Detector Testing and Analysis for the PIONEER Experiment

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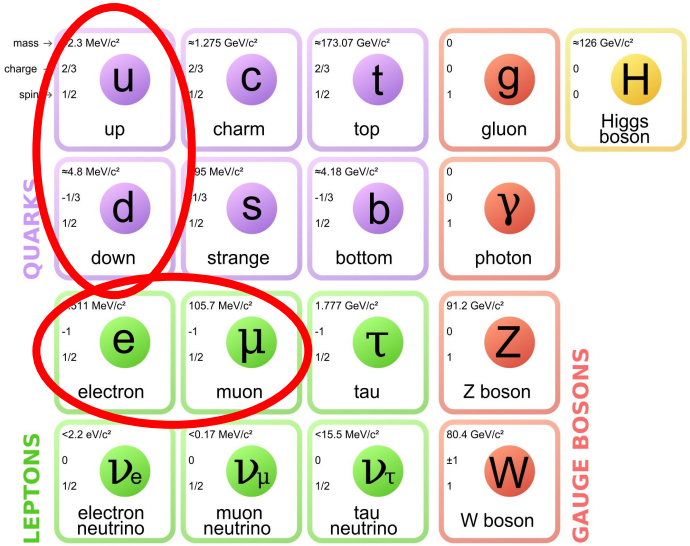
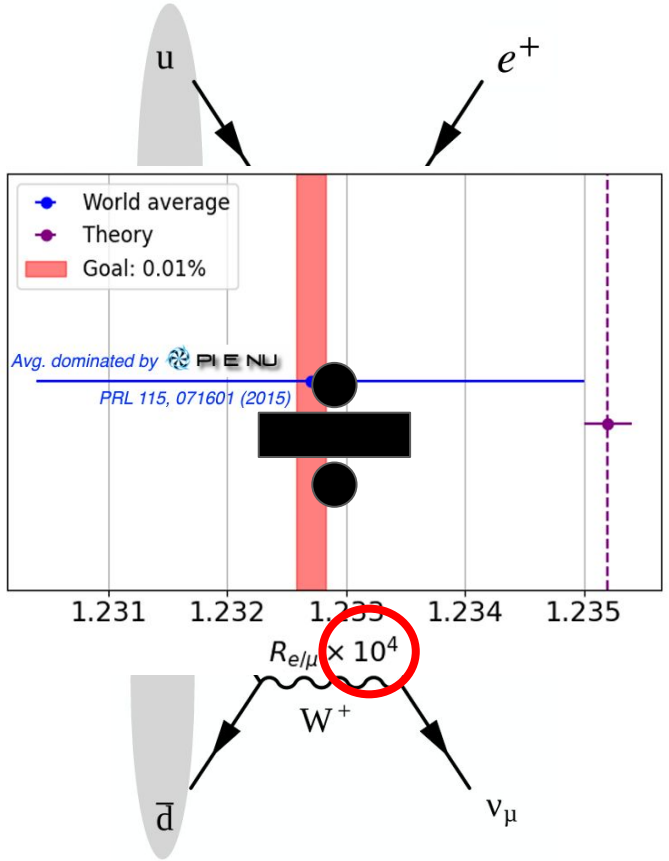
The Standard Model

- Fermions, bosons, and composite particles
- There are a number of limitations and inconsistencies
- The pion is an especially good particle to study!
  - We can make beam lines and stop them
  - Doesn't decay as fast and easier to find if charged



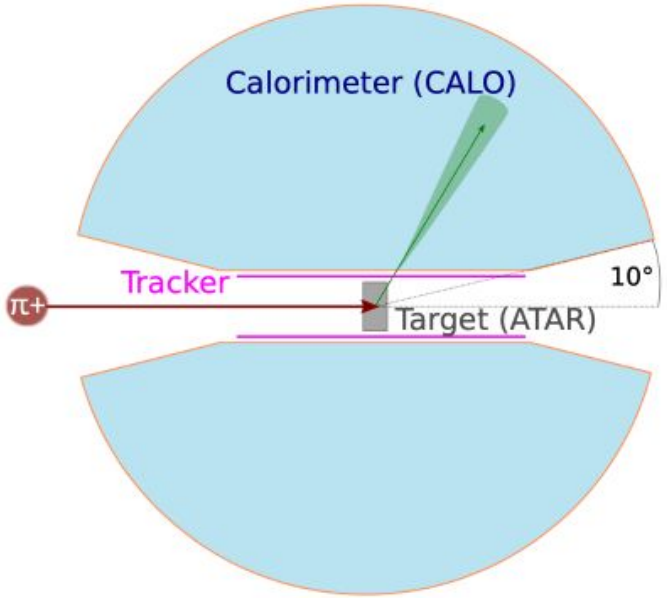
The Search for New Physics

- Branching ratio of decay rates
- Lepton flavor universality
  - Electron-type particles have identical weak interaction strengths
- Sensitive probes for unitarity matrices and new particles
- We need to be much more precise to match Standard Model prediction



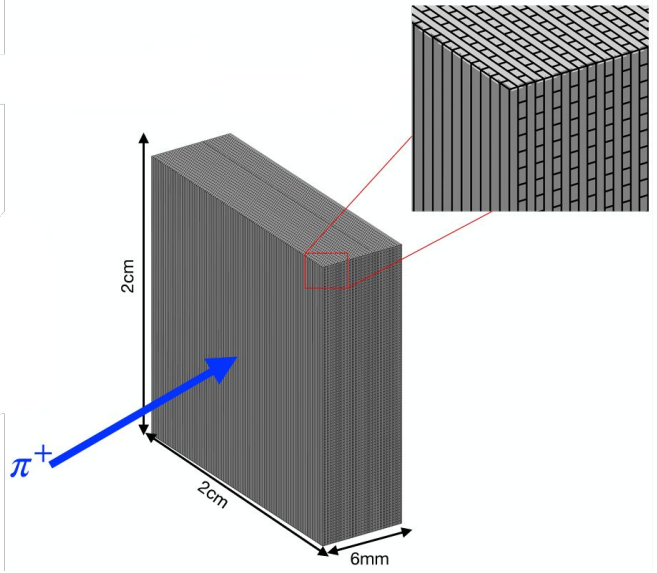
PIONEER

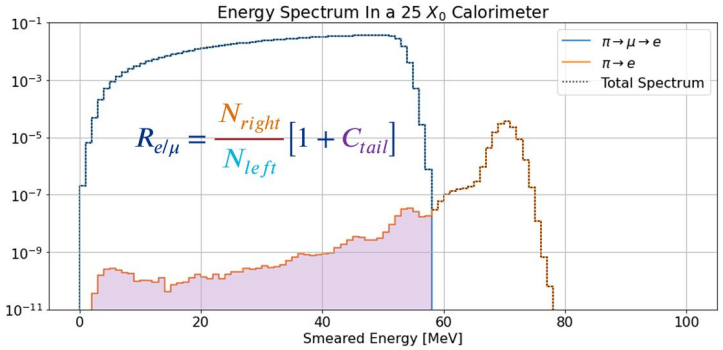
- Next generation experiment to improve $R_{e/\mu}$ by an order of magnitude through improved energy and time resolution
- DTAR to slow particles, ATAR to stop, high speed electronics (< ns)
- Fast, high acceptance calorimeter



Active Target (ATAR)

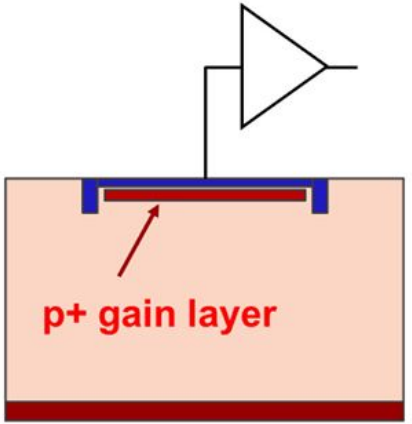
- What is it?
  - 48 layers, each is 120 μm thick
- Segmented design allows for event reconstruction
- 5D tracking (space, time, and energy)
- Have to differentiate the π-e energy tail from the π-μ energy tail
  - Need a way to amplify π-e

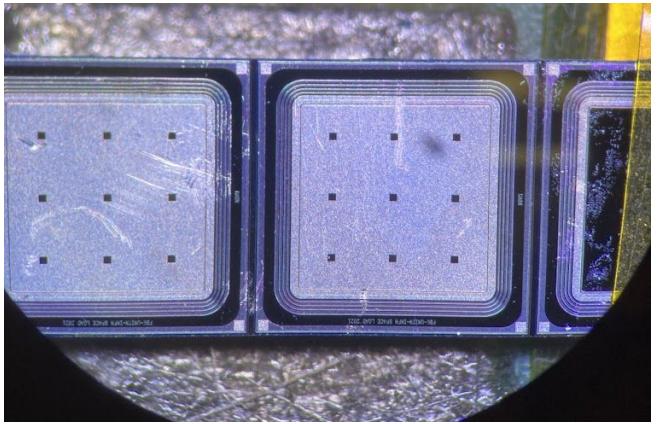




Low-Gain Avalanche Detectors

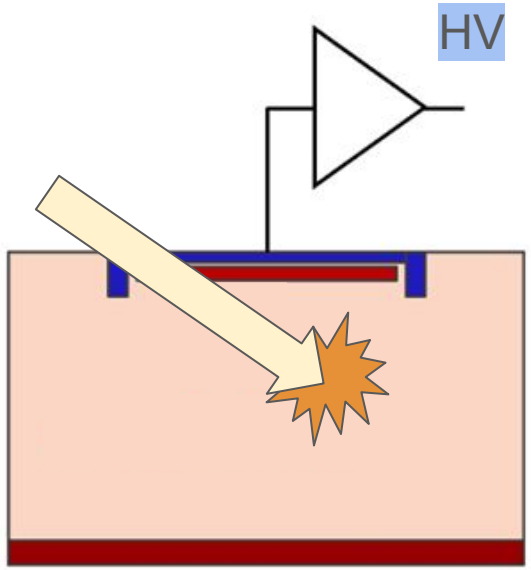
- Signal amplification due to impact ionization caused by electric field
  - Also referred to as an “avalanche multiplication”
- Good energy and time resolution (~17 ps)
- How do these compare to other detectors, like PIN diodes?
- We expect large charge deposits in PIONEER; how do LGADs behave?





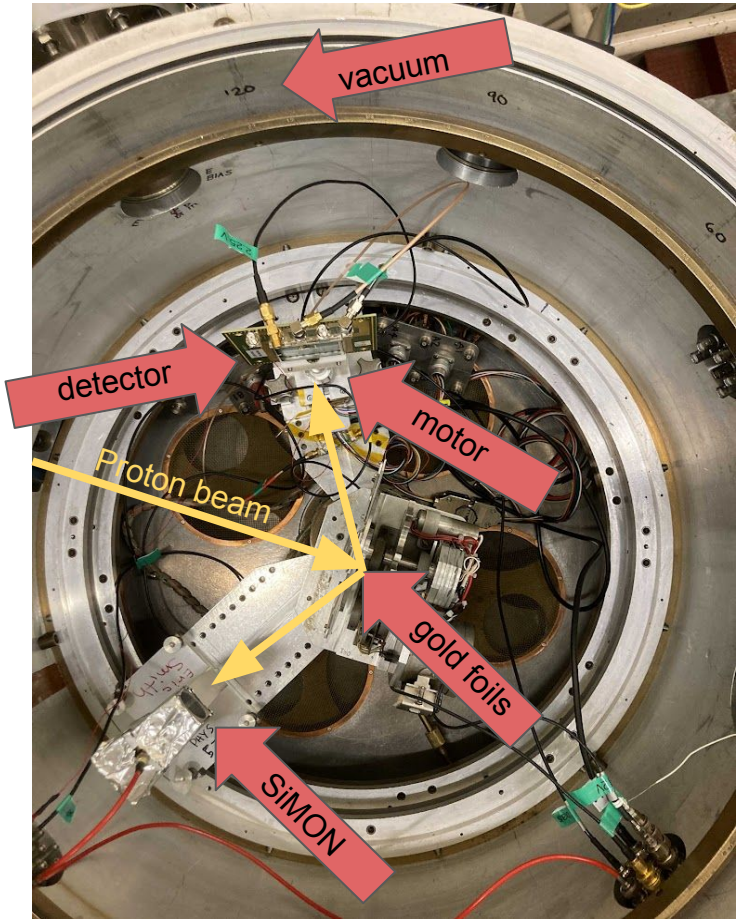
Gain

- Ability to increase amplitude of a signal
  - Proportional to charge deposited (and thus energy)
- Gain suppression / saturation turns our linear response non-linear
  - But, we still need to amplify the signal
- What can we control, and what needs to be tested?
  - Bias voltage, angle, charge deposited
- The goal: Test lower gains to see if we still get a usable signal



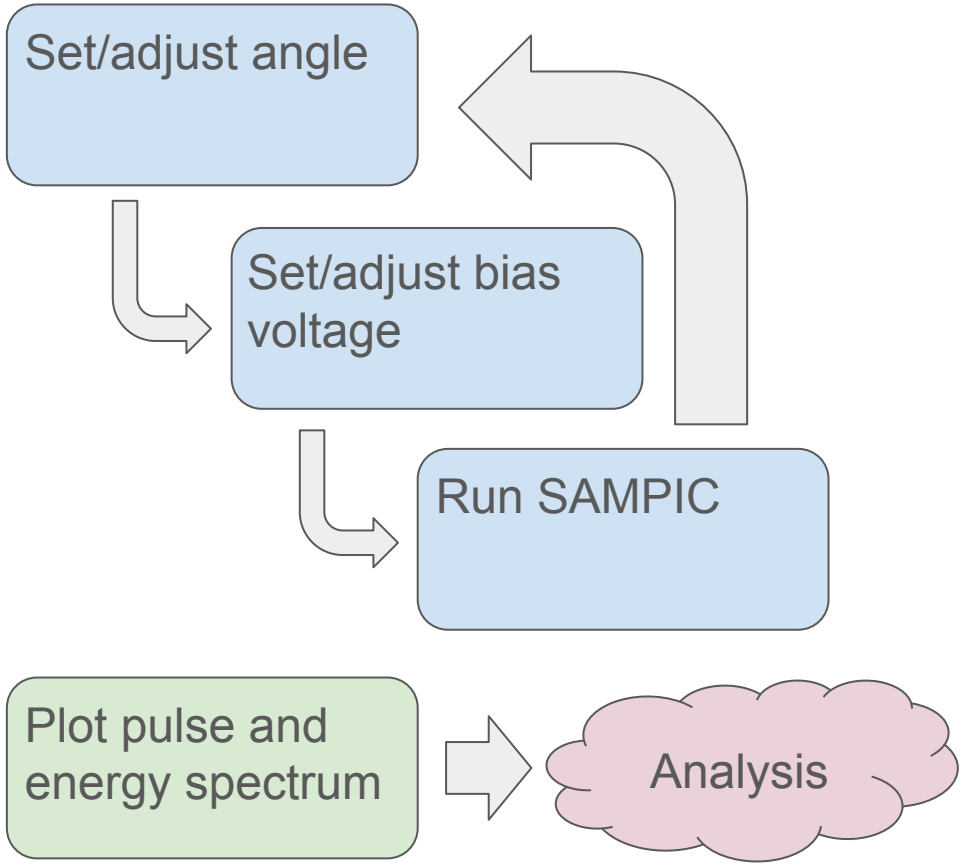
Experimental Set-Up

- Rutherford back-scattering (RBS)
  - Tandem Van De Graaff accelerator of protons
- Silicon Monitor Detector (SiMon): Measures beam output
- Detectors: LGADs and PINs mounted onto FAST board
  - Connected with wires to our readout electronics
- A very similar study was run in 2023



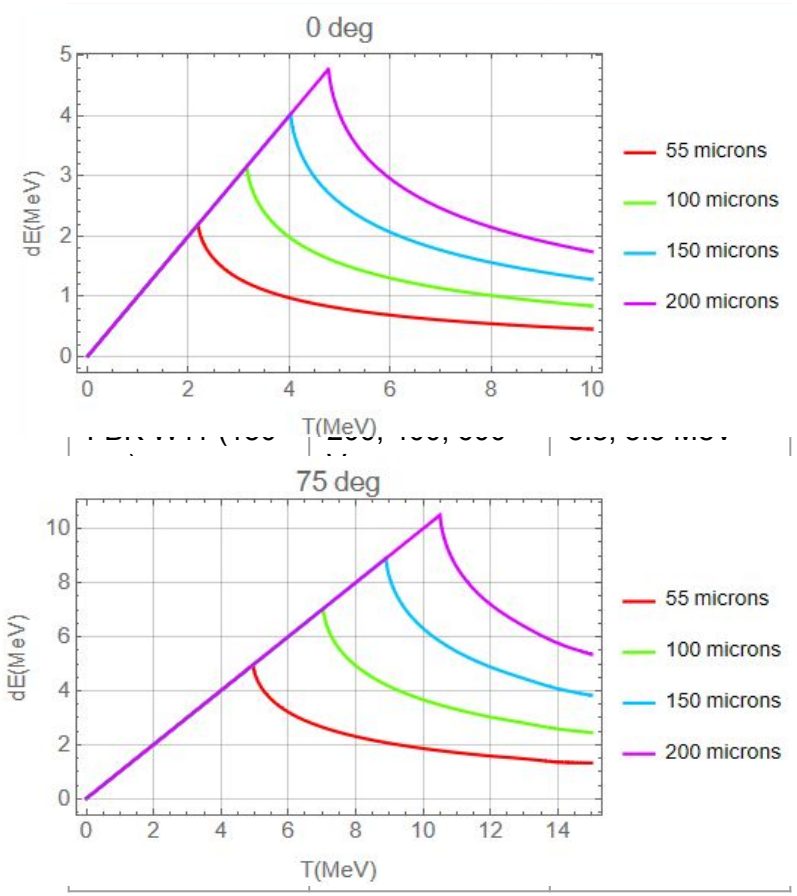
DAQ System

- SAMPIC is our fast readout device
  - Records our pulses into something that can be analyzed
  - Keeps up with the data rates
- Runs automatically for specified parameters (HV, angle, detector, etc.) which is very advantageous



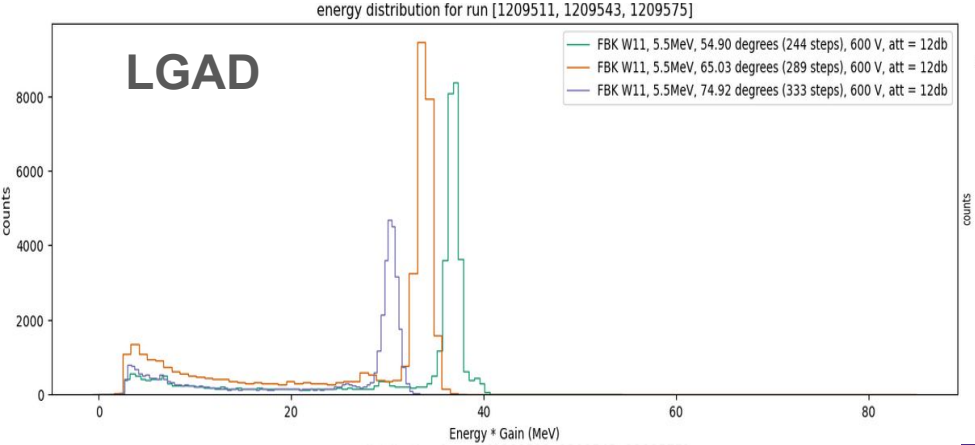
How Do We Test?

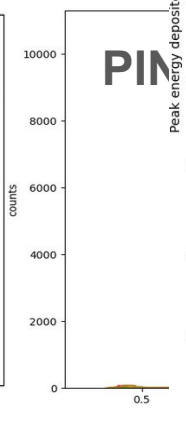
- We have new detectors this year that are thicker and from a different producer
- How do we determine the right energy to run at for different angles and thicknesses?
  - It's time consuming and difficult to adjust the beam intensity
- Coordination as a group

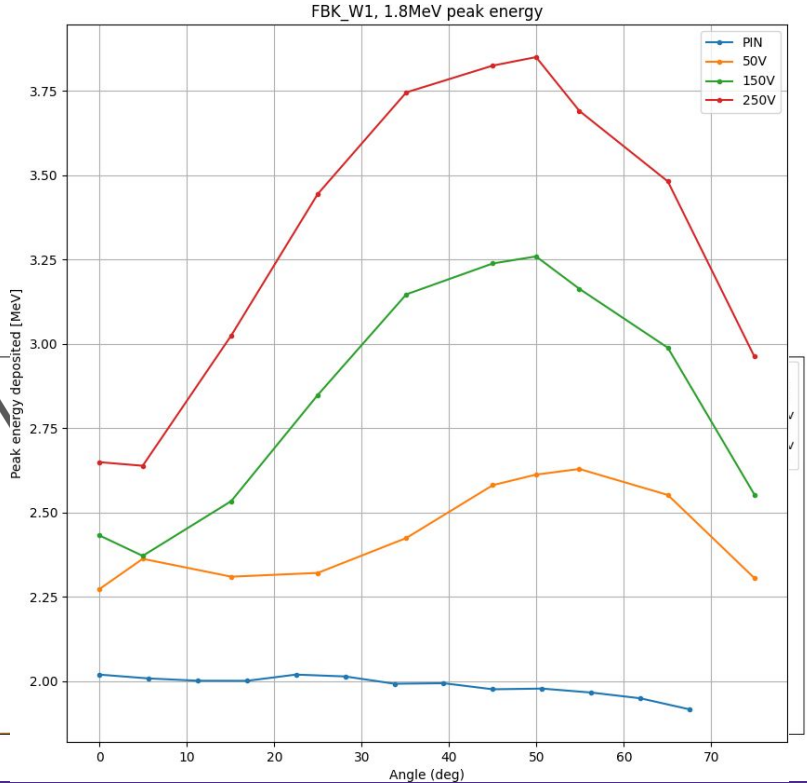


Initial Analysis: Stopped Particles

- LGAD: We get saturation
- PIN: No gain, so energy deposited is the same each run

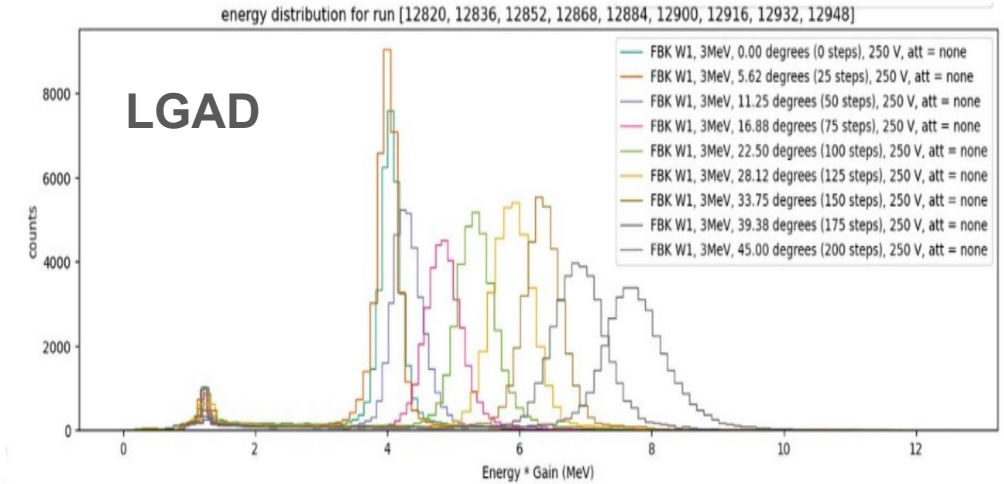


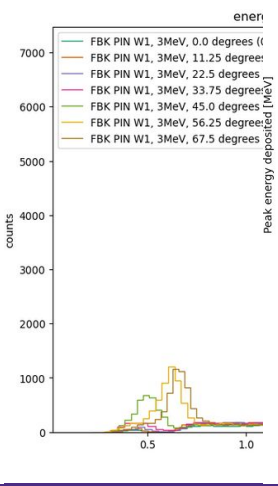


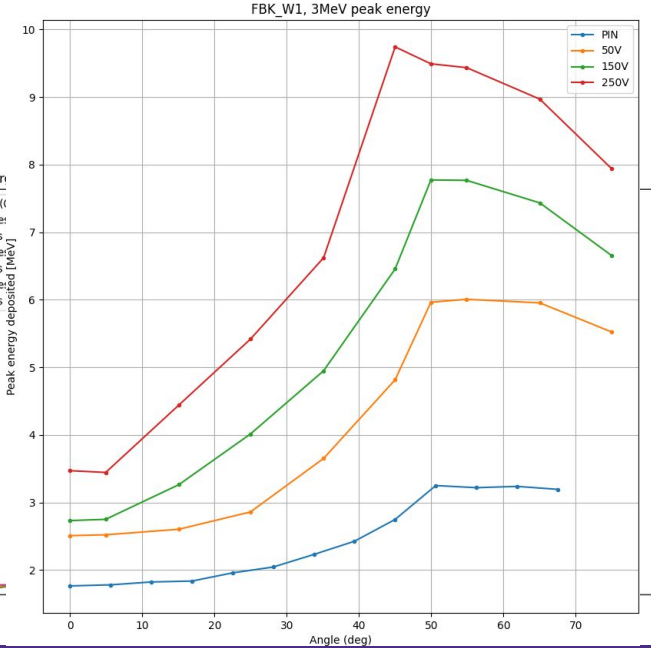


Initial Analysis: Punch-Through Particles

- LGAD: More linear response due to less saturation
- PIN: Detector doesn't collect full charge (and thus not full energy)

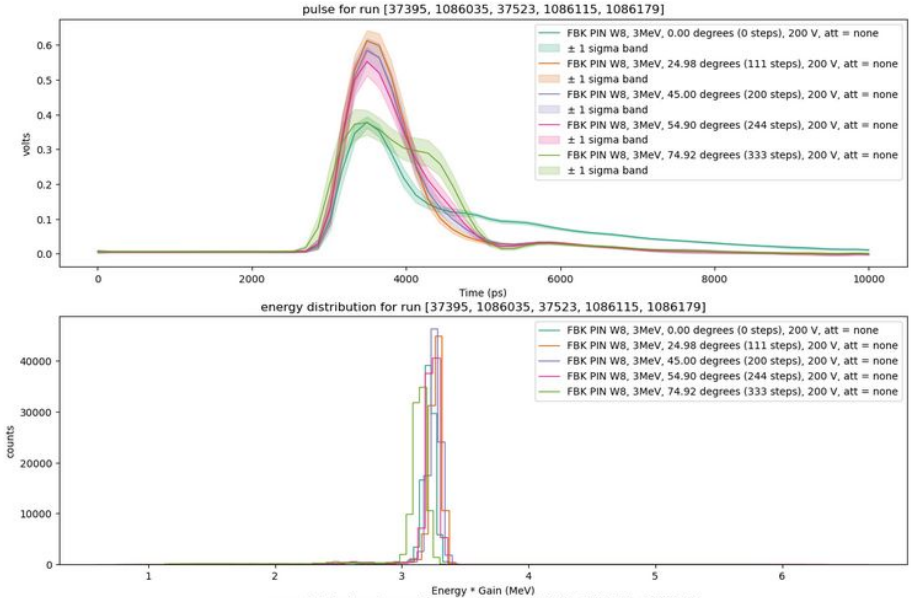






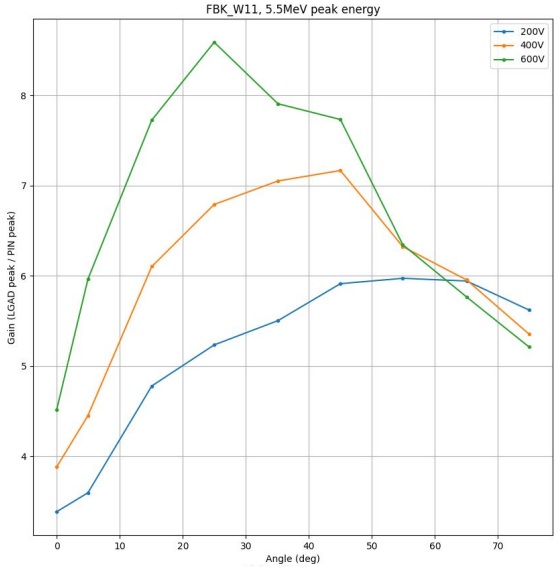
Cleaning Up Our Data

- Tail and double peak
  - Energy plots are still consistent with what is expected
- Want to know what is causing these (could be related to how we took data, angle, etc.) and if it impacts analysis
- Determine which runs are “good”

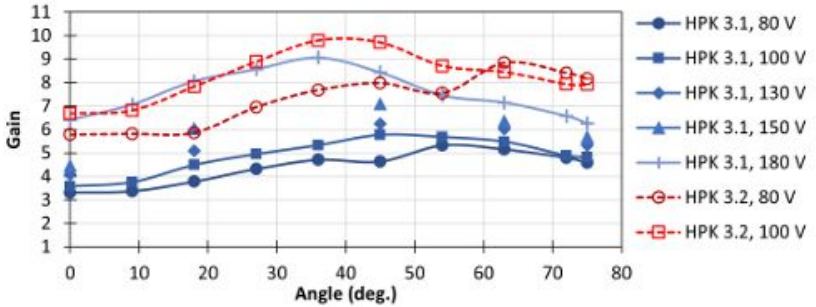


Initial Gain Analysis

- Last year: Ran at 1.8, 3 MeV
  - Gain decreases starting around 50°
- This year: Ran at much higher energies (up to 8 MeV)
  - Saturation at lower angles
- However, many things must be taken into consideration, and this is very preliminary analysis compared to the published results!



3 MeV



Looking Further Ahead

- Tidy up our data
- Data analysis to determine if we can reduce suppression by operation at a lower gain
    - This will consist of similar analysis as to what was done last year (calculating gain, energy resolution)
- Decide on a final detector for PIONEER's large-scale prototype test in ~2 years

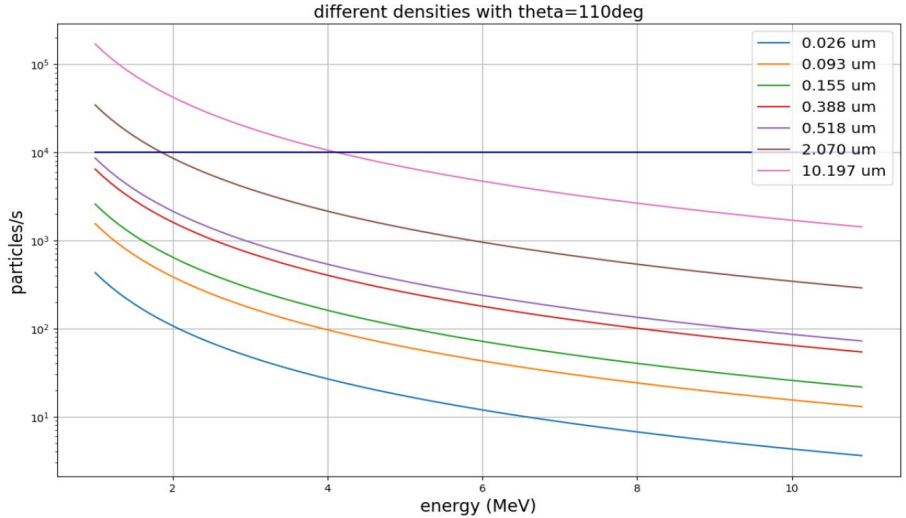
Acknowledgements

- Quentin Buat
- PIONEER Collaboration
- Center for Experimental Nuclear Physics and Astrophysics
- Institute for Nuclear Theory
- National Science Foundation

Backup Slides

RBS Rates and DAQ

- Don’t want to overwhelm SAMPIC
- Will also depend on the angle of the RBS arm in the chamber



CKM Unitarity

- Contains information about flavour-changing in the weak interaction
- Reliant on experimental data and theoretical calculations
- We use pion beta decay to study this (lets us probe those experimental values)