

# PHOTON BASED WORKSHOP

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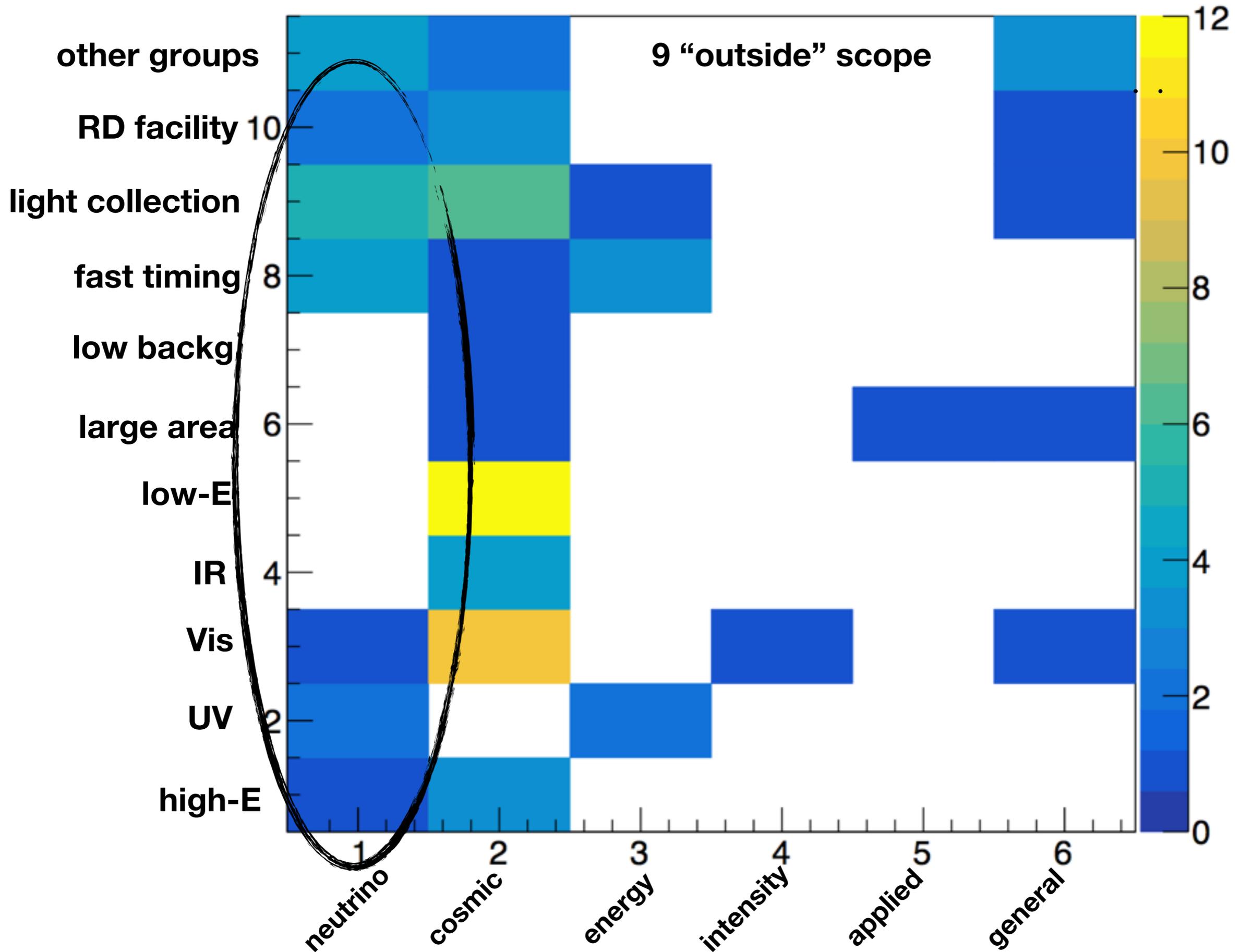
# INSTRUMENTATION FRONTIER (PHOTODETECTORS): IF02

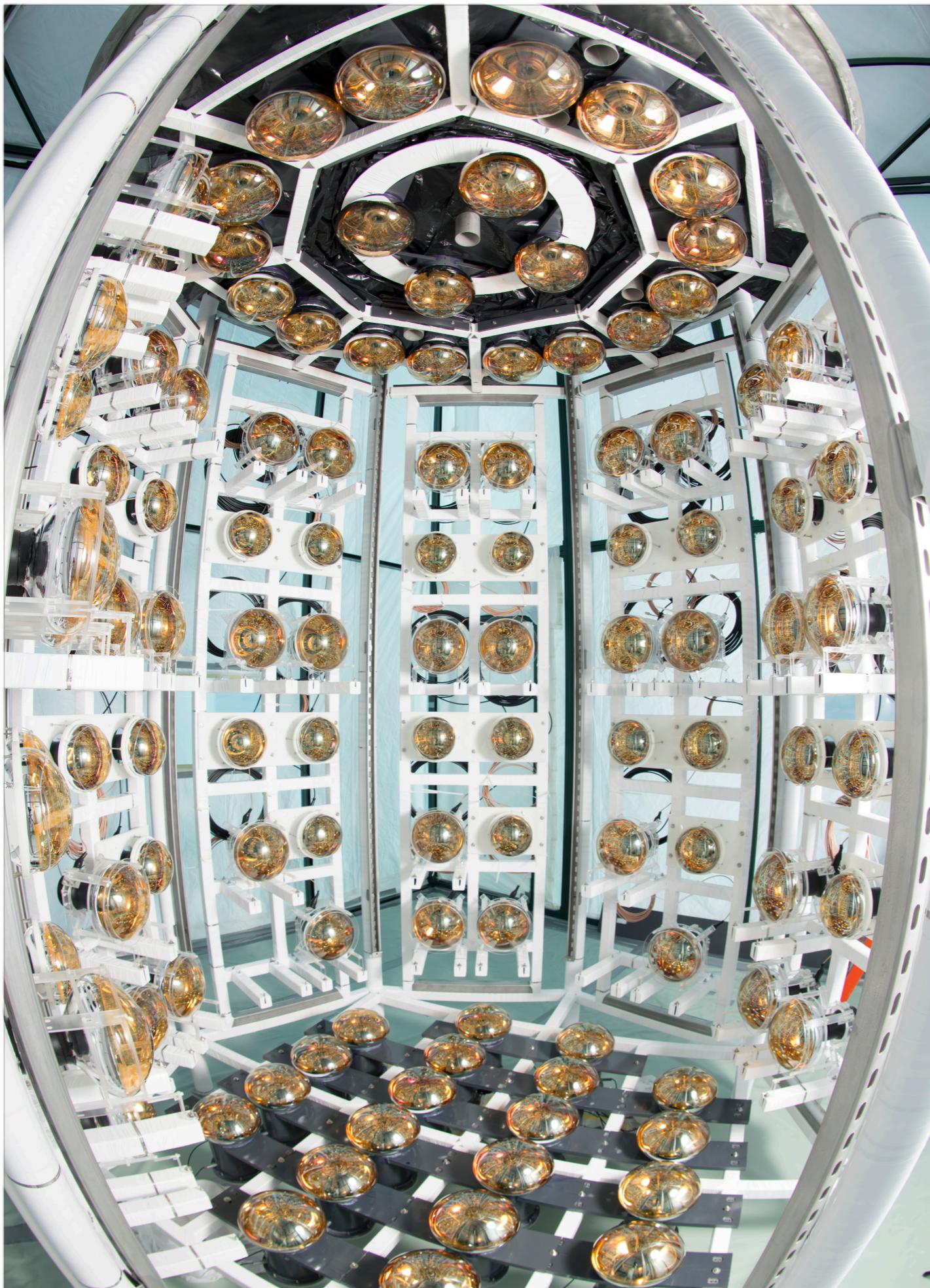
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➤ We had defined the following categories where

	Neutrino Frontier 1	Cosmic Frontier 2	Energy Frontier 3	Rare & Precision 4
Sensors <u>hiE</u> (1)		●		
Sensors UV (2)	●	●		●
Sensors VIS (3)	●	●	●	●
Sensors IR (4)		●		
Sensors <u>μwave</u> /Radio (5)		●		
Large Area (6)	●			●
Low Background (7)				●
Fast Timing (8)	●	●	●	
Light collection (9)	●	●		●
RD facility (10)				

# 77 LOIS IN IF02





# The ANNIE Experiment

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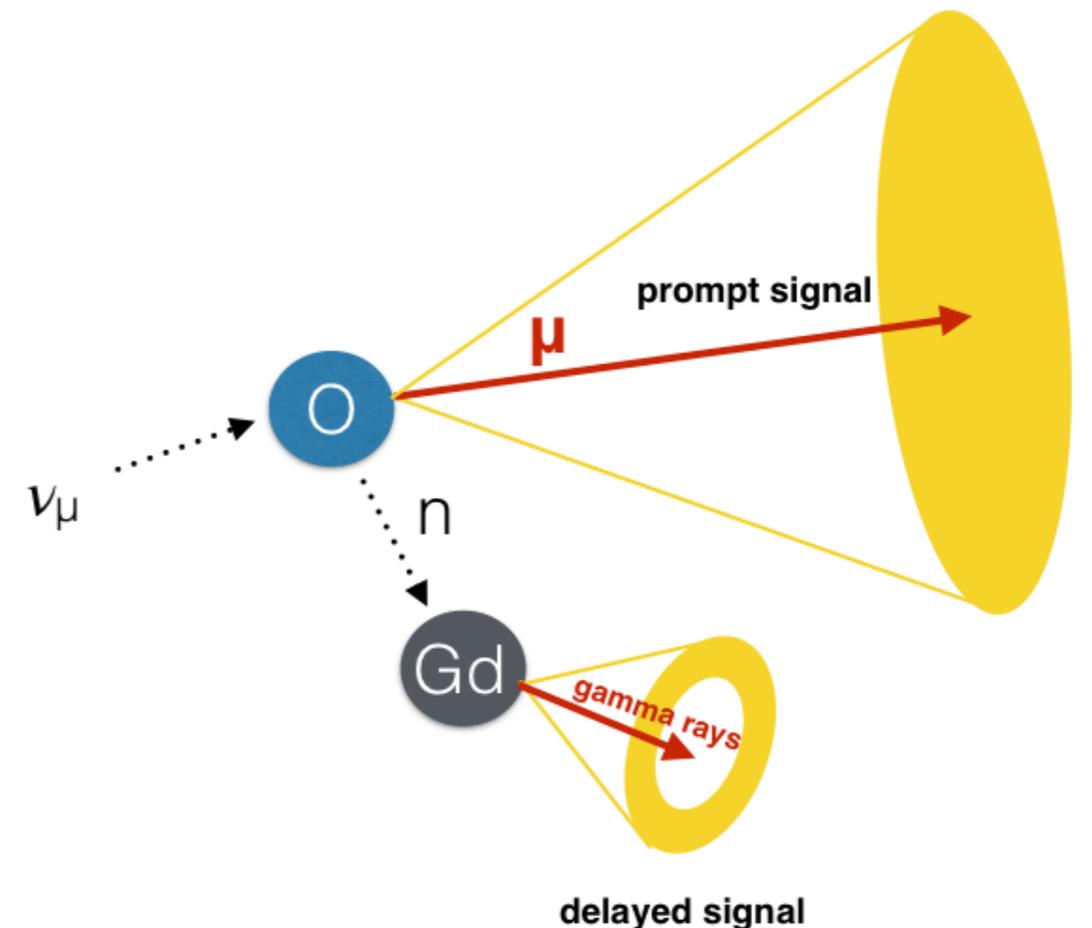
# The Accelerator Neutrino Neutron Interaction Experiment (ANNIE)

- ANNIE is a neutrino experiment deployed on the Fermilab Booster Neutrino Beam.
  - It is aimed at better understanding neutrino-nucleus interactions, specifically the neutron yield.
- It is also an R&D platform to develop and demonstrate new neutrino detection technologies/techniques.
  - Fast photosensors (LAPPDs) and detection media (Gd-loaded water and eventually water-based liquid scintillators).



# Enabling Technology: Gd-loading of water

- Efficient neutron counting is made possible by Gadolinium loading of water.
- ANNIE uses 52 kg of gadolinium sulfate for a 0.1% Gd-load.
- Gd has a high neutron capture cross section for thermal neutrons.
- These captures produce a delayed ( $O(10)$   $\mu\text{sec}$ )  $\sim 8$  MeV gamma cascade, detectable in water from its Cherenkov light.

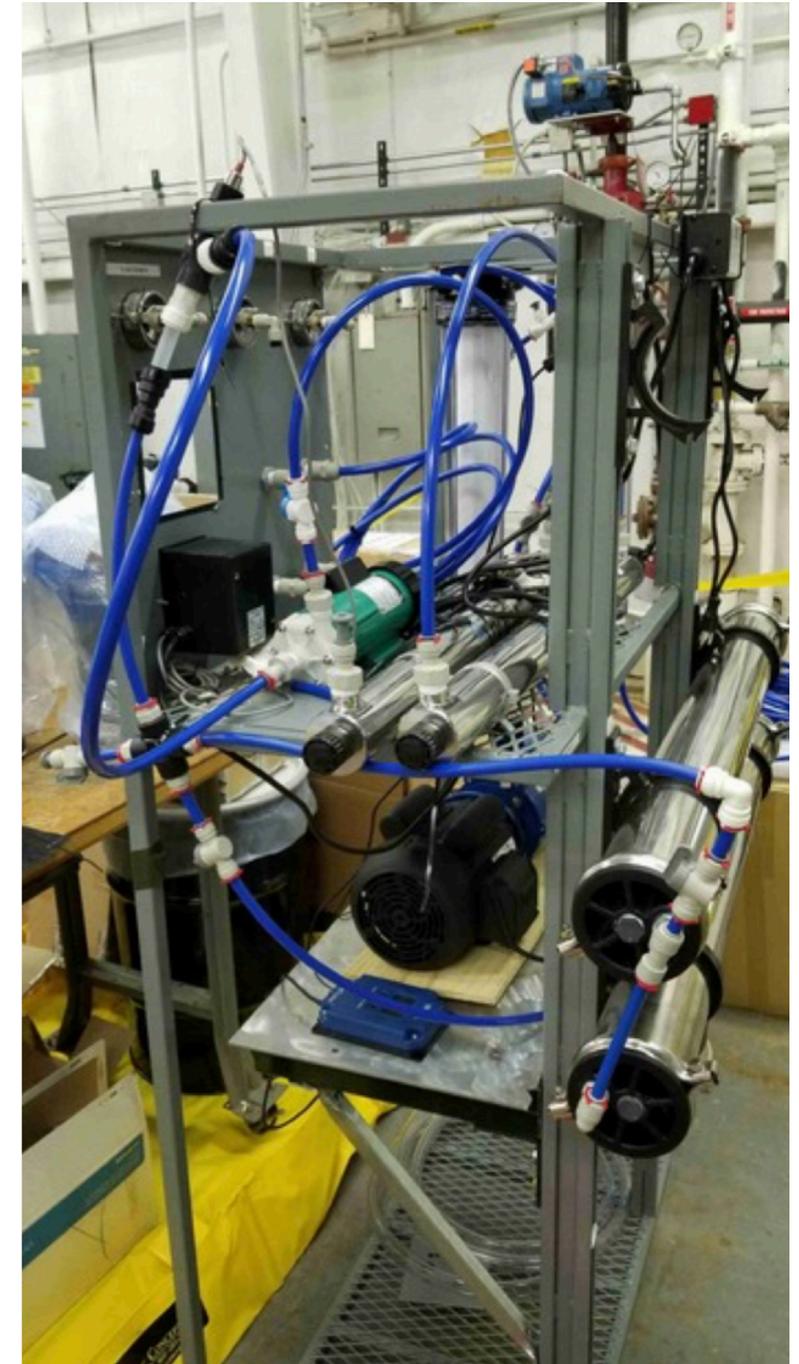


**ANNIE is now the first Gd-loaded water Cherenkov detector on a neutrino beam**

# Enabling Technology: Gd-loading of water

- Significant work on testing Gd material-compatibility for all components of the detector including teflon wrapping/liner.
- Development of a low-cost purification system for smaller scale Gd-water deployments.
- Developed a method for making low-cost, sulfate-loaded resin using commercially available materials.
  - Removes nitrates and free radicals from the water, leaving the Gd-sulfate in solution.

ANNIE water skid

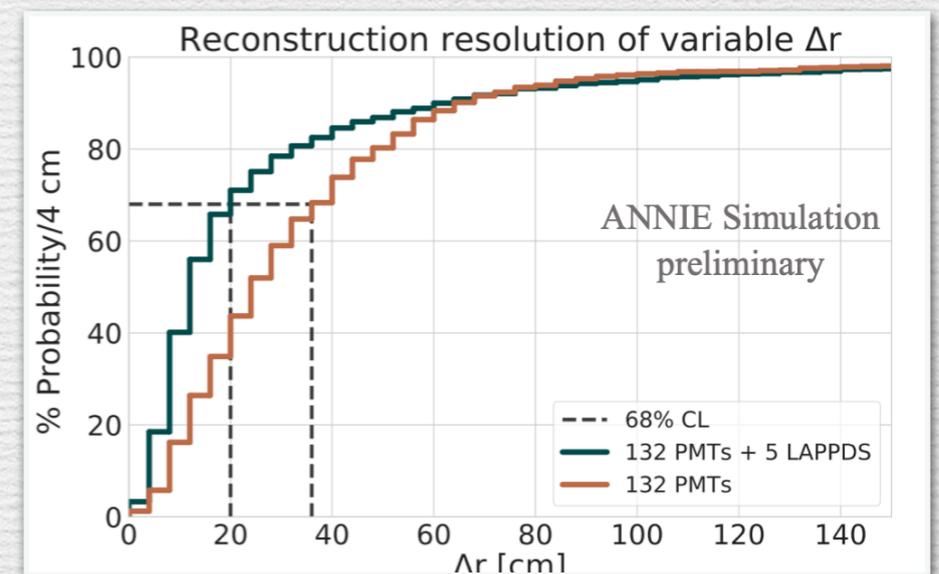
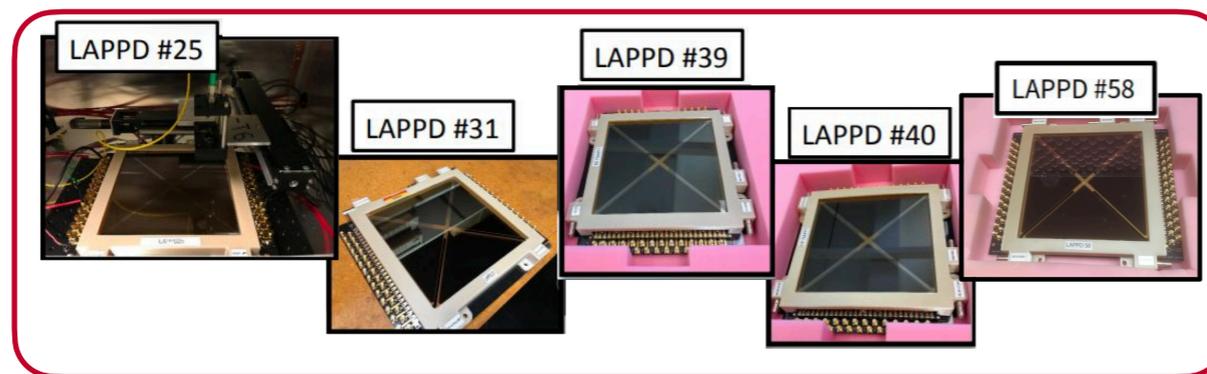


**Novel purification method published**

# ANNIE's Enabling Technology: LAPPDs

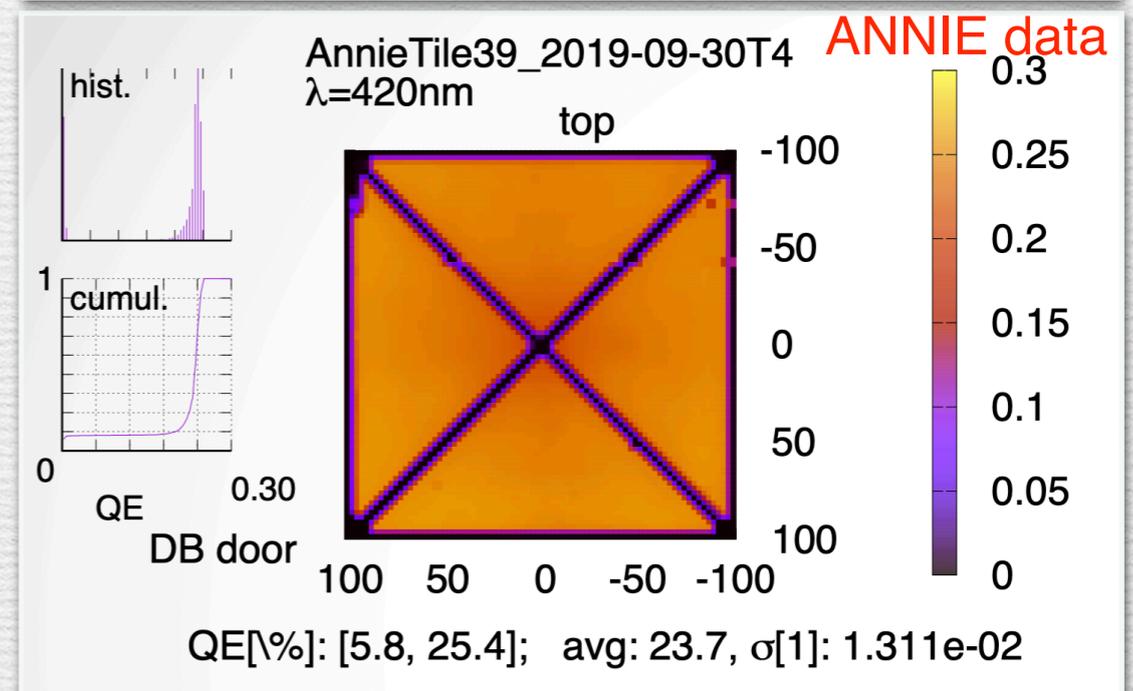
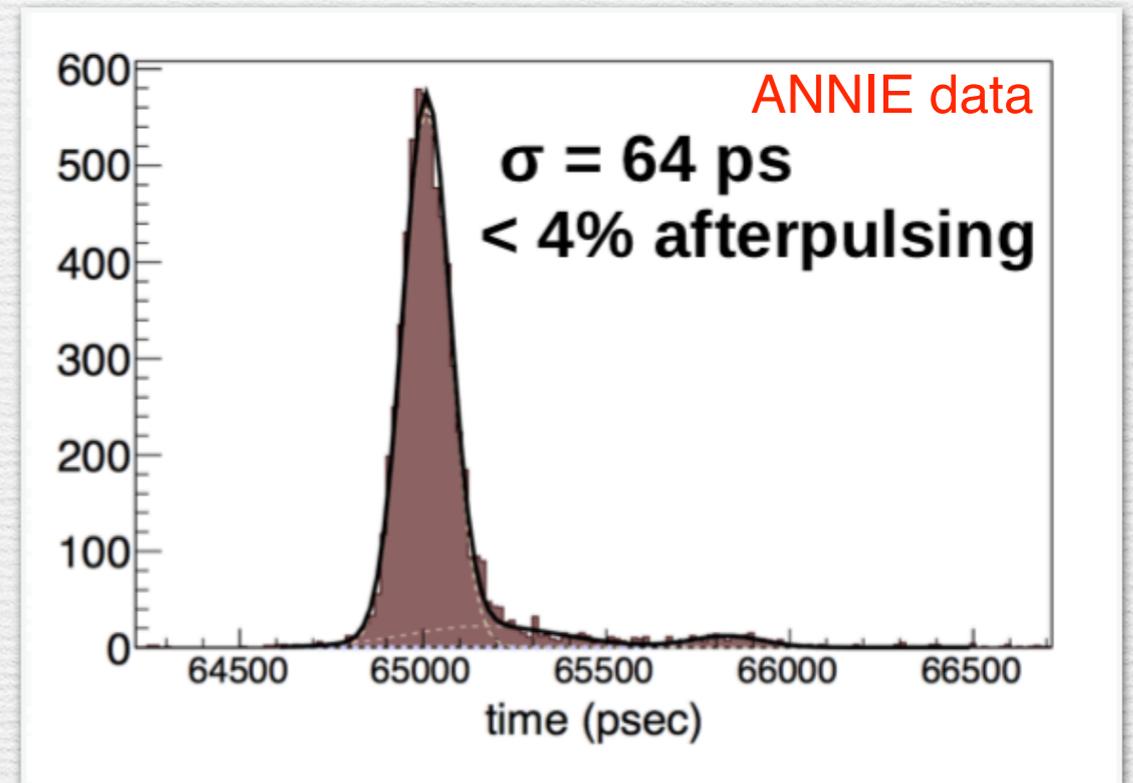
- Large Area Picosecond Photo-Detectors (LAPPDs) are 20 x 20 cm tiles based on microchannel plates with resistive and emissive coating and microstrip anode readout.
- Fast photodetector capabilities ( $\sim 60$  psec time resolution) and excellent position resolution (mm-cm scale).
- ANNIE has obtained and is characterizing 5 LAPPDs at Fermilab to be deployed in the tank later this summer.
- Both angular and spatial resolutions benefit substantially from using LAPPDs.

ANNIE LAPPDS



# ANNIE's Enabling Technology: LAPPDs

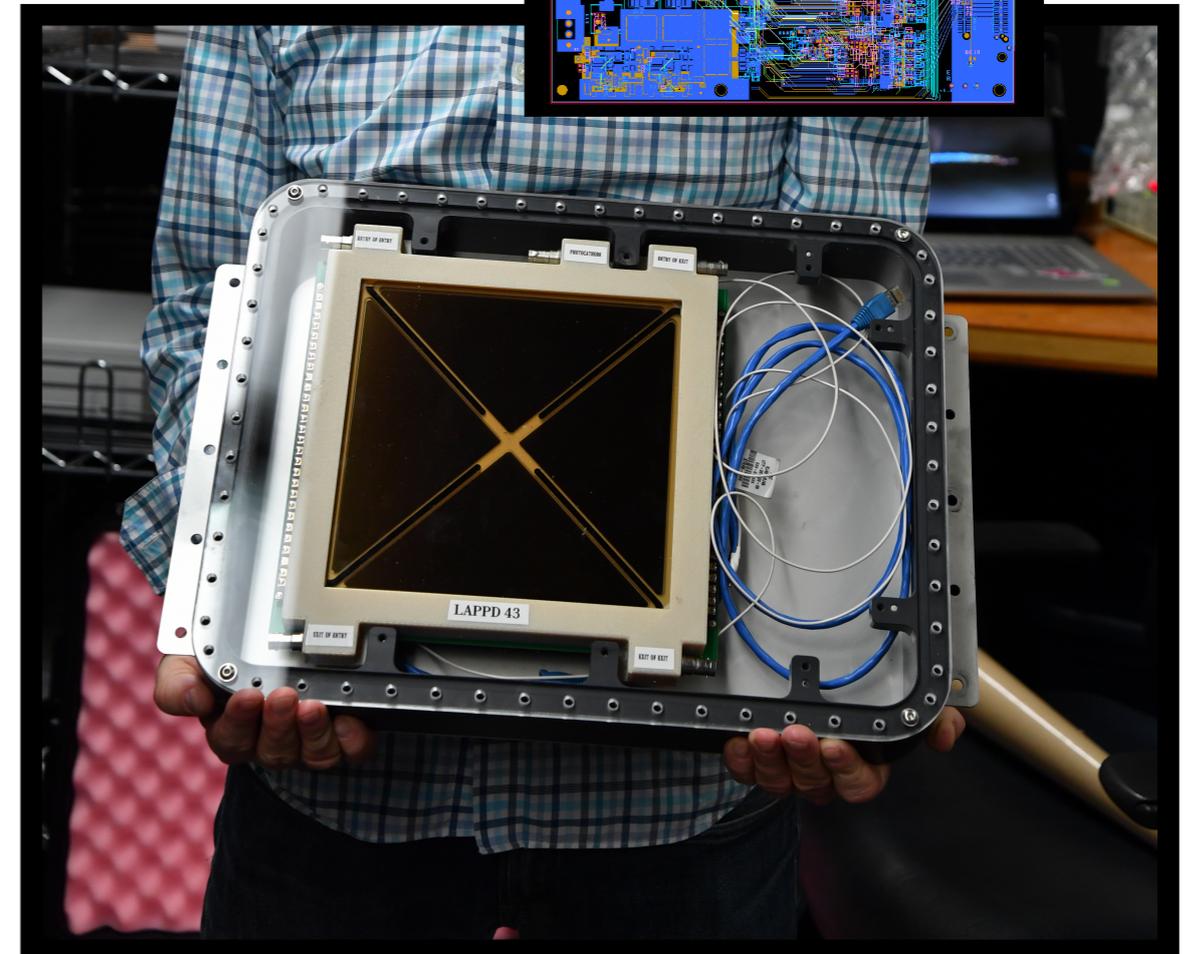
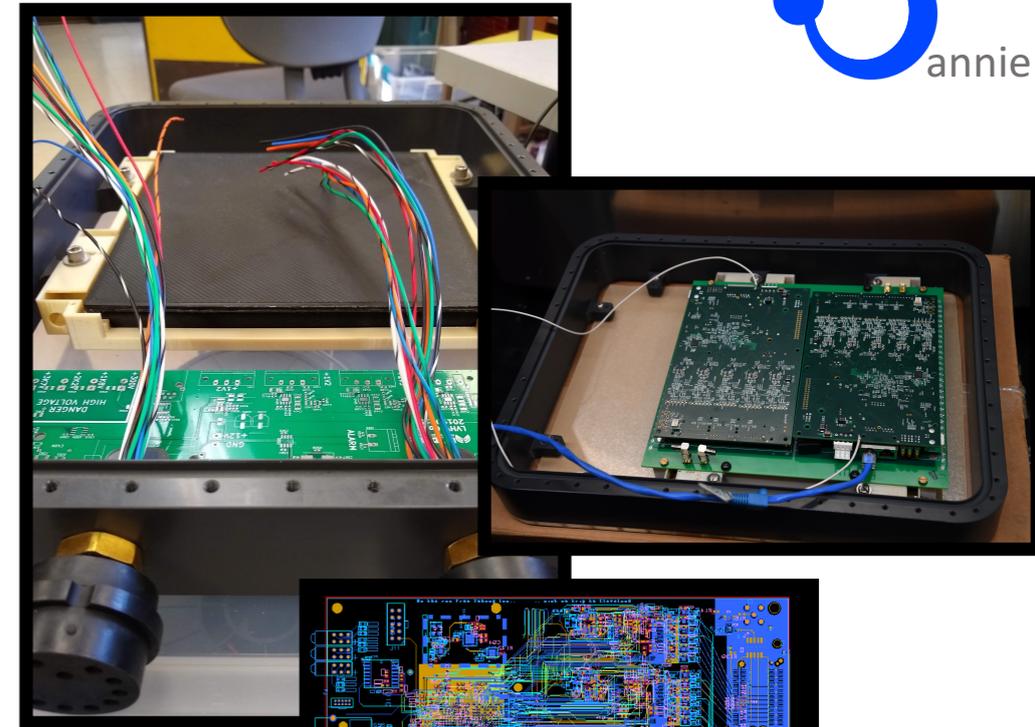
- Characterization underway at Fermilab. Systematic tests of all 5 LAPPDs at dedicated facility.
  - Quantum Efficiency (QE) gain and timing calibration automated scans.
- Timing resolution and after pulsing within ANNIE specs: ~60 second and < 4 % afterpulsing.
- Scan results for tile show average QE at 23.7% and very uniform distribution over whole area.



# Enabling Technology: LAPPDs

- Current design of the LAPPD package consists of
  - a waterproof housing with
    - acrylic window
    - steel backplane
    - PVC sidewalks
  - a board (Analog Pickup Board) that mounts to the back of the LAPPD and brings signals to the two readout mezzanine cards
  - two readout cards (ACDC cards)
  - a trigger logic board
  - a slow controls board (LV-HV card)
- All boards are built and undergoing testing in preparation for deployment.

First experience in deploying a multi-LAPPD system



# ANNIE Readout Architecture

The ANNIE readout architecture offers a robust system, field-tested on

- An experiment of similar channel count to AIT/NEO but different physics (KOTO)
- An experiment with similar physics but a smaller channel count (ANNIE)

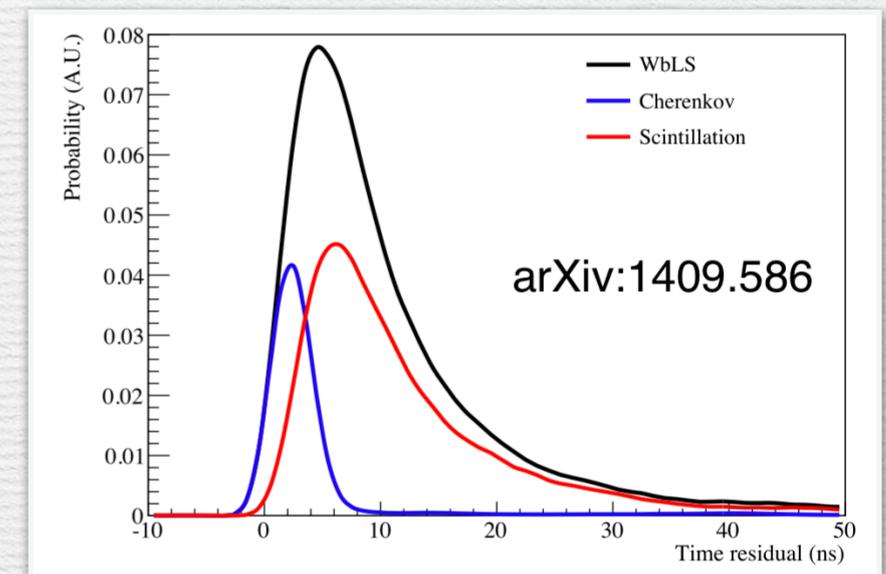
This DAQ solution provides 12-bit dynamic range, 500 Msample/sec readout based off-the-shelf ADCs and FPGAs. **Price can be significantly reduced by using a 250MHz version of the digitizer chips.**

The hardware and overall trigger and data handling architecture is already well tested in KOTO and the logic is being implemented in ANNIE.

The software interfaces are already integrated with the ToolDAQ DAQ software framework, as well as the ToolAnalysis reconstruction and online monitoring framework

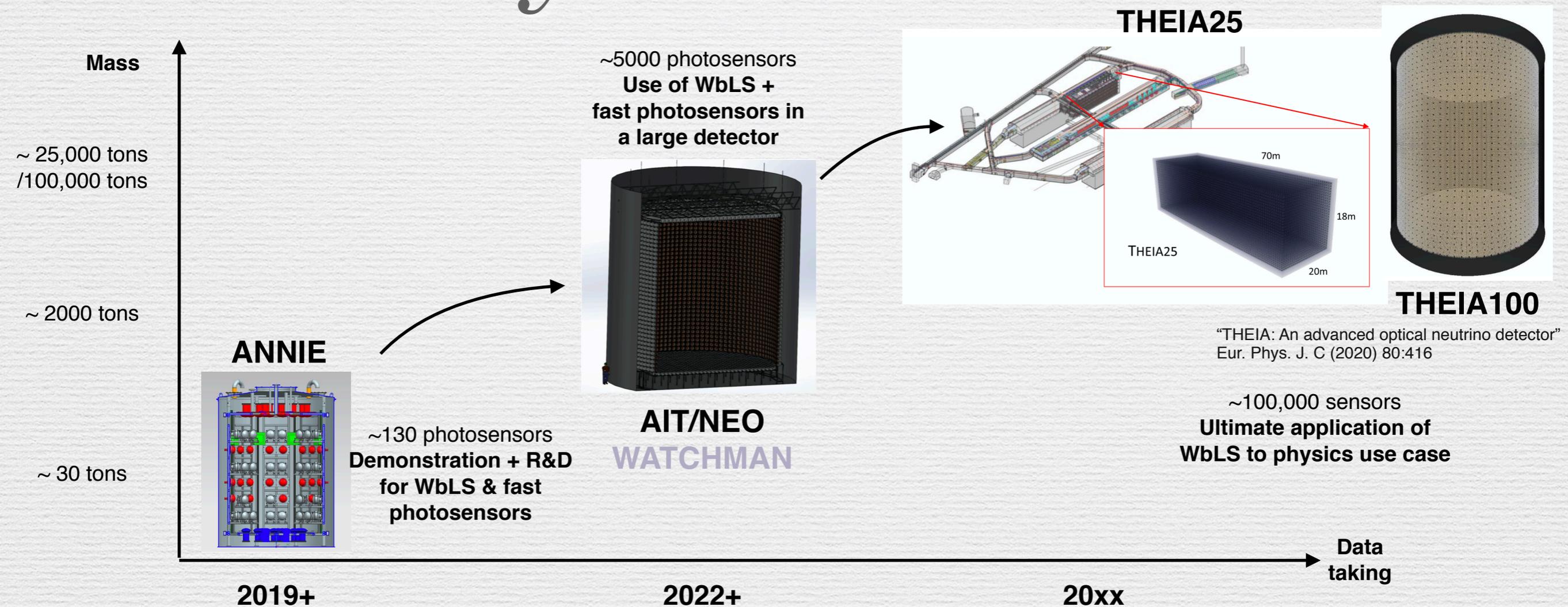
# Future of ANNIE

- Water-based Liquid Scintillator (WbLS) is a novel detection medium in which liquid scintillator droplets are dissolved in water.
- It promises to combine the best of both worlds: **directionality and kinematic reconstruction from Cherenkov light**, and **high light yield and calorimetric reconstruction from scintillation light**; while maintaining high transparency and low cost.
- Combined with fast photosensors it would be possible to separate Cherenkov from scintillation light.
- We are planning the deployment of 500 liters of WbLS into ANNIE at different LS loading 1%, 5%, 10% to study the benefits on reconstruction.



WbLS vessel for potential deployment in ANNIE

# Beyond ANNIE



- ANNIE is the first step in a series of efforts to develop a series of detectors that will offer new capabilities.
- WbLS efforts in ANNIE will offer valuable input to AIT/NEO and THEIA. Phase III not currently approved.