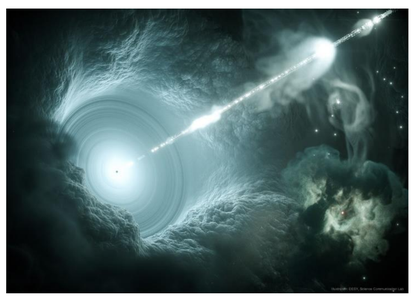
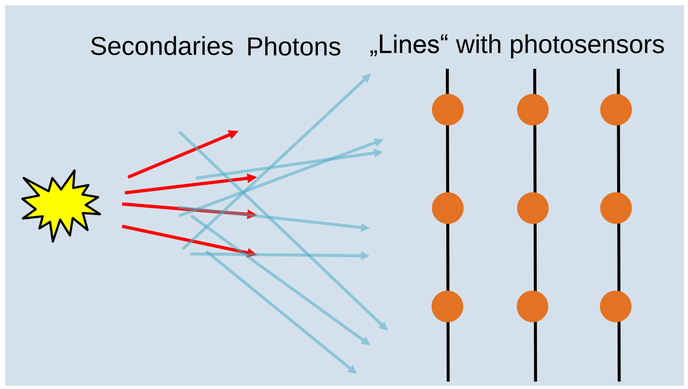
Machine-learning based detector optimization of the future P-ONE neutrino telescope

Christian Haack, *ECP, TU Munich*
christian.haack@tum.de

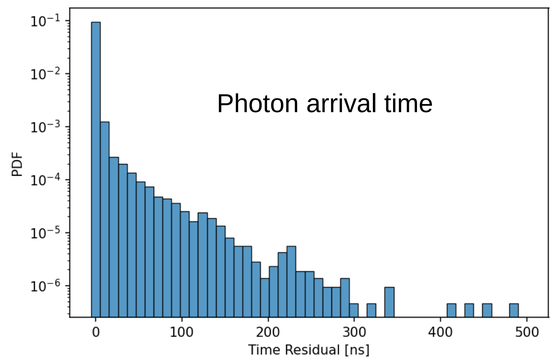
Neutrino Telescopes



Neutrinos



Transparent Natural Medium (Water / Ice)

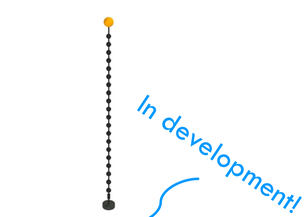


Science:

- Multi-messenger astronomy
- Astrophysical accelerators Galactic & Extra-Galactic
- Transient phenomena
- Cosmic ray transport
- BSM-Physics
- Multi-disciplinary science

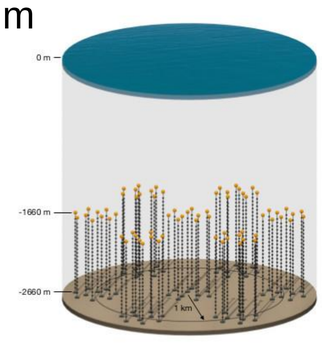
Pacific Ocean Neutrino Explorer (P-ONE) [1]

- Next-generation neutrino telescope in the Pacific Ocean
- Vision for complete detector: around 70 mooring lines, multi-km³ instrumented volume
- P-ONE-1 (1st detector line) with 20 modules and total length of 1000 m

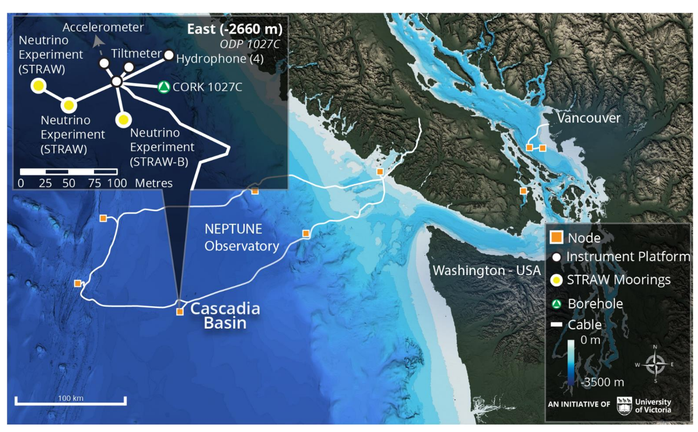


Design Parameters:

- Sensor spacing (vertical / horizontal)
- Cluster structure
- Trigger



P-ONE-1 — **Design Optimization** — **Vision**

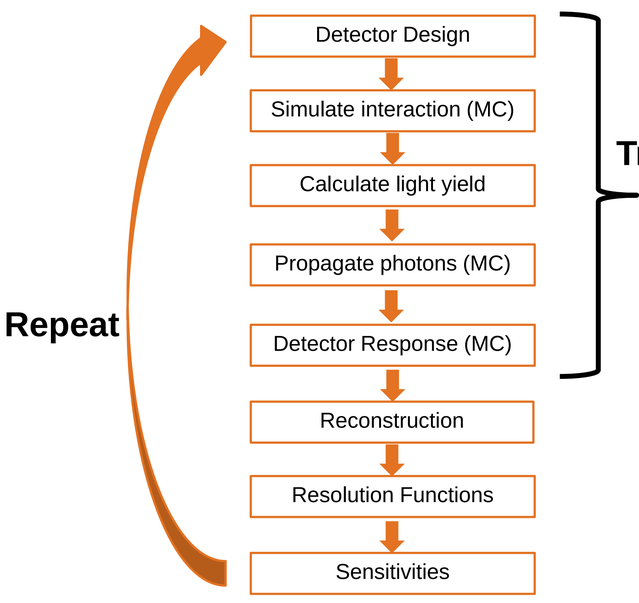


Integrated into deep-sea infrastructure: Ocean Networks Canada

[1] Agostini, M., Böhmer, M., Bosma, J. *et al.* The Pacific Ocean Neutrino Experiment. *Nat Astron* **4,** 913–915 (2020). https://doi.org/10.1038/s41550-020-1182-4

Detector Optimization

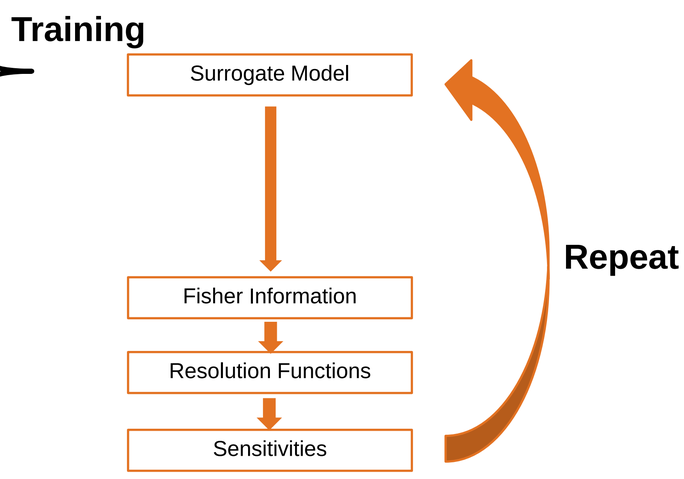
Traditional Optimization



Each iteration is expensive (1000‘s of CPU & GPU hours)

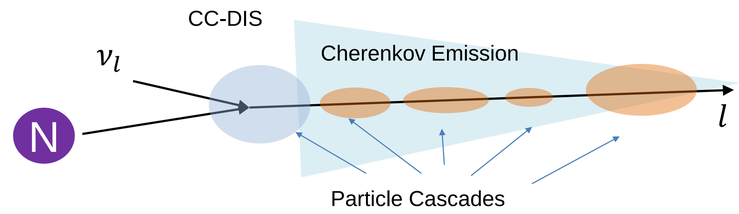
ML-Based Optimization

Use interpolation capabilities of neural networks to efficiently scan design parameter space.

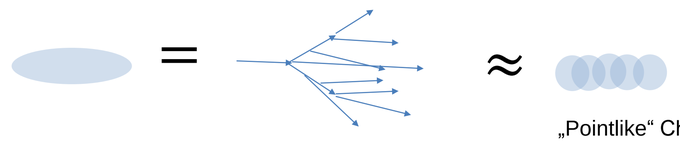


Once surrogate is trained, iteration is cheap

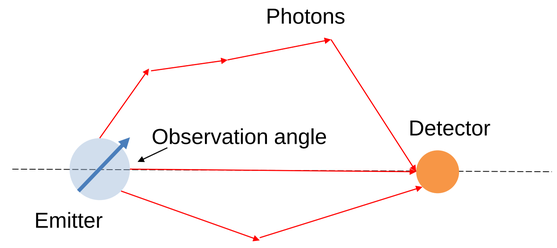
Building a Surrogate Model



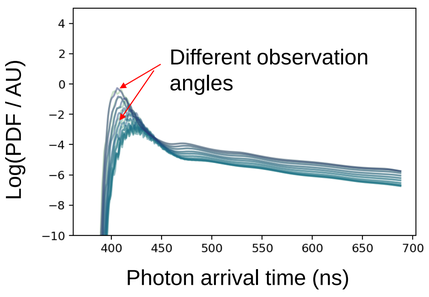
Approximate cascades as linear combination of „pointlike“ emitters



Propagate photons as function of observation angle and distance

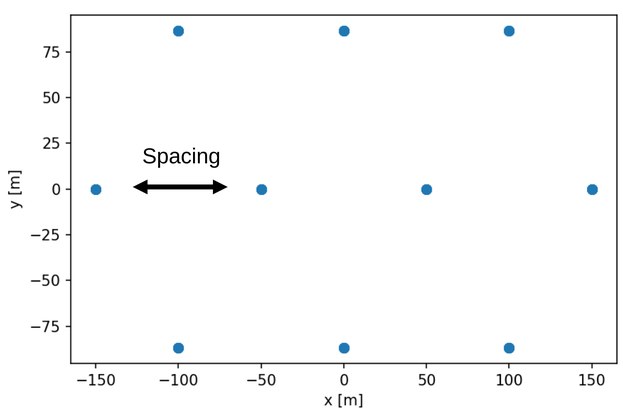


Parametrize arrival time PDF with normalizing flow

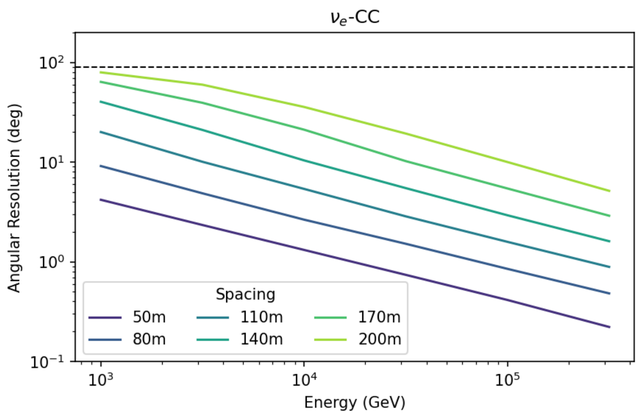


Example Optimization Results for Toy Detector

Toy detector with 10 lines and 20 modules per line, 50m vert spacing



Statistical limit of electron neutrino angular resolution



Future Plans

- Extend optimization workflow to all detection channels
- Integrate resolution functions into analyses framework
- Define figures of merit (physics sensitivities)
- Optimize detector design with external constraints (site limitations, budget, …)