Status DMNI Experiments
(Dark Matter New Initiatives)

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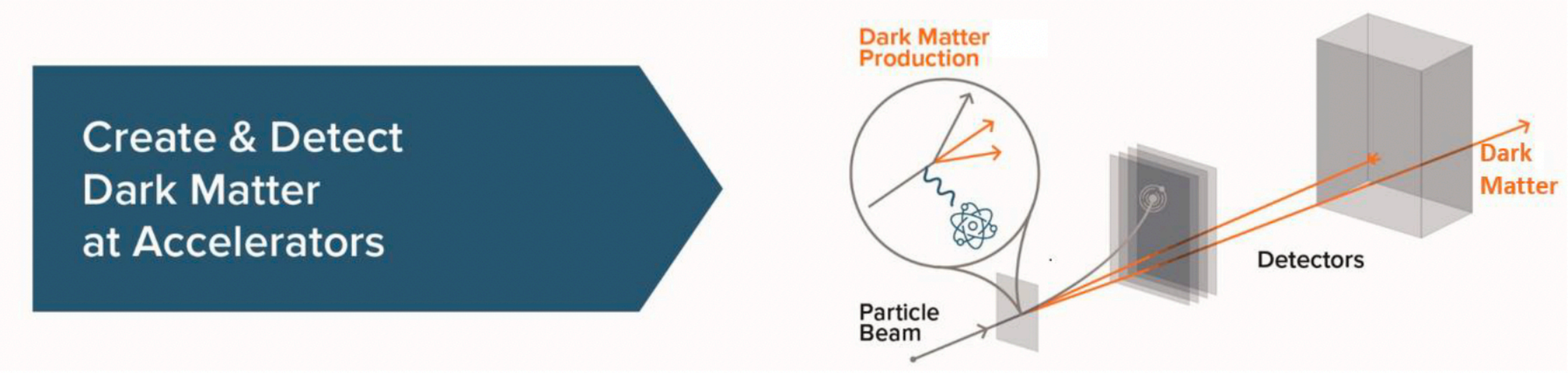
https://www.osti.gov/biblio/1659757

In response to growing excitement in the community fueled by theory advances in phenomenology and cosmology and experimental technological advancements including quantum sensing, DOE High Energy Physics organized a Basic Research Needs Workshop

PRD 1: Create and detect dark matter particles below the proton mass and associated forces, leveraging DOE accelerators that produce beams of energetic particles.

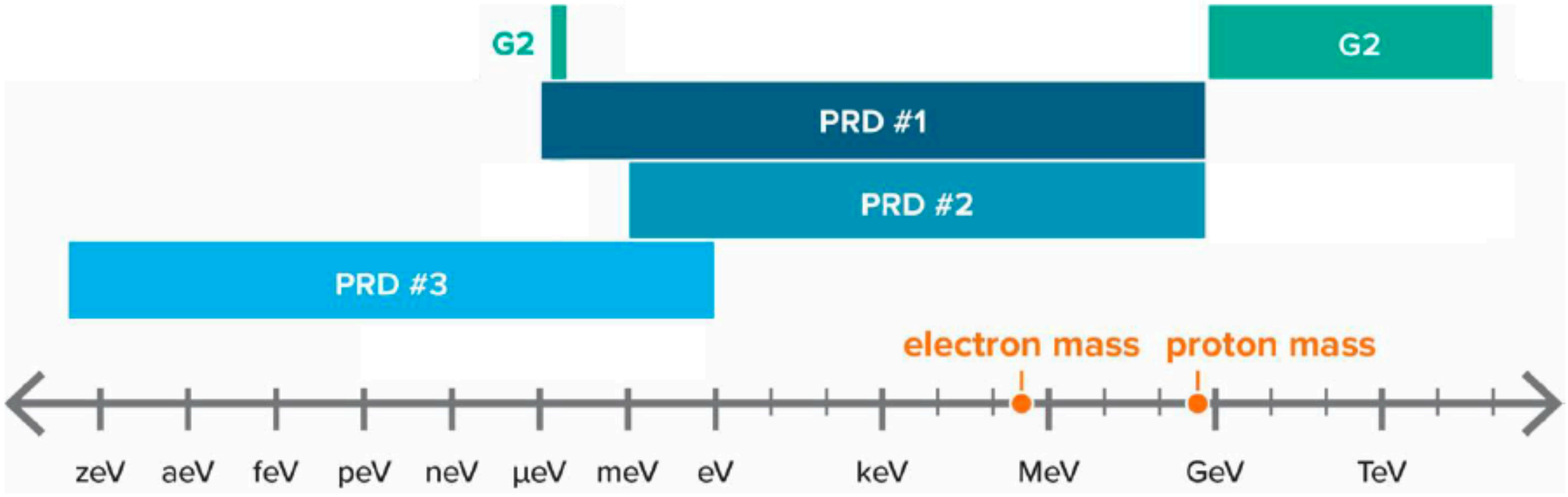


PRD 2: Detect individual galactic dark matter particles below the proton mass through interactions with advanced, ultra-sensitive detectors.

PRD 3: Detect galactic dark matter waves using advanced, ultra-sensitive detectors with emphasis on the strongly motivated QCD axion. [1]

Defines 3 Priority Research Directions (PRD)….

which enables a major expansion in the dark matter parameter space explored….

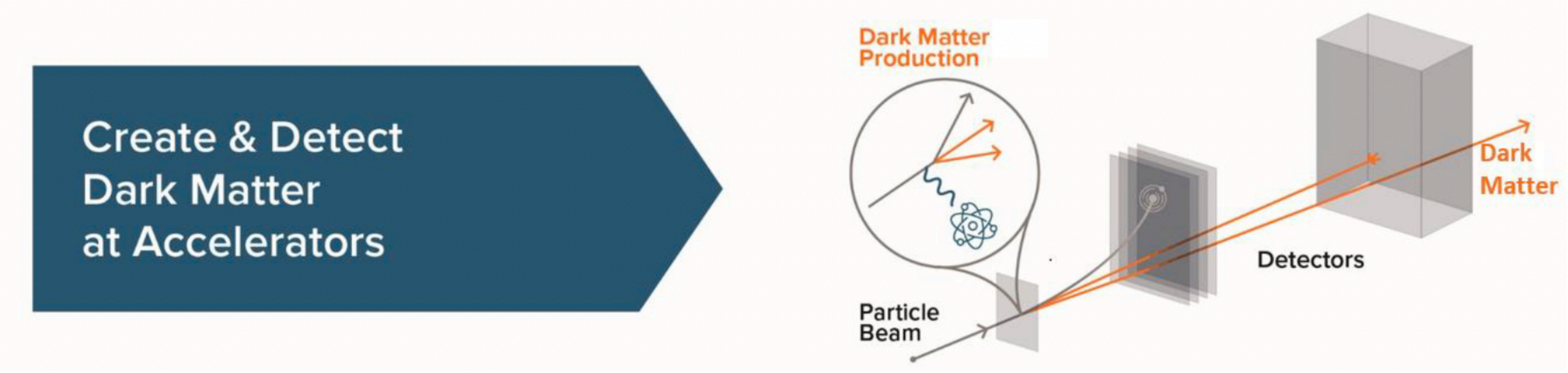


An FOA followed and the community responded enthusiastically with many excellent proposals.

Five were funded for project design studies and one for construction.*

** This is my description, may not be official.*

PRD 1: Create and detect dark matter particles below the proton mass and associated forces, leveraging DOE accelerators that produce beams of energetic particles.



PRD 1: CCM and LDMX

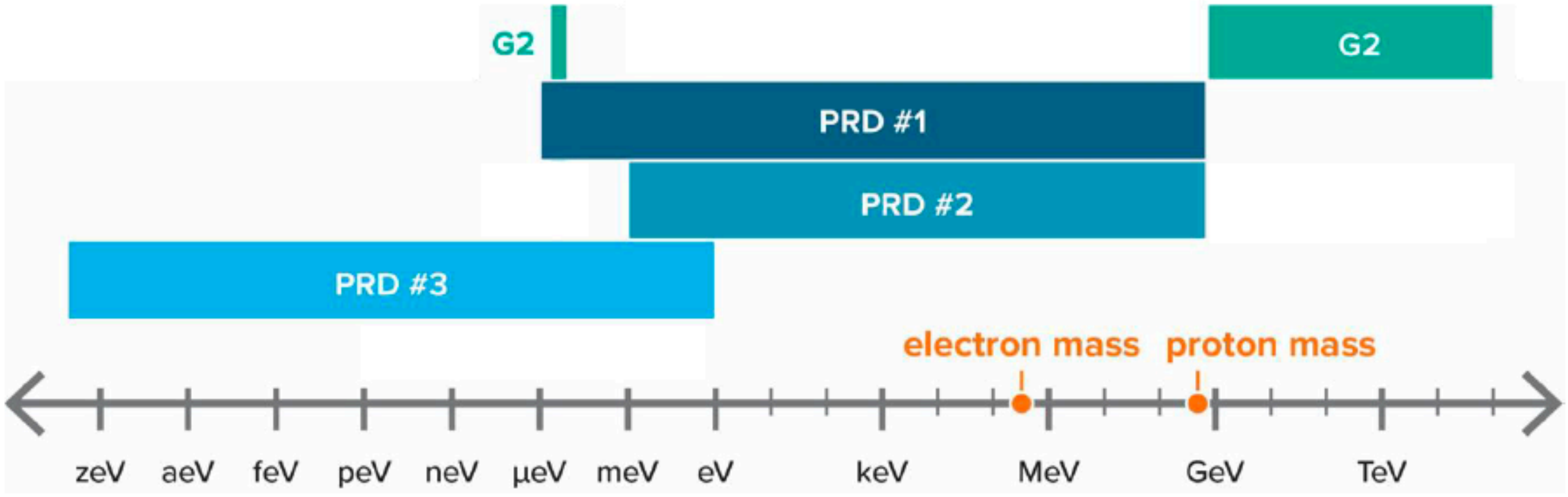
PRD 2: Detect individual galactic dark matter particles below the proton mass through interactions with advanced, ultra-sensitive detectors.

PRD 2: TESSERACT and OSCURA

PRD 3: Detect galactic dark matter waves using advanced, ultra-sensitive detectors with emphasis on the strongly motivated QCD axion. [1]

PRD 3: DMRadio-m³ and ADMX-EFR

PRD #1 - Create Dark Matter at Accelerators



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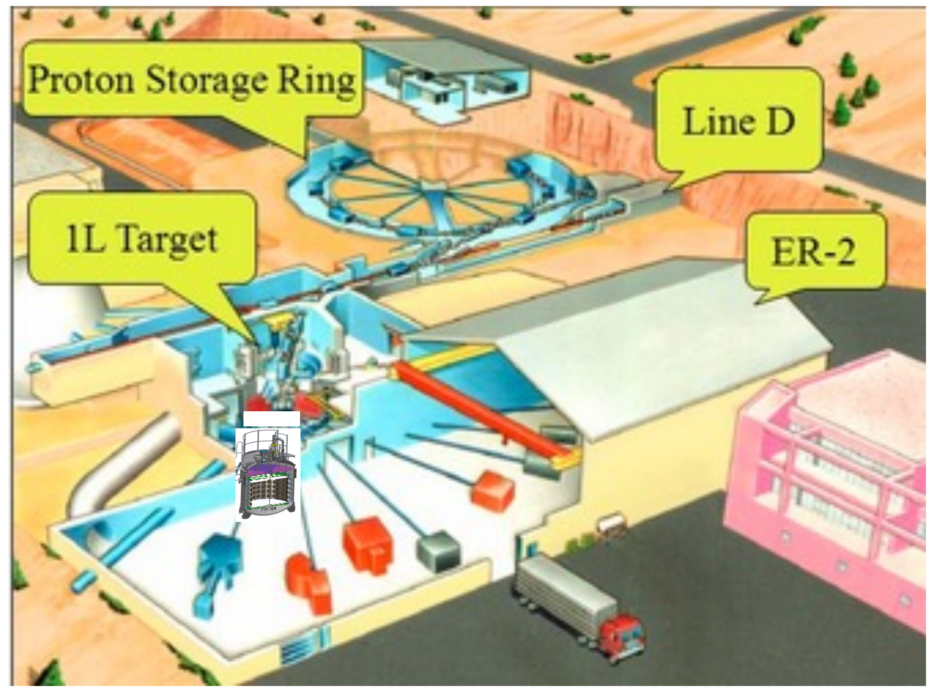
Coherent Captain Mills (CCM) at LANL

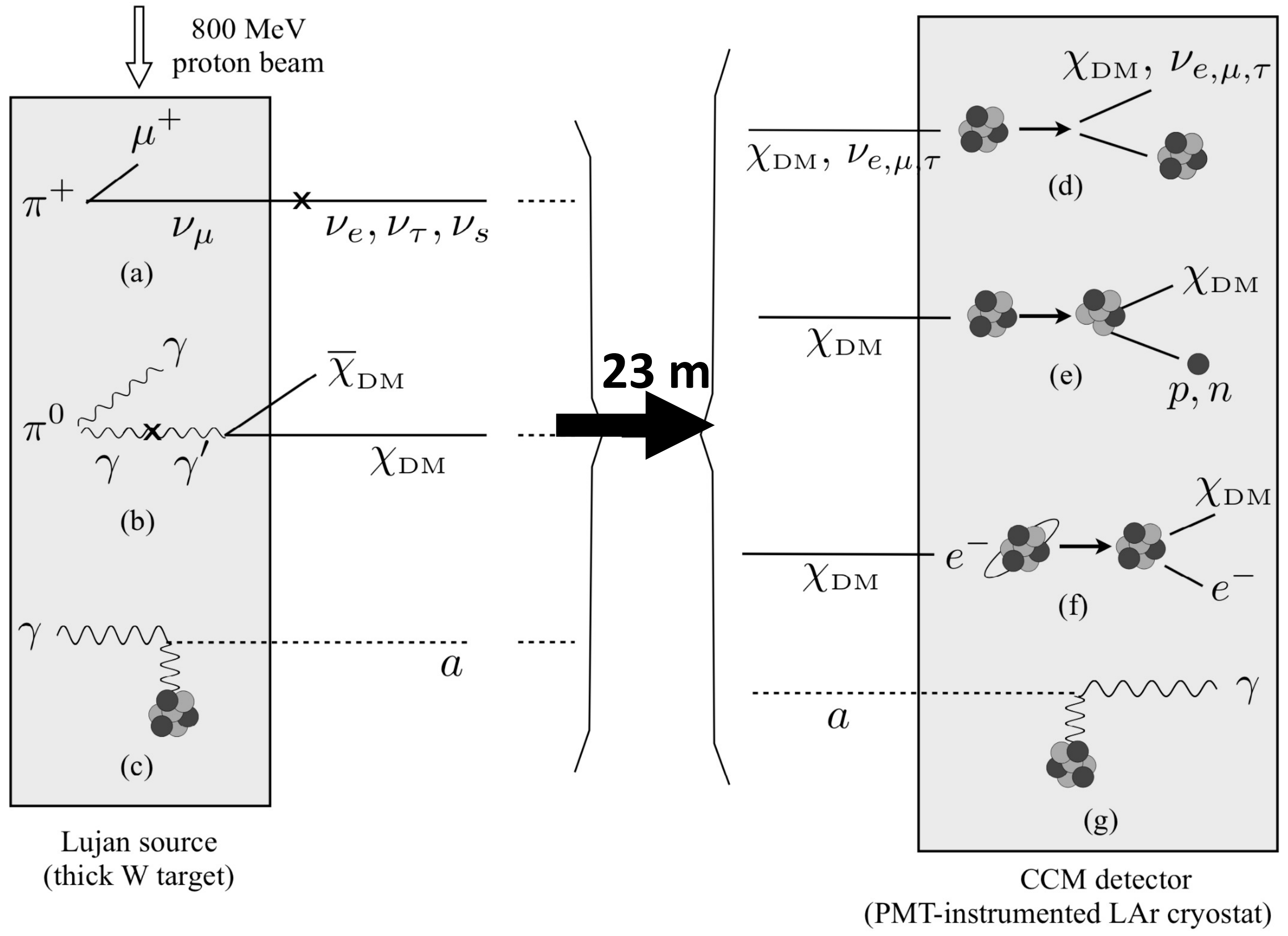
Richard Van de Water, LANL

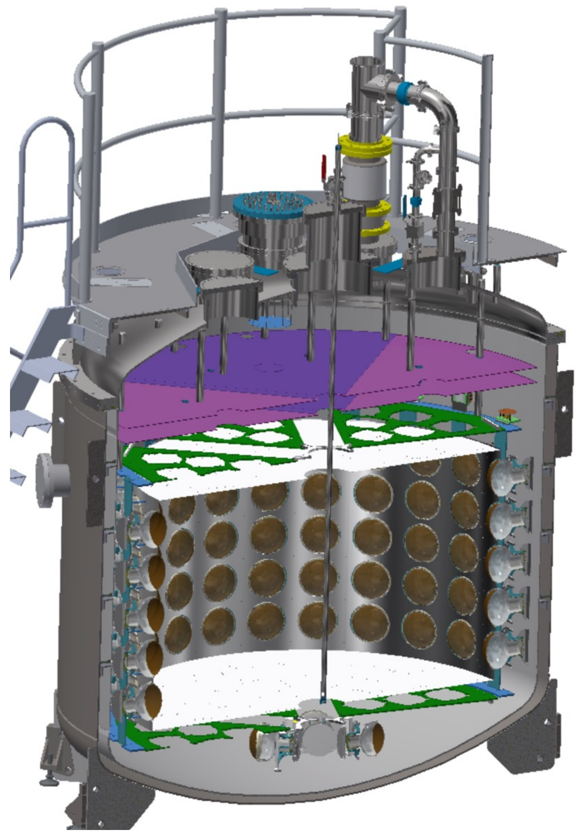
Impactful Neutrino Physics and Dark Sector Searches at LANSCE with the Coherent CAPTAIN-Mills (CCM) Experiment

800 MeV protons, 100kW, 285 nsec pulsed beam



LANSCE-PSR-Lujan Target: Prolific source of charged/ neutral pion and photons that produce neutrinos and potential dark sector particles.





CCM: 10-ton Liquid Argon (LAr) scintillation detector instrumented with 200 8” Photo-multiplier tubes, veto region, shielding, fast electronics.

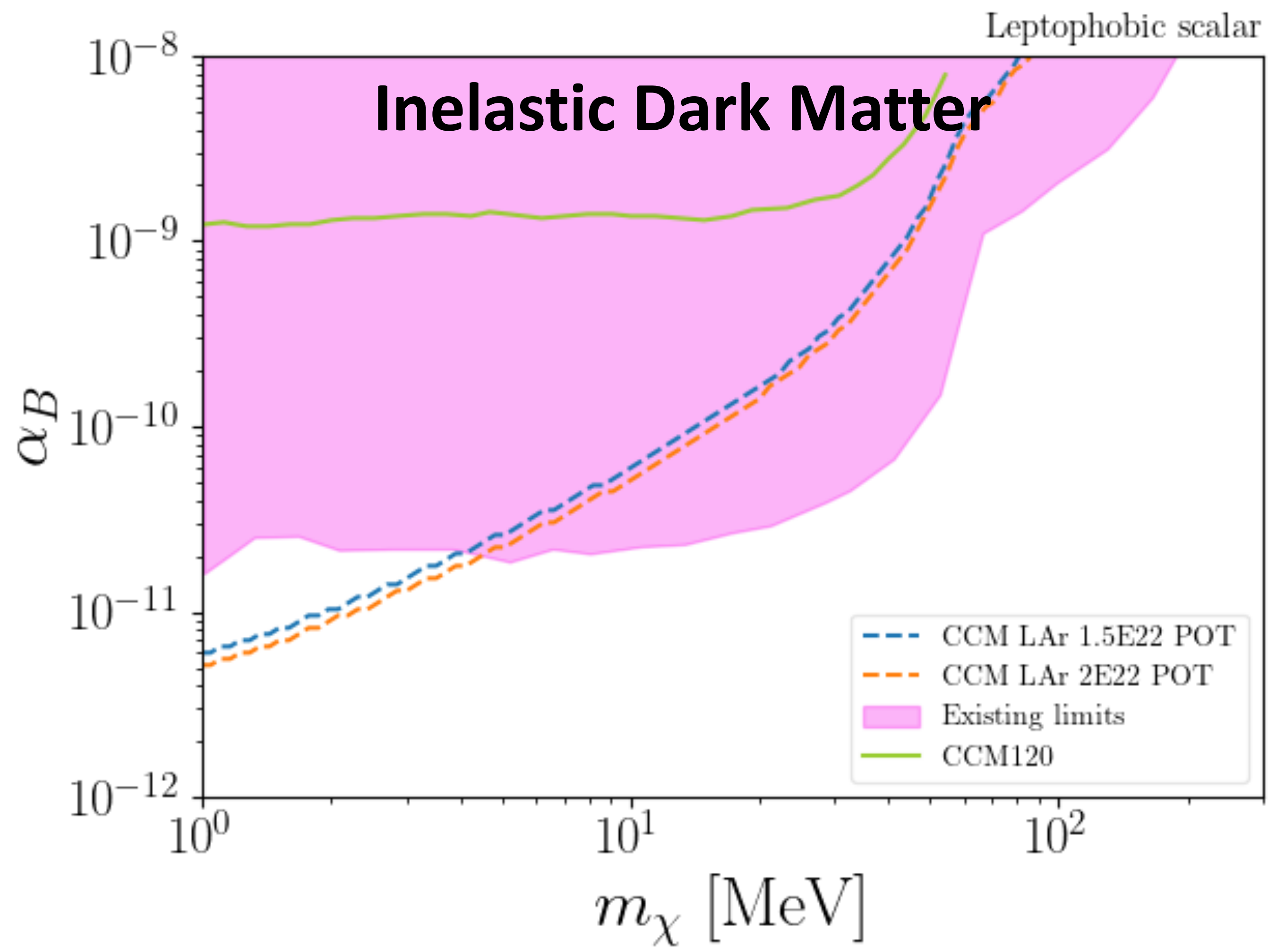
- Built and commissioned CCM detector in FY2022 (LANL LDRD and HEP-DMNI funding).
- Intense short pulsed proton beam and fast 10-ton LAr detector will probe unexplored parameter space for dark matter, axions, and meson portal model test of MiniBooNE.
- CCM addresses 2023 P5 call for small scale experiments to perform exploratory research, BSM searches, and enhance workforce development and creativity.
- **Completed four-year beam run (2022-25) collecting 0.9E22 Protons on Target (POT) – 60% of goal.**

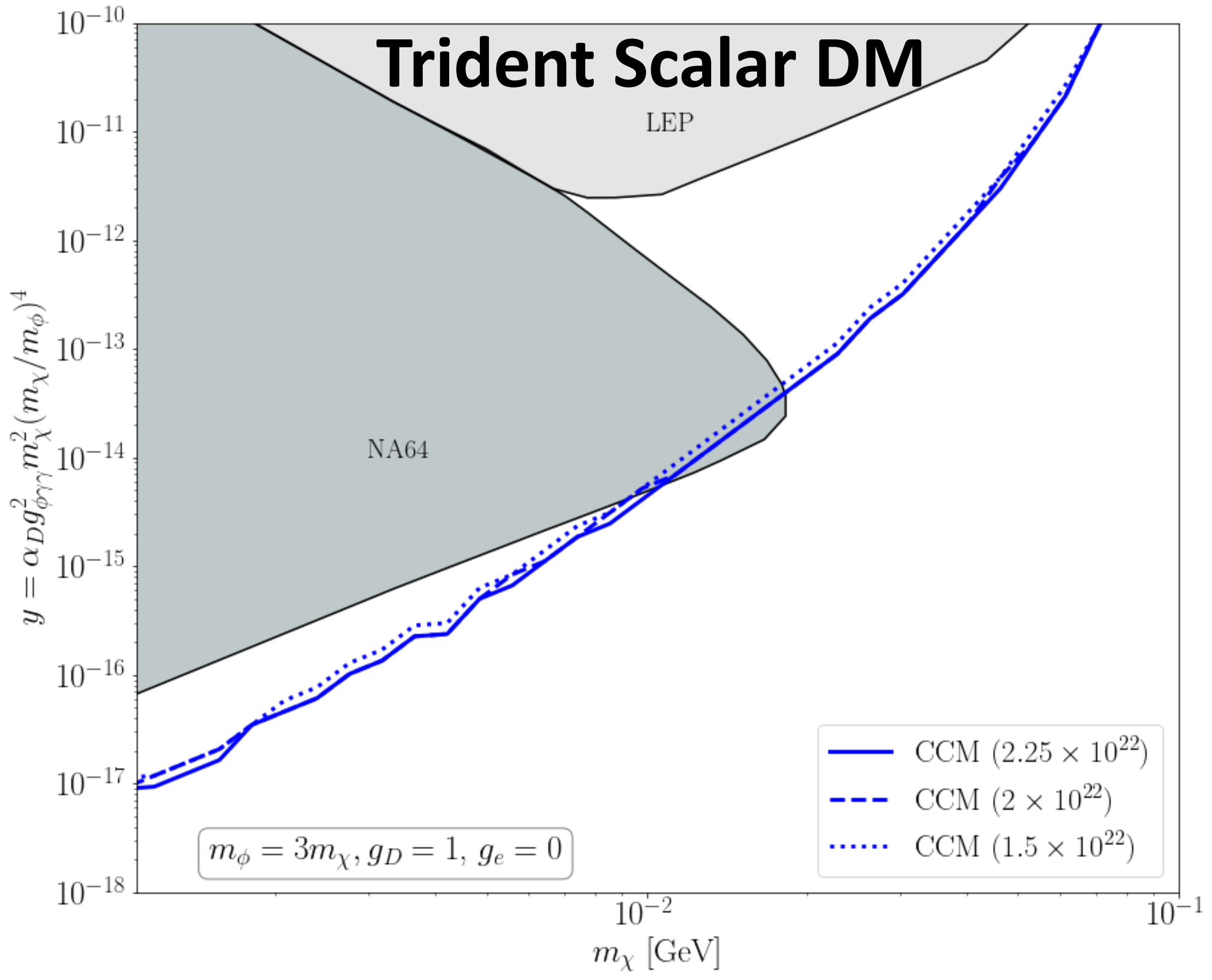
CCM200 successfully constructed during COVID, begun running early Oct 2021

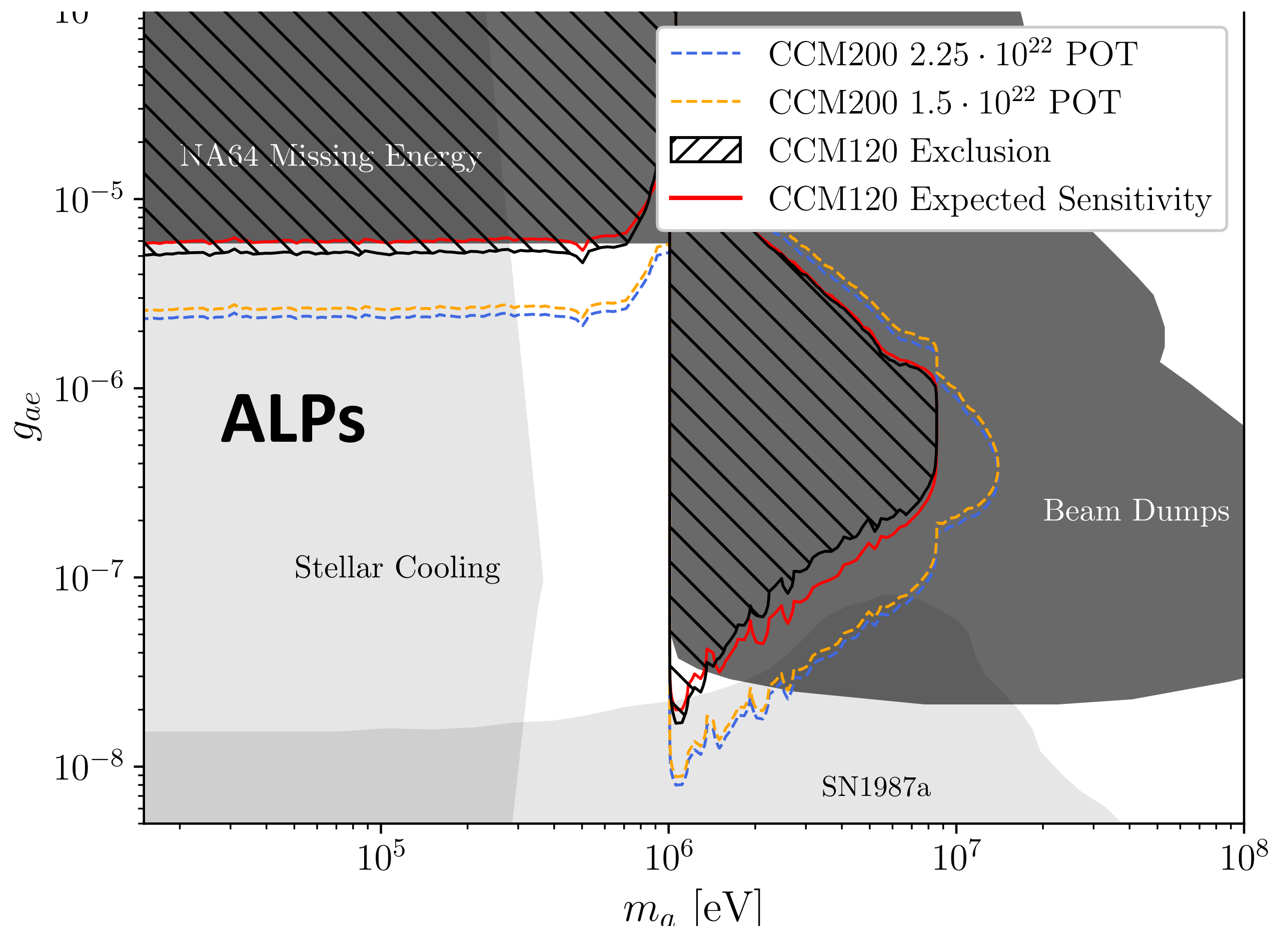
Huge effort by installation team (left to right):
- -TJ Schaub (LANL Postbac)
- -Mayank Tripathi (GS -UFlorida)
- -Will Thompson (LANL PostBac)
- -Ed Dunton (GS - ColumbiaU)
- -LANL/Lujan technicians
- -Summer students.

All collaborators participate in operations and calibrations.

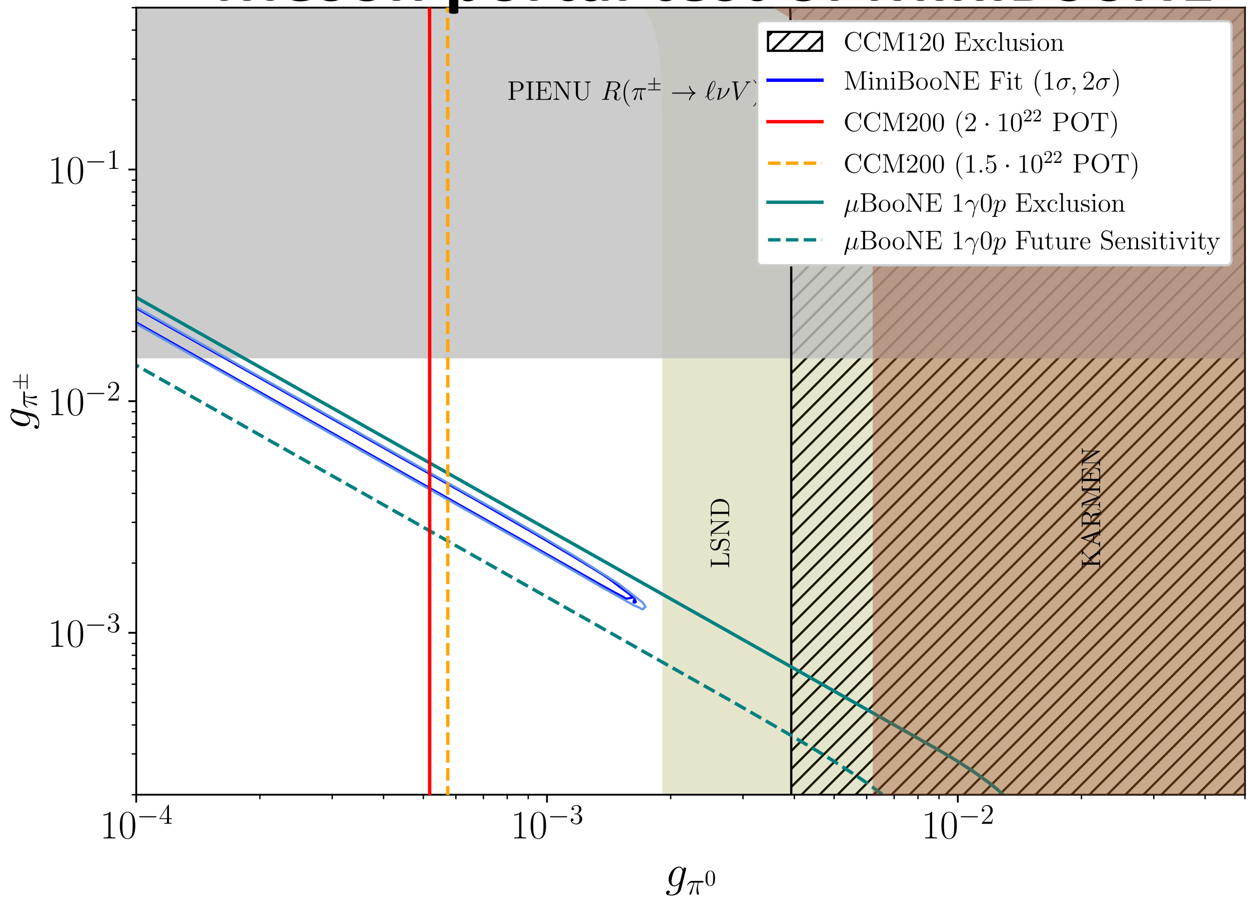
Rich list of BSM theory models developed and motivated by CCM







Meson portal test of MiniBooNE



Reduced 0.9E22 POT does not significantly affect BSM searches.

Sensitivities assume conservative background rates from 2021 measurements

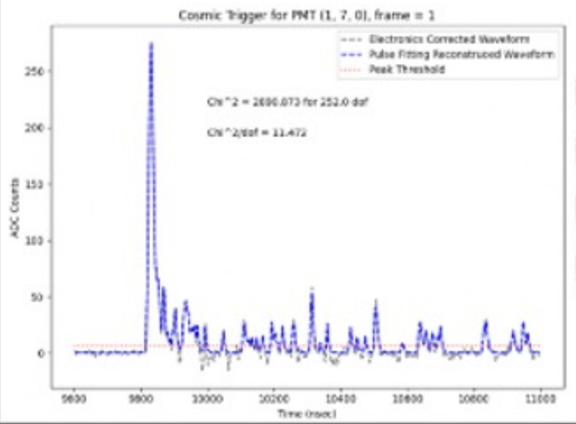
More models being developed and tested: Dark photon, ATOMKI, Heavy Neutral Leptons, elastic DM,

New Reconstruction on 2022 Data (Darcy Newmark – MIT, Austin Schneider – LANL)

Ultimate goal is first identification of Cherenkov light on event-by-event basis in LAr

Promising signs that we will be able to identify Cherenkov down to 1 MeV

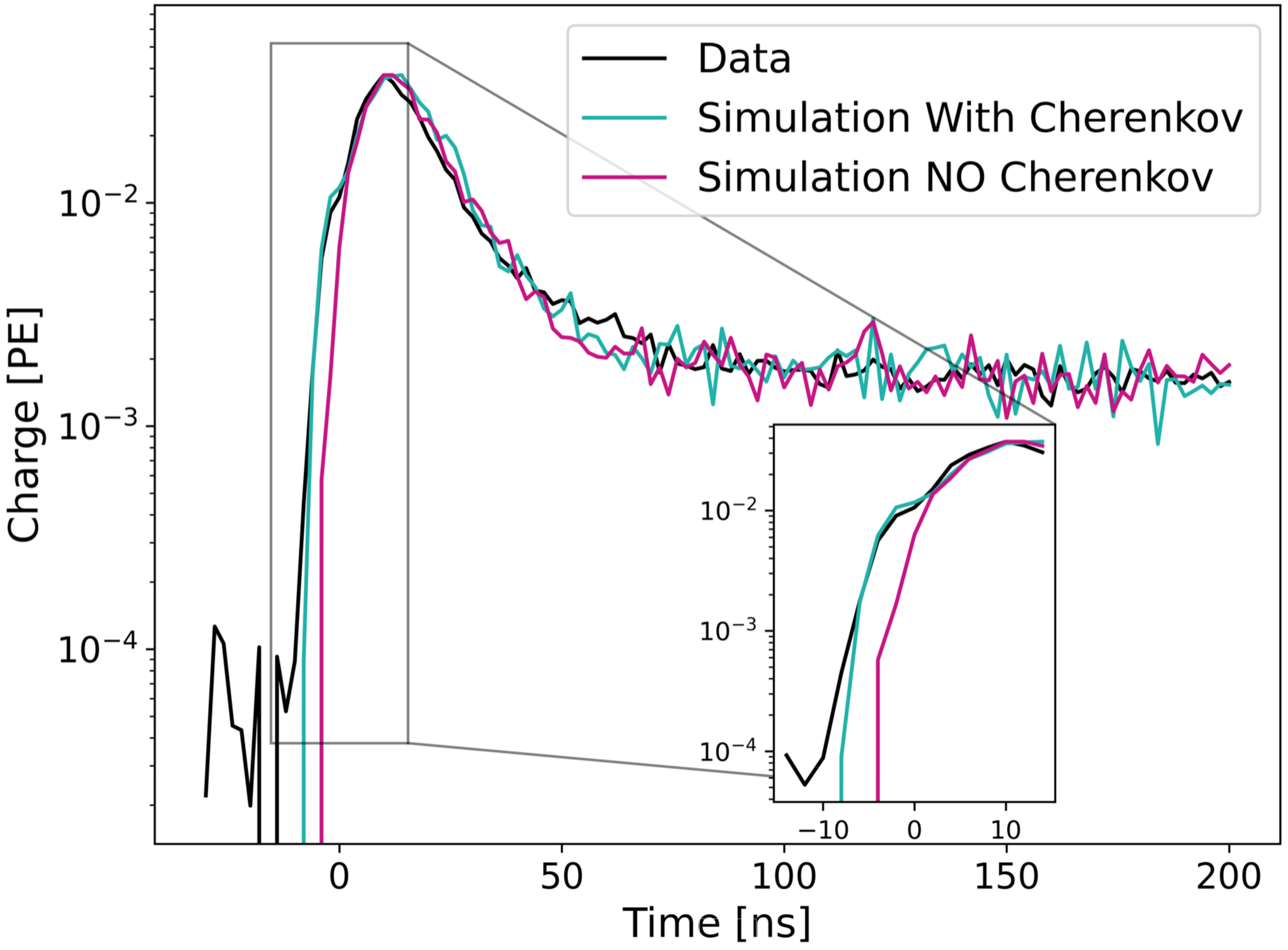
Improved pulse finding



- ☑ Baseline correction
- ☑ Electronics correction
- ☑ Single PE shape fit
- ☑ Pulse unfolding using least squares regression

Uncoated PMT waveform

- ☑ Sensitive to only visible light (WLS scintillation light and broad spectrum Cherenkov light)
- ☑ Early time structure indicates fast (~picosecond) Cherenkov light
- ☑ Percent level effect consistent with Cherenkov light at ~1MeV



Potentially separate neutron backgrounds (scintillation only) from signal photon/electron interactions

Reduced backgrounds will improve search sensitivities on previous slide.

Requires extensive simulation and ML training on LANL's Chicoma open supercomputer.

These advanced techniques will be ported over to SBND

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Office of Science

CCM@LANL Highlights and Summary

- Completed four-year beam run (2022-25) collecting 0.9E22 Protons on Target (POT) – 60% of original goal.
- **To date CCM has six physics papers published**
  - *Physical Review Letters* Vol. 129, No. 2 (2022), *“First Leptophobic Dark Matter Search from Coherent CAPTAIN-Mills“* (64 citations).
  - *Physical Review D* 106, 1, (2022), *“First dark matter search results from Coherent CAPTAIN-Mills”* (24 citations).
  - *Physical Review D* 107, 9, (2023), *“Prospects for Detecting Axionlike Particles at the Coherent CAPTAIN-Mills Experiment”* (24 citations).
  - *Physical Review* D 109, 9, (2024) , *“Testing Meson Portal Dark Sector Solutions to the MiniBooNE Anomaly at CCM”.*
  - Phys. Rev. D 112, no.7, (2025) “Measurement of the liquid argon scintillation pulse shape using differentiable simulation in the coherent CAPTAIN-Mills experiment”.
  - Phys. Rev. Lett. 135, no.17 (2025) “First Event-by-Event Identification of Cherenkov Radiation from Sub-Mev Particles in Liquid Argon”.
- Applying improved ML and Cerenkov light reconstruction fitter analysis to 2022-2025 beam data set. Expect 2-3 papers on significant search for sub-GeV dark matter, ~MeV scale ALPs, and testing meson portal model solutions to the MiniBooNE anomaly – Final results within the next year!
- Beyond CCM ideas include a 100-ton fast Scintillation/Cerenkov detector based on successful CCM design at a stopped pion source such as LANL, SNS, or FNAL.

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Note scaled down run but still very successful!

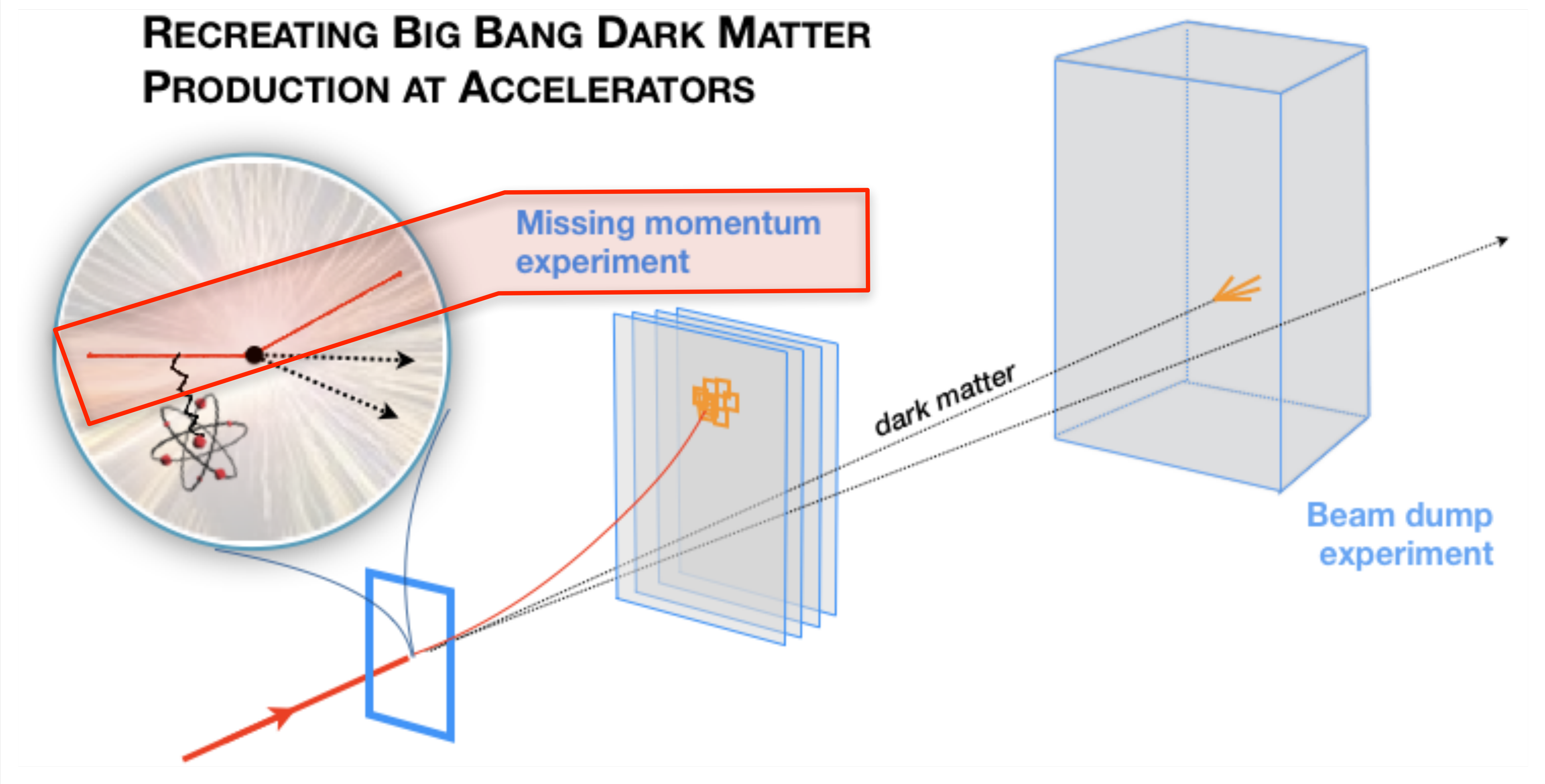
Dark Matter New Initiatives Basic Research Needs: Priority Research Direction 1

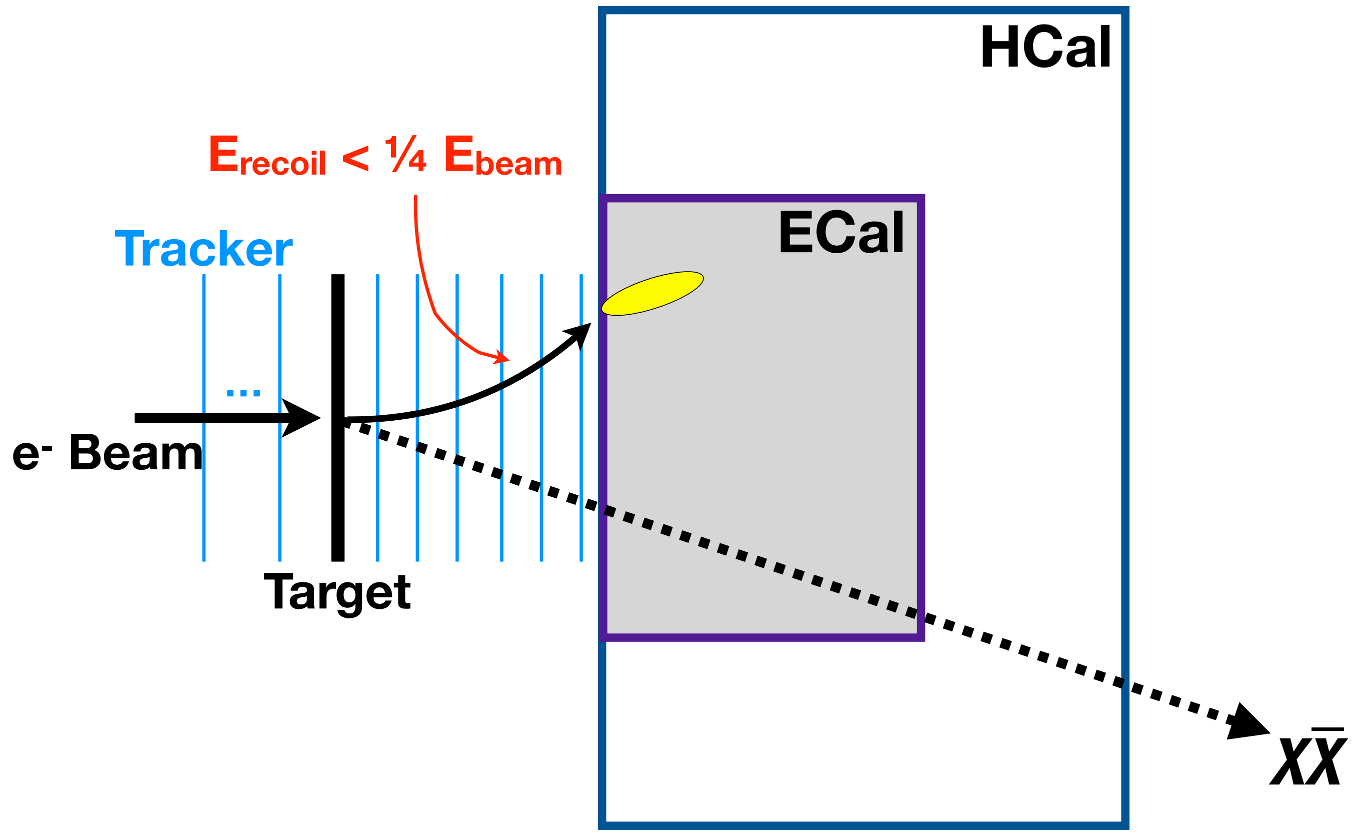
From: T. Nelson (SLAC)

LDMX

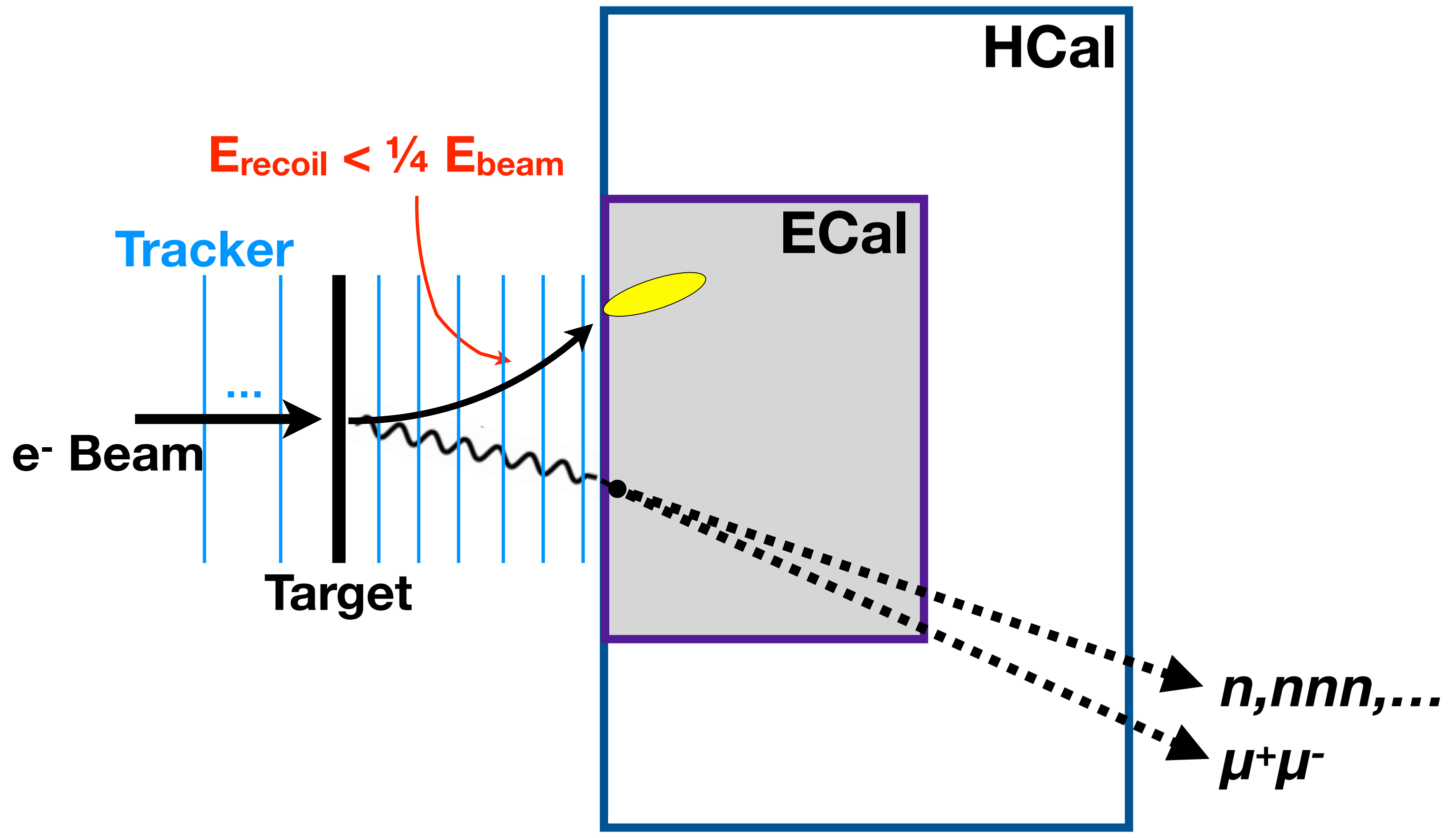
Thrust 1 (near term): Through 10- to 1000-fold improvements in sensitivity over current searches, use particle beams to explore interaction strengths singled out by thermal dark matter across the electron-to-proton mass range.

Missing momentum experiments, using modern detectors operating directly in a low-current lepton beam, identify dark matter production events based on the kinematics of visible particles recoiling from the production event. Such experiments in a continuous-wave electron beam offer a path to reach 1000-fold improvement in sensitivity over a broad mass range …





Signal: **only** the low-energy recoil electron



Background: veto on **any** additional activity in event

Light Dark Matter eXperiment

Scaled Pathfinder Ready to Go.

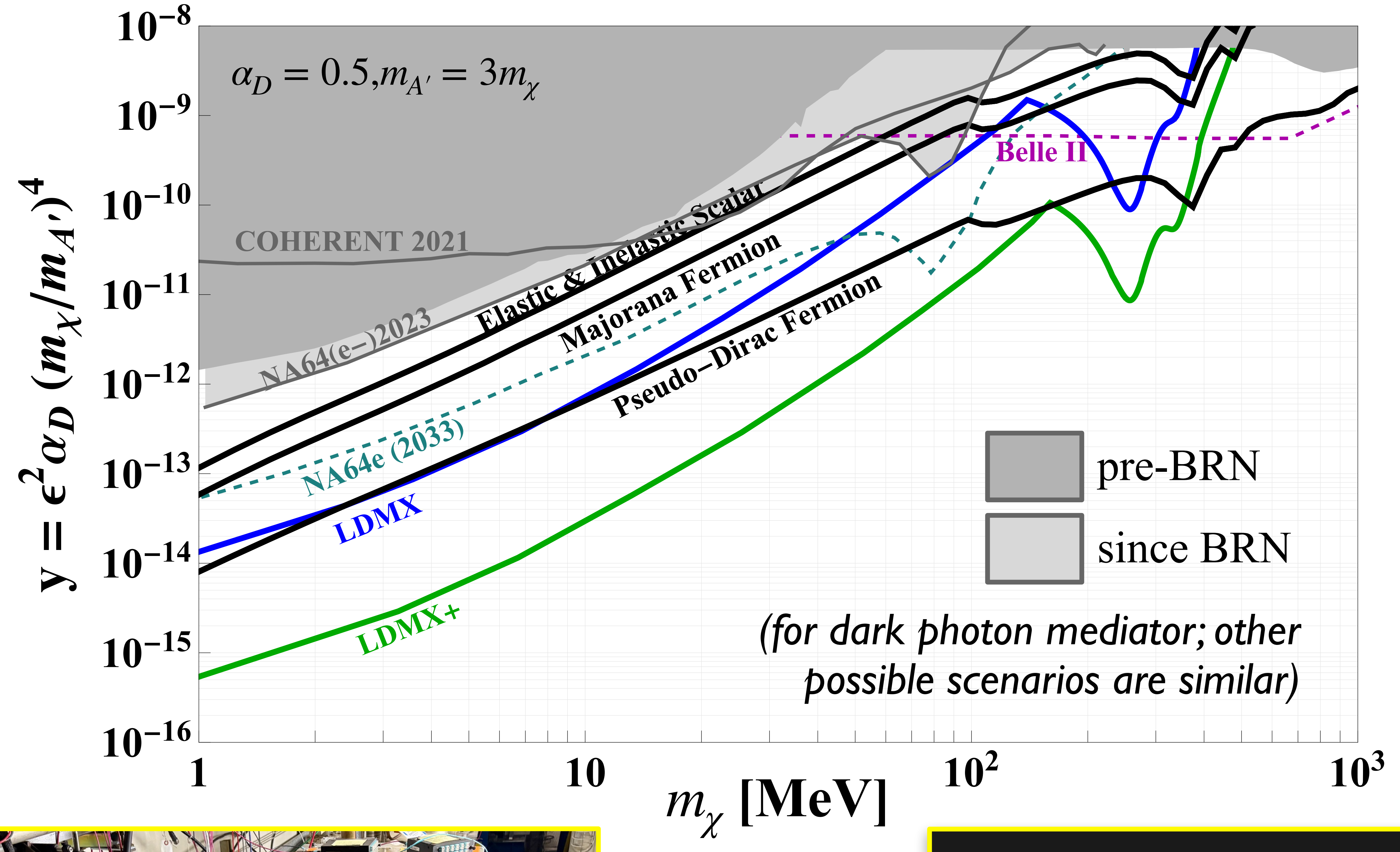
LDMX

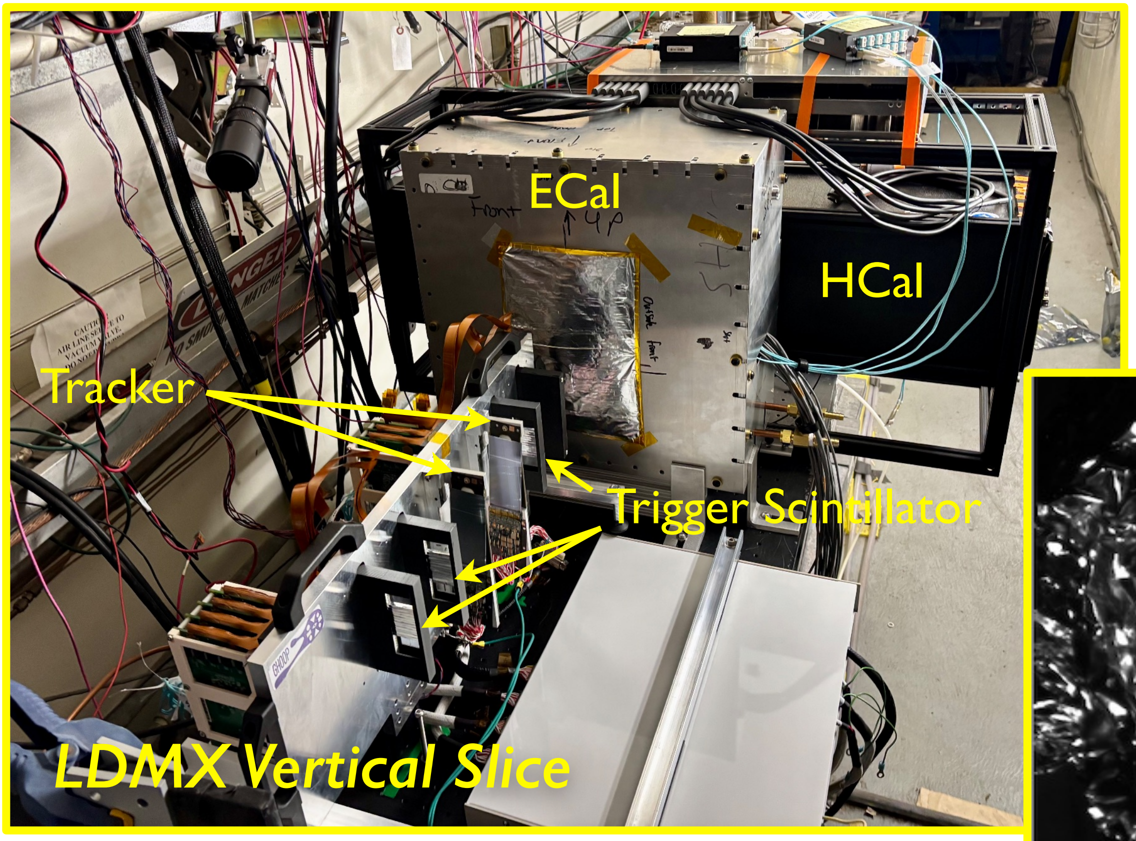
The DMNI BRN emphasized the unique scaling and unparalleled sensitivity of *missing energy/momentum* to light thermal relics. This has become the leading approach.

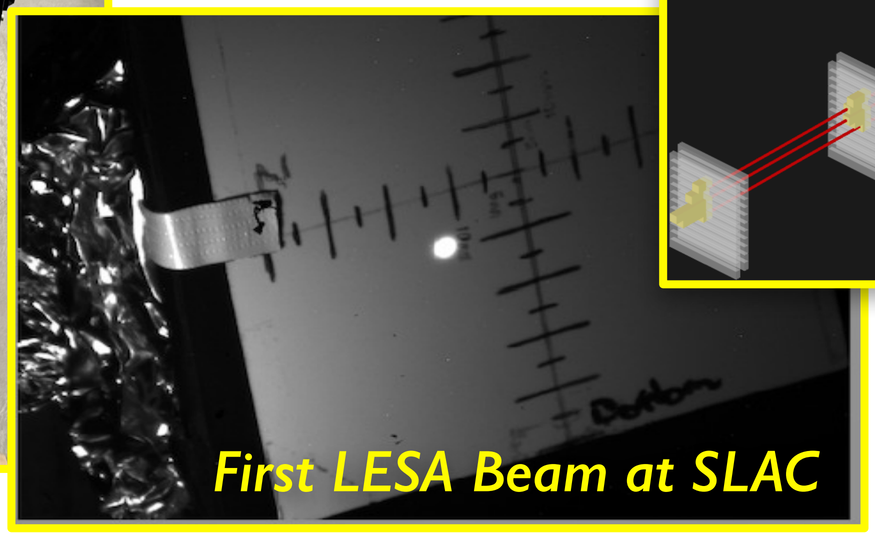
High-rate LESA beam and LDMX detector granularity+ML analysis techniques enable rapid sensitivity gains over competing experiments, as well as a broad program spanning dark sector physics, rare meson decays, and eN scattering measurements for DUNE.

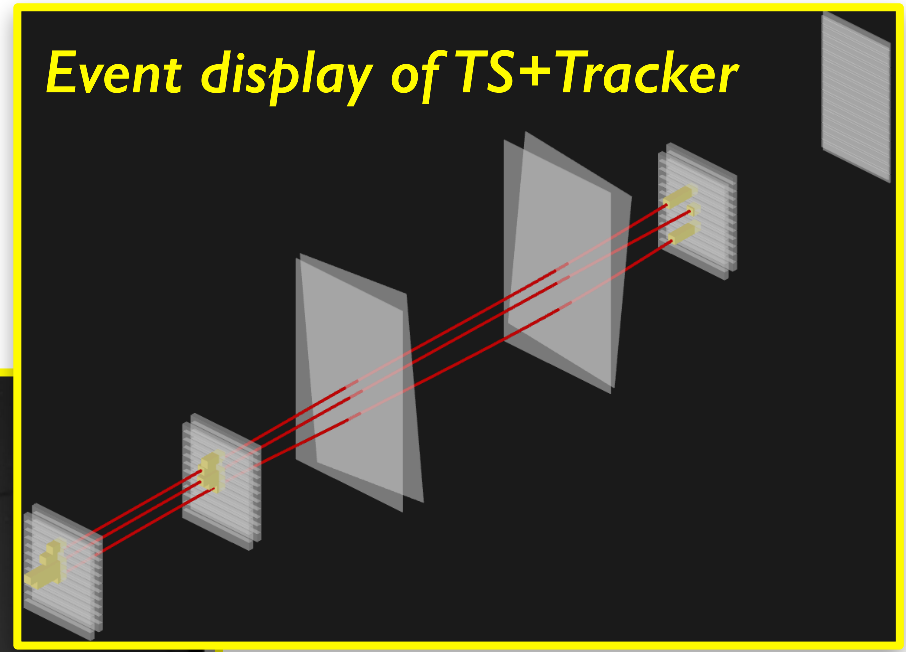
TPC has been cut in half to ~$10M through scope and risk reduction from recent LDMX Vertical Slice test in first LESA beam and much smaller hadronic calorimeter (HCal) required to veto background for a 10% pathfinder experiment, which still has world-leading sensitivity.

A future "LDMX+" upgrade to enlarge the HCal is straightforward and would enable 10x greater sensitivity.

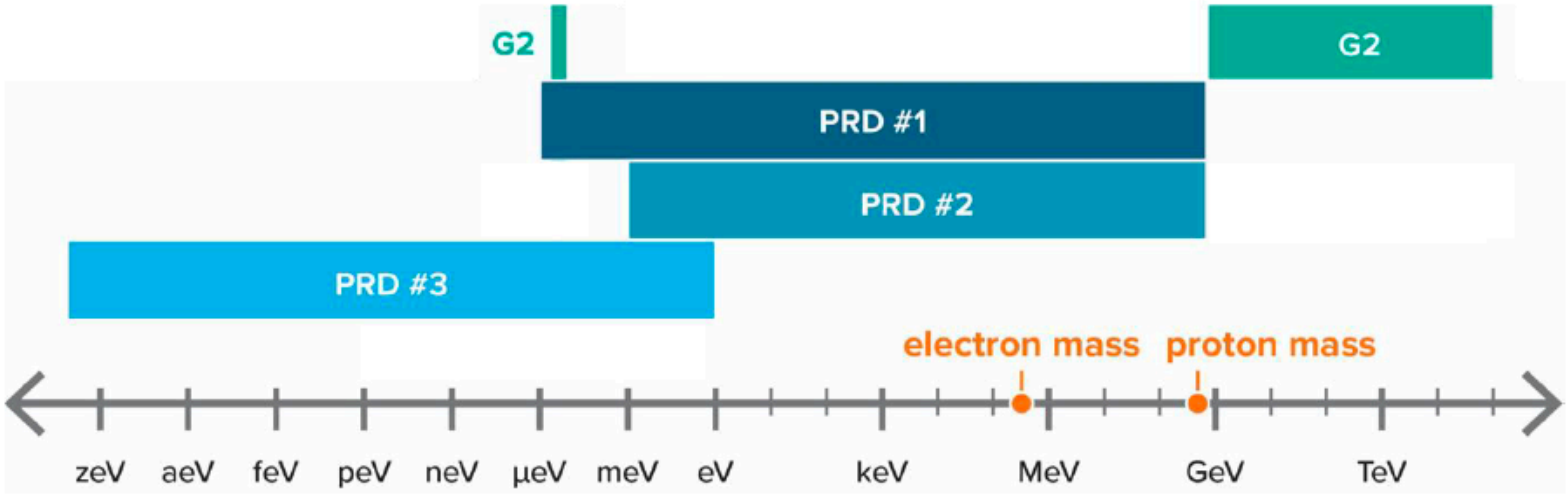








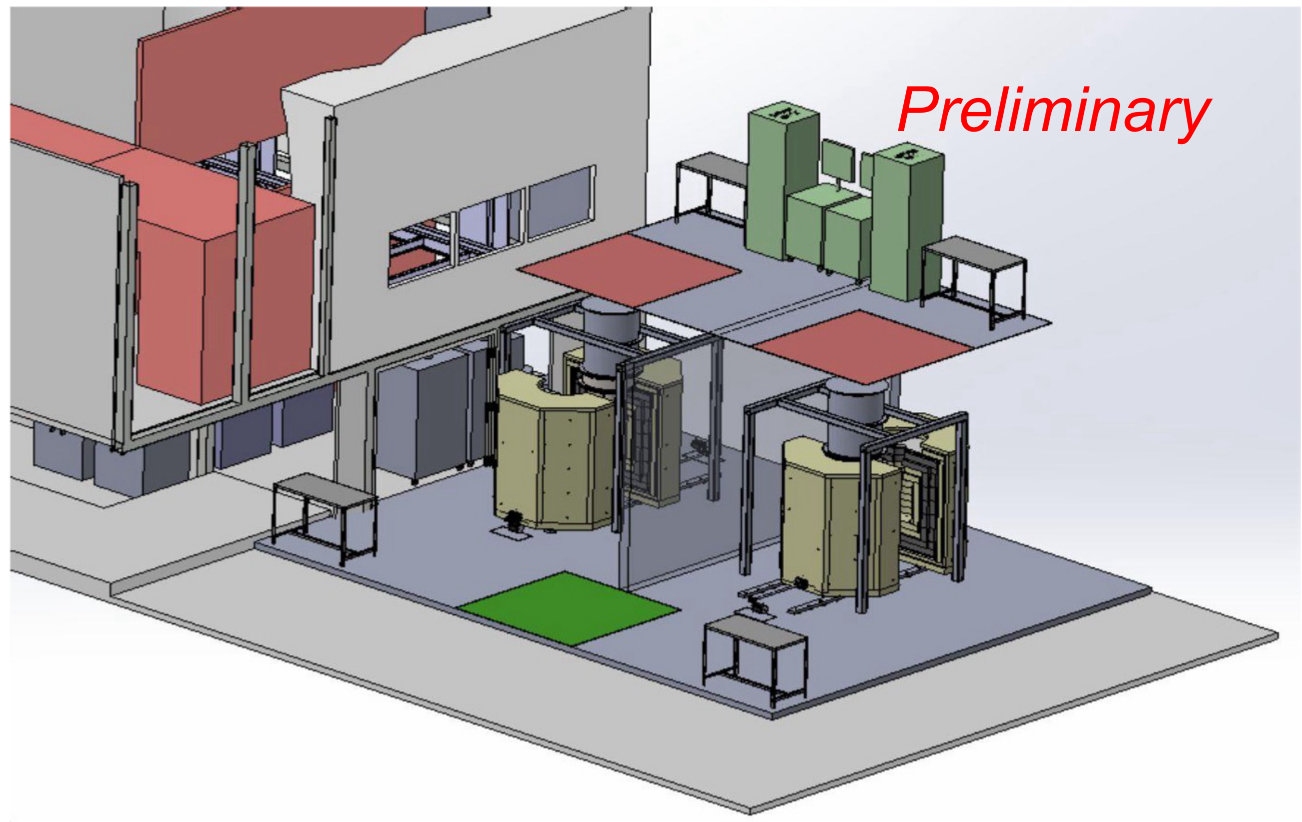
PRD #2 - Detect Dark Matter Underground (Lower Thresholds)



Operations to begin in 2029!

TESSERACT = Transition-Edge Sensors with Sub-eV Resolution And Cryogenic Targets

- Direct searches for light-mass and ultralight dark matter (100 meV – 1 GeV).
- Multiple targets (Superfluid helium, sapphire, gallium arsenide, germanium, silicon) using athermal phonon readout with transition edge sensors.
- Multiple signal channels and coincidence-based background rejection will lead to improved dark matter sensitivity.
- TESSERACT is designed for flexibility and straightforward detector replacement, with a common infrastructure of shielding, cryostat, dilution refrigerator, vibrational decoupler, cold electronics, and DAQ.
- There will be 2 identical setups, each installed underground at Laboratoire Souterrain de Modane (LSM)



TESSERACT has existing detectors with exquisite energy resolution that can provide dark matter science as soon as they are underground in a low-background, cryogenic setup.

DOE-HEP and CNRS Nuclei & Particles are allocating equipment, postdocs, students, and permanent staff working on the project. Switzerland (SNSF) is also supporting TESSERACT research.

In July 2025 TESSERACT passed a DOE gateway review, shepherding TESSERACT into the Project phase, with approval to start purchasing major equipment. The TESSERACT Operations Phase will begin in 2029.

TESSERACT Collaboration Meeting, LPSC Grenoble, May 2026

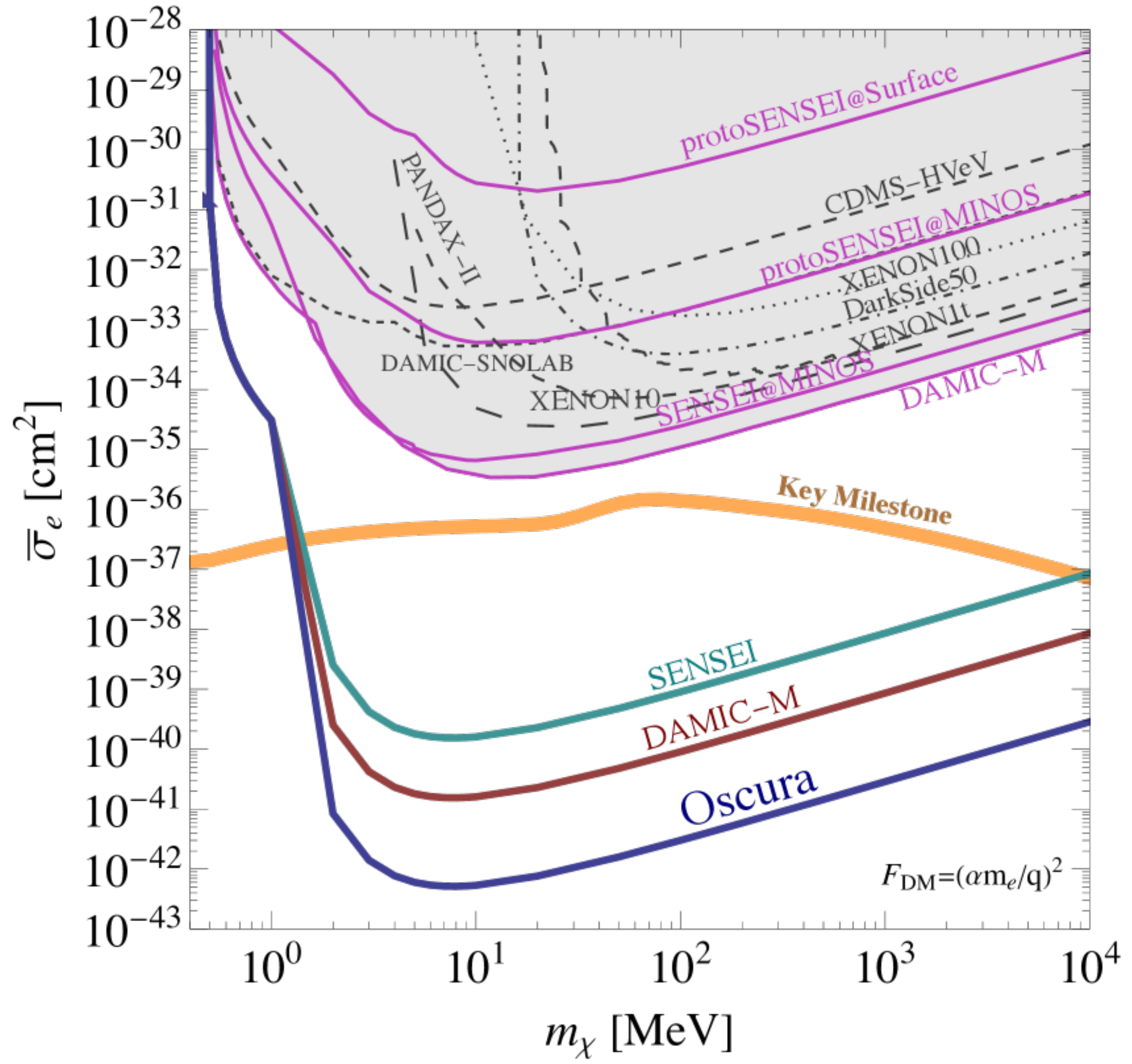
OSCURA: future of Skipper CCDs for dark matter

OSCURA is the 10kg scale-up of skipper CCDs for sub-GeV dark matter. Skipper CCDs have produced leading limits with gram-scale detectors and kilogram-day exposures. OSCURA brings the same single-electron threshold to a 0.01dru, 30kg-year search at SNOLAB.

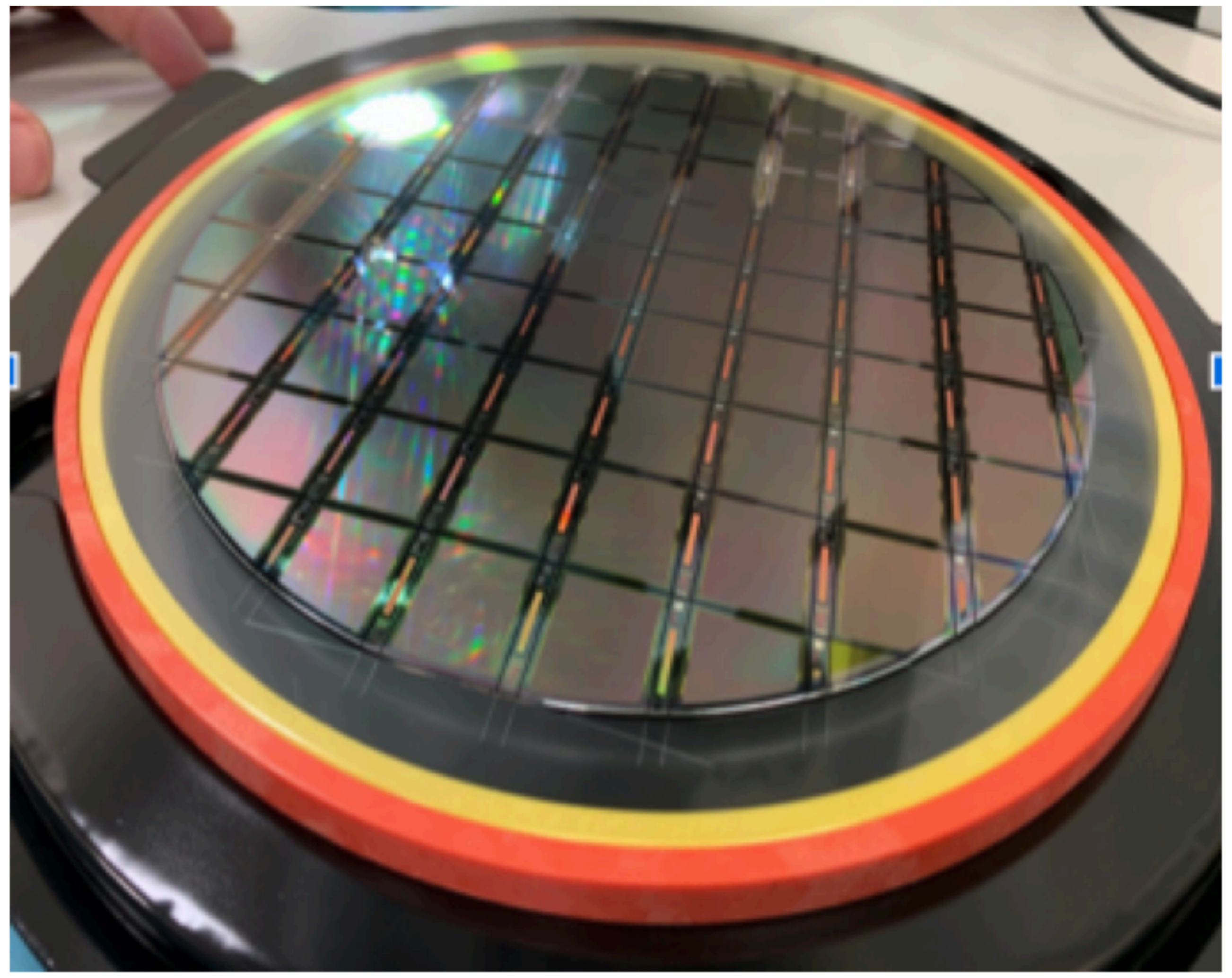
The experiment is ready to build. Sensors exist. Space at SNOLAB exists. Multi-chip modules (MCMs), low-background packaging, cold readout electronics R&D completed.

The scale-up path is now practical. Commercial-foundry Skipper CCDs have been fabricated and tested. Robotic wire bonding and MCM assembly are being developed at BNL, path to the first fully robot-assembled dark matter experiment.

OSCURA was not chosen in the DOE DMNI down-select. This leaves the U.S. without a clear path to a multi-kg Skipper CCD program, despite mature technology, demonstrated performance, and world-leading sub-GeV reach. **Remains a high-impact small-experiment opportunity.**



JINST 18 P08016 (2023)



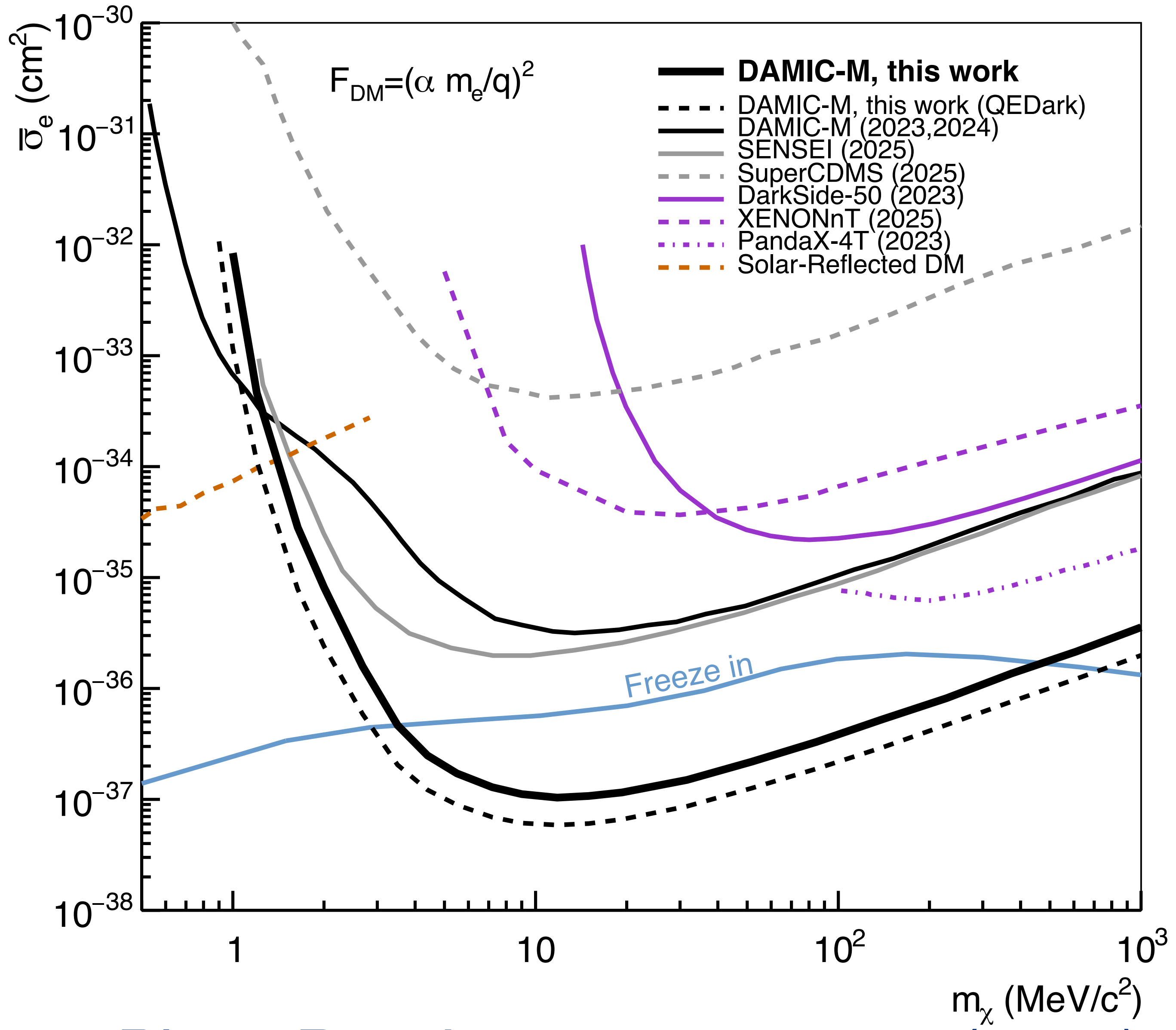
DAMIC-M: near-term discovery reach for light DM

DAMIC-M is the leading low-background skipper CCD experiment for sub-GeV dark matter. Prototype data at LSM already produced world-leading constraints and excluded benchmark hidden-sector freeze-in targets with only kilogram-day exposures.

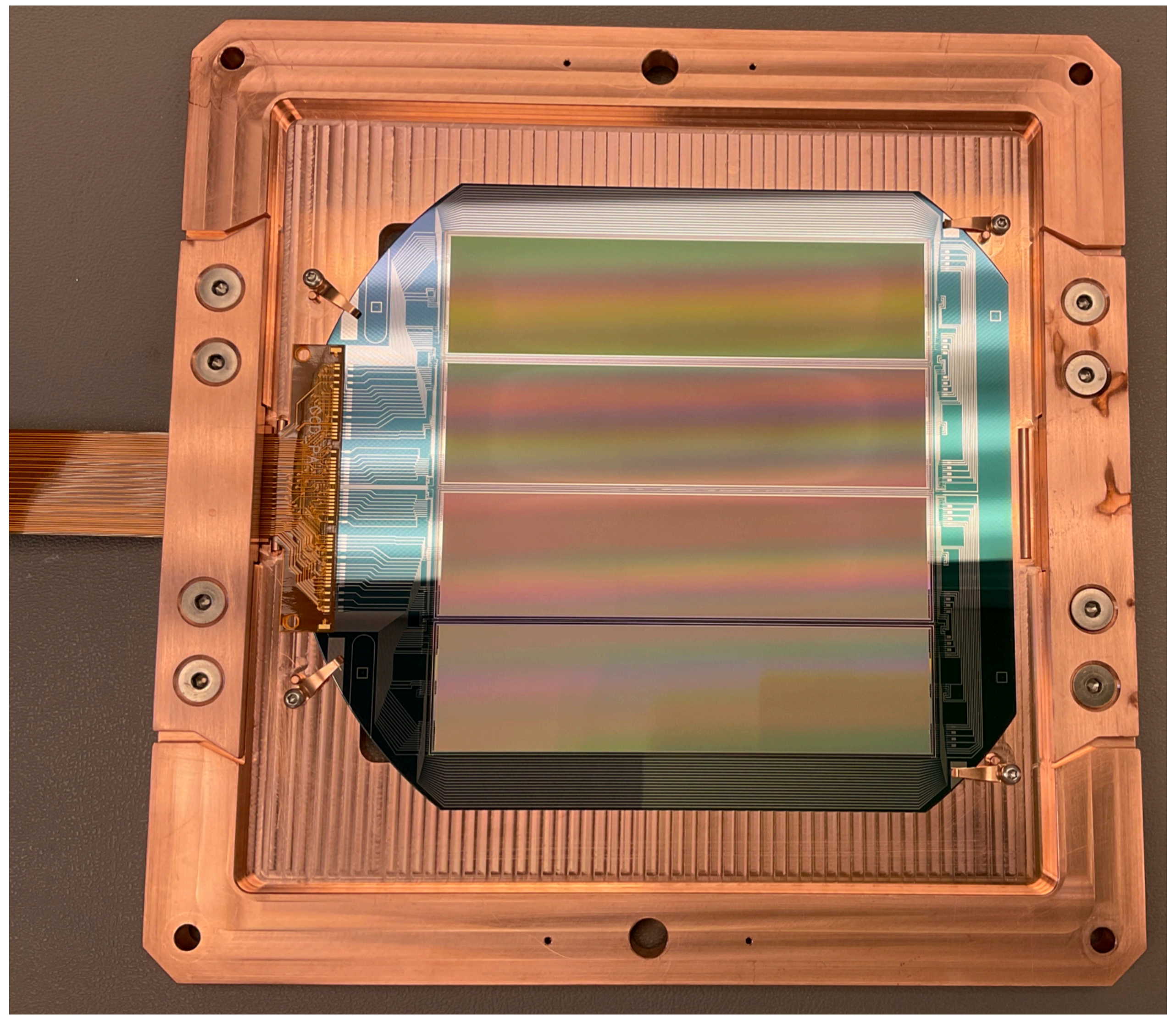
The full detector is not a concept: the CCDs have been produced and tested. 26 modules have been packaged, about 350g active mass, and tested underground. Planned for operation by end 2026.

The technology is uniquely powerful at threshold. Single-electron charge resolution provides eV scale energy thresholds, while 15 um spatial resolution provides 3D event reconstruction and background rejection (e.g., crystal defects that dominate the dark current) that non-imaging detectors cannot duplicate

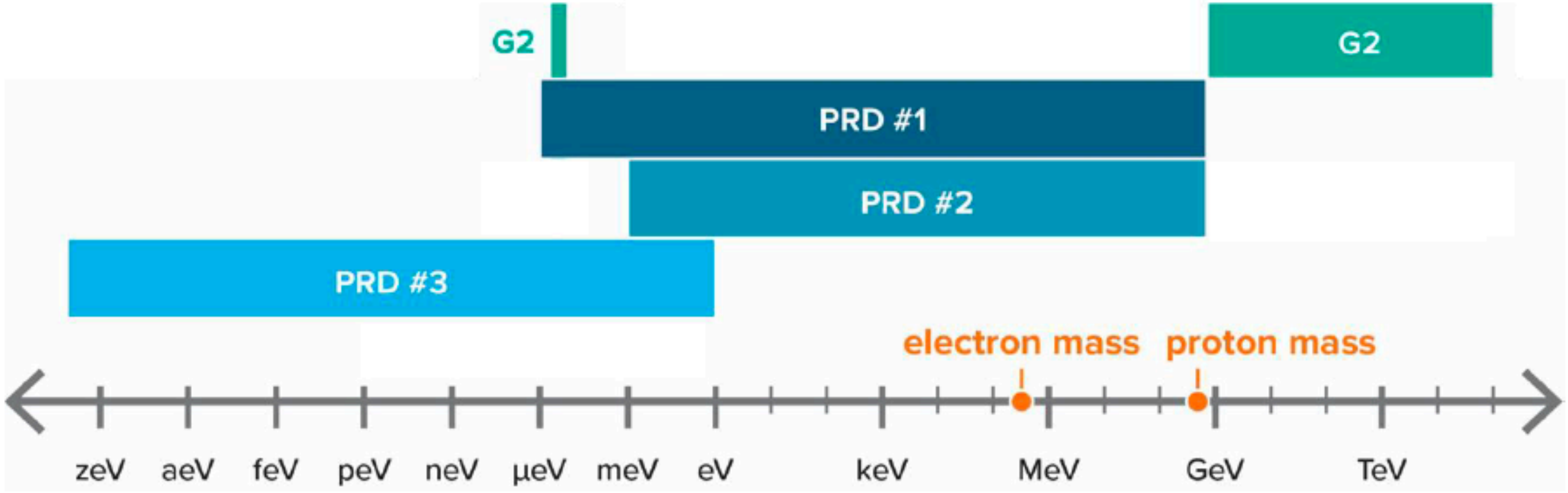
DAMIC-M is a near-term discovery opportunity that should be protected in the small-experiments portfolio. It is already underground and demonstrated rapid progress by uncovering several orders of magnitude of sub-GeV parameter space in recent years.



Phys. Rev. Lett. 135, 071002 (2025)



PRD #2 - Detect Wave Dark Matter in the Lab



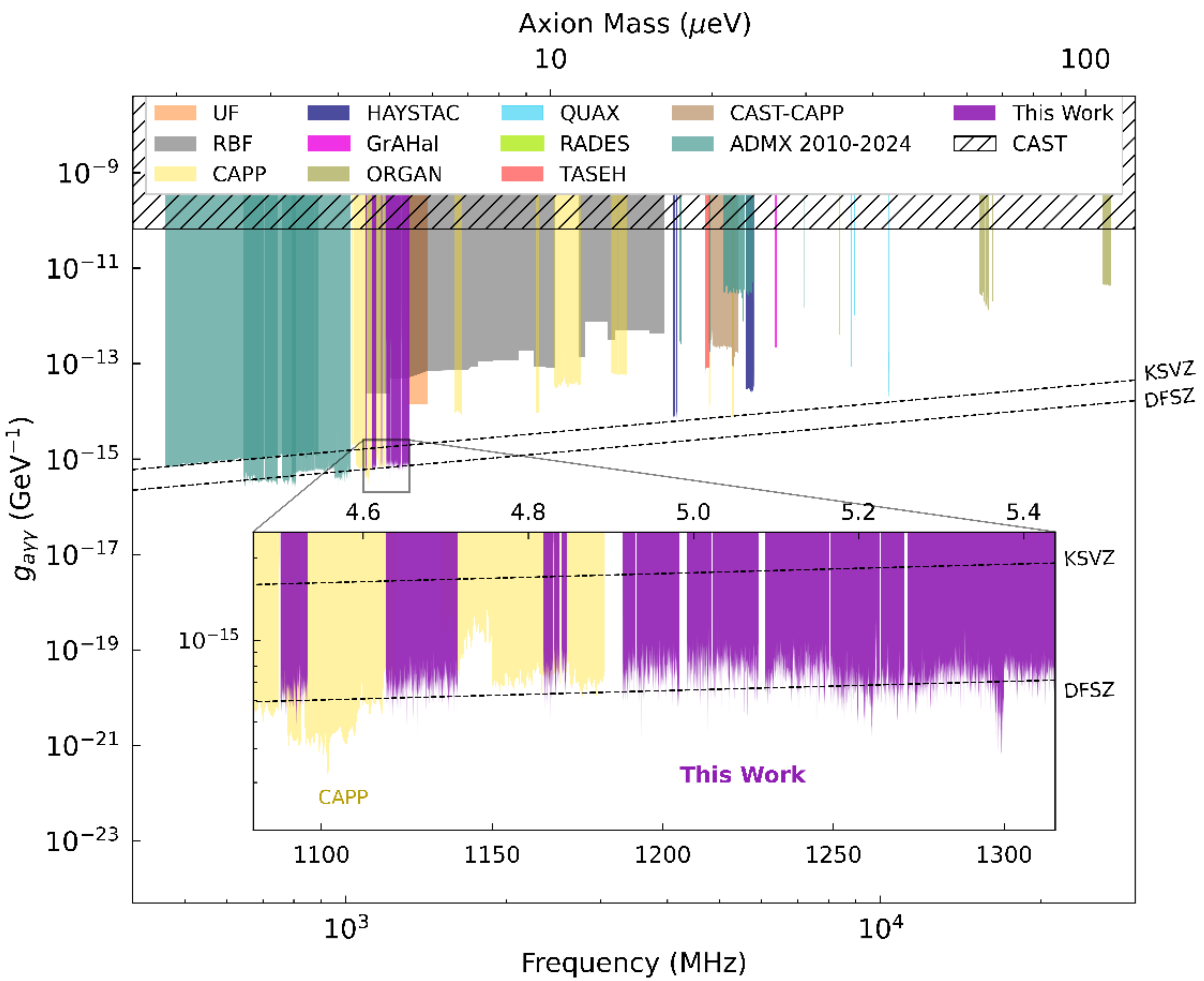
ADMX G2 is running.

ADMX 2024

Over the range explored:

KSVZ Axion Model at nominal dark matter density excluded at 90% confidence between 1 GHz and 1.3 GHz

DFSZ Axion Model at slightly higher densities excluded



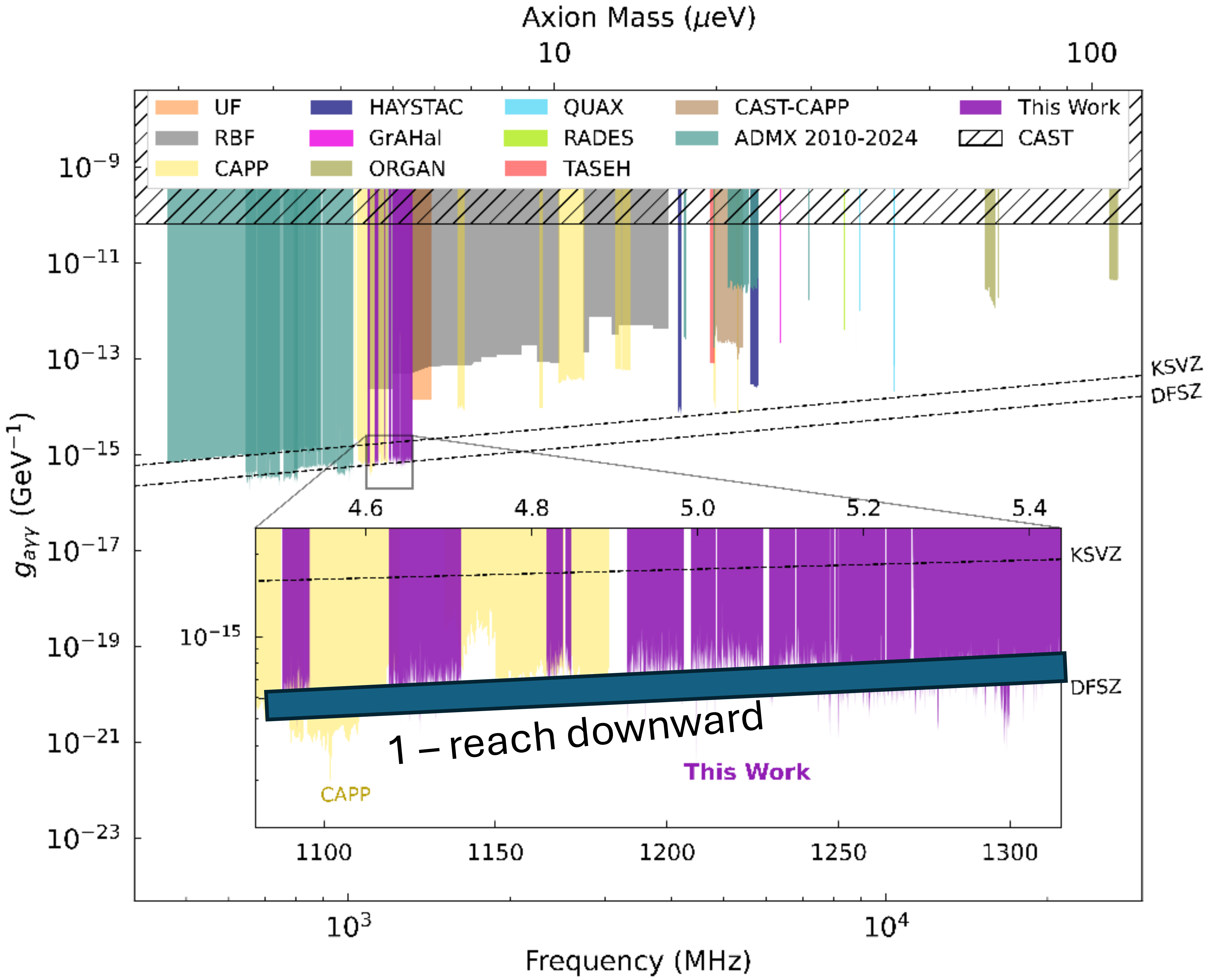
Carosi et al. PRL (2025) https://arxiv.org/abs/2504.07279

ADMX 2026

Plan: Extend reach down to DFSZ at below-nominal dark matter density

Method: Improve amplifiers to lower system noise temperature.

Status: Data taking began January 2026, though currently fixing magnetic field fault



Rybka – DMNI Report - 2026

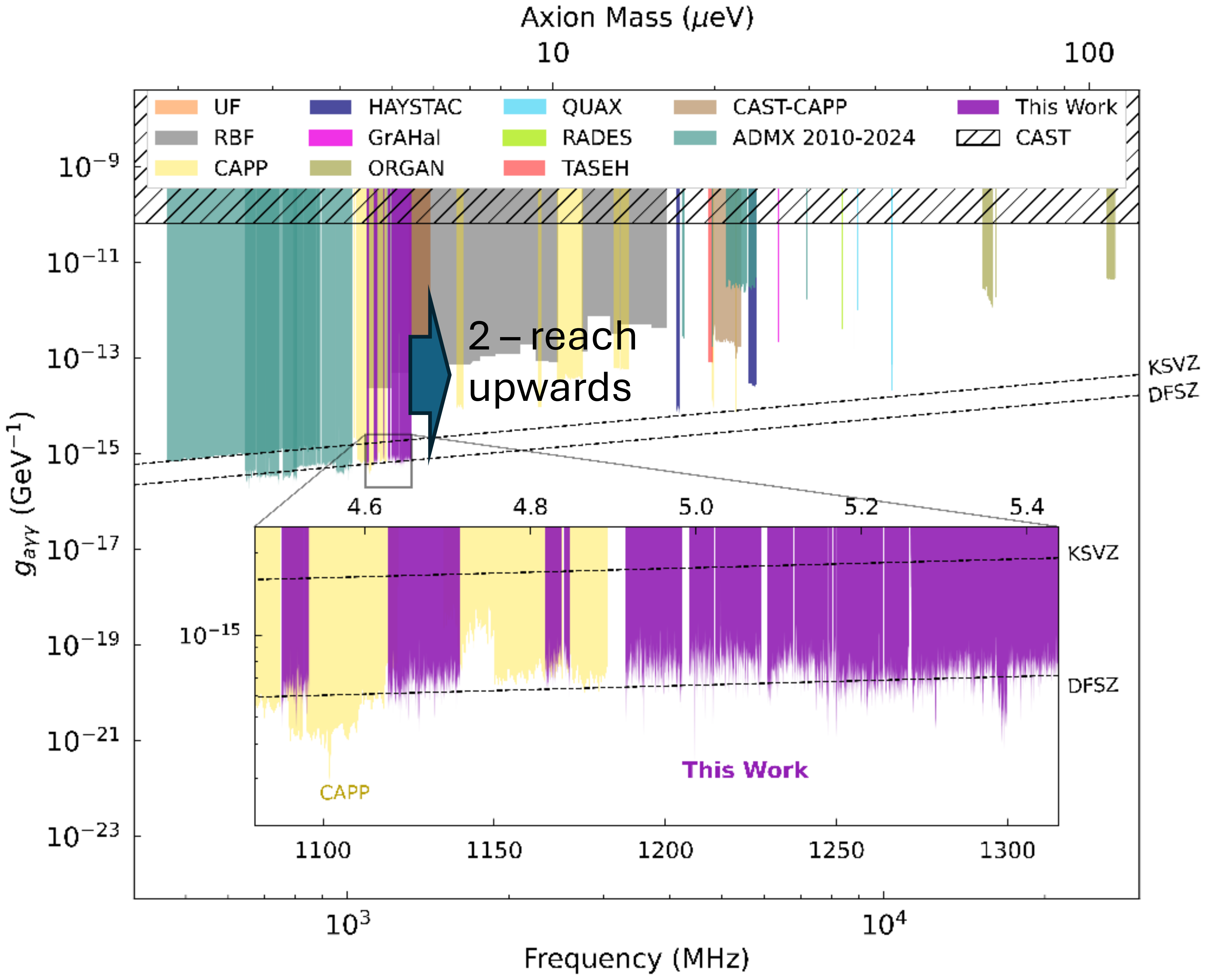
Go to higher frequencies within current infrastructure.

ADMX Near Future

Beyond next year:

Goal: Extend sensitivity to higher masses using a multicavity system

Method: Multiple cavity system

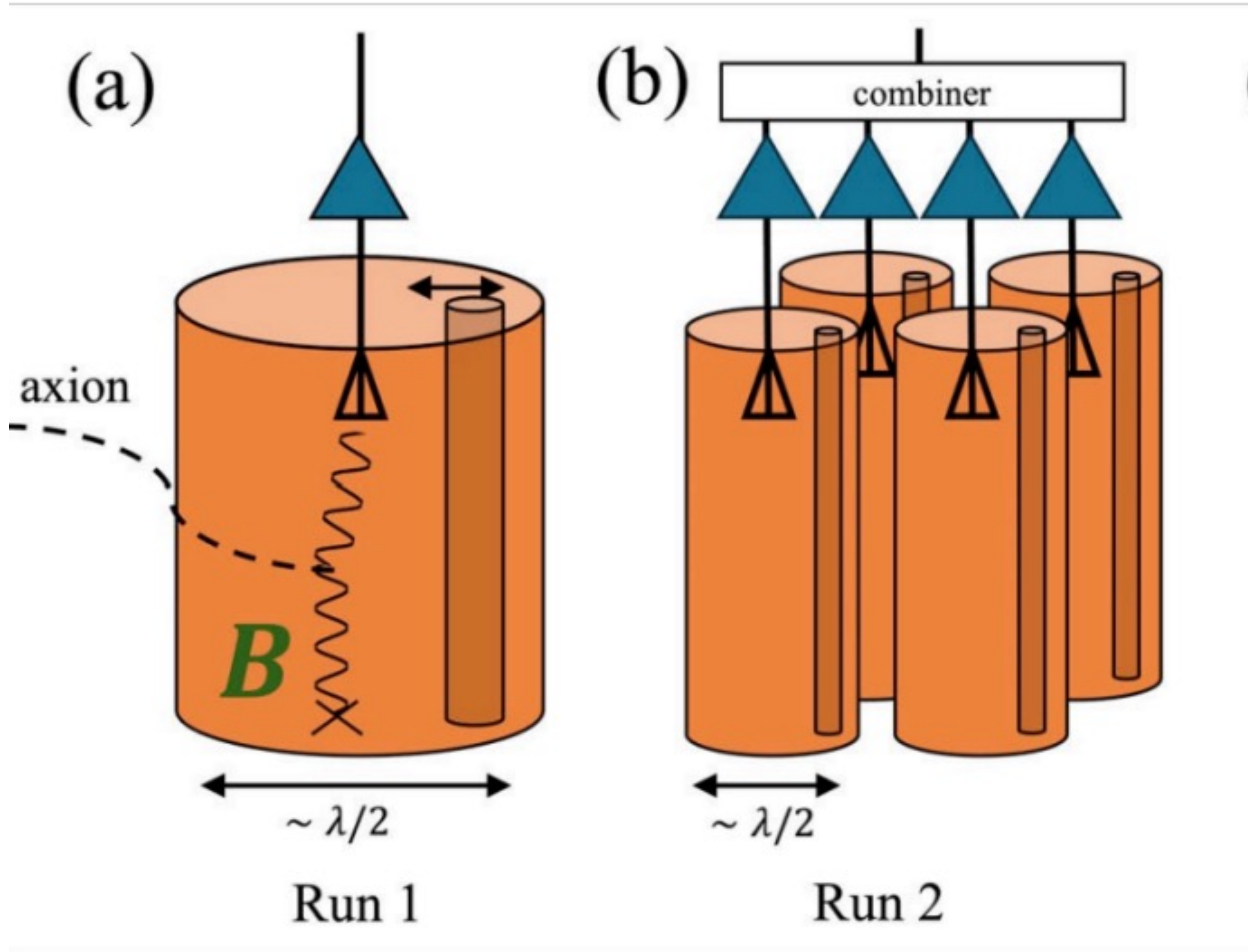


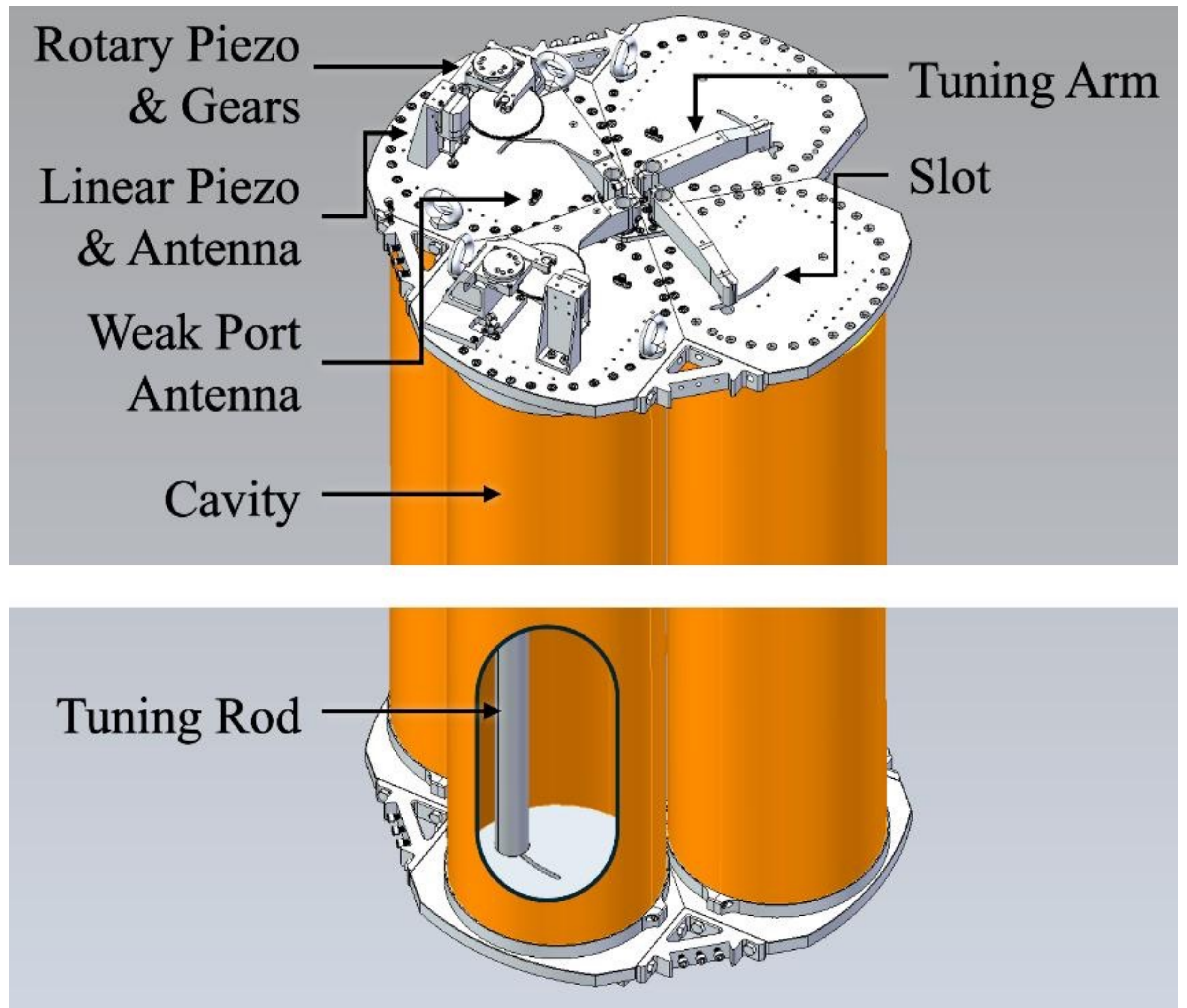
Rybka – DMNI Report - 2026

Go to higher frequencies within current infrastructure.

ADMX 4-cavity system

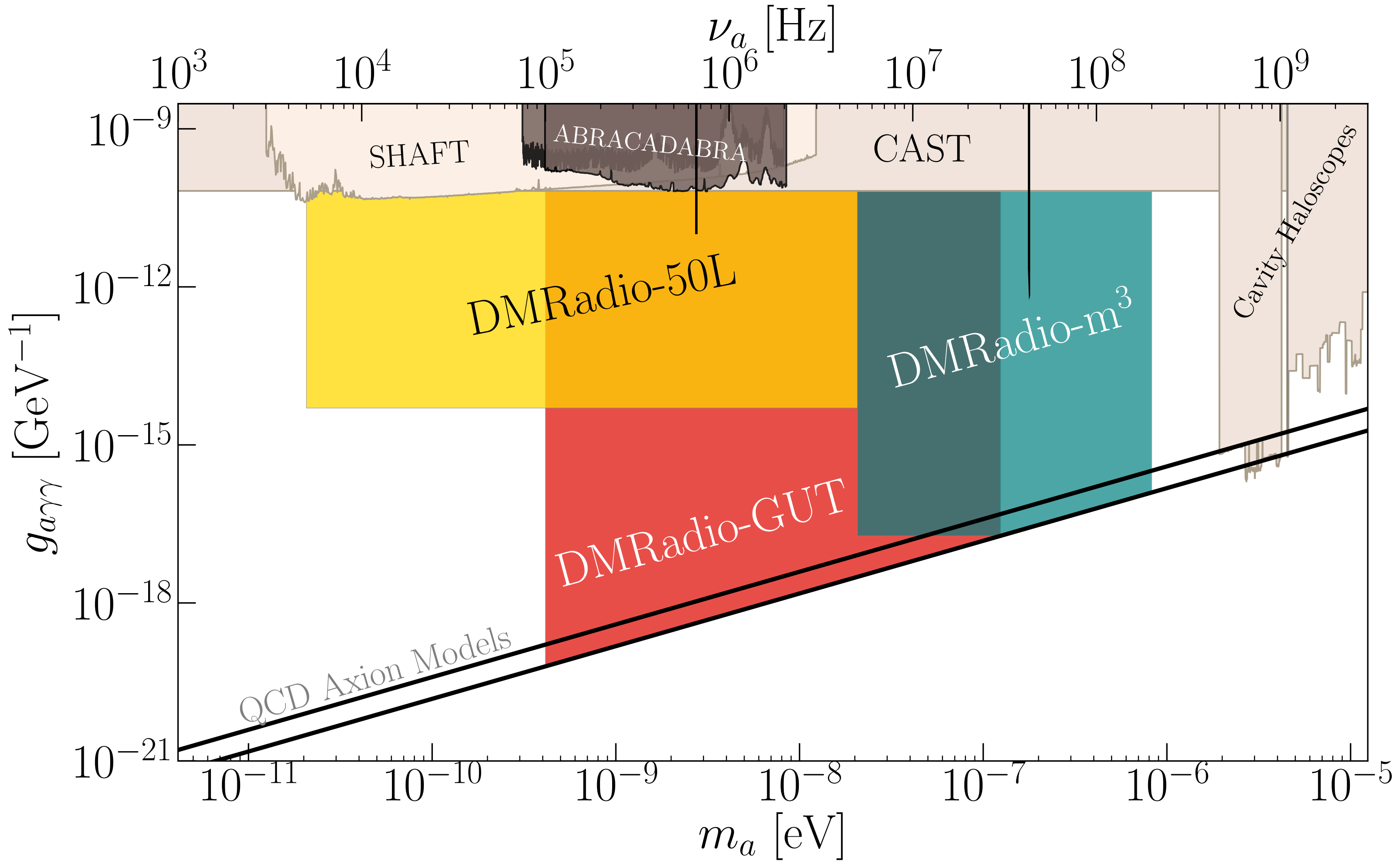
- Reach higher frequencies with multiple resonators
- Maintain axion conversion volume with multiple cavities
- Challenge: coherent signal combining between cavities

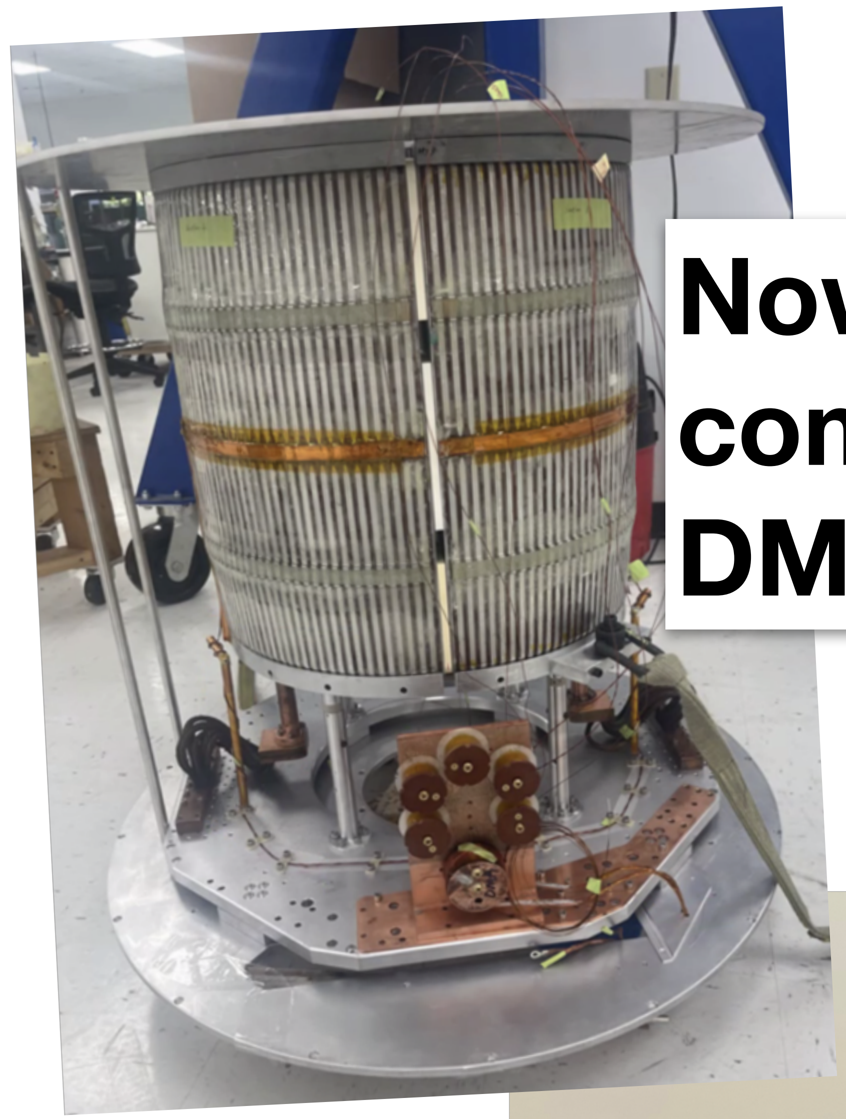




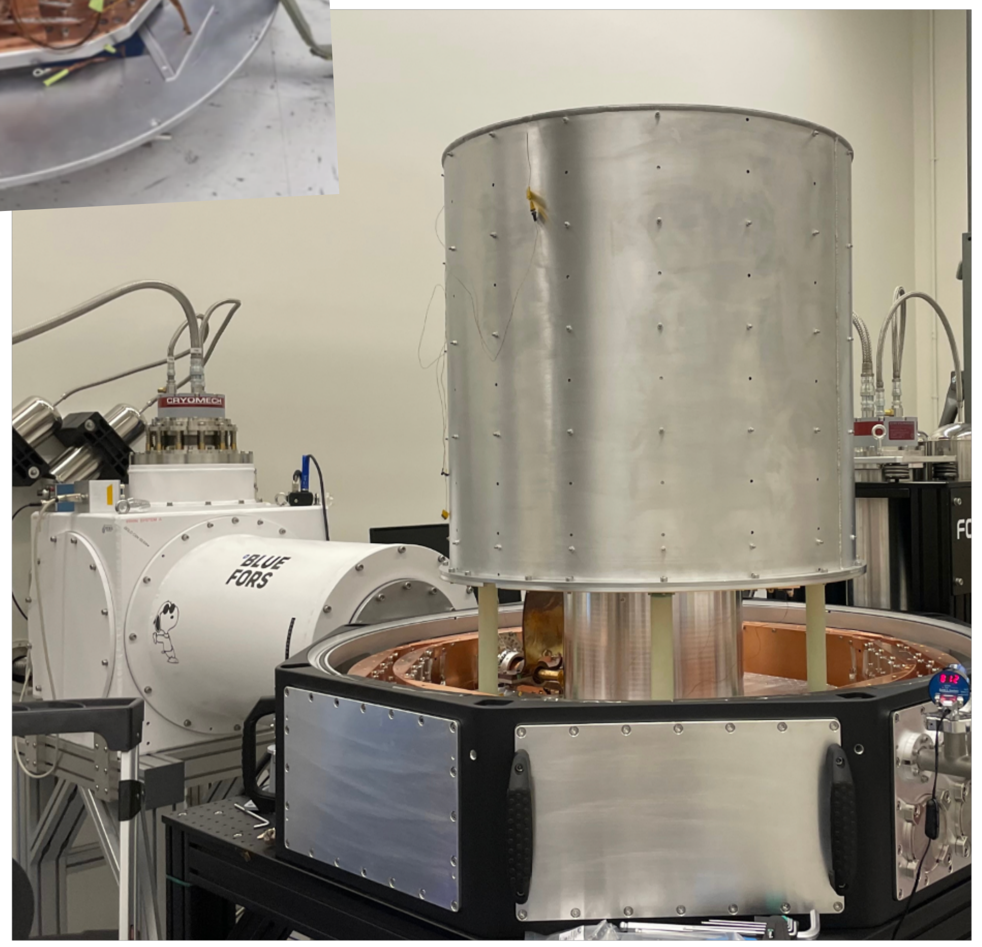
Rybka – DMNI Report - 2026

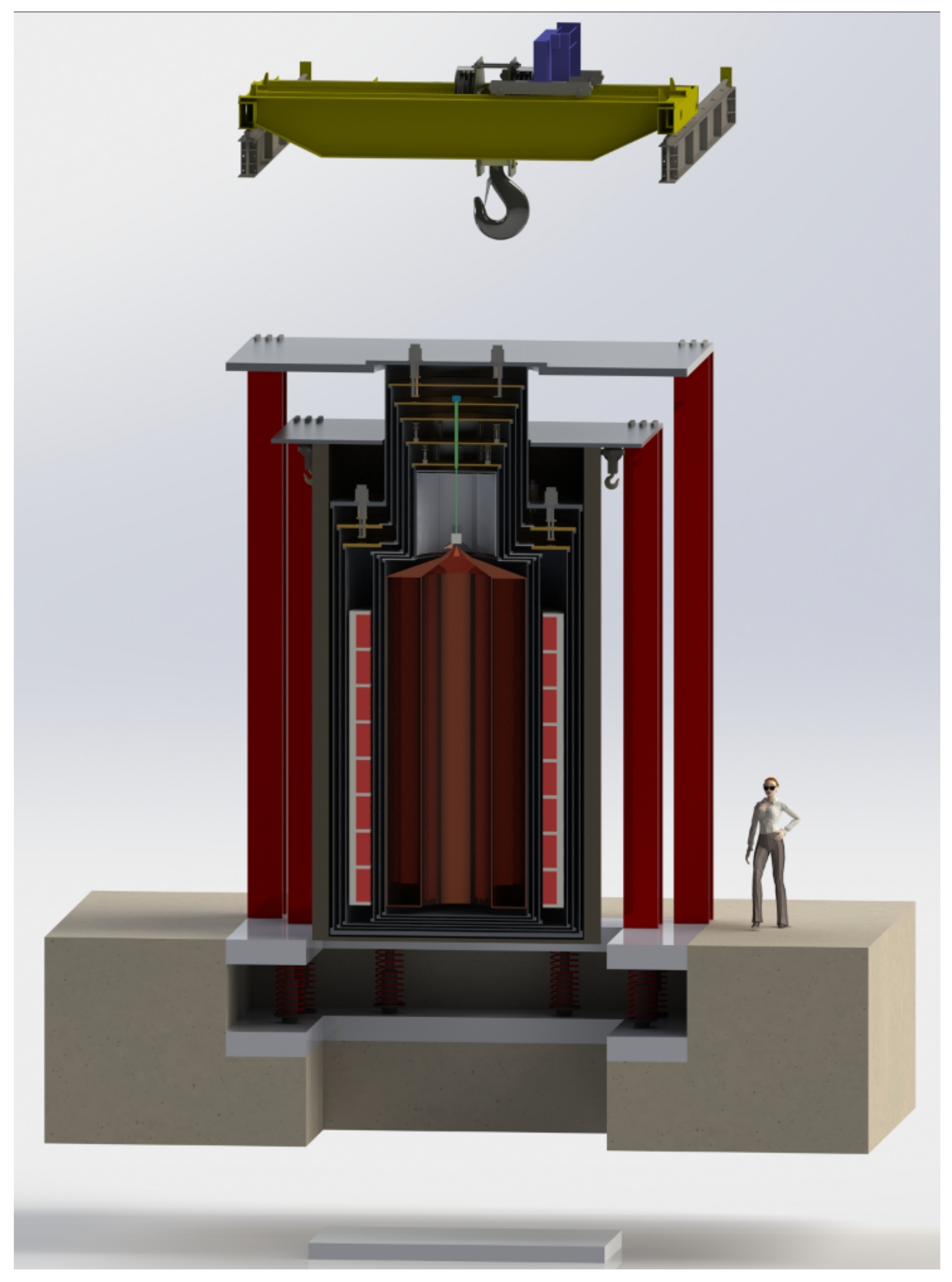
The DMRadio Program





Now commissioning DMRadio-50L





A program to make a definitive search for GUT-scale axions and find a pre-inflation relic!

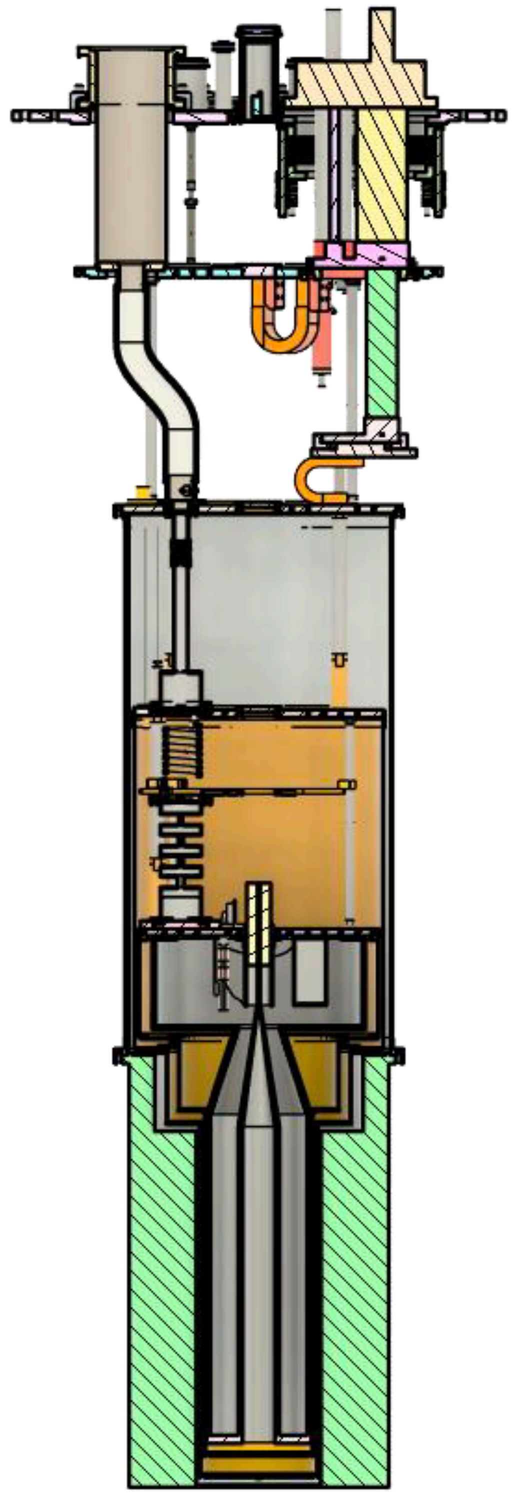
SLAC NATIONAL ACCELERATOR LABORATORY · MIT · Stanford University · Berkeley UNIVERSITY OF CALIFORNIA · KIPAC · PRINCETON UNIVERSITY · BERKELEY LAB · SANTA CLARA UNIVERSITY 1851 · GORDON AND BETTY MOORE FOUNDATION · NSF · U.S. DEPARTMENT OF ENERGY Office of Science · HEISING-SIMONS FOUNDATION

While working on a staged R&D program for DMRadio-GUT.

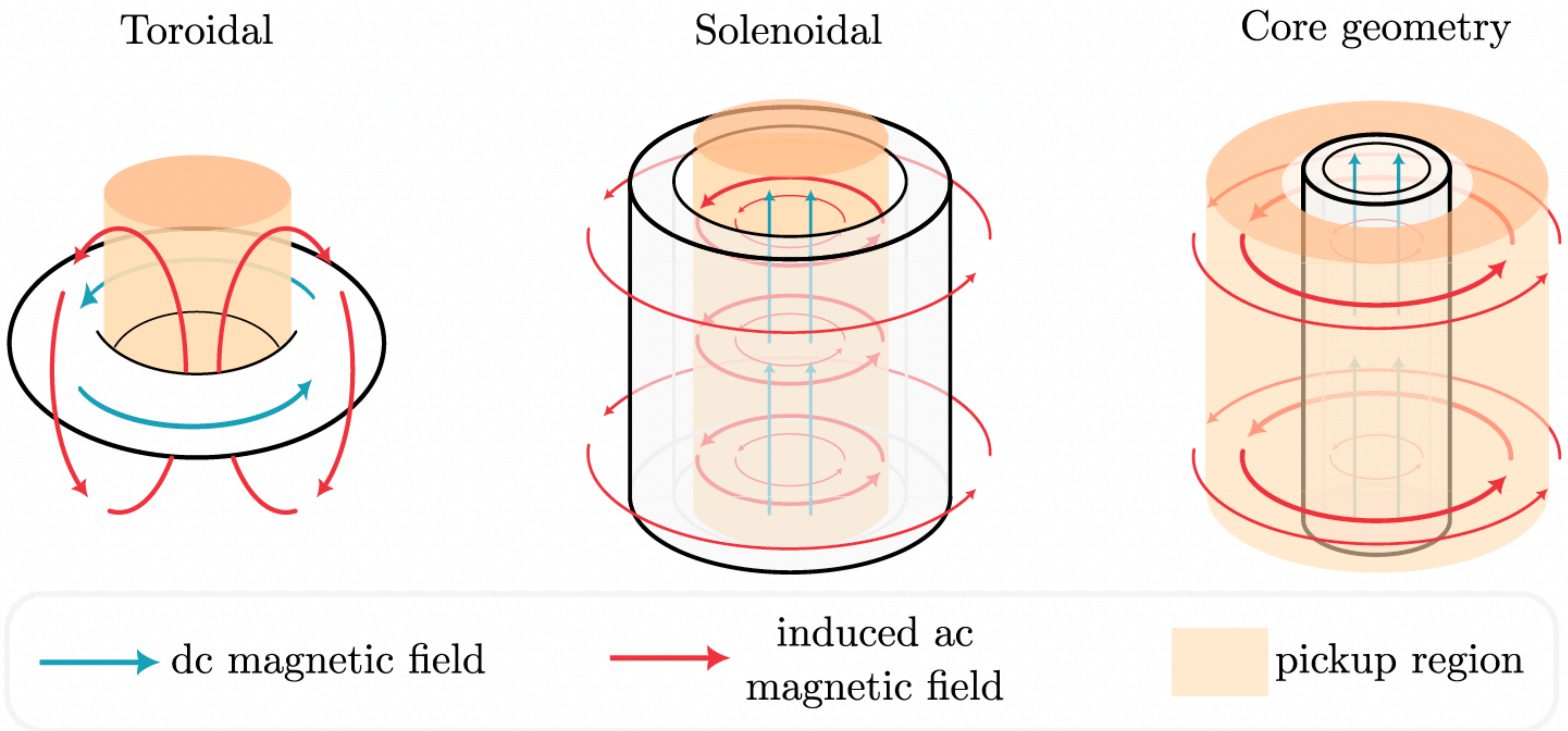
The DMRadio Program

Before 2029:
A more modest scan in the DMRadio-m³ parameter space with the CAL-Pathfinder.

a DMRadio experiment



In 2029:
Be ready with a full project execution plan for a larger experiment including a detailed alternatives analysis.



See ArXiv:2604.16602 for recent work on the DMRadio-Core geometry.

Summary

- This portfolio of experiments is very strong. It has produced physics results and matured concepts into full projects.

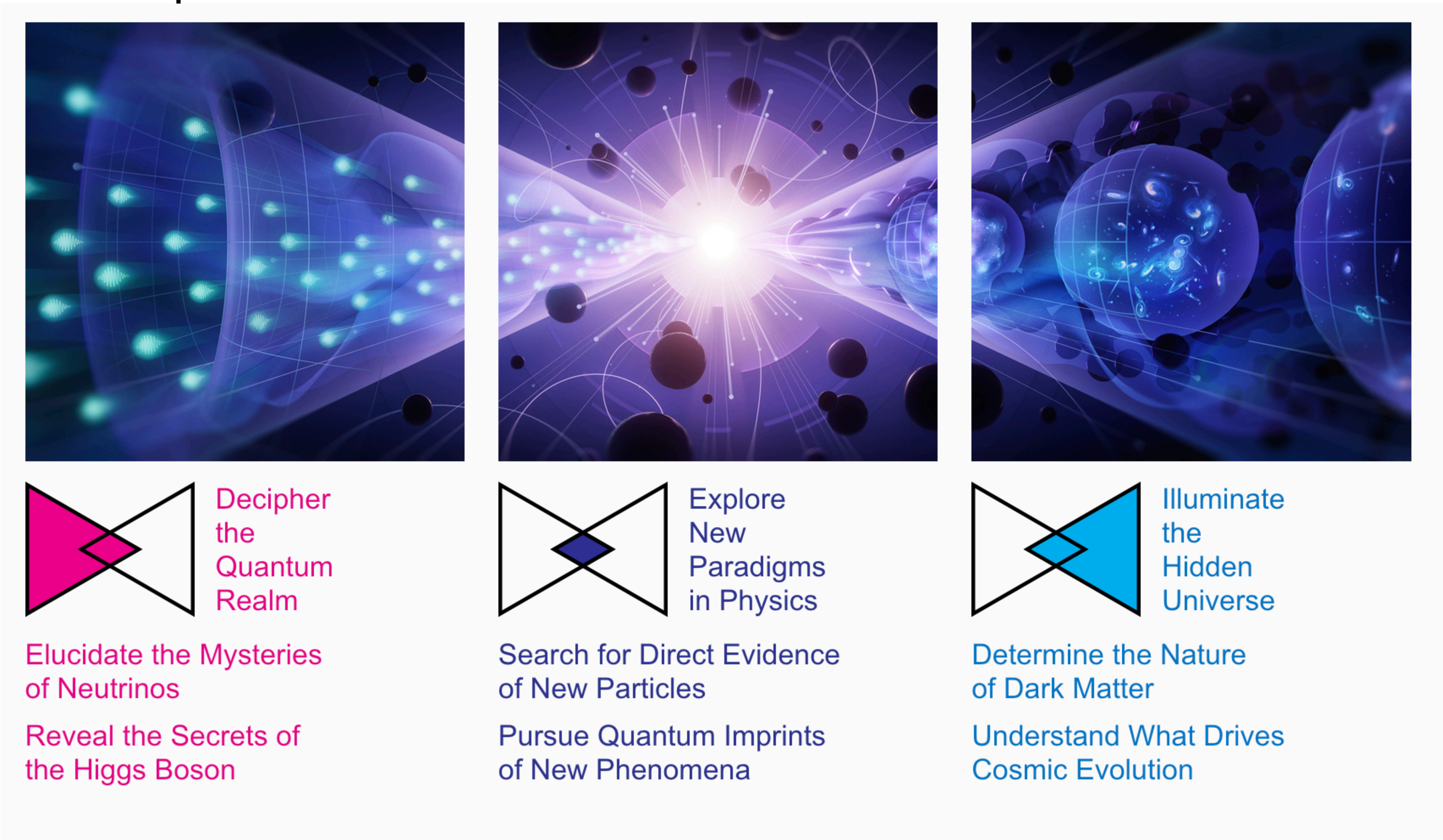
- The excitement in the community has not waned and new ideas to tackle even more difficult parameter space continue to mature.

- Collaboration continues to be key, even at this smaller scale, both internationally and across funding bodies.

- Ultimately, flexibility is key, flexibility in the scale and budget, flexibility in the reach, flexibility in the collaboration.

Final Thoughts

P5 Report: arXiv2407.19176

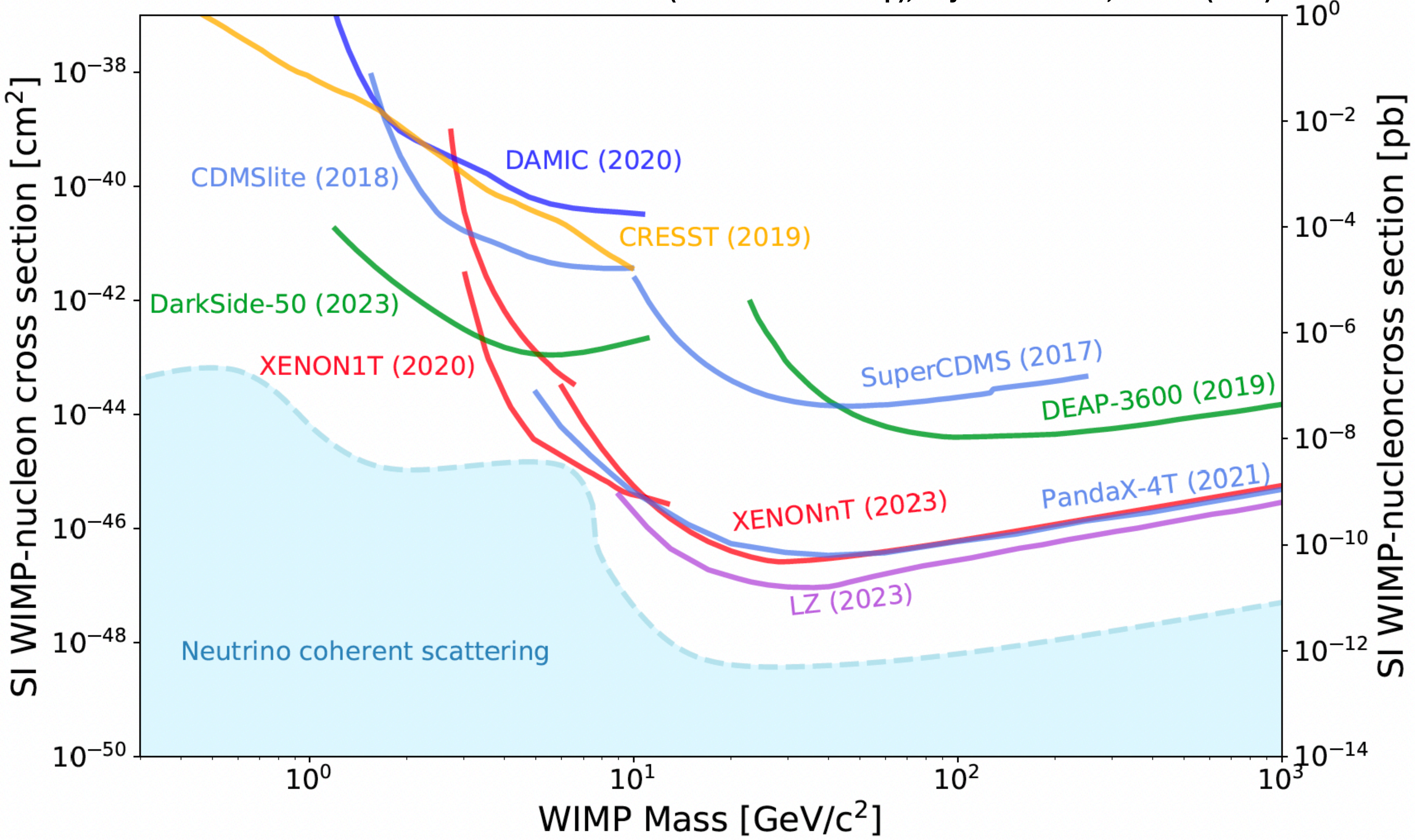


*Small experiments are needed for discovery across **HEP (and NP - HENP)**, as either auxiliary measurements or discovery machines in their own right.*

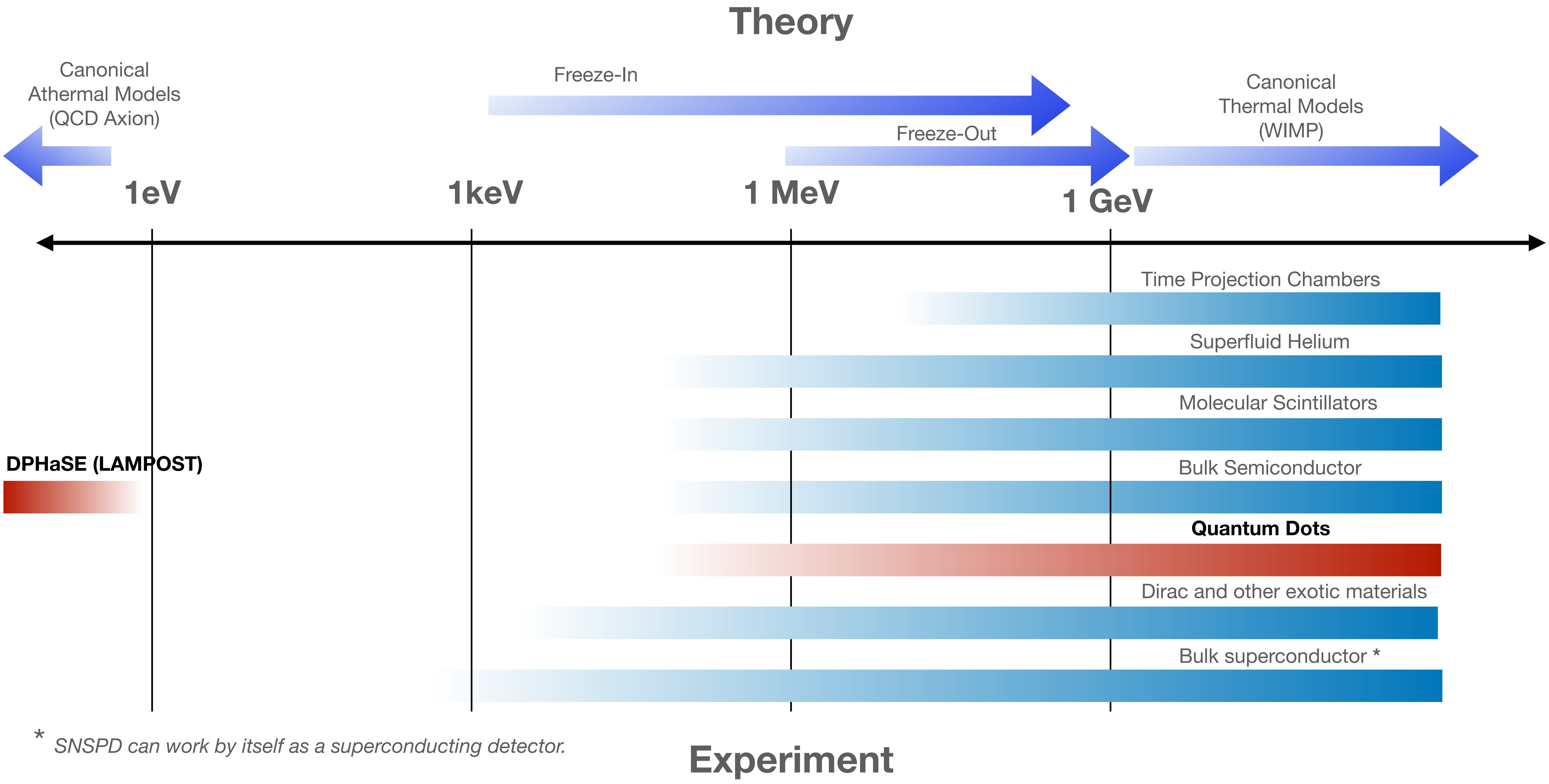
Back-up Story of Dark Matter Across Scales

Current Bounds on WIMP Dark Matter

S. Navas et al. (Particle Data Group), Phys. Rev. D 110, 030001 (2024)



← **Push to lower energies**



Theory
Canonical Athermal Models (QCD Axion)
Freeze-In
Freeze-Out
Canonical Thermal Models (WIMP)
1eV
1keV
1 MeV
1 GeV
Time Projection Chambers
Superfluid Helium
Molecular Scintillators
DPHaSE (LAMPOST)
Bulk Semiconductor
Quantum Dots
Dirac and other exotic materials
Bulk superconductor *
* SNSPD can work by itself as a superconducting detector.
Experiment

And lower ….

New Horizons:
Scalar and Vector Ultralight Dark Matter
arXiv:2203.14915
Editors: M. Safronova and S. Singh