Development of a High-Resolution, High-Dynamic-Range Charge Detector for Ion Beam Monitoring

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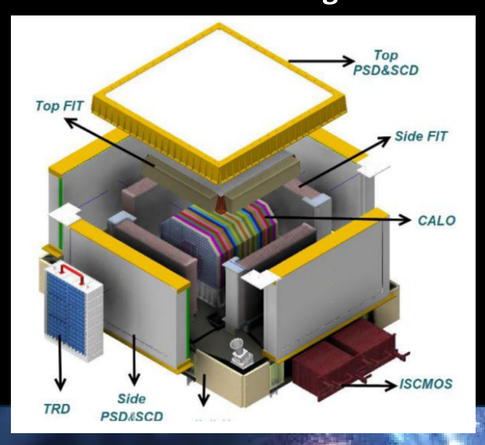
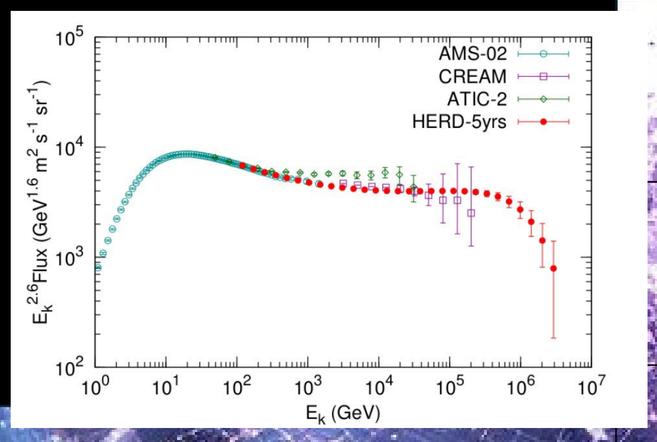
1. The research group background.

Our research group is involved in several space experiments for the direct measurement of cosmic-ray, with one notable example being HERD. HERD, a calorimeter designed for measuring protons and nuclei up to energies of 10^{15} eV

Tentative HERD design



Expected proton flux measured by HERD



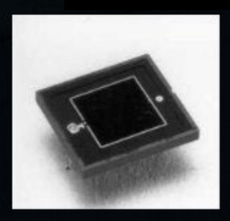
2. An ion beam monitor for HERD

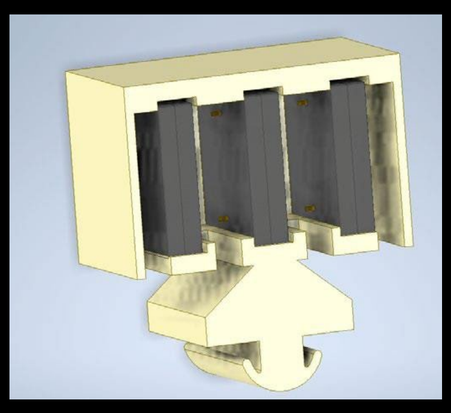
2022 HERD beam test with ions at SPS, the collaboration needed:
– a beam monitor to quickly check the composition of the beam,
– a reliable and independent charge measurement.
The detector has been designed with the following features:
– Ease of mounting and dismounting due to HERD's mechanical constraints
– Prompt online analysis for quick results
– Thin construction to minimize the incidence of fragmented nuclei in the detector
– high dynamic range to measure charge from 1 to ~80 (Pb).
Additionally, a significant challenge was the limited time available before the test.

3. Design of the first prototype

Due to the time restriction, well known components have been employed. The prototype were made of 6 PIN diodes [1] VTH2090 which is a large area (9.2 x 9.2 mm2) PD. Measured depletion depth is ~ 220 um .

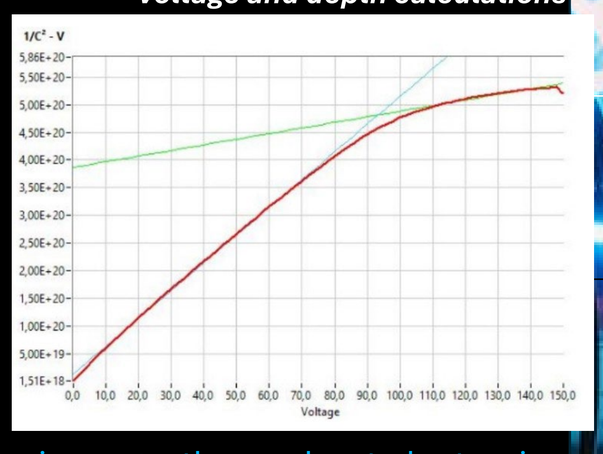
VTH2090





A very simple mechanical structure was designed

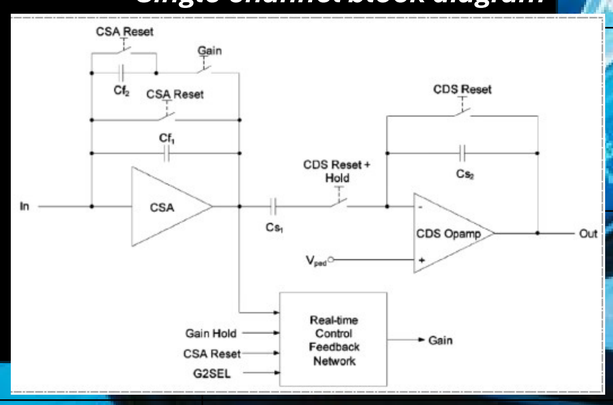
Capacitance measurements for depletion voltage and depth calculations



To achieve the necessary high dynamic range, the read-out electronics of the calorimeter photodiode system were employed. Specifically, a custom chip HiDRA, version 2, developed by INFN-Trieste (Italy), was utilized.[2].

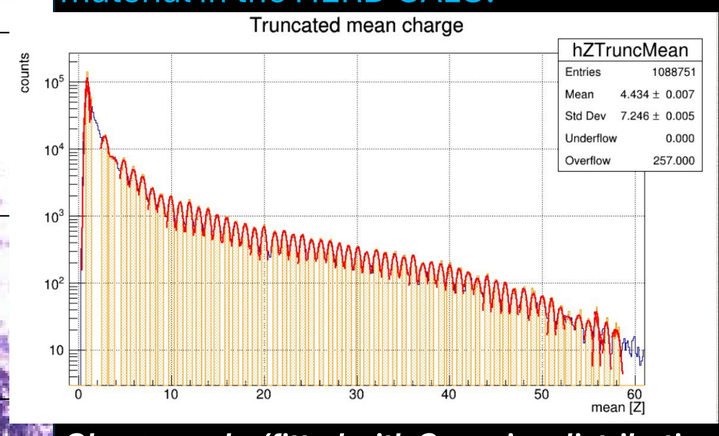
– Double gain CSA with automatic-gain selection circuitry
– High dynamic range (~ 5* 10^5)
– Low power consumption ~ 3.5 mW/chan
– Low noise: ENC ~2500e
– 16 input channels
– Self-trigger system

Single channel block diagram



4. First Results

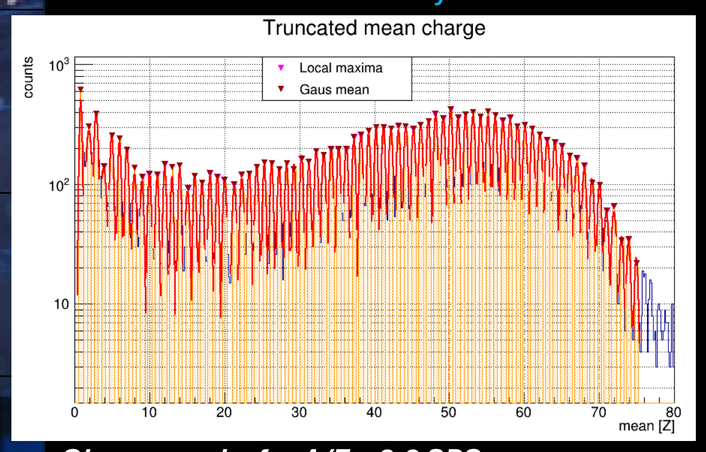
In 2022, we utilized the initial prototype during the HERD beam test with ions at the SPS. The primary objective was to identify nuclei and assess the nonlinearity of the LYSO scintillator, which serves as the active material in the HERD CALO.



Charge peaks (fitted with Gaussian distributions) up to Z ~ 60.

We implemented a simple analysis strategy:
– Convert ADC -> MIP
– Convert MIP -> Z
– Evaluate if ADC signal > threshold.
– Selection: number of diodes above noise threshold > 3.

In 2023, within the context of the HERD project, nuclei tagging was implemented to evaluate the performance of the large-scale prototype with nuclei.
Simultaneously, in 2023, the AMS-02 experiment conducted its first test outside the HERD collaboration. The data collected from this test were utilized for independent charge tagging and evaluation of charge reconstruction efficiency.



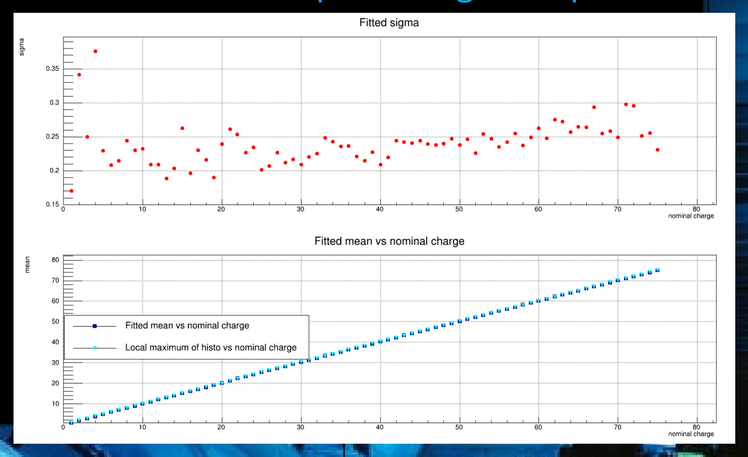
Charge peaks for A/Z ~ 2.2 SPS ion beam.

The obtained charge resolution is better 0.3 charge unit from Z =4 to Z = 75 and just slightly increase with Z.

Good response linearity is also achieved.

Improved analysis strategy:
– Evaluate the number of consistent diodes with the one considered.
– Selection criterion:: select a maximum of 6 consistent diodes.

Optimized diodes bias:
The bias voltage has been raised to 100 V to maximize the depleted region depth.



5. New project: BeER

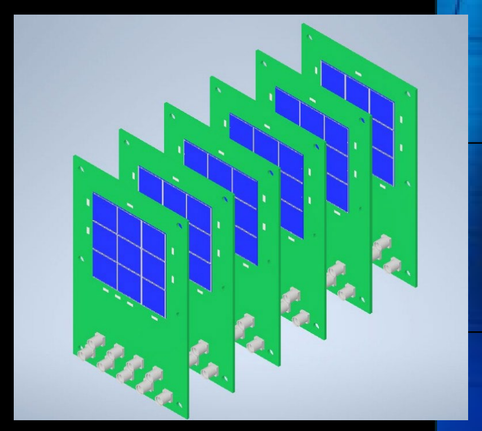
We have just decided to start a project dedicated to this detector named "Beam-monitor with Extreme Range" (BeER).
We are investigating possible applications of BeER:

- on-line monitor of high energy ion beams (e.g. SPS),
- event-by-event charge tagging system for off-line analysis for ion beam user like ASM-02.
- on-line monitor of high multiplicity beams (e.g. LNF-BTF).
- application in experiments, e.g. nuclei cross section measurement, heavy ion identification in cosmic rays, ...

We are completely open to suggestions about BeER application and future design.

We are currently in the process of implementing a new design for our detector::

- new sensors VTH2021 (10x10 mm active area, no package)
- Enlarge the active area of the detector by adding more diodes (matrix 3x3)
- 6 layers with 3x3 matrix
- Adjust the mechanics for the new design, add motorized sliders.
- Adjust the electronics to read-out more channels using HiDRA 2 chip.



6. References

1. O. Adriani et al 2019 JINST 14 P11004
2. O. Adriani et al 2022 JINST 17 P09002