HERD: the space-borne High Energy cosmic-Radiation Detection facility

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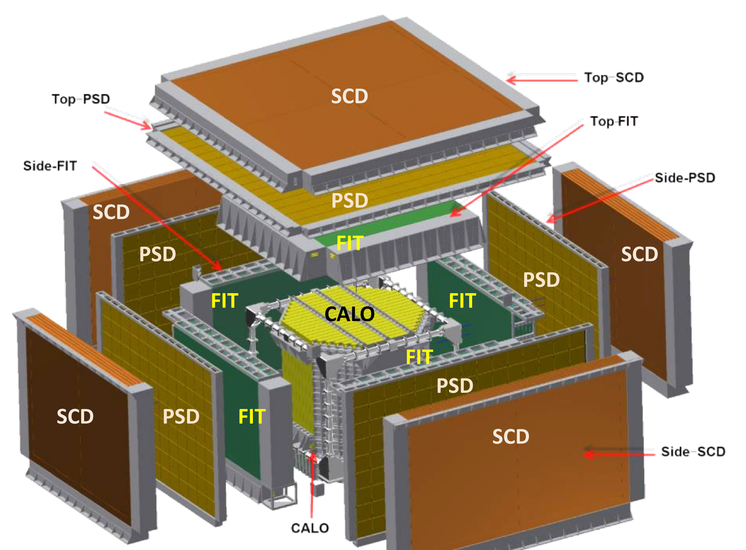
on behalf of the HERD Collaboration

HERD in a nutshell

The High Energy cosmic-Radiation Detection (HERD) facility has been proposed as one of several space astronomy payloads onboard the **China's Space Station (CSS)**, planned for operation starting around 2027 for about 10 years.

The experiment is based on a 3D, homogeneous, isotropic and finely-segmented **calorimeter** that will measure the **cosmic ray** flux up to the *knee* region, search for indirect signals of **dark matter** and monitor the full **gamma-ray** sky.



CSS expected to be completed in 2022

CALO: CALOrimeter
- Energy measurement
- Electron/proton separation

FIT: FIber Tracker
- Track reconstruction
- Low energy γ ray conversion ($\gamma \rightarrow e^+ e^-$)
- Charge measurement (|Z|)

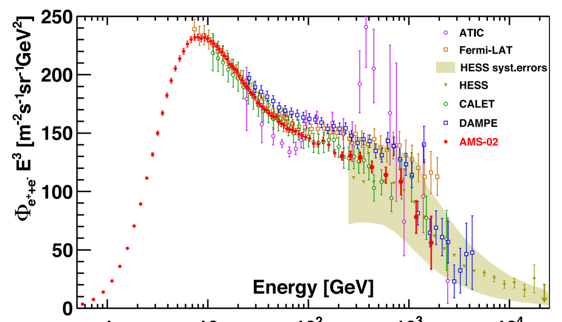
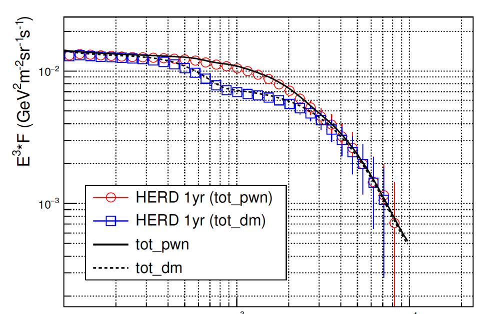
PSD: Plastic Scintillator Detector
- Charge measurement (|Z|)
- γ ray identification

SCD: Silicon Charge Detector
- Charge measurement (|Z|)

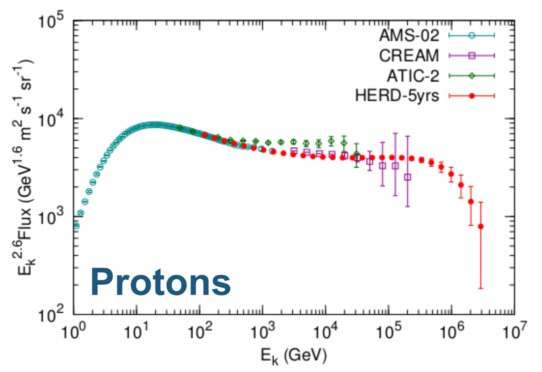
TRD: Transition Radiation Detector
- Energy calibration of TeV nuclei

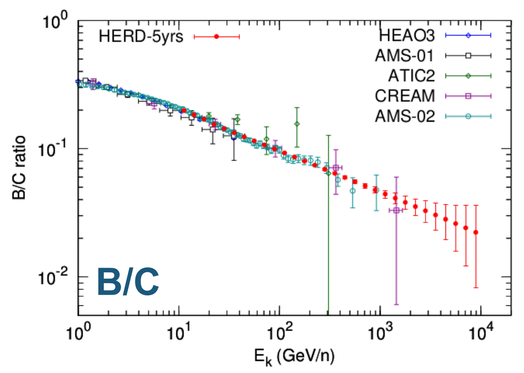
Orbit	Circular low Earth orbit (LEO)	**Field of view**	+/- 70° off the zenith
Altitude	340 km – 450 km	**Power**	< 1.5 kW
Inclination	42°	**Mass**	< 4 t

The objectives of HERD

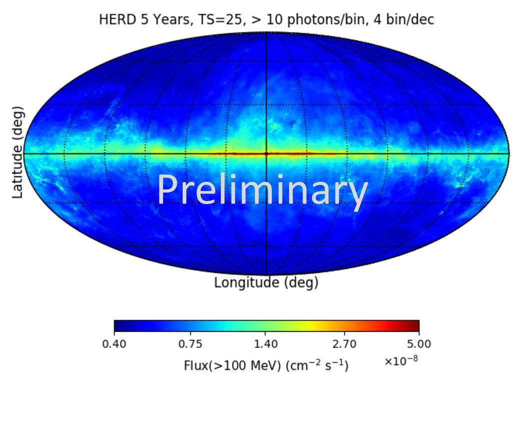
Search for signatures of annihilation/decay products of **dark matter** in:
- energy spectrum and anisotropy of high energy electrons+positrons (10 GeV – 100 TeV);
- gamma-rays (100 MeV – 100 TeV).

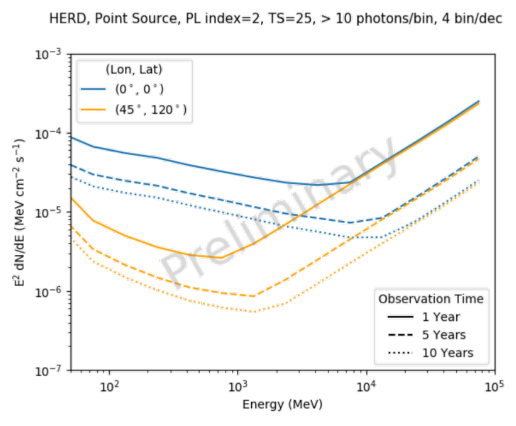




Measurements of **energy spectrum** of p and He up to a few PeV and heavier nuclei up to a few hundreds of TeV/n.

- The first direct measurement of p and He knees will be very important to understand the physical nature of the knee of cosmic rays.
- The extension of the B/C ratio to high energy will probe the propagation mechanisms of cosmic rays.

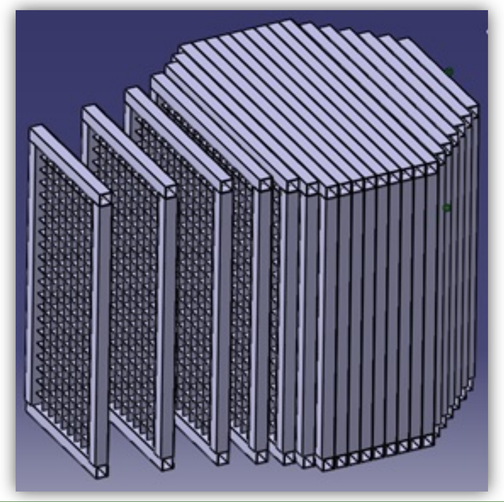




Monitoring of the **gamma-ray sky** from 100 MeV to
- extend the Fermi-LAT catalog to energy > 300 GeV;
- increase the chance to detect rare gamma-ray events;
- search for dark matter signatures;
- study of galactic and extragalactic gamma-ray sources and diffuse emission;
- detection of high energy gamma-ray bursts.

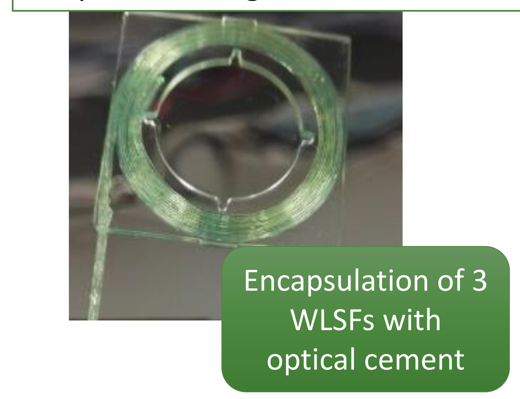
Multi-messenger astronomy
Possible synergy with other experiments designed for: γ (CTA, LHAASO), neutrinos (KM3NeT, IceCube), and gravitational waves (LIGO, Virgo).

CALO

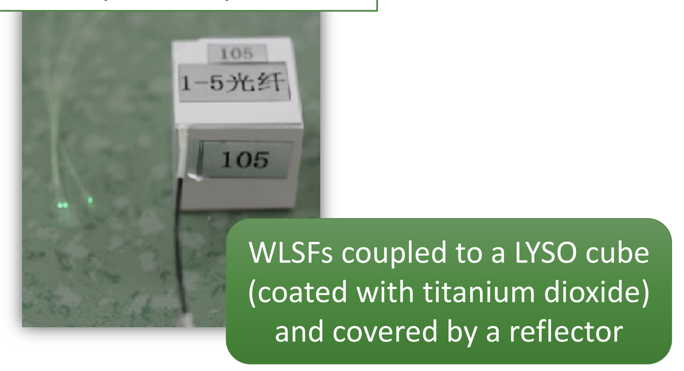


Number of crystals	**~ 7'500 LYSO (X_0 = 1.14 cm)**	
Crystal dimensions	**~ 3 x 3 x 3 cm³**	
Radiation length	55 X_0	**~ 21 LYSO crystals**
Nuclear interaction length	3 λ_{int} (simulation → > 2 λ_{int} for 100 TeV & > 3 λ_{int} for PeV CR @20% energy resolution)	
Fiber readout	**3 WLSF (⌀ = 0.3 mm)/crystal** (low & high range, trigger)	

First readout system: Wavelength shifting fibers (WLSFs) coupled to Image Intensified scientific CMOS (IsCMOS) cameras

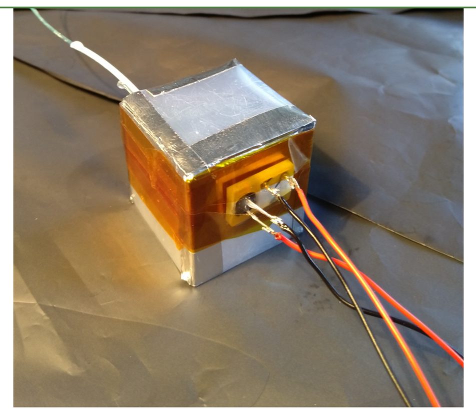


Encapsulation of 3 WLSFs with optical cement

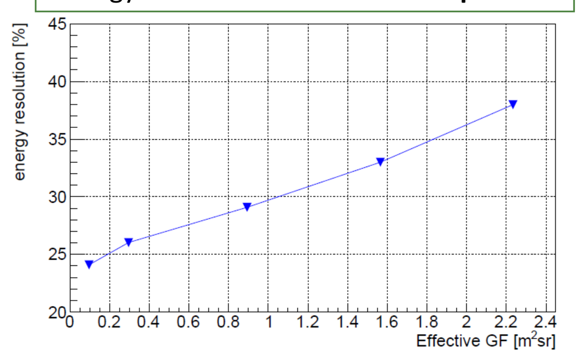


WLSFs coupled to a LYSO cube (coated with titanium dioxide) and covered by a reflector

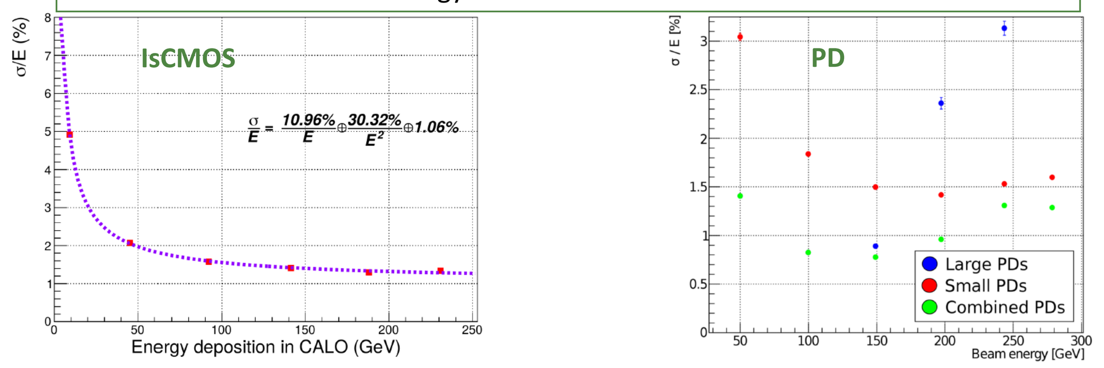
Second readout system: Photodiodes (PD)



Energy resolution for Montecarlo **protons**

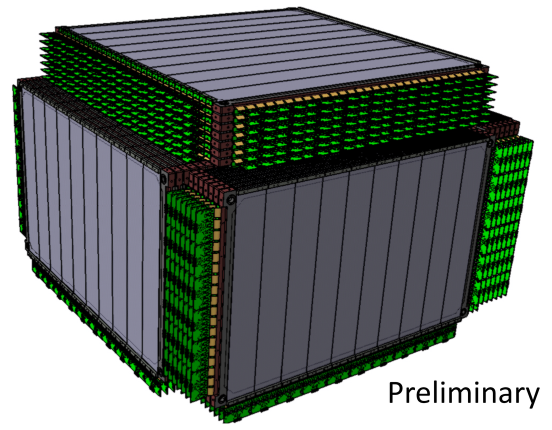


Energy resolution for **electrons**



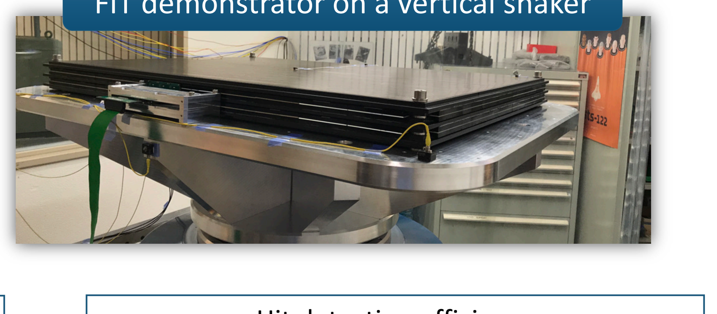
FIT

- 7 x-y tracking planes in each sector (1 top and 4 side sectors)
- 6 x + 10 y in each side plane
- 10 x + 10 y in each top plane
- Module = 1 fiber mat + 3 silicon photomultiplier (SiPM) arrays

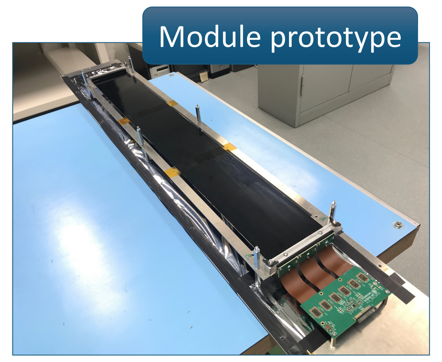


Preliminary

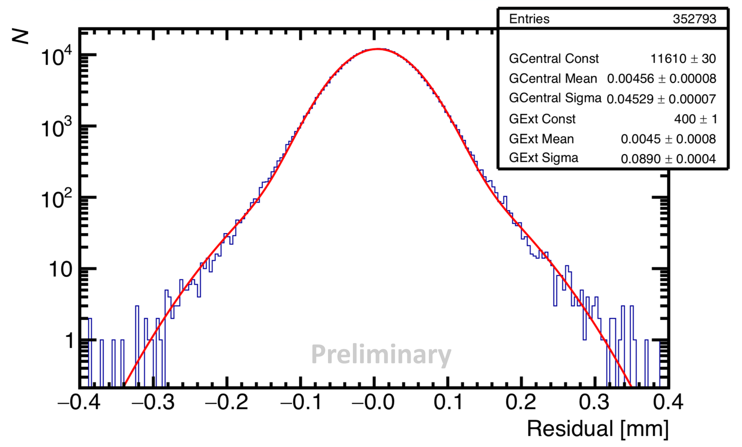
FIT demonstrator on a vertical shaker



Module prototype

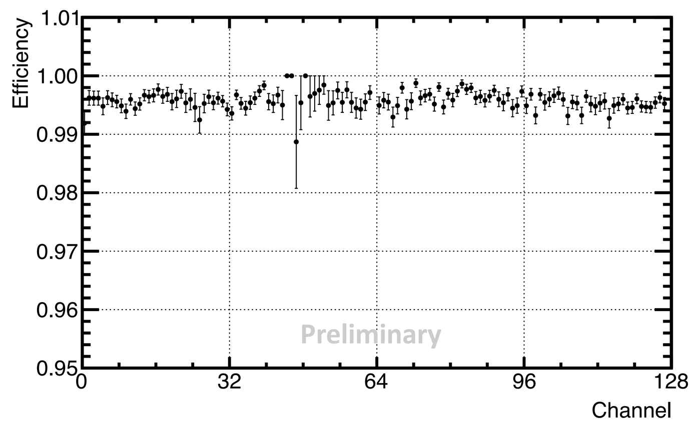


Position residual distribution



Spatial resolution = (45.0 ± 0.1) μm
(taking into account the external beam telescope resolution)

Hit detection efficiency



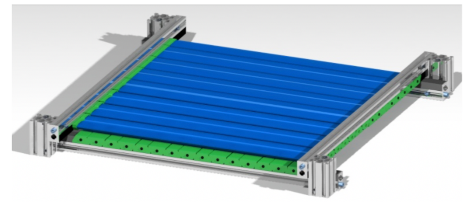
Mean efficiency = 99.6 %

Charge resolution for nuclei heavier than **protons**

Z	μ	σ	σ/μ
2	1.99	0.31	15 %
3	3.07	0.40	13 %
4	4.01	0.51	12 %

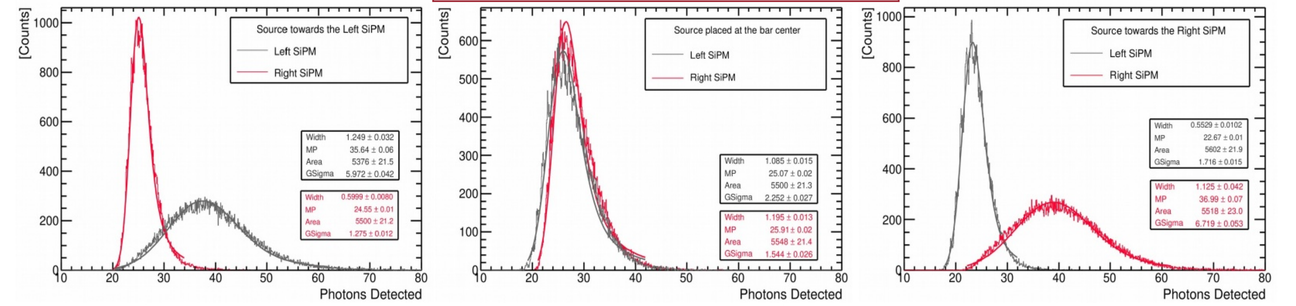
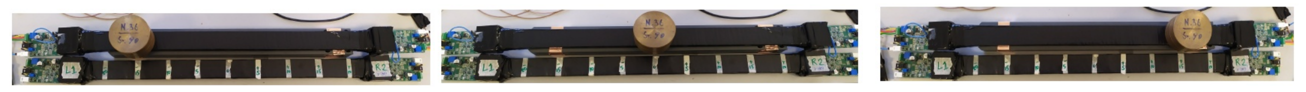
PSD

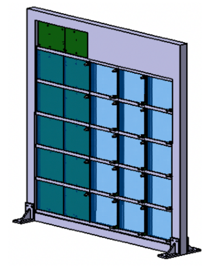
- PSD provides **γ identification** (VETO of charged particles) and **nuclei identification** (energy loss ∝ Z²).
- Requirements:
  - high **efficiency** in charged particles detection (> 99.98 %);
  - high **dynamic range** to identify nuclei at least up to iron;
  - finely **segmented** to minimize the contamination of backscattered particles in the charge measurement.
- Two configurations are under investigation: one with **long bars** (160 cm – 180 cm) and one with **square tiles** (10 cm × 10 cm) both coupled with Silicon Photomultipliers (SiPMs).



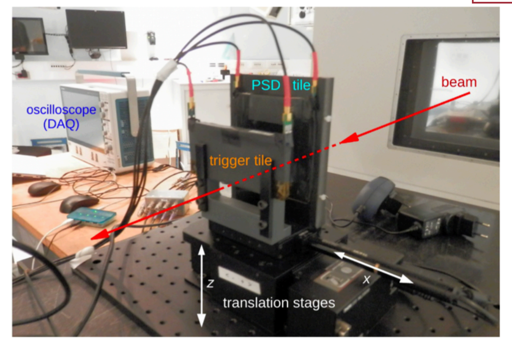
Test prototype with bars

Light yield for ^{90}Sr electrons

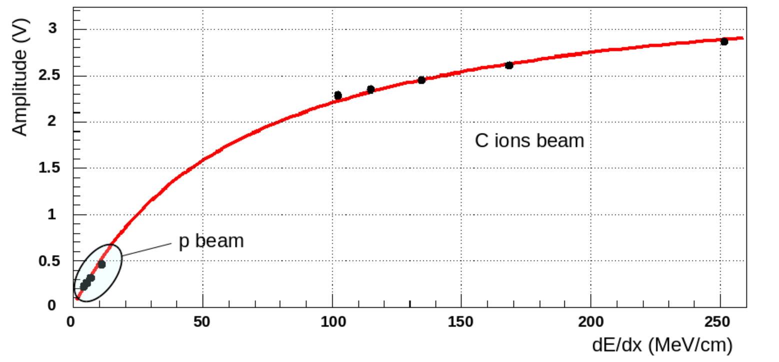





Test prototype with tiles



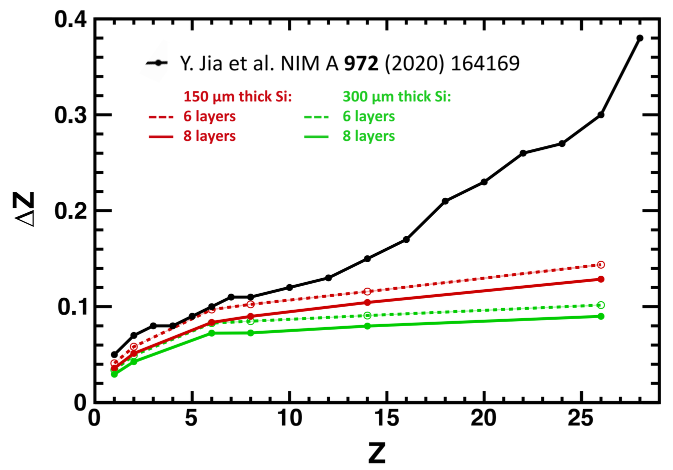
Birks saturation



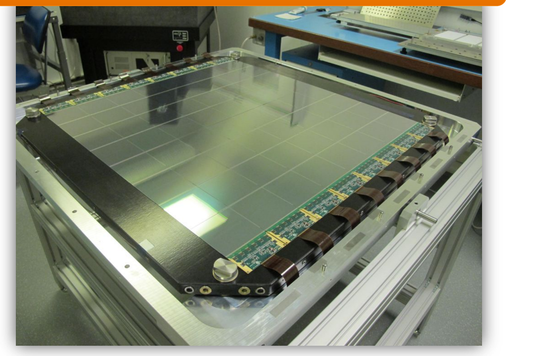
SCD

- It is the outermost detector to avoid earlier charge-change interactions.
- It is finely segmented to minimize the contamination of backscattered particles in the charge measurement.
- Design based on the DAMPE Silicon-Tungsten tracker converter.

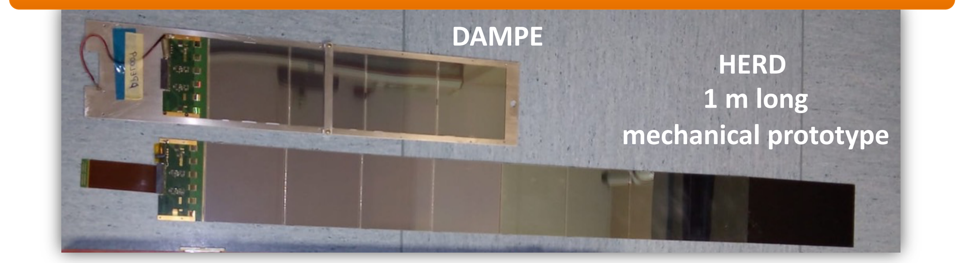
Charge resolution for Montecarlo ^{1}H, ^{4}He, ^{12}C, ^{16}O, ^{28}Si, ^{56}Fe of 10 GeV/n



1 DAMPE tracking layer = 16 ladders

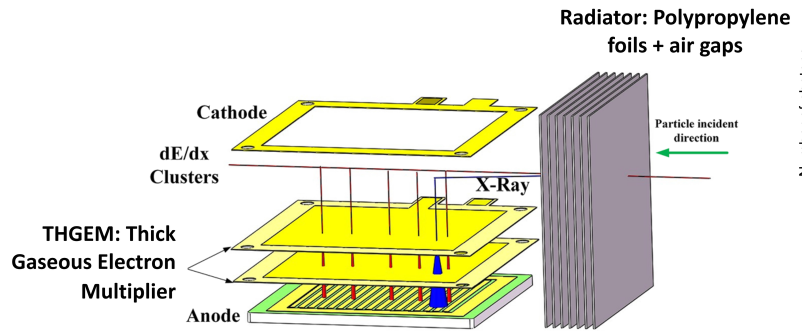


1 DAMPE ladder = 4 single-sided Silicon micro-Strip Detectors (SSDs)

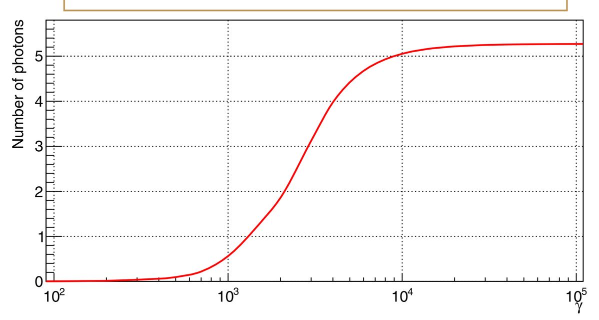


TRD

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



Number of TR photons as a function of the Lorentz factor



- TRD response calibrated using [0.5 GeV, 5 GeV] electrons in space (and beam test).
- CALO response calibrated using [1 TeV, 10 TeV] protons from TRD.