NF09 - Artificial Neutrino Sources

Snowmass AF02 Town Hall

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Outline

- Introduction to NF09: Artificial Neutrino Sources
- NF09 LOIs
- NF09 Workshop Recap
- Next draft table of accelerator requirements for neutrino programs
- NF09 plans going forward

Intro to NF09: Artificial Neutrino Sources

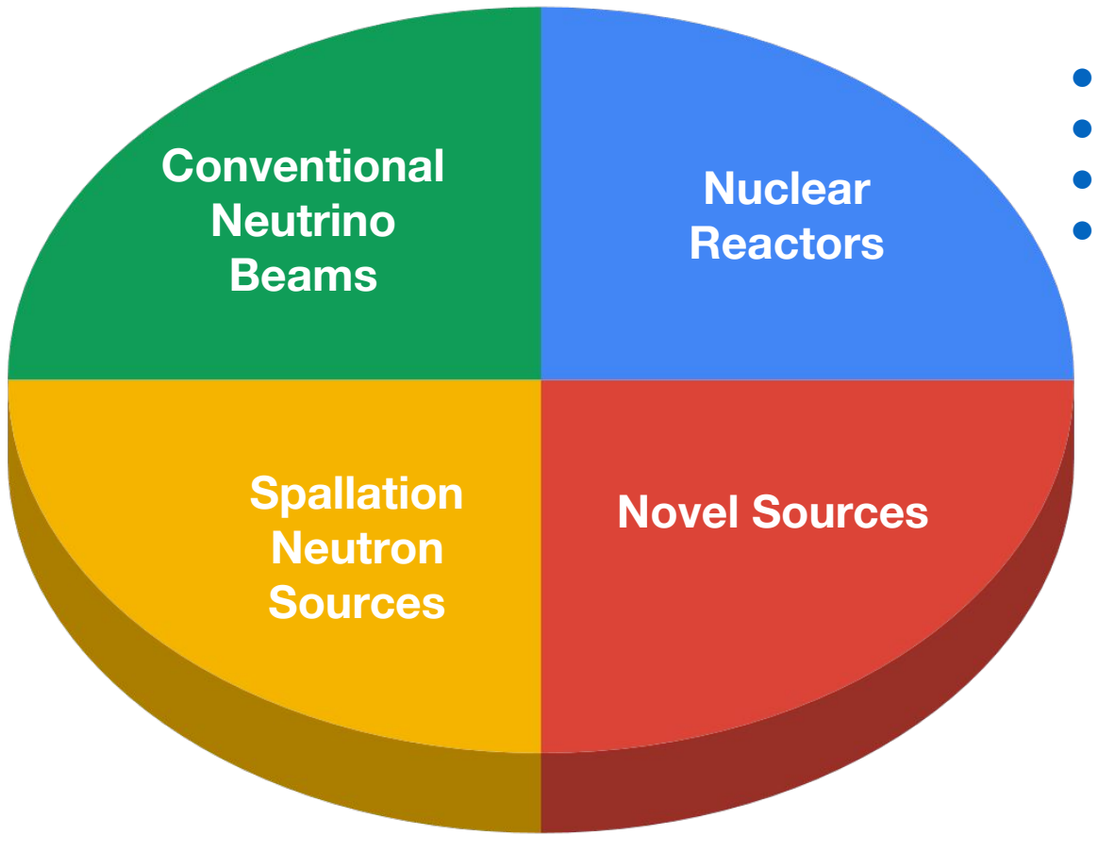
Our group covers the development of new or upgraded artificial neutrino sources, as well as efforts to characterize/understand these sources. Current landscape:

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

- NuMI at Fermilab
- BNB at Fermilab
- LBNF (under construction at Fermilab)
- T2K Beamline at JPARC

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

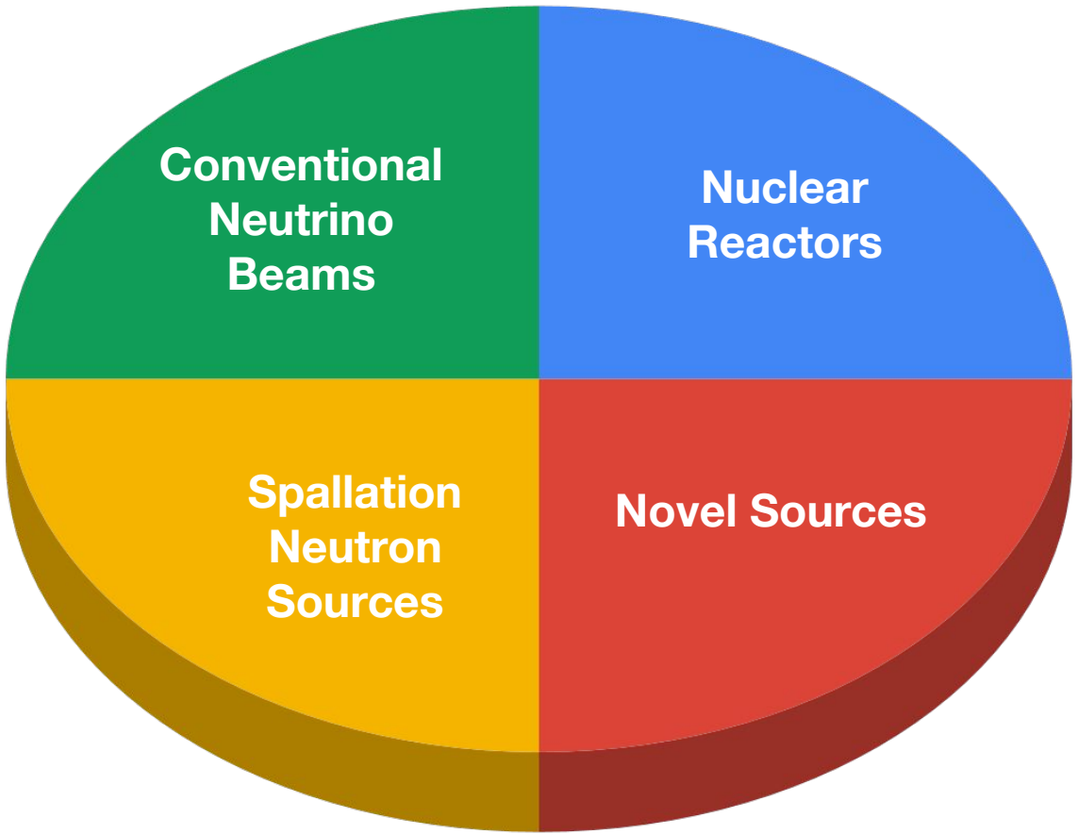
- Daya Bay (China)
- JUNO and JUNO-TAO (China)
- WATCHMAN (UK)
- PROSPECT (US)

- BEST
- IsoDAR

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

Intro to NF09: Artificial Neutrino Sources

In this talk, I'm going to concentrate on accelerator-based neutrino sources, so conventional neutrino beams, spallation sources, and some novel sources.



Letters of Interest Received

- A total of 69 LOIs fell under our group's purview:
  - We are the **primary** group within the NF for **16** of them:

Unique ID	Title	Subcategory	
AF092	*Versatile Multi-MW Proton Facility with Synchrotron Upgrade of Fermilab Proton Complex*	Conventional neutrino beams	
AF025	*The Need for Research into Early Conceptual Integration and Optimization, and Maturity evaluation of Future Accelerators*	Conventional neutrino beams	
NF116	*The use of Precision Beam Timing in LBNF/DUNE.*	Conventional neutrino beams	
AF190	*R&D for MW Pion Production Targets for Next Generation Long Baseline Neutrino Facilities*	Conventional neutrino beams	☆
NF173	*The EMPHATIC Table-Top Spectrometer: Enabling Hadron Scattering and Production Measurements for Improved Beam Simulations*	Hadron production and ancillary measurements	
NF069	*The future NA61/SHINE program on hadron production*	Hadron production and ancillary measurements	

(Unique ID numbers link to the LOI pdf)

- NF09 topical group **primary** LOIs, continued:

Unique ID	Title	Subcategory
NF062	*The ESS neutrino Super Beam Design Study (ESSnuSB) and the High Intensity Frontier Initiative (HIFI)*	Spallation neutron sources
NF108	*ORNL Neutrino Sources for Future Experiments*	Spallation neutron sources and Reactor Sources
NF140	*High-Resolution Multiphysics Reactor Modeling for the Antineutrino Source Term*	Nuclear Reactors
NF117	*Prediction and Measurement of the Reactor Neutrino Flux and Spectrum*	Nuclear Reactors
NF035	*The JUNO-TAO Experiment*	Nuclear Reactors
NF086	*Legacy of the Daya Bay Reactor Antineutrino Experiment*	Nuclear Reactors
AF121	*Progress with the IsoDAR Cyclotron*	Novel sources
AF081	*Tau neutrino Production at a Multi-TeV Lepton Collider*	Novel sources
NF047	*The IsoDAR (Isotope Decay At Rest) nu-e-bar source*	Novel sources
NF038	*Physics with Electron Capture Neutrino Sources*	Novel sources

(Unique ID numbers link to the LOI pdf)

- There are several other LOIs involving the development of artificial sources and/or their characterization that are also very high on our radar:

Unique ID	Title	Subcategory	Relevance to NF09
NF187	*The Hyper-Kamiokande Experiment*	Conventional neutrino beams	uses J-PARC beam
NF145	*The NOvA Physics Program through 2025*	Conventional neutrino beams	discusses NuMI beam upgrades
NF130	*T2K Experiment: future plans and capabilities*	Conventional neutrino beams	discusses T2K beam upgrades
RF099	*Fixed-Target Searches for New Physics with O(1 GeV) Proton Beams at Fermi National Accelerator Laboratory*	Conventional neutrino beams	possible beam dump facility at Fermilab
IF095	*Coherent LOI 5: Instrumentation Development*	Hadron production and ancillary measurements	includes D20 detector to determine neutrino flux
NF118	*3D-projection Scintillator Tracker (3DST) in SAND, a DUNE Near Detector Subsystem*	Hadron production and ancillary measurements	Instrumentation to monitor neutrino beam
EF038	*FASER 2: Forward Search Experiment at the HL LHC*	Novel sources	LHC as a source for TeV neutrinos
NF126	*Tau Neutrino Physics*	Novel sources	new sources for tau neutrino physics?
NF080	*Neutrino Physics with IsoDAR*	Novel sources	us of proposed novel source (IsoDAR)
NF082	*Neutrinos from stored muons; nuSTORM*	Novel sources	stored muon ring source

(Unique ID numbers link to the LOI pdf)

- LOIs high on NF09's radar, continued:

Unique ID	Title	Subcategory	Relevance to NF09
AF215	*LANSCE-PSR Short-Pulse Upgrade for Improved Dark Matter and Sterile Neutrino Searches*	Spallation neutron sources	possible beam upgrade to search for steriles and dark matter
NF128	*The JSNS^2 Experiment*	Spallation neutron sources	use of spallation neutron source
NF095	*Future COHERENT physics program at the SNS*	Spallation neutron sources	relies on potentially upgradable spallation neutron source
NF111	*COHERENT Sensitivity to Dark Matter*	Spallation neutron sources	relies on potentially upgradable spallation neutron source
NF067	*Far-Future COHERENT physics program at the SNS*	Spallation neutron sources	relies on potentially upgradable spallation neutron source
NF161	*Neutrino Opportunities at the ORNL Second Target Station*	Spallation neutron sources	potential offered by neutrino source

(Unique ID numbers link to the LOI pdf)

Omissions from LOIs

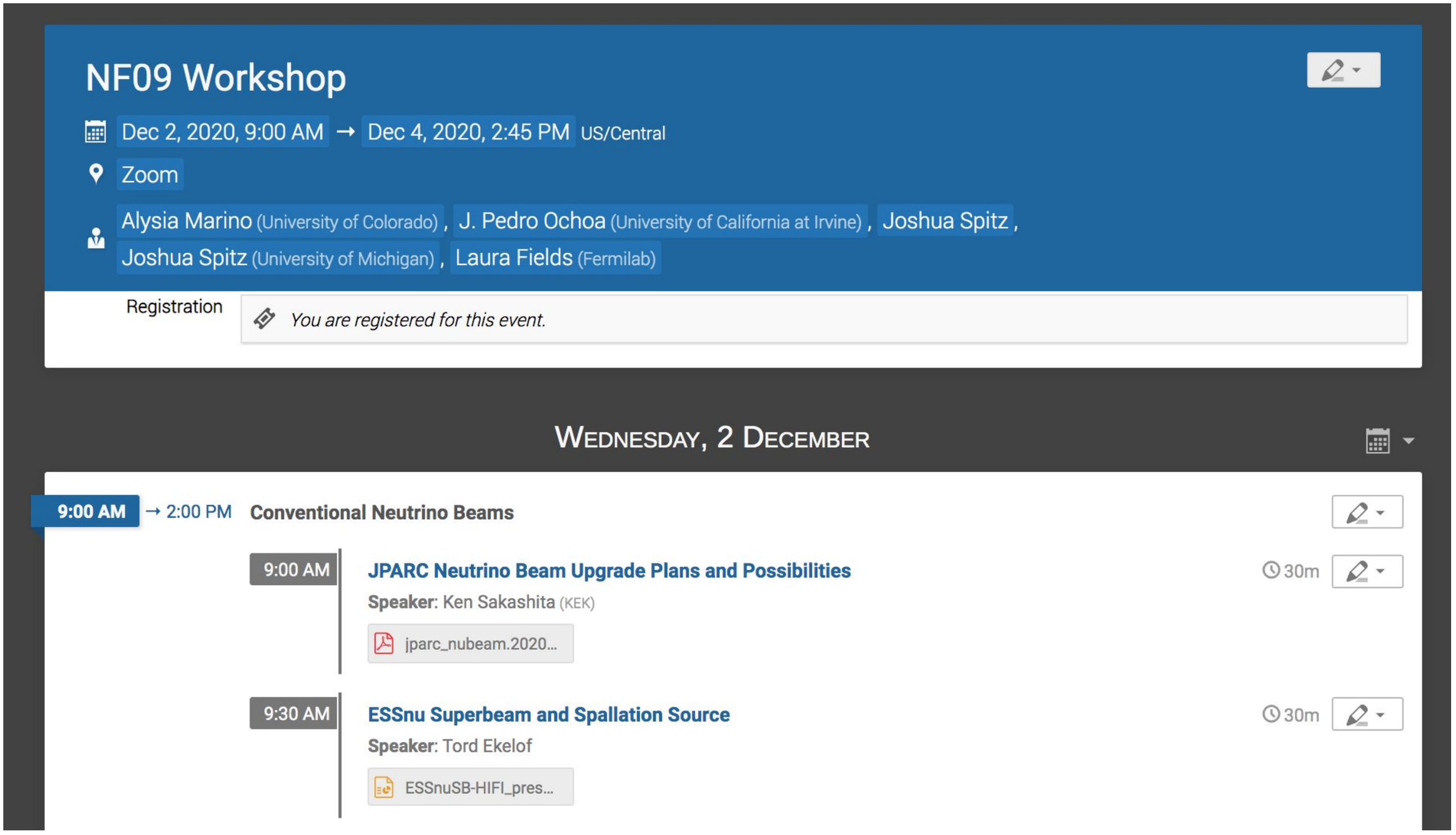
- After getting the LOIs, we attempted to identify areas of activity related to artificial neutrino sources that were not covered with LOIs, or where we need information beyond what is supplied in LOIs:
  - Physics case for LBNF 2.4 MW upgrade
    - DUNE has agreed to write a white paper on this
  - Beams for tau neutrinos
    - Have solicited a white paper on this
  - Protvino to ORCA - P2O
    - Have found limited information on this
  - Enubet concept for tagged beamline
    - Proponents are supportive of Snowmass and willing to work with us
  - Beta beams
    - No one appears to be pursuing beta beams right now
  - Neutrino factories
    - See next slide

Omissions from LOIs

- Neutrino factories
  - Many members of the neutrino community are interested in a neutrino factory (and have contacted us inquiring about neutrino factory activity)
  - It appears that no one is actively working on a neutrino factory concept right now
  - Many recent proponents are concentrating their efforts on the possibility of NuStorm @ CERN and are hesitant to distract from that by discussing neutrino factories
  - Energy Frontier Snowmass participants are considering a muon collider; a neutrino factory would be a natural step between NuStorm and a muon collider
  - The fact that no one is working on neutrino factories in the US is in part due to the last P5 report.
  - Our plan is attempt to summarize this situation in our report and (to the extent we can in a process that doesn't include prioritization) advocate for resources to develop a Neutrino Factory in the future
    - State that NuStorm/MOMENT is the clear next step towards a Neutrino Factory

NF09 Workshop

- Last week, we held a three-day NF09 workshop



See the full agenda at: https://indico.fnal.gov/event/46020/

NF09 Workshop

- More on workshop:
  - Had talks from all(?) LOI submitters
  - And some covering additional topics:
    - Future horn/target options
    - ENuBet
    - LBNF far future (non-CP) upgrade possibilities
    - MOMENT
  - The NF09 conveners found the workshop talks a useful resource that we will be drawing from as we work through our report
  - 113 people registered

From the CPM: A first attempt at 'Requirements'

Experiment/accelerator	LOI(s)	Relevant beam params./comments
FNAL complex synchrotron upgrade	AF092,RF099	12 GeV, 1.15 MW; 120 GeV, 2.4 MW; Fixed-target 800 MeV-GeV-scale, 500 kW
Compact cyclotron (IsoDAR)	AF121,NF047, NF080	60 MeV H_2^+, 600 kW
Multi-TeV muon collider (Dallavalle *et al.*)	AF081	Multi-TeV leptons
LBNF w/ tighter timing (Wetstein *et al.*)	NF116	100 ps proton bunches
ESSnuSB (Ekelof *et al.*)	NF062	2-2.5 GeV, 5 MW
FNAL test-beam (EMPHATIC)	NF173	beam exists
CERN test-beam (NA61/SHINE)	NF069	low-E (1-20 GeV) upgrade
ORNL SNS	NF108,NF095, NF111,NF067, NF161	1 GeV, 2 MW upgrade (w/ 2nd target)
LANL LANCSE w/ tighter timing	AF215	800 MeV, 100 kW (30 ns upgrade)
FASER 2 @ LHC, near ATLAS	EF038	LHC Run 3
J-PARC main-ring (T2K) upgrade	NF187,NF130	30 GeV, 1.3 MW
FNAL LBNF (vanilla)	NF118	60-120 GeV, 1.2-2.4 MW
FNAL NuMI upgrade	NF145	120 GeV, 900 kW
J-PARC SNS	NF128	3 GeV, 1 MW
NuSTORM	NF067	100 GeV protons w/ muon storage ring

Working Towards Requirements

- When we showed that table at the CPM, the AF02 asked for more detail (physics, timing, etc)
- We have expanded the table with more detail (and broken it into multiple tables)
- Still has a lot of missing information
  - Goal today is to agree with AF02 that this (or some variation of this) is what you want
  - Then we will work with the proponents of the different concepts to fill in as much detail as we can

Updated Requirements Table

Table 1: Summary of projects using neutrino beams that are existing or under construction, including potential upgrade.

		Secondary Beam				Primary Beam					
Project	Primary Physics Goals	Particle	Energy	Spatial Characteris-tics	Timing	Particle	Energy	Power	Timing	Comments	Docs
NuMI/NOvA Upgrade	ν_μ LBL oscillations,	$\nu_\mu, \bar{\nu}_\mu$	2 GeV	Pulsed-horn forward beam		p	120 GeV GeV	900+ kW			NF145
T2K Upgrade	ν_μ LBL oscillations	$\nu_\mu, \bar{\nu}_\mu$	2 GeV	Pulsed-horn forward beam		p	30 GeV	1.3 MW			NF187
LBNF/DUNE 1.2 MW	next gen ν_μ LBL oscillations	$\nu_\mu, \bar{\nu}_\mu$	0.5-4 GeV	Pulsed-horn forward beam	Low duty factor	p	30-120 GeV	2.4+ MW	Low duty factor		DUNE TDR
LBNF/DUNE 2.4 Upgrade	CP Violation	$\nu_\mu, \bar{\nu}_\mu$	0.5-4 GeV	Pulsed-horn forward beam	Low duty factor	p	30-120 GeV	2.4+ MW	Low duty factor		AF092, DUNE TDR
LBNF/DUNE Timing Upgrade	CP Violation	$\nu_\mu, \bar{\nu}_\mu$	0.5-4 GeV			p	120 GeV	1.2 MW	1.2 ps bunches		NF116
LBNF/DUNE LE Upgrade	CP Violation, Solar Oscillation Parameters	$\nu_\mu, \bar{\nu}_\mu$	0-4 GeV	Pulsed-horn forward beam	Dual BNB/MI timing	p	30 **and** 120 GeV		Dual BNB/MI timing		AF092, DUNE TDR
LBNF/DUNE High Energy Upgrade	τ Appearance; Unitarity,NSI	ν_μ	0.5-10 GeV	Pulsed-horn forward beam	Low duty factor	p	120 GeV	1.2+ MW	Low duty factor		AF092, DUNE TDR
FASER2		all ν fla-vors				p				Facility (LHC) exists	EF038
ORNL SNS	BSM, ν Interactions, Dark Matter					p	1 GeV	2 MW			NF108, NF095, NF111, NF067, NF161
LANL SNS											AF215
JPARC SNS											NF128

Updated Requirements Table

Table 2: Summary of projects requiring new neutrino beams.

		Secondary Beam				Primary Beam					
Project	Primary Physics Goals	Particle	Energy	Spatial Characteris-tics	Timing Characteris-tics	Particle	Energy	Power	Timing Char-acter-ists	Comments	Docs
$\mathcal{O}$(1 GeV) Beam Dump	Dark Matter and Sterile Search	ν_μ,BSM	$\mathcal{O}$(1 GeV)	Beam dump	Low duty factor	p	$\mathcal{O}$(0.1–1 MW)	Low duty factor			AF092 RF099
BNB Beam Dump	BSM and Dark Matter Search	BSM		Beam dump	15 HZ	p	8 GeV	80 KW	15 HZ	Not really a neutrino beam	AF092 RF084
IsoDAR	Sterile search	$\bar{\nu}_e$				p	60 MeV 600 kW				AF121,NF047, NF080
ESSnuSB	CP violation	ν_μ	2-2.5 GeV			p	2 GeV	5 MW			NF062
TeV Muon Collider	Tau Neutrino Physics	ν_τ				μ					AF081
NuStorm						p	100 GeV			Requires muon storage ring	NF067
Moment											
ENUBET											
Moment											

Hadron production experiment (NA61 and EMPHATIC) and other test-beam efforts are not included here as they are not neutrino sources, but they do use accelerator-beams, so AF02 should keep them in mind

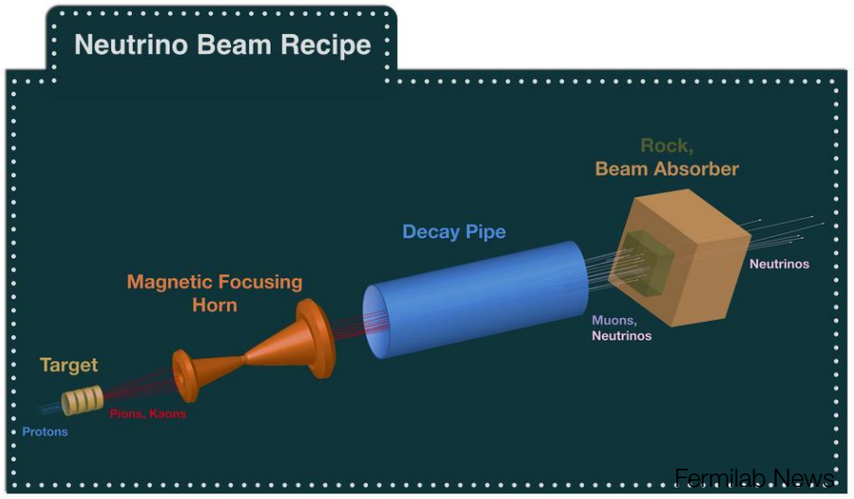
Going Forward

- Timeline going forward is a little up in the air due to the possible delay of Snowmass
- Regardless of the schedule, we will continue coordinating with the accelerator frontier:
  - Continue meetings with AF02 (accelerators for neutrinos)

Backup

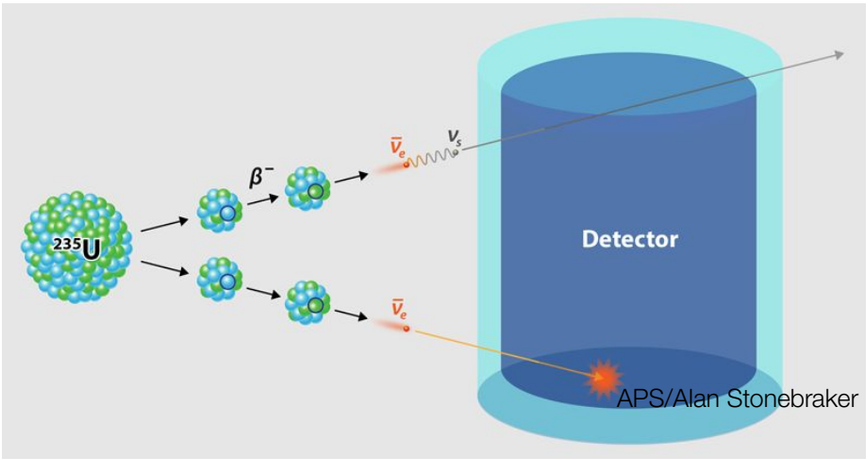
Intro to NF09: Artificial Neutrino Sources

GeV-scale proton beams on fixed targets + hadron focusing and decay volumes

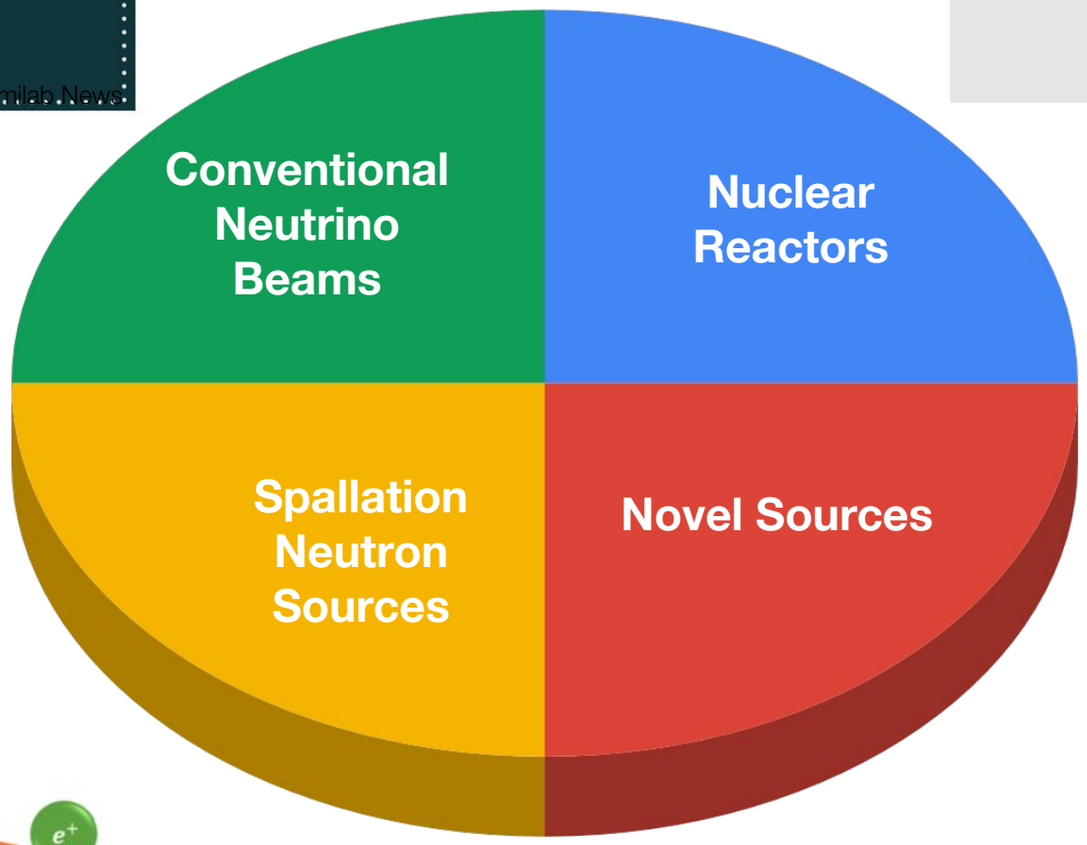


Fermilab News

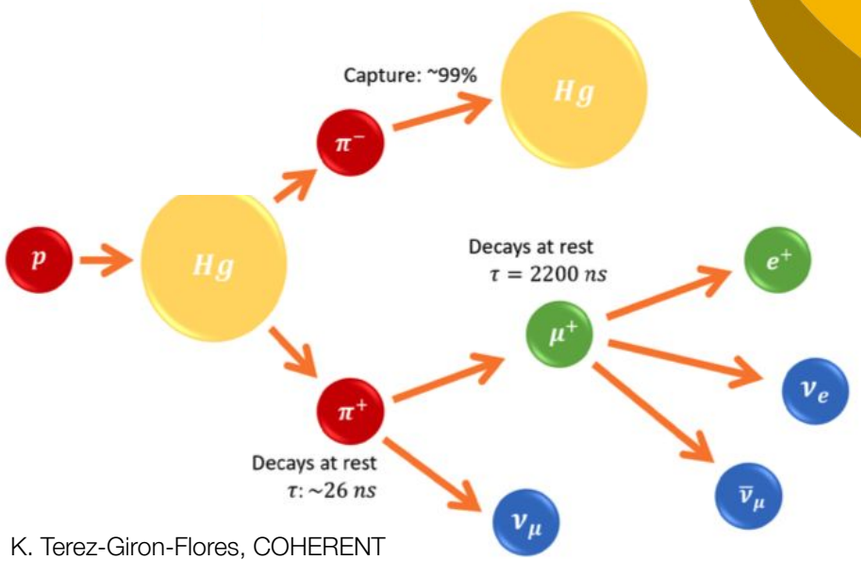
Beta decay of neutron-rich fission fragments at nuclear power plants.



APS/Alan Stonebraker



Neutrino by-products of spallation neutron production



K. Terez-Giron-Flores, COHERENT

Everything else

Electron capture sources, beta beams, neutrino factories, etc

Going Forward

- We plan to hold a workshop in early December:
  - Three days: **December 2-4 (W-F)**
  - Virtual, 3-4 hours per day, morning US time
  - Organized around list of “big topics” (different colors) from previous lists
  - Open to all, talks most likely by invitation only

nuclear reactor session likely held jointly with NF07 (applications) group

details to be announced soon

- Also plan to continue coordinating with the accelerator frontier (AF):
  - Continue regular meetings with AF02 (accelerators for neutrinos) (add AF07?)
  - Need to understand accelerator requirements associated with various neutrino physics goals

get in touch with us, even if you did not submit an LOI

- Join the SNOWMASS-NF09-ARTIFICIAL-SOURCES list!
- Get in touch with us: ljf26@fnal.gov, amarino@colorado.edu, jpochoa@uci.edu, spitz7@fnal.gov

Tentative Outline: Conventional Beams

- Summary of existing sources and understanding of those sources (LOI: includes NF145, NF130)
- Source Development / Upgrades
  - Fermilab beam upgrade plans/possibilities (LOI: AF092 on beam upgrade path, but **physics case not detailed in LOIs**)
  - JPARC neutrino beam upgrade plans/possibilities (LOI:NF130, NF187)
  - Beams for tau neutrinos: (LOI: NF126 on physics, **No submissions on beam development**)
  - Time-bunched sources: (LOI: NF116)
  - Protvino to ORCA- P20: (**No submissions**)
- Neutrino flux determination and hadron production measurements
  - EMPHATIC (LOI: NF173)
  - NA61/SHINE (LOI: NF062)
  - SAND for DUNE (LOI: NF118)
  - ENubet (**No submissions**)

Tentative Outline: Nuclear Reactors

- Short summary of existing methods to predict flux and shape of reactor antineutrinos
- Importance of reactor antineutrino predictions
  - For basic science and reactor monitoring (LOI: NF117, NF140)
  - For nuclear physics and engineering (**No submissions**)
- Strategy on how to move forward (white paper supporting?)
- Predictions vs. experiment: current status
  - PROSPECT-I (LOI:NF168)
  - Daya Bay - Legacy (LOI: NF086)
  - Other experiments (no submissions but can make a summary)
- Expected improvements in predictions:
  - High-resolution multiphysics reactor modeling (NF140)
  - Others (e.g. beta decay data)? **(No submissions)**
- Future experiments and reactors:
  - HIFR, PROSPECT-II (LOI: NF169, NF108)
  - JUNO (LOI: NF034)
  - JUNO-TAO (LOI: NF135)
  - SNO+ (LOI: NF185)
  - NEOS?
  - Others? Need more submissions
  - Beyond? Effort to come together? Join reactor monitoring + oscillation physics? (Patrick Huber may be working on question of what a “definitive” detector should look like).
- Interplay between basic science and reactor monitoring: (standalone short-ish whitepaper with broad authorship)
  - CHANDLER (LOI: NF075)
  - ROADSTR (LOI: NF184)
  - Mutual benefits (LOI: NF128)

Tentative Outline: Neutrinos from Spallation Sources

- Spallation sources and development
  - Future and far-future COHERENT program (LOI: NF095, NF067, NF108)
  - ORNL Second target station (LOI: NF161)
  - ESSnu Superbeam (LOI: NF062)
  - JSNS^2 at J-PARC Spallation Source (LOI: NF128)
- Flux monitoring and hadron production
  - D2O flux monitor at SNS (LOI: IF095)
  - Low energy beam upgrade in NA61 to measure production on Hg targets (LOI: NF062)

Tentative Outline: Novel Sources

- Beta beams (**No submissions**)
- nuSTORM (LOI: NF082)
- Neutrino factories (**No submissions**)
- IsoDAR (LOI: AF121, NF047, NF080)
- Intense radioactive sources
  - Electron capture sources (LOI: NF038)
  - Radioactive source for BEST (no submissions, but data taking is now complete)
- Beam dump sources
  - LANSCE (LOI: AF215)
  - FNAL beam dump (LOI: RF099)
- Hadron and electron colliders
  - LHC/Faser2 (LOI: EF038)
  - FCC (LOI:EF017)
  - multi-TeV lepton collider as a tau neutrino source (LOI: AF081)
- In general, LOIs are **light on physics cases for major new facilities**
  - E.g. beams that could study study ALL neutrino oscillation channels (e.g. nue ->nux)

- LOIs high on NF09's radar, continued:

Unique ID	Title	Subcategory	Relevance to NF09
NF034	*The JUNO Experiment*	Nuclear reactors	Reactor physics at JUNO + possibility of cyclotron source
NF185	*Reactor and Geo Neutrinos at SNO+*	Nuclear reactors	Reactor antineutrino measurements at SNO+
NF075	CHANDLER: A Technology for Surface-level Reactor Neutrino Detection	Nuclear reactors	characterization of reactor antineutrino emission
NF168	*Forthcoming Science from the PROSPECT-I Data Set*	Nuclear reactors	characterization of reactor antineutrino emission
NF169	*The Expanded Physics Reach of PROSPECT-II*	Nuclear reactors	characterization of reactor antineutrino emission
NF128	*Mutual Benefits derived from the Application of Neutrino Physics to Nuclear Energy & Safeguards*	Nuclear reactors	characterization of reactor antineutrino emission
NF184	*ROADSTR: A Mobile Antineutrino Detector Platform for enabling Multi-Reactor Spectrum, Oscillation, and Application Measurements*	Nuclear reactors	characterization of reactor antineutrino emission

(Unique ID numbers link to the LOI pdf)