

One Theorist's Take on the Recent Short-Baseline Results

**Kevin J. Kelly, CERN
IRN Neutrino Meeting, 1-2 December 2021**

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[\[2111.10359\]](https://arxiv.org/abs/2111.10359) with many great collaborators

Outline

- How did we get here?
 - Anomalies and additional neutrino states

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- The latest & greatest results
 - Interpretation in four-neutrino framework

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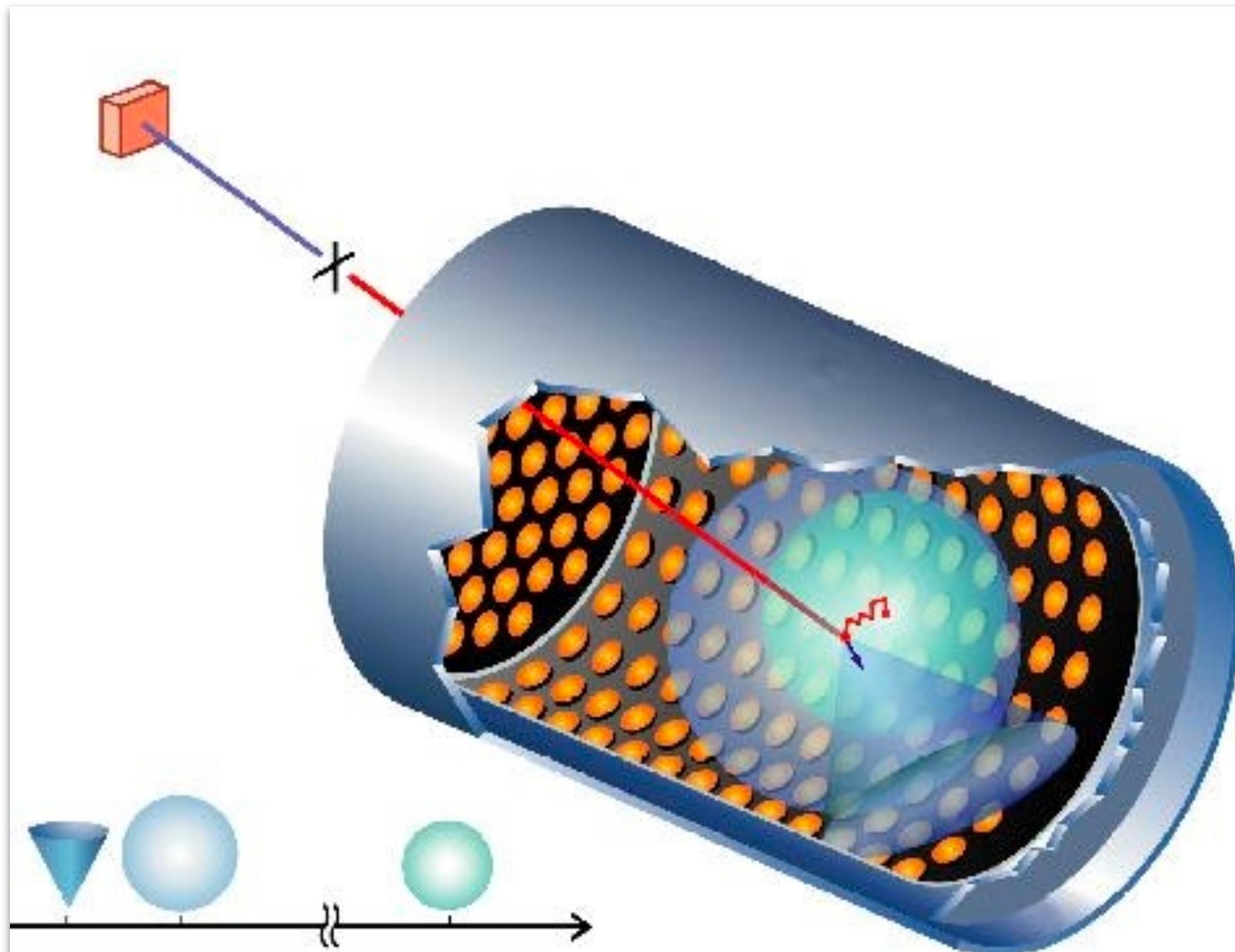
- How did we get here?
 - Anomalies and additional neutrino states
- The latest & greatest results
 - Interpretation in four-neutrino framework
- Beyond the sterile neutrino picture
 - Testable new-physics in current & upcoming experiments

How did we get here?

Anomalies!

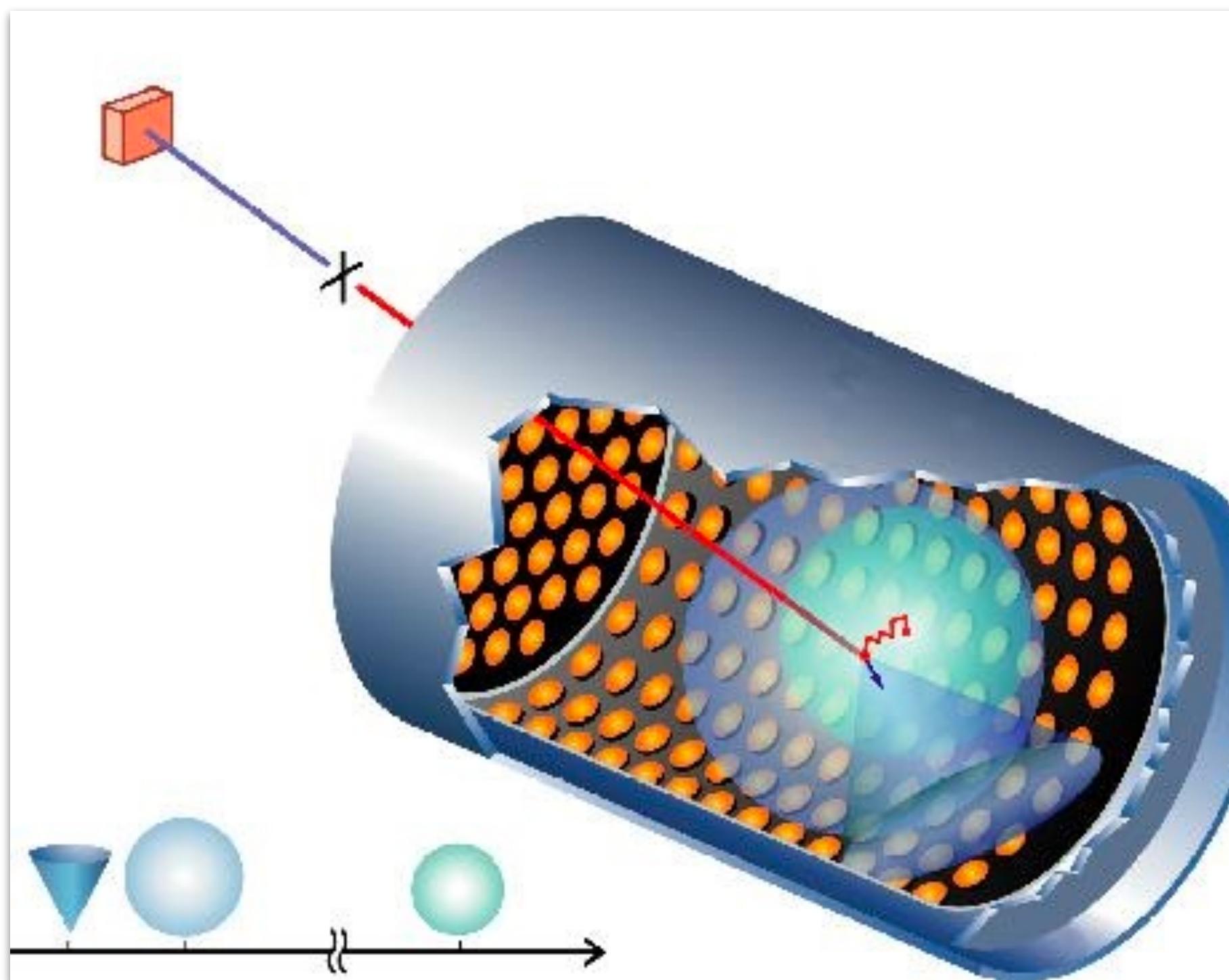
Anomalies!

LSND

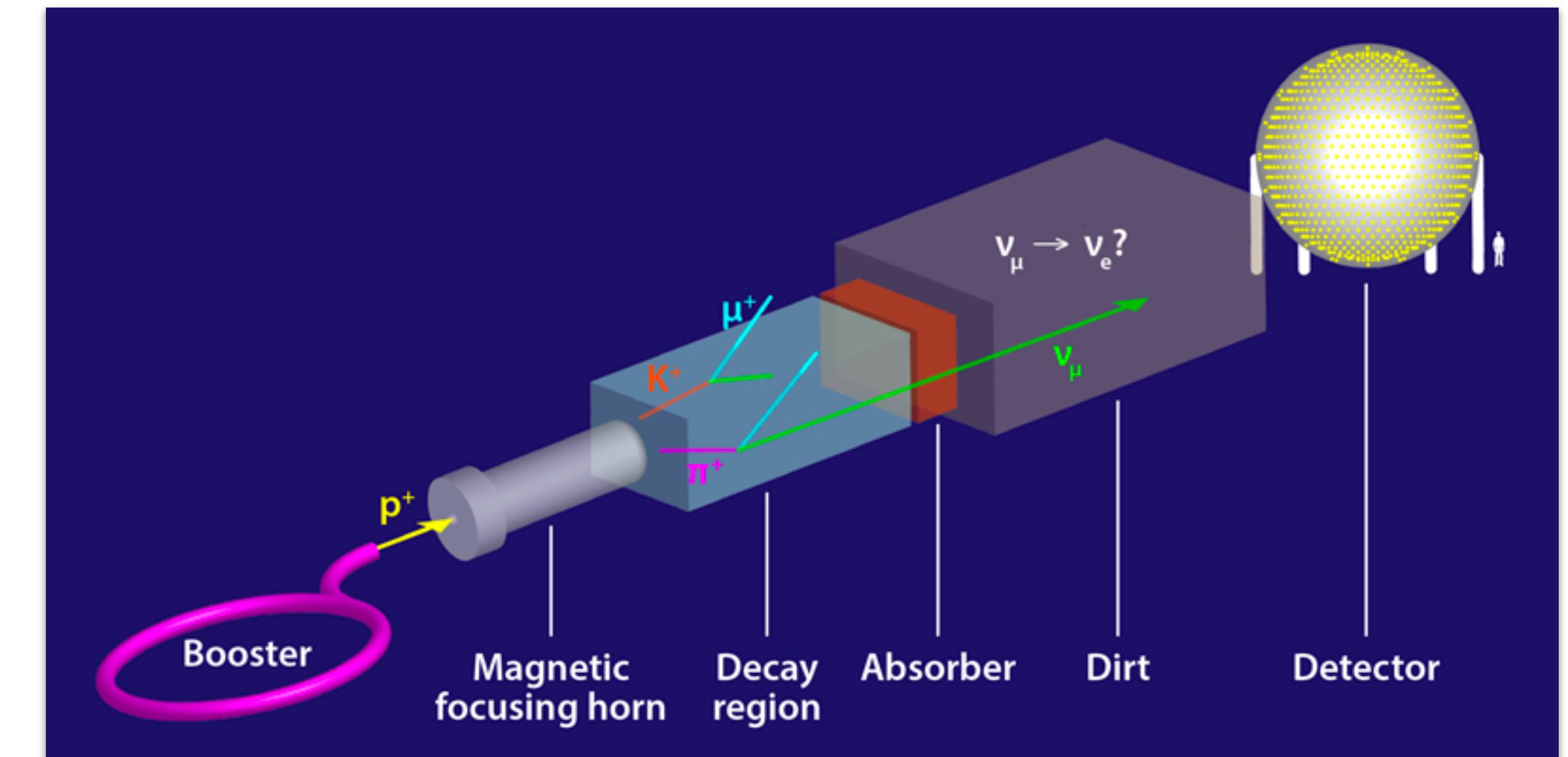


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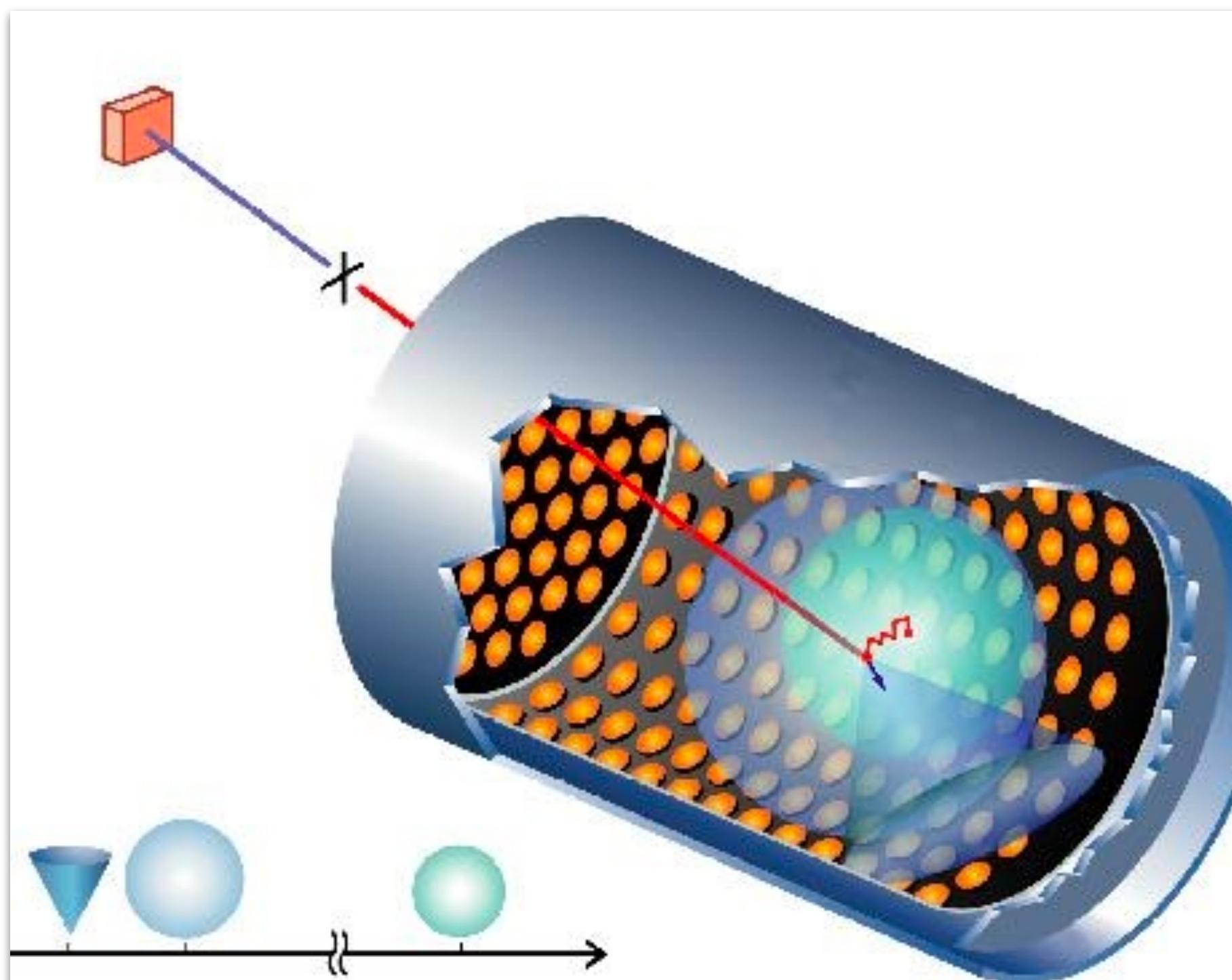


MiniBooNE

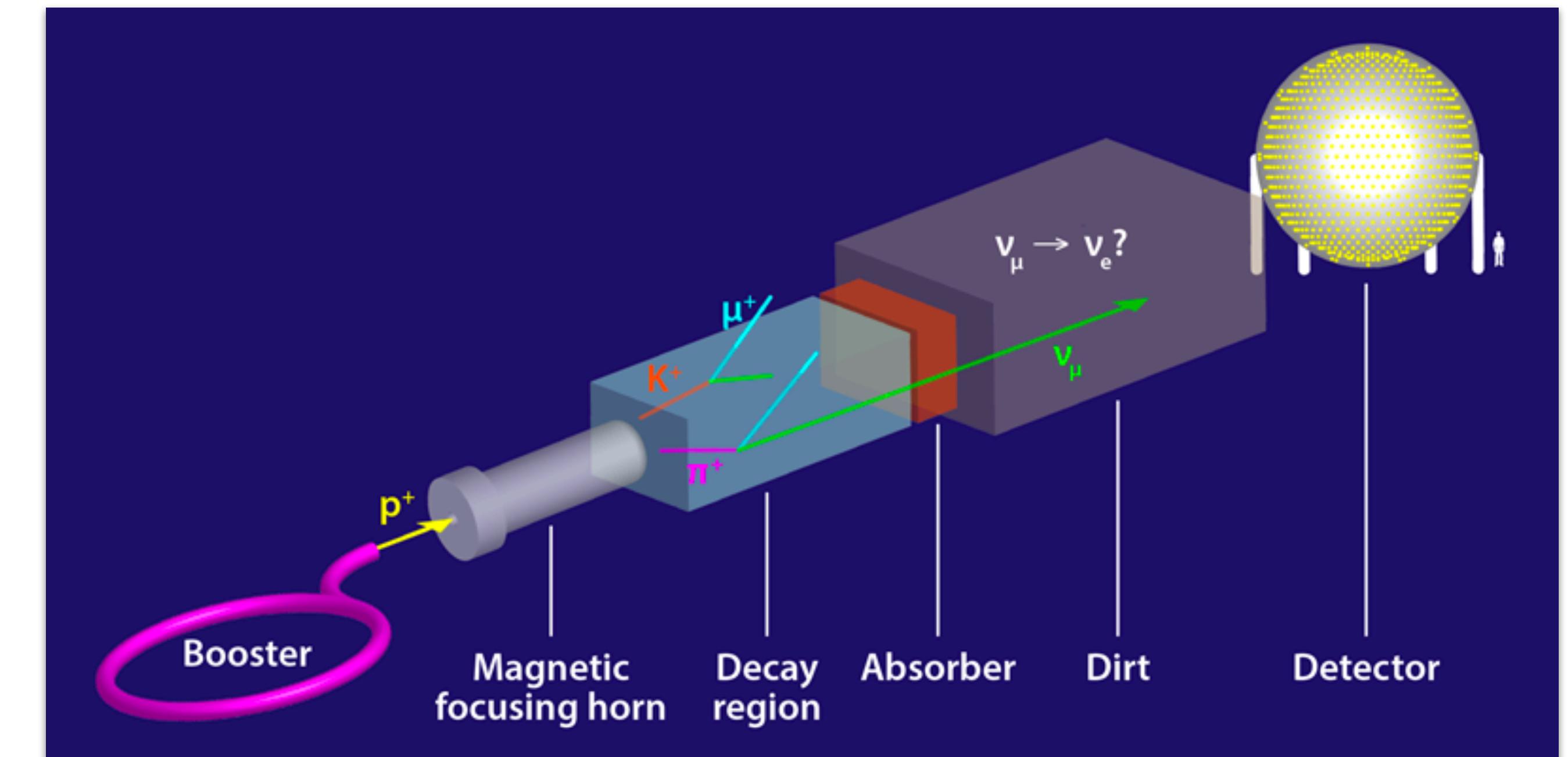


Anomalies!

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MiniBooNE



$$\nu_\mu \rightarrow \nu_e ?$$

Invoking a New (sterile) Neutrino

$$P(\nu_\mu \rightarrow \nu_e) = \sin^2(2\theta_{\mu e}) \sin^2\left(\frac{\Delta m_{41}^2 L}{4E_\nu}\right)$$

- Add in a new (fourth) neutrino mass eigenstate with a significantly larger mass than the three “light” ones. This extends the Leptonic mixing matrix to 4x4 instead of 3x3.

Invoking a New (sterile) Neutrino

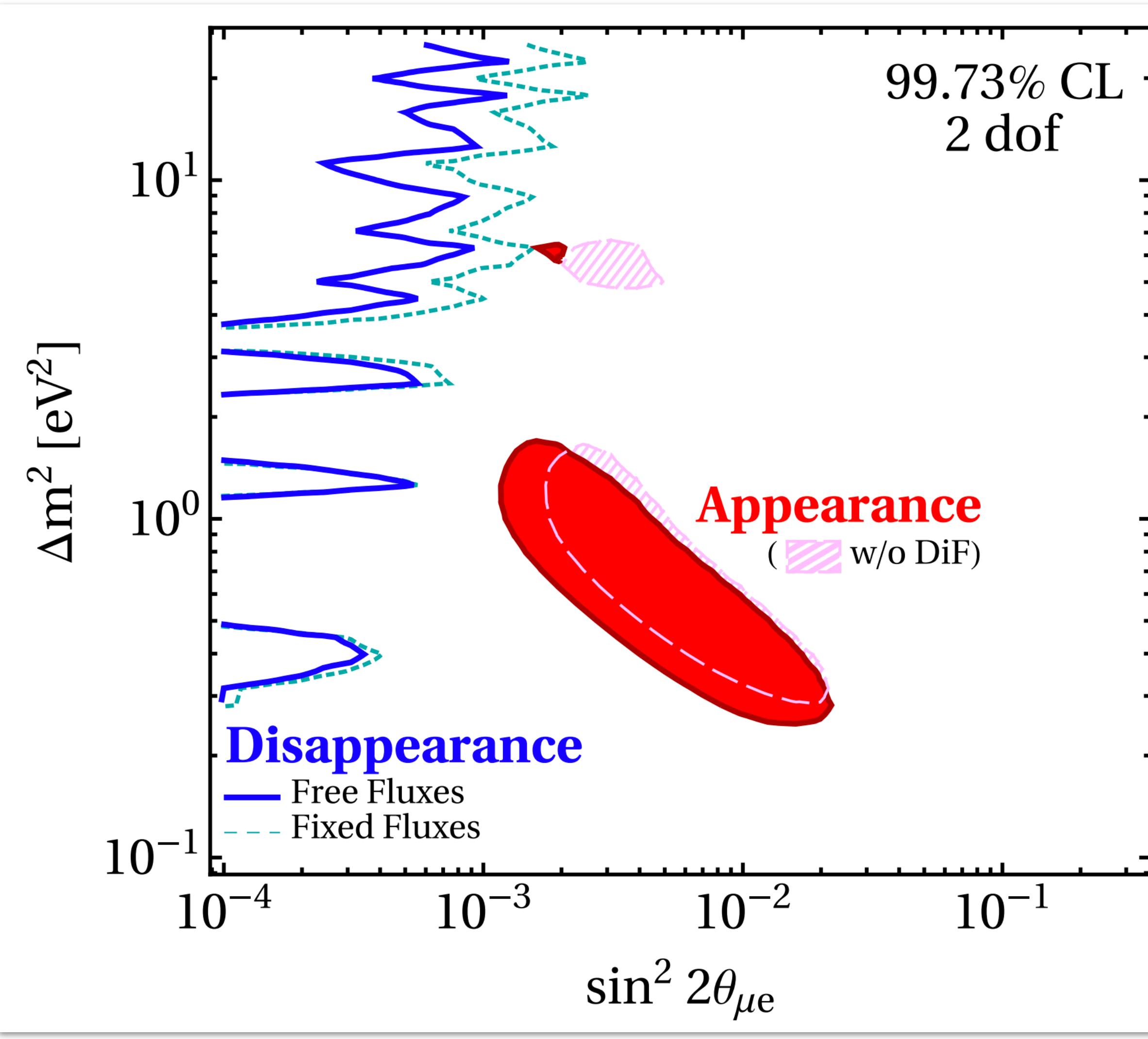
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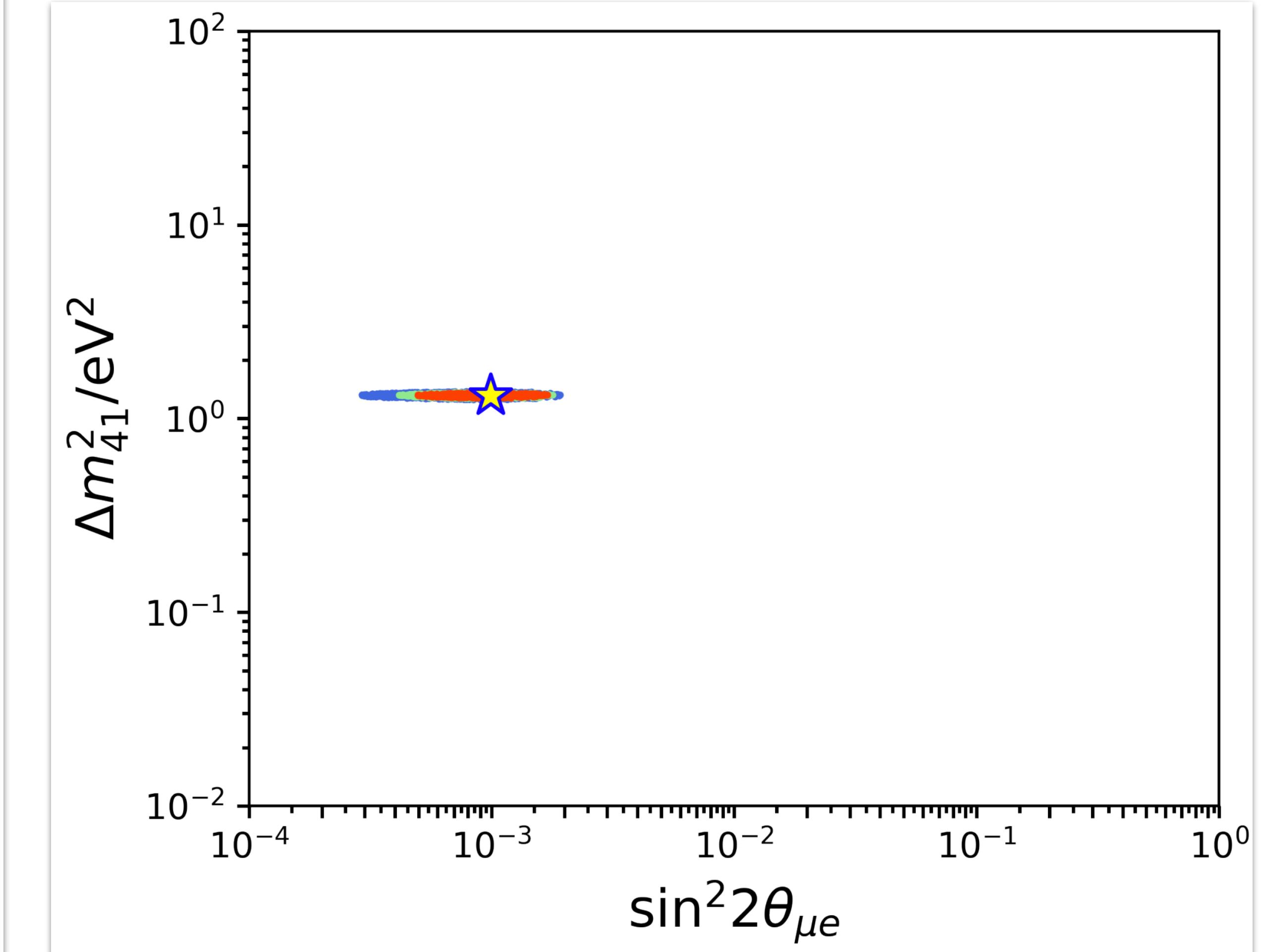
$$\sin^2(2\theta_{\mu e}) \equiv 4 |U_{e4}|^2 |U_{\mu 4}|^2$$

- Electron-neutrino appearance is driven by a product of the new matrix elements. Each of these being non-zero predicts electron-neutrino and muon-neutrino disappearance at the same neutrino energy/distance.

Sterile Neutrino Global Fits ca 2019



Dentler et al [1803.10661]

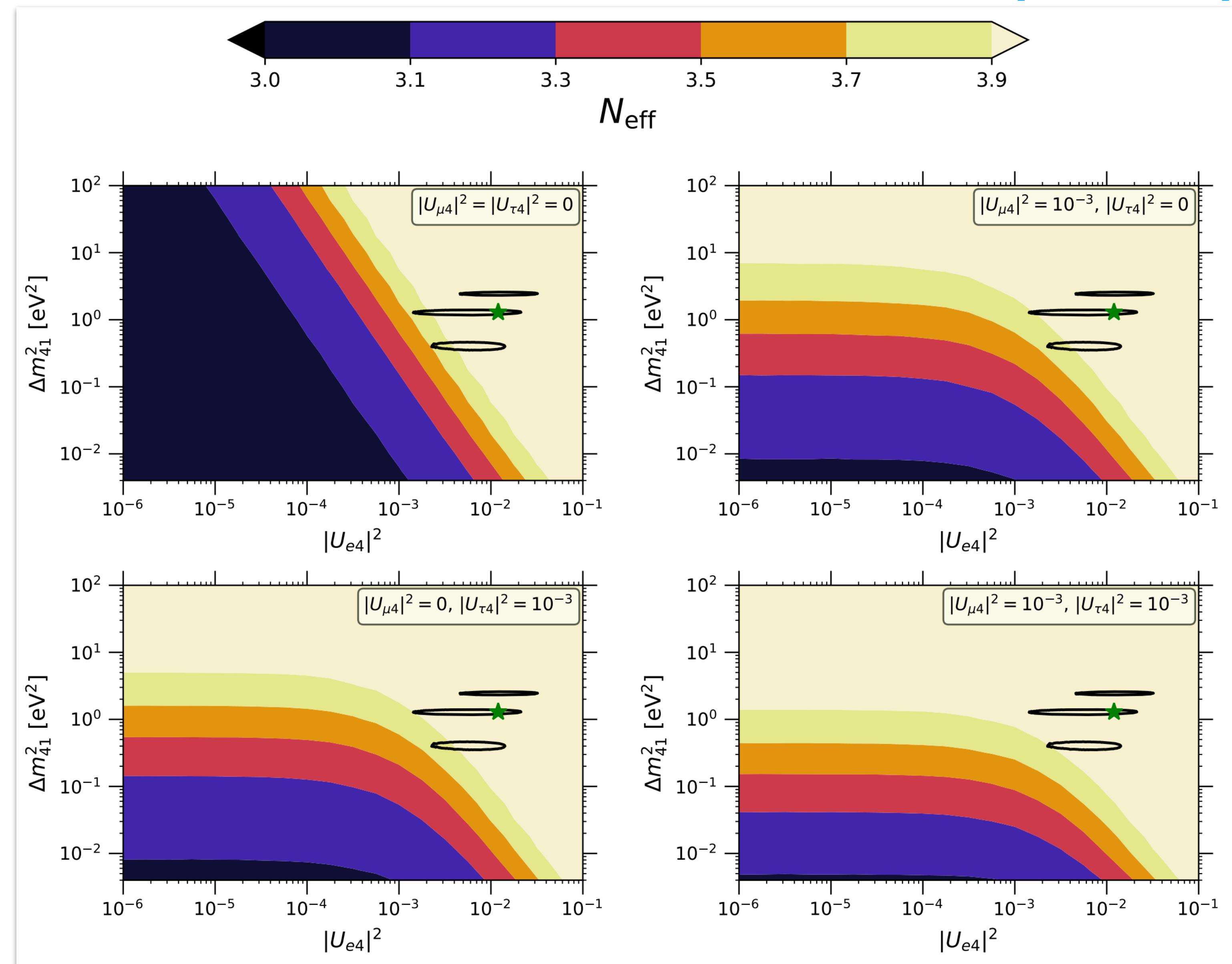


Diaz et al [1906.00045]

Sterile Neutrinos & Cosmology

Gariazzo et al, [1905.11290]

A new, eV-scale massive fermion that mixes (even with small mixing angles) with the SM neutrinos will be thermalized in the early universe. Cosmological probes (precision measurements of Big-Bang Nucleosynthesis and the Cosmic Microwave Background) are highly sensitive to the number of relativistic species.



My thoughts in 2019?

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Let's wait and see what happens next.

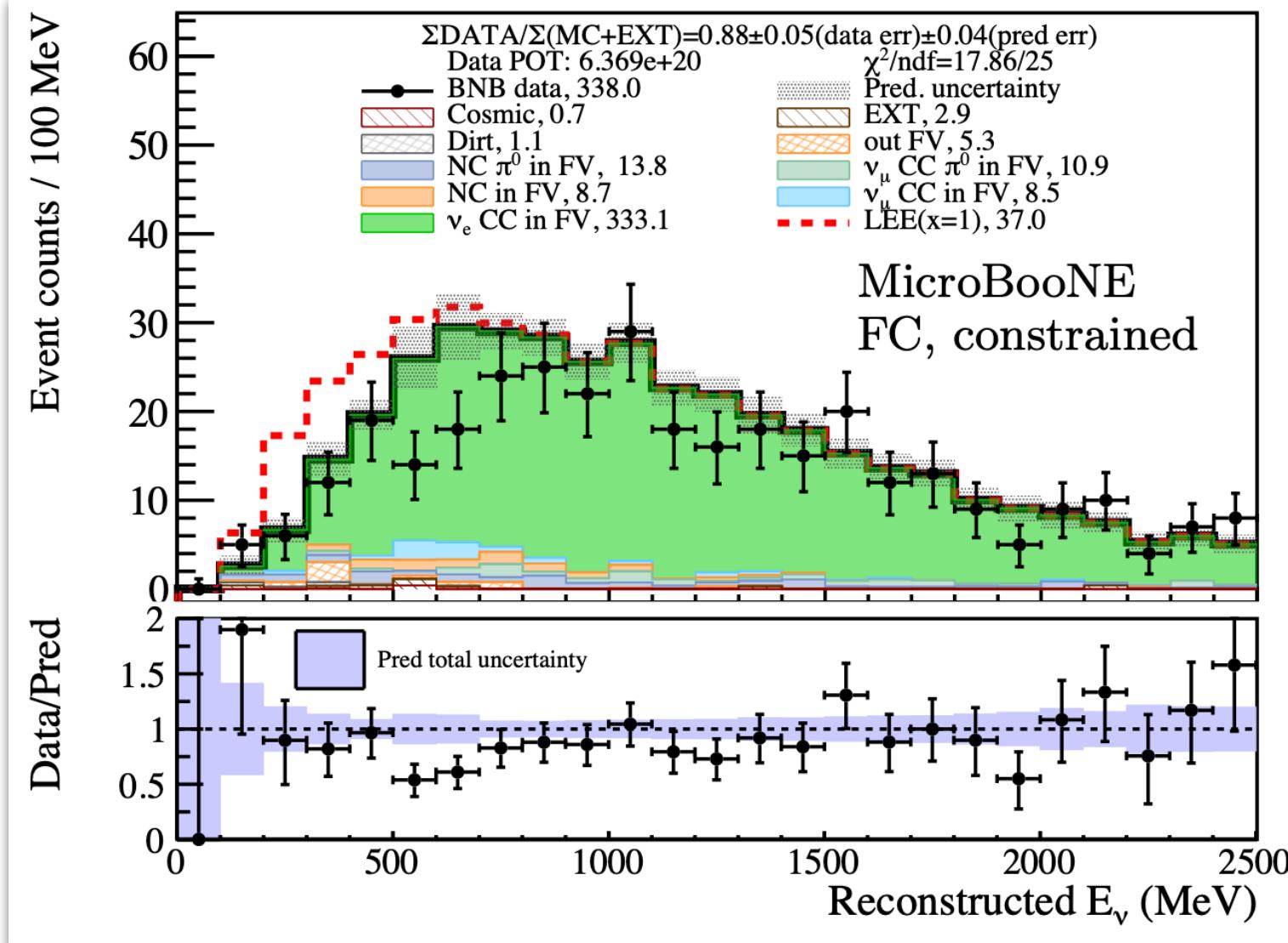
Recent Experimental Results

– MicroBooNE

MicroBooNE Electron Analyses

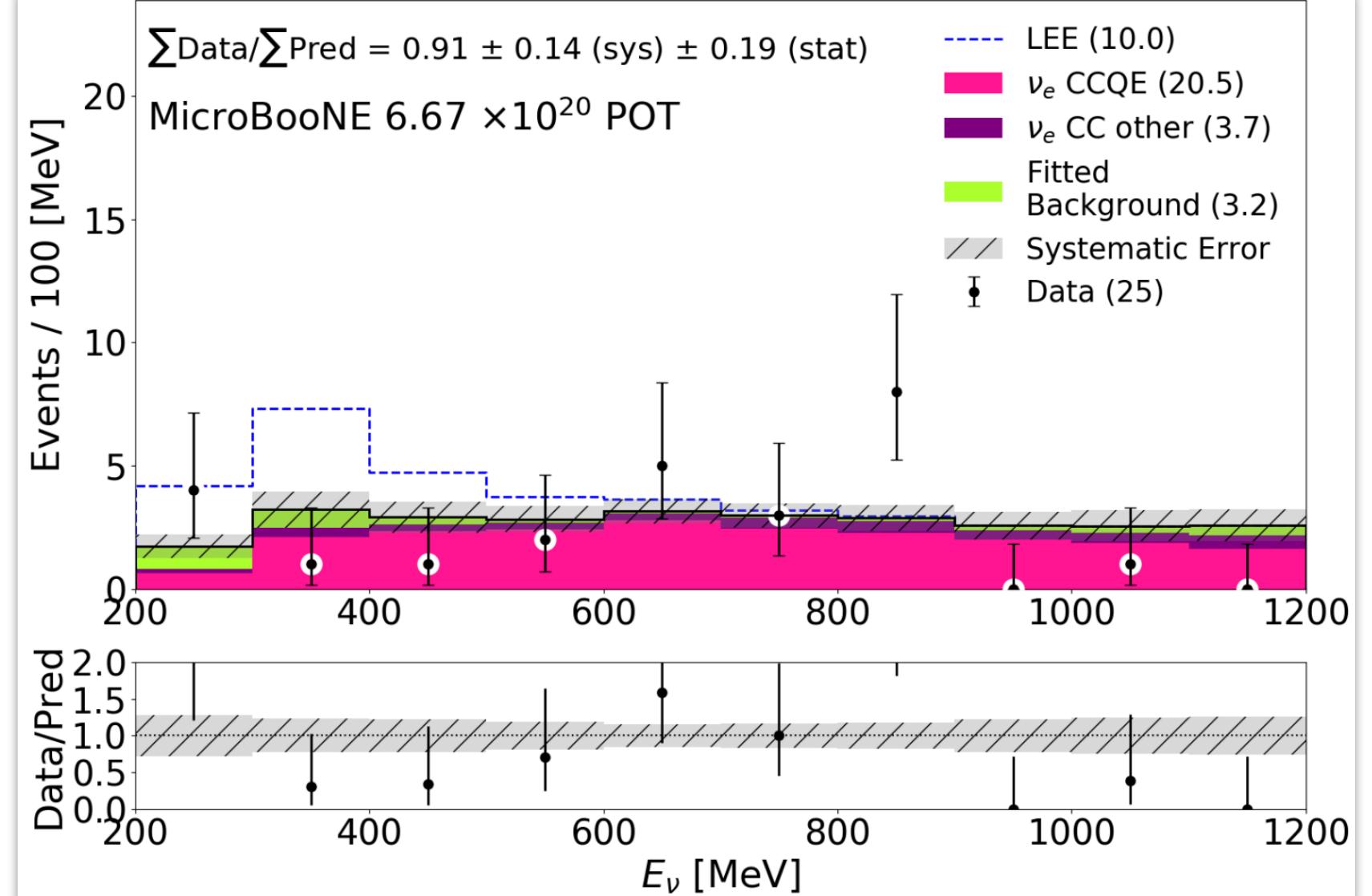
“Inclusive”

[\[2110.13978\]](#)



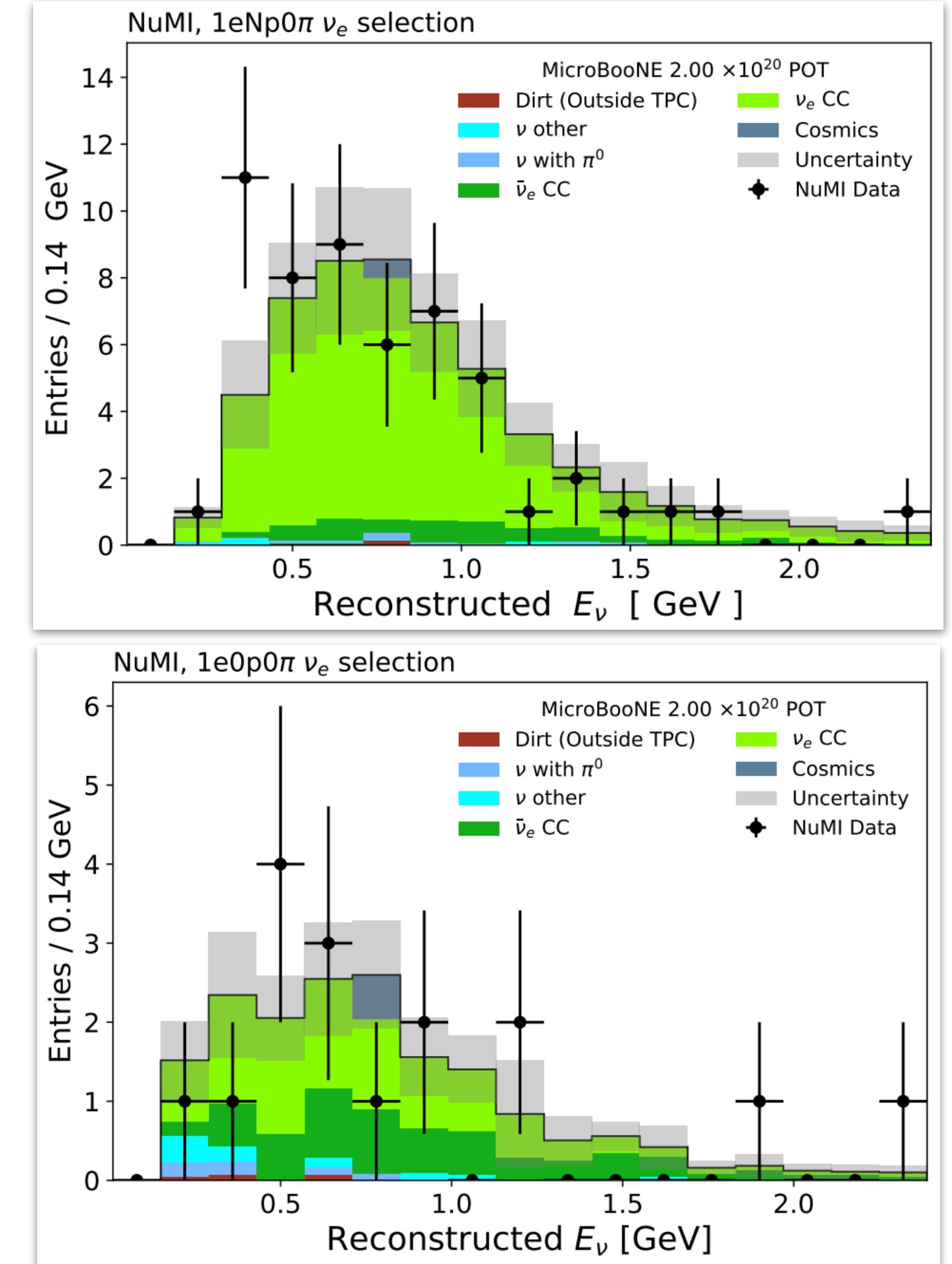
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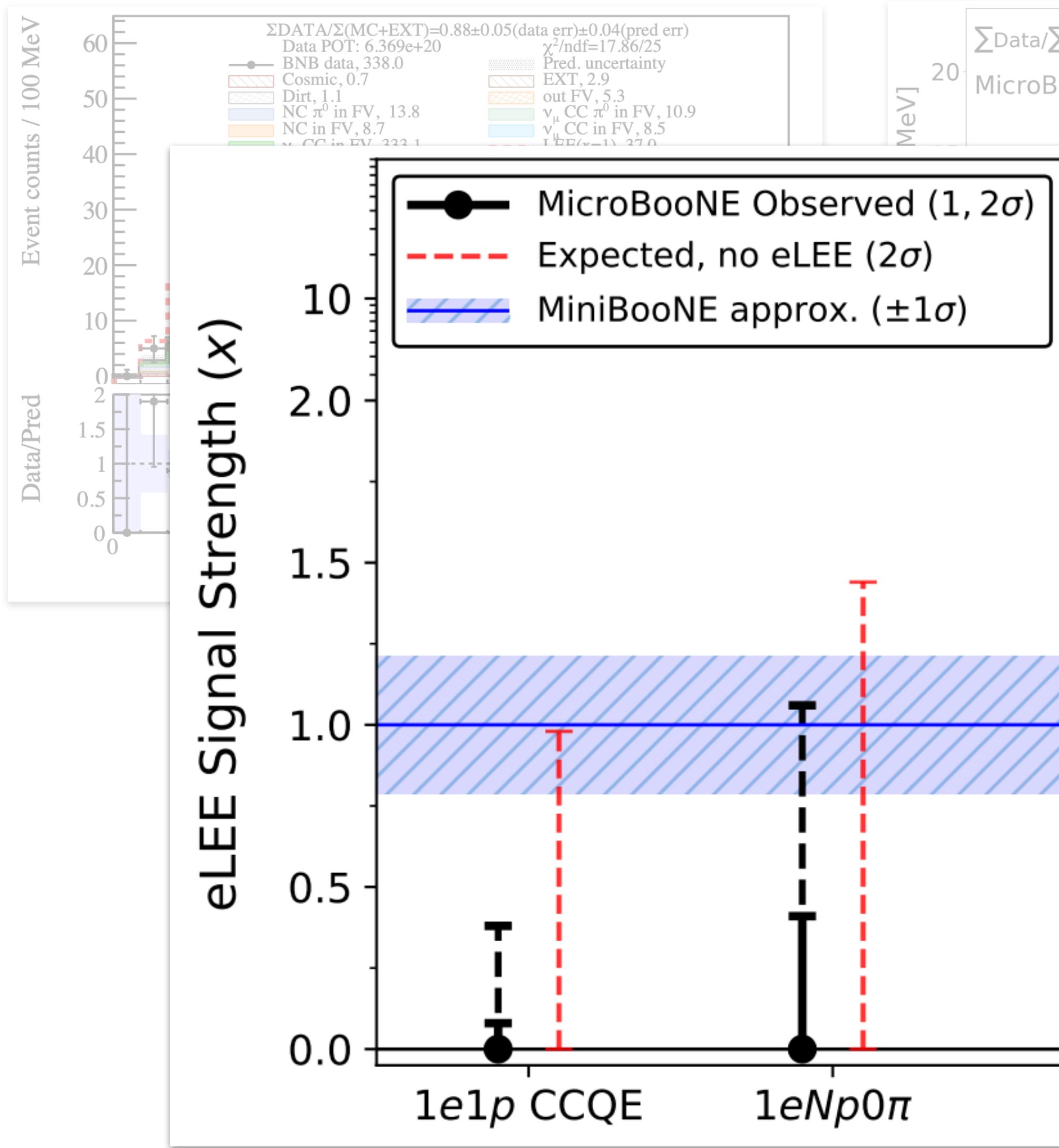
“Pionless”

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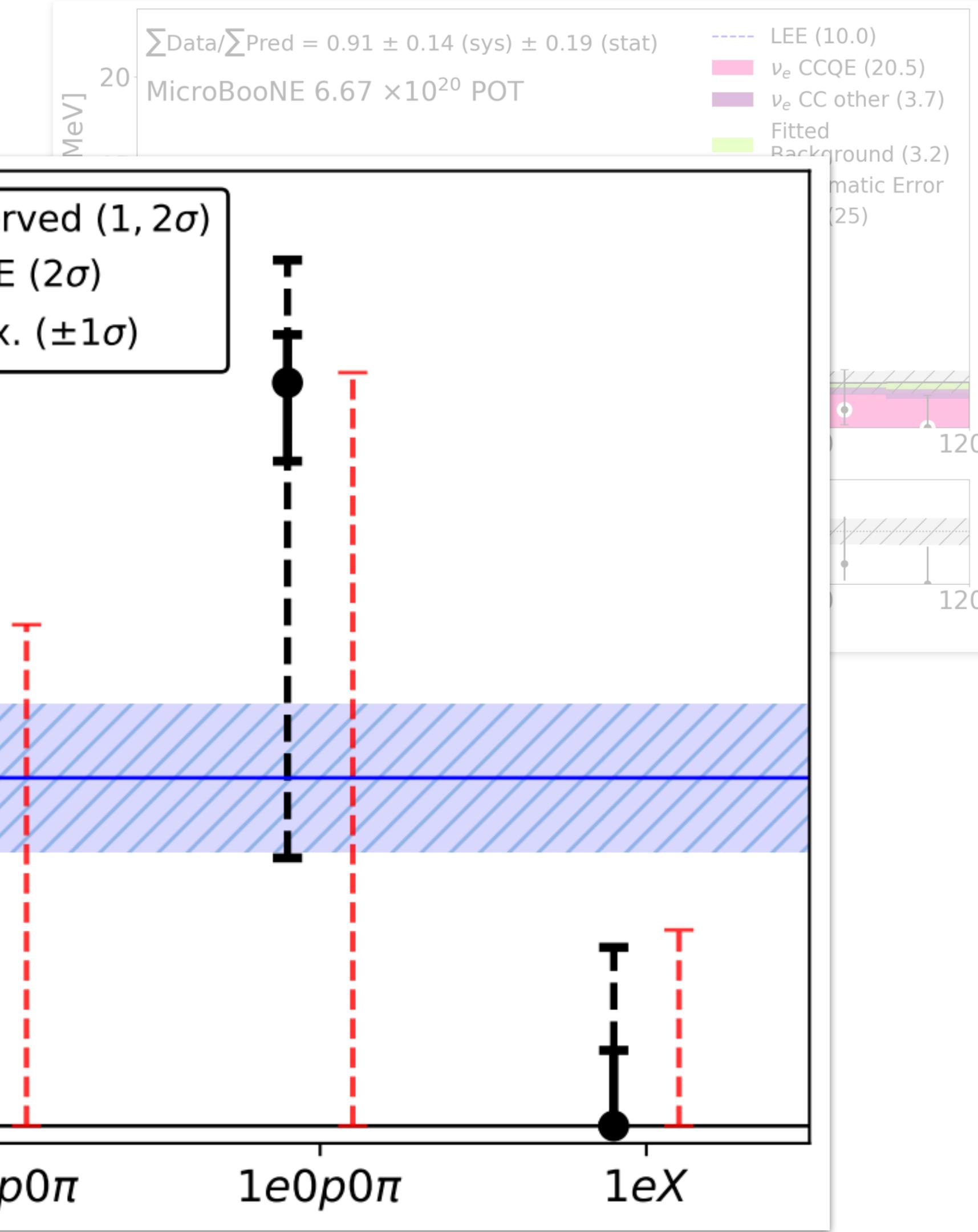


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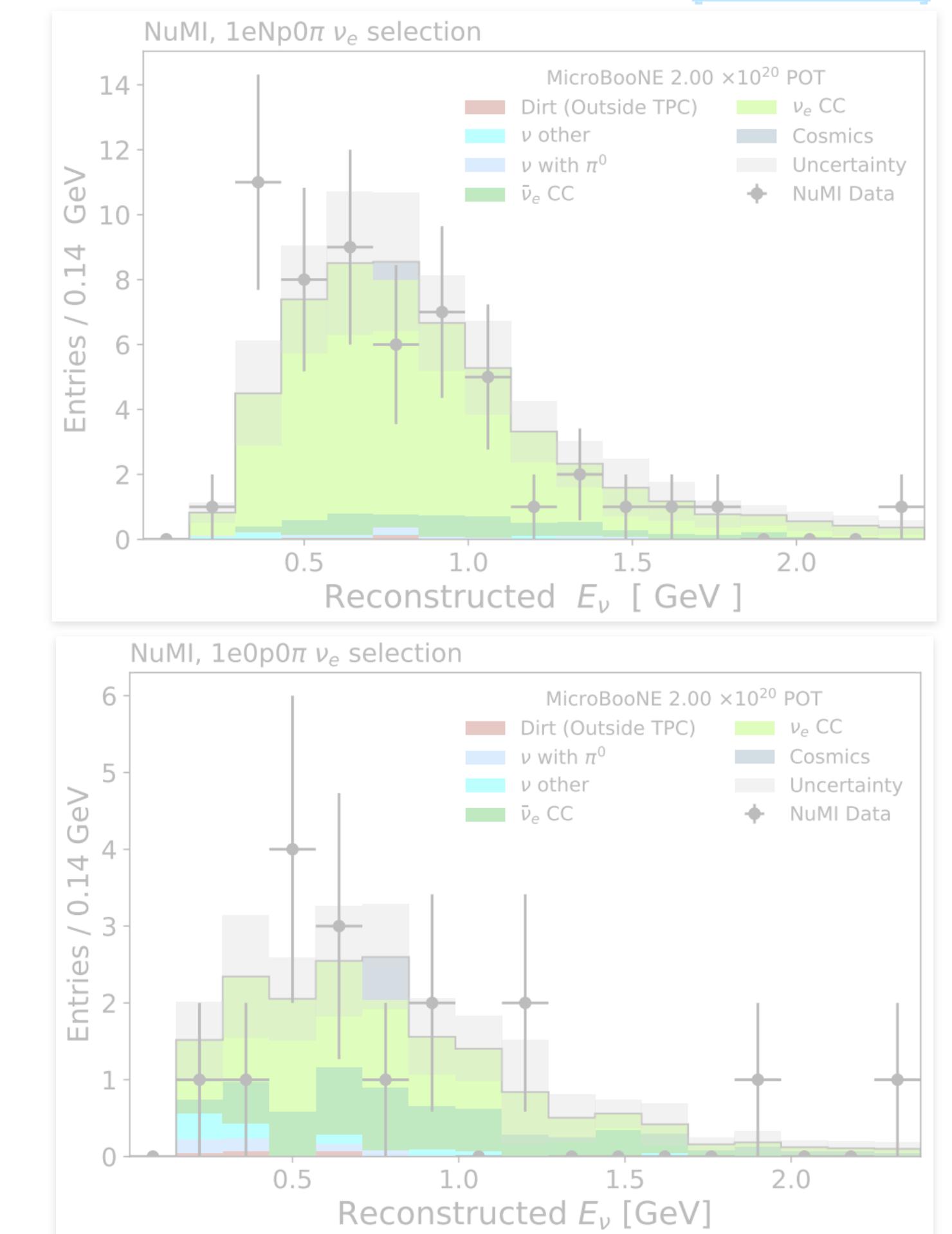
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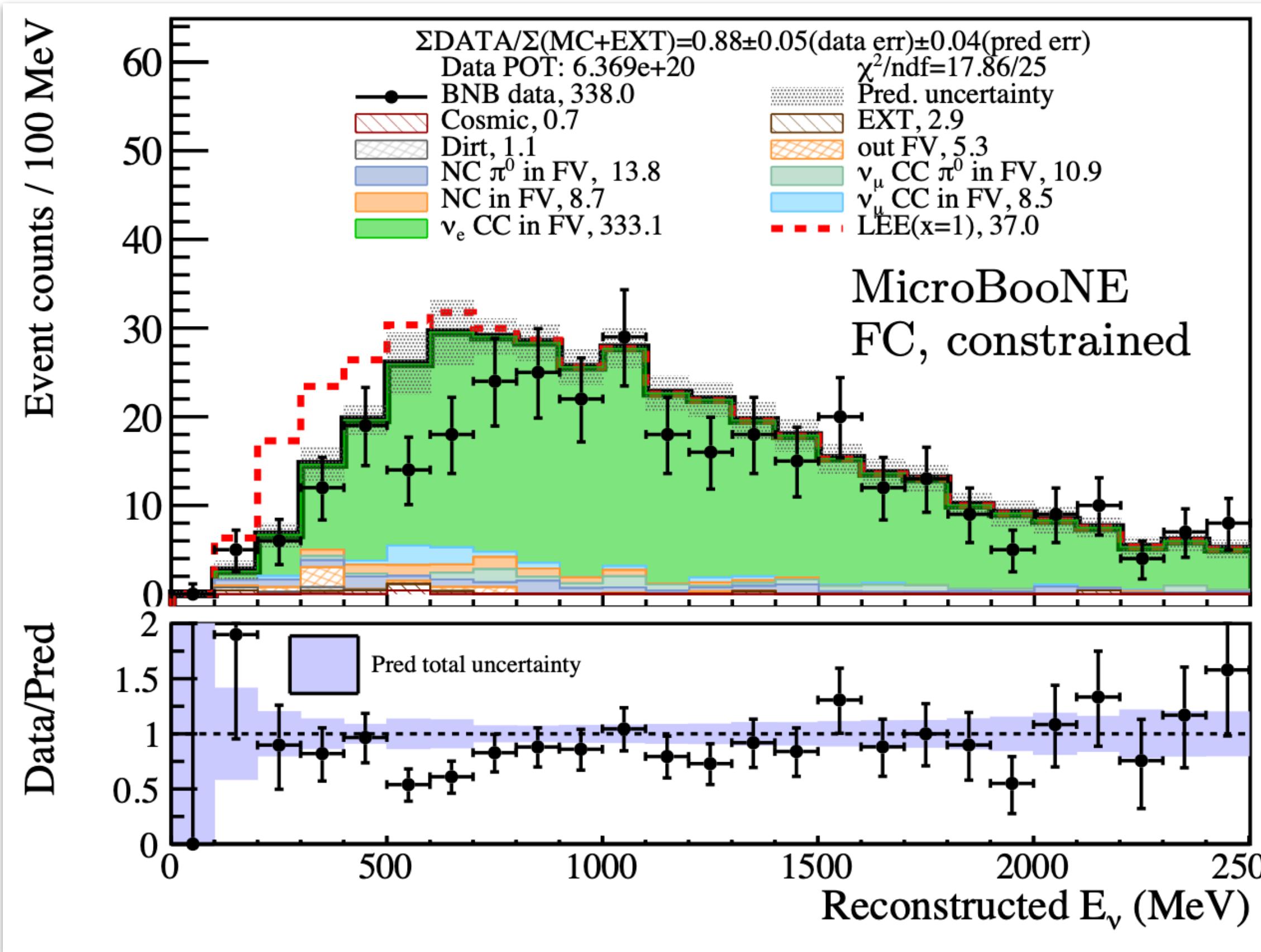
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Complementarity of Inclusive/CCQE

“Inclusive”

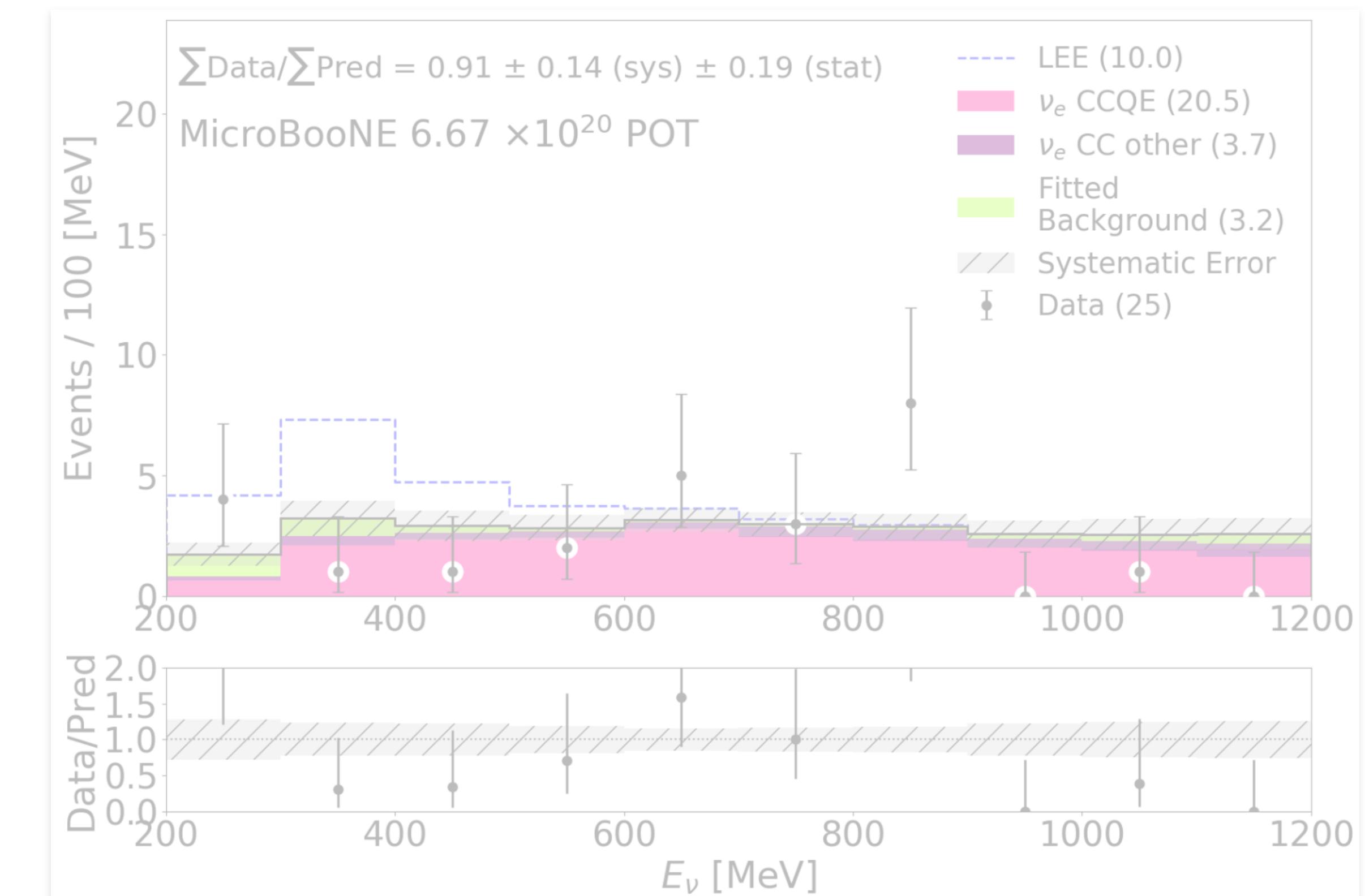
[\[2110.13978\]](#)



- Large electron-neutrino and muon-neutrino (not shown) samples.
- Large (expected) excess from muon-neutrino to electron-neutrino oscillation

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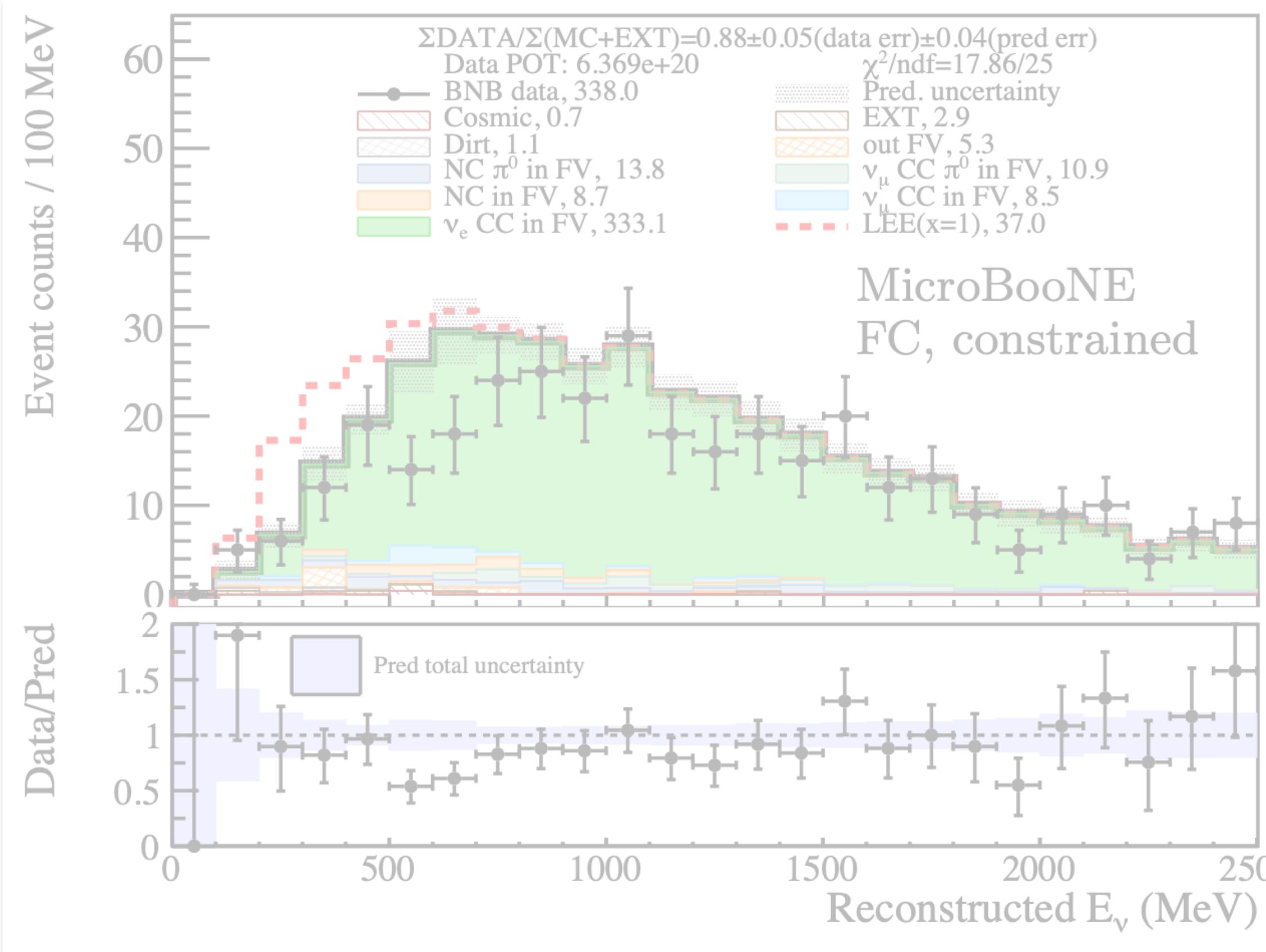


- Very pure sample, low background expectations.
- Expected excess from muon-neutrino to electron-neutrino oscillation is (relatively) large

Complementarity of Inclusive/CCQE

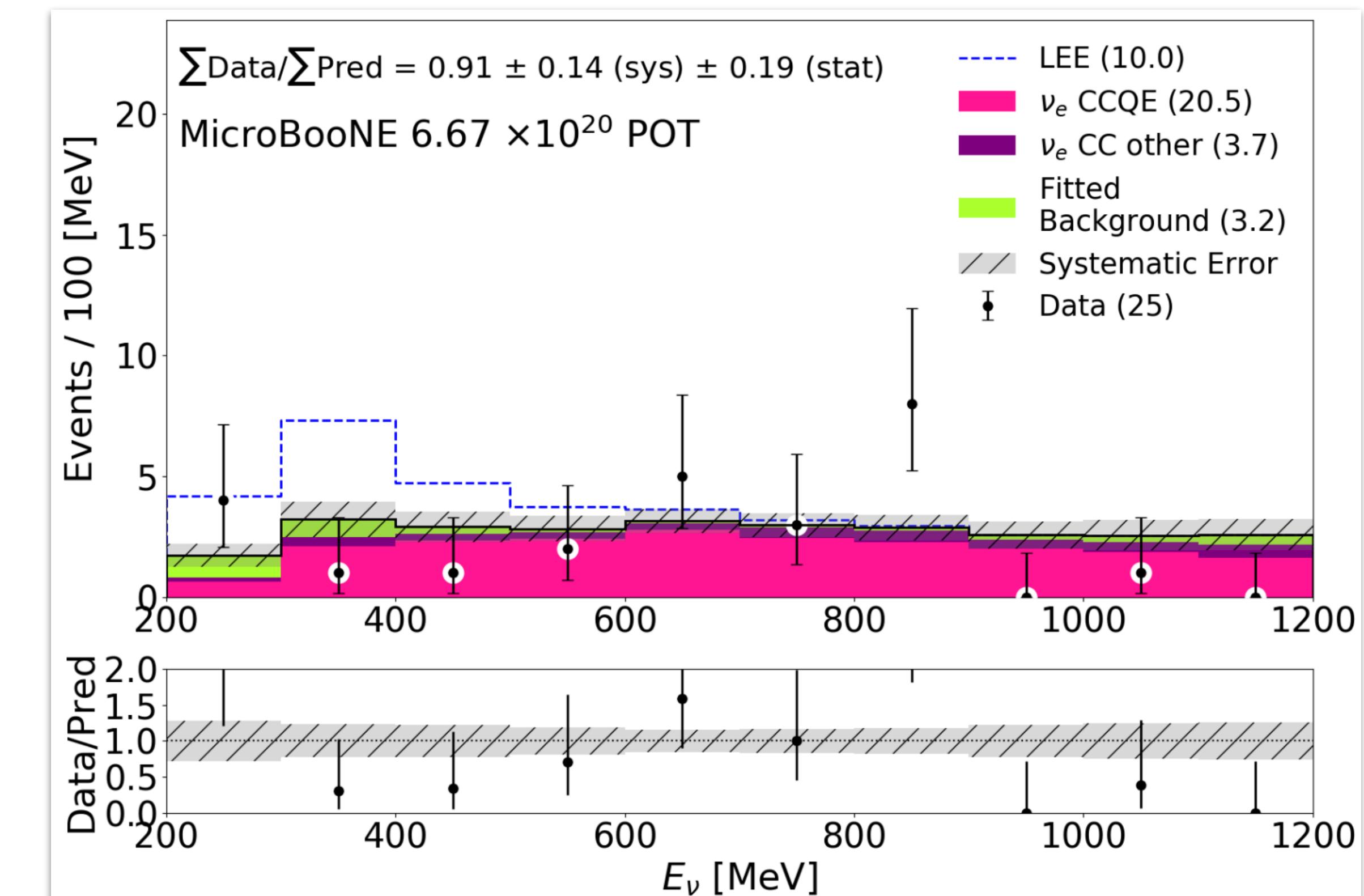
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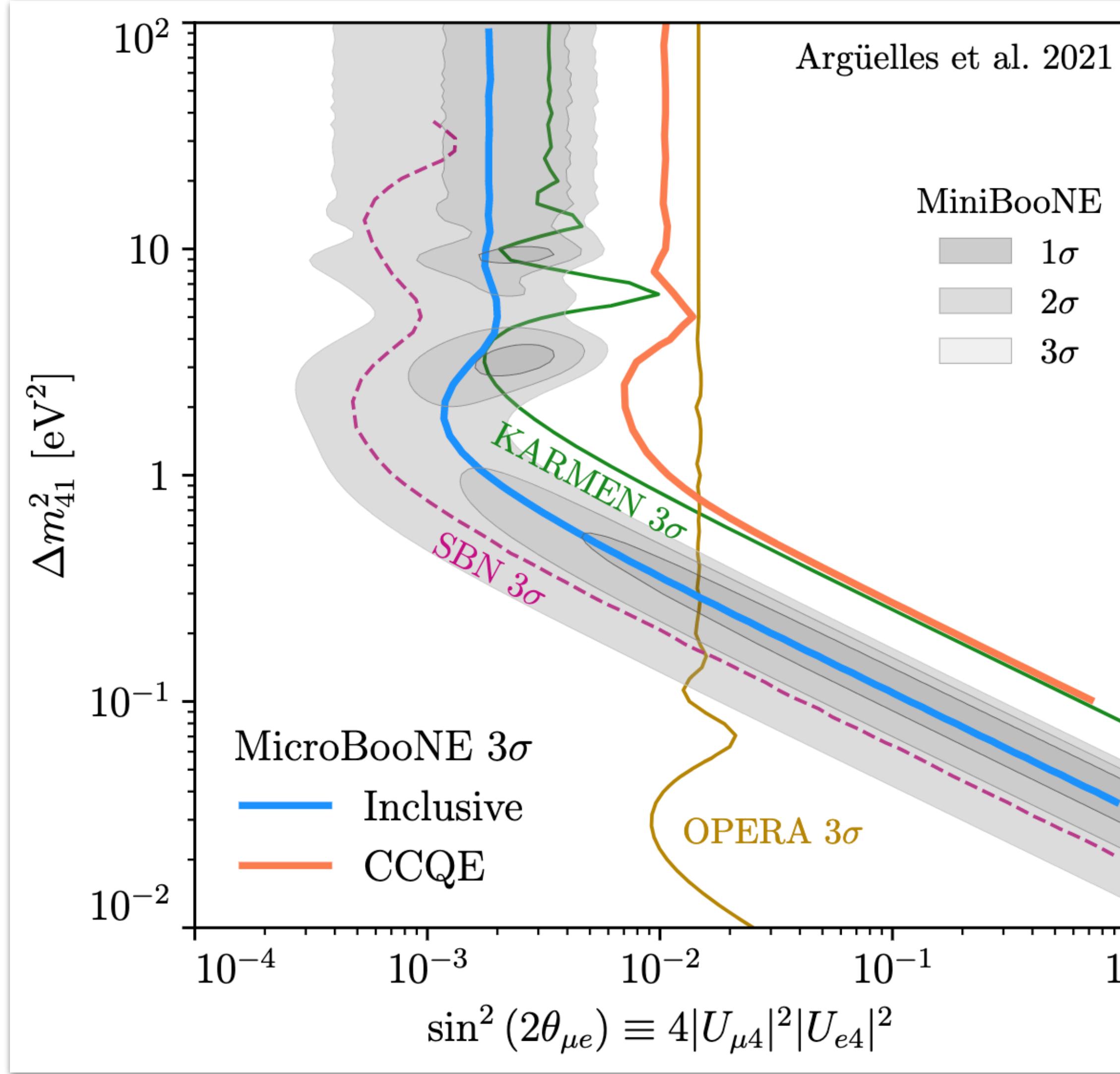


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MicroBooNE and Sterile Neutrinos

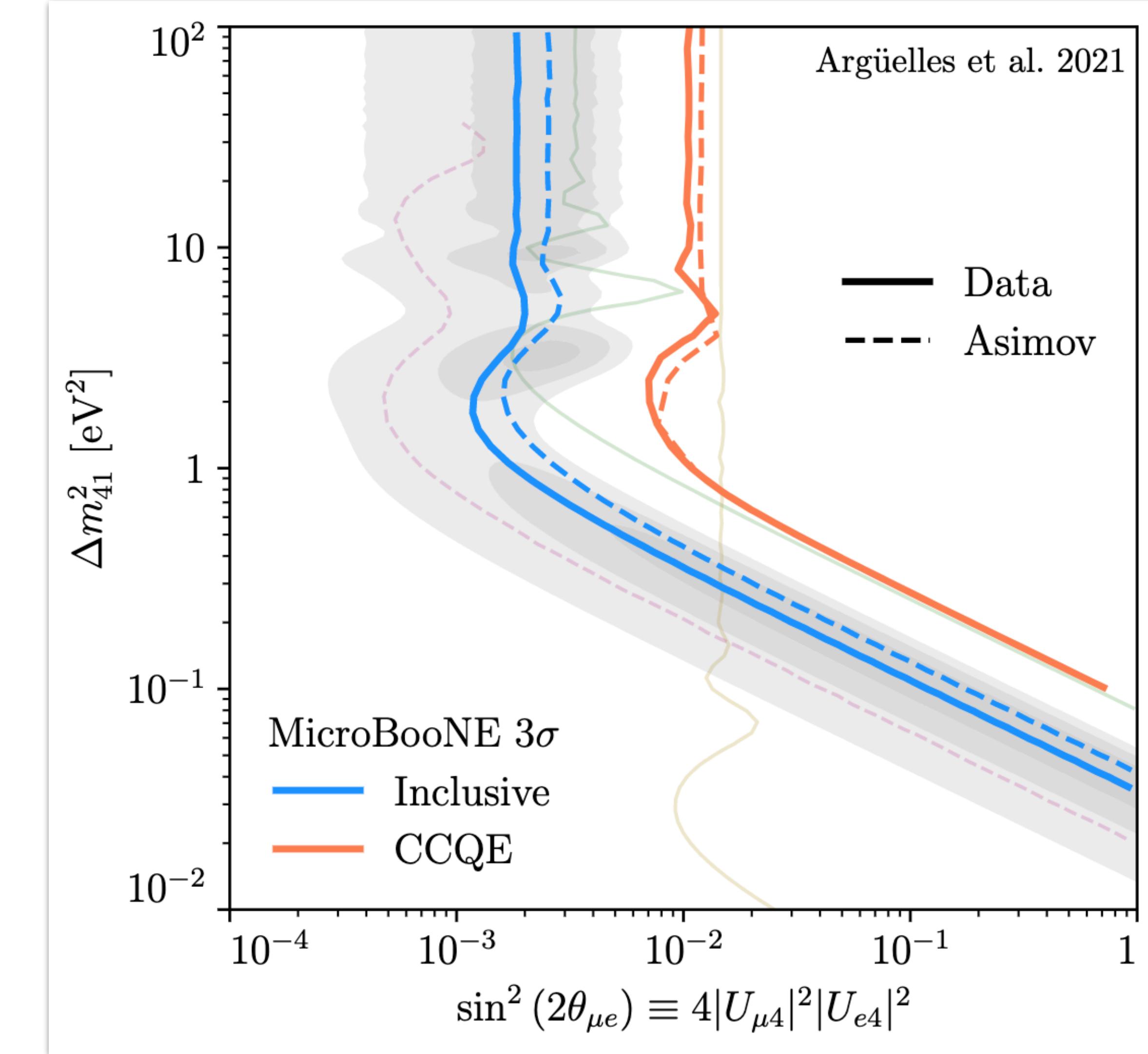
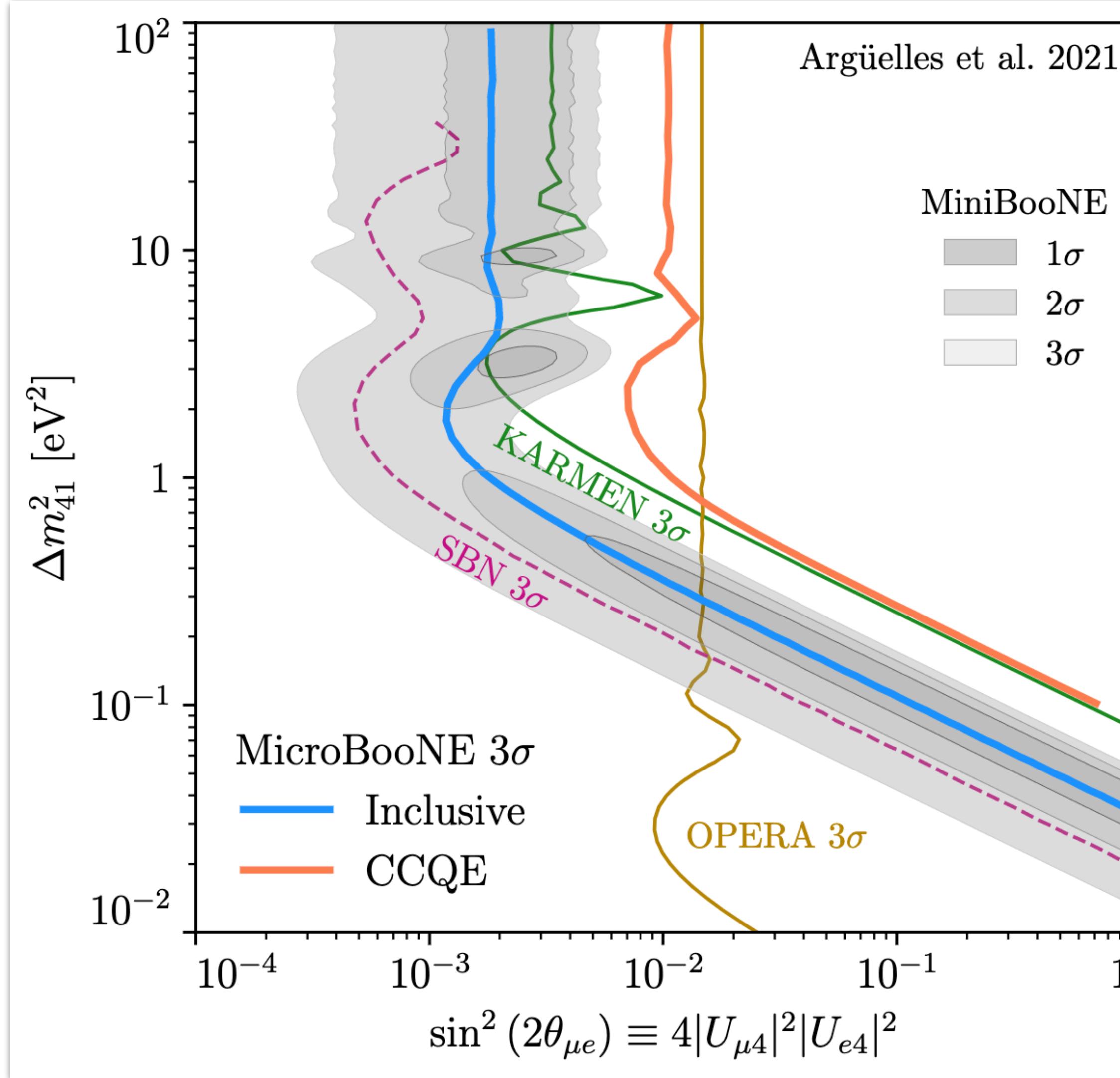
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[2111.10359]

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Complete 3+1 Neutrino Framework

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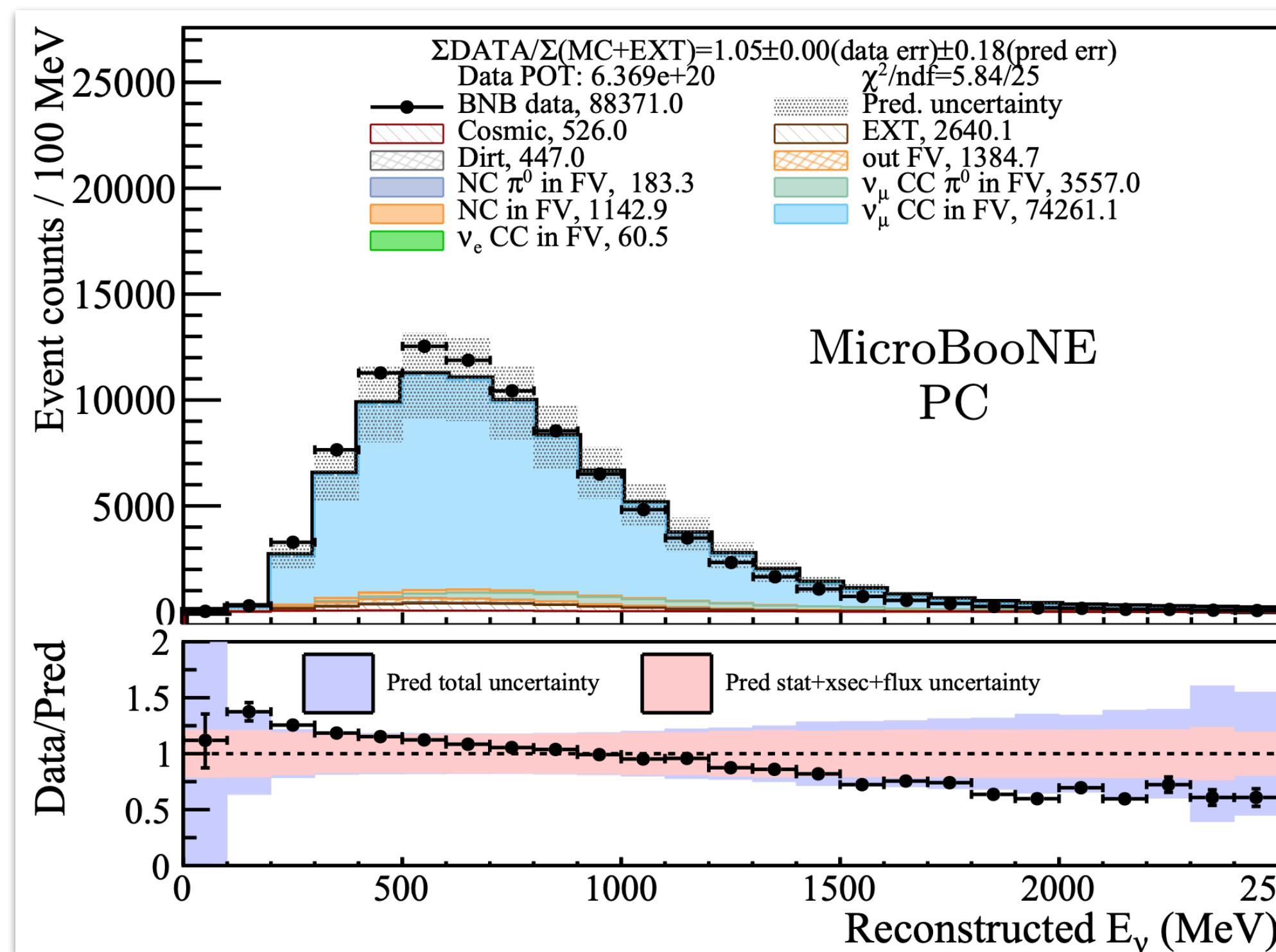
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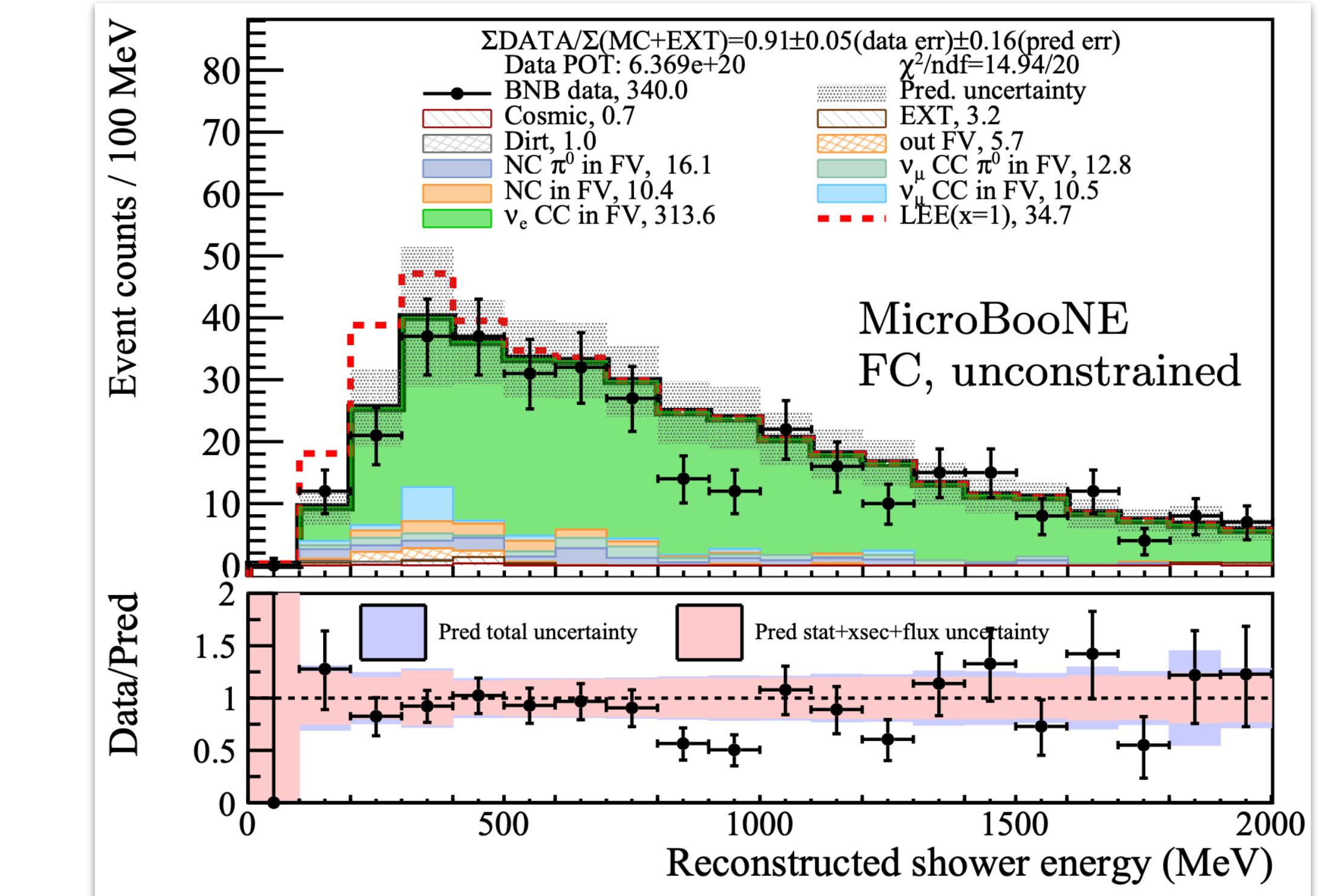
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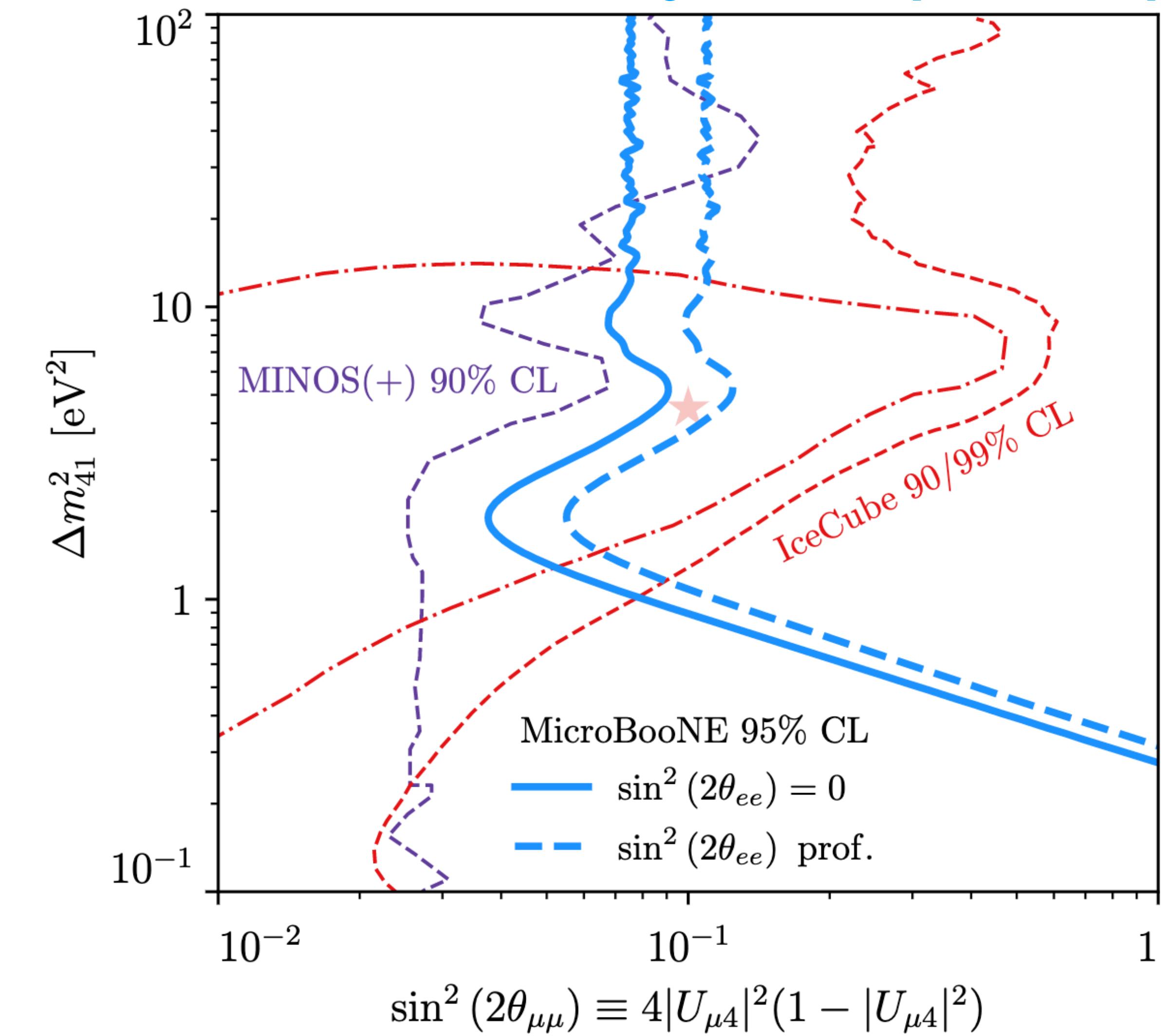
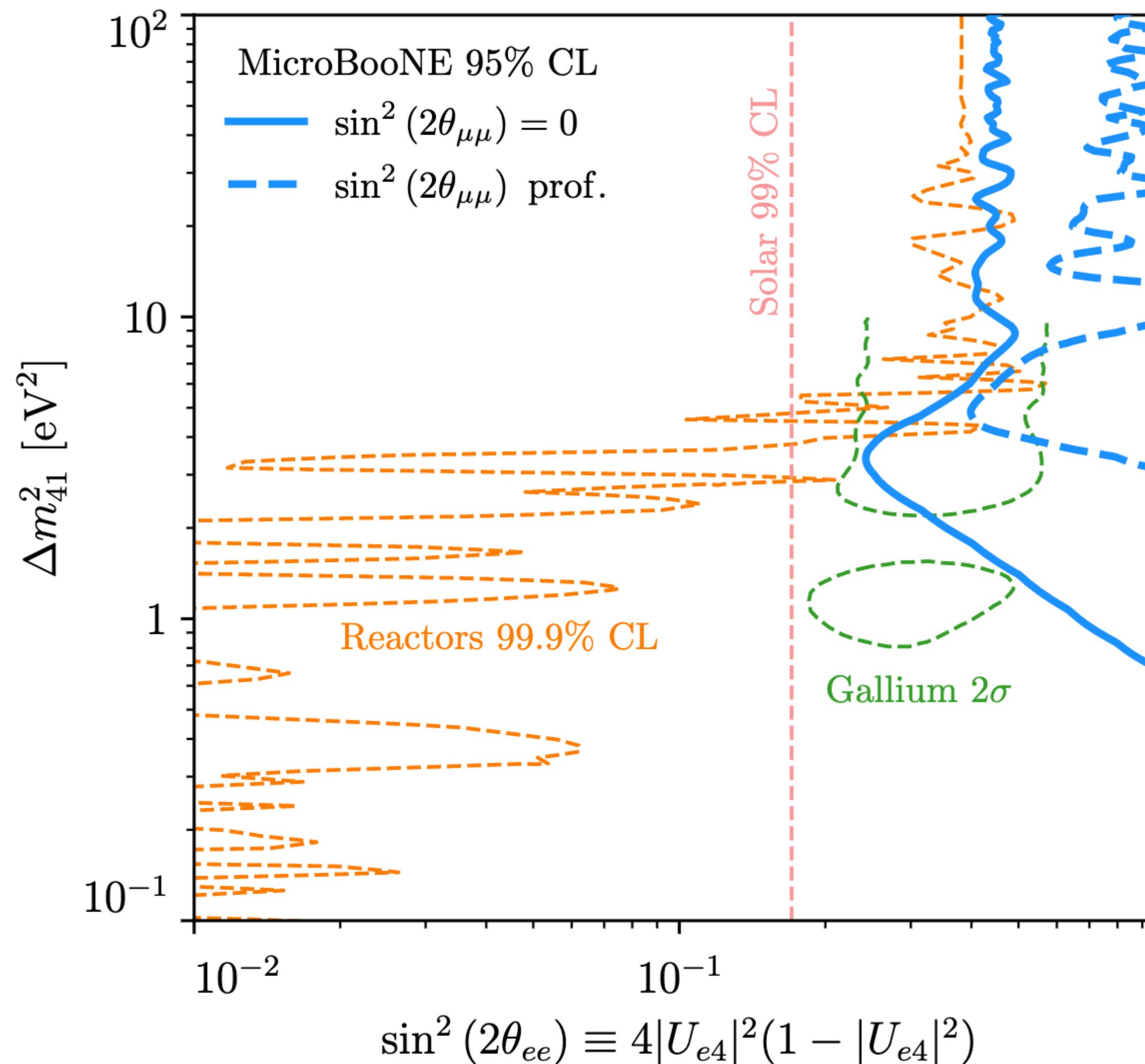
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MicroBooNE, [2110.13978]

Four-Flavor Results

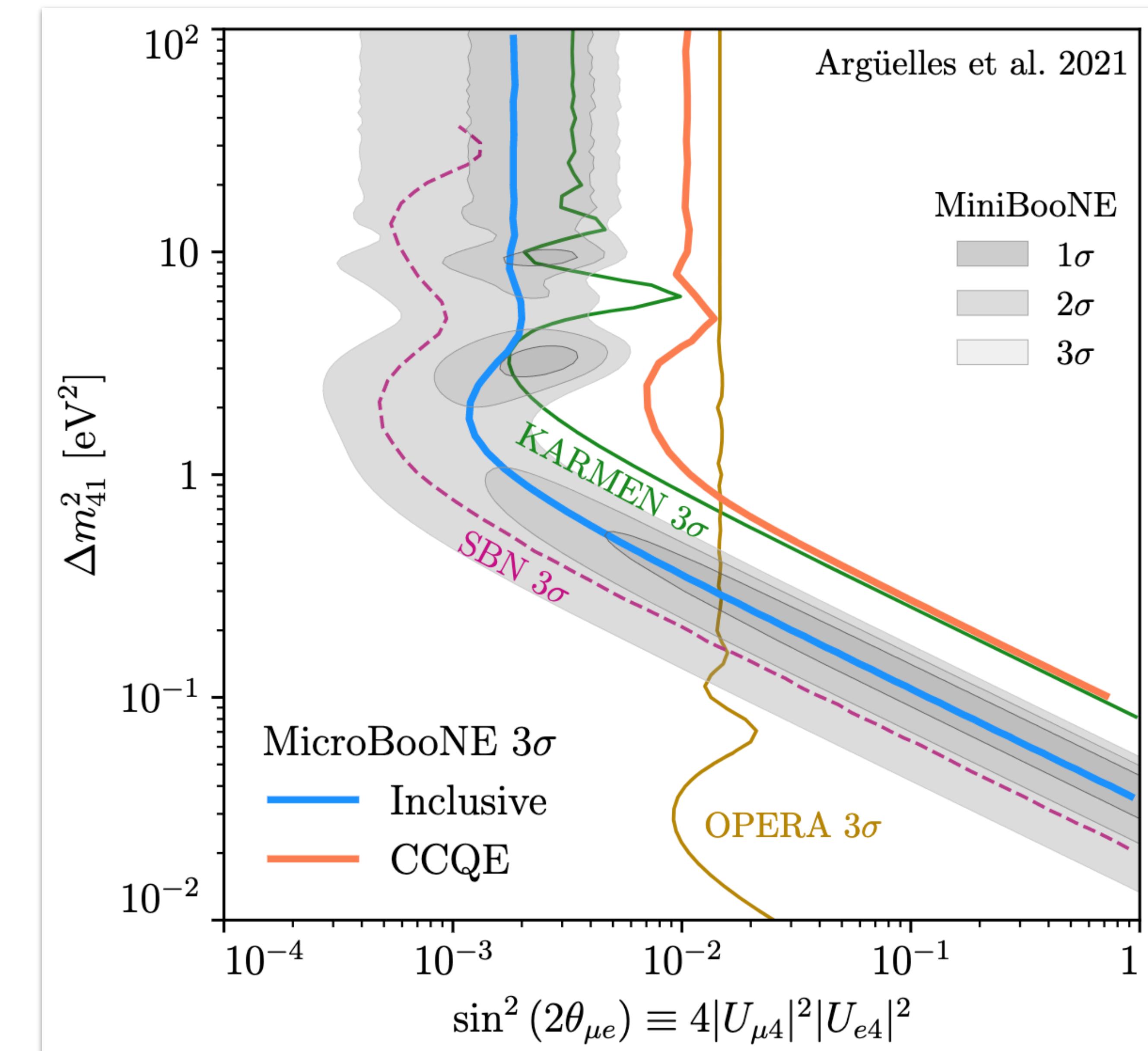
Argüelles et al, [2111.10359]



Four-Flavor, Appearance

[2111.10359]

Profiling over unseen mixing angle,
how does sensitivity change?

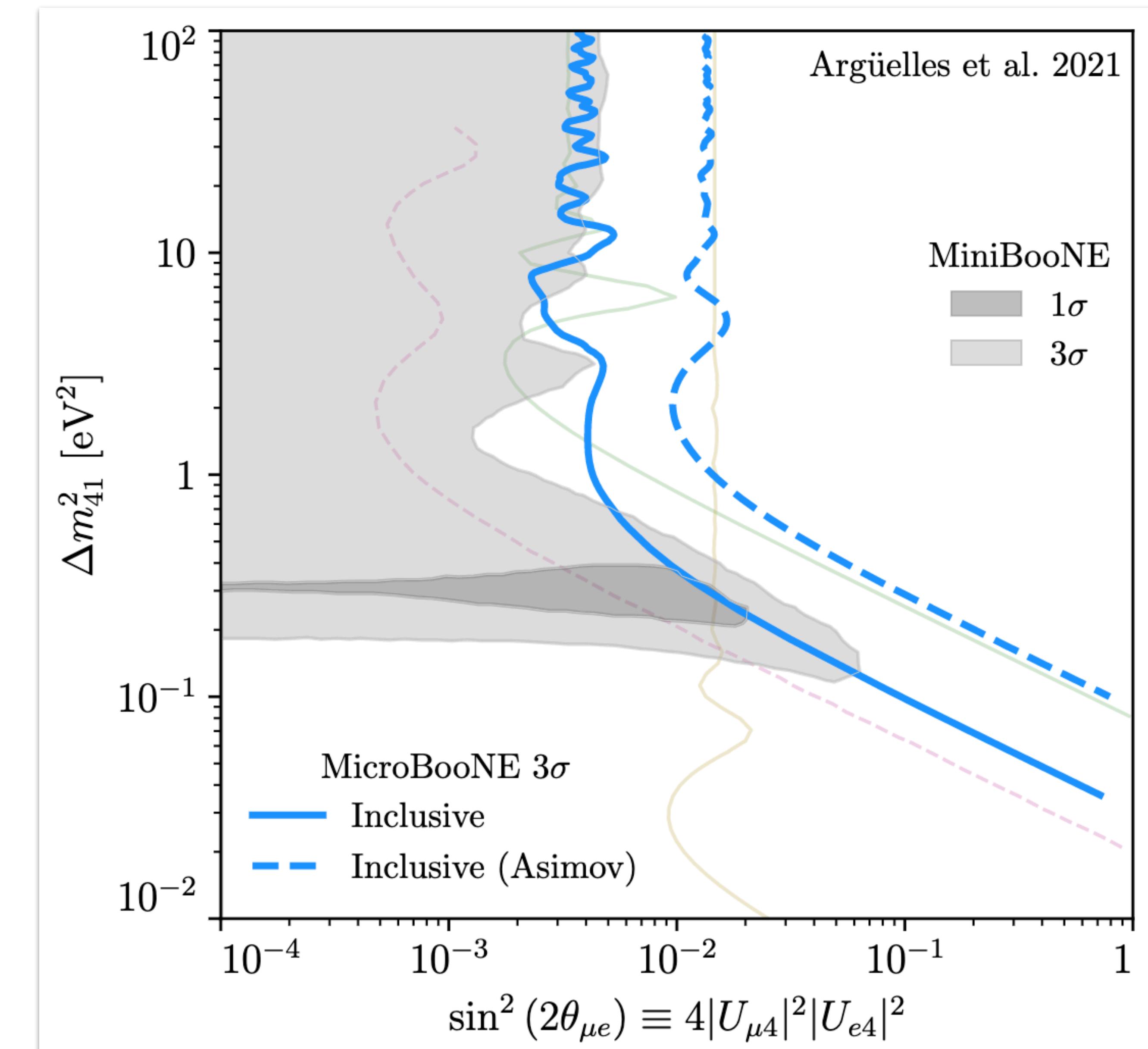


Four-Flavor, Appearance

[2111.10359]

**Profiling over unseen mixing angle,
how does sensitivity change?**

For better or worse, opens up parameter space for consistency between MiniBooNE and MicroBooNE – the MiniBooNE anomaly persists...



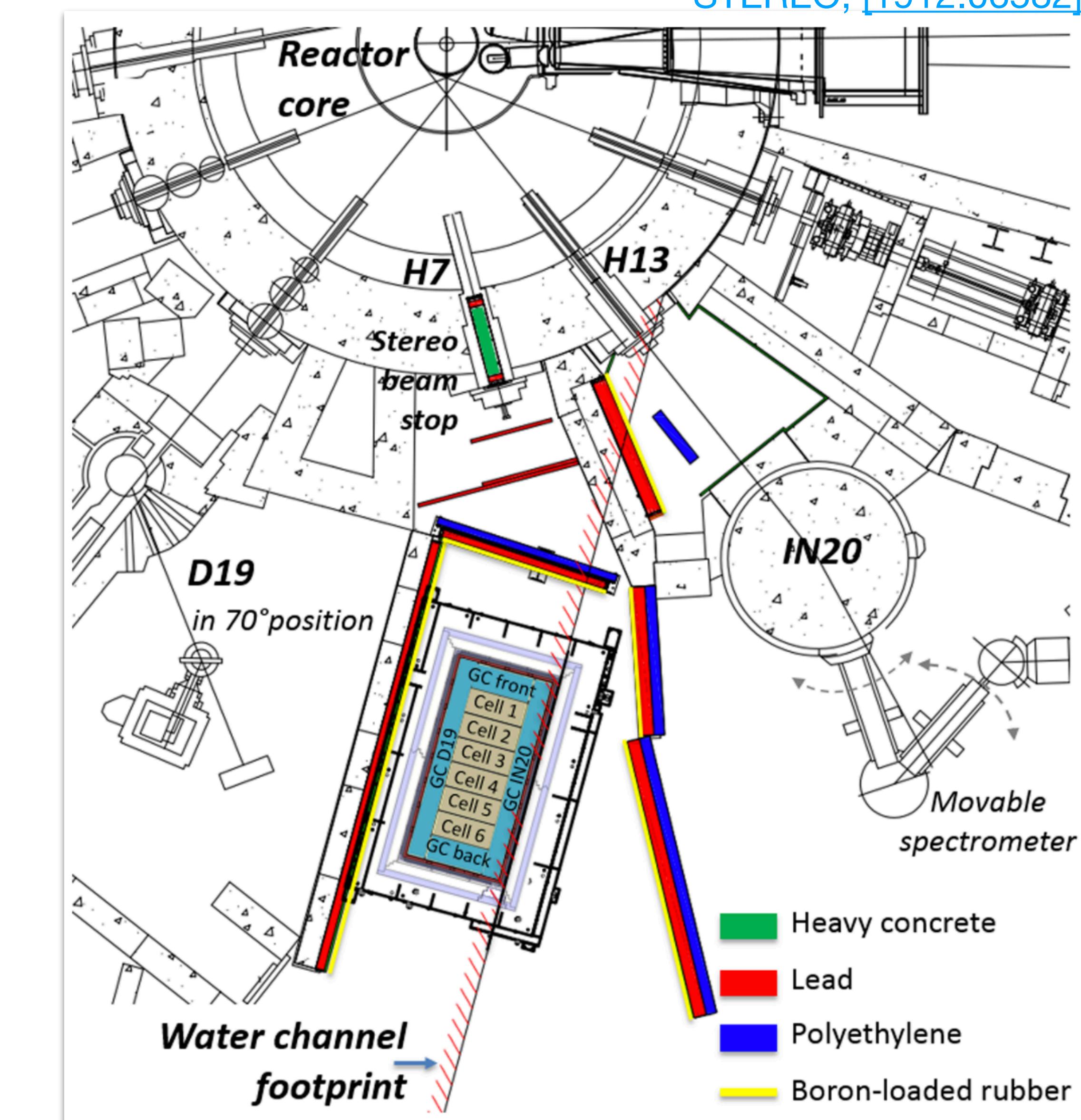
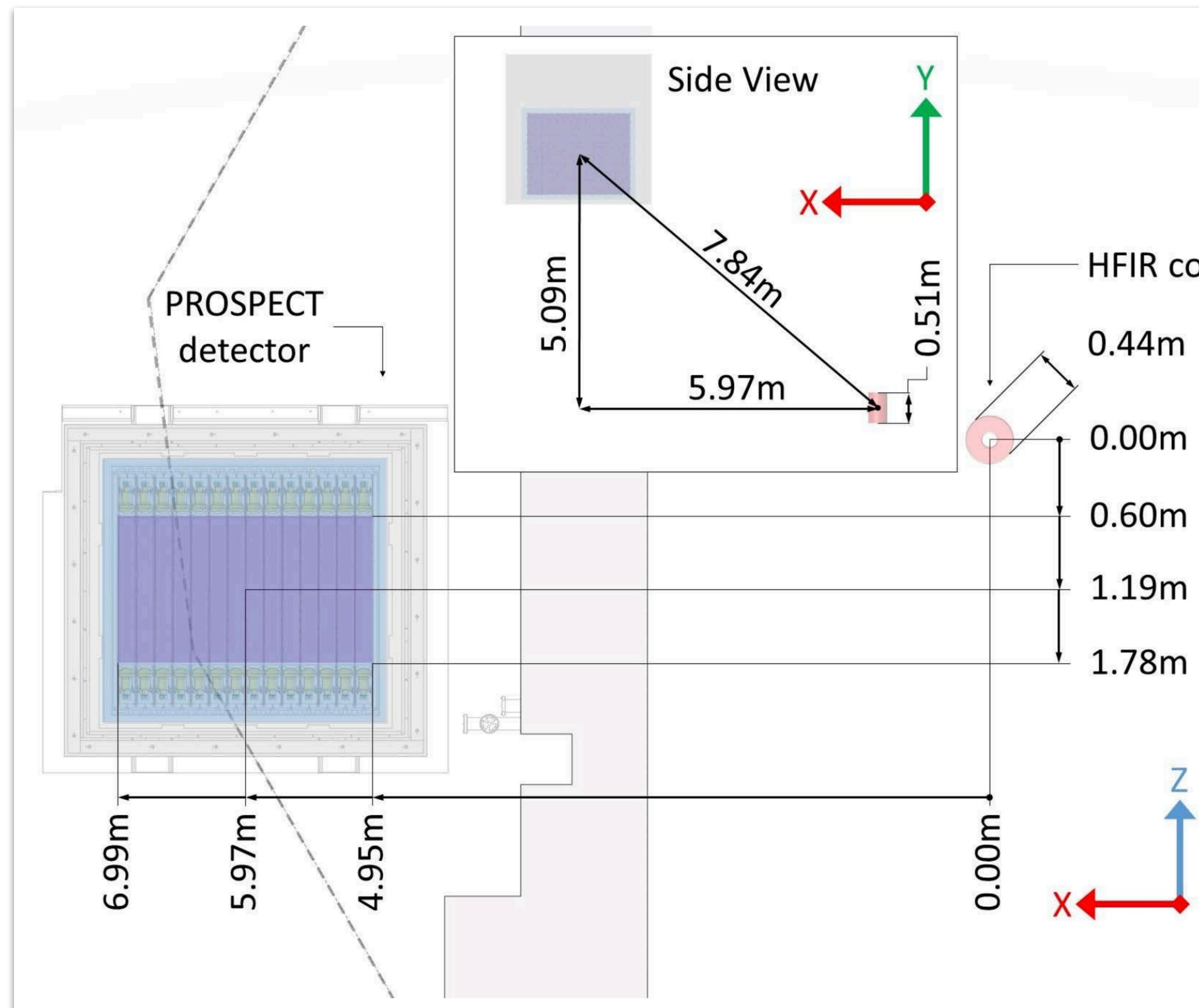
Recent Experimental Results

– Reactor Antineutrinos

PROSPECT, STEREO

[STEREO, \[1912.06582\]](#)

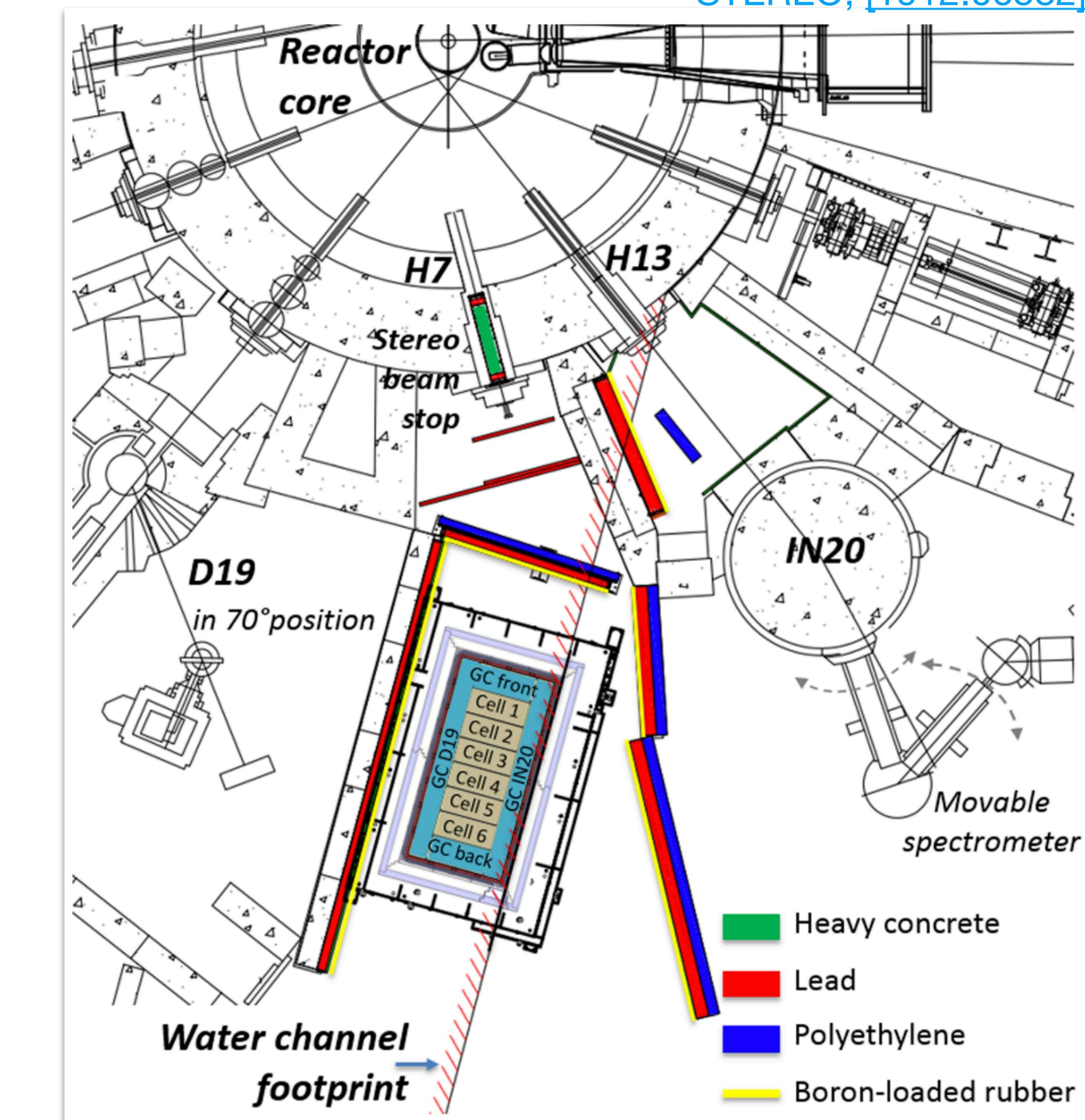
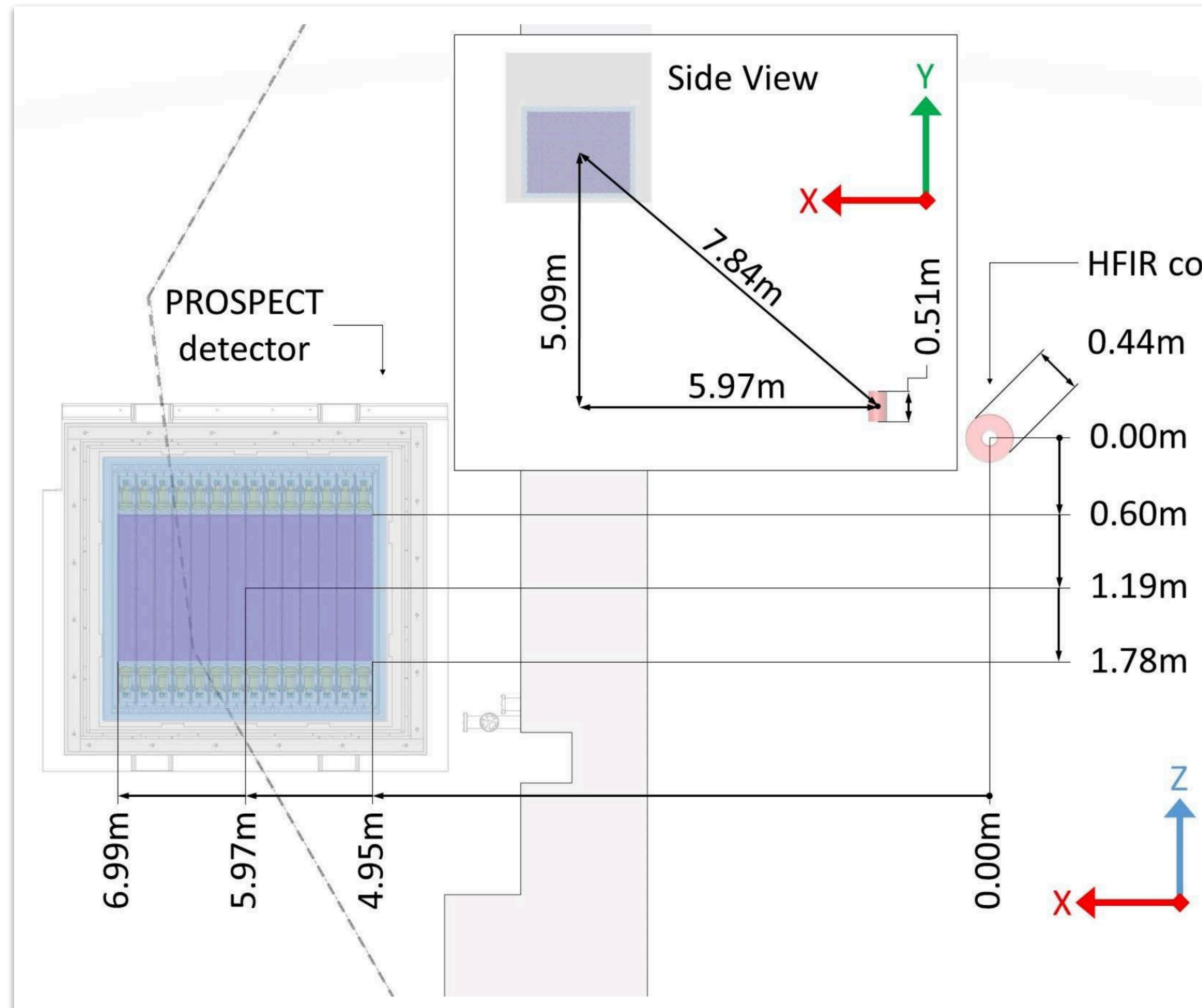
[PROSPECT, \[2006.11210\]](#)



PROSPECT, STEREO

STEREO, [1912.06582]

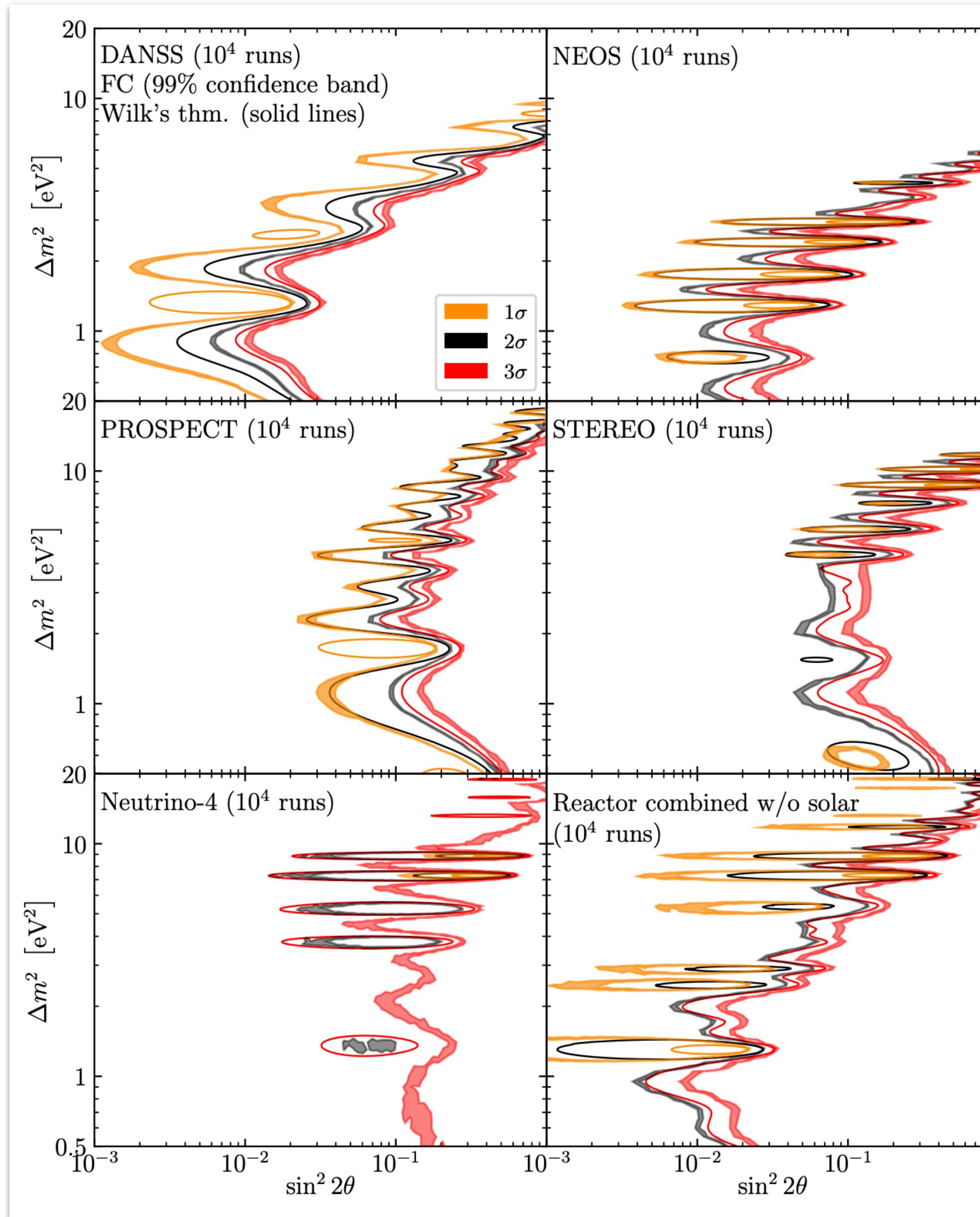
PROSPECT, [2006.11210]



No significant deviations from expectations...

Feldman-Cousins Corrections

See also Giunti et al [2101.06785]

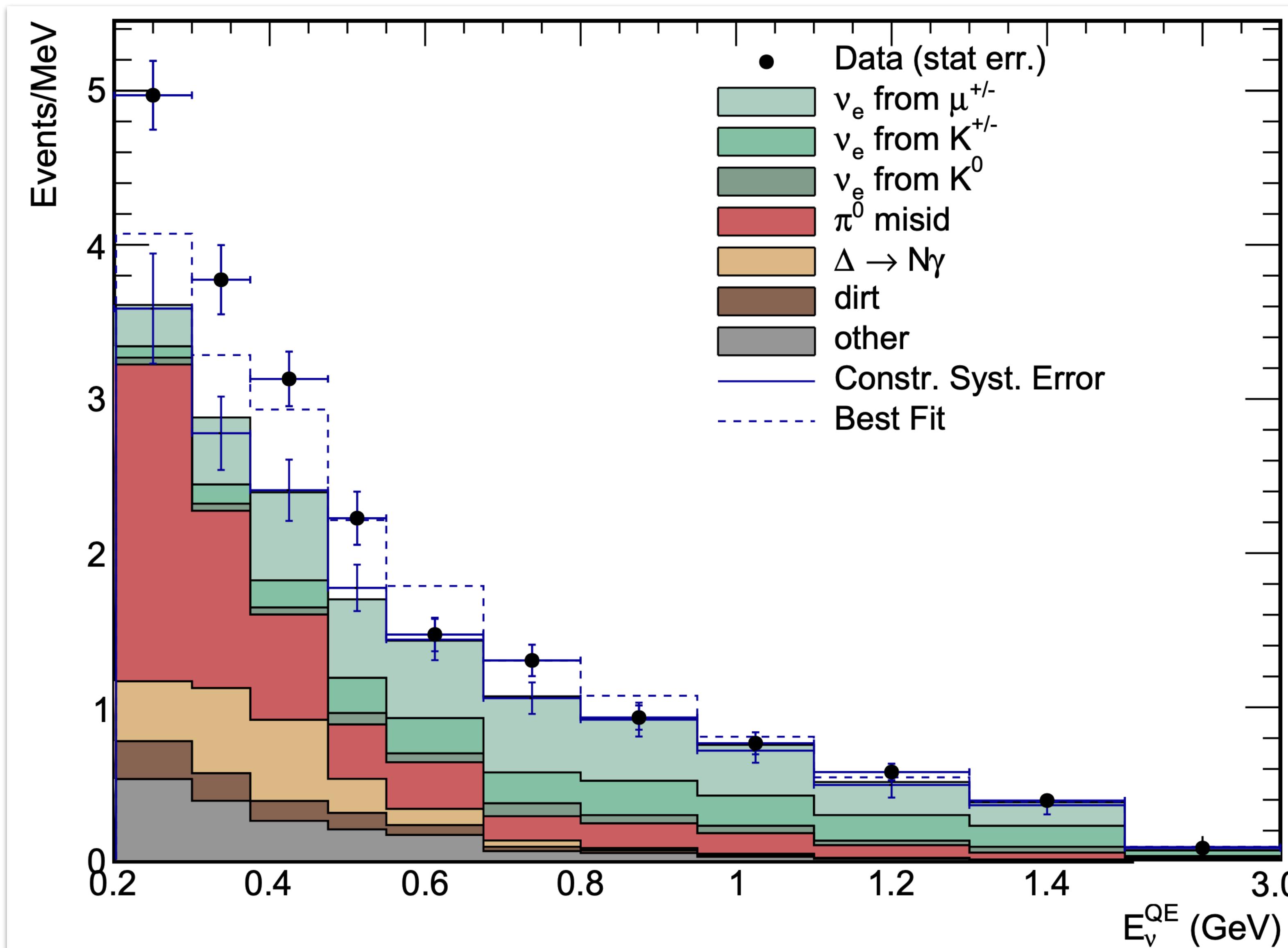


Short-baseline reactor antineutrino experiments are searching for a small-amplitude, high-frequency oscillation on top of a large rate. This situation leads to many statistical difficulties which must be taken into account. Feldman-Cousins corrections of test-statistics are crucial for interpreting significances.

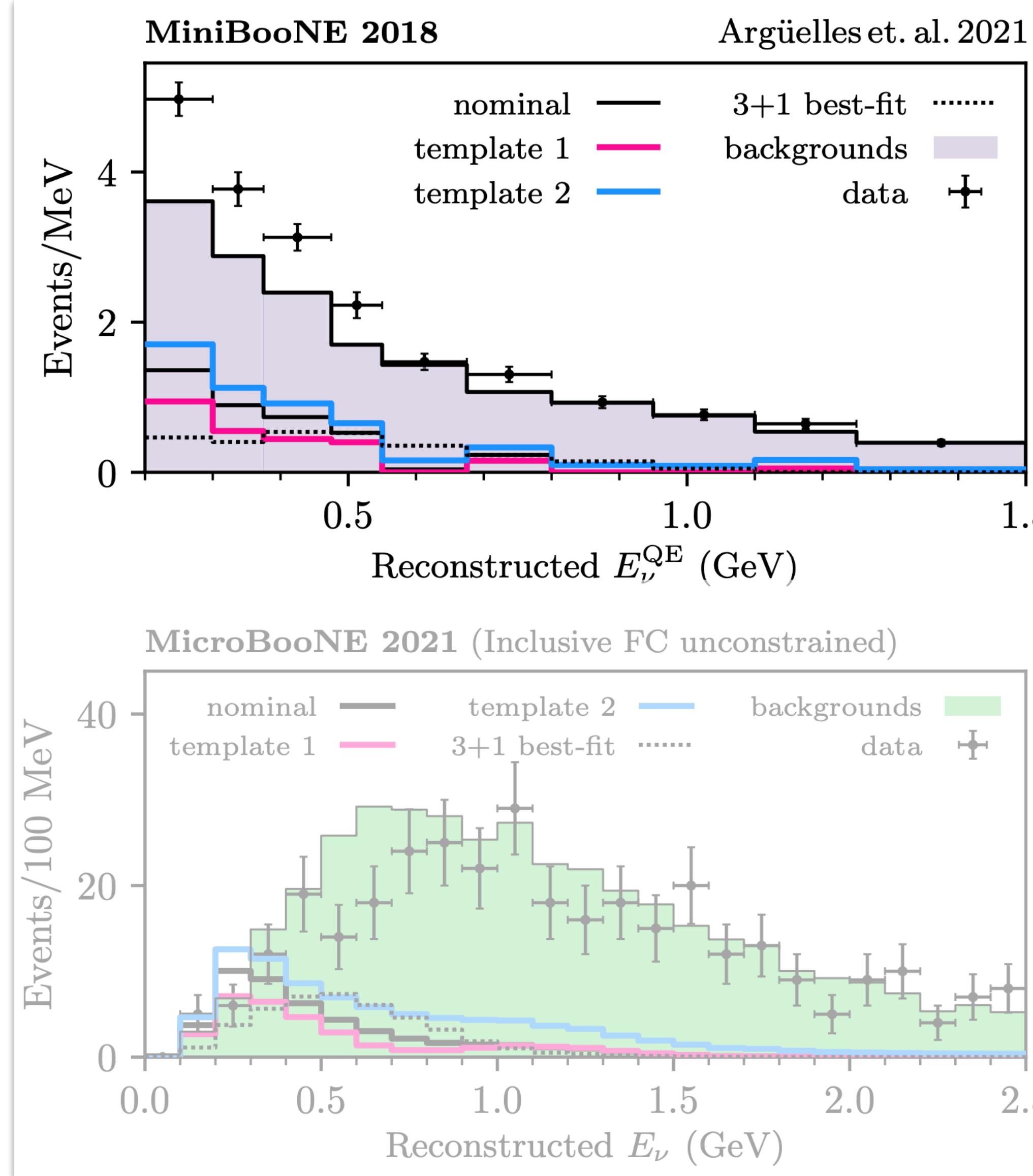
Beyond Sterile Neutrinos

Other Electron-Neutrino Explanations?

Electron-like events in MiniBooNE

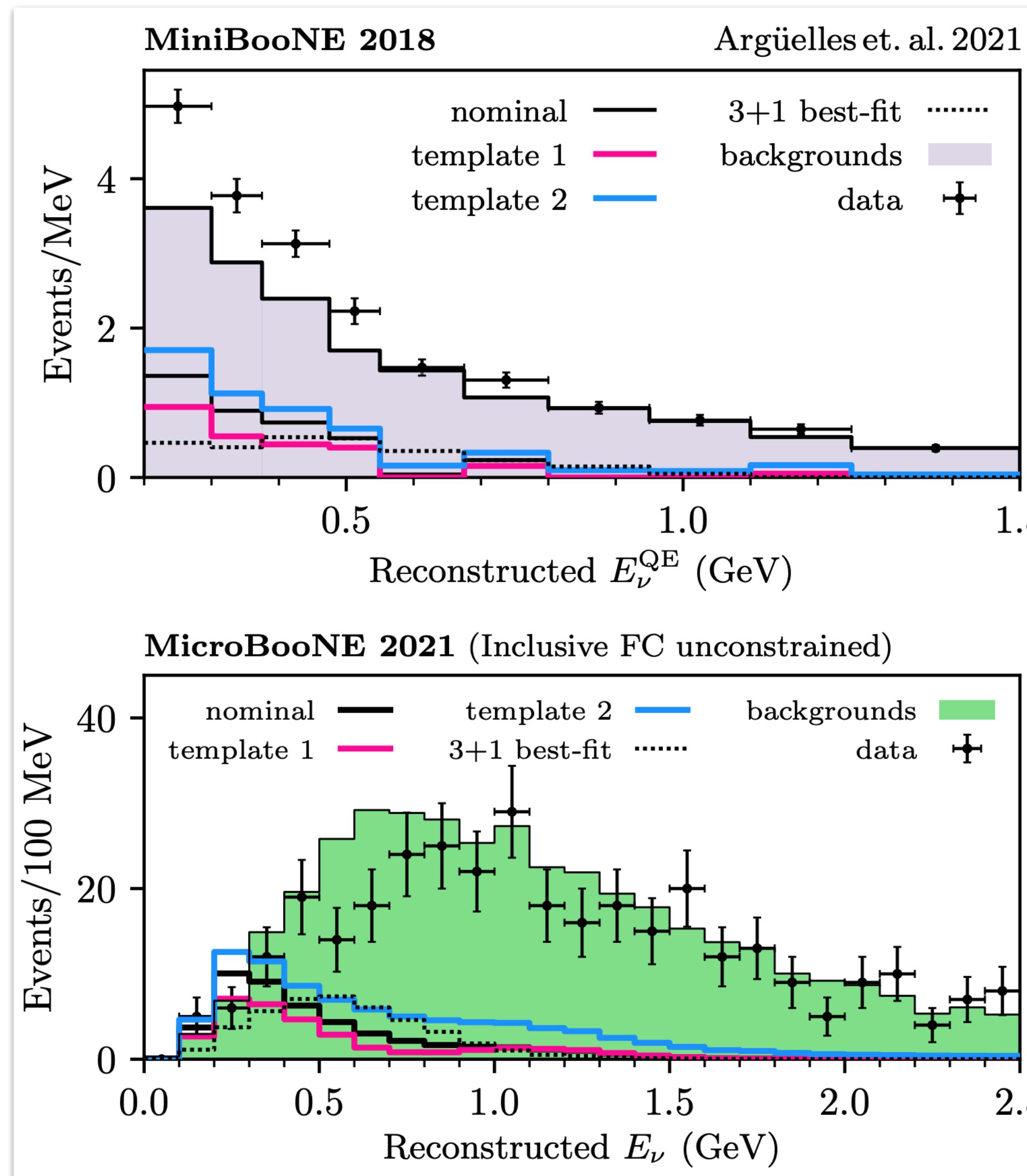


“Good” Templates for MiniBooNE, in MicroBooNE?



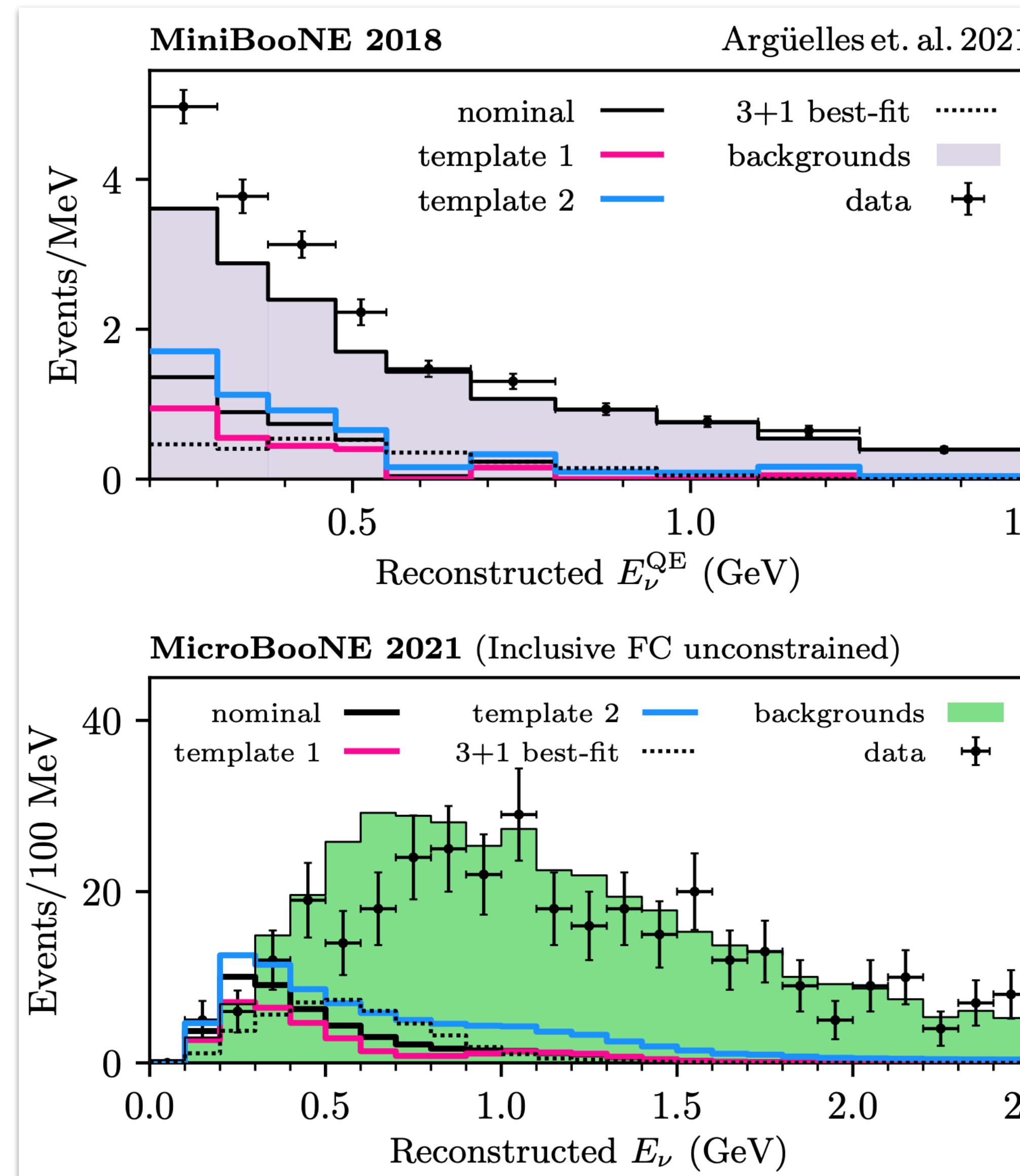
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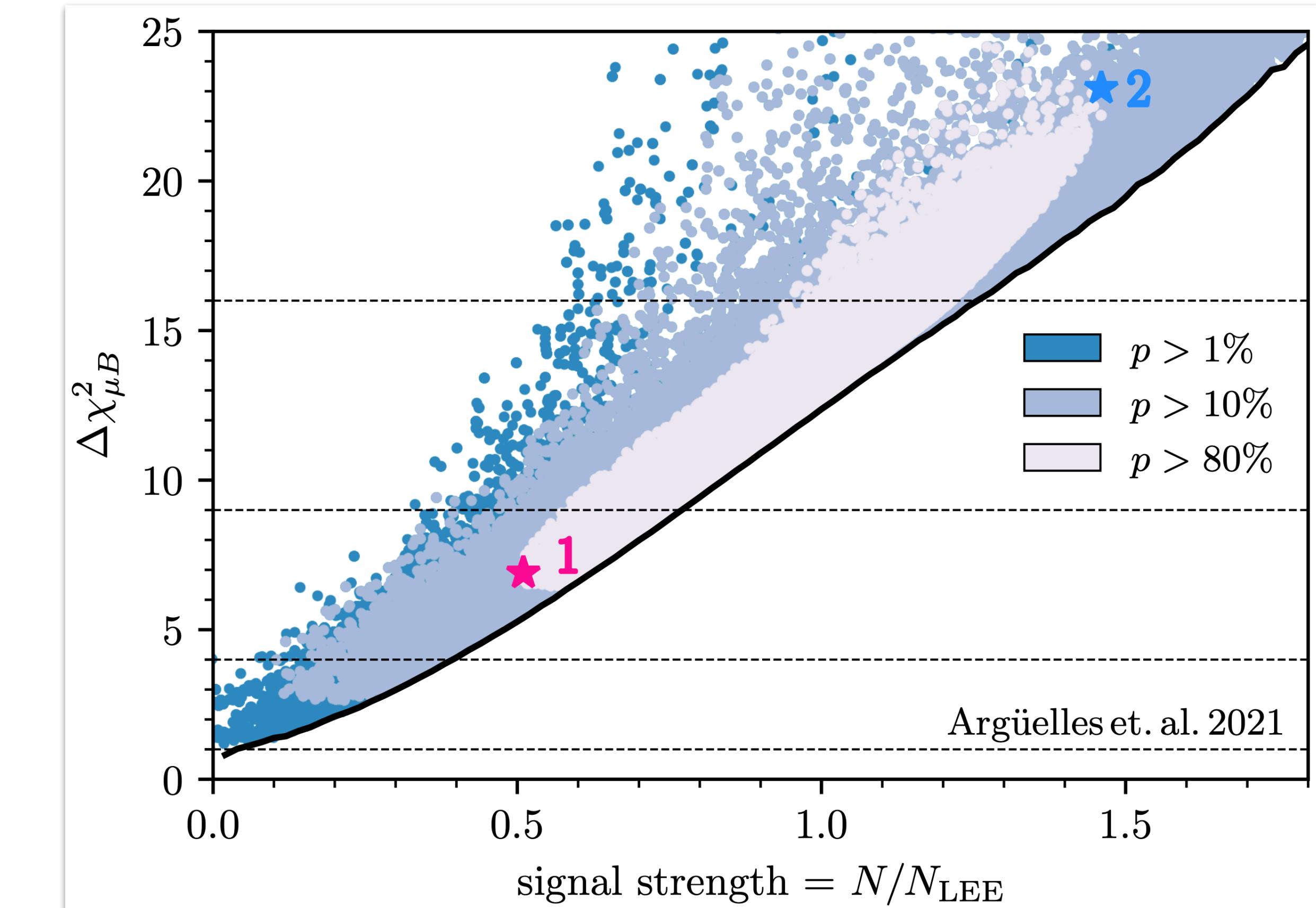


[2111.10359]

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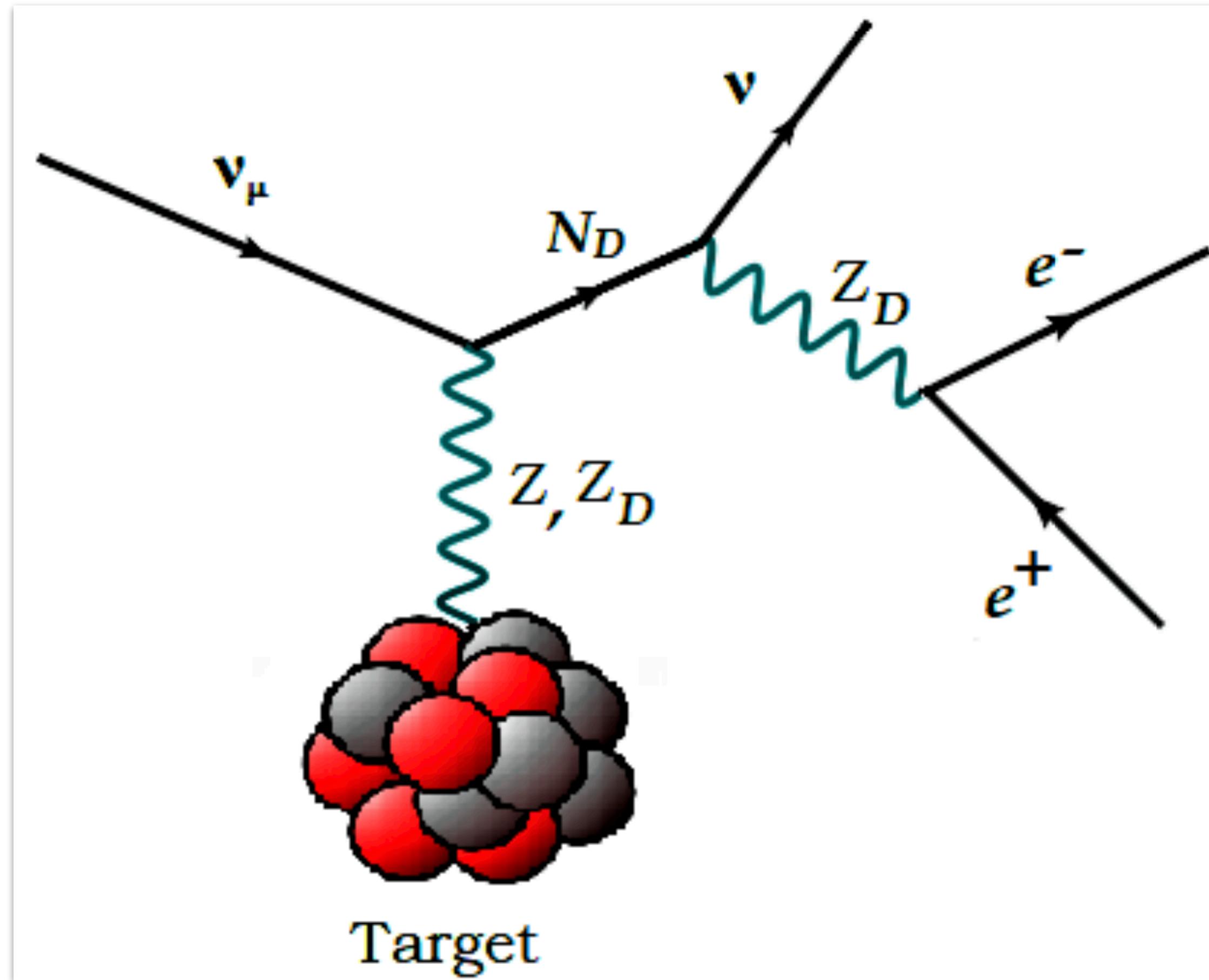
[2111.10359]



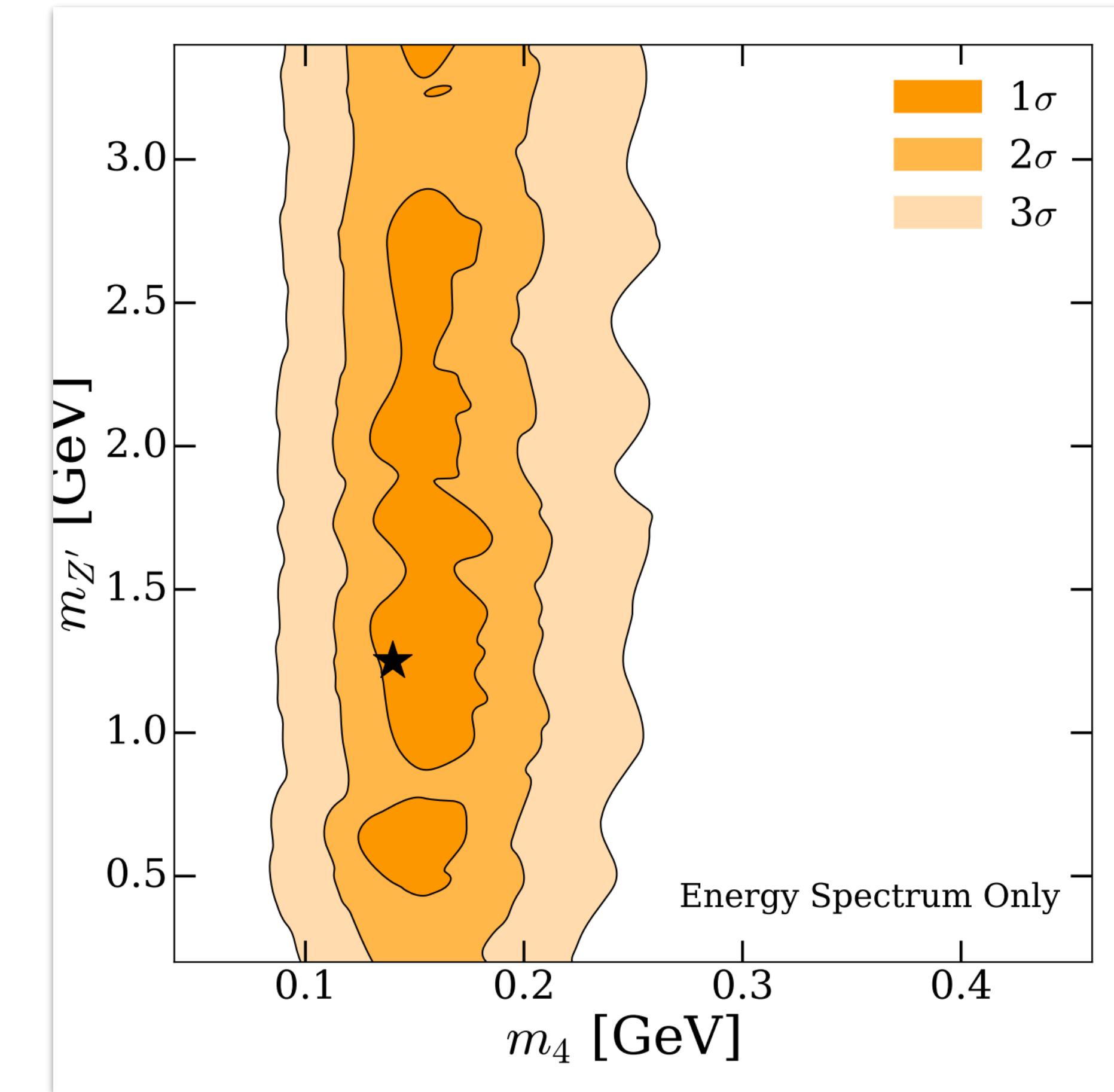
- Plenty of templates that fit MiniBooNE well that MicroBooNE hasn't (yet) ruled out significantly — are any of these spectra predicted in a new-physics model?

“Dark” Neutrinos

Bertuzzo et al [1807.09877]



Ballett et al [1808.02915]



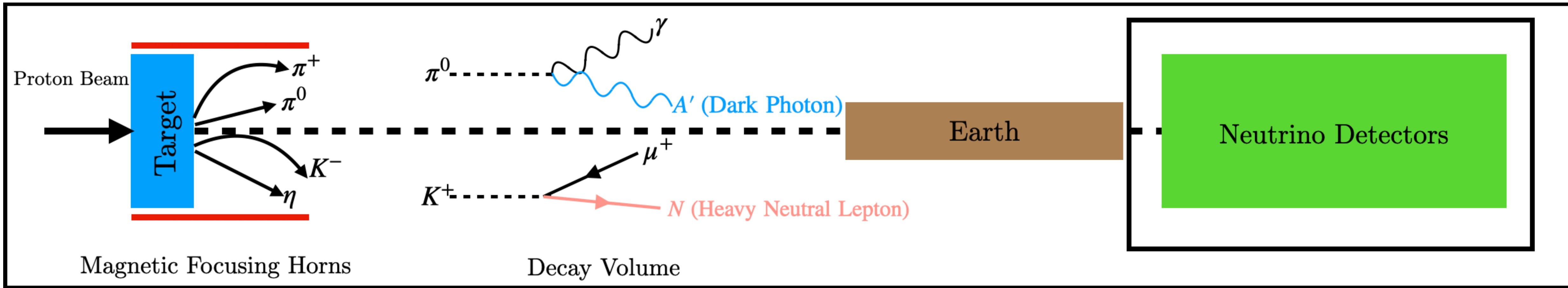
Idea: MiniBooNE is actually observing *di-electron* signals from new-physics contributions and can't tell this apart from a standard electron-neutrino signature. Logical next-step test for MicroBooNE after their single-photon and single-electron analyses.

Neutrino Facilities as Beam-Dumps

Beyond searching for explanations of the MiniBooNE + LSND excesses, upcoming neutrino near-detector facilities are excellent places to search for new-physics processes, if thought of as beam-dump facilities.

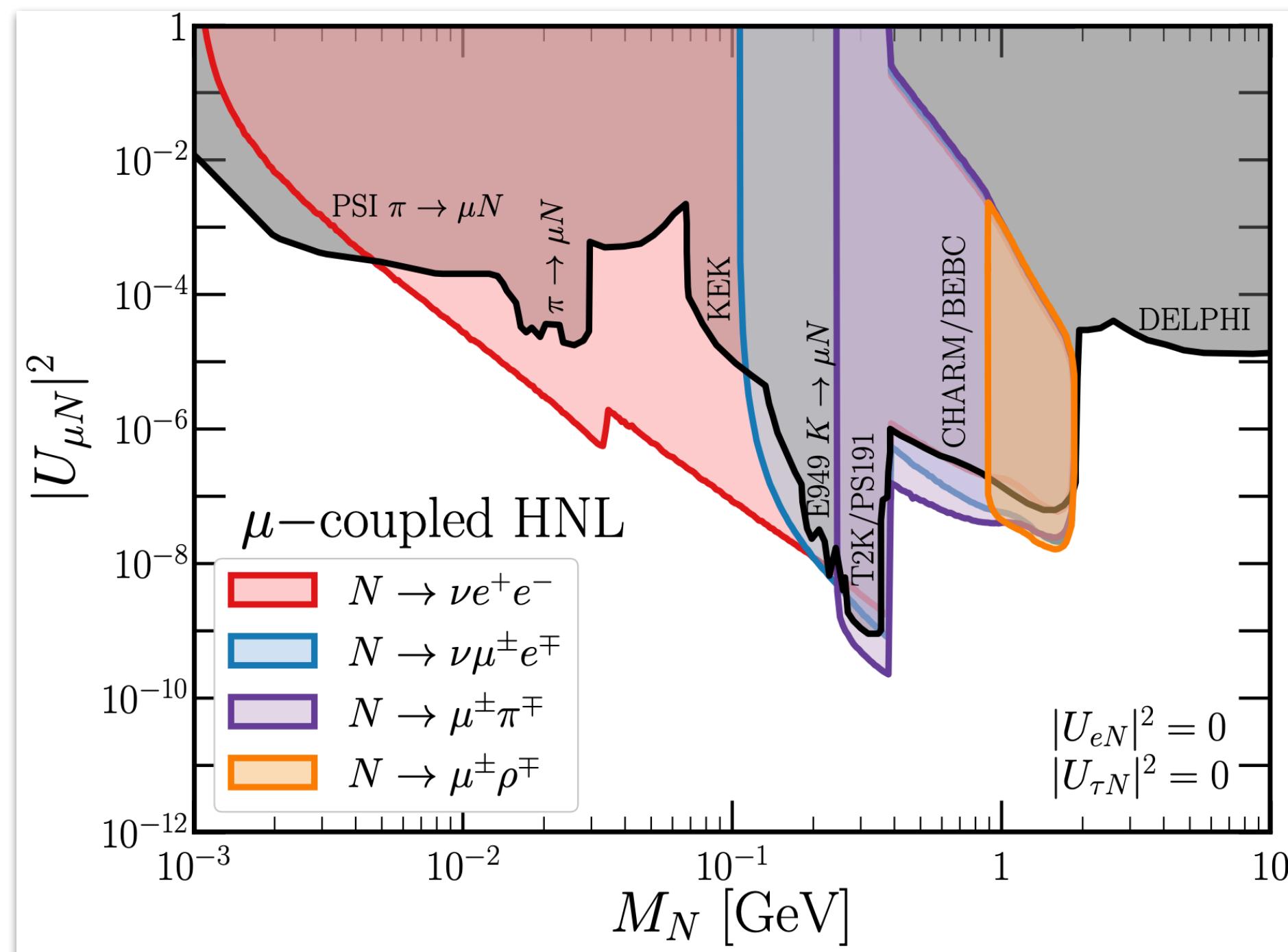
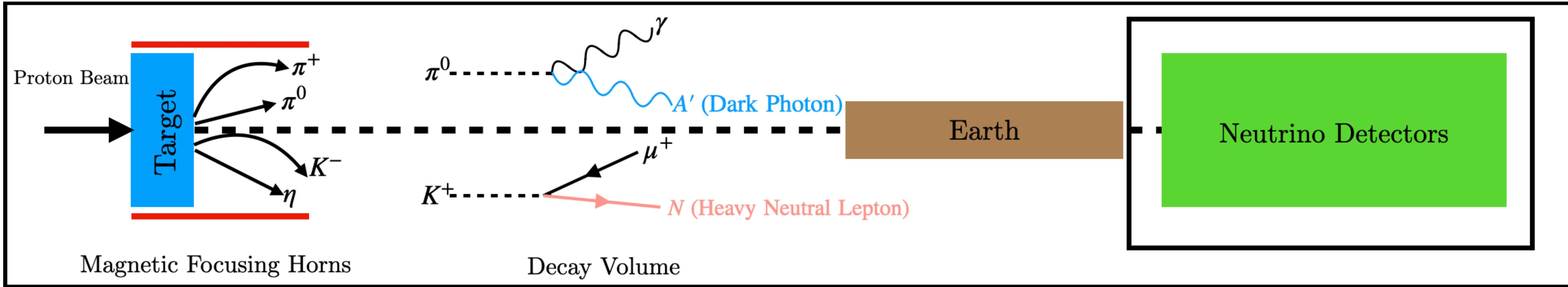
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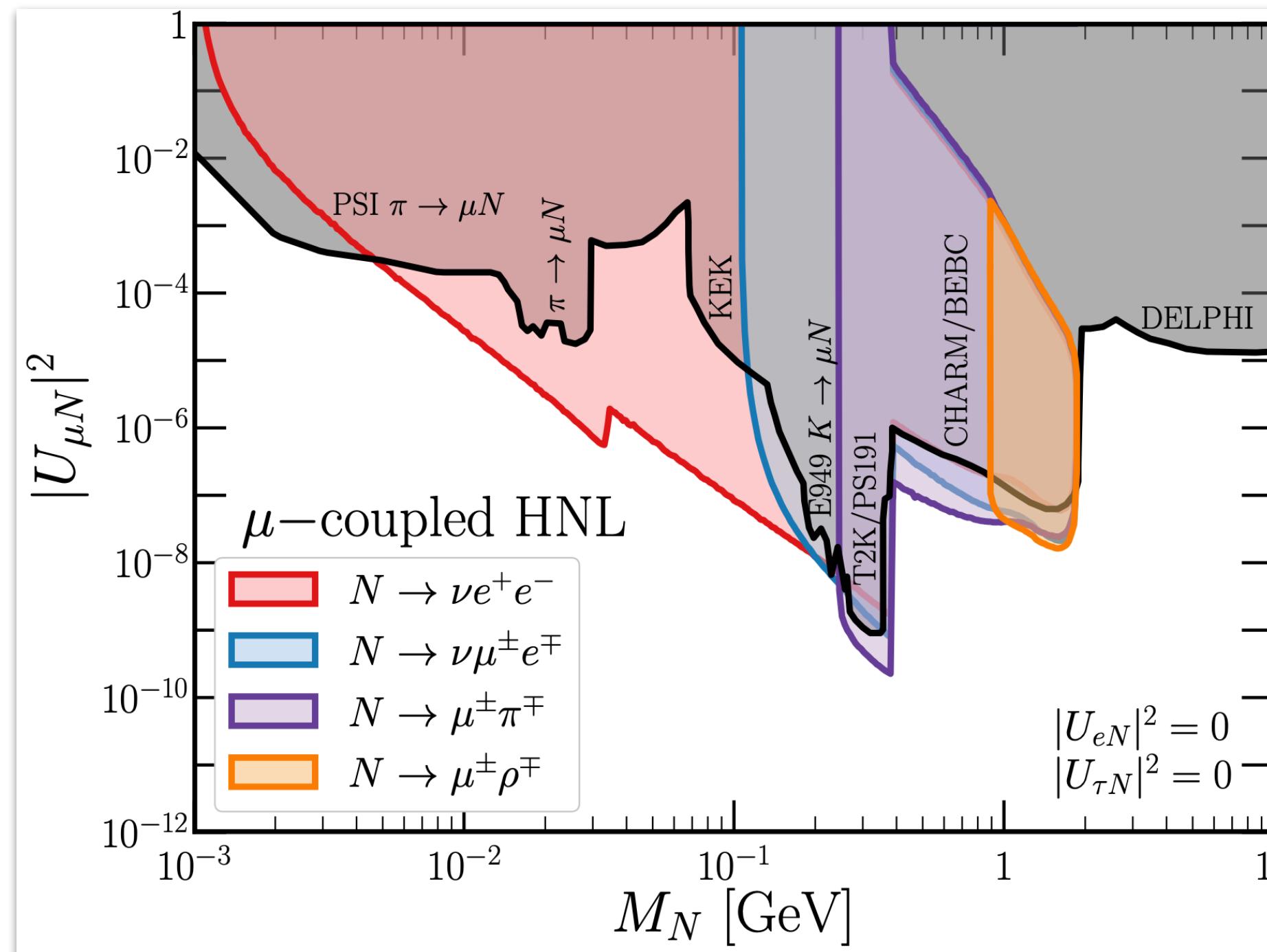
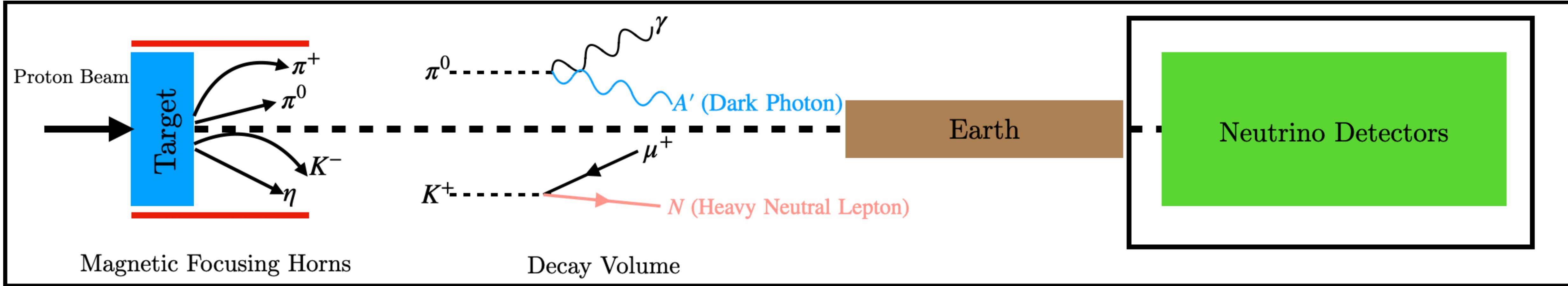
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Types of new-physics that can be tested in this context:

- Heavy Neutral Leptons
- Dark Photons
- Dark Higgs Bosons
- Axions/Axion-Like Particles
- Light Dark Matter scattering
- ...

An *incomplete* list of references, ones including me in blue:

- [1912.07622], [1905.00284], [2007.03701], [2102.03383], [2106.00568],
 [1909.11670], [2106.06548], [2011.05995], [2011.07054], [1903.10505],
 [2108.03262], [2106.04584], [2104.07681], [2106.13684]

Takeaways

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Thank you!