A tile prototype of the Plastic Scintillator Detector for HERD based on long Printed Circuit Board: design and test with ion beams at CNAO

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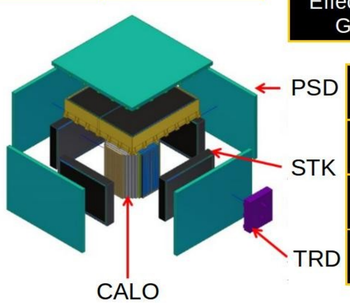
The Herd detector

HERD detector and requirements

$\sigma_\theta(\gamma)$	0.1° @ 10 GeV
Z	1 - 26
σ_z	0.1 - 0.15 e
e/p	10^6

	e	p, nuclei
Energy Range	10 GeV - 100 TeV	30 GeV - 3 PeV
Energy resolution	1% @ 200 GeV	20% @ 100 GeV -1 PeV
Effective GF	> 3 m²sr @ 200 GeV	> 2 m²sr @ 100 TeV



CALO	Energy Reconstruction e/p Discrimination
STK	Trajectory Reconstruction Charge Identification
PSD	Charge Reconstruction LE γ Identification
TRD	Calibration of CALO response for TeV proton

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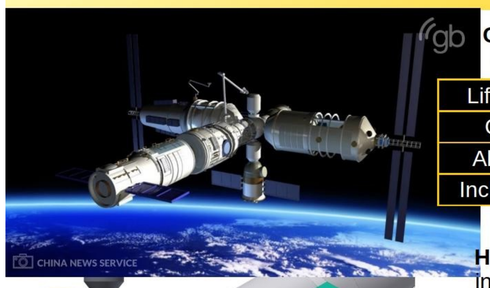
HERD will be located on the CSS.

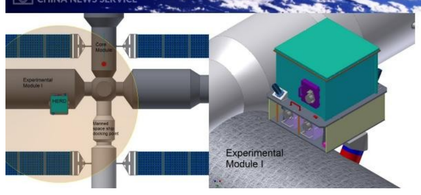
The Chinese Space Station

HERD on board CSS



CSS expected to be completed in 2022

Life time	> 10y
Orbit	Circular LEO
Altitude	340-450 km
Inclination	42°



HERD expected to be installed around 2026

Life time	> 10y
FOV	+/- 70°
Power	< 1.5 kW
Mass	< 4 t

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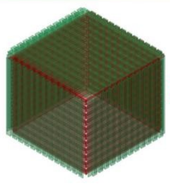
The Plastic Scintillator Detector

HERD Plastic Scintillator Detector (PSD)



Bars or Tiles readout by SiPM

SiPM

Plastic scintillator bar: 160cm x 3cm x 1cm

Plastic scintillator tile: 10(5)cm x 10(5)cm x 1cm

PSD Layers

- 1 Top XY
- 4 Lateral XY
- 1 Bottom X

	Advantages
Bars	Lower number of readout channels Simpler mechanics
Tiles	Better id of backscattered particles More powerful trigger

The correct identification of backscattered particles is crucial to avoid:

- charge misreconstruction in case of incident charged particles
- self veto in case of incident γ

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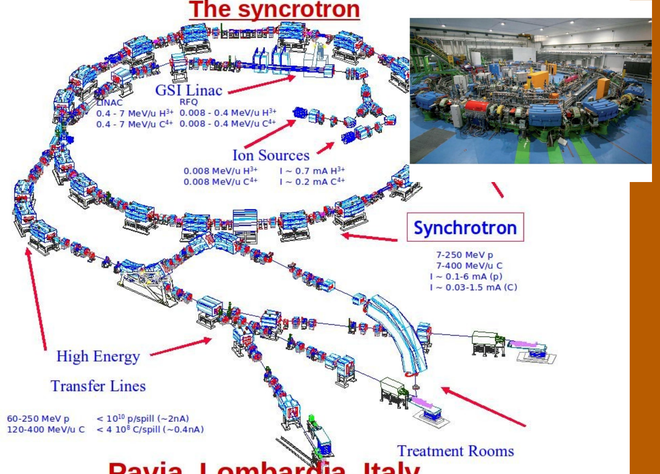
CNAO facility for beam test

Centro nazionale adroterapia oncologica

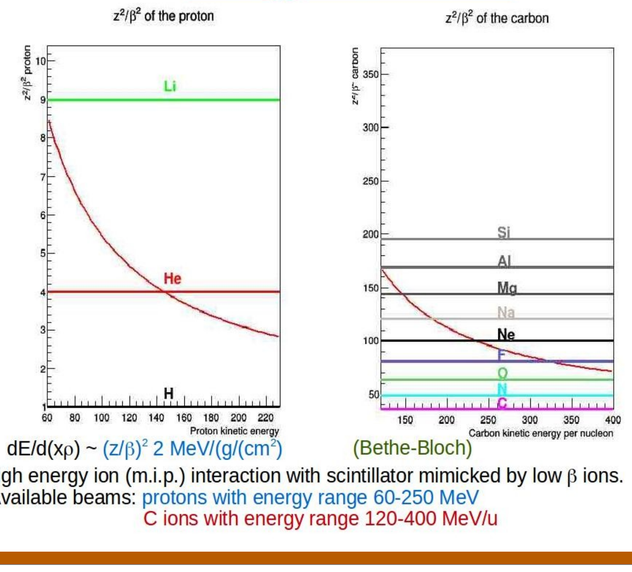
The syncrotron



Pavia, Lombardia, Italy

CNAO provides low energy ion beams (p,C)
Energy loss of low β ions (p,C) compared to high-Z high energy ions

Energy loss of ions

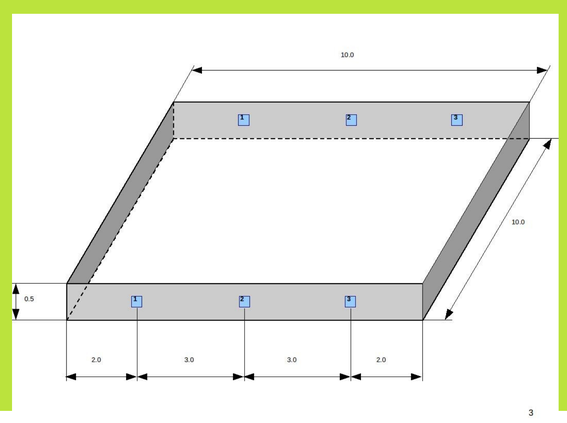


dE/d(xρ) ~ (z/β)² 2 MeV/(g/(cm²)) (Bethe-Bloch)

High energy ion (m.i.p.) interaction with scintillator mimicked by low β ions.
Available beams: protons with energy range 60-250 MeV
C ions with energy range 120-400 MeV/u

Beam Test 2019-2020

Test scintillator tile (EJ200) 10 cmx10cmx0.5cm
Read out by 3+3 Hamamatsu S12572 50 μm SiPM (3x3 mm²) (opposite sides) in parallel



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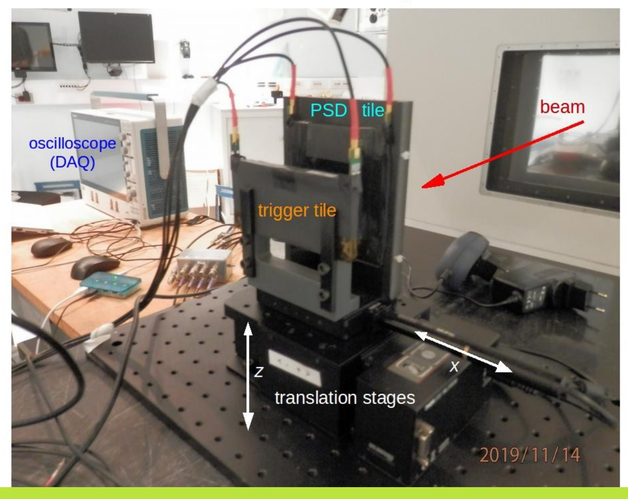
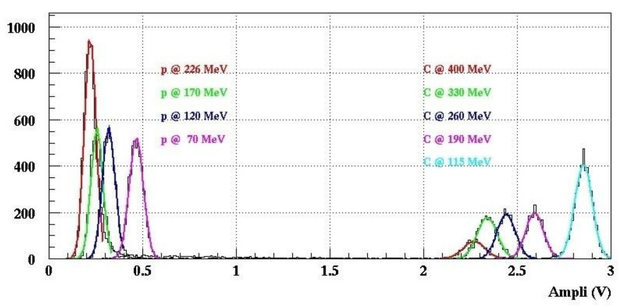
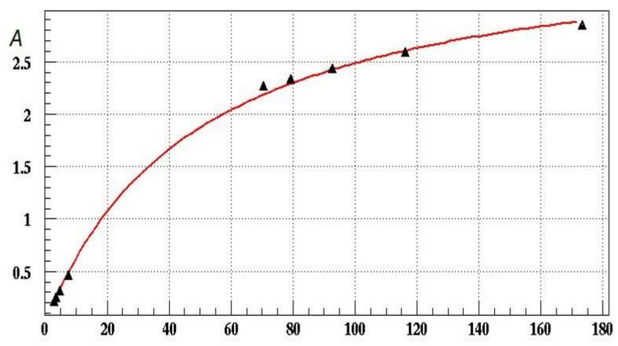
Beam test setup



Signal amplitude analysis



Birks' law



The correlation between the signal amplitude and the dE/dx (Z^2/β^2) is well fitted with a Birks' law

$$A = P_1 \frac{dE/dx}{1 + P_2 dE/dx} \qquad P_1 = 0.0756 \quad P_2 = 0.0204$$

The 2019-2020 results proved the concept of using low energy (p,C) ions to provide energy losses as large as high-Z high energy ions. Saturation in light production following Birks' law was confirmed and its parameters measured.

Beam Test 2021: the long PCB

A new design of the tile is required to satisfy the requirements:

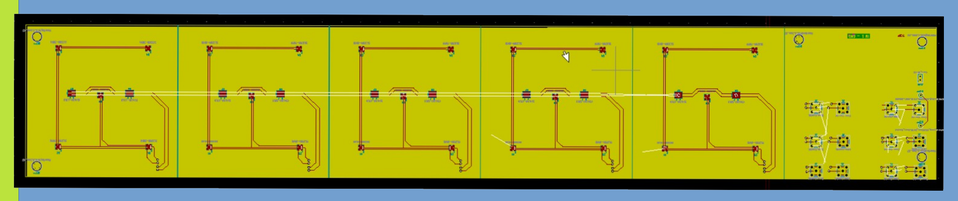
- full hermeticity (no dead space between tiles)
- mechanical support for the tile structure
- uniformity of response on tile surface
- two readout channels per tile with low-high gains to match the broad dynamic range in energy loss from proton to iron and beyond

Possible solution: long Printed Circuit Board (PCB) 50 cm long (to be extended to 100 cm) hosting 5 tile (10) 10x10x0.5 cm^3 each.
Two sets of SiPMs located on the wide face to avoid dead space between tiles.

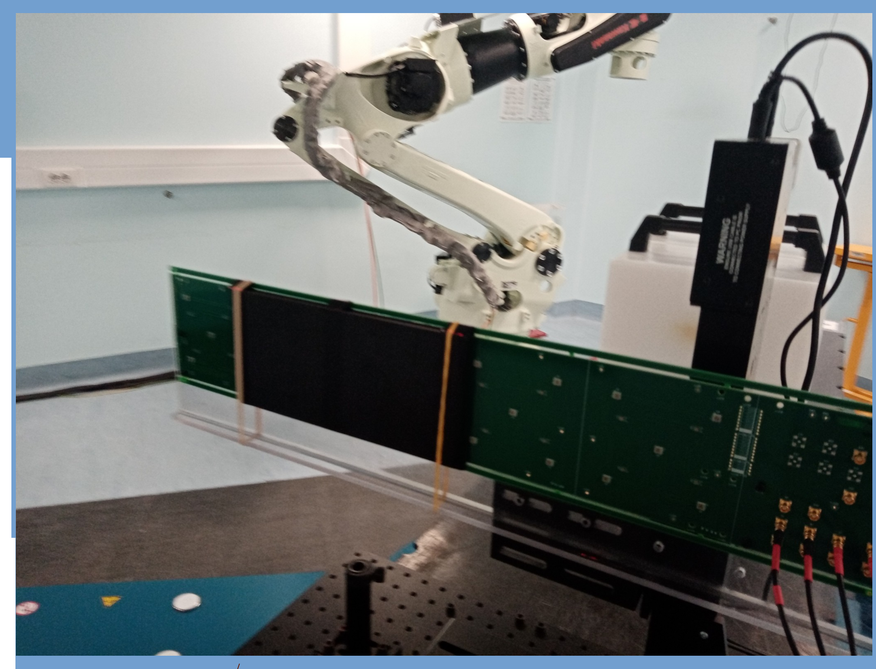
One set, 3x3 mm^2 with large gain, the other 1.3x1.3 mm^2 with low gain.
SiPM are located to guarantee a good light collection uniformity for both sets.

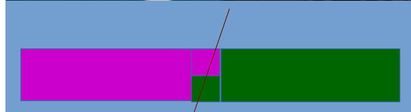
The 50 cm long PCB

The PCB 50 cm long is designed to house 5 tile 10x10x0.5 cm^3 each read by 5 SiPM 3x3 mm^2 connected in parallel (high gain) and by 4 1.3x1.3 mm^2 connected in parallel (low gain). Signals are routed to the connectors (left side below).
Two of these PCB can be ganged together to form a 1 m long PCB with 10 tiles.



We put under test at CNAO a long PCB with 2 adjacent tiles.

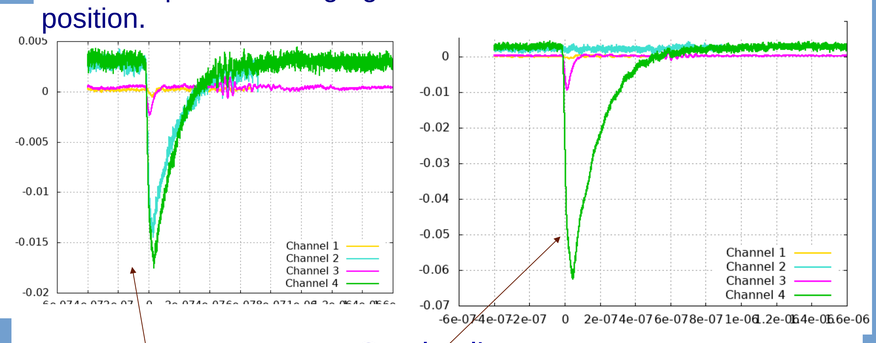




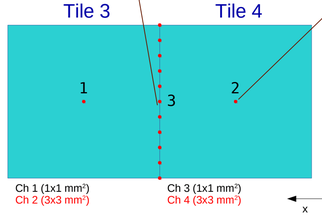
PCB edges are shaped as step to enhance hermeticity.

Some results

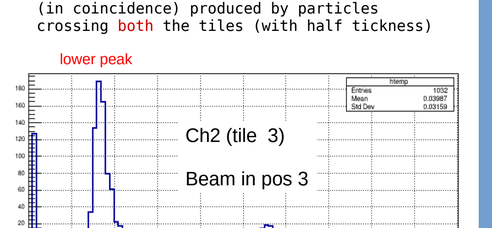
Pulse shapes of low-high gains channels for C beam in different position.

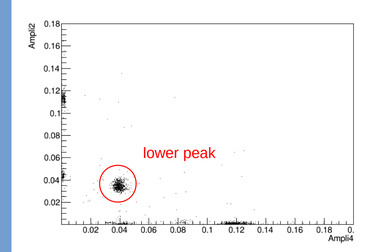


Overlap line

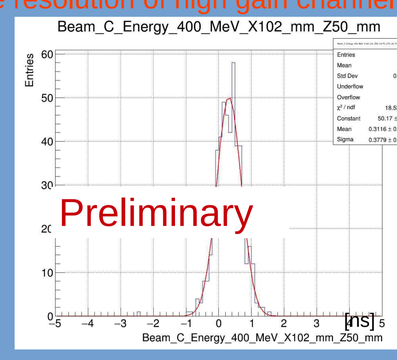


The signal amplitude shows two peaks
The lower one is due to correlated signals
(in coincidence) produced by particles
crossing both the tiles (with half tickness)





Time resolution of high gain channel



Conclusions

Prototypes of the HERD PSD have been tested with ion beams at CNAO. Saturation effects in scintillator are measured. The principle of long PCB read out is proved.
Amplitude measurements in low-high gain channels correspond to the expectations. The time resolution is adequate for the requirements of the experiment.