Istituto Nazionale di Fisica Nucleare
SEZIONE DI FIRENZE

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

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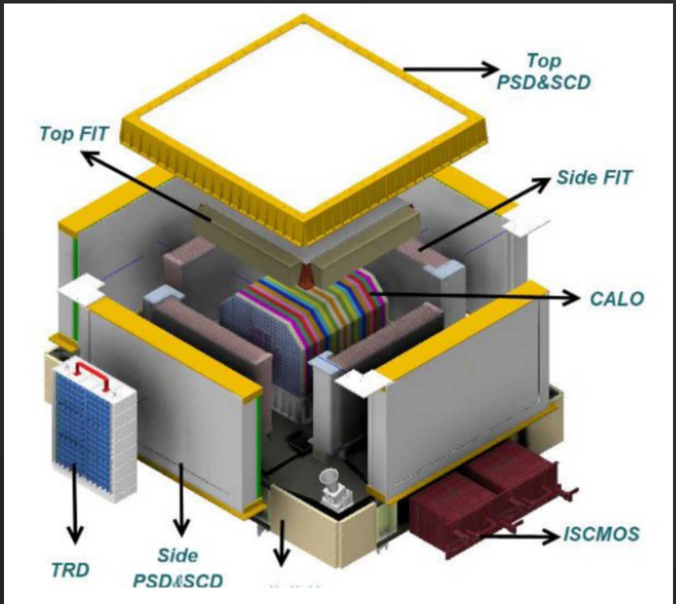
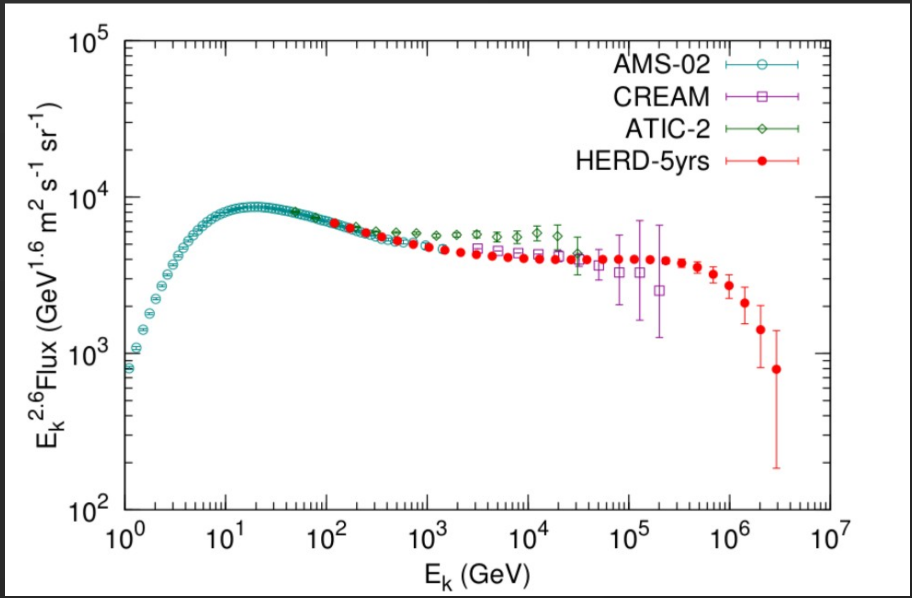
The research group background.

- 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



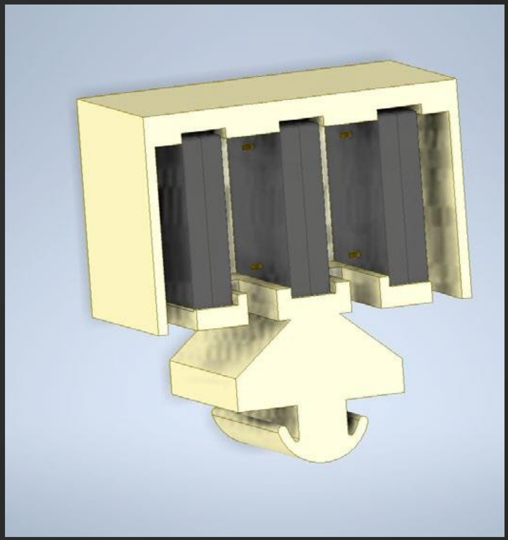
A ion beam monitor for HERD

- 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.

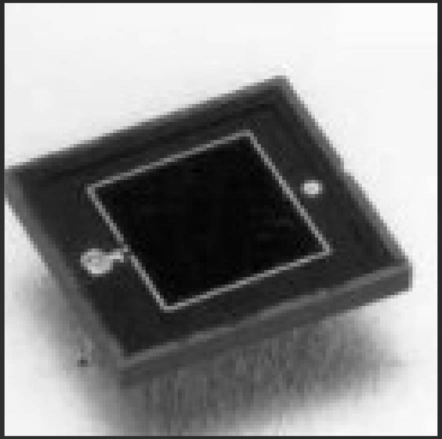
Design of the first prototype

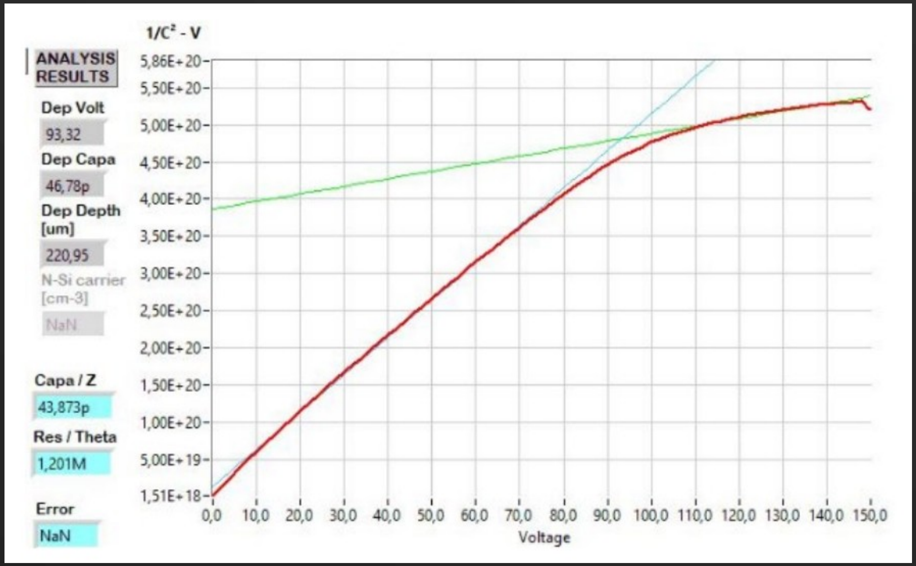


The sensor: VTH2090

- 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

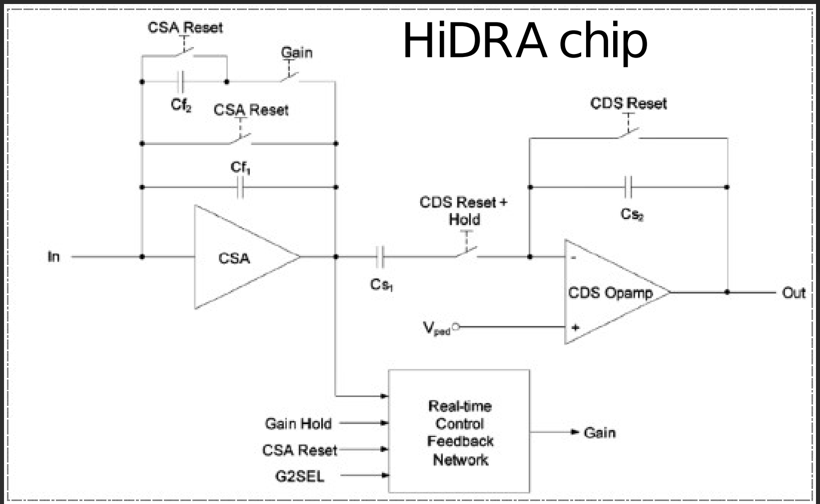


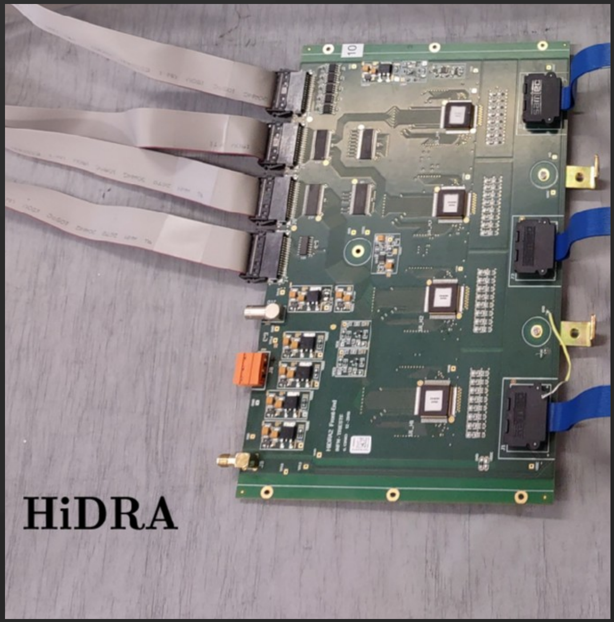


The obtained depletion depth is ~ 220 um

The electronics: HiDRA chip

- Custom chip HiDRA, designed by INFN-Trieste (Italy), v2.
- Double gain CSA with automatic-gain selection circuitry.
  - High dynamic range (~ $5*10^5$)
  - Low power consumption ~ 3.5 mW/chan.
  - Low noise: ENC ~2500e
  - 16 input channels.
  - Self-trigger system.
- See: *"O. Adriani et al 2022 JINST 17 P09002"*

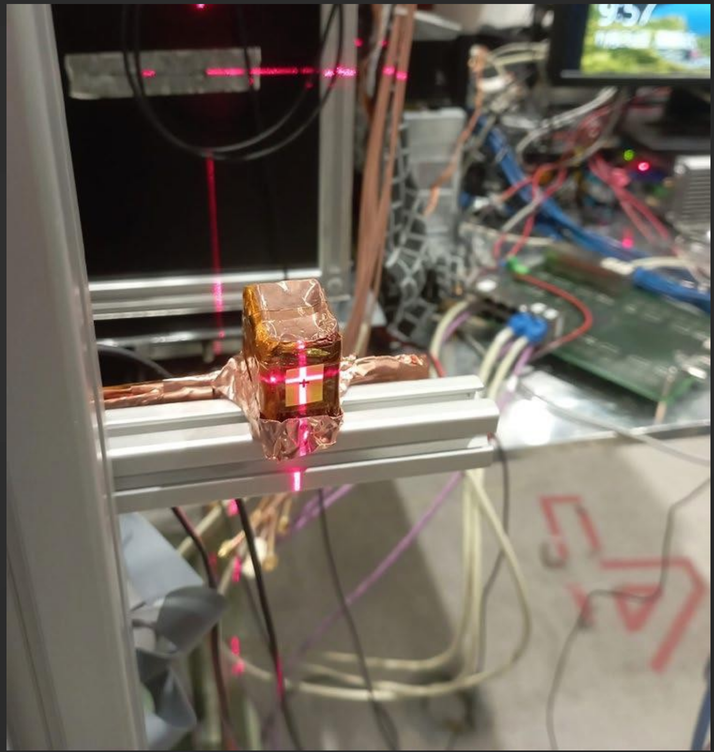




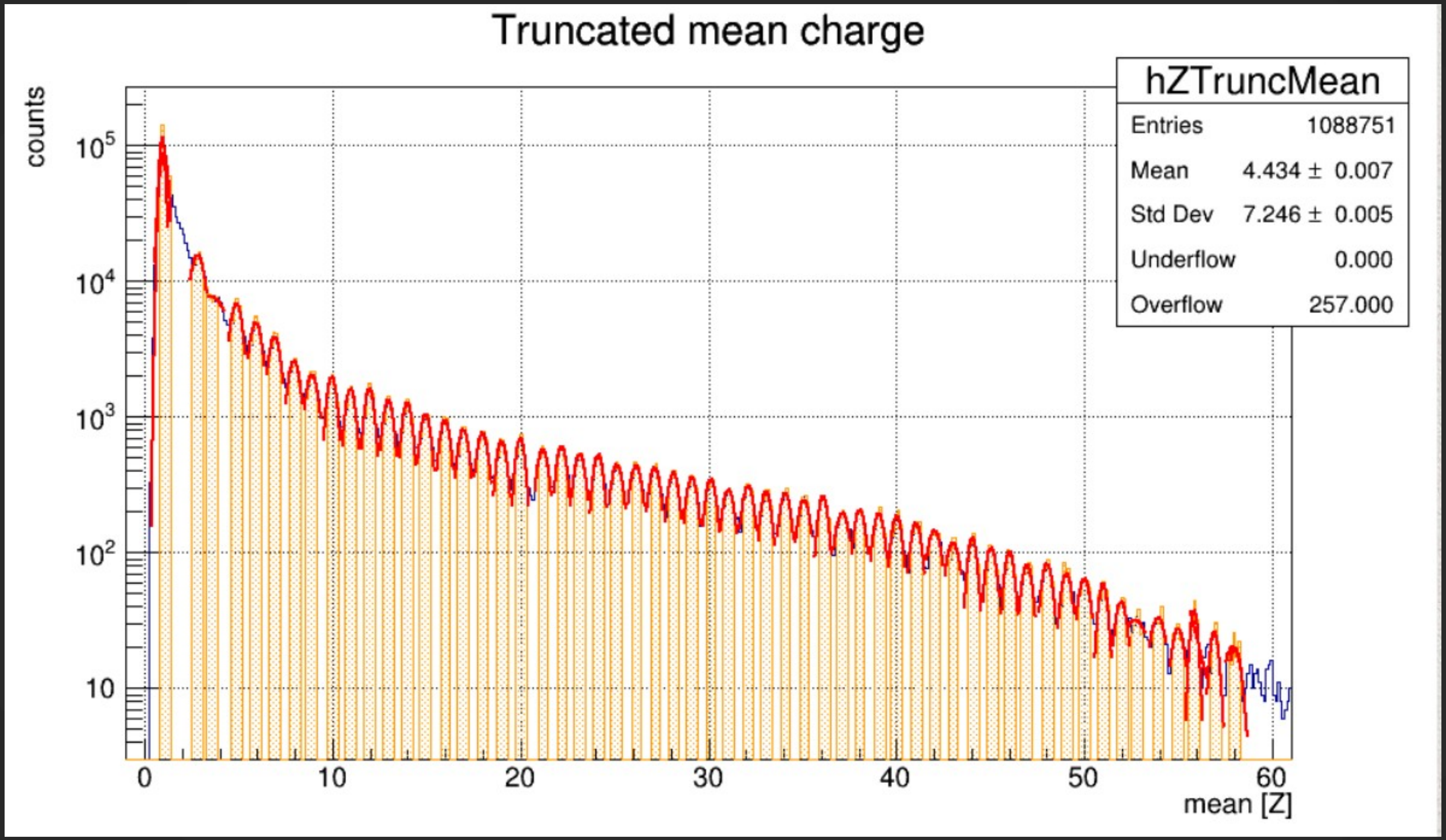
The first test: 2022 HERD.

- 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

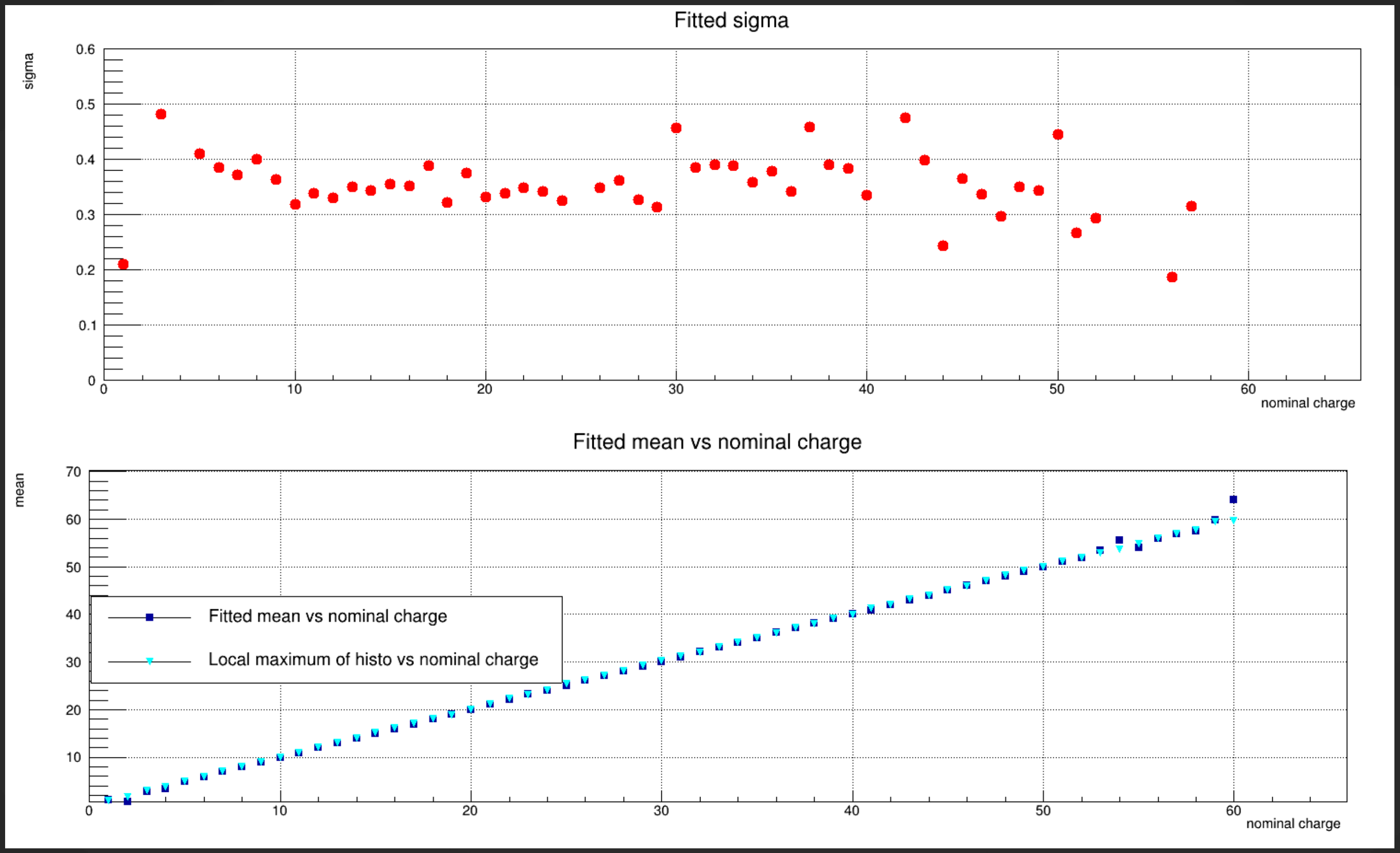


2022 beam test result: ion peaks



- First prototype: charge peaks (fitted with Gaussian distributions) up to Z ~ 60.

2022: resolution and linearity

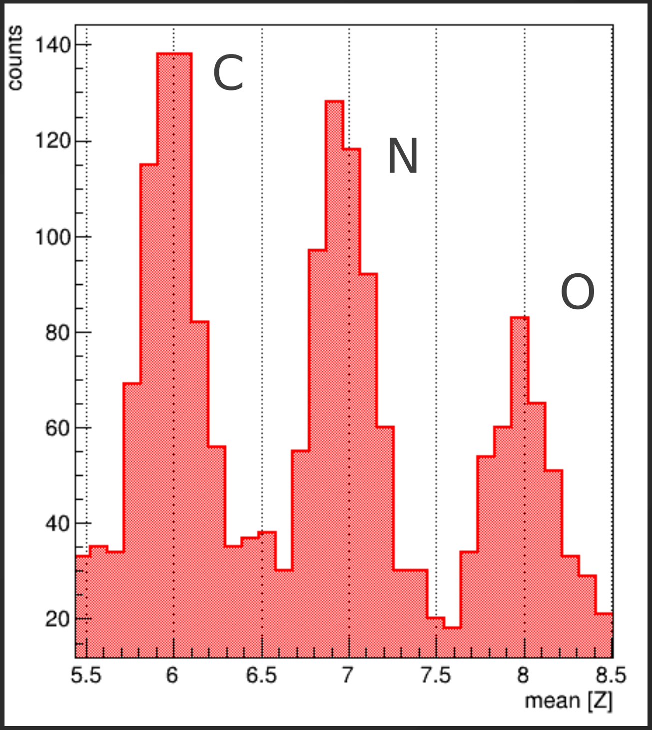


- The charge resolution is ~< 0.4 charge unit and almost flat in the entire range
- Linearity response is also achieved.

Second and third test.

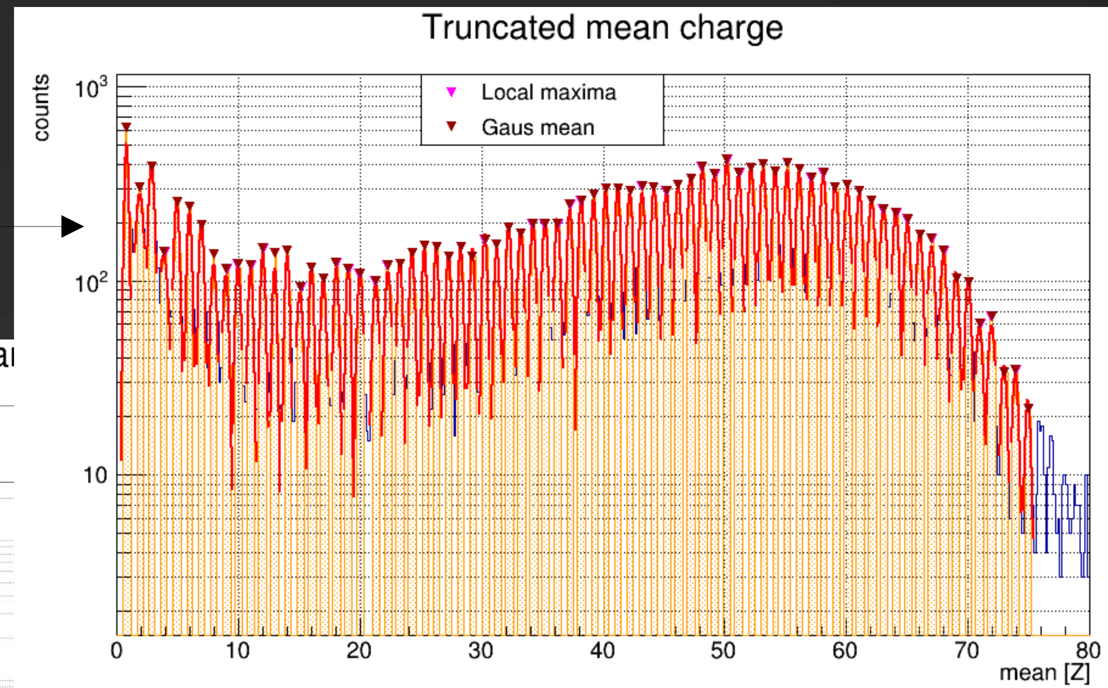
- 2023 HERD: nuclei tag used to check the performance of large scale prototype with nuclei.
- 2023 AMS-02: first test outside the HERD collaboration. Data are employed for independent charge tag and charge reconstruction efficiency evaluation.
- Improved analysis strategy.
  - Evaluate the number of 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.

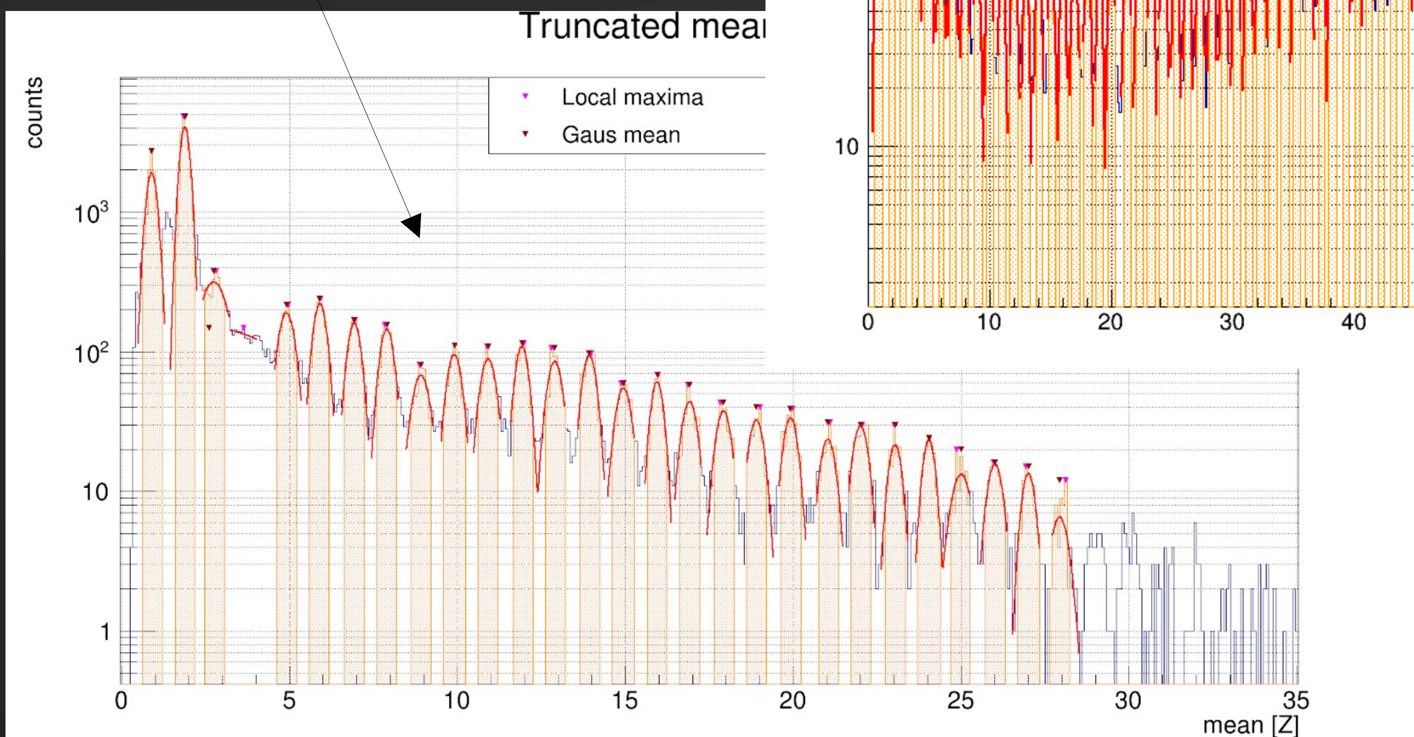
CNO nuclei peaks



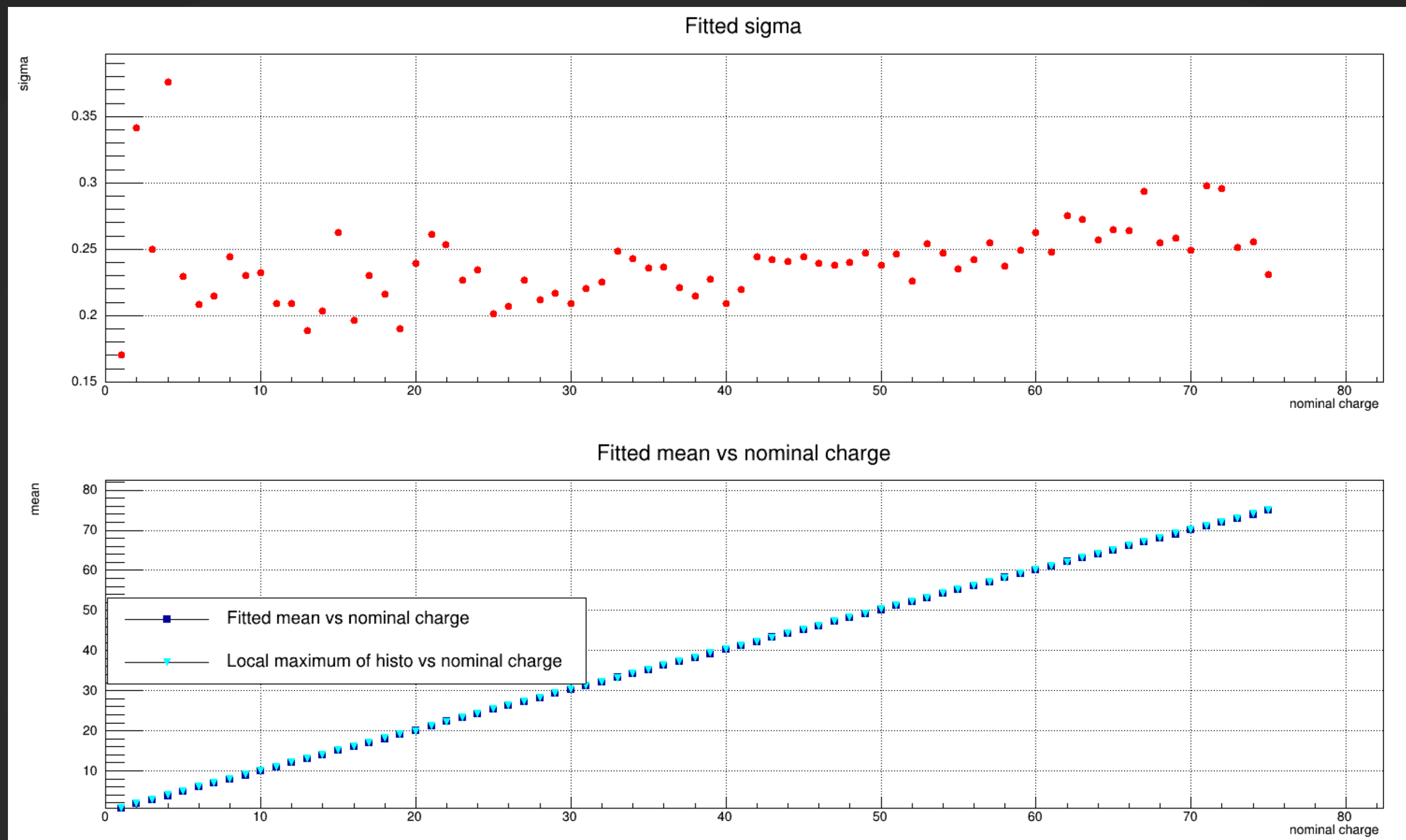
2023 beam test results: ion peaks

- Two different SPS ion beams:
  - 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).

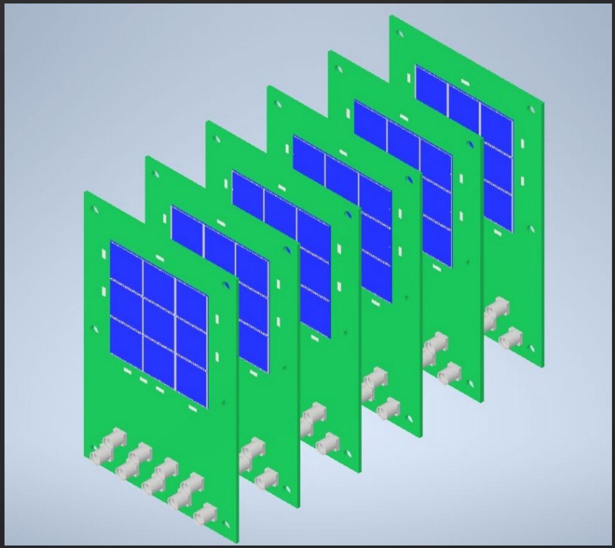
- We are investigating possible applications of BeER:
  - on-line monitor of high energy ion beams (e.g. SPS),
  - event-by-event charge tagging system
  - on-line monitor of high multiplicity beams (e.g. LNF-BTF).
  - application in experiments, (e.g. cosmic rays...)
- We are completely open to suggestions 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 (of BTTB presentation)

- 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.

Discussion: long-term possibility

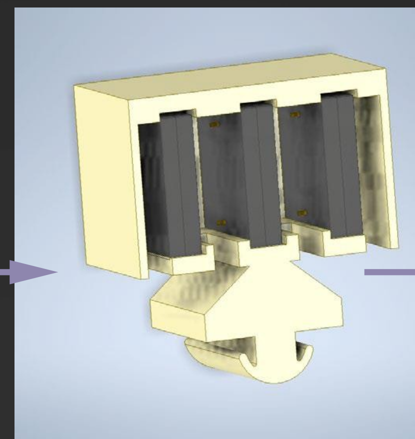
- Lon-term activity also depends on founding, here two possible development are presented.
- Electronics: HiDRA2 is great but it is slow (1 kHz), then ~10% of events must be rejected (see backup for details).
  - We are currently evaluating SKIROC2a (from Weeroc) but the dynamic range is not enough.
  - We could discuss with HiDRA designer but the development of a new chip requires money and man-power.
- Sensor: blind PD are a very cheap and ready-to use solution but it is not the best one. With a custom chip we could:
  - optimize passive/active material, reducing the fragmentation,
  - optimize the charge collection, improving S/N,
  - Usually custom sensor require a money (hundreds of k$) for NRE by private company (Excelitas).

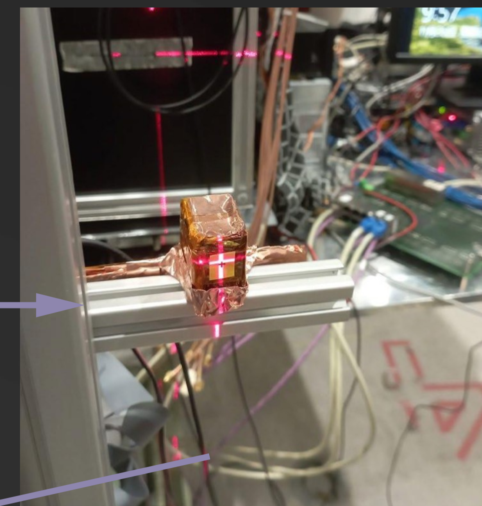
Discussion: project with CERN support

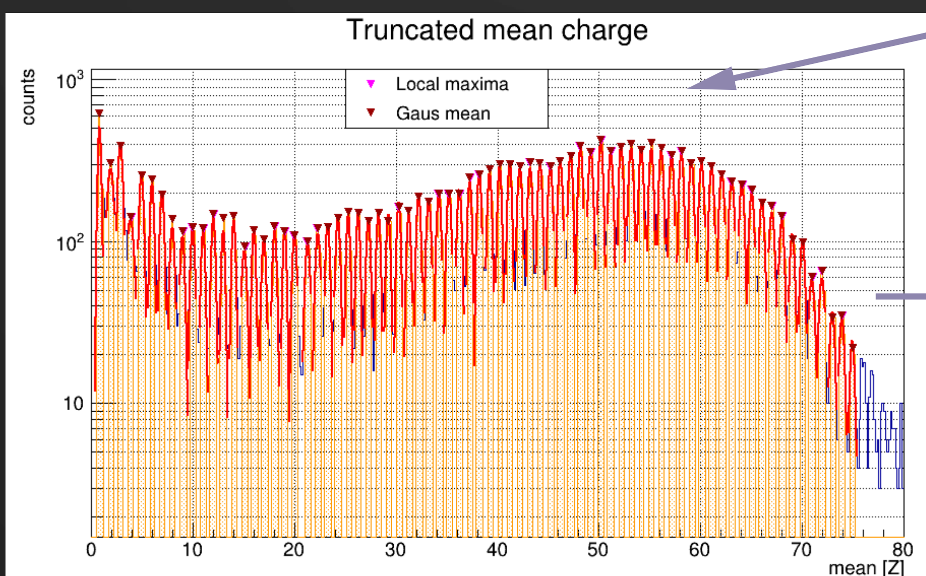
- Right now BeER is financed from INFN as a sub-activity of HERD.
- We are evaluating to open a dedicated project about this instrument.
  - Most likely we will do it during the 2025
- Having the support of CERN could help our group to establish a new well accepted project.
- We are planning a TB ad SPS with ion with ASM-02 and/or HERD, so we will obtain new results soon.

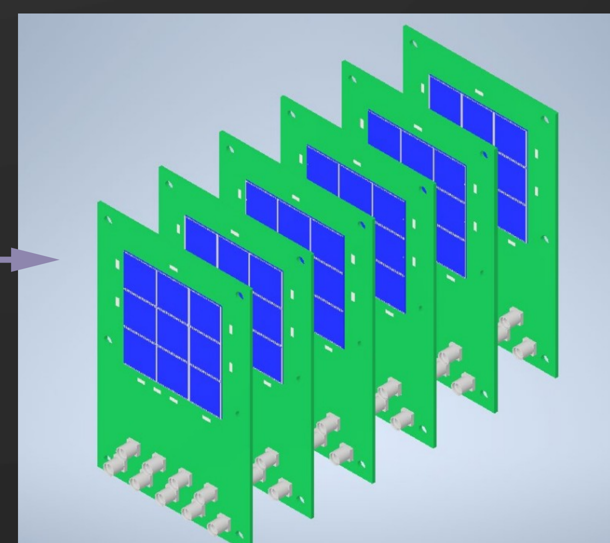
Thank very much you for taking the time to participate in this discussion

BeER in a nutshell









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