Advanced Optical Detectors:

Water-based Liquid Scintillator

WANDA 2020

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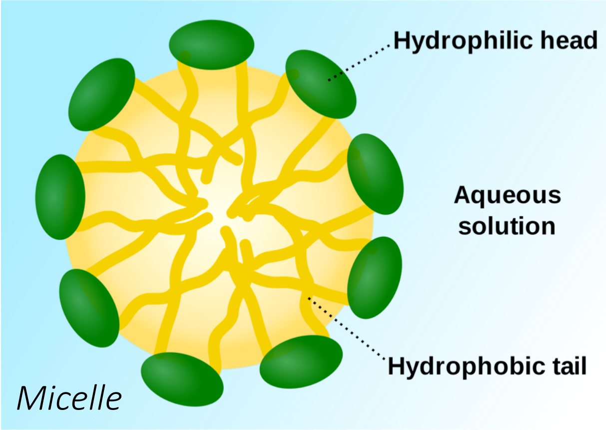
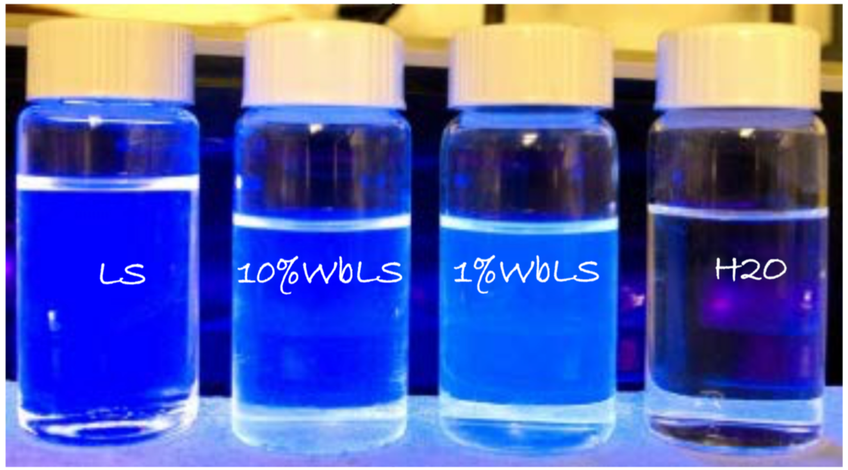
Water-based Liquid Scintillator (WbLS)

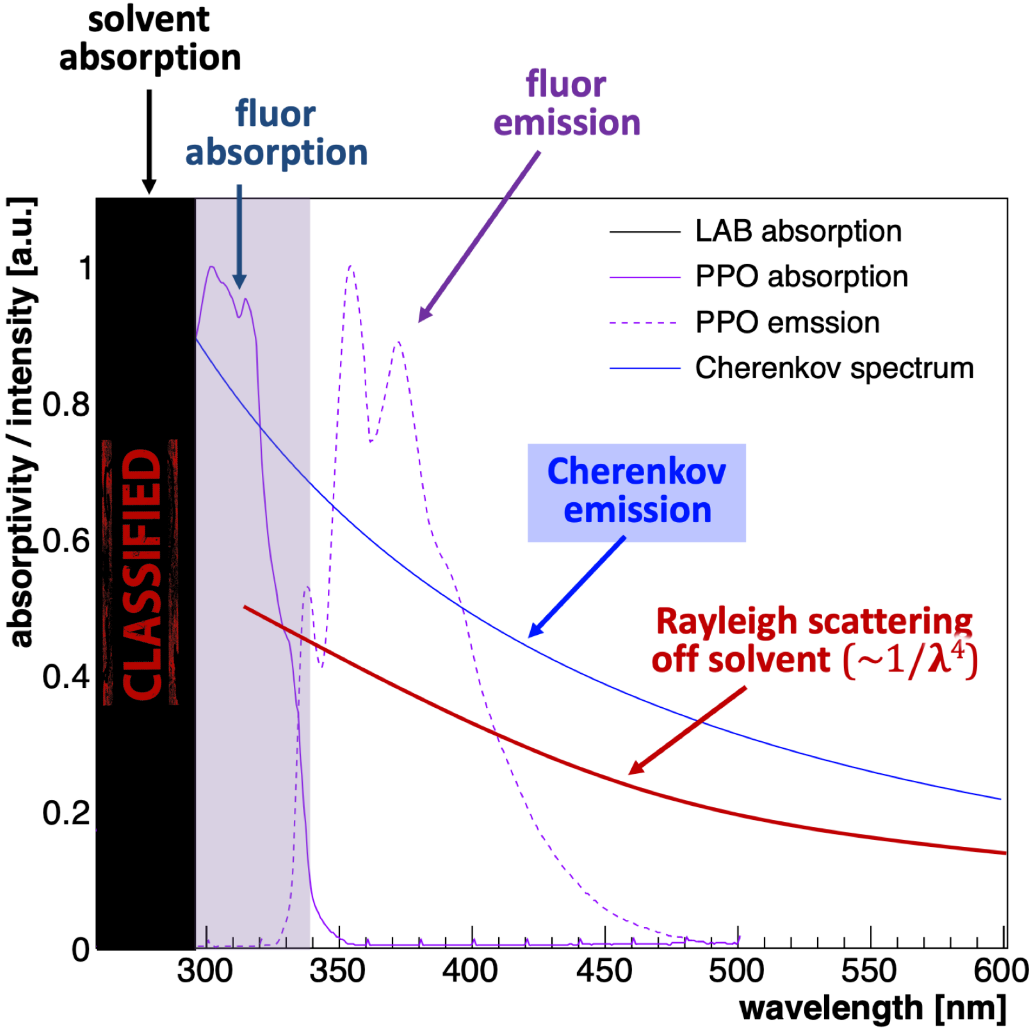
Small nano-droplets of Liquid Scintillator (**solvent + fluor**) are encapsulated inside *micelles* formed by chemical surfactant.





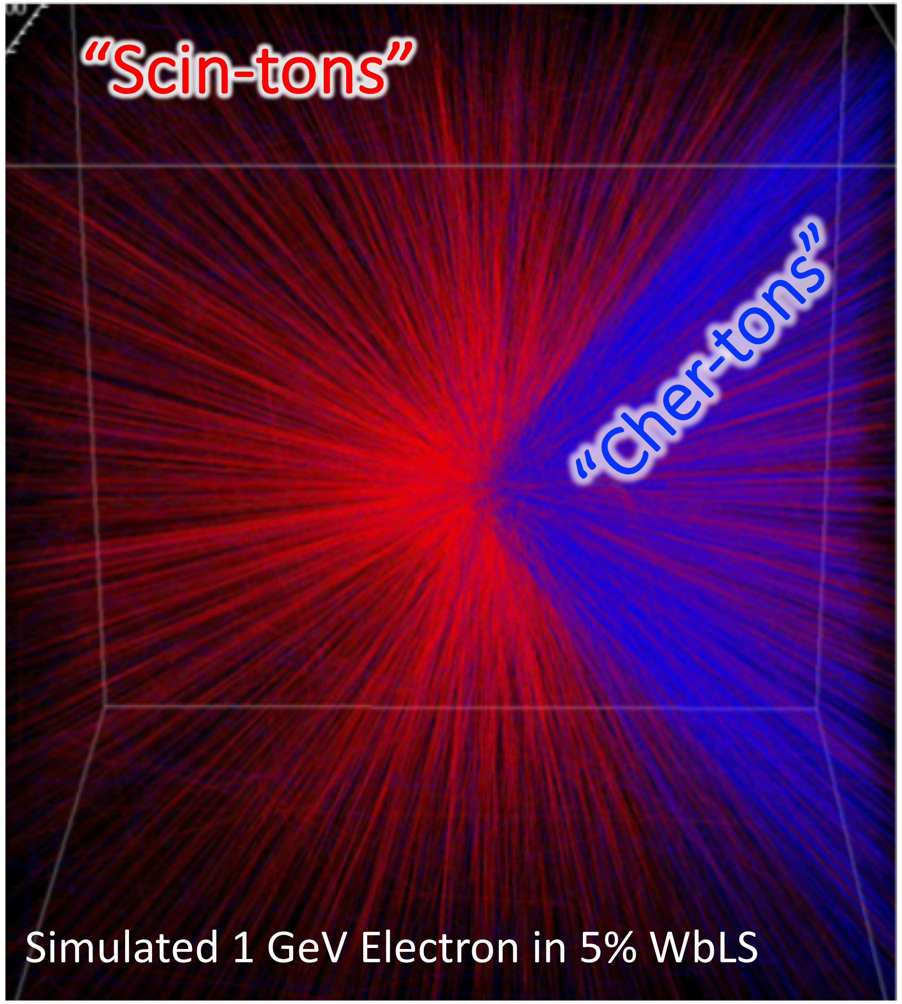
Performance depends on the relative fractions of different components

Tune your detector performance as you wish!



For details see **M. Yeh, et al. NIM A 660 (2011) 51–56**

A Hybrid Optical Detector for Particle Physics?



Advantages of a Cherenkov Detector:

- High transparency → light propagates long distances
- Particle ID with ring imaging
- Directionality
- Potential for metal-loading (capture targets)

Advantages of a Scintillator Detector:

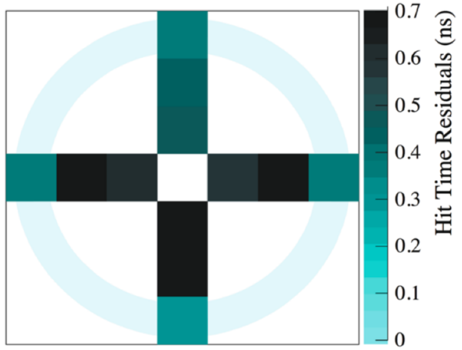
- High light yield
- Good energy and vertex resolution
- Low-energy threshold (sub-Cherenkov detection of particles)
- Particle ID with pulse-shape discrimination

Water-based liquid scintillator (WbLS) *provides everything in one detector!*

WbLS Performance in Particle Detectors

Optical data is critical for understanding detector performance

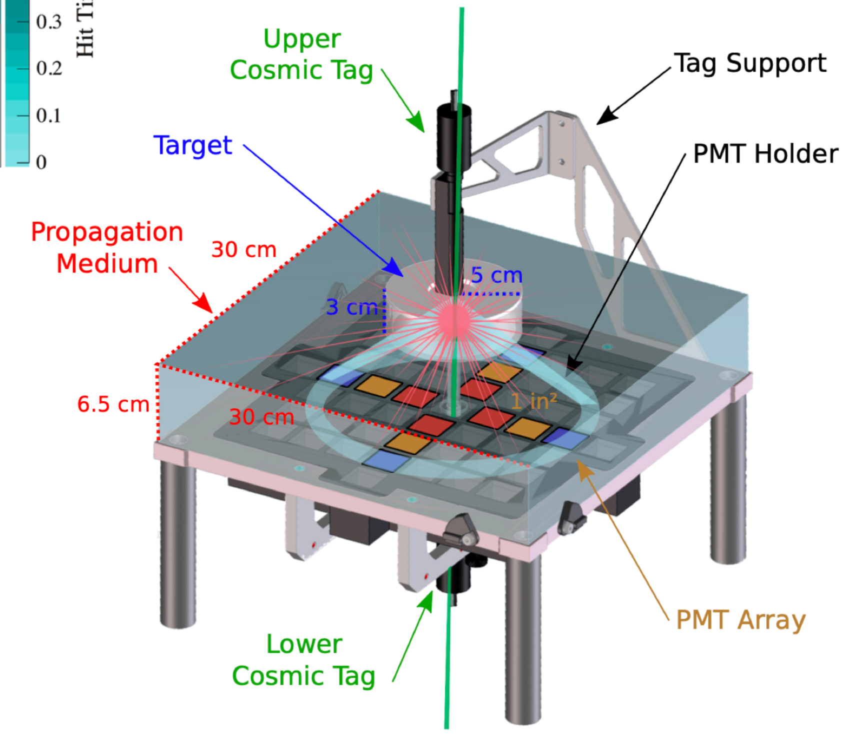
- Scintillation wavelength emission profile
- Timing profile (scintillation rise + decay times)
- Optical attenuation (absorption + scattering) and light yield
- Cherenkov/Scintillation separation (with respect to timing resolution and % concentration of scintillator in water)
- Optical parameter stability over time



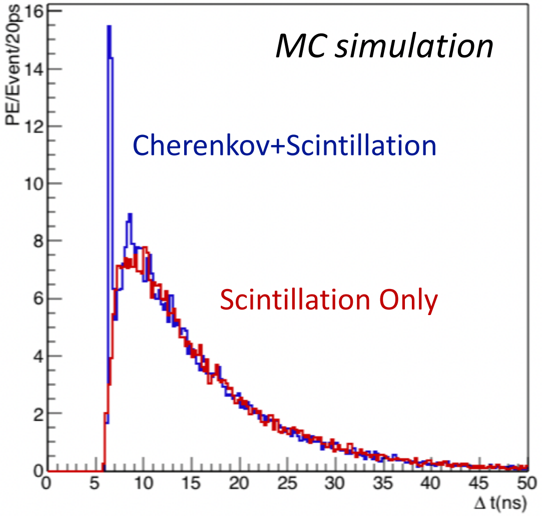
CHESS @ LBL

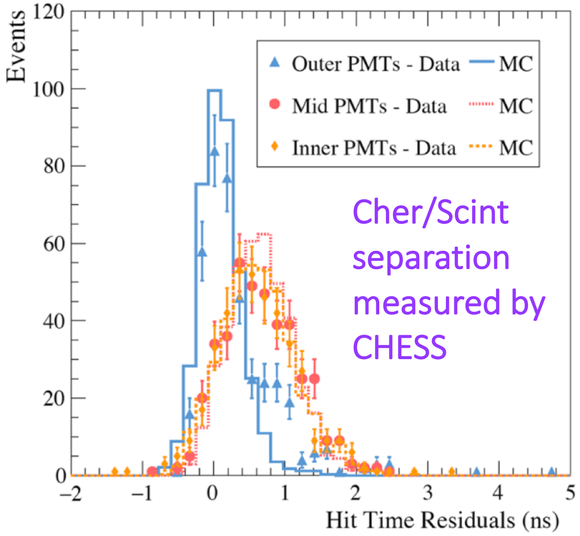
CHErenkov/Scintillation Separation

Eur. Phys. J. C (2017) 77 :811



Cherenkov light ***arrives earlier*** than scintillation light





Quenching in WbLS

Quenching data is important for understanding non-linear energy response

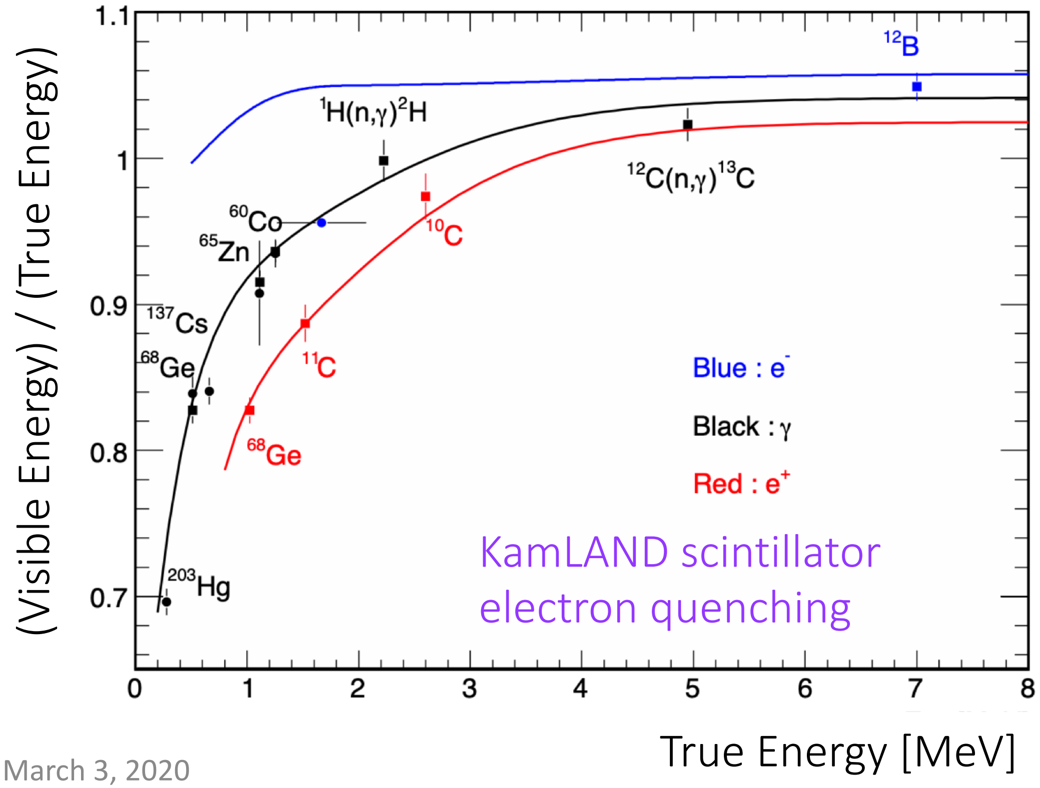
Light yield from ionizing particle energy deposits in liquid scintillators is **non-linear due to non-radiative energy transfer.** This effect **depends on particle types and their energies.**

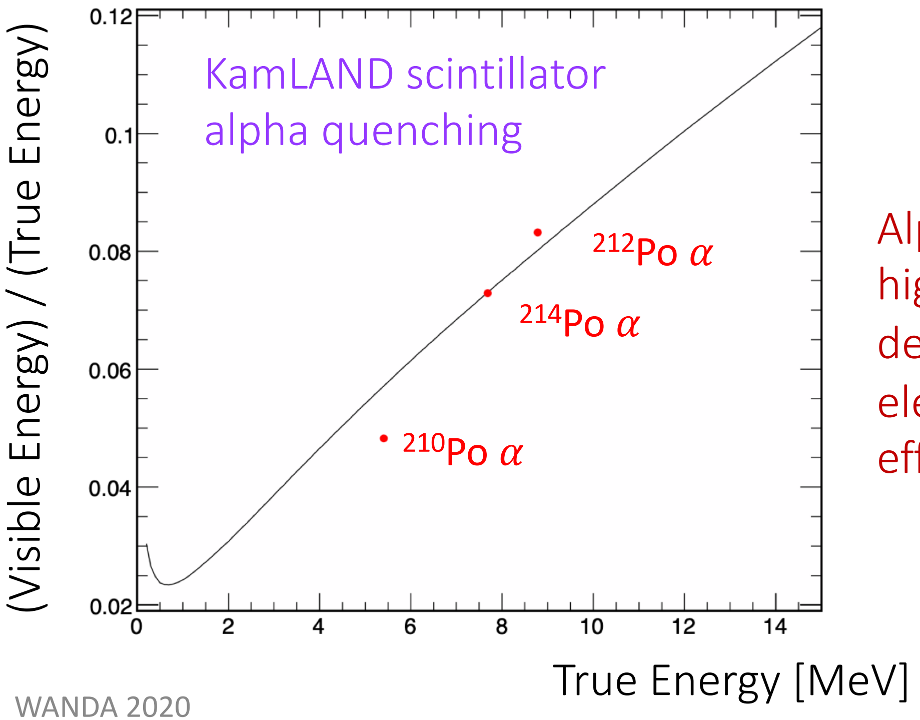
Semi-empirical Birks' Law:

$$\frac{dL}{dx} = L_0 \frac{\frac{dE}{dx}}{1 + k_B \frac{dE}{dx}}$$

k_B = Birks' constant

L_0 = luminescence at low specific ionization density





Alpha particles have high specific ionization density compared to electrons → quenching effect is much stronger

Quenching Measurements in WbLS

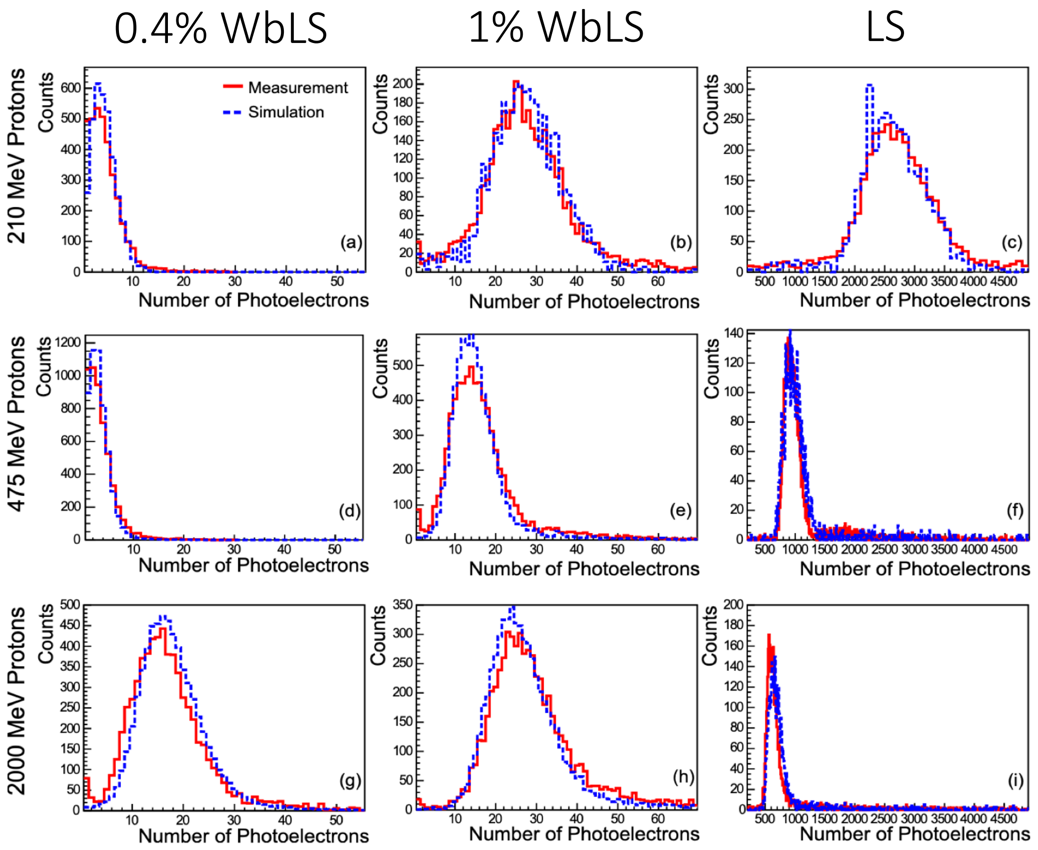
Quenching data is needed for different particle types ($\boldsymbol{p}, \boldsymbol{\alpha}, \boldsymbol{e^-}, \ldots$)

- **We need more data** for different particles over a broad range of energies to understand **non-linear energy response**
- Measurements could use particle accelerators (primary or secondary beams), for example:
  - LBNL 88-inch Cyclotron
  - UC Davis Crocker Cyclotron
  - ORNL Spallation Neutron Source
  - …

Proton quenching in WbLS measured at BNL

L. J. Bignell et al 2015 *JINST* **10** P12009

	Material	Light Yield (photons/MeV)	Quenching Parameter (mm/MeV)
0.4%	WbLS-1	19.9 ± 1.1 (stat.) ± 2.0 (sys.)	0.70 ± 0.12 (stat.) ± 0.07 (sys.)
1%	WbLS-2	108.9 ± 0.8 (stat.) ± 10.9 (sys.)	0.44 ± 0.01 (stat.) ± 0.04 (sys.)
	LS	9156 ± 42 (stat.) ± 916 (sys.)	0.07 ± 0.01 (stat.) ± 0.01 (sys.)

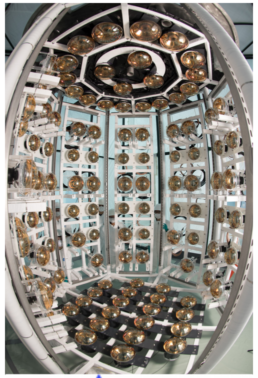


Summary

- WbLS is an advanced detector medium – could revolutionize particle detection in research, industry, and medicine
- In order to understand how this medium performs, we need detailed optics characterization and measurements of ionization quenching for differing particle types and energies

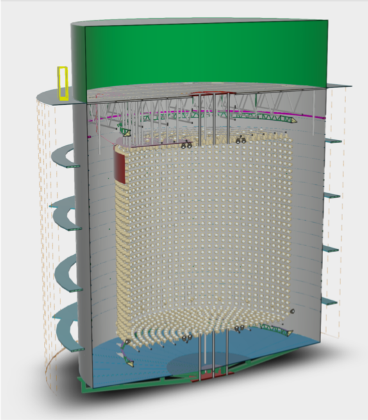
Planned WbLS Deployments…

26 tons



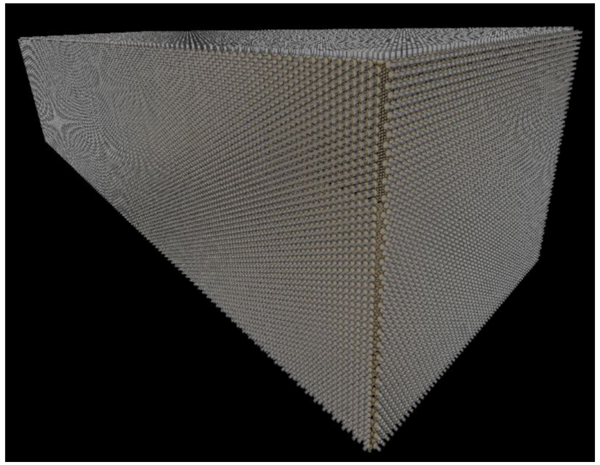
annie

~1 kiloton



WATCHMAN

~25 kiloton



~100 kiloton

THEIA: An Advanced Optical Neutrino Detector

arXiv:1911.03501