Neutrino Physics
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P5 Science Drivers

Pursue the physics associated with neutrino mass

Explore the unknown: new particles, interactions, physical principles

Science Impacts

Precision tests of the three-flavor neutrino paradigm

Expand the regime of neutrino measurements in source, energy and intensity

Search for BSM physics
Science Impact #1: Precision tests of the three-flavor paradigm

- Precision measurements of neutrino mixing
- Neutrino unitarity
- Measure the absolute neutrino mass
- Determine the nature of neutrino mass (i.e., Dirac or Majorana, NLDBD)
- Measure the Majorana phases
Discover the cosmic neutrino background

Measure supernova burst neutrinos in all three flavors in real time

Measure diffuse supernova neutrino

Measure lower-energy neutrinos (e.g. pp solar, thermal solar) in real time with high statistics

Solar neutrino measurements (e.g. solar - reactor $\Delta m_{12}^2$ tension)

Measure neutrinos at macroscopic energies from cosmic distances
Science Impact #3: Searches for physics beyond the Standard Model [in neutrino detectors]

Neutrino magnetic moment
Sterile neutrinos
Neutrino tridents
Proton decay
Dark matter, axions,...
Millicharged particles...

Both:
• BSM in the neutrino sector
• BSM in other sectors that can be done with neutrino detectors
What is generally desired for neutrino detectors?

Of course emphasis depends on specific aim, but frequently:

- Large mass (at low cost)
- Resolution for reconstructed quantities: energy, momentum, time, particle ID... high granularity
- Energy threshold (range relevant to physics)
- Low background

Tried to turn the question around:

**what transformative physics do we want to do with neutrinos?** (or neutrino detectors) What do we need to do it?
Information comes from neutrinos over ~25 orders of magnitude in energy!

From BRN report
Information comes from neutrinos over ~25 orders of magnitude in energy!
Information comes from neutrinos over ~25 orders of magnitude in energy!
Neutrino detector masses and sensitive energy ranges
Neutrino detector masses and sensitive energy ranges

A few examples...
First, here, in the category of “precision measurements of the 3-flavor sector”...
Many things will improve with better technology, but it’s not trivial to quantitatively tie detector improvements to specific oscillation parameter precision (work already underway!) … improvements are likely to be incremental.

Will instead highlight some items which will broaden the physics program… Enable detection of neutrinos in new regimes, with new capabilities.
Novel detector technology for oscillation experiments

- Precision measurements of neutrino mixing
- Measure appearance and disappearance of accelerator and natural neutrinos
- Novel charge detection, light production and detection; magnetization
High-statistics tau neutrino appearance in real-time detectors

- Neutrino mixing matrix unitarity
- Measure tau neutrino appearance in real time with high efficiency
- Resolve short tracks (0.1 mm at 10 GeV) in 10 kt detectors
The ultra-high-energy frontier
Ultra-high energy neutrinos

Measure neutrinos at macroscopic energies from cosmic distances

Sensitivity to neutrino fluxes \(\sim 1/\text{km}^2/\text{decade}\) at low energy threshold

Low power (<<1 W) digitizers sampling at >3 GHz, triggering at O(1) S/N

Calibration pulser mimicking a neutrino signal from ARA
Few to few tens of MeV regime: solar and supernova neutrinos
Improved solar neutrino measurements

Resolve solar/reactor $dm^2$ tension

Measure solar 8-B, hep, and neutrino regeneration in the Earth with S/B>1 above 5 MeV

Reduction of radiogenic backgrounds by a factor of 100-1000 in argon; high spatial resolution and light yield

Also good for burst supernova, relic supernova
Measure all flavor components of a burst supernova flux

- Measure SN burst neutrinos of all three flavors in real time
- CEvNS glow/buzz in argon or scintillator
- High efficiency photo-detection, reduction of radiogenic backgrounds by 100-1000
Very low energy: pp solar, geoneutrinos... and unknown territory!

Below charged-current threshold (IBD on protons threshold ~1.8 MeV)

... need elastic scattering, CEvNS, ...
BSM physics with sub-MeV neutrino sources

- BSM physics in sub-MeV (sub-keV) neutrinos in real time
- Sensitivity to very low energy CEvNS recoils in real time
- 10 eV detector thresholds in multi-ton to kton-scale detectors; recoil directionality

Geoneutrinos, pp neutrinos, solar thermal, artificial radioactive source neutrinos with multiple physics applications
Cosmic relic neutrino background

Discover the relic Big Bang neutrinos, test of cosmological models

Measure cosmic neutrino capture on nuclei

10 meV energy resolution at beta endpoint; source w/ <10 meV energy loss/distortion and O(1 kg)

arXiv:1902.05508v3
Many different technologies are relevant!
Summary: many ideas, much blue sky to explore...

- Ultra high energies
- More mass, lower threshold
- Better resolution, new sources