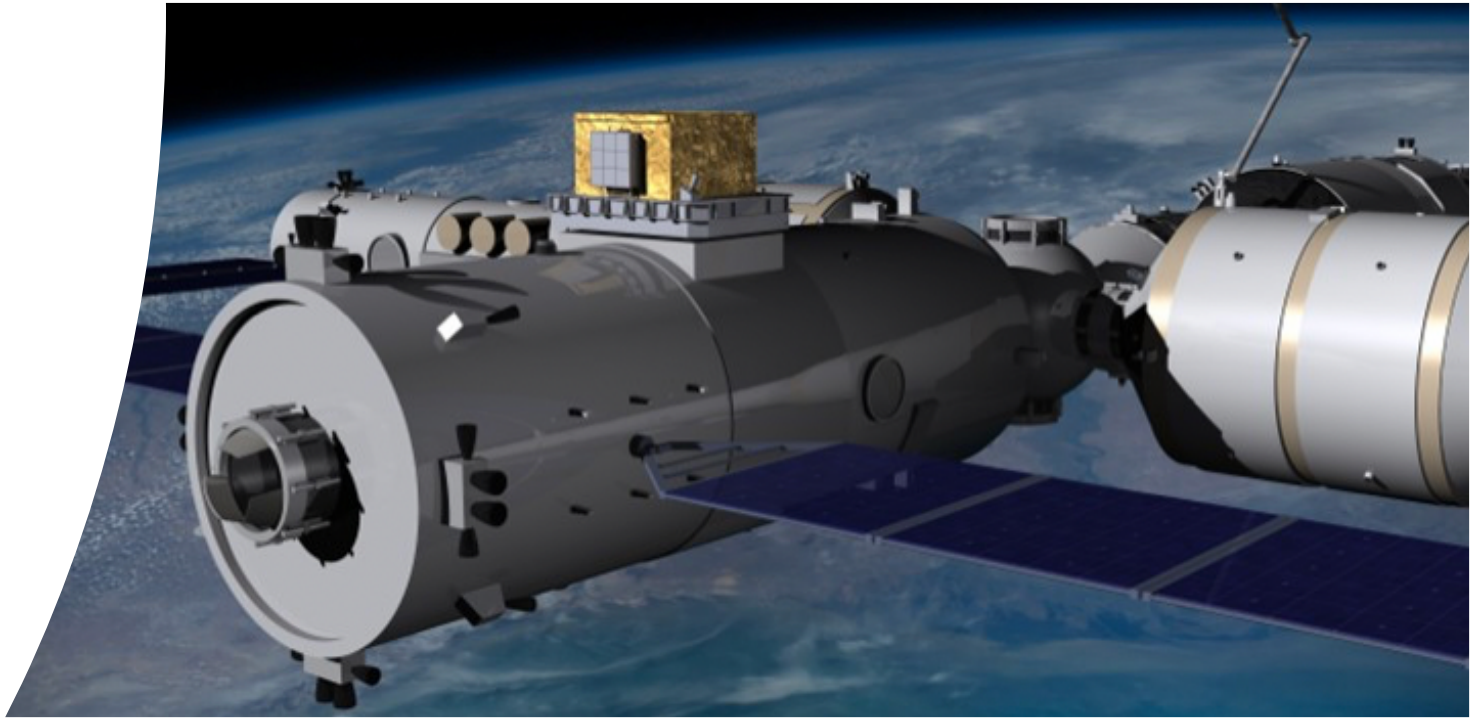
TeVPA 2023

HERD: A Key for Progressing in Our Understanding of Cosmic Rays

Chiara Perrina

on behalf of the HERD Collaboration

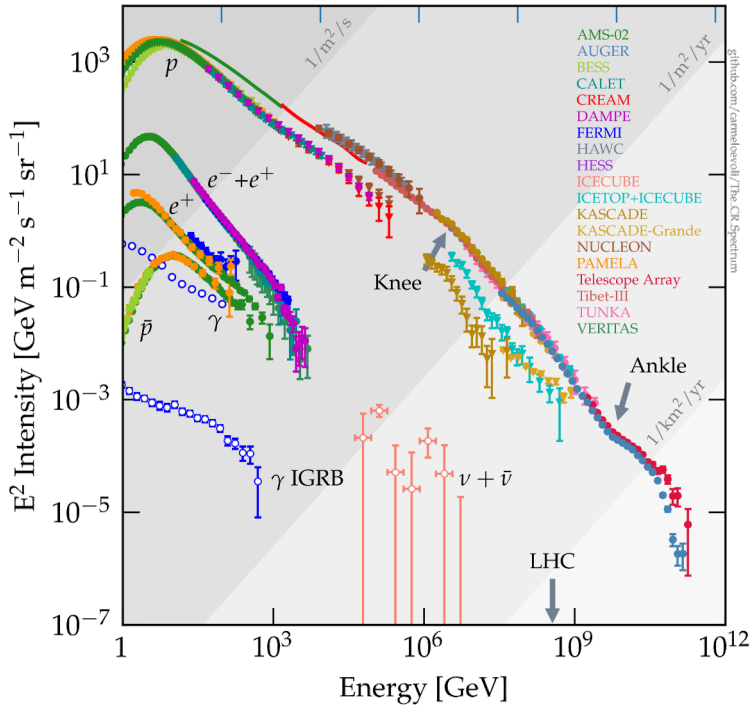
EPFL



Open questions in astroparticle physics

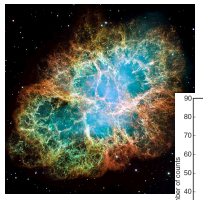
Cosmic rays

Sources, acceleration, propagation

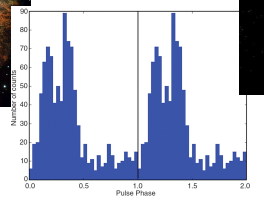


High energy cosmic photons

Sources, interactions, non-thermal physics

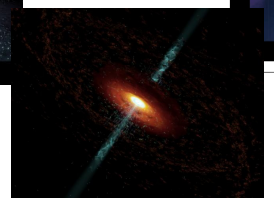


SNRs

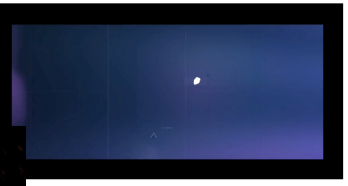


Pulsars

Galactic structures



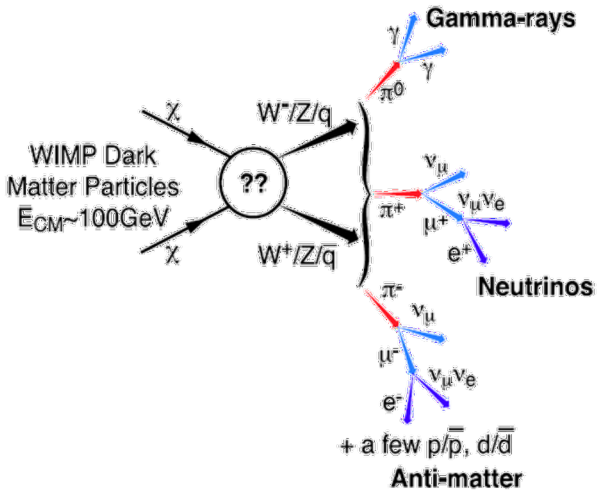
Blazars

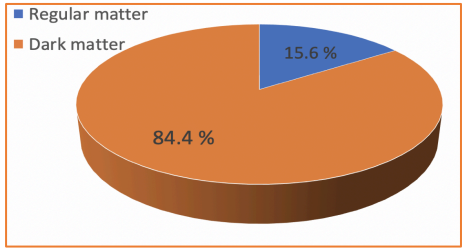


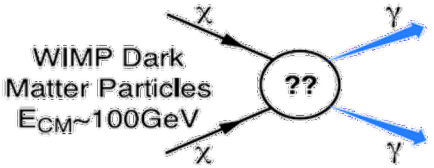
Tidal disruption events

Dark matter

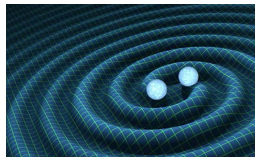
Nature, origin, properties



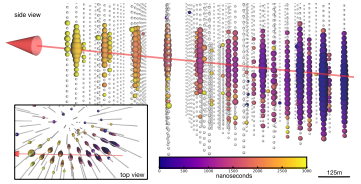




Multimessenger astrophysics



γ-ray counterpart of gravitational waves

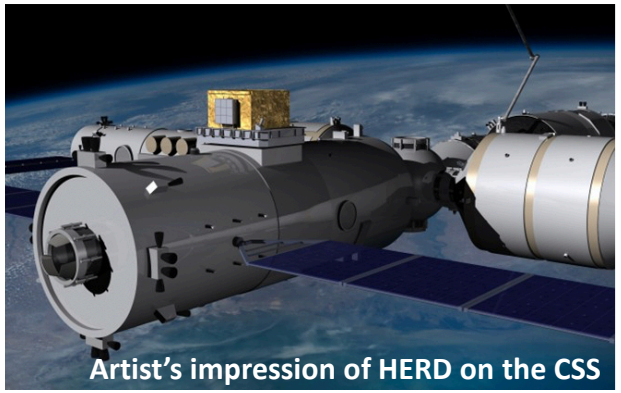


γ-ray counterpart of neutrinos

Exotic particles

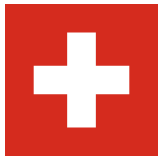
HERD

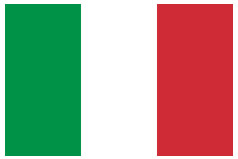
- The **H**igh **E**nergy cosmic-**R**adiation **D**etection facility (HERD) is a space-borne calorimetric experiment.
- HERD will be launched and installed onboard the China Space Station (CSS) in 2027, operational for at least 10 years.


Artist's impression of HERD on the CSS

International scientific collaboration counting 270+ scientists from China and Europe.


Lead by IHEP


University of Geneva
EPFL - Lausanne

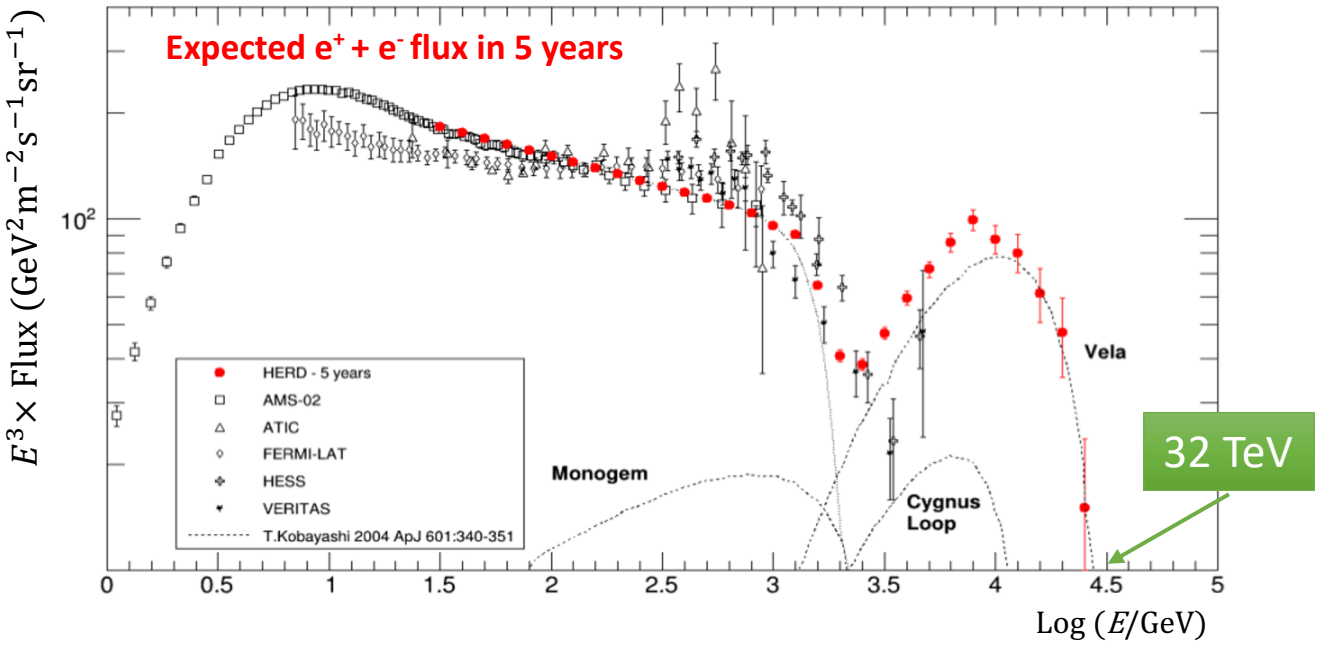

University and INFN of Bari, Bologna, Catania, Firenze, Lecce, Napoli, Pavia, Perugia, Pisa, Roma2, Trieste, LNGS and GSSI.


CIEMAT – Madrid
ICCUB – Barcelona
IFAE - Barcelona

1) HERD observables and physics goals

Electrons + positrons up to several tens of TeV

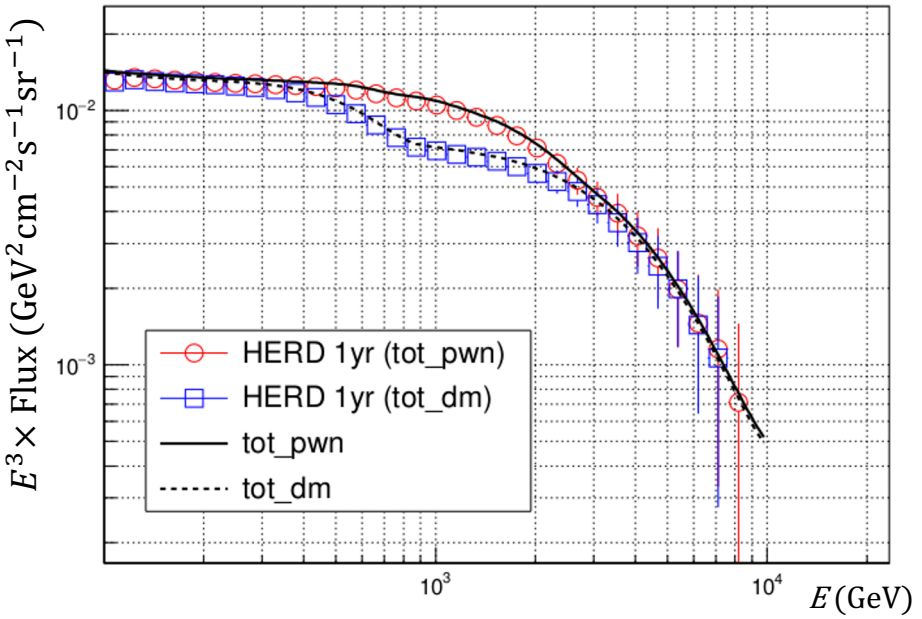
Acceleration and propagation studies



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

- spectral cutoff at high energy
- local nearby astrophysical sources of very high energy e^-
- additional information from anisotropy measurement

Dark matter indirect searches

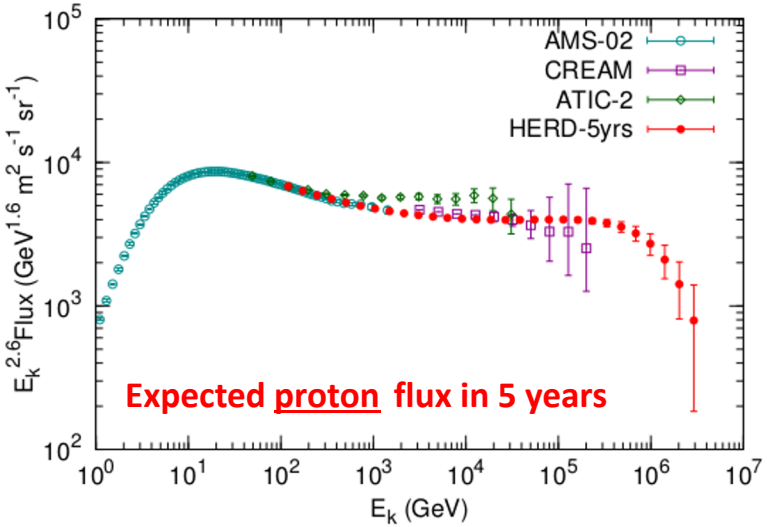


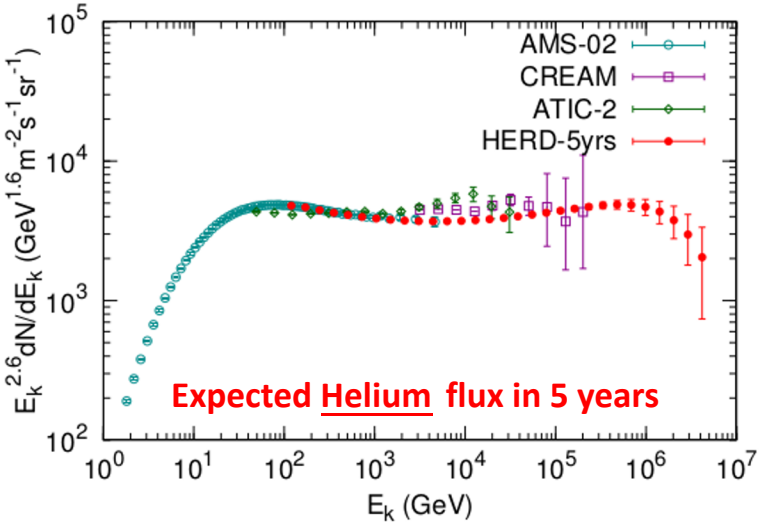
HERD will give important indications on the origin of the positron excess, i.e. to distinguish the dark matter origin of the excess from other astrophysical explanations, thanks to the precise measurement of the $e^+ + e^-$ flux.

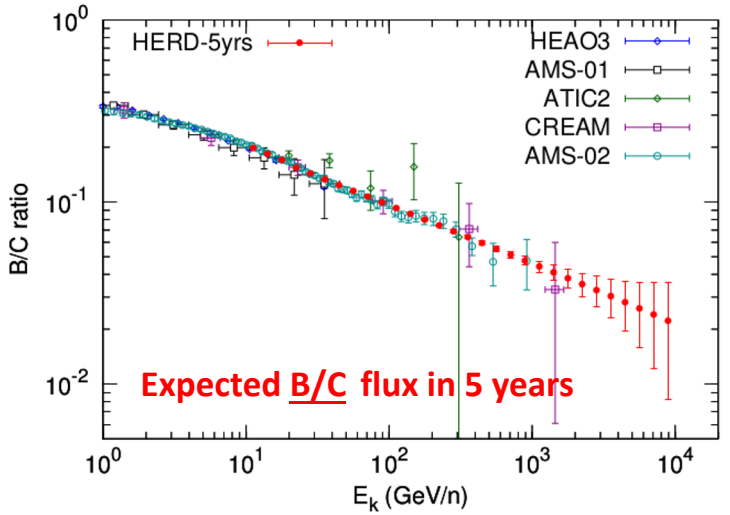
2) HERD observables and physics goals

Hadrons up to the knee

Acceleration and propagation studies







HERD will measure the flux of nuclei:

- p and He up to a few PeV
- heavier nuclei with (|Z| <= 28) up to a few hundreds of TeV/n

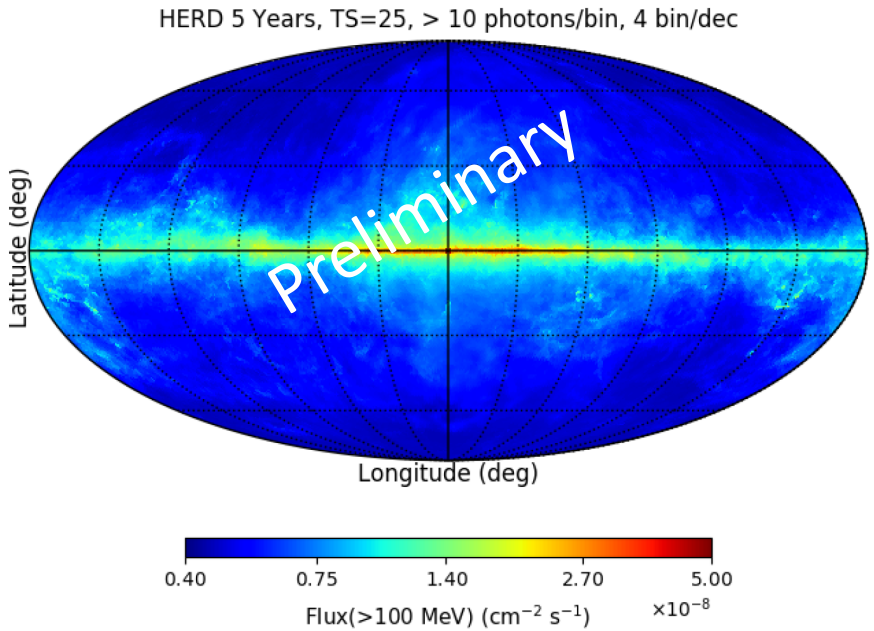
Extension of the B/C ratio to high energy will provide further insights into the propagation mechanisms of cosmic rays

3) HERD observables and physics goals

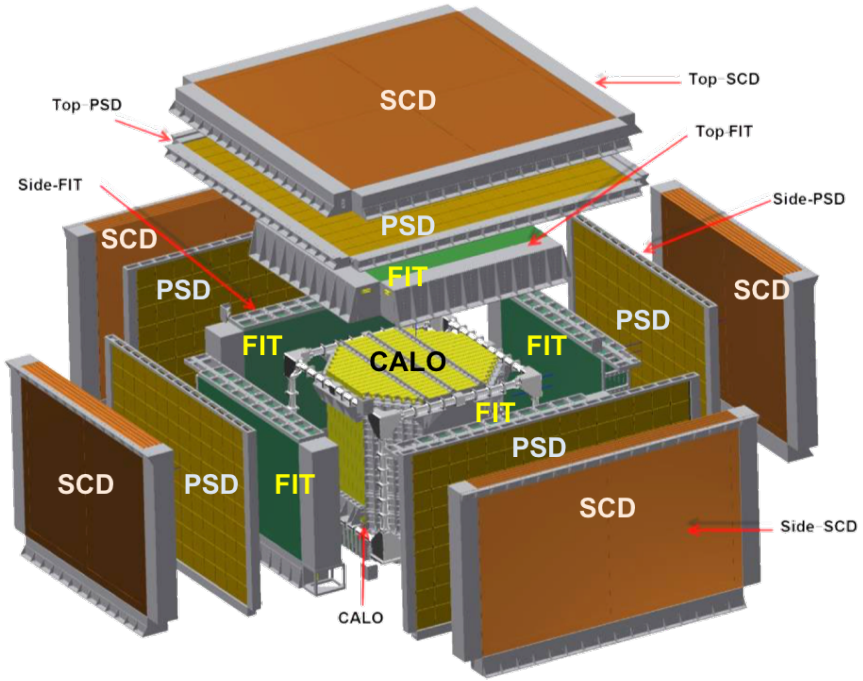
Gamma rays from 100 MeV

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

- study of galactic and extragalactic γ sources
- study of galactic and extragalactic γ diffuse emission
- extend Fermi-LAT catalog to higher energy (> 300 GeV)
- search for indirect dark matter signatures



The HERD detector



- To maximize the acceptance: novel "isotropic" design with a 3D calorimeter + a sector of FIT+PSD+SCD on 5 sides.

Needed: **particle identification**, **energy** and **direction** measurements.

CALO: CALOrimeter (55 X_0)

- Energy measurement
- Electron/proton separation

FIT: FIber Tracker (5 sides)

- Track reconstruction
- Low-energy γ–ray conversion (γ → e^+ e^-)
- Charge measurement (|Z|)

PSD: Plastic Scintillator Detector (5 sides)

- Charge measurement (|Z|)
- γ–ray identification (fast veto < 200 ns)

SCD: Silicon Charge Detector (5 sides)

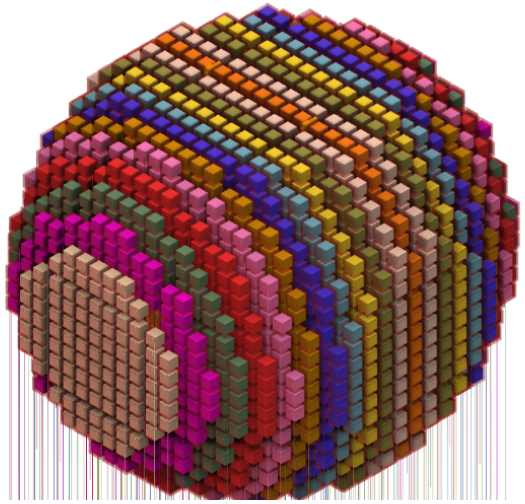
- Charge measurement (|Z|)
- Track reconstruction

TRD: Transition Radiation Detector (1 side)

- Energy calibration of CALO for TeV nuclei

Calorimeter (CALO)

CALO consists of about **7500 LYSO cubes** with edge length of 3 cm arranged into a spherical shape.

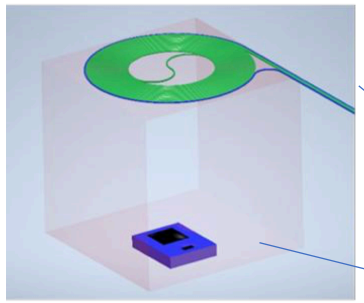


Deep homogeneous ($55\ X_0$, $3\ \lambda_I$) → **High energy** and good **energy resolution**

Isotropic 3D → **Large geometric factor**

Finely segmented → **Good e/p discrimination**, reconstruction of shower starting point and shower axis

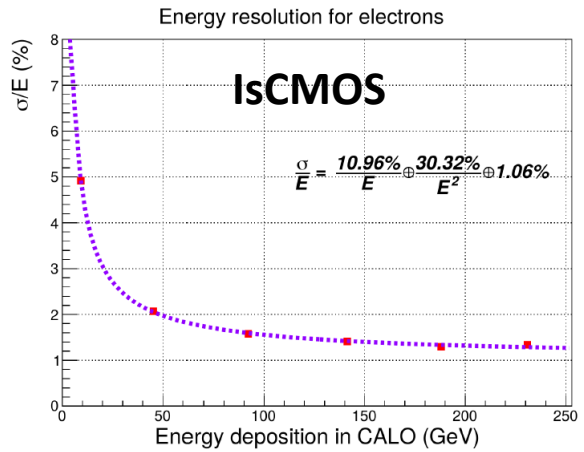
To reduce systematics (especially on the absolute energy scale), each cube is **read out by 2 systems** (redundancy, independent trigger, and cross calibration).

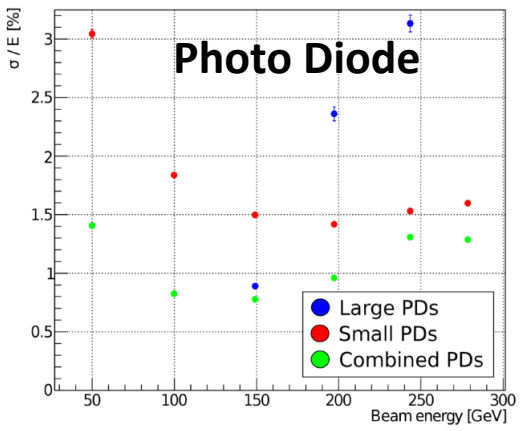


Wavelength shifting (WLS) fibers read out by two Intensified scientific CMOS cameras

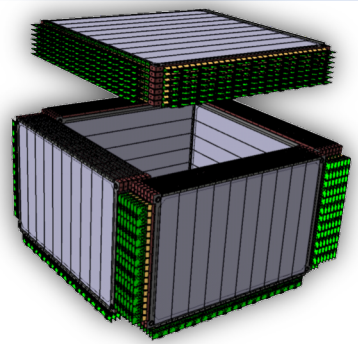
2 Photo-diodes (PD)

Energy resolution
Beam test **electrons**

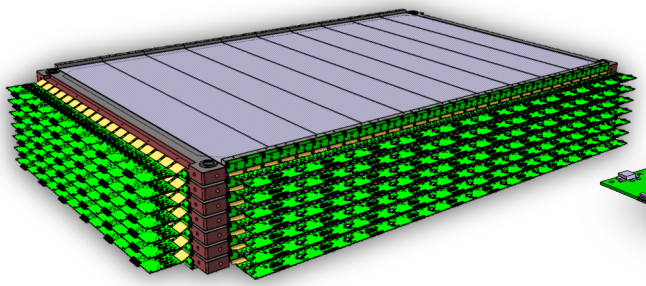




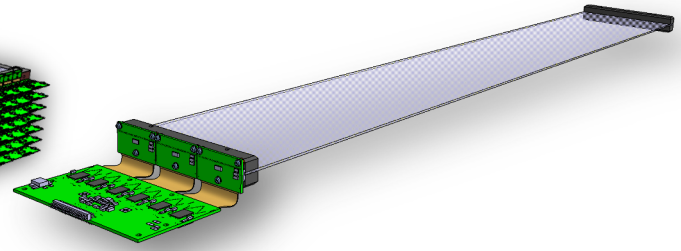
Fiber Tracker (FIT)



FIT = 5 sectors



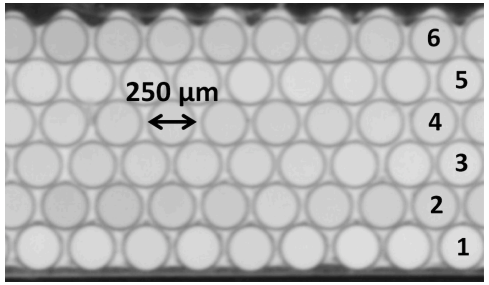
Sector = 7 x-y tracking planes

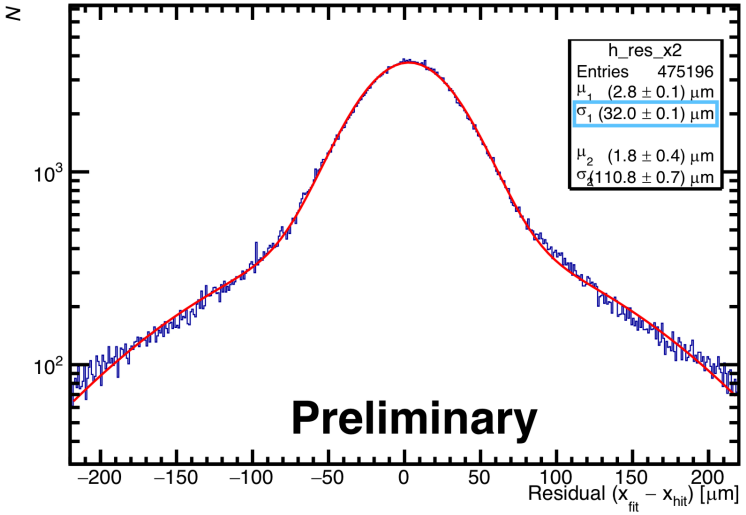


Module = 1 fiber mat + 3 SiPM arrays

Total: ~600 fiber mats
> 225k read-out channels

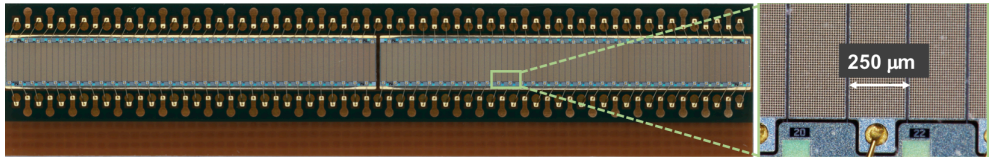
- Fiber mat: 6 layers of fibers
- Fiber type: **KURARAY SCSF-78MJ**
  - round section with diameter = 250 μm
- Mat width ≅ 97.80 mm to match 3 SiPM arrays



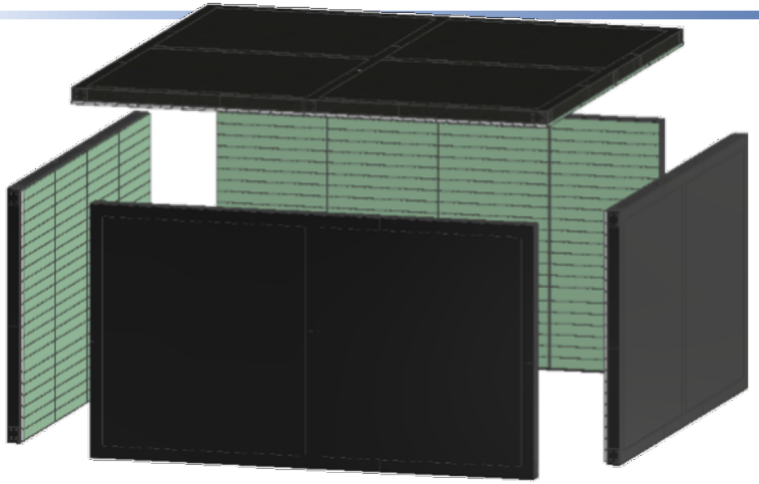


Spatial resolution = (32.0 ± 0.1) μm

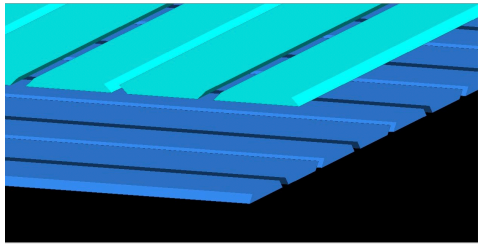
- SiPM array (S13552-10): 128 channels
- Channel size: 230 μm × 1630 μm
- Pixel size: 10 μm × 10 μm
- 23 x 163 pixels/channel
- Pitch: 250 μm



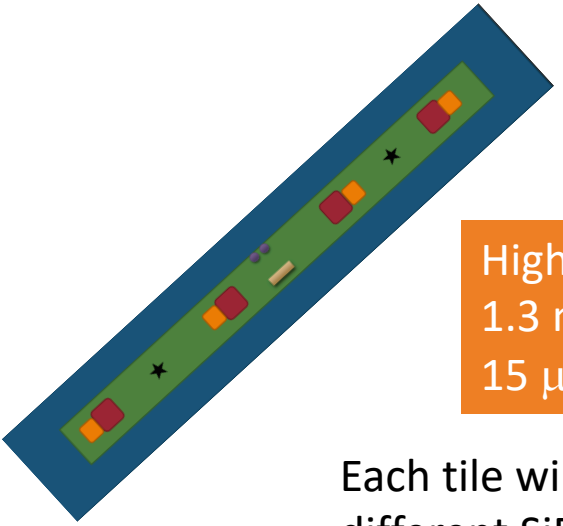
Plastic Scintillator Detector (PSD)



Sector = 1 x-y layers of trapezoidal plastic scintillating tiles to increase the hermeticity and the VETO efficiency.



Total number of tiles: ~1000

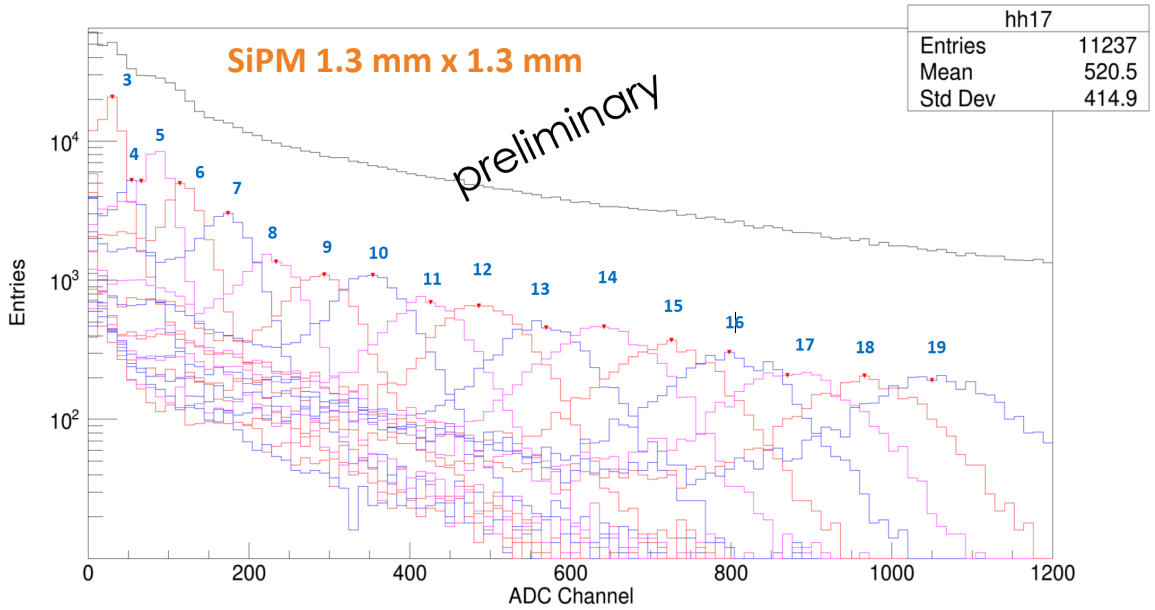


Low-Z SiPM
3 mm x 3 mm channel
50 μm x 50 μm pixel

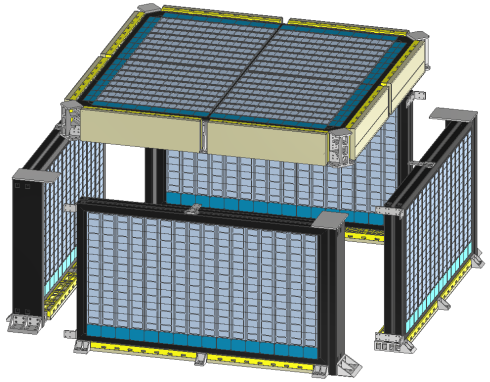
High-Z SiPM
1.3 mm x 1.3 mm channel
15 μm x 15 μm pixel

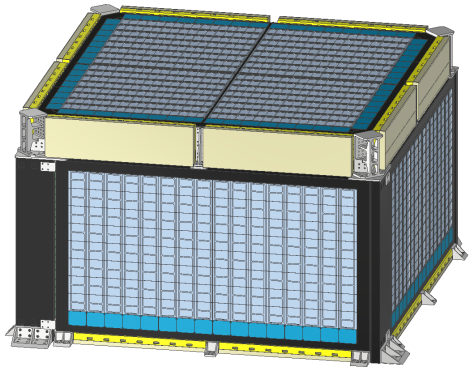
Each tile will be read out by 2 different SiPMs to increase the light detection efficiency and the dynamic range for nuclei identification.

Fragments produced by **Pb beam 150GeV/n on Be target**

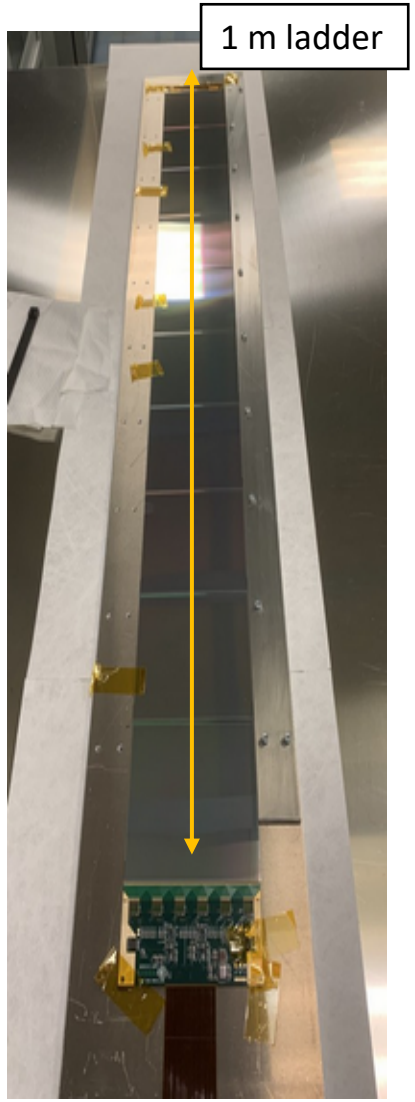


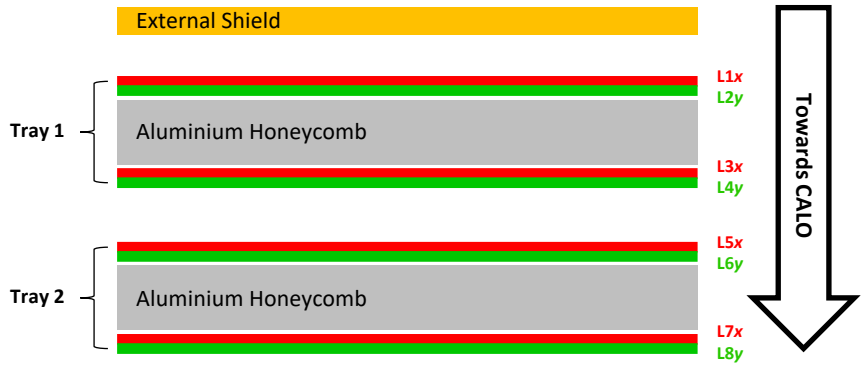
Silicon Charge Detector (SCD)

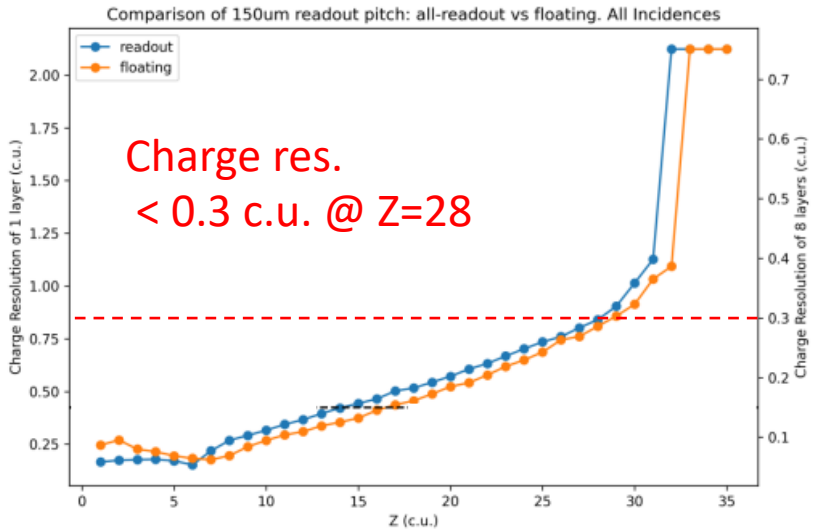




- **Silicon strip detector.**
- **Sector** = 4 double side x-y layers → 8 independent. ionization measurements → Z =1 to 28.
- 10 silicon strip detectors (SSDs) bonded in a row.
- Customized SSD and ASIC for large dynamic range.
- The **outermost** detector to verify the nuclei fragmentation.

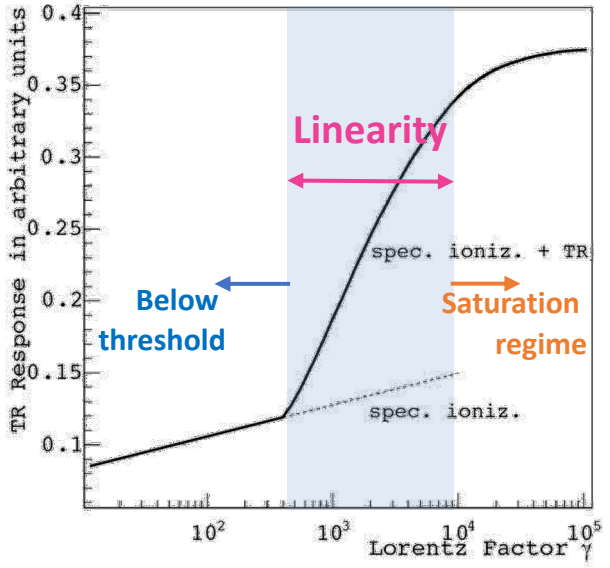






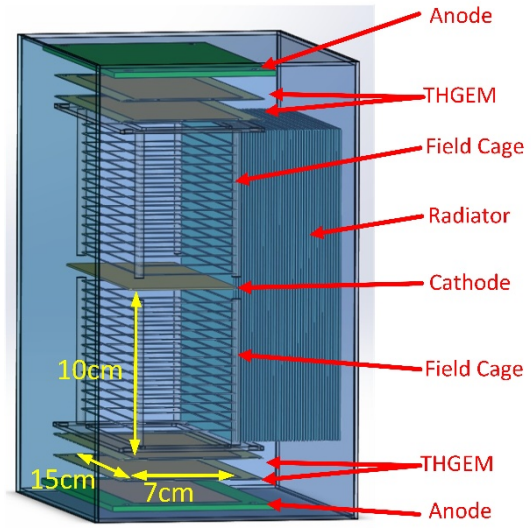
Transition Radiation Detector (TRD)

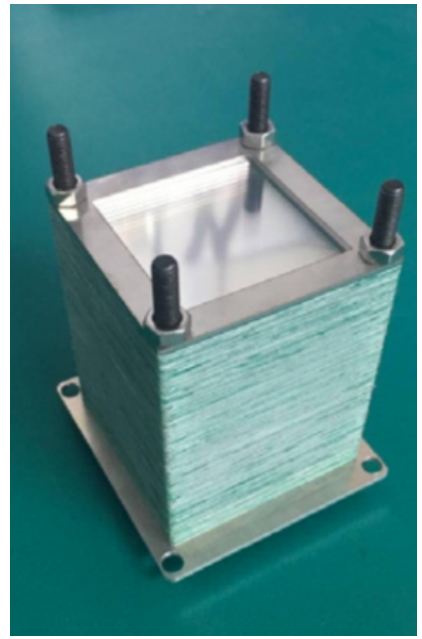
The TRD, installed on one lateral face of the detector, is needed to **calibrate the response of the calorimeter to high-energy hadronic showers**.



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

- Electrons: 0.5 GeV $< E_e <$ 5 GeV
- Protons: 1 TeV $< E_p <$ 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)

Radiator:

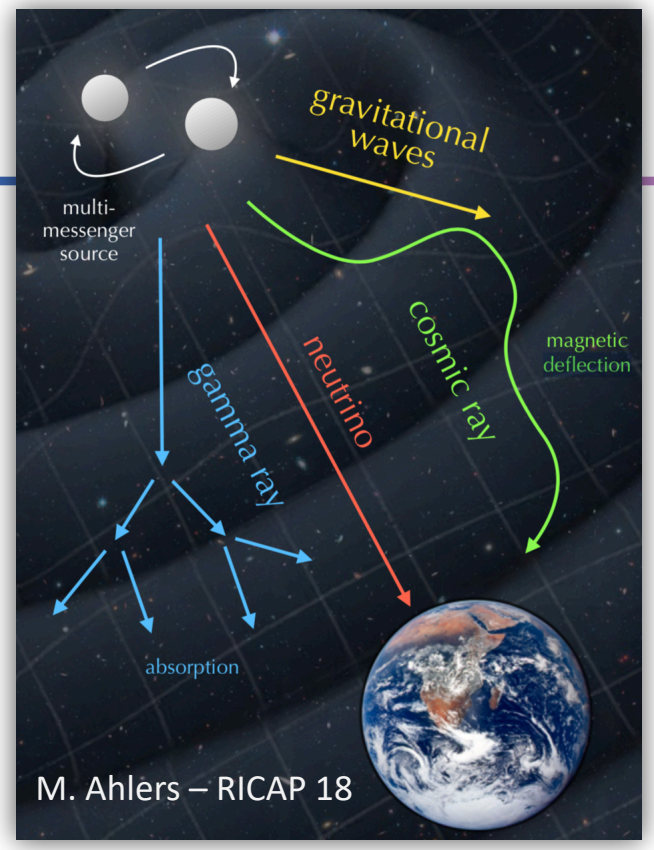
- multi-layer Polyimide thin foils

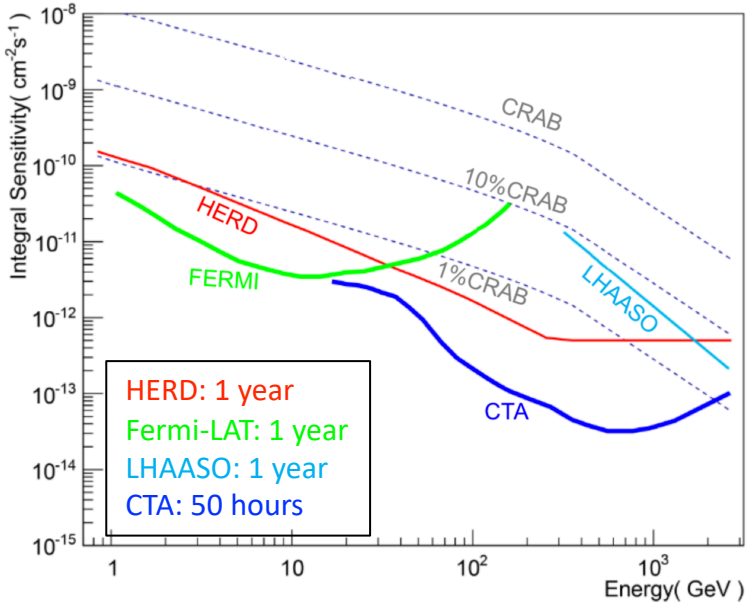
Detector:

- 1 atm Xe
- side-on THGEM (THick Gaseous Electron Multiplier)

Multi-messenger astronomy

- HERD with its unusual large **field of view** and unique **energy coverage** will play a unique and complementary role in
  - multi-wavelength studies across the electromagnetic spectrum with other space and ground telescopes involving radio, optical, X-ray, γ-ray
  - search for electromagnetic counterpart of gravitational waves and of neutrinos (IceCube, KM3Net).
- HERD will produce alerts: AGN, novae, binary systems, …





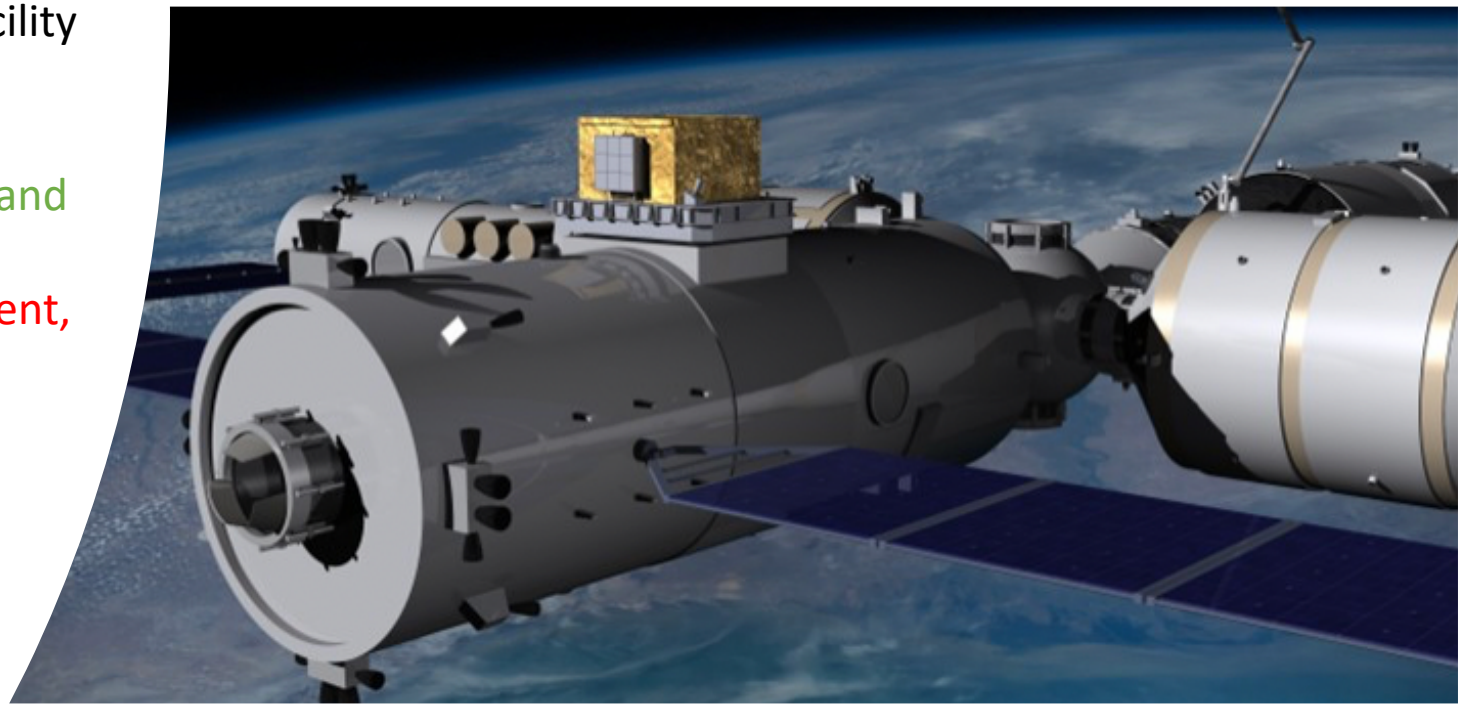
HERD + CTA + LHAASO

- Simultaneous coverage of the same sources from few GeV to 1 PeV
- Overlap of measured spectra
  - ➢ Distinguish diffuse emission from localized contributions, to disentangle acceleration and propagation mechanisms in SNRs, PWN, pulsars, and in more extended objects as the Fermi bubbles.
  - ➢ Study transient phenomena, which is crucial to analyse the properties of jets, and can help determining the extragalactic background light, intergalactic magnetic fields, and the validity of the Lorentz invariance.

Summary and outlook

- HERD will be a calorimetric detector with unprecedent acceptance, launched and installed on the CSS in 2027.
- Frontier scientific goals in cosmic ray physics, gamma-ray astronomy, and dark-matter search.
- HERD could become the only space-borne high-energy gamma-ray detector, once the Fermi satellite will stop its operations.
- General payload-level design is completed.
  - Conceptual layout design with ergonomics consideration
  - Preliminary design on mechanical, thermal, electronics, data flow…
  - Assembly, integration and testing (AIT) facility

- Completed: Phase B : Study of key technology and key components, prototype for beam tests
- 2024 & 2025: Phase C: Space Traffic Management, Qualification Model
- 2026 & 2027: Phase D: Flight Model
- 2027: Launch
- 2027 - 2037+: data taking



Thank you!