ANNIE - The Accelerator Neutrino Neutron Interaction Experiment

Leon Pickard[1] and Mayly Sanchez[2] on behalf of the ANNIE collaboration
[1] UC Davis - ljpickard@ucdavis.edu, [2] Iowa State University - mayly.sanchez@iastate.edu

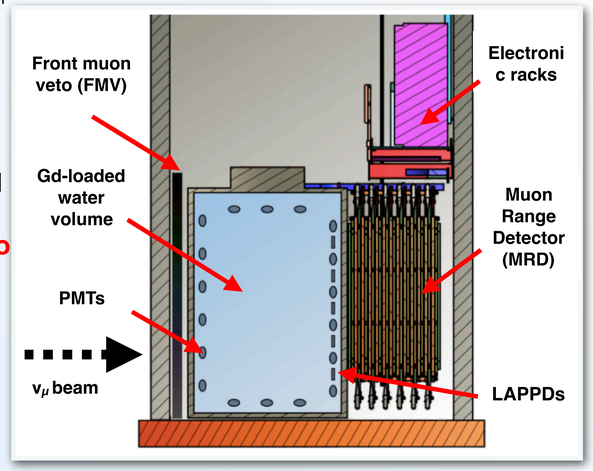
Goal: To measure the final-state neutron multiplicity in neutrino-nucleus interactions whilst simultaneously pioneering the use of advanced photosensors and provide a testbed for the next generation of neutrino experiments.

1. Introduction

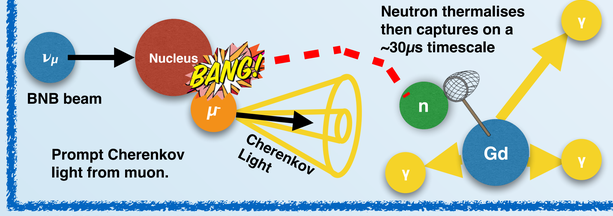
- The complex nature of **neutrino-nucleon interactions** makes them challenging to model.
- ANNIE will measure the neutron multiplicity as a function of momentum transfer for ν_μ interactions.
- ANNIE will achieve such with the use of Large-Area Picosecond PhotoDetectors (**LAPPDs**) - next-generation photosensors with **sub-cm** spacial and **~60ps** temporal resolution.
- ANNIE could provide a world-leading experimental testbed for future novel technologies such as Water-based Liquid Scintillator (**WbLS**).

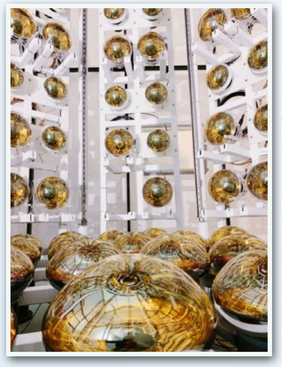
2. ANNIE Design and Methodology

- ANNIE consists of a 3m diameter and 4m tall cylindrical tank filled with 26 tonnes of **gadolinium-doped deionised water**.
- Gadolinium, with its **huge** neutron capture cross-section, enables neutrons to be detected **efficiently**.
- Located in the **Booster Neutrino Beam** (BNB) at Fermilab.
- This will produce ~26,000 charged-current ν_μ interactions in the fiducial volume per year.
- The water volume is instrumented with **132 PMTs, with 5 LAPPDs** to be installed imminently.



- The MRD consists of 11 layers of scintillator sandwiched between 11 layers of iron to reconstruct the energy and momentum of outgoing muons.
- The FMV has 2 layers of scintillator paddles and vetos upstream neutrino interactions.

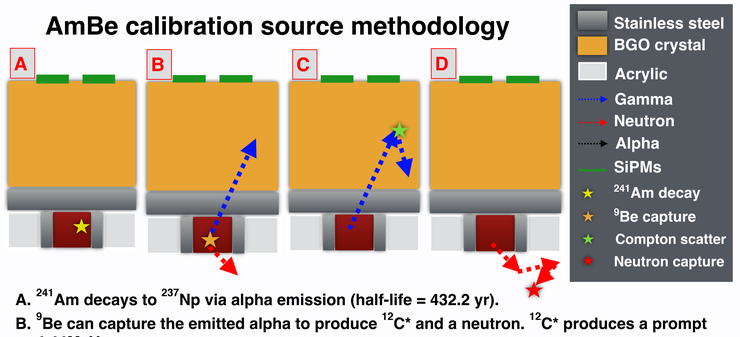




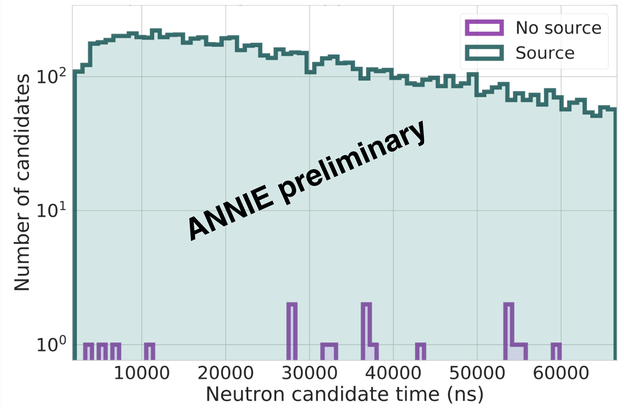
3. Neutron capture calibration results

- To probe the neutrino-nucleon interactions we need to reconstruct final-state muons and have a **high neutron capture detection efficiency**.
- A tagged AmBe source has been built and deployed.

AmBe calibration source methodology

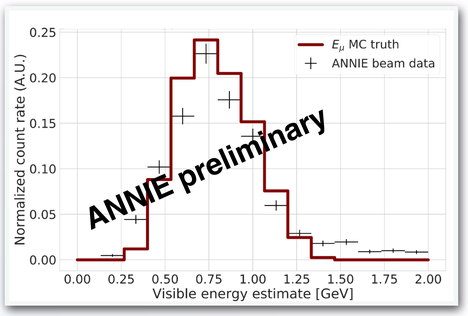


A. ^{241}Am decays to ^{237}Np via alpha emission (half-life = 432.2 yr).
B. ^{9}Be can capture the emitted alpha to produce ^{12}C* and a neutron. ^{12}C* produces a prompt 4.44MeV gamma.
C. 4.44 MeV gamma can Compton scatter in the BGO crystal - this gives us a trigger seen by the SiPMs.
D. Neutron thermalises in ANNIE and is captured on Gd.

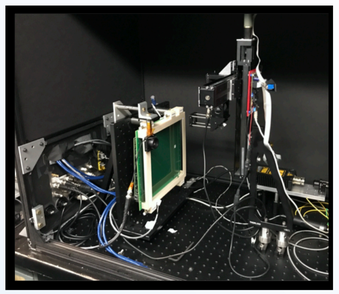


Reconstructed neutron capture candidates with and without AmBe source deployed

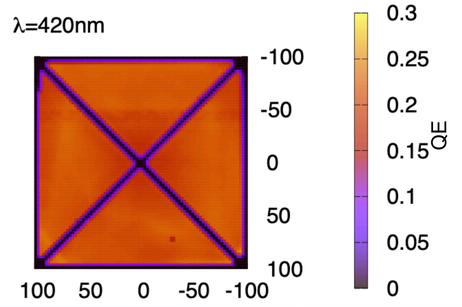
4. Beam data and LAPPD performance



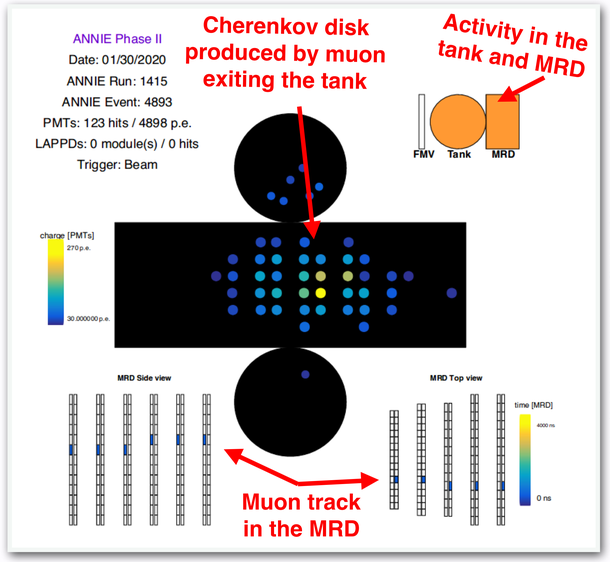
- ANNIE has detected its **first neutrino interactions.**
- In addition to the ability to detect the delayed neutron capture, **reconstruction of the interaction vertex** is under development.
- **LAPPDs to be installed** in October 2020 - the first use of such in a working neutrino experiment.

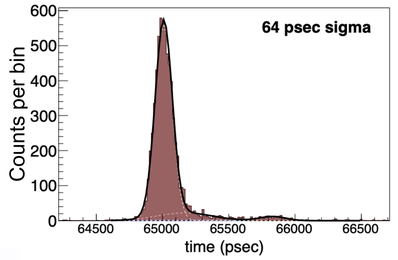


LAPPD undergoing testing prior to tank installation



Homogeneous LAPPD quantum efficiency as a function of position





Pico-second level LAPPD timing resolution has been achieved

5. Conclusions

- ANNIE will measure the neutron multiplicity of neutrino-nucleon interactions - vital for the next generation of neutrino experiments.
- The detector is now operational and has demonstrated the ability to detect both the prompt Cherenkov signal and delayed neutron signal of neutrino-nucleon interactions.

Acknowledgements

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