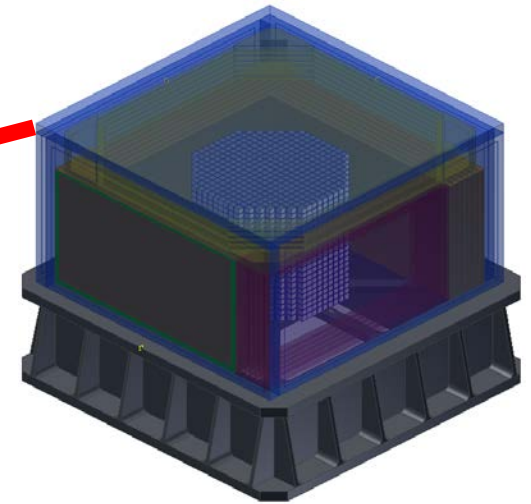
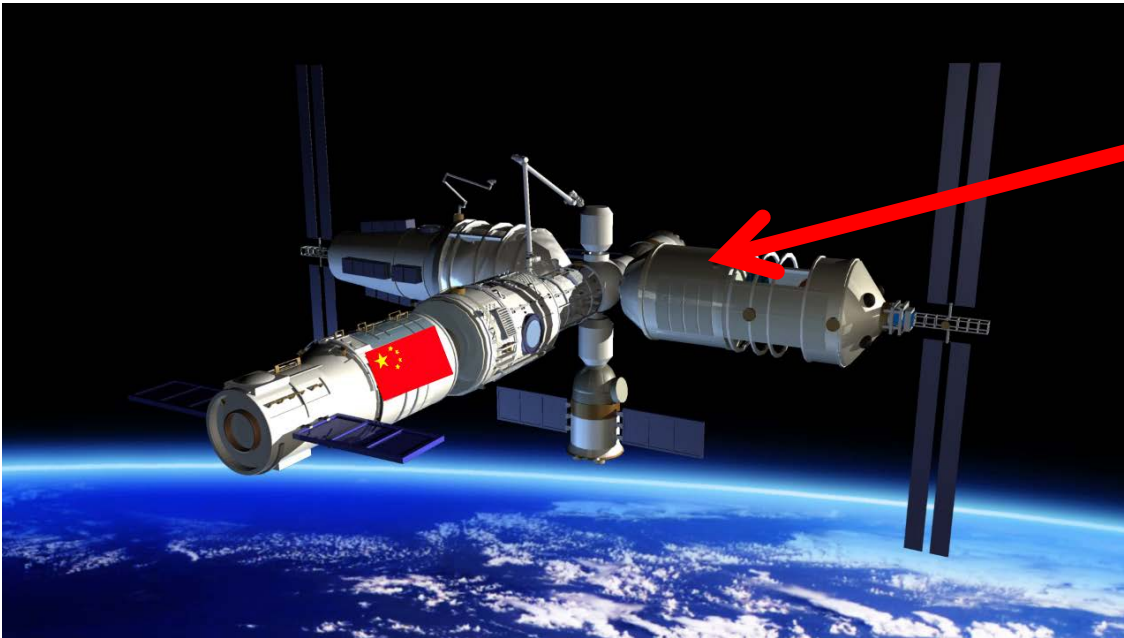


Introduction of HERD proposal

Joint contribution from China and Europe
Preliminary version

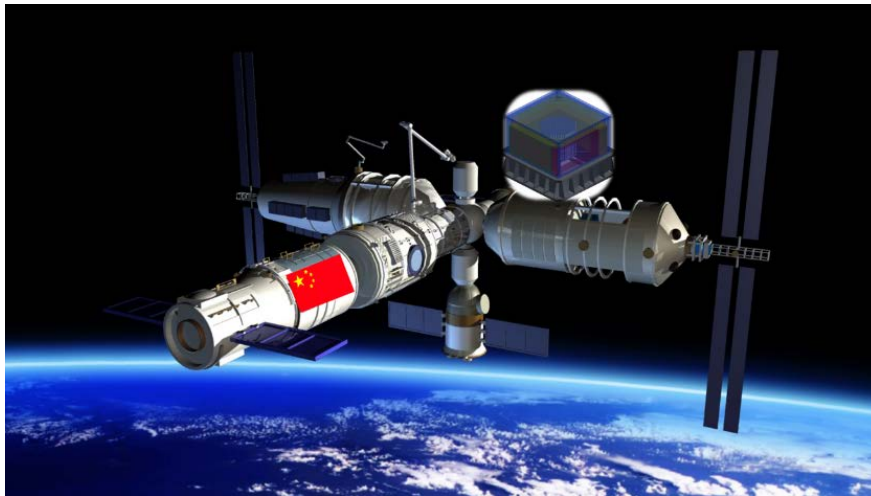


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HERD concept

- Sciences
 - Indirect dark matter search with unprecedented sensitivity
 - Precise cosmic ray spectrum and composition measurements up to the knee energy
 - Gamma-ray monitoring and survey
- HERD: a flagship and landmark scientific experiment onboard the China's Space Station
- Planned launch 2023-2025; 10+ years lifetime



Science requirements

- **Functions**

- Survey observation of high energy cosmic radiation with large acceptance.
- Measurement of "knee" region cosmic rays, high energy electrons and gammas with high energy resolution.
- Measurement of cosmic rays with high charge resolution.
- High particle discrimination power.
- Real-time identification and measurement of GeV gammas.
- In-orbit instrumental calibration.
- Data acquisition, data management and TC/TM.
- Automatic temperature control.
- Interfaces for arm and manual operation with proper ergonomics design.
- Interfaces for necessary in-orbit maintenance, replacement or upgrade.

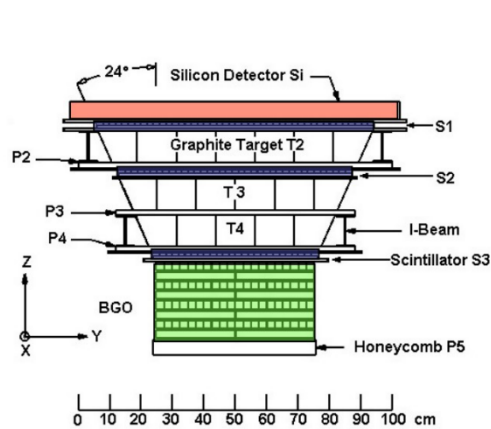
Science requirements (need more input from science)

- DM search requires enlarged searching parameter space and increased observation sensitivity.
 - To get a 5 sigma annihilation signal in the diffuse gamma spectrum within 1 year observation, the calorimeter shall have an energy resolution of 1% @100 GeV, a particle discrimination power of 10^{-5} and an effective geometric factor of 3 m²Sr.
- "knee" region CR measurement requires large statistics and good energy resolution.
 - A N.I.L. of 2 is required to measure 100 TeV particles.
 - A N.I.L. of 3 guarantees energy resolution of 20% for cosmic rays.

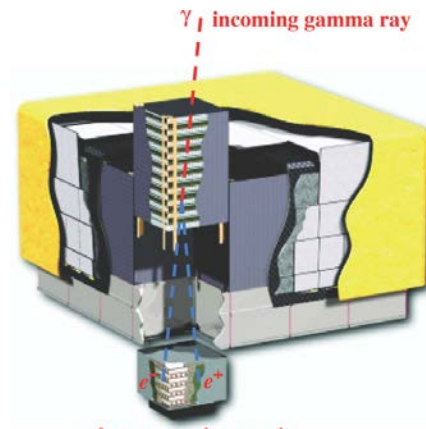
Science requirements on payload

Item	HERD	DAMPE
Energy range(e/ γ)	10 GeV - 100 TeV (e/ γ) 0.5GeV - 10 GeV(γ)	10 GeV – 10 TeV
Energy range (CR)	30 GeV - PeV	30 GeV – 100 TeV
Angle resolution	0.1 deg. @10 GeV	0.1 deg. @10 GeV
Charge meas.	0.1-0.15 c.u	0.1-0.15 c.u
Energy reso.(e)	1% @200 GeV	1% @200 GeV
Energy reso.(p)	20% @100 GeV-PeV	50% @100GeV-100TeV
e/p discri.	$\sim 10^{-6}$	$\sim 10^{-5}$
G.F. (e)	>3 m ² sr @200 GeV	0.3 m ² sr @200 GeV
G.F. (p)	>2 m ² sr @100 TeV	0.12 m ² sr @100 TeV

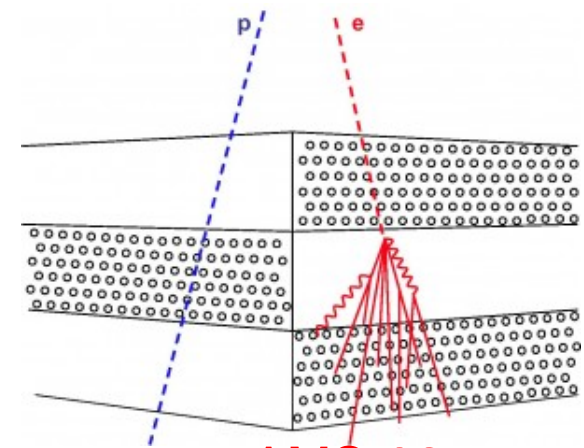
Calorimeter – from bars to cubes



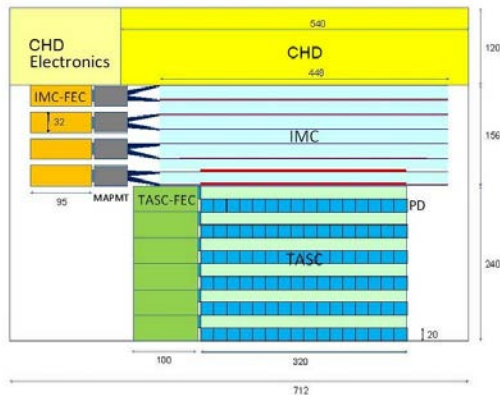
ATIC



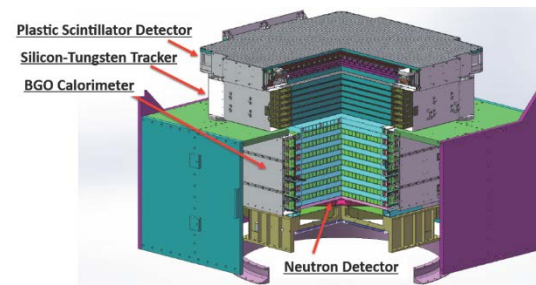
electron-positron pair
FERMI



AMS-02

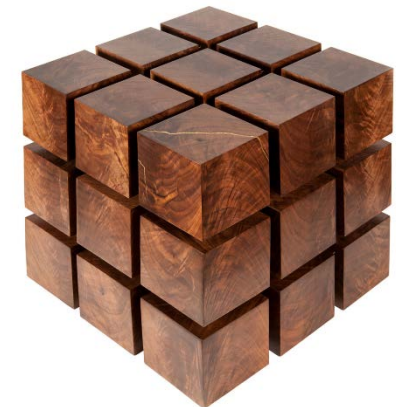


CALET



W converter + thick calorimeter (total 33 X₀)
+ precise tracking + charge measurement →
high energy γ -ray, electron and CR telescope

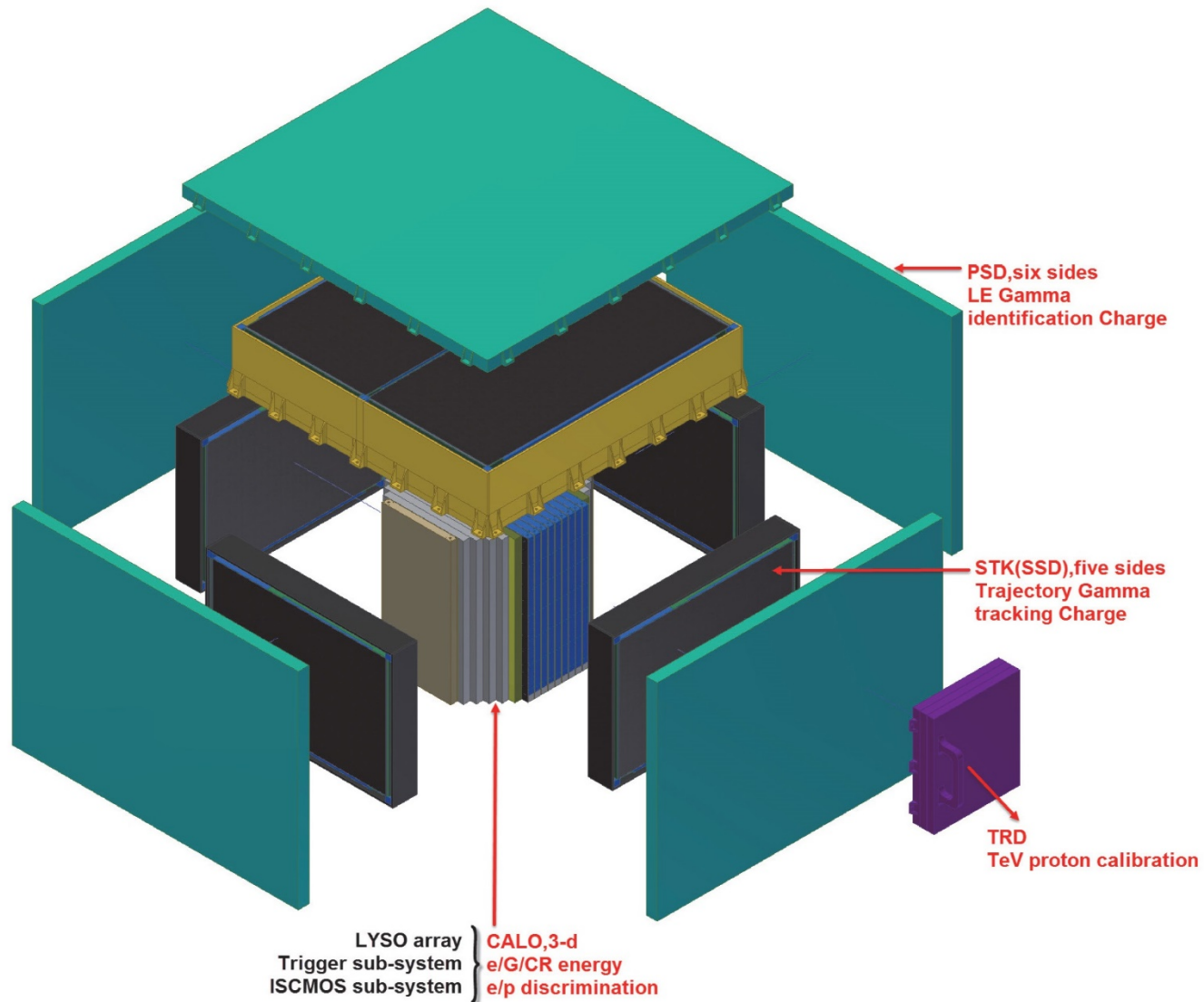
DAMPE



HERD

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

Payload configuration

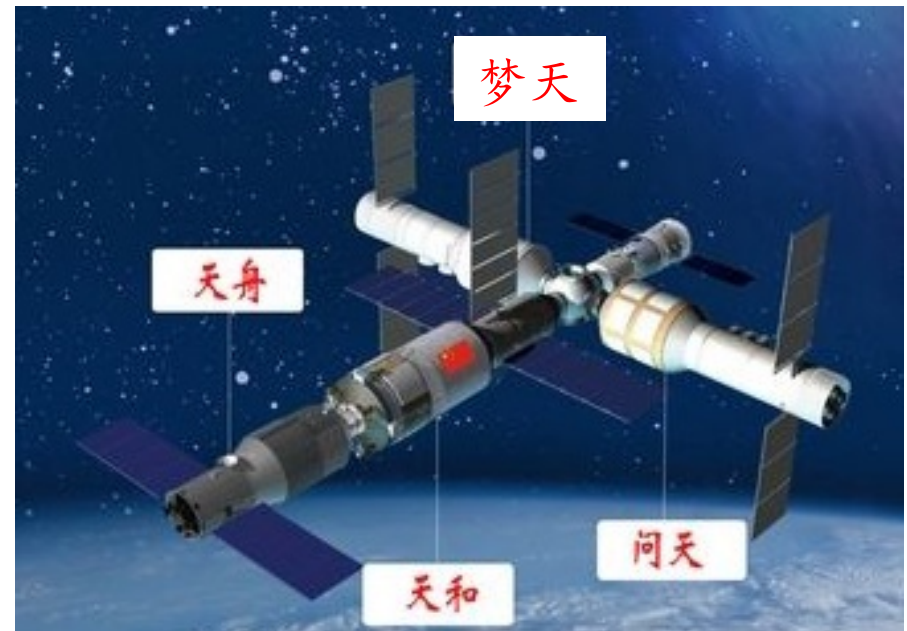
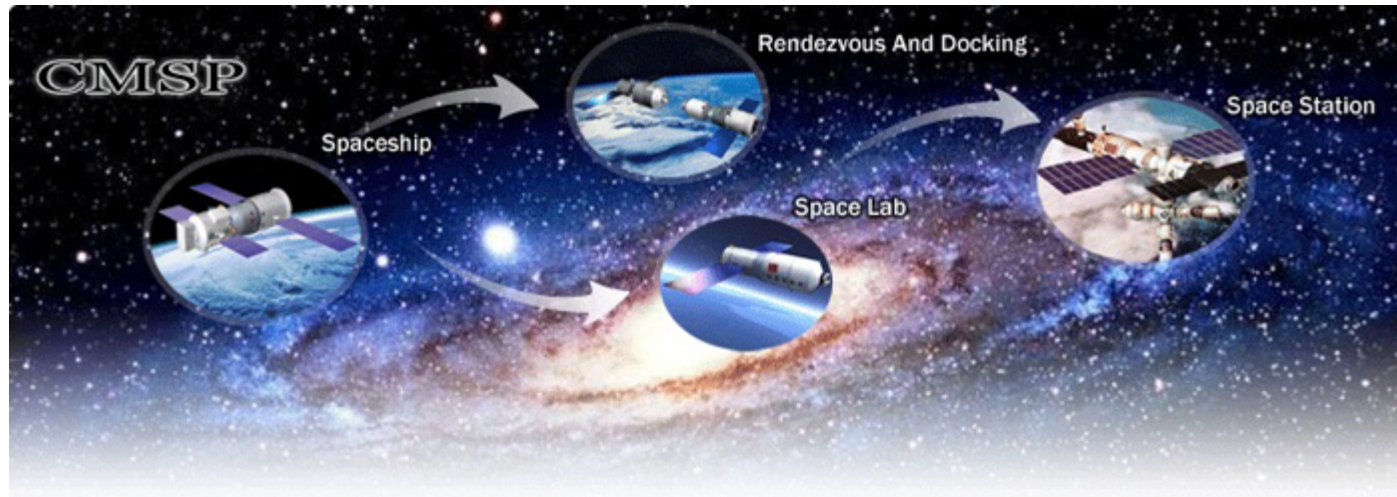


Science requirements on platform

- Large geometric factor requires large FoV.
- Measurement of particle direction requires precise attitude and angular speed measurement.

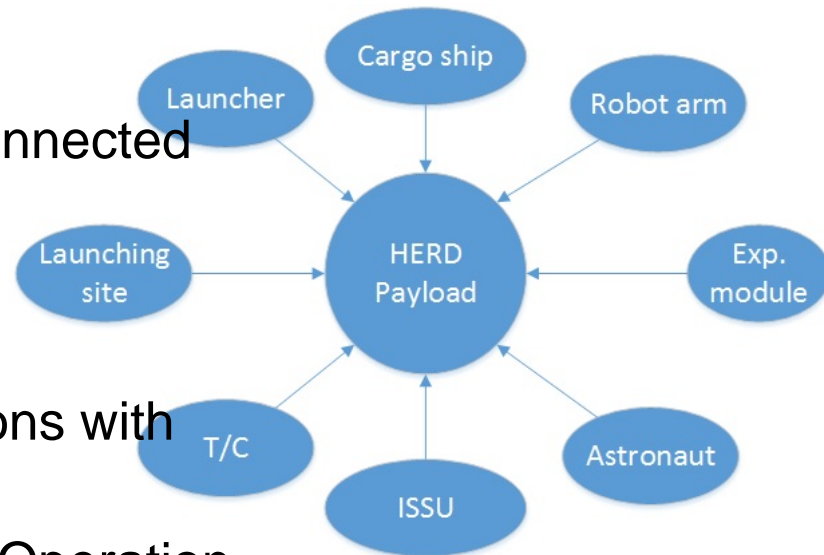
Item	Value
Pointing	Zenith
Field of View	+/- 70 deg
Measurement accuracy of attitude	0.1 deg
Measurement accuracy of angular speed	0.005 deg/s
Lifetime	>10 years

The CMSP and CSS

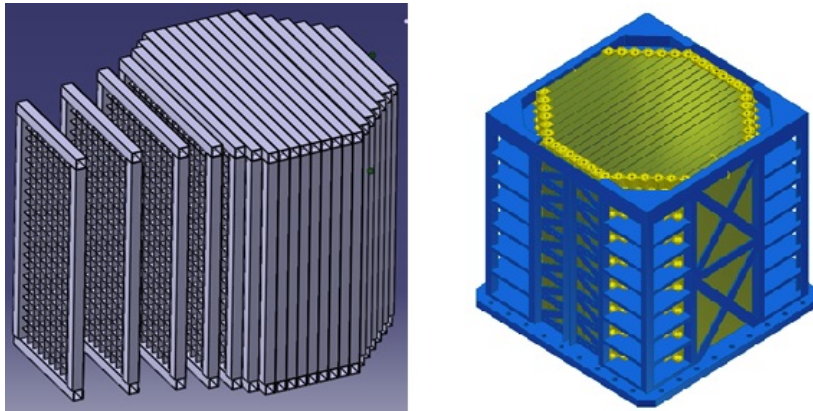
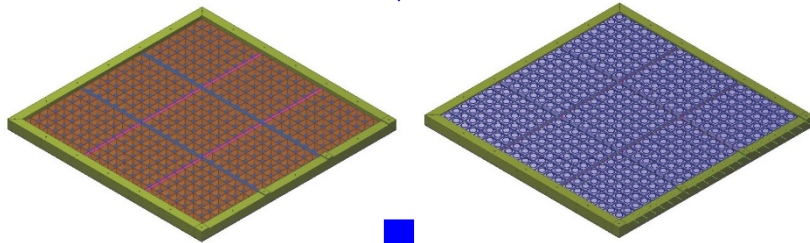
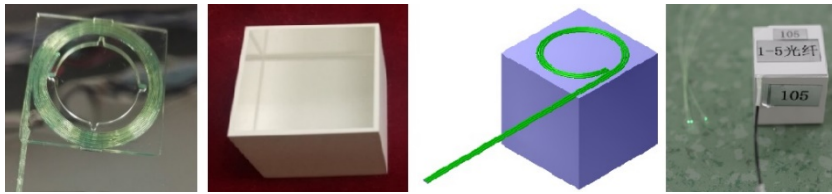


HERD mission profile

- HERD will be launched in a cargo ship at Wenchang Launching Site by CZ-7.
- After docking, HERD will be transported by the enhanced robotic arm to the dedicated mounting point of Experiment Module I.
- With the assist of astronauts, HERD is mechanically installed and electrically connected with the CSS.
- HERD will be working continuously.
- Payload data is processed by ISSU and downloaded through T/C to ground stations with the help of relay satellites.
- All science data go through the Payload Operation and Application Center (POAC) and then finally accumulated at the Science Data Center (SDC).
- Some key devices of HERD are planned to be upgraded regularly or to be replaced.



Payload design - CALO



- 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.

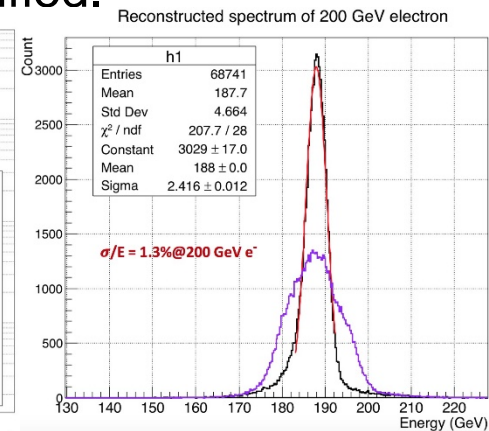
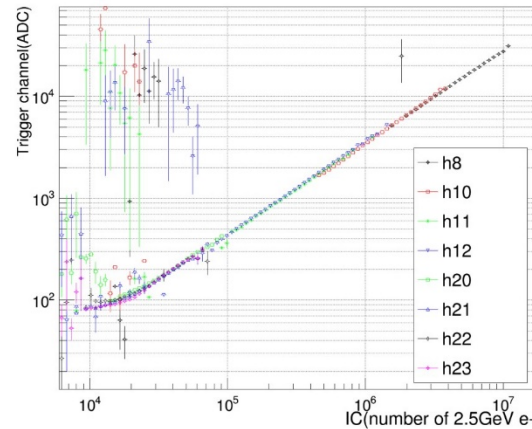
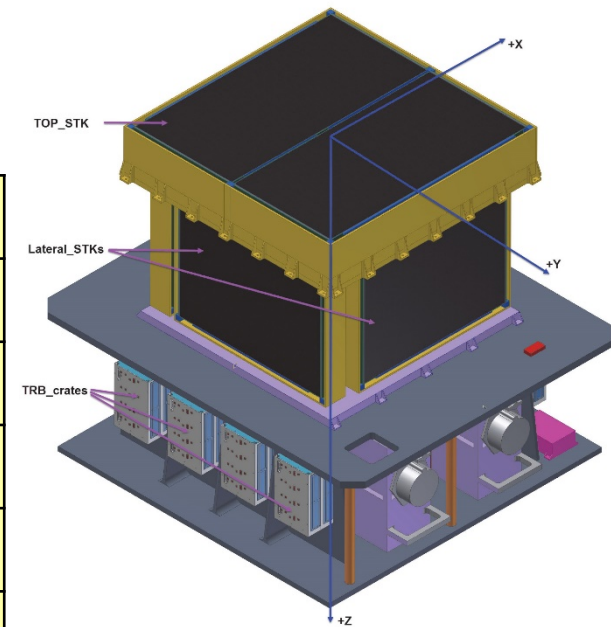


Photo diode readout is under study.

Payload design - STK

- CR/e trajectory
- Gamma ray conversion & tracking

Item	Value
Coverage ratio	>80%
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

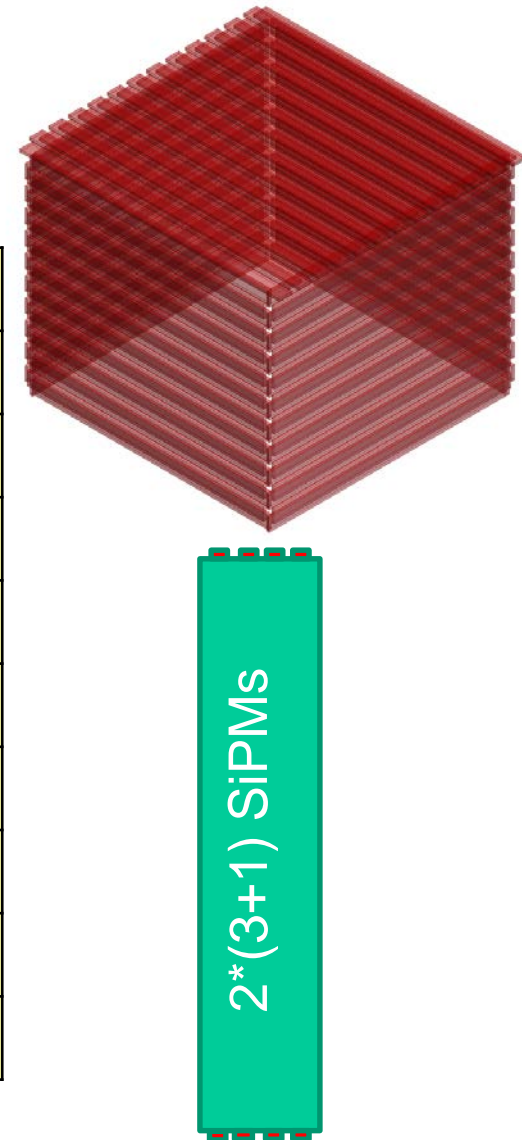


Fiber tracker (FIT) and Tracker In Calorimeter (TIC) are also under study.

Payload design - PSD

- Low energy gamma identification
- Charge measurement

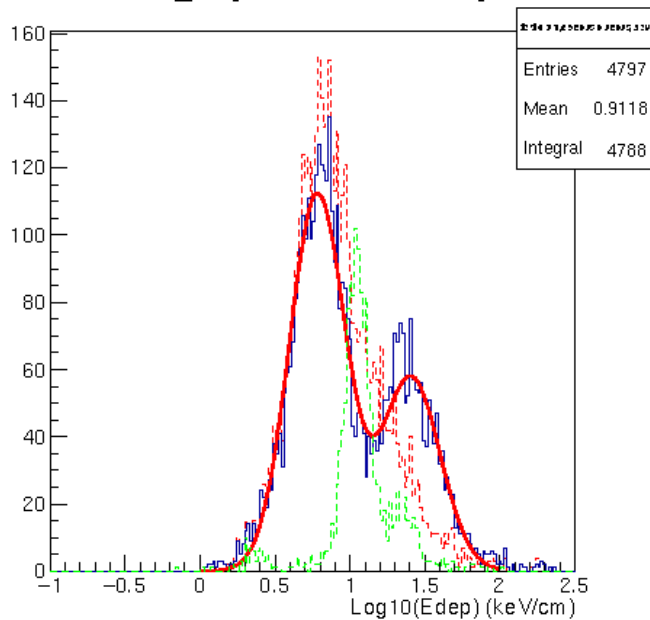
Item	Value
Coverage ratio	>99.9%
Layers	1 layer of PS bars
Charge measurement	1-20 (26)
Veto time	<100 ns
Dead time	<10 μ s
Working mode	External trigger; real-time veto
Eff. Area (top)	1.6m*1.6m
Eff. Area (lateral)	1.6m*1.2m
Channels	<1k



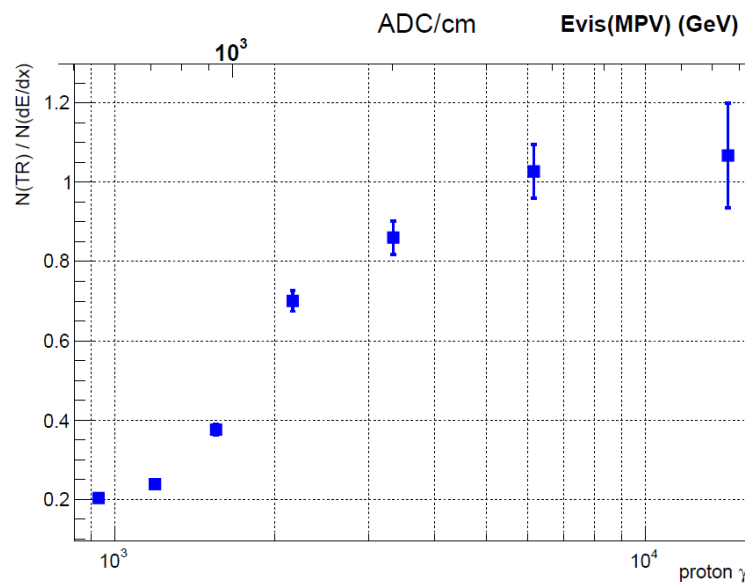
PSD in different geometry is under study.

Payload design - TRD

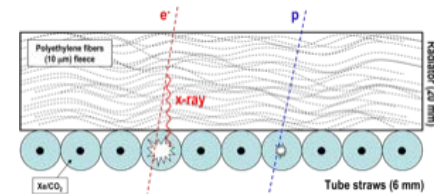
- Energy calibration of TeV protons and other nuclei
- A complete calibration in 2-3 months in-orbit operation



MWPC energy response to [2.25, 2.5] TeV protons



2 months simulated observation, $\sim 6300\text{cm}^2$ TRD.



Straw tube

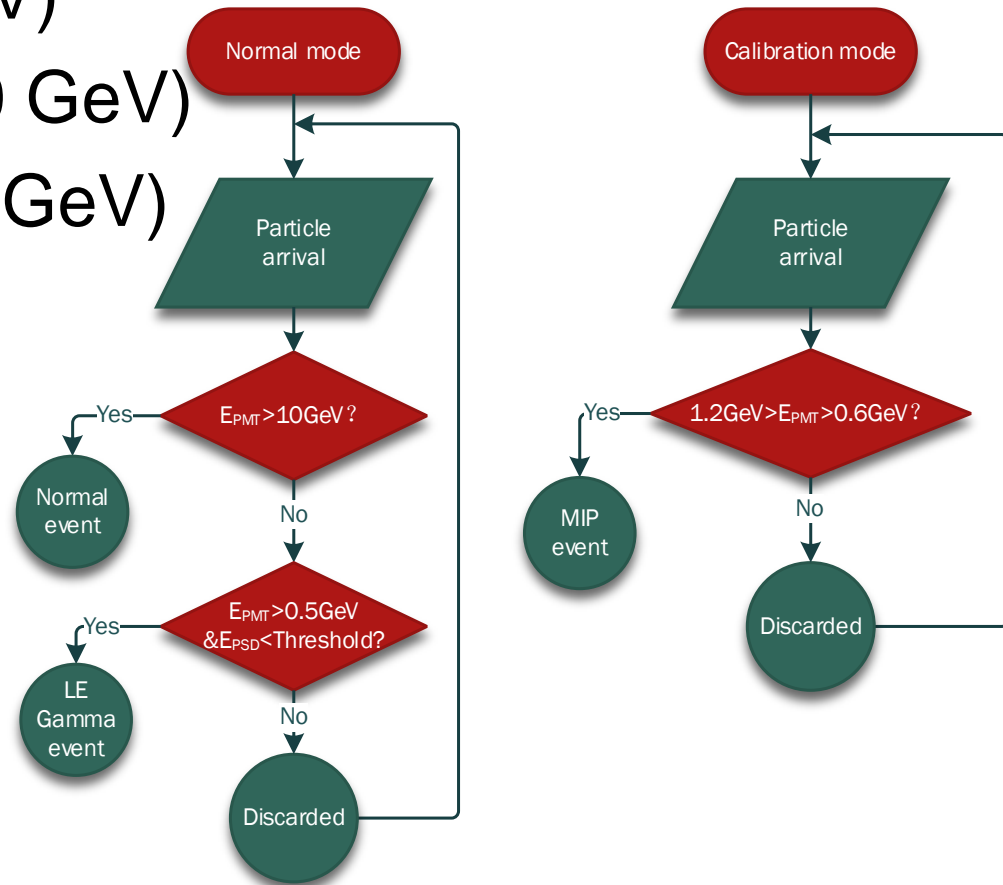


Large area MWPC

TPC readout scheme is under study.

Trigger strategy

- Normal mode
 - HE particle (>10 GeV)
 - LE gamma ($0.5 - 10$ GeV)
 - LE electron ($0.5 - 5$ GeV)
- Calibration mode
 - MIP proton



Payload budget

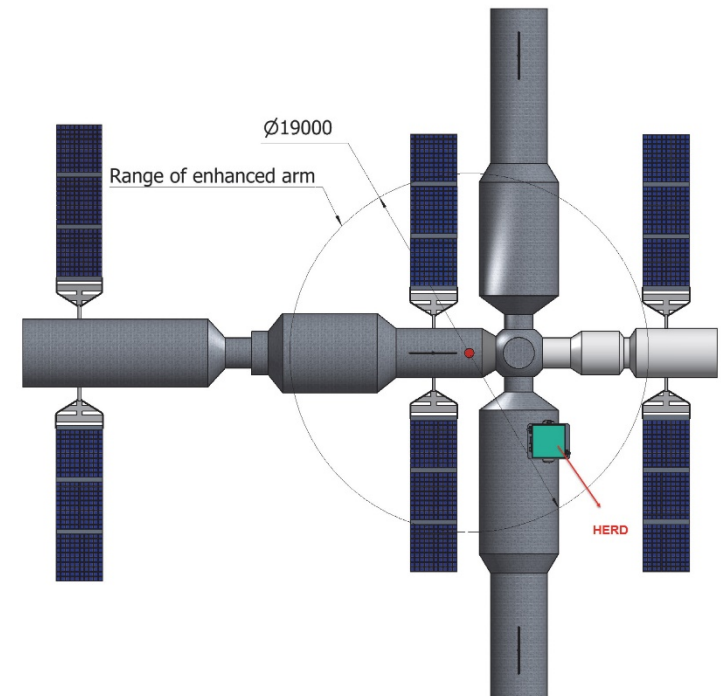
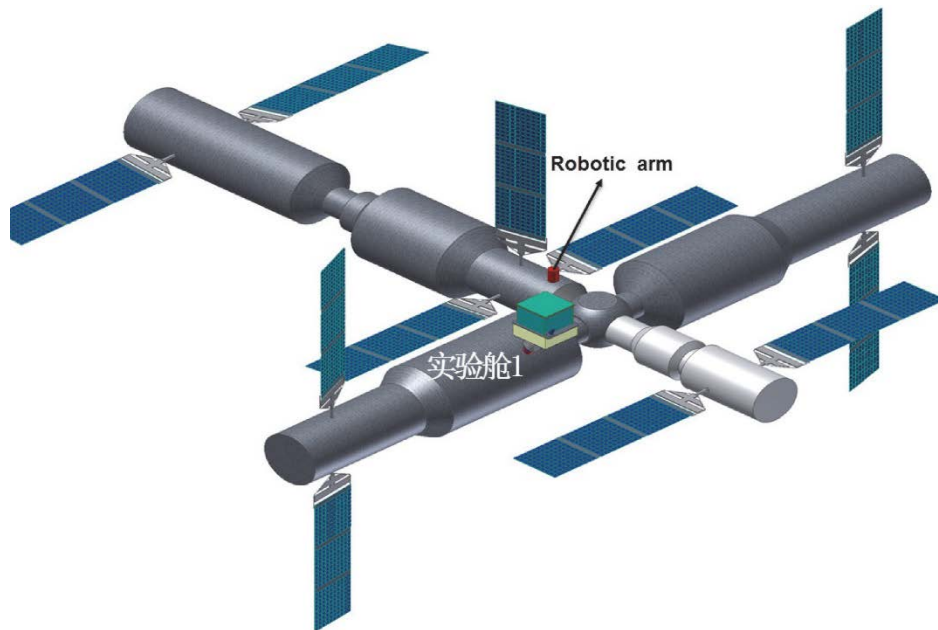
- Mass <4000 kg
- Power < 1200 W
- Envelope < 2400*2400*2400 mm³

Table 4.4 HERD payload budget (To be updated)

Name	Quantity	Envelope	Mass(Kg)	Power(W)
Crystal	7497	/	1500	0
CFRP	21	798*792*792	210	0
Epoxy	/	/	50	0
Fiber	22491	/	20	0
IsCMOS	4	300*300*400	60	428
Trigger	2	200*200*100	20	24
Top Tracker	1	1490*1490*304	390	70.5
Side Tracker	4	1050*823*138	208	43.6
STK EBX	8	370*235*178	52	180
STK EBX2	1	200*150*100	15	20
Top PSD	1	1750*1750*60	80	12
Side PSD	4	1600*1157*60	240	49
PSD EBX	2	250*160*90	15	28
TRD	1	560*480*228	20	10
TRD EBX	1	250*160*90	5	20
PSU	1	500*400*300	15	176
PDHU	1	500*400*300	15	30
Star tracker	2	340*358*440	10	10
Arm adapter	7	/	45	0
Thermal control	/	/	80	20
Harness	/	/	40	0
Screws	/	/	10	0
CALO structure	1	973*973*823	TBD	0
STK&PSD structure	1	1750*1750*1187	TBD	0
Main structure	1	2200*1800*797	TBD	0
Bridge structure	1	2350*600*540	110	0
Sum		<2400*2400*2400	<4000	<1200

System requirement – Launch, transportation and installation

- 4 tons; envelope $<2400*2400*2400$ mm³
- Requirements
 - Full-open ship
 - Docking at the front docking point (for manned space ship)
 - Two neighbor mounting points
 - Large FoV not blocked by other devices



System requirement - operation

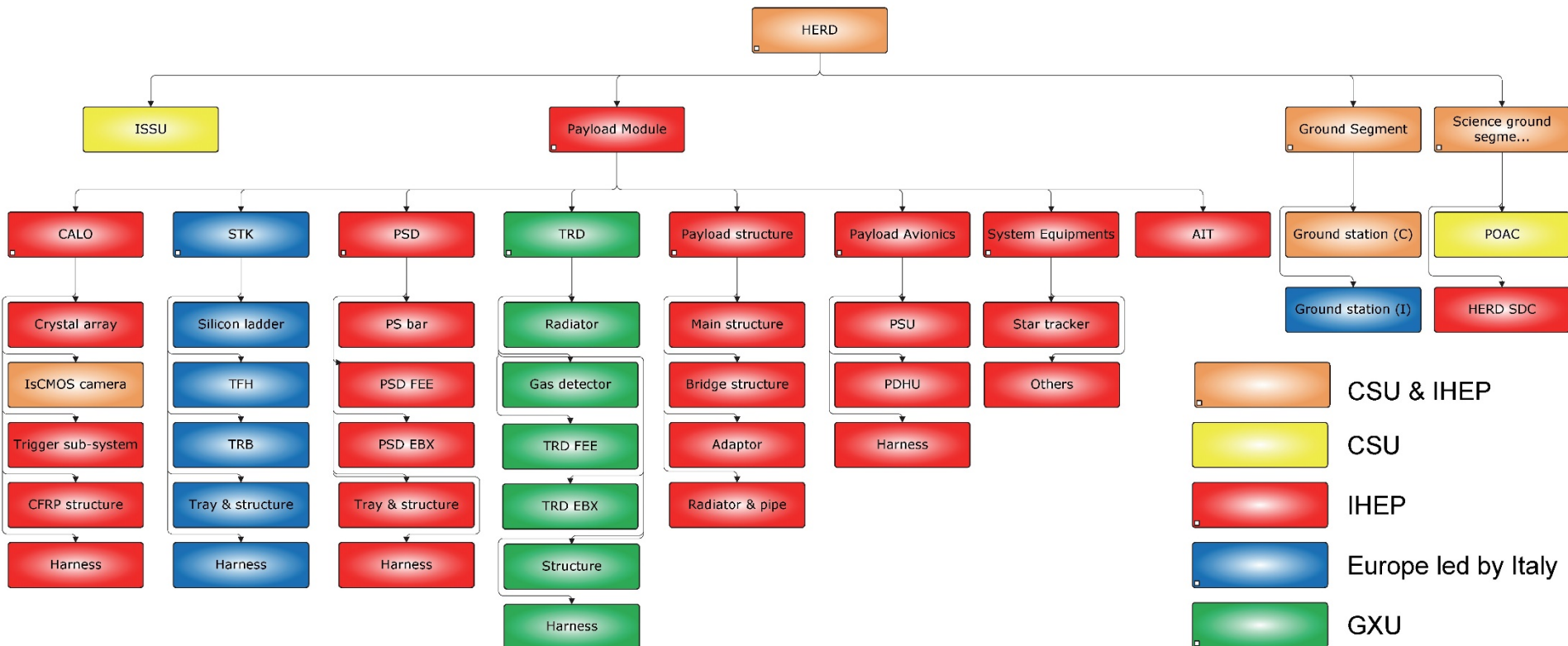
- Two star trackers installed on HERD
- High measurement accuracy, no strong requirement on stabilization or pointing accuracy
- ~1200 W power supply and liquid coolant.
- Data processing in ISSU (event selection, shower discrimination, tracker identification, data compression, etc.)
- Relay satellite and/or global ground stations for continuous telemetry data rate (equivalent to 100 Mbps in average)

System requirement - replacement

- Upgrade of IsCMOS
- Possible replacement of IsCMOS and TRD.

Programmatic issues – product tree

- HERD is an international cooperative project with hardware contribution from Europe (Italy) and a international consortium for joint science study.
- The HERD mission is jointly led by CSU and IHEP, who take responsibilities at engineering level and science level respectively.



Model philosophy and project schedule

- Model matrix (to be discussed and tailored)
 - The engineering/electrical model (EM). For some devices, Dummy Model (DM) or Bread Board Model (BBM) may be used instead.
 - The Structural-Thermal model (STM).
 - The Qualification model (QM).
 - The Flight Model (FM).
 - The Flight Spare (FS). Redundancy detectors with a few channels can be used as FS.
- Project schedule (Launch time before 2025)
 - Phase A, 2018.01 - 2019.06 (18 months)
 - Phase B, 2019.06 - 2020.10 (16 months)
 - Phase C, 2020.10 - 2022.02 (16 months)
 - Phase D, 2022.02 - 2023.10 (20 months)

Operation

- A HERD Joint Science Working Group (JSWG) will be formed and be co-chaired by one Chinese representative and one European representative.
 - This Group will be responsible for the joint science management of the HERD mission.
 - In particular, the group will be responsible for management of calibration and validation of the Payload Instrument Data.
- Two science data centers shall be established, one in China and one in a European country
 - All data are stored in both centers supported with the same or similar analysis software.
 - JSWG is responsible for overseeing both centers.
 - The data shall be stored and maintained during the whole mission life time of HERD and at least 10 years after the mission ends.

Data policy

- All data and data products generated by HERD are jointly owned by China and the European consortium and are intended for scientific research only;
- Any other use of HERD data and/or data products will have to be negotiated and agreed by all parties of the HERD collaboration.
- It is anticipated that the HERD raw data will not be made public beyond the HERD collaboration. However, high level science data products shall be made public at certain stages (the specific conditions may be determined later by JSWG) in order to maximize the scientific returns of HERD.
- All major technical and scientific publications on HERD and HERD results shall include all members of HERD collaboration working on HERD and HERD data. The ordering of the authorship should reflect the contributions of the individual authors and his/her institutions. The detailed rules shall be determined later by JSWG.

Cost budget

- In the baseline design, the Cost at Completion of HERD payload module on China side is about 800M RMB.
- The costs of rocket, launching, cargo ship, SDC, etc. are not calculated.
- Budget from Italy (Europe) strongly relies on the selection of technical scheme for tracker and calorimeter. TBD.

Summary

- HERD, as a China-led mission with a large international collaboration, is a flagship and landmark scientific experiment onboard China's Space Station
- Advanced scientific objectives in DM search, CR observation and gamma-ray astronomy
 - May confirm the pulsar origin of positron/ electron excess measured at AMS-02
- Novel design of 3-D calorimeter, verified in CERN beam test
- Expected launch time before 2025

