Summary
WG2: ν cross sections & detectors

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Statistics

- Total of 28 presentations
  - 2 plenary talks
  - 4 joint WG1+2
  - 4 joint WG1+2+3
  - 10 theoretical talks

Motivation

- *WG2 activity pursues a better understanding of ν cross sections in order to achieve the precision goals in neutrino oscillation measurements and to extract reliable information about the axial properties of the nucleon and baryon resonances*

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- Really?
- QE and Resonance models in most MC generators:
  - Relativistic Global Fermi Gas Smith, Moniz, NPB 43 (1972) 605
  - Rein and Sehgal D. Rein, L. M. Sehgal, Ann. Phys. 133 (1981) 79.

Motivation

- *WG2 activity pursues a better understanding of ν cross sections in order to achieve the precision goals in neutrino oscillation measurements and to extract reliable information about the axial properties of the nucleon and baryon resonances*
- Really?
- Now we know more (U. Mosel):
  - Properties of baryon resonances: p(e,e'), Mainz, JLab
  - Hadrons in the medium: γA, πA, etc
  - Nucleon optical potentials and spectral functions
  - MEC in A(e,e')

Motivation

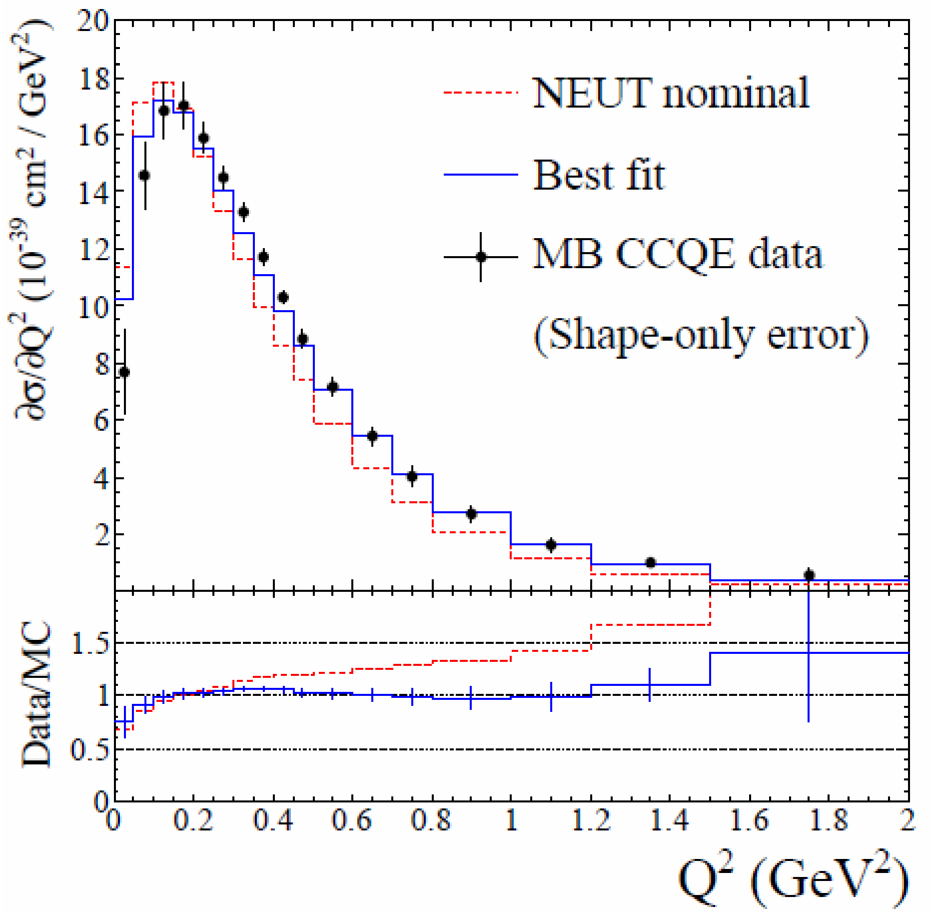
- Sound results in ν oscillation physics have been obtained without dramatic improvement of MC:
  - MC tuning
  - Near Detectors

MC tuning for T2K

- P. Rodrigues
- NEUT tuned to fit world data on relevant c.s. for T2K
- Uncertainties set from fits to MiniBooNE data
- SciBooNE, K2K datasets used as cross check
- Ad hoc parameters if necessary for data/MC agreement

MC tuning

- P. Rodrigues
- NEUT tuned to fit world data on relevant c.s. for T2K
- Uncertainties set from fits to MiniBooNE data
- Example: CCQE



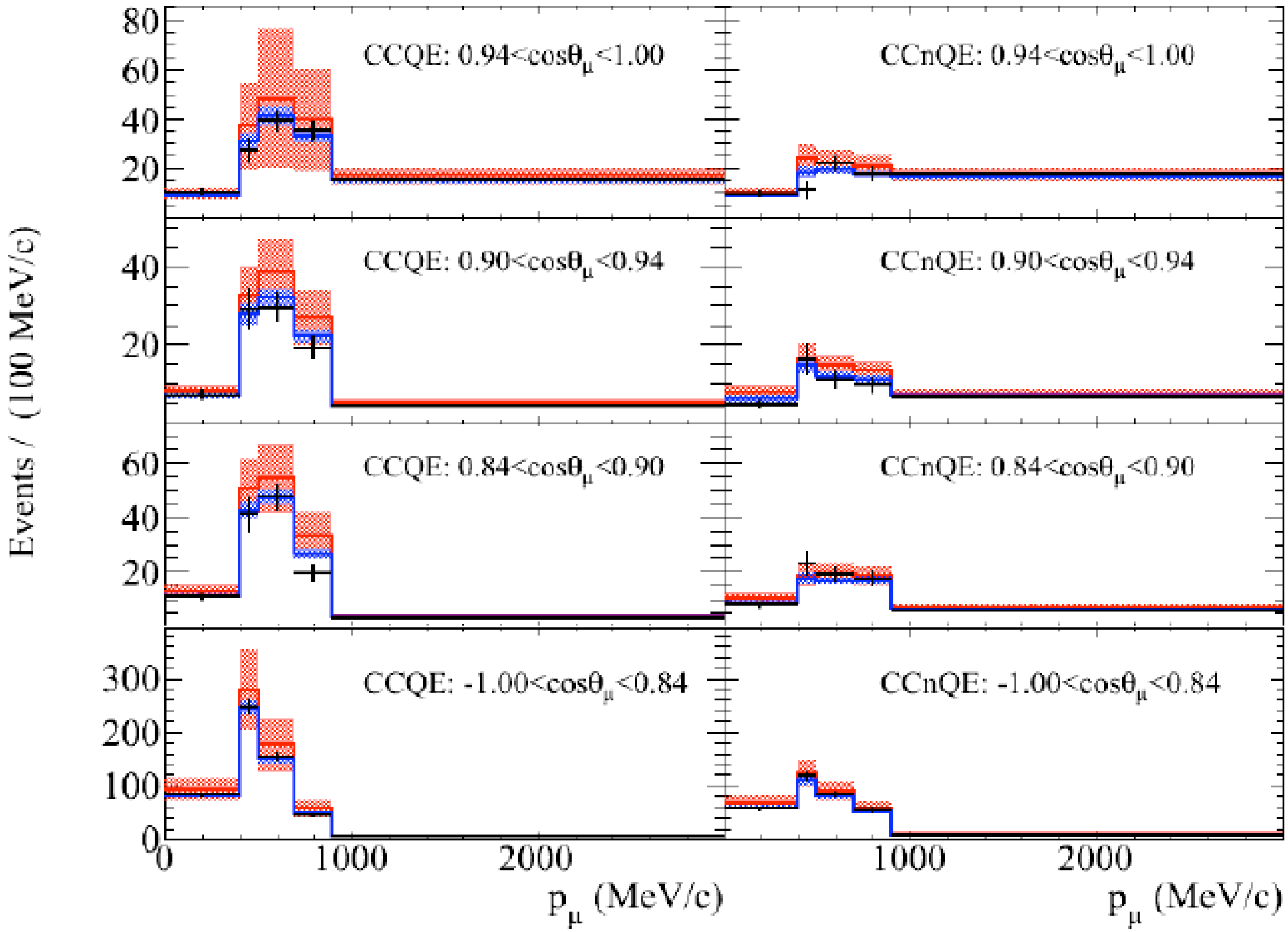
$$M_A = 1.64 \pm 0.04 \text{ GeV}$$

Taking $G^n_E \neq 0$ will reduce M_A (suggested by A. Bodek)

Systematic effects in T2K

- K. Mahn

without ND information
with ND information



- Total systematic uncertainty from ν_e appearance:

  22 % $\rightarrow$ 10% after ND measurement

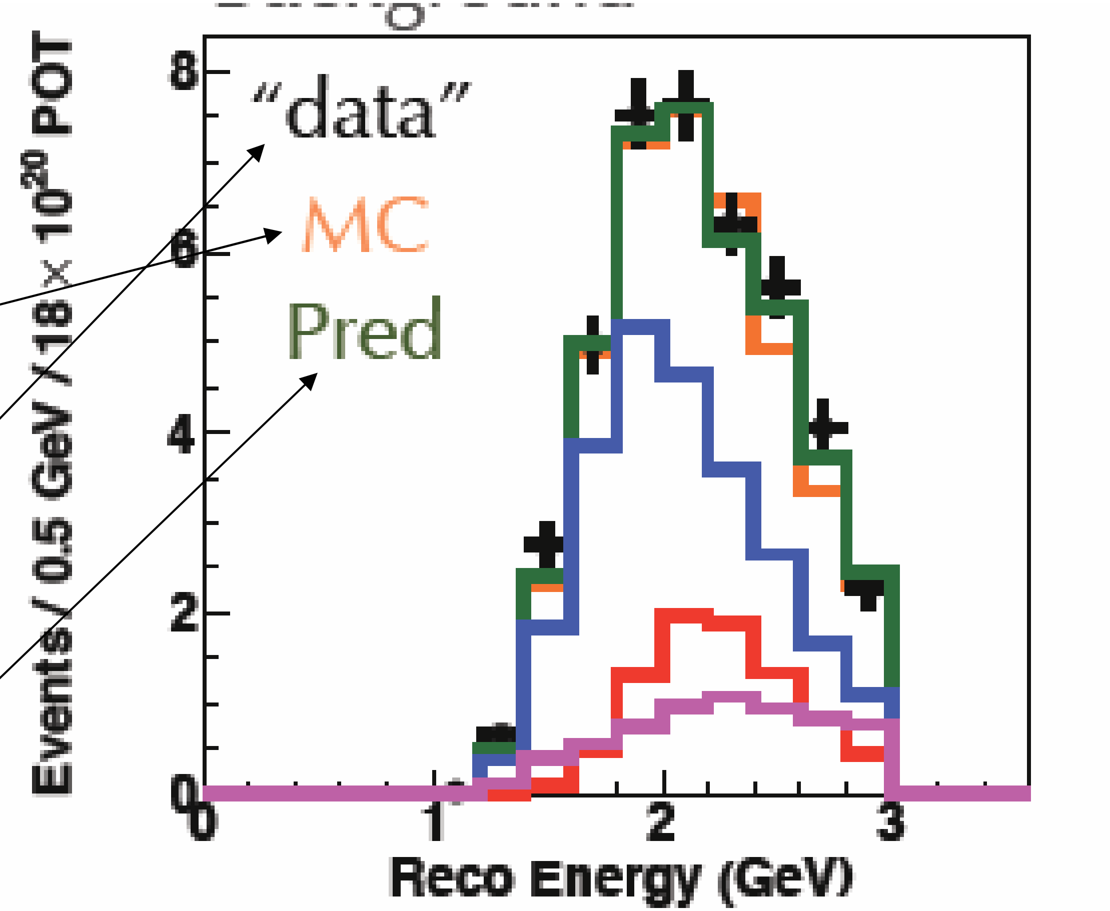
Systematic effects in NOVA/MINOS

- M. Sanchez

- The **neutrino interaction systematic errors** are modified in this study:
  - **Cross-section:** M_A(QE) and M_A(RES) varied by ± 20%.
  - **Hadronization model** changes:
    - The π^0 selection probability in the hadronization model changed by ± 33%.
    - Change in average P_t resulting in broader showers.
    - Re-weighting P_t and X_f distributions of hadron distribution.
  - **Intranuclear** formation zone changed by ± 50%.
- These **systematics should mostly cancel**, however they can be affected by **Far/Near detector differences**.
  - We expect the most significant of them to be:
    energy spectra, light levels and event energy containment.

Systematic effects in NOVA/MINOS

- M. Sanchez
- Procedure for evaluating systematics in MINOS/NOVA
- **Standard MC**
- Shifted MC = “mock data”
  - **FD mock data**
  - **FD prediction from ND mock data**
- **Conclusion: ND mock data takes out systematic shifts**



Shift here altered shower shape

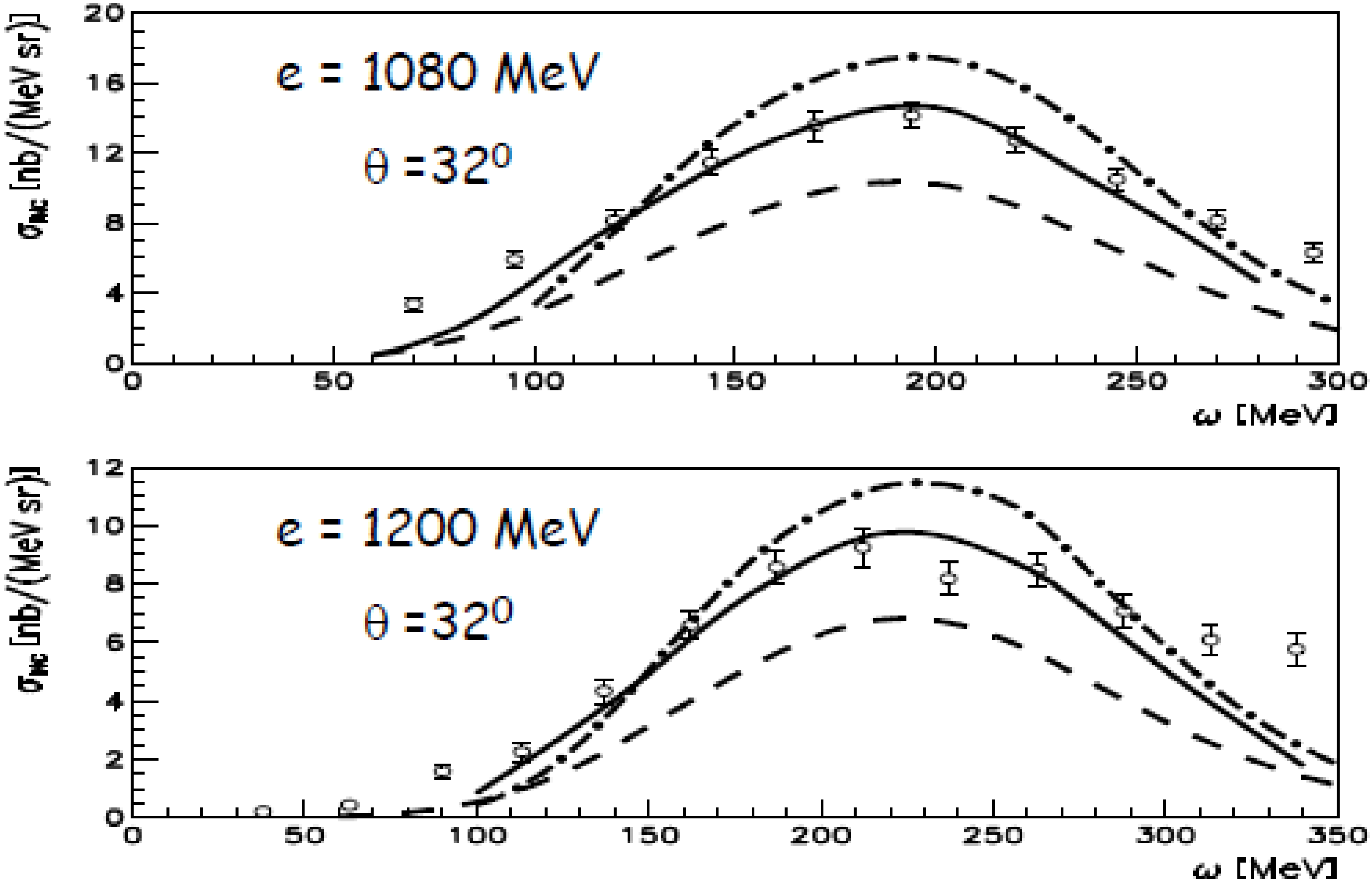
Motivation

- Sound results in ν oscillation physics have been obtained without dramatic improvement of MC:
  - MC tuning
  - Near Detectors

- Large $\theta_{13} \Rightarrow$ systematic effects (and c.s.) will be crucial to establish CP violations
- Perhaps some theory input is needed…

Theoretical approaches to QE scattering

- C. Giusti
- Green function approach with phenomenological (complex) optical potentials for the final nucleon

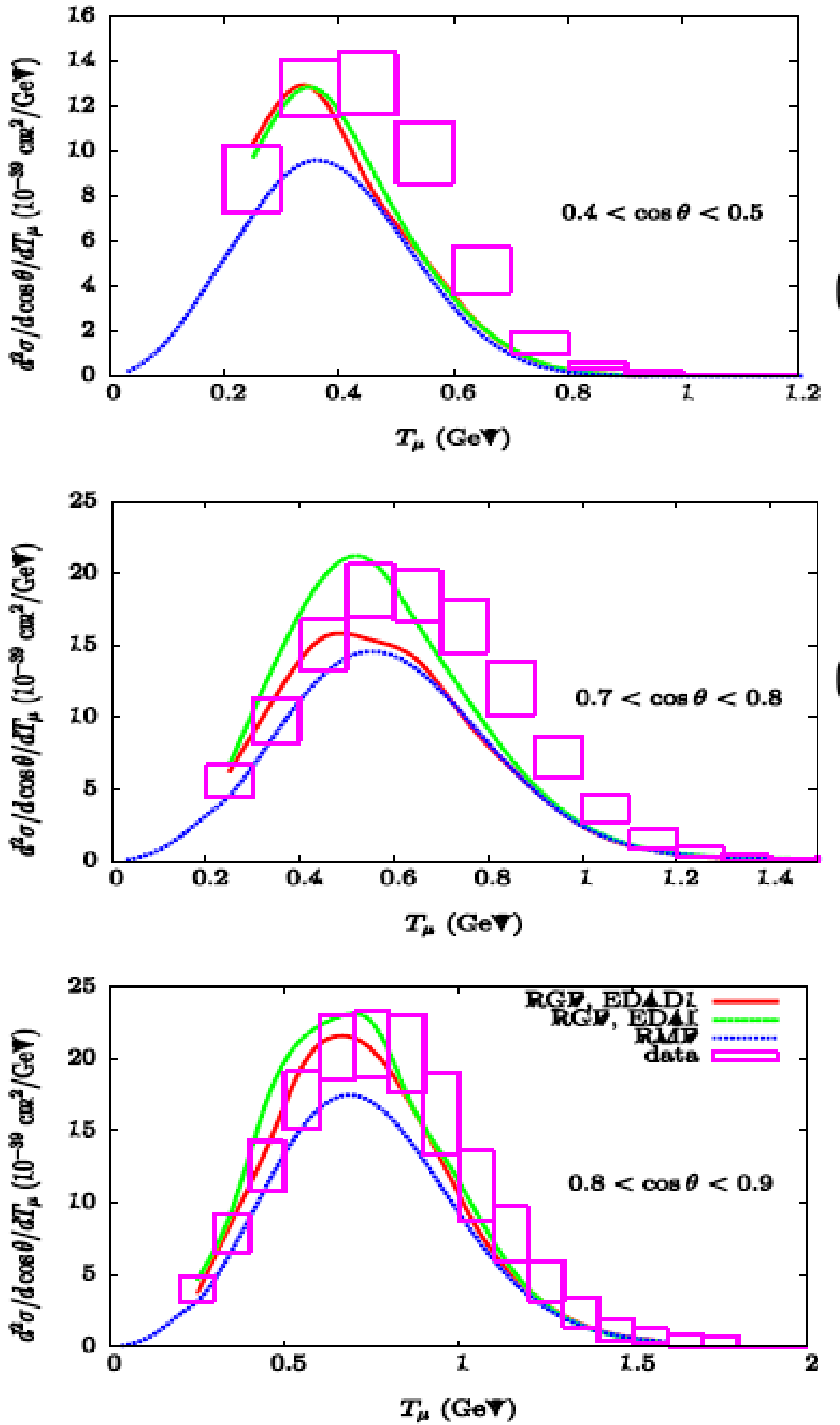


$^{16}O(e,e')$

- Excellent agreement at the QE peak

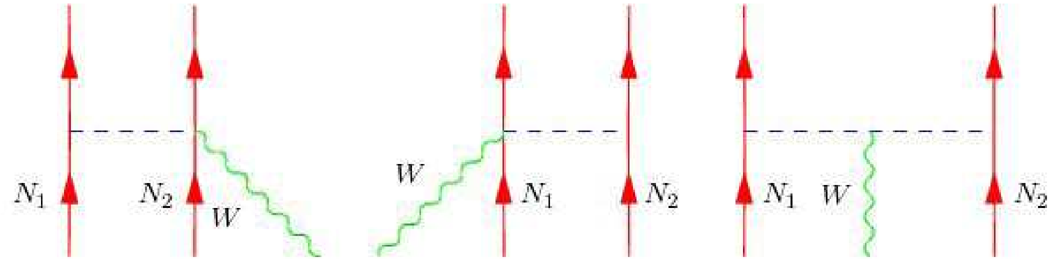
Theoretical approaches

- C. Giusti
- Green function approach with pl
(complex) optical potentials for t
- Comparison to MiniBooNE:
- Results depend on the V_{opt} parametrization
- Some 2p2h contributions contained in V_{opt}

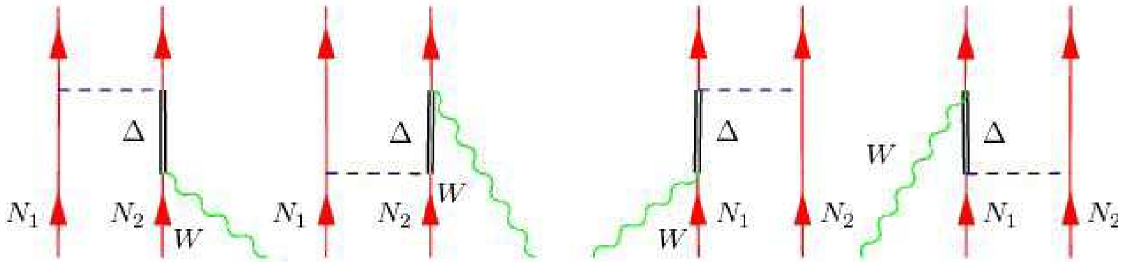


Theoretical approaches to QE scattering

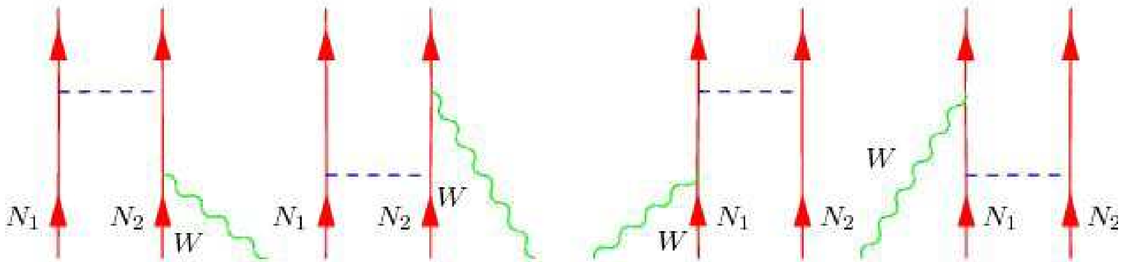
- J. Sobczyk
- 2p2h contributions to νA (Martini, Nieves, Amaro et al.)



Contact and *pion-in-flight* diagrams



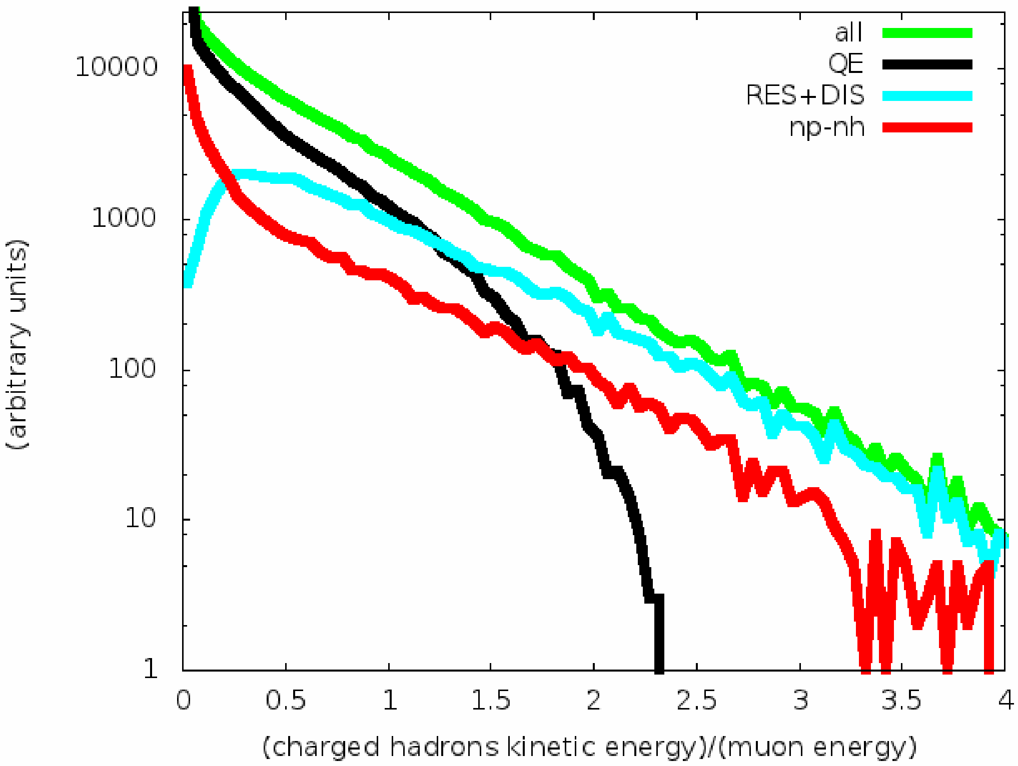
Δ-Meson Exchange Current diagrams



Correlation diagrams

Theoretical approaches to QE scattering

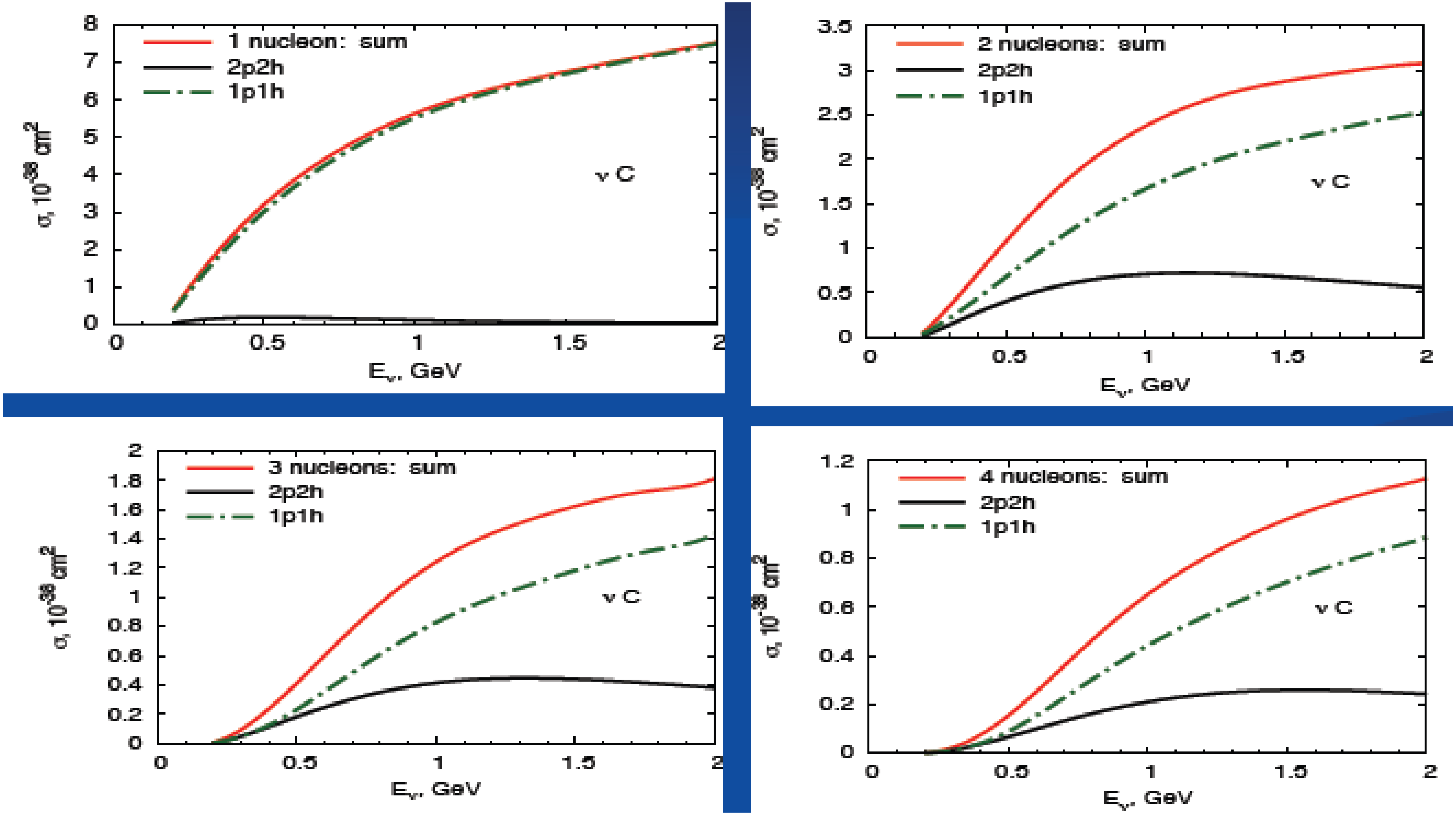
- J. Sobczyk
- 2p2h contributions to νA (Martini, Nieves,Amaro et al.)
- Can they be isolated by looking at the nucleons in the final state?



- FSI are very important
- Idea 1: Observe a pair of knocked out protons
- Idea 2: Integrated proton kinetic energy

Theoretical approaches to QE scattering

- U. Mosel



- Large contributions from single nucleon (+FSI)
- Difficult to observe

Theoretical approaches to QE scattering

- H. Gallagher

Conclusions

Tuning and validation of GENIE 2.8.0 underway.

Utilizes data from electron, neutrino and hadron scattering experiments. Makes much use of neutrino data and theoretical work of the last five years.

New models:

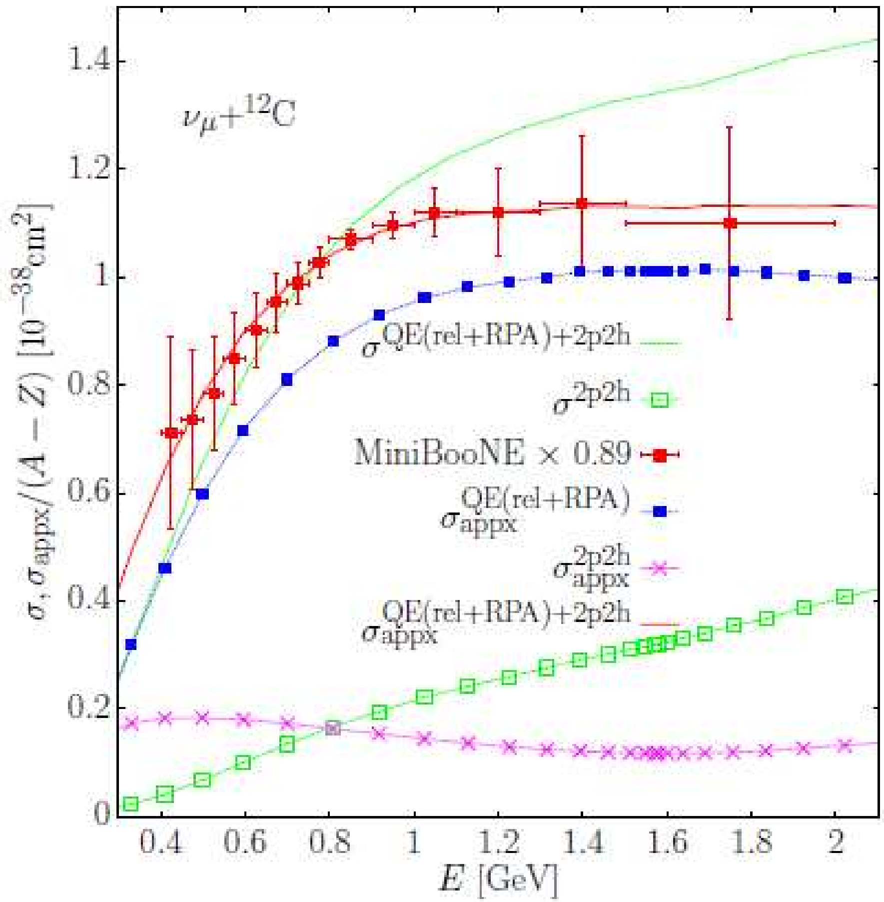
- *np-nh scattering*
- *new intranuclear rescattering model (hA)*
- *spectral functions*

Theoretical approaches to QE scattering

- Model 1: Fermi Gas with M_A = 1.35 GeV
- Model 2: Fermi Gas with M_A = 1 GeV + 2p2h

$\Rightarrow$ (basically) same $< d^2\sigma/dE_\mu d\cos\theta_\mu >$

$\Rightarrow$ very different reconstructed E_ν



Ruiz Simo

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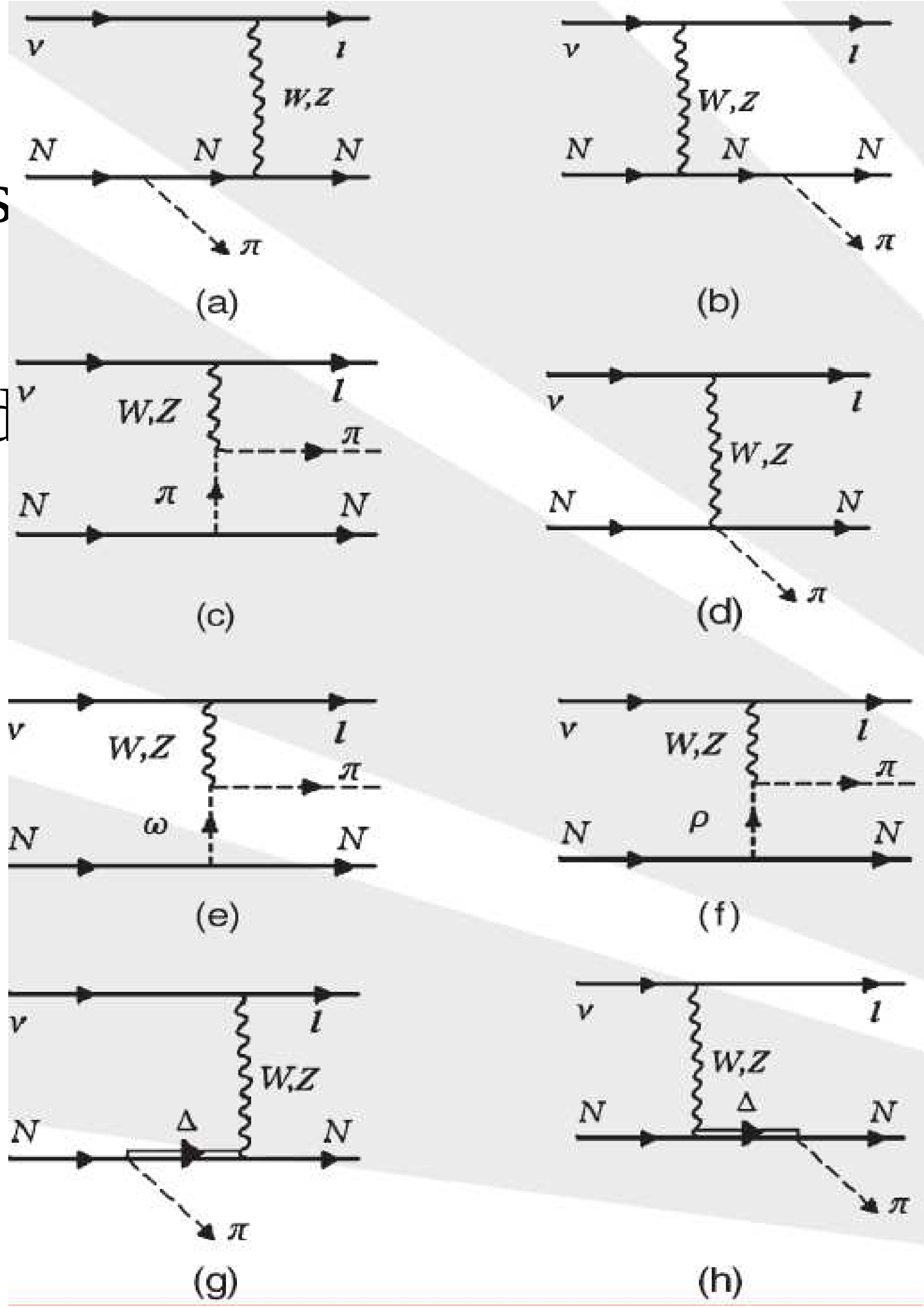
Theoretical approaches to π production

- A. Mariano
- $\nu N \rightarrow l^- \pi N'$ at low energies
- dominated by $\Delta(1232)$
- threshold behavior determined by chiral symmetry
- Limited by lack of exp. info to constrain N-$\Delta(1232)$ axial ff (ANL, BNL data)

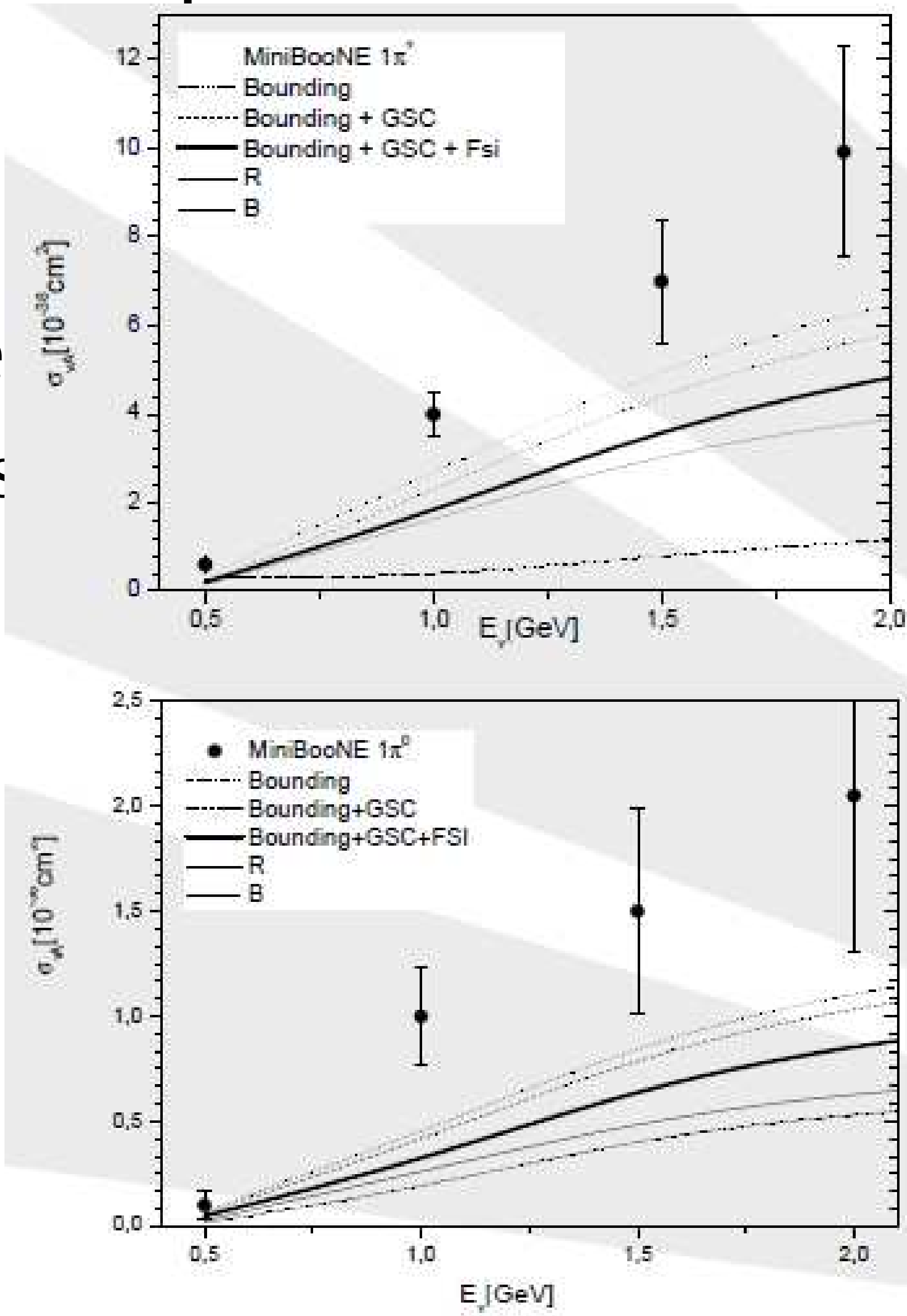


Theoretical approaches to π production

- A. Mariano
- $\nu A \rightarrow l^- \pi X$
- Elementary amplitude + Δ in the medium + FSI
- In a toy FSI model (eikonal π absorption)

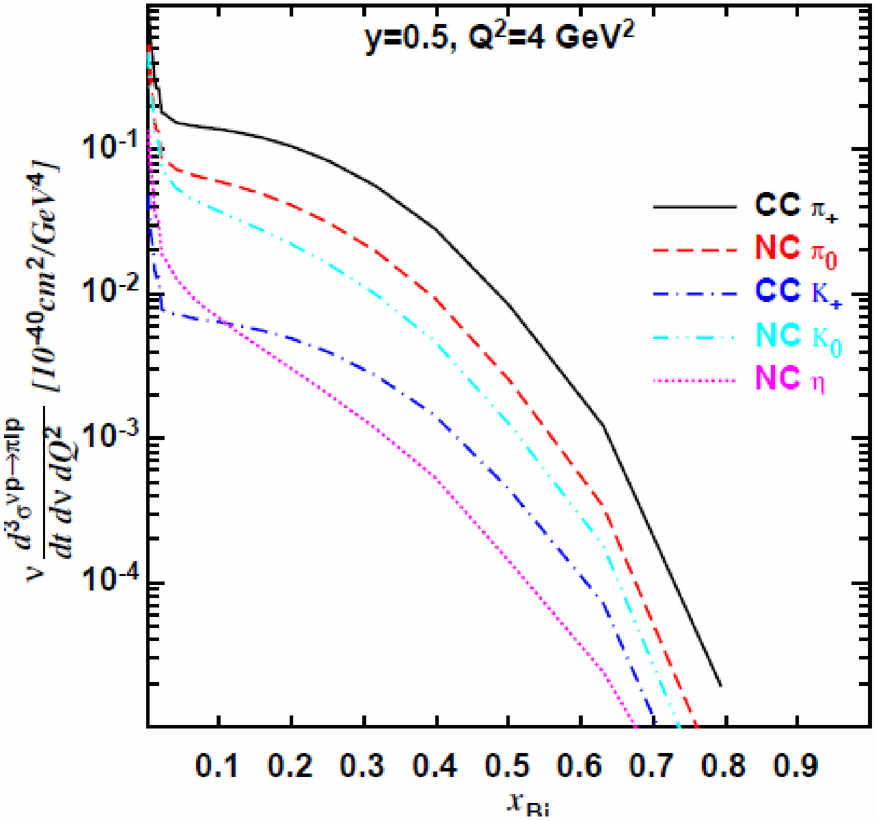
Theoretical approaches to π production

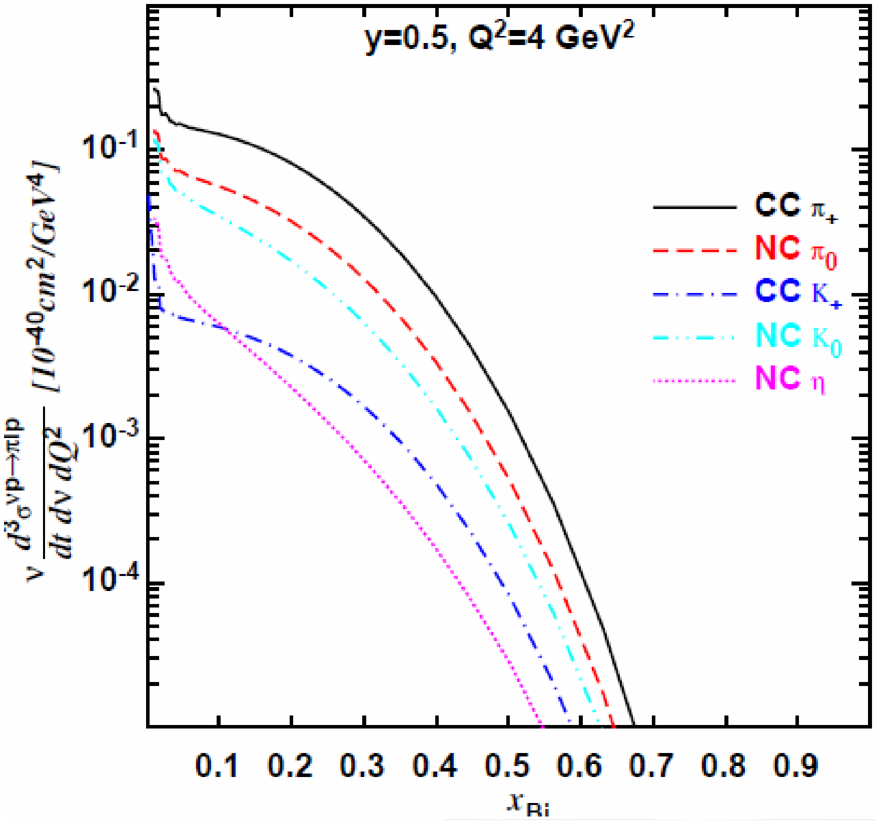
- A. Mariano
- $\nu A \rightarrow l^{-} \pi X$
- Elementary amplitude + Δ in the
- In a toy FSI model (eikonal π abs
- MiniBooNE data understimated
- Also in GiBUU
- 2p2h1π ?



Diffractive meson production

- M. Siddikov
- meson = π, K, η (in the Bjorken regime)
- probe the flavor structure of the GPD
- axial contributions to H, E, complement to HERA, JLab
- estimates with different GPD models:





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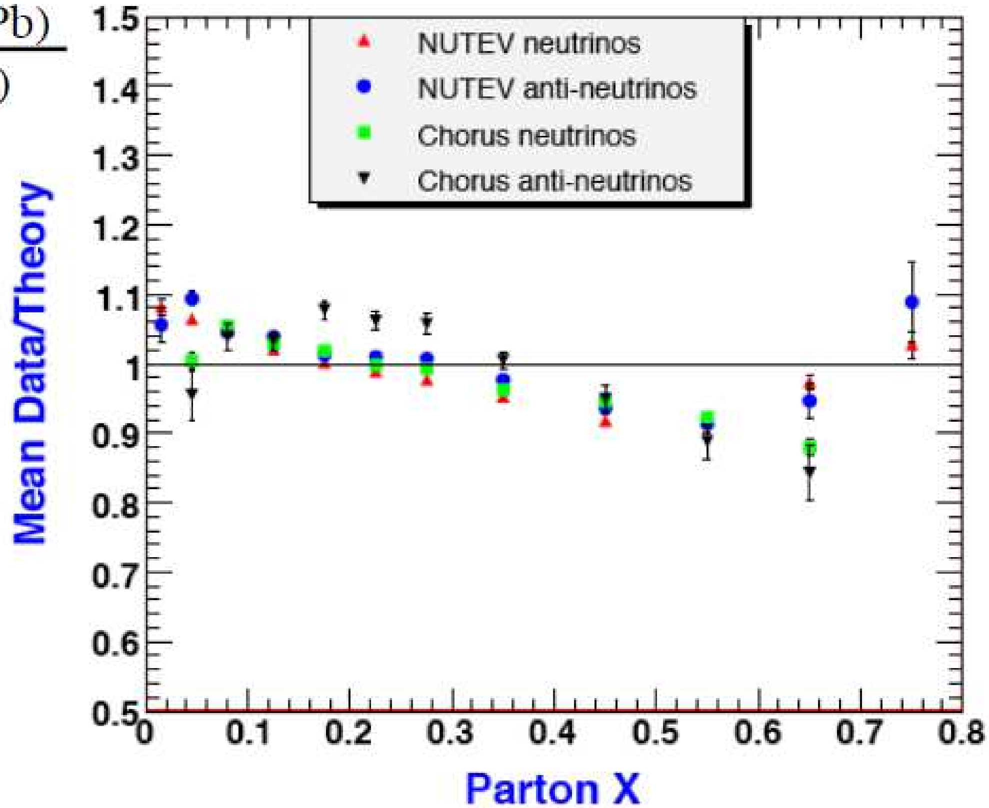
ν DIS

- J. Morfin
- Parton distribution functions within a nucleus are different than in an isolated nucleon (known from eA)
- Nuclear effects should be different in νA because of the axial current

$$\frac{\sigma(\nu\text{Fe or }\nu\text{Pb})}{\sigma(\nu\text{"n+p"})}$$



no nuclear corrections

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ν DIS

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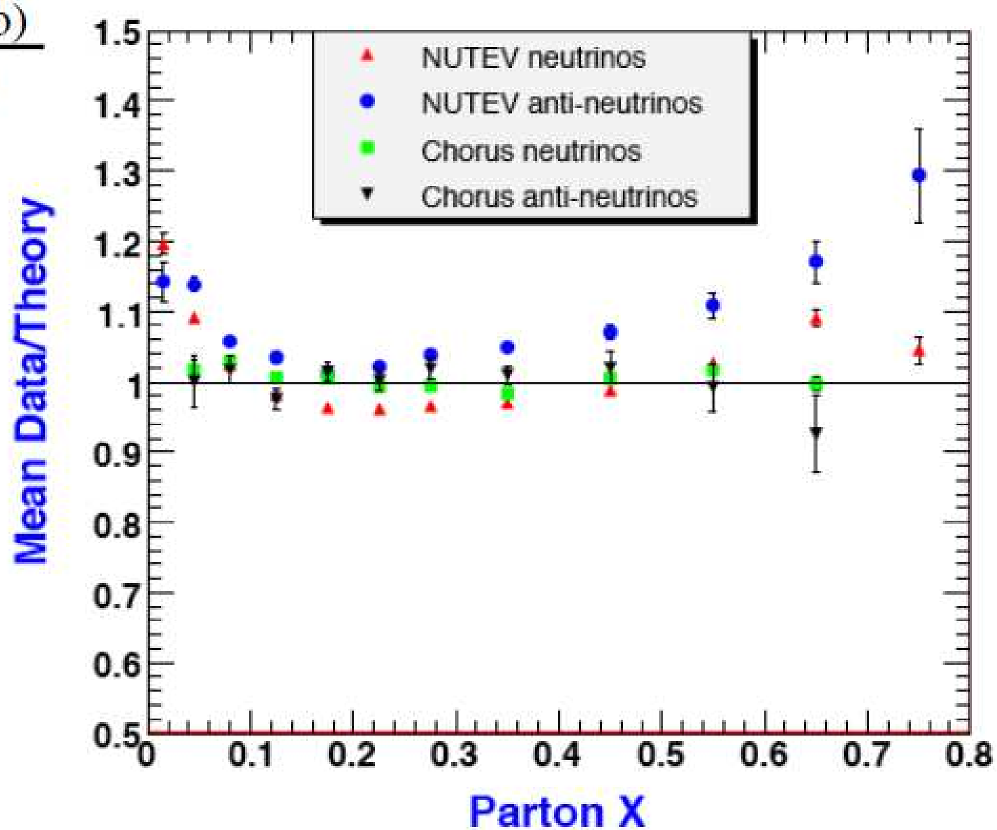
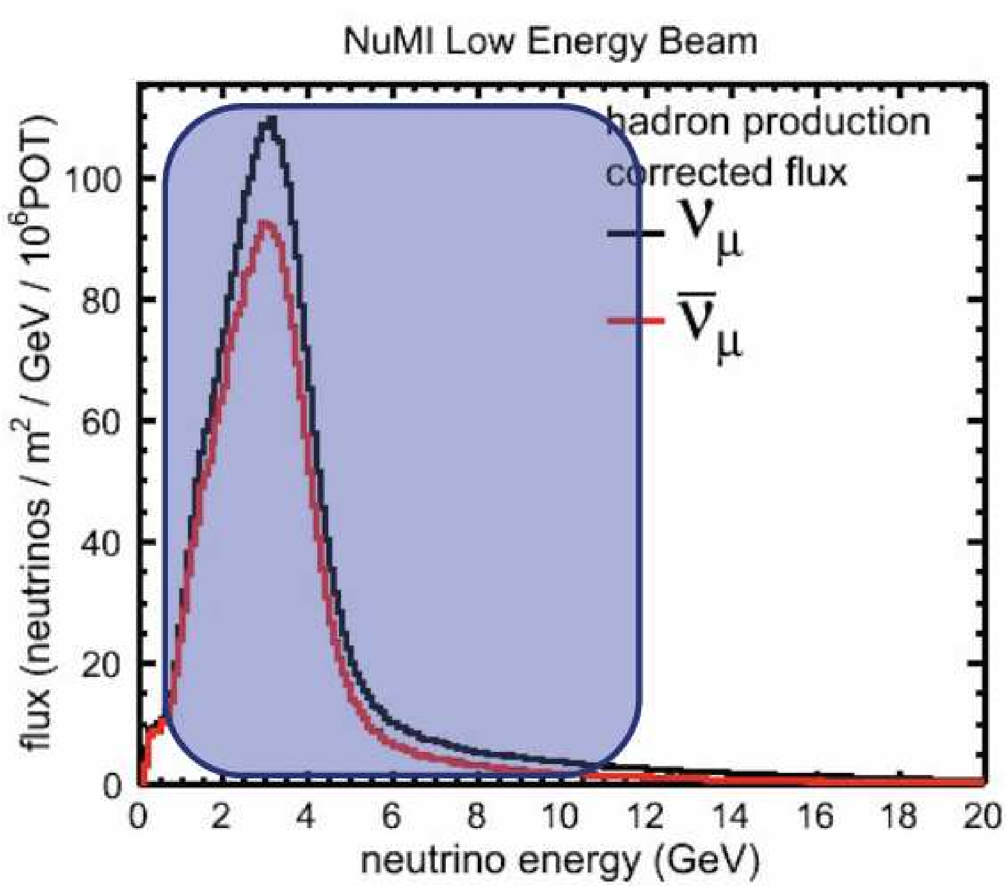


Kulagin-Petti nuclear corrections make the agreement worse

Further info from Minerνa

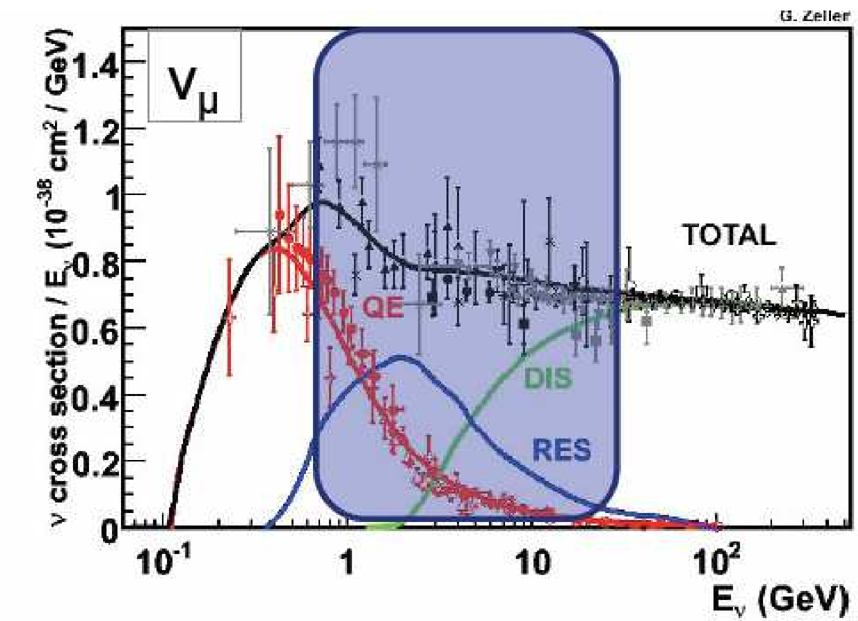
Mineνa in the Low Energy NUMI beam

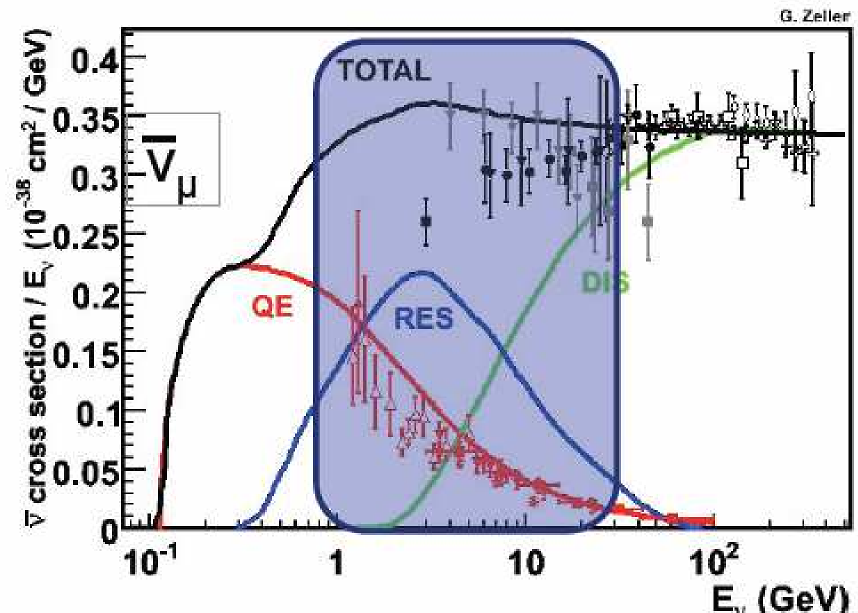


Data collected:

ν_μ LE 3.98x10^{20} POT

$\bar{\nu}_\mu$ LE 1.7x10^{20} POT



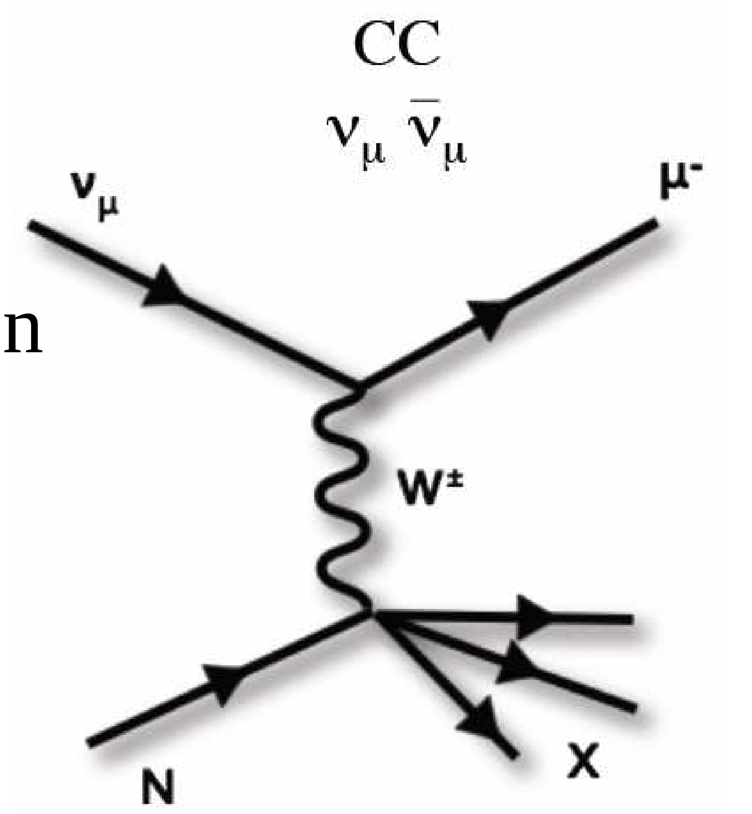


Talks by: J. Morfin, J. Chvojka, J. Park, B. Eberly

Minerνa inclusive CC cross section

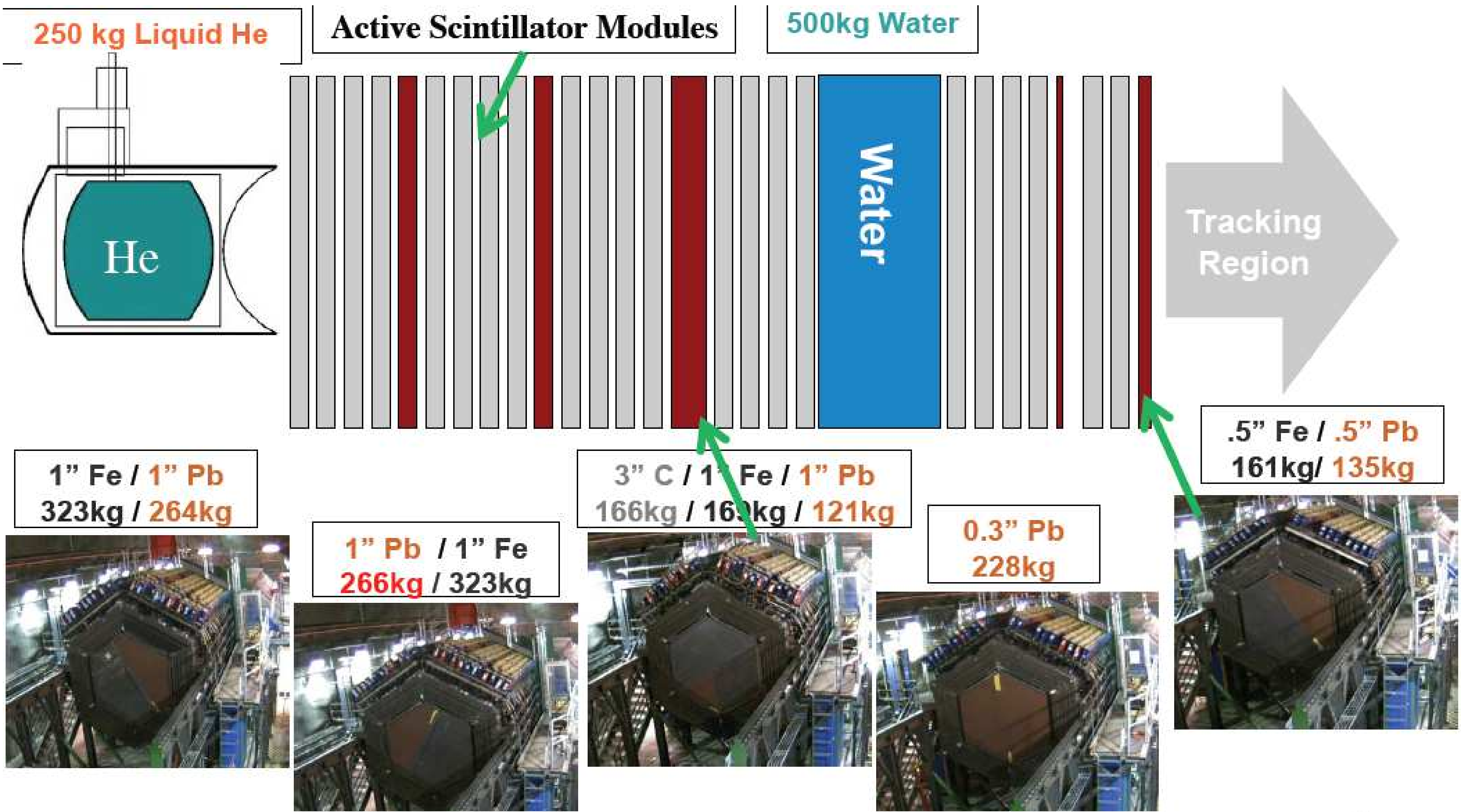
- J. Morfin
- Ratio: $r = \sigma(\bar{\nu})/\sigma(\nu)$
- Particularly interesting in the transition from exclusive states to DIS
- Related to the participation of anti-q

$$\frac{\bar{q}}{q+\bar{q}} = \frac{1}{2}\frac{3r-1}{r+1}$$



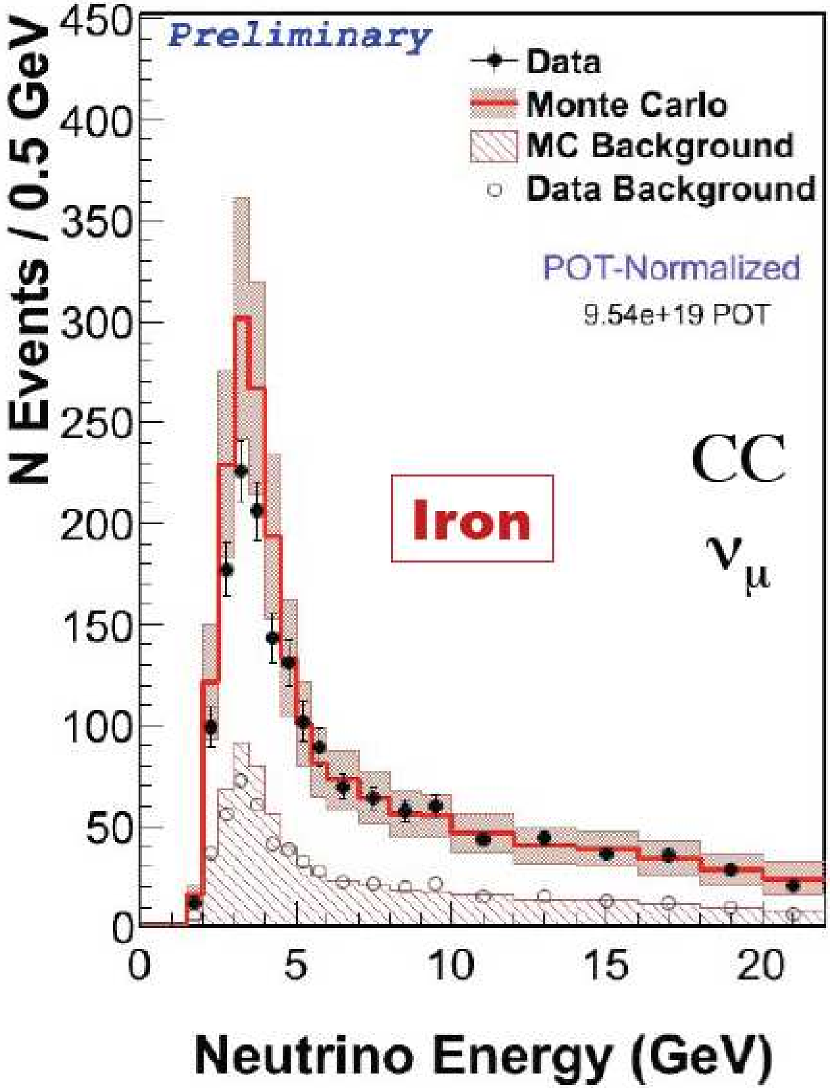
Minerνa inclusive CC cross section

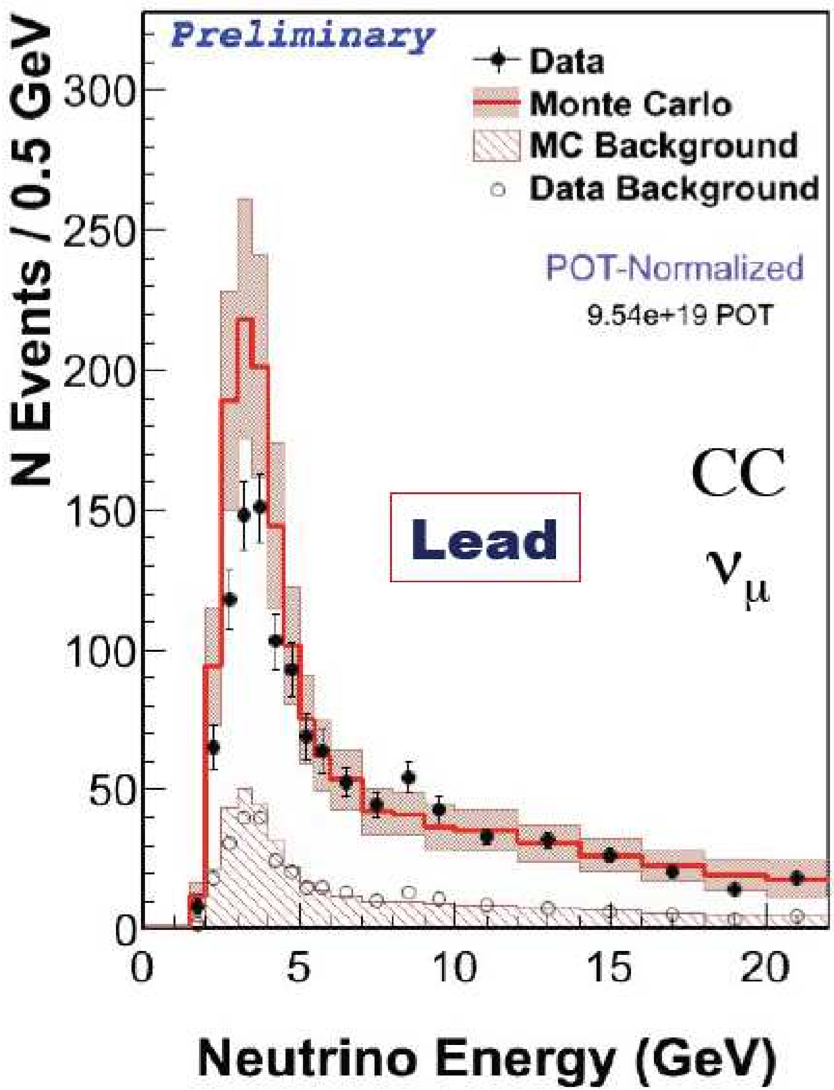
- J. Morfin
- Several Nuclear Targets



Minerνa inclusive CC cross section

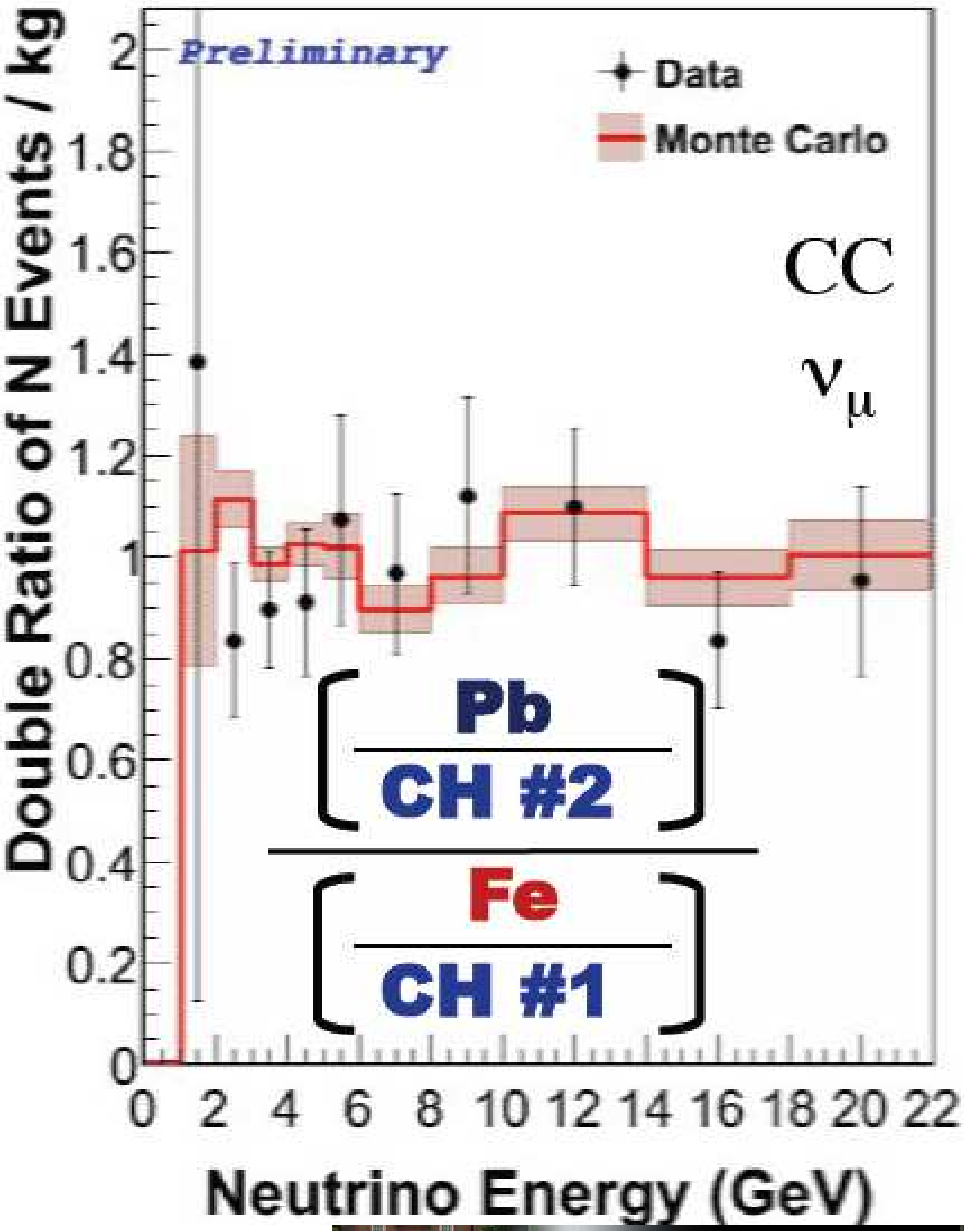
- J. Morfin
- Only 25% ν data, 20% Fe, Pb target mass





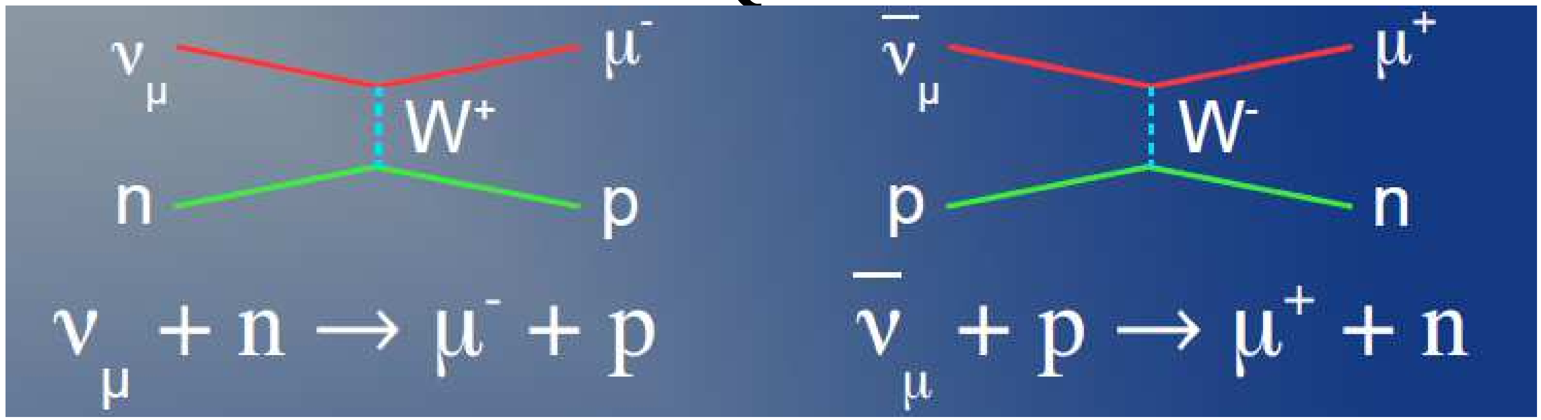
Minerνa inclusive CC cross section

- J. Morfin
- Only 25% ν data, 20% Fe, Pb
- Ratios: partial cancellation of (flux, acceptance) errors
- Errors should go down significantly



Minerνa CCQE

- J. Chvojka



- νbar and ν single track analyses underway
- Kinematic E_ν and Q^2 reconstruction

$$E_{\nu_\mu}^{QE} = \frac{2M_n' E_\mu - (M_n'^2 + m_\mu^2 - m_p^2)}{2(M_n'^2 - E_\mu + p_\mu \cos\theta_\mu)}$$

$$M_n' = m_n - \varepsilon_B$$

$$E_{\bar{\nu}_\mu}^{QE} = \frac{2M_p' E_\mu - (M_p'^2 + m_\mu^2 - m_n^2)}{2(M_p'^2 - E_\mu + p_\mu \cos\theta_\mu)}$$

$$M_p' = m_p - \varepsilon_B$$

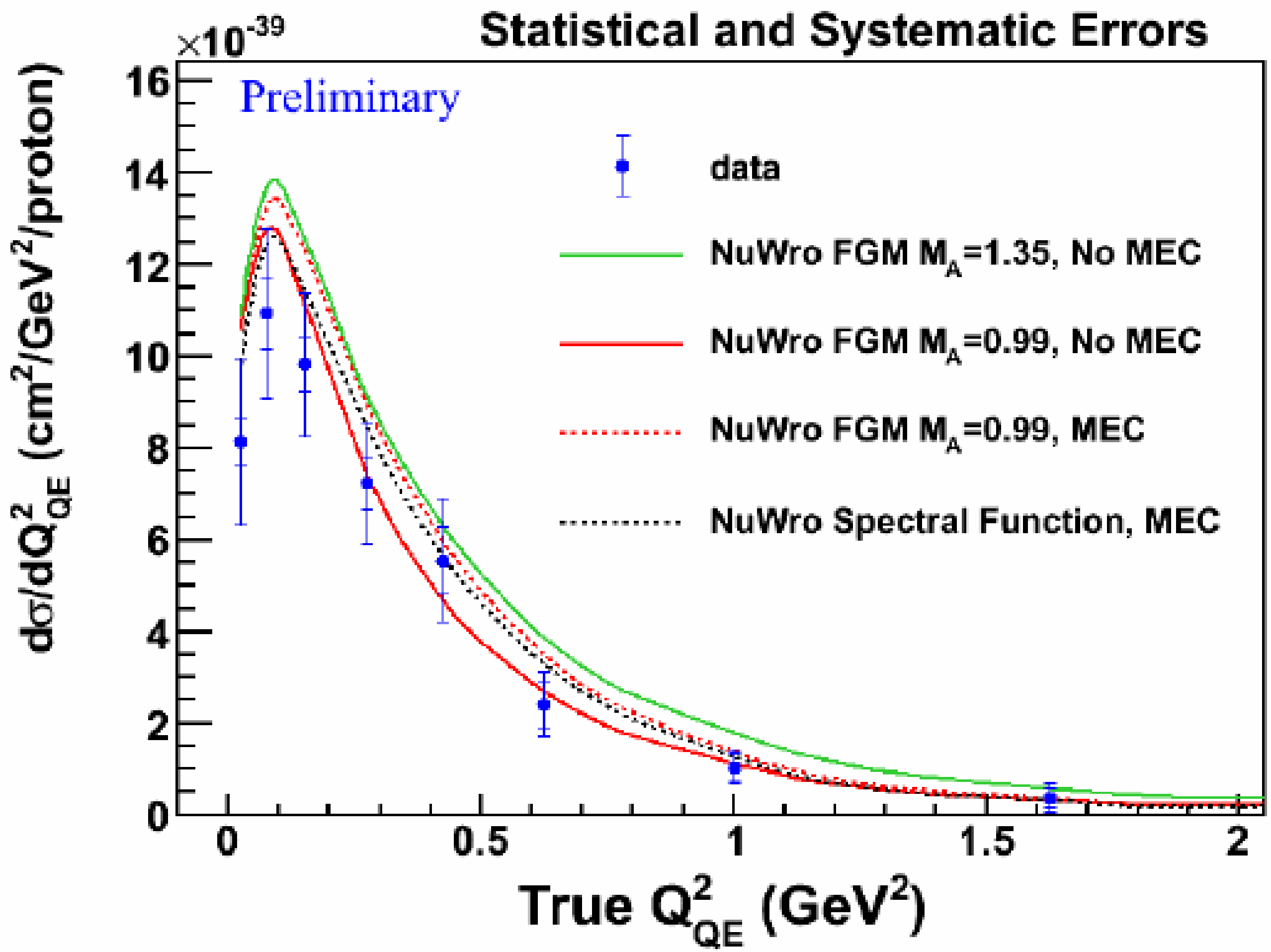
$$\varepsilon_B = 30\, MeV$$

$$Q^2 = 2E^{QE}(E_\mu - p_\mu \cos\theta_\mu) - m_\mu^2$$

$$E^{QE} = E_{\bar{\nu}_\mu}^{QE} \text{ or } E_{\nu_\mu}^{QE}$$

Minerνa CCQE

- J. Chvojka
- νbar single track analysis (19 x10^{19} POT, 16 % of total)
- Data consistent with M_A=1 GeV



EM final states in Minerνa

- J. Park
- π^o final states

NC Resonant π^0

$$\nu_\mu + p \to \nu_\mu + p + \pi^0$$
$$\nu_\mu + n \to \nu_\mu + n + \pi^0$$

NC Coherent π^0

$$\nu_\mu + A \to \nu_\mu + \pi^0 + A$$
$$\bar{\nu}_\mu + A \to \bar{\nu}_\mu + \pi^0 + A$$

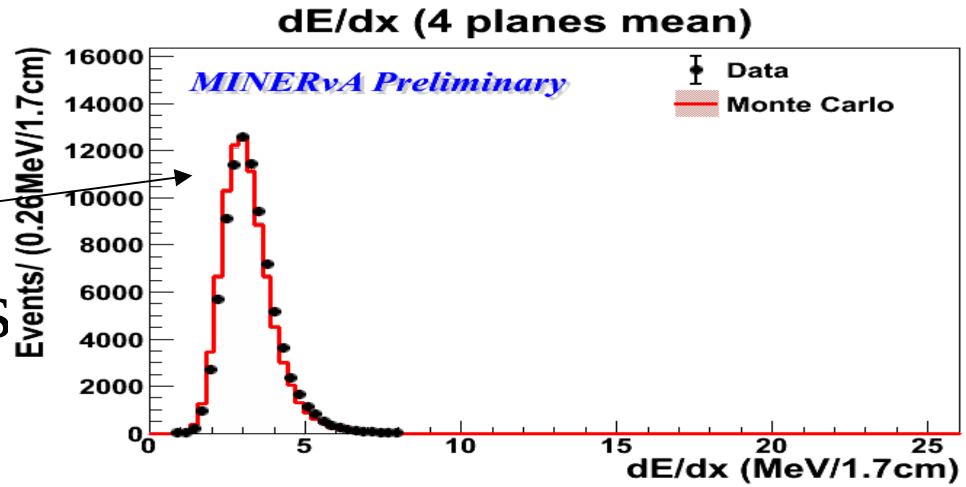
CC Resonant π^0

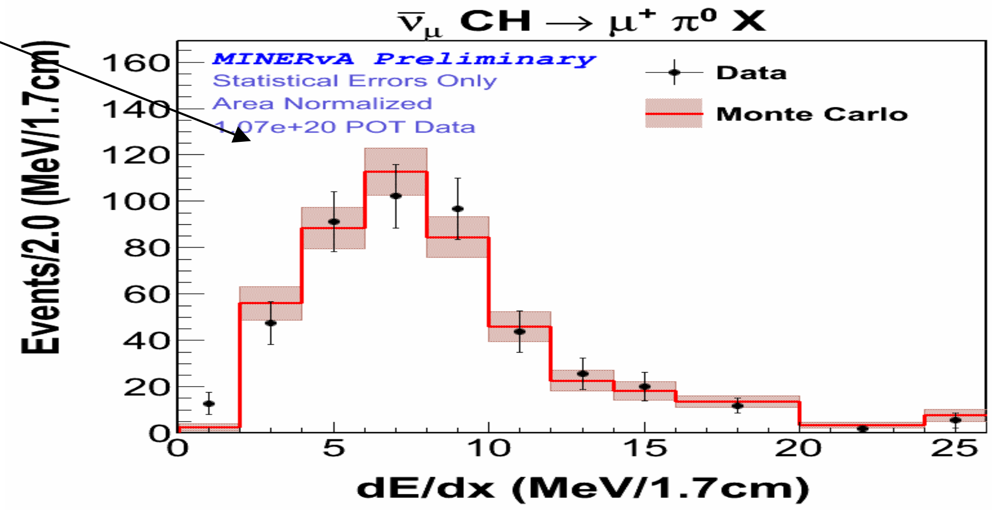
$$\nu_\mu + n \to \mu^- + p + \pi^0$$
$$\bar{\nu}_\mu + p \to \mu^+ + n + \pi^0$$

- ν_e CCQE: important to measure beam backgrounds in ND
- $\nu_\mu + e^- \to \nu_\mu + e^-$: gives a constraint on beam flux

EM final states in Minerνa

- J. Park
- Electron vs. photon identification
- Electrons from Michel decays
- Photons from π^o
- Looks like dE/dx can have power
- Good news for LAr

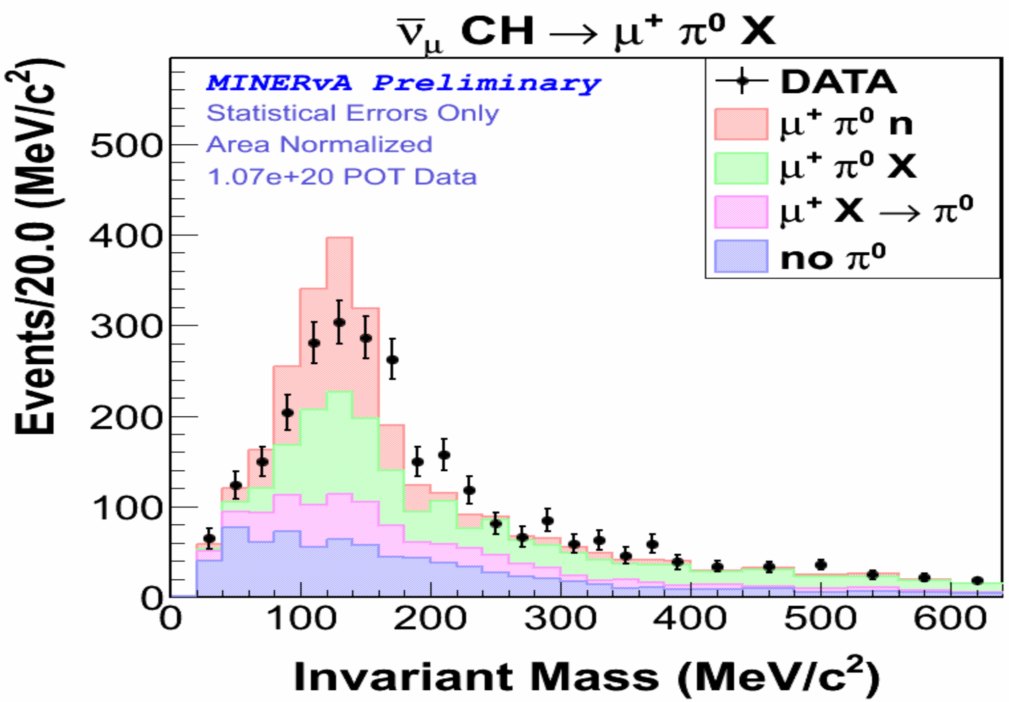




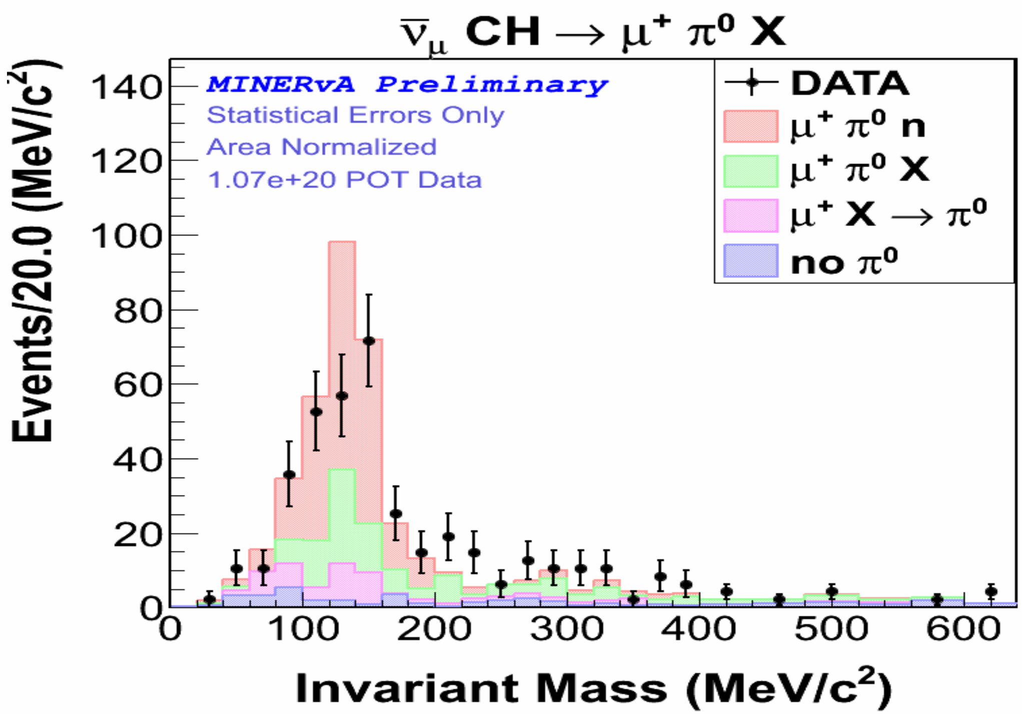
EM final states in Minerνa

- J. Park
- π^o final states:
- CC π^o mass reconstruction:

before dE/dx cut



after dE/dx cut



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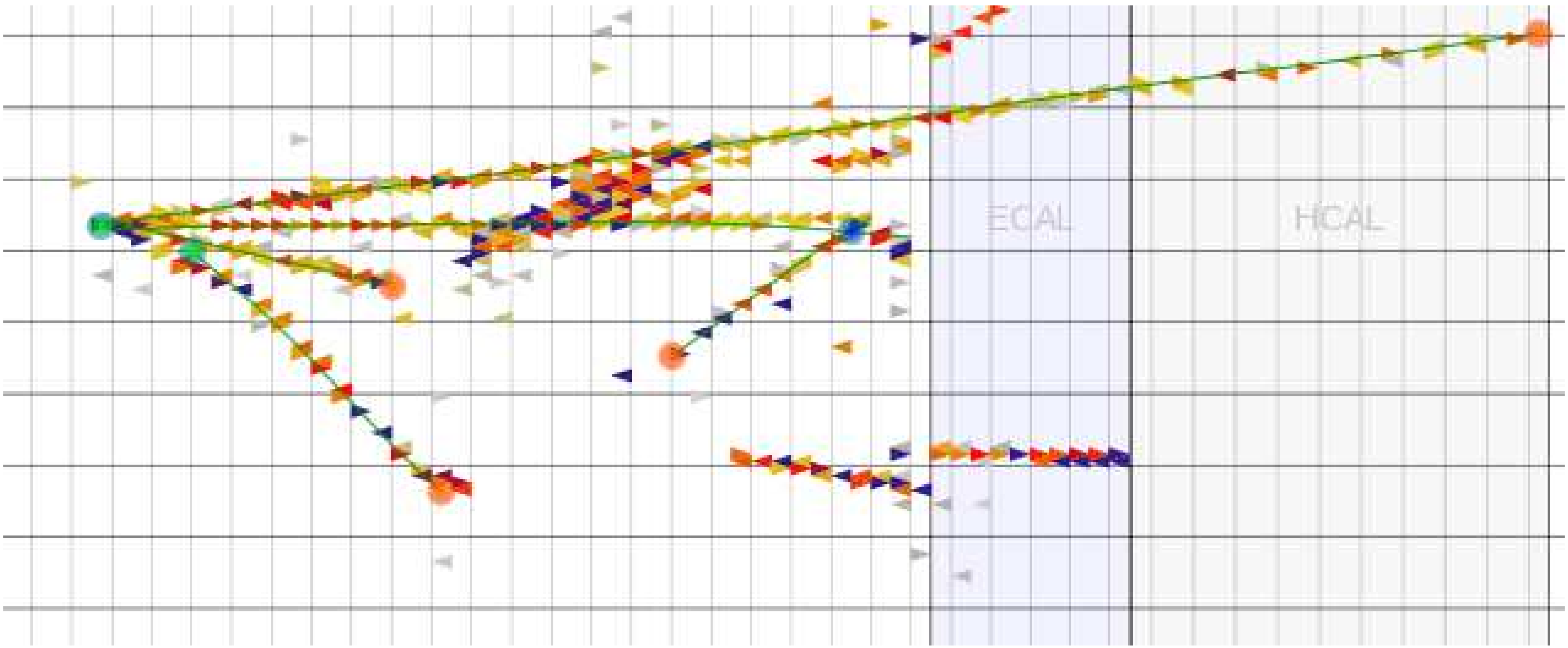
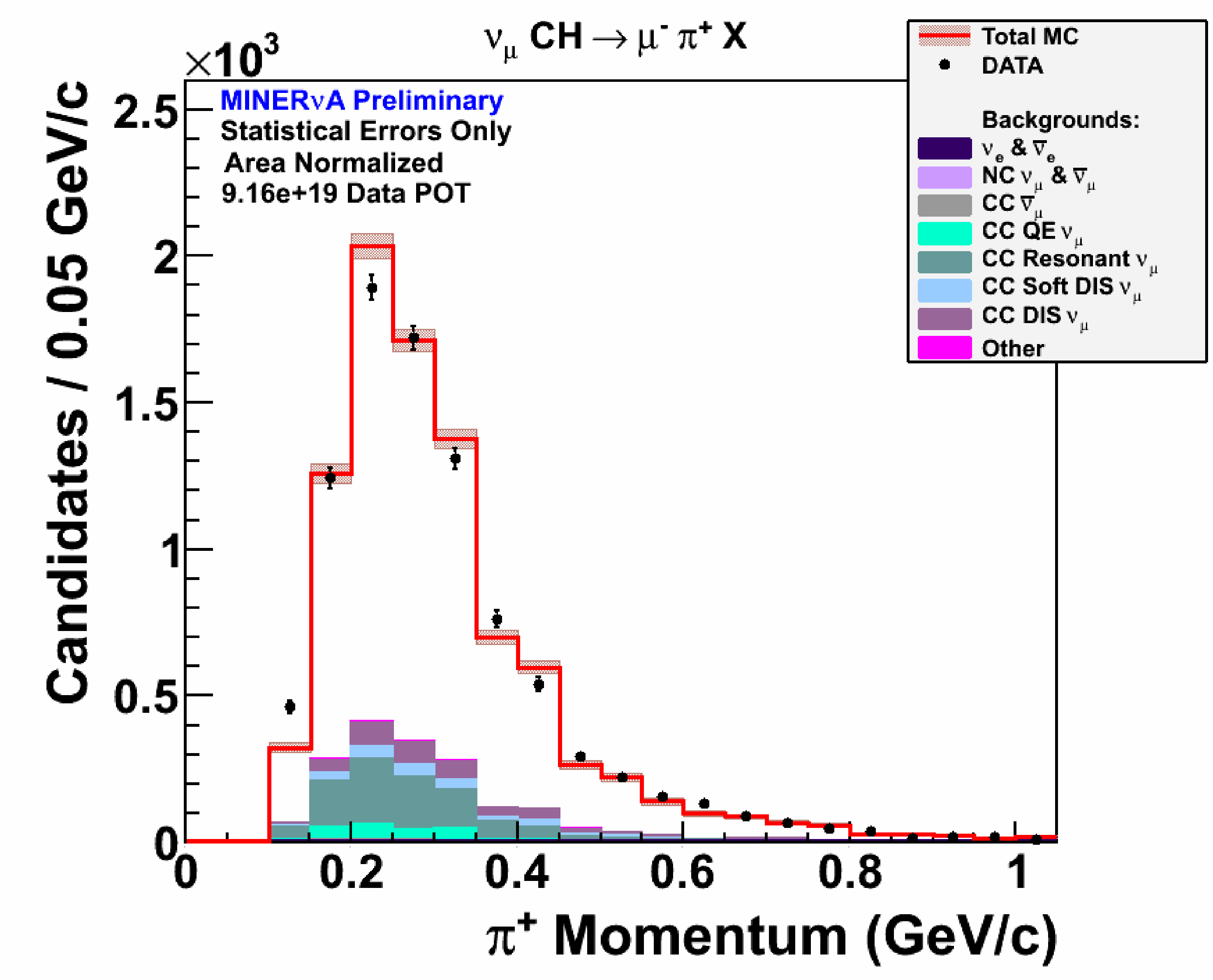
π production @ Minerνa

- J. Park
- Challenging π reconstruction
- Example:



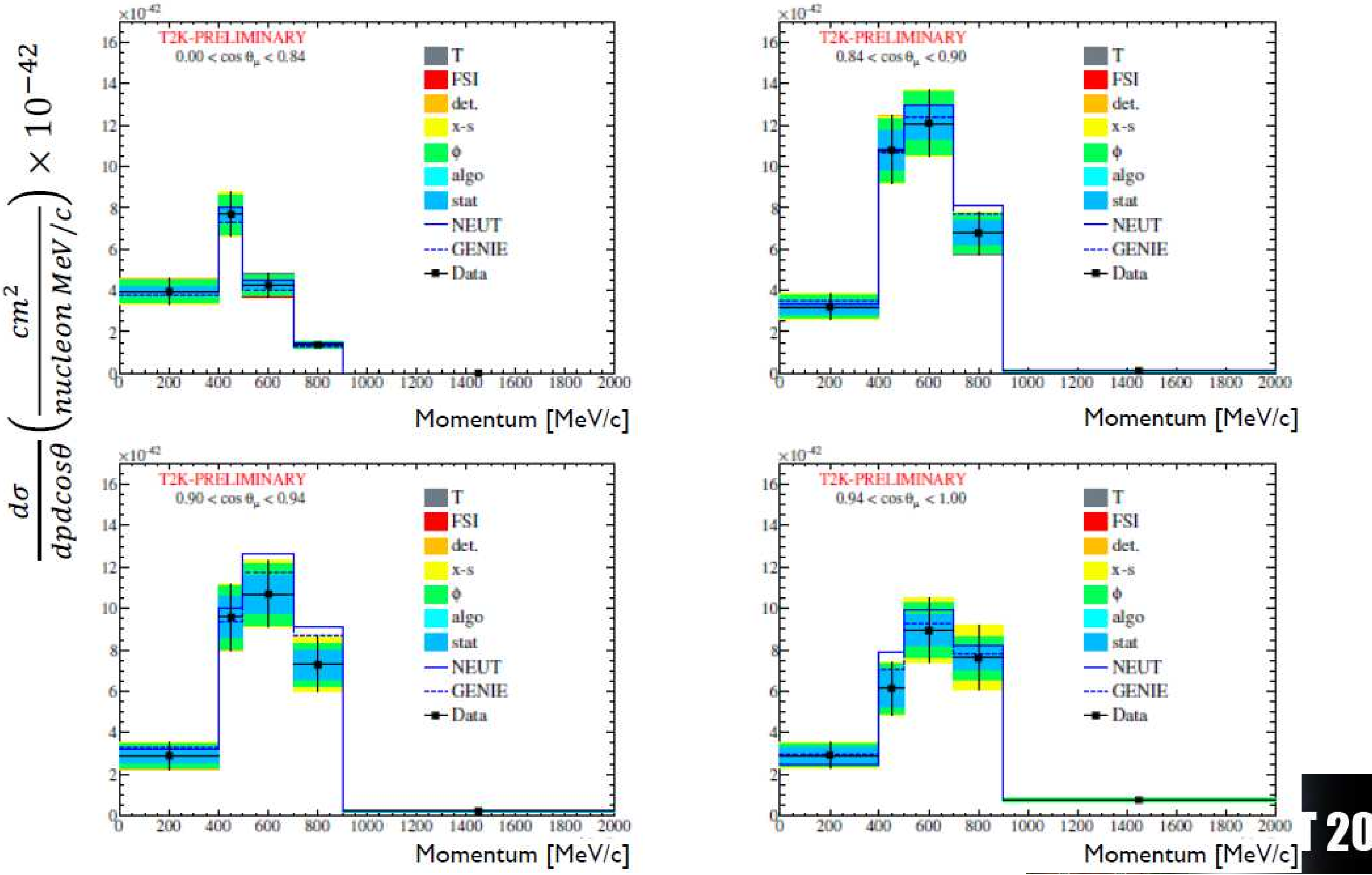
π production @ Minerνa

- Statistical errors are very small



T2K inclusive CC cross section

- G. Christodoulou
- Measurement at the 2.5° off-axis near detector ND280



2012

T2K inclusive CC cross section

- G. Christodoulou
- Measurement at the 2.5° off-axis near detector ND280

$$\langle\sigma_{CC}\rangle_{\Phi} = \left(6.93 \pm 0.13(stat) \pm 0.85(syst)\right) \times 10^{-39} \frac{cm^2}{nucleons}$$

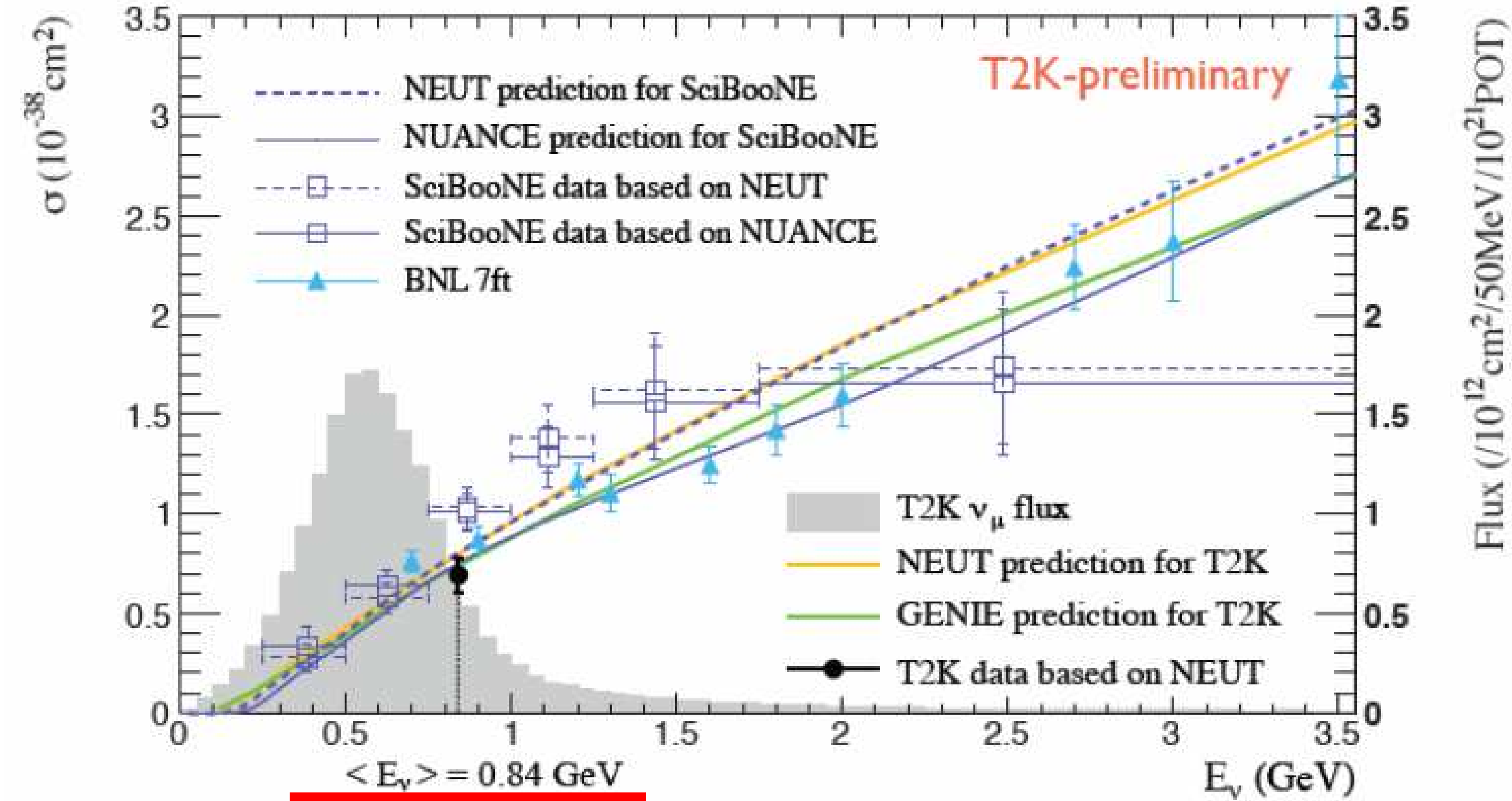
NEUT prediction $\langle\sigma_{CC}\rangle_{\Phi} = 7.26 \times 10^{-39} \frac{cm^2}{neutrons}$

GENIE prediction $\langle\sigma_{CC}\rangle_{\Phi} = 6.68 \times 10^{-39} \frac{cm^2}{neutrons}$

- Recall that NEUT: $M_A = 1.21$GeV
  GENIE: $M_A = 1$ GeV

T2K inclusive CC cross section

- G. Christodoulou
- Measurement at the 2.5° off-axis near detector ND280



Only mean E_ν

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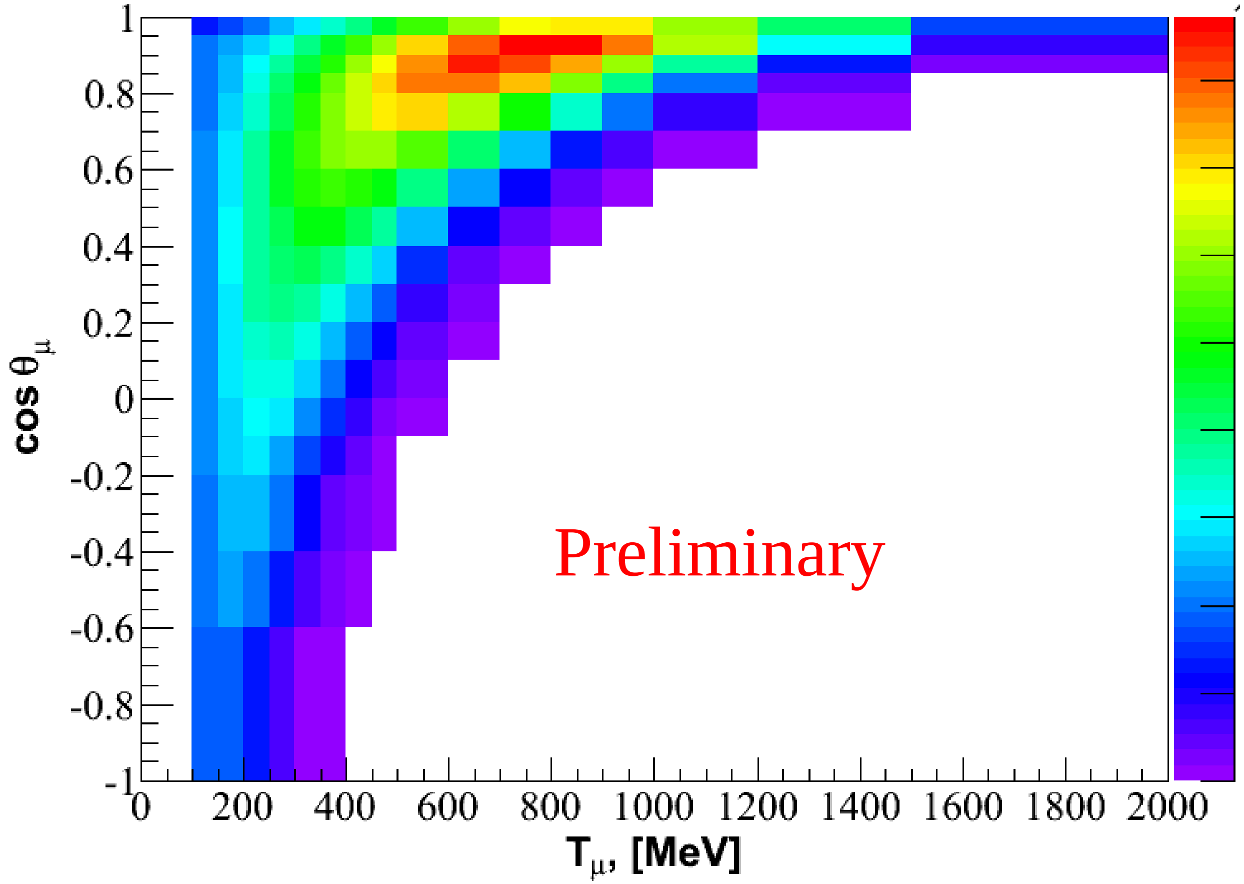
MiniBooNE inclusive cross section

- M. Tzanov
- New analysis: not just CCQE + CCπ^+ + CCπ^o
- Muon kinematics from 2-track likelihood fit
- E_ν determination: detector used as calorimeter



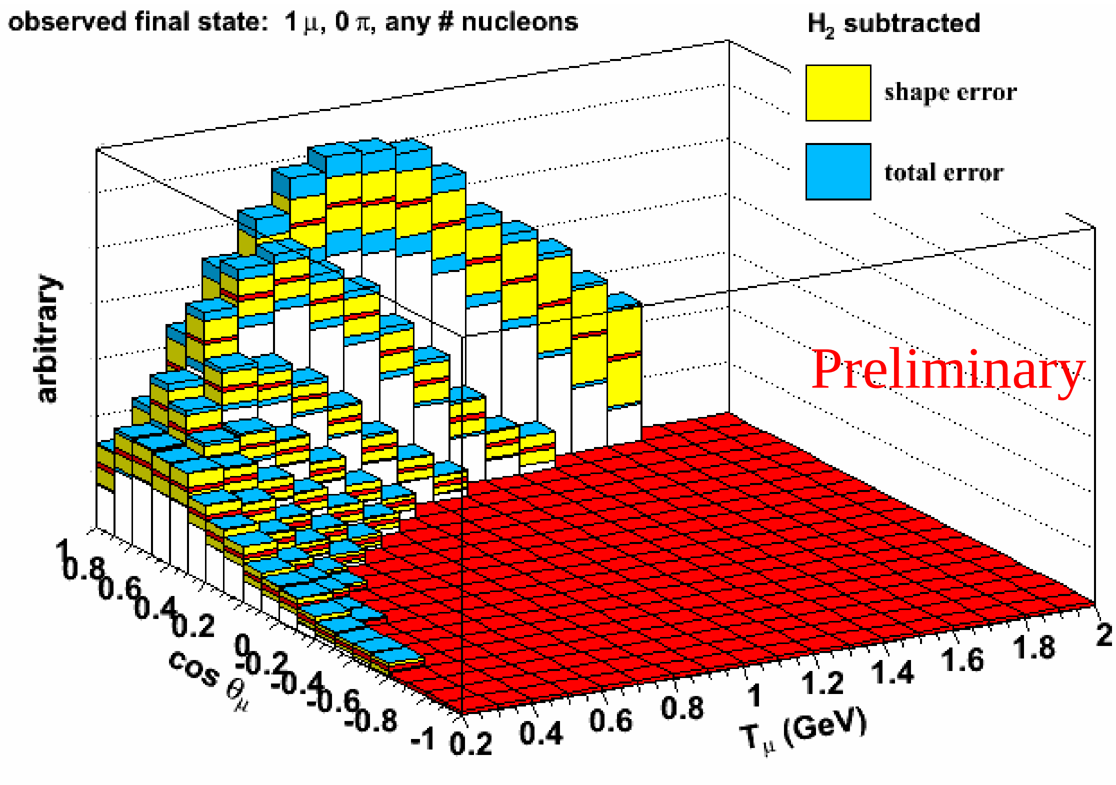
$$< d^2\sigma/dE_\mu d\cos\theta_\mu >$$

MiniBooNE inclusive cross section

- M. Tzanov
- New analysis: not just CCQE + CCπ^+ + CCπ^o
- Muon kinematics from 2-track likelihood fit
- E_ν determination: detector used as calorimeter
- Coming soon: $d^2\sigma/dT_\mu d\cos\theta_\mu$ (E_ν), $d\sigma/dQ^2$ (E_ν), $d\sigma/dT_\mu$ (E_ν), $d\sigma/d\cos\theta_\mu$ (E_ν)

MiniBooNE inclusive cross section

- M. Tzanov
- New analysis: not just CCQE + CCπ^+ + CCπ^o
- Muon kinematics from 2-track likelihood fit
- E_ν determination: detector used as calorimeter
- and also νbar CCQE and NCE



The low ν method

- A. Bodek
- $\nu = E_{had} = E_\nu - E_\mu$

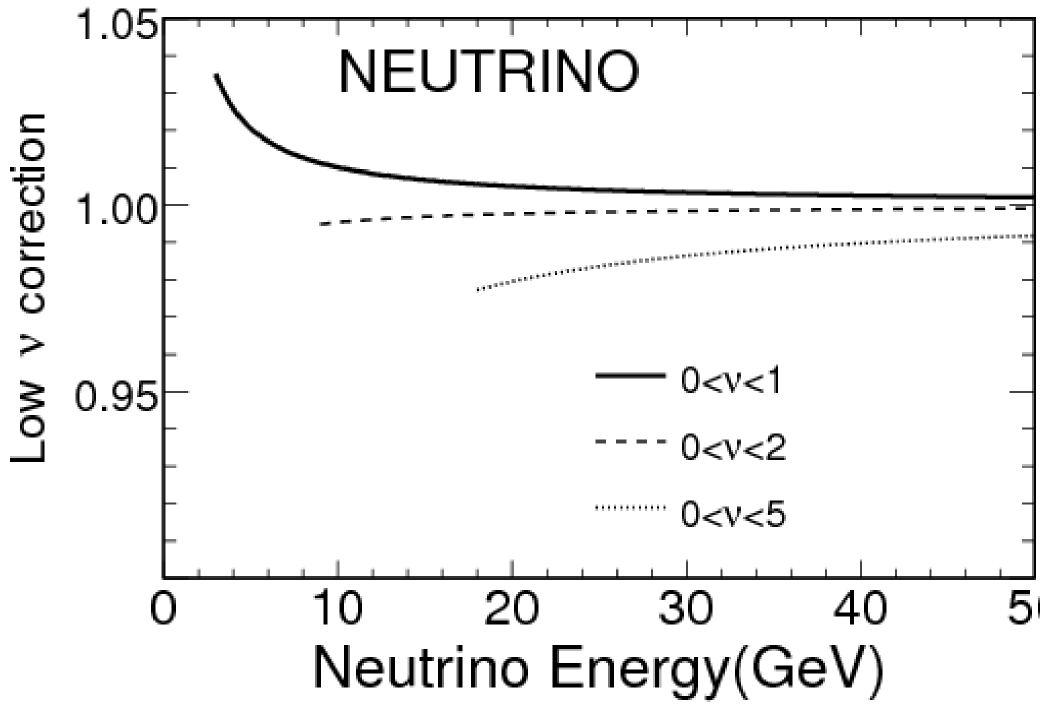
$$\frac{d\sigma}{d\nu} = A\left[1 + \frac{B}{A}\frac{\nu}{E} - \frac{C}{2A}\frac{\nu^2}{E^2}\right]$$

As $\frac{\nu}{E} \to 0$ $\quad \frac{d\sigma}{d\nu} \to A = \text{constant}$

Event rate: $\frac{dN}{d\nu} = \frac{d\sigma}{d\nu} \times \Phi$

At finite ν/E: $\Phi(E) \propto \boxed{\frac{\sigma(\nu<\nu_0, E\to\infty)}{\sigma(\nu<\nu_0, E)}} N(\nu<\nu_0, E)$

"Low ν correction"



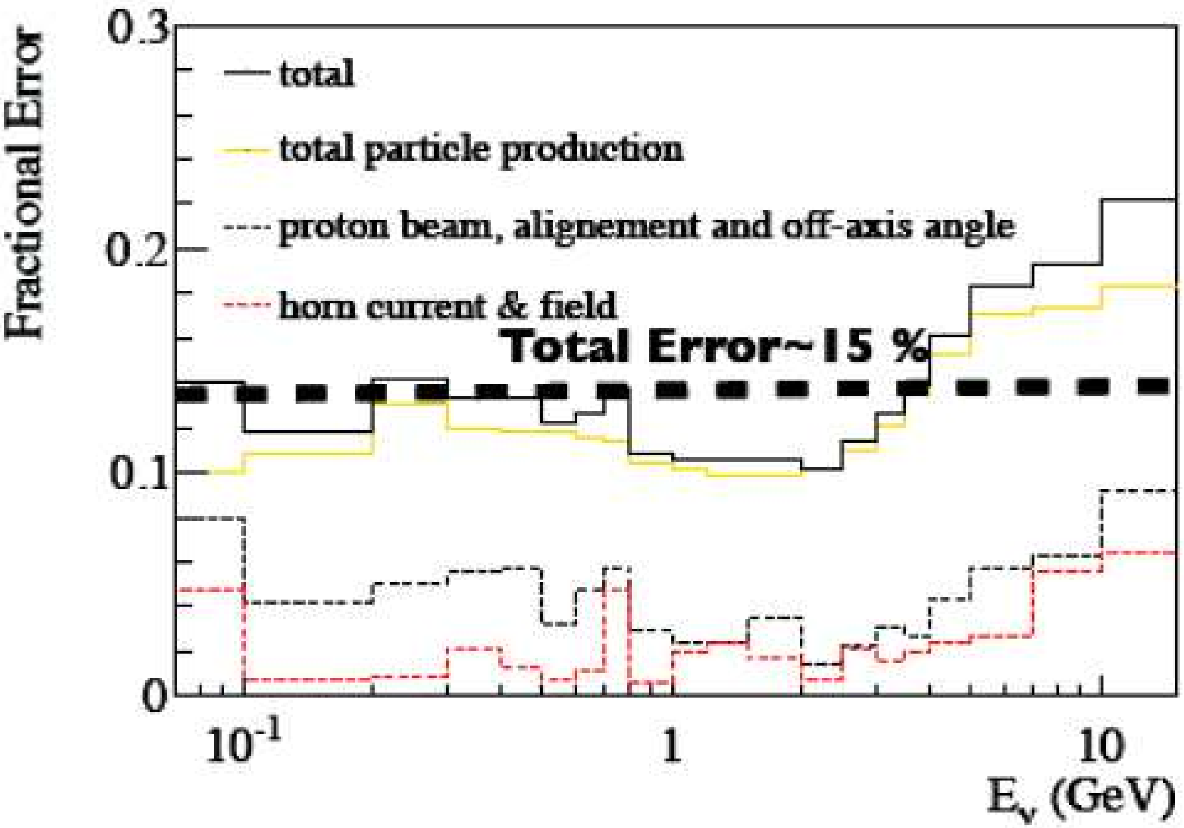
Strong claim: the correction Can be calculated with few % uncertainties

M. Kordosky: I want to believe

Can anyone see a problem?

Hadron production

- Basic principle: $p\ A \rightarrow \pi,\ K \rightarrow \mu\ \nu$
- Measurements of π, K x_F, p_T spectra to constrain the flux
- S. Murphy (T2K), L. Aliaga Soplin (Minerνa)
- Data from NA61, NA49
- With high statistics (and lots of work) maybe systematics on hadron production can be reduced to ~5 %
- Other sources of error become important



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Other talks

- Model independent determination of the axial mass parameter in CCQE neutrino nucleon scattering, R. Hill
- Differences in Quasi-Elastic Cross-Sections of Muon and Electron Neutrinos, M. Day
- Constraining Systematics using ND for Neutrino Factory/LBNE, S. Mishra
- Beta Beams Option Studies, T. Mendonca
- Uncertainties in Determining Parton Distributions at Large x: Results from the CTEQ-JLab Collaboration, C. Keppel
- Pion Electroproduction at CLAS and other JLab Measurements, T. Mineeva
- Strangeness content of the nucleon, K. Paschke

Conclusions

- New interesting experimental cross sections data underway
- Theoretical work being done in parallel
- Input from theory (and manpower) is needed to make better event generators (collider exps. have this)
- Experiments are cautioned about the consequences of pulling known model parameters far outside of their physical range
- Barrier between new models and generators needs to be broken
  - Idea: common event format so theorists can provide small samples to experiments (H. Gallagher)
    - can expt see these events?
    - does the new theory look more like reconstructed data?