The HERD space mission

Dr. Felicia Barbato – On behalf of HERD collaboration
GSSI and INFN

16th Marcel Grossmann Meeting

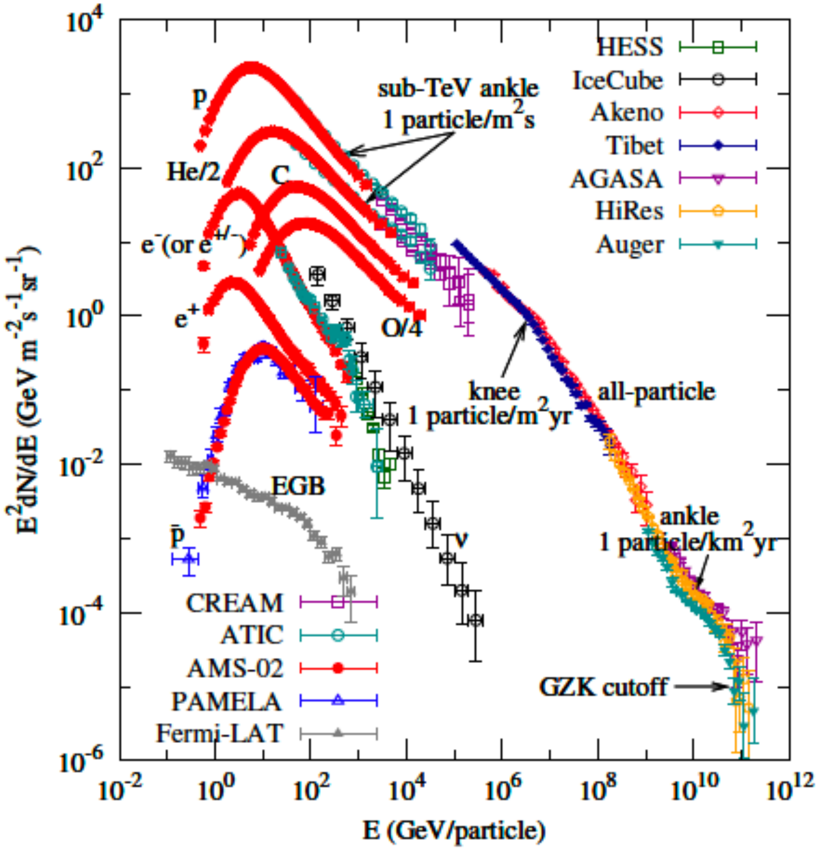
Measuring the all particle spectrum at knee

Still open question about cosmic rays…

where are they produced?

how are they accelerated to such high energies?

how do they propagate in the Galaxy and the Universe?



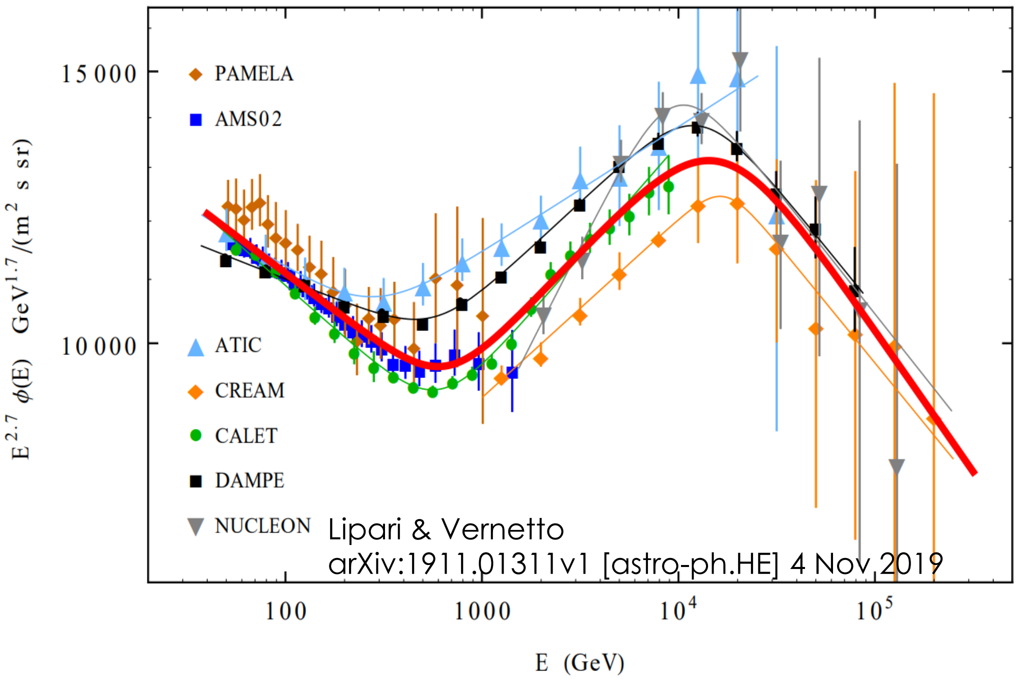
Necessity to study the sub-PeV region to understand the (dominant) origin of the knee

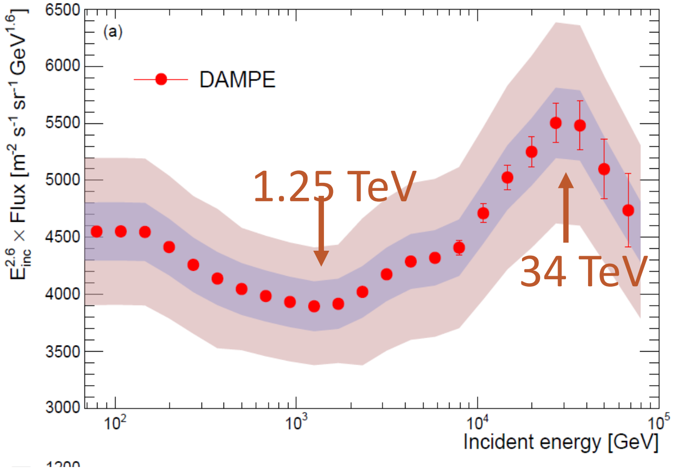
Is it due to the maximum energy achievable at the source or to diffusion processes in the Galaxy?

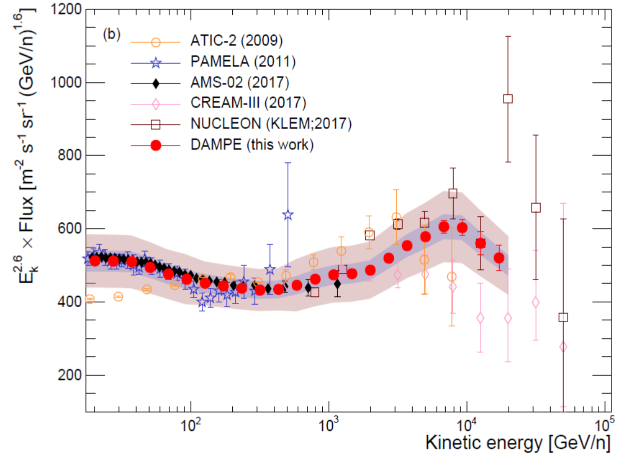
Measuring the all particle spectrum at knee

Current data suggest a hardening of the spectra above about 0.2 TeV/nucleon

- $\gamma_{(E>0.2TeV/nucleon)} \simeq$ -2.6 for all considered elements
- $\gamma_{(E>0.2TeV/nucleon)} \simeq$ -2.7 for protons







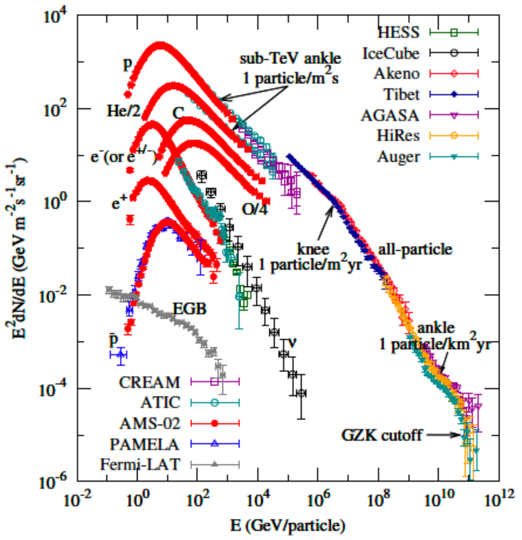
The hardening @ ≈ 200-400 GeV is well established since first observation by Pamela -> Implication on the acceleration mechanism

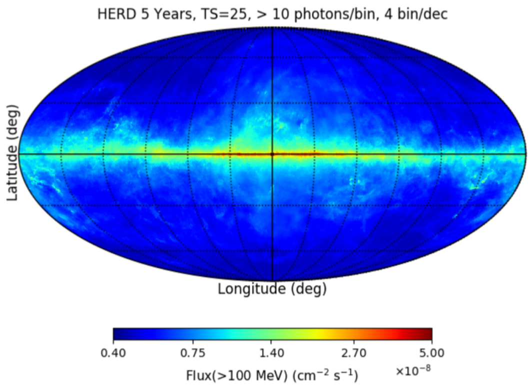
The softening @ ≈ 10 TeV is observed by different experiment with the 1st strong evidence in DAMPE data

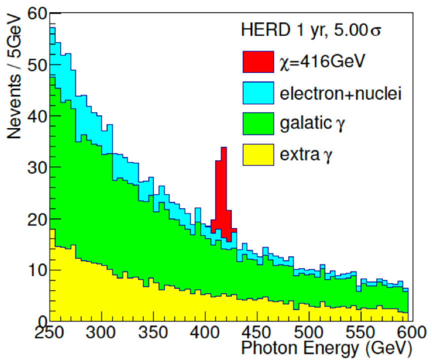
Scientific objectives

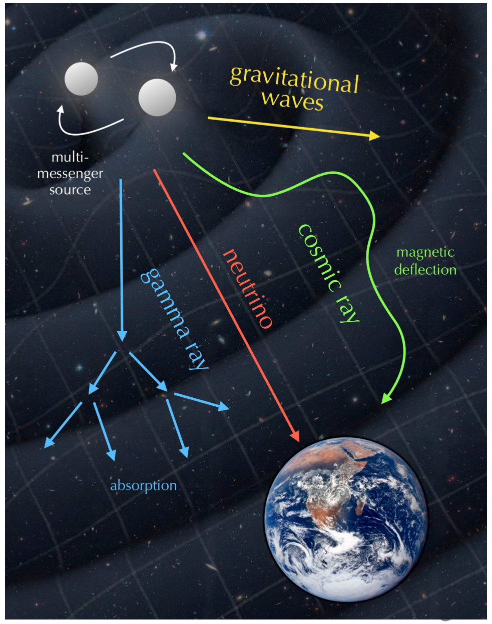
HERD primary scientific goals include

- precise measurements of the energy spectra of CR individual species up to few PeV
- study electrons and photon of spectra from GeV up to tens of TeV
- indirect dark matter search
- contributing to multi-messenger observations together with other satellites and ground-based experiments

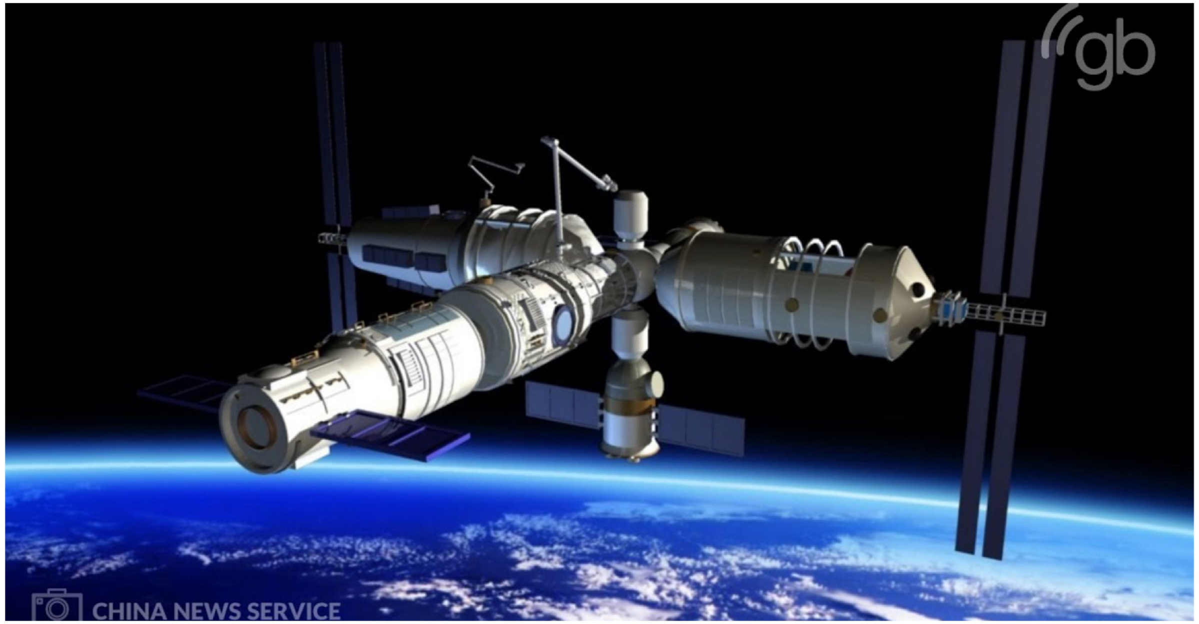








The HERD collaboration



The **High Energy cosmic-Radiation Detection** (HERD) facility is an international space mission that will start operation around 2027 to make cosmic ray direct measurements at the highest possible energies with current technologies

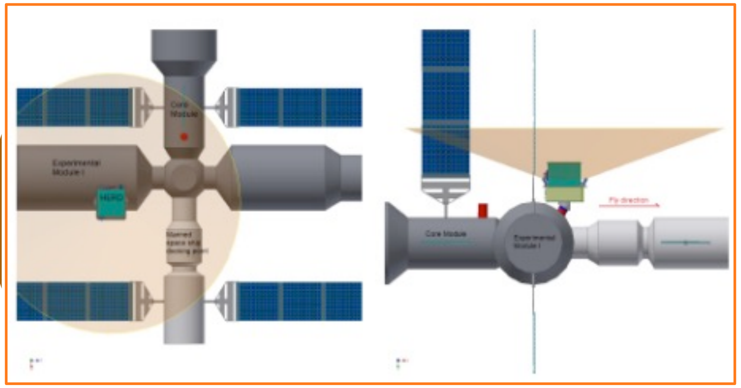
CHINA
- Institute of High Energy Physics, CAS (IHEP)
- Xi'an Institute of Optical and Precision Mechanics, CAS (XIOPM)
- Guangxi University (GXU)
- Shandong University (SDU)
- Southwest Jiaotong University (SWJTU)
- Purple Mountain Observatory, CAS (PMO)
- University of Science and Technology of China (USTC)
- Yunnan Observatories (YNAO)
- North Night Vision Technology (NVT)
- University of Hong Kong (HKU)
- Academia Sinica

SPAIN
- CIEMAT - Madrid
- ICCUB – Barcelona
- IFAE – Barcelona

ITALY
- L'Aquila University
- INFN Bari and Bari University
- INFN Bologna
- INFN Firenze and Firenze University
- INFN Laboratori Nazionali del Gran Sasso and Gran Sasso Science Institute (GSSI)
- INFN Lecce and Salento University
- INFN Napoli and Napoli University
- INFN Pavia and Pavia University
- INFN Perugia and Perugia University
- INFN Pisa and Pisa University
- INFN Roma2
- INFN Trieste

SWITZERLAND
- University of Geneva
- EPFL - Lausanne

Mission Profile



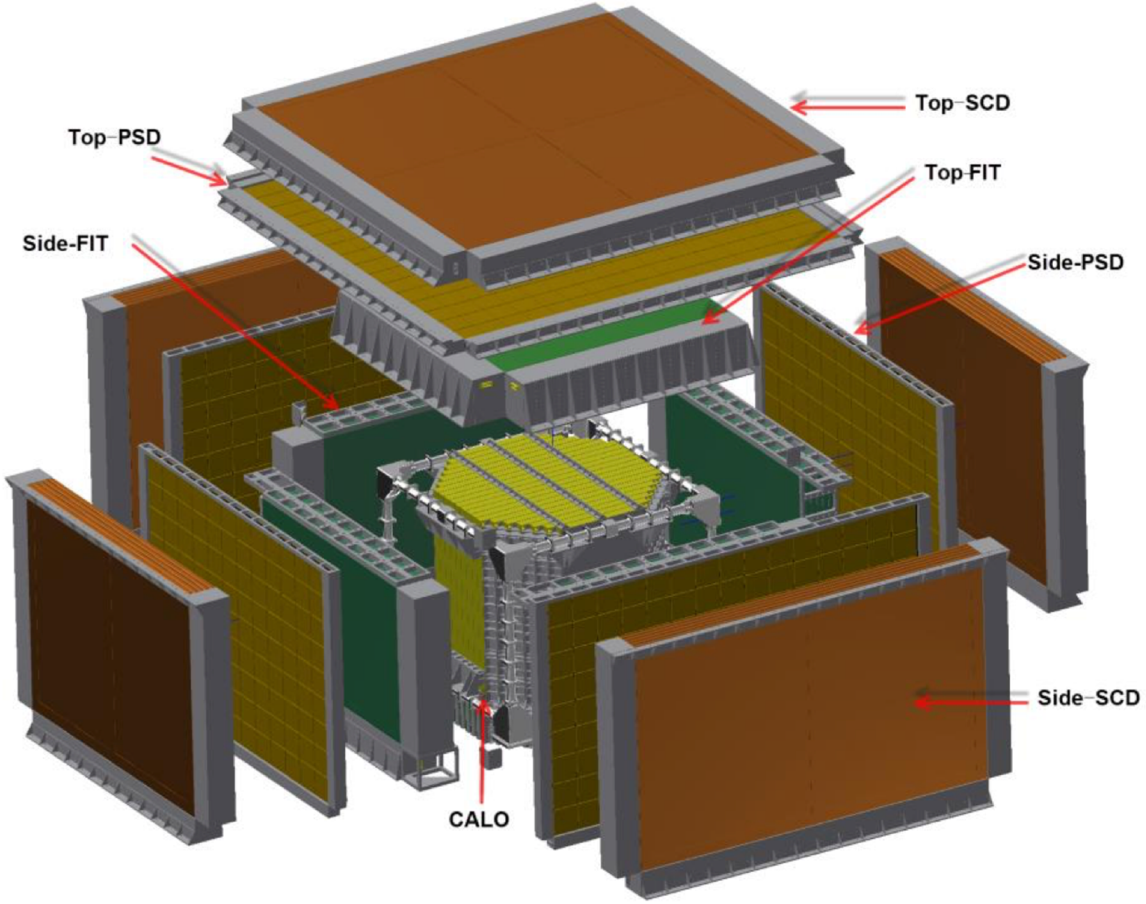
CSS expected to be completed in 2022

Life time	> 10y
Orbit	Circular LEO
Altitude	340-450 km
Inclination	42°

HERD expected to be installed around 2027

Life time	> 10y
FOV	+/- 70°
Power	< 1.5 kW
Mass	< 4 t

The payload

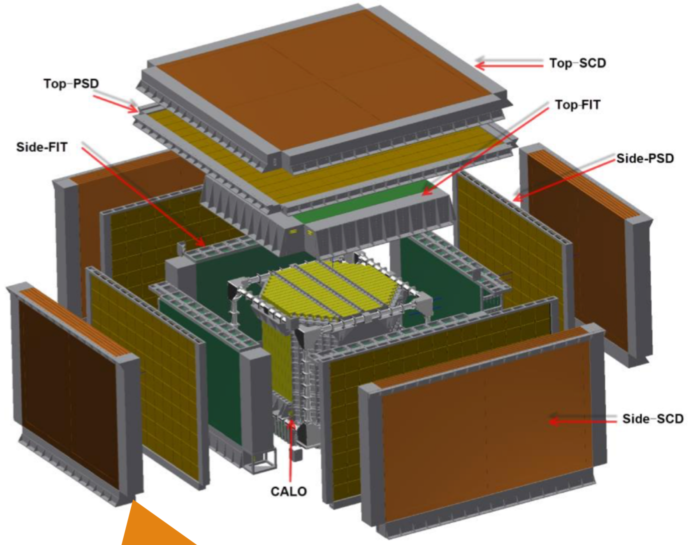


SCD	Charge Reconstruction
PSD	Charge Reconstruction γ Identification
FIT	Trajectory Reconstruction Charge Identification
CALO	Energy Reconstruction e/p Discrimination
TRD	Calibration of CALO response for TeV protons

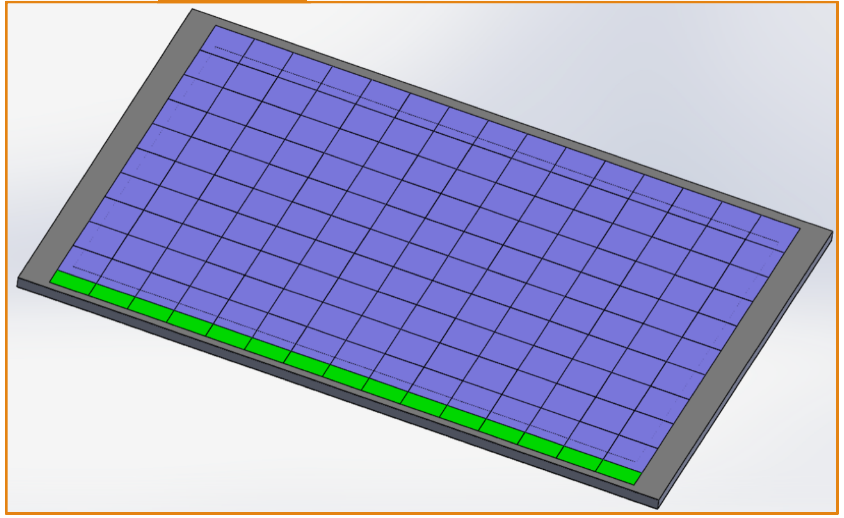
Main requirements

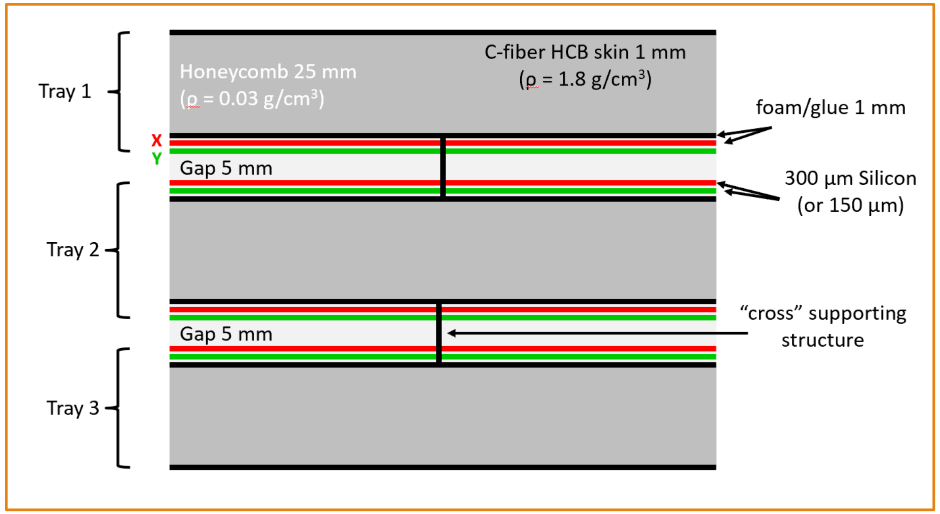
	γ	e	p, nuclei
Energy Range	>100MeV	10 GeV 100 TeV	30 GeV 3 PeV
Energy resolution	1% @ 200 GeV	1% @ 200 GeV	20% @ 100 GeV -1 PeV
Effective Geometric Factor	>0.2 m^2sr @ 200 GeV	>2 m^2sr @ 200 GeV	>1 m^2sr @ 100 TeV

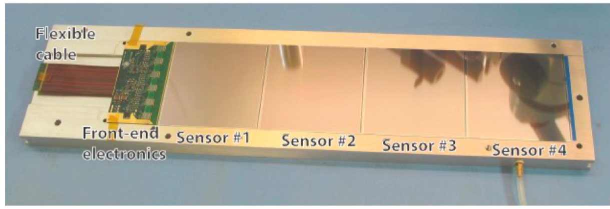
Silicon Charge Detector (SCD)



- SCD is made by **silicon micro-strip** detectors that will measure with precision the impinging particle charge |Z|
- It is the **outermost** detector to avoid early charge-change interactions in the PSD
- It is highly **segmented** to minimize the backscattered secondary particles coming from the CALO

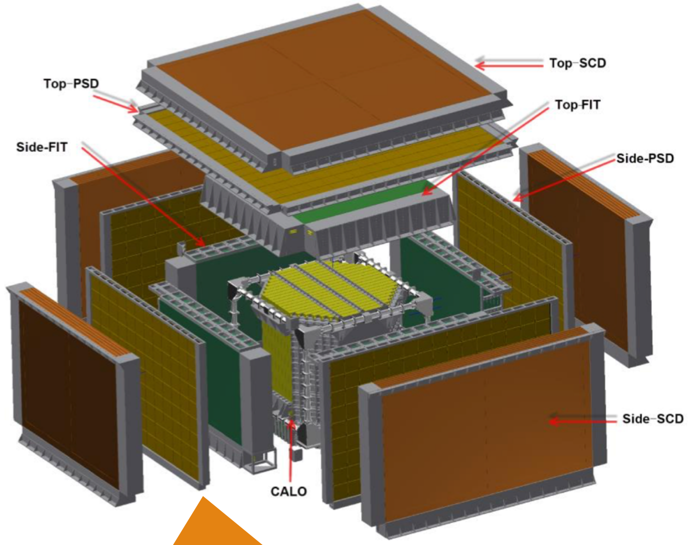


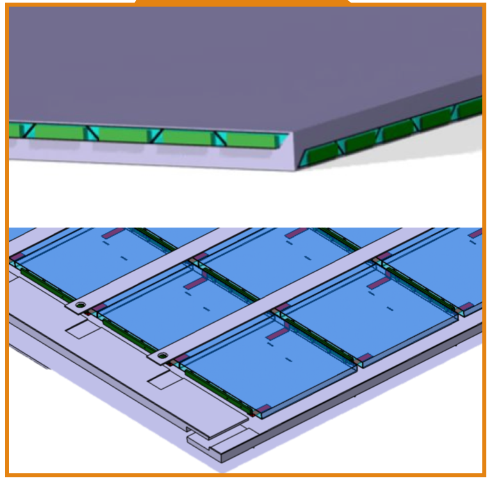




Plastic Scintillator Detector (PSD)

PSD | Charge Reconstruction and γ Identification



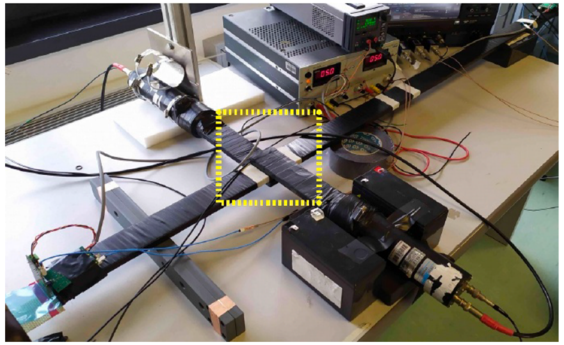


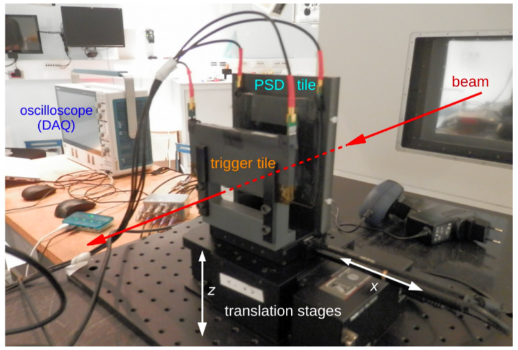
BARS VERSION

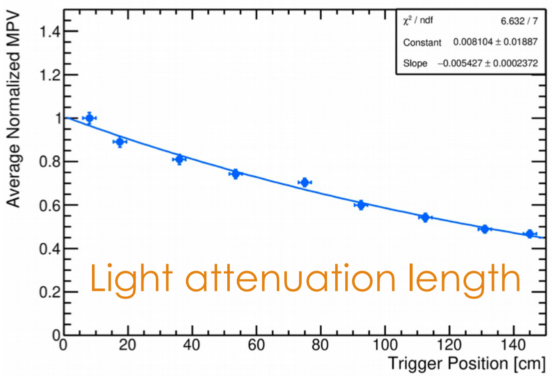
TILES VERSION

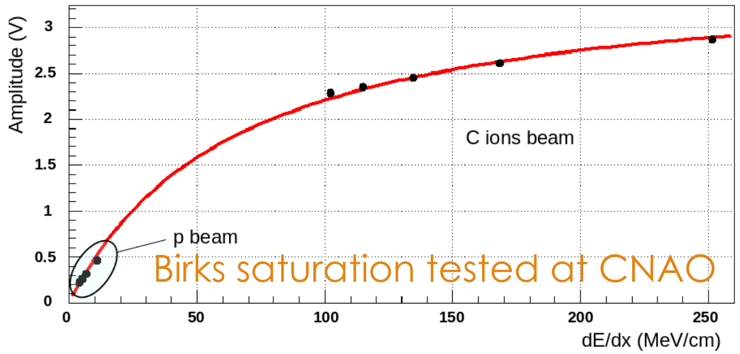
Requirements:

- high efficiency in charged particles detection (>99,98%)
- high dynamic range to identify nuclei at least up to iron
- segmented to reduce the Back-scattering particles from the calo



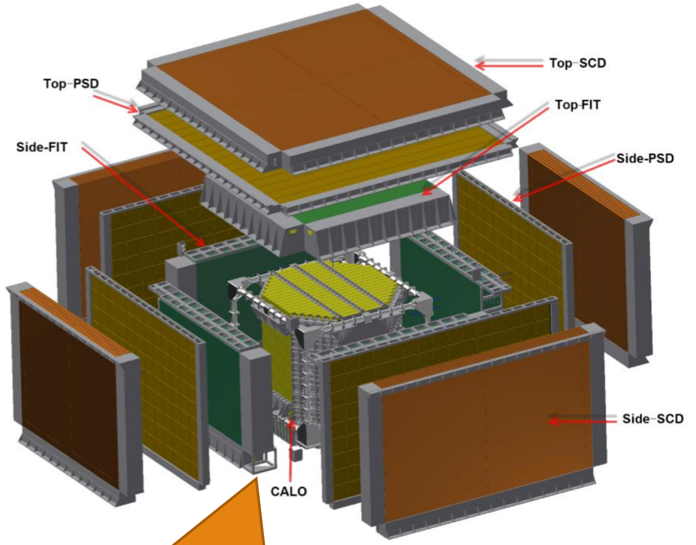


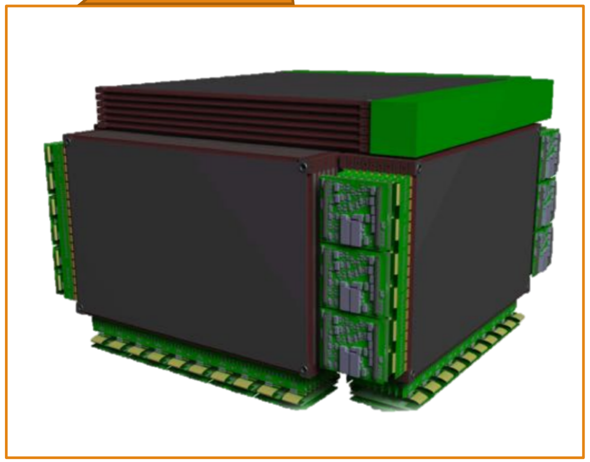




Fiber Tracker (FIT)

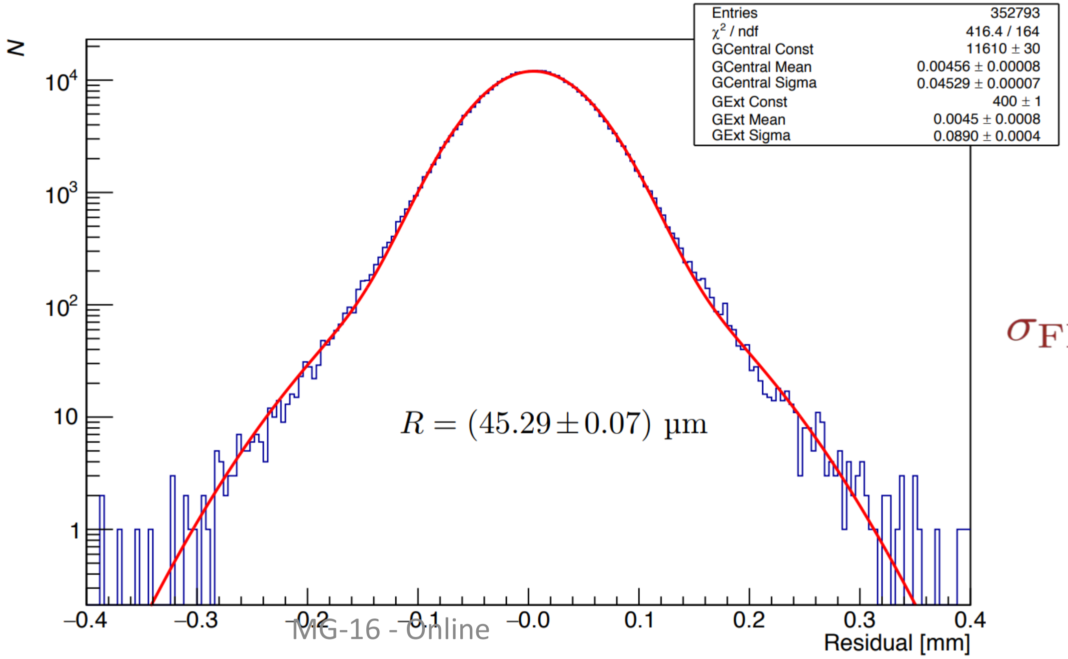
FIT	Trajectory Reconstruction and Charge Identification





- 4 identical side sectors + 1 top sector
- 7 x-y planes in each side sector
- 5 x-y planes in the top sector
- 6 x modules (106 cm fiber length) in each x plane
- 10 y modules (77 cm fiber length) in each y plane
- 1 fiber mat + 3 silicon photomultiplier (SiPM) arrays

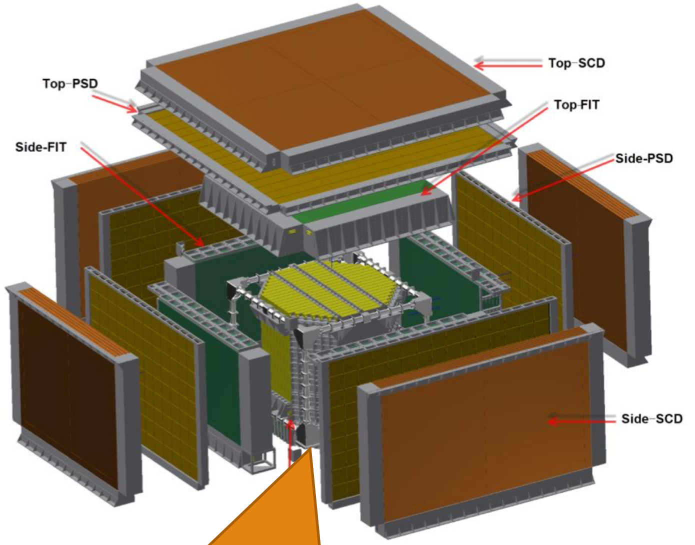
Residual distribution for the reconstructed tracks

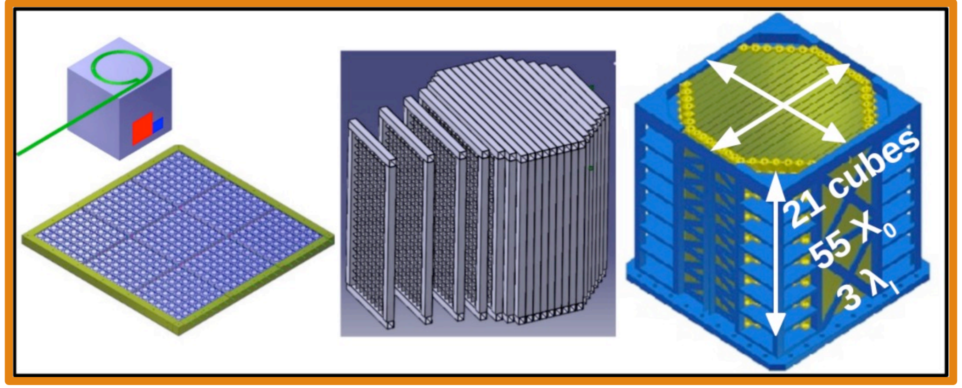


$$\sigma_{\mathrm{FIT}} = (45.0 \pm 0.1)\ \mu\mathrm{m}$$

Calorimeter (CALO)

CALO	Energy Reconstruction and e/p Discrimination

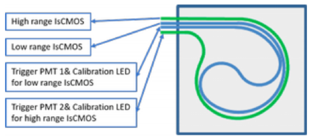


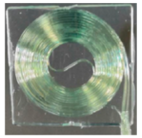


- **7500 LYSO cubes** with edge length of 3 cm
- It accepts particles coming from each surface

Particle	Energy	Effective acceptance	Energy resolution
Protons	≤ 1 PeV	> 1 m^2sr	~ 30%
Electrons	≤ 10 TeV	~ 2 m^2sr	~ 2%

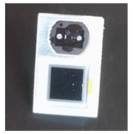
First readout system

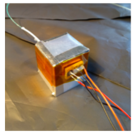




- WaveLength Shifting fibers (WLS)
- Image Intensified scientific CMOS
- Frame rate: > 800 frames/sec
- Low read-out noise (< 1.5e)

Second readout system





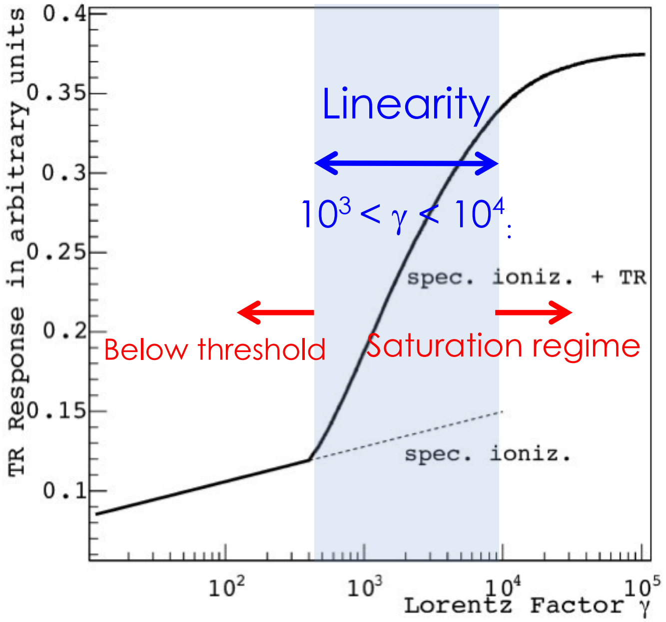
- Photo-diodes with different active areas connected to HIDRA chips
- The S/N ratio for MIP is >= 4
- Expected saturation level ~ 250 TeV

The double read-out scheme will strongly improve both the calibration and trigger capabilities

Transition Radiator Detector (TRD)

TRD | Calibration of CALO response for TeV protons

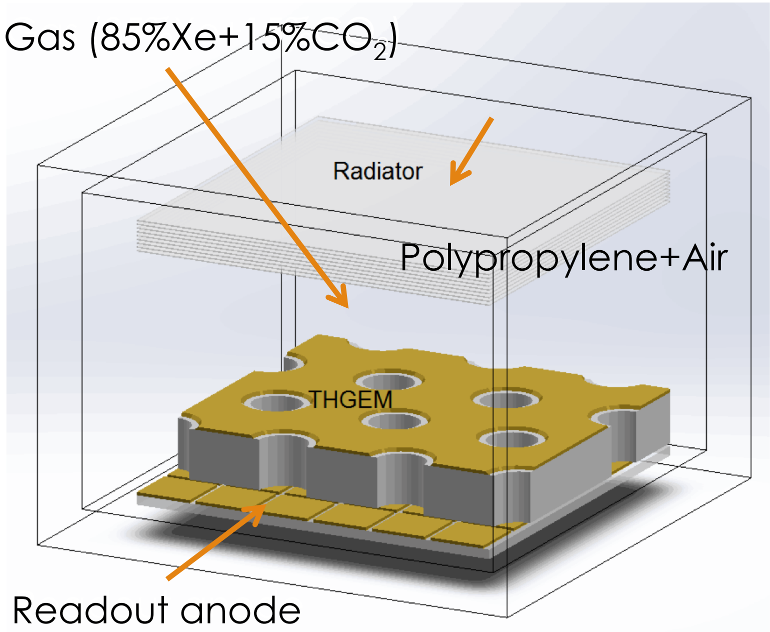
The TRD, installed on a lateral face of the detector, is needed to calibrate the response of the calorimeter to high energy hadronic showers



Linearity for $10^3 < \gamma < 10^4$

Electron 0.5 GeV < E < 5 GeV

Proton 1 TeV < E < 10 TeV

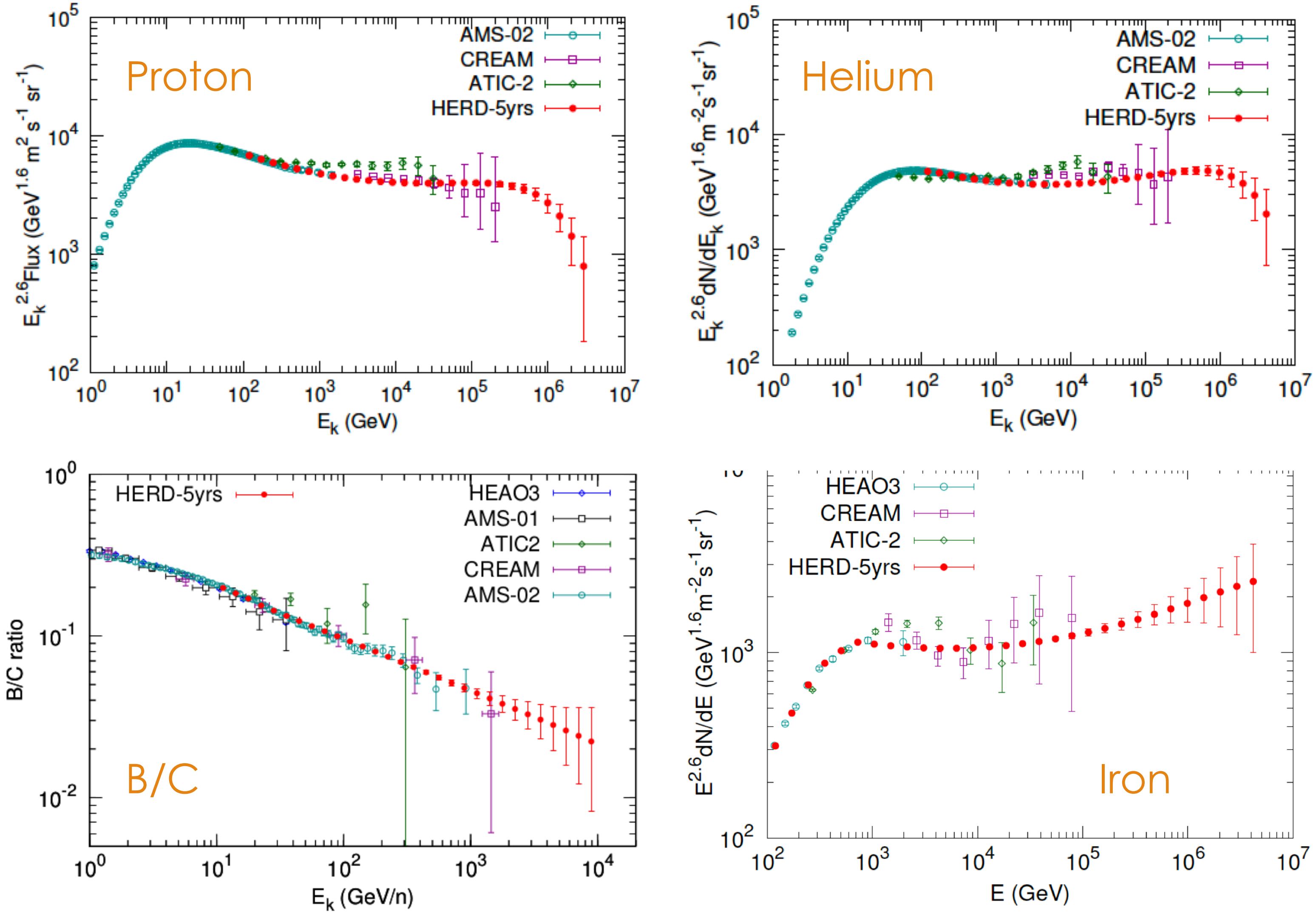


Calibration procedure

- Calibrate TRD response using [0.5 GeV, 5 GeV] electrons in space (and beam test)
- Calibrate CALO response using [1 TeV, 10 TeV] protons from TRD

HERD potential

5 years of HERD exposure



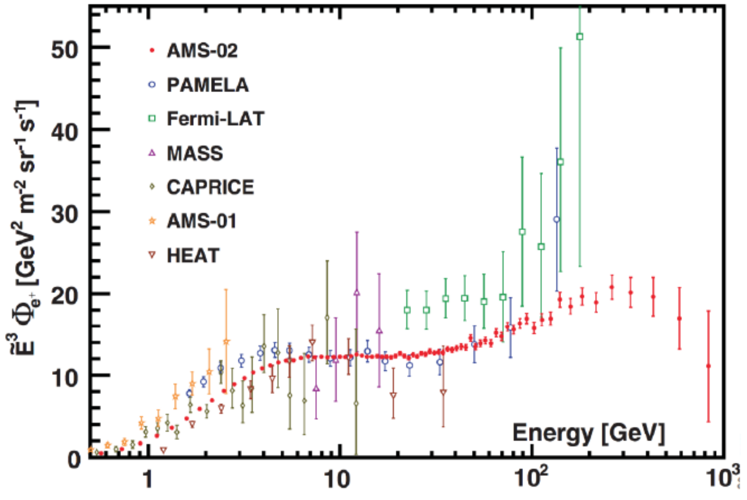
1. The HERD data can clearly reveal the knees of both protons and Helium nuclei and can critically address the Z-dependence, A-dependence, or constant knee of different compositions, which are very important to understand the physical nature of the knee of CRs

2. B/C is important to probe the propagation of CRs. The HERD measurements will extend the precise B/C ratio to a few TeV/nucleon, and thus can precisely determine the propagation behaviour of CRs

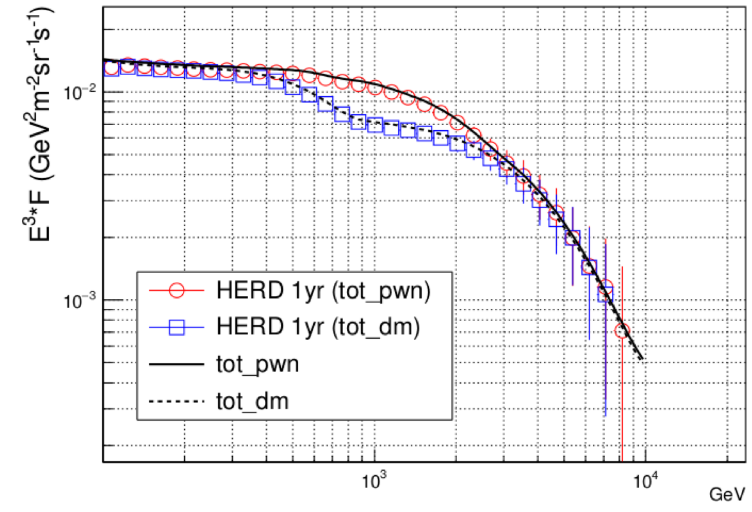
3. The Iron nuclei are the end products of stellar nucleosynthesis. The heavy nuclei in CRs are thus very good tracer of the acceleration sites of CRs. HERD is expected to strongly improve such measurements.

Electrons and positrons

Precision measurements by AMS of the positron flux to 1 TeV.

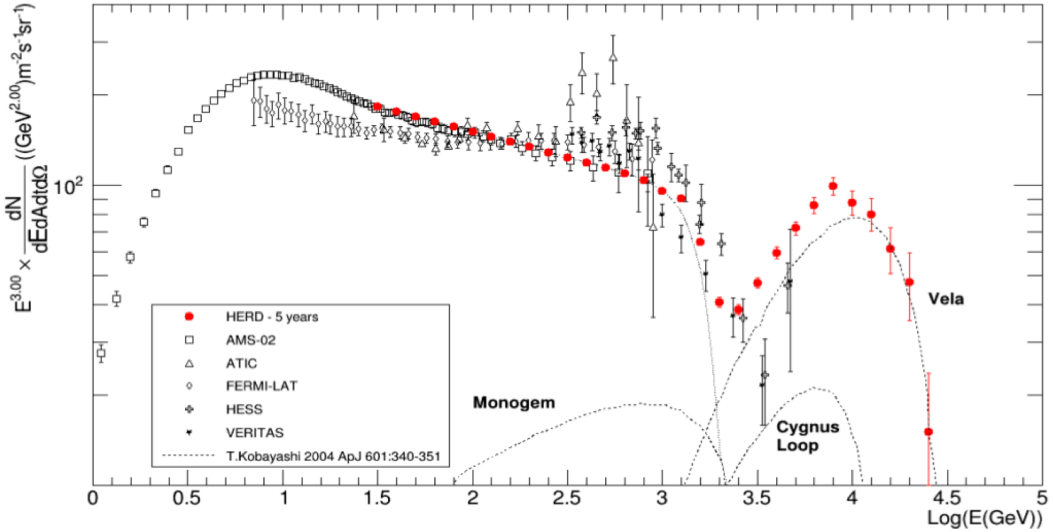


Expected e^{+}+e^{-} flux in 1 year with PWN or DM sources



HERD will measure the all electron flux up to several tens of TeV in order to detect:
spectral cutoff at high energy
local SNR sources of very high energy e^{-}
... and additional information from anisotropy measurement!

Expected e^{+}+e^{-} flux in 5 years



"The different behavior of the cosmic-ray electrons and positrons measured by AMS is clear evidence that most high energy electrons originate from different sources than high energy positrons"
PRL 122 041102 (2019)

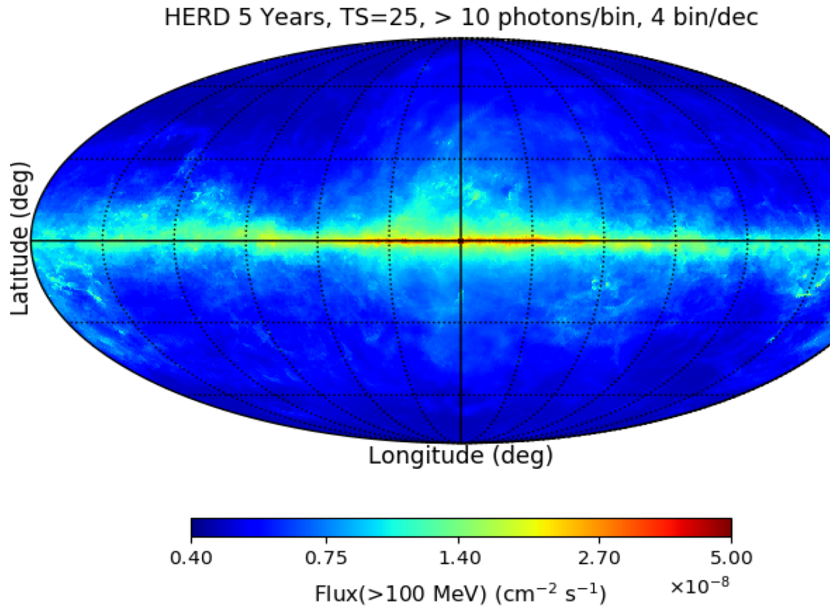
Gamma ray observatory

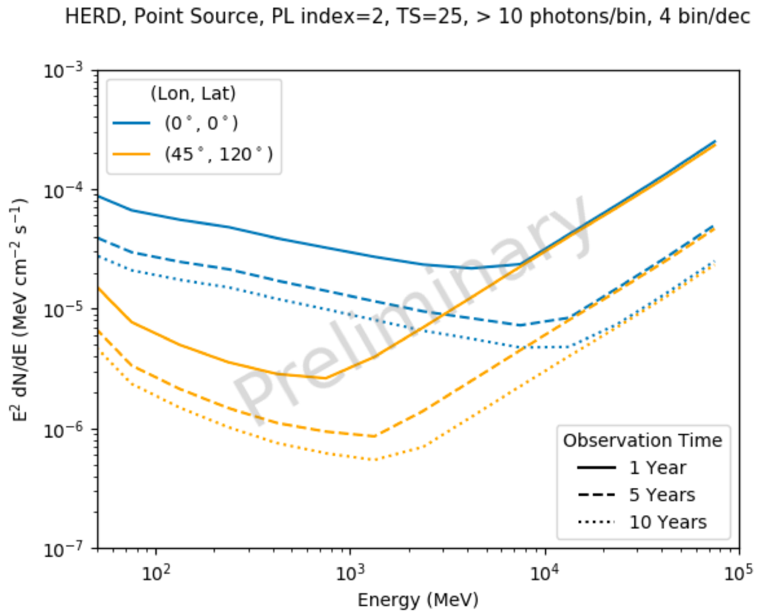
Thanks to its large acceptance and sensitivity, **HERD** will be able to perform a full gamma-ray sky survey in the energy range >100MeV

- extend Fermi-LAT catalog to higher energy (>300GeV)
- increase the chances to detect rare γ events

Targets of Gamma-Ray Sky Survey:

- search for dark matter signatures
- study of galactic and extragalactic γ sources
- study of galactic and extragalactic γ diffuse emission
- detection of high energy GRBs





Summary

The High Energy cosmic-Radiation Detection (HERD) space mission is now being designed, as a result of an international collaboration among several chinese and european institutions, to make cosmic ray (CR) direct measurements at the highest possible energies with current technologies.

HERD primary scientific goals include

- extend the measurement of p and He flux up to a few PeV testing the theory of the knee structure as due to acceleration limit
- extend the measurement of e^{+}+e^{-} flux up to several tens of TeV testing the hypothesis of the expected cutoff at high energy distinguishing between DM or astrophysical origin of positron excess
- large acceptance, high sensitivity to γ up to several hundreds of GeV searching for γ line associated to DM annihilation accomplishing a γ sky survey up to very high energy

BACKUP

GSSI and INFN

CALO PERFORMANCES