Current State of Low-Energy Neutrino Physics in US-HEP

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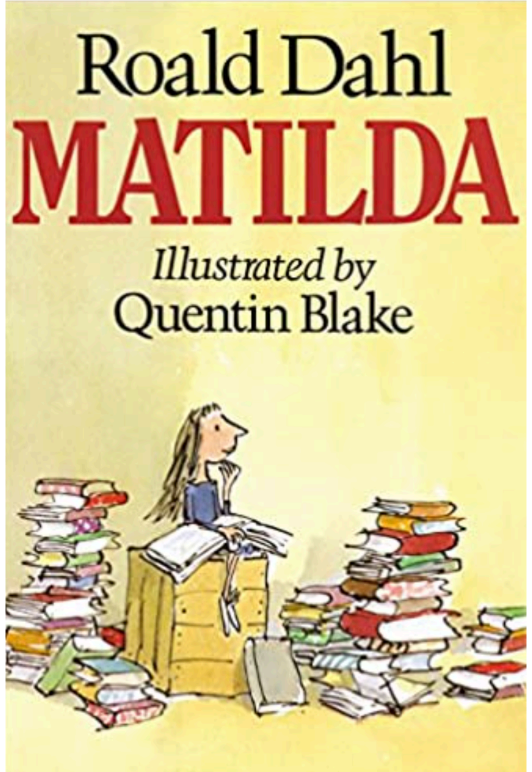
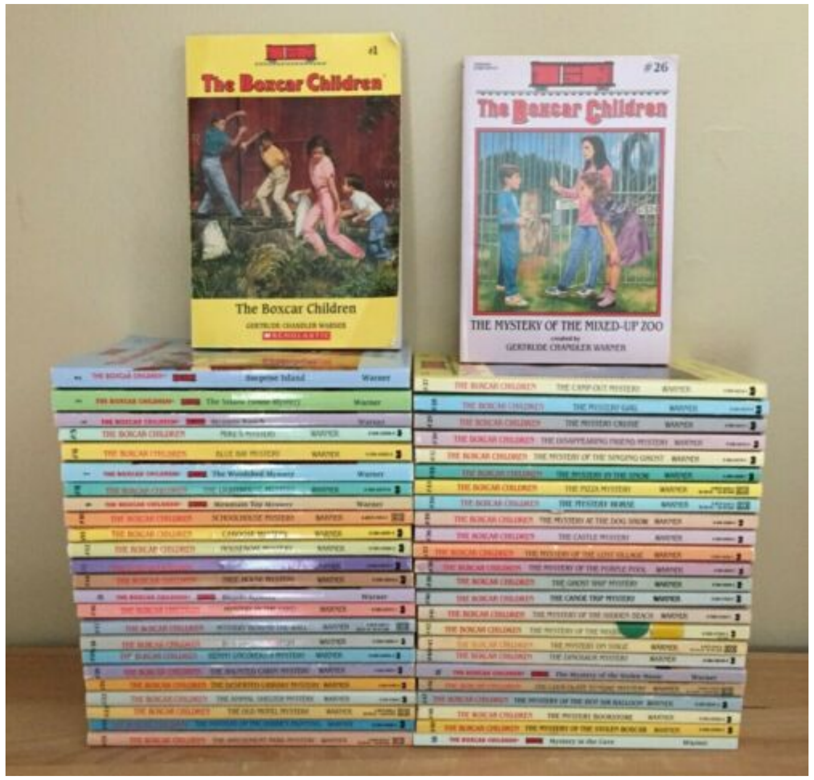
Talk Overview

- 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:

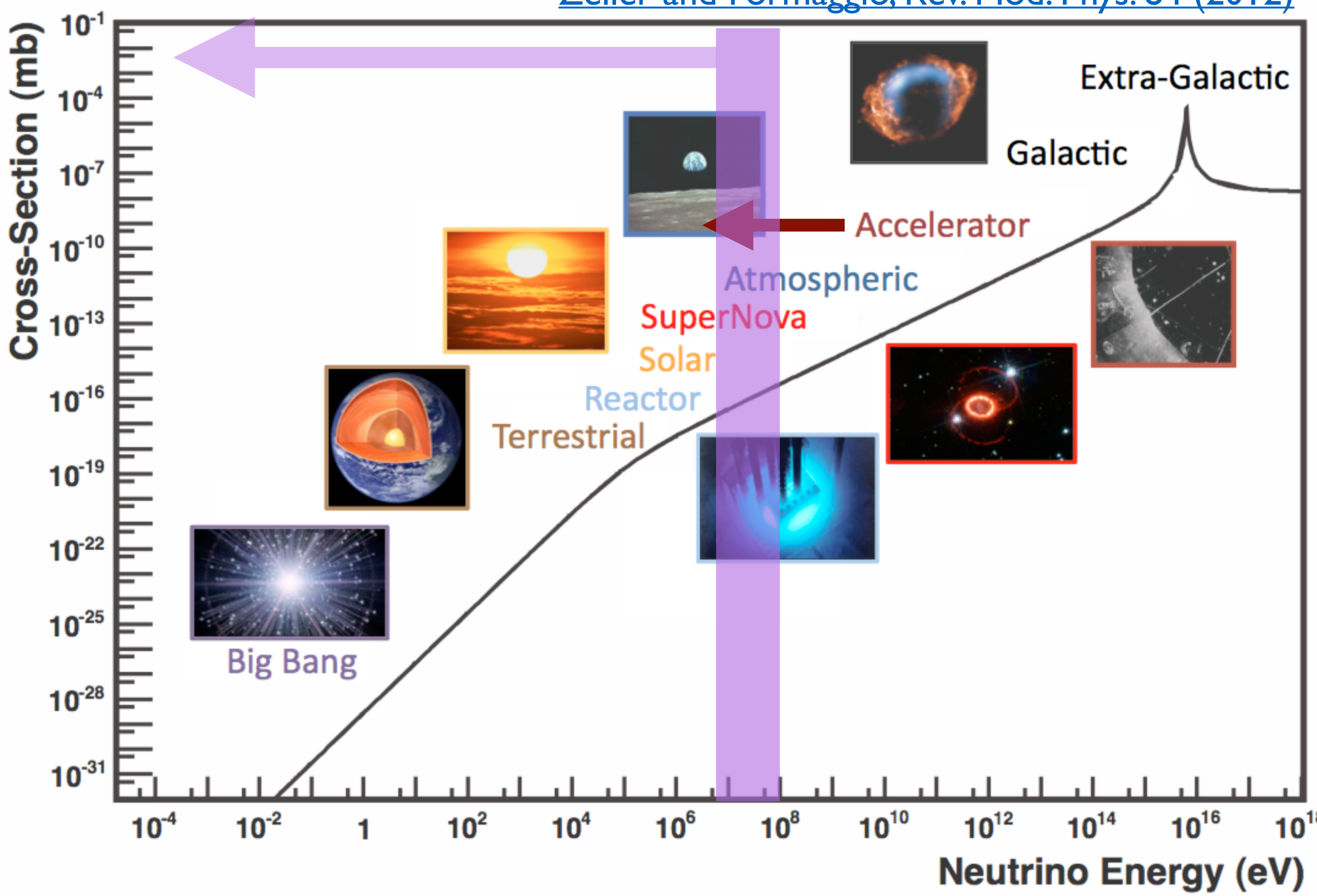


- Advance apology for speeding through your experiment/topic!
  - It turns out there’s a lot of recent ‘low-energy’ activity in US-HEP…
  - Also, line between ‘US’ and ‘non-US’ is fuzzy (US based? US supported?) and I will not attempt to define or use a consistent definition in this talk

NF04/NF09: 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

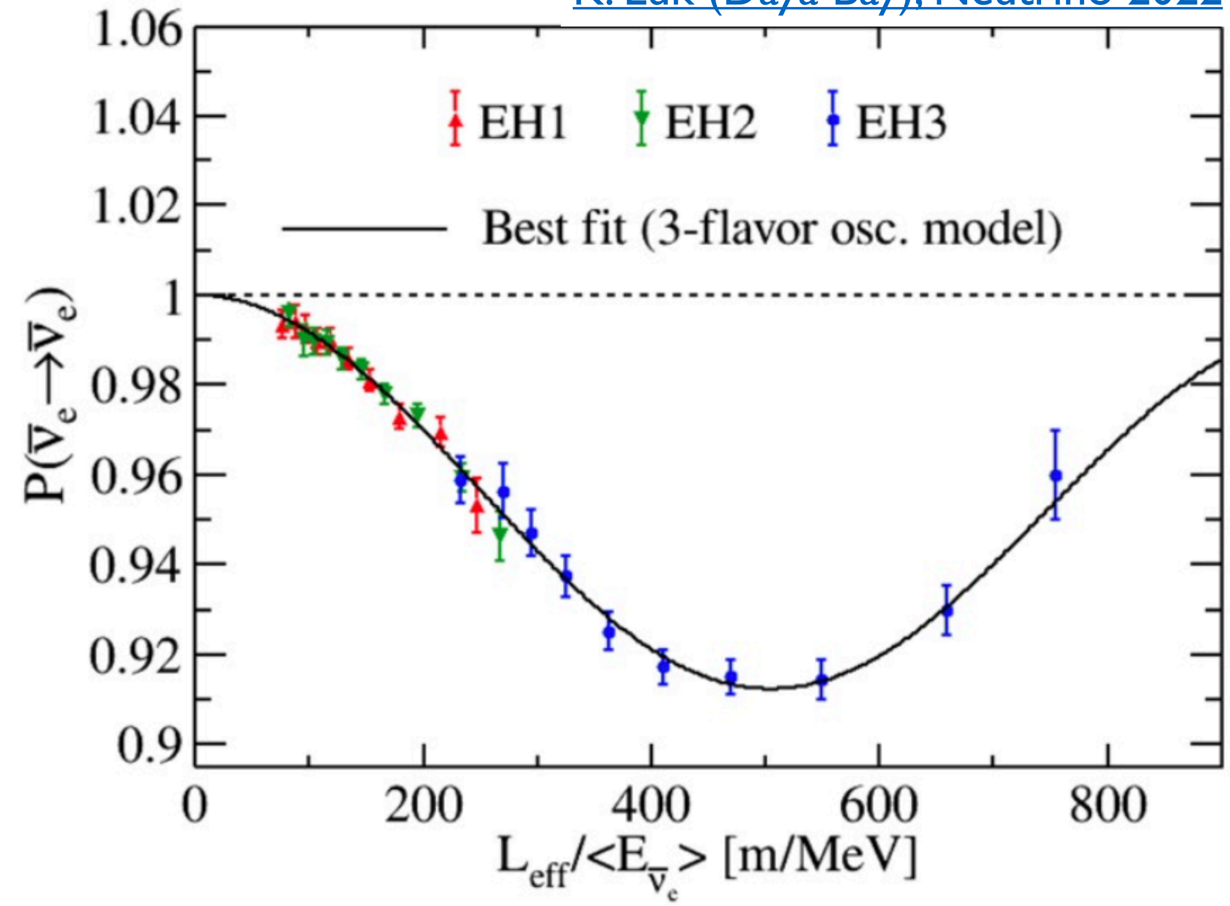
Underline = US-based

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

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 θ_{13}
  - **Super-K**'s recent improved solar analysis shifted/tightened its Δm^2_{12} parameter bounds
- Minor US support for impending **JUNO** reactor experiment, which aims for major improvements in θ_{12}, Δm^2_{12}, mass hierarchy knowledge

K. Luk (Daya Bay), Neutrino 2022



T. Schwetz (NuFit), Neutrino 2022

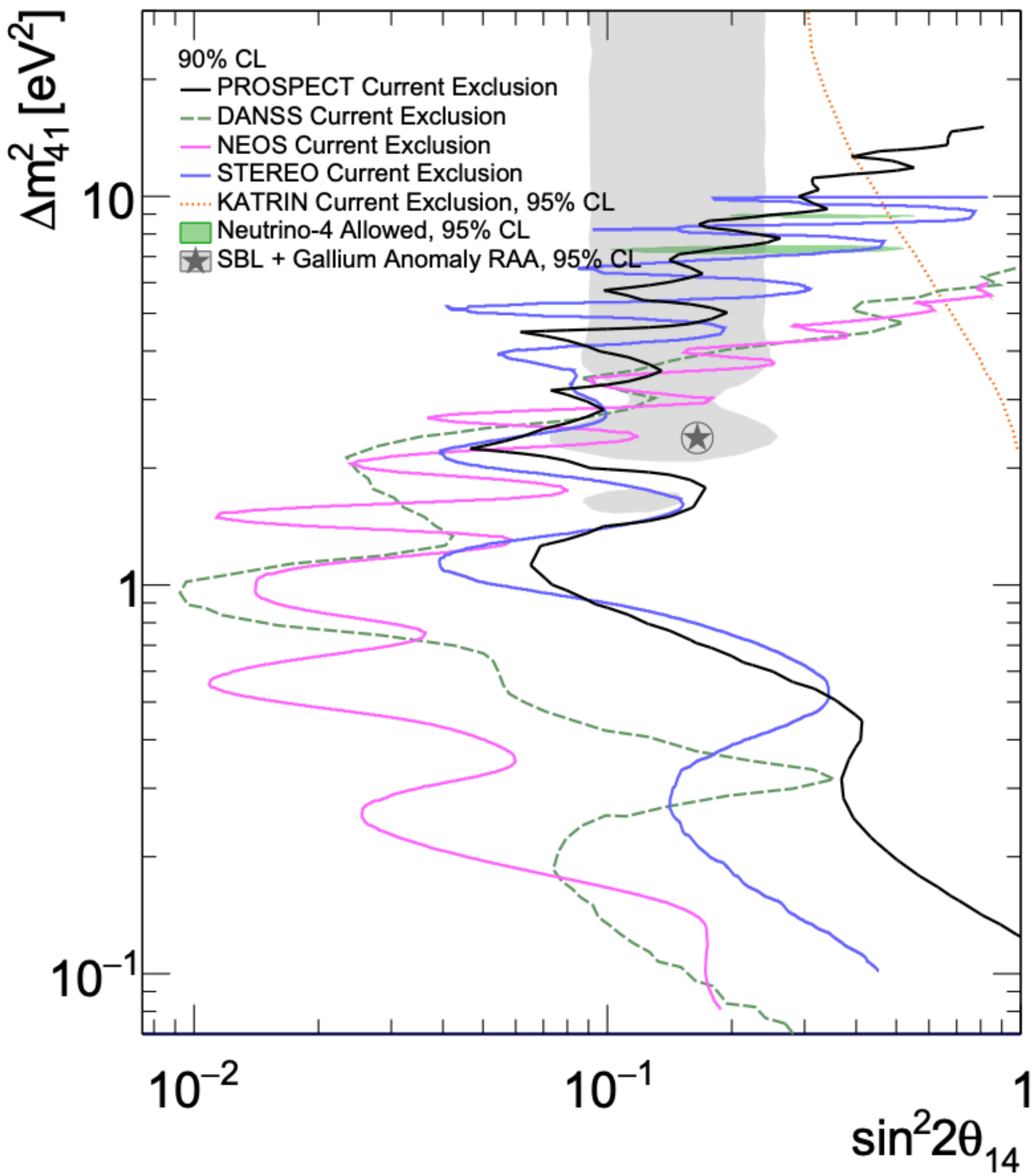
(relat. precision at 3σ)		for quarks
θ_{12}	(14%)	0.6 %
Δm^2_{21}	(16%)	
$\lvert\Delta m^2_{31}\rvert$	(7%)	
θ_{13}	(9%)	8.3 %
θ_{23}	(24%)	5.2%

NF02: Neutrino Anomalies

- 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 ν 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 Δm².
  - Limited yet essential US support for **JSNS**, which is now taking data to directly address LSND at JPARC

PROSPECT, hep-ex[2107.03934]

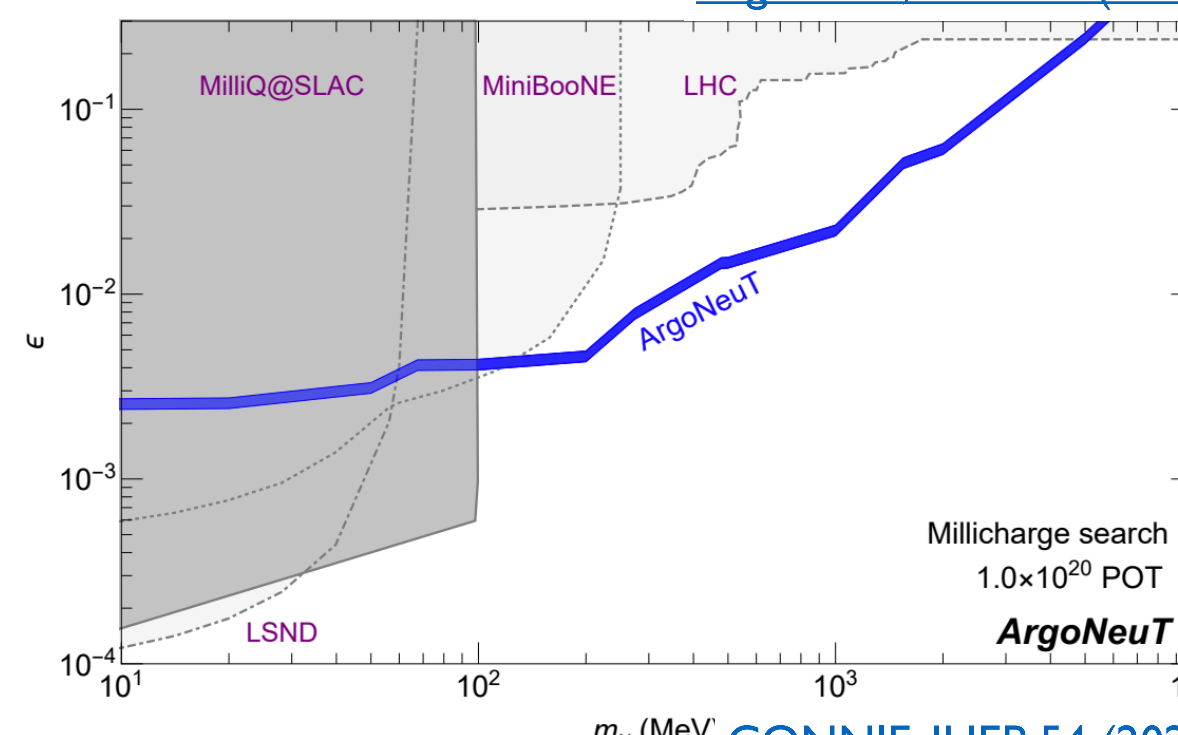


NF03: BSM

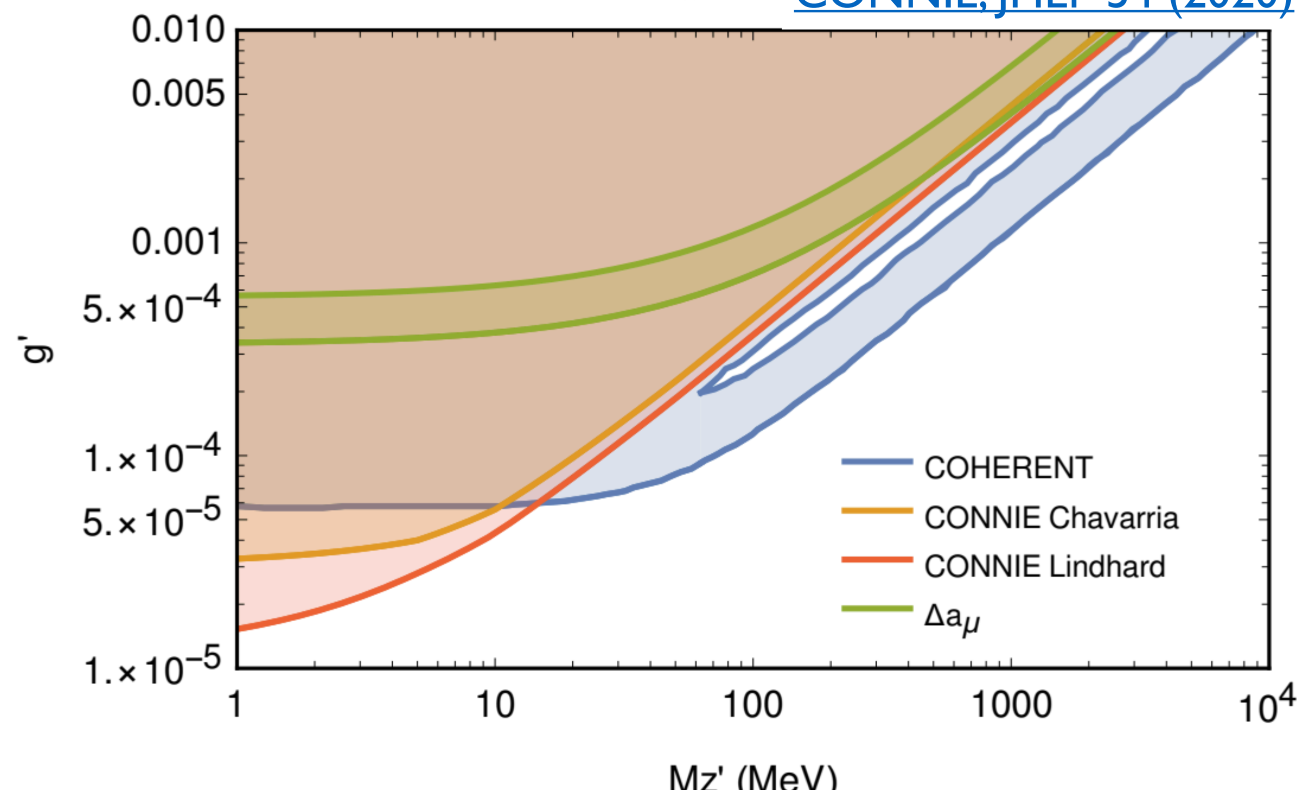
- Low-energy experiments, just like high-energy experiments, have hopped aboard the Neutrino BSM train.

- 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 datas

ArgoNeuT, PRL 124 (2020)



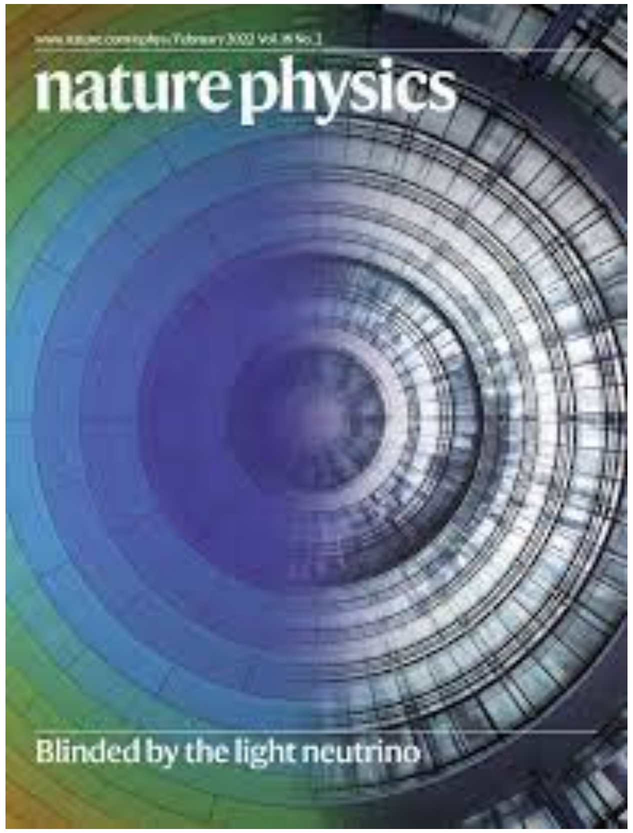
CONNIE, JHEP 54 (2020)



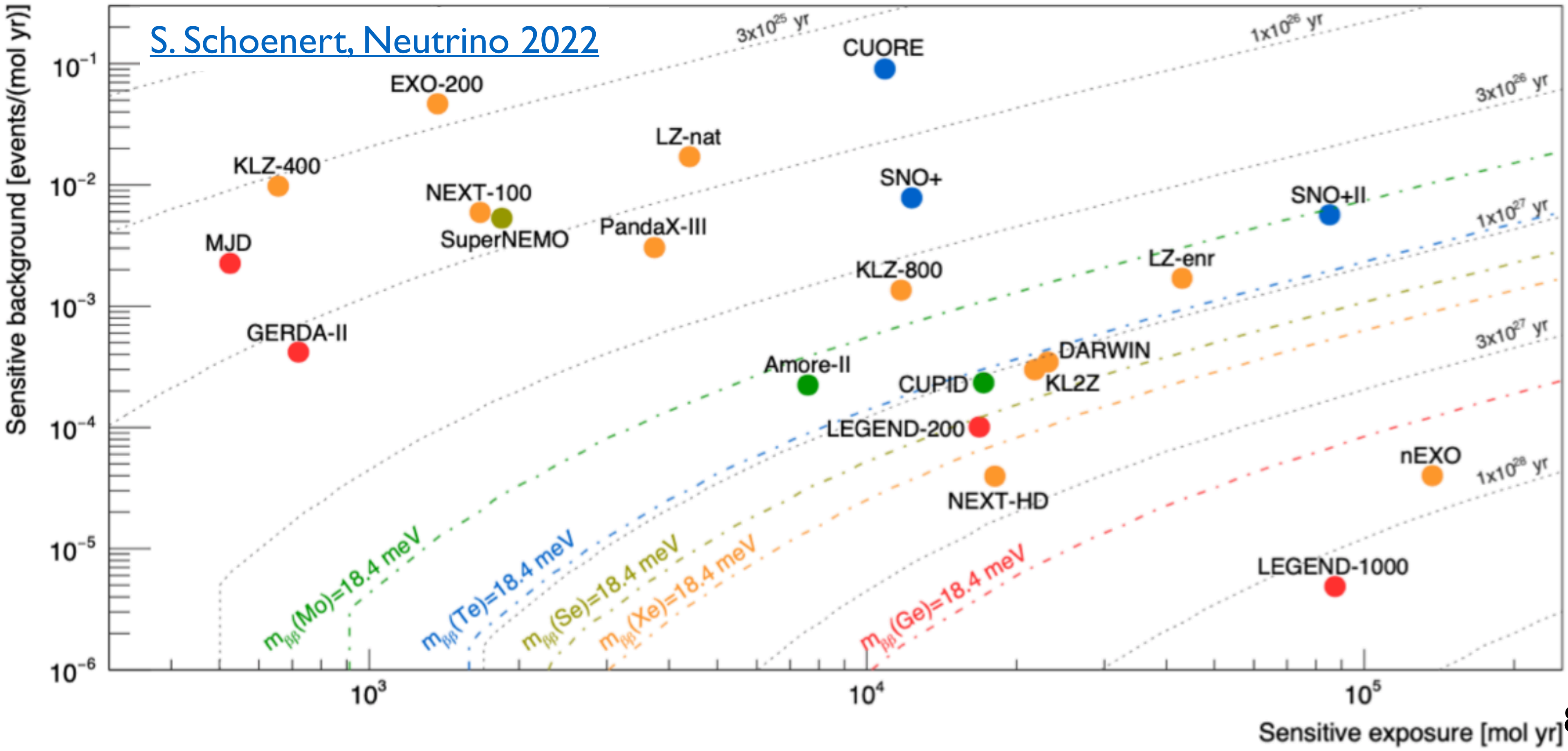
NF05: Neutrino Properties

- 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

KATRIN, Nature Physics 18 (2022)



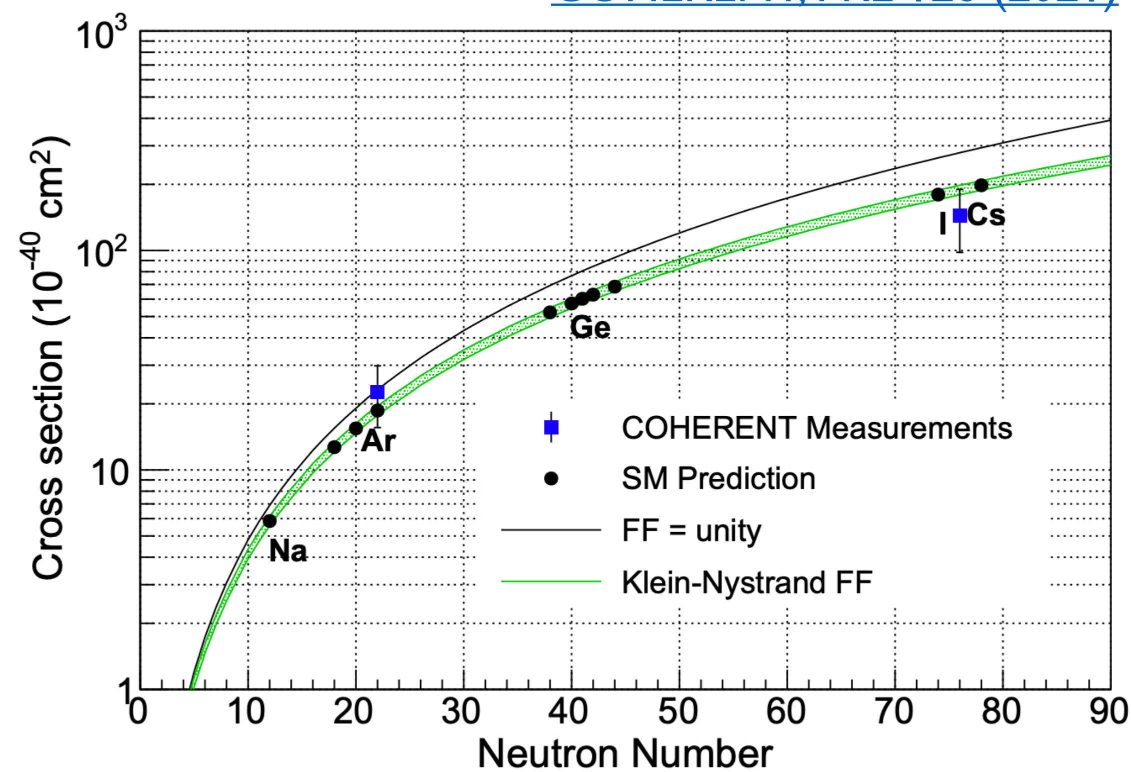
S. Schoenert, Neutrino 2022



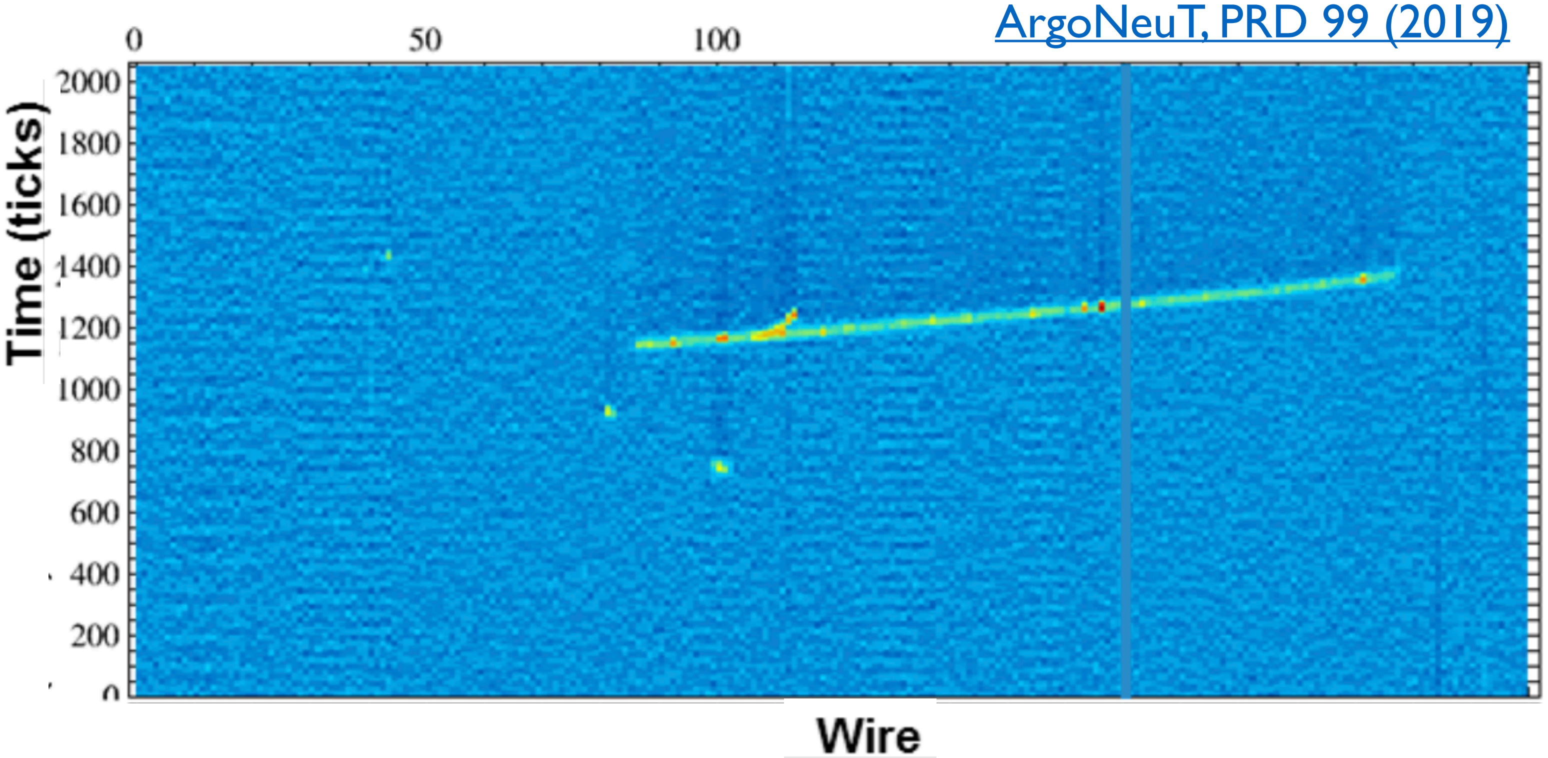
NF06: Neutrino Cross-Sections

- **ArgoNeuT**, **MINERvA**, **ANNIE**: Analysis of low-energy features in GeV-scale ν 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

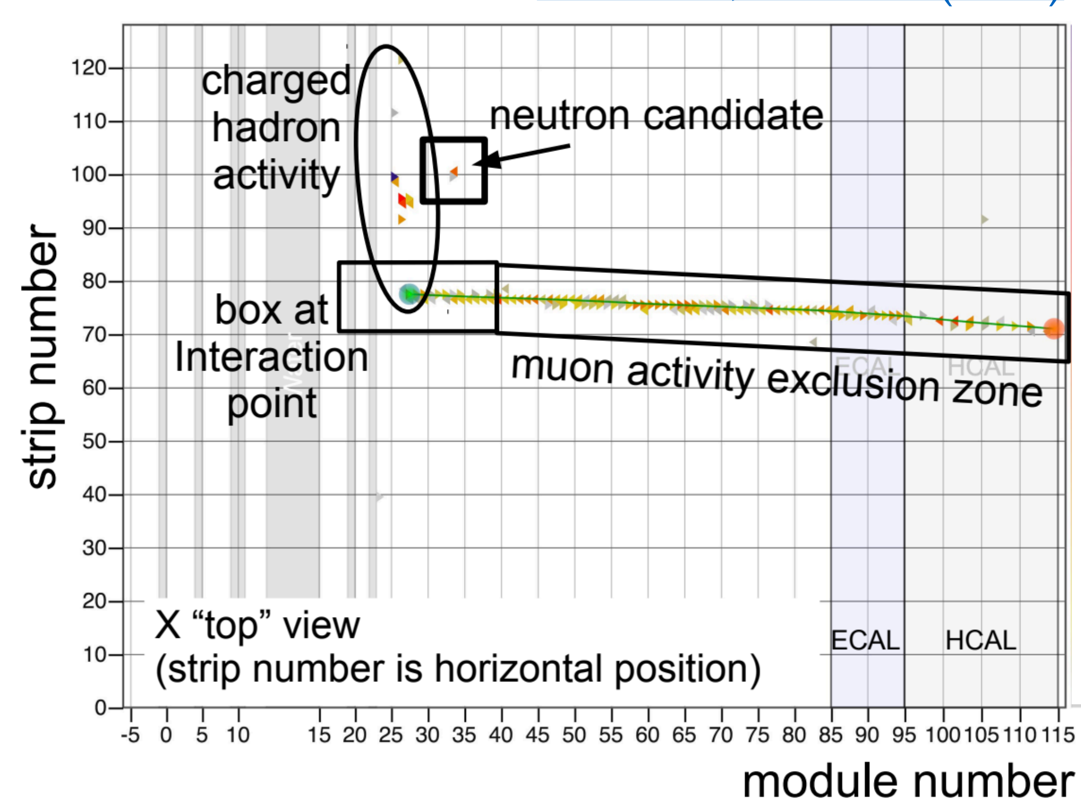
COHERENT, PRL 126 (2021)



ArgoNeuT, PRD 99 (2019)

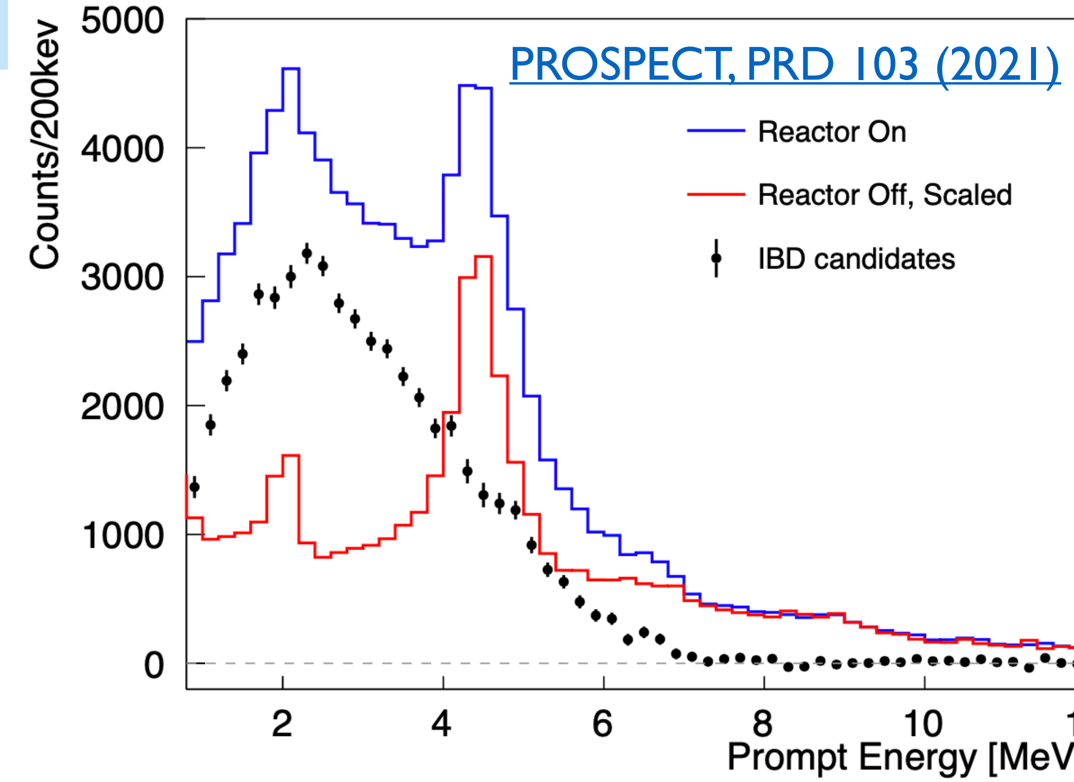


MINERvA, PRD 100 (2019)

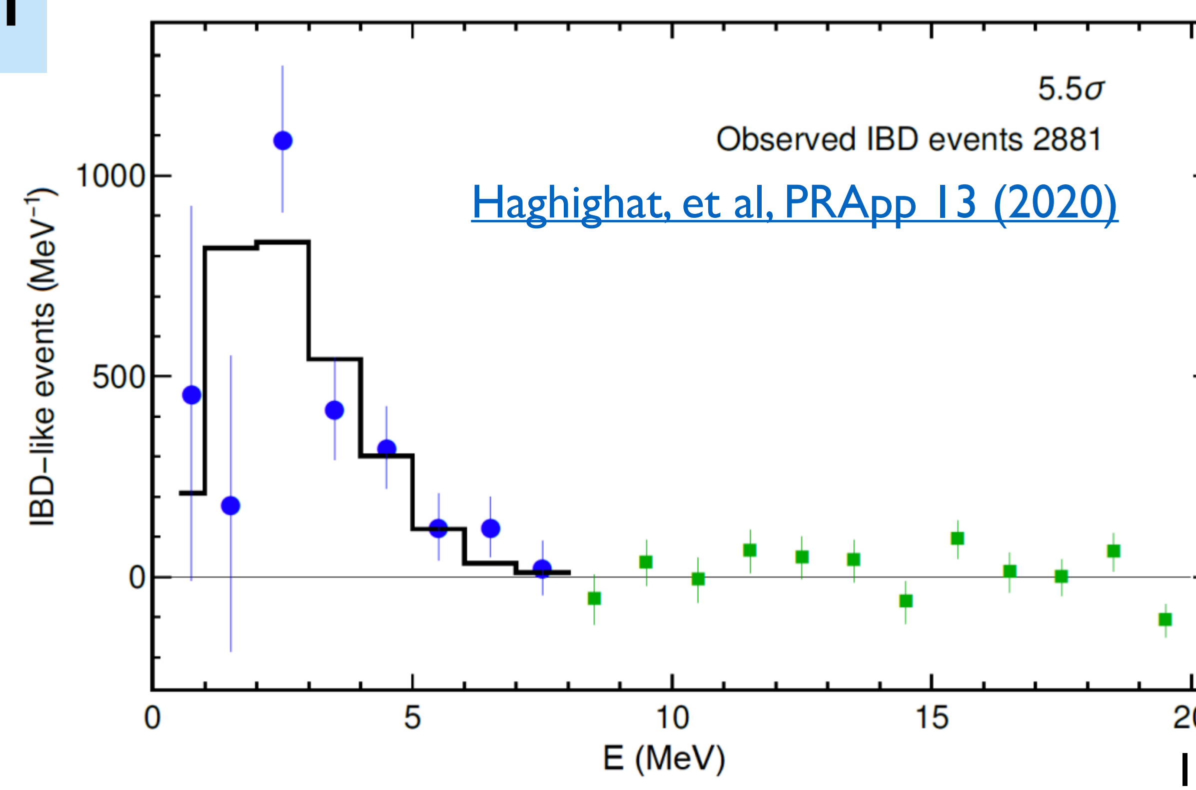


NF07: Applications

- $\bar{\nu}_e$-based reactor monitoring: a go-to response when a layman asks 'What are neutrinos good for?'
  - **CHANDLER** and **PROSPECT** have demonstrated on-surface ν_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



Summary

- Experiments observing neutrinos and neutrino-related physics below ~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!