

# **Prometheus: Open-Source Simulation for Neutrino Telescopes**

**Jeffrey Lazar**

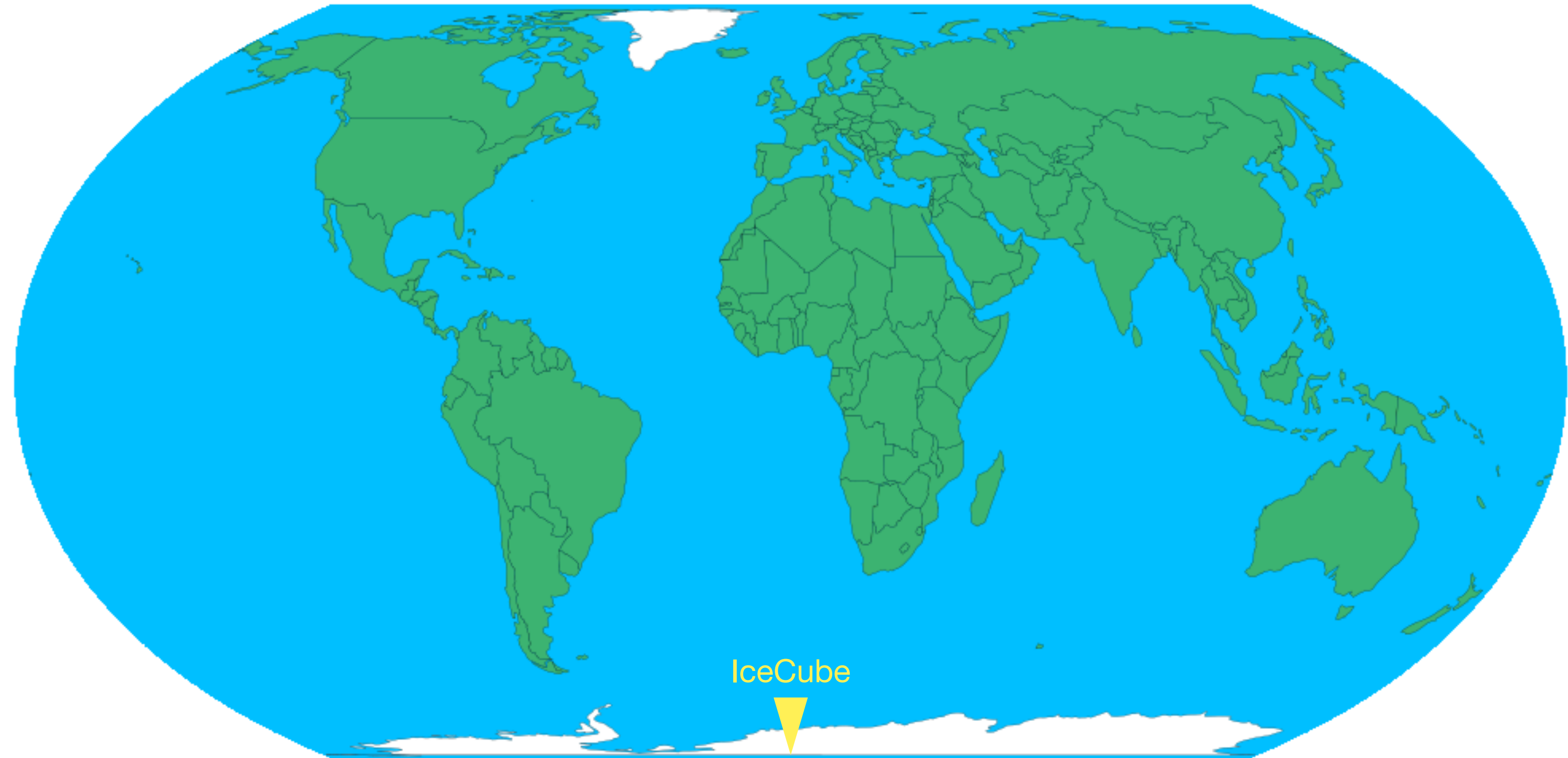
**Belgian Neutrino Meeting**

**Louvain-la-Neuve, Belgium**

**08 Mar., 2024**

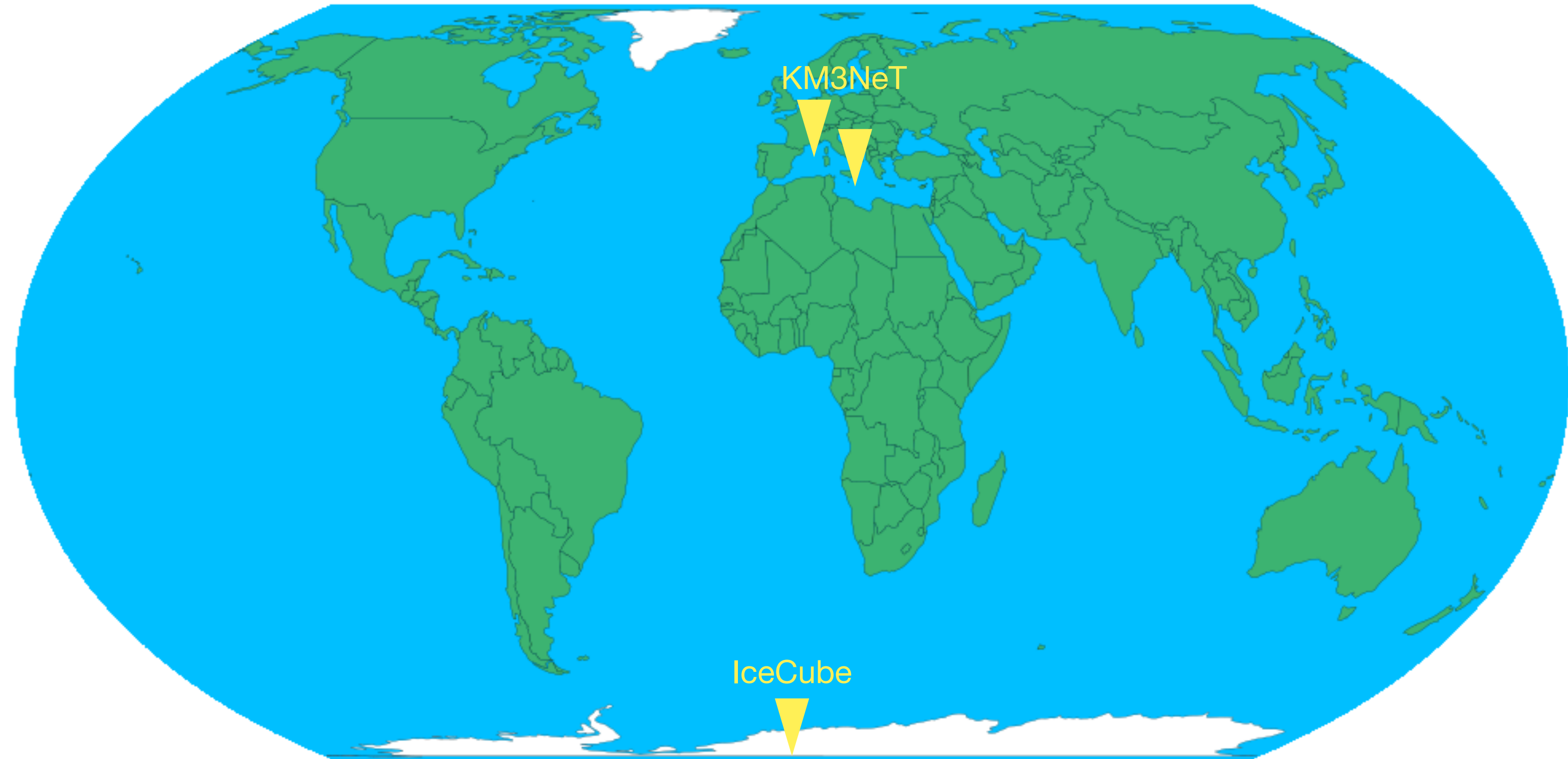
# A Growing, Global Network

- For most of the last decade, IceCube has been the only gigaton-scale neutrino telescope
- This is changing, and we will have five such detectors in the next decade



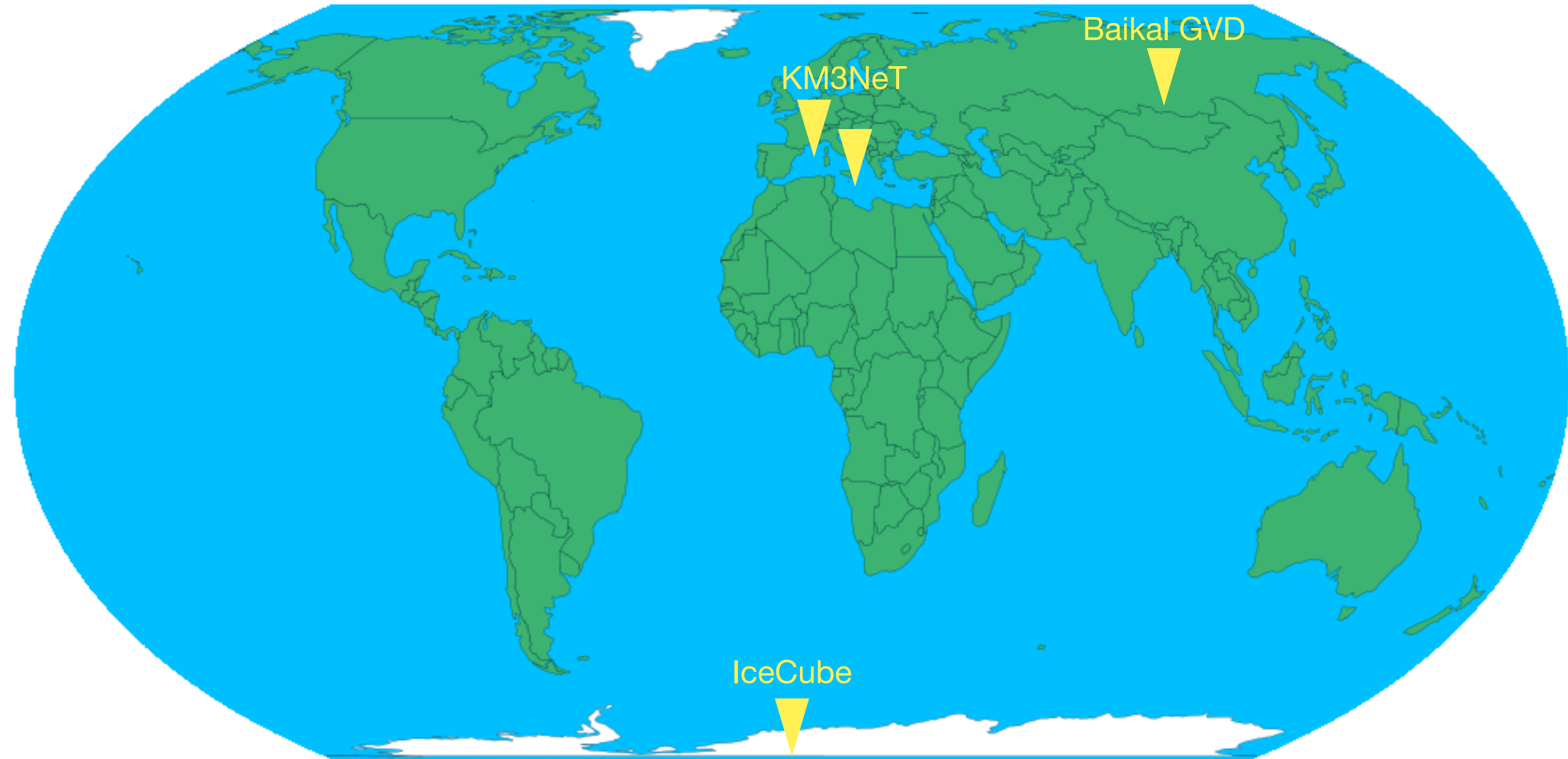
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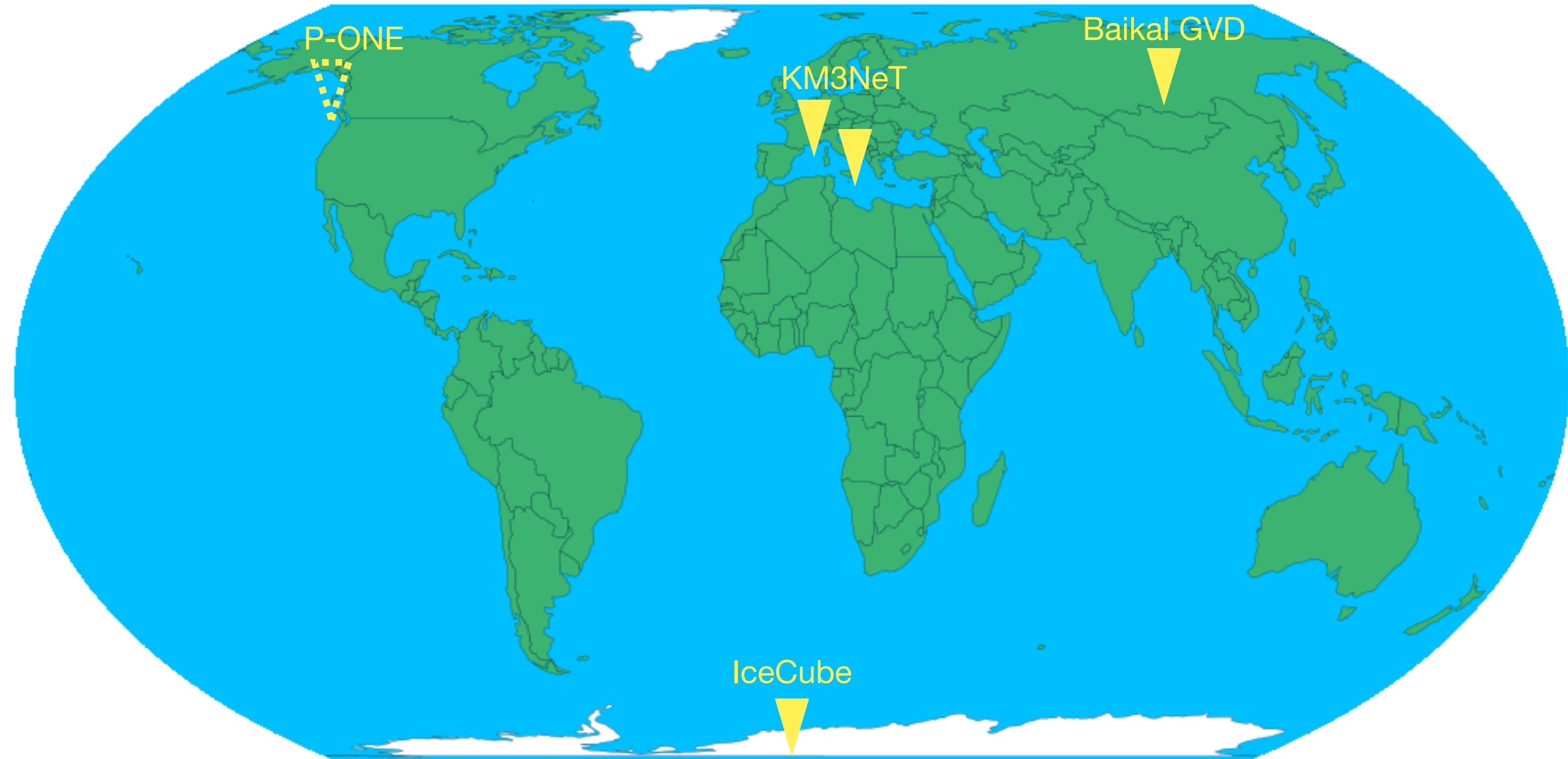
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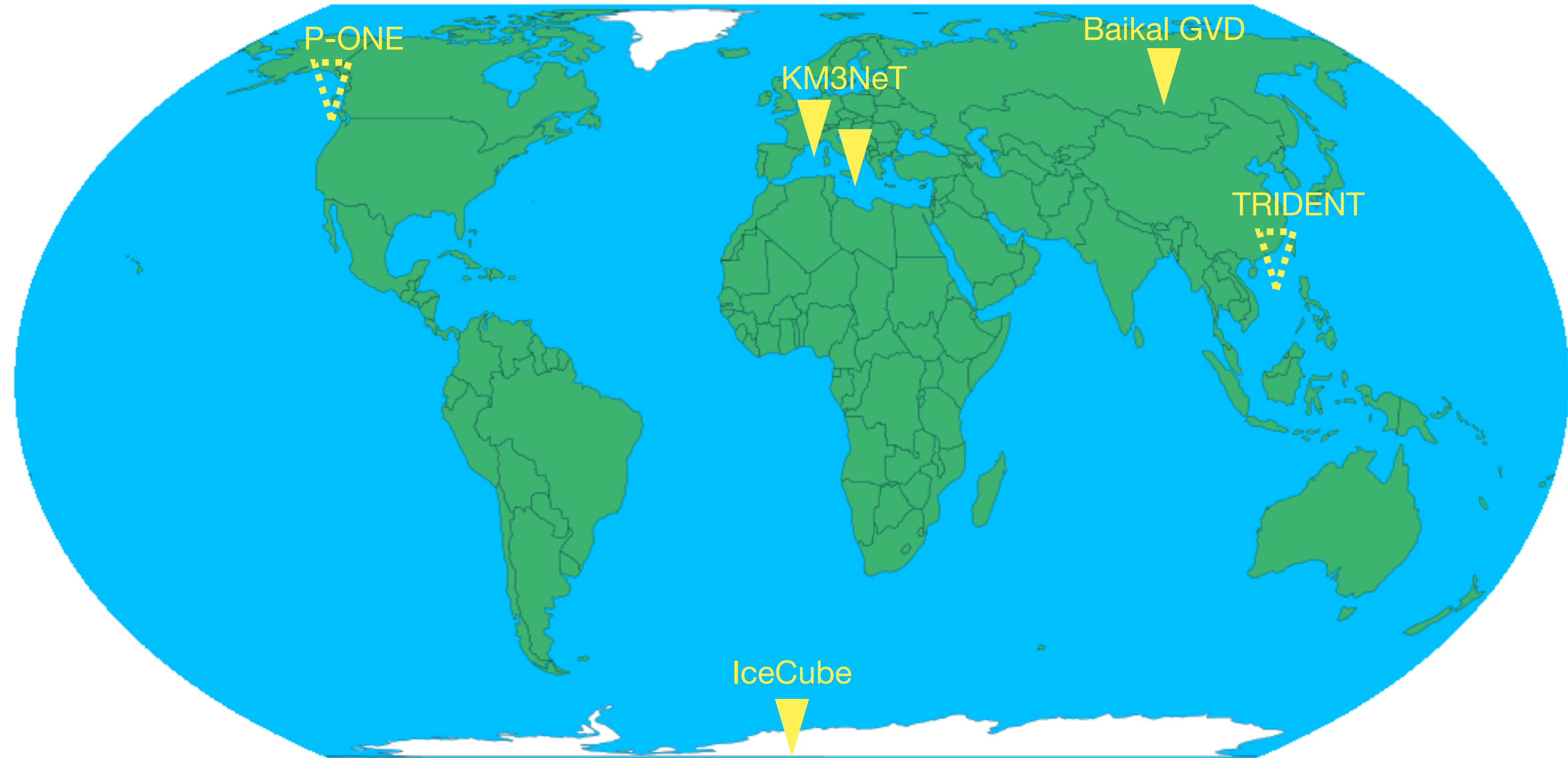
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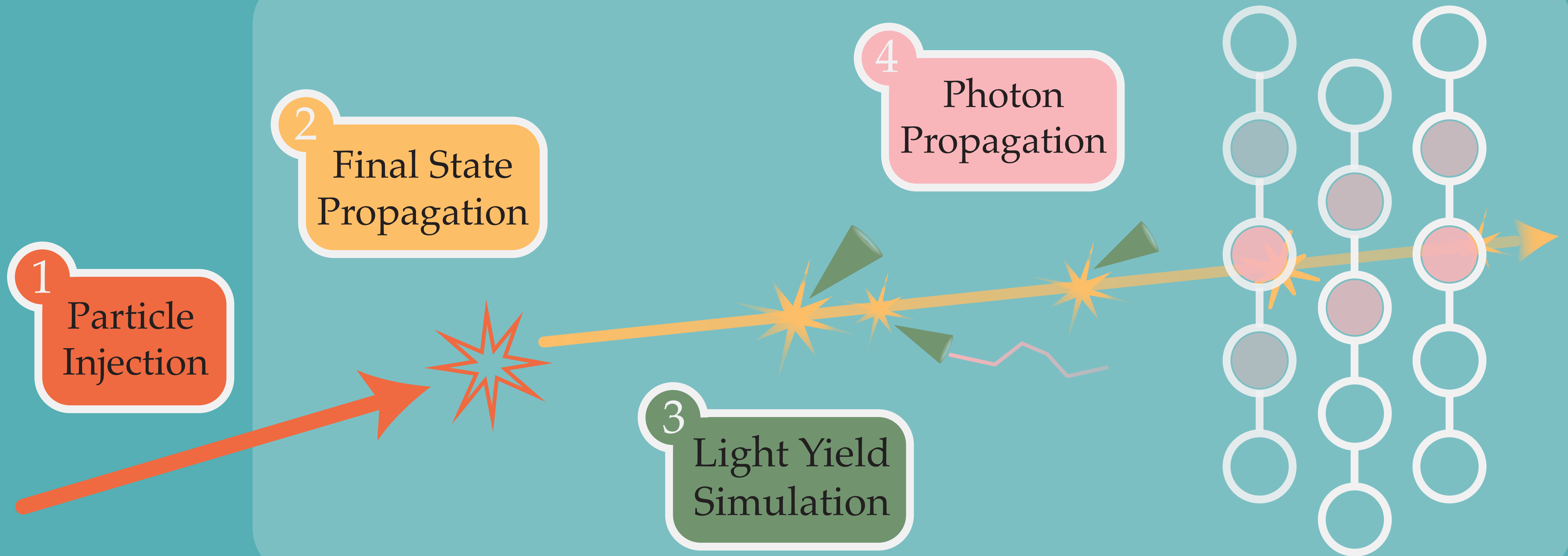


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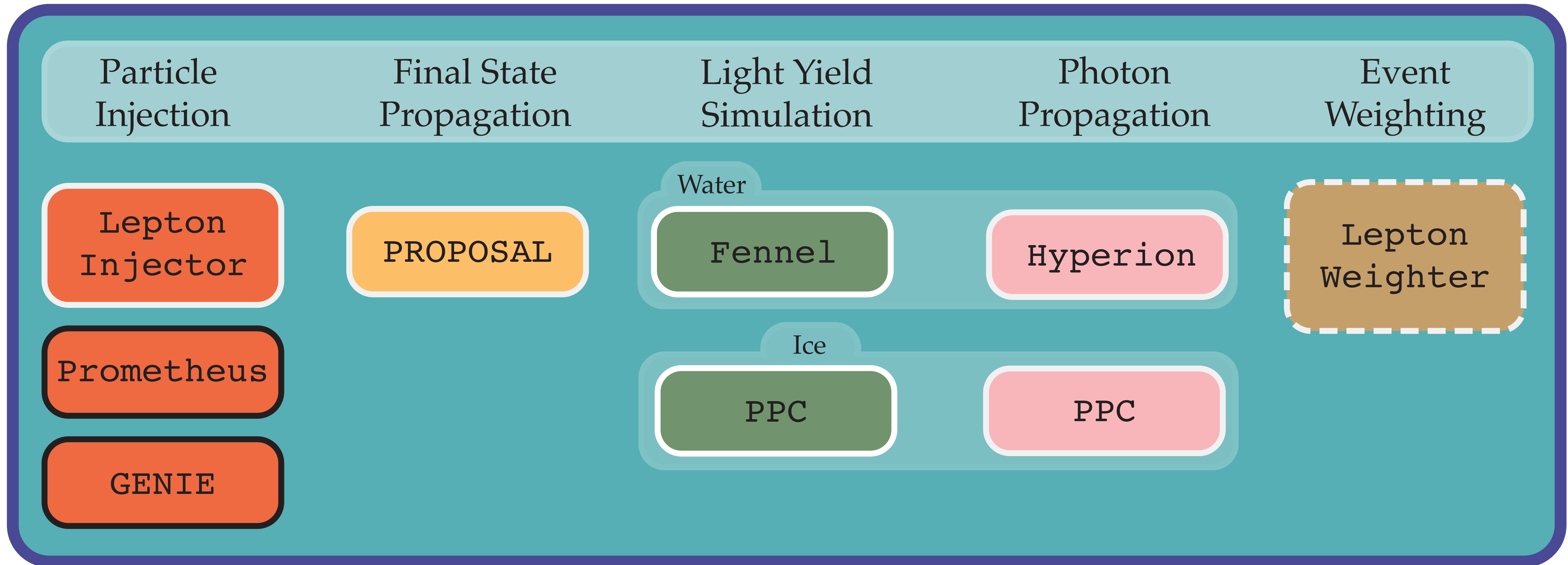
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# An Opportunity to a Collective Approach



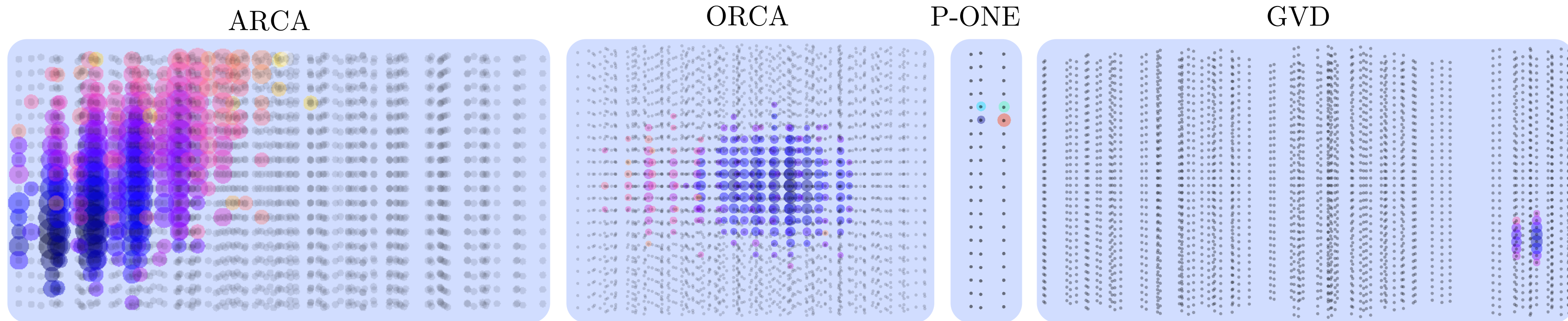
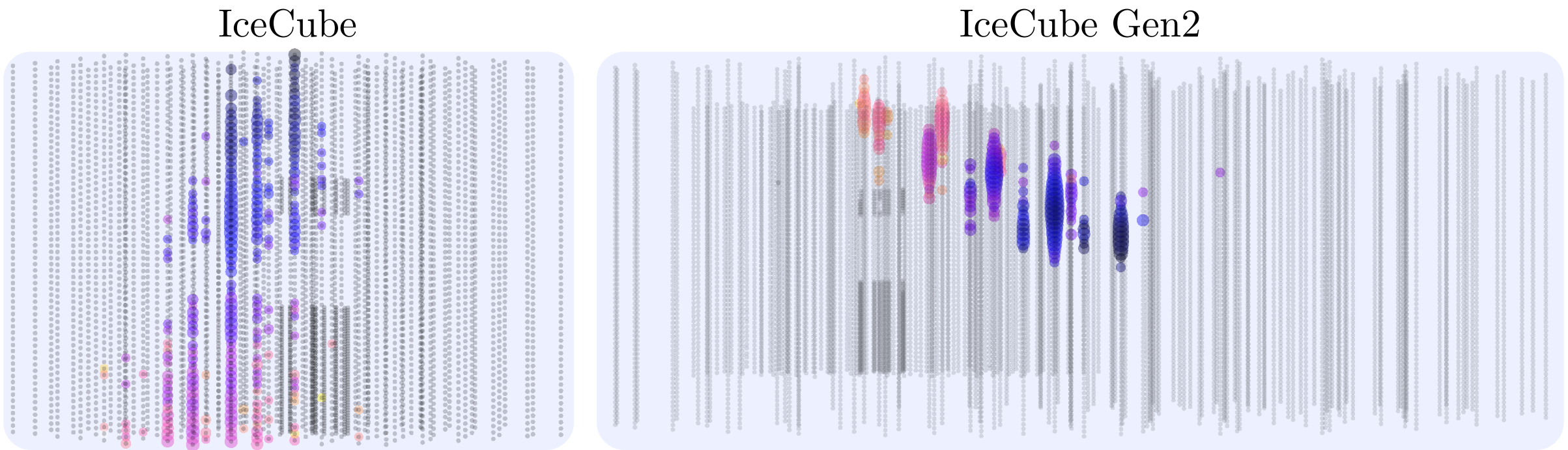
# Open-Source Answers



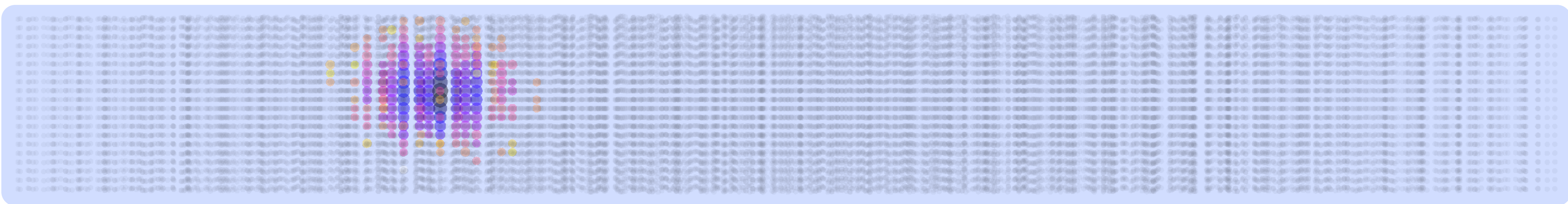


# A Full, Open-Source Simulation

Prometheus is the first-of-its-kind simulation that gives photon-level information for arbitrary detectors in ice and water

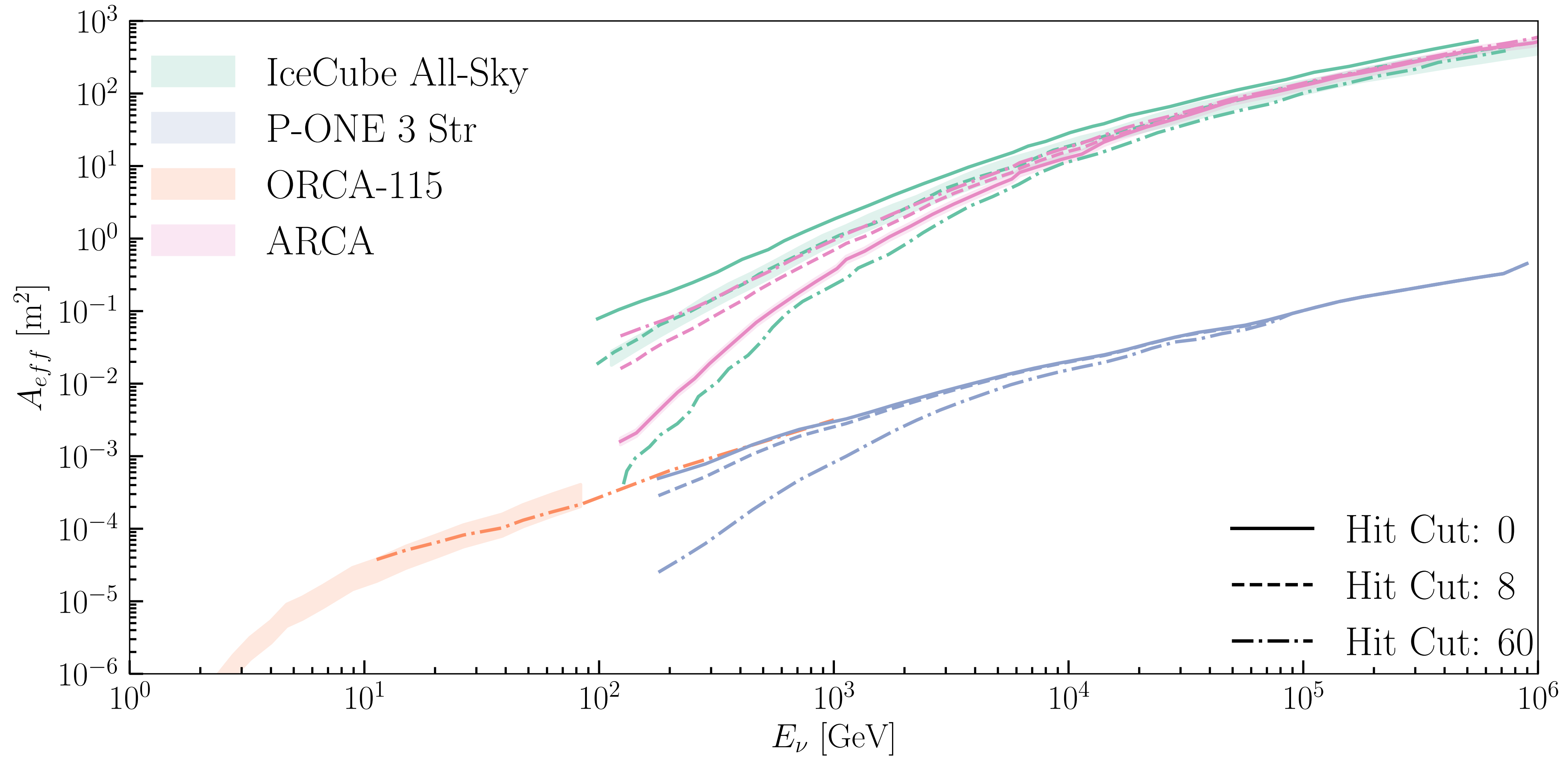


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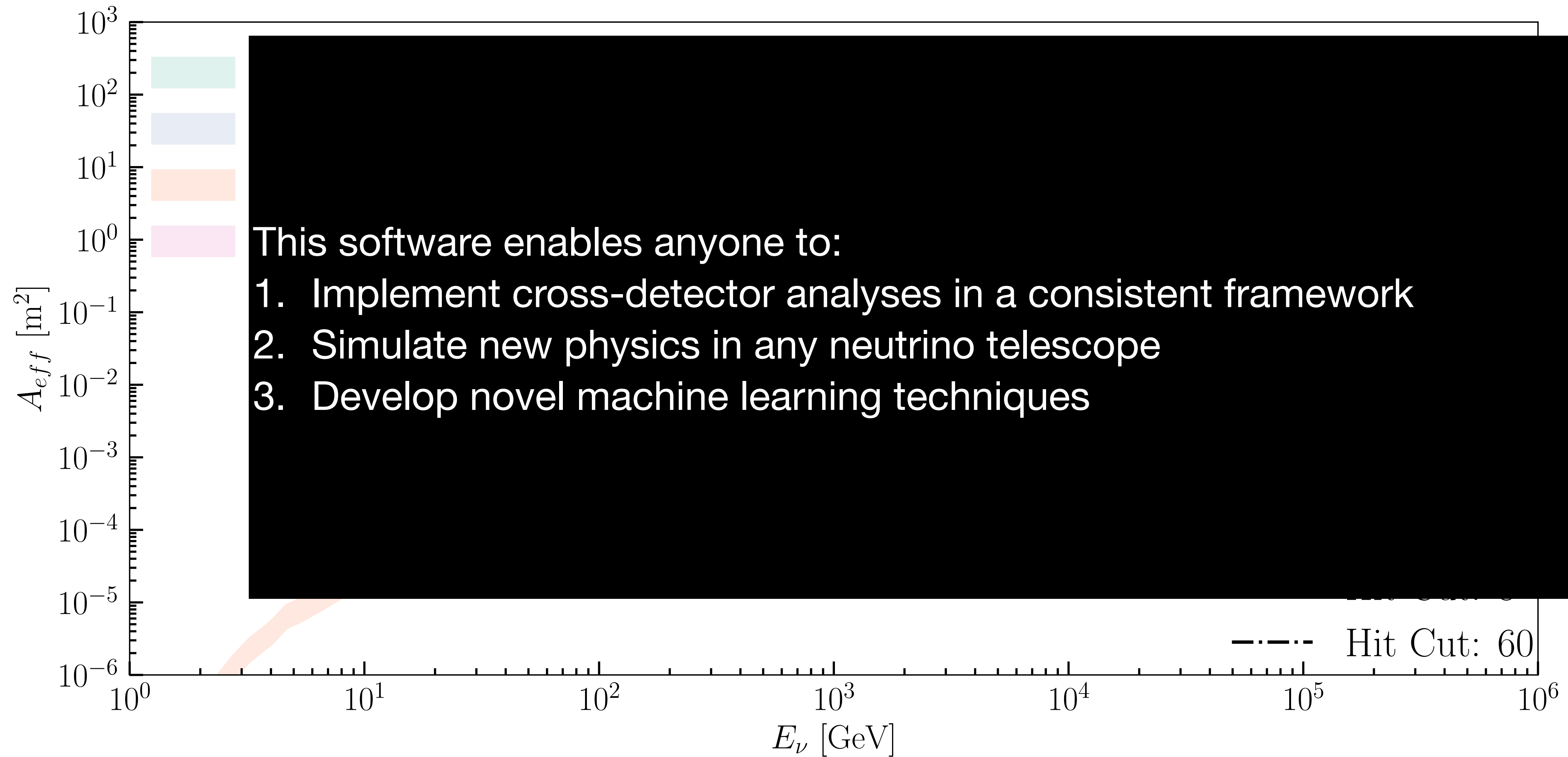
JL, S. Meighan-Berger, C. Haack, D. Kim, S. Giner, and C.A. Argüelles: [ArXiv:2304.14526](https://arxiv.org/abs/2304.14526)

# Reliable Results



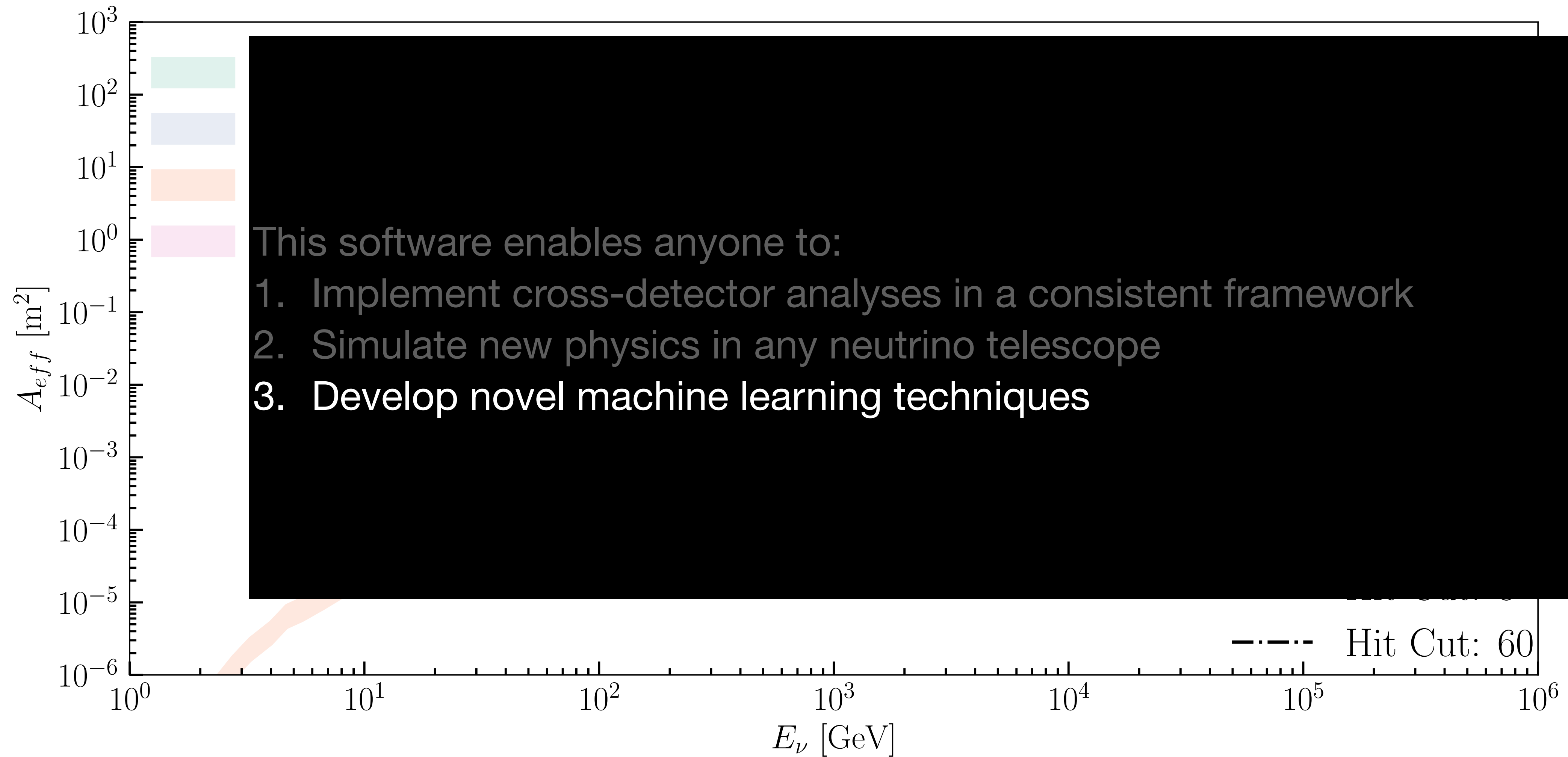
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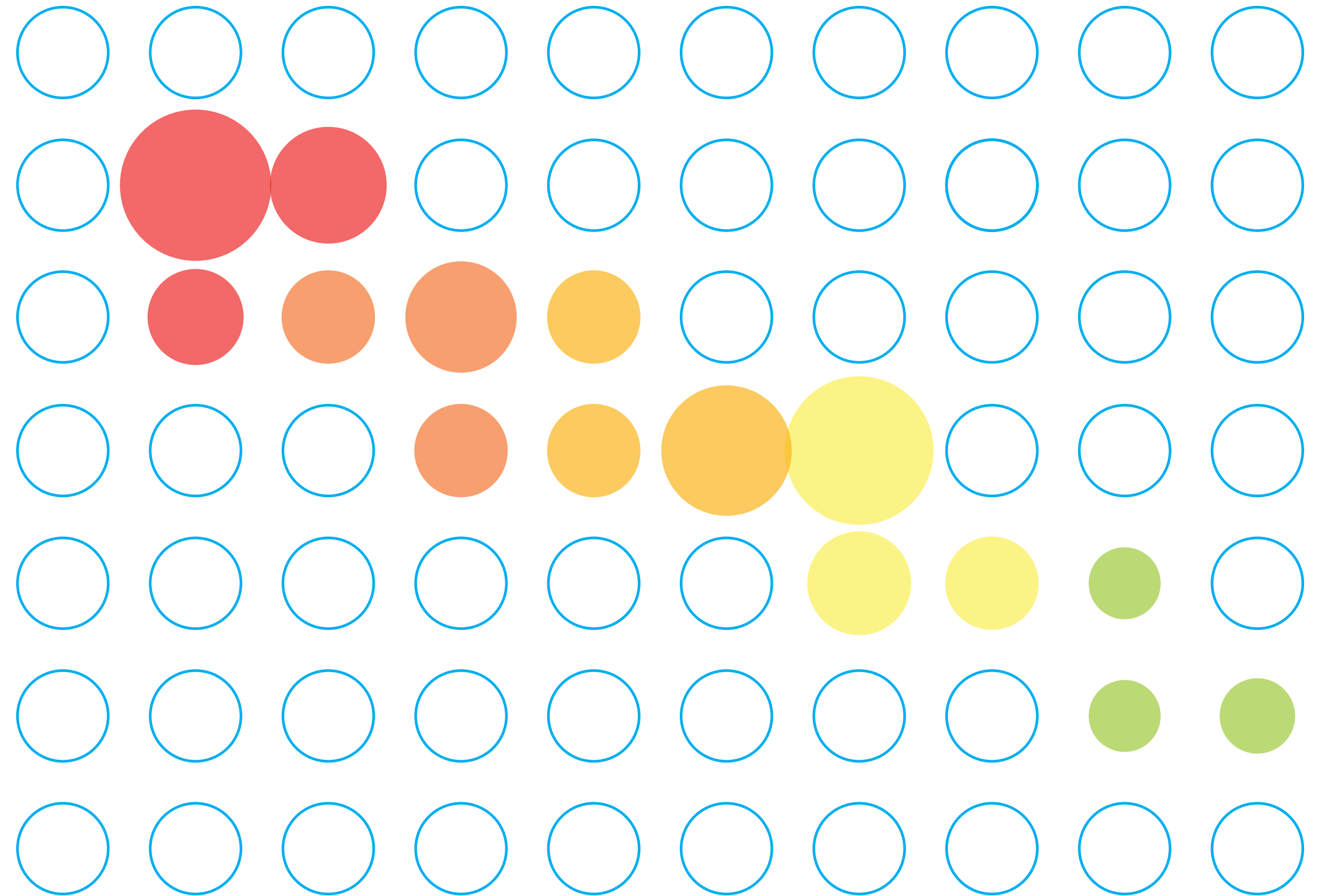
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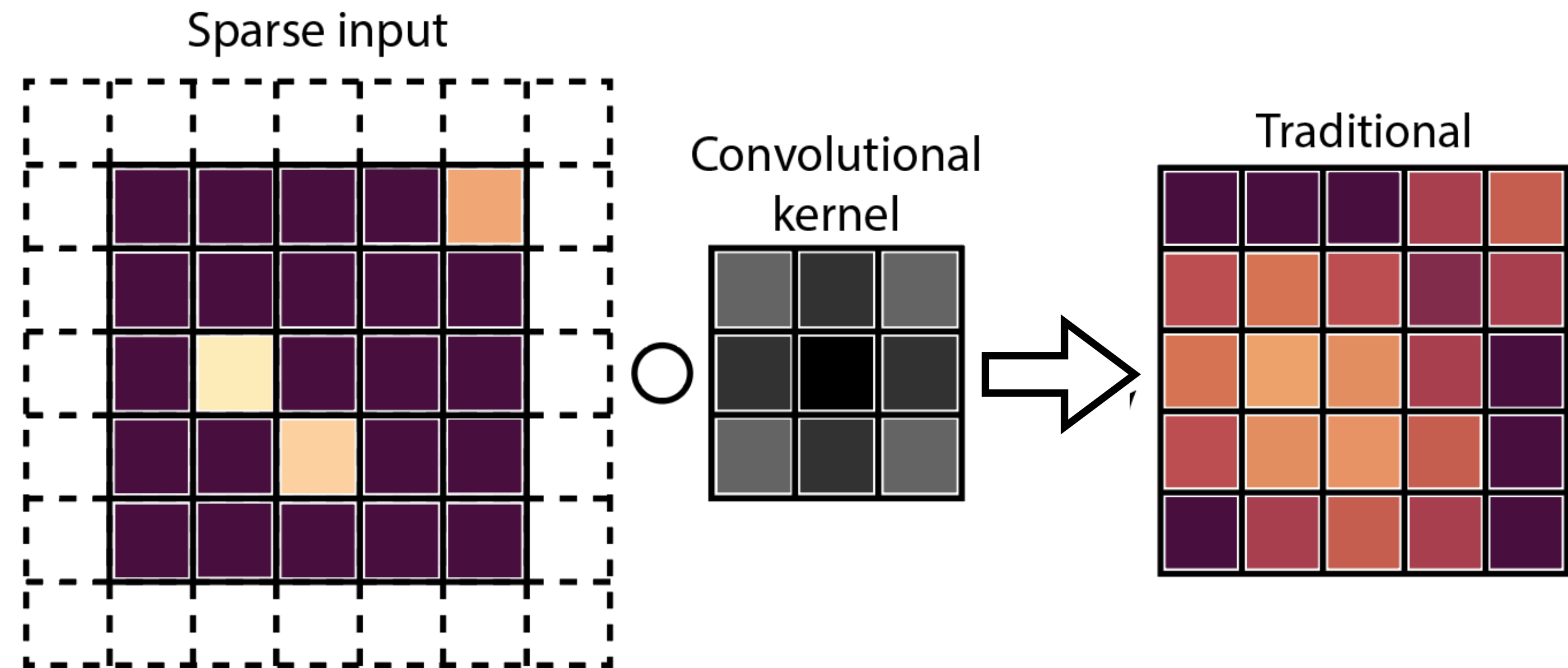
# Troubles of CNNs

- Hexagonal geometry forced into cartesian grid to work with convolutional networks
- Very few OMs see light in a given time window → sparse data → lots of wasted computation



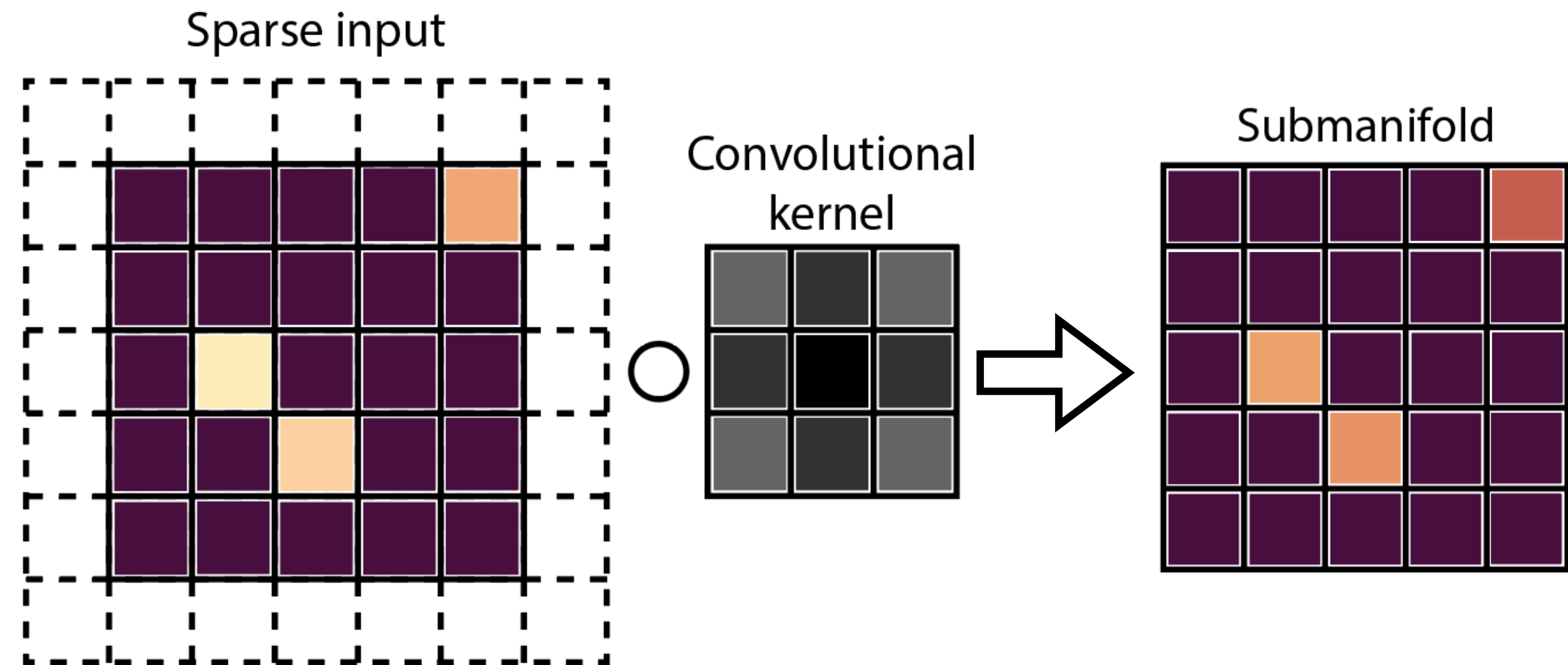
# But Sparse Data is Not New

- Sparse data is not a new challenge to computing
- What about using sparse matrix multiplication techniques
- This leads to bleeding, which worsens each layers



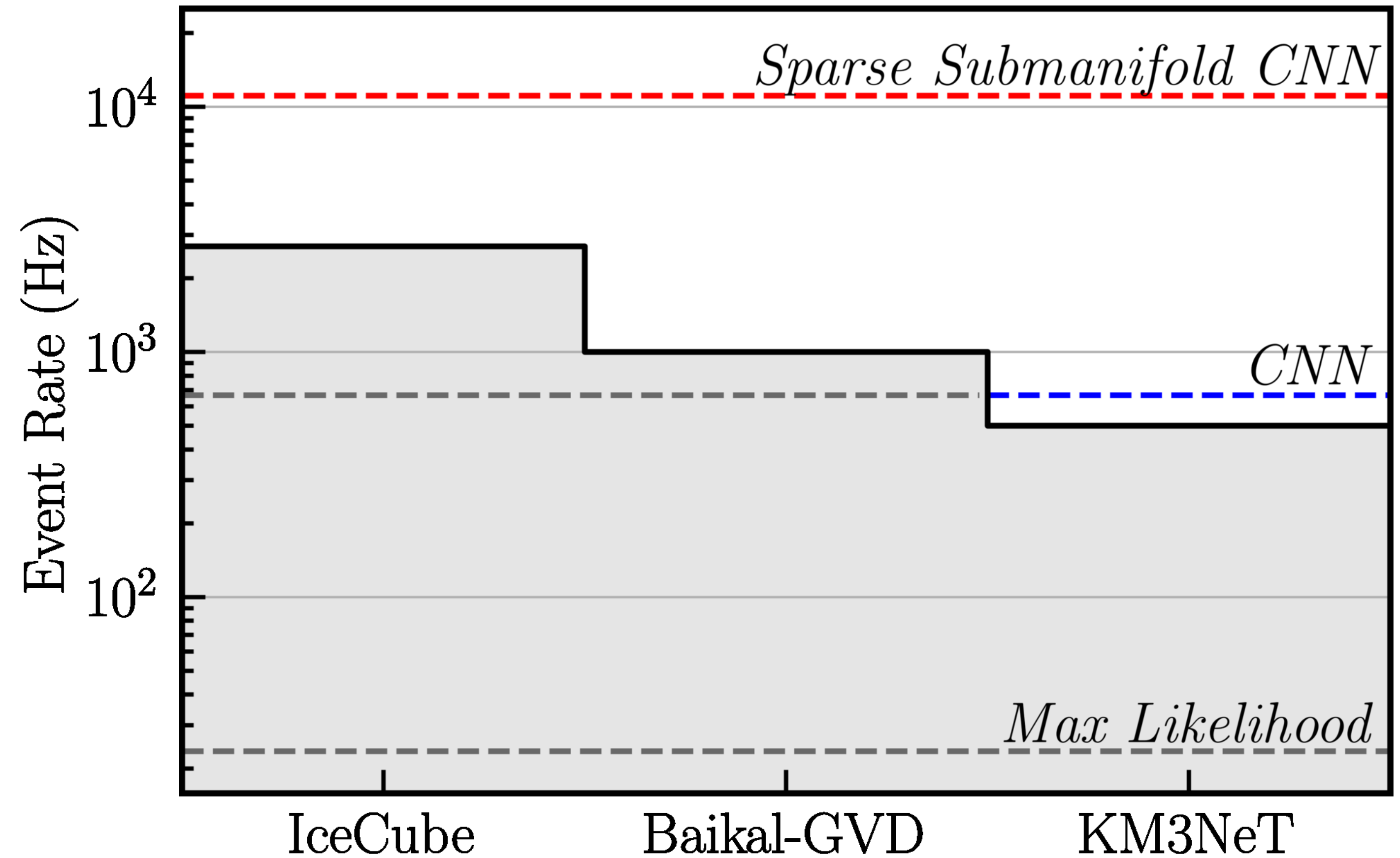
# Maintaining Sparsity

- Restrict ourselves to submanifold where input is non-zero
- This enforces that the sparsity is constant from layer to layer
- Huge speed up !



# Trigger Rate Learning

- GPU acceleration allows us to run at  $\sim 11$  kHz, *i.e.* nearly 4x IceCube's trigger rate !
- We can run this in real time on all triggered events !



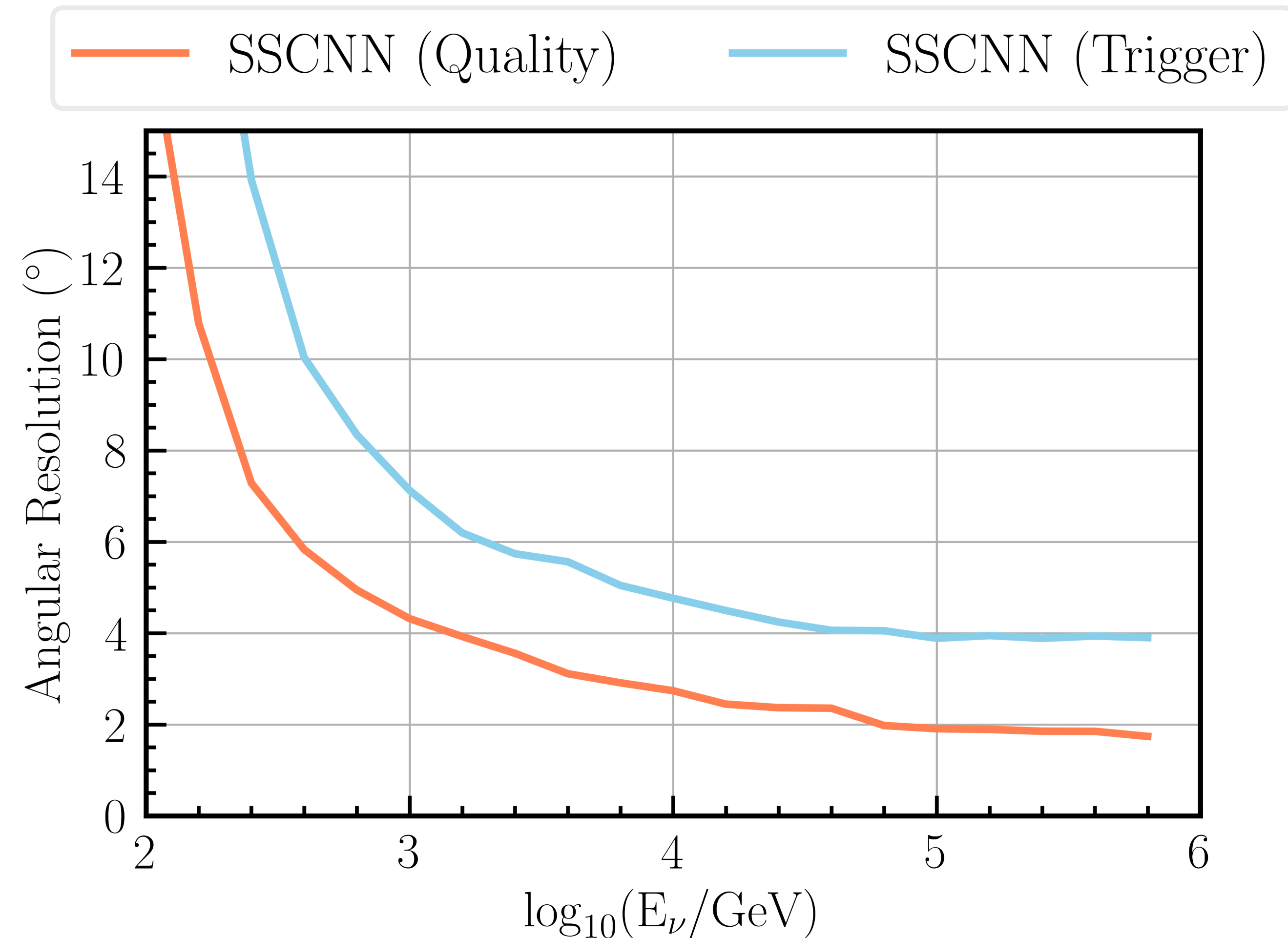
<b>SSCNN (GPU)</b>	<b><math>0.090 \pm 0.007</math> ms</b>
<b>SSCNN (CPU)</b>	<b><math>65.22 \pm 117.04</math> ms</b>
Max Likelihood (CPU)	$42.6 \pm 175$ ms

F. Yu, JL, C.A. Argüelles: [DOI: 10.1103/PhysRevD.108.063017](https://doi.org/10.1103/PhysRevD.108.063017)



# Angular Resolution

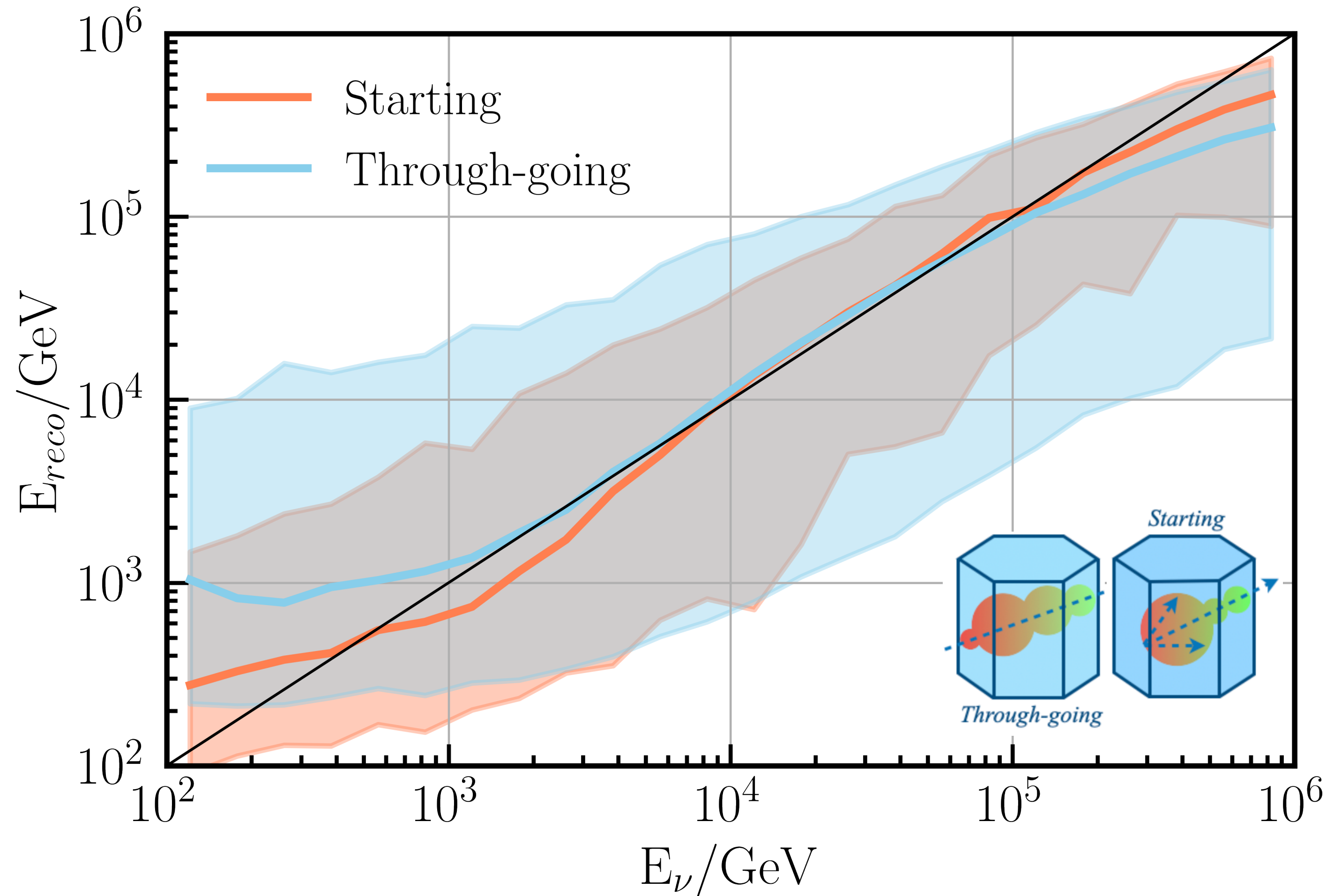
- Current trigger-level reconstruction has an angular resolution of  $\sim 8^\circ$
- SSCNN achieves resolution of  $6^\circ - 4^\circ$  above a TeV
- Recall: Background scales like  $1 - \cos \Delta\psi \simeq \Delta\psi^2$



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# Energy Reconstruction

- Current trigger level reconstruction *does not have an energy reconstruction*
- Energy resolution within an order of magnitude
- Best reconstructions go down to 0.3 of an order of magnitude



# Cross-Detector Simulations

- Prometheus is being used to generate simulations the upcoming for the GraphNeT workshop
- One goal of the workshop is an apples-to-apples comparison of different ML techniques in across telescopes

## 4th GraphNeT Workshop: Graph Neural Networks and Beyond

May 6 – 9, 2024  
TUM Institute for Advanced Study  
Europe/Berlin timezone

### Overview

#### Application

#### Workshop Activities

└ Hackathons

└ Poster Session

└ Joint Publication

#### Practical Information

└ Travel and Accommodation

└ Venue & Local Information

Timetable

Participant List

### What is it about?

This is the fourth workshop dedicated to [GraphNeT](#) – A deep learning library for neutrino telescopes. The goal is to bring together researchers working at the intersection of neutrino telescope experiments and machine learning to meet likeminded researchers, discuss the latest progress, and develop new solutions to physics challenges by applying deep learning where it matters, using GraphNeT.

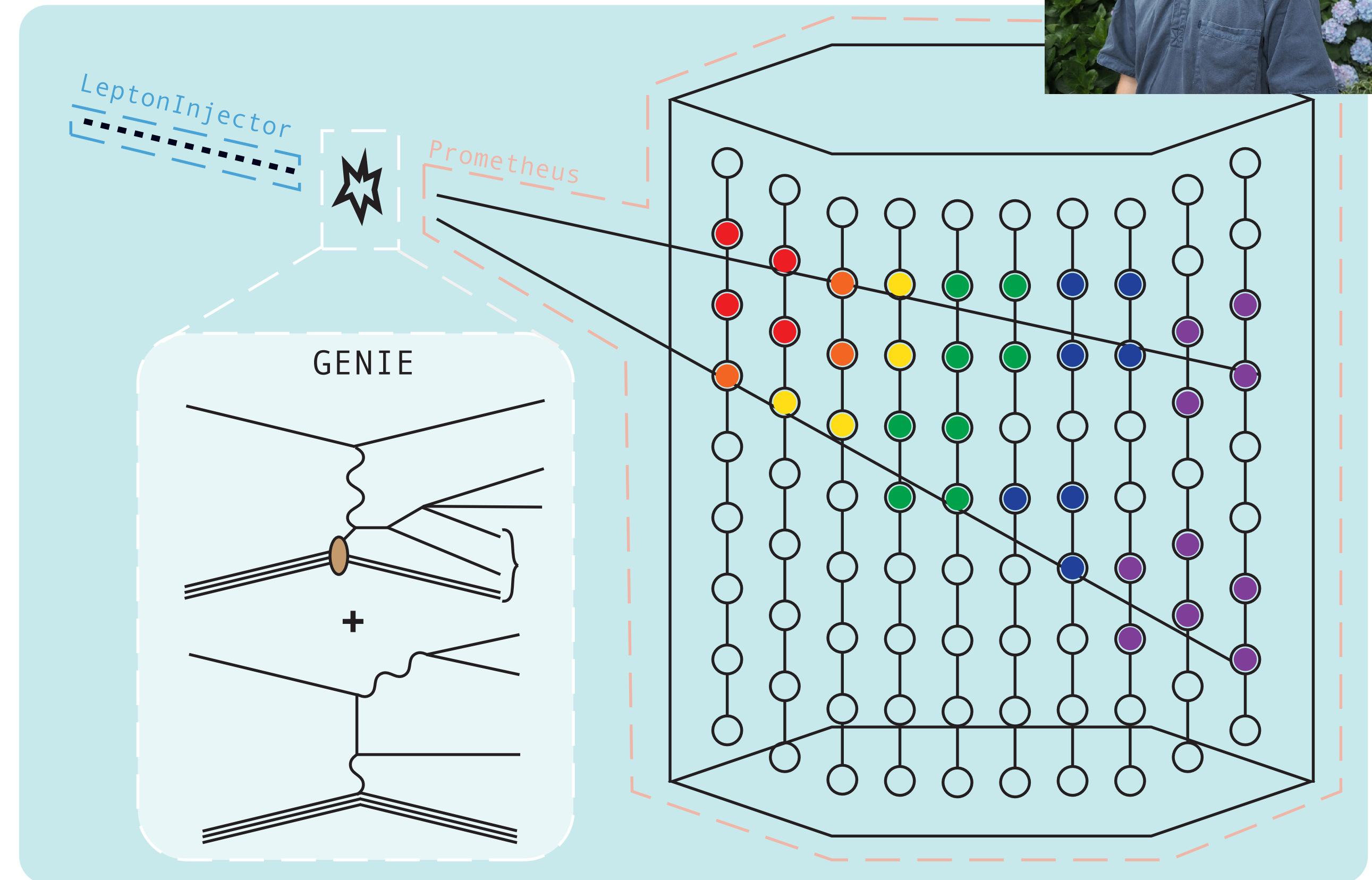
This May, we're celebrating the launch of GraphNeT 2.0 which extends functionality beyond graph neural networks into other deep learning paradigms like normalizing flows, transformers, autoencoders and several of the winning solutions from the [IceCube Kaggle Competition](#).

The workshop, and particularly the two half-day hackathons, are focussed on putting the GraphNeT framework into use for physics – in IceCube, P-ONE, KM3NeT and other experiments. In this way, we hope to foster collaboration on common tools in order to advance physics research faster than individual experiments can on their own.

During the workshop, participants will be presented an opportunity to get involved in a joint publication that aims to provide the first-ever apples-to-apples comparison of deep learning techniques from different neutrino telescopes on a series of open-source datasets specifically prepared for this workshop by the team behind open-source simulation tool [Prometheus](#).

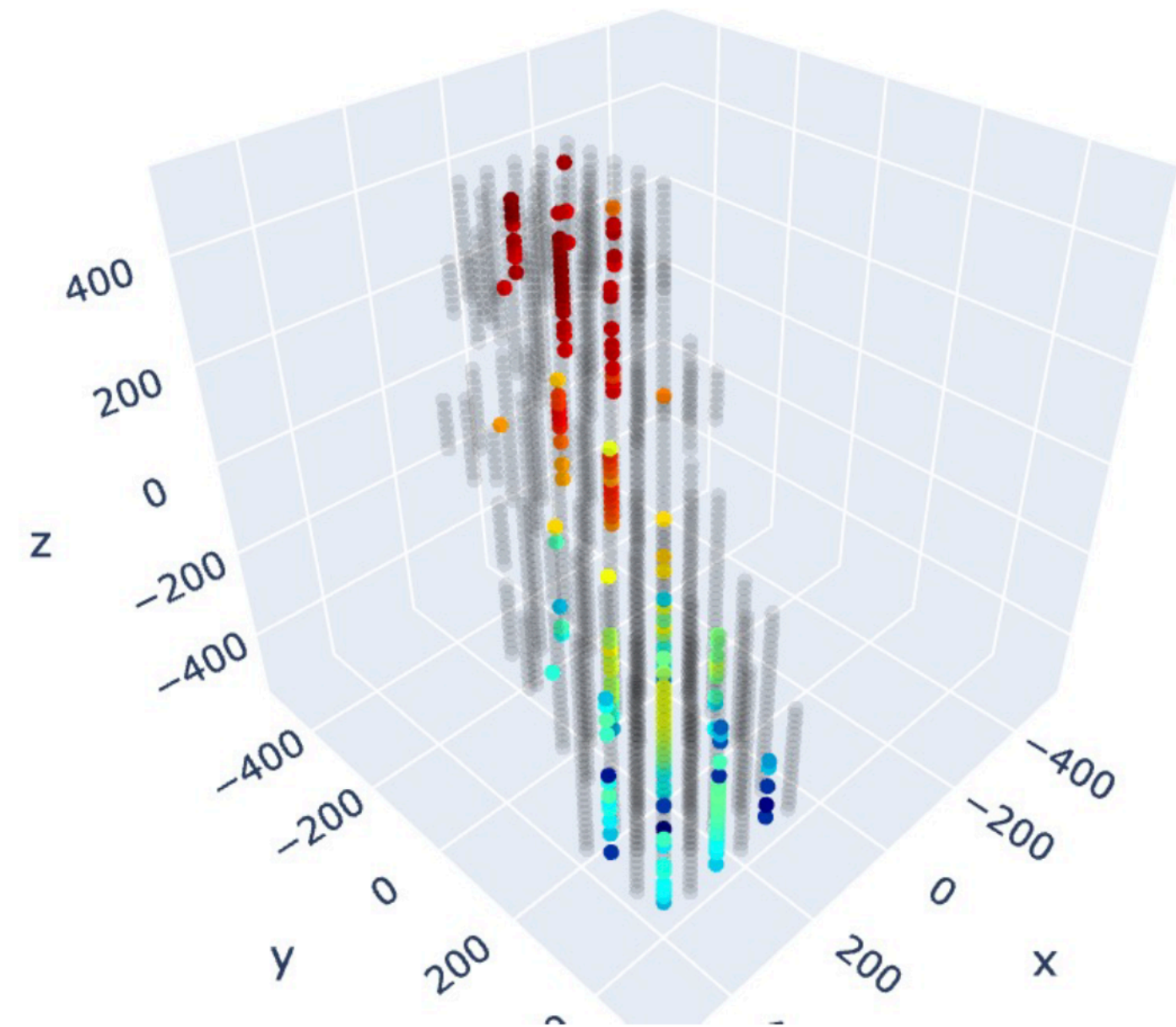
# Simulating New Physics

- Currently working with Eliot Genton to generate dimuon events and differentiate them from single muon events
- Plans in the works to inject events directly from MadGraph to make simulating BSM physics easier

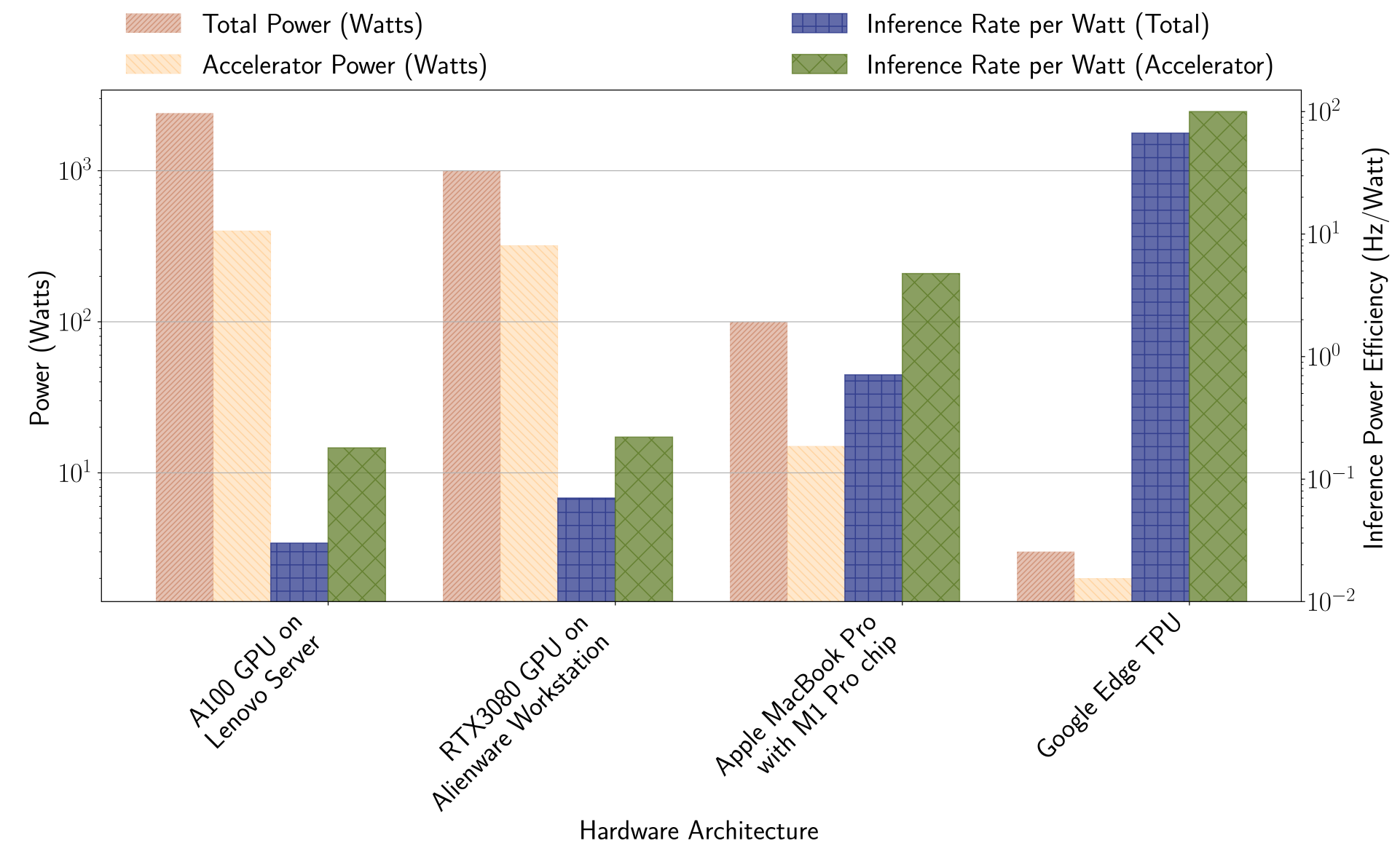


# Other Things in the Pipe

## Event Upscaling



## TPU-based reconstructions



# Conclusions

- The growing network of neutrino telescopes will afford new opportunities to address challenges jointly
- With `Prometheus`, there is not an open source option to simulate detectors within the same framework allowing cross-detector analyses, novel physics simulation, and ML prototyping
- `Prometheus` has already been shown to be useful for developing ML-based reconstructions and more are coming, and will be used in an upcoming workshop to better understand ML techniques

**Thank you :-)**