Very Large Area gamma-ray Space Telescope (VLAST)

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(on behalf the collaboration)

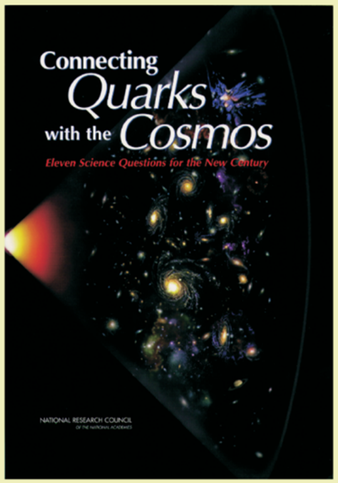
May 9, 2024, Xichang

Outline

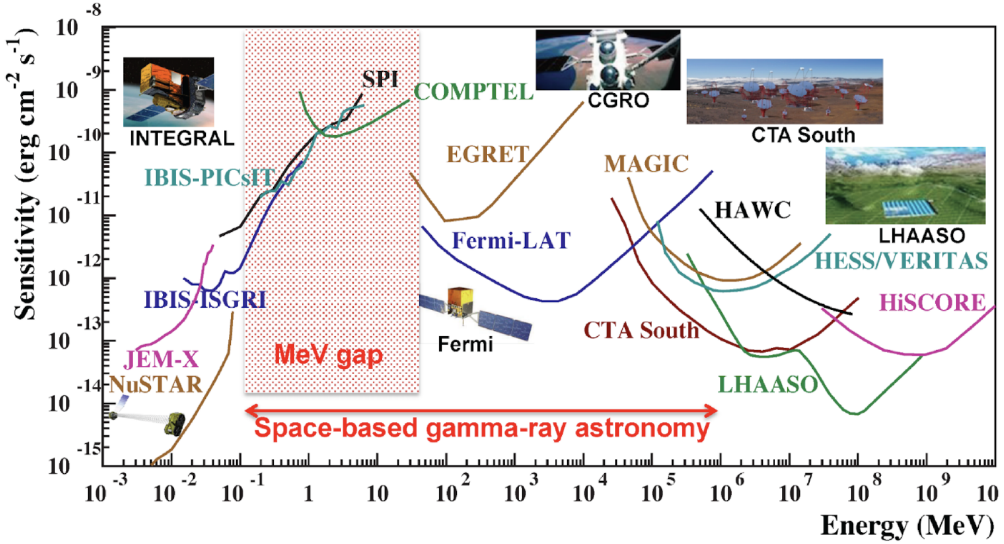
- Scientific Objectives
- Detector design
- R & D progress
- Summary

MeV – TeV gamma-ray detection

The Eleven Questions Identified by the *Connecting Quarks with the Cosmos* Report

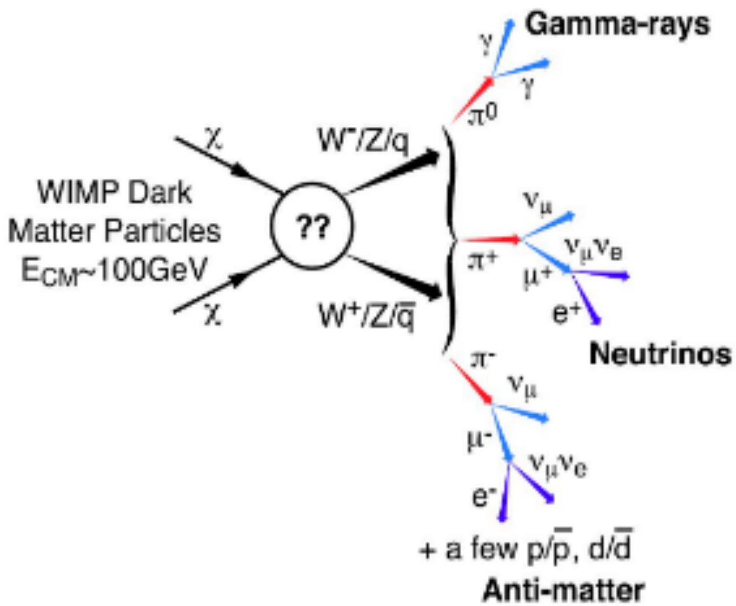


1. What is Dark Matter?
2. What is the Nature of Dark Energy?
3. How Did the Universe Begin?
4. Did Einstein Have the Last Word on Gravity?
5. What are the Masses of the Neutrinos and How Have They Shaped the Evolution of the Universe?
6. How do Cosmic Accelerators Work and What are They Accelerating?
7. Are Protons Unstable?
8. What Are the New States of Matter at Exceedingly High Density and Temperature?
9. Are There Additional Space-Time Dimensions?
10. How Were the Elements from Iron to Uranium Made?
11. Is a New Theory of Light and Matter Needed at the Highest Energies?

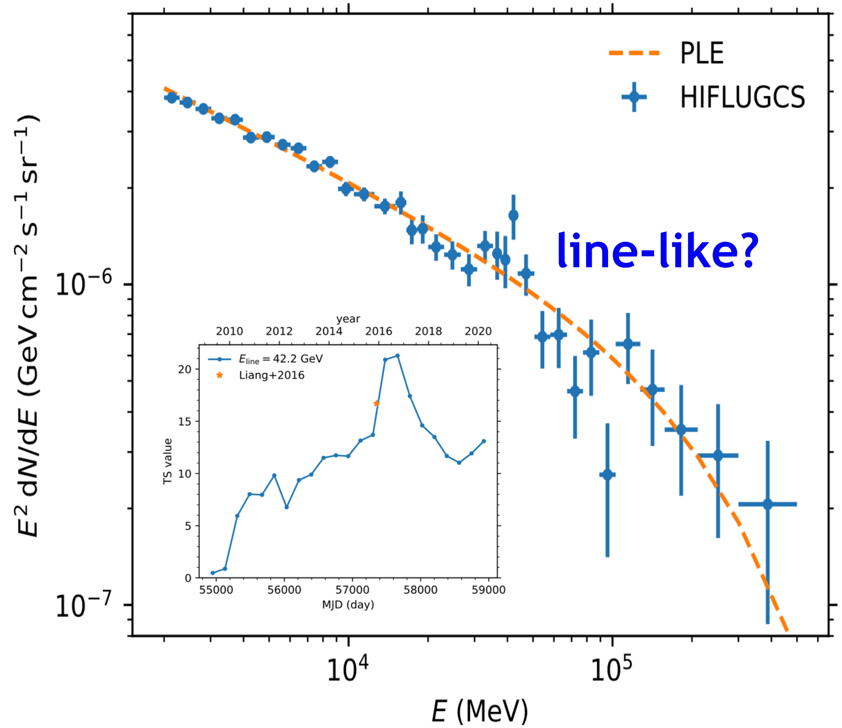


There are fantastic scientific opportunities on dark matter detection, time-domain astronomy, cosmic ray physics and origination of elements above Iron via MeV - TeV space-based gamma-ray observations.

dark matter indirect detection

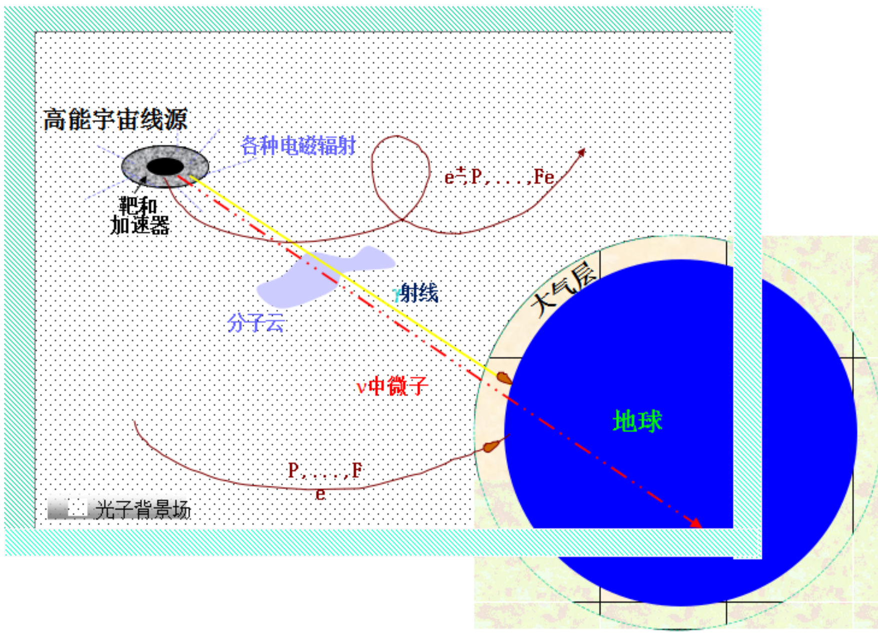


Shen, Xia & Fan 2021

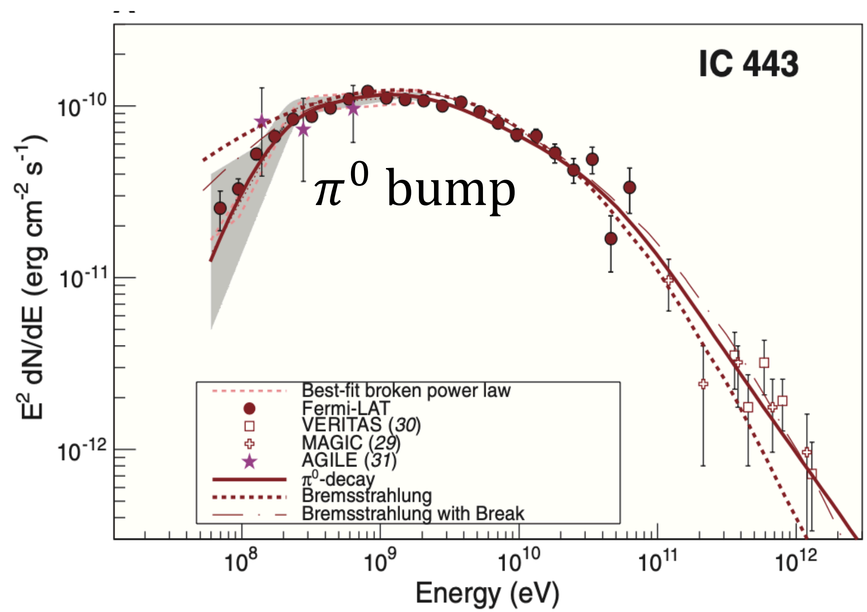


Dark matter may annihilate or decay to gamma-ray lines. A new detector with sensitivity over 10 times more than current detectors could validate or discover line candidates, leading the research on gamma-ray-based dark matter indirect detection.

cosmic ray origination

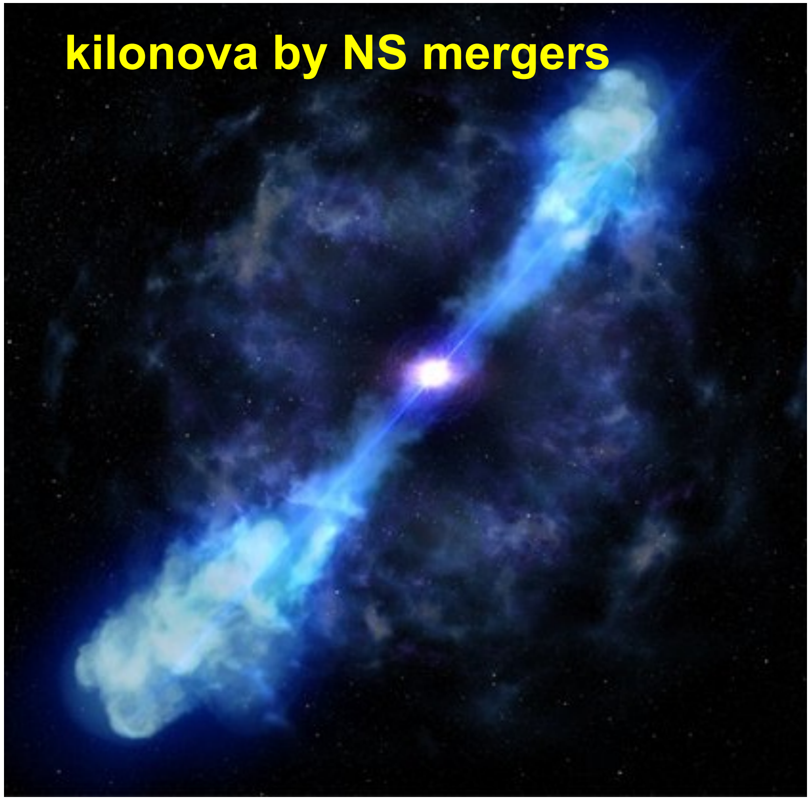


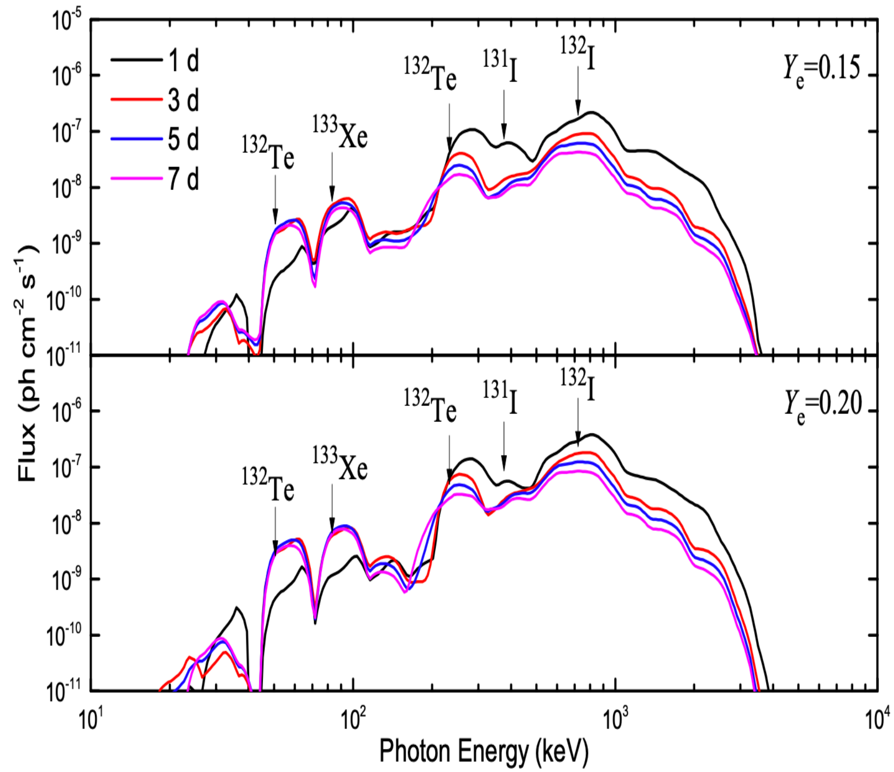
Fermi collaboration (2013 Science)



- **The π^0 bump can validate the hadronic cosmic ray sources**
- **3D distribution of cosmic rays can be obtained by high-precision gamma-ray observations**
- **Reveal the origin, acceleration and propogation of cosmic rays**

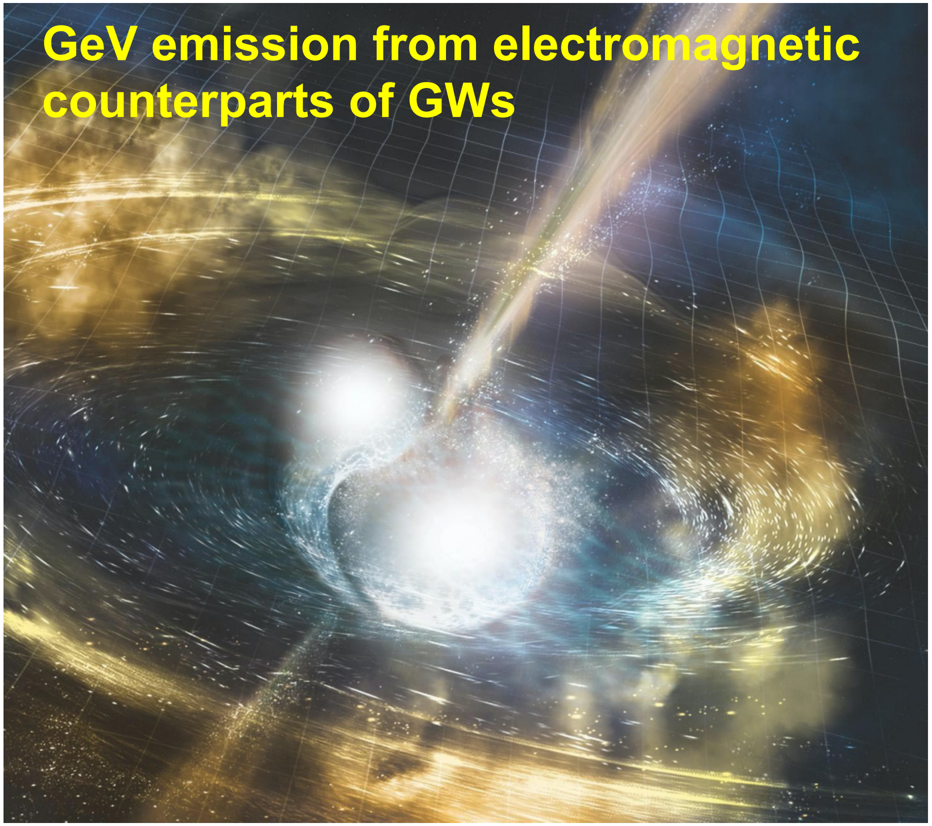
elements above Iron

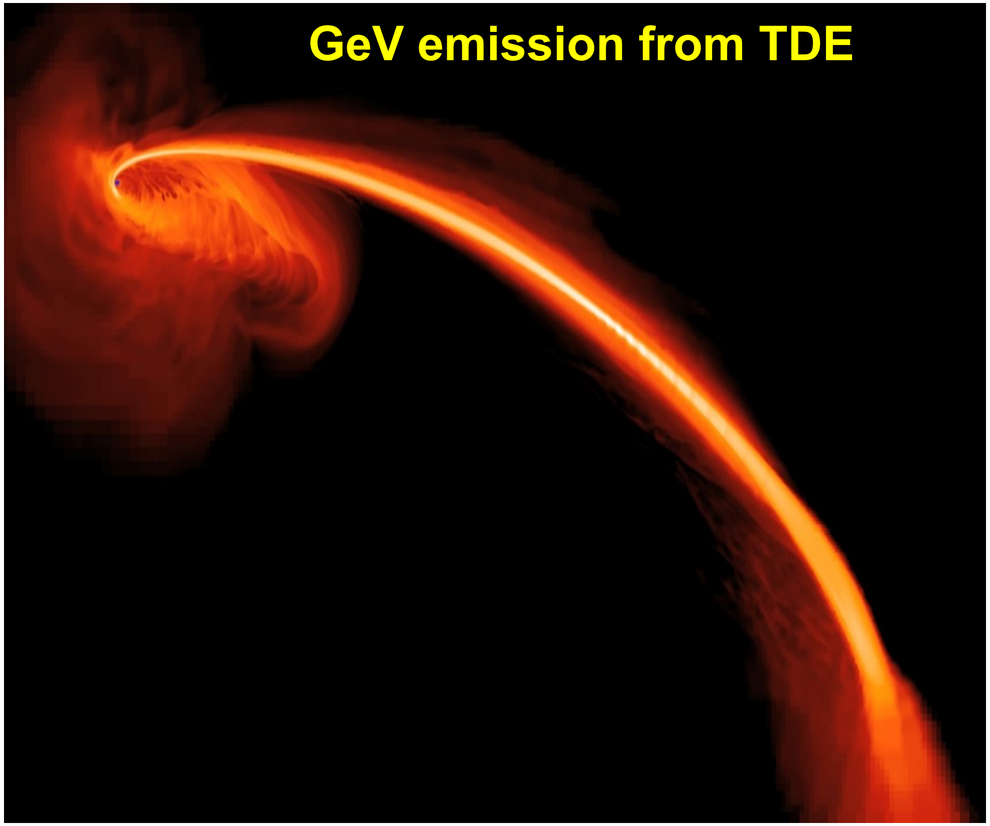




- MeV emission from neutron star merger / kilonova
- Direct observation by a new high-sensitivity gamma-ray detector
- Discovery of the source of elements above Iron in the Universe

time-domain astronomy

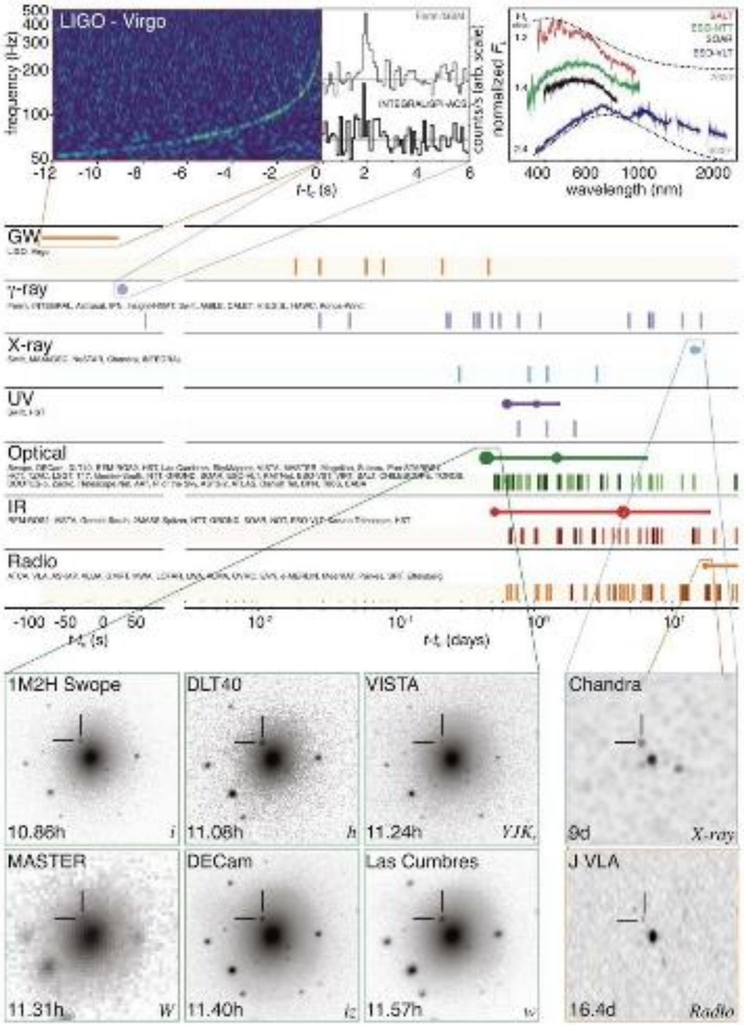




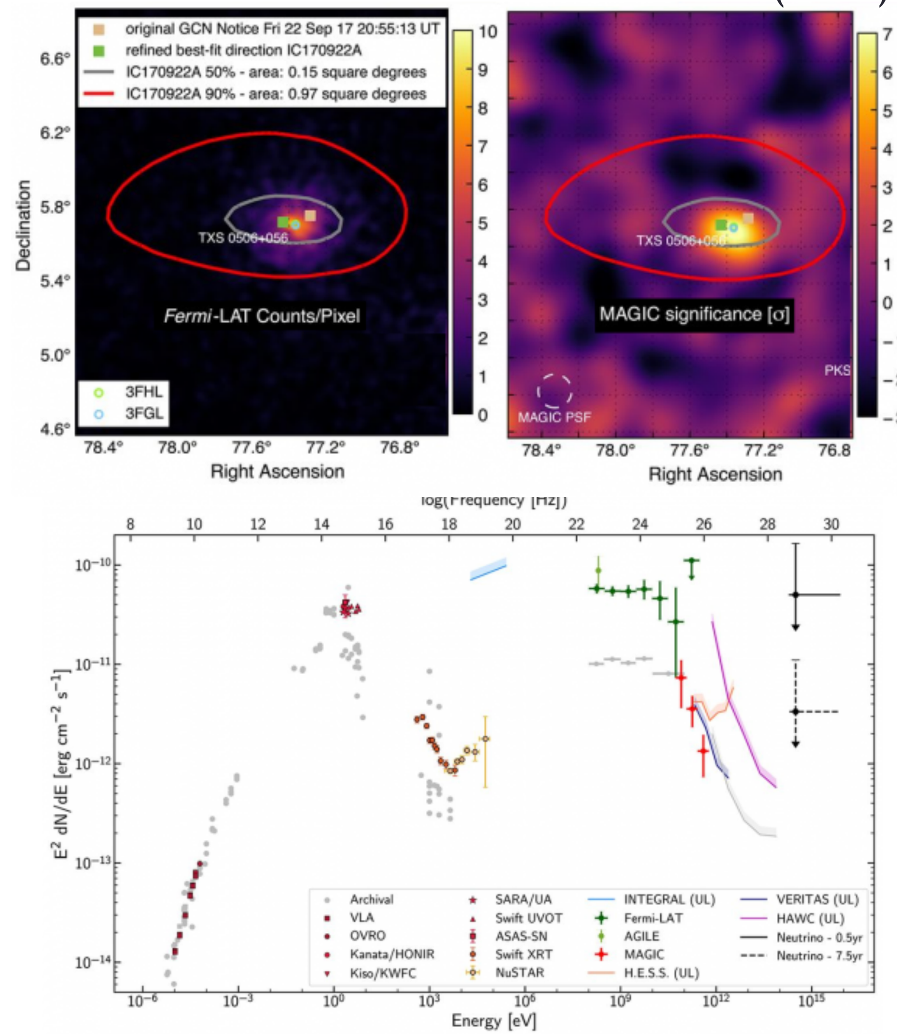
- Monitoring the GeV emissions/bursts
- Revealing new mechanisms of NS merger, TDE, etc.

multi-messenger astronomy

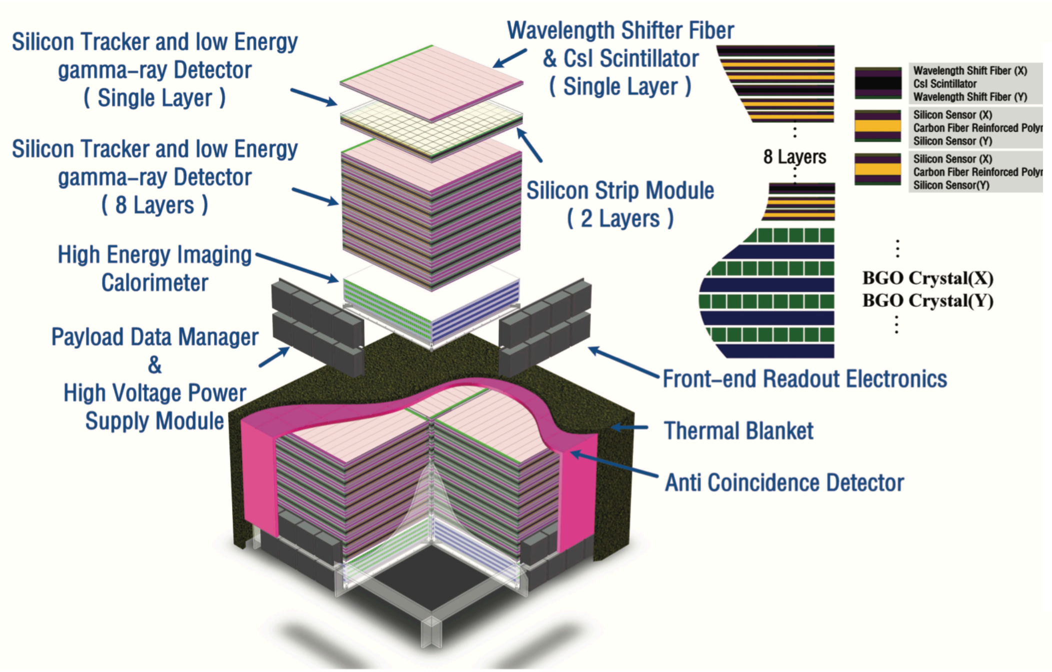
LIGO (2017)

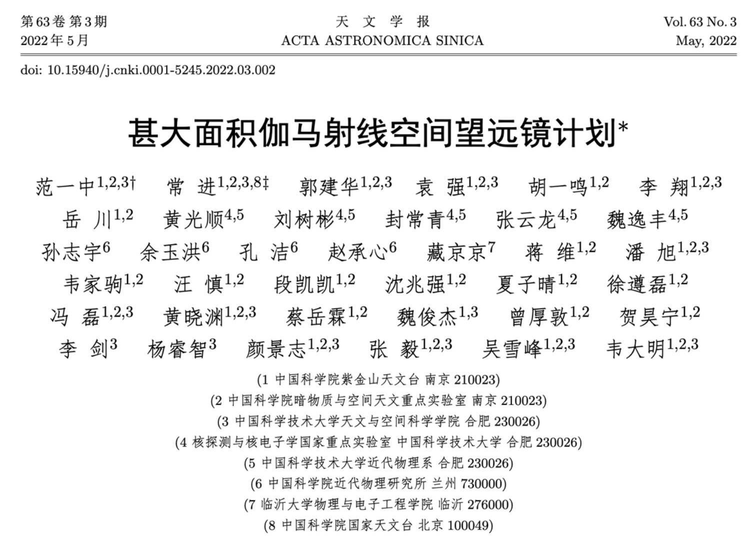


IceCube et al. (2018)



VLAST





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甚大面积伽马射线空间望远镜计划*

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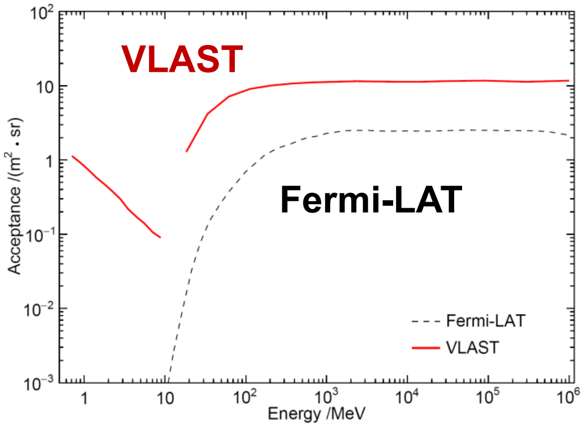
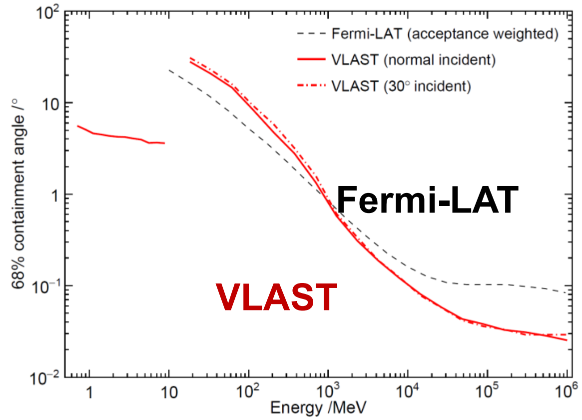
- **Very Large Area gamma-ray Space Telescope (VLAST), the successor of DAMPE**
- **The first 10 m^2 sr level gamma-ray satellite (~20 tons)**
- **Leading the research on dark matter detection and time-domain astronomy based on MeV - TeV gamma-rays**

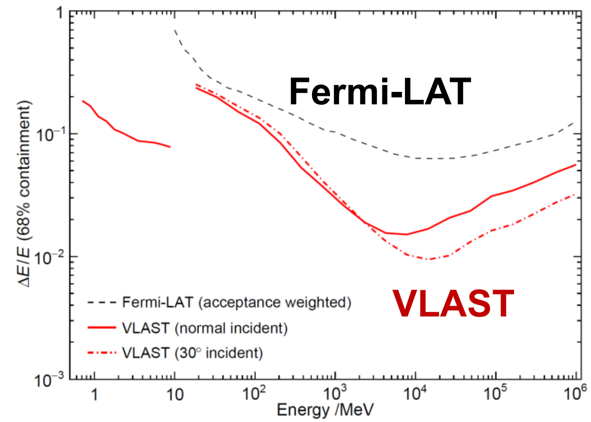
VLAST -- IRFs



large accepance



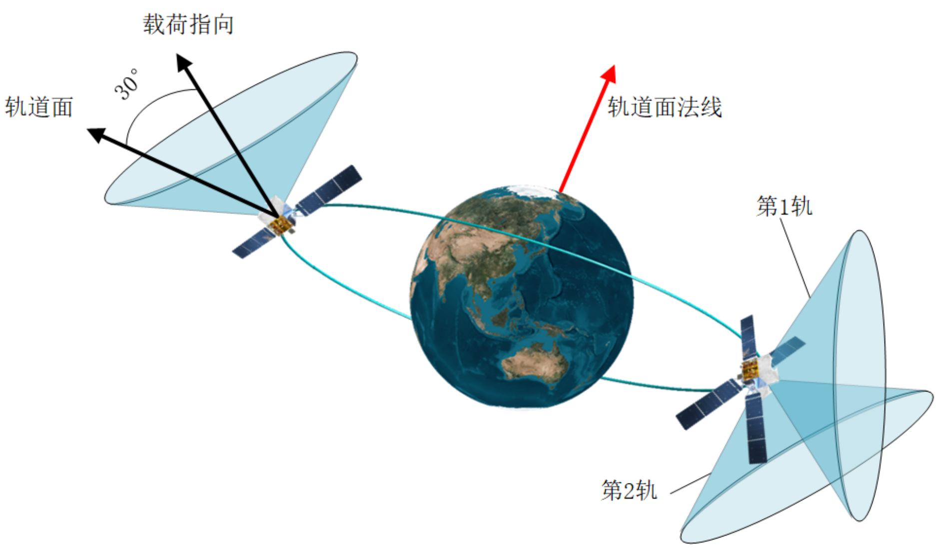
high angular resolution



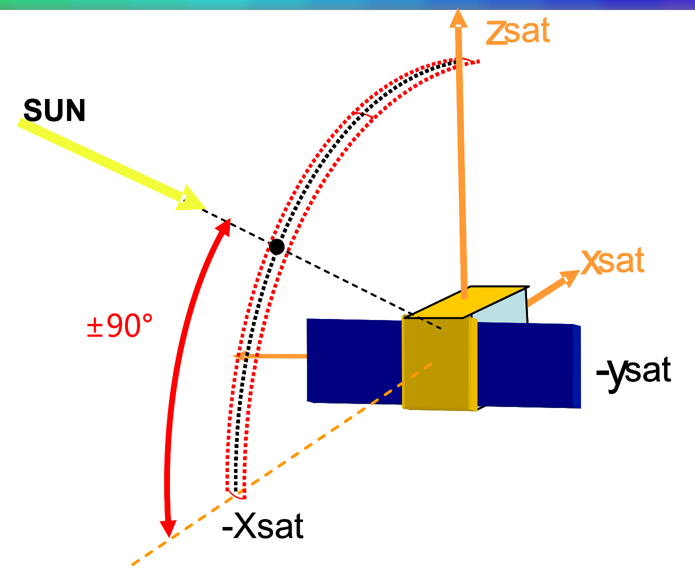
high energy resolution

some space-based gamma-ray missions				
facility	acceptance (m^2 sr)	energy range	energy resolution (@10GeV)	angular resolution (@50GeV)
Fermi-LAT	**~ 2**	**20 MeV-300 GeV**	**~6.0%**	**~ 0.10 deg**
DAMPE	**~ 0.2**	**5 GeV-10 TeV**	**~1.5%**	**~ 0.10 deg**
AMS-100 (concept)	**~30**	**0.1 GeV-10 TeV**		**~ 0.03 deg**
APT	**~20**	**1 MeV-10 TeV**	**~ 20%**	**~ 0.10 deg**
HERD	**~2**	**0.5 GeV-10 TeV**	**~1.5%**	
VLAST	**~10**	**1 MeV-10 TeV**	**~1.5%**	**~ 0.10 deg**

observation mode



sky survey



– Design of observation modes

- sky survey：full sky survey in two orbits
- pointing mode：specific points/regions

– opportunity mode

- Transient source：rely on Beidou communications within 120s

Outline

- Scientific Objectives
- Detector design
- R & D progress
- Summary

design of VLAST

- **VLAST consists of**

(a)Anti-Coincidence Detector :

> ➢**top and four sides, charge measurement**

(b)Silicon Tracker and low Energy gamma-ray Detector :

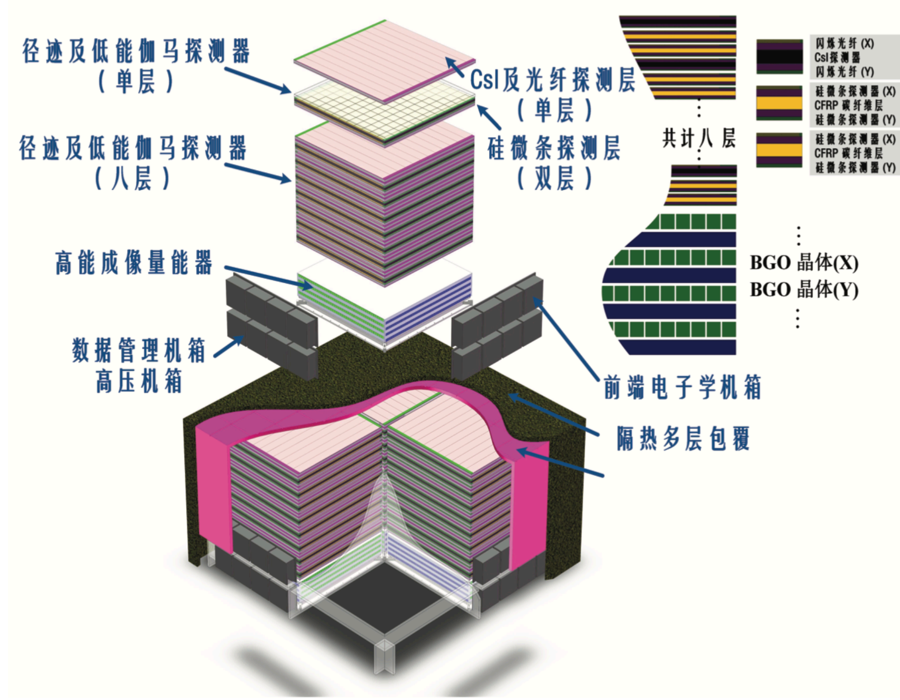
> ➢**tracker for GeV photons**
>
> ➢**Compton photons (MeV)**

(c)High Energy Imaging Calorimeter :

> ➢**Energy measurement for GeV photons**

(d)Payload Data Manager :

> ➢**trigger and DAQ**

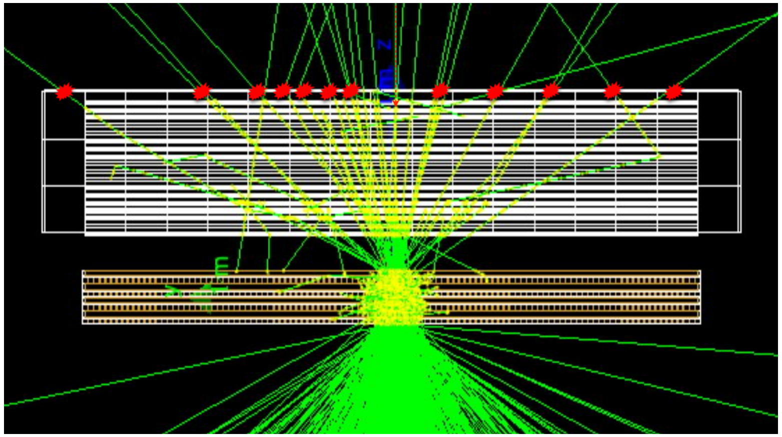


范一中 et al.，2022，天文学报，63，27

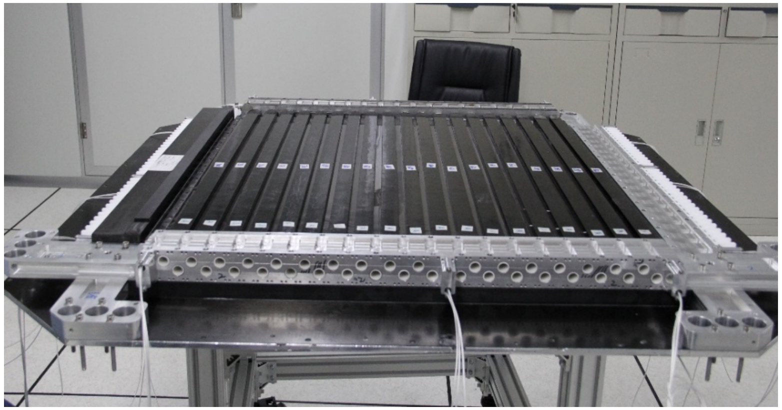
2×2 matrix, with the size of each unit as 1.2 m

Anti-Coindicence Detector

- **Design logic:**
  - light mass
  - high efficiency for charged particles
  - plastic scintilator
- **Some considerations:**
  - back-splash particles from calorimeter
  - small size to distinguish back-splash and incident particles
  - trigger threshold : low or high
  - position uniformity



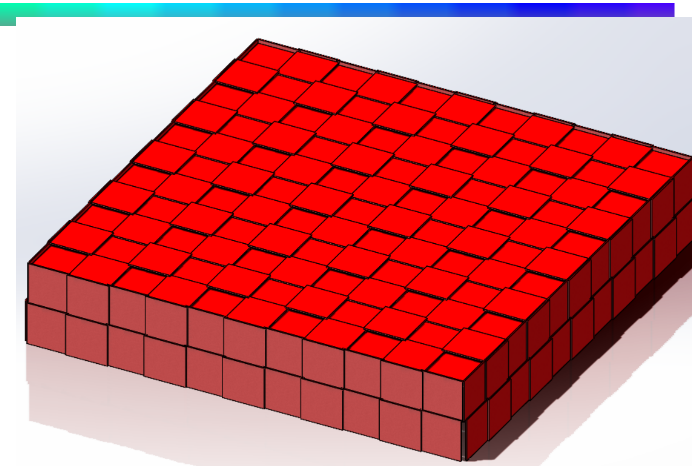
a 50 GeV photon in the VLAST



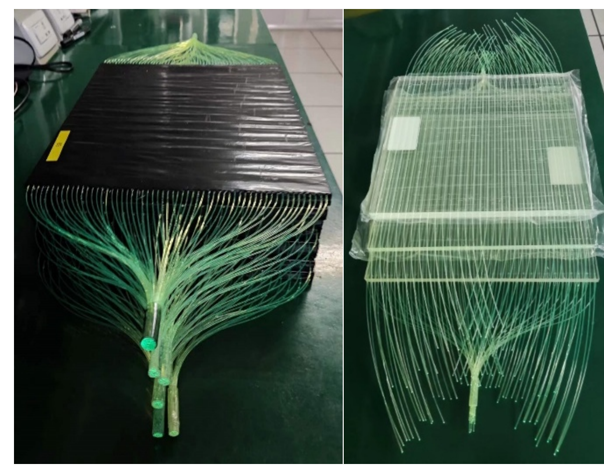
application in DAMPE

Anti-Coindicence Detector

- **Major functions**
  - **distinguish electron/gamma**
  - **measuring charge for light nuclei**
- **Major technical indices**
  - **unit size：<1000cm²**
  - **charge range : electron, nuclei (Z=1~8)**
  - **efficiency : better than 99.97%**
  - **trigger signal for charged particles**
  - **10 kHz/m²**
- **Detector**
  - **top: 3100mm×3100 mm**
  - **side:3100mm× 600 mm**
  - **unit size: 300mm×300 mm**
  - **readout: WLSF**
- **electronics**
  - **PMT (or SiPM) +charge ASIC**



structure



unit

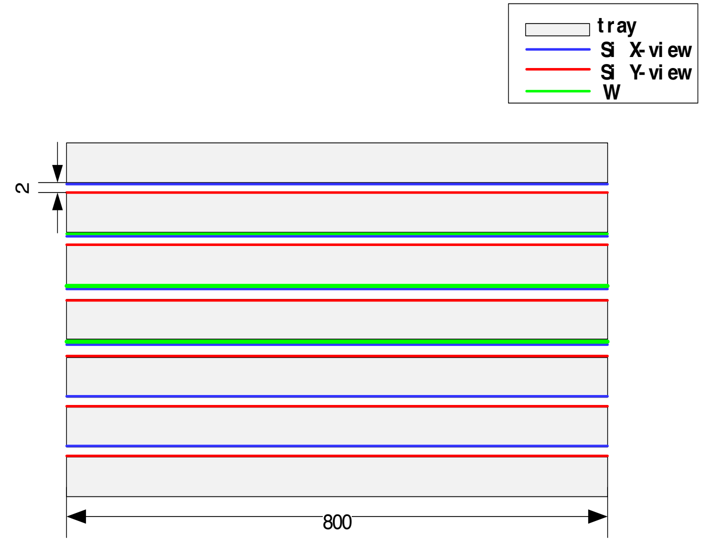
Silicon Tracker and low Energy gamma-ray Detector

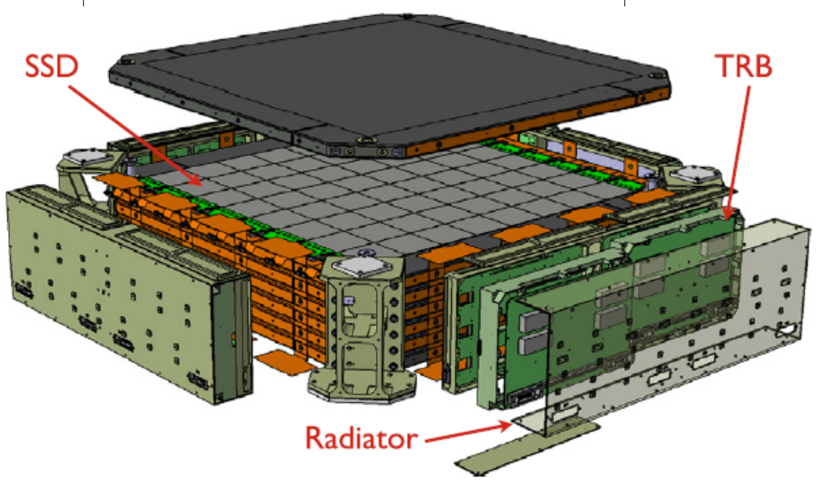
❑Design logic:

- GeV gamma : pair conversion , high efficiency, low back-splash
- MeV gamma : both position and energy measurement, less insensitive materials

❑Some considerations:

- Use CsI instead of tungsten
- track : silicon microstrip (<50um), scintillating fiber (~250um , less expensive)





Silicon tracker of DAMPE

Silicon Tracker and low Energy gamma-ray Detector

■ Major functions

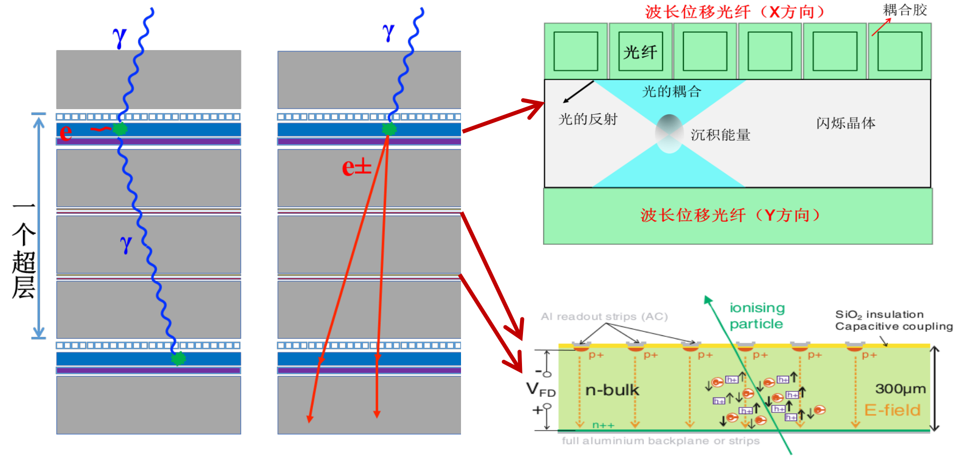
- GeV- TeV: track measurement for pair converted electrons
- MeV: direction and energy

■ Major technical indices

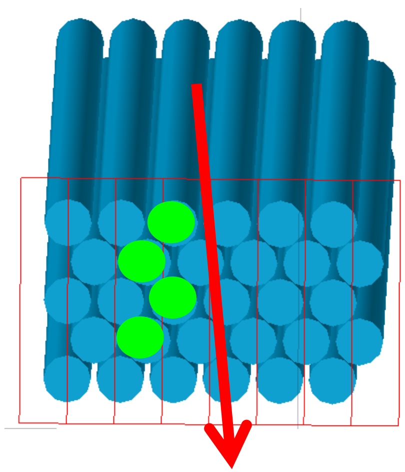
- layers : 8 superlayers (one CsI layer + two silicon layers)
- area : >= 2800mm×2800 mm ;
- energy range : 1-100 MeV
- angular resolution <0.1°@50GeV

■Detector + electronics

- CsI+WLSF , SiPM+waveshape
- inheriting current techniques of silicon microstrip tracker at DAMPE
- exploring the fiber substitute for silicon microstrip



CsI layer + silicon tracker layer



scintillator fiber

High Energy Imaging Calorimeter

■ Major functions

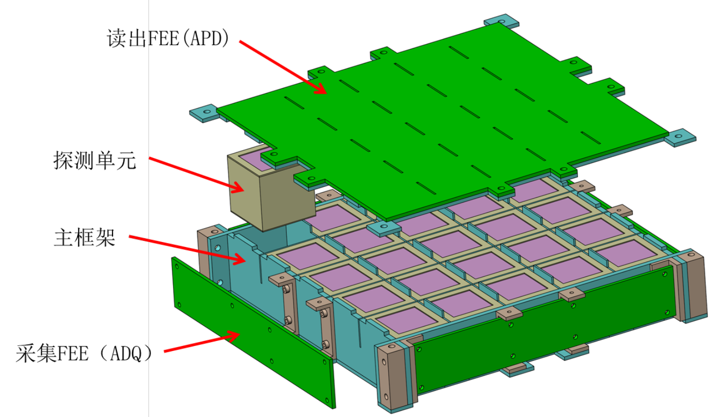
- energy measurement
- proton/electron discrimination
- trigger

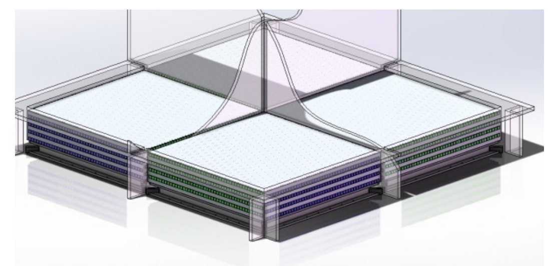
■ Major technical indices

- area：~2400mm×2400 mm
- energy range：0.1GeV~20TeV (gamma)
- energy resolution: <2%@50GeV
- proton rejection: $>10^4$@50GeV
- trigger threshold：<0.5MIPs

■ Detector + electronics

- 3D pixels：~3cm cubes
- long bars：$1200\times25\times25$ mm^3，4 layers (X+Y)， 2×2 matrix
- multi-gain readouts





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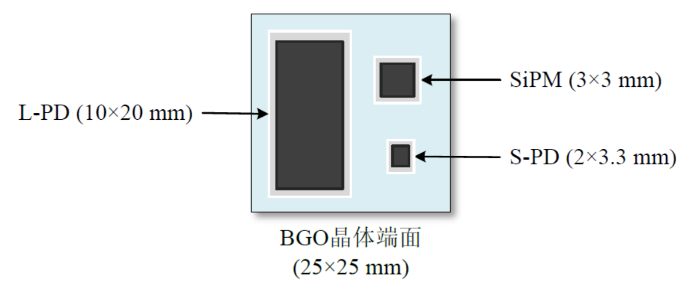

bar readout

Payload Data Manager

Major functions

- trigger and DAQ
- on-orbit multi-level trigger algorithm, reducing the event rate

Major technical indices

- event rate : 2kHz on average
- data storage : 64GByte per day ?

trigger approach

- MeV gamma: CsI independent
- GeV gamma: ACD + STED + HEIC combined
- >5GeV: HEIC only

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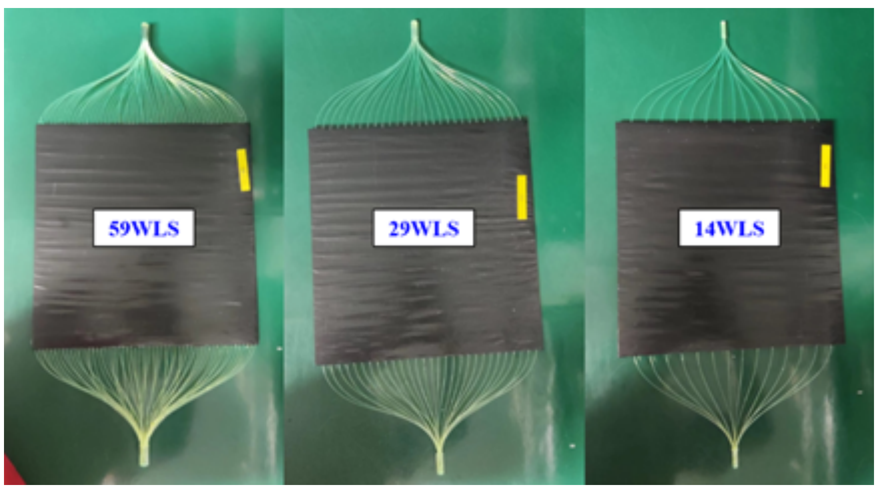
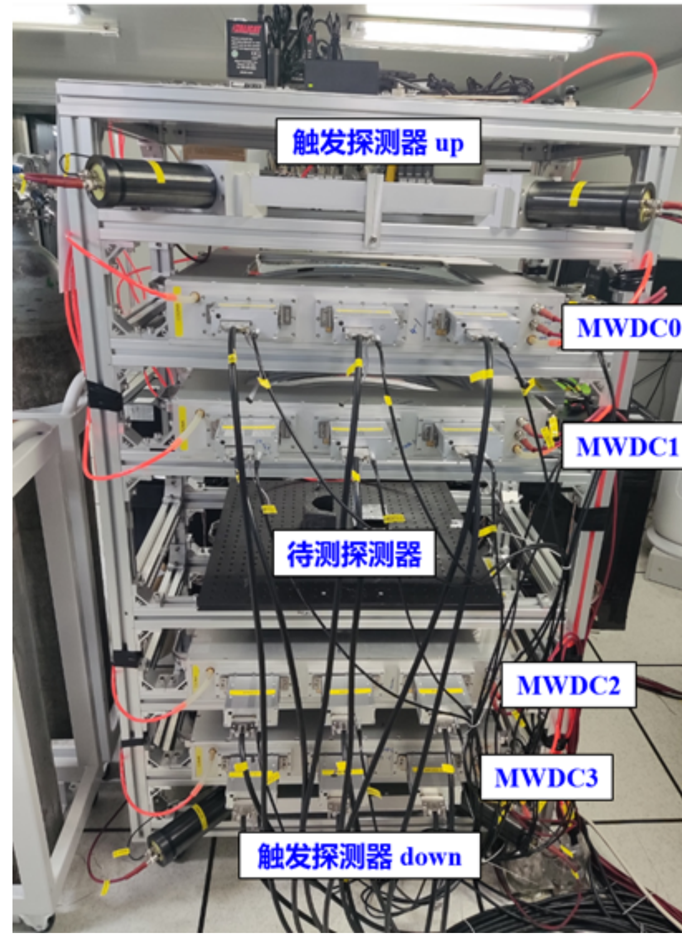
Anti-Coindicence Detector

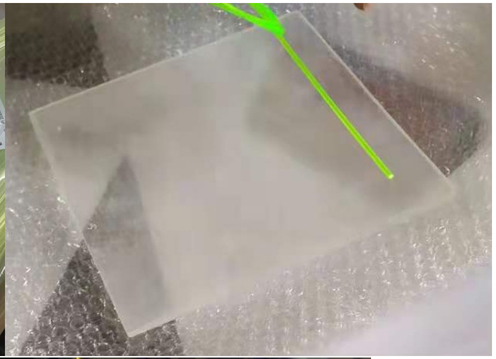
❑ACD

- **unit product: done**
- **unit test: efficiency >99.99%**
- **prototype development on-going**





Silicon Tracker and low Energy gamma-ray Detector



❑ CsI readout

- ➢ crystal: done
- ➢ fiber: cut and polish done
- ➢ encapsulation: on-going

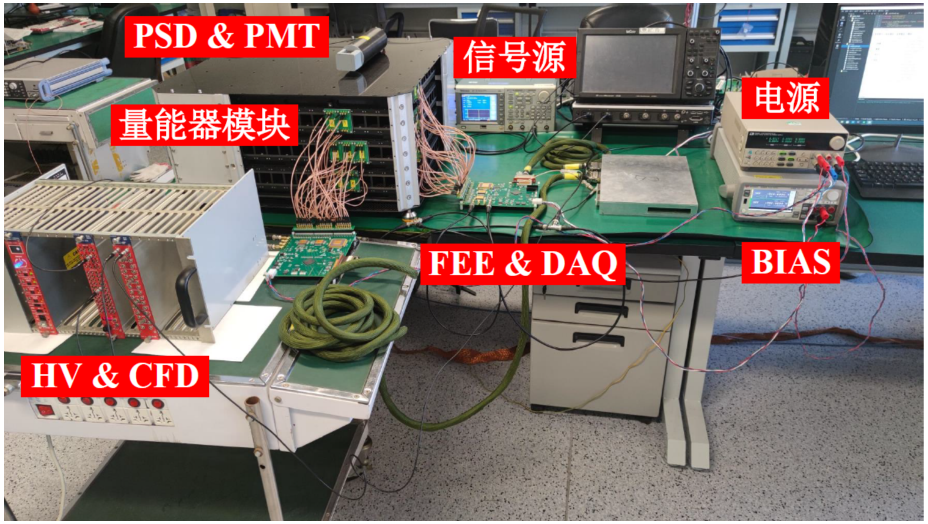
❑ silicon tracker

- ➢ module: 40cm and 70cm
- ➢ prototype: 11 ladders, on-going

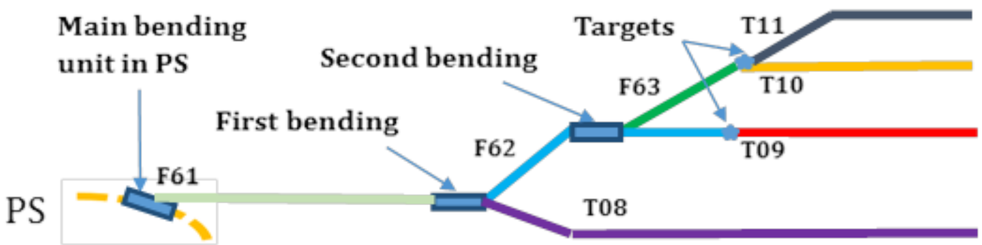
High Energy Imaging Calorimeter

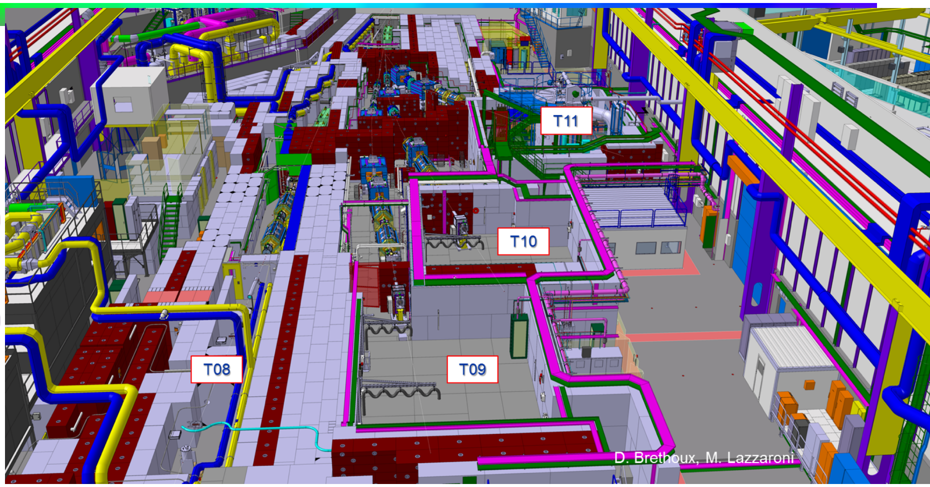
❑long bar
- ➢ **electronics: done**
- ➢ **prototype：25mm*25mm*600mm, 5 layers, on-going**

❑ **3D pixels**
- ➢ **design done**
- ➢ **pixel: 30mm*30mm*30mm**
- ➢ **prototype: 4 layers, on-going**

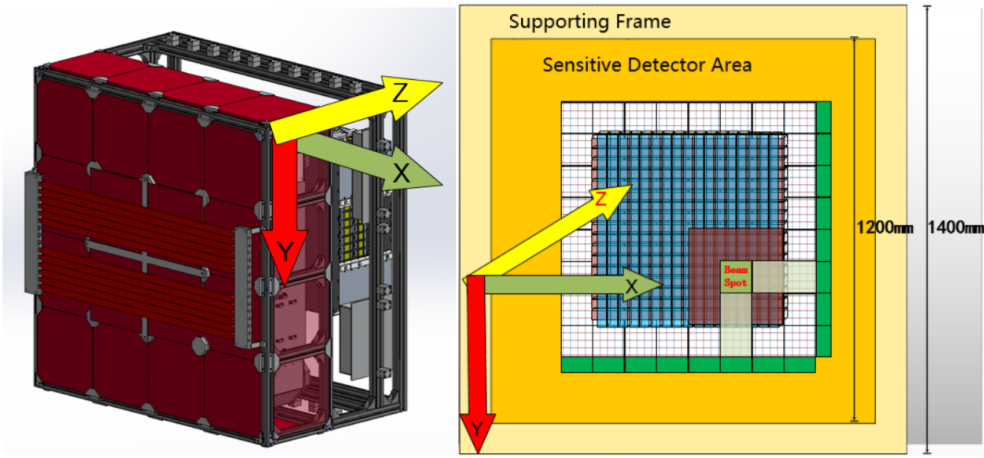


Beam Test @ CERN





- ❑ **Beam Test 2023 at CERN :**
  - ➢ **Week37, PS-T9, 1 week**
  - ➢ **Week40, SPS-H8, 1 week**
- ❑ **status for prototype :**
  - ➢ **ACD (pile + long strip)**
  - ➢ **STED (Silicon + CsI)**
  - ➢ **HEIC (3D pixel + long bar)**



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Summary/Overview

- ❖ A flagship for space-based gamma-ray detection：Very Large Area gamma-ray Space Telescope（VLAST）
- ❖ Leading the researches on gamma-ray-based dark matter indirect detection and time-domain astronomy

Scientific objectives：

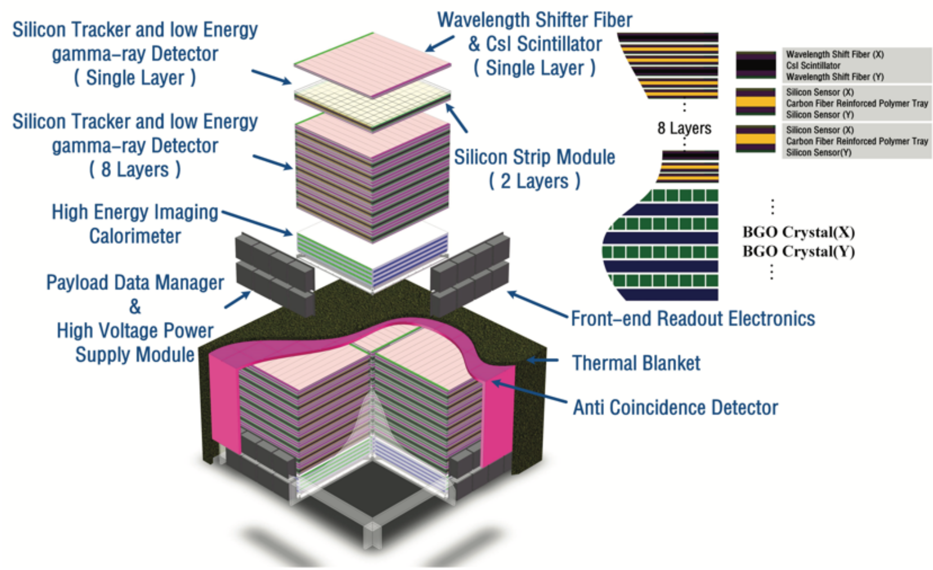
- ➢ Indirect detection of dark matter (DM) particles
  1) GeV emission by DM annihilation/decay from regions like dwarf spheroidal galaxies
  2) Line-like structure by DM annihilation/decay
  3) Axions or axion-like particles
  4) DM signals in cosmic ray electrons
- ➢ Gamma-ray astronomy
  1) Electromagnetic counterparts of gravitational waves, neutrinos and tidal disruption events
  2) New GeV bursting or high-z sources
  3) Measuring the GeV gamma-ray horizon of the Universe
- ➢ Cosmic ray physics
  1) Nearby electron sources
  2) New spectral structures in high-energy range

Major payloads:

ACD (Anti Coincidence Detector)

STED (Silicon Tracker and low Energy gamma-ray Detector)

HEIC (High Energy Imaging Calorimeter)



- ➢ The prototype is going to be done within 3 months and sent to CERN for Beam Test
- ➢ Handle the key techniques in 2-3 years

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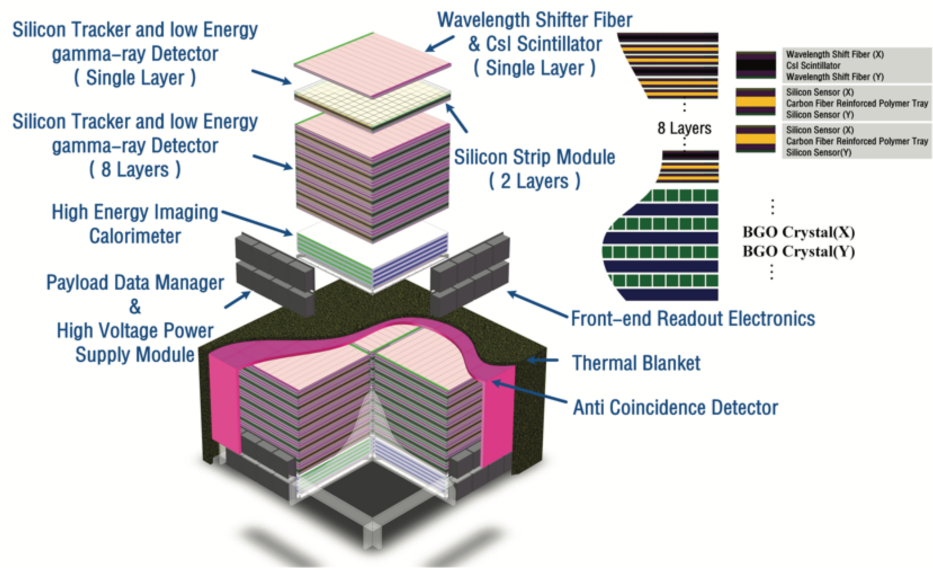

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