NF06: Report Status

Neutrino Interaction Cross Sections

Did we missing material? Key conclusion feedback?

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Snowmass: “define the most important questions in the field of particle physics and identify promising opportunities to address them

1. GOALS: Planning for 2025-2035 with a view toward 2050 (comments welcome on each from any frontier)
    - What are the important scientific questions in your frontier of particle physics during this period?
    - What enabling tools, technologies, or facilities studied by your frontier are needed to address the pressing scientific questions in particle physics during this period?
    - How can we ensure that the US particle physics community is vibrant, inclusive, diverse, and capable of addressing the scientific questions identified, and of fulfilling our obligations to society during this period?
2. CONTEXT: What can be expected from ongoing, approved, planned, or proposed scientific, technical, or community programs in addressing the issues identified by your frontier?

3. OPPORTUNITIES:
    - What opportunities identified by your frontier are there for new scientific, technical, or community activities to create transformative change in particle physics, on what timescales could these occur, and what resources are required to realize these activities?
    - What investments need to be made during 2025-2035 for the continuing scientific, technical, or community progress identified by your frontier in the decades beyond, on what timescales can these be implemented, and what resources would be required?
4. COLLABORATION: What opportunities exist for cross-frontier, cross-disciplinary, or international collaboration and cooperation in the coming decade to enhance our ability to address the issues identified (including training or mentorship)? How do these collaborations affect the timescales or resources needed for these activities?

5. ADDITIONAL INPUT: Are there other issues identified by your frontier that are not included in the responses to the questions above?
    - In particular, are there adverse scientific, technical, or community impacts from the COVID-19 pandemic that still need to be addressed?

NF06 Scope

Neutrino interactions on a wide range of target nuclei and across the full spectrum of neutrino energies.

- Measurements relevant for current and future:
  - Oscillation experiments
  - e/pi/p/n scattering experiments
  - Supernova detection and physics
  - Exotic or BSM searches, e.g. hidden sector searches as backgrounds
- Theoretical developments and modelling
  - Theoretical efforts
  - Event generators

NF06 : not in scope but broad overlap with …

- Physics derived from cross section measurements
  - NF01 Neutrino Oscillations
  - NF02 Neutrino Anomalies
  - NF03 BSM
  - NF05 Neutrino Properties
- Detector/Source technologies required to make meaningful measurements
  - NF04 Natural Sources
  - NF09 Artificial Sources
  - NF10 Neutrino Detectors
- Theory NF08/TF11

NF06 Scope

- Areas of focused overlap
  - Theory
  - Event Generators
  - Parity violating electron scattering measurements

Initial Community input

Total of 79 Letters directly relevant to NF06
Subset of 22 Letters where NF06 is primary

Preliminary Groupings and Themes:

- Low Energy Neutrino Nuclear Cross Sections
- Near Detector, service experiments
- Electron Scattering
- Event generators

Workshops Organized by NF06

- **Neutrino Cross Section Data Usage and Archival - Sep 2020**
  - https://indico.fnal.gov/event/45059/
- **Electron Scattering Dec 2020**
  - https://indico.fnal.gov/event/46620/
- **Low Energy Neutrino and Electron Scattering Workshop Dec 2021**
  - https://indico.fnal.gov/event/51519/

➢ NF06 Contributed White paper (outcome of two workshops): Electron Scattering and Neutrino Physics

White papers NF06 is anticipating

S. Pastore - Theoretical tools for neutrino scattering: the interplay between lattice QCD, EFTs, nuclear physics, phenomenology, and neutrino event generators

V. Cirigliano - Theory for neutrinoless double beta decay

K. Scholberg - COHERENT

L. Strigari - Coherent elastic neutrino-nucleus scattering: Terrestrial and astrophysical applications

M Toups - Fixed-Target Searches for New Physics with O(1 GeV) Proton Beams at Fermi National Accelerator Laboratory

K Scholberg - Neutrino Physics at the Spallation Neutron Source Second Target Station

K Scholberg - Low Energy Physics in Liquid Argon

V. Pandey - Electron Scattering and Neutrino Physics: A Snowmass White Paper

R. Hill - Neutrino Scattering Measurements on Hydrogen and Deuterium

A. Marino - A Gaseous Argon-Based Near Detector for DUNE to Enhance Physics Capabilities

C. Jackson - Low Background kTon-Scale Liquid Argon Time Projection Chambers

J. Newby - Neutrinos at ORNL

H. Reno - Forward Physics Facility

J. Issacson - Event Generators for High-Energy Physics Experiments

Report Outline

1. What we do and do not know about neutrino cross sections…
    1.1. Threshold-less and Low Energy Nuclear Processes E_ν ~ 0 - 100 MeV
    1.2. Intermediate Energy Cross Sections E_ν ~ 100 MeV - 20 GeV
    1.3. High Energy Cross Section E_ν ~ 20 GeV - 1 EeV

Report Outline

1. What we do and do not know about neutrino cross sections…
   1.1. **Threshold-less and Low Energy Nuclear Processes E_ν ~ 0 - 100 MeV**

CEvNS physics: predictions and measurements of neutron form factors

SNB physics: Key features need to be predicted and measured exclusive final states on Ar

Report Outline

1. What we do and do not know about neutrino cross sections…

   1.2. Intermediate Energy Cross Sections E_ν ~ 100 MeV - 20 GeV
   1.3. High Energy Cross Section E_ν ~ 20 GeV - 1 EeV

Osc physics: semi inclusive -> exclusive predictions for a variety of processes

(also important at some level for exotica, BSM searches)

Primary information provided from oscillation experiment’s near detectors

Complementary role of pion and electron scattering (+neutron, proton)

External measurements and theory anticipate problems and develop complete model of uncertainties

Report Outline

1. What we do and do not know about neutrino cross sections…

    1.3. High Energy Cross Section E_ν ~ 20 GeV - 1 EeV

BSM searches at very high energies: typically, statistics and detectors are the limiting factors…

Report Outline - non-neutrino measurements

2a). Pion scattering - *used to constrain FSI and SI models*

LArIAT, DUET measurements

ProtoDUNE plans

2b). Electron scattering - measure vector piece, important to develop semi inclusive models, test FSI

- See WP, range of measurements planned with relevant kinematics/targets for future programs
- PVES for LE program

Report Outline - HE neutrino measurements (1)

3a). Current and future near detectors

T2K: ND280 -> upgrade, WAGASCI+BabyMIND, SK Gd

NOvA: ND

DUNE: ND-LAr, ND-GAr, PRISM, SAND H measurements

HK: ND plan, IWCD

3b) Short baseline experiments

MicroBooNE

SBND

ICARUS

Have reached out to some but not all collaborations yet, we want to talk to confirm your plans!

Report Outline - HE neutrino measurements (2)

3b). Dedicated cross section programs

ANNIE

MINERvA

NINJA

nuSTORM (white paper)

New H/D (white paper)

Far forward neutrinos at LHC (white paper)

Have reached out to some but not all collaborations yet, we want to talk to confirm your plans!

Report Outline - LE program measurements

- Coherent Elastic Neutrino Nucleus Scattering (CEvNS) at reactor and stopped pion sources
  - For physics: BSM, EM properties, etc
  - Backgrounds for hidden sector searches
- Inelastic neutrino nuclear scattering measurements
  - For physics: Weak nuclear properties
  - Source and detection normalization
- Parity Violating Electron Scattering measurements
  - Weak form factor connection to CEvNS - NF03 WP

WPs: Theoretical tools… (S. Pastore), COHERENT, CEvNS(L. Strigari) - Fixed-Target Searches … (M Toups), SNS-STS(K Scholberg), LEPLAr (Scholberg), H D Scattering (R. Hill) Low Background kTon LAr TPC (C. Jackson), Neutrinos At ORNL (J. Newby) , Others?

CEvNS Experiments

Experiment	Source	Target
COHERENT	πDAR	Na, Ar, Ge, CsI,
Coherent CAPTAIN Mills	πDAR	Ar
JSNS^2	πDAR	
ESS	πDAR	
CHILLAX	Reactor	Ar
CONNIE	Reactor	Si
CONUS	Reactor	Ge
MINER	Reactor	Ge, Si
NEON	Reactor	Na
NUCLEUS	Reactor	
NUXE	Reactor	Xe
PALEOCCENE	Paleo	
Ricochet	Reactor	Ge, Zn
RED-100	Reactor	Xe
NuGen	Reactor	
SBC	Reactor	Ar
TEXONO	Reactor	Ge
NEWSG	Reactor	H, He, C, Ne

Report Outline - generators and data archival

4) Generators - *white paper + panel discussion at theory WP workshop*

5) Data archival - *summary of workshop*

Report Outline - (HE) executive summary

- *A dedicated exercise, seeded by oscillation experimental programs but involving theory and external measurements, to assess the benefits of the suite of new cross section measurements on oscillation physics, and refine what specific measurements are needed, is important.*

- *Generators are a critical part of the physics program but it is difficult to rapidly improve them. It is crucial to bring all the stakeholders together to define a path forward and develop suitable incentives. We endorse important grassroots efforts to solve duplication of effort and increase involvement.*

- *Collaborations which provide cross section measurements should be encouraged to have data preservation plans to allow for re-analysis of data into the future.*

Feedback most welcome…

- Did we miss your experiment or effort?
- Comments, thoughts on conclusions or framing