
July 18, 2022

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Talk Overview

- **Charge:** overview the recent achievements and present state of the ‘low-energy’ part of the US-HEP community

- If today’s talks were school book reports:
  - Previous talks in this session:
  - This Talk:

- Advance apology for speeding through your experiment/topic!
  - It turns out there’s a lot of recent ‘low-energy’ activity in US-HEP…
  - Also, line between ‘US’ and ‘non-US’ is fuzzy (US based? US supported?) and I will not attempt to define or use a consistent definition in this talk
What Is ‘Low-Energy’?

Looking below 100 MeV, what sources have we been sensitive to in the last P5 period with the US neutrino program?

Artificial sources (NF09):
- Accelerator decay-at-rest neutrinos
- Nuclear reactors

Natural Sources (NF04:)
- Solar neutrinos
- Supernova neutrinos (if one had happened…)

Important additions:
- Non-ν measurements: tritium, 0nubb, etc.
- Low-energy detection plays an important role for higher-energy neutrino sources too!

Zeller and Formaggio, Rev. Mod. Phys. 84 (2012)
NF10: Low-Energy Detectors

- A wide dynamic range of signals from the sub-keV to 10s of MeV necessitates a use of diverse detection technologies

- Organic / inorganic / noble element scintillation detectors
  - Captain-Mills, CHANDLER, COHERENT, Daya Bay, JUNO, KamLAND-Zen, PROSPECT, SNO+, ...

- Solid-state ionization detectors
  - Majorana, reactor CEvNS, etc.

- Bolometers
  - CUORE, reactor CEvNS, etc.

- Time Projection Chambers
  - EXO, SBN/MicroBooNE, ArgoNeuT, etc.

- Cherenkov Detectors
  - ANNIE, Super-K, etc.

- Electrostatic, CRES Spectrometers
  - KATRIN, Project8

- Indicates that future progress for low-energy US-HEP requires broad/diverse detector R&D initiatives.

Underline = US-based
NF01: Neutrino Oscillations

- Low-energy neutrinos are the source of best precision on many standard model neutrino flavor mixing parameters

- Recently:
  - **Daya Bay** reactor experiment greatly improved its 2012 first measurement of $\theta_{13}$
  - **Super-K**’s recent improved solar analysis shifted/tightened its $\Delta m^2_{12}$ parameter bounds

- Minor US support for impending **JUNO** reactor experiment, which aims for major improvements in $\theta_{12}, \Delta m^2_{12},$ mass hierarchy knowledge
• Three of the four ‘canonical’ short-baseline anomalies exist in the low-energy regime: the Reactor, Gallium, and LSND

• Recently:
  
  • **PROSPECT** set new active-sterile oscillation limits; it and other global reactor efforts ruled out much of the suggested Anomaly space
  
  • **Daya Bay**, **PROSPECT** improved knowledge of reactor $\nu$ models, another possible source of the Reactor Anomaly
  
  • **KATRIN**, other US-NP efforts (i.e. **BeEST**) set complimentary new active-sterile coupling limits at even higher $\Delta m^2$.
  
  • Limited yet essential US support for **JSNS**, which is now taking data to directly address LSND at JPARC
Low-energy experiments, just like high-energy experiments, have hopped aboard the Neutrino BSM train.

There are more low-energy BSM signatures searches than I can name in one slide. Let me try a few:

- **ArgoNeuT**: Millicharged particles
- **CAPTAIN-Mills, COHERENT**: Accelerator-produced dark sector particles
- **COHERENT**: NSI parameter limits
- **CONNIE**: reactor-produced dark matter
- **Daya Bay / Double Chooz**: CPT violation, wave packet decoherence
- **PROSPECT**: Boosted dark matter
- Not to mention the pheno studies that could not be performed without these datasets
The neutrino’s absolute mass and Dirac/Majorana nature are probed in nuclear decays at the MeV scale and below.

Recent:

- **CUORE, EXO, Majorana, KLZ** limits on the effective neutrino mass are marching ever closer to or are breaking into the inverted hierarchy regime; big R&D questions for future ton-scale experiments have been answered.

- **KATRIN** has pushed its direct neutrino mass limit below 1eV, and first phases of next-gen CRES technology R&D by **Project8** have been done.

*S. Schoenert, Neutrino 2022*
NF06: Neutrino Cross-Sections

- **ArgoNeuT, MINERvA, ANNIE**: Analysis of low-energy features in GeV-scale $\nu$ beam data tells about the neutrons produced when they interact.

- **NOvA, MicroBooNE** continue the trend

- **COHERENT**: different detectors probe the N-dependence of the well-predicted CEvNS x-section
NF07: Applications

- $\bar{\nu}_e$-based reactor monitoring: a go-to response when a layman asks ‘What are neutrinos good for?’
- **CHANDLER** and **PROSPECT** have demonstrated on-surface $\nu_e$ detection with plastic and liquid scintillators
- This milestone has generated interest, development in near-field monitoring tech
- Low energy analyses have also furthered development of US AI/ML expertise via HEP research
  - Just a few examples:
    - **ArgoNeuT**: finding <200keV signals in LArTPC images
    - **KamLAND-ZEN**: picking out 0nubb candidates from background

**PROSPECT, PRD 103 (2021)**

**Haghighat, et al, PRApp 13 (2020)**
Summary

- Experiments observing neutrinos and neutrino-related physics below $\sim 100$ MeV have yielded many high impact discoveries and observations for US HEP in the past 10 years.

- The scope of physics delivered by low-energy neutrino experiments has been broad, touching each of the Neutrino Frontier topical groups for Snowmass 2021/2022.

- While this talk focused on present achievements, many CSS talks and Snowmass Reports/Whitepapers will explain exciting prospects for low-energy physics during the next P5 period.

My school report:
The books were all great, they solved all the mysteries, and all the kids survived!