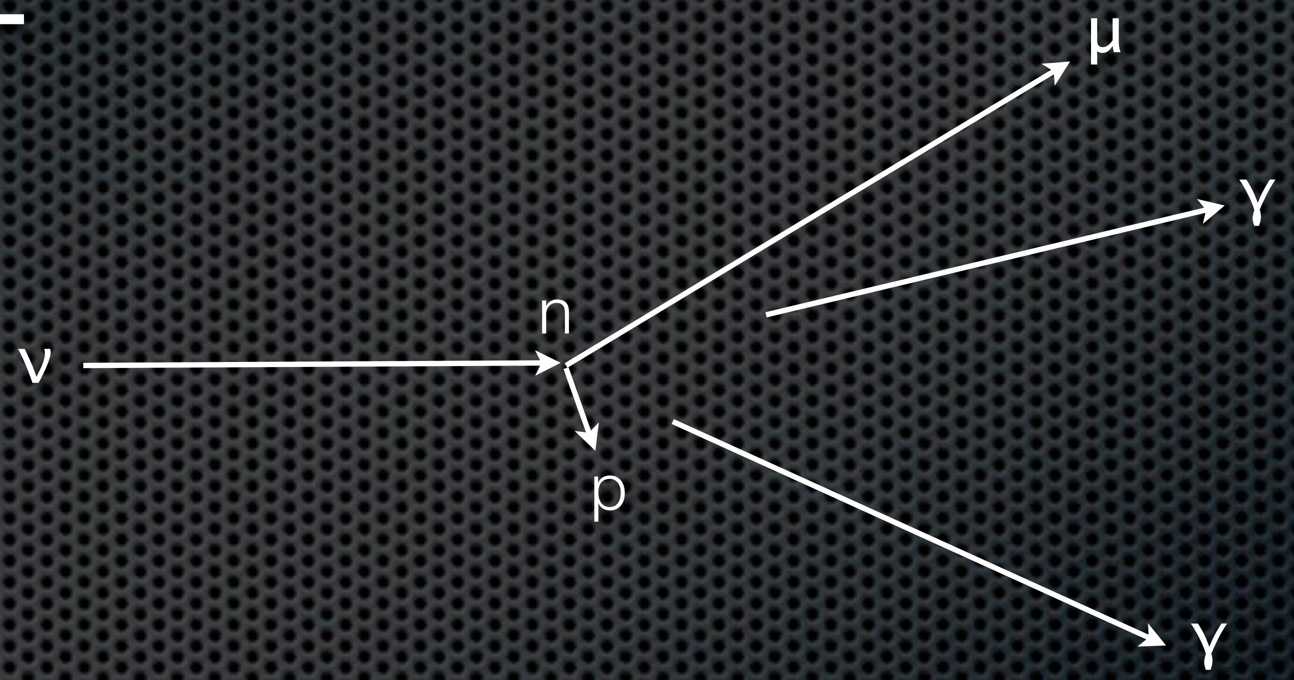
CCπ^0 Event Reconstruction at MiniBooNE



Robert Nelson

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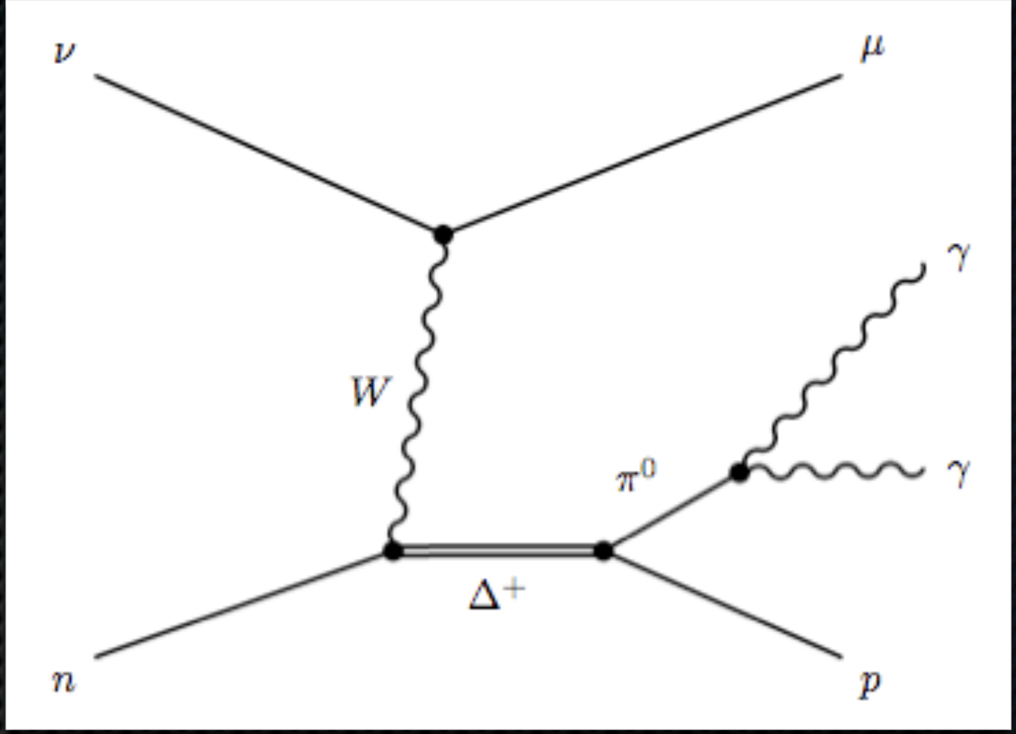
2009.5.21

NuInt09 - single pion session

Sitges, Barcelona

$CC\pi^0$ events



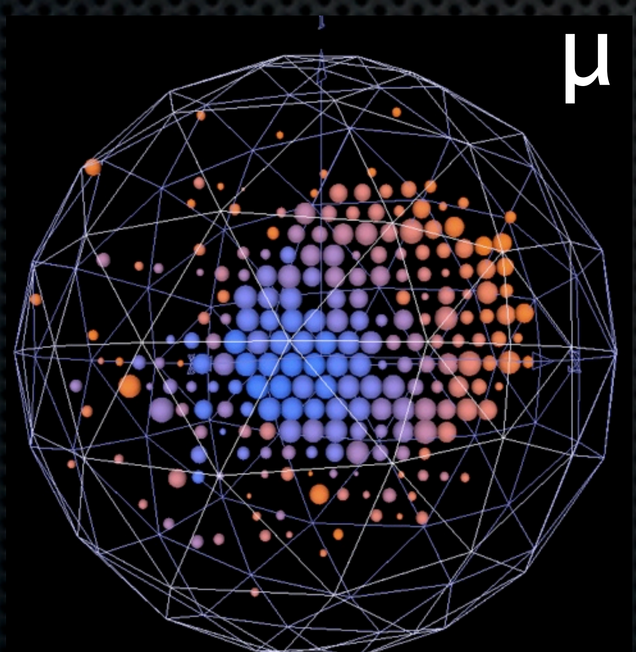
- $\nu + n \rightarrow \Delta + \mu$
  - ↳ $p + \pi^0$
    - ↳ $\gamma + \gamma$
- There is no coherent mode for these events only resonant.
- Observed $CC\pi^0$ events are any event where a π^0 exits the nucleus.
  - These include charge exchanged $CC\pi^+$ events.
  - This does not include π^0 produced in the tank.
- The observed $CC\pi^0$ measurement should be independent of nuclear modeling and FSI.

Difficulties

Data: $6.3 \cdot 10^{20}$ p.o.t.
MC: $41.1 \cdot 10^{20}$ p.o.t.

Sample	events	purity
total MC	267007	100%
CCQE	168723	63%
$CC\pi^0$	16504	6%
$CC\pi^+$	66268	25%
Data	341272	
Data/MC	1.28	

- This mode is buried beneath a mountain of CCQE.
- The three tracks tend to have overlapping rings.



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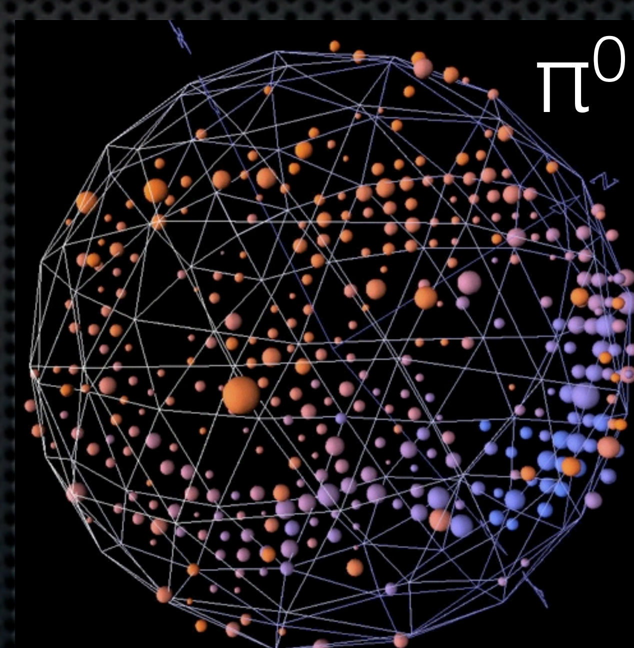


= $CC\pi^0$ three ring mess....

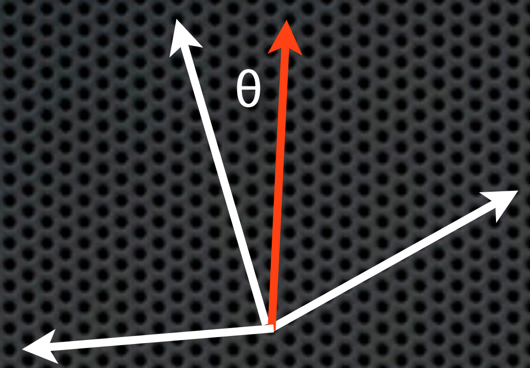
Track reconstruction

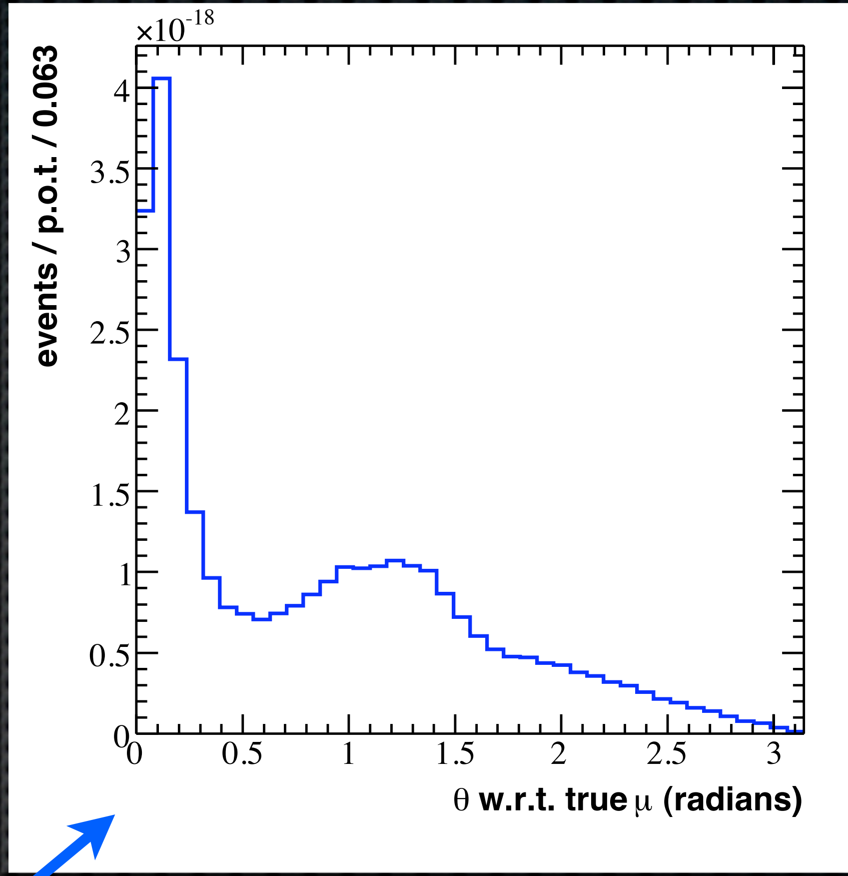
- A 7 parameter track hypothesis (x, y, z, t, θ, φ, E) generates predicted charge and hit time pdfs for all PMTs in the tank.
- Čerenkov and scintillation light are handled separately.
  - The charge predictions are added together.
  - The hit time pdfs are dominated by the Čerenkov hits.
- For multiple tracks their charge predictions are added together, and the time predictions are weighted by the track closest to a given PMT.

Three-track fitting

- We start with a muon one-track fit.

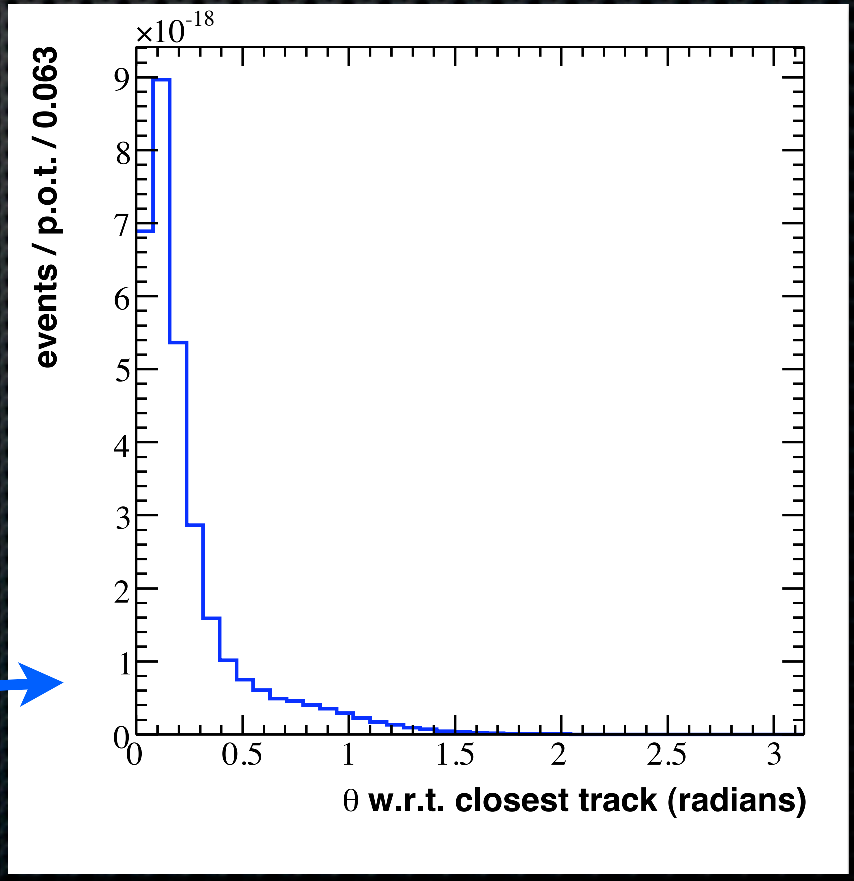
: true track
: reconstructed track shifted to the true vertex





- That fit only finds the true muon ~1/3rd of the time.

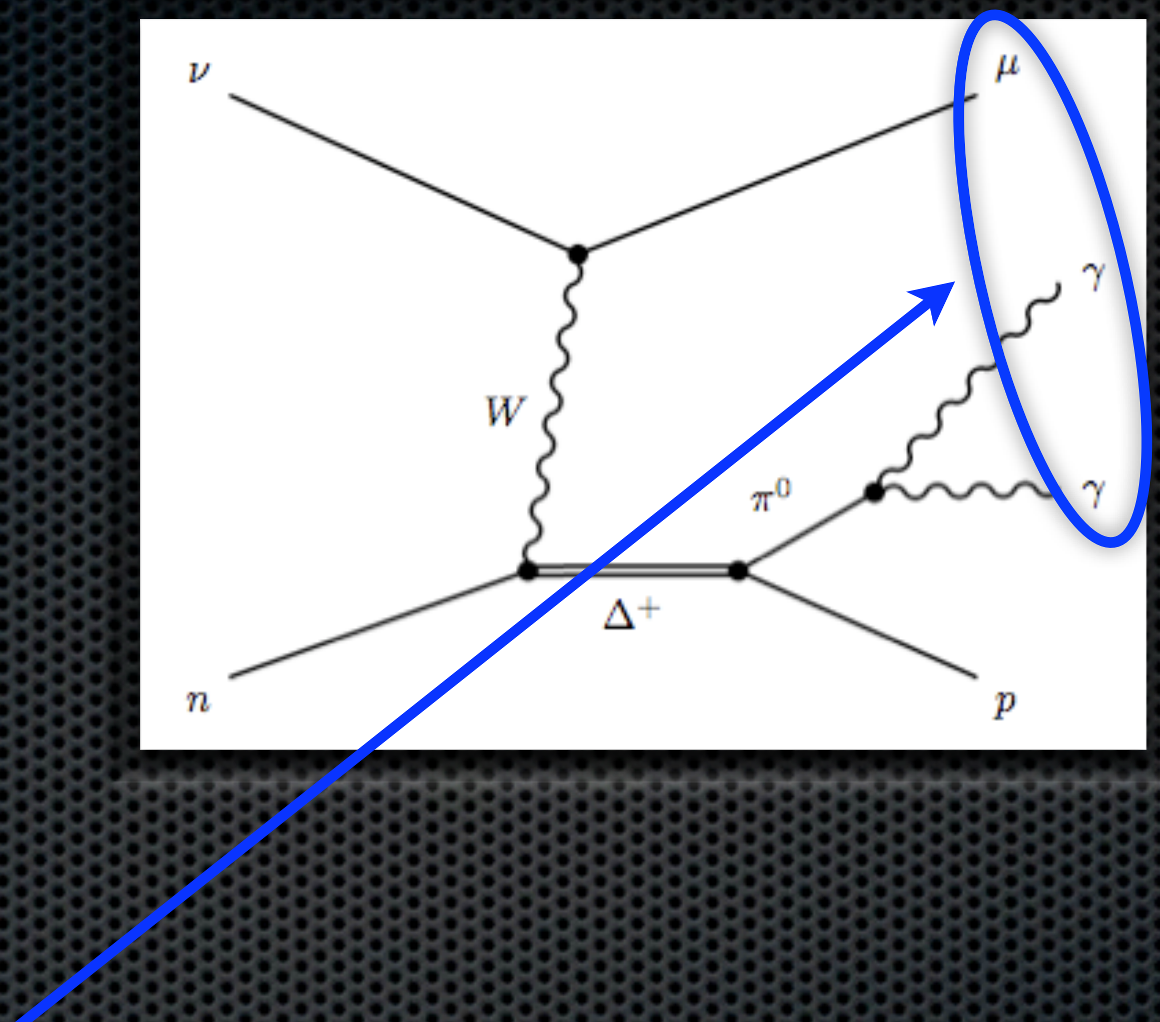
- However, it does a good job of finding one of the three rings.



Three-track fitting

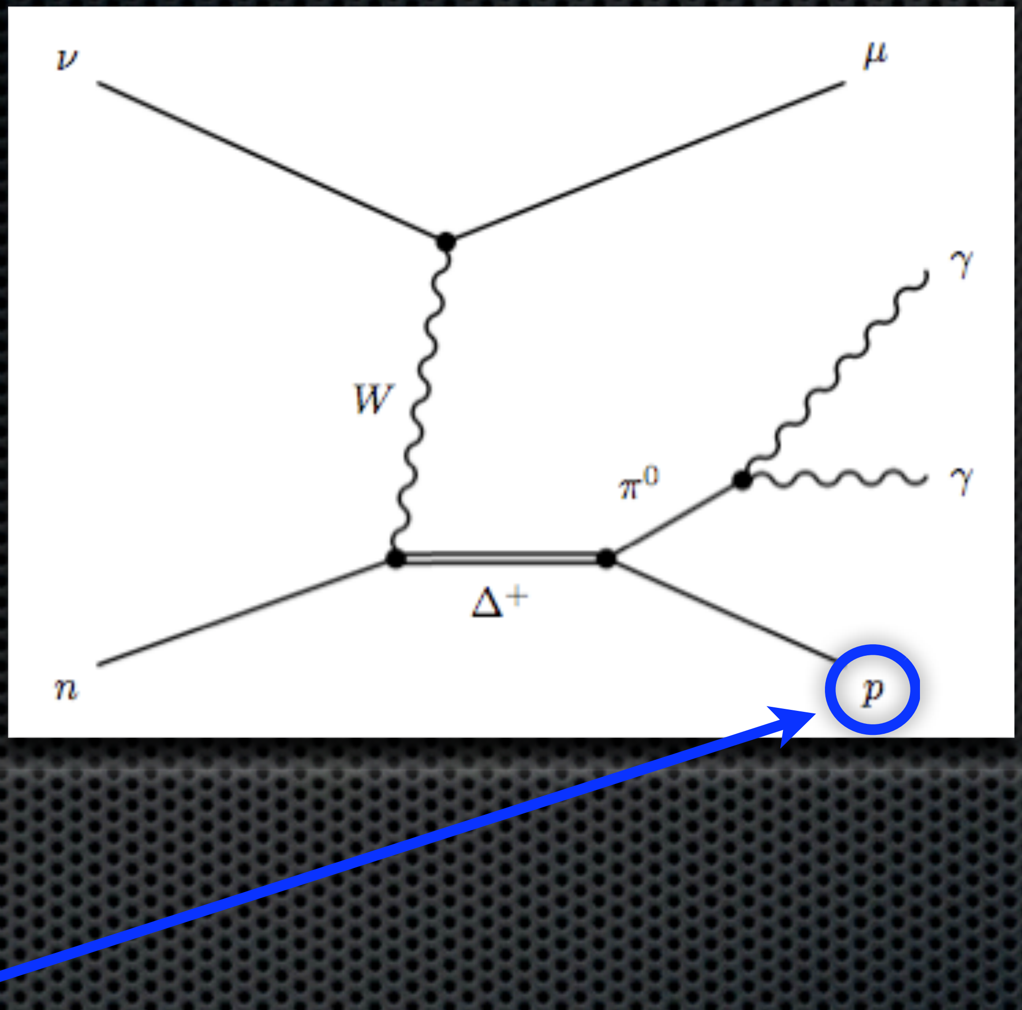
- The next two rings are found by scanning with tracks about the event vertex in solid angle and fitting those tracks at each stage.
- The tracks are then fit for the three possible particle ID hypotheses.
- Particle ID is done by combining both the fit likelihoods and the decay electron vertex direction vs. track direction.
    - PID has been tuned to find the muon.
- No π^0 constraint is enforced.

Fit kinematics



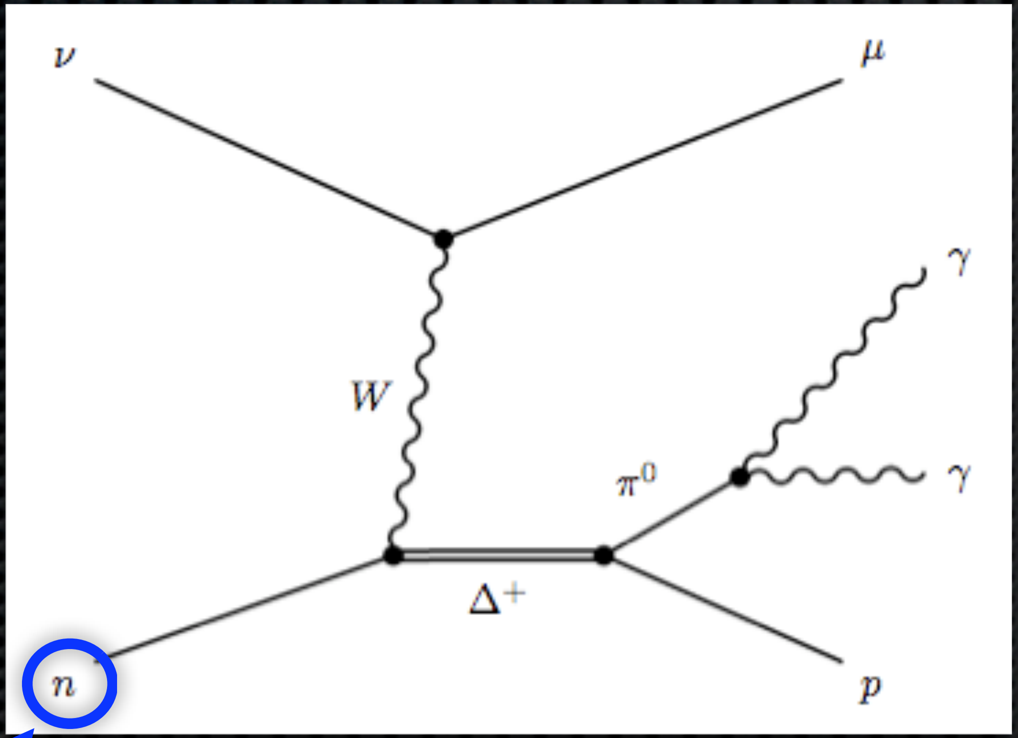
- The kinetic energy and direction of the muon and two photons are returned by the fit.

Assumptions



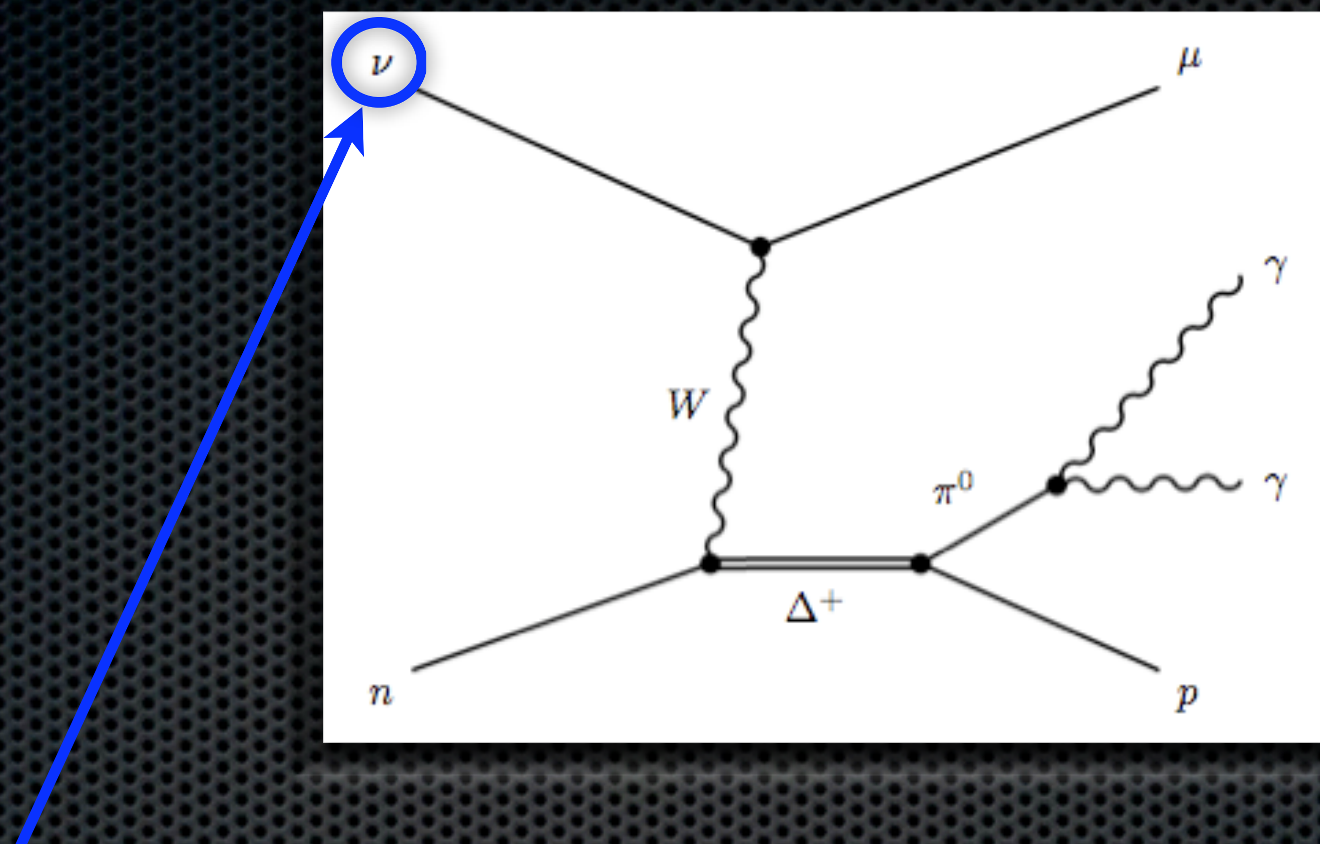
- The proton can be treated frame independently and therefore only appears as its mass.

Assumptions



- The neutron is assumed to be at rest (not a great assumption, but since we do not measure the proton it will have to do).

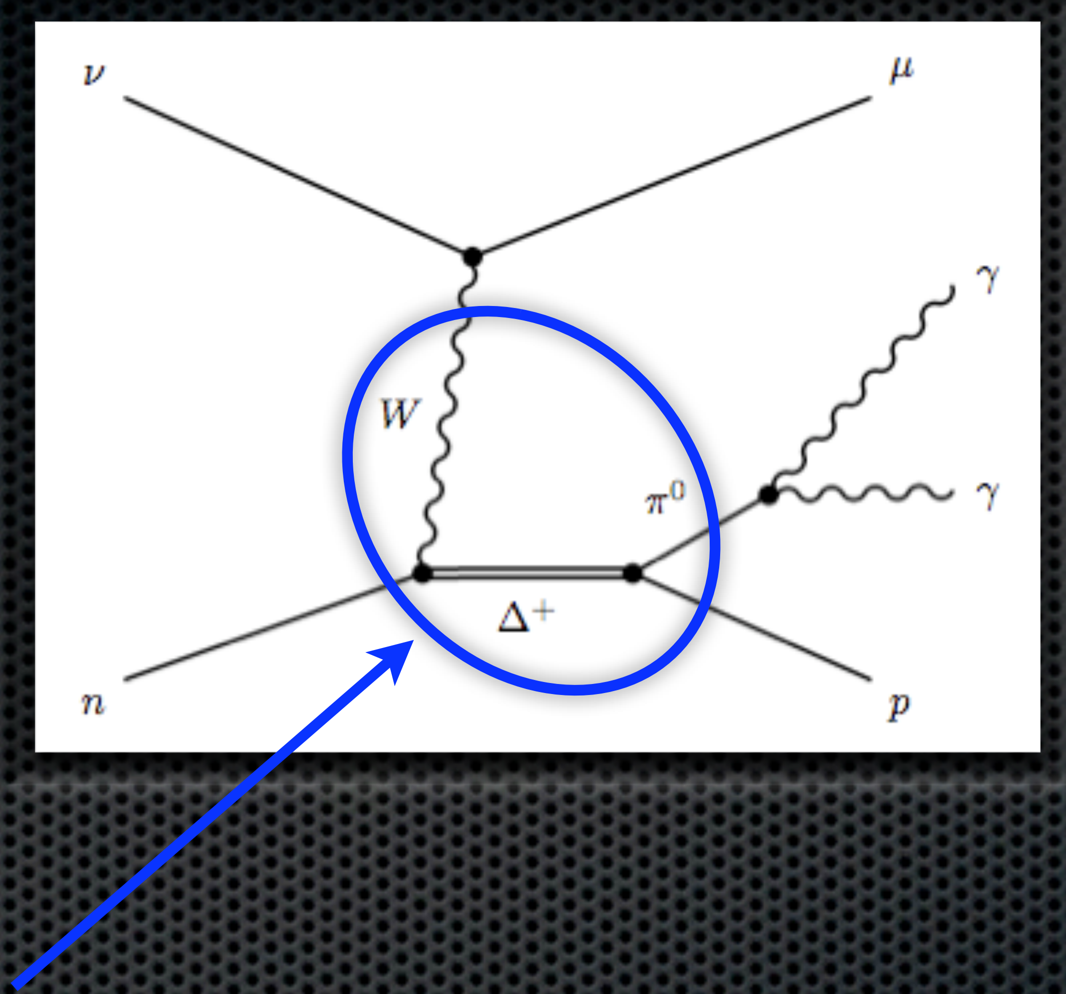
Calculations



- The neutrino is assumed to be traveling in the beam direction.
- The energy can be derived in the lab frame through 4-momentum conservation.

$$E_\nu^{CC\pi^0} = \frac{2m_n(E_\mu + E_1 + E_2) - 2E_1(E_\mu - |\vec{p}_\mu|\cos\theta_{\mu 1}) - 2E_2(E_\mu - |\vec{p}_\mu|\cos\theta_{\mu 2}) - 2E_1E_2(1-\cos\theta_{12}) + \Delta m_{pn}^2 - m_\mu^2}{2(m_n - E_\mu - E_1 - E_2 + |\vec{p}_\mu|\cos\theta_{\nu\mu} + E_1\cos\theta_{\nu 1} + E_2\cos\theta_{\nu 2})}$$

Intermediate states



- The π^0, the Δ, and the W can be reconstructed since all initial and final states are specified.

Selection Cuts

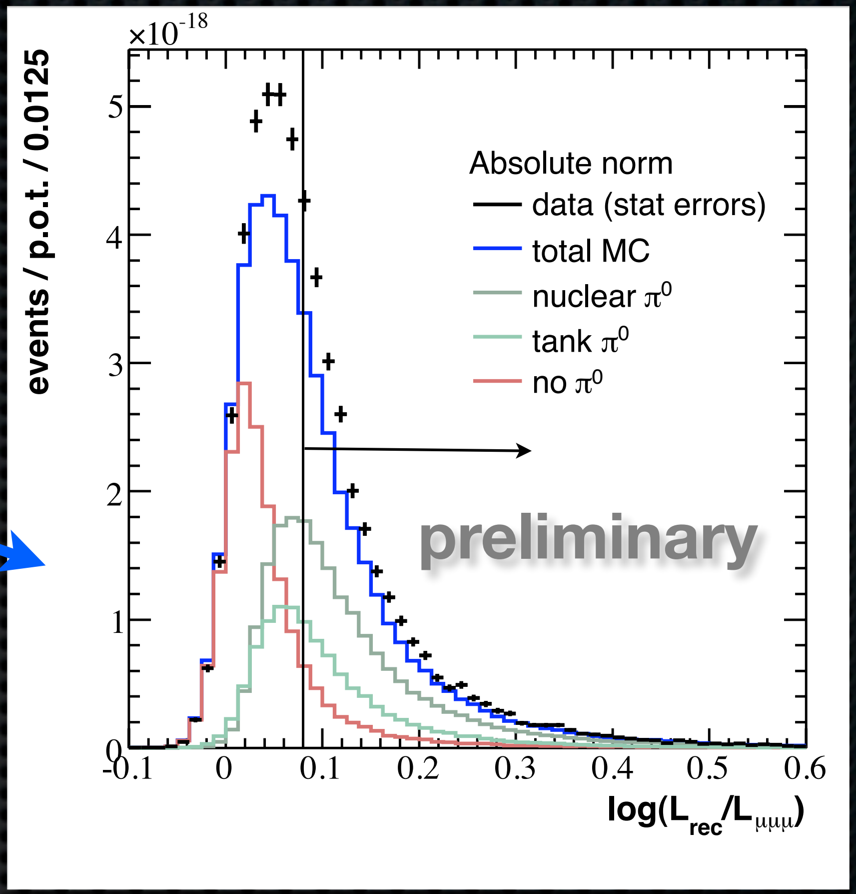
- 2 sub-event cut.
- Tank and veto hits cuts.
- One-track likelihood ratio (e/μ) vs energy cut to isolate this sample and remove CCQE.
- R < 500 cm

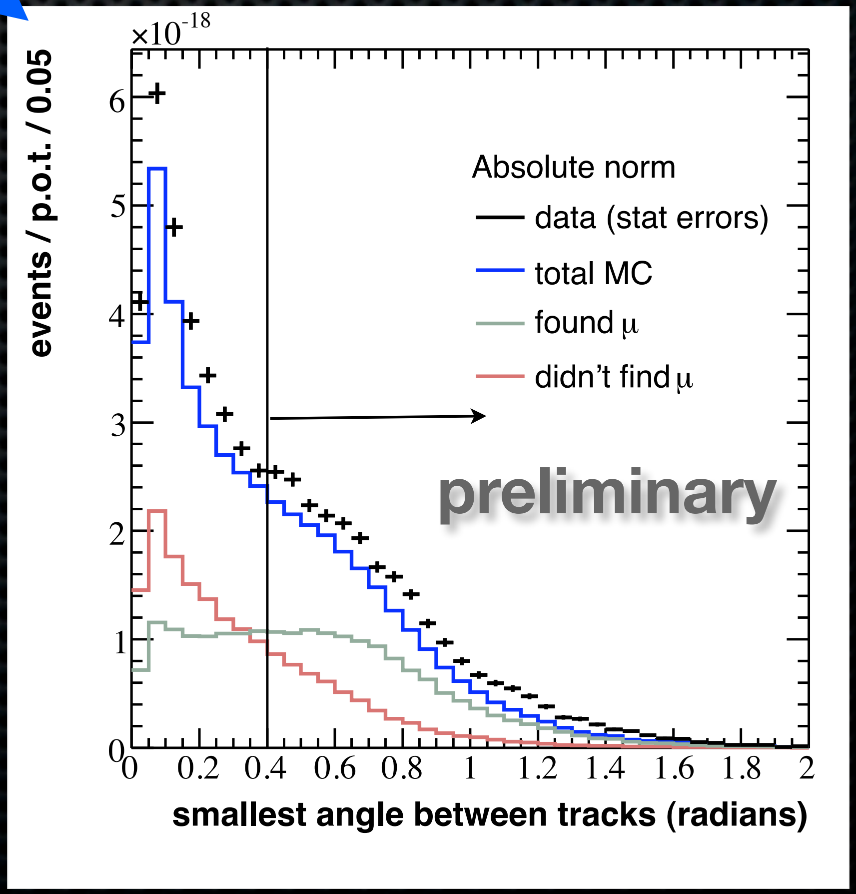
Sample	events	purity
total MC	30017	100%
CCQE	4686	16%
$CC\pi^0$	7033	23%
$CC\pi^+$	12933	43%
Observed $CC\pi^0$	12482	**42%**
Tank π^0	6867	23%
Data	35068	
Data/MC	1.17	

Analysis Cuts

- Three-track likelihood ratio cut.
- Misreconstruction cut.
- Data has statistical errors only.
- Absolute normalization.

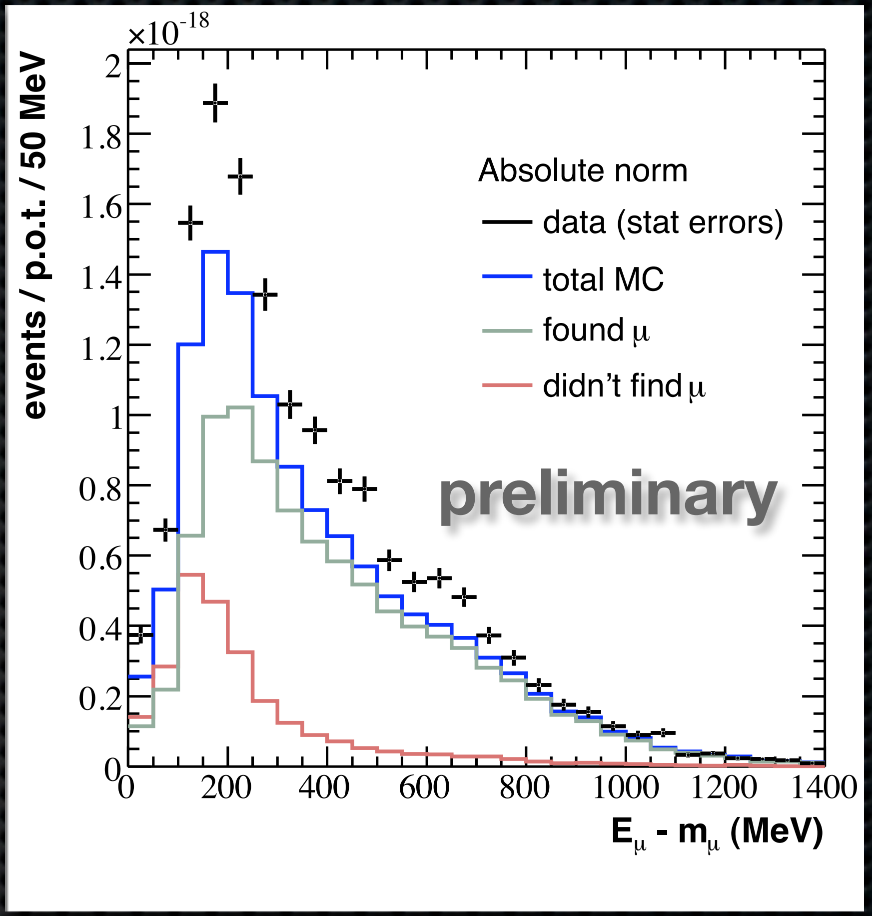
Sample	events	purity
total MC	7414	100%
CCQE	786	11%
CCπ^0	2533	34%
CCπ^+	2662	36%
Observed CCπ^0	4585	**62%**
Tank π^0	2162	29%
Data	9375	
Data/MC	1.26	

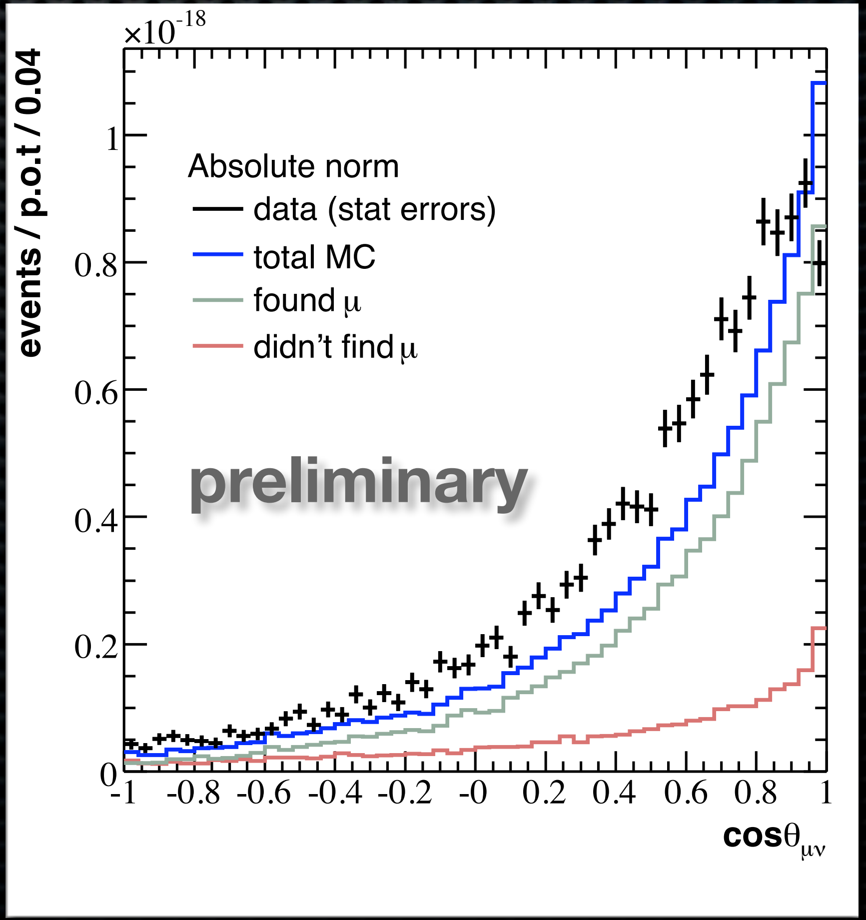




Muon kinematics

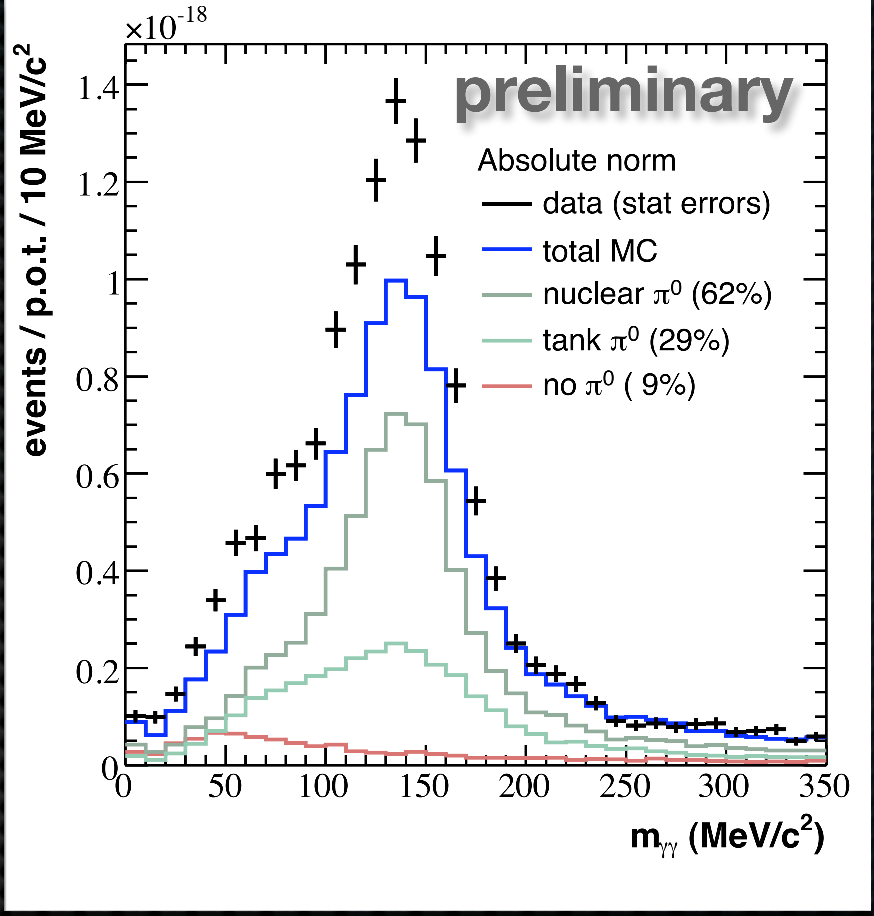
- The fitter correctly identifies the muon 78% of the time.
- The kinetic energy shows the effect of discrete misreconstruction.
- The muon kinetic energy resolution is 16%.
- The angular distribution shows a turn over in data that is seen in other modes.

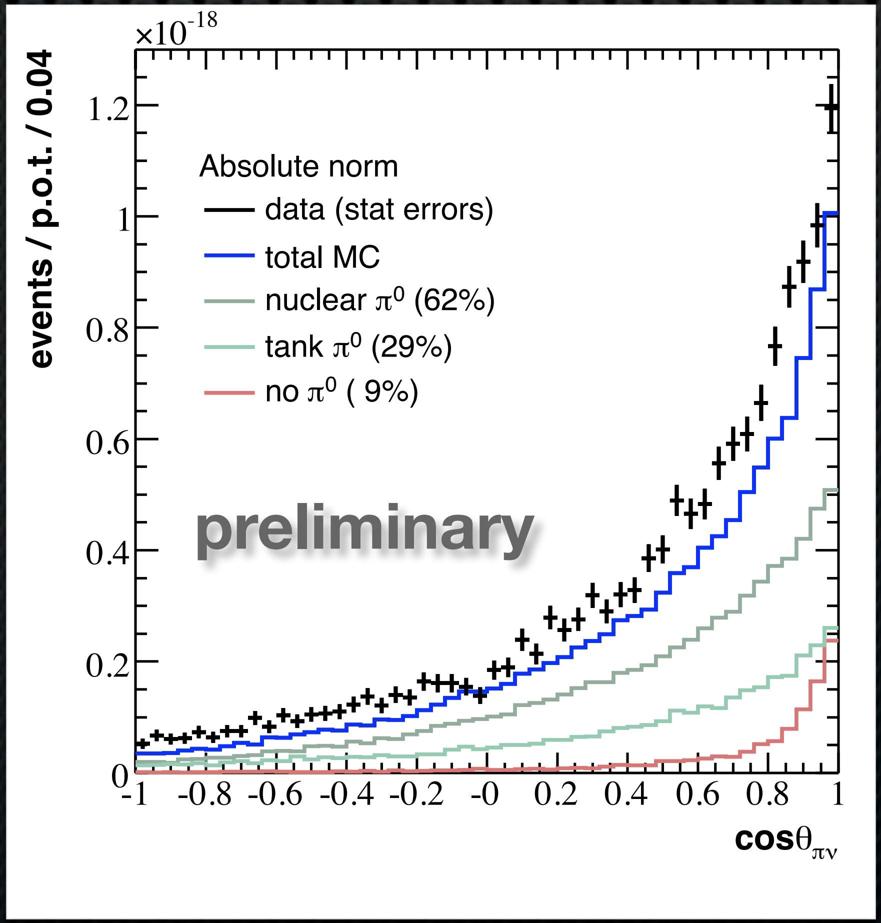


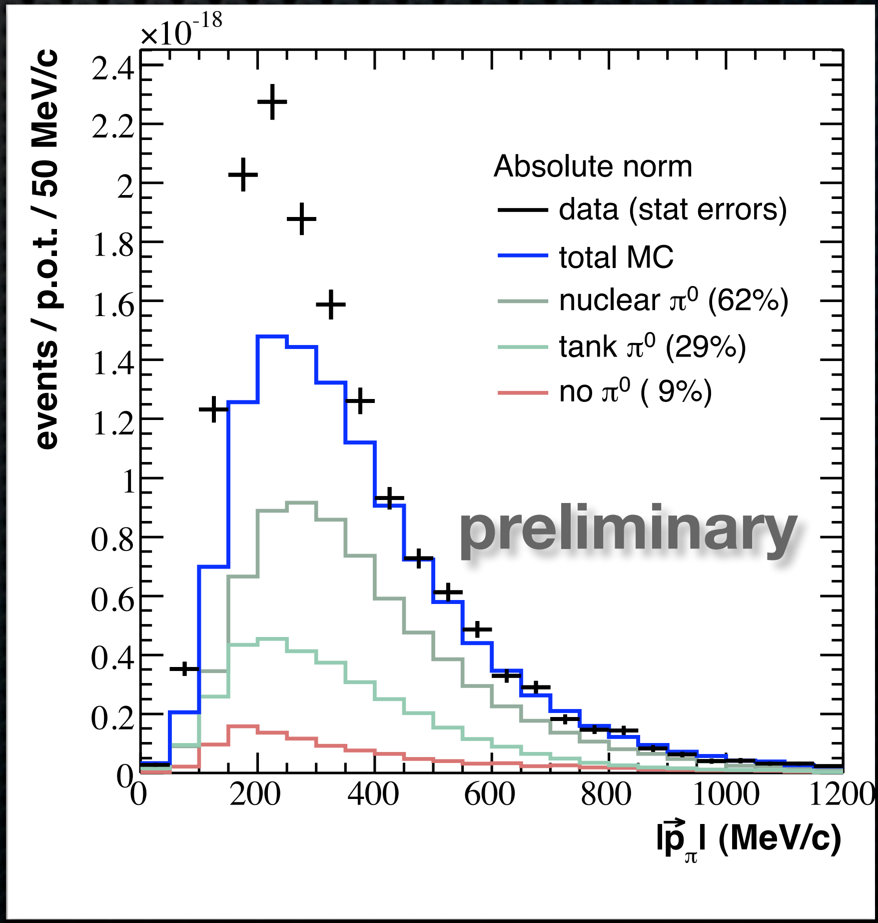


Pion kinematics

- The γγ invariant mass shows a clear peak at the expected π^0 mass.
- Non-π^0 backgrounds bulk at low mass and small angles.
- MC predicts a harder momentum distribution. Also seen in the NC sample.
- Muon ID rate is over 80% about the π^0 mass peak.

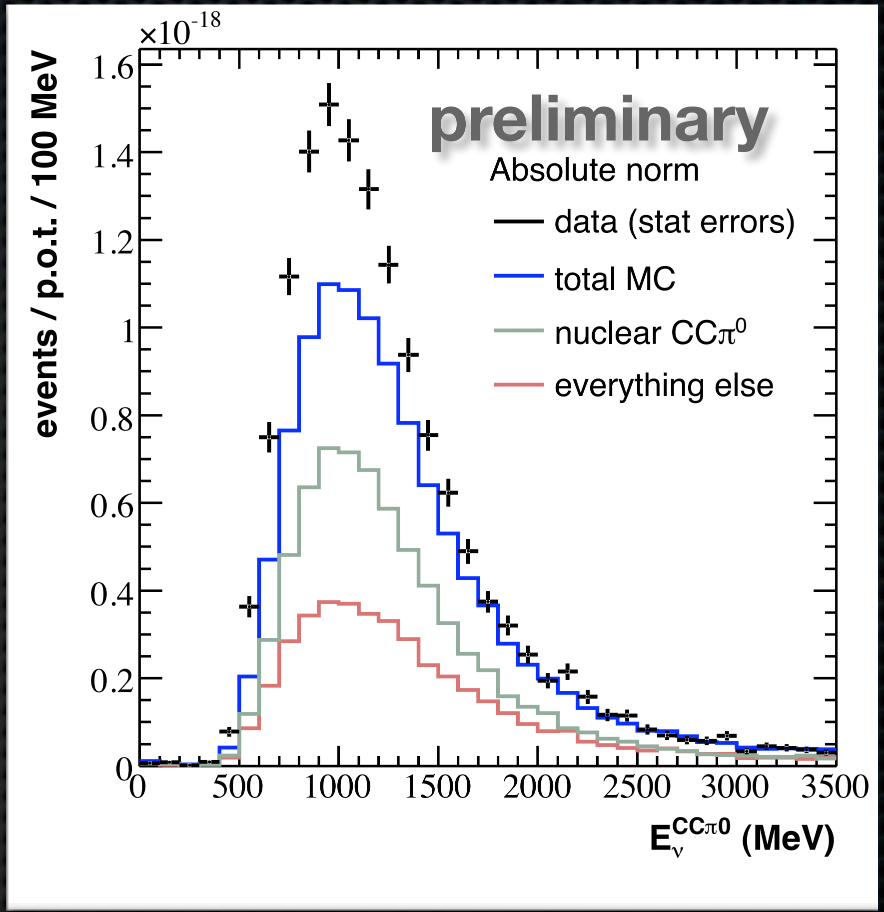


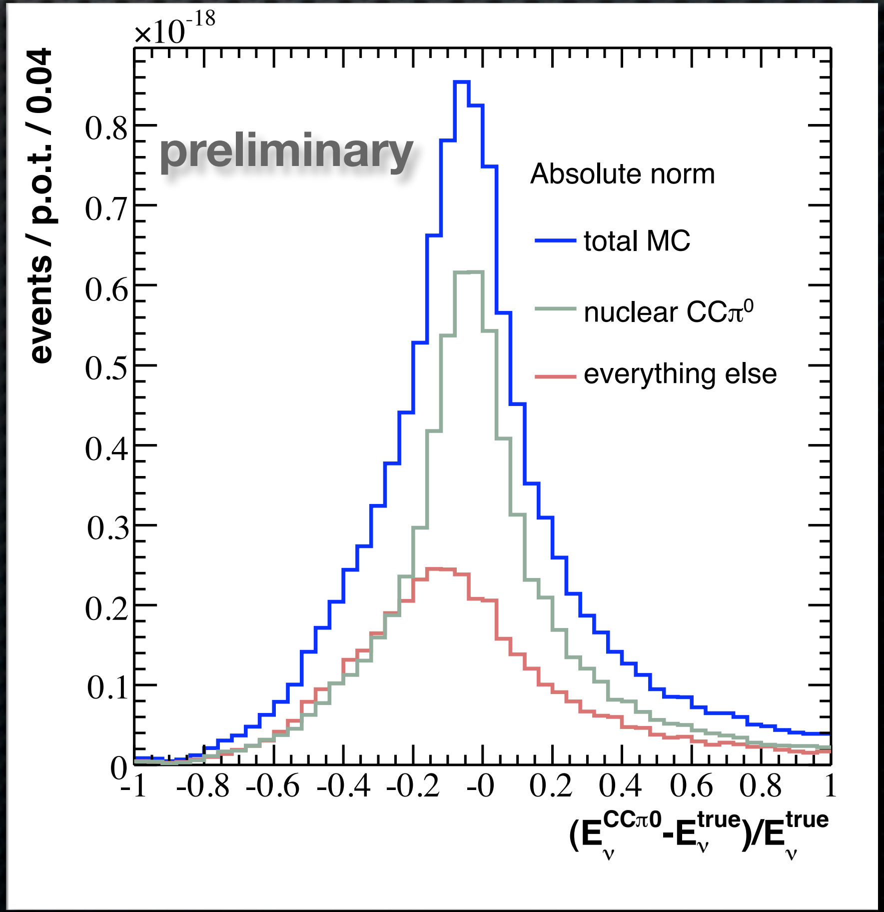




Neutrino energy

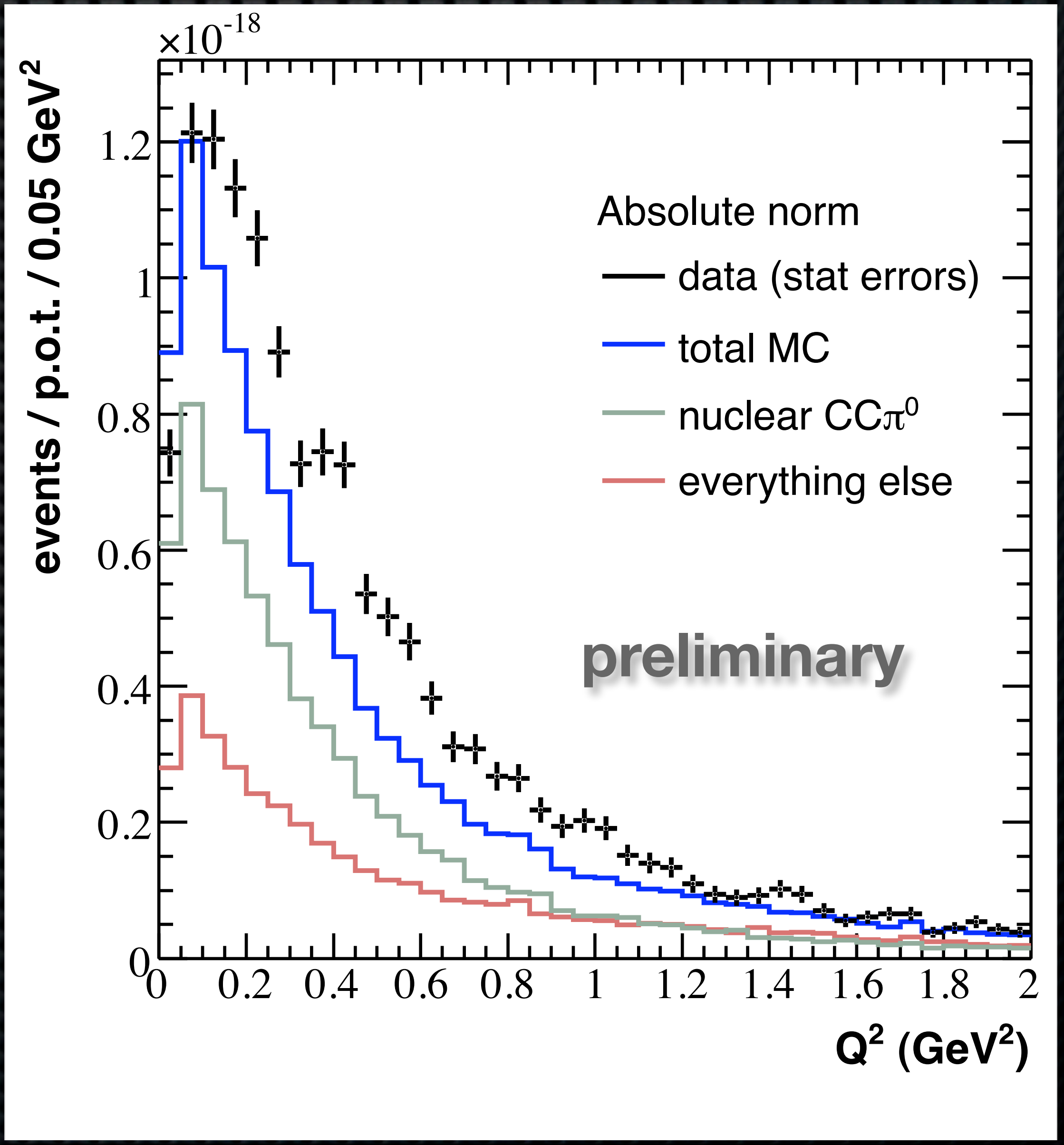
- The energy resolution for effective $CC\pi^0$ events is 14%.
- However, the calculation still does a decent job overall.
    - $E_\nu \simeq E_\mu + E_\pi$ + corrections
      $\simeq$ visible energy



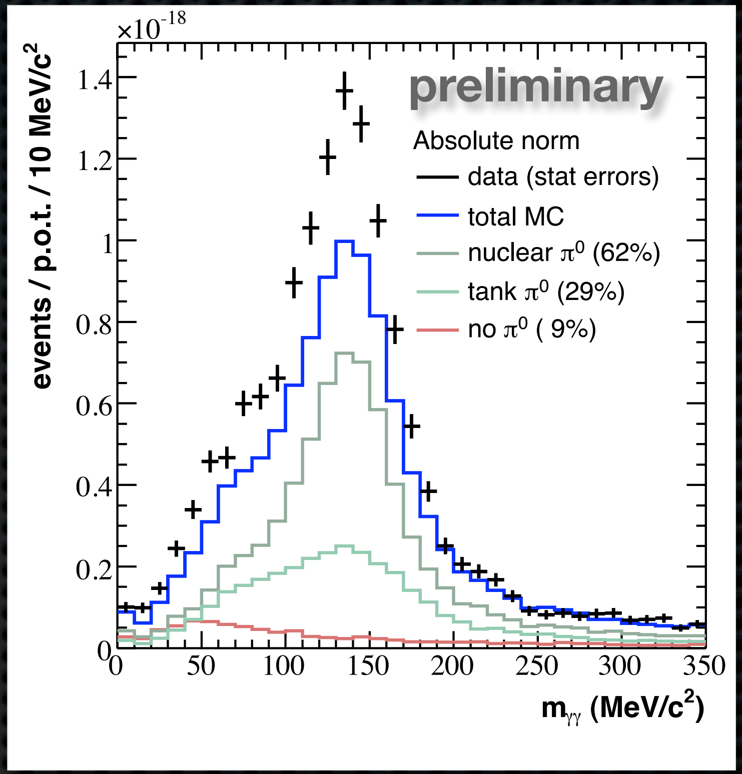


Q^2

- Subject to discrete misreconstruction.
- A larger fall off in the first bin as seen in other modes.



Conclusions



- We have developed a well functioning 3-ring fitter and have used it to isolate a sample of $CC\pi^0$ events.
- With some basic cuts a 62% pure sample can be extracted.
- Kinematic distributions are coming out as expected.
- Systematic errors are in the works.
- This will enable us to measure the observed differential $CC\pi^0$ cross-sections for multiple variables.
  - Expect them by the end of this year.