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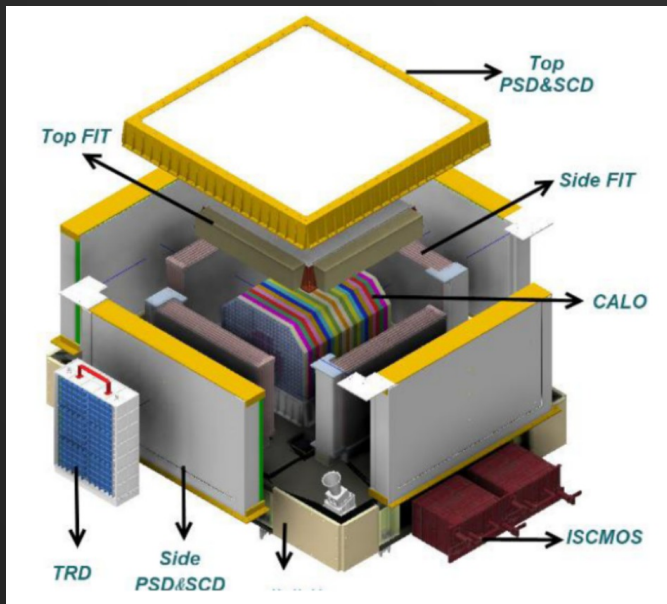
Lorenzo Pacini

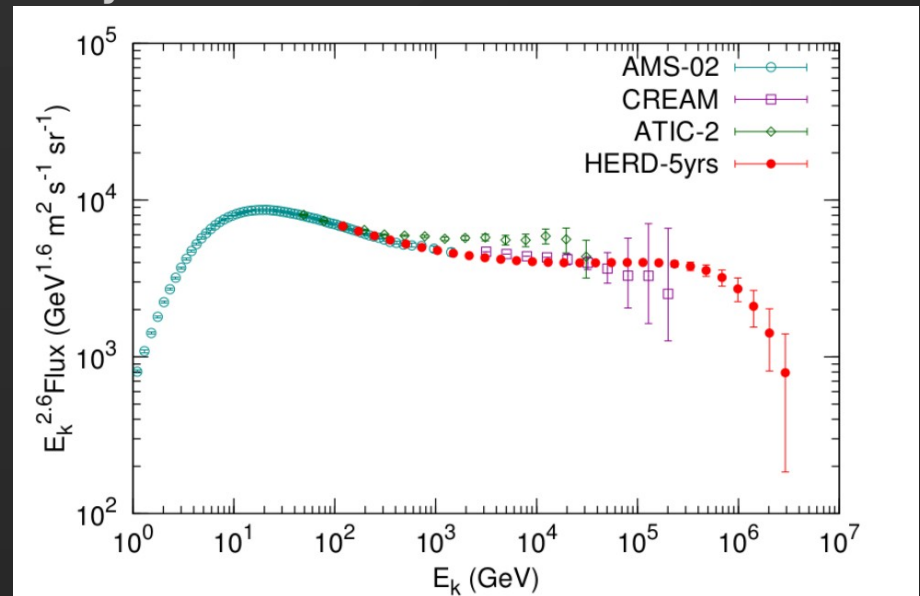INFN, Florence, Italy

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The research group background.

- Our research group is involved in several space experiments for the direct measurement of cosmic-ray, e.g. HERD.

- HERD is a calorimeter for the measurements of protons and nuclei up to 10^{15} eV.

Tentative HERD design

Expected proton flux measured by HERD

A 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:
  - simple and easy to mount (dismount) due to HERD mechanical restriction,

  - quick on-line analysis results,

  - thin in order to avoid large number of fragmented nuclei in the detector,

  - high dynamic range to measure charge from 1 to ~80 (Pb).

- A further difficulty was the short time available before the test.

Design of the first prototype.

- Due to the time restriction, well known components have been employed.

- The prototype were made of 6 blind photo-diodes: VTH2090 (see slide 5).

- This sensor was already characterized in details for the CaloCube R&D project ("O. Adriani et al 2019 JINST 14 P11004")

- To match the required high dynamic range, the read-out electronics of the calorimeter PD-system was used (see silde 6):

  – It is based on HiDRA front-end chip.

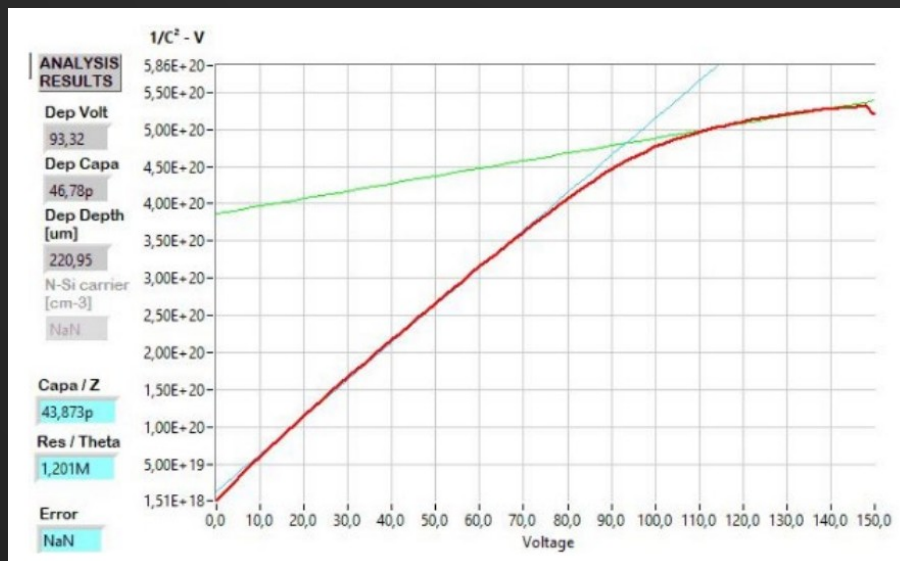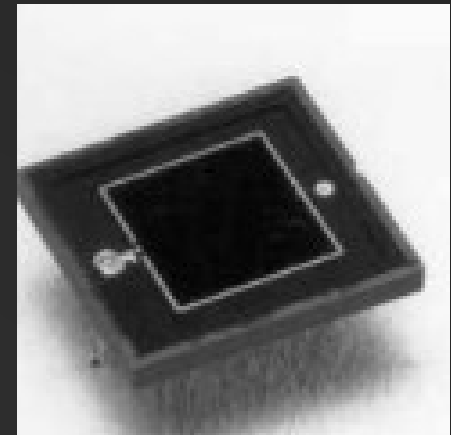- A very simple mechanical structure was also designed.

Design of the first prototype
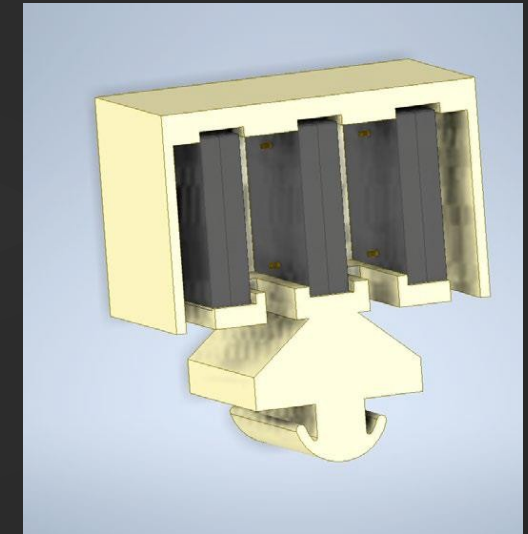
The sensor: VTH2090

- The VTH2090 is a large area PD (9.2 x 9.2 mm^2).

- Accurate information of electro-optical characteristics is presents but detailed information regarding the diode thickness is unavailable

- We measured the PD capacitance.

VTH2090

**The obtained depletion depth is ~ 220 um**

The electronics: HiDRA chip

- Custom chip HiDRA, designed by INFN-Trieste (Italy), v2.

- Double gain CSA with automatic-gain selection circuitry.

  – High dynamic range ($\sim 5*10^5$)

  – Low power consumption $\sim$ 3.5 mW/chan.

  – Low noise: ENC ~2500e

  – 16 input channels.

  – Self-trigger system.

- See: *"O. Adriani et al 2022 JINST 17 P09002"*


HiDRA chip
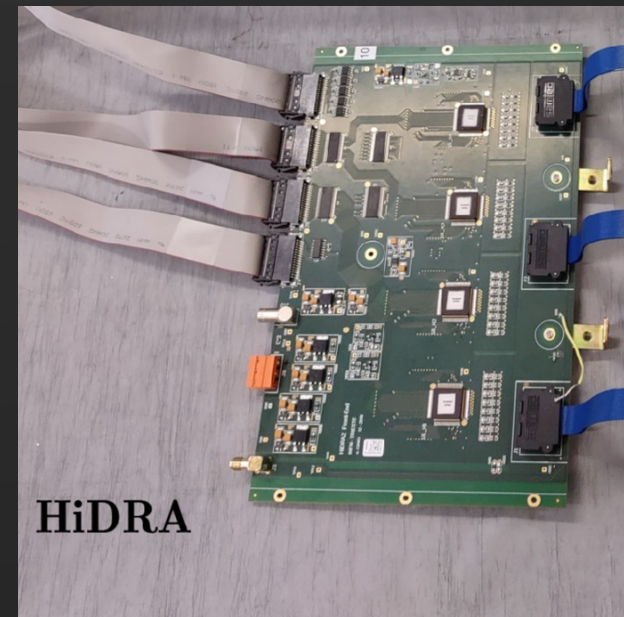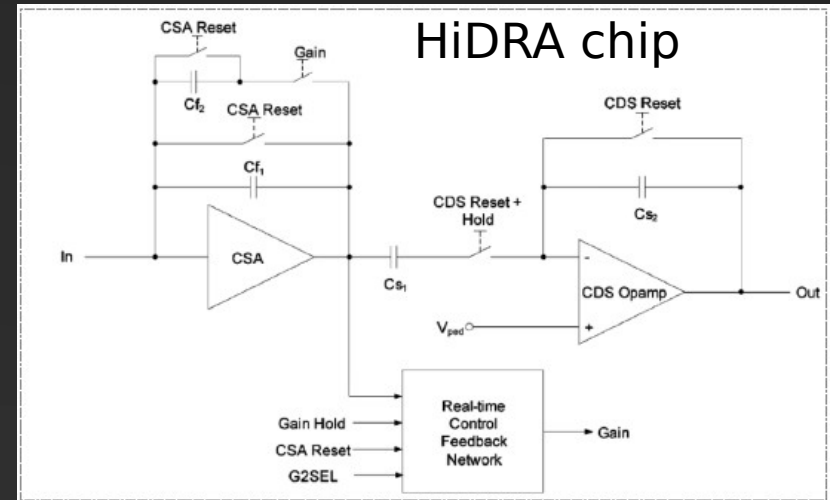
The first test: 2022 HERD.

- We employed the first prototype in 2022 for the HERD with ion @ SPS.

- The main purpose was nuclei identification to check the non-linearity of the LYSO scintillator (HERD CALO active material).

- 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.
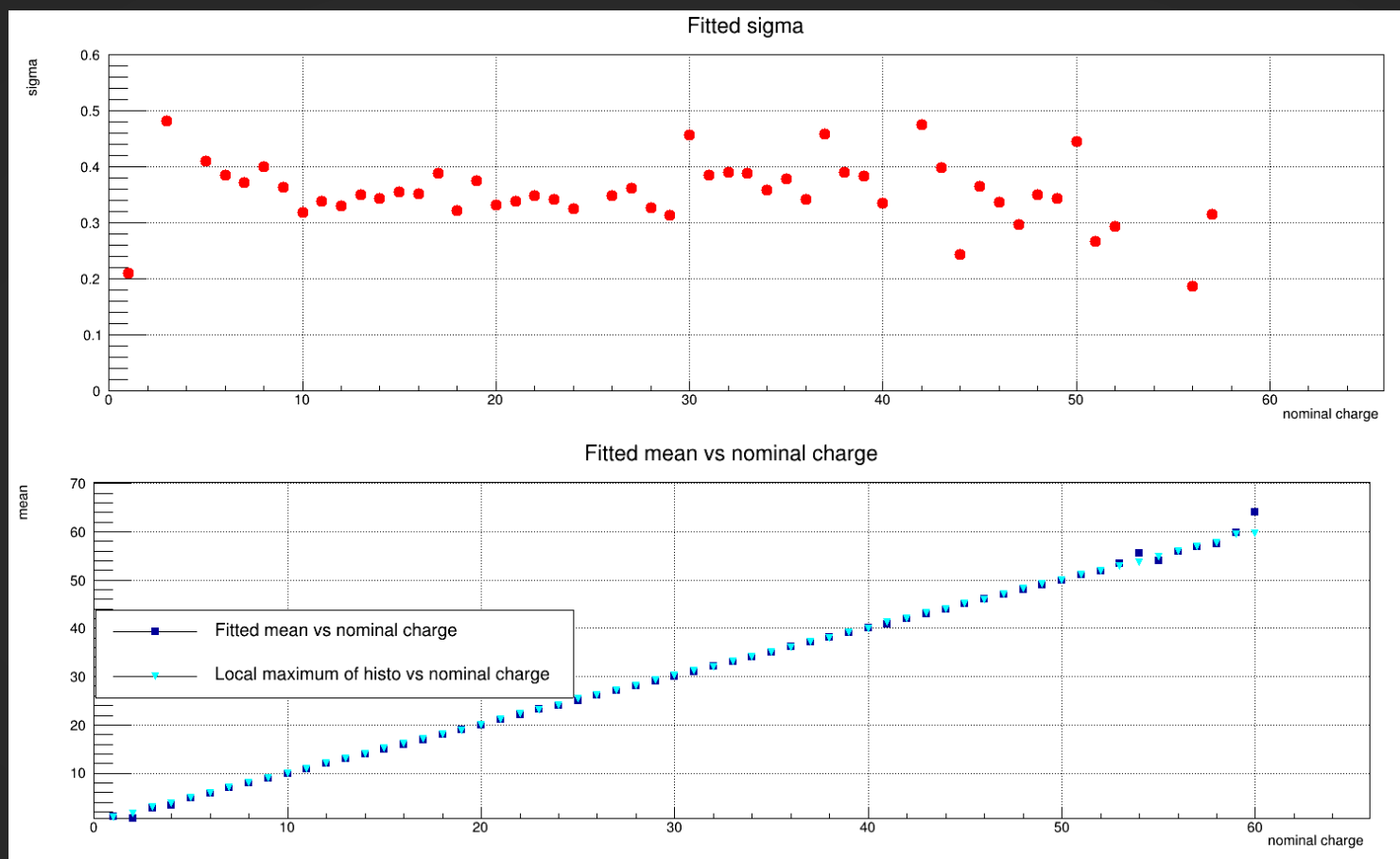
A picture of the prototype
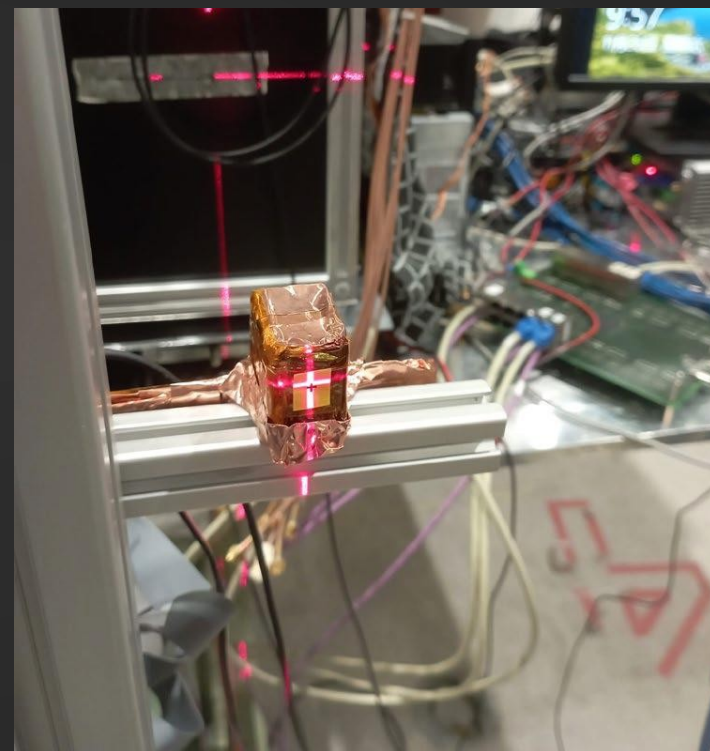
2022 beam test result: ion peaks
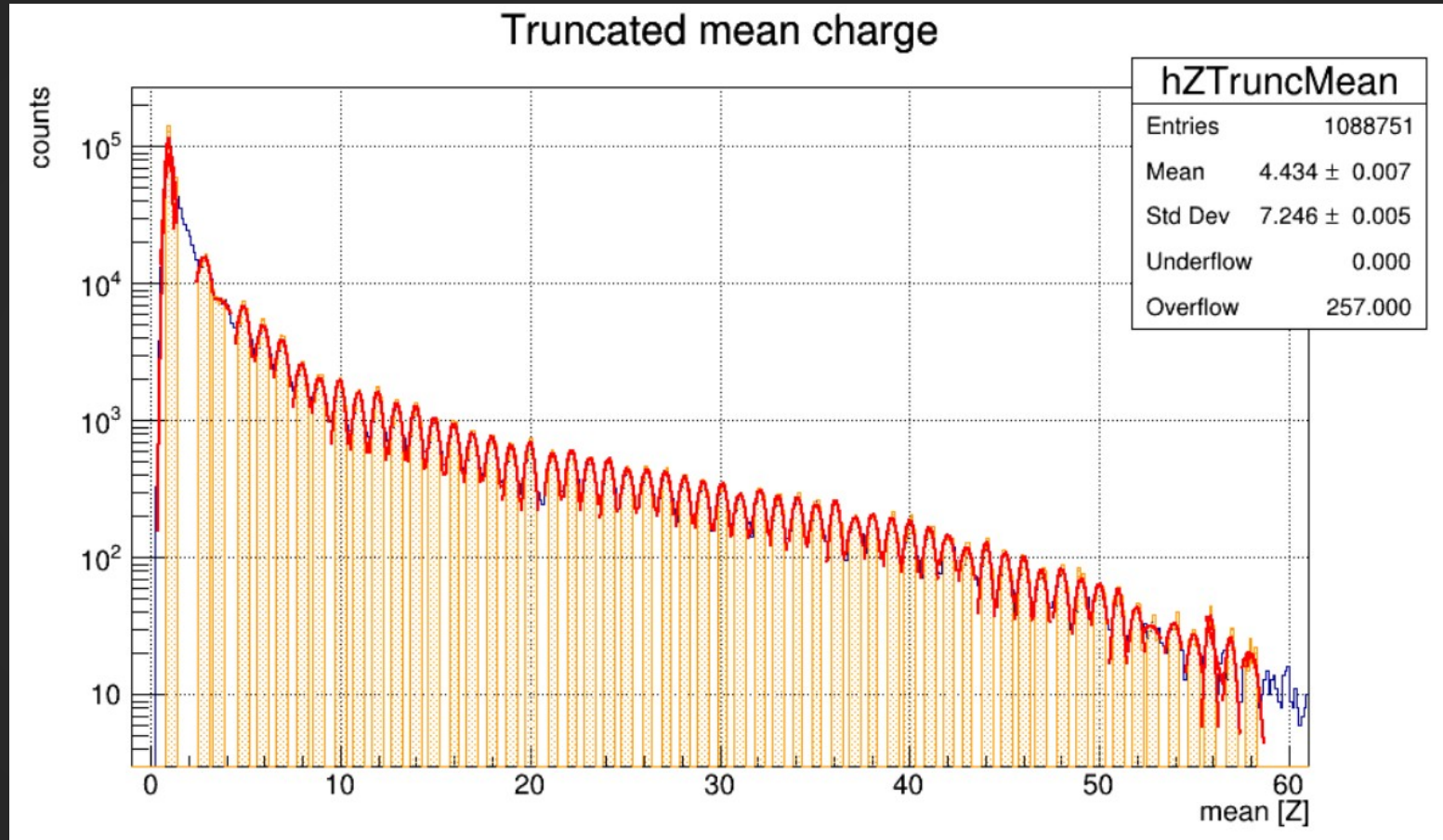
- First prototype: charge peaks (fitted with Gaussian distributions) up to Z ~ 60.

2022: resolution and linearity
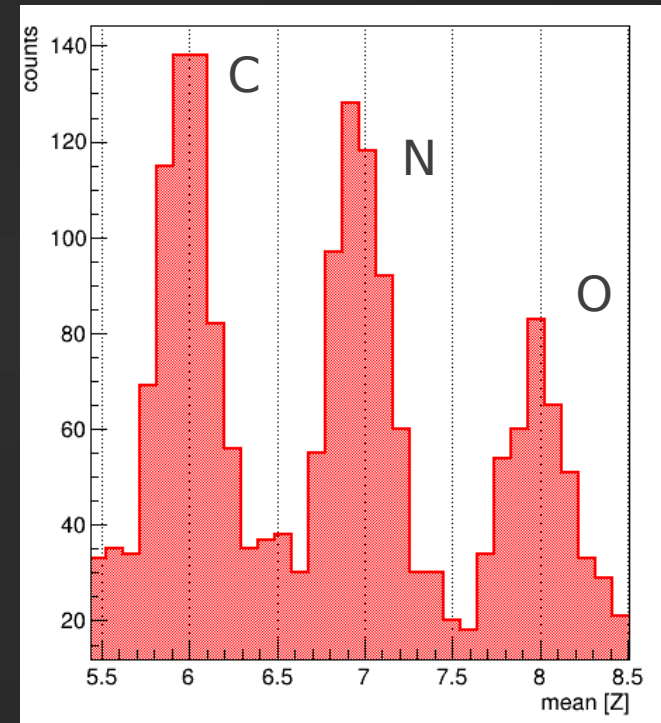

- The charge resolution is ~< 0.4 charge unit and almost flat in the entire range

- Linearity response is also achieved.

Second and third test.

- 2023 HERD: nuclei tag used to check the performance of large scale prototype with nuclei.

- 2023 AMS-02: <u>first test outside the HERD collaboration</u>. Data are employed for independent charge tag and charge reconstruction efficiency evaluation.

- Improved analysis strategy.
  - Evaluate the number of consistent PDs with the one considered.
  - Selection: maximum number of consistent diodes = 6,

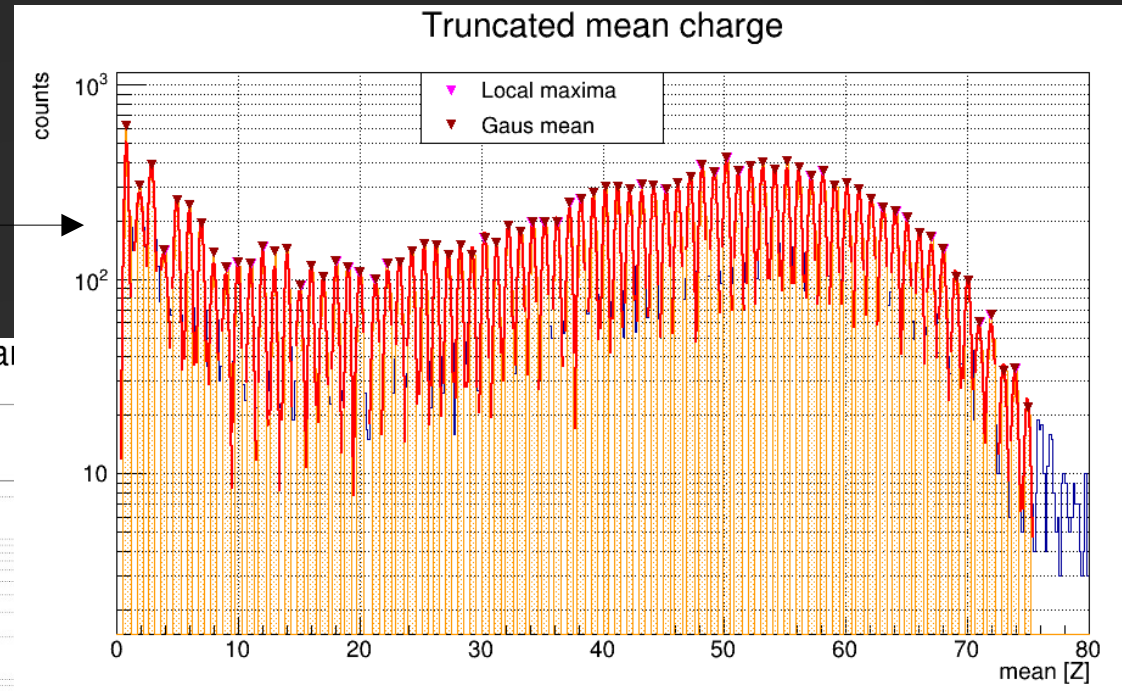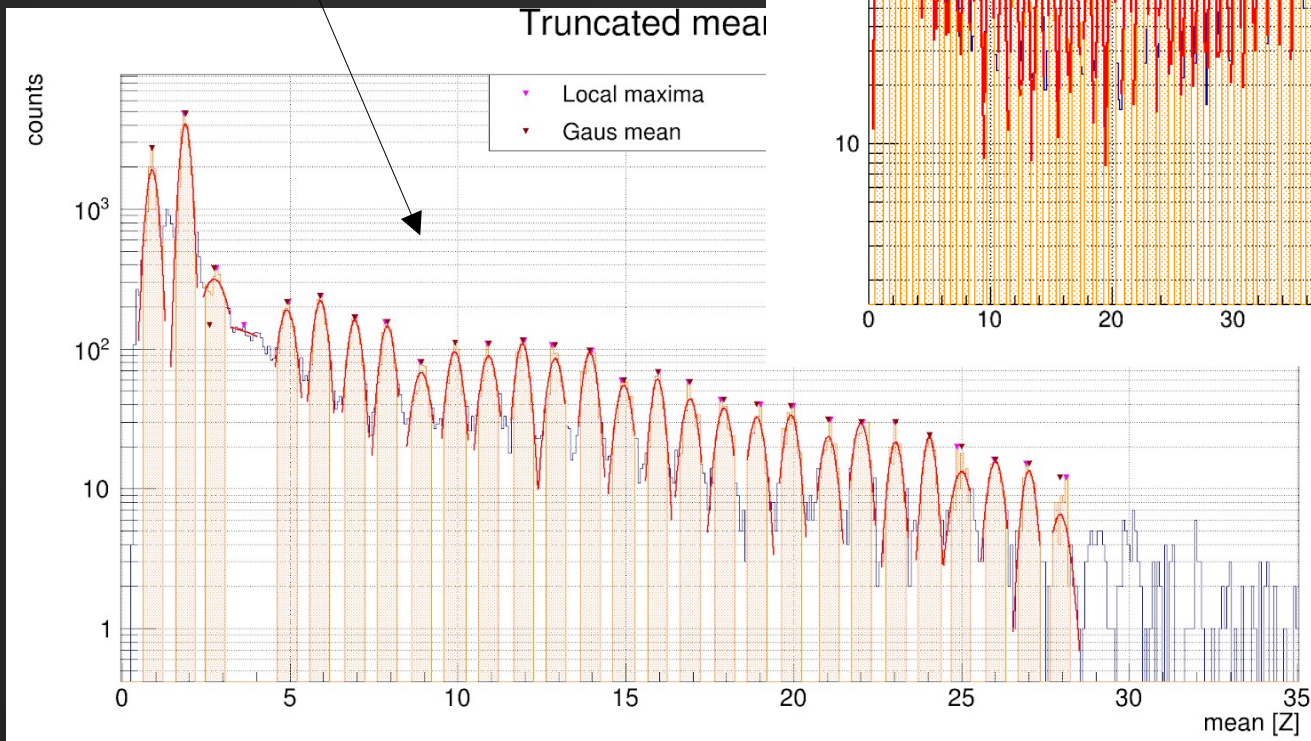- Improved PD bias: from 40 V to 100 V to maximize the depleted region.
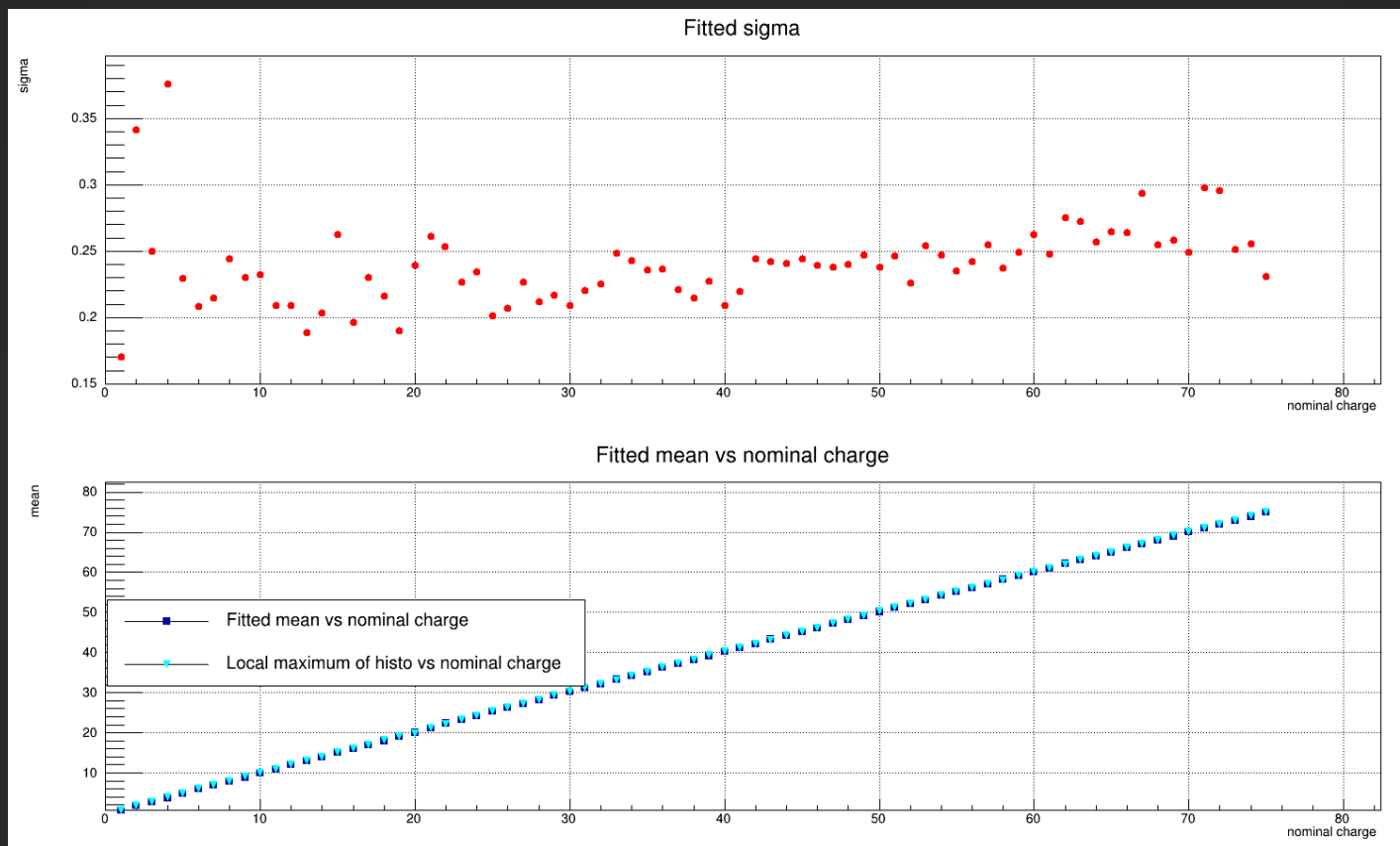
CNO nuclei peaks

2023 beam test results: ion peaks

- Two different SPS ion beaks:
  - A/Z ~ 2.2
  - A/Z ~ 2

2023: resolution and linearity

- The charge resolution is ~< 0.3 charge unit and just slightly increase with Z.

- The fitting procedure could be improved especially for Z < 5.

A new project: BeER.

- Thanks to:
  - good results of 2022 and 2023 beam tests,
  - good feedback received from several SPS ion beam users,
- 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
  - on-line monitor of high multiplicity beams (e.g. LNF-BTF).
  - application in experiments, (e.g. cosmic rays...)
- We are completely open to suggestions about BeER application and future design.

Next steps: short-term (2024).

- VTH2090 is discontinued:
  - new sensor is VTH2021.

- Enlarge the active area of the detector by adding more PDs.
  - 6 layers, 3x3 PDs

- Adjust the mechanics for the new design, add motorized sliders.

- Adjust the electronics to read-out more channels with HiDRA 2 chip.

- Test the new prototype at:
  - LNF-BTF (Frascati) (June)
  - SPS (CERN) (TBD)

VTH2021: 10x10 mm^2
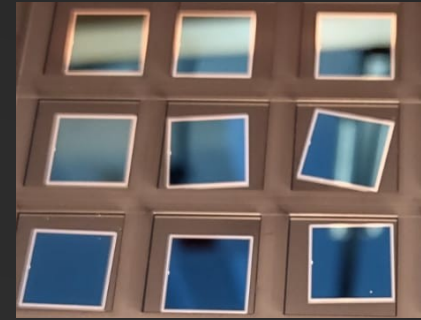
New prototype design
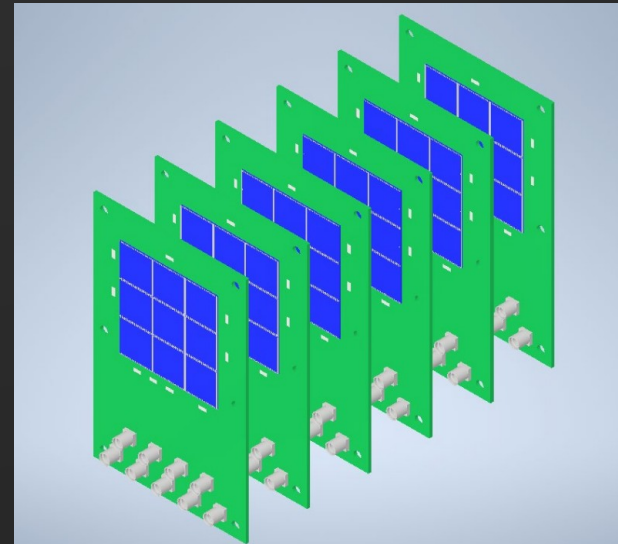
Conclusion

- Starting from the HERD requirements, a high-dynamic range charge detector was developed (BeER)

- The main features are:
  - good S/N for MIP (proton peak) >~4,
  - high saturation level (Z>100),
  - easy to use and simple analysis procedure (quick look),
  - the instrument is not expensive (e.g. ~15 € for each PD).

- First prototypes have been tested with SPS ion beam and very good performance has been confirmed:
  - we are going to submit a paper about BeER.

- We are collecting suggestions on possible uses of BeER:
  - long-therm plan will be defined according to the feedback of the scientific community.

Thank you for your attention