High Energy cosmic-Radiation Detection (HERD) Facility onboard the China Space Station
—— STATUS and PLAN

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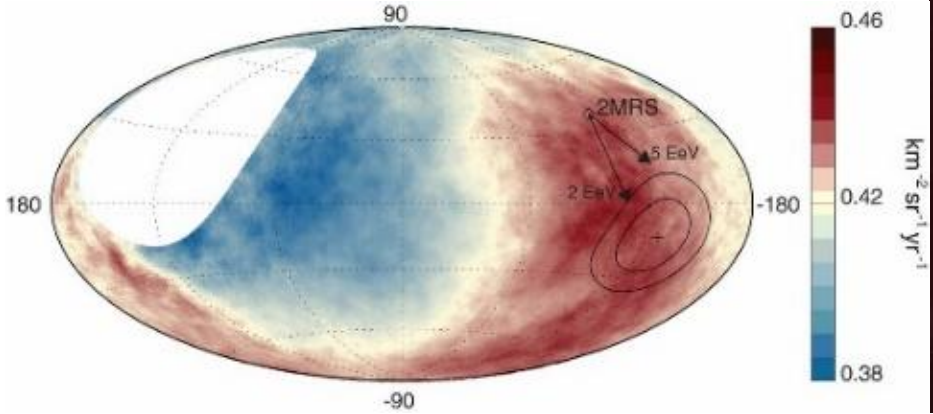
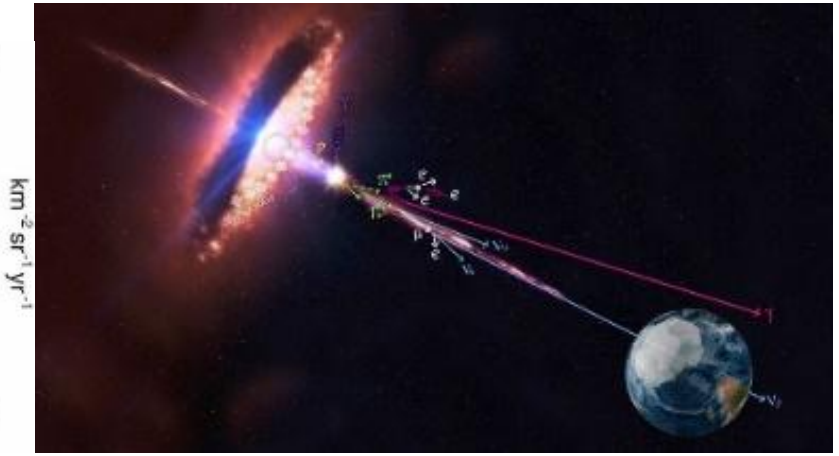
HERD collaboration

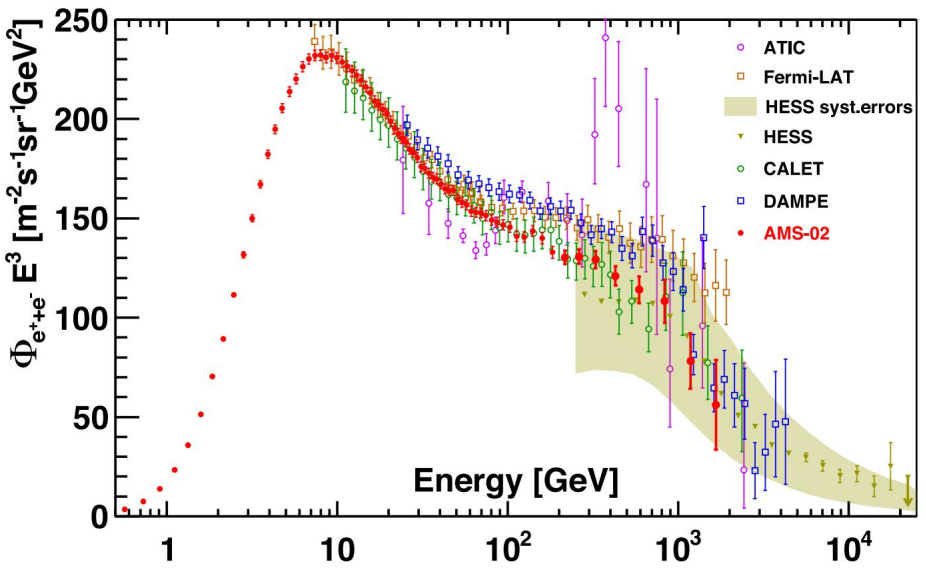
HERD: High Energy cosmic-Ray Detection facility

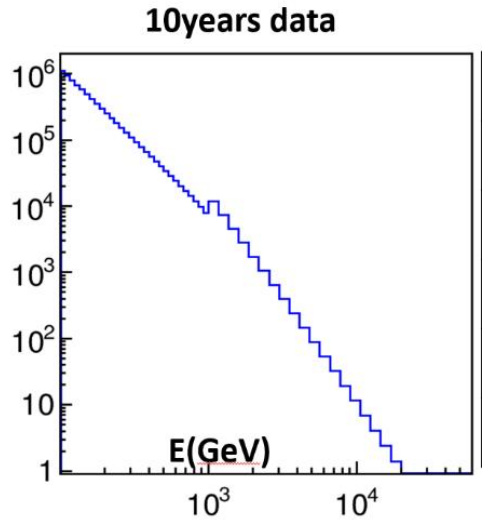
- HERD, as a space particle experiment and gamma ray observatory, is a China-led large international collaboration with key European contributions led by Italy.
- One of the two flagship scientific experiments onboard China Space Station
- Main Scientific Objectives:
  - Dark matter: Indirect dark matter search with unprecedented sensitivity
  - Cosmic-ray: Precise & direct cosmic ray spectrum and composition measurements up to the PeV energy
  - Gamma-ray: Gamma-ray monitoring and full sky survey



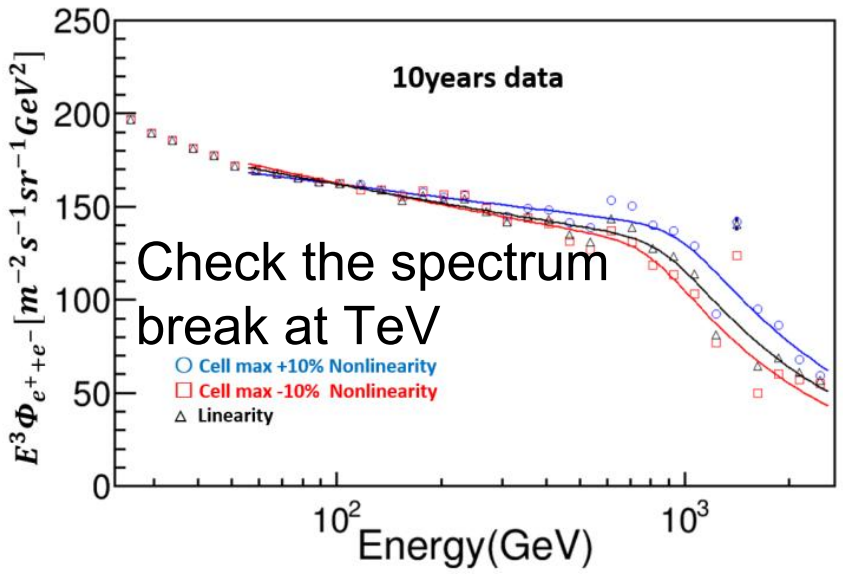


Direct measurement of cosmic electron spectrum

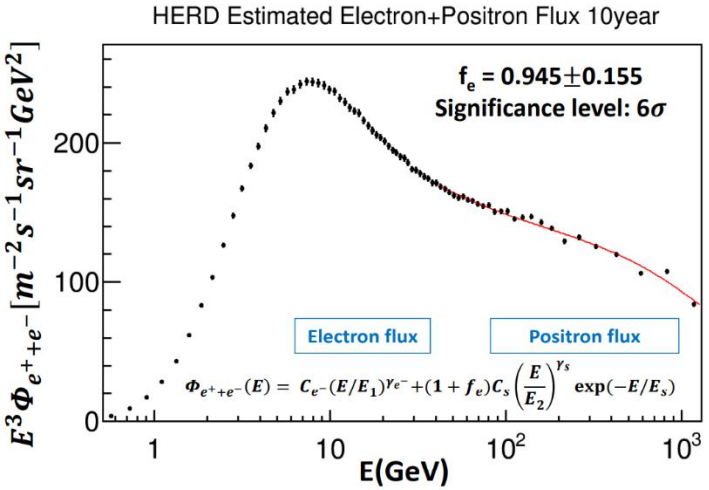




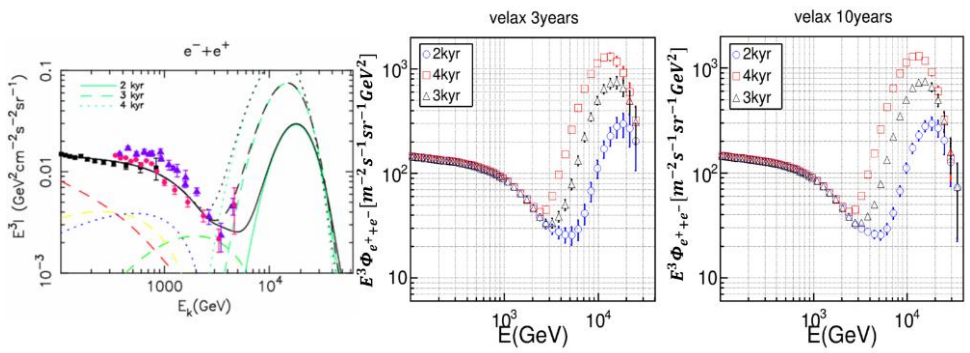
Up to highest energy, ~15 TeV



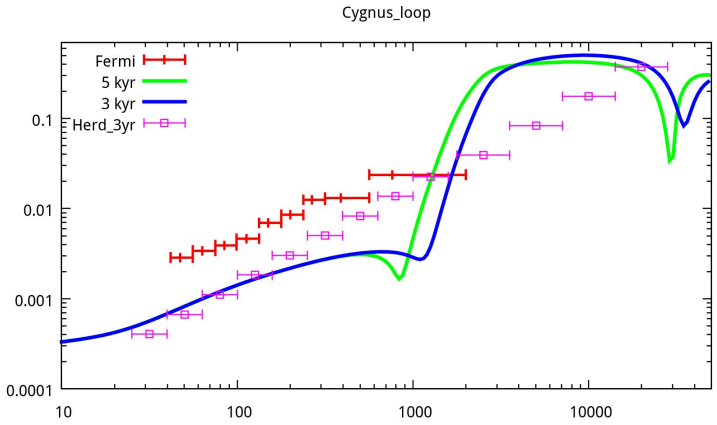
Check the spectrum break at TeV



Examine the extra positron sources in AMS-02 spectrum

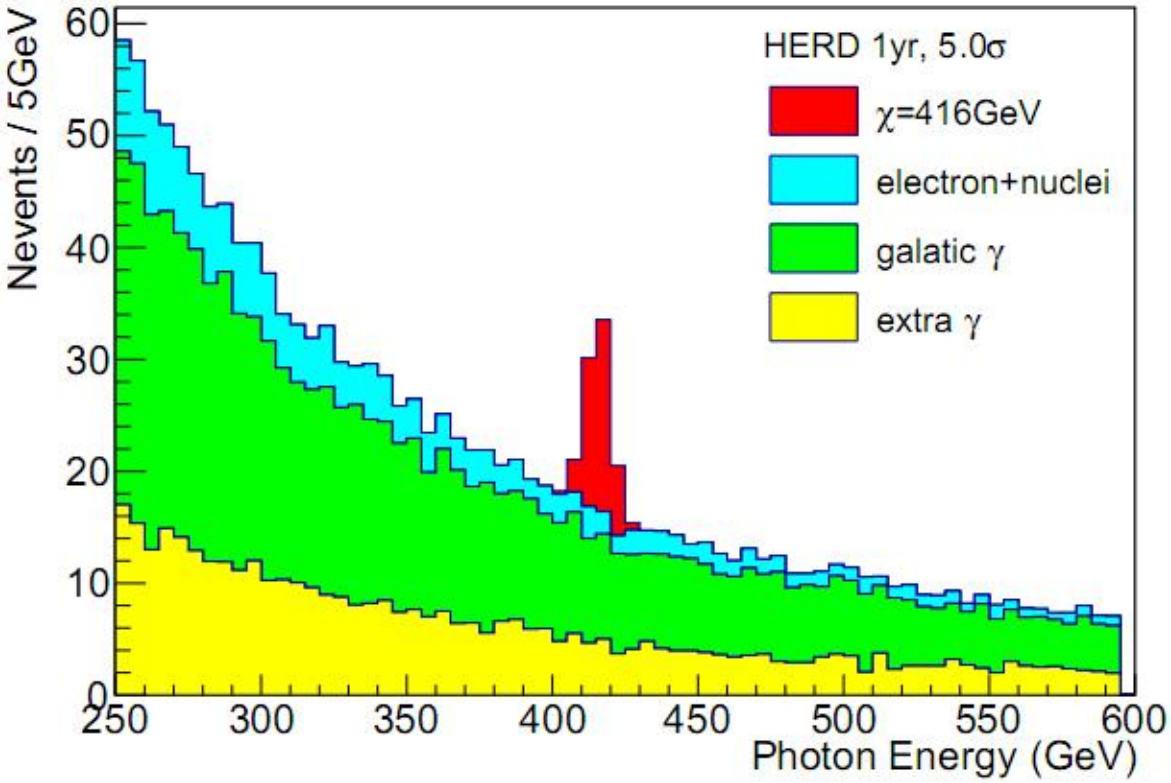


Spectrum bump of HE electrons from nearby sources



Anisotrophy of HE electrons from nearby sources

High sensitivity in dark matter search



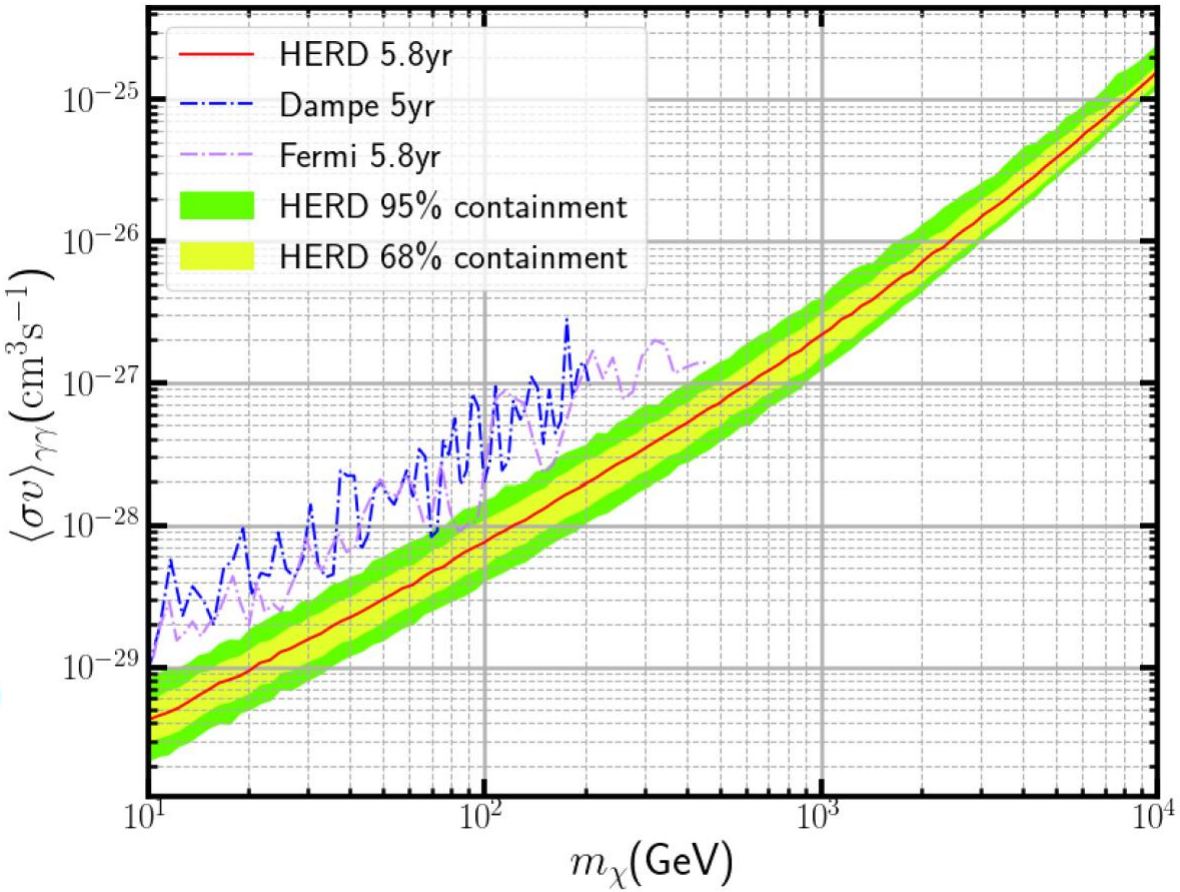
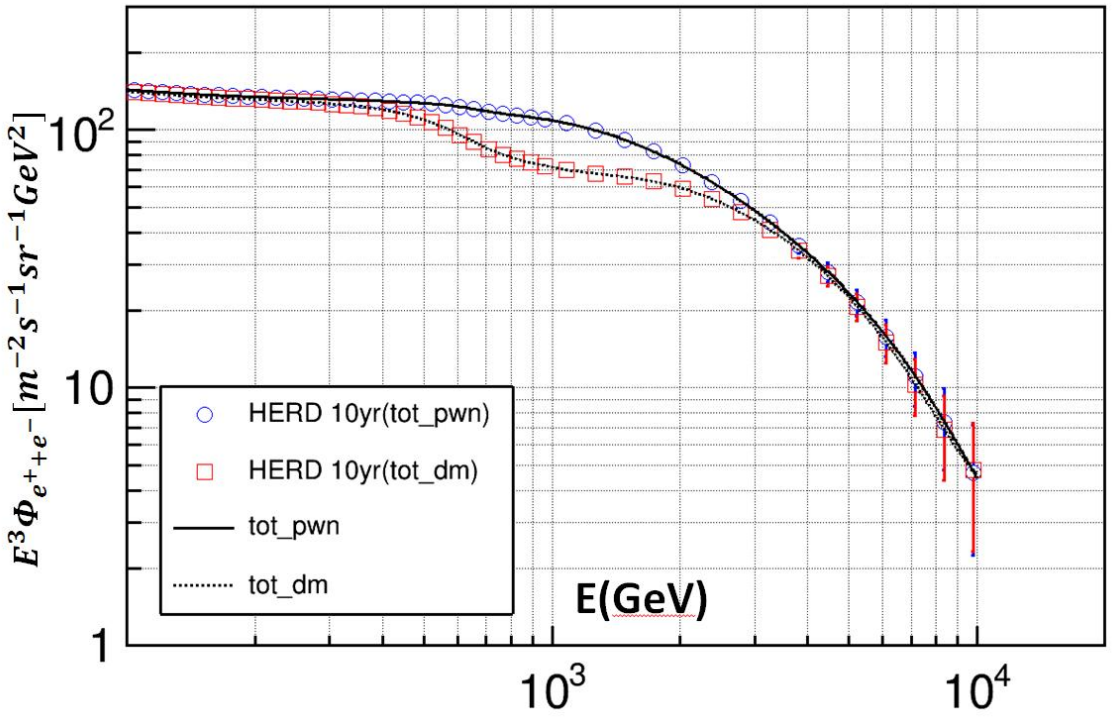
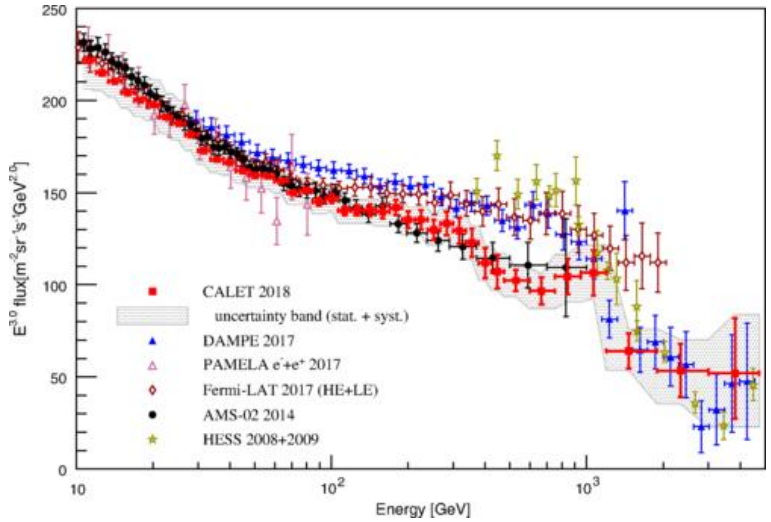


图 3-10 HERD 对暗物质湮灭线谱探测灵敏度

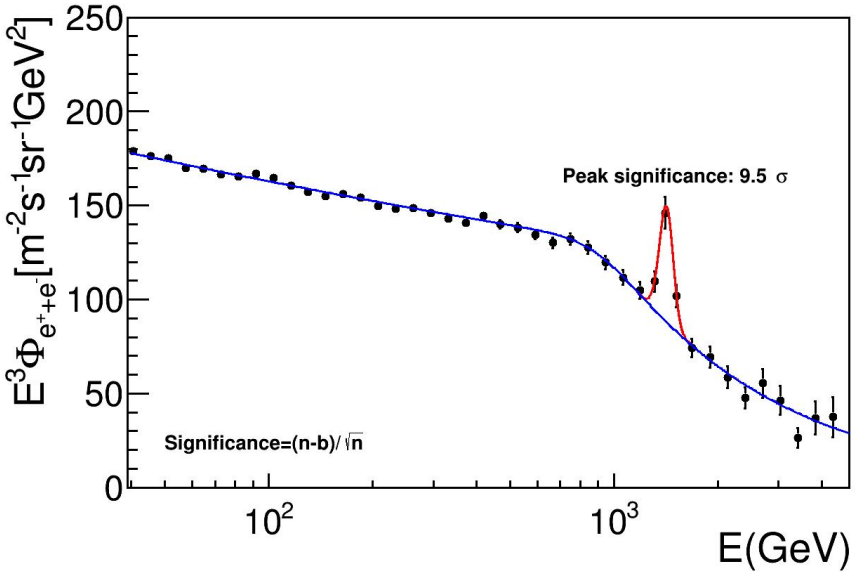
Dark matter signals?



Search the annihilation signals of dark matter particles

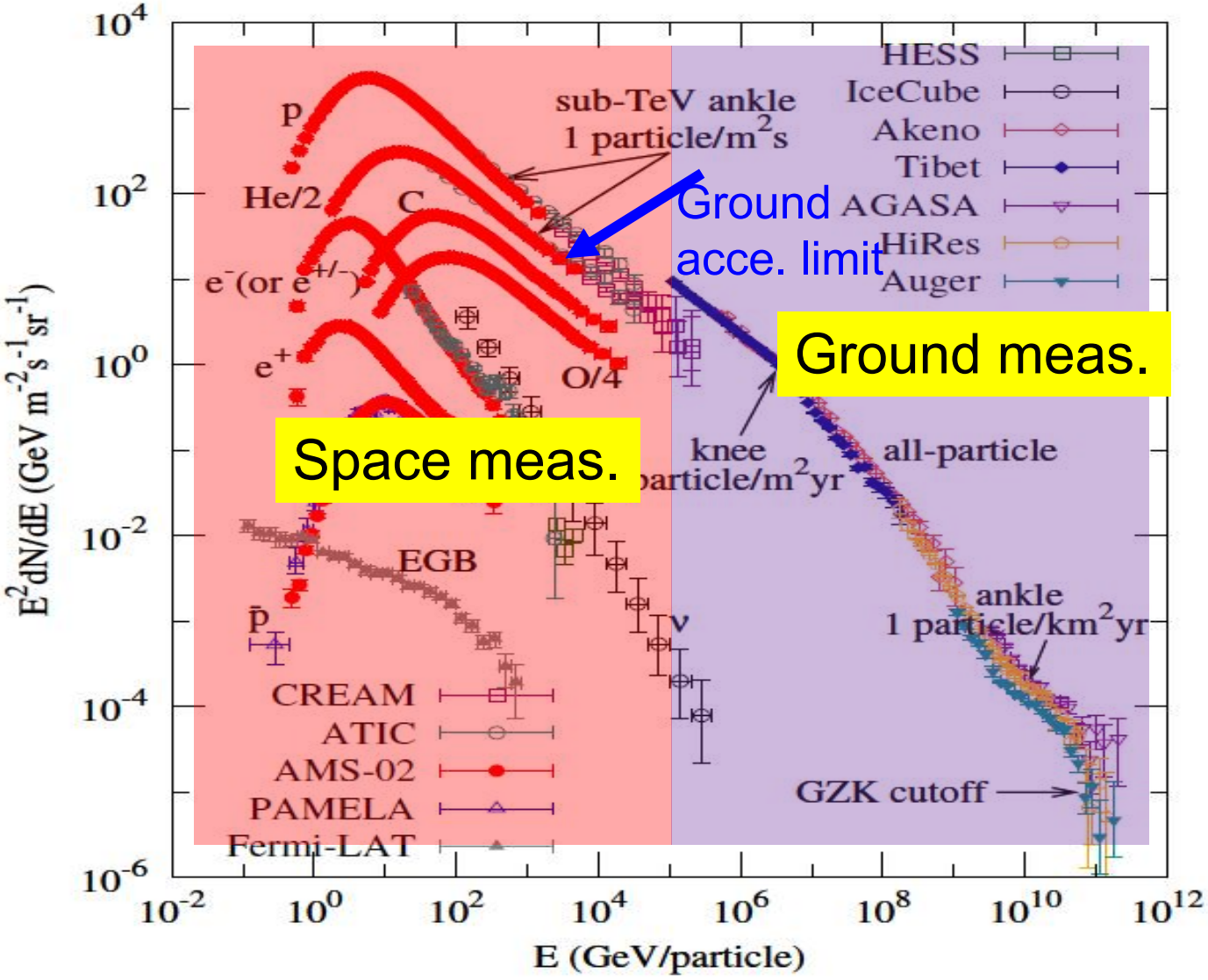


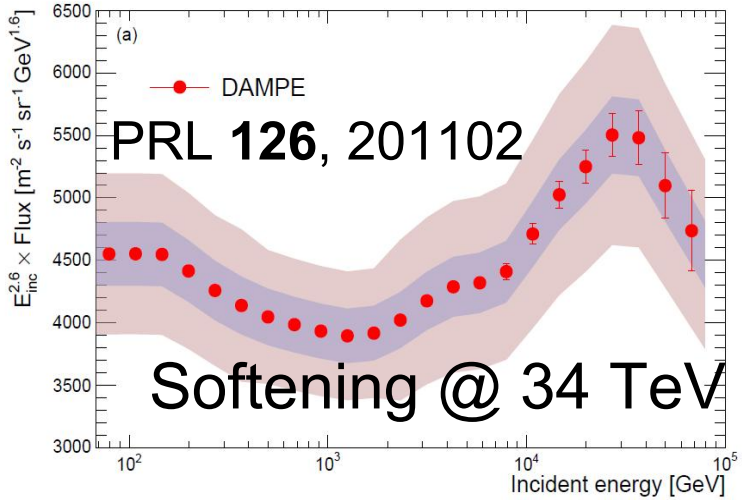
HERD Estimated Electron+Positron Flux 1year Energy Resolution 1.5%

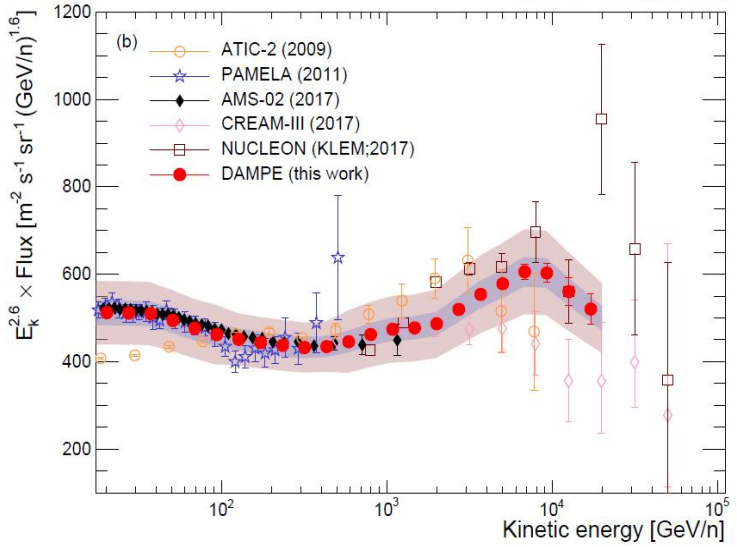


Peak at the DAMPE electron spectrum

Origin of cosmic rays

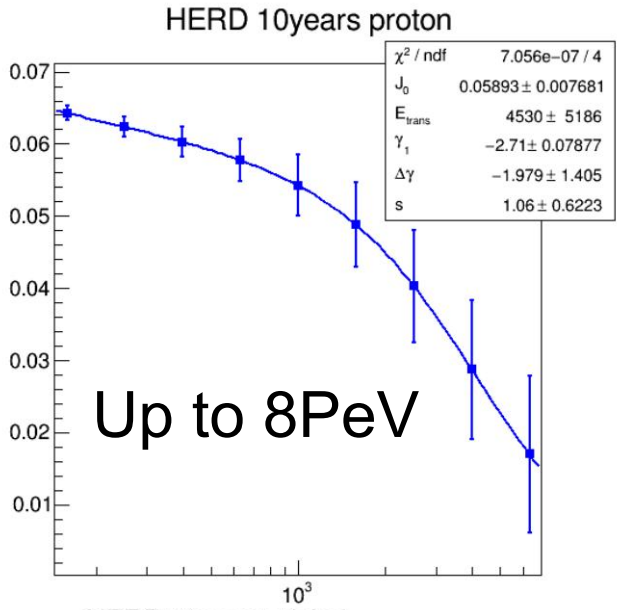


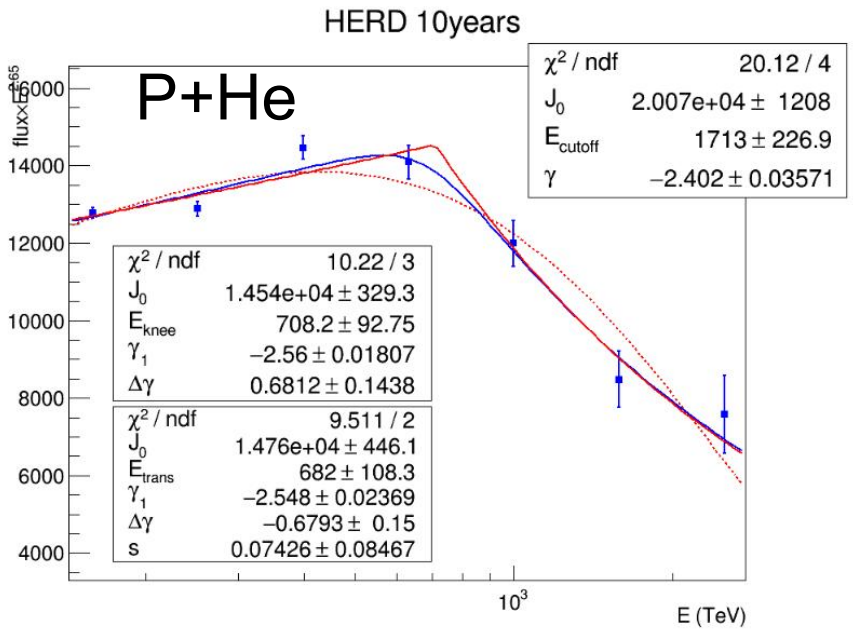


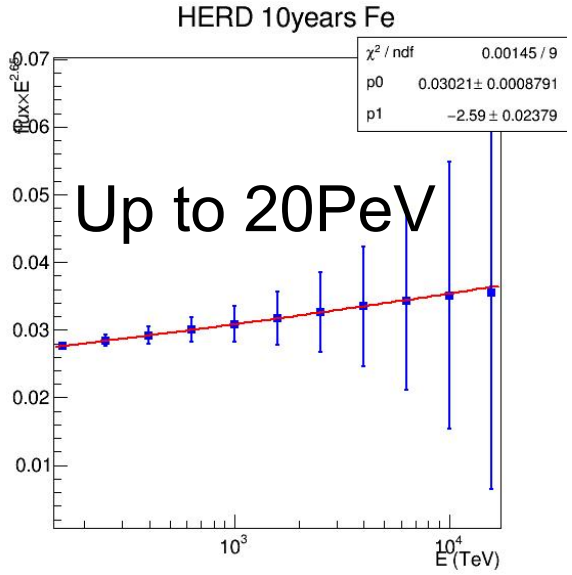


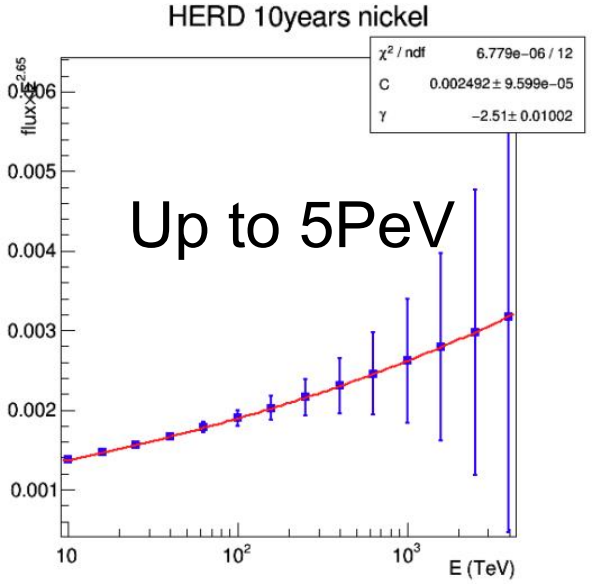
Expected CR spectrum

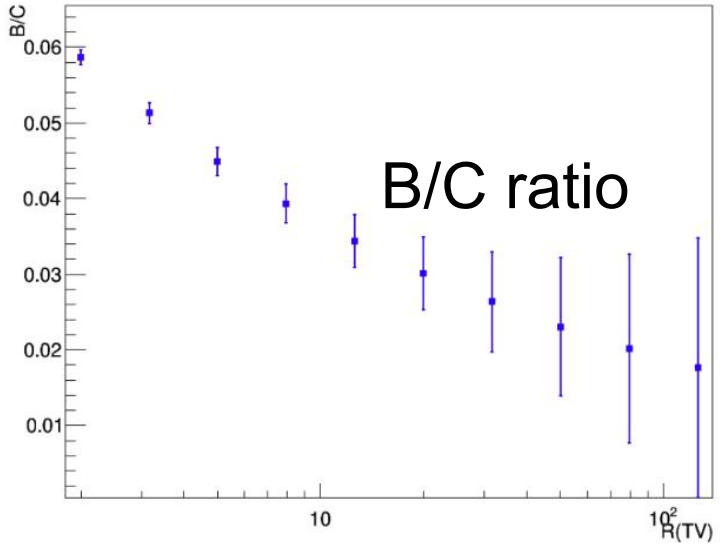
- First direct measurement of CR “knee”
- Nuclei up to Ni





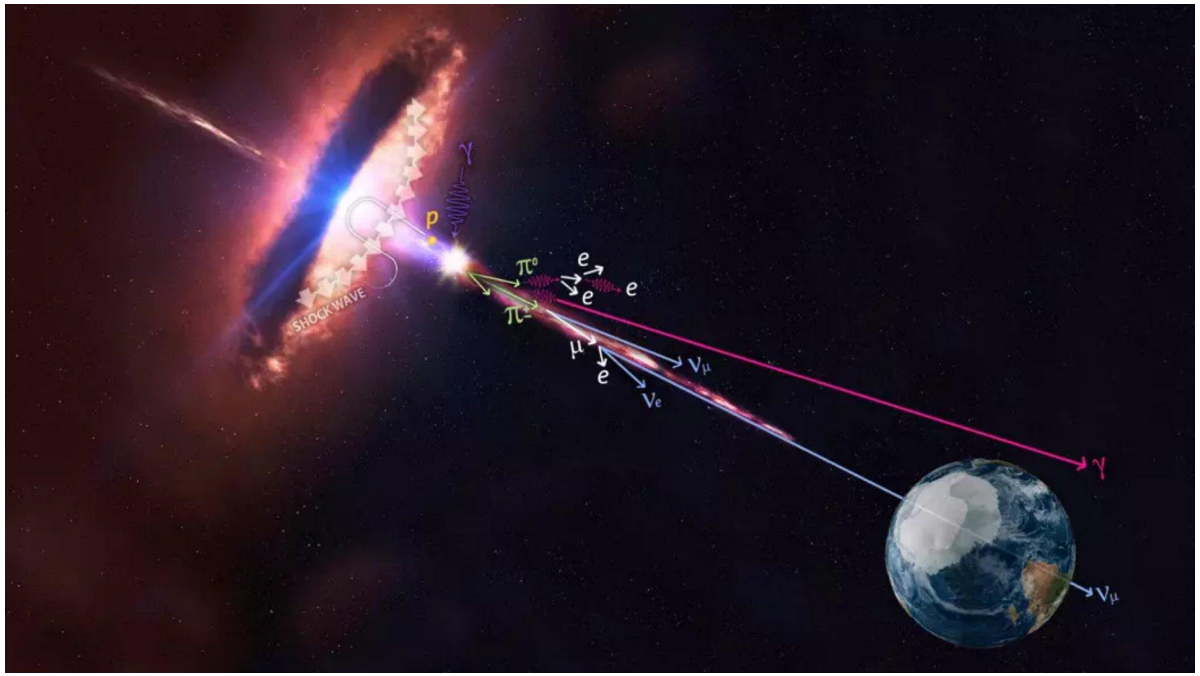


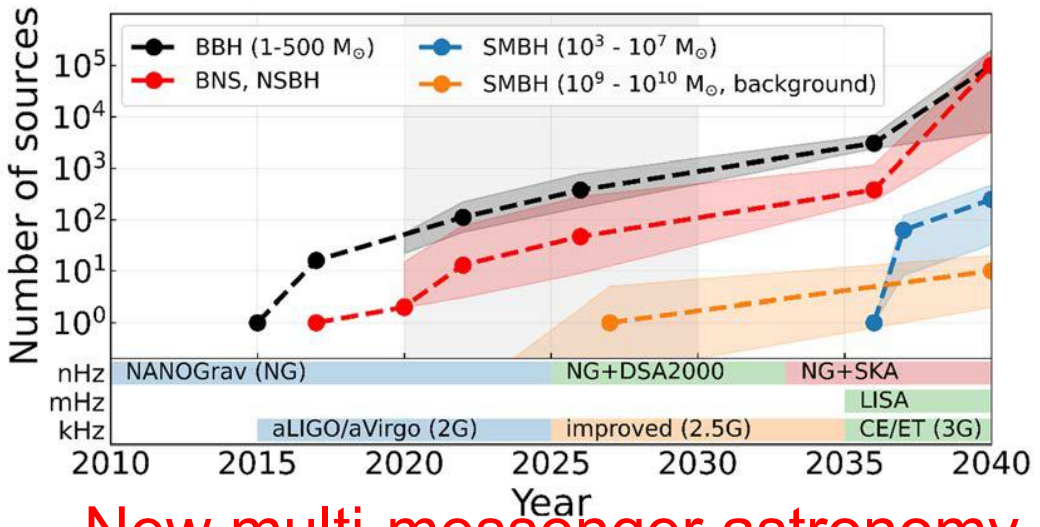




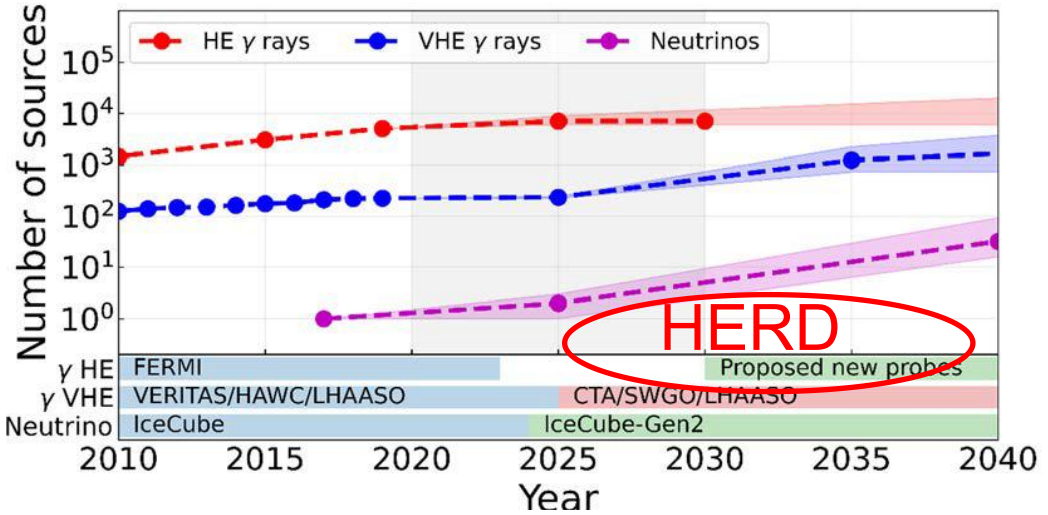
Gamma ray monitoring & survey

- Largest FoV for monitoring and sky survey
- Multi-messenger astronomy



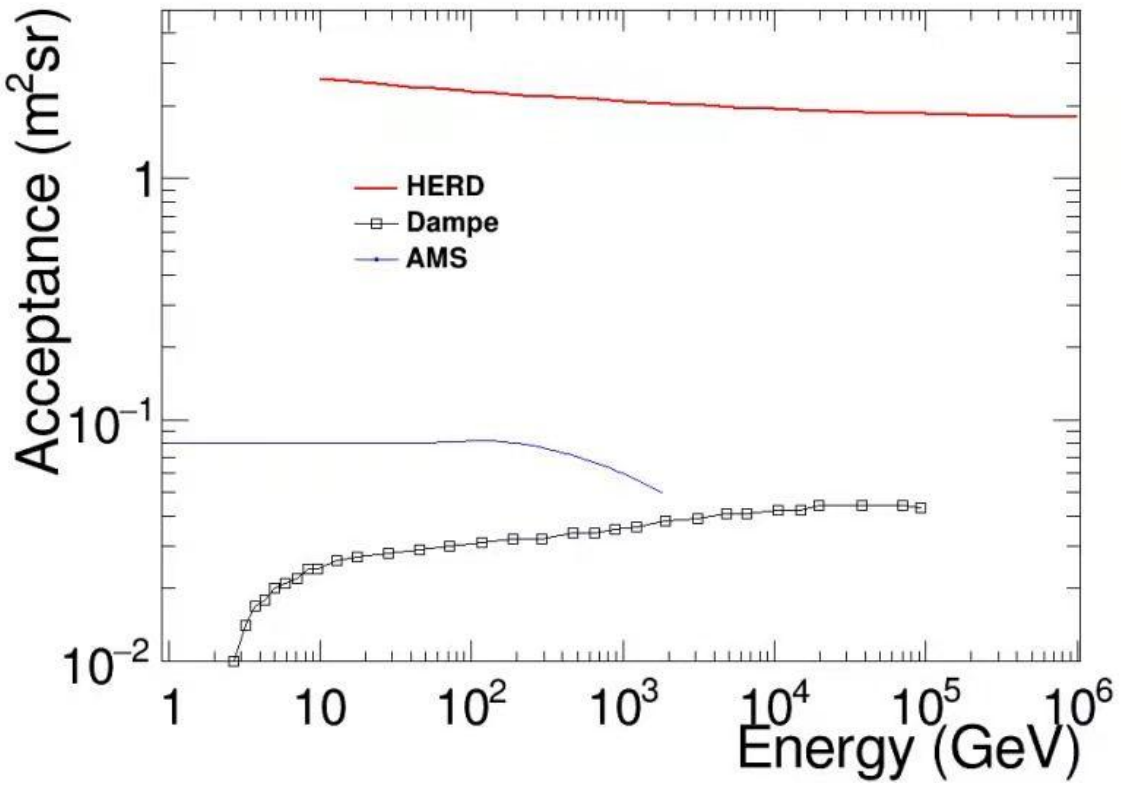


New multi-messenger astronomy

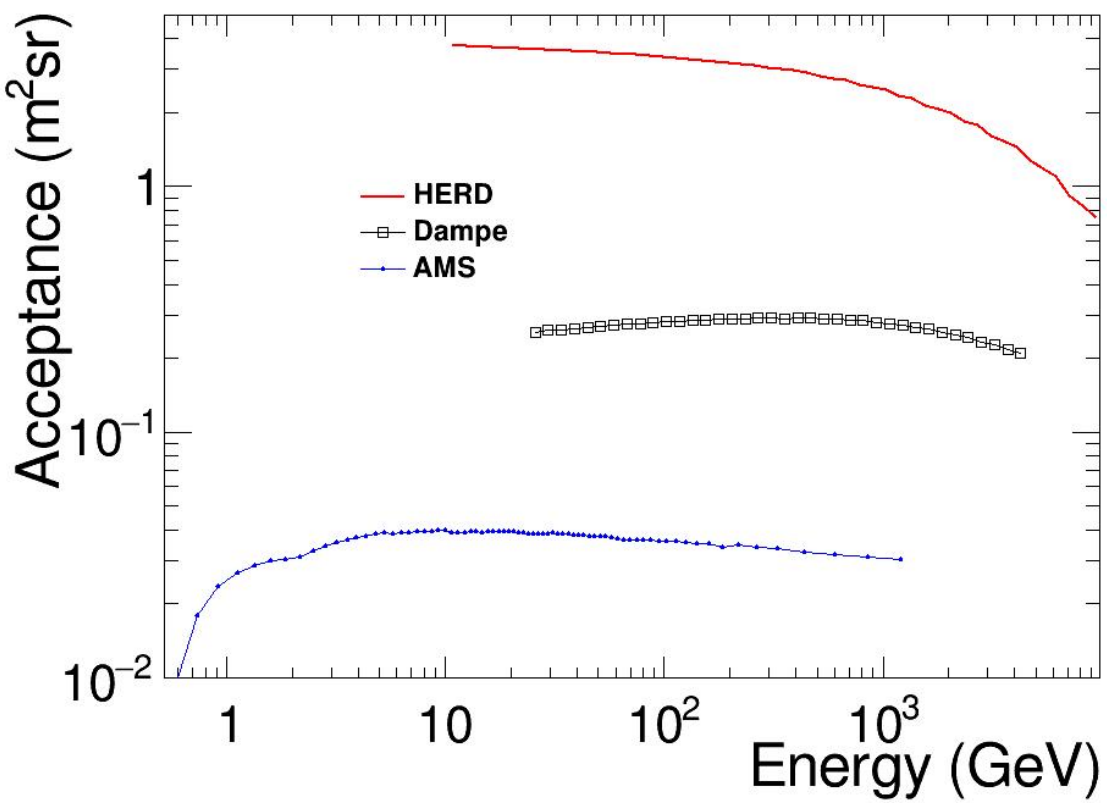


Acceptance comparison

Proton Acceptance



Electron Acceptance



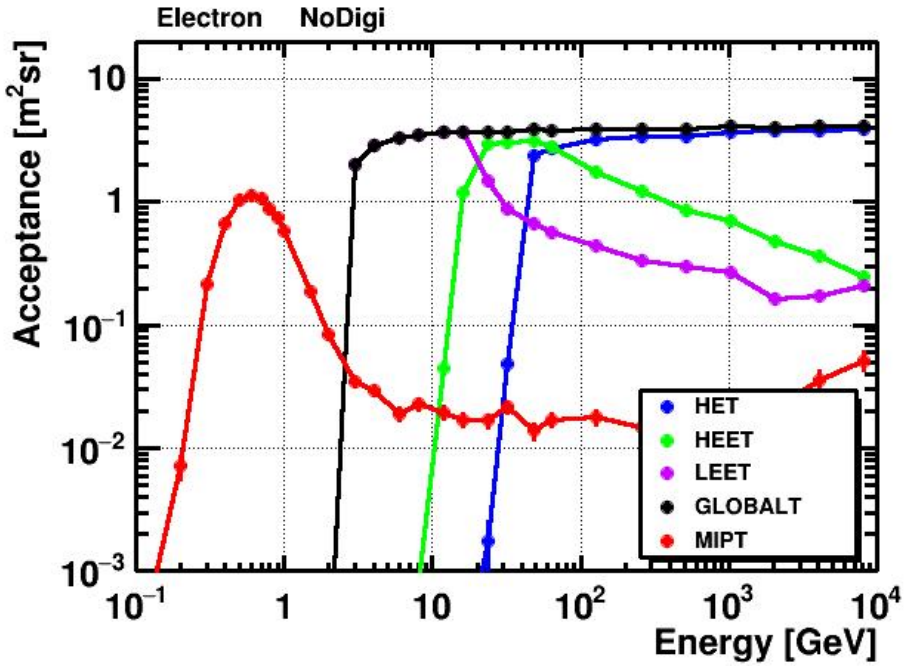
Onboard Trigger strategy

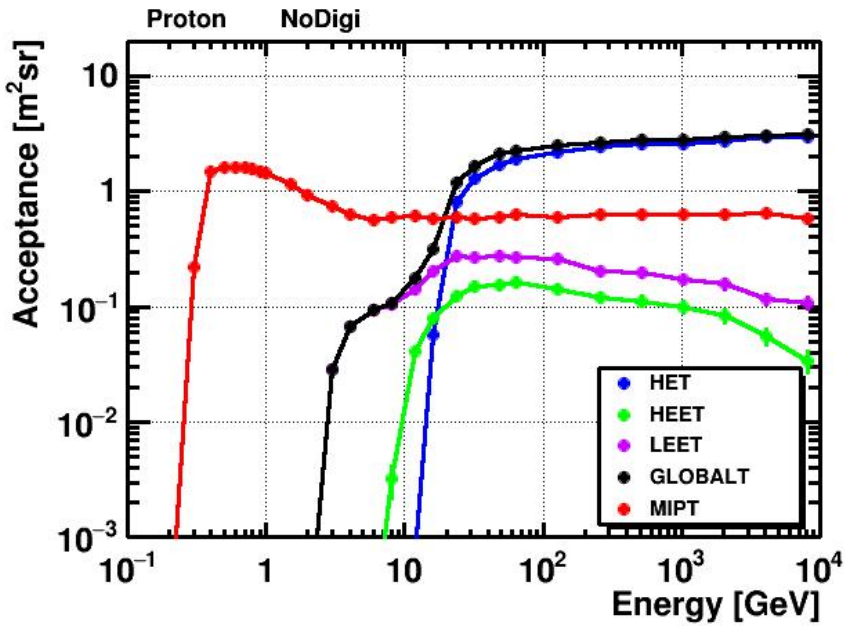
China, Spain

- Optimization: LEG (~100MeV), LE & High Z (~GeV)

Subtrigger	Energy Thresholds [GeV]
HE	$E_{CALO\_TOT} > 15$
LEG	$((E_{CALO\_SHELL} > 0.35 \,\&\, (E_{PSD\_SIDE} < 0.001)) \,\&\, (E_{CALO\_BOT} < 0.1)$
LEE	$((E_{CALO\_TRD} > 0.35) \,\&\, (E_{CALO\_CORE} < 0.06)) \| ((E_{CALO\_TRD} > 1.00) \,\&\, (E_{CALO\_CORE} < 0.60))$
UNB	$E_{CALO\_SHELL} > 0.35$
CALIB	$(0.1 < E_{CALO\_SHELL} < 0.8) \,\&\, (E_{CALO\_SHELLS} < 0.1) \,\&\, (E_{CALO\_CORE} > 0.5)$

Baseline design





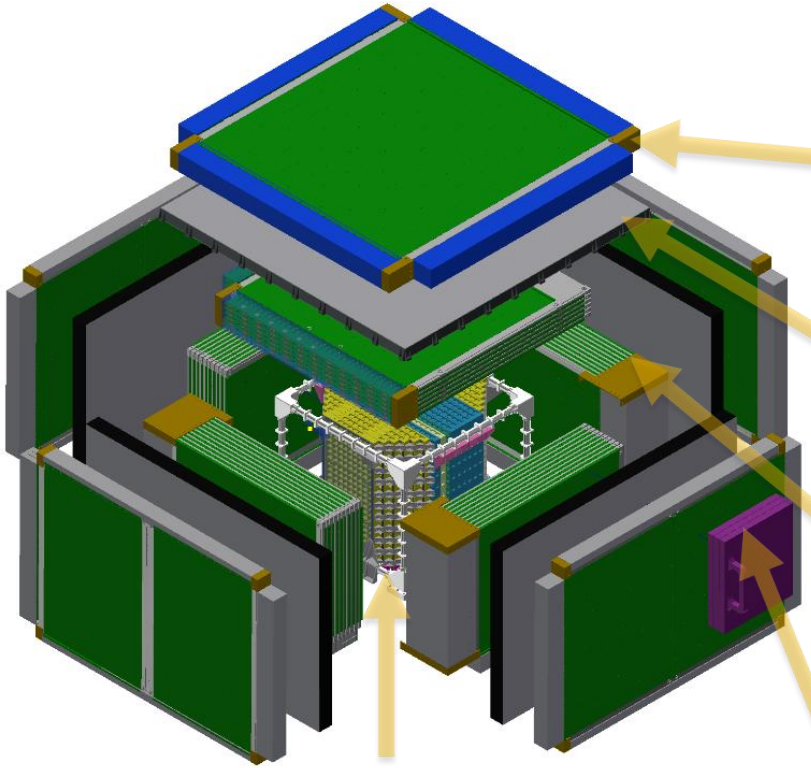
Advanced design

HERD vs. other experiments

Experiment (time)	Energy (e/γ)	Energy (p)	ΔE/E (e/γ)	ΔE/E (p)	e/p ID	e accep. m^2sr	p accep. m^2sr
FERMI (2008)	1GeV-300GeV	30GeV-10TeV	10%	40%	10^3	0.9	<0.28
ISS-AMS02 (2011)	1GeV-1TeV	1GeV-1.8TeV	2%	-	10^6	0.12	0.12
ISS-CALET (2015)	1GeV-10TeV	50GeV-10TeV	2%	35%	10^5	0.12	--
DAMPE (2015)	5GeV-10TeV	40GeV-100TeV	≤1.5%	25-35%	$3*10^4$	0.3	0.04
HERD (~2027)	10GeV-100TeV 0.5GeV-100TeV (γ)	30GeV-PeV	1%	20%	10^6	>3 (10X DAMPE)	>2 (50X DAMPE)

HERD is a next generation experiment, following AMS02 and DAMPE, with much better performance on direct high energy e, p, gamma-ray detection.

HERD payload



SCD
Z measurement

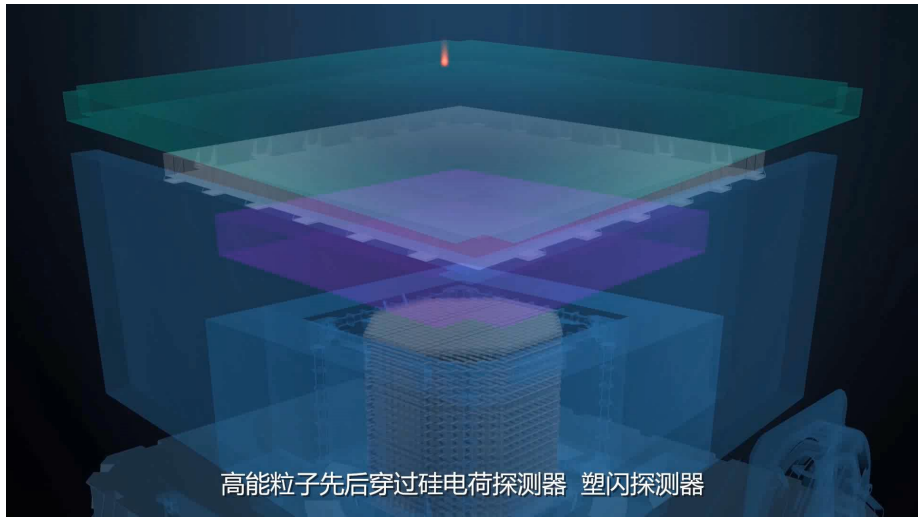
PSD
Gamma ID.
Z measurement

FIT
Tracking
Gamma conv.

TRD
TeV nuclei calibration

CALO
Energy measurement
Particle ID

Mass:	≤4000 kg
Envelope:	~3.0*2.3*1.7 m^3
FoV:	+/-90°
Power:	~1900 W
Telemetry:	100 Mbps
Lifetime:	>10 years

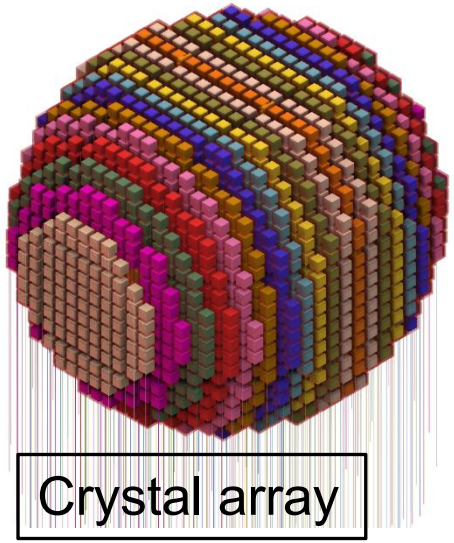


Energy range (e/γ)	10 GeV - 100 TeV (e); 0.5 GeV - 100 TeV (γ)
Energy range (CR)	30 GeV - 3 PeV
Angular resolution	0.1 deg.@10 GeV
Charge resolution	0.1-0.15 c.u
Energy resolution (e)	1%@200 GeV
Energy resolution (p)	20%@100 GeV – PeV
e/p separation	~10^{-6}
G.F. (e)	>3 m^2sr@200 GeV
G.F. (p)	>2 m^2sr@100 TeV

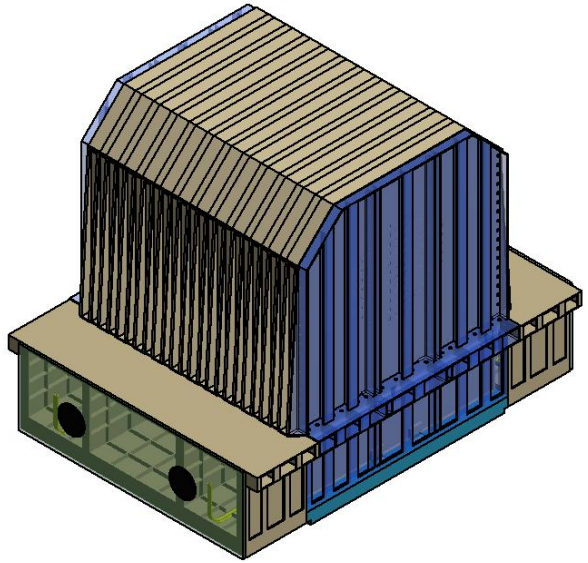
CALOrimeter

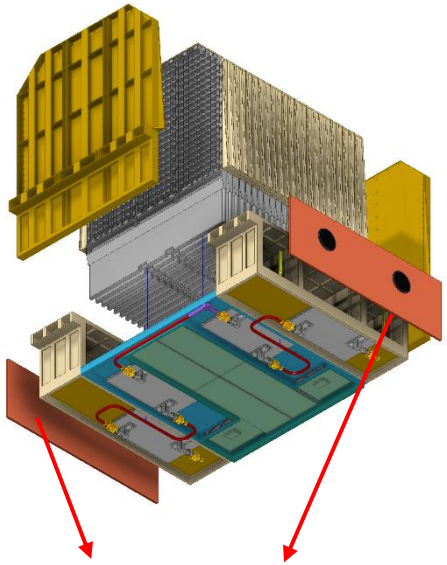
China, Italy, Spain

- CALOrimeter (3 N.I.L. and 55 R.L.)
  - ~7500 LYSO crystals
- From octagon to sphere. +8% acceptance



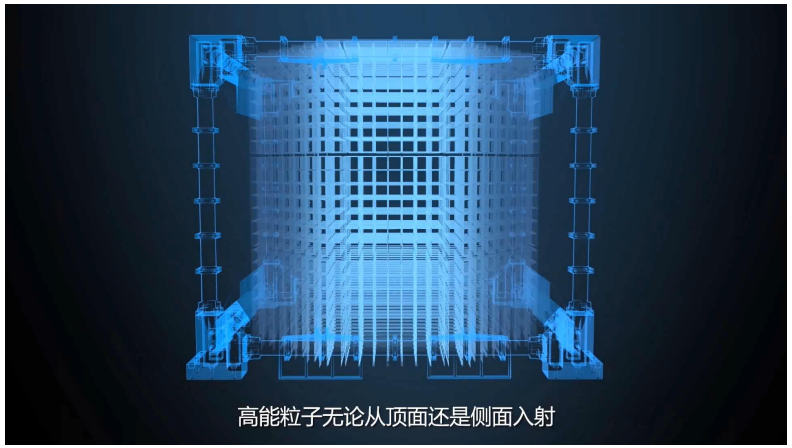
Crystal array

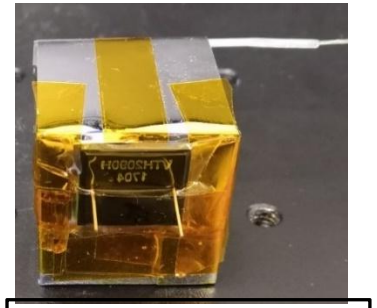




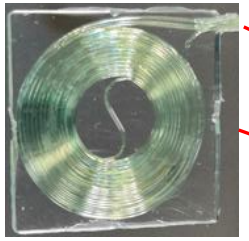
Trigger interface

Camera interface



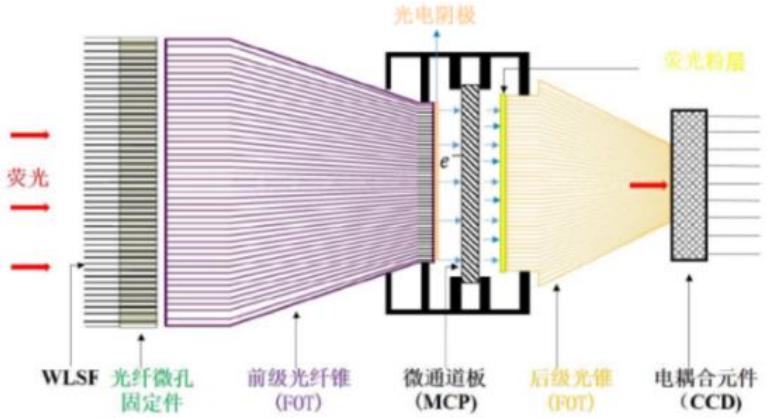


PD SYSTEM



Trigger system

IsCMOS camera



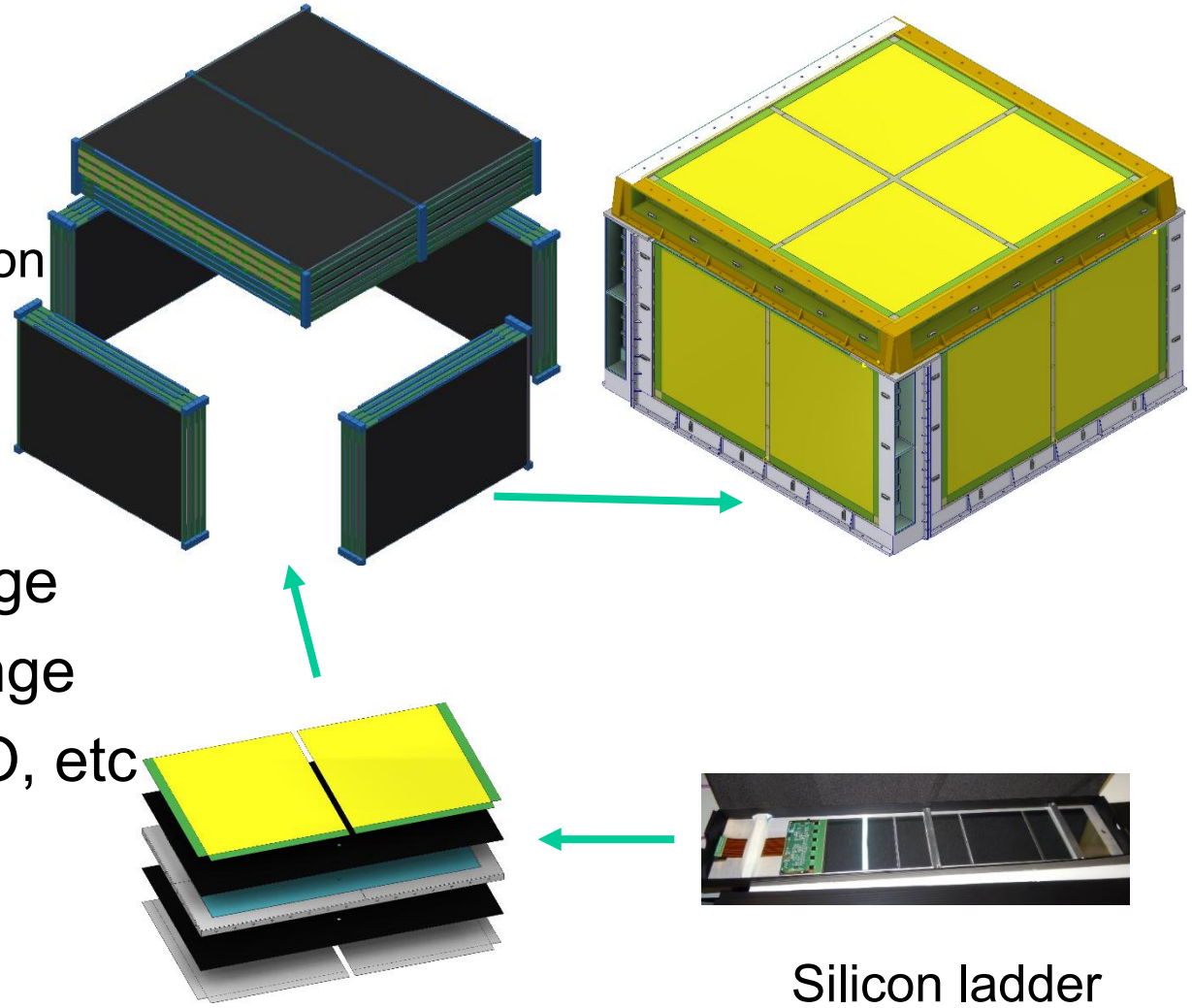
IsCMOS camera

Silicon Charge Detector (SCD)

Italy, China

- Charge measurement

- Features of SCD
  - Located at outmost to avoid ion fragmentation
  - Large detection area
  - Z =1 to 28
- 10 SSDs at most bonded in a row
- Customized SSD for large dynamic range
- Customized ASIC for large dynamic range
- INFN Perugia, INFN Torino, IHEP, PMO, etc

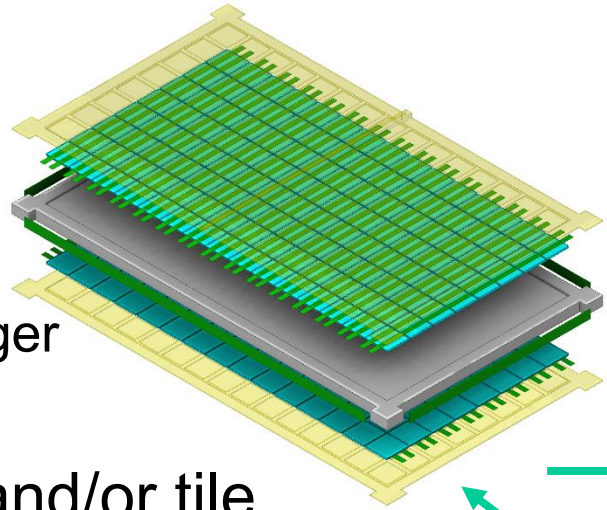


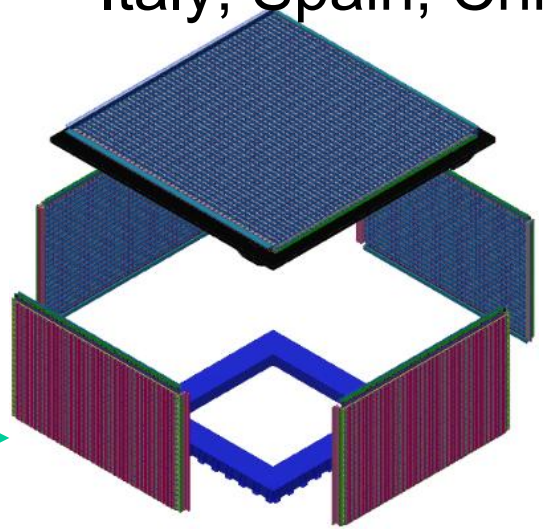
Silicon ladder

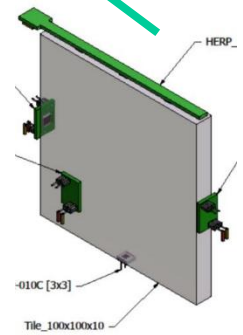
Plastic Scintillation Detector (PSD)

Italy, Spain, China

- Gamma-ray ID.
- Charge measurement
- Basic requirements
  - Full coverage of CALO for LEG trigger
  - Fast veto signal within 200ns
- Geometry of detection unit: Bar and/or tile
  - To reduce impact of backsplash effect
- PS readout by SiPMs
- INFN Bari, INFN Pavia, INFN Lecce, GSSI, ICCUB, IFAE, IHEP, etc.



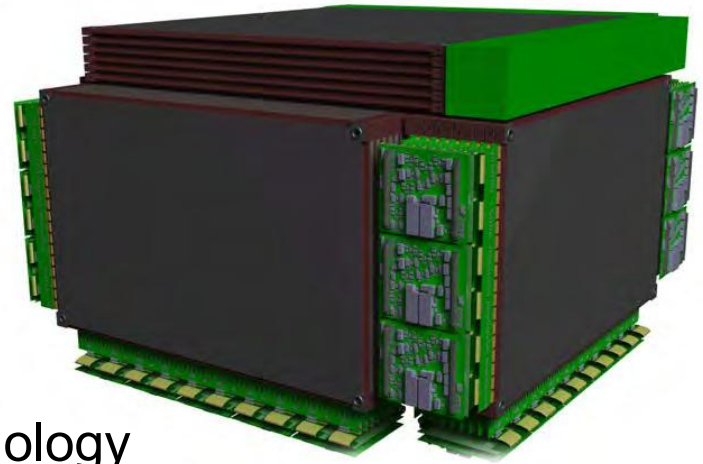


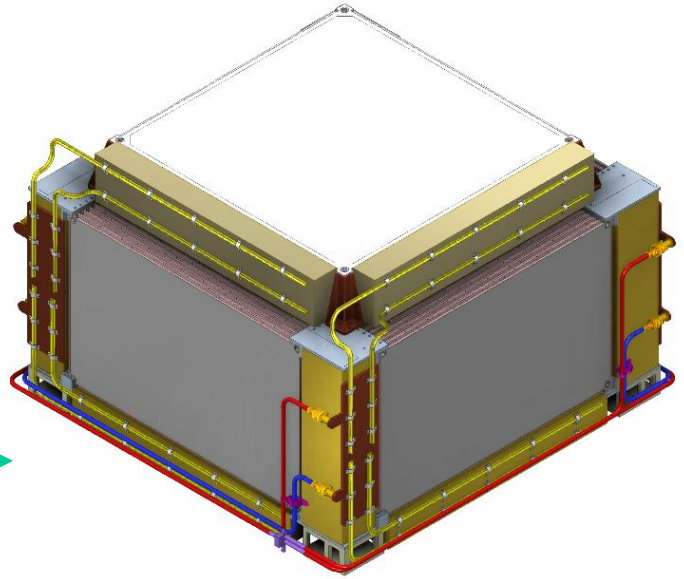


FIber Tracker (FIT)

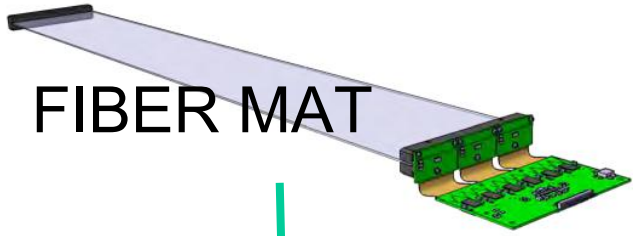
Switzerland, Spain

- Tracking
- Charge measurement

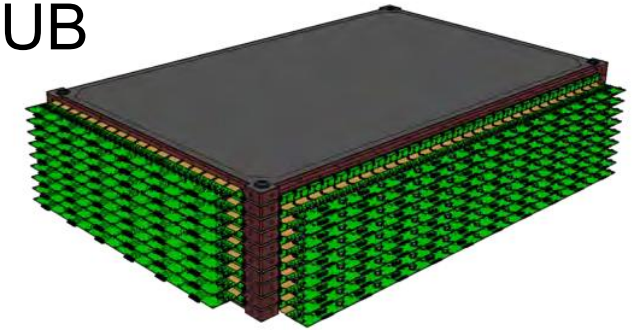


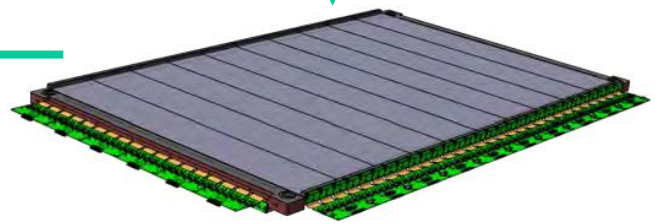


- Heritage of FIT
  - Based on LHCb & Mu3e technology
  - Robust design for high coverage ratio
- Diameter of scintillator fiber:~250um
- FIBER MAT is readout by SiPMs
- Univ. of Geneva, EPFL, ICCUB



FIBER MAT

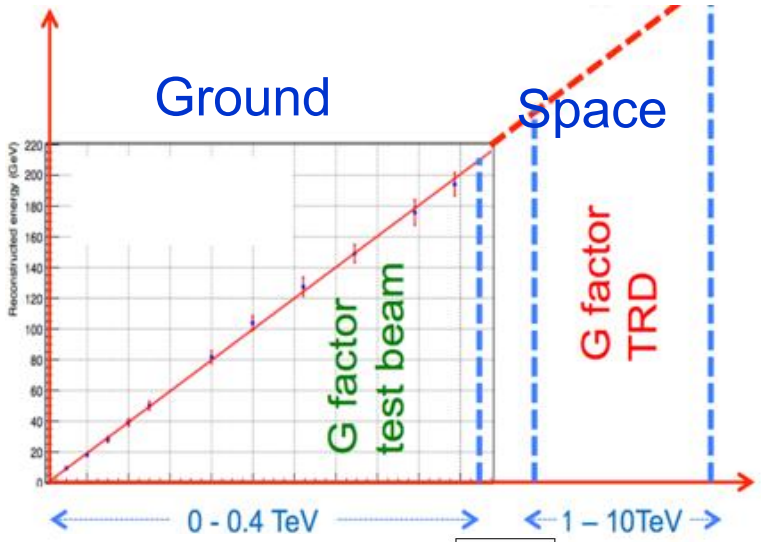


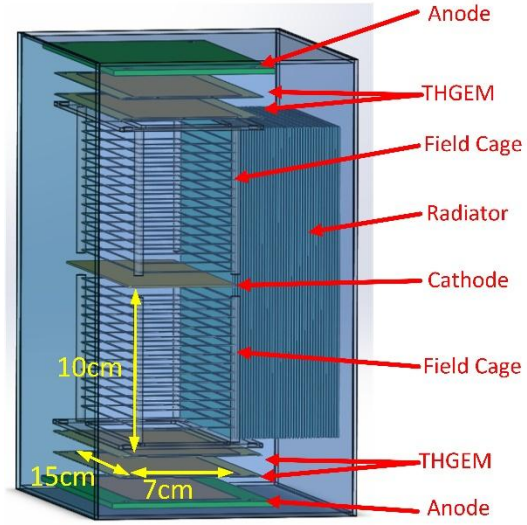


Transition Radiation Detector (TRD)

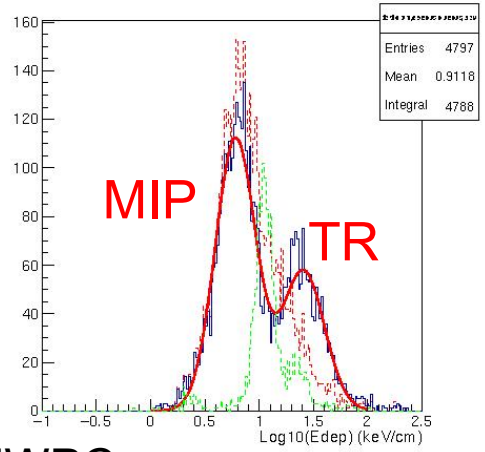
China

- Energy calibration of TeV nuclei

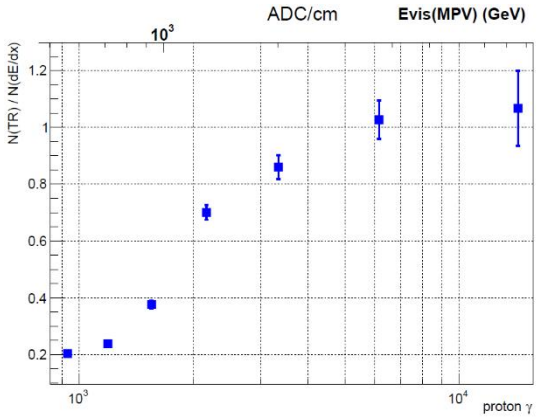




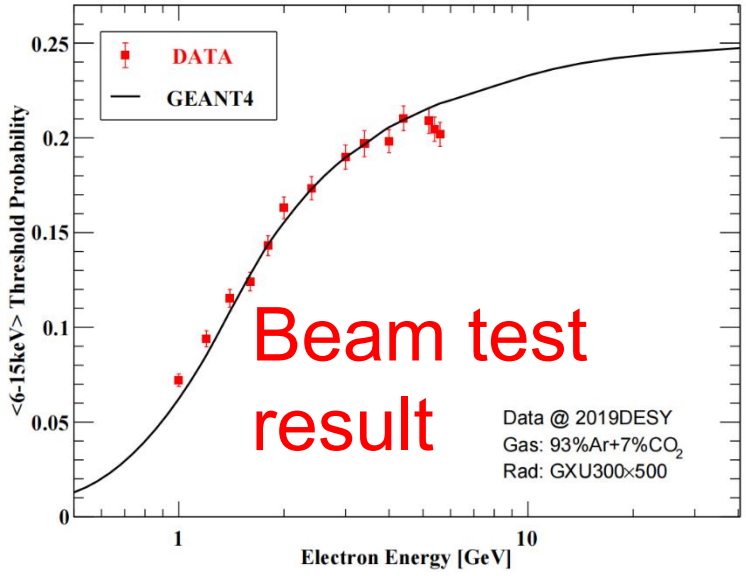
Radiator: multi-layer thin foils
Detector:
1 atm Xe
side-on THGEM



MWPC energy response to [2.25, 2.5] TeV protons



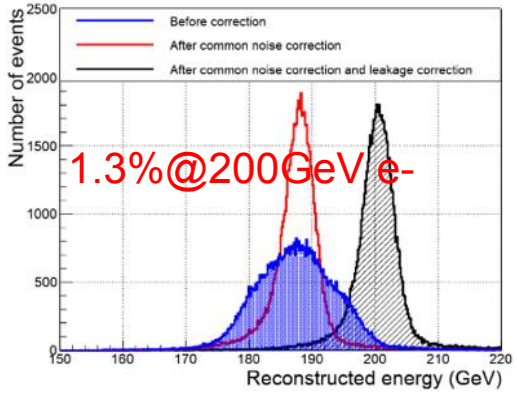
2 months simulated observation, ~6300cm^2 .

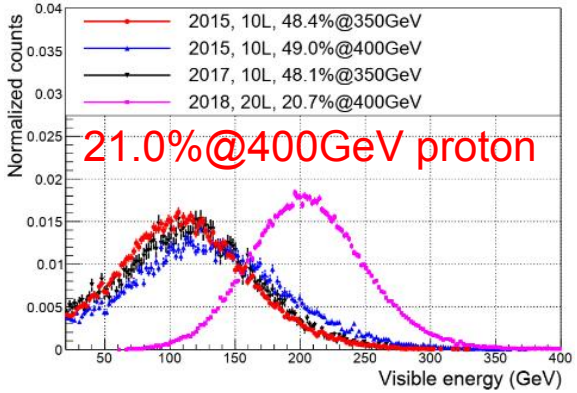


Joint study of key performances of HERD detectors

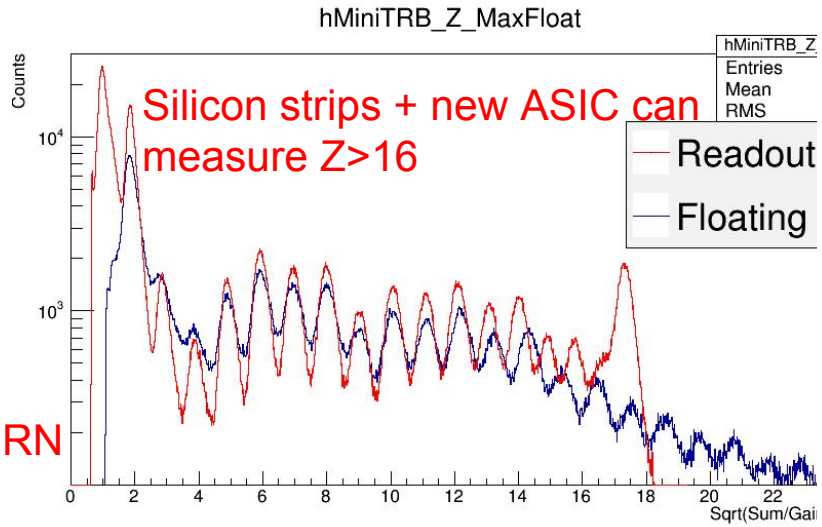
- 5 rounds of CERN beam tests were carried out (from 2015 to 2022).

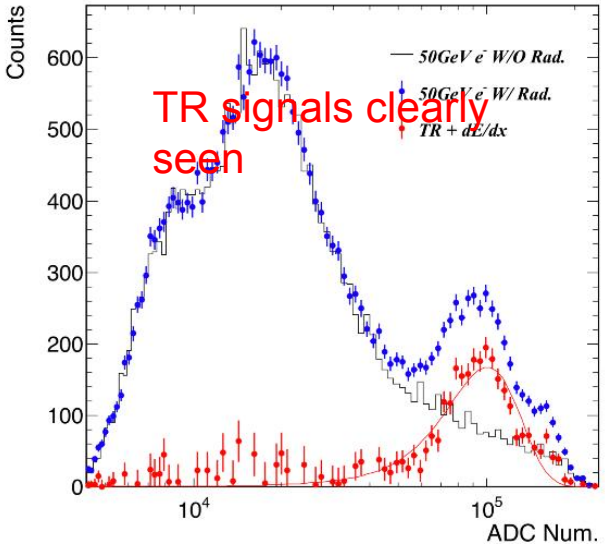

CALO prototype (500 LYS

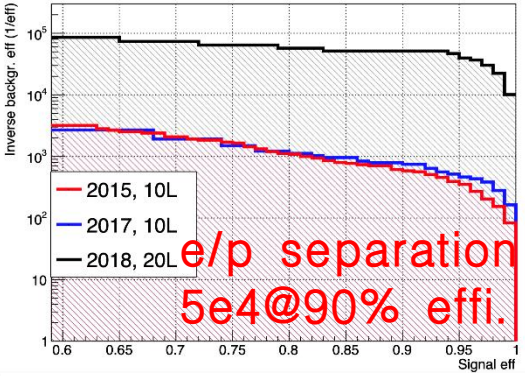





HERD prototypes at CERN

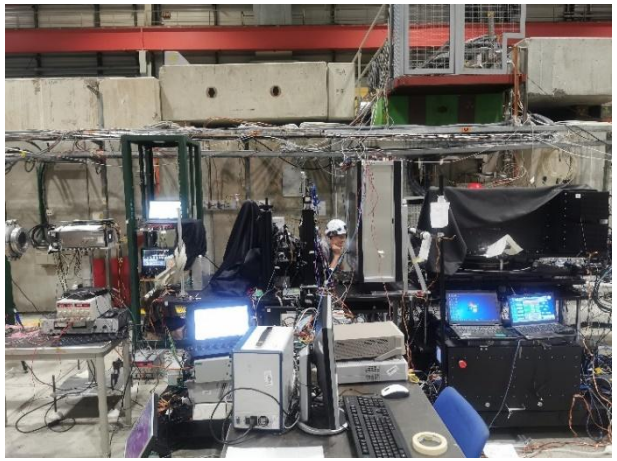
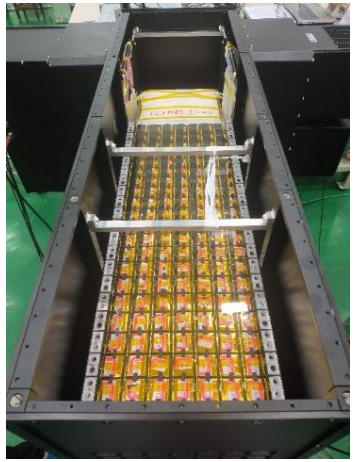
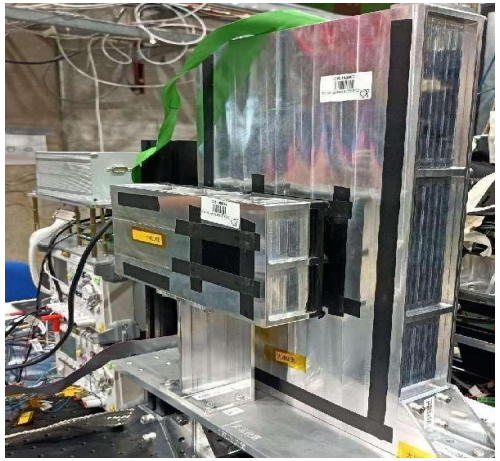
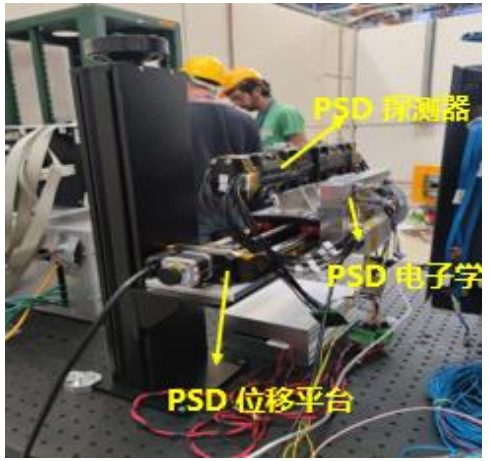




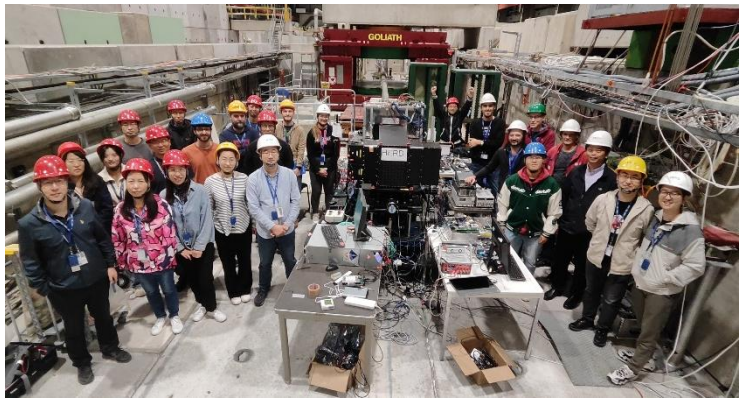


2023 beam test at CERN completed successfully

- Longest beam test with the most participants: 40 from China, 40 from Europe.
- All experimental goals achieved:
  - All key technologies tested. 1/8 calorimeter prototype ; image intensifiers with large dynamic range; double drift TRD prototype; SCD and PSD made in China tested.



HERD consortium

- The HERD consortium includes ~200 scientists from China and Europe.
  - Most of the members have been collaborating on previous high energy experiments in science and hardware development.
- 8 international workshops (in person) have been organized in China and Europe since 2012.
- 6 CERN beam tests on HERD prototypes have been successfully implemented by Chinese and European colleagues.
- Managing structure: Institution Leaders Board; Technical Executive Board; Publication Board

	Participating institutions
Payload Module	IHEP
CALO	IHEP, XIOPM, NNVT, CMBA; INFN Florence; CIEMAT
SCD	INFN Perugia, INFN Torino, etc.; IHEP, PMO
FIT	Univ. of Geneva, EPFL; ICCUB
PSD	INFN Bari, INFN Pavia, INFN Lecce, GSSI, etc.; ICCUB, IFAE; IHEP
TRD	GXU, CCNU, IMP
Trigger	IHEP, CIEMAT, IFAE, etc.
Ground calibration	IHEP, GXU, INFN sections, Univ. of Geneva, CERN
Science center	IHEP, SDU, ASDC & INFN-CNAF (Italy)
Sciences	IHEP, PMO, USTC, YNO, NAOC, SDU, GXU, TSU, PKU, NJU, YNU, SWJTU, HKU, Academia Sinica, and institutions from Italy, Switzerland, Spain, etc.

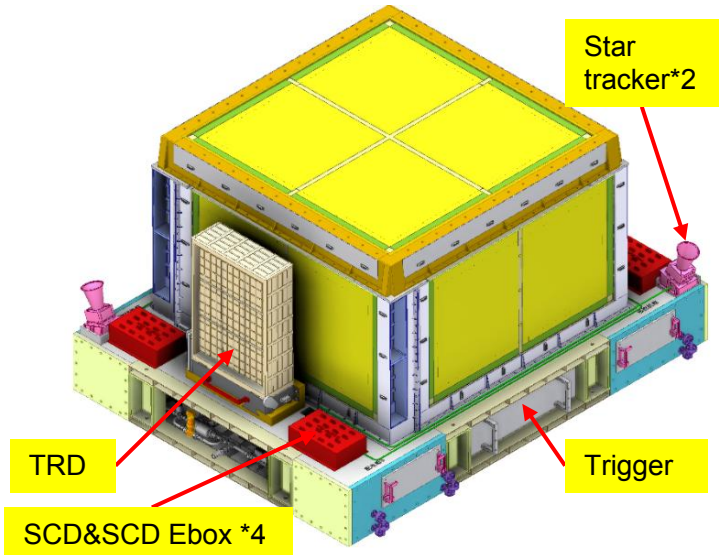
The HERD consortium

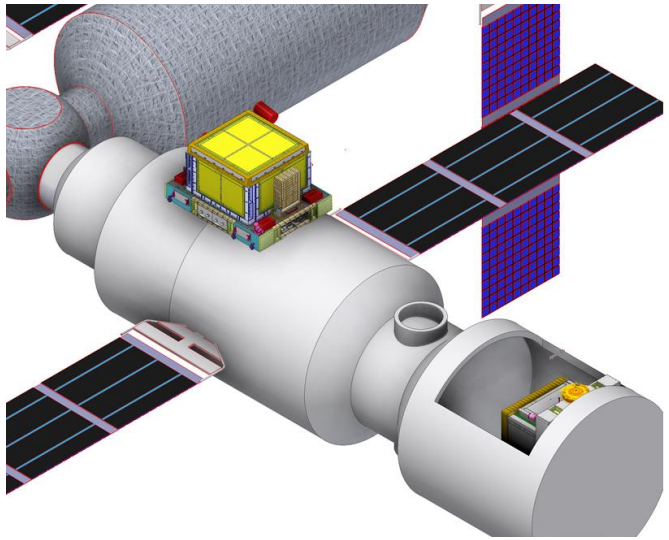
General progress

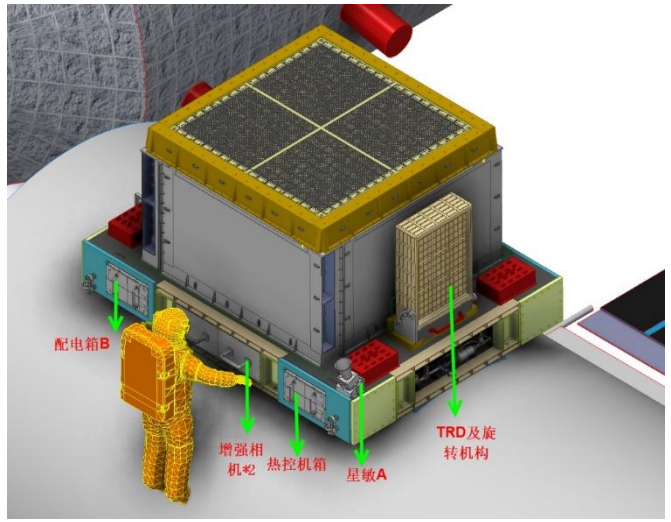
- Successfully reviewed by the the joint review meeting organized by ASI and CSU of CAS in May 2018.
- The HERD experiment is written into the joint declaration between China & Italy in March 2019.
- Reviewed by Ministry of Finance (mandated by CMSA) in 2021
  - 1st in scientific merits and technical feasibility, full budget allocated.

General progress in China

- Construction of the China Space Station (CSS) has been completed.
- General payload-level design jointly performed by CSU and IHEP
  - Conceptual layout design with ergonomics consideration
  - Preliminary design on mechanical, thermal, electronics, data flow…
  - Payload AIT
- Study of key technologies and specifications completed
- HERD will be carried to CSS by the new Multi-Functional Module (MFM) in 2027
- Worst scenario (wrt international hardware contributions) backup plan available.
- We welcome international collaborations at all levels!







We look forward to HERD in space! Thanks!