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 $V_{ud}$: 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.

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 $R_{e/\mu}$.

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.

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.

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).

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).

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.

https://arxiv.org/abs/2203.01981


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