B.T.Fleming
NuINT07
June 1, 2007

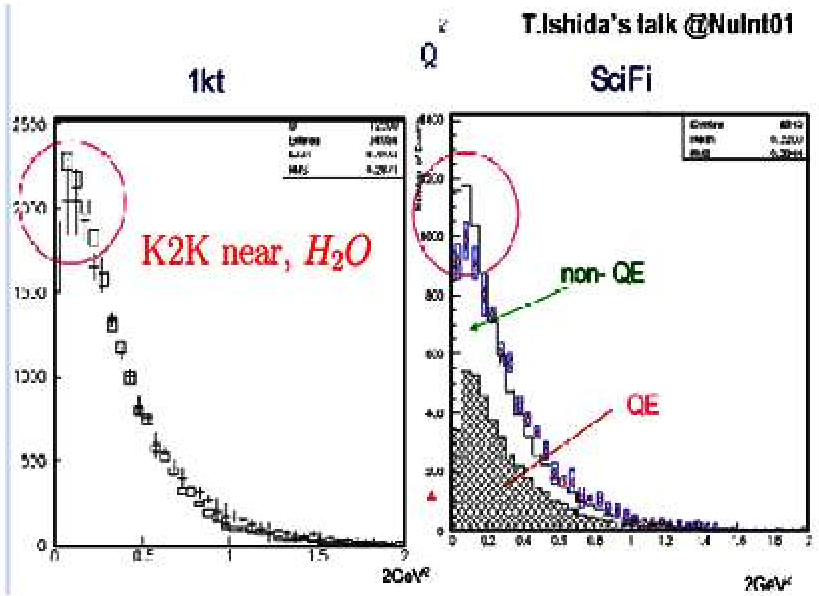
Measurement of $CC\pi^+$ events at MiniBooNE

- $CC\pi^+$ events in MiniBooNE
- Comparisons to model predictions
- First look at neutrino content in anti-neutrino mode using $CC\pi^+$s

Why are $CC\pi^+$ events so interestng?

- Rich channel with resonant and coherent interactions -- lots to learn!
- Largest background to CCQE sample
- Possible signal channel for the oscillation analysis
- Use as cross check to constrain wrong sign flux in anti-neutrino mode

Disagreement in low Q^2 seen in MiniBooNE and other experiments



Interest in CCπ^+:

- Rich channel with resonant and coherent interactions -- lots to learn!
- Largest background to CCQE sample
- Possible signal channel for the oscillation analysis
- Use as cross check to constrain beam flux (anti-neutrino mode)

K2K charged current pion production

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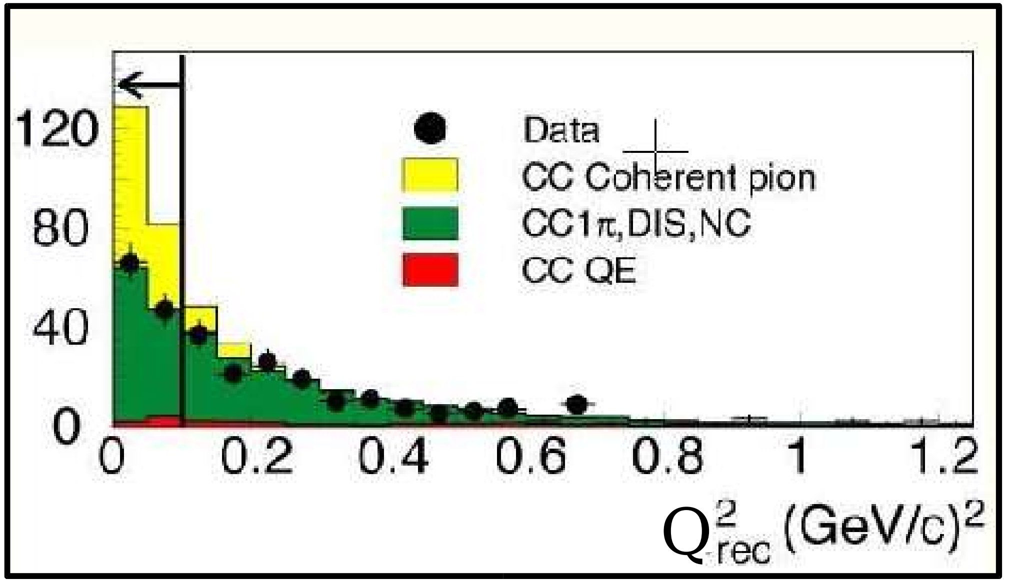
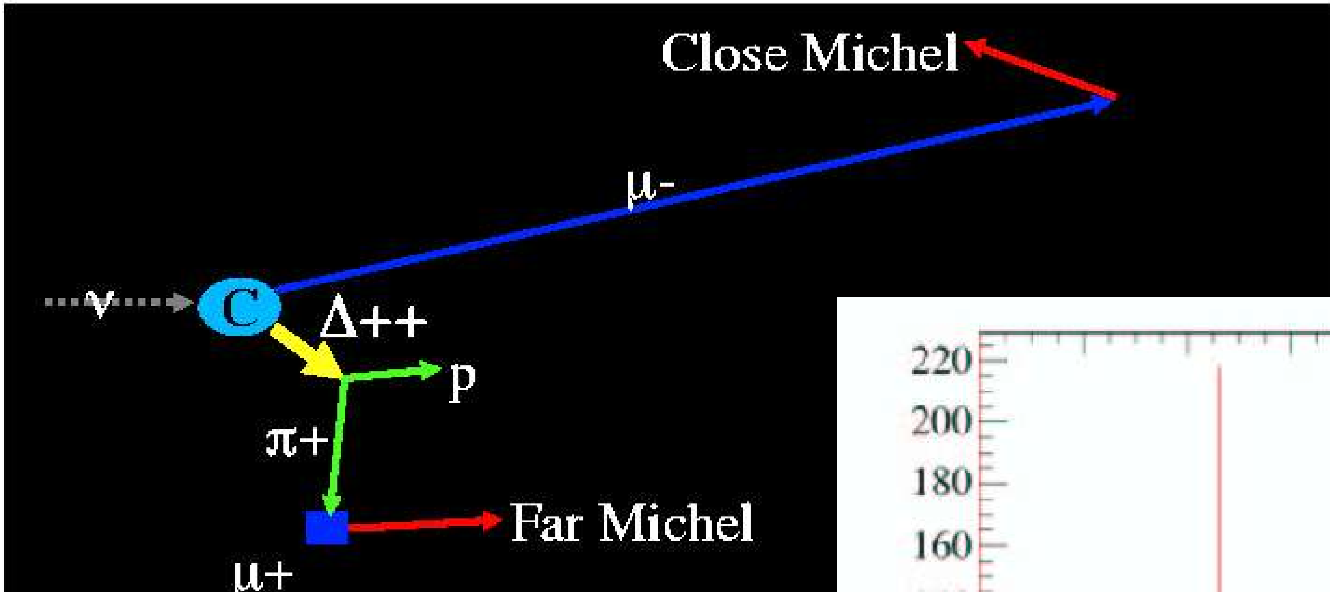
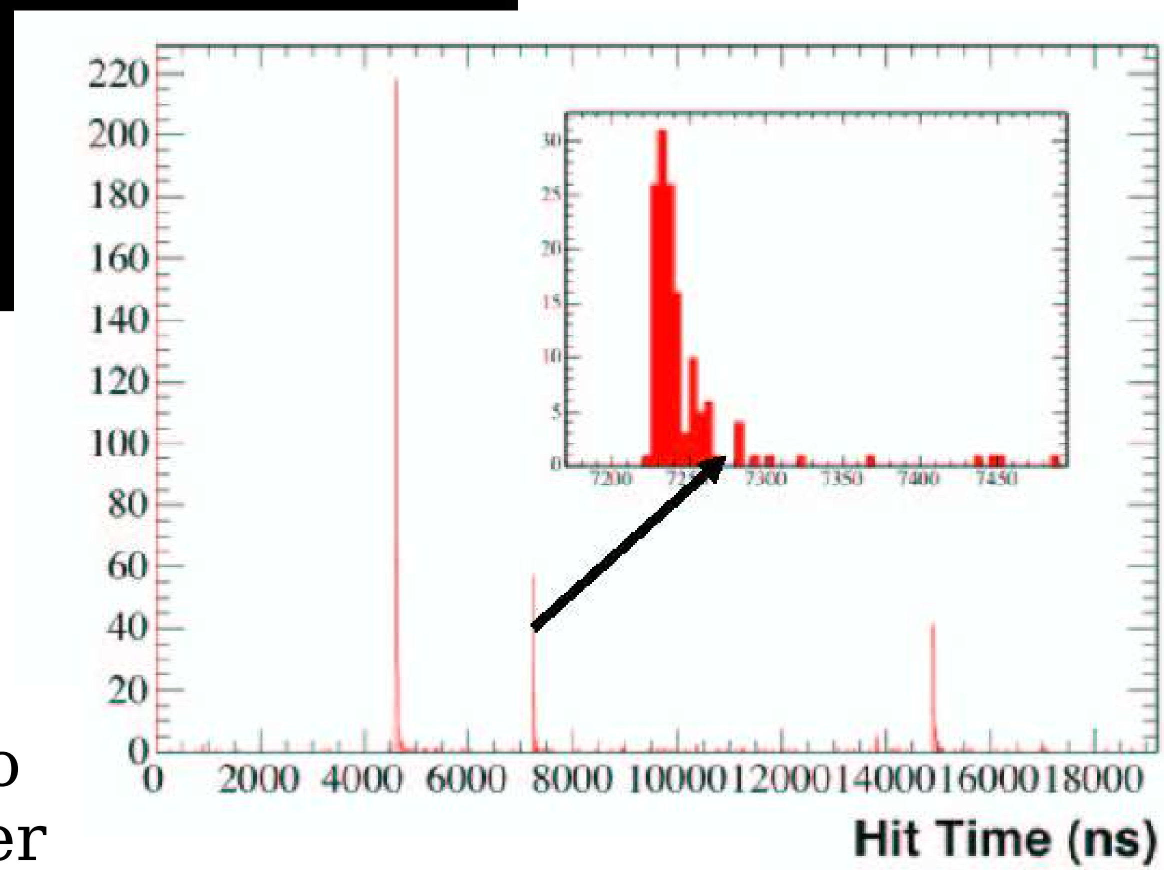


$CC\pi^+$ events in MiniBooNE: tagged via outgoing muon and decay products of outgoing π^+



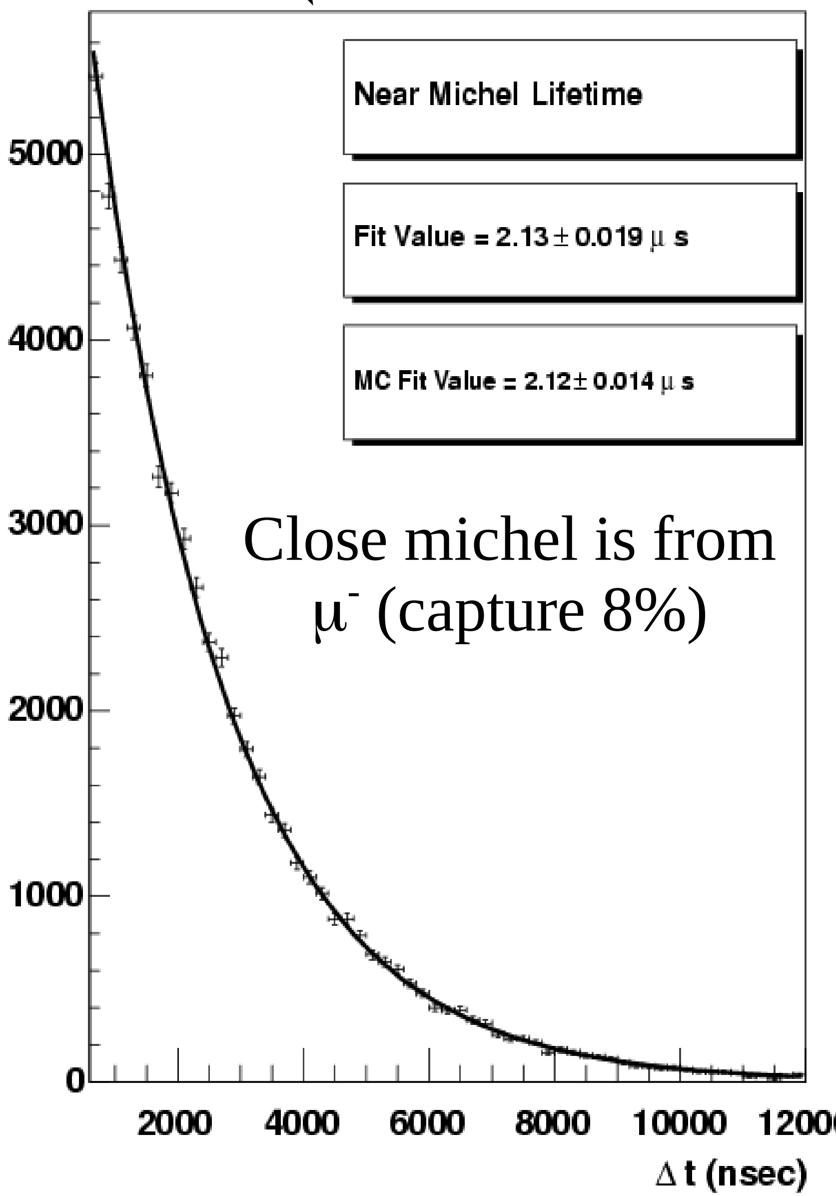
Two “subevents” from muon and “close” michel



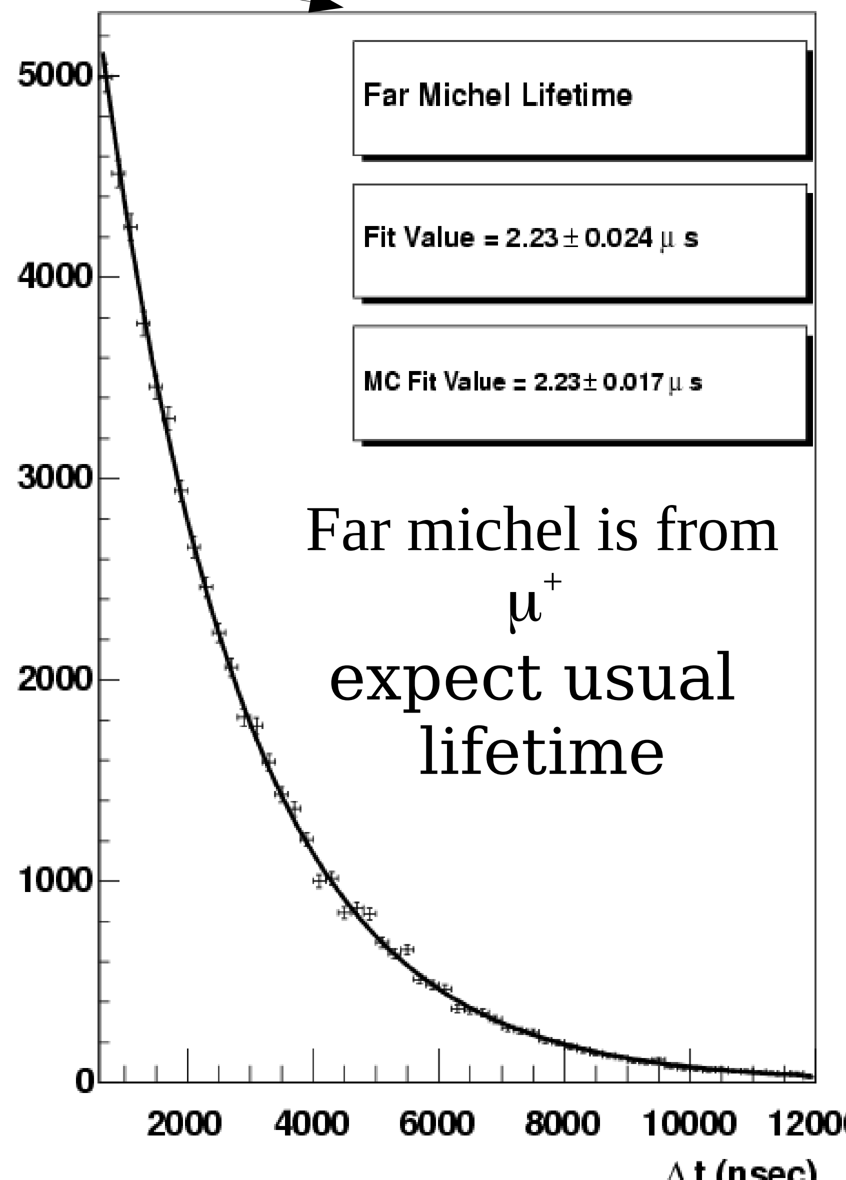
A third “subevent” from “Far” Michel

First subevent consistent with neutrino interaction vertex. Later subevents consistent with michels

Close and Far Michels come from muons with different lifetimes.....

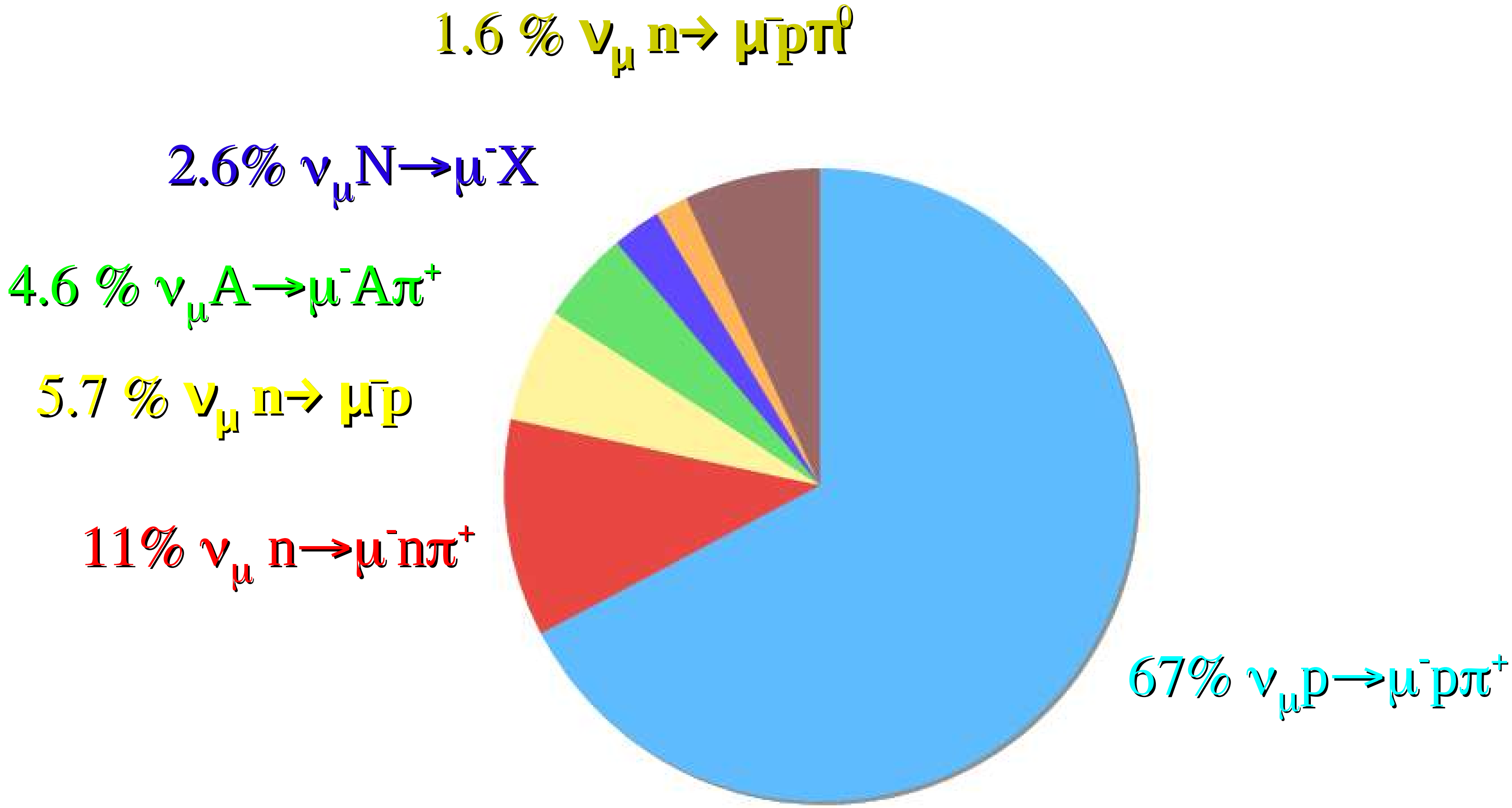


Close michel is from μ^- (capture 8%)



Far michel is from μ^+
expect usual lifetime

~70,000 events total for 5.8E20 pot
(entire neutrino data set)



83% pure $CC\pi^+$

Modeling CCπ^+ interactions at MiniBooNE:

v3 NUANCE Monte Carlo to generate events (Casper)

- Resonance Model: Rein-Sehgal, Fermi Gas Model, $M_A^{1\pi}$=1.1 GeV, added non-isotropic Δ decay (Garvey)
- Coherent model: Rein-Sehgal, M_A^{coh}=1.0 GeV, constraint from NCcoh π° (MiniBooNE)
- DIS: Bodek-Yang
- FSI: Partnuc model tuned to external π-^{12}C data

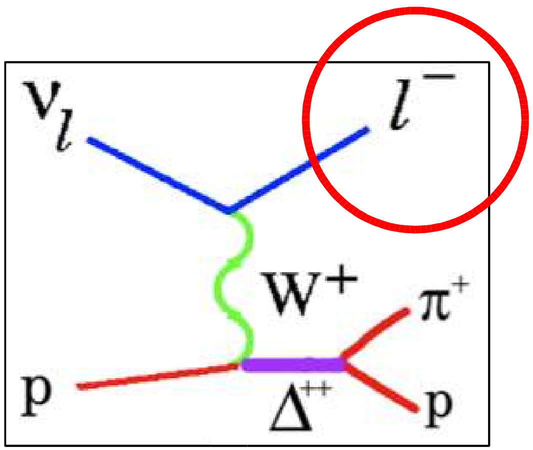
Systematic errors shown on MC include uncertainties on

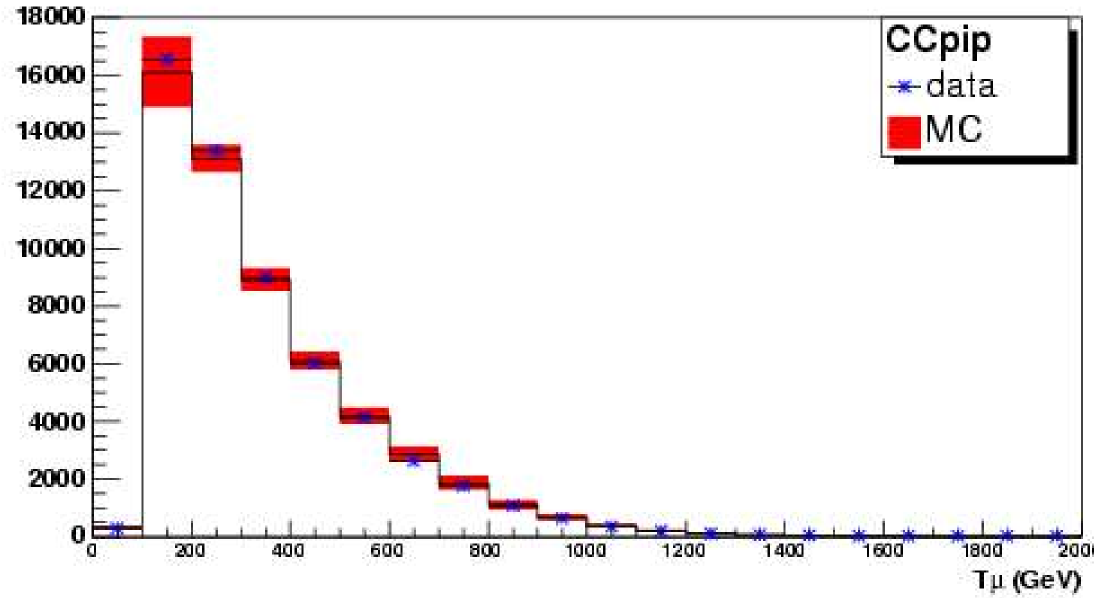
- Flux
- Cross sections
- Optical model

(fully correlated error matrix)

Comparing data with Monte Carlo

Muon kinetic energy

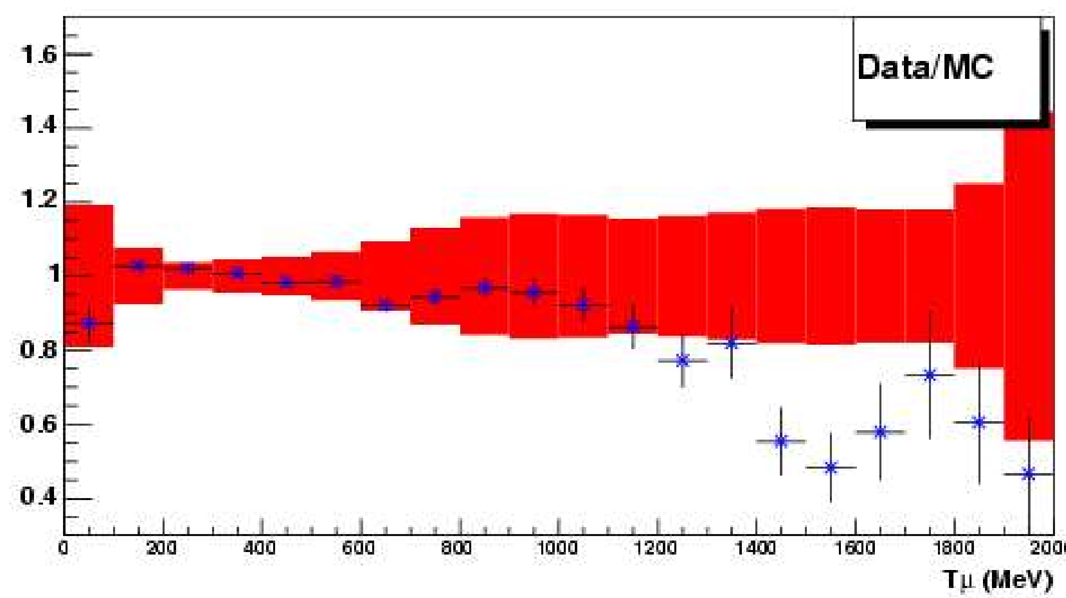




data compared with MC

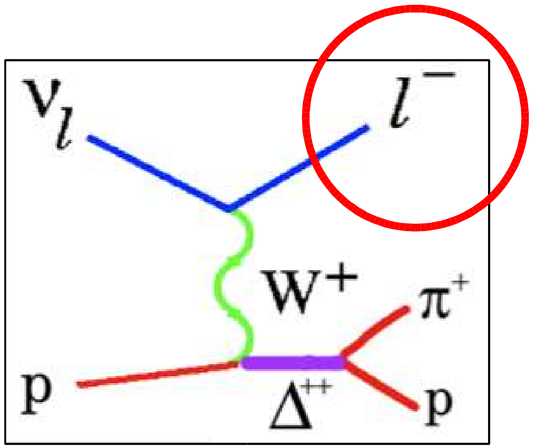
•error bars are statistics plus systematics - fully correlated

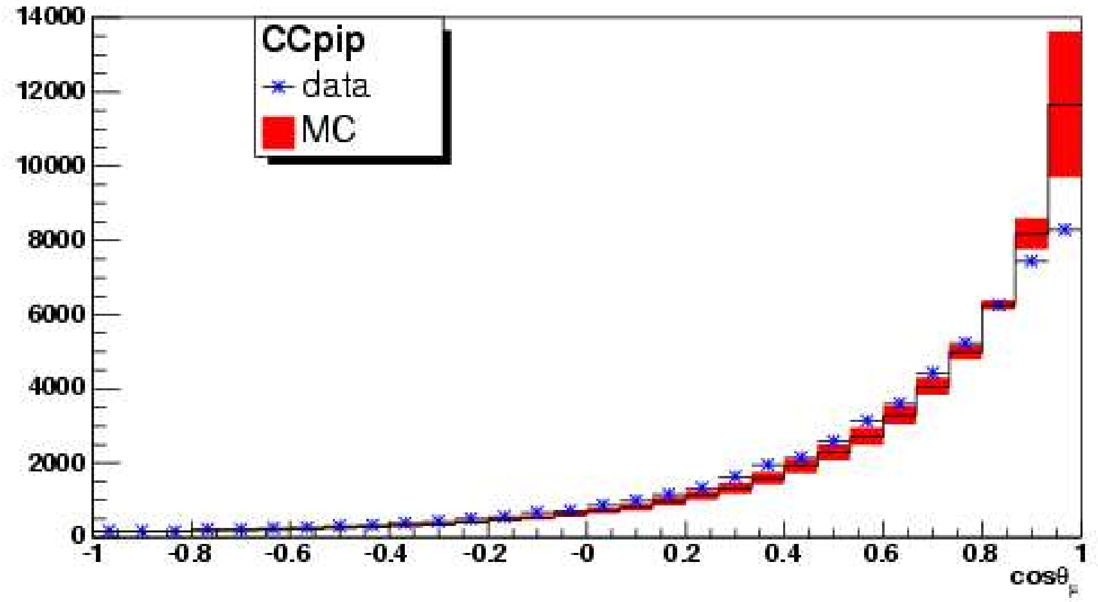
•plots are relatively normalized



J. Nowak

Muon angluar distribution





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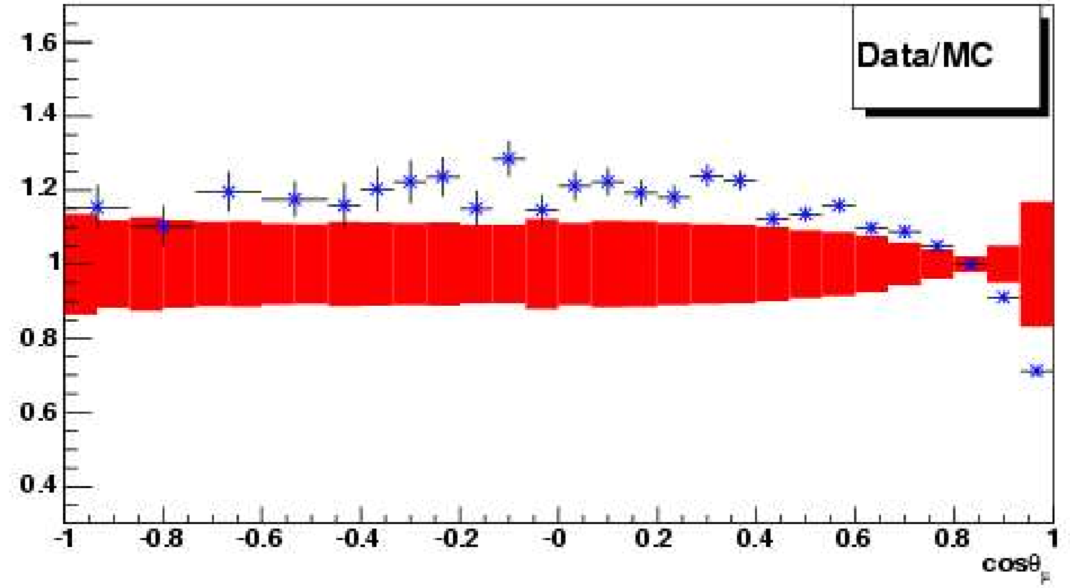

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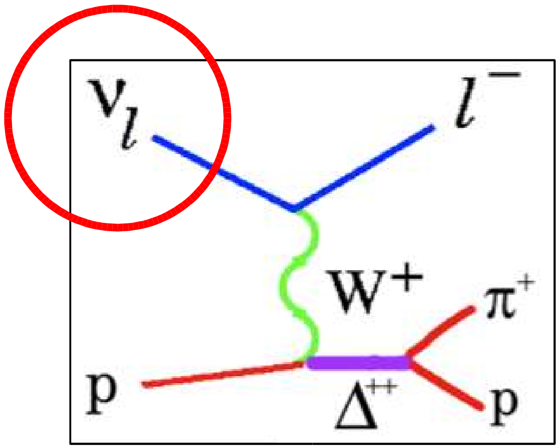
Reconstructed neutrino energy



$$E_\nu^{QE} = \frac{1}{2}\frac{2M_pE_\mu - m_\mu^2 + (m_\Delta^2 - m_p^2)}{M_p - E_\mu + \sqrt{(E_\mu^2 - m_\mu^2)}\cos\theta_\mu}$$

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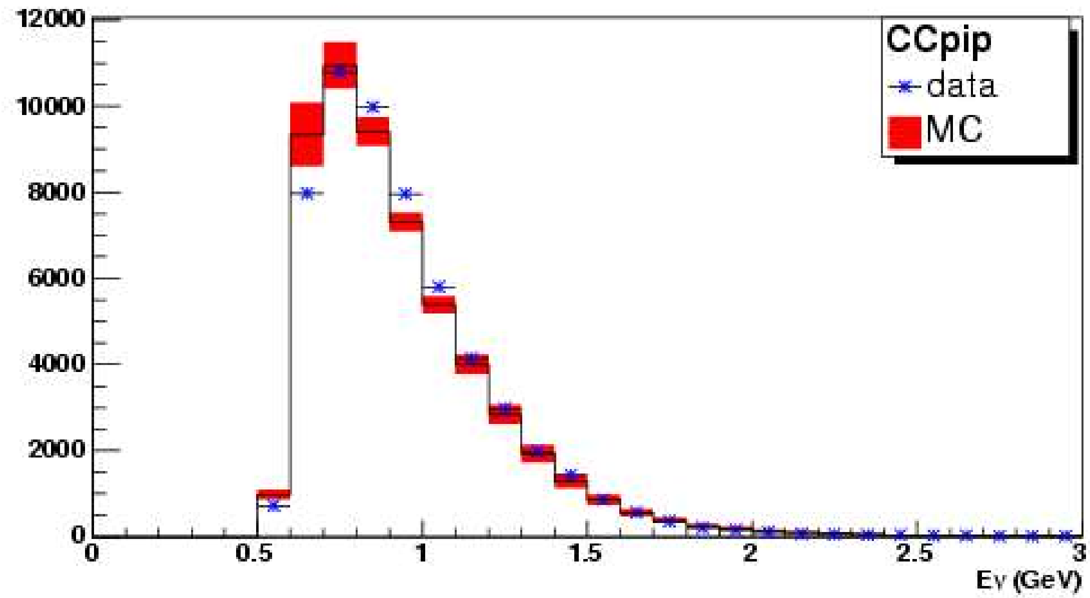

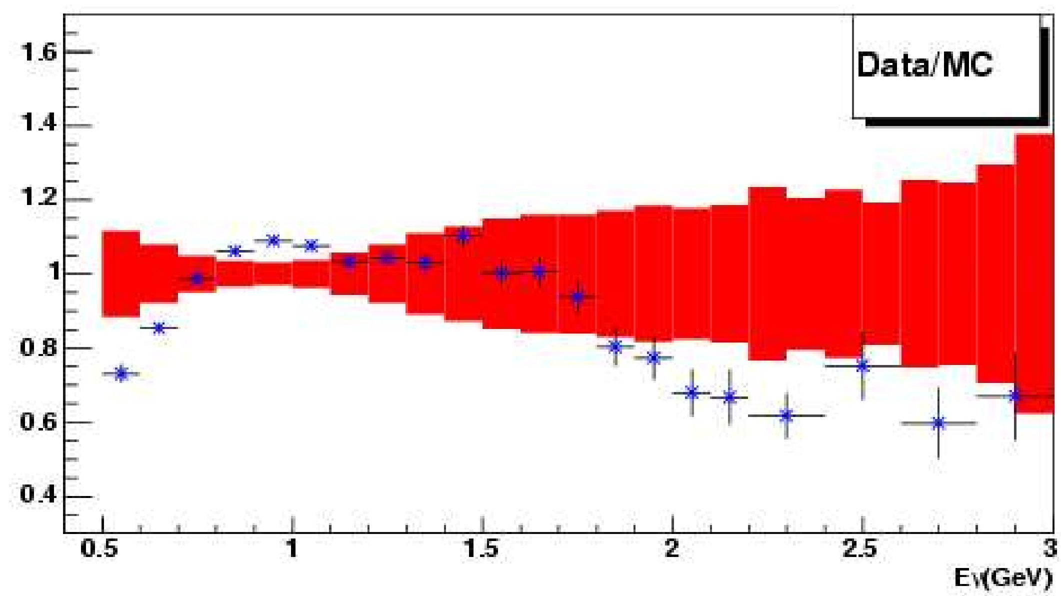

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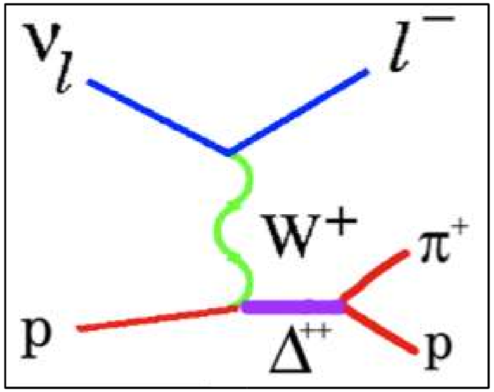
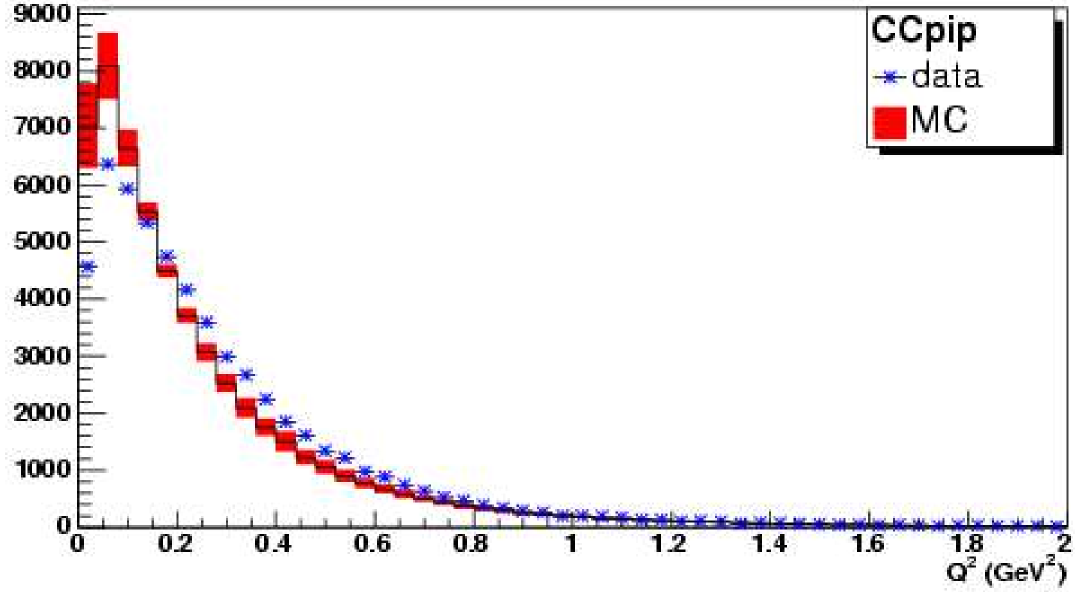
Momentum Transfer, Q^2





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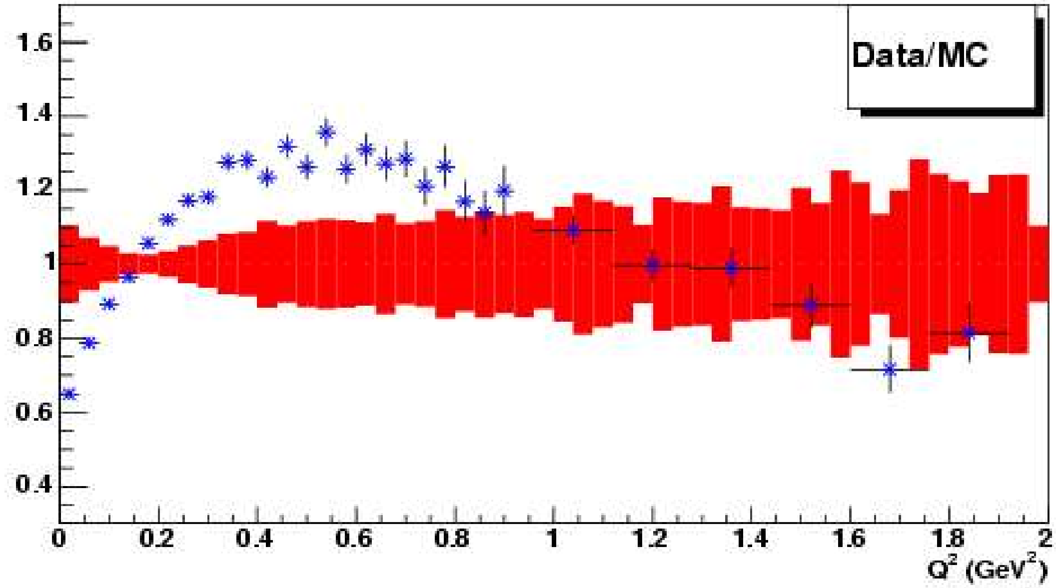

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Understanding Q^2 dis-agreeement

→ *work in progress*

- Differing predictions from event generators?
- Nuclear effects missing in nuclear model?
- Outdated vector form factors in R-S?
- Outdated Fermi Gas Model? (need LDA)
- $M_A^{1\pi}$?
- Axial form factors?
- ...

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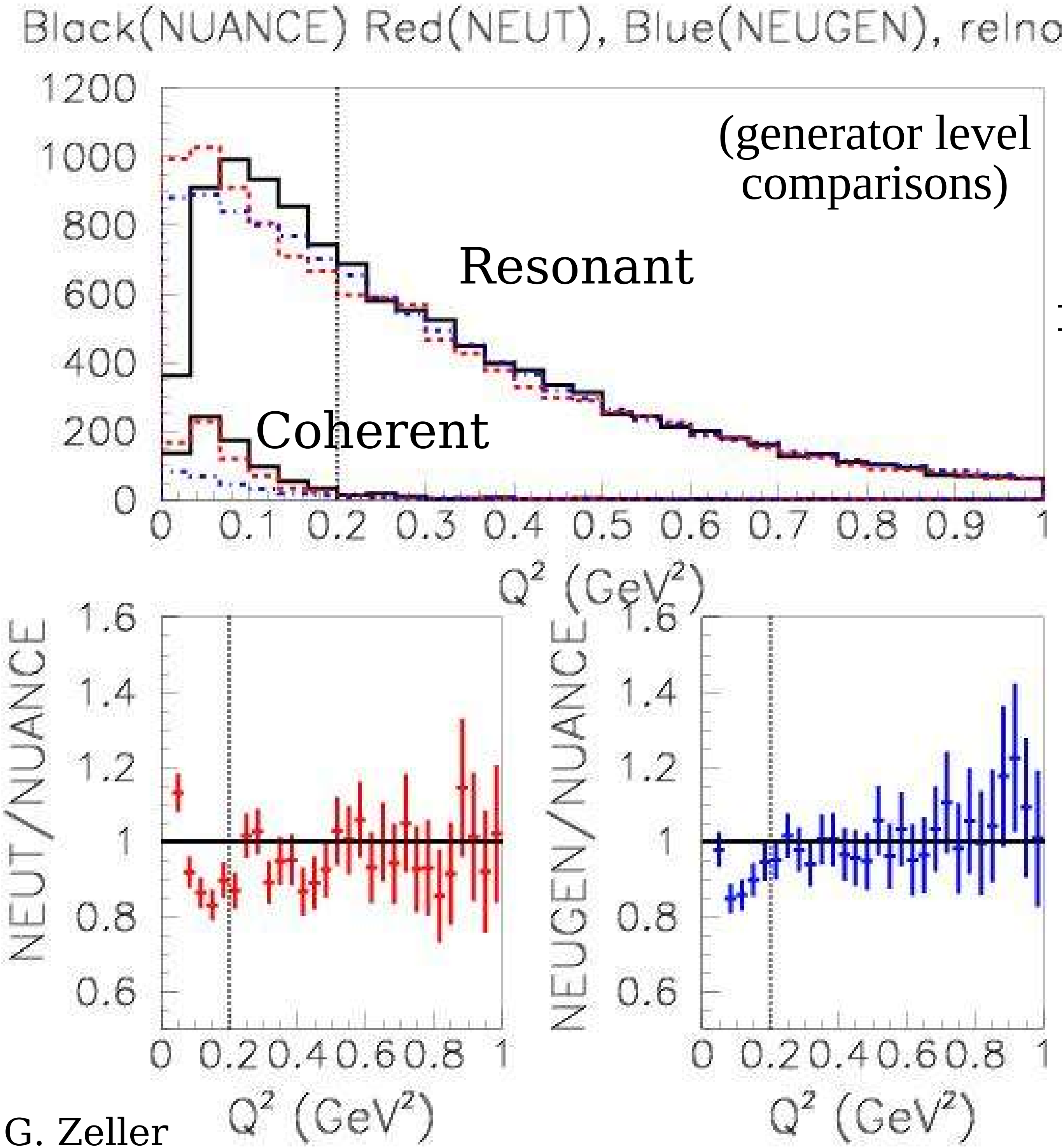
MC event generator "owners" prepared special samples using MiniBooNE flux for these comparisons

- NUANCE (Casper)
- NEUGEN (Gallagher)
- NEUT (Hayato)

generator level comparisons for starters......

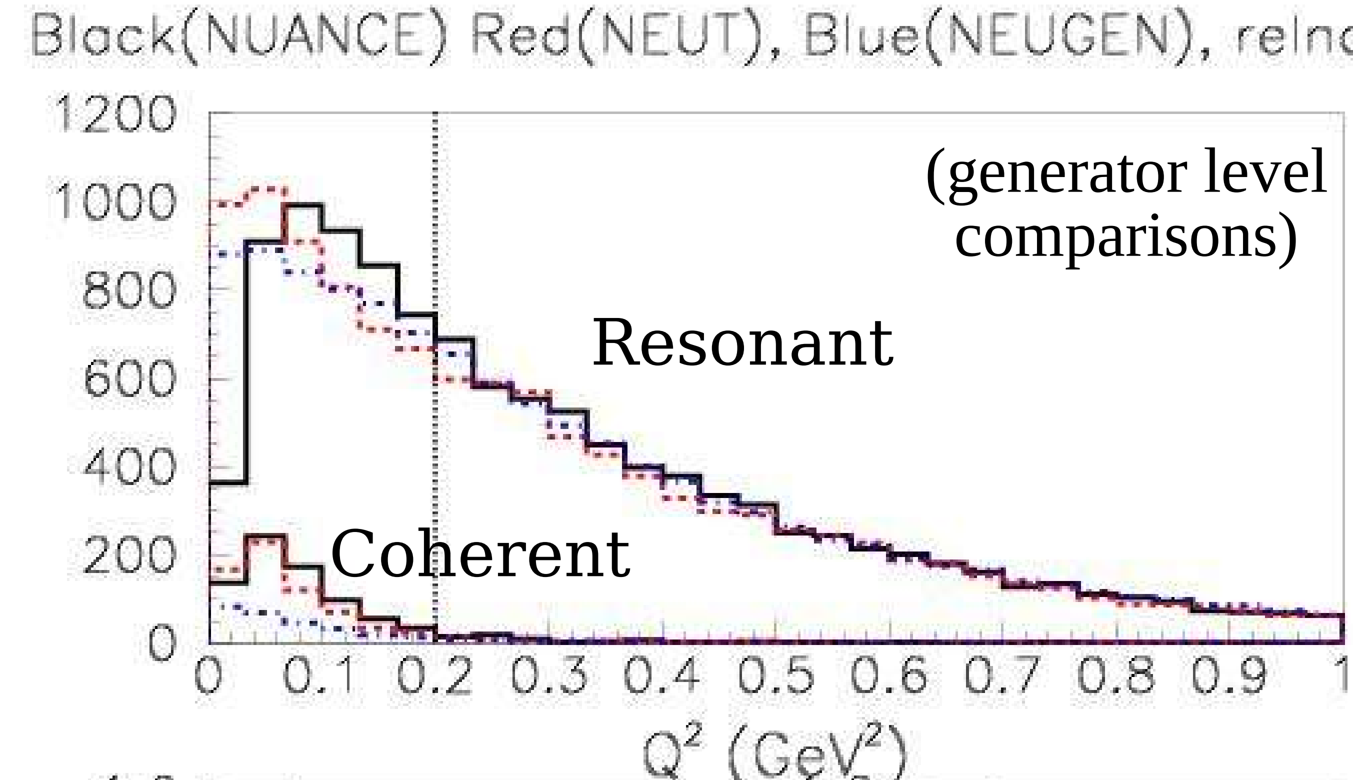


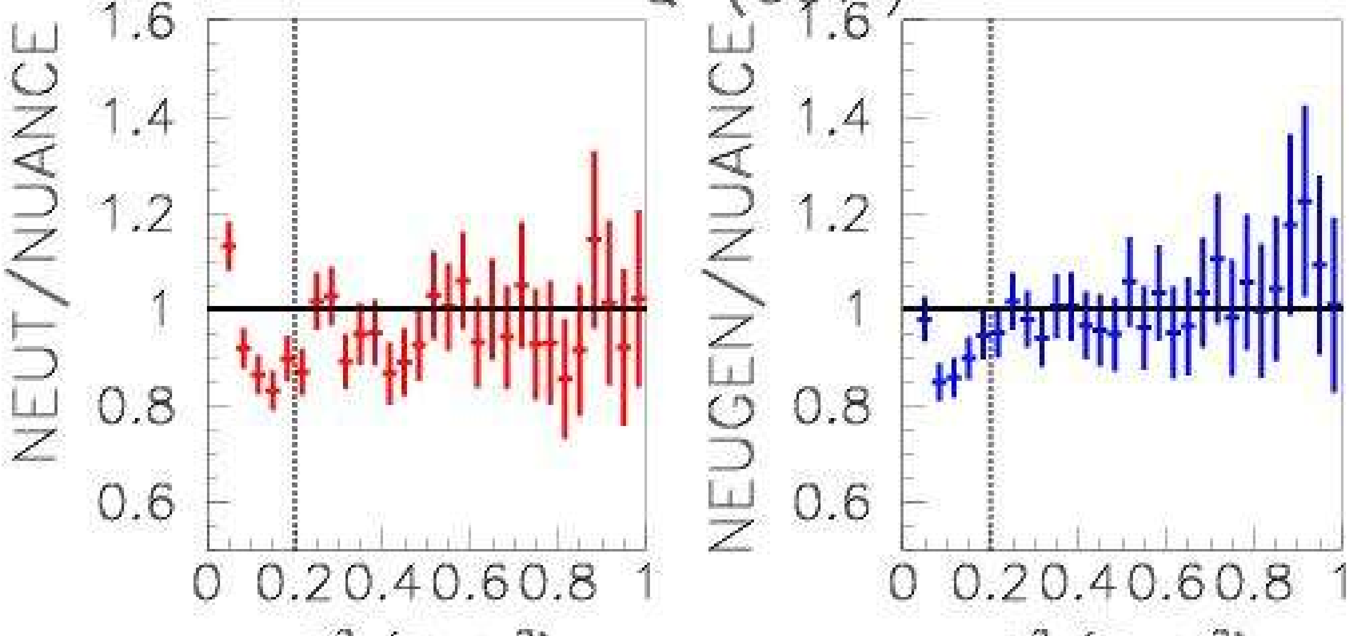
Look at differences in predictions for Q^2 distribution for NUANCE compared to NEUT and NEUGEN

All generators are R-S based

NEUGEN: extensive tuning using e scattering data

G. Zeller





G. Zeller

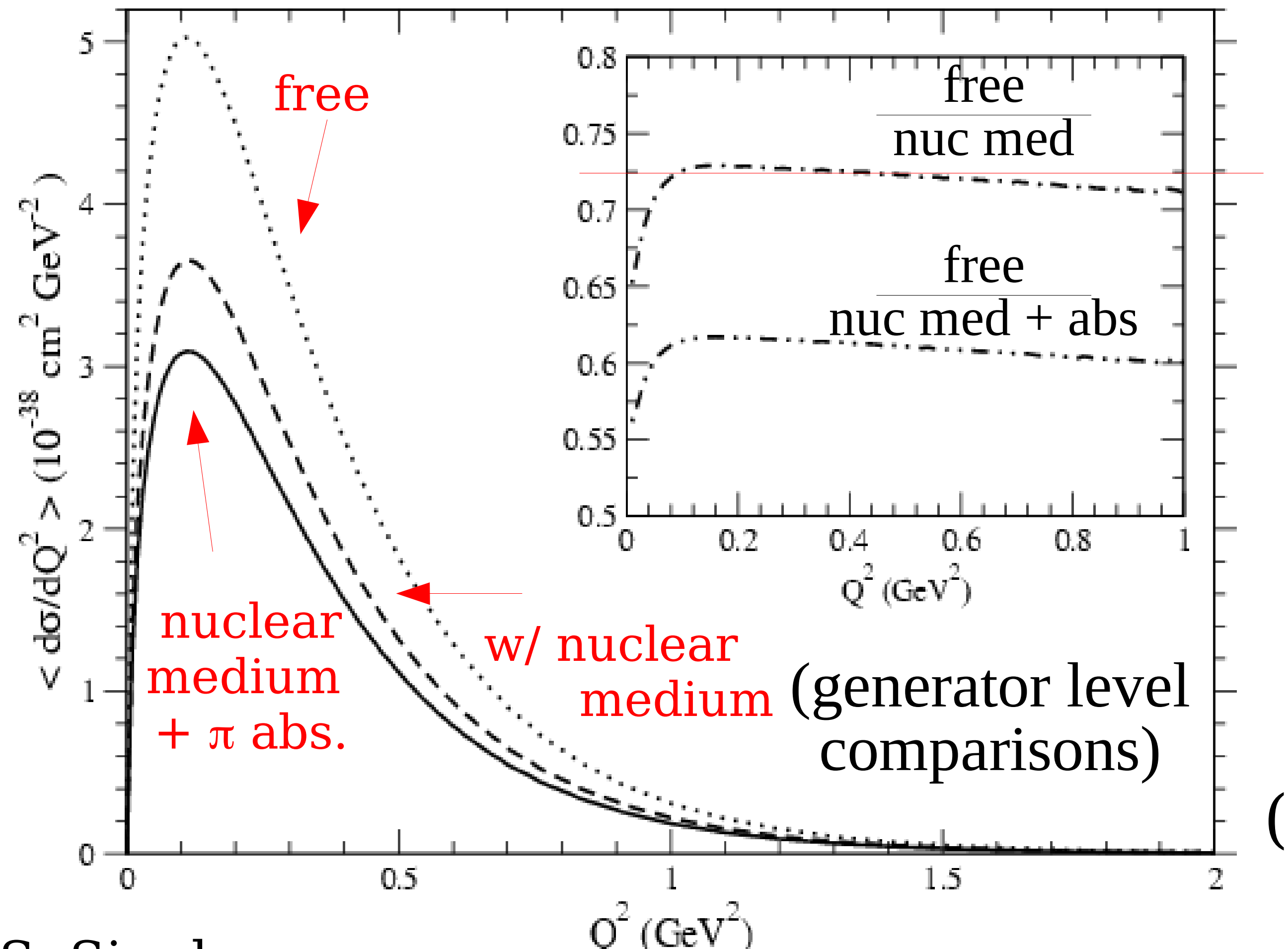
Look at differences in predictions for Q^2 distribution for NUANCE compared to NEUT and NEUGEN

Q^2 predictions are very similar

some differences below Q^2=0.2 GeV^2

Modeling of nuclear effects not understood?

Compare to Singh model integrated over MiniBooNE flux to get a feel for the effects of using different models....



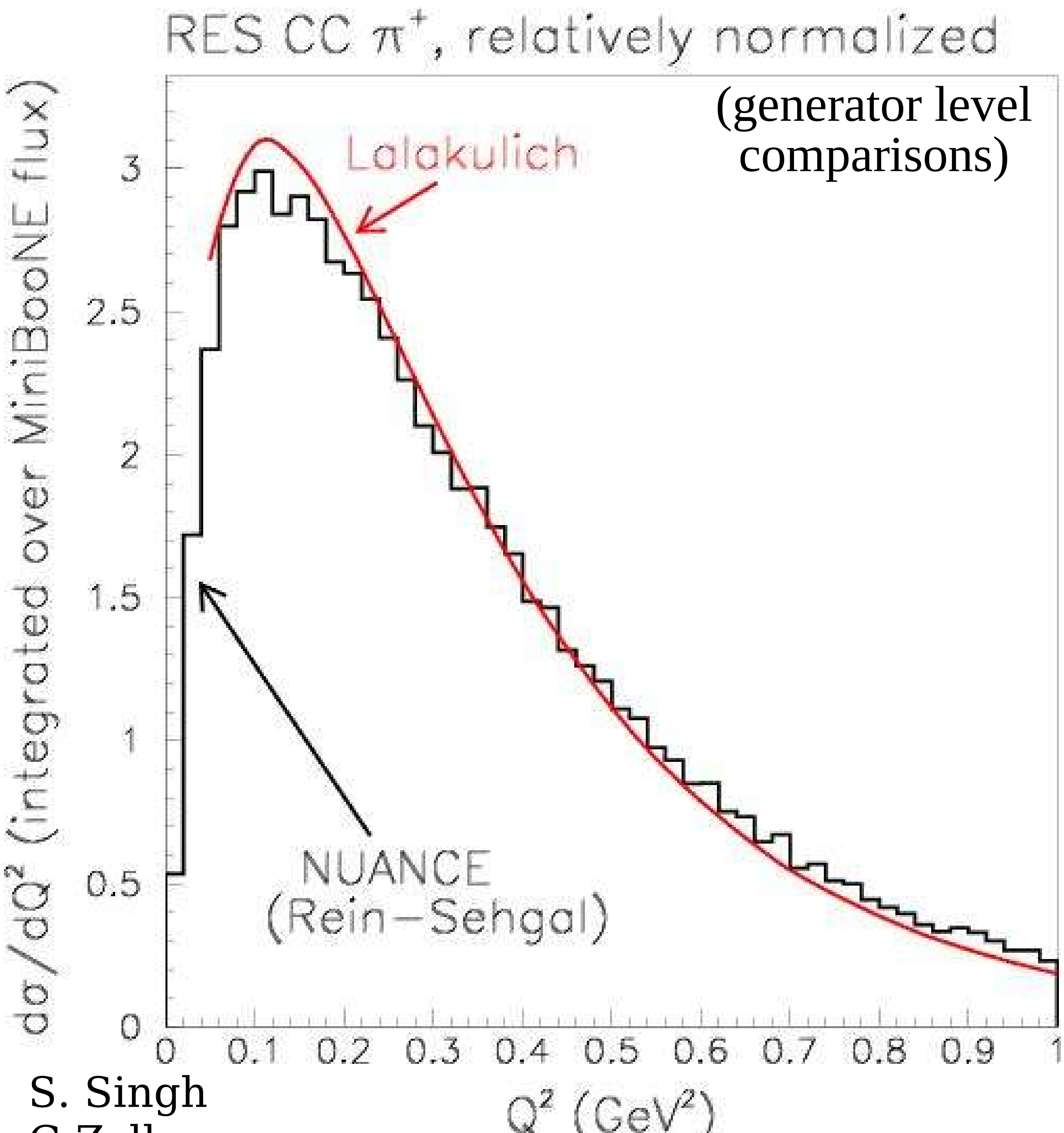
S. Singh

Supression due to nuclear effect is ~28%

fairly flat

relatively little suppression at low Q^2

(compare 7% to ~35%)



(generator level comparisons)

S. Singh
G.Zeller

Can different vector form factors make a difference?

Compare NUANCE (R-S) to Lalakulich (Rarita-Schwinger formalism coupled with extensive fitting to electro-production data)

Relatively normalized comparison

consistent with each other!

Understanding Q^2 dis-agreeement

→ *work in progress*

- Differing predictions from event generators?
- Nuclear effects missing in nuclear model?
- Outdated vector form factors in R-S?
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- $M_A^{1\pi}$?
- Axial form factors?
- ...

So far, no smoking gun --> still investigating.....

~1000 events so far from CCπ^+ interactions from (Wrong Sign) neutrinos in anti-neutrino mode

larger impurities from anti-nu channels

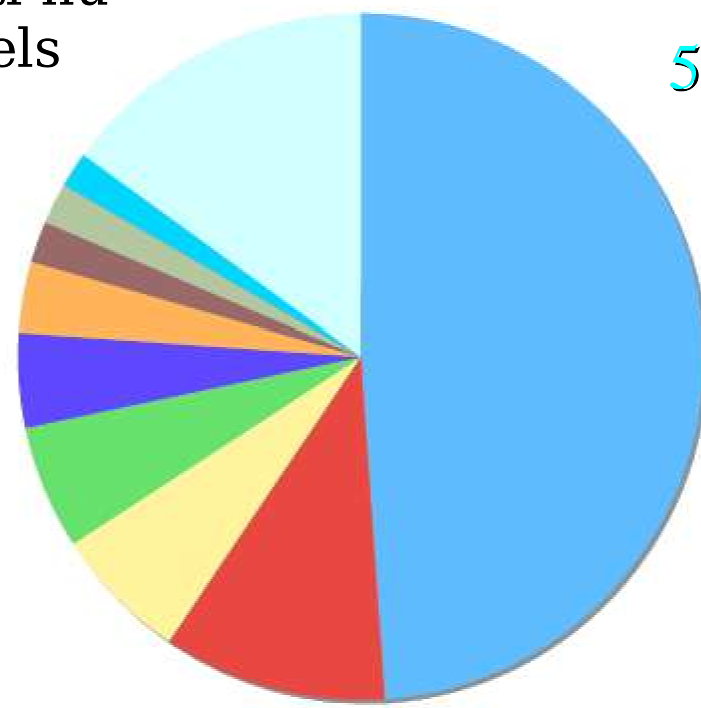
50% $\nu_\mu p \to \mu^- p \pi^+$

6.5% ν_μ n$\to$ $\mu^- p \pi^0$

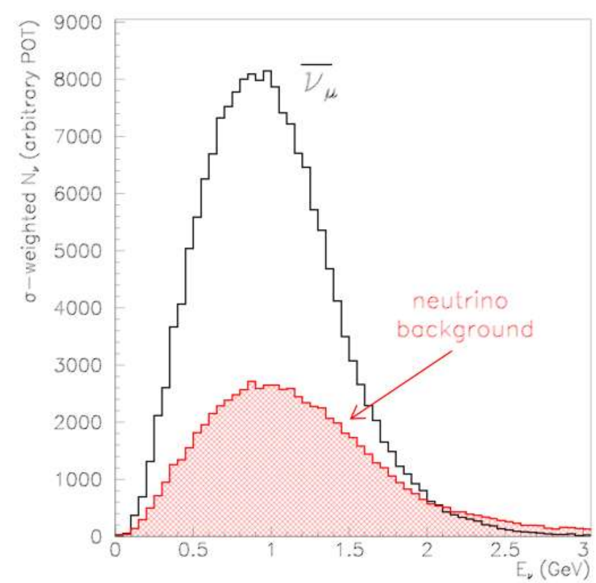
4.6% $\nu_\mu N \to \mu^- X$

5.9 % $\nu_\mu A \to \mu^- A \pi^+$

6.5 % ν_μ n$\to$ $\mu^- p$

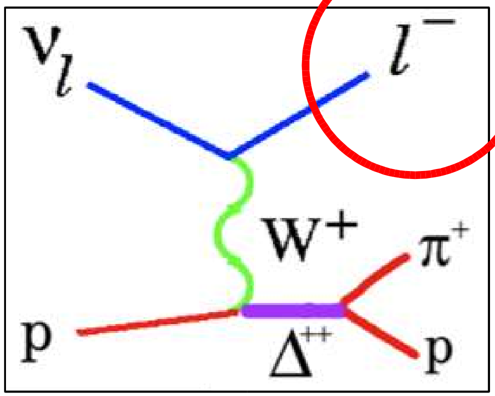


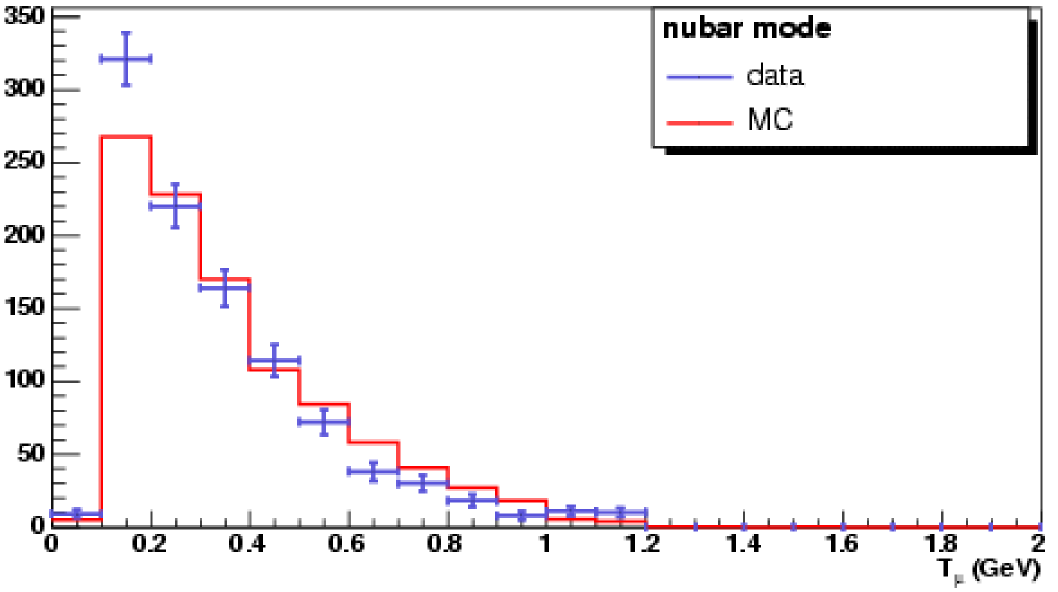
11% ν_μ n$\to \mu^- n \pi^+$



good check of WS content in anti-nu mode!

Anti-neutrino mode
CCπ^+ muon energy

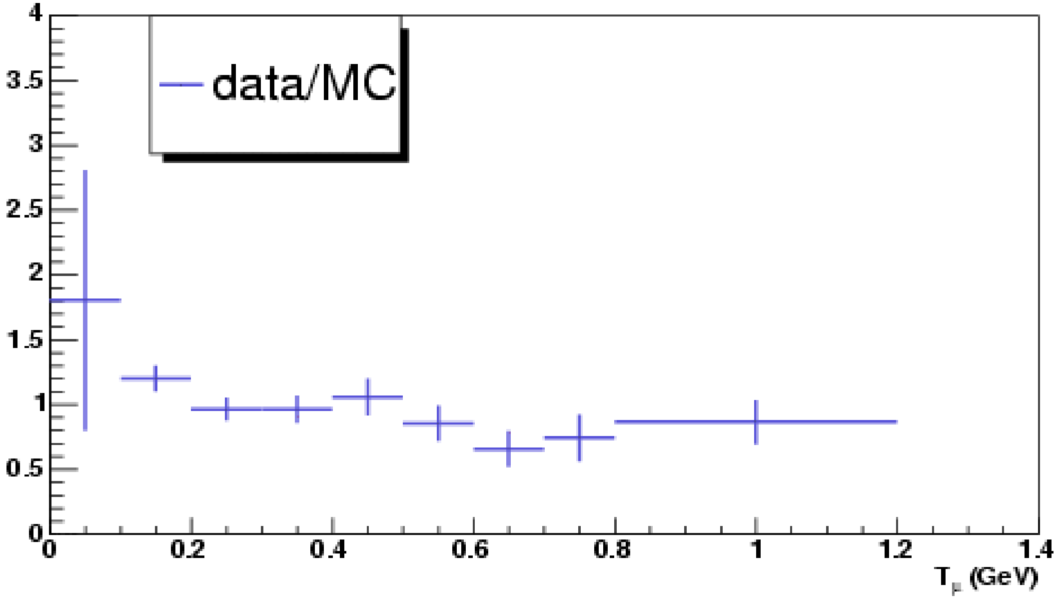




data compared to MC

↓

- Relatively normalized
- statistical errors only



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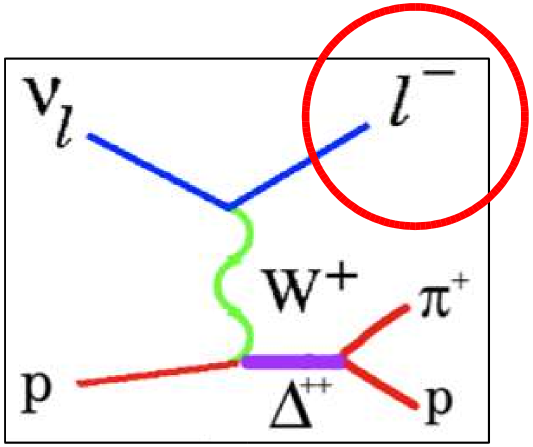
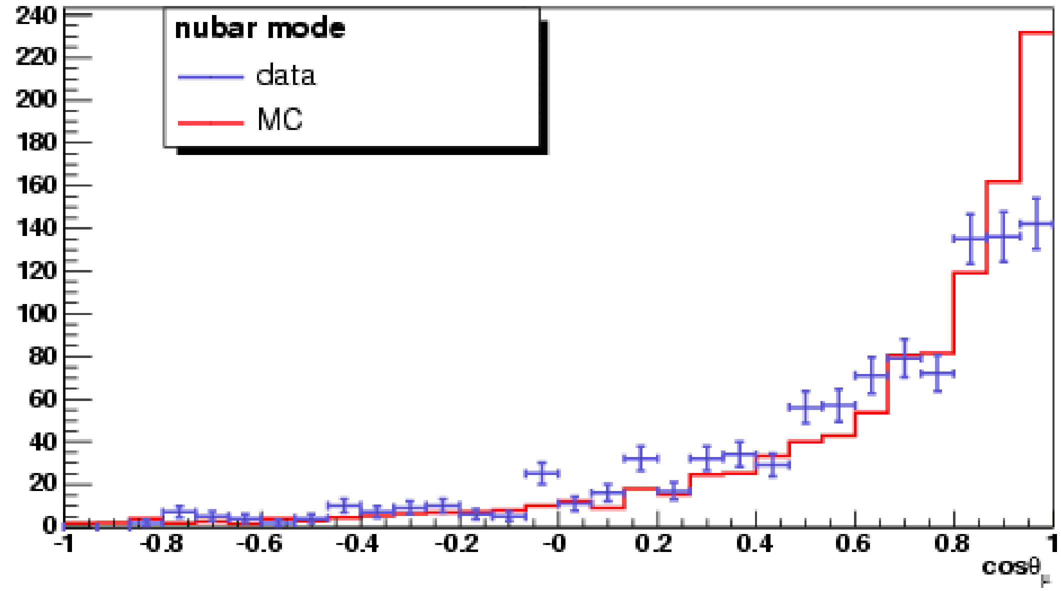
Anti-neutrino mode
CCπ^+ muon angle





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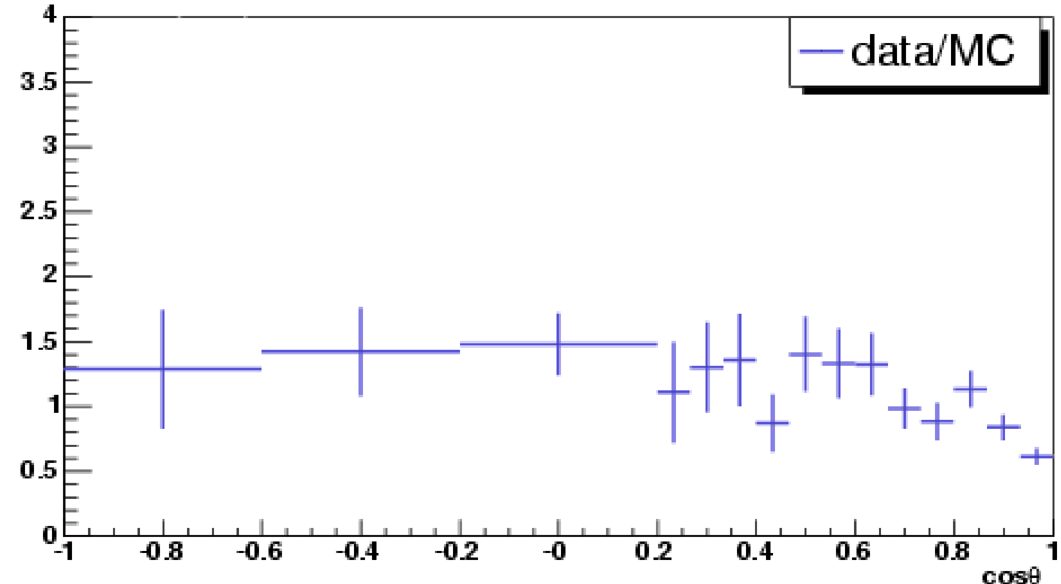

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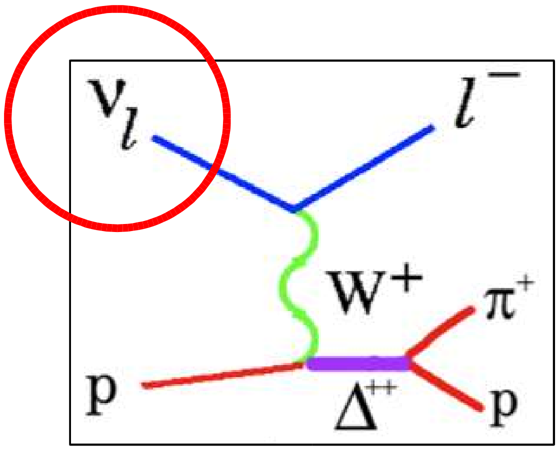
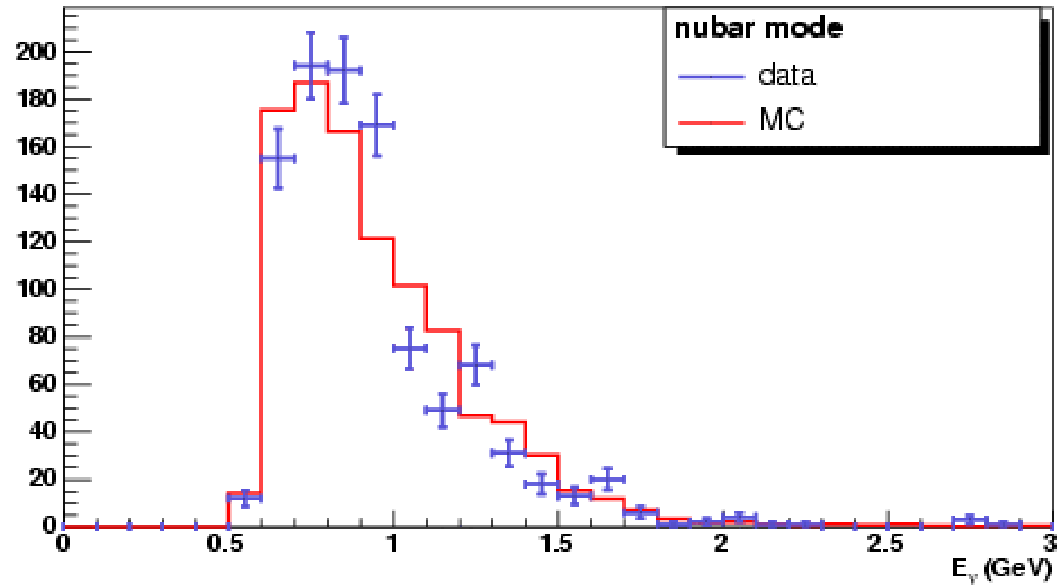
Anti-neutrino mode
CCπ^+ neutrino energy





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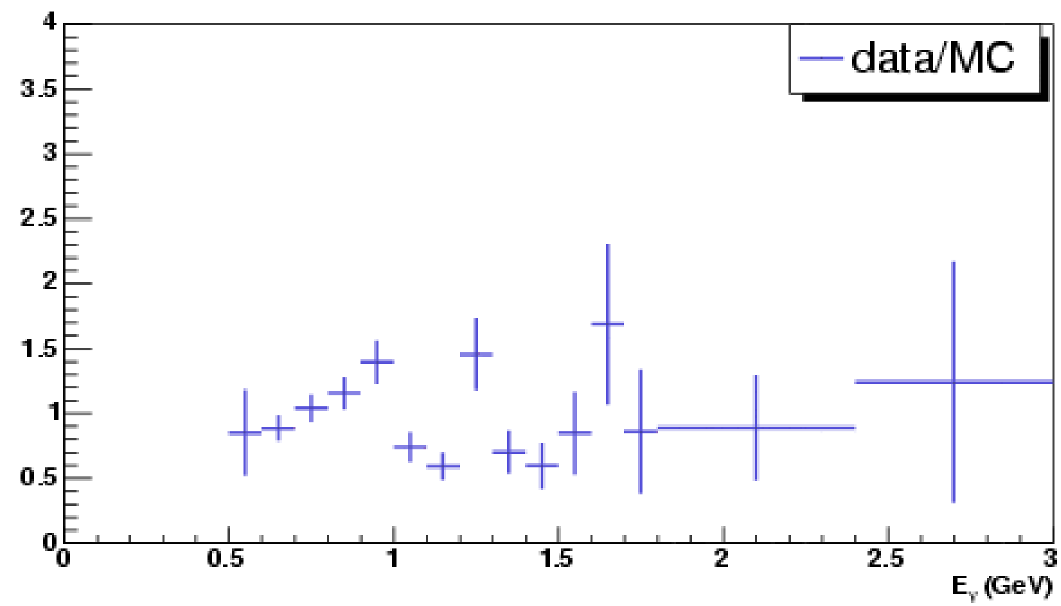

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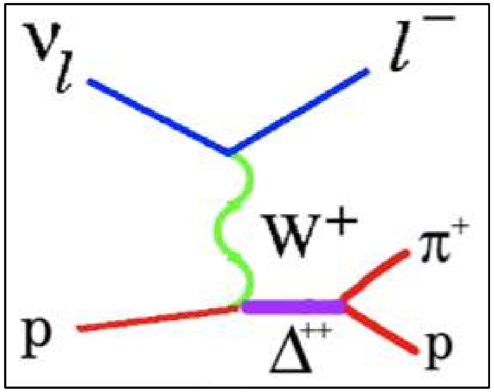
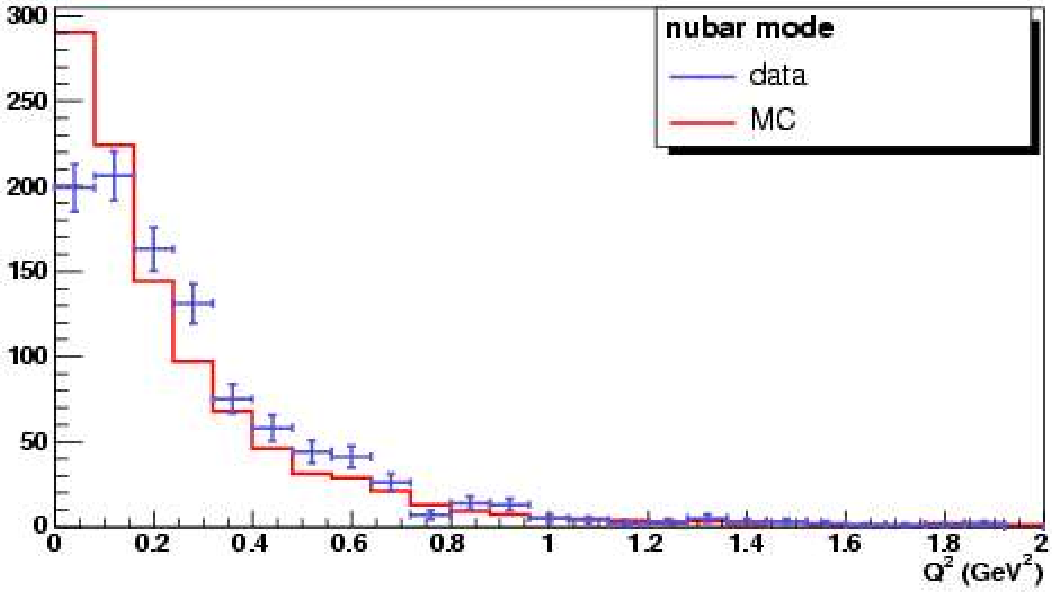
Anti-neutrino mode $CC\pi^+$ Momentum Transfer





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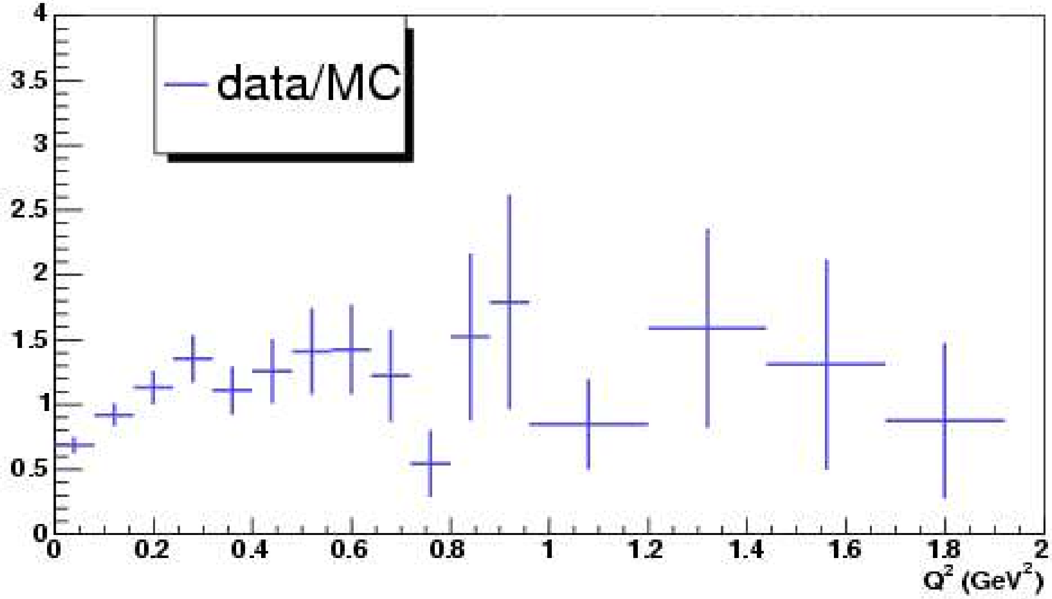

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Conclusions

- $CC\pi^+$ sample
  - ~70K events in neutrino mode!
  - working to understand Q^2 distribution
  - new data from anti-neutrino mode

- Ultimate Goals
  - $CC\pi^+$/CCQE ratio
  - $M_A^{1\pi}$ extraction
  - differential cross section
  - coherent contribution

Exciting time for cross section physics on MiniBooNE!