

## Latest Advancements of the HERD space mission

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for the HERD collaboration

Gran Sasso Science Institute (GSSI) & INFN-LNGS

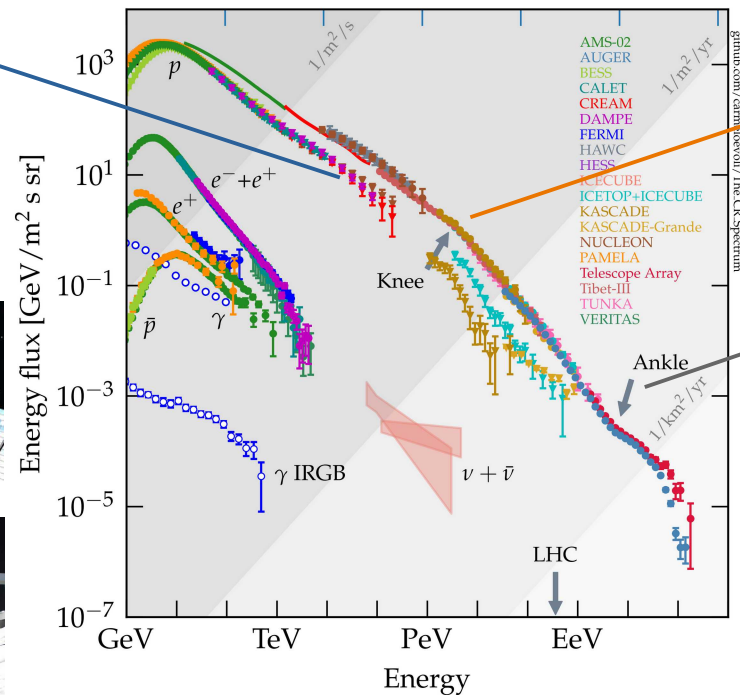


# The Cosmic Ray Landscape

Energies achieved with **current space – borne direct CR experiments** (~ 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**





Experiments w/ **large acceptance**, operating over **several years** 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

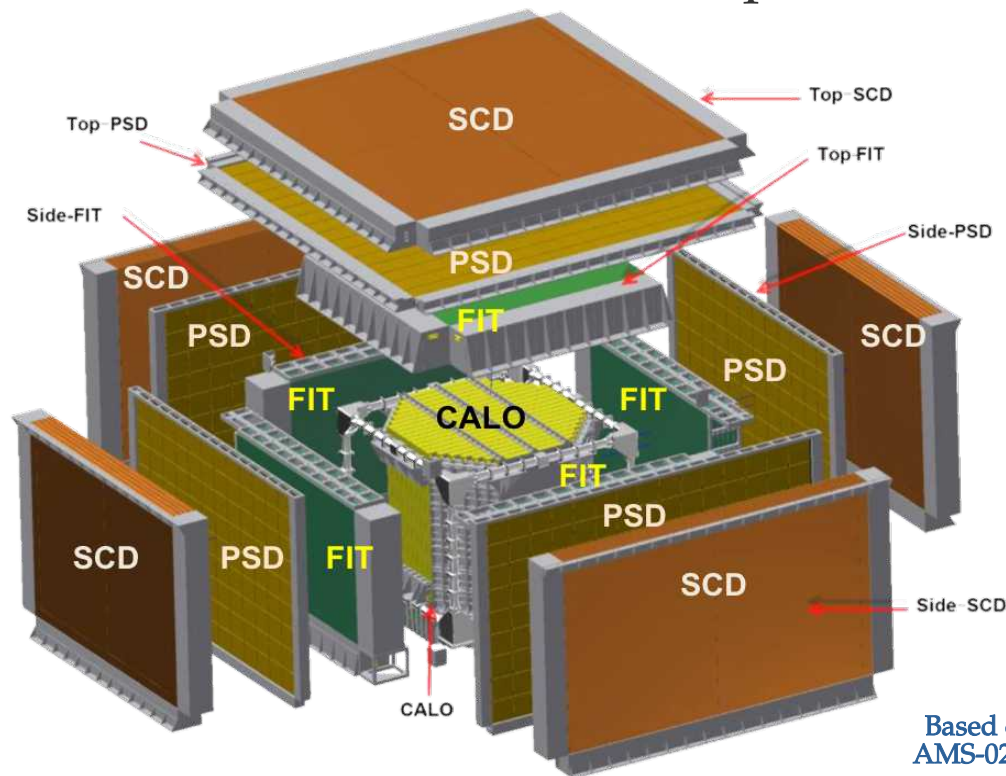
D. Kyratzis, Phys Scr, 97, 054010 (2022)

### The Collaboration

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



# HERD: Detector Description



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

**Deep** ( $\sim 55 X_0$ ,  $3 \lambda_I$ ) **3D cubic calorimeter (CALO)**, octagonal prism, accurately measuring deposited energy + e/p separation

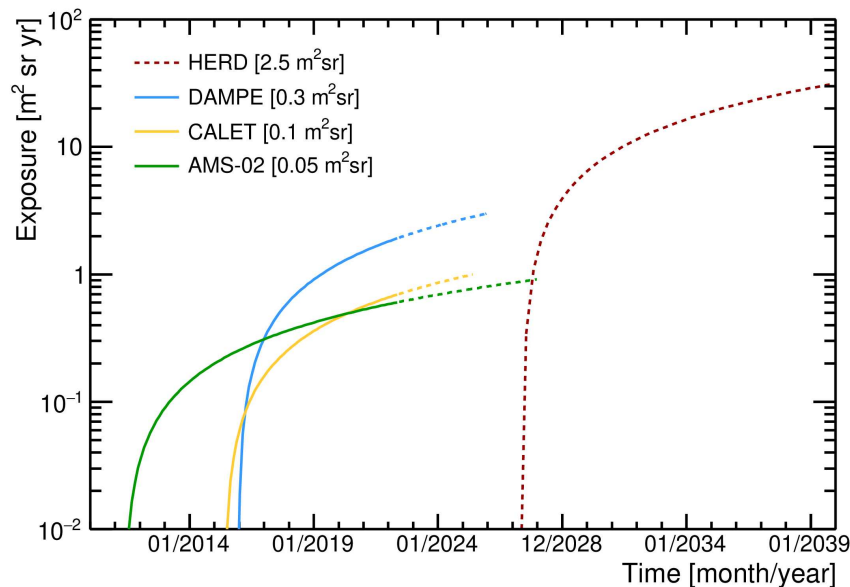
**Fiber Tracker (FIT)**, determining tracks of impinging particles.

**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



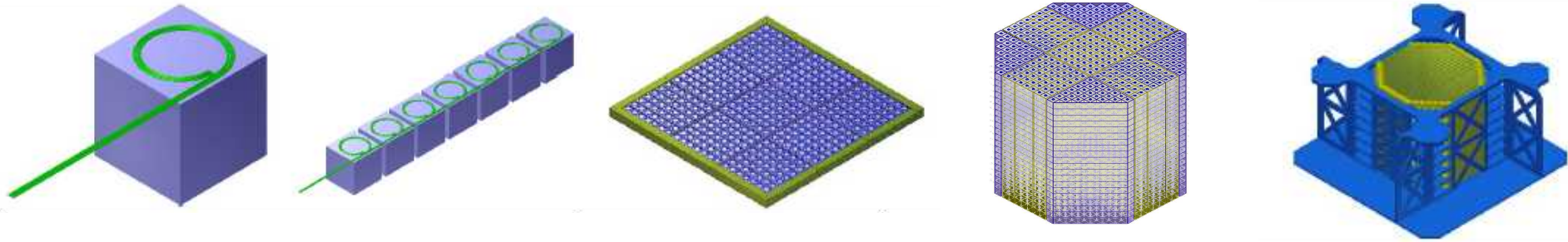
One order of magnitude upgrade in exposure wrt to current gen CR experiments:

**15 – 20 m² sr yr**

## Main Requirements

Energy range (e/ $\gamma$ )	10 GeV-10s TeV(e); > 100 MeV ( $\gamma$ )
Energy range (CRs)	30 GeV – 3 PeV
Angular resolution	0.1 deg. @ 10 GeV
Energy resolution (e/ $\gamma$ )	1-2% @ 200 GeV
Energy resolution (p)	20-30% @100 GeV – PeV
e/p separation	$\sim 10^{-6}$
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	$\sim 10$ years

# HERD sub-detectors: Calorimeter (CALO)



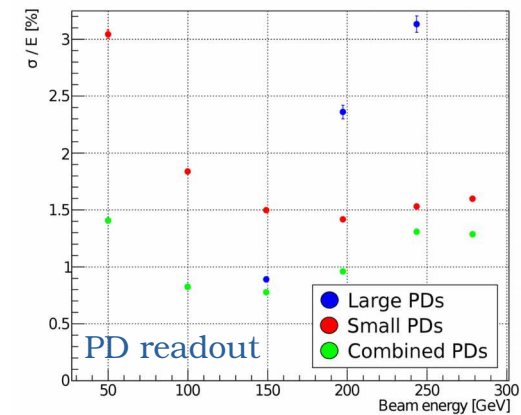
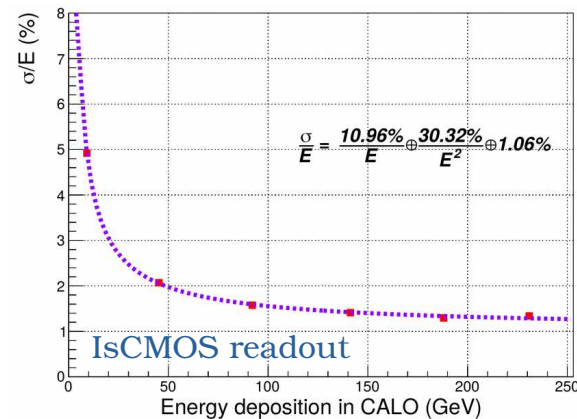
Item	Value
Type of crystal	LYSO
Nuclear interaction length	3 (55 $X_0$ )
Number of crystals	~7500
Crystal dimension	$3 \times 3 \times 3 \text{ cm}^3$

Scintillation light is readout independently by:

- 1) WLS fibers coupled to IsCMOS cameras
- 2) Photodiodes connected to custom front-end electronics

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

Energy resolution for electrons

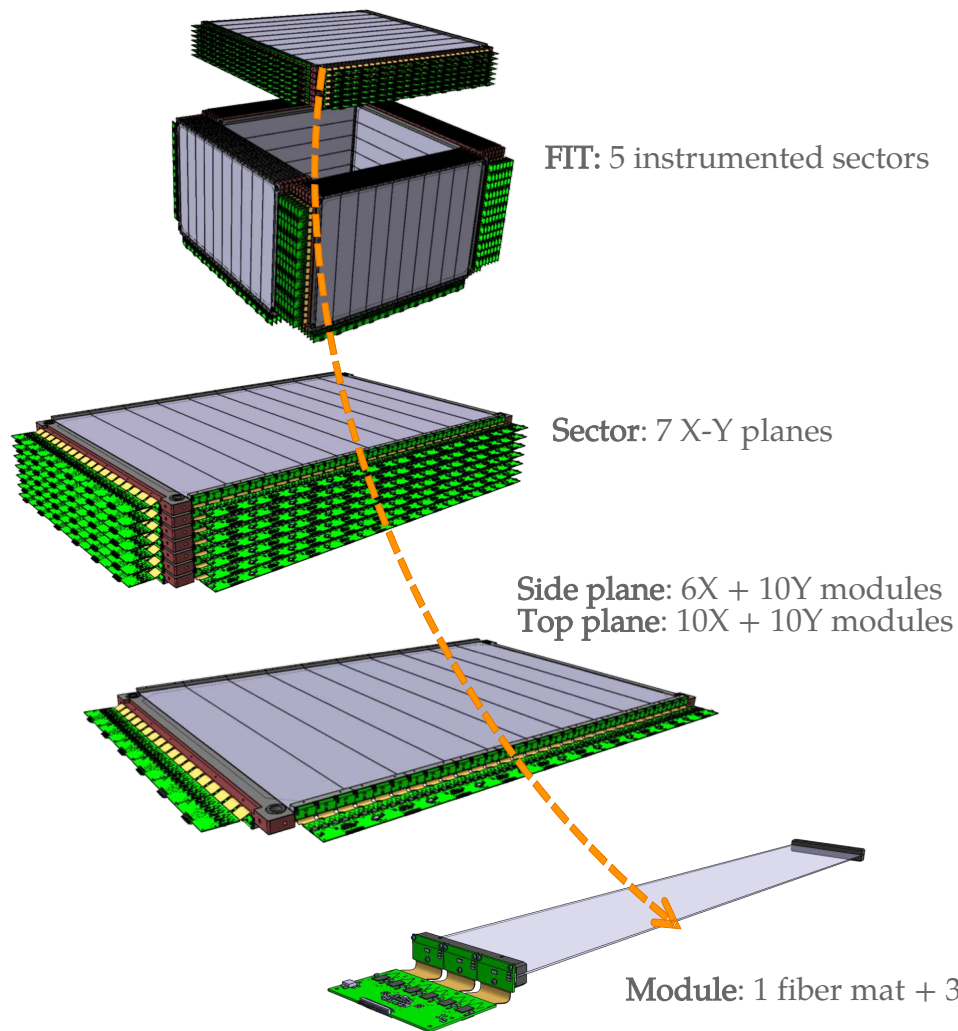


...from beam tests at CERN – SPS

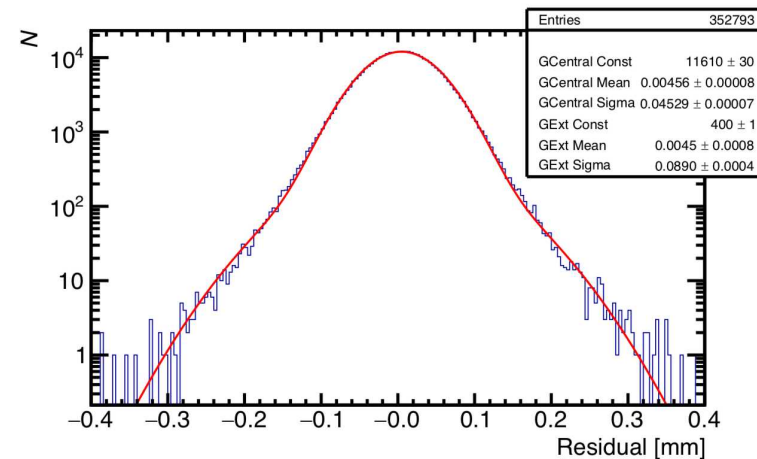
L. Pacini et al, PoS, ICRC2021(2021) 066



# HERD sub-detectors: Fiber Tracker (FIT)



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

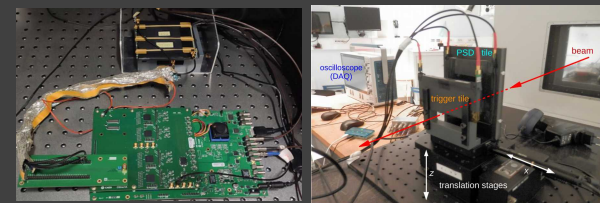
# HERD sub-detectors: Plastic Scintillator Detector (PSD)

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

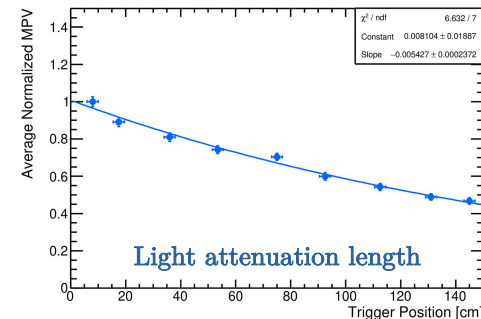
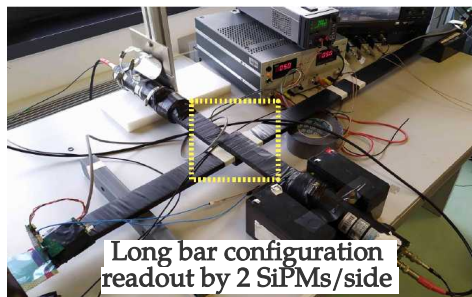
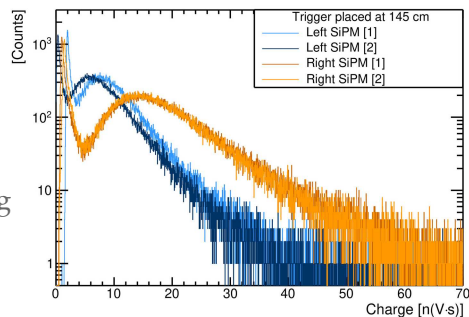


Two scintillator design layouts investigated:  
one w/ long bars while the other w/ square tiles  
both coupled with SiPMs.

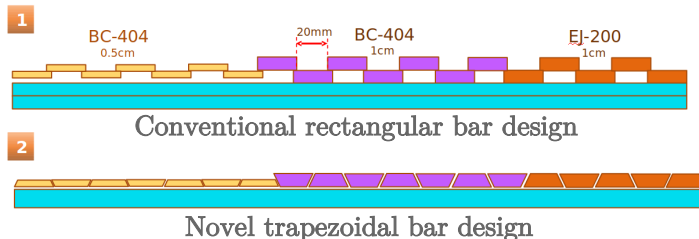
D. Kyratzis et al, PoS, ICRC2021(2021) 054



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)

Additional info on this meeting's posters:

The Plastic Scintillation Detector for the HERD experiment  
by Corrado Altomare

A tile prototype of the Plastic Scintillation Detector for HERD based on long Printed  
Circuit Boards: design and test with ion beams at CNAO  
by Massimo Rossella

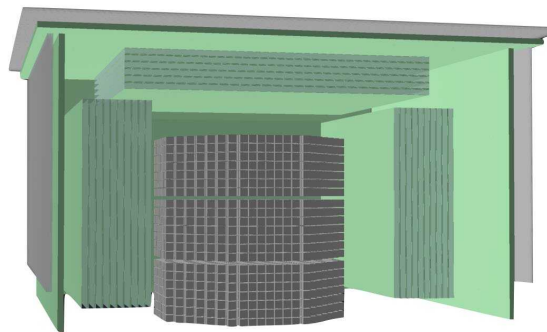


# HERD sub-detectors: Silicon Charge Detector (SCD)

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

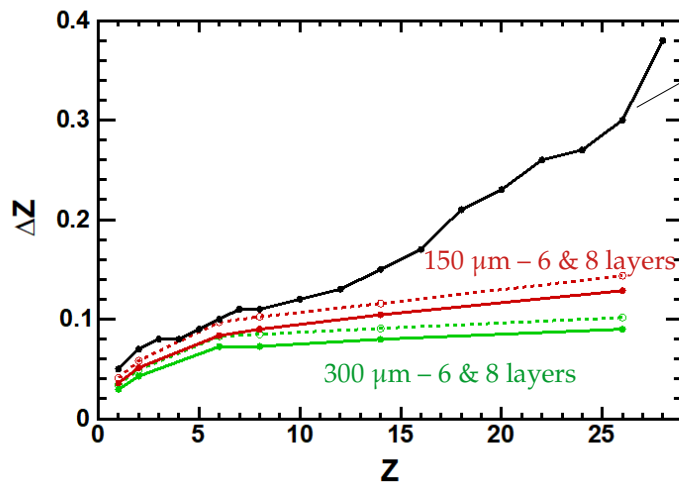
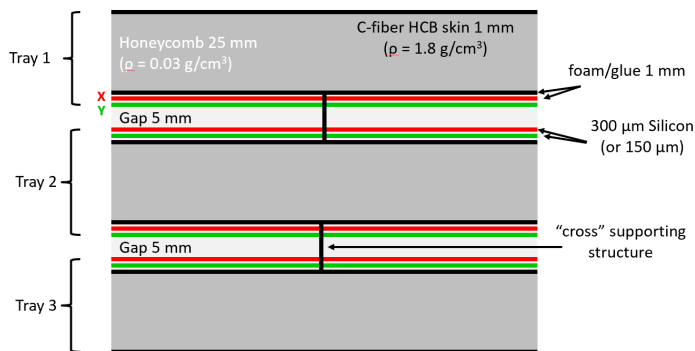
Additional info on this meeting's poster:

The Silicon Charge Detector of the High Energy Cosmic Radiation Detection facility  
by Matteo Duranti

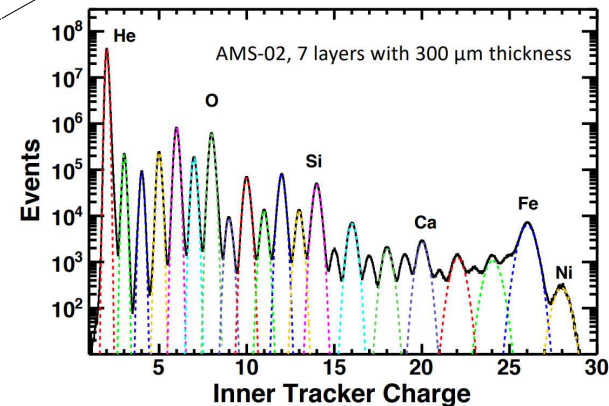


Being the **outermost** detector the SCD aims to avoid early charge – modifying interactions in the PSD

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

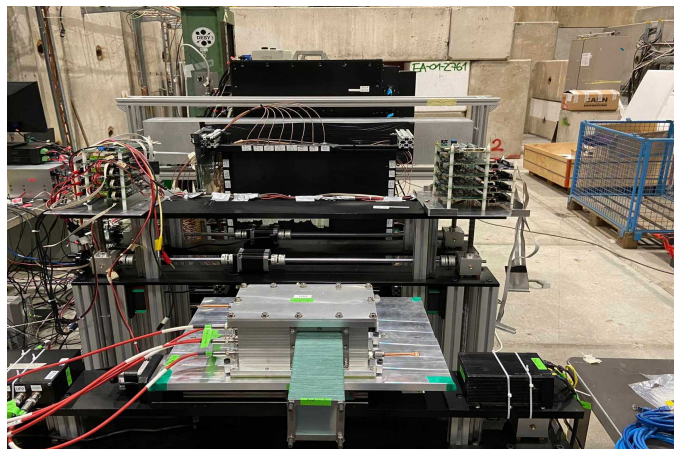


Y. Jia et al. NIM A 972 (2020)



# HERD campaigns @ CERN SPS & PS [2021]

A multitude of performance aspects for HERD were thoroughly tested  
@ CERN SPS & PS in Oct and Nov 2021

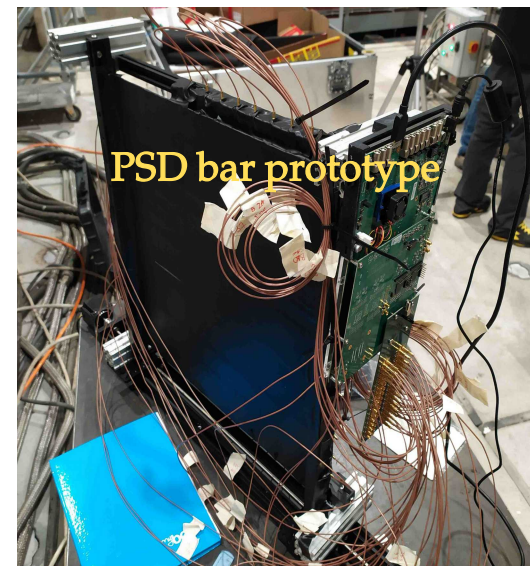
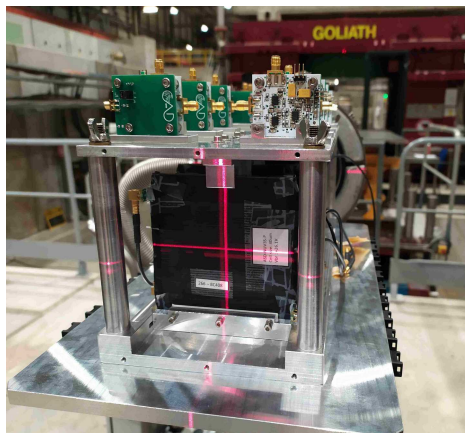


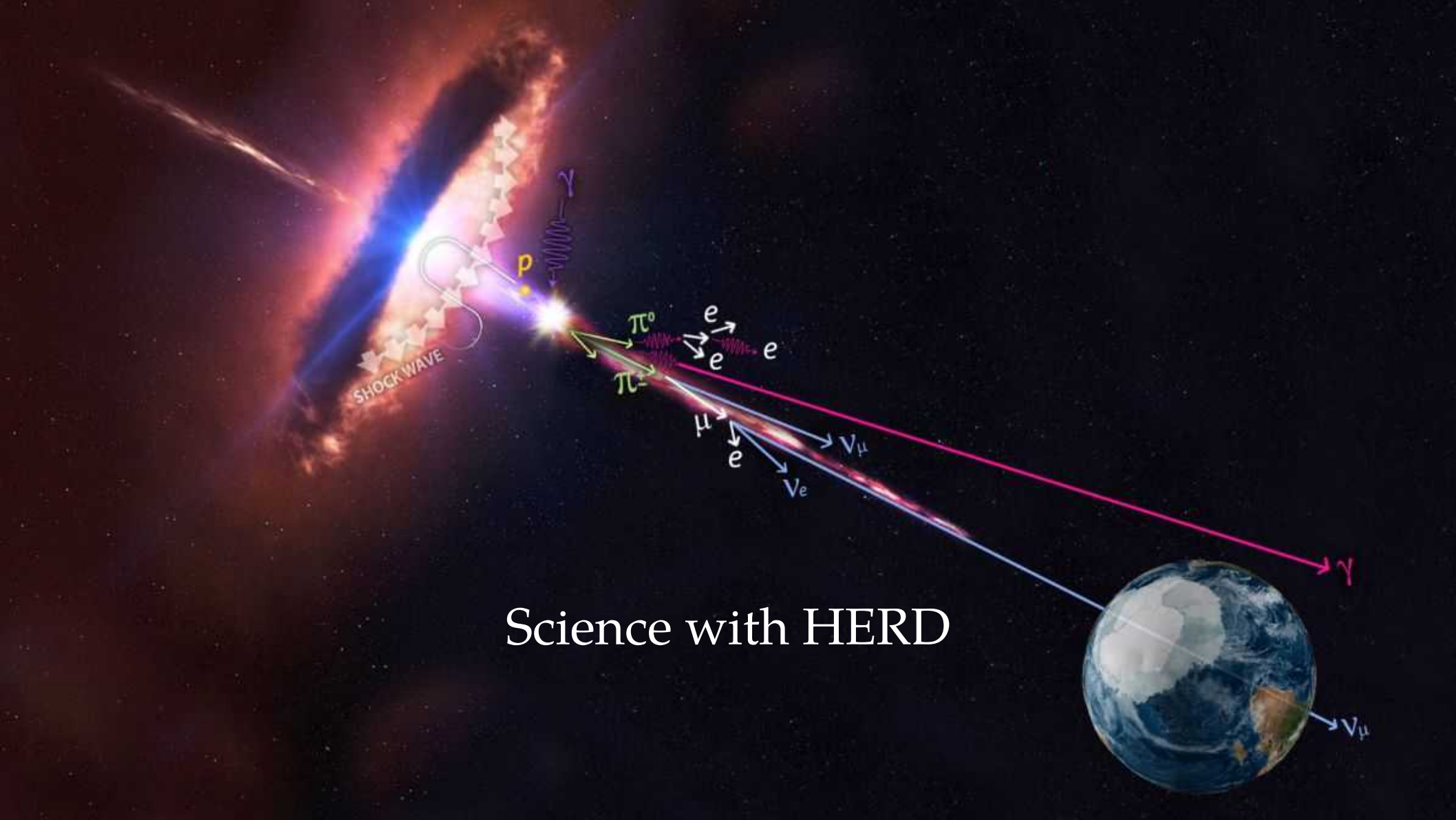
All sub-detectors were irradiated with:

**Protons:** up to 350 GeV

**Electrons:** up to 250 GeV

**Pions ( $\pi^+, \pi^-$ ):** 10 GeV



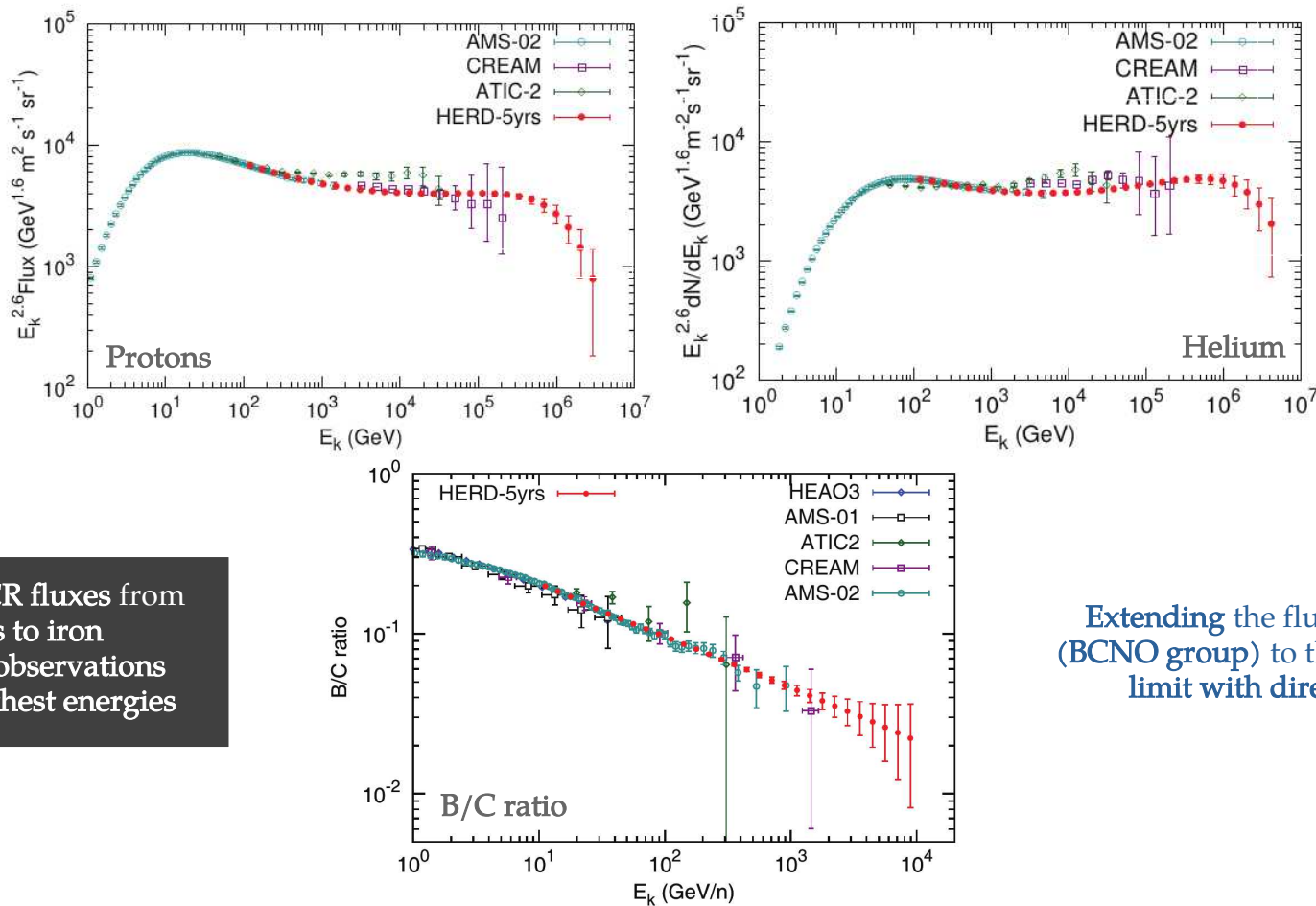


Science with HERD



# Cosmic Ray Nucleonic Spectra

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

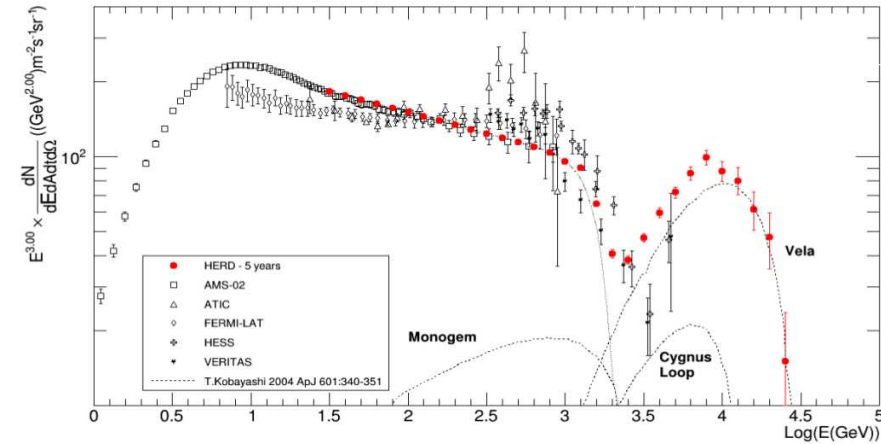


Measuring CR fluxes from  
protons to iron  
with direct observations  
up to the highest energies

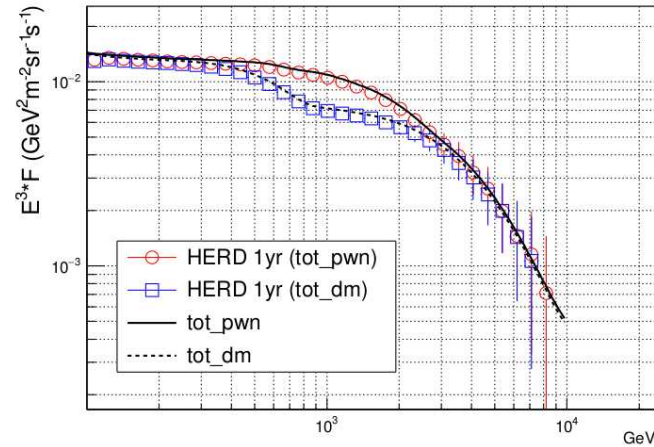
Extending the fluxes of medium mass  
(BCNO group) to their highest achievable  
limit with direct measurements

# Cosmic Ray Electrons & Gamma – Rays

Expected flux after 5 years of operation

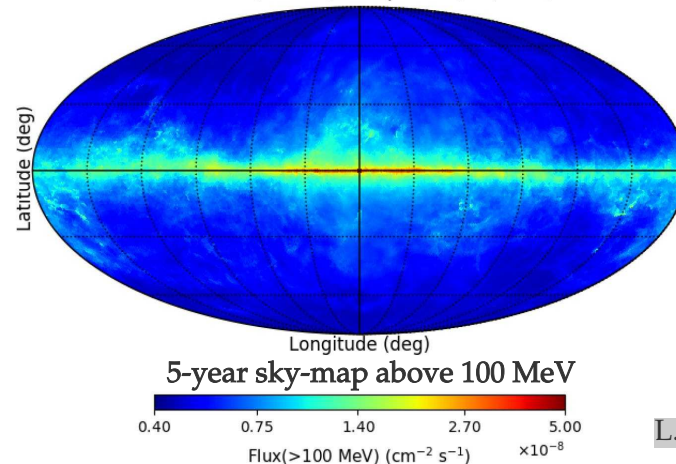


Astrophysical or Dark Matter sources?



Accurately determining the all – electron flux up to several tens of TeV

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



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

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

## Multimessenger Era

Possible synergy w/ experiments specialized on:

Gamma – rays (CTA, LHAASO)

& in the MeV range: **Crystal Eye** (see F. Barbato talk)

Neutrinos (KM3NeT, IceCube)

Gravitational Waves (Ligo, Virgo)

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

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

**State-of-the-art detector techniques + Pioneering design = Order of magnitude increase in acceptance**

Ongoing and future work in HERD foresees: continuous development efforts through: dedicated **hardware R&D** and **MC simulations**.

Dedicated beam test campaigns at **CERN SPS and PS**, (latest one) during Oct and Nov 2021 crucial in evaluating **performance aspects** of the full HERD prototype + further **optimization efforts** towards the **final detector design**.



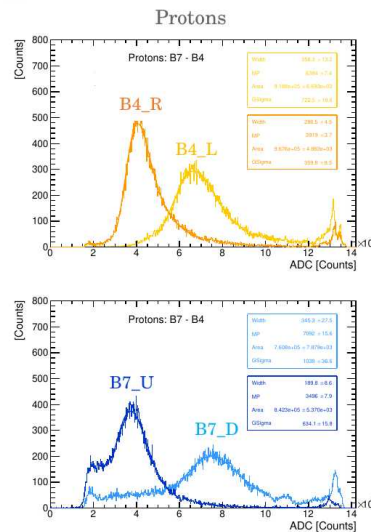
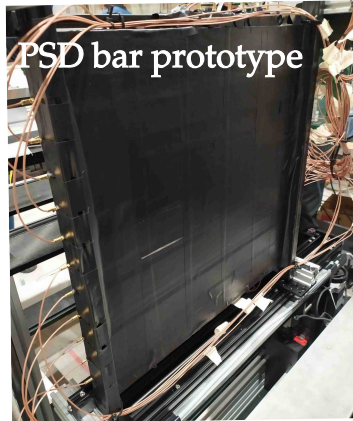
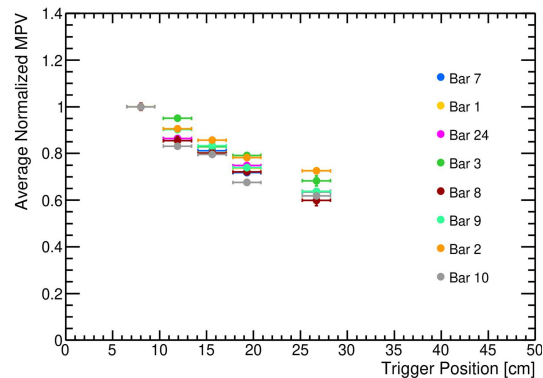
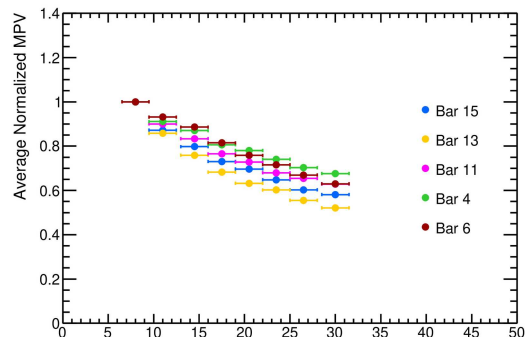


## Additional Info

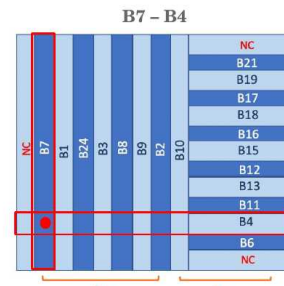


# Few preliminary beam test results...

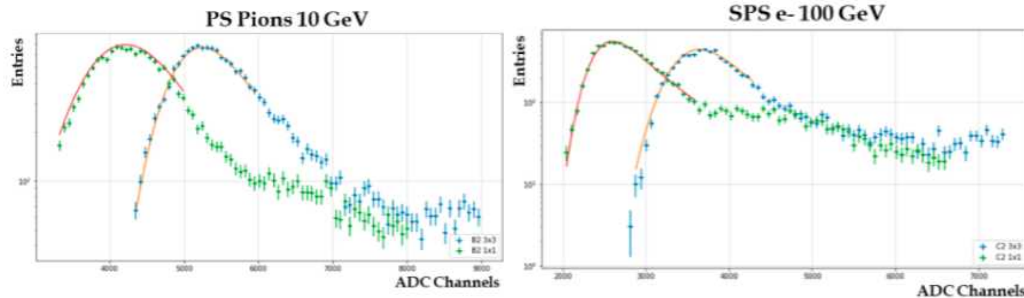
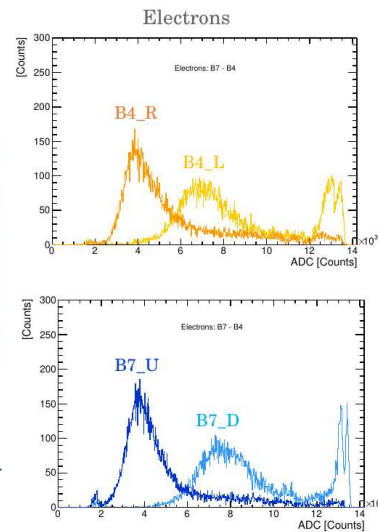
Evaluation of **average MPV**  
**behaviour** regarding 13  
tested bars in various  
beam trigger positions



PSD bar frame



p & e beam results on  
specific bars



Charge distributions extracted from **PSD tiles**,  
irradiated with pions and electrons of  
10 and 100 GeV, respectively