An LGAD-based fully active target for the PIONEER experiment

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On behalf of the PIONEER collaboration

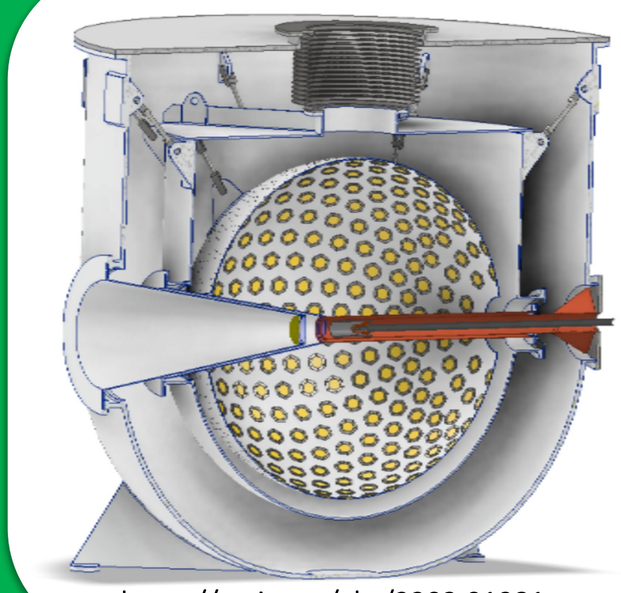
The Experiment: PIONEER

PIONEER is the "successor" of PIENU/PEN/PiBeta. **The PIONEER experiment goal is to improve the precision of $R_{e/\mu}$ and B($\pi^+ \rightarrow \pi_0 e^+ \nu$) by an order of magnitude.**

- $R_{e/\mu}$ is the ratio of pion decay to electron a muon: **most precise measurement of lepton flavor universality**
- **B($\pi^+ \rightarrow \pi_0 e^+ \nu$)** potentially is the cleanest measurement of Vud: **very important to test CKM matrix unitarity**

PIONEER will be running at the ring cyclotron at the Paul Scherrer Institut (PSI)

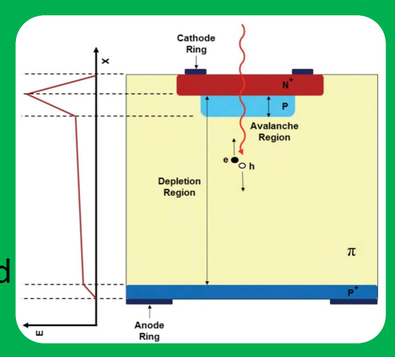
PIONEER is composed by two main detectors: a fully active silicon Active TARget (ATAR) and 25 X_0 high resolution Liquid Xenon calorimeter.



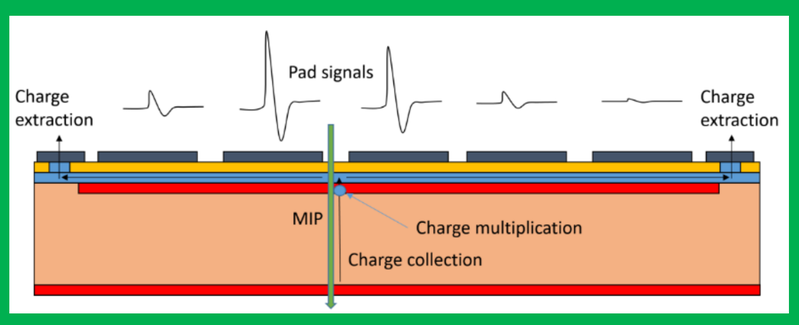
https://arxiv.org/abs/2203.01981

The Technology: AC-LGADs

LGADs are silicon detectors with an additional highly-doped gain layer. The high field region result in an **internal gain of ~5 to ~30.** LGADs are thin (50-100um) resulting in fast rise time and full collection time



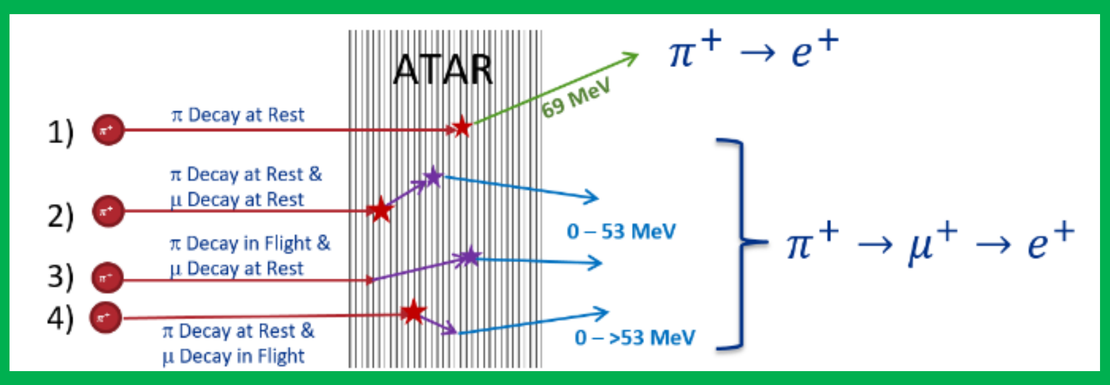
High S/N ratio and fast rise time result in the **exceptional time resolution as low as 20 pS**



However the granularity for normal LGAD technology is limited to the mm scale. **To achieve higher granularity a new type of LGADs is needed: AC-coupled LGAD (AC-LGAD).**

Identification and tagging of decays

ATAR with fast timing and high segmentation allows to identify and tag $\pi \rightarrow e\nu$ and $\pi \rightarrow \mu\nu \rightarrow e\nu\nu$ events by detecting and separating every single energy deposition. The combination with the good energy resolution of the calorimeter enables a high precision measurement of $R_{e/\mu}$.



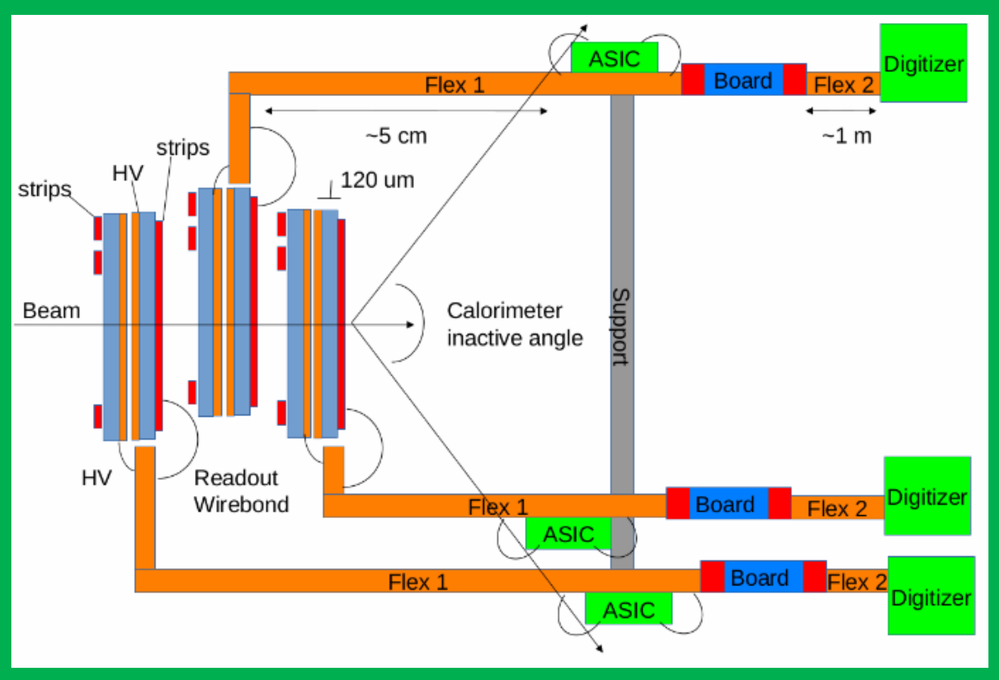
AC-LGAD testing

AC-LGAD has intrinsic charge sharing between pixels: charge sharing can be a great feature for low density tracking environment.
With a sparse pixelation of 200 um a spatial hit precision of <10 um can be achieved!

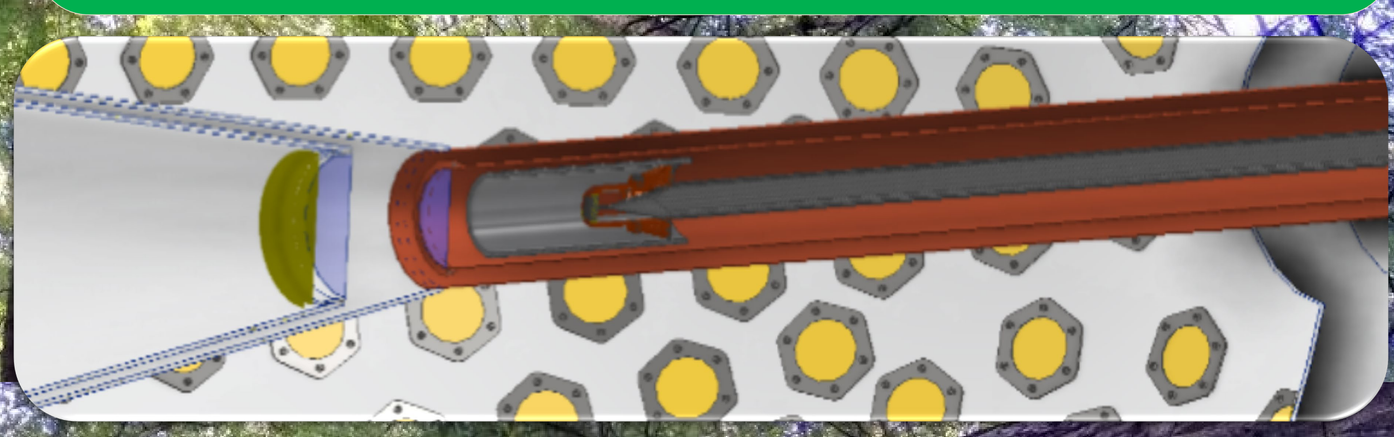
The detectors were tested **with a proton test beam** at Fermilab and in laboratory with a IR laser TCT system. **LGADs** are produced by FBK (Italy) and Brookhaven national Laboratories (US).

ATAR design

ATAR initial design: 48 layers of 120um thick AC-LGADs, compromise between granularity, total active area, timing and dead material. LGAD signal is transmitted via a flex to the readout ASIC and then to the digitizer stages in the back end

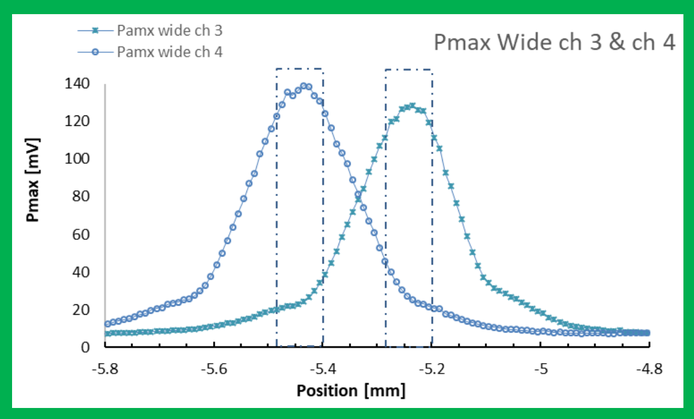


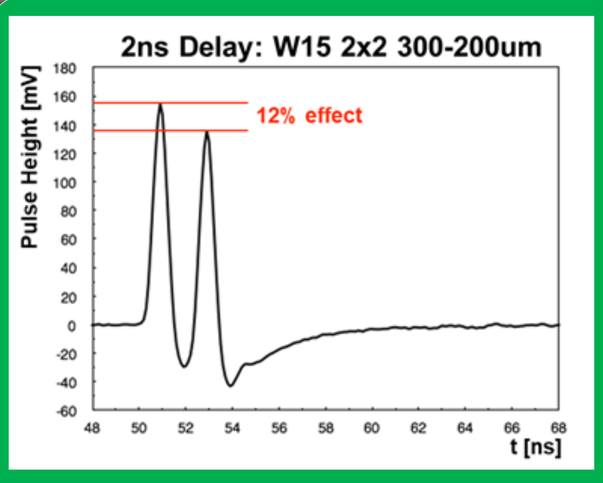
https://www.mdpi.com/2410-390X/5/4/40



BNL AC-LGAD prototypes results

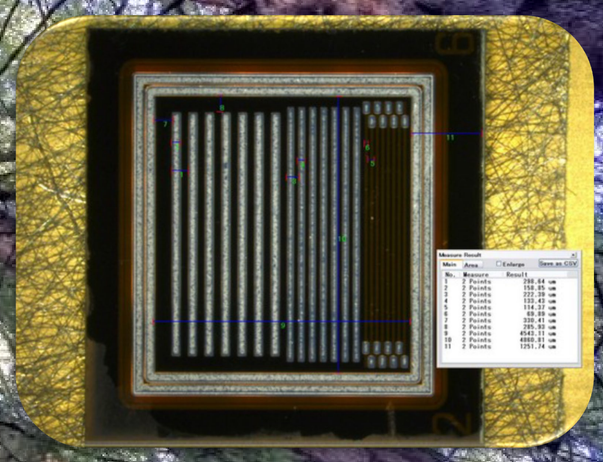
Prototype BNL strip AC-LGAD response of two neighboring strips with pitch of 200 um and strip width of 80 um. In the plot the Pulse maximum as a function of position across the strip is shown, the position of two strips is highlighted by the boxes.





FBK AC-LGAD prototypes results

Two pulses subsequent in time separated by 2ns of a prototype FBK AC-LGAD. Thanks to the fast full collection time thin LGADs can resolve pulses as close as 1 ns. **The high granularity and time resolution of the ATAR allows for energy deposits separation in time and space.**



This work was supported by the United States Department of Energy, grant DE-SC0010107-005