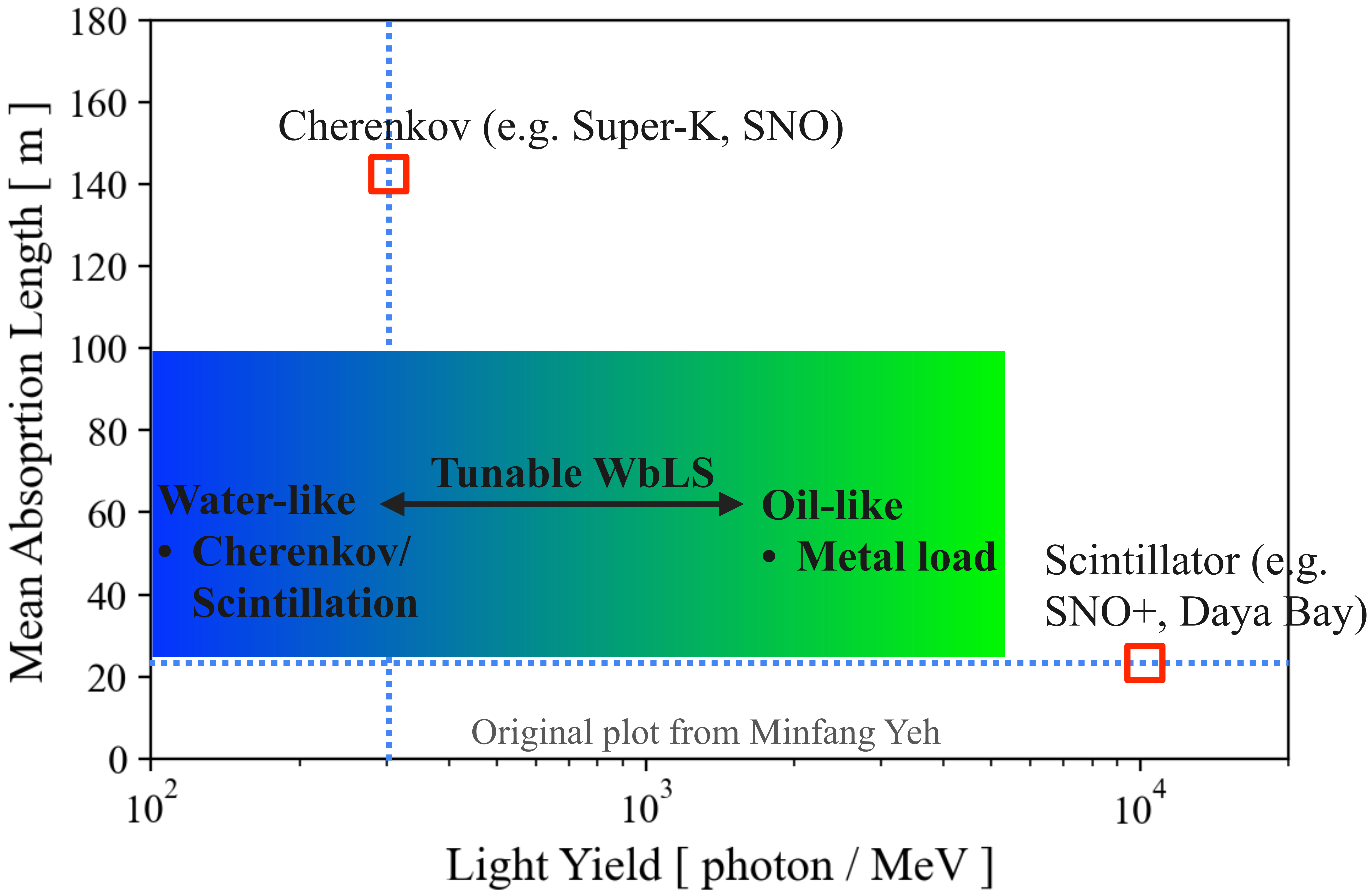
Status and Early Results of Water-based liquid scintillator facility at BNL

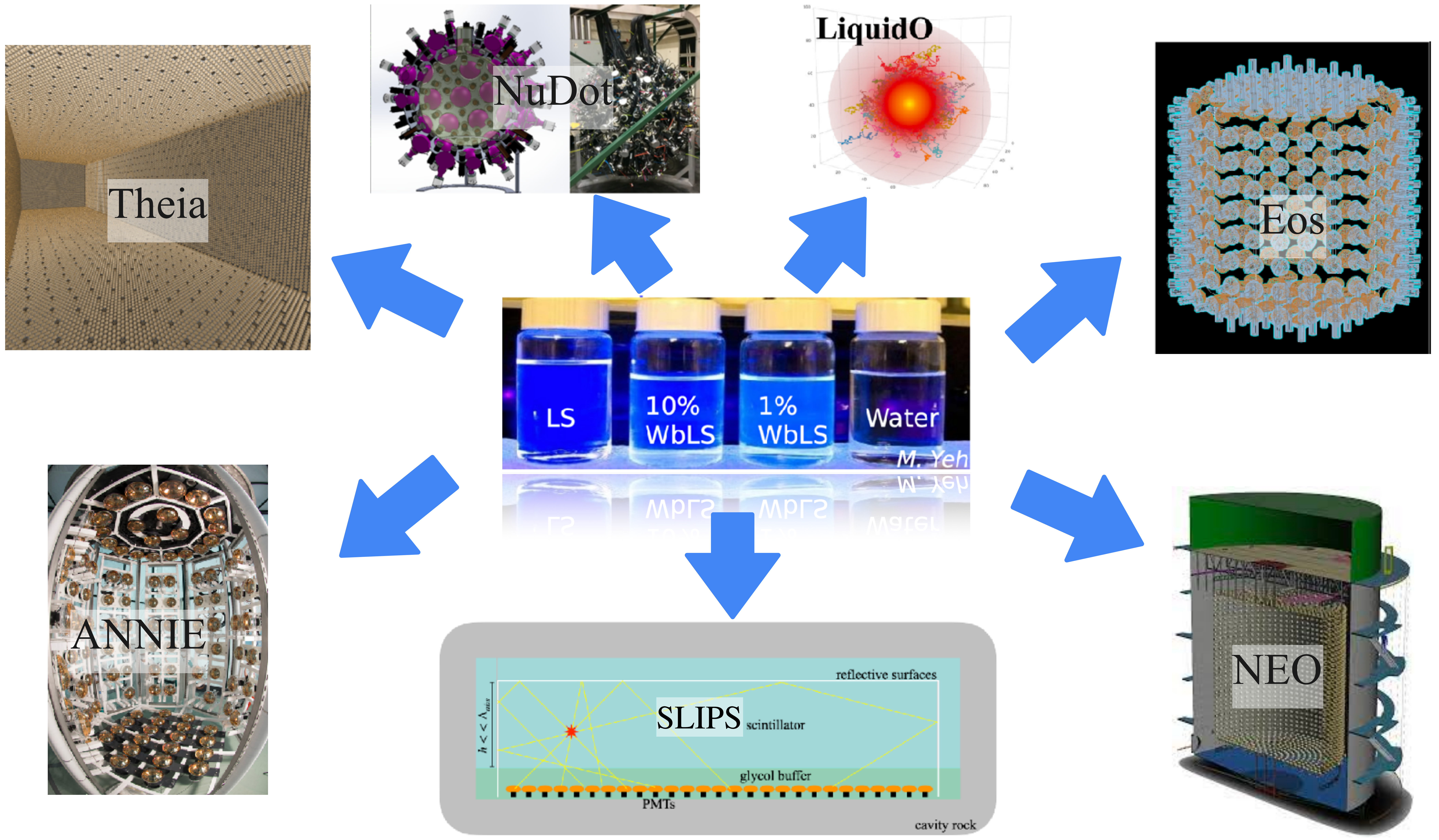
Xin Xiang, Ph.D.
On behalf of BNL WbLS group
CPAD 2022 @ Stony Brook University

Water-based Liquid Scintillator (WbLS)



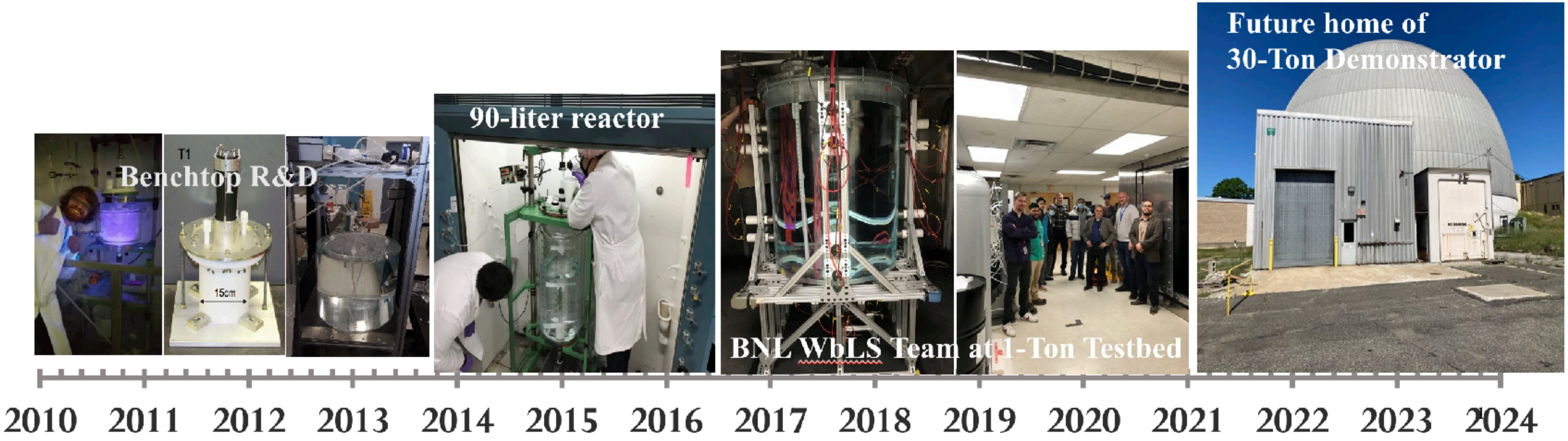
- Benefit water-based liquid scintillator cocktail
  - Directional reconstruction via Cherenkov while enhanced threshold via scintillation
  - Adjustable light yield
  - Relative long attenuation length
  - Particle ID via Cherenkov/ Scintillation seperation (C/S)
  - Affordable
  - Environmental friendly

A variety of potential applications



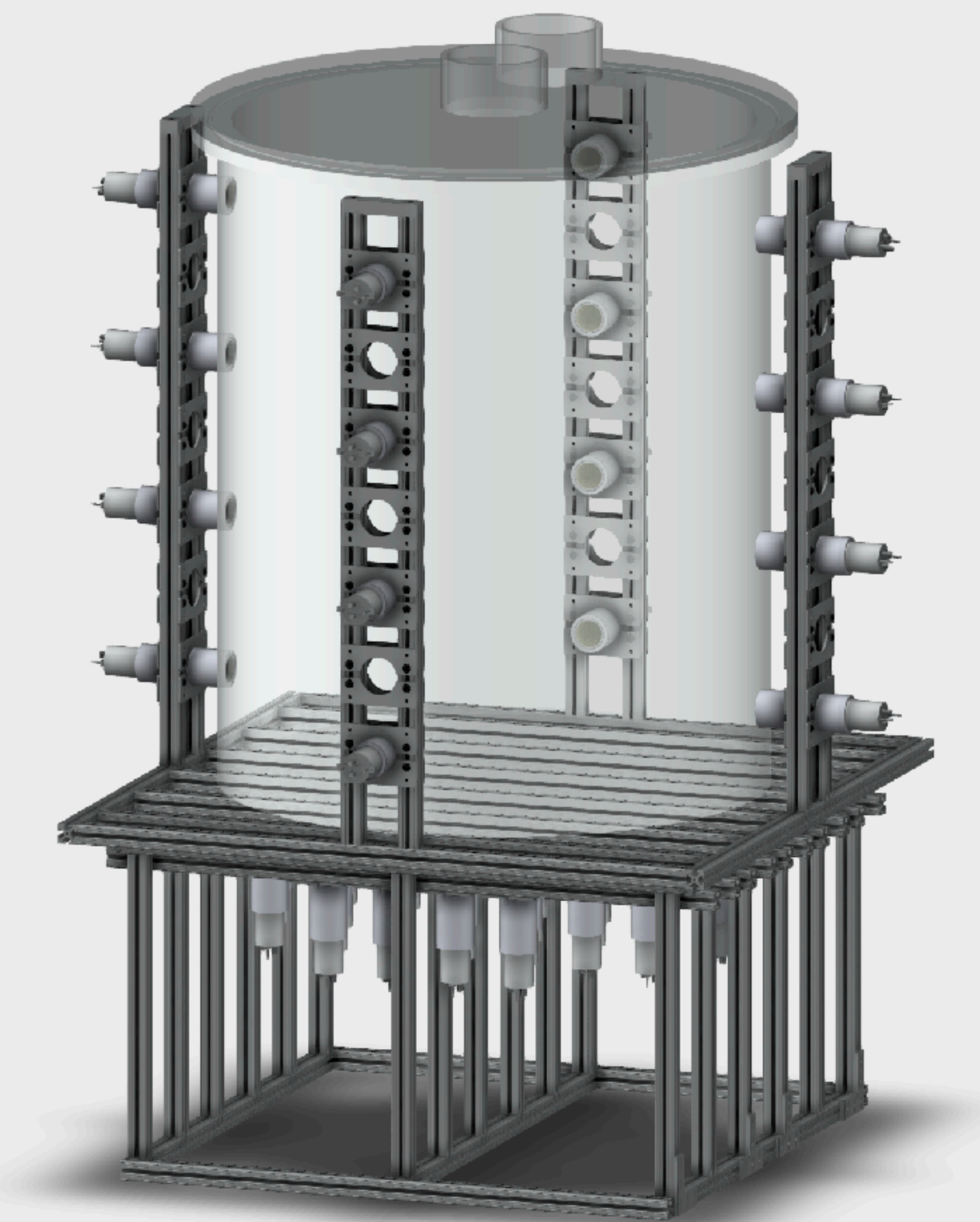
WbLS Development at BNL

- LS research laboratories with state-or-art equipment
  - Bench top R&Ds and mid-scale (10-100 liter) study
  - Host students and collaborators >5 per year
  - **ANNIE, WATCHMAN, THEIA**
- Ton-scale liquid scintillator production facility (large production readiness in Q3/2023)
- 1-ton Testbed (1TBNL, commissioned in FY22)
- 30-ton Demonstrator (30T BNL in Q1/2024)



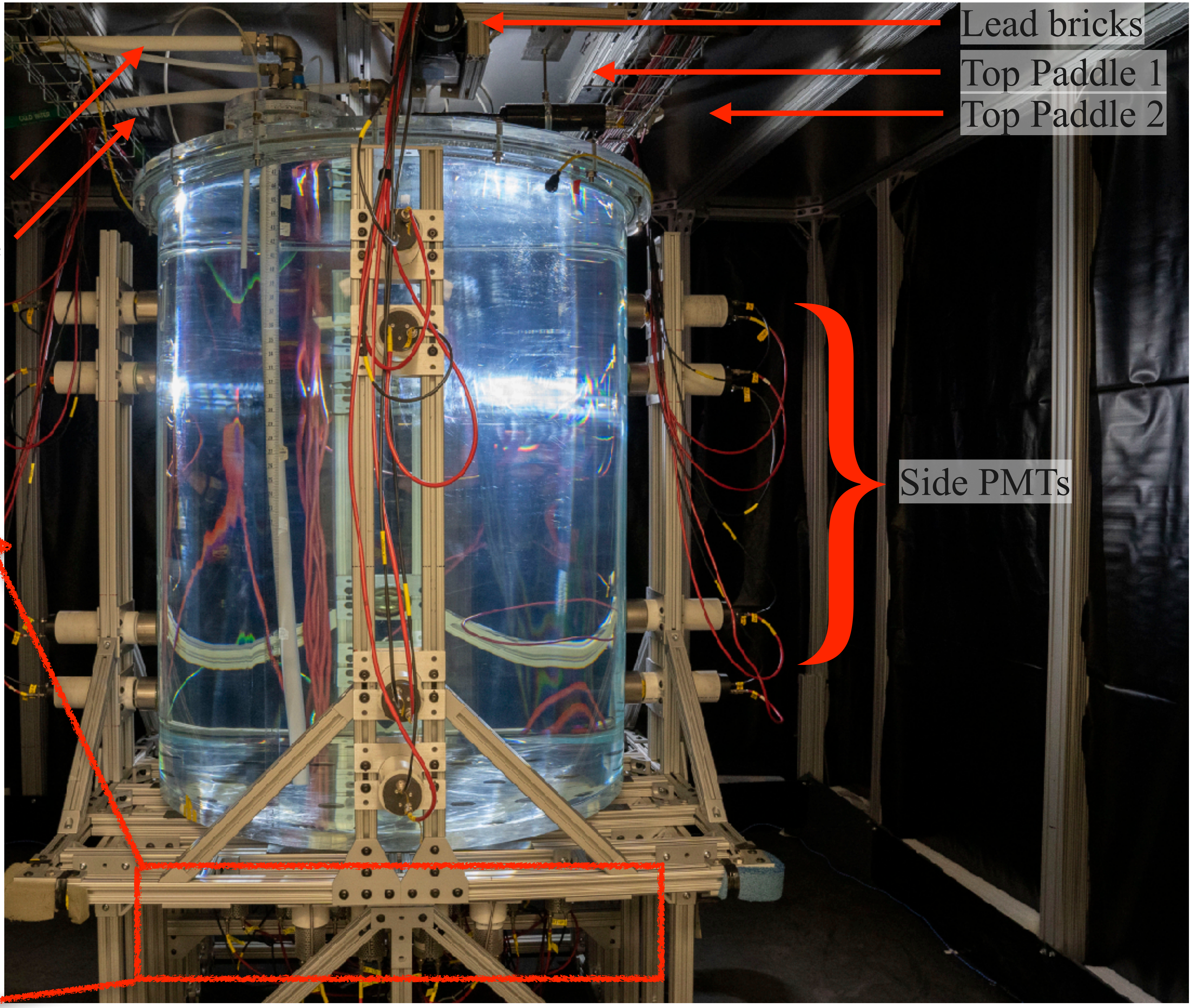
The 1-ton detector

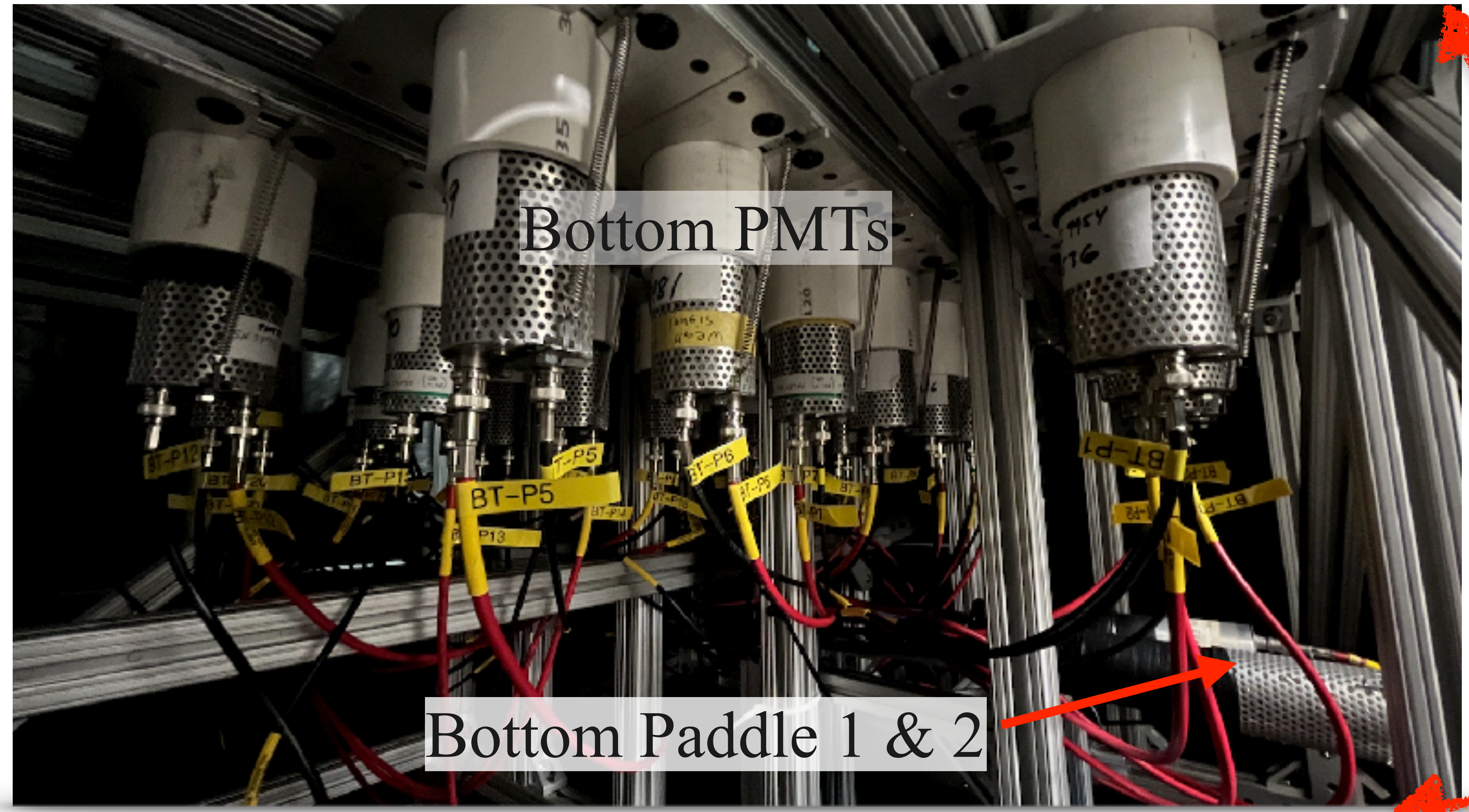
- An acrylic tank containing 1 ton of water or WbLS is surrounded by 46 fast PMTs
- Custom-made optical coupling by BNL technicians to match the curvature of the tank on the side
- Nitrogen blanket in the chimneys
- Completed two phases of operations:
  - Phase 0: pure-water
  - Phase 1: 1% WbLS (LAB-PPO)



Note: locations of side PMTs are out of date in this drawing

Photos of the actual 1-ton detector

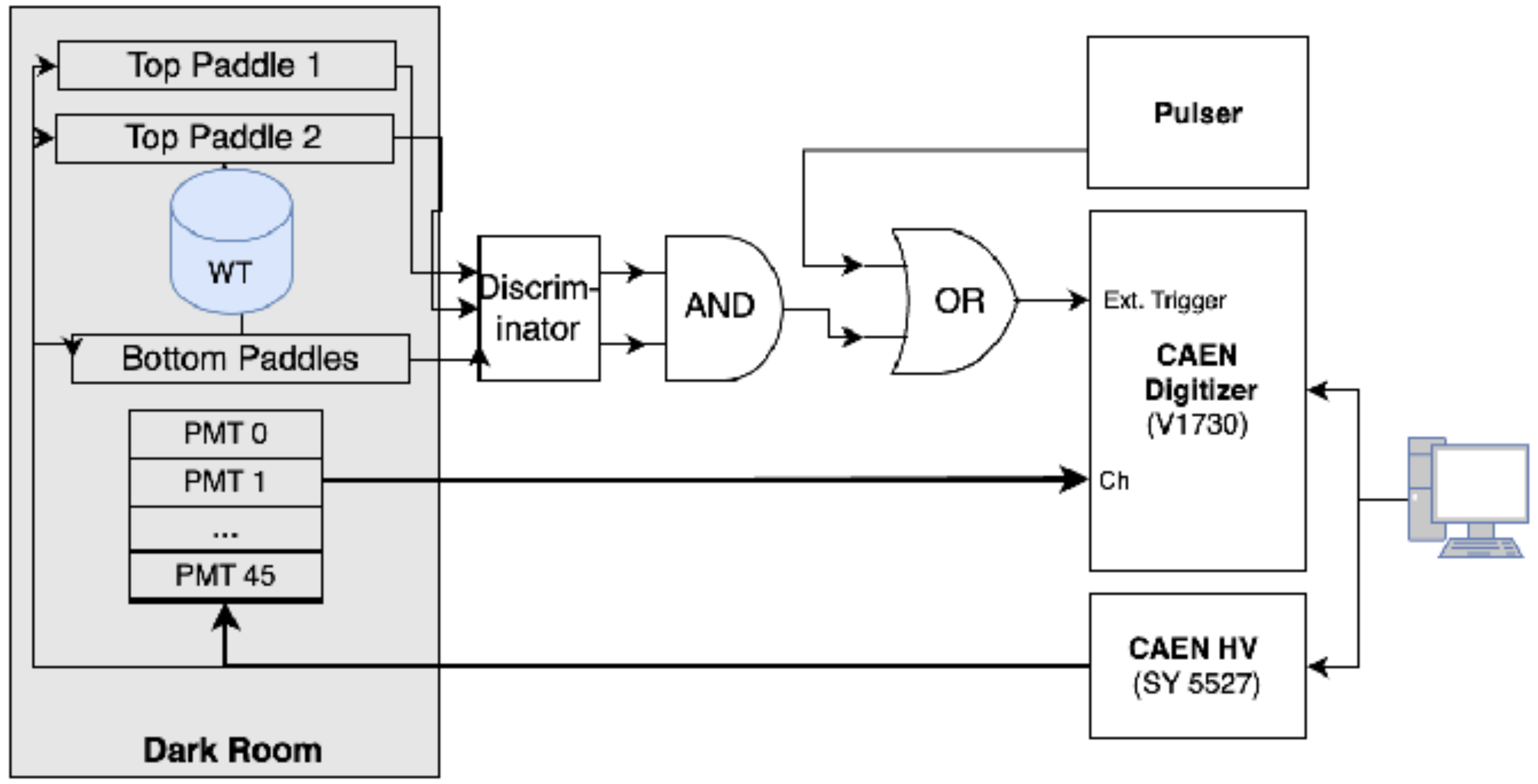




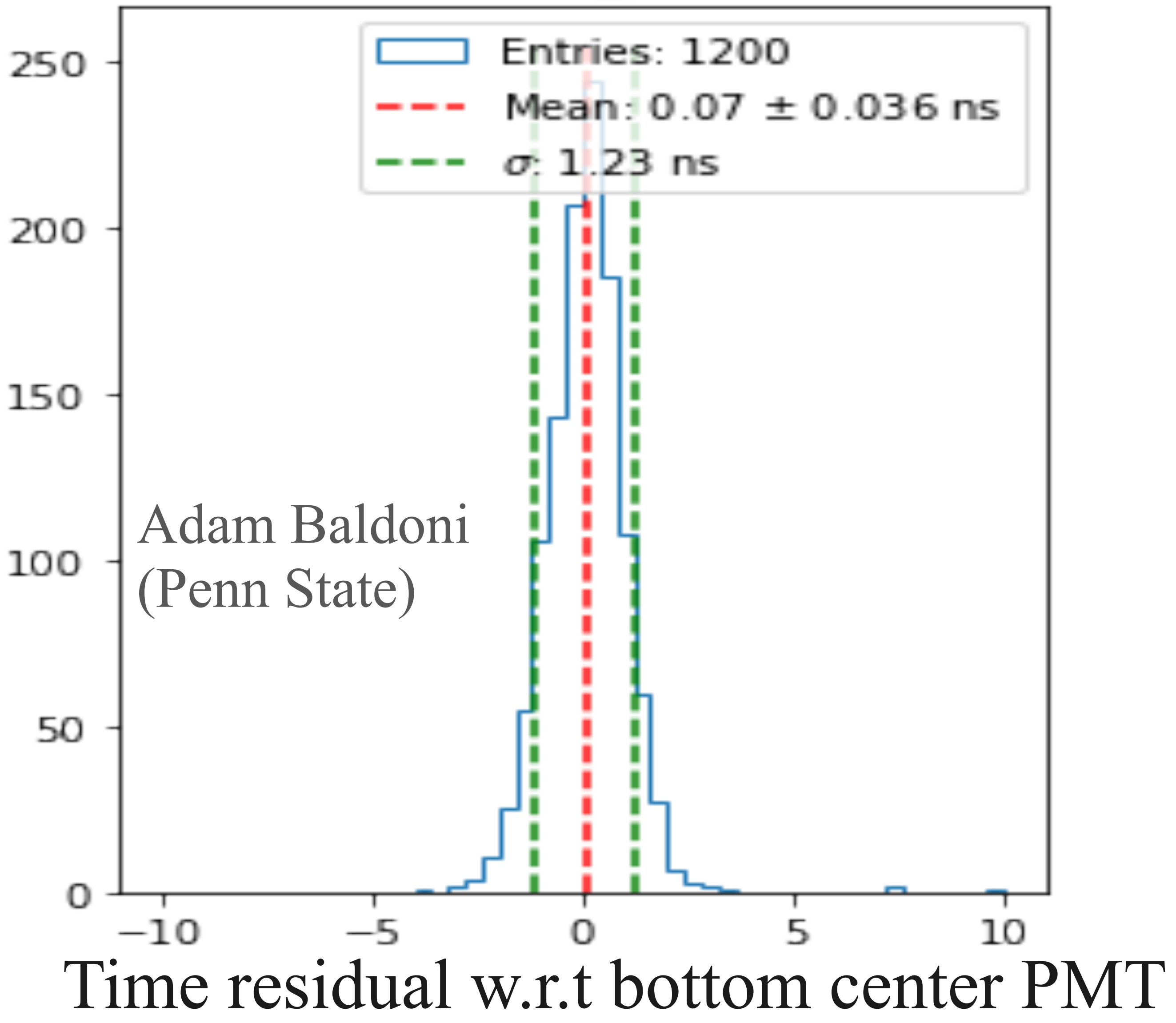
Photos of the actual 1-ton detector

The PMT & DAQ Calibration

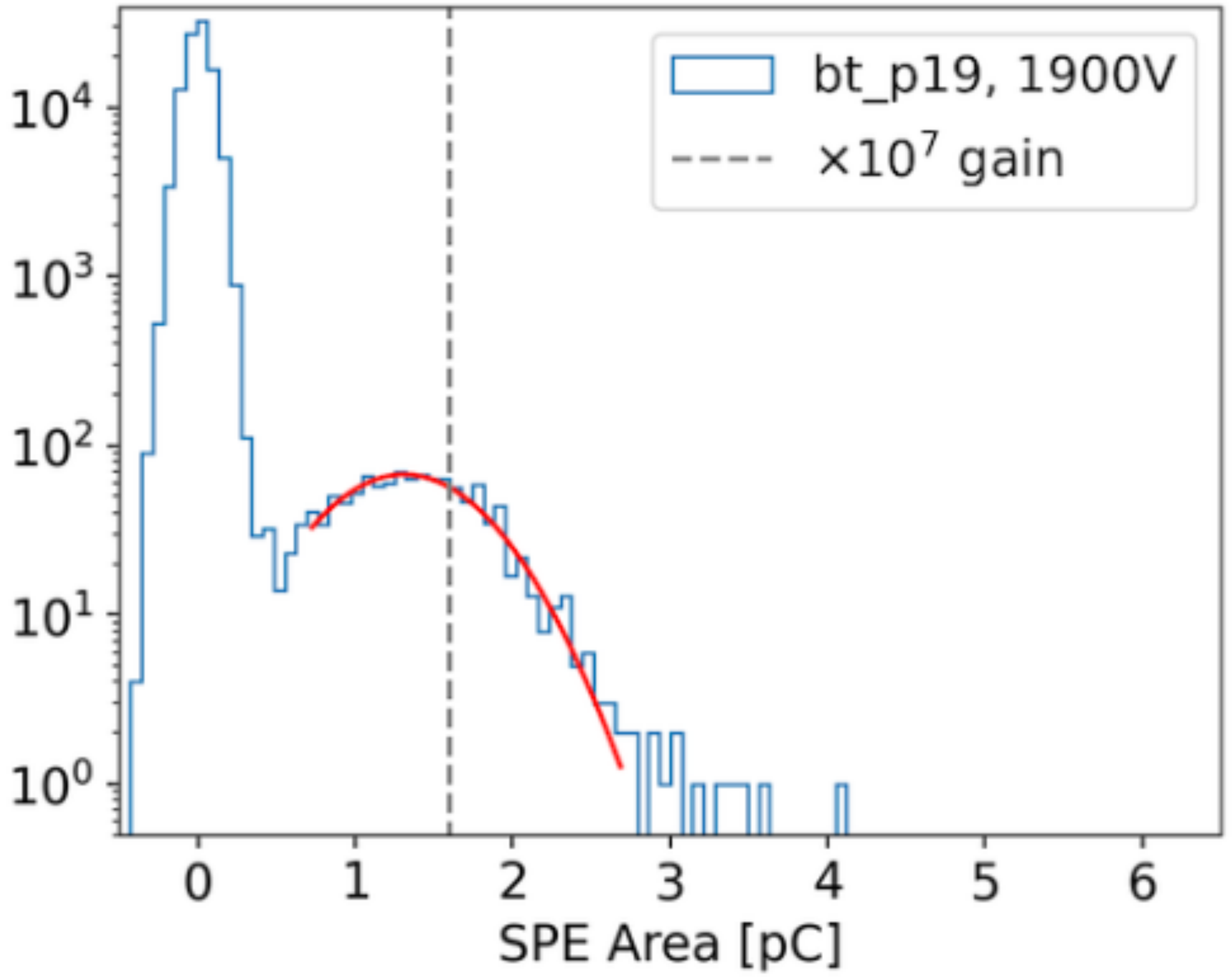
Electronic schematic



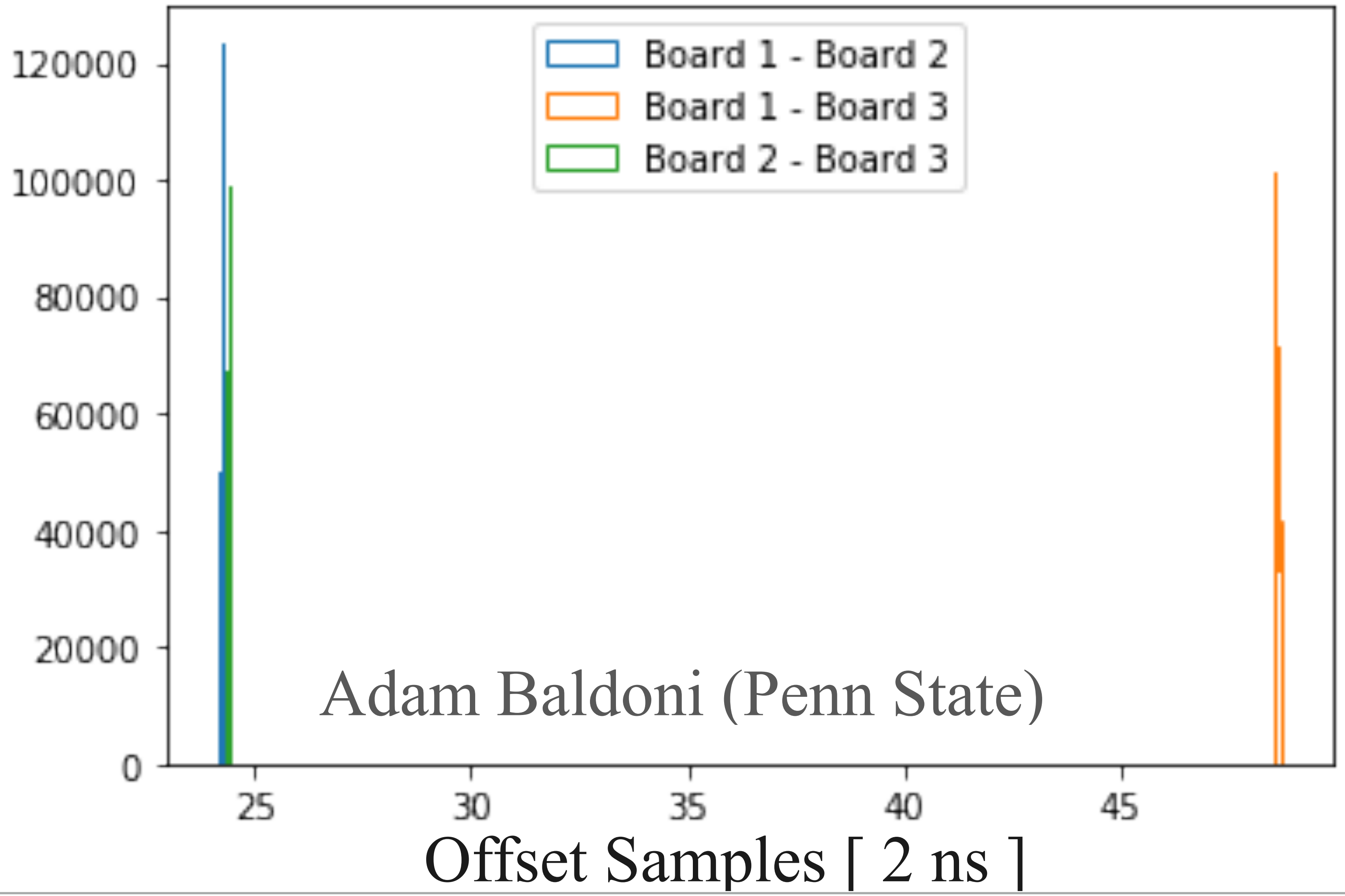
Relative PMT timing calibration



PMT SPE calibration



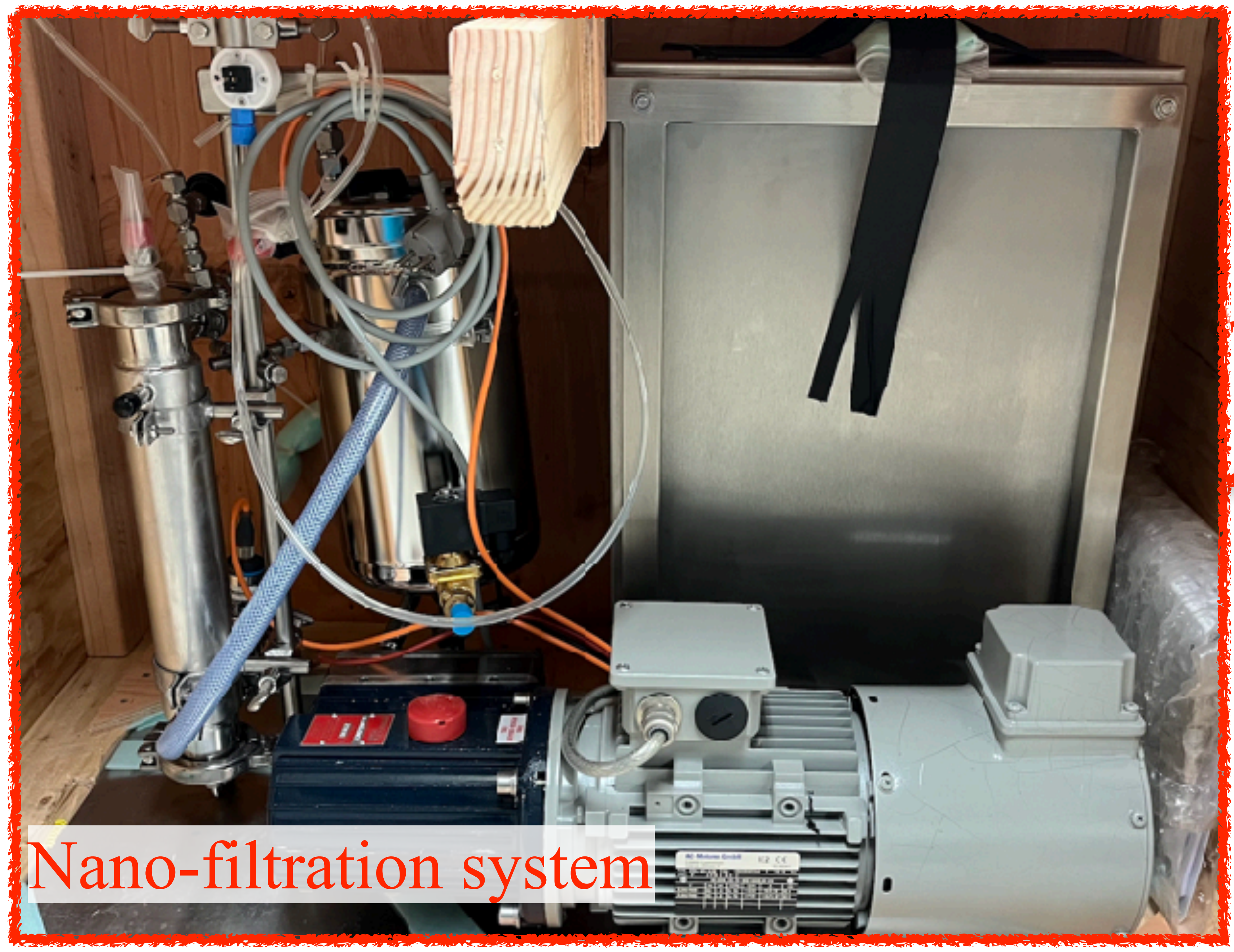
Trigger delay calibration for the daisy-chained digitizers



PMTs and the DAQ have been calibrated extensively!

Circulation System

- Purification system achieves 18 MOhm water
- High purity WbLS operated for weeks without needing purification (optical property same as laboratory samples measured at >40m scattering length)
- All systems are inside secondary containment as per BNL safety.

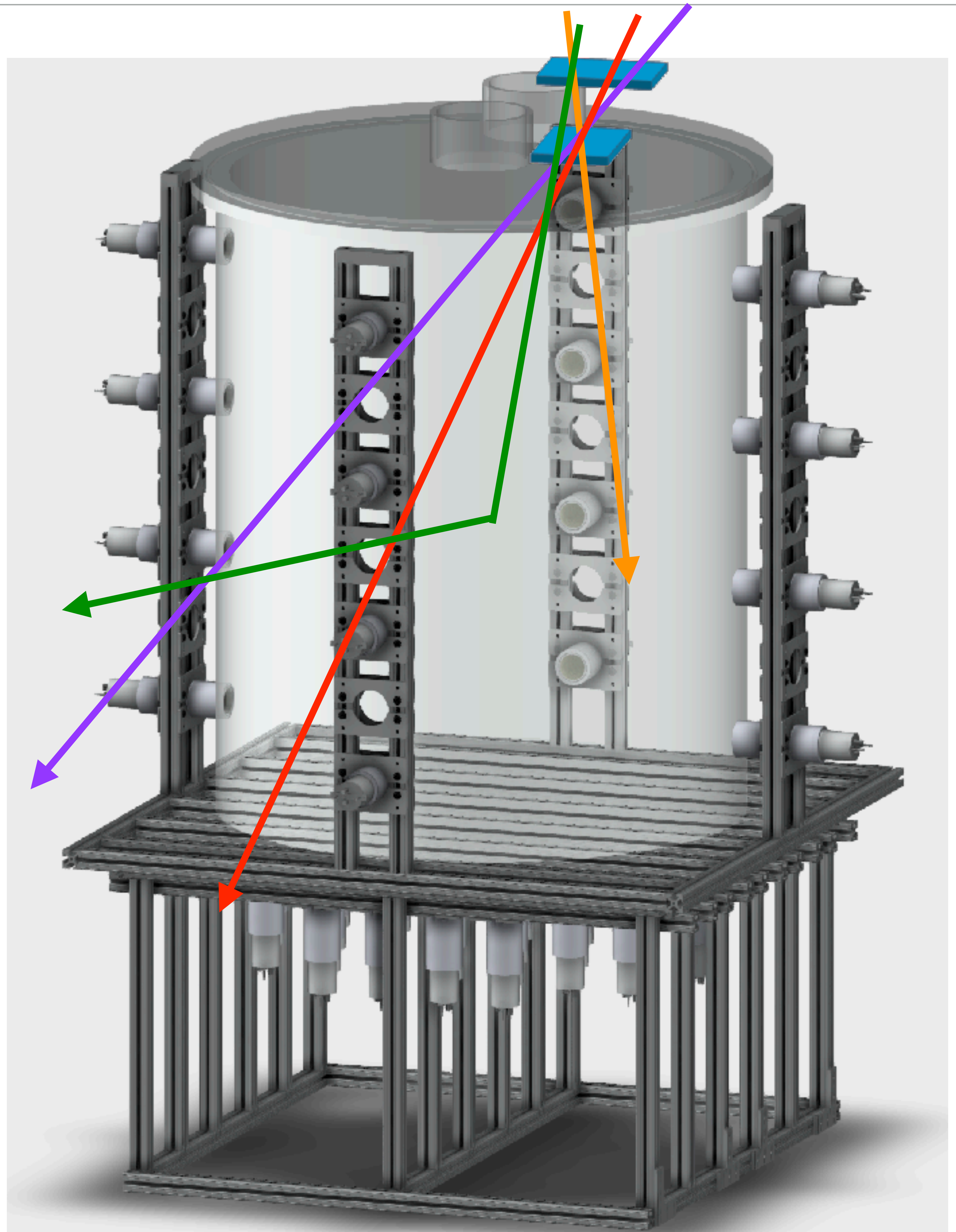


To be tested in phase-II operation

Use muons to light up the detector

Brookhaven National Laboratory

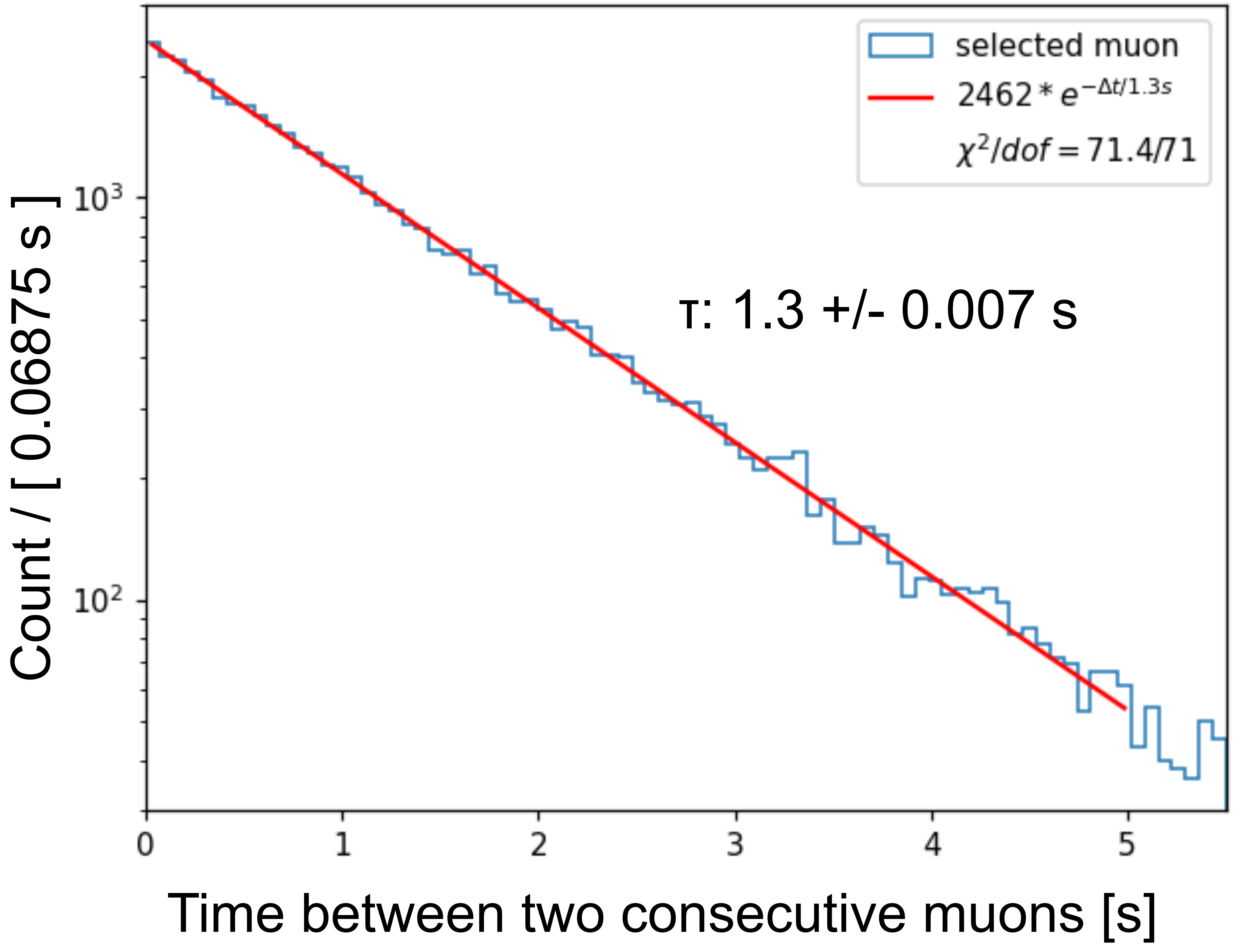
- Two scintillator paddles above the acrylic tank to trigger on muons
  - The Crossing Area: 4x4 inch; separation: 2.5 inch (or 4.5 inch)
- Frequent event topologies
  - Side-way crossing muons (exit from the side)
  - Vertical crossing muon (exit from the bottom)
  - Scattered muons
  - Stopped muons (Michel electron, cascade)

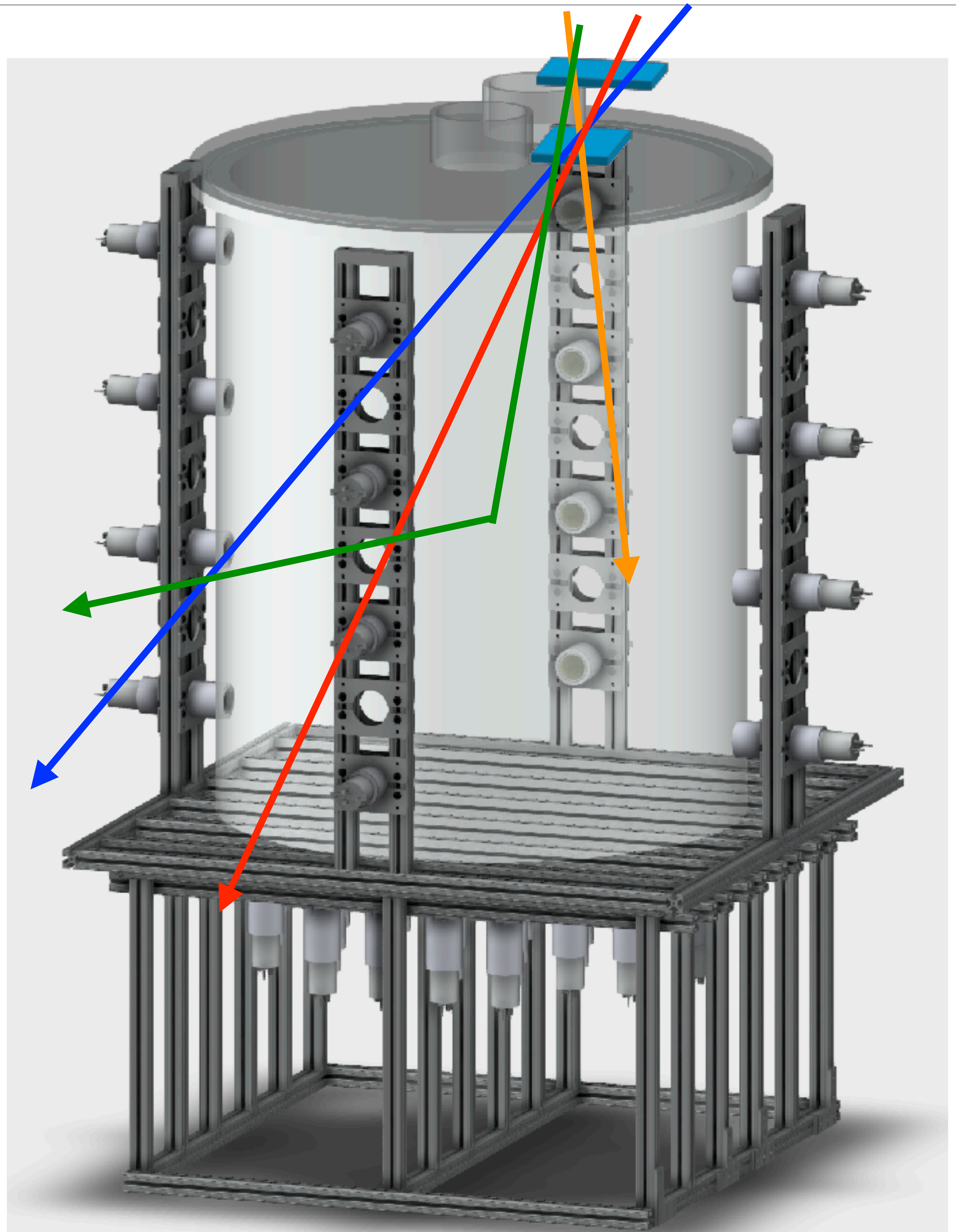


Note: locations of side PMTs are out of date in this drawing

Use muons to light up the detector

- Two scintillator paddles above the acrylic tank to trigger on muons
  - The Crossing Area: 4x4 inch; separation: 2.5 inch (or 4.5 inch)
- Overall muon rate observed: 0.76 Hz





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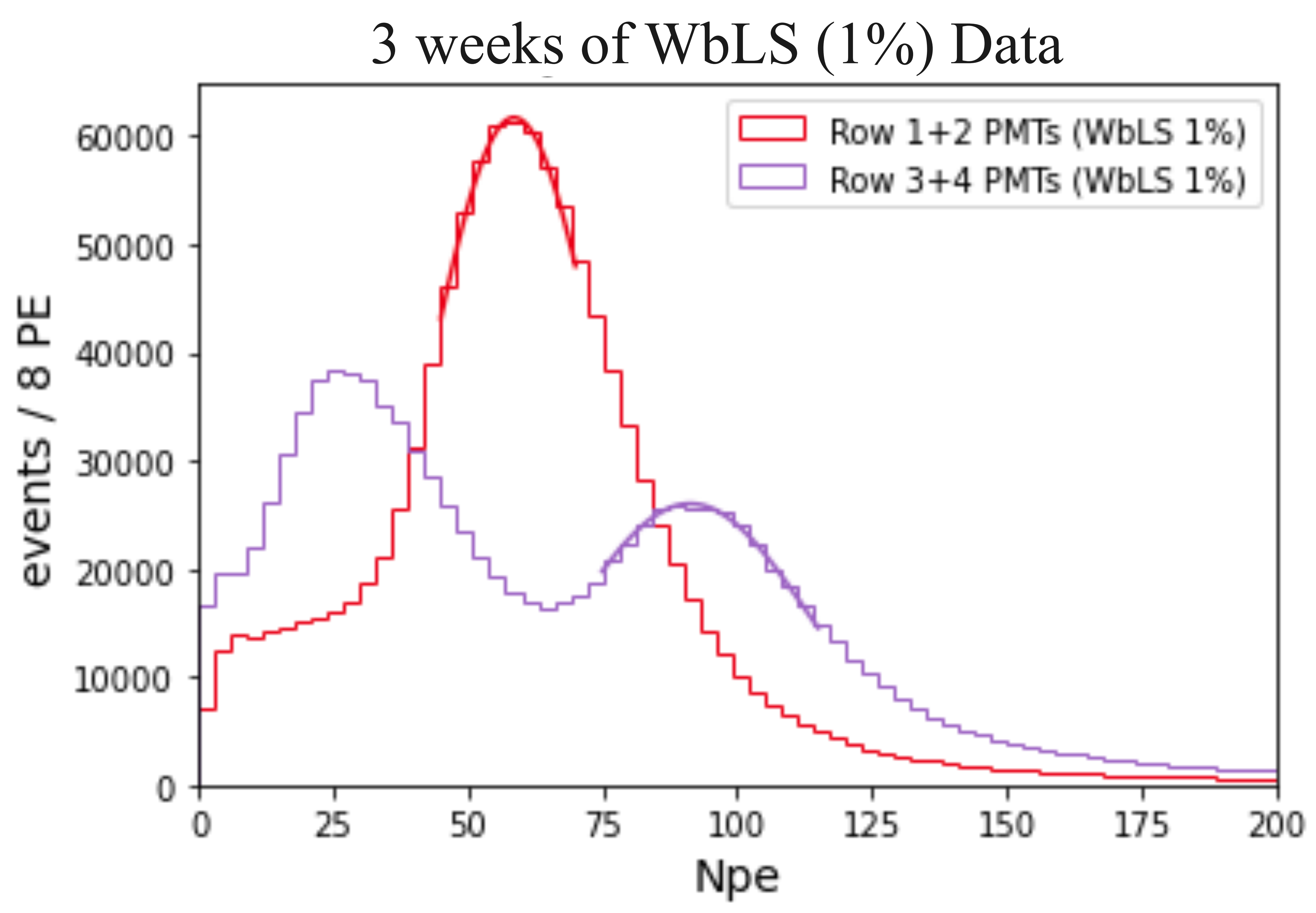
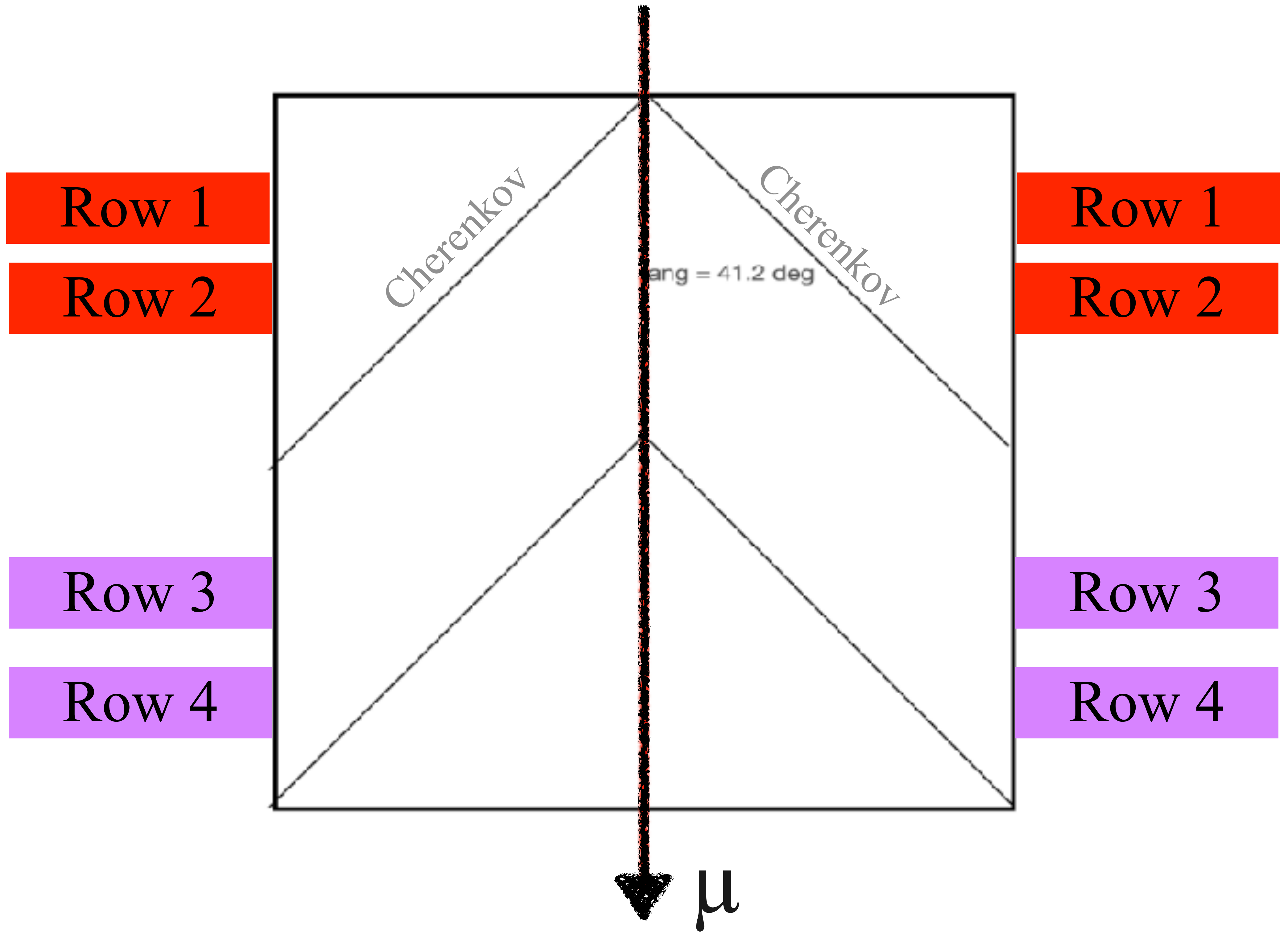
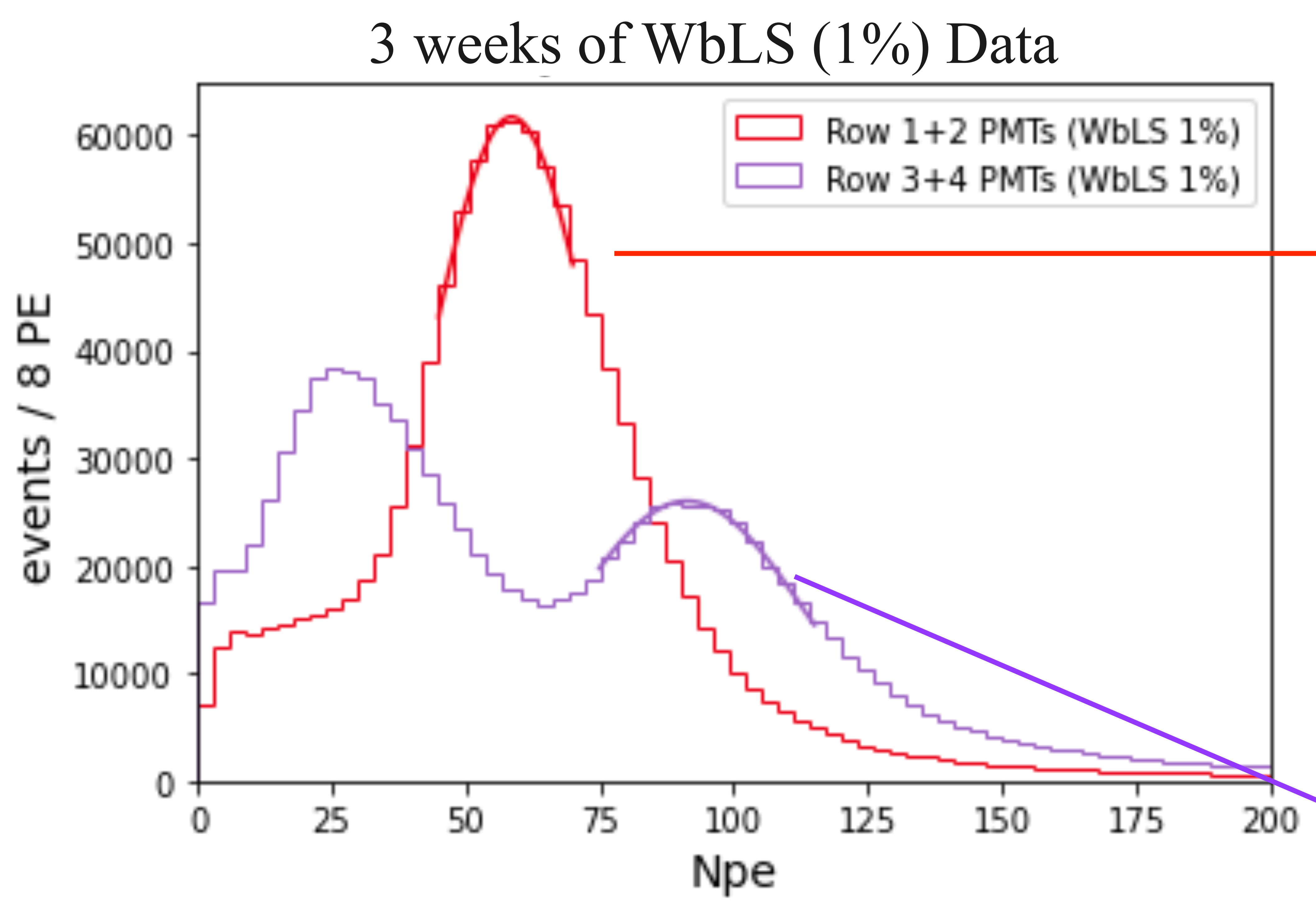
Light seen by the side PMTs

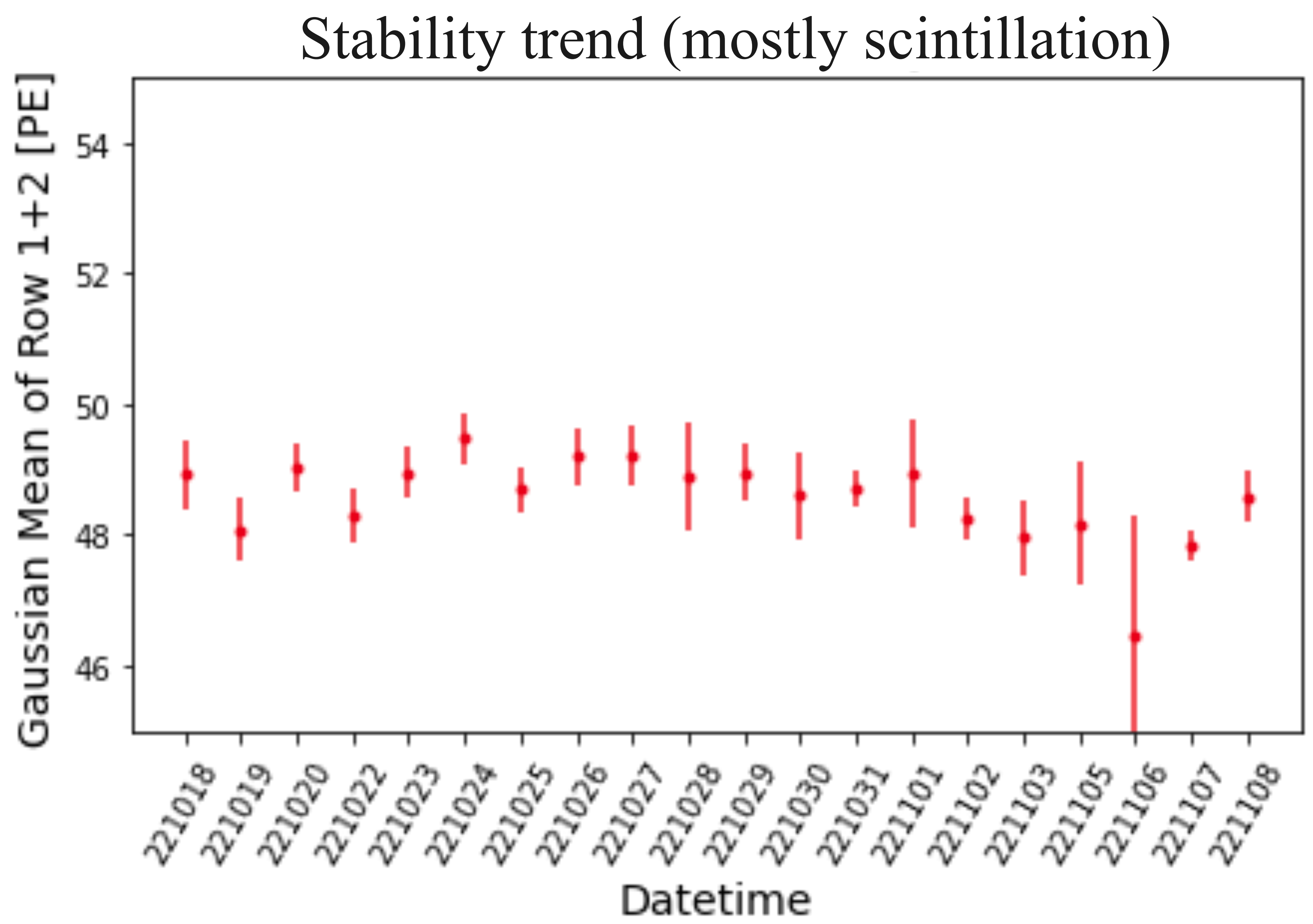


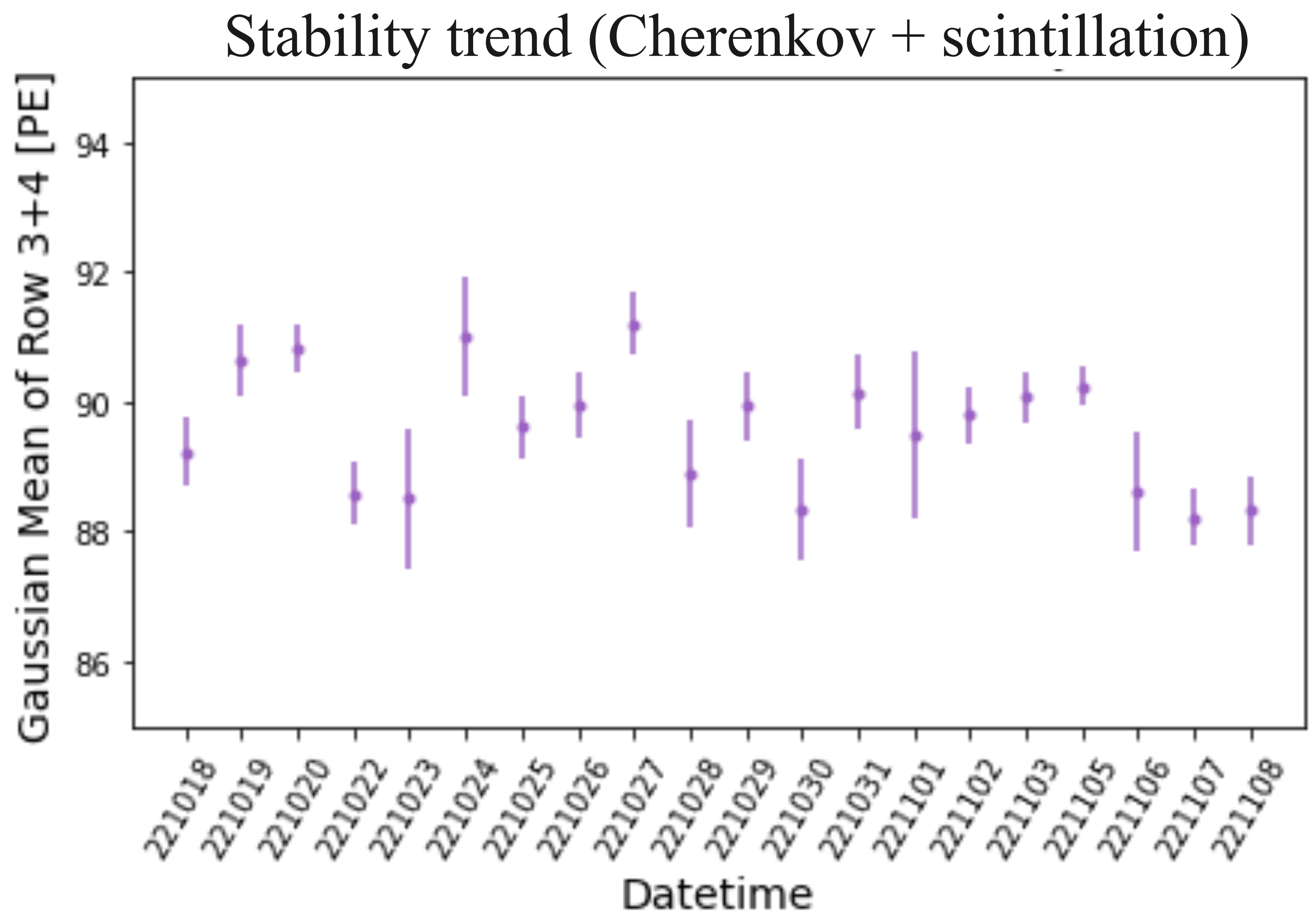


- Row 1+2 PMTs are not exposed to direct Cherenkov light from vertical crossing muon
- Row 3+4 PMTs are exposed to both Cherenkov and scintillation, and can be used for a rough selection of crossing muons.

Stability of WbLS

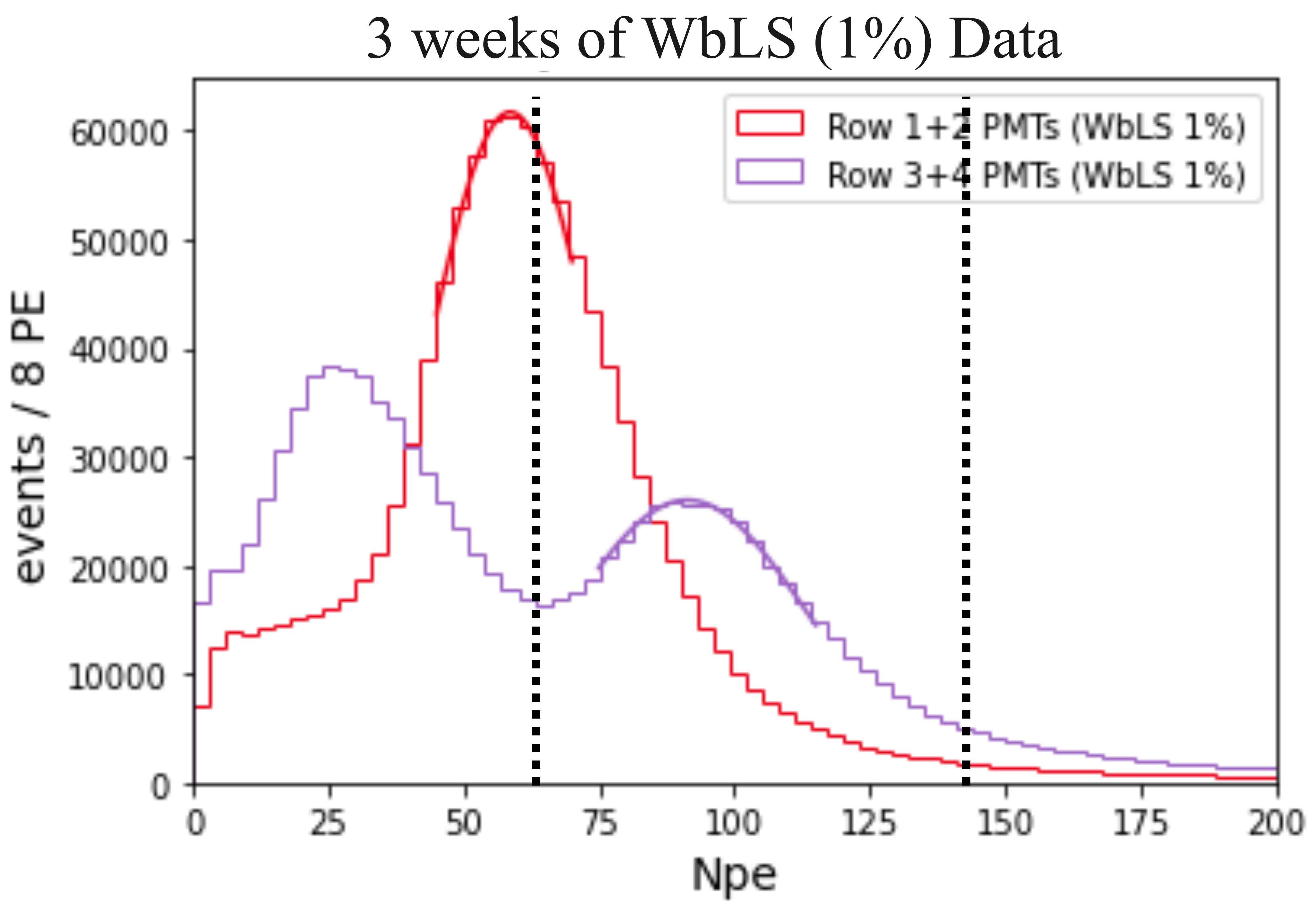


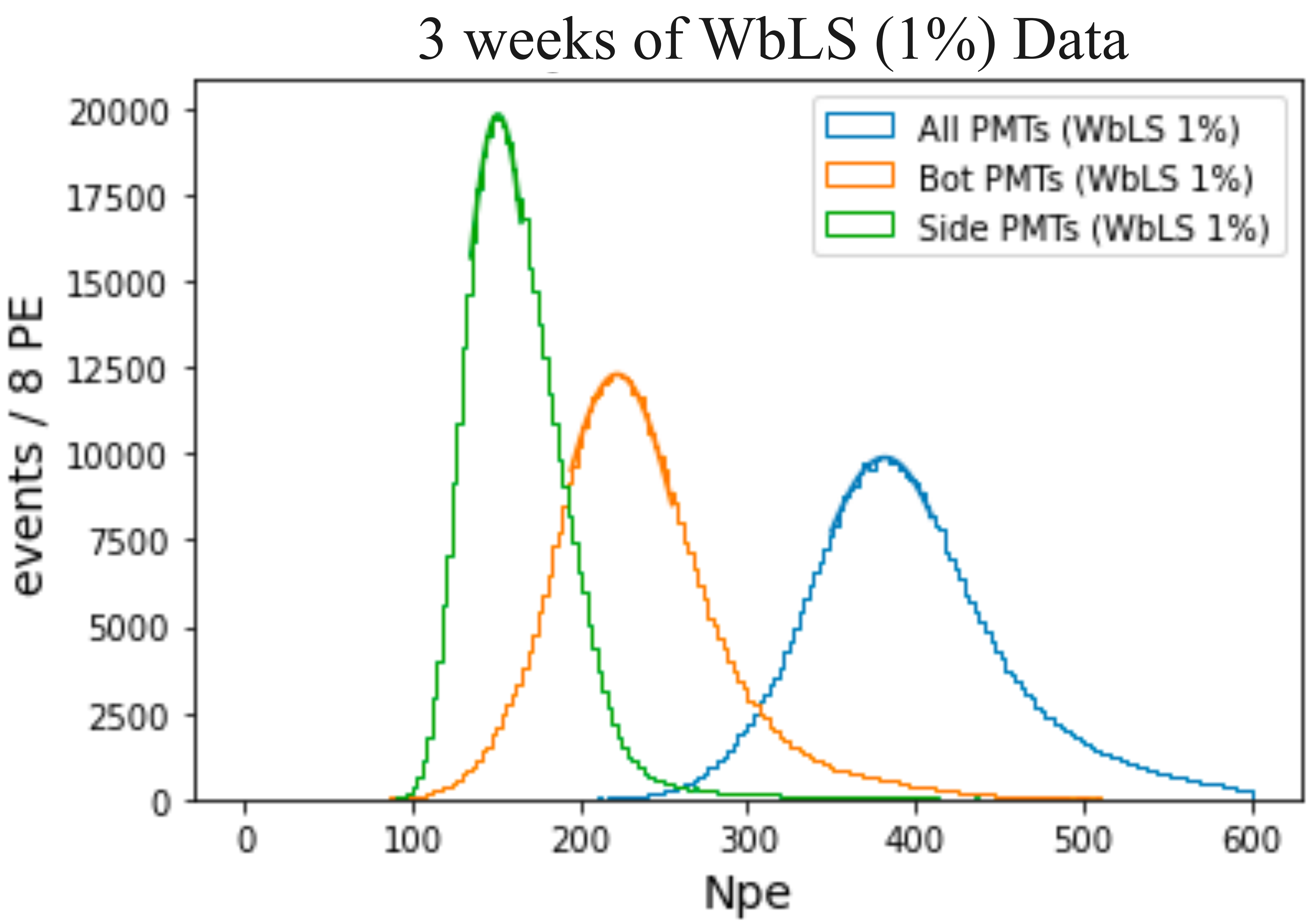




- We want to track vertically crossing muons
- **Stable light yield** was observed for the side tubes within ±1% over 3 weeks
  - Calibration is being refined to reduce the systematical error in the stability

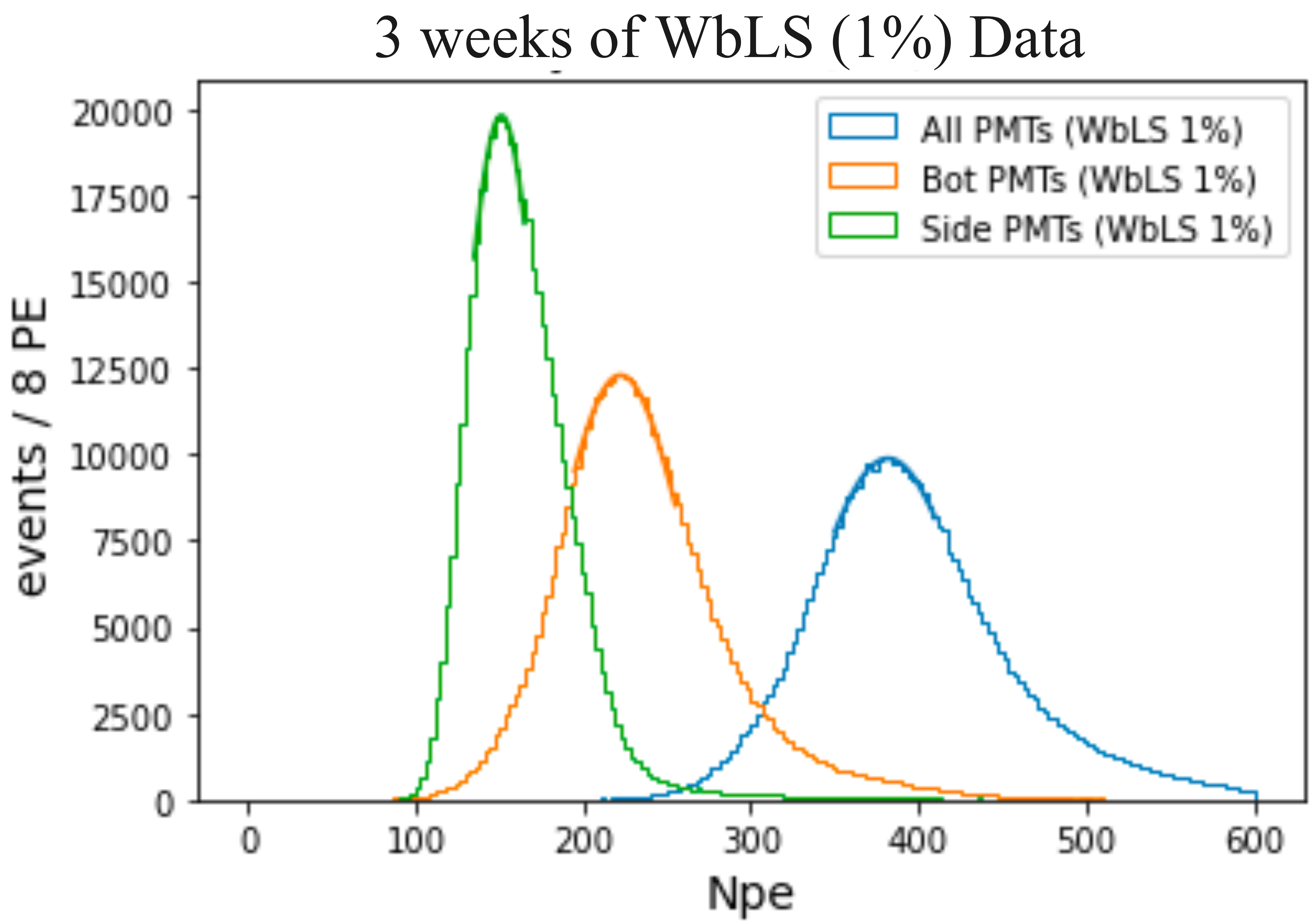
Vertically crossing muons selection (roughly)

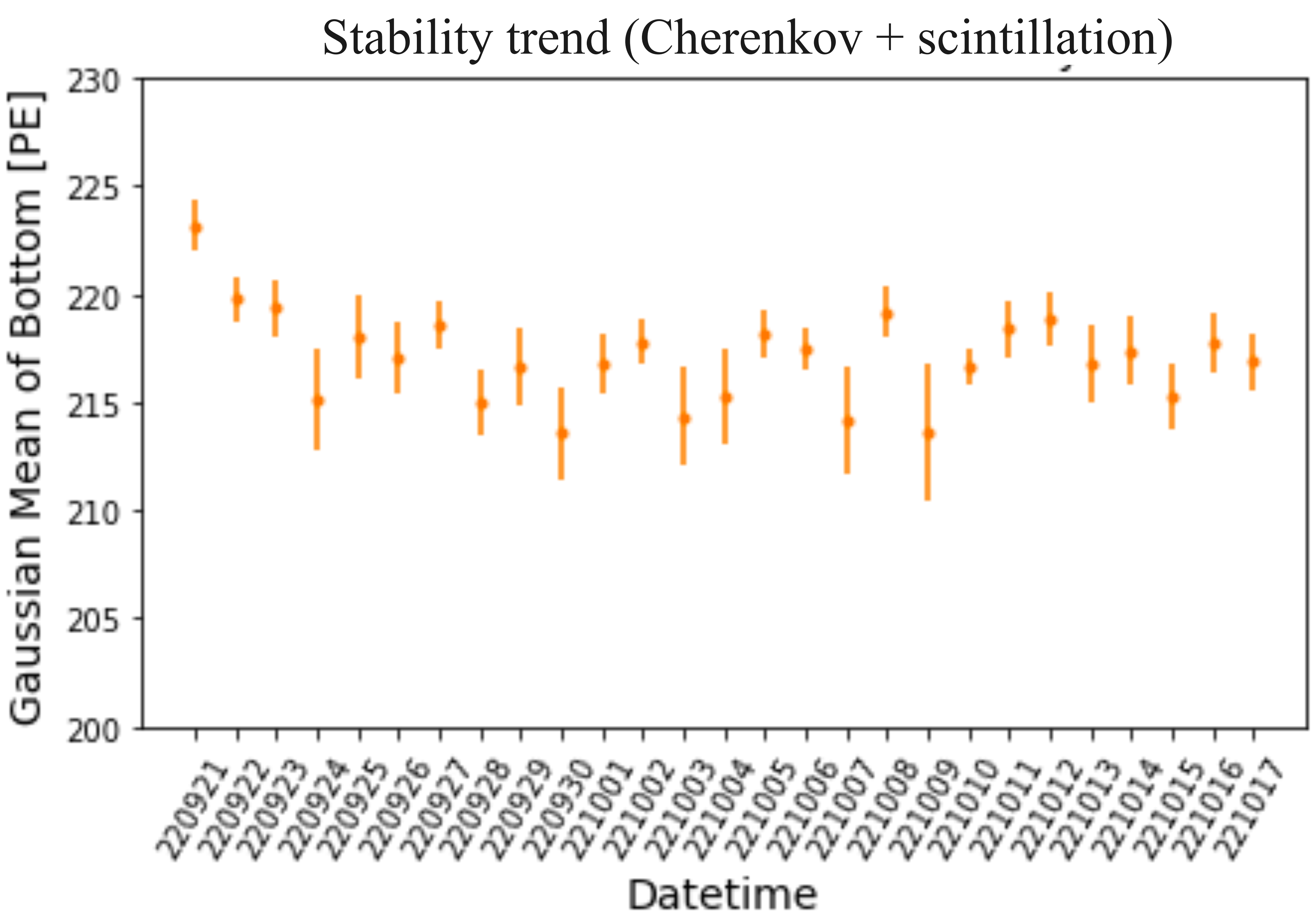




- We can select vertically crossing muons by cutting on the row 3+4 spectrum (dashed)
- Vertically crossing muons have well-defined spectrum peaks by:
  - the side PMTs
  - the bottom PMTs
  - all PMTs

Stable light yield observed

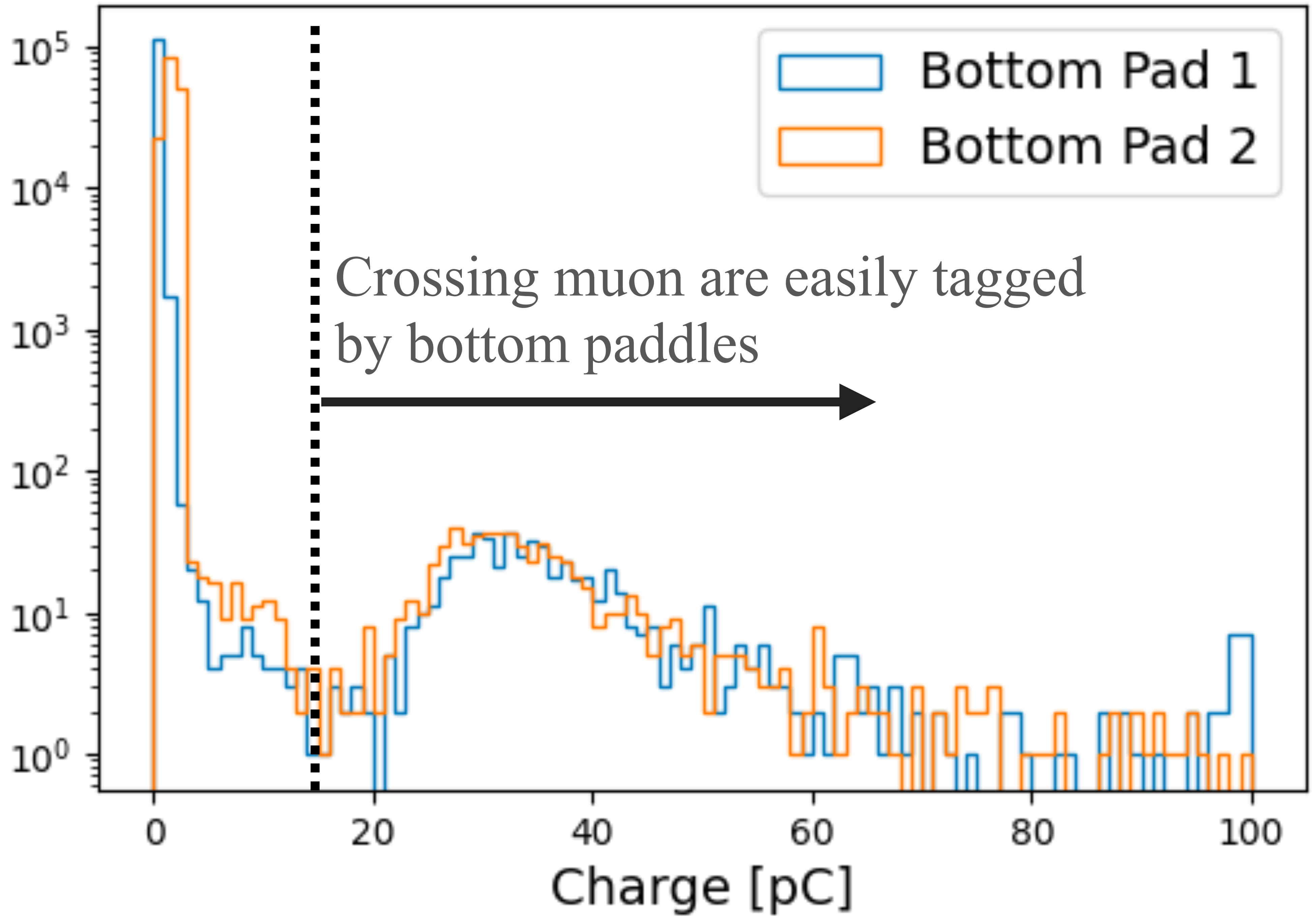


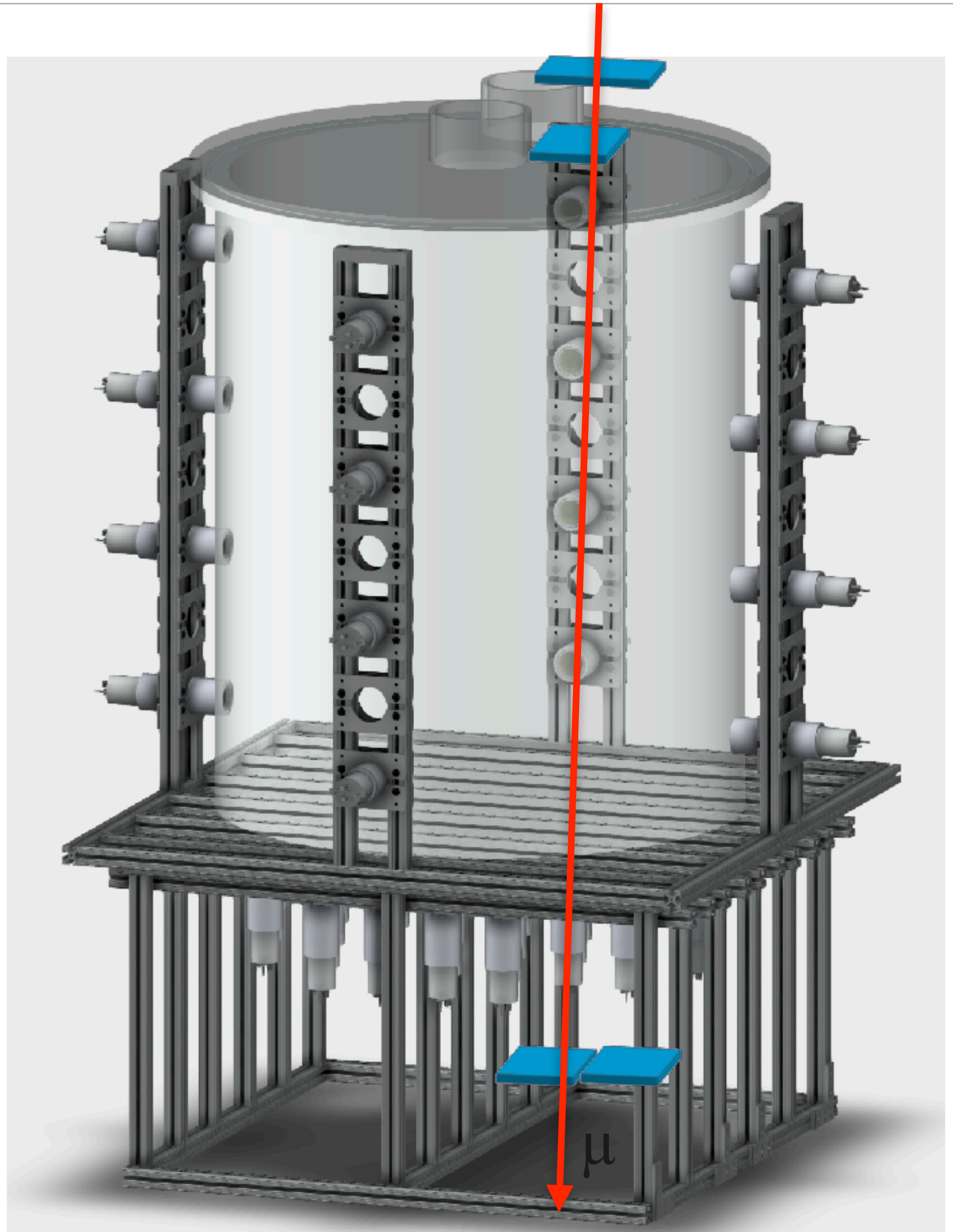


- Stable light yield was observed for the vertically crossing muons from the bottom PMTs
- Initial drop is artificial due to calibration systematics

Use crossing muons as "the standard candle"

- Two scintillator paddles below the acrylic tank to tag crossing muons
- Lower statistics, but well-known event topology





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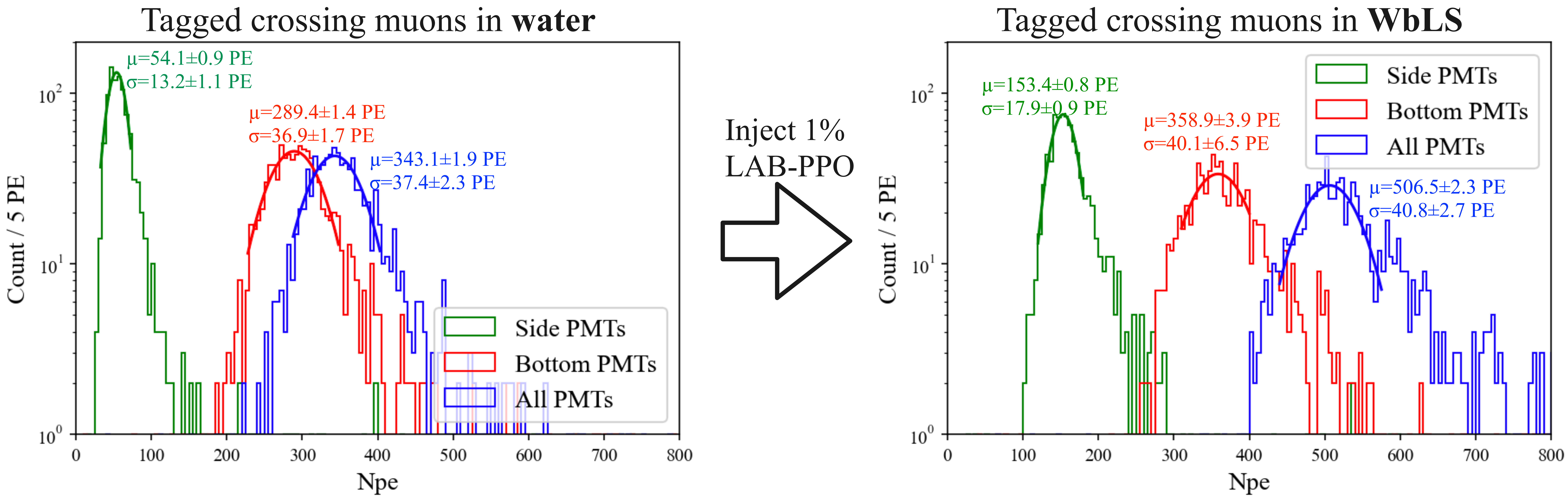
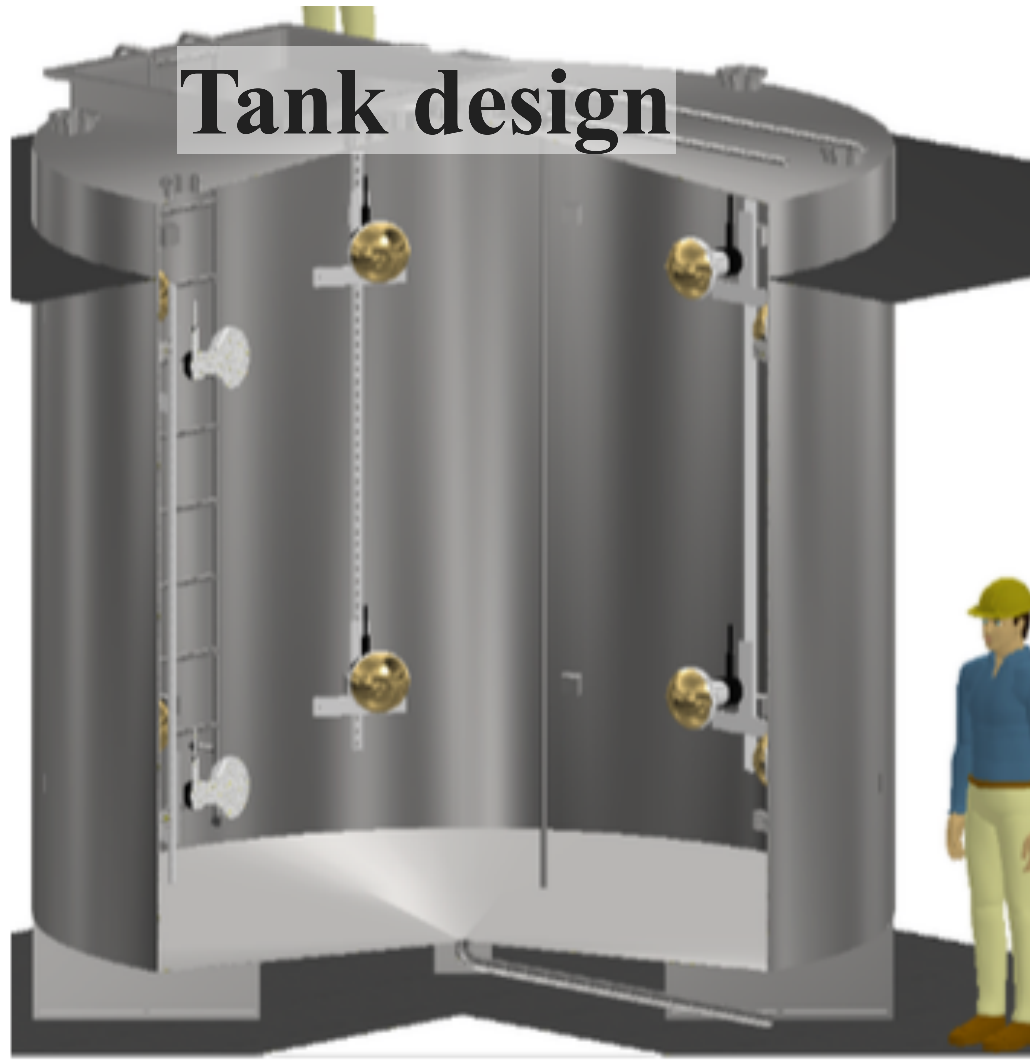
WbLS compared to water

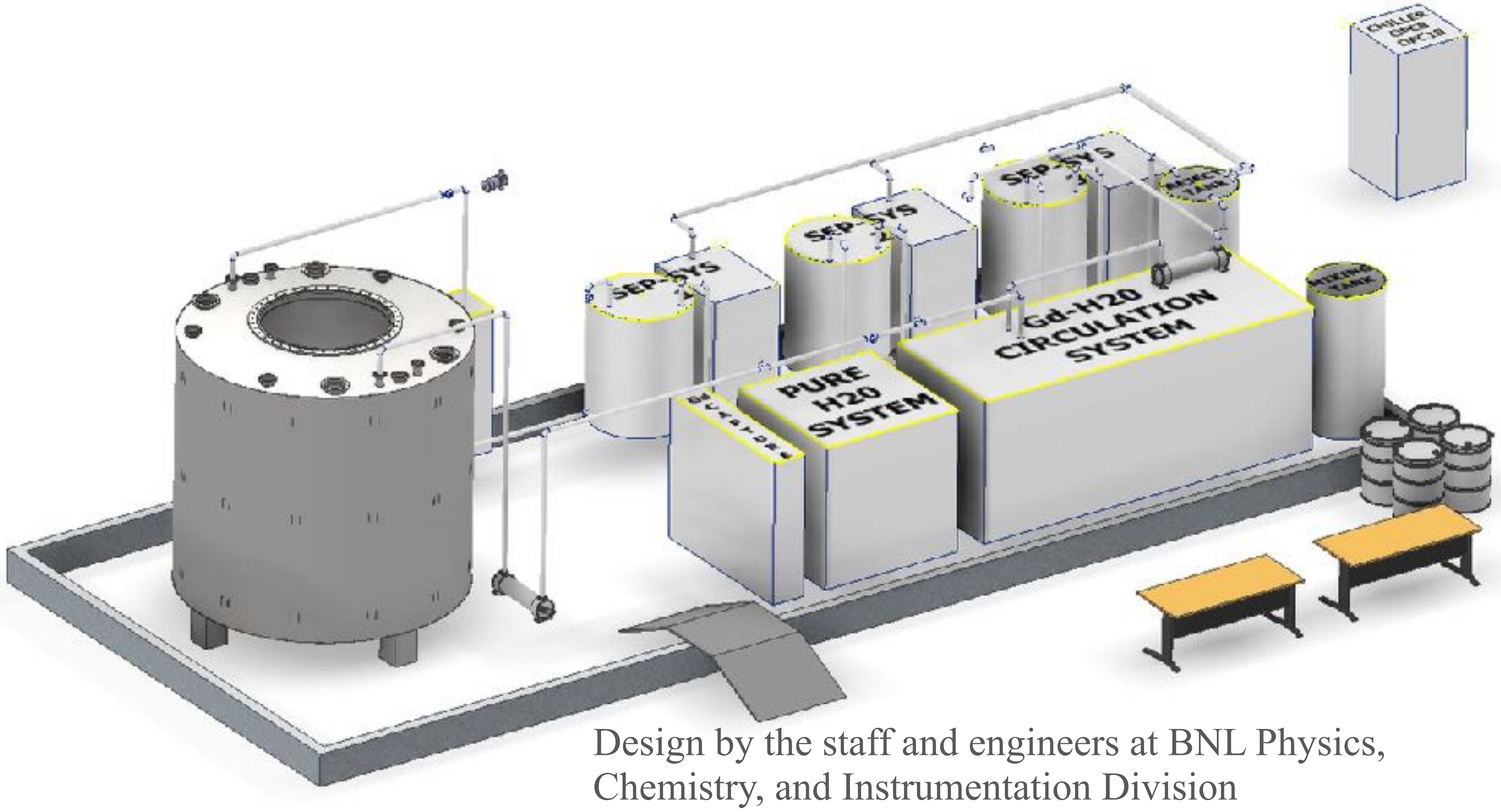


- Much enhanced light production from the tagged crossing muons with merely 1% injection of LAB-PPO.
- Data is consistent with scintillation LY of ~100-200 pe/MeV
- Detailed analysis of light yield is in progress (to account for reflections, and attenuation using a detailed *ratpac* MC).

30-ton demonstrator

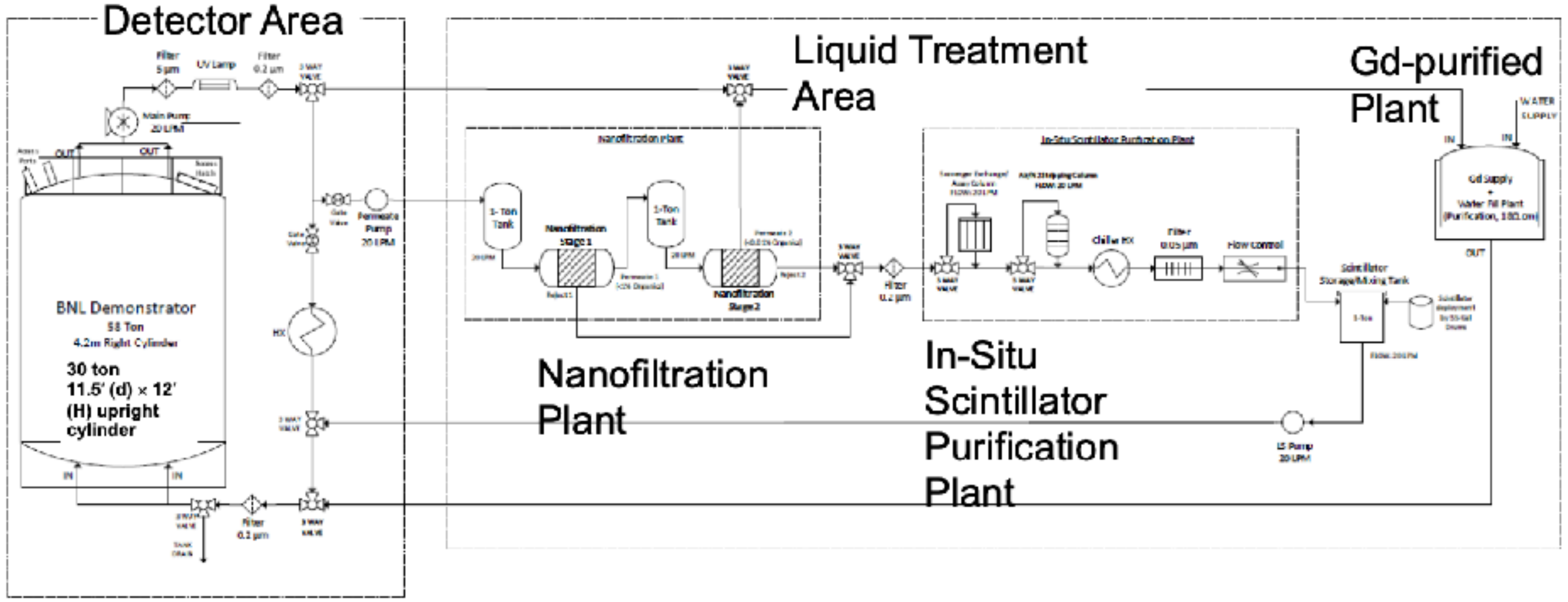
- Goal: demonstrate a scaled up deployment scheme for a kiloton-scale detector:
  - Operation parameters: flow rate, turnover rate, Gd purity
  - Separation and recombination via Nano-filtration system
  - Performance stability





Design by the staff and engineers at BNL Physics, Chemistry, and Instrumentation Division

Circulation scheme for 30-ton



Summary

- We have successfully constructed and operated a 1-ton WbLS muon detector
- Early commissioning results from the 1-ton detector is encouraging
  - WbLS cocktail is stable!
  - Significant enhancement in light yield.
- The same measurements will be repeated with an upgraded 1-ton detector:
  - Add more PMTs to the side.
  - Deliberated calibration with radioactive sources for
  - Fine-tuned PMT timing
  - Relative detector efficiency at various spatial locations
  - Exercise nano-filtration system
  - And more …
- The Construction of a 30-ton demonstrator is ongoing.

Acknowledgements - Thank You!

Key Collaboration Institutes (in alphabetical order):

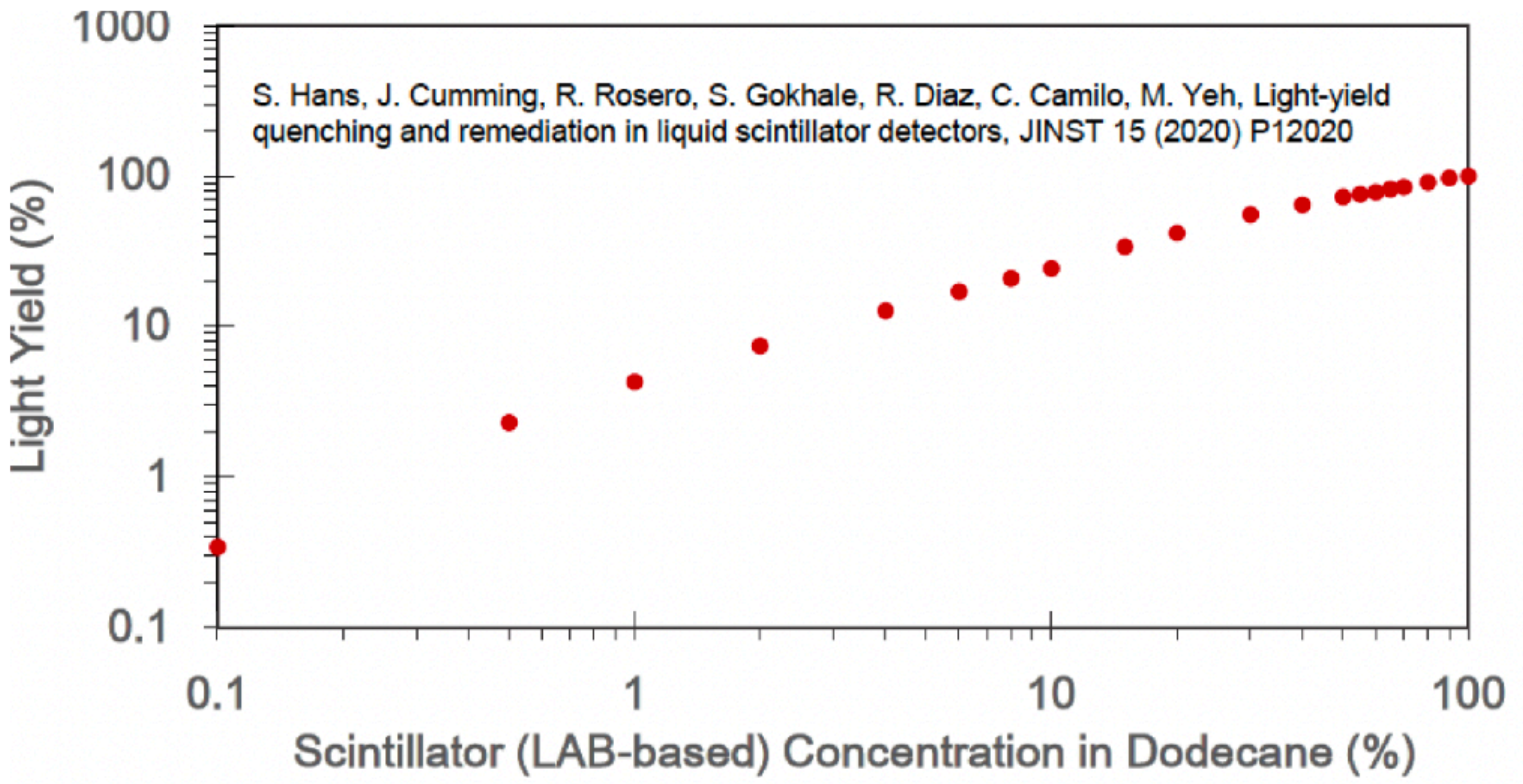
- Brookhaven National Laboratory
- Bronx Community College
- Lawrence Berkeley National Laboratory
- Lawrence Livermore National Laboratory
- Penn State University
- Stony Brook University
- University of Alabama
- University of California, Berkeley
- University of California, Davis
- University of California, Irvine

And other US/UK WATCHMAN/THEIA collaborators

Research supported by NNSA (DNN) and Office of Science (OHEP/ONP).

Back up

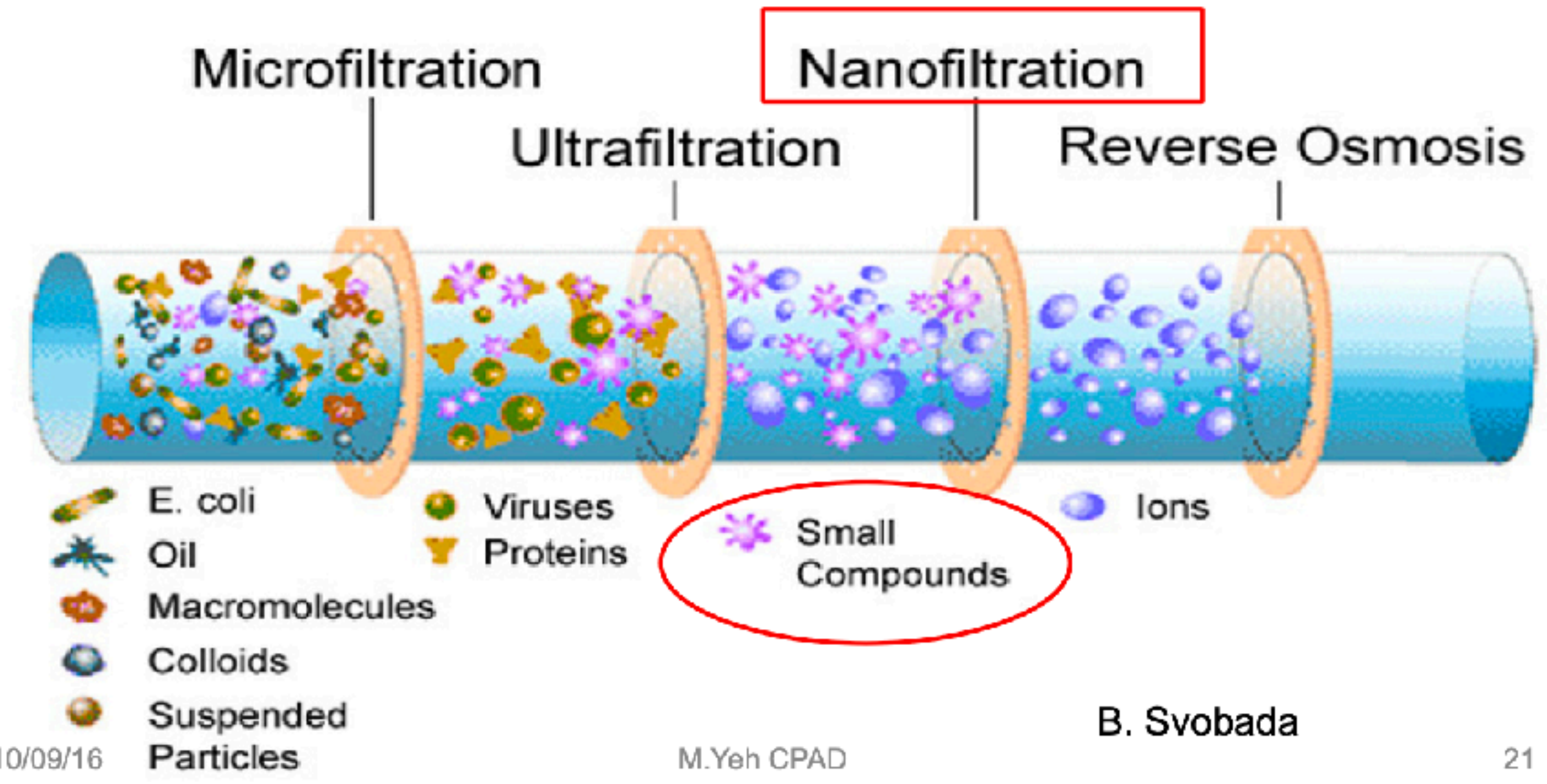
Tunable Ly


S. Hans, J. Cumming, R. Rosero, S. Gokhale, R. Diaz, C. Camilo, M. Yeh, Light-yield quenching and remediation in liquid scintillator detectors, JINST 15 (2020) P12020
Light Yield (%)
1000
100
10
1
0.1
0.1
1
10
100
Scintillator (LAB-based) Concentration in Dodecane (%)

Filtering

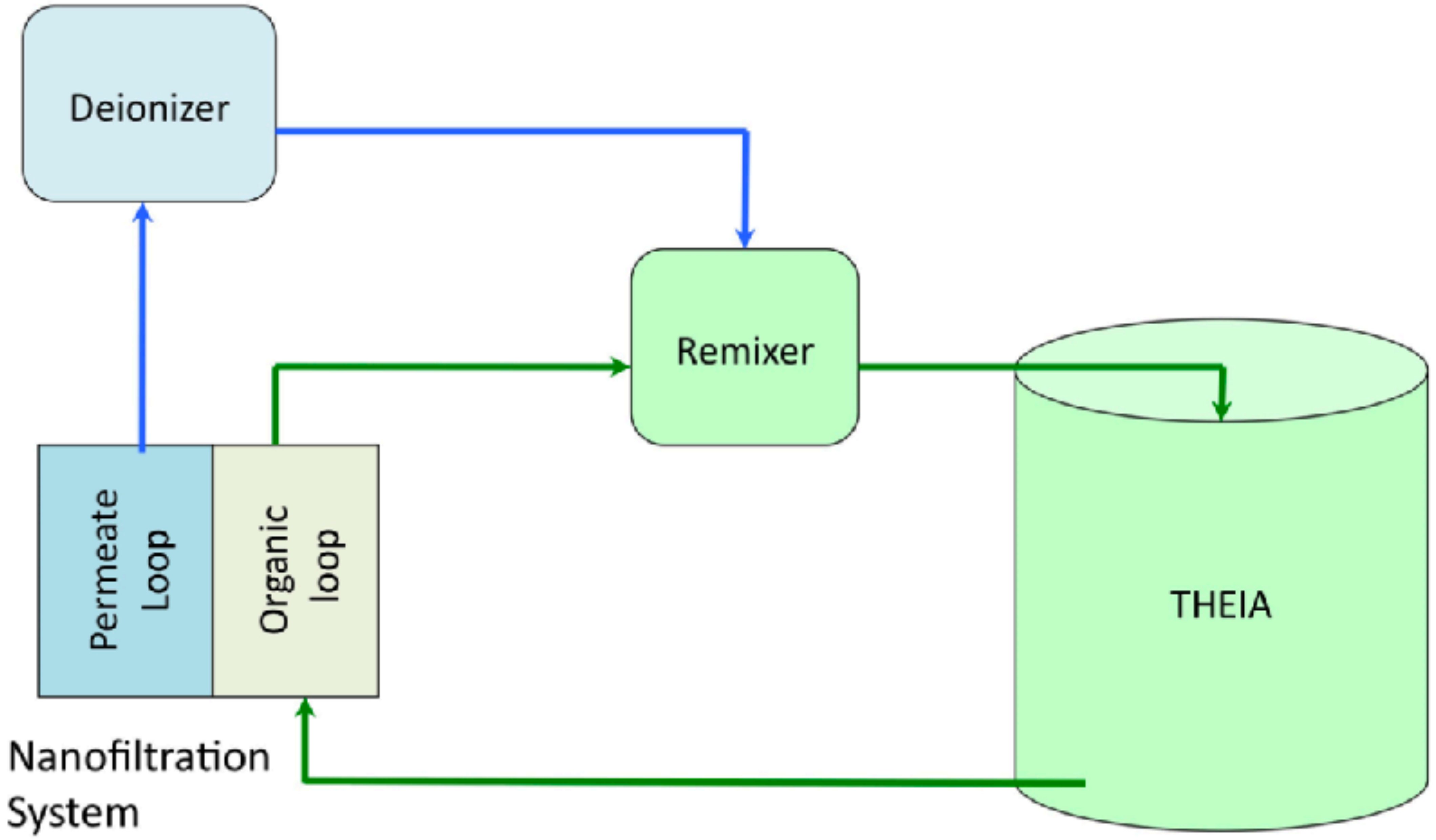
Contaminants such as iron ions degrade optical transparen of water detectors so they need to be constantly purified.

How to do this for WbLS where the organic compounds need to stay in solution?



B. Svobada

One could try and separate the organic and water stream, purify the water stream, then remix.



THEIA recirculation concept

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