NuINT15: Summary of Quasielastic Session

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Key Developments in Quasielastic Physics at NuINT 2015

- 1. So much new data!
- 2. Improving models of nuclear effects
- New observables and methods for looking at data which promise to help to discriminate between models
- 4. A dramatic conclusion for NuINT15 quasielastic scattering

2015 QE session

- CC and NCQE Cross Section Measurements at ND280 Ms. REDIJ, Asmita
- Nue CCQE Measurement Dr. WOLCOTT, Jeremy
- Numu QE Cross Section measurements at MINERvA Dr. BETANCOURT, Minerba
- Measurement of 2p2h kinematic region at MINERvA Dr. RODRIGUES, Philip
- ArgoNeuT Opion results + future prospects in LAr detectors including MicroBooNE Dr. PALAMARA, Ornella
- Nuclear effects direct measurement by comparing neutrino and antineutrino CCQE cross-sections Dr. WILKINSON, Callum
- Low energy excitations in RPA calculations Dr. JACHOWICZ, Natalie
- Nucleon-knockout Cross Sections in NC Scattering on Oxygen Dr. ANKOWSKI, Artur

So much new data!

- We can do more than stare at $\sigma(CCQE)$ vs "E_v" from MiniBooNE and NOMAD on the "Teppei plot"
 - Τ2Κ CC0π
 - MINERvA v_e CCQE
 - MINERvA semi-inclusive μ +p,



- MINERvA calorimetric q_0 - q_3 at low recoil
- We also know there is much more to come in the future from MINERvA, T2K and the oncoming proliferation of LAr TPCs at FNAL BNB and NuMI

Homework Corrections: See Flux!



 MINERvA is recalculating its flux using more hadroproduction data, ve elastic scattering

Betancourt

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- Expect shift in cross-sections of ~20% for CCQE d\sigma/dQ^2 , ~5% for ve constrained v_e CC0\pi and ~10% for others
- Integrated uncertainties from ~11% to 7-8%



T2K Low Energy CC0pi

Redij

- Two ND280 analyses, with separate selections (70% overlapping) and cross section calculation methods
 - with and without information from proton in final state
 - consistent results! Check of model independence
 - Confront with data
- Preference for 2p2h contributions in regions preferred by Nieves model
 - More data (RHC?) desired! NuINT15 QE Summary: KSM, JN, RW



Wait, don't we also want to know what electron neutrinos do?

- MINERvA selection is 84% v_e with 62% of those CCQE-like
- Several innovative cuts to achieve electron/gamma separation
- First v_e cross section result consistent with GENIE 2.6.2
 - Ratio of CCQE muon and electron, with smaller flux uncertainties, is similarly consistent
- Uncertainties of the 10-20% region, statistics and systematics



Speaking of Uncertainties...





Wolcott

- Yikes! Who ordered that? Evidence it is forward neutral pions at high energy with some proton recoils at vertex
- Even Luis agrees kinematics suggest a diffractive mechanism (high W). Seen before in bubble chambers?
- Must put in models for oscillation experiments!

ArgoNeuT CC0π

Palamara



• Novel energy reconstruction method using muon+protons

$$E_{\nu} = E_{\mu} + \sum T_{p_i} + T_X + E_{miss}$$

• Tension? Relieved by requiring low-ish proton multipicity?

Nuclear Models: RPA

- RPA understanding is essential for oscillation
 - Detector acceptance depends on Q² but other things in model (2p2h) can cause a change in Q² dependence



Jachowicz

Nuclear Models: Predictions for NC

• Very challenging to measure NC reactions

Ankowski

Rely on nuclear models



47% (33%) difference at 0.6 GeV (1.5 GeV)

• Surprisingly large difference between RFG and other models shown here! Critical to make progress here.

New Observables

- Combination of neutrino and anti-neutrino to extract nuclear effects directly
- Semi-inclusive CC0π+p
- LAr mapping of final state hadrons
- Low recoil q₀-q₃

Direct measure of vp CCQE events in hydrocarbons

Wilkinson

- Combination of neutrino and antineutrino
 - Antineutrino only scatters from free protons in CH, but neutrino and antineutrino from carbon. Correct neutrino/antineutrino difference.
 - Works best at high energy. Limited statistics for now
 - See also Xianguo Lu in inclusives session

The fitted χ^2 and $p_{\rm F}$ values for MINER ν A are:





- Agreement of data to model with FSI-tuned background in much better agreement than without FSI
- Double differential cross sections transverse and longitudinal muon momentum produced for both neutrinos and antineutrinos
- More general transverse variables [Pickering, inclusive session]



 Future experiments with higher statistics (MicroBooNE and SBND) can help quantify nuclear effects in LAr

Proton Mapping with LAr



 $\sigma_{CC0\pi}^{\bar{\nu}} = 0.58 \pm 0.03(stat.) \pm 0.06(syst.)10^{-38} cm^2/nucleon$

• GENIE prediction generally too high in proton multiplicity. Other FSI models?

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Calorimetric reconstruction of Momentum/Energy Transfer

Rodrigues

- Low recoil q₀-q₃
 - RPA and 2p2h populate distinct regions of phase space
 - Approach a CC inclusive sample from MINERvA in these variables
- Observe:
 - RPA-like suppression at low energy transfer
 - Data excess in q₃ dip region beyond RPA 2p2h predictions
 - Evidence for multi-nucleon knockout (not shown)





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Dramatic Conclusion

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- It's time to say goodbye to M_A^{effective}



 Going forward, expect to use this data directly constrain two body current effects on precision oscillation measurements