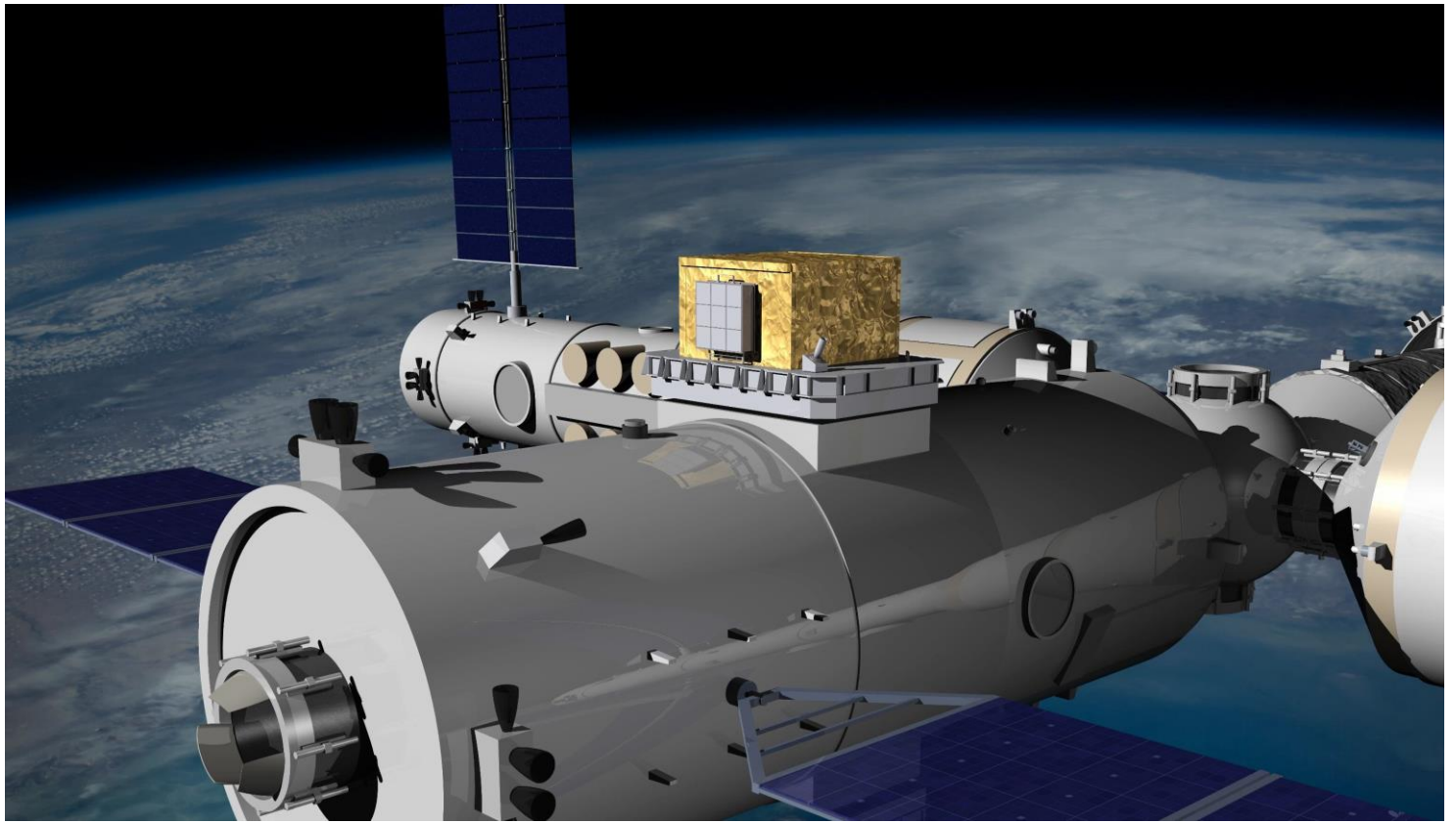
Status of the High Energy cosmic-Radiation Detection (HERD) mission

Giulio Lucchetta (IFAE-BIST)
glucchetta@ifae.es
on behalf of the HERD collaboration

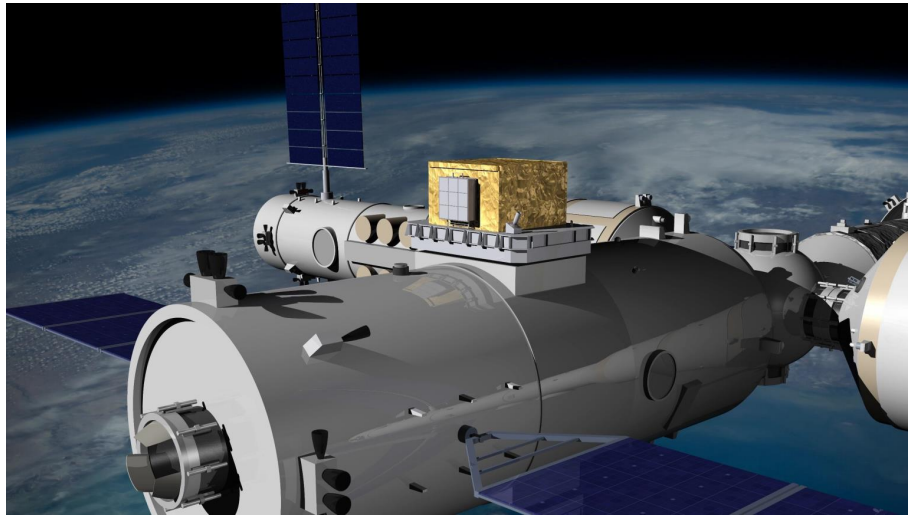


TeV Particle Astrophysics (TeVPA)
Chicago, 26–30 August 2024

IFAE Institut de Física d'Altes Energies
BIST Barcelona Institute of Science and Technology

HERD experiment

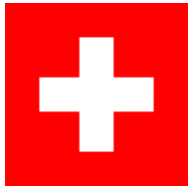
- ✓ The **H**igh **E**nergy cosmic-**R**adiation **D**etection facility (**HERD**) is a space-borne cosmic-ray and gamma-ray telescope.
- ✓ Flagship experiment on-board the China's Space Station (CSS).
- ✓ Installation around 2027, operating for at least 10 years.
- ✓ International collaboration: 270+ scientists from China, Italy, Spain and Switzerland.



IHEP, XIOPM, GXU, SDU, SWJTU, CCNUU, SDU, PMO, USTC, YNAO, NVT, HKU

University and INFN of Bari, Lecce, Firenze, Pisa, Bologna, Pavia, Perugia, Napoli, Roma, Trieste, l'Aquila, GSSI

CIEMAT- Madrid, IFAE – Barcelona, ICCUB -Barcelona

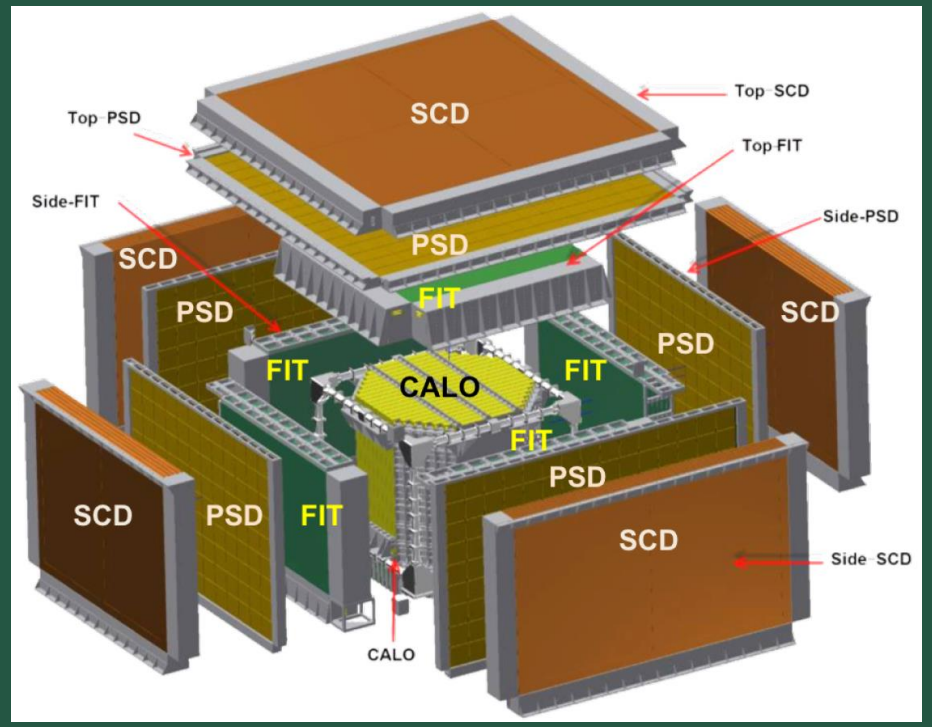


University of Geneve, EPFL - Lousanne

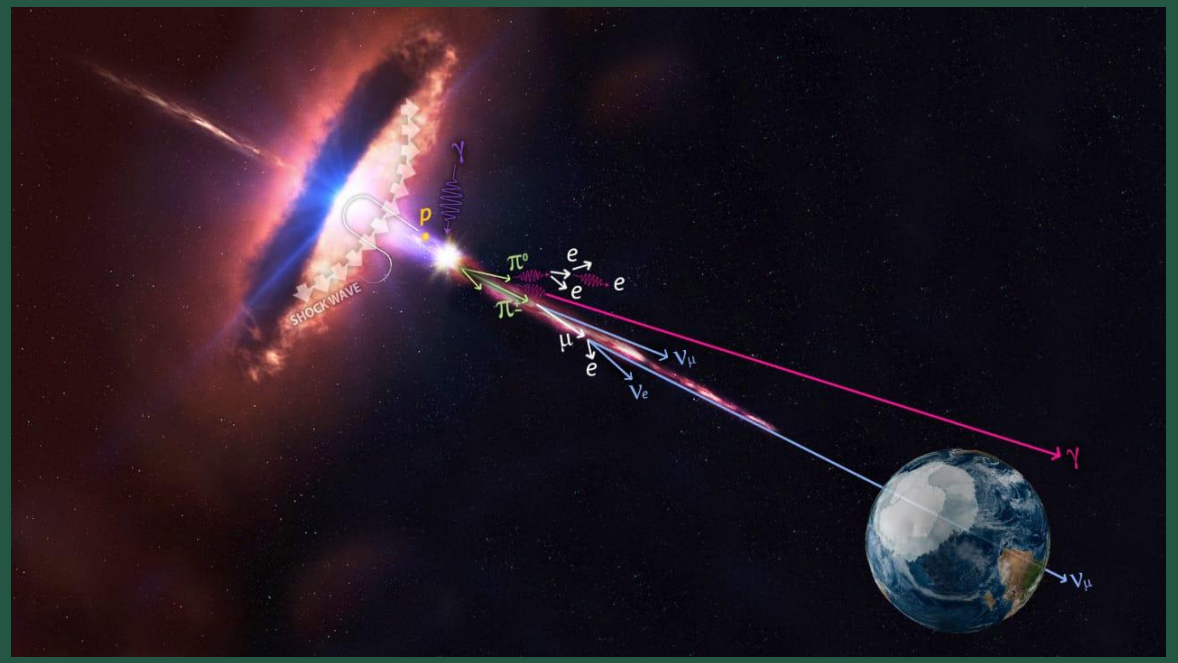
HERD on CSS

Orbit	LEO, ~400 km
Inclination	42°
Lifetime	> 10 years
Mass	< 4 t
Power	~ 1.5 kW
Telemetry	100 Mbps

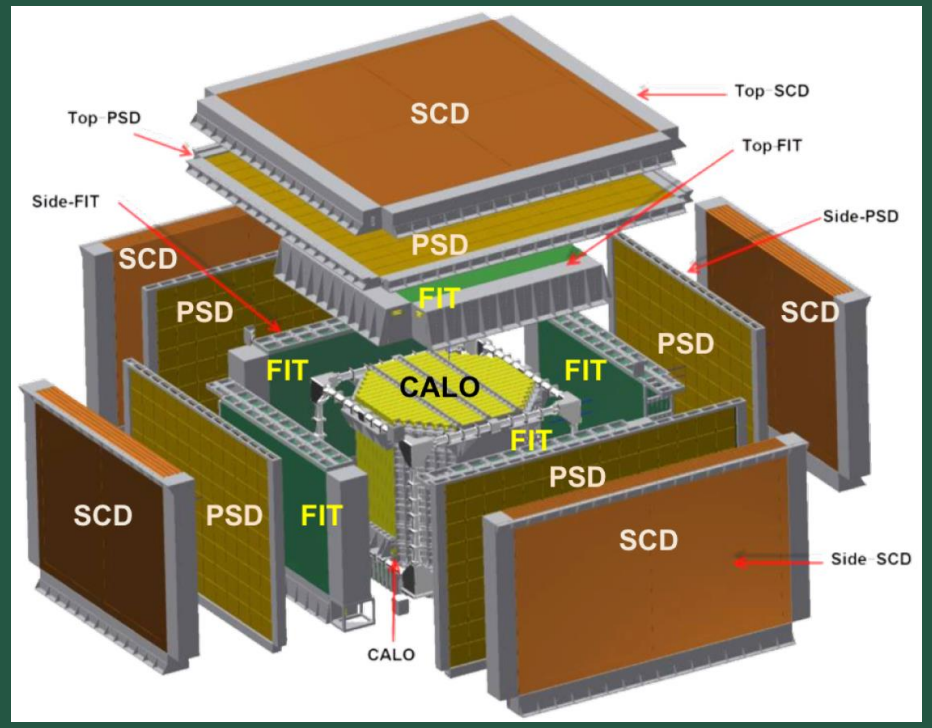
Instrument



Science goals



Instrument

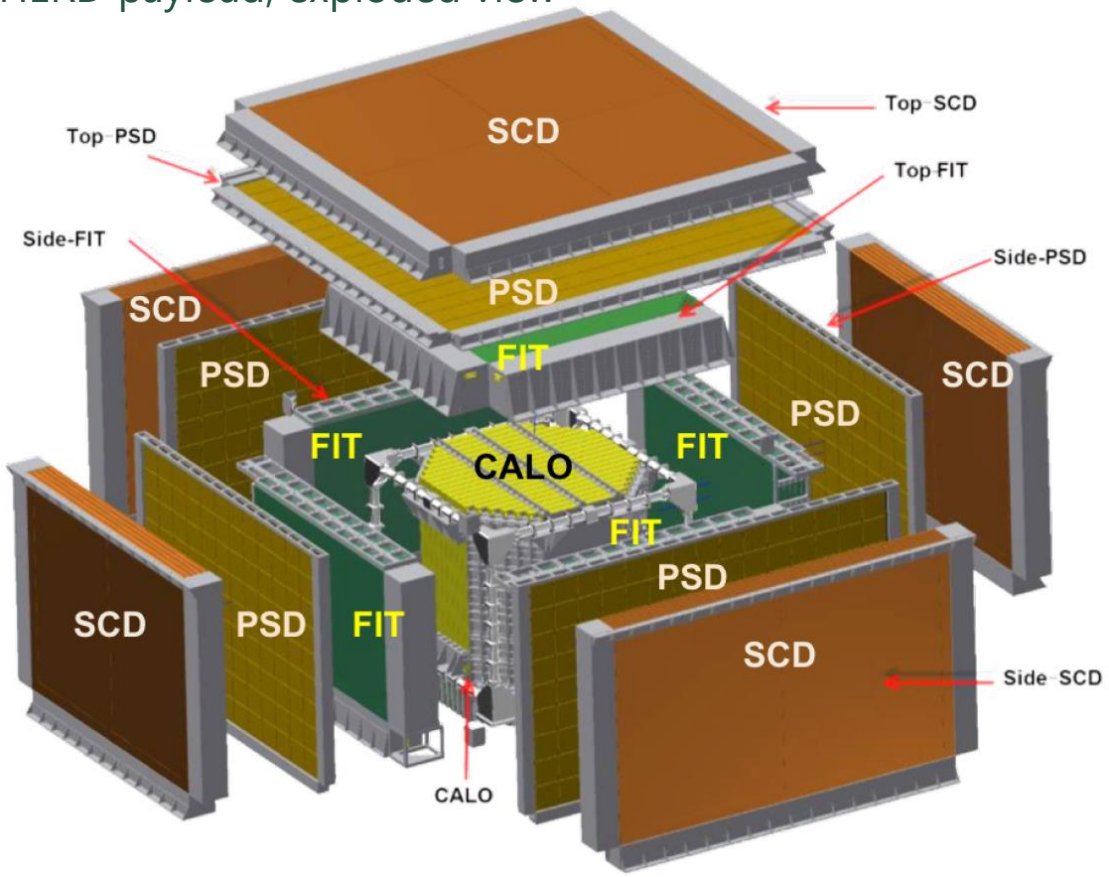


- ✓ HERD payload.
- ✓ Highlight key features and technologies of each sub-detector.
- ✓ Results from prototypes tested in several test beam campaigns from 2015 to 2023.

Test beam set-up at CERN

HERD payload

HERD payload, exploded view

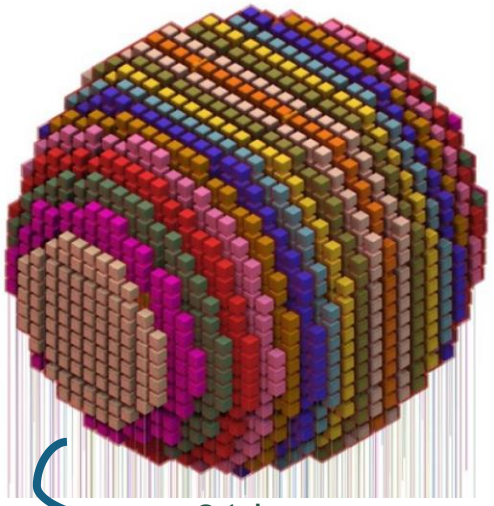


Calorimeter (CALO)	✓ Energy reconstruction ✓ e/p separation
Fiber tracker (FIT)	✓ γ-ray conversion ✓ Track reconstruction ✓ Charge reconstruction
Plastic scintillator detector (PSD)	✓ γ-ray identification (fast veto) ✓ Charge reconstruction
Silicon charge detector (SCD)	✓ Charge reconstruction
Transition radiation detector (TRD)	✓ Calibration of CALO for TeV nuclei

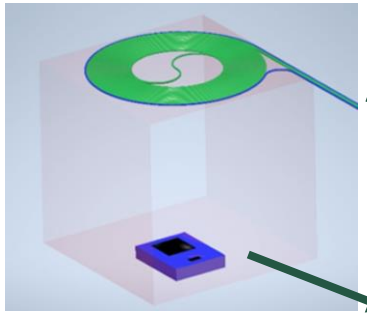
Maximize telescope's acceptance: isotropic 3D calorimeter surrounded by FIT+PSD+SCD on 5 sides: one order of magnitude improvement with respected previous cosmic-ray space experiments.

Calorimeter (CALO)

CALO array



21 layers
55 X_0, 3 λ_I



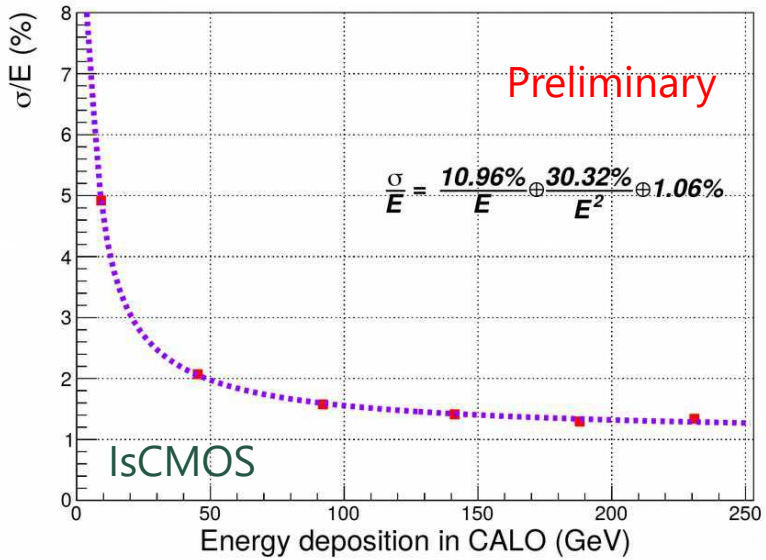
WLS + IsCMOS

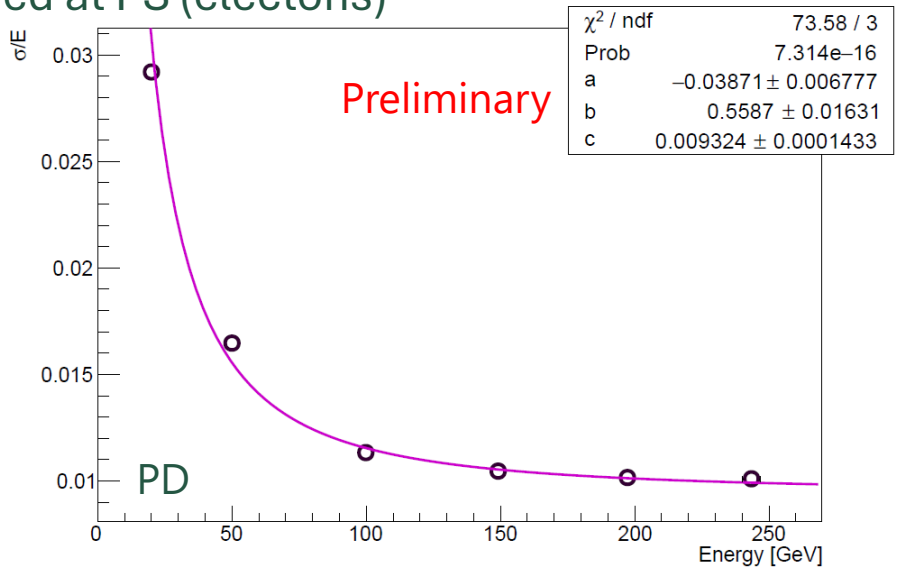
PD

CALO read-out

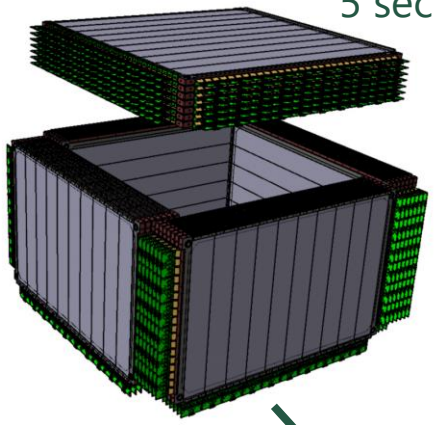
- ✓ ~7500 LYSO crystals (3cm-side cube each), 55 radiation lengths, 3 nuclear interaction lengths:
  - Isotropic 3D ⟶ high energy/good resolution;
  - Finely segmented ⟶ good e/p discrimination.
- ✓ Two independent read-out systems: ⟶ cross calibration/reduce systematics
  - WLS fibers + Intensified scientific CMOS (IsCMOS) cameras;
  - Photodiodes (PD) + custom read-out electronics.
- ✓ Energy resolution: ~20% for p, ~1% for e/γ at 200GeV.

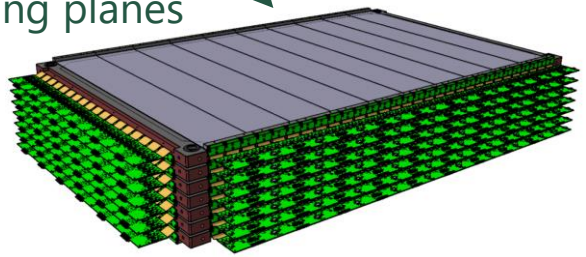
En. res. measured at PS (electons)

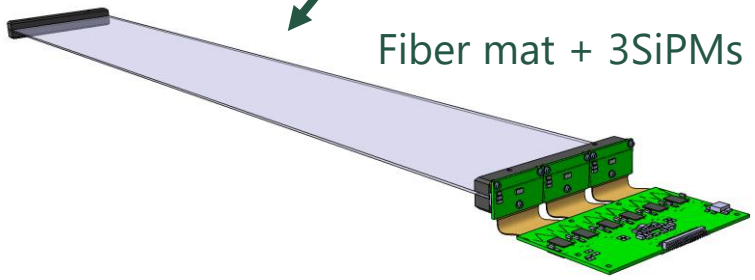




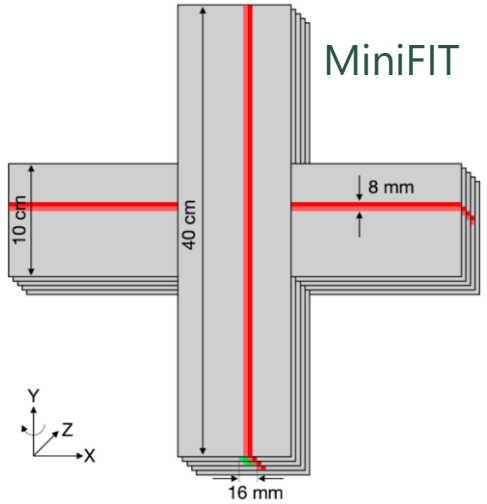
Fiber Tracker (FIT)

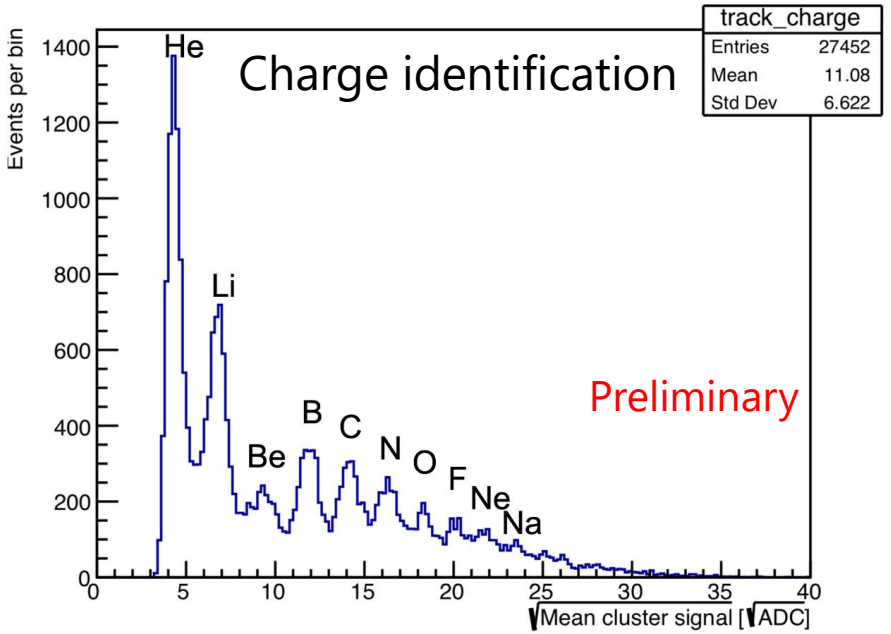




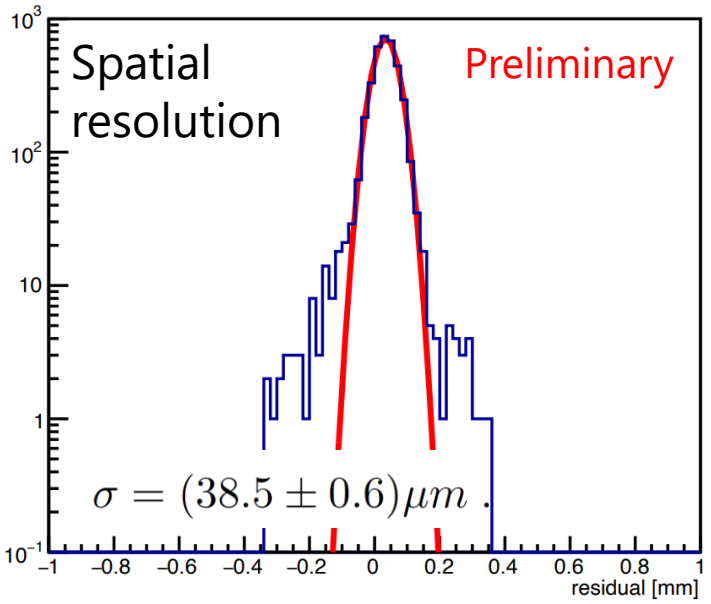


- ✓ Scintillating fibers: Kuraray SCSF-78MJ.
- ✓ Read-out: S13552-10 SiPM array + Beta ASIC.
- ✓ 588 fiber mats in total, >225k read-out channels.
- ✓ FIT prototype (miniFIT) tested at PS and SPS beam tests at CERN.

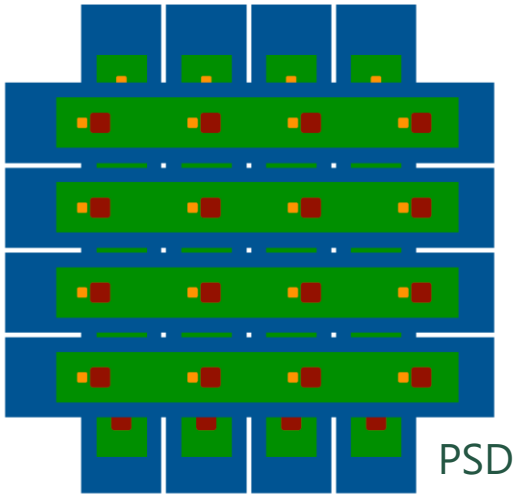




Hit residuals (X tower, layer 3)



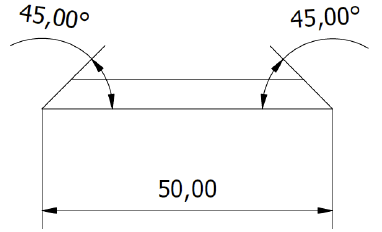
Plastic Scintillator Detector (PSD)



PSD prototype

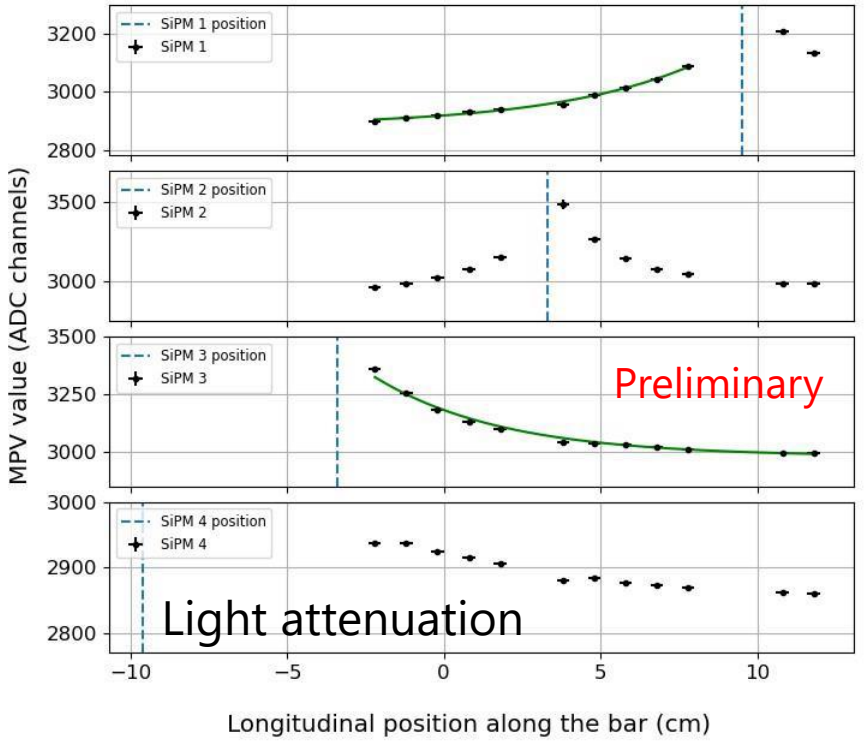
PSD bar

- ✓ 2 layers of staggered "short" bars (40cm x 5cm x 0.5cm) with trapezoidal section:
  - improve hermeticity;
  - minimize self-veto from backscattered particles.
- ✓ Read-out: 2 sets of SiPMs ("low-Z"/"high-Z") + Beta ASIC, ensuring:
  - high triggering efficiency;
  - wide dynamic range.

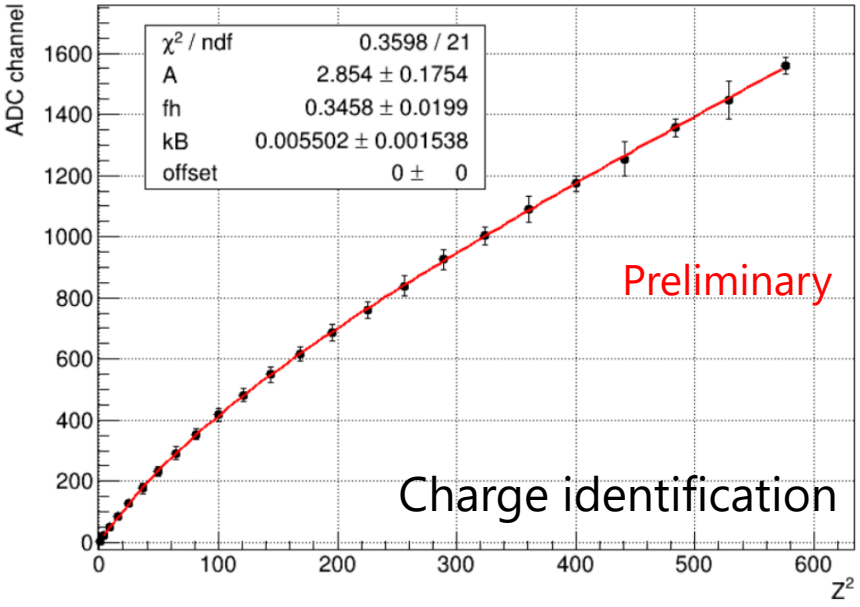


"High-Z" SiPMs (S14160-1315):
1.3mm x 1.3mm
15µm x 15µm cell size

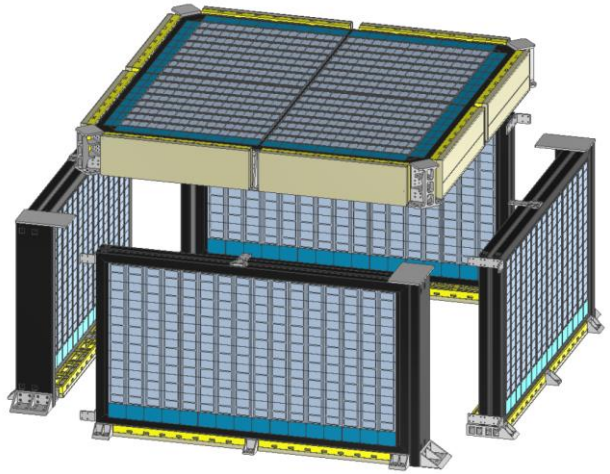
"Low-Z" SiPMs (S14160-3050):
3.0mm x 3.0mm
50µm x 50µm cell size



Birks' law: $\frac{dL}{dx} = A \cdot \frac{(1 - f_h) \cdot \frac{dE}{dx}}{1 + k_b \cdot \frac{dE}{dx}} + A \cdot f_h \frac{dE}{dx}$

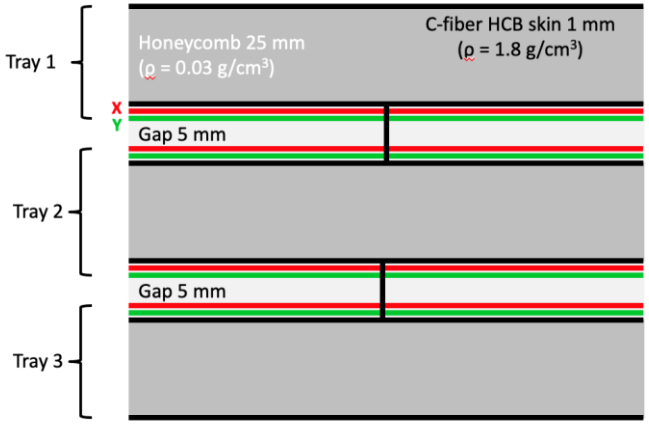


Silicon Charge Detector (SCD)

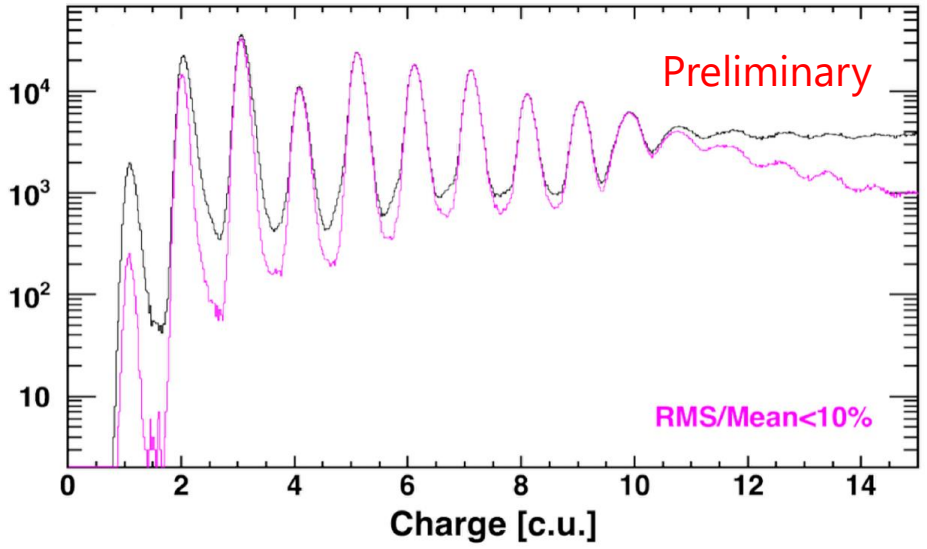


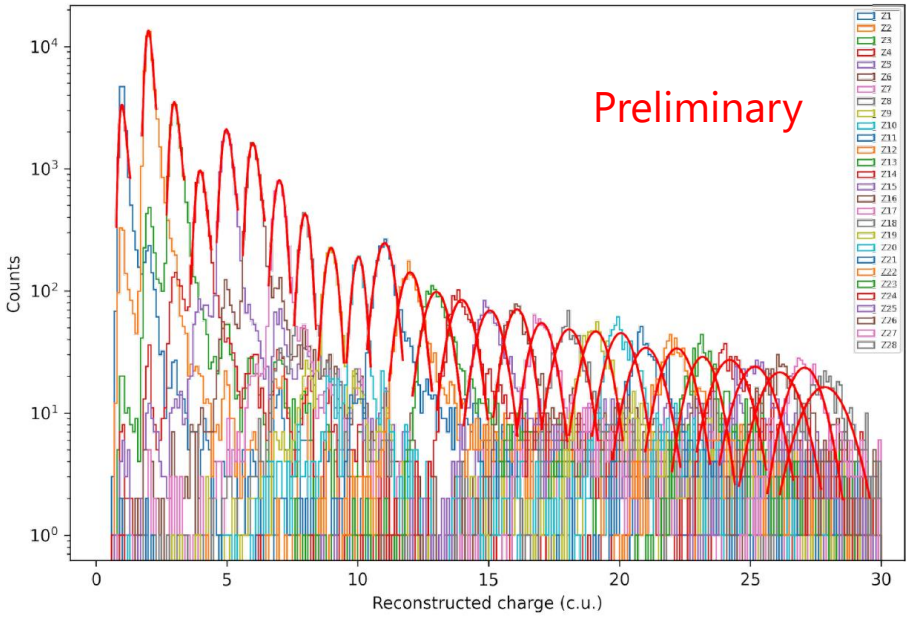
- ✓ Outermost detector, precise charge measurements (Z=1 to 28).
- ✓ 4 double x-y layers of single sided Silicon Strip Detectors (SSDs).
- ✓ SCD ladder: 10 SSDs daisy-chained together.
- ✓ SSD size: 9.5cm x 9.5cm.
- ✓ Detector prototypes of different thickness (300μm/150μm), strip pitch and read-out techniques have been tested.

SCD layout



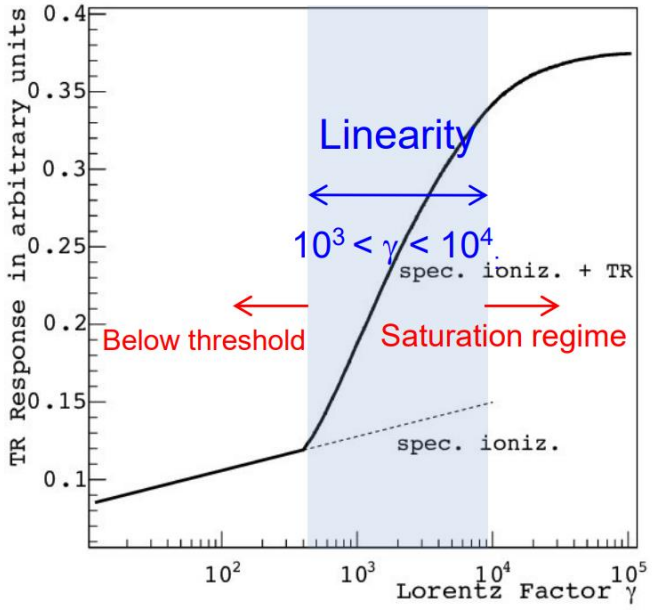
Charge identification





Transition Radiation Detector (TRD)

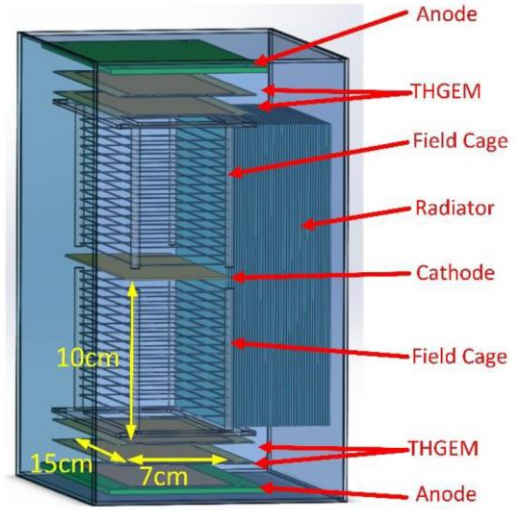
- ✓ Installed on one lateral side; calibrate the CALO response for high energy particles.
- ✓ Radiator: 170 layers of thin polyimide (PI) foils.
- ✓ Detector: Xenon gas + 2 side-on THGEM (thick-gas electron multiplier).

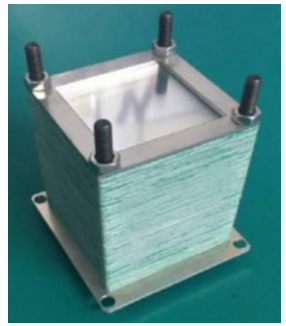


Linearity: $10^3 < \gamma < 10^4$

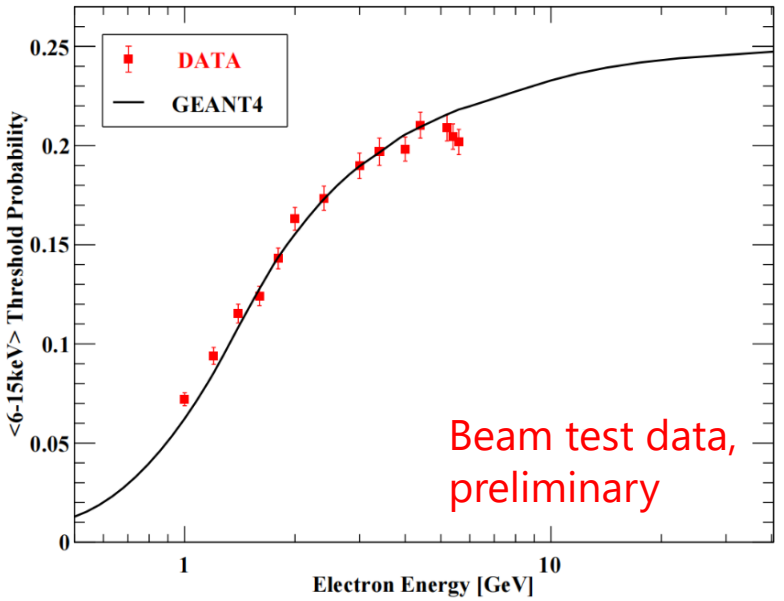
Electrons: $0.5\ GeV < E < 5\ GeV$

Protons: $1\ TeV < E < 10\ TeV$





TRD design

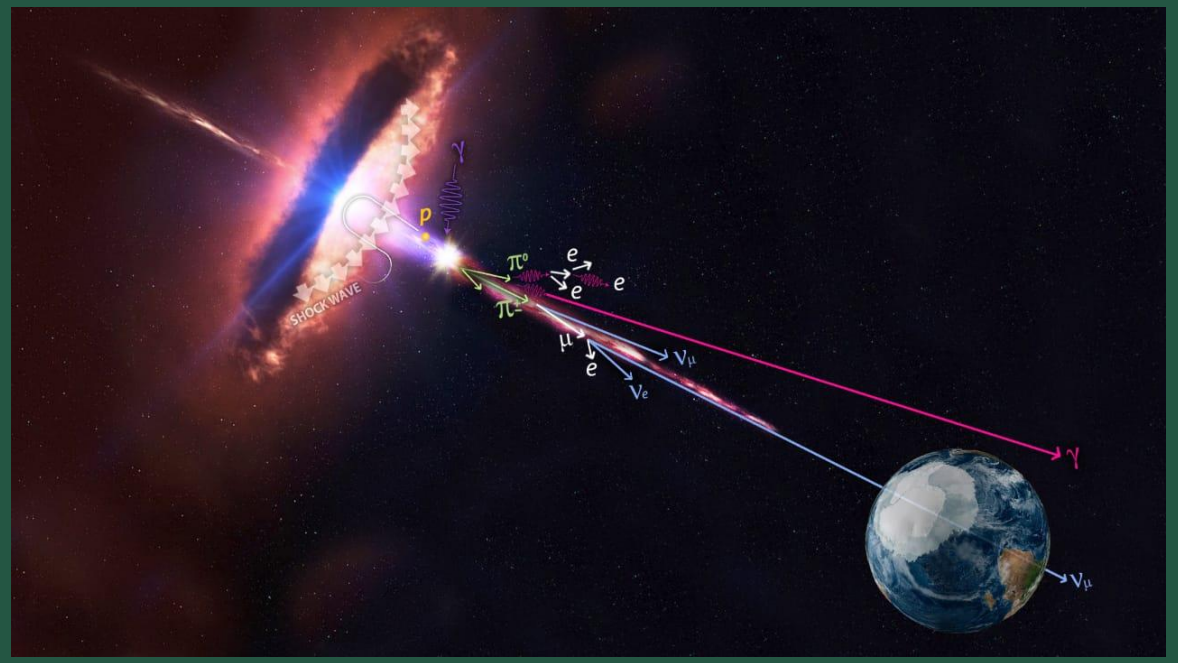


Calibration procedure:

- Calibrate TRD response with electrons in the beam tests and space.
- Calibrate CALO response with protons from TRD.

Science goals

- ✓ Present the scientific objectives of the mission.
- ✓ Highlight performance as accessed through simulations.

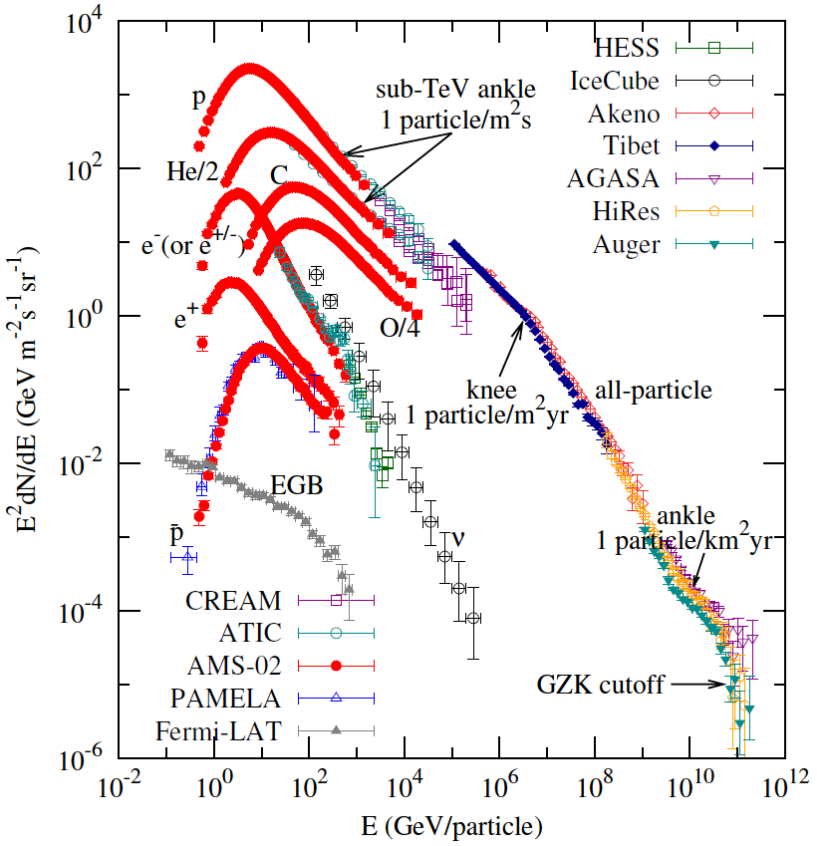


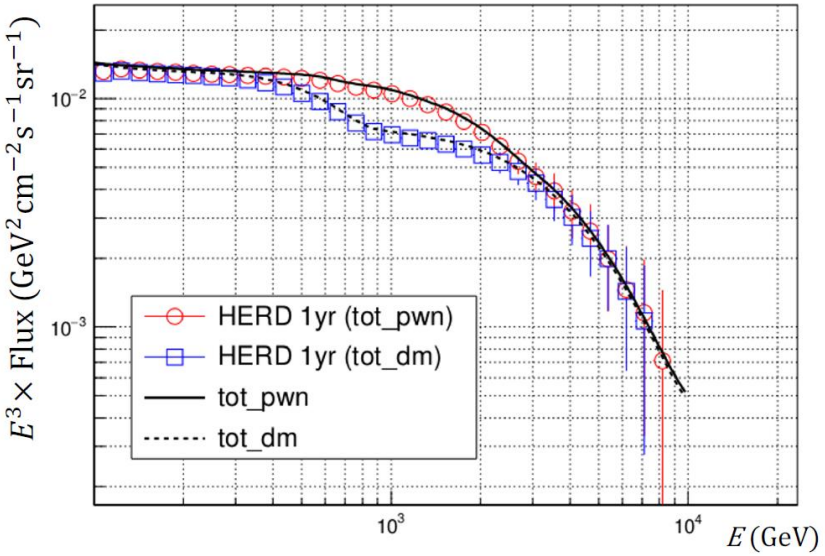
HERD scientific objectives

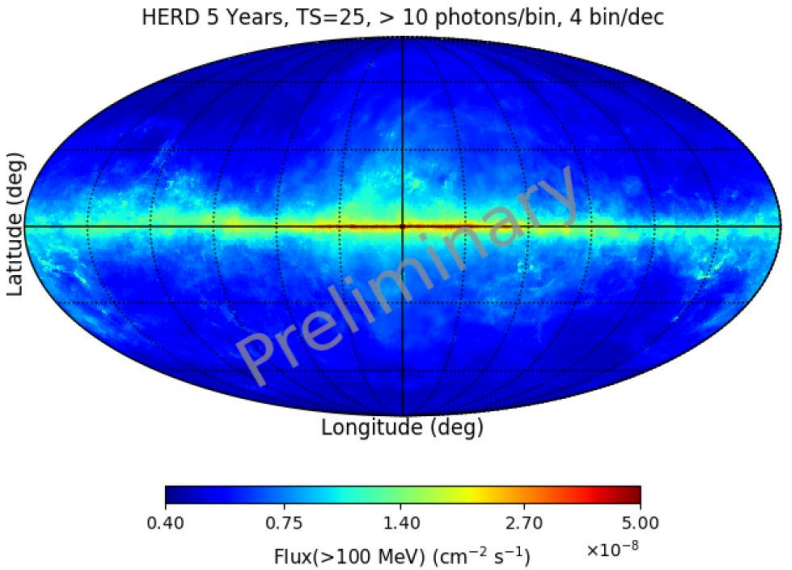
Precise measurements of cosmic-ray (CR) spectra and composition up to a few PeVs ("knee" region).

Dark matter (DM) searches from high-energy electron/positron and gamma-ray spectra.

Monitoring the high-energy gamma-ray sky at energies >100 MeV. Contribution to multi-wavelength and multi-messenger observations.





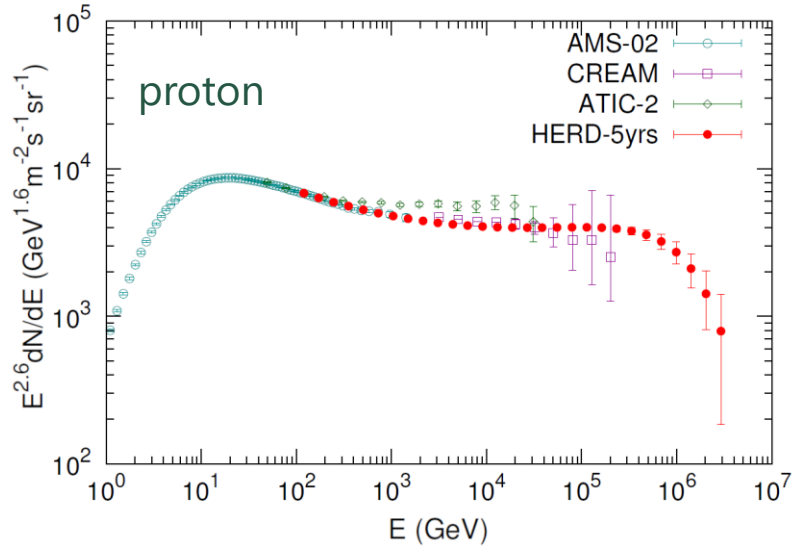


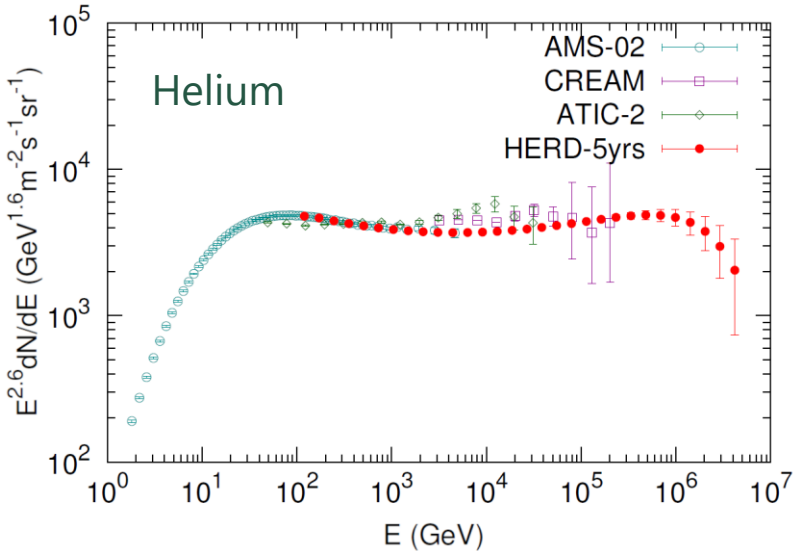
HERD science goals: protons and nuclei

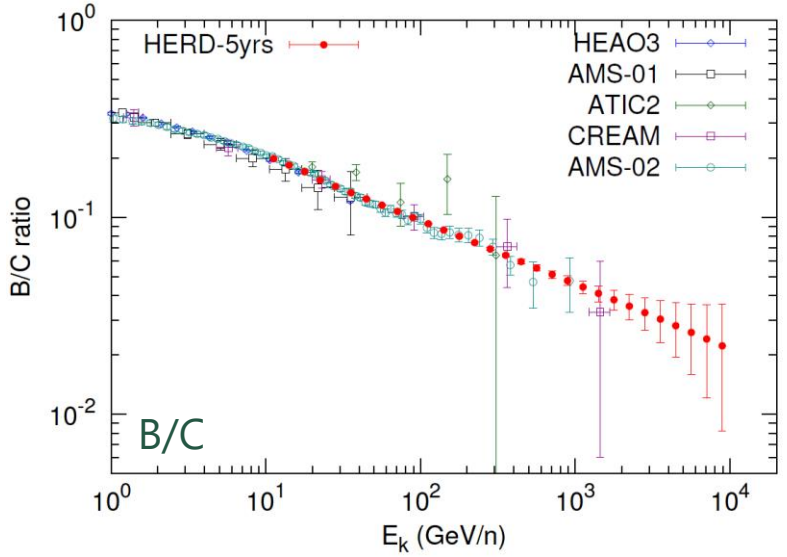
1) Measure the proton and helium fluxes up to the PeV energy range; provide the first direct measurements of the knee structure.

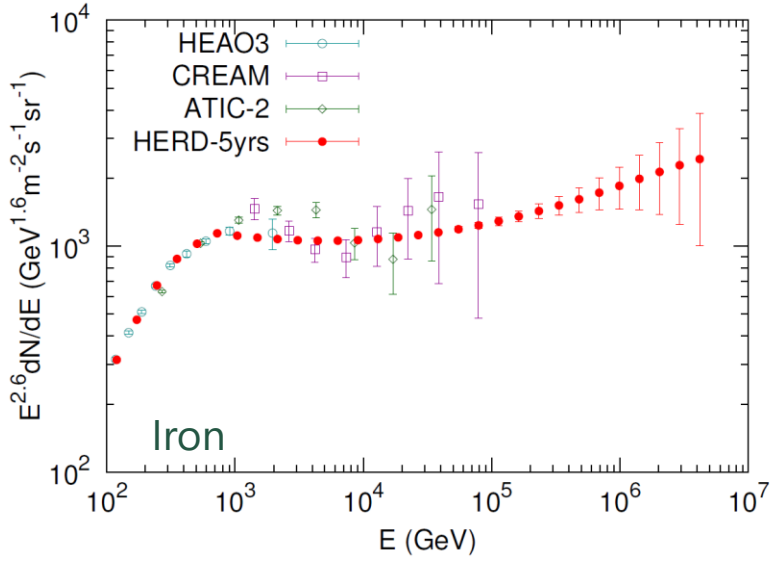
2) Extend the Boron-to-Carbon ratio measurement up to a few TeV/nucleon: further test the propagation mechanisms of CRs.

3) Strongly improve current measurements for heavy nuclei up to hundreds of TeV/nucleon.

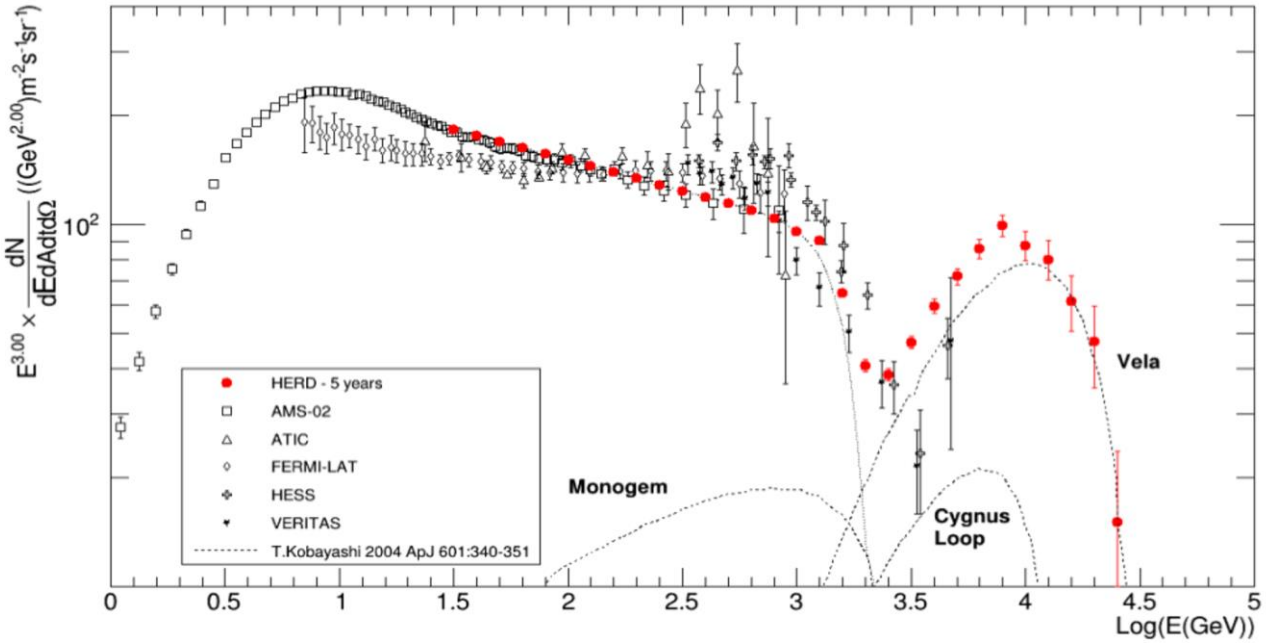


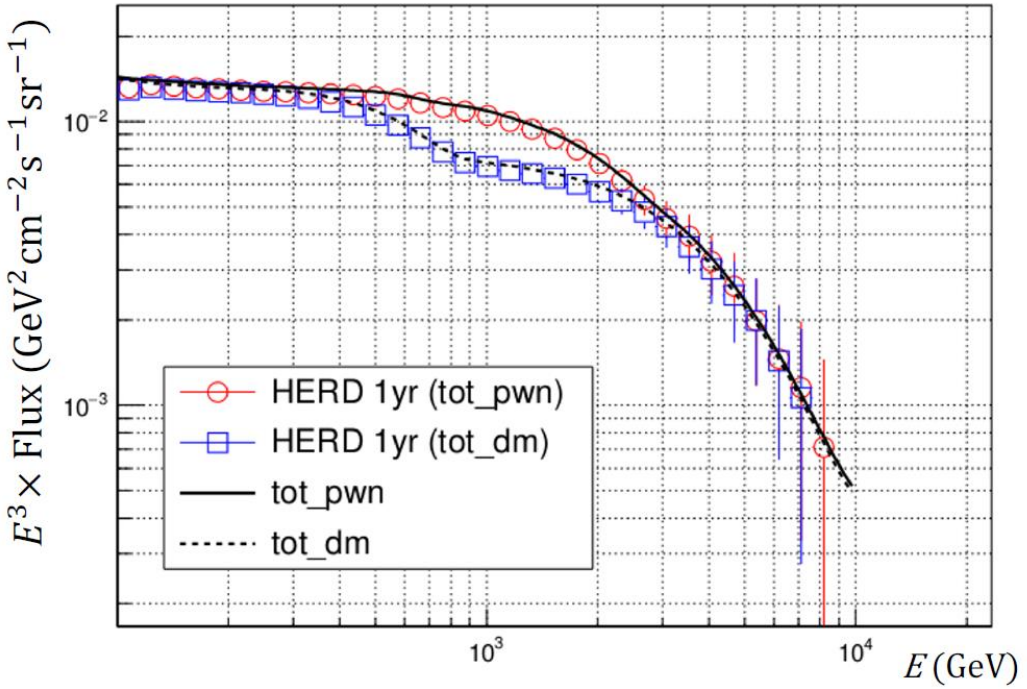






HERD science goals: electrons and positrons





Measure the all-electron flux up to several tens of TeV:

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

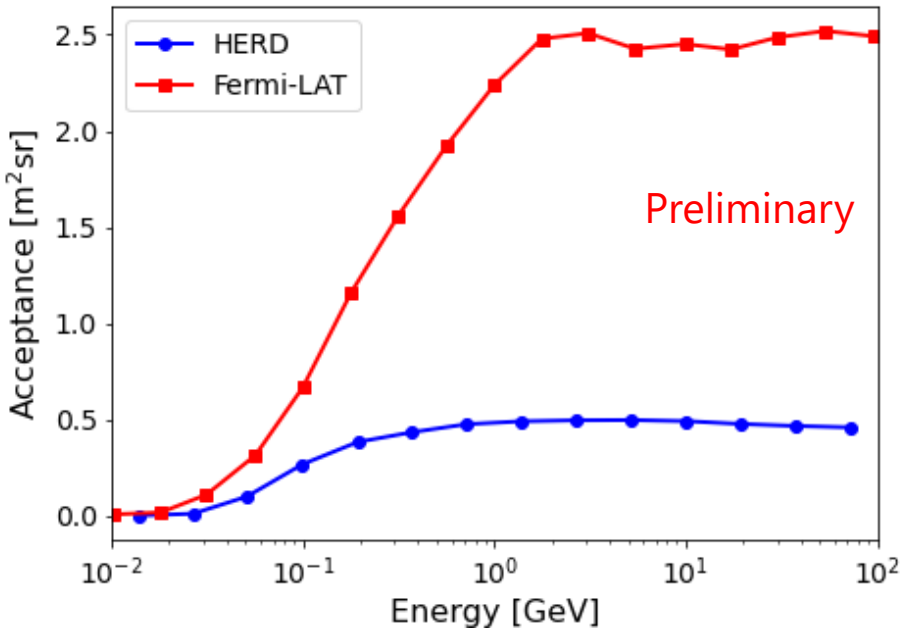
Provide important insights on the positrons excess (measured by PAMELA and AMS-02):

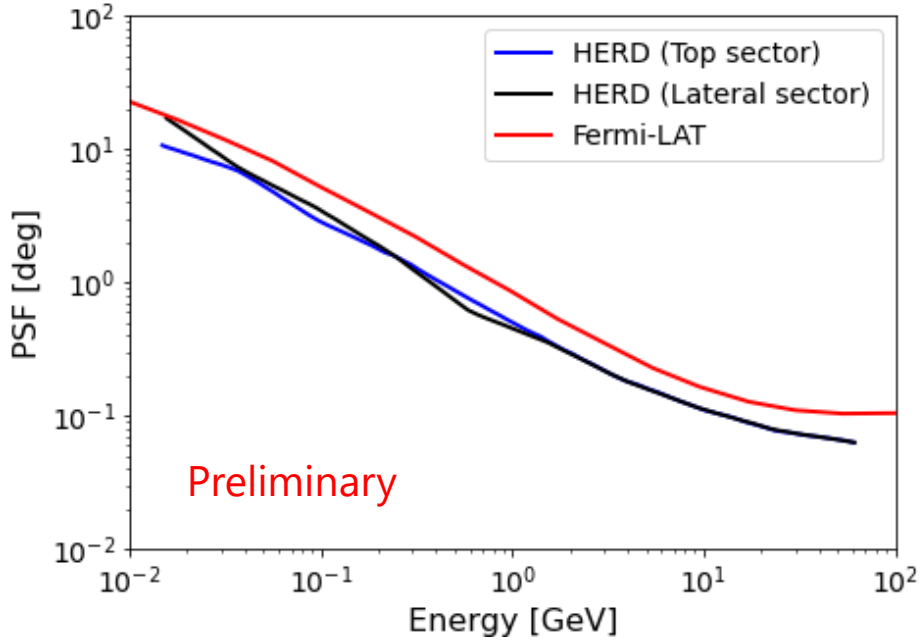
- Dark matter annihilation.
- "Canonical" astrophysical sources: nearby pulsars and PWNe.

HERD science goals: gamma rays

No high-Z conversion foils in the tracker: → lower effective area/acceptance with respect Fermi-LAT.

→ better angular resolution.

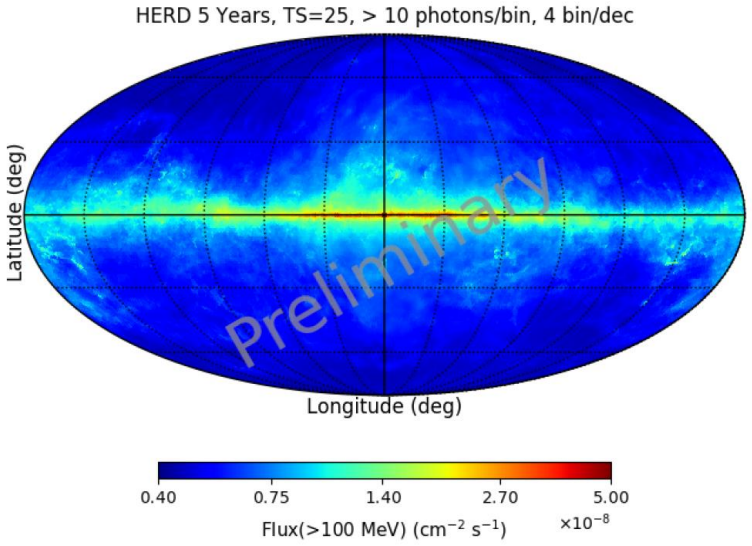


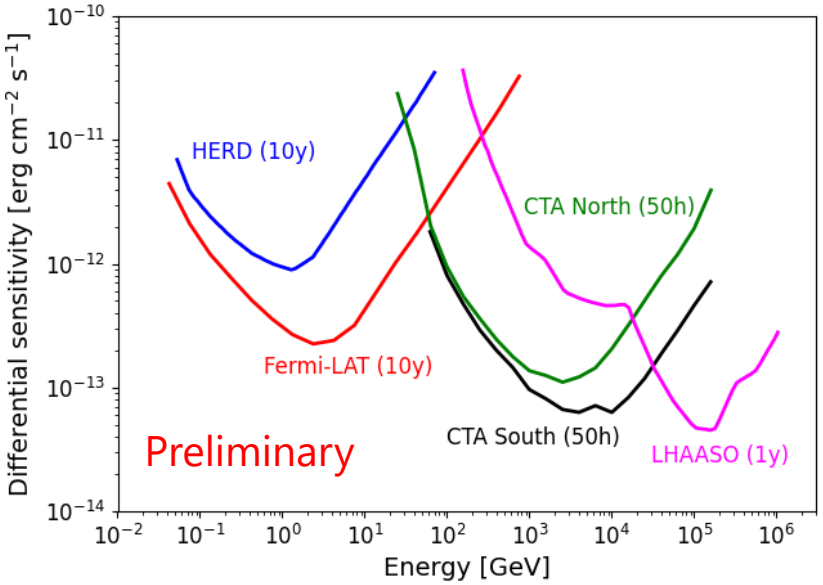


	Acceptance	PSF	Energy resolution
HERD	0.5 m^2 sr	~ 0.1° @ 10 GeV	1% @ 200 GeV
Fermi-LAT*	2.5 m^2 sr	~ 0.2° @ 10 GeV	8% @ 200 GeV

*Fermi-LAT performance from: https://www.slac.stanford.edu/exp/glast/groups/canda/lat_Performance.htm

HERD science goals: gamma rays





1) Full survey of the gamma-ray sky at energies >100 MeV:

   - Study of galactic and extragalactic sources.
   - Study of galactic and extragalactic diffuse emission.
   - Search for dark matter signatures.
   - Detection of transient events: GRBs, AGN flares, …

2) Multi-messenger astronomy:

   - Gamma-rays: synergies with ground-based observatories: CTA, LHAASO → Simultaneous coverage of the same sources from hundreds of MeVs to PeVs.
   - Neutrinos: KM3NeT, IceCube.
   - Gravitational waves: Ligo, Virgo, Kagra.

Conclusions and outlook

- ✓ China's Space Station (CSS) has been completed in 2022.
- ✓ HERD will be launched and installed on-board CSS around 2027.
- ✓ HERD will be a calorimetric experiment with unprecedent acceptance aiming to:
  - Measure with high statistics and high resolutions charged cosmic rays up to a few PeV.
  - Conduct indirect DM searches.
  - Monitor the gamma-ray sky at energies > 100 MeV.
- ✓ Performance of key technologies and sub-detector prototypes evaluated during several test beam campaigns:
  - Additional beam tests in 2024 and 2025.
  - Moving toward the production of qualification models.