The High Energy cosmic-Radiation Detection (HERD) Facility onboard China's Space Station

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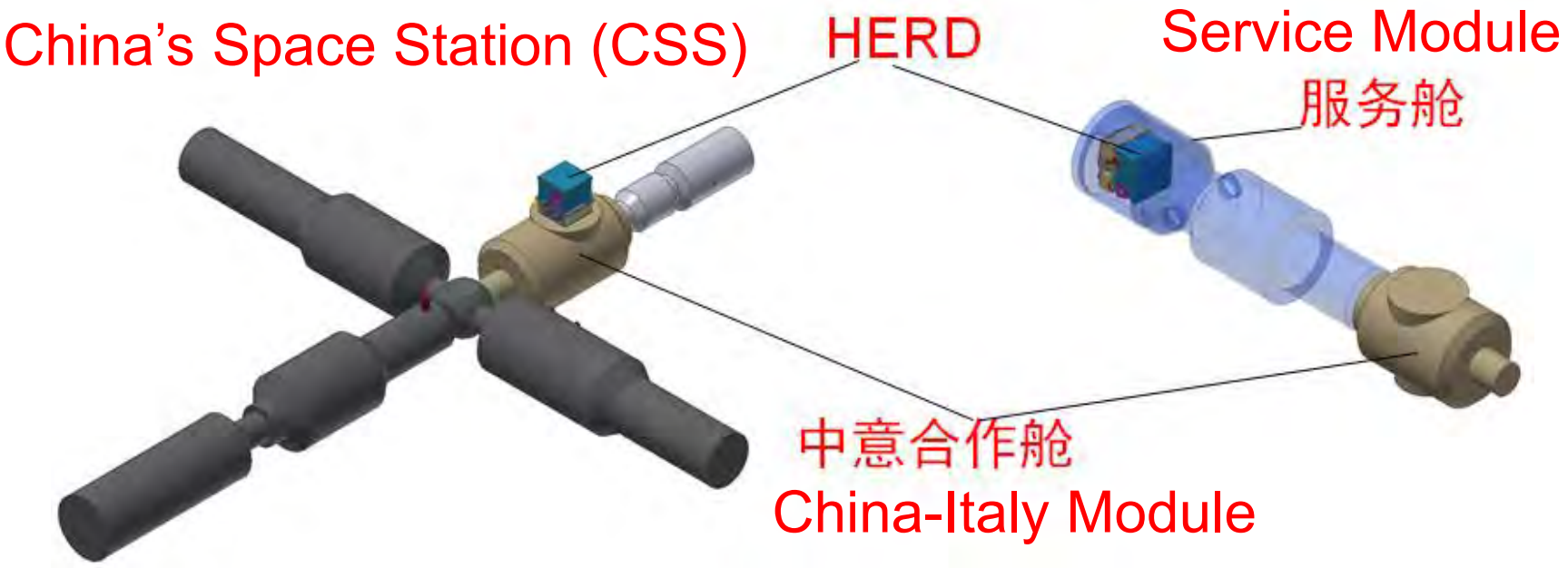
Progress report on behalf of the HERD International Consortium

High Energy cosmic-Ray Detection (HERD)

- HERD: flagship and landmark scientific experiment onboard the China's Space Station, China-led large international collaboration
- Main Scientific Objectives:
  - Dark matter: dark matter search with unprecedented sensitivity
  - Cosmic-ray: Precise cosmic ray spectrum and composition measurements up to the knee energy
  - Gamma-ray: Gamma-ray monitoring and full sky survey



Search for Dark Matter

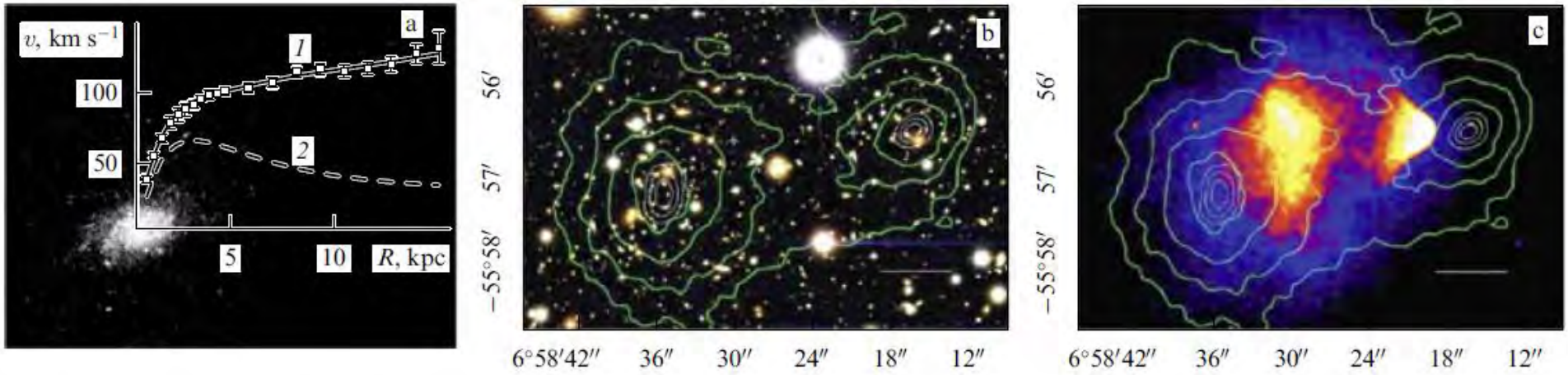


Figure 2. (a) Rotation curves for the M33 galaxy [4]: *1*, the observed curve, *2*, theoretical curve of the glowing galactic disk. (b) Optical and (c) X-ray images of cluster 1E0657-558 obtained with the Hubble and Chandra telescopes, respectively. The curves show mass density contours reconstructed by gravitational lensing [5]. Horizontal axes are the inclination angles, vertical axes are the ascention angles.

- Dark Matter exists
- Ratio of DM to ordinary matter generated from the extreme progress of the BIG BANG is 6:1.
- DM particle NOT found yet

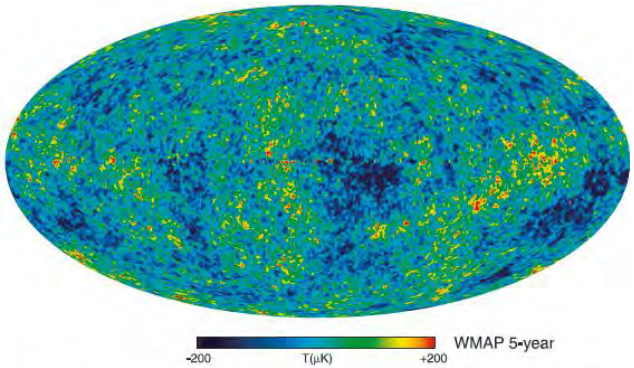
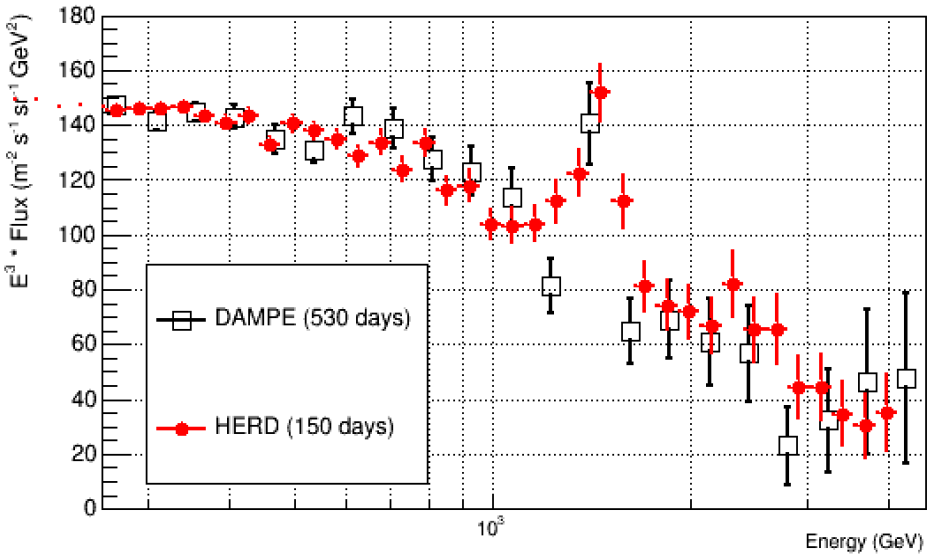


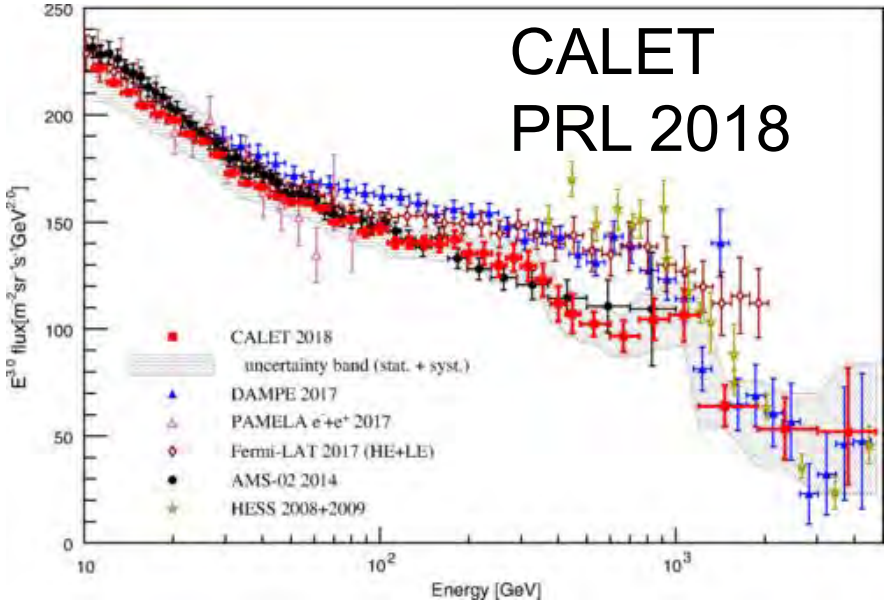
Figure 12. The foreground-reduced Internal Linear Combination (ILC) map based on the five year *WMAP* data.

Total e+/- spectrum

- HERD can confirm ~TeV features in the electron spectrum
- HERD can distinguish different origins of excess and new features in the electron spectrum.

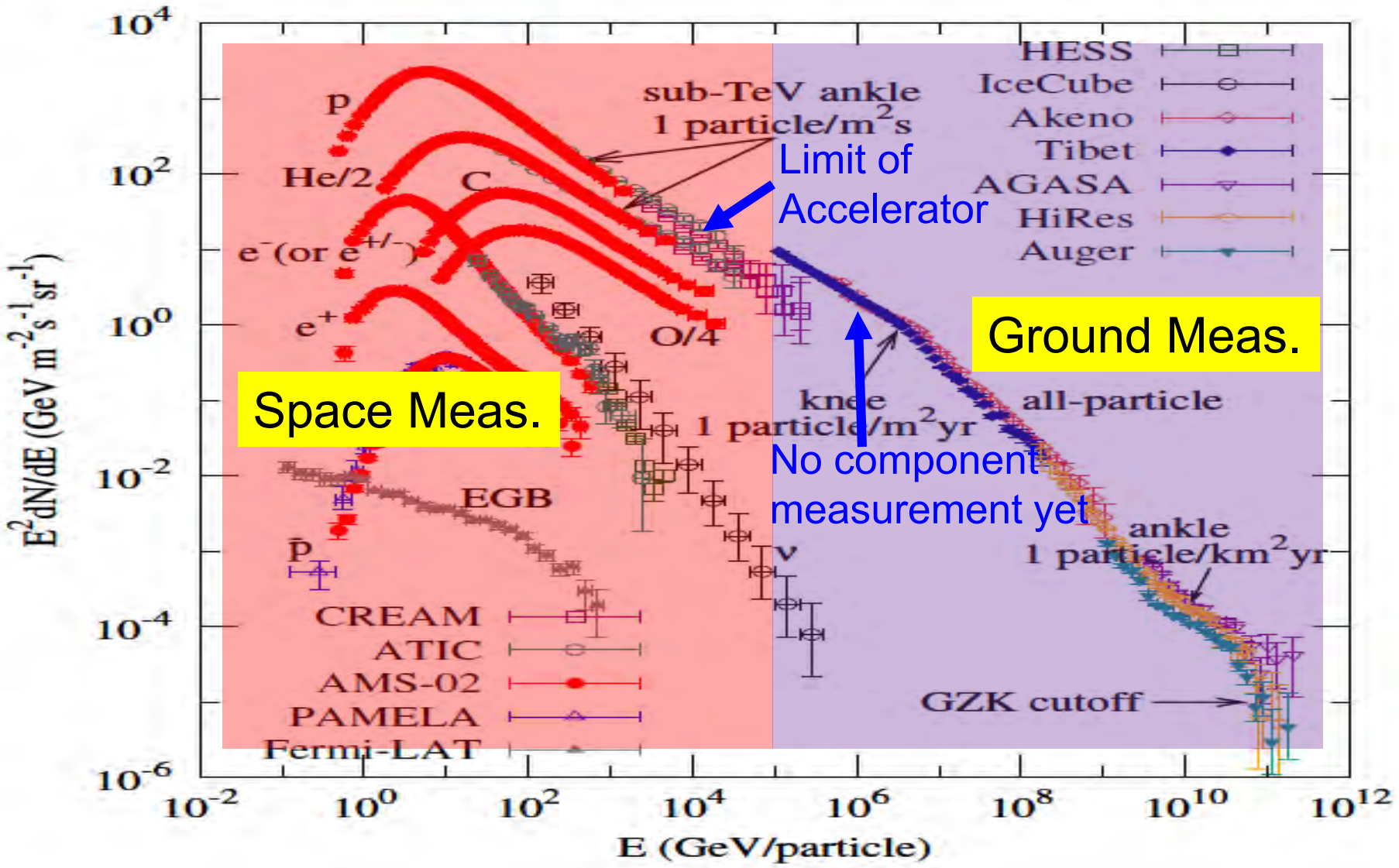


HERD can verify the sharp peak at the DAMPE spectrum in 6 month observation.

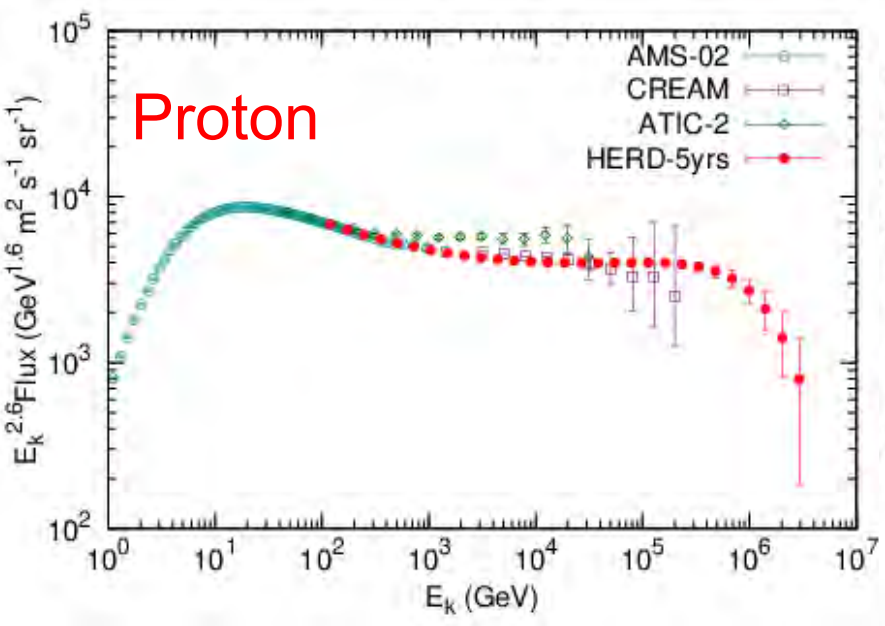


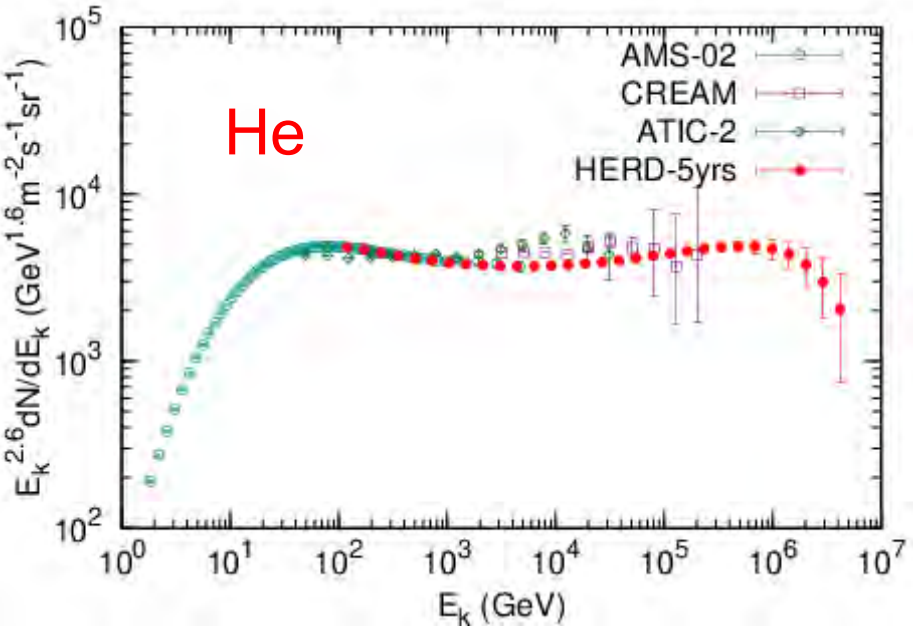
"The flux in the 1.4 TeV bin of DAMPE's spectrum is not compatible with CALET results at a level of 4σ significance, including the systematic errors from both experiments."

Cosmic-ray Physics



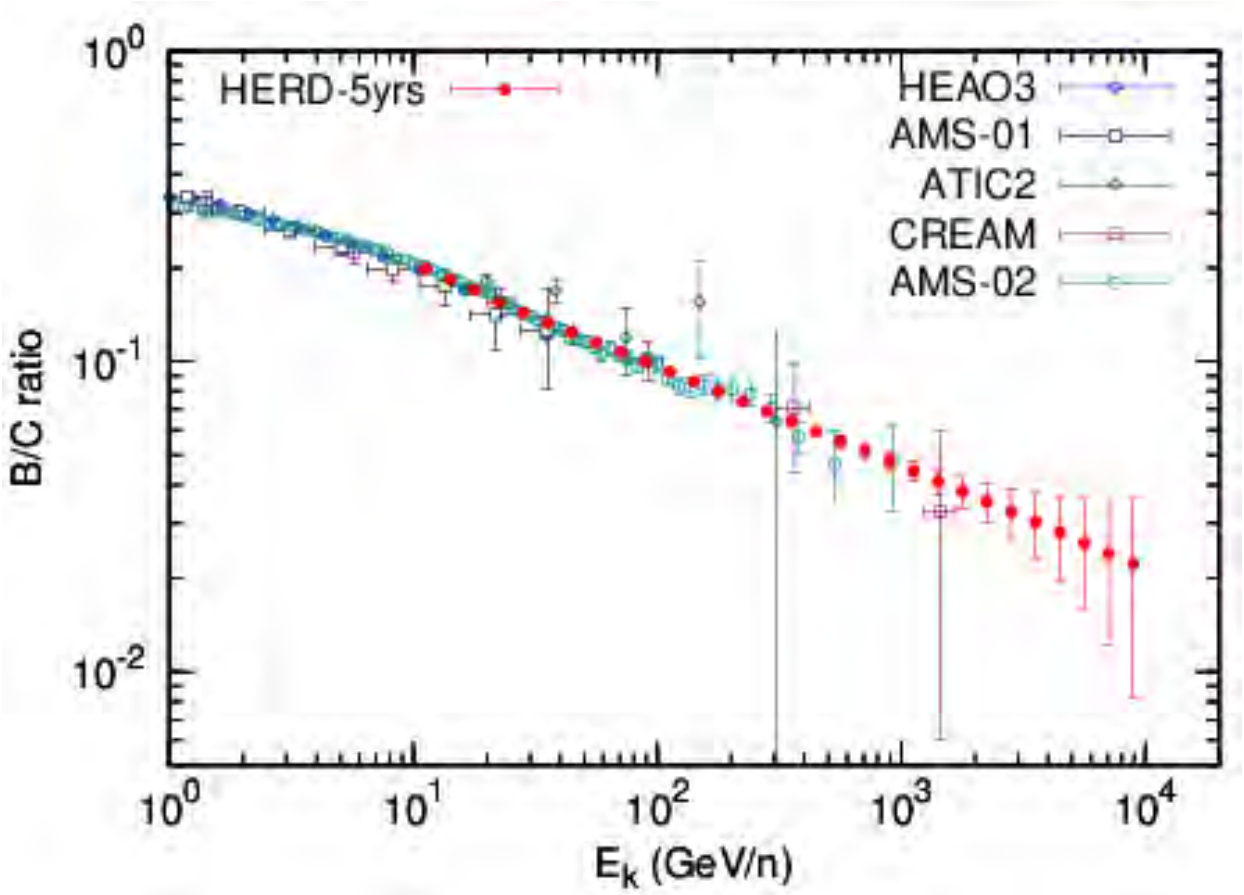
Expected HERD Proton and He Spectra





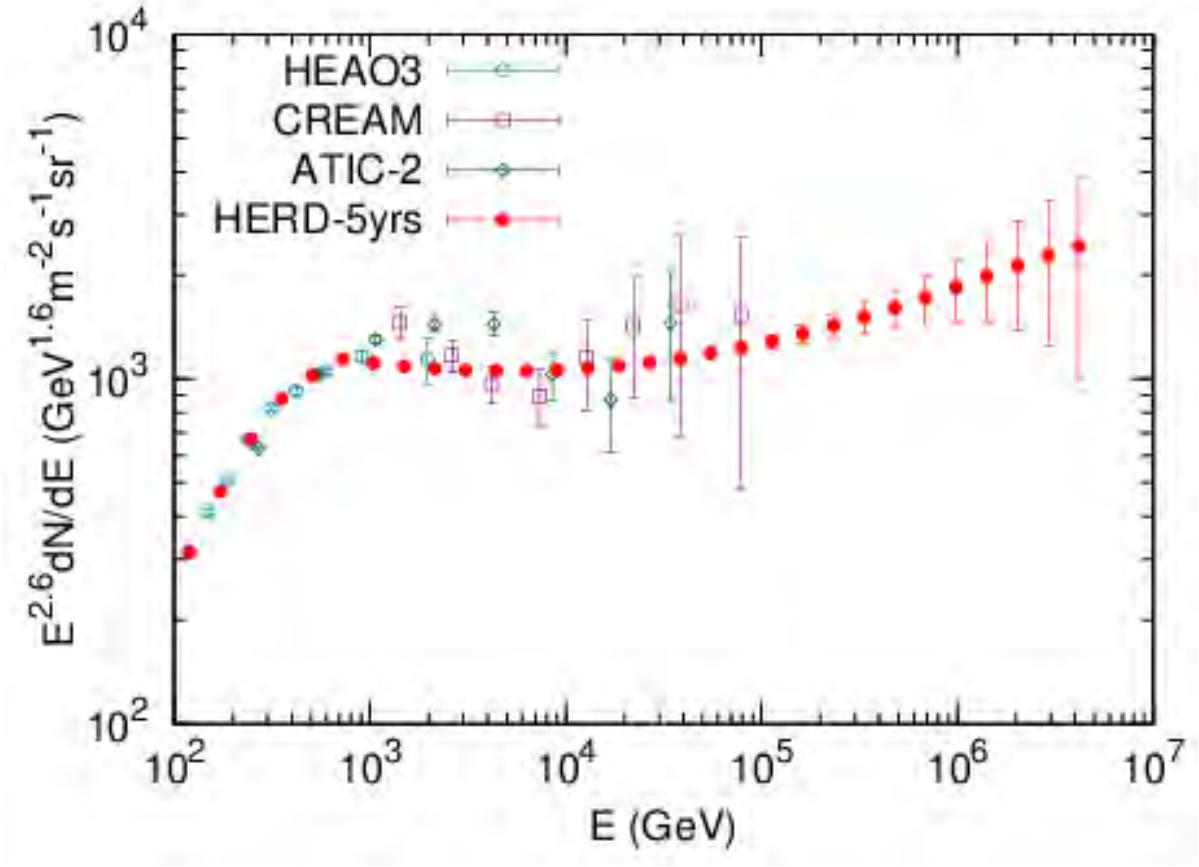
- Well extended to PeV energies
- Critically test any structures between TeV and PeV
- Clearly reveal the knee of light components (Z- or A-dependence)

B/C measurement with HERD



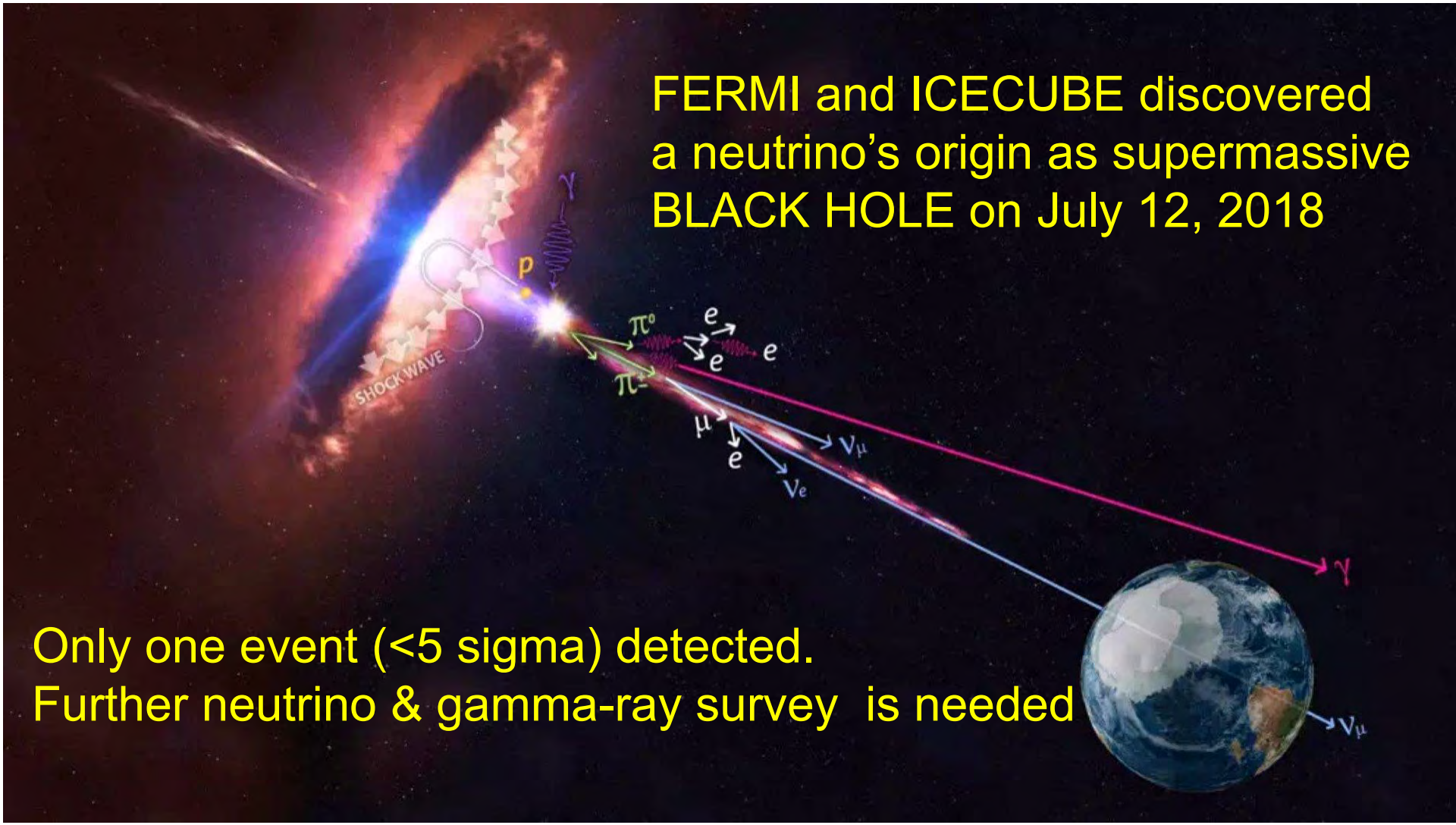
B/C is adopted to determine the CR propagation parameters and origin of break at the primary nuclei spectra

Iron nucleon and super-iron elements

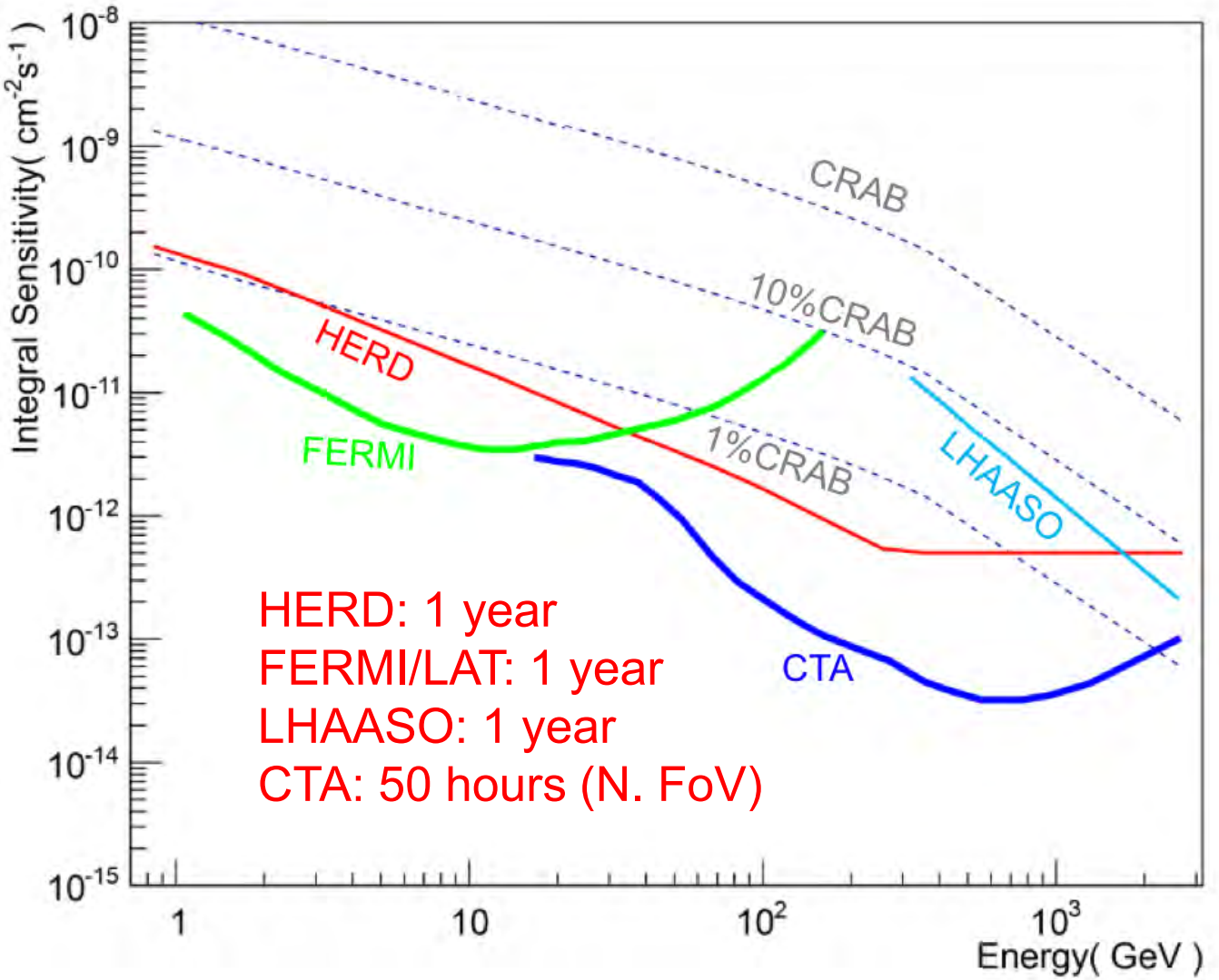


HERD can detect or set very stringent limit on super-iron elements

Gamma-ray monitoring & survey



Gamma-ray sky survey

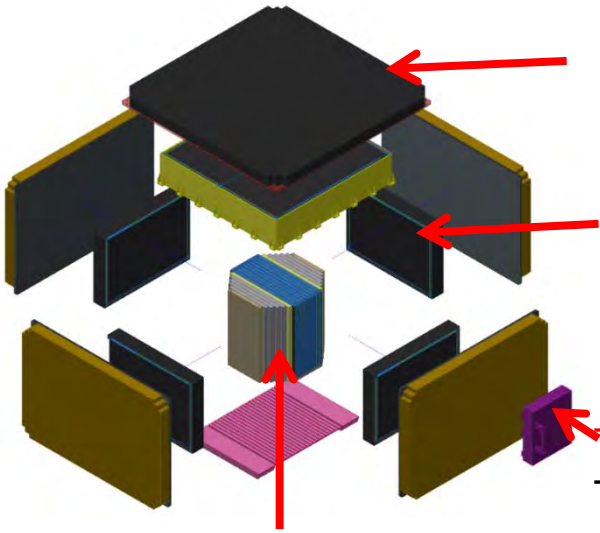


Expected HERD gamma-ray sky survey sensitivity (5σ)

HERD specifications

Item	Value
Energy range (e/γ)	10 GeV to >10 TeV (e); 0.5 GeV-10 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
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

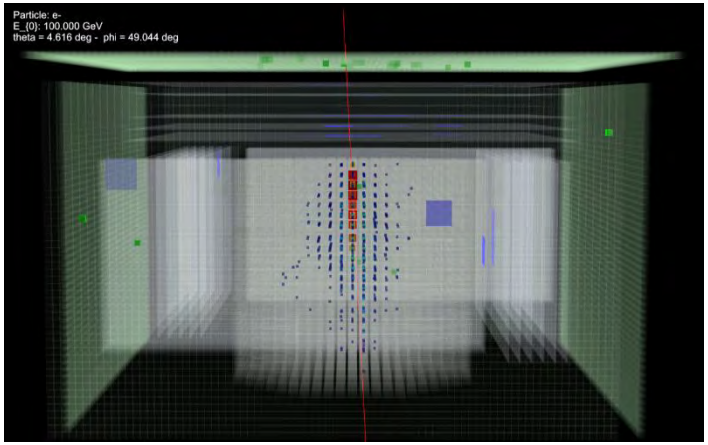
HERD payload



PSD
Gamma identification
Charge measurement

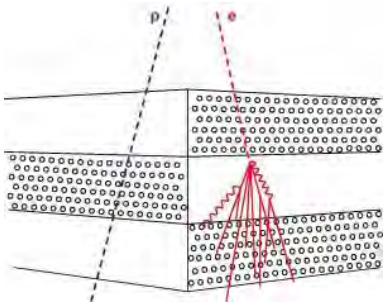
Tracker
Charge measurement
CR trajectory
Gamma converting & tracking

TRD
TeV CR calibration

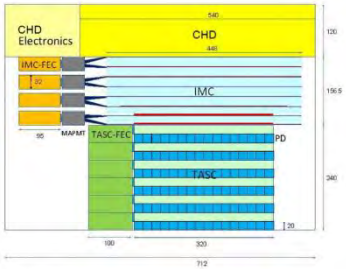


CALO: 3-d imaging calorimeter: Energy measurement & Particle identification

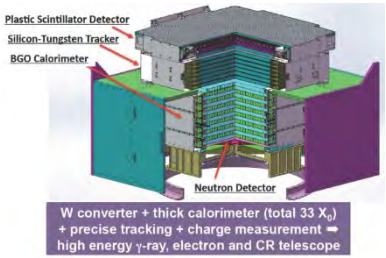
The novel design of 3-d imaging calorimeter could significantly increase GF, improve particle discrimination and reduce systemic error



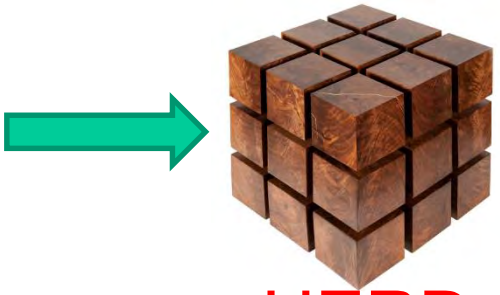
AMS-02



CALET

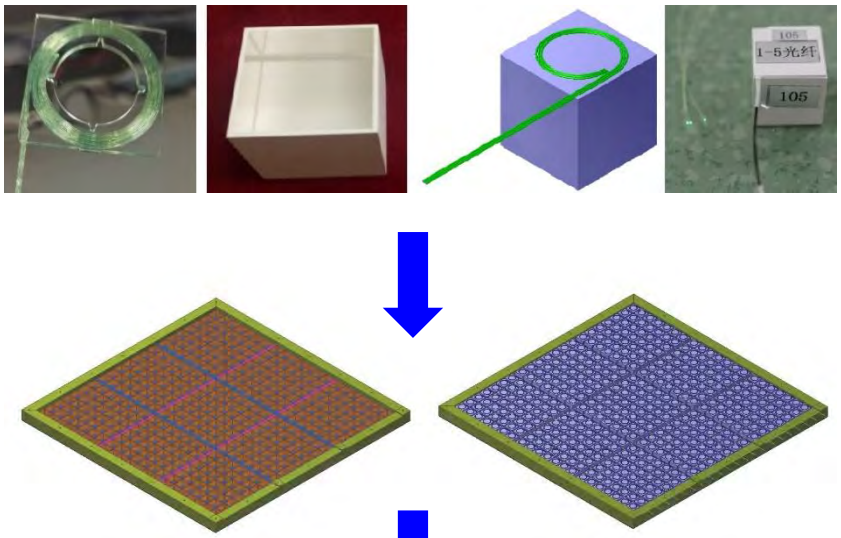


DAMPE

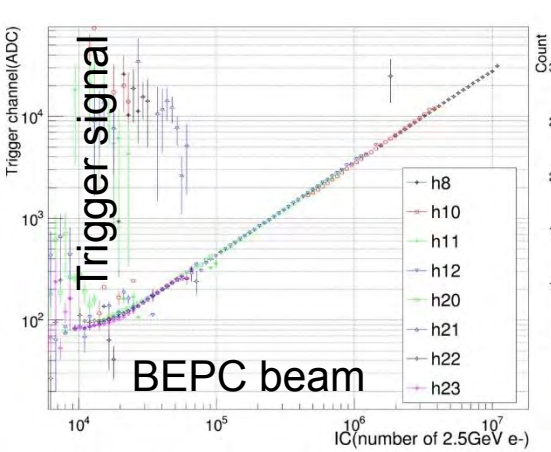


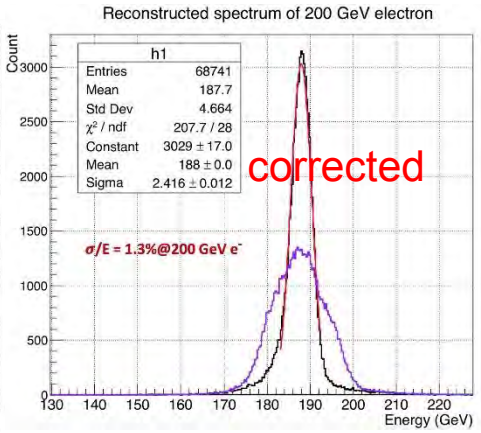
HERD

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 verified.
  - Energy measurement of WLSF + IsCMOS is verified.

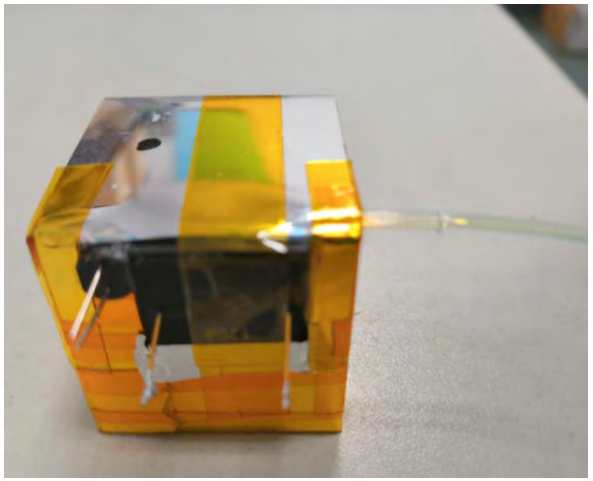




Joint study on mixed CALO readout is ongoing in IHEP and INFN Florence

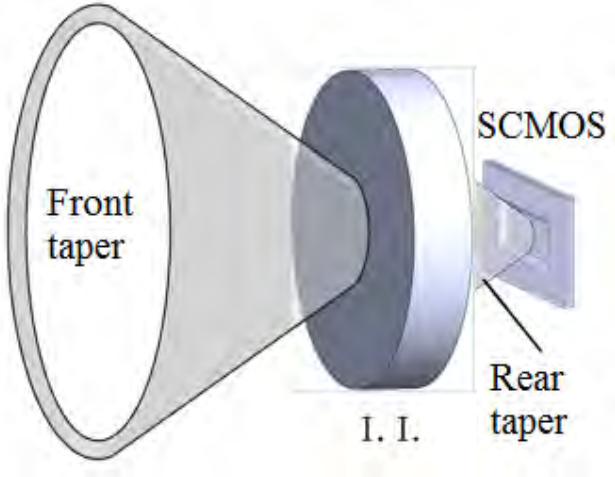
Dual readout of CALO

- Joint study on dual (WLSF & PD) readout of crystals is ongoing in IHEP and INFN Florence
  - No significant impacts on each other are seen when WLSF and PD are both attached.
  - Joint development of 30 LYSO crystals with dual readout is ongoing.
  - A beam test at Frascati is arranged at the end of 2019.
- With no showstopper in the future, one crystal is to be readout by
  - 1 large PD covering 1-10^4 MIP
  - 2 WLSF covering 1-10^6 MIP
  - 1 WLSF for trigger logic



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



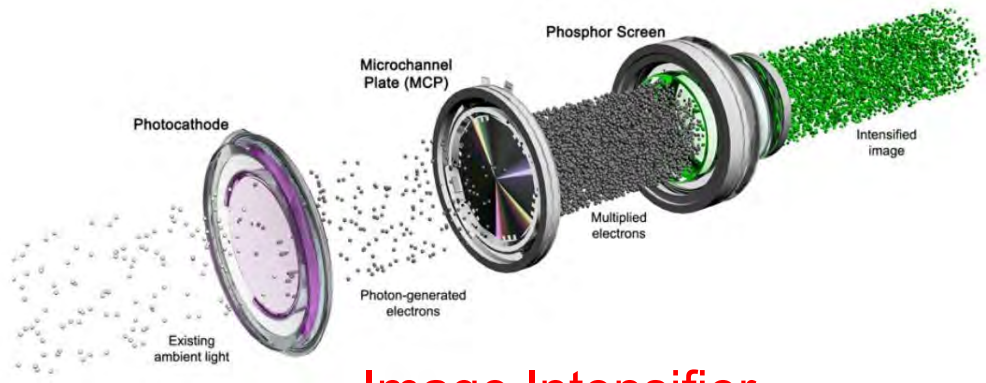
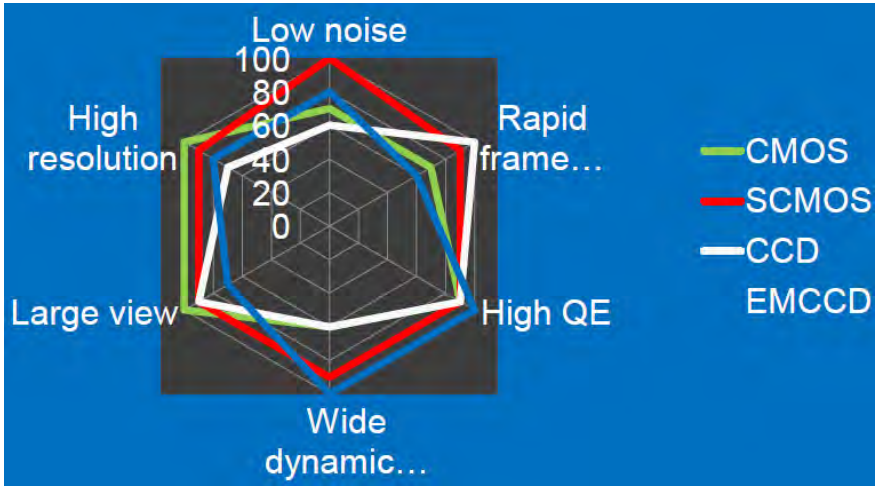


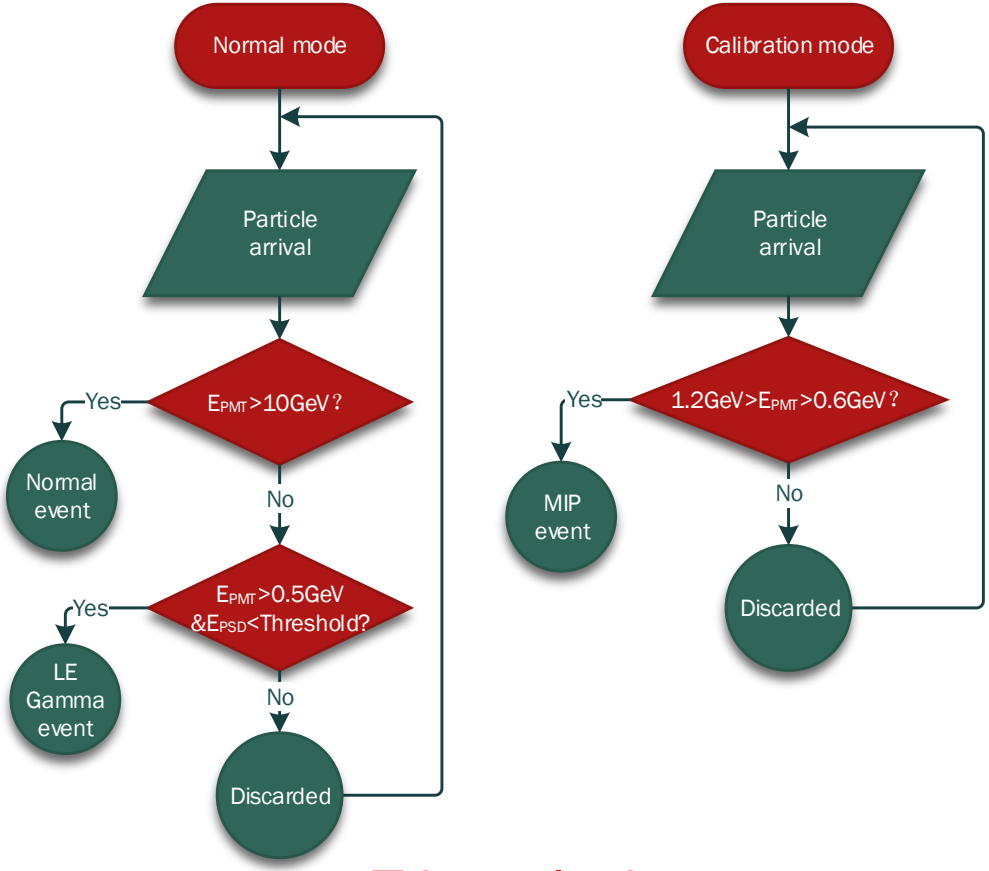
Image Intensifier



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

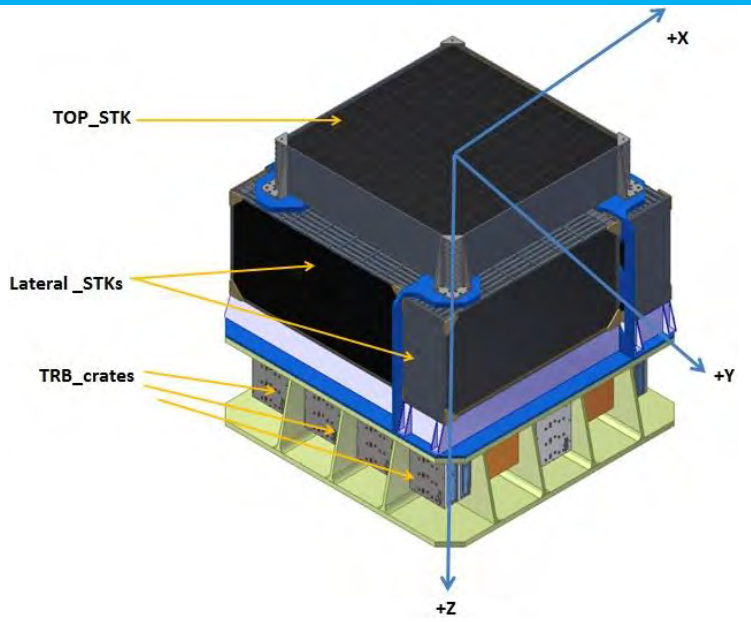


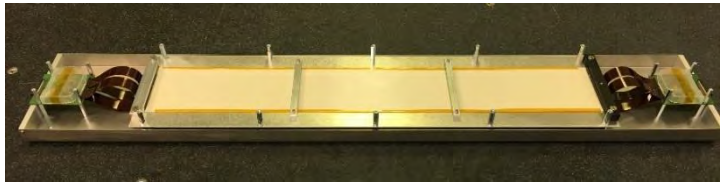
Trigger logic

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	~240,000/368,000



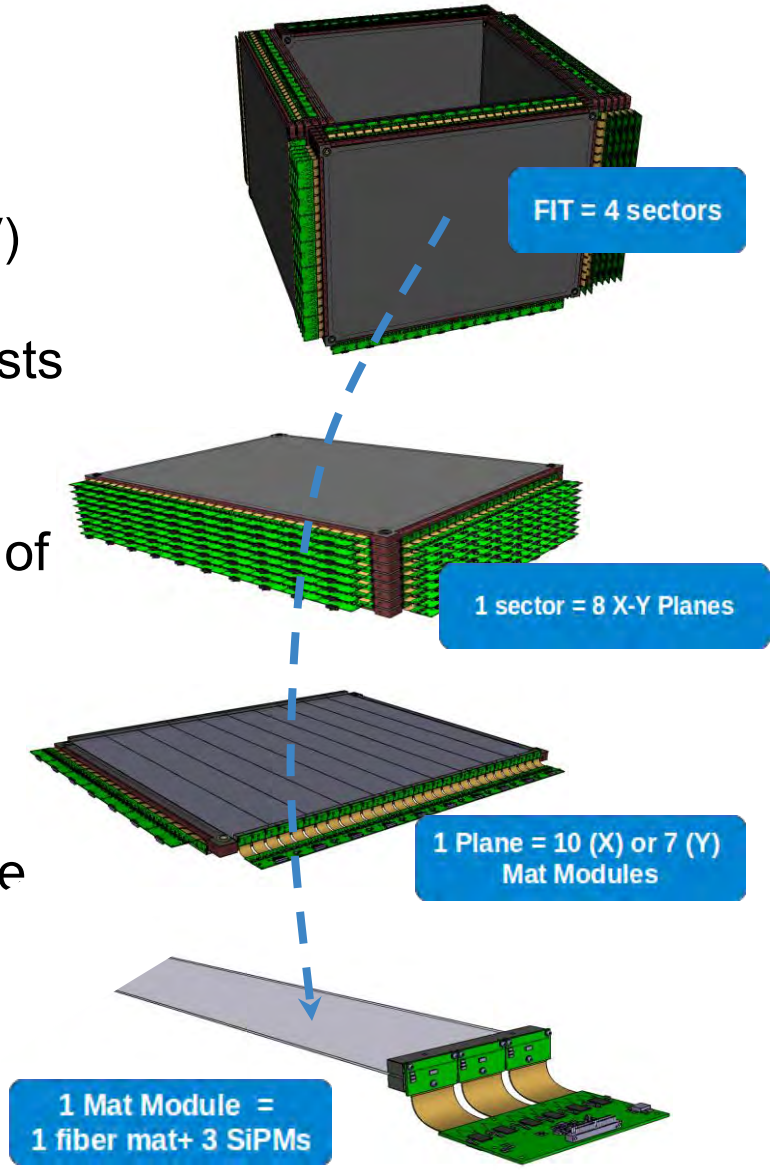


DAMPE STK ladder

Alternative approach: Fiber Tracker (FIT) using SiPMs

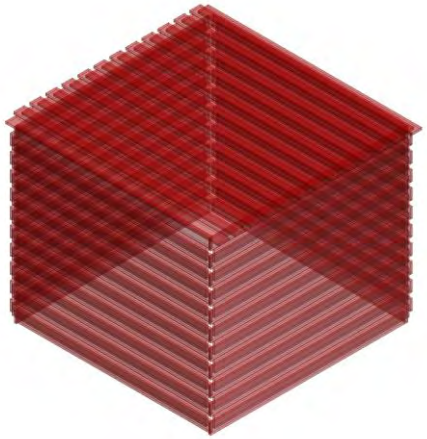
The FIber Tracker (FIT) progress

- New “10 μm” SiPM arrays tested during 2018 beam test:
  - Spatial resolution: σ = 51 μm;
  - Light yield: MIP Mean Peak Value (MPV) ~9 p.e. (400 GeV/c proton)
- The 1st FIT module space qualification tests and readout electronics are in progress.
- The procurement of fiber mats will be completed this week, then the production of the modules will start after mats delivery.
- The design of the prototype tray is being finalized. Then prototype trays will be assembled.
- The Barcelona (ICCUB) group has obtaine funding to design the FIT FE ASIC.
- The simulation for a single FIT module been completed, the overall simulation is in progress.

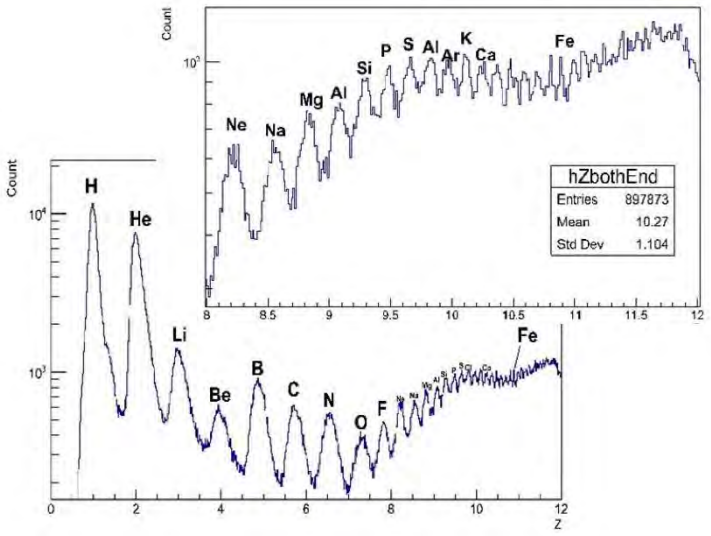


PSD payload

- 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



2017 CERN SPS measurements

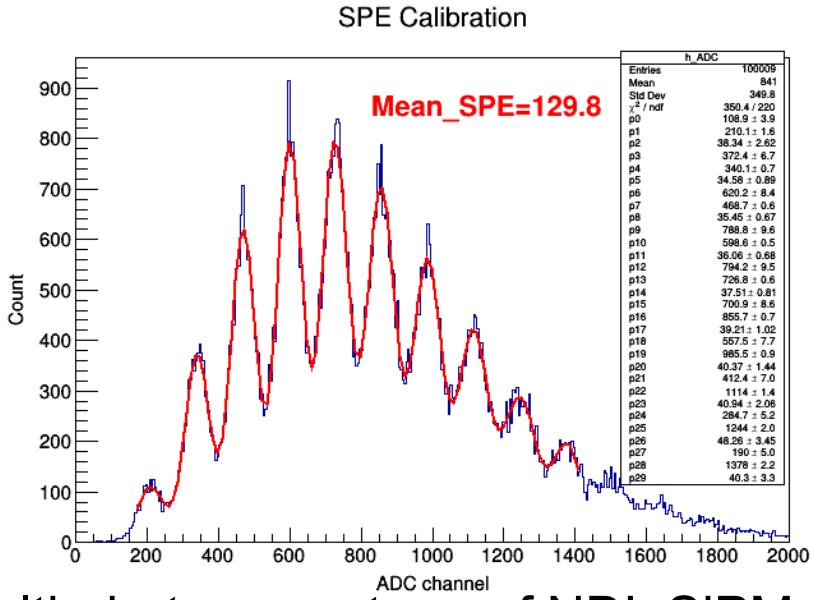


PS bar readout by
2*N SiPMs

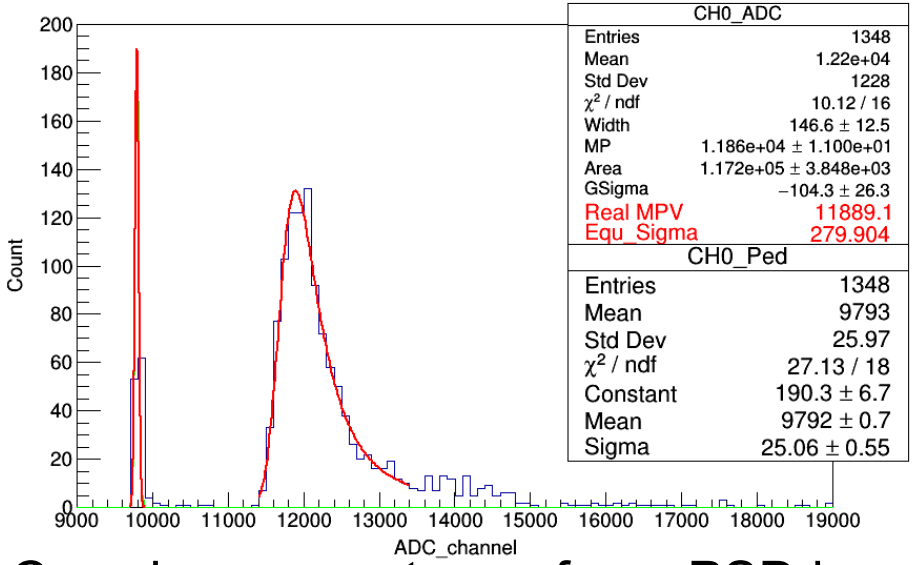
Alternative approach: Tile geometry

Design optimization of PSD

- Joint study on PSD is ongoing in IHEP and INFN Bari
  - A student in IHEP is to be sent to INFN Bari supported by joint PhD student program of CSC.
  - A beam test at Frascati is arranged in 2019.
- Progress of bar solution in IHEP
  - Customized large-area & small-pixel SiPMs are in production.



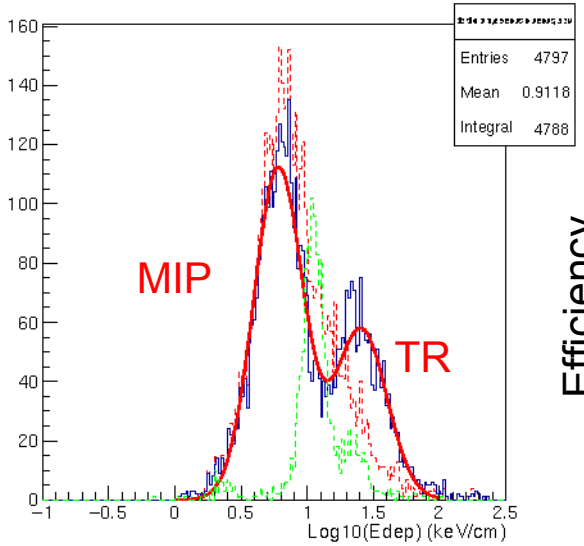
Multi-photon spectrum of NDL SiPM (3mm×3mm, 10μm pitch)



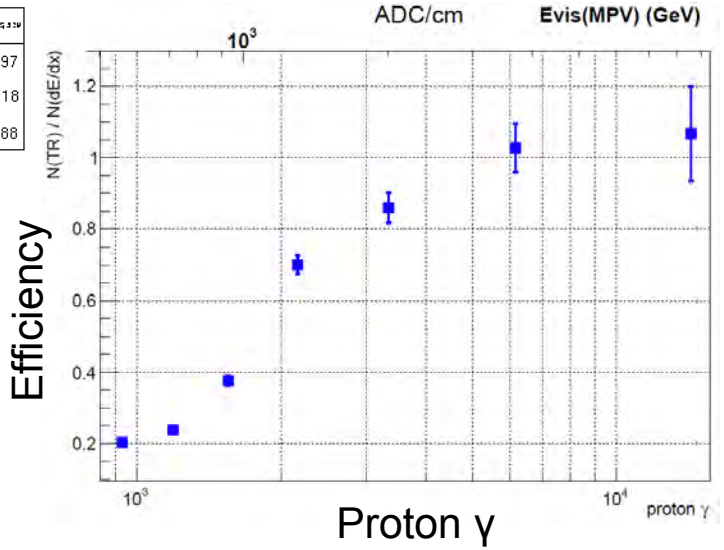
Cosmic ray spectrum of one PSD bar, readout by 4 SiPM

TRD payload

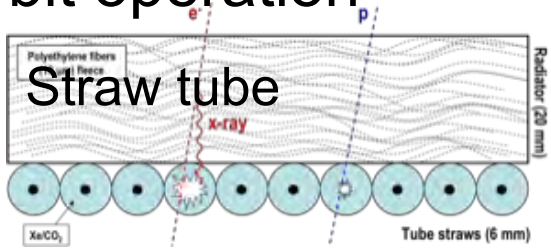
- Energy calibration of TeV protons and other nuclei
- A complete calibration in 2-3 months in-orbit operation

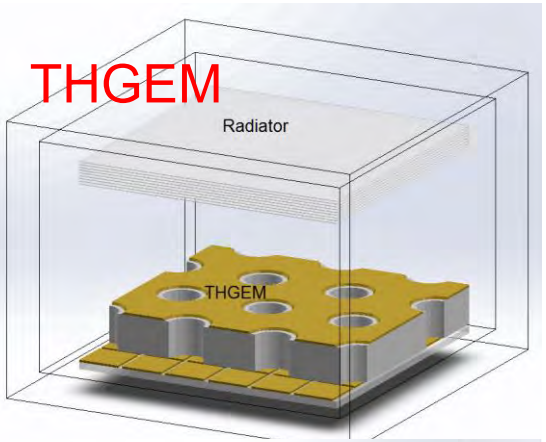


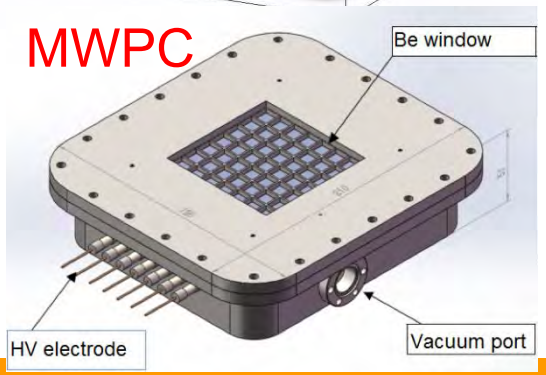
MWPC energy response to [2.25, 2.5] TeV protons



2 months simulated observation, ~6300cm² TRD.

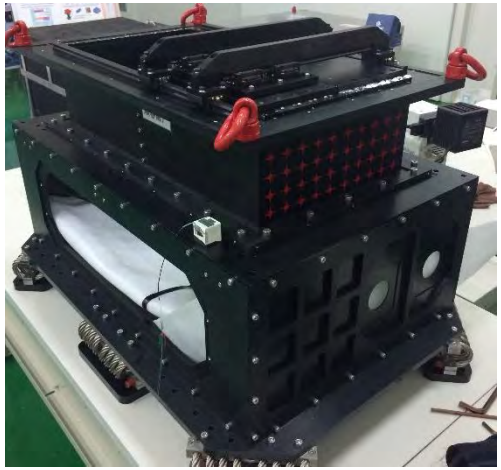




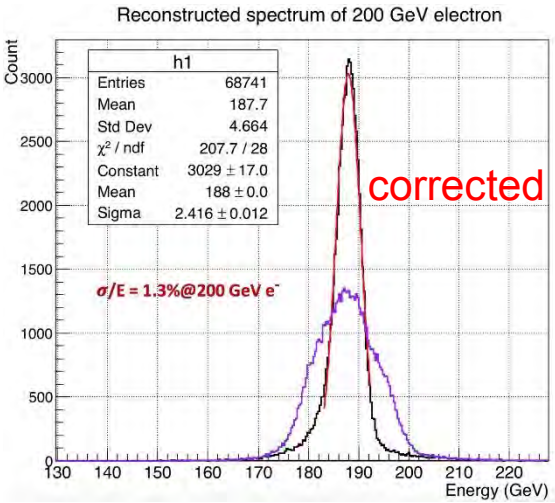


Beam test of HERD prototypes

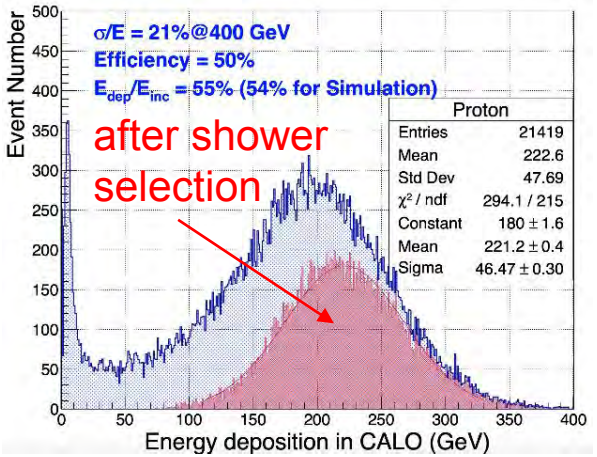
- All key specifications of HERD instruments were tested & verified in the CERN SPS beam tests, with major help from INFN sections.



CALO prototype (500 LYSO)

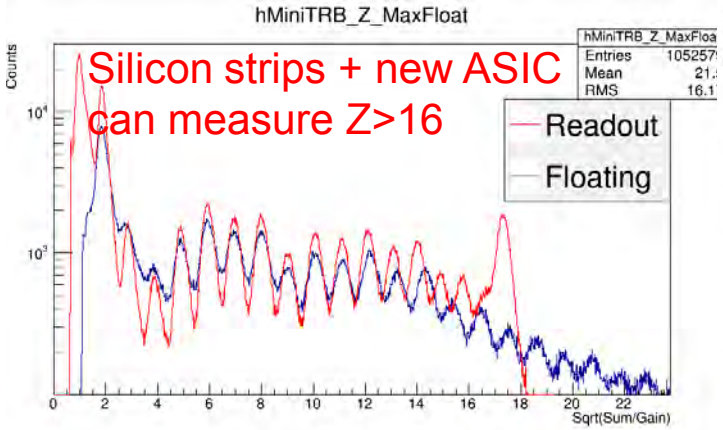


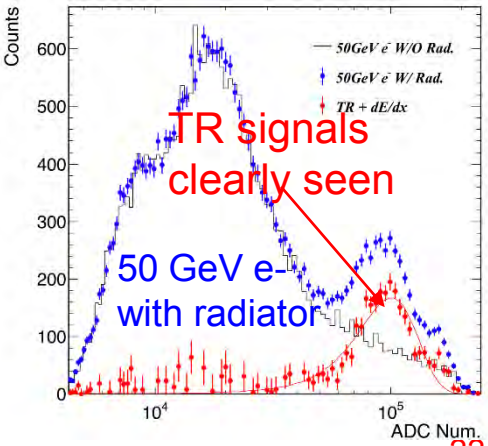
1.3%@200GeV e-



21.0%@400GeV proton

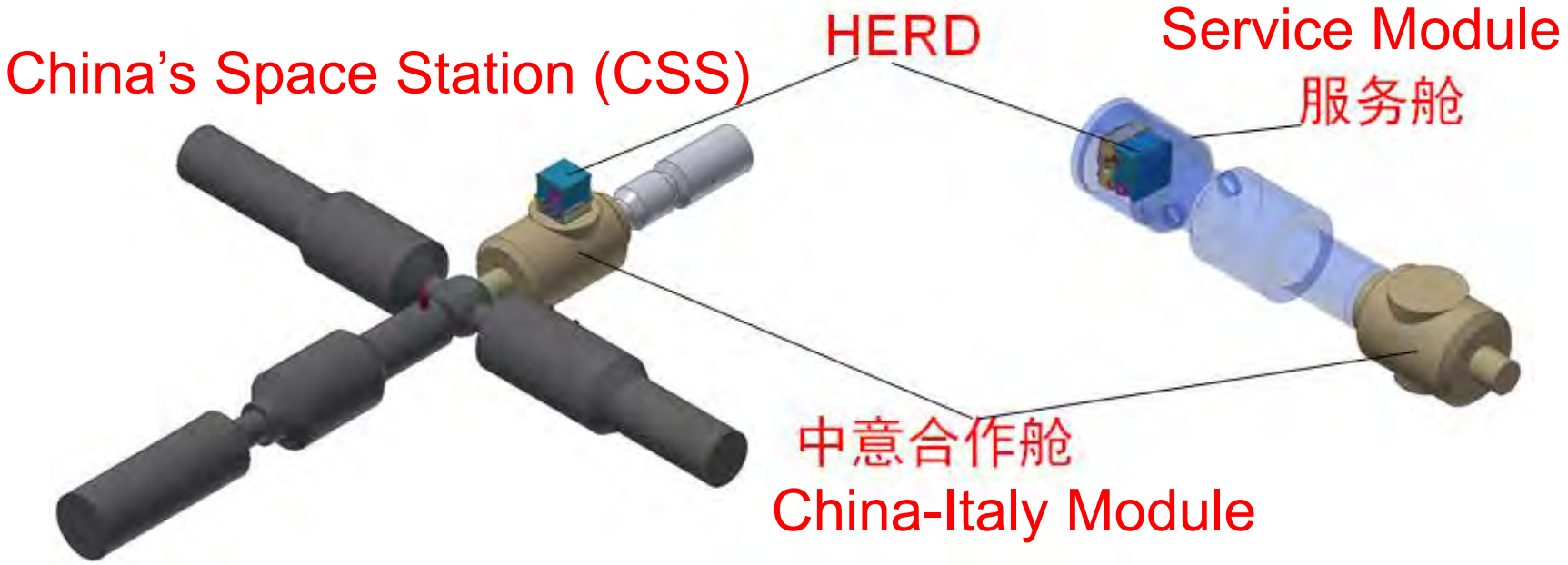
HERD prototypes at CERN





HERD mission concept

- Launch with the Italian Module: after docking with CSS, HERD will be installed on top of the Italian Module.
- Periodic calibration will be performed 3-6/months.
- Several devices to be replaced or upgraded 3-4/years.
- Data selection with Information System of Utilization.
- All data are stored & processed in the HERD science center.



General progress of HERD

- Joint Working Group on space science and utilization between ASI and CSU in Feb. 2018, including HERD Joint Working Team.
- The HERD proposal was submitted to the Review Board in April, 2018, reviewed positively at the joint review meeting on May 11th 2018 at ASI.
- The HERD experiment is written into the joint declaration between China & Italy during the visit of President XI Jinping in March 2019.
  - Part of the CMSA-ASI Joint agreement
  - CMSA-ASI MoU to be signed explicitly on HERD

HERD consortium

- The HERD consortium includes 130+ scientists from China and Europe.
- Most of the members have been collaborating on AMS-02 and DAMPE experiments in science and hardware development.
- Since 2012, the HERD international consortium has organized seven international workshops in China and Europe on the related scientific topics and technological developments of HERD.
- Together with European colleagues, three CERN beam tests on HERD have been successfully implemented for the verification of HERD novel design and performances.

HERD responsibilities

Name	Responsible institutions
HERD	
Payload Module	IHEP
CALO	IHEP, XIOPM, INFN Florence, CIEMAT
STK	INFN Perugia, University of Geneva, CIEMAT, IHEP
PSD	INFN Bari
TRD	Guangxi University
Ground calibration	IHEP, Guangxi Univ., Italy, Switzerland, CERN
Science center	IHEP, Italy, Switzerland
Sciences	IHEP, PMO, USTC, NAOC, IGG, XAO, TSU, PKU, SYSU, YNU, GXU, NJU, Taiwan, Hongkong Italy, Switzerland, Spain, Germany, Denmark, Sweden, Japan ,Russia

HERD Summary

- HERD: led by China and with key European contributions, more international collaborations are welcome!
- 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 claimed by DAMPE, and extend the energy range up to >10 TeV
  - Direct measurements of CR composition up to PeV
  - Large acceptance & sensitive high-E γ-ray sky monitoring
- Planned for launch & operation in ~2025 for ~10 years.

Many thanks!