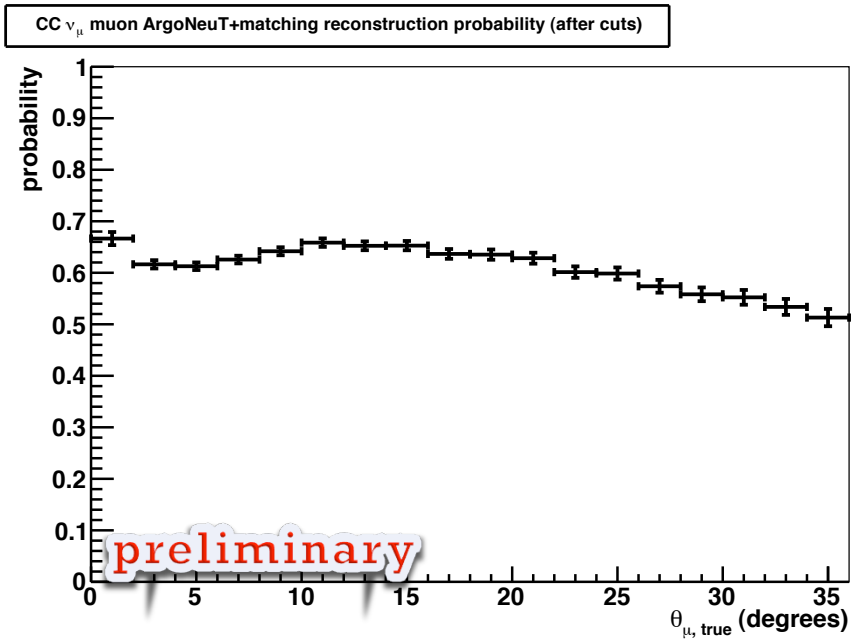
# Reconstructing CC events

$$\text{ArgoNeuT + matching reco. probability} = \frac{\#\text{ of completely reconstructed CC } \nu_\mu \text{ events in FV}}{\#\text{ of CC } \nu_\mu \text{ events in FV with a } (-)\text{charged particle reconstructed by MINOS}}$$

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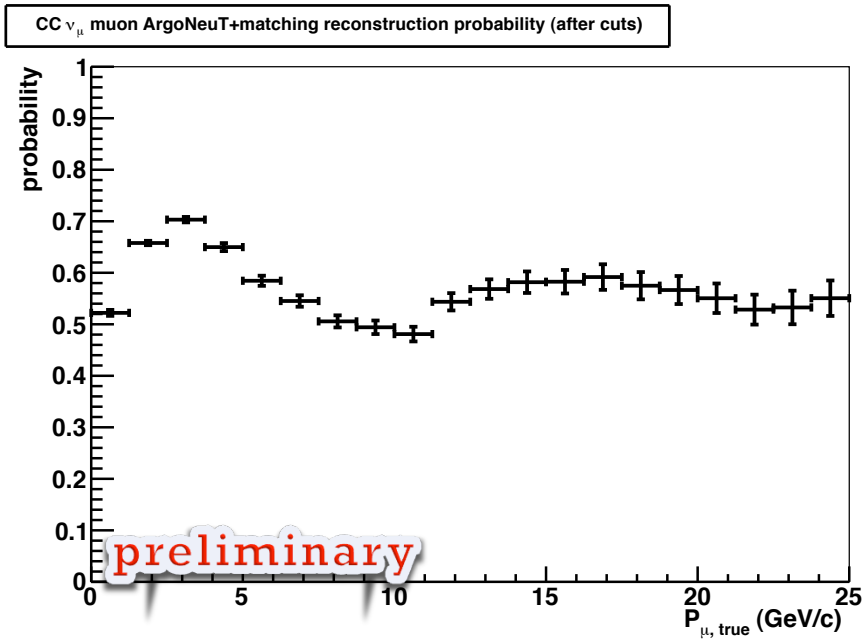


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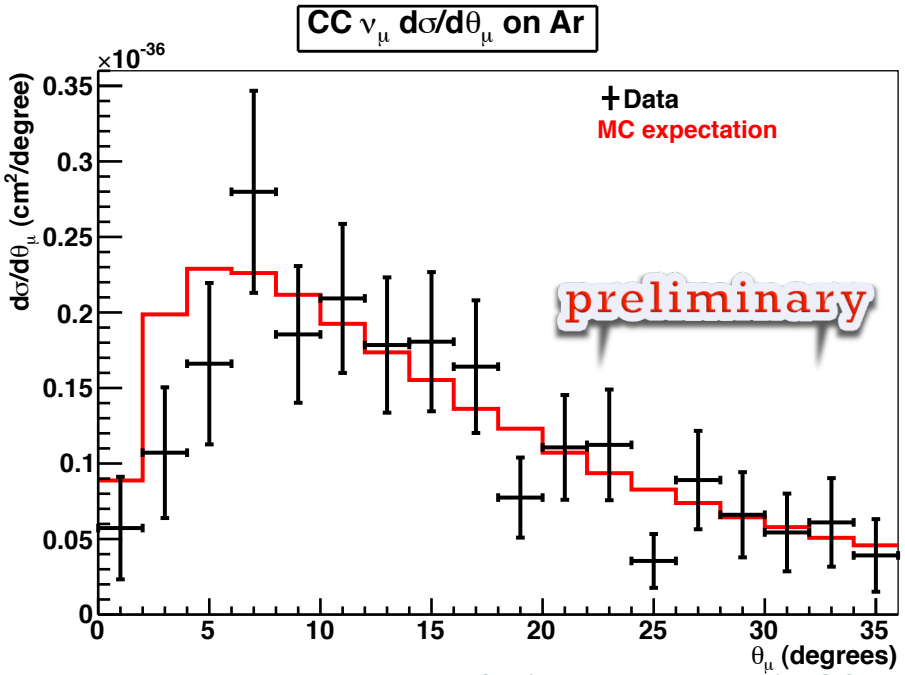
# Background contamination

- 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 pion that enters MINOS
- A through-going muon that enters ArgoNeuT and is reconstructed by MINOS

| | |
|---|---|
| Signal (CC $\nu_\mu$) reconstruction probability | 51.3% |
| Signal (CC $\nu_\mu$) purity | 95.5% |
| NC/WS background contamination | 2.1% |
| TG muon background contamination | 1.2% |
| NC match w/ TG muon background contamination | 1.1% |

# Measurement!

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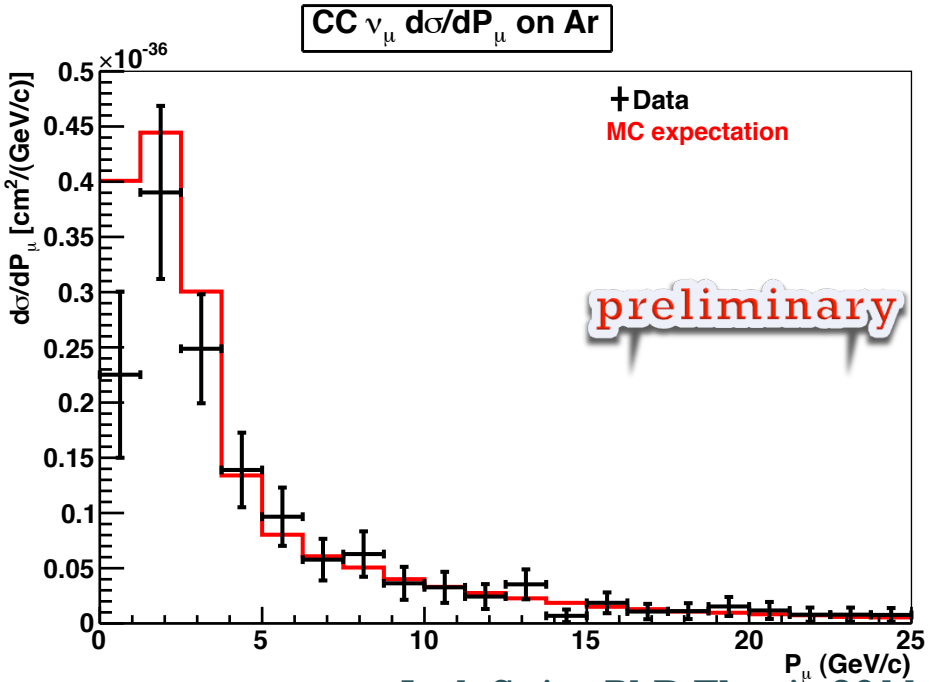


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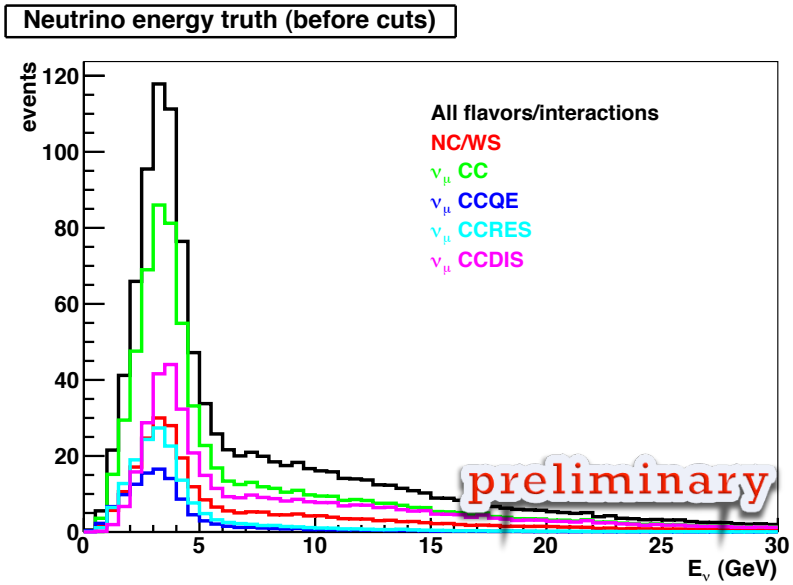
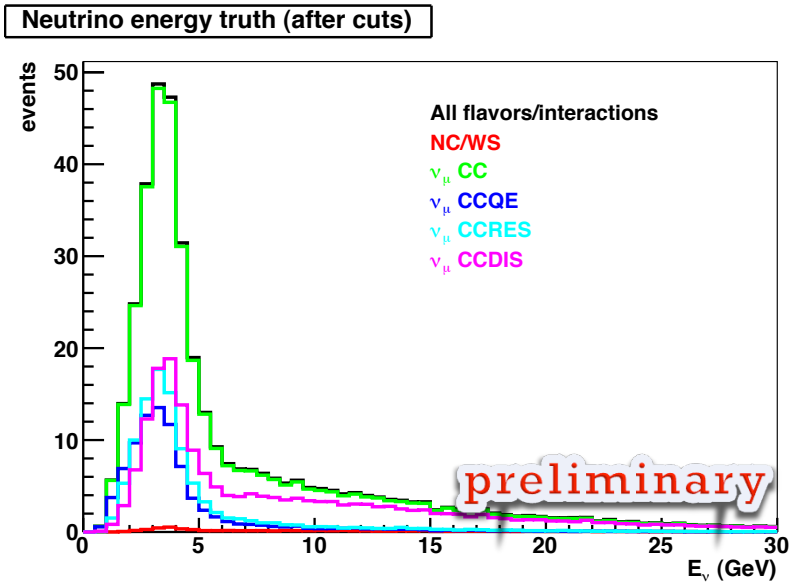
# Conclusions

- ArgoNeuT took 2 weeks of data in neutrino mode
- The neutrino data have been analyzed to make a CC-inclusive measurement
- Full reconstruction software operational
- First CC-inclusive differential cross section measurement
- The anti-neutrino mode data will be analyzed with higher (~15x) statistics for CC-inclusive double differential cross section
- Exclusive channels analysis will be performed soon

# Backup slides

# True energy distributions

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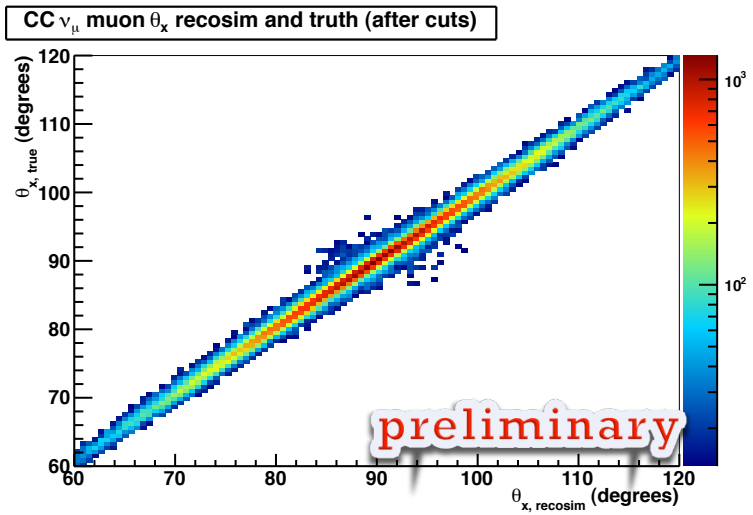
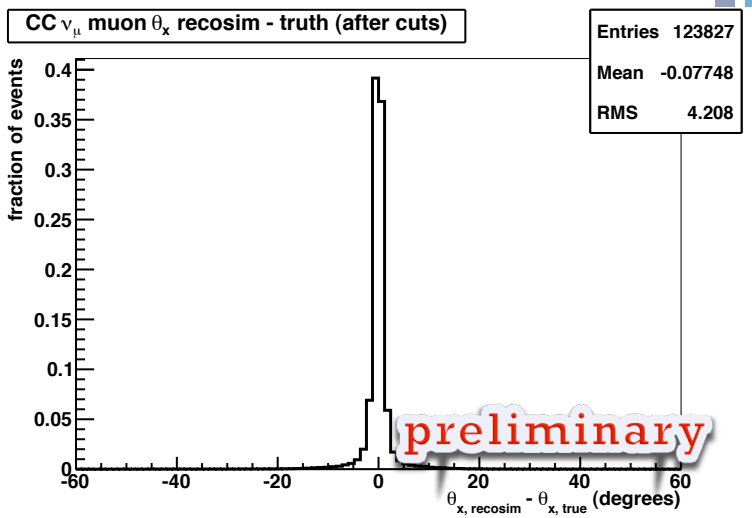
# Reconstruction probability (per channel)

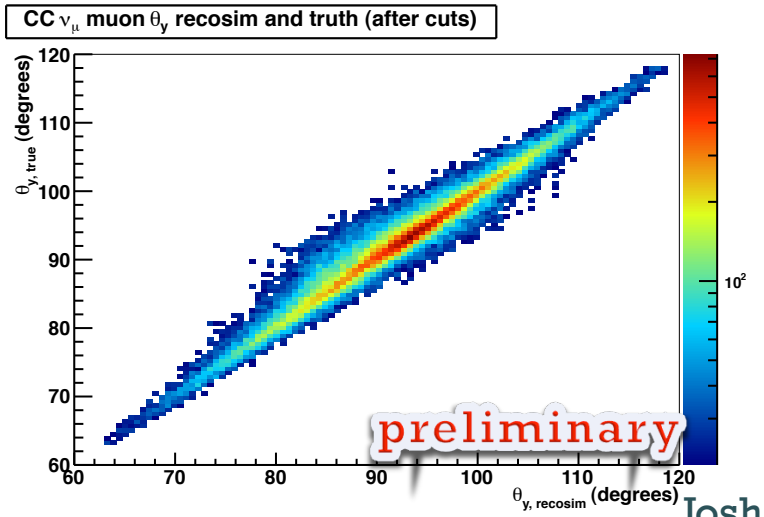
| | Total reconstruction probability |
|---|---|
| $\nu_\mu$ CC | 51.3% |
| $\nu_\mu$ CCQE | 76.4% |
| $\nu_\mu$ CCRES | 59.4% |
| $\nu_\mu$ CCDIS | 42.3% |

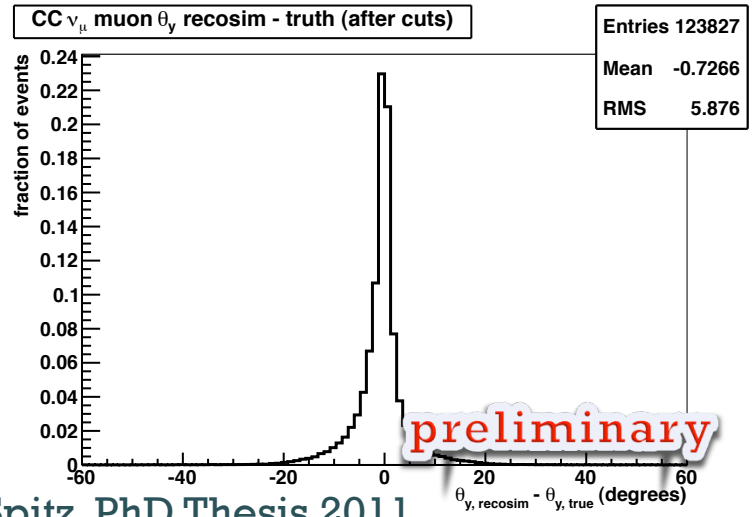
| | ArgoNeuT+matching reconstruction probability |
|---|---|
| $\nu_\mu$ CC | 61.5% |
| $\nu_\mu$ CCQE | 84.5% |
| $\nu_\mu$ CCRES | 69.2% |
| $\nu_\mu$ CCDIS | 52.4% |

# Reconstructed muon parameters

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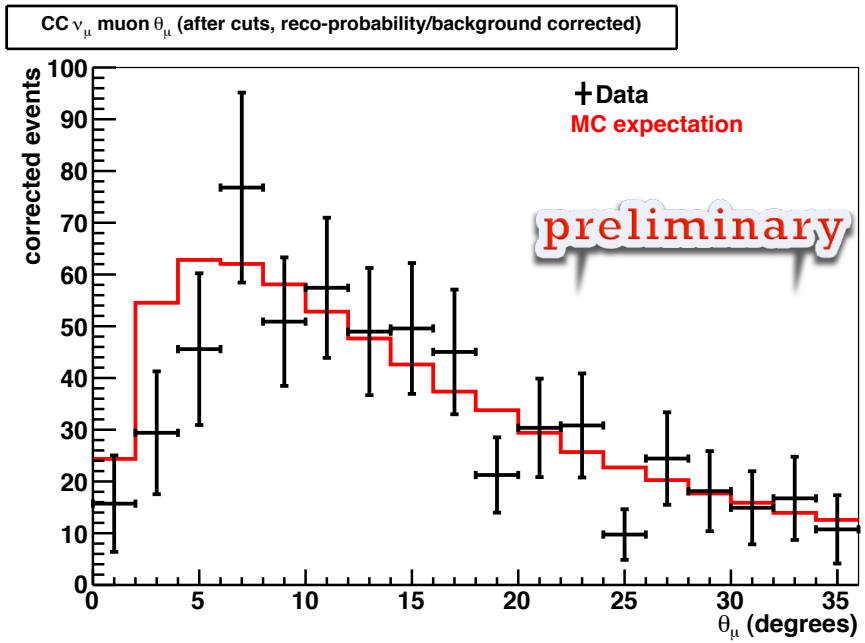
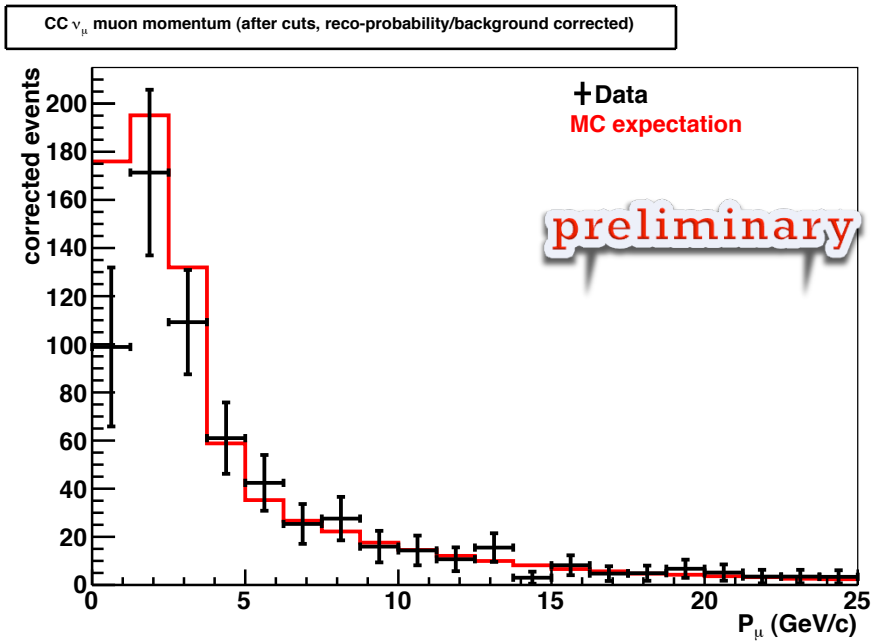
# Event rates (MC vs Data)

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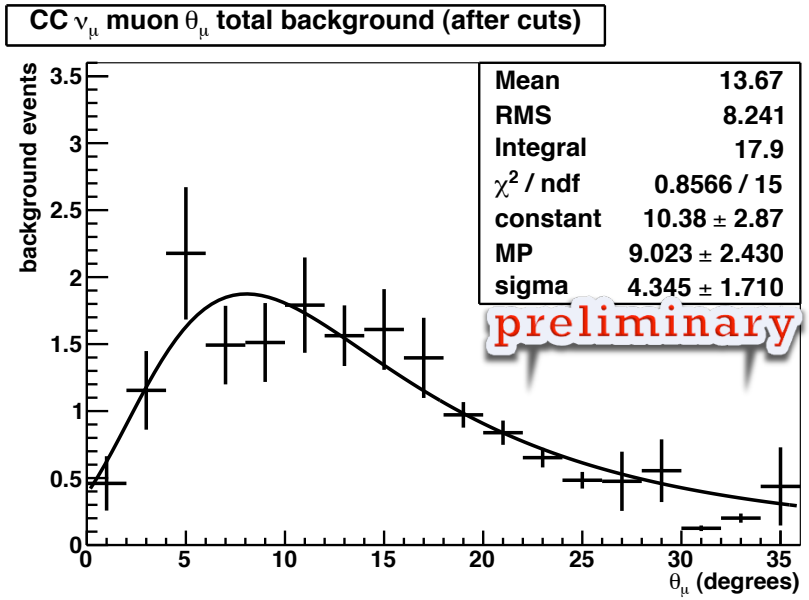
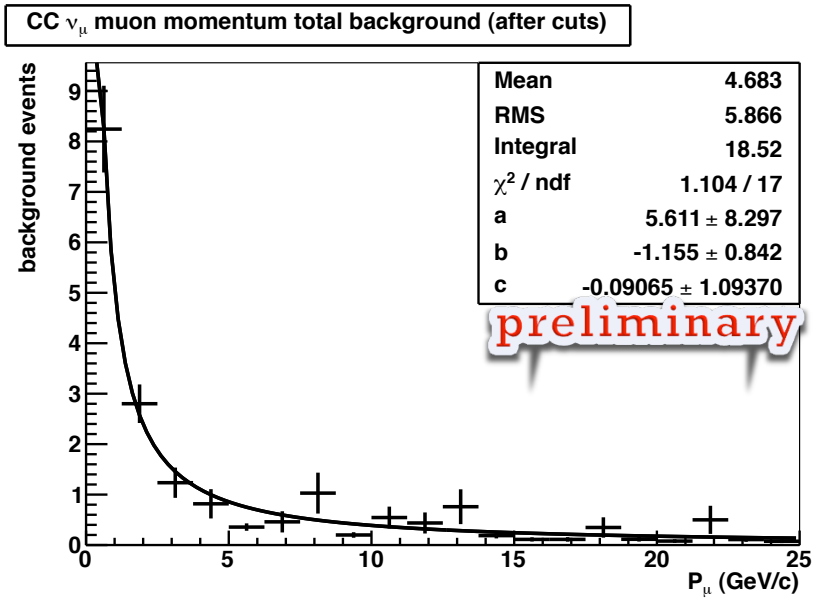
# Backgrounds

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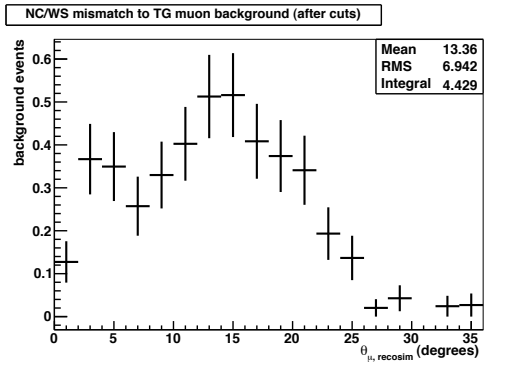
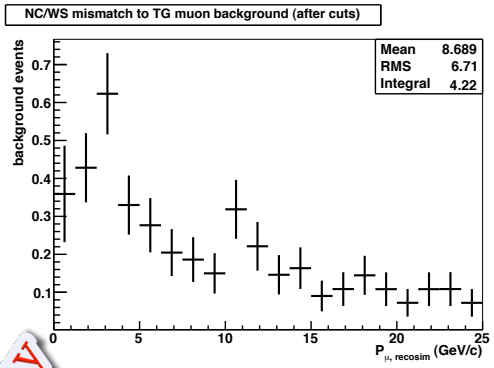
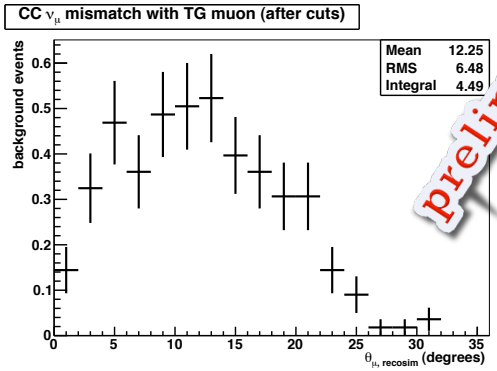
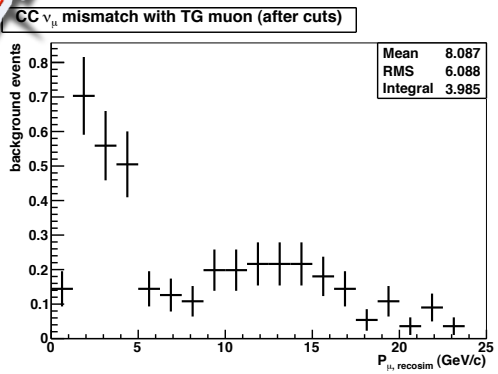
# Backgrounds

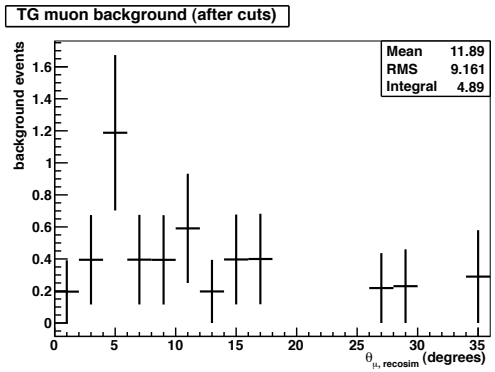


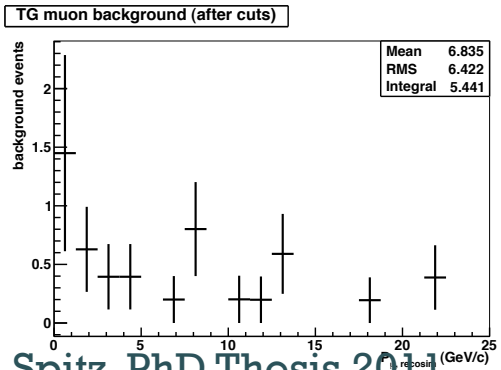




preliminary

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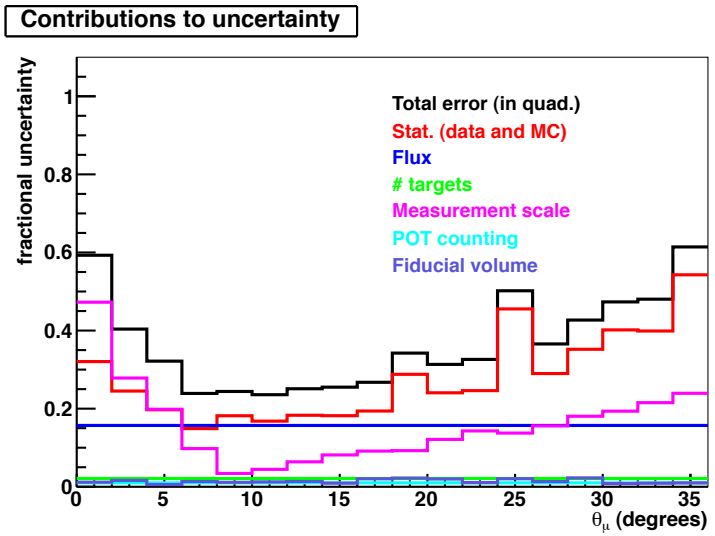
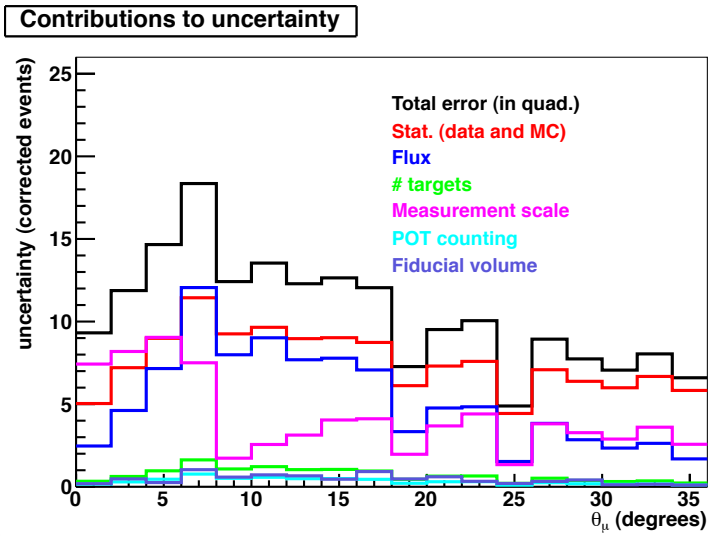
# Measurement errors

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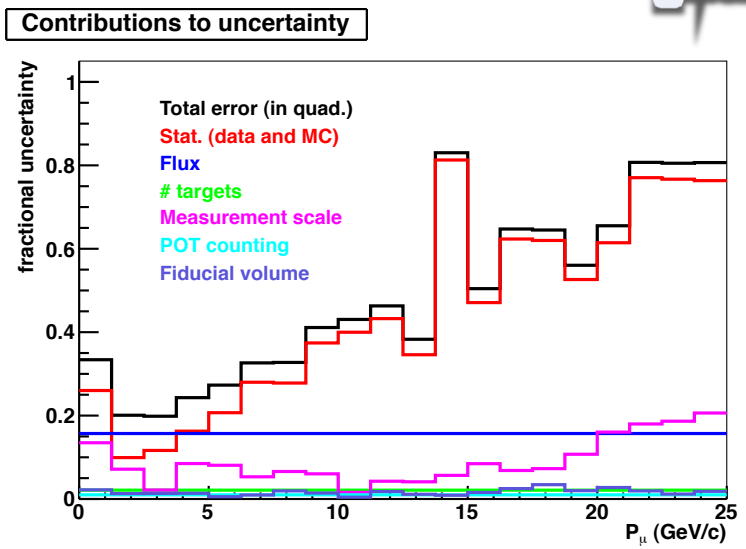


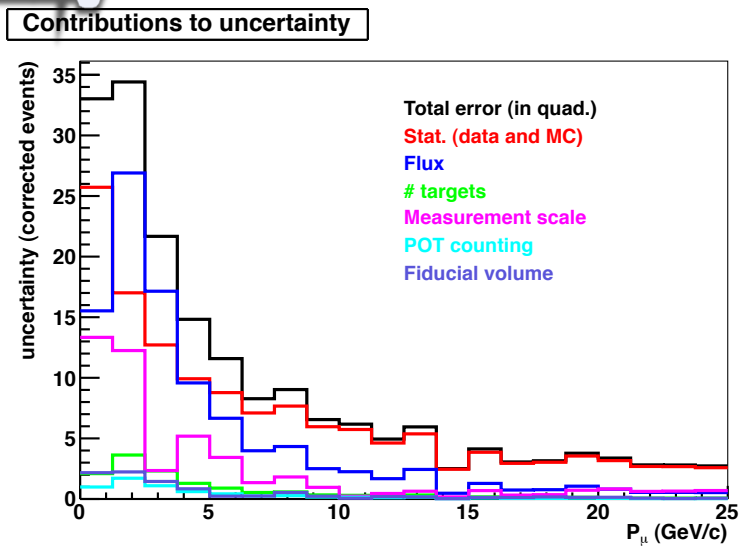


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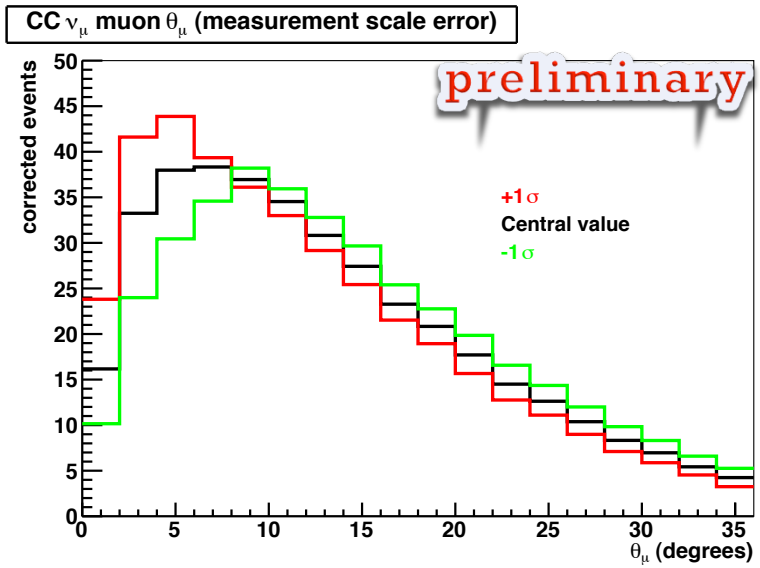
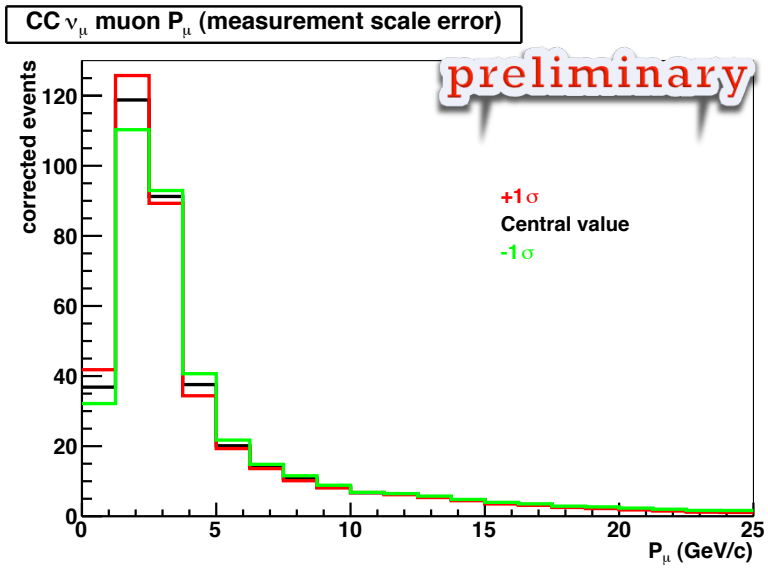
# Measurement errors
# Muon angle

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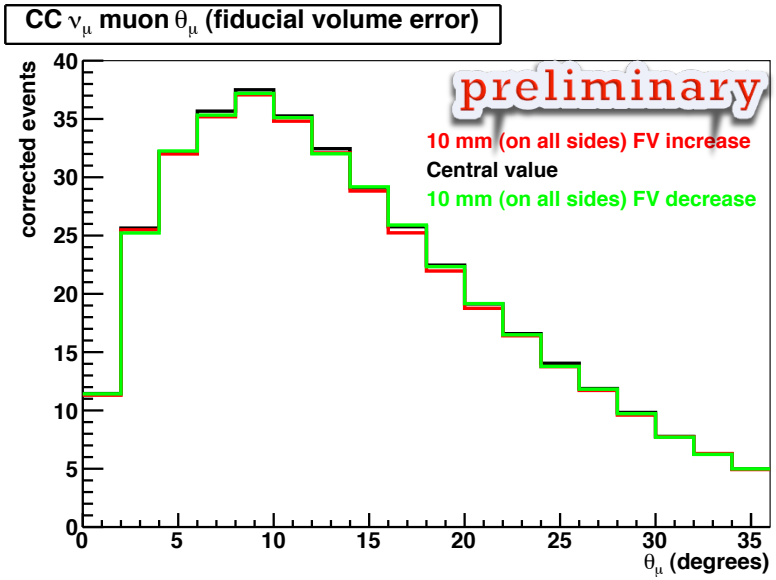
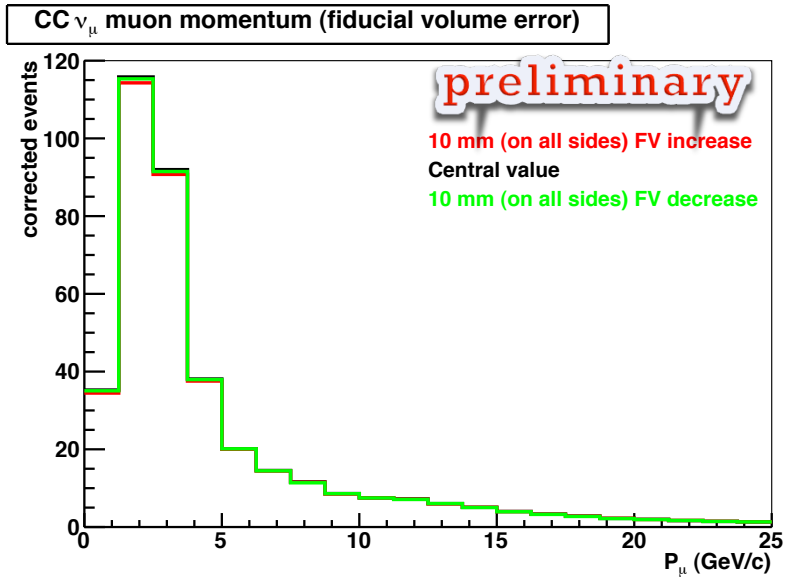
# Measurement errors
# Fiducial volume

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