CC and NC elastic scattering experimental introduction

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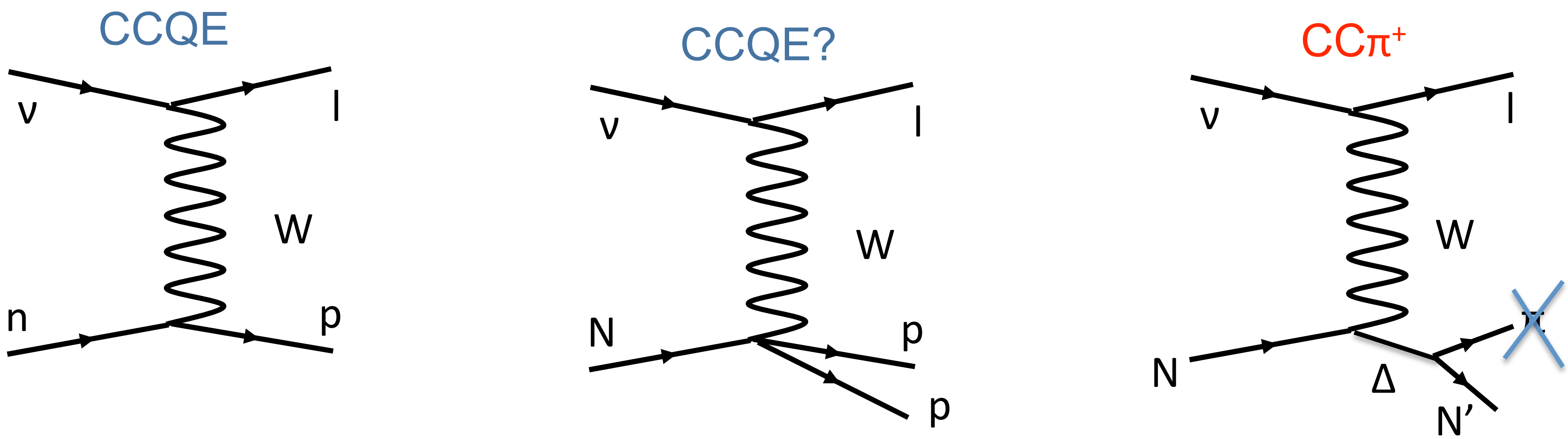
Lets review recent experimental measurements of CC and NC elastic scattering, through the lens of NuInt conferences

What have we called CCQE?



1. "μ+p"
- Simple dipole axial FF as free parameter
- Relativistic Fermi gas representation of nucleon bound in nucleus

2. "np+nh"or "2p2h"
- "multinucleon" process with correlated pairs of nucleons
- Not included, historically

3. "QE-like" topology
- CC1π backgrounds
- Complicated by choice of internuclear (FSI) model

Experiments may have different definitions of "CCQE"
- What model does the measurement correspond to? Is it background subtracted ("true CCQE") or inclusive ("QE-like")
- What is the observable used to select CCQE? (muon, with or without proton, rejection of pions)

Disclaimer

Most experiments have used the measurement of simple dipole axial FF (M_A^{eff}) with RFG to define agreement (or disagreement) in cross section

- Recognized this is an effective parameter, won't necessarily correspond to true value for single nucleon, M_A
- Easiest way to compare between experiments
- Recent movement towards differential distributions instead

Experimentalists also hope to improve the models in the generator, too

MiniBooNE CCQE measurement

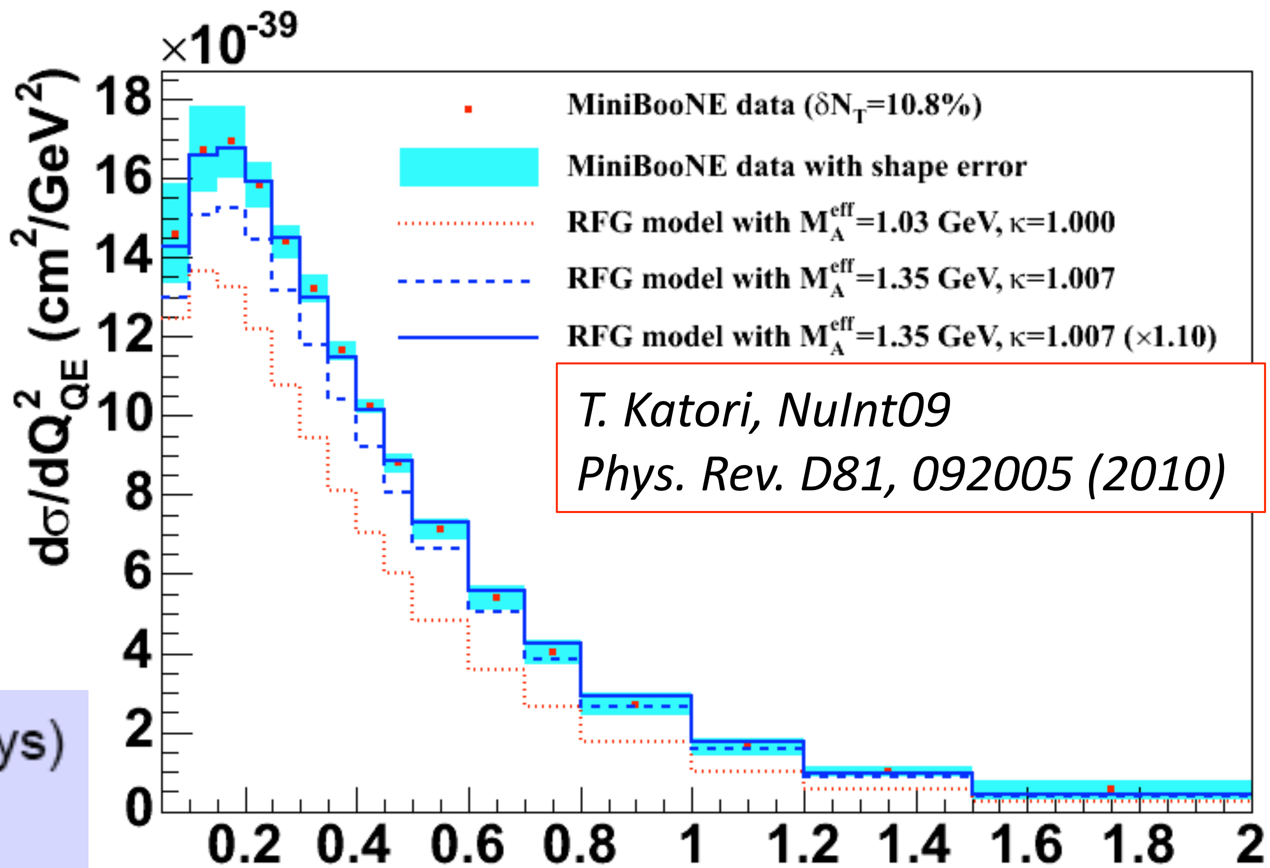
800 ton, spherical mineral oil Cherenkov detector (E_ν~1 GeV, carbon target)

- Muon identified with decay electron, no direct selection on proton
  - Purity: 75.8%, efficiency: 26.5%
- CC1π background are constrained based on CC1π selected event sample
- NUANCE generator

Data favors a higher value of M_A^{eff} as compared to earlier bubble chamber data, consistent with K2K results

Shape fit produces agreement in muon KE and angle important for oscillation analysis

M_A^{eff} = 1.35 ± 0.17 GeV (stat+sys)
$\kappa = 1.007^{+0.007}_{-\infty}$ (stat+sys)
χ^2/ndf = 47.0/38



T. Katori, NuInt09
Phys. Rev. D81, 092005 (2010)

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

MINOS CCQE measurement

Scintillator-steel sandwich detector (E_ν ~2.5 GeV, iron target)

- Select muon candidate and uses hadronic shower energy to reject DIS, RES
  - Purity: 61%, efficiency: 53%
- Flux tuned from data in different beam configurations
- NEUGEN generator

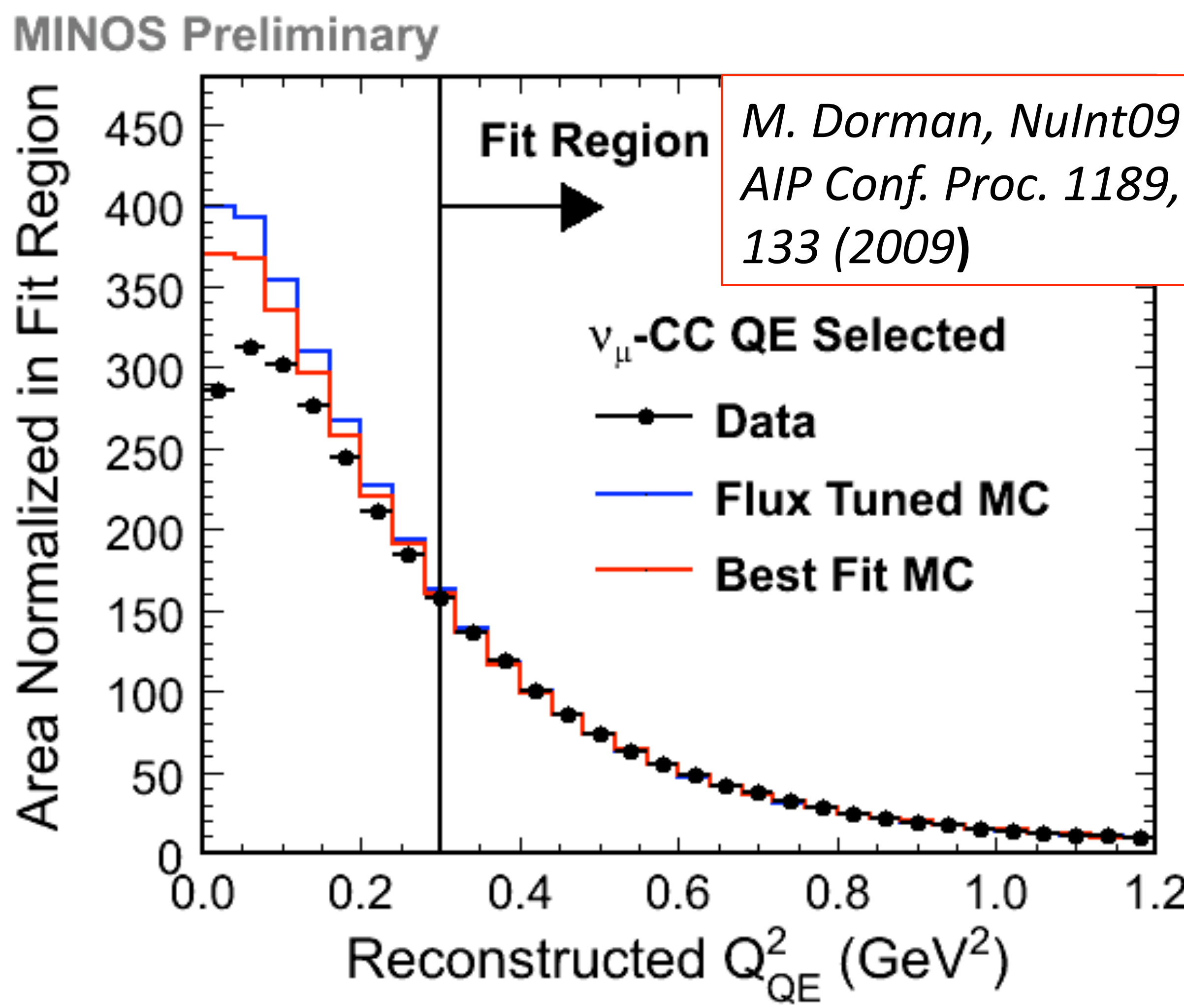
"Data wants more low Q^2 suppression and a flatter spectrum at higher Q^2."

$M_A^{eff} = 1.26\ ^{+0.12}_{-0.10}\ ^{+0.08}_{-0.12}$ GeV

Common approach to fit Q^2>0.2

Reduces (some) dependence on

- background prediction
- nuclear model



M. Dorman, NuInt09 AIP Conf. Proc. 1189, 133 (2009)

NOMAD CCQE measurement

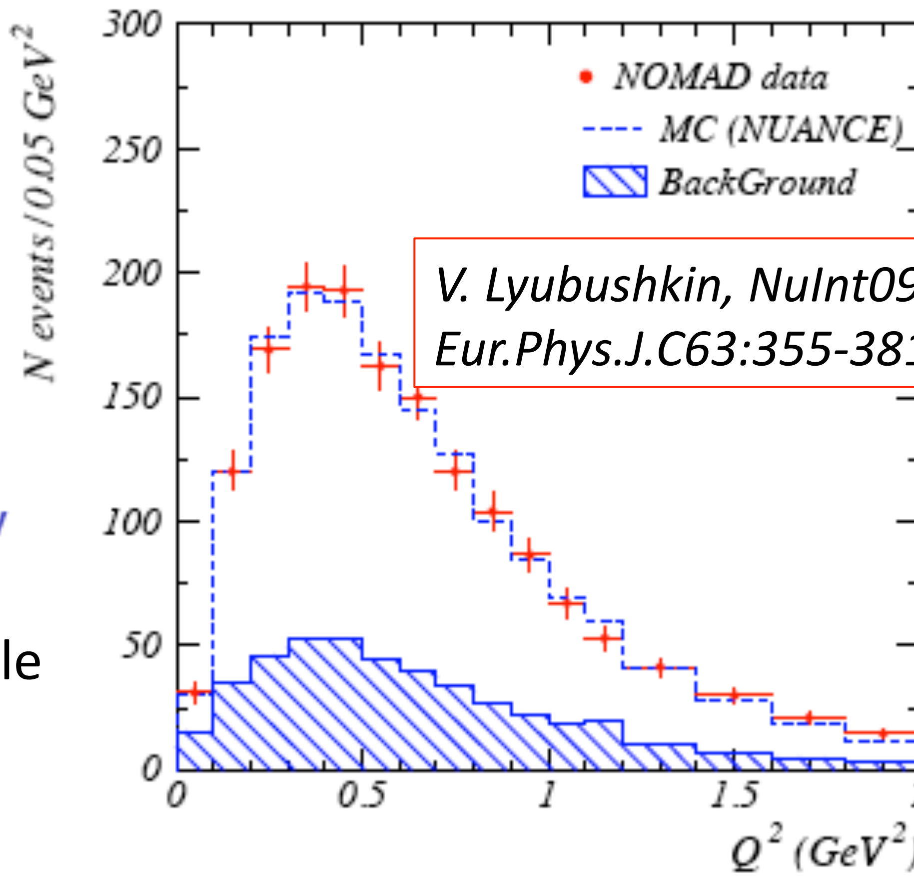
Drift chambers with hadronic calorimeters and muon detectors situated in magnetic field (E_ν ~24 GeV, carbon target)

- "1 track" (muon only, ~10k) and "2 track" (muon, proton,~3.5k) samples
    - Purity: 50.3%, efficiency:34.6%
- Flux normalized based on inverse muon decay (~400 events)
- Smith-Moniz MC with intra-nuclear cascade model (DPMJET based)

"Our measured M_A is found to be in good agreement with the world average value obtained in previous deuterium filled bubble chamber experiments"

$$M_A = [1.05 \pm 0.02(stat) \pm 0.06(syst)]\ \text{GeV}$$

Value consistent with 2 track only sample fit and with NUANCE generator fit



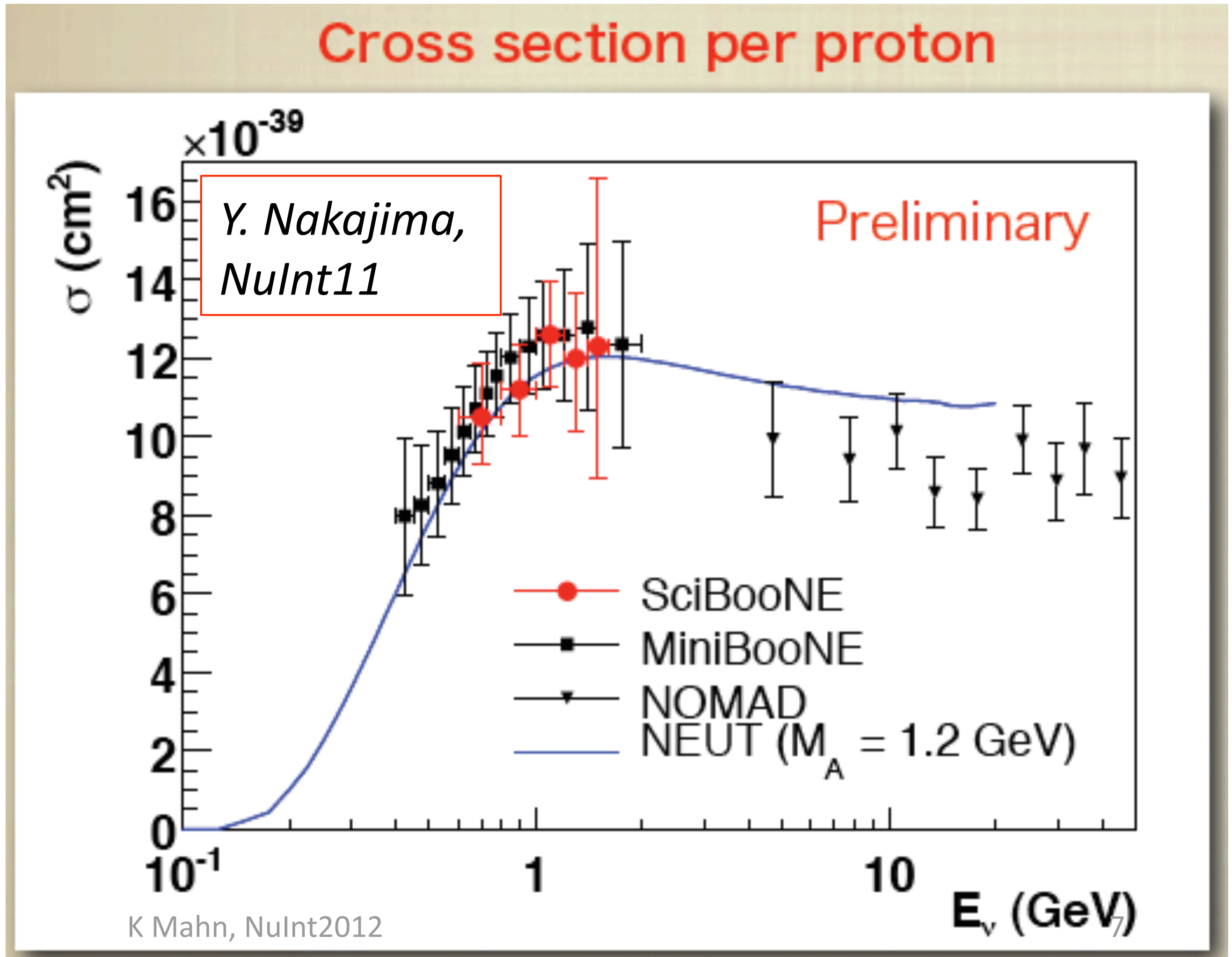
V. Lyubushkin, NuInt09
Eur.Phys.J.C63:355-381,2009

SciBooNE CCQE measurement

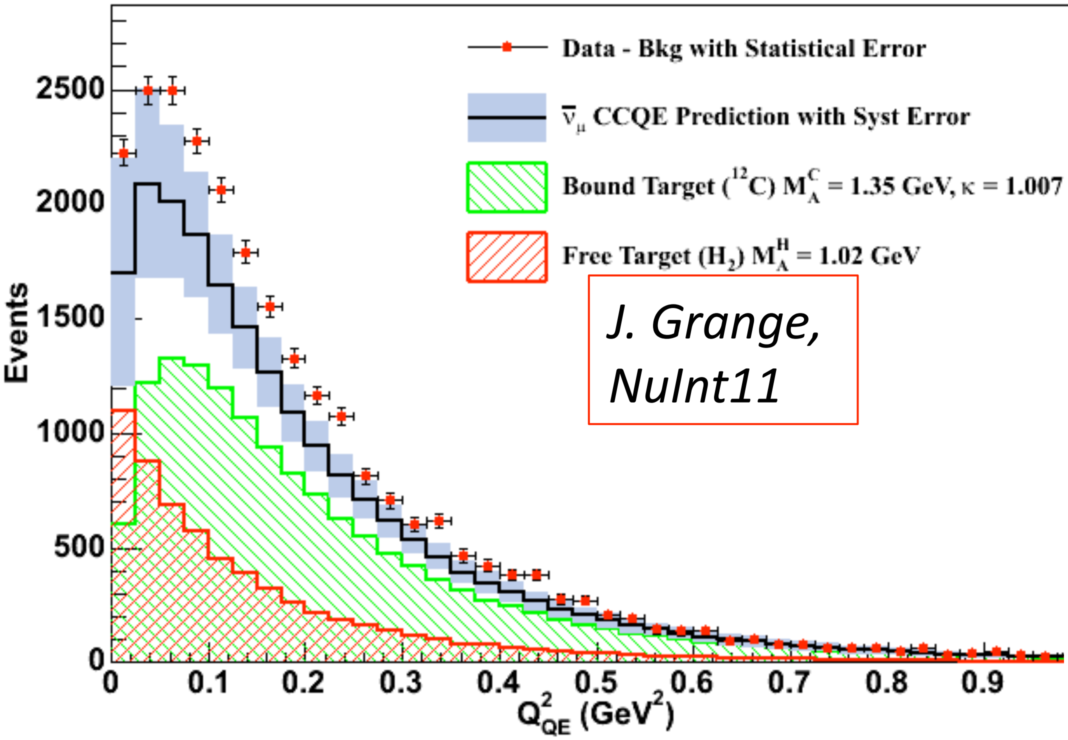
Scintillator sandwich detector with electron calorimeter, muon range detectors (E_ν ~1 GeV, carbon target)

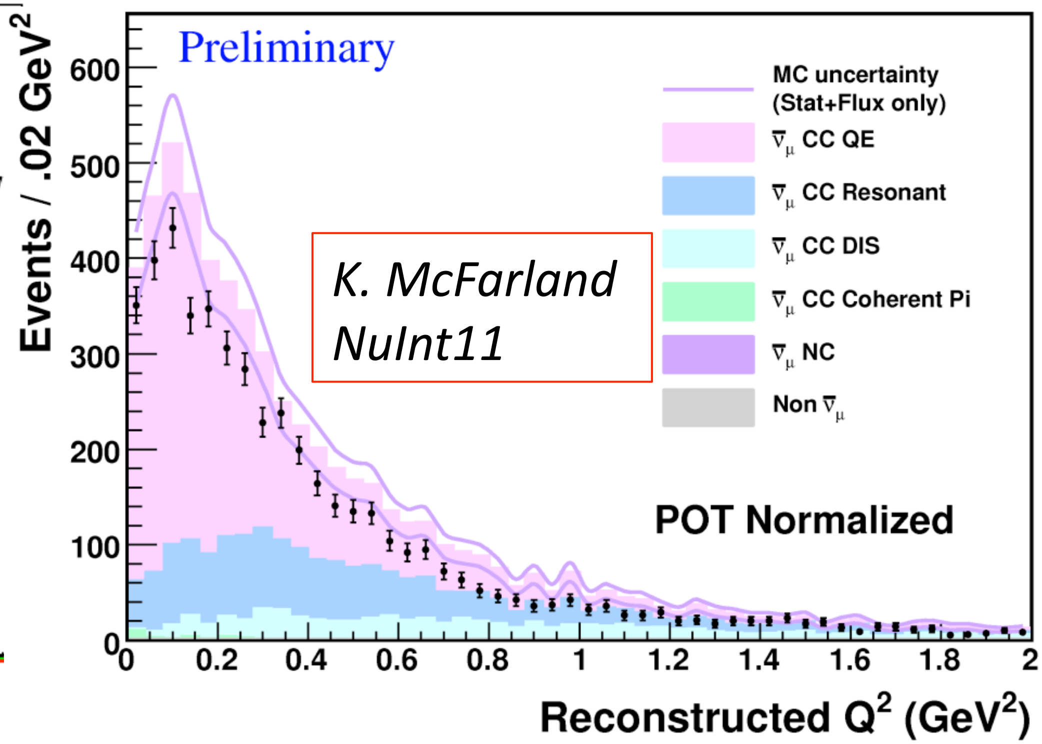
- "1 track" (muon only, ~13.5k) and "2 track" (muon, proton, ~3k events) used
  - Purity: 66.2% (1 track), 68.5% (2 track)
  - "2 track" (mu+π, ~1.5k) also included to constrain backgrounds
- NEUT generator

Consistent with higher value of M_A^{eff} and MiniBooNE's energy dependence of cross section



Antineutrino CCQE measurements





MiniBooNE antineutrino data has similar Q^2 shape as MiniBooNE neutrino data

- Purity: 64%
- Backgrounds from neutrino interactions ("wrong sign") constrained with dedicated data samples (e.g. CC1π+)
- Normalization difference larger than neutrino mode but within errors

Minerva event deficit is flat with Q^2, not with E_ν

- Scintillator sandwich detector with electron calorimeters, MINOS muon range detector
- E_ν ~2.5 GeV, multiple targets (CH shown)
- GENIE generator

NOMAD antineutrino data is consistent with the neutrino data:

$$M_A = [1.06 \pm 0.07(stat) \pm 0.10(syst)]\ \text{GeV}$$

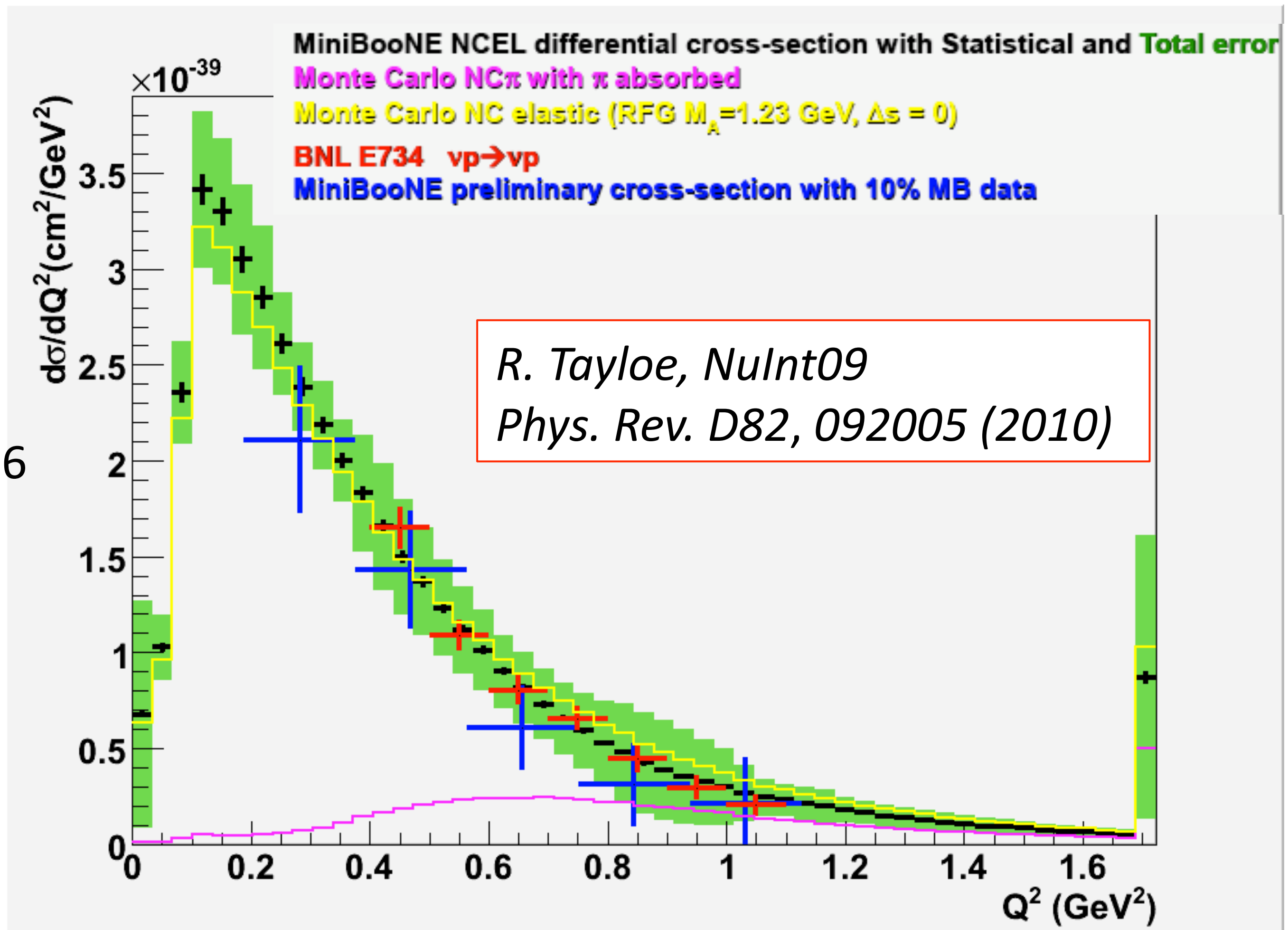
MiniBooNE NCEL measurement

800 ton, spherical mineral oil Cherenkov detector (E_ν~1 GeV, carbon target)

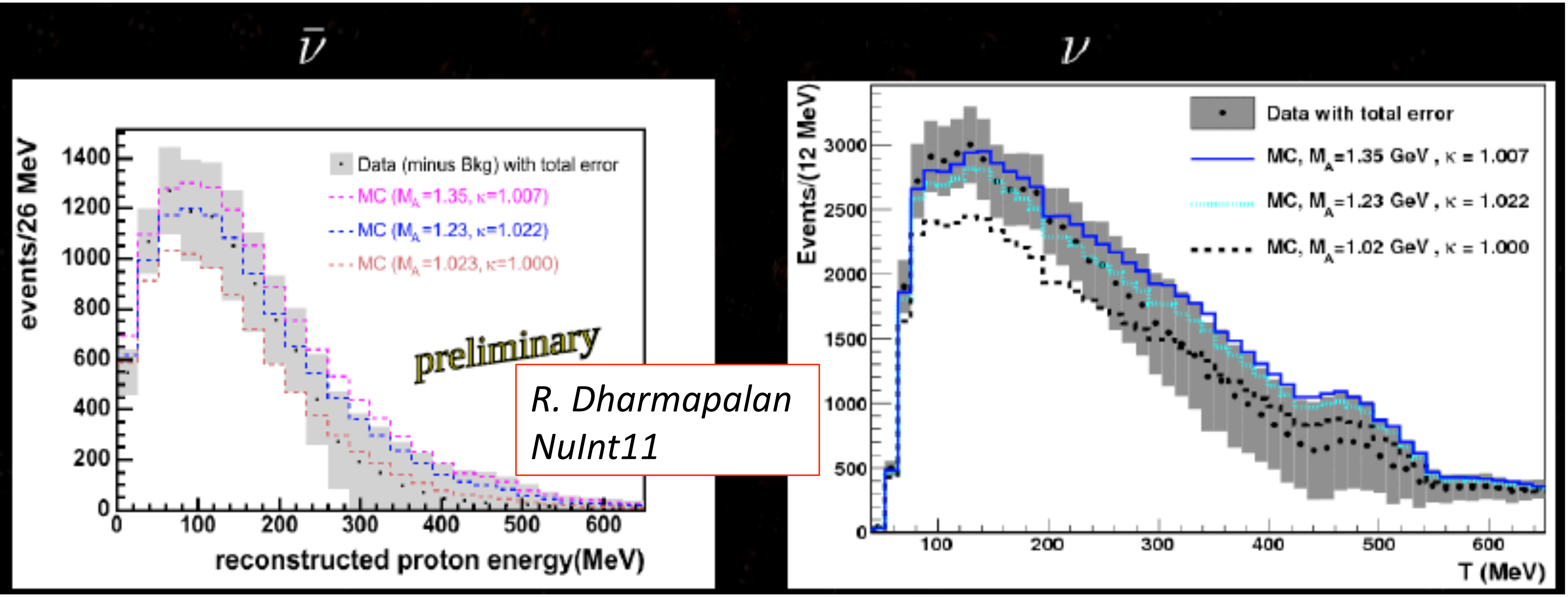
- Signature: 0 μ, 0 π selection + N nucleons (from scintillation light)
  - Purity: 65%, efficiency: 35%
- Two main backgrounds: irreducible NCπ (pion absorbed) and events from interactions outside the detector; constrained with a enhanced sample at high radius
- NUANCE generator

Additional HE proton selection used to determine ratio of NCE/CCQE and measurement of Δs = 0.08 ± 0.26

- Nucleon is proton with KE>350MeV
- Future NCEL measurements may have different observable signatures



MIniBooNE NCEL antineutrino measurement



MiniBooNE antineutrino data is consistent with neutrino data

- Purity: 57%, efficiency: 33%
- Neutrino backgrounds constrained from same samples as CCQE antineutrino analysis
- External, irreducible backgrounds treated like neutrino-mode analysis

"Monte Carlo with values of MA 1.23 GeV and 1.35 GeV gives a better fit to the data, than 1.02 GeV, especially at low energies."

Summary

The last three years have produced a wealth of experimental results:

- MiniBooNE, NOMAD, SciBooNE, Minerva, and MINOS
- CC and NC, neutrinos and antineutrinos

The experimental picture is far from clear but is evolving rapidly:

- Disagreement in CCQE cross section at LE (Sci/MiniBooNE) and HE (Minerva, NOMAD)
- Agreement in MiniBooNE NC, NOMAD CC between neutrinos and antineutrinos
- Possible tension between NOMAD/Minerva and MiniBooNE antineutrino data?

What will we learn this week, experimentally?

- MiniBooNE, Minerva updated results!
- T2K's potential contributions and current activities
- ArgoNEUT: Ar target and FSI information

What I'll be thinking about in the session

Next generation of experiments can and should make more complex comparisons beyond M_A^{eff} which are as model independent as possible:

- Differential cross sections in kinematic variables (p_μ, θ_μ, p_p, θ_p)
- Different selections (muon only, muon+proton, muon+!pion... and muon+pion)
- Calorimetric quantities (e.g. vertex activity)

This conference is useful for establishing common language and conventions

- How does each experiment define QE?
- How does each experiment treat background processes and inter-nuclear processes like FSI?

How do we best compare between experiments? When is a comparison with the same generator/MC more valuable than a comparison of differential cross sections?

- MiniBooNE and T2K (lower energy fluxes)
- Minerva and MINOS (shared flux)
- MiniBooNE-Minerva-NOMAD (antineutrino data)
- What can we learn from ArgoNEUT which is applicable to lighter targets?

Backup slides