PD24

The **Plastic Scintillator Detector** for the future High Energy cosmic-Radiation Detection facility on board the Chinese Space Station

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Outline

- The role of the HERD PSD
- The layout
- Prototype and test
- Conclusion

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Xi'an Institute of Optical and Precision Mechanics, CAS (XIOPM)
Guangxi University (GXU)
Shandong University (SDU)
Southwest Jiaotong University (SWJTU)
Purple Mountain Observatory, CAS (PMO)
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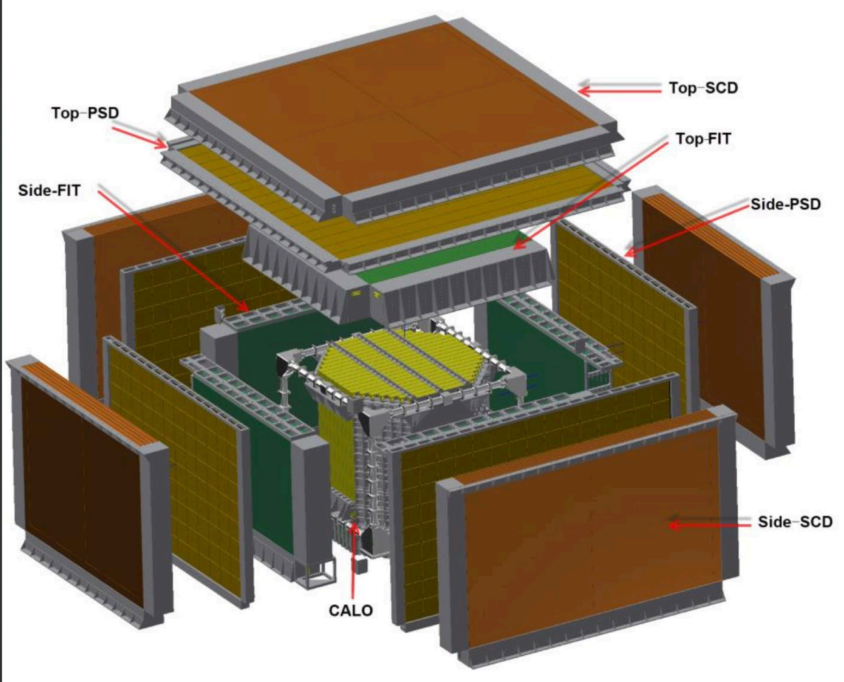
The **High Energy cosmic-Radiation Detection** (HERD) facility is an international space mission based on a **3D, homogeneous, isotropic and finely-segmented calorimeter** that will measure the cosmic ray flux up to the knee region, search for indirect signal of dark matter and monitor the full gamma-ray sky



SCD	Charge Reconstruction
PSD	Charge Reconstruction γ Identification
FIT	Trajectory Reconstruction Charge Identification
CALO	Energy Reconstruction e/p Discrimination
TRD	Calibration of CALO response for TeV protons

Main requirements

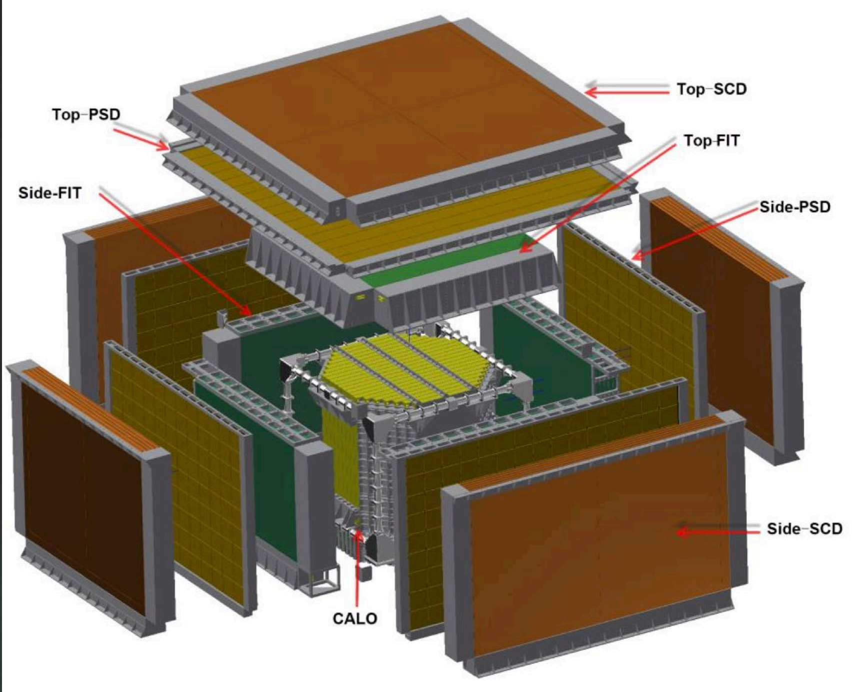
	γ	e	p, nuclei
Energy Range	>100MeV	10 GeV 100 TeV	30 GeV 3 PeV
Energy resolution	1% @ 200 GeV	1% @ 200 GeV	20% @ 100 GeV -1 PeV
Effective Geometric Factor	>0.2 m^2sr @ 200 GeV	>3 m^2sr @ 200 GeV	>2 m^2sr @ 100 TeV

The PSD will have **different tasks** to accomplish in HERD

- It will be used in the trigger logic as VETO detector for charged particles when γ **selection** is needed
- It will be used as charge measurement detector for **nuclei identification** (energy loss $\propto Z^2$)
- It will provide timing information (1ns resolution) that will help in **track reconstruction** and **backscattered particle rejection**

In order to fulfill all these task there are strong **requirements**:

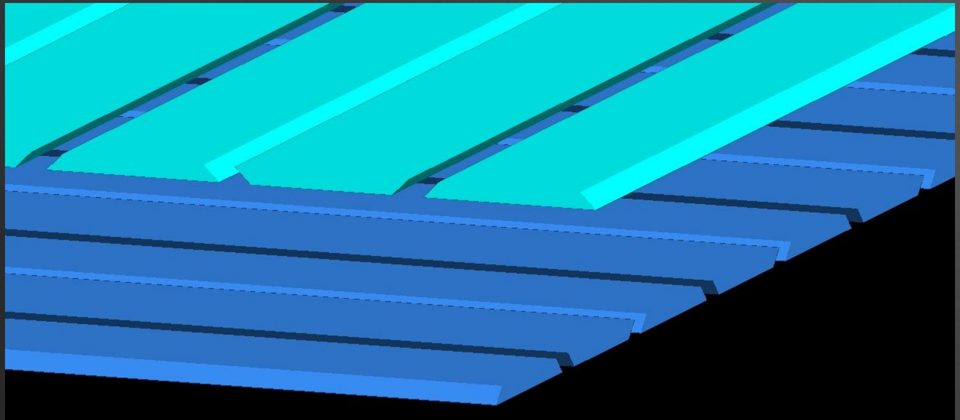
- high efficiency in charged particles detection (>99,8%)
- high dynamic range to identify nuclei at least up to iron
- Charge resolution <30%
- highly segmented design to reduce the self VETO due to back scattered charged particles and to provide useful timing information



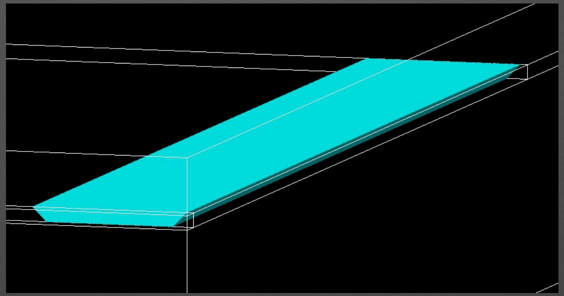
1 TOP plane and 4 SIDE plane
SCD and PSD will share the same mechanical structure

Dimensions:
- TOP 180x180 cm^2
- SIDE 170x95 cm^2

Each plane is composed of two layers to increase the **hermeticity** and so the VETO efficiency



The gap between the tiles is increased for visualization



Each layer is composed by short trapezoidal **plastic scintillating** tiles 40cm long and 5/4cm wide

TOP plane: 400 tiles
SIDE plane: 160 tiles

Total number of tiles: ~1000

Readout design of a bar

Each tile will be readout by different SiPMs in order to increase the light detection efficiency and the dynamic range for nuclei identification

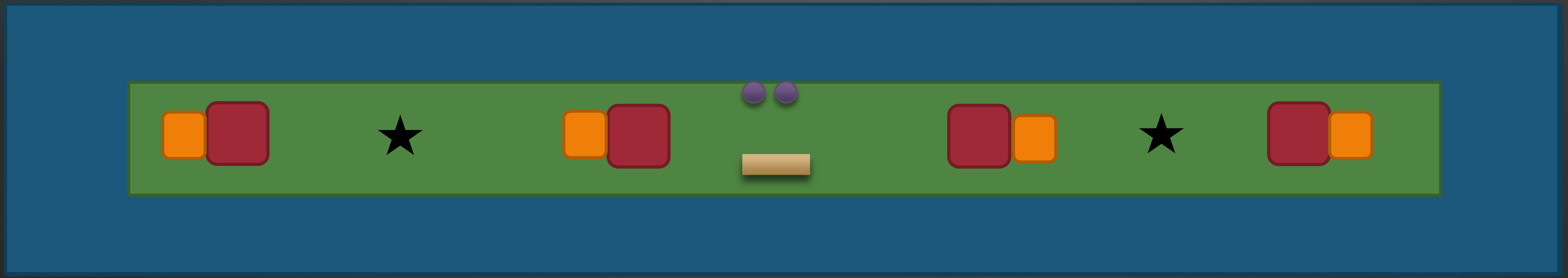
- 4 SiPM (3.0x3.0mm2 – 50umcell) - **Low Z**
- 4 SiPM (1.3x1.3 mm2 – 15um cell) - **High Z**
- 2 LED for calibration
- ★ 2 Temperature sensors
- High density coaxial cable connector for space application

LowZ SiPM
High detection efficiency for MIPS
Small dynamic range

- 3x3mm^2 : Increase light collection
- 50um cell: Increase gain

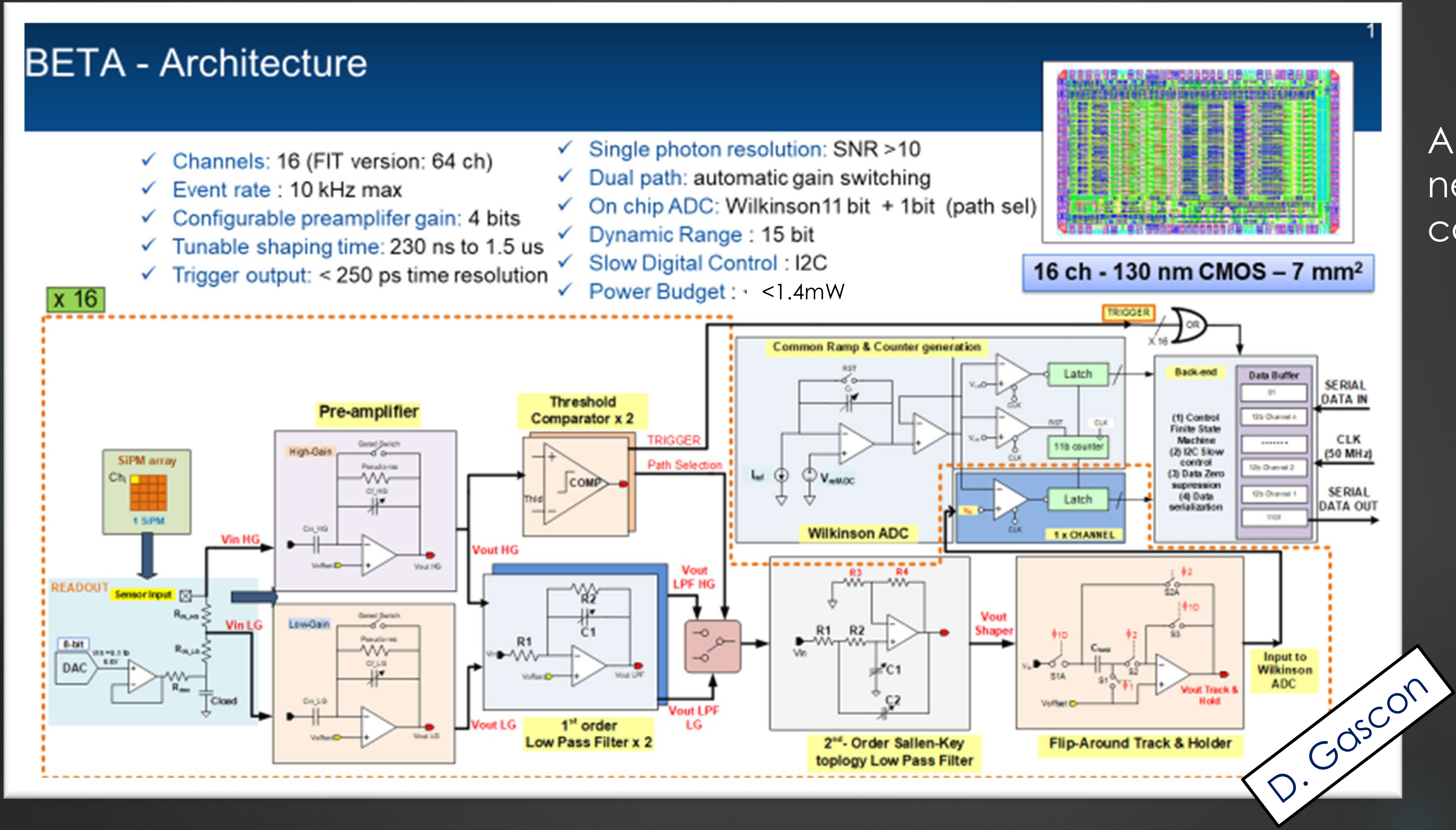
HighZ SiPM
Lower detection efficiency for MIPS
Higher dynamic range

- 1.3x1.3mm^2 : reduce collected light
- 15um cell: reduce cell saturation



Front-end β-Chip

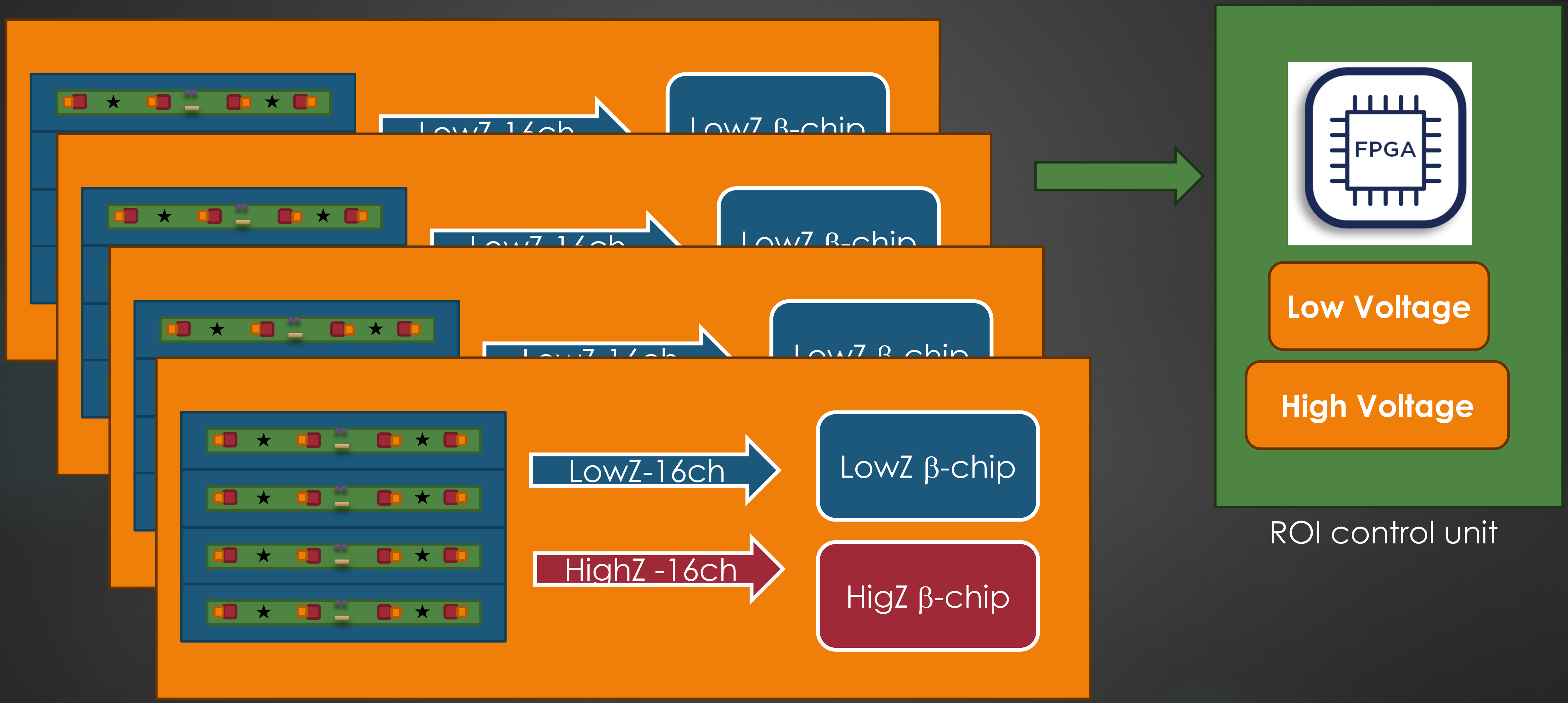
The **ICCUB group** has designed the **β-chip** for the readout of SiPMs for both PSD and FIT in space application (**low power consumption**, **high dynamic range**)



Almost **500** 16-ch β-chip needed: <15W of power consumption

Readout design

4 tiles will be readout by 2 β-chip: one for LowZ and one for HighZ



Each ROI (Region of interest) control unit will be connected to 16 tiles and will provide:

- Setting of the 8 β-chip
- Readout of the 8 β-chip
- Power supply
- Temperature monitor and active HV feedback
- LED control for calibration
- Trigger signals for VETO logic
- Time ordered fired bars identification

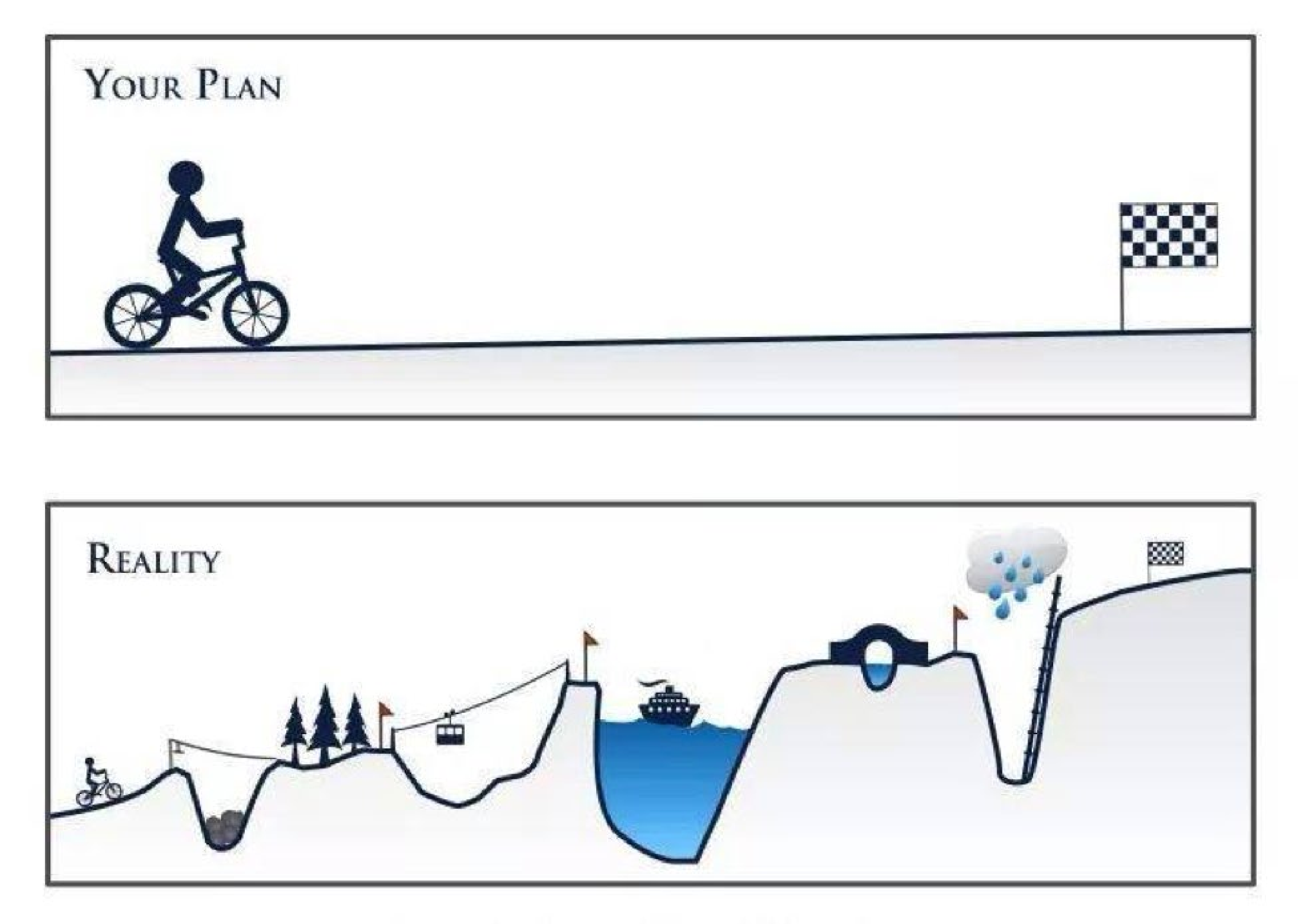
ROI	ROI	ROI	ROI
ROI	ROI	ROI	ROI
ROI	ROI	ROI	ROI

TOP plane **25 ROI control unit**

SIDE plane **10 ROI control unit**

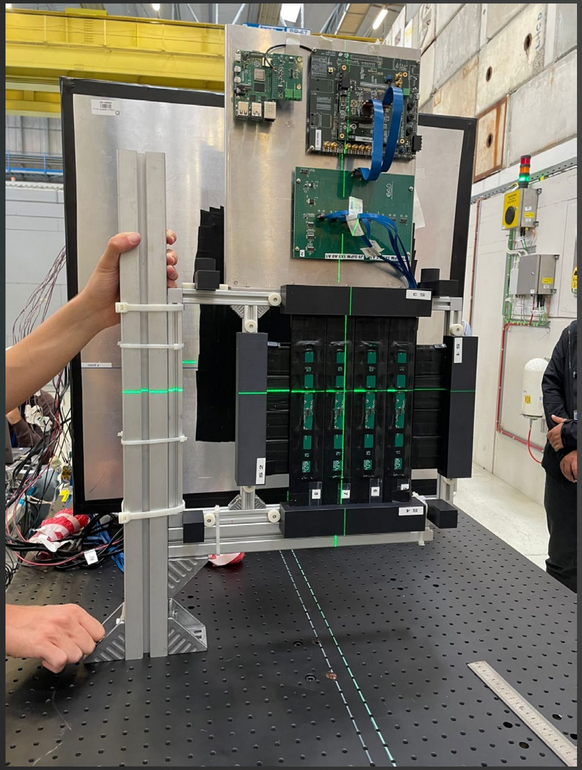
All the ROI control unit of a single plane will be connected to an FPGA that will take care of all the communications with the Main DAQ control unit

From design to prototype

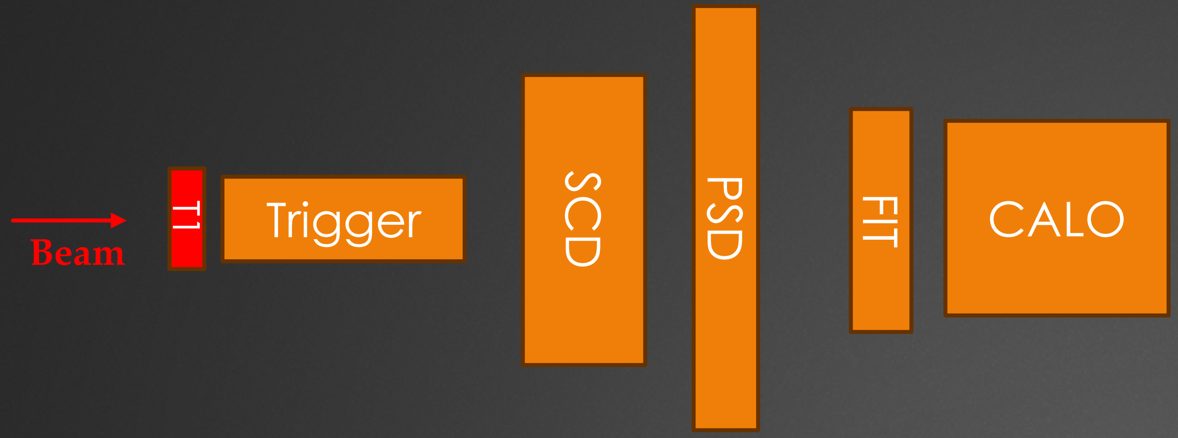


Protype and beam test

- In the next slides I will focus on the 2023 test beam at CERN (PS+SPS)
- During these test we have tested a prototype as close as possible the PSD design. All the prototype are readout with a preliminary version of β-chip
- 4 tiles of EJ200 (30 x 5/4 cm) for each layer. X-Y layers.



SiPM : Hamamatsu	S14160-3050	S14160-1315
Size	3x3 mm^2	1.3x1.3 mm^2
Pixel pitch	50 um	15 um
Number of pixels	3531	7284
Refractive index	1.57	1.57
Peak sensitivity wavelength	450 nm	460 nm
PDE	50%	32%
Vbr	38 V	38 V



Beam test set-up with all the HERD sub-detectors

For the analysis reported in this talk we have used the **combined data of PSD and SCD**

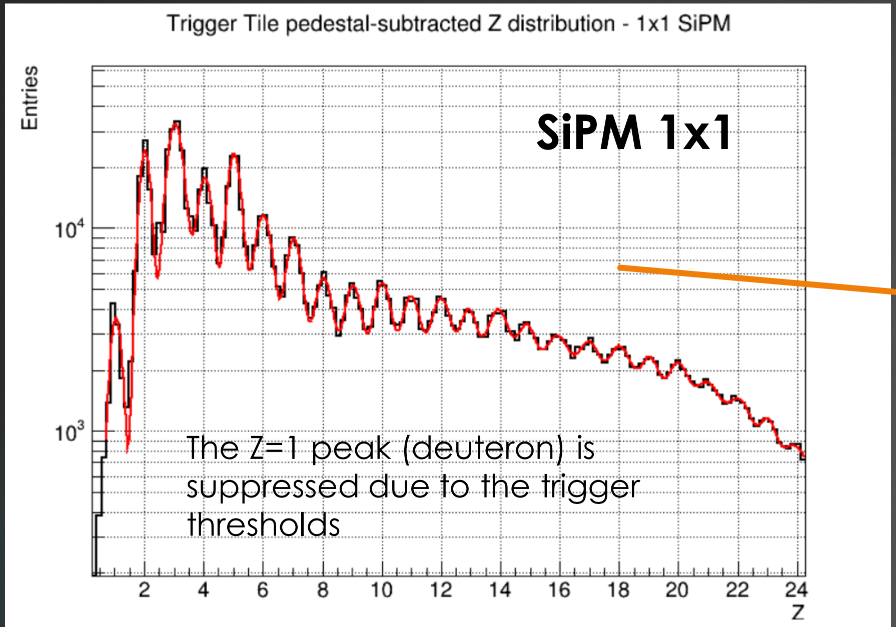
T1 is a squared plastic scintillators tiles (BC-404) 100x100x5 mm3 used as **charge tagger** to monitor the beam composition and provide ancillary information

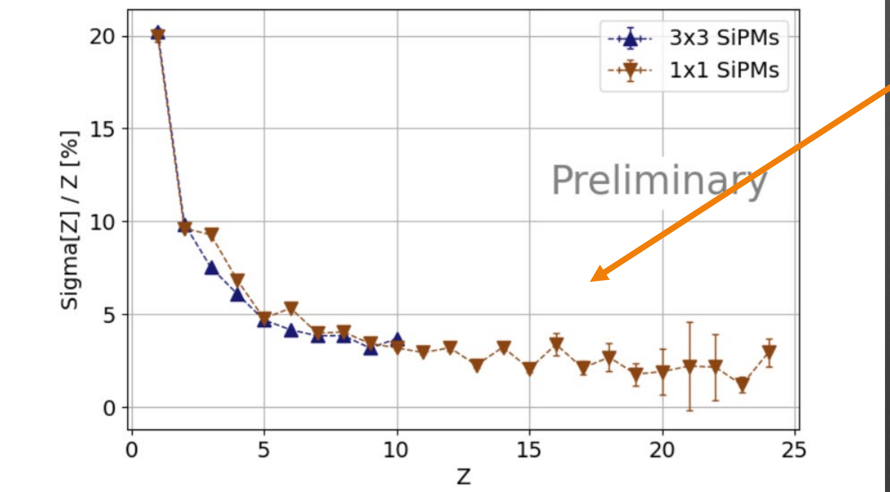
It is equipped with 3 SiPM S14160-3015 on one side and 3 SiPM S14160-1315 on the other side to increase the synamic range

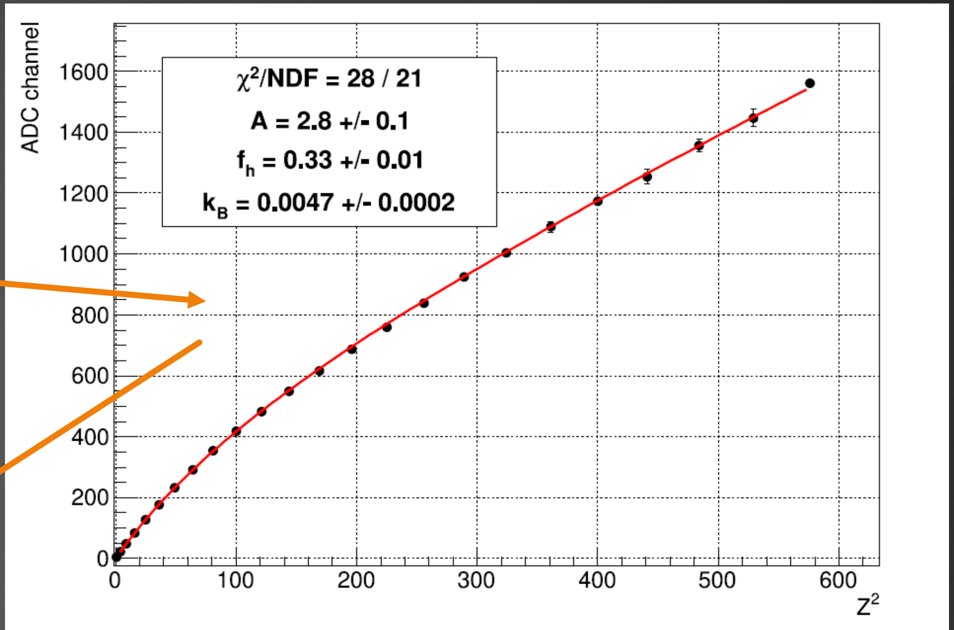
SiPM : Hamamatsu	S14160-3015	S14160-1315
Size	3x3 mm^2	1.3x1.3 mm^2
Pixel pitch	15 um	15 um
Number of pixels	39984	7284
Refractive index	1.57	1.57
Peak sensitivity wavelength	460 nm	460 nm
PDE	32%	32%
Vbr	38 V	38 V

Charge tagging

Fragments produce by **Pb beam on Be target @150GeV/n**







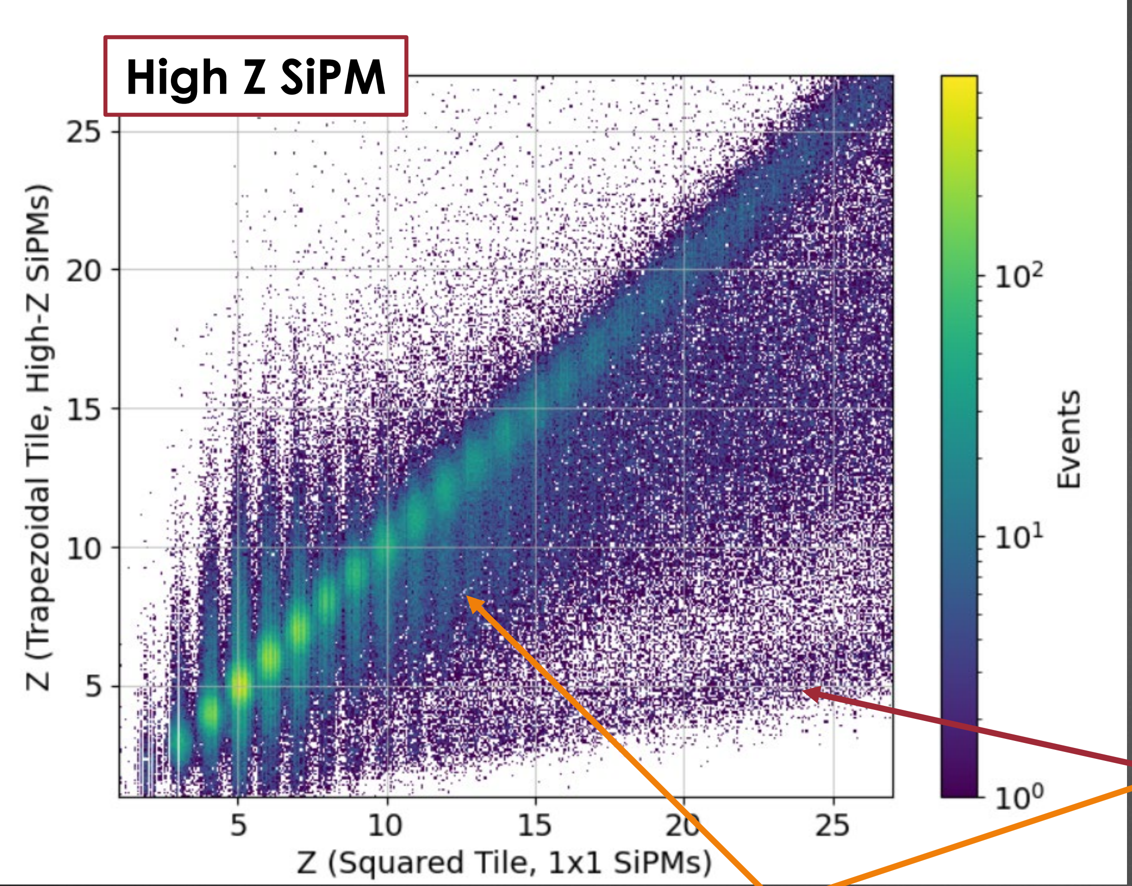
The Birks quenching effects in high excitation density conditions is evaluated from the multi-gaussian fit and applying the relations

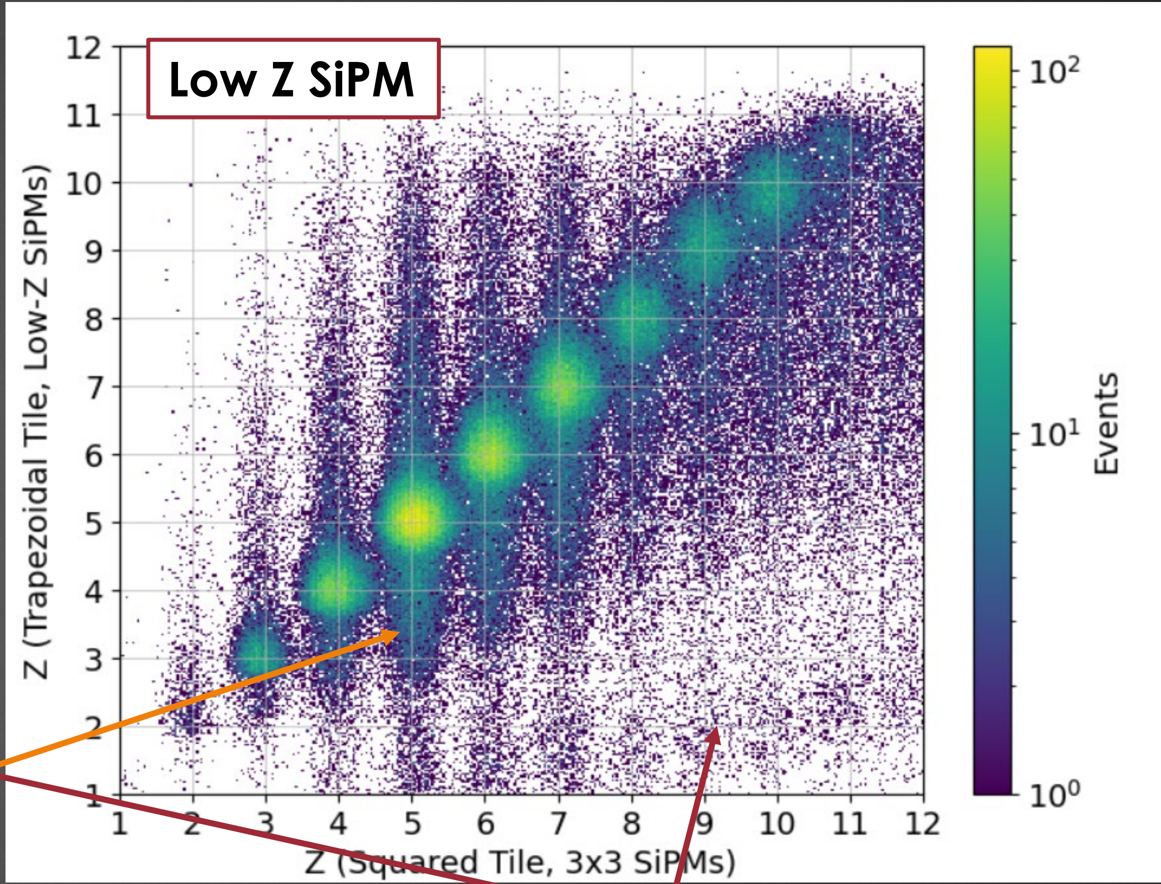
$$\frac{dL}{dx} = AZ^2 L_B$$

$$L_B = \frac{1 - f_H}{1 + k_B \frac{dE}{dx}} + f_H$$

PSD – Correlation with the charge tagger

With the charge tagger we can identify different ions in the PSD



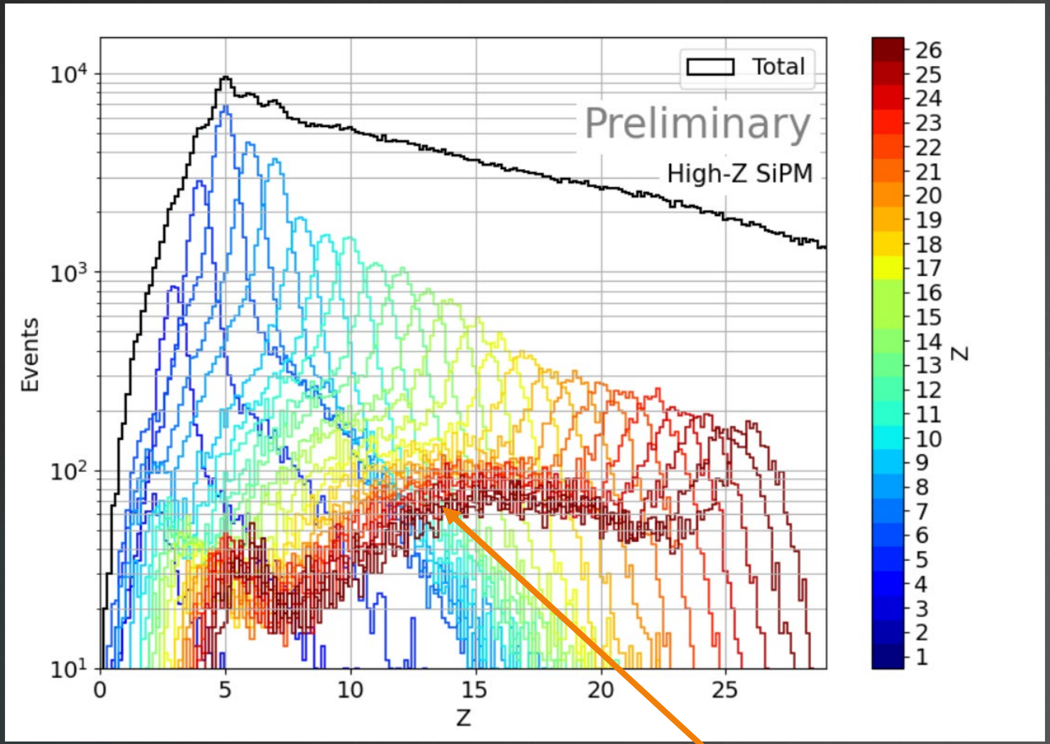


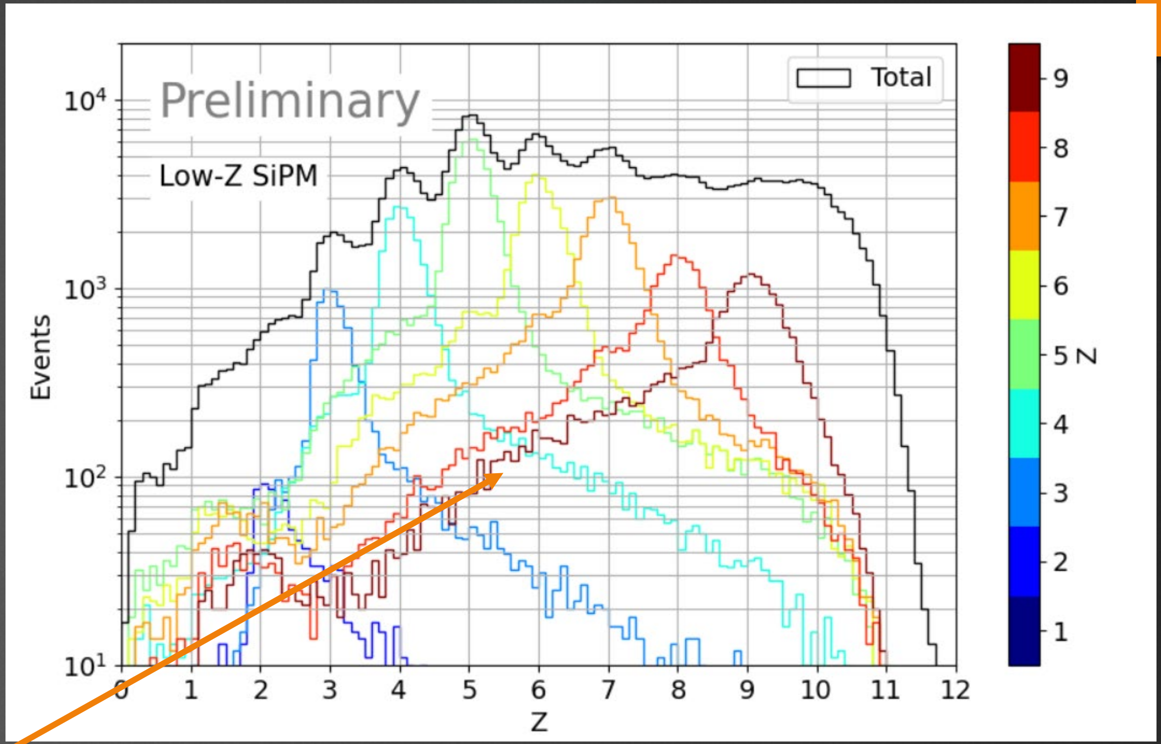
Ions fragmentation in the SCD

Low Z beam halo
(the PSD active area is bigger than T1 area

Tile Z values are corrected for Birks saturation

PSD Spectra





Nuclei fragments

With High Z SiPM we menage to identify nuclei up to **Z=26** while with the LowZ we reach **Z=9**

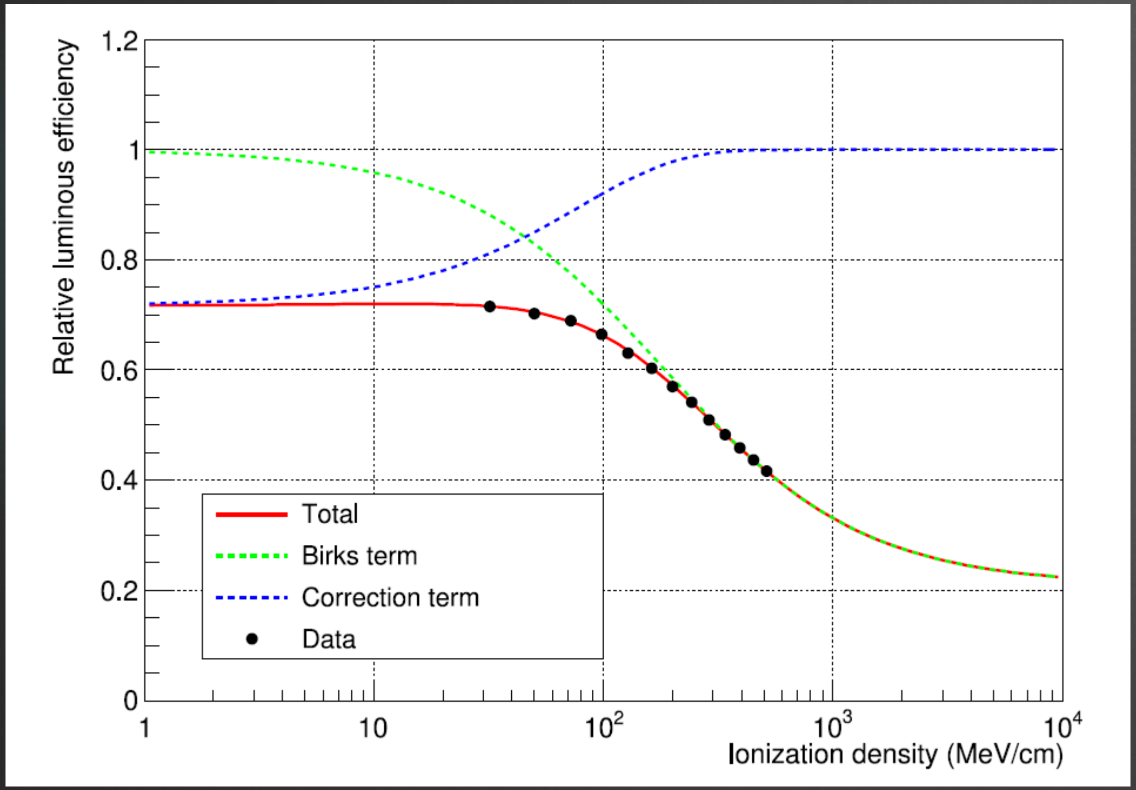
PSD – Birks correction

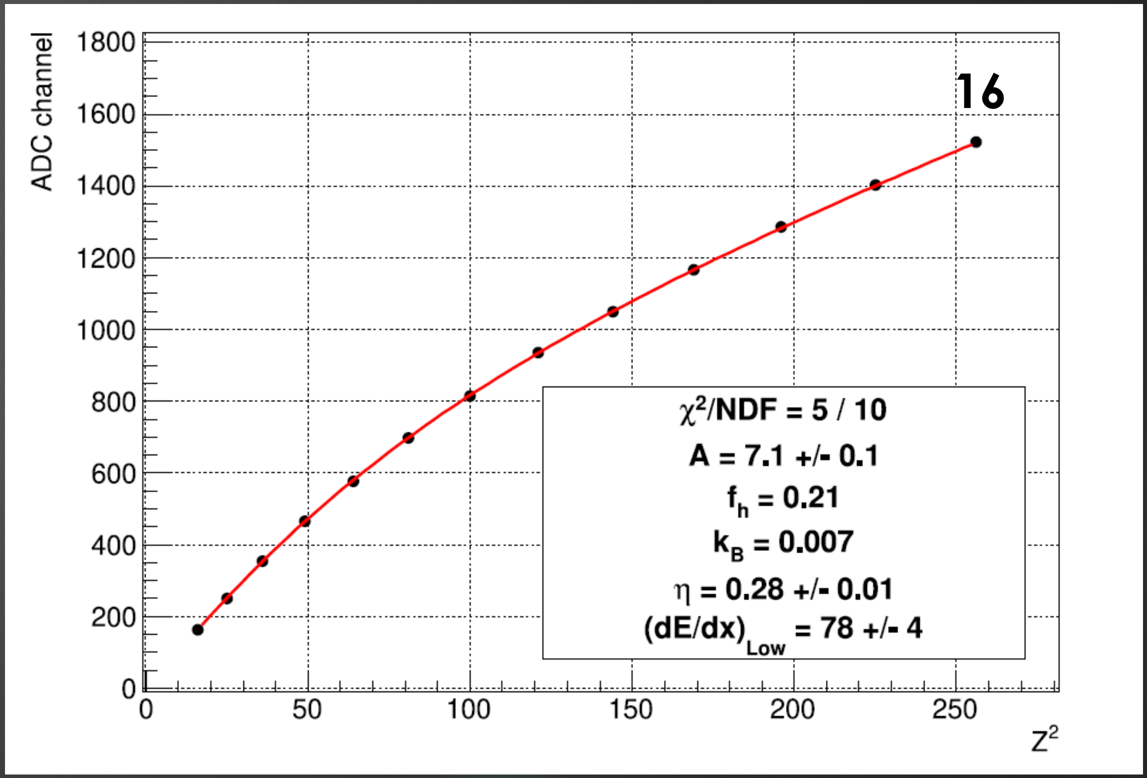
Several studies on inorganic scintillators proved that additional non-Birks effects can dominate the light yield quenching at low excitation densities We found that also in plastic scintillators an additional correction term is necessary to properly model the **low excitation density quenching effects**.

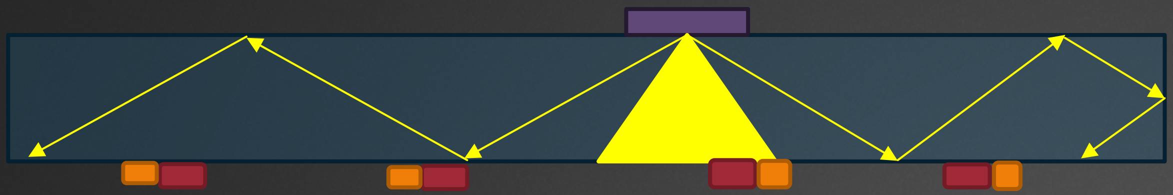
$$L_B = \frac{1 - f_H}{1 + k_B \frac{dE}{dx}} + f_H$$

$$L_{Low} = 1 - \eta \exp\left(-\frac{dE/dx}{(dE/dx)_{Low}}\right)$$

$$\frac{dL}{dx} = AZ^2 L_B L_{Low}$$

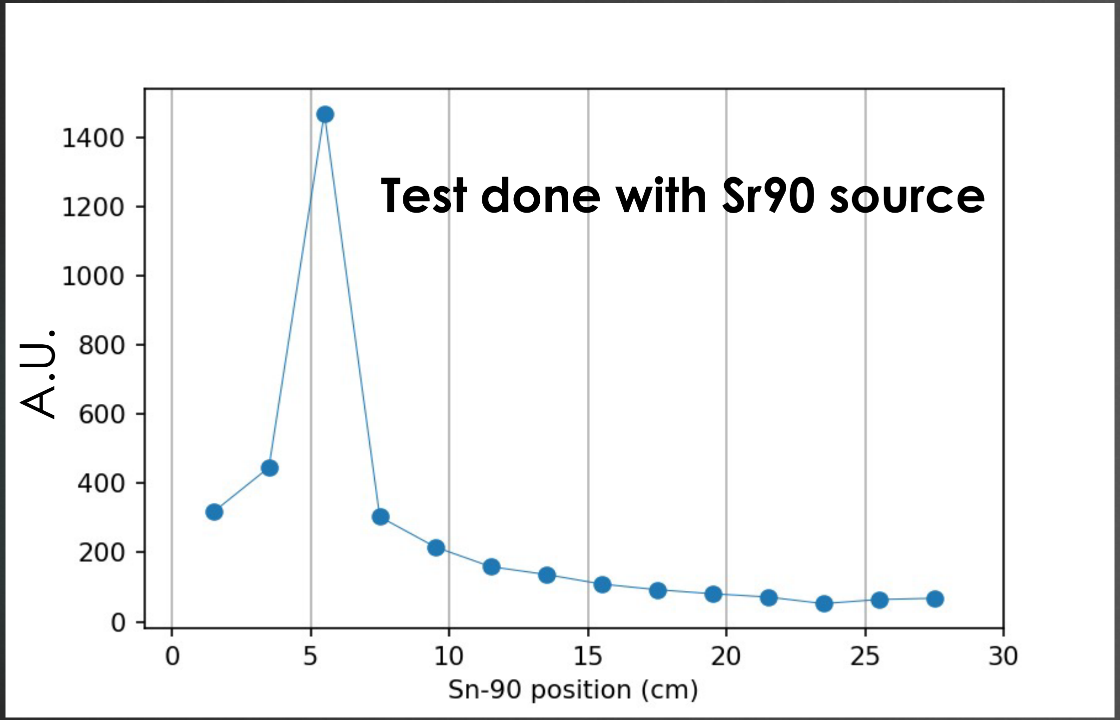


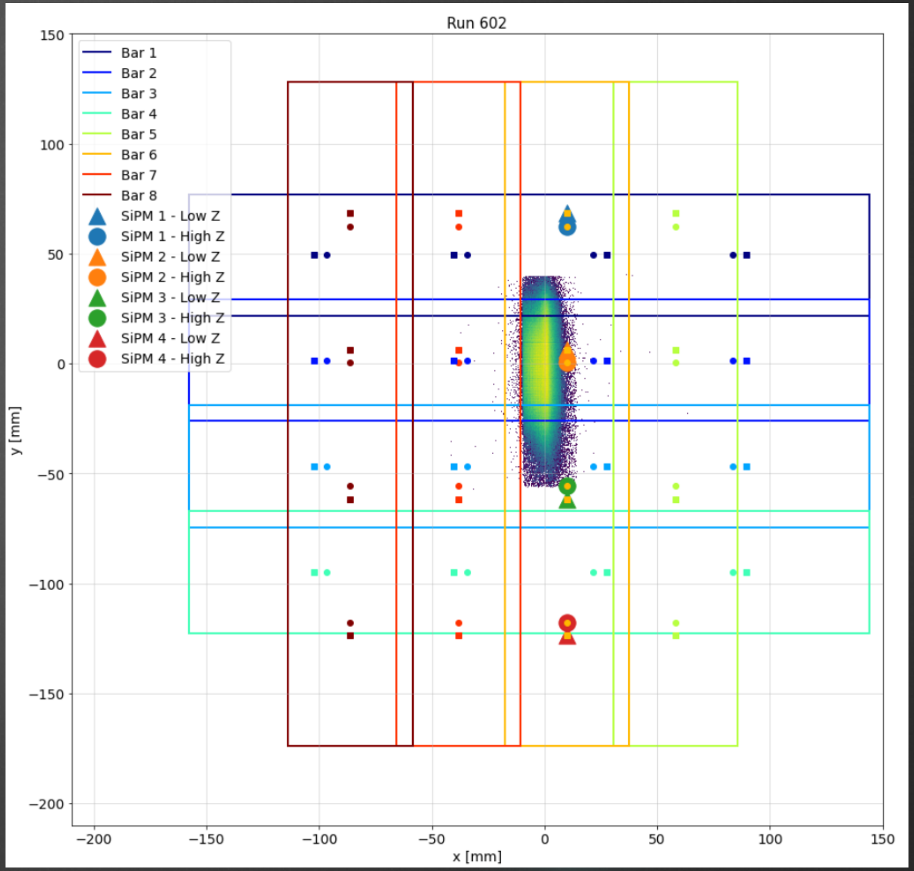




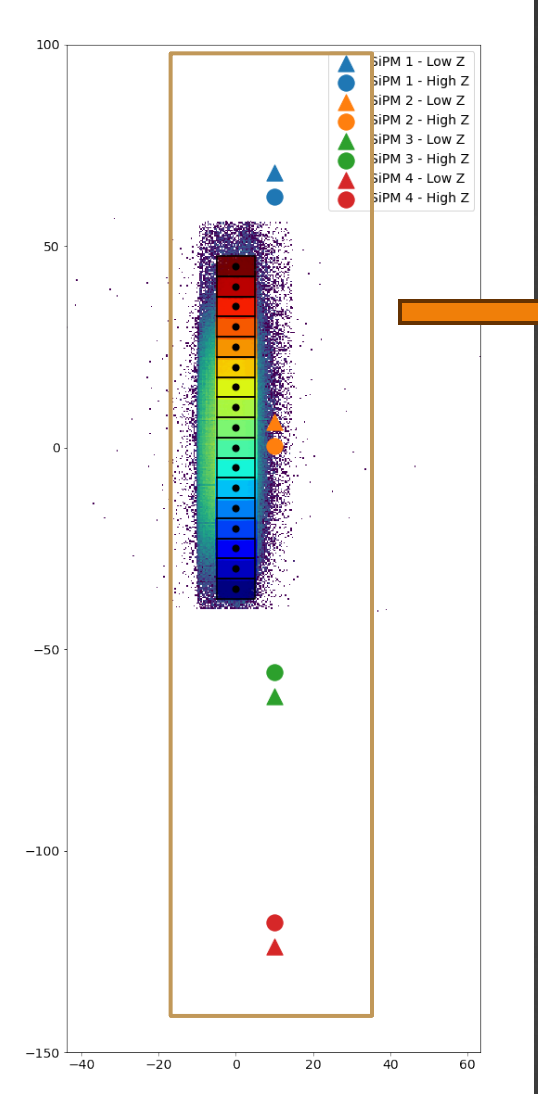
Since the readout is done from the top of the tile we expect direct scintillating lights and indirect light (from internal reflection)

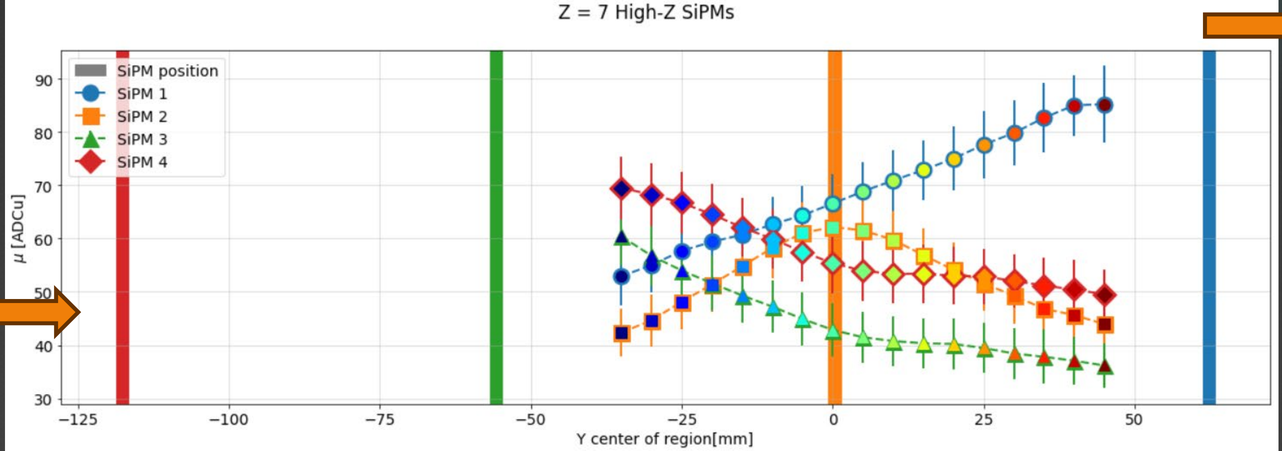
The light propagation effect has been measured during the beam test with the help of **SCD data** that allow us to know the impact point of the nuclei on the PSD



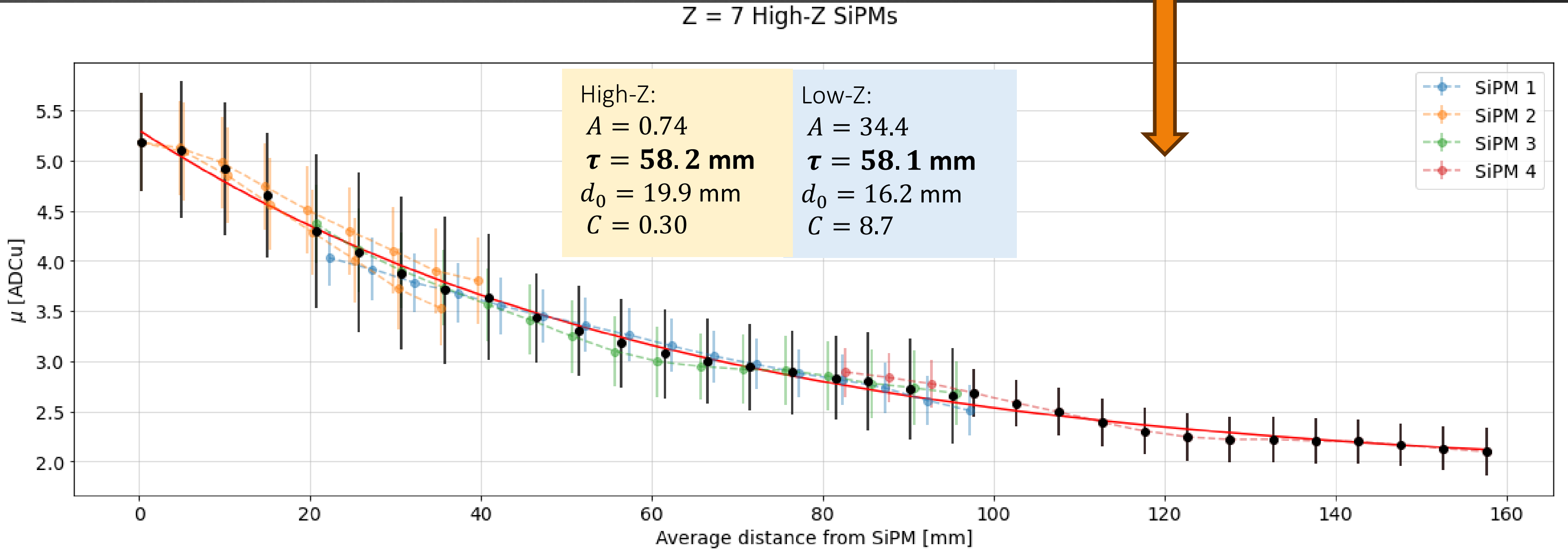


PSD – Effective attenuation lenght





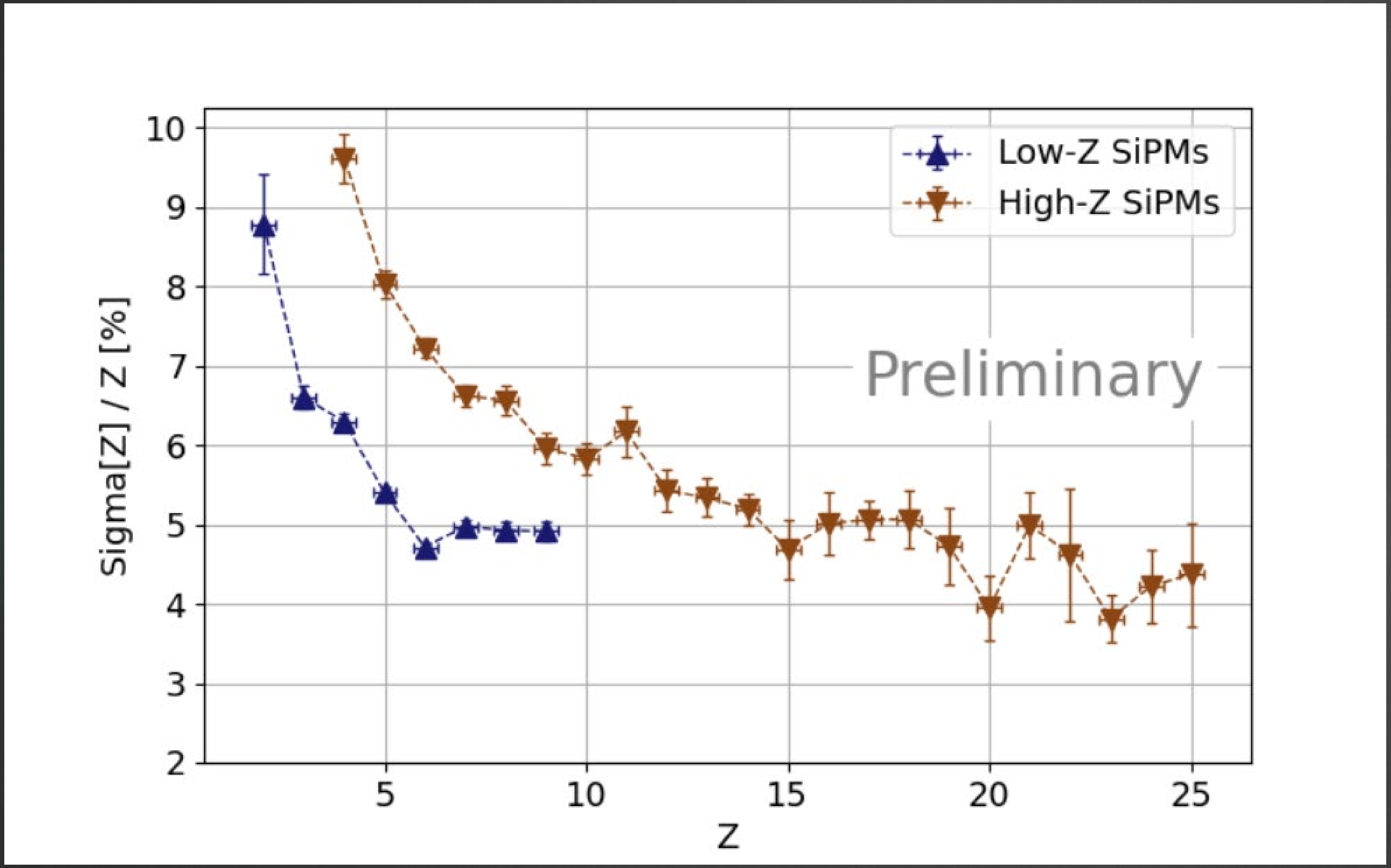
We have used the combined results from different SiPM (after equalization) to measure the effective attenuation length



N.B effect of direct light have been removed due to saturation

PSD – Charge resolution

Once we have implemented all the corrections (SiPM gain disuniformity , Bircks saturation effect and light attenuation we obtain the charge resolution vs Z both for Low-Z and High-Z SiPMs



The Low-Z SiPMs show a lower charge resolution for nuclei Z<5/6
the High-Z SiPMs show a charge resolution of 5-6% for Z>12

Conclusion and on going activities

- We have built and test a prototype that fulfil all the design requirements.

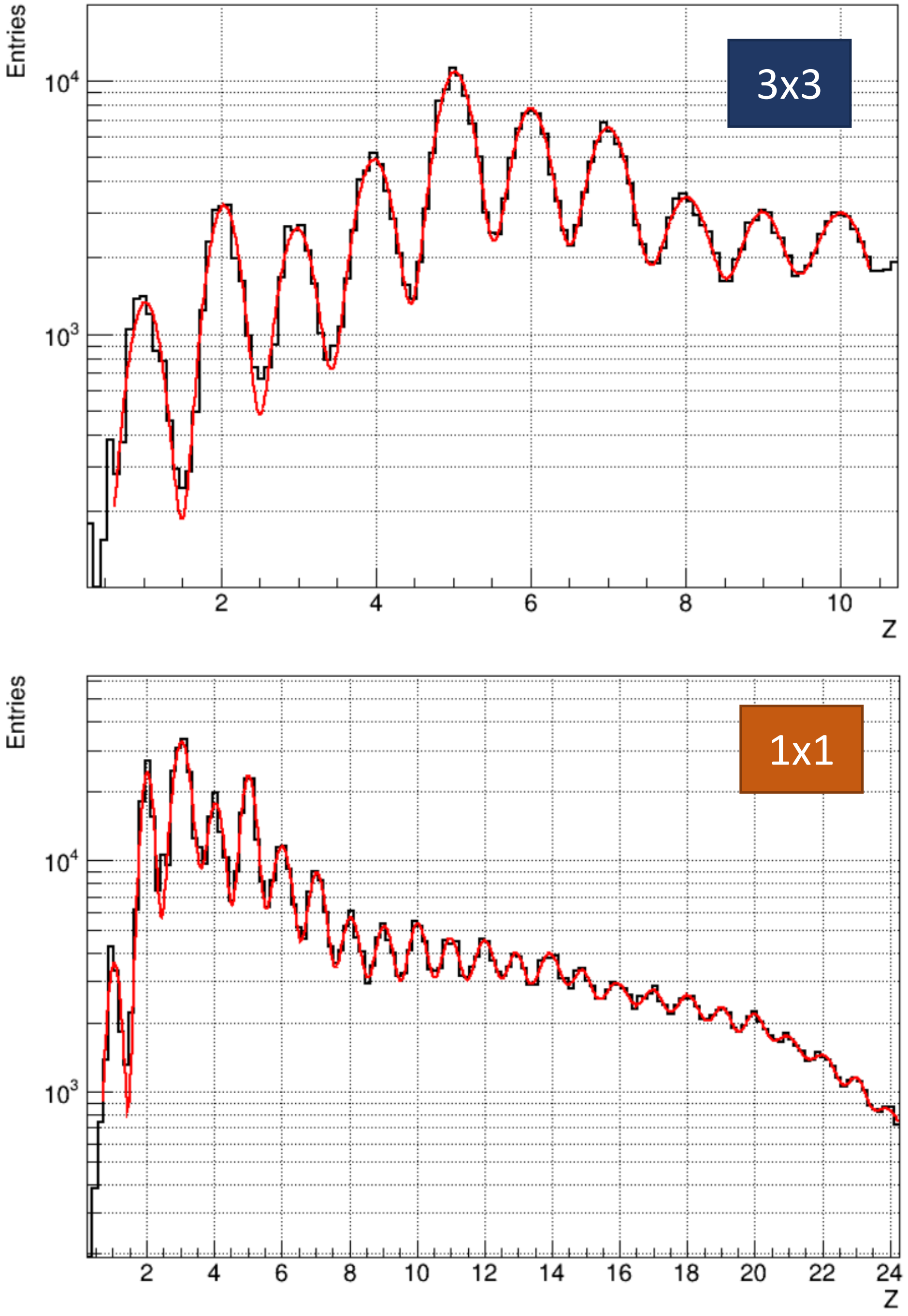
- Unfortunately, over the course of 2024, the international situation evolved in a way that forced us to reassess our commitments to the HERD project

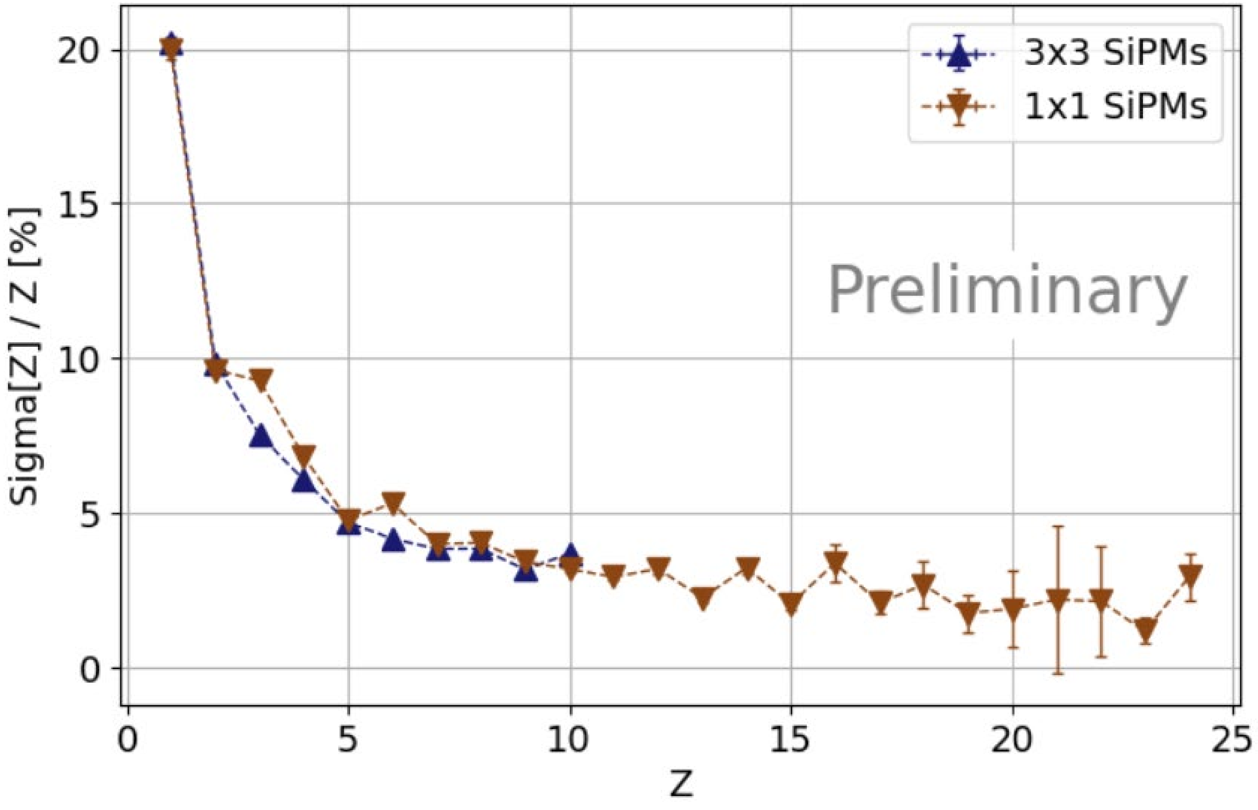
- We will do another beam test in November at CERN at SPS with a new prototype very close to the final design, with the new version of the β-chip and a readout logic very similar to the final one that allow us to check deeply all the design parameters (INFN-ASI agreement)
- During this beam test we will also test different kinds of SiPMs produce by FBK according to our specification (RadHard, Low Cross Talk, Low HV) that should improve the overall performances of the PSD

Thanks for your attention

Backup slide

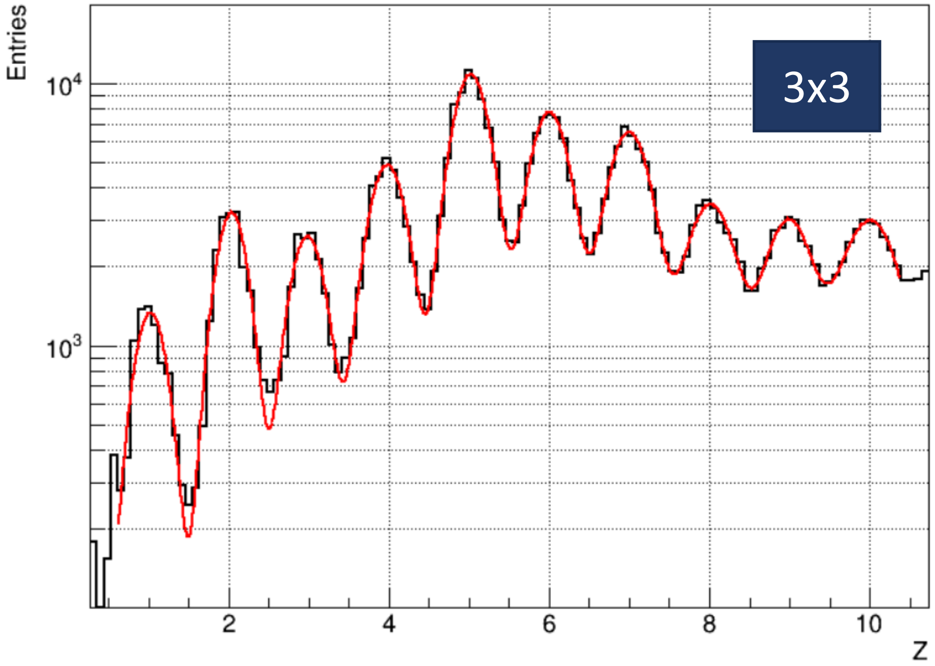
Squared Tile

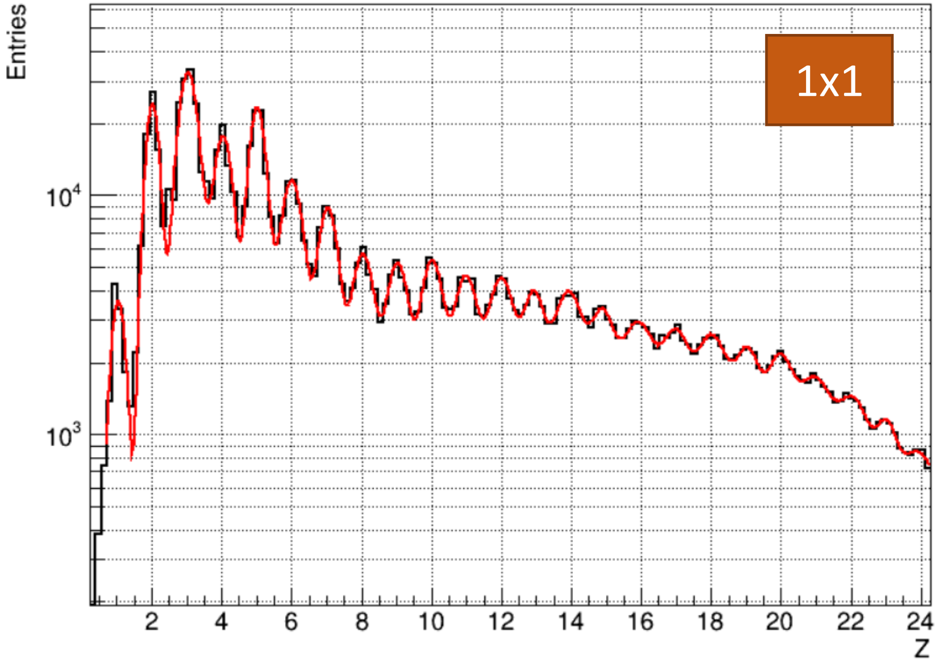


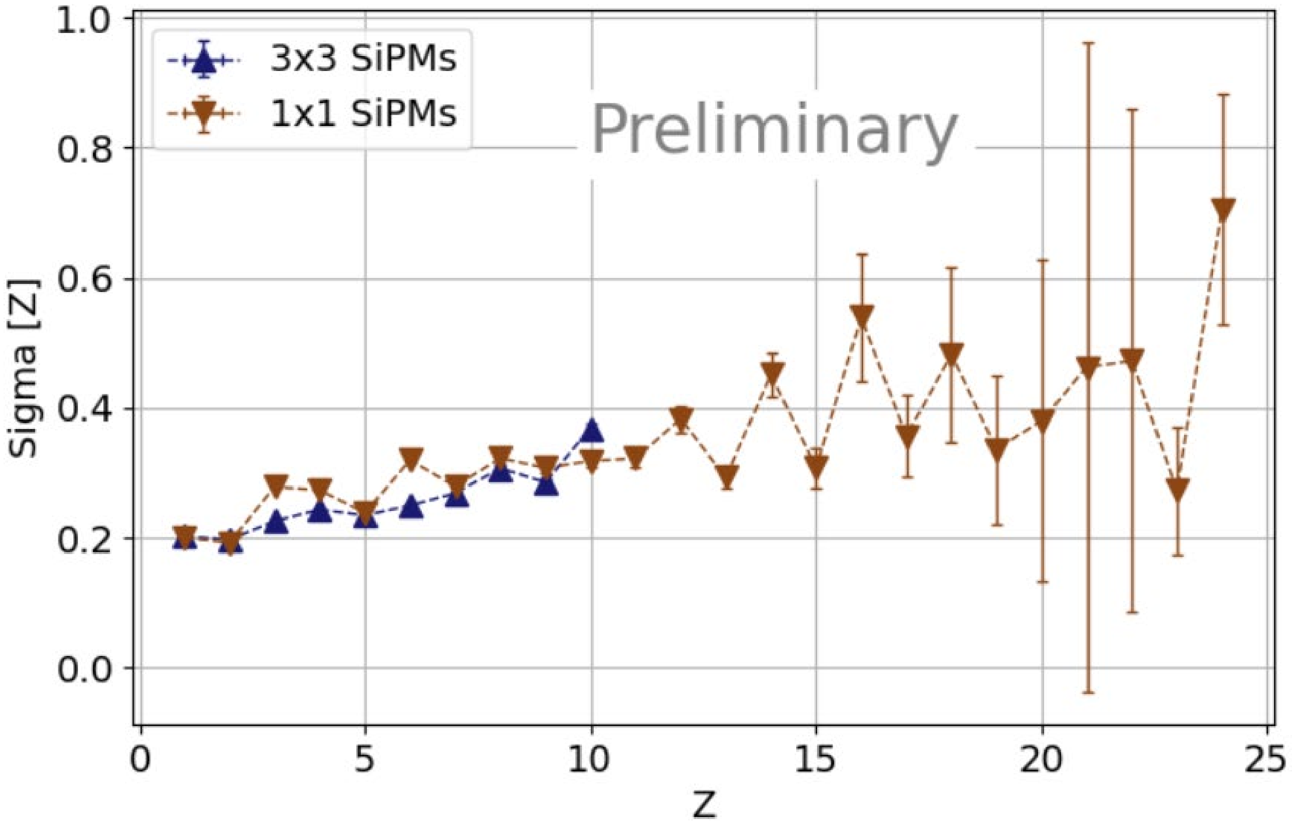


Z spectra and charge resolution for the 1x1 and 3x3 SiPMs

Squared Tile



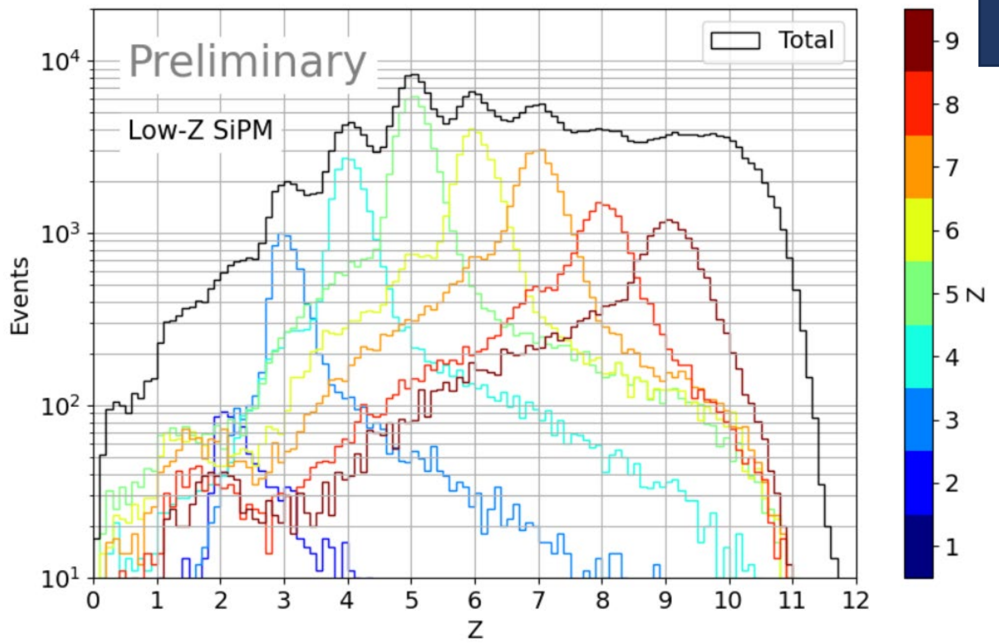


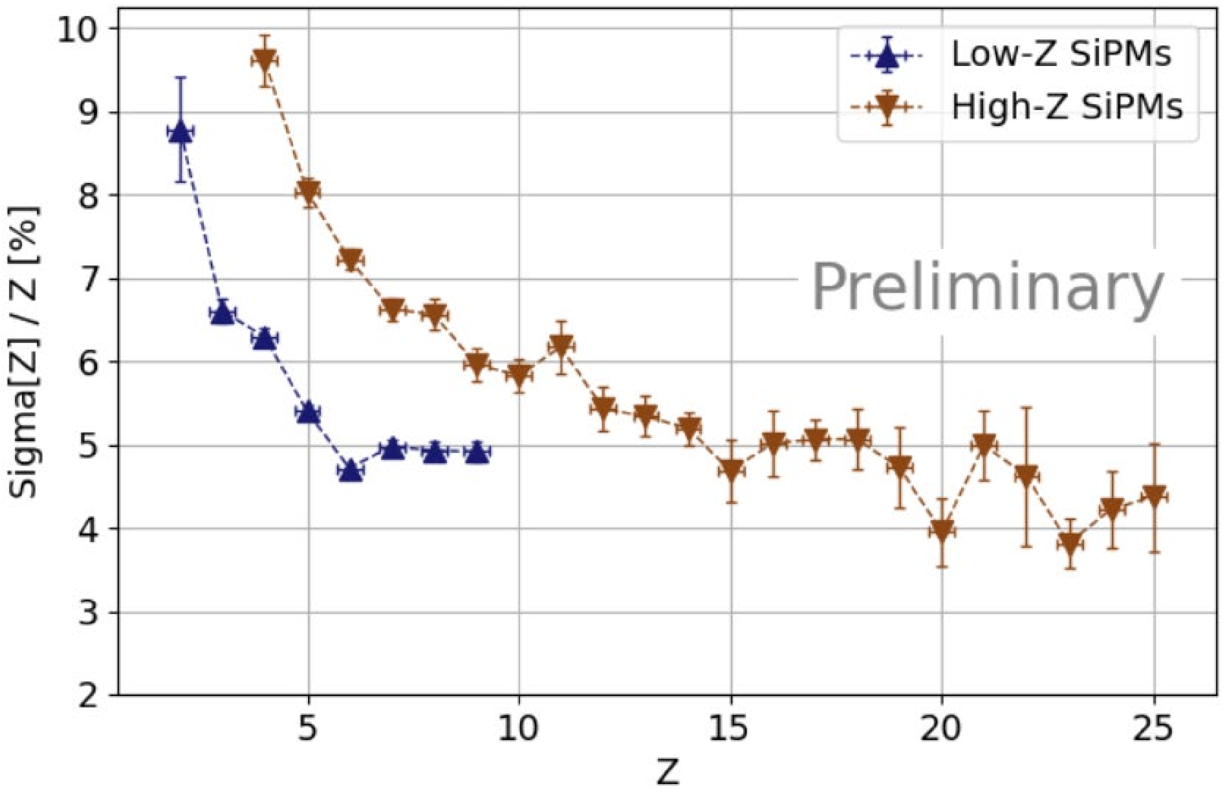


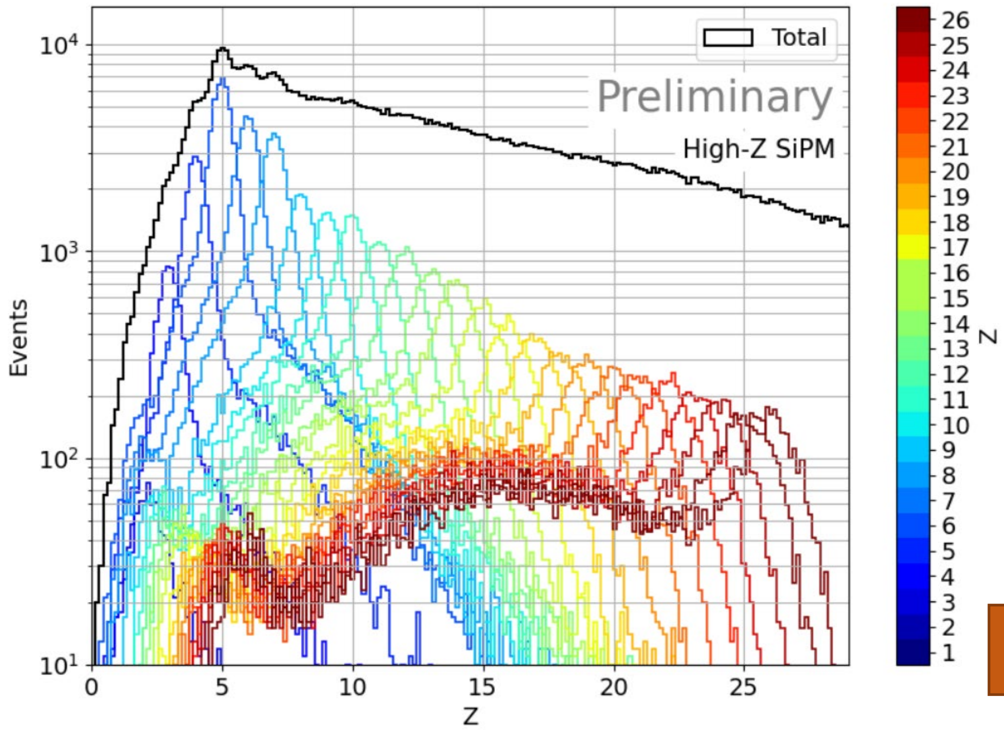
Z spectra and charge resolution for the 1x1 and 3x3 SiPMs

Trapezoidal Tile

Low-Z SiPMS





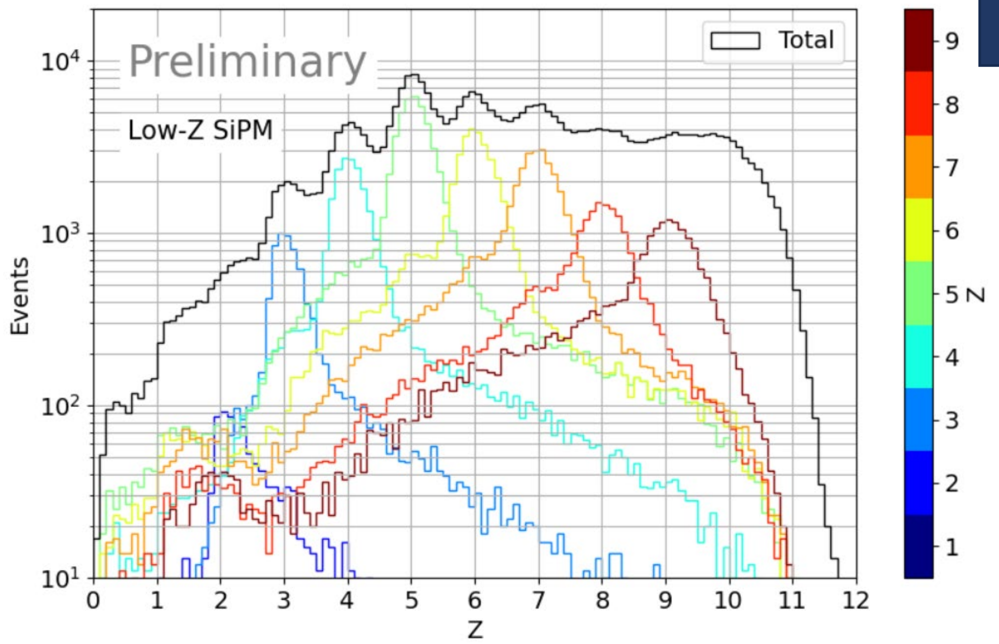


High-Z SiPMS

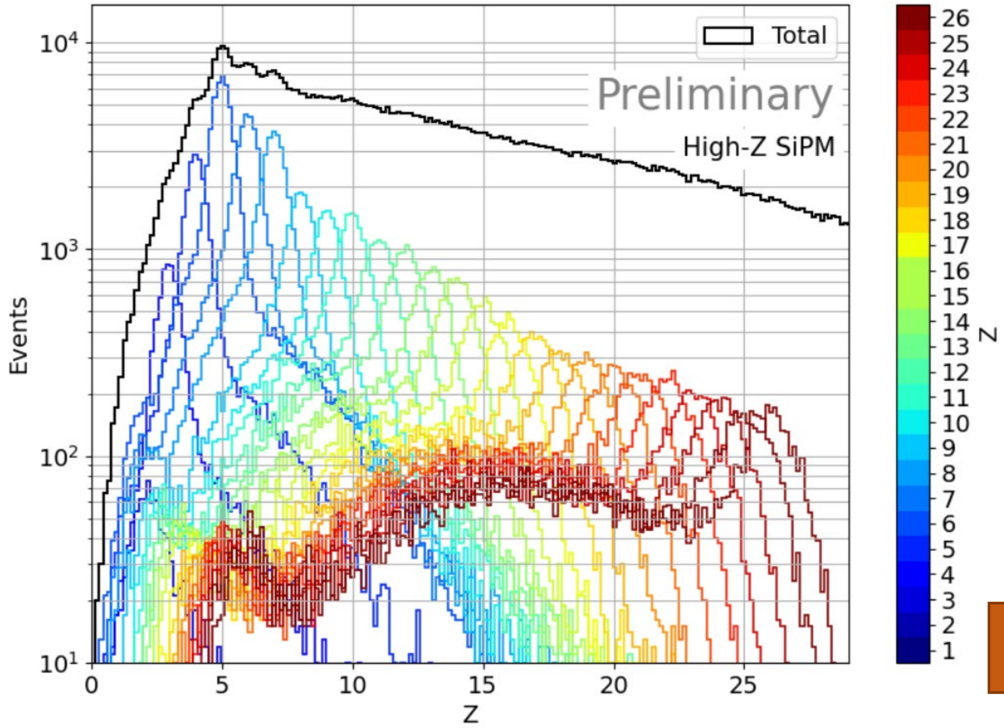
Z spectra and charge resolution for the high-Z and low-Z SiPMs

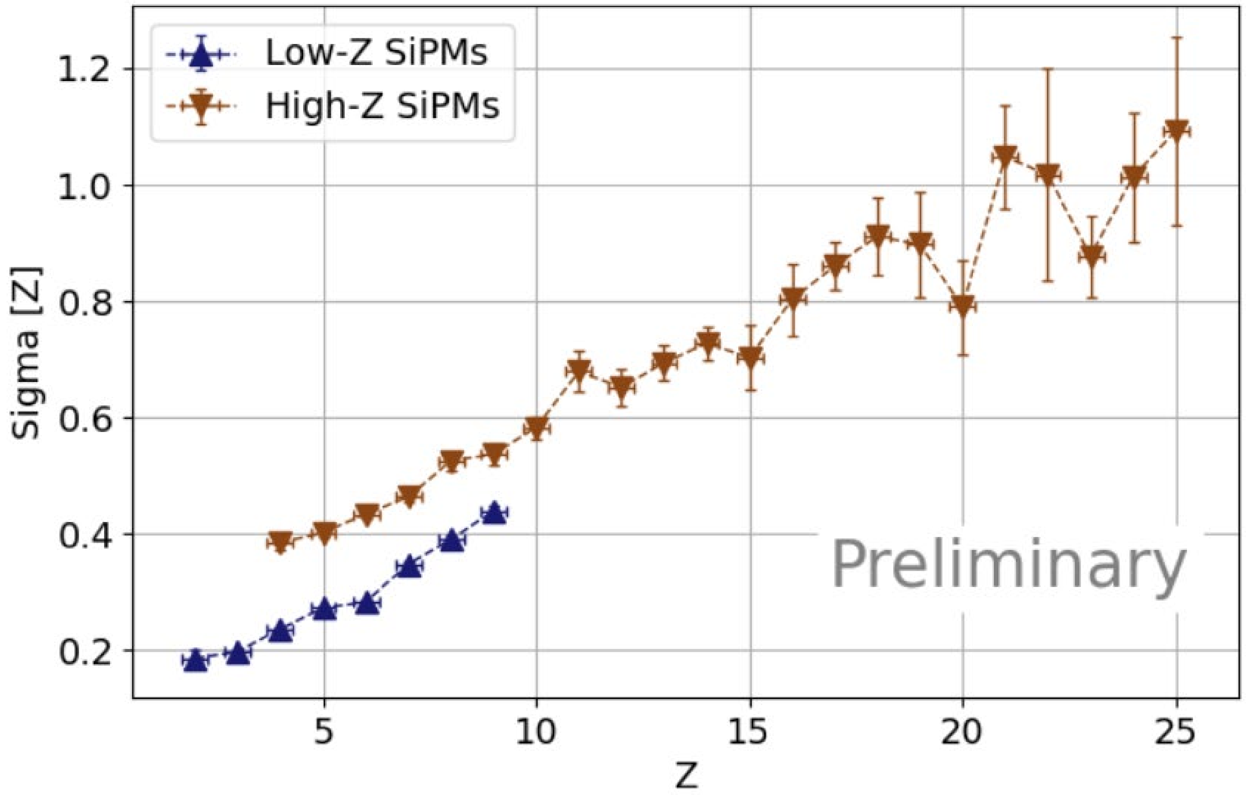
Trapezoidal Tile

Low-Z SiPMS



High-Z SiPMS





Z spectra and charge resolution for the high-Z and low-Z SiPMs

Charge tagger - low ionization density correction