CPS-HEP Annual Conference 2026

Probing the Dark Universe Via Cosmic Antinuclei & MeV Gamma Rays with A Novel Tracking Calorimeter

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Dark Matter Indirect Detection

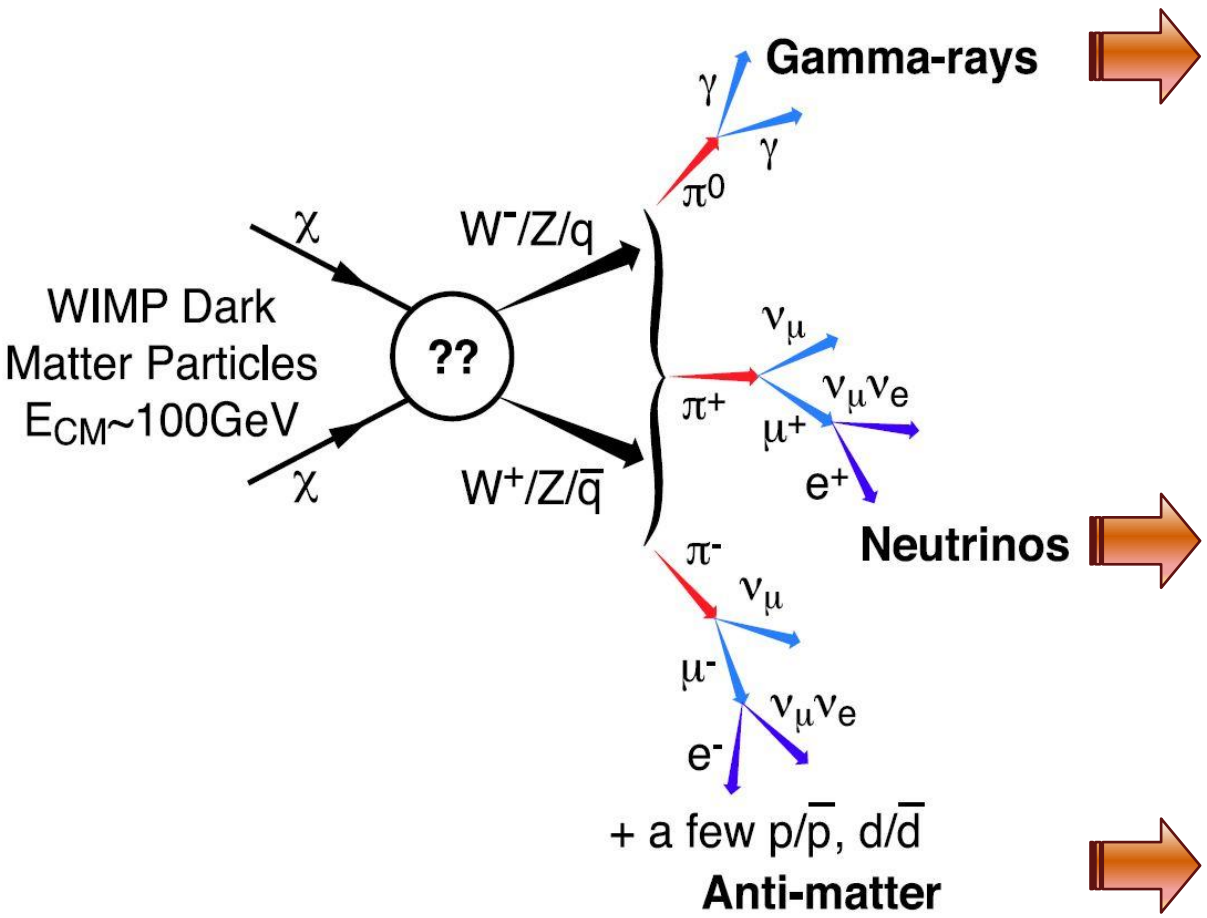



Image credit: Fermi-LAT


Image credit: LHAASO

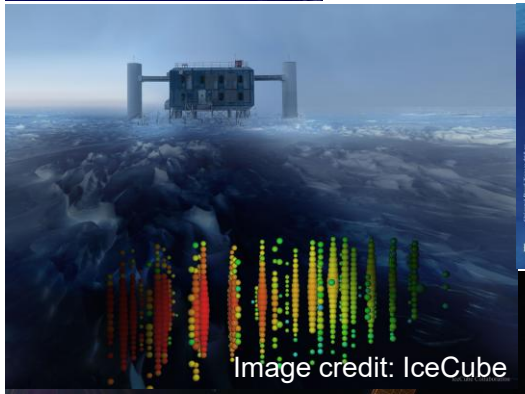


Image credit: IceCube

Image credit: TRIDENT

Image credit: AMS-02

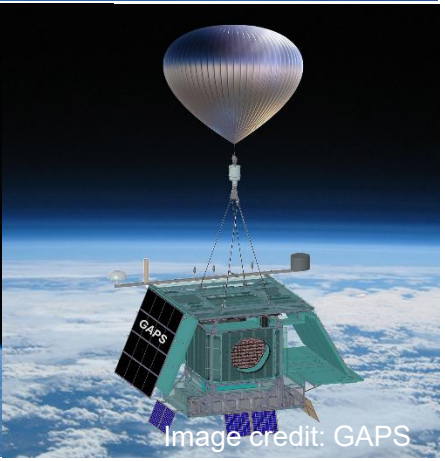
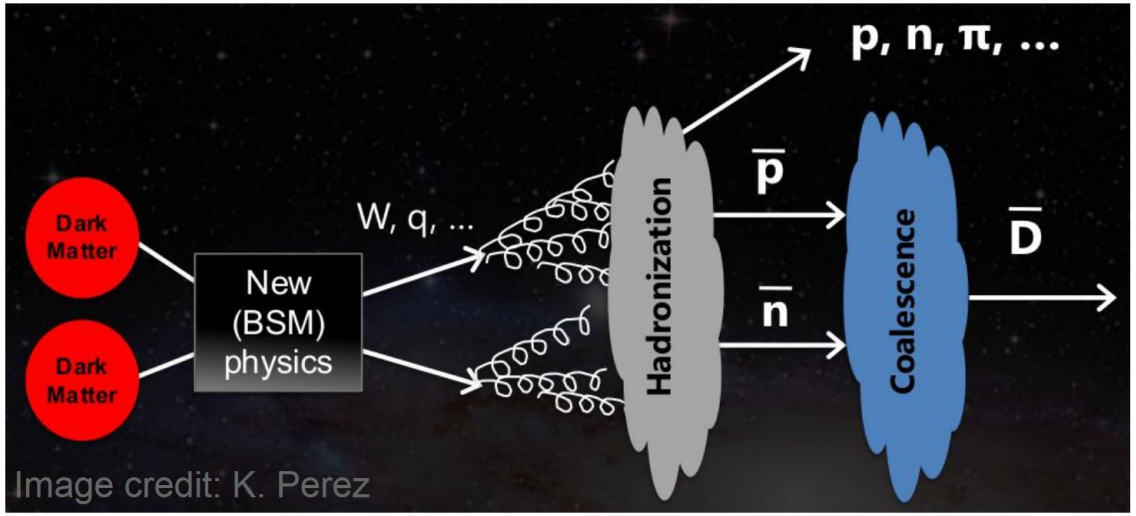
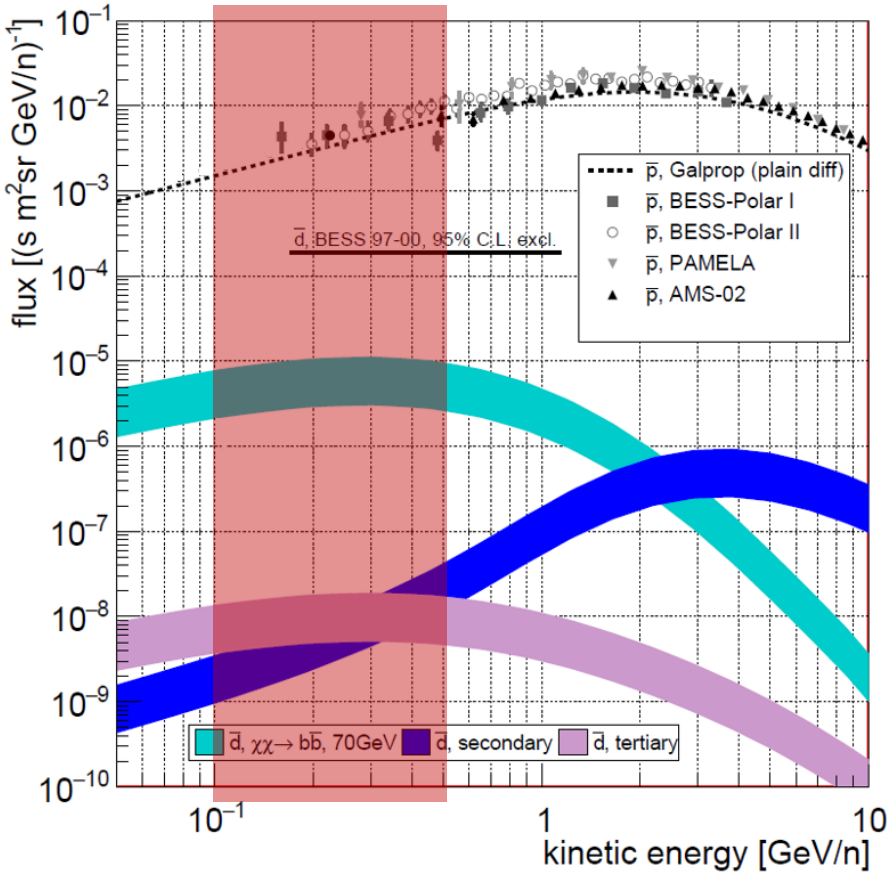


Image credit: GAPS

Low-Energy Antinuclei

- Low-energy (KE<300 MeV/n) cosmic $\bar{d}/\overline{He}$: "smoking gun" signature of dark matter annihilation/decay, complementary to AMS-02 but with lower astrophysical bkg.

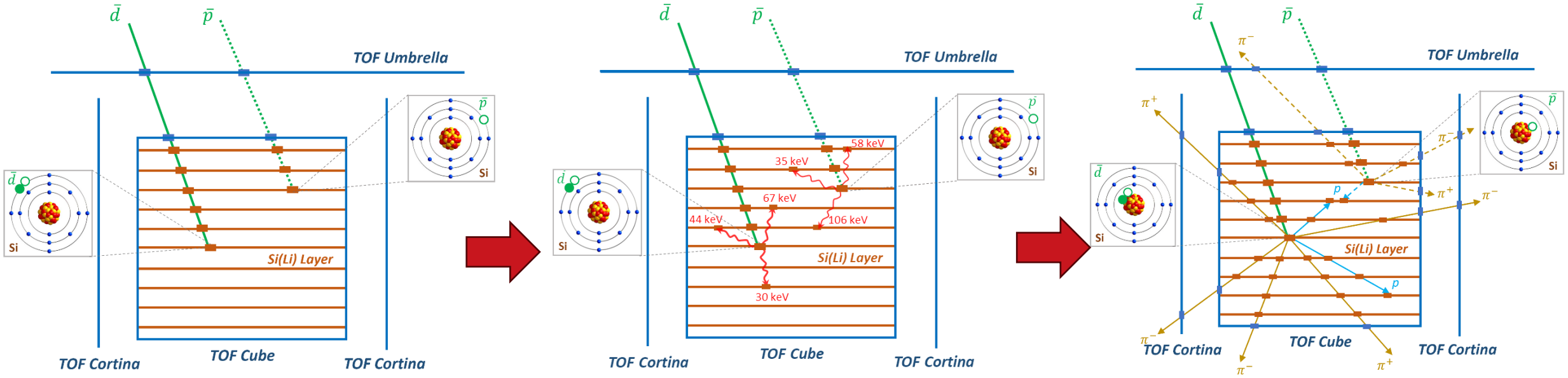




- Low-energy (KE<300 MeV/n) cosmic $\bar{p}$: unexplored region.
  - Cross check the $\bar{p}$ excess observed by AMS-02.
  - Primordial black hole, cosmic ray propagation…

Low-Energy Antinuclei

❑Novel detection technique: exotic atomic formation and decay.

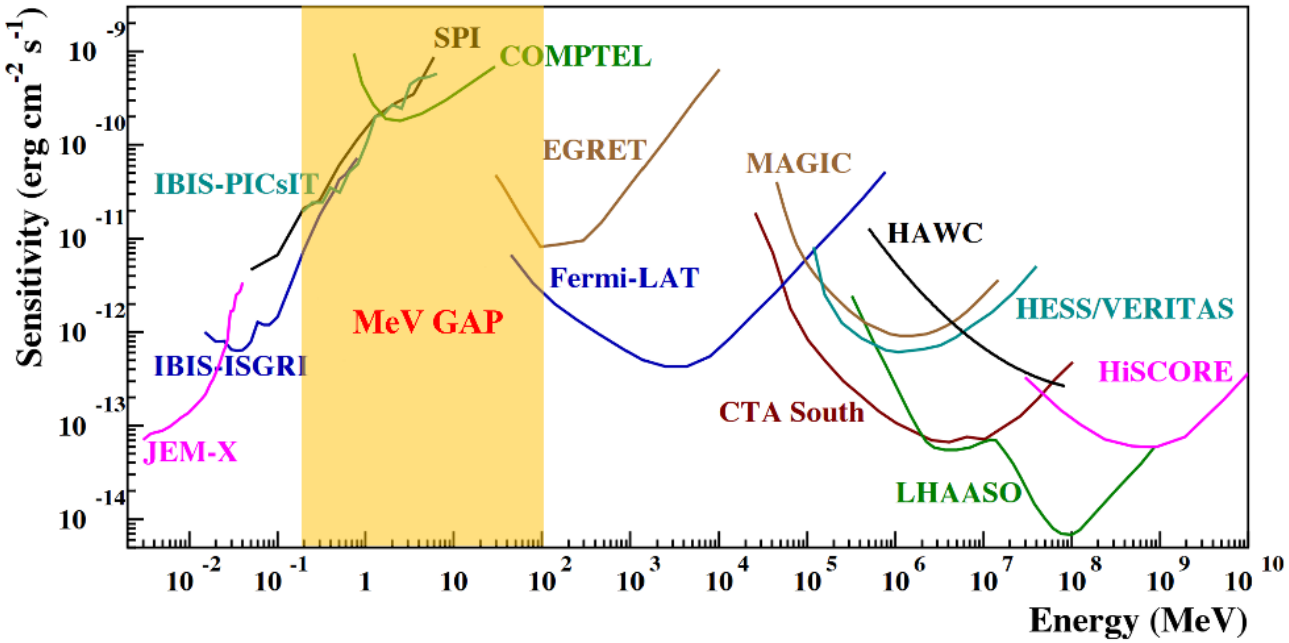


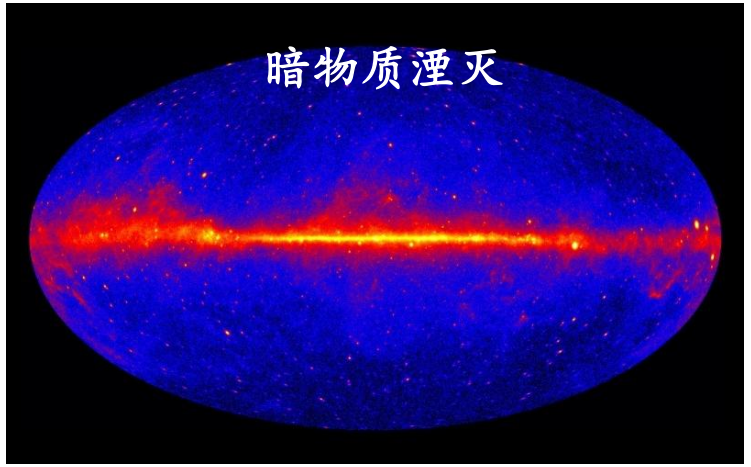
- Stopping range: heavier antiparticle (same β) stopped in deeper layers
- Exotic atom decay: x-rays with characteristic energies
- Annihilation: multiplicity of charge particles (i.e. $\pi^{\pm}$)

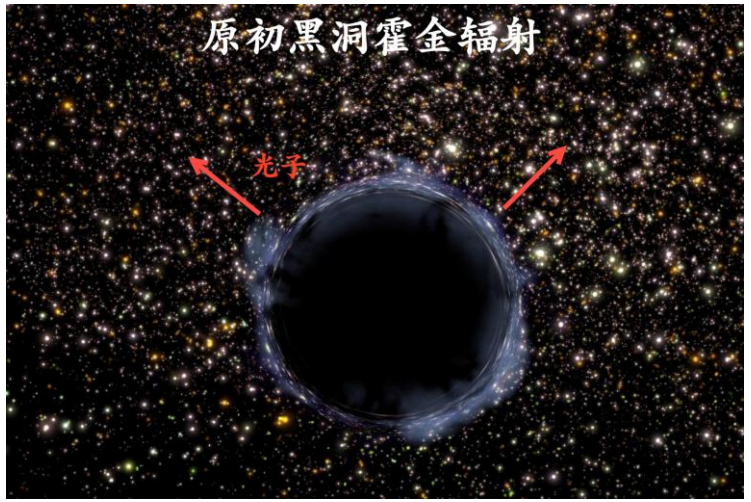
❑ Validated at KEK with $\bar{p}$ beam and applied at GAPS Antarctic balloon experiment (SJTU is the only Chinese institute), but yet used in space.

MeV Gamma Ray

- MeV gamma: unexplored energy region in gamma astronomy→ **"MeV gap".**







- Precise measurement: probe *primordial black hole*, *nucleosynthesis* & *chemical evolution* of the Galaxy, *dark matter annihilation*, etc.

MeV Gamma Ray

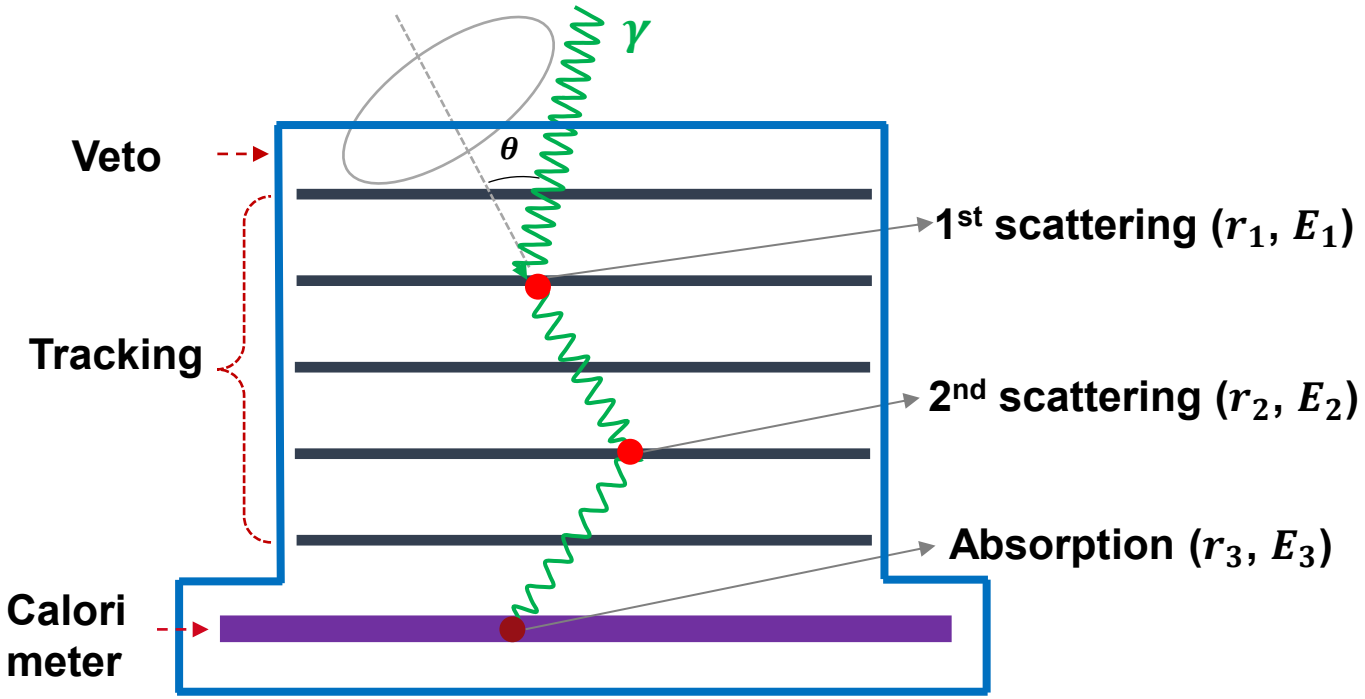
❑Multiple-layer Compton imaging for MeV gamma measurement.

- **Energy reconstruction:**

$$E_\gamma = E_1 + E_2 + E_3$$

- **Angular reconstruction:**

$$\cos\theta = 1 - m_e c^2 \left(\frac{1}{E_2 + E_3} - \frac{1}{E_\gamma}\right)$$



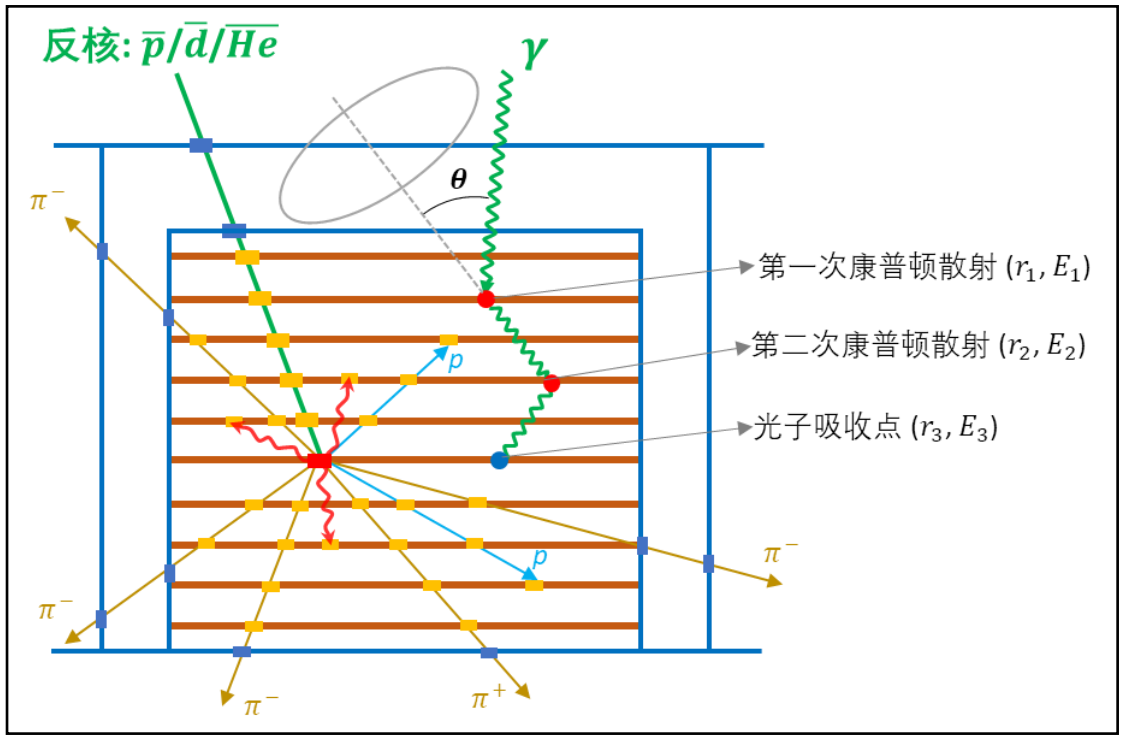
➢Main detection approach for next-generation MeV gamma experiments.

Novel Tracking-Calorimeter

❑**A compact and multi-purpose microsatellite payload**: precise measurement of low-energy antinuclei ($\bar{p}/\bar{d}/\overline{He}$) and MeV gamma rays simultaneously.

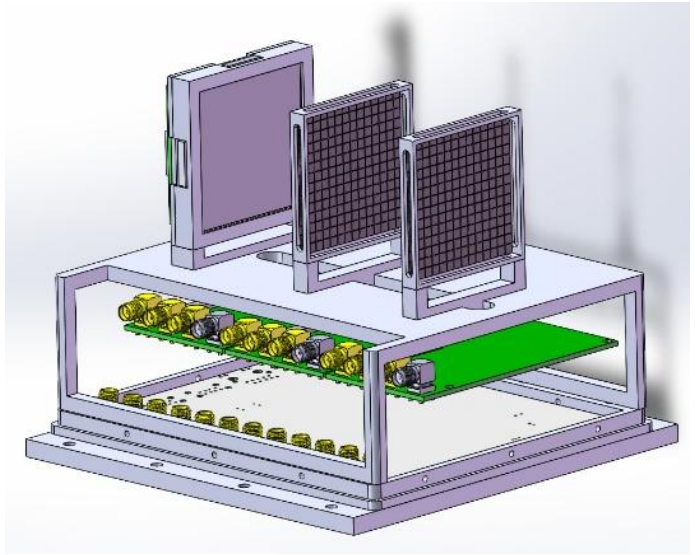
- **Antinuclei:** exotic nucleus formation/decay
- **MeV gamma:** multi-layer Compton imaging

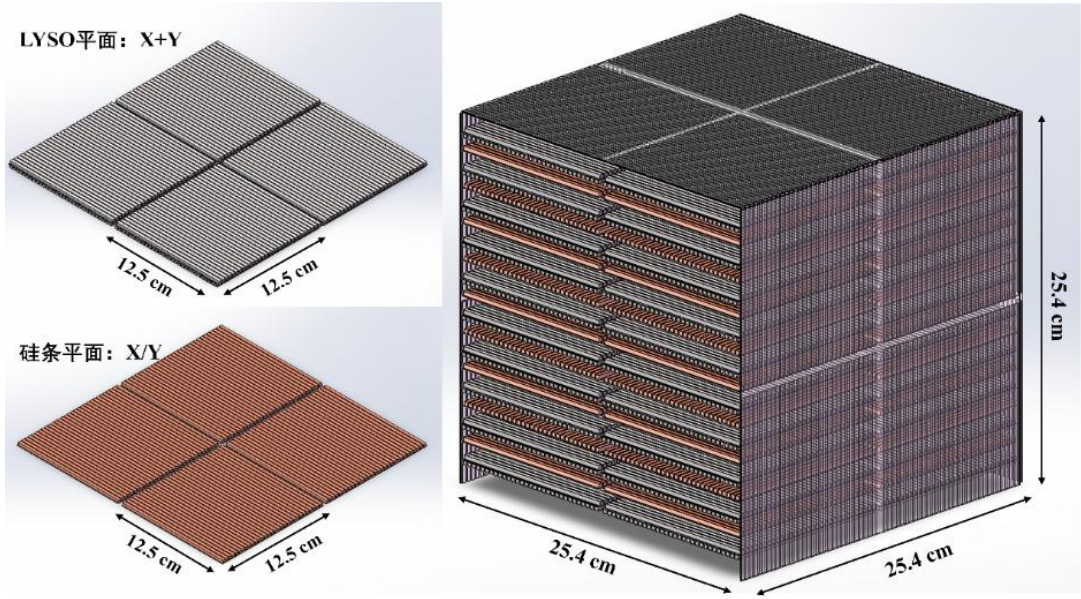
➢ **Key instrument: on-orbit tracking-calorimeter（在轨径迹量能器）**



SJTU Microsatellite Project

See Pingwei Sun's talk at Parallel-V on Jul. 16th



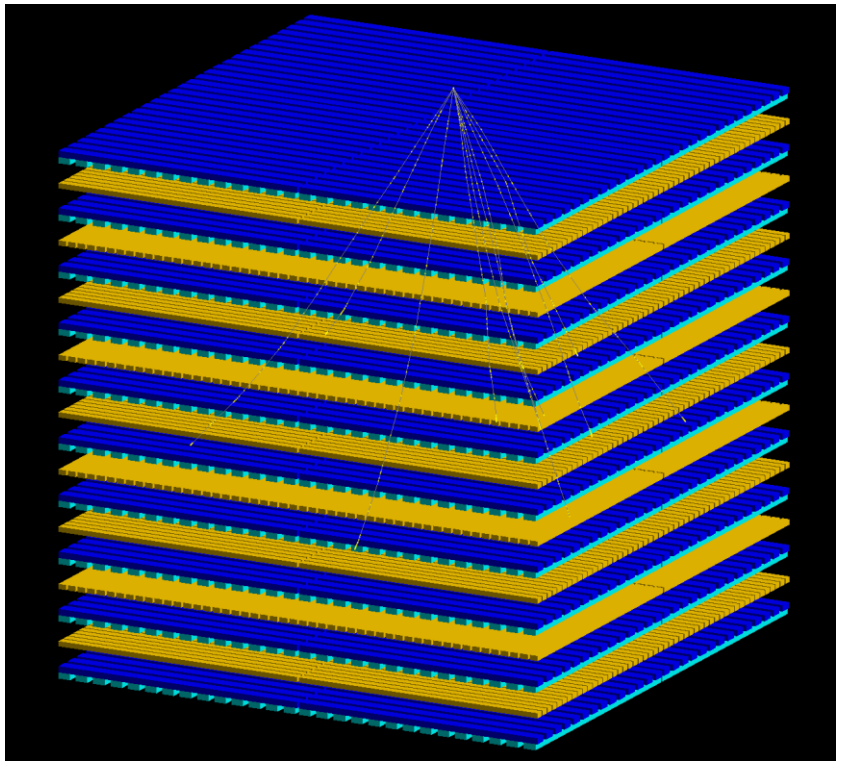


- **Pathfinder:** ~1 kg payload focuses on MeV gamma, **piggyback** on commercial satellite in 2026 summer.
- **1st stage:** ~30 kg payload, simultaneously measures MeV gamma & low-energy cosmic antinuclei, to be launched (**primary payload**) in 2027, funded by SJTU State Key Laboratory of Dark Matter Physics.

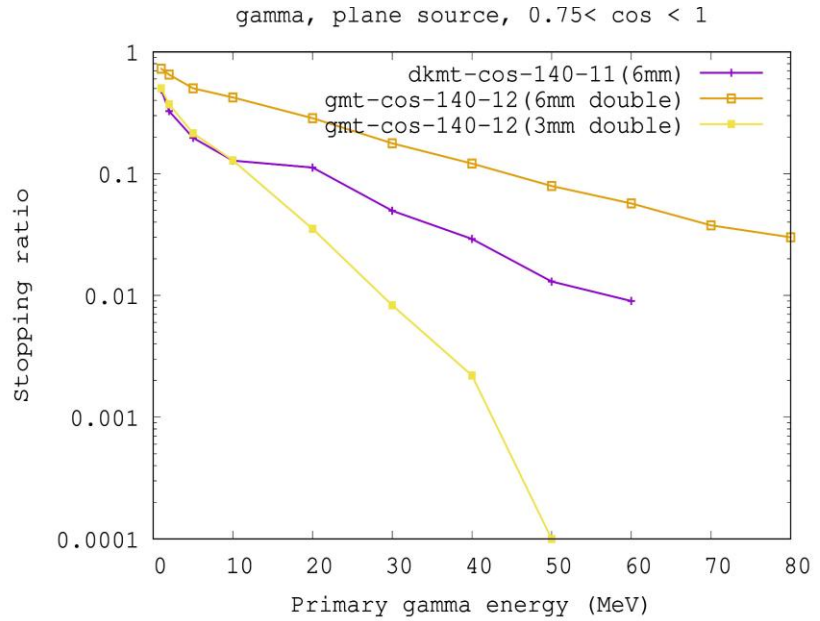
注：上海交大牵头“面向未来MeV伽马射线空间探测的技术研发和理论研究”已获科技部重点研发专项（青年科学家）资助（National Key R&D Program of China, 2025.12-2030.11）

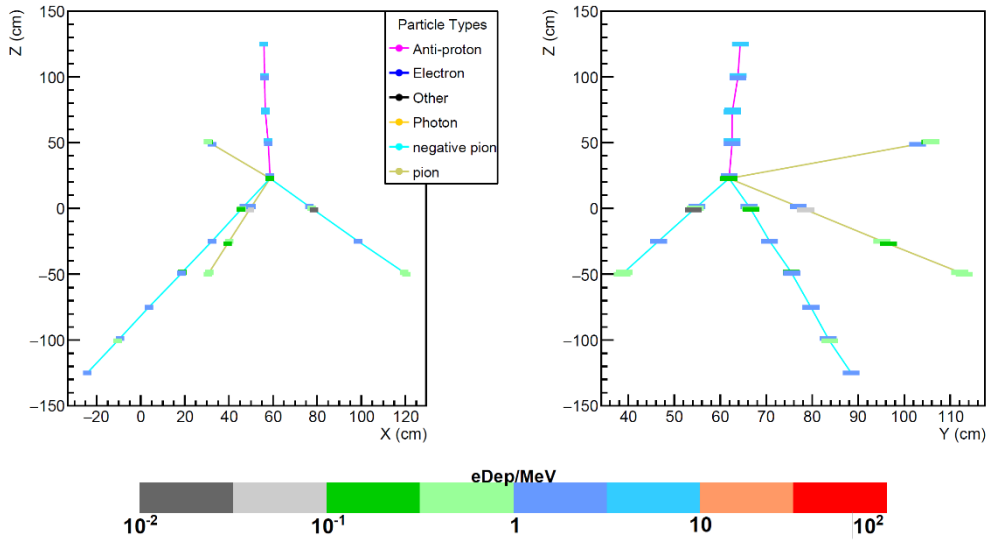
SJTU Microsatellite Project

❑ Simulation results with Geant4



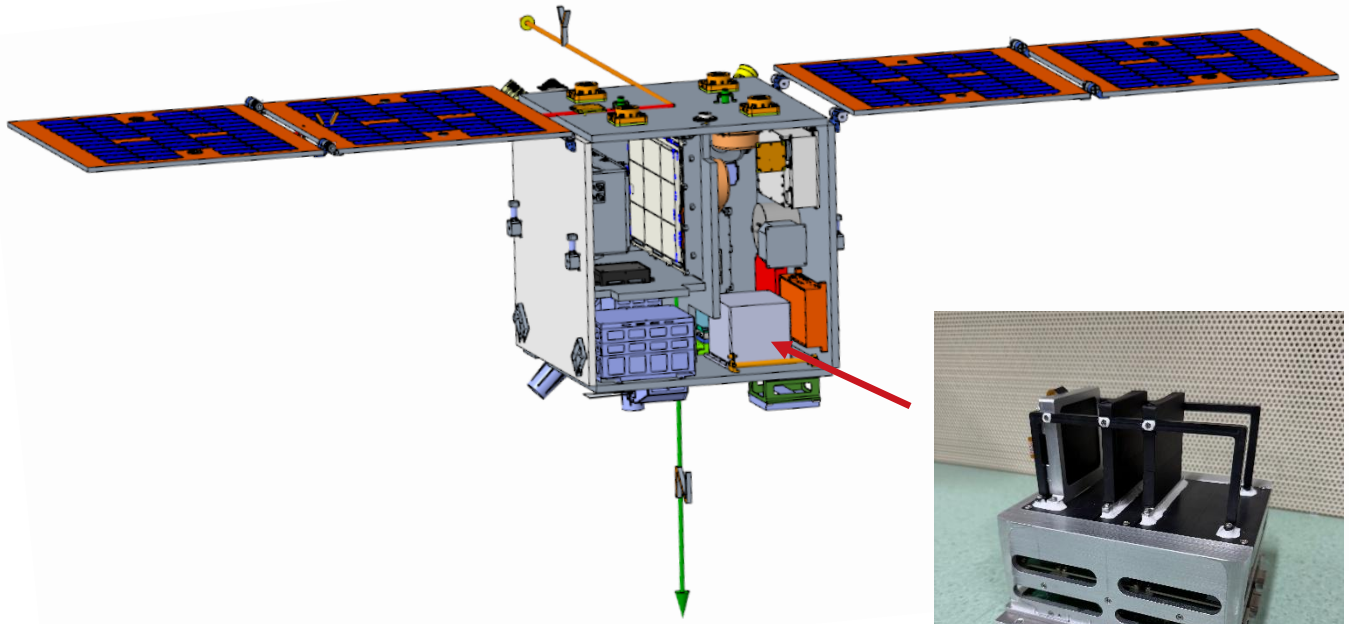
- 30kg tracking-calorimeter

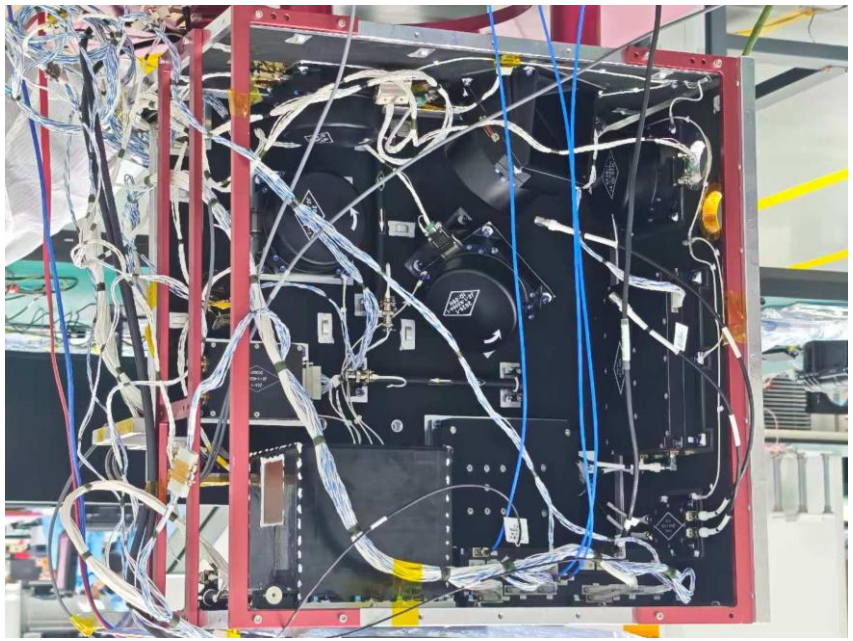




SJTU Microsatellite Project

- On satellite: pathfinder integration with the satellite, done!





- Orbit height is 525 km and the camera points to the Galactic Center, to be launched in summer of 2026!!

Summary & Outlook

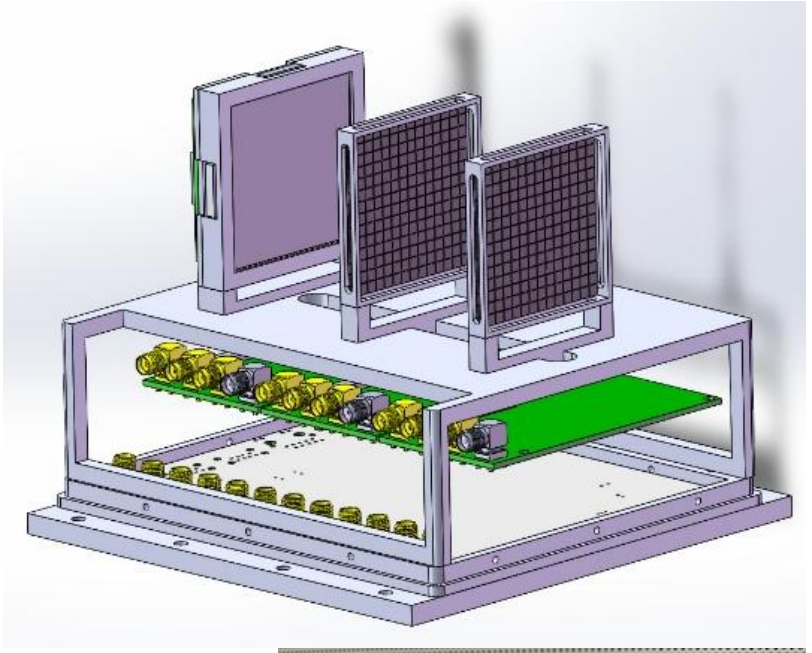
- Low-energy antinuclei and MeV gamma provide unique window for many cutting-edge researches: dark matter annihilation, primordial black hole, nucleosynthesis & chemical evolution of the Galaxy, etc.
- A novel Compton camera as a pathfinder of SJTU micro-satellite serial projects has been delivered for MeV gamma measurement, ***stay tune for the upcoming data soon!***
- A muti-purpose compact micro-satellite payload is under developing, and ***welcome collaborators!***

Thank You!

Novel Compton camera

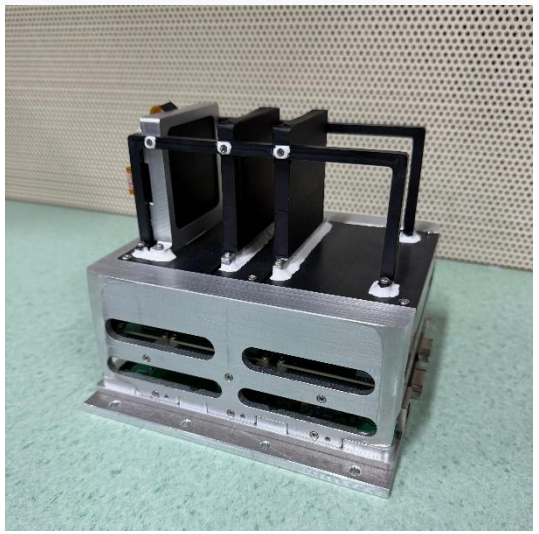
❑ Detector with novel scintillators:

- **Tracker:** 2 layer YSO (ρ= *4.5 g/cm^3, LY=28 ph/keV, decay time=60 ns*), ~50×50×3 mm, 14×14 pixels (each pixel 3x3mm and coupled with 1 SiPM);
- **Calorimeter:** 1 layer LYSO (ρ=*7.2 g/cm^3, LY=35 ph/keV, decay time=40 ns*), ~50×50×6 mm, four sides are coupled with SiPM arrays.



❑ Electronic readout: total power ~7W

- Total 12 readout channels: capacitive multiplexing to process 14×14 SiPMs with 4 chans (keep the position information).
- Critical electronics (FPGA, digitizers, OPA, etc) are qualified for the space application.

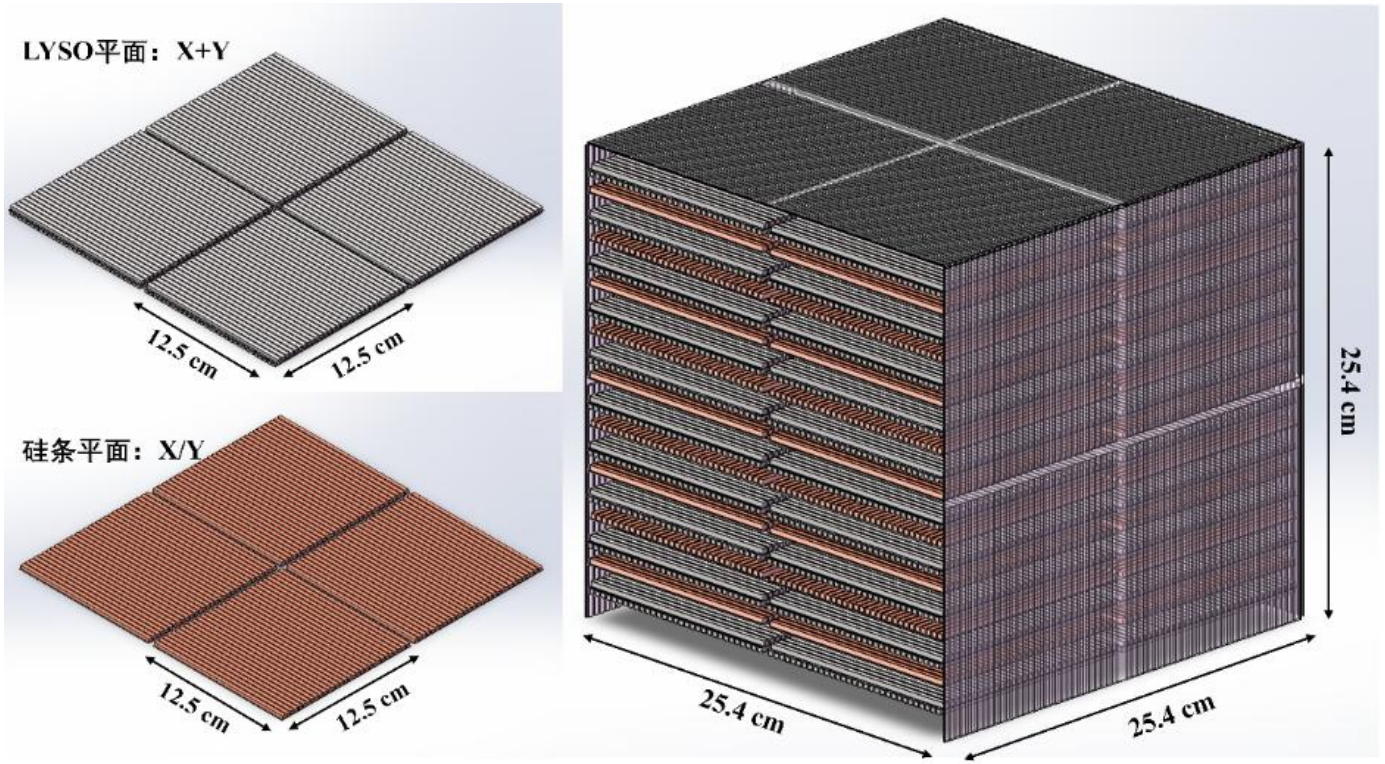


➢ Pathfinder of SJTU micro-satellite serial projects!

Multi-purpose Payload

- **LYSO/YSO array**:
  - 10 layers, 3mm XY strips orthogonal placed;
  - SiPM reads out energy & time from each strip at two ends.

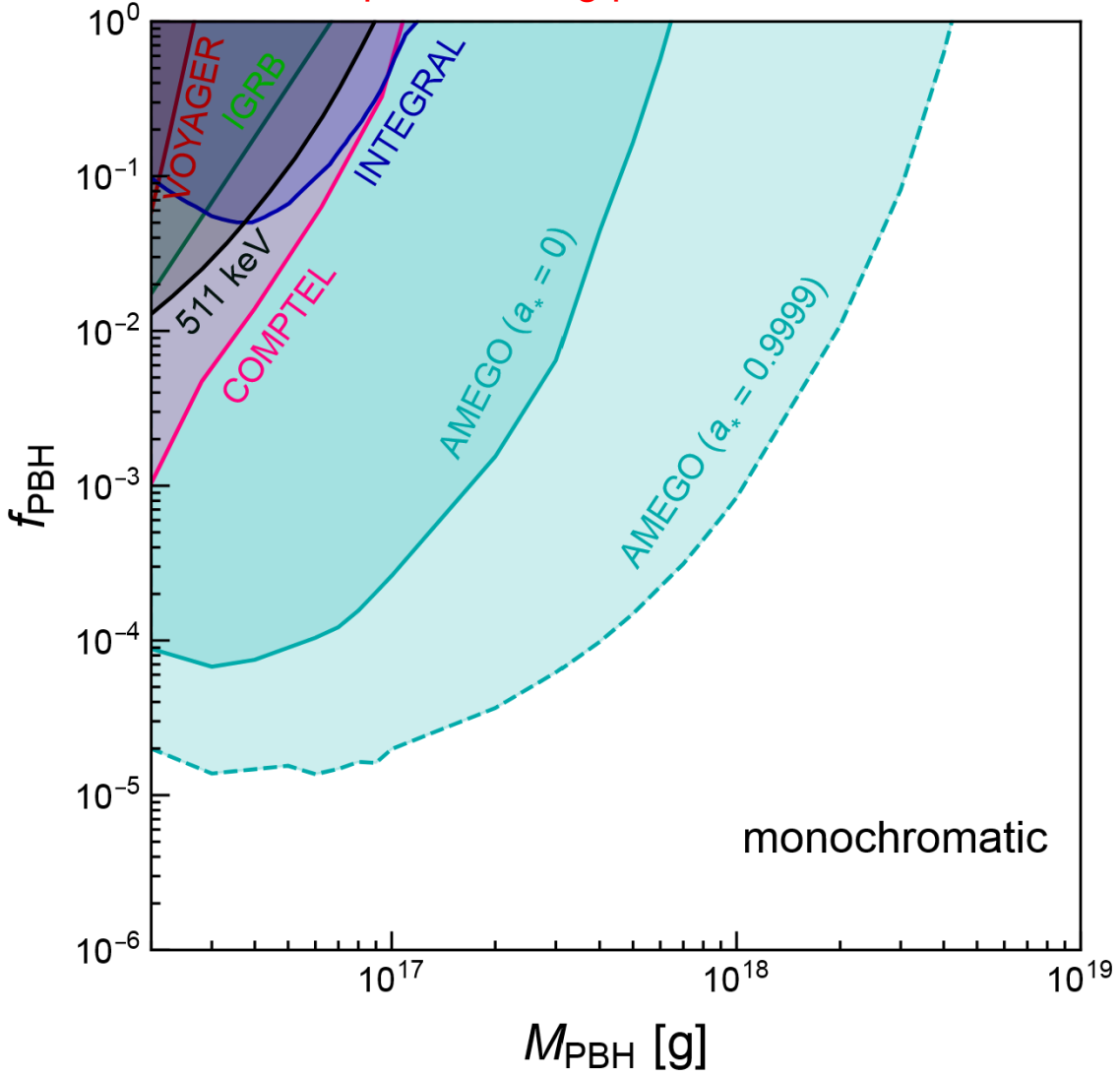
- **Silicon array**:
  - 9 layers, 5mm XY strips orthogonally placed;
  - ASIC to read out the charge.



- **Payload: ~30×30×30 cm, ~30kg.**

MeV Gamma Physics

https://arxiv.org/pdf/2102.06714



https://arxiv.org/pdf/2411.00087