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

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

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## Monte Carlo simulations

This session was about MC simulations.

From the motivation/review talk given by 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.
**Total systematic uncertainties < a few ~ 5 %**
2) Need to know the characteristics of anti-$\nu$
and differences between $\nu$ and anti-$\nu$

*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 $E_\nu$)
- ▶ 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?

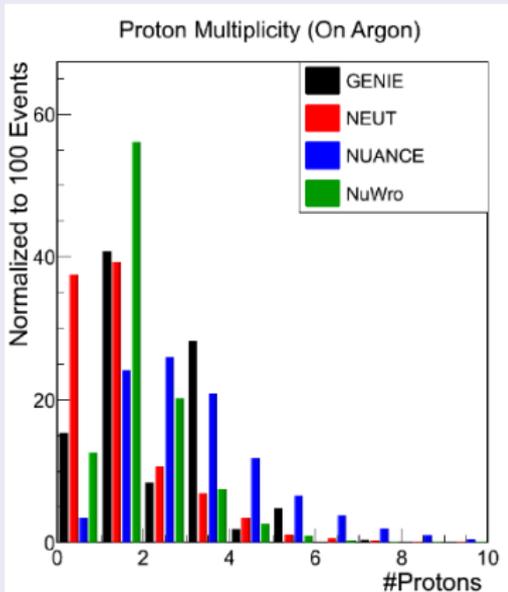From Steve Dytman presentation
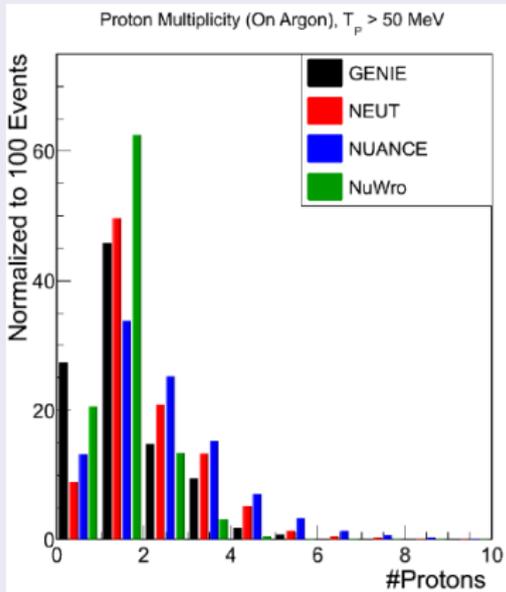
## Example: total visible energy
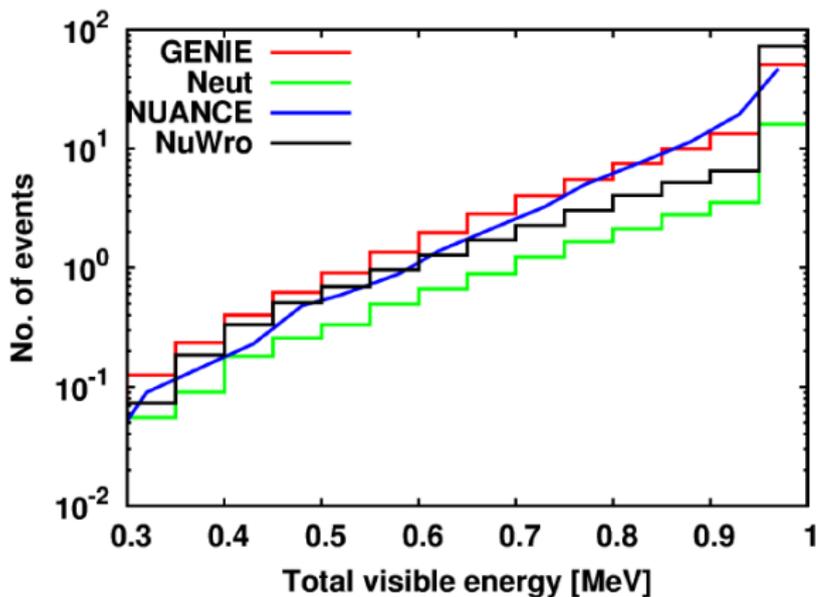


From Tomasz Golan presentation

## Example: LAr, neutrino energy 2.5 GeV



From Nathan Meyer presentation

## After 4 days we have the data to compare with



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

$\overline{\nu}_\mu$ - anti-neutrino mode

| Multiplicity | Genie | Genie % of Total | DATA | DATA % of Total |
|---|---|---|---|---|
| 0p+1mu | 553±11 | 60% | 422±42 | 58% |
| 1p+1mu | 160±6 | 17% | 266±53 | 37% |
| 2p+1mu | 68±4 | 7% | 30±6 | 4% |
| 3p+1mu | 50±3 | 5% | 3±1 | 0.4% |
| 4p+1mu | 32±3 | 4% | 3±1 | 0.4% |
| TOTAL (including >4p) | 925±15 | - | 727±68 | - |

data 21% lower

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

| Multiplicity | Genie | Genie % of Total | DATA | DATA % of Total |
|---|---|---|---|---|
| 0p+1mu | 46±3 | 14% | 60±12 | 23% |
| 1p+1mu | 163±6 | 48% | 154±31 | 59% |
| 2p+1mu | 46±3 | 13.6% | 33±7 | 13% |
| 3p+1mu | 23±2 | 7% | 9±2 | 3.5% |
| 4p+1mu | 16±2 | 5% | 4±1 | 1.5% |
| TOTAL (including >4p) | 337±9 | - | 260±34 | - |

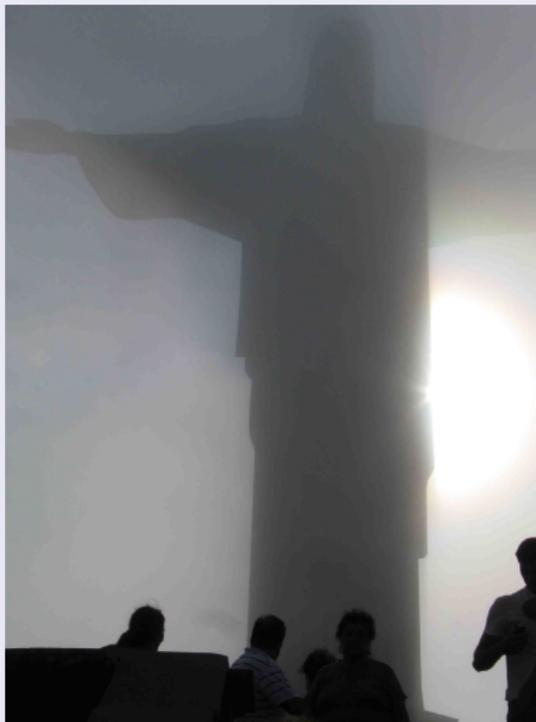data 23% lower

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.

## MEC in Monte Carlo generators

It is very important to have MC implementation of MEC models.

### MC implementation of MEC model

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

A resume slide prepared by Teppei Katori

## Important question: how large is $1\pi 2p - 2h$ contribution?
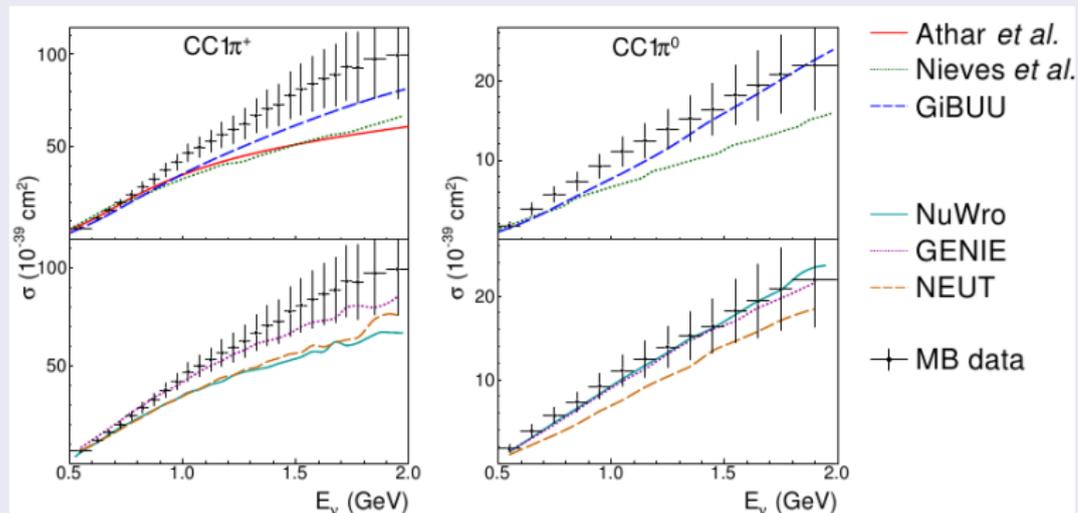


- Disagreements in normalization and shape
- Agreement in $CC1\pi^+$ $\nleftrightarrow$ Agreement in $CC1\pi^0$

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 accomodate sophisticated theoretical models?
    - which format of models predictions is most suitable both for theorists and MC authors?
    - response functions?