The High Energy cosmic-Radiation Detection (HERD) facility: a future space instrument for cosmic-ray detection and gamma-ray astronomy

Eugenio Berti
University of Florence and INFN
on behalf of the ***HERD Collaboration***

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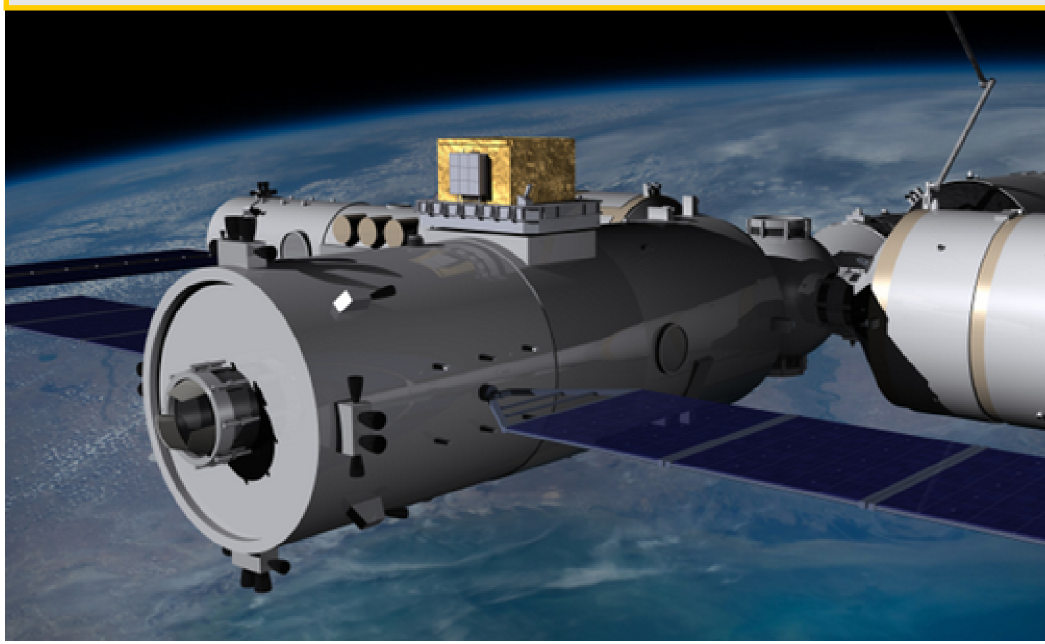
Overview

The **High Energy cosmic-Radiation Detection** (HERD) facility will be installed aboard the China's Space Station in 2027

Main observation channels
p, nuclei fluxes up to few PeV
e^-+e^+ flux up to tens of TeV
Gamma-ray above 100 MeV

Xi'an (CN), 16-18 Dec 2019



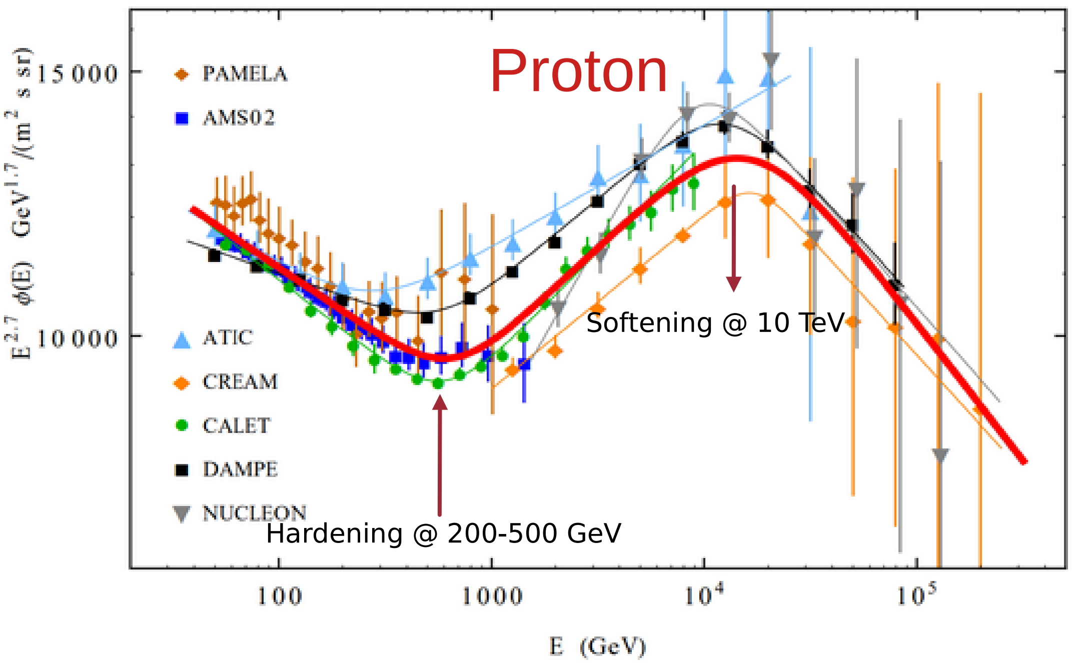
Main scientific goals
Understanding of CR acceleration and propagation mechanisms
Search for e^-/e^+ nearby sources and possible indirect evidences of DM
Study of γ sources, search for DM signatures, detection of GRB

Physics motivations

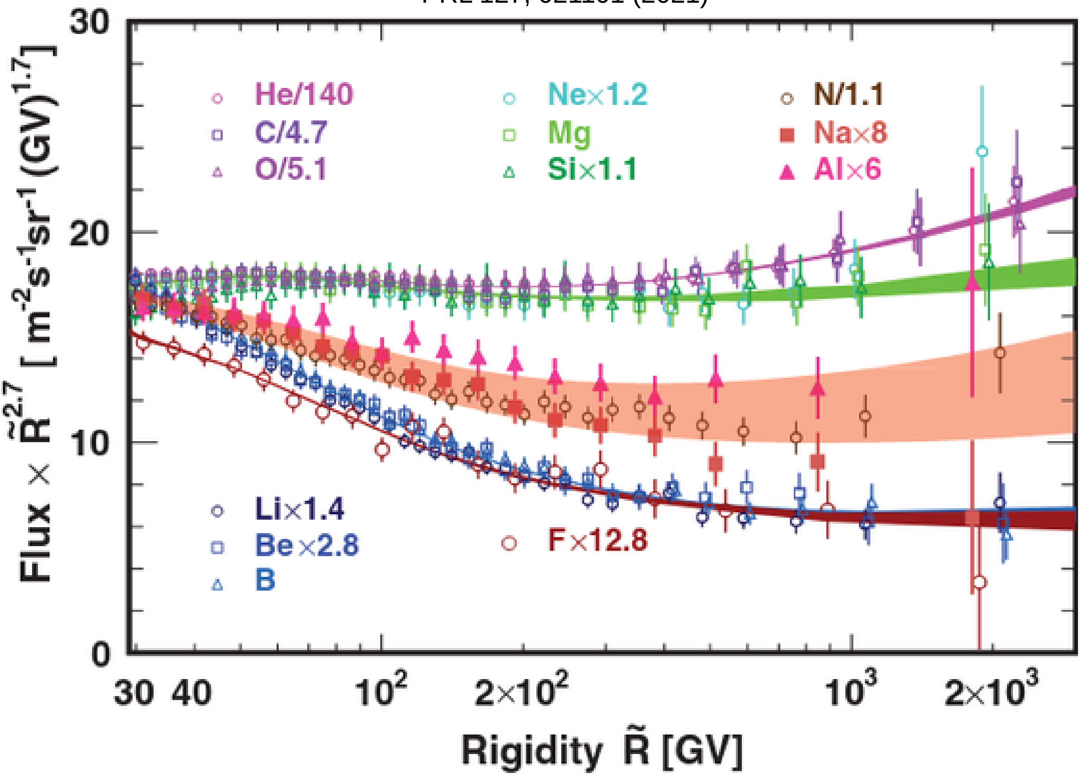
Protons and Nuclei

Present status

Lipari & Vernetto, arXiv:1911.01311v1 [astro-ph.HE] 4 Nov 2019



PRL 127, 021101 (2021)



Indirect measurements indicate particle-dependent knee energy but <u>no direct measurement of the knee</u>

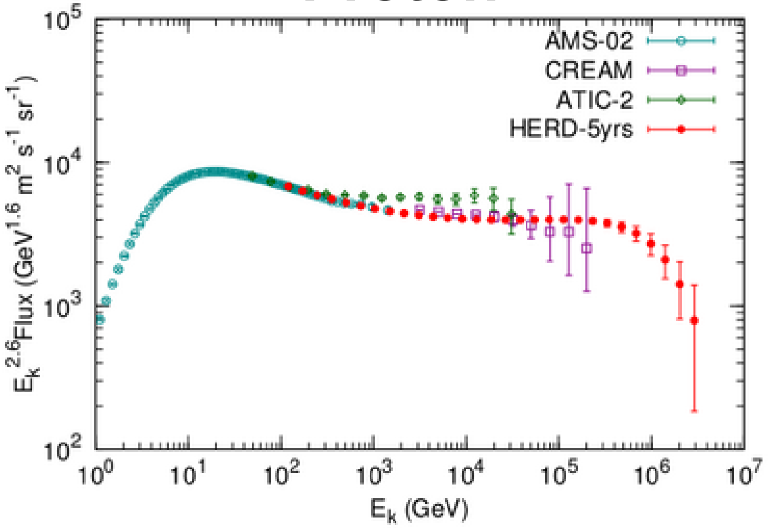
Clear **hardening** structure in the flux of most nuclear species at rigidities of 200-500 GV (PAMELA, AMS-02)

Clear **softening** structure in the flux of p, He at energies of about 10, 30 TeV (DAMPE, CALET)

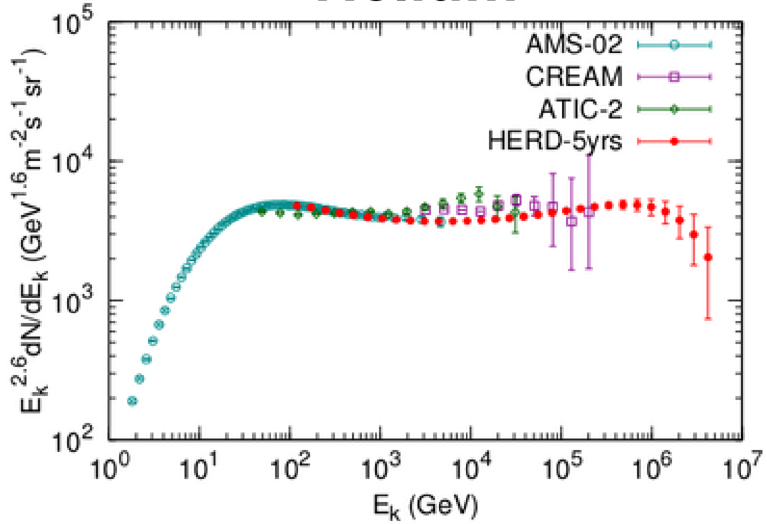
The picture of CR is much richer than we expected and measurements to higher energies are needed

Protons and Nuclei
HERD expectations

Proton

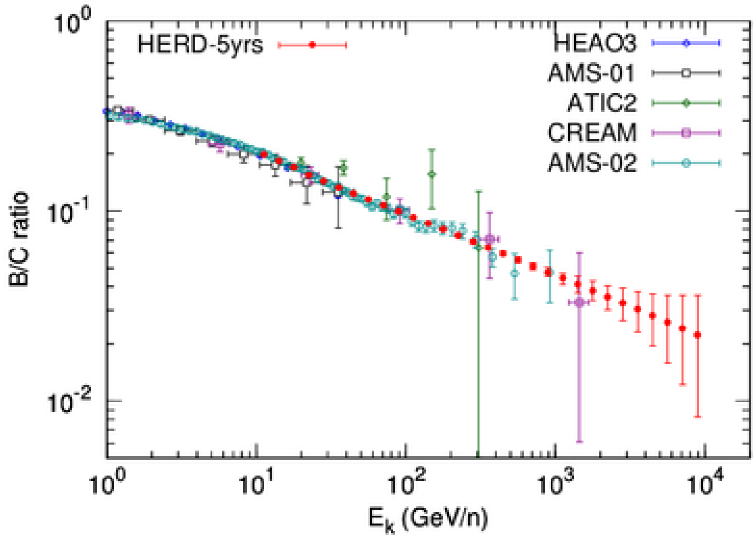


Helium



Expected flux
in 5 years

B/C



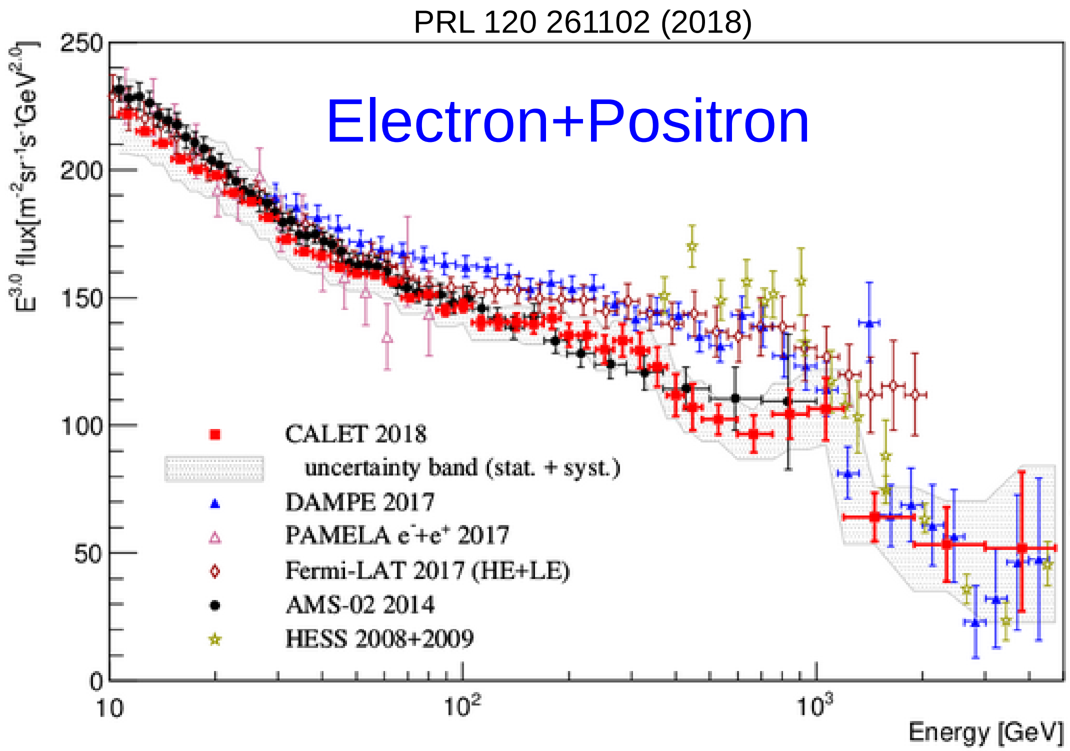
HERD will measure the flux of nuclei:
- proton and helium up to a few PeV
- nuclei up to a tens/hundreds of TeV/n

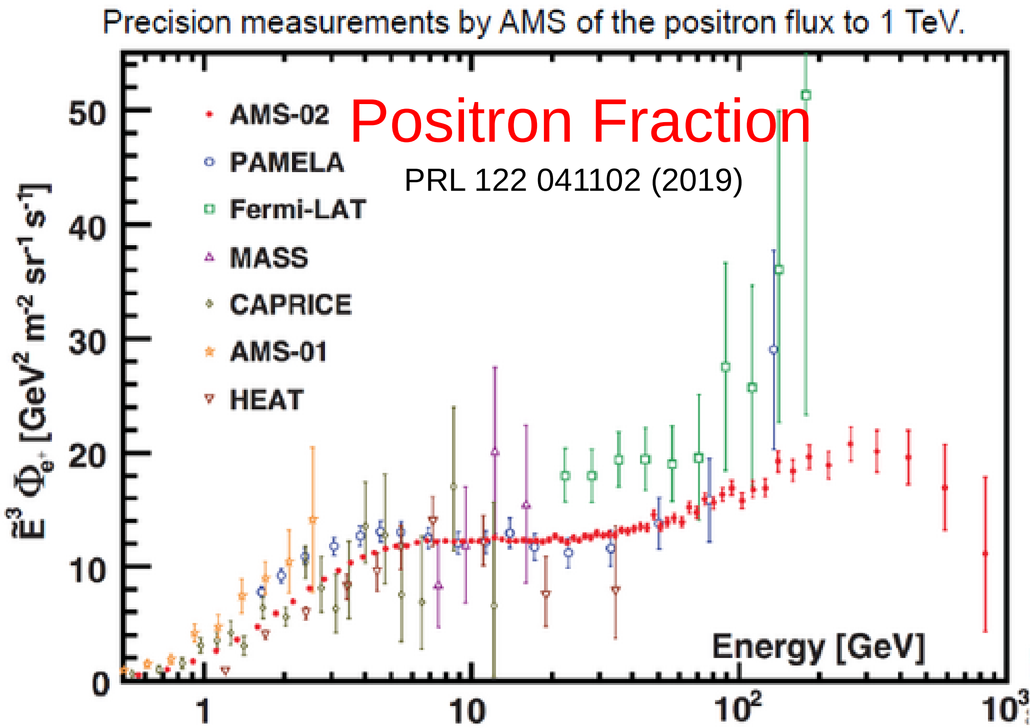
First direct measurement of p and He knees will test our current understanding on the origin of the knee structure

Extension of the B/C ratio to high energy will improve our understanding on propagation mechanisms of cosmic rays

Electrons and Positrons

Present status





Around 1 TeV we expect a cutoff and possible structures due to local sources if present...

...but there is a **large deviation** among the different measurements (Fermi-LAT, CALET, DAMPE)

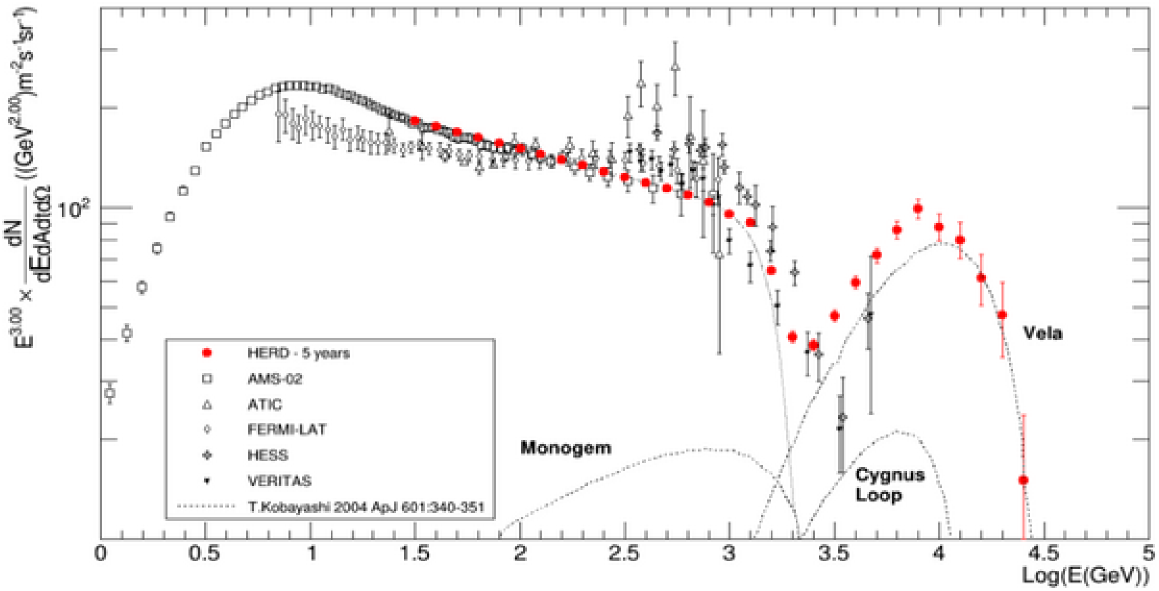
Positron excess respect to pure secondary production (PAMELA, AMS-02)

Two hypotheses

- Dark Matter (DM) annihilation
- Nearby Pulsar Wind Nebulae

Electrons and Positrons
HERD expectations

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

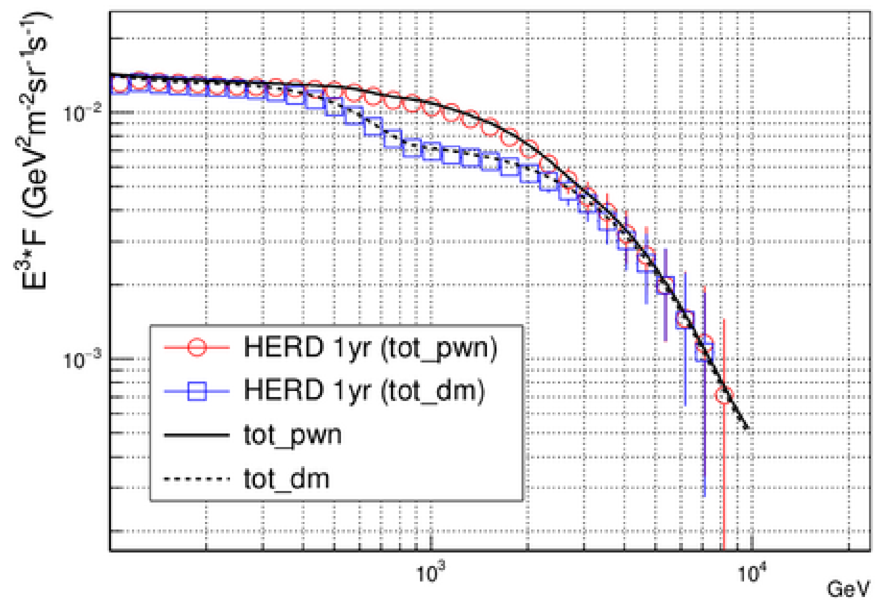


<u>HERD</u> <u>will measure the "all electron" flux up to several tens of TeV</u>:

- confirmation of cutoff at high energy
- structures due to local sources

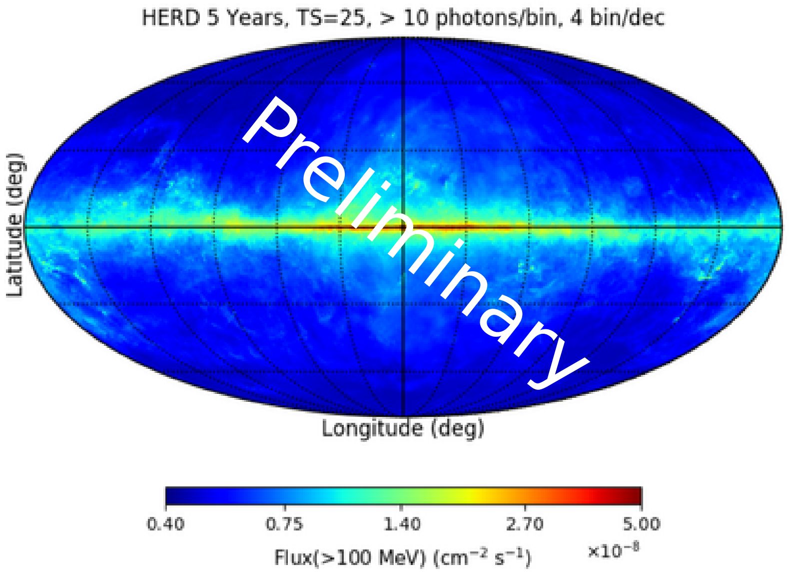
... and additional information from anisotropy measurement!

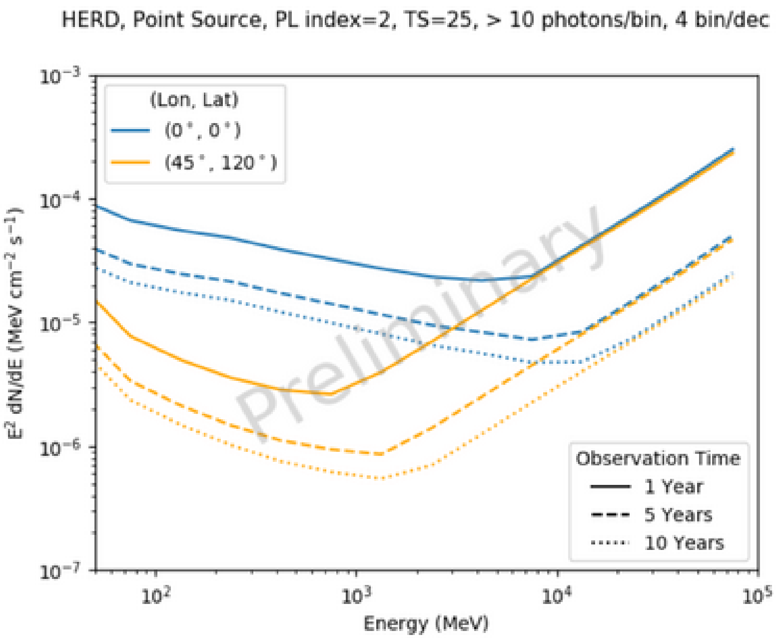
Expected $e^+ + e^-$ flux in 1 year with PWN or DM sources



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

Gamma-Ray Sky Survey
HERD expectations





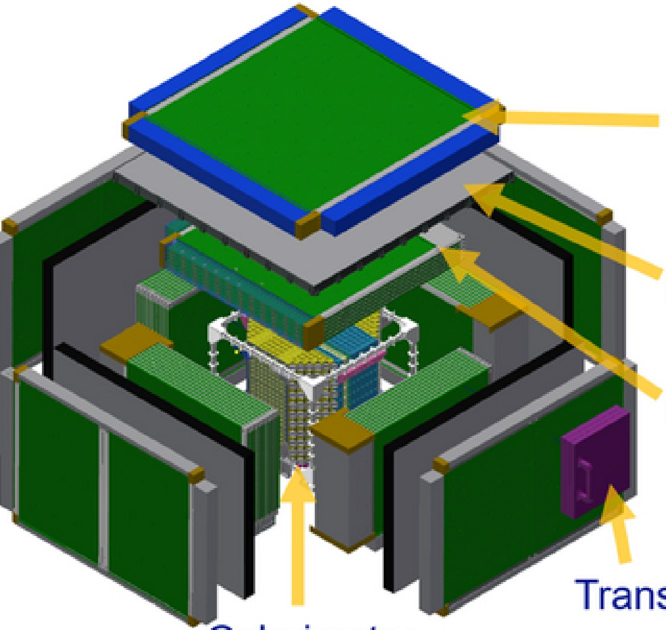
<u>**HERD** will perform full gamma-ray sky survey above 100 MeV</u>:
- extension of Fermi gamma catalog above 300 GeV
- increases the coverage for rare gamma events

GRB, gamma-ray sources, diffuse emission, DM search

Multi-messenger astronomy
Possible synergy with other experiments designed for Gamma-Rays (CTA, LHAASO), Neutrinos (IceCube, KM3NeT), Gravitational Waves (LIGO, Virgo)

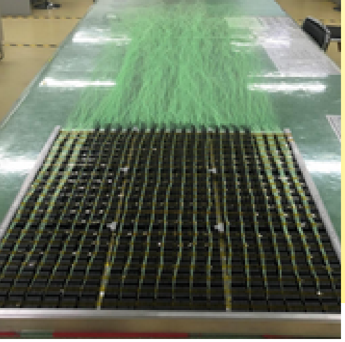
The experiment

HERD detector

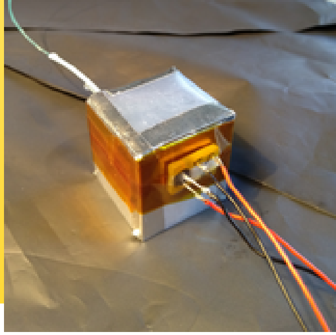


CALO	Energy Reconstruction e/p Discrimination
FIT	Trajectory Reconstruction Charge Identification
PSD	γ Identification Charge Reconstruction
SCD	Charge Identification Trajectory Reconstruction
TRD	Calibration of CALO response for TeV protons

Main requirements			
	γ	e^-+e^+	p, nuclei
Energy Range	>100 MeV	10 GeV - 30 TeV	30 GeV - 3 PeV
Energy resolution	1% @ 200 GeV	1% @ 200 GeV	25% @ 100 GeV-1 PeV
Effective GF	> 0.2 m^2sr @ 200 GeV	> 3 m^2sr @ 200 GeV	> 2 m^2sr @ 100 TeV



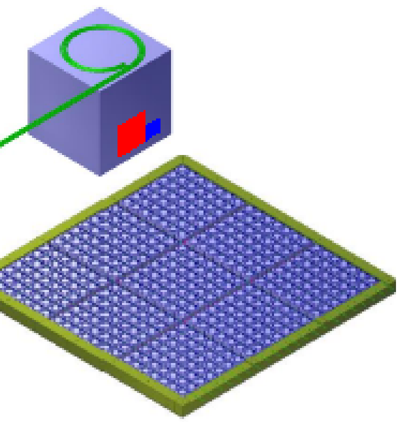
CALOrimeter (CALO)

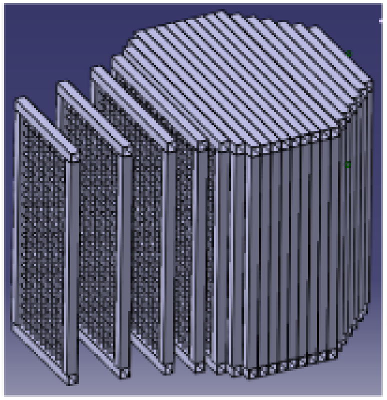


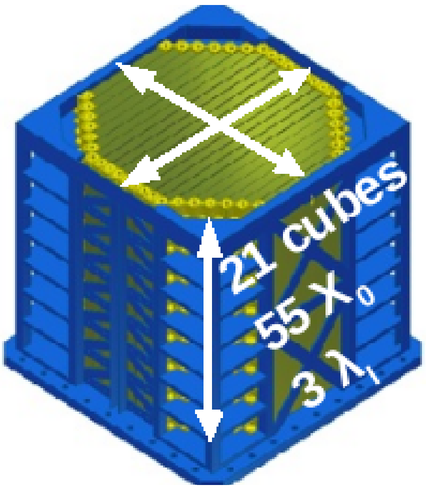
HERD is based on a **homogeneous, isotropic, 3D-segmented** calorimeter made of about 7500 LYSO cubic crystals of 3 cm side ($2.6\ X_0$ and $1.4\ R_M$) instrumented with a <u>double readout system</u>:

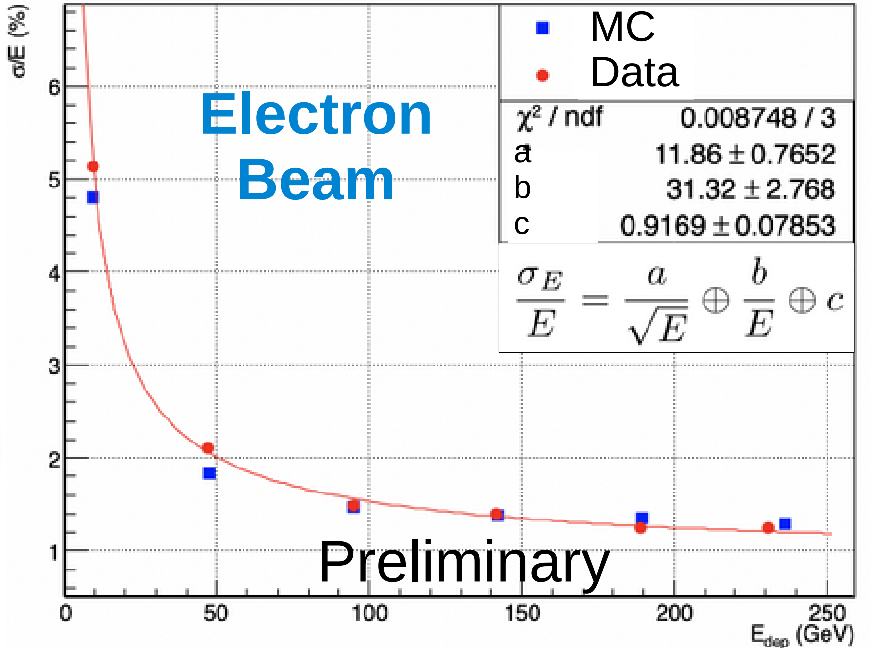
- WLS fibers coupled to Intensified scientific CMOS (IsCMOS)
- PD couple connected to custom front-end electronics (HIDRA)

The double readout system allows for **redundancy, independent trigger, and cross calibration** in order to reduce the systematic uncertainties (especially on the absolute energy scale)

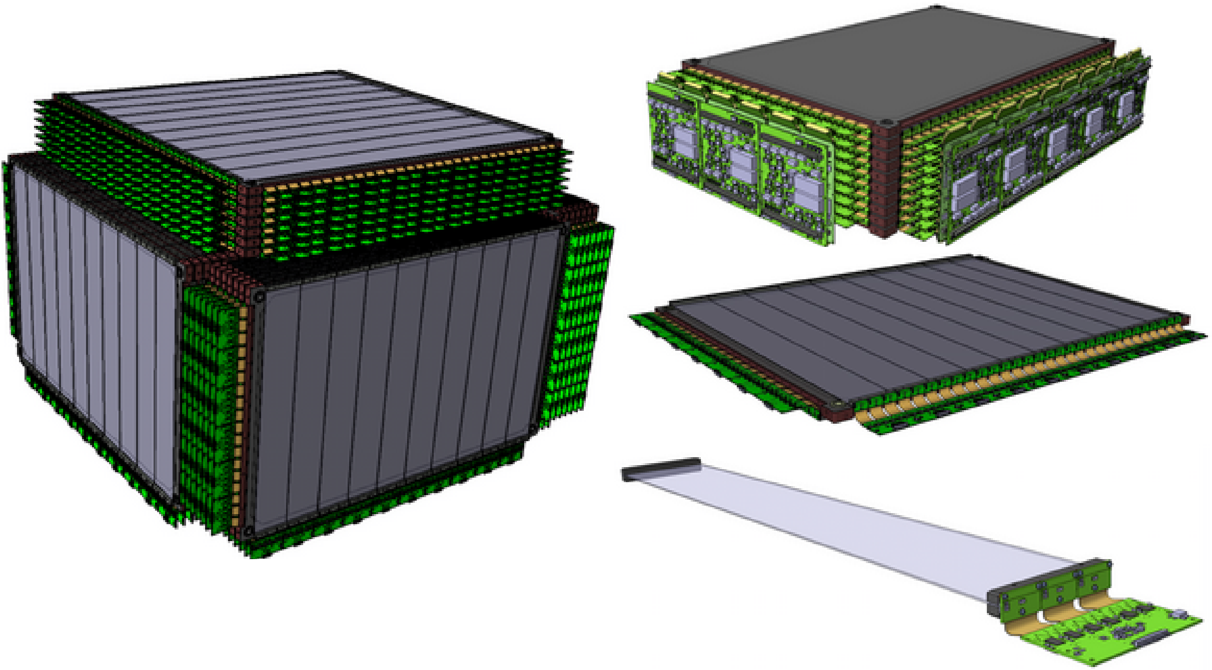








FIber Tracker (FIT)

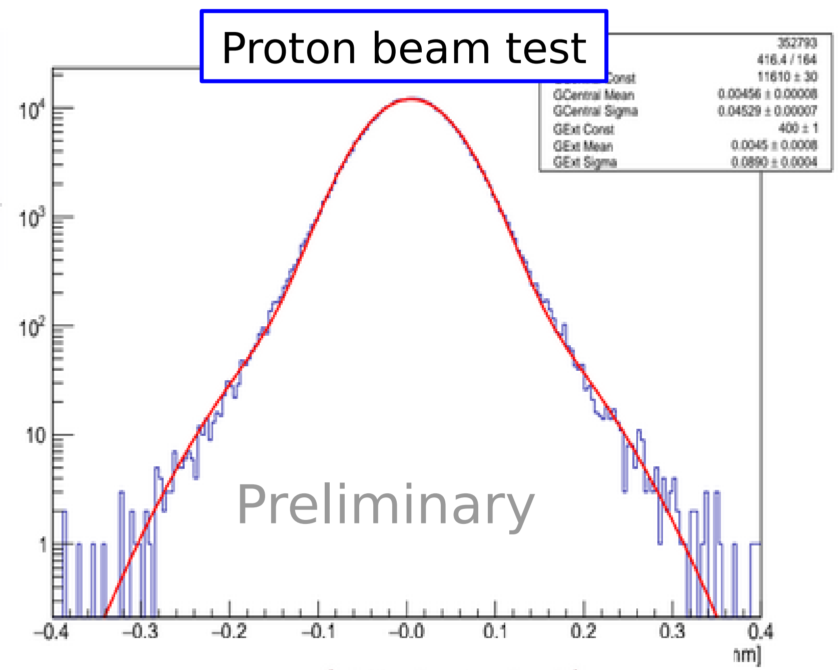


FIT, composed by 7 x-y layers
for each of the five sectors, is made
of scintillating fibers readout by SiPM:
each module consist in 1 fiber mat
coupled to 3 SiPM arrays

Charge resolution

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 %

Track resolution



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

Including the external tracker resolution

Plastic Scintillator Detector (PSD)

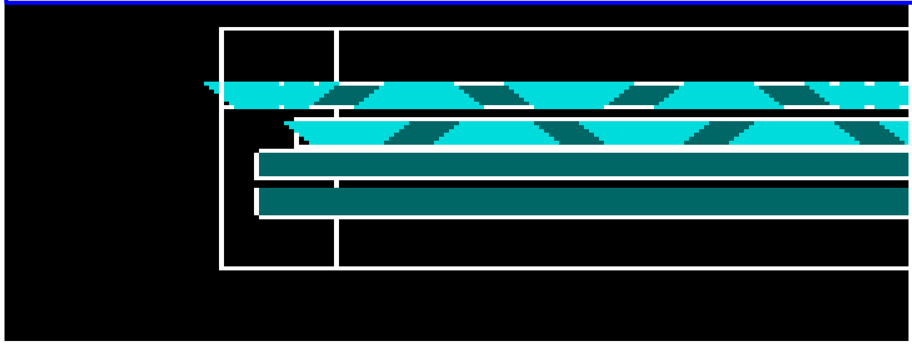
PSD, composed by 2 layers for each of the five sectors, is made of <u>plastic scintillator readout by SiPM</u>

It will identify nuclei up to iron with efficiency>99.98% and will work as a VETO for gamma-rays

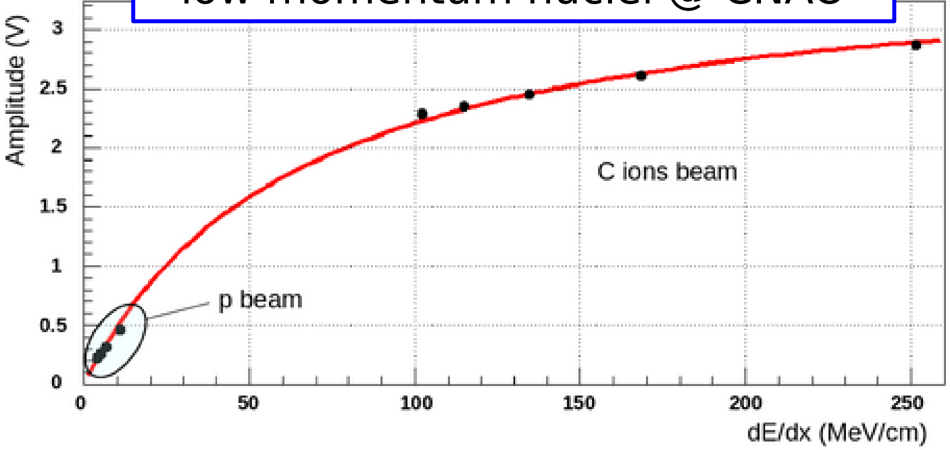
Fine segmentation is necessary to reduce the impact of backscattering from calorimeter showers

The final detector geometry is being optimized using simulation study and beam test verification

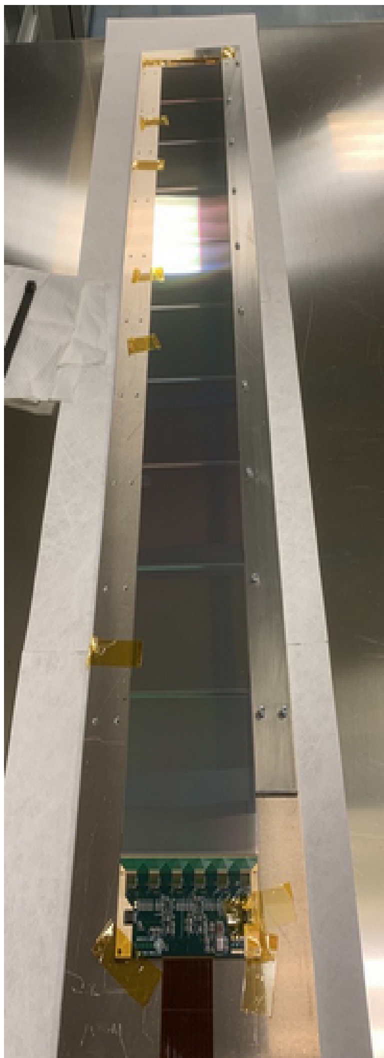
Possible geometry made of rectangular tiles with trapezoidal profile

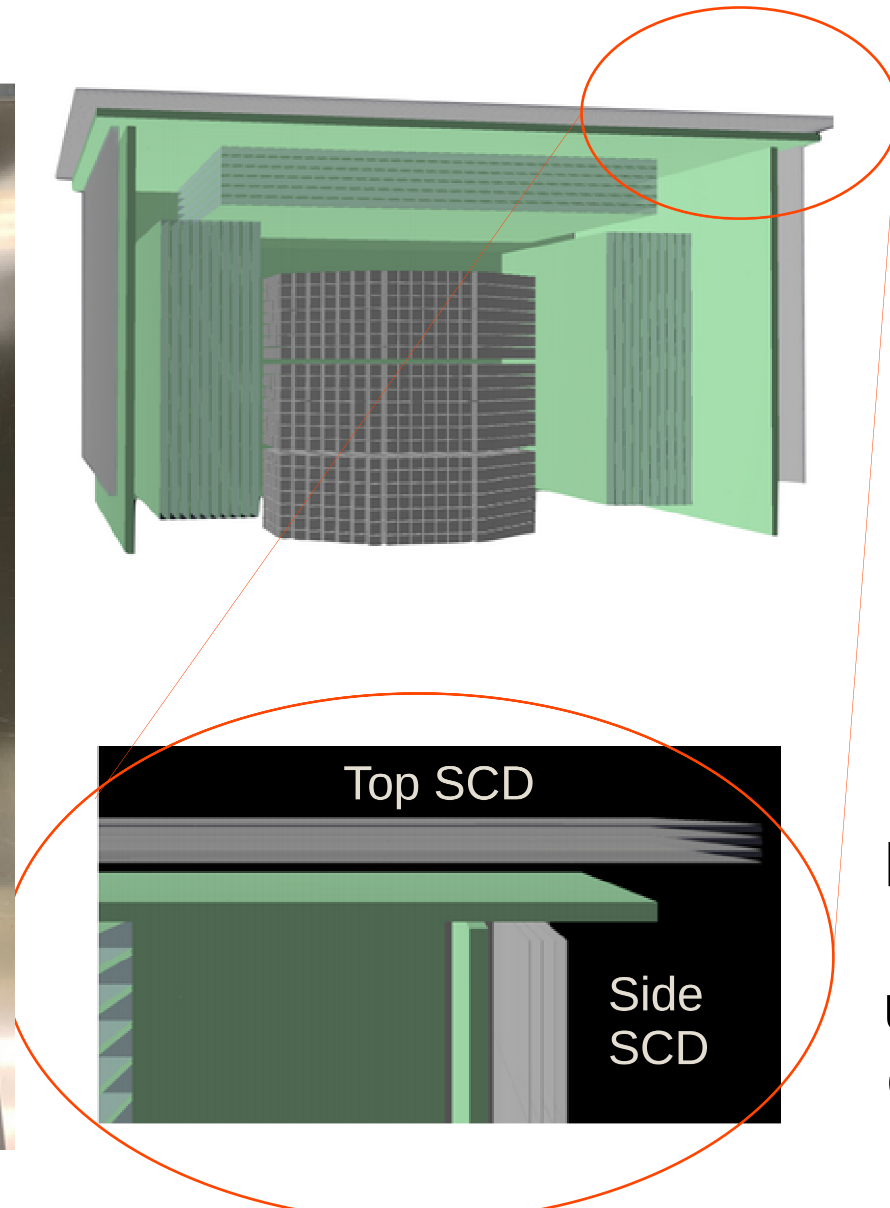


Birks saturation effect tested with low momentum nuclei @ CNAO



Silicon Charge Detector (SCD)





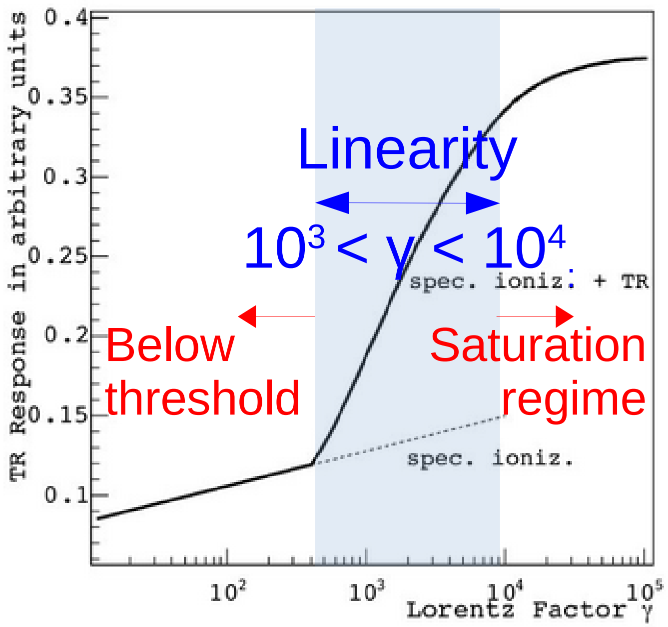
SCD, composed by 4 x-y layers for each of the five sectors, is made of silicon <u>microstrip detector</u>

Fine segmentation is necessary to reduce the impact of backscattering from calorimeter showers

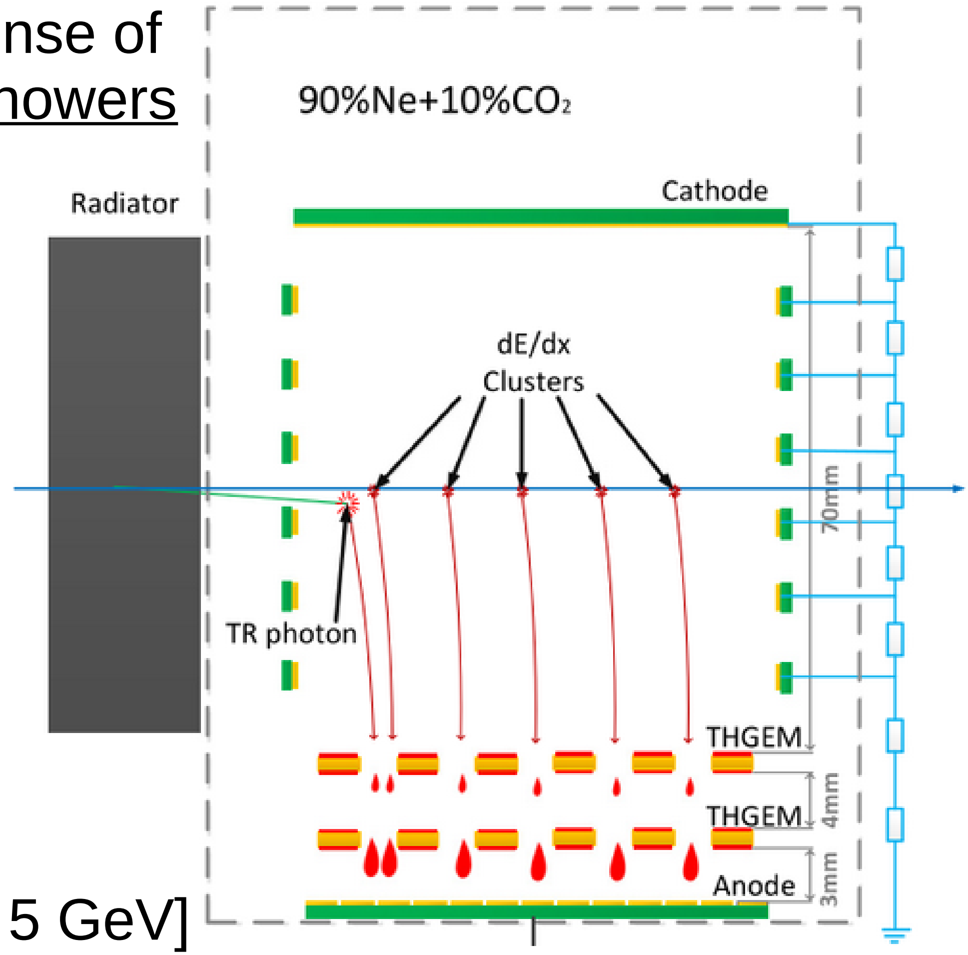
It is the **outermost detector** to reduce the systematic uncertainty on reconstructed charge due to fragmentation

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



Calibration procedure



Side-on geometry

- calibrate TRD response using [0.5 GeV, 5 GeV] electrons at beam test (and verified in space)
- calibrate CALO response using [1 TeV, 10 TeV] protons from TRD (3 months data required)

Summary

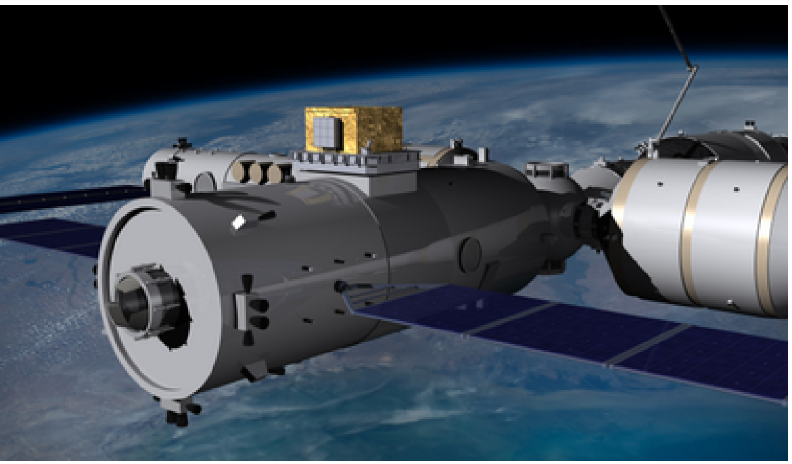
The **High Energy cosmic-Radiation Detection** facility, set to operate from 2027 aboard the China's Space Station, will:

- Extend the measurement of p and nuclei fluxes up to few PeV
  → Test the propagation and acceleration mechanisms
- Extend the measurement of e^{-}+e^{+} flux up to several tens of TeV
  → Test the expected cutoff and search for dark matter
- Monitor the gamma-ray sky at energies higher than 100 MeV
  → Look for transient events and dark matter annihilation lines

This extension in energy is possible thanks to its **novel design**, based on homogeneous, isotropic and 3D-segmented detector, which will also be optimized to decrease systematic uncertainties:

- better knowledge of the **absolute energy scale** thanks to double readout system and in-flight calibration with the TRD
- better **charge reconstruction** thanks to the outermost position and the fine segmentation of the charge detector (SCD)

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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