Thoughts on Small Experiments

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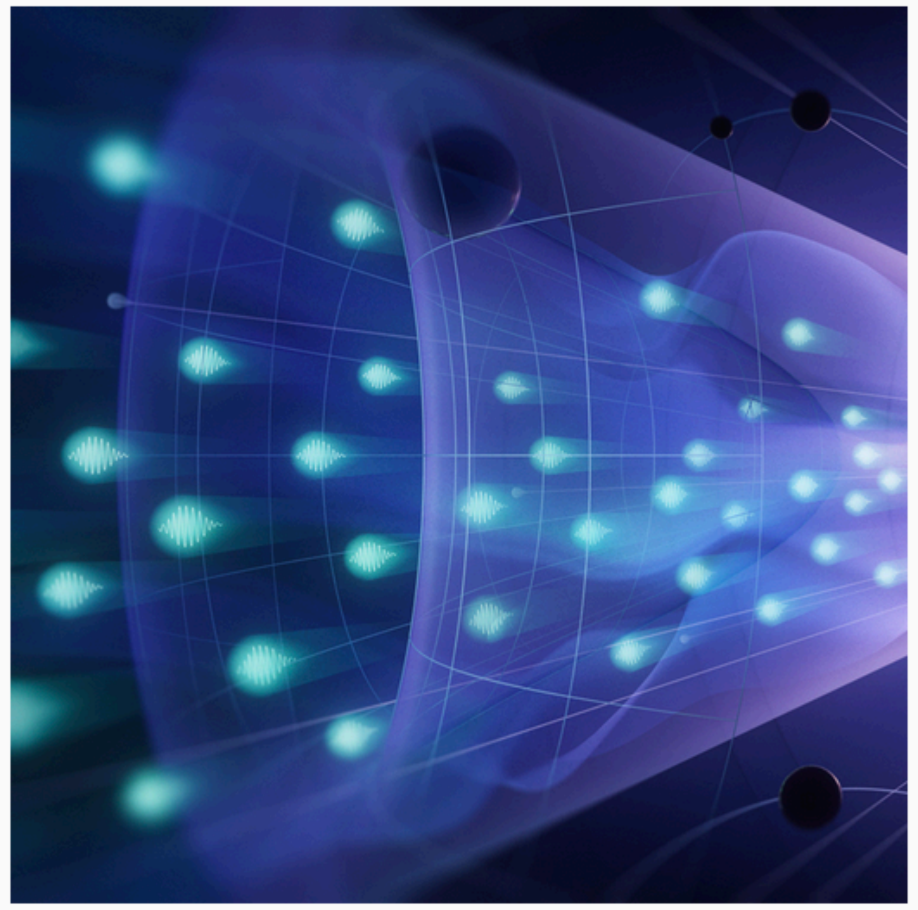
First Thought: Physics

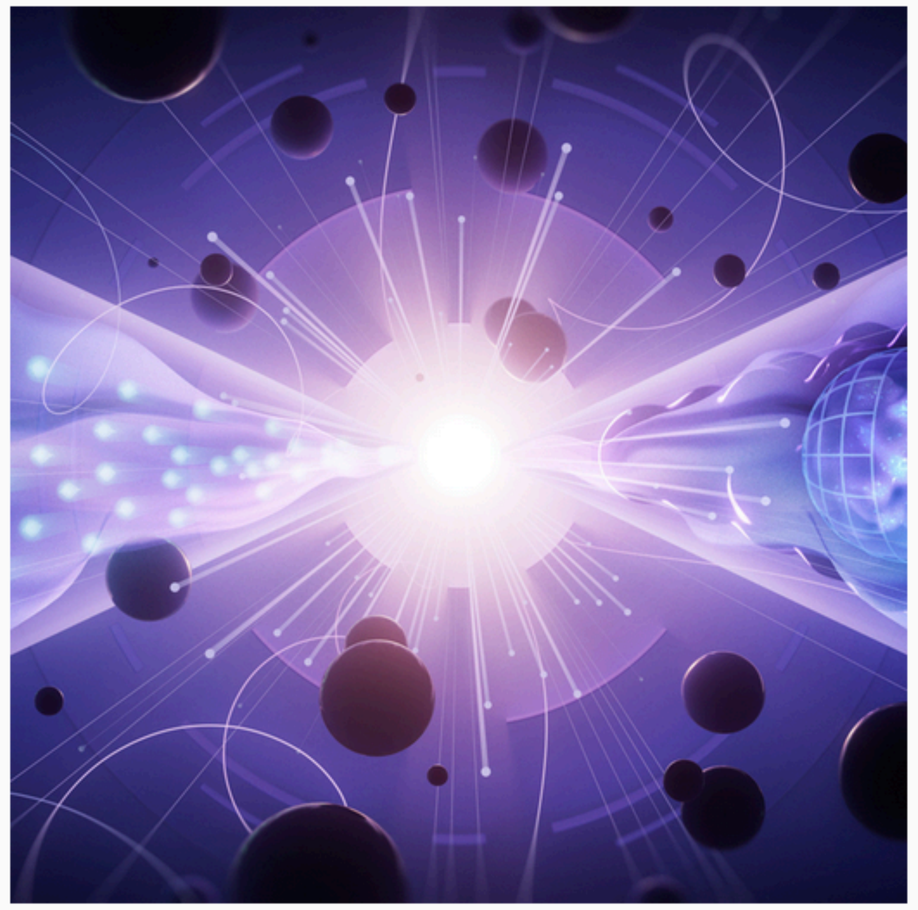
P5 Report: arXiv2407.19176



Decipher the Quantum Realm

Elucidate the Mysteries of Neutrinos

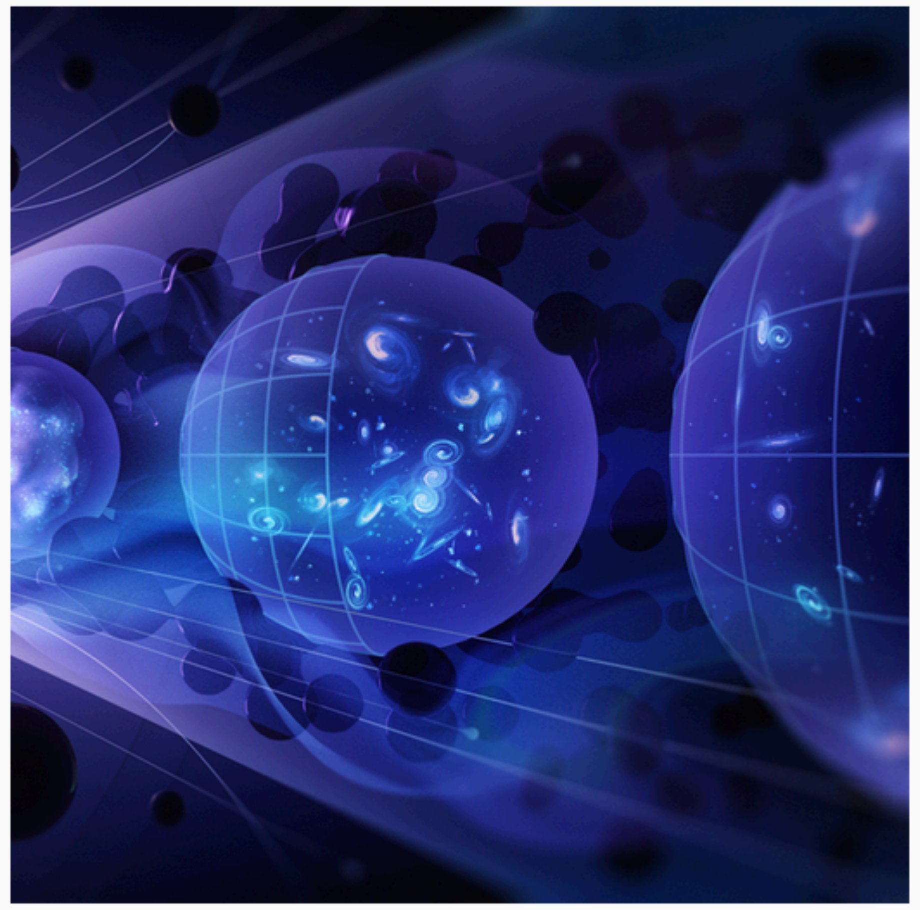
Reveal the Secrets of the Higgs Boson



Explore New Paradigms in Physics

Search for Direct Evidence of New Particles

Pursue Quantum Imprints of New Phenomena



Illuminate the Hidden Universe

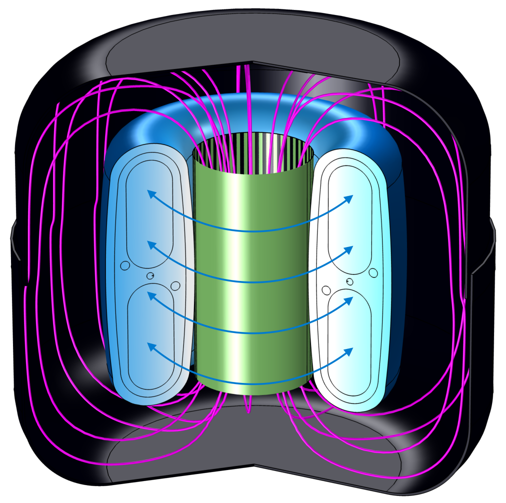
Determine the Nature of Dark Matter

Understand What Drives Cosmic Evolution

Small experiments are needed for discovery across HEP, as either auxiliary measurements or discovery machines in their own right.

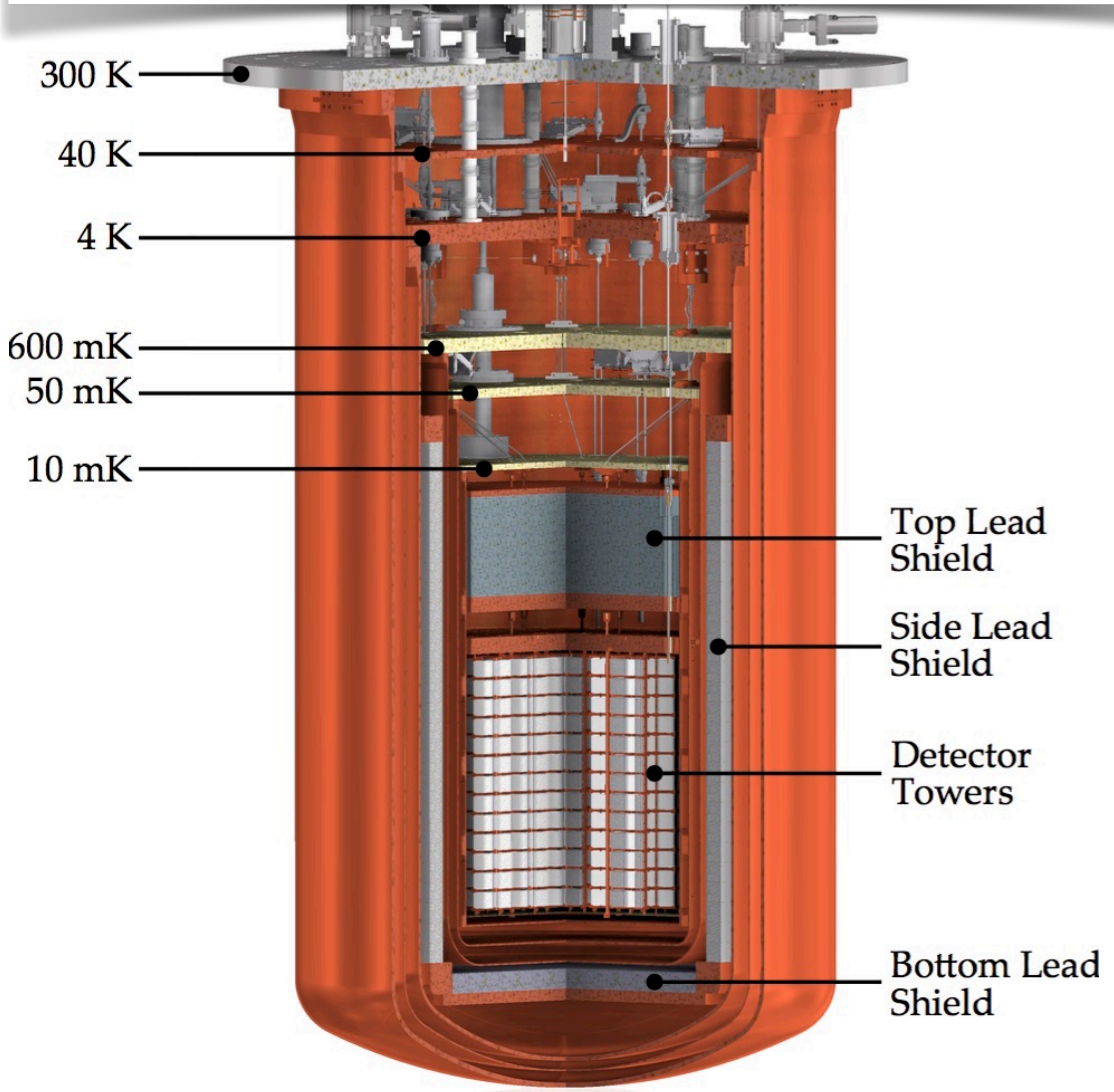
Second Thought: A Definition

Small experiments exist on a continuum, but they share the fact that the team doing the analysis is the same that is constructing and running the experiment.



ABRACADABRA-10cm
team O(10), runs at MIT

CUORE
team O(100), runs at LNGS



Third Thought: The Data

Category #1

Detectors designed for specific signals

Axions, Double-Beta Decay, eDMs…

Category #2

Traditional multi-detector system experiments

Beam dumps, auxiliary experiments…

Third Thought: The Data

Category #1

Smaller data volumes
Low information

Axions, Double-Beta Decay, eDMs…

Category #2

Higher data volumes
High information

Beam dumps, auxiliary experiments…

KamNET - Example Category #1

PHYSICAL REVIEW C **107**, 014323 (2023)

Editors' Suggestion

KamNet: An integrated spatiotemporal deep neural network for rare event searches in KamLAND-Zen*

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Rare event searches allow us to search for new physics at energy scales inaccessible with other means by leveraging specialized large-mass detectors. Machine learning provides a new tool to maximize the information provided by these detectors. The information is sparse, which forces these algorithms to start from the lowest level data and exploit all symmetries in the detector to produce results. In this work we present KamNet, which harnesses breakthroughs in geometric deep learning and spatiotemporal data analysis to maximize the physics reach of KamLAND-Zen, a kiloton scale spherical liquid scintillator detector searching for $0\nu\beta\beta$. Using a simplified background model for KamLAND, we show that KamNet outperforms a conventional convolutional neural network (CNN) on benchmarking Monte Carlo simulations with an increasing level of robustness. Using simulated data, we then demonstrate KamNet's ability to increase KamLAND-Zen's sensitivity to $0\nu\beta\beta$ and $2\nu\beta\beta$ decay to excited states. A key component of this work is the addition of an attention mechanism to elucidate the underlying physics KamNet is using for the background rejection.

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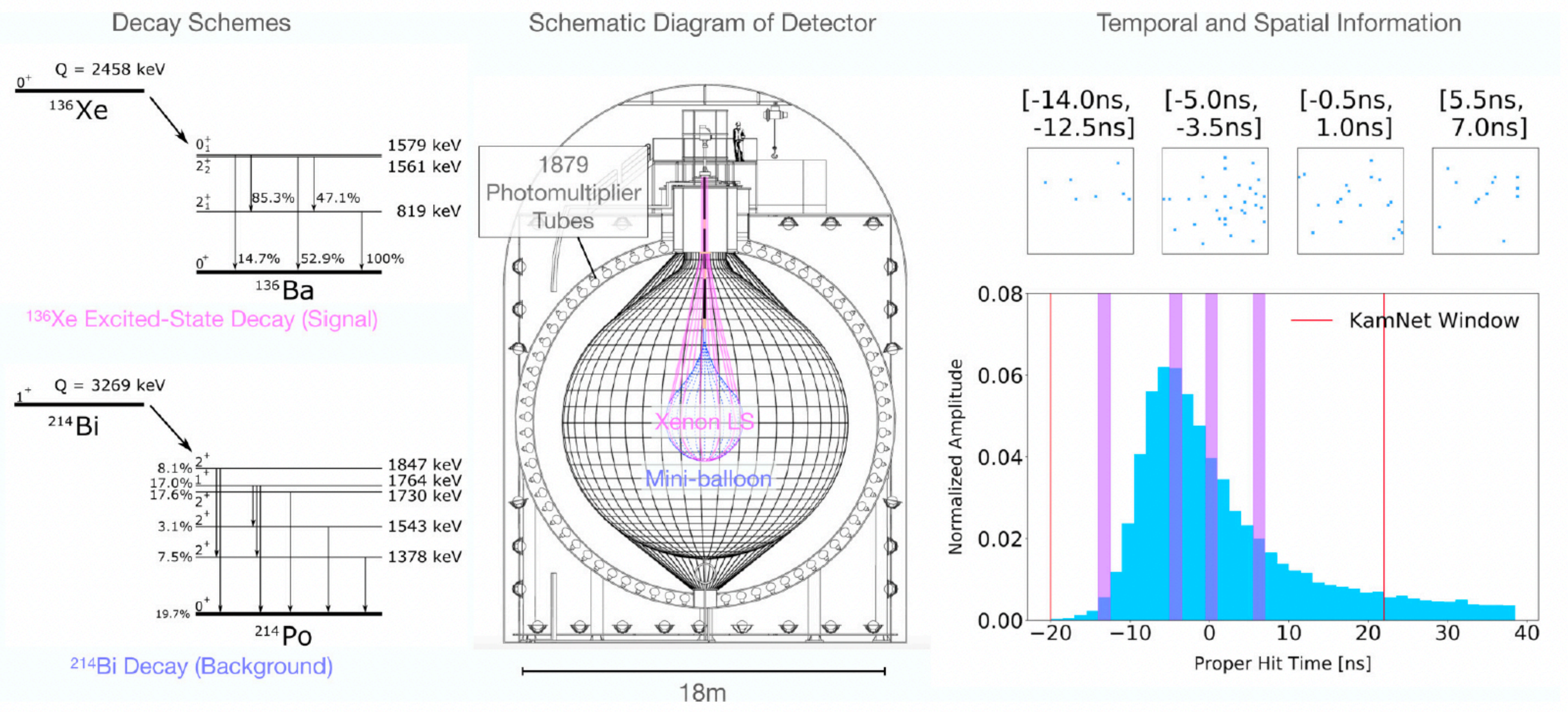

FIG. 1. Left: The decay schemes for ^{136}Xe and ^{214}Bi with branching ratios <1% are omitted for simplicity. Center: The schematic diagram of the KamLAND-Zen detector. Right: The distribution of PMT hit times for typical physics events. The spatial distribution of the PMT hit times highlighted in violet are shown above.

Improve the main analysis…

With Prof. Aobo Li (UCSD) and Prof. Chris Grant (BU)

TIDMAD - Example Category #1

NeurIPS Spotlight led by Jessica Fry (MIT) with Prof. Aobo Li (UCSD)

TIDMAD: Time Series Dataset for Discovering Dark Matter with AI Denoising

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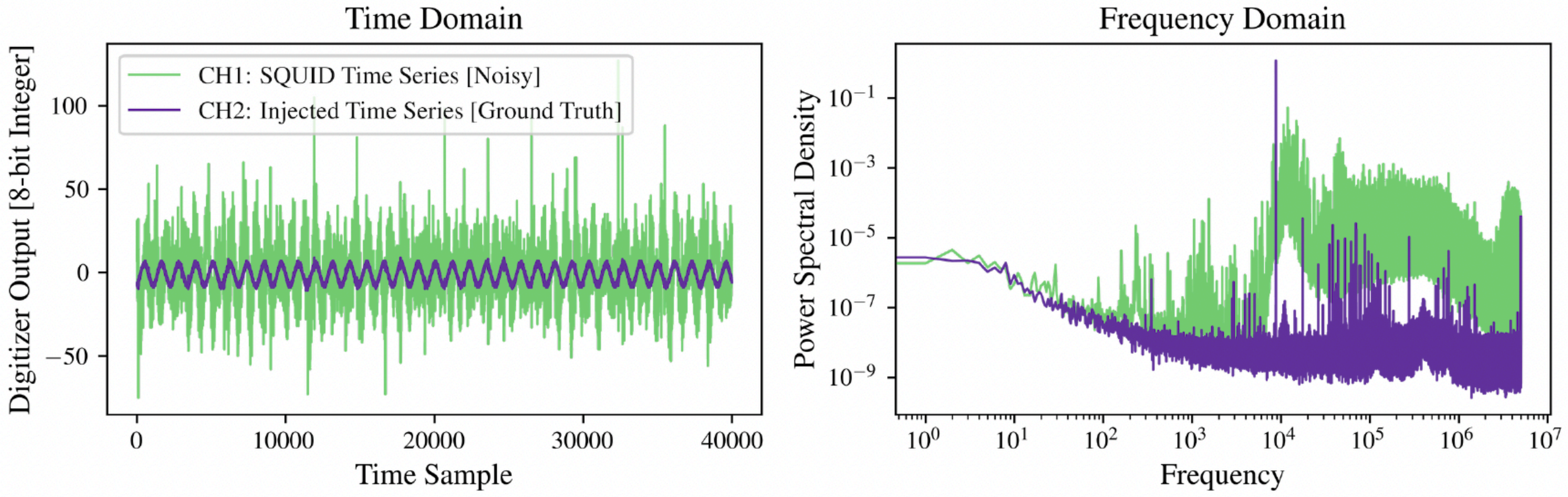
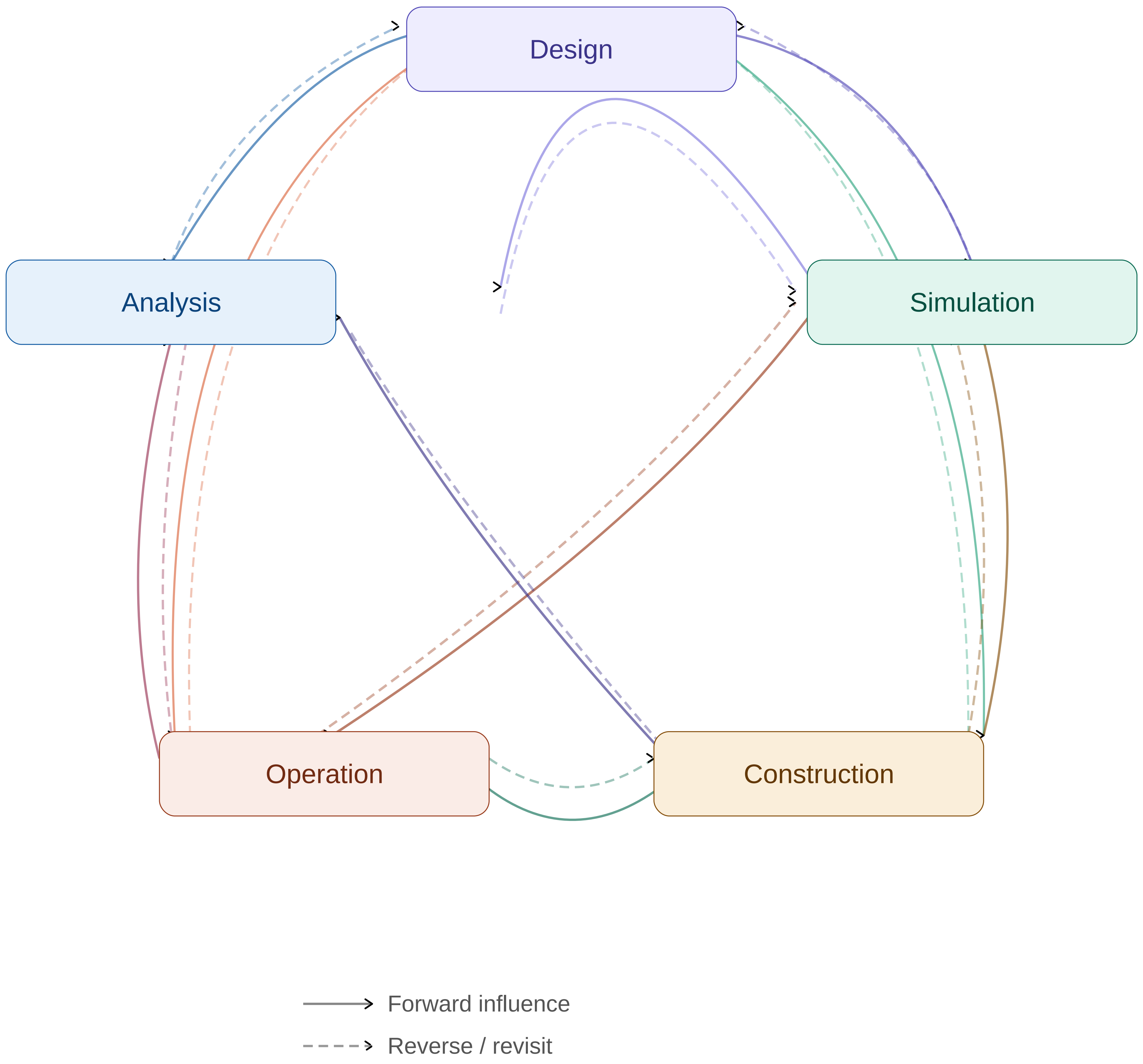


Figure 2: 10-millisecond snapshot of the time series in TIDMAD training dataset compared to the power spectral density of the same data snapshot.

Search for non-standard signals…

Pulling these thoughts together

These steps cannot be treated independently and we need better tools for each task and integration of these tasks.



Current Ecosystem - CUORE/CUPID

ELOG - operations, shifts
Indico - meetings
DocDB - archive
Wiki - organization
MongoDB - slow monitoring

PgSQL - DAQ
C++ - DAQ
ROOT-based Analysis
Geant4-based Simulation
Materials database
CAD drawings

Current Ecosystem - ABRACADABRA

ELOG - operations, shifts
Dropbox - pictures
DocDB - archive+meeting
Wiki/Confluence
Grafana - slow monitoring

C++ - DAQ
Python-based Analysis
COMSOL Simulation
CAD drawings

Setting Up An Ecosystem - DarkSNSPD

HEP QuantISED project: need to track production and characterization of devices.

And Meetings, DAQ, COMSOL, Geant4 etc.

Summary and Final Thoughts

- Small Experiments provide unique and complementary datasets and problems that can be explored with AI.

Summary and Final Thoughts

- Small Experiments allow universities to have more leadership and they are well-equipped to take leadership in small projects in this space as well (in fact it is critical for them to do so).

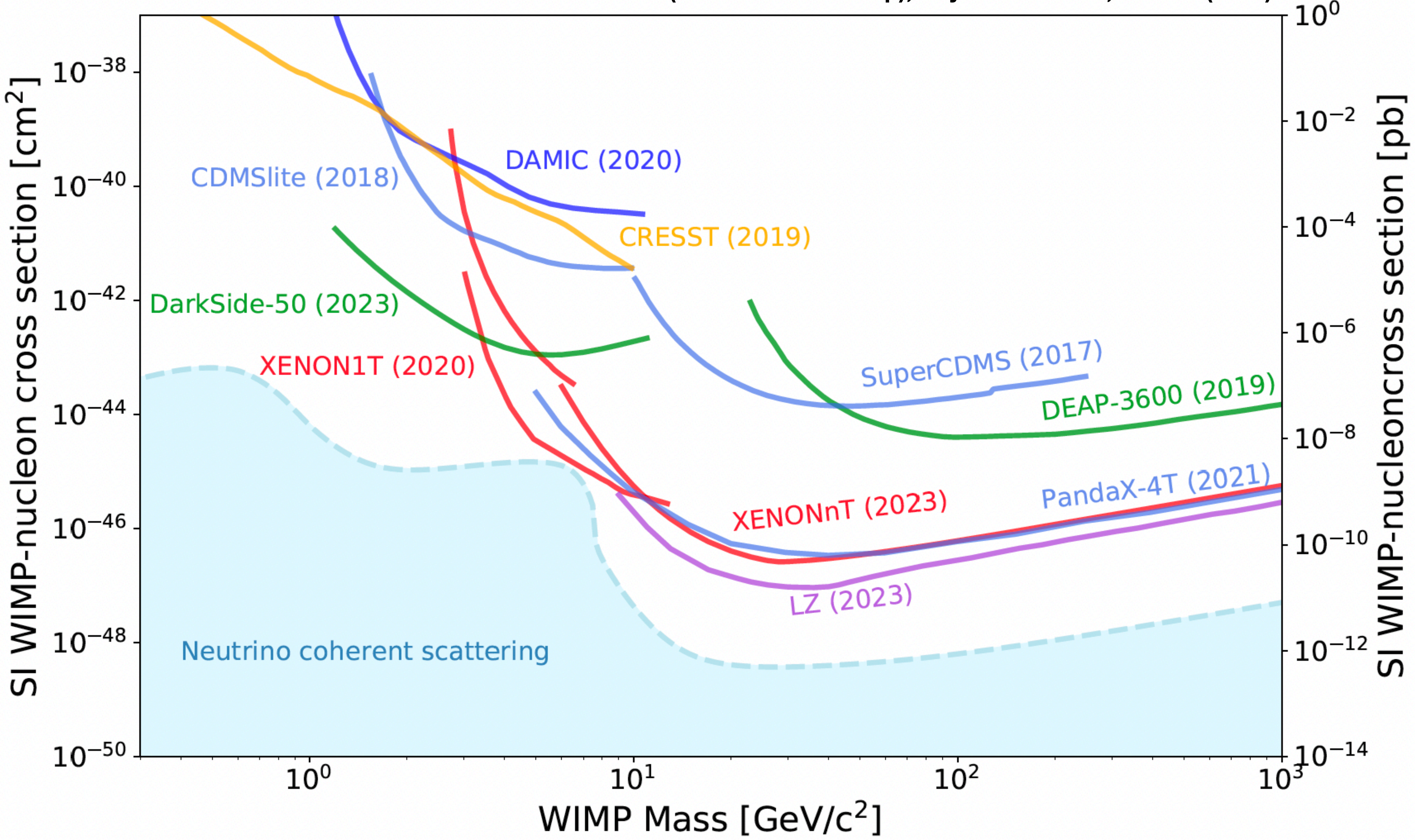
Summary and Final Thoughts

- Due to their size, increased efficiencies in the design, management, operation and analysis of experiments are even more critical.
- Workshops to spread best practices for AI workflows for software and experiment design.
- A modern version of ELOG and DocDB that can be interfaced to AI natively.

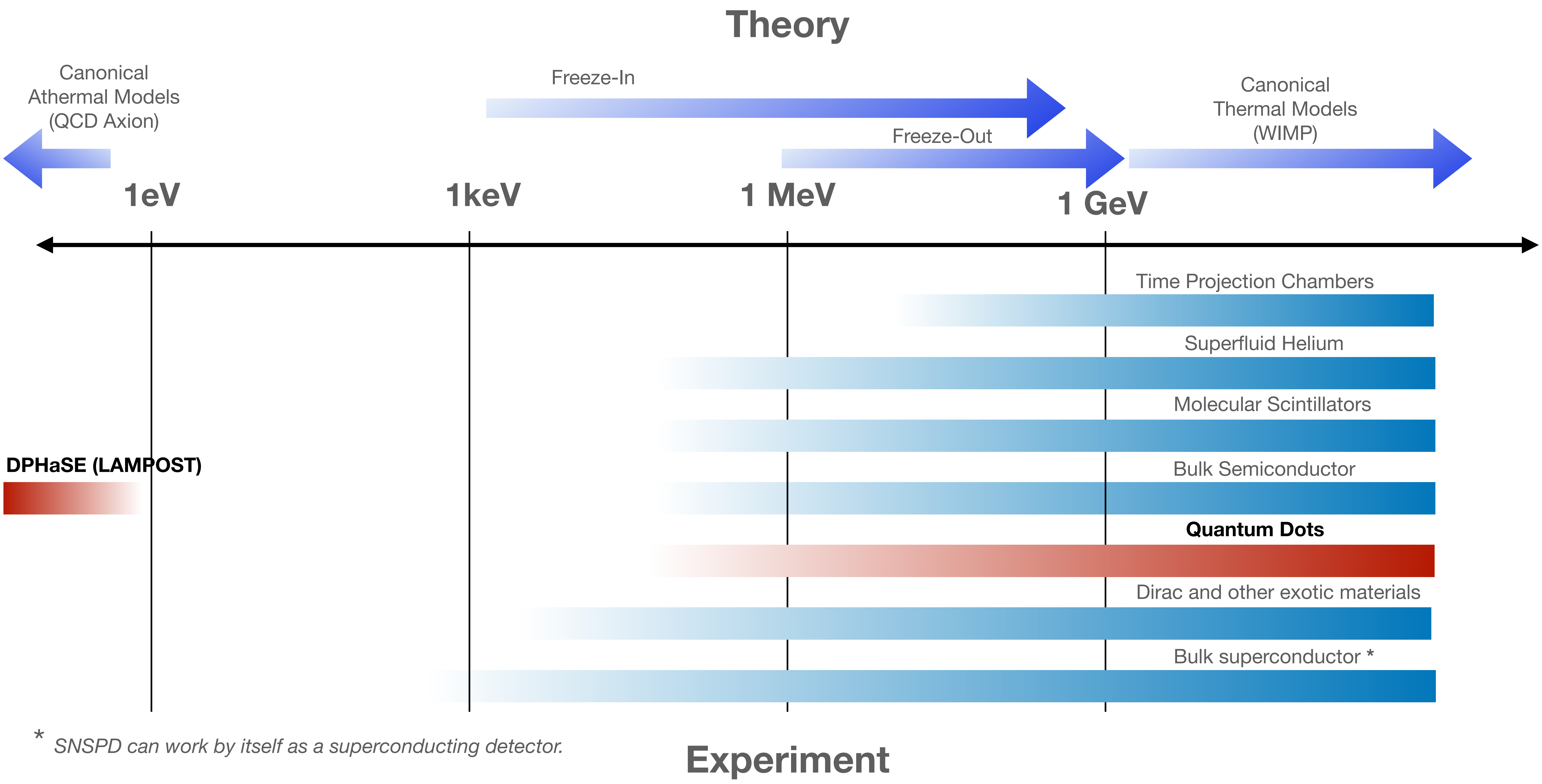
Back-up Story of Dark Matter Across Scales

Current Bounds on WIMP Dark Matter

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



← **Push to lower energies**



* *SNSPD can work by itself as a superconducting detector.*

And lower ….

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