Istituto Nazionale di Fisica Nucleare
SEZIONE DI FIRENZE

BeER (Beam-monitor with Extreme Range): a high dynamic range charge tagger for ion beams.

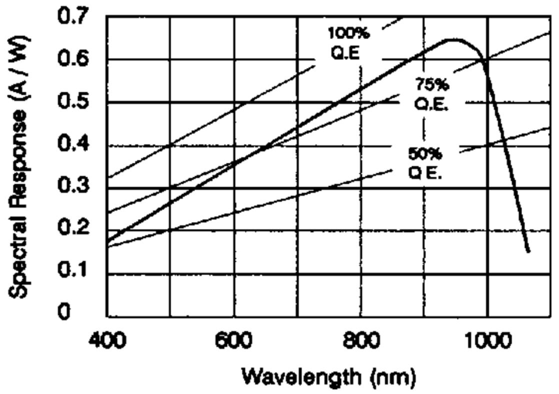
Lorenzo Pacini, INFN-Firenze, 2024/01/29.

Conception of the first prototype.

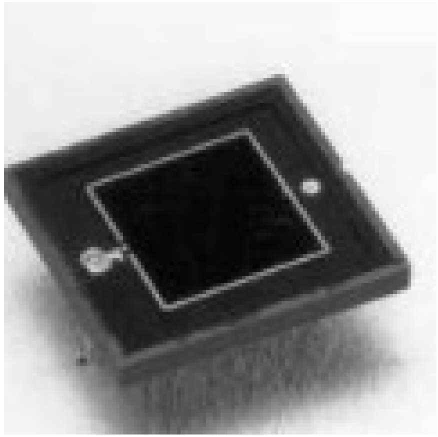
- The first prototype was designed to monitor the ion beam at SPS for a beam test of the HERD experiment:
  - a quick check of the beam composition was needed,
  - a event-by-event independent charge measurement was also convenient,
- So, the detector has been designed with the following features:
  - 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).
- First prototype tested in 2022, slightly different versions tested in 2023.

Design of the first prototype: sensors.

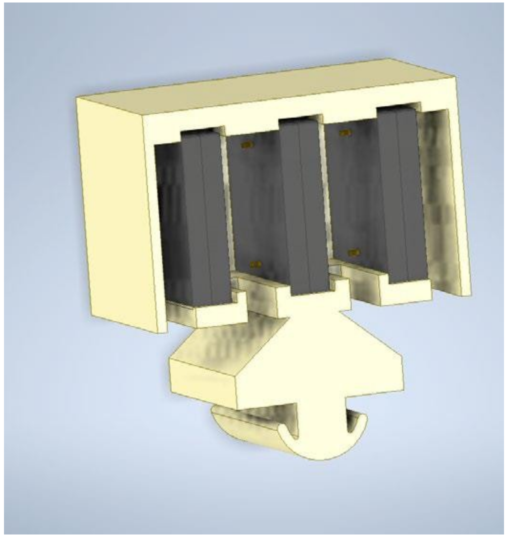
- 6 blind PDs: VTH2090, active area 9.2x9.2 mm2. This sensor were employed for the CaloCube project ("O. Adriani et al 2019 JINST 14 P11004").
- Simple "home-made" plastic mechanical structure.



VTH2090



3D model

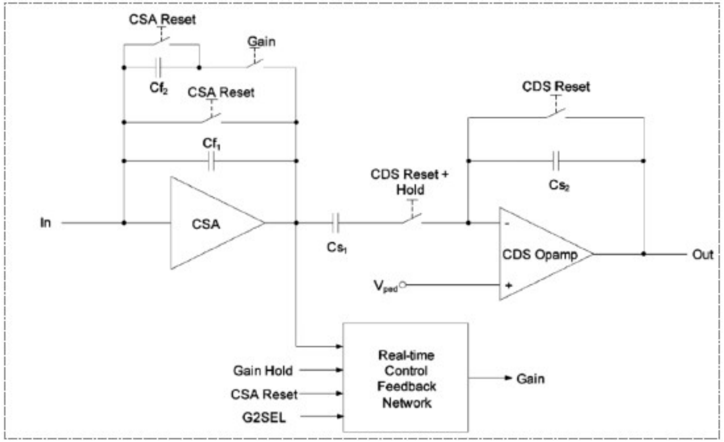


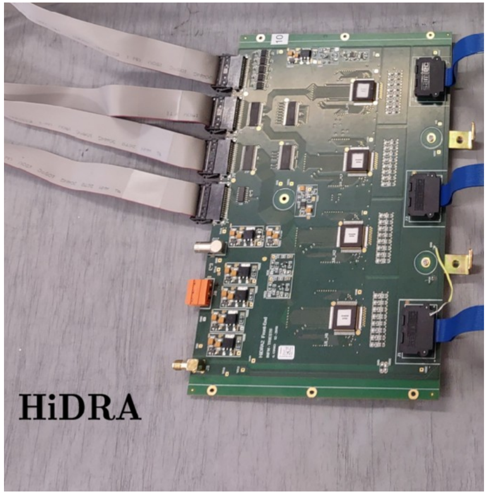
ELECTRO-OPTICAL CHARACTERISTICS @ 25° C

PART NUMBER	PEAK SPECTRAL RESPONSE λ_P, TYP. (nm)	RADIANT SENSITIVITY S_R TYP (A / W)				SHORT CIRCUIT CURRENT I_{SH} 100 LUX (μA)		DARK CURRENT I_D		JUNCTION CAPACITANCE C_J, TYP. V_R = 30 V (pF)	RISE TIME t_r TYP (ns)	NEP V_R = 30 V TYP. (W / $\sqrt{Hz}$)	D* V_R = 30 V TYP ($\frac{cm \sqrt{Hz}}{W}$)
		480 nm	540 nm	633 nm	940 nm	MIN.	TYP.	V_R = 30 V (nA) MAX.	TEMP. COEFF. TC, TYP. (% / °C)				
VTH2090	960	.25	.30	.40	.60	65	80	10	15	70	15	4×10^{-14}	2.6×10^{13}
VTH2091	960	.25	.30	.40	.60	65	80	5	15	70	15	4×10^{-14}	2.6×10^{13}

Design of the first prototype: electronics.

- Diodes are read-out with custom chip HiDRA, designed by INFN-Trieste (Italy), version 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.
- FFE board includes 4 HiDRA2 chip
- See: *“O. Adriani et al 2022 JINST 17 P09002”*





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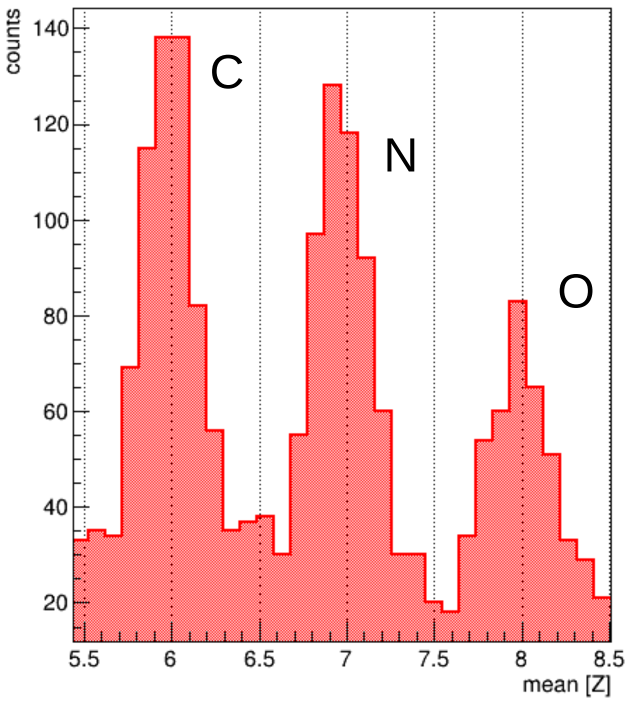
Data analysis strategy

- For each blind diodes:
  - Convert ADC -> MIP
  - Convert MIP -> Z
  - Evaluate if ADC signal > noiseThreshold.
  - Evaluate the number of consistent PD with the one considered,
    - applied only during 2023 test beam.
- Selection for plot:
  - Number of diodes above noise Threshold > 3
  - Maximum number of consistent diodes = 6,
    - applied only during 2023 test beam.

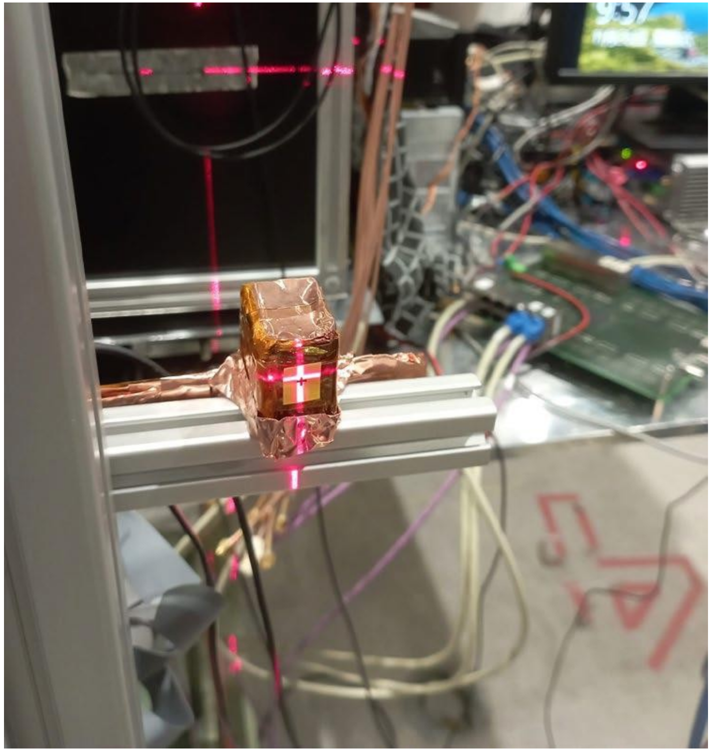
The peaks of C, N, O observed in 2023



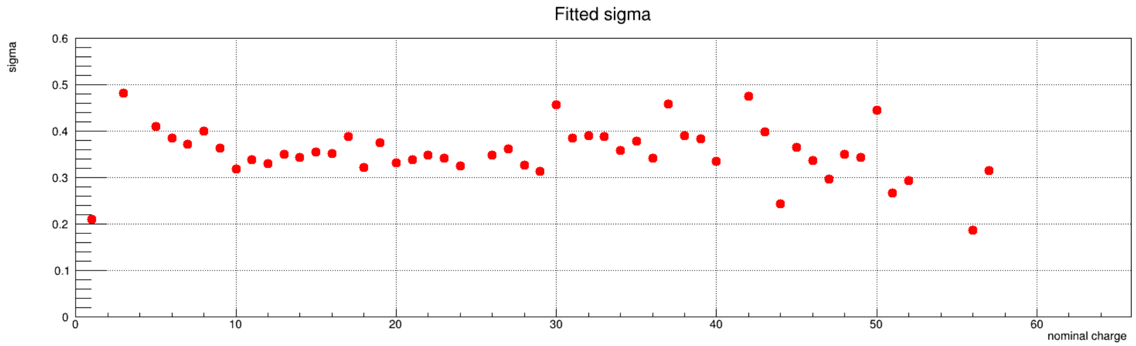
Test history and data usage.

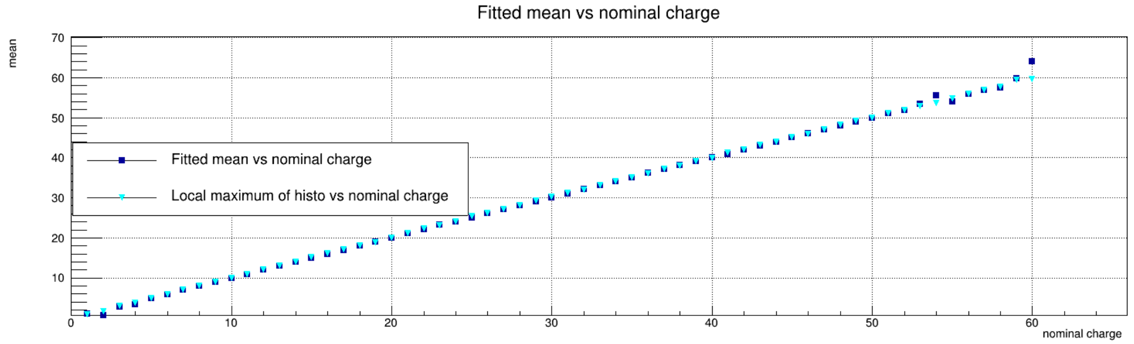
- BeER has been employed in different tests at SPS with ion beam:
  - 2022 HERD: nuclei tag used to check the non-linearity of the LYSO scintillator (HERD CALO active material).
  - 2023 HERD: nuclei tag used to check the performance of large scale prototype with nuclei.
  - 2023 AMS-02: first test outside the HERD collaboration. Data are employed for independent charge tag and charge reconstruction efficiency evaluation.
- On-line results has been always very useful as ion beam monitor.

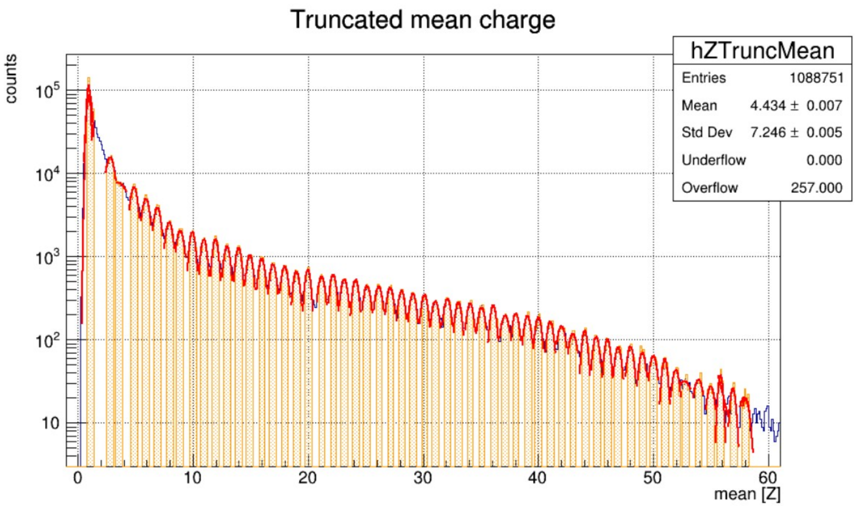
Photograph of 2022 prototype



Performance of 2022 BeER.







The first version of the prototype have a charge resolution better than 0.5 up to Z = 60.

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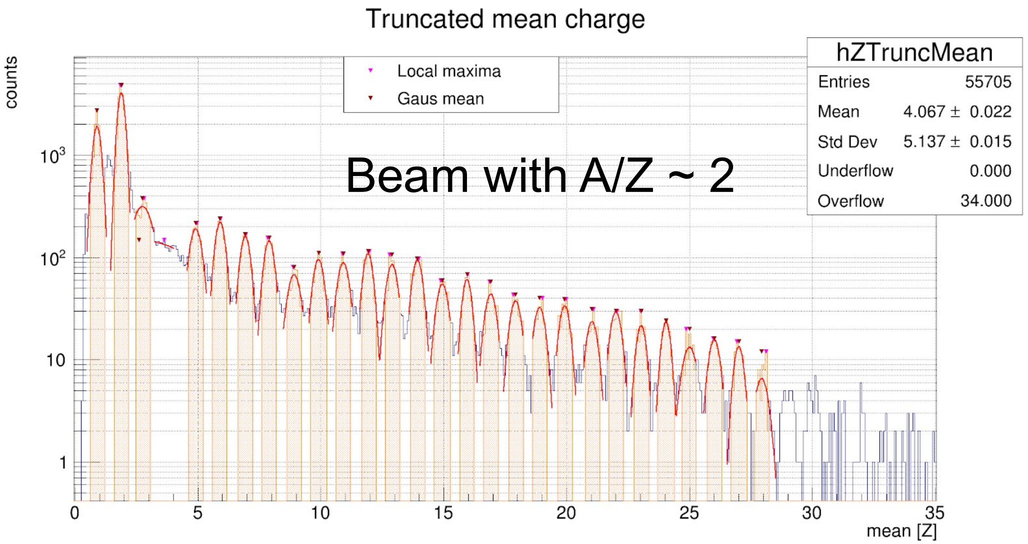
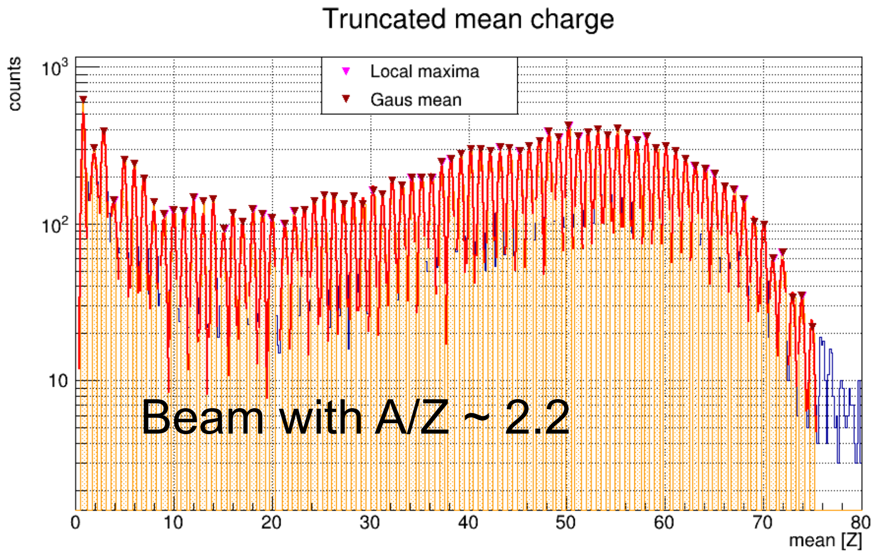
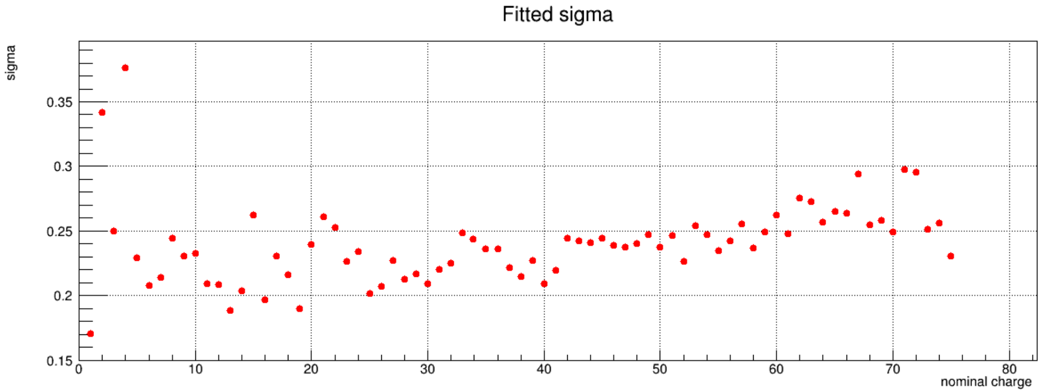
Performance of 2023 BeER.







Charge resolution than 0.3 charge unit from Z =4 to Z = 75. This major improvement is due to the refined event selection.

Next steps.

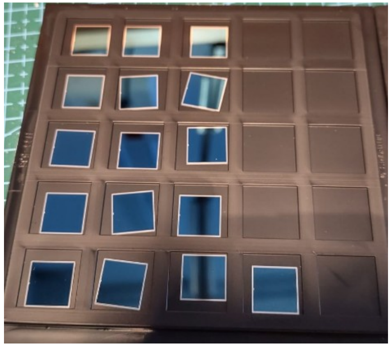
- Hardware study for 2024, already financed by INFN:
  - Enlarge the active area of the detector by adding more PDs.
  - Adjust the mechanics for the new design, add motorized sliders.
  - Adjust the electronics to read-out more channels (by using HiDRA 2 chip).
  - Test the new prototype at SPS (CERN) and/or BTF (Frascati)
- Future activities (which have not been financed yet):
  - Study different read-out electronics which is optimized for application to accelerators (e.g. faster response with respect to current version).
  - Study a custom Silicon sensor for this application (blind PD is a cheap solution but it is not the best one)
- Expanding the applications of the detector: high energy ions beam, high multiplicity low energy beams, ….

Backup: new sensors and electronics

New PD: VTH 2120

Low capacitance silicon photodiode chip designed for alpha particle detection. Assembly compatible with conductive epoxy mount.

Need a bonding procedure.



		Chip ID:	5 mm	10 mm	
Parameter	**Symbol**	**Conditions**			**Unit**
Breakdown voltage	V_{BR}	100 uA	> 100	> 100	V
Junction capacitance	C_J	20 V	< 30	< 120	pF
Dark current	I_D	20V	< 2	< 5	nA
		40 V	< 5	< 10	nA
Depletion layer thickness	t	20 V	> 0.09	> 0.09	mm
Dead layer	t_d	Si equivalent	< 150	< 150	nm

Nominal values at room temperature (22°C)

Electronics HiDRA vs SKRIC2a

- HiDRA 2:
  - S/N per MIP ~ 4 (measured).
  - Saturation level > Z ~ 100 !!! (measured up to Z = 80)
  - Self-trigger: threshold ~ 1 MIP (measured)
  - Low acq. rate: ~ 1kHz now, maximum rate is not easy.
  - CSA with reset → 10 % of events ar not properly acquired.
- SKIROC2a
  - S/N MIP ~ 8 (TBC)
  - Saturation level ~ 25 (TBC)
  - Self-trigger: threshold << MIP (measured)
  - High acq rate (TBD, now it is very slow due to the LabView software!!)

SKIRC2a: BTF 2022 results

- HG noise $\sim$ 1.5 ADC (12 bit), LG noise $<$ 1 ADC TBC with 16bit ADC
- **Noise SKIROC / HiDRA $\sim$ 1.35**
- **High gain SKIROC / HIDRA $\sim$ 4.2**
- **Low gain SKIROC / HIDRA LG $\sim$ 9**
- Saturation level, pedestal subtracted $\sim$ 1300 12bitADC (TBC with laboratory test)
  - HiDRA saturation, pedestal subtracted: $\sim$ 35k 16bitADC $\rightarrow$ 2200 12bitADC
  - SKIROC/HIDRA saturation (it is not corrected for different gain) $\sim$ 0.6
- **Saturation SKIROC/HIDRA, gain corrected $\sim$ 0.065**
- Dynamic range:
  - **SKIROC: 1300*9.2/1.5 $\sim$ 8k (data-sheet features 25k, is it affected by 12bit ADC?)**
  - **HiDRA: 35k*20/18 $\sim$ 40k (data-sheet features: 125k (50pC/1fC))**
  - **SKIROC / HiDRA = 0.2**