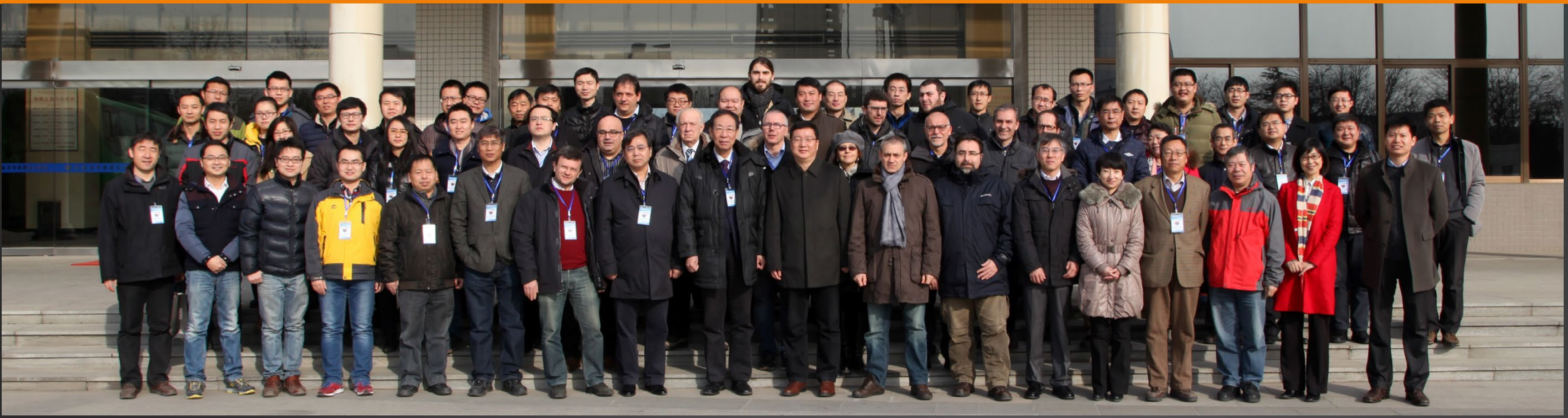
The High Energy cosmic-Radiation Detection facility (HERD):

a probe for high-energy cosmic rays' physics and multimessenger astronomy

F.GARGANO ON BEHALF OF THE **HERD** COLLABORATION

INFN - BARI

COLLABORATION



CHINA

- **Institute of High Energy Physics, CAS, Beijing**
- Xi'an Institute of Optical and Precision Mechanics, China
- Purple Mountain Observatory, CAS, Nanjing
- University of Science and Technology of China, Hefei

ITALY

- INFN Bari and University of Bari
- INFN Firenze and University of Firenze
- INFN Perugia and University of Perugia
- INFN Pisa and University of Pisa
- INFN Lecce and University of Salento
- INFN Laboratori Nazionali del Gran Sasso and GSSI Gran Sasso Science Institute

SPAIN

- CIEMAT - Madrid
- ICCUB - Barcellona

SWITZERLAND

- University of Geneva

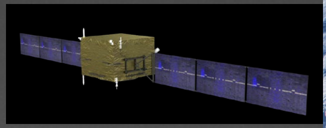
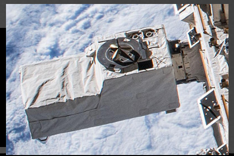
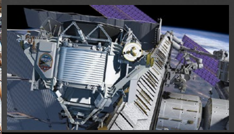
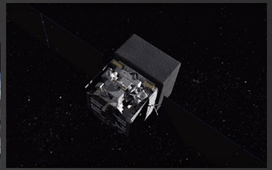
The **High Energy cosmic-Radiation Detection** (HERD) facility is a China-led international space mission that will start operation around 2026.

The experiment is based on a **3D, homogeneous, isotropic and finely-segmented calorimeter** that fulfills the following requirements and goals

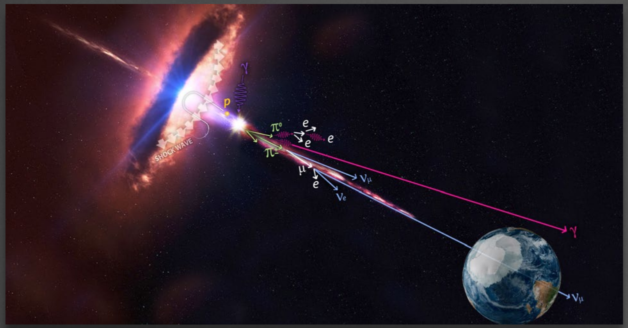
Main requirements

	γ	e	p, nuclei
Energy Range	0.5 GeV 100 TeV	10 GeV 100 TeV	30 GeV 3 PeV
Energy resolution	1% @ 200 GeV	1% @ 200 GeV	20% @ 100 GeV -1 PeV
Effective Geometric Factor	>1 m^2sr @ 200 GeV	>3 m^2sr @ 200 GeV	>2 m^2sr @ 100 TeV

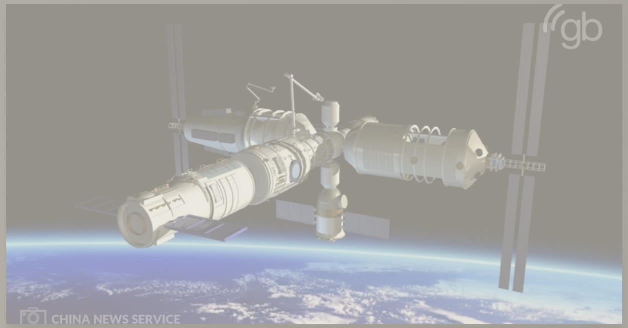
Main Scientific goals
Direct measurement of cosmic rays flux and composition up to the knee region
Gamma-ray monitoring and full sky survey
Indirect dark matter search (e^++e^-, γ,...)

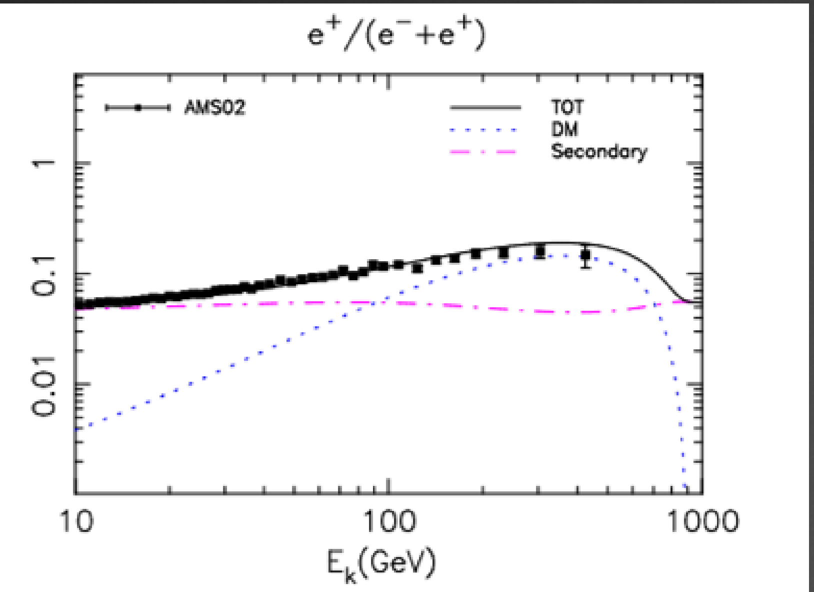
	HERD	DAMPE	CALET	AMS-02	Fermi LAT
e/γ Energy res.@100 GeV (%)	<1	<1.5	2	3	10
e/γ Angular res.@100 GeV (deg.)	< 0.1	<0.2	0.2	0.3	0.1
e/p discrimination	$>10^6$	$>10^5$	10^5	10^5 - 10^6	10^3
Calorimeter thickness (X_0)	55	32	27	17	8.6
Geometrical accep. (m^2sr)	>3	0.3	0.12	0.09	1

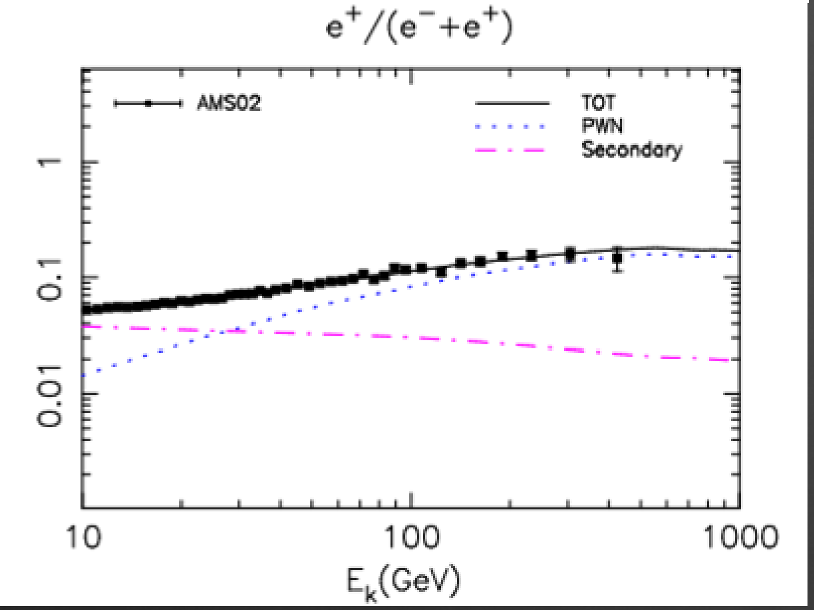


Physics



Instrument



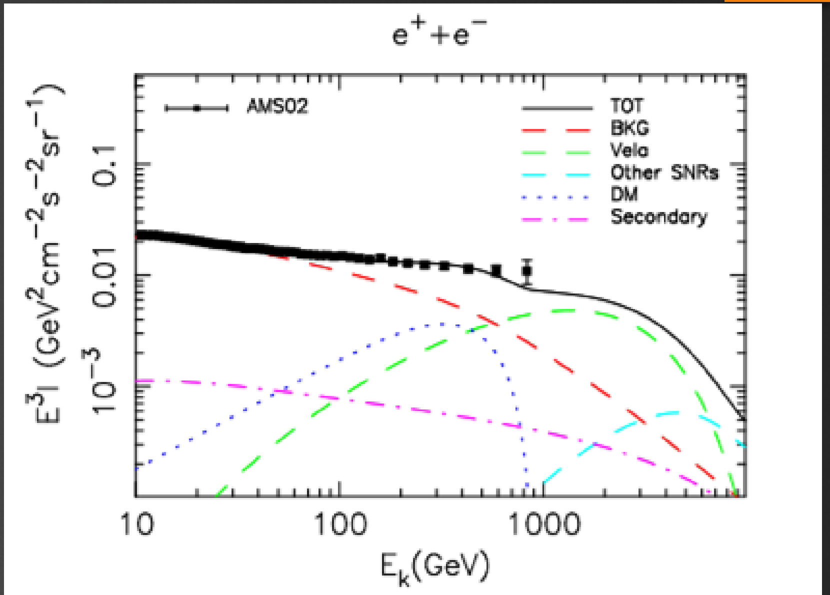


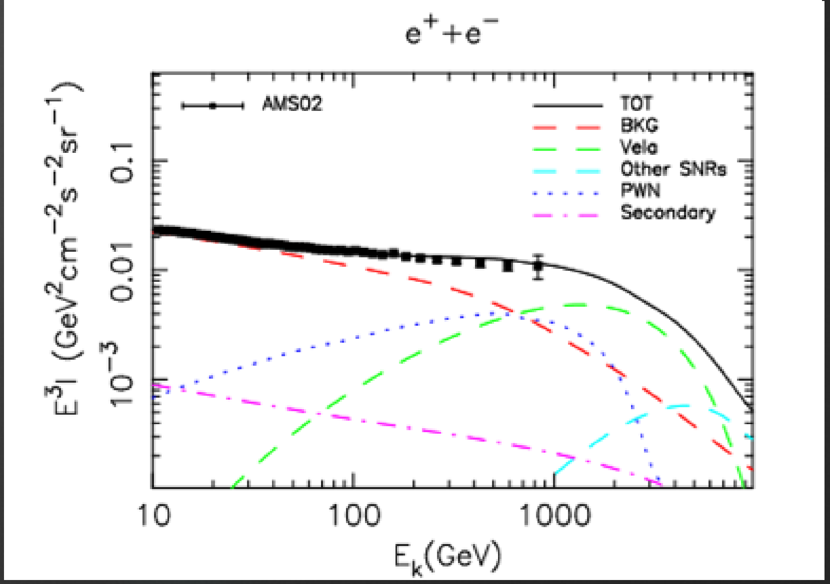
Positron excess respect to pure secondary production (PAMELA, AMS-02)

Two hypotheses
Dark Matter (DM) annihilation
Nearby Pulsar Wind Nebulae (PWN)

How to distinguish among them?

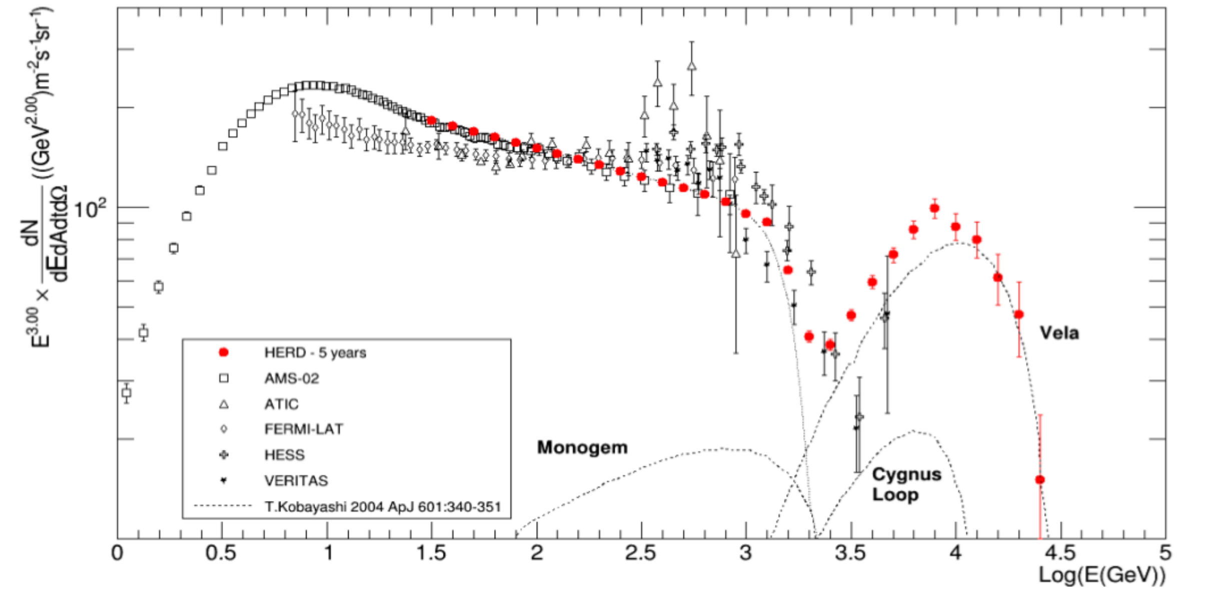
An important contribution to our understanding can be obtained by **high energy (calorimetric) measurement of the e^++e^- flux**





Electrons and Positrons (**HERD**)

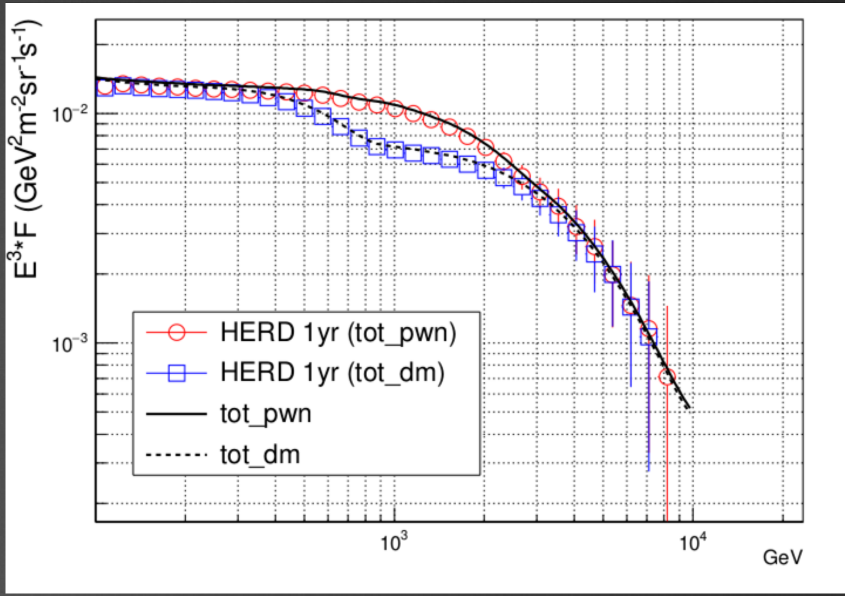
Expected $e^{+}+e^{-}$ flux in 5 years



HERD will measure the flux up to several tens of TeV in order to detect:
spectral cutoff at high energy
local SNR sources of very high energy e^{-}

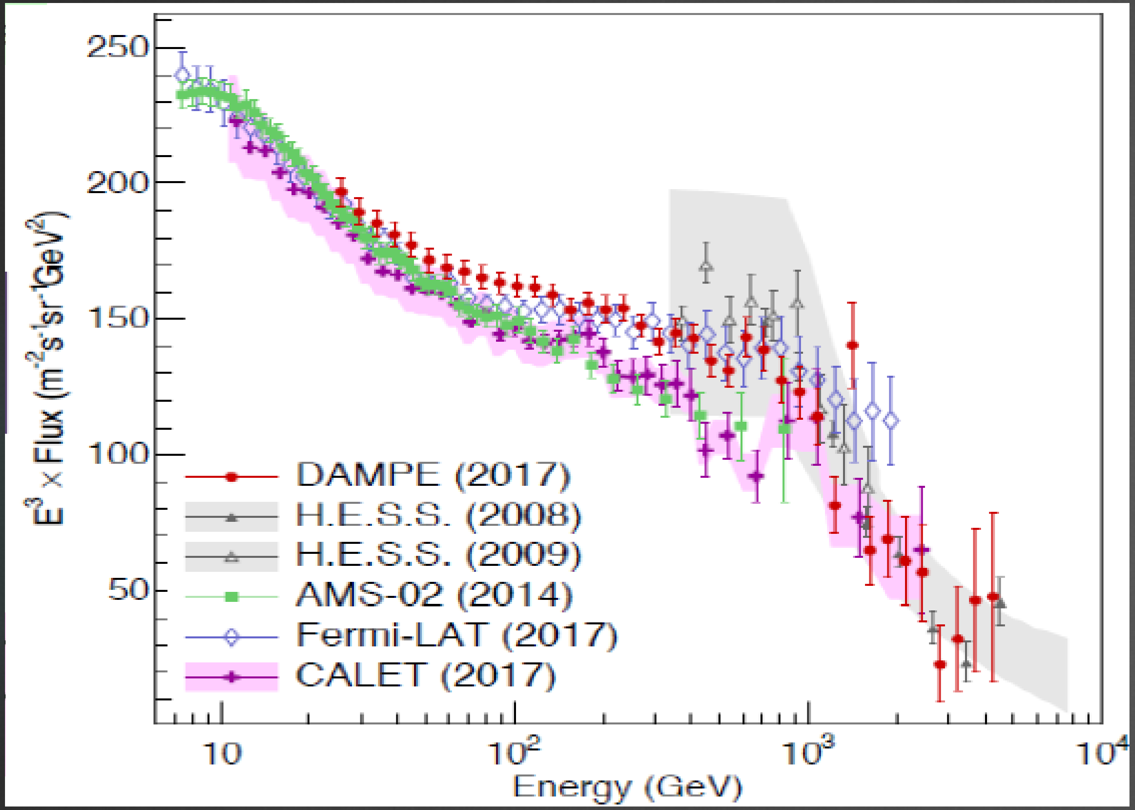
... and additional information from anisotropy measurement!

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

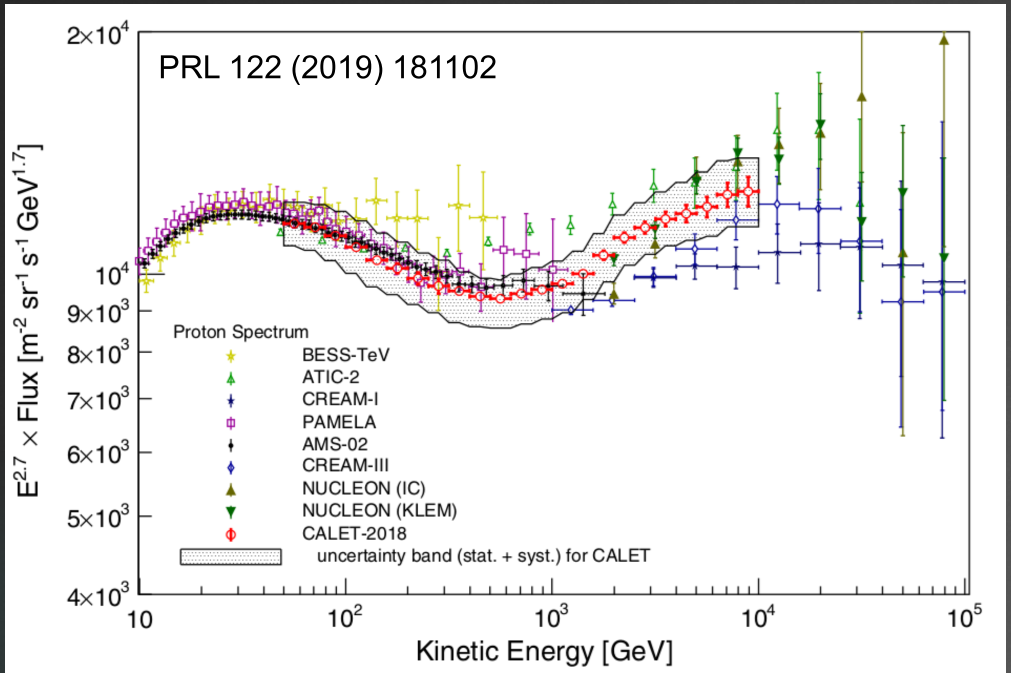
Recent calorimetric measurement of the $e^{+}+e^{-}$ flux (Fermi-LAT, CALET, DAMPE) lead to **very different results** and **no clear conclusion**

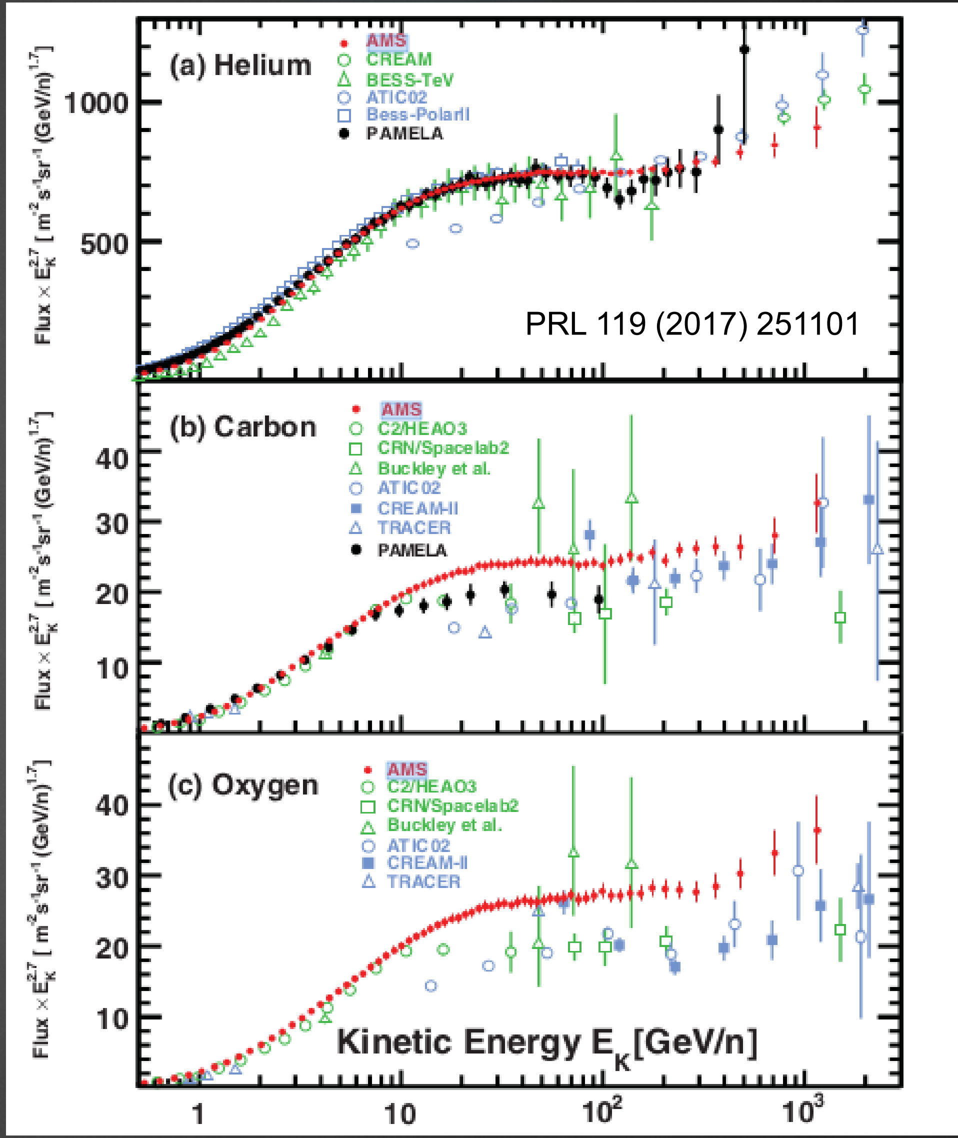


DAMPE data shows a cutoff at 1 TeV and a "sharp peak" at 1.4 TeV – NATURE 552 (2017)
CALET data are consistent with a single power law without cutoff - PRL 120 (2018)

HERD could help in resolving the "conflict" between different measurements:
improving the precision of the measurement
extending the measurement to higher energy

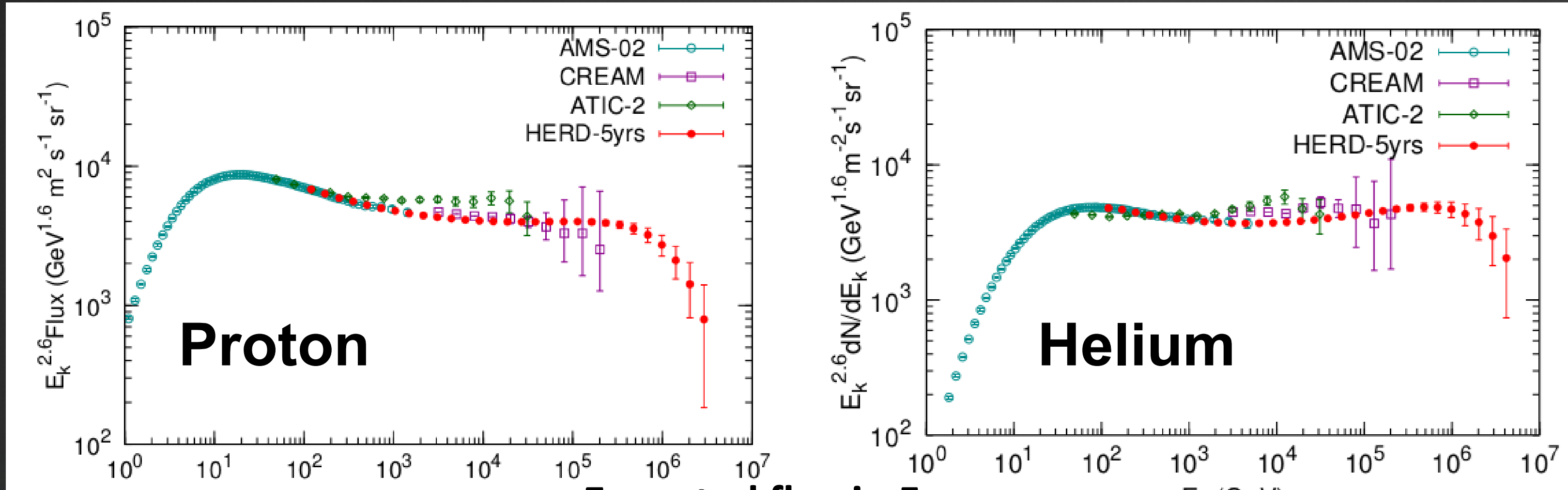
Protons and Nuclei



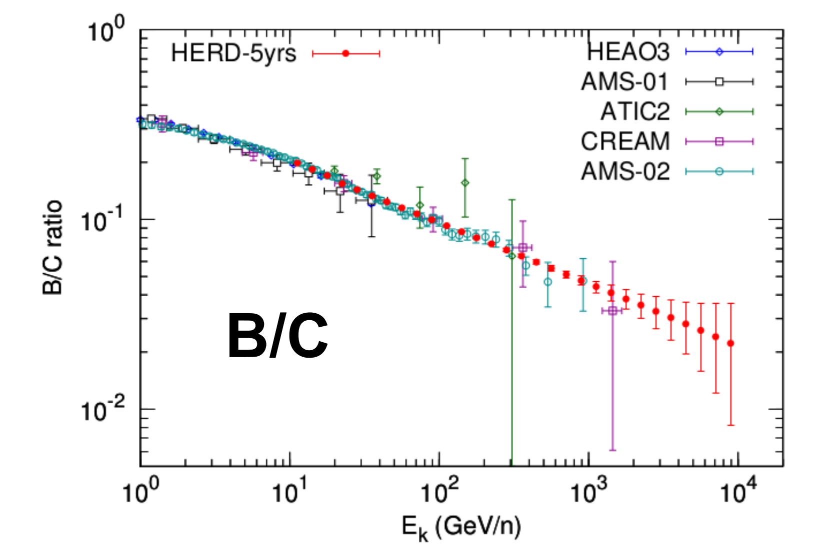


Proton flux measured up to 100 TeV but with large uncertainties:
spectral hardening at 200 GeV
spectral softening > 10 TeV
(DAMPE preliminary analysis)

Still no direct measurement of proton and helium knee
He spectral hardening > 100 Gev/n
(DAMPE preliminary analysis)



Expected flux in 5 years



HERD will measure the flux of nuclei:

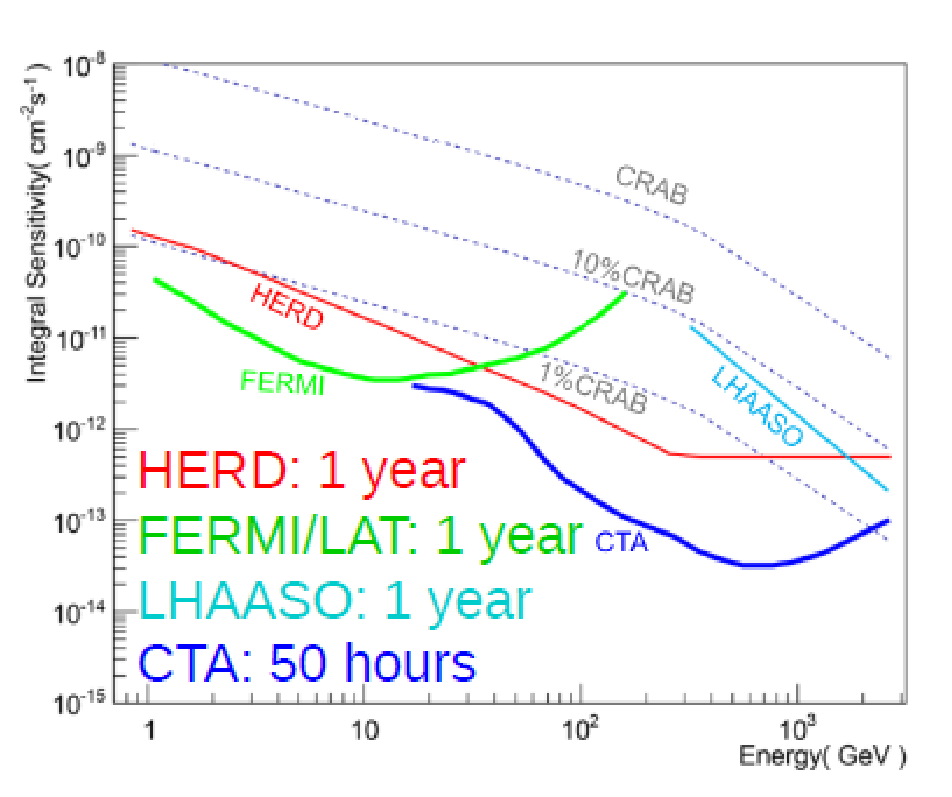
- p and He up to a few PeV
- nuclei up to a few hundreds of TeV/n

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

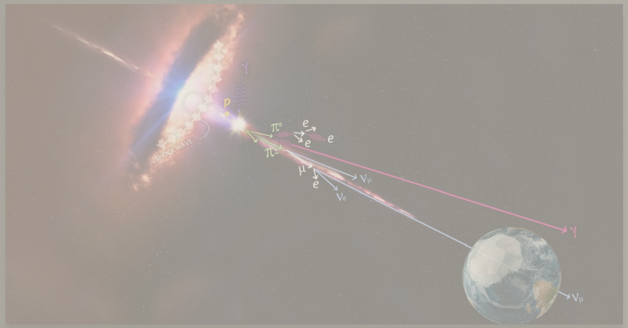
Gamma ray sky-survey (**HERD**)

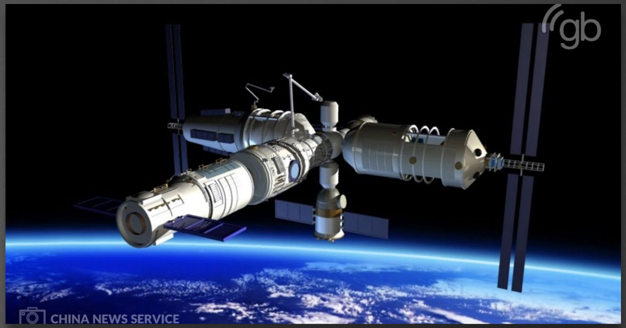
Sky survey 5σ sensitivity



Multi-messenger astronomy
Possible synergy with other experiments designed for γ (CTA), ν (KM3, IceCube), GW (Ligo, Virgo)

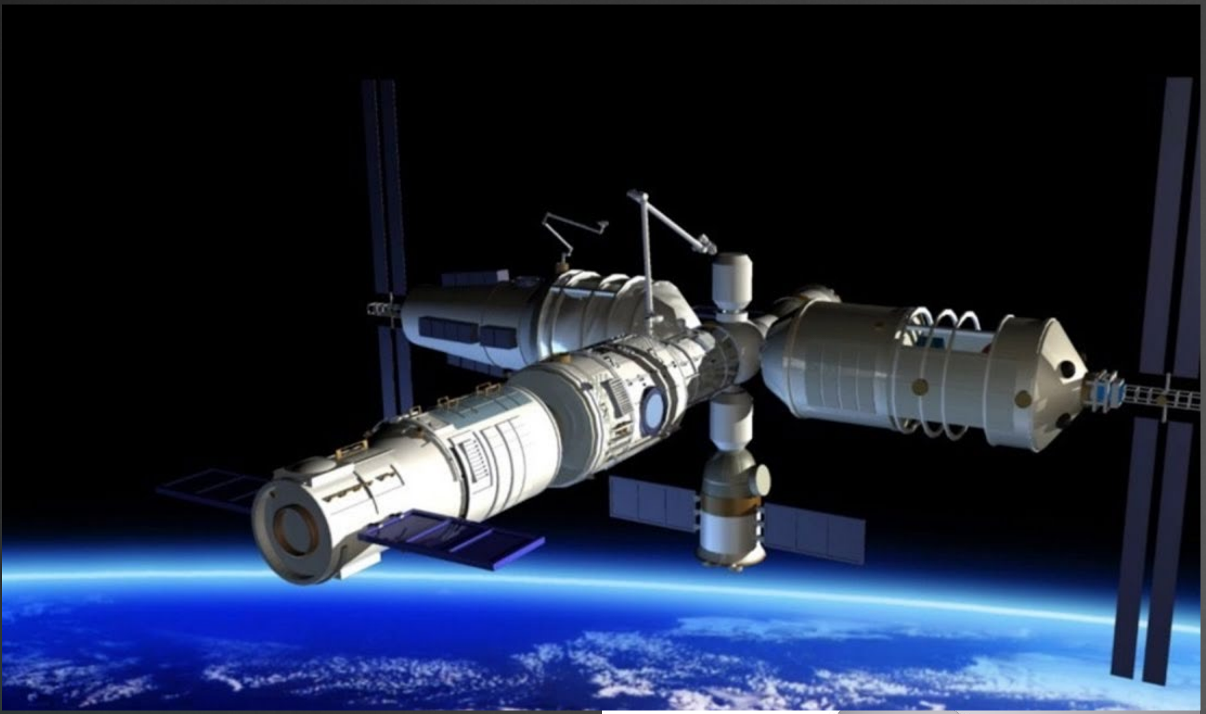
- Thanks to its large acceptance and sensitivity, **HERD** will be able to:
  - improve Fermi-LAT measurements between 10 and 100 GeV
  - extend Fermi-LAT catalog to higher energy (between 0.1 and 100 TeV)
  - increase the chances to detect rare γ events
- **Targets of Gamma-Ray Sky Survey**:
  - search 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

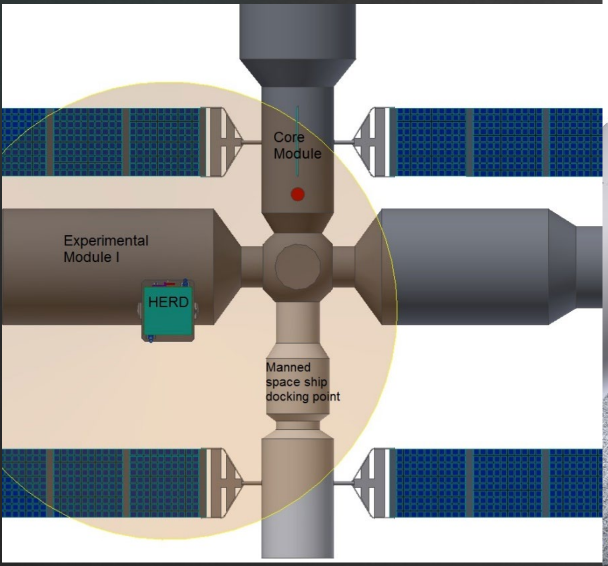


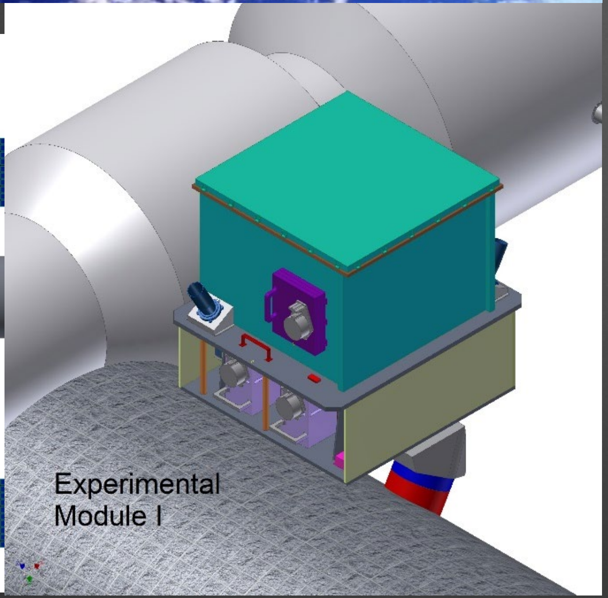


Physics

Instrument







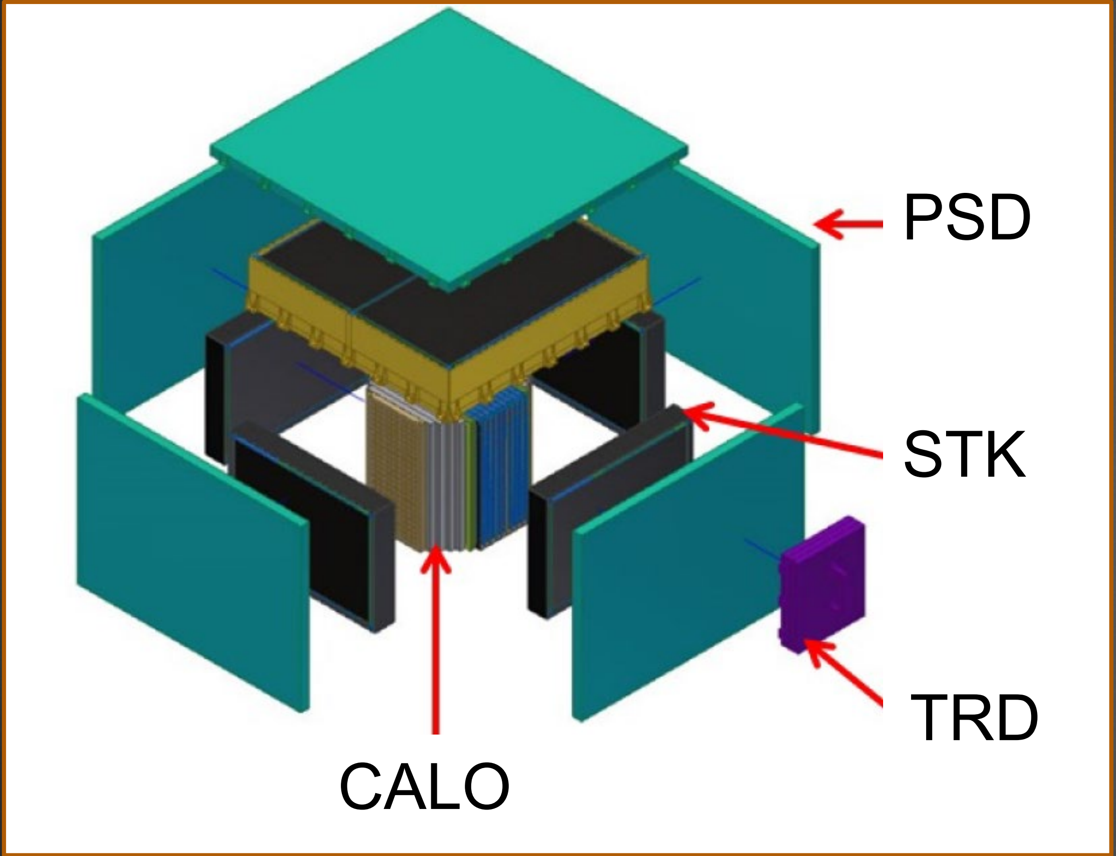
CSS expected to be completed in 2022

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

HERD expected to be installed around 2026

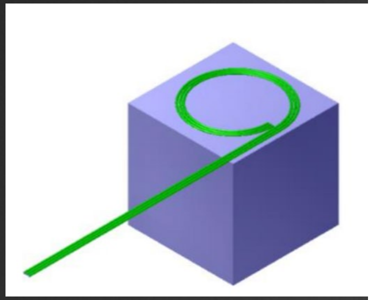
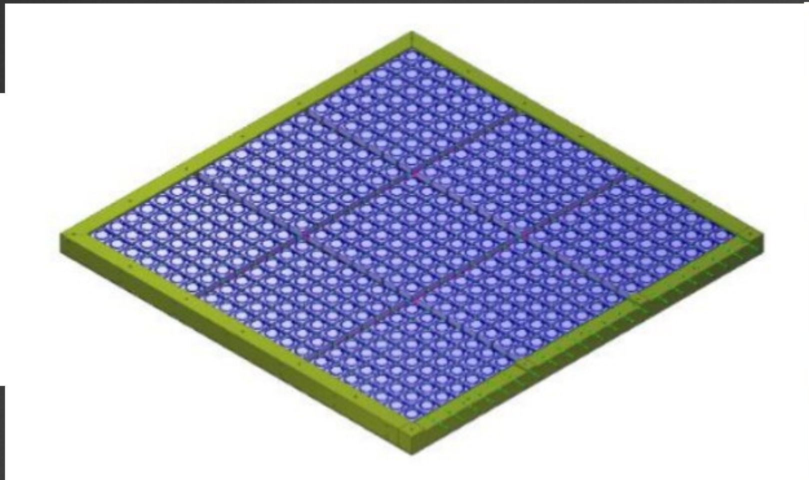
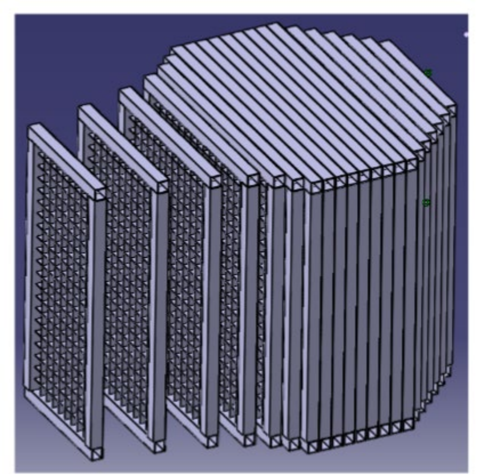
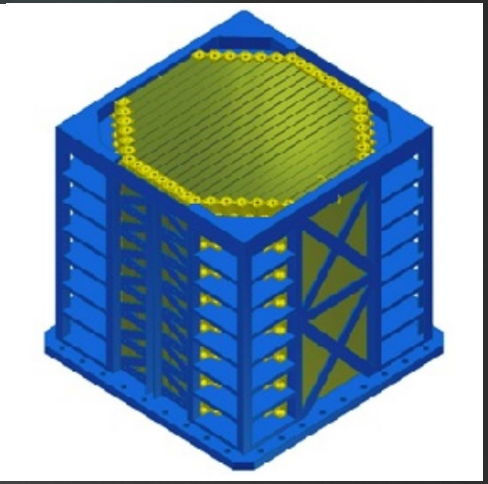
Life time	> 10y
FOV	+/- 70°
Power	< 1.5 kW
Mass	< 4 t

HERD sub-detectors



CALO	Energy Reconstruction e/p Discrimination
STK	Trajectory Reconstruction Charge Identification
PSD	Charge Reconstruction γ Identification
TRD	Calibration of CALO response for TeV proton

HERD CALOrimeter (CALO)

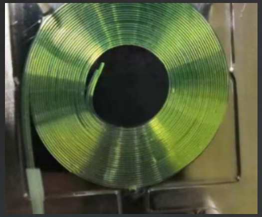
Octagonal Prism made of about 7500 LYSO cubic crystals (80x80x80 cm^3):
each crystal has 3 cm side

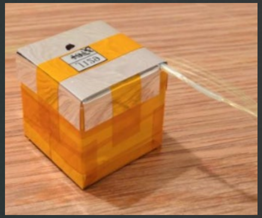
Deep homogeneous calorimeter	Good energy resolution
Isotropic 3D geometry	Large geometric factor (top + lateral faces)
Shower imaging with 3D segmentation	Good e/p discrimination, identification of shower axis and of shower starting point

HERD CALO READOUT

Dynamic range of 10^7 is needed to detect from a MIP (~30 MeV released in a single crystal) to a PeV proton (~20 TeV released in a single crystal)

WLS read-out

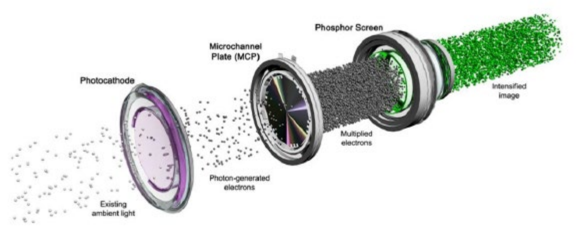


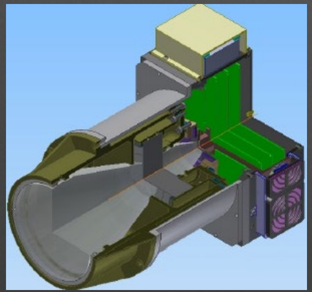


Each cube is read-out by 3 WLS fibers.

One of the fiber is used for triggering and the light signal is readout by a fast PMT

The light signal from the other two fibers is amplified by an Image Intensifier (two gains) and read-out by a IsCMOS camera

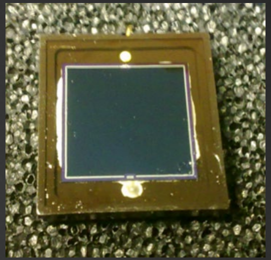


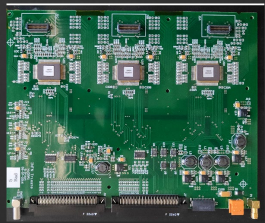


PIN-Diode read-out

Each cube is read-out by 2 PIN-Diode of different area (1:100 ratio)

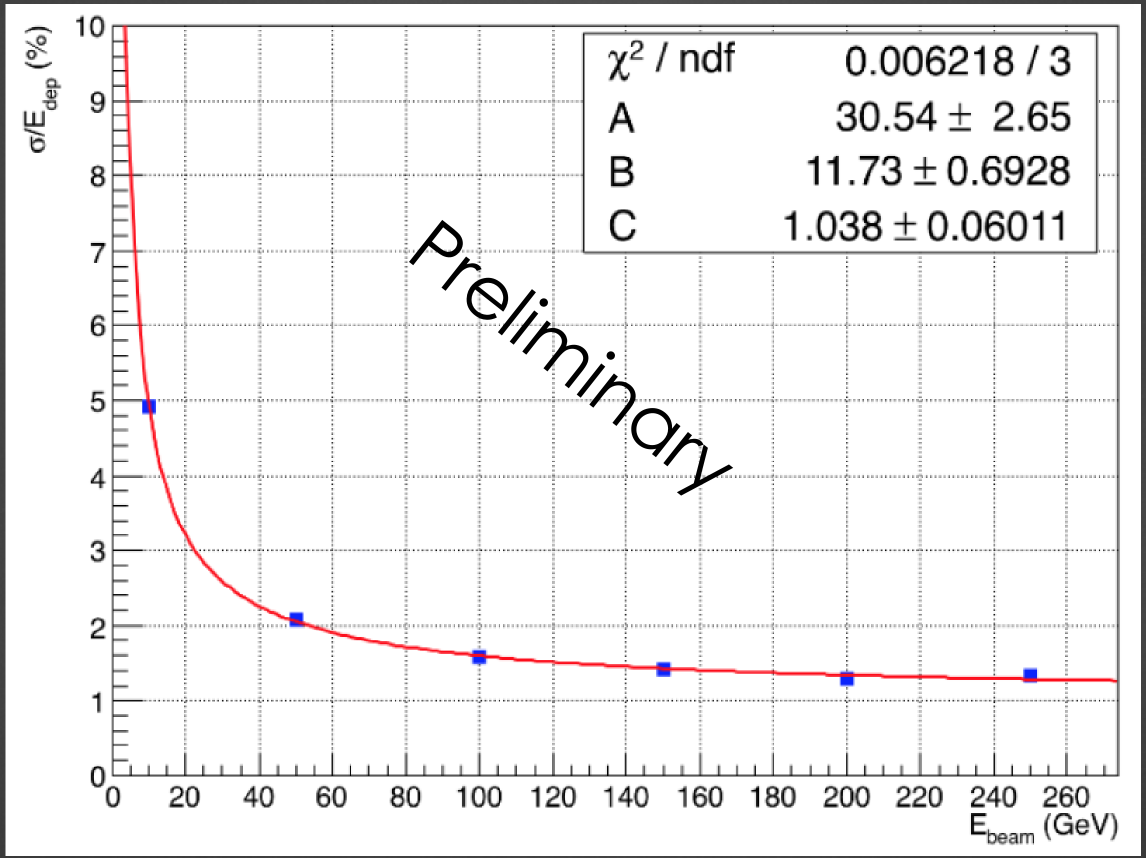
Each PIN-Diode is read-out by CASIS chip with two gains and trigger capability



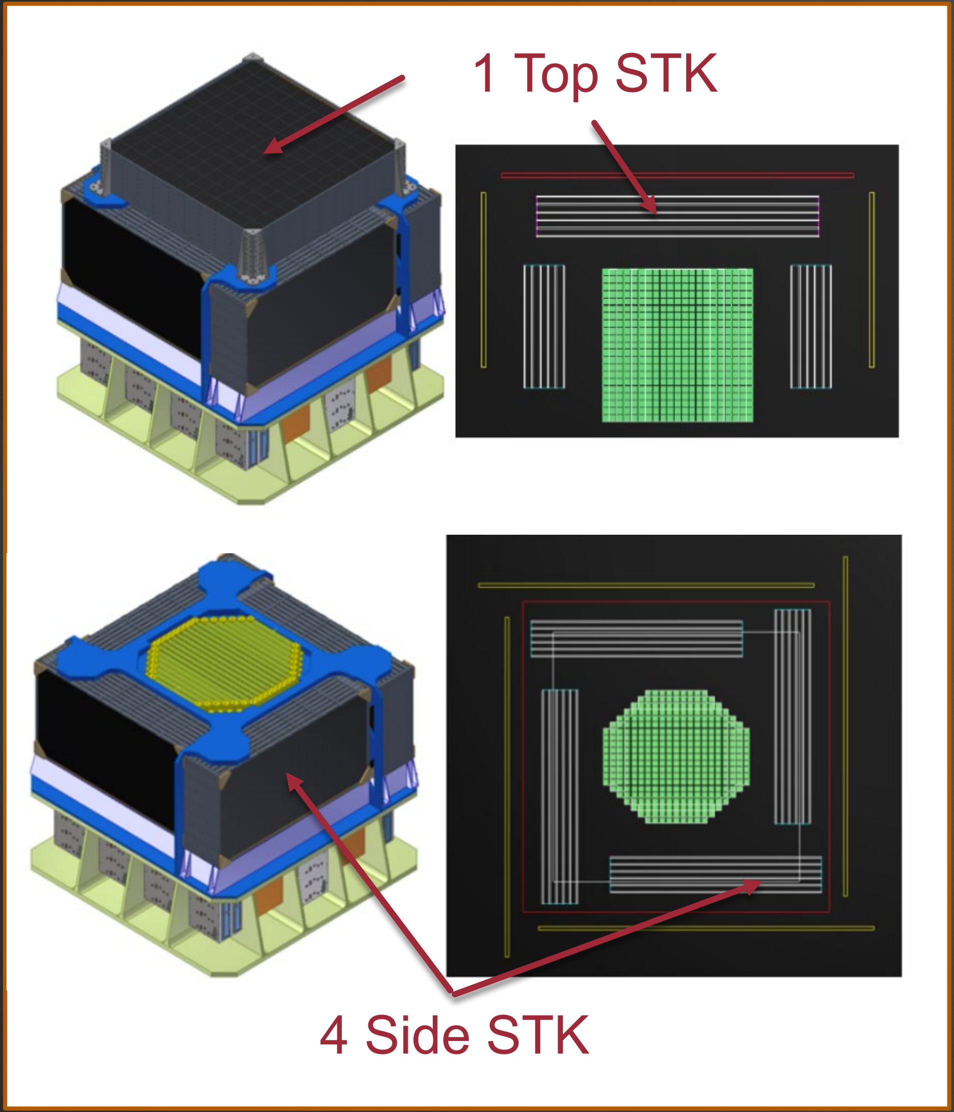


Beam Test at CERN – SPS (2017) with a prototype of 250 crystals with WLS read-out

Energy resolution < **1.3% at 200 GeV/c** (electrons)



HERD Silicon TracKer (STK)



1 Top STK

- 6 Layers of XY SSD
- Baseline: W foils for γ conversion (FERMI-LAT, DAMPE)
- Alternative: LYSO crystal as active converter
- Active Area 133 cm x 133 cm

4 Lateral STK

- 3 Layers of XZ or YZ SSD
- Active Area 95 cm x 66.5 cm

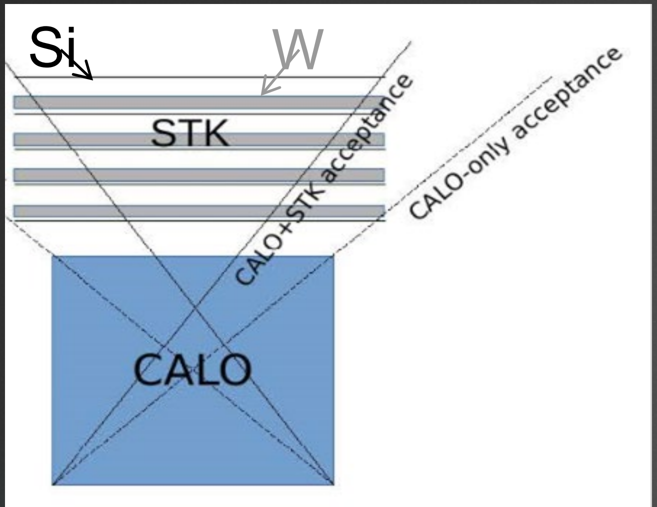
SSD

- Implantation Pitch= 121 μm
- Readout Pitch = 242 μm
- Expected resolution σ = 40 μm

Alternative design: FIber Tracker instead of Silicon TracKer

HERD Tracker in Calorimeter (TIC)

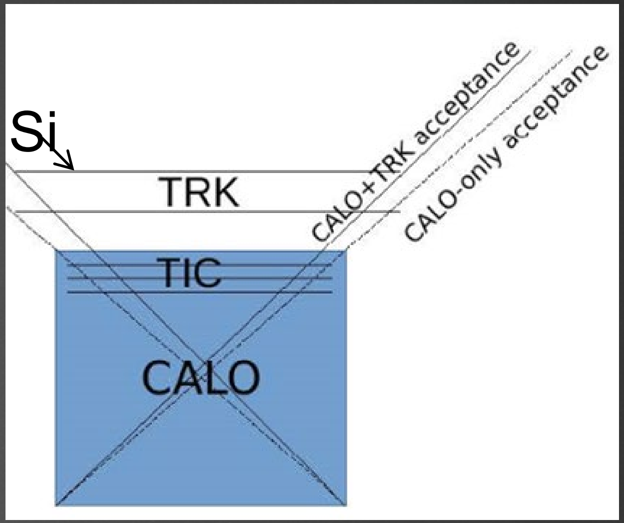
W- converter



γ Conversion in W foils in the STK

Direction reconstructions by e^+e^- tracking in the Si-tacker planes

TIC



γ Conversion in Lyso crystals in top layer of the CALO

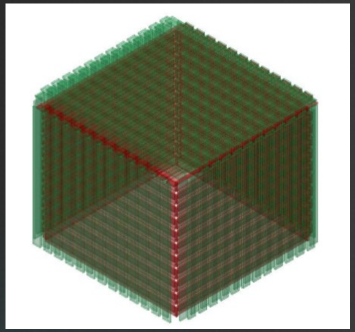
Fine sampling of the e.m. shower with Si-tracker planes inside the CALO

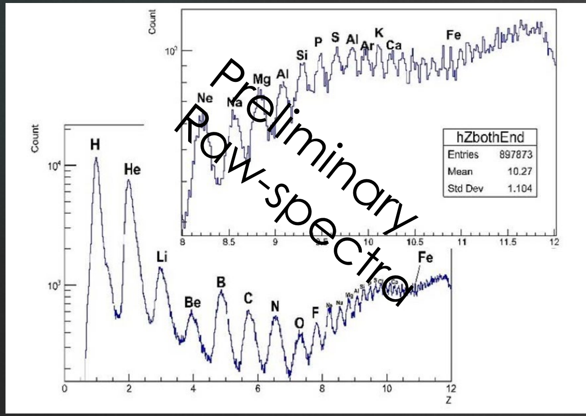
TIC Pro	TIC Cons
- decrease the amount of mass used for passive material (W) - reduce hadron fragmentation in passive material - increase the geometric acceptance	- worst PSF for low energy γ (< 10 GeV)

HERD Plastic Scintillator Detector (PSD)

PSD provide γ **identification** (VETO of charged particles) and **nuclei identification** (energy loss $\propto Z^2$)

Back-scattering can greatly degrade the performances



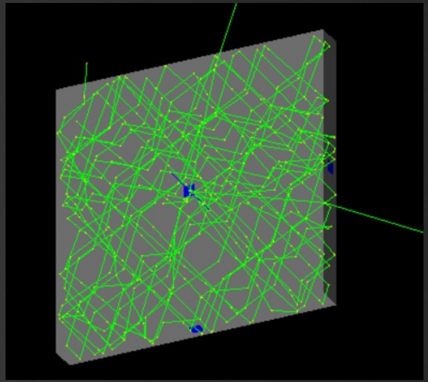


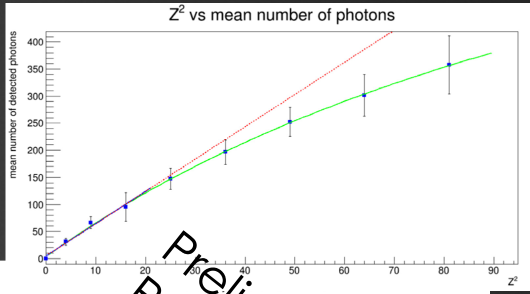
Bar - option

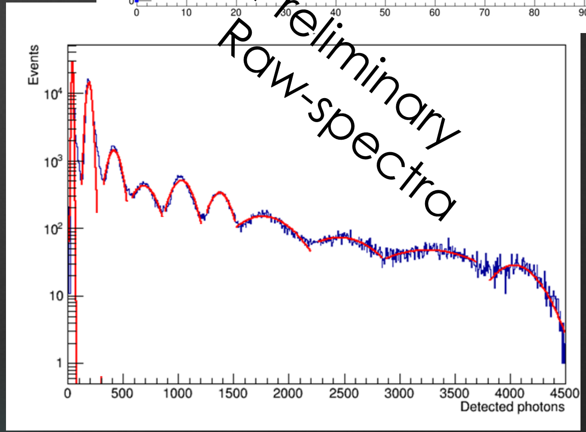
- Long bars 160x3x1 cm^3
- Each layer made by two staggered sub layer to increase hermeticity
- Read-out with 4 SiPM (two for each end)
- PRO
  - Less number of readout channel
- CONS
  - Higher Back-scattering problem

Tile - option

- Small square tile 10x10x1 cm^3
- Two layer of tiles to increase nuclei identification power
- Each tile is readout by 4 SiPM (one for each side)
- PRO
  - Reduce back-scattering problem
- CONS
  - Higher number of readout channel

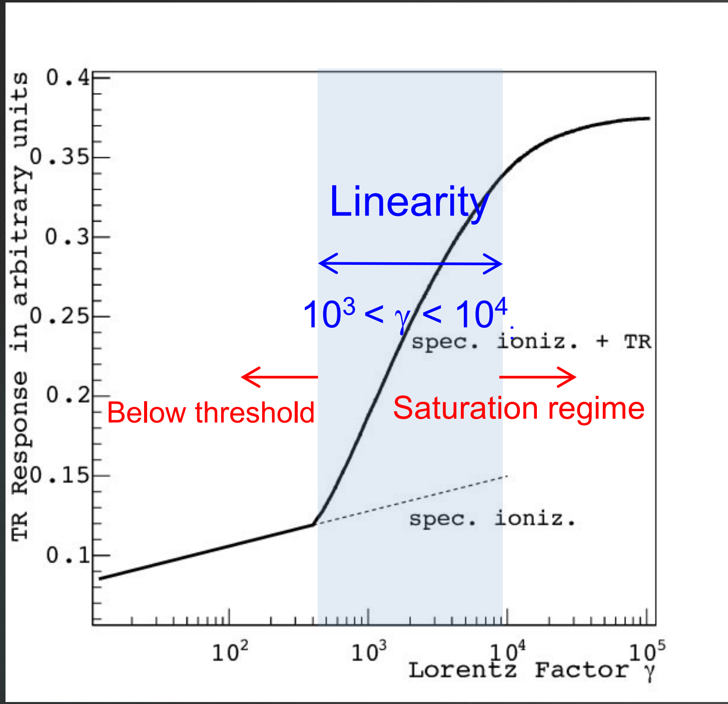






HERD Transition Radiation Detector (TRD)

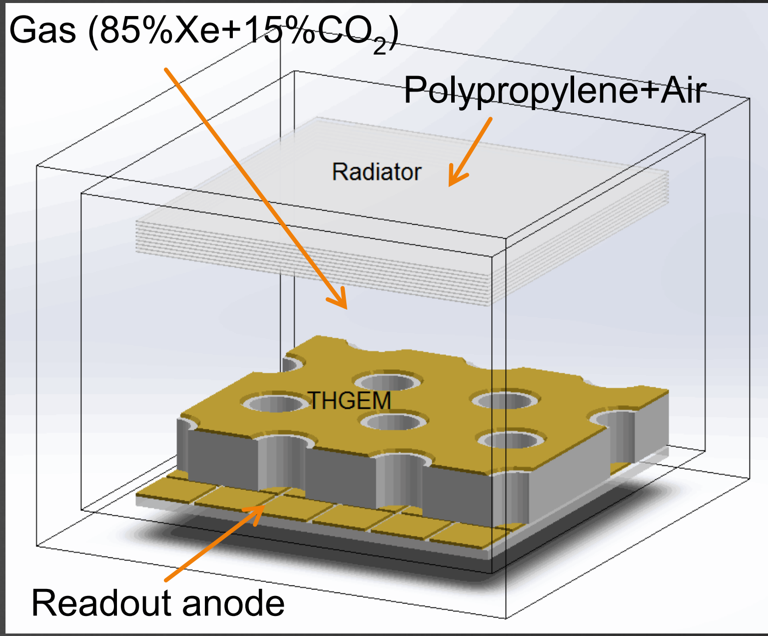
The TRD, installed on a lateral face of the detector, is needed to calibrate the response of the calorimeter to high energy hadronic showers



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 at beam test)

calibrate CALO response using [1 TeV, 10 TeV] protons from TRD (3 months data required)

The **High Energy cosmic-Radiation Detection** facility is a China-led international space mission that will start its operation around 2026 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

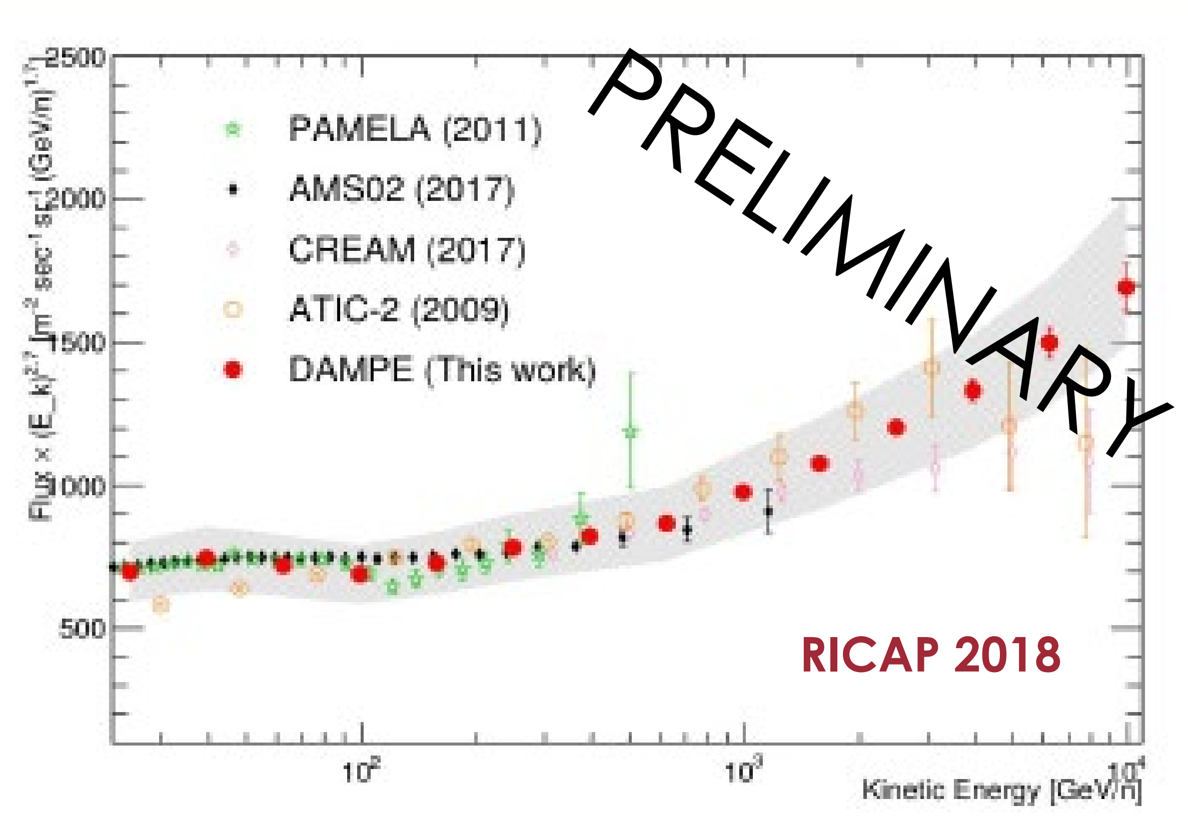
- extend the measurement of p and He flux up to a few PeV
  - testing the theory of the knee structure as due to acceleration limit

- large acceptance, high sensitivity to γ up to several tens of TeV
  - searching for γ line associated to DM annihilation
  - accomplishing a γ sky survey up to very high energy

BACKUP

DAMPE preliminary

DAMPE Helium Preliminary Spectrum



DAMPE Protons Preliminary Spectrum