

Research and Development Studies for Reactor Neutrino Experiments in Turkey (RNET)

Ayşe BAT | Erciyes University

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Erciyes Neutrino
Research Group

Kayseri, TÜRKİYE

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Bologna | ITALY

Our goals are :

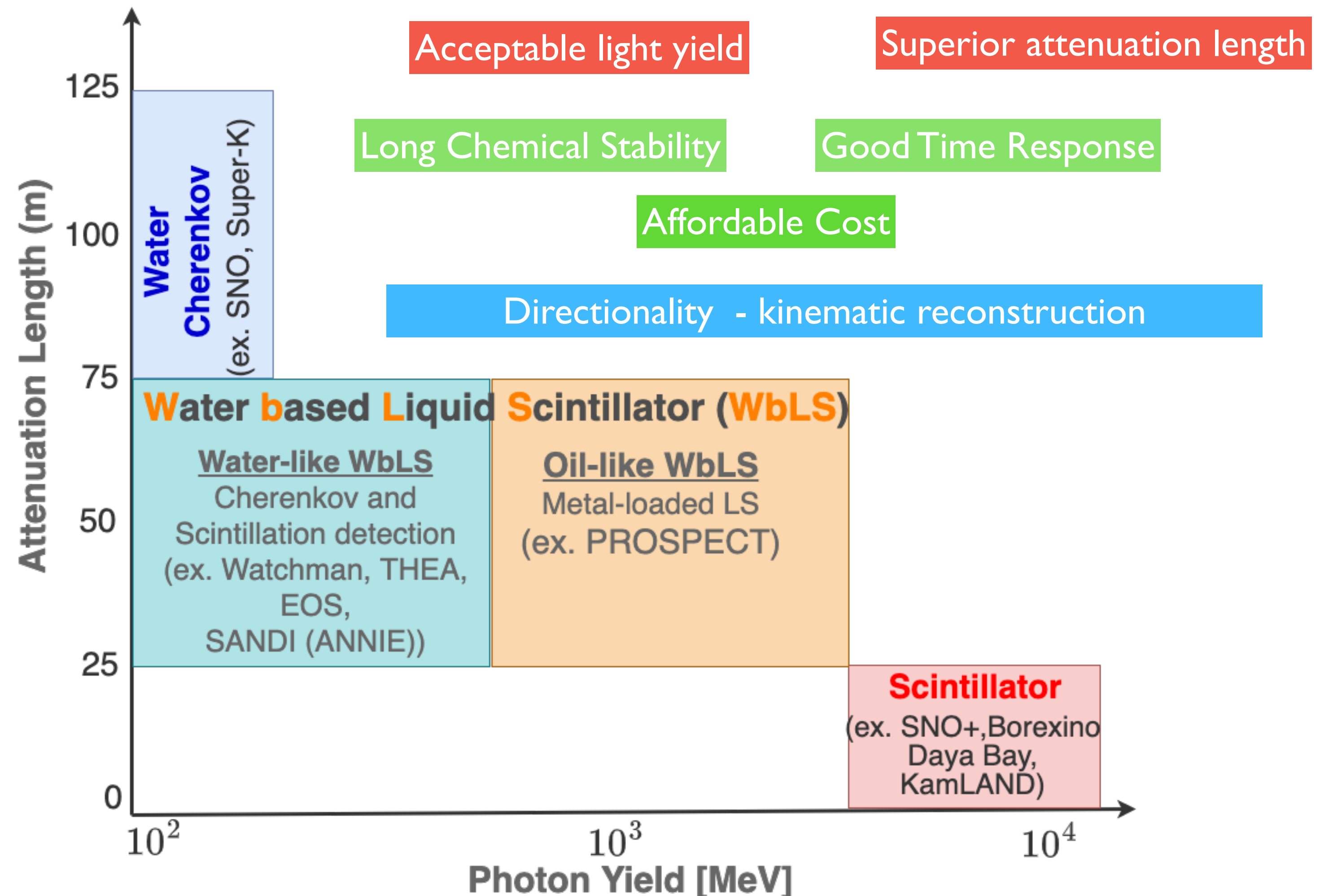
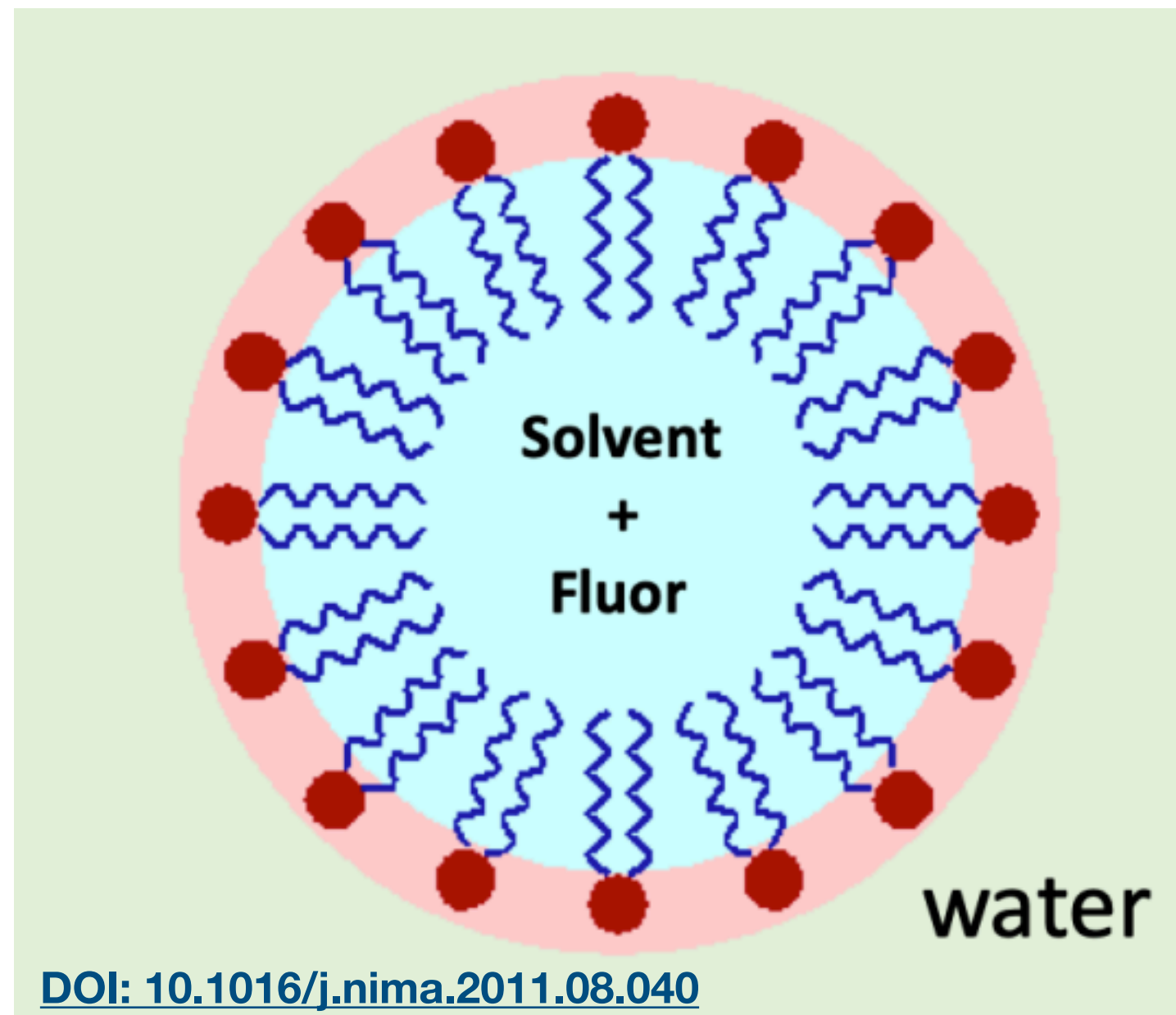
- ▶ Building a 30-ton (in future) and 2-3 ton (near-future) Water-based Liquid Scintillator Detectors (WbLS).
- ▶ Having a portable small-size detector near (100m) the Akkuyu Nuclear Power Plant (ANPP).
- ▶ Building a 30-ton WbLS detector from 1km from the reactor core and 100m underground.
- ▶ Being a testbed for new detector technologies : WbLS, Isotopic Loading (Gd, Li), New Photo-detectors (LAPPDs).
- ▶ Studying low-energy reactor anti-neutrinos with WbLS detector.

What is our motivation?

- ▶ Developing a Research and Development (R&D) program based on neutrino physics in Turkey.
- ▶ In a short term, this detector is aimed to be used as a safeguard monitoring of the Akkuyu NPP.
- ▶ It would be a testbed for new neutrino detection technologies.
- ▶ It also aims to train young researchers in experimental particle and neutrino physics.

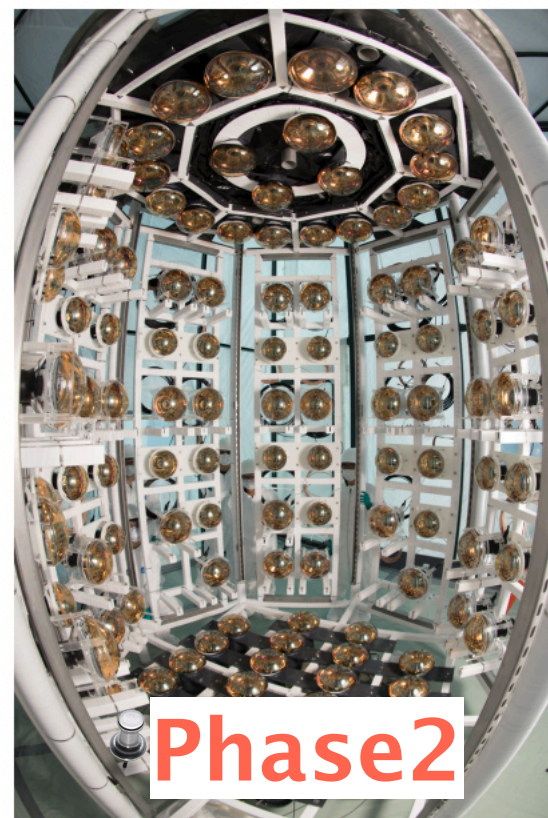
Water Based Liquid Scintillator (WbLS)

Water-based liquid scintillator (WbLS) is a novel scintillation medium, in which scintillating organic molecules encapsulated in surfactant micelles that are thermodynamically stable in water.

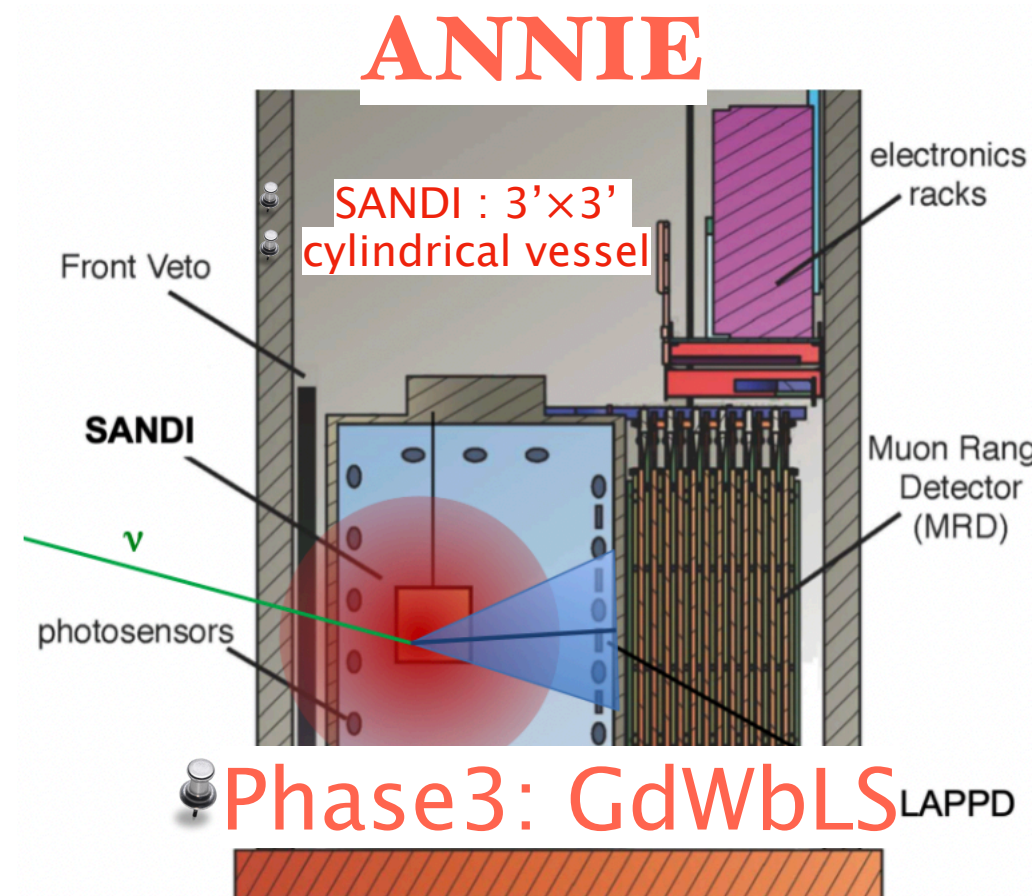


Water Based Liquid Scintillator (WbLS)

Accelerator Neutrino Neutron Interaction Experiment

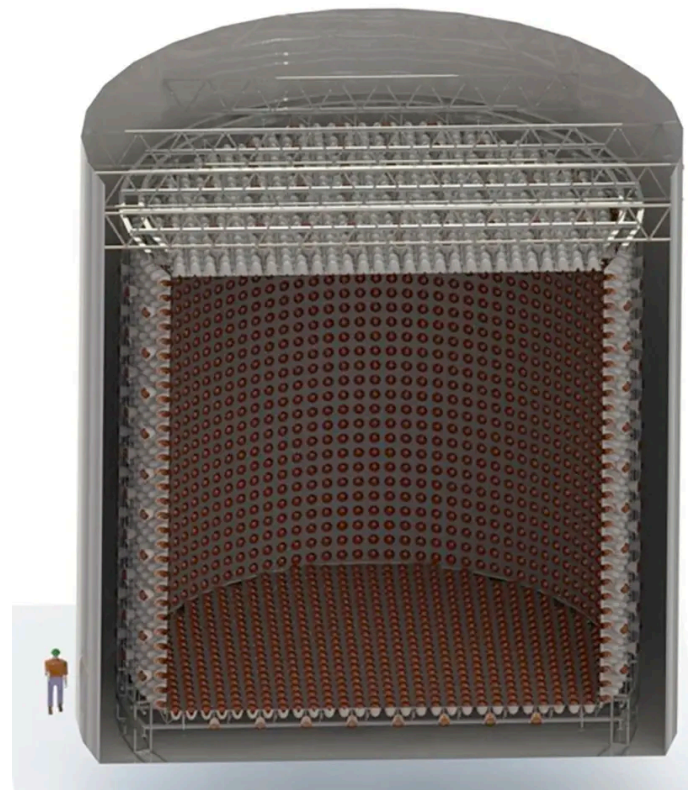


Phase2



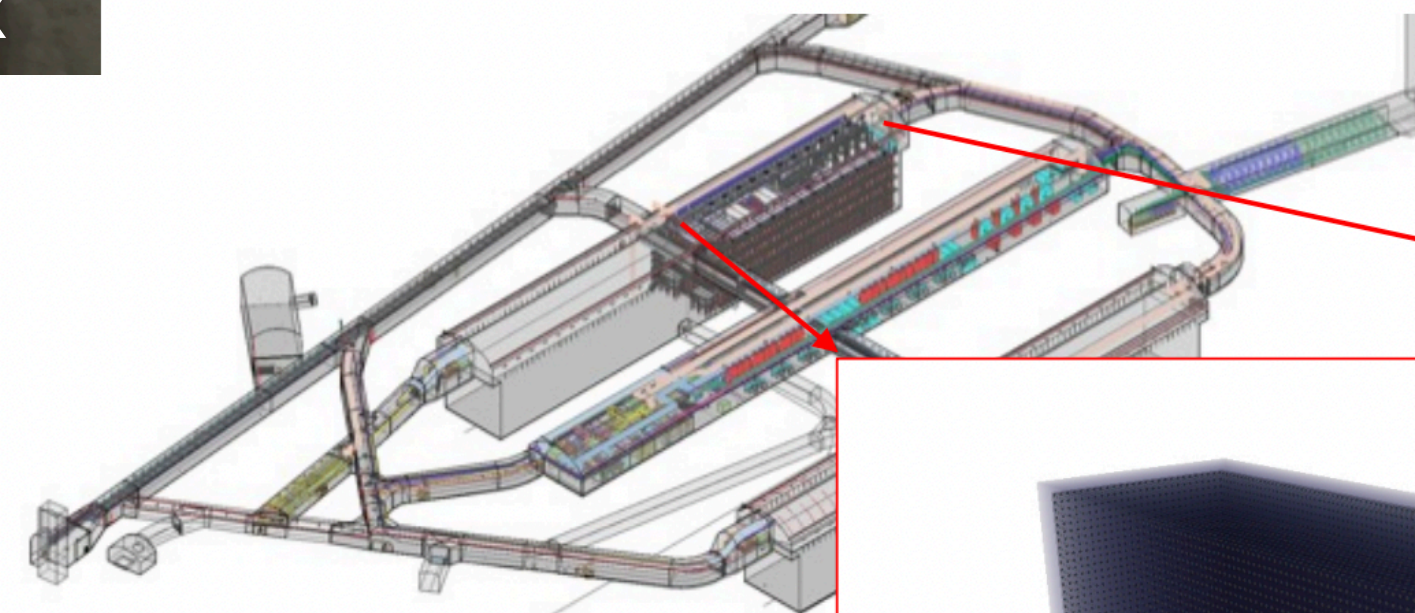
SANDI Box

- 26 ton 0.1% of Gd-Water Cherenkov detector
- Booster Neutrino Beam (93% pure ν_μ) at Fermilab
- First neutrino measurement using LAPPDs.
- First deployment of a small WbLS-filled vessel (SANDI)
- SANDI: Scintillator for ANNIE Neutron Detection Improvement

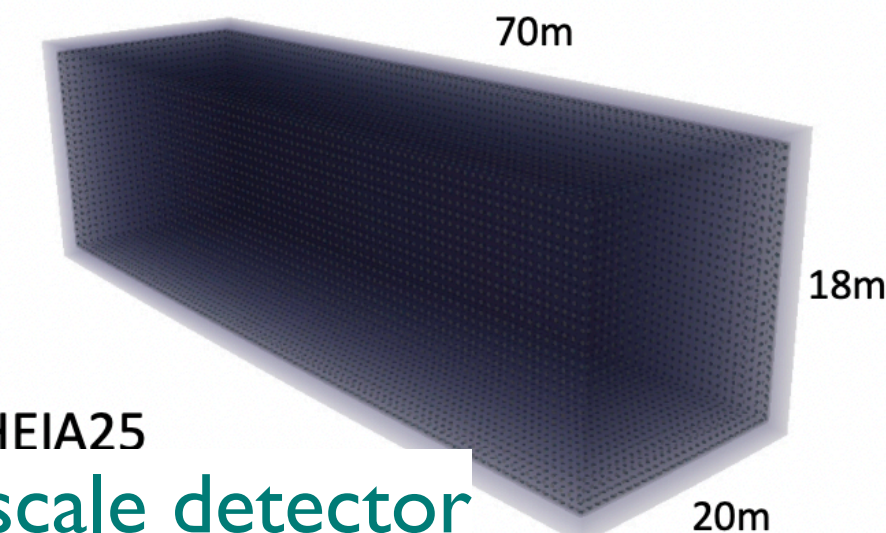


- K-ton scale
 - 21m height
 - 20 m diameter
 - Gd - water Cherenkov detector
 - Phase2 could be the WbLS loaded.
 - 13 km nuclear reactor in the US.
- WATCHMAN**
- Water Cherenkov Monitor for Antineutrinos
- [arxiv: 1502.01132](https://arxiv.org/abs/1502.01132)

- A tonne-scale testbed for hybrid neutrino detector.
- EOS will be constructed at UC Berkeley.
- The detector will consist of a 4-ton acrylic inner vessel filled with WbLS.
- 2024: Data-taking with deployed radioactive source.

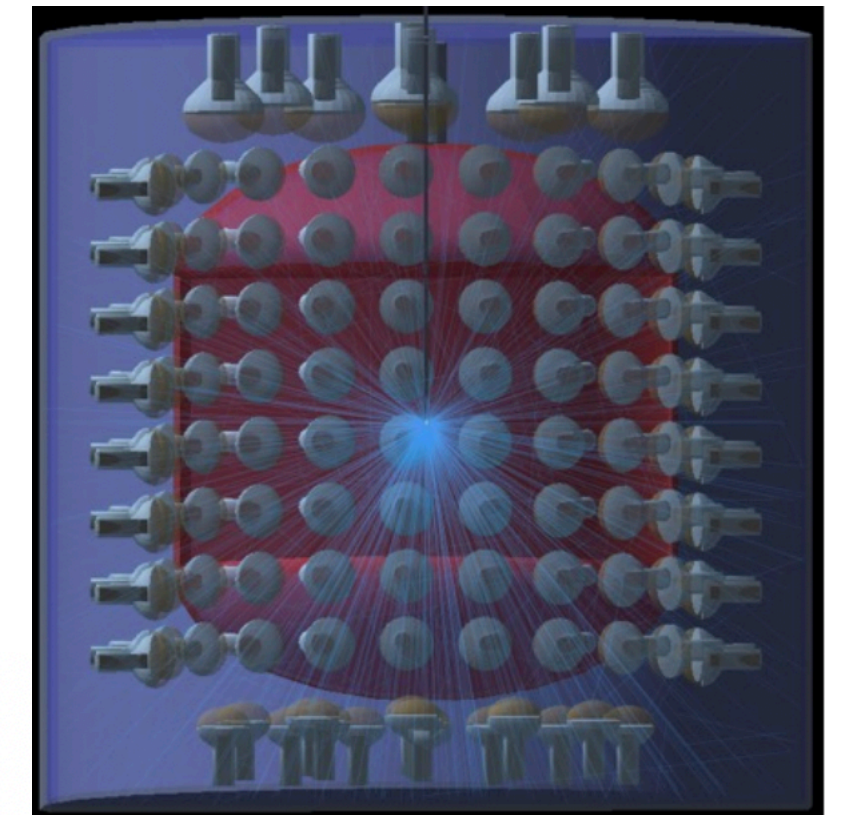


THEIA25

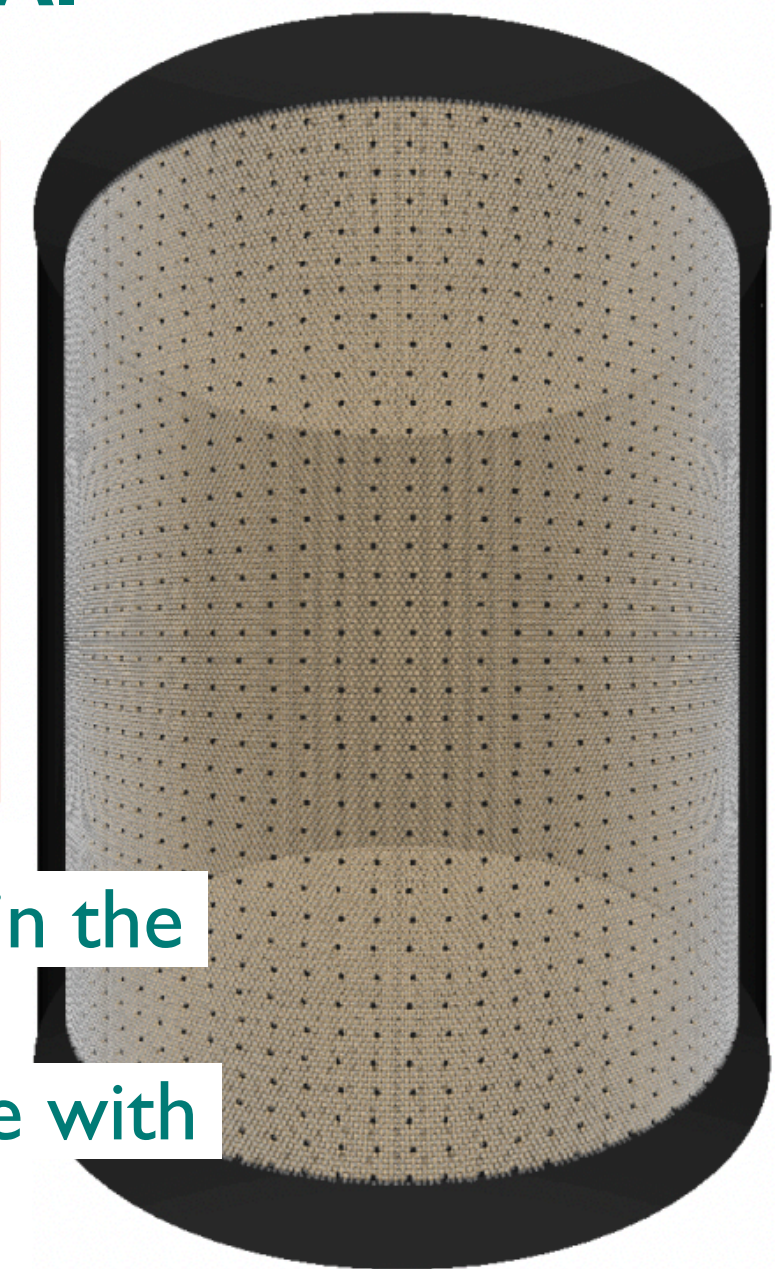


- Future k-ton scale detector
- Hybrid detection technology.
- Theia-25: it is considered to be deployed in the planned one of the four DUNE caverns.
- Theia-100: 10-inch PMTs, and 4% coverage with LAPPDs.

EOS

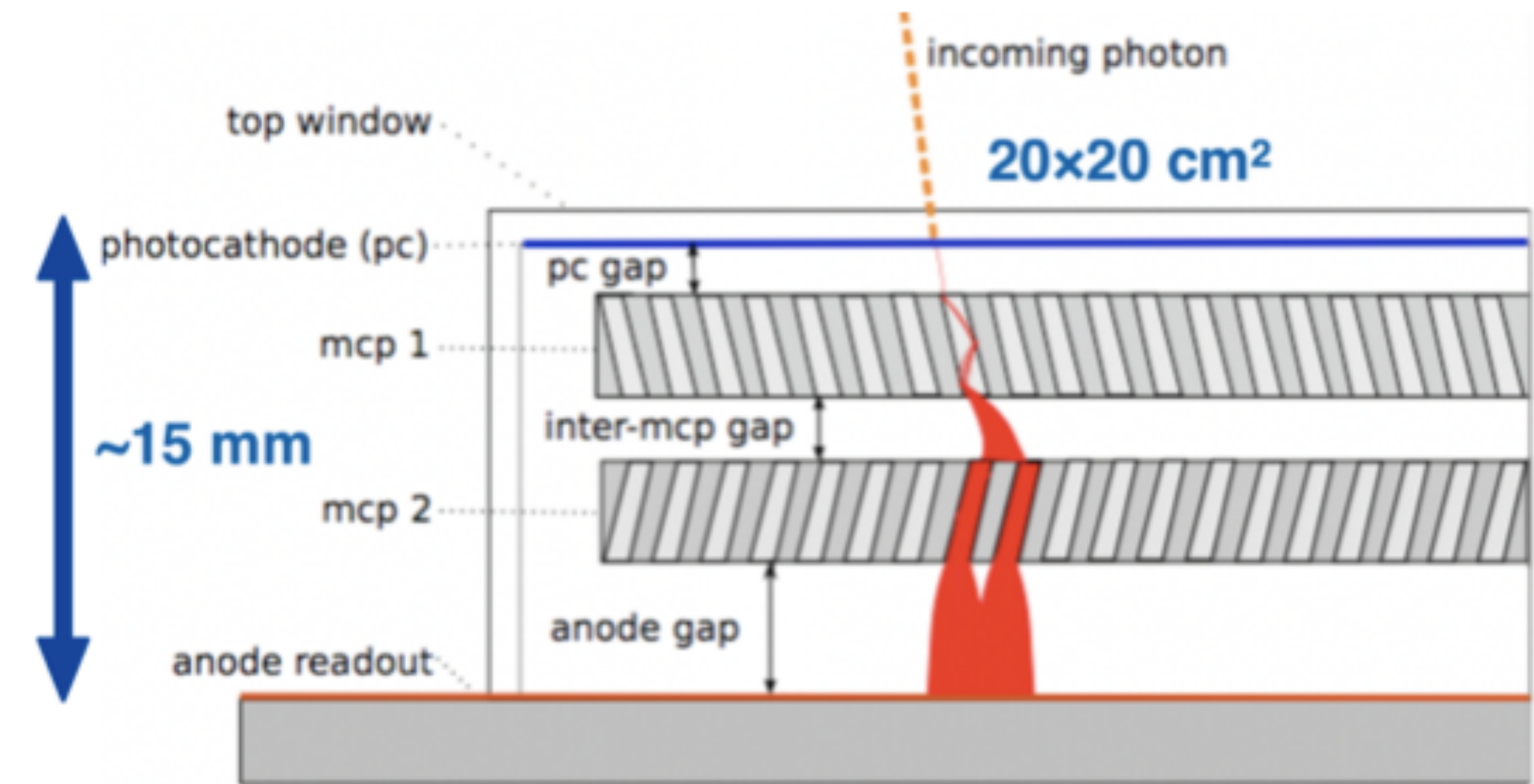
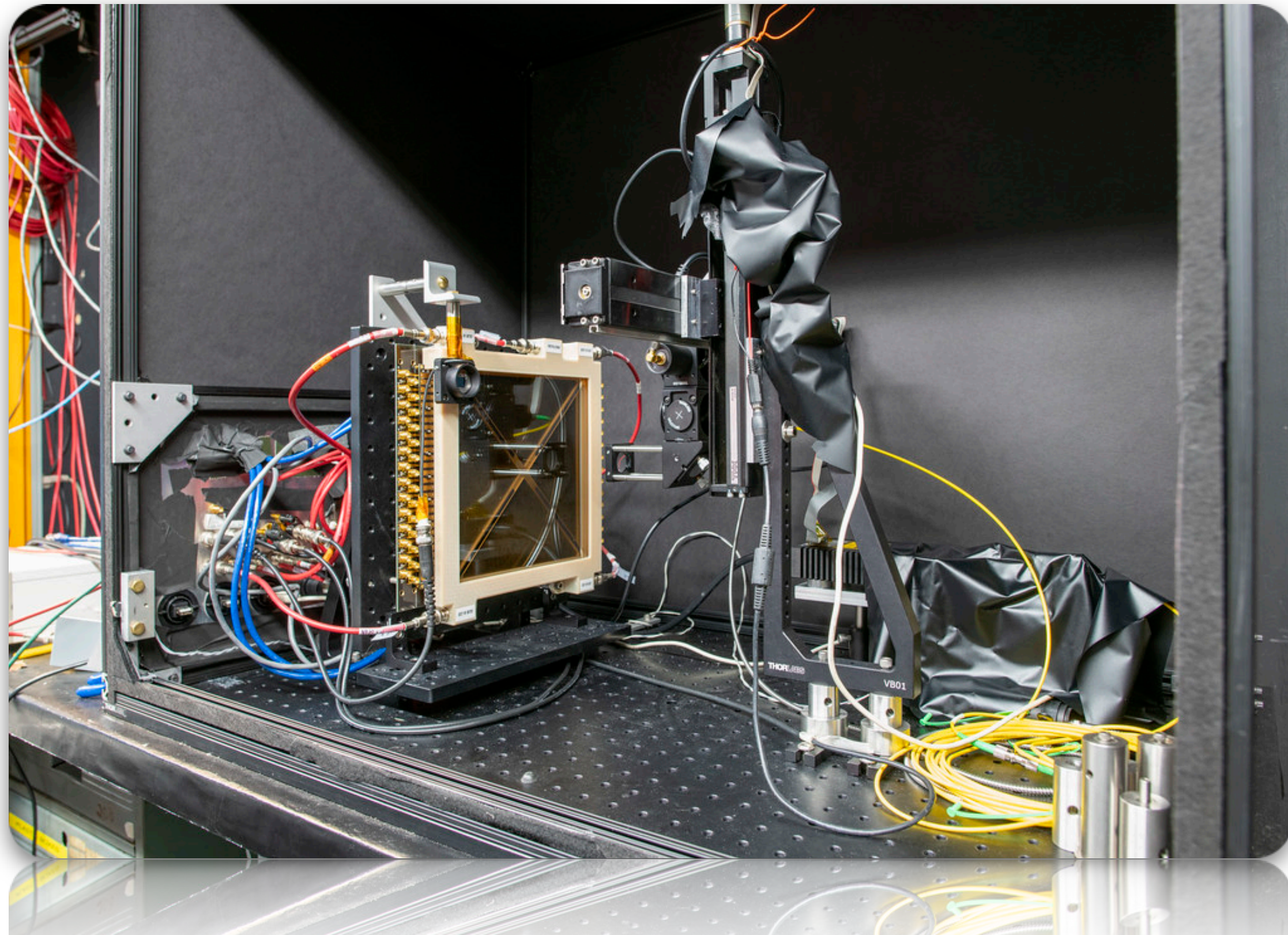


THEAI



Large Area Picosecond Photo - Detector (LAPPDs)

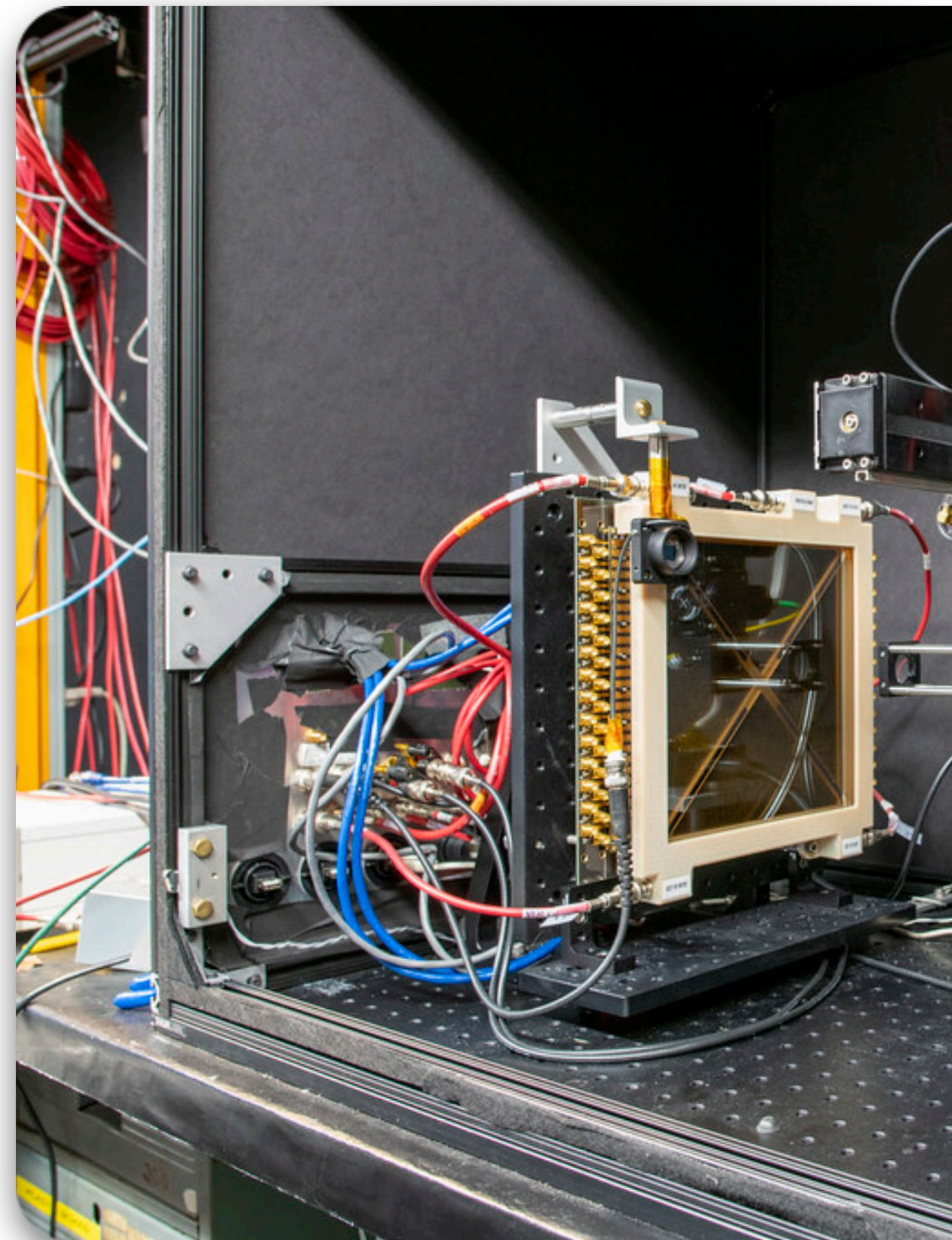
LAPPDs are MCP-based imaging and timing photo-sensors with a spatial resolution of <1 cm across the strip and <5 mm along the strip.



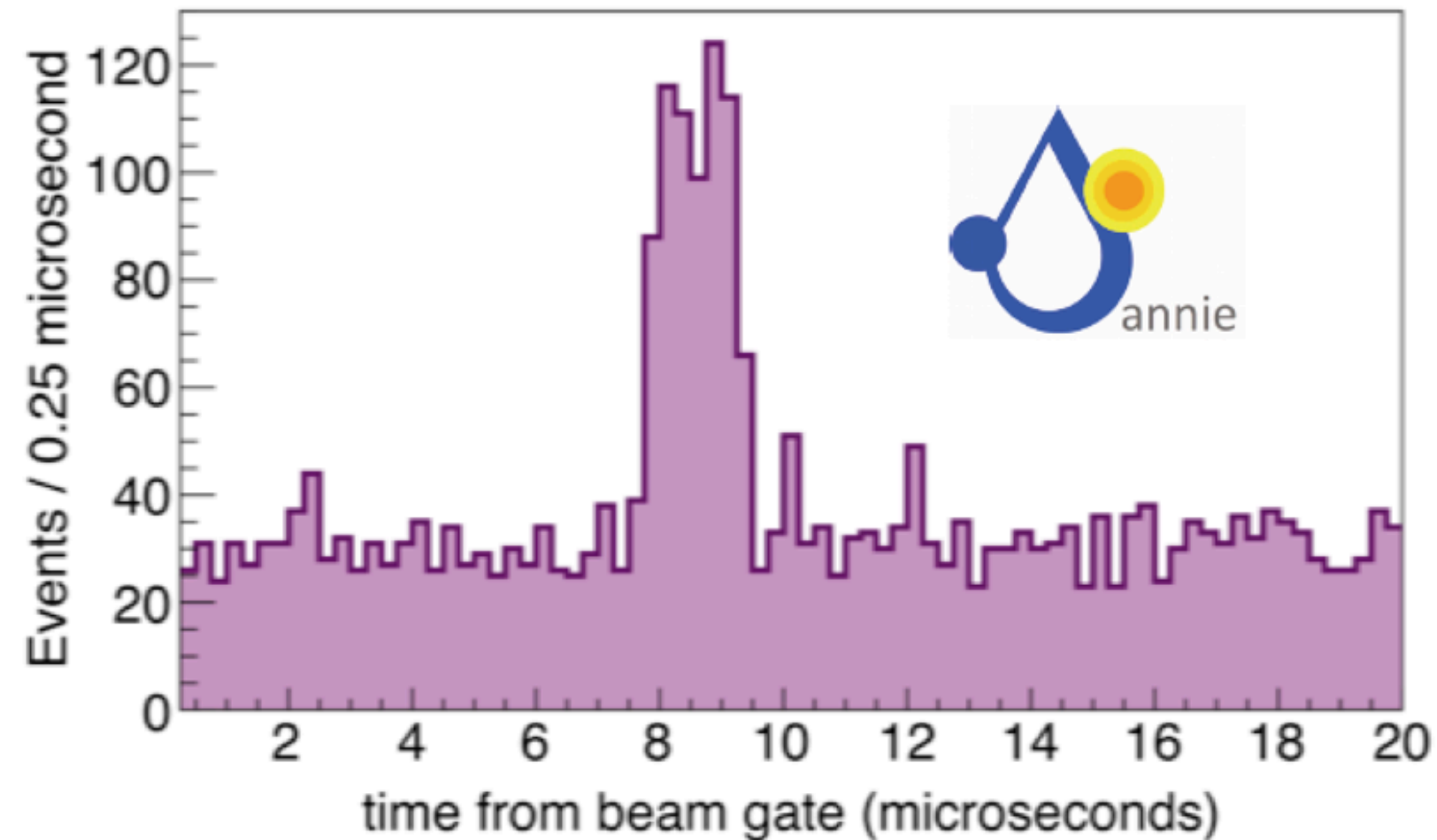
- ▶ Quantum Efficiency (QE) is more than 20%.
- ▶ Timing resolution is less than 60 psec.
- ▶ Fast timing: better vertex reconstruction, improved background rejection and energy reconstruction in higher energy beams ...
- ▶ Imaging: each photon is reconstructed by a location and time, finer granularity ...

Large Area Picosecond Photo Detector (LAPPDs)

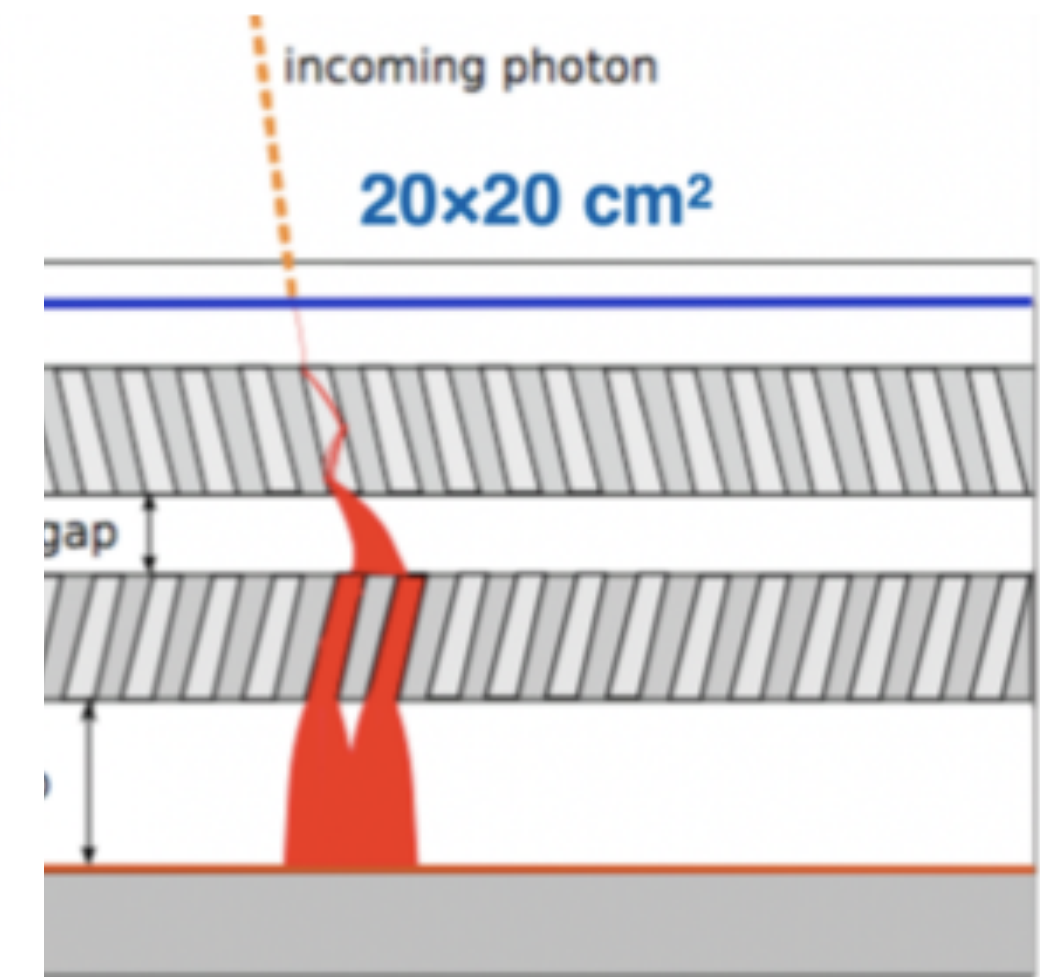
LAPPDs are MCP-based photo-sensors with a 5 cm across the strip and



Neutrinos with LAPPDs



Status of the ANNIE experiment - Michael Nieslony - 07 June 2022 - 11:45 AM

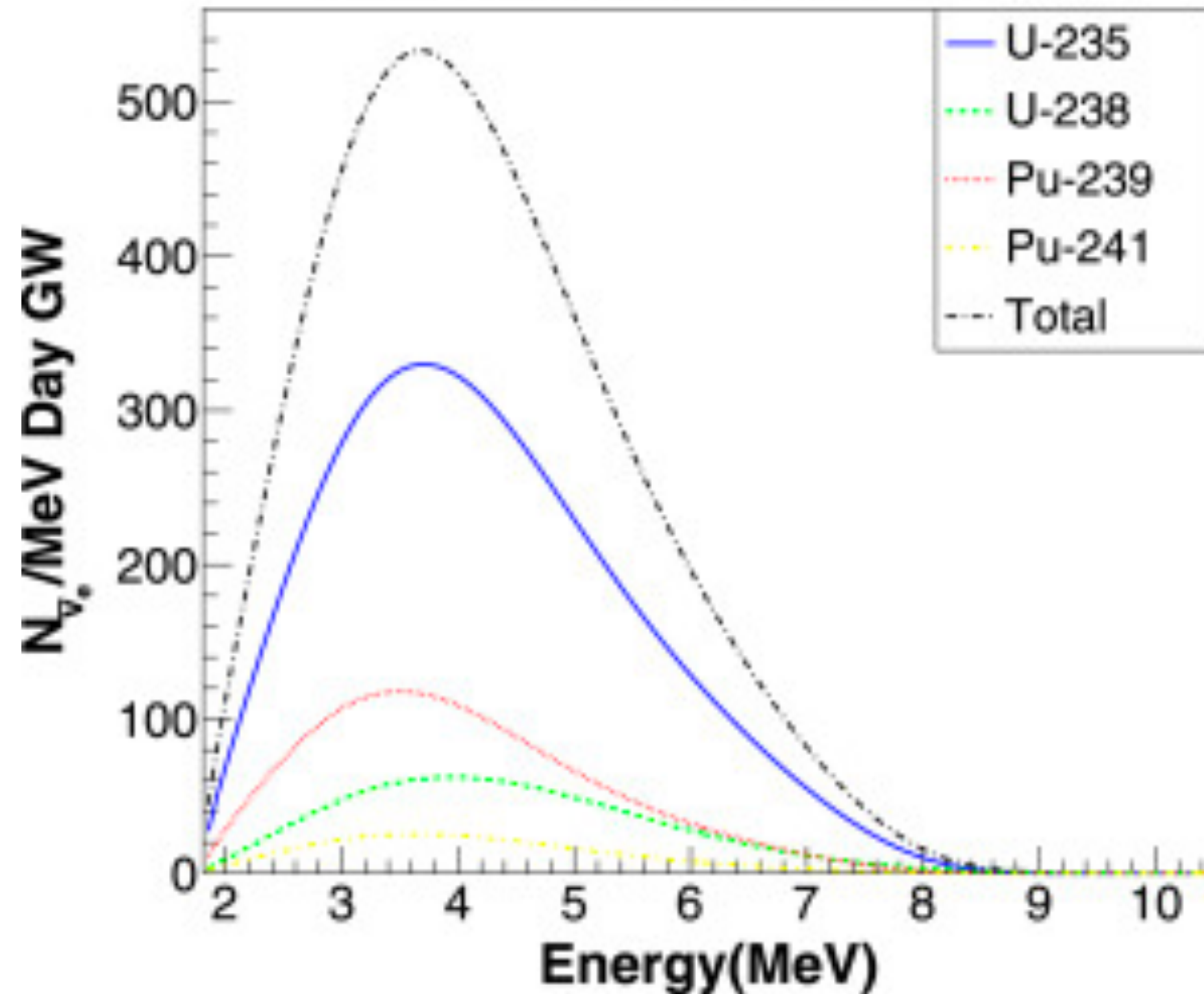


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► Imaging: each photon is reconstructed by a location and time, finer granularity ...

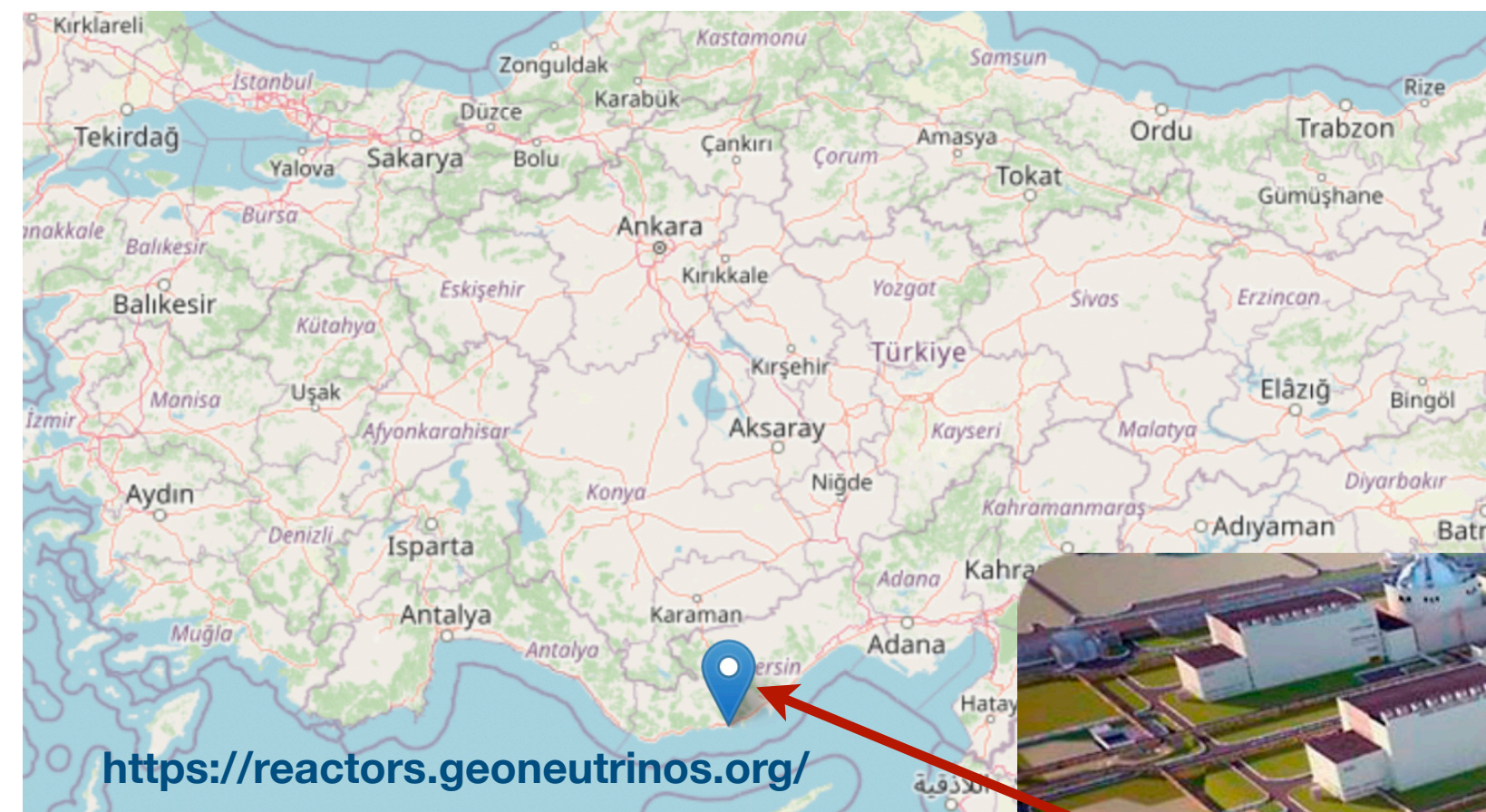
Akkuyu Nuclear Power Plant (ANPP)

Expected $\bar{\nu}_e$ energy spectra



- $\bar{\nu}_e$ are emitted from subsequent β -decays fission products.
- They are dominated by 4 isotopes ^{235}U , ^{238}U , ^{239}Pu , ^{241}Pu .
- Average 6 $\bar{\nu}_e$ released.

Each nuclear reactor is a very powerful source of antineutrinos, and researchers worldwide investigate the possibilities of using antineutrinos for reactor monitoring.



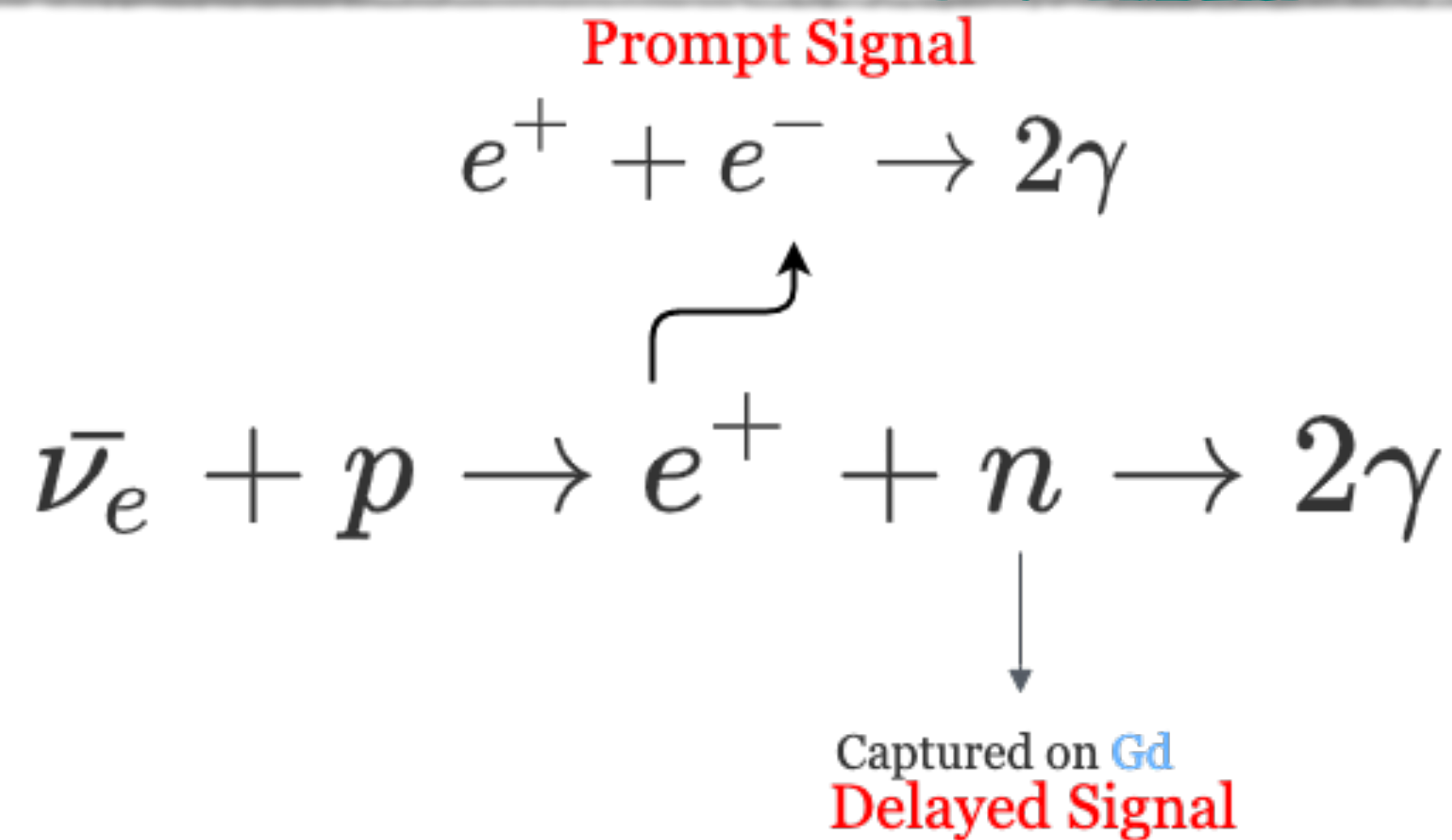
Nuclear reactors are one of the major sources of human-generated antineutrinos.

- Akkuyu nuclear power plant is comprised of four power units with VVER-1200 reactors with a total capacity of 4800 MW on the southern coast of Turkey in Mersin province.

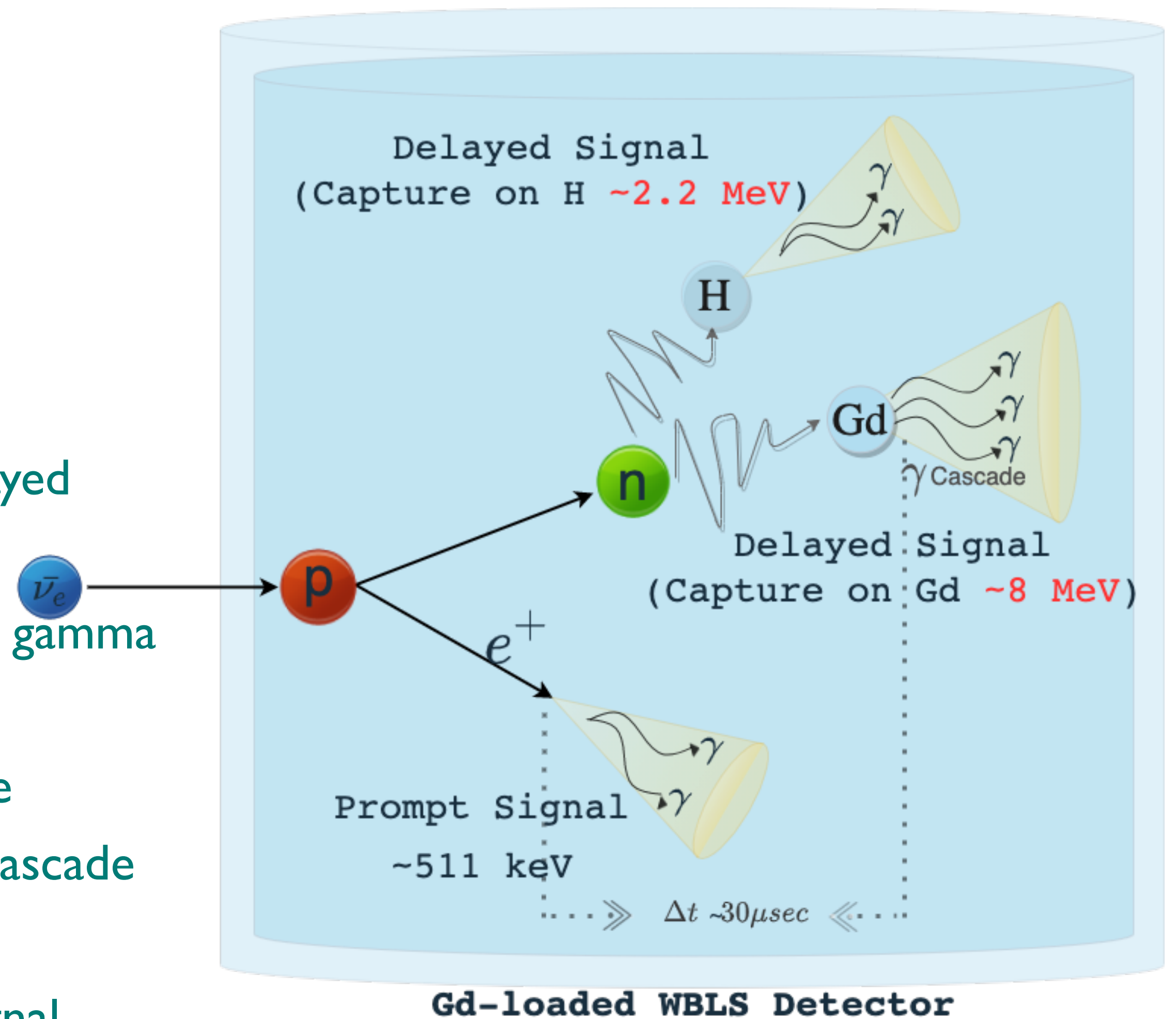
- It is being planned to be put into operation in **2023**.



Inverse Beta Decay (IBD) Events



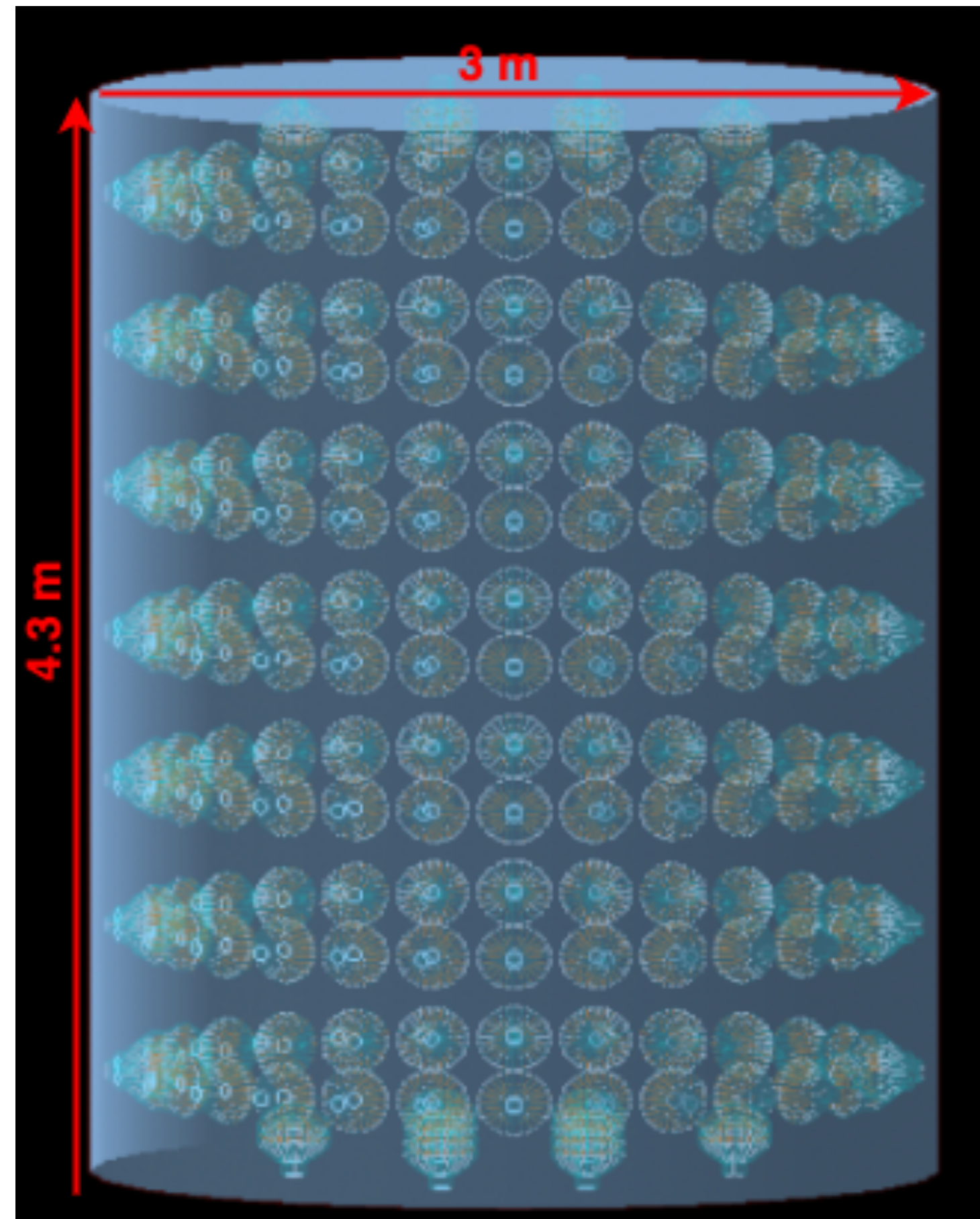
- IBD releases two distant signals; 1) prompt signal and 2) delayed signal.
- Prompt Signal: Positron annihilates with an electron, and two gamma photons are produced (511 keV)
- Delayed Signal: Neutrons are thermalized and captured by the Hydrogen atoms or Gadolinium atoms and release a gamma cascade at ~2.2 MeV or ~8 MeV, respectively.
- These two signals distinguish in the time since the second signal occurs in tens of microseconds (~30-40 micro sec.)



30 - ton WbLS Far Detector Design

Water-based Liquid Scintillator detector as a new technology testbed for neutrino studies in Turkey

V.Fischer, E. Tiras (NIM-A.2020.163931)

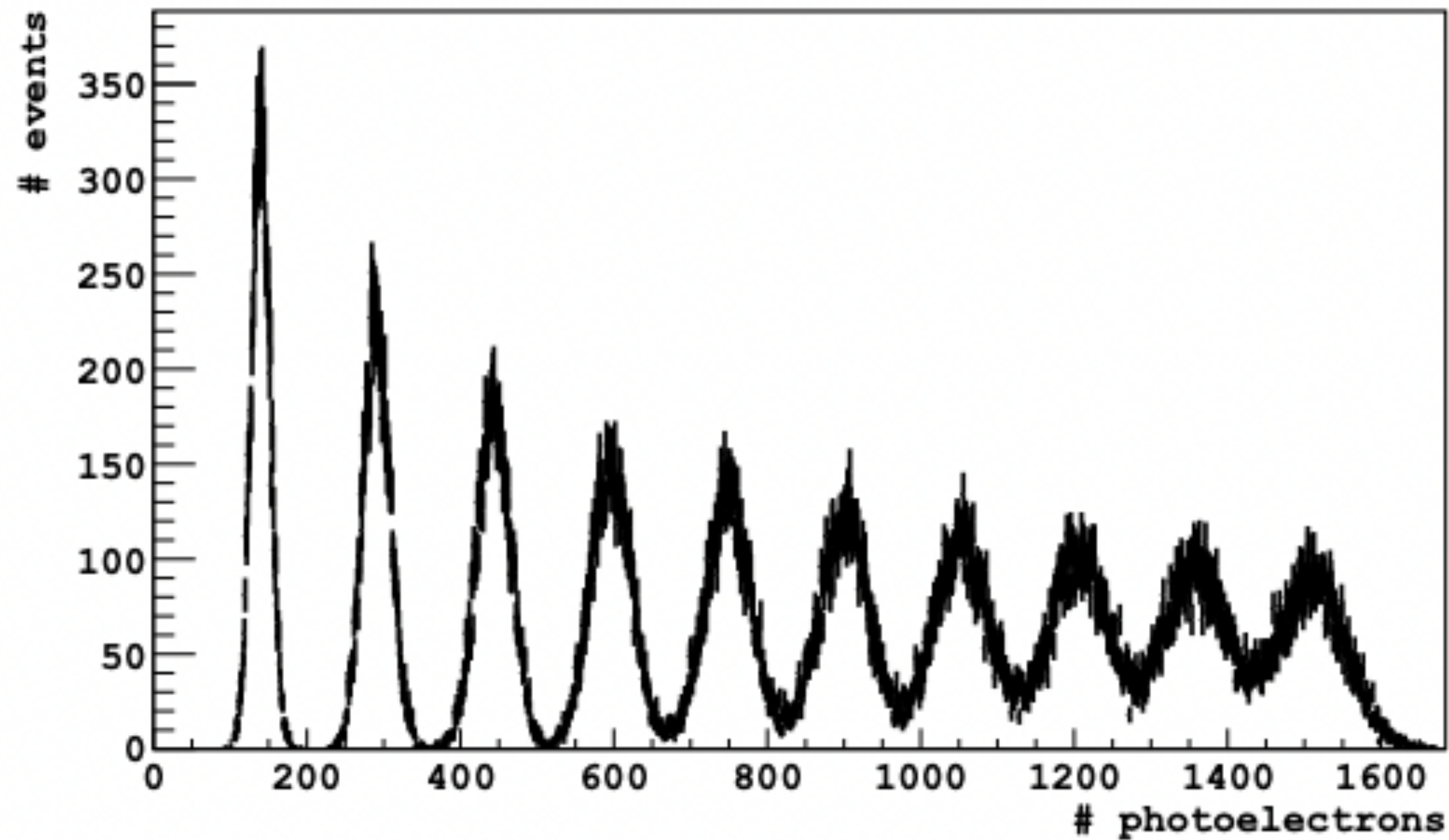


30 ton WbLS detector

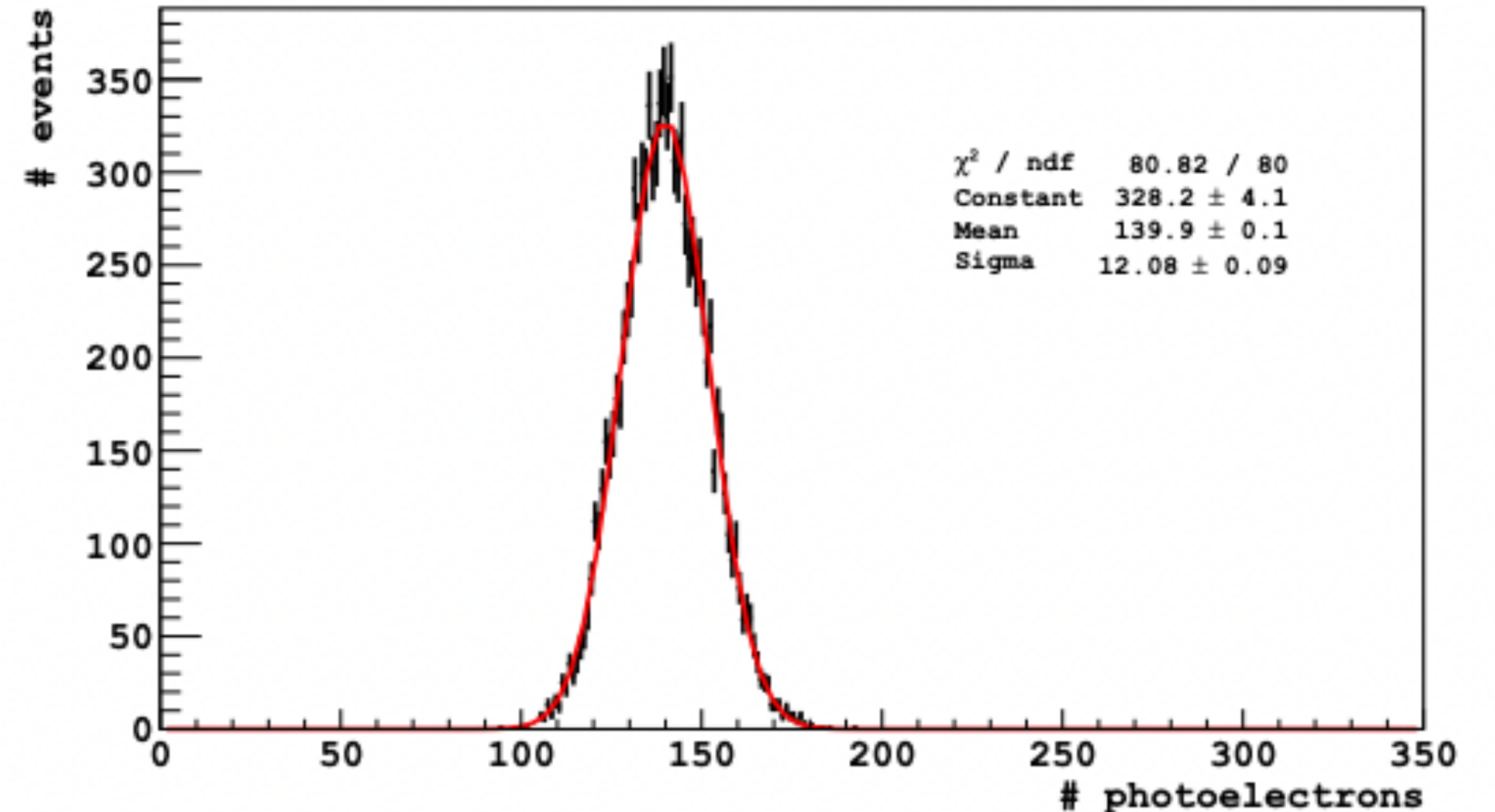
RAT-PAC Simulation

- ✓ RATPAC (Reactor Analysis Tool Plus Additional Codes) is a simulation and analysis package built with GEANT4, G4GLsim, ROOT, and C++
- The detector consists of a 30-ton cylindrical volume, 4.3 m high and 3 m in diameter.
- Filled with Water-based Liquid Scintillator with a 10 % liquid scintillator content and a gadolinium loading of 0.1%Gd.
- Instrumented with 227 10-inch High Quantum Efficiency PMTs.
- Providing a total photo-coverage of around 30%.
- Planned to be installed underground (100 meters) and 1 km away from the reactor core.
- All simulations were performed using the GEANT4-based RAT-PAC simulation package.

30 - ton WbLS Far Detector Simulation Results



Photoelectron distribution of electrons generated at the center of the detector with energies ranging from 1 to 10 MeV in increments of 1 MeV

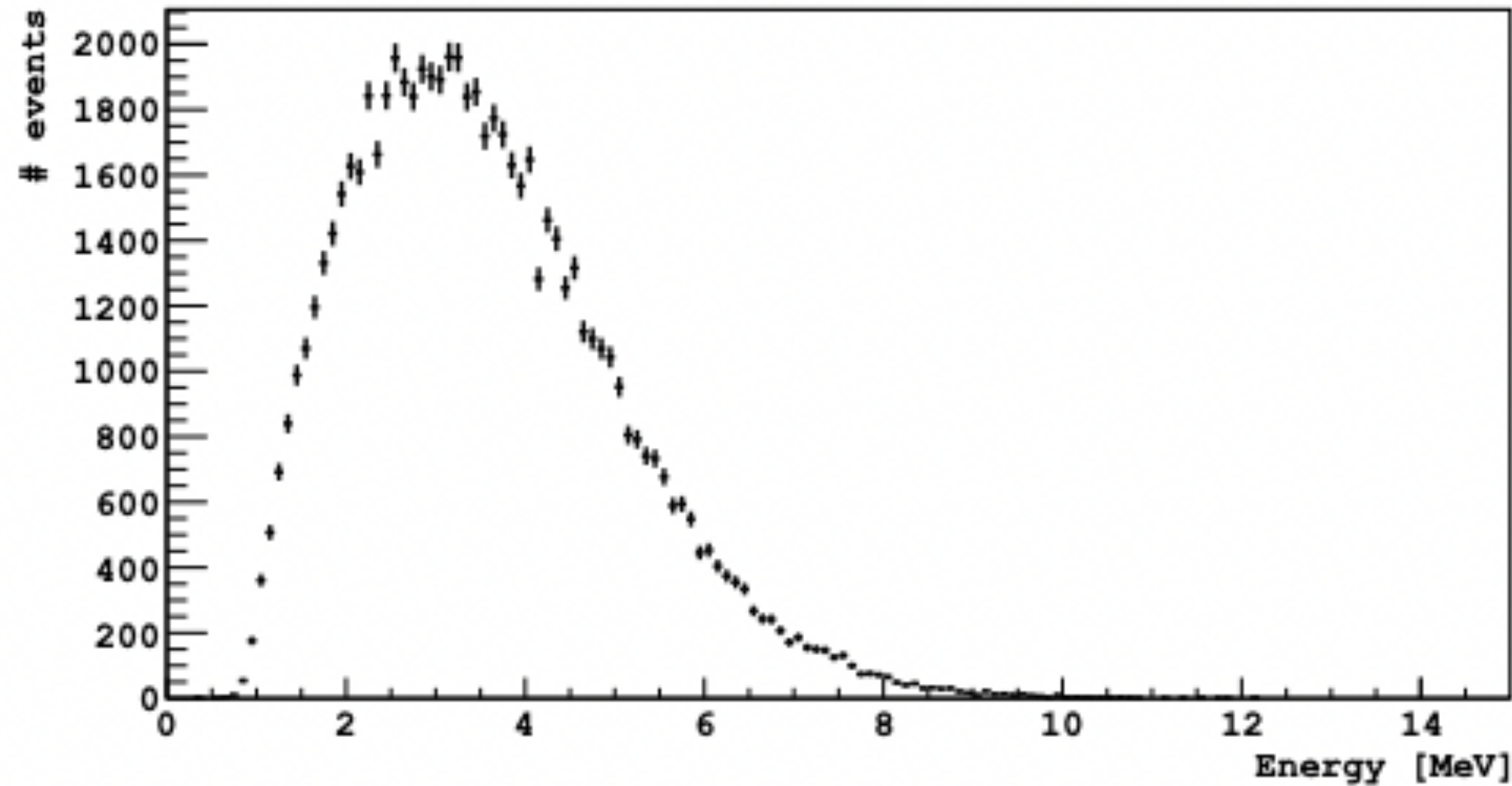


Photoelectron distribution of 1 MeV electrons generated at the center of the detector and fitted with a Gaussian distribution.

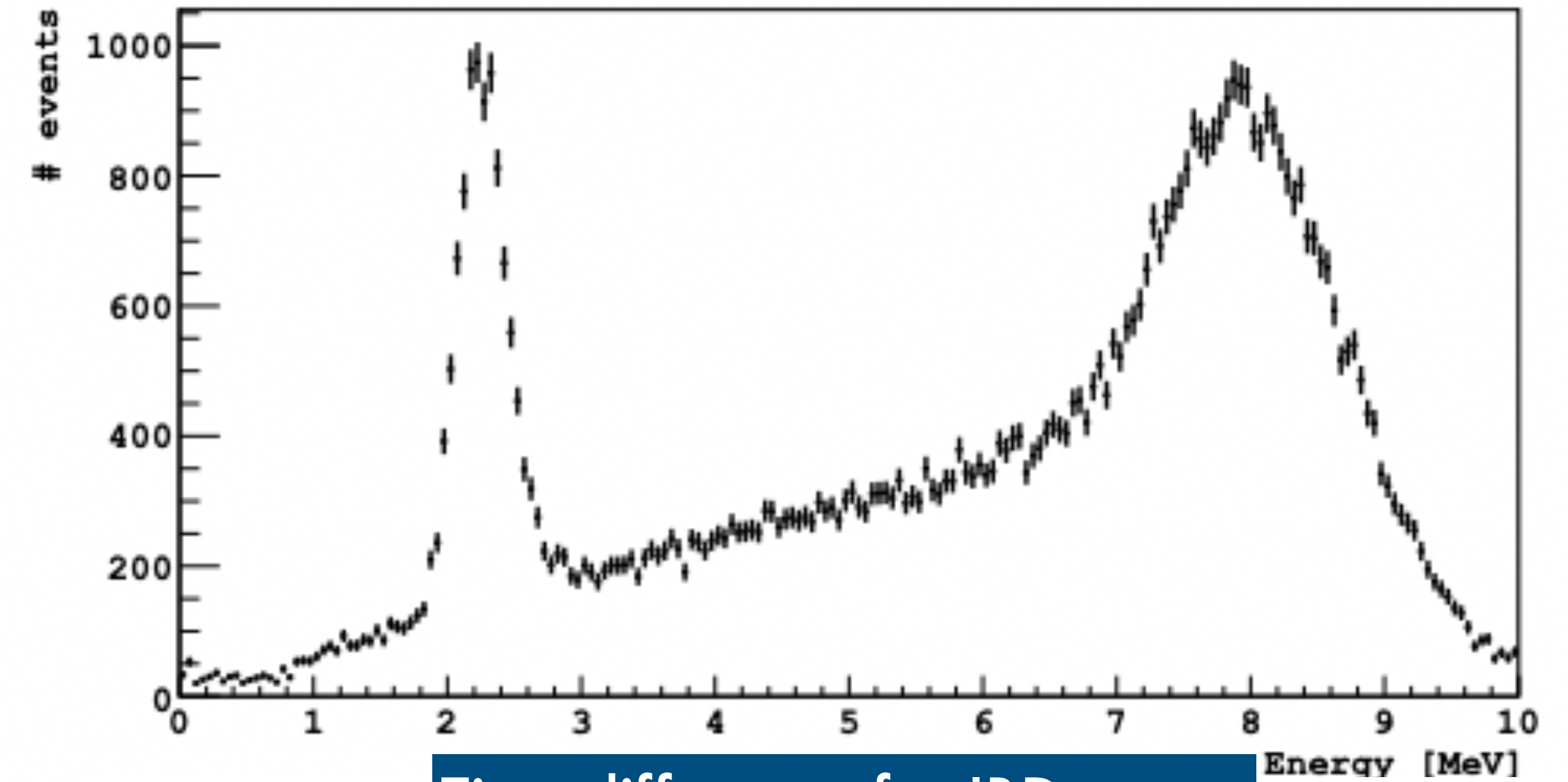
- To understand the detector response and assess its efficiency to detect reactor neutrinos, we simulated Inverse Beta Decay (IBD) events in the entire detector volume.
- The conversion between deposited energy and the number of photoelectrons detected by the PMTs was established from simulations of electrons at the center of the detector.

30 - ton WbLS Far Detector Simulation Results

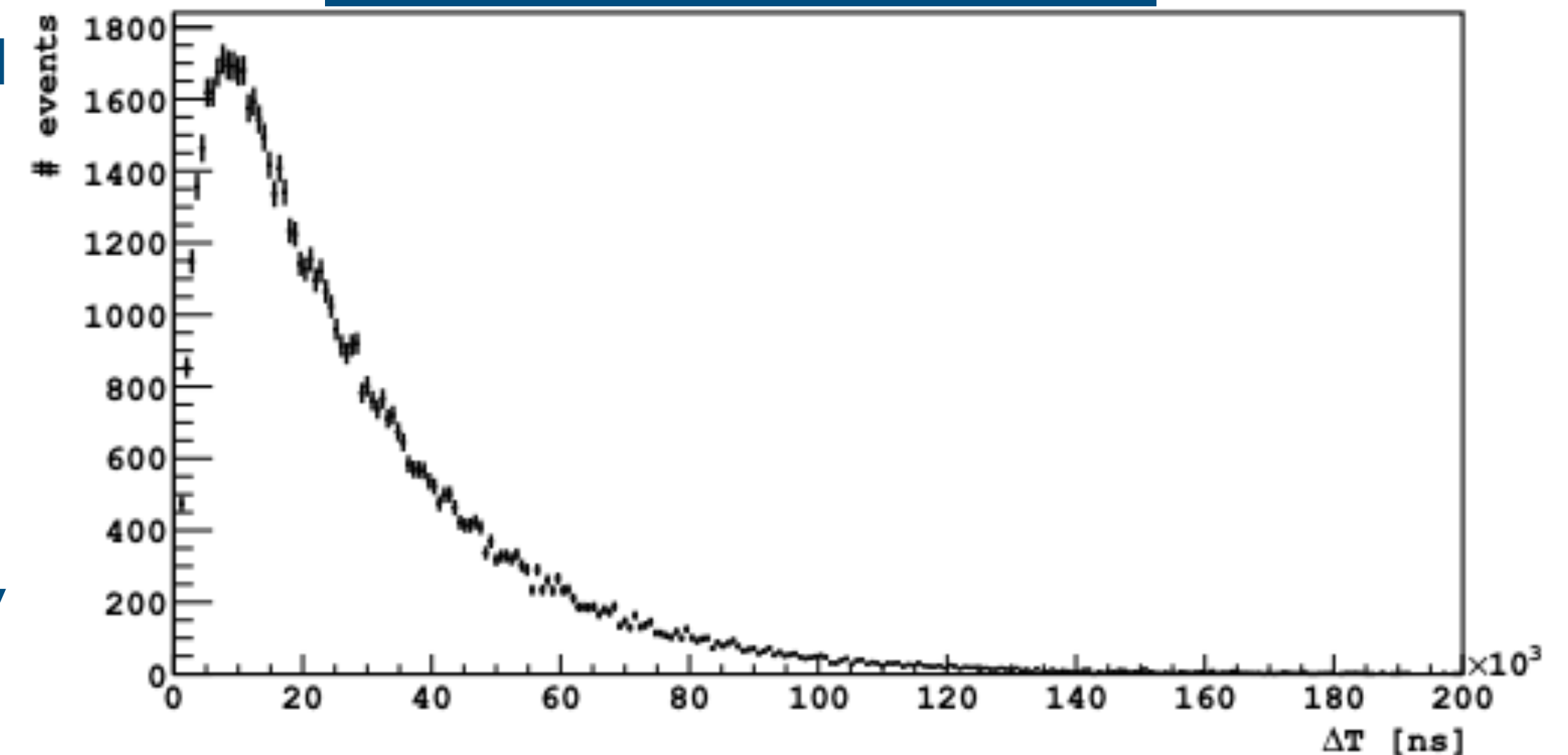
Reconstructed prompt energy distribution



Reconstructed delayed energy distribution



Time difference for IBD events

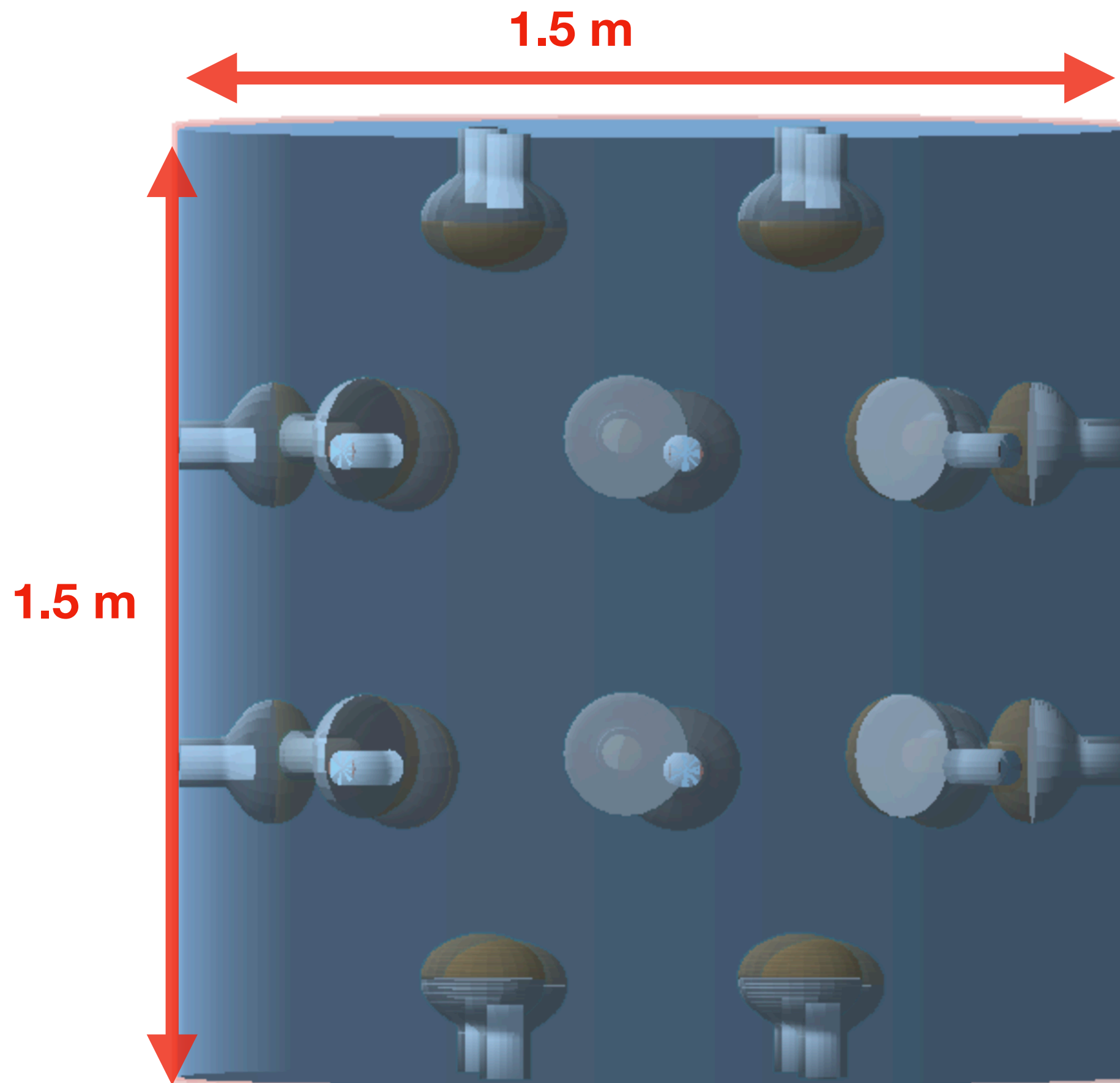


- ✓ The prompt energy corresponds to the visible energy deposited by positrons in the detector.
- ✓ The delayed energy distribution peaks at:
 - ★ 2.2 MeV from neutron capture on Hydrogen.
 - ★ 8 MeV neutron capture on Gadolinium
- ✓ The time differences between prompt and delayed events follow an exponential distribution with $24\mu s$ mean decay time.

~3ton - WbLS Compact Detector Design

Low Energy Neutrino Detection with a Portable Water-based Liquid Scintillator Detector

A.Bat, E.Tiras, V.Fischer, M.Kamislioglu (arXiv:2112.03418, Under Review in EPJ-C)



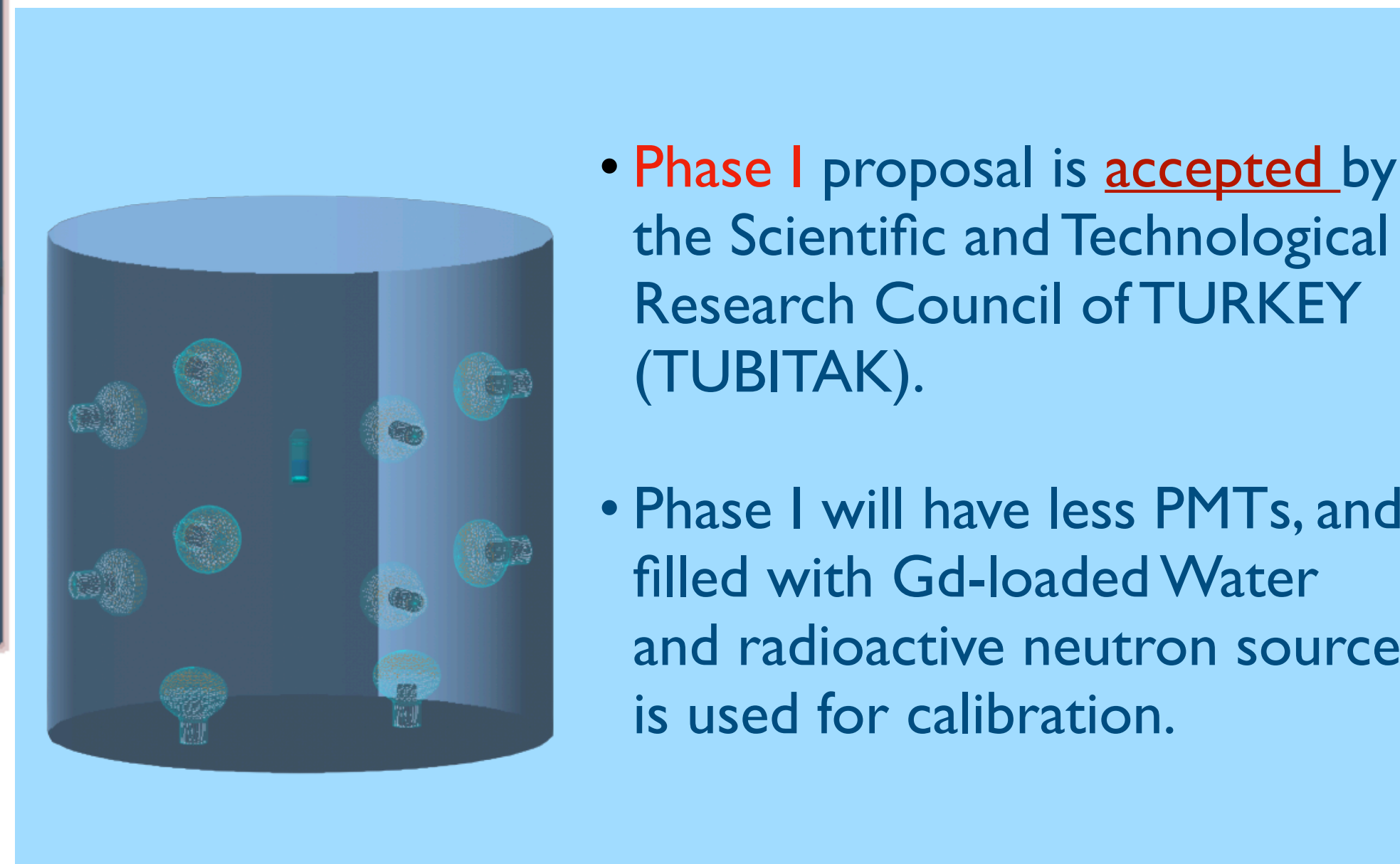
✓ The detector is a 1.5-m high and 1.5-m wide cylindrical stainless steel tank, and filled with WbLS.

✓ 24 8-inch R5912 HQE PMT are placed.

✓ 8 of them are placed on the top and bottom of the detector.

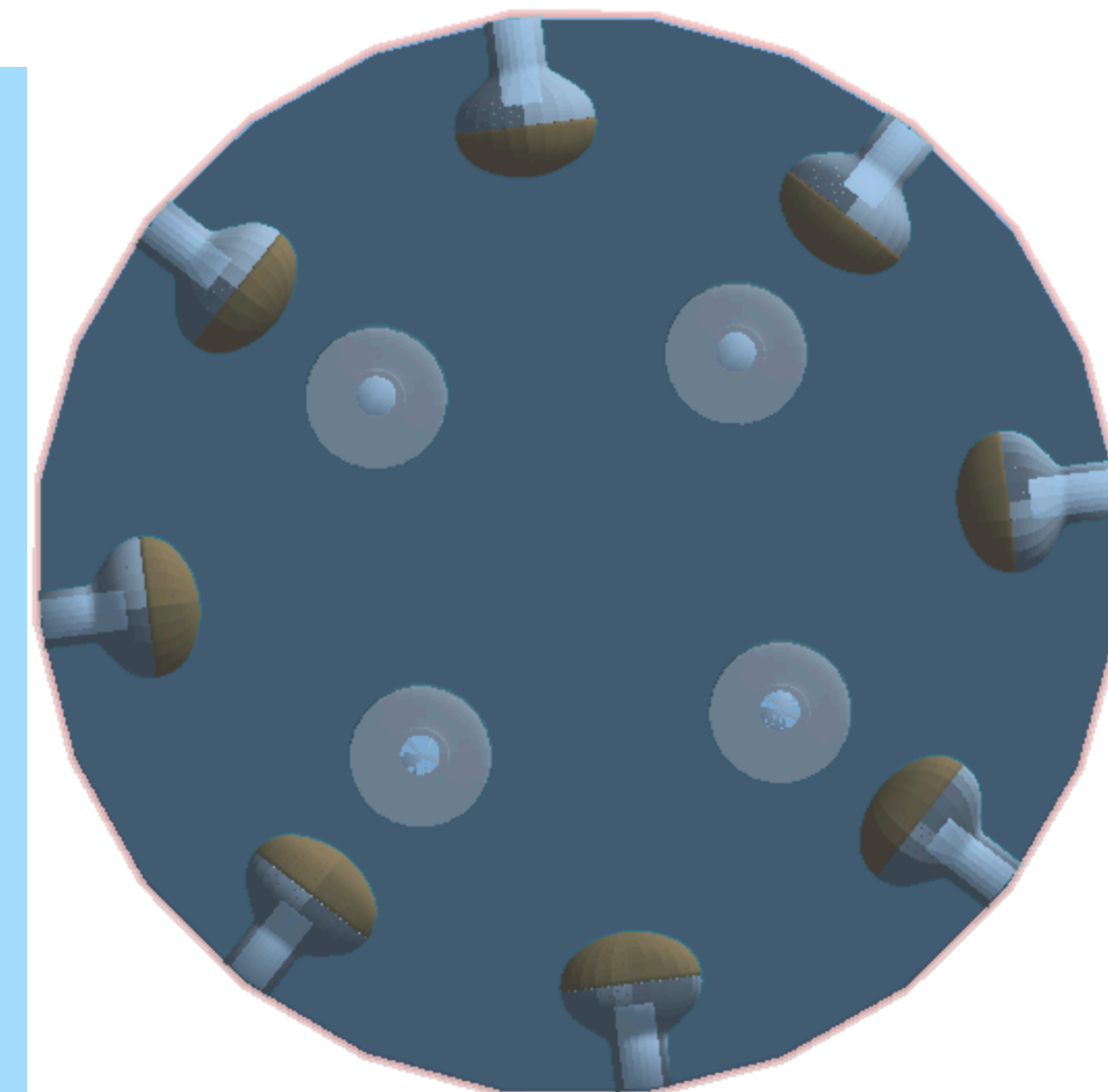
✓ 16 of them are placed on the side walls.

✓ ~28% Photo Coverage.



- **Phase I** proposal is accepted by the Scientific and Technological Research Council of TURKEY (TUBITAK).

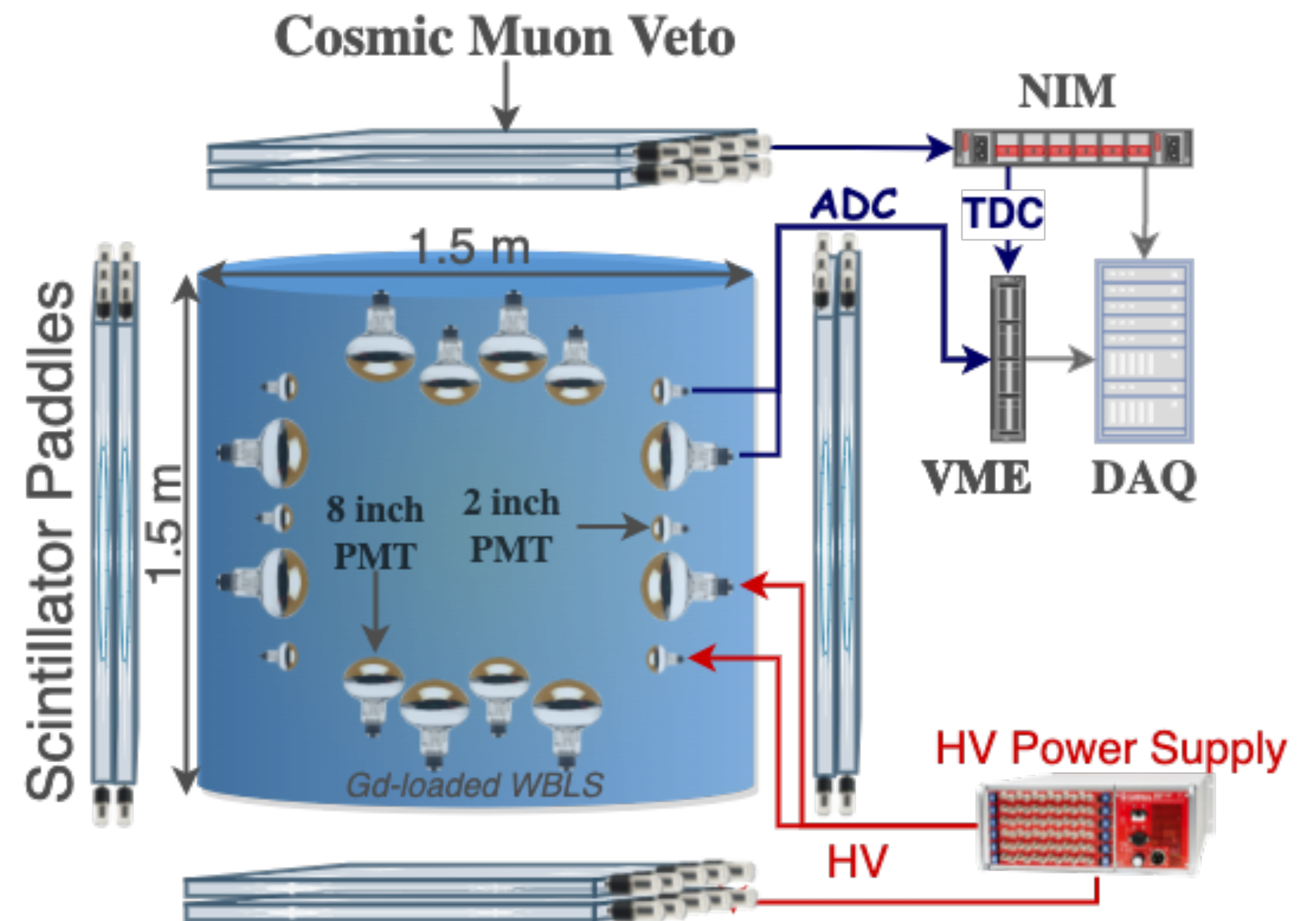
- Phase I will have less PMTs, and filled with Gd-loaded Water and radioactive neutron source is used for calibration.



TOP VIEW

~3ton - WbLS Compact Detector Design

- ✓ A 2-3 ton portable WbLS detector designed near the Nuclear Power Plant.
- ✓ The whole detector system consists of 3 main parts:
 - ▶ A stainless steel tank filled with WbLS and covered with PMTs.
 - ▶ Cosmic Muon Veto (2 layers of 4-inch wide plastic scintillators).
 - ▶ Electronics and DAQ system. (Purchased and obtained from another project.)
- ✓ Inside the WbLS volume, 8-inch and 2-inch HQE PMTs are placed homogeneously.
- ✓ PMT signals will be digitized by VME ADCs.
- ✓ Cosmic Muon Veto signals will be digitized by NIM and CAMAC electronics.
- ✓ Digitized signals will be recorded by a custom DAQ system.



~3 - ton WbLS Compact Detector Simulation Results

Photo-electron distributions of prompt energy for several WbLS cocktails (1%, 3%, and 5% LS)

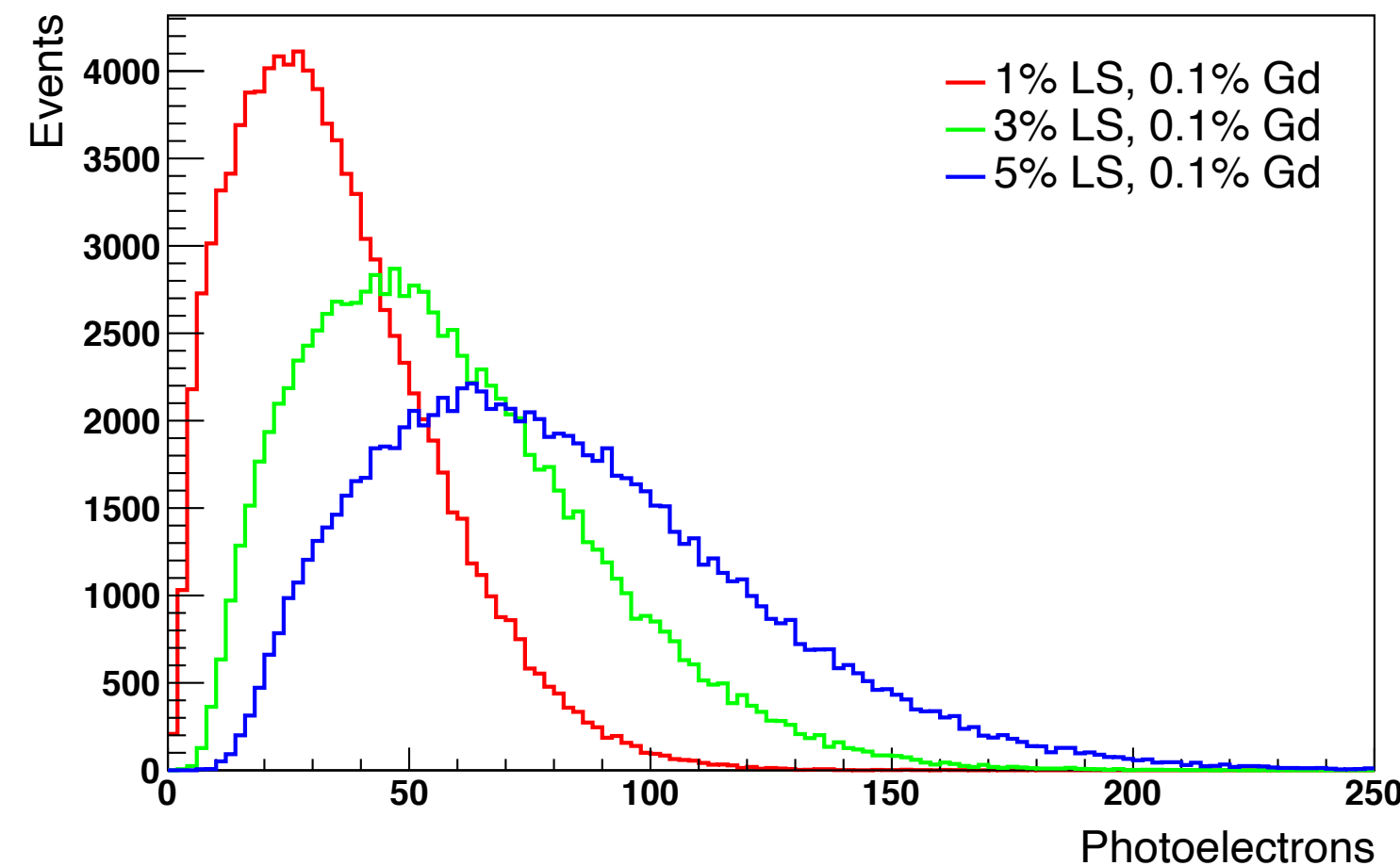
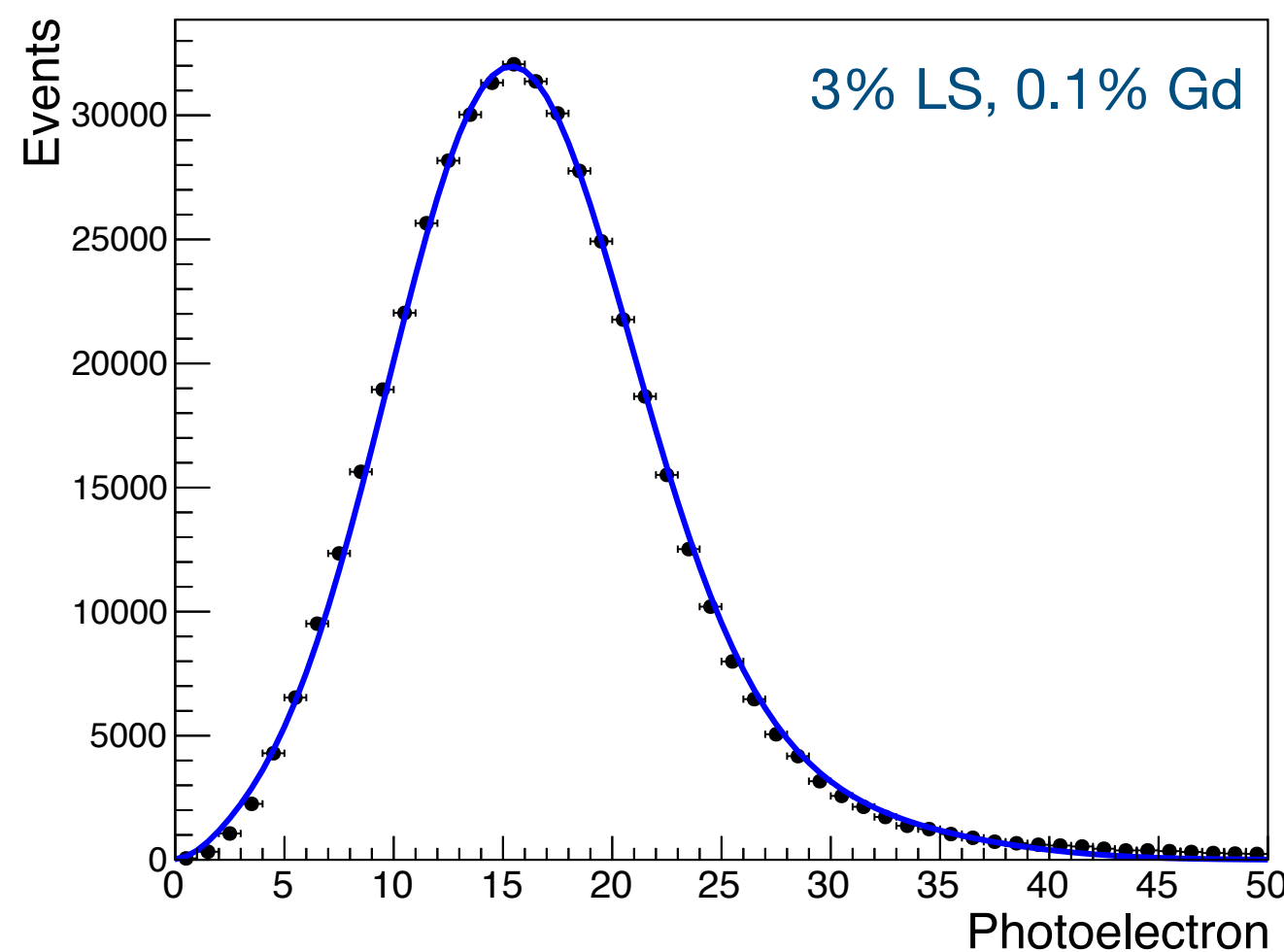
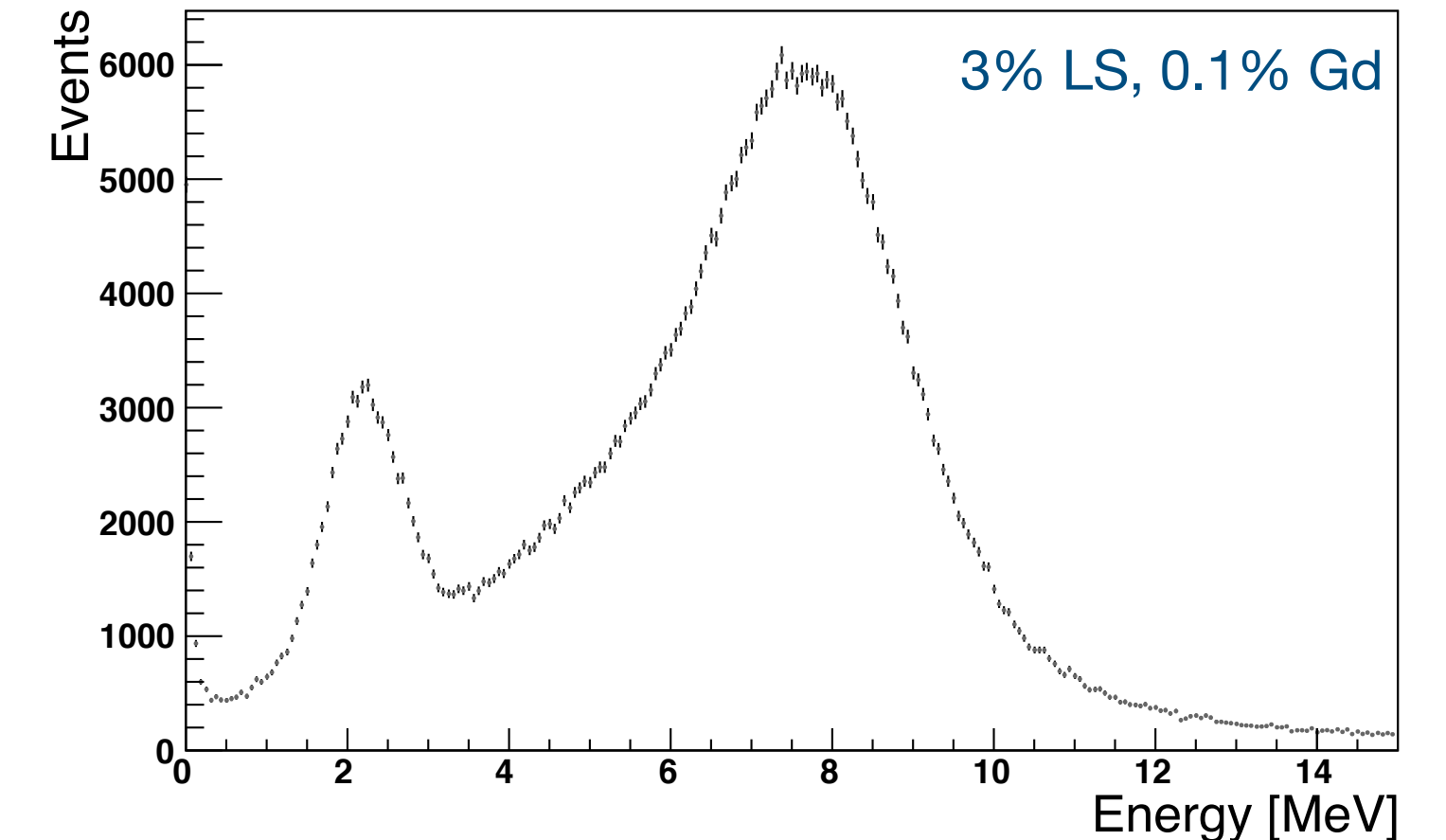


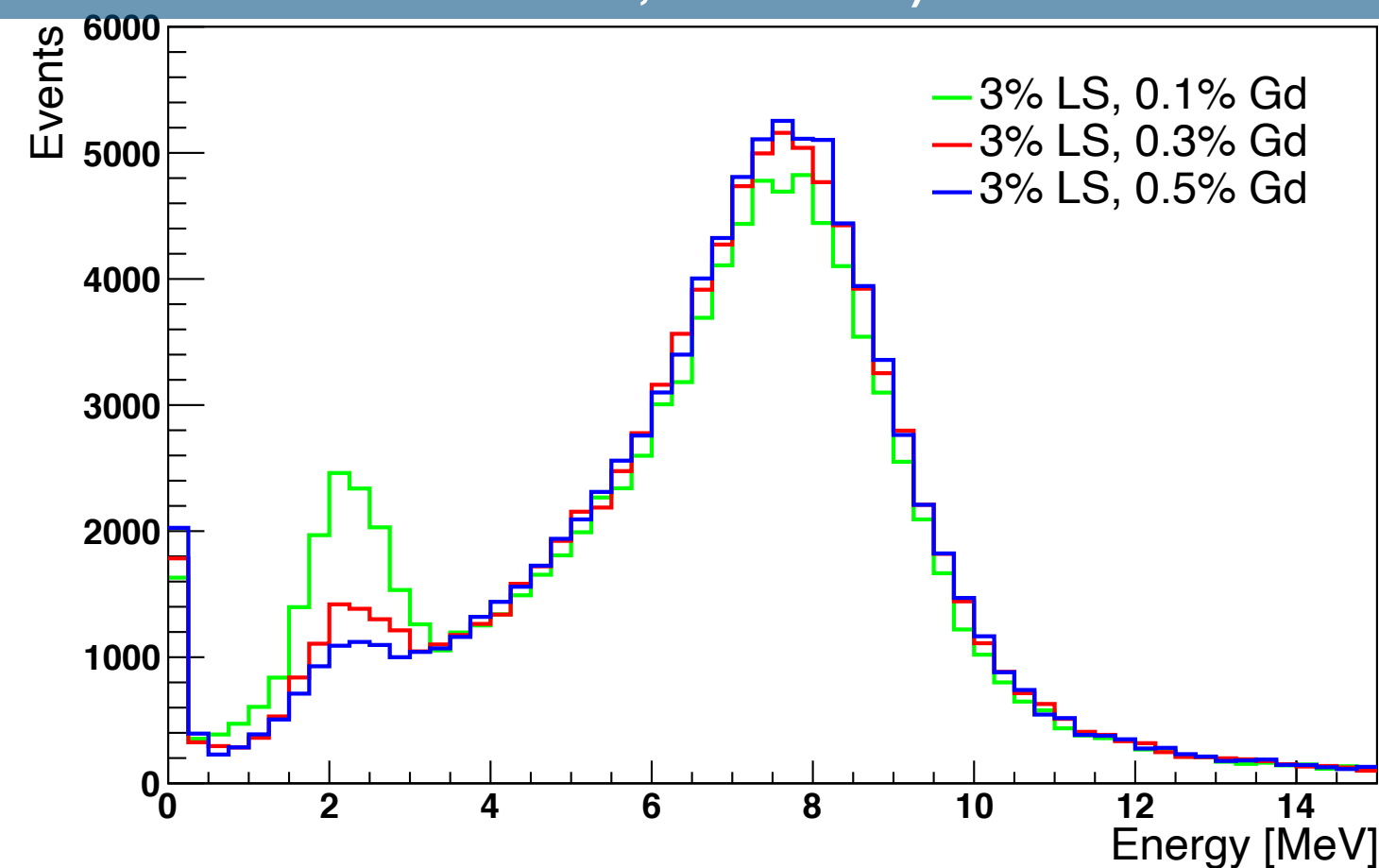
Photo-electron distribution of 1 MeV electrons simulated uniformly in the inner fiducial volume of the detector and fitted with a convolution of Gaussian and Landau function using RooFit.



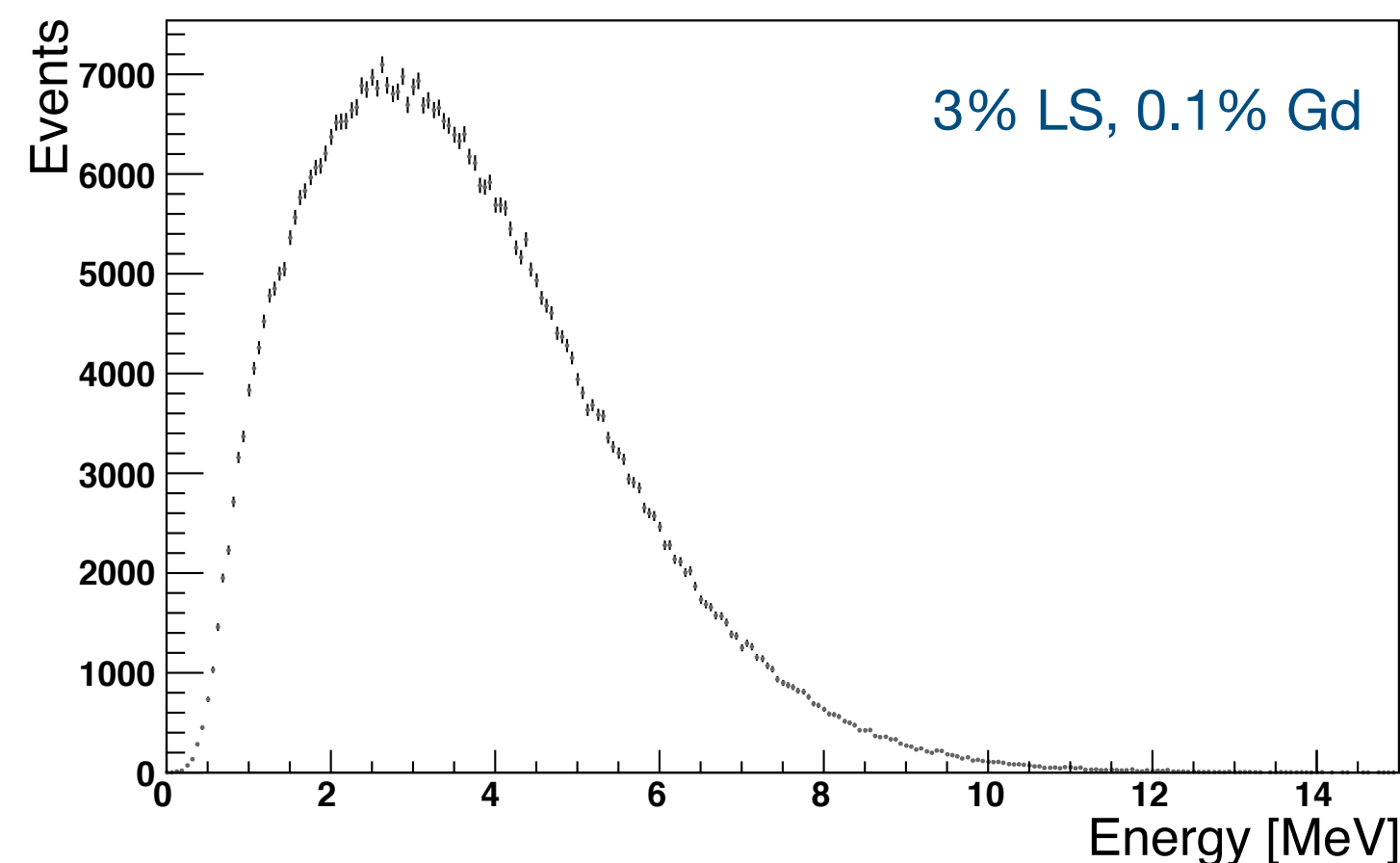
Reconstructed delayed events energy distribution from the simulated IBD events.



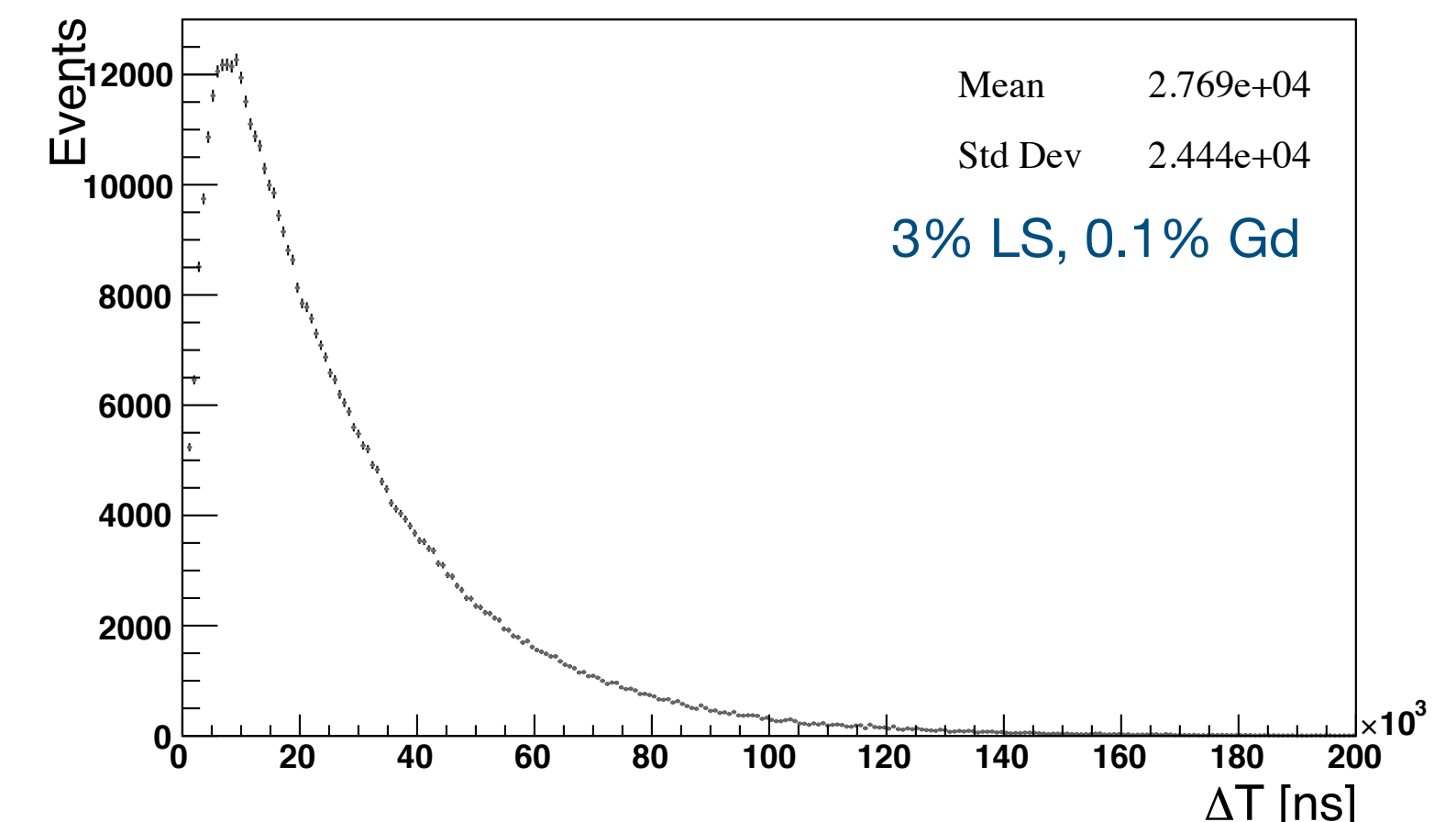
Reconstructed delayed energy, distributions for several WbLS cocktails with different mass fractions of Gd (0.1%, 0.3%, and 0.5%)



Reconstructed prompt events energy distribution from the simulated IBD events.



Time difference between prompt and delayed events for IBD events.

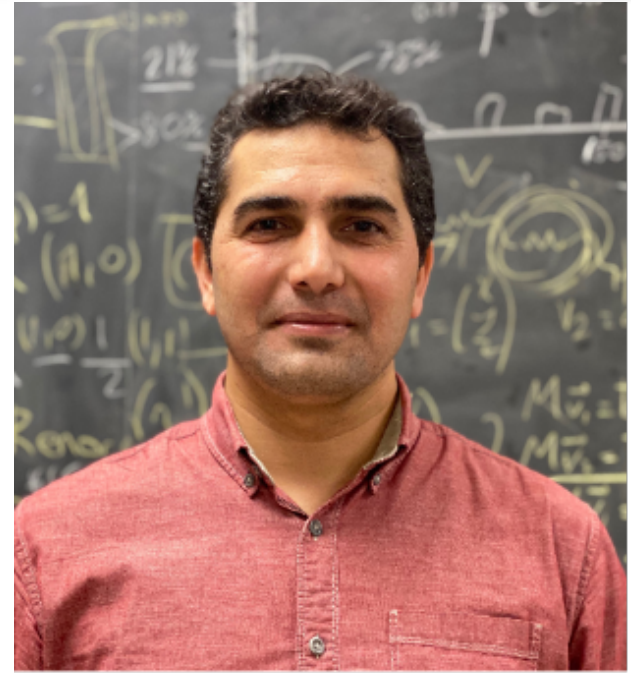


Conclusion

- ✓ Akkuyu NPP is under construction and the first reactor core is aimed to start working in 2023
- ✓ It's a great opportunity for both monitoring purposes and neutrino physics studies in Turkey.
- ✓ The reactor neutrino studies would be the first step towards development of a future reactor neutrino oscillation experiment in Turkey.
- ✓ All of the studies we have done so far are simulation studies and related proposals for detector R&D.
- ✓ Phase I project proposal is under review in TUBITAK.

This study was supported by Erciyes University BAP, DOSAP with the project code of “FDS-2021-10856”

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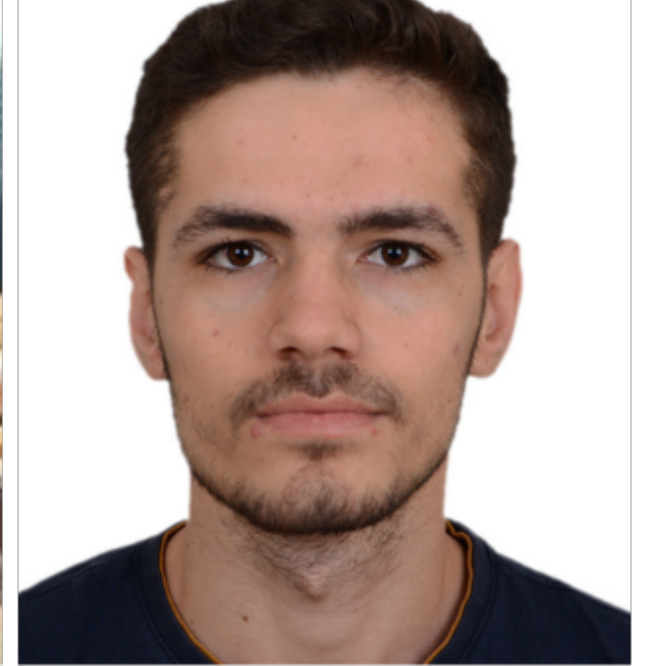
Erciyes University



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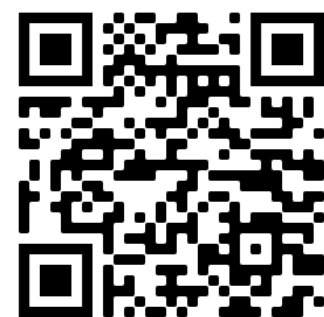
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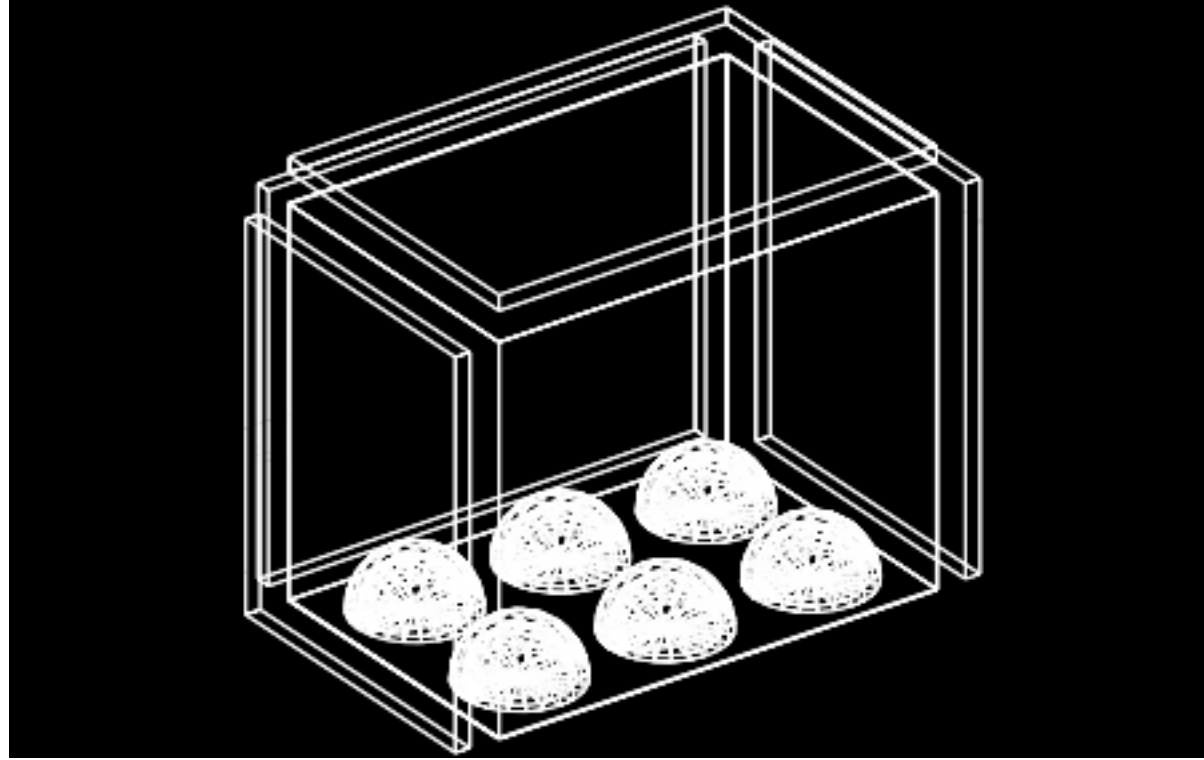
ERCIYES NEUTRINO RESEARCH GROUP

BACK UP

Other Low Energy Neutrino Studies in Turkey

Monitoring Akkuyu Nuclear Reactor Using Antineutrino Flux Measurement

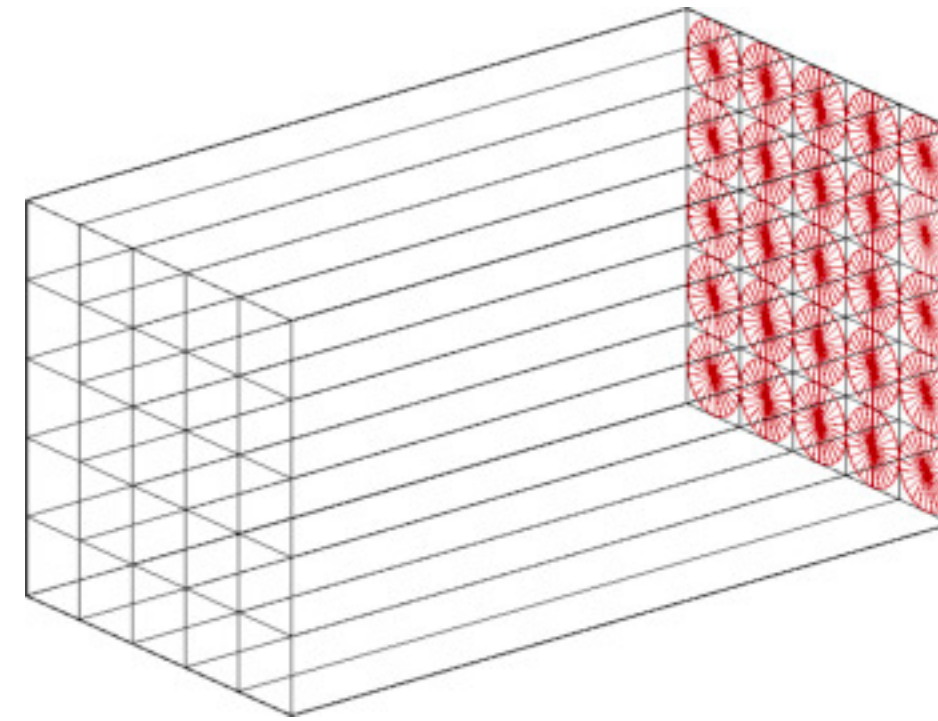
S.Ozturk, A .Adiguzel, V. E.Ozcan, ,G.Unel



- Monitoring Akkuyu Nuclear Power Plant's activity using antineutrino flux originating from the reactor core
- Used the Geant4 simulation toolkit.
- The shape of a prism with dimensions $80 \times 100 \times 120$ cm
- Filled with 1 ton of Gd-doped water.
- Planned to be place 30 m away from the reactor core.
- 1050 anti-electron neutrinos per day.

Nuclear reactor monitoring with gadolinium-loaded plastic scintillator modules

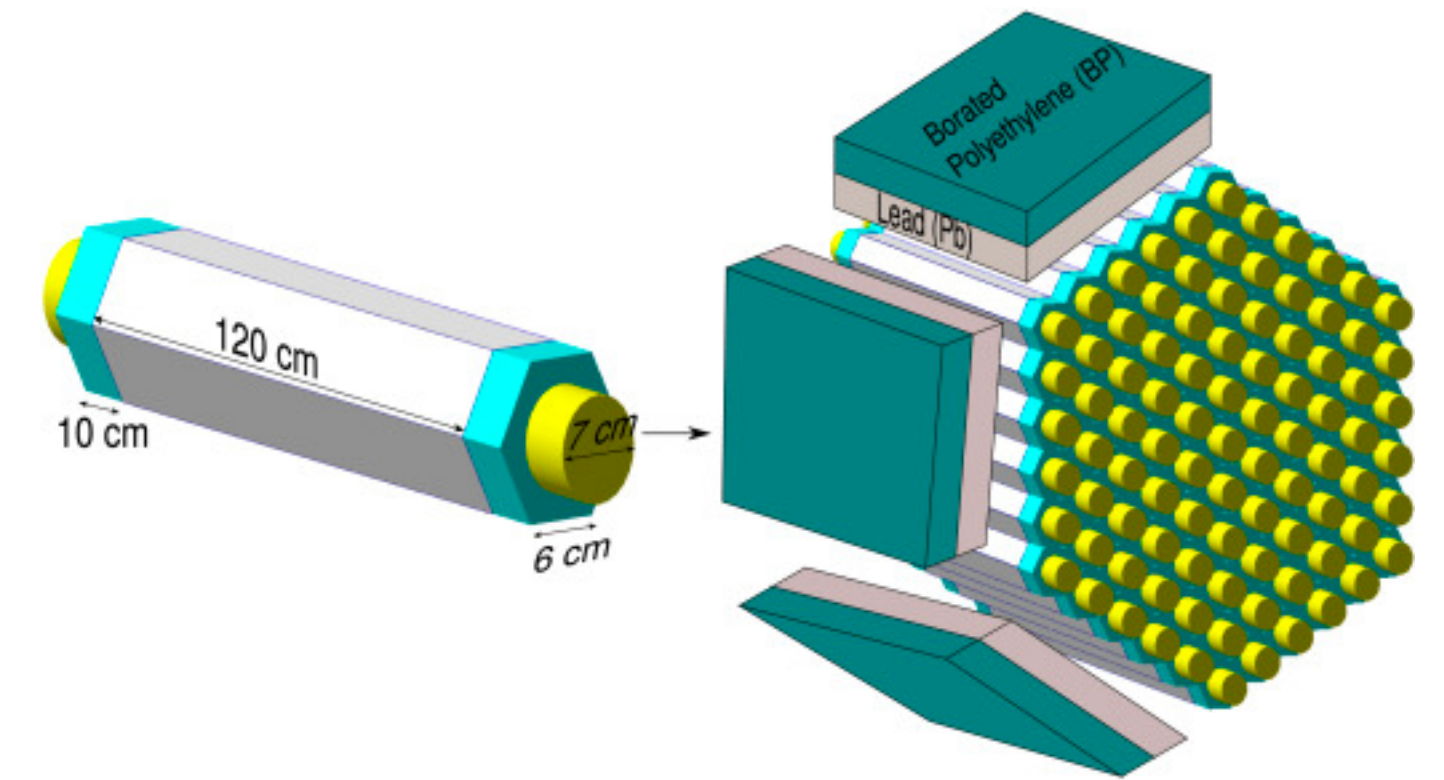
S.Ozturk



- A gadolinium-loaded segmented plastic scintillator detector.
- 25 identical $10 \times 10 \times 100$ cm Gd-loaded plastic scintillators.
- The detector is about 250 kg.
- 1185 antineutrino events can be observed per a day when it is placed 50 m

A reactor antineutrino detector based on hexagonal scintillator bars

M.Kandemir, A. Cakır



- A segmented antineutrino_detector based on hexagonal plastic scintillator bars
- Used the Geant4 simulation toolkit
- Each unit has a hexagonal plastic bar (EJ-200, ELJEN Technology)
- A side length of 6 cm and a height of 120 cm, two light guides with a side length of 6 cm and a height of 10 cmc
- Plastic bars are coupled at both ends via light guides to PMTs ((9265B, ET Enterprises).