Prototyping PIONEER with the CENPA Accelerator

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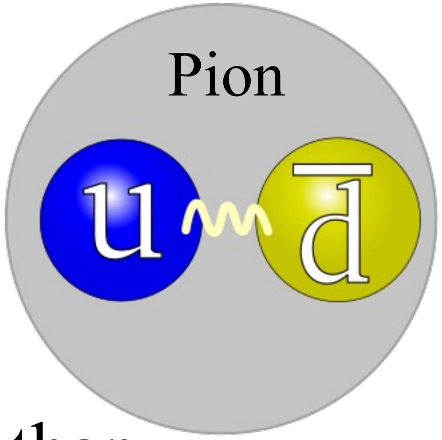
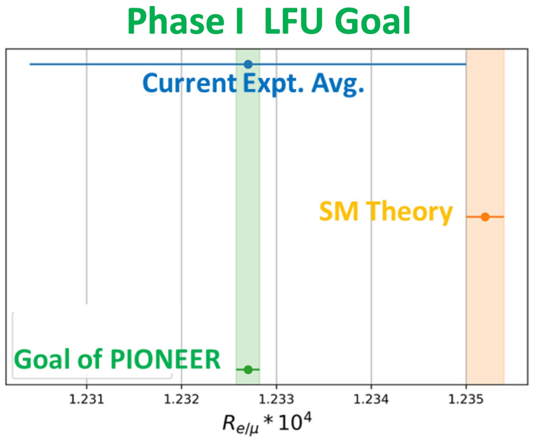
CENPA
Center for Experimental Nuclear Physics and Astrophysics
UNIVERSITY of WASHINGTON

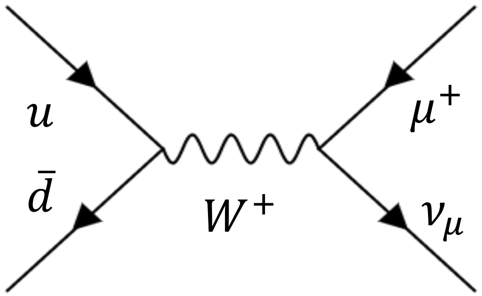
PIONEER

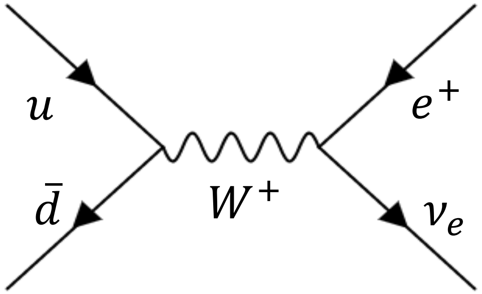


- PIONEER is a next gen. experiment aimed at measuring the branching ratio of rare charged pion decays with higher precision than the SM
- $R_{\frac{e}{\mu}SM} = 1.2324(15)\times10^{-4} \rightarrow R_{\frac{e}{\mu}exp.} = 1.23270(230)\times10^{-4}$
- Potential violation of Lepton Flavor Universality

$$R_{e/\mu} = \frac{\Gamma(\pi \to e\nu(\gamma))}{\Gamma(\pi \to \mu\nu(\gamma))}$$

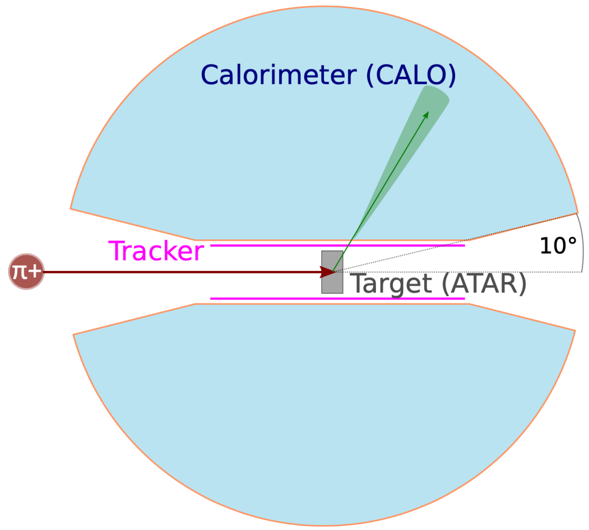


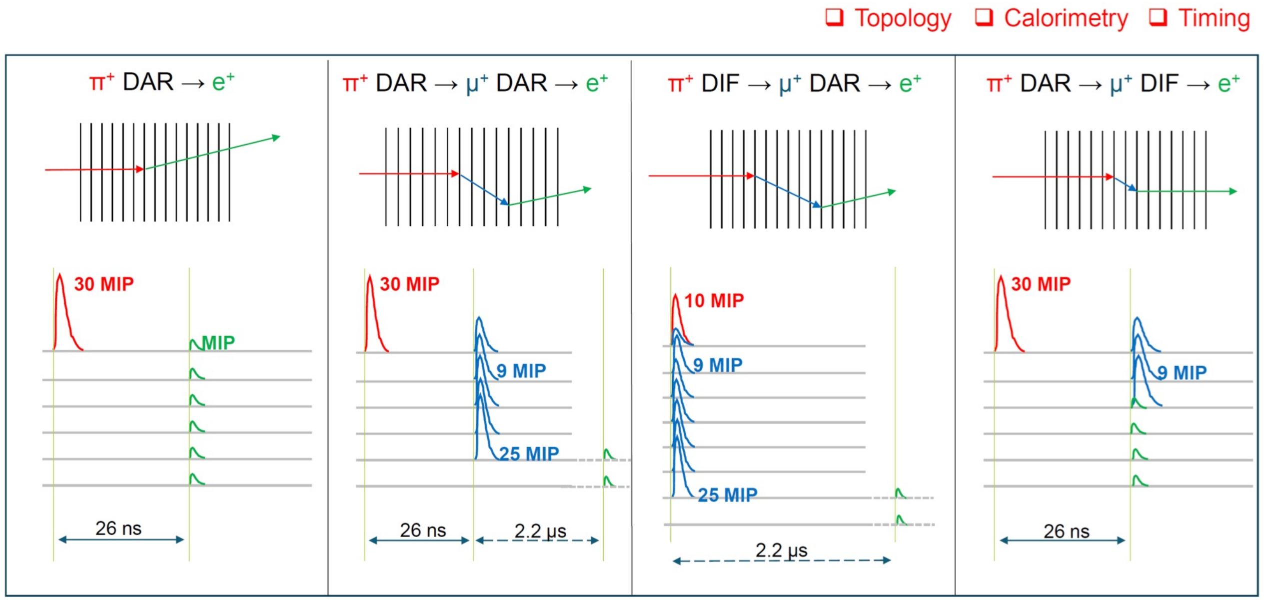




The Experiment - ATAR

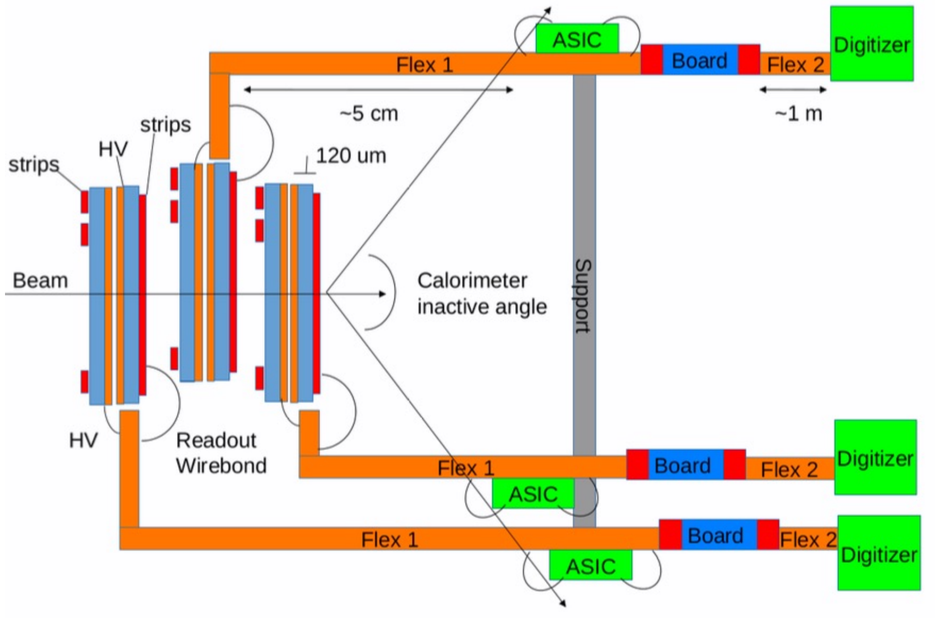
- ATAR – Active Target (solid state particle detector)
- ATAR needs to tell the difference between particles and trace their paths
- 4D tracking (x,y,z,t) (also measures Energy) →solution = silicon sensors
- MIPs – Minimum Ionizing Particles





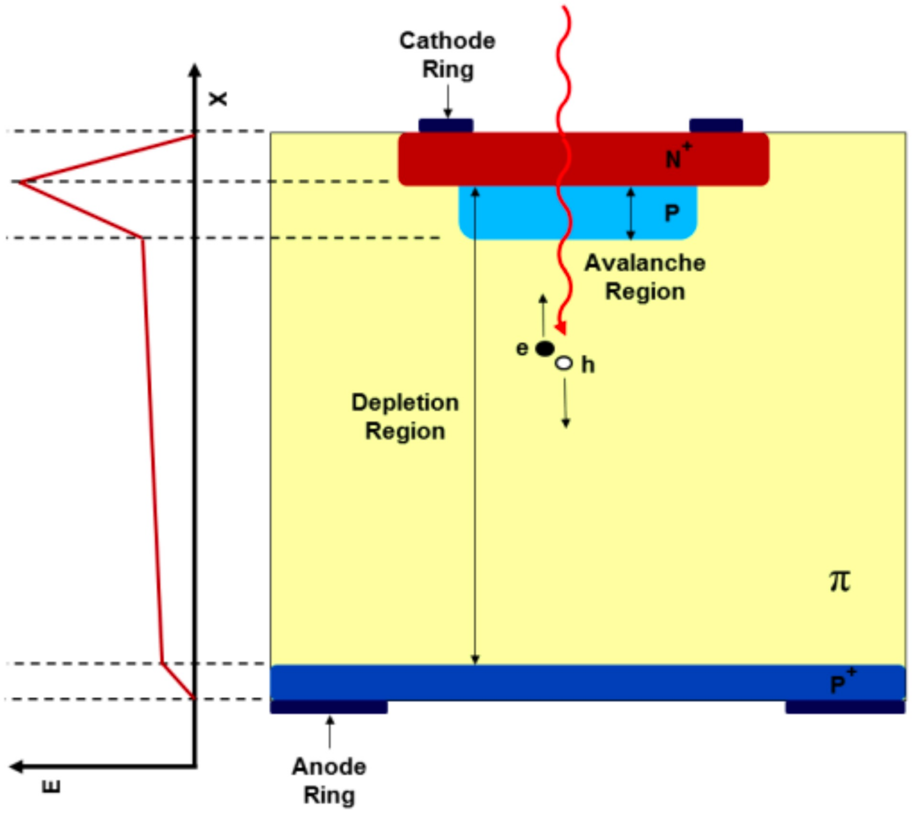
The ATAR

- Using LGADs (Low Gain Avalanche Diodes) for the ATAR
- Current design of ATAR: total of 48 LGADs stacked tightly, each 120um thick, 2x2 cm^2 area, total thickness of ~6mm
- Fast time resolution and a good energy resolution of ~10%



LGAD's

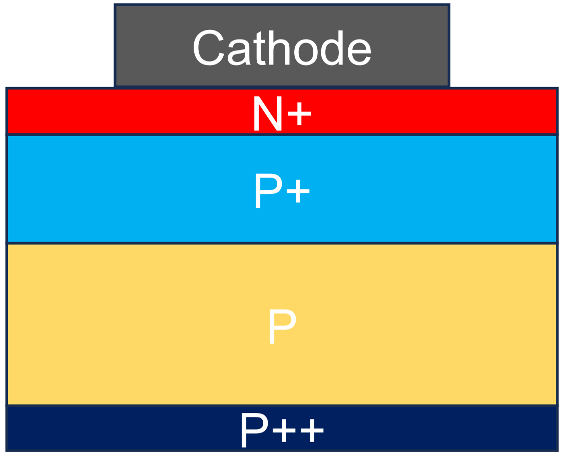
- Addition of a heavily doped P layer increases the electric field in that region
- Electrons entering the gain layer cause an "avalanche" effect amplifying the signal
  - Electron multiplication



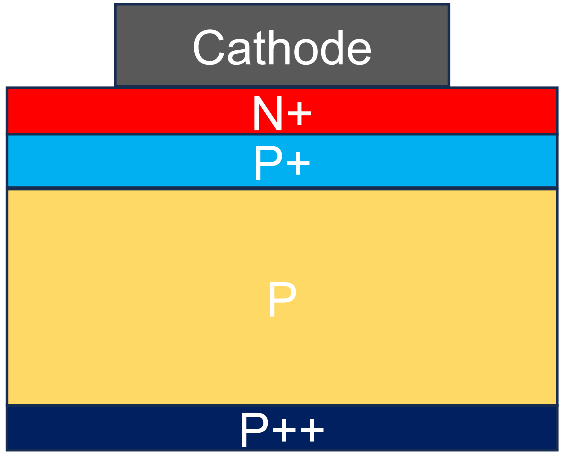
LGAD's

- HPK 3.1 has a smaller gain layer, 3.2 is deeper
- PIN has no gain layer so there is no gain

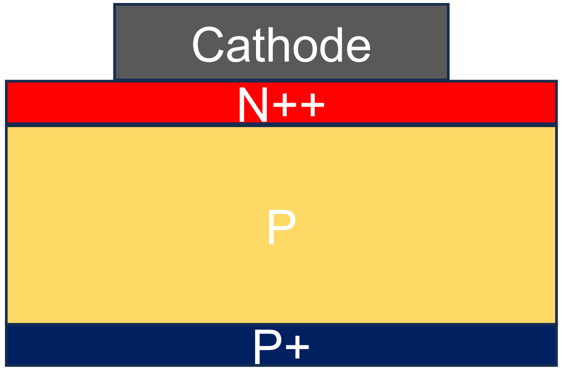
LGAD: HPK 3.2



LGAD: HPK 3.1

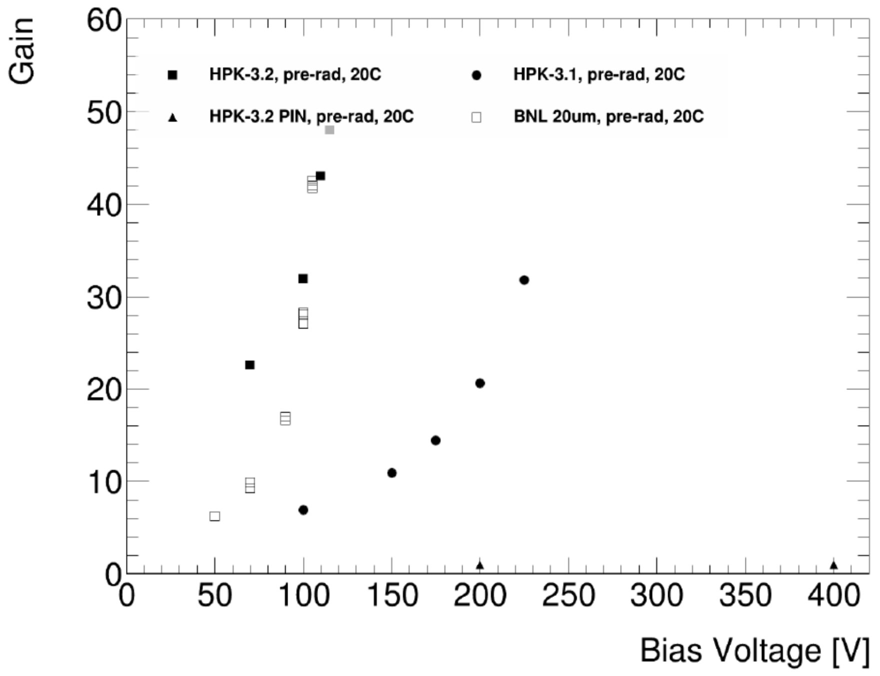


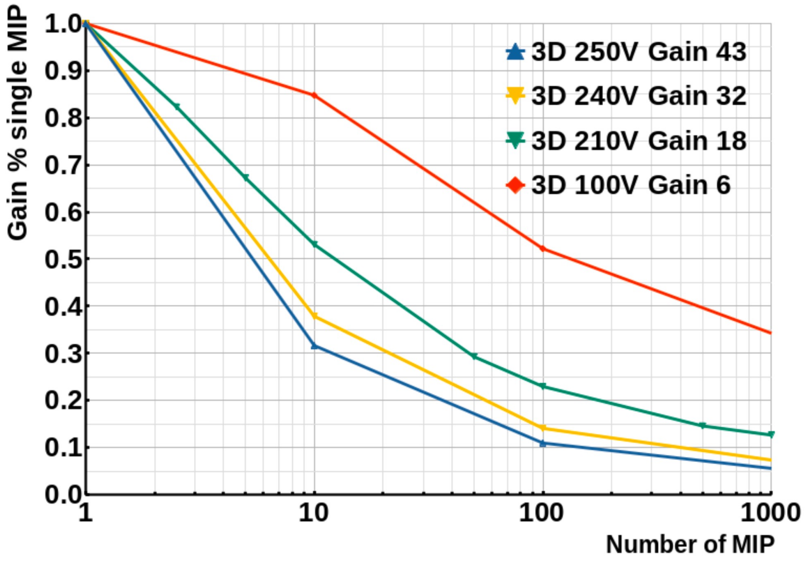
Silicon Detectors (PiN)



LGAD's

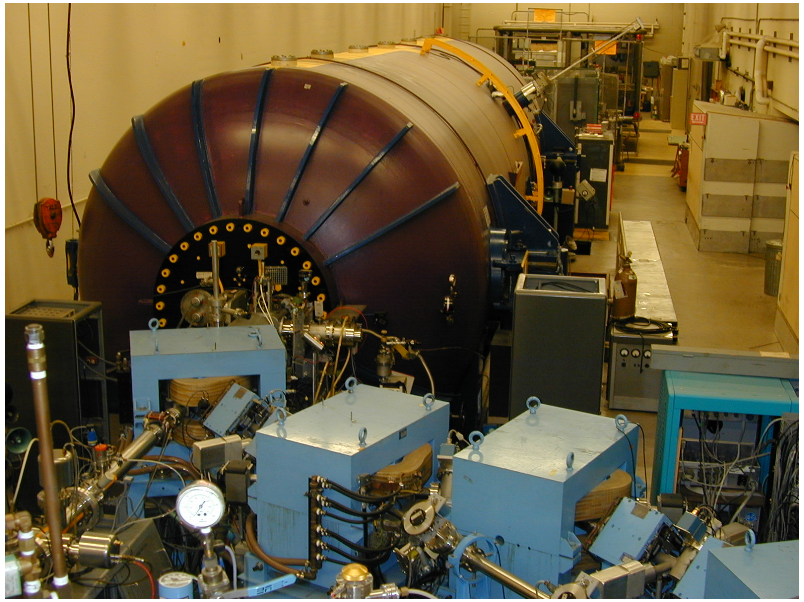
- For LGADs gain increases with increasing voltage bias
- PIN gain stays at 1
- Higher the gain LGAD = higher gain suppression for high energy deposits
- Example: Muon depositing 9 MIPs with 250V
  - Gain = 43
  - Gain percent = 35%
  - Final MIPs = 9*43*0.35 = 135.5 MIPs
  - Without gain suppression: 9*43 = 387 MIPs

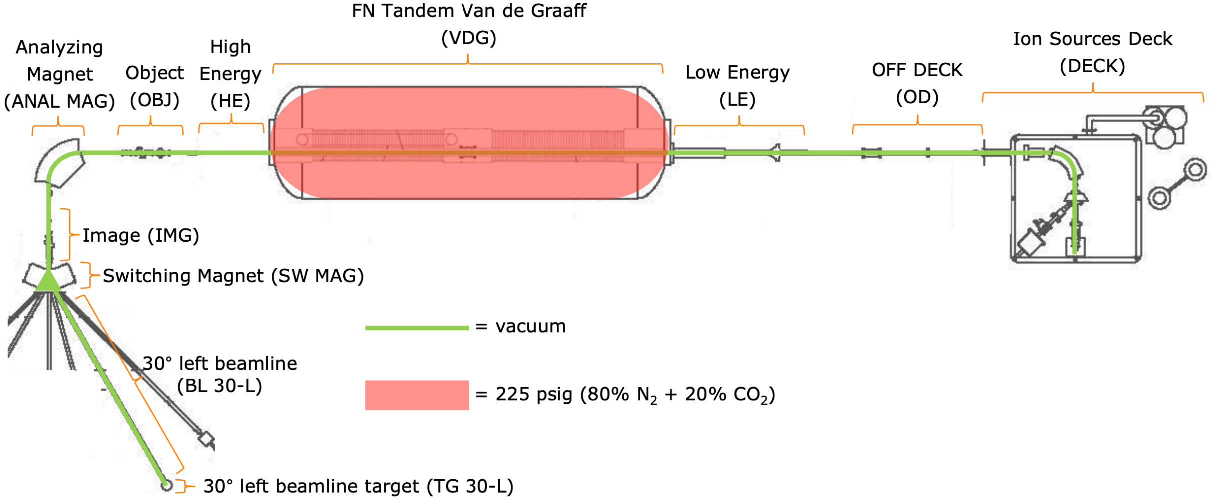




The Particle Accelerator

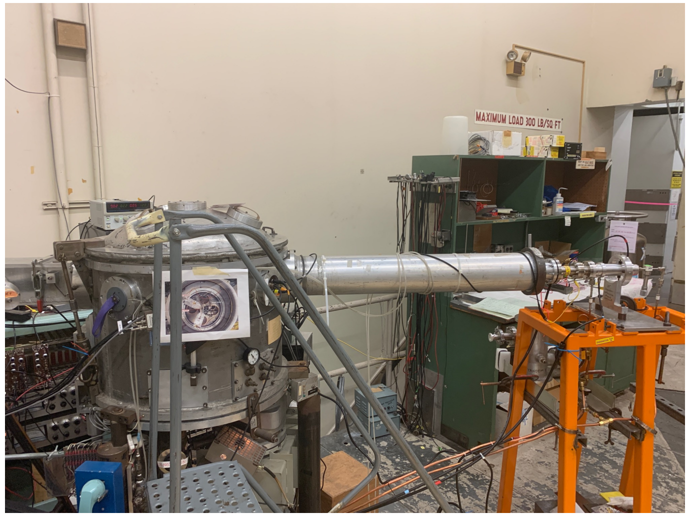
- Huge potential difference created
- Ion injected into the accelerator from an ion source
- Voltage accelerates negatively charged particles away and into the Tandem Accelerator
- Stripper foils inside the accelerator strip particles of their charge until they are now positively charged and then accelerated again
- Used hydrogen for the proton beam

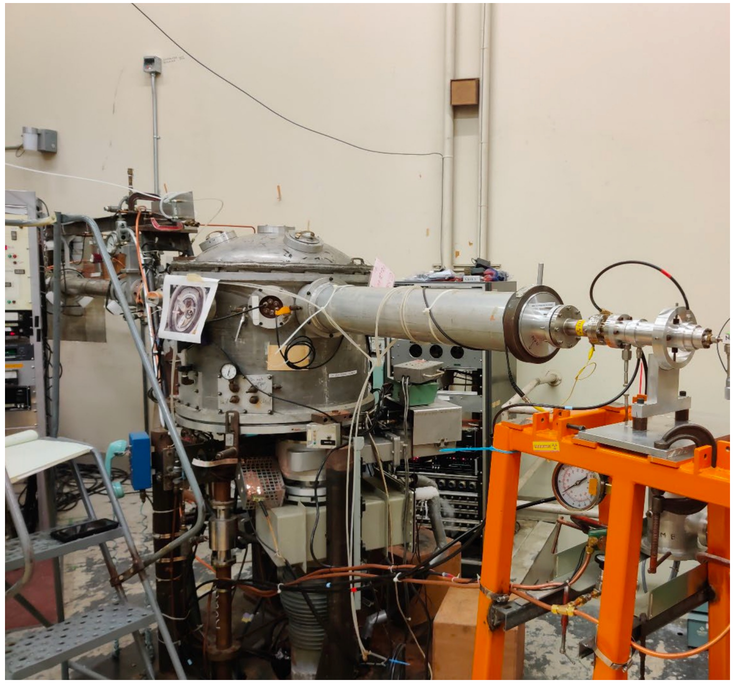




The Experimental setup

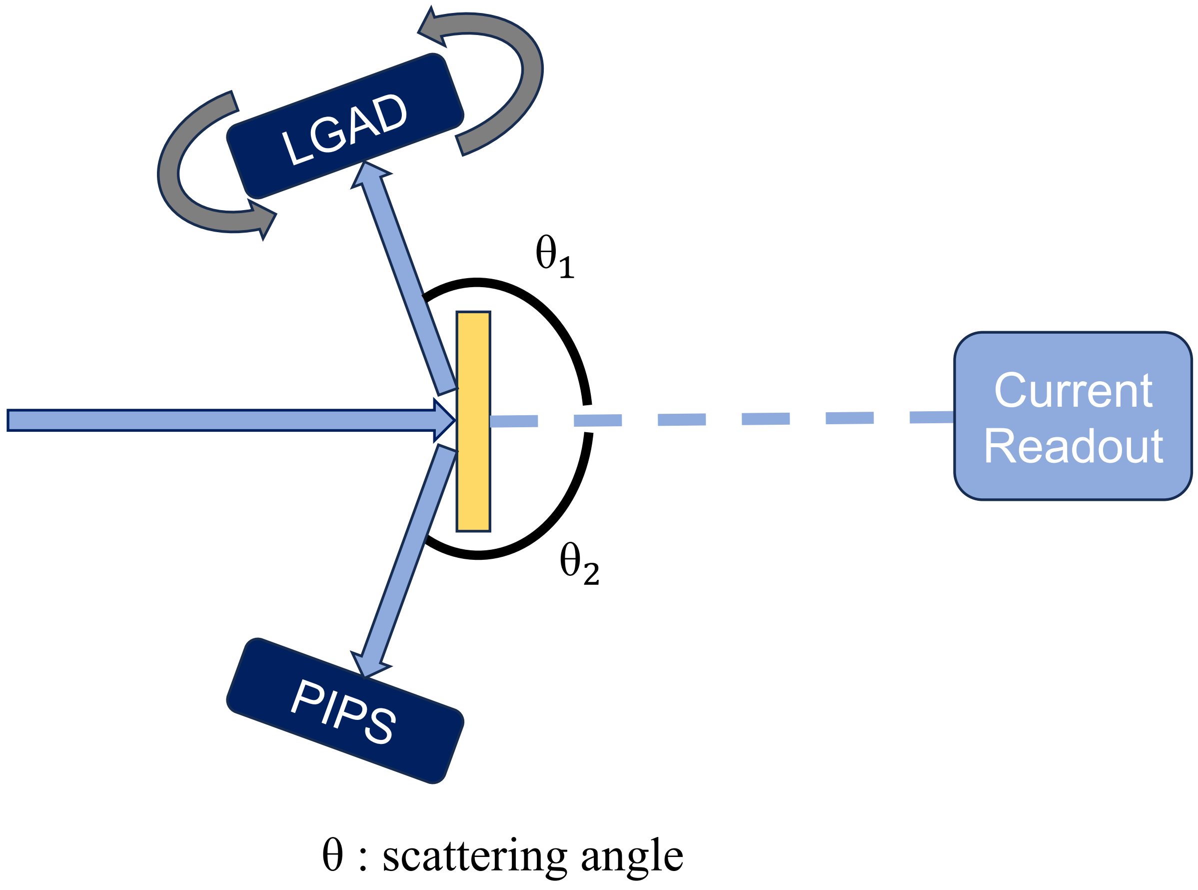
- Particles collide in 24” vacuum chamber
- Current is read at two locations
  - After leaving the accelerator and after passing through the foil
- Don’t know the current that is going to the detector





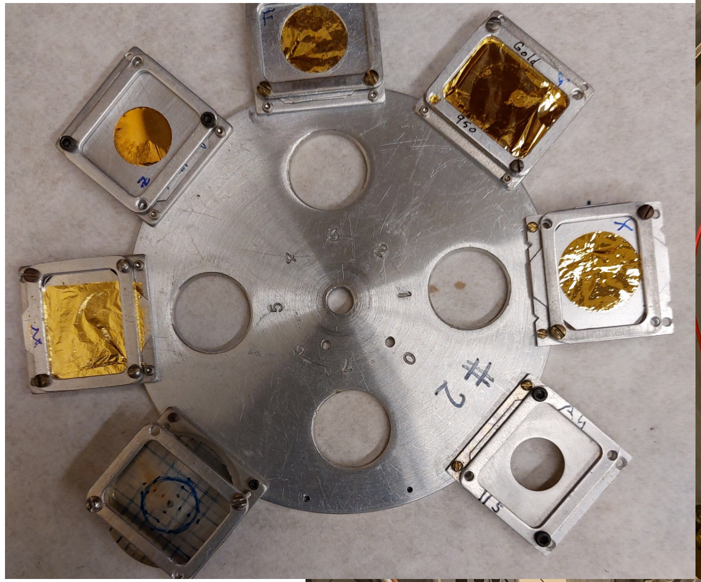
Rutherford Backscattering Spectrometry (RBS)

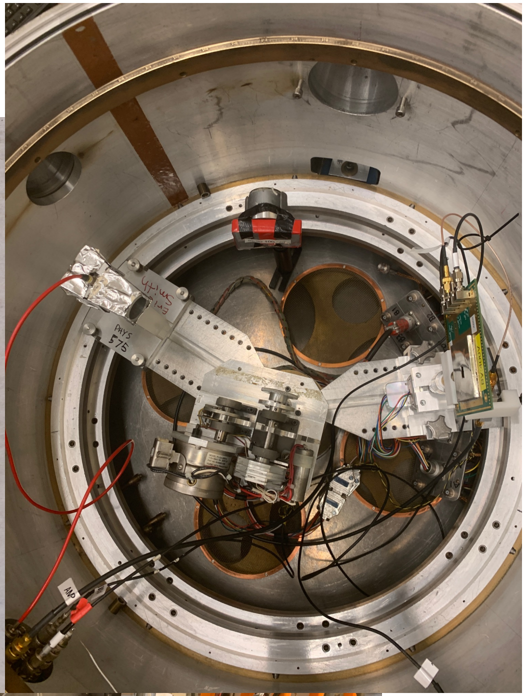
- Particle beam hits a gold target and some of the beam ricochets off it and into a detector
- Reduces rates to a reasonable amount
- Use gold for its high mass/density
- PIPS – Passivated Implanted Planar Silicon



The Experimental setup

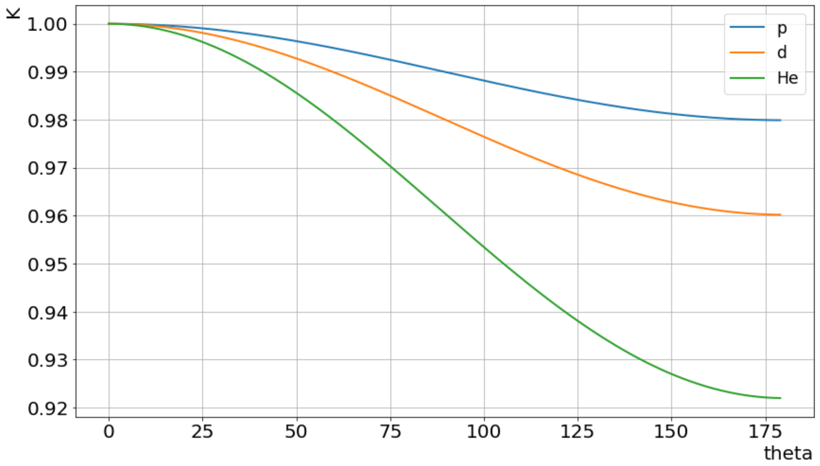
- Inside we have the RBS setup
  - Gold foil in the center
  - LGADs on the right
- Strontium 90 used for calibration (of the LGADs and PIN)
- Motor setup on peters computer
  - Rotates the detector
- Oscilloscope to read out the signal

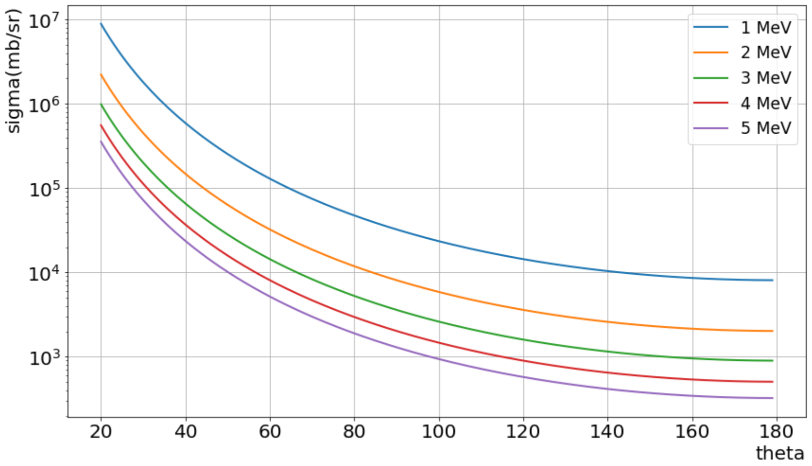


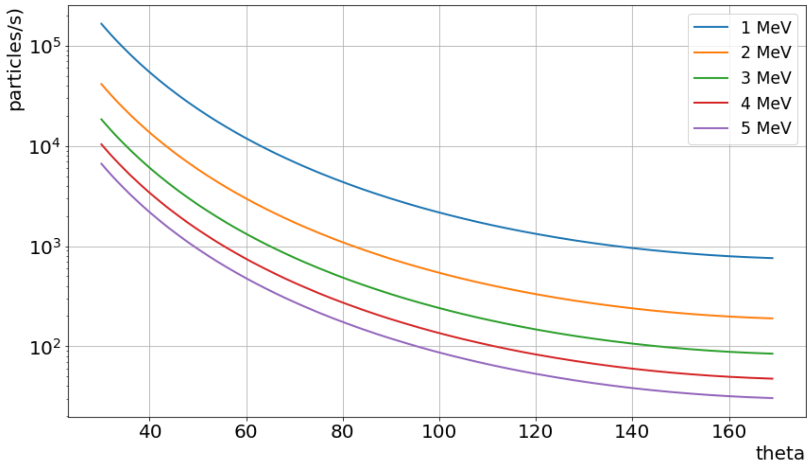


Simulations – what to expect

- Plots give us what to expect and what we values we want to test for
- Kinematic factor: $K = \frac{E_1}{E_0}$
- Rates (particles/second, or Hz)
- Around 110 degrees theta looked promising

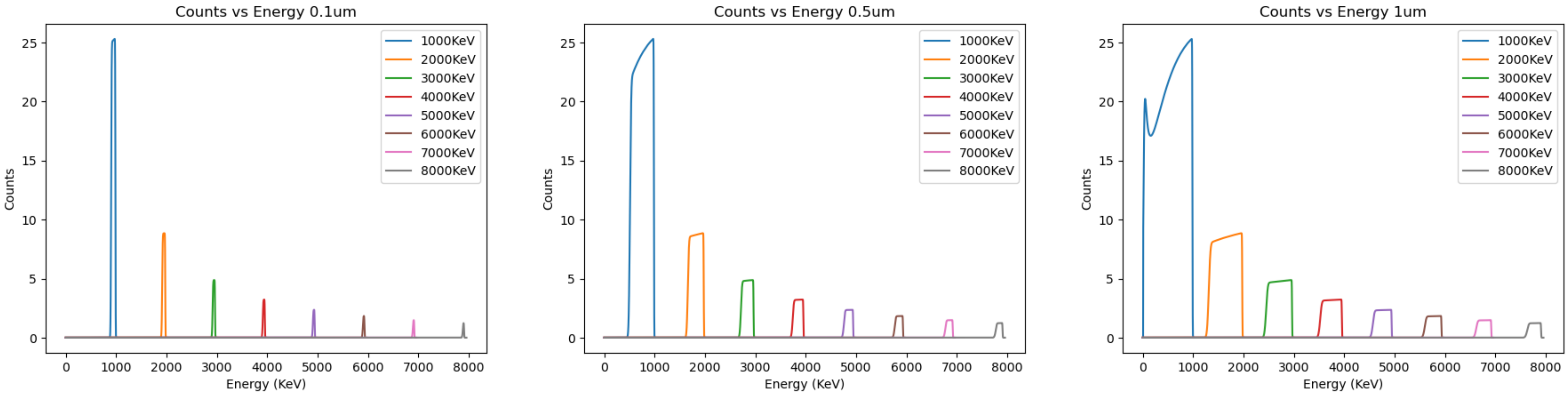






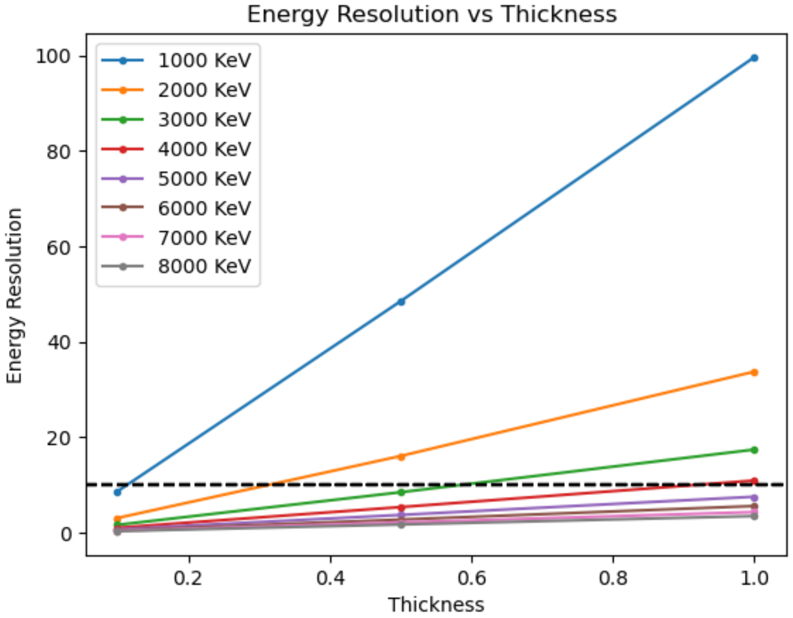
Simulations – Predicting using SIMNRA

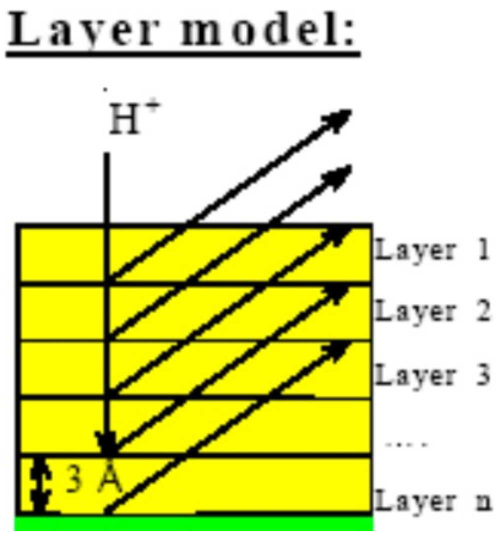
- Simulations varying Scattering angle, proton energies, beam current, thickness and dimensions of both the detector and gold foil

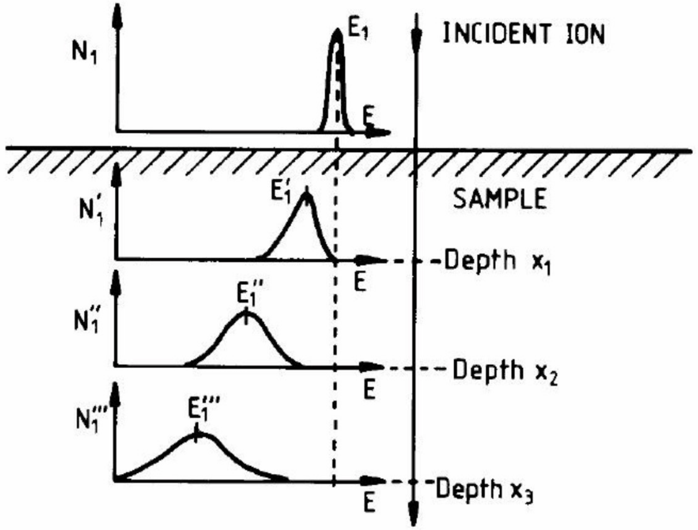


Simulations – Energy Resolution

- Energy resolution increases with increasing gold thickness because of energy straggling



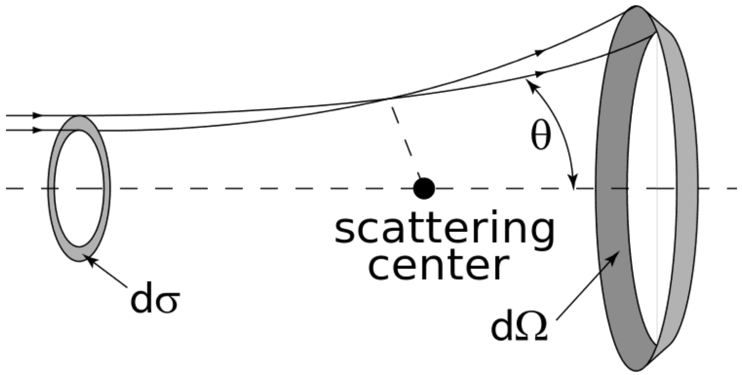


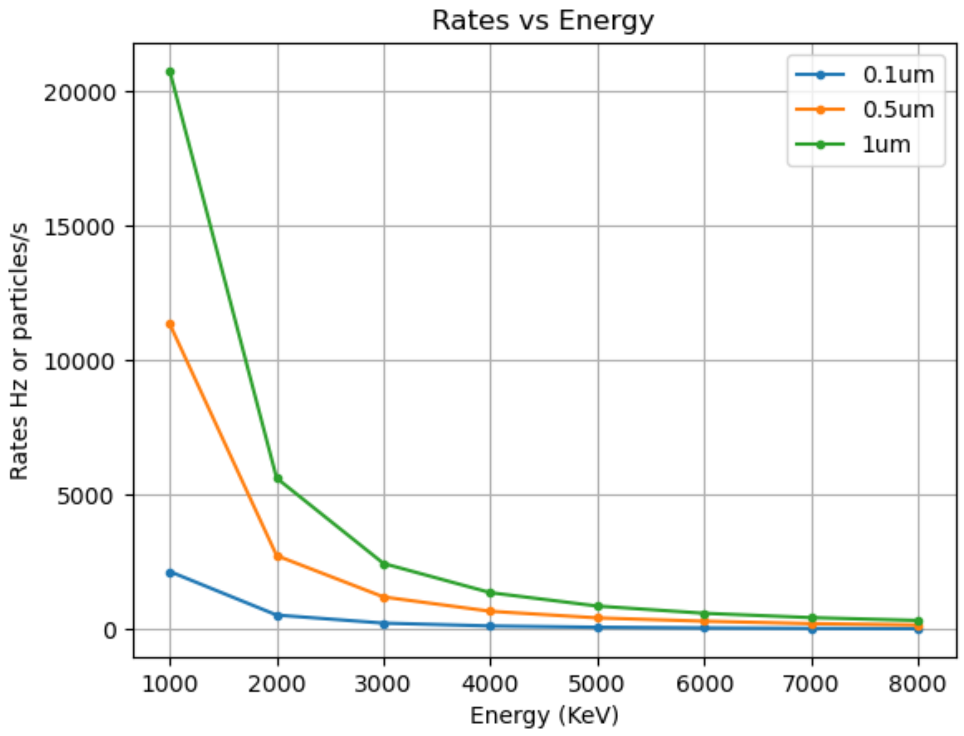


Simulations – Scattering Cross-Section

- Increasing the energy decreases rates due the differential scattering cross section decreasing

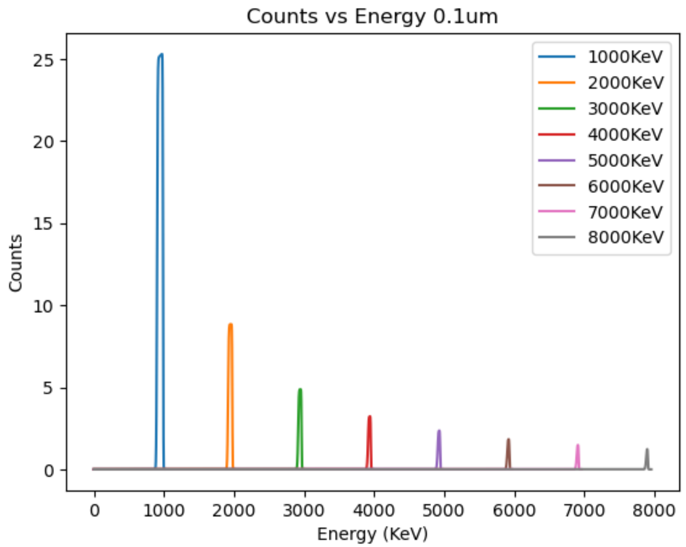
$$\frac{d\sigma}{d\Omega} = \left[\frac{Z_1 Z_2 \alpha \hbar c}{4E\sin^2\frac{\theta}{2}}\right]^2$$

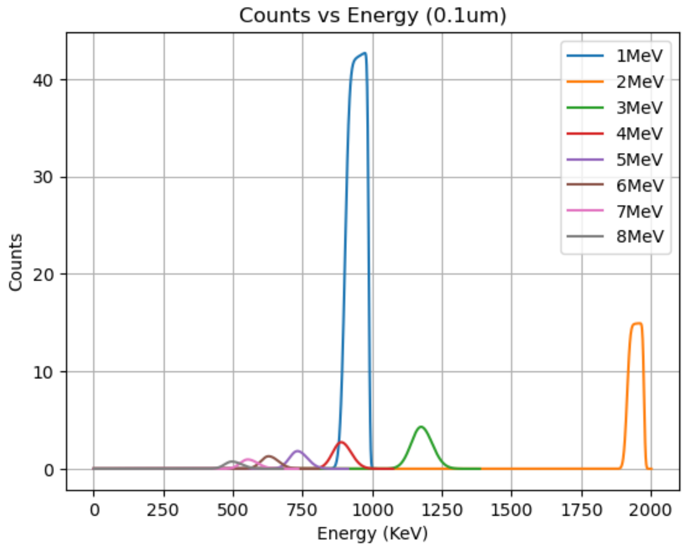




Simulations - infinite vs finite detector thickness

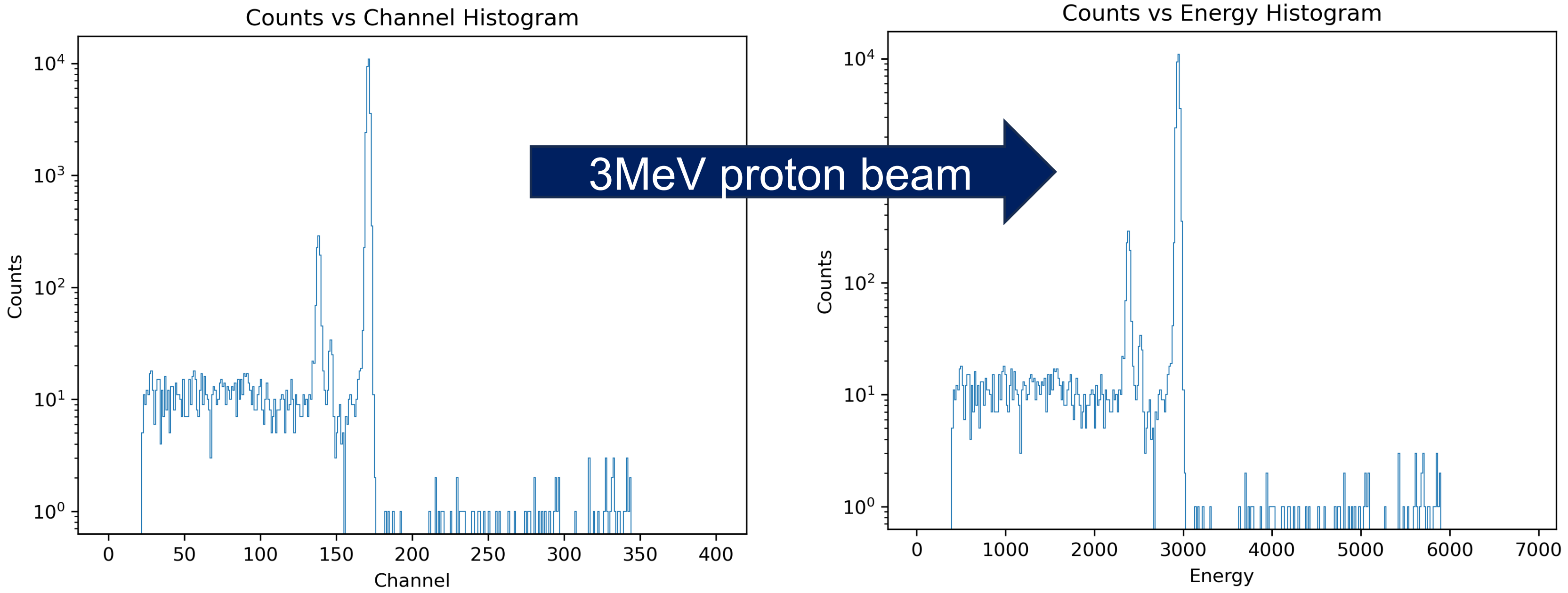
- For a finitely thick detector, after a certain energy, the beam will punch though and deposit less and less energy
- This is due to the Stopping Power of silicon



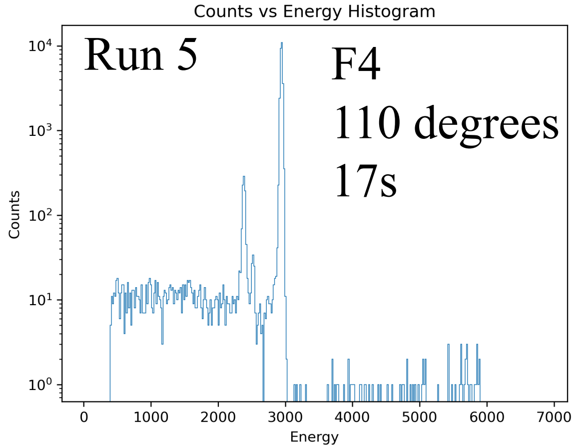


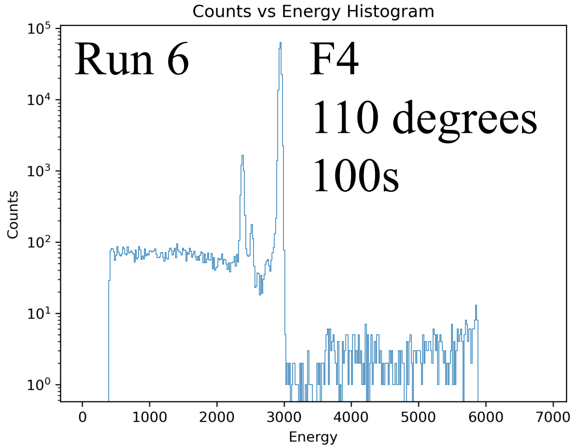
Calibration Data with the PIPS

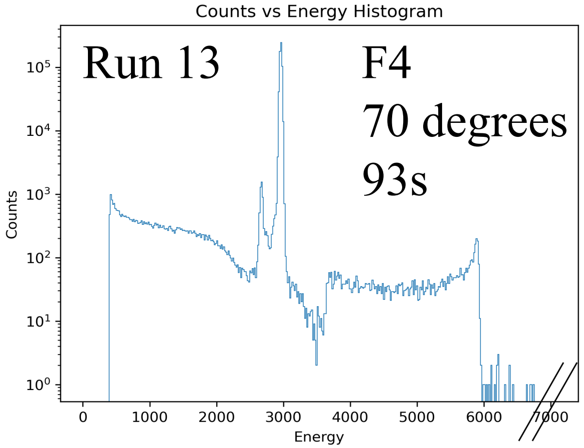
- Americium 241 for Calibration of the PIPS
- Am-241 alpha decay 5.486 MeV known precisely
- Adjust peak until it matches up with 5.486 MeV



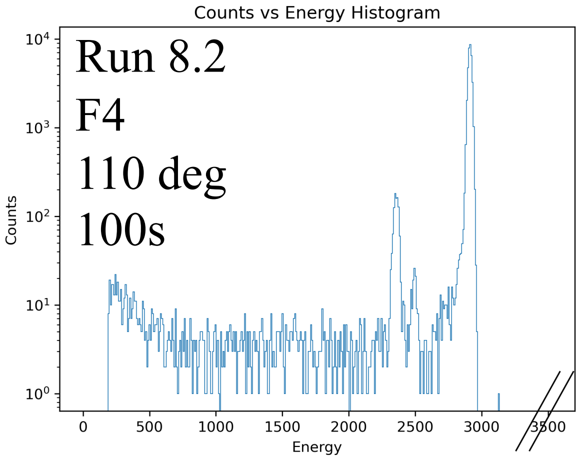
Calibration Data with the PIPs

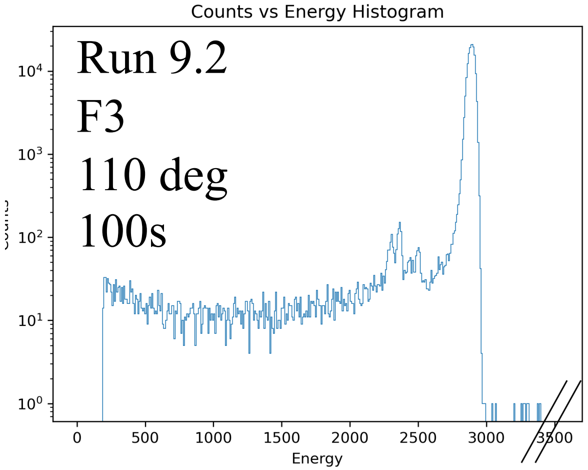


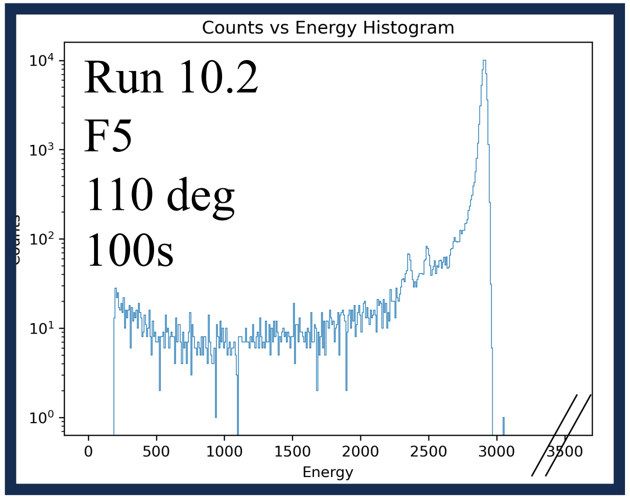


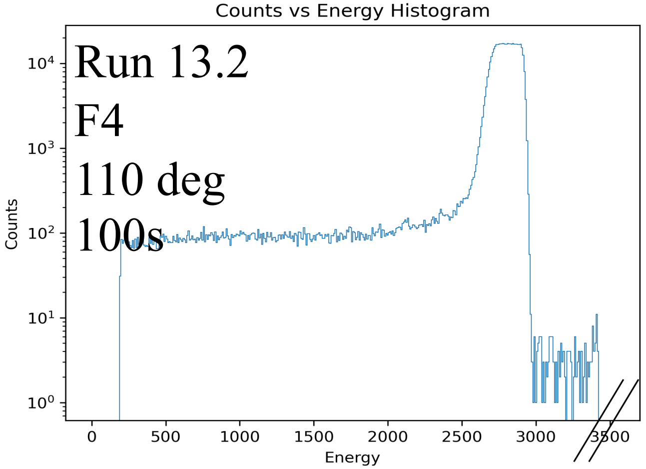


F2 = 950 ug/cm^2
F3 = 320 ug/cm^2
F4 = 150 ug/cm^2
F5 = 220 ug/cm^2



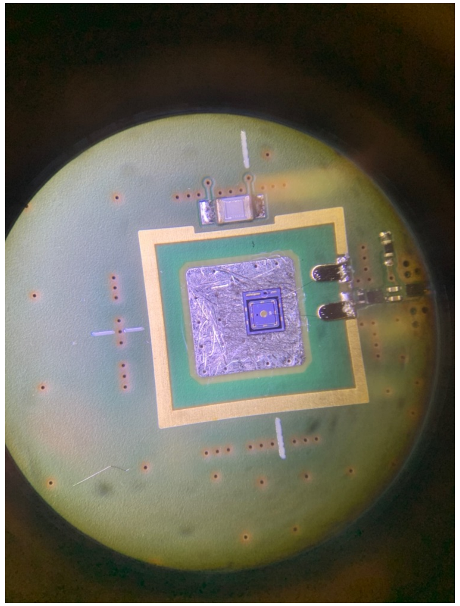


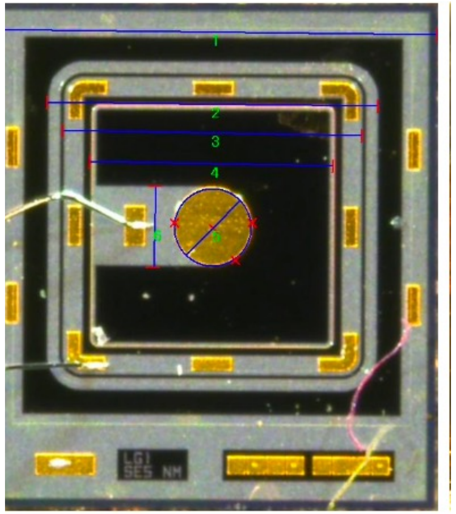


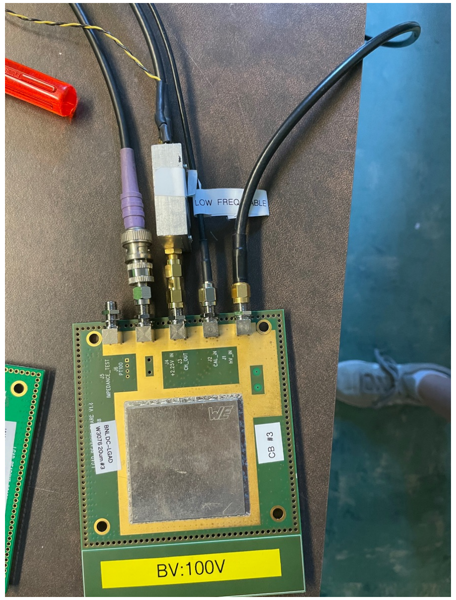


Tested LGAD's

- Goal of this test run: test the LGADs in the MeV range and test the gain saturation/suppression
- Used HPK 3.1 and 3.2 and PIN
- PIN (Not an LGAD, similar to PIPS)
- Bottom left – geometry of all sensors
- Bottom right – connections to the board



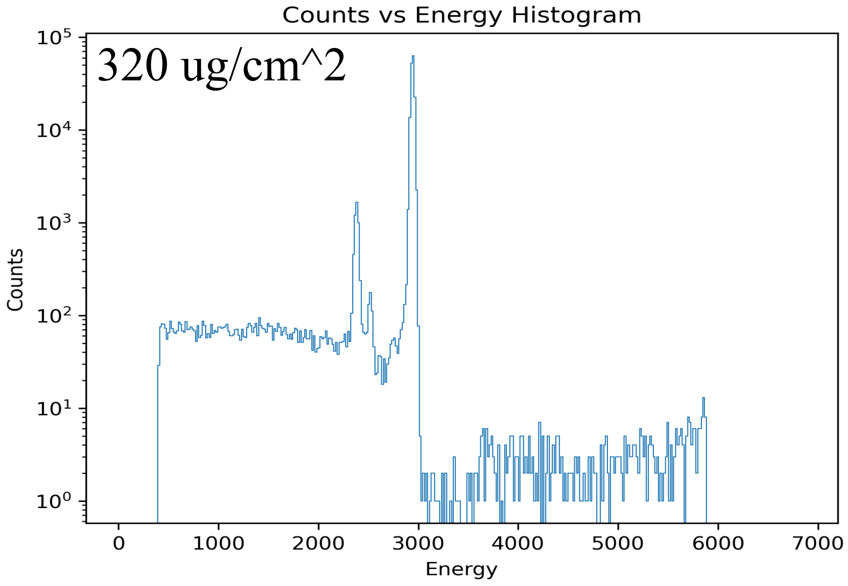


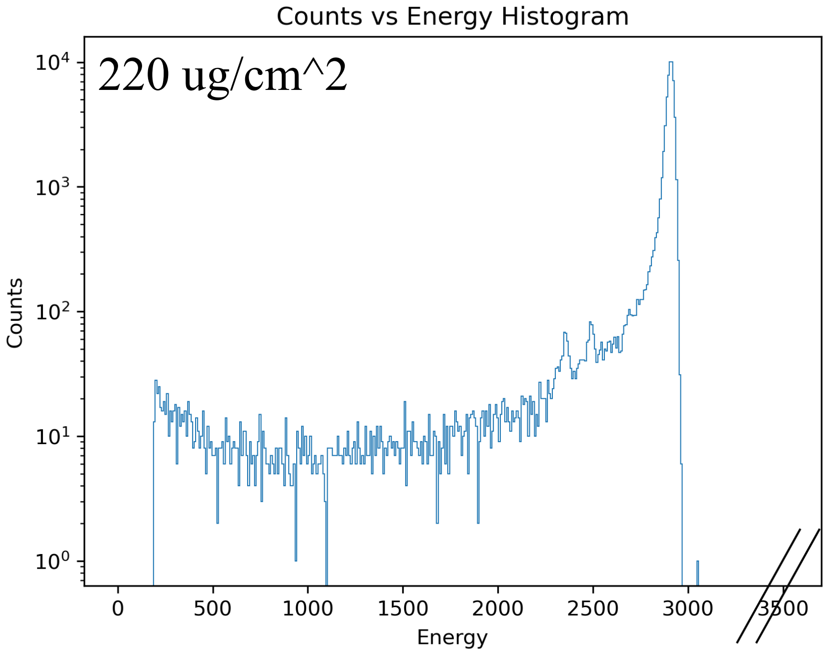


LGAD’s - Setup

- Kept the scattering angle at 110 degrees
  - Optimized rates
- Tested 220 and 320 ug/cm^2 gold foil

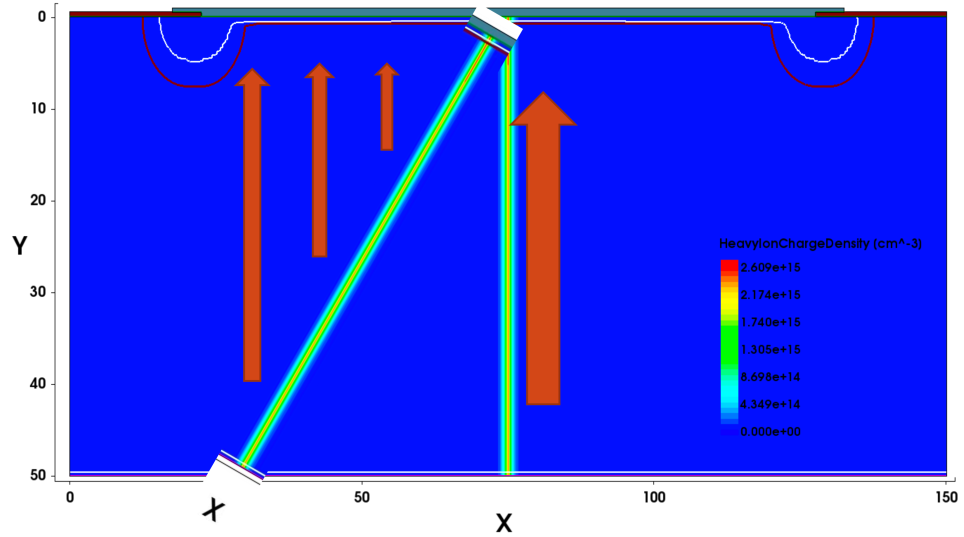
	220 ug/cm^2	320 ug/cm^2
Energy deposited	good	bad
Rates	low	high
State of foil	clean	dirty

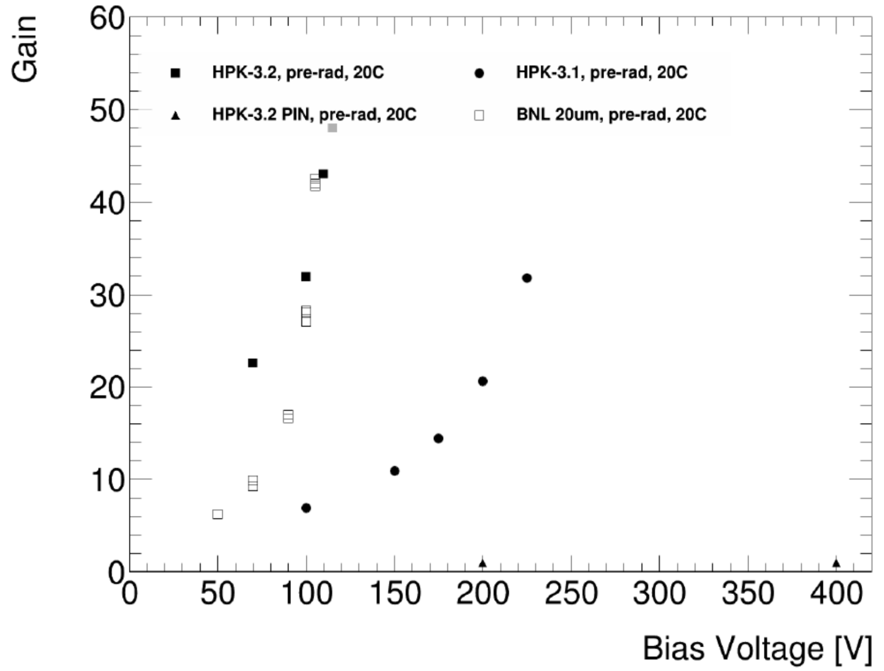




LGAD’s - Setup

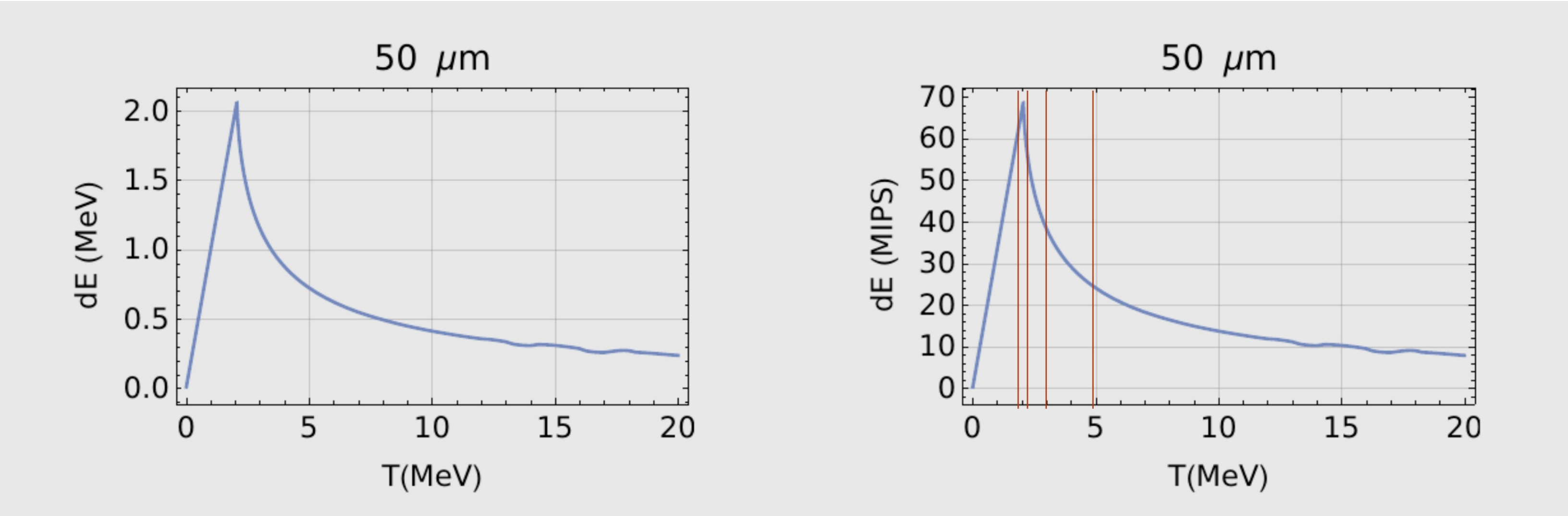
- We adjusted the angle of the LGADs w.r.t. the incoming beam
  - 0 – 75 degrees
  - Changing path length through detector
- Varying voltage bias across the sensors
  - Test different gain
  - HPK 3.1 → 80V-180V
  - HPK 3.2 → 80V-120V
  - PIN → 30V and 200V





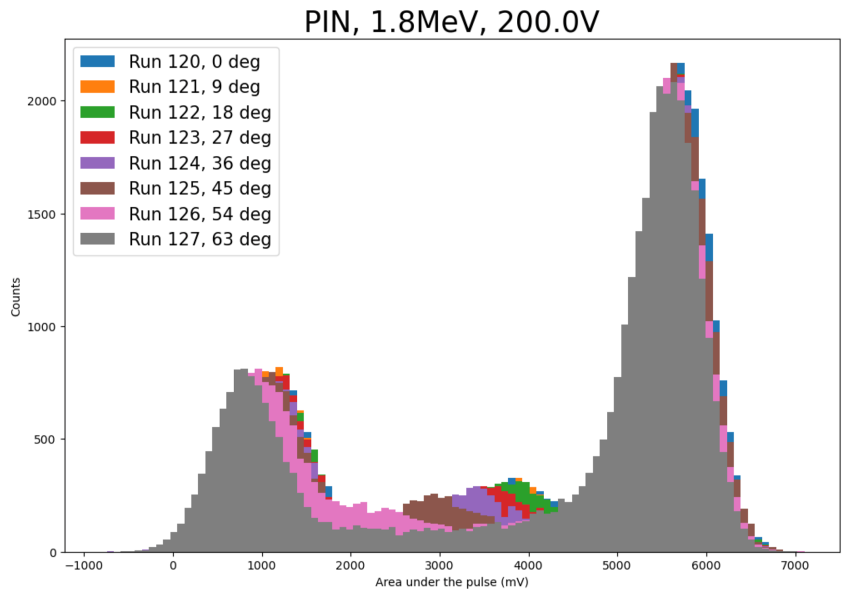
LGAD’s - Setup

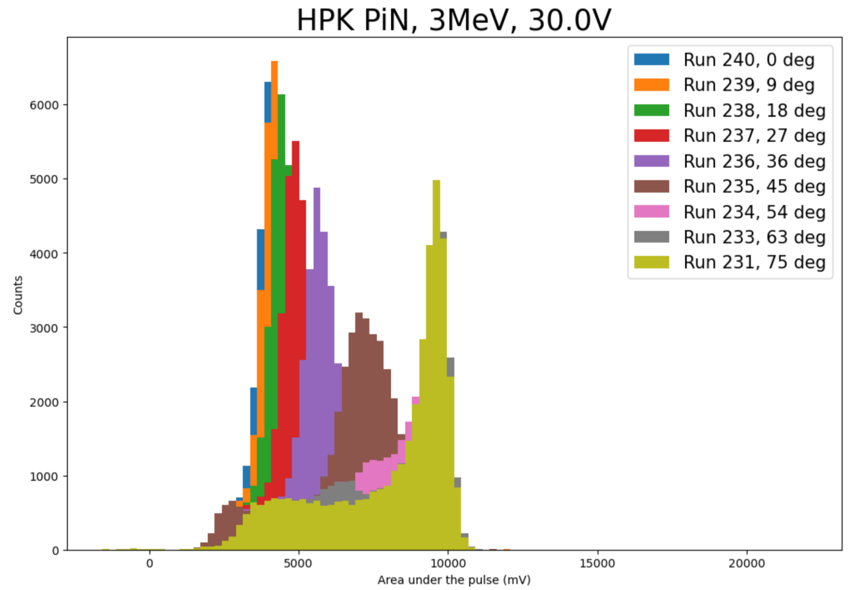
- Energy: 1.8, 2, 3, 5 MeV
  - Vary expected energy deposition
  - Vary whether or not proton stops
- Total of 349 runs (2 weeks of data)

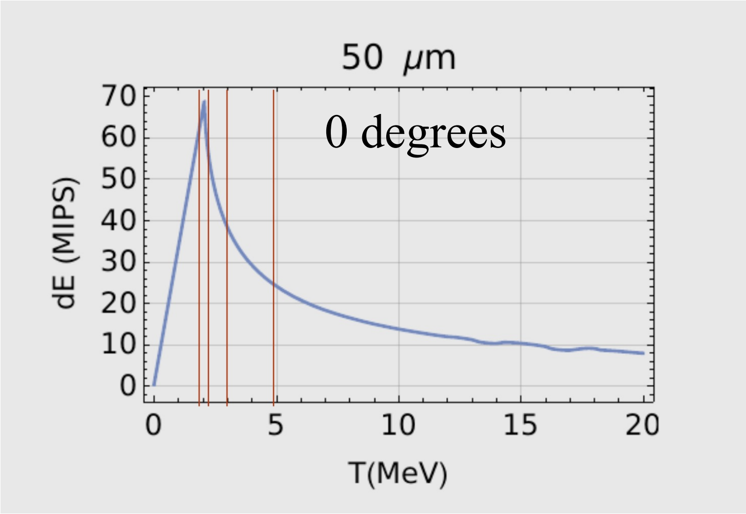


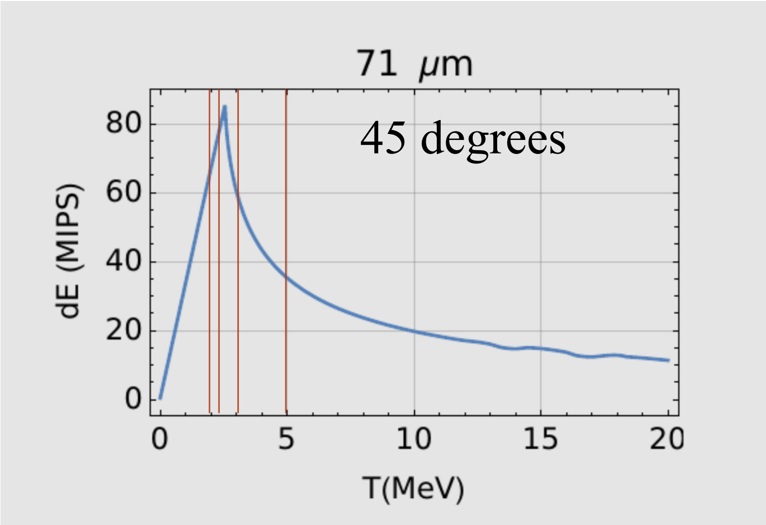
LGAD's Data

- PIN 1.8MeV
  - Peaks all in same spot→ proton stops
- PIN 3MeV
  - Peaks shift due to energy deposition up to stopping at ~50 degrees



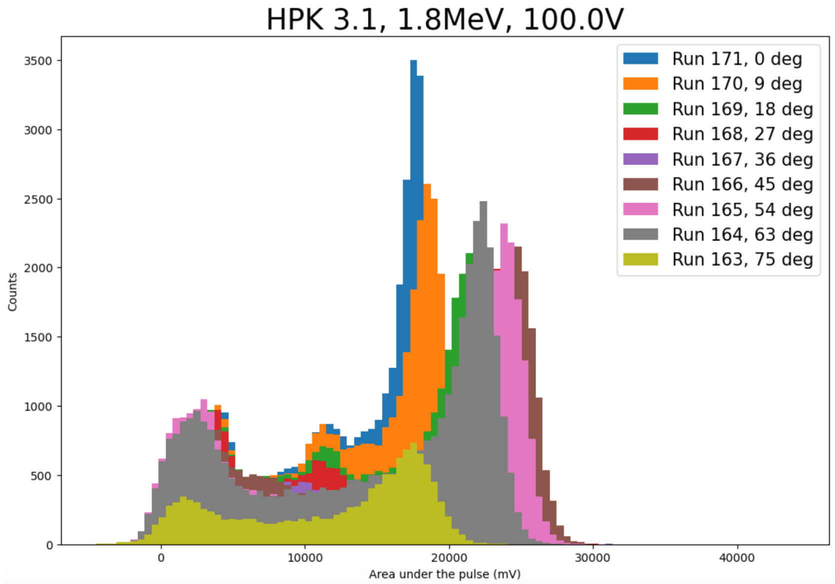


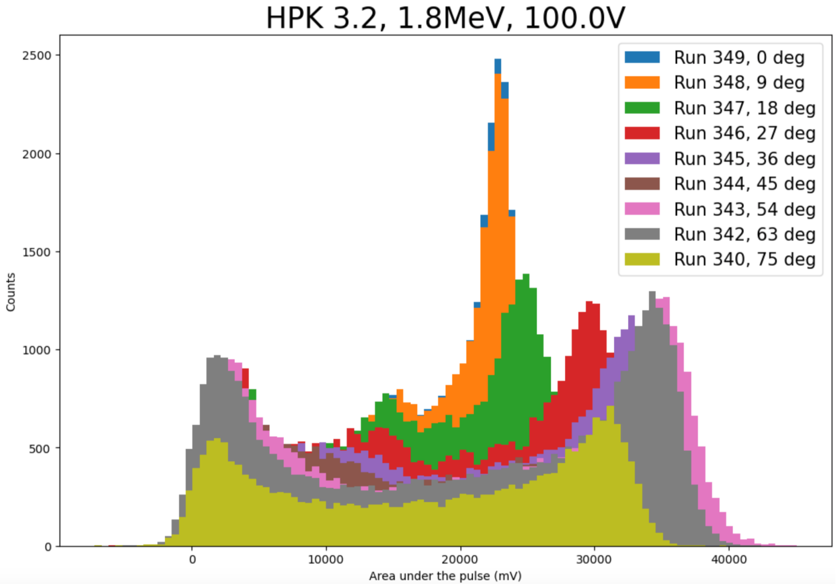


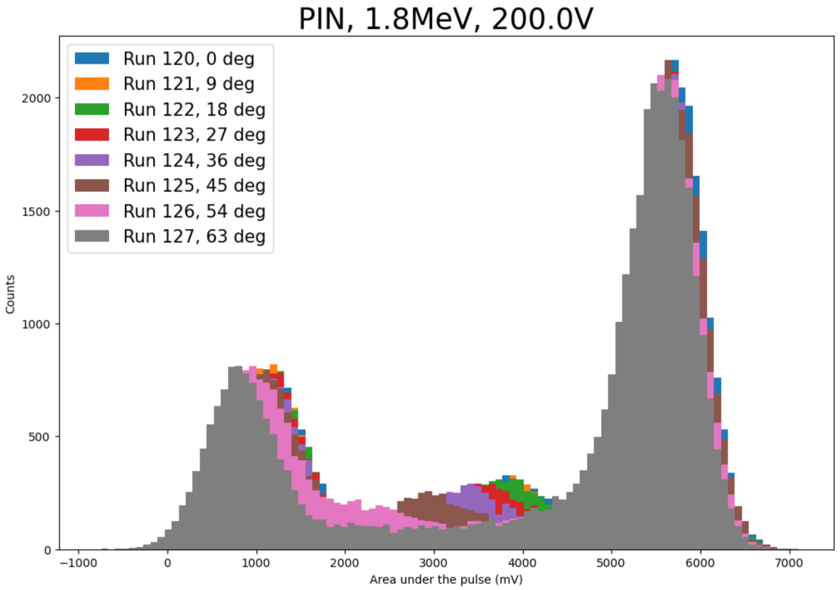


LGAD's Data

- Gain suppression less at high angles → Peaks spread out
- HPK 3.2 has a higher gain than HPK 3.1

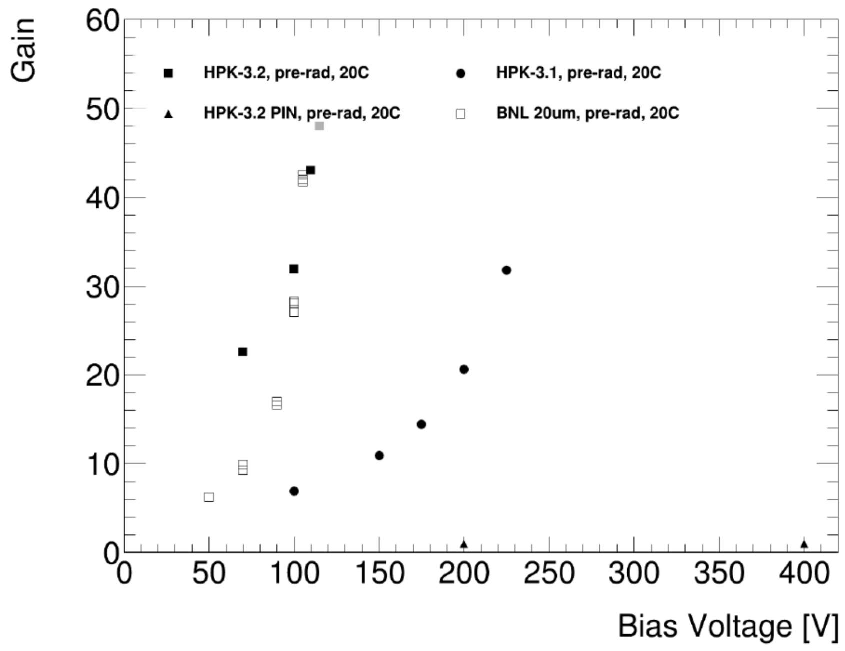


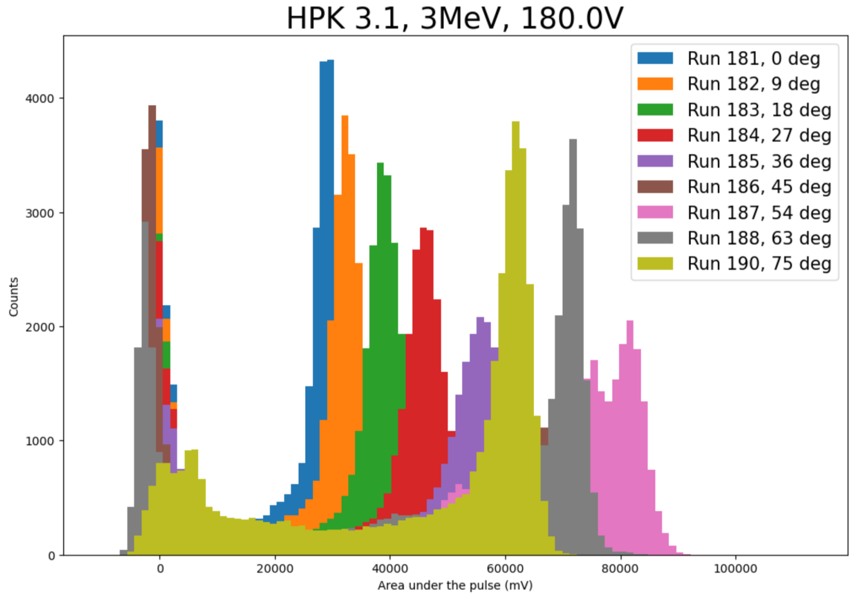


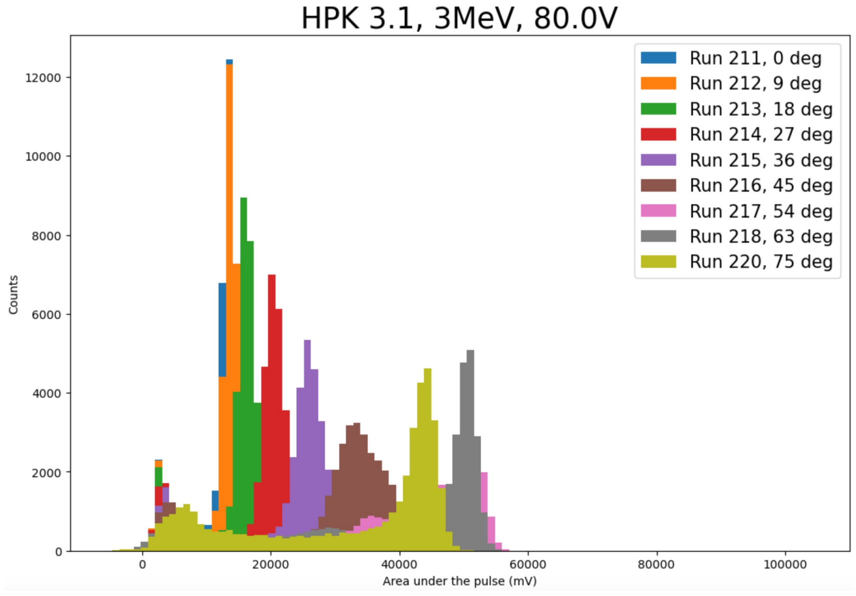


LGAD's Data

- Greater gain at higher bias voltage

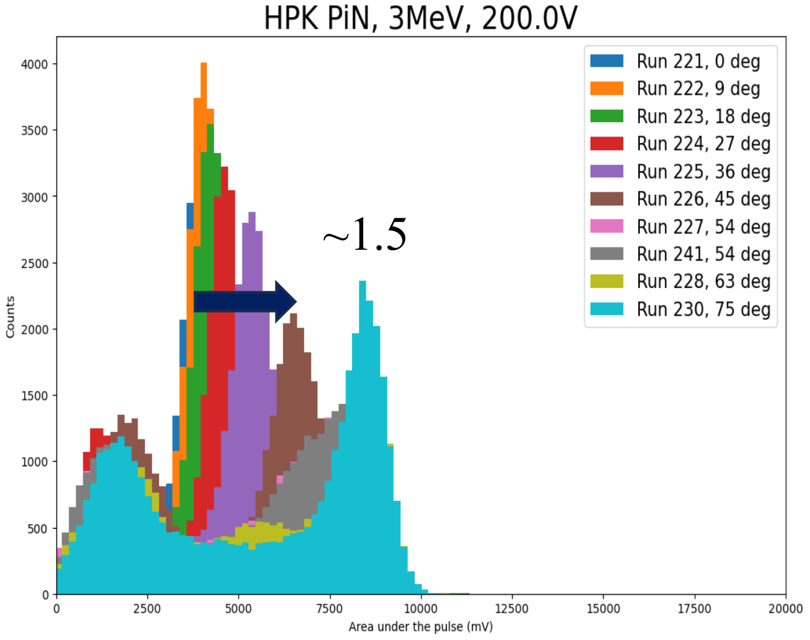


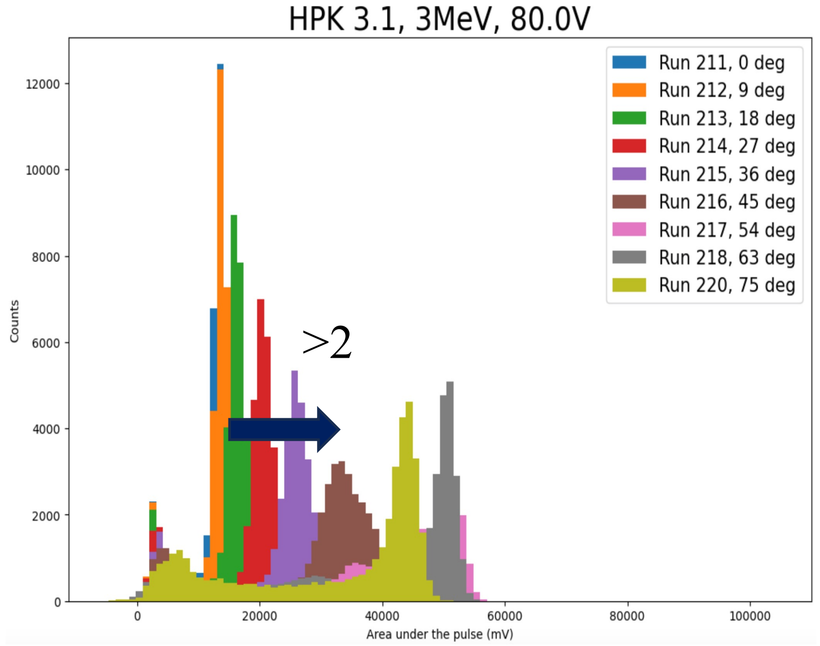


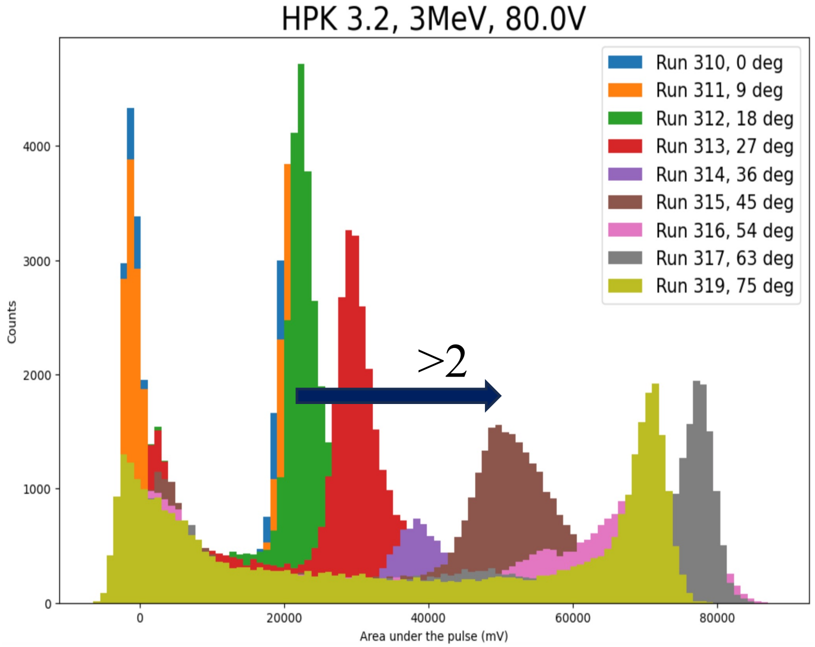


LGAD's Data

- PIN increase with angle linearly and stops after ~50 degrees
- LGADs has greater increase with angle and is nonlinear

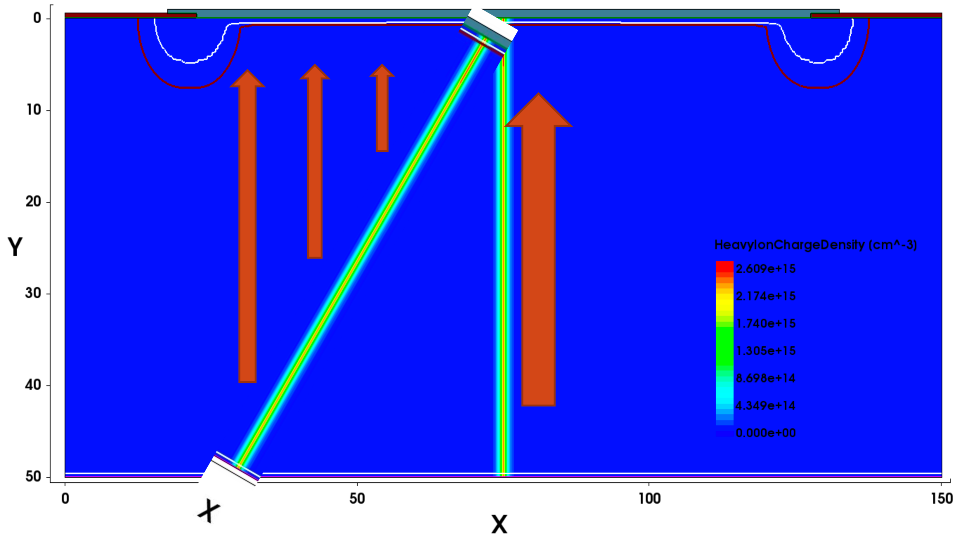


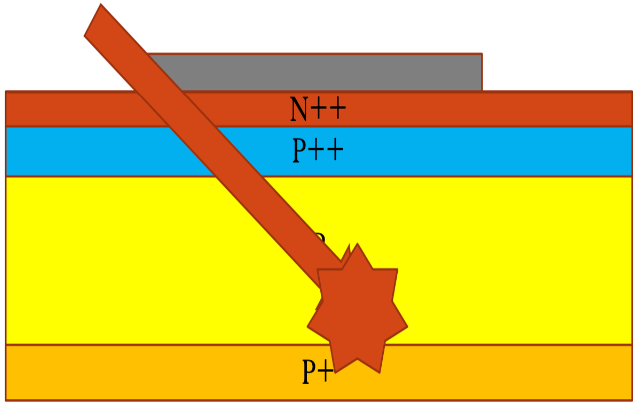


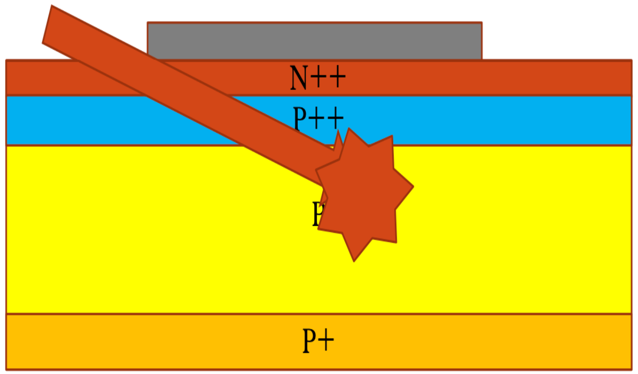


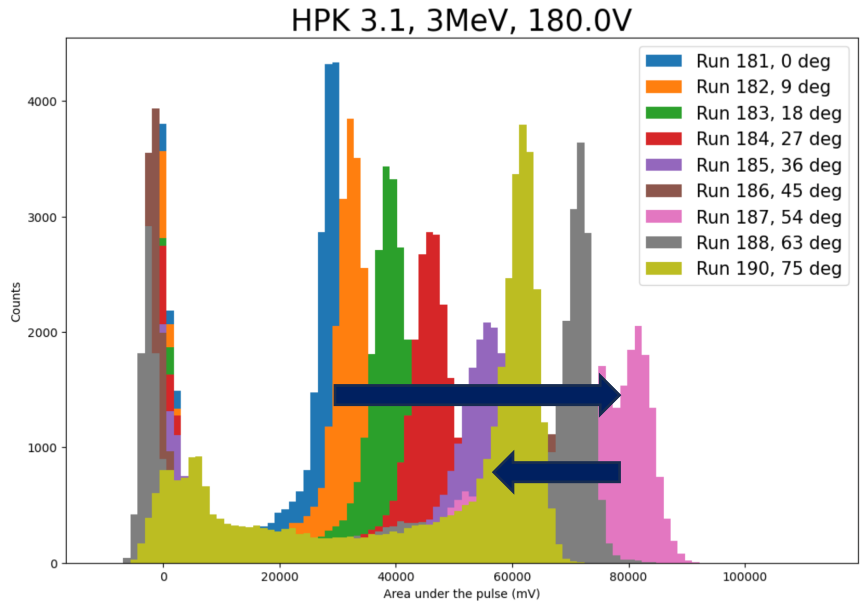
LGAD's Data

- 0 degrees concentrated in one area
- 45 degrees spread out
- Still trying to figure out why at ~50 degrees the gain starts to decrease









Conclusions

- The preliminary data looks promising for the eventual testing of the 120um LGADs → Plan test beam in October
- Still have to solve this issue of bipolar signals to cut out the noise
- We need to reduce the gain suppression for PIONEER
- Further study is needed on why the gain starts to decrease after a certain angle

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LGAD’s - Troubleshooting

- Second stage amplifier was bad
- Beam stopping in the middle of data taking
- Bad stripper foil
- Current fluctuations
- LGAD cover upside down
- Gold foil bent in opposite direction of beam flow
- Problems with trigger threshold
- Breakdown Voltage issues – When bias voltage is so large that there’s a leakage current