The Beam-monitor with Extreme Range (BeER) detector: an innovative detector for the characterization of different particle beams

E. Gensini [1,2]

[1]University of Florence, [2]INFN Sezione di Firenze

The Beam Monitor with Extreme Range (**BeER**) detector is an innovative detector developed and built at the INFN Sezione di Firenze. It employs a 3×3 matrix of **silicon photodiodes**, repeated across six layers, to **measure** the **energy loss** due to **ionization of charged particles** traversing the silicon sensors. The first prototypes [1] of the BeER detector were designed during the High Energy cosmic-Radiation Detection (**HERD**) detector development phase, to overcome the need for accurate and reliable **beam quality monitoring** during HERD subsystems testing with **heavy ion beams** at SPS.

The BeER detector

Six 3x3 matrices of unpackaged **PIN photodiodes** (PDs)

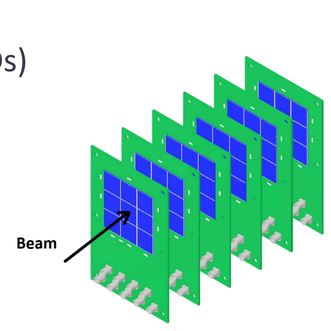
Photodiode - VTH2120 [2], by Excelitas

- 10×10 mm² active area
- 100 V applied reverse-bias
- Depletion region thickness ~ 250 µm

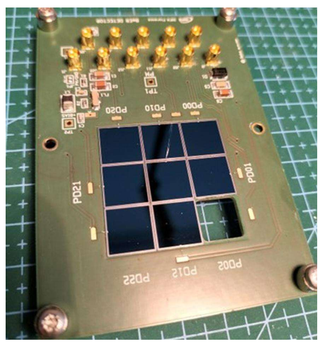
Electronics - **HiDRA v2** readout ASIC [2], 16 channels

- Dynamic range: few fC ÷ 52 pC (dual-gain CSA)
- Low noise: ENC ~ 2500e
- Low power consumption: ~ 3.75 mW/channel
- Self-trigger capability

Custom-designed printed circuit board (PCB) [2] for electrical and mechanical PD support



Design of the BeER detector.



Assembling of a 3x3 matrix of unpackaged PDs on the printed circuit board.

Requirements:

→ **prompt** online **analysis** for quick results

→ **high dynamic range**: charge measurement Z = 1 ÷ 80

→ **good signal-to-noise ratio**

→ **low material budget** to minimize incident nuclei fragmentation

→ **scalability** and **flexibility** for different beamline geometries

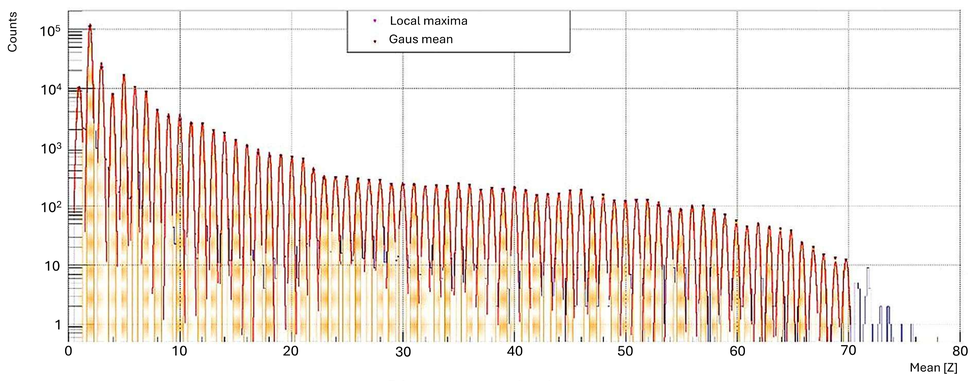
BeER tests:

- **high-energy ion beam** monitor at **SPS (2024)** in support of HERD and AMS-02 test beam campaigns
- **low-energy** and **high-multiplicity e⁻ beam** monitor at **BTF (2024)**

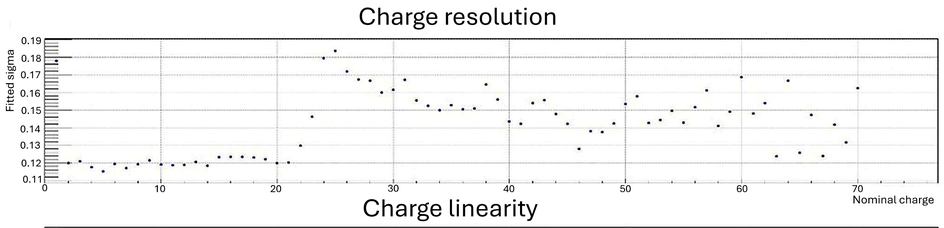
Charge measurement of high-energy ion beams at SPS

Pb beam, Z = 82, 150 GeV/nucleon → Be target → ion beam with selected A/Z = 2.2, Z = 1 ÷ 82 → BeER

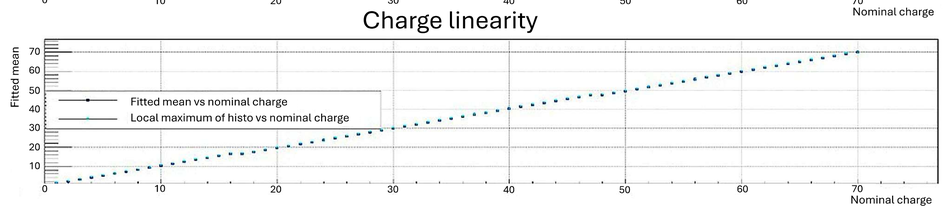
Truncated mean charge distribution



Charge resolution



Charge linearity



- **Charge resolution** less than **0.18 charge units** up to Z = 70
- **Linearity** of BeER response verified across the full charge range

Analysis strategy [2]

Steps applied to each horizontal line (6 PDs in a row)

- ♦ each PD signal > threshold
- ♦ ADC → MIP → Z conversion
- ♦ all six PD signals differing by less than 1.5 charge units

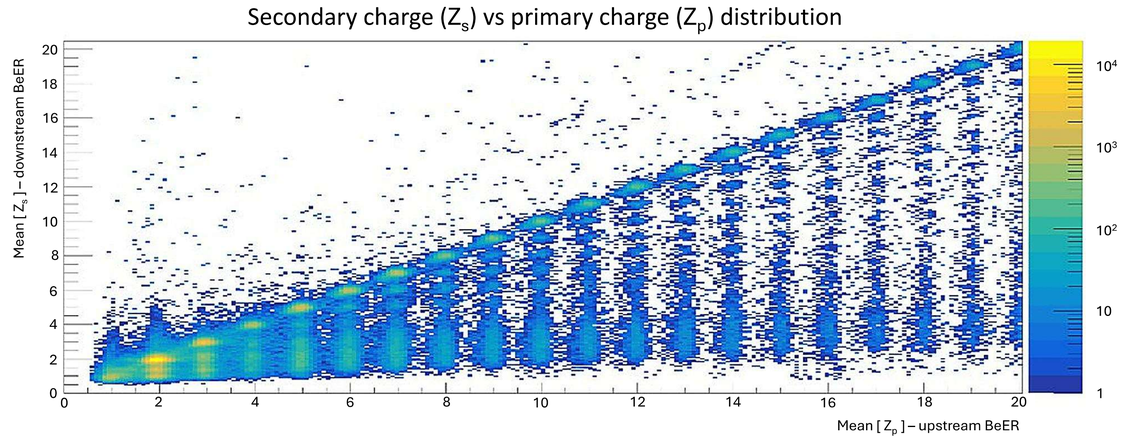
Select the line with the highest reconstructed charge

Measurement of fragmentation products from primary ion beams

Two BeER detectors employed

Pb beam → Be target → Primary ion beam $A_p / Z_p = 2.2$, $Z_p = 1 \div 82$ → BeER upstream → Passive material → Secondary ion beam $Z_s \leq Z_p$ → BeER downstream

Secondary charge (Z_s) vs primary charge (Z_p) distribution



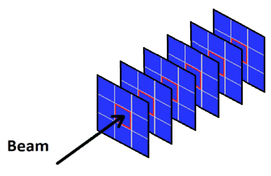
Measurement of multiplicity of low-energy electron beams at BTF

e⁻ beam, ~ 300 MeV, with multiplicities ranging single e⁻ ÷ tens of thousands e⁻ → BeER + BTF calorimeter information (reference for multiplicity measurement)

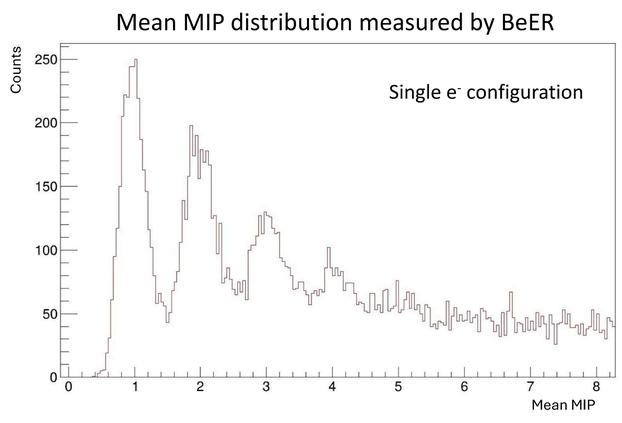
Analysis strategy [3]

Steps applied to central horizontal line, where beam is centered

- ♦ at least 4 PD signals > threshold
- ♦ all 6 PD signals must be consistent
- ♦ ADC → MIP conversion

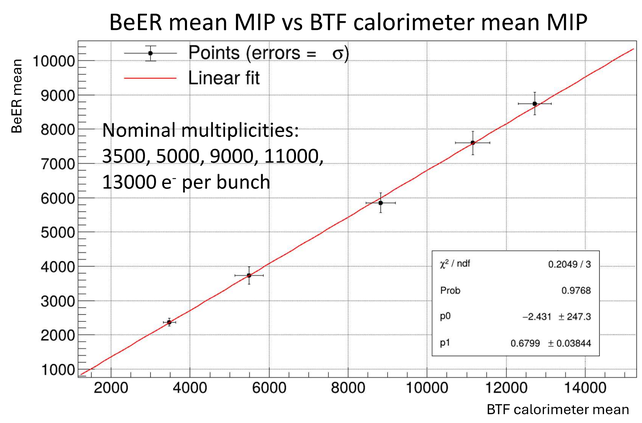


Mean MIP distribution measured by BeER



- BeER response in single e⁻ configuration
- Configuration used for ADC → MIP calibration

BeER mean MIP vs BTF calorimeter mean MIP



- BeER response vs BTF calorimeter response
- **Verified linearity** of BeER response as a function of the beam multiplicity

Conclusions

→ Excellent performance of the BeER detector as a **beam monitor** for **high-energy ion beams** and **high-multiplicity e⁻ beams**

→ BeER and its prototypes [1] performed successful tests in support of **HERD** (2022, 2024) and **AMS-02** (2023, 2024) test beams

→ Versatility and reliability of the BeER detector for future applications, from **accelerator beam monitoring** to **cosmic-ray experiments** and **measurements** of total and partial **nuclear cross sections**, relevant to high-energy astrophysics

References

[1] O. Adriani et al 2025 JINST 20 P01019

[2] O. Adriani et al 2025 JINST 20 C07046

[3] A. Baronio, Bachelor's Thesis, 2025

Info

elena.gensini@unifi.it

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