ICHEP 2024

The HERD experiment: beyond the current energy limits in direct detection of cosmic rays

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University and INFN Firenze

Prague
18-24 July 2024

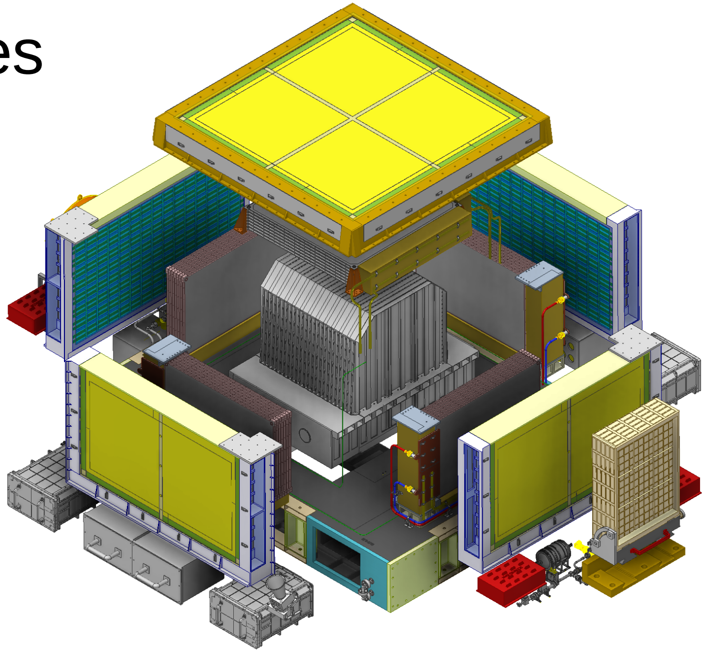
UNIVERSITÀ DEGLI STUDI FIRENZE

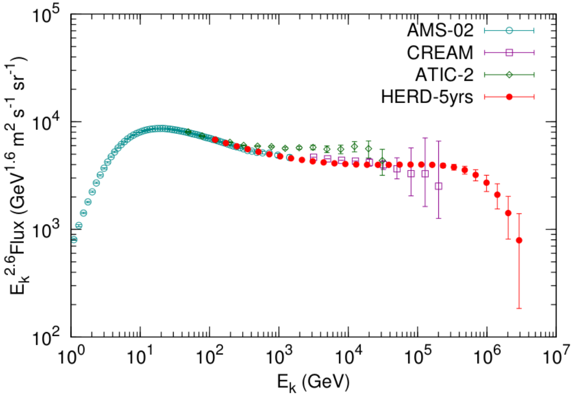
INFN

ASI Agenzia Spaziale Italiana

Outline

- Introduction
- Scientific objectives
- The payload

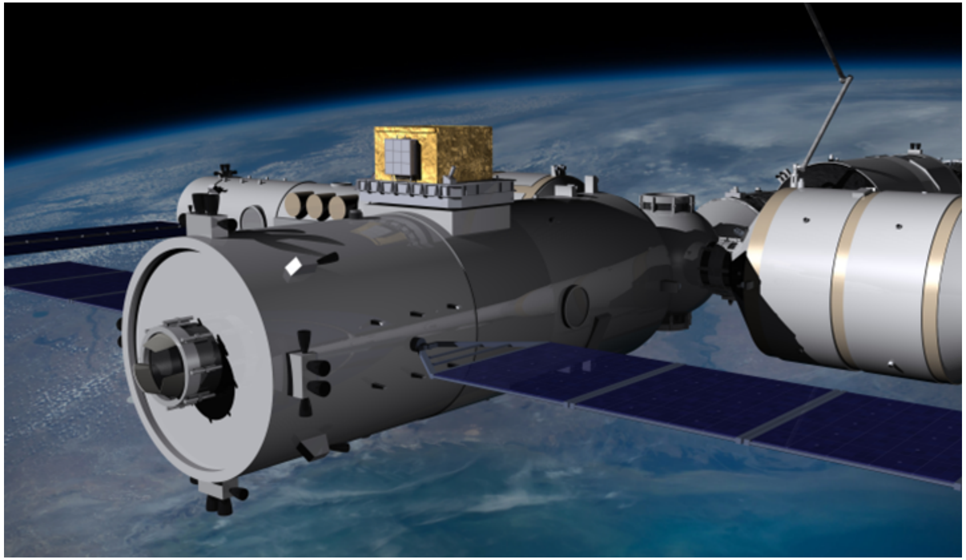




Introduction

HERD: High Energy cosmic-Radiation Detection facility

The HERD experiment is an innovative experiment for the direct detection of high energy cosmic rays to be installed on the Chinese Space Station in 2027

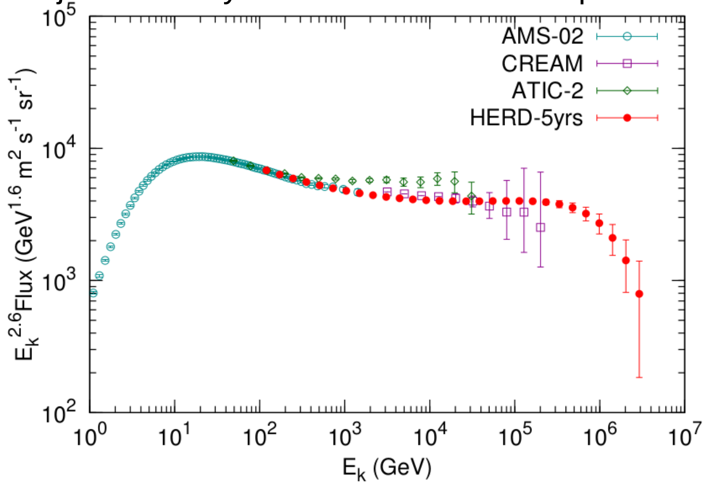


- Detector based on a spherical calorimeter
- Main objectives: extend direct measurement of high energy cosmic rays, search for dark matter signals and gamma-ray sky observation

Scientific objectives – Proton and Nuclei

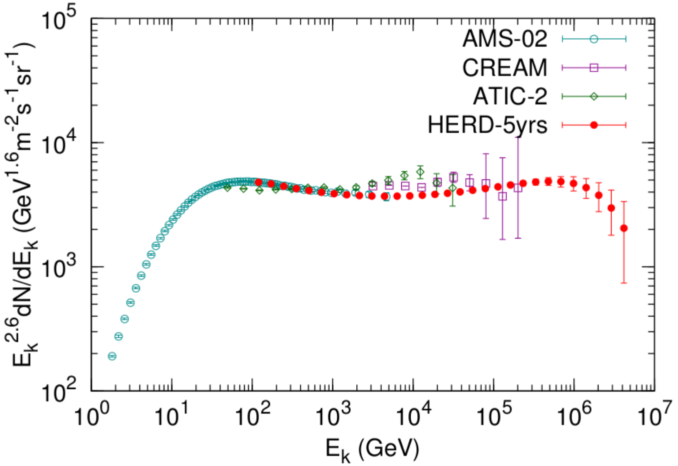
- Extend direct measurement of proton and nuclei fluxes up to ~PeV/n
- First direct measurement of proton and helium *knee*

Projection of 5-yrs measurement HERD proton flux



Nuclear and Particle Physics Proceedings 306–308 (2019) 85–91

Projection of 5-yrs measurement HERD Helium flux



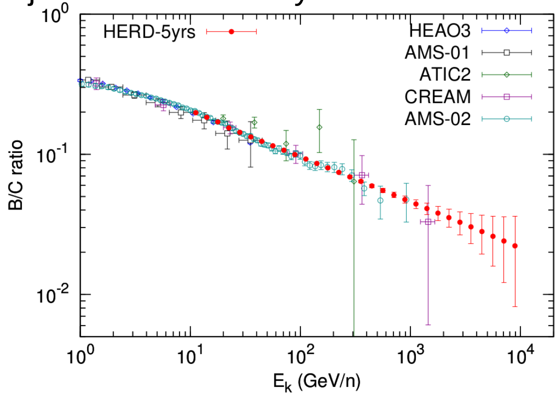
Nuclear and Particle Physics Proceedings 306–308 (2019) 85–91

Scientific objectives – Proton and Nuclei

Measure nuclei fluxes at high energies is a very important item

- Measure ratio of different nuclei abundances (as B/C) to study cosmic ray propagation
- Measure hardening and softening (variations of spectral index) of nuclei spectra and study its origin
- Searching for new spectral features
- Observation of Iron and beyond

Projection of HERD 5-yrs measurement of B/C ratio



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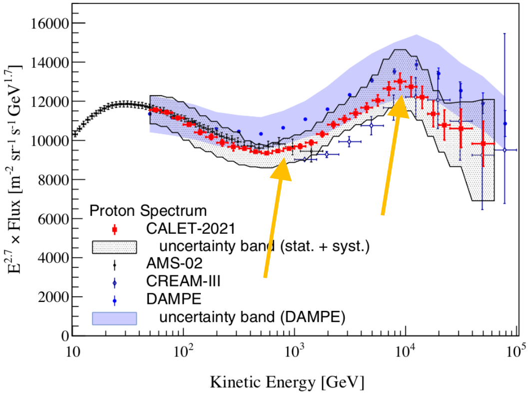
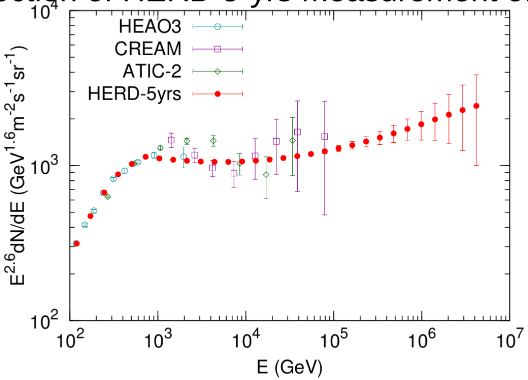
Proton flux



PHYSICAL REVIEW LETTERS 129, 101102 (2022)

Projection of HERD 5-yrs measurement of Iron flux



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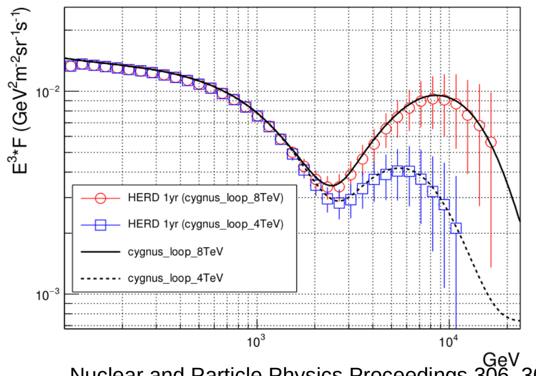
Scientific objectives – Electron+Positron

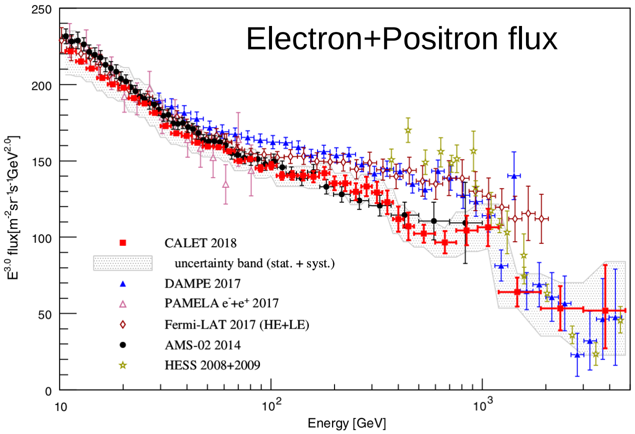
- Search for local sources of electrons/positrons
  - Spectral features
  - Anisotropy
- Search for indirect signals of Dark Matter
  - Spectral features
  - No anisotropy

- Most accurate measurement of e^+e^- flux at high energies, solve the problem of discrepancy of different measurements in the 100GeV–1TeV region



Projection of HERD e^+e^- flux for SNR Cygnus loop as source for two different e^+e^- acceleration cutoff energies

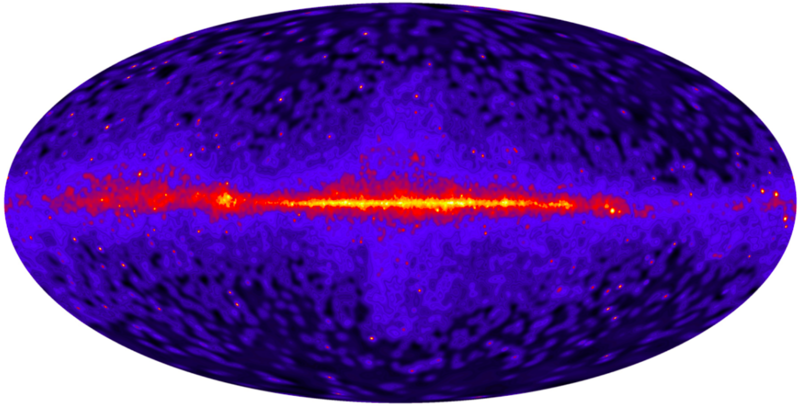
Nuclear and Particle Physics Proceedings 306–308 (2019) 85–91



PHYSICAL REVIEW LETTERS 120, 261102 (2018)

Scientific objectives – Gamma-ray

- Gamma-ray observatory
  - Multi-messenger astronomy
  - Look for gamma-ray sources
  - Investigate diffuse gamma-ray emission



Nuclear Physics B - Proceedings Supplements
Volumes 243–244, October–November 2013, Pages 58-63

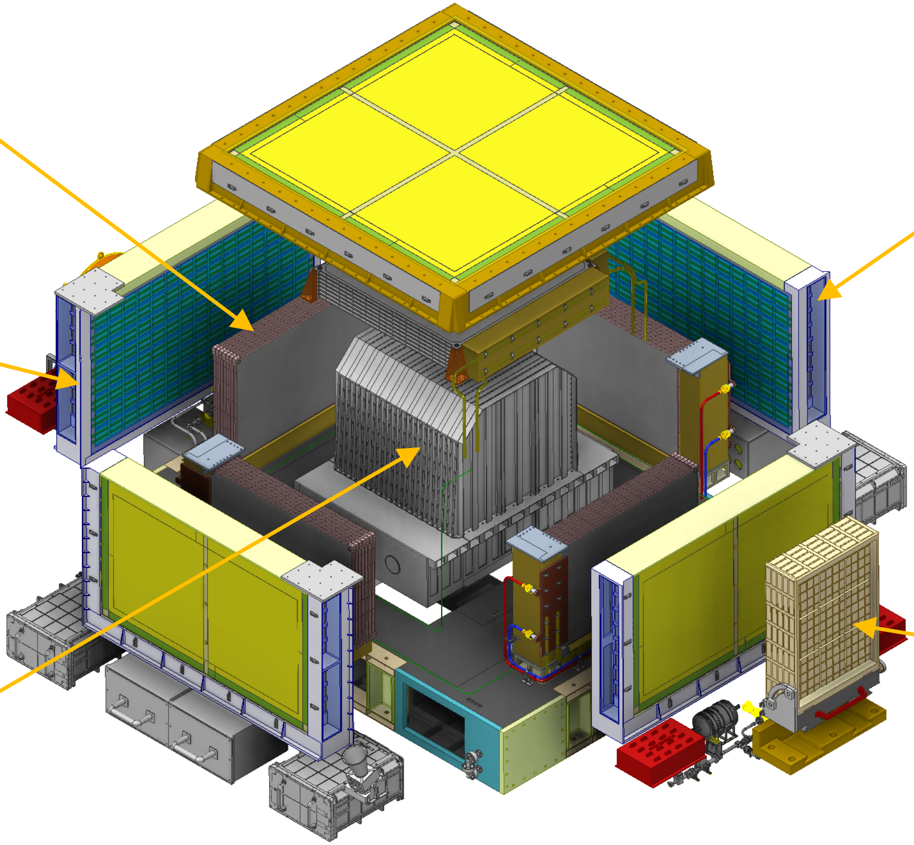
- Search for indirect signals of Dark Matter
  - DM particle-antiparticle annihilation in ɣɣ
  - Can produce a structure in gamma-ray spectrum

The payload

FIT (FIber Tracker):
- tracking

SCD (Silicon Charge Detector):
- charge measurement
- tracking

PSD (Plastic Scintillator Detector):
- anticoincidence system
- charge measurement

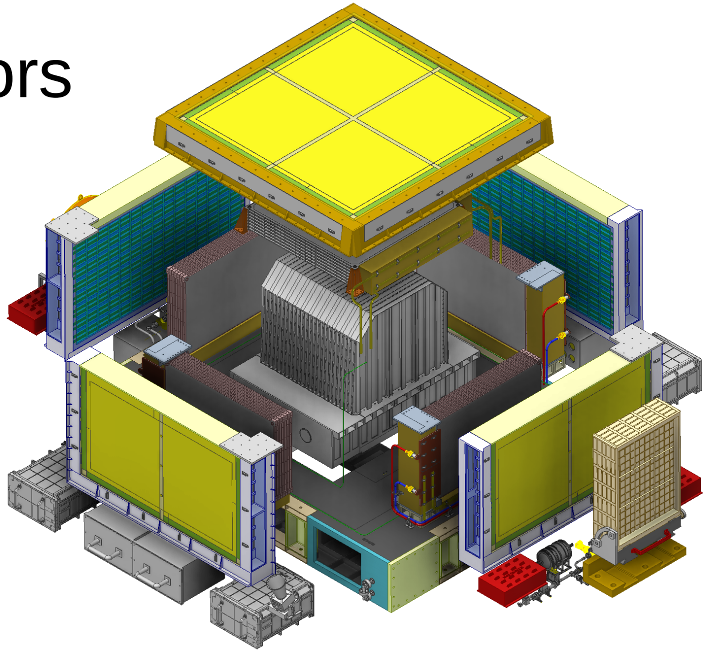


CALO (CALOrimeter):
- energy measurement
- e-h discrimination

TRD (Transition Radiation Detector):
- calibration

The payload

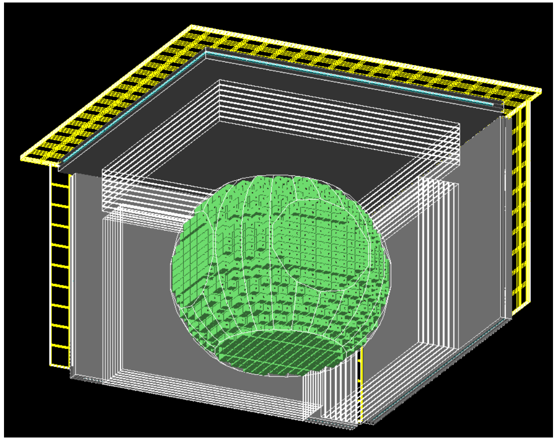
- Calorimeter reconstructs particles from every direction
- Surrounded on five faces by subdetectors

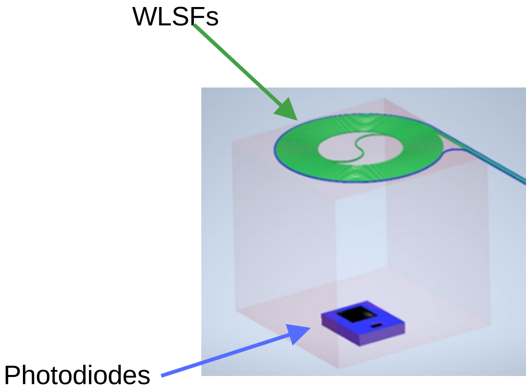


- Much larger effective geometric factor compared to current in-orbit calorimeter: ~2.5 m^2sr for electrons, ~1 m^2sr for protons

The payload - Calorimeter

- Innovative geometry and structure:
  - Finely segmented (about 7500 LYSO cubic scintillating crystals of side 3 cm)
  - Spherical shape
  - Homogeneous
  - Isotropic
  - 3D
  - Deep (55 X_0, 3 λ_I)
  - Large effective geometric factor
  - Good energy resolution (~2.5% for electrons, <30% for protons)
- Double read-out systems:
  - Wavelength Shifting fibers coupled to Intensified Scientific CMOS
  - Double PhotoDiode read-out system
  - Strong check of the energy scale
  - Independent triggers
  - Redundancy





The payload - Calorimeter

Energy deposit to measure in every crystal:
- Calibration via MIP: ~30 MeV
- Hadrons up to PeV/n: ~250 TeV

-Extremely large dynamic range: >10^7
-Saturation level of the single channel more then 20 times of currently in-orbit experiments
-Number of channels more then 20 times of currently in-orbit experiments

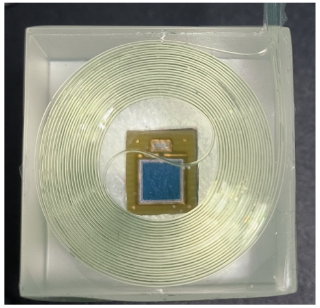
Also needed:
Low power consumption
Low noise

Developing ad hoc sensors and read-out electronics

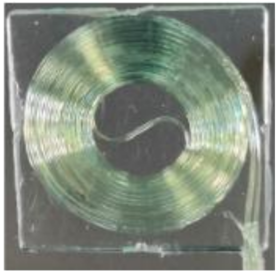
~250 TeV

~10 MeV

The payload - Calorimeter

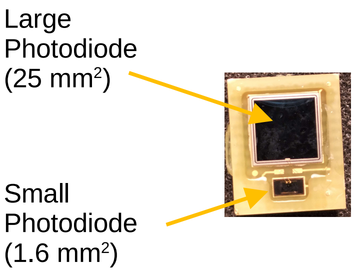


- Double read-out systems:
  - Extremely high dynamic range for every channel: >10^7
  - Number of channels more than 20 times of currently in orbit experiments



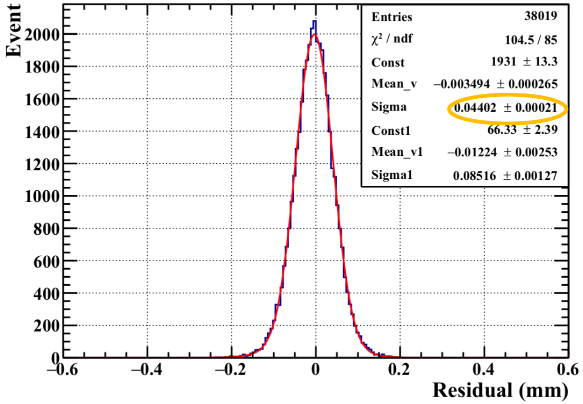
- **Wavelength Shifting fibers read-out system**:
  - Two different IsCMOS: high gain and low gain → extend dynamic range
  - No electric signal inside the calorimeter
  - Innovative system never used in space

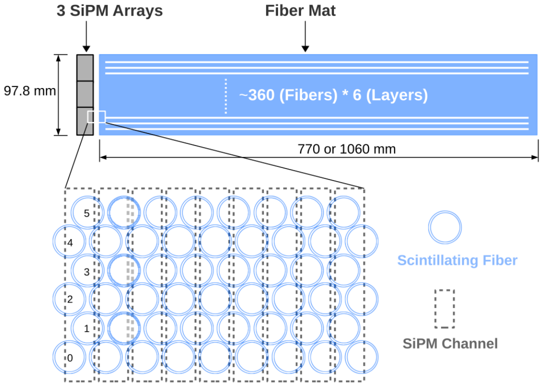
- **Double Photodiode read-out system:**
  - Two PDs with different active areas → extend dynamic range
  - FEE chips with automatic gain selection (high gain / low gain ≈ 20) → extend dynamic range
  - Similar sensors already used in space



The payload - Subdetectors

https://doi.org/10.1007/s41605-021-00262-9



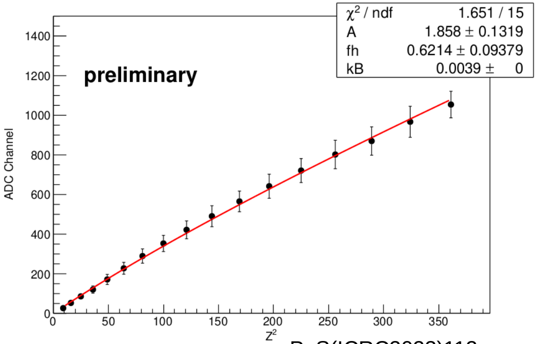


Fiber Tracker:

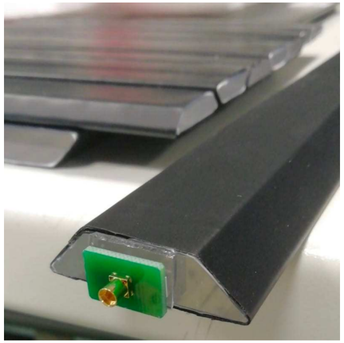
- Track measurement (spatial resolution 40 μm)
- Plastic scintillating fibers of 250 μm diameter, read-out by SiPMs

Plastic Scintillator Detector:

- Charge measurement (for Z 1-26) and anticoincidence system
- Trapezoidal section bars read-out by SiPMs



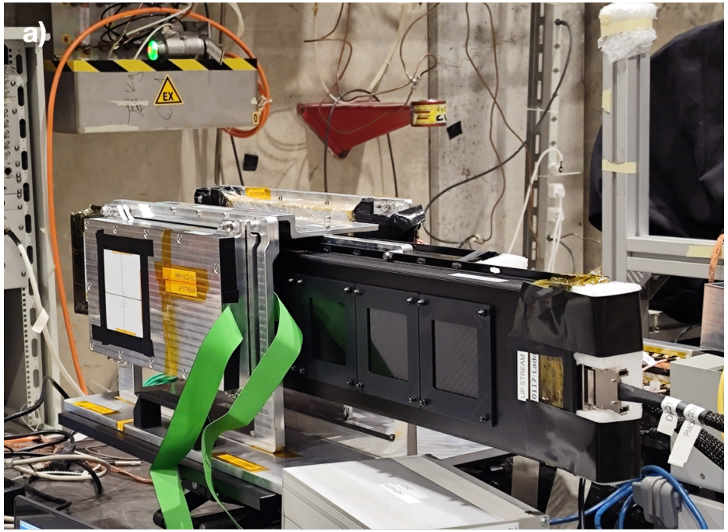
PoS(ICRC2023)112

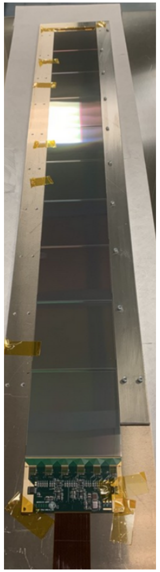


PoS(ICRC2023)140

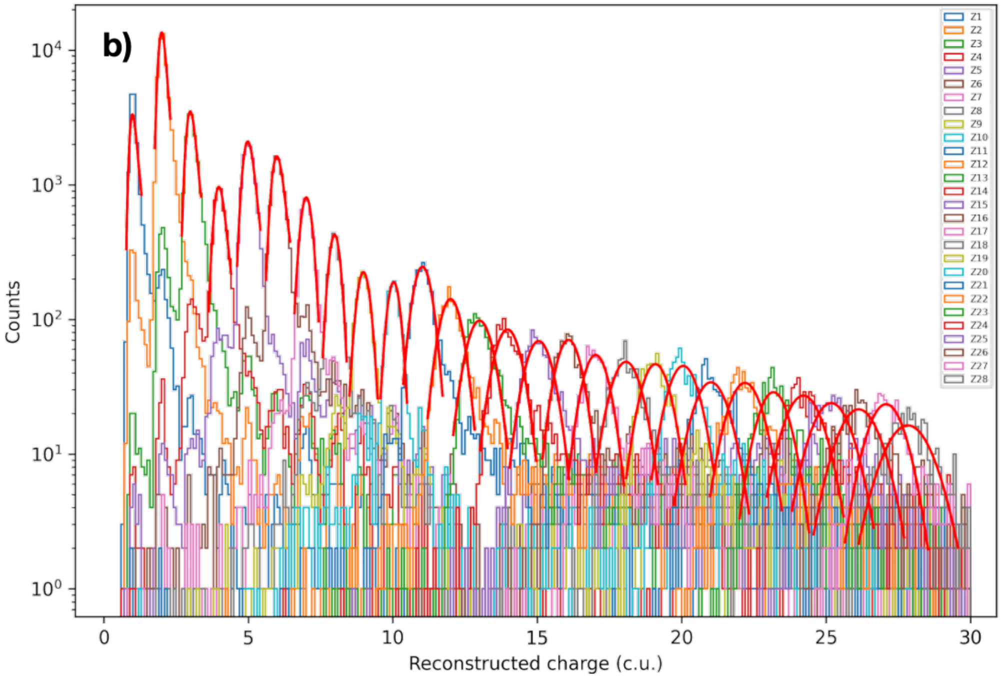
The payload - Subdetectors

Silicon charge detector:
- Charge (for Z 1-26) and track measurement
- Silicon strips detector (300 μm thickness, 60 μm implantation pitch)





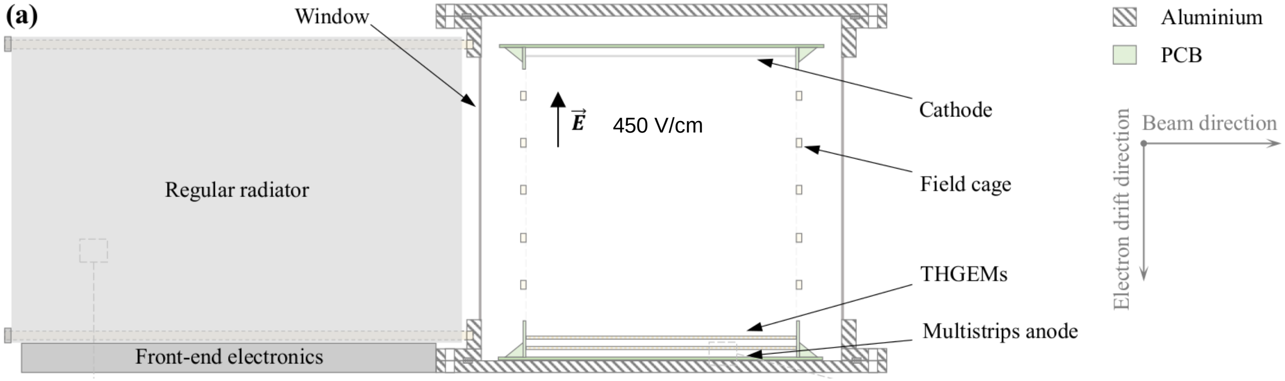
PoS(ICRC2023)087



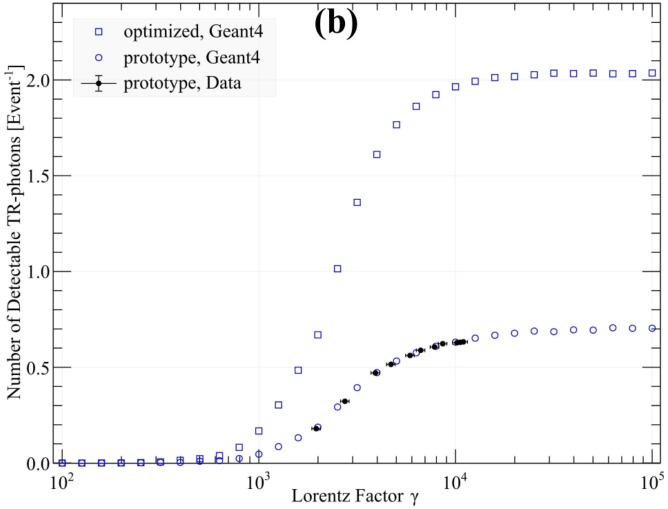
The payload - Subdetectors

Transition Radiation Detector:

- TeV energy range calibration of the calorimeter
- Radiator with polypropylene foils
- Based on a Thick-Gas Electron Multiplier (Ar/CO_2, 93:7)



Cong Dai et al 2023 JINST 18 P03045



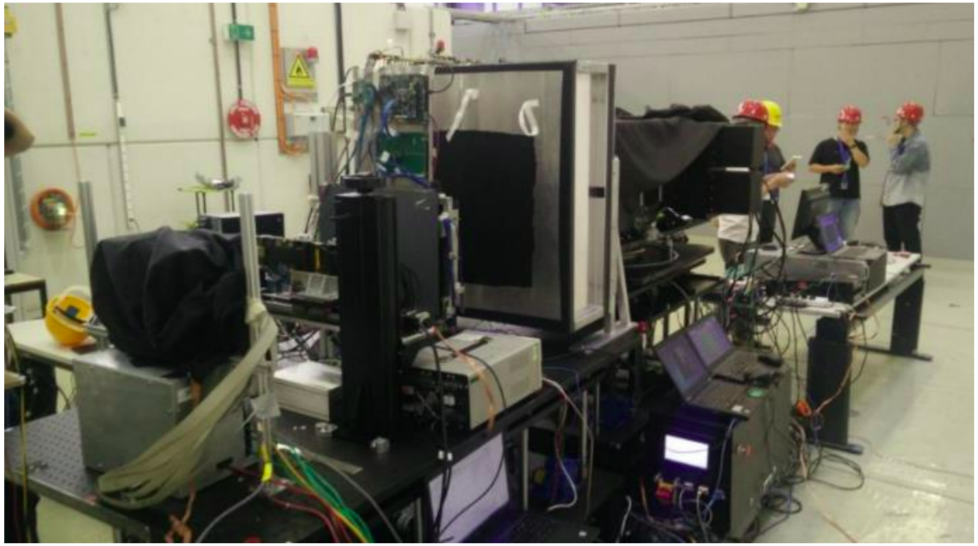
- Calibrated with @GeV electron beam at ground facilities (DESY, CERN PS)
- Same Lorentz gamma factor of @TeV protons

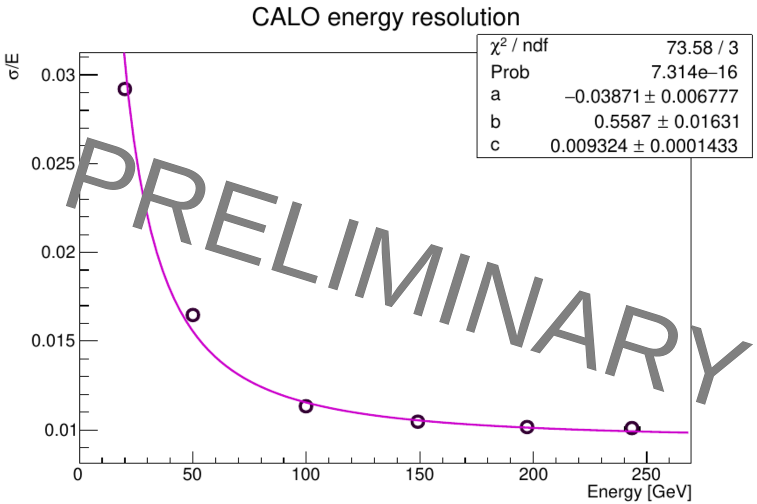
Optimized with:

- Kapton foil for radiator
- Xe mixture gas

Current Status

- Detector finalization and space qualification process
- PS-SPS September-October 2023 ~2 months beam test with all detectors prototypes with muons, electrons, protons and heavy ions → analysis ongoing



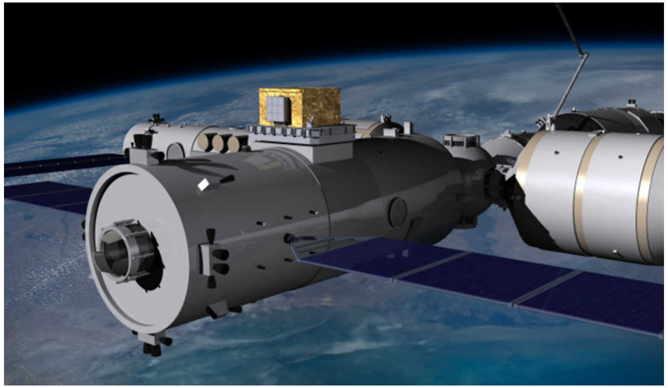


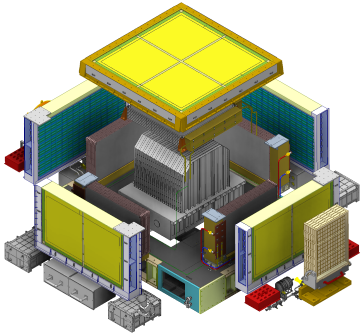
Energy resolution for electrons

Activities supported by the Italian Space Agency through the ASI - INFN n. 2023-8-HH.0

Summary

- Herd experiment to be launched on 2027
- Extend proton and nuclei fluxes at higher energy to study the cosmic ray *knee* and propagation mechanism
- Extend electron+positron flux to higher energy to search for indirect signals of dark matter and local sources
- Gamma-ray detection to higher energy to search for indirect signals of dark matter, cosmic ray sources and multi-messenger astronomy





- Innovative calorimeter and detector geometry
- Currently finalization of the detectors and space qualification process

Thank you for the attention!

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)
- North Night Vision Technology (NVT)
- University of Hong Kong (HKU)

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- ICCUB – Barcellona
- IFAE – Barcellona

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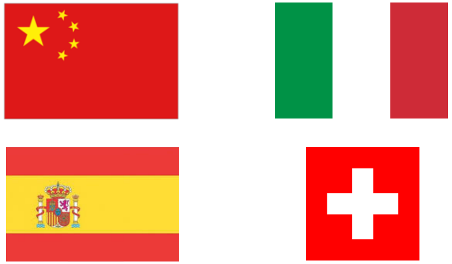
- INFN Firenze and Firenze University
- INFN Pavia and Pavia University
- INFN Perugia and Perugia University
- INFN Pisa and Pisa University
- INFN Laboratori Nazionali del Gran Sasso and GSSI Gran Sasso Science Institute
- INFN Lecce and Salento University
- INFN Napoli and Napoli University
- INFN Roma2 and Tor Vergata University
- INFN Trieste and Trieste University

SWITZERLAND

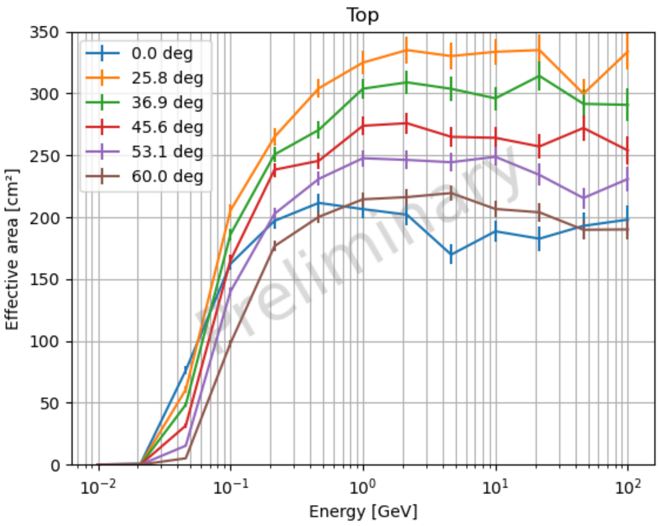
- University of Geneva
- EPFL - Lausanne

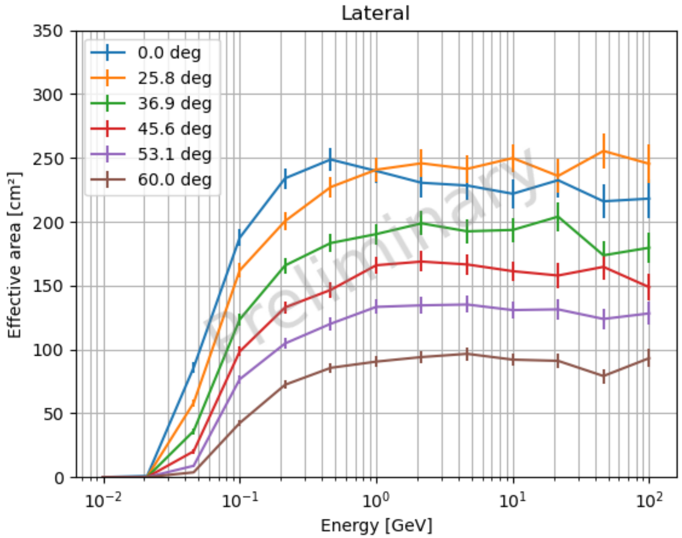
Xi’an (CN), 16-18 Dec 2019



HERD Gamma-Ray Performances

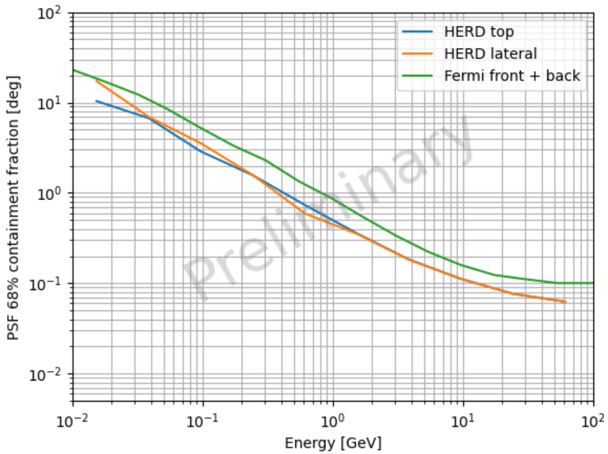
Effective Area





Lack of tungsten is compensated by larger field of view

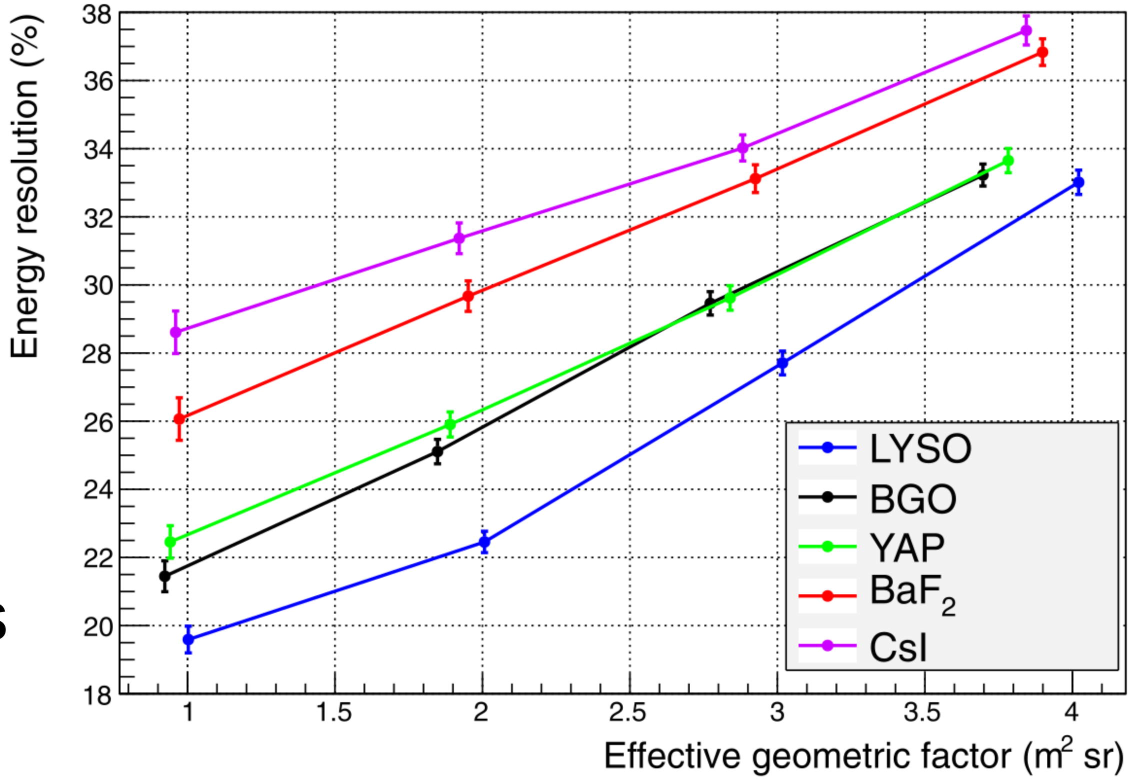
Angular Resolution



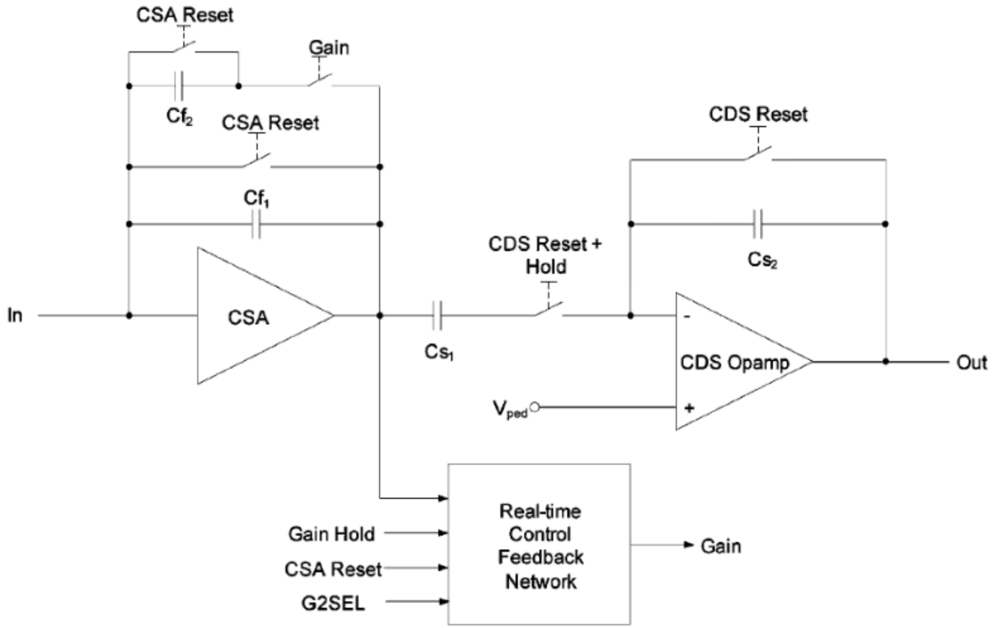
Due to the lack of tungsten, the **effective area** is 10-20 smaller than Fermi-LAT, but the **angular resolution** is better at all energies

Why LYSO?

1 TeV protons



HiDRA2 chip



CSA Reset
Gain
Cf2
CSA Reset
Cf1
CDS Reset
Cs2
CDS Reset +
Hold
In
CSA
Cs1
CDS Opamp
Out
Vped
Real-time
Control
Feedback
Network
Gain Hold
CSA Reset
G2SEL
Gain

IsCMOS