Gain suppression studies at the CENPA tandem accelerator

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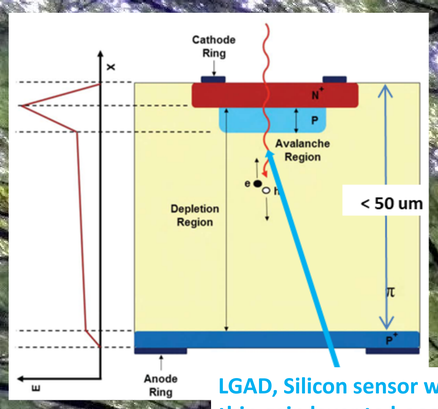


LGADs are thin (20-50um) silicon detectors with moderate (10-50) internal gain that can have exceptional time resolution (down to 20ps)

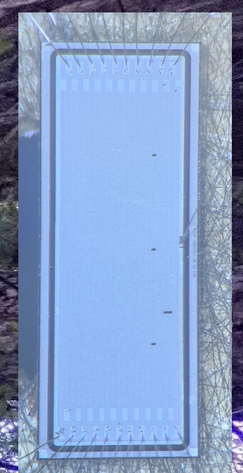
- First application: timing layer for detectors at HL-LHC

Granularity is limited at ~mm scale, solution: AC-coupled LGADs or Trench-Insulated LGADs

- Near future applications of AC-LGADs and TI-LGADs: PIONEER and ePIC (electron-ion collider)

However, gain is limited by gain suppression mechanism: critical issue for the PIONEER experiment

Gain saturation studied with heavy ions at the CENPA Tandem Van de Graaf

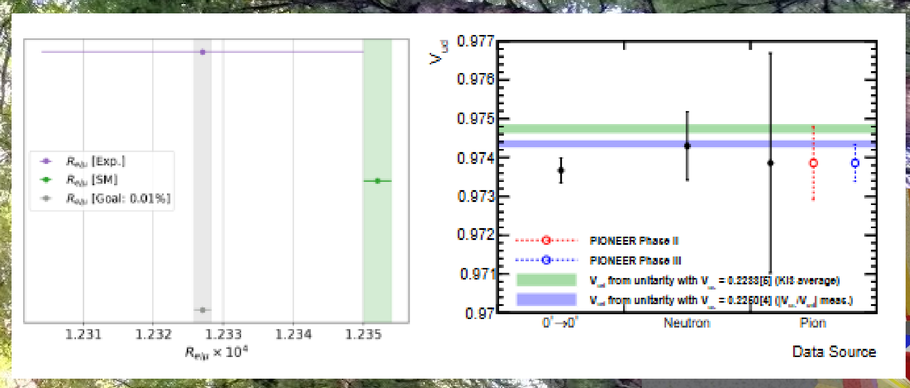


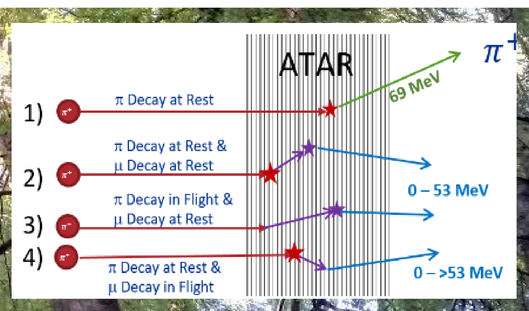
Context: The PIONEER experiment

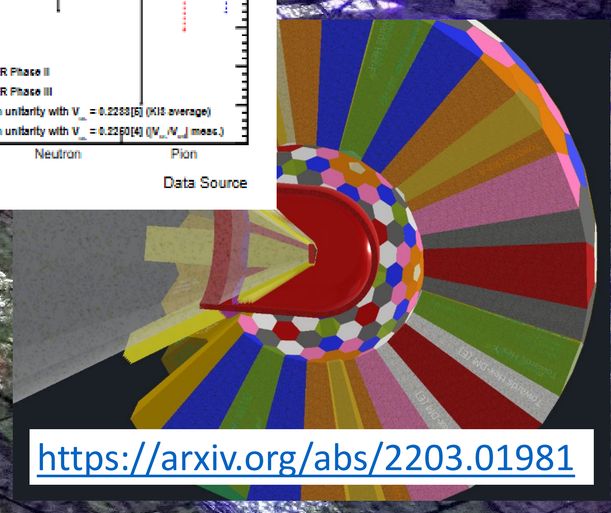
- PIONEER is a next generation rare Pion decay experiment at PSI
  - Phase I: improve measurement of charged lepton flavor universality Re/μ by an order of magnitude, reaching SM calculation precision
  - Phase II/III: precise measurement of Pion beta decay BF. Important to test CKM unitarity (clean Vud measurement)

Three main detectors: Active Target (ATAR), Calorimeter (LXe or LYSO) with <2% energy resolution, Low mass tracker (μ-RGROVE) in between

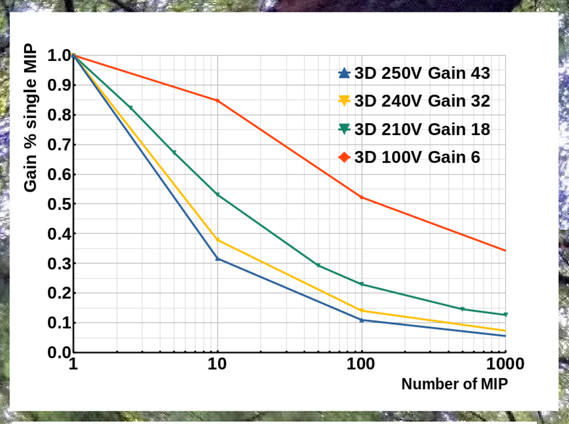
- The ATAR is a 2x2 cm wide, 6 mm thick silicon tracker with high granularity in (X/Y/Z) and high position/energy/time resolution
  - The chosen sensor is a high granularity LGAD detector (AC-LGAD, TI-LGAD)
- Large difference in energy deposits by positron, pion and muon
- **Need to understand linearity of response over a large dynamic range**

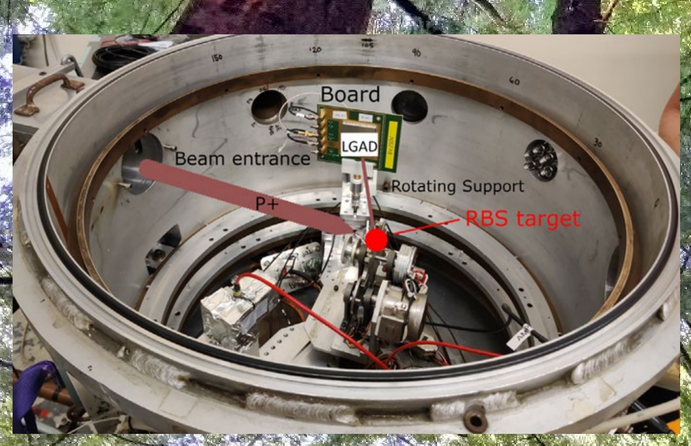


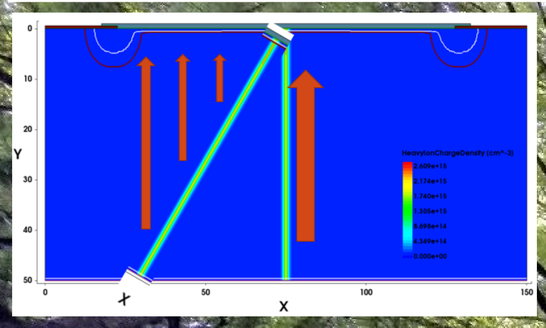




https://arxiv.org/abs/2203.01981







- **LGAD gain suppression mechanism**
  - Gain suppression observed experimentally with large energy depositions
  - Caused by the field shielding effect from the gain electrons/holes
- Tested at CENPA's (University of Washington) ion accelerator as a function of ion energy and deposition angle
- Simulate the gain suppression effects using TCAD simulation: shows that with a low gain sensor the gain reduction is less
  - Can gain suppression be reduced by adjusting the sensor design?
- Previous paper: https://doi.org/10.1016/j.nima.2024.169395
  - Large gain dependence on the angle observed
- **New tests in summer 2024 with LGAD sensors from Fondazione Bruno Kessler (FBK) with a reduced gain layer doping and larger thicknesses: 50um, 100um, 150um**
  - **Both PIN (no gain) and LGADs were tested to calculate the gain**

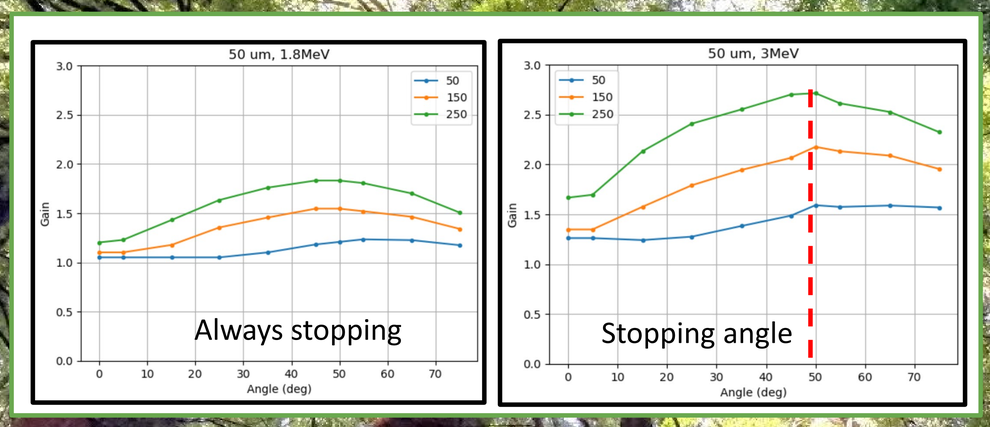
Setup: sensors mounted on a high bandwidth amplifier board on a rotation stage. Setup is in vacuum, and protons hit an RBS target, then the tested sensor.

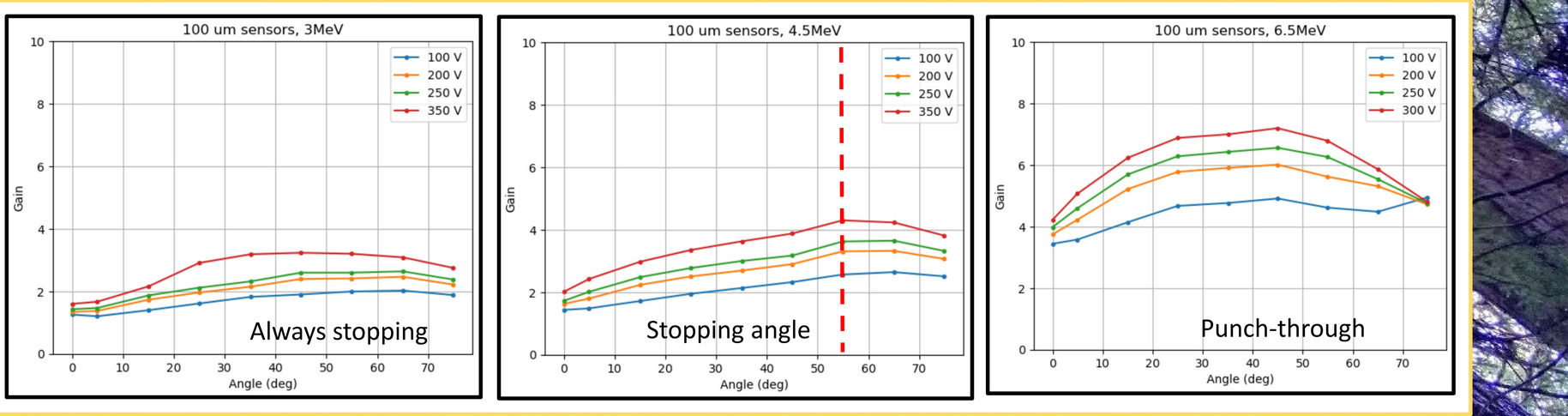
Protons either stop or punch through the device depending on the momenta.

Results: gain suppression is observed for all studied devices and injected energies.

The gain generally increases as a function of angle but decreases again at large angles due to proximity of the Bragg peak to the surface gain layer.

An lower gain was observed in respect to samples tested in Summer 2023, likely due to different gain layer design and doping. Studies to verify this effect are ongoing.





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The PIONEER experiment: https://pioneer.triumf.ca/

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