Prometheus: Open-Source Simulation for Neutrino Telescopes

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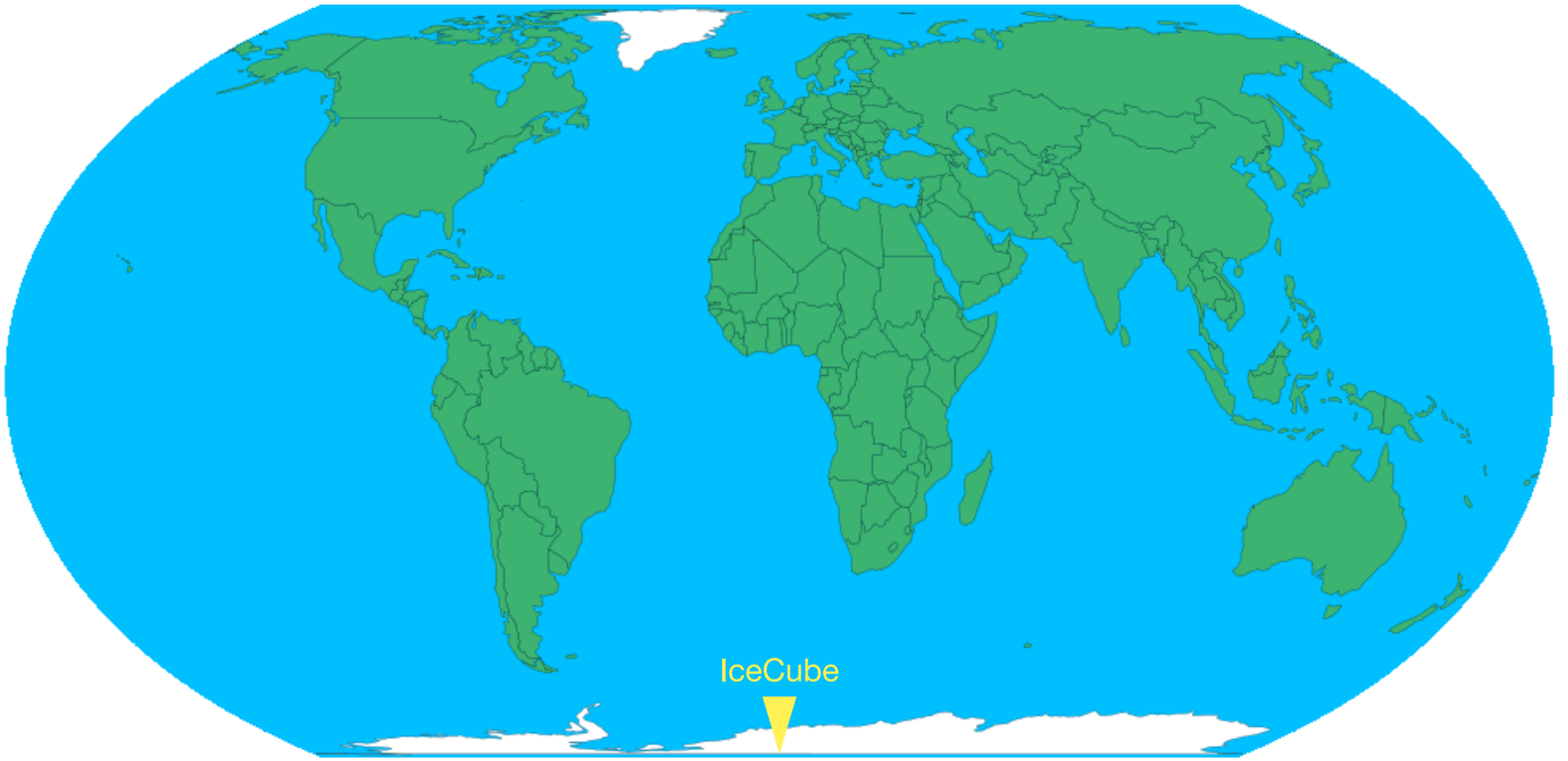
A Growing, Global Network

- 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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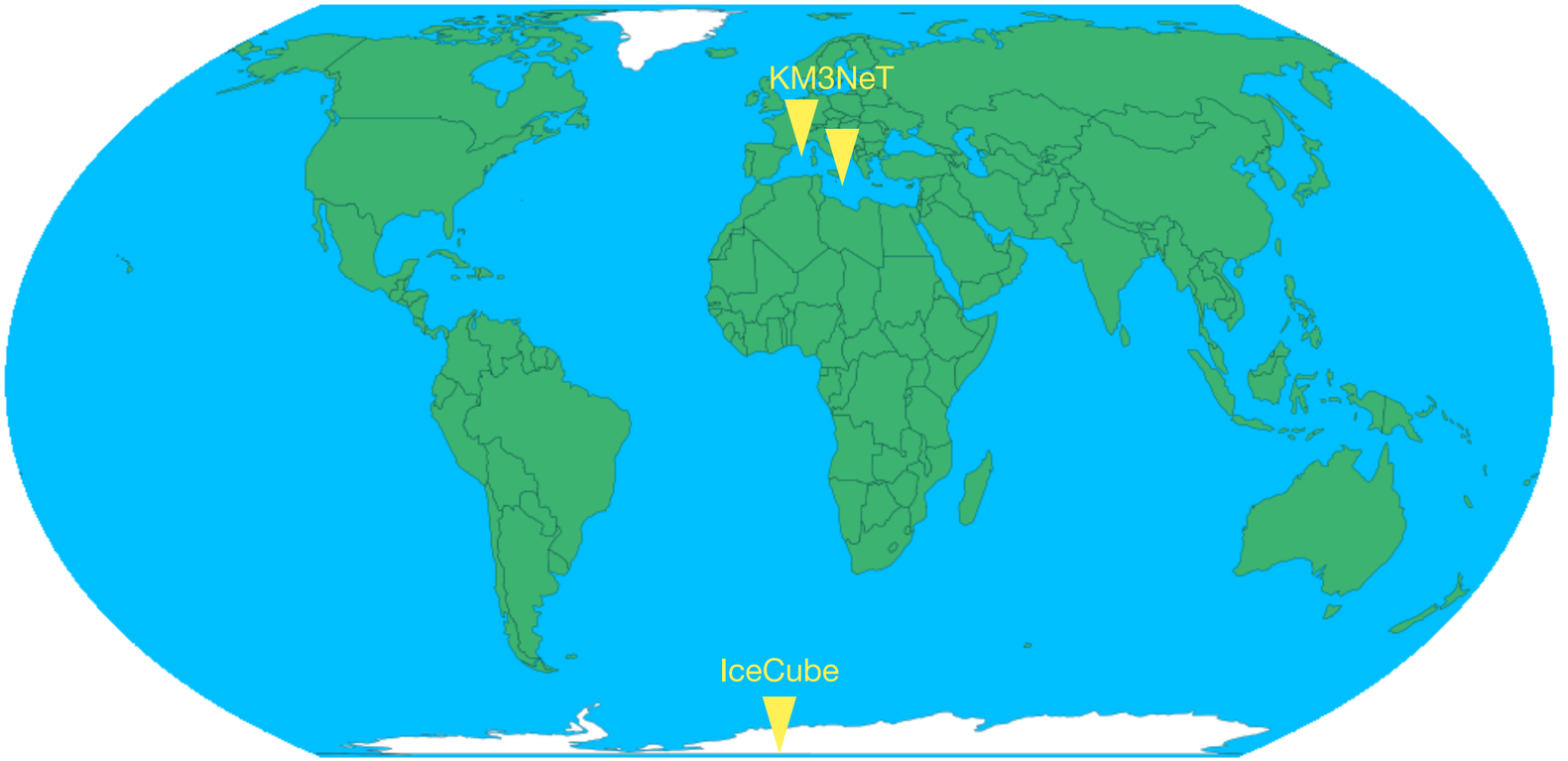

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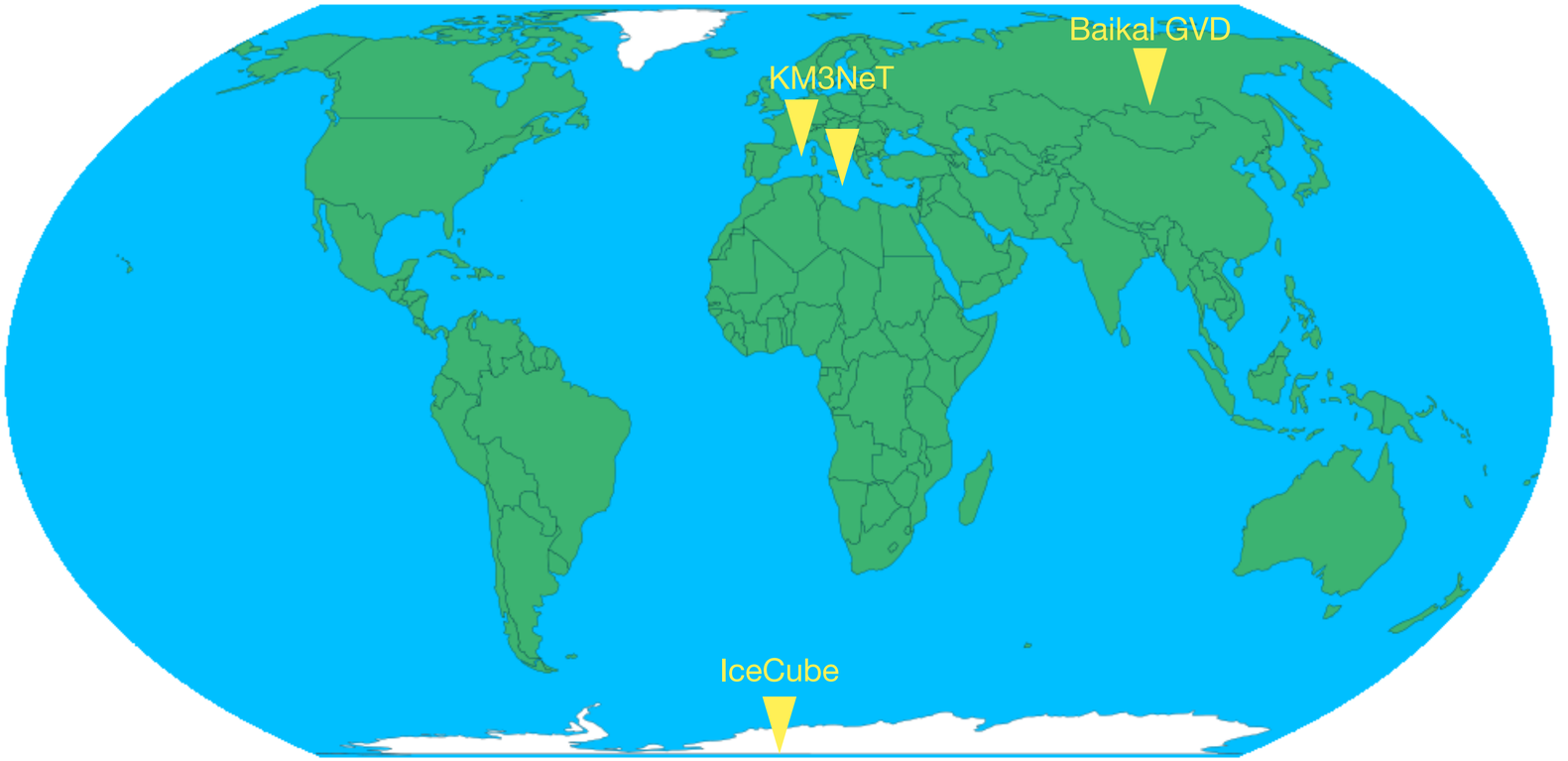

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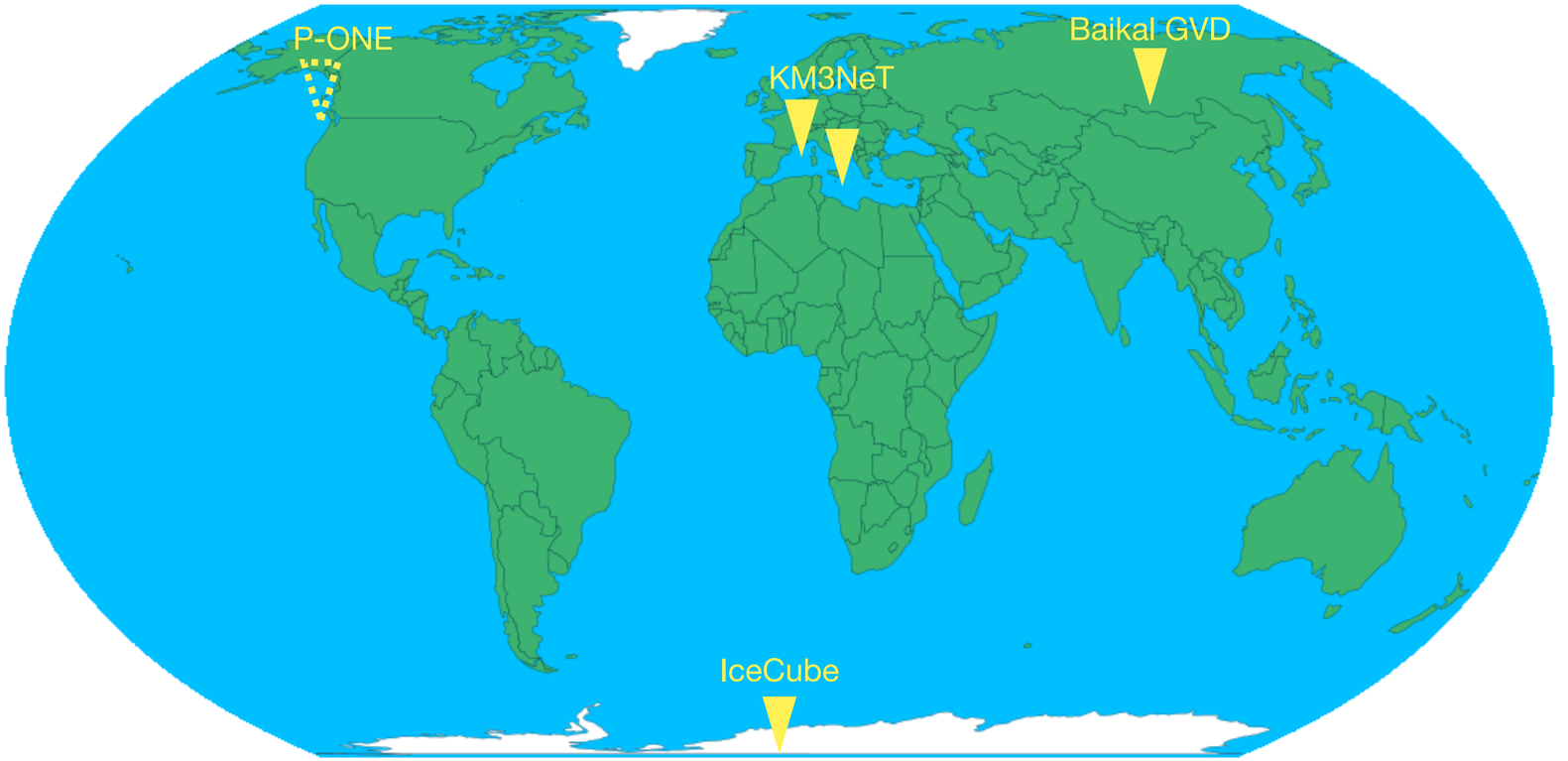

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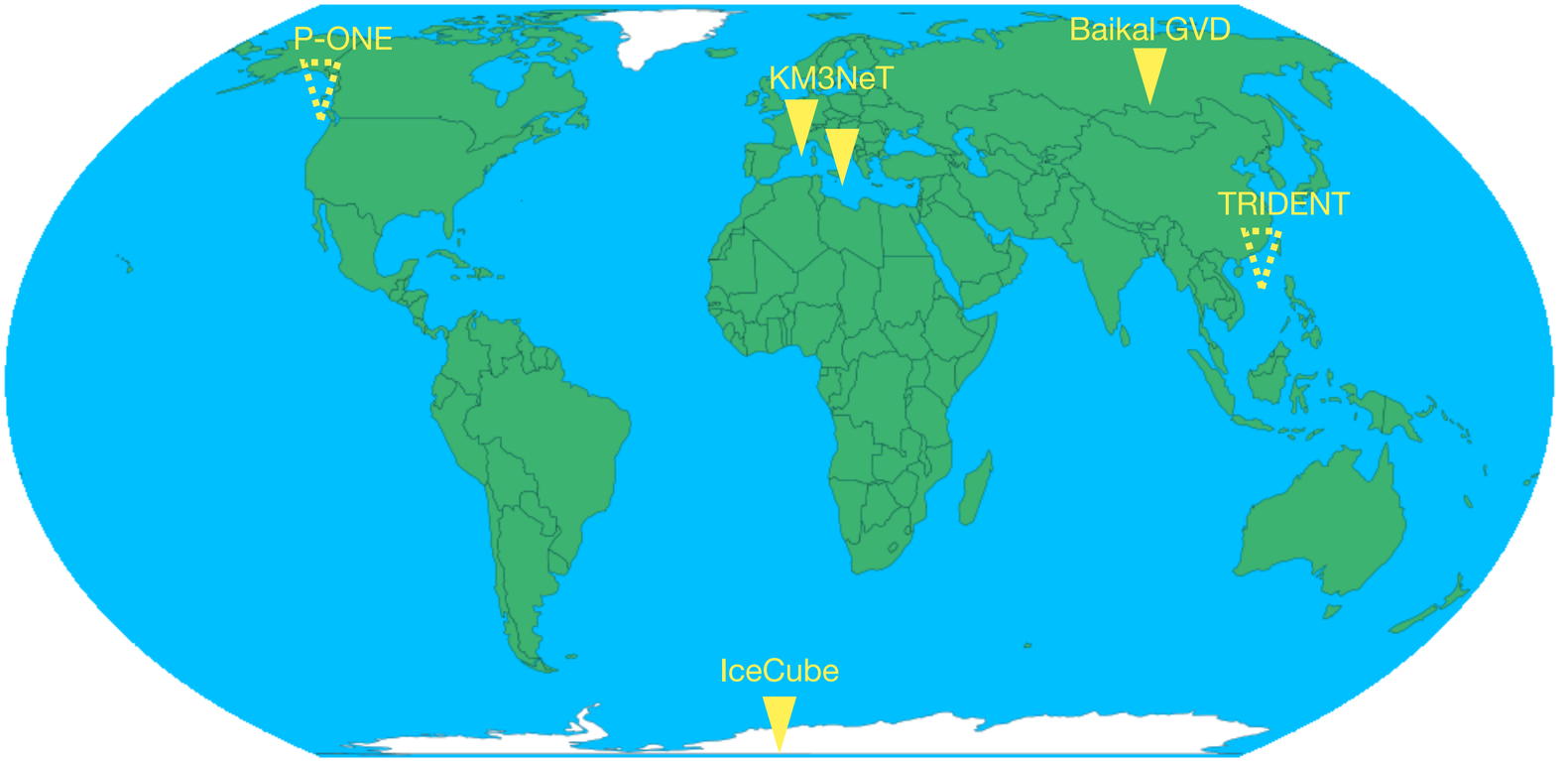
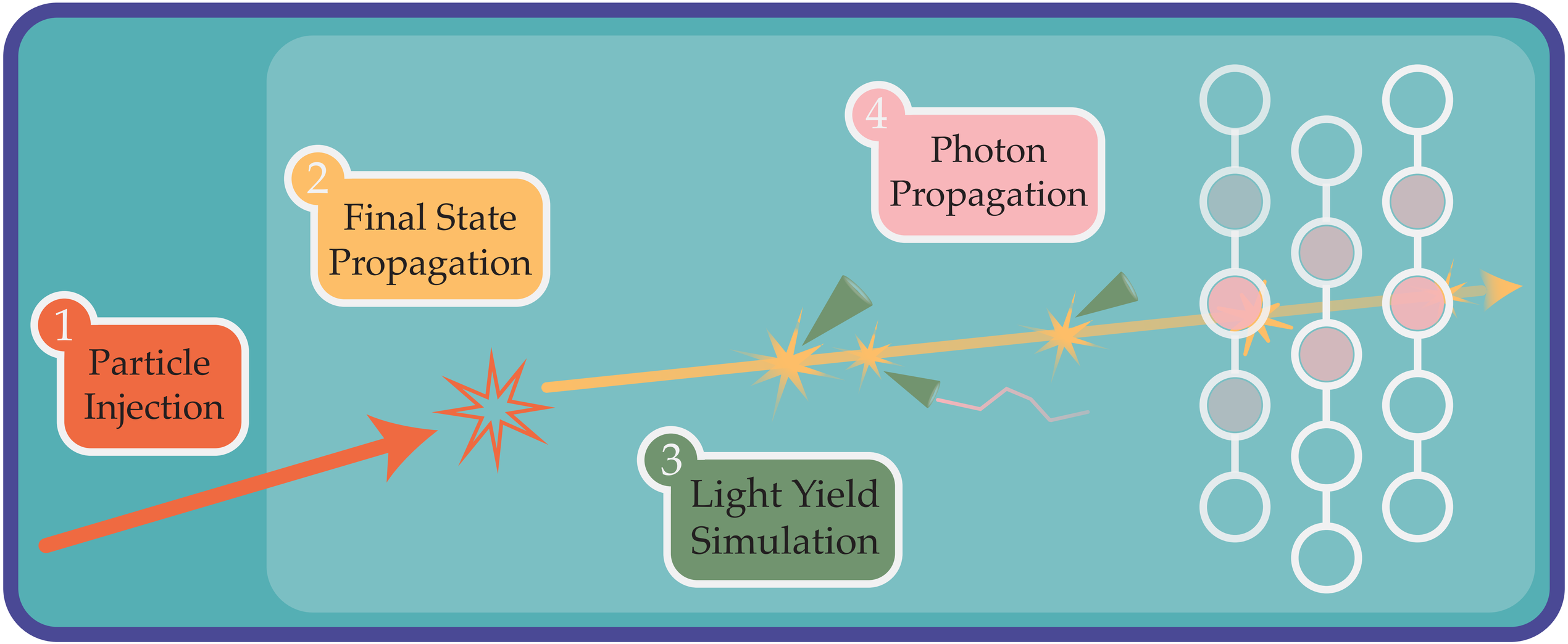
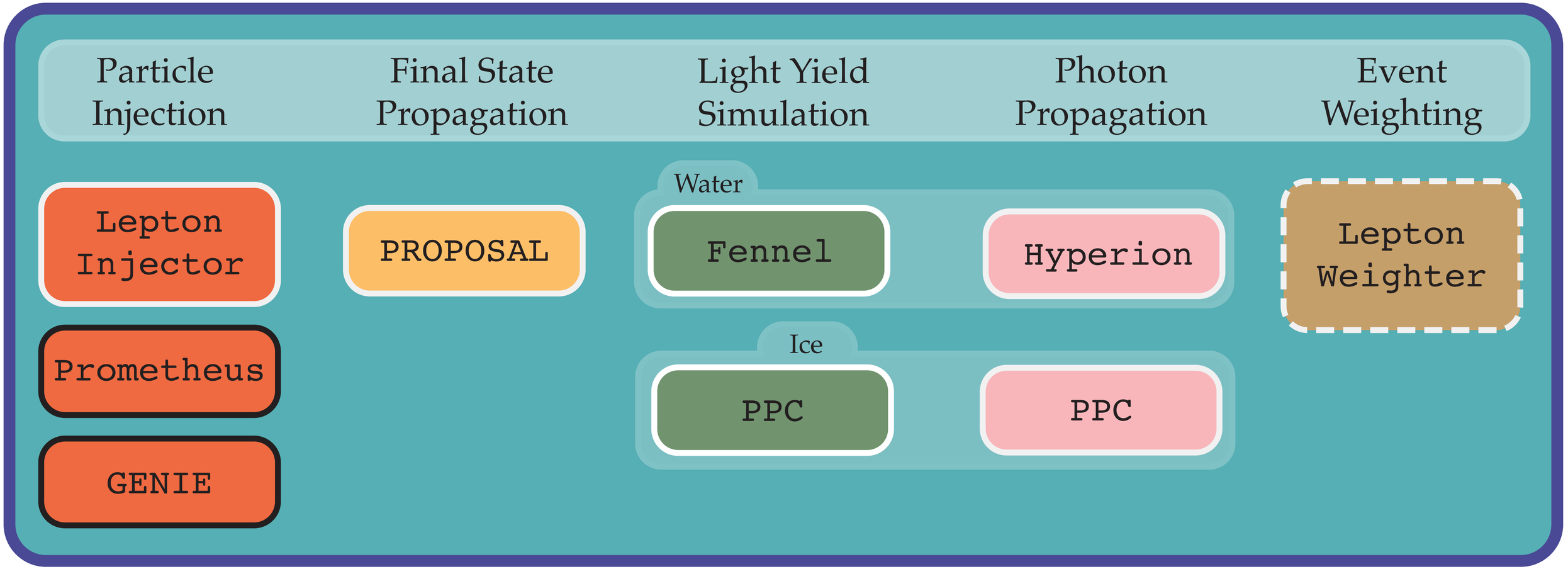


An Opportunity to a Collective Approach

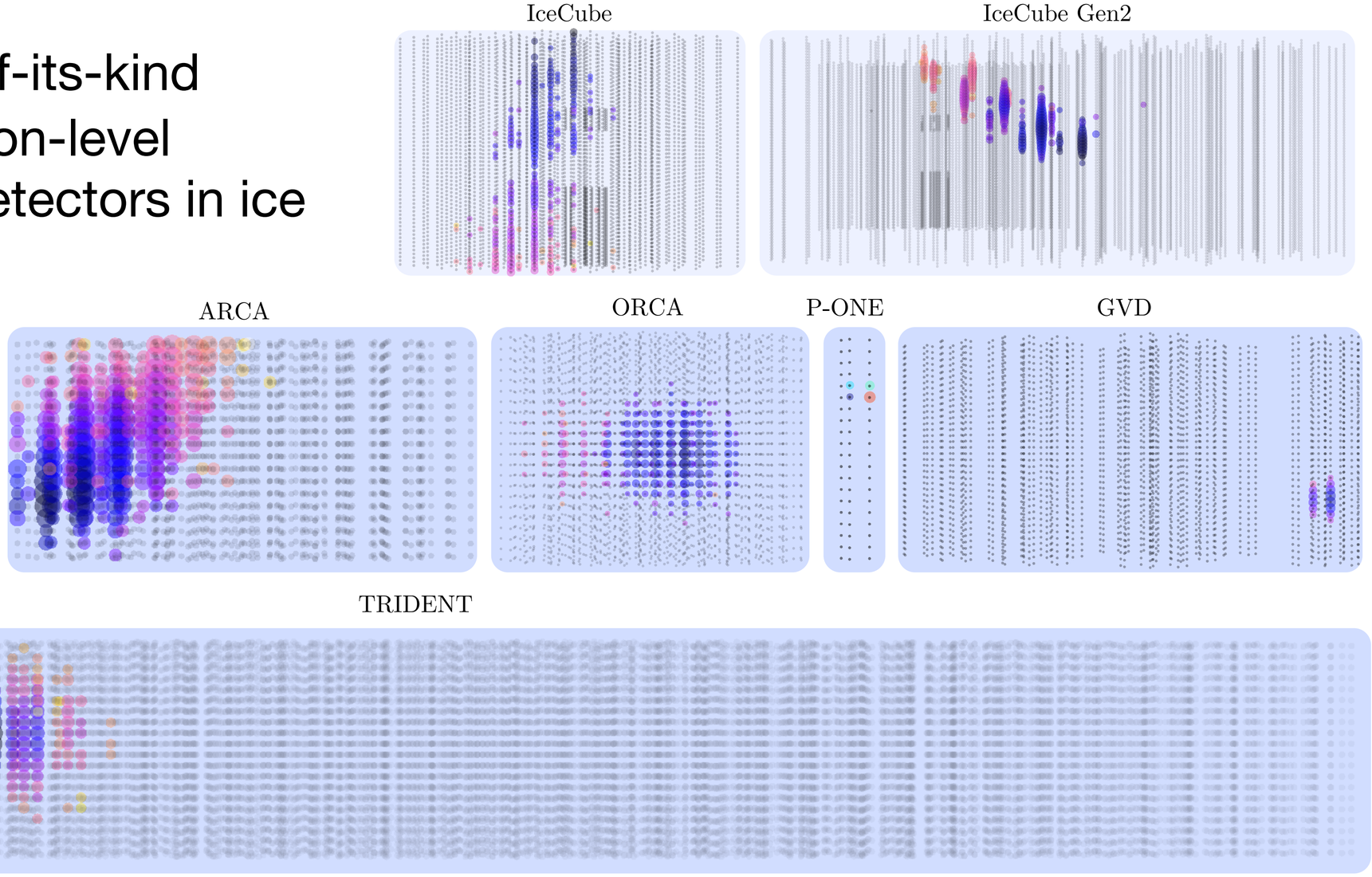


Open-Source Answers



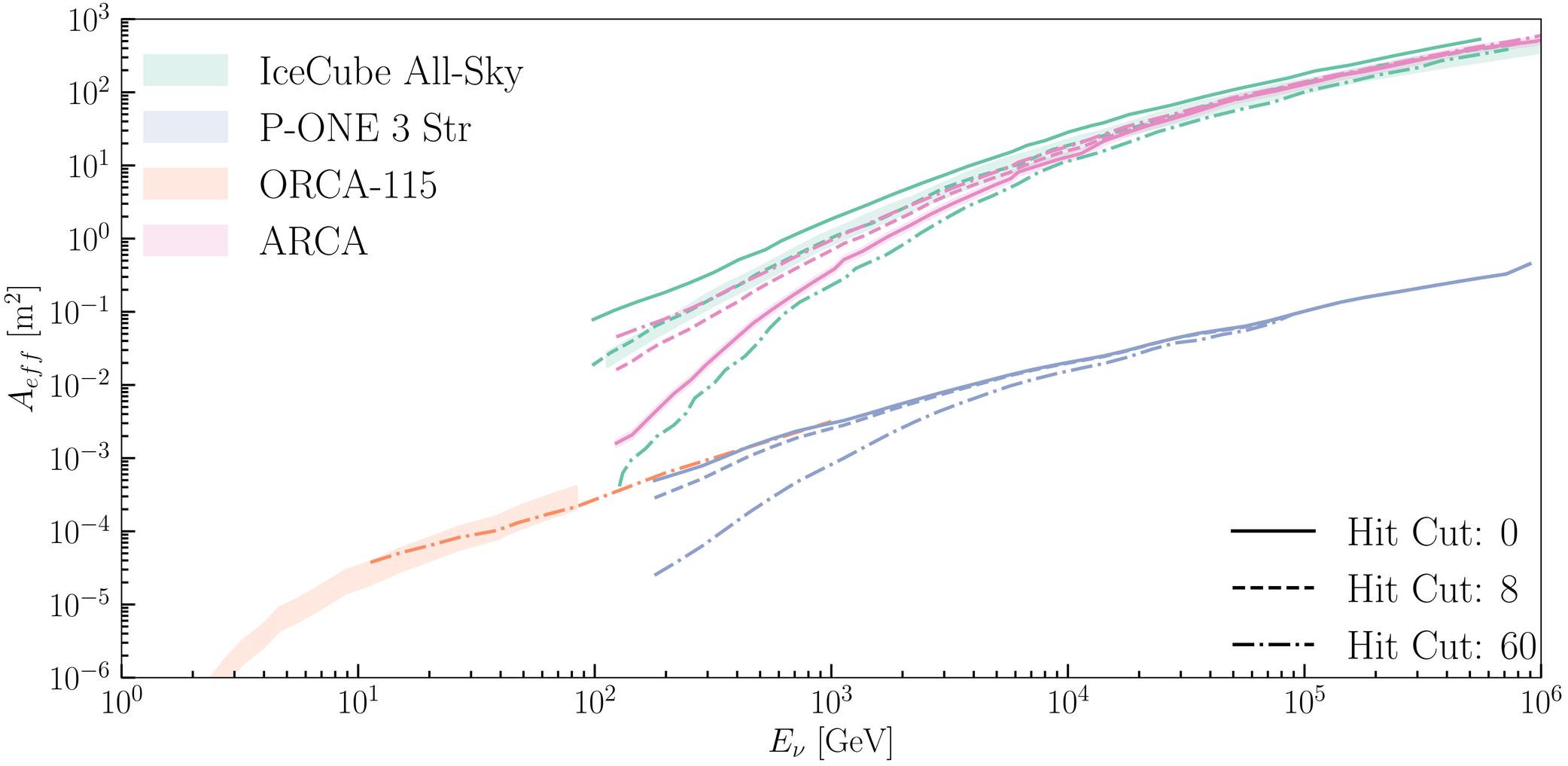
A Full, Open-Source Simulation

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



JL, S. Meighan-Berger, C. Haack, D. Kim, S. Giner, and C.A. Argüelles: ArXiv:2304.14526

Reliable Results



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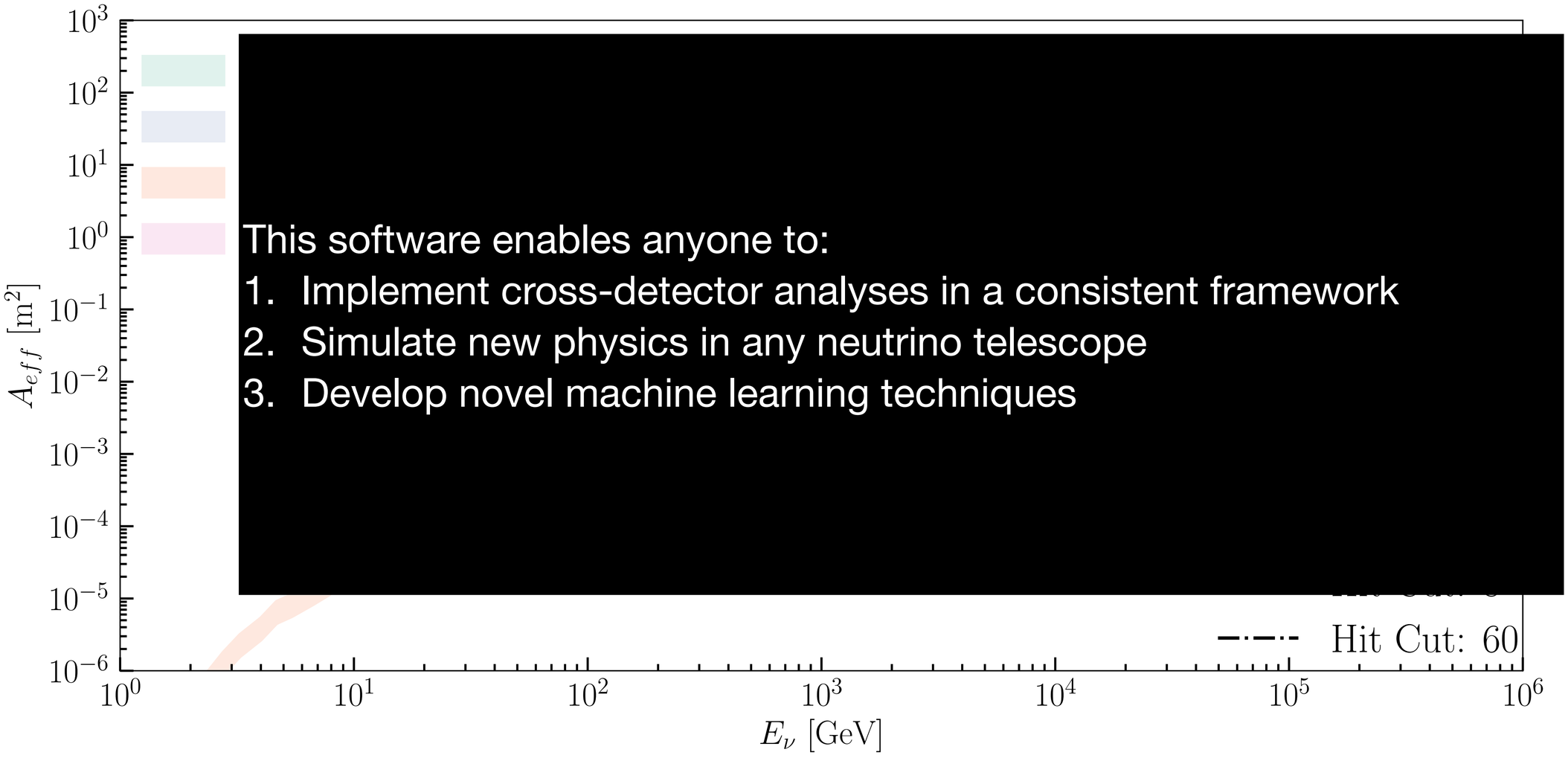

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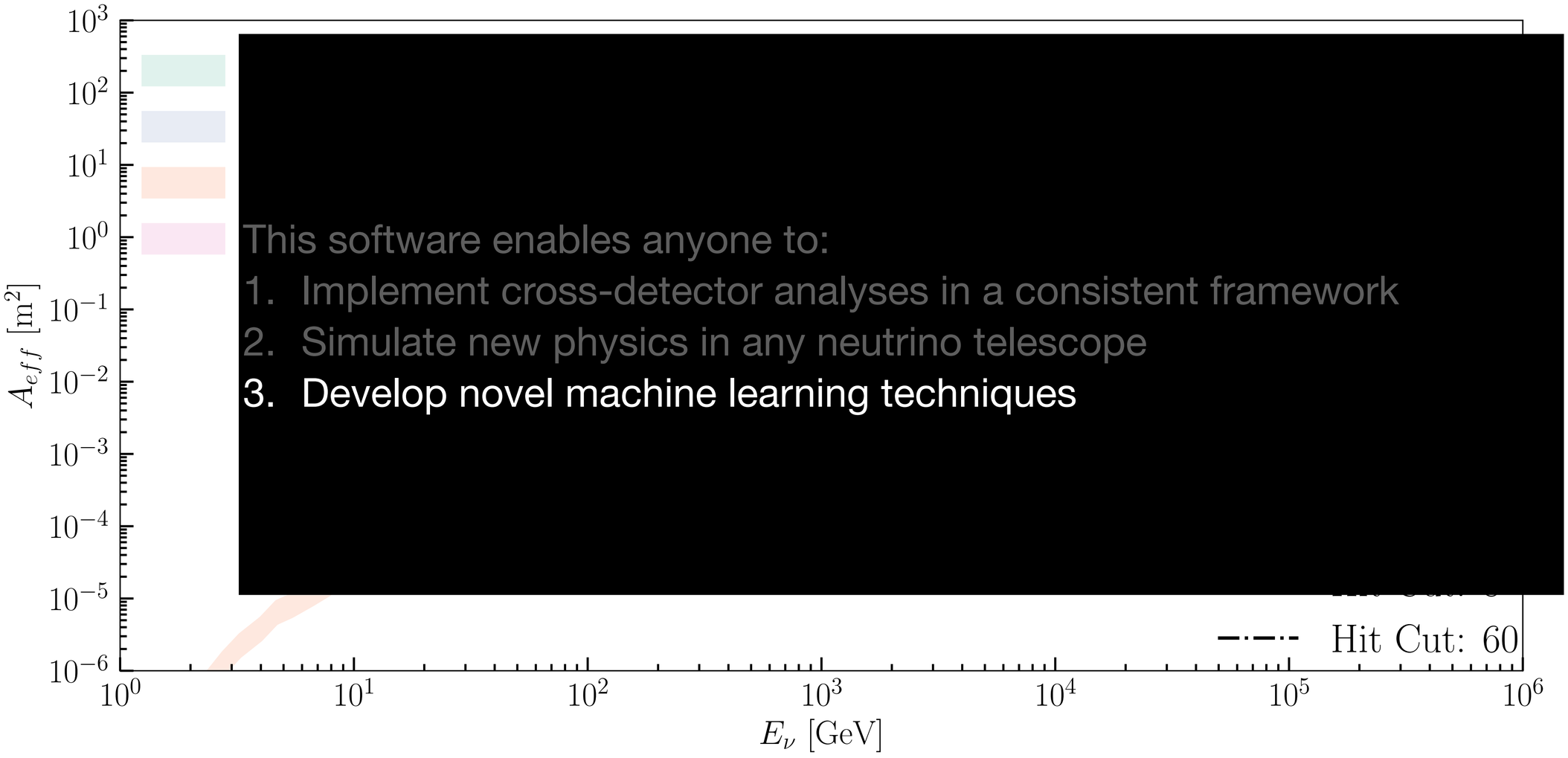

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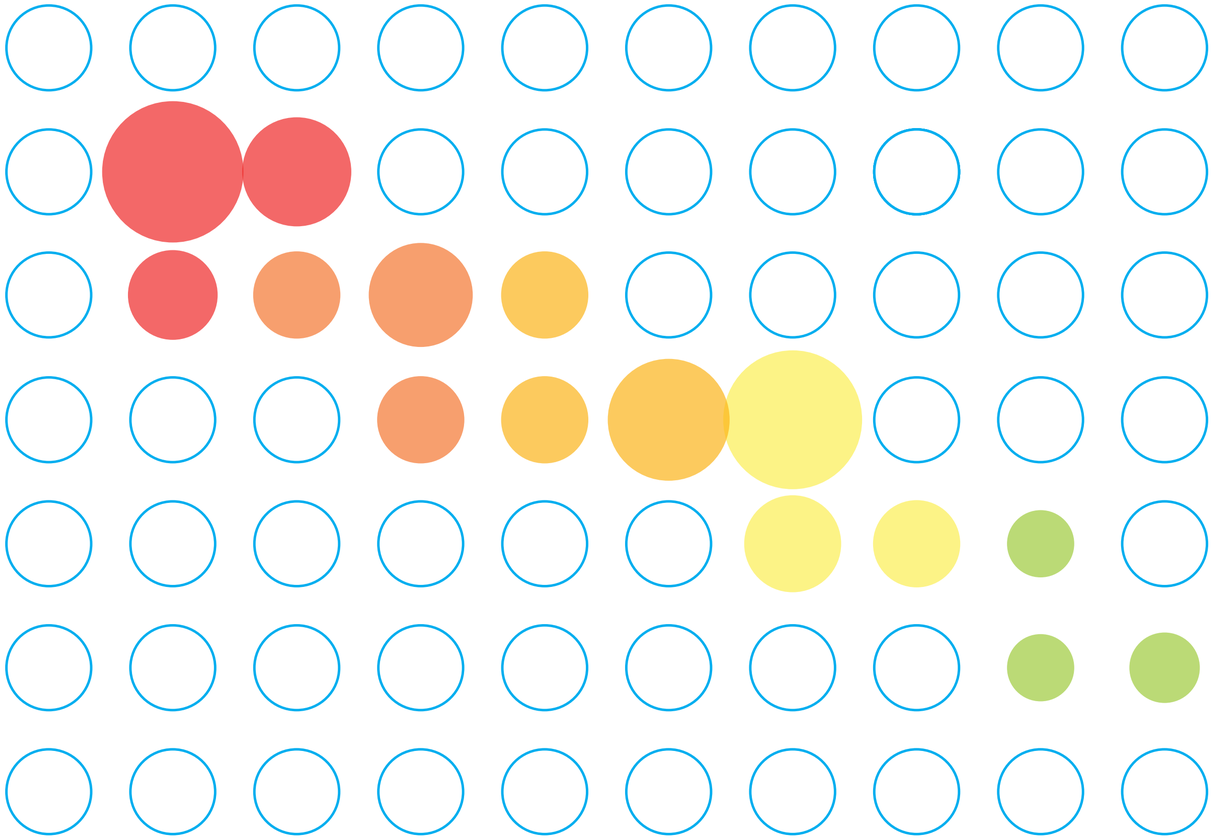
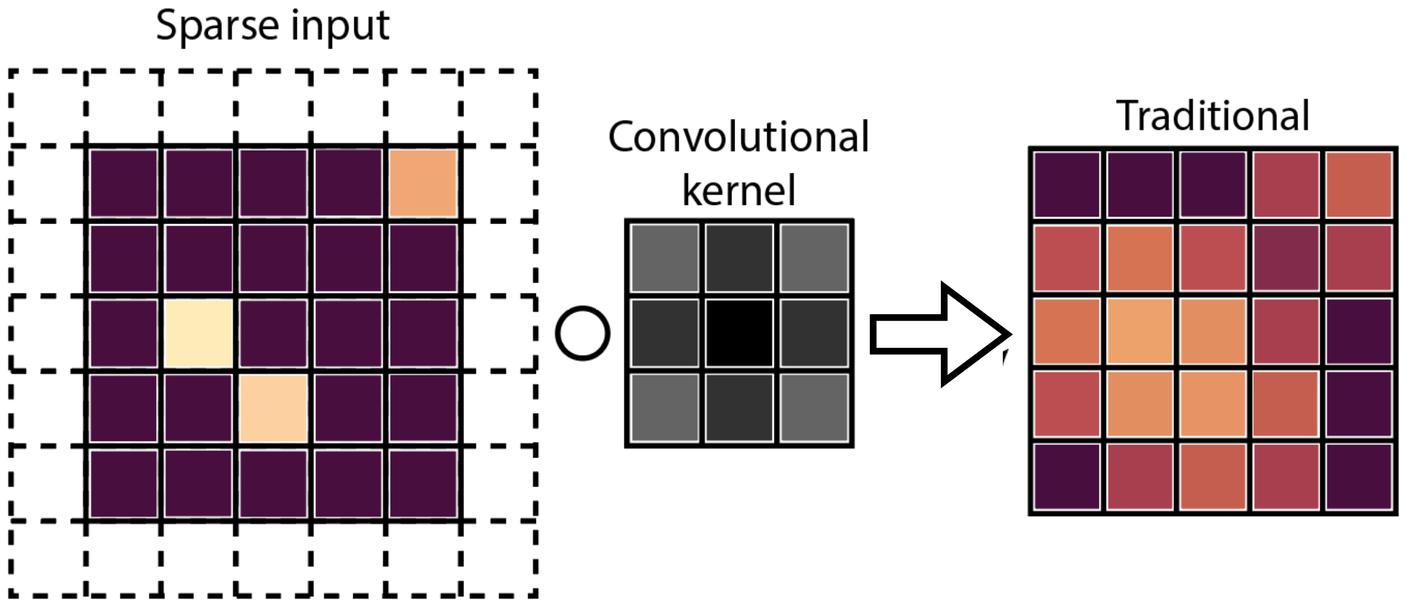
Troubles of CNNs

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



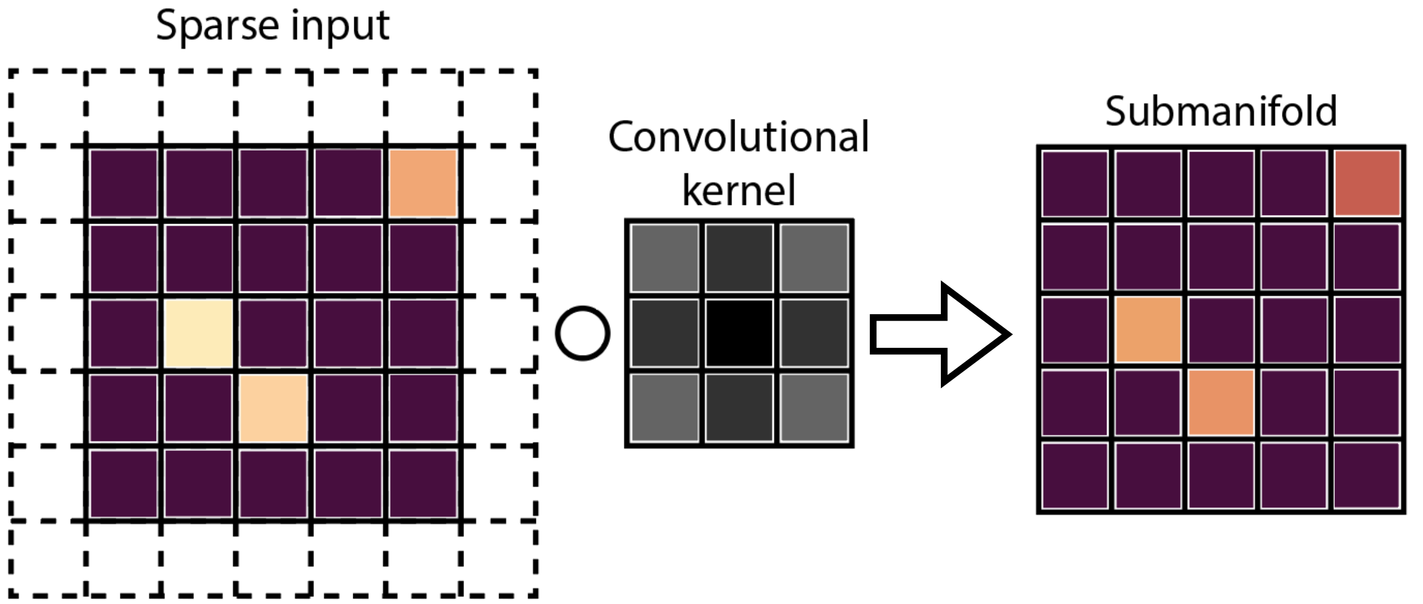
But Sparse Data is Not New

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



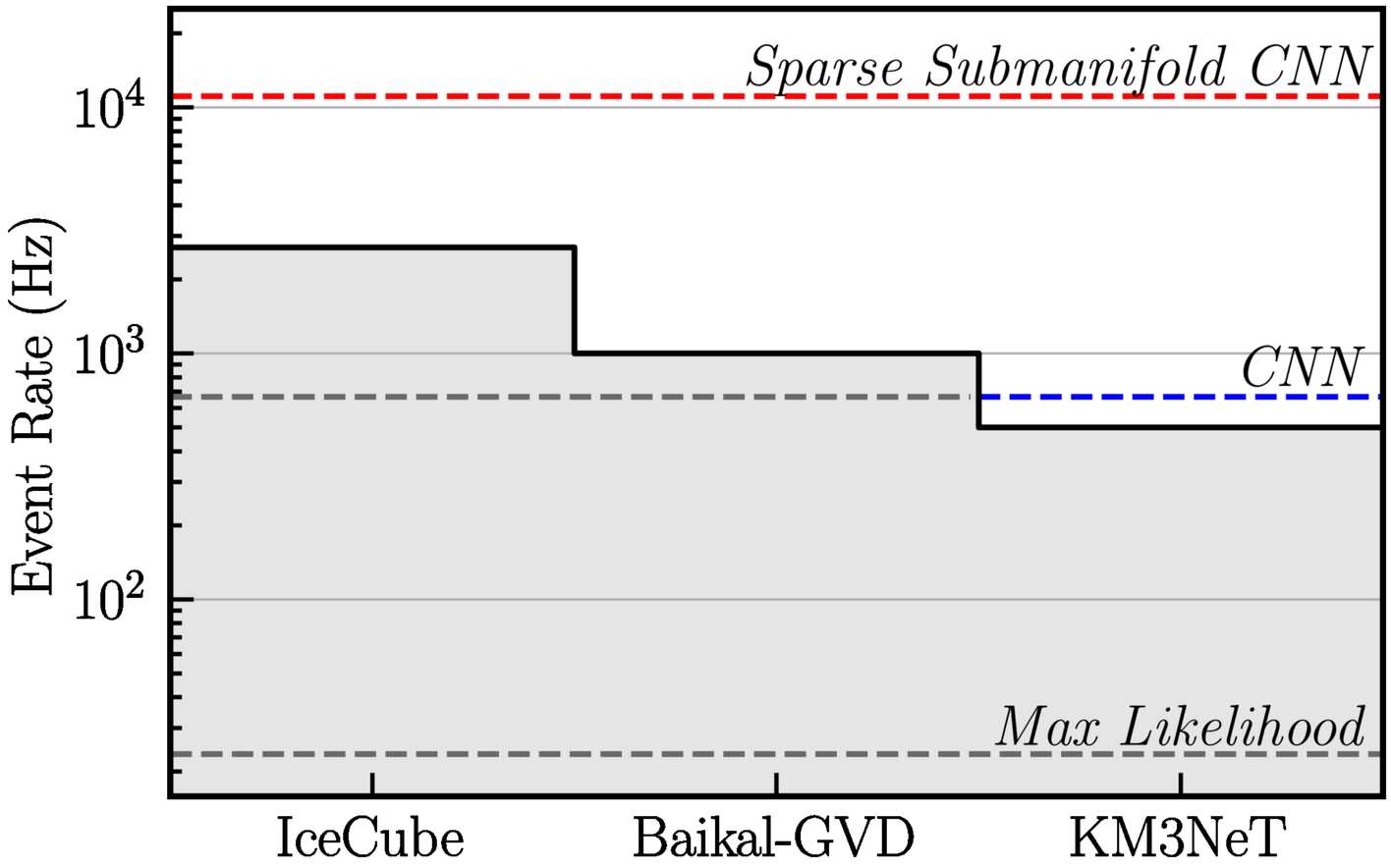
Mainting Sparsity

- Restrict ourselves to sub manifold 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 ~11 kHz, *i.e.* nearly 4x IceCube's trigger rate !
- We can run this in real time on all triggered events !

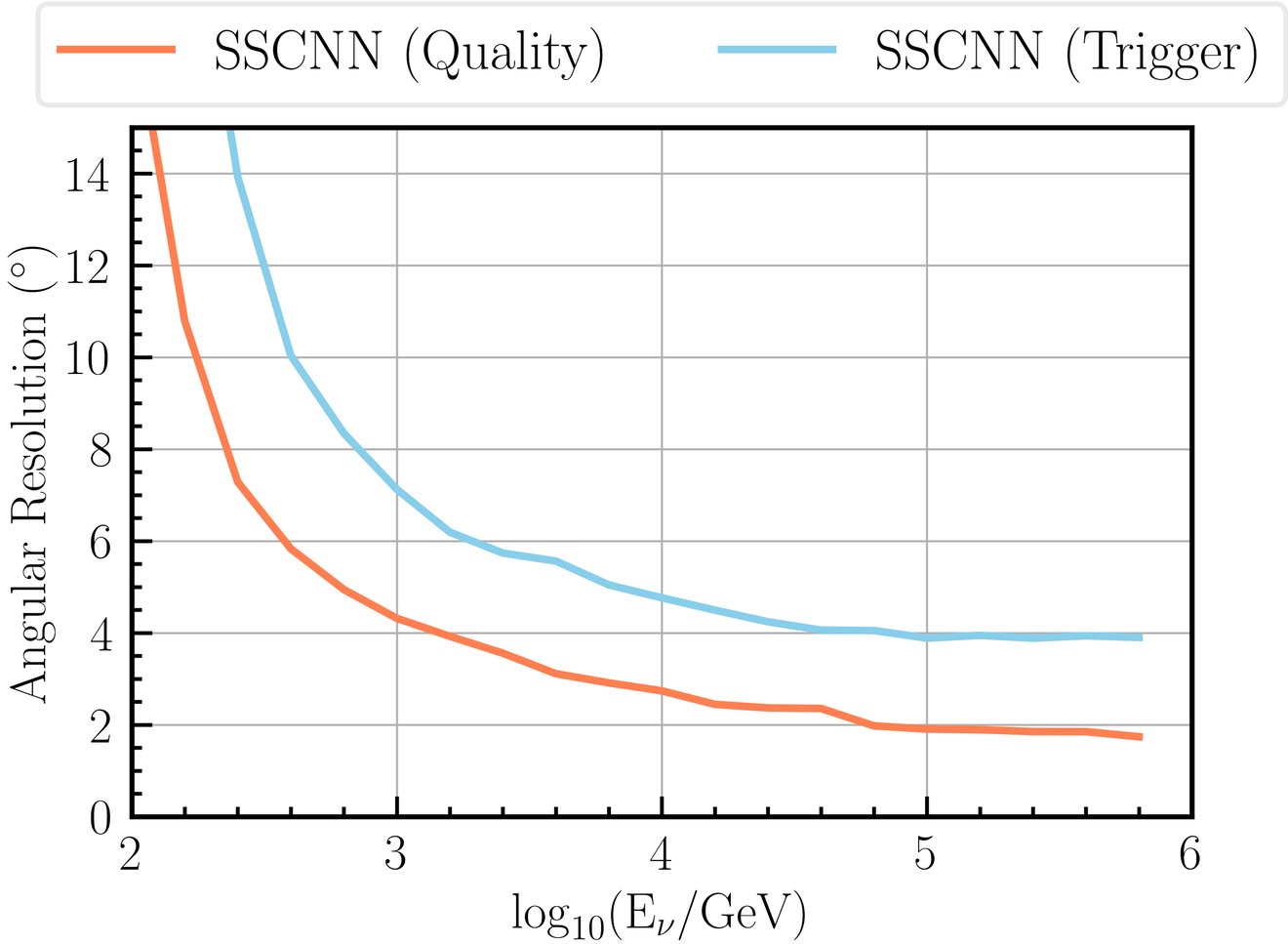


SSCNN (GPU)	**0.090 ± 0.007 ms**
SSCNN (CPU)	**65.22 ± 117.04 ms**
Max Likelihood (CPU)	42.6 ± 175 ms

F. Yu, **JL**, C.A. Argüelles: DOI: 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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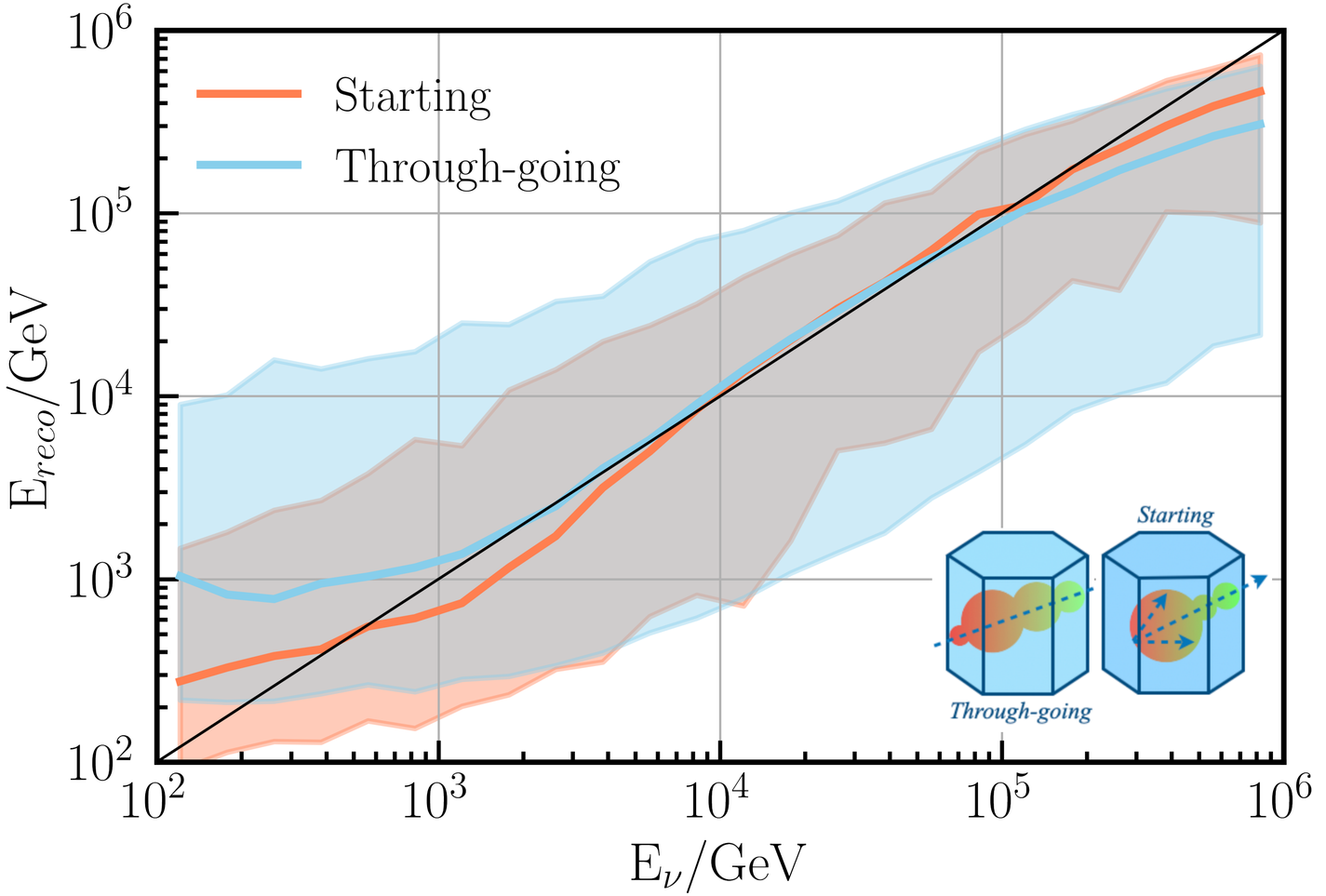
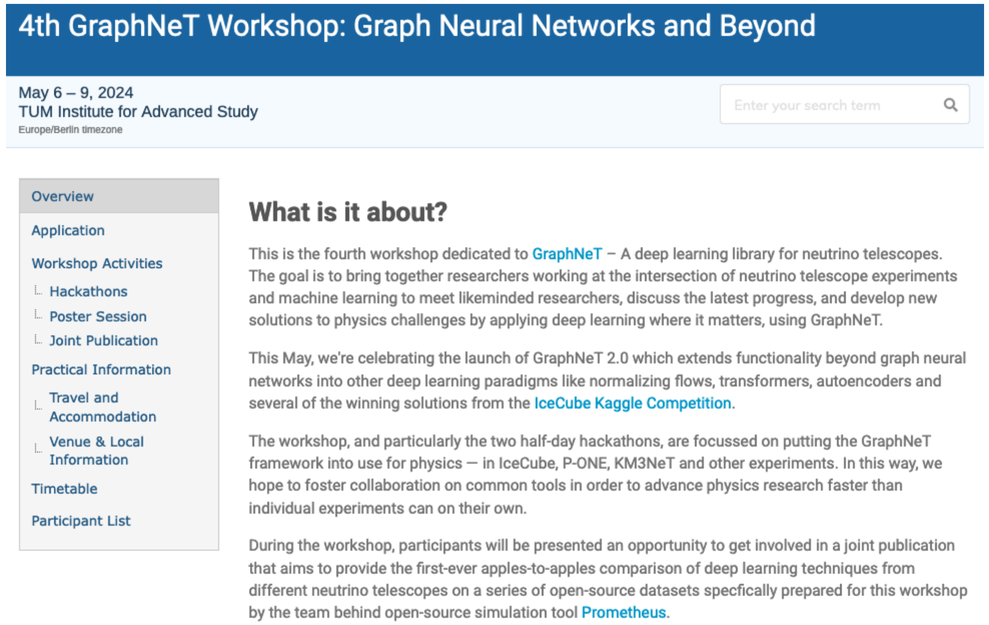
Energy Reconstruction

- 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

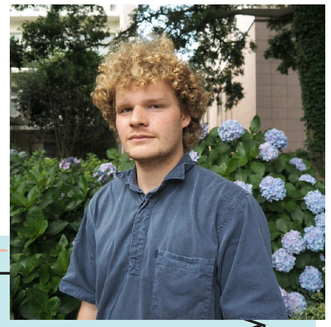


Cross-Detector Simulations

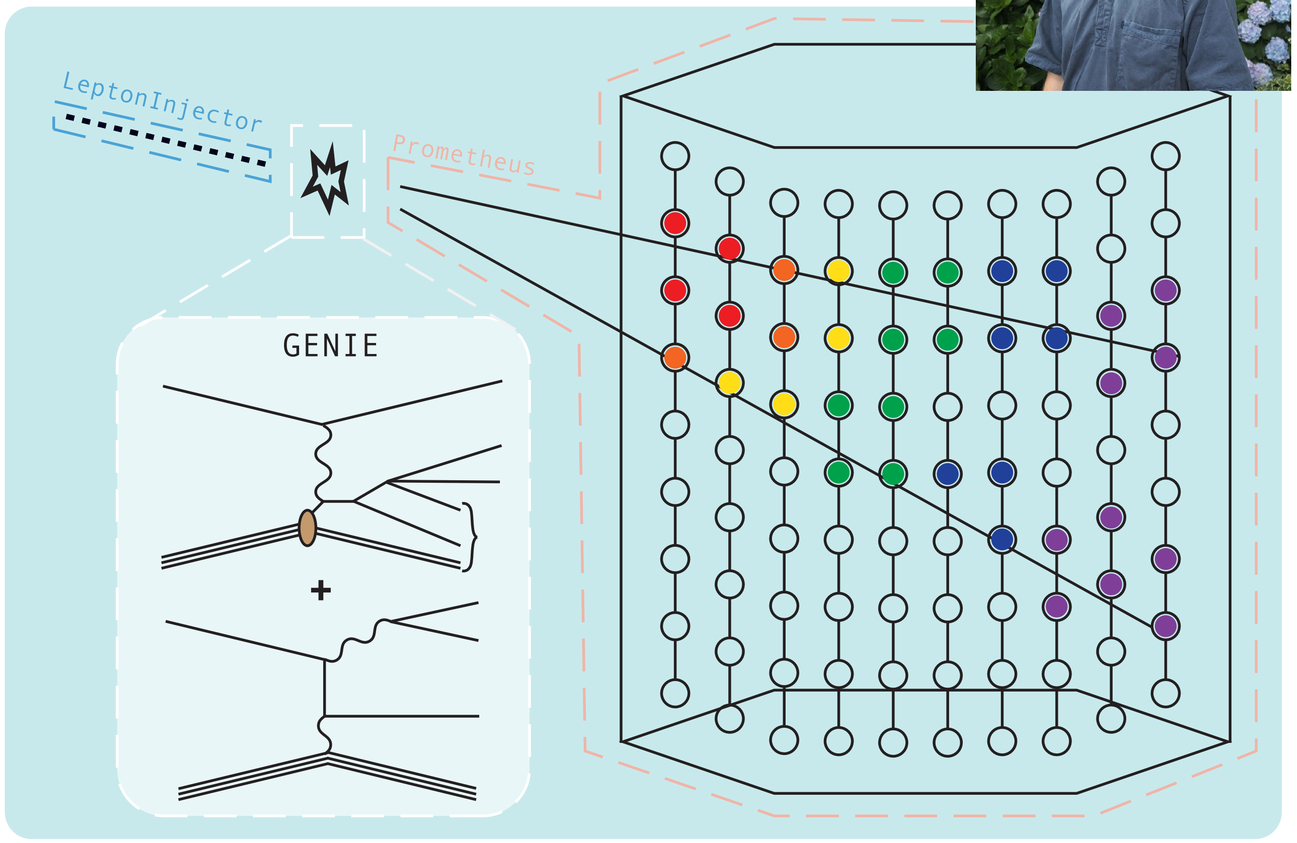
- `Prometheus` is being used to generate simulations the upcoming for the GraphNeT workshop
- One goal of the workshop is an apples-to-apples comparison of different ML techniques in across telescopes



Simulating New Physics

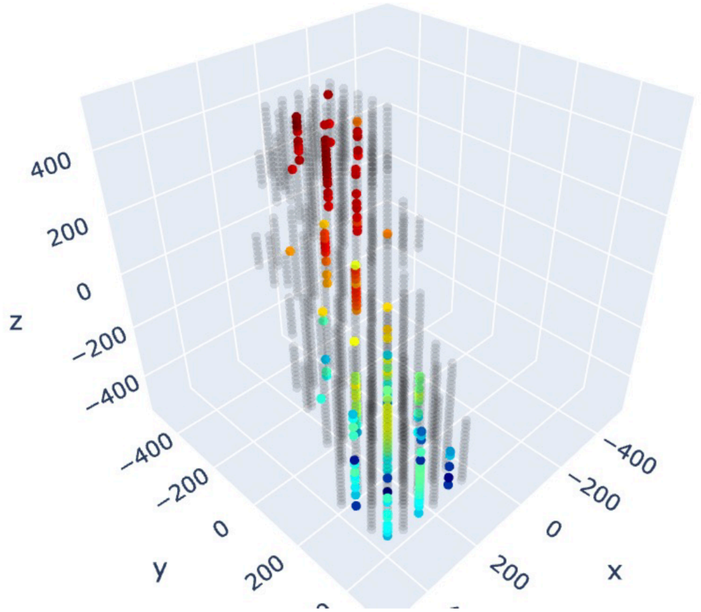


- Currently working with Eliot Genton to generate dimuon events and differentiate them from single muon events
- Plans in the works to inject events directly from MadGraph to make simulating BSM physics easier

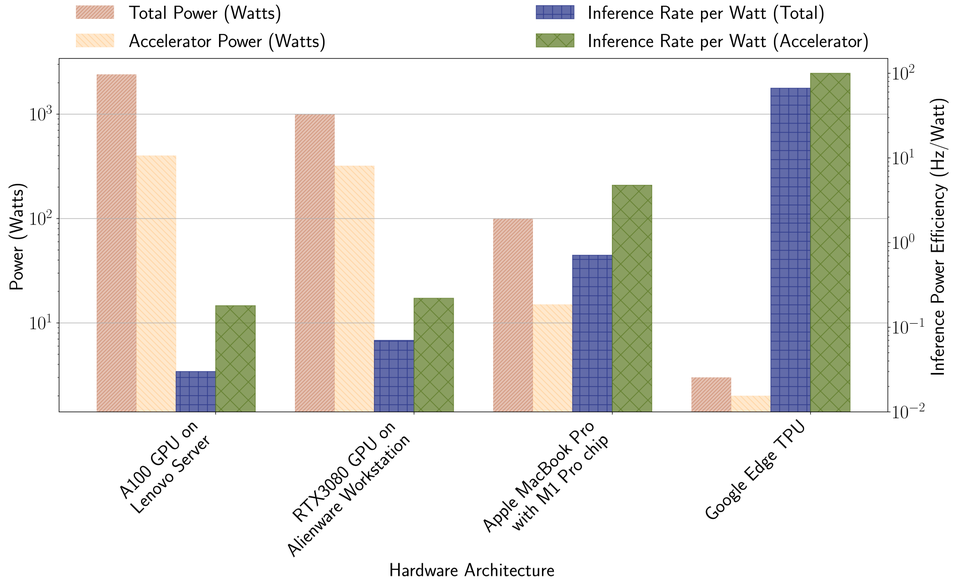


Other Things in the Pipe

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 :-)