Progress of HERD

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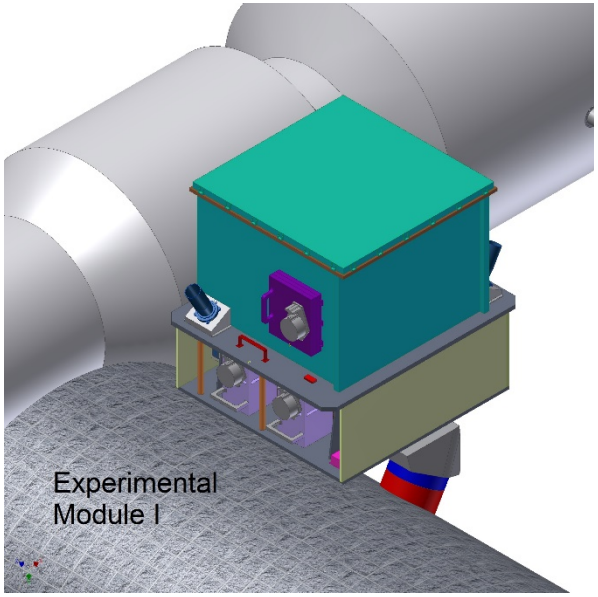
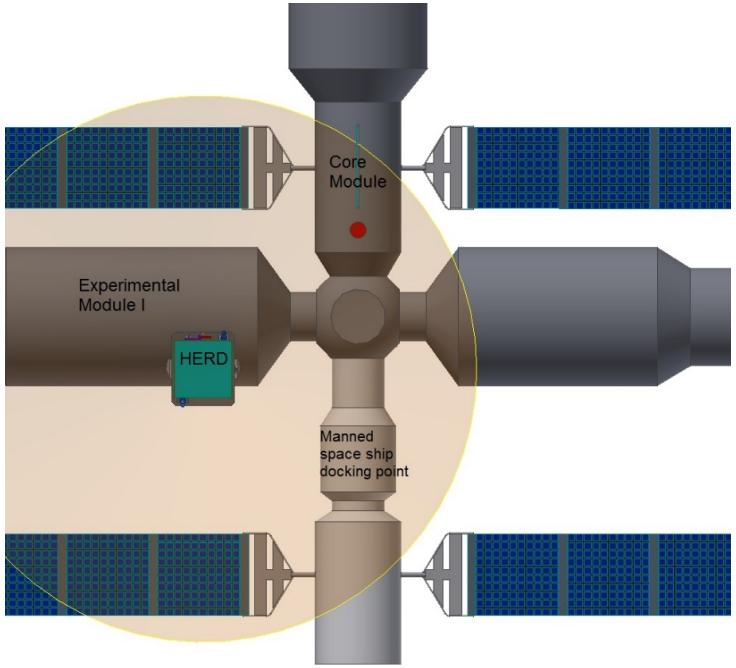
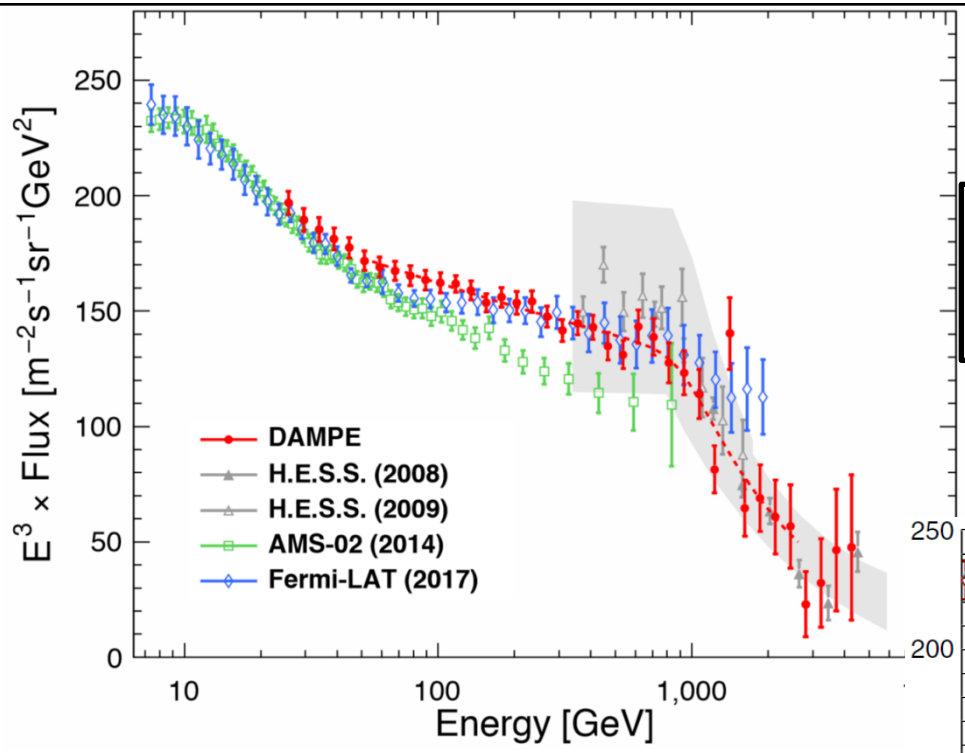
HERD Concept

- HERD: a flagship and landmark scientific experiment onboard the China's Space Station
- Sciences
  - Indirect dark matter search with unprecedented sensitivity
  - Precise cosmic ray spectrum and composition measurements up to the knee energy
  - Gamma-ray monitoring and full sky survey

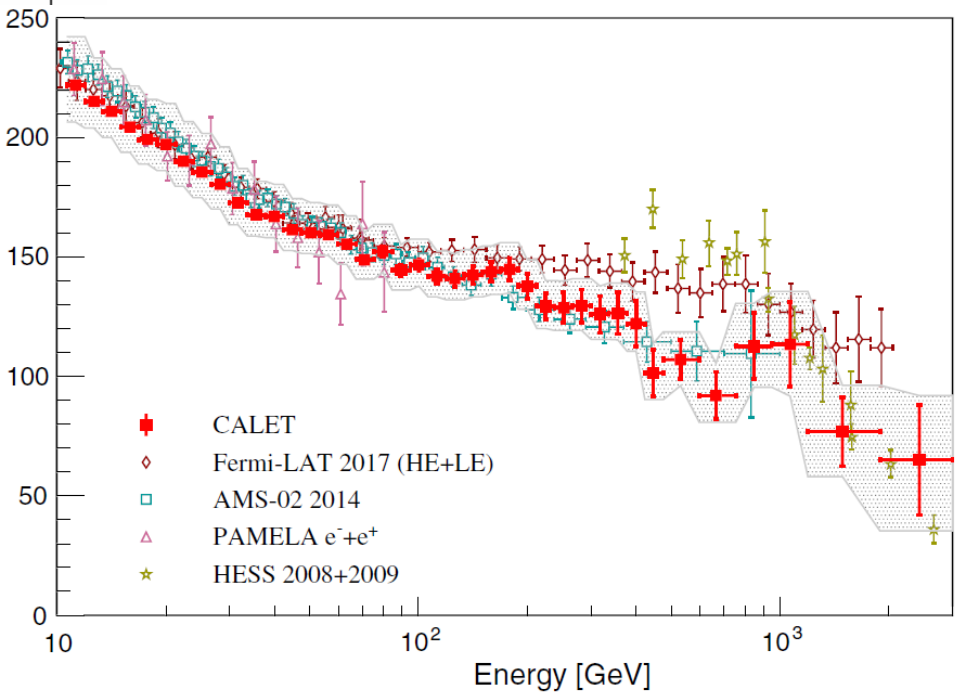




Status of electron spectrum measurements

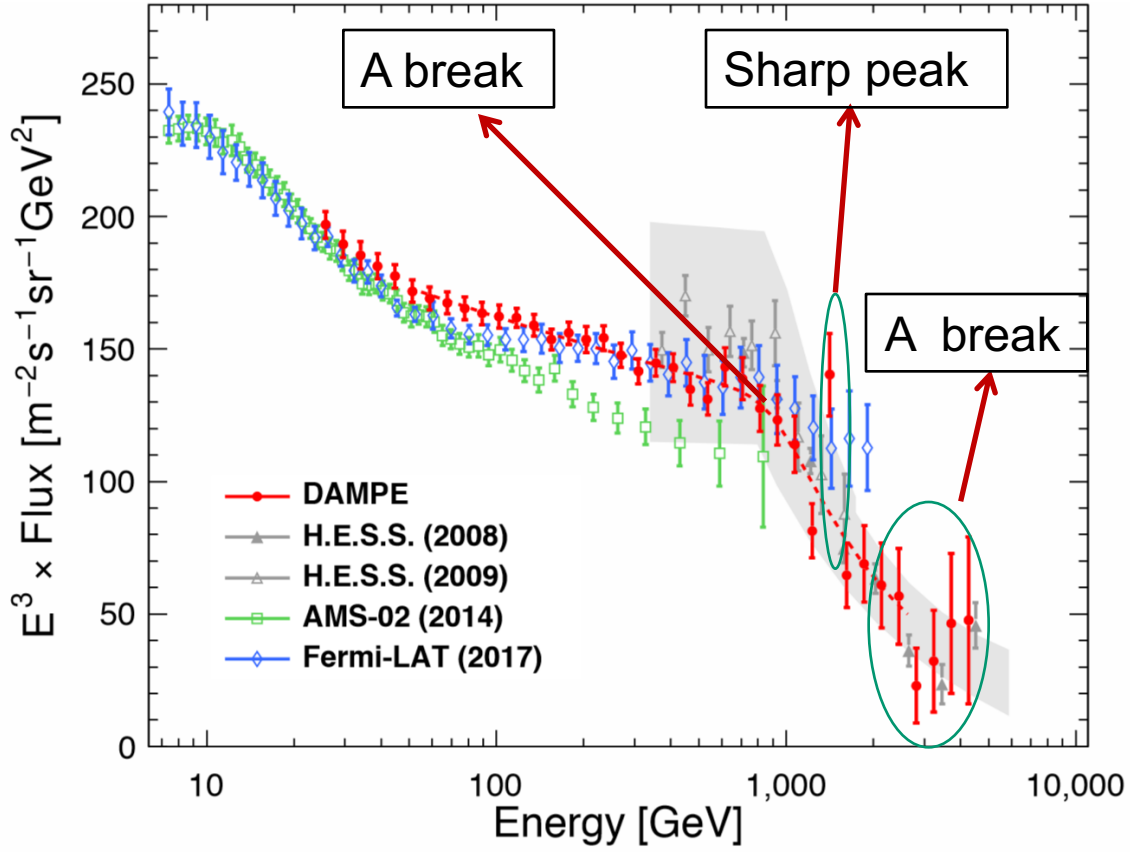


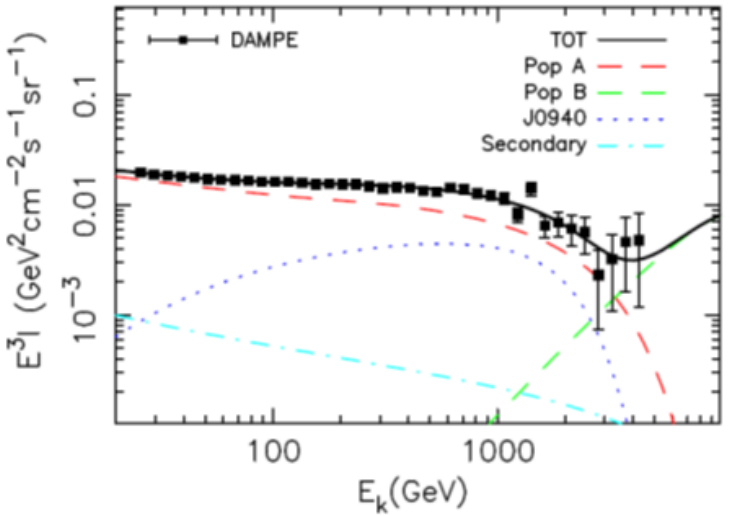
Four direct measurements with three results!



Latest DAMPE result

- A ‘knee’ is first measured at the electron spectrum
- A possible ‘sharp peak’ is detected
- A possible structure at the high energy end of the spectrum $e^- + e^+$



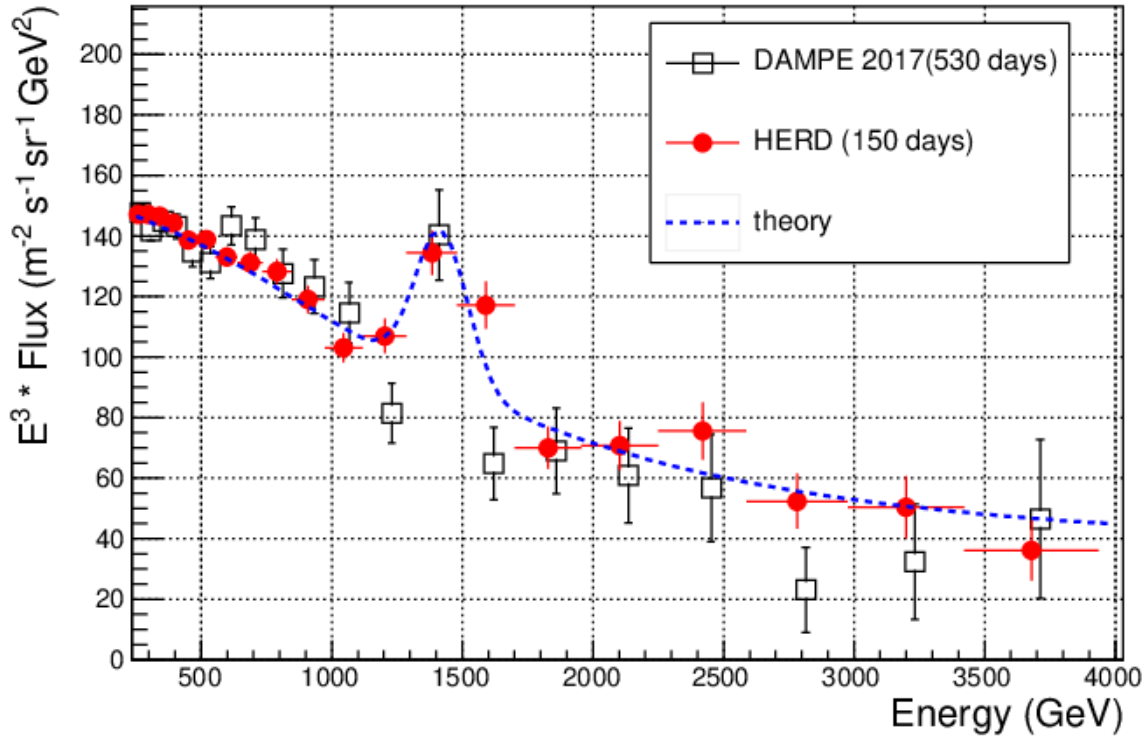


The knee at ~1 TeV is naturally explained by a SNR acceleration and release model; the break at high energy is induced by cosmic ray electron emission at the upstream.

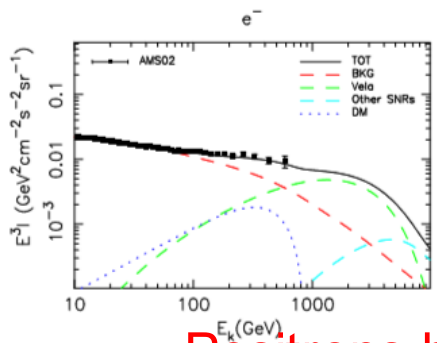
Fang et al. APJ 854 (2018), 57

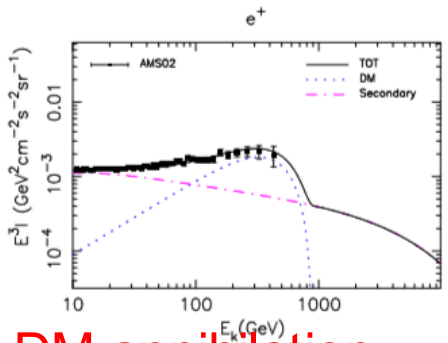
1. Measure the total e+- spectrum

- This is an obvious objective since the present measurements are not consistent
- To test the sharp peak at the DAMPE spectrum which is ~ 3σ but stimulated a lot of interests

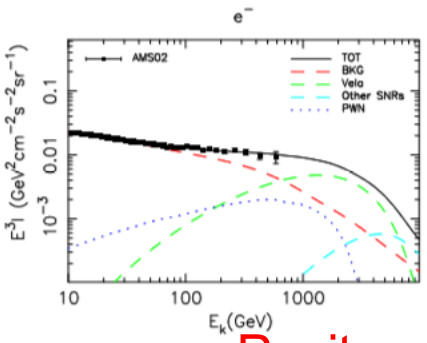


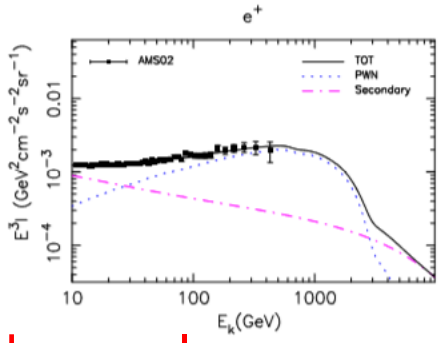
2. Fine structure in the spectrum



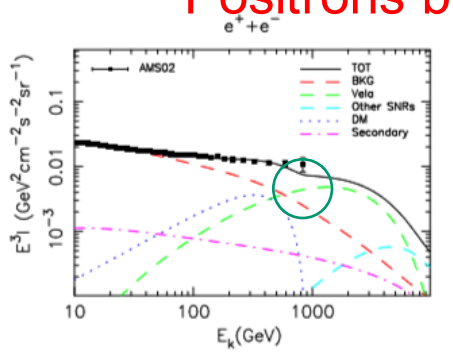


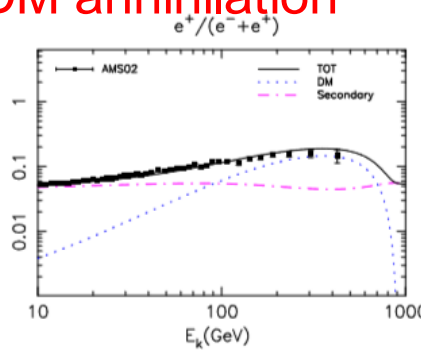
Positrons by DM annihilation

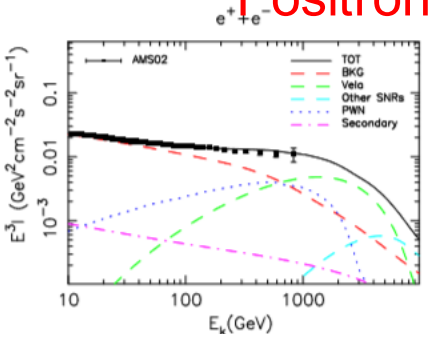


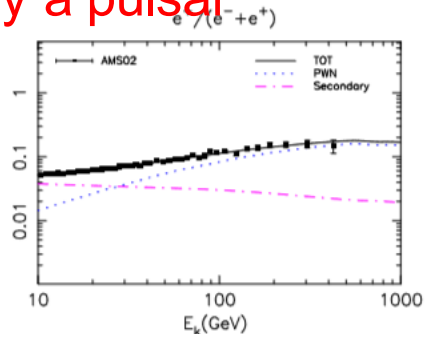


Positrons by a pulsar

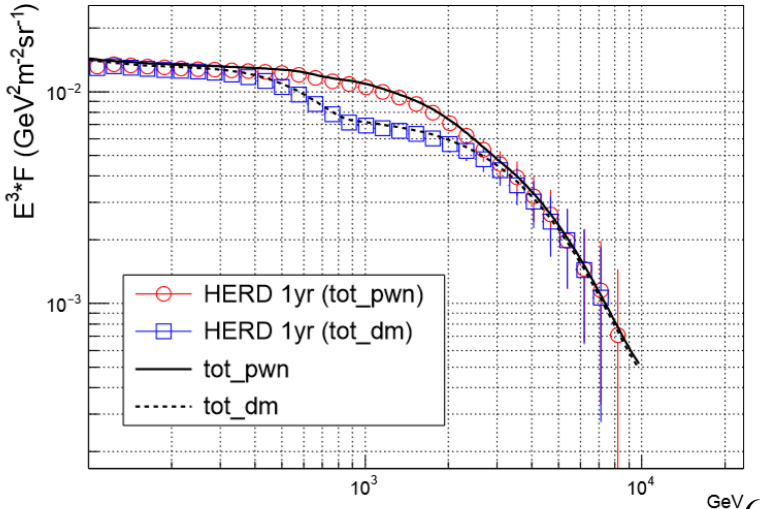




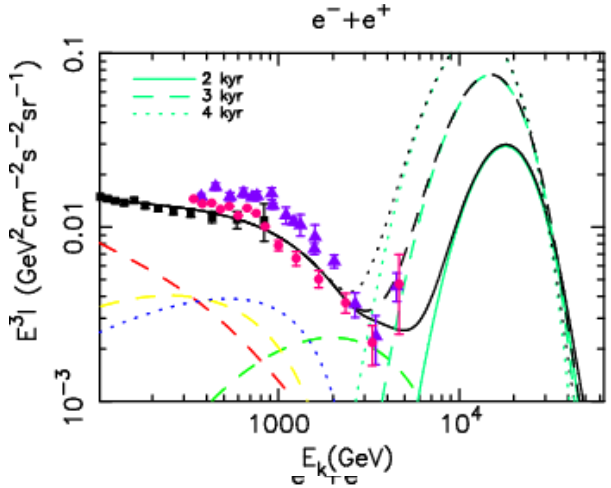


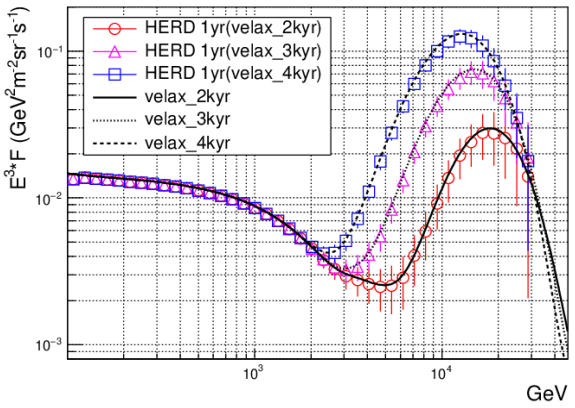


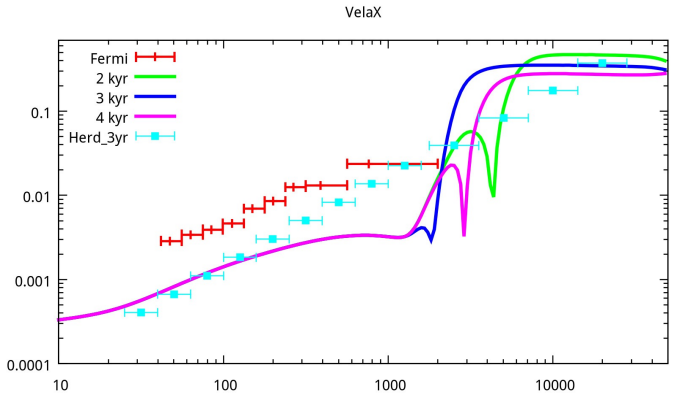
DM or pulsar can induce different shape of spectrum cutoff which induces a fine structure at the total spectrum. Simulation shows HERD can find such a feature in ~1 yr & determine the cutoff energy → DM mass!

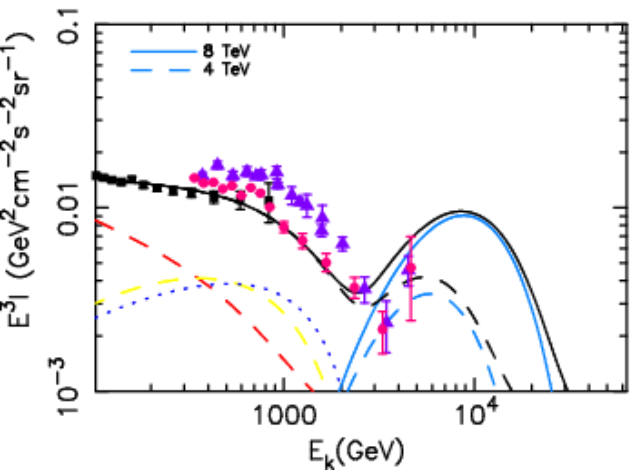


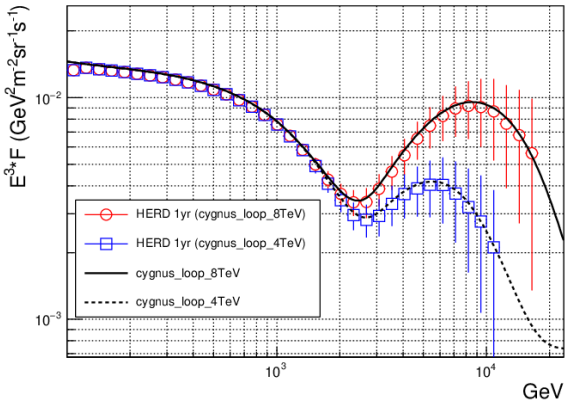
3. Detect the spectra & anisotropy from nearby sources

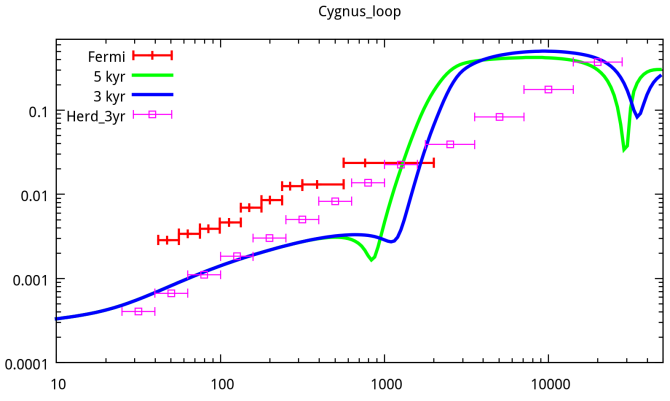






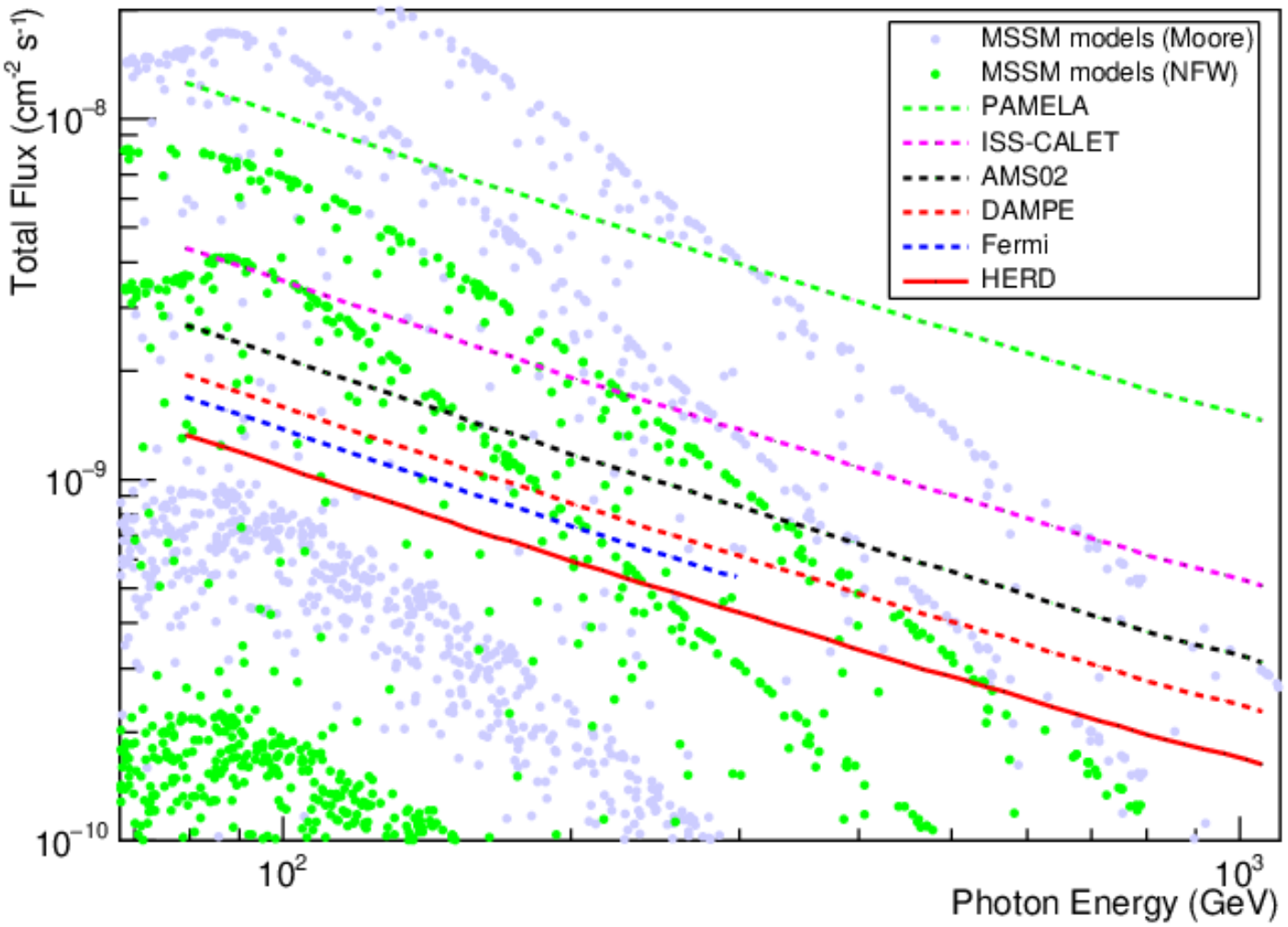






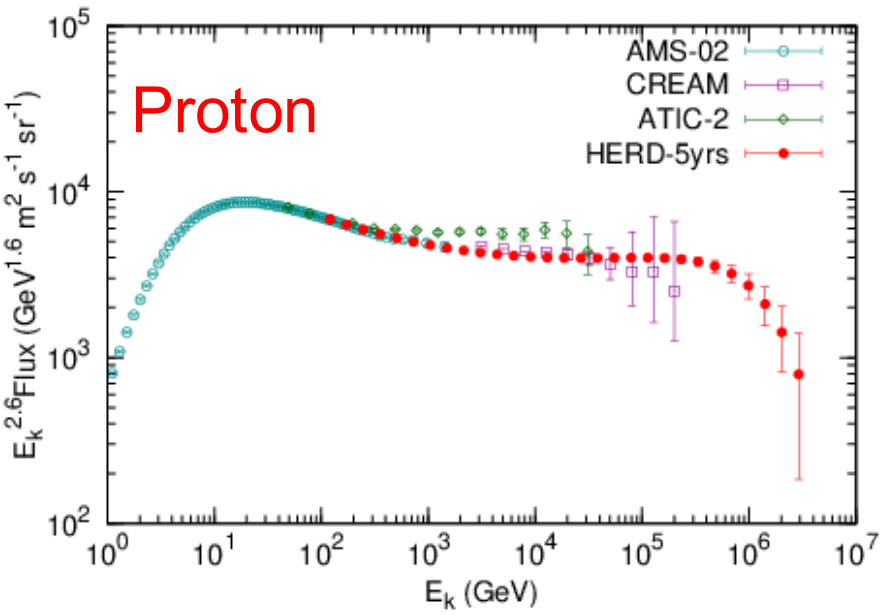
HERD can detect the bump > 10 TeV from the local sources → a pulsar origin of positron excess

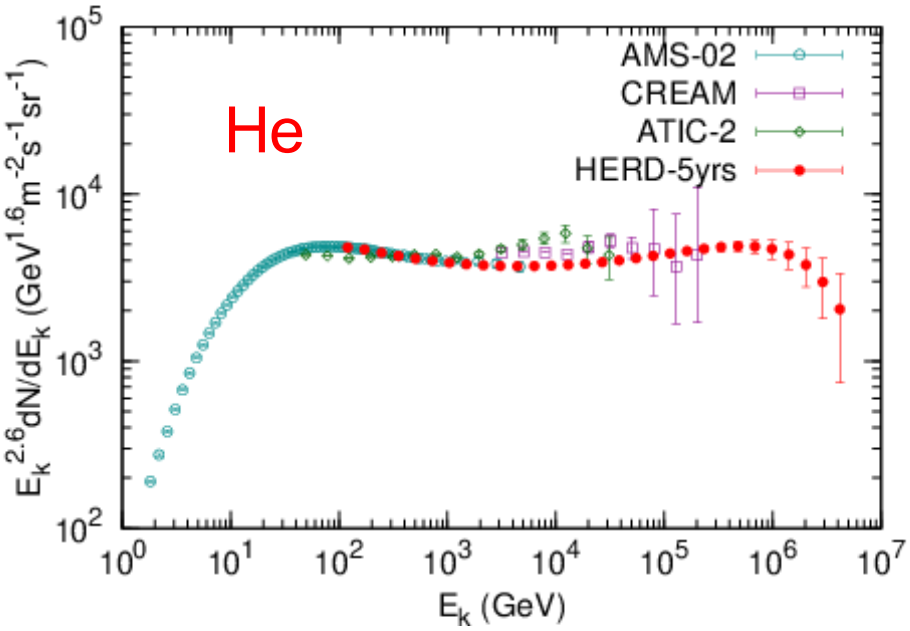
Sensitivity for γ-line of different experiments



PAMELA: 2006-2016 CALET: 2015-2020; AMS: 2011-2024;
DAMPE: 2015-2020; Fermi: 2008-2018; HERD: 1 year

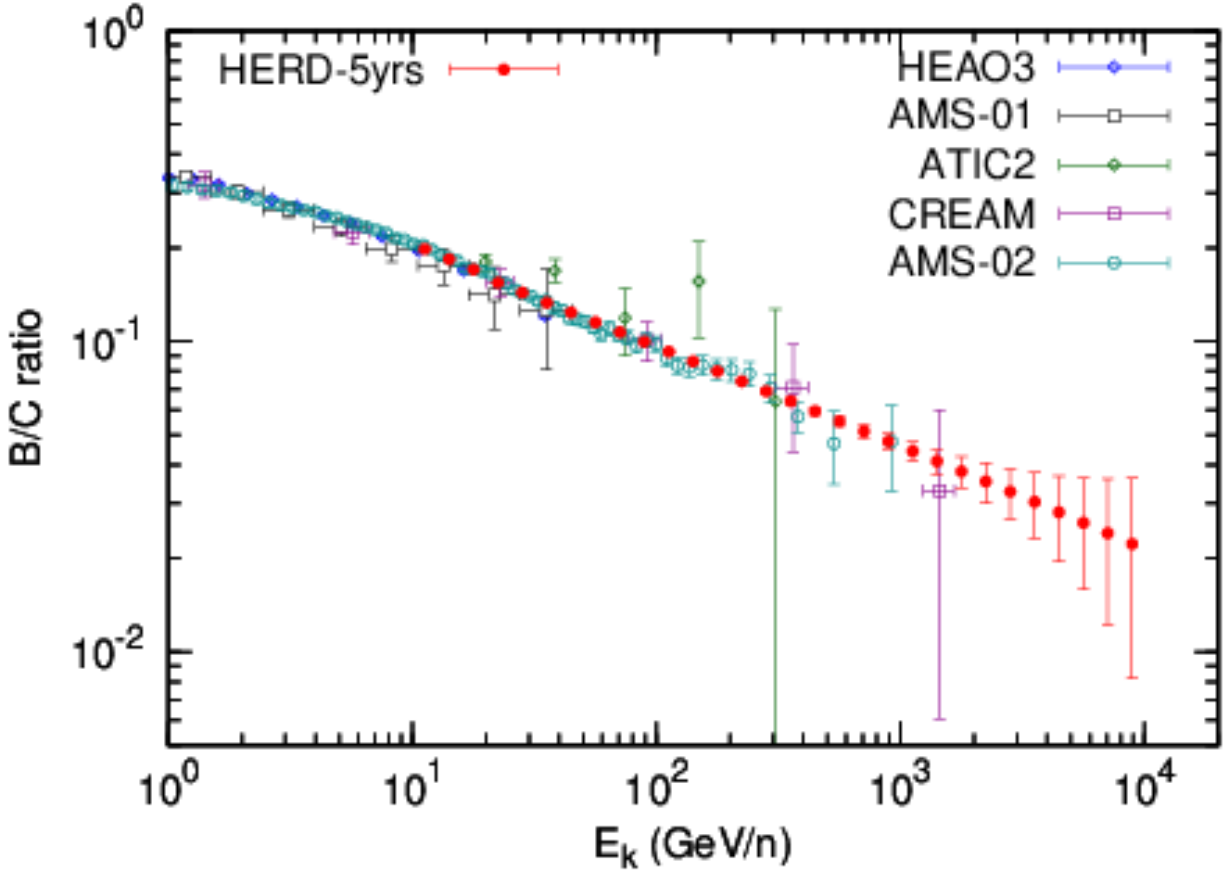
Expected HERD Proton and He Spectra





- Well extended to PeV energies
- Critically test any structures between TeV and PeV
- Clearly reveal the knee of light components (Z- or A-dependence)

B/C measurement at HERD



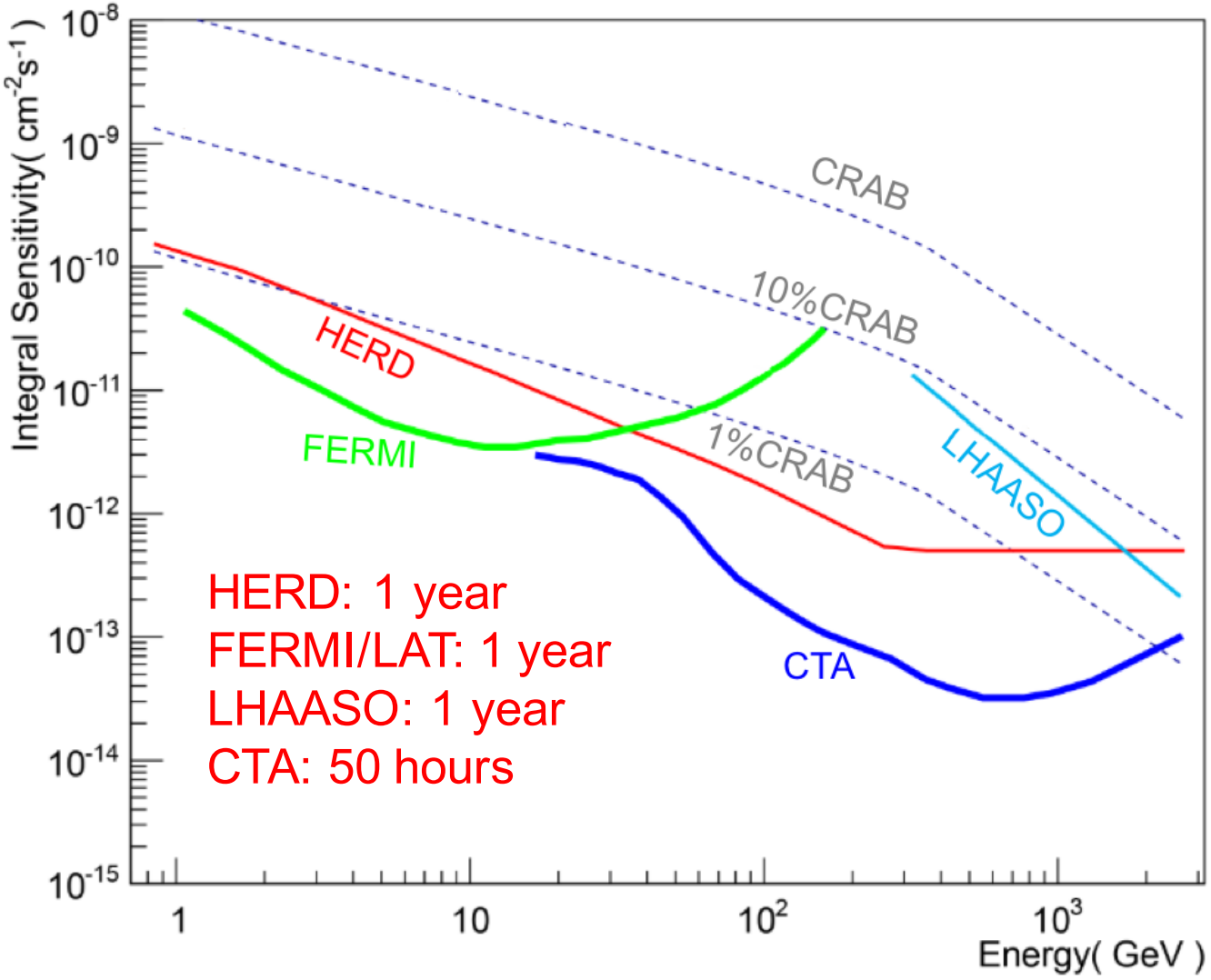
B/C is adopted to determine the CR propagation parameters and origin of break at the primary nuclei spectra

HERD's gamma-ray science goals

- Search for signatures of dark matter
- Studies of Galactic and extragalactic gamma-ray sources
- Galactic and extragalactic diffuse emission
- Gamma-ray transients, e.g. gamma-ray bursts, flares

Gamma-ray sky survey

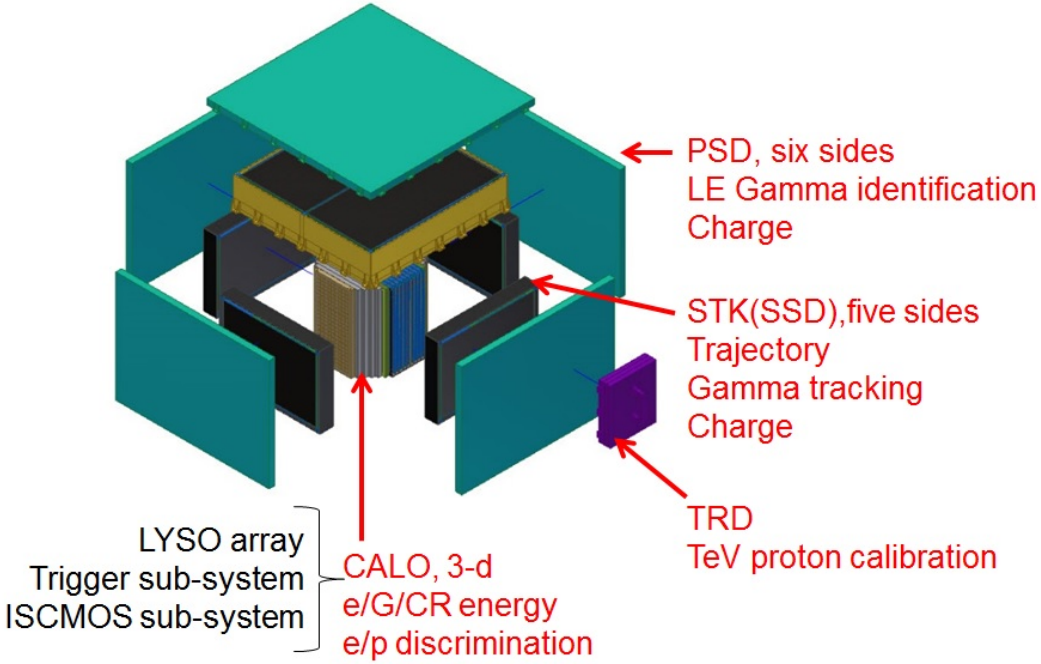
Expected HERD gamma-ray sky survey sensitivity (5σ)



HERD + LHAASO + CTA!

Science requirement

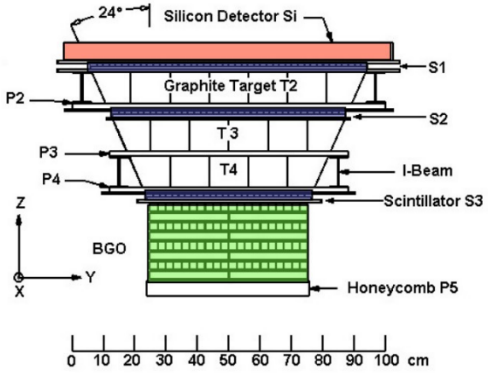
- Large exposure (i.e. > m^2sr & 10 yrs) -> 3-d CALO
- High particle discrimination power -> Tracker, PSD
- O(%) energy resolution for e/gamma -> Full absorbed CALO
- sub-degree angle resolution for e/gamma -> Tracker
- O(20-30%) energy resolution for CRs -> Large N.I.L CALO
- Real-time identification of GeV gamma-rays -> PSD
- In-orbit instrumental calibration -> TRD



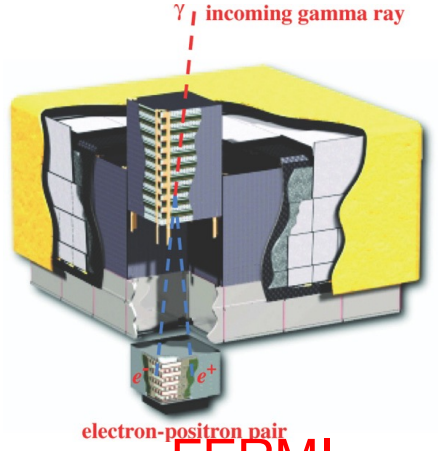
HERD specifications

Item	Value
Energy range (e/γ)	10 GeV-100 TeV(e); 0.5 GeV-100 TeV (γ)
Energy range (CR)	30 GeV－3 PeV
Angle resolution	0.1 deg.@10 GeV
Charge meas.	0.1-0.15 c.u
Energy resolution (e)	1%@200 GeV
Energy resolution (p)	20%@100 GeV - PeV
e/p separation	~10^{-6}
G.F. (e)	>3 m^2sr@200 GeV
G.F. (p)	>2 m^2sr@100 TeV
Pointing	Zenith
Field of View	+/-70 deg (targeting +/-90 deg)
Measure accuracy of attitude	<0.1 deg
Measure accuracy of angular speed	<0.005 deg/s
Lifetime	>10 years

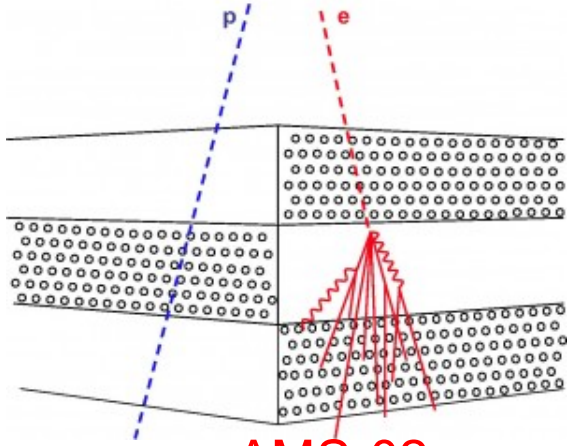
CALO - from bars to cubes



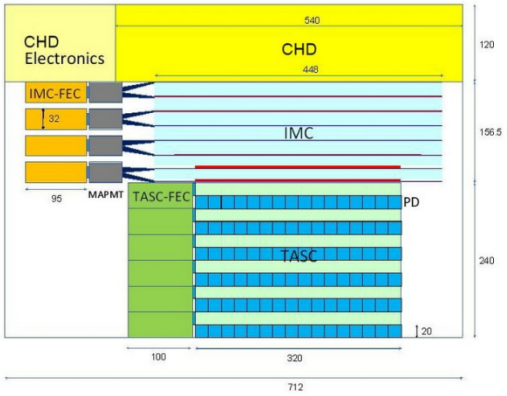
ATIC



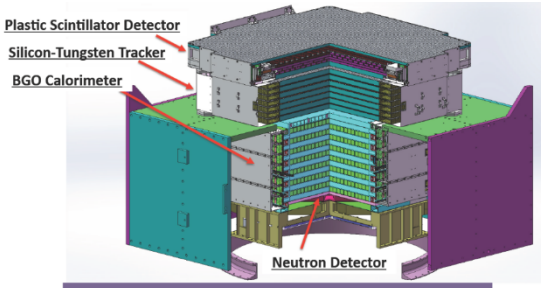
FERMI



AMS-02

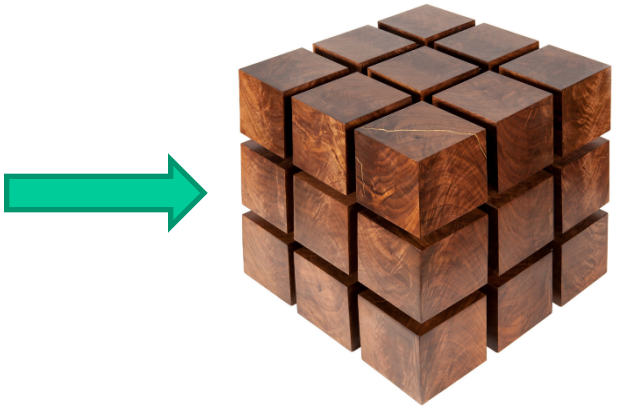


CALET



W converter + thick calorimeter (total 33 X_0) + precise tracking + charge measurement ➡ high energy γ-ray, electron and CR telescope

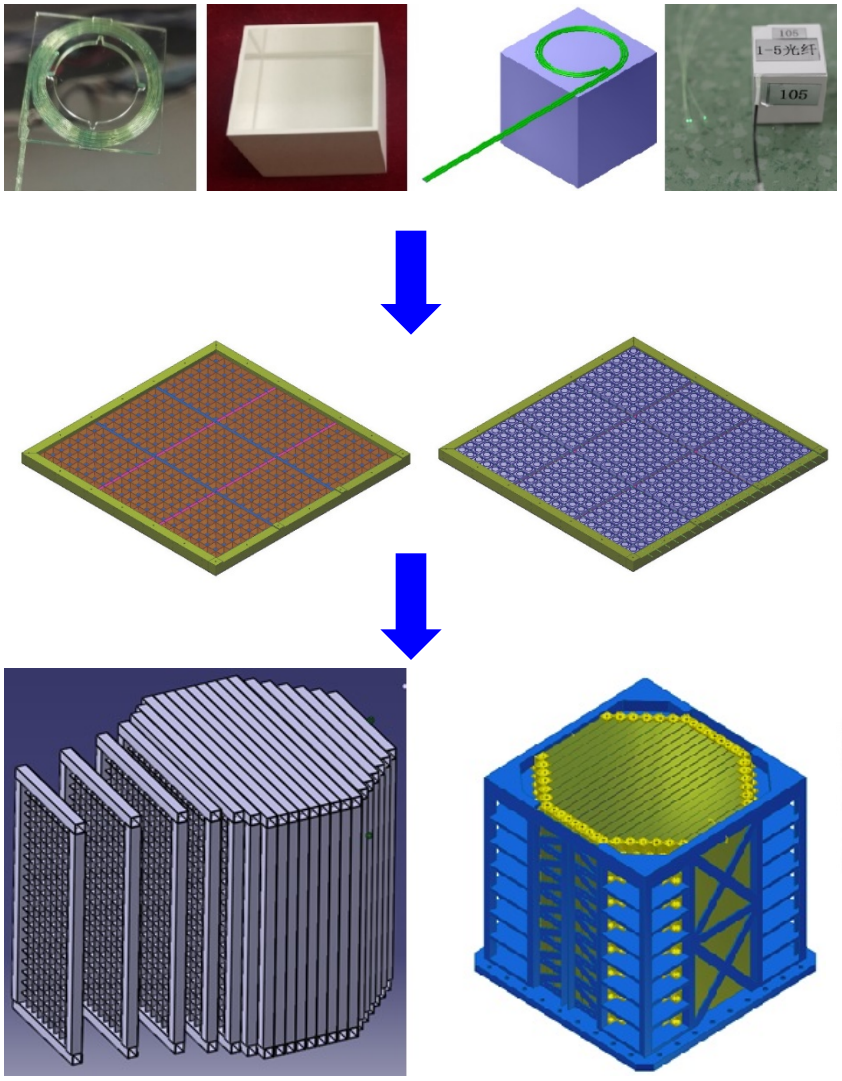
DAMPE



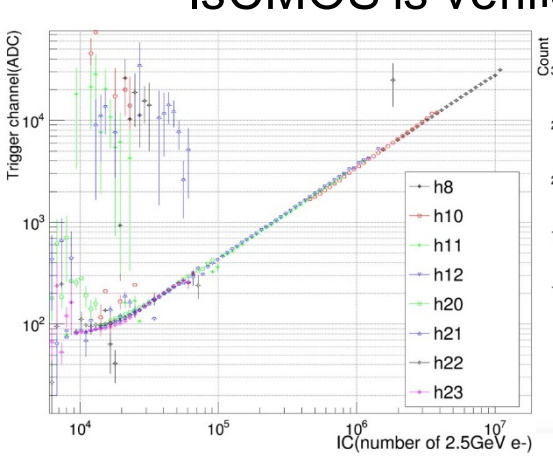
HERD

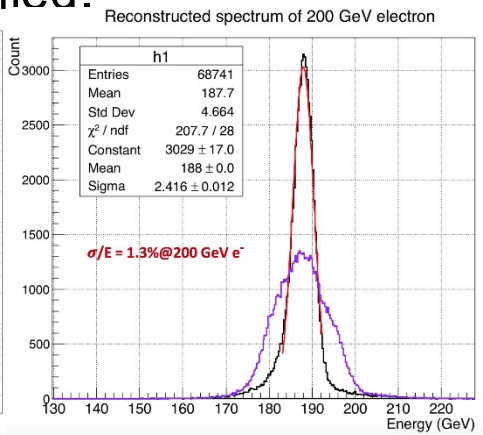
3-d calorimeter could significantly increase GF, improve particle discrimination and reduce systemic error

CALO Payload



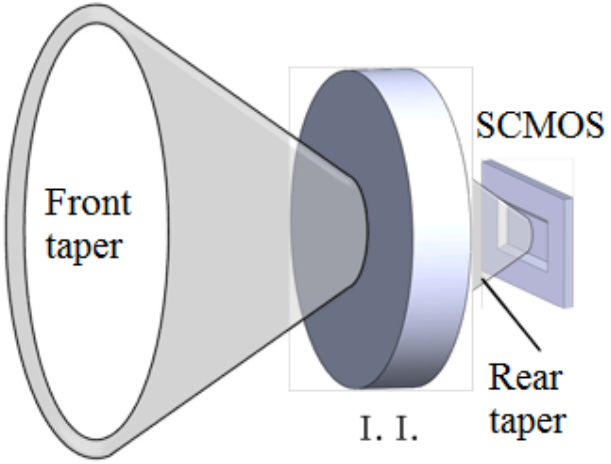
- CALOrimeter (3 N.I.L. and 55 R.L.)
  - A 3-d crystal array (~7500 LYSO)
  - IsCMOS camera
  - Trigger sub-system
- Novel readout method
  - WLSF + IsCMOS
  - Linearity of LYSO+WLSF is verified.
  - Energy measurement of WLSF + IsCMOS is verified.





CALO – ISCMOS sub-system

- IsCMOS to collect WLSF photons
  - Faster: Global shutter; ROI readout
  - Lower noise
- Accurate energy measurement
  - 1 fiber ~ 20*20 pixels
  - Saturation effect to increase DR



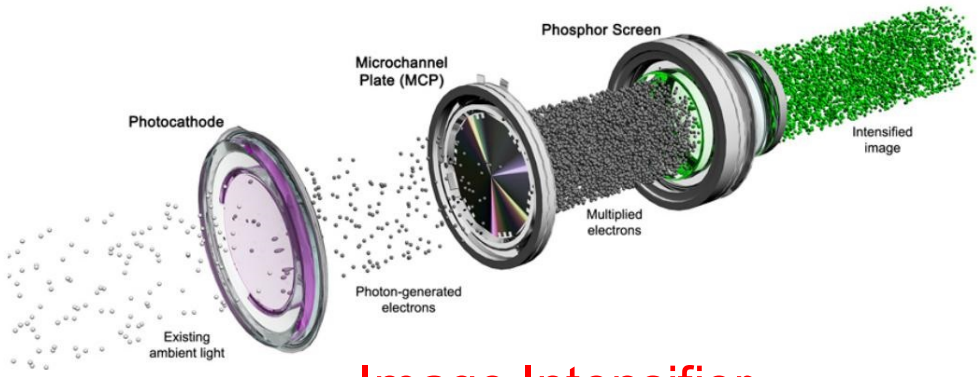
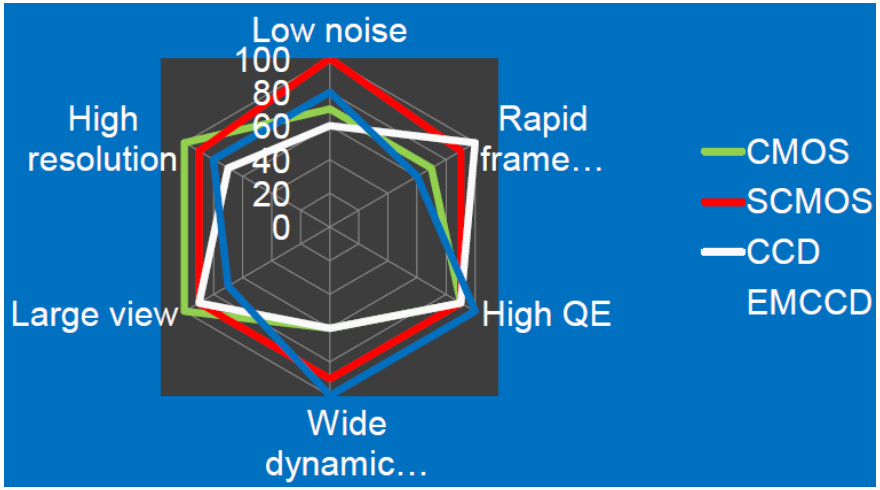


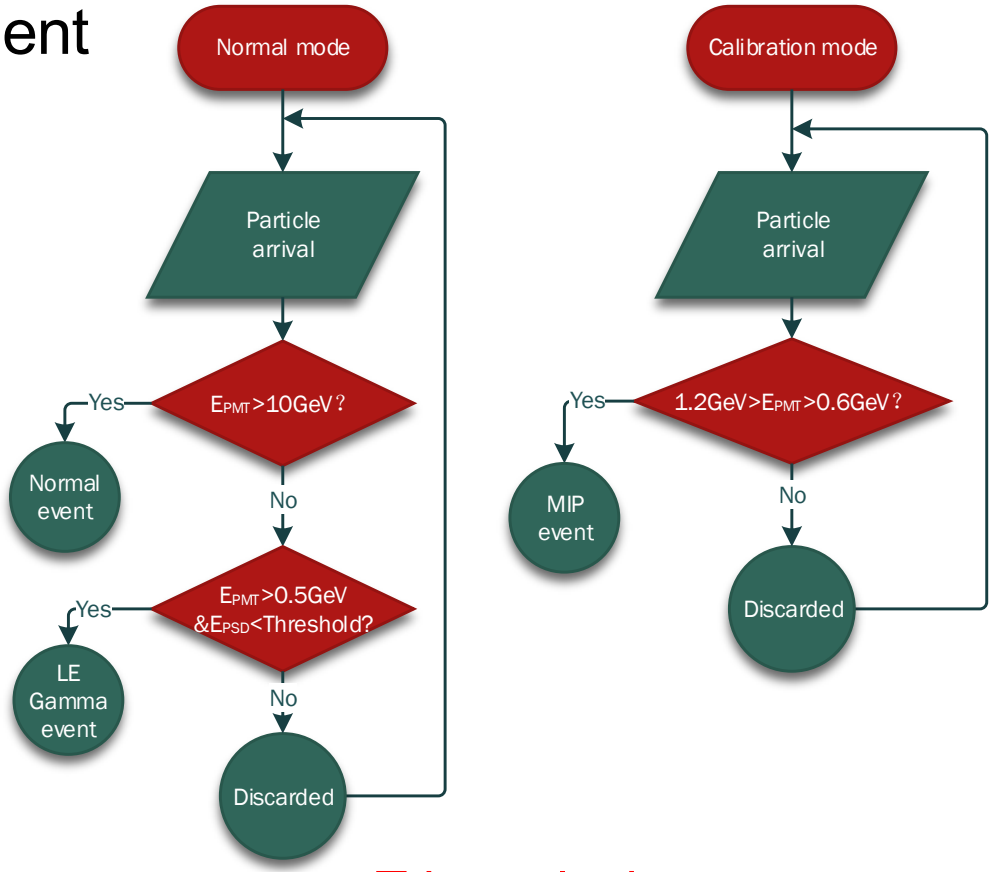
Image Intensifier



CALO – trigger sub-system

- To provide common trigger signal
  - Core/shell regions + PMTs
- Coarse energy measurement

- HERD working mode
  - Normal mode (150cps)
    - HE trigger
    - LE photon
    - LE electron
    - Unbiased trigger
  - Calibration mode (350cps)
    - MIP trigger

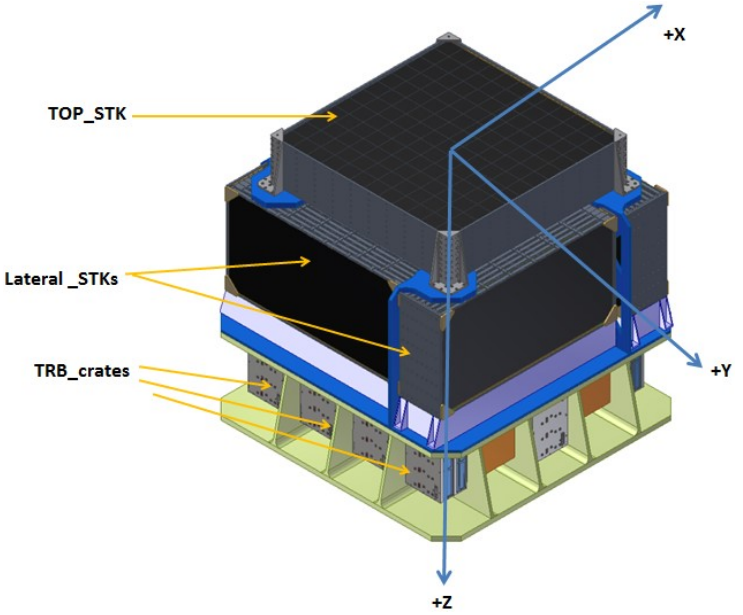


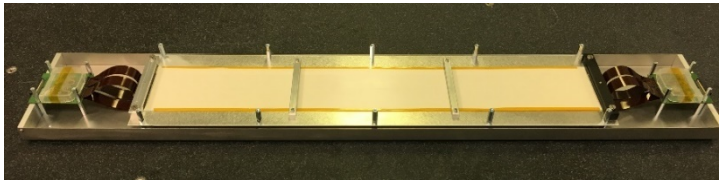
Trigger logic

STK payload

- Charge measurement
- CR/e trajectory
- Gamma ray conversion & tracking

Item	Value
Coverage ratio	>80%
Z measurement	Z = 1 - 20 (26); 0.1-0.15 c.u
Angle resolution	0.1 deg.@10 GeV
Layers of SSD	6 X/Y (top);3/6 X/Y (Lateral)
Active converter	1 R.L.
Dead time	<2 ms
Working mode	External trigger
Eff. Area (top)	~133 cm*133 cm
Eff. Area (lateral)	~114 cm*66.5 cm
Channels	~240,000



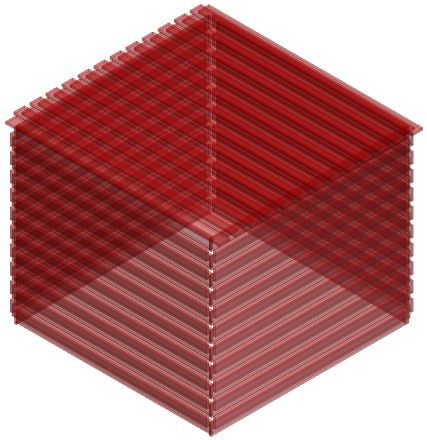


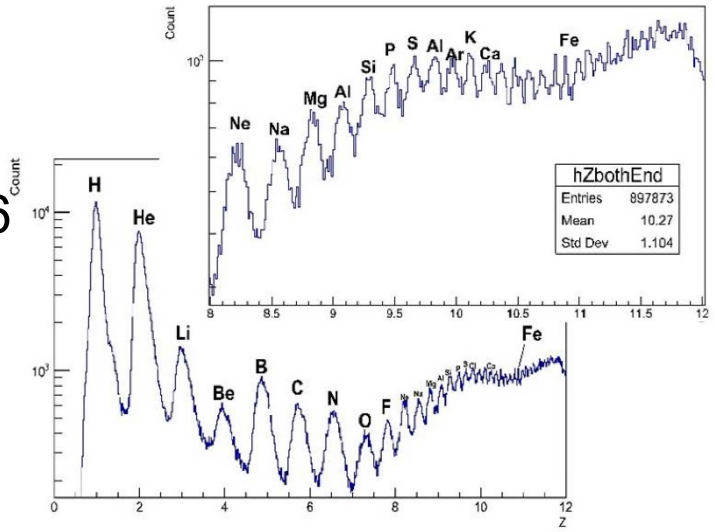
DAMPE STK ladder

Alternative approach: Fiber Tracker(FIT) using SiPMs

PSD payload

- Low energy gamma identification
- Charge measurement
- Design
  - 1 X/Y layer on top and 4 lateral sides
    - X layer for LE photon trigger
    - X & Y layers for Z measurement and e/gamma discrimination
  - 1 X layer on bottom side
  - SiPM + IDE3380 ASIC
    - Low & high range to cover Z=1-26
    - Redundancy SiPMs



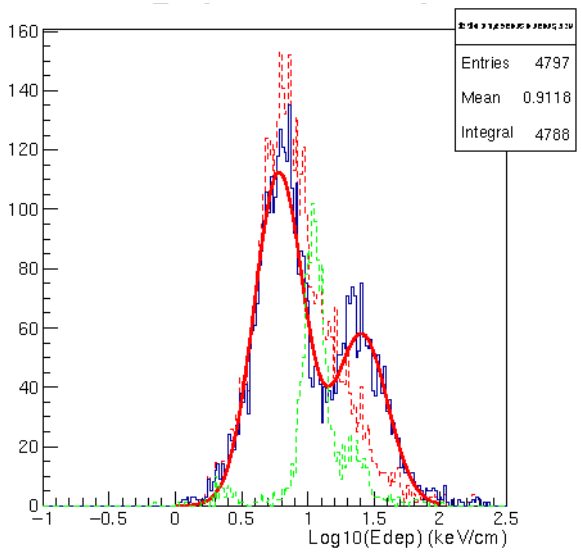


PS bar readout by
2*(3+1) SiPMs

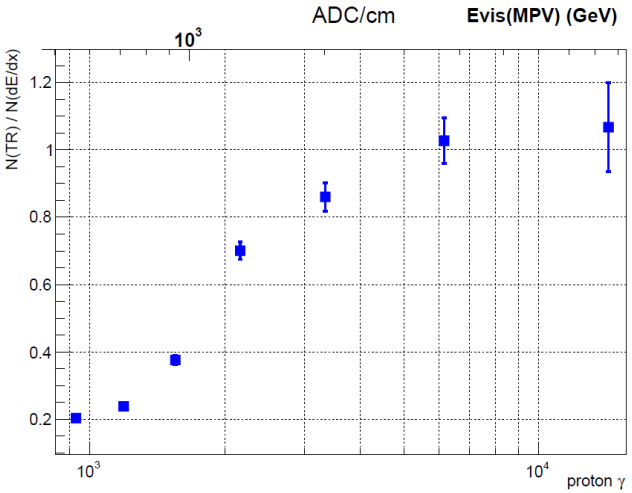
Alternative approach: tile geometry

TRD payload

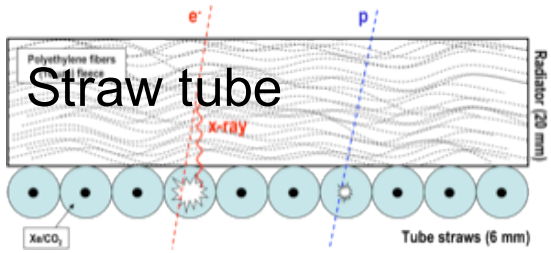
- Energy calibration of TeV protons and other nuclei
- A complete calibration in 2-3 months in-orbit operation

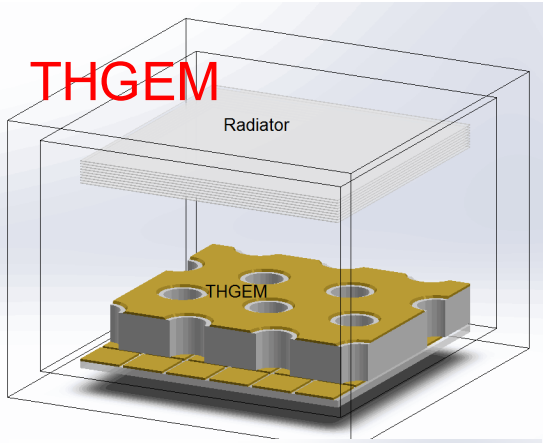


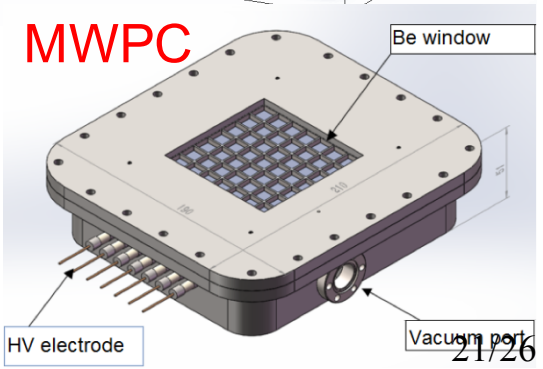
MWPC energy response to [2.25, 2.5] TeV protons



2 months simulated observation, ~6300cm^2 TRD.







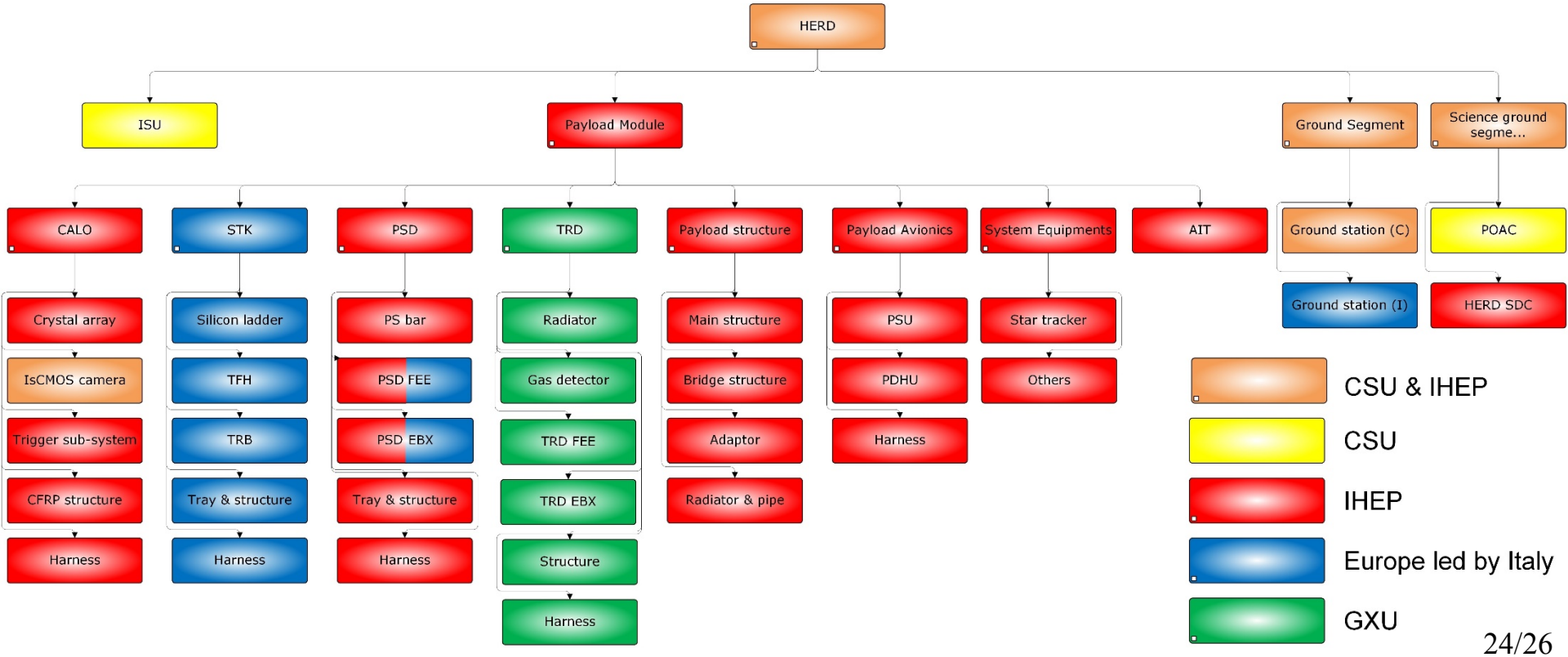
International collaboration (120+ colleagues)

Progress & schedule

- Joint HERD working group including CSU, IHEP, INFN sections, etc. was established in Jan. 2017.
- Agreement between the Italian Space Agency and the China Manned Space Agency was signed in Feb. 2017
- Letter of Intent for the collaboration on the design and implementation of the HERD scientific instrument between IHEP and INFN was signed in May 2017
- Joint Working Group on space science and utilization between ASI and CSU in Feb. 2018, including HERD JWT
- To have HERD proposal reviewed by a RB jointly organized by CSU and ASI in May 2018
- To submit proposal to CSU/CMSA and ASI for approval of China-Italy HERD collaboration
- To sign MoU on China-Italy HERD collaboration
- To sign MoUs with other agencies and ESA
- HERD formally kicked-off early 2019
- HERD launch around 2025

HERD product tree (current)

- HERD is jointly led by CSU and IHEP, who take respective responsibilities in the engineering and payload/science of the project.
- CMSA: launcher, cargo ship, launching, operation and service, data service
- CSU: general design of HERD and coordination with other systems.
- ASI/INFN: lead European participation with payload/science



Summary

- HERD: China-led mission with key European contribution led by Italy, & flagship and landmark scientific experiment, taking full advantages of China's Space Station
- Important and frontier scientific objectives in DM search, CR observation and gamma-ray astronomy
  - Distinguish between possible DM and astrophysical origins of positron/electron excess measured by AMS-02
  - Confirm & distinguish possible origins of the features in high-E electron spectrum found by DAMPE, and extend the energy range up to 100 TeV
  - Direct measurements of CR composition up to PeV
  - Large acceptance & sensitive high-E γ-ray sky monitoring
- Novel 3-D calorimeter, verified at two CERN beam tests
- Expected launch time around 2025.