The High Energy Cosmic-Radiation Detection (HERD) facility on board the Chinese Space Station: hunting for high-energy cosmic rays

F.GARGANO FOR THE HERD COLLABORATION

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HERD Collaboration

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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

ITALY

L'Aquila University
INFN Bari and Bari University
INFN Bologna
INFN Firenze and Firenze University
INFN Laboratori Nazionali del Gran Sasso and GSSI Gran Sasso Science Institute
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
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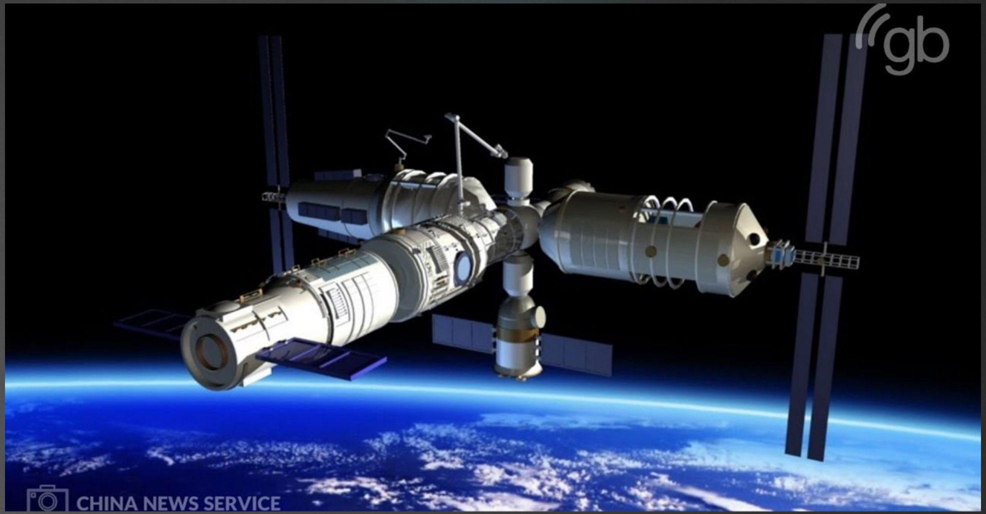
SPAIN

CIEMAT - Madrid
ICCUB – Barcelona
IFAE – Barcelona

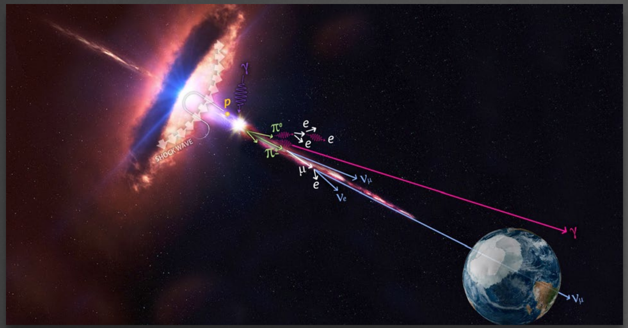
SWITZERLAND

University of Geneva
EPFL - Lausanne

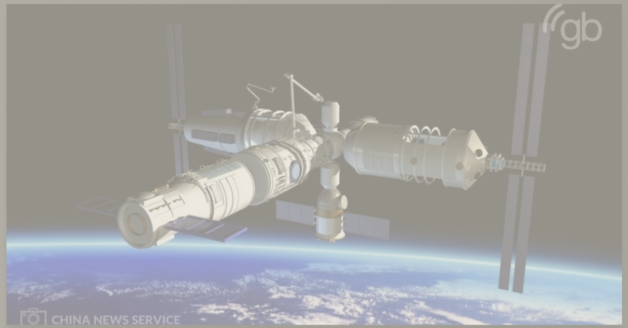


The **High Energy cosmic-Radiation Detection** (HERD) facility is an international space mission that will start operation around 2027.

The experiment is based on a **3D, homogeneous, isotropic and finely-segmented calorimeter** that will measure the cosmic ray flux up to the knee region, search for indirect signal of dark matter and monitor the full gamma-ray sky

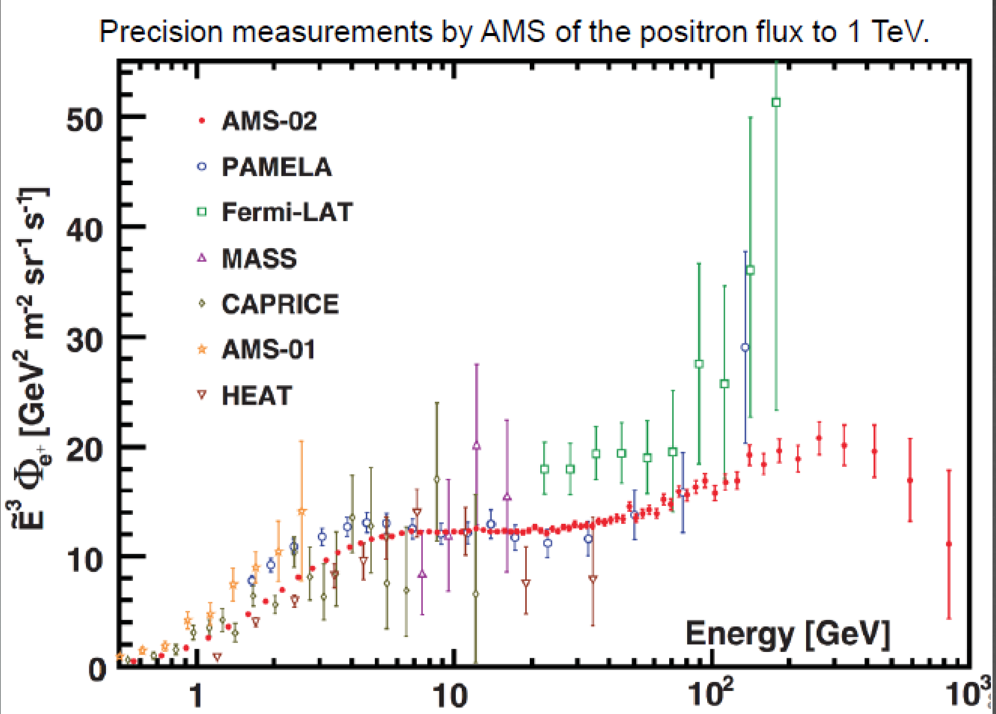


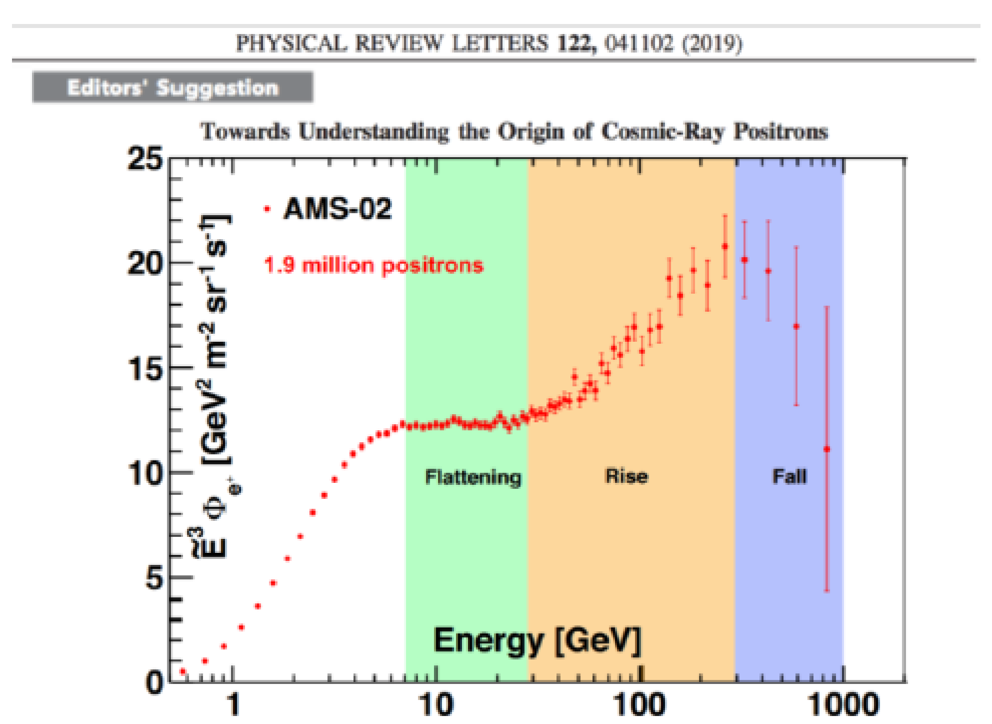
Science



Instrument

The positron excess (PAMELA and AMS-02)



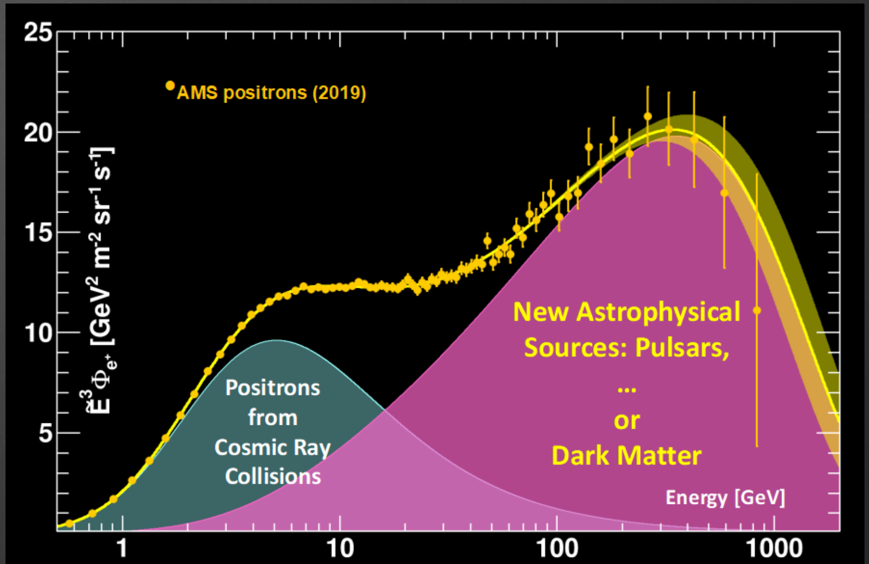


The positron flux shows a well-defined energy dependence:

- A rise @ 25.2 GeV
- A fall above 284 GeV

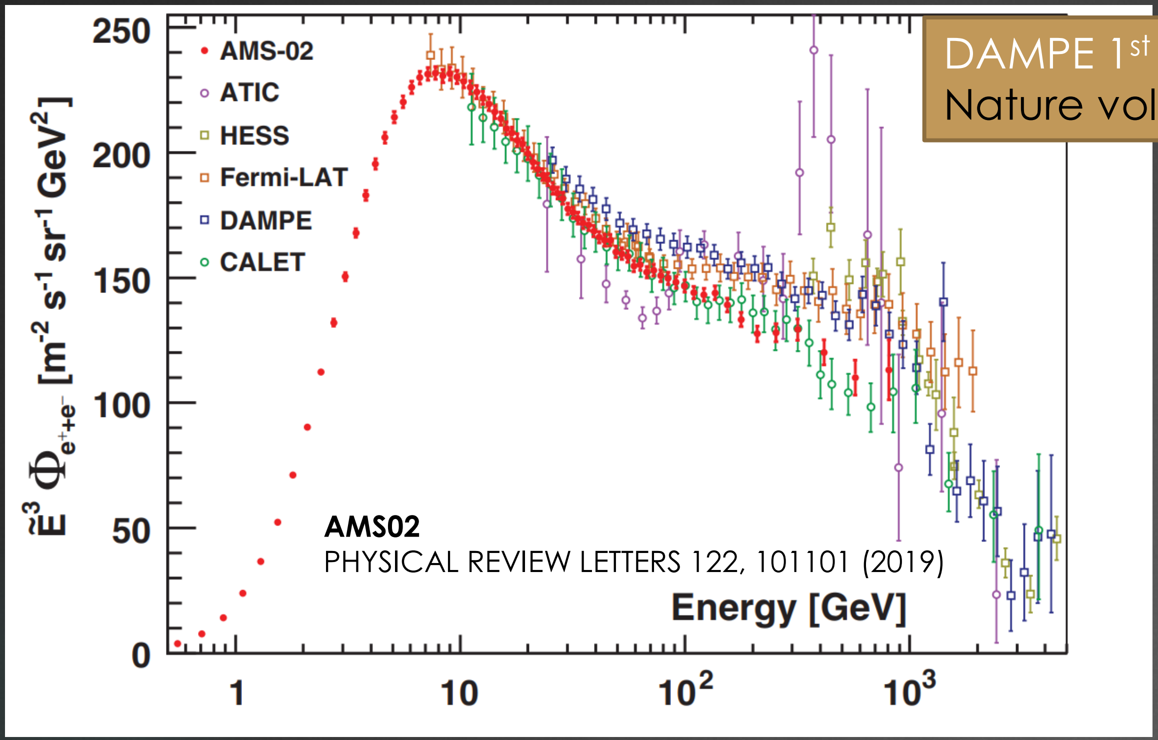
The positron flux could be described by the sum of a diffuse term and a new source term with a finite energy cutoff at almost 800 GeV

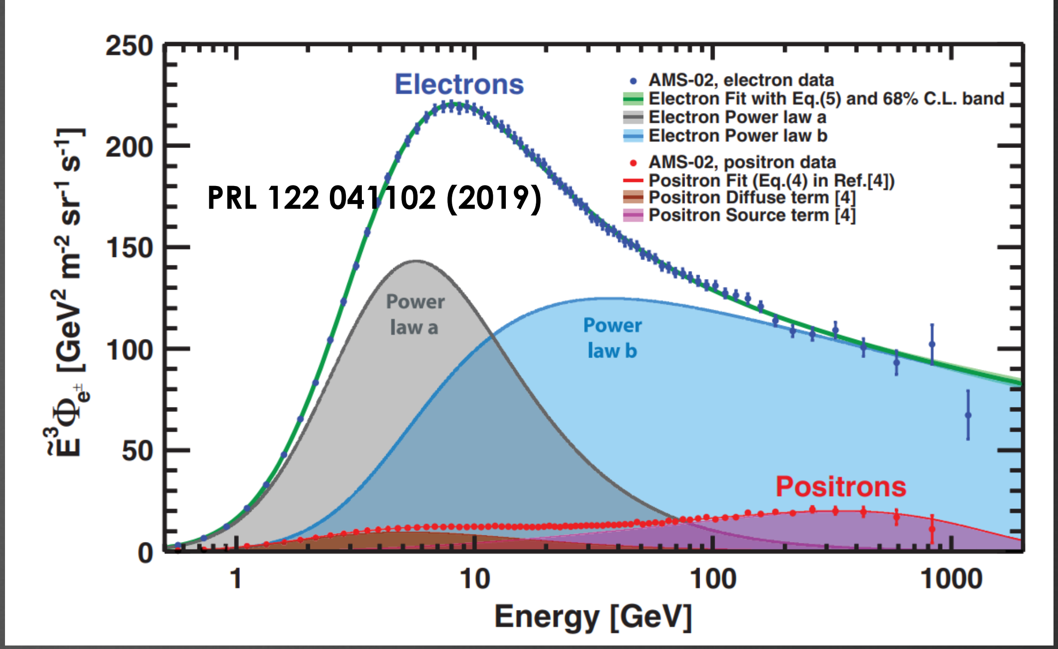
Complementary measurements are still needed to understand the source nature (gamma-ray emission from pulsars, anisotropy studies, antiproton spectrum, …)



All electron spectrum

DAMPE 1st direct detection of the break @ 1TeV
Nature volume 552, pages 63–66(2017)

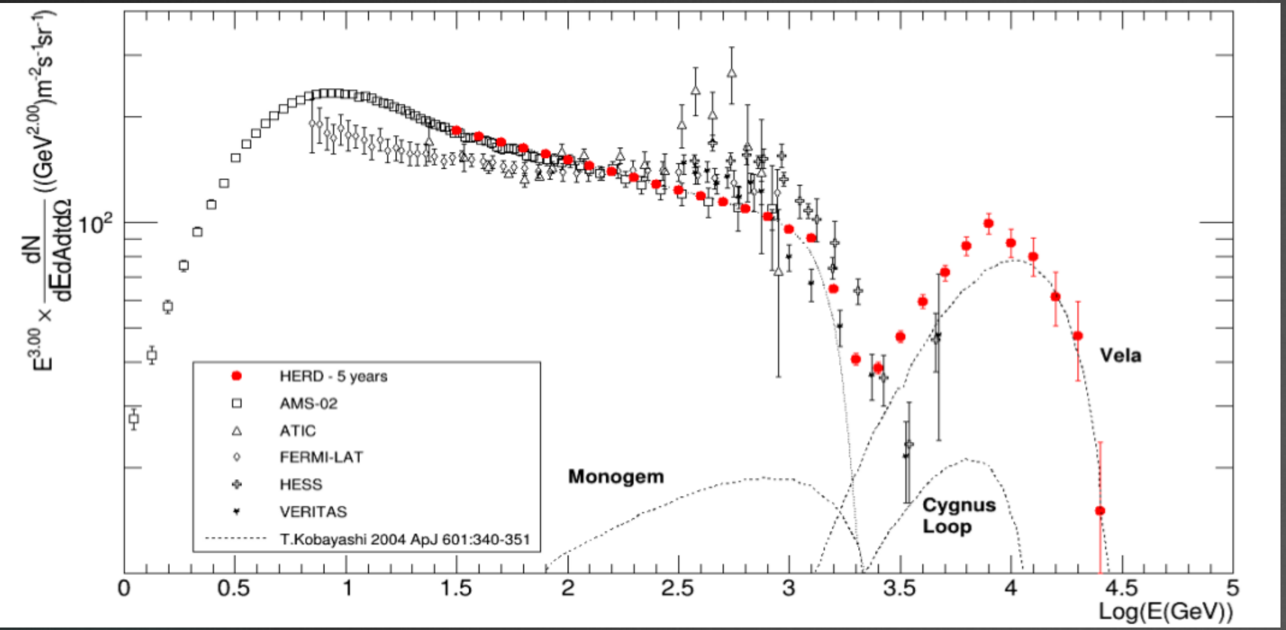




"The different behavior of the cosmic-ray electrons and positrons measured by AMS is clear evidence that most high energy electrons originate from different sources than high energy positrons"
PRL 122 041102 (2019)

Electrons and Positrons with **HERD**

Expected $e^+ + e^-$ flux in 5 years



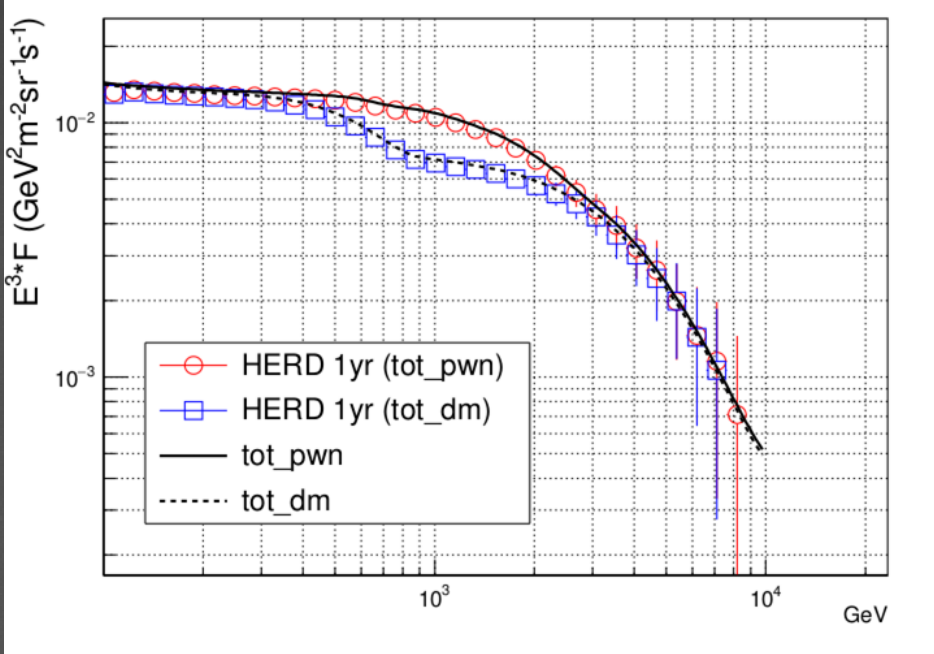
HERD will measure the all electron flux up to several tens of TeV in order to detect:

spectral cutoff at high energy

local SNR sources of very high energy e^-

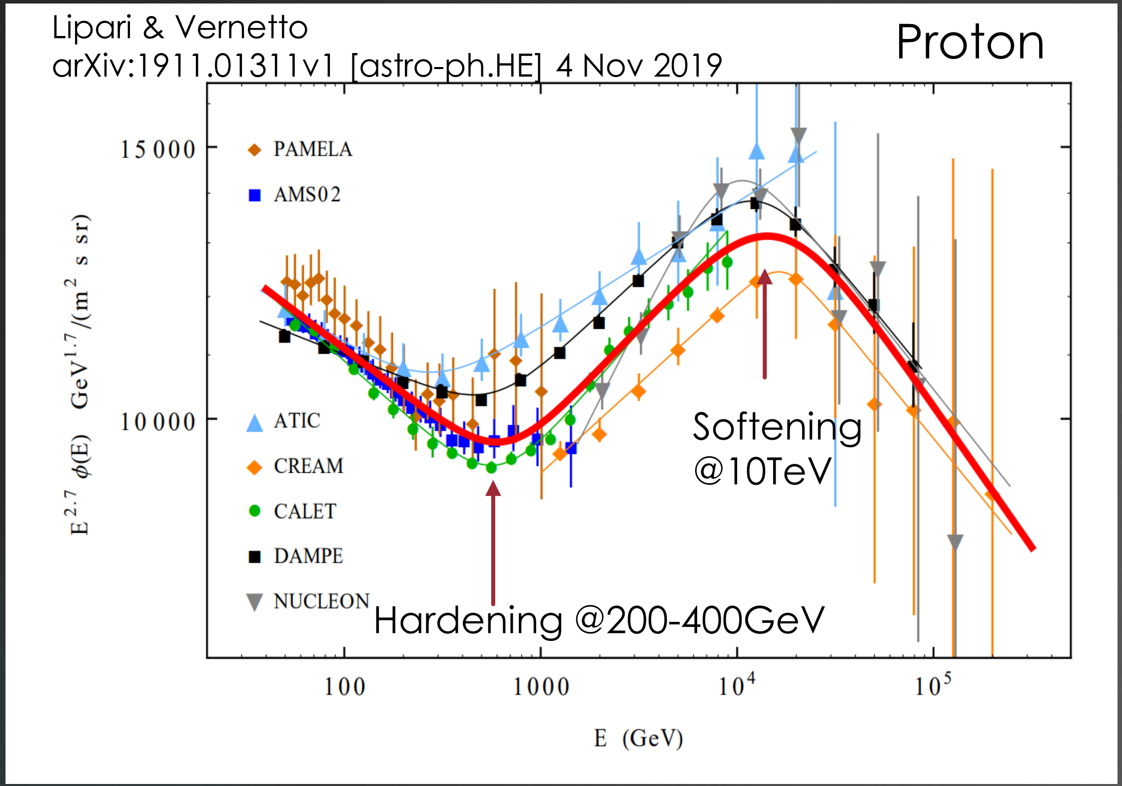
... and additional information from anisotropy measurement!

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



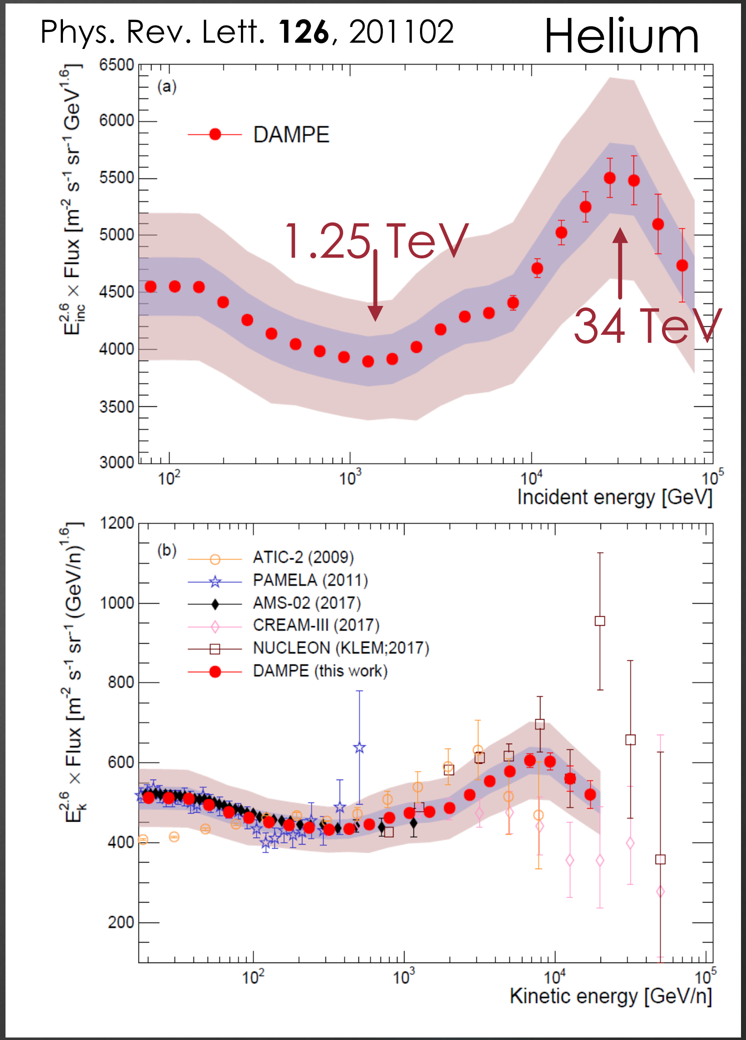
In case of additional PWN or DM production, **HERD** will give important indications on the two hypothesis thanks to precise measurement of the different spectral shape

The proton and helium spectra



Hardening @ 1.25 TeV

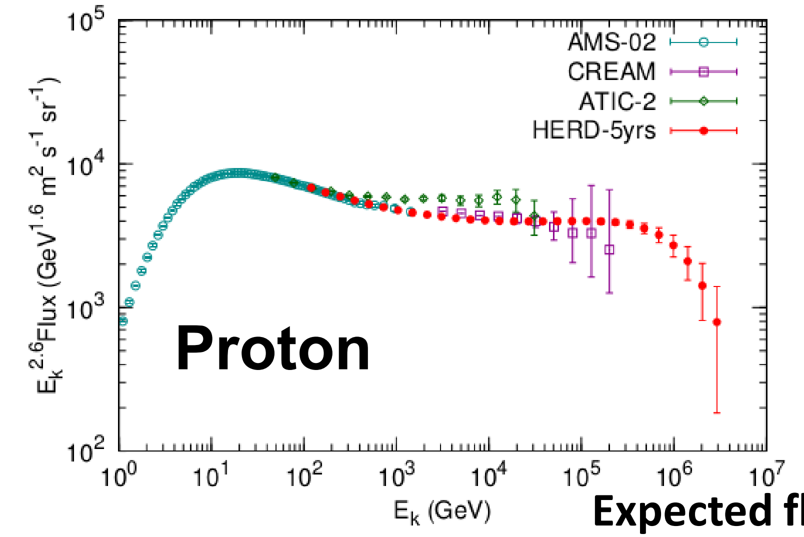
Softening @ 34 TeV (detected for the 1st time @ 4.3σ from DAMPE)

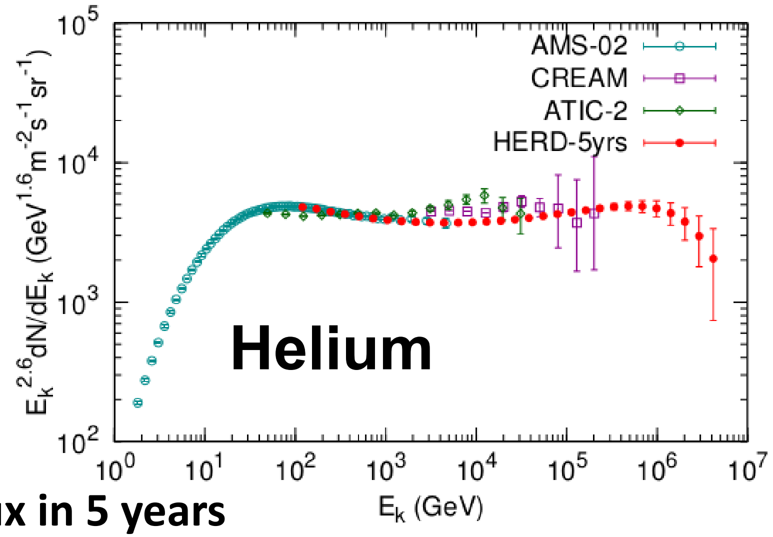


The hardening @ ≈ 200-400 GeV is well established since first observation by Pamela -> Implication on the acceleration and/or propagation mechanisms

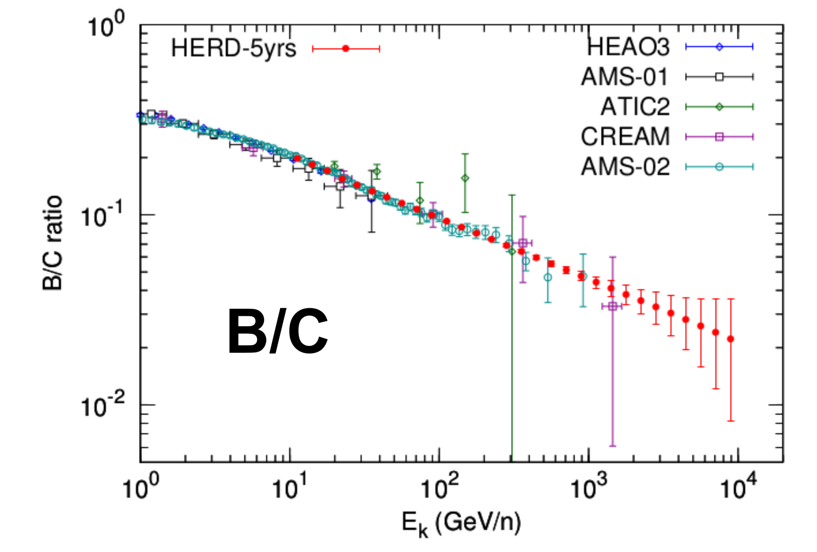
The softening @ ≈ 10 TeV is observed by different experiment with the 1st strong evidence in DAMPE data

Protons and Nuclei with **HERD**





Expected flux in 5 years



HERD will measure the flux of nuclei:

p and He up to a few PeV

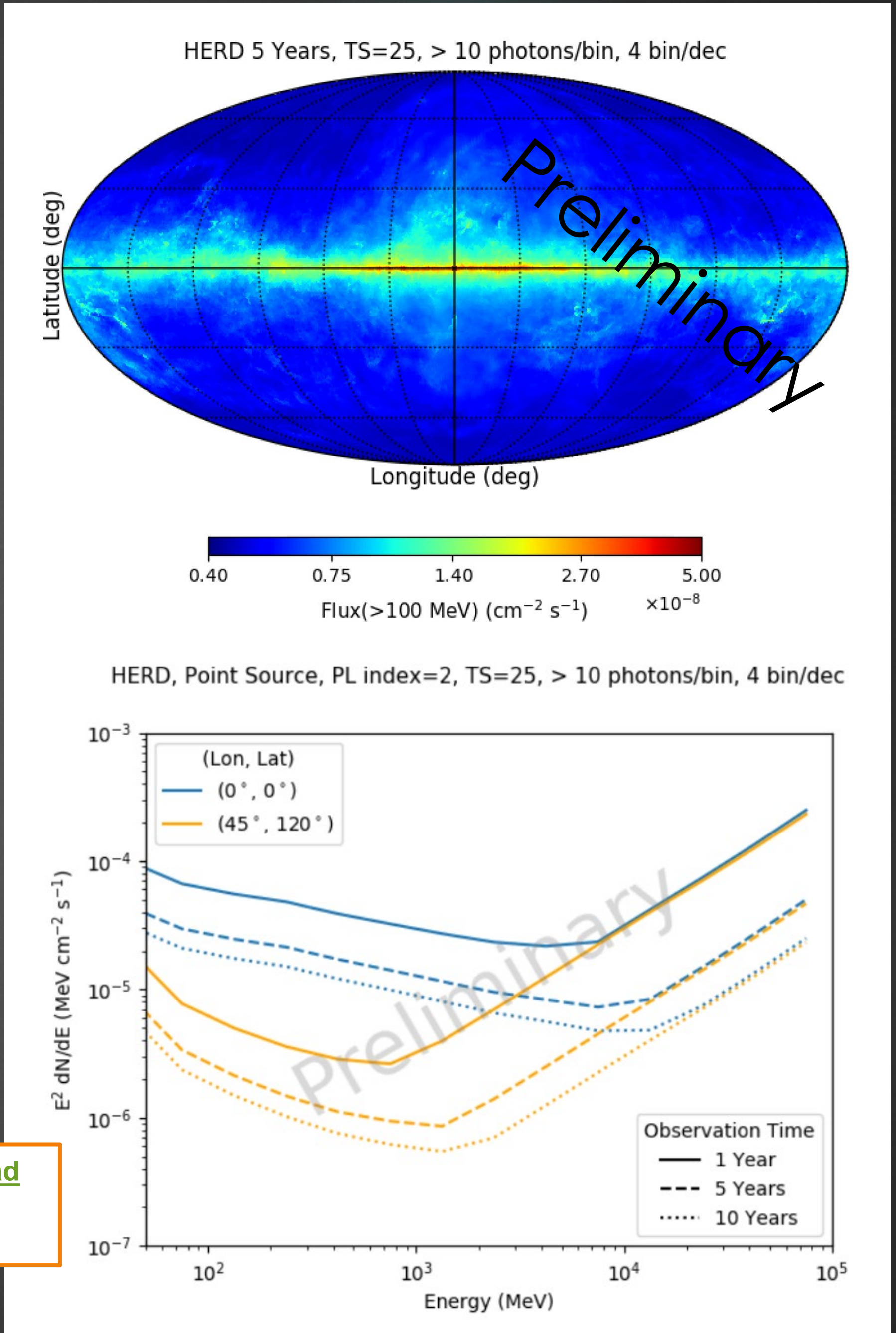
nuclei up to a few hundreds of TeV/n

First direct measurement of p and He knees will provide a strong evidence for the knee structure as due to acceleration limit

Extension of the B/C ratio to high energy will provide further test for the propagation mechanisms of cosmic rays

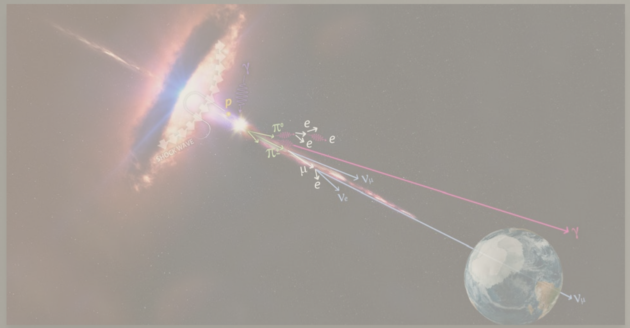
Gamma ray sky-survey (**HERD**)

- 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 γ Burst

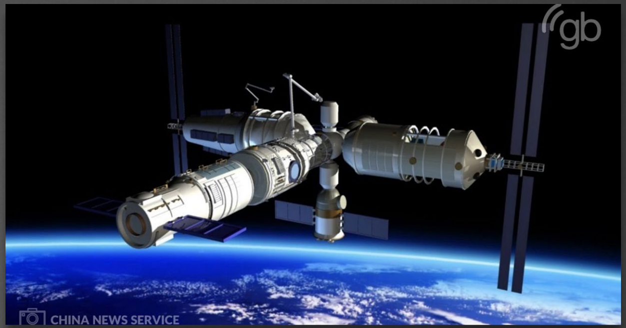


Multi-messenger astronomy
Possible synergy with other experiments designed for:
γ (CTA, LHAASO)
ν (KM3NeT, IceCube)
GW (Ligo, Virgo)

Gamma-ray performance study of the HERD payload
Mr Luis Farina (IFAE)
7/20/21, 6:00 PM

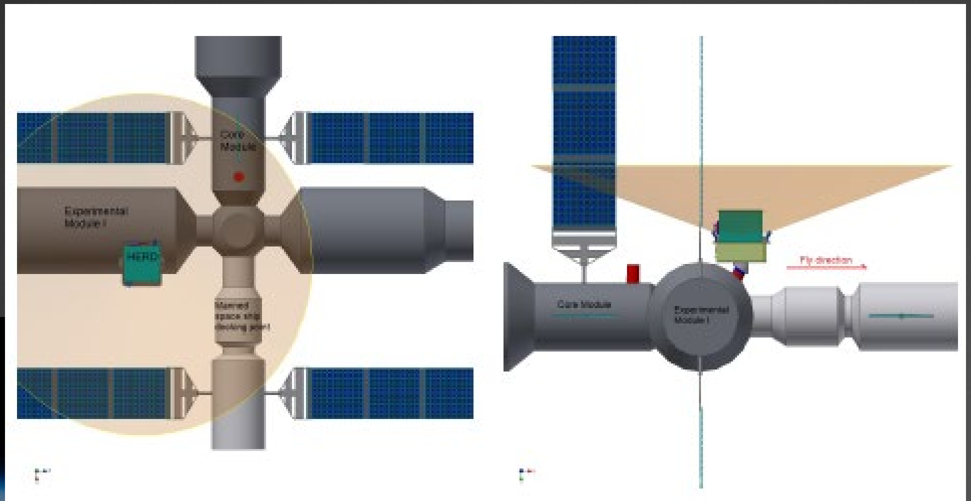


Science



Instrument

HERD on board CSS



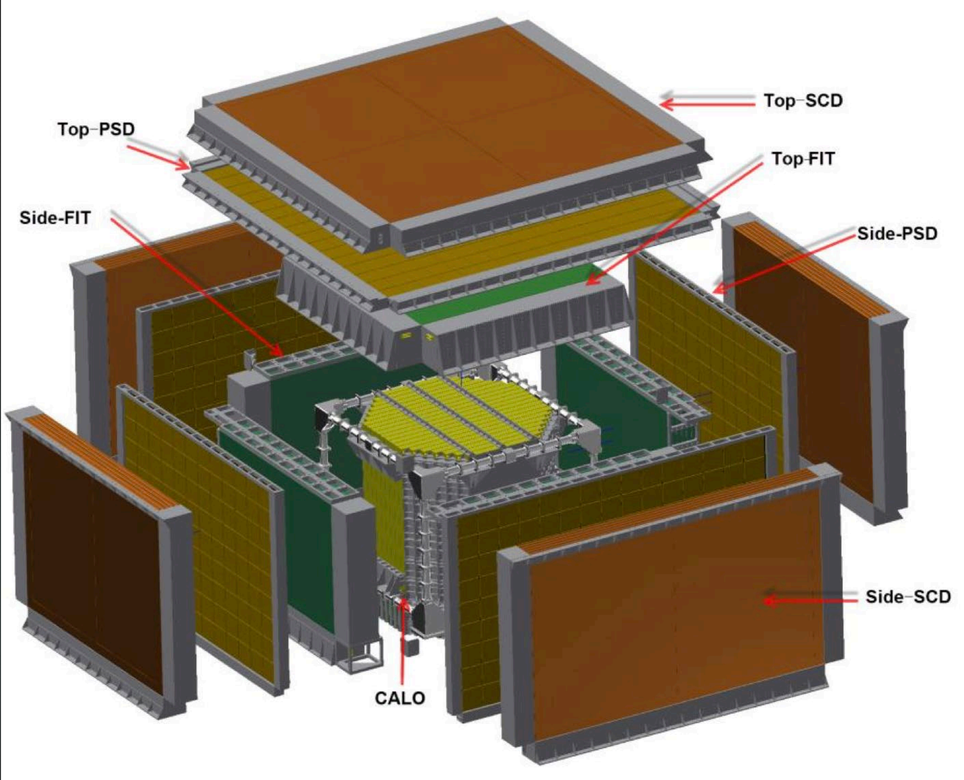
CSS expected to be completed in 2022

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 detector

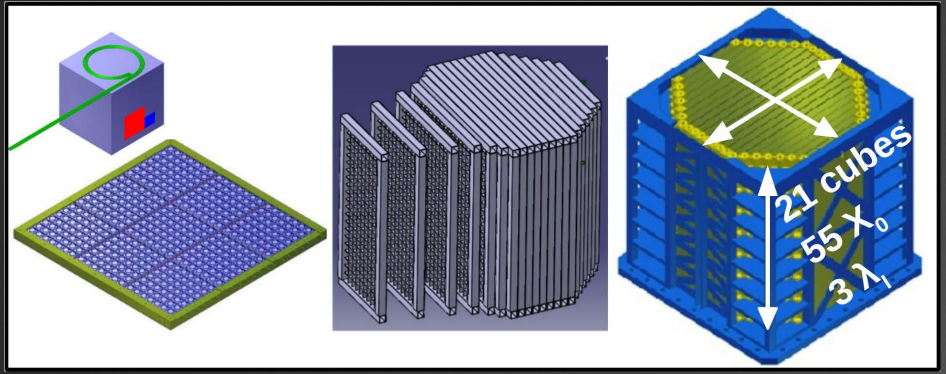


SCD	Charge Reconstruction
PSD	Charge Reconstruction γ Identification
FIT	Trajectory Reconstruction Charge Identification
CALO	Energy Reconstruction e/p Discrimination
TRD	Calibration of CALO response for TeV protons

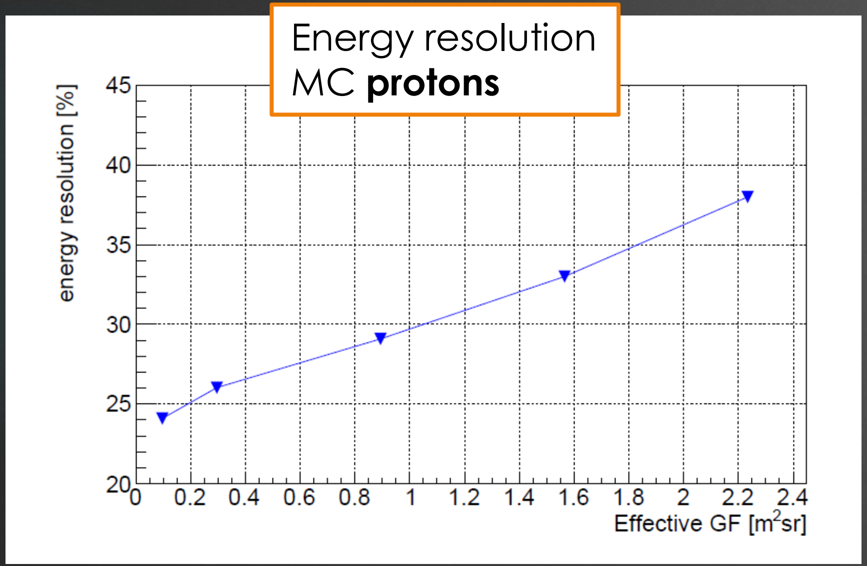
[The High Energy cosmic Radiation Detector (HERD) Trigger System](#)
Miguel Angel Velasco (CIEMAT)
7/16/21, 6:00 PM

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	>3 m^2sr @ 200 GeV	>2 m^2sr @ 100 TeV

CALOrimeter (CALO)



The effective geometrical factor is > 3 m²sr for electrons and > 2 m²sr protons

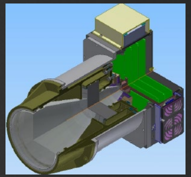


Design and expected performances of the large acceptance calorimeter for the HERD space mission.
Lorenzo Pacini (INFN Firenze)
7/16/21, 6:00 PM

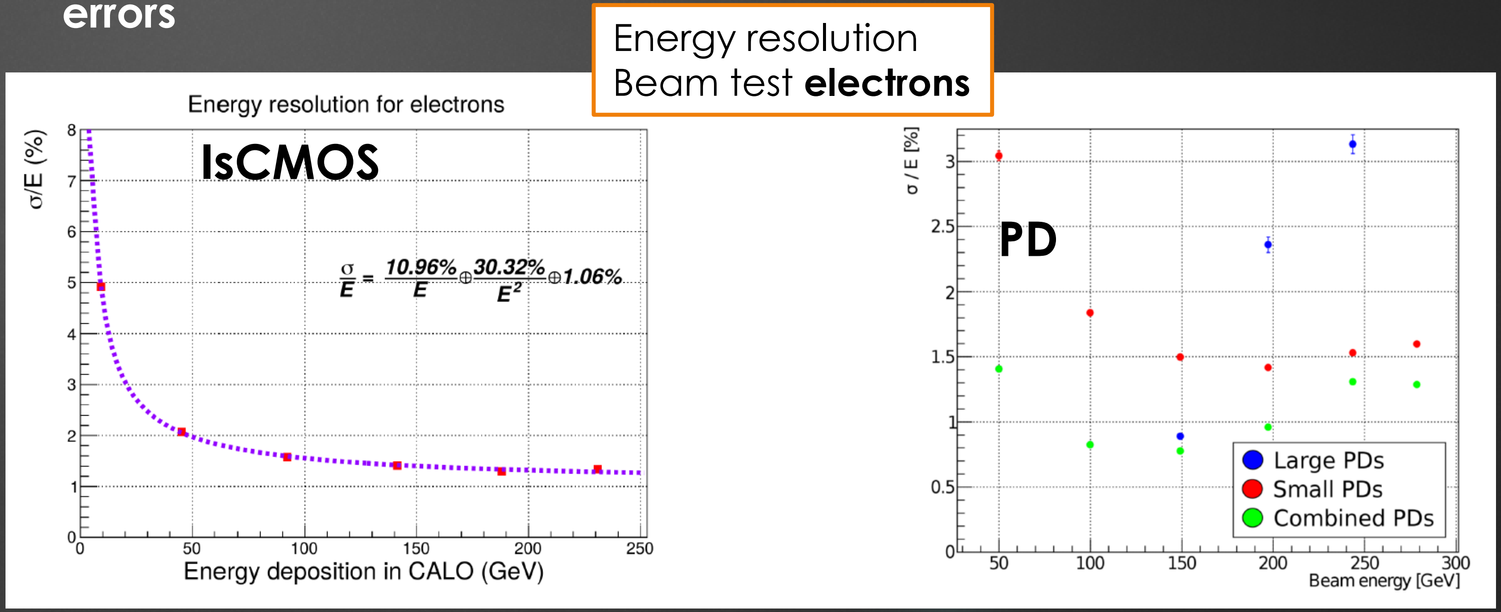
The design of the CALO consists of about **7500 LYSO cubes** with edge length of 3 cm, corresponding to about 2.6 X0 and 1.4 Molière radius

The scintillation light of each crystal is read-out by two independent systems:

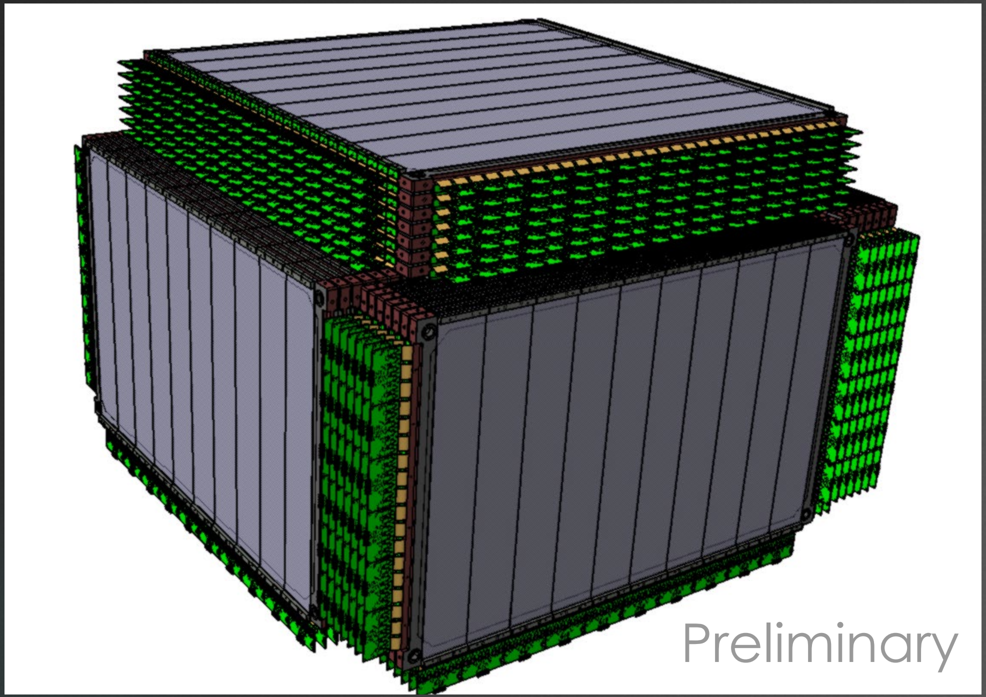
1. WLS fibers coupled to image Intensified scientific CMOS (IsCMOS) cameras
2. photo-diodes (PD) connected to custom front-end electronics (HIDRA)



The ***double read-out system*** achieves the capability of cross-calibrating the scintillation light measurement and help in **reduce the systematic errors**



FIber Tracker (FIT)

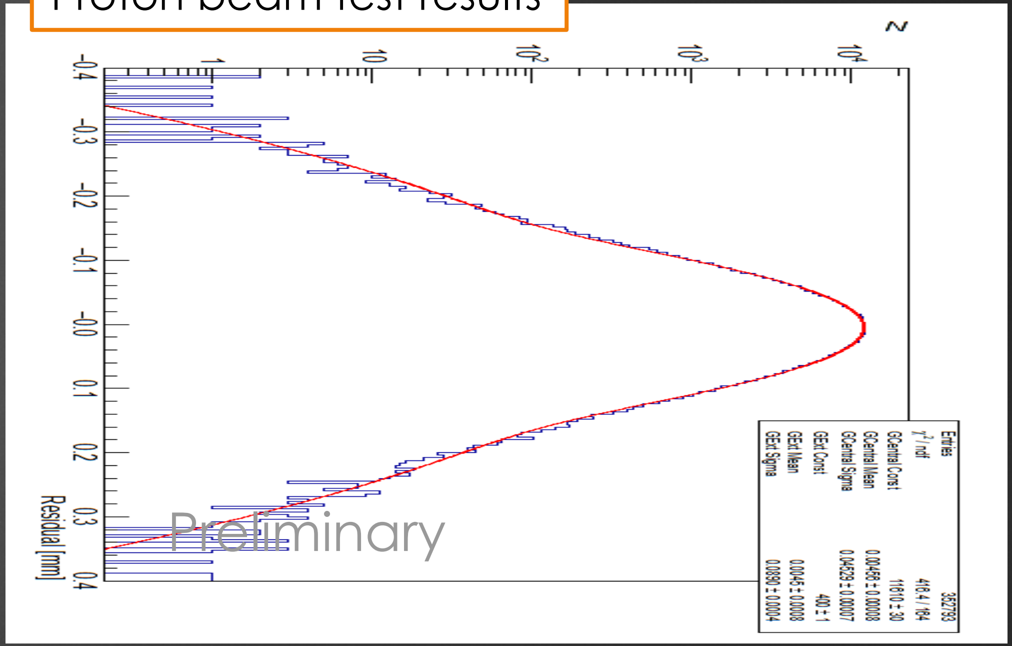


- 5 sides
- 7 x-y tracking planes in each sector
- 6 x + 10 y in each side plane
- 10 x + 10 y in each top plane
- Module = 1 fiber mat +
  3 silicon photomultiplier (SiPM) arrays

Charge resolution for nuclei heavier than p
Preliminary results

Z	μ_Z	σ_Z	σ_Z/μ_Z
2	1.99	0.31	15 %
3	3.07	0.40	13 %
4	4.01	0.51	12 %

Proton beam test results



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

Takes into account the external tracker resolution

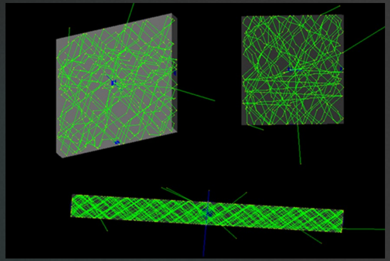
FIT: the scintillating fiber tracker of the HERD space mission
Chiara Perrina (EPFL)
7/16/21, 6:00 PM

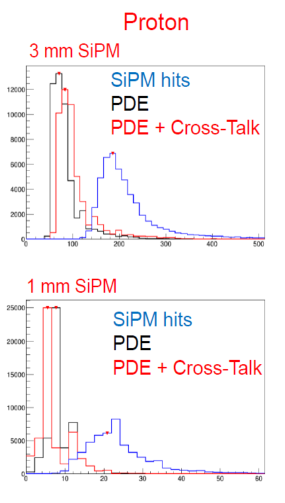
Plastic Scintillator Detector (PSD)

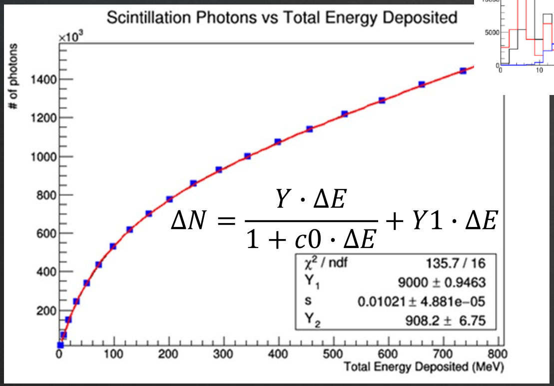
- PSD provide γ **identification** (VETO of charged particles) and **nuclei identification** (energy loss ∝ Z^2)
- Requirements:
  - high efficiency in charged particles detection (>99,98%)
  - high dynamic range to identify nuclei at least up to iron
  - segmented to reduce the Back-scattering particles from the CALO

Two layout configuration are under investigation one with **long bars** (160-180cm) and one with **squared tiles** (10x10cm)

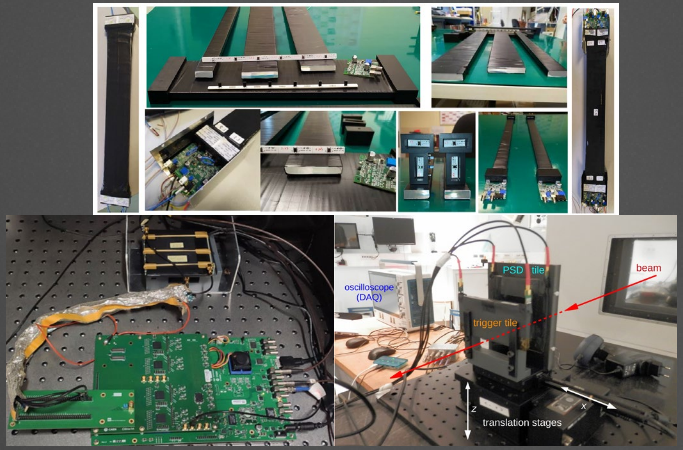
Simulations

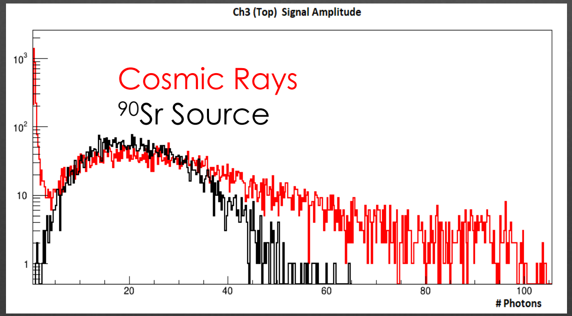




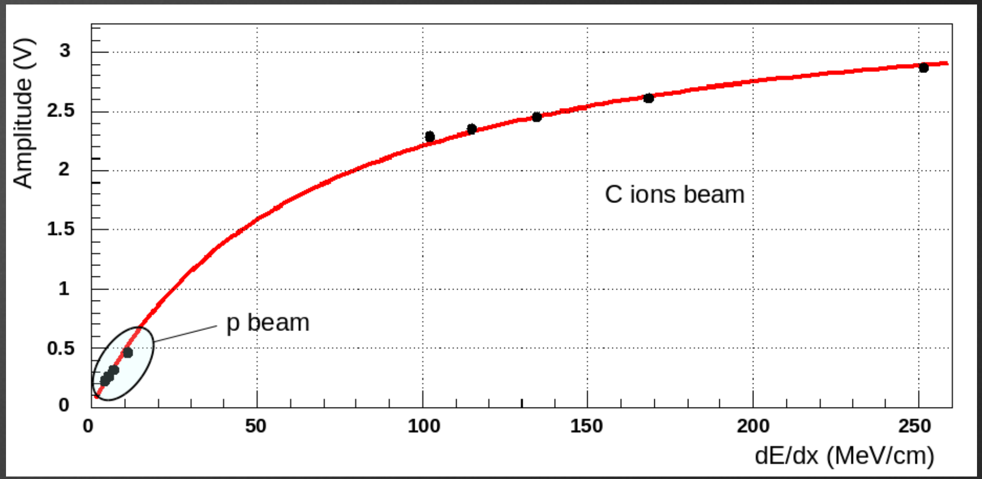


Lab. and Beam test





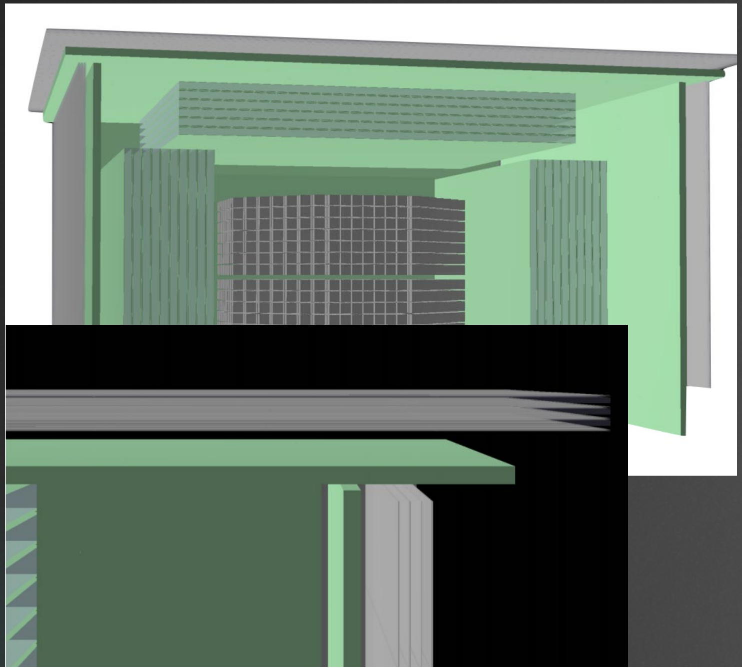
Birks saturation effect tested with low momenta nuclei @ CNAO

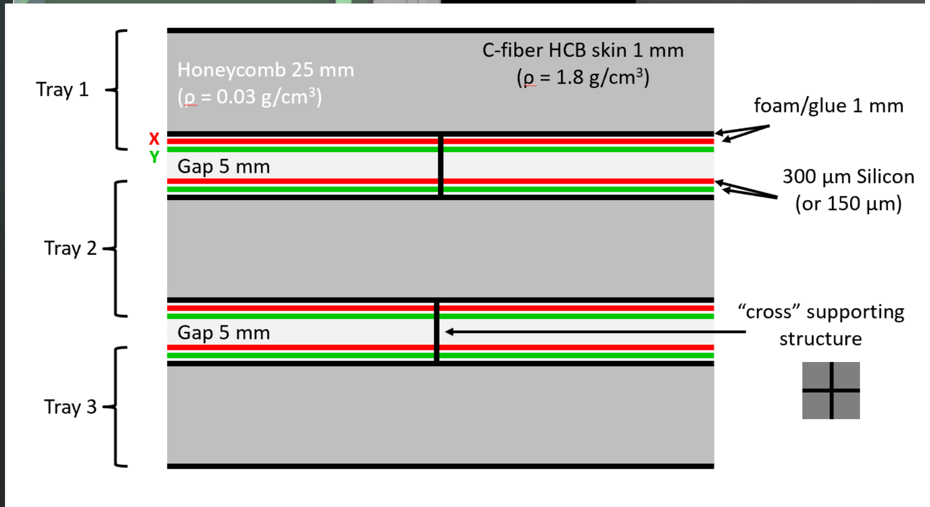


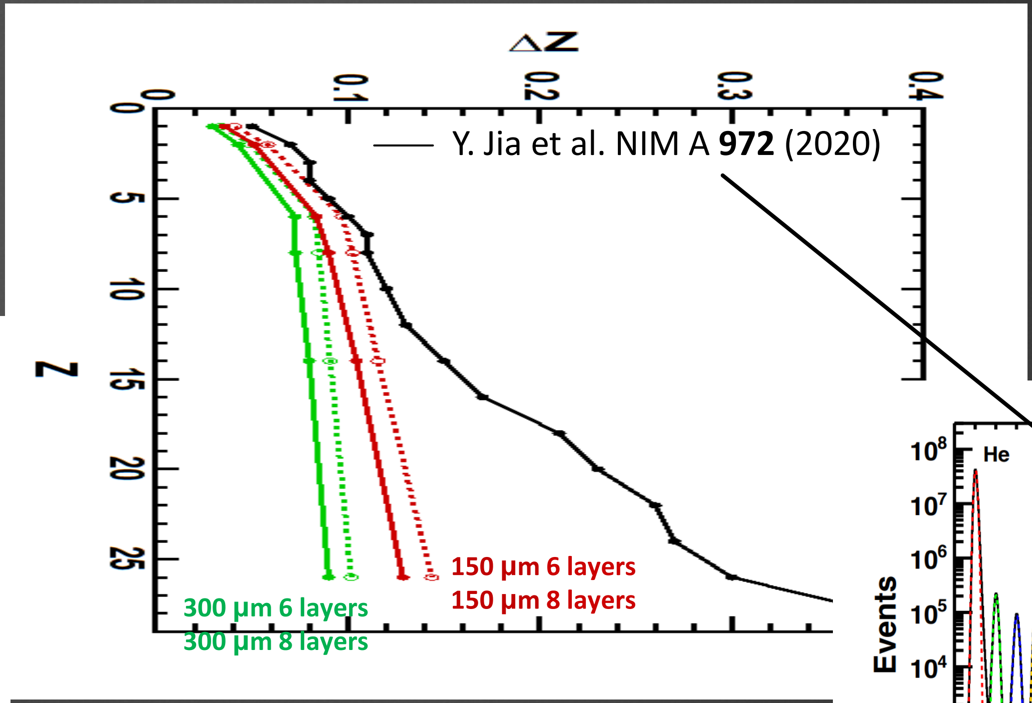
The Plastic Scintillator Detector of the HERD space mission
Dimitrios Kyratzis (Gran Sasso Science Institute (GSSI) & INFN-LNGS)
7/16/21, 6:00 PM

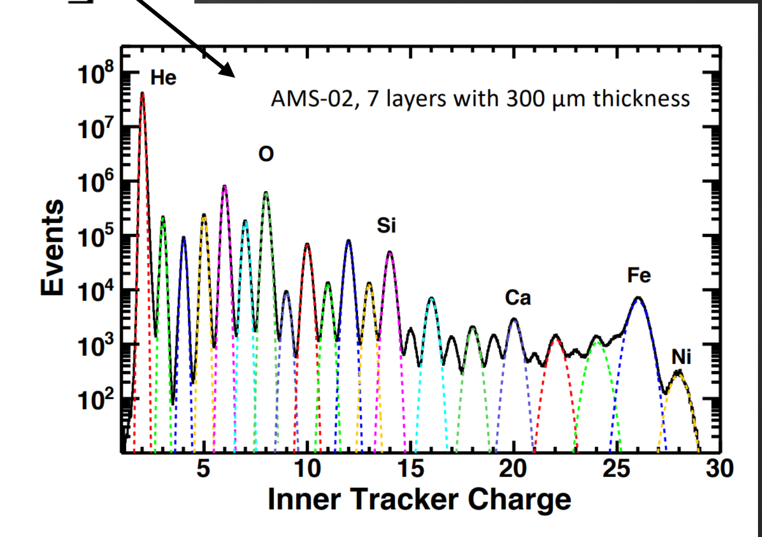
Silicon Charge Detector (SCD)

- SCD is a **silicon micro-strip** detector 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 unavoidable backscattered secondary particles coming from the CALO



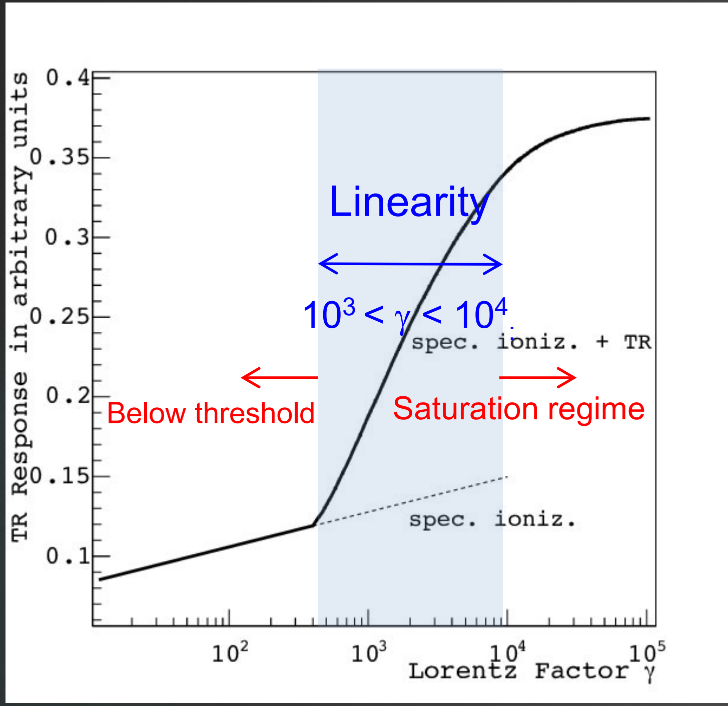






Transition Radiation Detector (TRD)

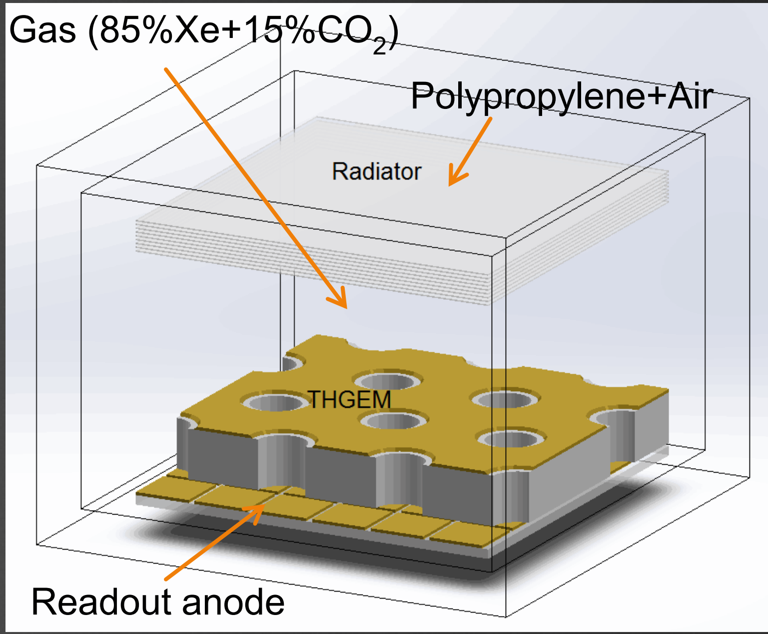
The TRD, installed on a lateral face of the detector, is needed to calibrate the response of the calorimeter to high energy hadronic showers



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 (3 months data required)

SUMMARY

The **High Energy cosmic-Radiation Detection** facility is an international space mission that will start its operation around 2027 on board the future China's Space Station.

Thanks to its **novel design**, based on a 3D, homogeneous, isotropic and finely-segmented calorimeter, HERD is expected to accomplish **important and frontier goals** relative to DM search, CR observations and Gamma-Ray astronomy:

- 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
- extend the measurement of nuclei flux up to a few PeV
  - testing the theory of the knee structure as due to acceleration limit
- 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