GRAN SASSO SCIENCE INSTITUTE
SCHOOL OF ADVANCED STUDIES
Scuola Universitaria Superiore

INFN LNGS
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali del Gran Sasso

The High Energy Radiation Detector experiment

Leandro Silveri
On behalf of the HERD collaboration

Gran Sasso Science Institute (GSSI) and INFN LNGS, L'Aquila, Italy

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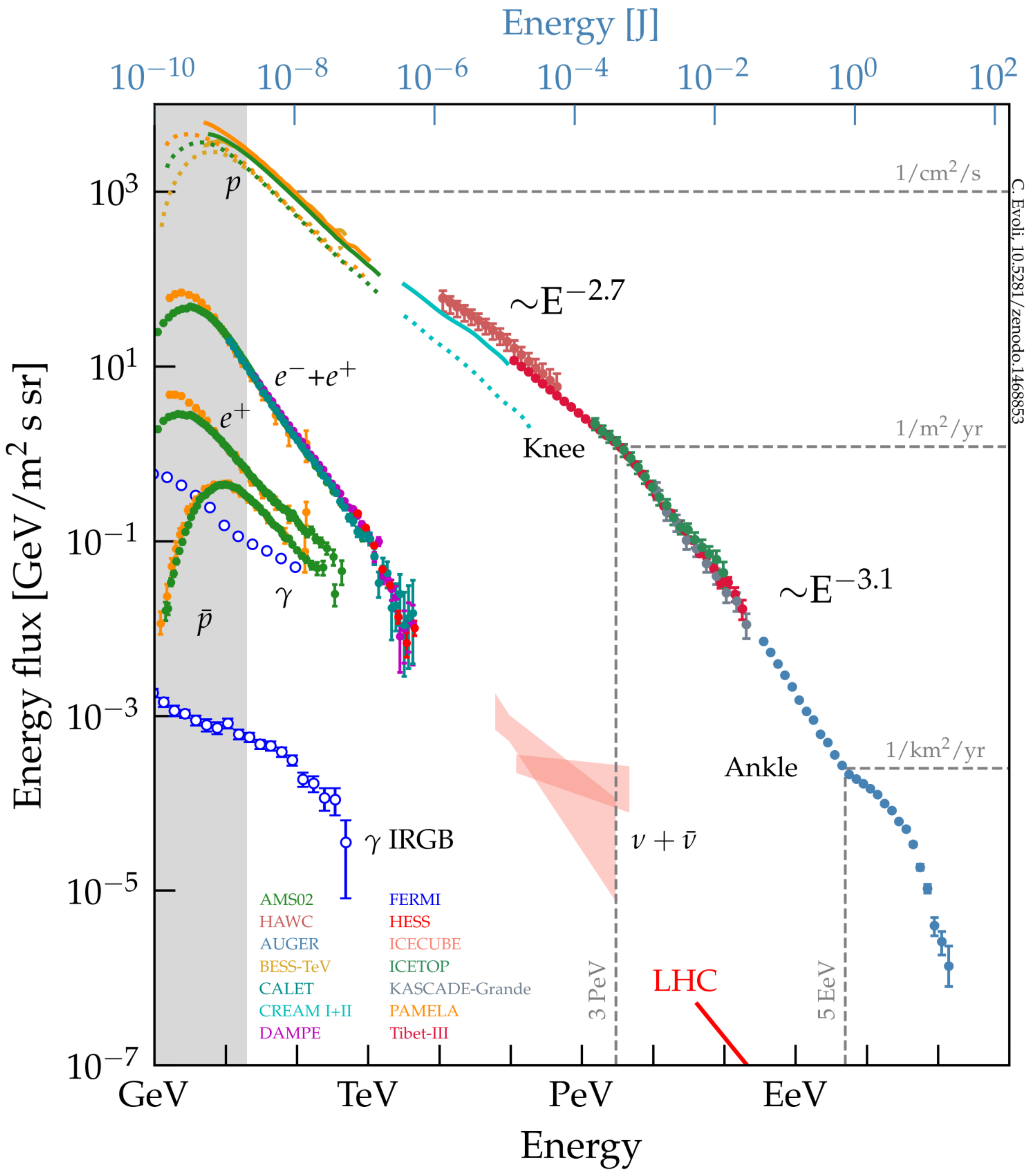
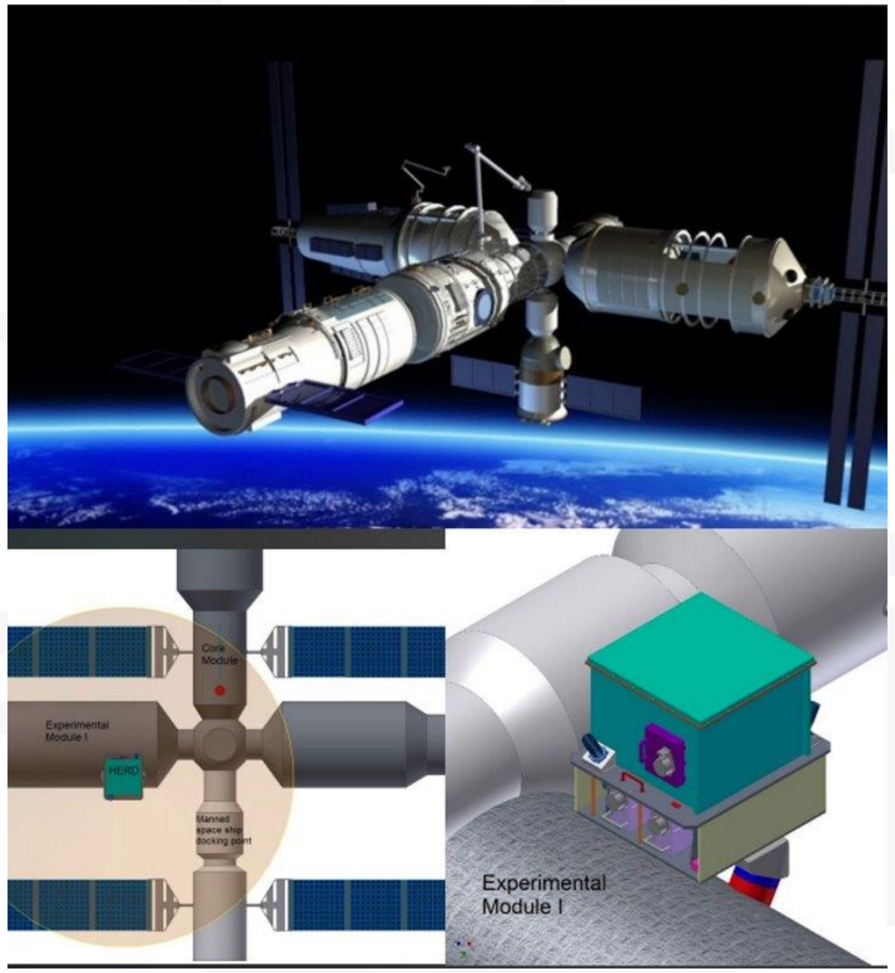
Issues with HE-GCR observation



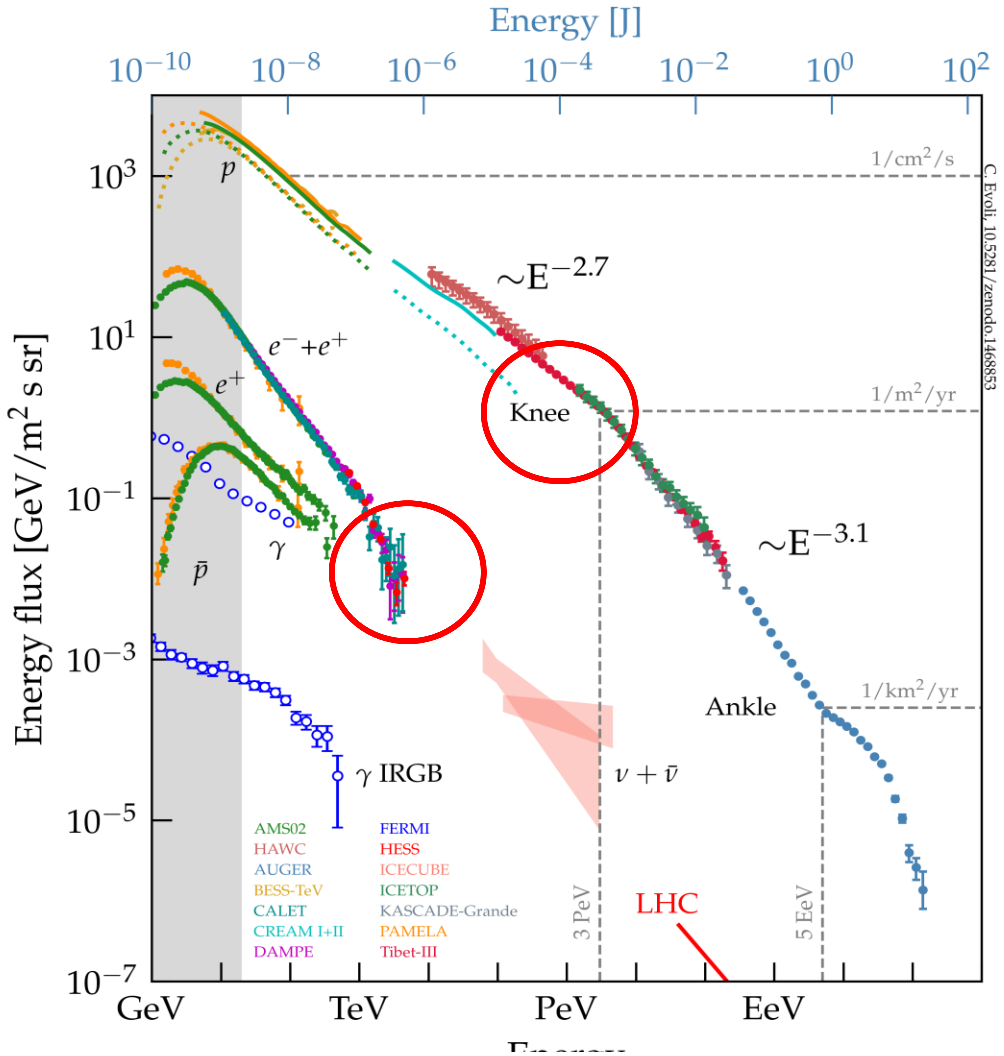
- Cosmic-rays flux is ~ a power law of the energy
- To explore the highest-energy regions of Galactic Cosmic Rays (> 100 TeV - few PeV) with enough statistics a **significant increase of exposure** is needed
- Size and weight are limited by space constraints
- Time is limited by payload lifetime
- HERD try to overcome these problems with its peculiar design

HERD Space Mission

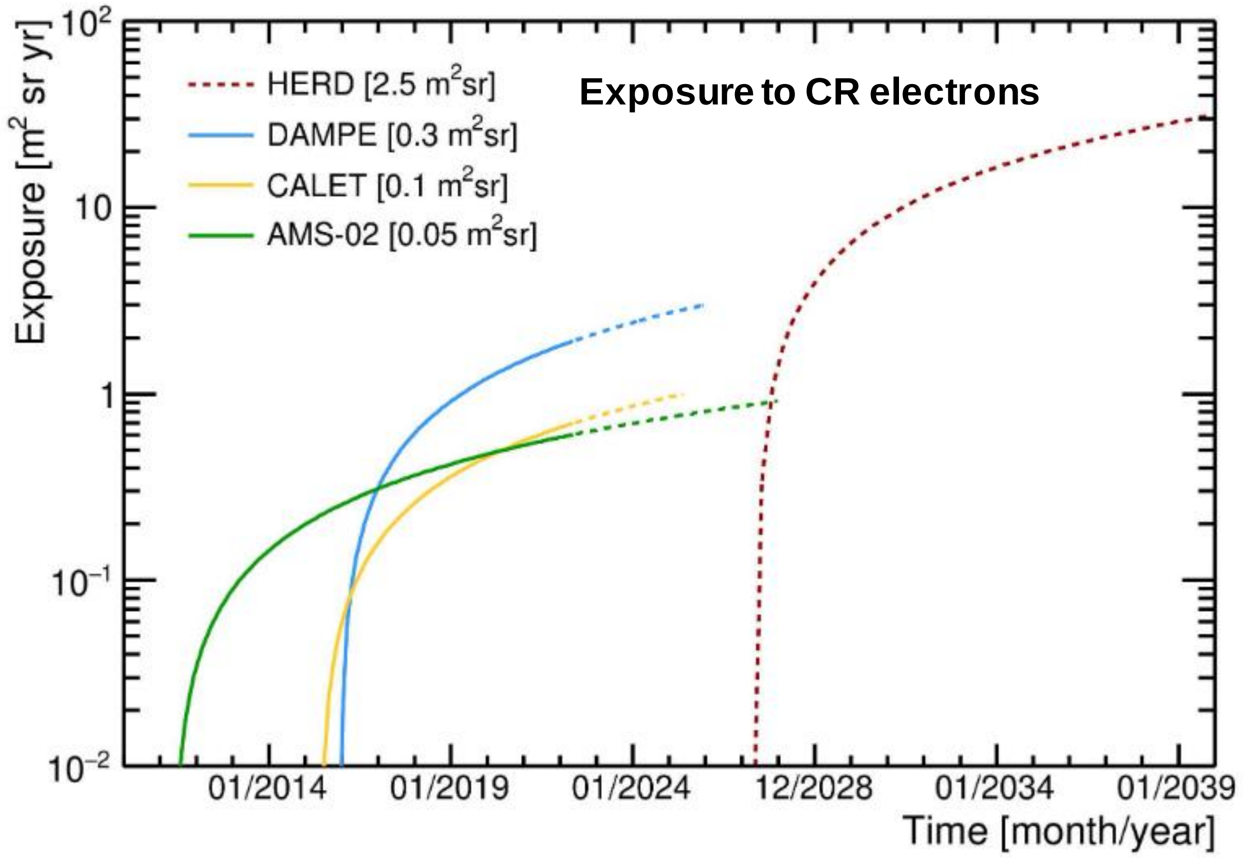


- Particle detector to be installed onboard the Chinese Space Station
- Planned launch in 2027
- Collaboration among Chinese, Italian, Swiss, and Spanish institutes
- Payload details:
  - Lifetime > 10 years
  - Power consumption < 1.5 kW
  - Mass < 4 ton

HERD Space Mission



- Scientific goals:
  - Direct measurement of Cosmic Ray energy spectrum up to the *knee* region (PeV scale)
  - $e^- + e^+$ energy spectrum up to 10 TeV
  - Gamma monitor and full sky survey up to 100 TeV
  - Indirect dark matter searches



	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

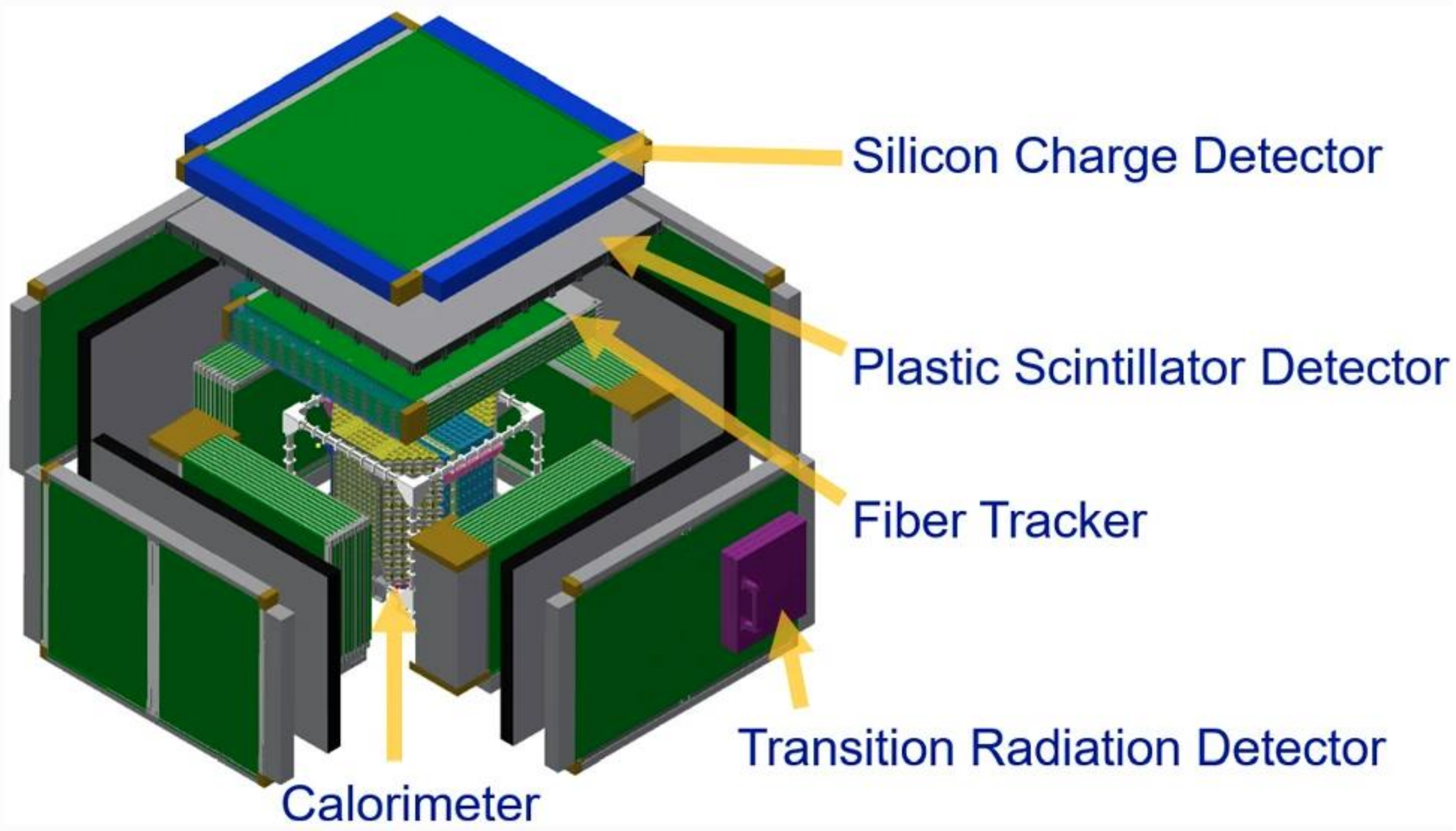
Expected Performances

compared with currently running experiments




	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

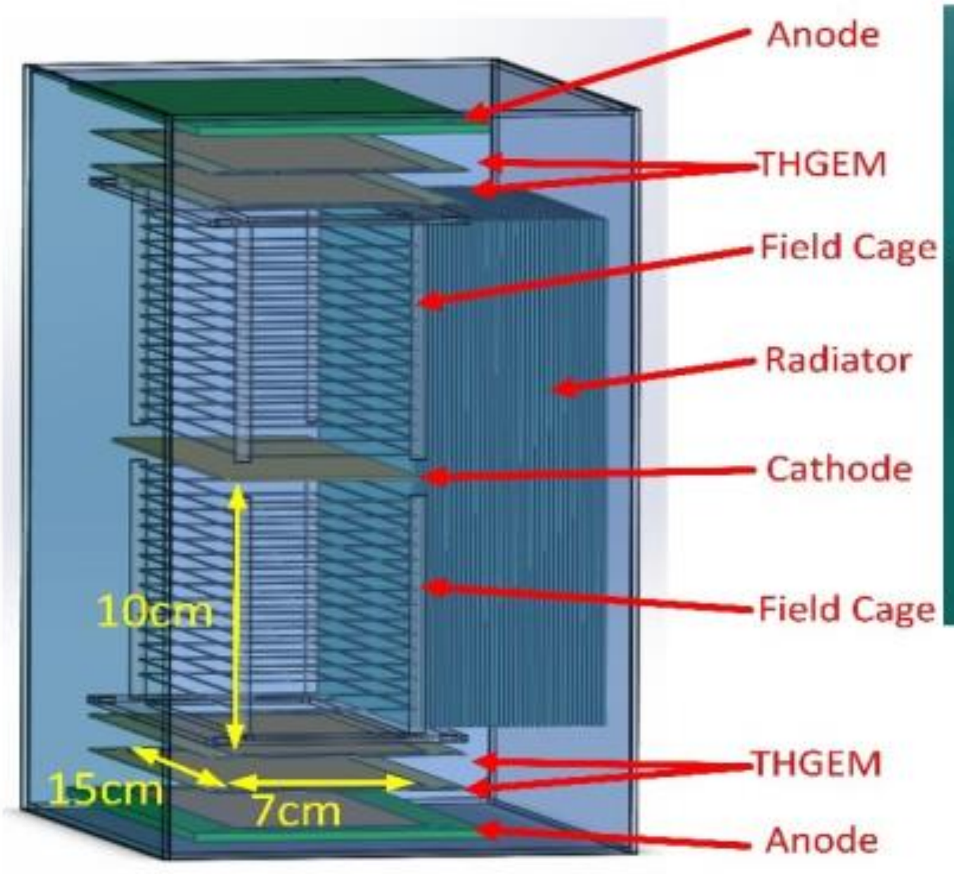
Preliminary Design

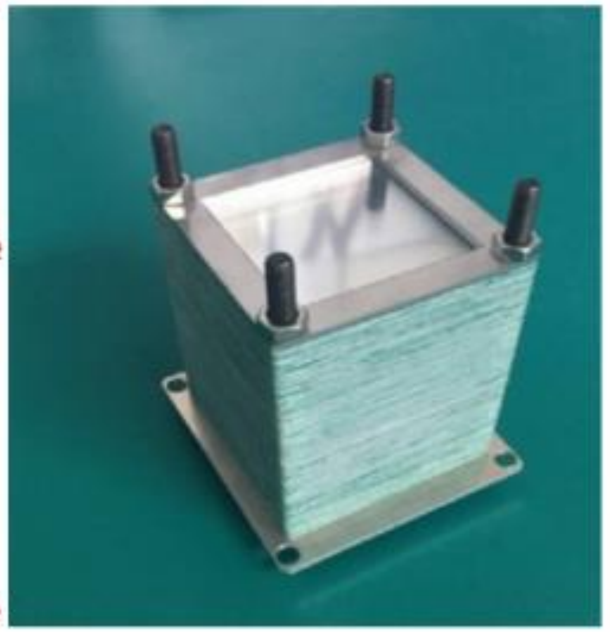


The use of **5 sensitive faces** increases significantly the detector acceptance without dramatically affecting the size

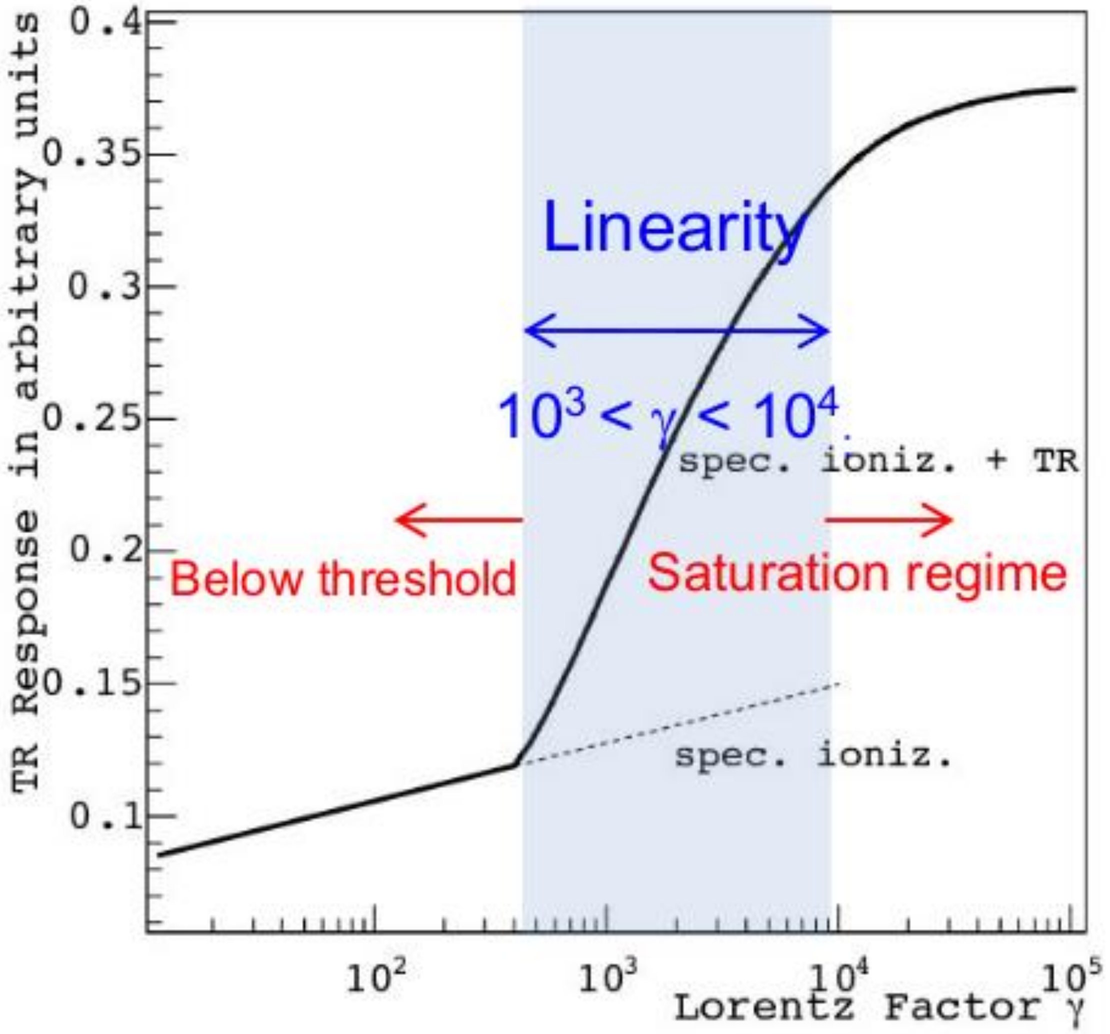
- **TRD** -> calibration
- **SCD** -> high-precision charge measurement
- **PSD** -> photon anticoincidence
- **FIT** -> tracking system
- **CALO** -> energy measure and shower imaging

Transition Radiation Detector (TRD)





- Placed on a single side
- It provides an additional calibration
- Protons in 1 TeV – 10 TeV range

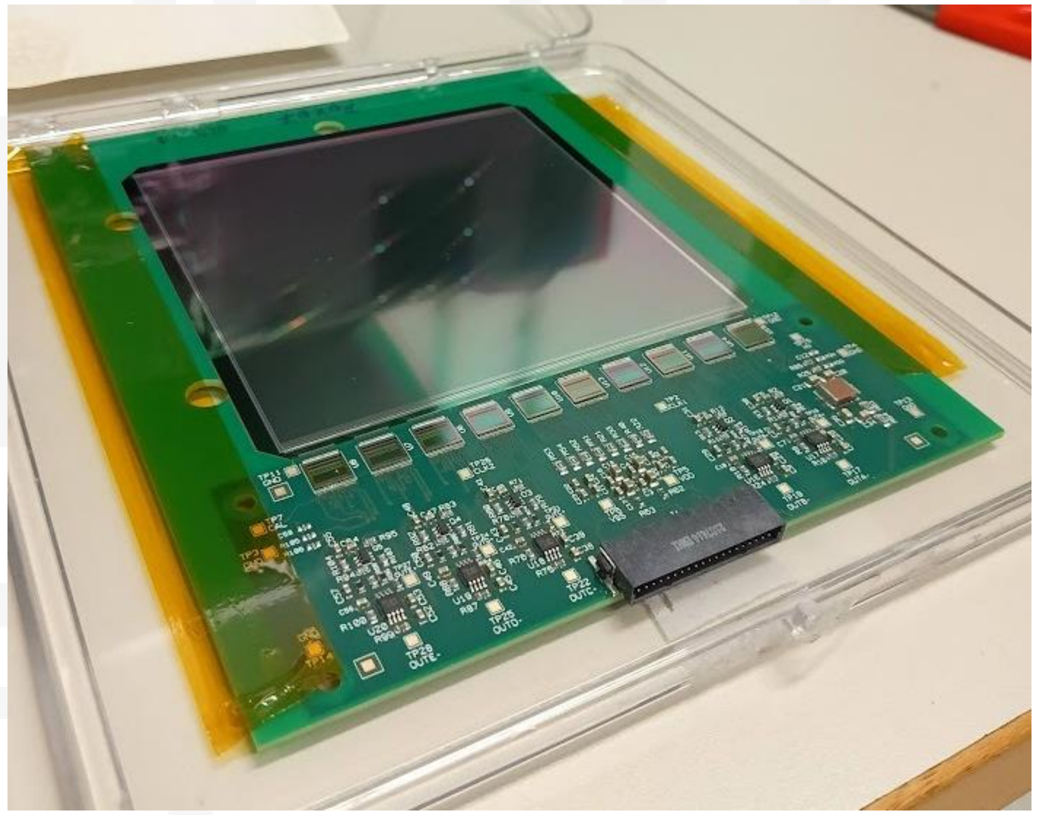


- Multi-layer Polyimide thin foils radiator
- Xenon - THGEM (THick GEM) detector
- Optimal pressure, quenching gas, and mixture currently under study

Silicon Charge Detector (SCD)

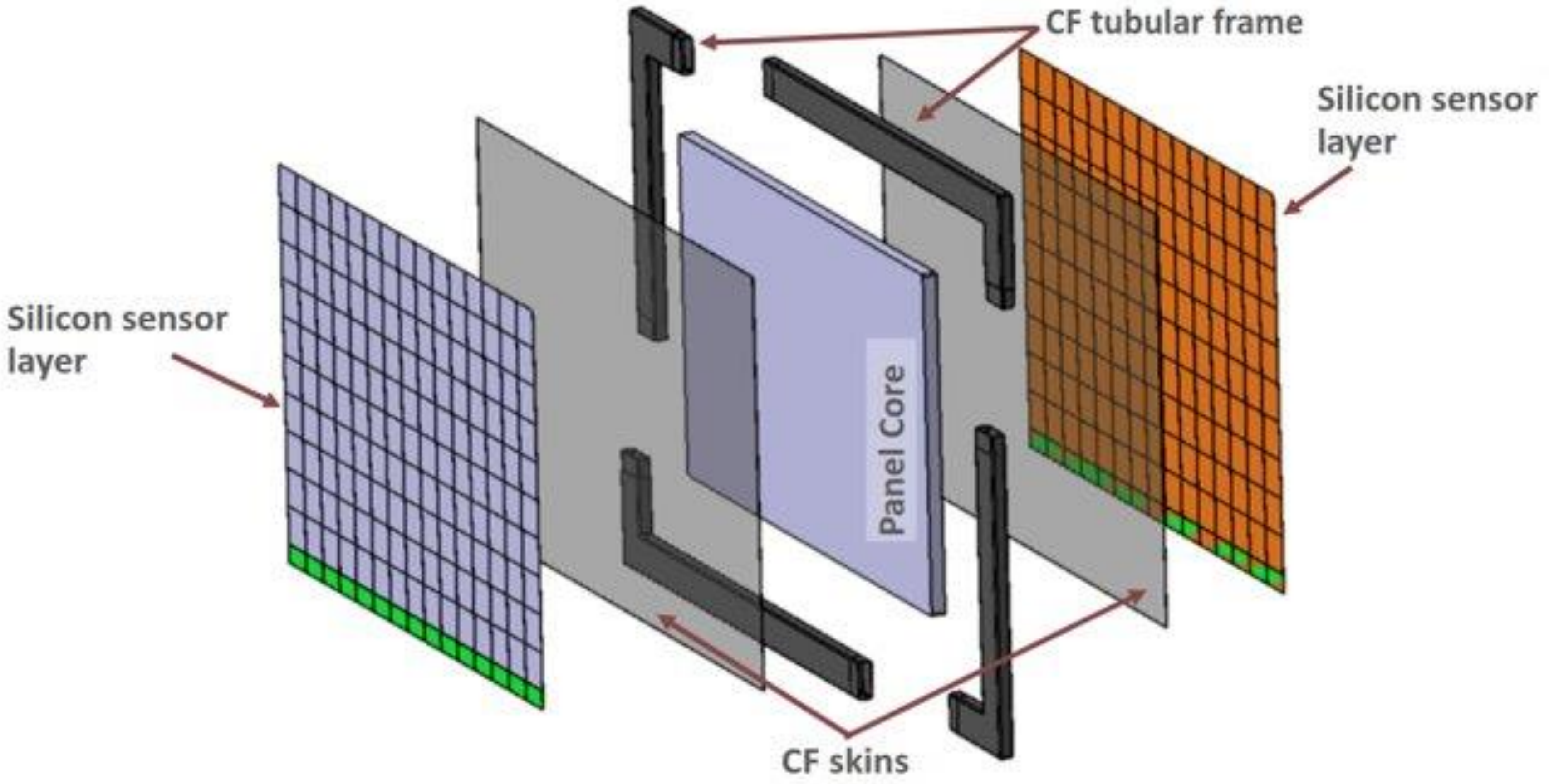
- Silicon microstrip detector, outermost shell
- Silicon ladders arranged in layers, on each side
- Total active area ~ 60 m^2
- High-precision charge measurement

More details in G. Silvestre's talk



Beam test prototype of single silicon microstrip detector

SCD Panel schematic view



Plastic Scintillator Detector (PSD)

2 Layers of Plastic Scintillator bars (40 cm long) on each side, with the goal of providing:

- Anticoincidence for γ
- Charge measurement for nuclei

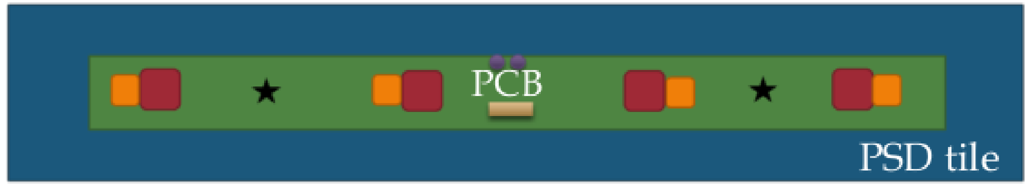
More specifically:

- Efficiency > 99.98%
- High dynamic range (id. up to Fe nuclei, signal ~ Z^2)
- Reduction of backscattered particles effects on the measurement, using finer segmentation + timing

Test beam prototype of the PSD with the PCBs mounted on the bars

4 SiPM (3.0x3.0mm2 – 50umcell) - **Low Z**

4 SiPM (1.3x1.3 mm2 – 15um cell) - **High Z**

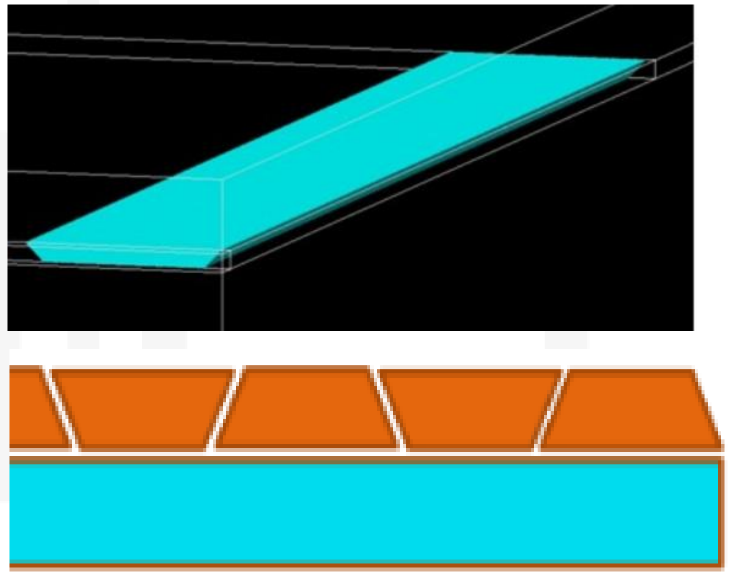


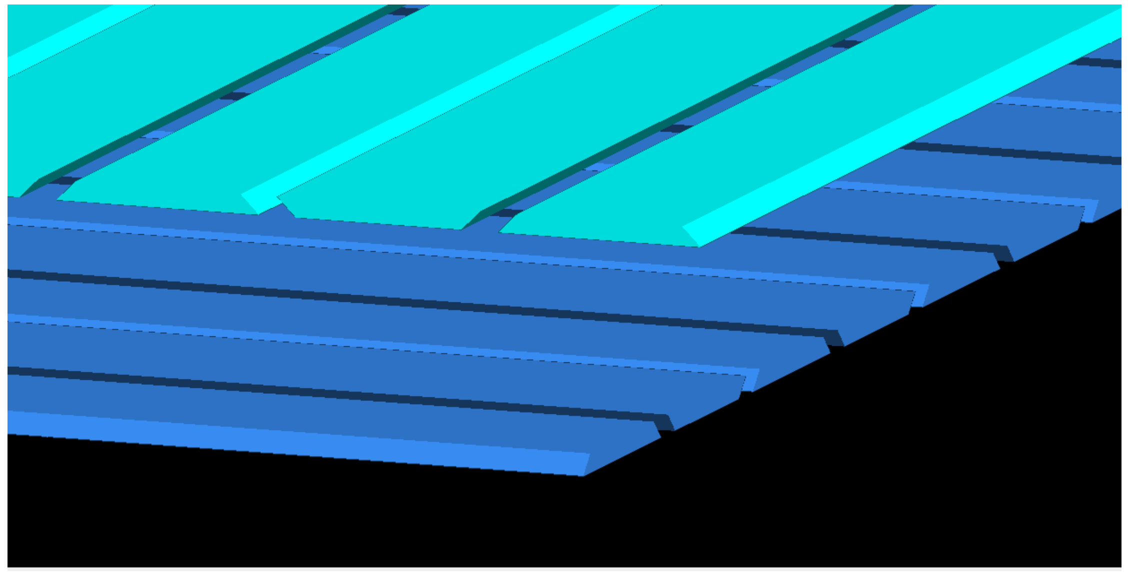
Led for calibration

coaxial cable connector

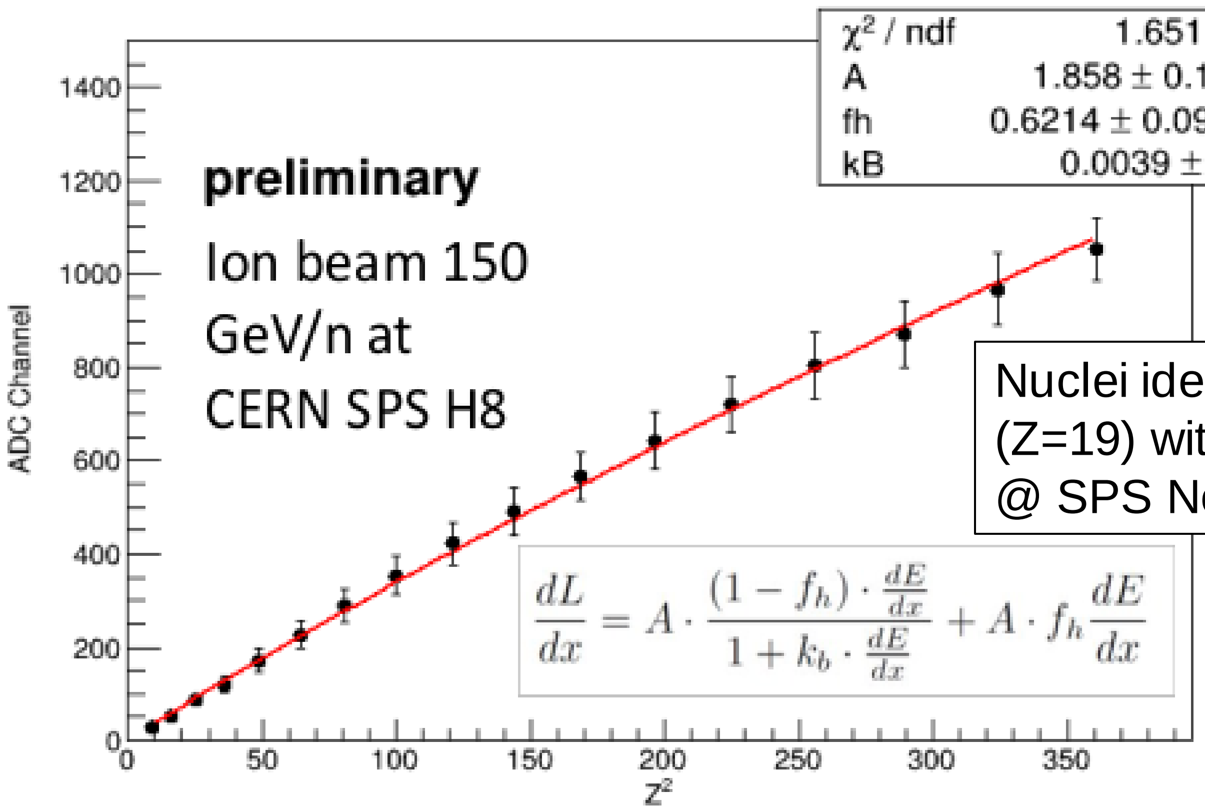
Temperature sensors

Plastic Scintillator Detector (PSD)



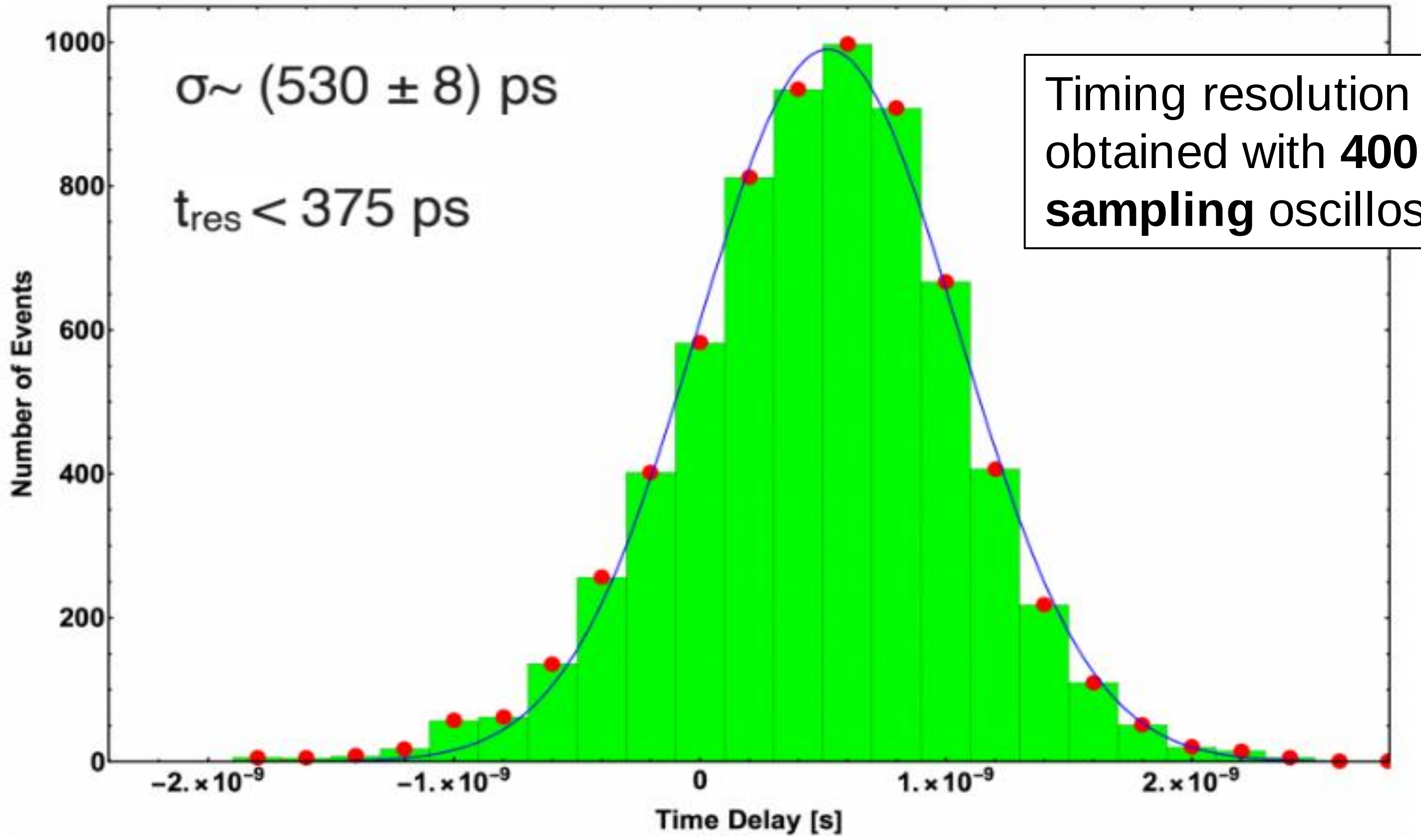


Trapezoidal bar shape helps increasing the hermeticity of the PSD layer



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

Nuclei identification up to K (Z=19) with a single SiPM @ SPS Nov 2022

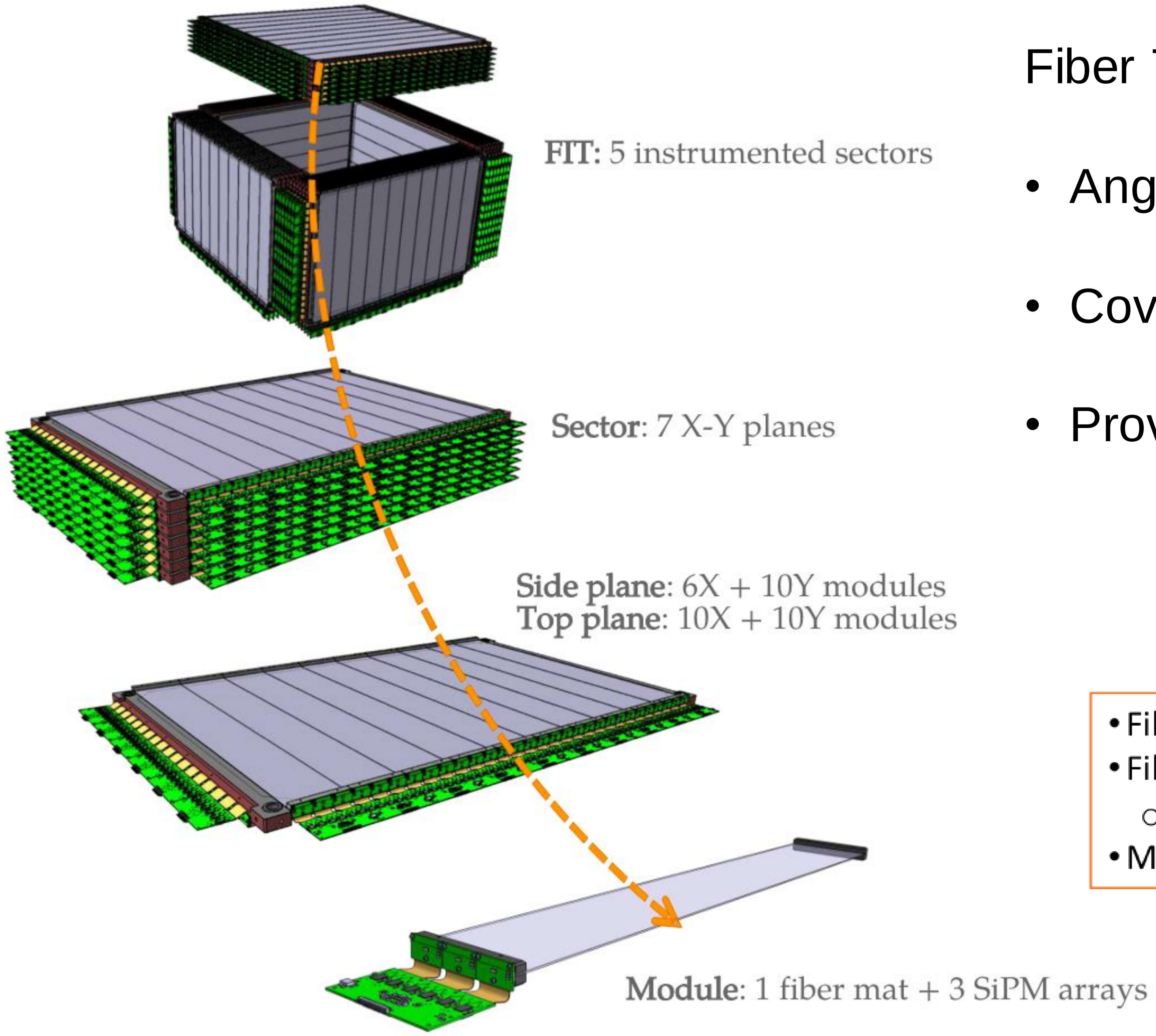


$\sigma \sim (530 \pm 8)$ ps

$t_{res} < 375$ ps

Timing resolution obtained with **400 ps sampling** oscilloscope

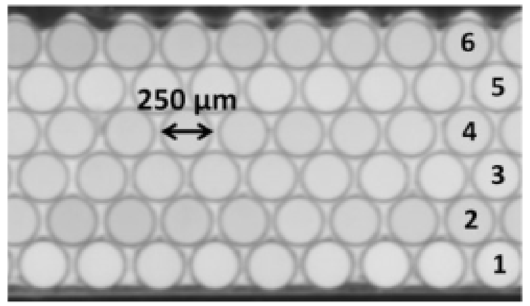
FIber Tracker (FIT)



Fiber Tracker goals:

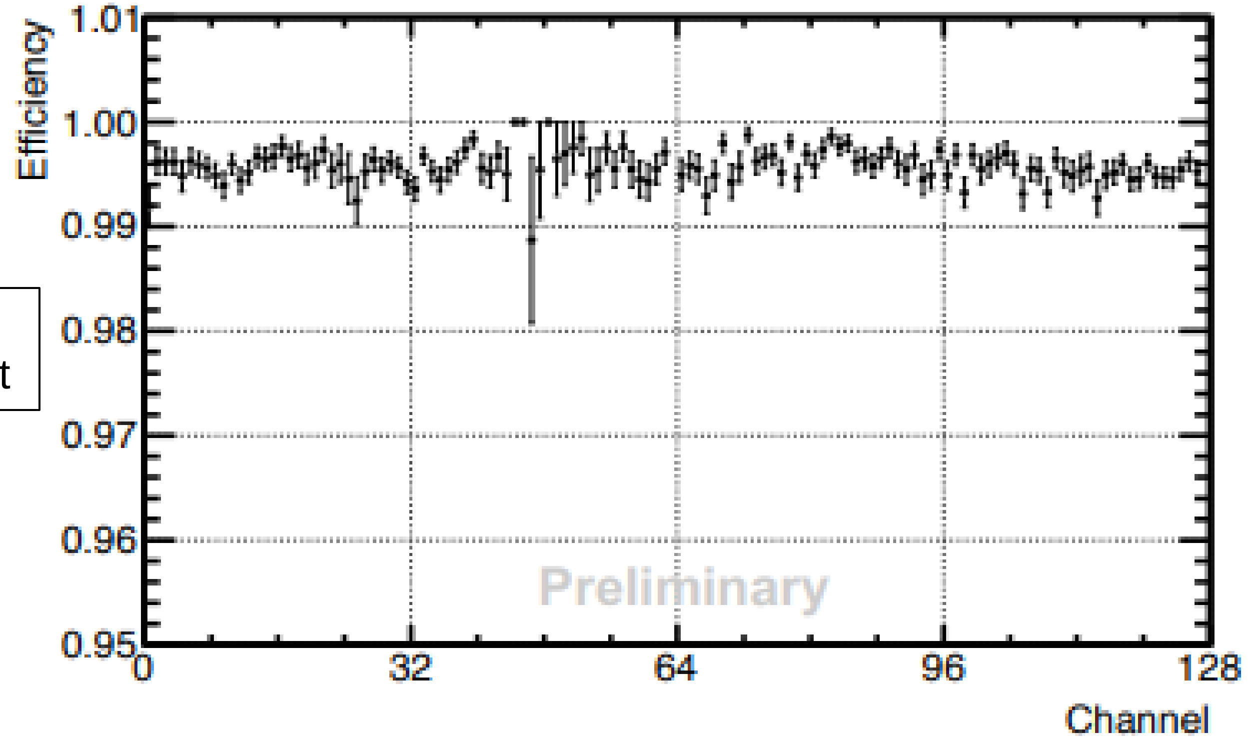
- Angular resolution < 0.6° @ 1 GeV
- Coverage ratio > 80%
- Provide an additional charge measurement

- 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



FIber Tracker (FIT)

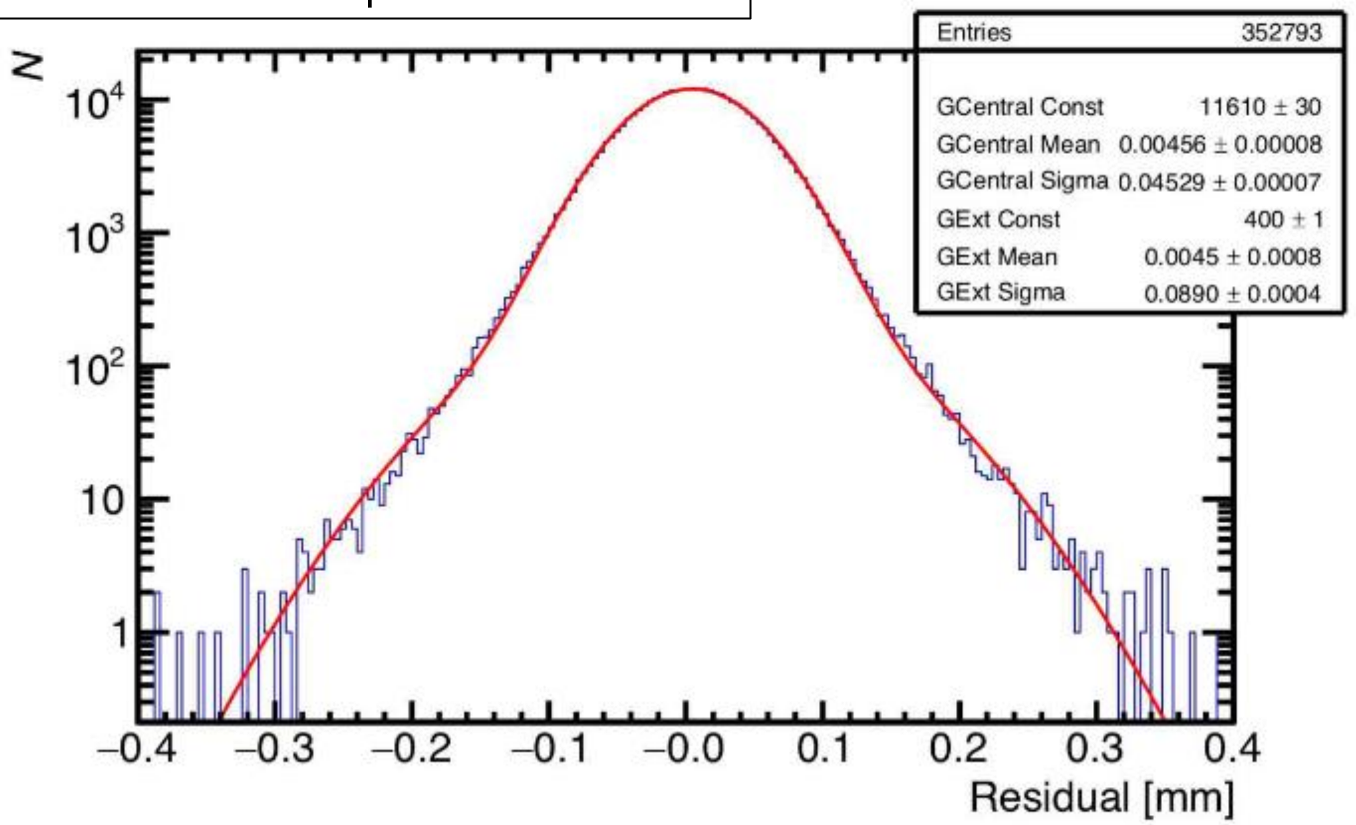
Efficiency of the 128 SiPM in the array used in beam test



Charge resolution for low Z nuclei
Preliminary Results

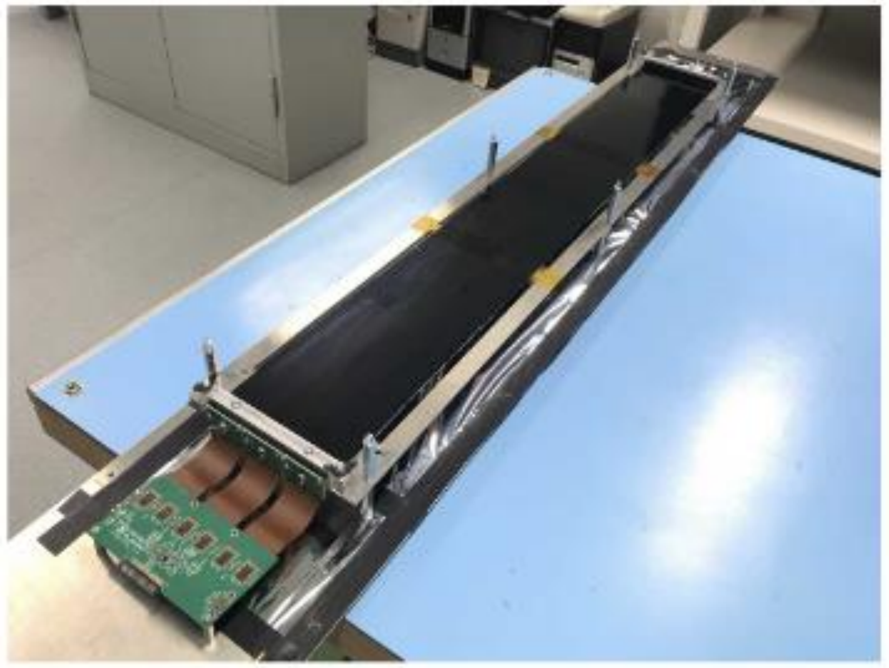
Z	μ_Z	σ_Z	σ_Z/μ_Z
2	1.99	0.31	15 %
3	3.07	0.40	13 %
4	4.01	0.51	12 %

Position Residuals from proton beam tests



$$\text{Spatial resolution} = (45.0 \pm 0.1)\ \mu\text{m}$$

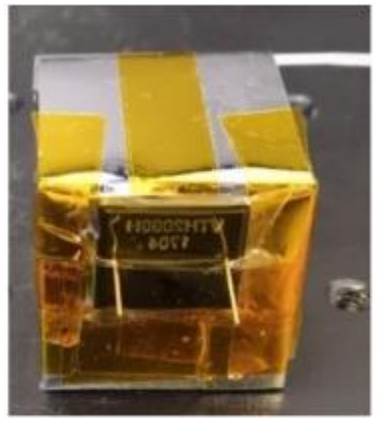
Picture of a Fiber Mat prototype



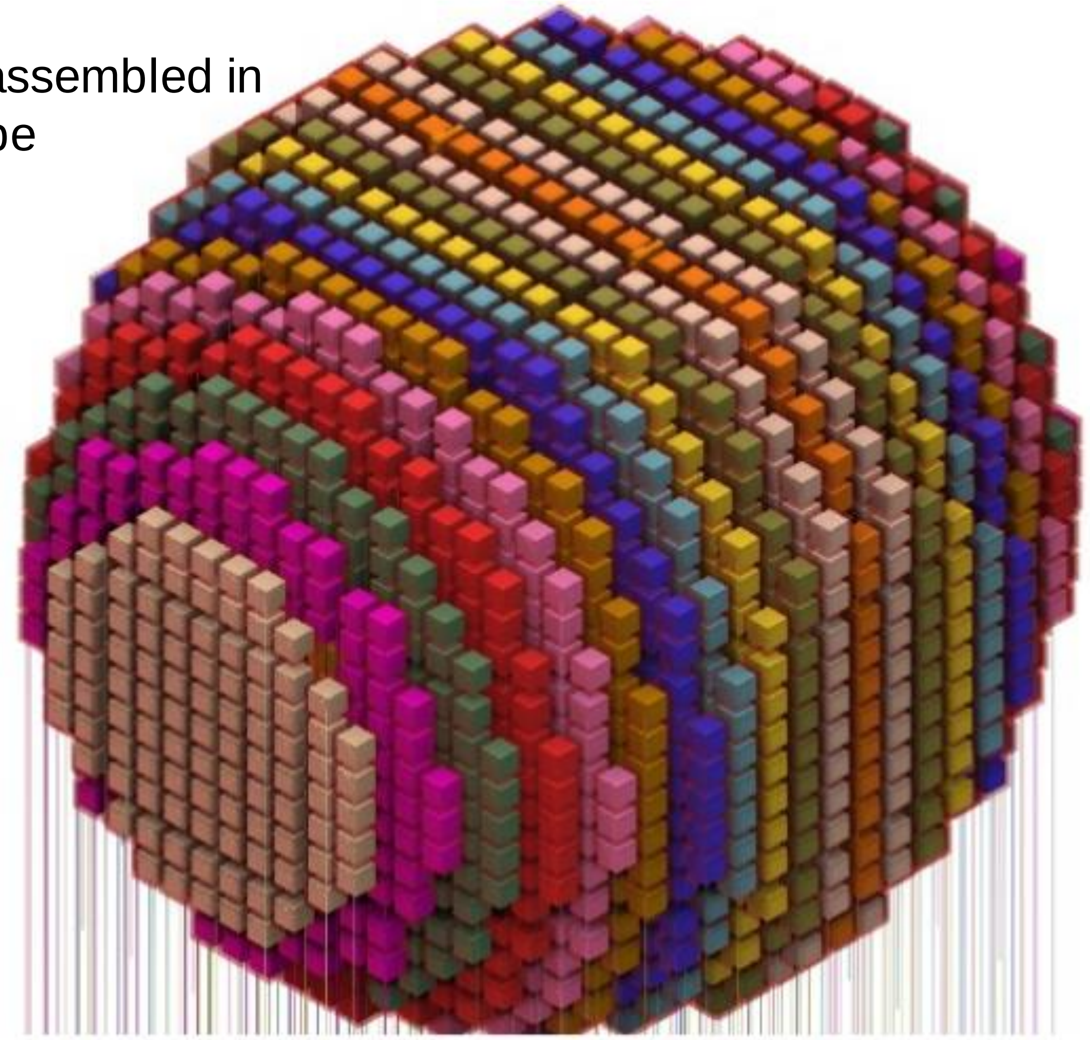
CALOrimeter (CALO)

- 7500 LYSO crystal cubes array, 55 X_0 radiation length
- Isotropic 3D geometry ensure a larger geometric factor
- 3D segmented shower imaging helps improving shower-type discrimination (hadronic vs electromagnetic)
- Energy resolution:
  - 1% electrons and γ
  - 20% protons
- Energy range:
  - 10 GeV – 100 TeV electrons and γ
  - 30 GeV – PeV protons and nuclei
- 2 readout systems in each cube, allowing for redundancy and cross-calibration to reduce systematic uncertainties

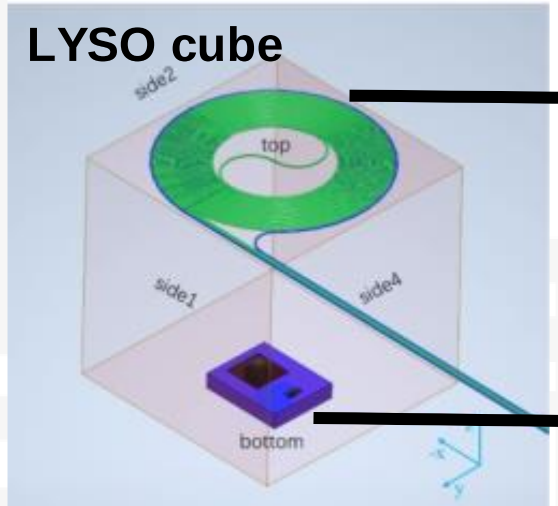
3x3x3 cm^3 LYSO cube



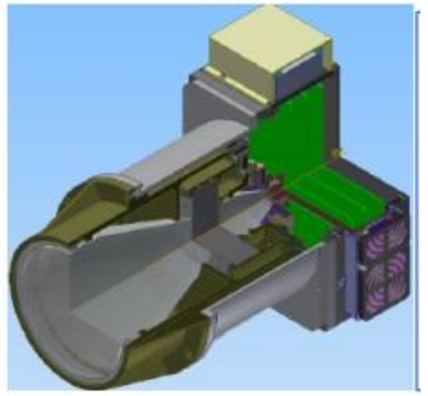
LYSO cubes assembled in spherical shape



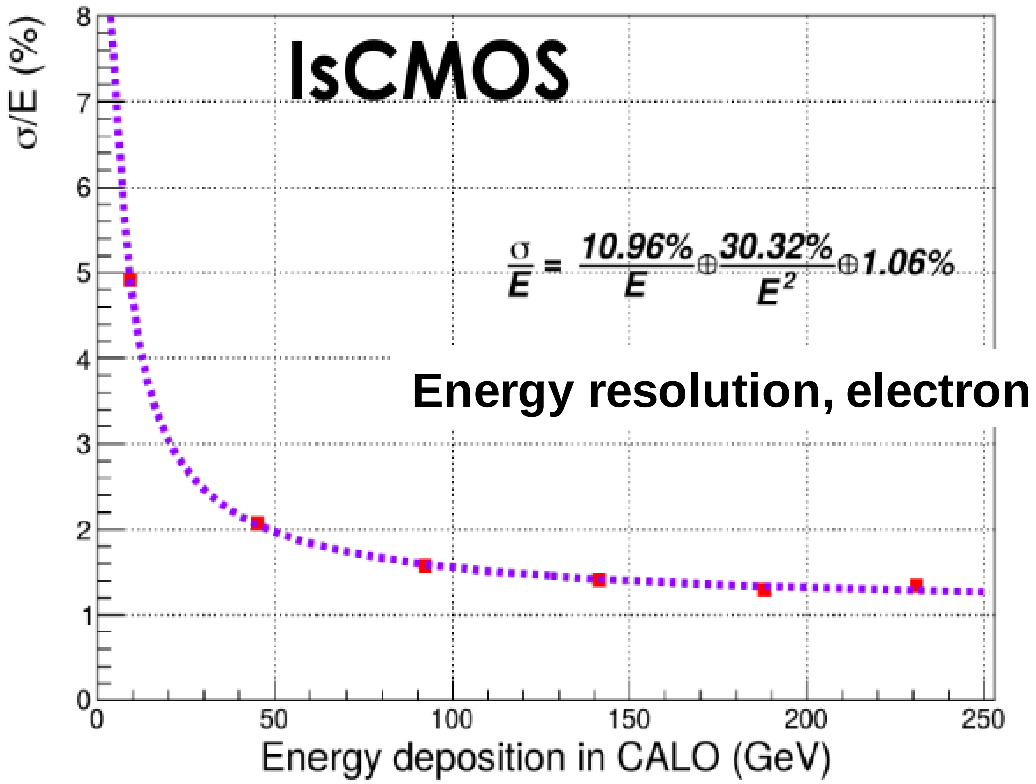
CALOrimeter (CALO) readout



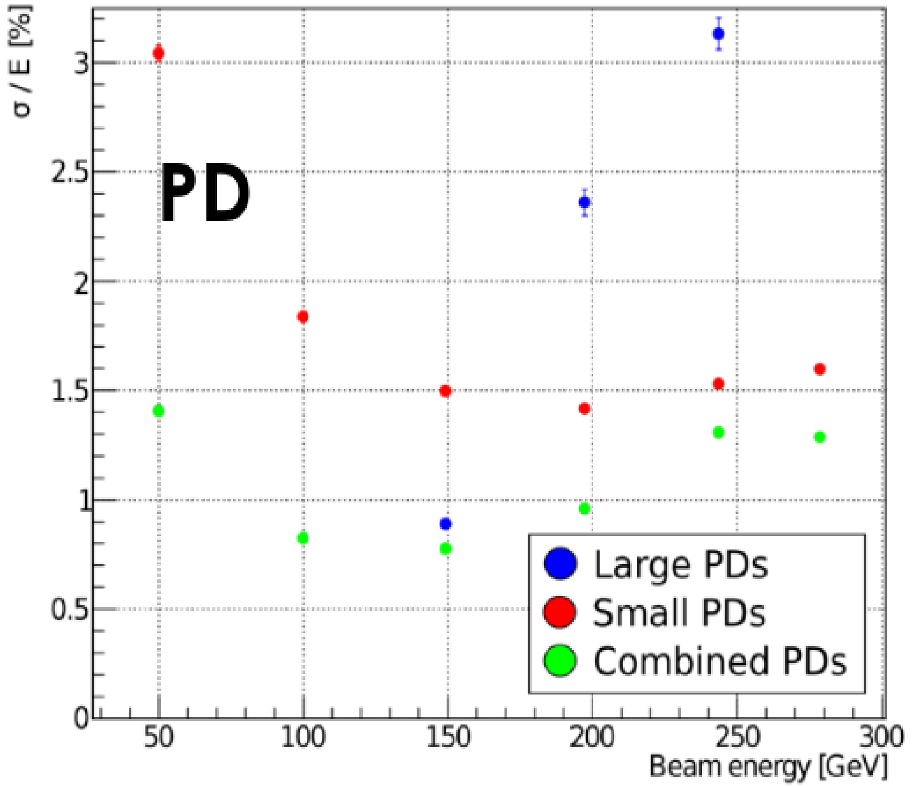
3 Wavelength Shifting fibers (WLS) → **Fast PMT + IsCMOS Camera**

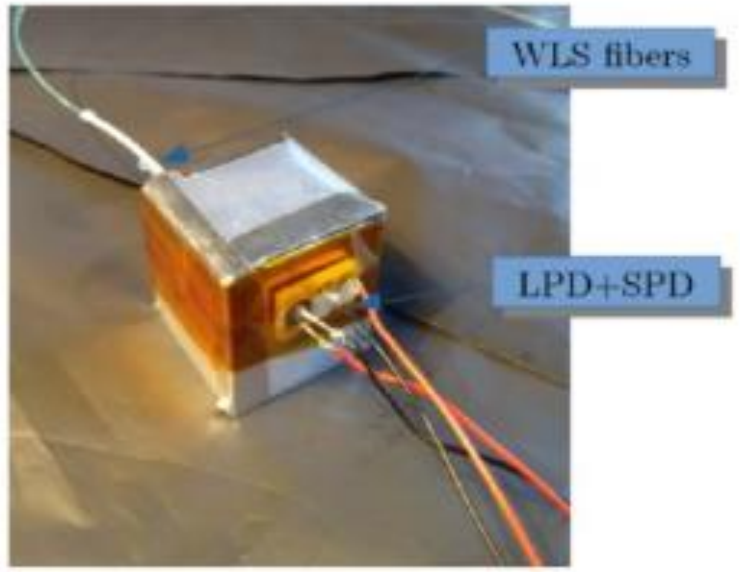


2 Photo-diode (PD) readout → **Large PD and Small PD**



Energy resolution, electron beam test





Picture of LYSO cube connected to its readouts

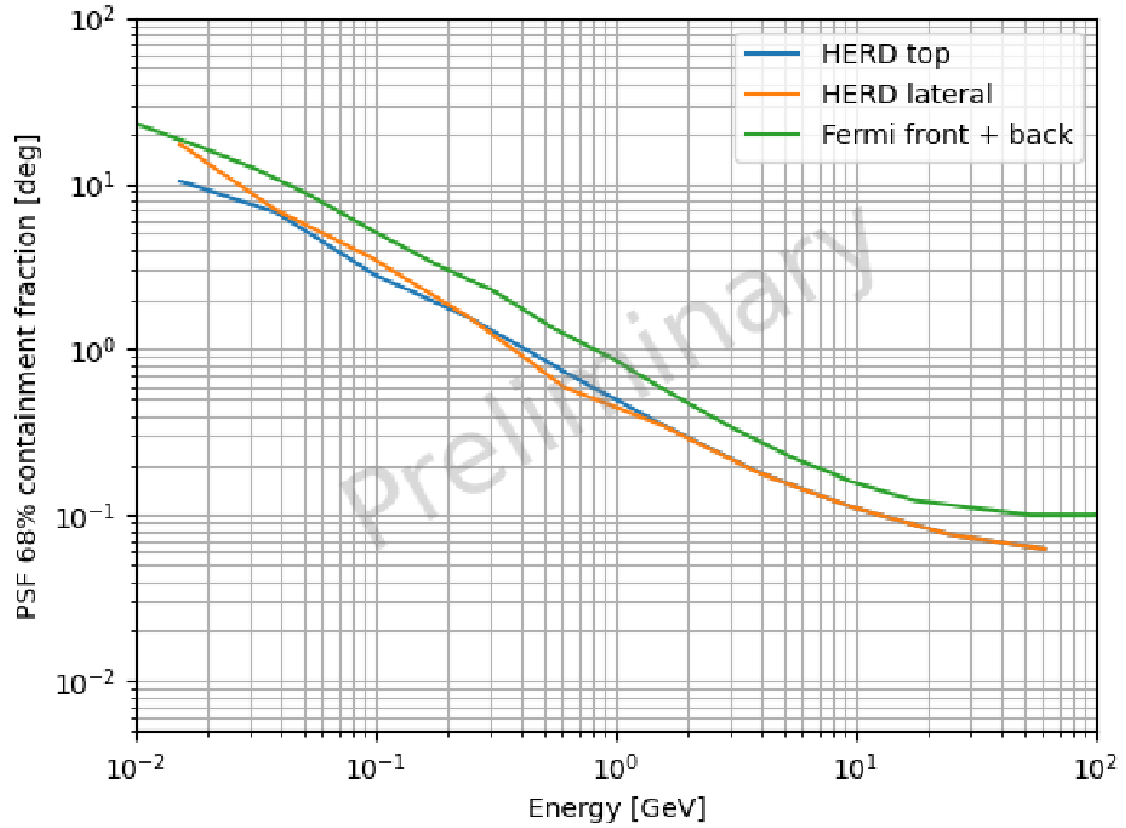
Summary

- HERD can be help us exploring the highest energies for galactic cosmic rays
- Its subdetectors are quite close to their target goals
- We are finalizing the detector optimization using data from simulations, beam tests, and cosmic-ray muons

Backup

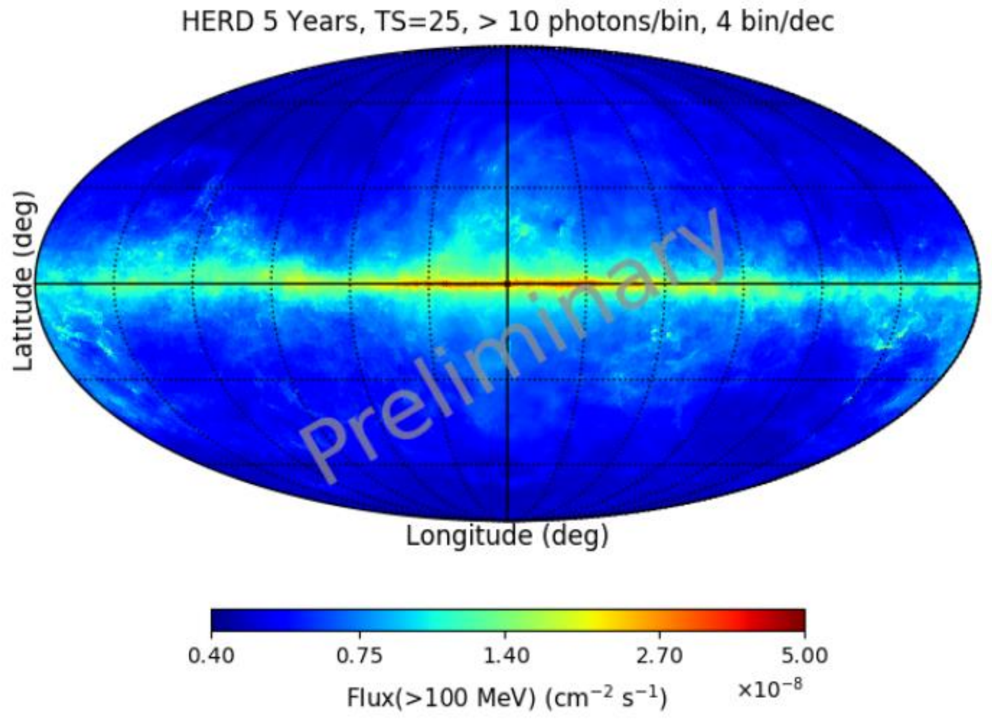
Outlooks on γ astronomy

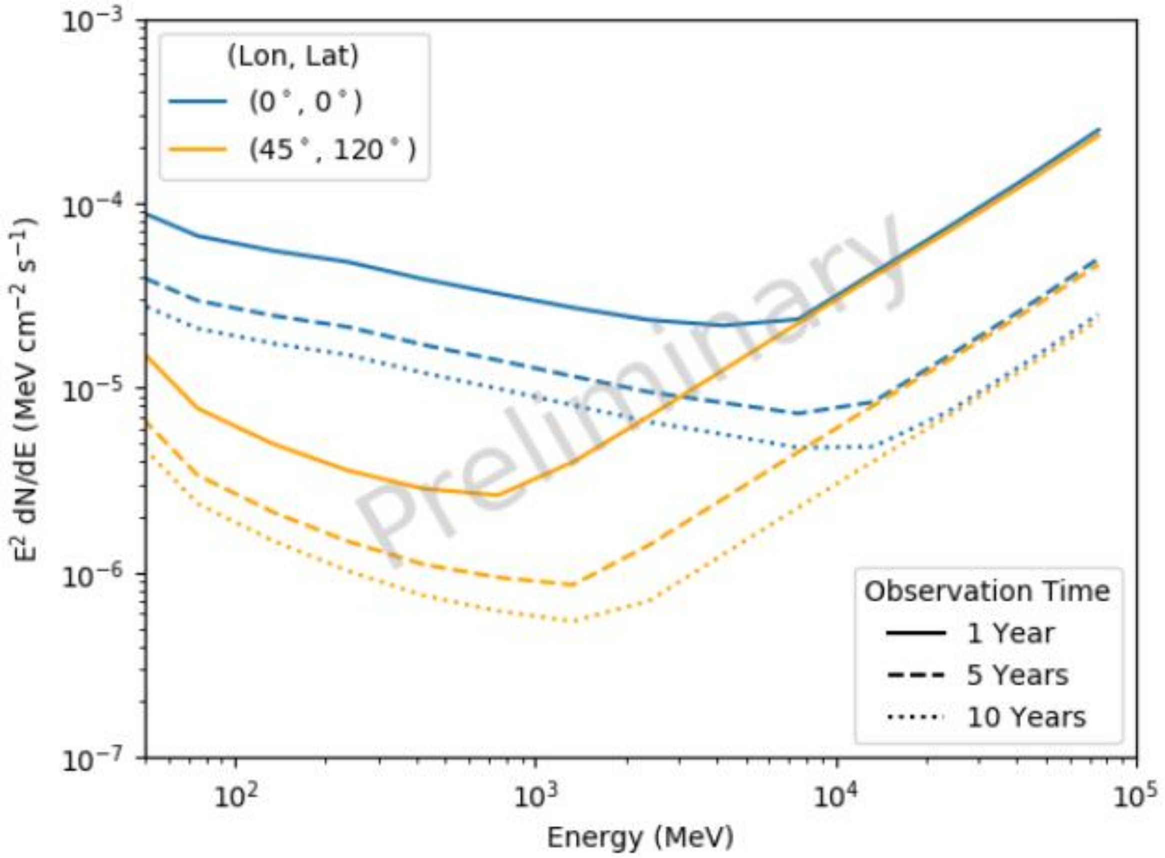
(L. Fariña et al., PoS ICRC 2021, 651)



PSF of top and lateral face
Compared with Fermi-LAT PSF

5 years Sky Map for E > 100 MeV





Differential sensitivity to point-like sources

Using its very large FoV and Energy coverage, HERD can produce alerts for MultiMessenger astronomy, and study **transient phenomena**, also combining data with CTA and LHAASO

Outlooks on CR nuclei

After 5 years of data taking:

- **Direct observation** of protons and helium at the knee of their spectra
- **Increased statistics** in the overall energy range of previous experiments