Water-based Liquid Scintillator (WbLS) @Brookhaven National Laboratory

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DPF-PHENO 2024

Ideal takeaways in the following 12 minutes

What is WbLS?

Why is WbLS?

Example use case for WbLS in HEP?

What is the R&D plan for WbLS?

What is happening at BNL?

Case study: Designing a large-scale neutrino detector

Depending on the source intensity at the location of interest, the detector can be massive/large -> statistics can be critical in neutrino detection.

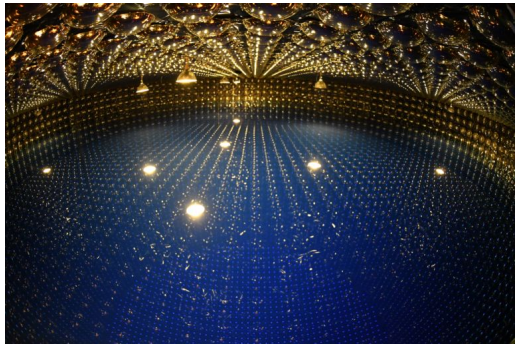
Installing large-scale detectors in liquid phase could be easier and likely cheaper.

The most straightforward material is water but a high particle detection threshold presents.

Optical detector with photomultiplier as the sensor was commonly used, thus the reliability was thoroughly proved.

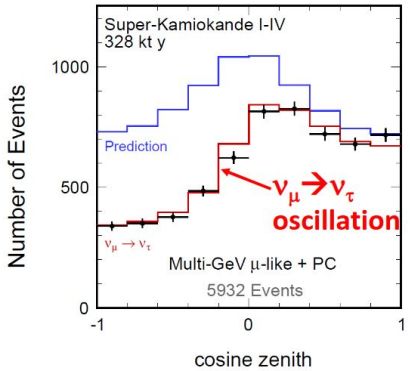
Operating/funded 10 kt scale OPTICAL neutrino detector

Super-K (22.5 kt)

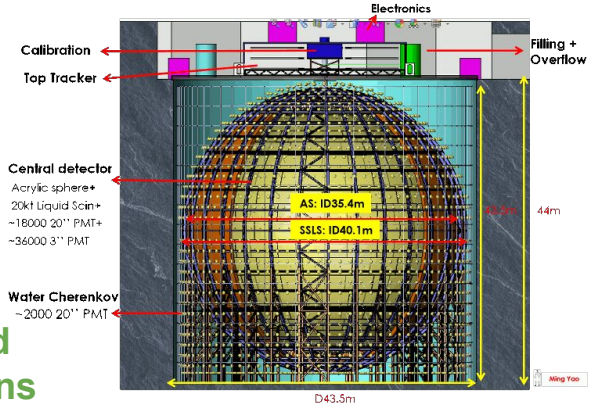


- Excellent Transparency
- Directionality
- Particle ID
- Cheap
- Potential for large Isotopic Loading

- No access to physics below the Cherenkov threshold
- Low light yield

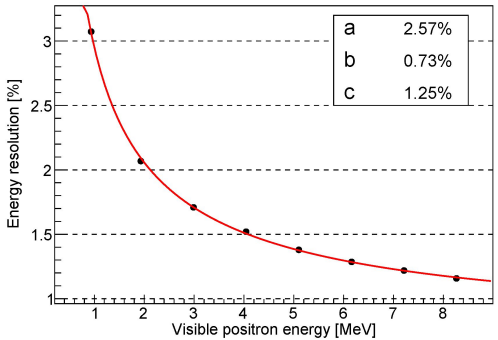


JUNO (22.5 kt)



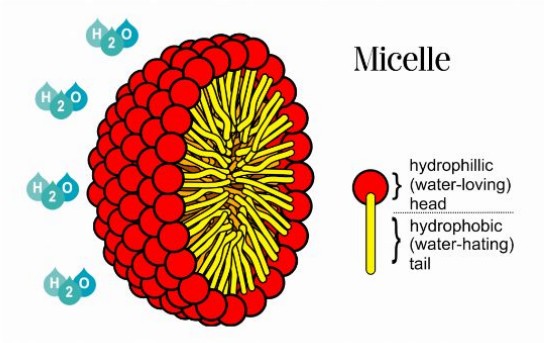
- High light yield
- Low energy threshold
- Good energy and position resolutions
- Can be radiologically very clean

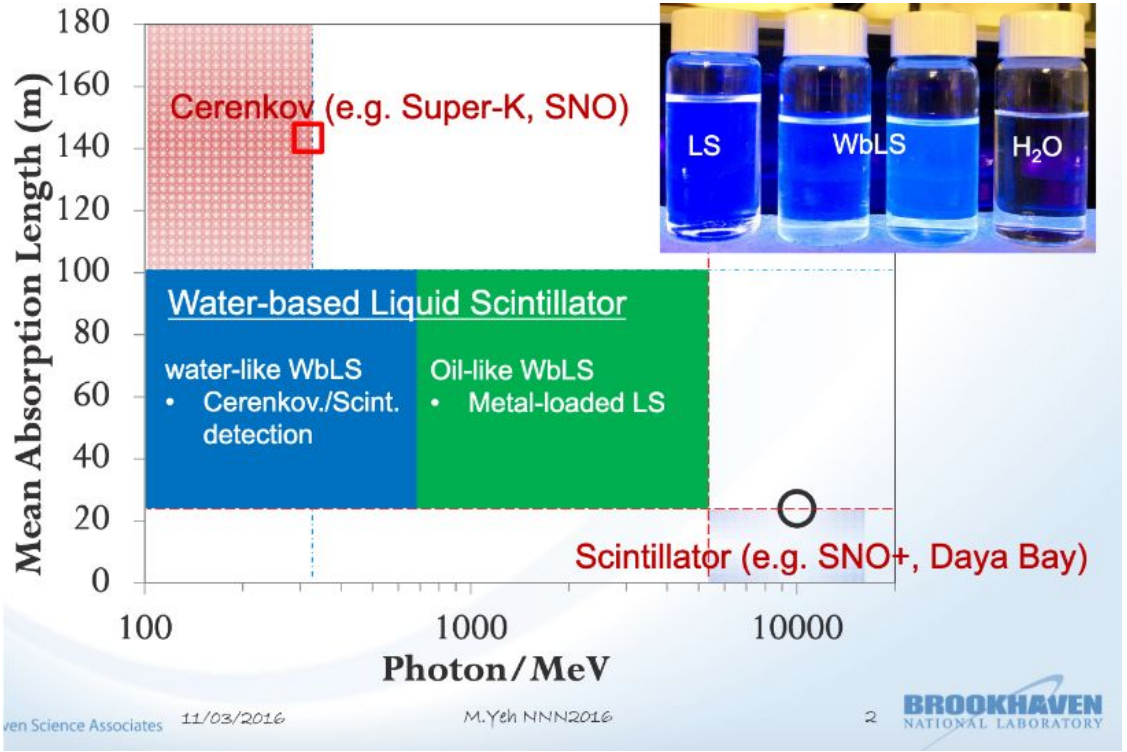
- Costy
- High absorption
- Limited directionality



Target at different energy range

Next-generation: Combining water and LS



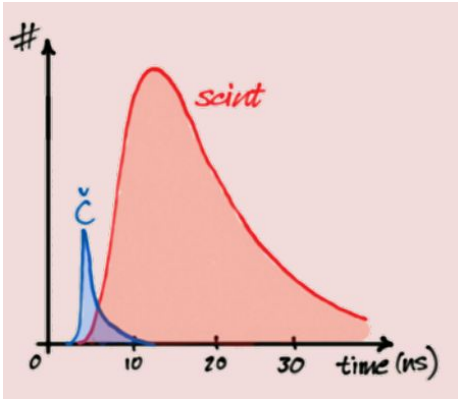


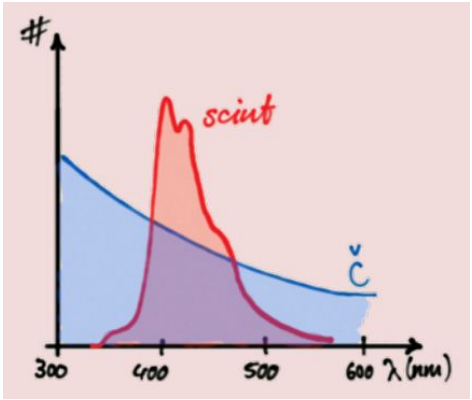
WbLS basic performance

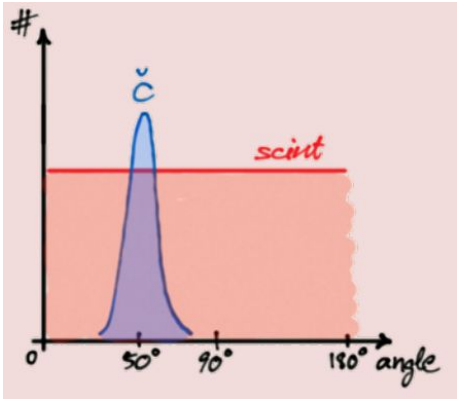
- **Developed and characterized a variety of WbLS formulas for multiple frontiers.**
- **In the context of neutrino physics, Cherenkov and Scintillation light separation is a key feature.**

In general:

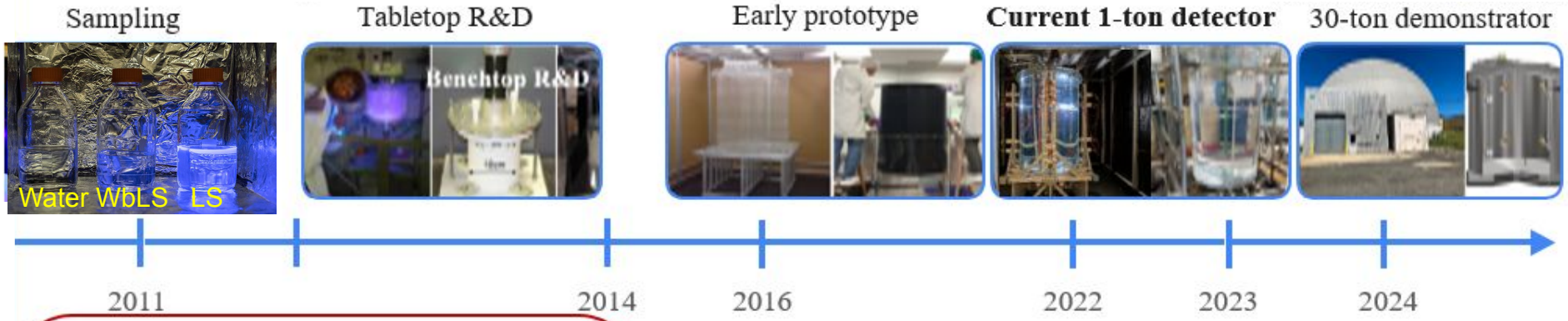
- **Scintillation light yield proportional to WbLS concentration**
- **Scintillation light later than Cherenkov light**
- **Scintillation light with a narrower wavelength distribution than Cherenkov light**
- **Scintillation light generated isotropically**

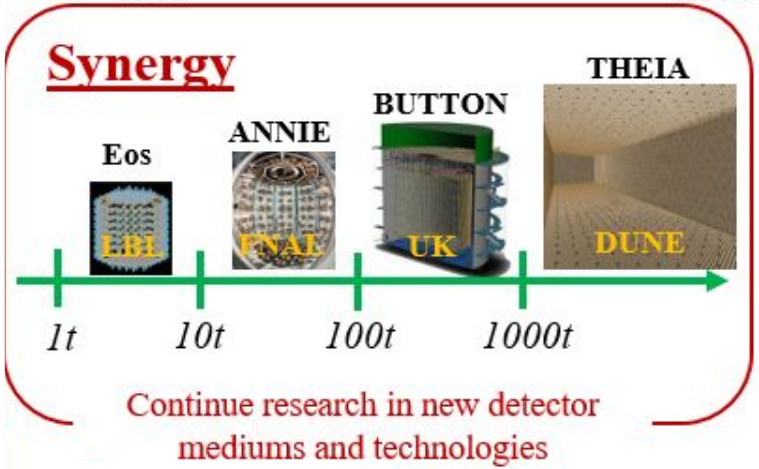






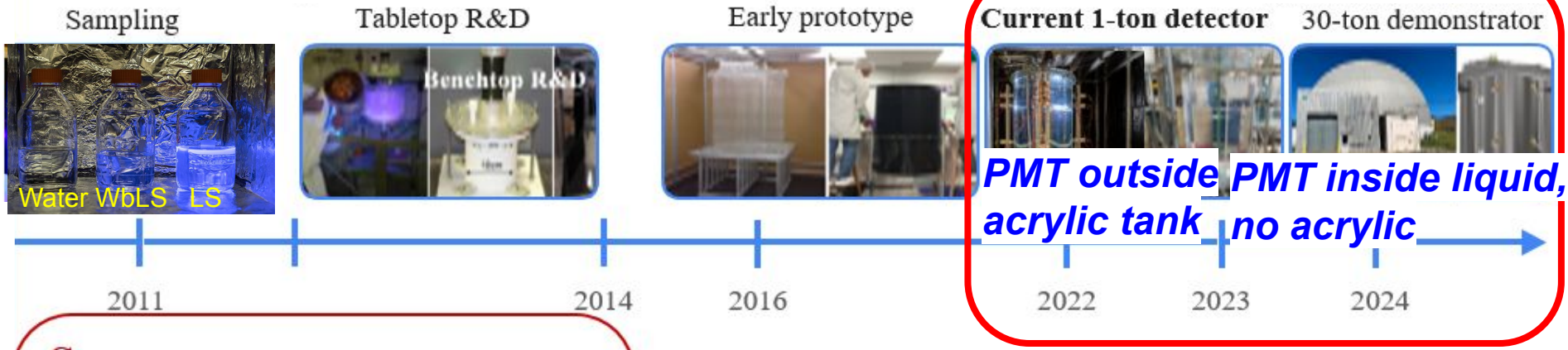
Roadmap





We are on a track of demonstrating and utilizing the WbLS toward multiple-ton scale neutrino detectors at BNL.

Roadmap



We are on a track of demonstrating and utilizing the WbLS toward multiple-ton scale neutrino detectors at BNL.

R&D purpose

WbLS stability: BNL1T, BNL30T

Light yield: BNL1T, BNL30T

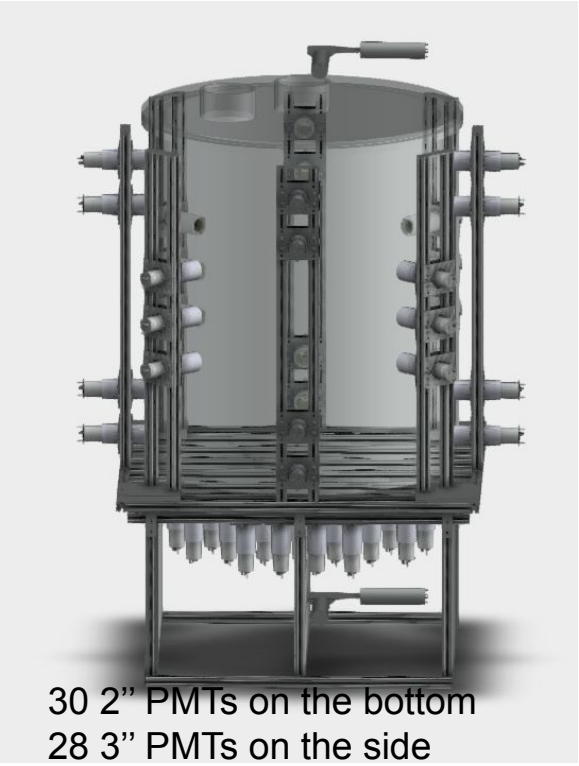
Optical modeling: BNL30T

Scalability: BNL30T

Metal loading capability: BNL30T

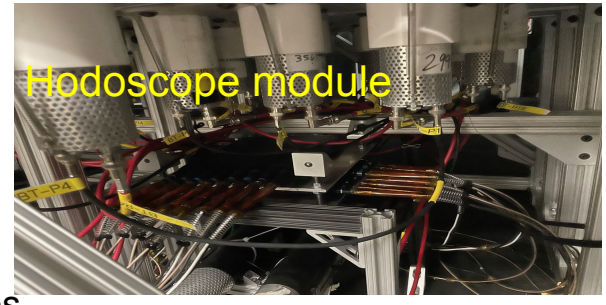
Cherenkov/Scintillation separation: Eos

BNL 1T detector

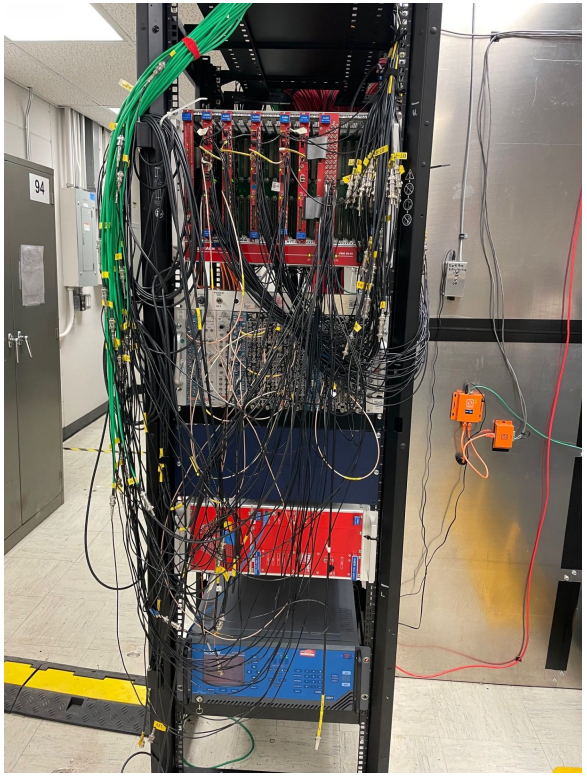


30 2” PMTs on the bottom
28 3” PMTs on the side
2 16-channel hodoscope modules

Nano-filteration system

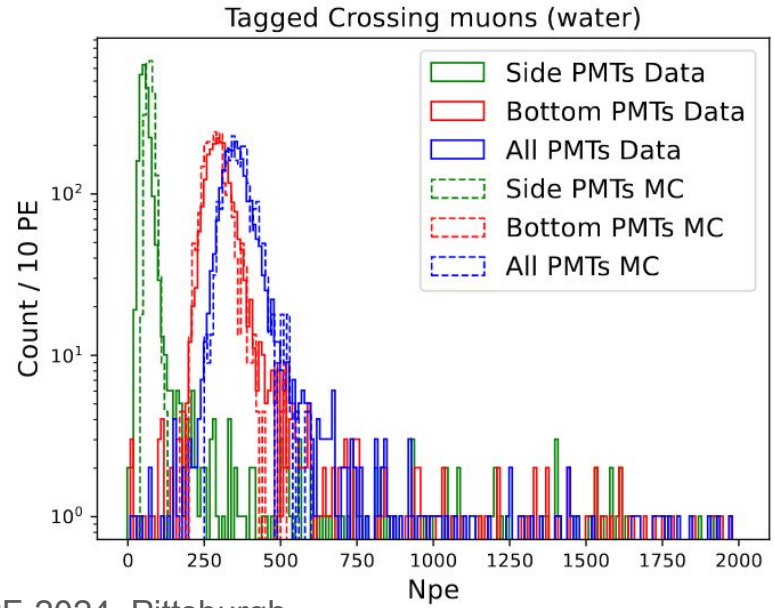


DAQ system

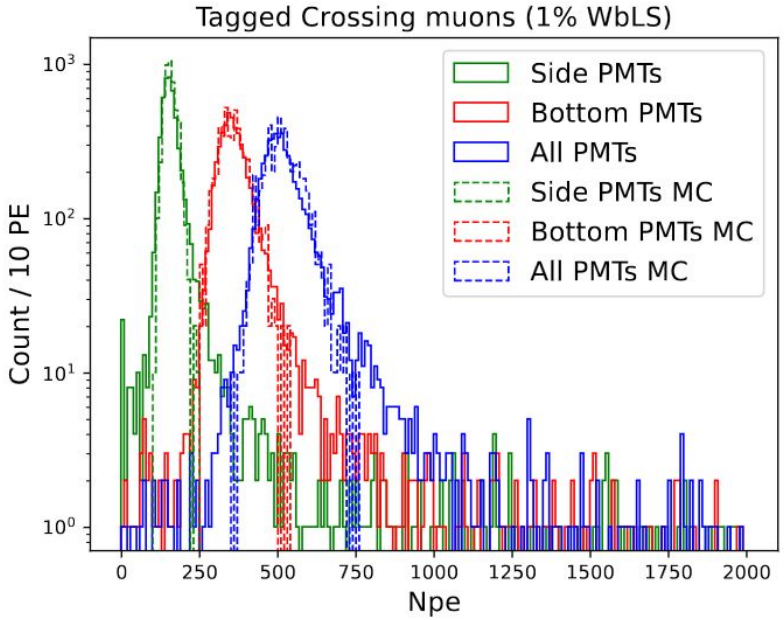


BNL 1T performance - Light yield estimate

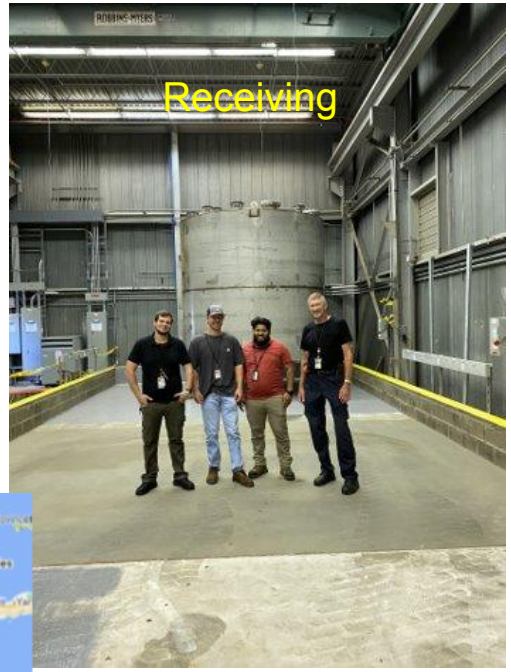
No MC modification
Good agreement

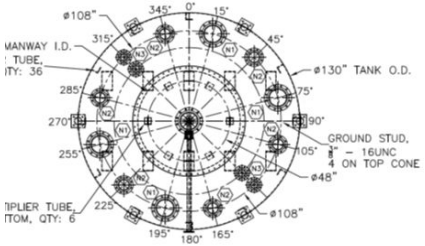


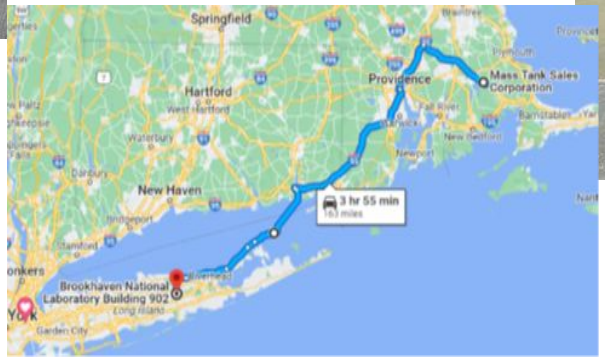
LY adjusted MC
non-Cherenkov yield:
127.6 +- 19.8 (syst.) +- 17.6 (stat.)



BNL 30T tank preparation





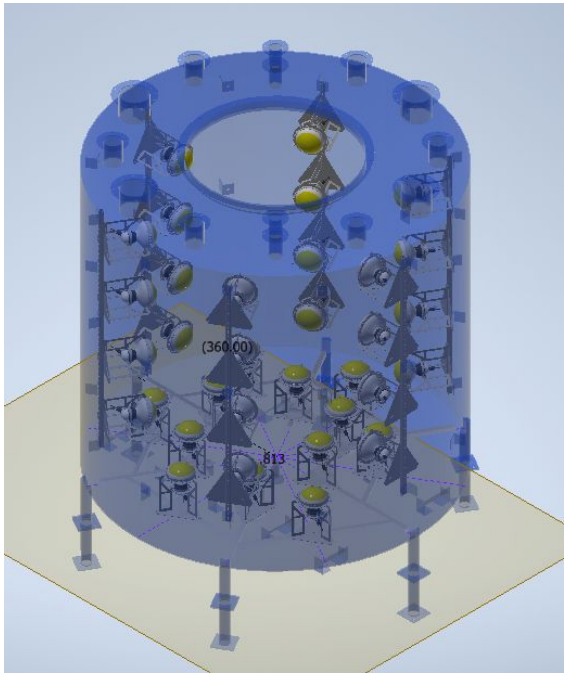


BNL 30T detector

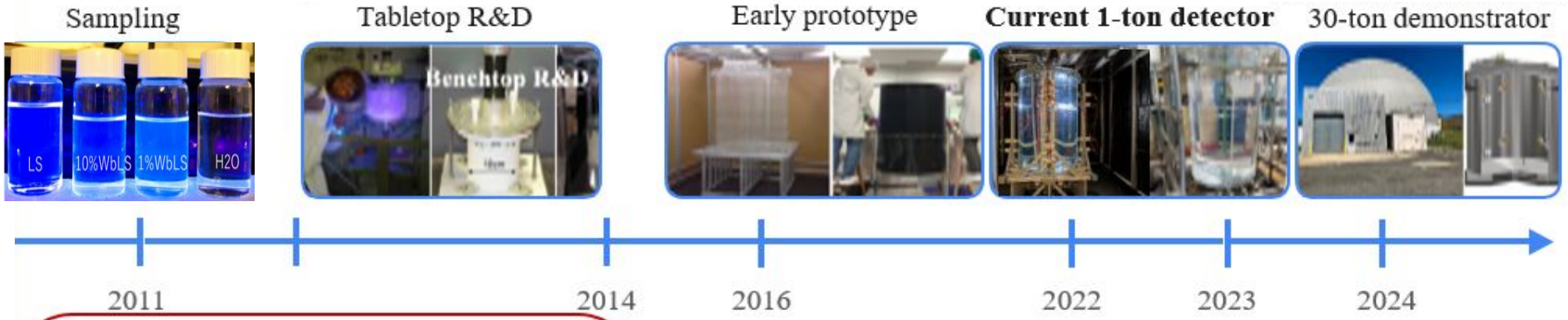
Detector facility - the old reactor building 751 with renovation

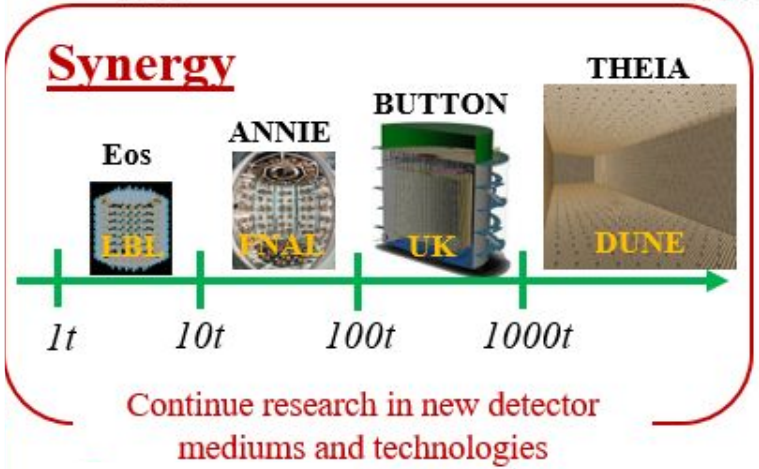
Completed tank work

36 10 inch PMT



Roadmap





The roadmap has been built.
Ton-scale production facility ready in 2023;
30ton demonstrator will operate in May, 2024.
Demonstration along with physics measurements with the 1ton and 30ton detectors will open the gate to the multi-ton scale WbLS neutrino detector.

Summary

BNL is actively participating in many liquid scintillator-based projects.

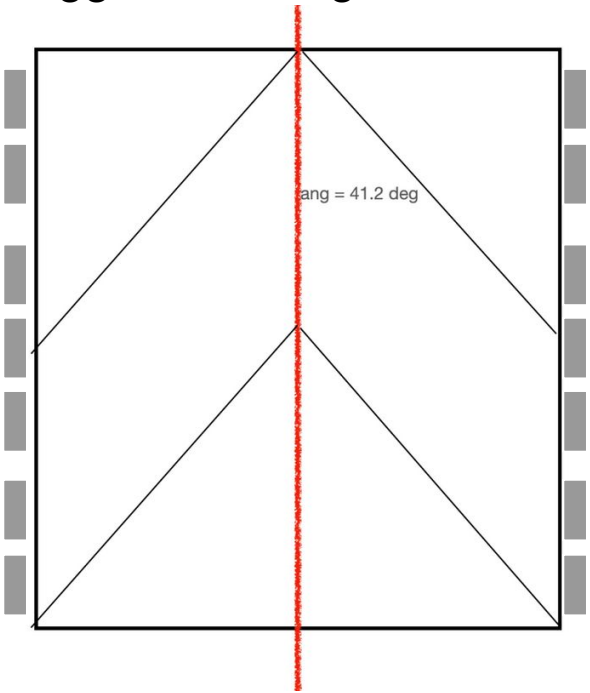
WbLS R&D is being developed in various institutions, from table top to 10s ton scale, demonstrating all components in a large-scale WbLS detector, including liquid filtering system, light yield, transparency and physics performances.

BNL has built a 1 ton and building a 30 ton WbLS detectors: open a new way of detecting particles!


LOOK AT ALL THIS WORK
I HAVENT DONE YET

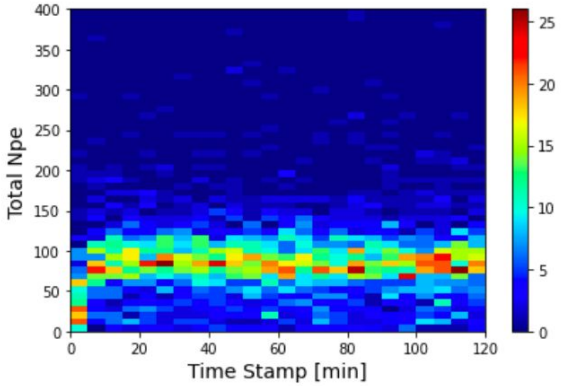
BNL 1T performance - Scintillation light detection

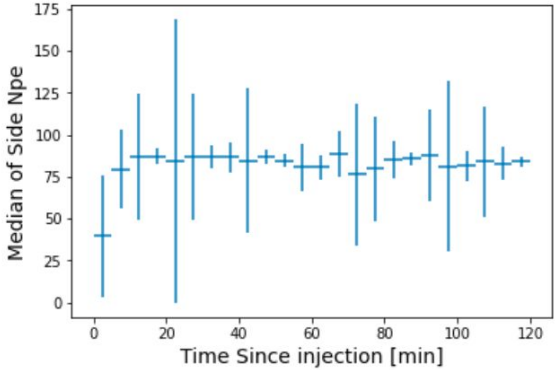
Tagged crossing muons

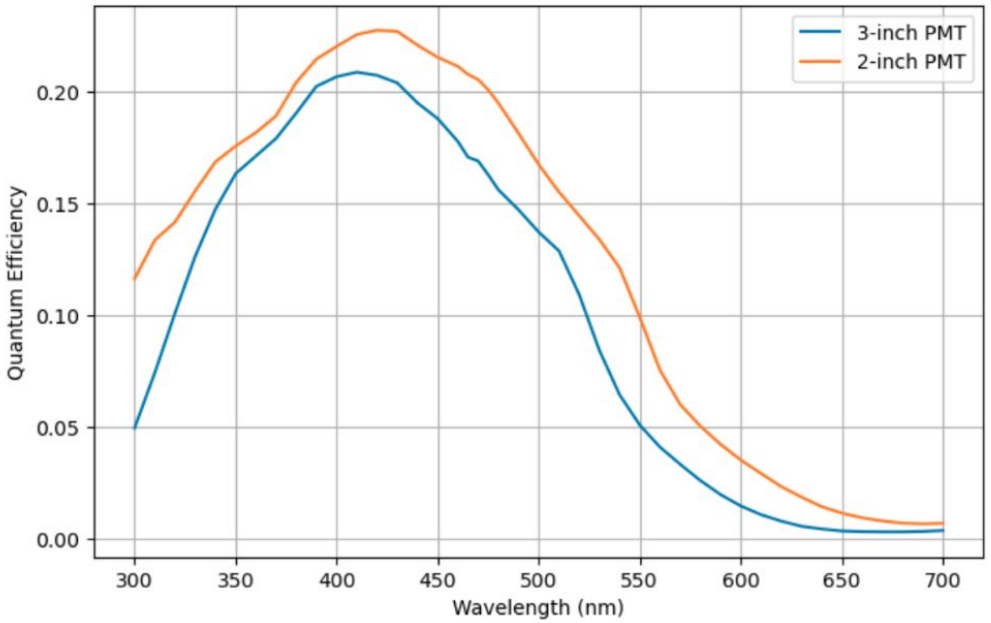


- **Top two rows only receive Scintillation light**
- **Other PMTs receive Scintillation + Cherenkov light**

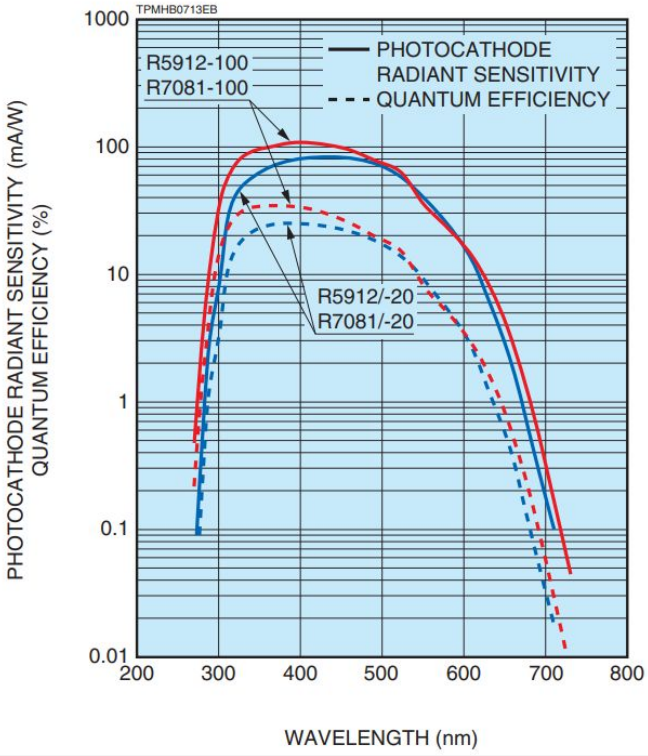
Top two rows

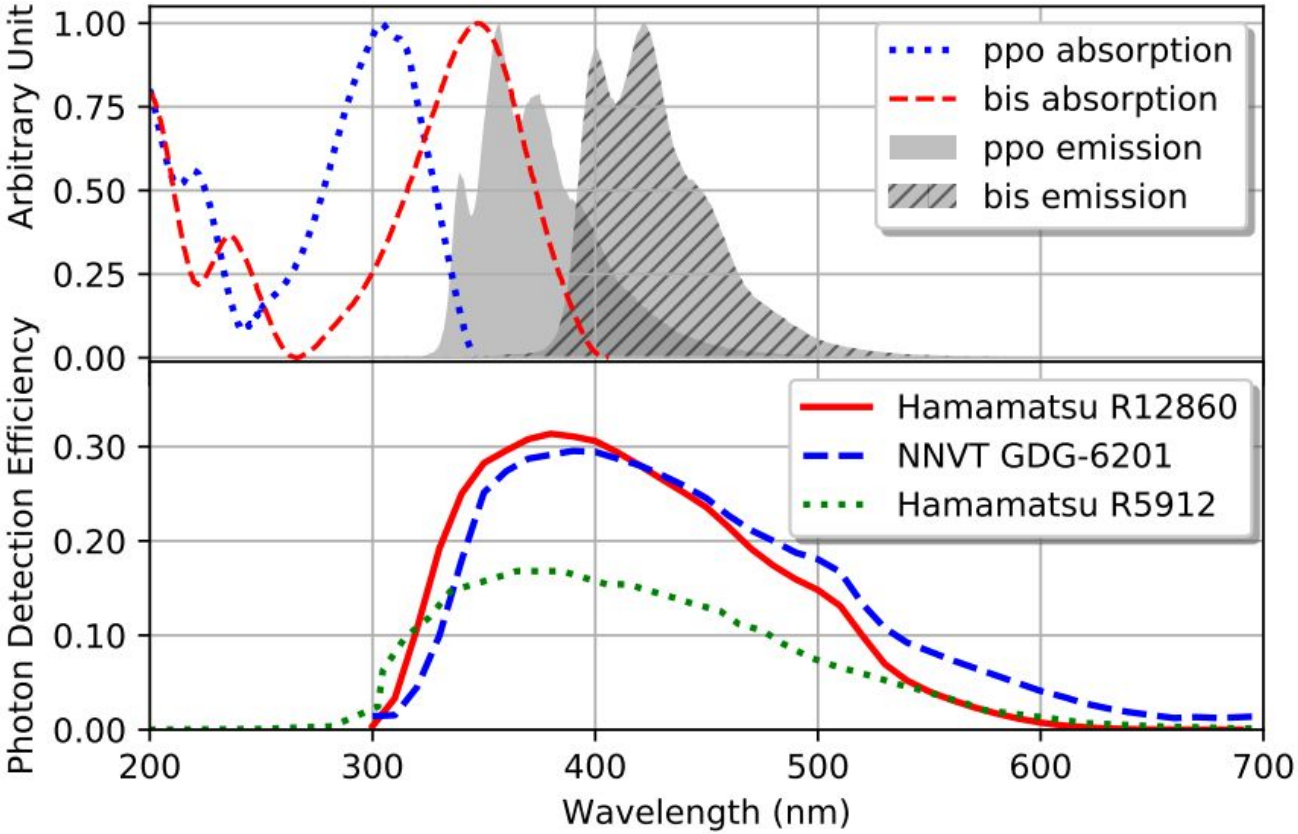




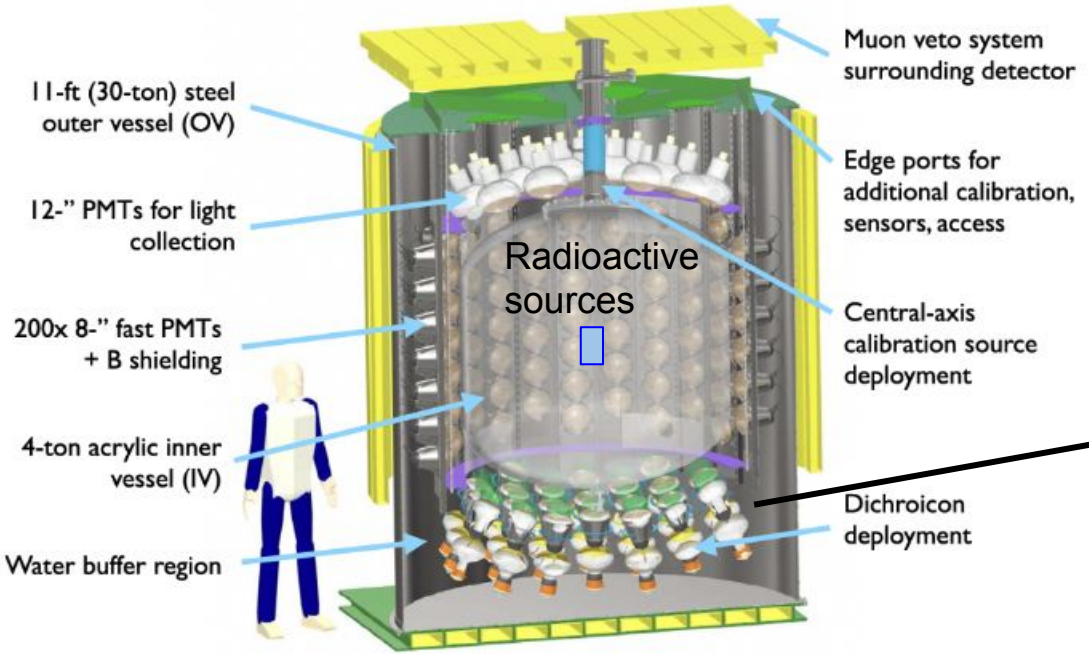


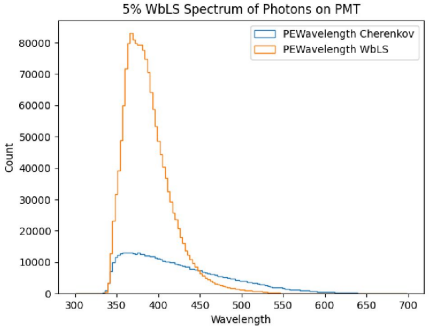
●R5912/-20/-100
●R7081/-20/-100

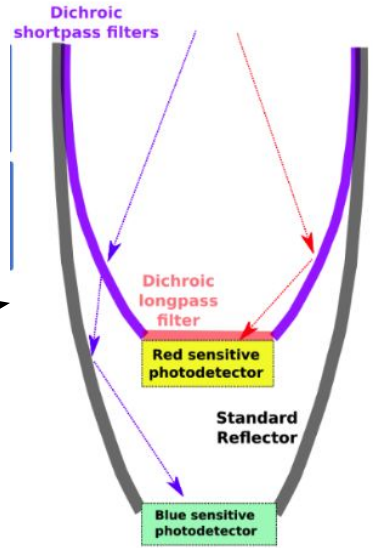



Arbitrary Unit
1.00
0.75
0.50
0.25
0.00
ppo absorption
bis absorption
ppo emission
bis emission
Photon Detection Efficiency
0.30
0.20
0.10
0.00
Hamamatsu R12860
NNVT GDG-6201
Hamamatsu R5912
200
300
400
500
600
700
Wavelength (nm)

Eos detector

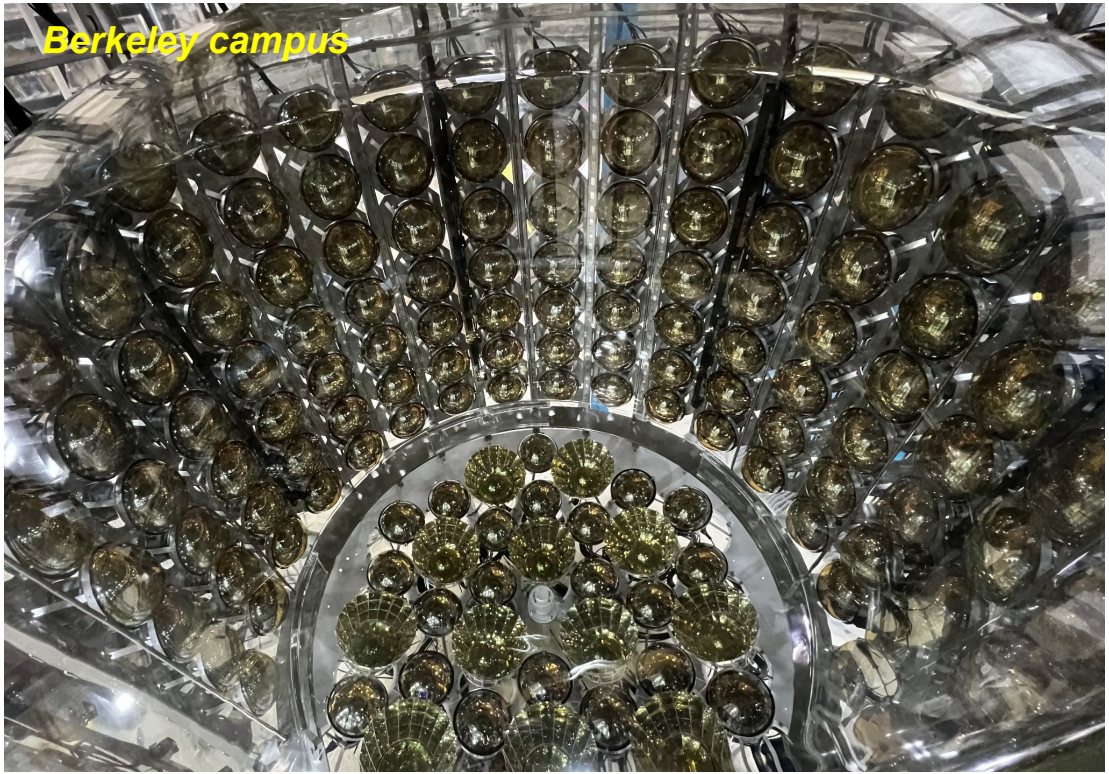






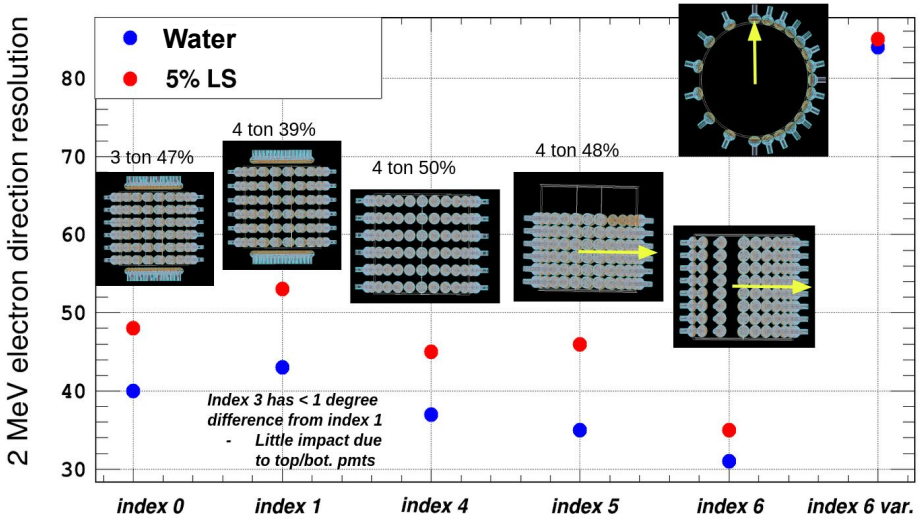
Concept of a Dichroicon

Eos detector



Eos expectation

The directionality can be measured and compared to models while preserving good energy resolution for a few MeV level particles.



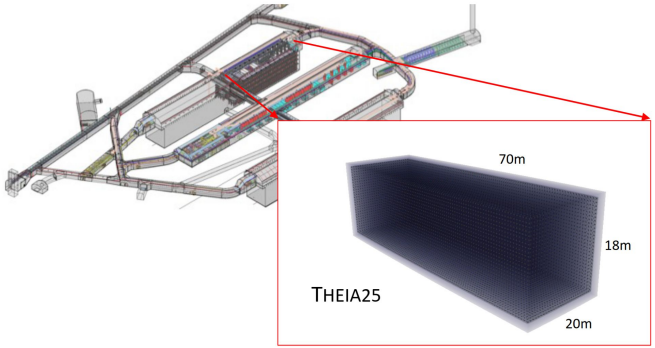
Theia long-baseline physics sensitivity

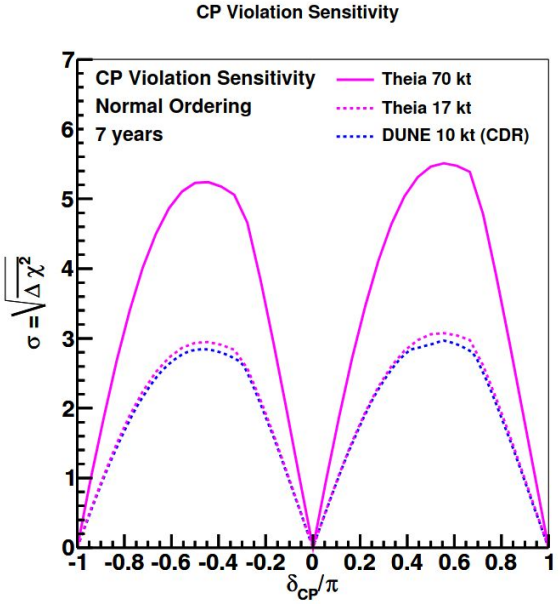
Assumed water detector performance for the sensitivity study

Further studies have shown that with 5% WbLS concentration, Cherenkov ring clarity can be preserved while the inclusive neutrino energy resolution can be at 10% level.

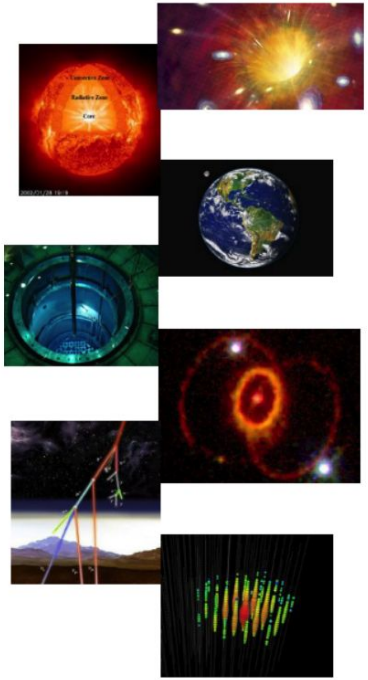
Work being updated by BNL and Berkeley

Theia white paper, assuming water performance





Additional physics with Theia



10^{-4} eV

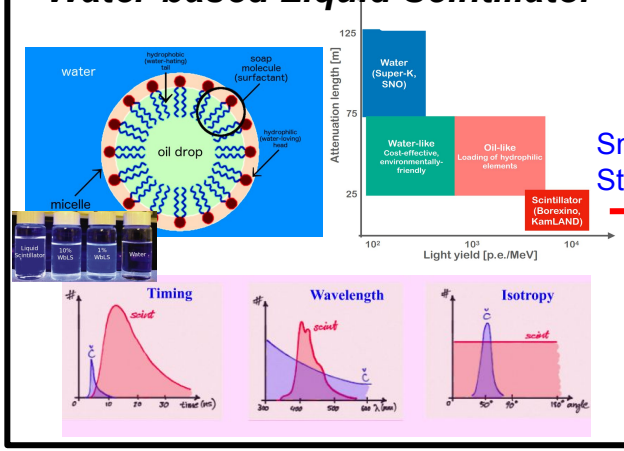
Neutrino Energy

10^{20} eV

- **Cosmic Neutrino Background**
- **Solar Neutrinos**
- **Geo Neutrinos**
- **Reactor Neutrinos**
- **Supernova Neutrinos**
- **Diffuse Super Nova Neutrino Background (DSNB)**
- **Atmospheric Neutrinos**
- **Astrophysical Neutrinos**

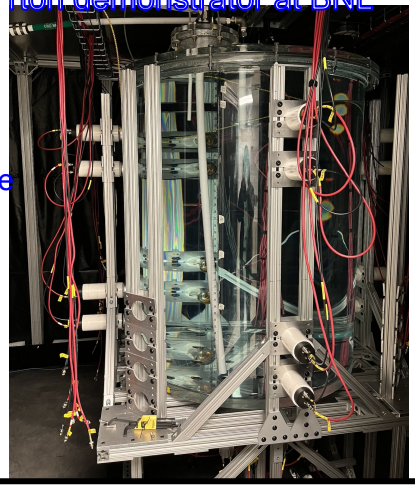
Check arXiv. 1911.03501

Water-based Liquid Scintillator



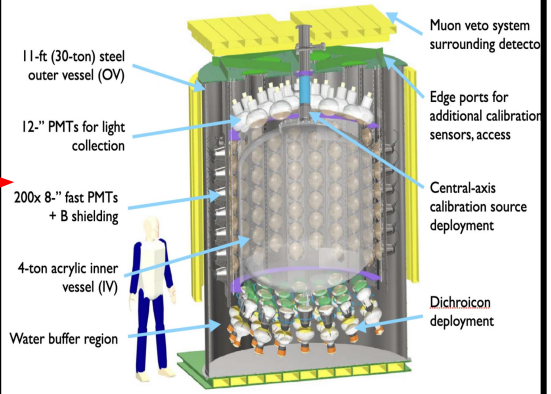
Smaller-scale Steps

1ton demonstrator at BNL



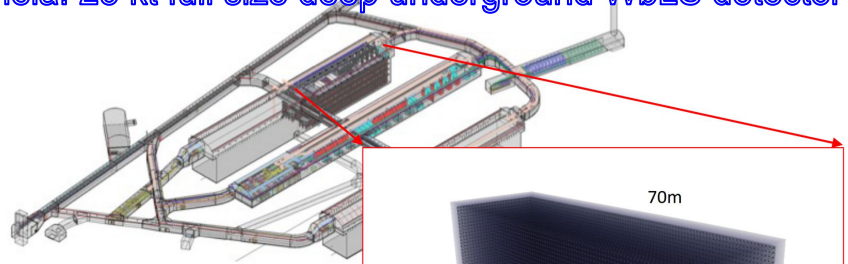
Eos: 4ton detector at Berkeley

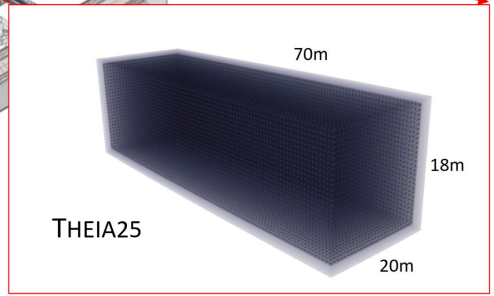
arXiv:2211.11969



30ton demonstrator at BNL

Theia: 25 kt full size deep underground WbLS detector





At DUNE far detector

arXiv:1911.03501

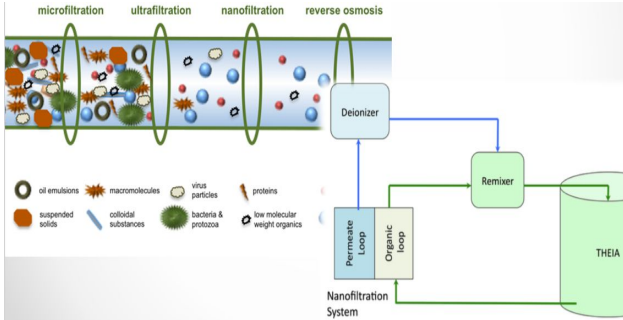
Developing tonne scale demonstrators

WbLS principle

BNL1T: demonstration of the liquid circulation system

BNL30T: detector operation principle and stability at unprecedented scale

Eos: several ton scale performance demonstrator



Stable kTon scale WbLS detector with the white-paper expected performance