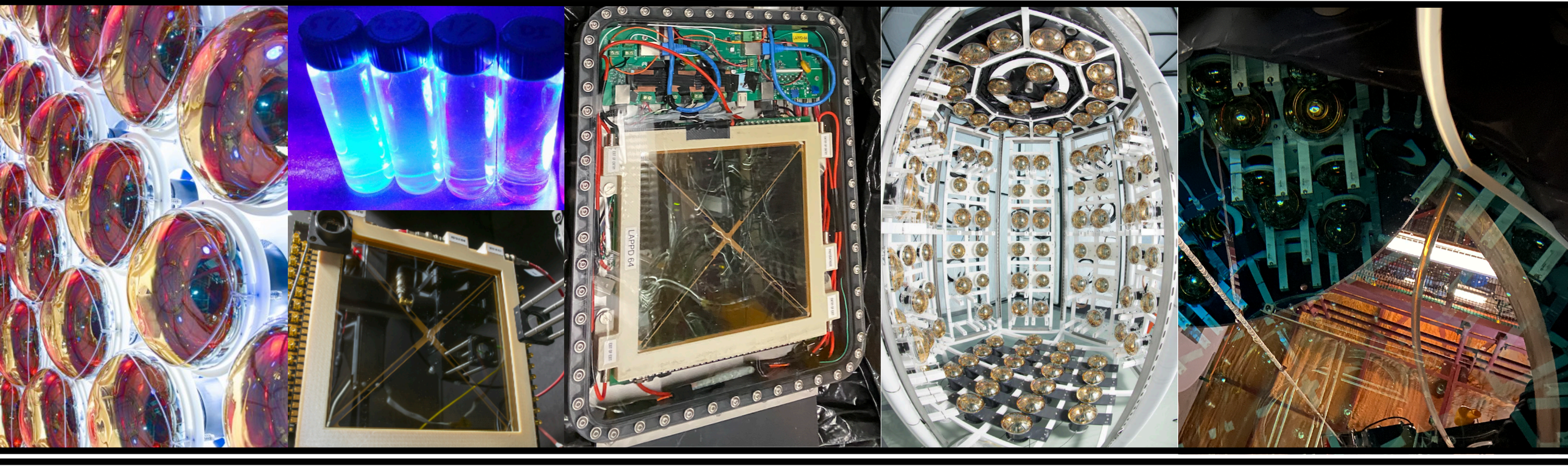


ANNIE in 10 minutes

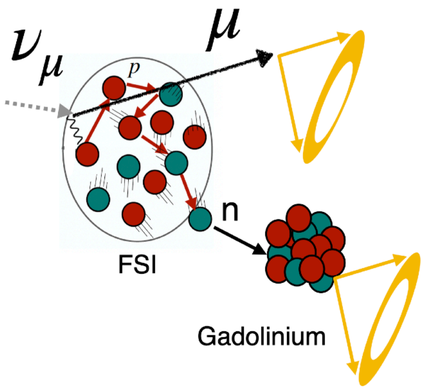
Marvin V. Ascencio-Sosa
On behalf of the ANNIE collaboration

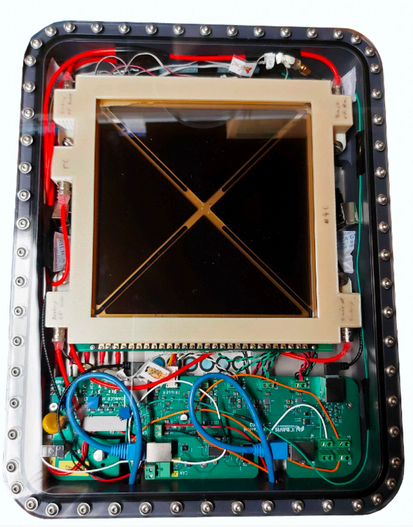
New Perspective, June 26, 2023

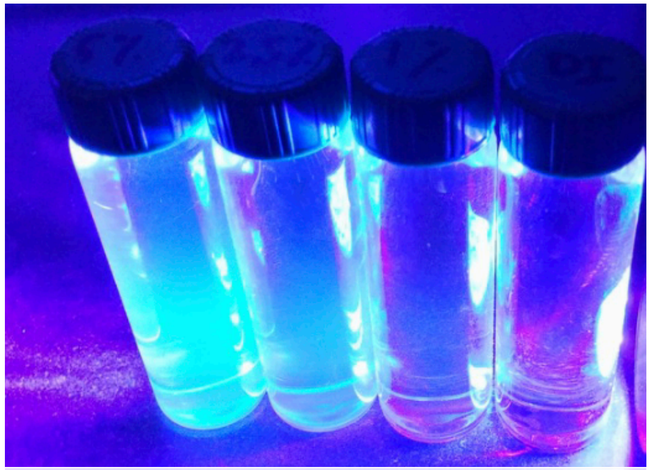
FERMILAB-SLIDES-23-107-ND.

Accelerator neutrino neutron interaction experiment

- An international collaboration:







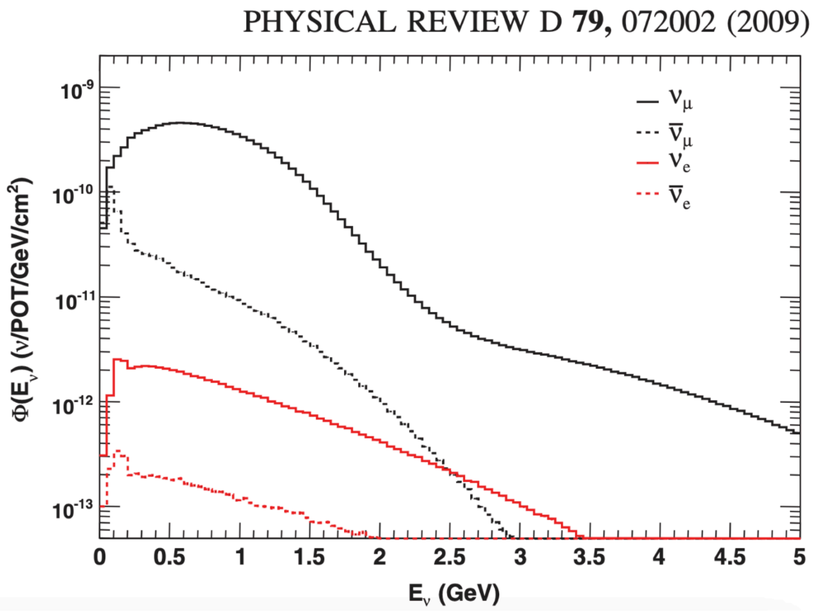
Goals:

- Physics: ANNIE aims for a unique final-state neutron yield measurement **from neutrino-nucleus interactions** and neutrino cross-section.

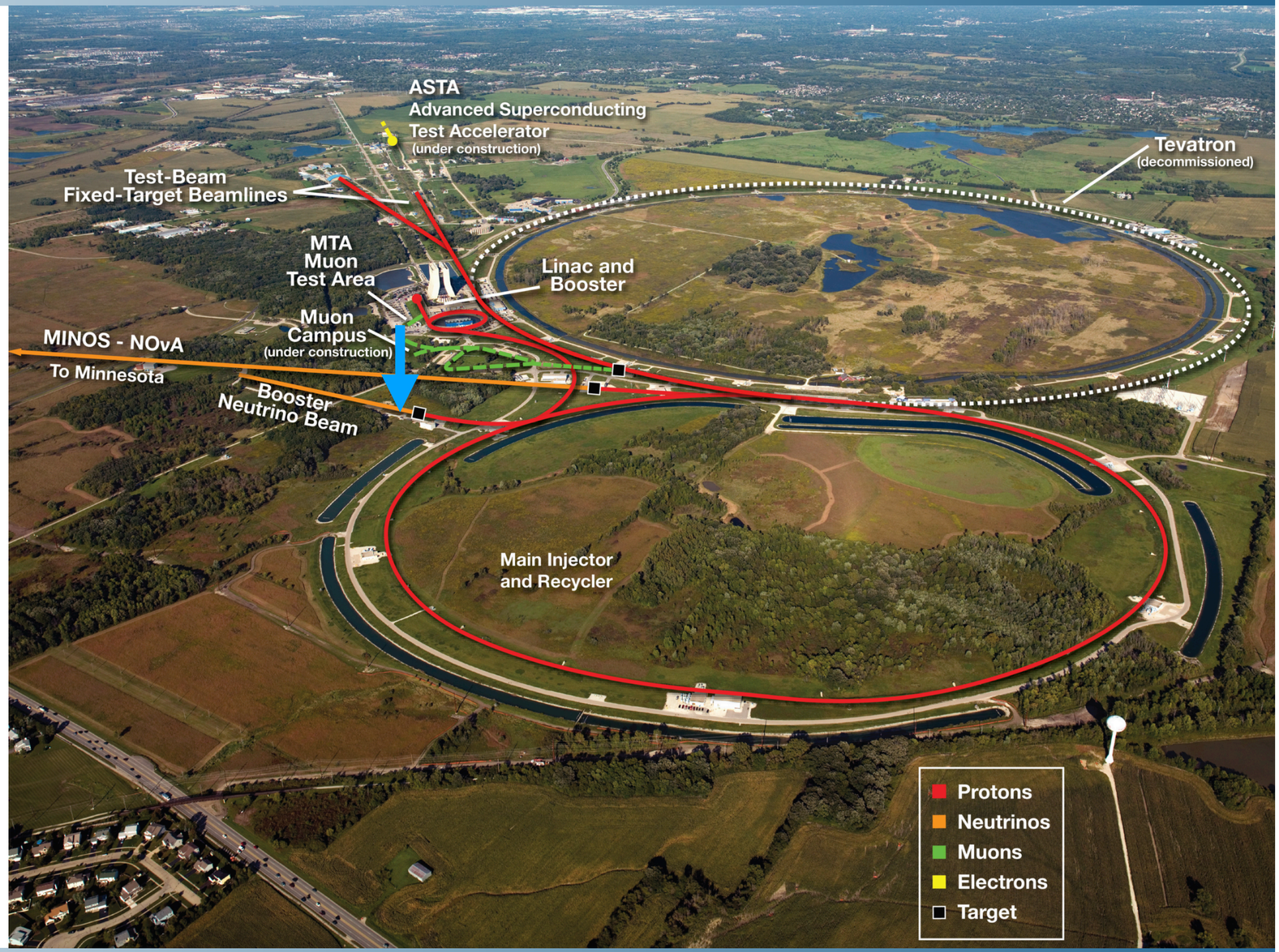
- Technology: **R&D** perform for the new neutrino detection technologies:
  - **Fast Photosensors (LAPPDs)**
  - **New detection media (Gd-loaded water and Water-based Liquid Scintillator WbLS)**

Accelerator neutrino neutron interaction experiment

- ANNIE is placed on-axis in the BNB beamline at Fermilab.



- Neutrino energy average less than 1 GeV.



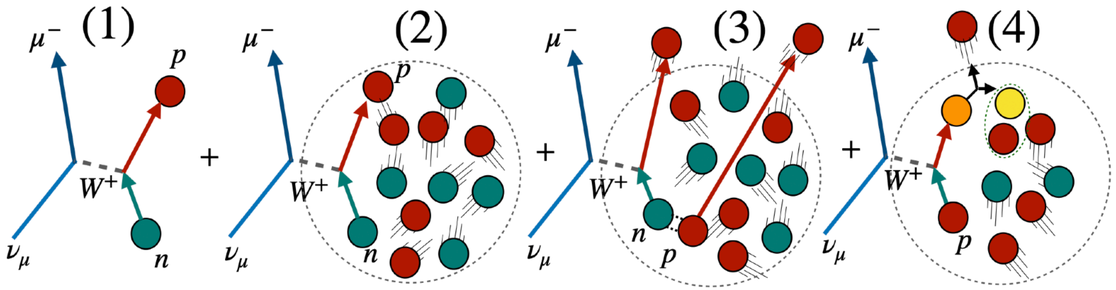
Physics Motivation

Neutrino **Oscillations** physics:

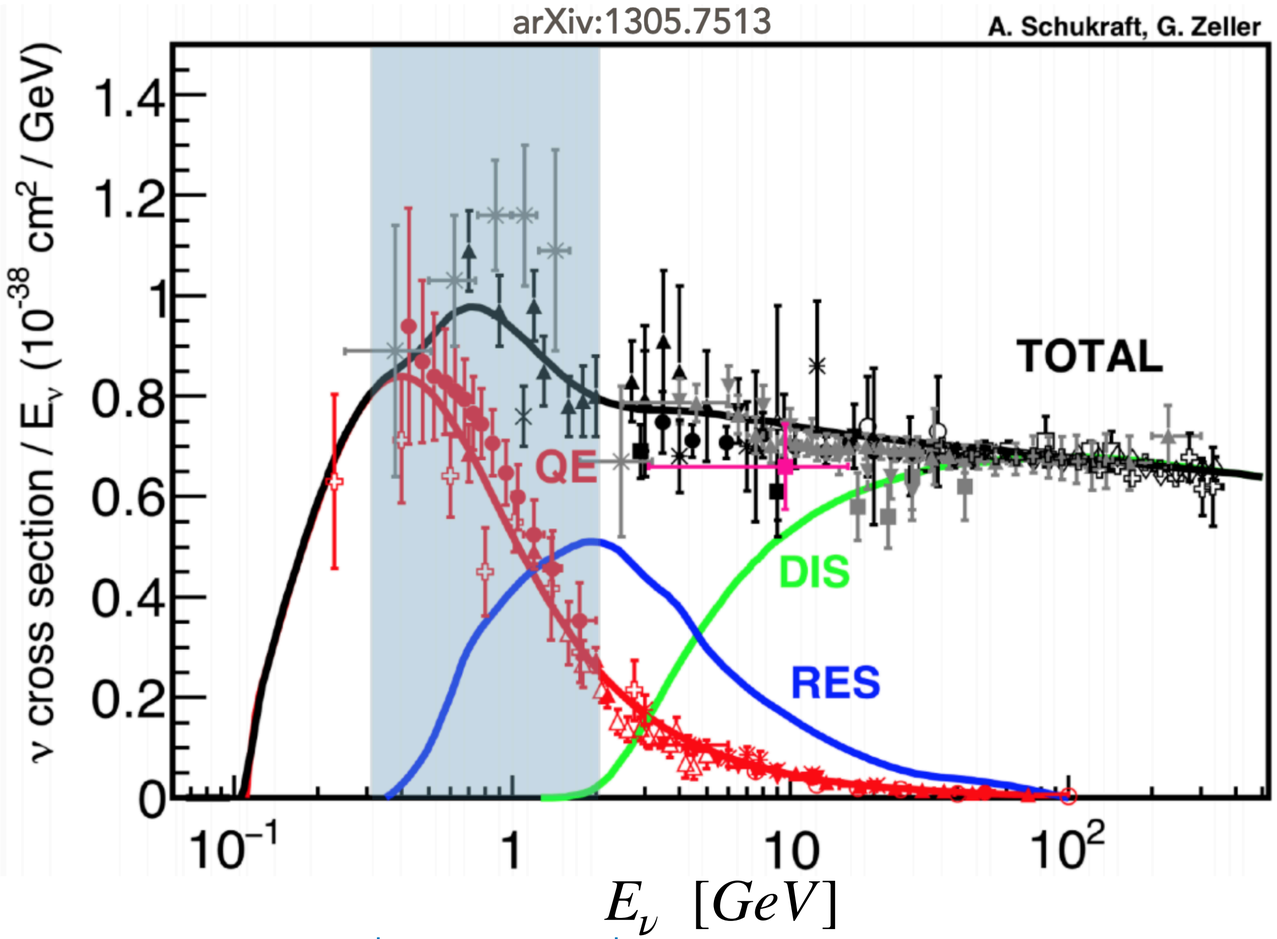
- Requires a precise neutrino energy reconstruction

$$N(E_{\text{reco}}) \sim \phi(E) \times P(E) \times \sigma(E) \times f_{\sigma}(E, E_{\text{reco}})$$

- δ CP oscillation parameter requires $\nu/\bar{\nu}$ events comparison. The number of final state neutrons impacts the hadronic recoil energy.



Free nucleon scattering | Initial Nuclear State | Nuclear Effects | Final State

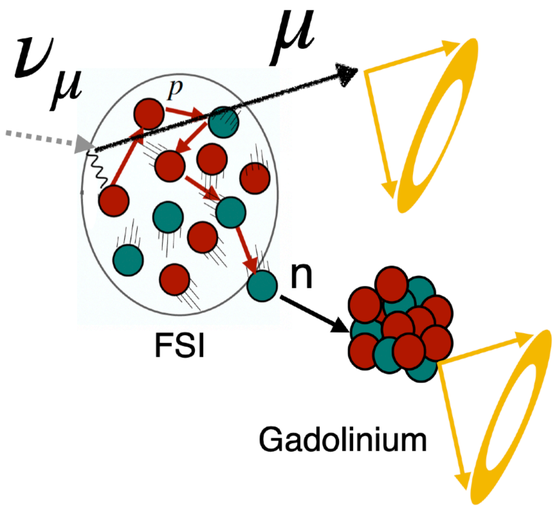


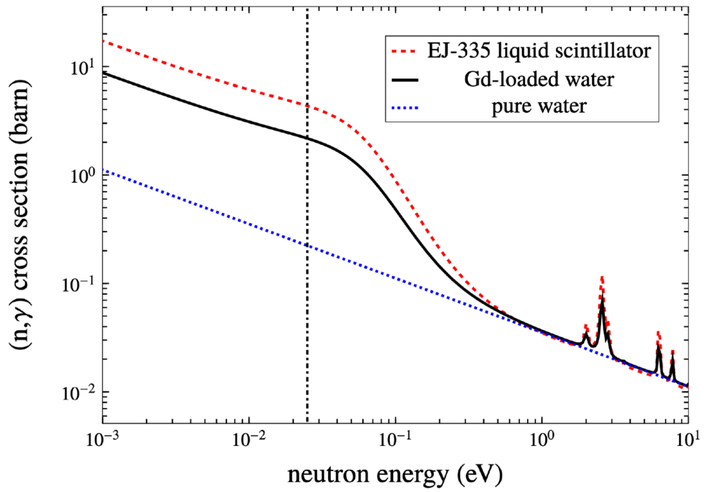
ANNIE (BNB)
NoVA (NuMI)
DUNE (LBNF)
HyperK (J-PARC)

ANNIE is interested
in NEUTRONS and secondary neutrons.

Technological motivation

The first application of Gd-loaded water **on a neutrino beam**



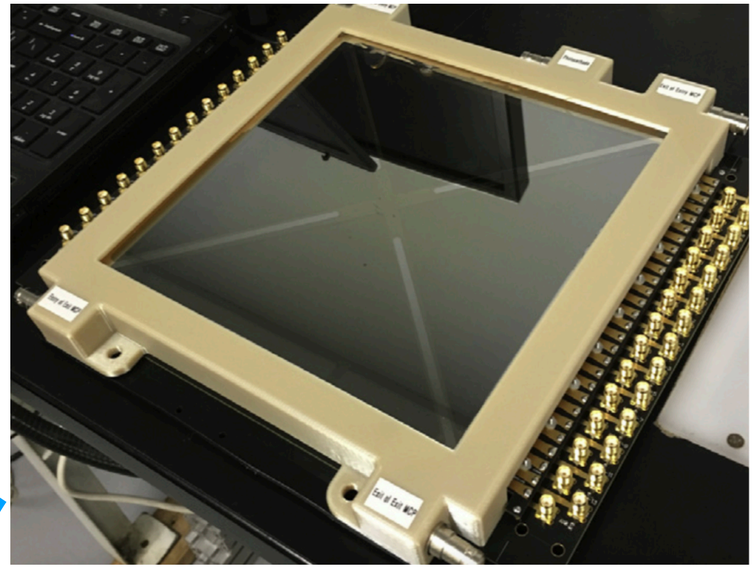


- Gadolinium's average neutron capture cross-section is high compared with pure water. Cross-section:
  * Gd: 49000 barns.
  * H: 0.3 barns.

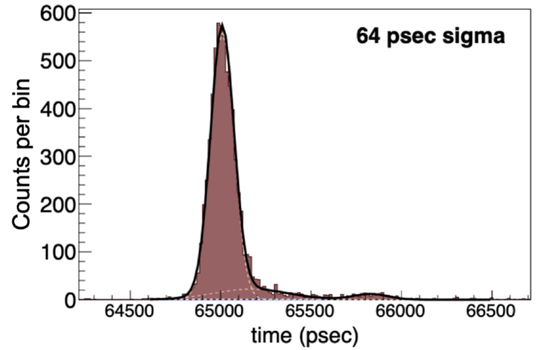
- Neutrons after thermalization, capture time:
  * Gd: 20 μs.
  * H: 200 μs.

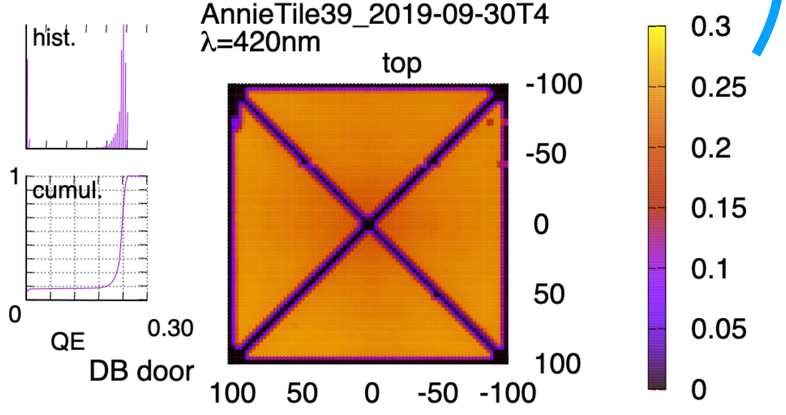
- Signature:
  * Gd: ~ 8 MeV γ cascade.
  * H: ~ 2.2 MeV γ cascade.

Technological motivation
Large Area Picosecond Photo Detector (LAPPD)



- LAPPDs are 20 x 20 cm tiles based on microchannel plates (MCPs) detectors. Each MCP is a borosilicate glass structure with millions of 20-micron-diameter **coated** capillary pores.
- The LAPPD contains 28 anode strip lines with double-sided readout mechanics, which enables a reconstruction of the photon hit on the differential timing information.
- Excellent position resolution (sub-cm scale) and timing (< 100 psec).





Nuclear Inst. and Methods in Physics Research, A 936 (2019) 527–531

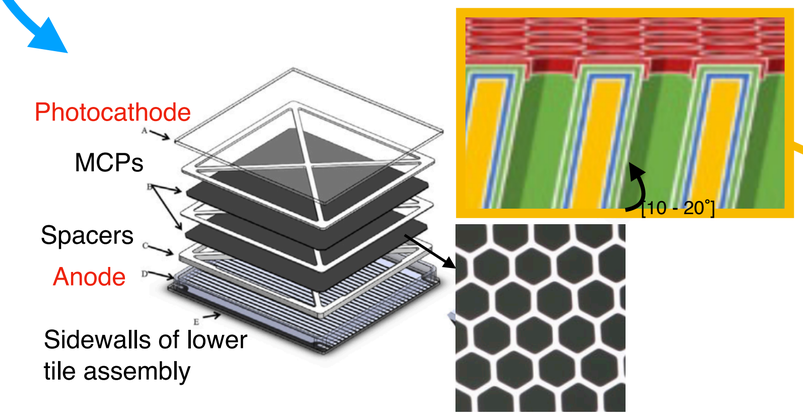
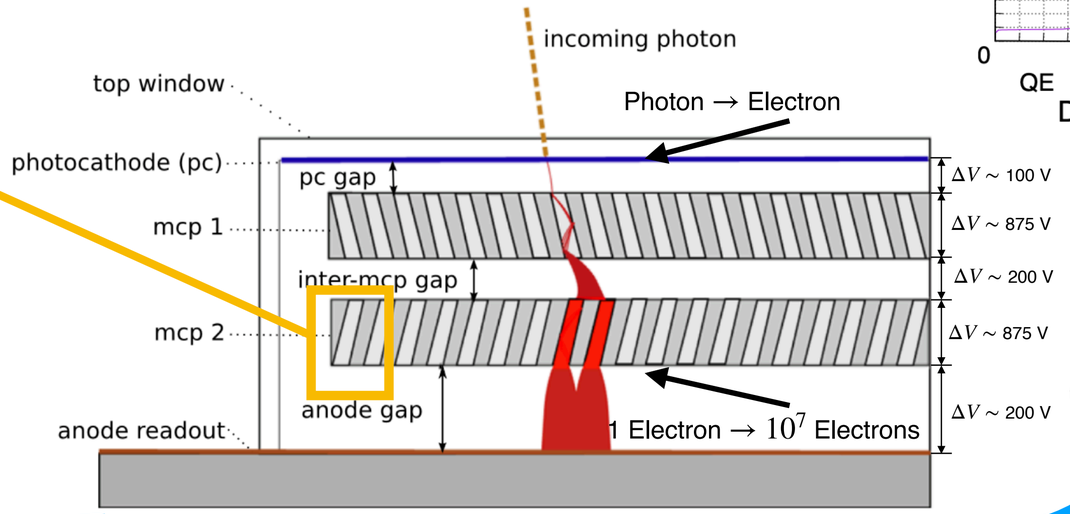
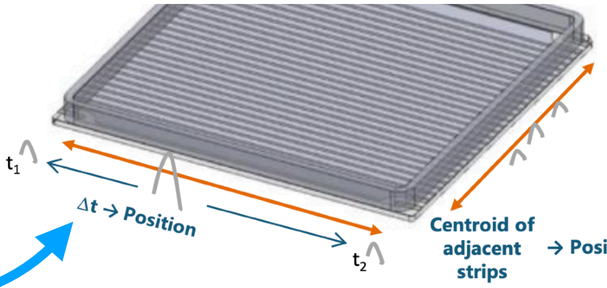
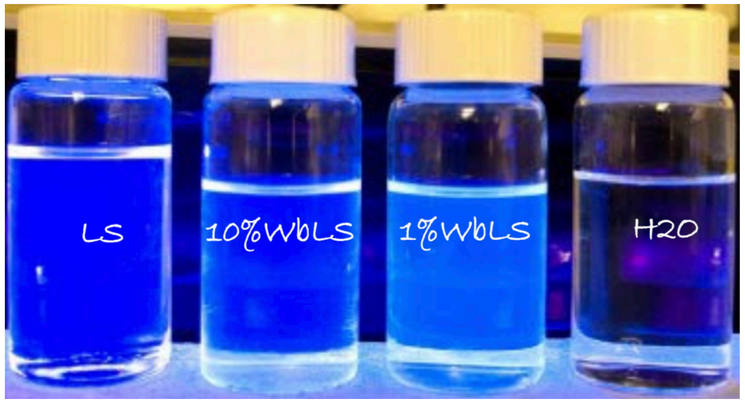


Fig. 1. Schematic design of the LAPPD.





Technological motivation
Water-based Liquid Scintillator (WbLS)

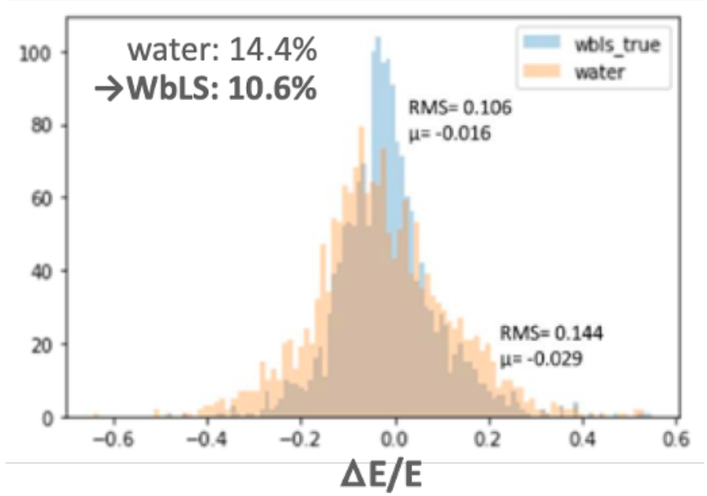


WbLS: We are using 99% water, 0.5% surfactant, 0.5% organic solvent Linear Alkyl Benzen (LAB), and 2,5-Diphenyloxazole (PPO) as fluor.

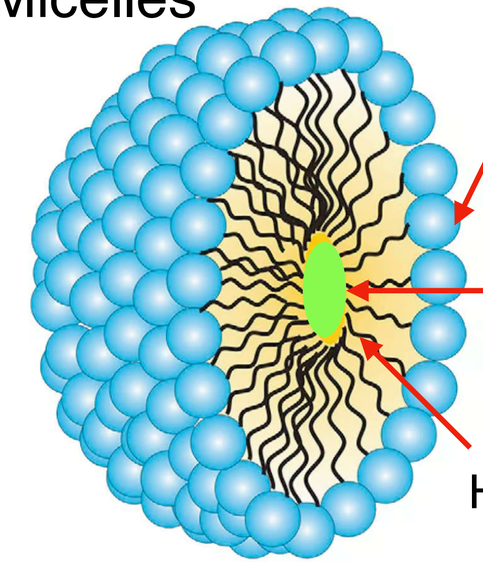
Allows hybrid detection of scintillation and (unabsorbed) Cherenkov signals.
1) Enhanced neutrino energy reconstruction.
2) Enhanced neutron signals.

WbLS for ANNIE produced at BNL (M. Yeh).
Studying possible Gd-loading.

Improved energy reco in ANNIE



Micelles

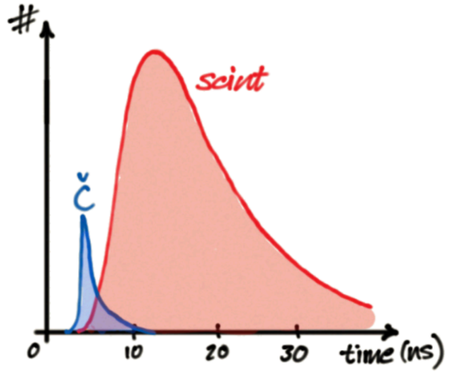


Hydrophilic head

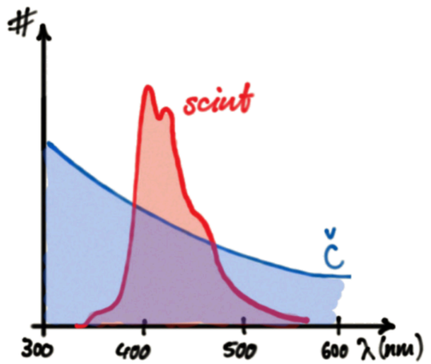
Solvent + fluor

Hydrophobic tail

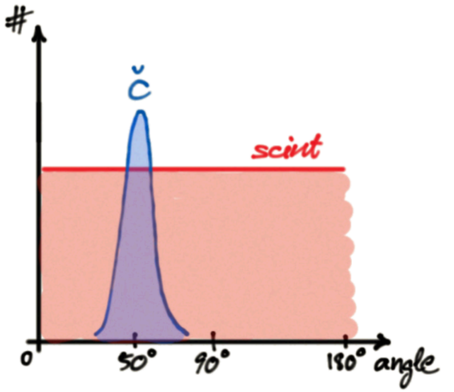
Credit: Gnác Capek



We will see in ANNIE



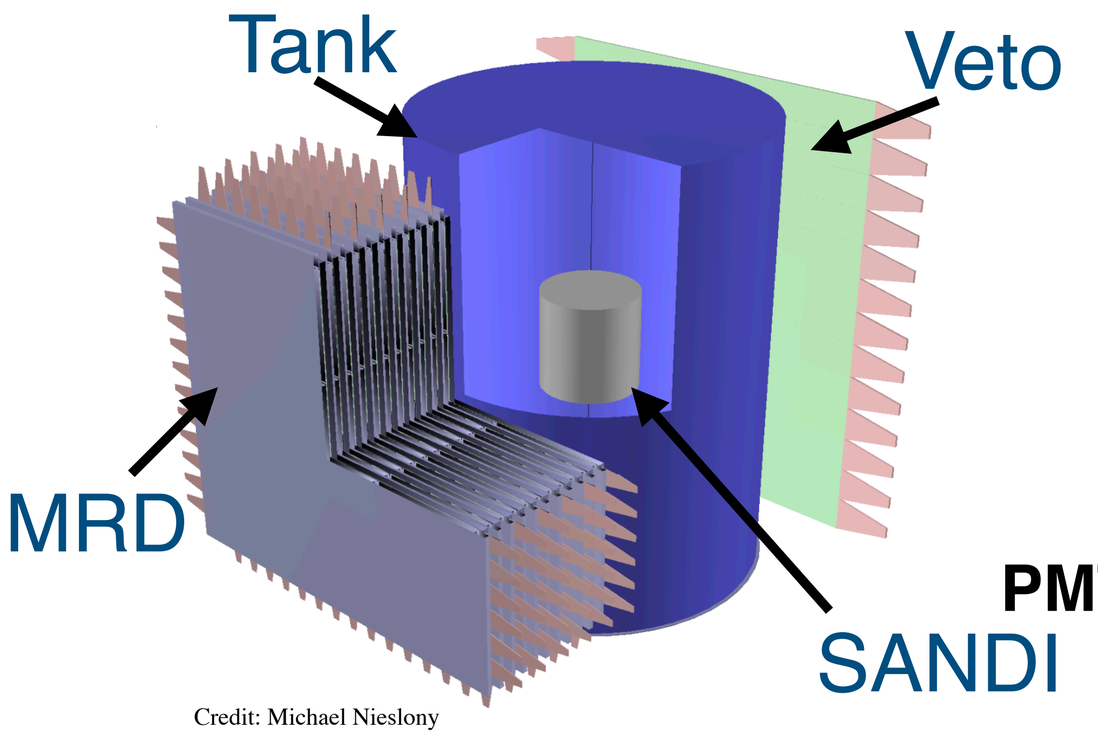
We won't see in ANNIE



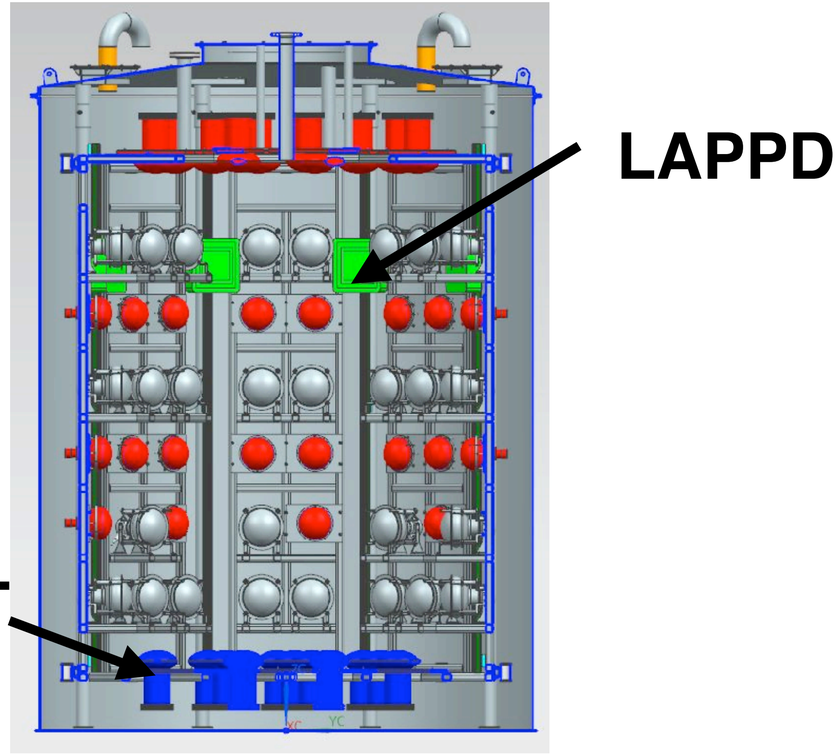
We will see in ANNIE

ANNIE Detector

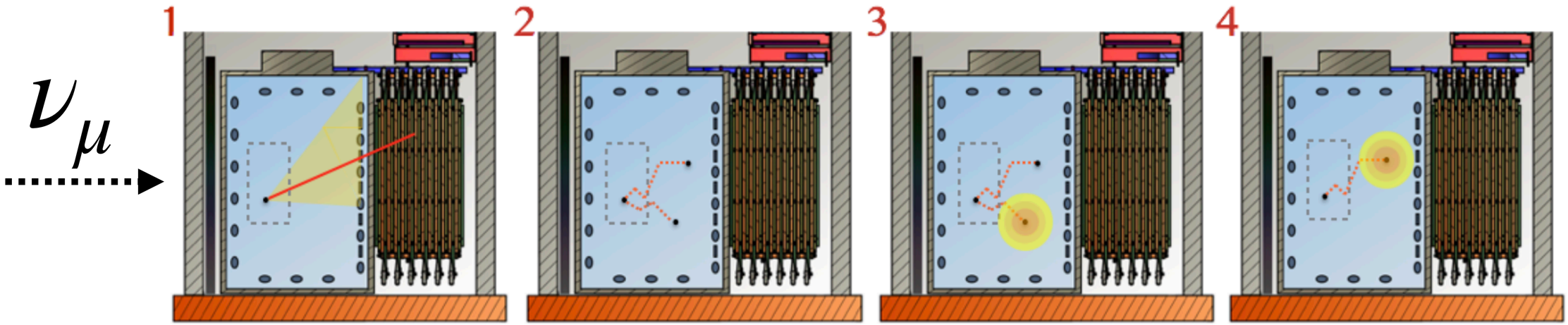
ANNIE detector components



Credit: Michael Nieslony



ANNIE



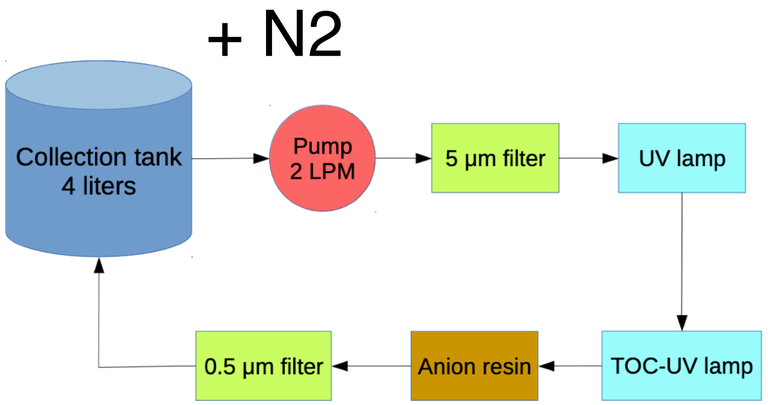
1. The neutrino interacts via CC in the fiducial volume producing charged lepton. Vertex reconstruction with LAPPDs and kinematics in MRD.

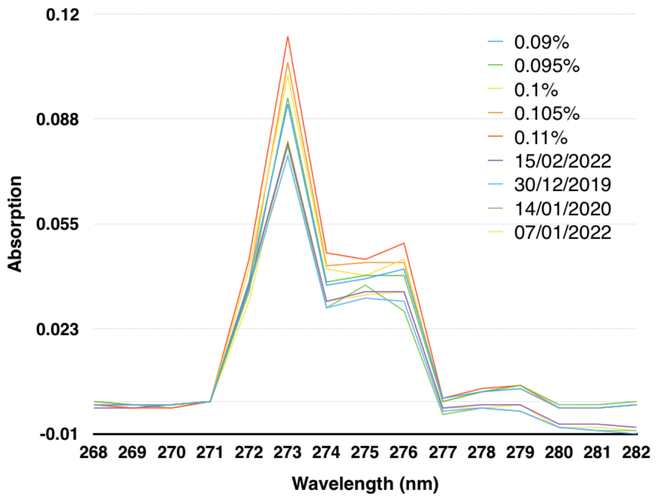
2. Neutrons travel, scatter, and thermalize.

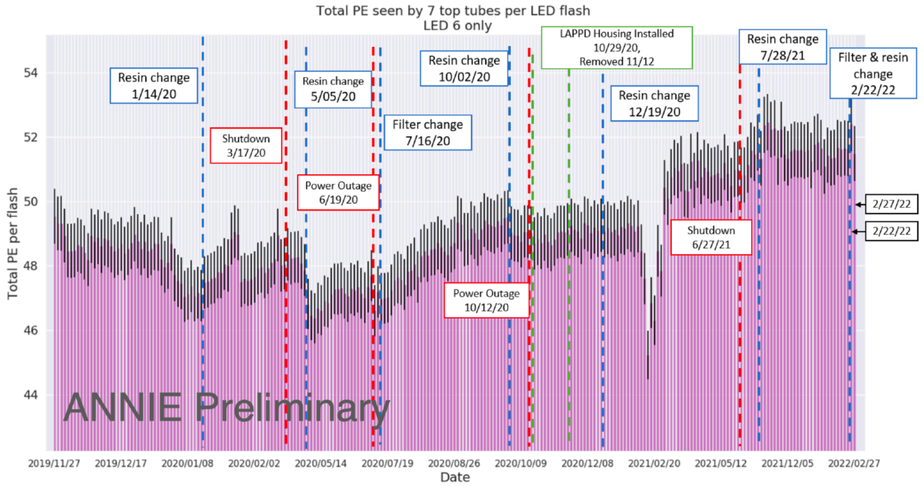
3 and 4. Thermalized neutrons are captured on the Gd producing flashes of light by standard PMTs.

Current ANNIE status

- Gd-Water







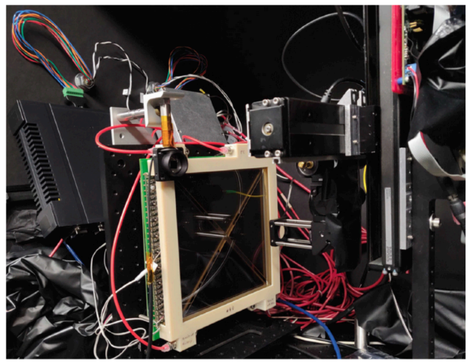
Taken from Emily Pottebaum

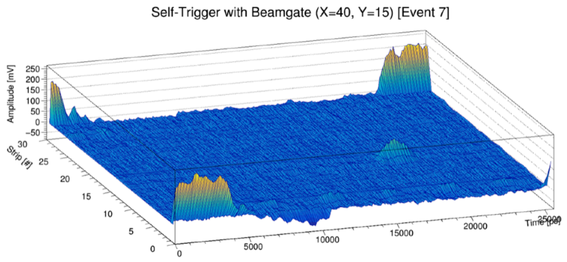
- ANNIE (27-ton Gd-H2O) has a water system to clean the Gd-water.
- UV-vis measurements are performed regularly to monitor the Gd concentration,
- With the LED system installed in the tank, we monitor the water transparency.

Current ANNIE status

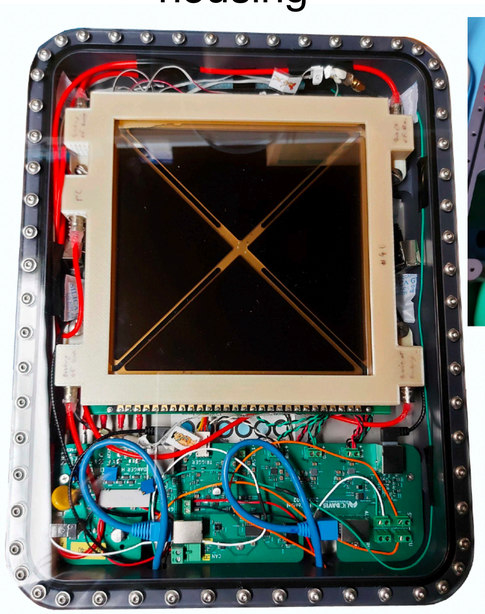
LAPPDs

Characterization and Integration Testing

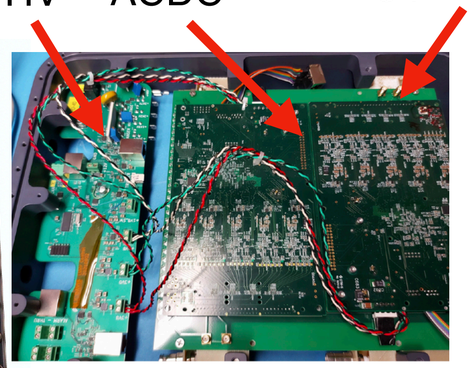


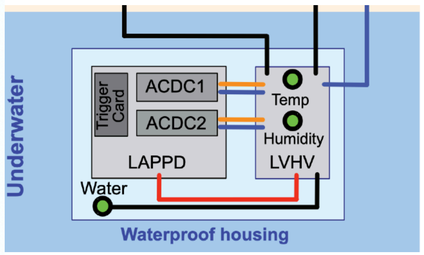


Waterproof housing



LVHV ACDC Analog pickup card

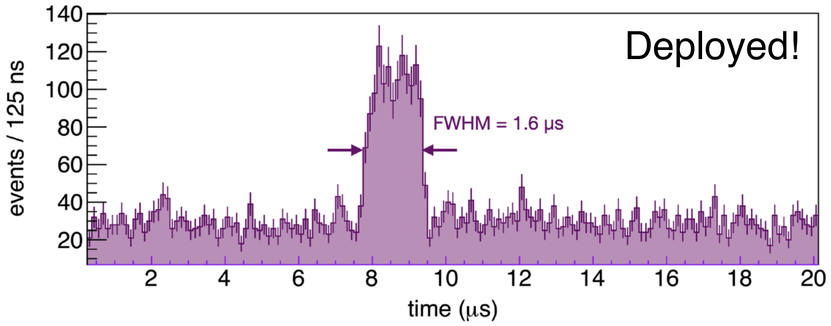




Credit: Michael Nieslony

Fast Electronics

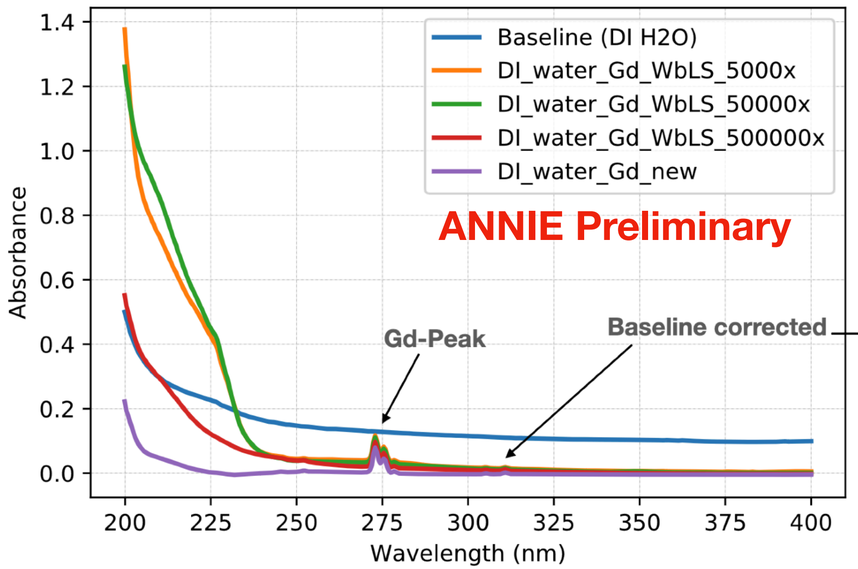
- ACDC: PSEC chips capture signals from both sides of each stripline and it has 10 GS/s, 25 ns buffer.
- LAPPD triggers asynchronously within a 20 us (adjustable) beam window.

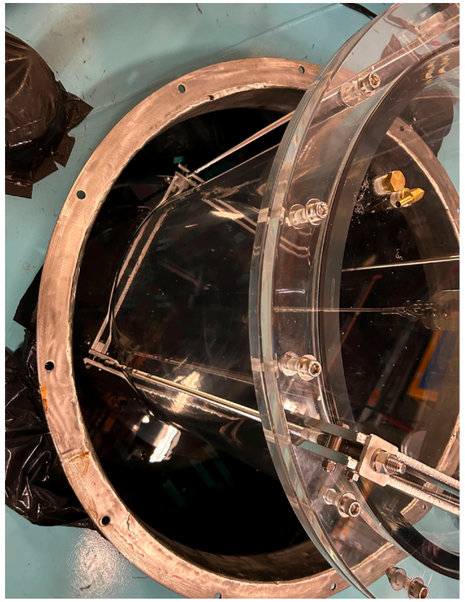


- ANNIE aims to deploy 5 LAPPDs.
- We deployed 1 last year and 2 this year. So, we have **3 working LAPPDs in Gd-Water.**
- Data acquisition with multiple LAPPDs

Current ANNIE status

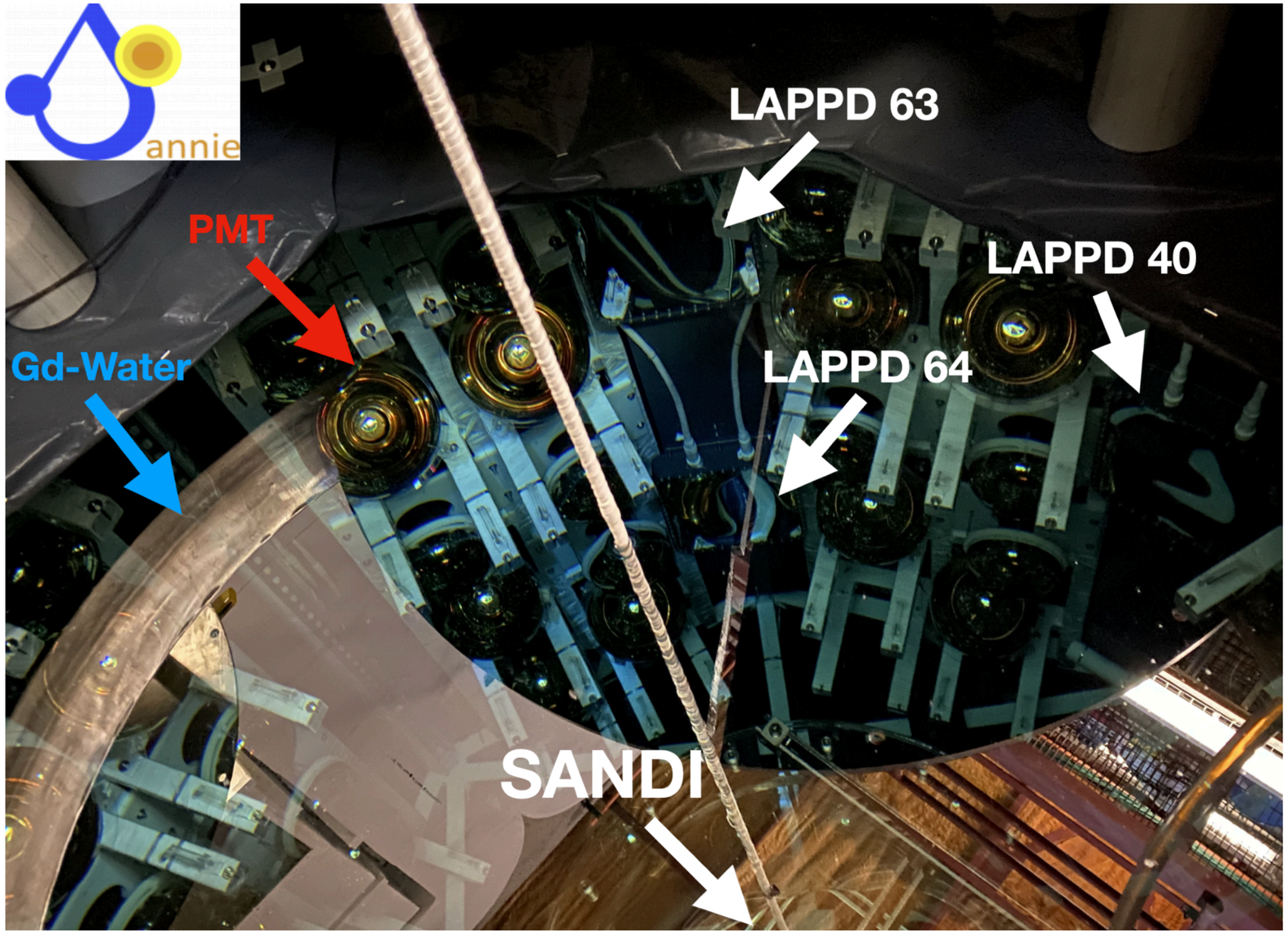
- WbLS





- The Scintillator for ANNIE Neutrino Detection Improvement (SANDI) is an acrylic vessel of ~ 365 kg of WbLS.
- SANDI with WbLS was **deployed**.
- We collected data from March to May 2023.
- The first analysis is ongoing.

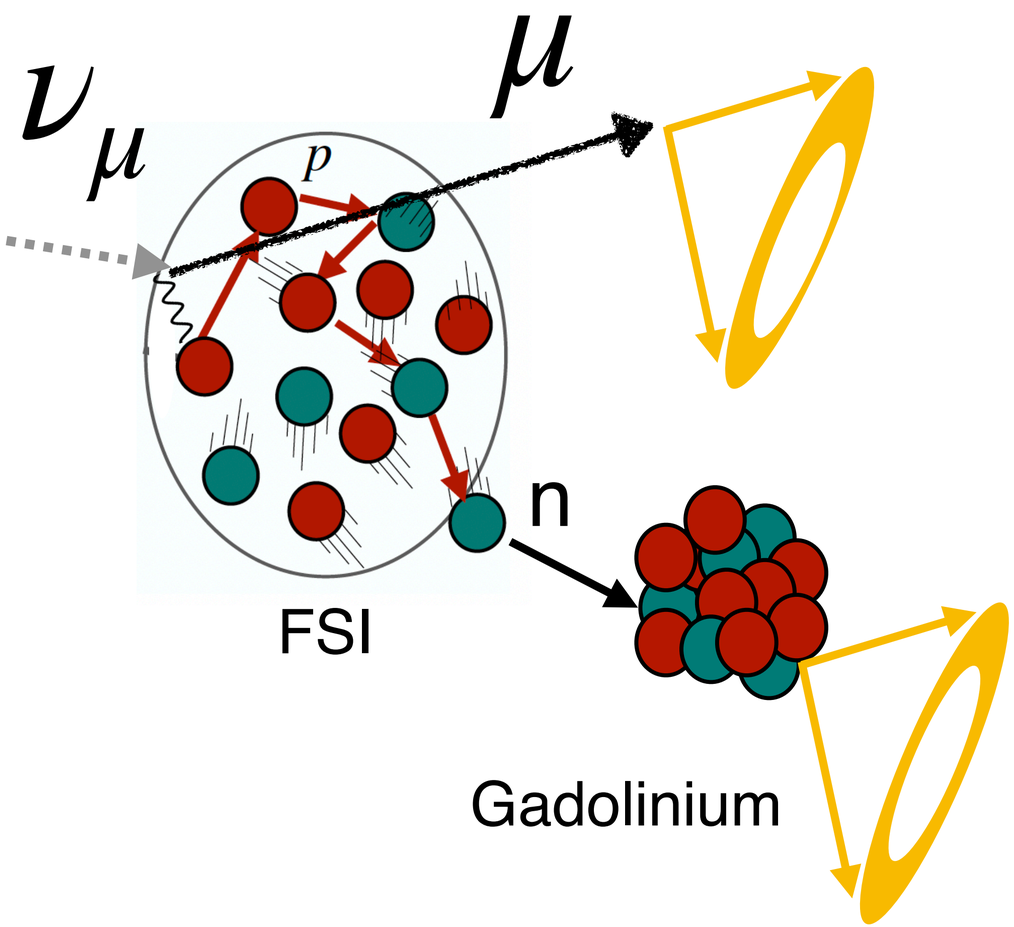
Summary



Thank you!

Backup slides

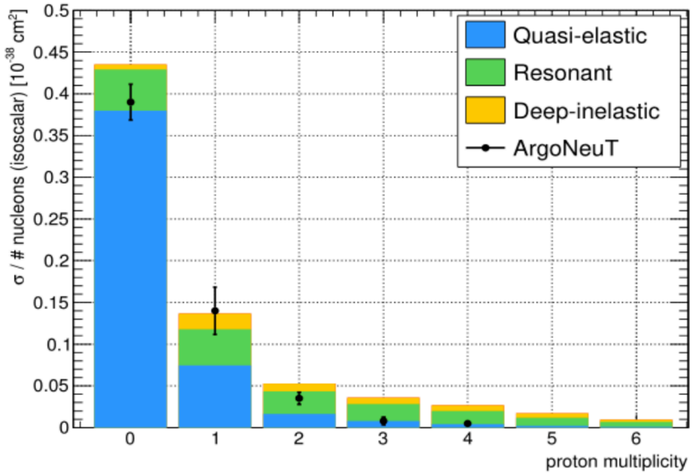
First application of Gd-loaded water on a neutrino beam

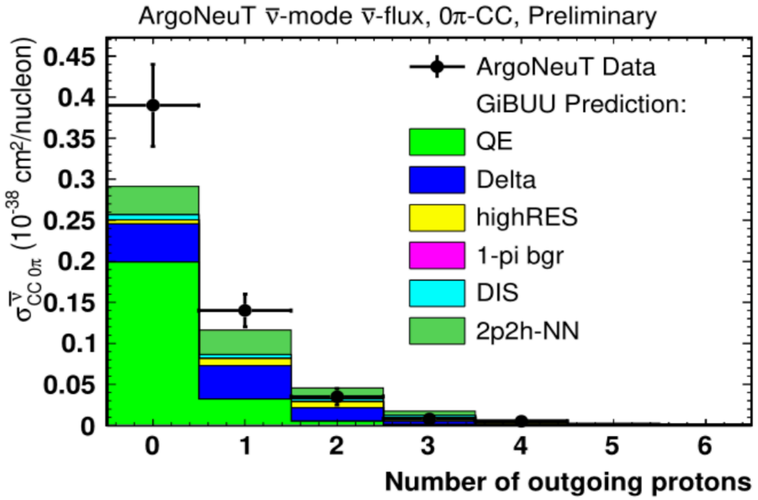


- Gadolinium's average neutron capture cross-section is high compared with pure water. Cross-section:
  * Gd: 49000 barns.
  * H: 0.33 barns.
- Neutrons after thermalization, capture time:
  * Gd: 20 μs.
  * H: 200 μs.
- Signature:
  * Gd: ~ 8 MeV γ cascade.
  * H: ~ 2.2 MeV γ cascade.

Backup slides

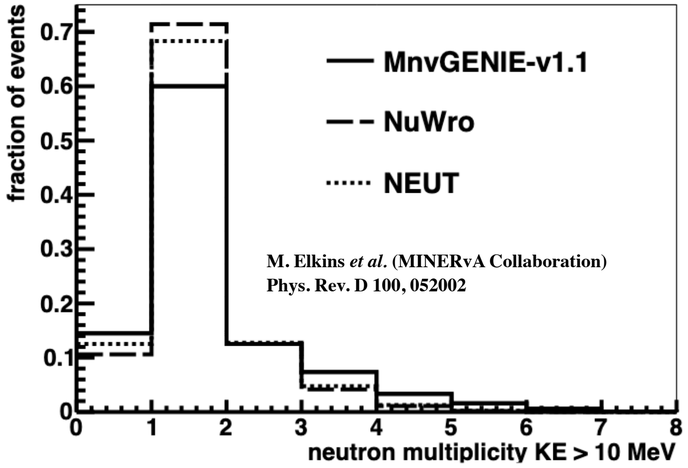
Liquid Argon **proton** multiplicity





https://doi.org/10.7566/JPSCP.12.010017

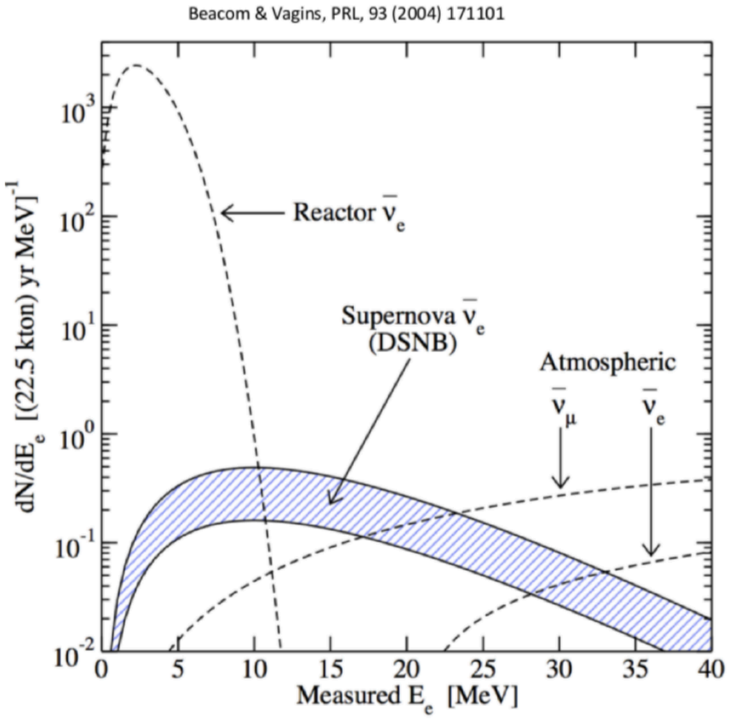
Monte Carlo **neutron** multiplicity



Study the multiplicity of final state neutrons from neutrino-nucleus interactions in water.

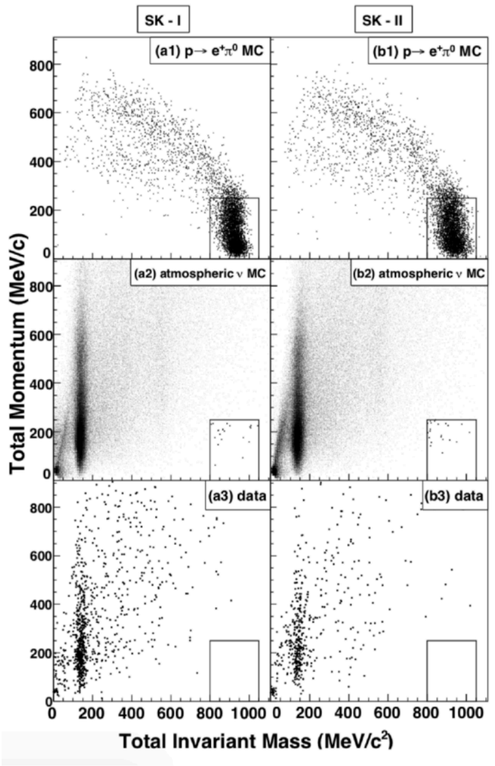
Backup slides

DSNB search



Proton decay search

PRL 102 (2009) 141801



proton decay

atmospheric

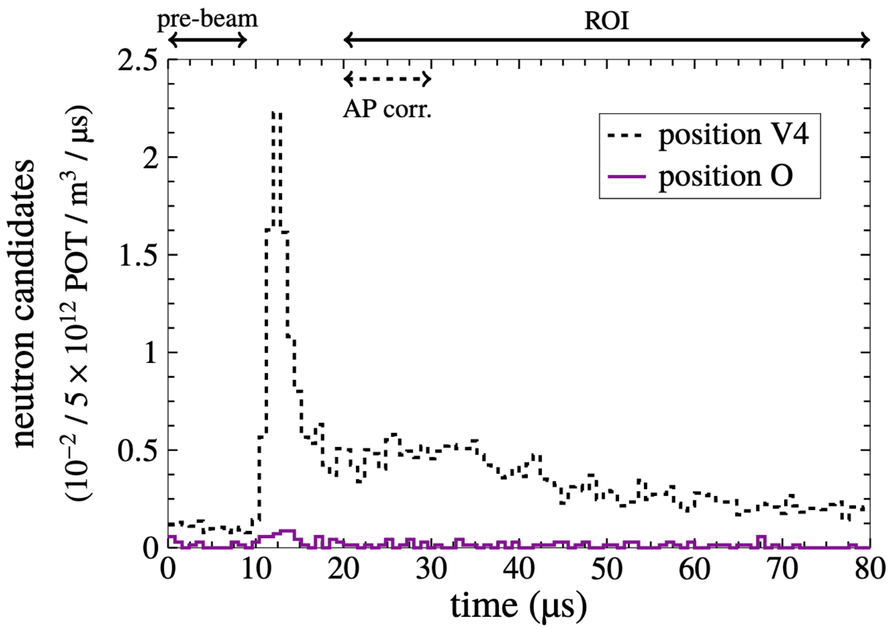
data

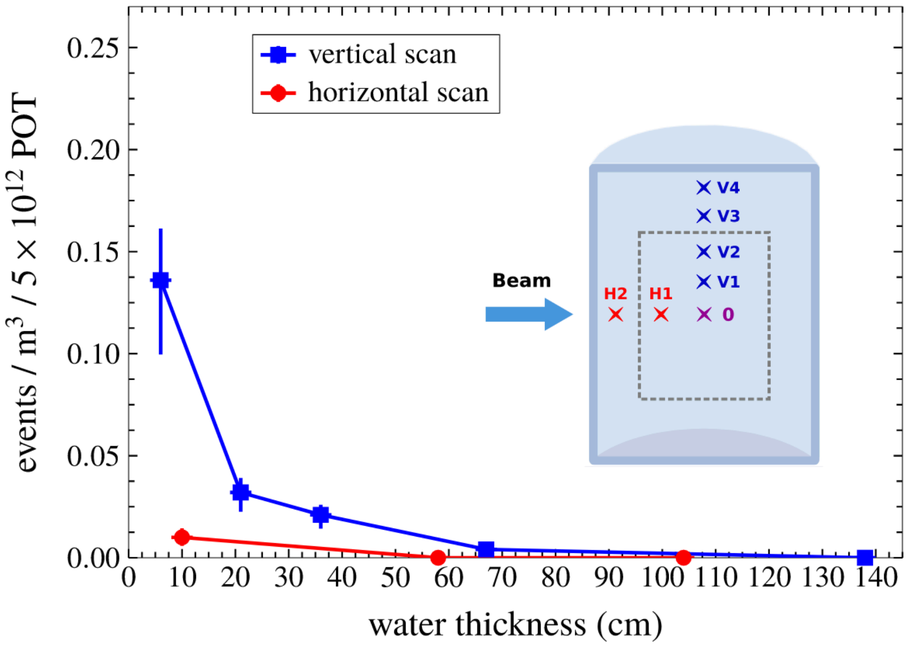
Neutron multiplicity helps to understand and reduce atmospheric neutrino backgrounds to **Proton Decay** and **Diffuse Supernova Neutrino** measurements.

Backup slides

Phase I results:

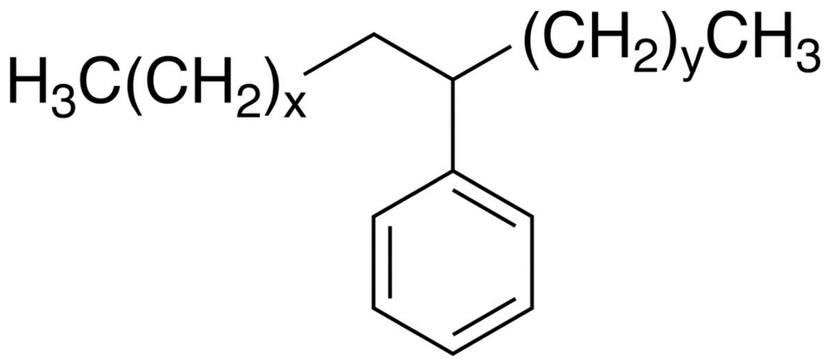
Beam-correlated neutron candidate event rates measured during ANNIE Phase-I.





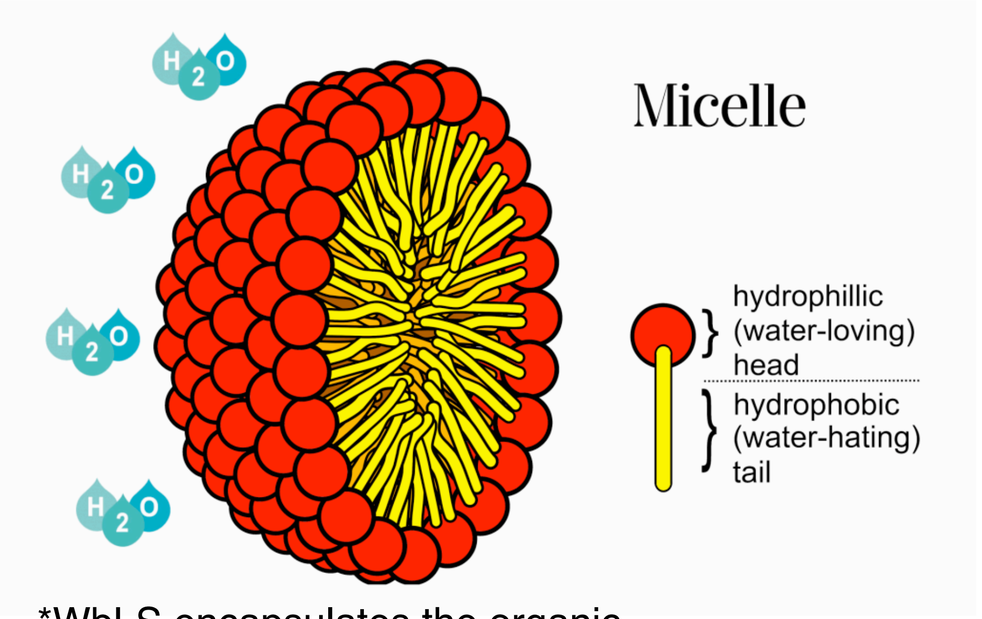
Backup slides

Conventional scintillator



*The charged particle excites the benzene ring via ionization.
*The ring is then de-excited by emitting a photon, which then is absorbed by a wave-shifting fluor.
*Organic liquids are almost always not miscible in water.

WbLS

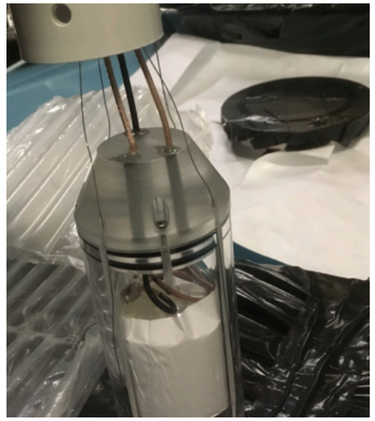


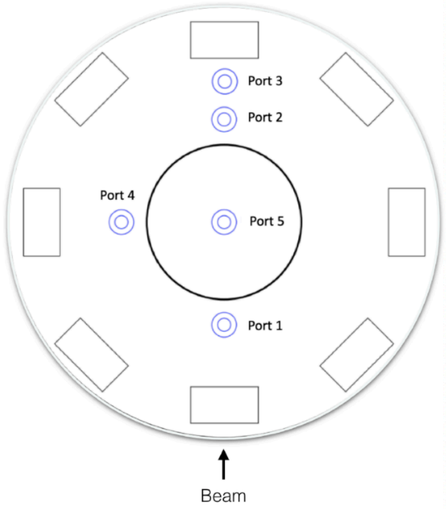
*WbLS encapsulates the organic liquid in tiny micelles (100-nanometer scale)

surfactants -> chain molecule
-> (hydrophillic and hydrophobic c. end)

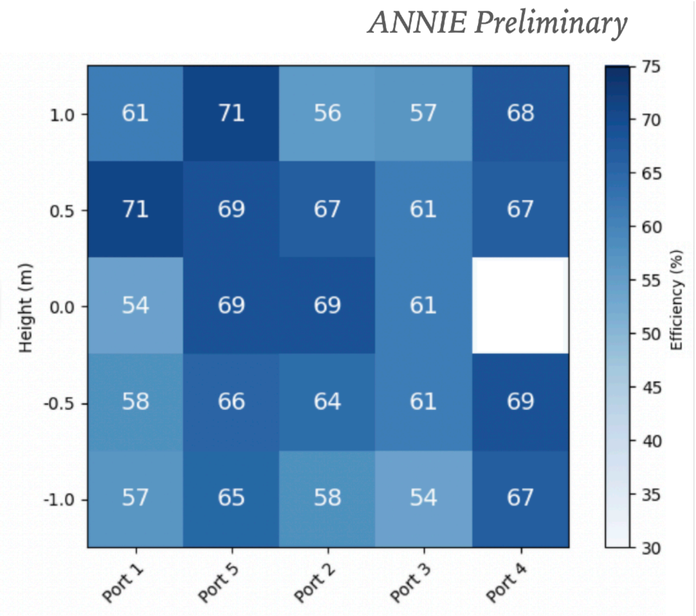
Backup slides

- AmBe source





courtesy of Leon Pickard



Calibration:

- We have to know the position-dependent neutron capture efficiency.