First neutron capture results in ANNIE

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UC Davis

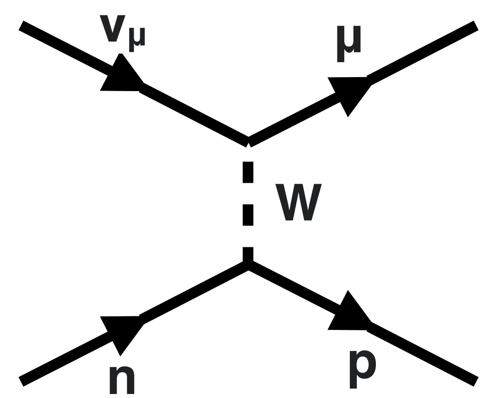
New Perspectives
20/07/20 - 21/07/20

Introduction

- What is ANNIE and what are its aims?
- Why do we need to detect neutrons?
- Development of the neutron calibration source
- ANNIE's first neutron results
- What's next…?

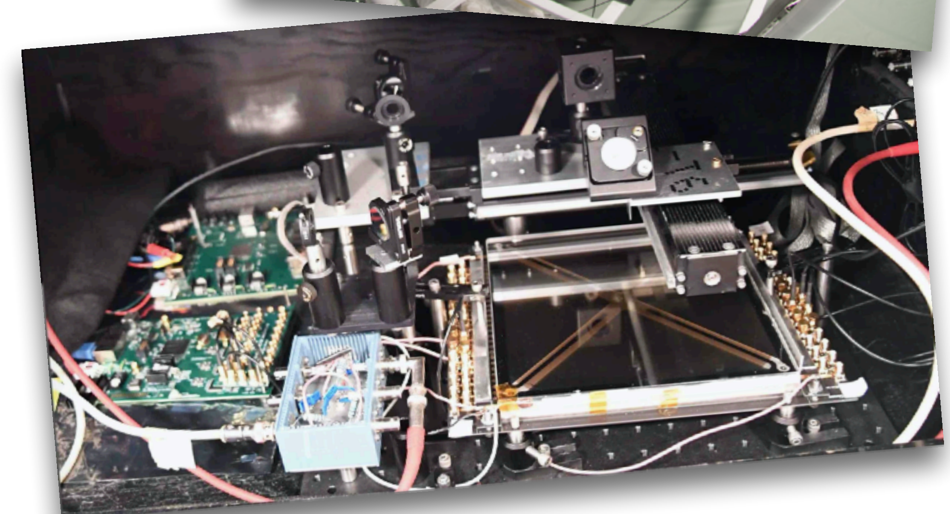
What is ANNIE and what are its main goals?

- ANNIE is the Accelerator Neutrino Neutron Interaction Experiment.
- It will measure the neutron multiplicity of ν_μ interactions as a function of momentum transfer and the ν_μ cross sections on water.
- The complex nature of neutrino-nucleus interactions makes them challenging to model.
  - This results in large systematic uncertainties in long-baseline experiments
  - Unknown contribution of atmospheric neutrino background to proton decay measurements
  - How often do “stealth” atmospheric neutrinos mimic DSNBs?
- Furthermore ANNIE provides a world leading testbed for future technologies:
  - The first use of Large Area Picosecond Photodetectors (LAPPDs) in a running neutrino experiment
  - Potential introduction of a Water-based Liquid Scintillator (WbLS) volume
  - Neutron calibration source provides a prototype for similar implementations in WATCHMAN and THEIA



ν_μ CCQE interaction

See “The Future of ANNIE in 10 minutes” by Michael Nieslony



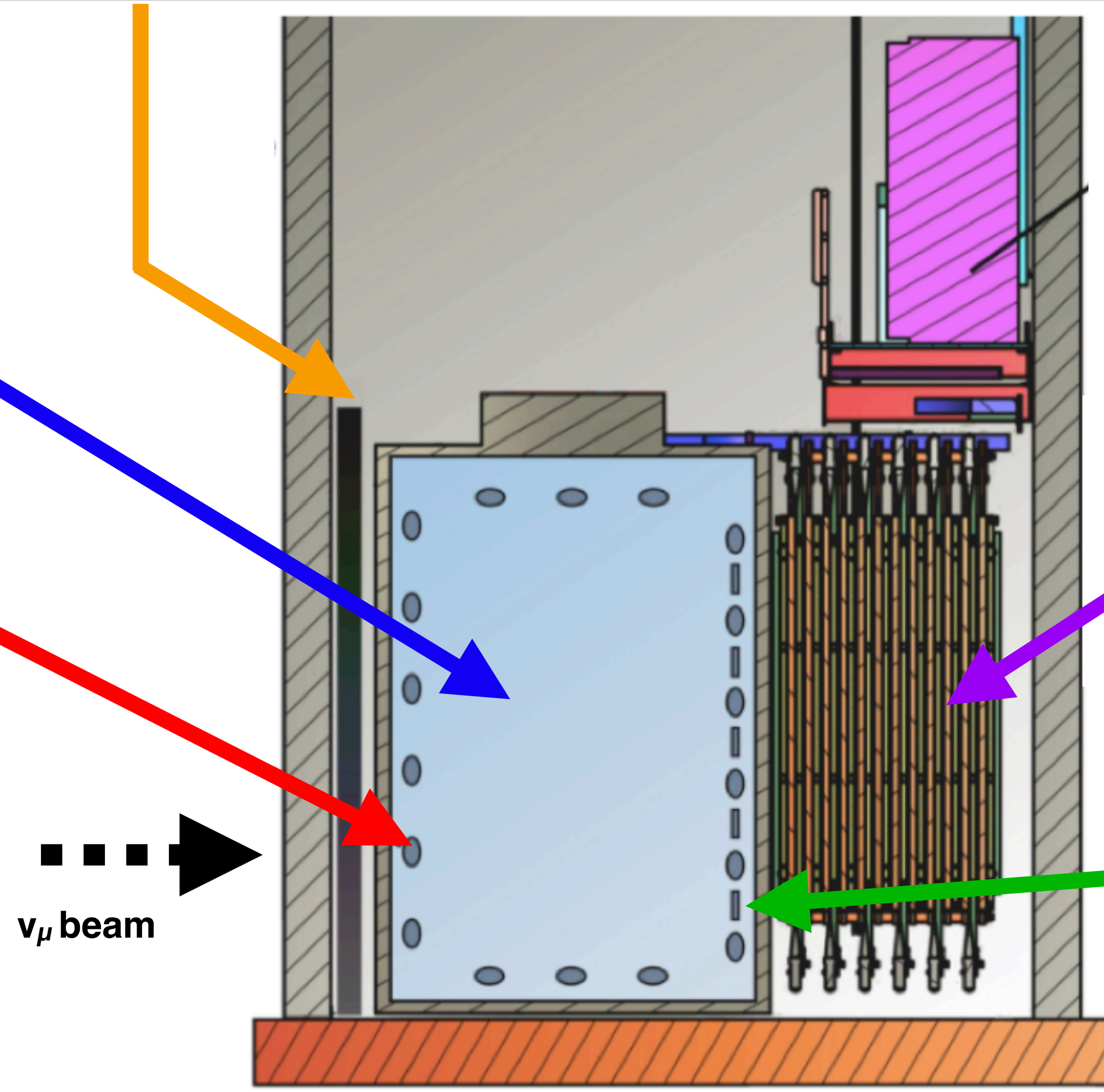
Introducing the ANNIE detector

- **ANNIE has a 3m diameter and 4m tall cylindrical tank filled with 26 tonnes of gadolinium-loaded (0.1%) deionised water.**
- **Gadolinium, with its huge neutron capture cross-section (~50,000 barns), enables neutrons to be detected efficiently.**

The water volume is instrumented with 132 PMTs, giving a 20% photocathode coverage

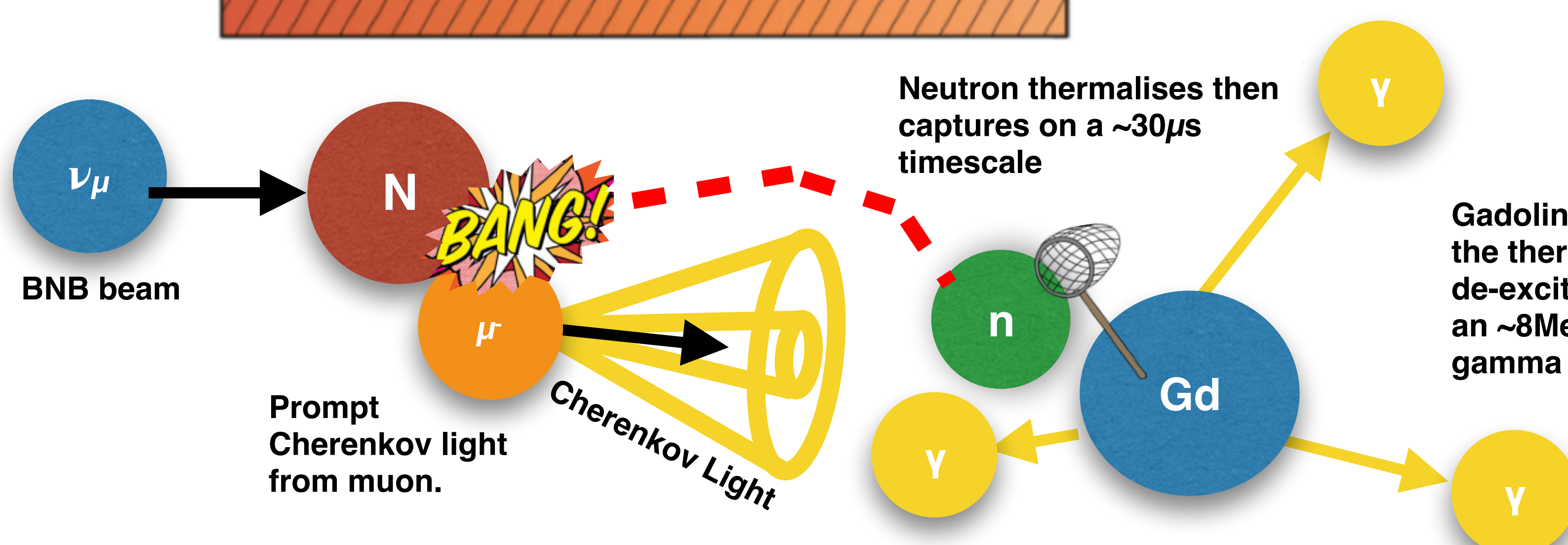
- **Located 100m downstream in the Booster Neutrino Beam (BNB) at Fermilab.**
- **~26,000 charged-current ν_μ interactions in the fiducial volume per year.**

The Front Muon Veto (FMV) consists of 2 scintillator paddle layers and is used to vetos upstream neutrino interactions.



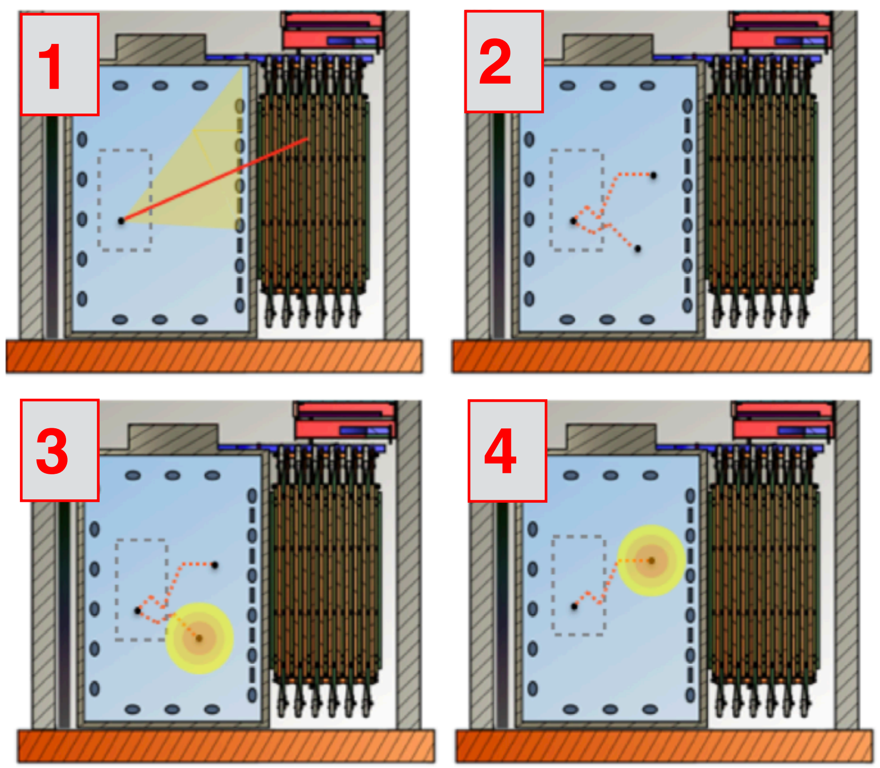
The Muon Range Detector (MRD) consists of 11 layers of scintillator sandwiched between 11 layers of iron. This enables energy and momentum reconstruction of outgoing muons.

5 LAPPDs with sub-cm spacial, and ~60ps temporal, resolution are to be installed imminently. This will further enhance reconstruction capabilities.



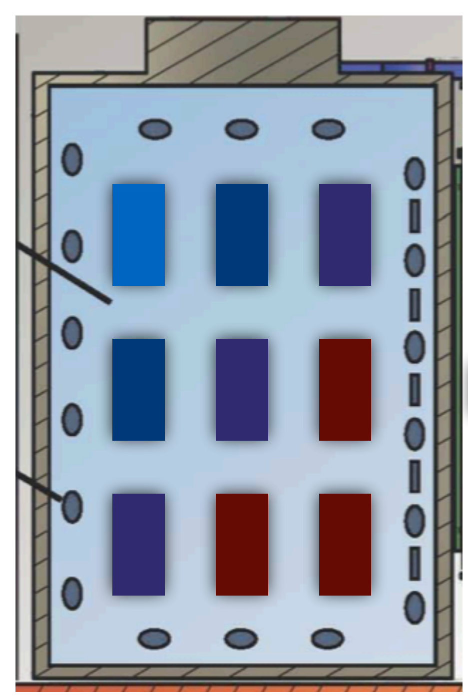
ANNIE's neutron capture detection efficiency must be precisely mapped

- To achieve ANNIE's main goals, it is imperative that we fully understand the position-dependent neutron capture efficiency
- By designing and deploying a neutron source at specific locations within the tank, the efficiency as a function of position can be mapped.
- Thus, we need to design a calibration source that produces a single neutron AND can be tagged.

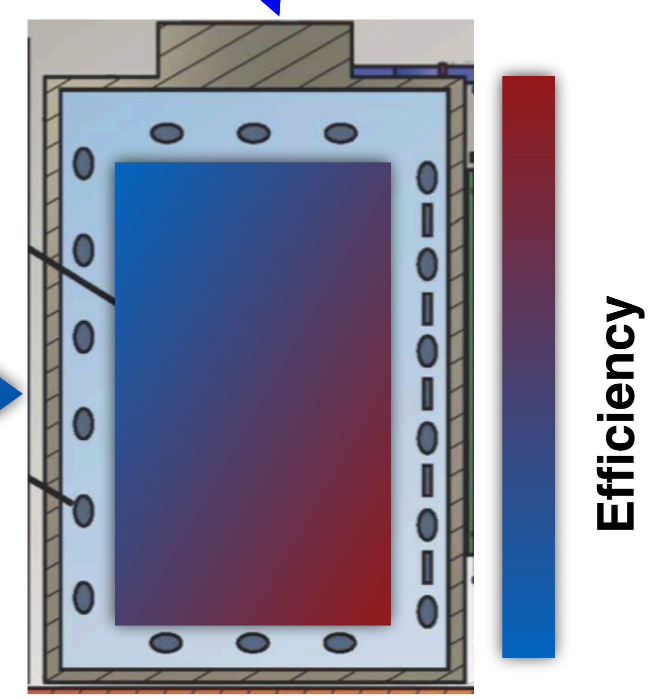


To measure neutron multiplicities, ANNIE's position-dependent neutron detection efficiency must be well measured.

1. A prompt muon interacts in the fiducial volume, producing a Cherenkov ring and a track in the MRD.
2. Final state neutrons are produced. Scattering and thermalising.
3. & 4. After ~10s μs each neutron is captured on Gd, producing an 8 MeV gamma cascade.



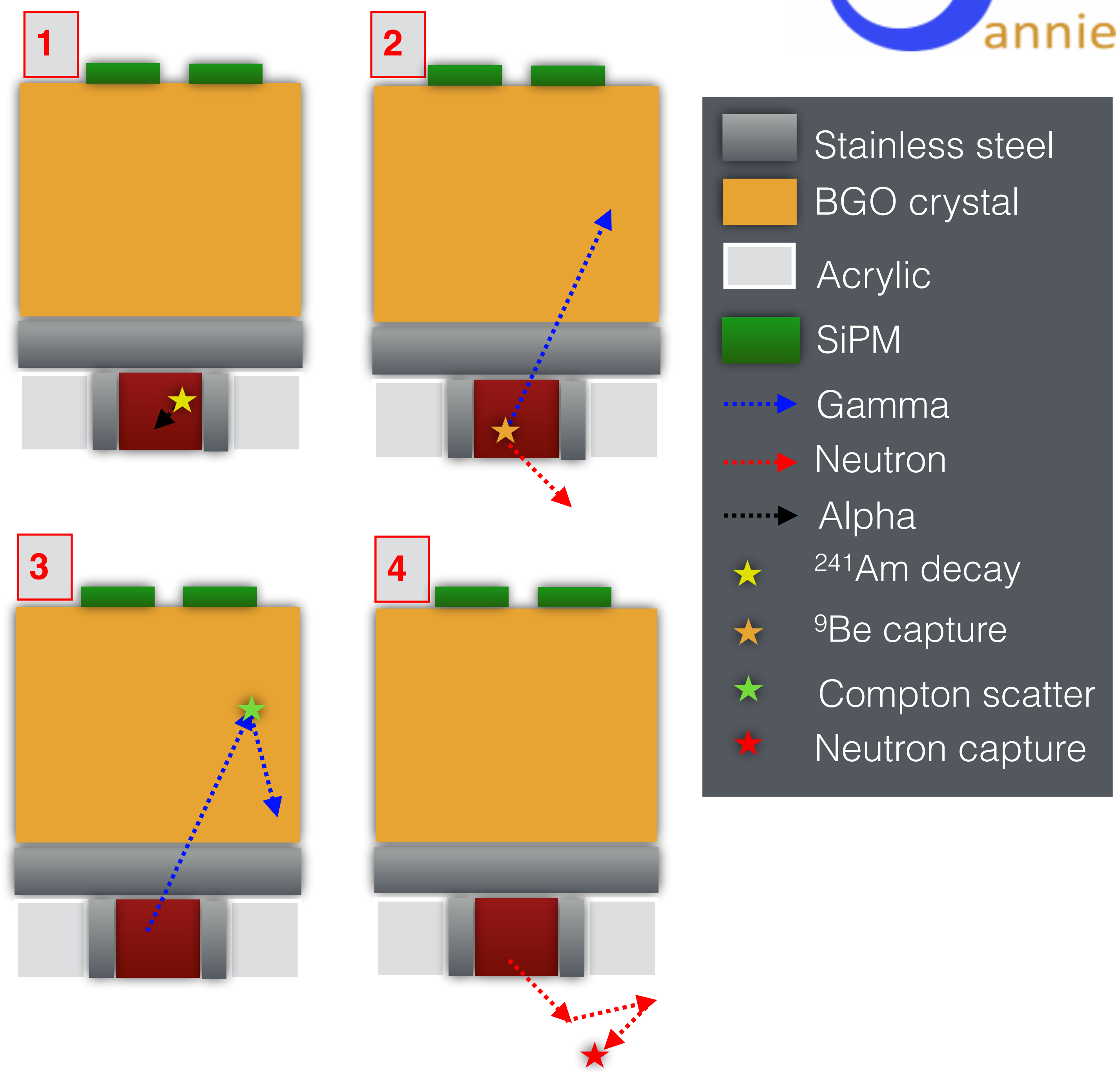
By placing a calibration source throughout the detector....



...the neutron capture detection efficiency will be mapped.

Introducing the AmBe source…

- The AmBe source is a mixture of ^{241}Am and ^{9}Be.
- Produces a neutron and a 4.44 MeV gamma.
- SiPMs and a bismuth germanium oxide (BGO) crystal are used to detect this gamma.
  - High light yield of ~8500 photons per MeV.
  - Emits in a favourable wavelength regime (480 nm peak emission with a range of 375-650 nm).
  - Dense (7.13 g/cm^3), increasing Compton scatter likelihood.
- The neutron detection efficiency is then determined by searching for the 8MeV gamma cascade produced upon capture.

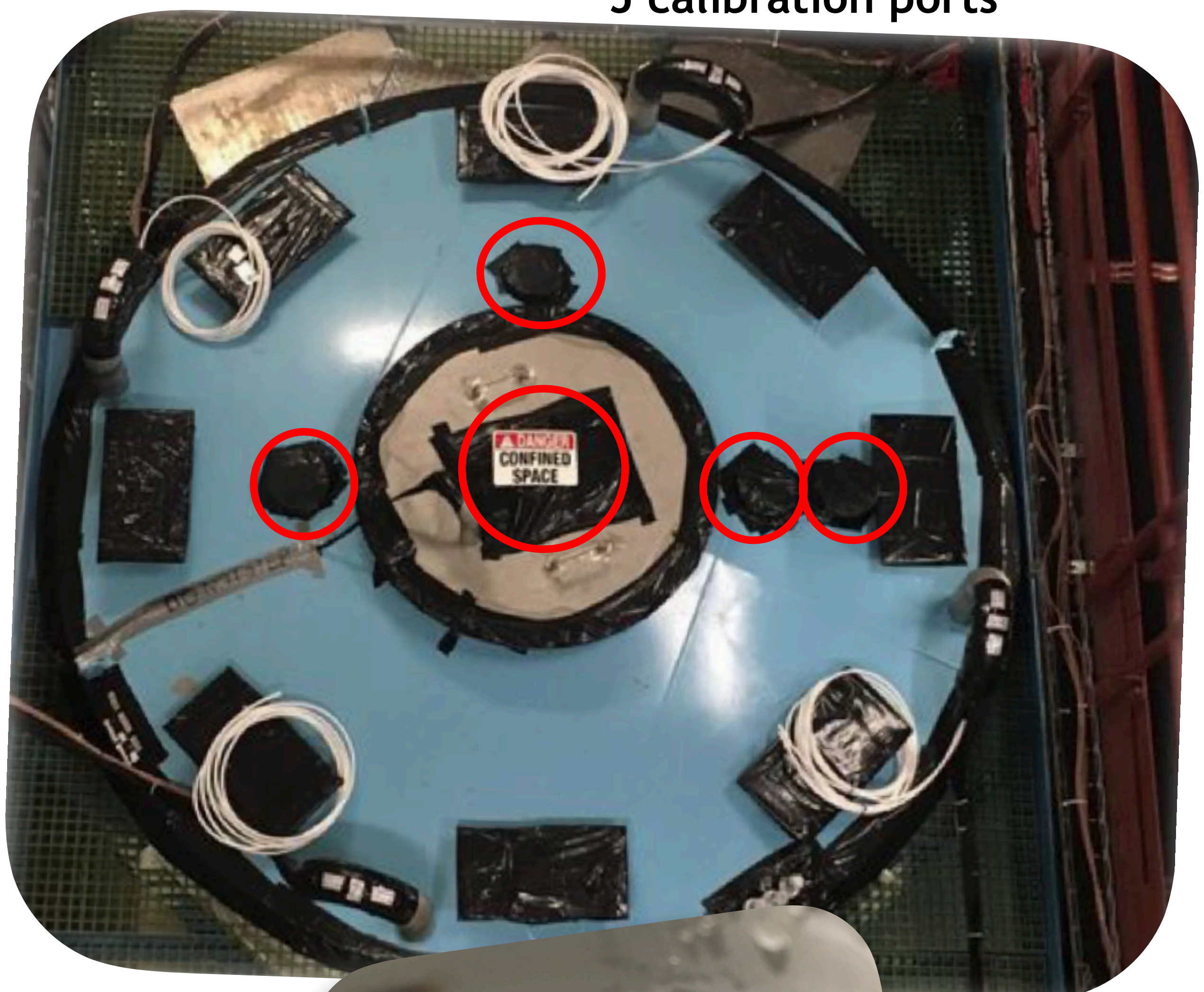


1. **^{241}Am decays to ^{237}Np via alpha emission (half-life = 432.2 yr).**
2. **^{9}Be can capture the emitted alpha to produce ^{12}C* and a neutron. ^{12}C* produces a prompt 4.44MeV gamma.**
3. **4.44 MeV gamma can Compton scatter in the BGO crystal - this gives us a trigger.**
4. **Neutron thermalises in ANNIE and is captured on Gd.**

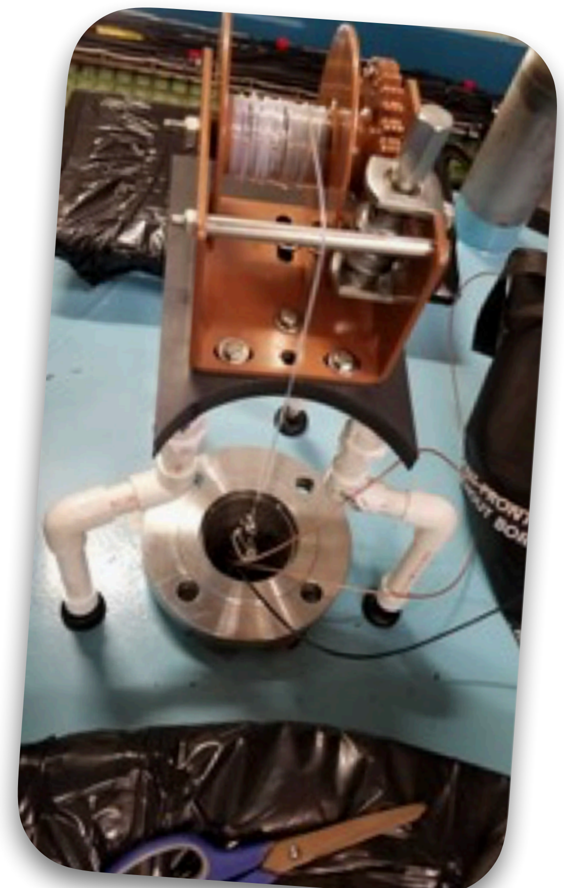
Assembly of the source

The calibration campaign has begun!

5 calibration ports

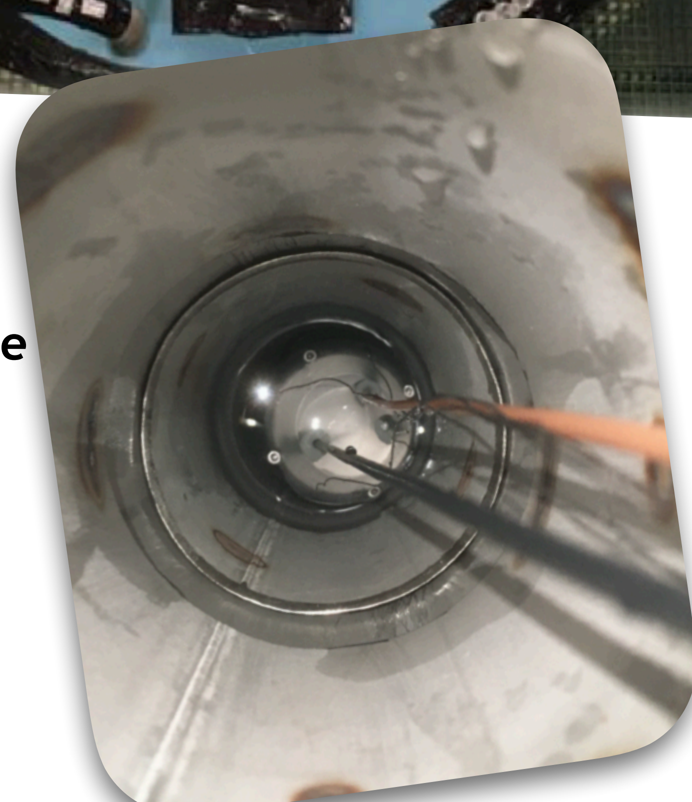


Deployment winch

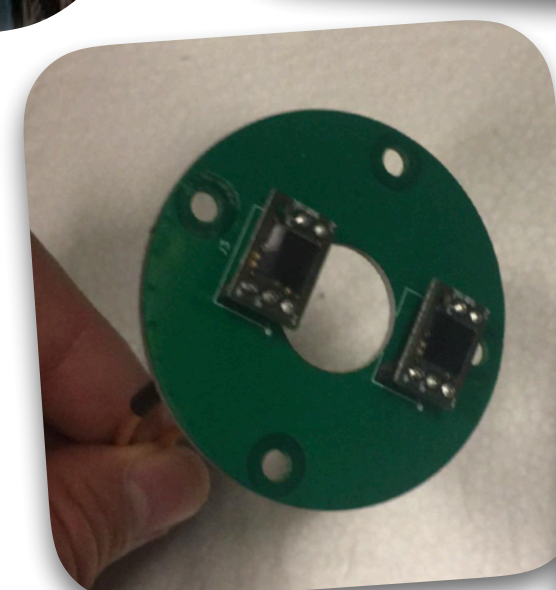


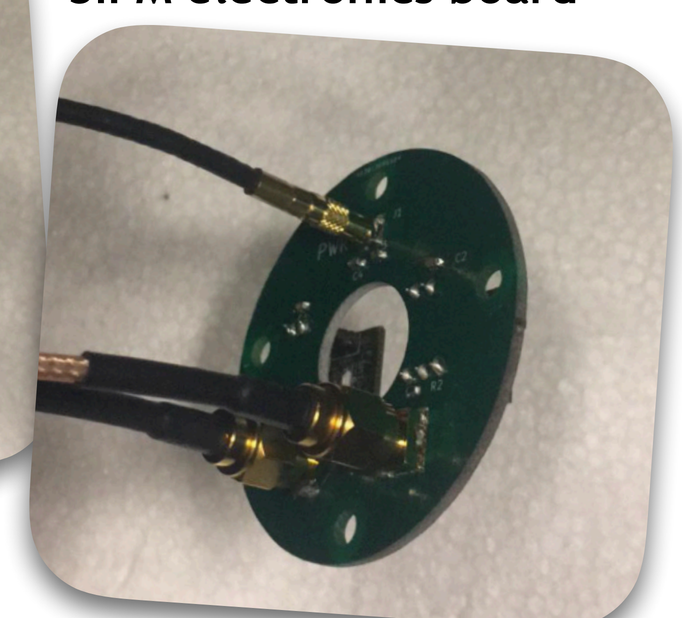
UVT acrylic container

Submerging the
AmBe source
container



SiPM electronics board

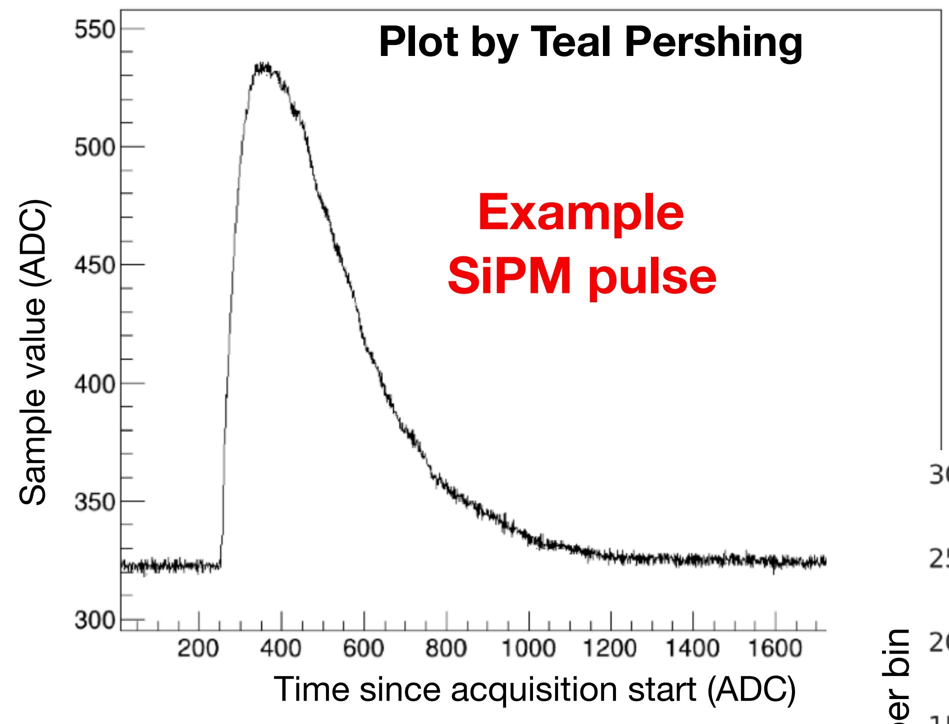


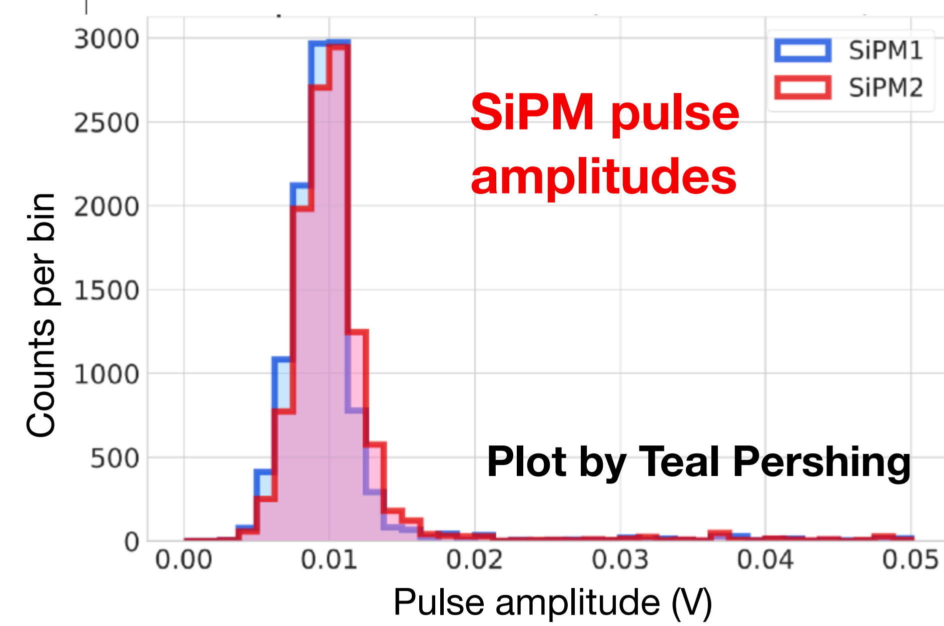


AmBe data selection

SiPM cuts

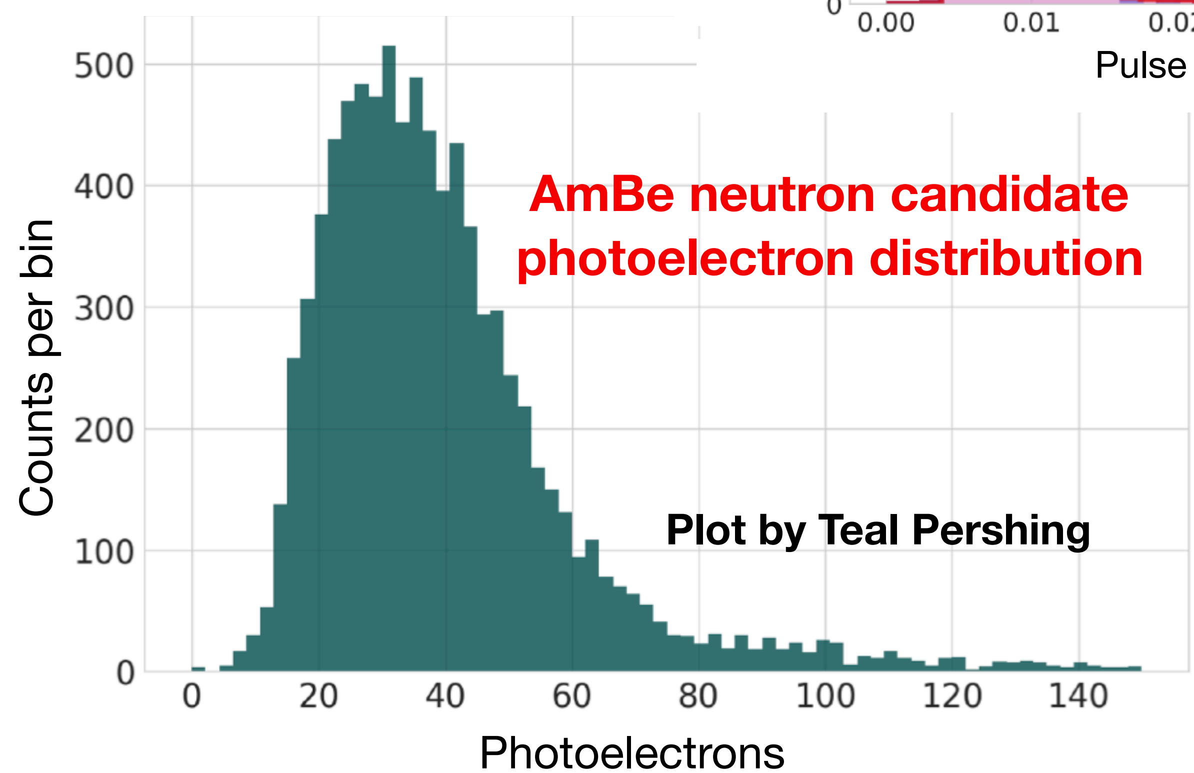
- Both SiPMs trigger in coincidence (with 6mV amplitude)
- Only one pulse in each SiPM acquisition



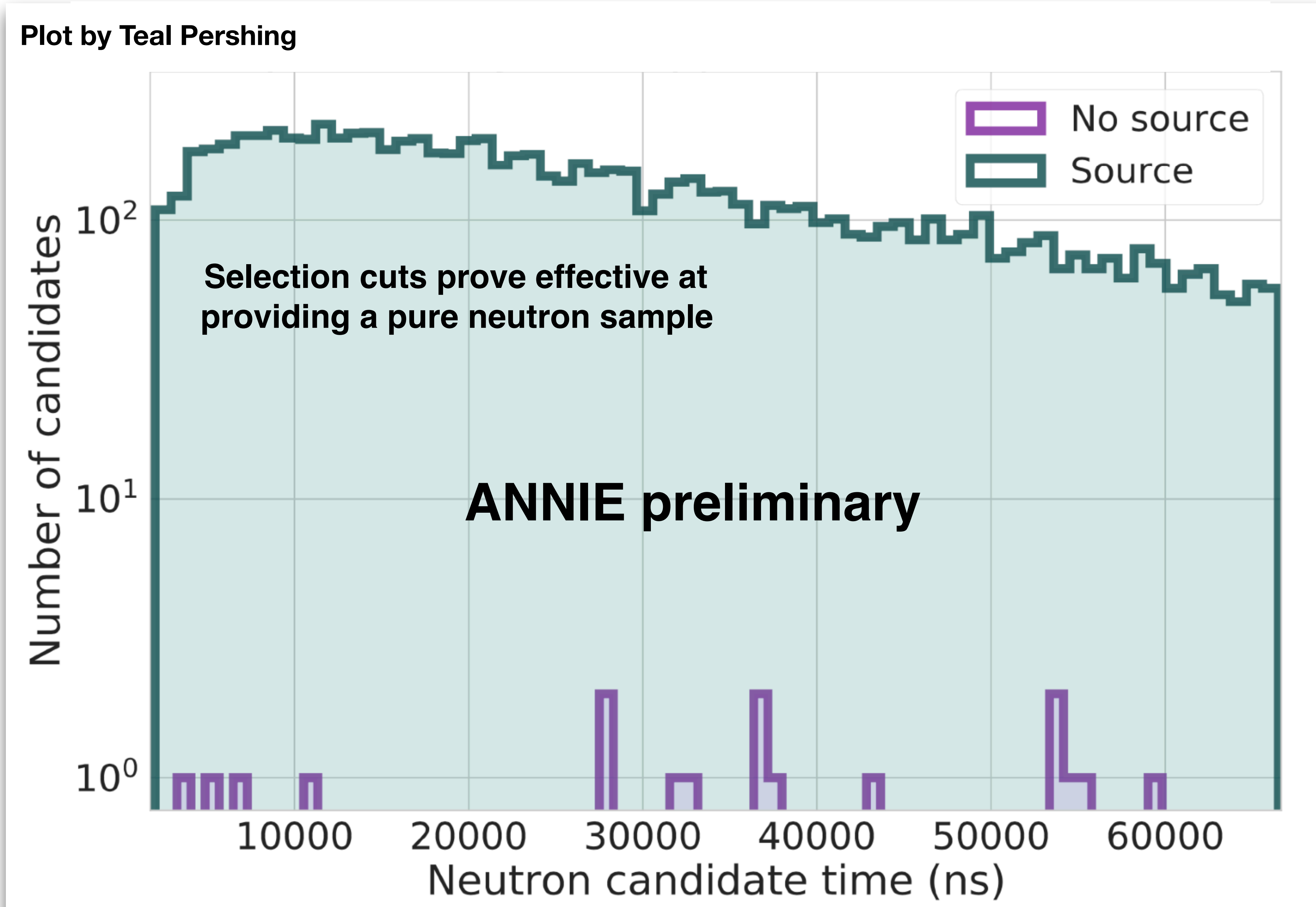


Tank activity

- No neutron candidates within 2μs of SiPM trigger - reduces through-going muon background
  - A “candidate” occurs when at least 5 PMTs see a pulse within 50ns.

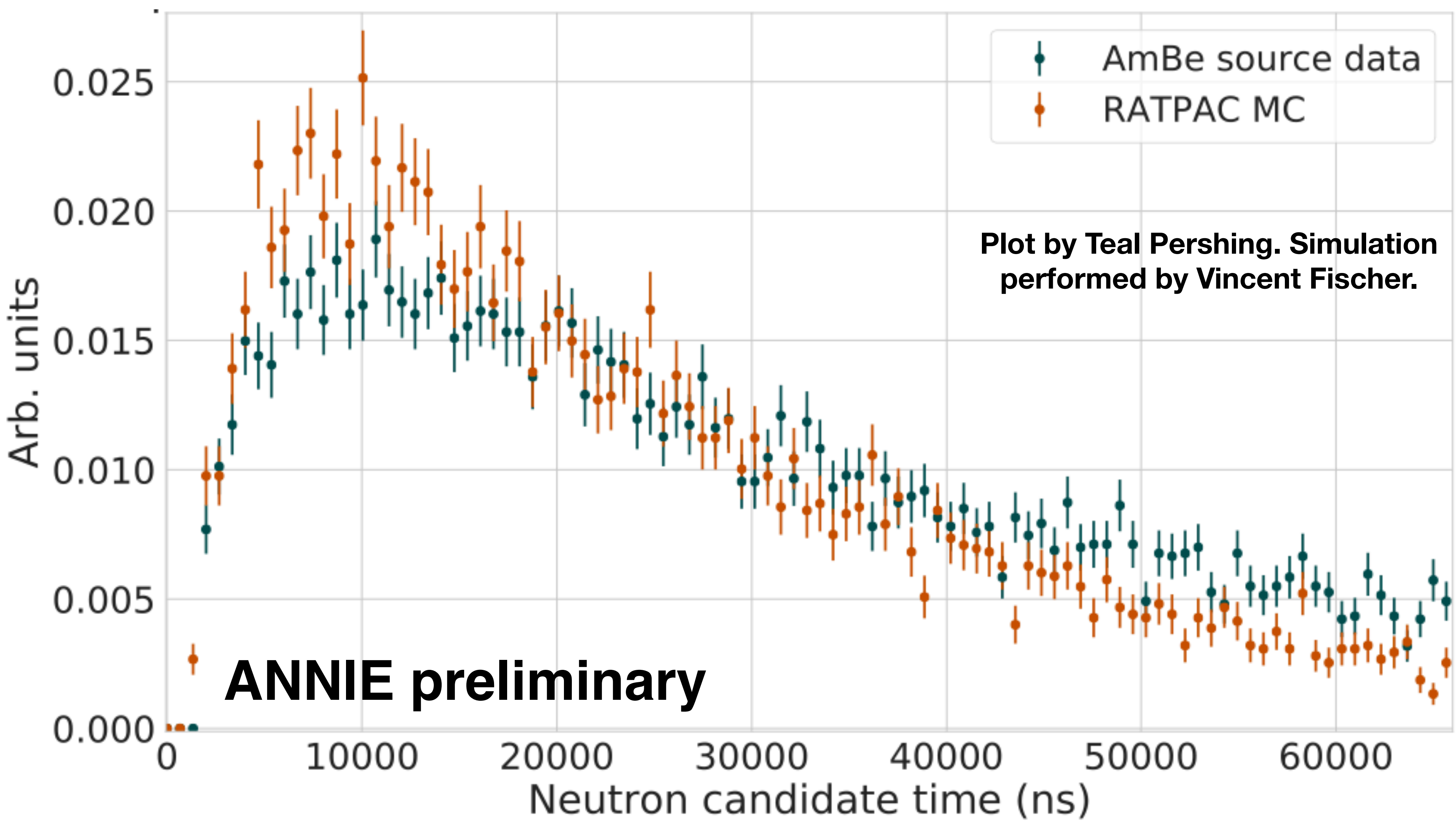


ANNIE has detected its first neutrons



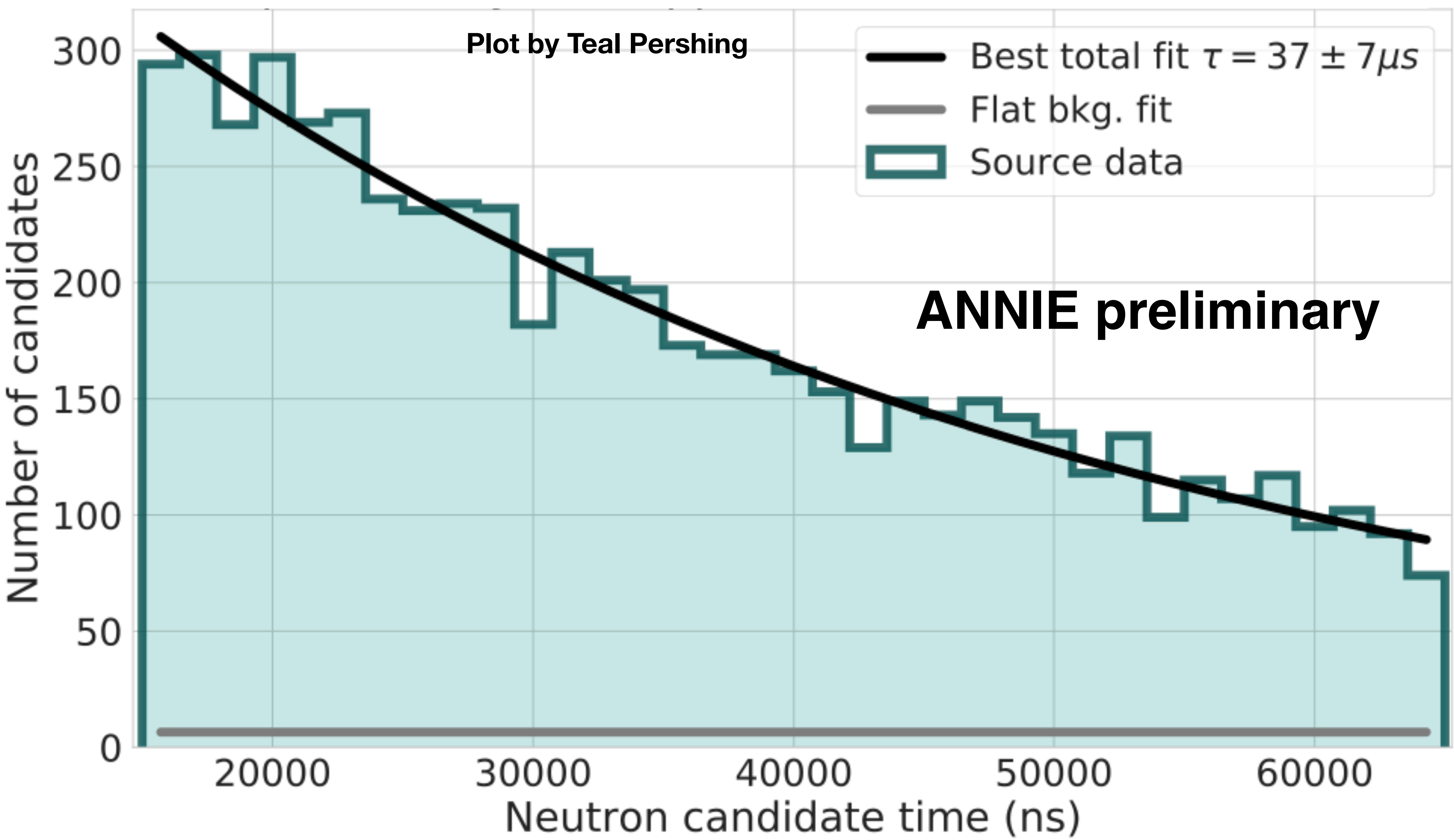
Reconstructed neutron capture candidates with and without AmBe source deployed

Data Vs Monte Carlo



Data/MC comparison of neutron candidate time for a central deployment

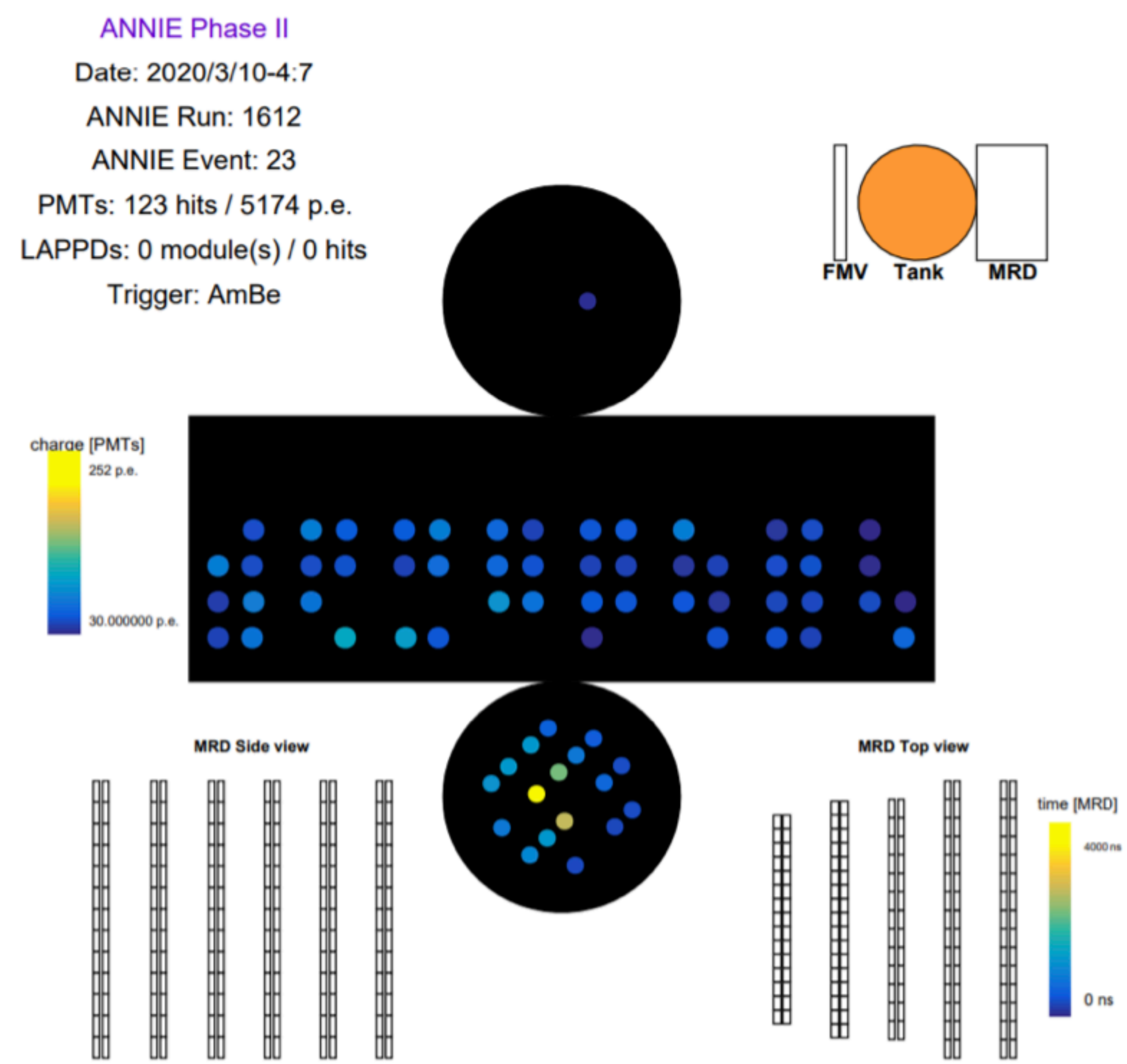
Capture timescale is consistent with expectation



Capture time of neutron candidates

What's next…?

- Now that ANNIE has its first neutron captures, the neutron detection efficiency calculation has begun.
- Analysis is in advanced stages (Dr. Teal Pershing - PhD Thesis)
- Complimentary analysis is under development
- Many ongoing systematic studies
  - 25 systematic uncertainties are being considered:
    - n captures on BGO
    - Gammas from n capture on Gd trigger SiPM
    - Multiple AmBe decays in acquisition window
    - …
- Continuation of AmBe deployment throughout the detector volume to resume later in the year.



ANNIE event display of suspected through-going muon during an AmBe background run.

Conclusions

- Neutrino-nucleus interactions are extremely challenging to model.
- This results in large systematic uncertainties for long-baseline neutrino experiments.
- ANNIE aims to measure the neutron multiplicity of neutrino-nucleon interactions as a function of momentum transfer.
- Thus, ANNIE's position-dependent neutron capture detection efficiency must be well understood.
- As such the AmBe calibration source was designed, built and has now been deployed within ANNIE.
- ANNIE has now detected its first neutrons with the efficiency analysis well developed.
- Systematic uncertainty determination is underway.
- A longer calibration campaign is expected to resume later this year.

Backup

J Series performance parameters

Parameter (Note 4)	30035		40035		60035		Unit
	Overvoltage						Unit
	+2.5 V	+6 V	+2.5 V	+6 V	+2.5 V	+6 V	
PDE (Note 5)	38	50	38	50	38	50	%
Dark Count Rate	50	150	50	150	50	150	kHz/mm^2
Gain (anode-cathode)	2.9×10^6	6.3×10^6	2.9×10^6	6.3×10^6	2.9×10^6	6.3×10^6	
Dark Current – typical	0.23	1.9	0.35	3.0	0.9	7.5	μA
Dark Current – maximum	0.31	3.00	0.45	4.0	1.25	12.0	
Rise Time (Note 6) – anode-cathode output	90	110	90	110	180	250	ps
Microcell Recharge Time Constant (Note 7)	45		48		50		ns
Capacitance (Note 8) (anode output)	1070		1800		4140		pF
Capacitance (Note 8) (fast output)	40		70		160		pF
Fast Output Pulse Width (FWHM)	1.5		1.7		3.0		ns
Crosstalk	8	25	8	25	8	25	%
Afterpulsing	0.75	5.0	0.75	5.0	0.75	5.0	%

Photon detection efficiency

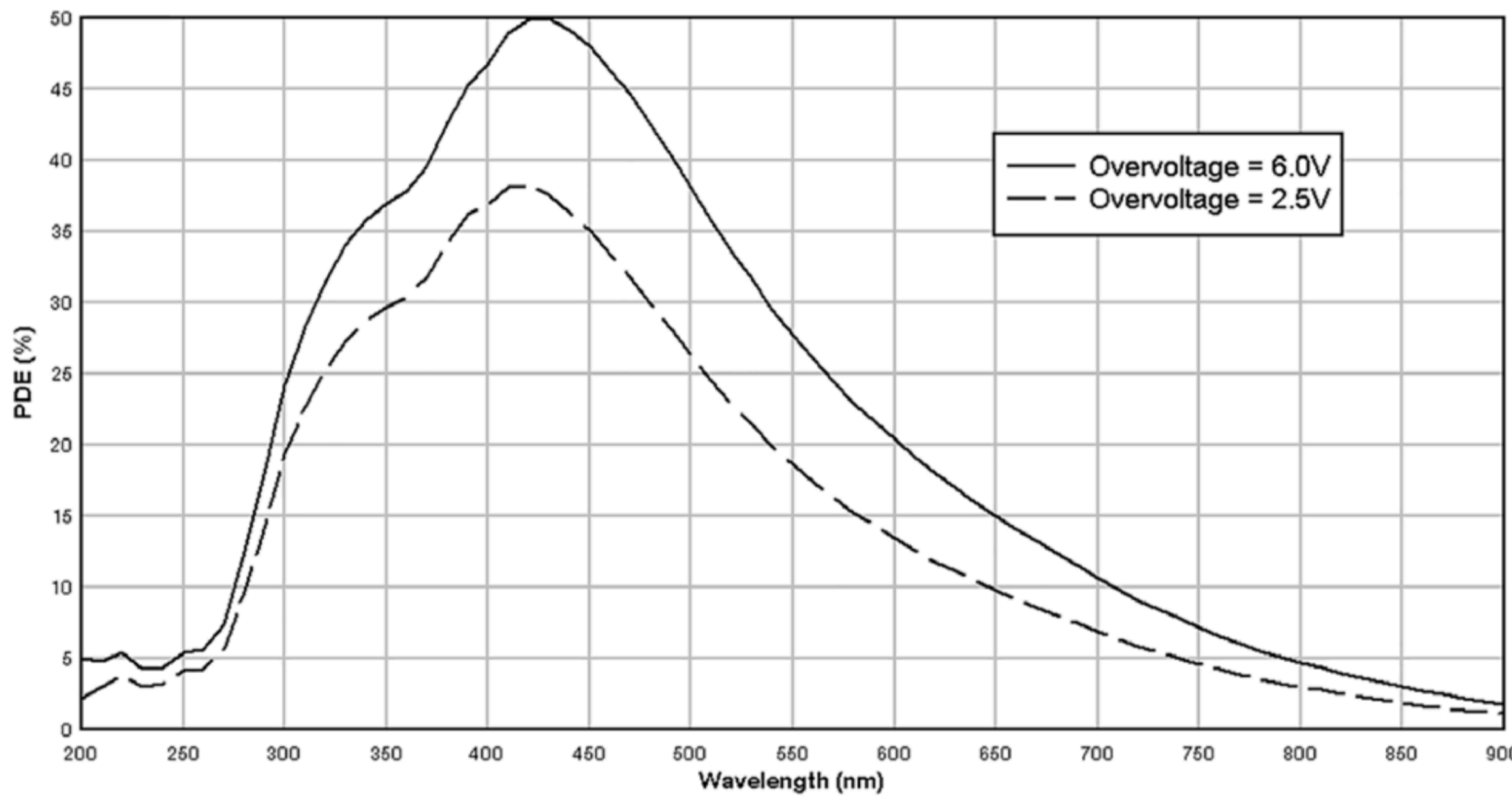


Figure 1. Photon Detection Efficiency (PDE)
(MicroFJ–60035–TSV)

Gain

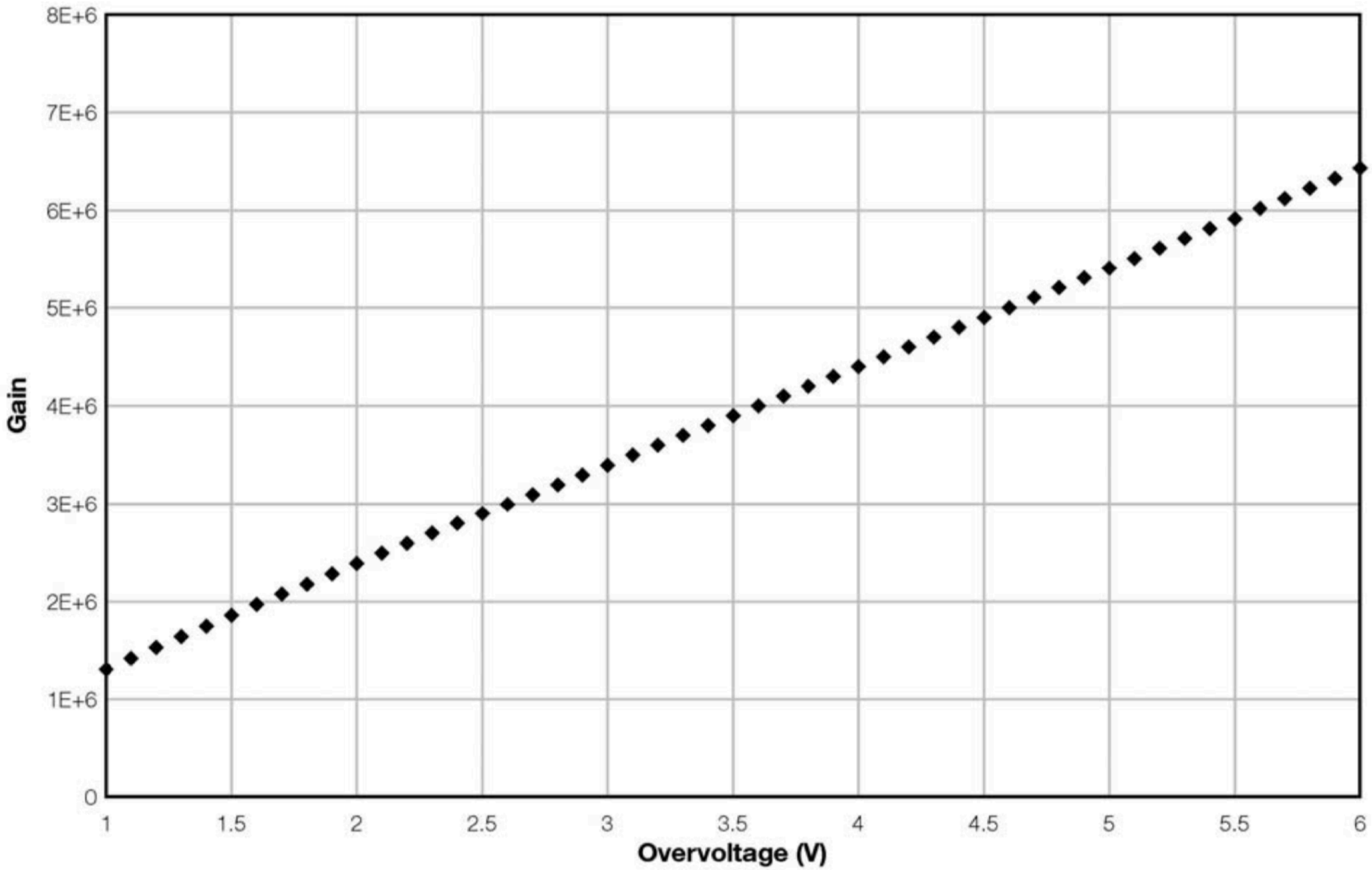


Figure 4. Gain vs. Overvoltage

(MicroFJ–30035–TSV)