WG2 Cross Section Summary

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<table>
<thead>
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<th>Time</th>
<th>Monday</th>
<th>Tuesday</th>
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</table>
| 09:00-10:30 | 09:00-10:30 | **CAV** Or Hen  
Modelling tensions  - Joanna Sobczyk  
μBooNE & Adrien Hourlier | | | Generator status  - Luke Pickering |
| 11:00-12:30 | 11:00-12:30 | MINERvA  
Tejin Cai | | | Theory |
| 14:00-15:30 | 14:00-15:30 | Experiment | | Joint with Oscillations | Theory + Generators |
| 16:00-17:30 | 16:00-17:30 | Experiment | | Joint with Oscillations | Experiment + Discussion |
Experimental results
Experimental results

The Spallation Neutron Source at Oak Ridge National Laboratory

COHERENT collaboration observed CEvNS process using different target material detectors

CENNS-10 (LAr) is almost ready to report the first physics results

CsI data analysis in progress
Experimental results

Neutrino Interaction research with Nuclear emulsion at the J-PARC Accelerator

Passed feasibility test.

Looking towards a Nov. 2019 physics run
Awaiting results for NuFact2020

Tsutomu Fukuda & Hitoshi Oshima
Experimental results

Study of $\nu^{16}\text{O}$ NCQE interaction with T2K and SK

External experiment to measure production cross sections of gamma rays emitted by the knocked-out neutron–$^{16}\text{O}$ interaction

Coherent inelastic processes are more dominant than expected

Maurel Alice
Experimental results

Fitting Near detector data in $\mu$ momentum for both C and O targets to be used for Oscillation analysis.

![ND280 data fit](image1)

- Fit to data binned in $\mu$ momentum and angle, with both C and O targets.
- Post-fit is in much better agreement with the data.
- Constrains event rates and greatly reduces systematic parameter errors.

![Data fit](image2)

ND280 data fit
MiniBooNE observes a low energy $\nu_e$-like excess with a significance of $4.8\sigma$, compatible with the LSND excess.
Experimental results

\( \nu_{\mu} \text{CC} \)

\( \nu_{\mu} \text{CC}\pi^0 \)

made significant progress towards testing MiniBooNE’s excess: Signal processing, calibration and detector physics, CS measurements

Constraining systematics by using in situ measurement of \( \nu_{\mu} \)

Pip Hamilton
Experimental results

$\overline{\nu}_\mu CC\pi^-$

Statistically limited and showing disagreement in $\mu$ and $\pi$ angles
arXiv:1903.01558, submitted for publication

Transverse variables

Also helped improving GENIE, its tuning. Especially FSI, $\pi$ absorption leading to asymmetry
arXiv:1906.10576

Neutron multiplicity

disagreement in dip and $\Delta$ rich regions mainly from low energy events
arXiv:1901.04892v1
Experimental results

NC coherent $\pi^0$

arxiv:1902.00558, submitted to PRD

$\nu_{\mu}$CC Semi Inclusive $\pi^0$

$\nu_{\mu}$CC Inclusive

$\nu_{e}$CC Inclusive

Hongyue Duyang, Erica Smith
Experimental results

The Neutrino Elastic-scattering Observation experiment with NaI[Tl] crystal (*NEOM*)

To observe coherent elastic $\nu A$ scattering (CNNS) from reactor neutrinos at Tendon Gallery of Habit Nuclear Power Plant

Observing CNNS
aiming for precision measurement
maybe $\nu$-e interaction
Experimental results

Two phase LAr detector
1500 L cryostat
with a new optical readout as an alternative to charge, using high sensitivity cameras to catch secondary scintillation light

ARIADNE at CERN
Run spring 2018
Collected data 0.5-8 GeV
Bridging between $\nu$ and $N$ communities

The neutrino community needs:

- Valid predictions for different interaction channels
- Heavy nuclei studies

The electron scattering experiments measures and theorist predicts:

- Inclusive rates vs. energy transfer
- Only lower $A$ nuclei till now
Two different levels of difficulty:
Hadron physics: Poorly known axial couplings to the nucleon
Nuclear Physics: Nucleus is an interacting many body system, need to account for e.g. long-range correlations, nuclear medium effects, multinucleon knockout, FSI, ...
For inclusive electron scattering data, many theoretical models seem to work reasonably well but can give varying predictions for exclusive observables. Current and future neutrino experiments probe a huge range of phase space, and we need a description for everything. The coherent sum of different contributions can lead to degeneracy.
Theory input
Neutrino-induced pion production
Angular distributions of pions produced in neutrino reactions are non-trivial. In MC generators they are usually isotropic in CMS, this is far from what theory finds
Distributions vary strongly with the channel and the kinematics of the process

Specific areas of worry:
Separation Energy
Low Q2 Suppression
Neutron Energy
Pion Multiplicity
Optical potentials
Hadronic rescattering

If the models predicting Observable $\rightarrow$ True mappings are wrong:
Inferred oscillation parameter constraints can also be wrong
Cross Section model constraints

\[ e4V \]

Leveraging wide phase space electron scattering from CLAS to constrain neutrino generators

Biases in the reconstruction of the incoming lepton energy reconstruction can lead to biased oscillation parameters extraction.

Working close with neutrino generators to improve existing models
For forward scattering angles and low momentum transfer the ratio of electron to muon cross section is different.
From the lepton vertex one expects the electron neutrino induced cross section to be Larger 
Nuclear effect lead to larger nuclear responses for the muon-induced process at forward angles.

Non-trivial ratio of electron versus muon neutrino cross sections have a significant overlap with the T2K oscillated flux weighted cross section.
### Flux constraints

| Hadron Production measurements | $\nu$-e scattering measurements | Monitored neutrino beams |
Theory input: $\nu$-e scattering

neutrino scattering of atomic electrons is standard candle to constrain flux uncertainty

Ongoing analyses reducing uncertainty for MINERvA & NOvA

Goal - EFT based calculation with accuracy below %
Analytic results and first error estimate at 0.2-0.4% level

- analytic results and first error estimate at level 0.2-0.4%

O. Tomalak and R. Hill (2019)
Hadron Production

Presenting measurements with various relevant targets and energies. Working close with T2K and NOvA Fermilab experiments

Looking for feedback and input: Which measurements are useful for various neutrino experiments?

Encourage members of the various neutrino experiments involved in neutrino beams to join the NA61/SHINE collaboration!
ENUBET first monitored neutrino beam!

1% in neutrino flux
1% flavour composition
low neutrino energy resolution (20% - 8% at 1 -4 GeV)

Radiation harness problems have been solved
Full simulation is completed
Towards a full conceptual design by 2021

F. Terranova (Univ. of Milano-Bicocca and INFN)
Summary

Thank you all for participating in a fascinating program and giving a clear picture of Cross Section measurements status, challenges and prospects!

While various experiments are going with the important work of creating a first of a kind Cross Section measurements data base to be used by oscillation experiments, there are many supporting efforts!
Summary

Bridging between the nuclear and neutrino community is crucial

There’s a long way to go with cross section models, by improving theory, incorporating newer models into generators and using external measurements!

Flux constraints are improving in parallel promising avenues.