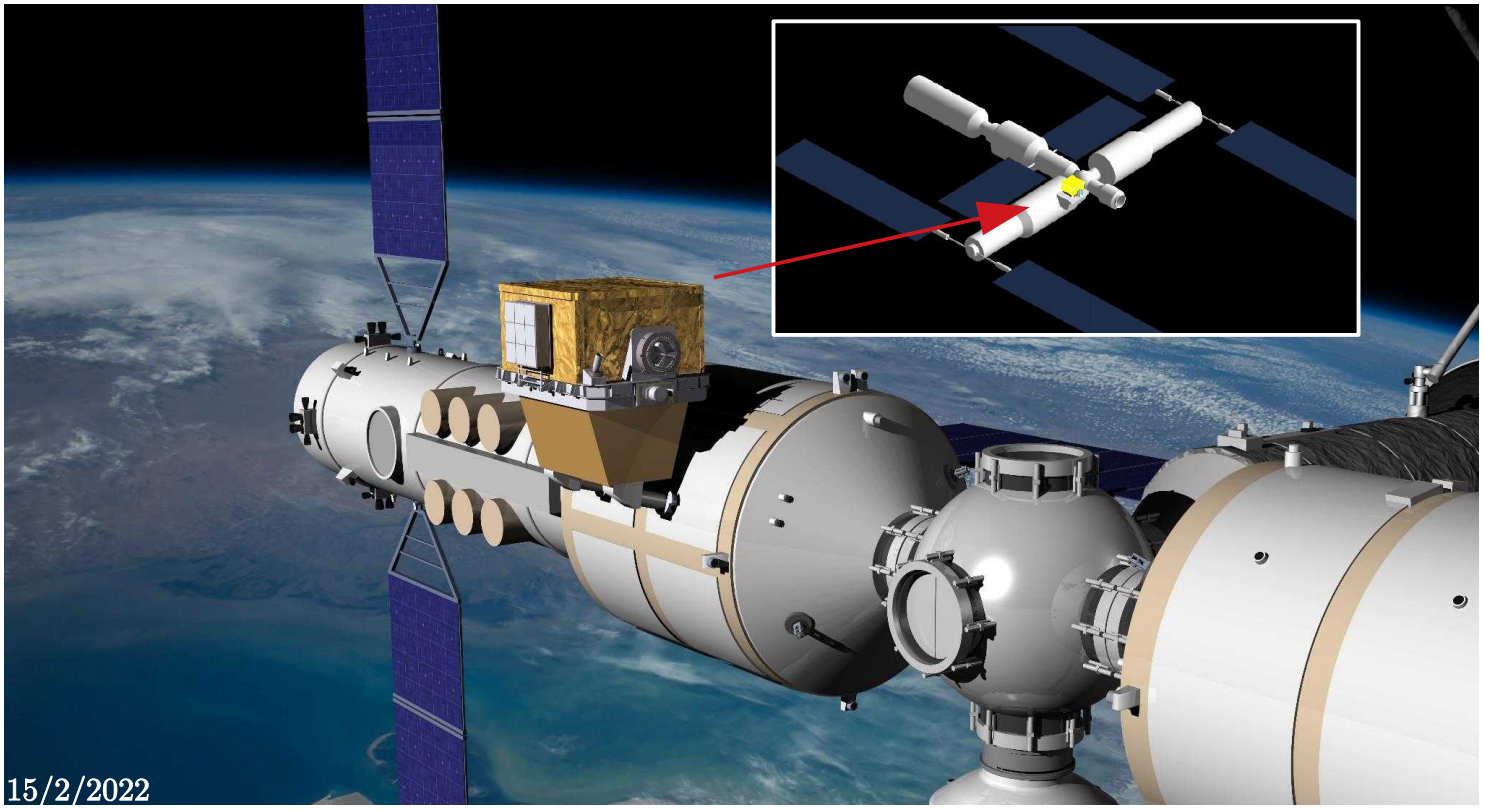
Astroparticle Physics Scientific Fair



The HERD space mission: Detecting Galactic Cosmic Rays at the Highest Energies

D. Kyratzis, F. Alemanno, F. Barbato, I. De Mitri, A. Di Giovanni,
M. Di Santo, M. Fernandez Alonso, A. Parenti, L. Silveri, A. Suma, L. Wu

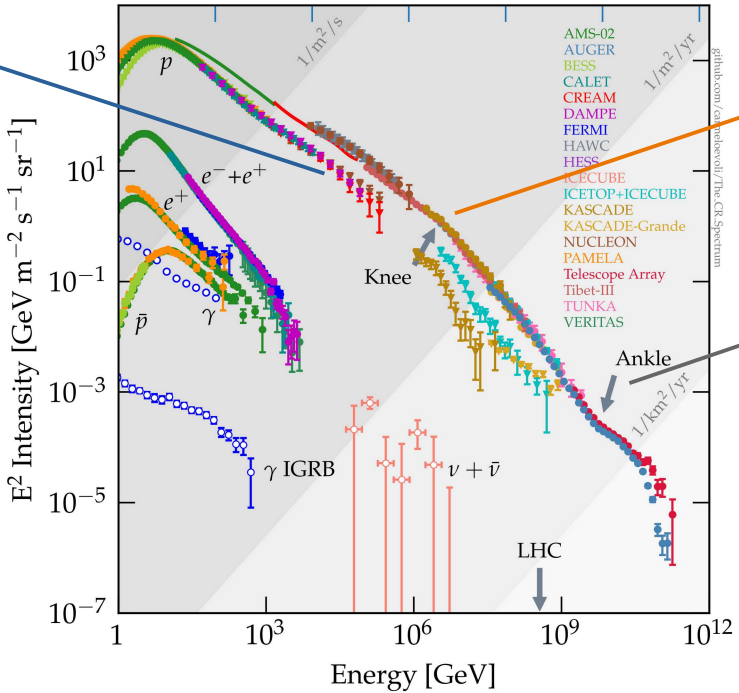
Gran Sasso Science Institute (GSSI) & INFN-LNGS

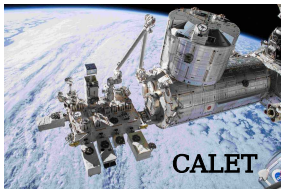
The Cosmic Ray Landscape

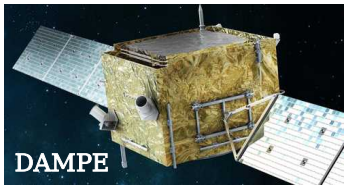
Energies achieved with current space – borne direct CR experiments (~ hundred TeV)

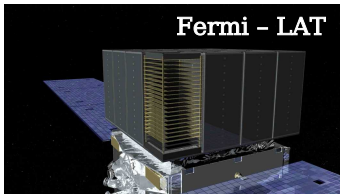
Maximal energies achieved with direct detection CR experiments (~ PeV)

Region covered by indirect CR experiments (~ 10^{20} eV)









Direct CR experiments

Precise measurement of particle charge and energy

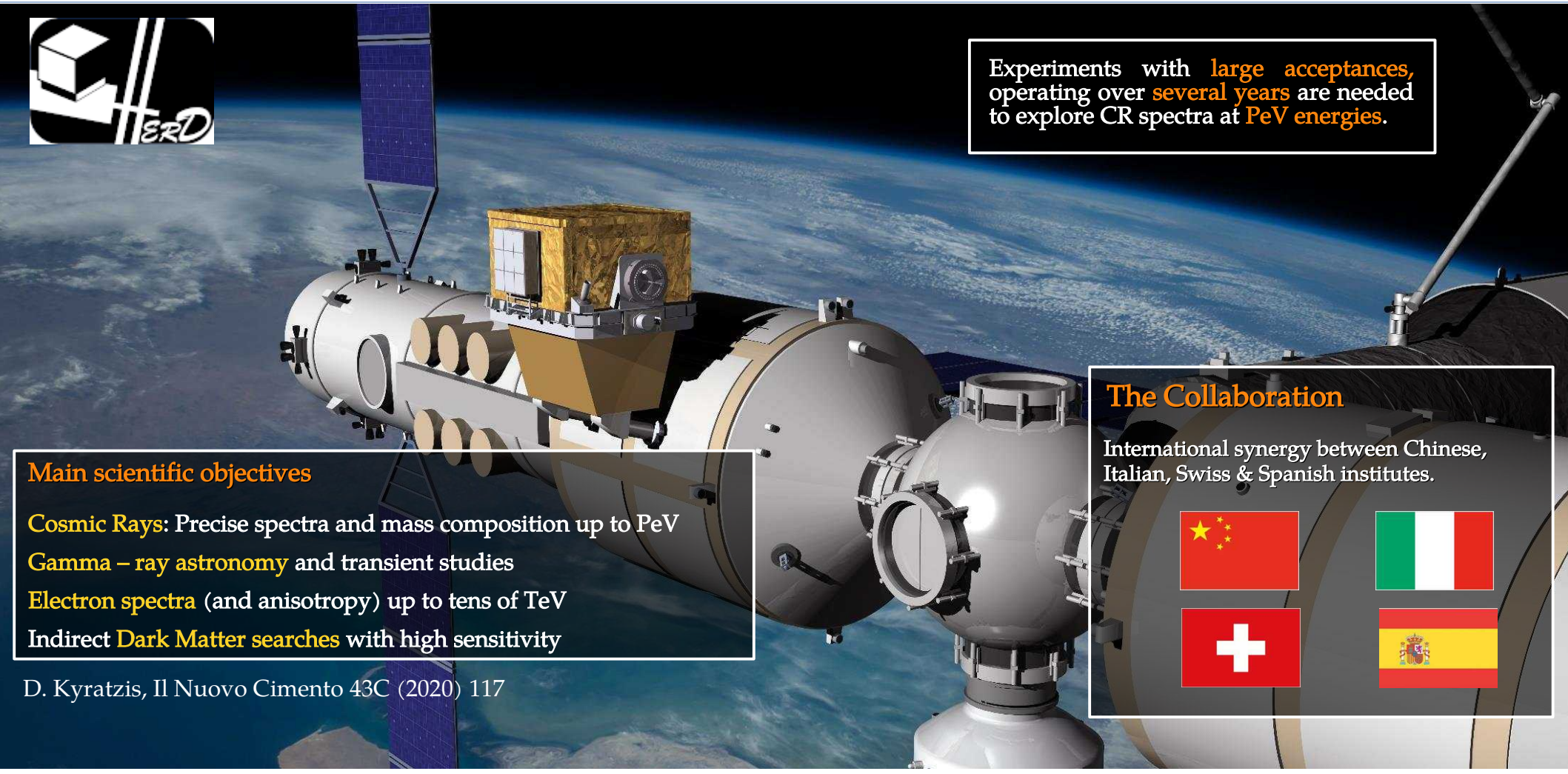
Small exposure to provide statistically meaningful measurements above few tens of TeV.

Indirect CR experiments

Huge achievable energies

Difficulty in making composition studies with small systematics

The High Energy cosmic-Radiation Detector



Experiments with large acceptances, operating over several years are needed to explore CR spectra at PeV energies.

Main scientific objectives

Cosmic Rays: Precise spectra and mass composition up to PeV

Gamma – ray astronomy and transient studies

Electron spectra (and anisotropy) up to tens of TeV

Indirect Dark Matter searches with high sensitivity

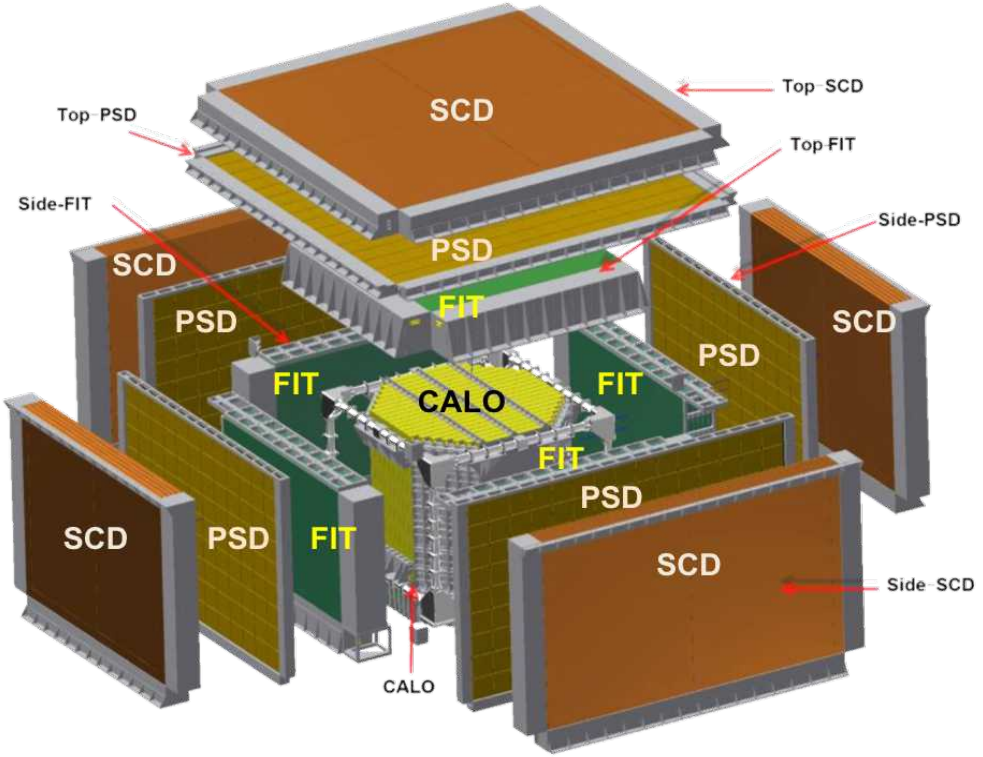
D. Kyratzis, Il Nuovo Cimento 43C (2020) 117

The Collaboration

International synergy between Chinese, Italian, Swiss & Spanish institutes.

HERD: Detector Description

Based on previous experience with AMS-02, FERMI & DAMPE missions



A deep (~55 X_0, 3 λ_I) 3D cubic calorimeter (CALO), octagonal prism, accurately measuring deposited energy + e/p separation

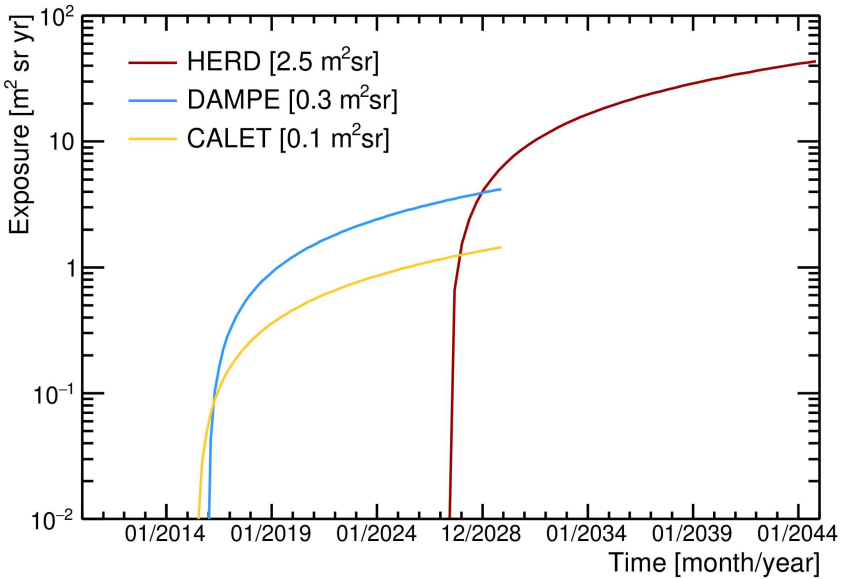
Fiber Tracker (FIT), determining tracks of impinging particles.

Plastic Scintillator Detector (PSD), providing gamma–ray and charged particle triggers + charge measurement.

Silicon Charge Detector (SCD), ensuring an additional charge measurement

plus A Transition Radiation Detector (TRD), placed on one of the lateral faces, providing energy calibration of nuclei (TeV region).

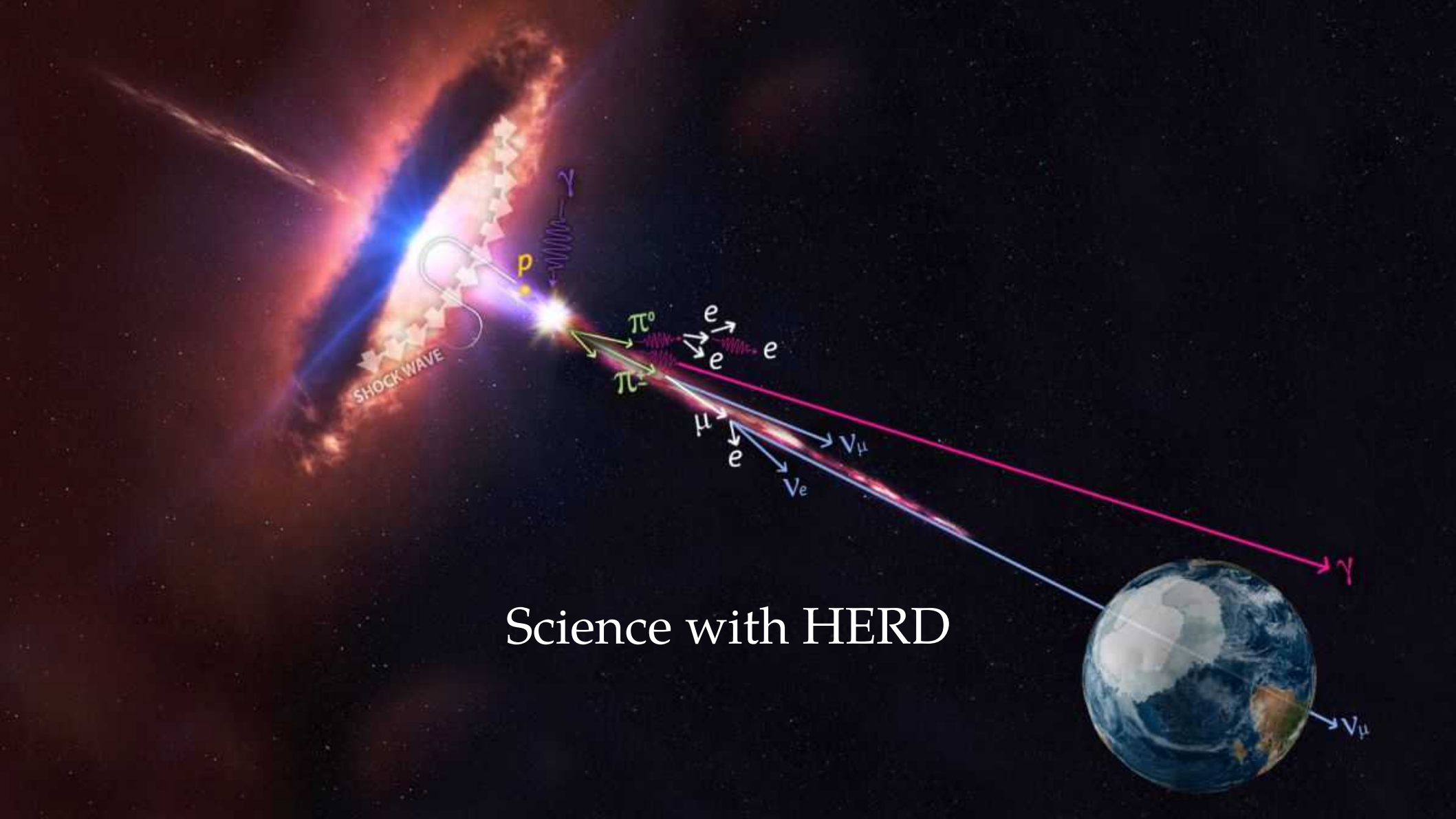
Expected performance



One order of magnitude upgrade in exposure wrt to current gen CR experiments:

15 – 20 m² sr yr

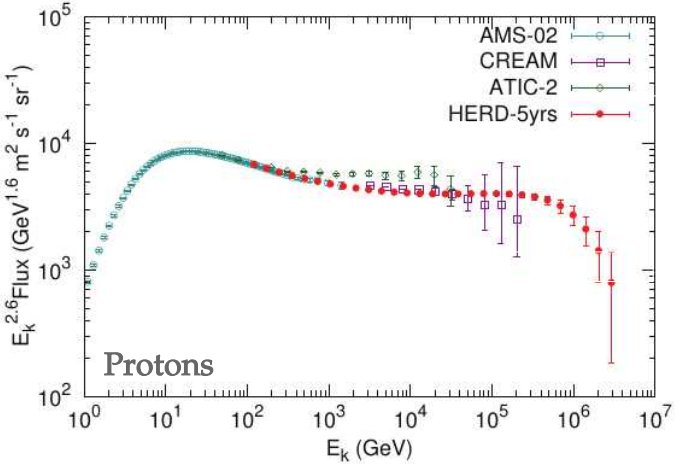
Main Requirements	
Energy range (e/γ)	10 GeV-10s TeV(e); > 100 MeV (γ)
Energy range (CRs)	30 GeV – 3 PeV
Angular resolution	0.1 deg. @ 10 GeV
Energy resolution (e/γ)	1-2% @ 200 GeV
Energy resolution (p)	20-30% @100 GeV – PeV
e/p separation	~10^{-6}
Geometric Factor (e)	>3 m²sr @ 200 GeV
Geometric Factor (p)	>2 m²sr @ 100 TeV
Pointing	Zenith
Field of View	+/-70 deg
Mass	< 4 tons
Lifetime	~10 years

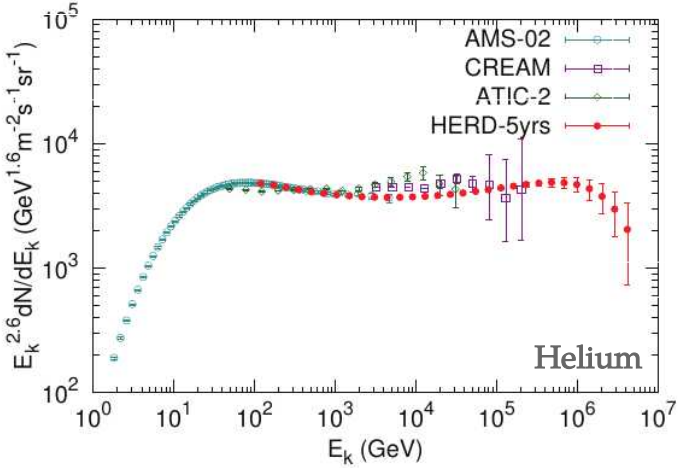


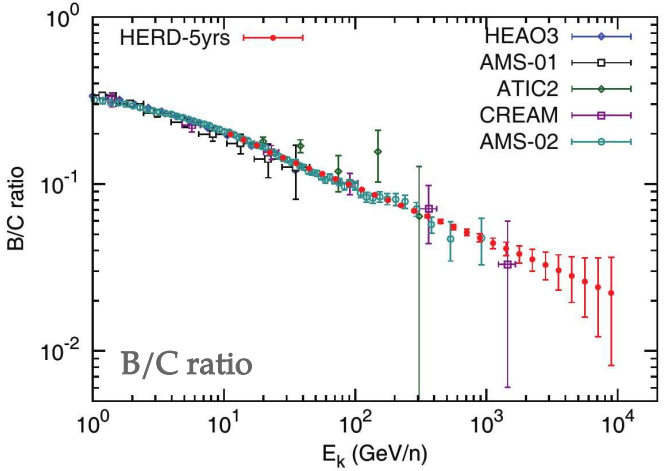
Science with HERD

Cosmic Ray Nucleonic Spectra

Pronounced features such as the **"knee"** in the CR spectrum can be examined via **direct p & He measurements**





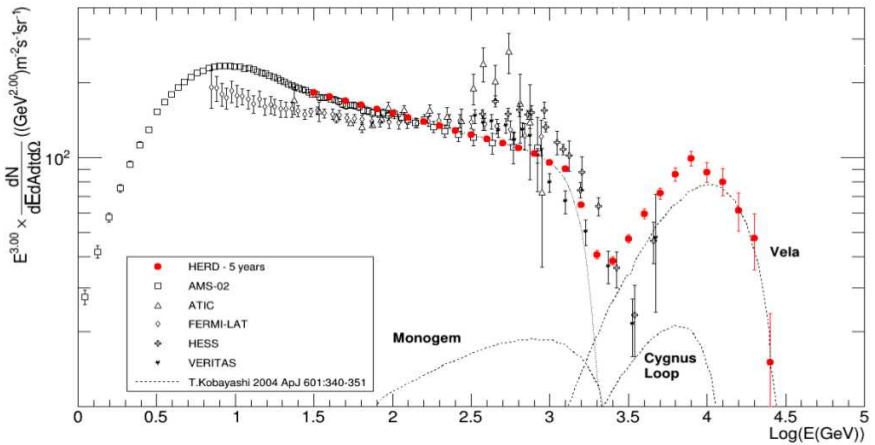


Measuring **CR fluxes** from **protons to iron** with **direct observations** up to the **highest energies**

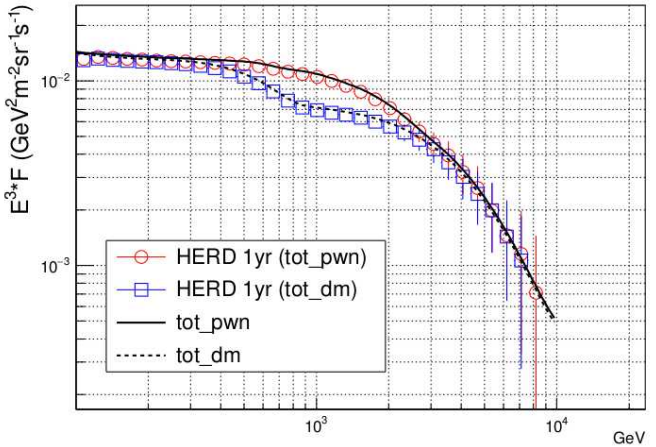
Extending the fluxes of medium mass **(BCNO group)** to their **highest achievable limit with direct measurements**

Cosmic Ray Electrons & Gamma – Rays

Expected flux after 5 years of operation



Astrophysical or Dark Matter sources?

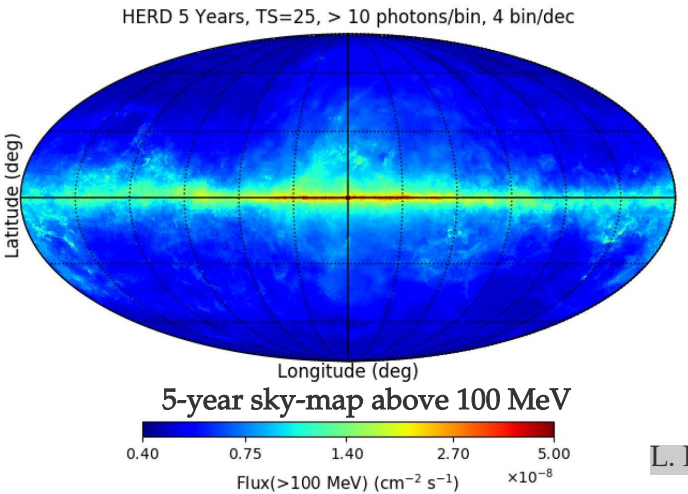


HERD will be able to accurately determine the **all – electron flux** up to **several tens of TeV**

Multimessenger Era

Possible synergy w/ ground-based experiments:

Gamma – rays (CTA, LHAASO)
Neutrinos (KM3NeT, IceCube)
Gravitational Waves (Ligo, Virgo)

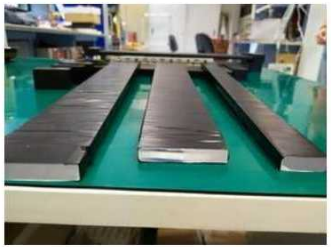


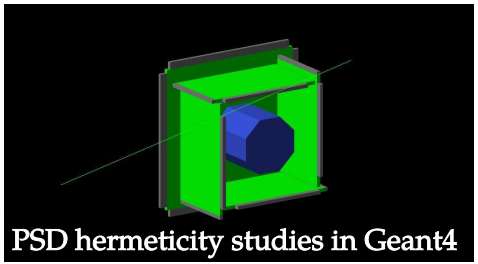
Owing to its **large acceptance & sensitivity**, HERD will be able to conduct **full gamma-ray sky** surveys (> 100 MeV)

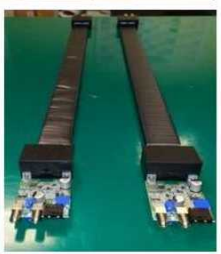
L. Farina et al, PoS, ICRC2021(2021) 651

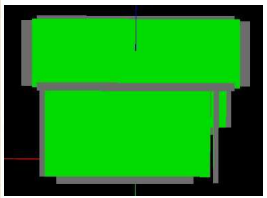
GSSI Group Activities

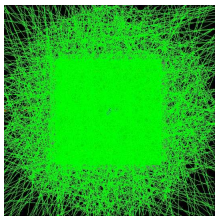
GSSI is heavily involved (in conjuction with other institutes) in the realization of the HERD PSD, via hardware R&D and MC simulations.

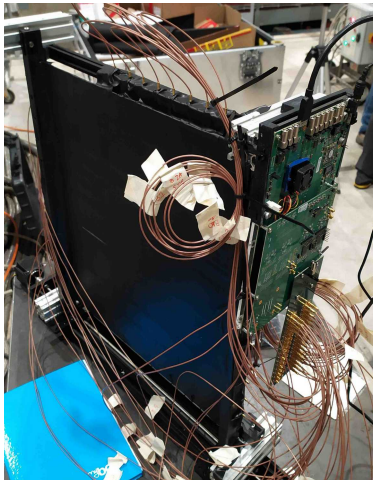












The PSD will operate as anti–coincidence providing charge measurements of incoming CR nuclei in a range of Z = 1 – 26.

Main requirements: high detection efficiency, broad dynamic range & good energy resolution.

Previous, current and upcoming activities concern:

Hardware

Preparation, assembly & performance validation of scintillator bars coupled w/ SiPMs + tested with a multitude of particles and beams

(configured at GSSI & LNGS)

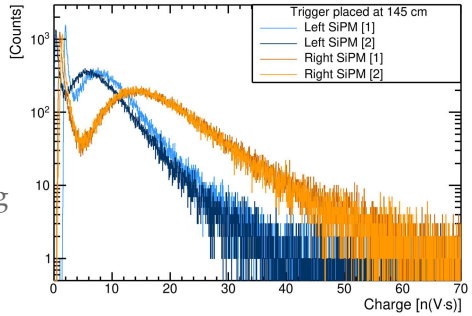
Software

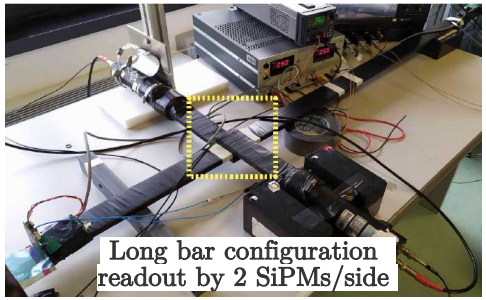
Dedicated GEANT4 – based simulation evaluating performances of various PSD configurations tested in the lab along with their inherent properties

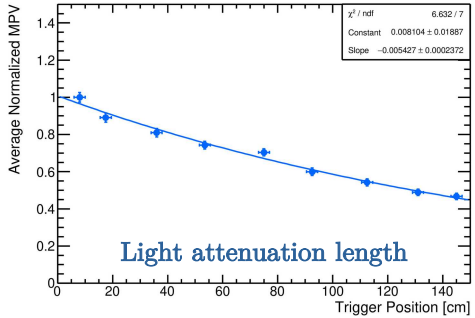
Few results...

Two scintillator geometries are currently investigated, one based on **long bars while the other on square tiles.**

Cosmic ray muon **charge distributions** measured in various **trigger positions** along the bar



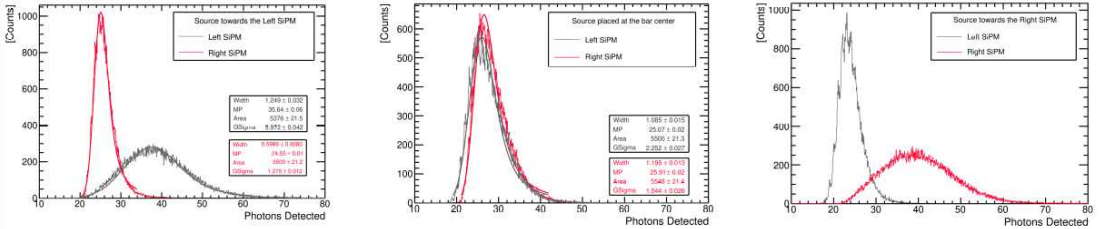




Measurement of **light attenuation length** extracted from all trigger positions

D. Kyratzis et al, PoS, ICRC2021(2021) 054

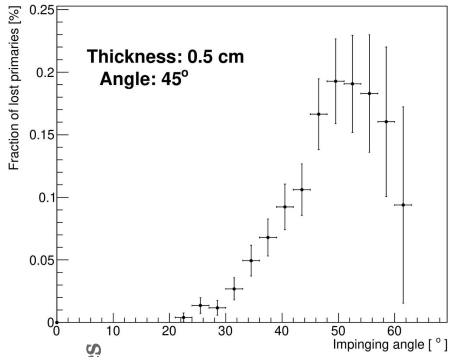
Common Gain: 5.5 x 10⁵ Photon Thr: 5.5 p.e



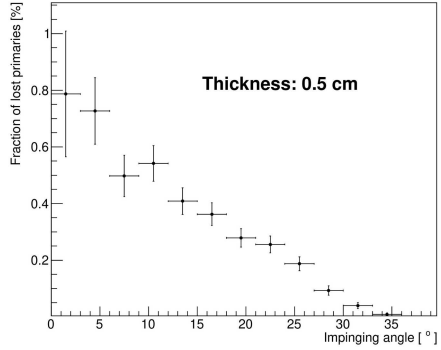
Measurements taken w/ ^{90}Sr in 3 positions along the bar

Radioactive source measurements, scanning the PSD configuration along **various bar positions**

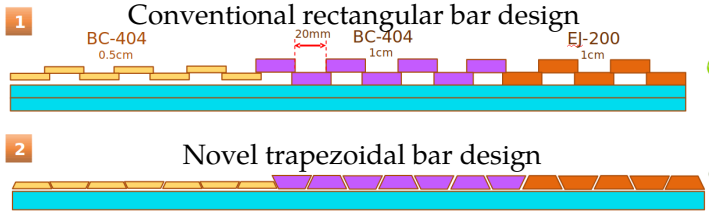
Trapezoidal Bars on GEANT4



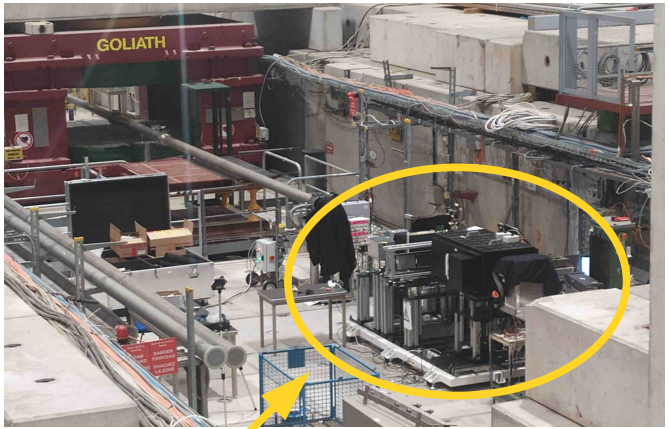
Rectangular Bars on GEANT4



Hermeticity studies

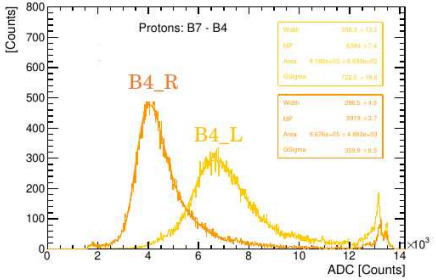


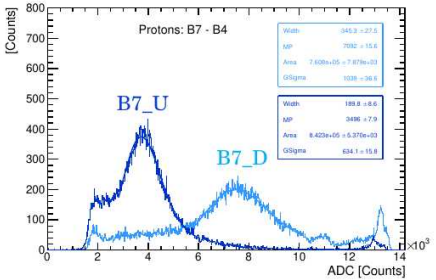
CERN SPS & PS campaigns

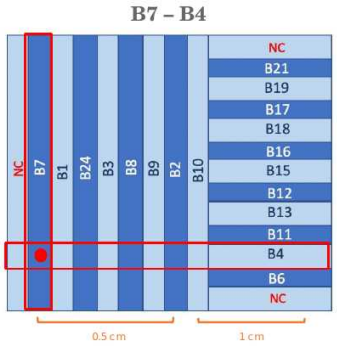


Installation @ CERN - SPS

Protons

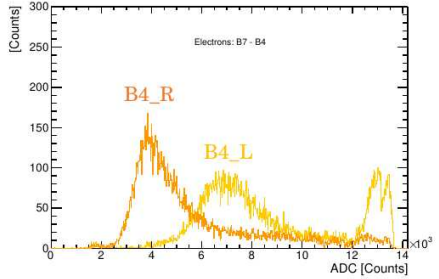


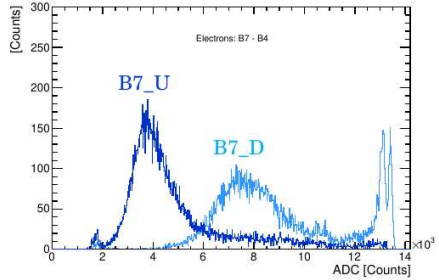


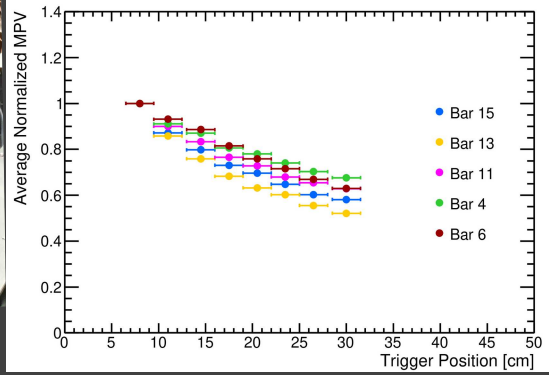


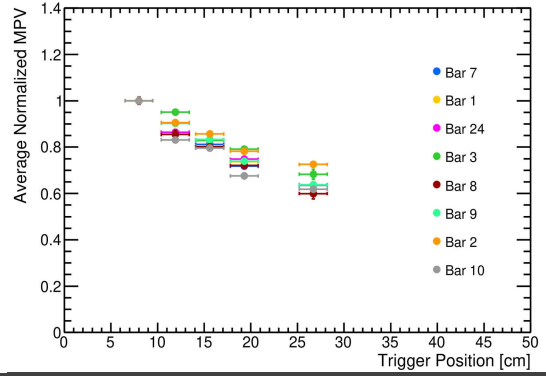
p & e⁻ beam results on specific bars

Electrons









Evaluation of average MPV behaviour regarding 13 tested bars in various trigger positions

Summary

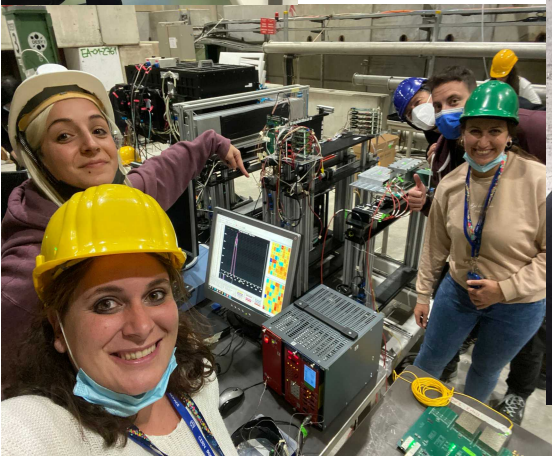
HERD is a novel space – borne detector, to be installed on–board **China's Space Station** (CSS) around 2027, with an **expected lifetime of ~10 years**.

Main scientific objectives revolving around **high energy galactic CRs**, **gamma – ray astronomy** and indirect **DM searches**.

Novel detector, comprising a deep **3-D calorimeter** (CALO), a **Fiber Tracker** (FIT), a **Plastic Scintillator Detector** (PSD) and a **Silicon Charge Detector** (SCD) instrumented on both the **top and lateral sides**, along with a **Transition Radiation Detector** (TRD).

Coupling **state-of-the-art detector techniques** with a pioneering design in HERD, an **order of magnitude increase in acceptance** can be attained, considering previous & current missions.

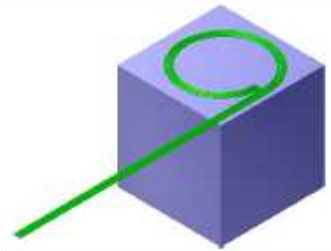
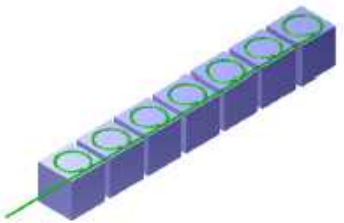
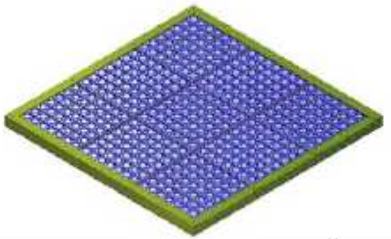
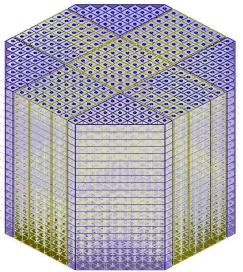
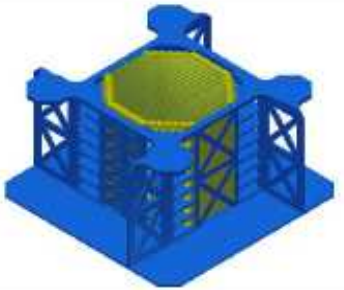
Ongoing and future work in HERD foresees continuous development efforts manifested through dedicated **hardware R&D** and **MC simulations** in order to verify its performances.



Greetings from the
GSSI Space Group!

G S
S I

HERD sub-detectors: Calorimeter (CALO)

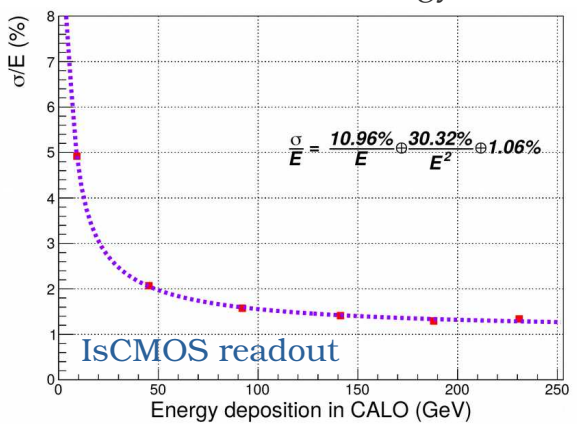
Item	Value
Type of crystal	LYSO
Nuclear interaction length	3 (55 X_0)
Number of crystals	~7500
Crystal dimension	3 x 3 x 3 cm^3

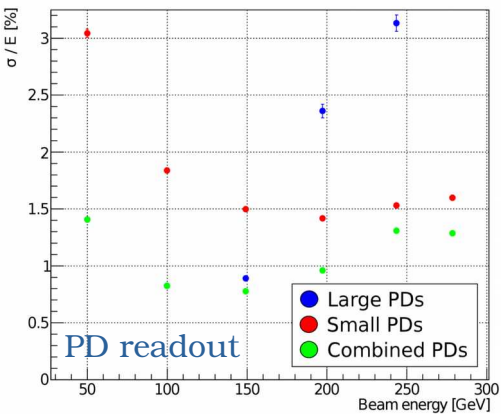
Scintillation light is readout independently by:

1) WLS fibers coupled to IsCMOS cameras
2) Photodiodes connected to custom frontend electronics

Partial readout of crystals with PhotoDiodes (Calocube) for calibration extended dynamic range & reduced systematics.

Energy resolution for electrons

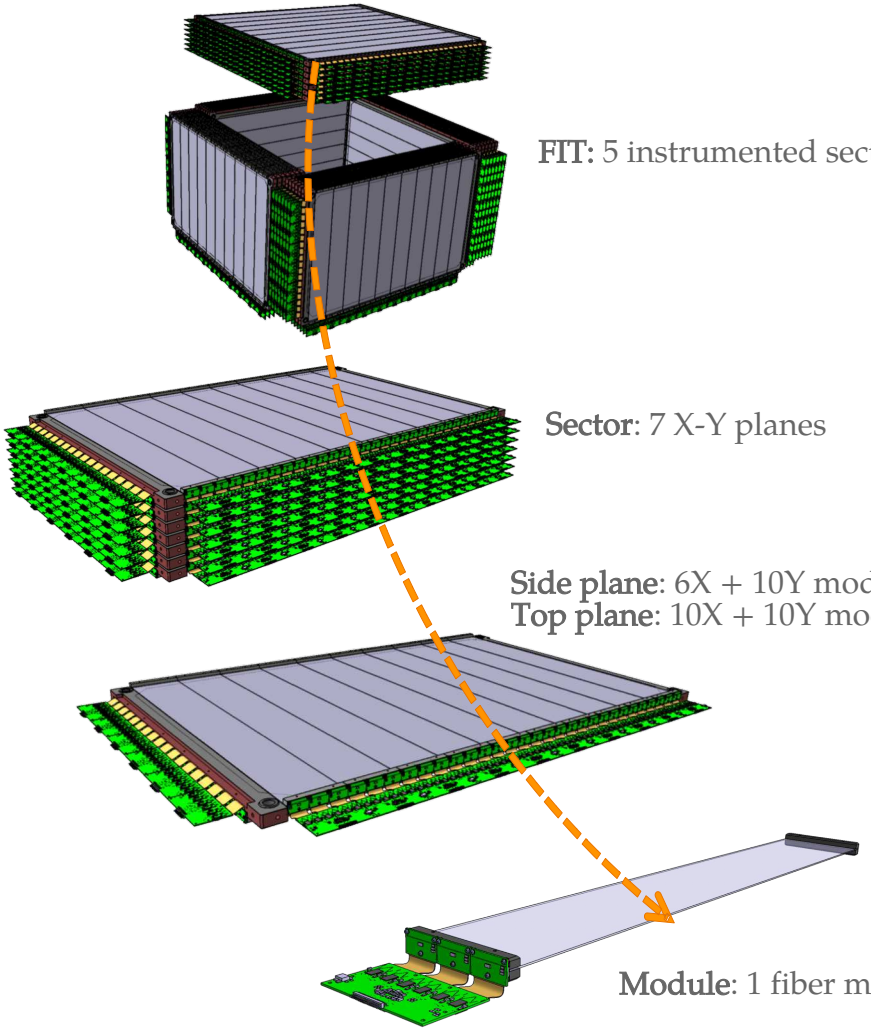




...from beam tests at CERN – SPS

L. Pacini et al, PoS, ICRC2021(2021) 066

HERD sub-detectors: Fiber Tracker (FIT)



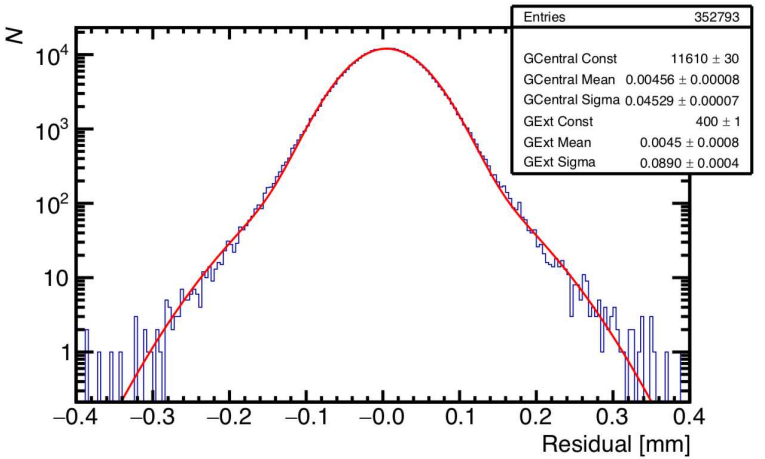
FIT: 5 instrumented sectors

Sector: 7 X-Y planes

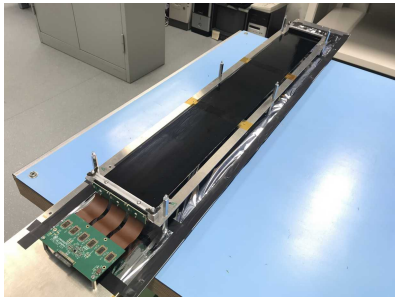
Side plane: 6X + 10Y modules
Top plane: 10X + 10Y modules

Module: 1 fiber mat + 3 SiPM arrays

Position residual distribution from proton beam tests



Spatial resolution = (45.0 ± 0.1) μm



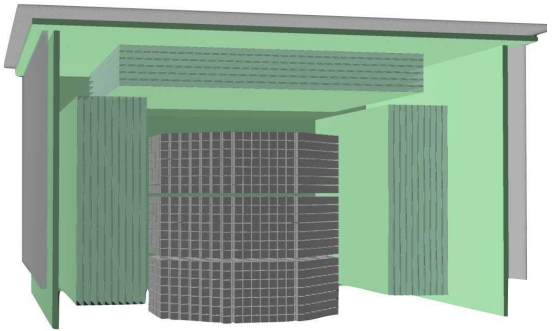
Z	μ_z	σ_z	σ_z/μ_z [%]
2	1.99	0.31	15
3	3.07	0.4	13
4	4.01	0.51	12

Charge resolution for nuclei heavier than protons

C. Perrina et al, PoS, ICRC2021(2021) 067

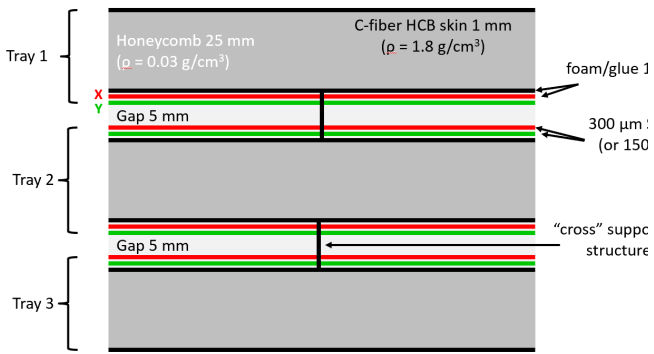
HERD sub-detectors: Silicon Charge Detector (SCD)

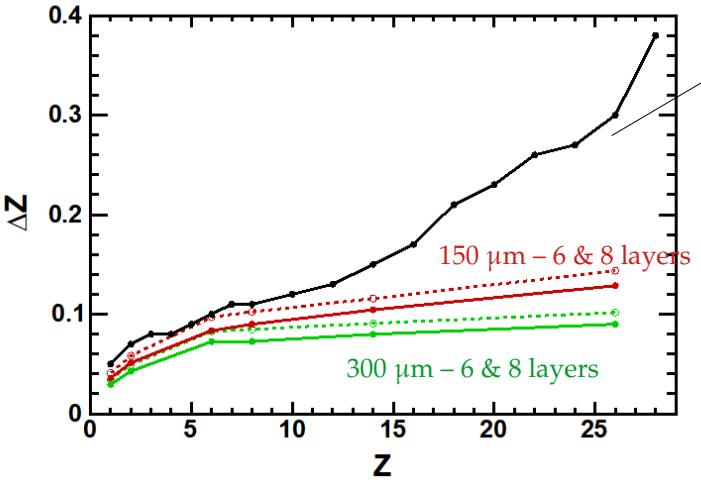
The SCD is a **silicon micro-strip** detector with the objective of precisely measuring the particle charge



Being the **outermost** detector the SCD aims to avoid early charge – modifying interactions in the PSD

Highly segmented to minimize backsplash events moving upward from the CALO





Y. Jia et al. NIM A **972** (2020)