Dark Matter & Neutrinos

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TEXAS A&M UNIVERSITY

What this talk is

- Impressive interplay between dark-matter experiments and neutrino experiments
    - What can we learn about one sector from the other's facilities?

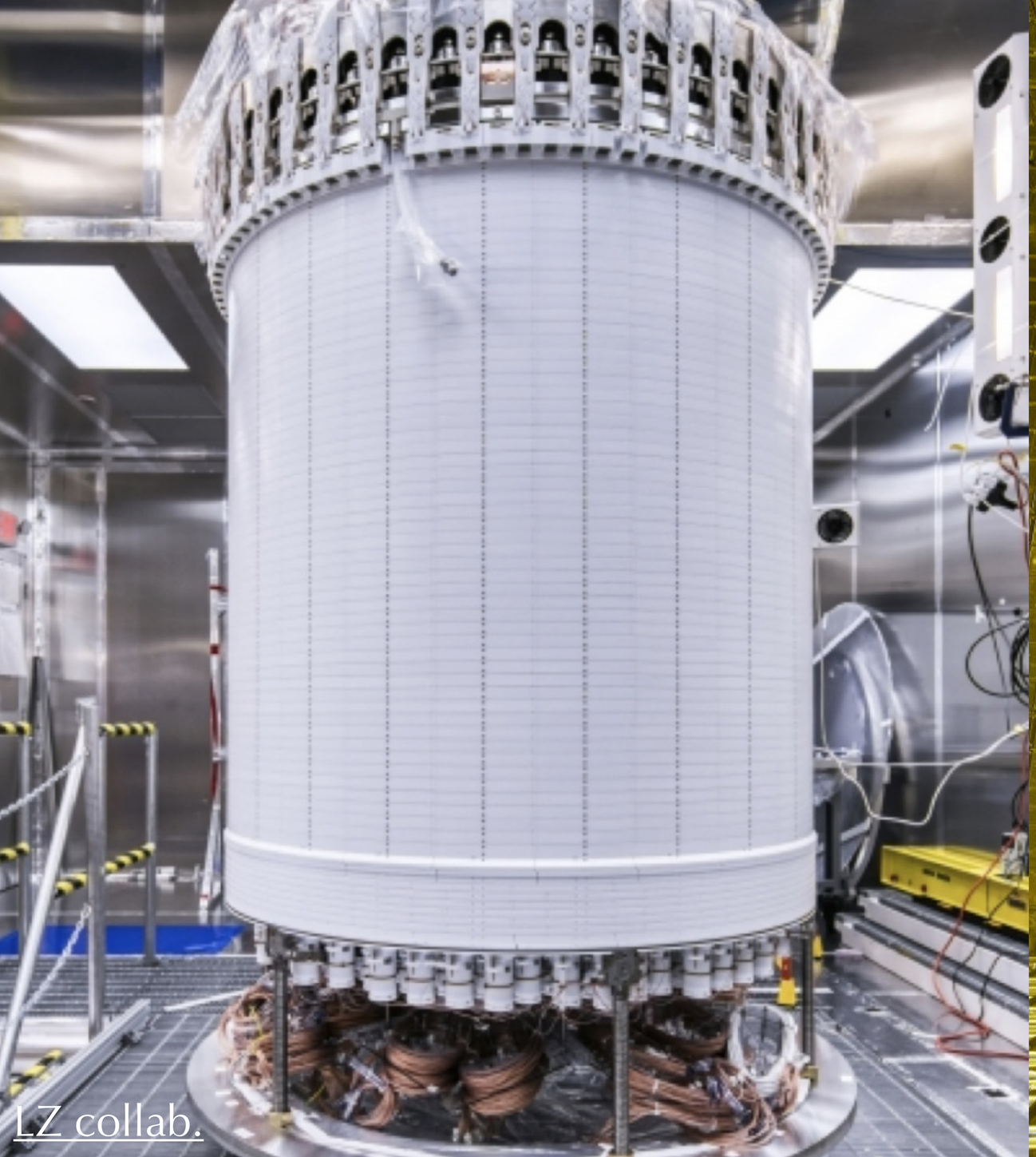
Image credit: Symmetry magazine

What this talk is *not*

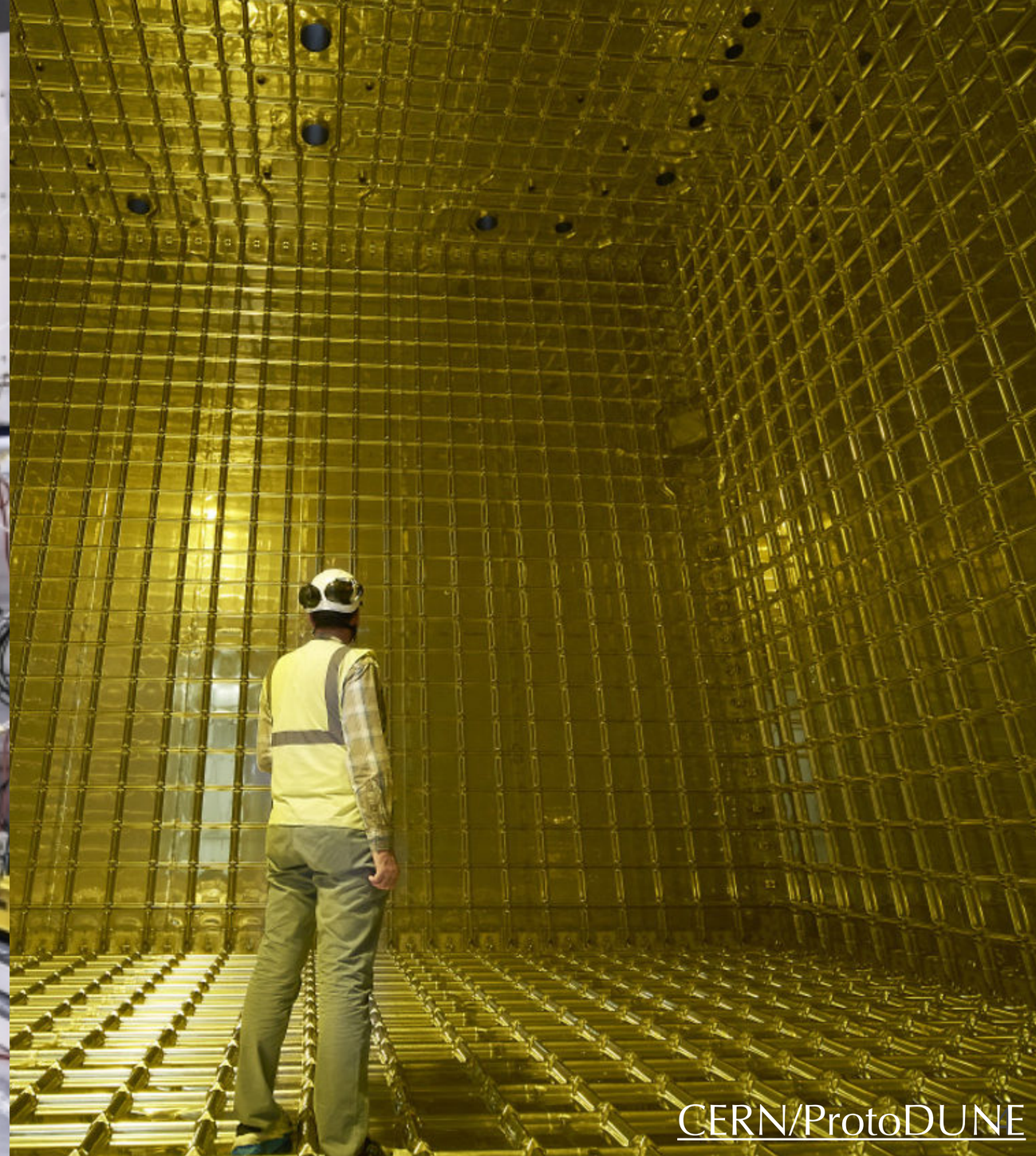
- A discussion of *whether* neutrinos may serve as the observed dark matter in the universe
- An exploration of whether neutrinos and dark matter have nontrivial “BSM” interactions

(see Graciela's talk from yesterday)

Image credit: Symmetry magazine



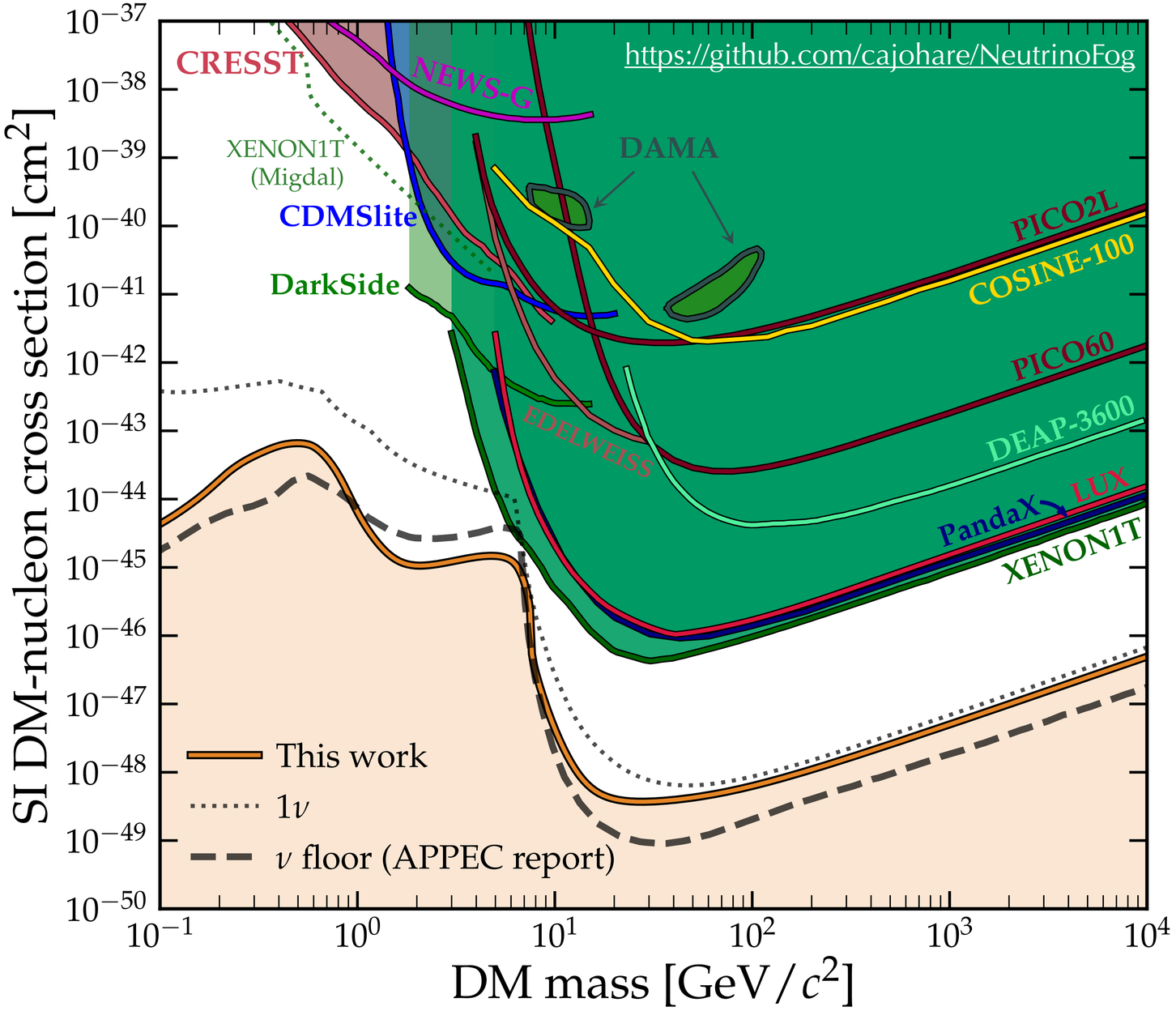
LZ collab.

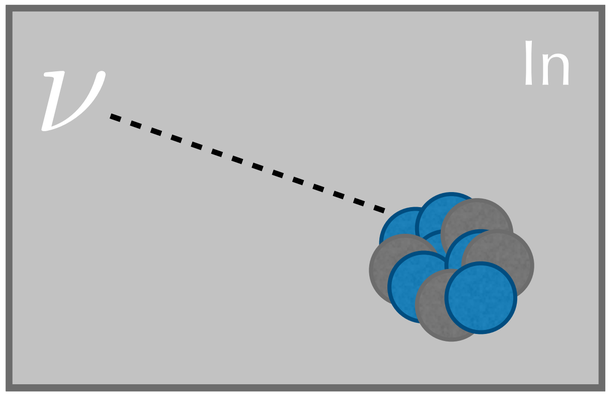


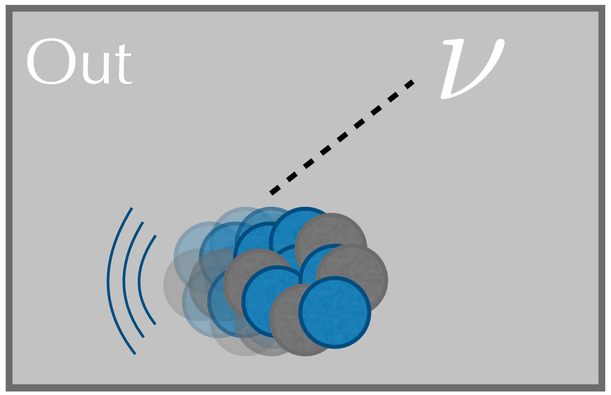
CERN/ProtoDUNE

Dark-Matter Facilities for Neutrino Physics

Enter: The Neutrino Floor

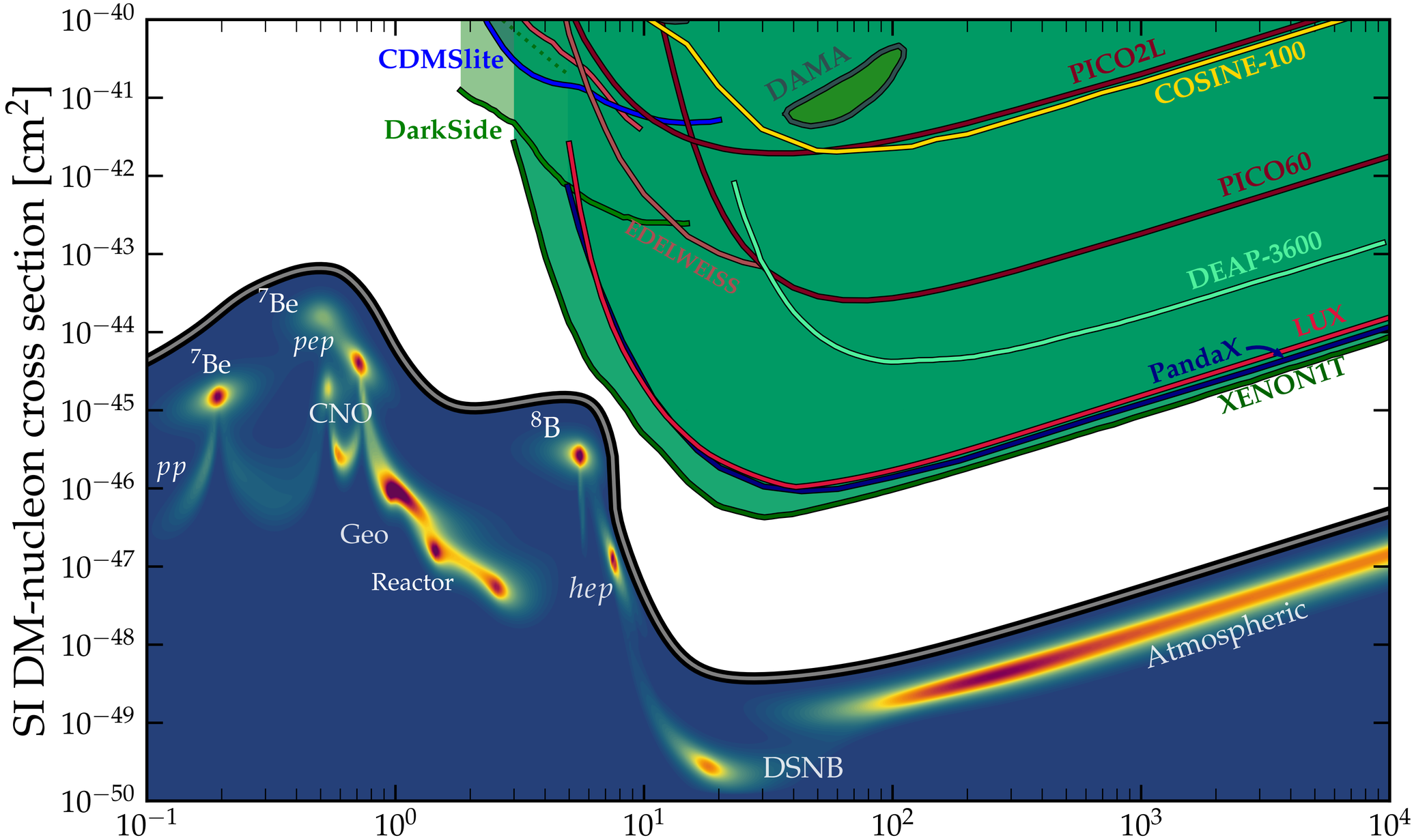






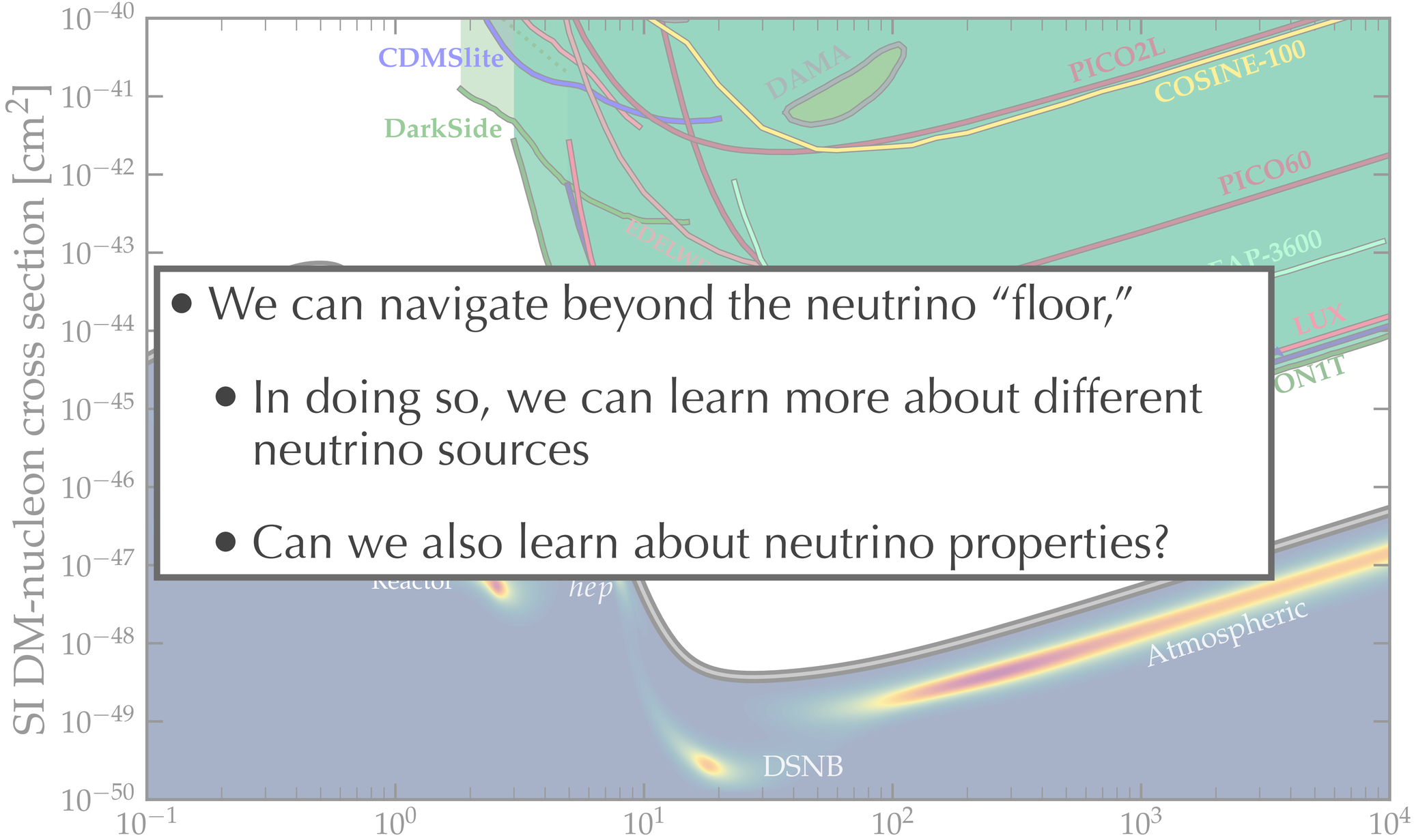
For certain dark-matter masses, neutrino scattering with specific incoming energies looks practically identical

Not a floor, but a fog…



https://github.com/cajohare/NeutrinoFog + [2109.03116]

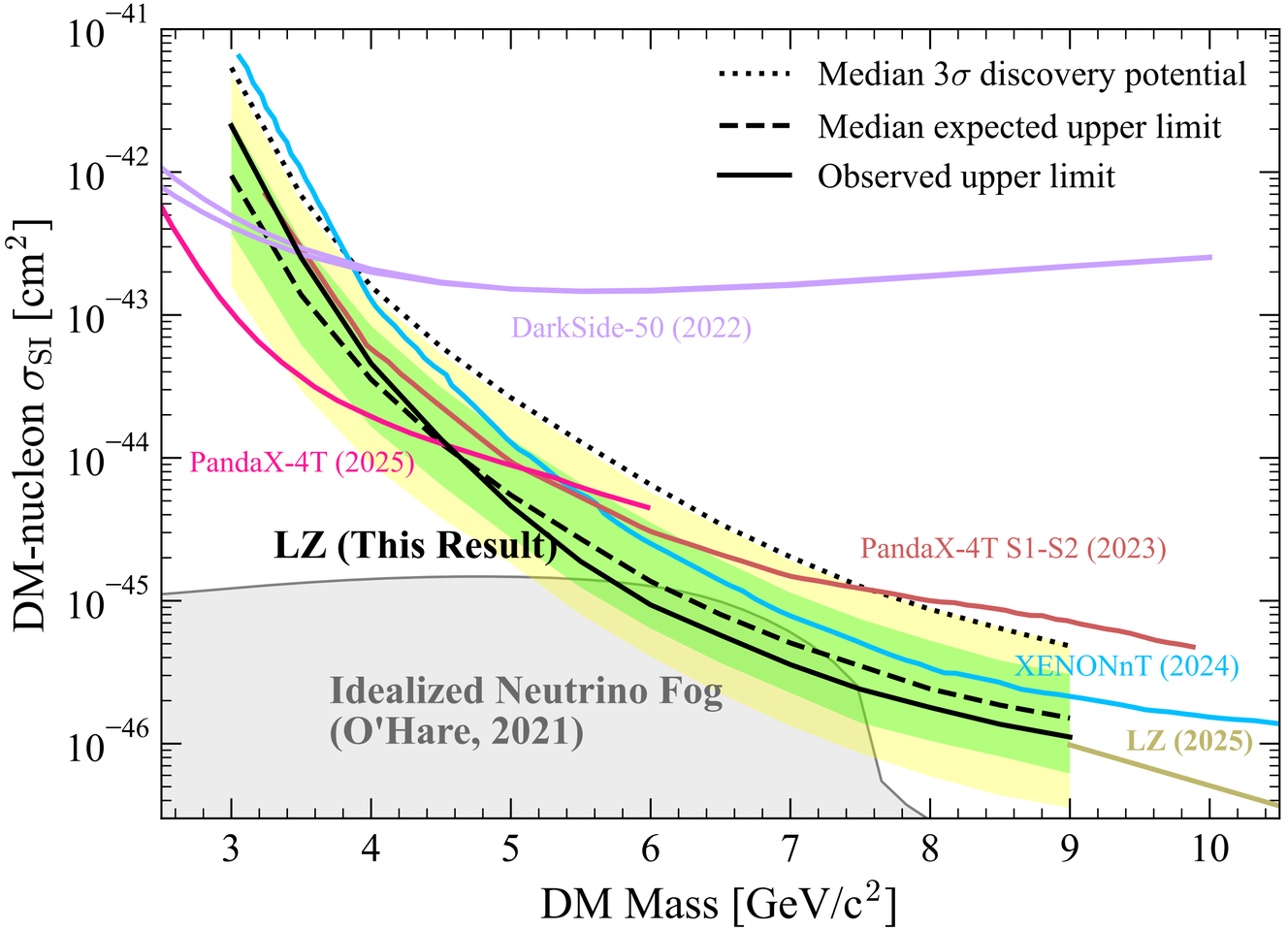
Not a floor, but a fog…

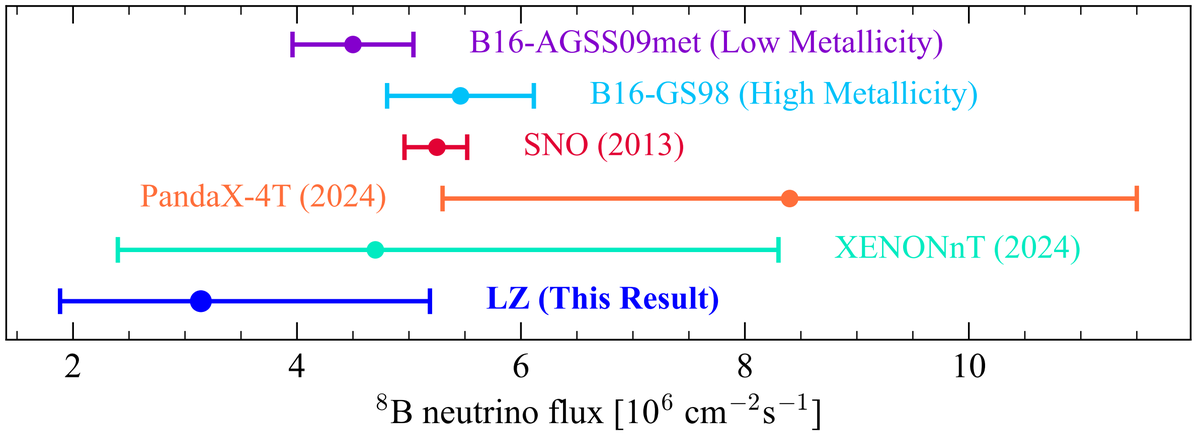


- We can navigate beyond the neutrino “floor,”
  - In doing so, we can learn more about different neutrino sources
  - Can we also learn about neutrino properties?

https://github.com/cajohare/NeutrinoFog + [2109.03116]

Amazing progress on this front!





Plots from LZ Collaboration: [2512.08065]

See also PandaX-4T: [2407.10892], XENONnT: [2408.02877], [2604.06002]

Direct-detection experiments have dived into the fog, specifically that sourced by ^{8}B solar neutrinos

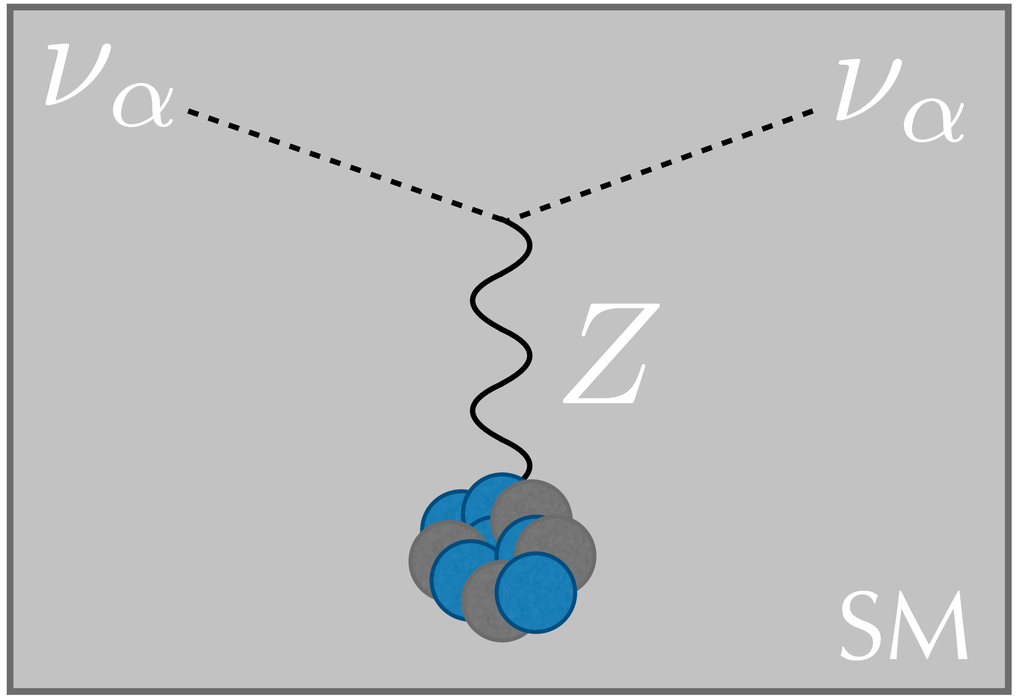
(see also the LZ and PandaX talks from earlier this week)

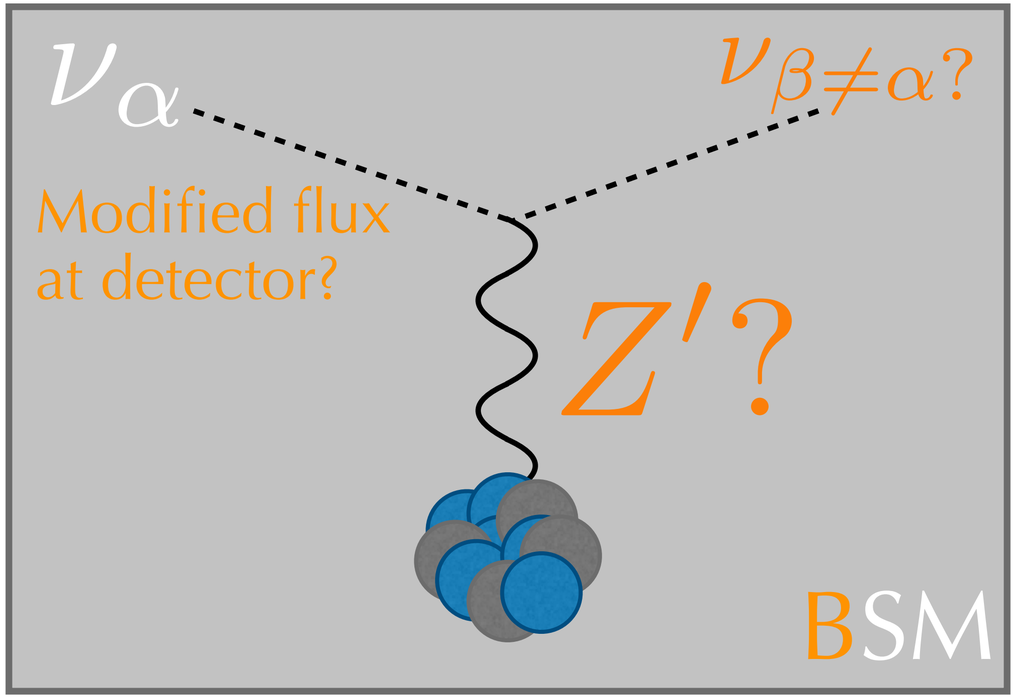
Leveraging for neutrino/BSM physics

Standard Model Prediction for Neutrinos

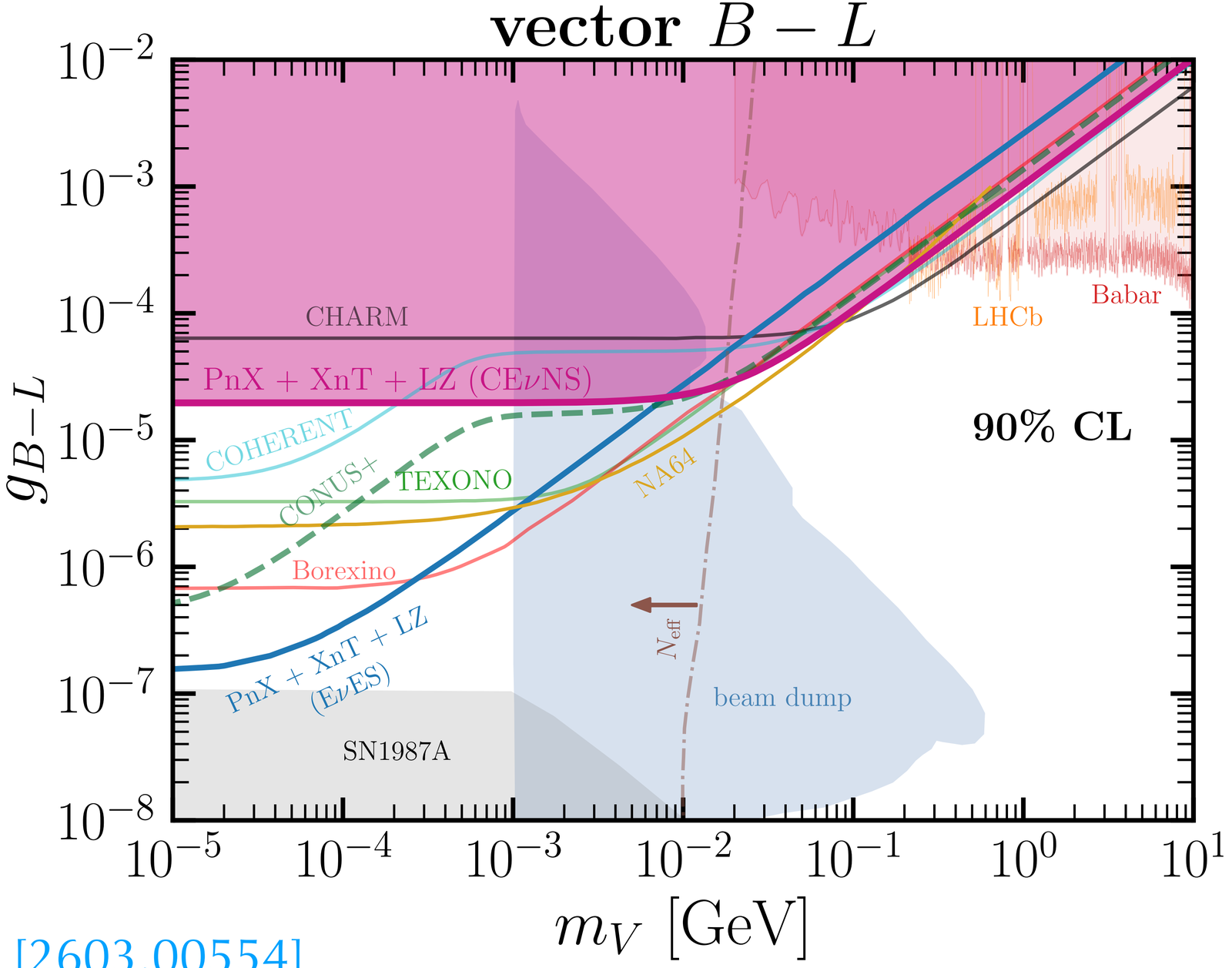
(see Janina's talk from Monday)

- In the SM, solar electron-neutrinos oscillate into muon/tau-neutrinos, depending on energy, mixing parameters, etc.
- CEvNS is (nearly) flavor-blind, governed by neutral-current scattering





Light Mediators with Solar CEvNS



De Romeri et al: [2603.00554]

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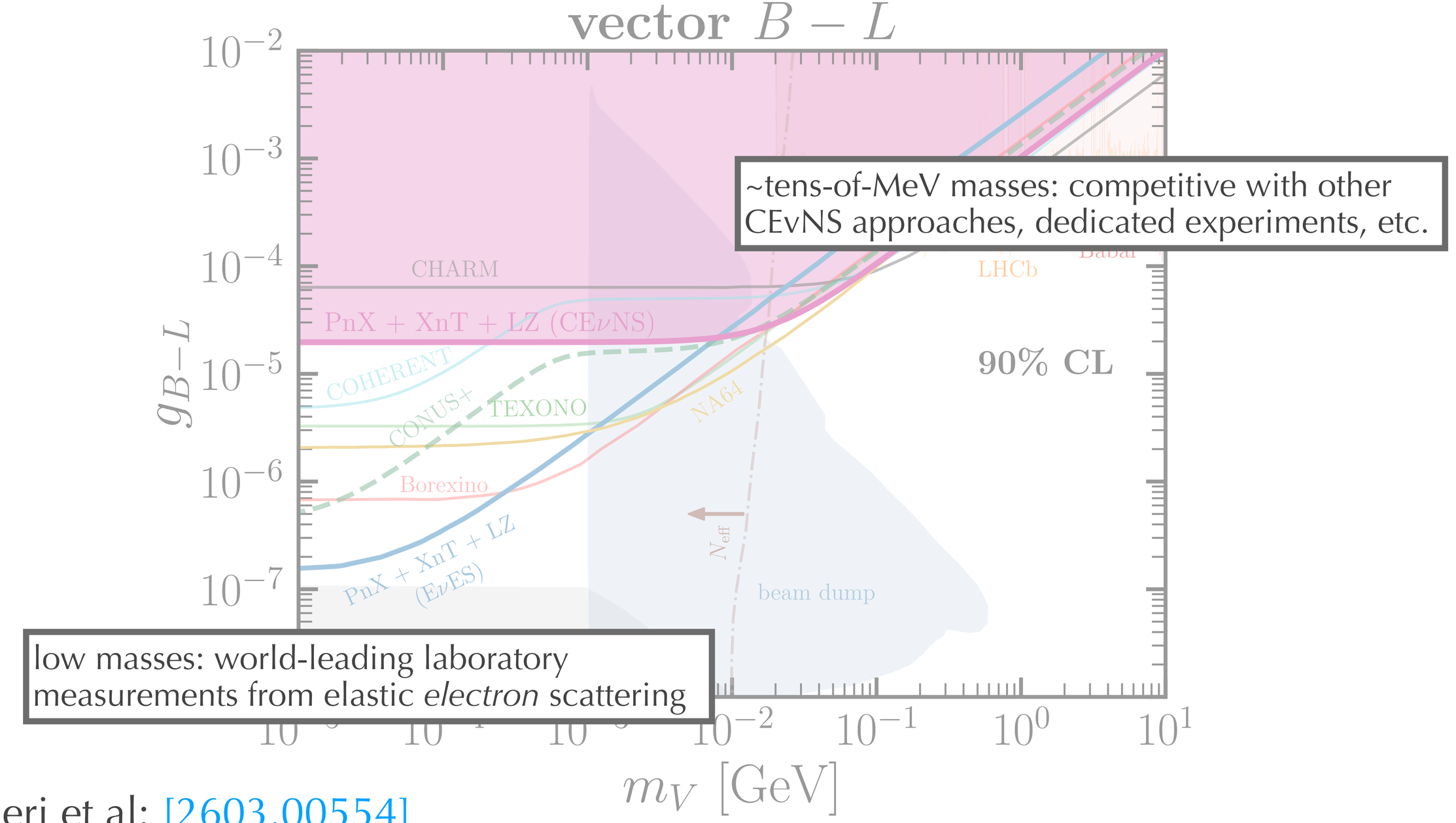


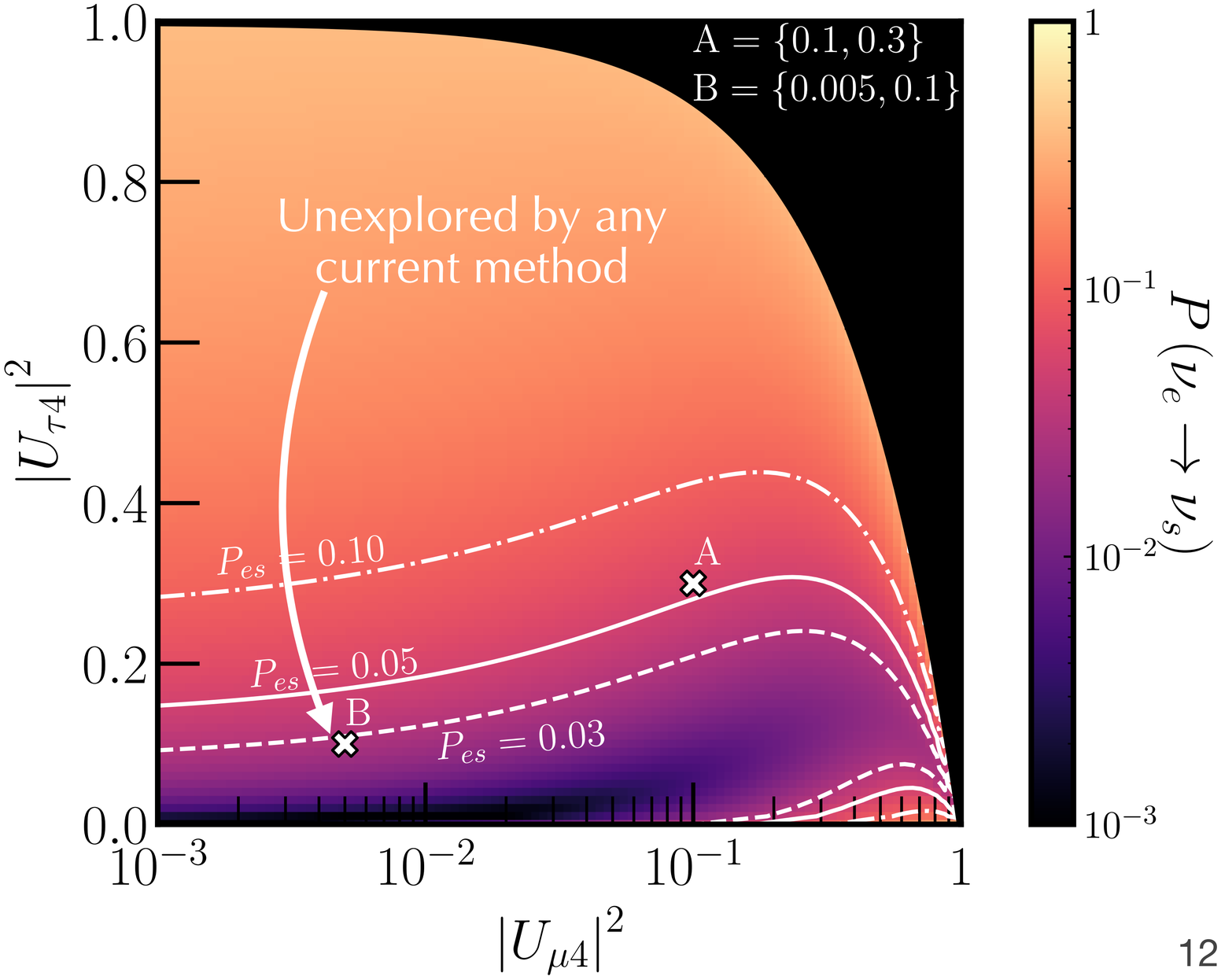
~tens-of-MeV masses: competitive with other CEvNS approaches, dedicated experiments, etc.

low masses: world-leading laboratory measurements from elastic *electron* scattering

De Romeri et al: [2603.00554]

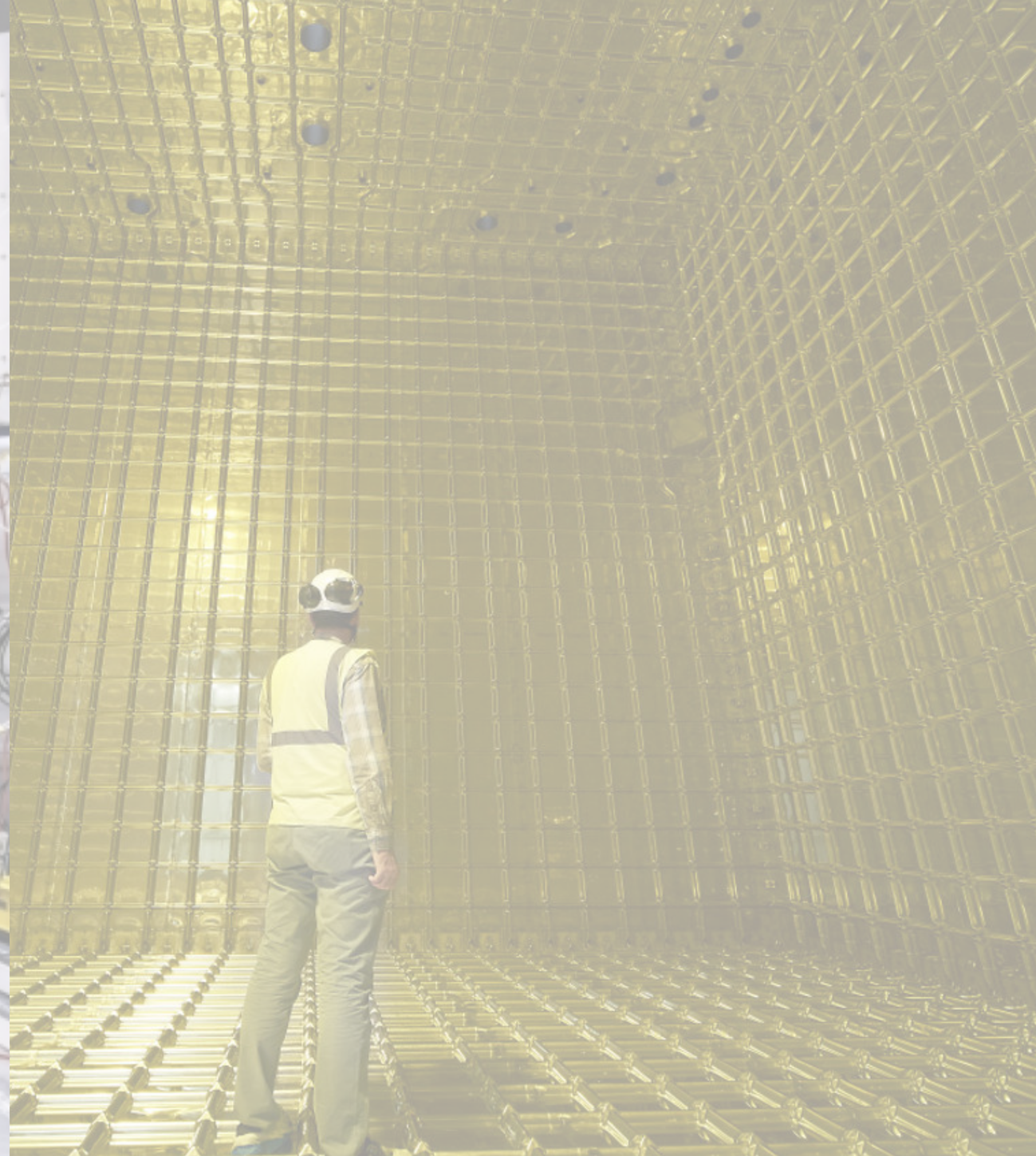
Sterile neutrinos with Solar CEvNS

- Steriles can lead to an overall disappearance effect in CEvNS from solar neutrinos.
  - Key limitations: statistics and overall systematics budget.
- Muon/Tau-neutrino components of solar neutrino flux allow for novel search with CEvNS.



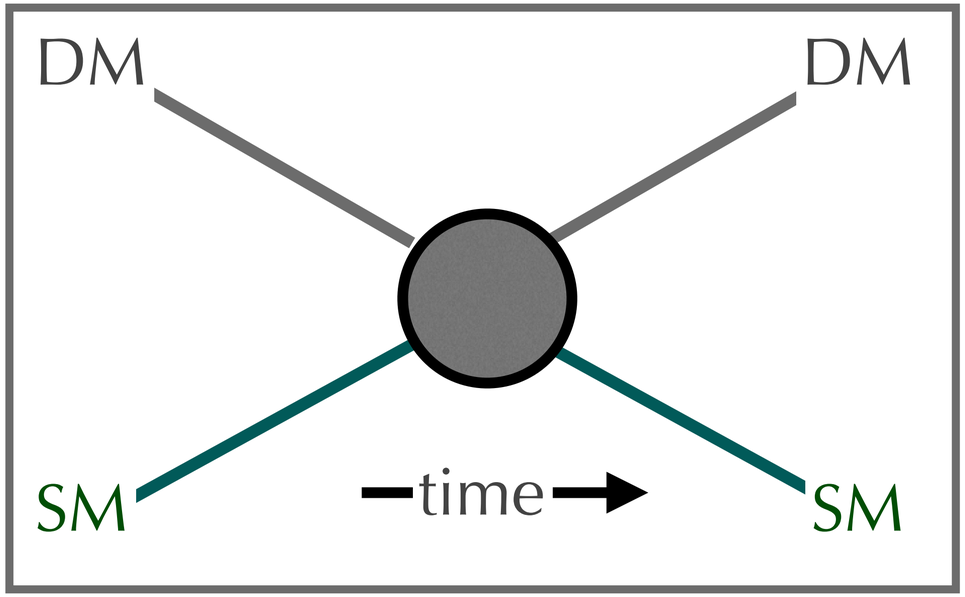
KJK, Mishra, Strigari: [2605.22935]

- With continued improvement, direct-detection experiments are probing the solar-neutrino portion of the νFog
- We're already learning about neutrino properties from this, and more is on the way.

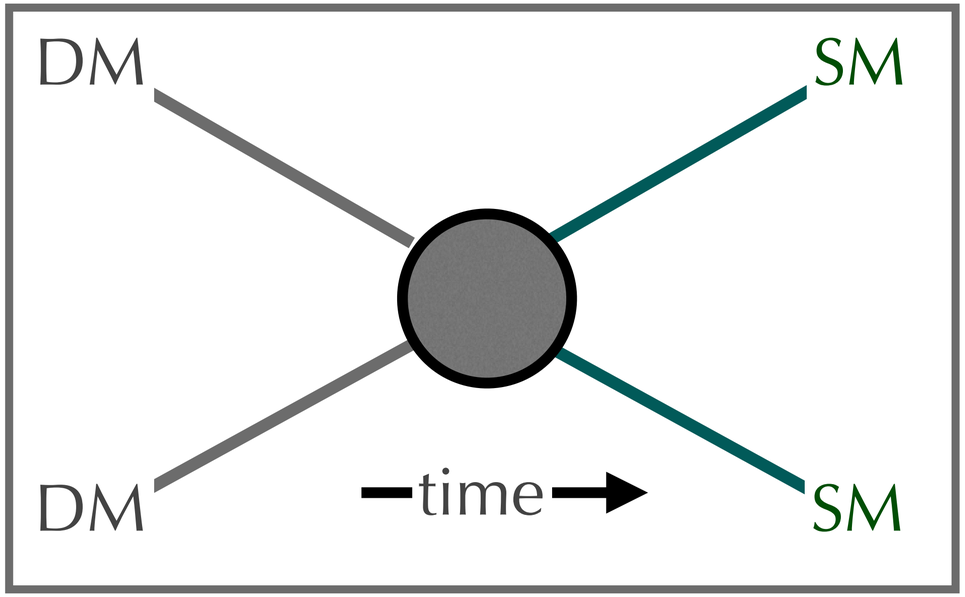


Neutrino Facilities for Dark-Matter Physics

Direct & Indirect Detection



most commonly,
SM = nuclei/nucleons



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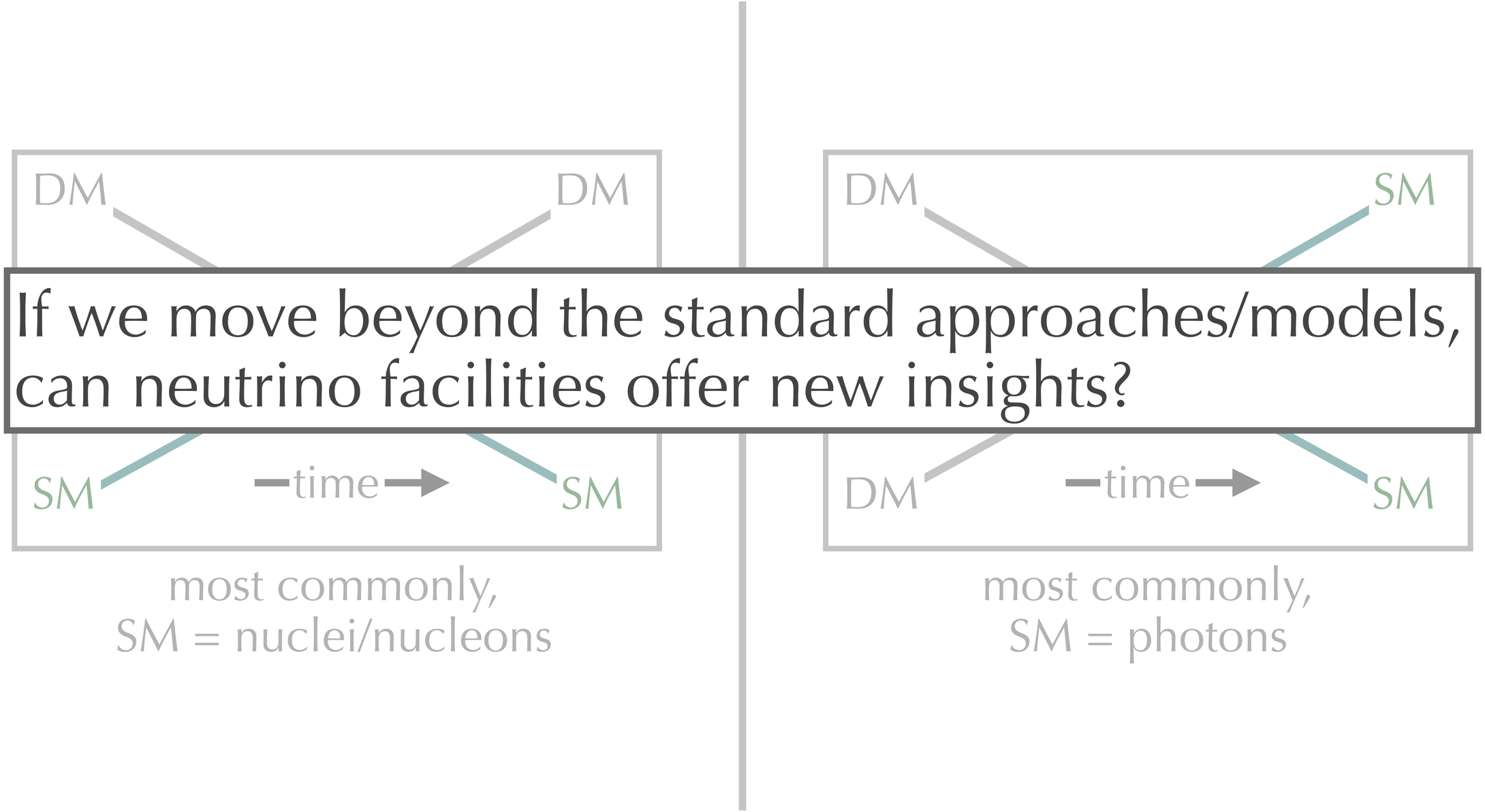

If we move beyond the standard approaches/models, can neutrino facilities offer new insights?

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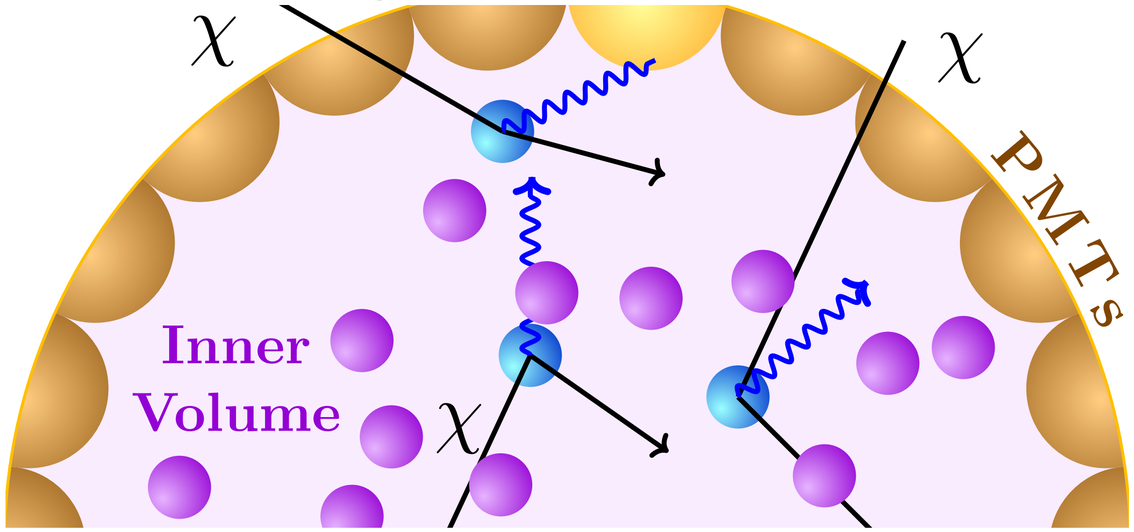
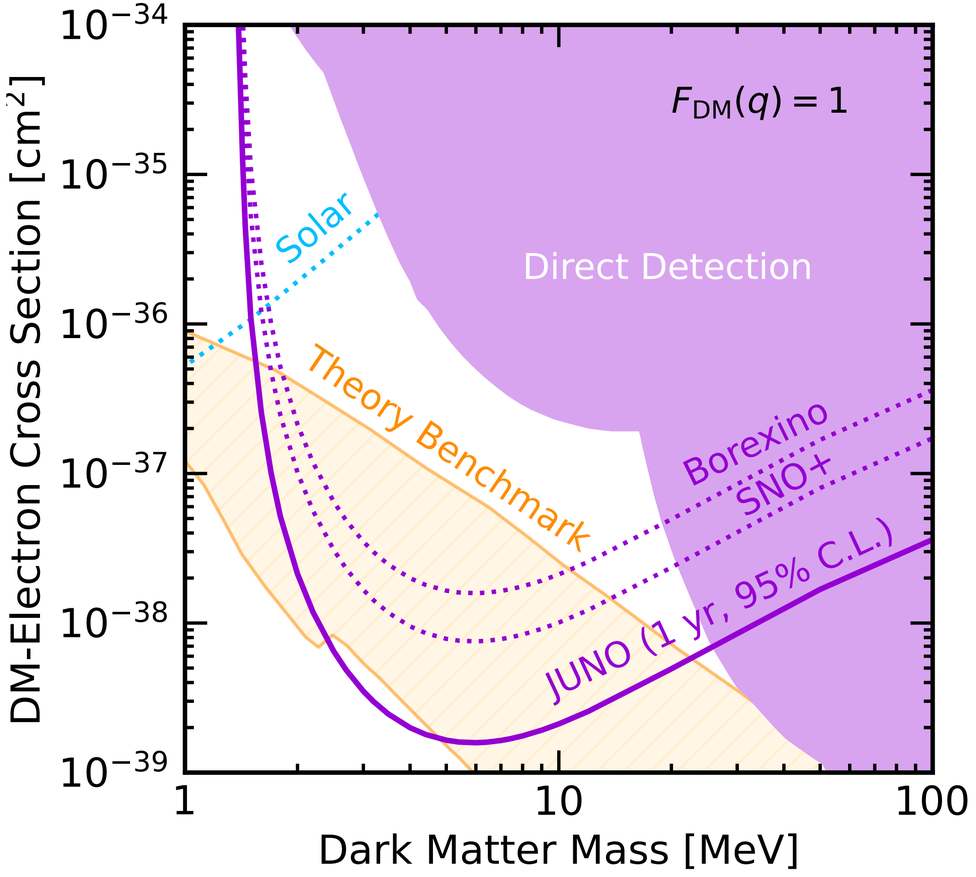
Large volumes…

- Neutrino detectors with large volumes/low thresholds offer a complementary mechanism of looking for dark matter interactions.

- Often less sensitive than dedicated experiments to “standard WIMPs,” but new techniques/model scenarios allow neutrino facilities to stand out.

JUNO low-threshold + electron scattering + annual modulation

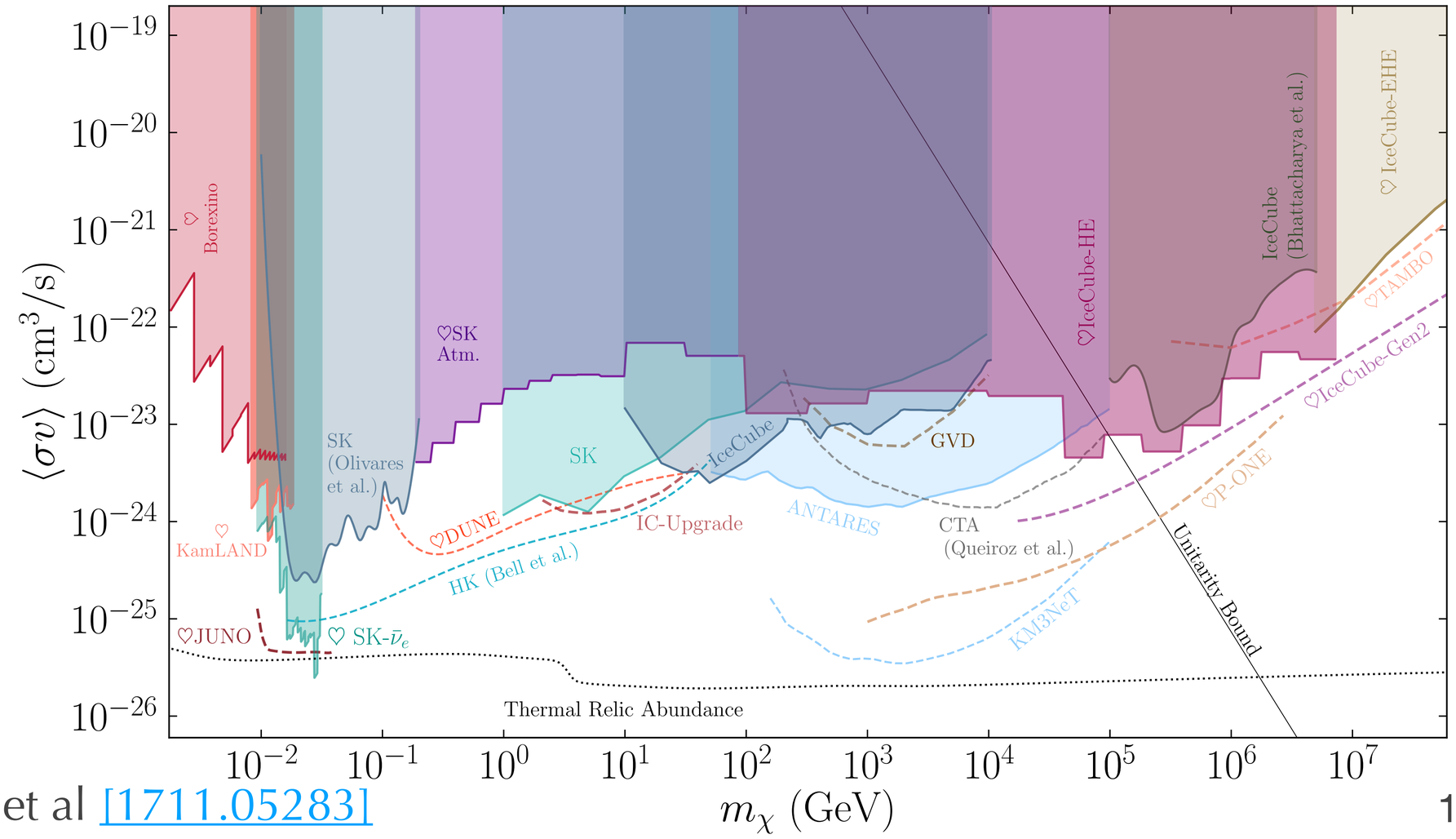




Leane & Beacom: [2503.09685]
See also Santos-Olmsted et al [2512.13779]

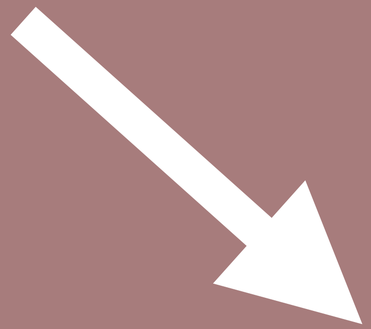
Neutrino Detectors as Indirect-Detection Facilities

- If relic DM in the galaxy today can annihilate to neutrinos, then large-volume detectors are the best observatories.
- Neutrino energy ~ inherited from DM mass: which experiment is best depends on the DM mass of interest.



Argüelles et al: [1912.09486]
See also Olivares-Del Campo et al [1711.05283]

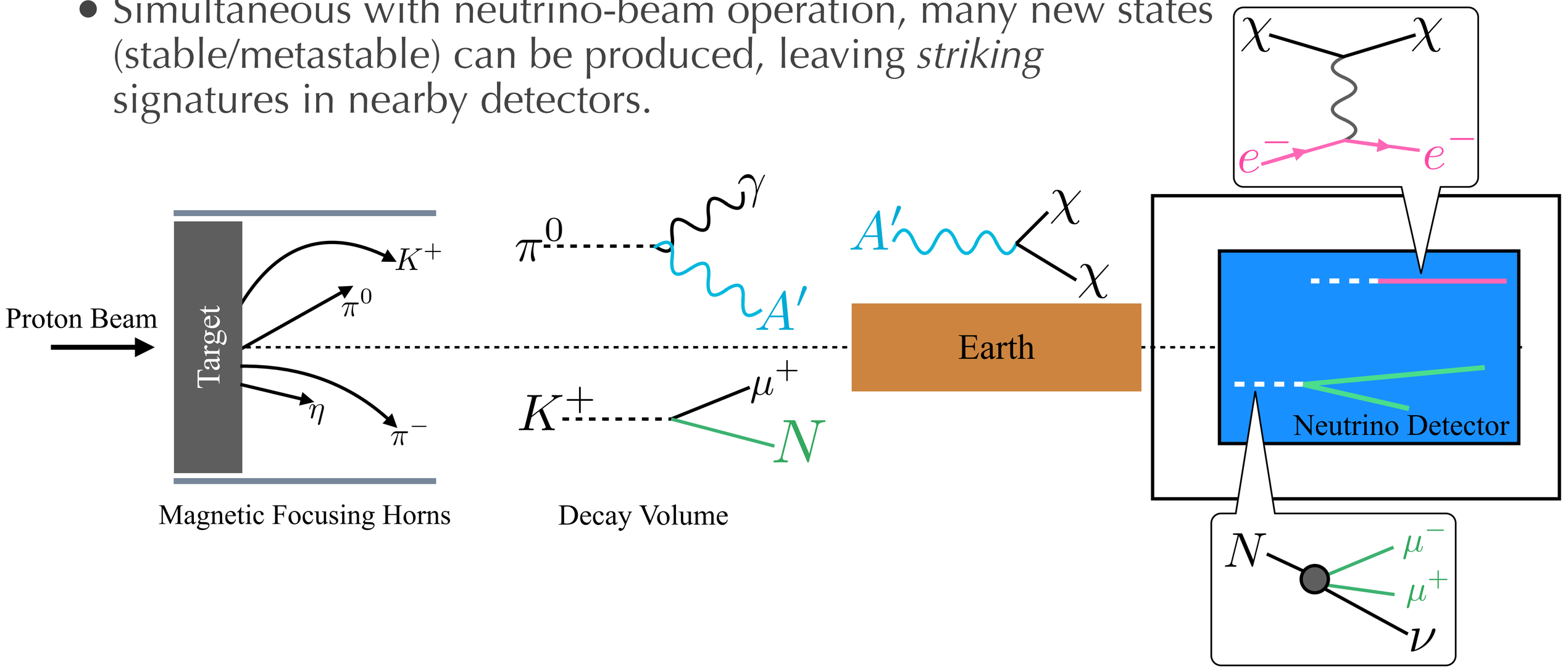
Large-volume Far Detectors



Intense Beams at Near Detectors

Near-Detector Facilities as New-Physics Machines

- Simultaneous with neutrino-beam operation, many new states (stable/metastable) can be produced, leaving *striking* signatures in nearby detectors.



More on Heavy Neutral Leptons from Renata's talk next

Near-Detector Facilities as New-Physics Machines

- Simu
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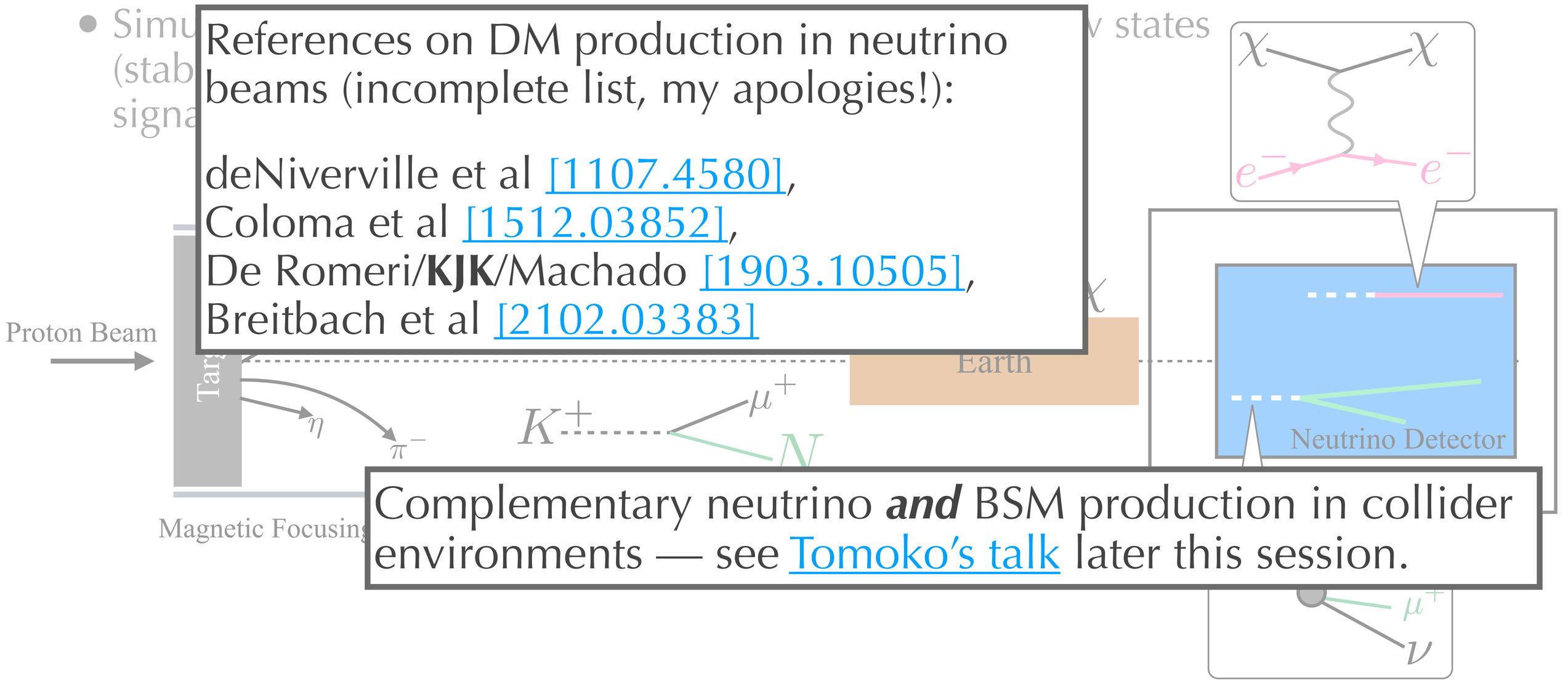
References on DM production in neutrino beams (incomplete list, my apologies!):

deNiverville et al [1107.4580],
Coloma et al [1512.03852],
De Romeri/**KJK**/Machado [1903.10505],
Breitbach et al [2102.03383]



Complementary neutrino ***and*** BSM production in collider environments — see Tomoko's talk later this session.

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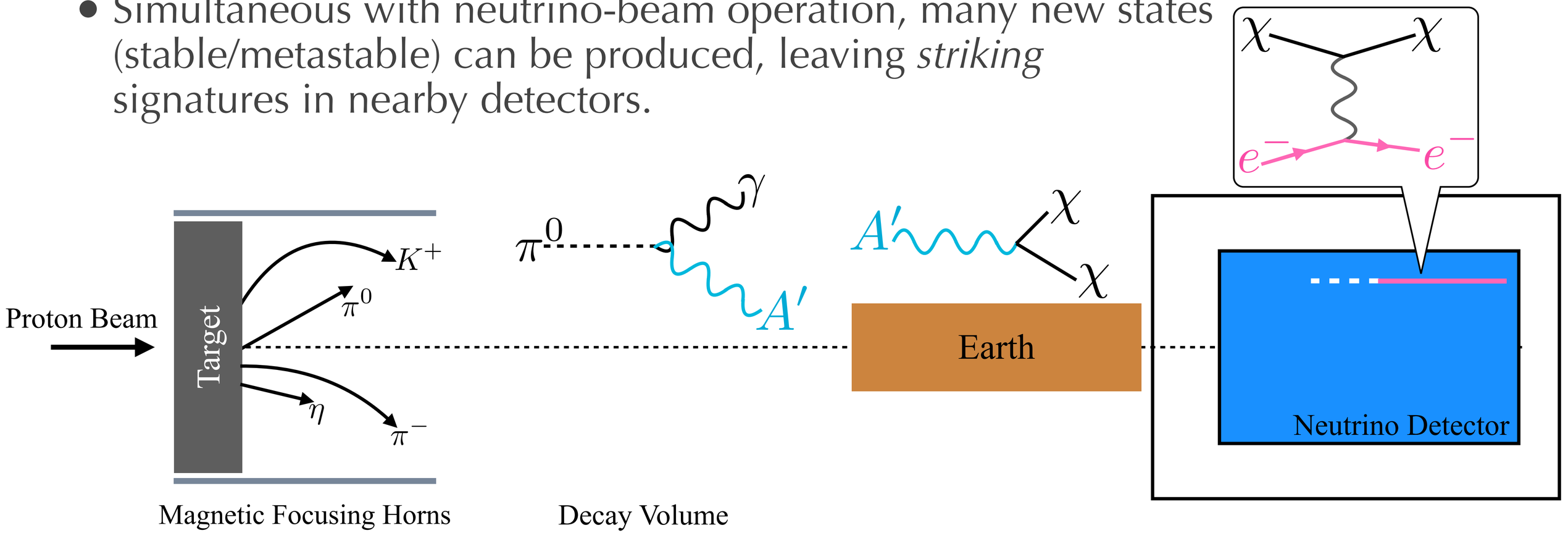
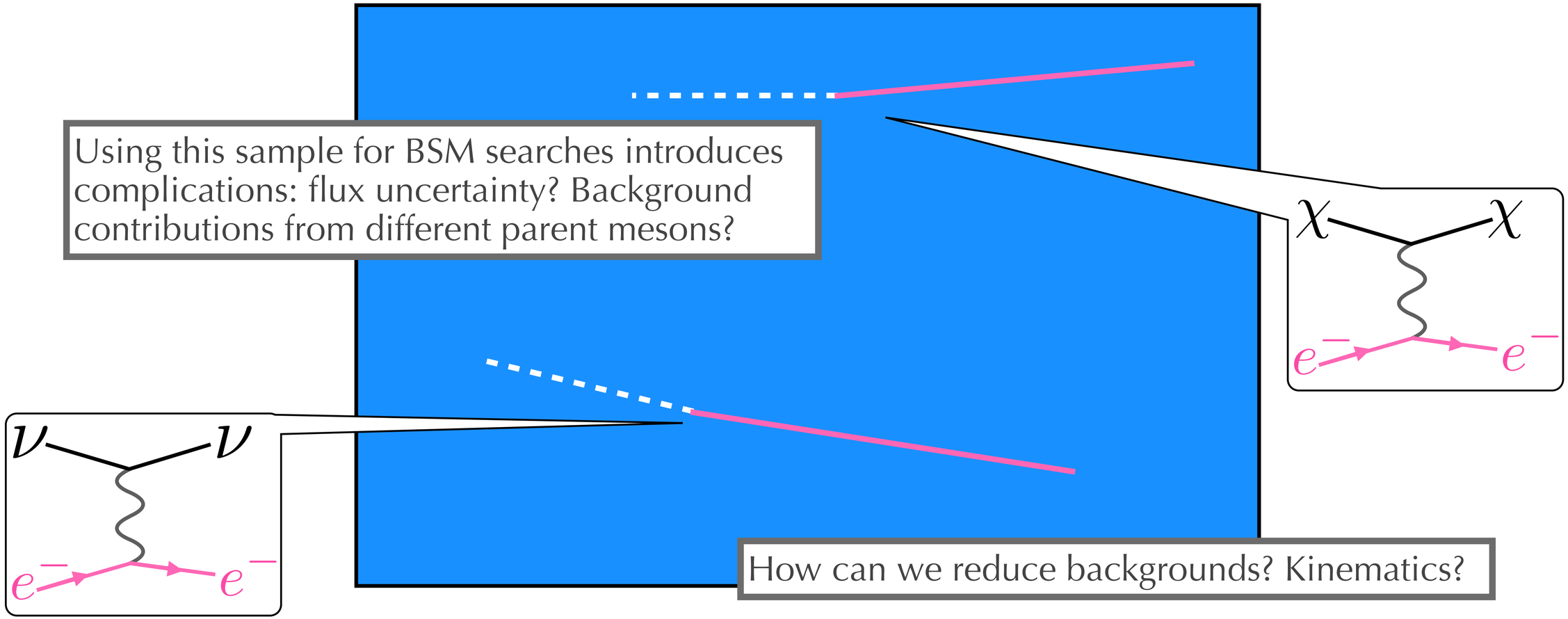


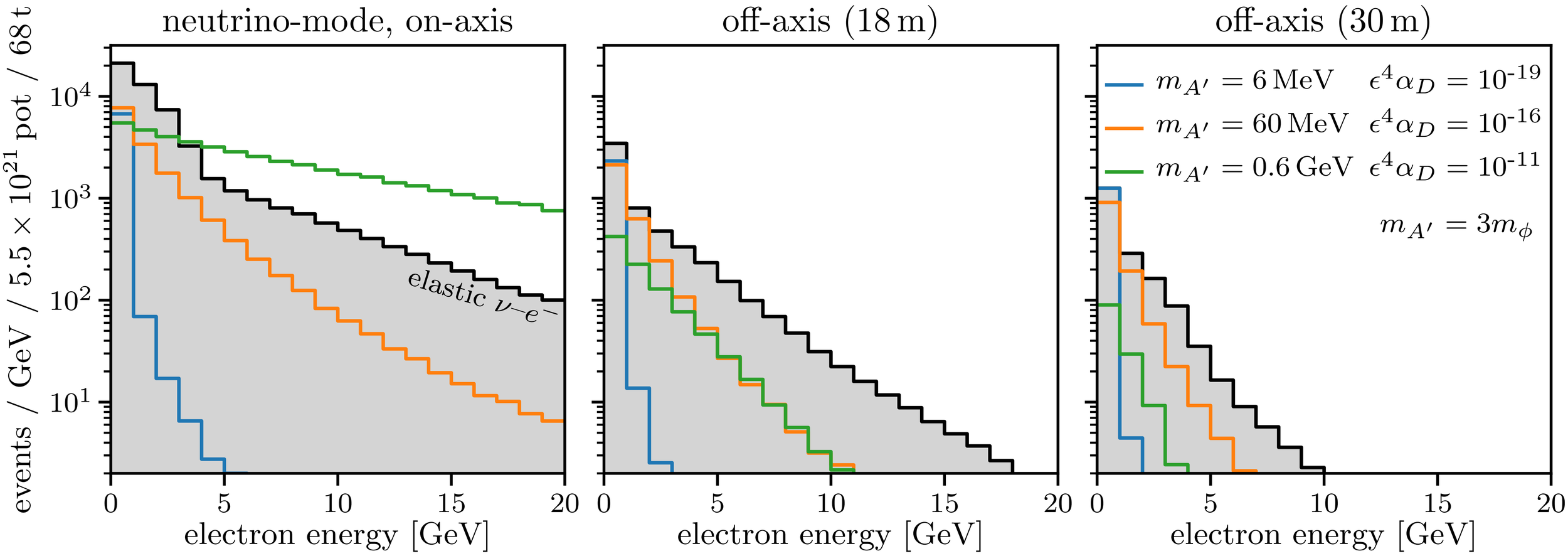
The challenge…

- Just as CEvNS could mimic WIMP dark-matter scattering, elastic DM/electron scattering can be mimicked by neutrino/electron scattering!



Off-axis measurements to the rescue

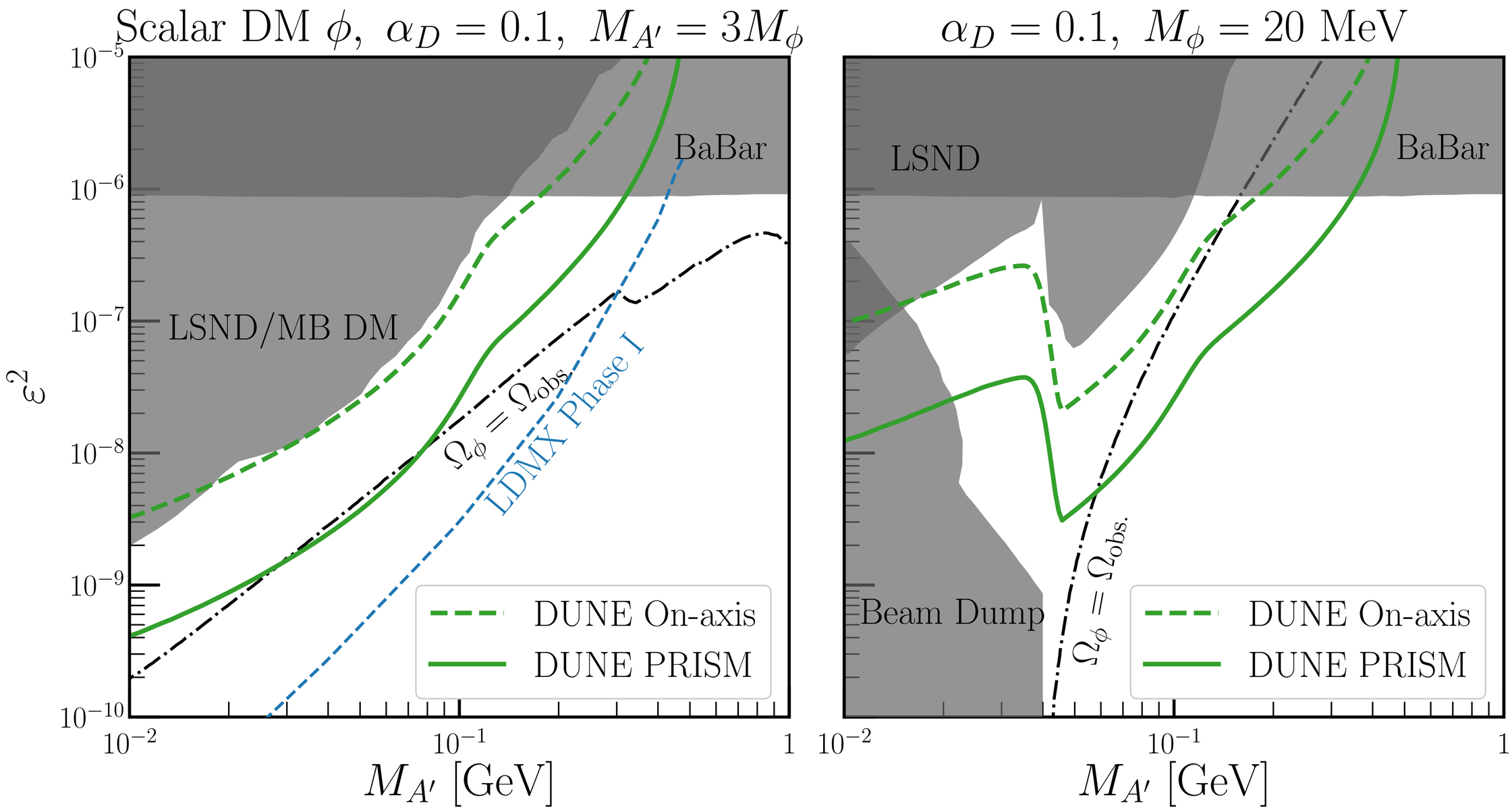
- Leverage DUNE-PRISM: neutrino rate vs. off-axis angle has substantial differences vs. DM signal



Breitbach et al [2102.03383]

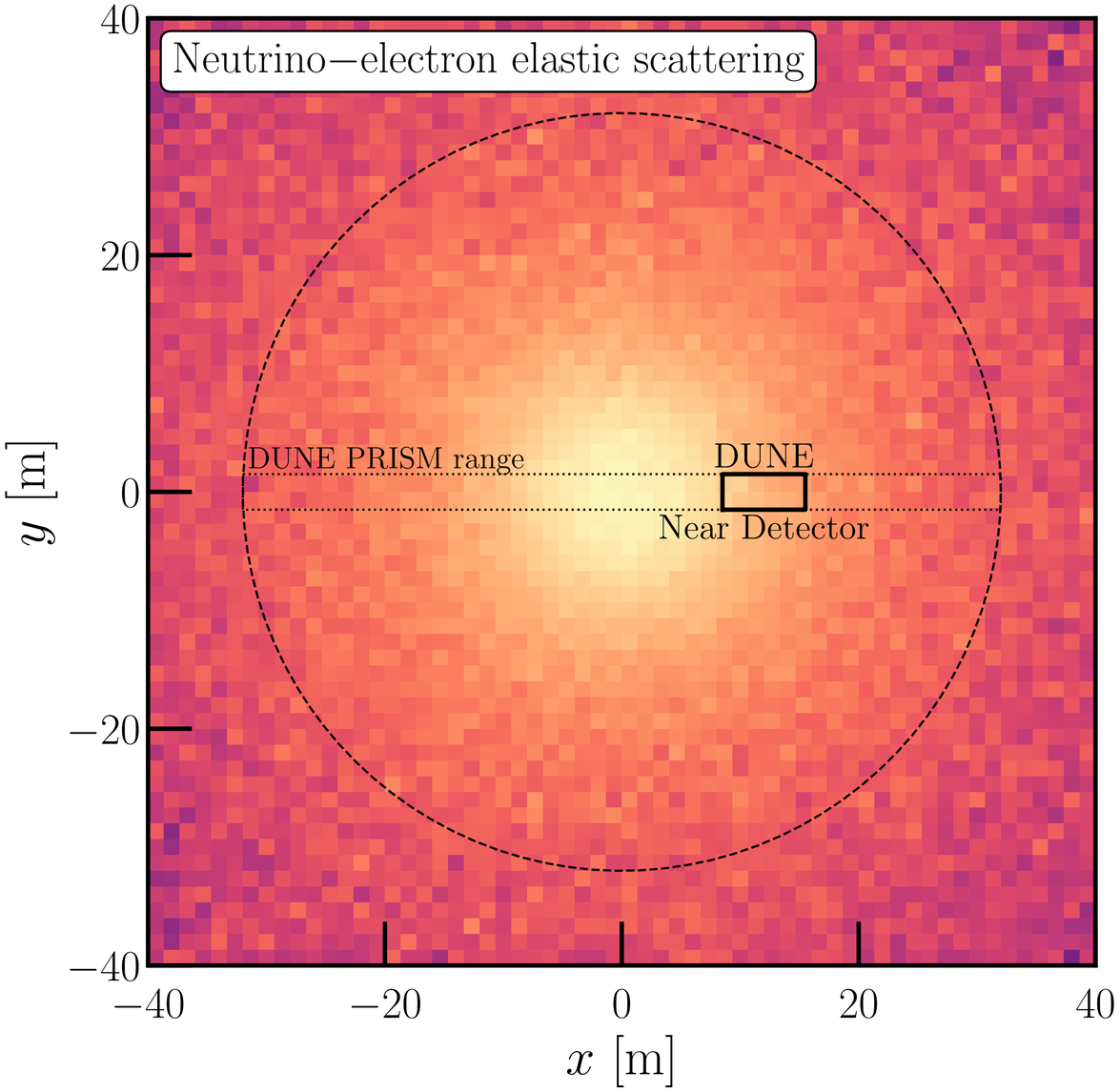
Sensitivity Attainable?

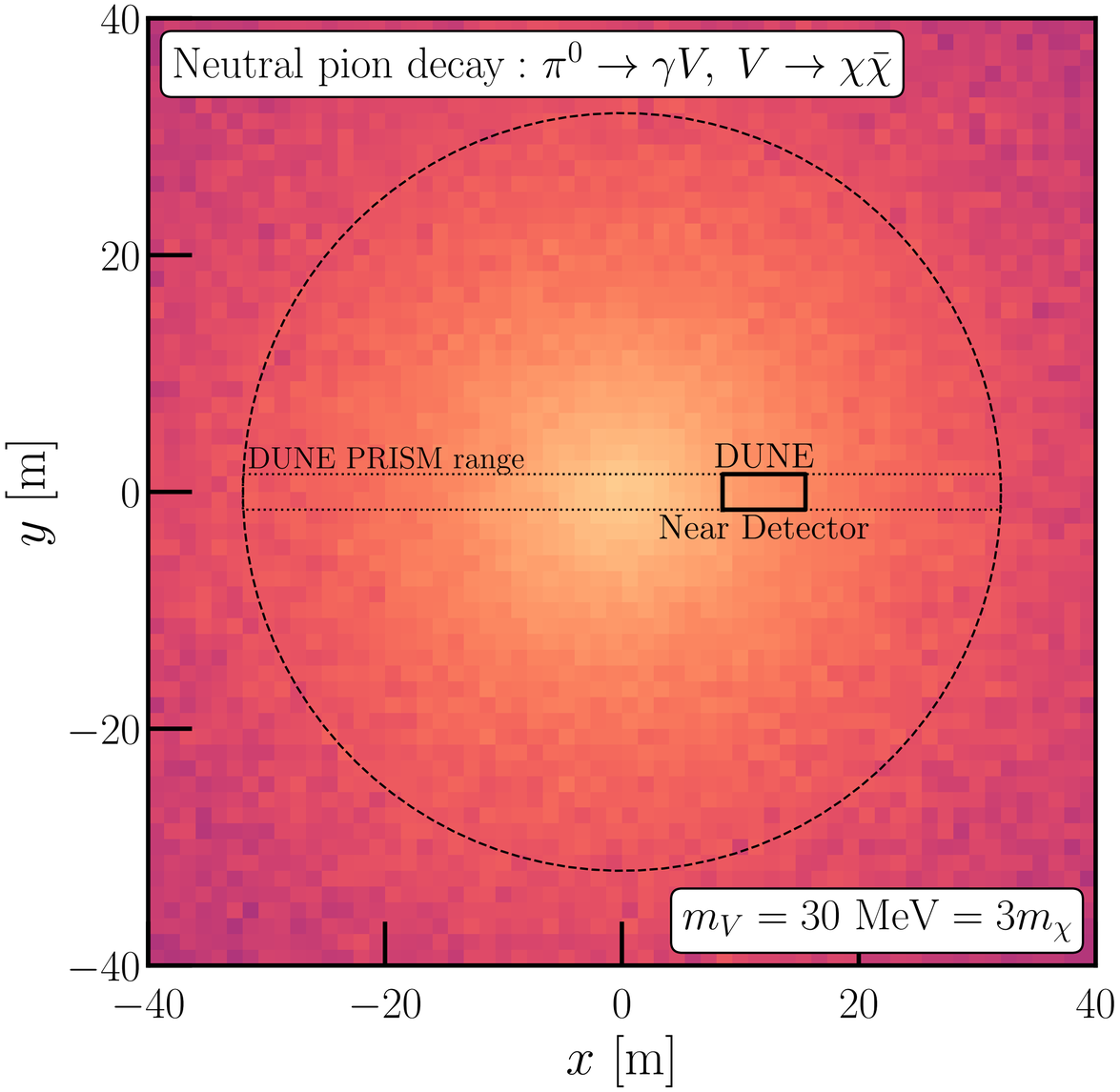
De Romeri/**KJK**/Machado [1903.10505]



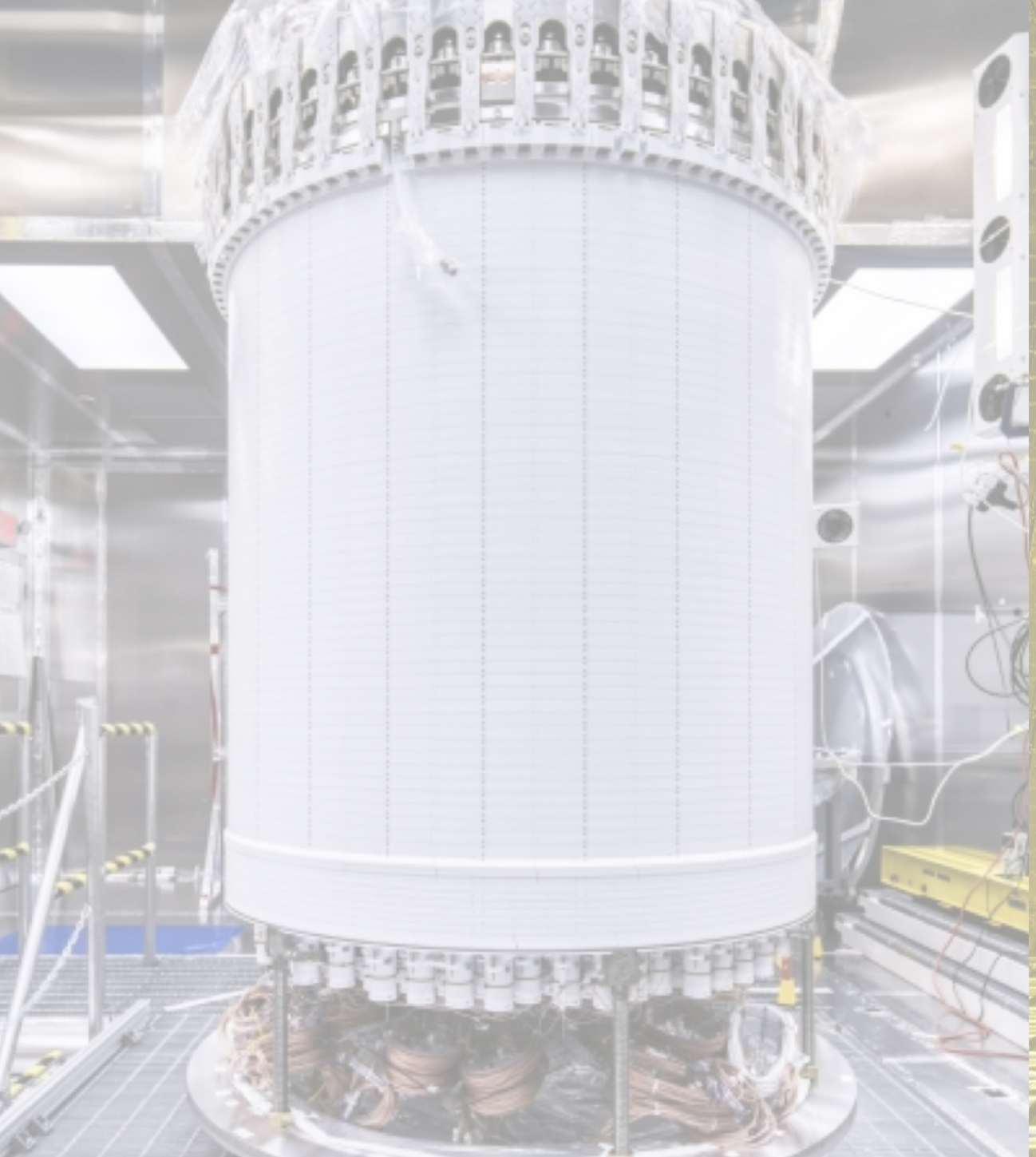
cm-scale vertex identification?

Airoldi et al in prep.





- Can we apply these strategies in detectors *now*? Yes! NOvA, ICARUS, SBND, …



- Large neutrino detectors offer novel ways to look for DM via direct & indirect approaches.
- Intense beams & precision near-detector facilities allow for copious BSM searches, including for dark sectors.

Takeaways

- Current dark-matter experiments are already probing the neutrino fog, and next-generation ones will delve even deeper. Let’s utilize this to understand neutrino sources & properties.

- Breadth of detection technologies allows for many novel searches in neutrino detectors (large and small). Let’s understand the possibilities and maximize our chances of discovery.