ANNIE:
Accelerator Neutrino Neutron Interaction Experiment

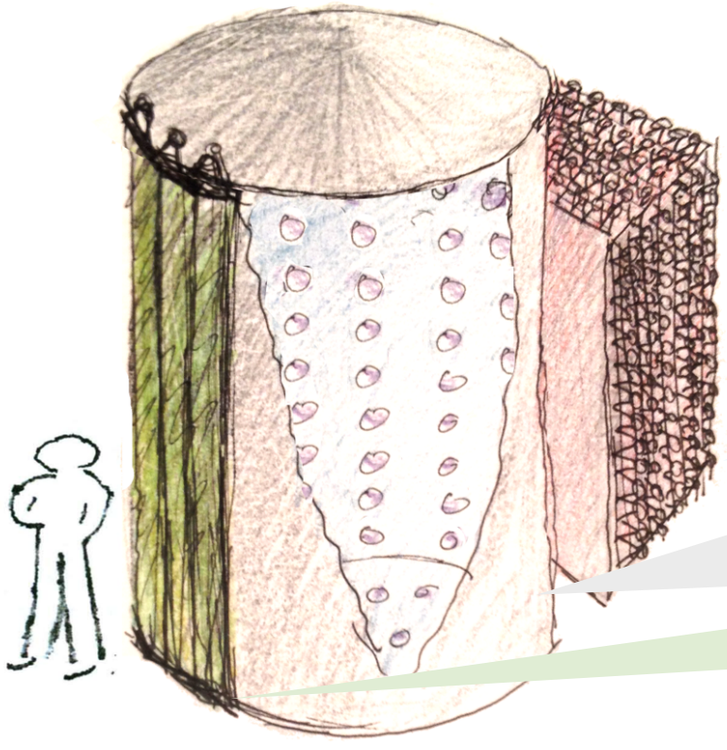
A physics experiment to understand the complexities of neutrino interactions with matter, measuring the abundance of neutrons knocked out by collisions with oxygen nuclei.

First application of LAPPDs in an HEP neutrino experiment.

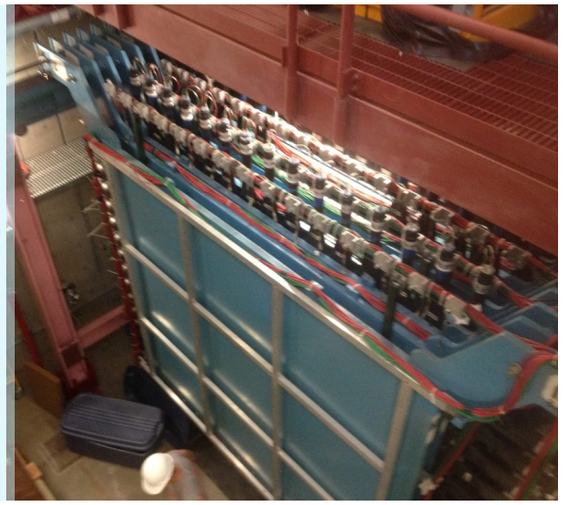
First use of Gd-loaded water on a high-E neutrino beam.

Phase I approved and under construction at Fermilab.

Proposal submitted for the main Physics Phase (w/ LAPPDs) through the DOE Intermediate Neutrino Program.

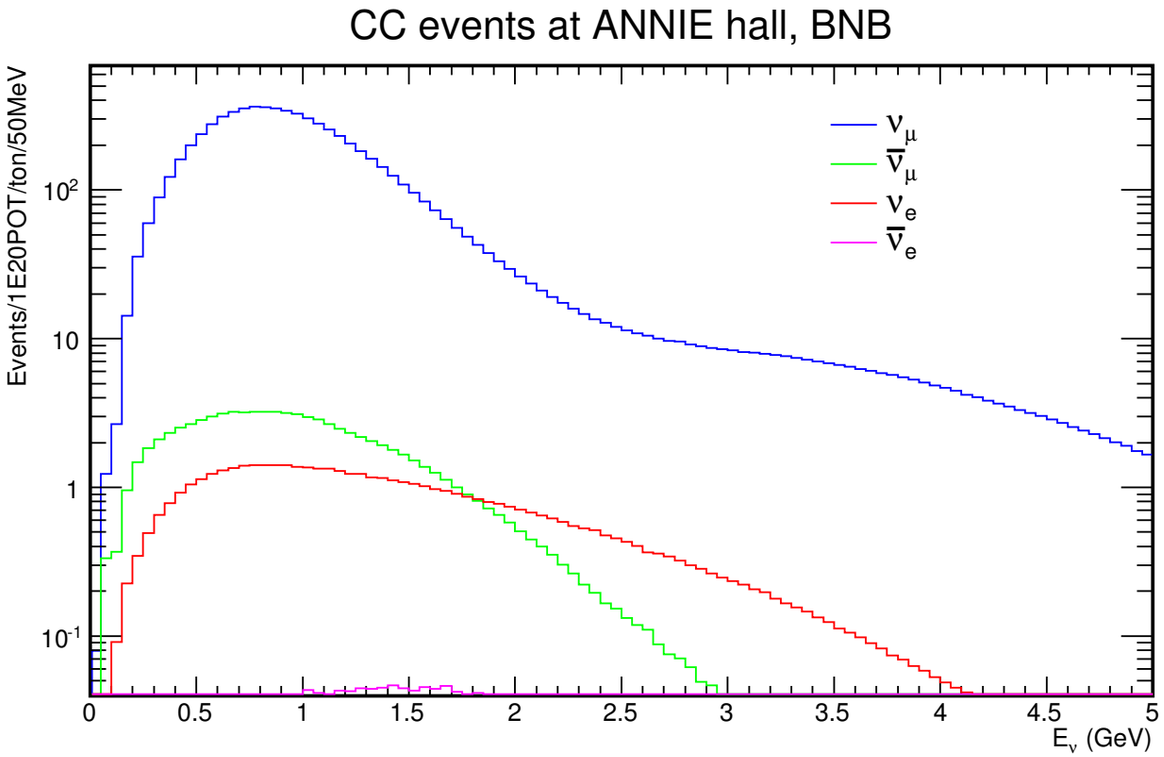


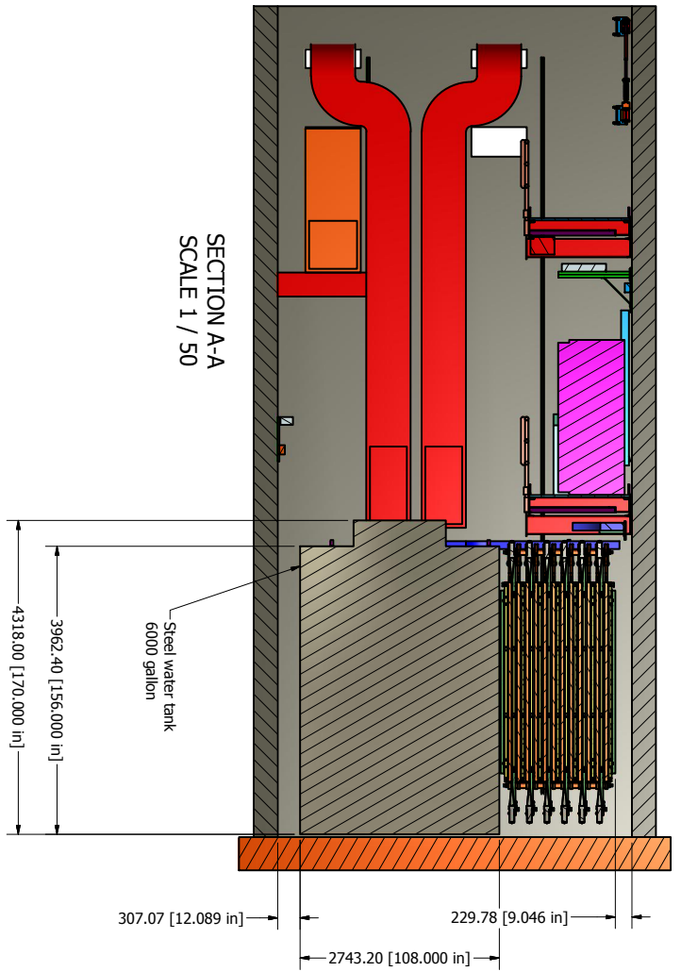
Participation from 10 institutions in the US and UK.



ANNIE: Beam and Facility

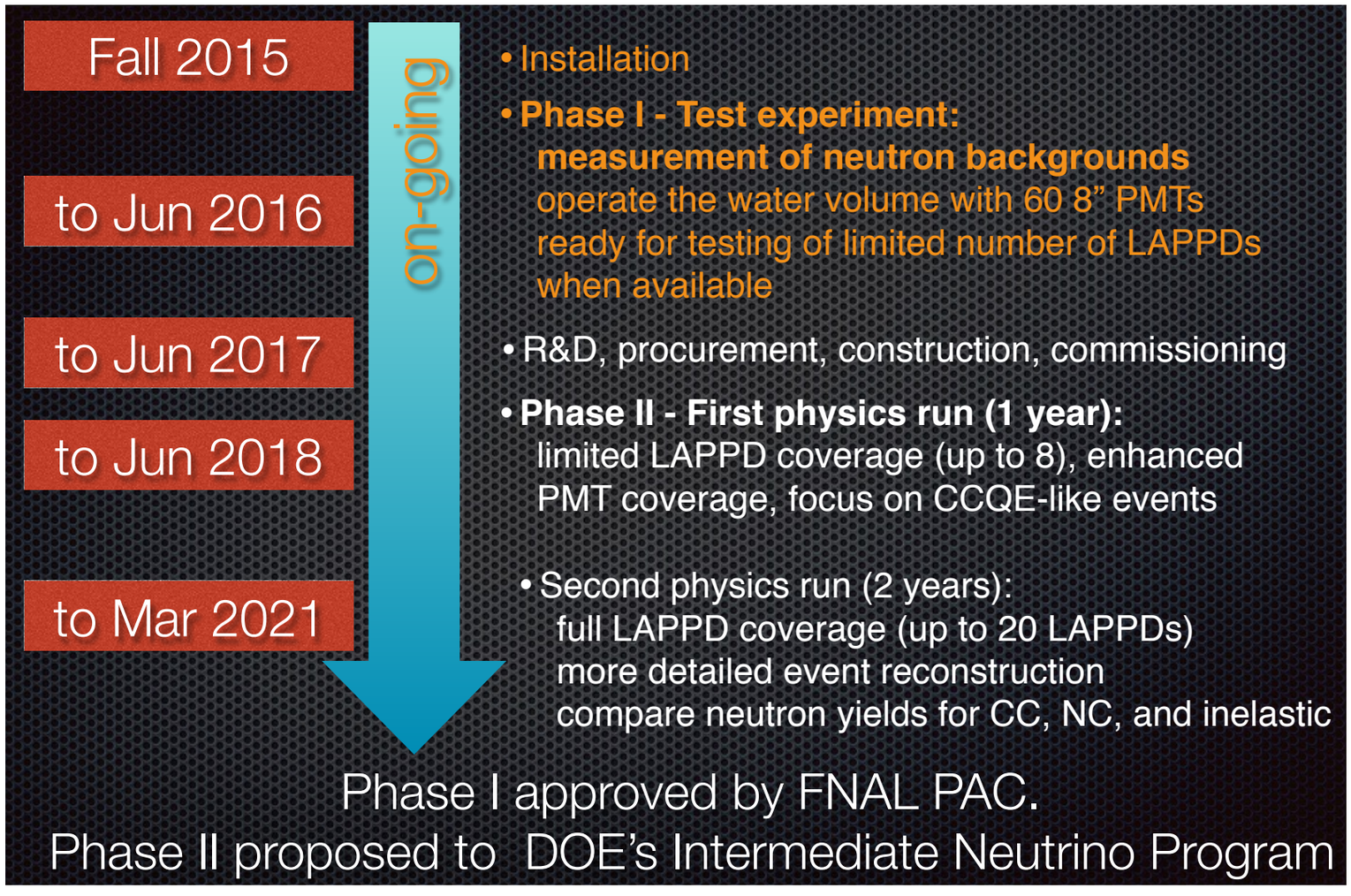
- “ANNIE Hall”: A neutrino test beam!
- High intensity: ~10k CC events per cubic meter per year
- Spill rate 7.5 Hz, <1 interaction per spill
- Part of the short baseline program (high priority running)
- Relevant energy for proton decay background studies.
- At turn-on for resonance events





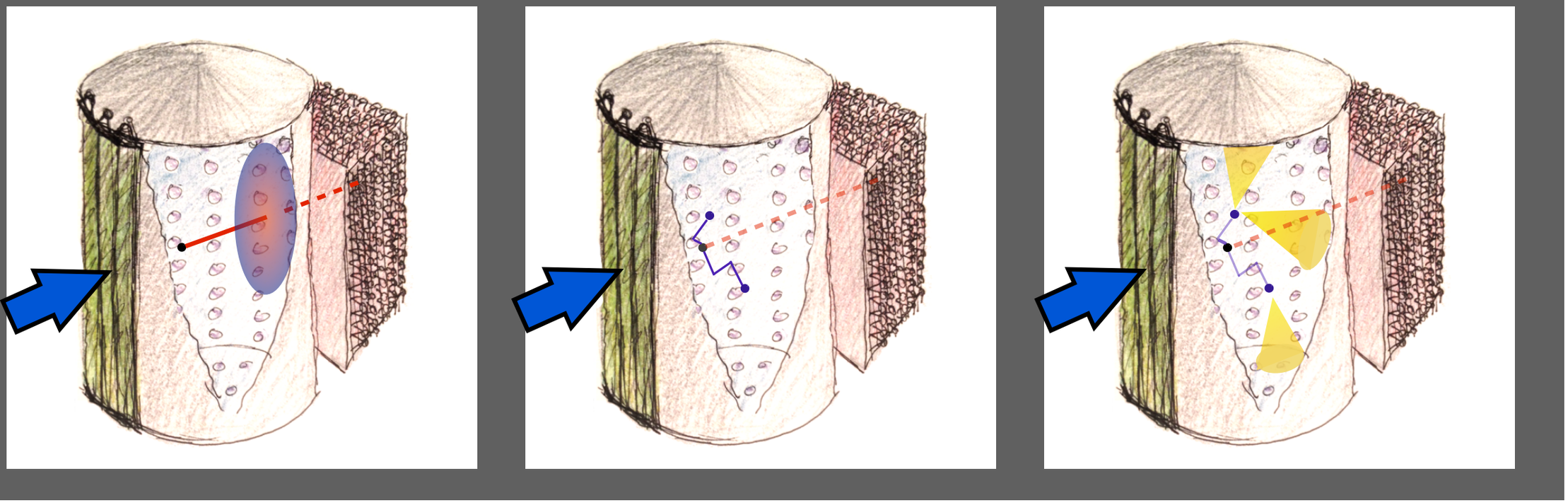
ANNIE: Status, timeline, and needs

By summer of this year ANNIE will offer a fully-built, beam-ready experiment in which to test LAPPDs and PSEC electronics. The PSEC system will primarily be used for the LAPPDs, but we are planning on also using it to read out conventional phototubes.



for more info: annie.fnal.gov

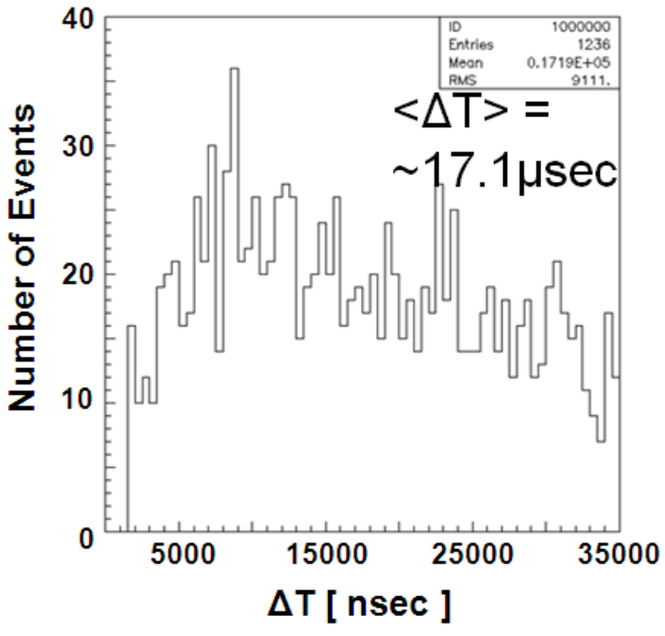
ANNIE: Event structure



prompt event (muon + stuff)

neutrons thermalize

Gd captures

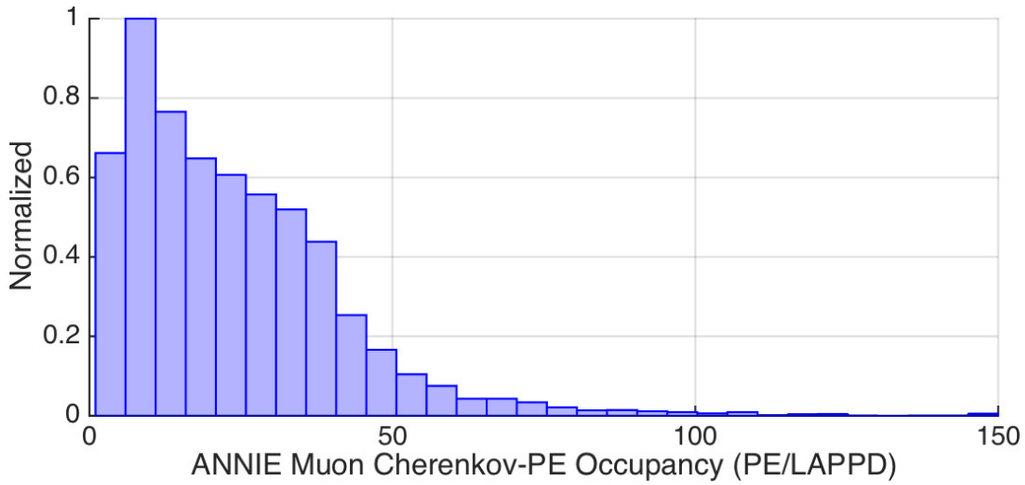


- Neutron captures happen on the order of tens of microseconds.
- In ANNIE, the prompt event will occupy many channels. Timing of the capture is close enough to be “on the edge” with respect to the channels being live on time.
- In larger detectors and at lower energies, prompt events might only render a sparse distribution of LAPPD channels dead.
- Still, multi-buffering (PSEC4a) would be nice

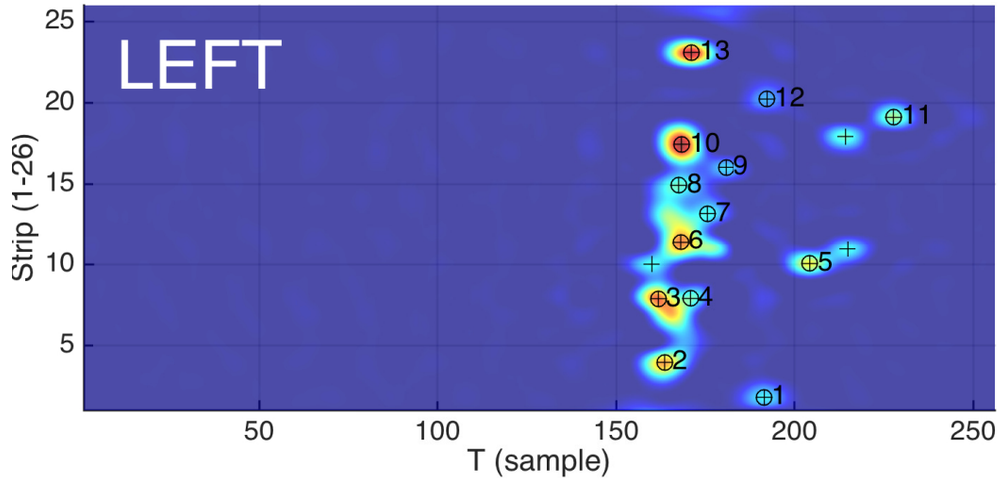
ANNIE: Photon Pileup

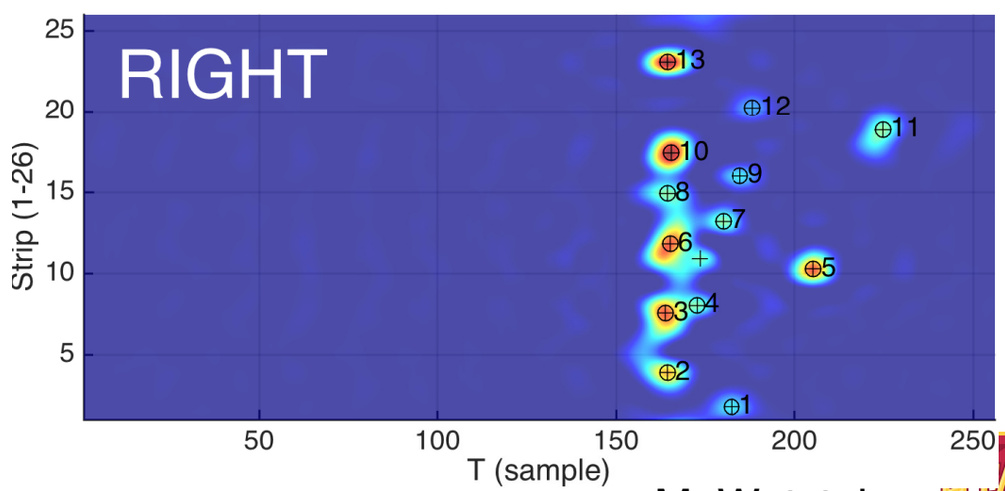
credit:

Glenn Jocher (Ultralytics, LLC)
Shawn Usman (NGA)

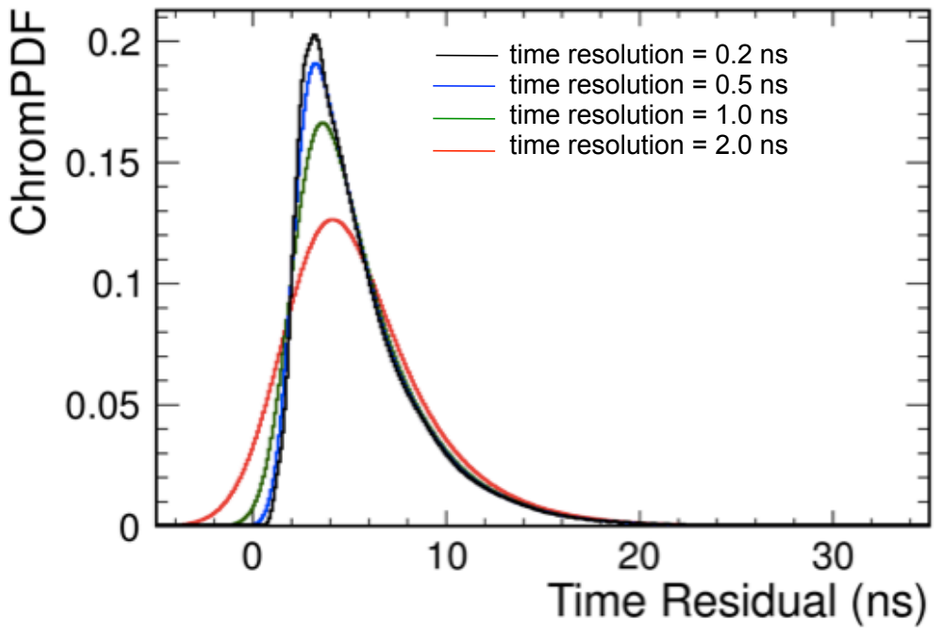


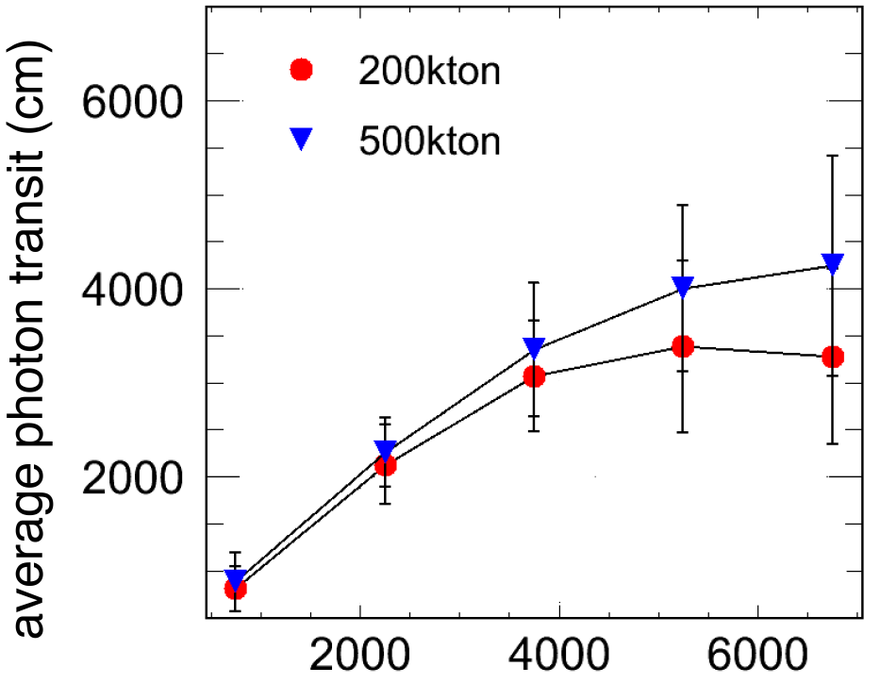
- With Cherenkov light, ANNIE will generally see ~1 hit per channel in LAPPDs.
- Given, the small form factor (10 ft x 13 ft) a high fraction of channels will be hit and some channels will receive multiple hits.

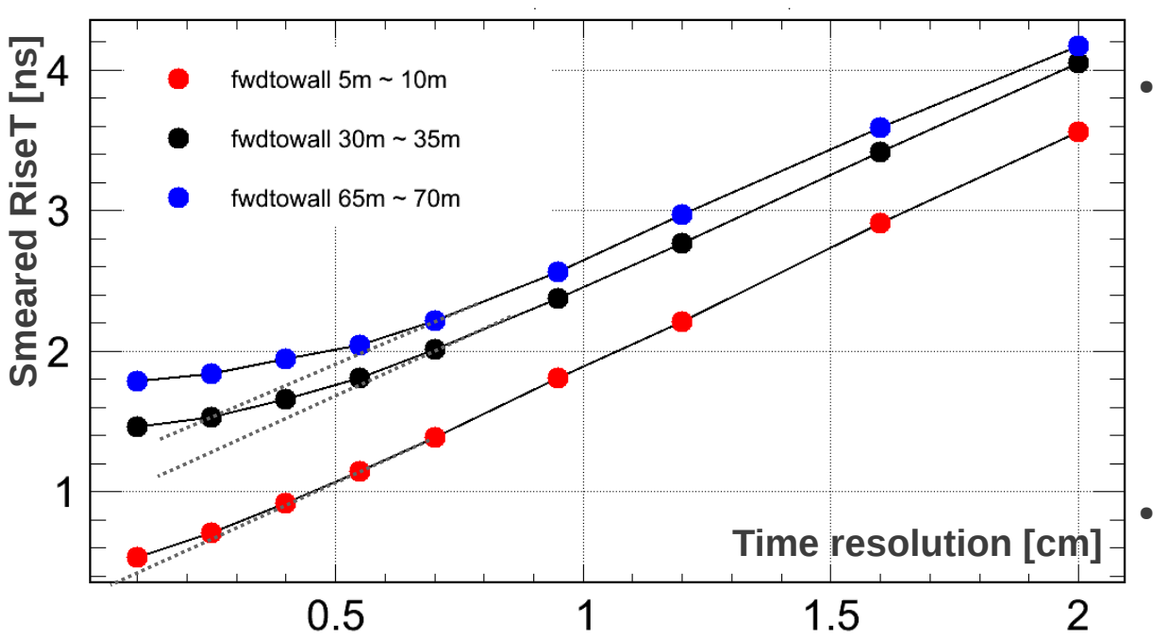


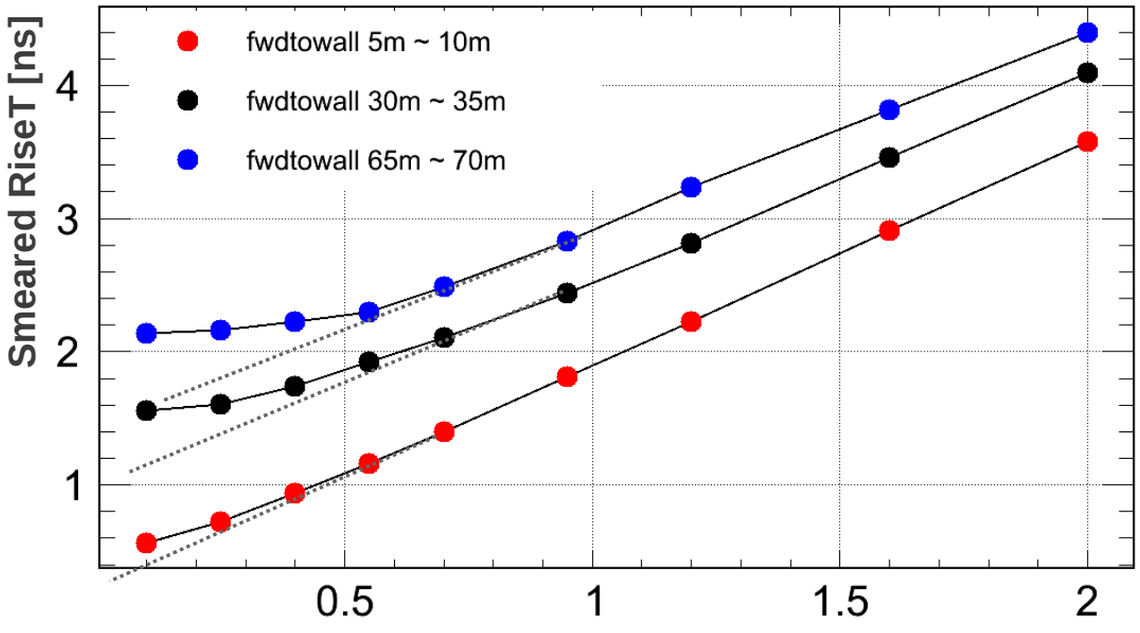


ANNIE: Timing needs for Cherenkov in general

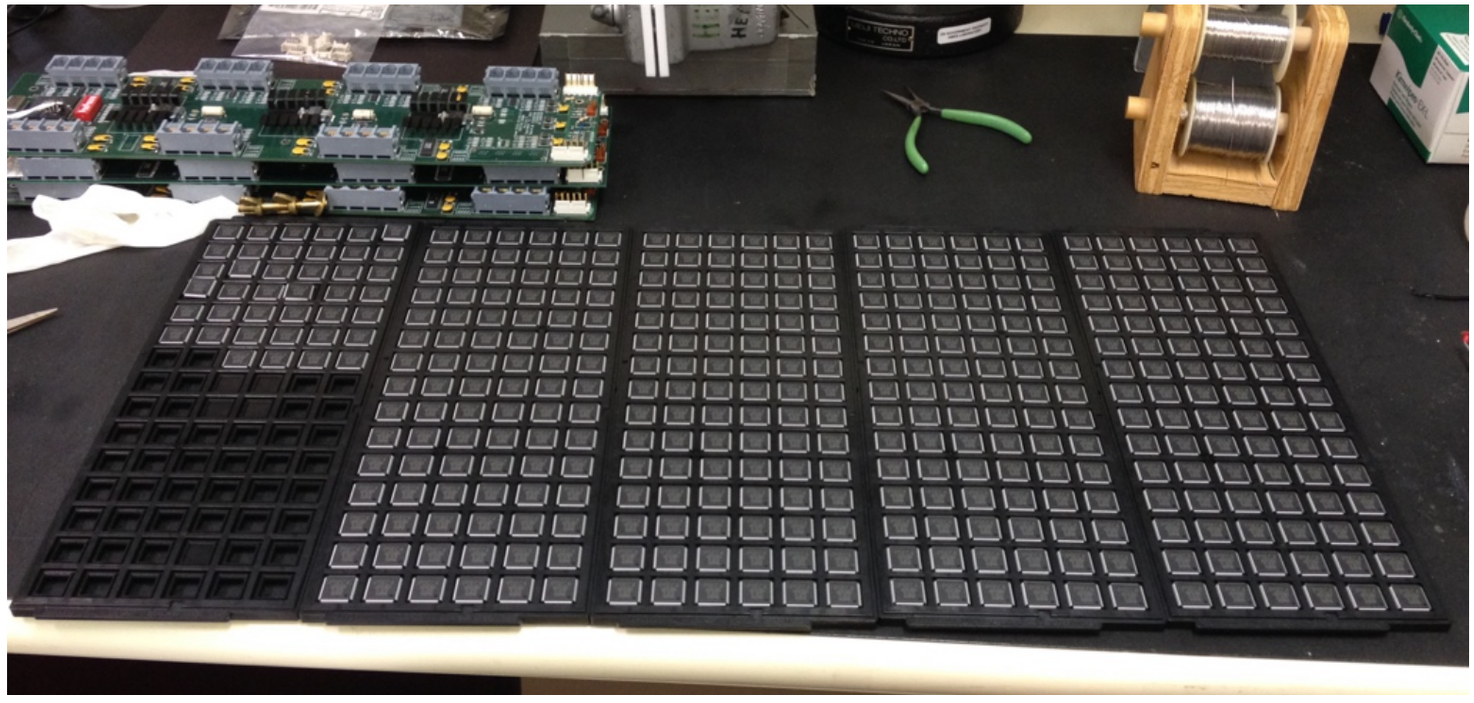








ANNIE and PSEC



- ANNIE will be using PSEC4, rather than PSEC4B
- The existing PSEC4 will work for our needs:
  - Prompt light will occur within the buffer
  - We have an alternative, conventional PMT system to see delayed Gd-captures
  - We can use PSEC chips like TDCs for the Gd capture, even while the prompt pulses are being digitized
  - Given the sparseness of the Cherenkov light, and low BNB event rate, many channels may still be live for the capture.
- *Triggering and readout of individual channels (rather than chips) would be nice.*
  - This is a firmware, not hardware issue (I think)

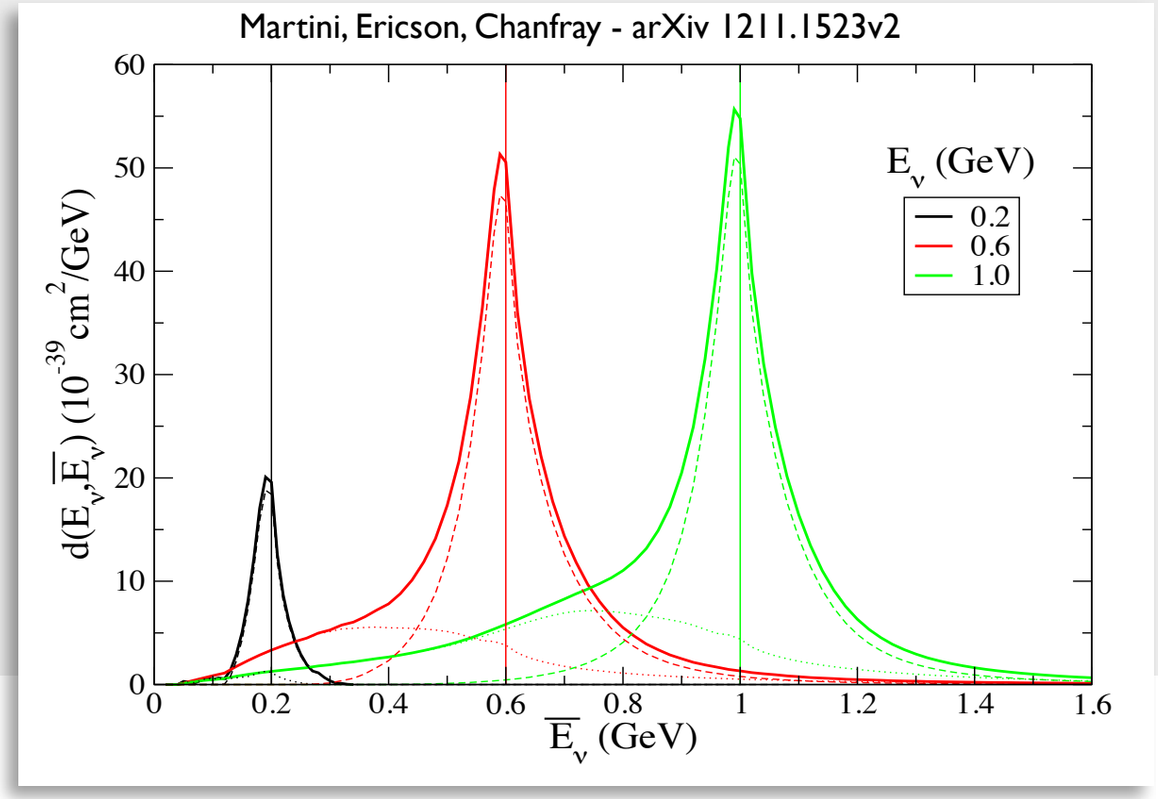
- Nonetheless, we want to take the opportunity to think about scaling to larger detectors

Backup Slides

ANNIE: Physics

To turn neutrino physics into a precision science we need to understand the complex multi-scale physics of neutrino-nucleus interactions.

- Dominant source of systematics on future long baseline oscillation physics
- Source of uncertainty and controversy in short baseline anomalies
- We need comprehensive and precise measurement for a variety of targets/E_ν



ANNIE is a final-state X + Nn program to complement X + Np measurements in LAr

The presence, multiplicity and absence of neutrons is a strong handle for signal-background separation in a number of physics analyses!

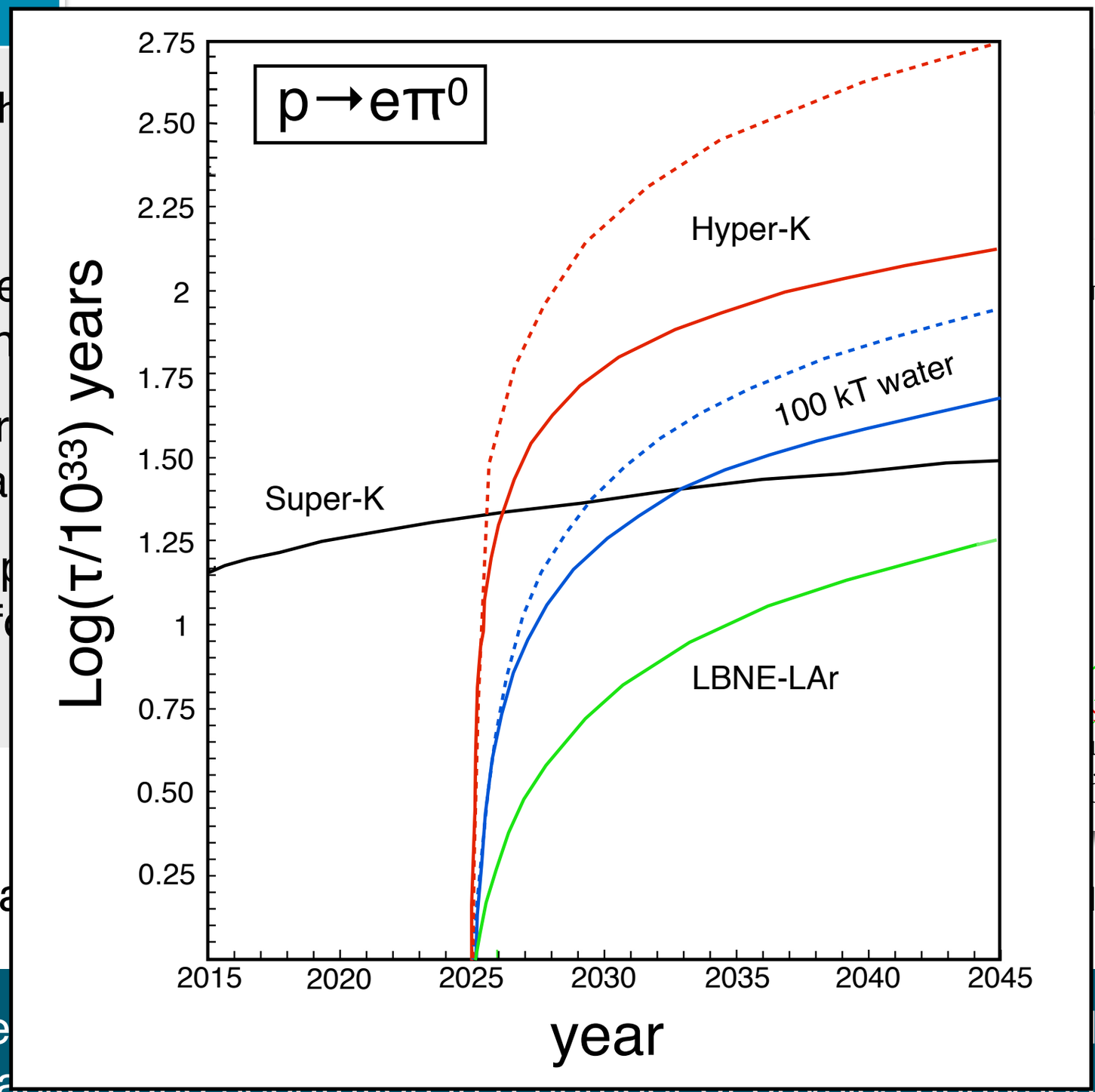
ANNIE: Physics

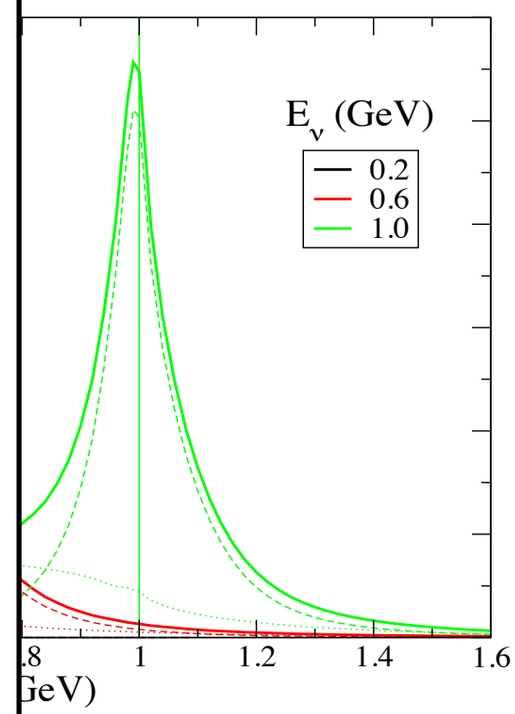
To turn neutrino ph… …omplex multi-

- Dominant source… long baselin…
- Source of uncer… short ba…
- We need comp… measurement f…

ANNIE is a fina… …rements in LAr

The presence… …le for signal-background separation in a number of physics analyses!





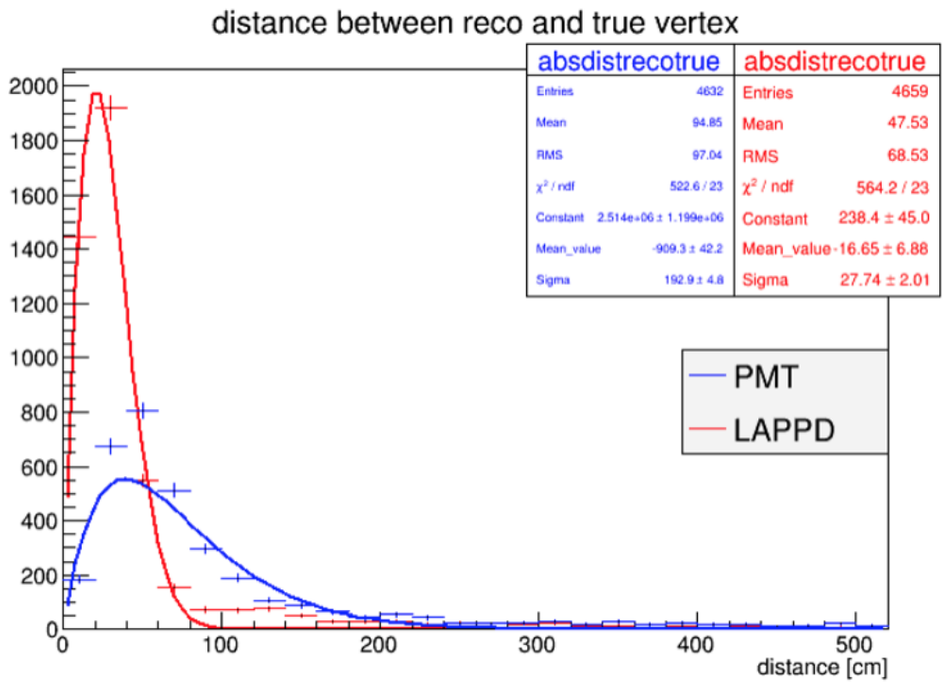
Timing and granularity are important

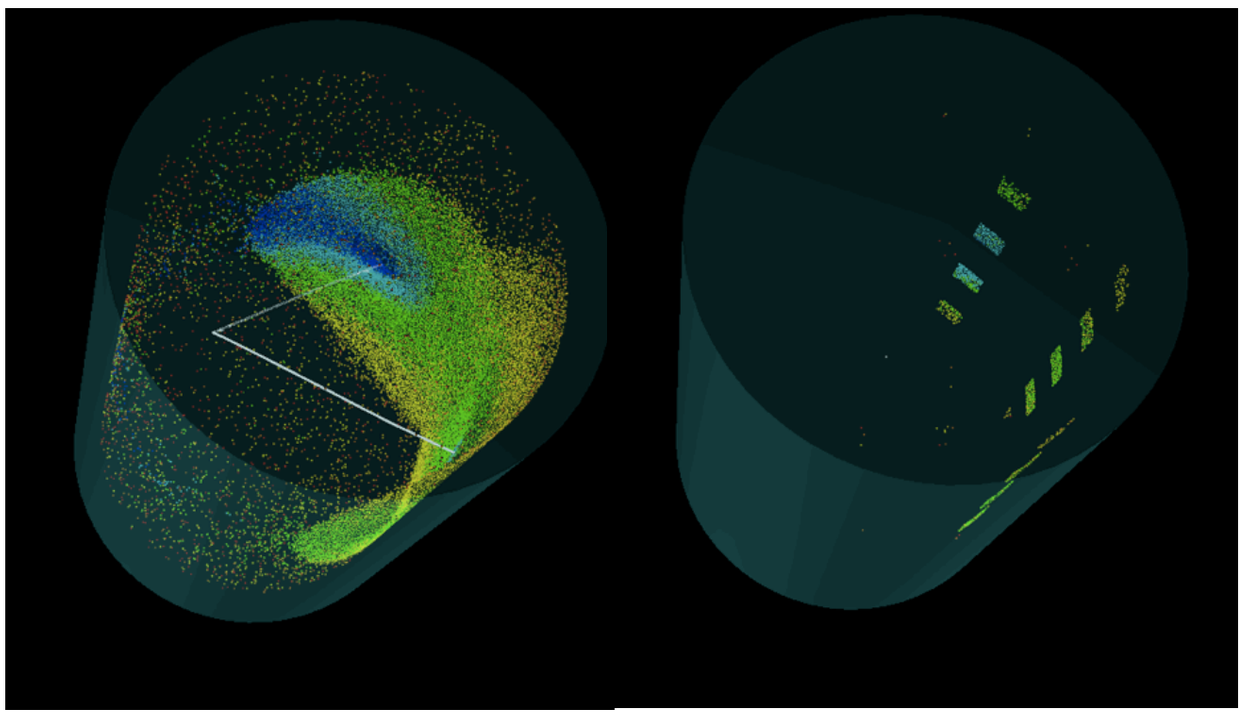
Good vertex reconstruction is important for fiducialization

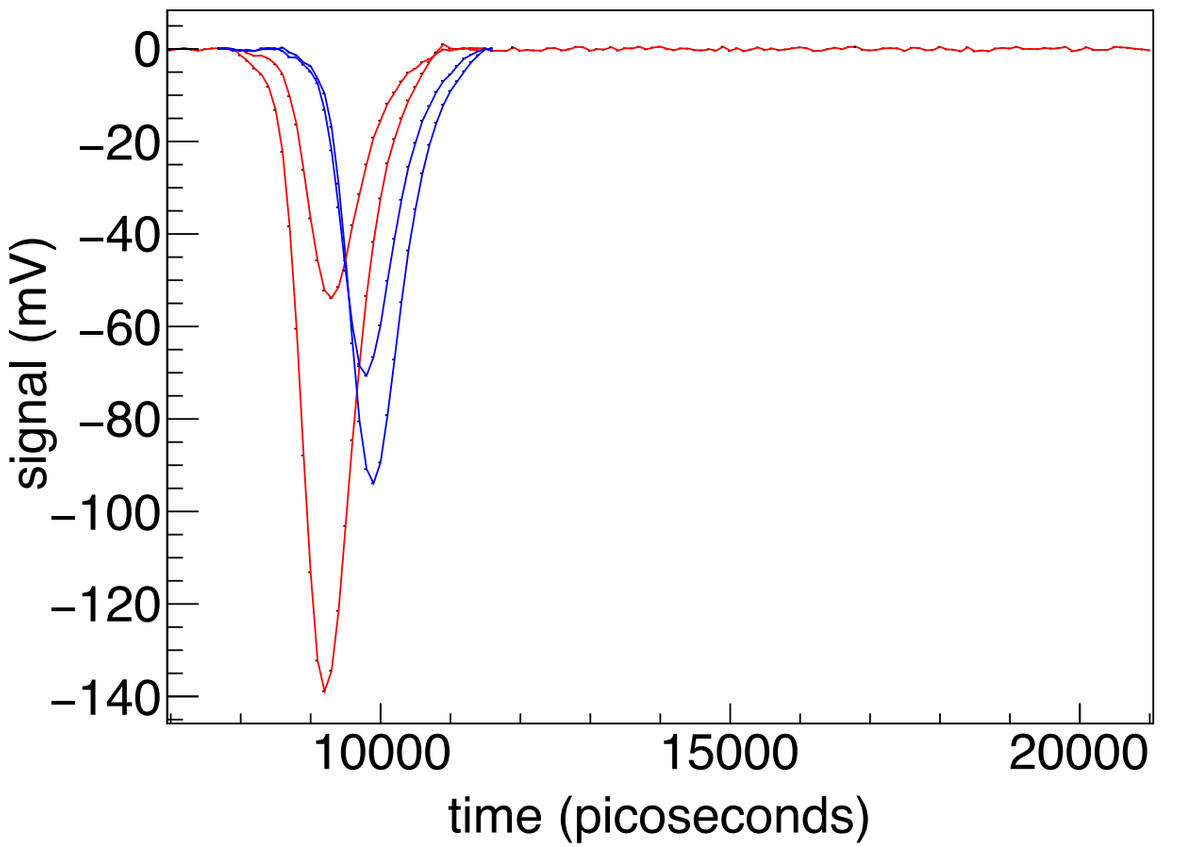
Track counting is important for separating between CCQE-like events and non-CCQE-like events.

Later runs with full LAPPD coverage will attempt to reconstruct NC and CC-RES events.

LAPPDs provide needed time resolution *and* spatial granularity







muon pion

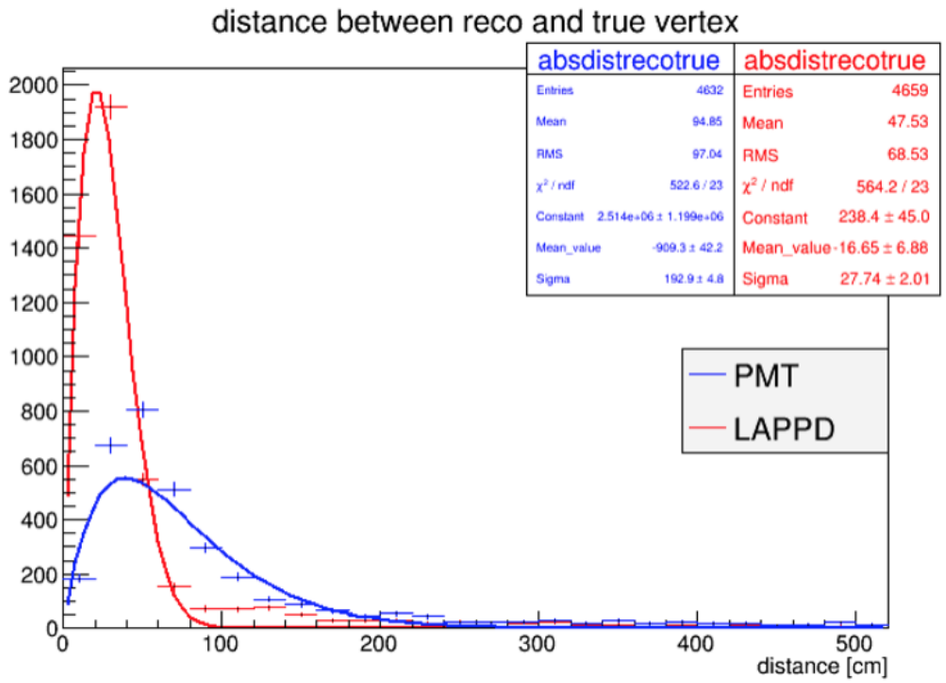
Timing and granularity are important

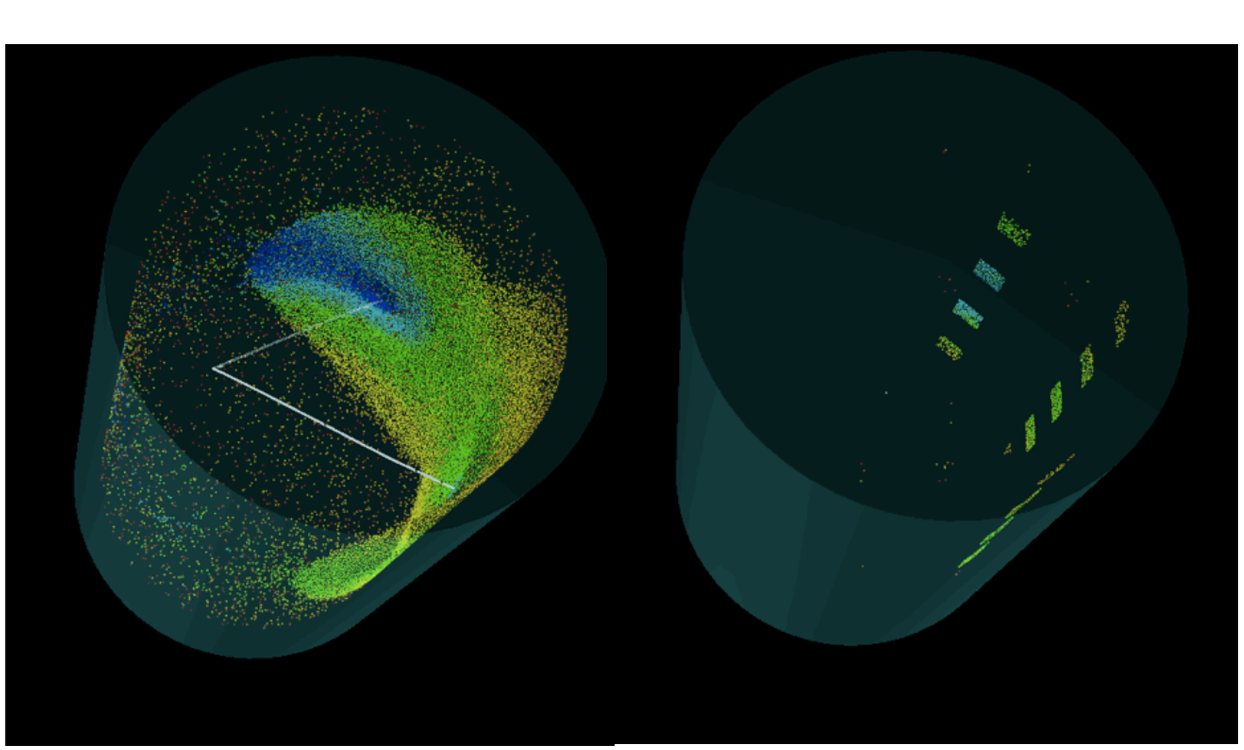
Good vertex reconstruction is important for fiducialization

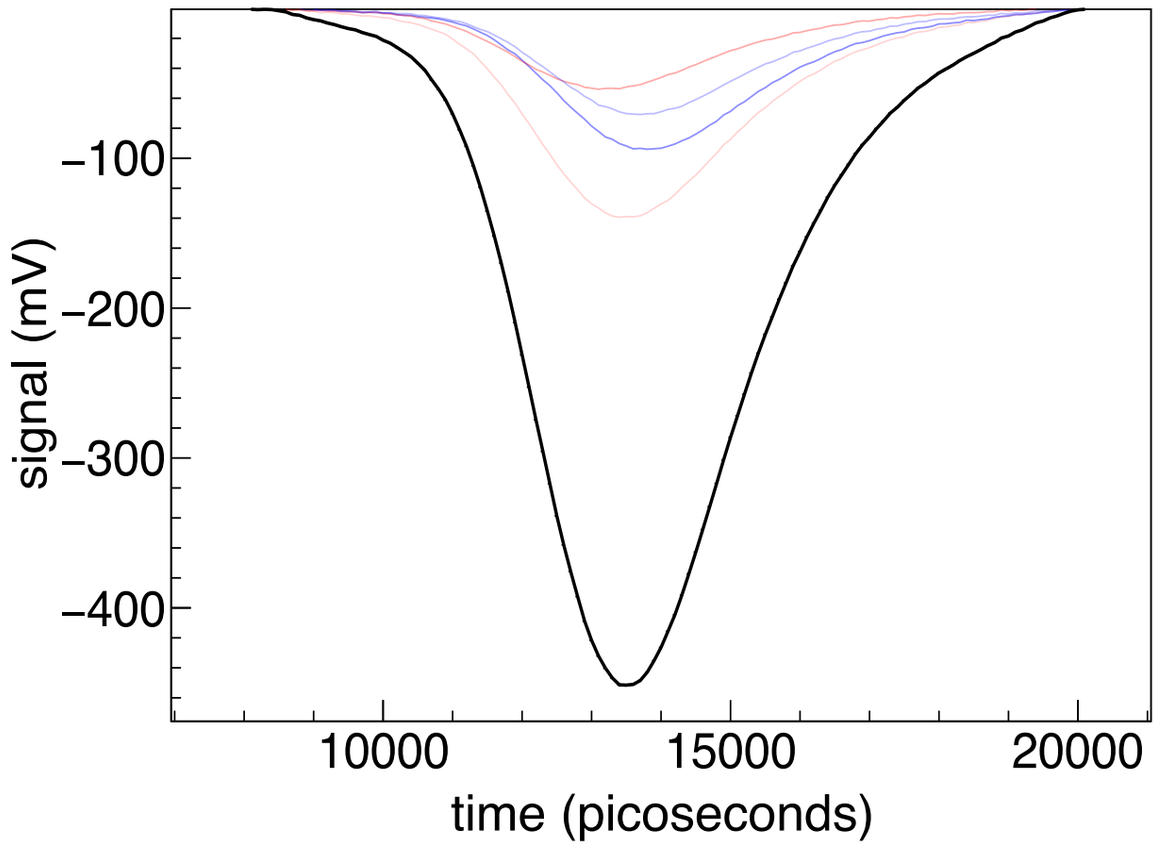
Track counting is important for separating between CCQE-like events and non-CCQE-like events.

Later runs with full LAPPD coverage will attempt to reconstruct NC and CC-RES events.

LAPPDs provide needed time resolution *and* spatial granularity







muon pion