

## Overview of the HERD space mission

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for the HERD collaboration

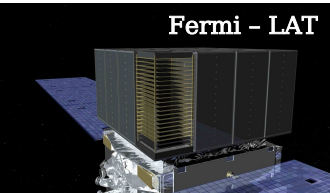
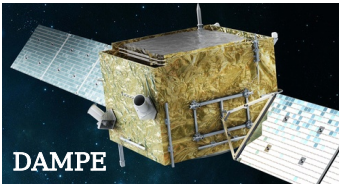
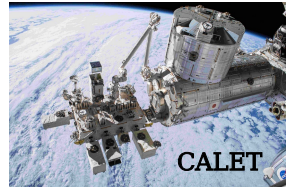
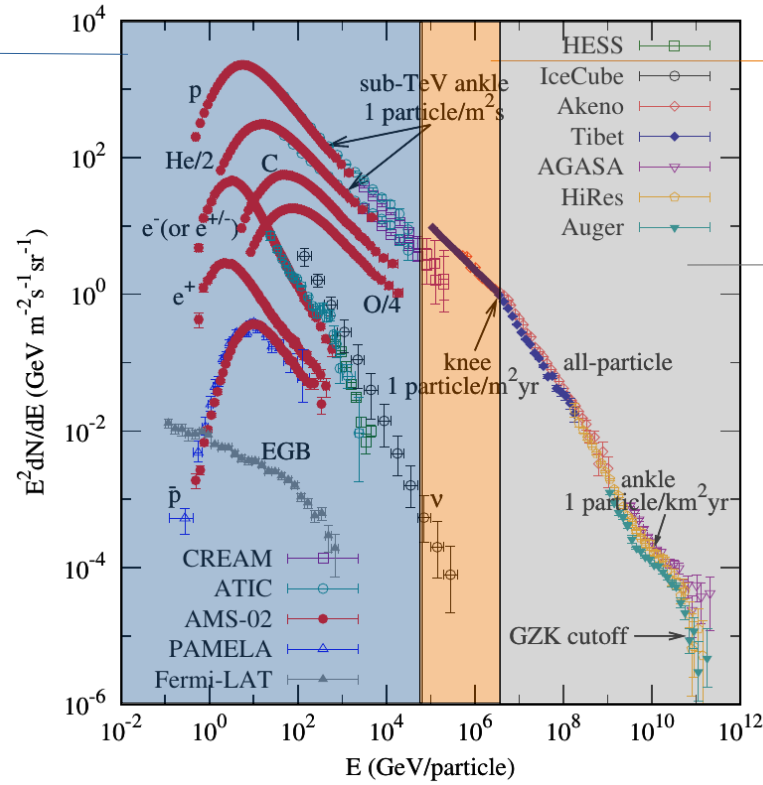
Gran Sasso Science Institute (GSSI) & INFN-LNGS

# The Cosmic Ray Landscape

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

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

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

## Main message

Due to **rapidly falling intensity** of CR fluxes with energy, experiments with **large acceptances**, operating over **several years** are needed to explore CR spectra at **PeV energies**.

## The HERD proposal

**HERD** is proposed as one of the prominent space-borne instruments to be installed **on-board the upcoming Chinese Space Station (CSS)** around 2027.

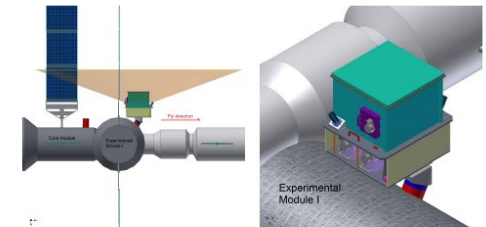
## The Collaboration

An international synergy between **Chinese, Italian, Swiss and Spanish institutes/universities**, formed around the HERD initiative.

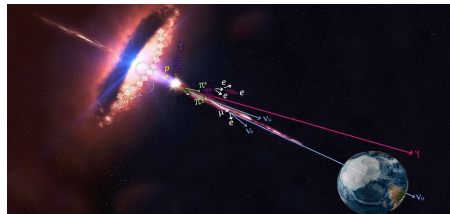


## Scientific goals of HERD

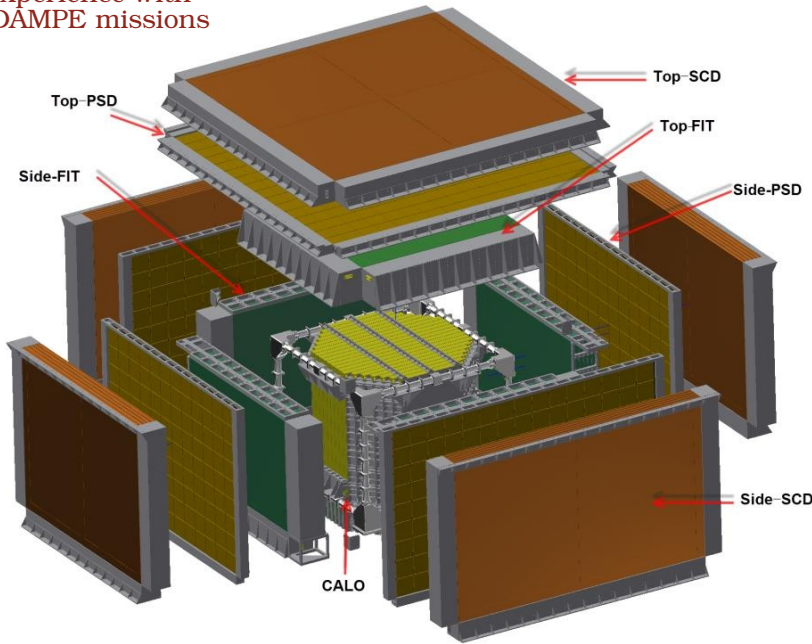
**Cosmic Rays:** Precise spectra and mass composition up to the PeV range  
**Gamma – ray astronomy** and transient studies (e.m. counterpart of GW)  
**Electron spectra** (and anisotropy) up to tens of TeV (nearby sources)  
 Indirect **Dark Matter searches** with high sensitivity



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



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



## Detector Description [From inner towards outer layers]

**A deep (~55  $X_0$ , 3  $\lambda_i$ ) 3D cubic calorimeter (CALO)**, forming an octagonal prism, to accurately measure the deposited energy and separate electron & proton induced showers.

**A Fiber Tracker (FIT)**, situated on all active sides, determining tracks of impinging particles.

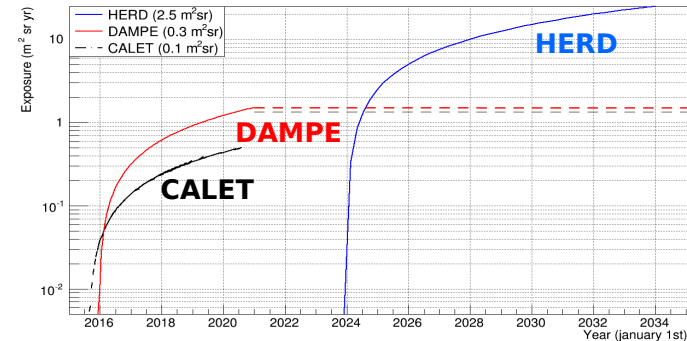
**A Plastic Scintillator Detector (PSD)**, covering the calorimeter and tracker, providing gamma-ray and charged particle triggers, with an additional level of charge measurement.

**A Silicon Charge Detector (SCD)**, that envelops all sub-detectors, ensuring an additional determination of the charge.

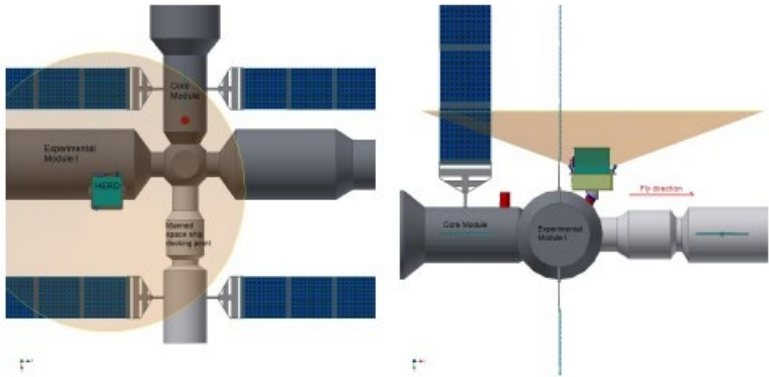
**plus A Transition Radiation Detector (TRD)**, placed on one of the lateral faces, providing energy calibration of nuclei (TeV region).

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

**15 – 20  $m^2 sr yr$**

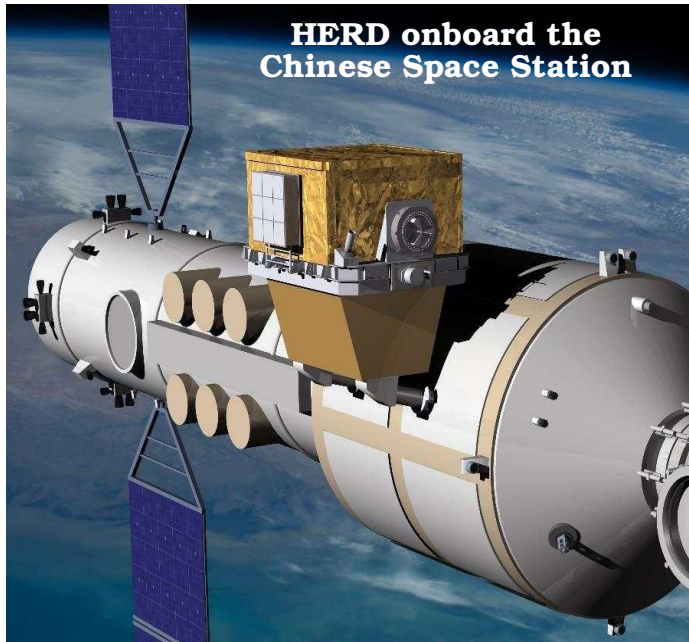




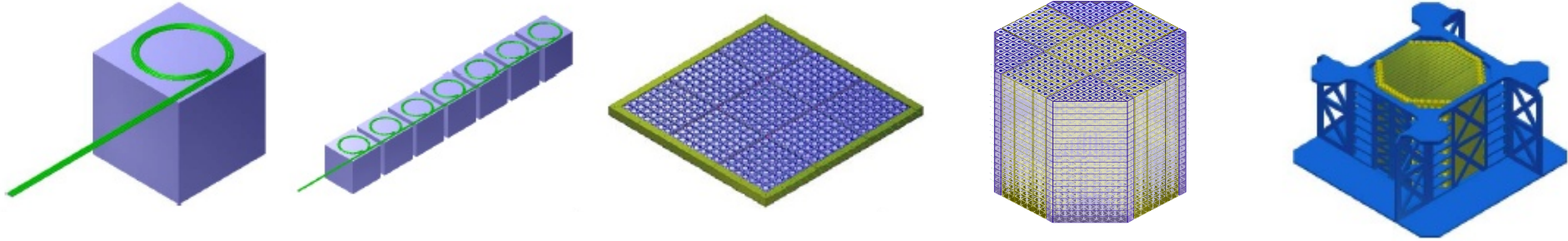


## Main Requirements

Energy range (e/γ)	10 GeV-100 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 <sup>-6</sup>
G.F. (e)	>3 m <sup>2</sup> sr @ 200 GeV
G.F. (p)	>2 m <sup>2</sup> sr @ 100 TeV
Pointing	Zenith
Field of View	+/-70 deg
Mass	< 4 tons
Lifetime	>10 years

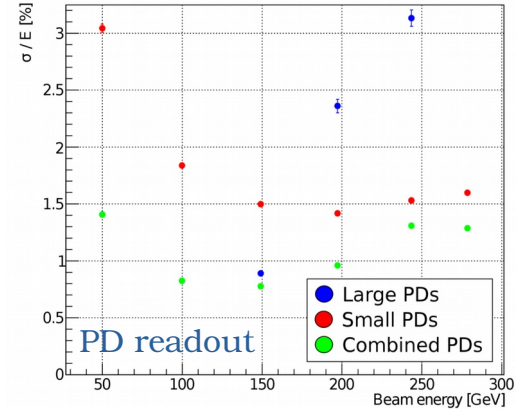
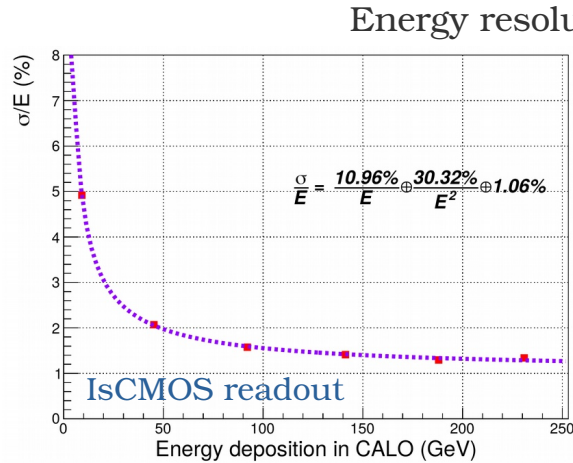


CSS to be completed in 2022  
HERD to be installed on – board the CSS around 2027



Item	Value
Type of crystal	LYSO
Nuclear interaction length	3 (55 X <sub>0</sub> )
Number of crystals	~7500
Crystal dimension	3 x 3 x 3 cm <sup>3</sup>

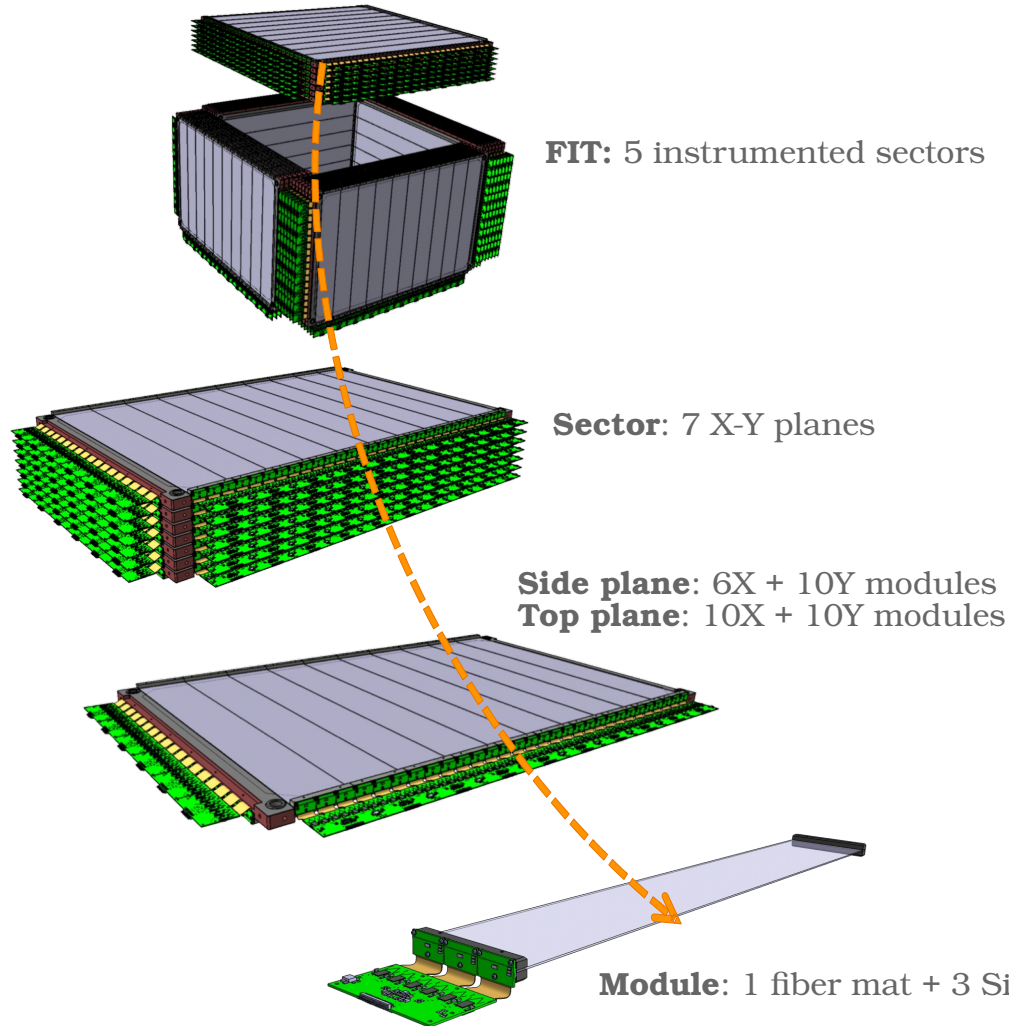
- Scintillation light is readout independently by:
- 1) WLS fibers coupled to IsCMOS cameras
  - 2) Photodiodes connected to custom frontend electronics



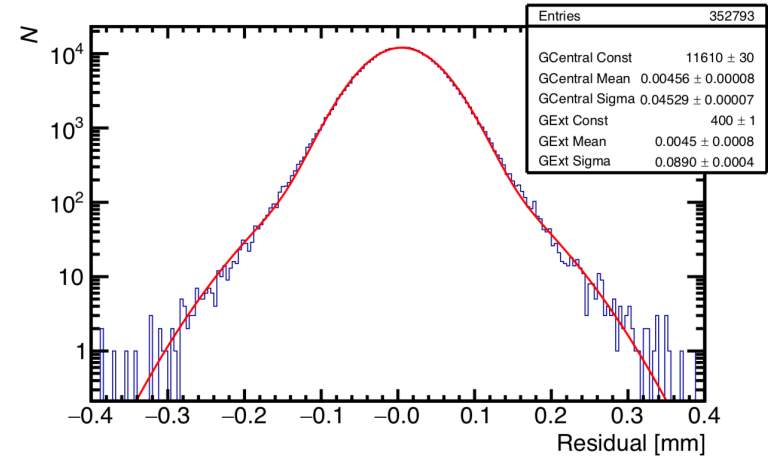
...from beam tests at CERN – SPS

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

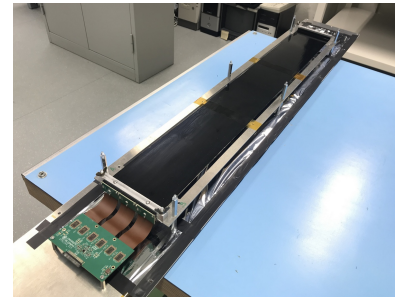
L. Pacini et al, PoS, ICRC2021(2021) 066



Position residual distribution from proton beam tests



Spatial resolution =  $(45.0 \pm 0.1) \mu\text{m}$



Z	$\mu_z$	$\sigma_z$	$\sigma_z/\mu_z$ [%]
2	1.99	0.31	15
3	3.07	0.4	13
4	4.01	0.51	12

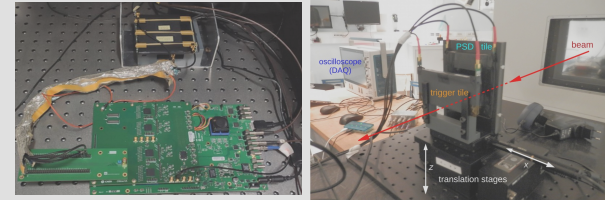
Charge resolution for nuclei heavier than protons

The PSD will provide  **$\gamma$  identification** (vetoing charged particles)  
w/ accurate **measurement of impinging charged particles**

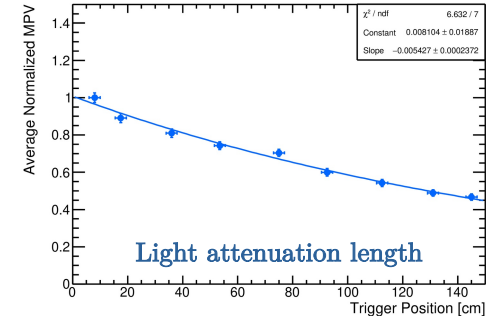
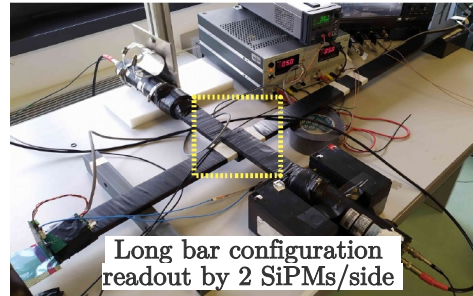
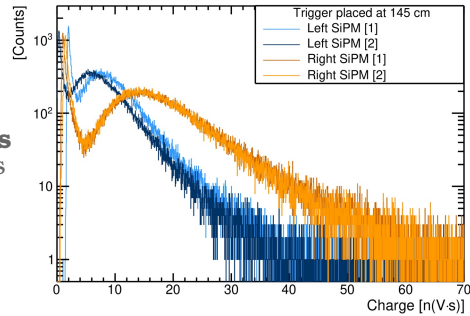


**Two design layouts** are currently investigated, one based on **long scintillator bars** while the other on **square tiles**, both coupled with SiPMs.

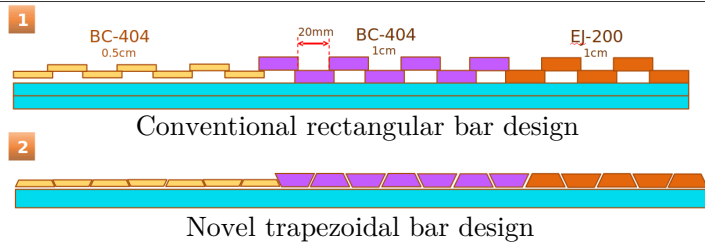
D. Kyratzis et al, PoS, ICRC2021(2021) 054



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

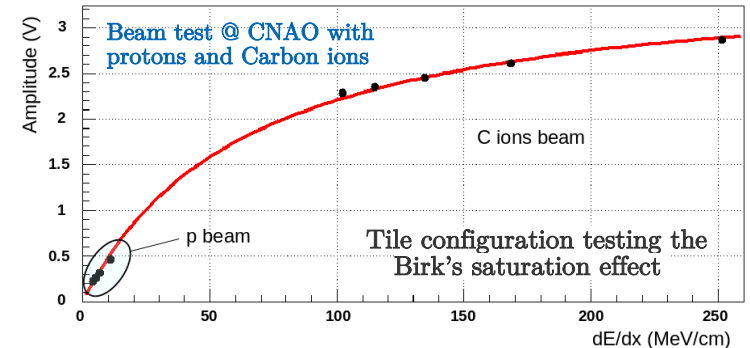


Measurement of **light attenuation length** extracted from all trigger positions



**Hermeticity studies** concerning the feasibility of **novel trapezoidal bars** (bottom) as opposed to default rectangular designs (top)

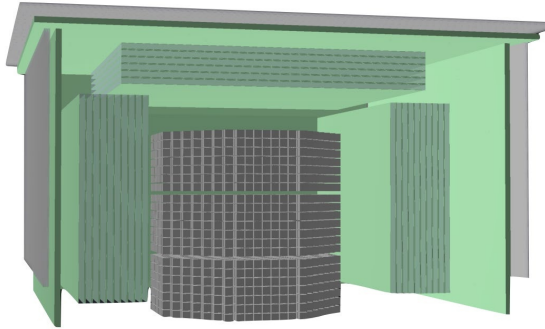
**Loss of linearity** well described by Birk's law (red line)





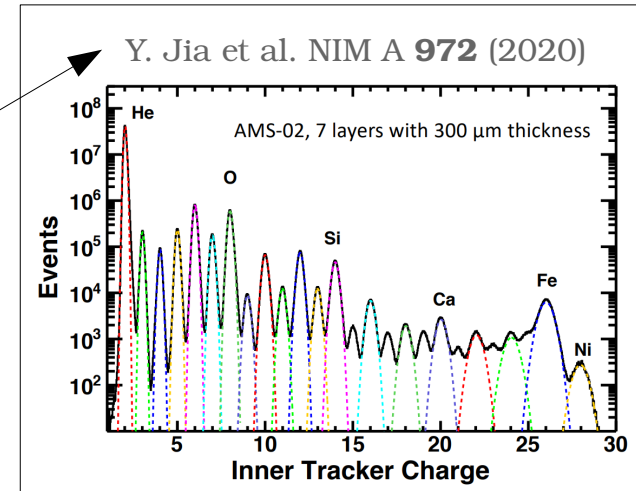
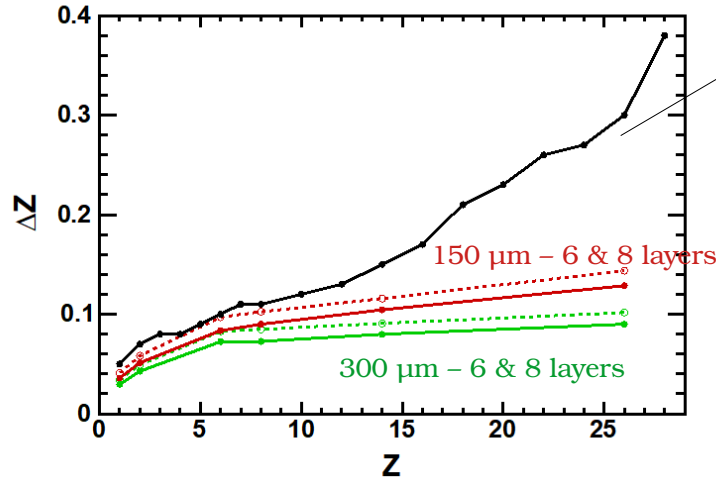
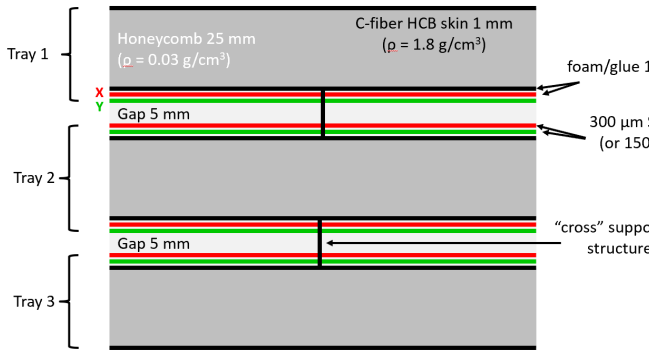
# HERD sub-detectors: Silicon Charge Detector (SCD)

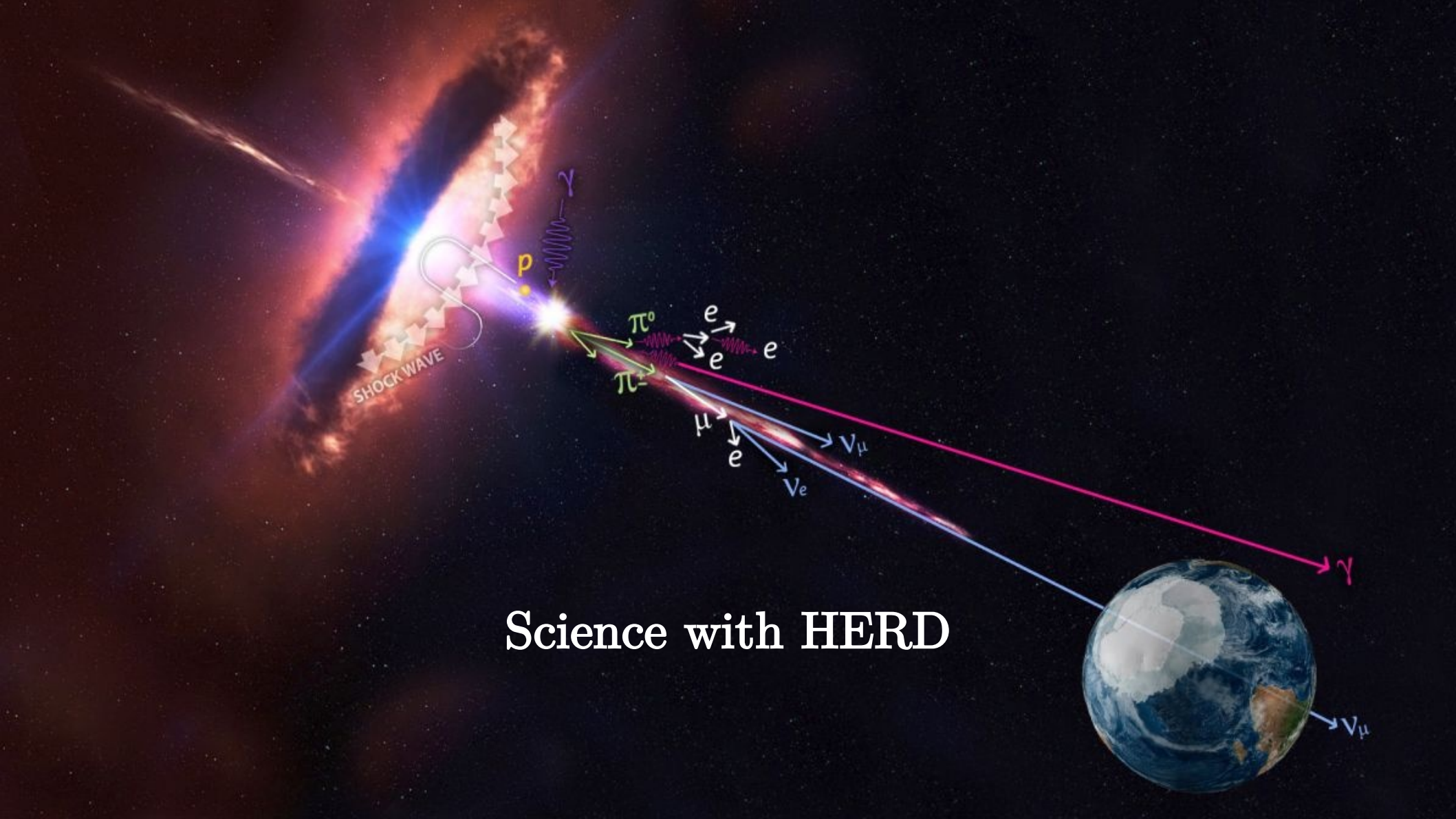
The SCD is a **silicon micro-strip** detector with the objective of precisely measuring the particle charge



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

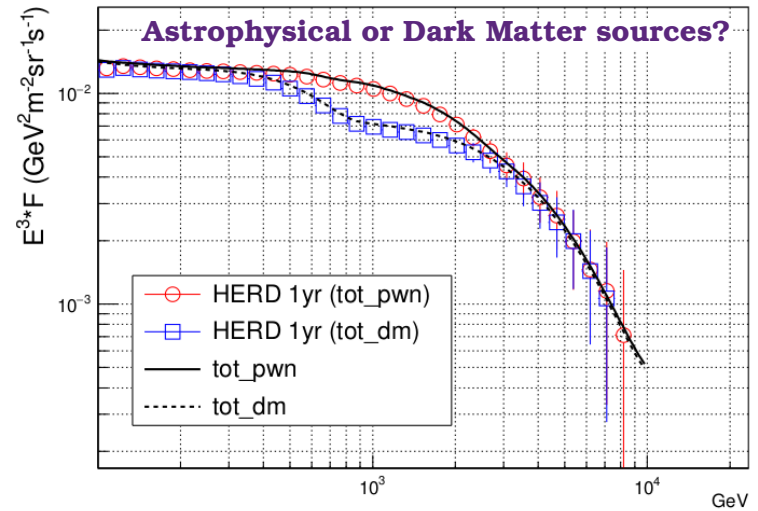
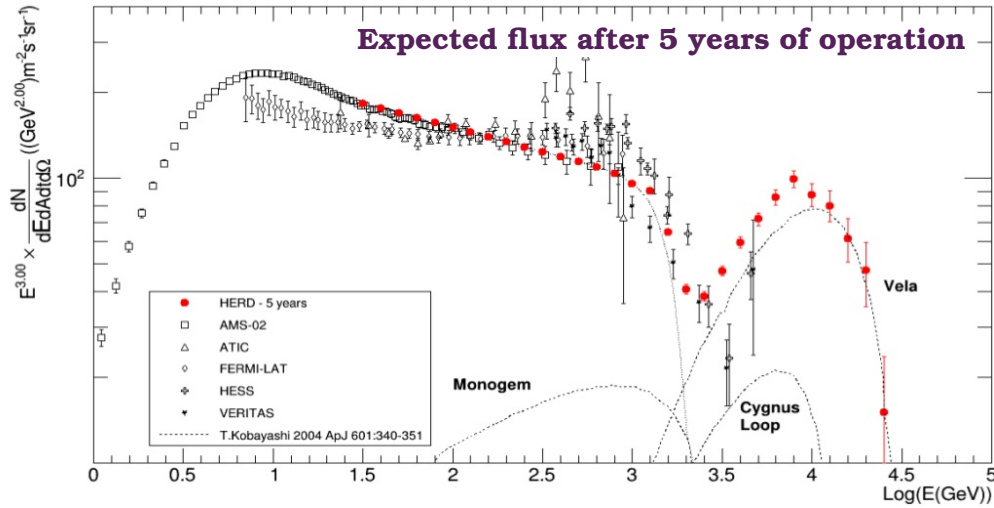
**Highly segmented** to minimize backslash events moving upward from the CALO





Science with HERD

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



**Main objectives:**

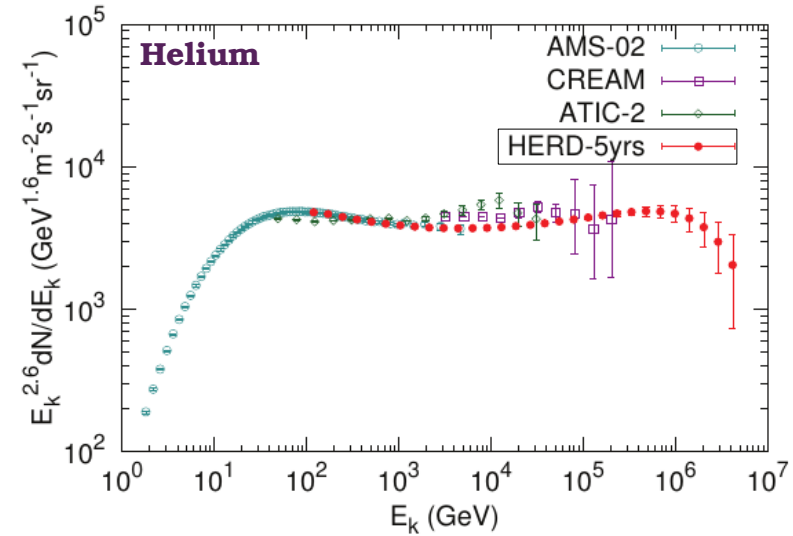
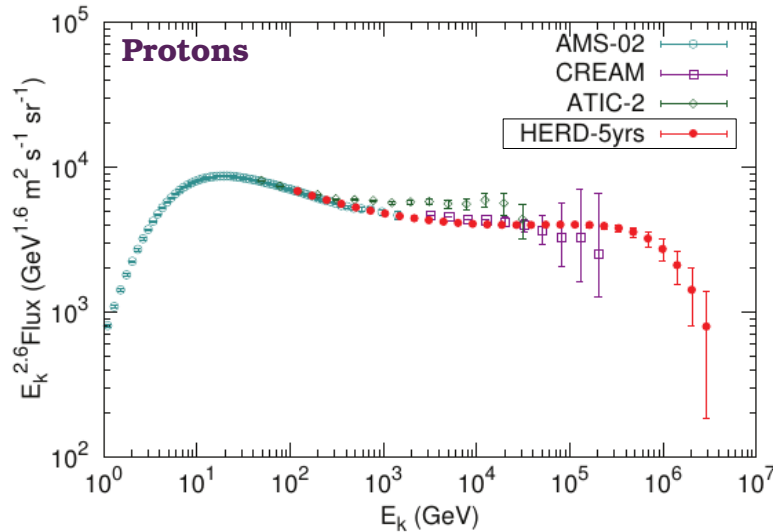
**Spectral cutoffs** and additional features at high energies

Probing **local SNR sources**

Insights from **CR anisotropy** studies

Hypotheses validation concerning **astrophysical or DM sources**

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

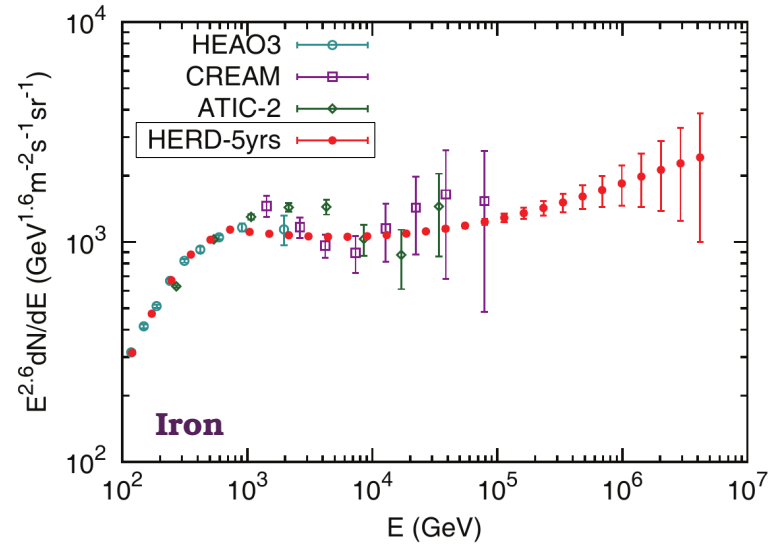
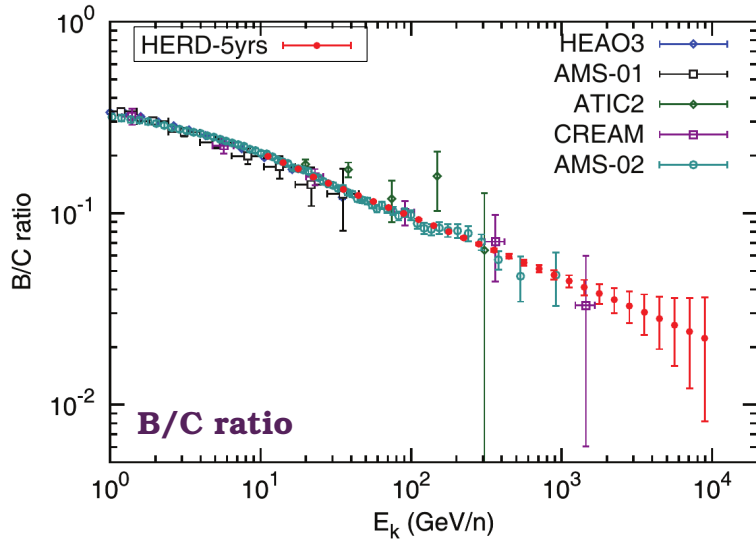


**Great test of the usual CR picture:**

**Steepening** of the spectrum associated with **maximum energy** reached at **galactic accelerators** (i.e., SNR shocks).

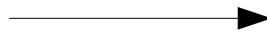


**Extending the fluxes of medium mass (BCNO group) and heavier (Fe) nuclei to their highest achievable limit with direct measurements**



## Understanding the CR propagation mechanism (and more...)

**Secondary nuclei (Li, Be, B)** produced via **spallation** from interactions of **heavier nuclei (C, N, O)** with the Interstellar Medium (ISM)



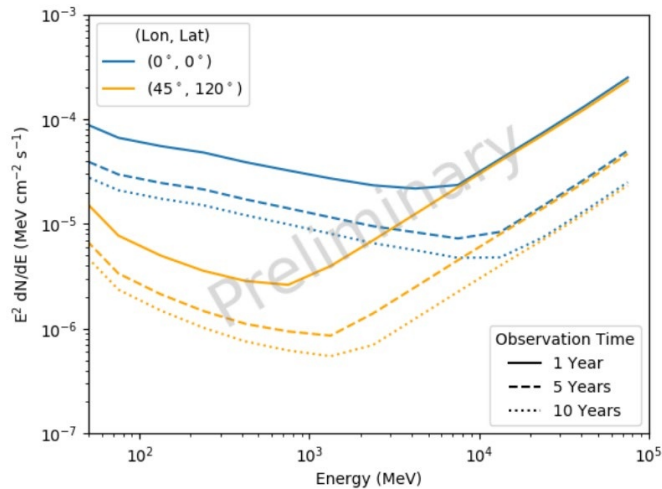
**Secondary - to - primary ratios** (like B/C, B/O) provide crucial information on the **CR propagation mechanism**

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

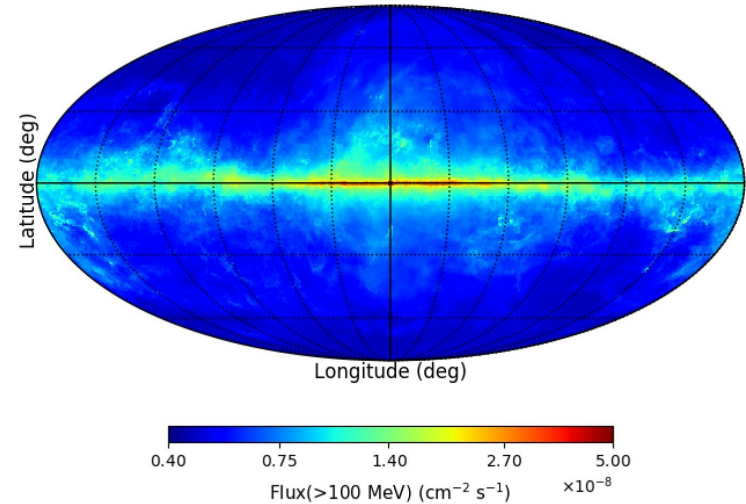
## Main Objectives

- Extending the Fermi – LAT catalog to **higher energies** (> 300 GeV)
- Searching for **galactic & extragalactic**  $\gamma$ -ray sources
- Detecting high energy **gamma-ray bursts**
- Searching for possible **Dark Matter candidates**

HERD, Point Source, PL index=2, TS=25, > 10 photons/bin, 4 bin/dec



HERD 5 Years, TS=25, > 10 photons/bin, 4 bin/dec



## Multimessenger Era

Possible synergy with ground-based experiments designed for:

**Gamma – rays** (CTA, LHAASO)

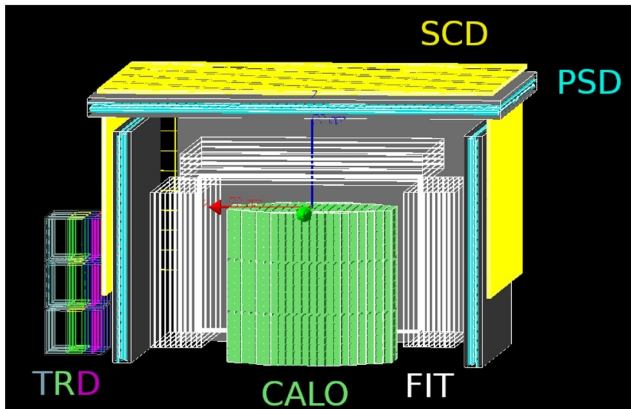
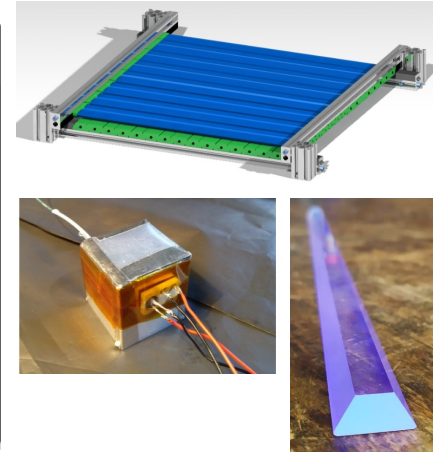
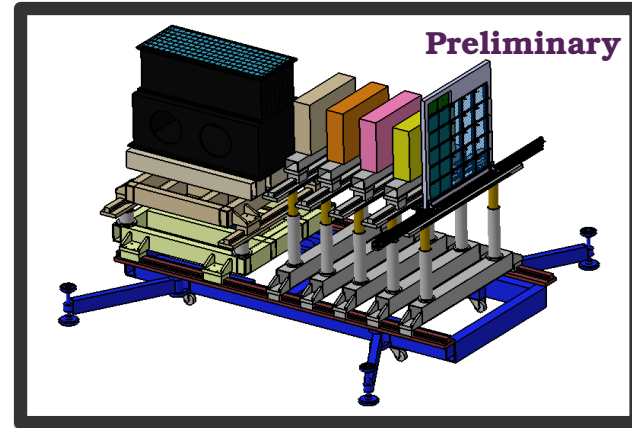
**Neutrinos** (KM3NeT, IceCube)

**Gravitational Waves** (Ligo, Virgo)

Continuous efforts towards an optimized version of the detector are carried out both from **hardware** and **software** aspects

## Beam Test @ CERN SPS

**Of great importance** in evaluating and determining the optimal HERD configuration, will be the **upcoming test beam campaign, taking place at CERN SPS** and scheduled for Oct/Nov 2021. Such an endeavor will lead to **systematic performance tests of all assembled prototypes.**



## HerdSoftware: A dedicated analysis framework

HerdSoftware is a **continuously updated framework for Monte Carlo simulation, event reconstruction and data analysis** for the experiment. It is conceived to provide a full solution for (almost) all its computation needs.

doi: 10.1016/j.nima.2021.165298

**The High Energy cosmic–Radiation Detector (HERD)** is a novel space – borne detector, to be installed on–board **China's Space Station (CSS)** around 2027, with an expected lifetime of 5–10 years.

Its main scientific objectives revolve around **high energy galactic CRs, gamma – ray astronomy** and indirect **DM searches**.

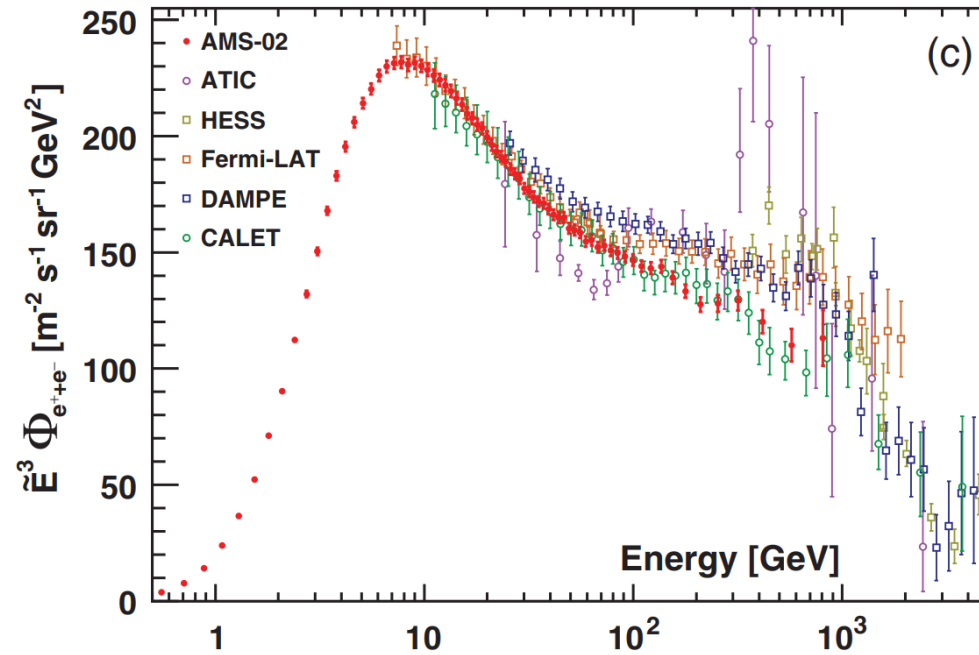
These objectives will be examined by a novel detector, comprising a deep **3-D calorimeter (CALO)**, subsequently enveloped by a **Fiber Tracker (FIT)**, a **Plastic Scintillator Detector (PSD)** and a **Silicon Charge Detector (SCD)** instrumented on both the **top and lateral sides**, along with a **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 **MC simulations**, dedicated **hardware R&D** along with **beam test campaigns** to verify its performances.



# Additional Info



DAMPE: First direct detection of a spectral break @ 1TeV

arXiv:1911.01311v1 [astro-ph.HE] 4 Nov 2019

