PANGU
盤古

A High Resolution Gamma-Ray Space Telescope

Meng Su

On behalf of the PANGU collaboration

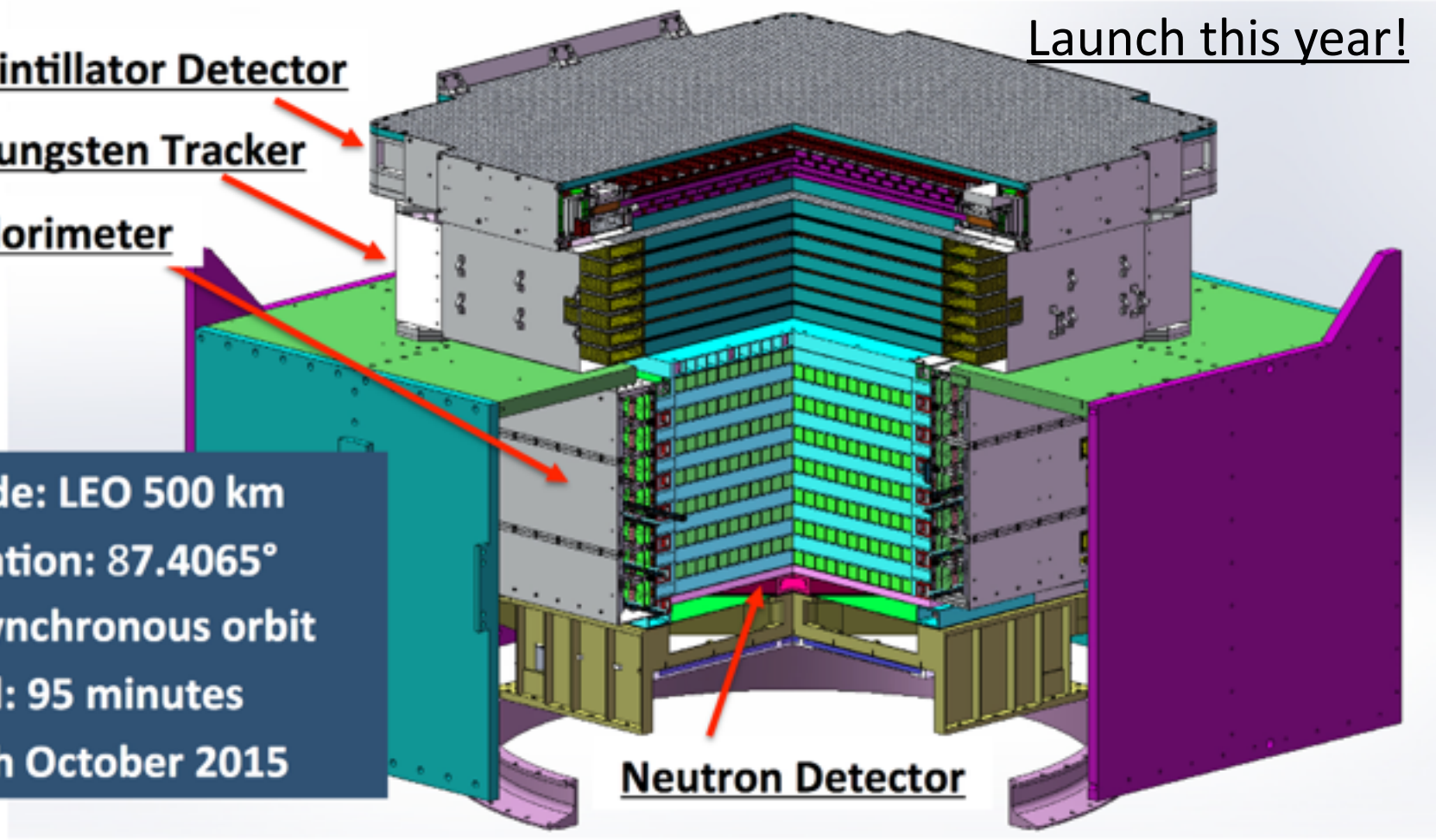
European PI: Xin Wu, Chinese PI: Jin Chang

Pappalardo/Einstein fellow
MIT

Future Space-based Gamma-ray Observatories

February 6th, 2015

The DAMPE Detector

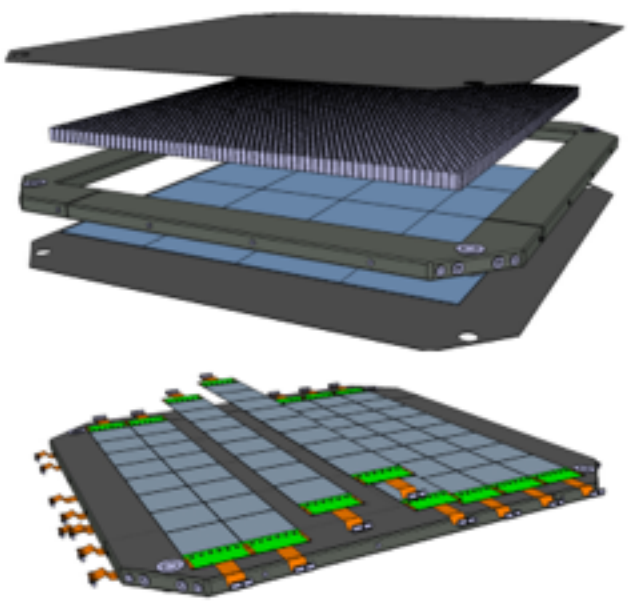


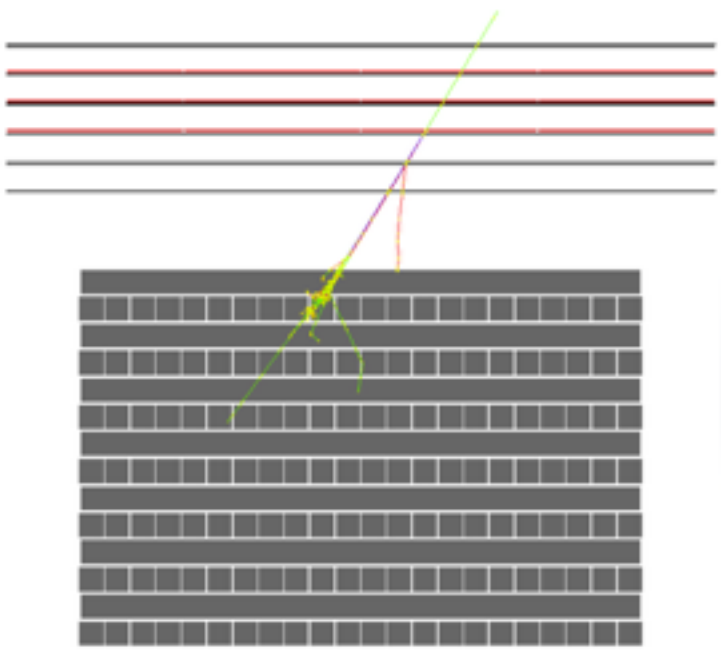
- Altitude: LEO 500 km
- Inclination: 87.4065°
- Sun-synchronous orbit
- Period: 95 minutes
- Launch October 2015

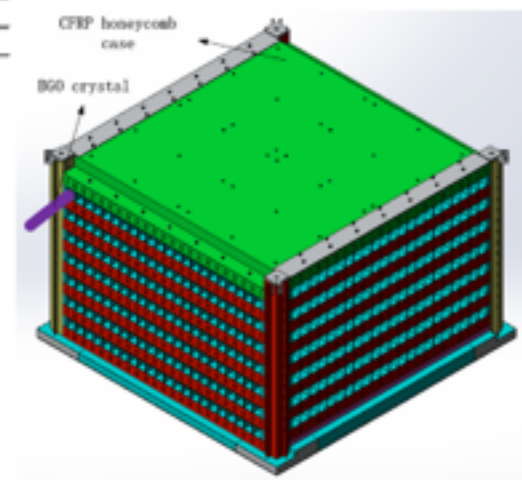
W converter + thick calorimeter (total 32 X_0) +
precise tracking + charge measurement ➡
high energy γ-ray, electron and CR telescope

Comparison with AMS-02 and Fermi

	DAMPE	AMS-02	Fermi LAT
e/γ Energy res.@100 GeV (%)	1.5	3	10
e/γ Angular res.@100 GeV (°)	0.1	0.3	0.1
e/p discrimination	10^5	10^5 - 10^6	10^3
Calorimeter thickness (X_0)	31	17	8.6
Geometrical accep. (m^2sr)	0.29	0.09	1



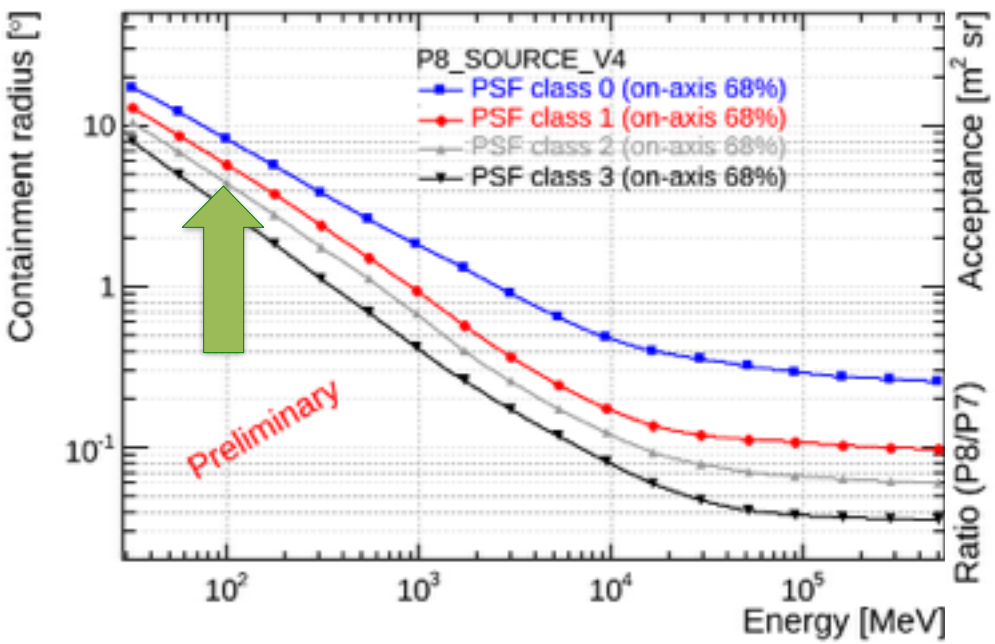


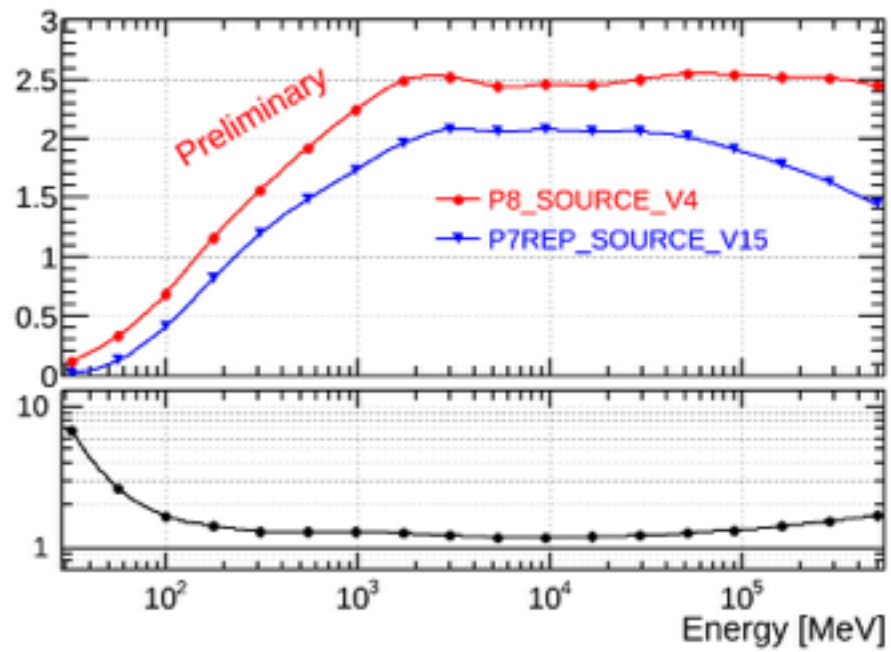


Sub-GeV detection is NOT improved

- **The science case for high resolution (≲ 1°) gamma-ray space telescope around 100 MeV is very compelling**
  - **But it has yet to be realized, best instrument up to now is FERMI**

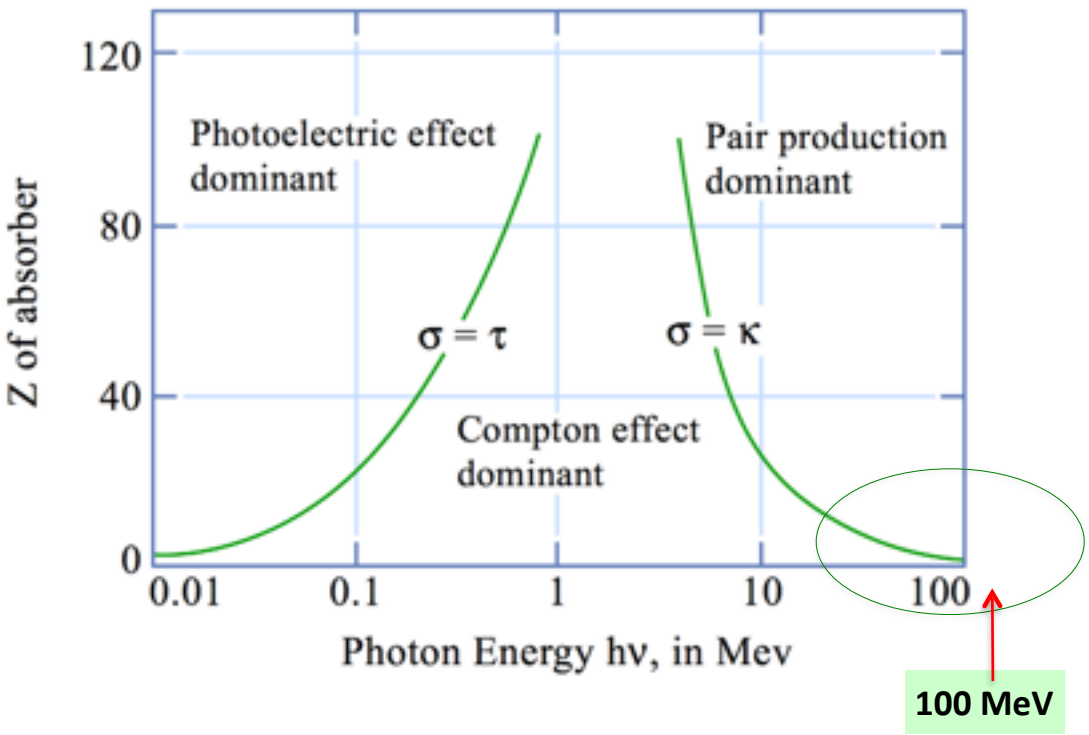
PSF 3°-8° @100 MeV after latest software (Pass 8) improvement

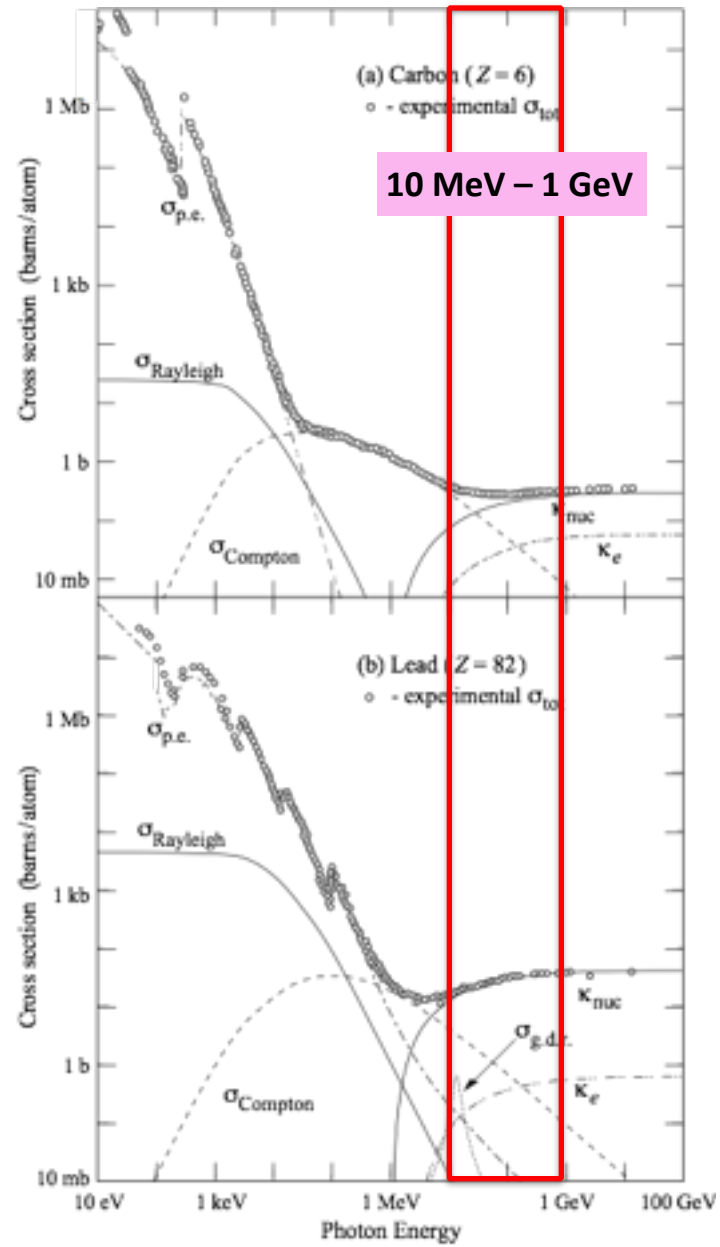




Gamma-ray detection principle

- **At ~100 MeV, pair production dominates**
  - **Very small cross section ⟹ need more material for good acceptance**
  - **Material is the limiting factor of angular resolution because of important multiple scattering at ~MeV**





PANGU
盤古

The first living being and the creator of the Universe from chaos in Chinese mythology.

Formless chaos

coalesced ↓

Cosmic egg

balanced ↓

Yin and Yang

woke up ↓

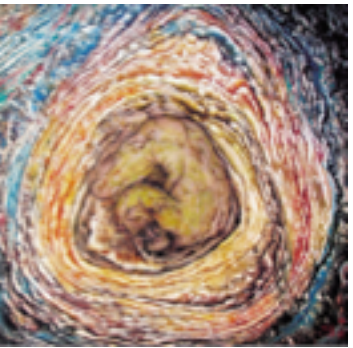
Pangu

What does PANGU mean to me?

PAir productioN Gamma-ray Unit

PANoramic Gamma-ray Unit

Polarized ANd Gamma-ray Universe



Wu et. al, arXiv:1407.0710

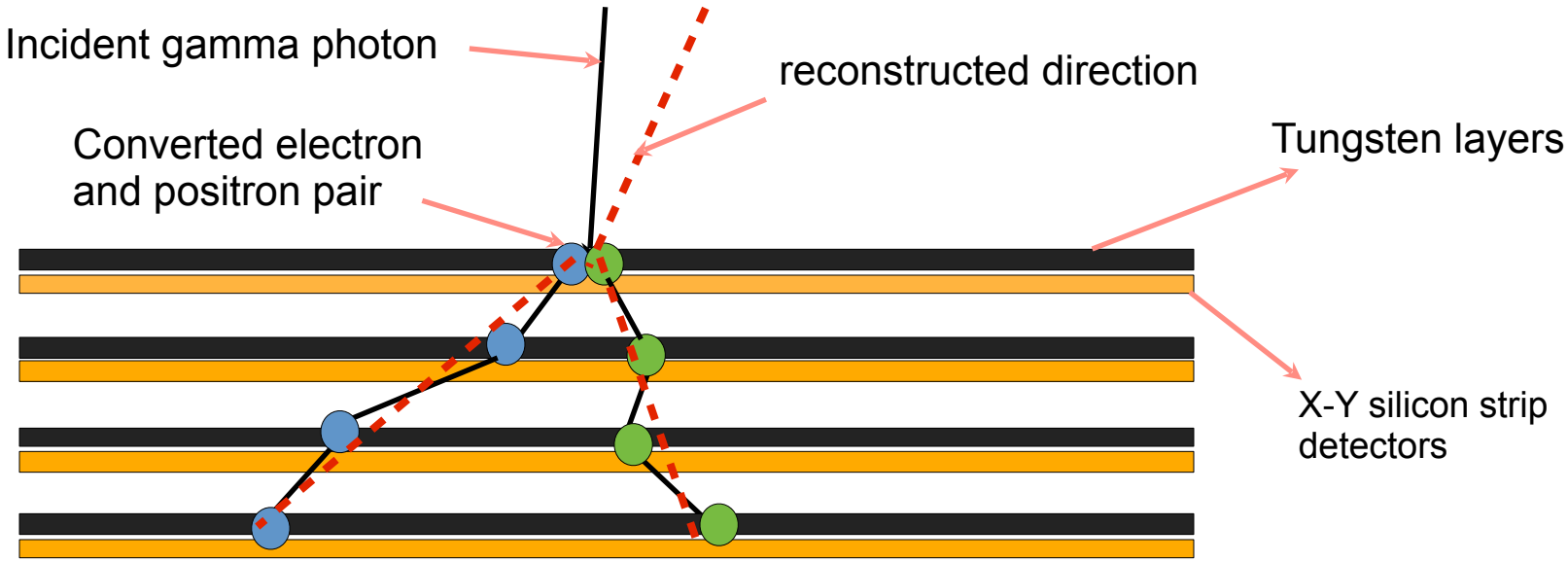
Overview

PANGU: PAir-productioN Gamma-ray Unit

- **Sub-GeV γ-ray telescope with unprecedented angular resolution**
  - **Energy range of 10 MeV – 1 GeV with $\lesssim$ 1° point spread function at 100 MeV**
  - **With polarization measurement capability**
- **Innovative payload concept for a small mission**
  - **Thin target material (SciFi or Si) (with magnetic spectrometer)**
- **Wide range of topics of galactic and extragalactic astronomy and fundamental physics**
  - **Complementary to the world-wide drive for a next generation Compton telescope (~0.1-100 MeV)**

An unique instrument to open up a frequency window that has never been explored with great precision

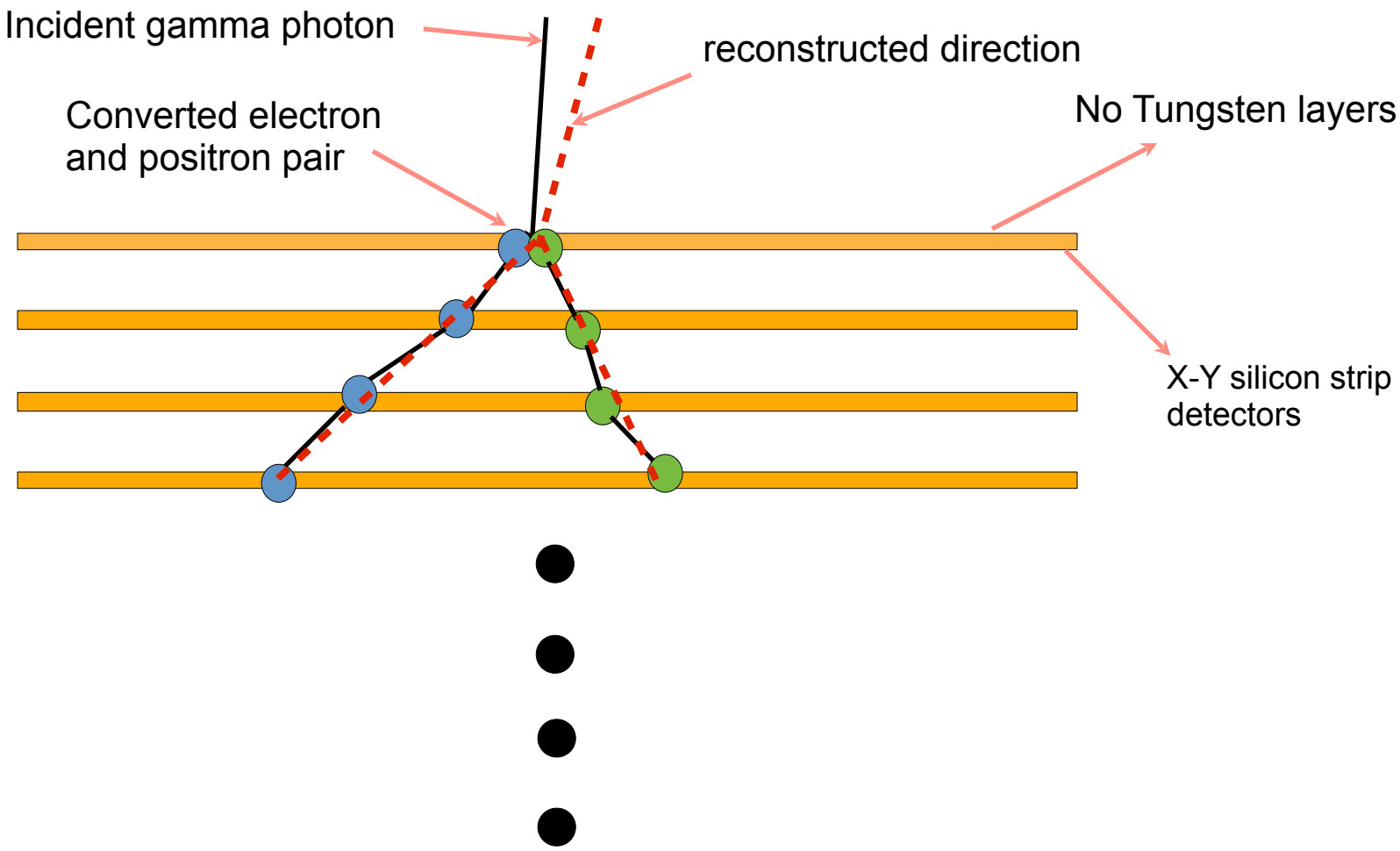
Detection principle:
How Fermi-LAT detects gamma-ray photons



Converted electron/positron pair carries information about the direction, energy and polarization of the gamma-ray photon

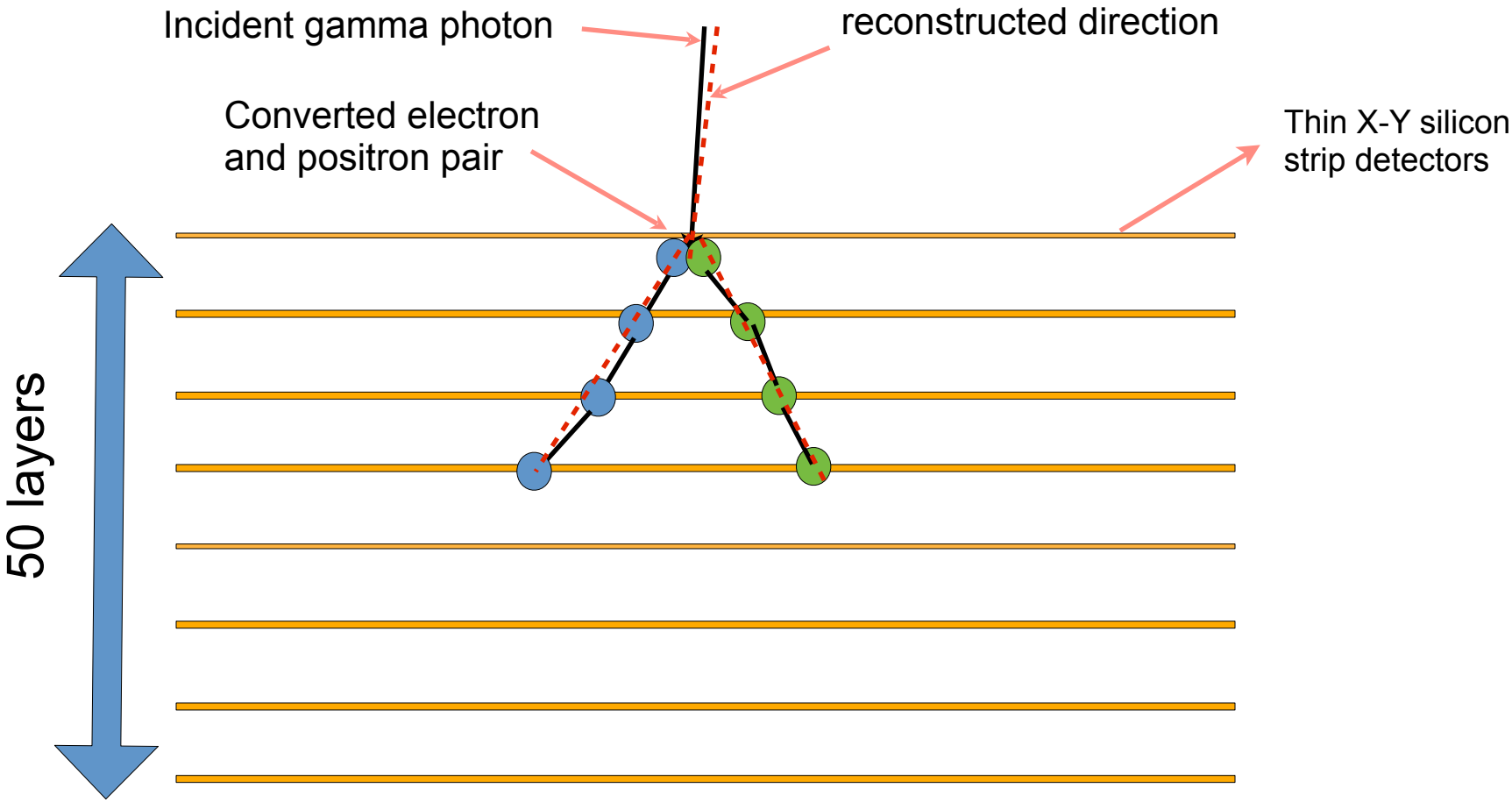
Detection principle:

How PANGU detects gamma-ray photons

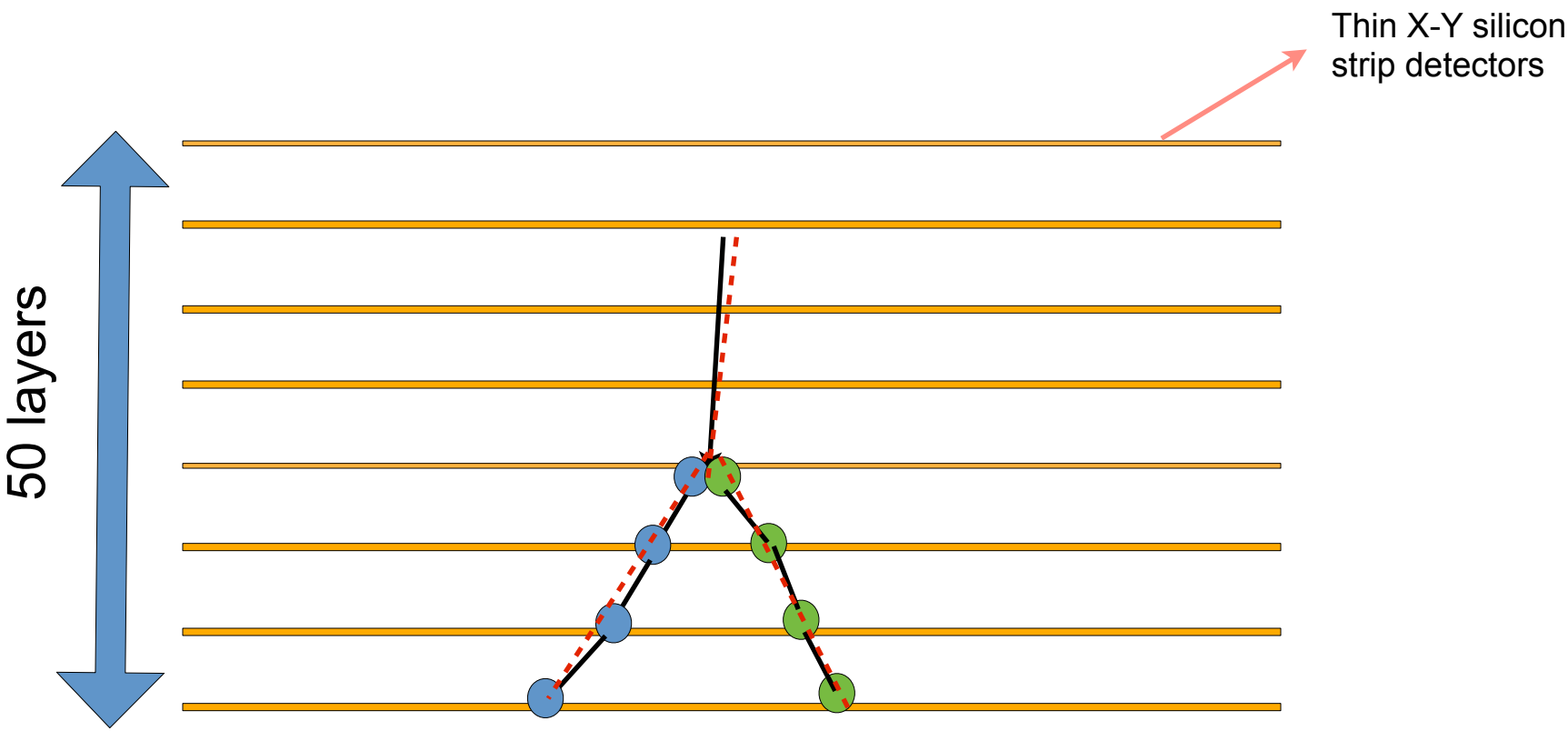


Detection principle:

How PANGU detects gamma-ray photons



Detection principle:
How PANGU detects gamma-ray photons



Response to the ESA-CAS small mission call for proposal

→ EUROPEAN SPACE AGENCY | ABOUT SCIENCE & TECHNOLOGY | FOR PUBLIC | FOR EDUCATORS

cosmic vision

esa

ESA | SCIENCE & TECHNOLOGY | COSMIC VISION

Missions
- Show All Missions

Cosmic Vision 2015-2025
- Cosmic Vision
- Candidate Missions
- M-class Timeline
- L-class Timeline

The four themes
- Planets and Life
- The Solar System
- Fundamental Laws
- The Universe

PLANNING FOR A JOINT SCIENTIFIC SPACE MISSION
AN INITIATIVE OF THE EUROPEAN SPACE AGENCY AND THE CHINESE ACADEMY OF SCIENCES

FIRST ANNOUNCEMENT

1st Workshop
Planning for a joint scientific space mission
Chinese Academy of Sciences (CAS) - European Space Agency (ESA)
Chengdu (China)
25-26 February 2014

http://sci.esa.int/esa-cas-workshop
http://jm.nssc.ac.cn

Search here

4-Apr-2014 13:52 UT

Shortcut URL
http://sci.esa.int/jump.cfm?oid=53072

Related Articles
- First Announcement
- Boundary conditions for the candidate missions
- Practical information
- Programme
- List of posters

Pre-defined Boundary Conditions

- ESA contribution comparable to "Small Mission" (53 M Euros) + a similar size from CAS
  - As it is usual for ESA science missions, the ESA Member States are assumed to provide (partly or fully) the European contribution to the payload elements
- Preliminary technical guidelines
  - Payload mass < = 60kg, Spacecraft wet mass <= 300kg
  - Payload average power consumption <= 65 W, peak <= 100 W
  - Operational lifetime of satellite three years.
- Technology readiness requirements: TRL >= 7 for platform elements, TRL >= 6 for payload, by the time of the call
- Launcher:

  - Long March launchers LM-2C or LM-2D, both launched from China,
  - European launchers, namely Vega, Soyuz and Ariane 5, launched from the Guyana Space Centre (CSG in Kourou). Note that for Soyuz or Ariane 5 cases, only an auxiliary/piggy-back passenger launch can be envisaged.

The PANGU Collaboration

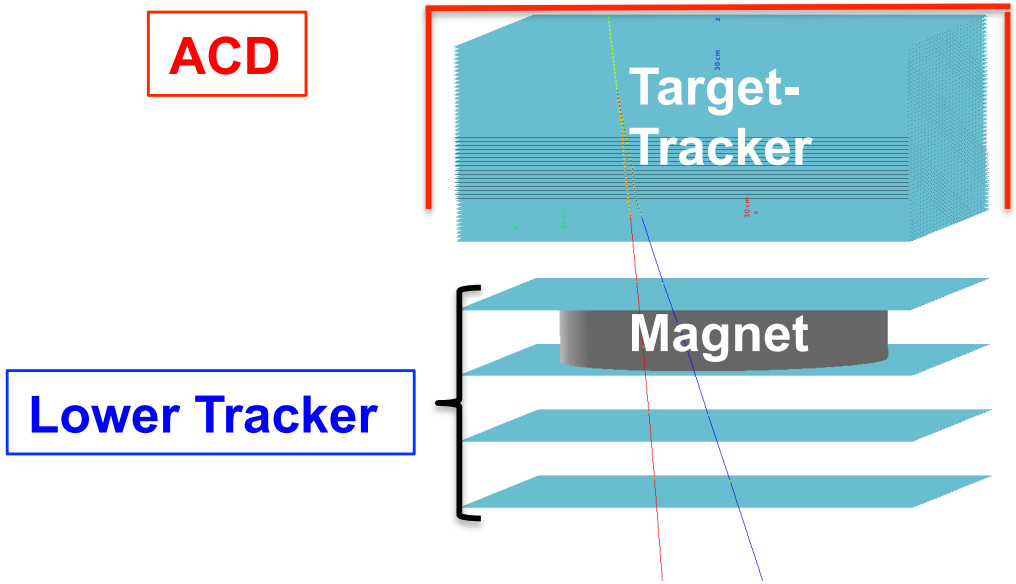
- A growing international collaboration from China, Europe and US
  - 64 members from 21 Chinese institutes
  - 24 members from 11 European institutes (Switzerland, Italy, Sweden, Germany, France, Netherlands)
  - 6 members from 4 US institutes

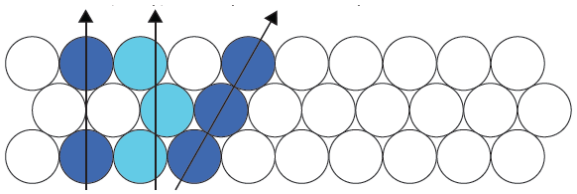
Strong interest and broad support from the Chinese and European astrophysics communities

Possible Detector Concepts

- To achieve ≲1° angular resolution passive material should be minimized and active detector should be thin or low density
  - To increase effective area (mass!) needs many layers or large volume
- Concepts for high resolution gamma pair telescope studied before
  - Low density gas (or liquid) TPC: *HARPO*, *AdEPT* (5-200 MeV), LArGO…
    - Potentially very good resolution
    - Need large pressure vessels (AdEPT: 6×1m^3 vessels for 20 kg gas)
  - All-silicon, many optimized as Compton telescope (with calorimeter):
    - MEGA/GRM: Double-sided SSD, distance 5 mm, 500 µm thick
    - CAPSiTT: Double-sided SSD, distance 1 cm, 2 mm thick
    - TIGRE: Double-sided SSD, distance 1.52 cm, 300 µm thick
    - Gamma-Light: single-sided, distance 1 cm, 400 µm thick
  - Scintillating fiber
    - Previous concepts with converter: *SIFTER*, *FiberGLAST*
  - PANGU: a new all-fiber or all-Si tracker light weight concept

Sketch of the Earlier PANGU Layout





Target and magnet sizes can be easily scaled to fit with resource constraints!

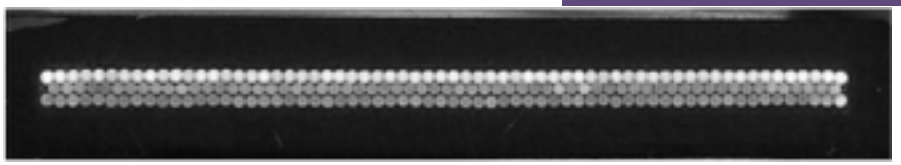
- **3 sub-systems: target-tracker, magnet + lower tracker, Anticoincidence**
  - **Target-tracker : ~ 70 x 70 x 30 cm^3**
  - **Magnet: B=0.1 T, h = 10 cm, field in +y direction**
    - **Halbach array with 1.5 T NdFeB magnet, r_2 (r_1) = 27 (25) cm, 21 kg**
  - **Lower tracker: one X-layer above, one X-layer, and two X-Y layers below, ~10 cm between**
  - **Anticoincidence detector (ACD) on 5 sides**

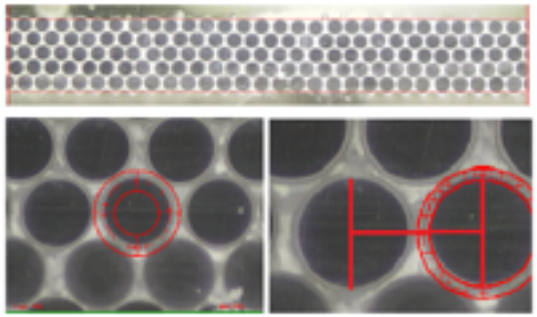
PANGU-Si vs PANGU-Fi

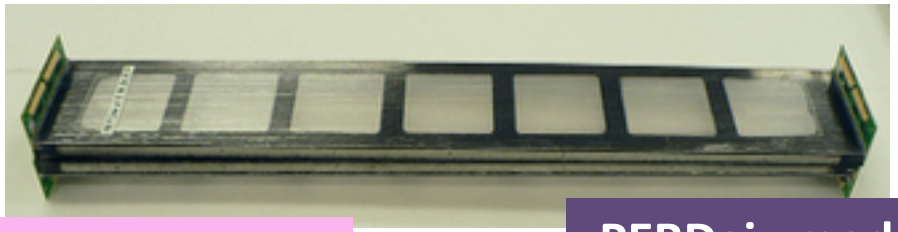
- Silicon and fibers trackers are both viable technologies
  - Challenges are mainly engineering: optimal use of the limited weight (ultra-light module) and power budgets (low power ASICs)
- Silicon has been successfully used in similar space missions
  - Fermi, AGILE, Pamela, AMS-02, …

- Fiber is cheaper, less fragile, more flexible geometry, but the technologies of scintillating photon detector (SiPM) and readout ASICs are newer (TRL < 6)
  - Recent developments in high energy physics, eg. LHCb, Mu3e, …
    - Also in space: balloon prototype PERDaix of PEBS
  - Position resolution ~70 µm can be achieved

Mu3e module







NIMA 628(2011)403

PERDaix module

The Target-Tracker

- Possible layout
  - x-y double layers with 6mm inter-distance, 50 double layers
- Tracking layer with ~0.3% X_0 total (requirement)
  - Silicon: 2 single sided SSD of 150 µm each
  - SciFi: 2 layers of ~0.65 mm each (Polystyrene equivalent), each layer formed by a stack of 3 layers of ø=250 µm fibers, readout by SiPM
- Total tracker active material
  - Silicon: ~17kg (silicon density ~2.33 g/cm^3)
  - Fiber: ~25kg (polystyrene density ~0.9 g/cm^3)
- Both need support substrate
  - Probably more for Si: biasing, bonding, more fragile
- Baseline: ~50kg for fiber/silicon, support structure, FE electronics
  - Plus: 30 kg for magnet, 20 kg for the rest (ACD, DAQ, …)

    $\Longrightarrow$ total weight ~100 kg
- Can be re-optimized to 60kg with reduced acceptance if limit is strict!

Power Consumption

- Total number of readout channels of 50 double-layers in the target + 6 layers in the lower tracker, with 250 µm readout pitch, is ~300k channels
  - Si strip detector pitch ~250µm, fibers can be readout by SiPM of 250 µm pitch
- Current Si readout ASIC consumes ~0.2mW/channel
  - Push for ~0.1mW/channel with some R&D
  - Similar for readout ASIC for SiPM
    - Total ASIC power ~30-60 W
- Total power consumption of payload 60-90 W
  - Including CPU for online selection

Satellite Platform and Mission Concept

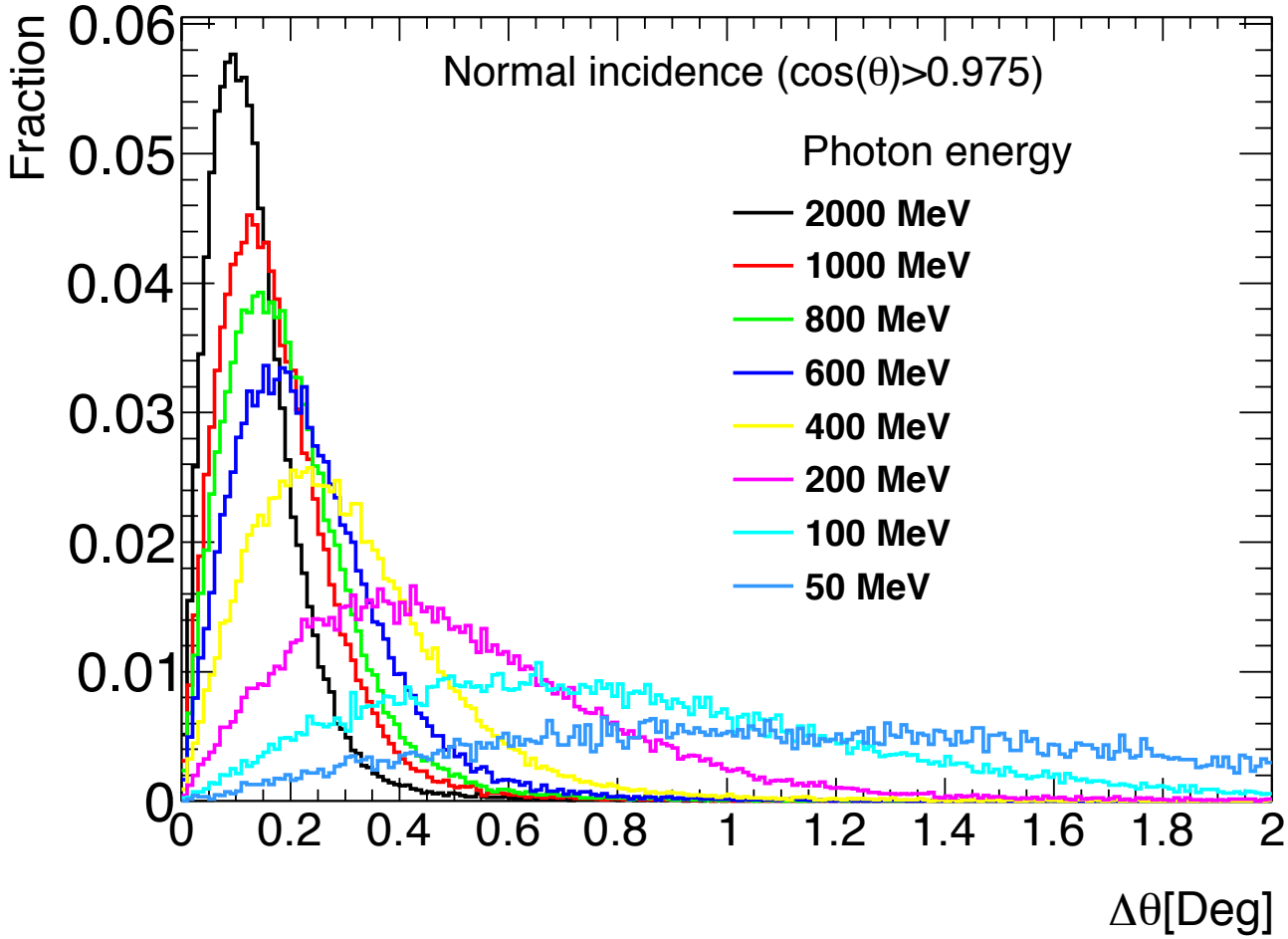
- Satellite platform
  - Temperature stability
    - Low temperature preferred for magnet and SiPM
  - Magnetic shielding
    - For satellite navigation system, not for payload
  - Pointing stability and precision
    - ~0.1° is sufficient
- Mission concept
  - Low earth orbit
  - All-sky survey and pointed observations
    - With possibility to rotate the payload to study systematic effect of polarisation measurement
    - GRB fast alert downlink
  - Minimum lifetime three years
  - Science data open to the world community

Potential Collaboration Projects

- **Many interesting and challenging topics for collaboration**
  - **Science study: Science potential of a high resolution detector**
  - **Conceptual Design: Payload performance and optimization**
  - **Permanent magnet: light weight, uniformity**
  - **SciFi tracking layer: automatic winding process, placement precision, gluing process, light weight support, …**
  - **Target-tracker: integration of layers on precise light weigh frame**
  - **Photon detector**
    - **SiPM: high efficiency, low dark current, high density**
    - **Other photon detection scheme?**
  - **FE ASIC: low power, trigger, timing**
  - **Trigger, Readout and DAQ: low power consumption, low dead time, robust trigger algorithm, flexibility for different observation mode**
  - **ACD: low weight, coverage, segmentation**
  - **On-ground data processing, science preparation: Science data center**

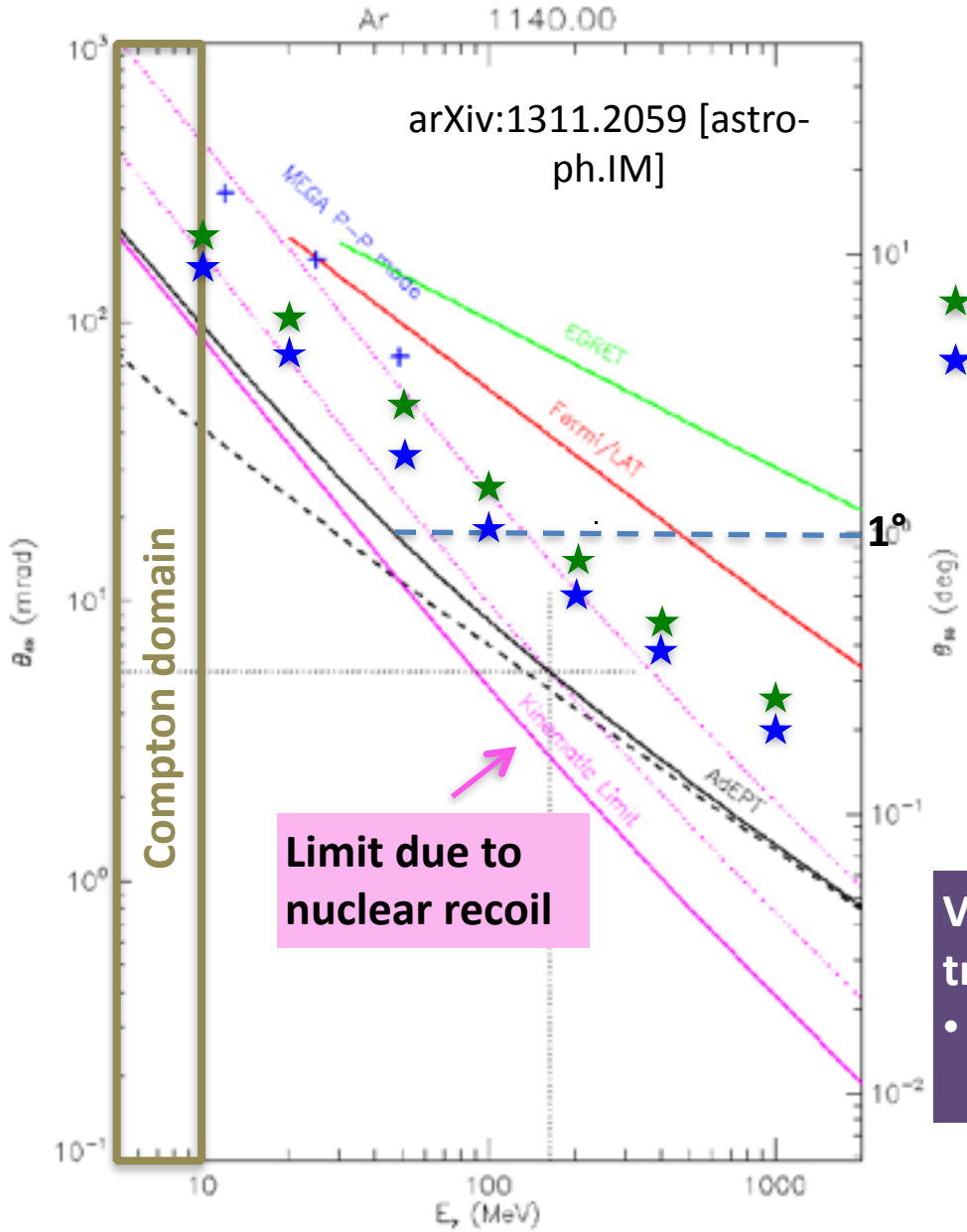
Photon Angle Measurement

- **For normal incidence (cos(θ)>0.975), both tracks in the lower tracker**



Measured photon direction = sum of two measured directions at the first measurement point weighted by measured momenta

Angular resolution of pair telescopes



Limit due to nuclear recoil

★ PANGU: both tracks in target

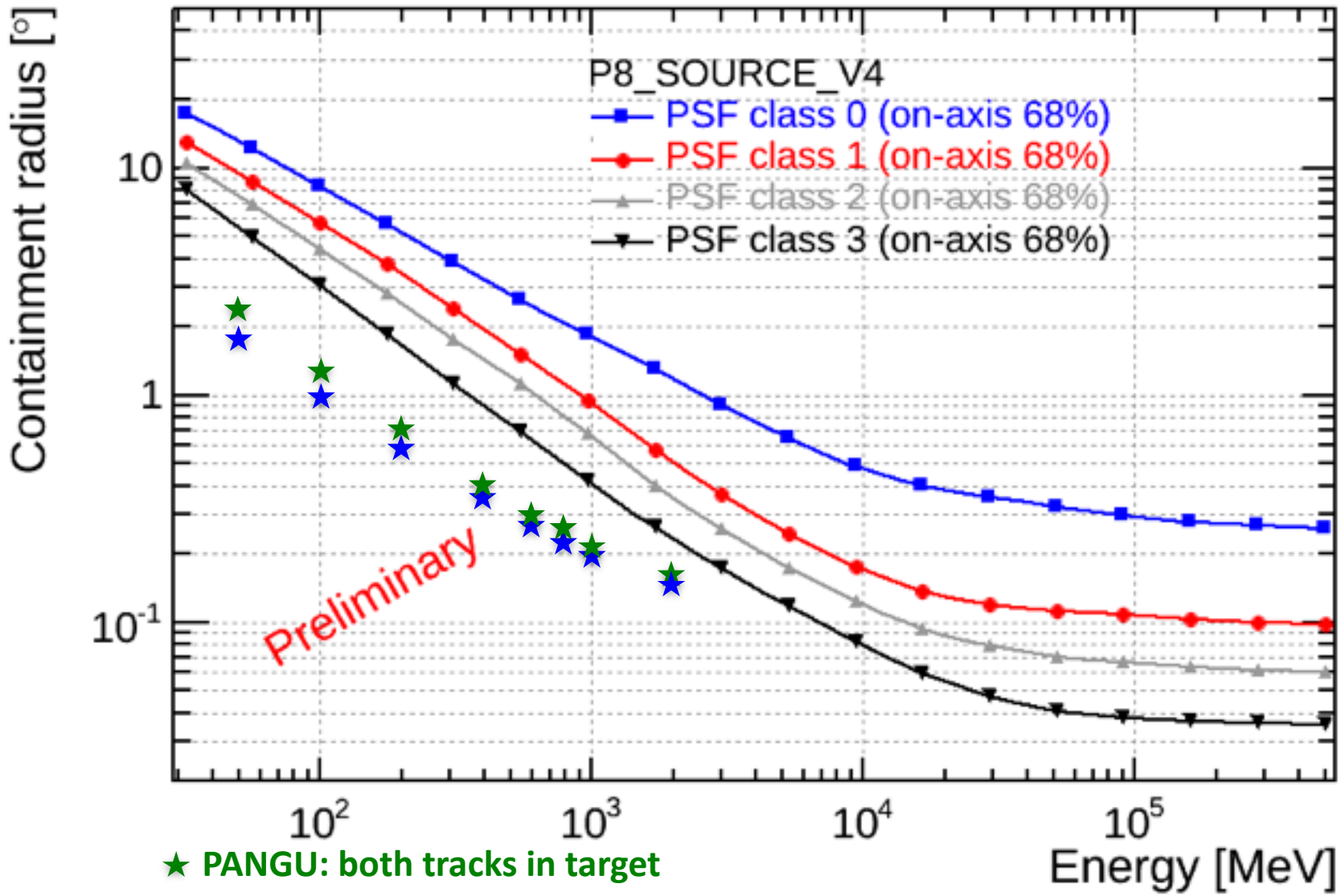
★ PANGU: both tracks in spectrometer

- Geant4 simulation with 150 µm thick single-sided Si detector, 242 µm pitch
  - ⟹ position resolution ~70 µm
- Results are preliminary

Very limited energy measurement if no tracks in spectrometer

- indication of energy with opening angle and dE/dx in tracker

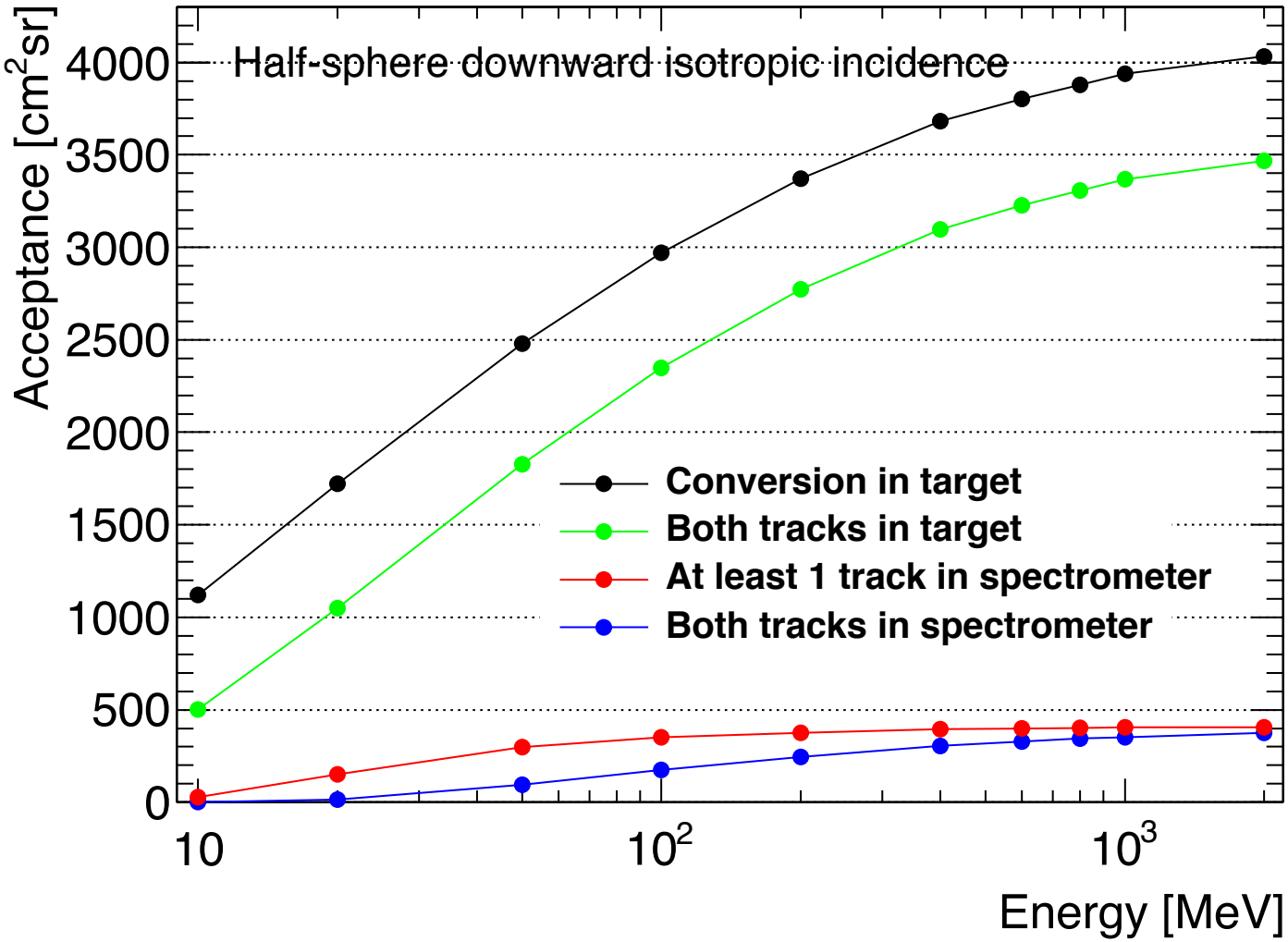
PSF Comparison with Fermi Pass 8



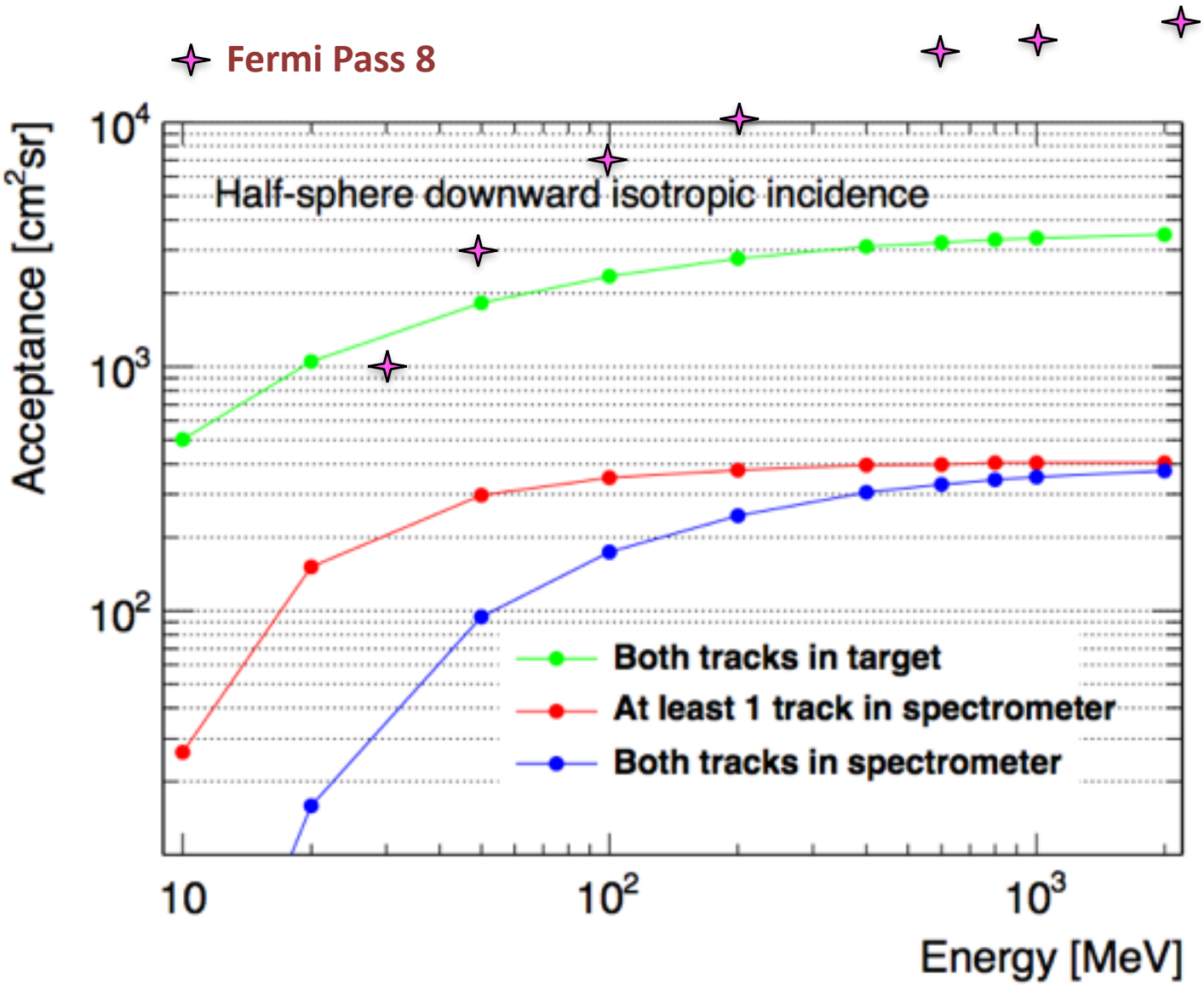
★ PANGU: both tracks in target

★ PANGU: both tracks in spectrometer

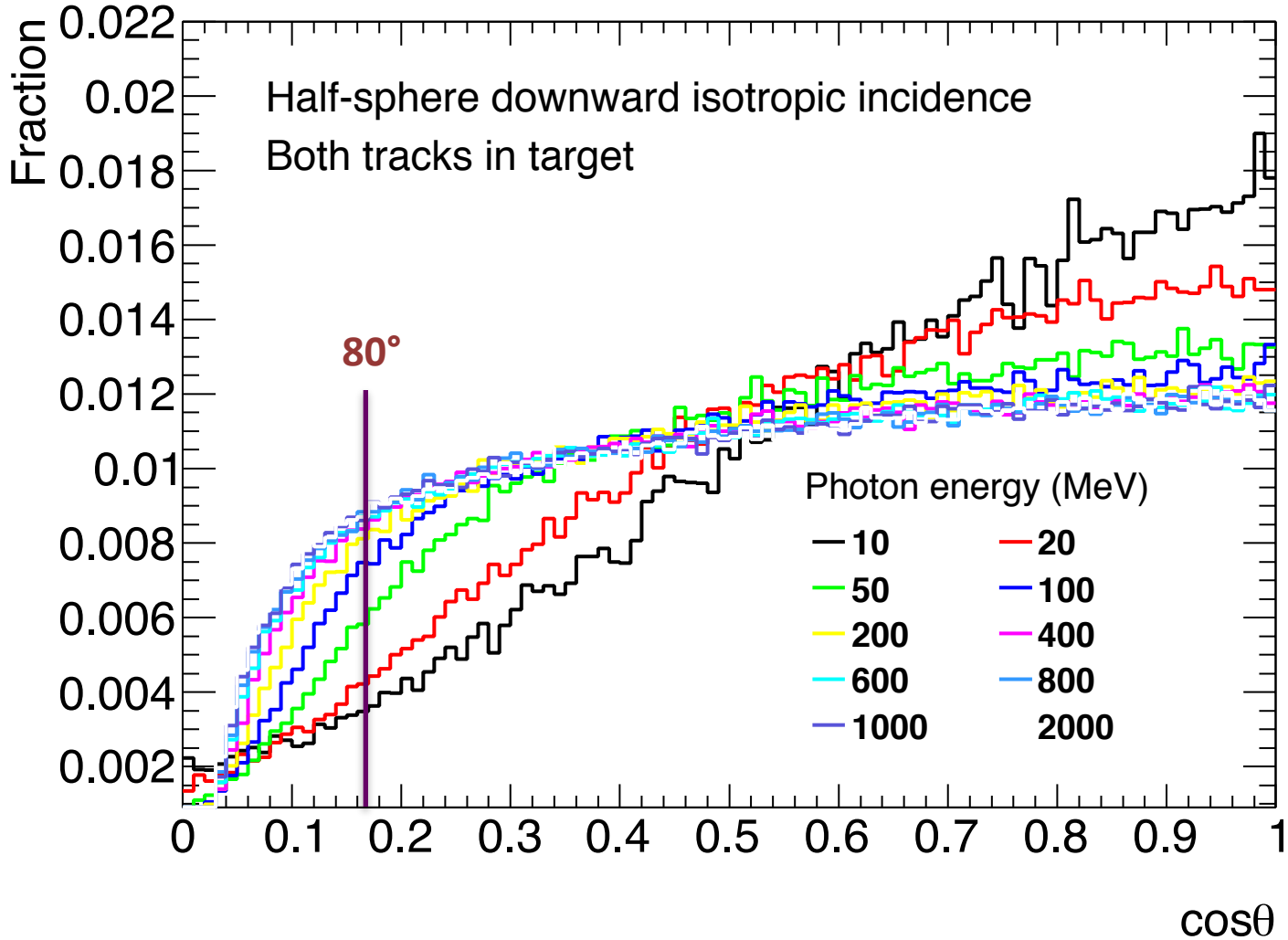
Acceptance


Half-sphere downward isotropic incidence
Acceptance [cm^{2}sr]
4000
3500
3000
2500
2000
1500
1000
500
0
10
10^2
10^3
Energy [MeV]
Conversion in target
Both tracks in target
At least 1 track in spectrometer
Both tracks in spectrometer

Acceptance Compared to Fermi Pass 8



Angular Relative Acceptance

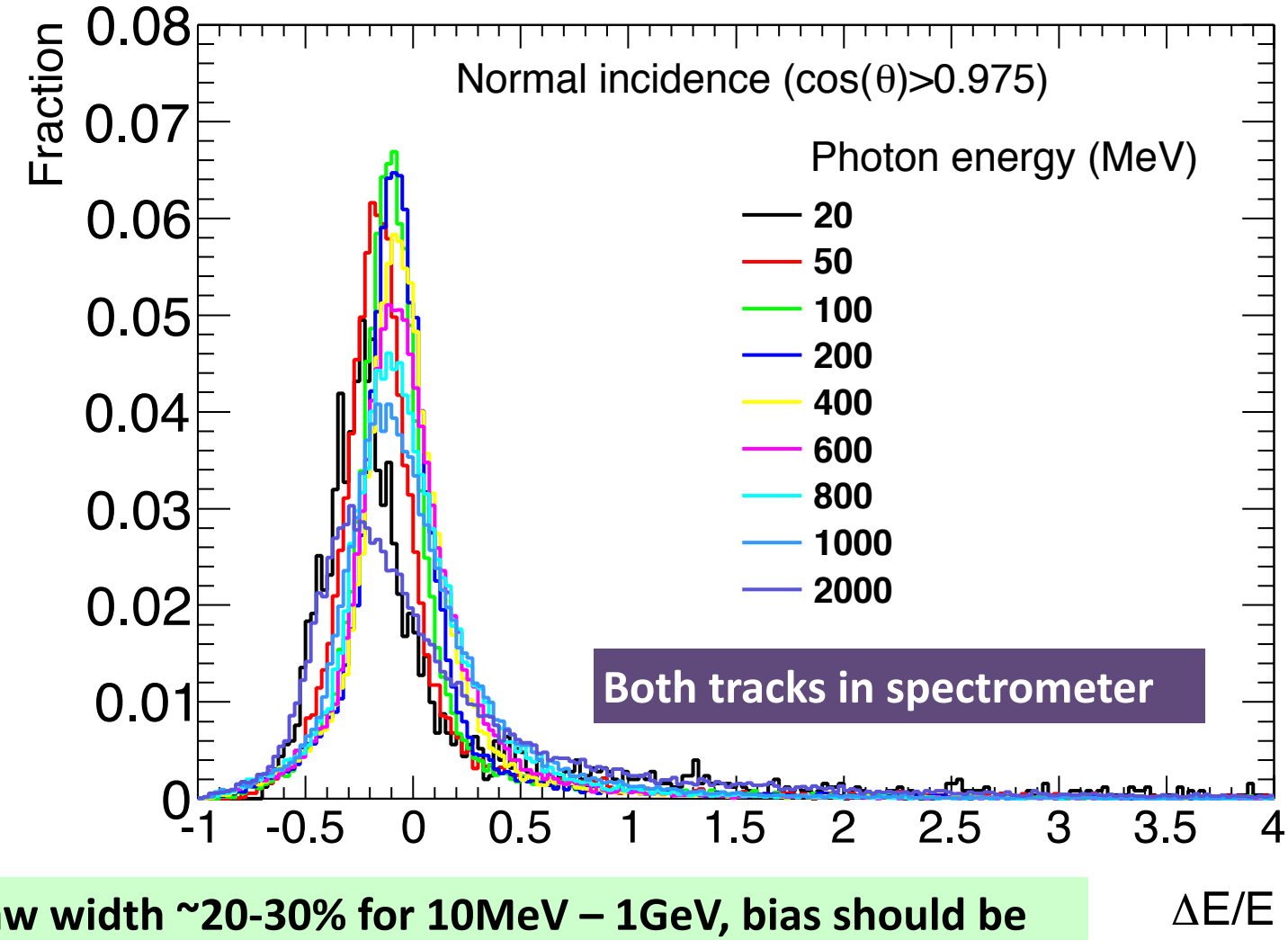


Large FOV for both tracks in target (limited energy measurement)

How about the energy measurement?

- Standard way is to use a calorimeter under the tracker
  - Eg. AGILE mini-calorimeter, CsI, $1.5X_0$, 37.5x37.5x3 cm^3, ~30 kg total, ~20kg active
    - Limited energy resolution ~70% at 100 MeV because of leakage
    - For PANGU (50x50x3 cm^3) would need ~53 kg for calorimeter
  - Eg. GAMMA-LIGHT calorimeter (50x50x4.5 cm^3) $\Longrightarrow$ ~80 kg total
  - Calorimeter not optimal if payload < 100 kg
- The PANGU approach: magnetic spectrometer with permanent magnet
  - Magnet below the tracker-target (light-weight configuration)
    - Magnet can be independently optimized
    - But limited FOV
  - Complication
    - Need to minimize stray field and shield sensitive satellite equipment

Energy Resolution

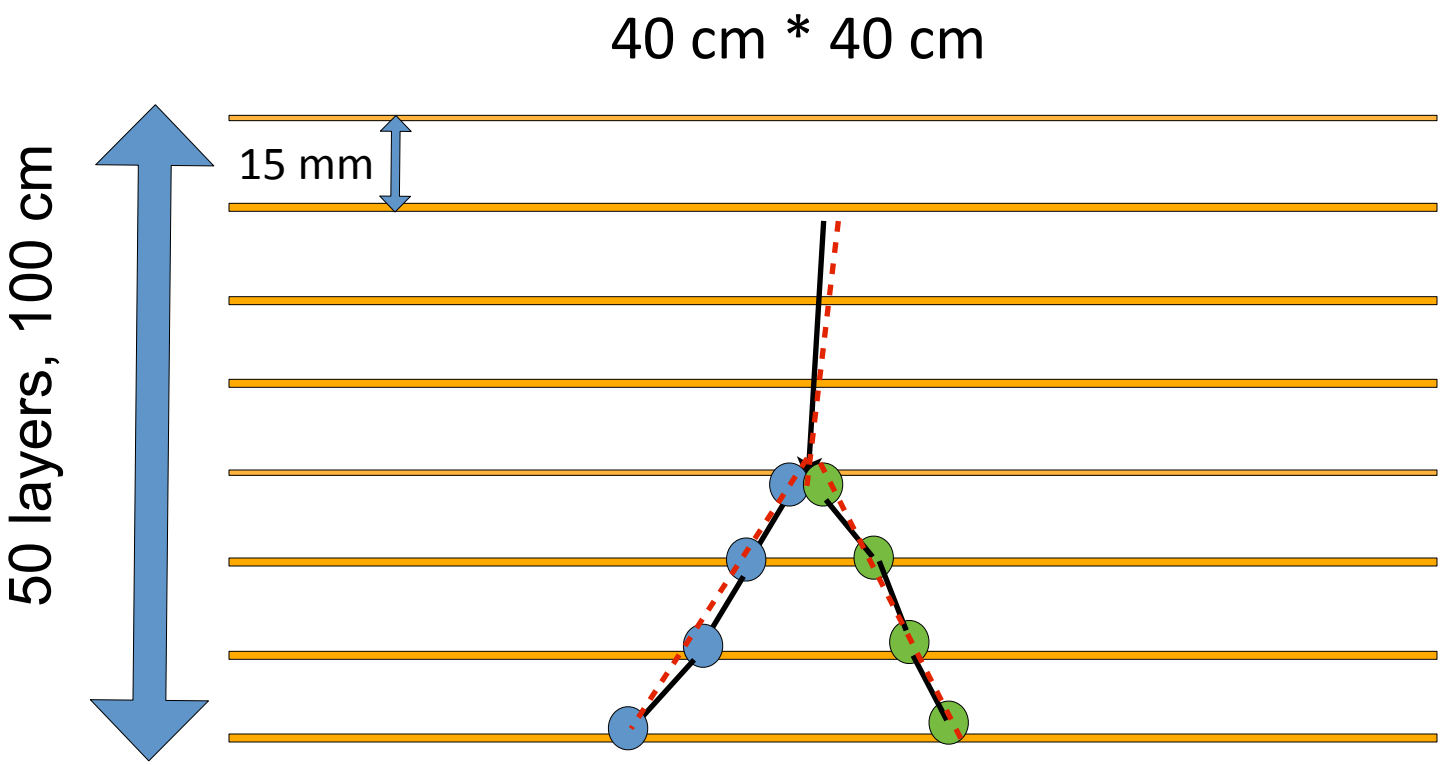


Raw width ~20-30% for 10MeV – 1GeV, bias should be corrected, e.g.. with energy measured in tracker

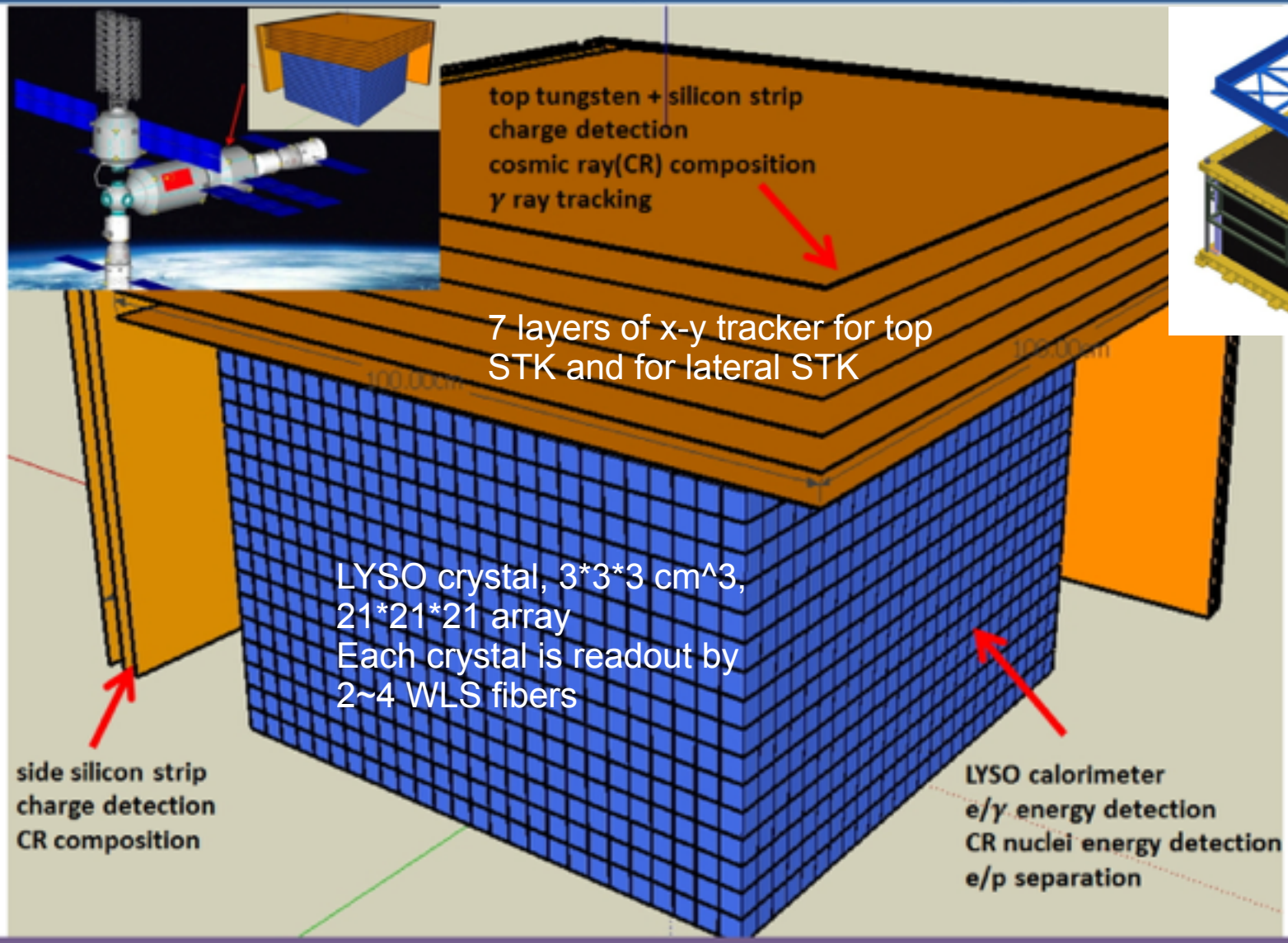
Scientific Objectives: highlights

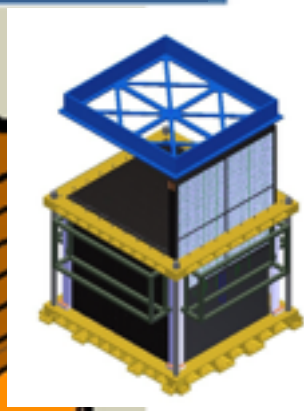
- Precise mapping of the gamma-ray sky at sub-GeV with high angular resolution
- Origin and acceleration of high energy cosmic rays
- Indirect dark matter search
- First detection of sub-GeV polarization
- Full-sky monitoring of a variety of soft gamma-ray transients (GRB/AGN/Solar flare/Terrestrial)
- Synergic multi-wavelength campaign
- Lorentz invariance/Baryon asymmetry in early universe

NOW: A tracker-only payload



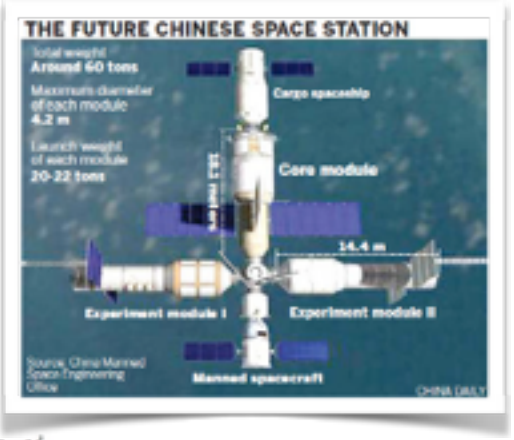
Pathfinder for HERD





Silicon-Tungsten Tracker + LYSO Calorimeter

Beam test at CERN this year!



~2020

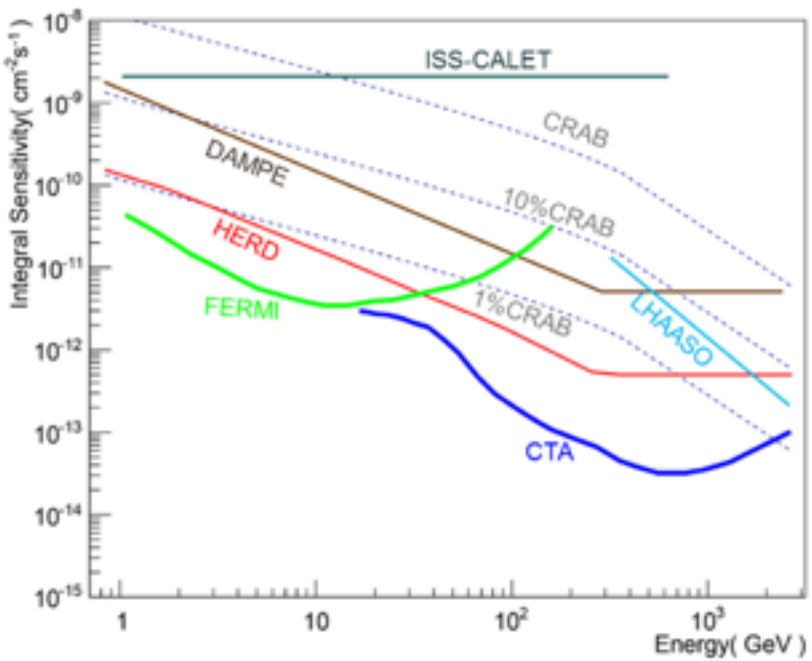
The High Energy cosmic-Radiation Detection (HERD) Facility onboard China's Future Space Station

S.N. Zhang[a], O. Adriani[p,q], S. Albergo[t], G. Ambrosi[r], Q. An[e], T.W. Bao[a], R. Battiston[r,s], X.J. Bi[a], Z. Cao[a], J.Y. Chai[a], J. Chang[c], G.M. Chen[a], Y. Chen[f], X.H. Cui[i], Z.G. Dai[f], R. D'Alessandro[p,q], Y.W. Dong[a], Y.Z. Fan[c], C.Q. Feng[e], H. Feng[h], Z.Y. Feng[a], X.H. Gao[d], F. Gargano[o], N. Giglietto[o], Q.B. Gou[a], Y.Q. Guo[a], B.L. Hu[d], H.B. Hu[a], H.H. He[a], G.S. Huang[c], J. Huang[a], Y.F. Huang[f], H. Li [a], L. Li[a], Y.G. Li[a], Z. Li[g], E.W. Liang[l], H. Liu[a], J.B. Liu[e], J.T. Liu[a], S.B. Liu[e], S.M. Liu[c], X. Liu[a], J.G. Lu[b], M.N. Mazziotta[o], N. Mori[p,q], S. Orsi[v], M. Pearce[w], M. Pohl[u], Z. Quan[a], F. Ryde[w], H.L. Shi[a], P. Spillantini[p,q], M. Su[x,y], J.C. Sun[a], X.L. Sun[b], Z.C. Tang[a], R. Walter[v], J.C. Wang[j], J.M. Wang[a], L. Wang[d], R.J. Wang[a], X.L Wang[e], X.Y. Wang[f], Z.G. Wang[b], D.M. Wei[c], B.B. Wu[a], J. Wu[n], X. Wu[a], X.F. Wu[c], J.Q. Xia[a], H.L. Xiao[a], H.H. Xu[a], M. Xu[a], Z.Z. Xu[c], H.R. Yan[g], P.F. Yin[a], Y.W. Yu[m], Q. Yuan[a], M. Zha[a], L. Zhang[k], L. Zhang[a], L.Y. Zhang[a], Y. Zhang[a], Y.J. Zhang[a], Y.L. Zhang[c], Z.G. Zhao[c]

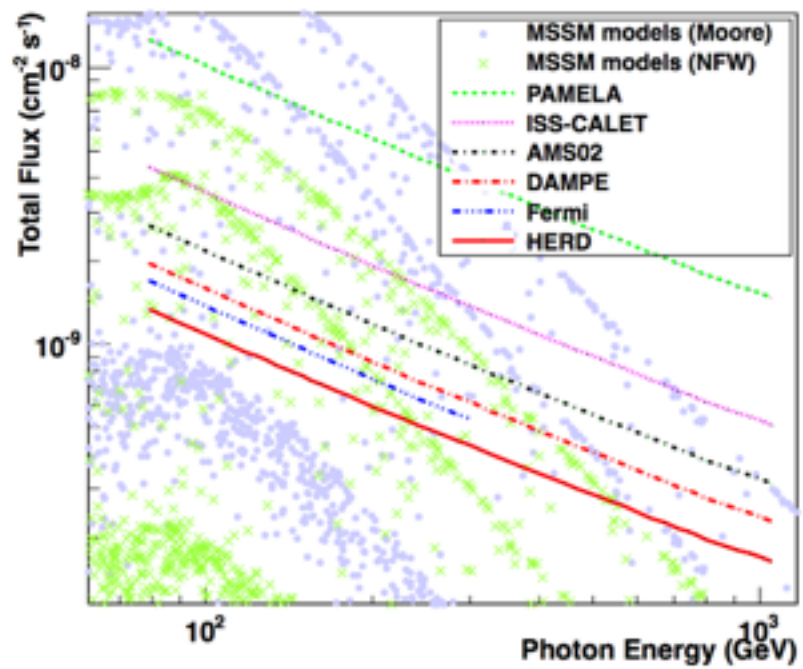
Science Group	First Leader	Second Leader
Gamma-ray astronomy	Meng Su	Roland Walter
Dark Matter search	M.Nicola Mazziotta	Qiang Yuan
Cosmic-ray astrophysics	Xiaojun Bi	Mark Pearce

SPIE proceeding: arXiv:1407.4866

Expected gamma-ray sky sensitivity of HERD



HERD 5σ continuum sensitivity for one year observation in comparison with all other missions with gamma-ray observation capability

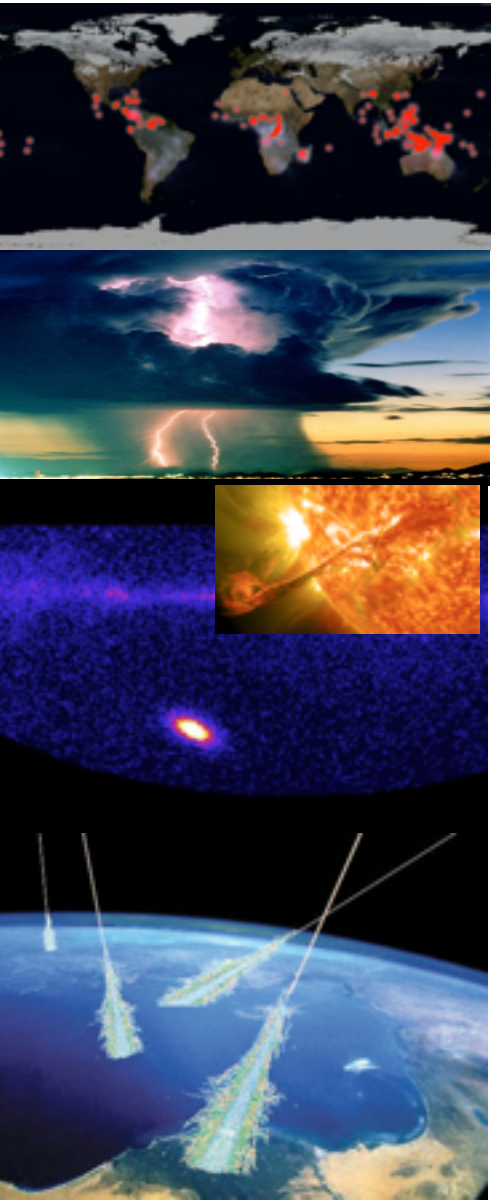


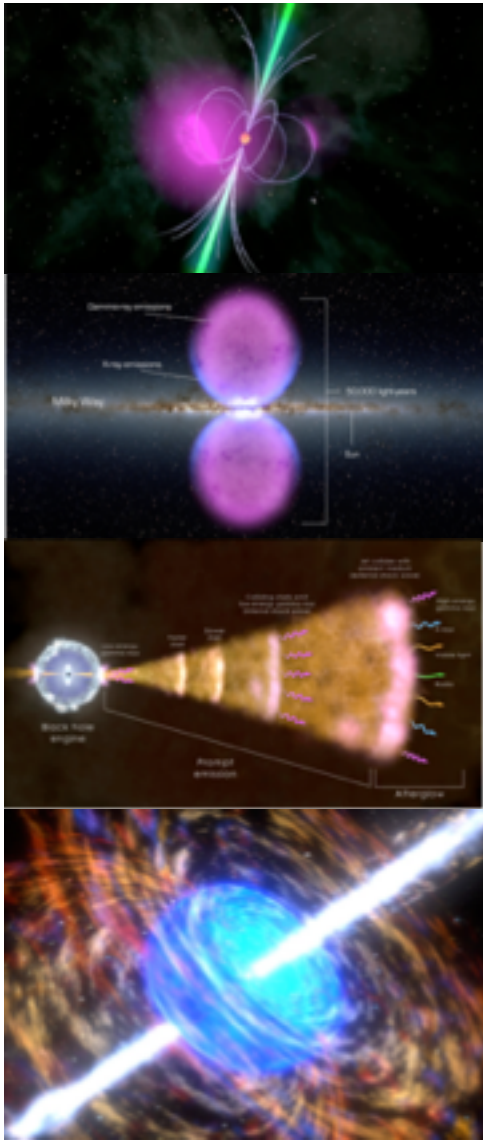
HERD one-year 5σ line sensitivity in comparison with predictions of different dark matter models

Conclusions

- **PANGU is an *unique and timely opportunity* for high energy astrophysics. It will resolve and monitoring the sub-GeV sky with unprecedented spatial resolution, separating diffuse gamma-ray emission from point sources**
  - **PANGU science is not "incremental science", it will lead to fundamental discoveries and understanding.**
- **PANGU is synergic with DAMPE, HERD, CTA, Gamma-400 and other ground-based and space detectors (e.g., radio, optical, X-ray, TeV, gravitational wave experiments)**
- **Payload concept is innovative but the technology is ready**
  - **TRL6-7 for silicon tracker**
  - **TRL5 for scintillating fiber tracker**

Thank You!





Welcome to join!