Discussion: Confronting theory and experiment
(path forward and future prospects)

Conveners: Hugh Gallagher, Yoshinari Hayato-san, Jan T. Sobczyk

October 27, 2012
Monte Carlo simulations

This session was about MC simulations.

From the motivation/review talk given by Hayato-san:

Precisions of neutrino mixing parameters

Already, uncertainties of neutrino interactions (incl. final state interactions) became one of the major sources of systematic error.

*) Error of T2K analyses are still statistically limited.
   But the systematic errors may limit our sensitivities before the T2K finished.

$\theta_{13}$ is known to be rather large. Good news!

→ Next goal: CP violated or not?
   1) Much higher precision is required.
      \textbf{Total systematic uncertainties < a few \sim 5 \%}
   2) Need to know the characteristics of anti-$\nu$ and differences between $\nu$ and anti-$\nu$

\textit{Generators are necessary to be improved to be used in those “next generation” experiments.}
Monte Carlo comparison project.

Good MC event generator is a treasure.

(a credit to Hugh Gallagher, Yoshinari Hayato-san and Sam Zeller as well!)
Monte Carlo comparison project

Summary

- Introduction to studies suggested by experiments.
- Many interesting themes
  - oscillation backgrounds
  - QE signal/bkgd (osc signal)
  - FSI effects (low energy nucleons)
  - coherent backgrounds
  - total visible energy (osc signal, common way to calc $E_v$)
- Now, let’s see the results! What to look for:
  - Each plot shows a quantity expt sees as important bkgd/syst
  - Look for deviations between MC codes
  - Look for physics that might cause those deviations.
  - If MC’s agree, is that because they all use same model?
Example: total visible energy

From Tomasz Golan presentation
Example: LAr, neutrino energy 2.5 GeV

From Nathan Meyer presentation
Discussion: Confronting theory and experiment (path forward and future prospects)

After 4 days we have the data to compare with

<table>
<thead>
<tr>
<th>Multiplicity</th>
<th>Genic</th>
<th>Genic % of Total</th>
<th>DATA</th>
<th>DATA % of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>0p+1mu</td>
<td>553±11</td>
<td>60%</td>
<td>422±42</td>
<td>58%</td>
</tr>
<tr>
<td>1p+1mu</td>
<td>160±6</td>
<td>17%</td>
<td>266±53</td>
<td>37%</td>
</tr>
<tr>
<td>2p+1mu</td>
<td>68±4</td>
<td>7%</td>
<td>30±6</td>
<td>4%</td>
</tr>
<tr>
<td>3p+1mu</td>
<td>50±3</td>
<td>5%</td>
<td>3±1</td>
<td>0.4%</td>
</tr>
<tr>
<td>4p+1mu</td>
<td>32±3</td>
<td>3%</td>
<td>3±1</td>
<td>0.4%</td>
</tr>
<tr>
<td>TOTAL (including &gt;4p)</td>
<td>925±15</td>
<td>-</td>
<td>727±68</td>
<td>-</td>
</tr>
</tbody>
</table>

**$\bar{\nu}_\mu$ - anti-neutrino mode**

$\mu^-/\mu^+(DATA)=0.36$

$\mu^-/\mu^+(MC)=0.36$

data 21% lower

<table>
<thead>
<tr>
<th>Multiplicity</th>
<th>Genic</th>
<th>Genic % of Total</th>
<th>DATA</th>
<th>DATA % of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>0p+1imu</td>
<td>46±3</td>
<td>14%</td>
<td>60±12</td>
<td>23%</td>
</tr>
<tr>
<td>1p+1imu</td>
<td>163±6</td>
<td>48%</td>
<td>154±31</td>
<td>59%</td>
</tr>
<tr>
<td>2p+1imu</td>
<td>46±3</td>
<td>13.6%</td>
<td>33±7</td>
<td>13%</td>
</tr>
<tr>
<td>3p+1imu</td>
<td>23±2</td>
<td>7%</td>
<td>9±2</td>
<td>5.5%</td>
</tr>
<tr>
<td>4p+1imu</td>
<td>16±2</td>
<td>5%</td>
<td>4±1</td>
<td>1.5%</td>
</tr>
<tr>
<td>TOTAL (including &gt;4p)</td>
<td>337±9</td>
<td>-</td>
<td>260±34</td>
<td>-</td>
</tr>
</tbody>
</table>

**$\nu_\mu$ - anti-neutrino mode run**

data 23% lower

From Kinga Partyka presentation

A good performance of MC nucleon FSI models is crucial for identifying MEC contribution to the CC inclusive cross section.
Multinucleon ejection contribution

Our aim is a clear identification of MEC but...

there is a lot of mist, mostly due to FSI effects.

It is very difficult to see what we would like to see.
It is very important to have MC implementation of MEC models.

<table>
<thead>
<tr>
<th></th>
<th>GENIE</th>
<th>NuWro</th>
<th>GiBUU</th>
</tr>
</thead>
<tbody>
<tr>
<td>What kind of Leptonic model?</td>
<td>Dytman model</td>
<td>np-nh model and TEM</td>
<td>Transverse projector for hadronic tensor</td>
</tr>
<tr>
<td>how to choose 2 nucleon momentum?</td>
<td>From Fermi sea, independently</td>
<td>From Fermi sea, independently</td>
<td>From Fermi sea, independently</td>
</tr>
<tr>
<td>how to choose 2 nucleon location?</td>
<td>both are random</td>
<td>both are random</td>
<td>both are random, but same location</td>
</tr>
<tr>
<td>Any correlations?</td>
<td>no</td>
<td>no</td>
<td>no, but xs is weighted by phase space density</td>
</tr>
<tr>
<td>what kind of pairs? n-p or n-n?</td>
<td>n-p : n-n = 1 : 4</td>
<td>n-p : n-n = 3 : 1</td>
<td>n-p : n-n = 3 : 1</td>
</tr>
<tr>
<td>How to share energy-momentum transfer by 2 nucleons?</td>
<td>nucleon cluster model</td>
<td>nucleon cluster model</td>
<td>not clear</td>
</tr>
</tbody>
</table>

A resume slide prepared by Teppei Katori
Important question: how large is $1\pi 2p - 2h$ contribution?

- Disagreements in normalization and shape
- Agreement in $CC1\pi^+$ ≠ Agreement in $CC1\pi^0$

From Phil Rodrigues presentation
More general issues

- MCs intend to be both able to reproduce the data and contain correct physics!
- MCs cannot be better than our knowledge of neutrino cross sections, and that is up to $\sim 20\%$
- what are most urgent improvements to be added to MC event generators?
- how to accommodate sophisticated theoretical models?
  - which format of models predictions is most suitable both for theorists and MC authors?
  - response functions?