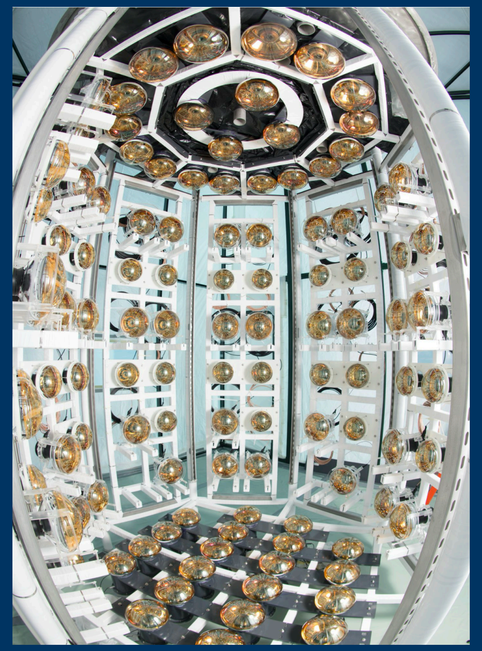


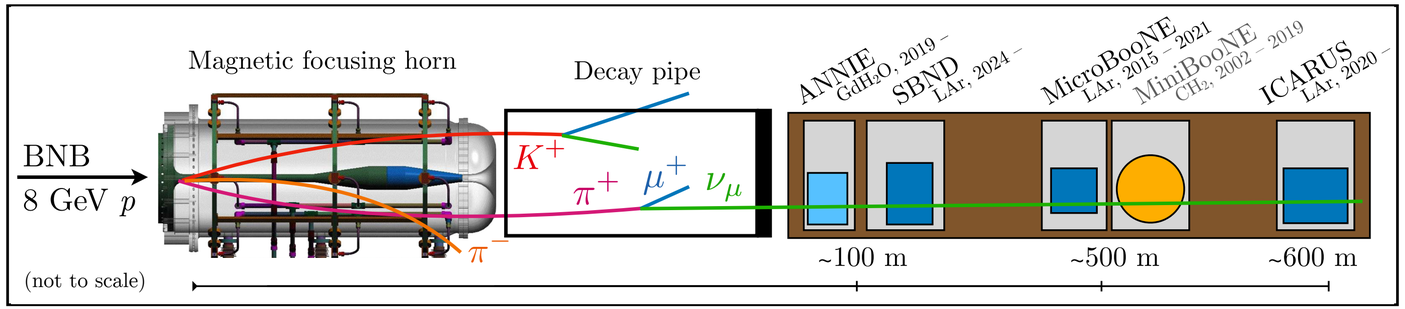
ANNIE with LAPPDs

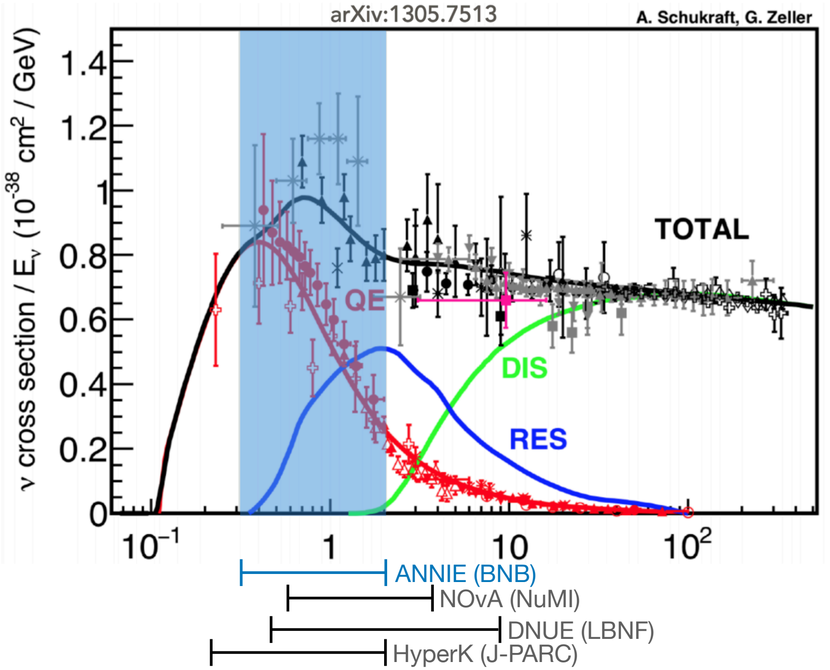
Accelerator Neutrino Nucleus Interaction Experiment with Large Area Picosecond Photodetector

Yue Feng on behalf of the ANNIE Collaboration
Iowa State University
yuef@iastate.edu

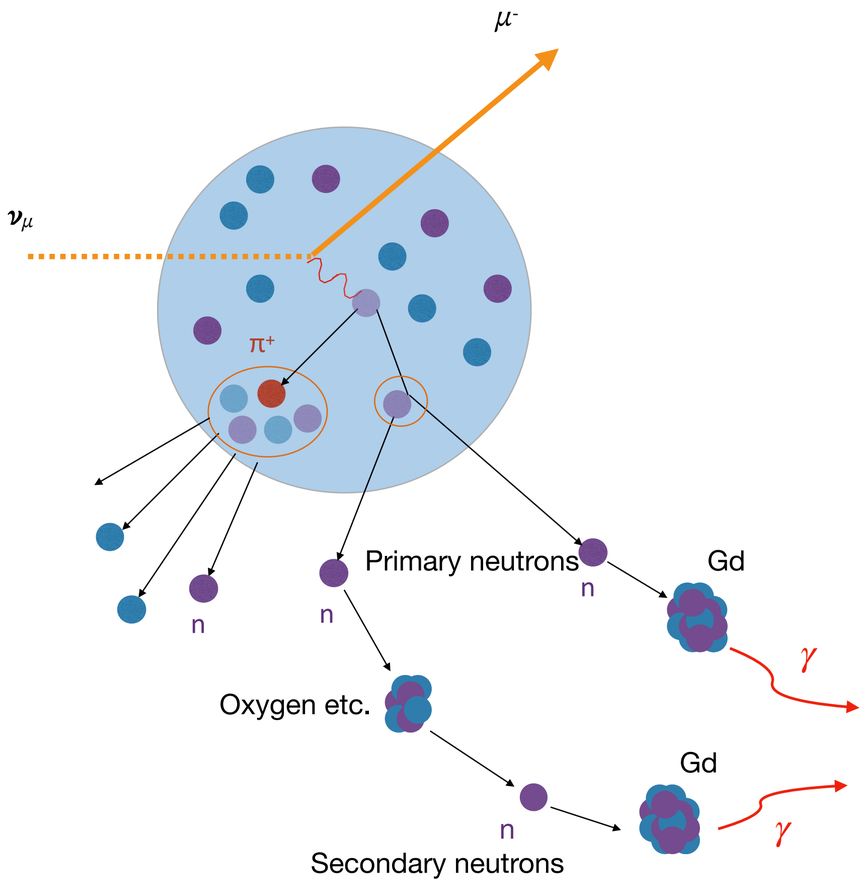
ANNIE physics

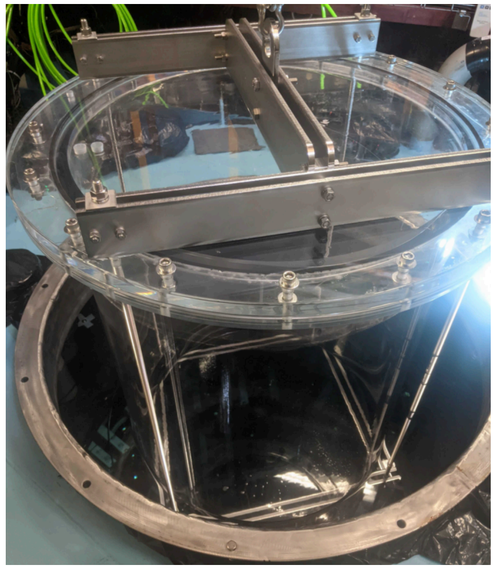
- ANNIE shares the BNB with several LAr experiments.
- Comparison of oxygen & LAr σ
- Direct relevance for long-baseline experiments, similar kinematic parameters with DUNE and HK FD.
- Neutron multiplicity from CC σ for event generators



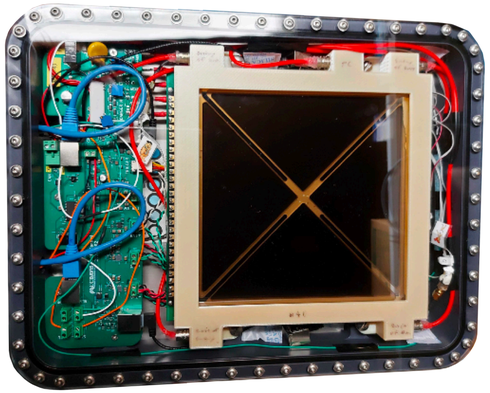


ANNIE technology





A 366L acrylic vessel for WbLS

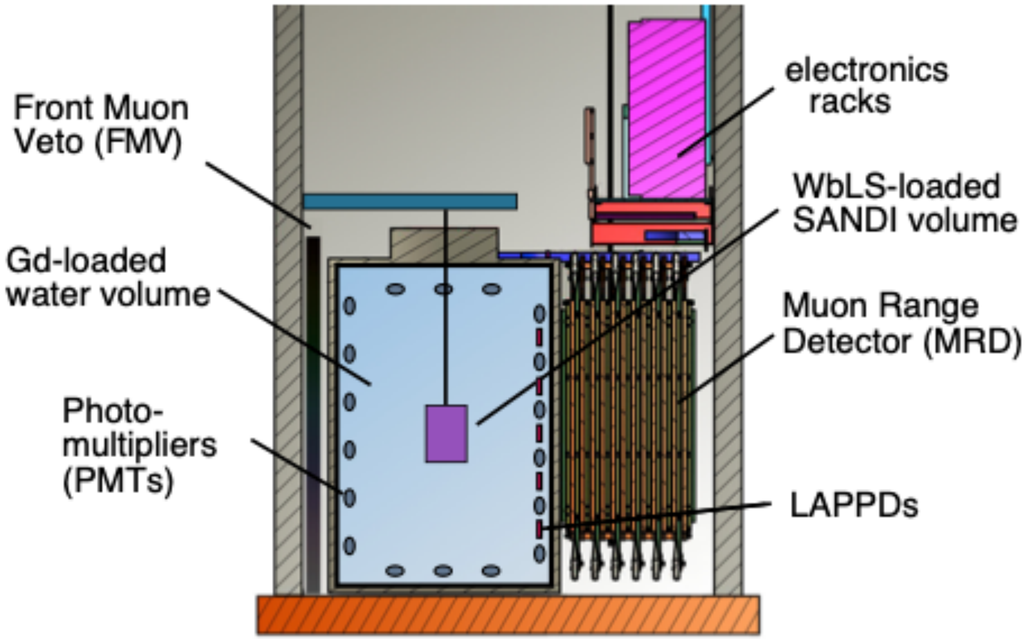


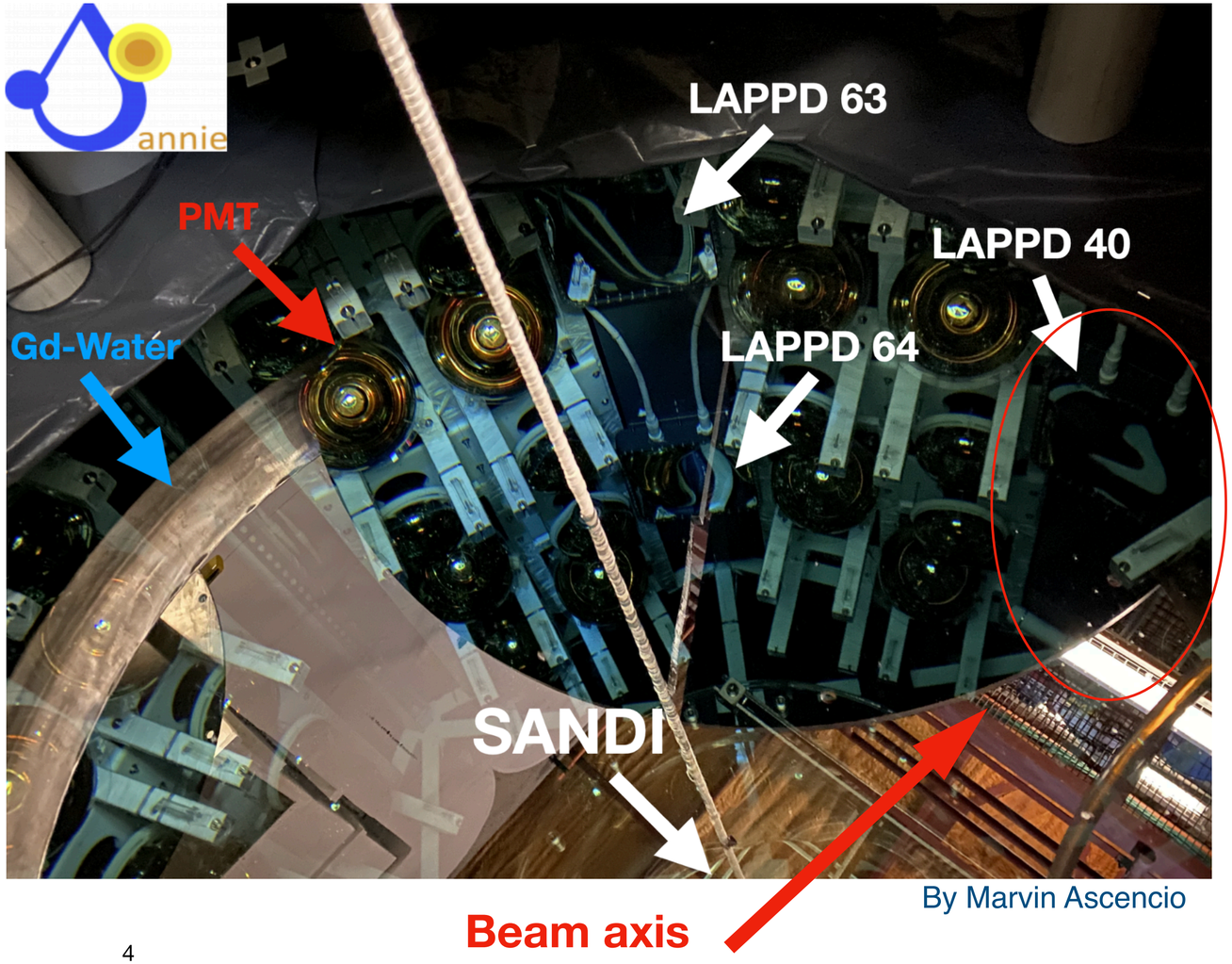
LAPPD package for deployment

- Gd for neutron multiplicity measurements.
  - Enhances thermalized neutron capture efficiency from ~10% to ~70%.
  - Shortens capture time from ~200 μs of H to ~20μs
  - Increase the captured γ energy from ~2.2MeV to ~8MeV
- WbLS test volume deployed.
  - Significant increase of light yield observed. (Paper here)
- LAPPD applied
  - In simulation with 5 LAPPDs, the vertex reconstruction can be improved from ~38 cm to ~12cm.

ANNIE detector

- ANNIE combined-detector has ~100 PMTs, a MRD, and a few LAPPDs with 26-ton Gd water, and a optional WbLS vessel.
- LAPPD: sub-nanosecond timing.
- Muon Range Detector (MRD): 11 X-Y arranged paddle shape scintillator layers with iron absorbers.

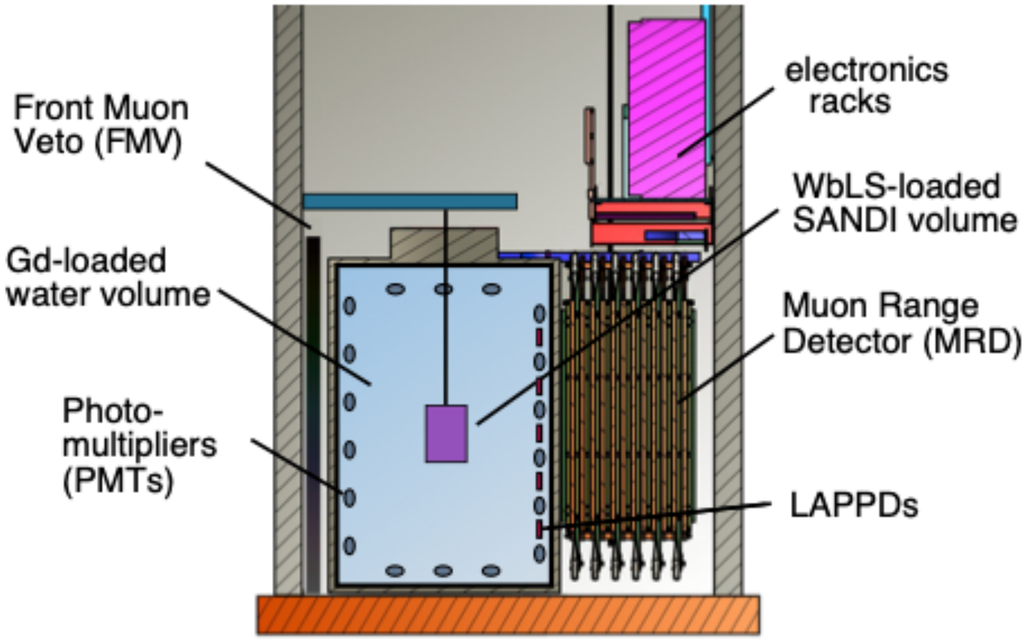


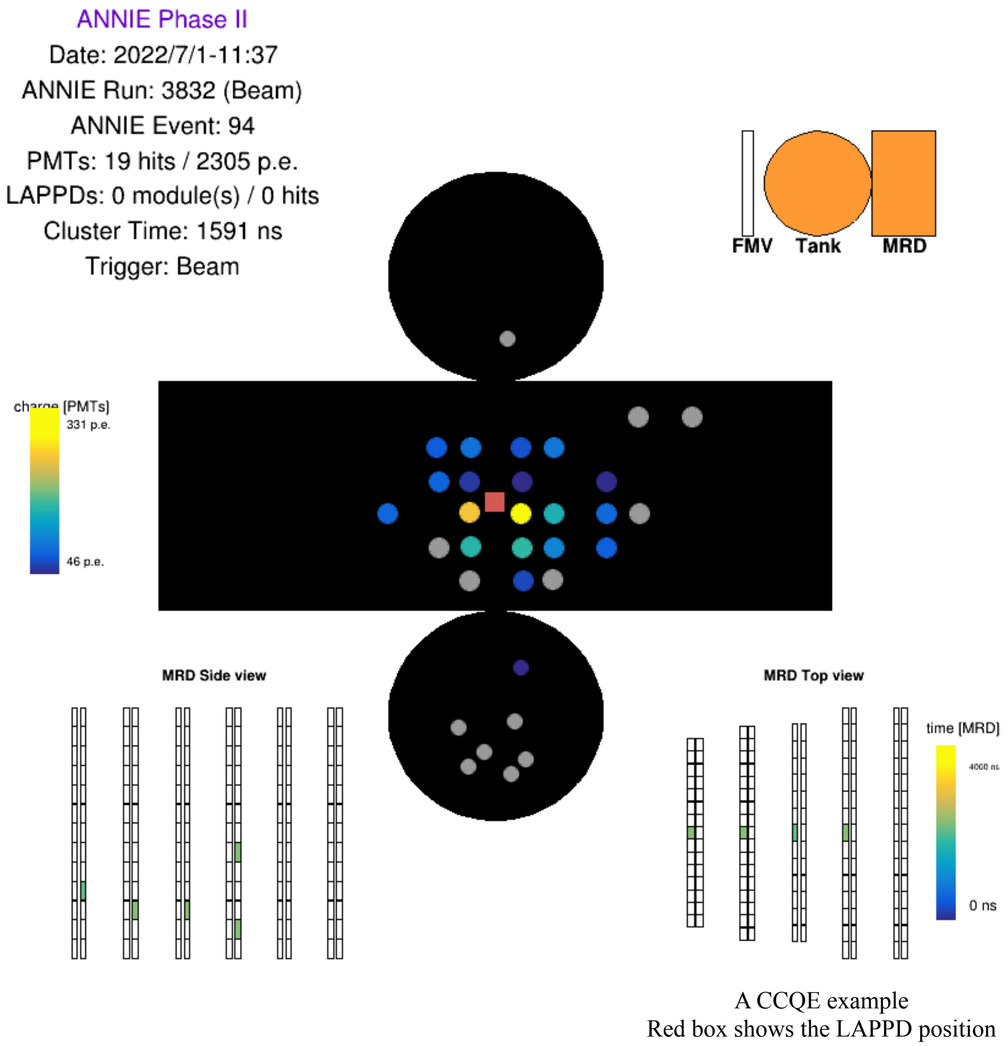


By Marvin Ascencio

An neutrino event in ANNIE detector

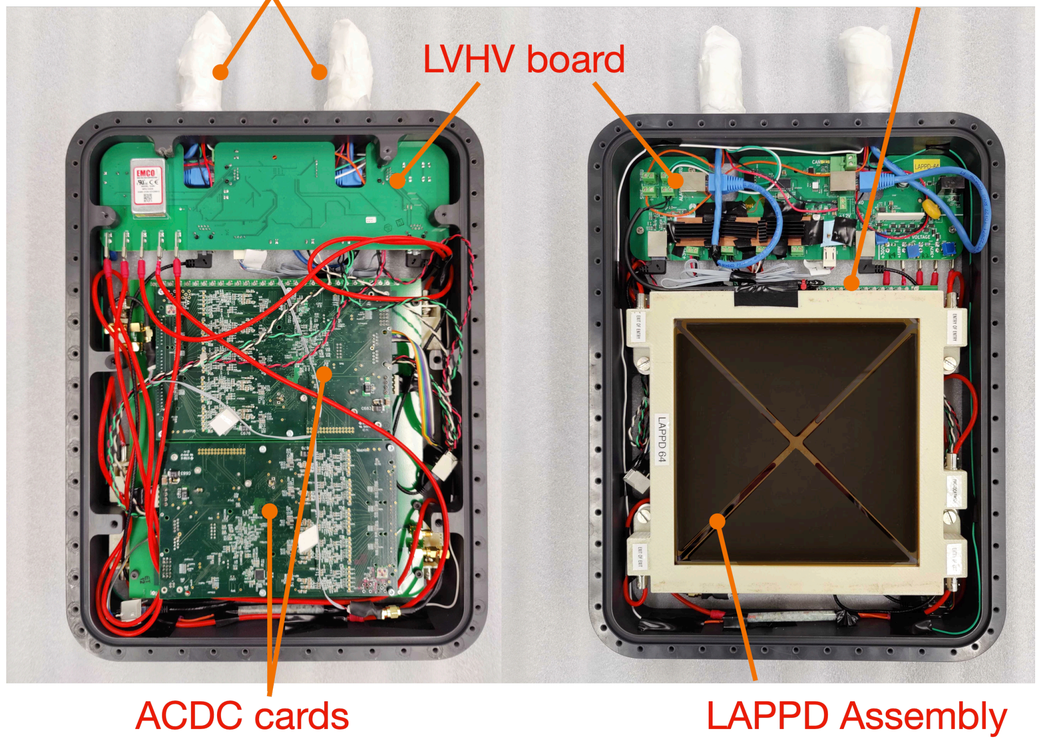
- One event contains data from tank PMTs, LAPPD, and MRD.
- Combined to give the information of a ν event.



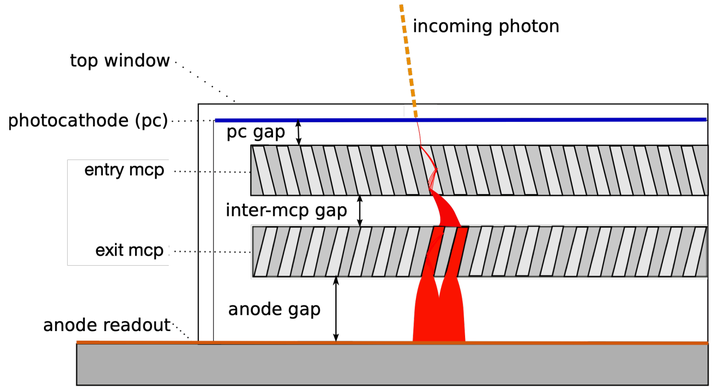


A CCQE example
Red box shows the LAPPD position

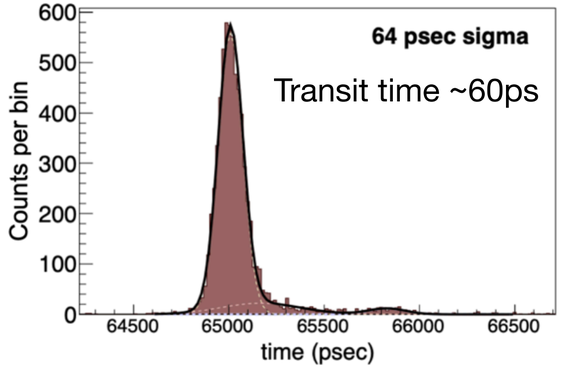
LAPPD mechanism

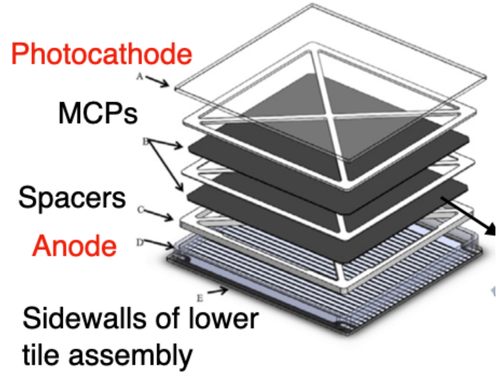


Structure of a LAPPD package

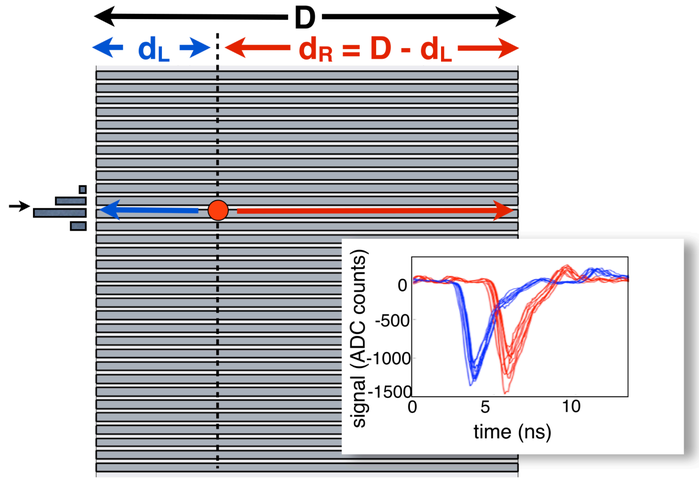


Detection process





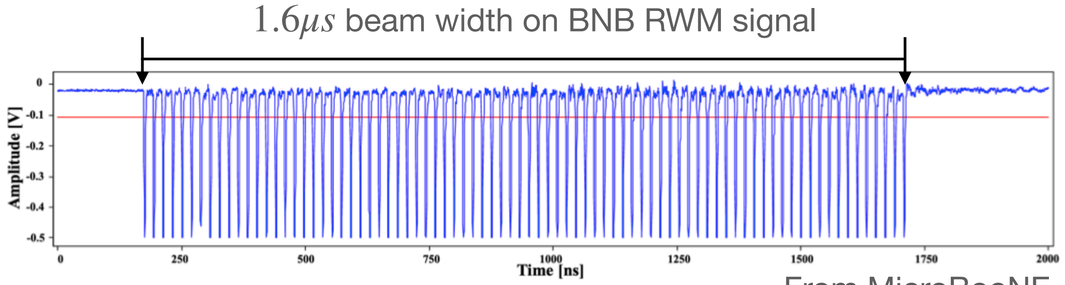
Inner structure of a LAPPD



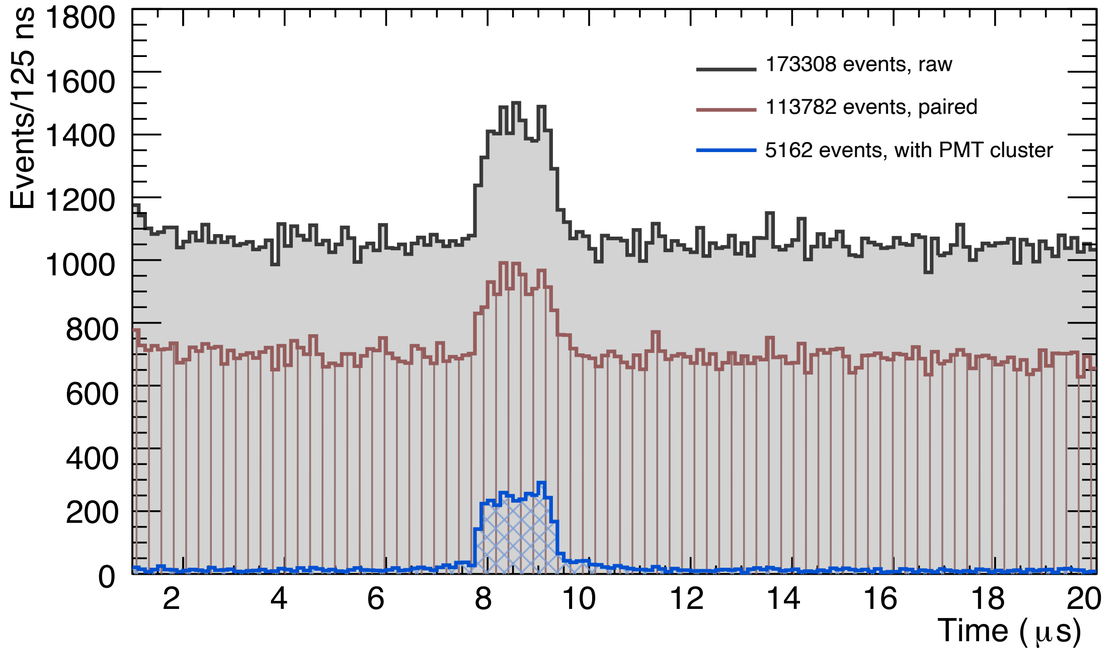
Timing reconstruction

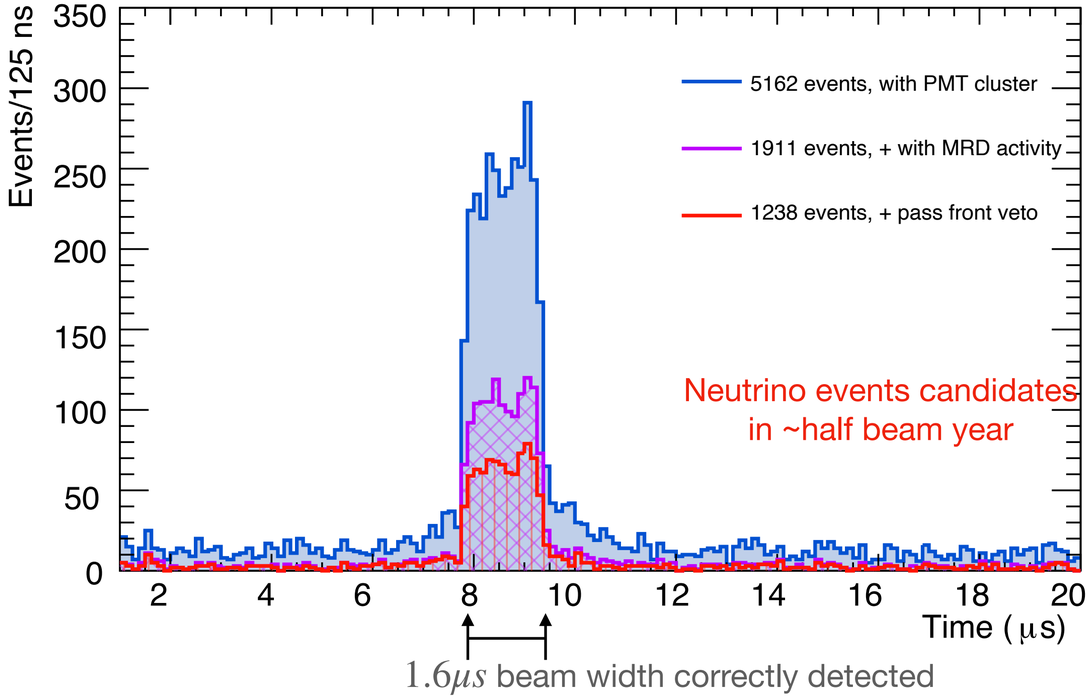
First-ever detection of neutrinos with LAPPDs

- BNB spill width $1.6\mu s$ was correctly detected.
- ~1200 neutrino candidates identified after cuts for data in ~half beam year. (~1e20 POT)



From MicroBooNE

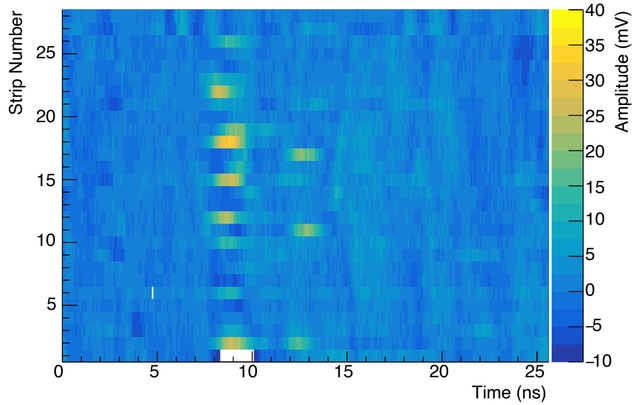


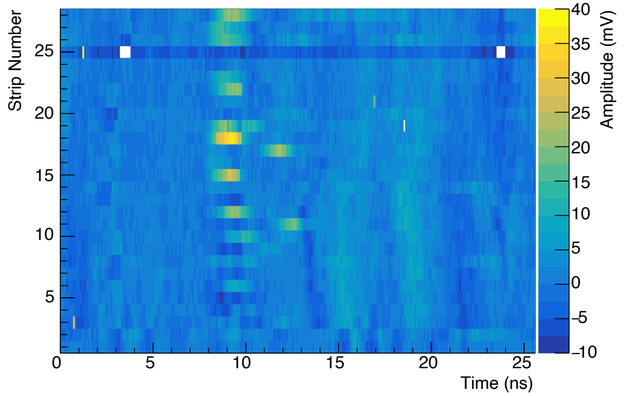


First-ever detection of neutrinos with LAPPDs

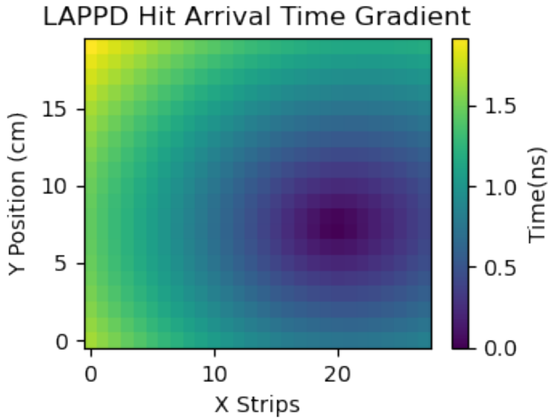
- BNB spill width $1.6\mu s$ was correctly detected.
- ~1200 neutrino candidates identified after cuts for data in ~half beam year.
- Pulse response on LAPPD strip lines detected.
- Imaging feature match the muon information.

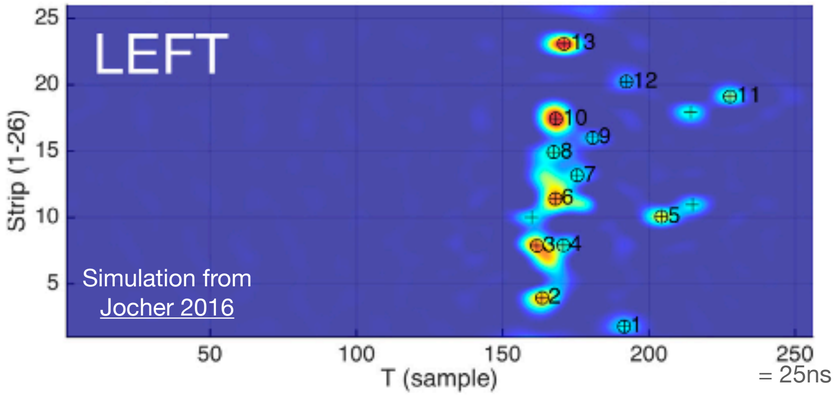
A neutrino candidate in 2023 beam year

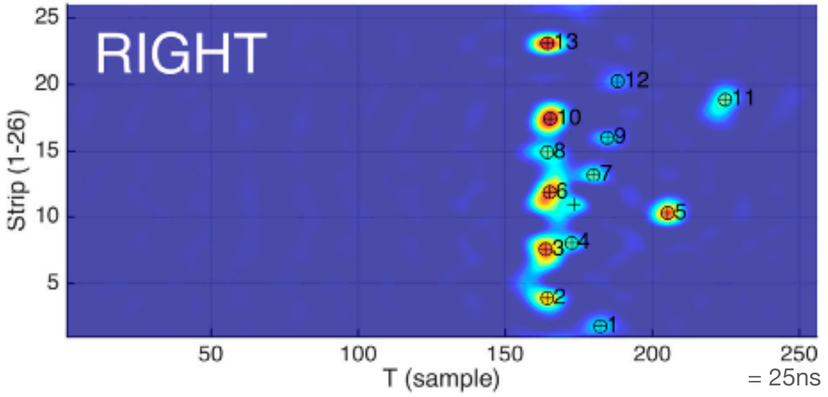


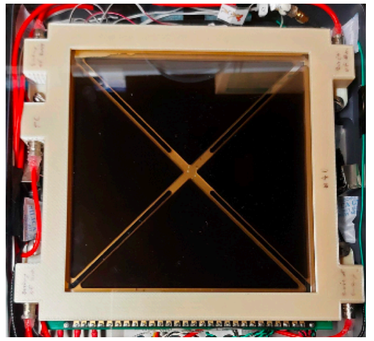


Calculated from corresponded muon





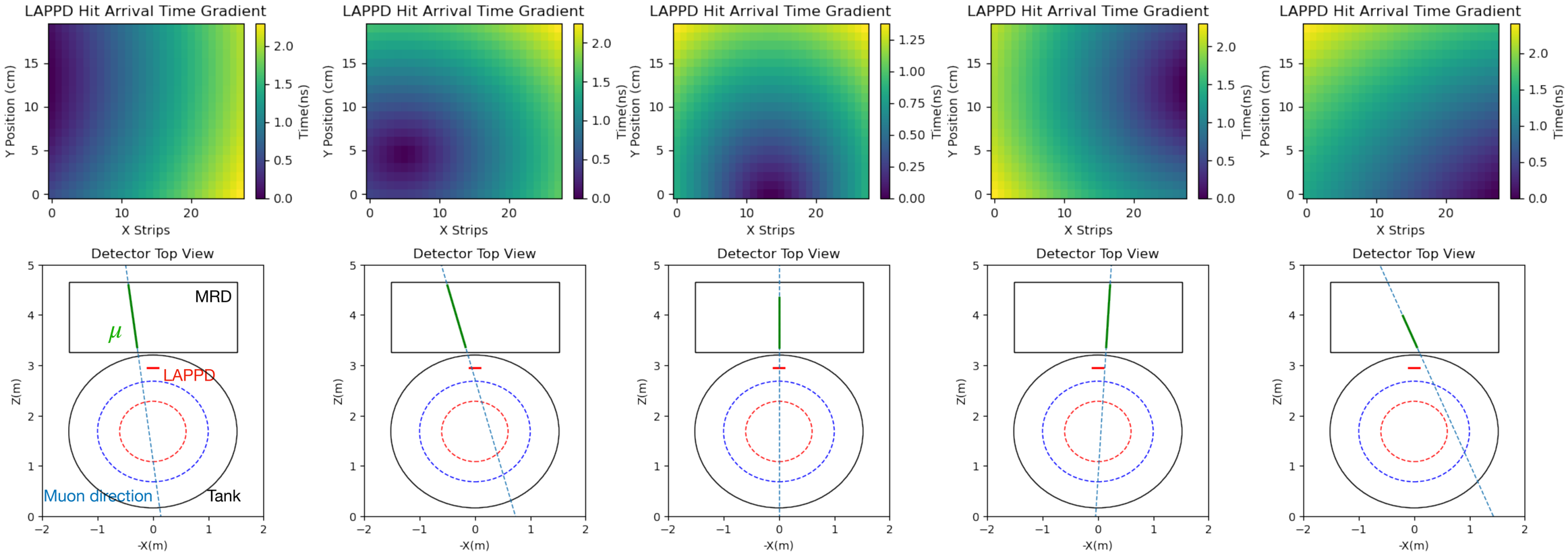




The 20*20cm LAPPD surface

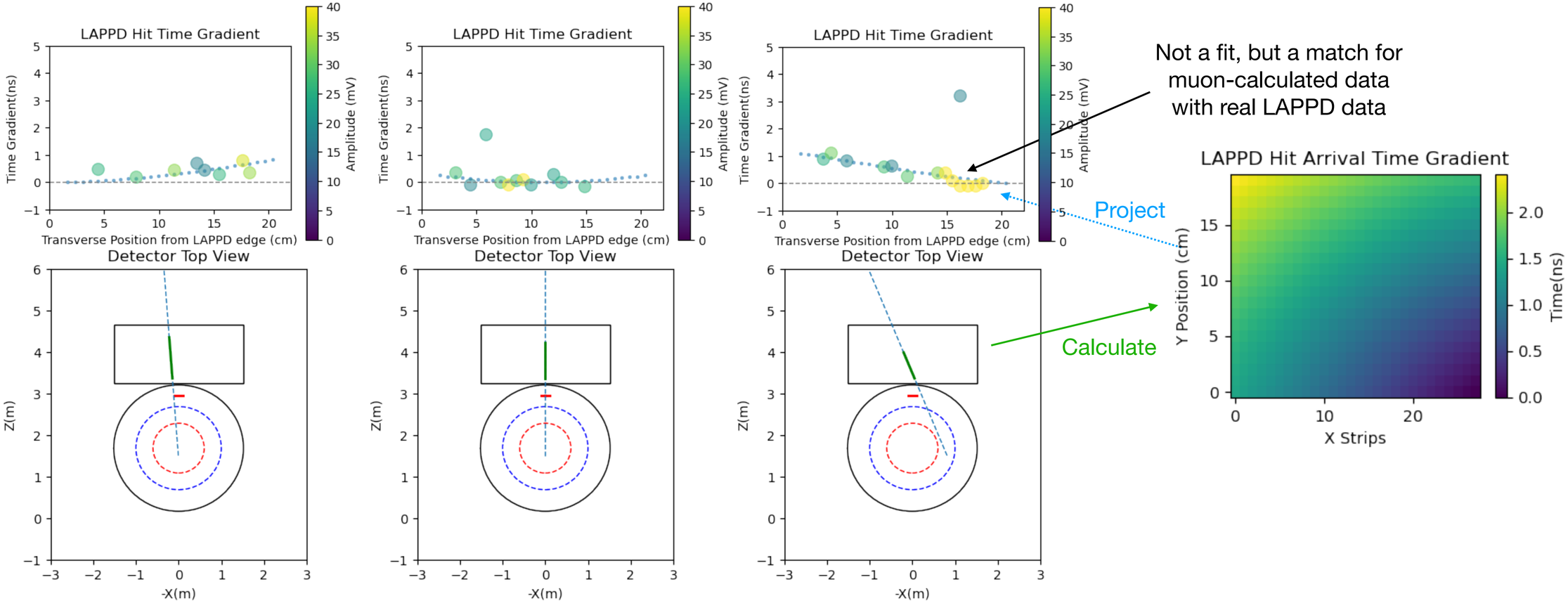
LAPPD imaging capability

- A LAPPD is a self-consistent 2D detector, which means ideally the relative timing between strips can give the event topology, before using all-detector reconstruction.
- For the muon track of each event, project the Cherenkov light to LAPPD surface.
- The projection highly depends on the relative position to the LAPPD.



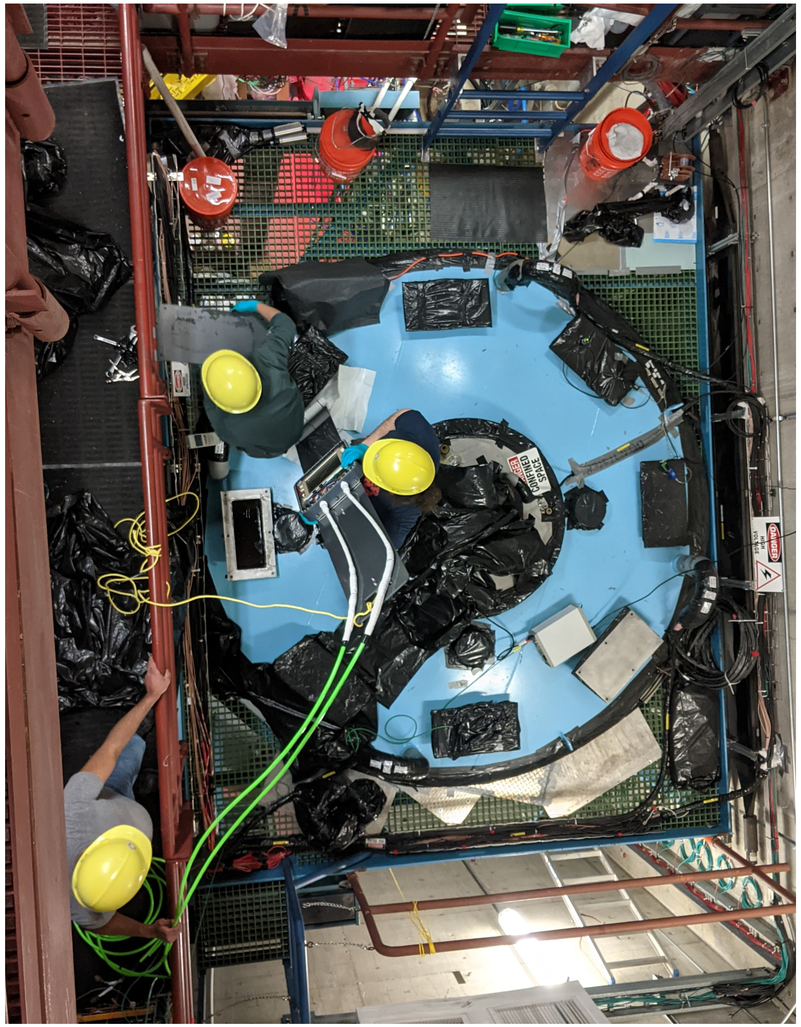
LAPPD imaging capability

- Without single photon disambiguation, we can still use the piled up “hit” to get the relative timing information between strip.
- Assume the Cherenkov light cover the whole LAPPD surface, pile up all photons on each strip to get a pulse, then get the initial arrival time of this “hit”.
- By using this arrival time between each strip, we can construct the LAPPD timing gradient of a muon track.



ANNIE summary

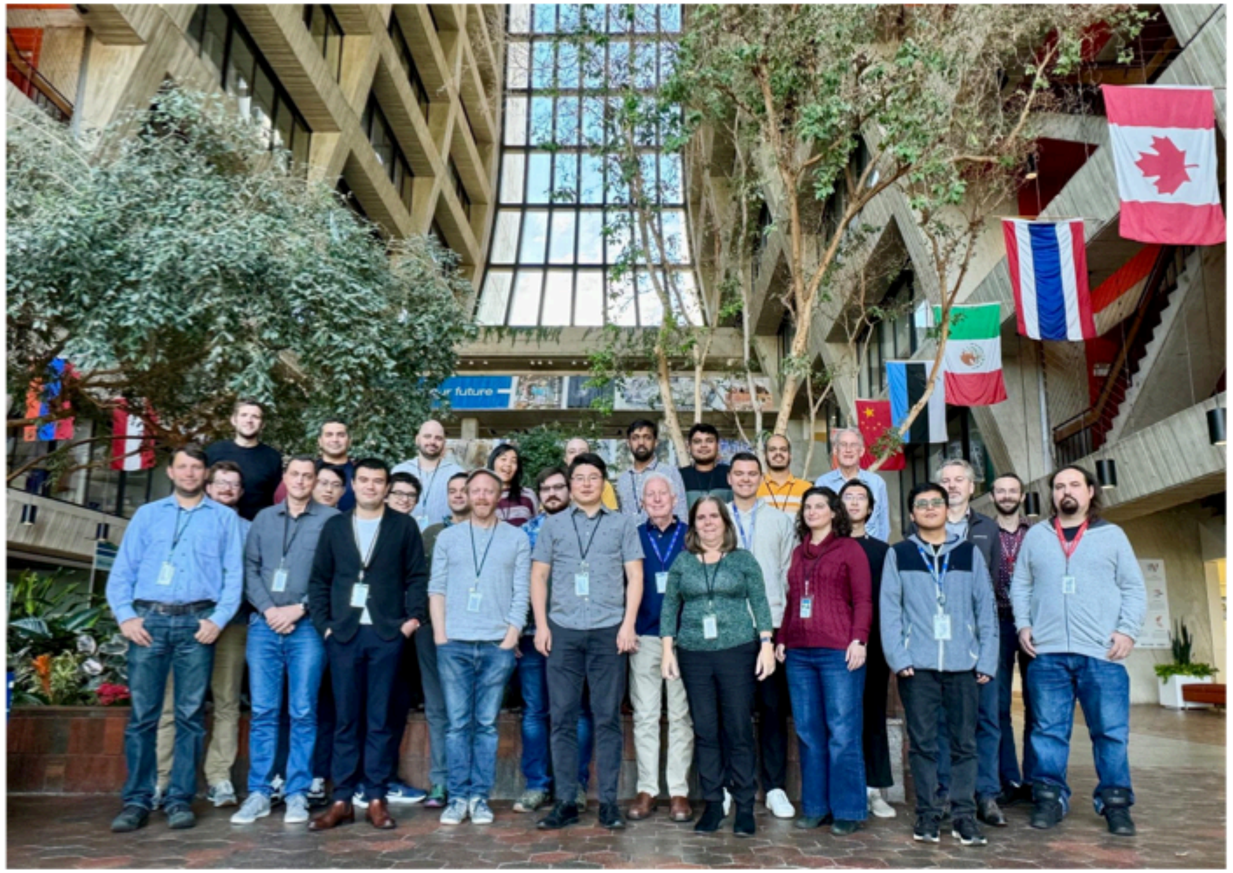
- ANNIE will measure neutrino nucleus cross section in water, directly comparable to SBND/MicroBooNE data in the same beam.
- ANNIE is a test bed for novel technologies.
  - LAPPDs successfully integrated with other subsystems.
  - First neutrino detected with LAPPD.
  - First demonstration of LAPPD imagine capability with beam neutrinos.
  - Deploying multiple LAPPDs for physics measurements in one system.
  - Possible application for LAPPD on Theia
- Apply Gd for neutron multiplicity measurements succeeded.
- First study with small WbLS volume and beam neutrinos.



ANNIE collaboration

United States

- Iowa State
- UC Davis
- Florida State
- UC Irvine
- Ohio State
- Rutgers
- SDSMT
- *Associate:*
  LBNL/UC Berkeley
  BNL
  Livermore



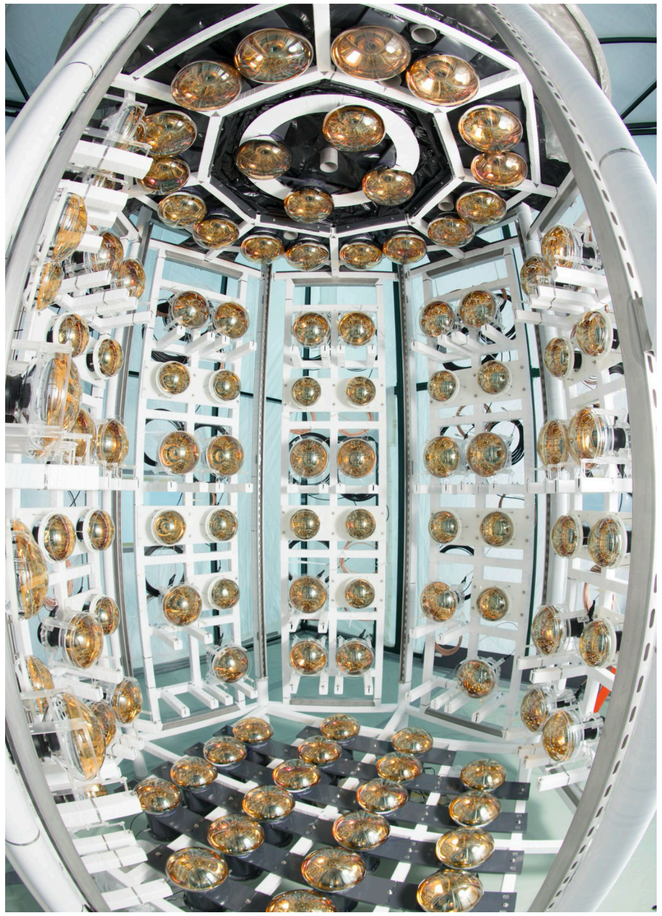
Abroad

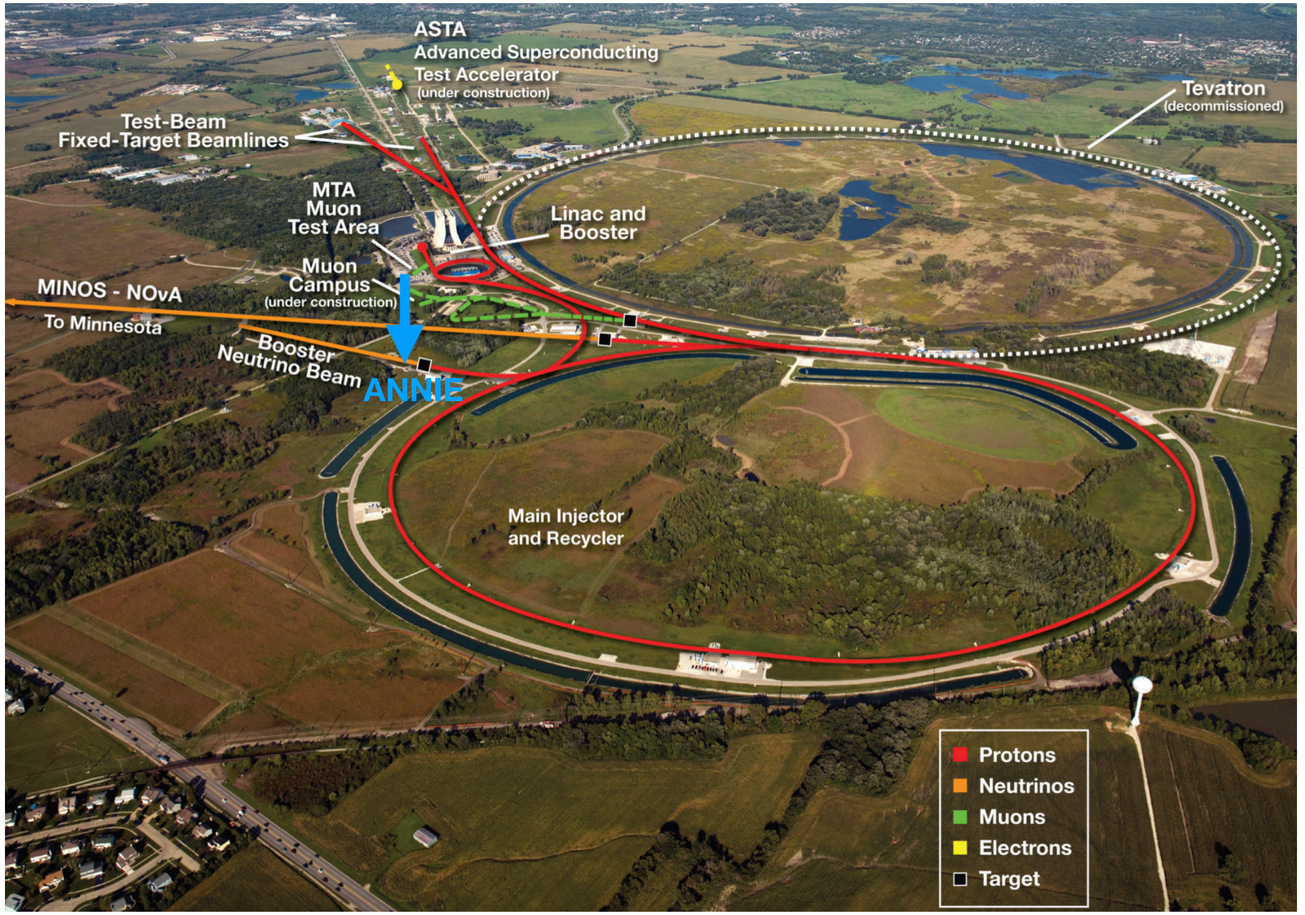
- Demokritos
- Erciyes
- Hamburg
- Kanpur
- Mainz
- Tübingen
- Warwick
- *Associate:*
  Sheffield

14 member institutions, 40+ active collaborators, new collaborators are welcome!

Backups

Where is ANNIE?

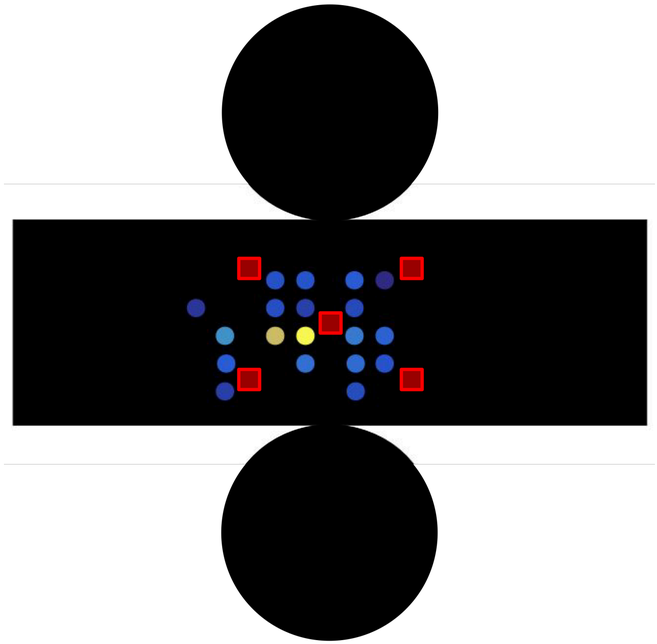


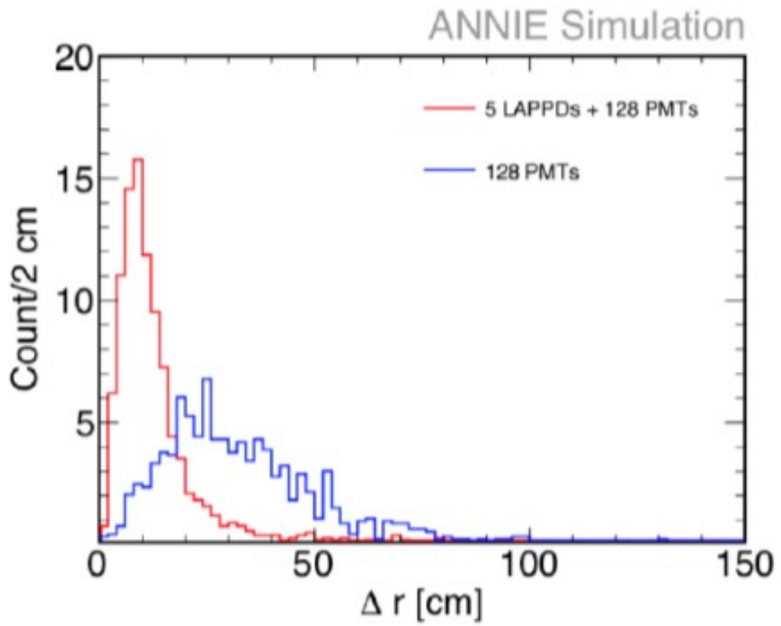


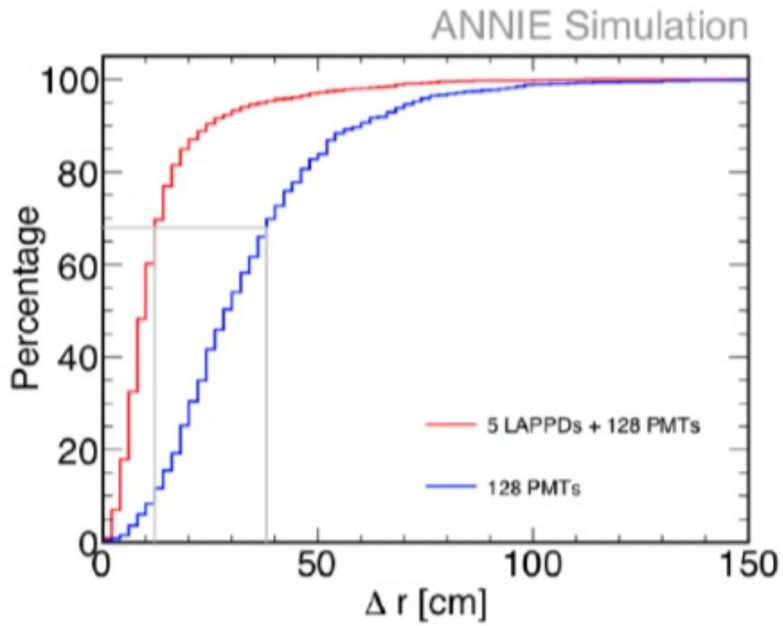
26 ton Gd-water Cherenkov detector at BNB, Fermilab

LAPPD reconstruction simulation

- In simulation with 5 LAPPDs, the vertex reconstruction can be improved from ~38 cm to ~12cm.
  - Improved knowledge of neutrino energy.
  - Better vertex reconstruction for neutron containment.

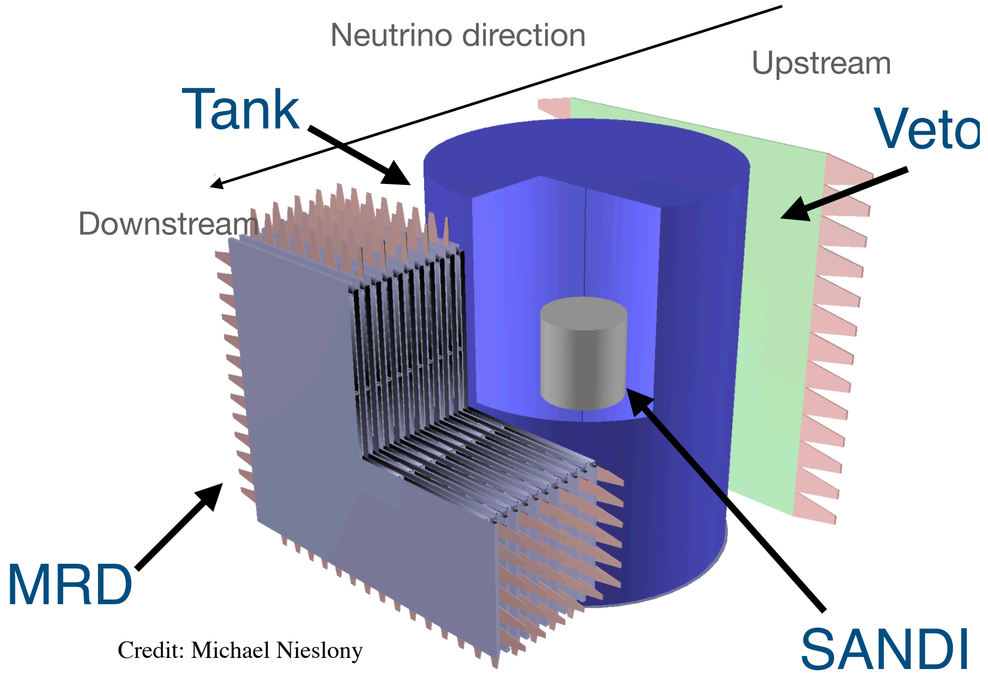


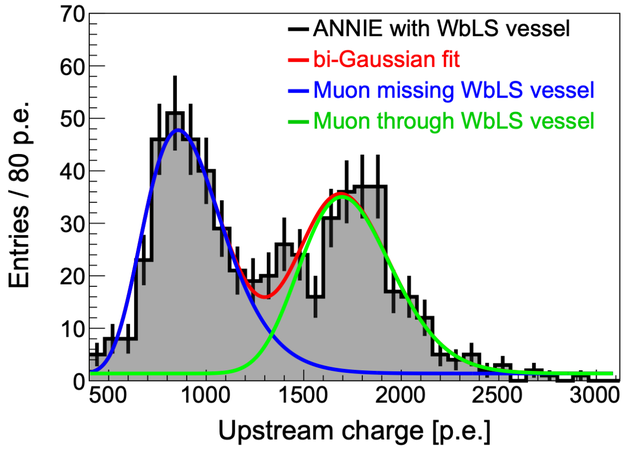


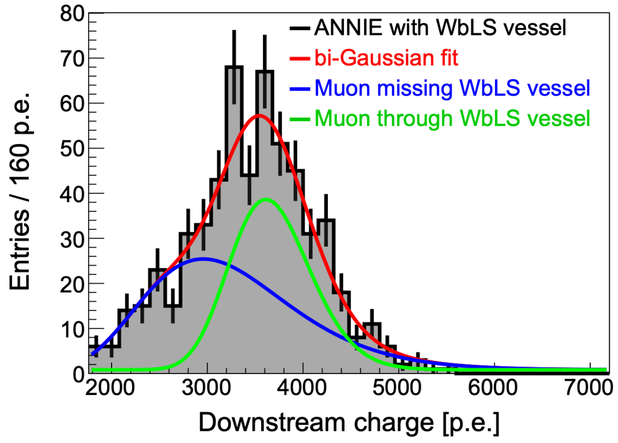


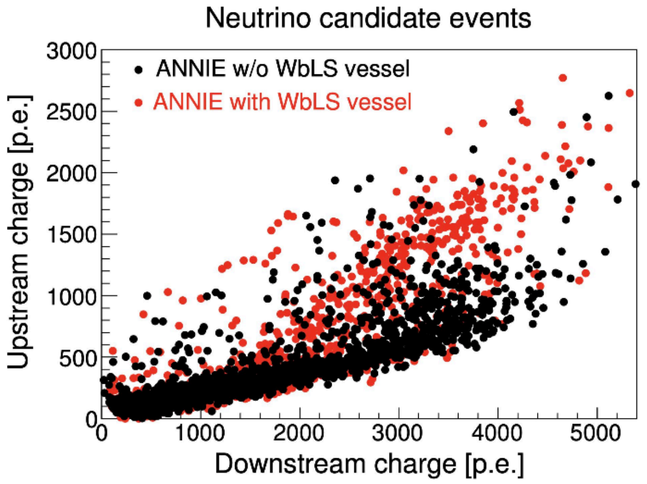
ANNIE with WbLS

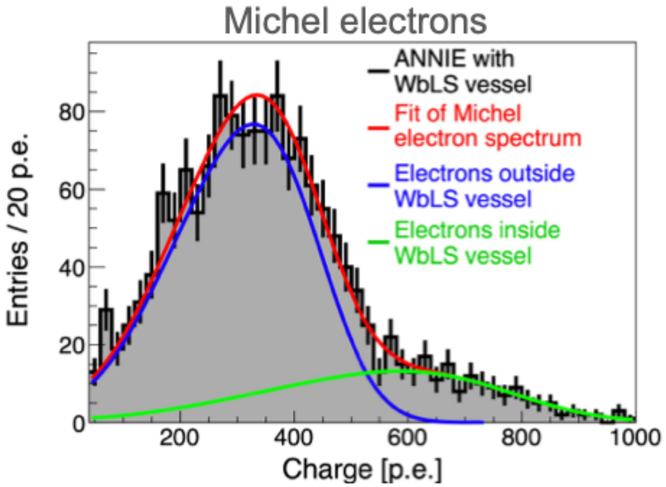
- Data with WbLS vessel SANDI successfully analyzed. (Scintillator for ANNIE Neutrino Detection Improvement)



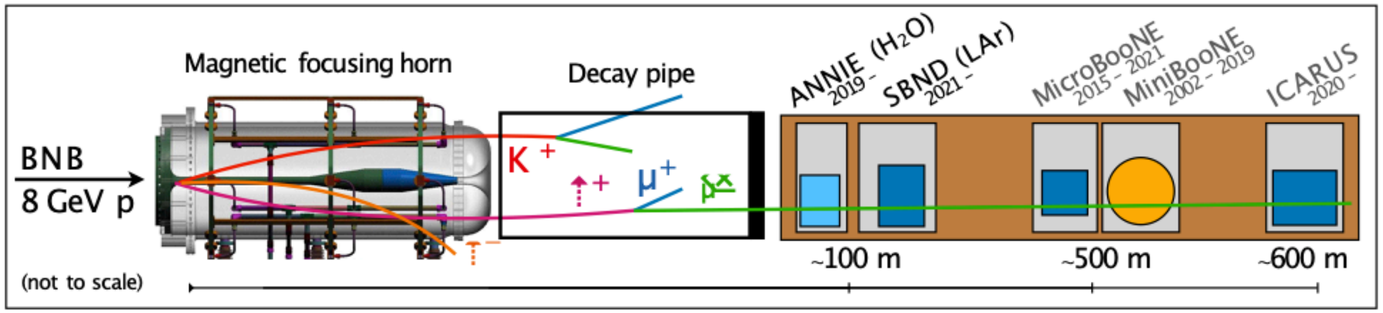


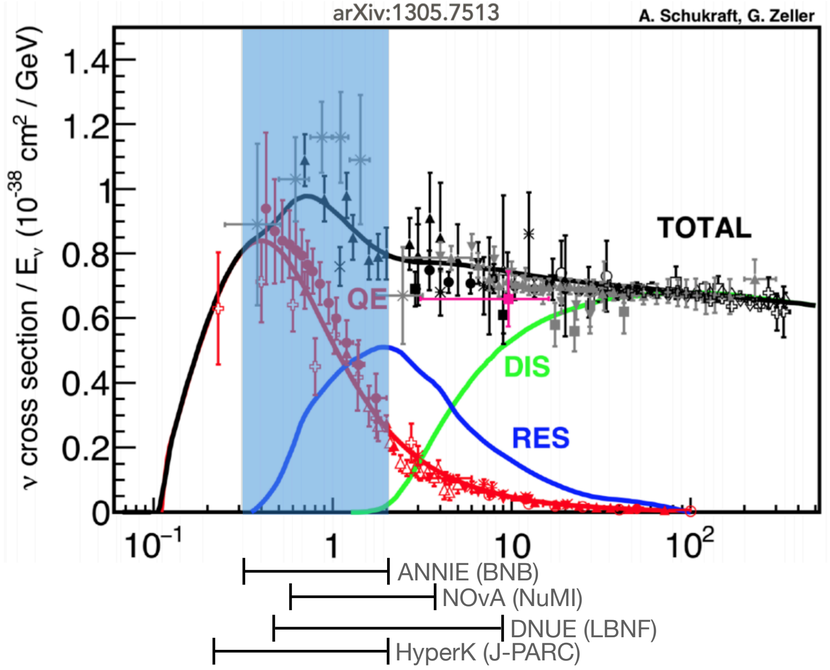


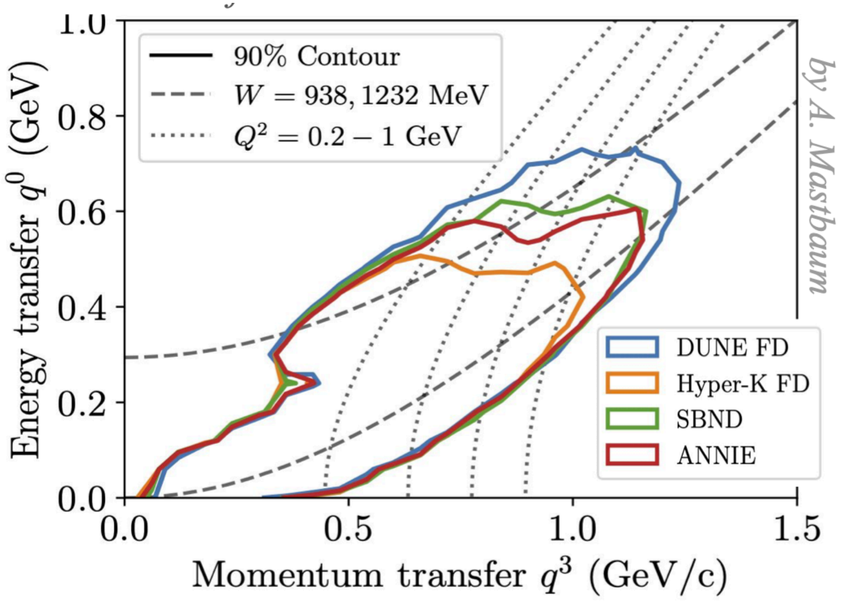




ANNIE physics

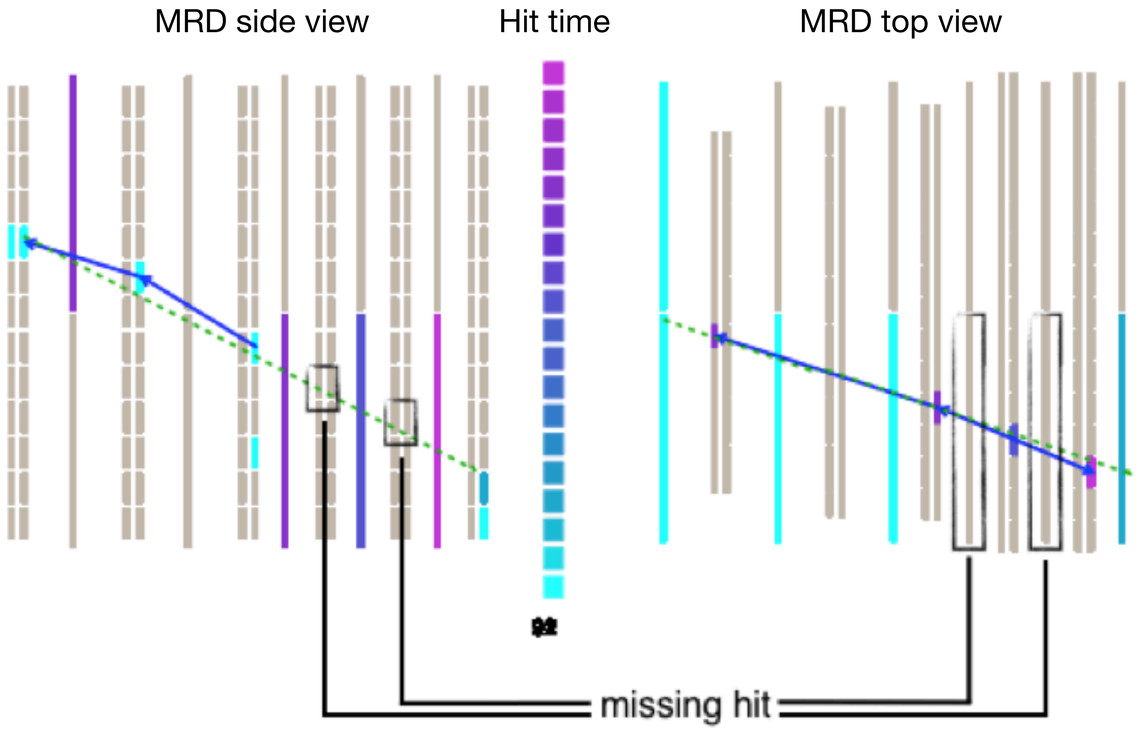


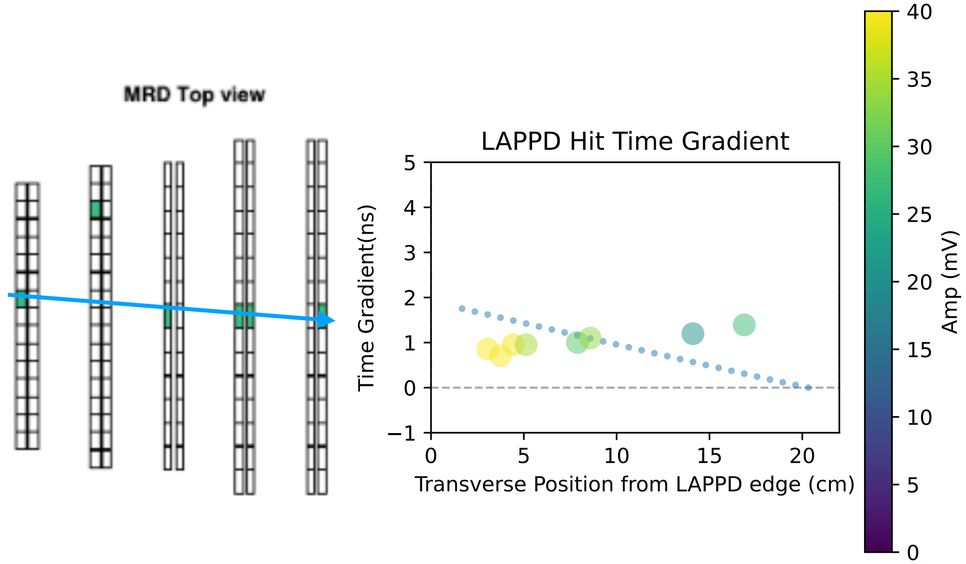


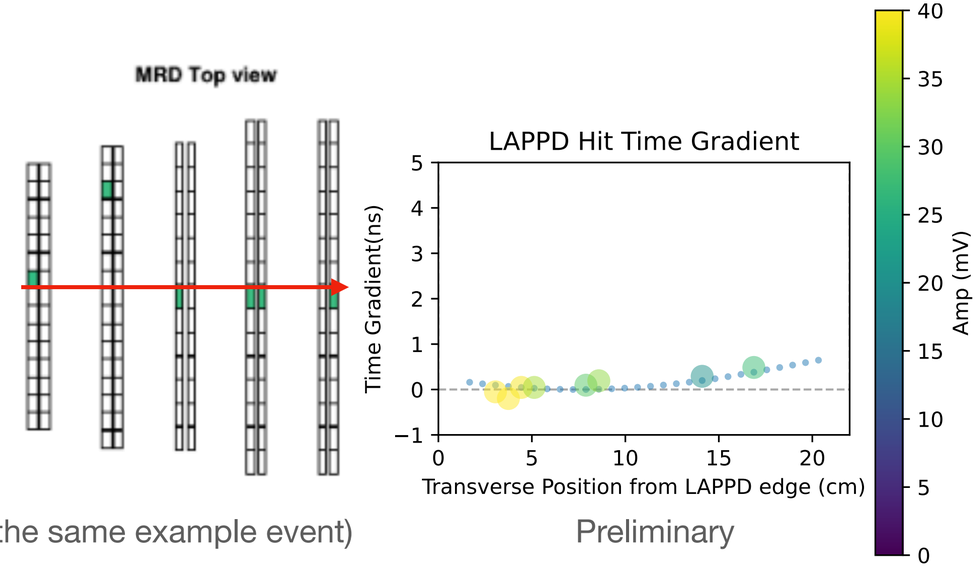


LAPPD for precise muon reconstruction

- The MRD has resolution limits ~40cm at the center of the tank.
- LAPPD can constraint the muon direction more!



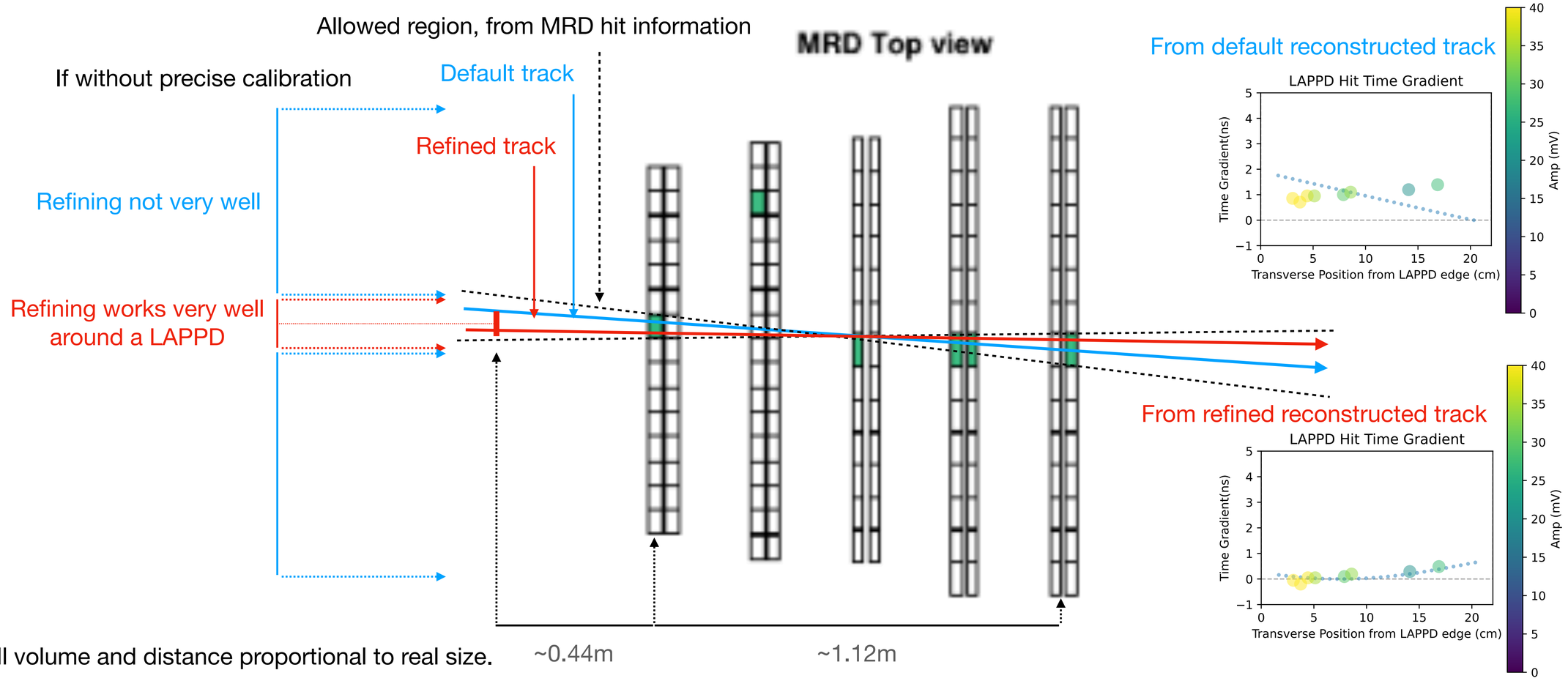




(not the same example event)

Preliminary

LAPPD for precise muon reconstruction



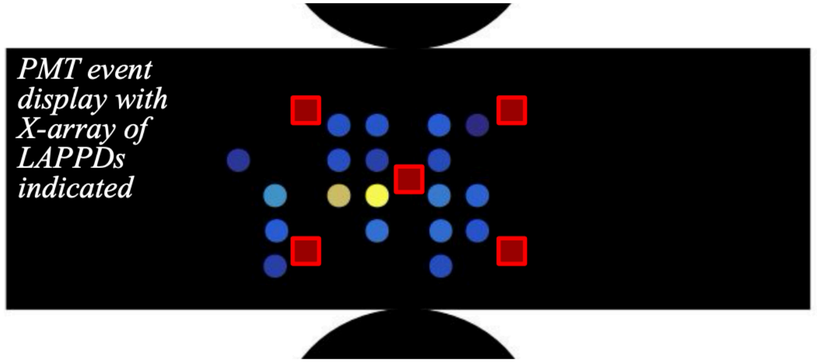
All volume and distance proportional to real size.

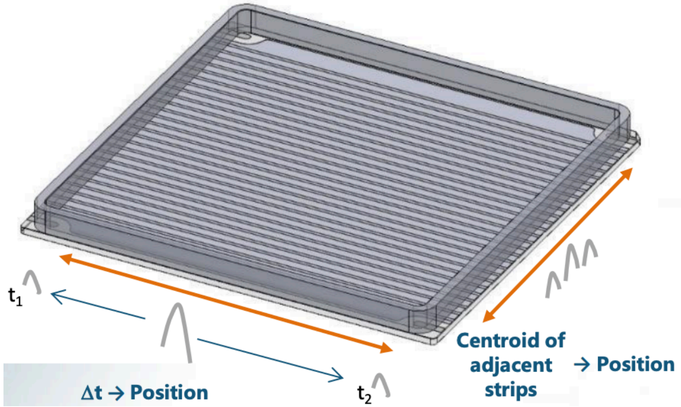
Waiting for more data to get a statistic performance for LAPPD imaging capability.

Preliminary

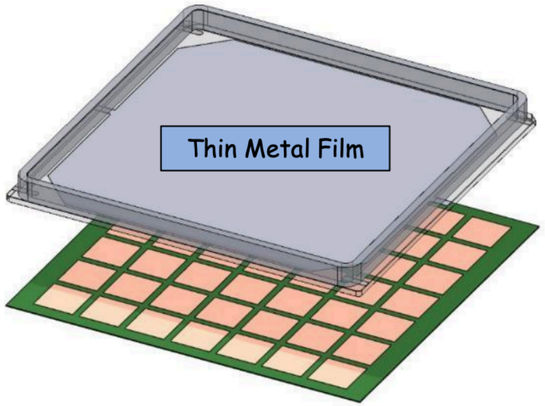
LAPPD in ANNIE: next

- All LAPPDs are somehow unique because of the MCPs and the photocathode.
  - Electronics need to be tested to match the the resistances of MCPs and the LAPPD package need to be tested before deployment.
- Multi-LAPPDs data are being analyzed.
  - How will the multi-LAPPD imaging change the reconstruction?
  - How will the Gen-II LAPPD change the game?
- LAPPD paper under internal review.



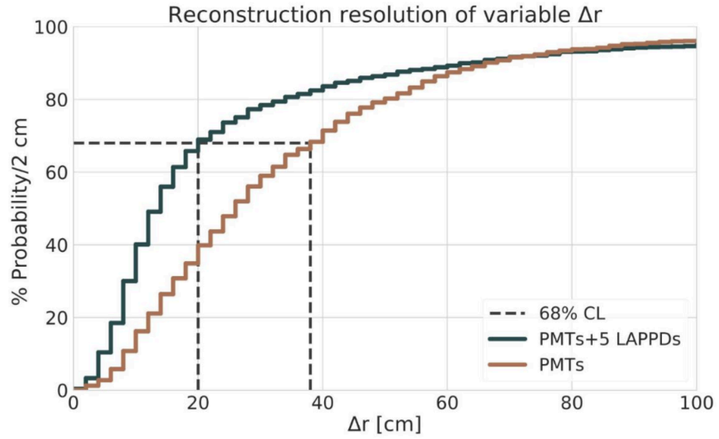


Gen-I strip line anode

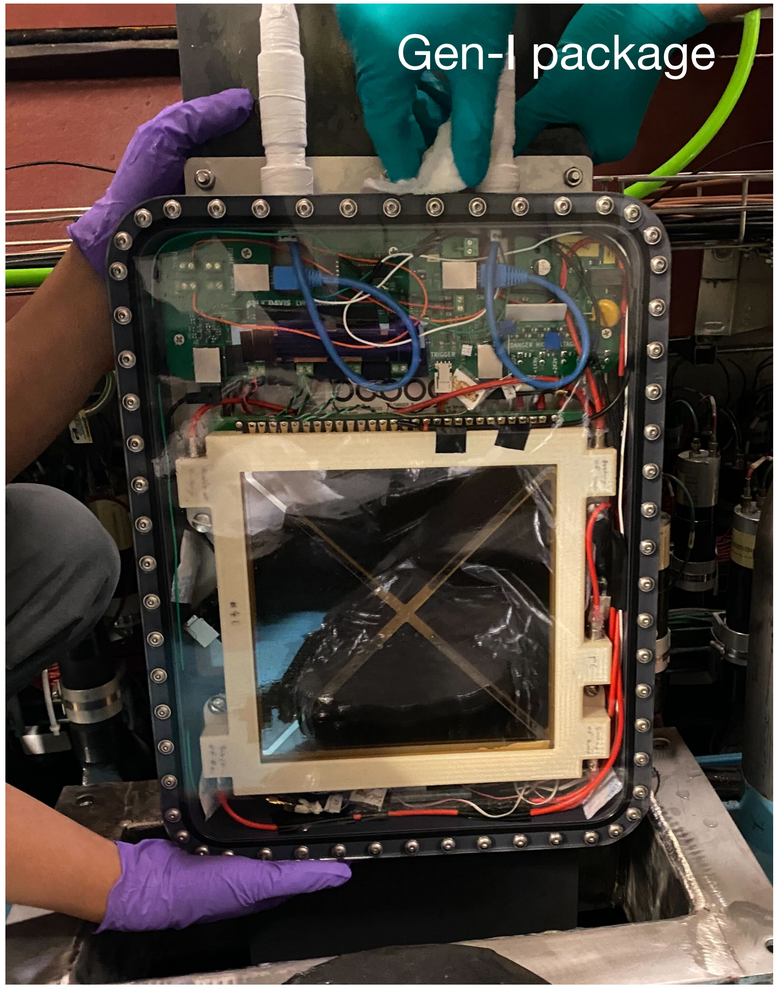


Gen-II metal film anode

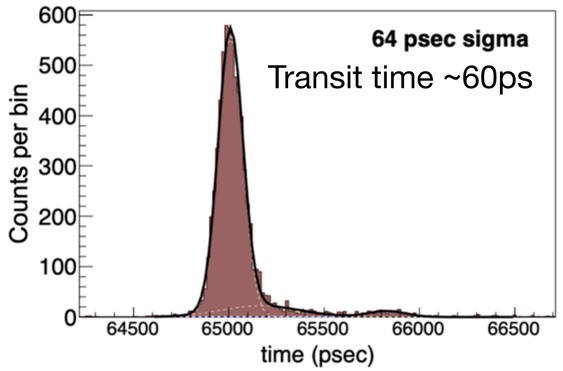
Simulation of vertex resolution with 5 LAPPDs (X-array) vs. PMTs-only

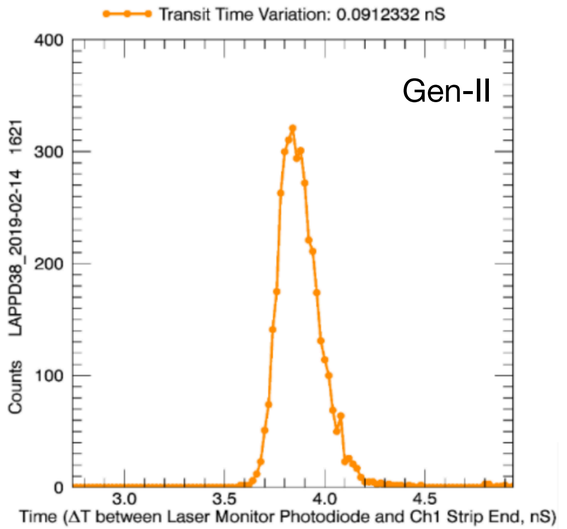


Gen-II LAPPD



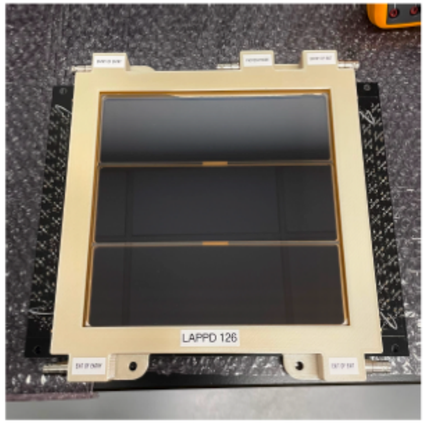
Gen-I

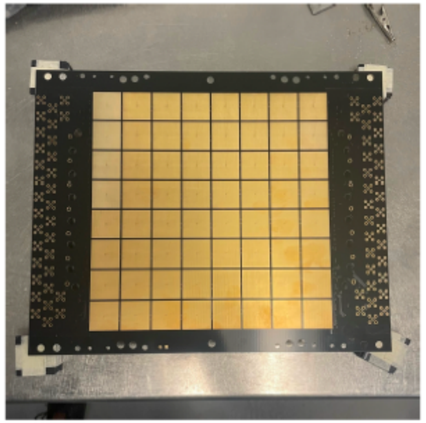


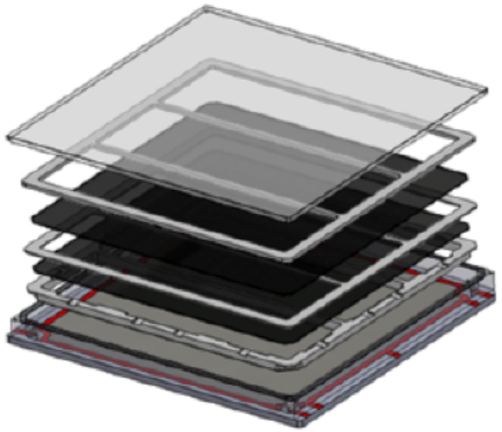


TTS measured : 91pS (FWHM)

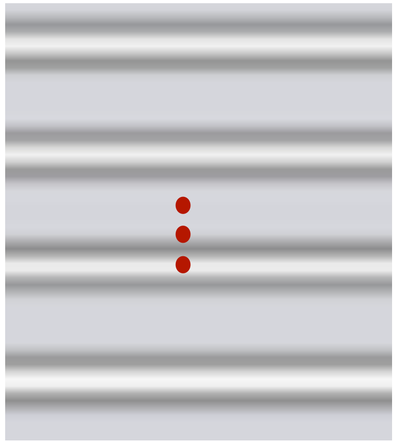
One kind of Gen-II example

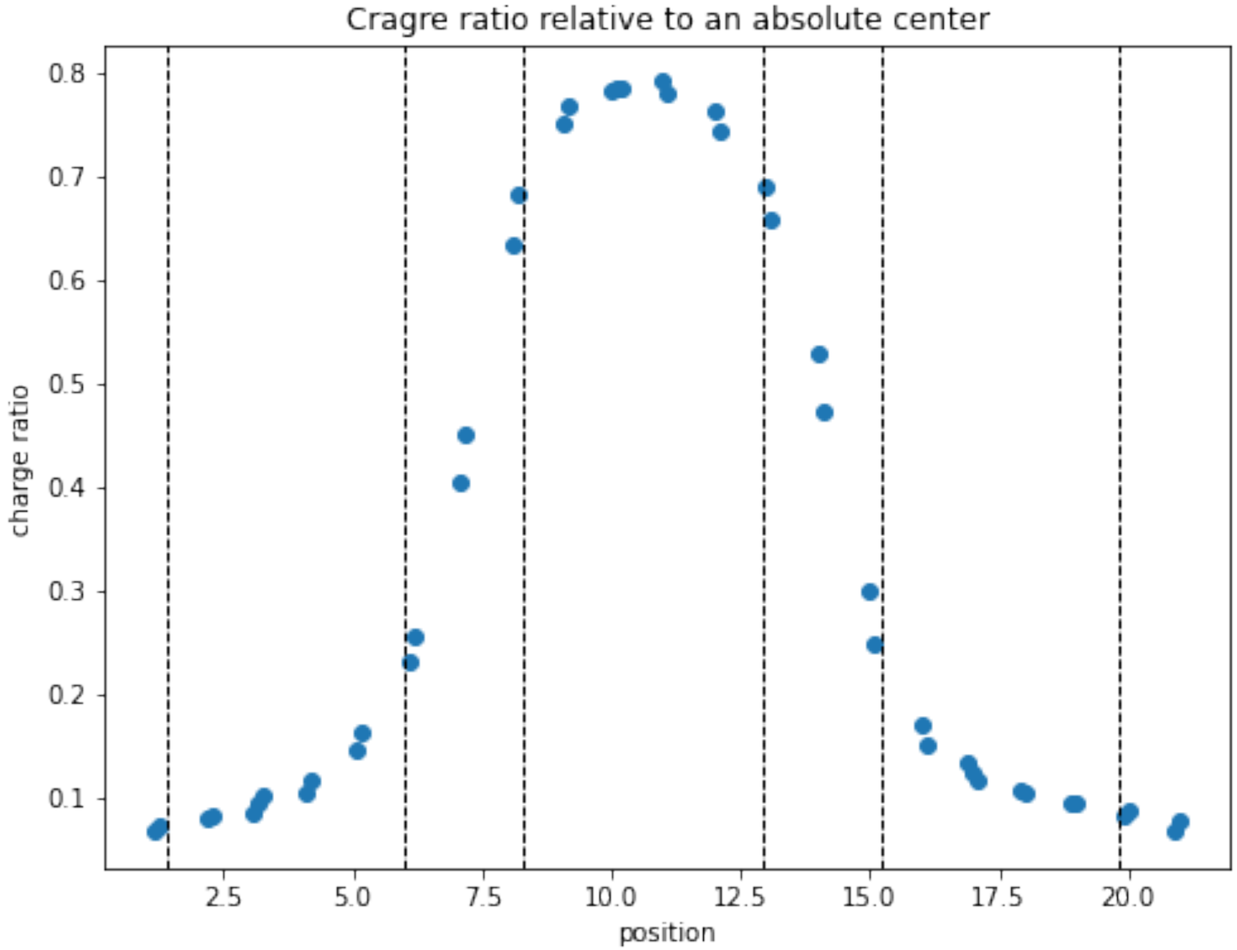




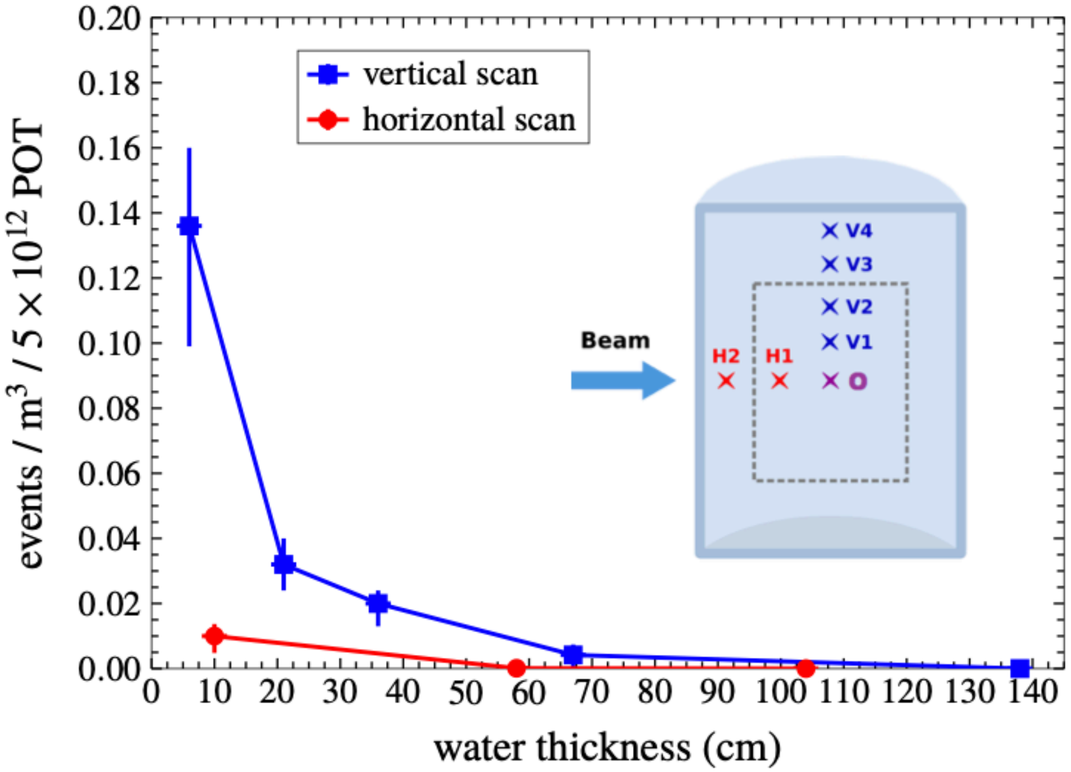


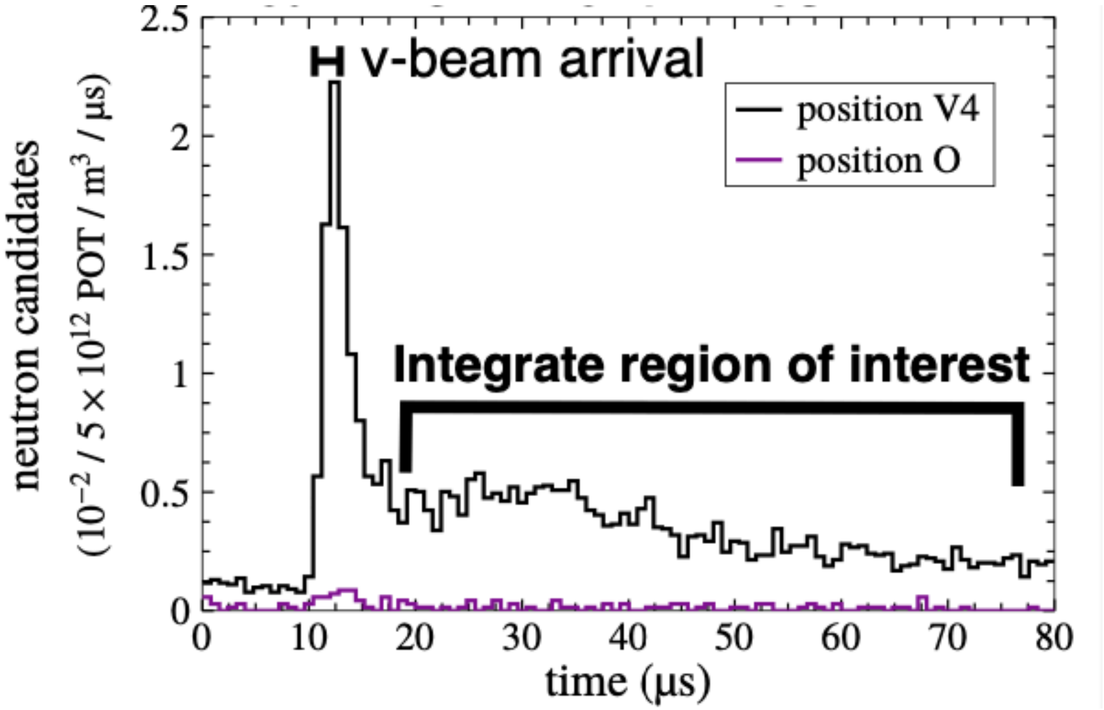
Charge ratio distribution for transverse fitting



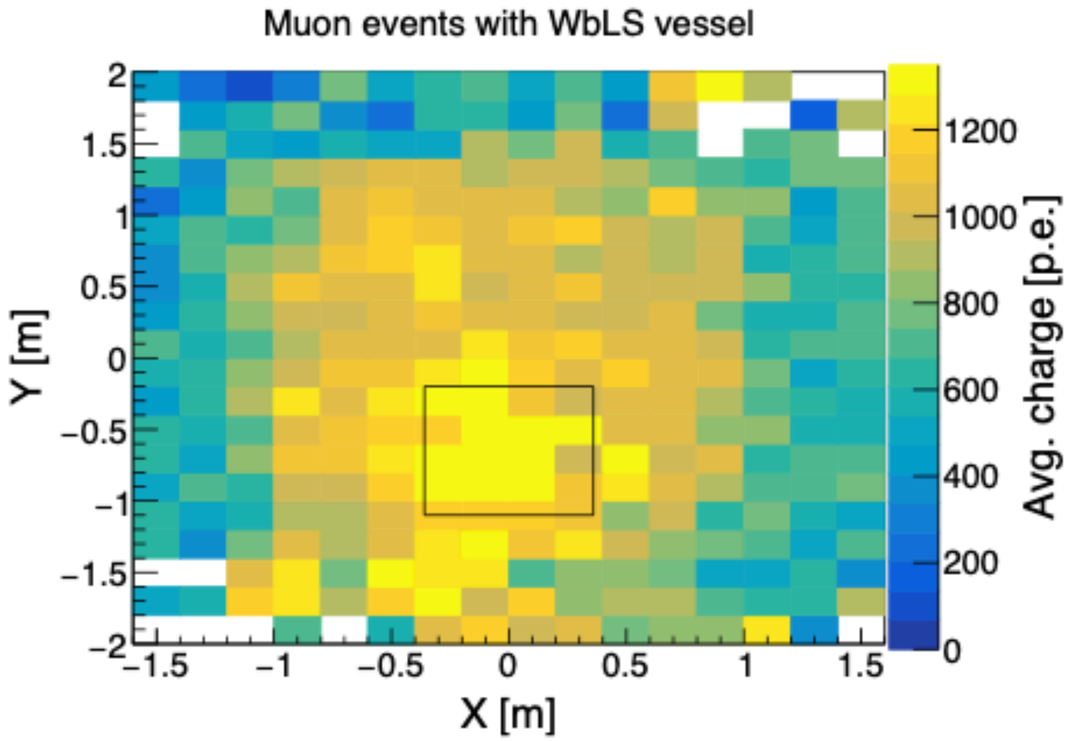


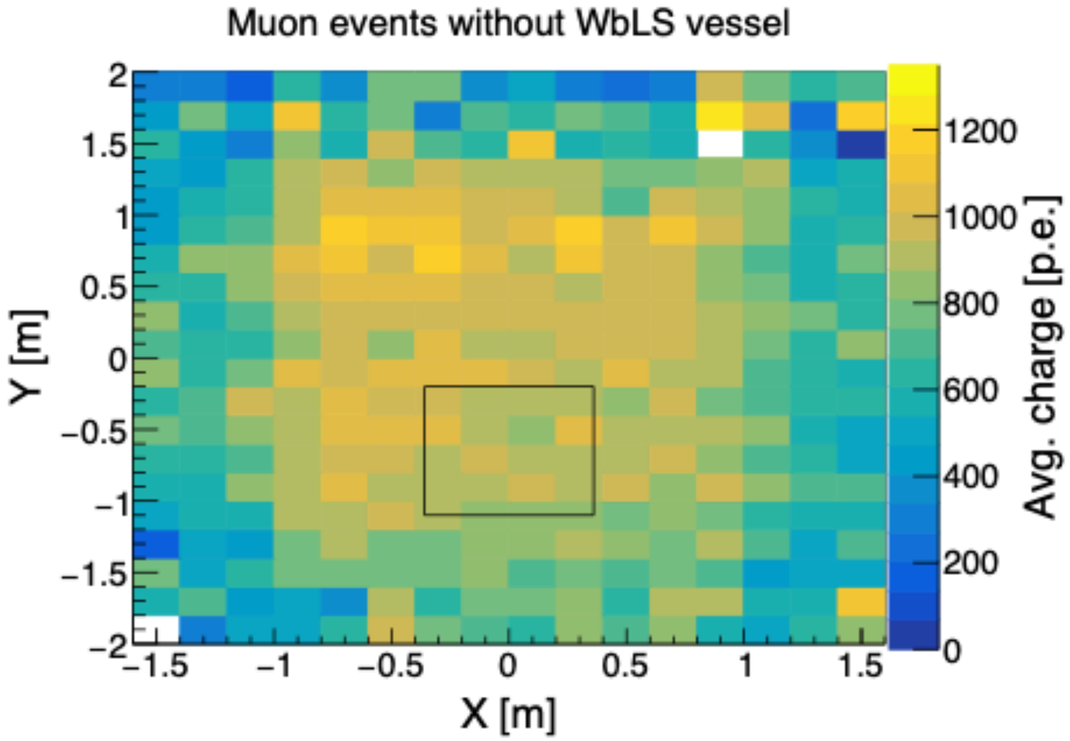
Neutron background



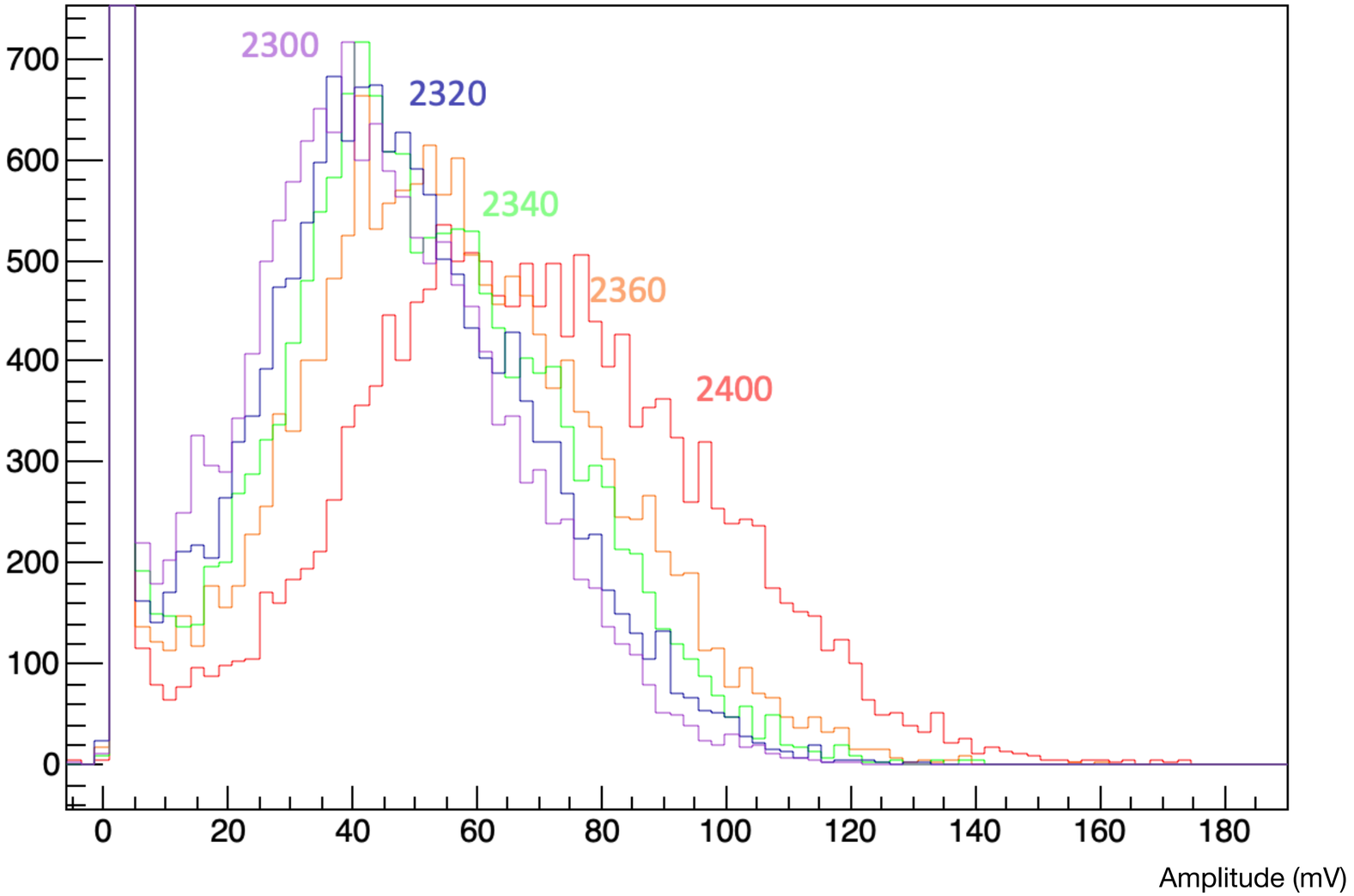


Muon distribution with/without WbLS

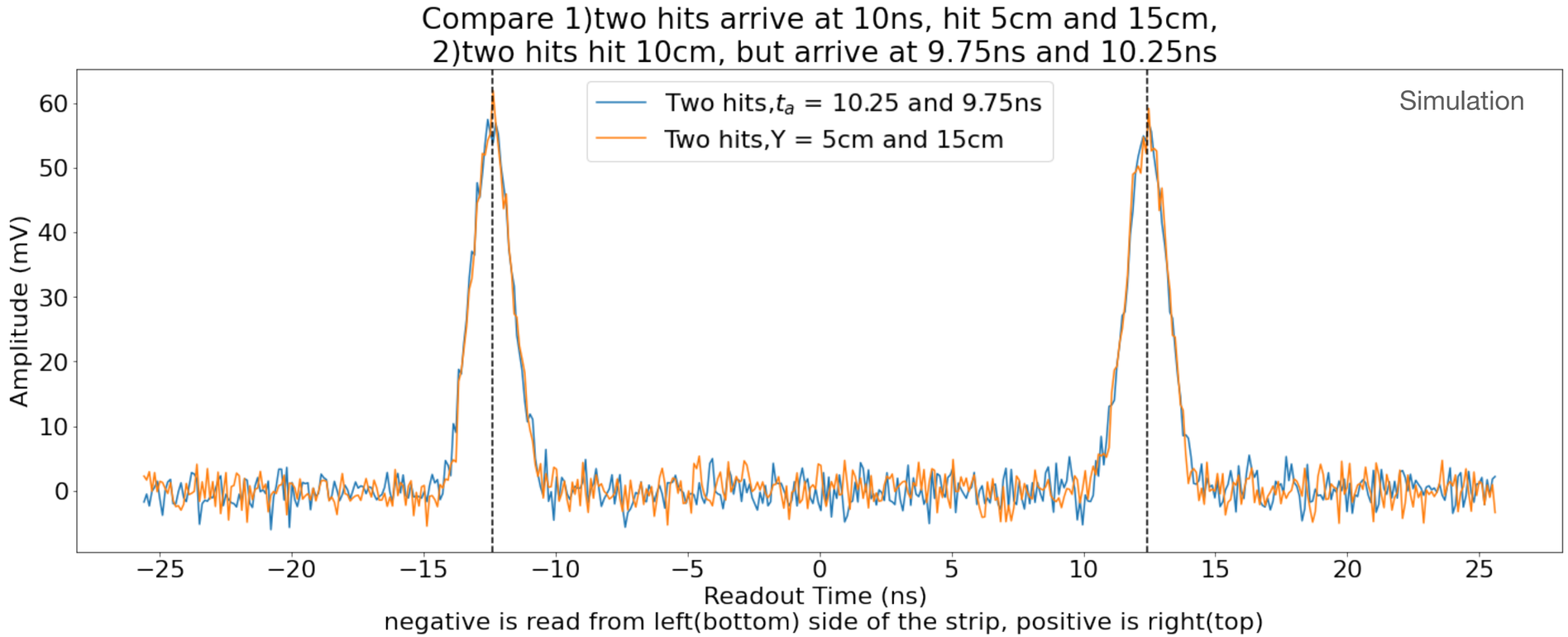




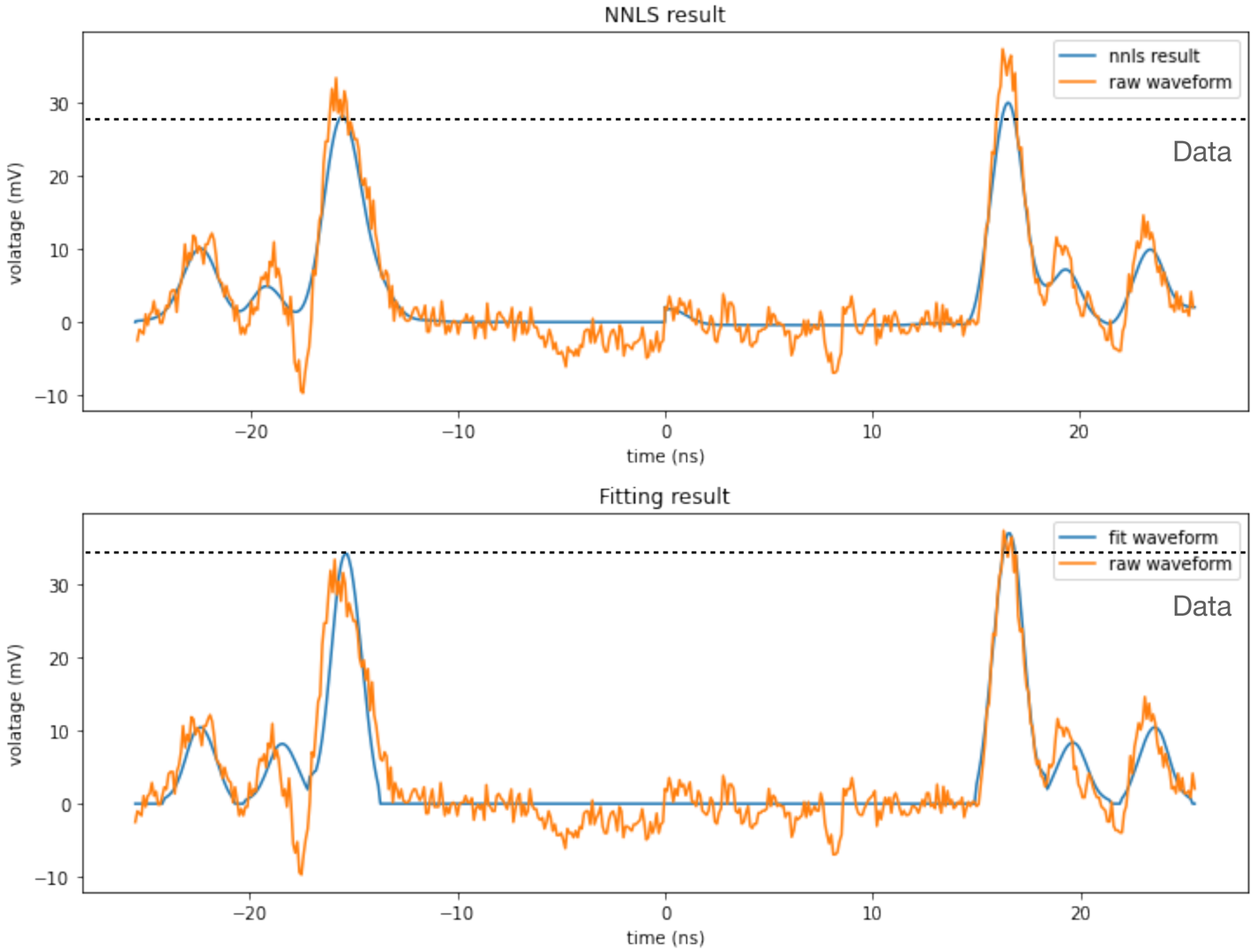
Amplitude distribution of different HV



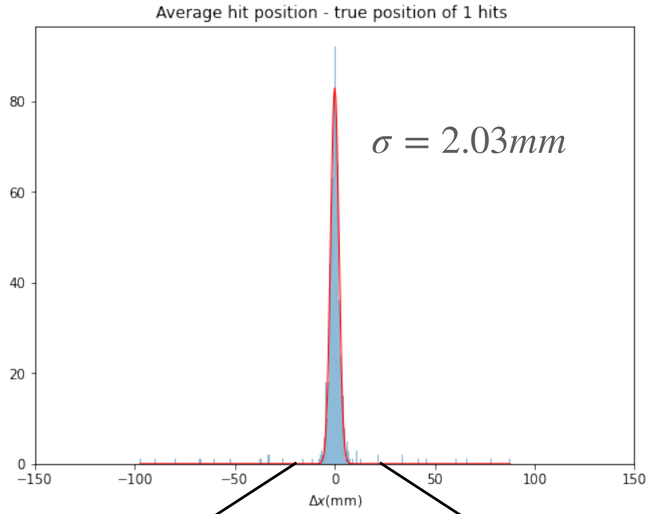
Disambiguation with noise, $\sigma = 2mV$

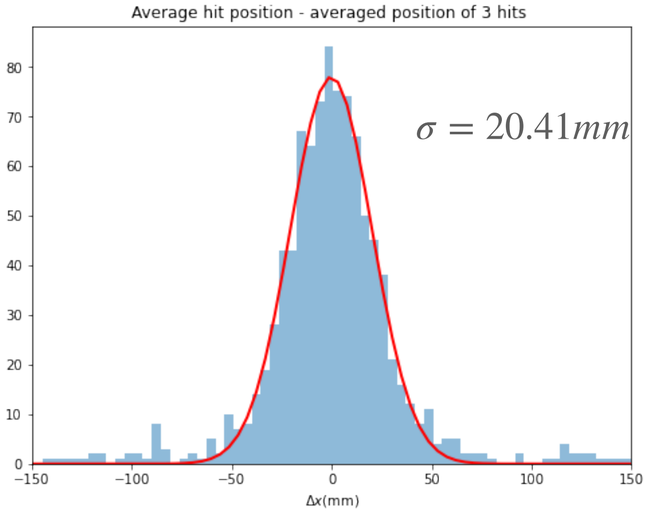


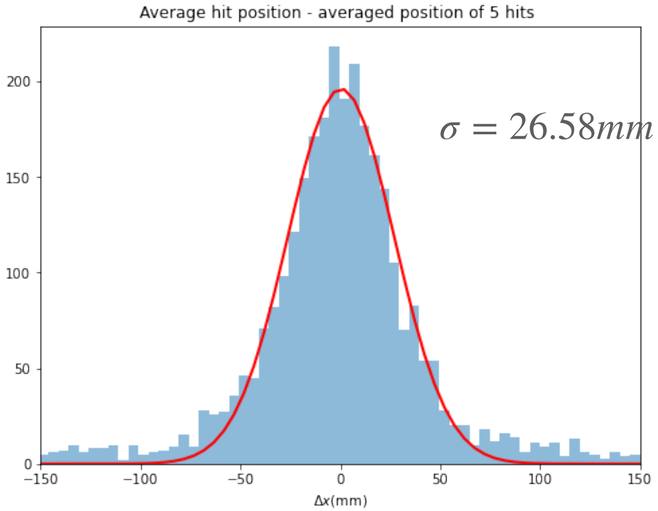
Comparison between NNLS and formula fitting

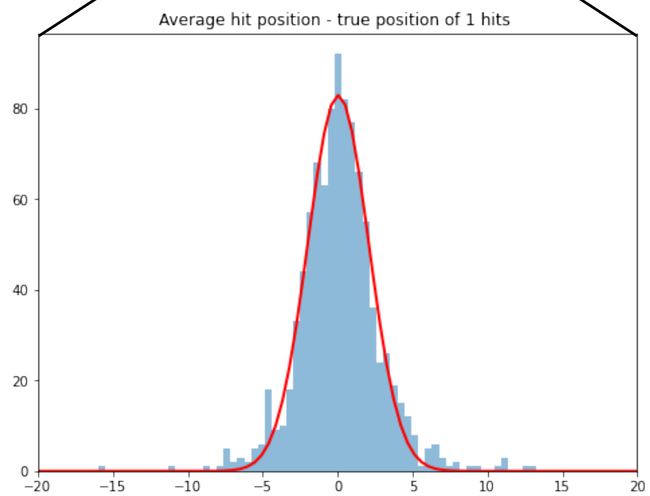


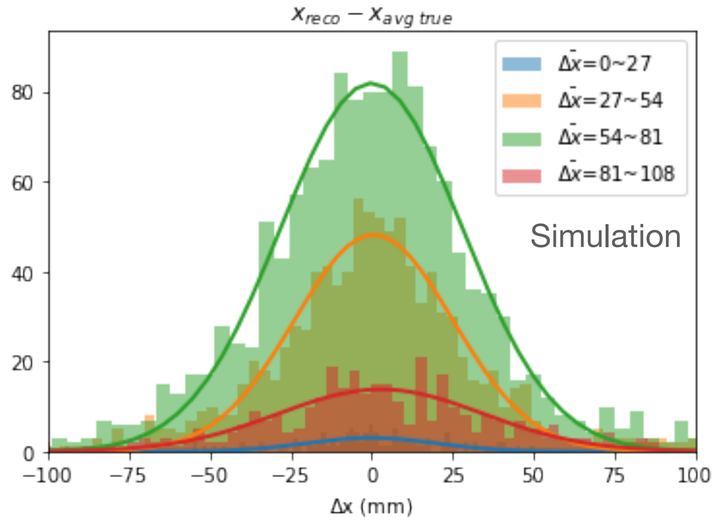
Resolution for Averaged fitting, $x_{reco} - x_{true}$









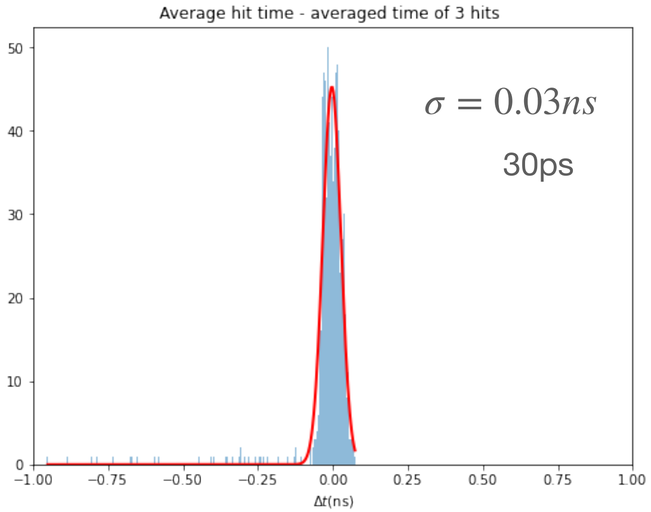


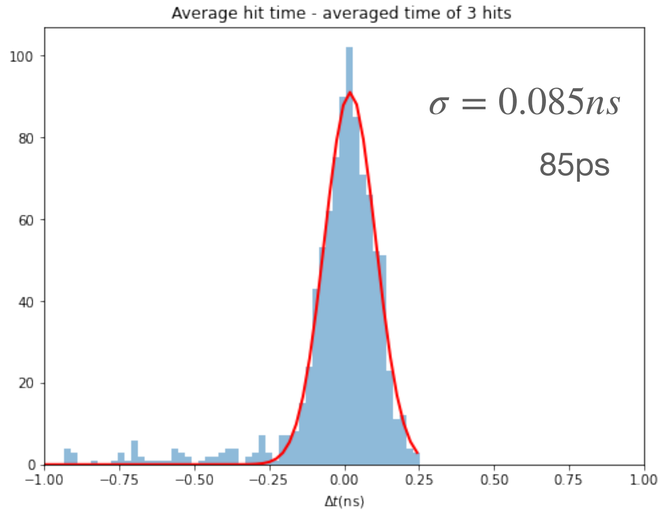
$\sigma_1 = 19.77mm$
$\sigma_2 = 24.43mm$
$\sigma_3 = 28.05mm$
$\sigma_4 = 31.66mm$

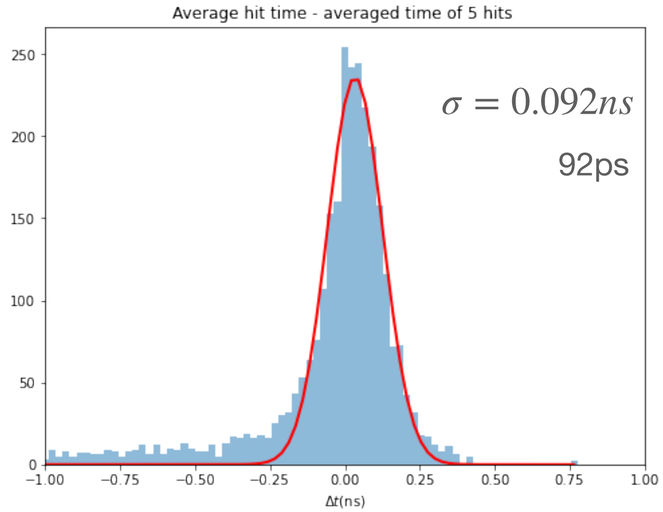
Result for multiple hits not showing the real behavior, but an estimation of noise effect and algorithm.

Simulation consider hits in the whole range of readout window.

Resolution for Averaged fitting, $t_{reco} - t_{true}$

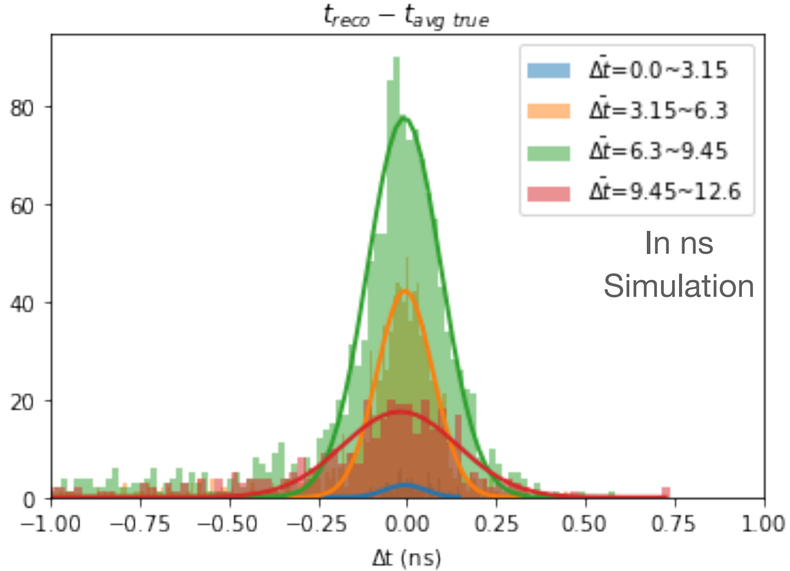






Result for multiple hits not showing the real behavior, but an estimation of noise effect and algorithm.

Simulation consider hits in the whole range of readout window.



$\sigma_1 = 0.056ns(56ps)$
$\sigma_2 = 0.078ns(78ps)$
$\sigma_3 = 0.102ns(102ps)$
$\sigma_4 = 0.161ns(161ps)$