NF09 - Artificial Neutrino Sources

Topical Subgroup Feedback Workshop

25 February 2022

L. Fields, A. Marino, P. Ochoa, J. Spitz

Outline

- Introduction to NF09: Artificial Neutrino Sources
- NF09 Report Outline
- Table of Accelerator Requirements for AF02

Intro to NF09: Artificial Neutrino Sources

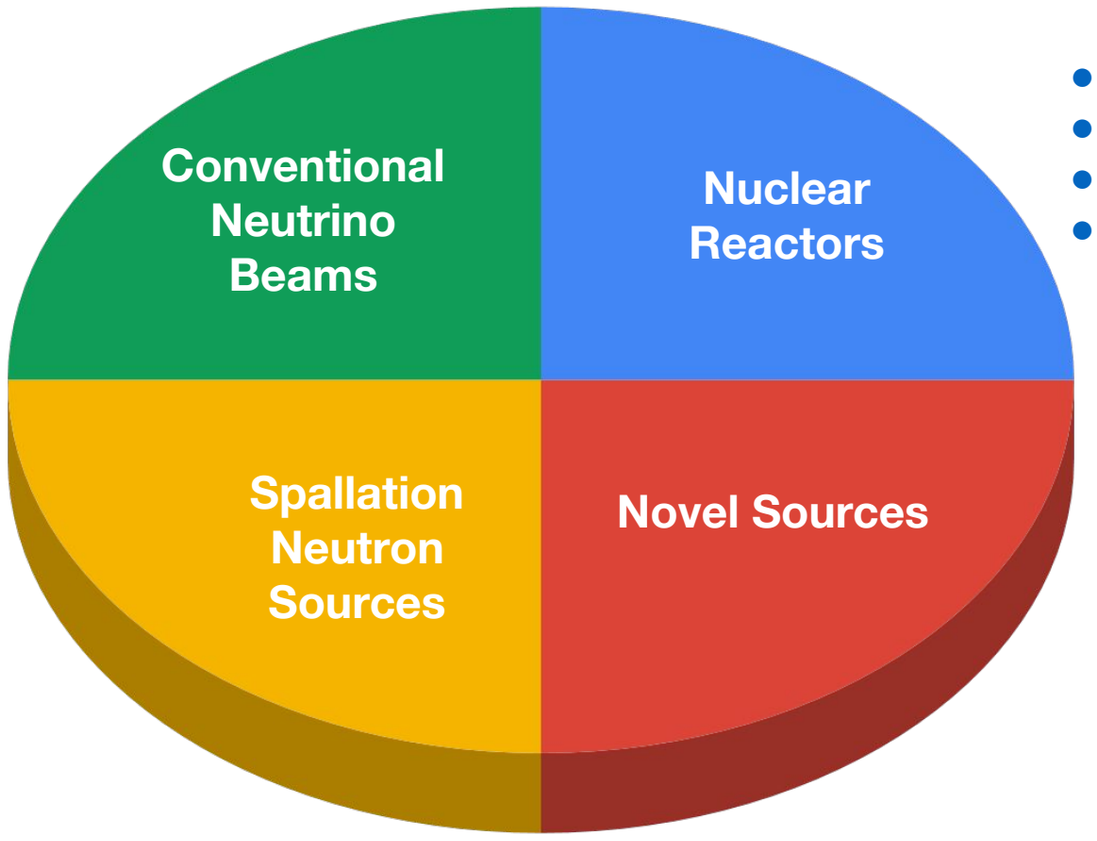
Our group covers the development of new or upgraded artificial neutrino sources, as well as efforts to characterize/understand these sources.

Precision measurements of 3-flavor oscillations (including δ_{CP}), mass ordering, sterile neutrinos and other BSM, neutrino interactions

- NuMI at Fermilab
- J-PARC neutrino beam
- LBNF (to be constructed at Fermilab)
- ESSnu SuperBeam
- Hadron production measurements

Coherent neutrino-nuclear scattering; cross sections for supernovae, tests of electro-weak theory, sterile neutrinos

- SNS at Oak Ridge
- LANSCE at Los Alamos
- JSNS in Japan
- ESS in Sweden
- ISIS in the UK
- SINQ in Switzerland
- CSNS in China



Precision measurements of 3-flavor oscillations, mass ordering, searches for sterile neutrinos and other BSM, reactor flux characterization

- Daya Bay (China)
- JUNO and JUNO-TAO (China)
- WATCHMAN (UK)
- PROSPECT (US)

- NuStorm
- IsoDAR
- LHC forward physics
- BEST

NF09 is aiming to document possibilities the community is considering for: upgrades to these facilities, new artificial neutrino sources, and improved characterization of new and existing sources

Overall Report Outline

NF09 report will describe sources and their unique capabilities. Will be overlap with AF02-Accelerators for Neutrinos, CF1-DarkMatter: Particle-Like, NF01-Neutrino Oscillations, NF02-Neutrino Anomalies, NF10-Neutrino Detectors, etc.

Major Sections of our Report

1. Introduction

2. Conventional Neutrino Beams (Alysia)

3. Neutrinos from Spallation Neutron Sources (Josh)

4. Nuclear Reactors (Pedro)

5. Novel Neutrino Sources (Laura)

6. Conclusion

Each section editor will now describe the content of their section

Section 2: Conventional Neutrino Sources Draft Outline

- Introduction and Summary of Current Landscape
  - BNB, NuMI, J-PARC neutrino beam
- NOvA Future Program
- J-PARC Upgrade
- LBNF Beamline and Upgrade
- ESSNu Super Beam
- Measurements to Characterize Neutrino Beams
  - Beam Instrumentation
    - ENUBET
  - Hadron Production Measurements
    - NA61/SHINE
    - EMPHATIC
    - NA65/DsTau
  - Near Detectors
    - NuPRISM
    - DUNE-PRISM
    - SAND

Potential Figures to be Included for Conventional Beams

- Will be contacting the community for assistance with these
  - J-PARC (HK era) flux spectra
  - LBNF flux spectra
  - DUNE sensitivity with and without 2.4 MW upgrade
  - Sample spectra from either NuPRISM or DUNE-PRISM to illustrate PRISM concept

Section 3: Neutrinos from Spallation Neutron Sources

- Introduction and Summary of Current Landscape
  - SNS at Oak Ridge, MLF at J-PARC, LANSCE at Los Alamos, ESS, ISIS, SINQ in Switzerland, CSNS in China
- Relevant characteristics of each beam (power, timing, space constraints and access)
  - Physics enabled by these characteristics
- Future and far-future COHERENT program
- ORNL second target station
- JSNS^2 and JSNS^2-II at J-PARC
- ESS spallation neutron (neutrino) source
- Flux monitoring and hadron production

Section 4: Nuclear Reactors

- **4:1** Nuclear Reactors as Neutrino Sources
  - Basics: detection channels, types of reactors, … etc.
  - Advantages: intensity, availability, cost-effectiveness and purity
  - Active field:

Figure: planned, ongoing, and recently completed reactor experiments. Image from "HEP Physics Opportunities Using Reactor Antineutrinos" white paper, under preparation

  - Motivate need for improved reactor models and data benchmarks
    - Future experiments
    - Resolution of experimental anomalies
    - Evaluation of nuclear data
    - Nuclear safeguards

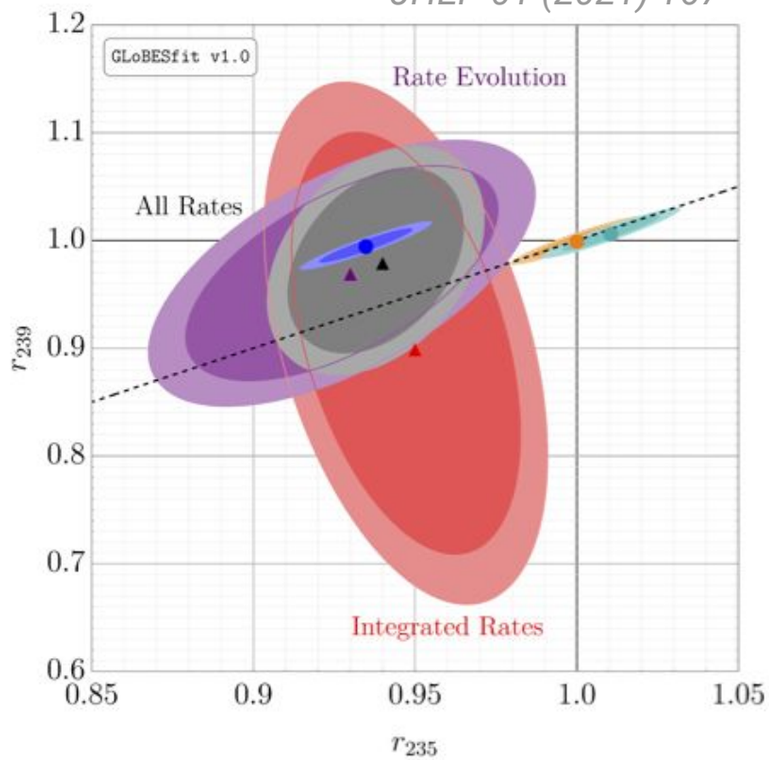
Section 4: Nuclear Reactors

- **4:2** Current Knowledge of Reactor Antineutrino Emission
  - **4.2.1** Data-Driven Models
    - Conversion
    - Summation (including recent developments)
  - **4.2.2** Neutrino Measurements
    - Huge advances in the last decade!
      - Daya Bay, Double Chooz, RENO, NEOS, PROSPECT, STEREO, … etc
      - LEU and HEU experiments, ~m to ~km baselines
    - Measured flux and spectral shape for avg. fission fractions and for 2 main isotopes

From "HEP Physics Opportunities Using Reactor Antineutrinos" white paper

Experiment	f_{235}	f_{238}	f_{239}	f_{241}	Measurements
Bugey-3	0.614	0.074	0.274	0.03	flux/spect
Bugey-4	0.614	0.074	0.274	0.03	flux
Daya Bay	0.630-0.511	0.075-0.077	0.253-0.345	0.042-0.068	flux/evol/spect
RENO	0.62-0.527	0.072-0.074	0.262-0.333	0.046-0.066	flux/evol/spect
Double CHOOZ	0.520	0.087	0.333	0.060	flux/spect
ILL	1	0	0	0	flux
Savannah River	1	0	0	0	flux
STEREO	1	0	0	0	flux/spect
PROSPECT	1	0	0	0	spect

JHEP 01 (2021) 167

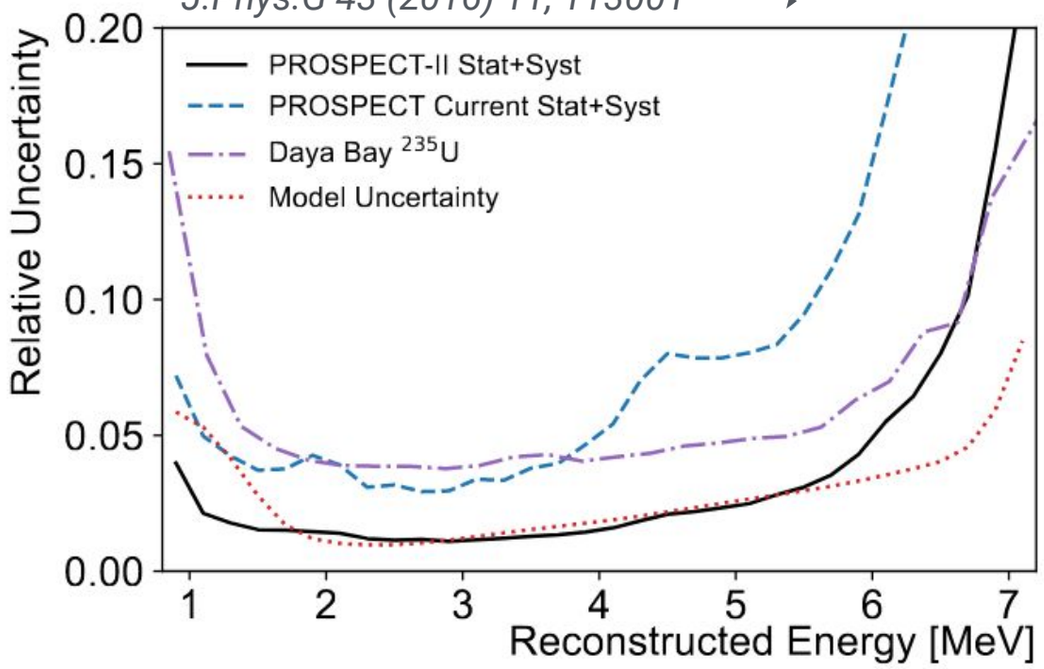


  - **4.2.3** Data vs. Model Discrepancies
    - Reactor Antineutrino Anomaly, 5 MeV bump
    - ^{235}U yield appears mismodelled, ^{239}Pu looks ok

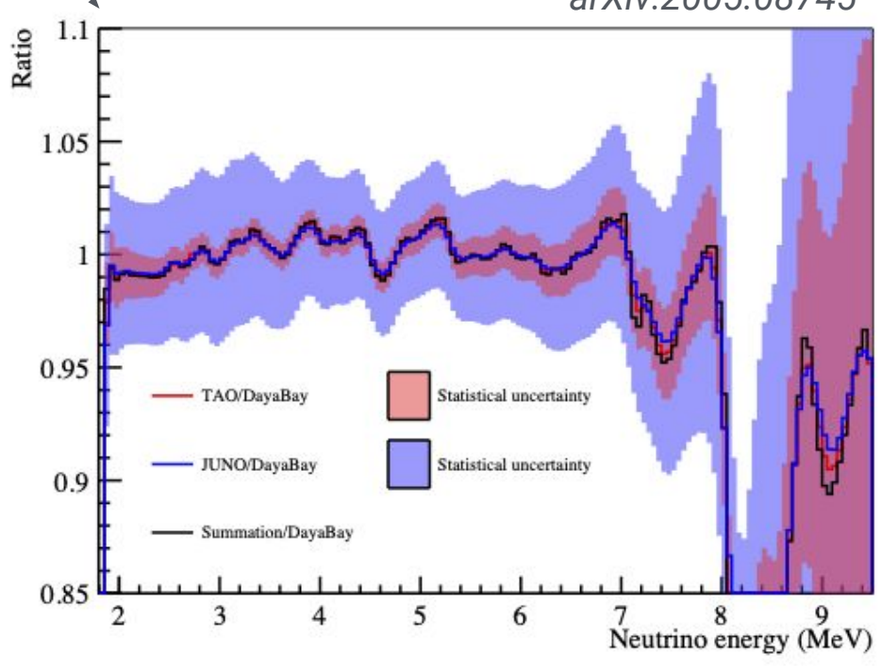
Section 4: Nuclear Reactors

- **4:3** Future Improvements
  - **4.3.1** IBD Measurements
    - Daya Bay, NEOS 2, PROSPECT II, JUNO-TAO

J.Phys.G 43 (2016) 11, 113001



arXiv:2005.08745



  - **4.3.2** Non-IBD Measurements
    - Recent results from Kurchatov Institute
    - Need for high-precision aggregate beta spectrum measurements
    - Need for measurement of beta spectrum shapes for a few forbidden beta decay transitions of high-Q isotopes
    - New TAGS measurements (limited impact?)
    - CEvNS measurements below 1.8 MeV IBD threshold

Section 5: Novel Sources

- Time bunched sources
- Beam-dump sources
  - O(1 GeV) Beam dump at Fermilab
  - O(10 GeV) Beam dump at Fermilab
  - SHiP @ CERN
- IsoDAR
- Intense radioactive electron capture sources
- NuStorm
- Neutrinos From the LHC
  - FaserNu and SND@LHC
  - Forward Physics Facility
- Lepton Colliders

Not technically a neutrino source, but a proposal to use a neutrino beam as a potential dark matter source

Aiming for short (1-3 paragraph) summary of each of these sources, with references to relevant white papers.

Awaiting white papers, particularly from NuStorm and Lepton Colliders

Accelerator Requirements Table

We have been working with AF02 and source proponents to develop a table of accelerator requirements:

		Secondary beam					Primary beam				
Project	Primary Physics Goal	Particle	Purity	Energy [GeV]	Spatial characteristics	Timing	Particle	Energy [GeV]	Power [MW]	Timing	References
NuMI/NovA Upgrade	LBLO	,		2	Pulsed-horn forward beam	?	p	120	>0.9	?	NF145
T2K Upgrade	LBLO	,		2	Pulsed-horn forward beam	?	p	30	1.3	?	NF187
LBNF/DUNE	LBLO	,		0.5-4	Pulsed-horn forward beam	Low Duty factor	p	30-120	1.2	Low duty factor	DUNE TDR
LBNF/DUNE Upgrade	CP violation	,		0.5-4	Pulsed-horn forward beam	Low Duty factor	p	30-120	>2.4	Low duty factor	AF092, DUNE TDR
LBNF/DUNE Timing Upgrade	CP violation	,		0.5-4	Pulsed-horn forward	Low Duty factor	p	120	1.2	<200 ps bunches	NF116
LBNF/DUNE Low Energy Upgrade	CP violation, solar oscillation parameters	,		0-4	Pulsed-horn forward beam	Dual BNB/MI timing	p	30 and 120	?	Dual BNB/MI timing	AF092, DUNE TDR
LBNF/DUNE HE Upgrade	nu_tau appearance : unitarity, NSI			0.5-10	Pulsed-horn forward beam	Low Duty factor	p	120	>1.2	Low Duty factor	AF092, DUNE TDR
FASER2/FASERν2	BSM, interaction, Dark matter	e, e,, , ,			Secondary beams emerging from collider IP	Continuous - 25 ns structure	p	7000	n.a.	Continuous - 25 ns structure	EF038
ORNL SNS	BSM, interactions, steriles, Dark Matter	e, ,	99% (https://arxiv.org/abs/2109.11049)	0-0.052	High-purity pion decay at rest	~400 ns width for prompt pidk, 2.2 us for mudk @ 60Hz	p	1-1.3	1.4 (First TS) then 2.0;eventually 1.8 at FTS+0.6 at STS	400 ns @ 60 Hz	NF108, NF095, NF111, NF067, NF161
LANL SNS	?	?		?	?	?	?	?	?	?	AF215
JPARC SNS	?	?		?	?	?	?	?	?	?	NF128

Table 1: Upgrades to existing sources

Accelerator Requirements Table

We have been working with AF02 and source proponents to develop a table of accelerator requirements:

		Secondary beam					Primary beam				
Project	Primary Physics Goal	Particle	Purity	Energy [GeV]	Spatial characteristics	Timing	Particle	Energy [GeV]	Power [MW]	Timing	References
O(1 GeV) Beam dump	Dark matter and Sterile search	BSM		O(1)	Beam dump	Low duty factor	p	?	0.1-1	Low duty factor	AF092 RF099
BNB Beam dump	BSM and Dark Matter search	BSM		2	Beam dump	15 Hz	p	30	1.3	?	AF092 RF084
IsoDAR	Sterile search	e					p	0.06	0.6		Not really a beam, AF092 RF084
ESSnuSB	CP violation			2-2.5	Pulsed Horn Forward Beam	14 Hz	p (H-)	2.5	5	1.4 µs duration	NF062
ESSnuSB-LEnuSTORM	cross sections, steriles	,e	50%/50%	0.4		14 Hz	p (H-)	2.5	5	1.4 µs duration	NF062
TeV Muon collider	Tau neutrino physics						µ				AF081
NuStorm							p	100			NF067 requires µ storage ring
Moment											
ENUBET	Precise measurement of nu cross sections, sterile nu using a beam with well known normalization	charged pions, kaons	K is ~5/10% of pions	4-9 GeV/c	after collimation and focusing O(10x10) cm2	O(1e10-11) pi+/K+ over a (2-4 s slow extraction) with quad focusing or a sequence of O(1) ms bursts with ~10 Hz (burst mode slow extraction) for horn focusing	proton s	30-120-400 GeV	100 kW or more	O(1e13) POT over a (2-4 s slow extraction) with quad focusing or a sequence of O(1) ms bursts with ~10 Hz (burst mode slow extraction) for horn focusing	https://cds.cern.ch/record/2759849?ln=en

Table 2: New Sources

Summary

- NF09 group report aims to catalog all artificial neutrino sources that are being considered for the future
- Report is coming together, but still needs a lot of input from white papers
- Please get in touch with us if you see omissions in this outline, or have other comments