NUINT12 Generator comparisons Introduction

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- significant effort by Sobczyk, Gallagher, Hayato-san organizing and calculating
- experiments make suggestions
- organizers, Nathan Meyer, Tomasz Golan put together comparisons THANKS!!

Basic outline

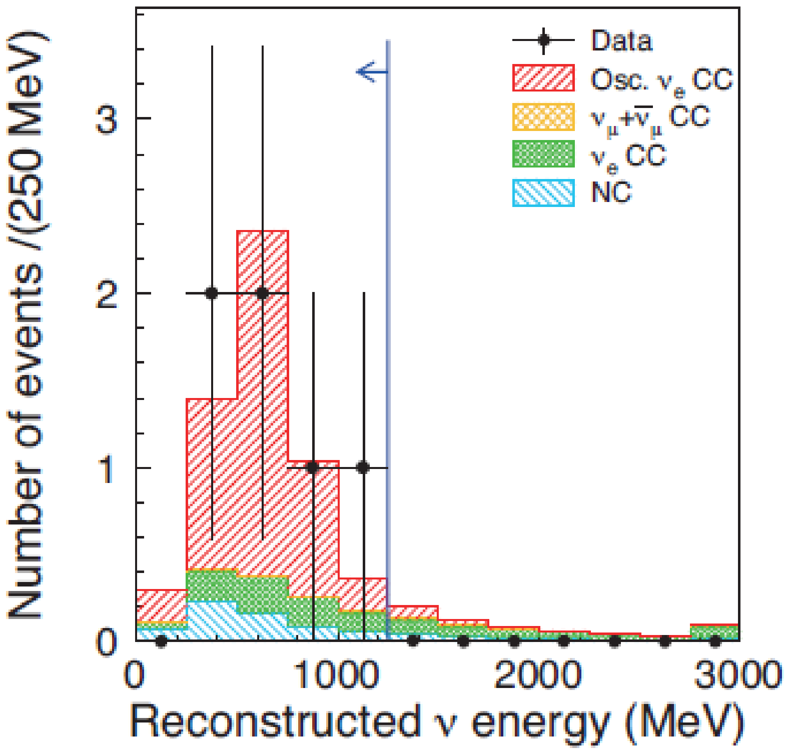
- Hugh Gallagher organized NUINT04
- SD and Steve Boyd organized theory/generator comparison for NUINT09. Roman Tacik and Jan Sobczyk had big impact getting final results together.
  - Coherent models out of date
  - QE models remarkably together for inclusive, but not for proton (right before MEC became important)
  - Pion production models vary widely
- This time, get ideas from experiments
  - MINOS, MiniBooNE, T2K, NOvA, LBNE– oscillation, cross section
  - ArgoNEUT, MicroBooNE – Liquid Ar test, cross section
  - MINERvA – cross section

Categories

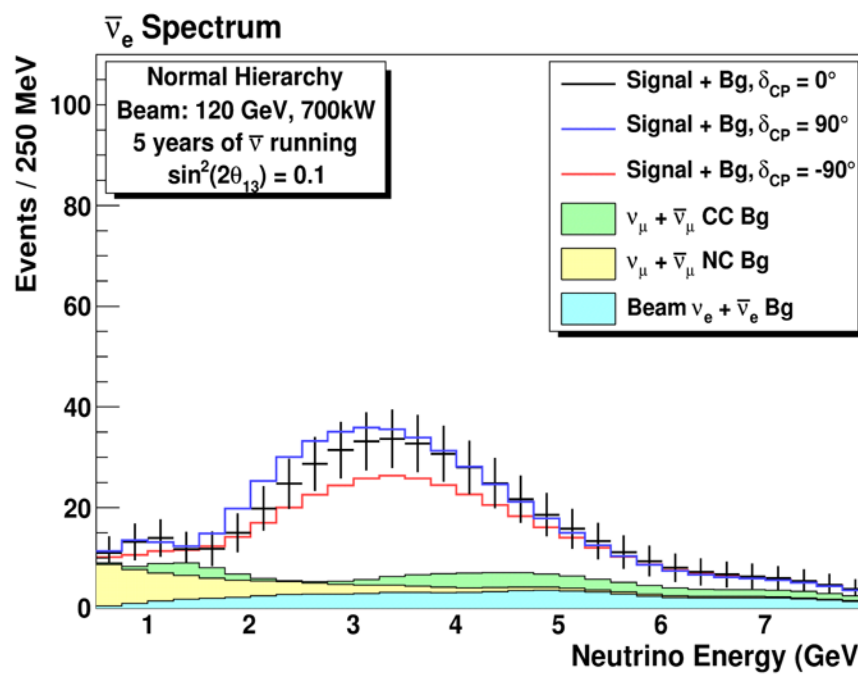
- Oscillation backgrounds (NC π^0)
- QE-like cross section (common oscillation signal)
- Coherent cross section (important osc bkgd)
- FSI issues (strongly affects, ‘masks’ all signals)
- Total Visible Energy (oscillation signal, E_ν measurement)
- *Experimenters are welcome to include their own thoughts*

I. Oscillation backgrounds in $\nu_\mu \rightarrow \nu_e$.

T2K PRL 2011



LBNE 2012 simulate ($\bar{\nu}$)



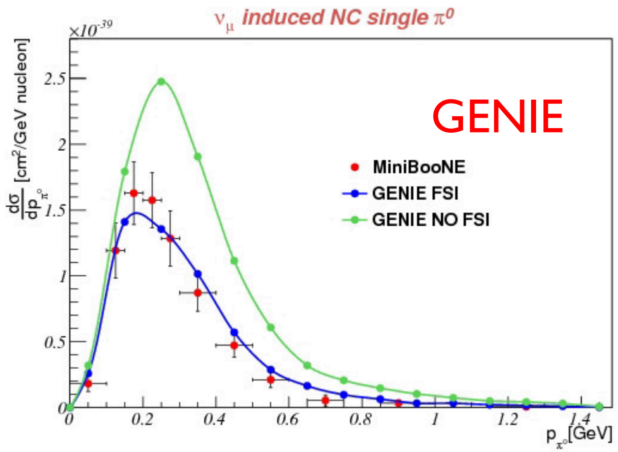
Primary bkgds: NC π^0, ν_e in beam

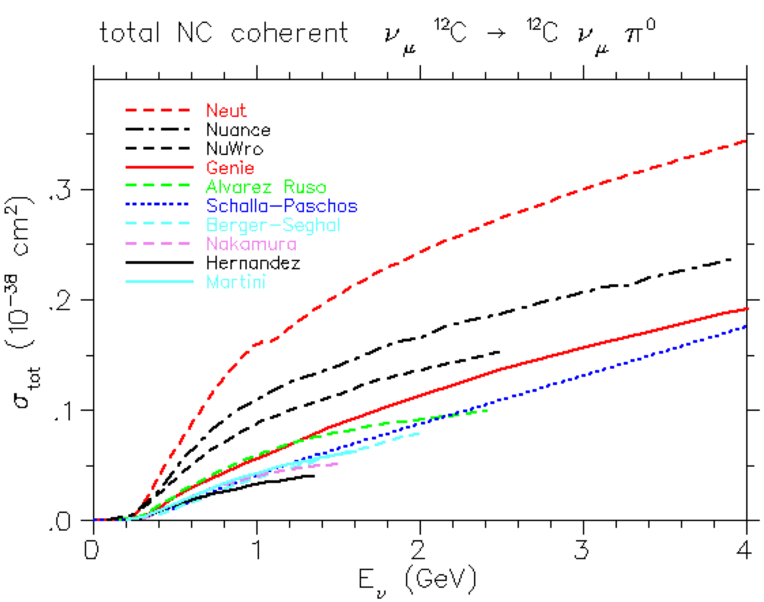
studies

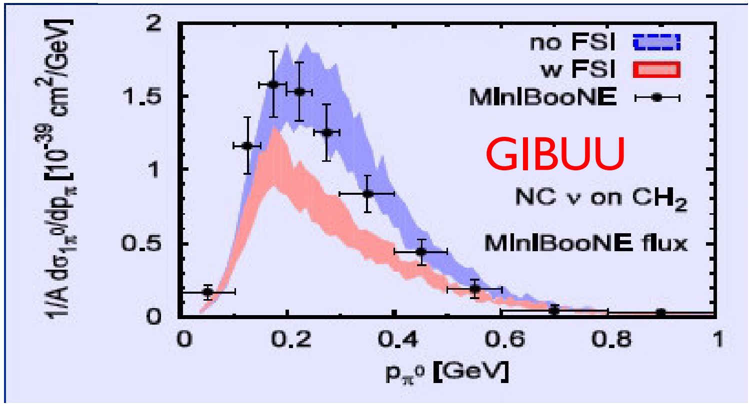
- NOvA A1: EM fraction for NC 2 GeV $\nu_\mu/\bar{\nu}$ C
  - EM fraction = summed γ and π^0 energy/ν [$\nu=E_\nu-E_\mu$]
- MINOS B1: π^0 from NC 5 GeV ν_μ Fe
  - $z=E_\pi/\nu$., i.e. fraction of hadron energy in π^0's.
- LBNE C1: total CC xs for 0-10 GeV $\nu_\mu/\bar{\nu}_\mu$ Ar?
  - total and no meson contribution (QE bkgd)
- thoughts:
  - Good general interest, involves processes not well understood
  - γ's from decays ok, but γ's from nuclear excitations?
  - Many sources of π^0's – DIS, RES

NC π^0 issues

- T2K 2011 result used empirical estimation of bkgd.
  - build events from atmospheric π^0 and MC $\pi^{+/-}$. Use regular analysis.
  - normal MC not trusted.
- MINOS used MC simulation.

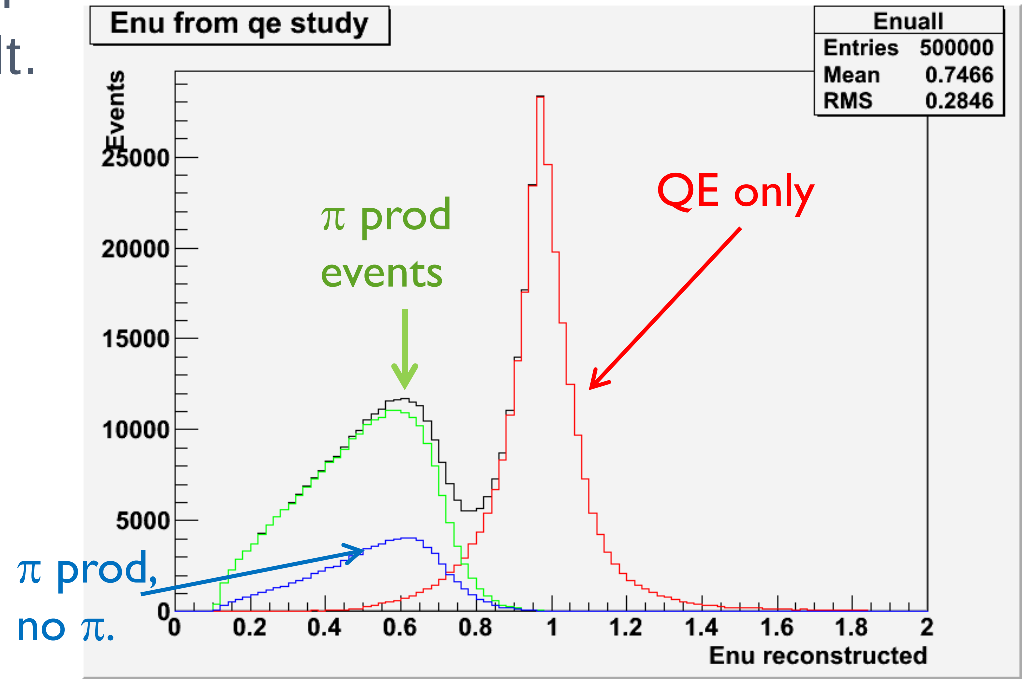






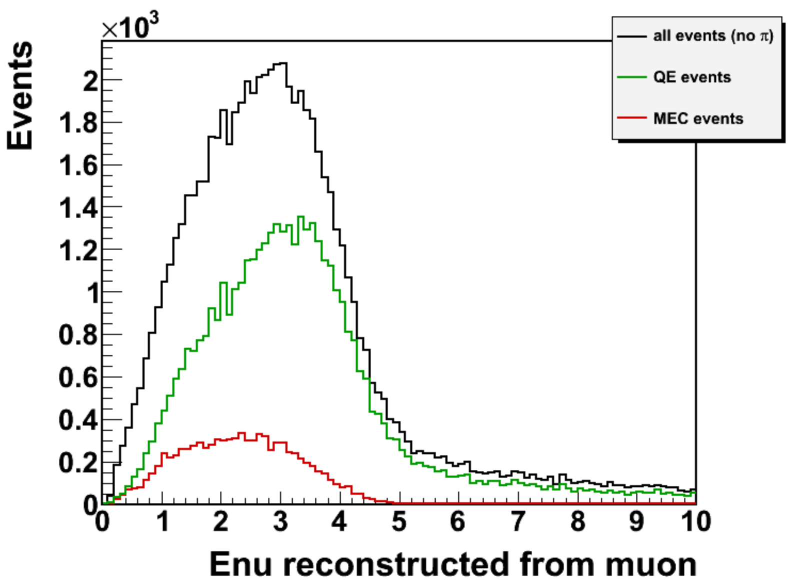
II. QE-like background

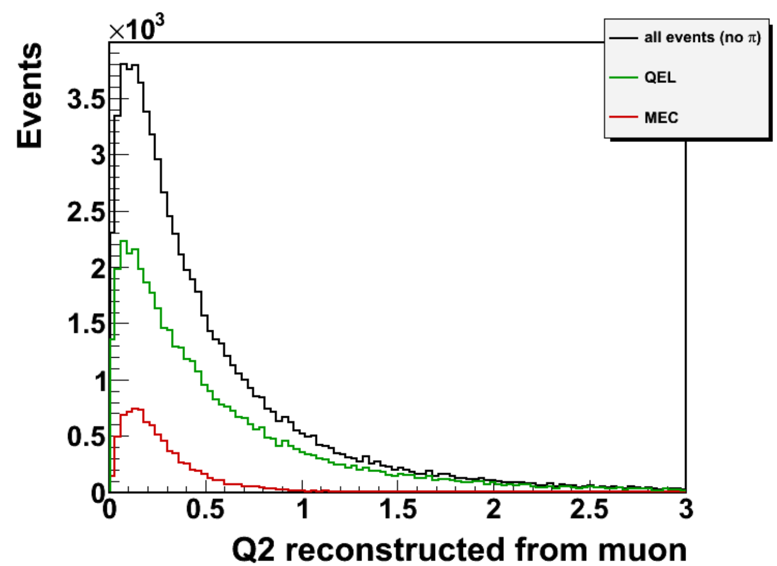
- Difficult to define QE signal
  - Only detect muon, strong bkgd from pion prod
  - Proton gives clean ID, but has strong FSI which is hard to model
  - Biggest problem seems to be pion abs, satisfies many cuts but gives wrong E_ν with QE hypothesis.
  - MEC makes it more difficult.
  - example shows QE/RES 1 GeV ν_μ C simulation. Width of QE peak shows Fermi motion and blue line shows π prod events Where no pion is emitted.



studies

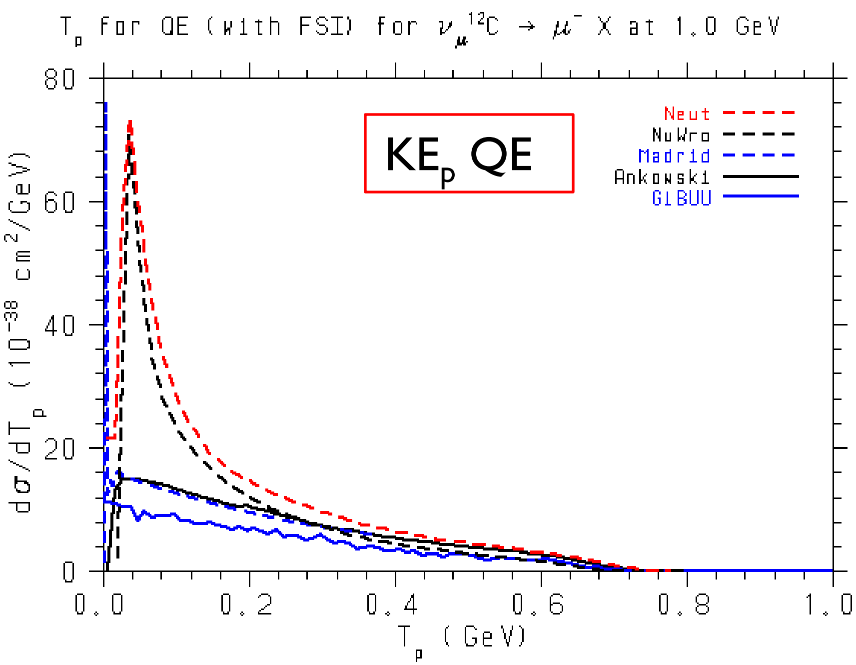
- MiniBooNE F1: total CC QE xs w/ and w/o MEC.
  - GENIE has draft version, NEUT has no MEC
- T2K G1: mu momentum vs. θ (2D) plot for 600 MeV ν_μ C with and without MEC
- plots below from GENIE (see Teppei Katori's talk later)
- thoughts:
  - Frontier of theory vs. data – lots of attention needed

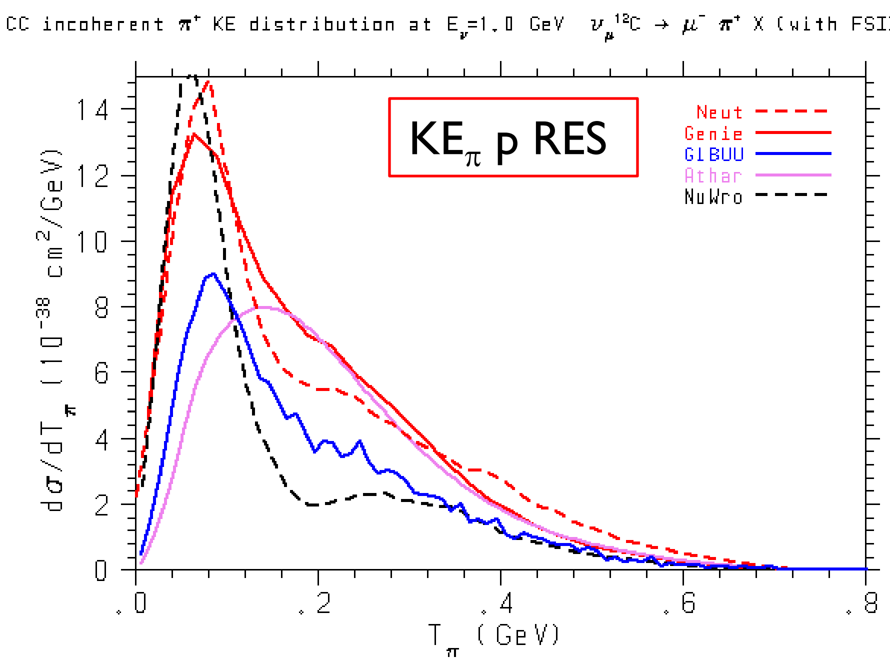




III. FSI influences

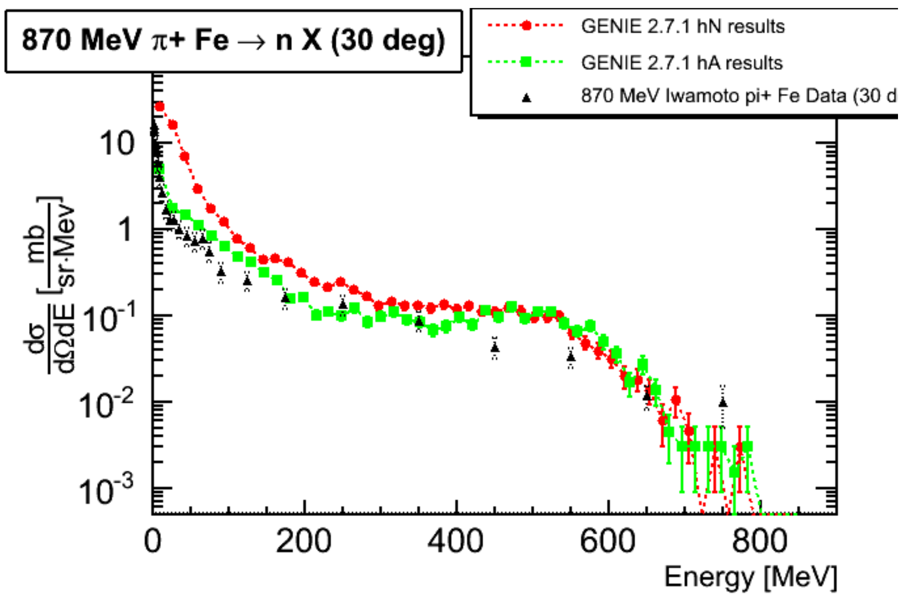
- examples from NUINT09 study [ν_μ Carbon at 1 GeV]
- proton KE from QE (left), π KE from CC1π (right)
- Theorists have little or no FSI, generators have full FSI.
- All curves in right plot except purple have full FSI.

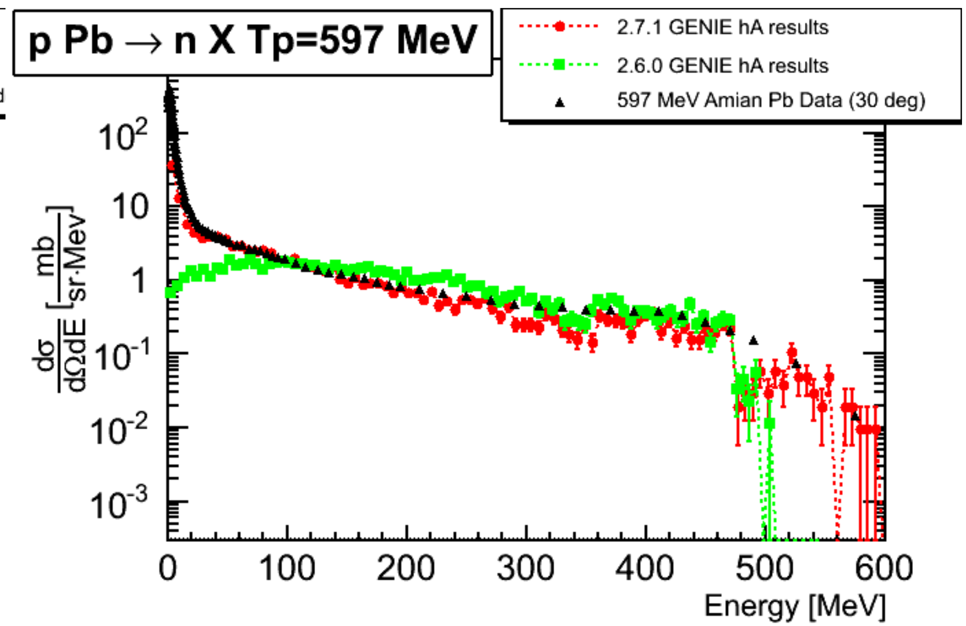




III. FSI influences

- Much of my time has gone to this (GENIE has 2 models)
- One effort has been to model low energy nucleons, best seen in data with neutrons in final state.





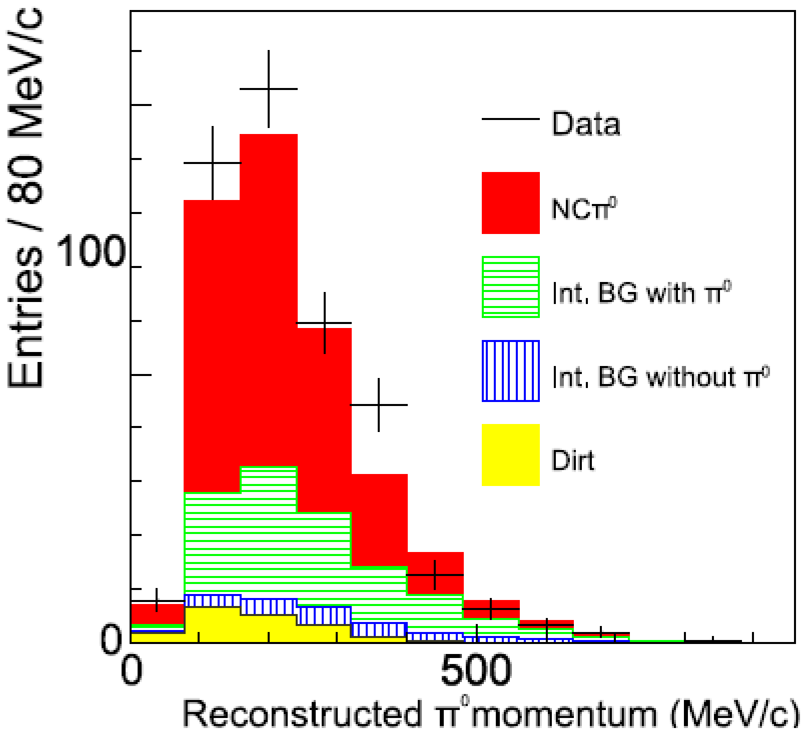
studies

- LBNE C2: look at proton multiplicity (all and with KE>50 MeV – common tracking problem) in 2.5 GeV ν_μ Ar.
  - No data so far, looking forward to ArgoNEUT this week.
- ArgoNEUT/MiniBooNE D1, E1: proton multiplicity (all and with KE>50 MeV) for 1, 3 GeV ν_μ Ar events with no mesons.
- thoughts:
  - Correct vertex energy changes E_ν calculation, new access with LAr
  - Large variations possible, need validation with neutrinos.

IV. Coherent xs

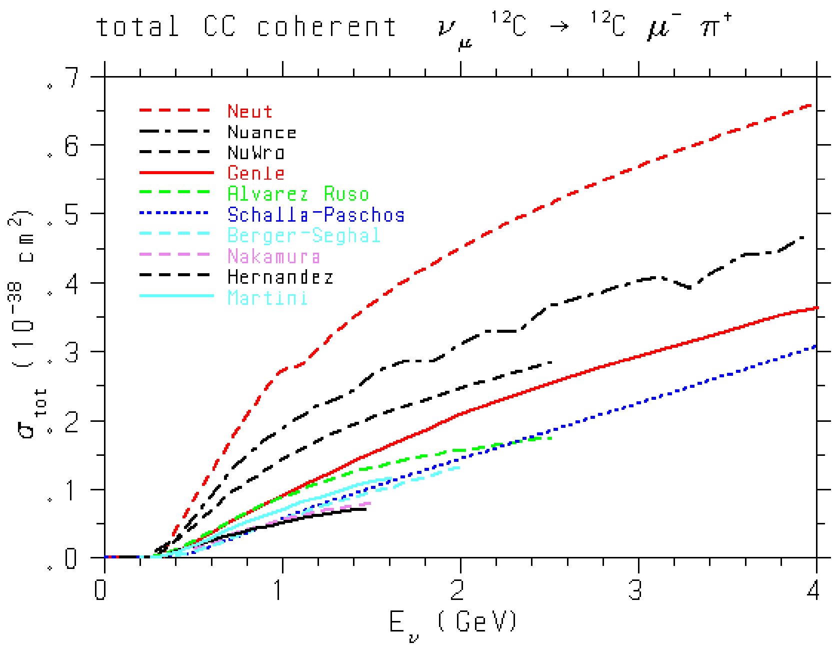
- SCIBooNE NC Coherent (Phys Rev D 81, 111102(R) (2010))
- measurement depends critically on MC understanding of bkgd and signal.
- efficiency=5.3%, purity=61%

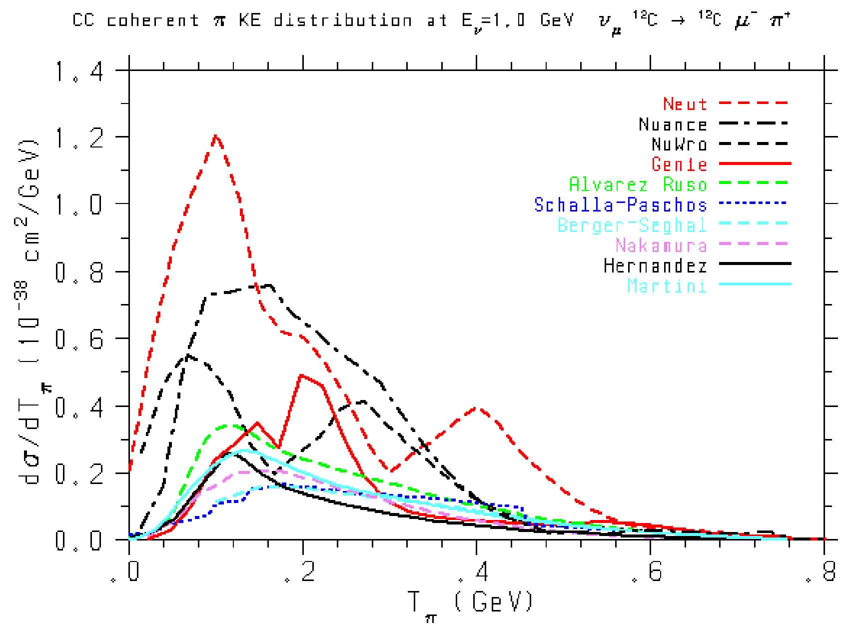
Interaction Type	# Events	Fraction(%)
CC quasi-elastic	53,363	41.4
CC single π via resonances	29,688	23.1
CC coherent π	1,771	1.4
CC single meson except π	839	0.7
CC DIS	6,074	4.7
NC elastic	22,521	17.5
NC single π^0 via resonances	6,939	5.4
NC coherent π^0	1,109	0.9
NC single meson except π^0	4,716	3.7
NC DIS	1,768	1.4



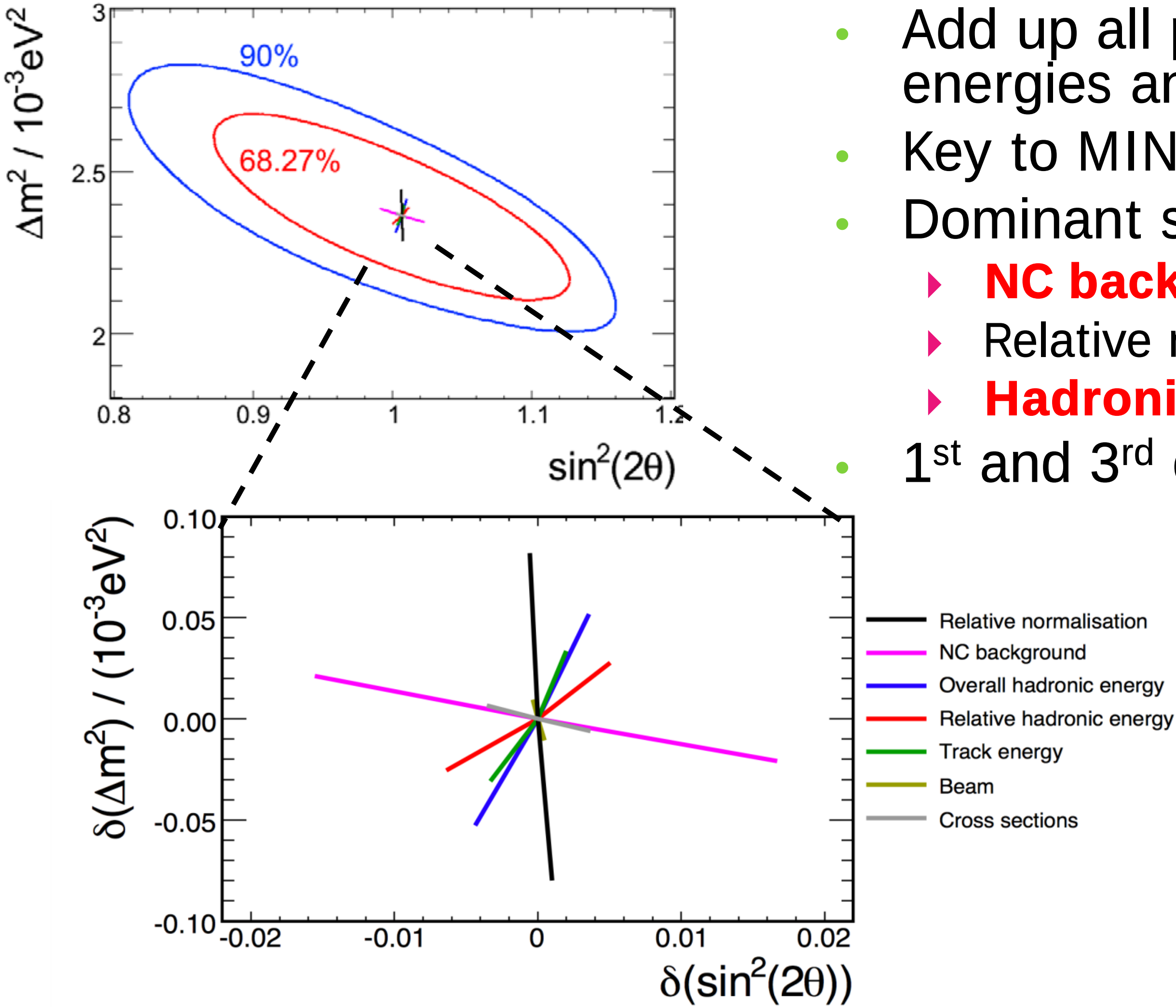
studies

- MINERvA H3-5: isolated pion energies for 5 GeV ν_μ C.
  - π^+(CC Coh signal), π^0(NC Coh signal), π^- (similar to π^+ in Minerva)
  - sources are RES, DIS in addition to coherent
  - since coherent is few% of RES, cuts are critical





V. Total visible energy (MINOS)

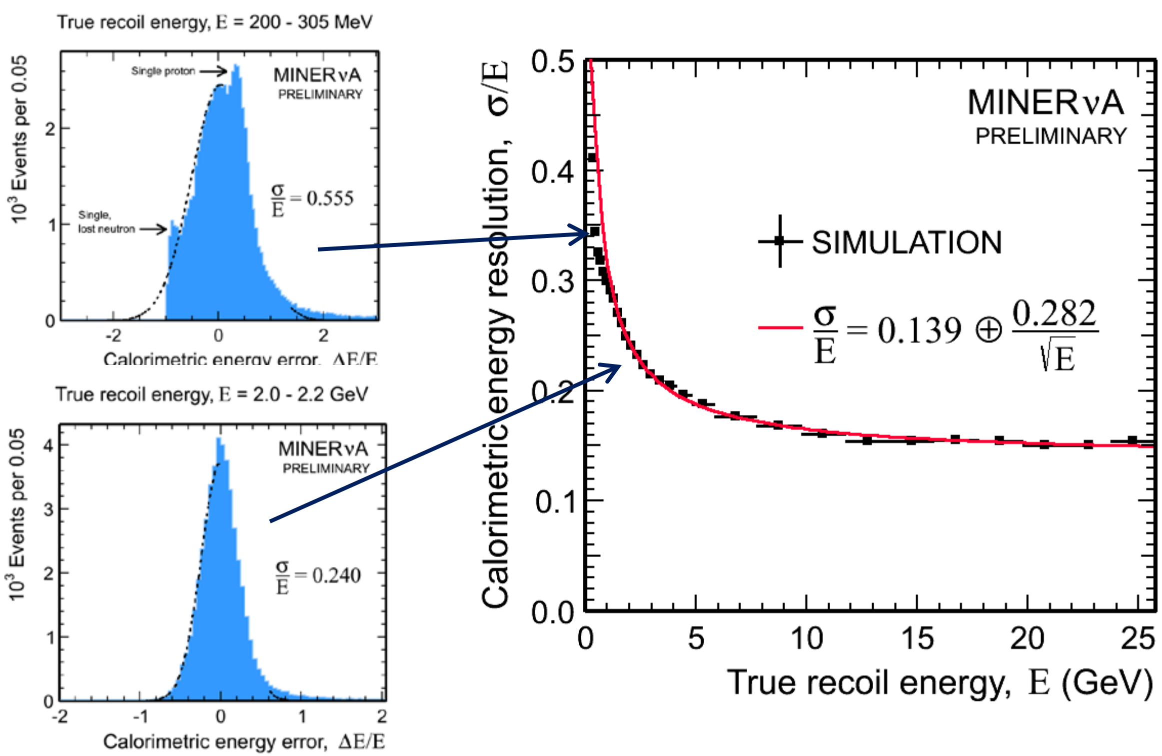


- Add up all pion, photon total energies and nucleon KE.
- Key to MINOS oscillation analysis
- Dominant systematic errors
  - **NC background (θ)**
  - Relative normalization (N-F) (Δm^2)
  - **Hadronic energy (Δm^2)**
- 1st and 3rd come from MC.

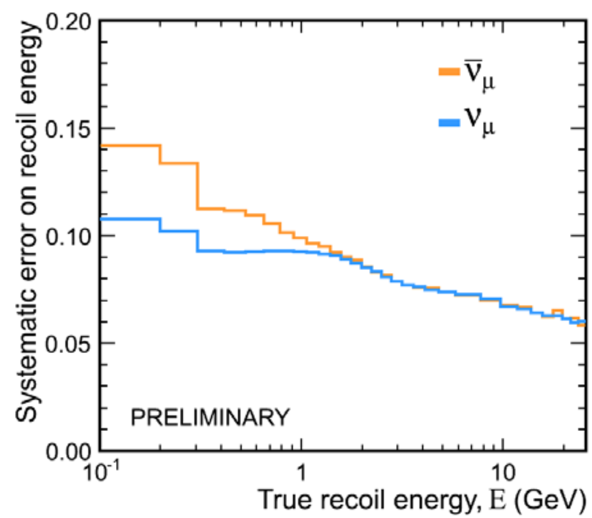
total visible energy (not muon) + calorimetric corrections. (test beam crucial) $E_\nu = E_\mu + E_{had}$.

V. Total visible energy (MINERνA)

- MINERνA composed of Scin, ECal, and HCal regions.
- Key to E_ν calculation for higher energies.
- Sensitive to missing energy of neutrals, low E hadrons.



Preliminary systematic errors



Studies

- MINOS B2: "E_{reco}" from CC 3 GeV ν_μ Fe
  - E_{reco}=1.3*$E_{\gamma,\pi 0}$ + KE_p (KE>150 MeV ? KE : 0) + KE_n (KE>300 ? 0.5*KE : KE) + $E_{\pi+/-\ldots}$.
  - Specific to their calorimeter (Fe-scin)
- ArgoNEUT/MiniBooNE D3, E3: total visible energy 1, 3 GeV ν_μ Ar (no ν, neutrons)
  - more general
- MINERvA H17, H18: distribution of n, p energy as function of ν. for 5 GeV ν_μ C.
  - shows variation in E_{vis} due to low vs. high energy p,n (FSI)
- Thoughts:
  - Tricky to interpret because many components.
  - 2D plots have more information

Summary

- Introduction to studies suggested by experiments.
- Many interesting themes
  - oscillation backgrounds
  - QE signal/bkgd (osc signal)
  - FSI effects (low energy nucleons)
  - coherent backgrounds
  - total visible energy (osc signal, common way to calc E_{ν})
- Now, let's see the results! What to look for:
  - Each plot shows a quantity expt sees as important bkgd/syst
  - Look for deviations between MC codes
  - Look for physics that might cause those deviations.
  - If MC's agree, is that because they all use same model?