Electrons for Neutrinos

08/03/2018

INT Workshop INT-18-1a - Nuclear ab initio Theories and Neutrino Physics

Introduction

Neutrino Oscillation Measurements are based on the incoming neutrino energy

\[ P(\nu_\mu \rightarrow \nu_x) = \sin^2(2\theta) \times \sin^2 \left( \frac{\Delta m^2 L}{4E_\nu} \right) \]

KamLAND, PRL 100, 221803 (2008)
Introduction

Neutrino side

The incoming energy is reconstructed from the final state
Highly dependent on the nuclear model
Introduction

Neutrino side

This problem can be addressed by:

- Improving the theories
- Use near detector
  - Where we wish to probe nuclear physics and no oscillation effects
  - But the flux model and the nuclear model are convoluted
- External constraints on nuclear model
Introduction
Nuclear physics input

We suggest looking at wide phase space ELECTRON DATA:
- In the semi classical regime the final state is similar.
- We know the incoming energy and can test its reconstruction.

Keeping in mind:
EM and not weak interaction is the dominant.
Different radiative effects.
CLAS

Incoming Electron beam 1 - 5 GeV

Large acceptance

Sub detectors:
- Tracking in a toroidal field
- TOF scintillators
- Cherenkov detector
- EM calorimeter

Detection threshold: 300 MeV/c

Open Trigger
CLAS Data

E2 experiment:
Beam energies: 2.2, 4.4 GeV
Targets: $^3$He, $^4$He, $^{12}$C, $^{56}$Fe

E2G experiment (less statistics):
Beam energy: 5 GeV
Elements: $^2$D, $^{12}$C, $^{27}$Al, $^{56}$Fe, $^{208}$Pb
CLAS Data

Acceptance

CLAS acceptance is large but not complete

FIG. 17: Fiducial region for electrons. Black: All events. Red: After applying the fiducial cuts. Green: After applying the fiducial cuts and demanding $x > 1$. The effect of the fiducial cuts on the edge of the distribution (Red vs. Black points) is clear. The missing section in sector 3 is due to dead wires on the region 3 drift chamber.
CLAS Data

Acceptance - Available for all

For each:
- target width
- target location
- outgoing particle type
- outgoing particle direction

The CLAS detector has a different efficiency, which we wish to publish as acceptance maps for public use.
To focus on QE events:

1 proton with momentum larger than 300 MeV/c
no additional charged hadrons
CLAS Fiducial cuts for proton and electron
CLAS Data

Scaling

Due to the difference between the neutrino vs. electron differential cross section

We’re applying an event by event weight:

\[ \frac{1}{\sigma_{\text{Mott}}} \]

To make sure we’re looking at the kinematically interesting regions
CLAS Data

2.2 GeV on $^3$He

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CLAS Data

2.2 GeV on $^3\text{He}$

Detected Gaps

Perfect acceptance

Subtracting undetected 2 proton events to get 1 proton sample the similar way

Subtracting undetected pions to get 0 pion sample

Proton multiplicity

Charged pion multiplicity

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**CLAS Data**

**Event Selection**

To focus on QE events:

- 1 proton above 300 MeV/c
- no additional charged hadrons
- CLAS Fiducial cuts for proton and electron

Given the detector acceptance map,

Any event with an additional hadron, implies more events of its kind where one of the hadron was not detected.
**CLAS Data**

**Background subtraction**

Two proton / pion subtraction method:

Using events with two hadrons, rotating the two outgoing hadron system around the q vector, each time checking if only the proton was detected.

Subtract contribution to QE-like events from the final distributions.
CLAS Data
Incoming Energy Reconstruction

Two methods for calculating the incoming energy:

\[ E_{\nu}^{\text{kin}} = \frac{2M\varepsilon + 2ME_1 - m^2_l}{2(M - E_1 + |k_1|\cos\theta)} \]

\( \varepsilon \approx 20 \text{ MeV} \) single nucleon separation energy
M-nucleon mass
\( m_l \) outgoing lepton mass
\( k_1 \) - lepton three momentum
\( \theta \) - lepton scattering angle

\[ E_{\text{Calorimetric}} = E'_e + \sum T_p + E_{\text{Binding}} + \sum E_\pi \]

\( E_{\text{Binding}} \) - Binding energy
\( T_p \) - kinetic energy of knock out proton
\( E'_e \) - energy of scattered electron
\( E_\pi \) - energy of produced meson

In use in Cherenkov detectors
Assuming QE interaction

In use in Tracking detectors
Need good hadronic reconstruction
CLAS Data

Results

\[ E_{\text{Calorimetric}} = E_e + T_p + E_{\text{binding}} \]

\[ E_{\text{Calorimetric}} \] (GeV)

\[ \text{Mariana Khachatryan} \]

\[ \text{preliminary} \]
CLAS Data

Results

\[ P_{\perp}^{\text{miss}} = P_{\perp}^{e'} + P_{\perp}^{p} \]

\[ N_\pi = 0 \]

\[ 3\text{He} \]

\[ 56\text{Fe} \]

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18
CLAS Data

Results 2.2 GeV - Calorimetric Energy

Increased tail for heavier nuclei.

Increased non QE background for higher values of missing transverse momentum.
CLAS Data

Results - Calorimetric Energy - different energies

Ee = 4.4 GeV

Ee = 2.2 GeV

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CLAS Data

Results 2.2 GeV - Leptonic Energy

Worse resolution for leptonic energy.

Increased tail for heavier nuclei.

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preliminary
CLAS Data

Results 4.4 GeV - Leptonic Energy

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**CLAS Data Results 4.4 GeV - Leptonic Energy**

- **1.** Increase in non-QE background with increasing energy.
- **2.** Radiative tail in E_calorimetric.
- **3.** Worse peak resolution for E_kin.
- **4.** Increase in non-QE background for heavier targets.

*Preliminary*
## Simulation

**GENIE**

<table>
<thead>
<tr>
<th>Nuclear model</th>
<th>Correlated fermi gas model</th>
</tr>
</thead>
<tbody>
<tr>
<td>QE</td>
<td>Lewellyn Smith for neutrino</td>
</tr>
<tr>
<td></td>
<td>Rosenbluth CS for electrons</td>
</tr>
<tr>
<td>MEC</td>
<td>Empirical Dytman model</td>
</tr>
<tr>
<td>Resonances</td>
<td>Rein Sehgal</td>
</tr>
<tr>
<td>FSI</td>
<td>data driven</td>
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</tbody>
</table>

Currently 1M events with **EM QE and MEC only**
Event Selection

Reminder:
1 proton above 300 MeV/c
no additional charged hadrons
CLAS Fiducial cuts for proton and electron

Additional Kinematics:
$Q^2 > 0.5 \text{ GeV}^2/c^2$
$W < 2 \text{ GeV}/c^2$
$|X_B - 1| < 0.2$
Data vs. GENIE MC comparison
Electron Kinematic Variables

\[^{12}\text{C}(e,e'p) \ @ \ E = 4.461 \text{ GeV}\]

Q\(^2 \geq 1 \text{ GeV}^2/c^2\), |x\(_B\) - 1| < 0.2, W < 2 GeV/c\(^2\)

- Data
- hA
- hA2014
- hA2015
- hN
- hN2014
- hN2015_XsecNNCorr
- hN2015_No_XsecNNCorr
- hN2015_No_FSI_or_NNCorr
- hN2015_No_FSI_with_NNCorr

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Data vs. GENIE MC comparison
Electron Kinematic Variables

$^{12}\text{C}(e,e'p) \ @ \ E = 4.461 \ \text{GeV}$

$Q^2 \geq 1 \ \text{GeV}^2/c^2$, $|l_B| < 0.2$, $W < 2 \ \text{GeV}/c^2$

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<th>hA2014</th>
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<td>E_p [GeV]</td>
<td>[Graphs showing data and MC comparison]</td>
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$^{12}\text{C}(e,e'p) \ @ \ E = 4.461 \ \text{GeV}$

$Q^2 \geq 1 \ \text{GeV}^2/c^2$, $|l_B| < 0.2$, $W < 2 \ \text{GeV}/c^2$

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Preliminary

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Data vs. GENIE MC comparison

Background subtraction effect

Simulation

$^{12}$C(e,e’p) @ E = 2.261 GeV

- Without Corrections
- With Pion Correction
- With 2-Proton Correction
- With Both Corrections

![Graph](chart_simulation)

preliminary

$E_p$ [GeV]

Data

$^{12}$C(e,e’p) @ E = 2.261 GeV

- Without Corrections
- With Pion Correction
- With 2-Proton Correction
- With Both Corrections

![Graph](chart_data)

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Data vs. GENIE MC comparison

Missing transverse momentum

$^{12}\text{C}(e,e'p) \ @ \ E = 4.461 \text{ GeV}$

$Q^2 \geq 1 \text{ GeV}^2/c^2, \ |x_B - 1| < 0.2, \ W < 2 \text{ GeV}/c^2$

$P_{\perp}^{\text{miss}} = P_{\perp} + P_{\perp}$

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Data vs. GENIE MC comparison
Missing transverse momentum C and Fe

\[ \text{preliminary} \]

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Summary

Presenting electron data to test the reconstruction energy method for neutrino experiments.

For QE-like events both leptonic and hadronic have bad resolution
- for heavier nuclei
- for high missing transverse momentum

We wish to compare the data to MC to obtain constraints on the nuclei models and show implication on oscillation measurements.

In addition we would like to make this data available for everyone by publishing CLAS acceptance maps.
Summary

Current available data: $^3$He, $^4$He, $^{12}$C, $^{56}$Fe

with incoming 2.2 GeV and 4.4 GeV
Future Plans

With CLAS12
Ten times more luminosity
Keeping the low threshold
300 MeV/c

Targets: $^4$He, $^{12}$C, $^{16}$O, $^{40}$Ar, $^{56}$Fe
with incoming electron energies 1.1, 2.2, (3.3), 4.4, 6.6 GeV
Thank you for your attention