Study of Plastic Scintillator Detector for the High Energy cosmic-Radiation Detection (HERD) facility

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for the HERD collaboration

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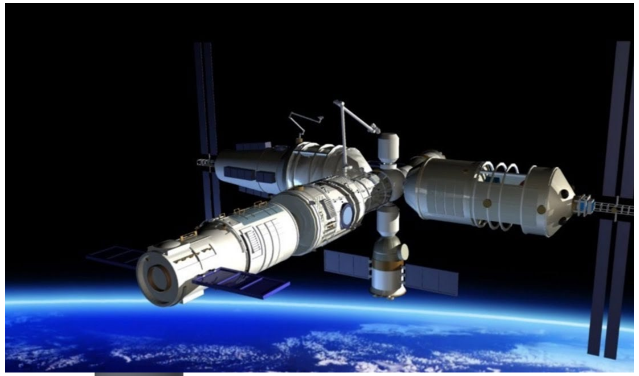
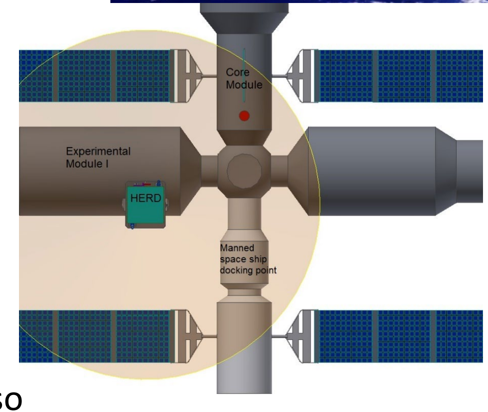
High Energy cosmic-Radiation Detection (HERD)



- International space mission to be installed onboard the Chinese Space Station (CSS) (to be completed in 2025)
- It will start operation around 2026
- Collaboration of several scientific institutions



CHINA:
Institute of High Energy Physics CAS (IHEP)
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)
University of Science and Technology of China (USTC)
Yunnan Observatories (YNAO)
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INFN Bari and Bari University
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SWITZERLAND:
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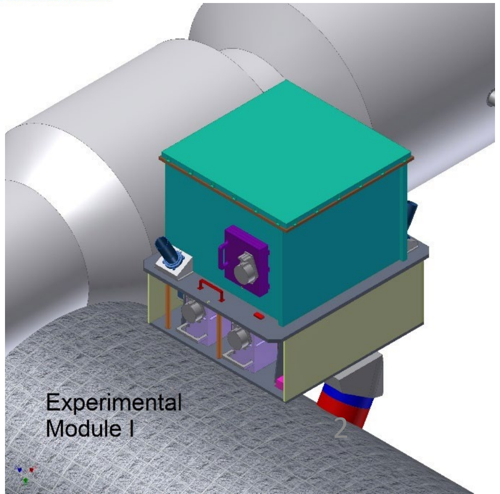
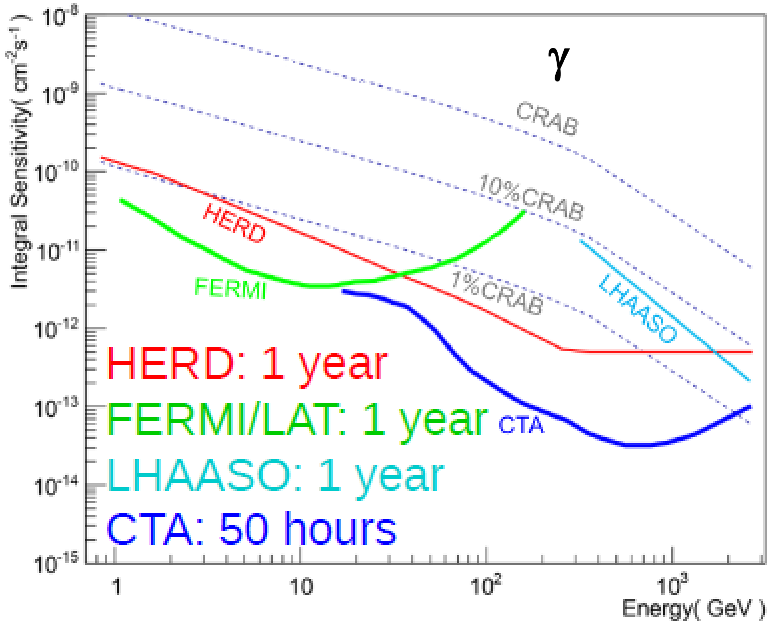
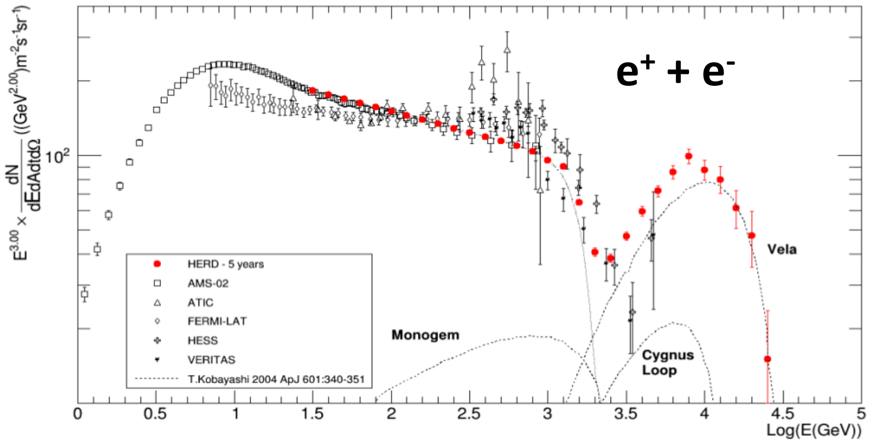
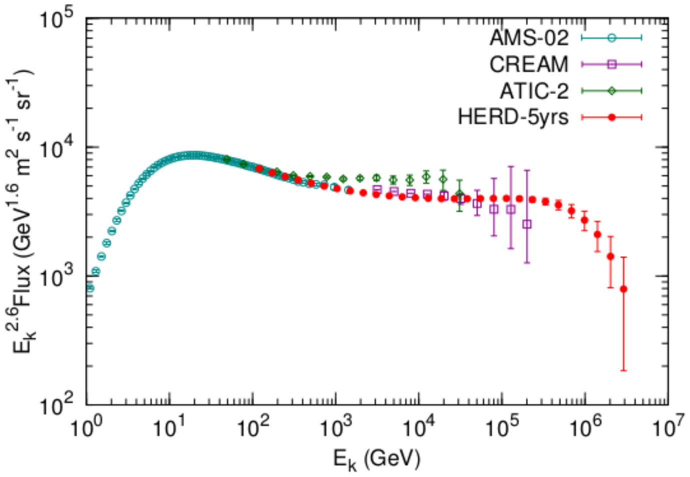


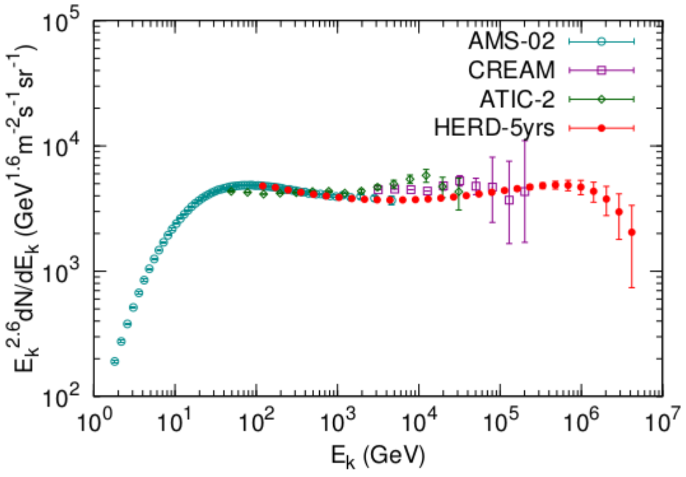
High Energy cosmic-Radiation Detection (HERD)

- **Main scientific goals:**
  - Cosmic Rays: Precise CR spectra and mass composition up to the PeV range
  - Electron spectra (and anisotropy) up to tens of TeV (nearby sources, ...)
  - Gamma – ray astronomy (spectral features at high energies) and transient studies (GRBs, flares)
  - Indirect Dark Matter searches with high sensitivity







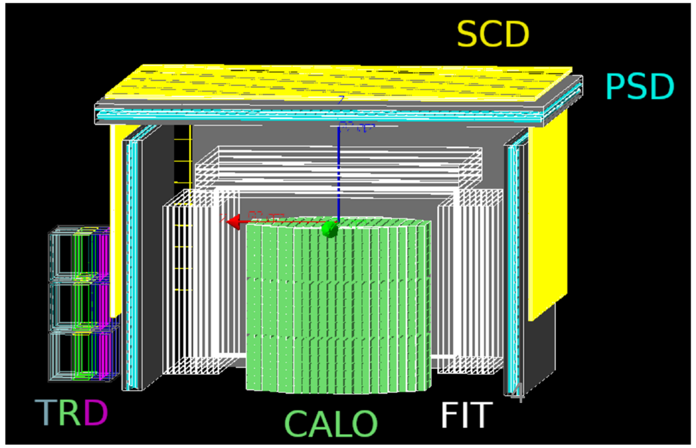


High Energy cosmic-Radiation Detection (HERD)

- **3D homogeneous, isotropic and finely-segmented calorimeter with following requirements**

	γ	Electrons	P, nuclei
Energy range	0.5 GeV – 10 TeV	10 GeV – 100 TeV	30 GeV – 3 PeV
Energy resolution	1% @ 200 GeV	1% @ 200 GeV	20% @ 100 GeV – 1 PeV
Effective geometric factor	> 1 m^2sr @ 200 GeV	> 3 m^2sr @ 200 GeV	> 2 m^2sr @ 100 TeV

- **<u>Subdectors:</u>**
  - **FIT**: *The CALO is surrounded by Fiber trackers (FiTs) (except the bottom)*
    - Trajectory Reconstruction, Charge Identification
  - **CALO**: *The HERD core is a 3D, homogeneous, isotropic and finely-segmented calorimeter*
    - Energy Reconstruction, e/p Discrimination
  - **PSD**: *The CALO and the FIT are covered by the plastic scintillator detector (PSD)*
    - CRs charge measurement, γ identification
  - **SCD**: *The silicon charge detector (SCD) is the outermost detector*
    - charge measurement
  - **TRD**: *A Transition Radiation Detector (TRD) will be located on the lateral side*
    - Calibration of CALO



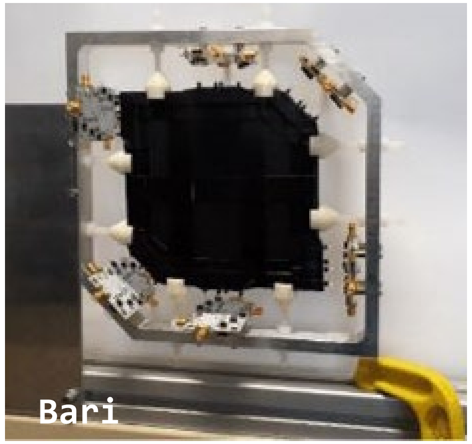
Plastic Scintillator Detector (PSD)

- Two main purposes:
  - gamma-ray identification (VETO of charged particles)
  - Charge measurement
- Must be highly segmented to avoid back splash effect
- Requirements:
  - High efficiency for charged particle identification
  - Good energy resolution and a frontend readout with high dynamic range for charge measurement
  - Low power consumption for space application
- Layout configuration – being studied:
  - Segmented scintillator (bar / tile geometry)
  - Silicon Photomultiplier (SiPM)

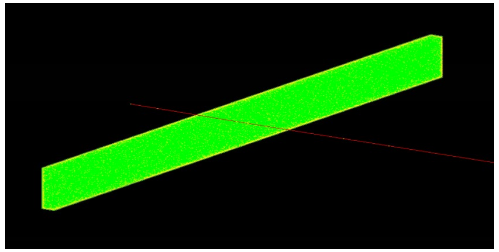
PSD proposed layout

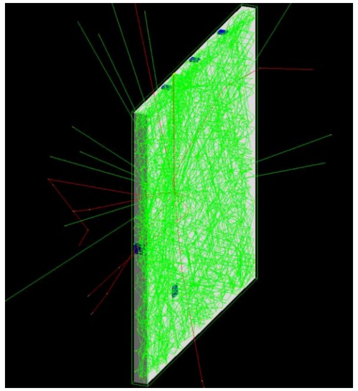
- Bars:
  - Two layers – one per view
  - Each layer made by two staggered sub layers to increase hermeticity
  - Readout with up to 6 SiPMs per bar (3 OR-ed SiPMs per side)
  - PRO: fewer readout channels
  - CON: higher back-splash contamination

- Tiles:
  - Two layers of squared tiles to improve efficiency and charge measurement
  - Readout with up to 6 SiPMs per tile (3 OR-ed SiPMs per side on two opposite sides)
  - PRO: better back-splash rejection
  - CON: higher number of readout channels

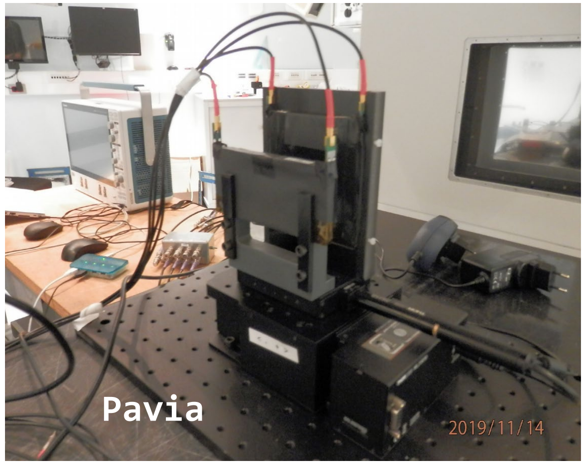


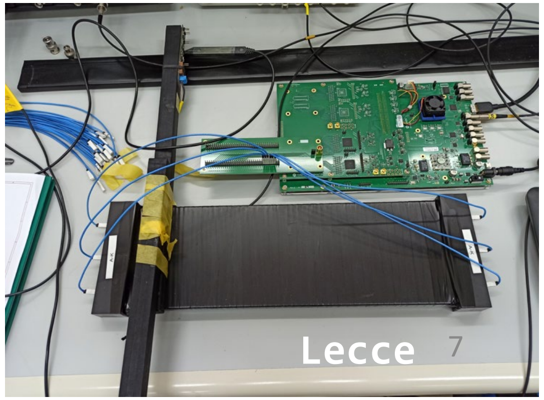
Prototypes and simulations





- Simulations:
  - GEANT4 simulation to track optical photons
  - Detailed study of scintillator wrapping and SiPM readout
  - Comparison of performance of bar/tile configurations
- Prototype tests:
  - Lab test with Cosmic Rays and radioactive sources
  - Beam test with protons and ions @CERN PS/SPS
  - Beam test with protons and carbon @CNAO (Pavia, Italy)
    - National Centre for Oncological Adrotherapy (CNAO): facility for hadron therapy for treating solid tumors
    - Beams of protons (60-250 MeV) and carbon ions (120-400 MeV/u)
    - Beam transverse size $\sigma_{x,y}$~ 5 mm
    - Beam intensity for therapy: up to 10^{12} for protons, 10^{9} for C ions

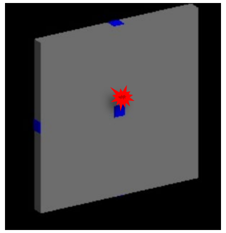




Simulation overview

- Geometrical settings:
  - Scintillator shape, size, width and material (BC-404, EJ200 ..)
  - Wrapping thickness and material
  - SiPMs size and position
- Set the bulk and the surface optical properties:
  - Light Yield and attenuation length of the scintillator material, refractive index, surface optical properties of the wrapping: e.g. a polished or rought-cut wrapping

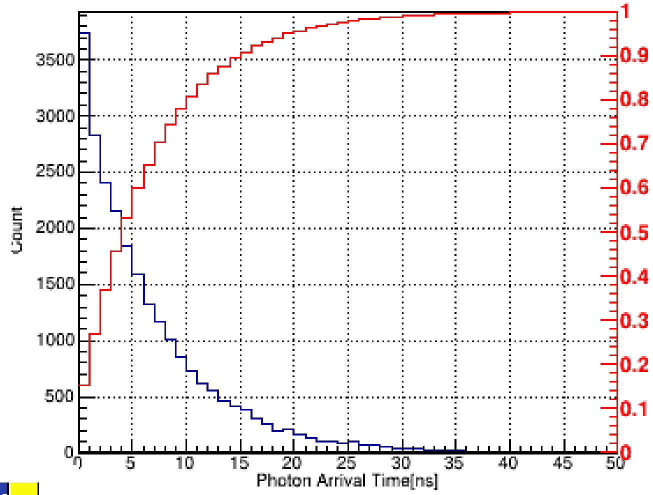
Simulation studies



10x10cm^2

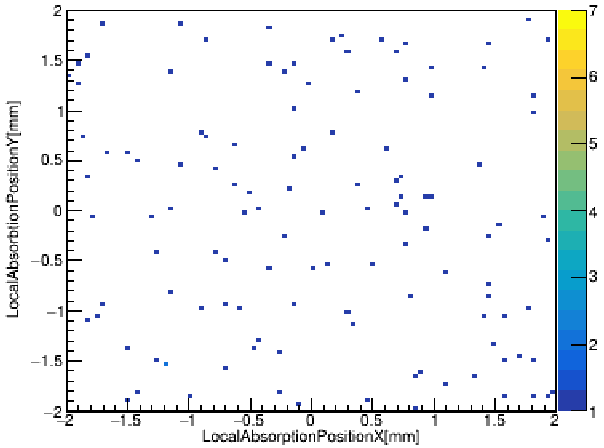
Tracking of all scintillation photons allows a detailed study of:

- Photon collection time → SiPM's timing response to optimize the electronic read-out
- Photon spatial density → SiPM's cell occupancy to optimize the SiPM design in terms of cell size in order to avoid the saturation



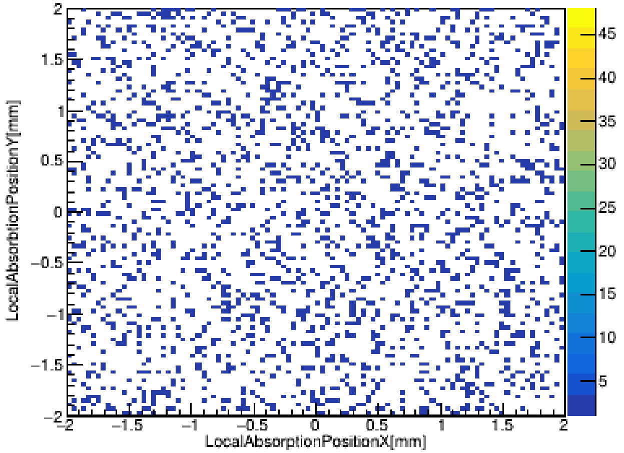
50% ph. in 5ns
80% ph. in 10ns

Protons



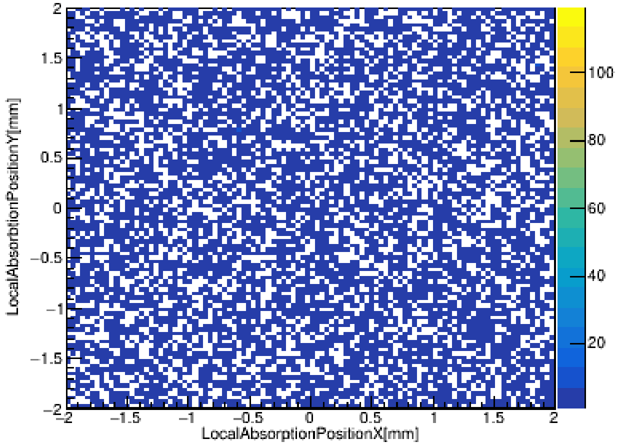
Fired cells/collected ph. = 1

Carbon



Fired cells/collected ph. = 0.87

Iron



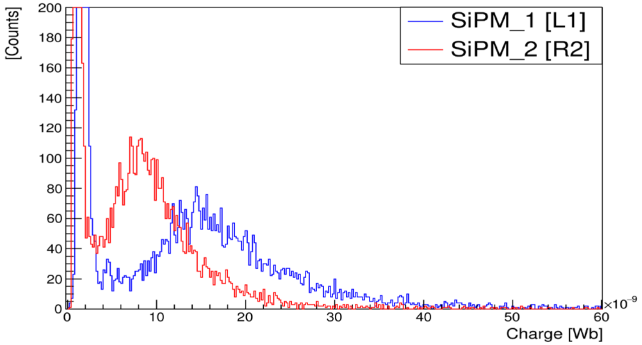
Fired cells/collected ph. = 0.59

4x4mm^2 SiPM
with 40µm cells

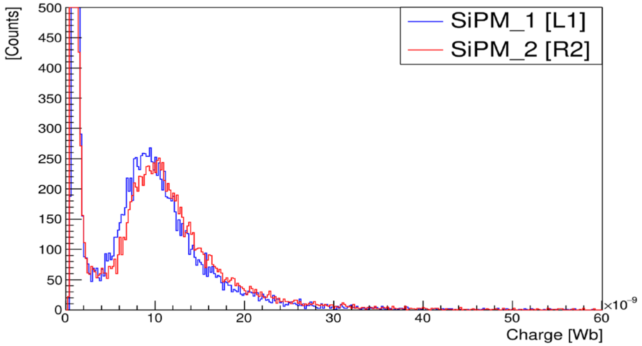
Laboratory tests

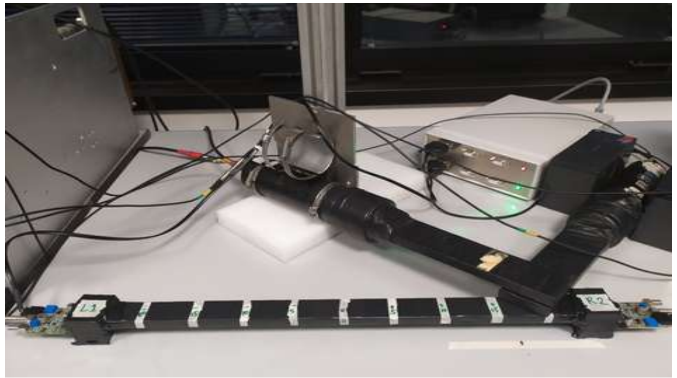
- **Study response to MIPs**
- EJ–200 50x3x1cm^3 scintillator bars coupled with 1,2 or 3 AdvanSiD / Hamamatsu SiPMs per side with cosmic rays (CRs)
- Readout: custom amplifier and CAEN DT5550W system based on CITIROC ASICs
- Two external scintillators used as external trigger

Configuration at -19.5 cm

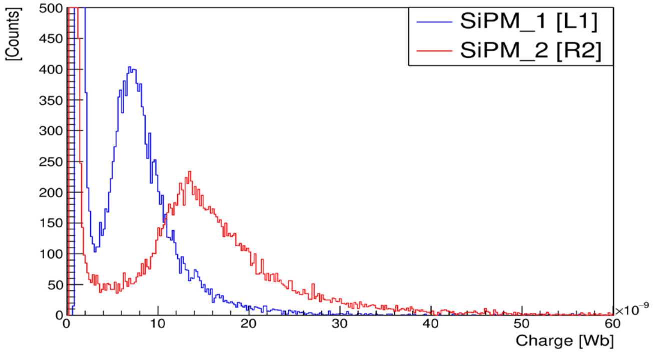


Configuration centered



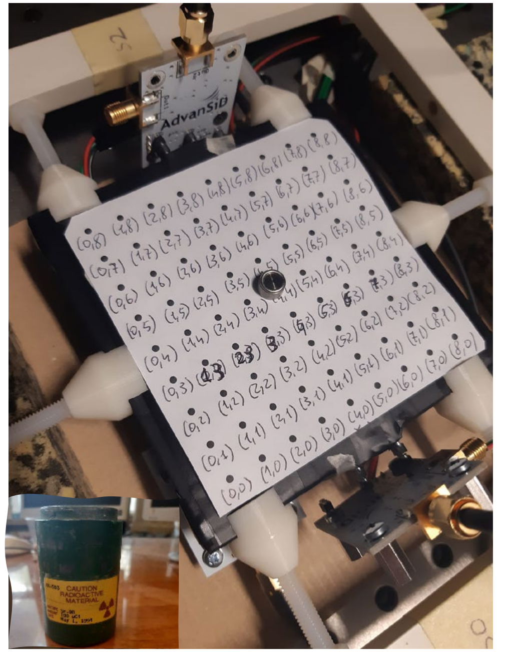


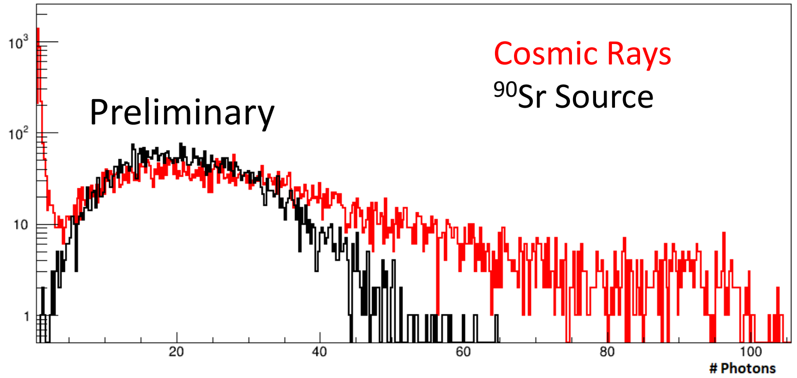
Configuration at +19.5 cm

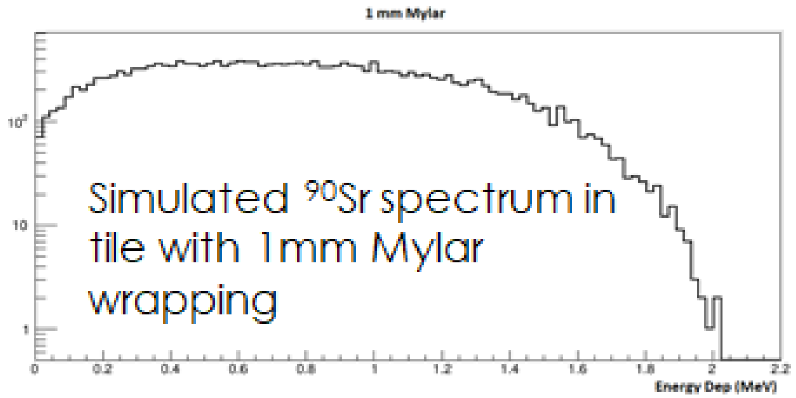


Laboratory tests (2)

- **Study response to MIPs**
- BC-404 scintillator 10x10x1cm^3 tile tested with CRs a ^{90}Sr radioactive source coupled to AdvanSid SiPMs
- AdvanSid trans-impedance preamplifier
- Trigger obtained from logic AND of two opposite SIPMs
  - Threshold set to reduce the noise trigger rate due to coincidence of dark noise of the two SiPMs

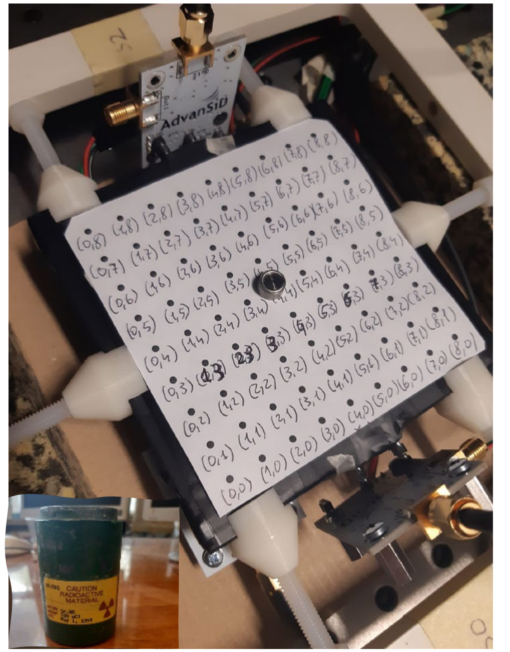


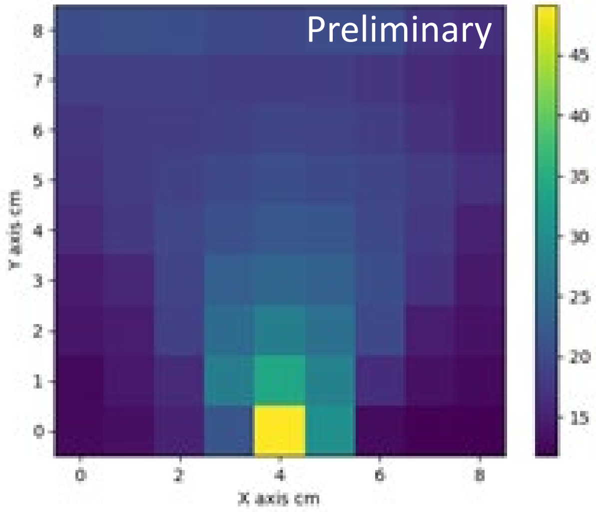


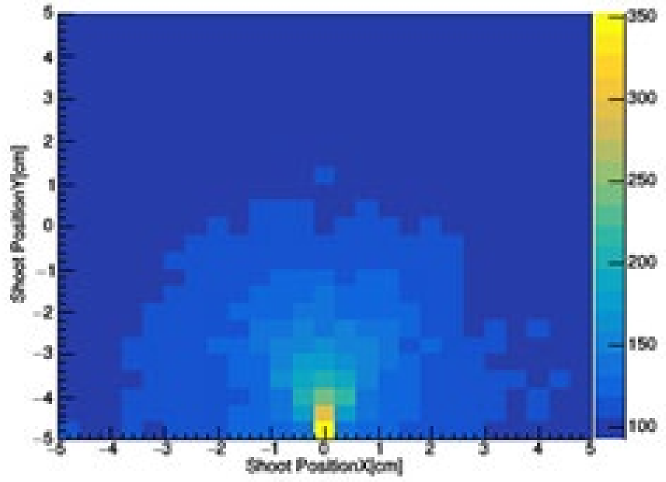


Laboratory tests (2)

- **Uniformity test**
- ^{90}Sr radioactive source placed in different positions with a 1-cm step to study the uniformity in light collection
- Compared to simulations where particles hit the tile in different positions

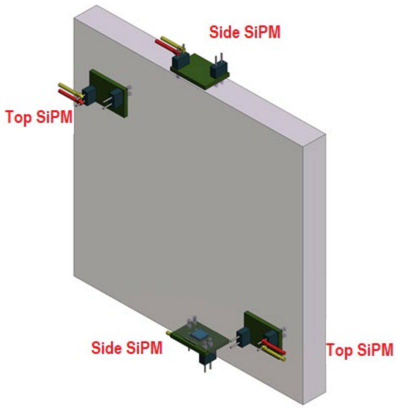




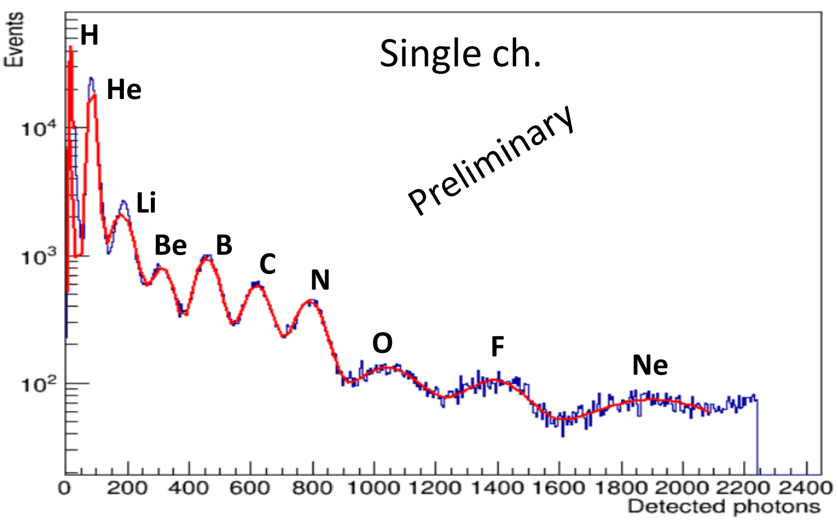


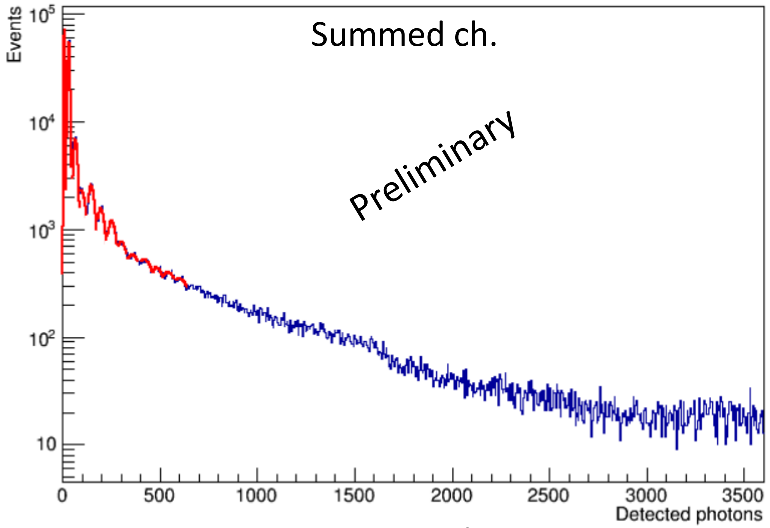
Similar distributions, but simulation does not take into account SiPM photon detection efficiency and SiPM/Scintillator optical coupling

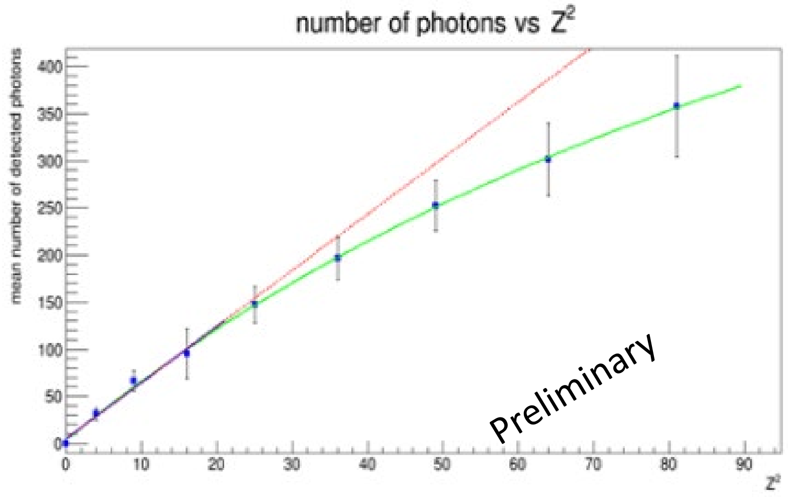
CERN beam test @SPS H4



- Primary beam of lead, with energy 150GeV/A, impinging onto a Beryllium target, selected momentum of 330 GeV/Z,
- Scintillator tile coupled to 4 SiPMs irradiated in the central position
- Aim: Capability to discriminate ion charge.
- Improvement obtained by summing together the signals from SiPMs

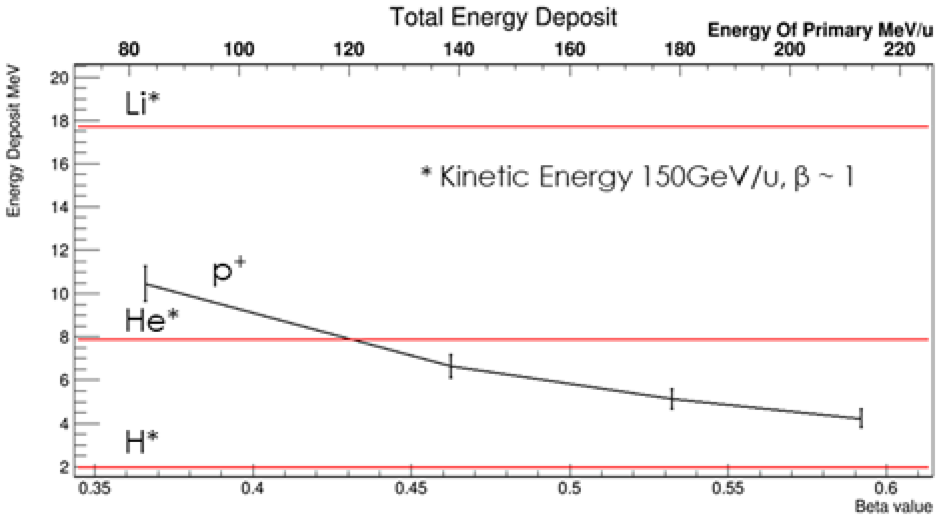


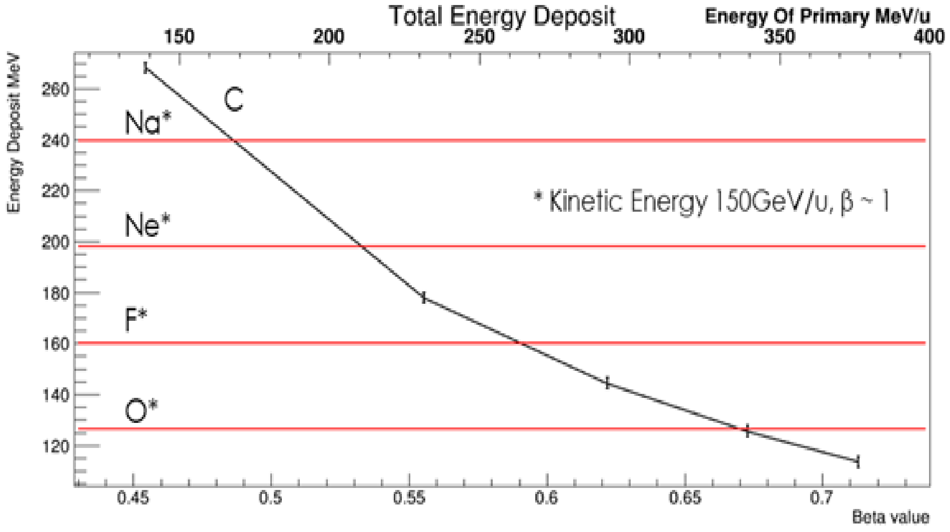




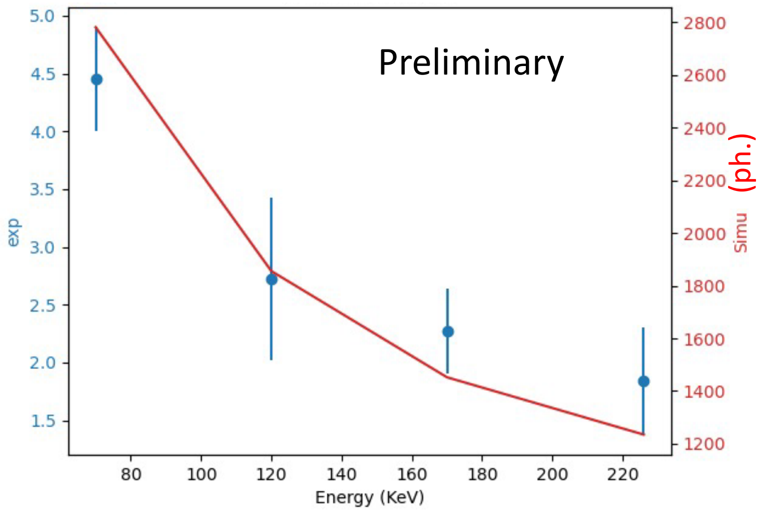
CNAO test beam

- The high energy ion (m.i.p.) interaction with scintillator can be mimicked by low β ions.
  - Scanning β allows to study Birks' law: saturation of light yield in presence of large local energy release.
- BC-404 tile coupled with Hamamatsu SiPMs (15 and 50 µm cell size)

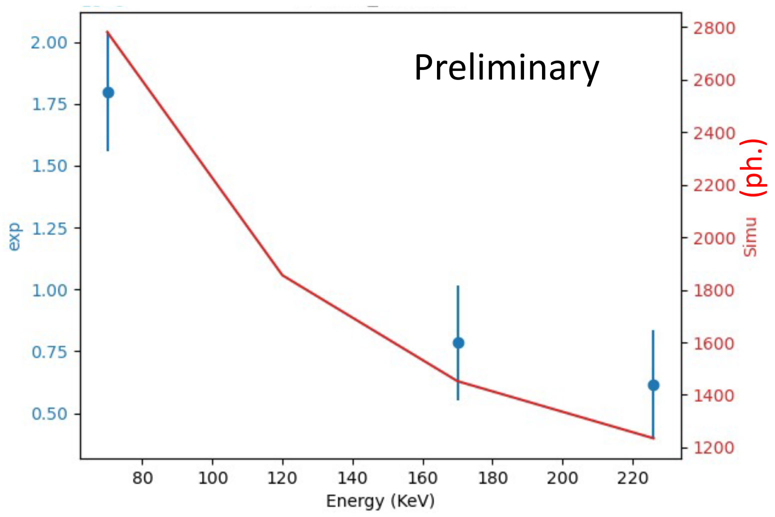




3x HAM-50µm cell



HAM-15µm cell



Conclusions

- The **High Energy cosmic-Radiation Detection** (HERD) facility will start its operation around 2026 onboard the China's Space Station.
  - It will provide high quality data on charged cosmic rays and gamma rays giving a valuable contribution in several scientific topics as dark matter searches, study of cosmic ray chemical composition and high energy gamma-ray observations.
- The PSD needs to have a very high detection efficiency for charged cosmic rays, which represent the main background for the identification of gamma rays, and a very good capability in identifying charged nuclei.
  - The choice of the proper PSD geometry is a critical aspect to reach the best particle identification performances
  - The future HERD space mission will employ Silicon Photomultipliers (SiPMs) instead of classical Photomultiplier Tubes to read out the scintillator light emission to exploit their smaller sizes and lower power consumption.
  - More beam tests @CNAO and CERN foreseen in 2020 and 2021