# PANGU

# 盘古

## A High Resolution Gamma-Ray Space Telescope

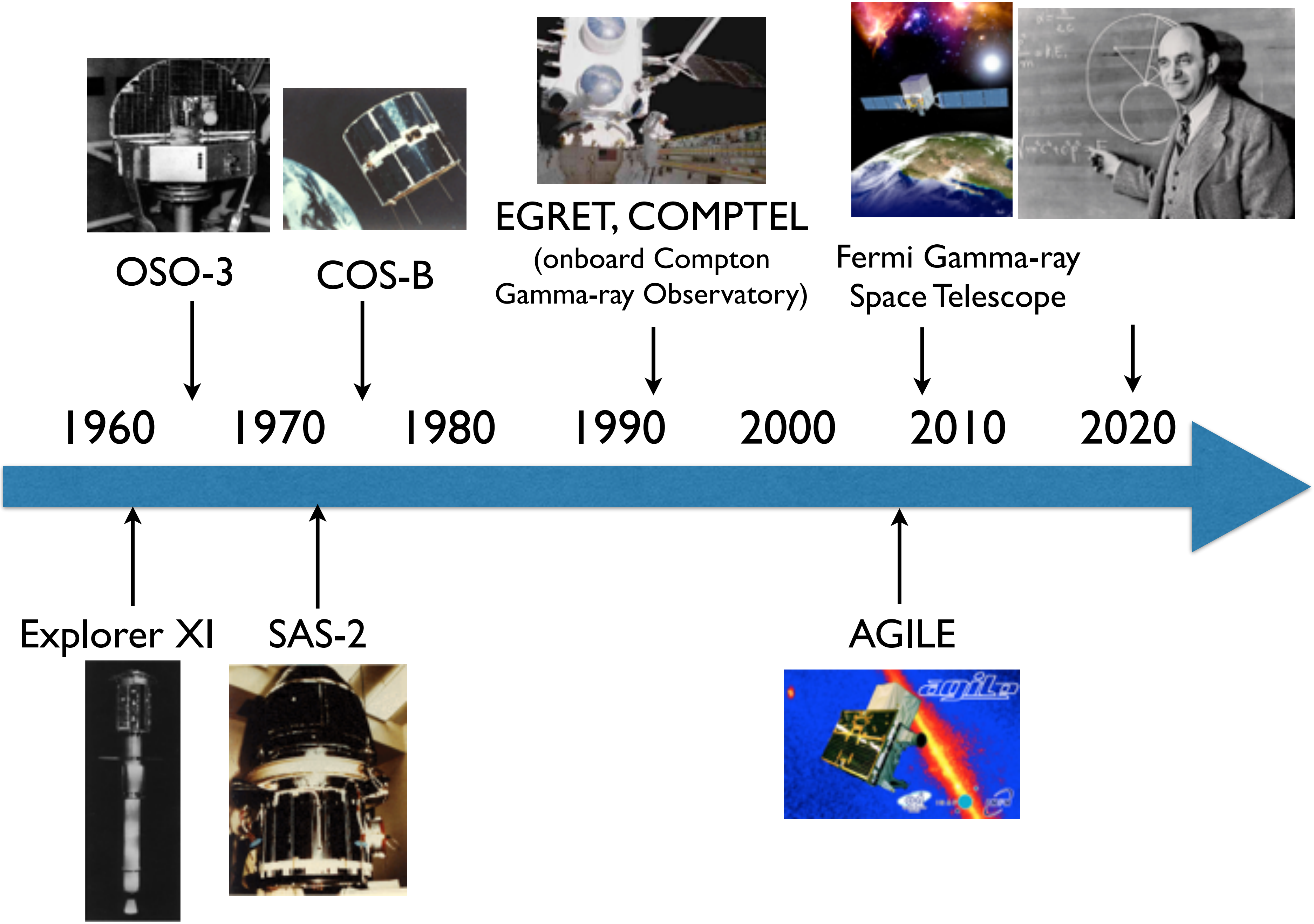

**Meng Su**

**On behalf of the PANGU collaboration**

**Pappalardo/Einstein fellow**
**MIT**


KIAA-WAP

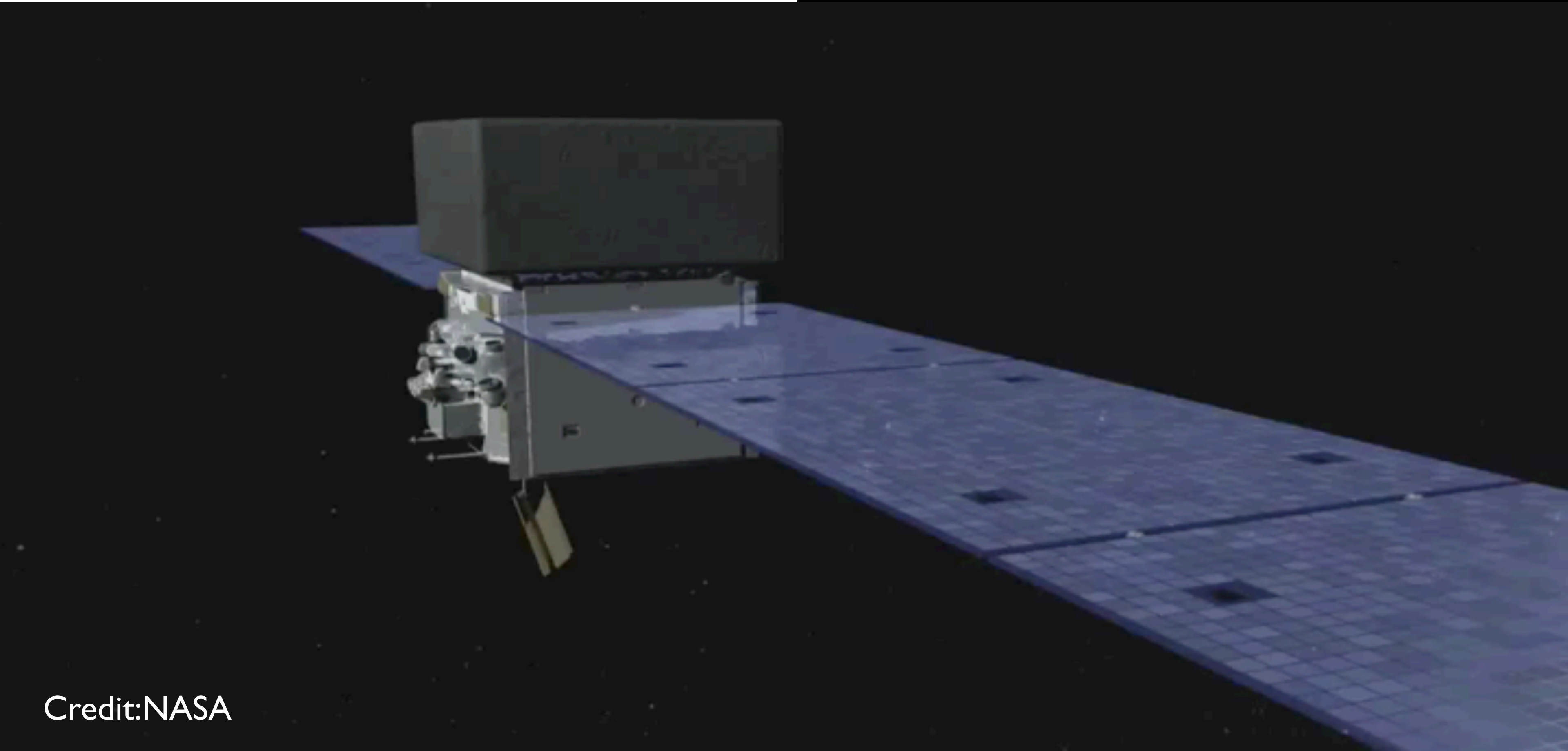
Sept. 30th, 2015


OSO-3
COS-B
EGRET, COMPTEL
(onboard Compton
Gamma-ray Observatory)
Fermi Gamma-ray
Space Telescope
1960
1970
1980
1990
2000
2010
2020
Explorer XI
SAS-2
AGILE

- ‘A Particle Physics Detector in Space’


Credit:NASA

# Launch of Fermi Gamma-ray Space Telescope (June 2008)!



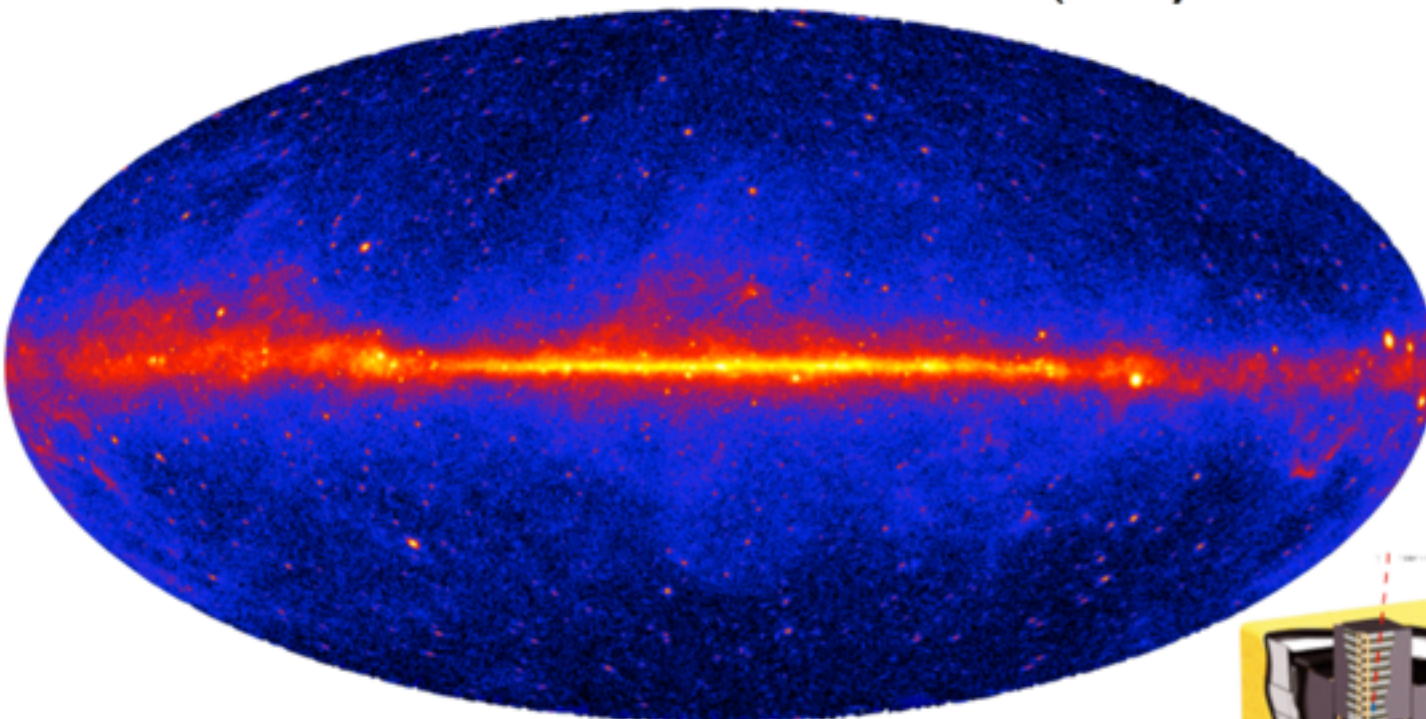
Credit:NASA

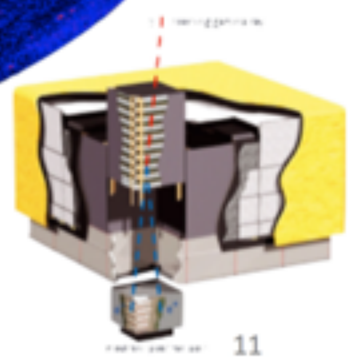
# Fermi-LAT (2008-2018?)

(>1GeV)

~> 3000 gamma-ray sources

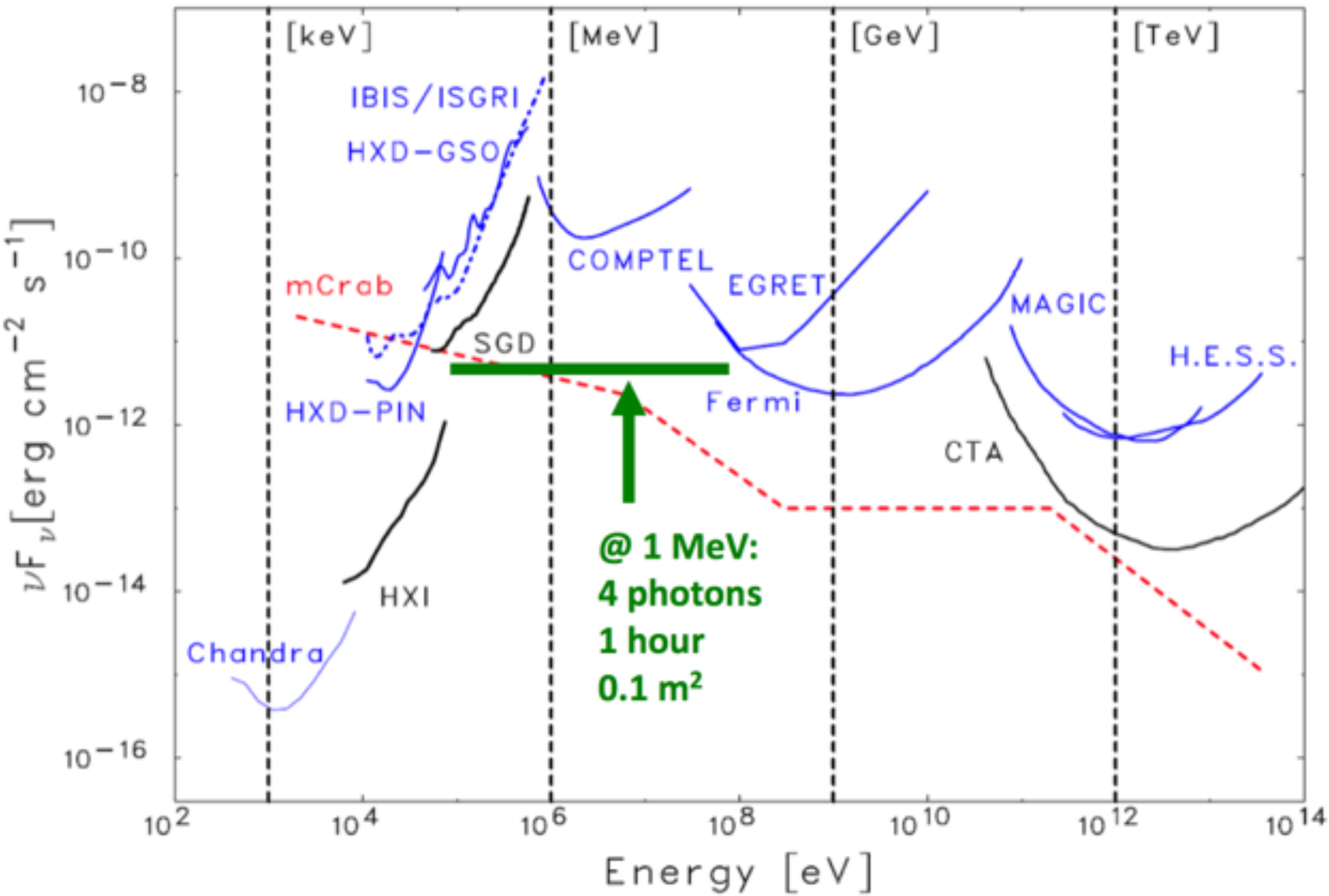
(~15 yrs after EGRET)






**Space-borne gamma-ray instruments on the timescale of 2008+15 ~2020 (post-Fermi era)?**

# Motivation: Sensitivity of current and previous instruments



# Sub-GeV is NOT improved by any future mission

- Planned instruments focus on "high energy end" of cosmic-ray/ gamma-ray spectrum (DAMPE, HERD, Gamma-400)
  - ~100 GeV (gamma-ray)
  - ~TeV (electron)
  - ~PeV (proton/nucleus)

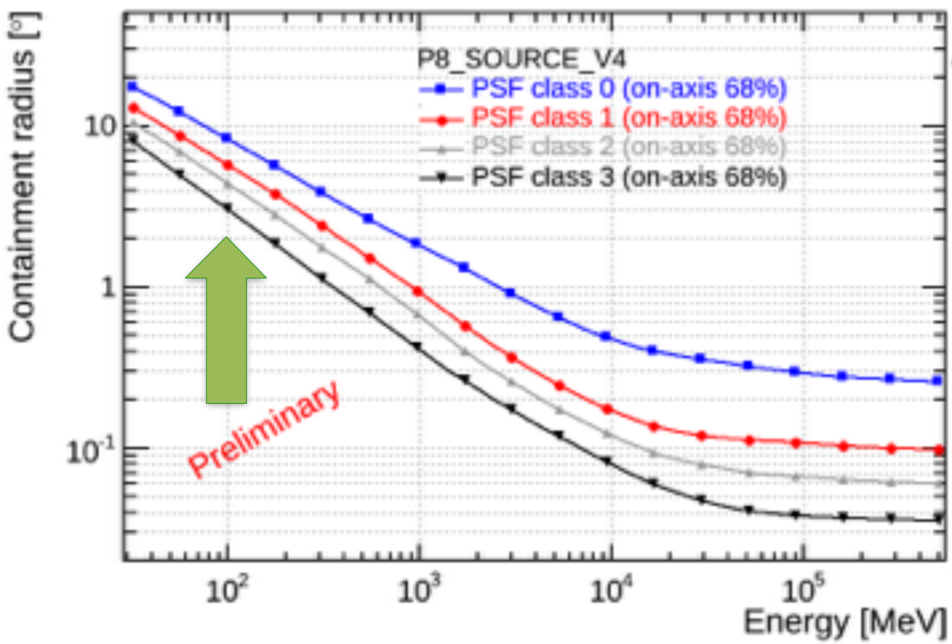
**NO planned missions to improve ~<GeV observations, a poorly covered energy domain**

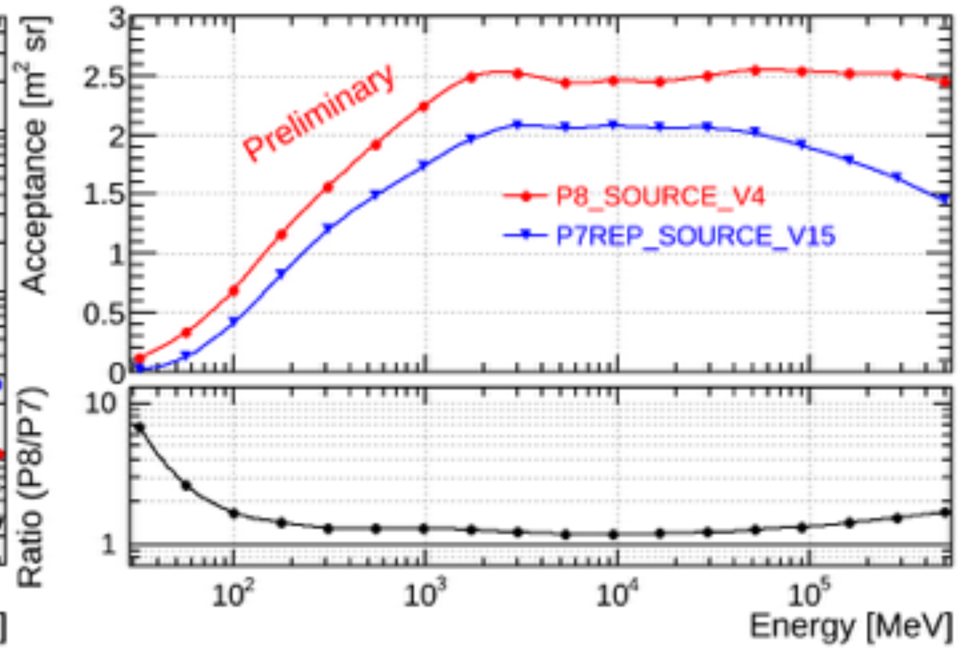
**PANGU can fill this gap with a small mission!**

# Sub-GeV Gamma Ray Detection

- 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**

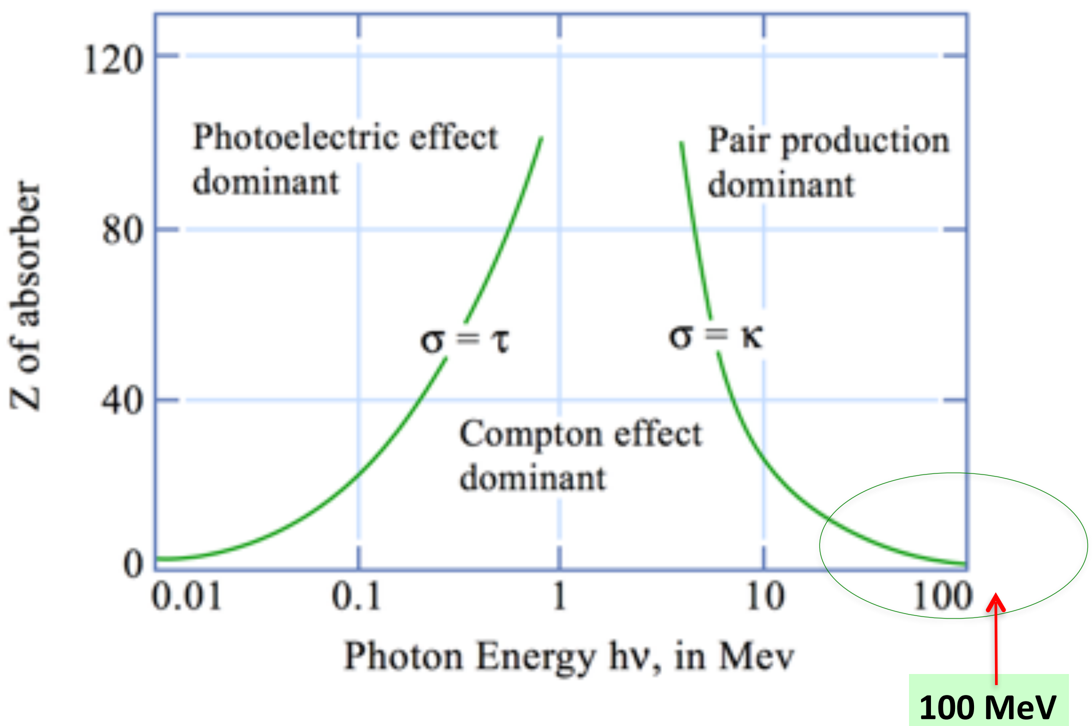


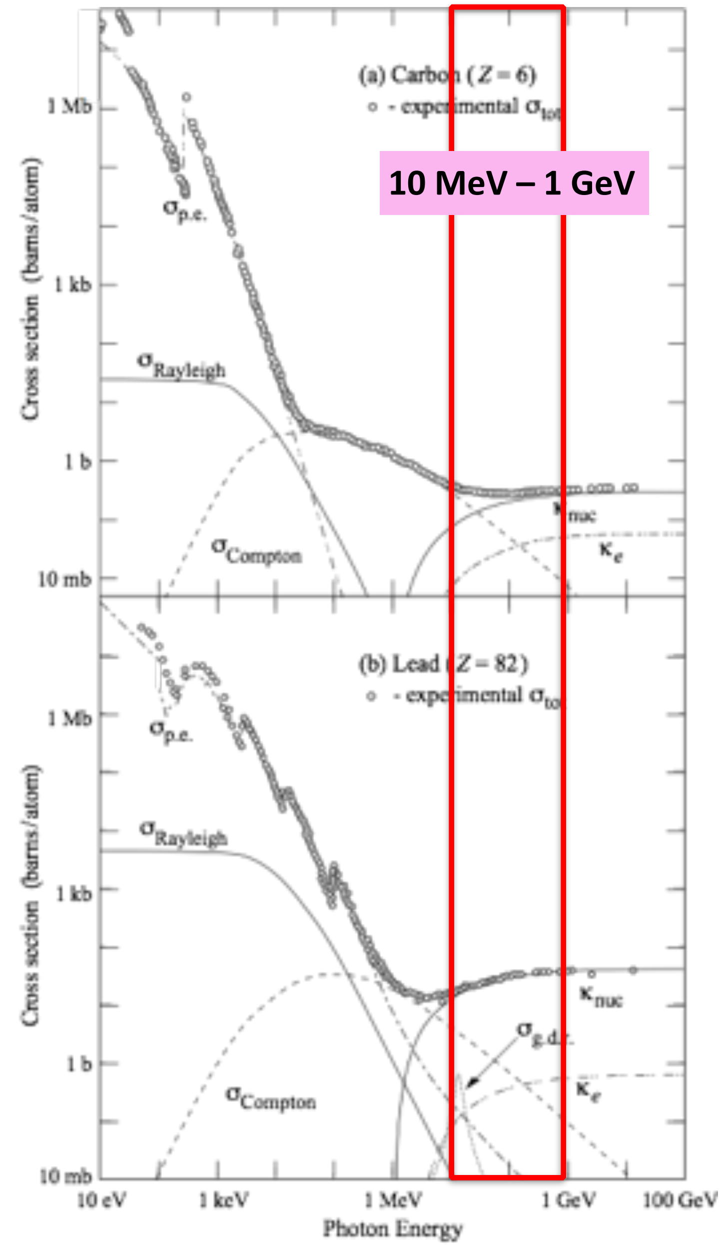




**How to improve?**

# 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**



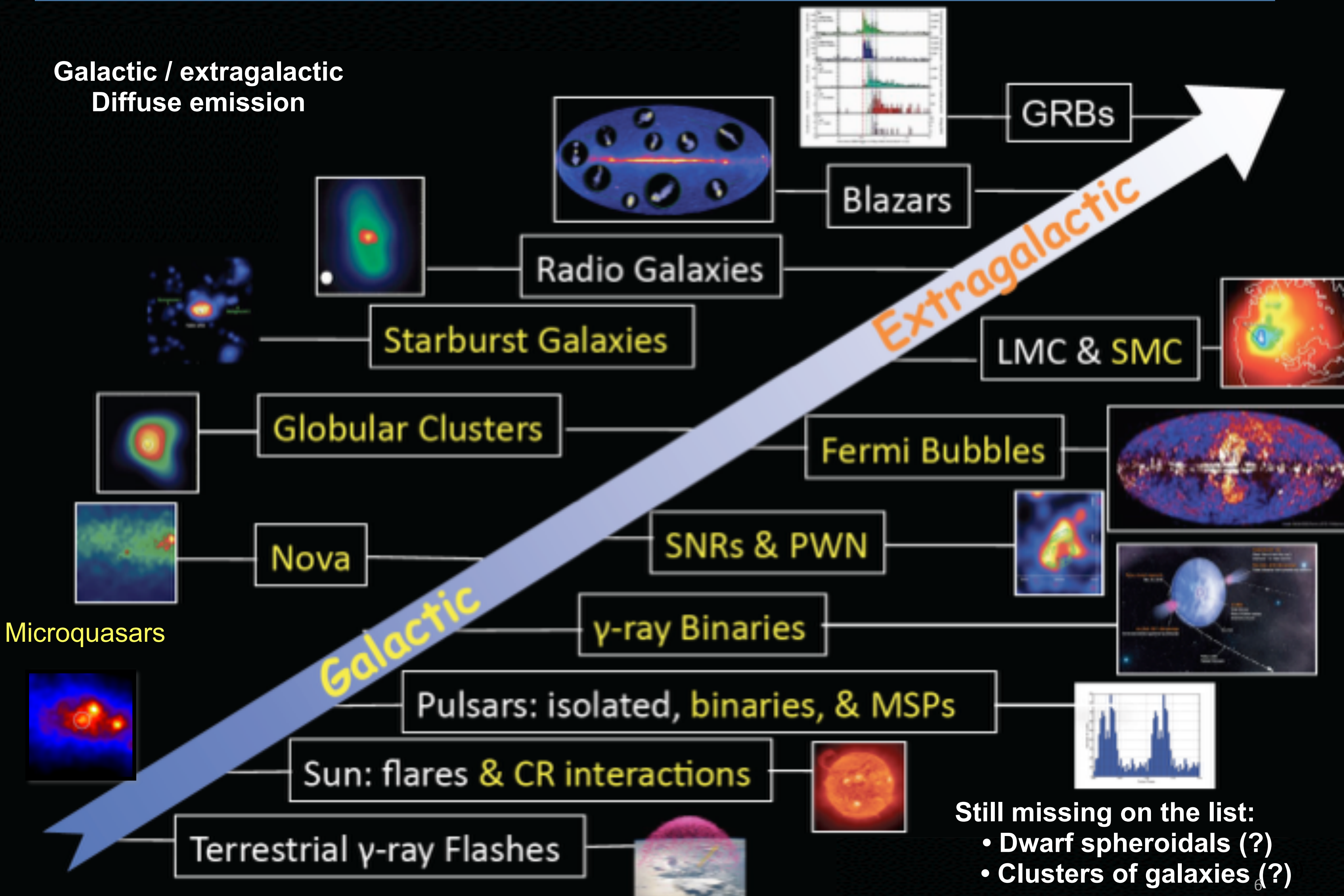
# What can we learn?

1. **Galactic and extragalactic cosmic rays**

2. **Particle acceleration in compact objects**

**3 Cosmology and fundamental physics**

# The sub-GeV sky is rich!




**Still missing on the list:**
- **Dwarf spheroidals (?)**
- **Clusters of galaxies (?)**

# PANGU
# 盤古

盤古氏

*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**





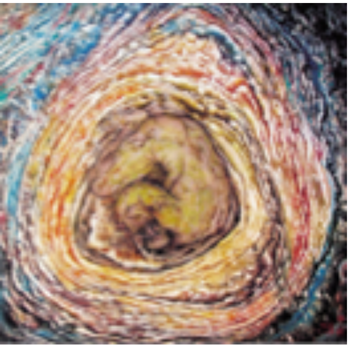


# What does PANGU mean to me?

**PAir productioN Gamma-ray Unit**

**PANoramic Gamma-ray Unit**

**Polarized ANd Gamma-ray Universe**




**Wu et. al, arXiv:1407.0710**

# Response to the joint call for a space mission from ESA and CAS


## JOINT CALL FOR A MISSION FROM THE CHINESE ACADEMY OF SCIENCES (CAS) AND THE EUROPEAN SPACE AGENCY (ESA)

19 January 2015

**The European Space Agency's (ESA) Directorate of Science and Robotic Exploration (ESA-SRE) and the Chinese Academy of Sciences (CAS) have agreed to jointly pursue a scientific space mission, to be implemented by the ESA Science Programme and the Chinese National Space Science Centre (NSSC) under the CAS. The present Joint Call for Missions solicits proposals for such mission from the scientific communities in the ESA Member States and in China. The proposal submission deadline is 16 March 2015, 12:00 (noon) CET/19:00 Beijing Time.**

It's the first time ESA works with another space agency on a joint mission

# Overview

## PANGU: PAir-productioN Gamma-ray Unit

- Sub-GeV $\gamma$-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
- 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)
- Innovative payload concept for a small mission

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

# PANGU Collaboration

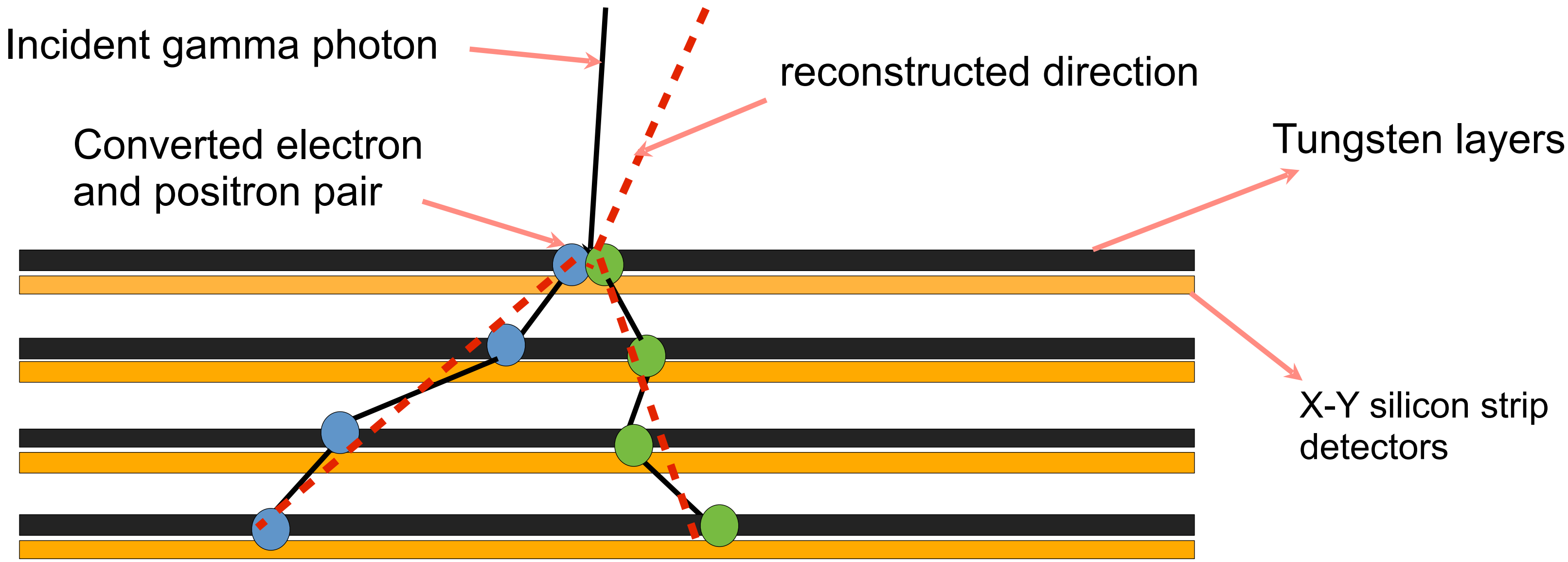
– More than 45 colleagues from 19 different institutes/ universities

– More than 30 colleagues from Switzerland, Italy, Sweden, Germany, France, Ireland, Netherlands, Poland, Spain)

**Strong support from both sides**

SPIE proceeding of PANGU:
Xin Wu et. al,
arXiv:1407.0710 [astro-ph.IM]

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

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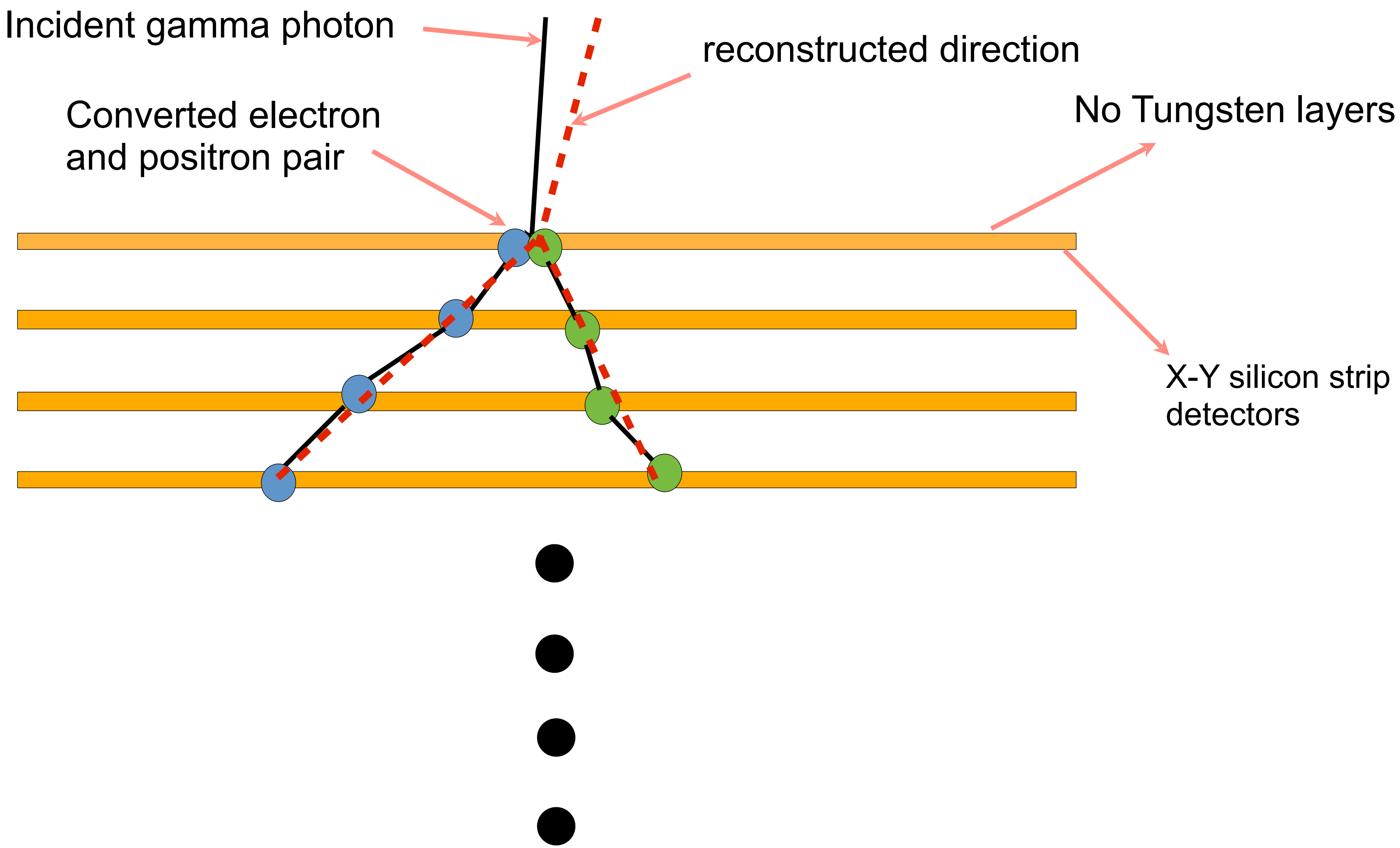
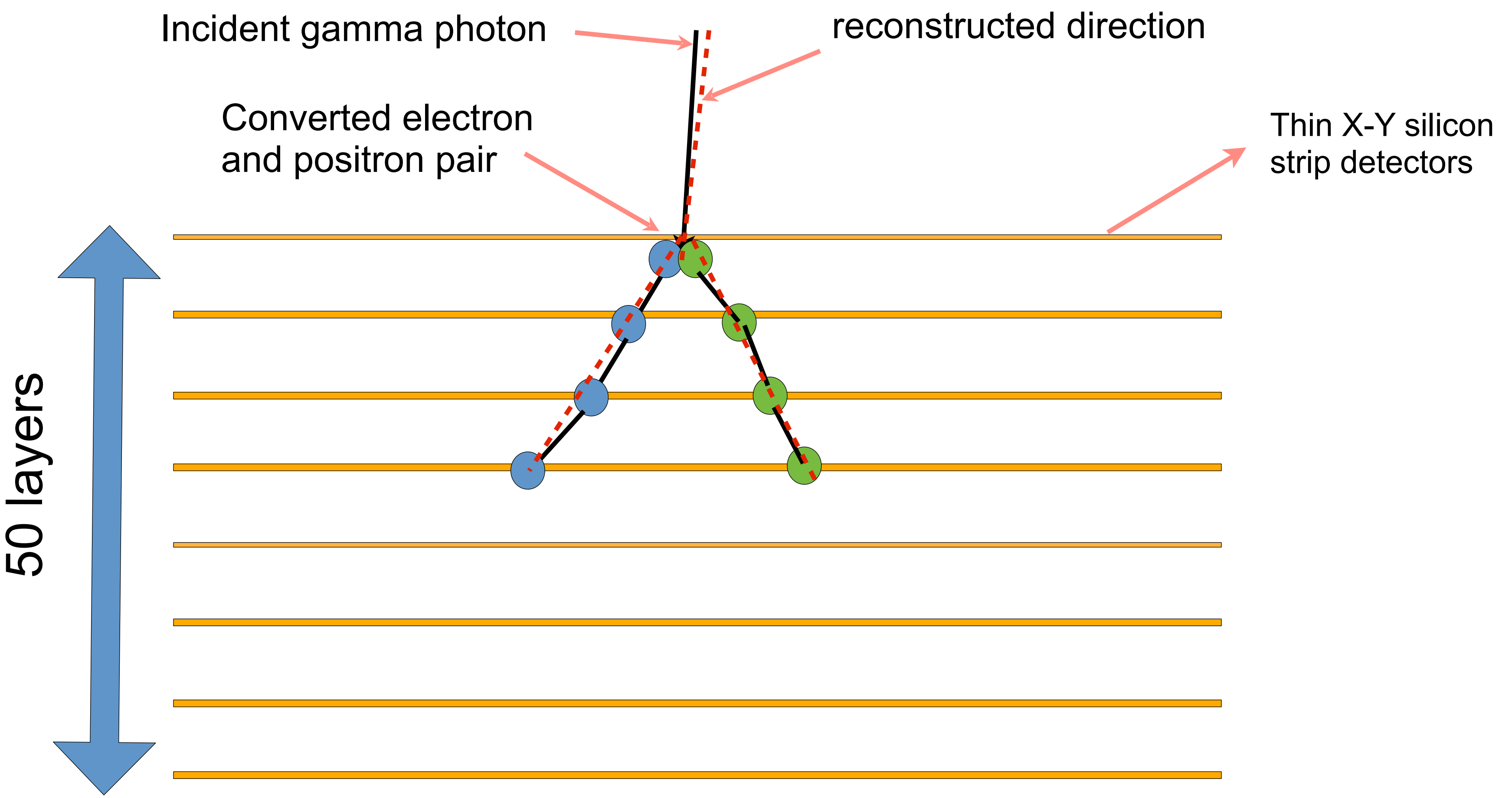
Converted electron/positron pair carries information about the direction, energy and polarization of the gamma-ray photon

# Detection principle:

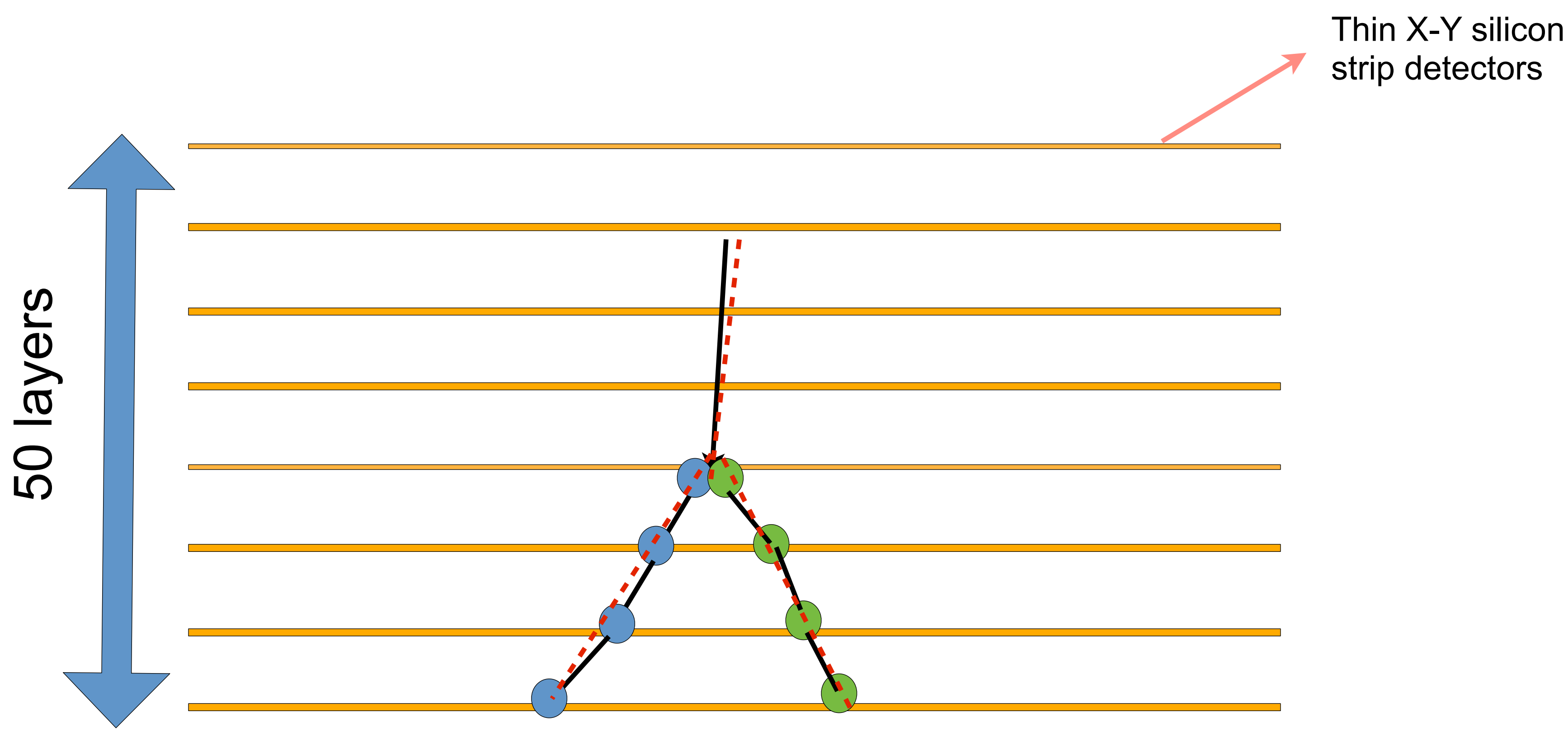
## How PANGU detects gamma-ray photons



# Detection principle:
## How PANGU detects gamma-ray photons



# Detection principle:
## How PANGU detects gamma-ray photons



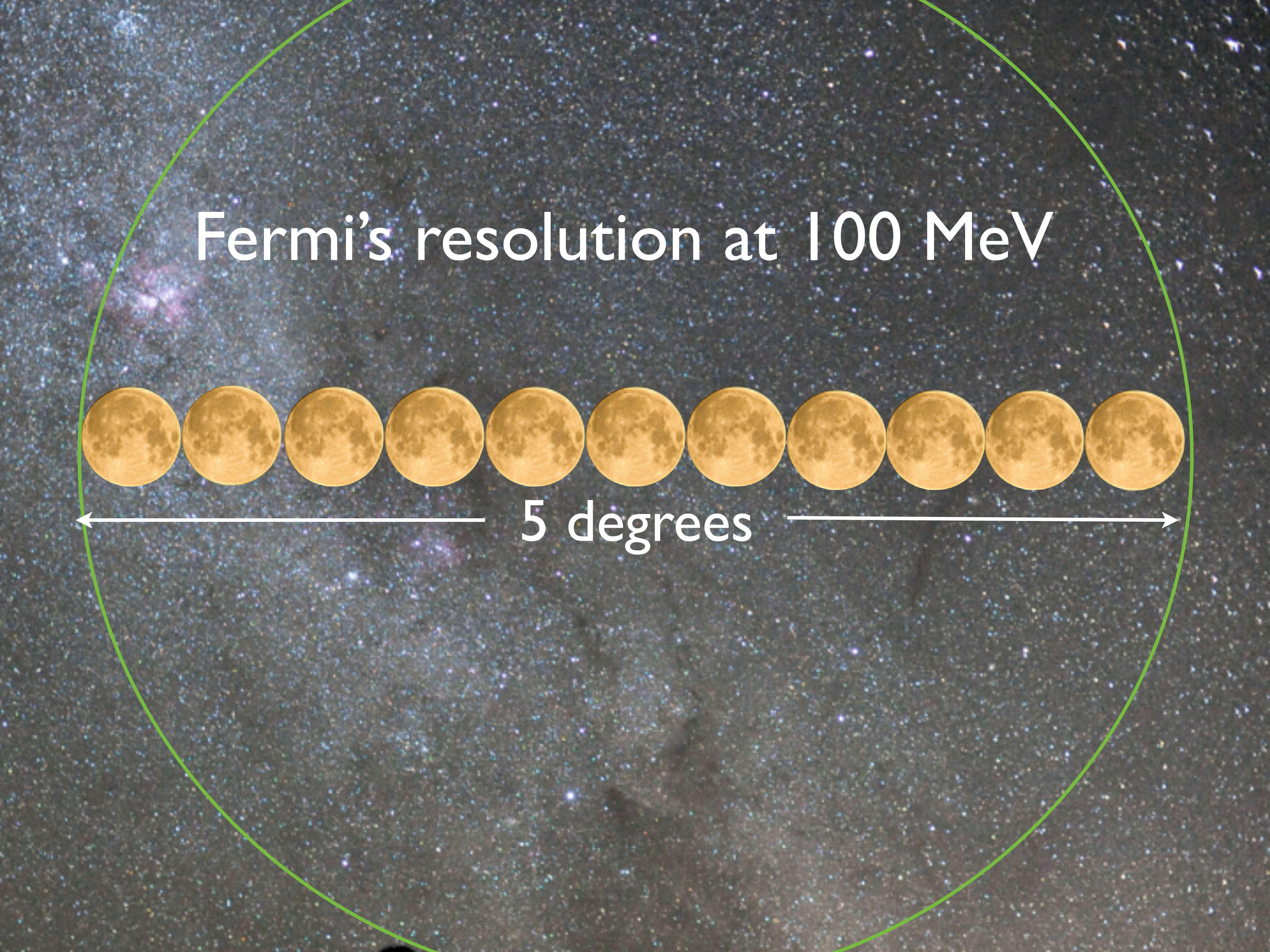
# PANGU v.s. Fermi

4,300 kg

30 MeV 300 MeV 3 GeV 30 GeV 300 GeV

30 MeV 300 MeV 3 GeV 30 GeV 300 GeV


<300 kg (60 kg payload)

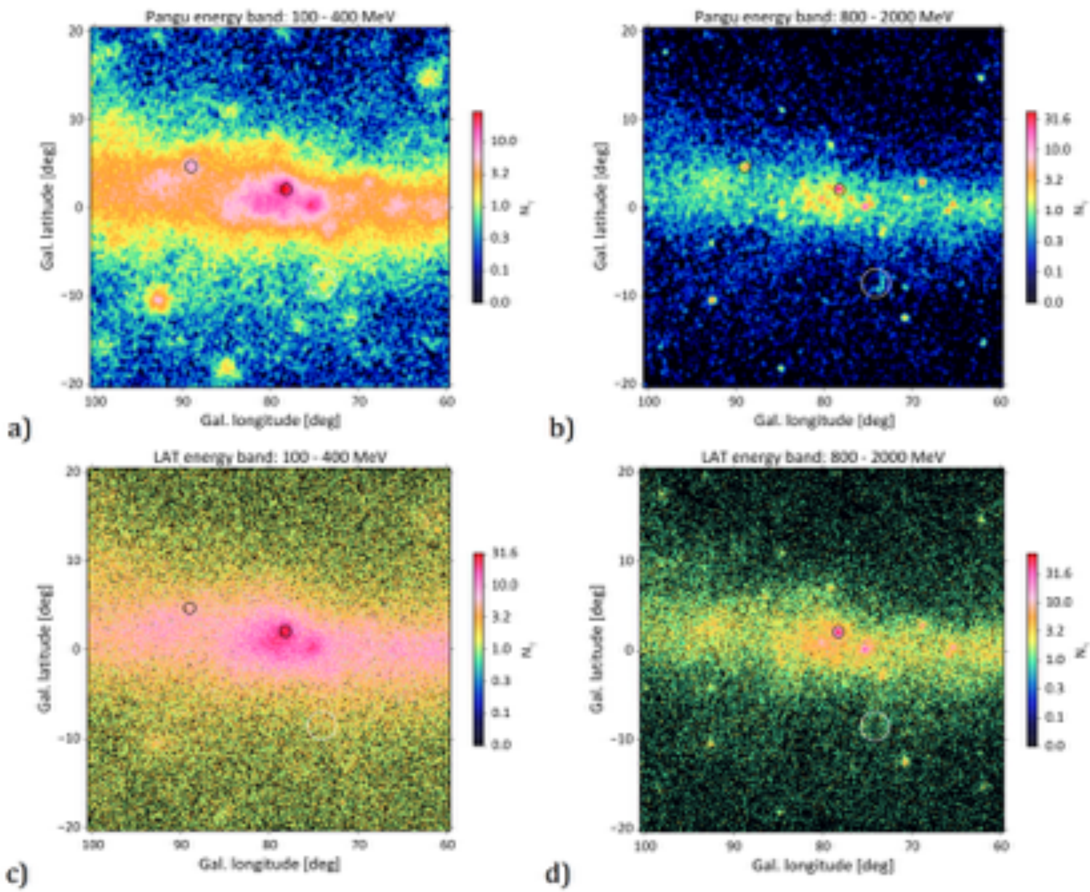

Fermi's resolution at 100 MeV
5 degrees

# PANGU's resolution at 100 MeV

<1 degree

# Comparing PANGU with Fermi

| | 10 – 100 MeV | 100 – 400 MeV | 800 – 2000 MeV |
|---|---|---|---|
| PANGU: | ? | a) | b) |
| Fermi: | X | c) | d) |



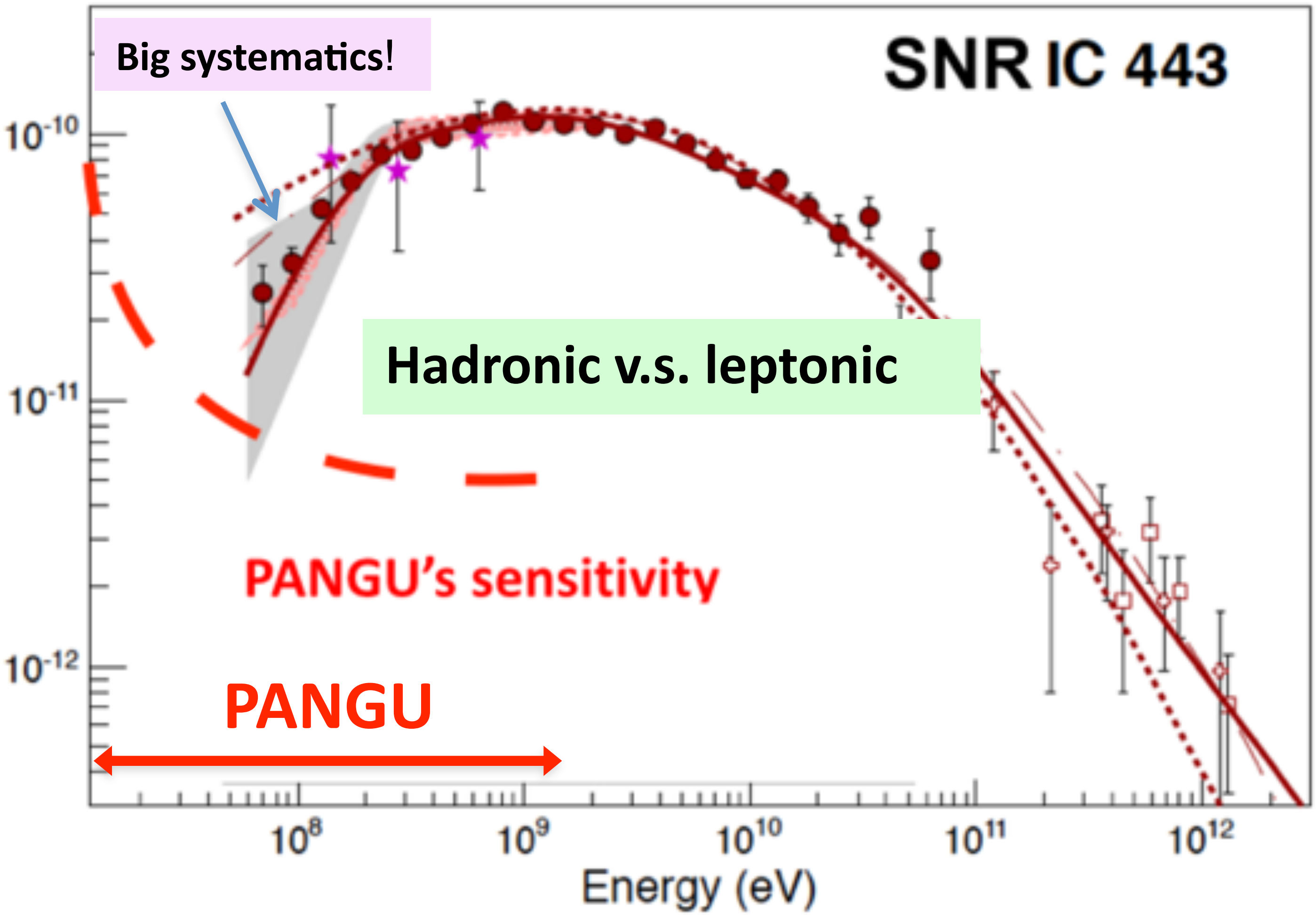
# ESA-CAS joint mission: Timeline

| 1st Announcement posted on web and sent to registered people | 22 November 2013 |
|---|---|
| Deadline for submitting extended abstracts | 20 December 2013 |
| Selection of oral and poster contributions | 10 January 2014 |
| 2nd Announcement posted on web | 30 January 2014 |
| Final Agenda distributed to attendees | 30 January 2014 |
| 1st CAS-ESA Workshop (Chengdu) | 25-26 February 2014 |
| 2nd CAS-ESA Workshop (Copenhagen) | 24-26 September 2014 |
| Joint Call for missions | 19 January 2015 |
| Deadline for proposals | 16 March 2015 |
| Technical and programmatic review | mid-April 2015 |
| Science case review | late April 2015 |
| Selection of mission(s) | May 2015 |
| Study Phase | 2 years |
| Implementation Phase | 4 years |
| Launch | 2021 |

Ranked after a space science mission

# Supernovae Remnants and Particle Acceleration

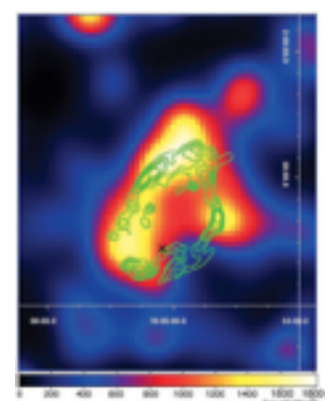
## *Science*'s Top 10 Breakthroughs of 2013!




*Science* 2013, 339, 807

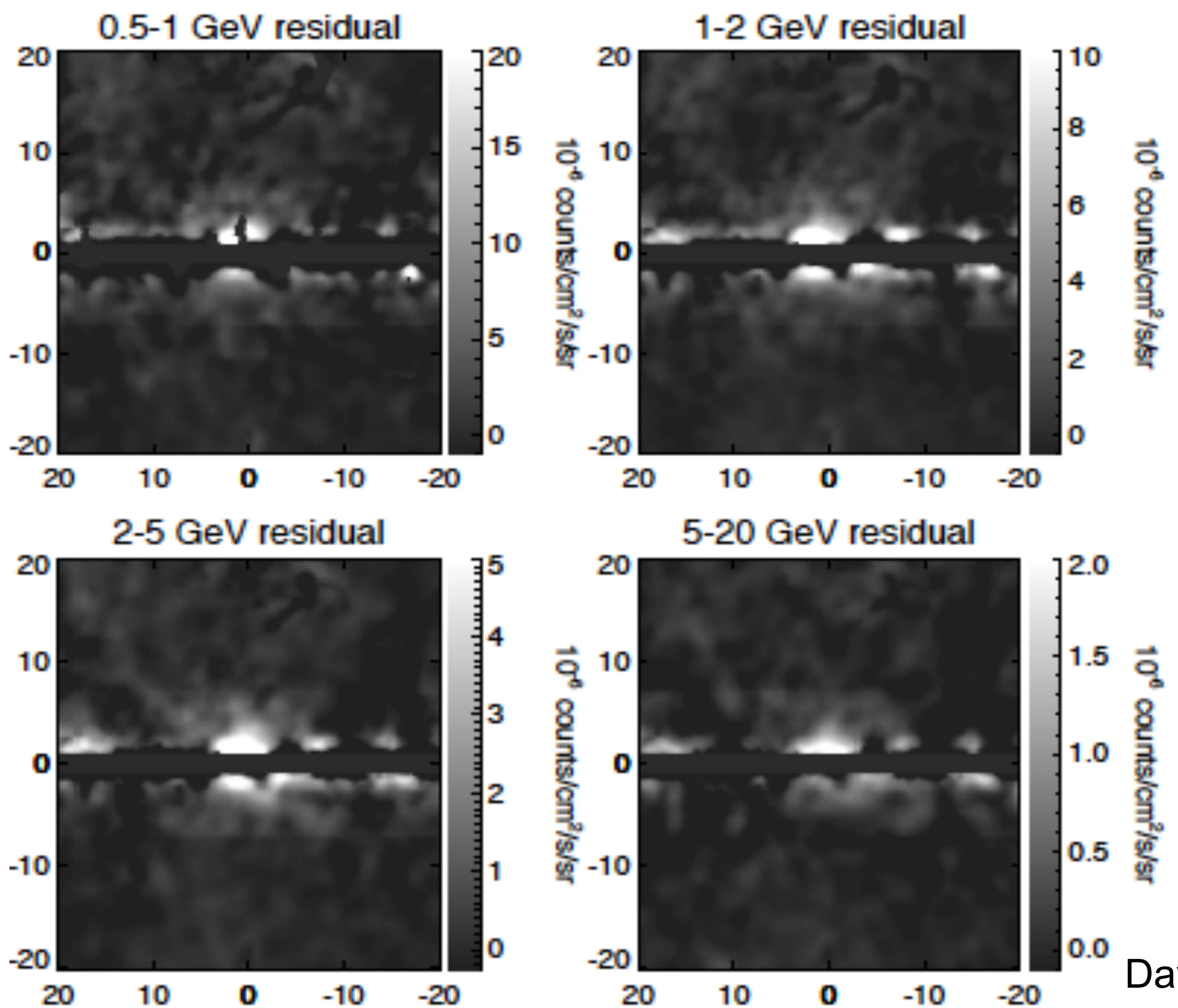
**PANGU will distinguish two scenarios without ambiguity**

**PANGU will detect more supernova remnants with ~5 times better PSF!**



W44
Fermi

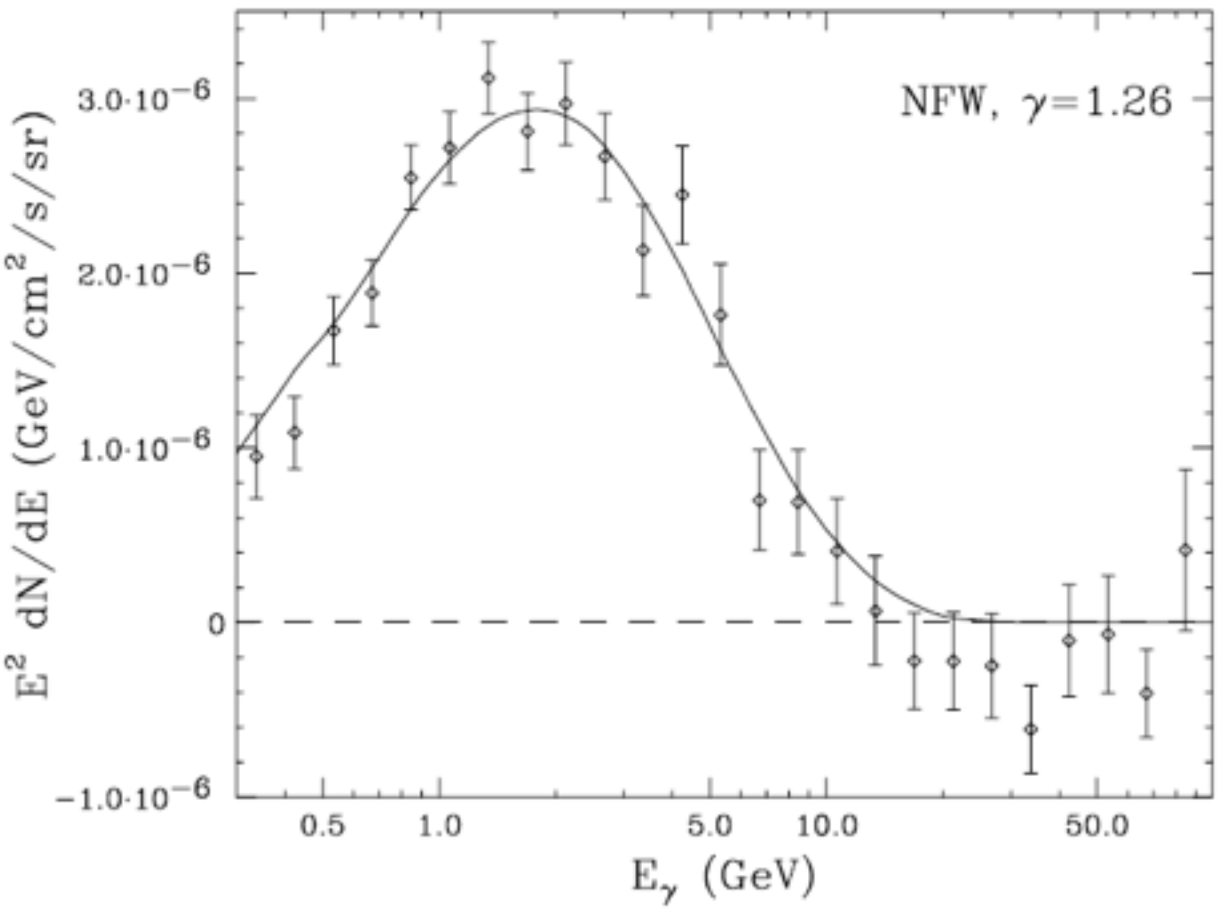
# The "GeV" excess




Daylan et al. (2014)

Zhou et al. (2014)

# Best fit spectrum

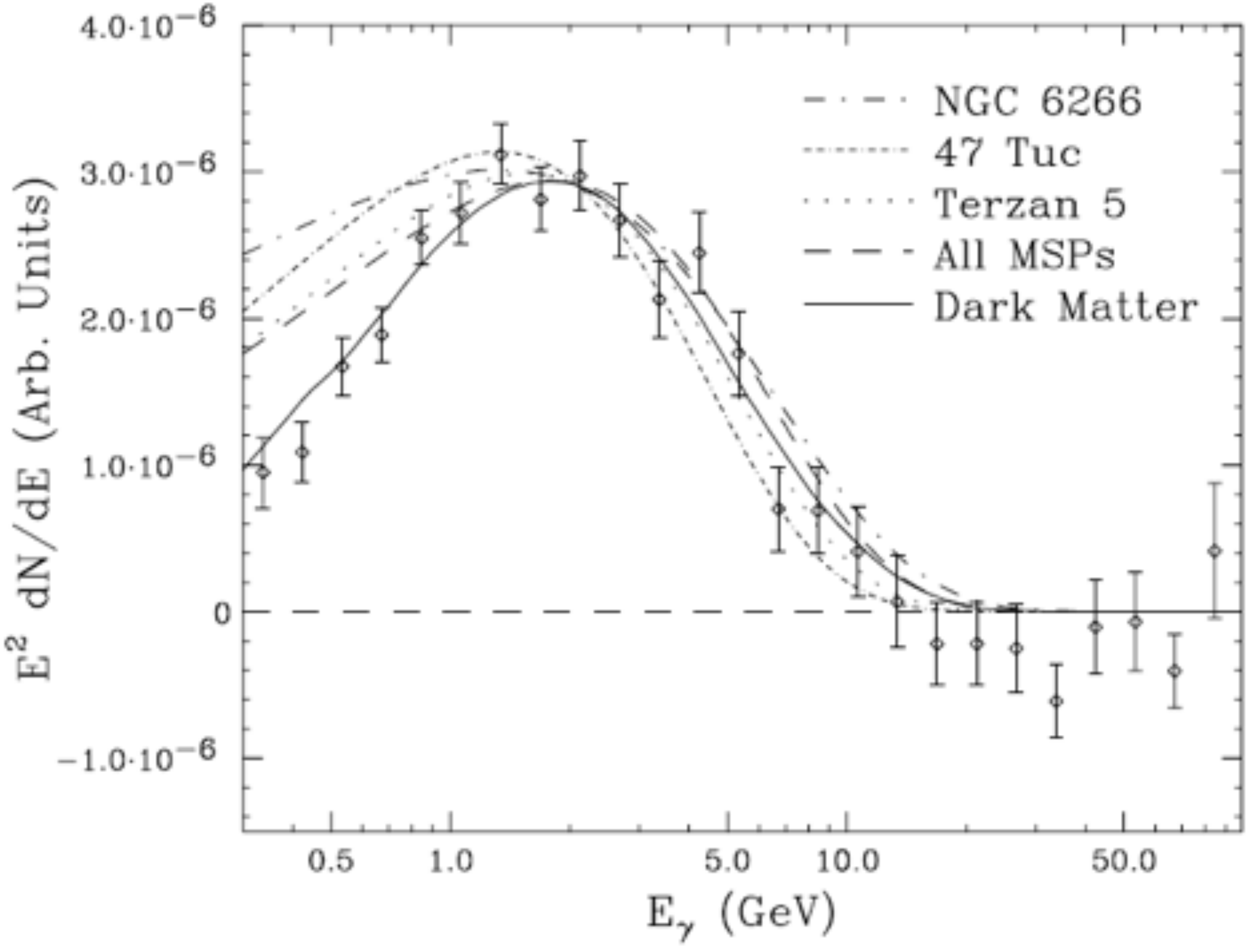



A ~35 GeV dark matter particle annihilating to bbar

$$\sigma v = 1.7 \times 10^{-26}\ \mathrm{cm}^3/\mathrm{s}\ \times [(0.3\,\mathrm{GeV/cm}^3)/\rho_{\mathrm{local}}]^2$$

Daylan et al. (2014)

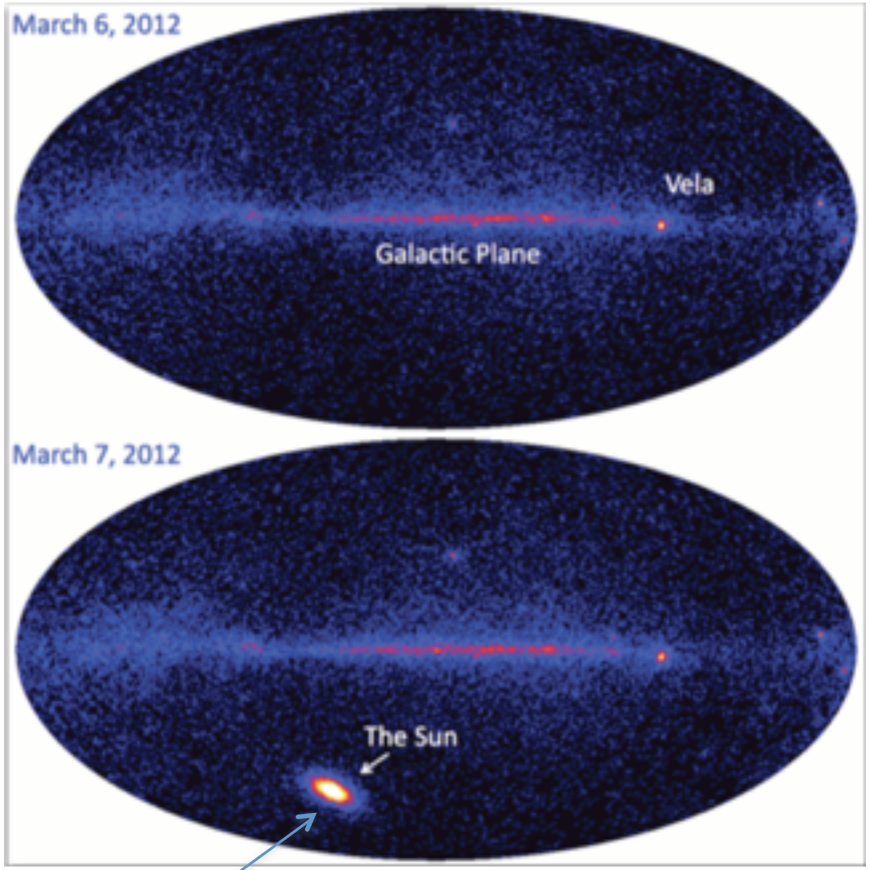
# Sub-GeV is the key!




Daylan et al. (2014)

# Gamma-ray Emission from Solar Flares

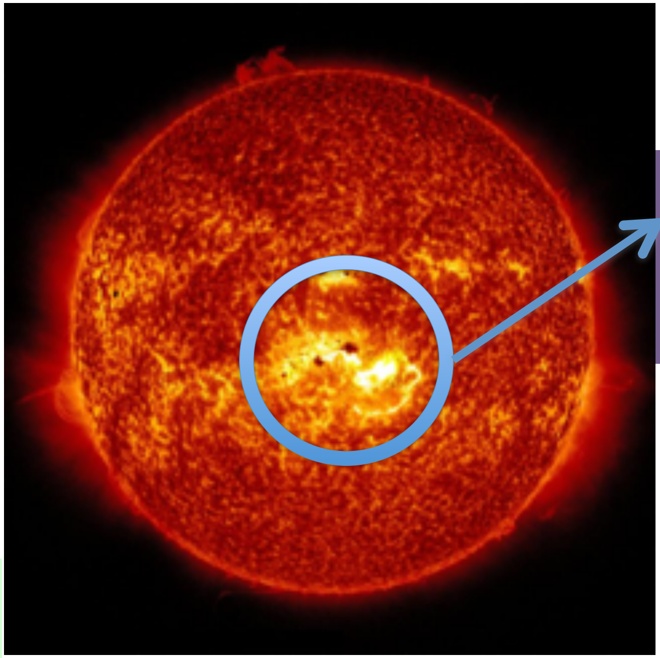
LAT 1 day all sky data >100 MeV




Bad PSF, cannot resolve the Sun ➠ no information on particle acceleration cite

**Bright solar flares have been detected by Fermi**

- 1000 time the flux of the steady Sun
- 100 times the flux of Vela
- 50 times the Crab flare
- High energy emission (>100 MeV, up to 4 GeV) lasts for ~20 hours
- Softening of the spectrum with time

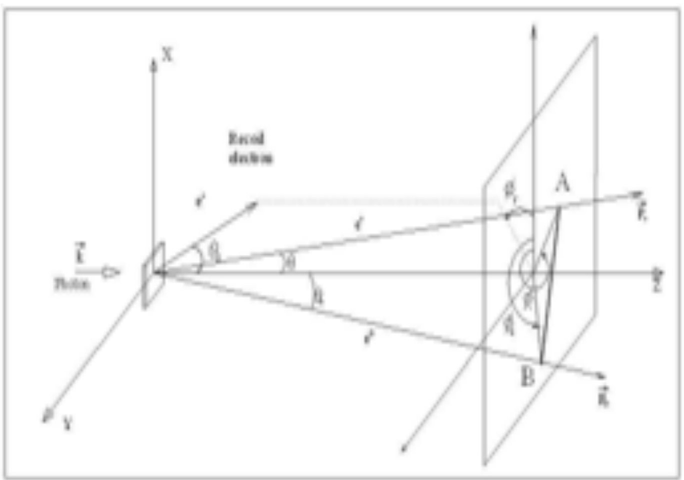


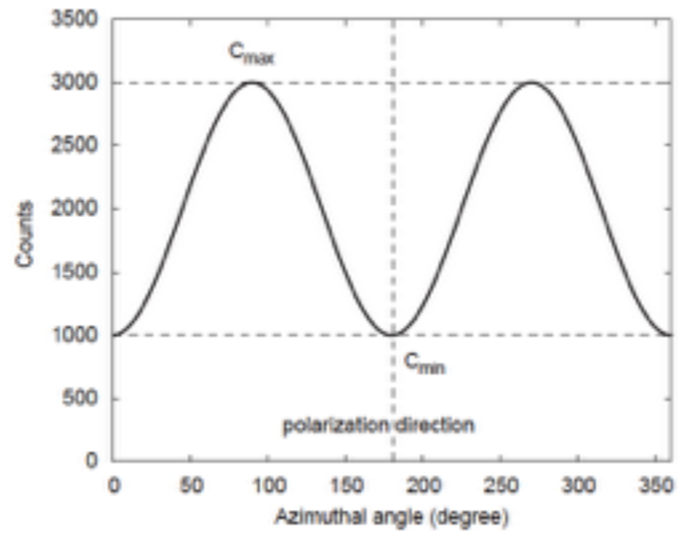
PANGU can resolve the flare in $\gamma$-ray!

# Polarizaation Measurement

$$d\sigma / d\varphi = 2\pi \sigma_0 \left(1 + P_\gamma \cdot A \cdot \cos(2\varphi - 2\varphi_{pol})\right)$$

- Azimuthal angle distribution in the plane perpendicular to the $\gamma$ direction
  - $P_\gamma$: degree of polarization; $\phi_{pol}$: polarization direction
  - A: Analyzing power, ~0.2 for pair production but kinematic dependent

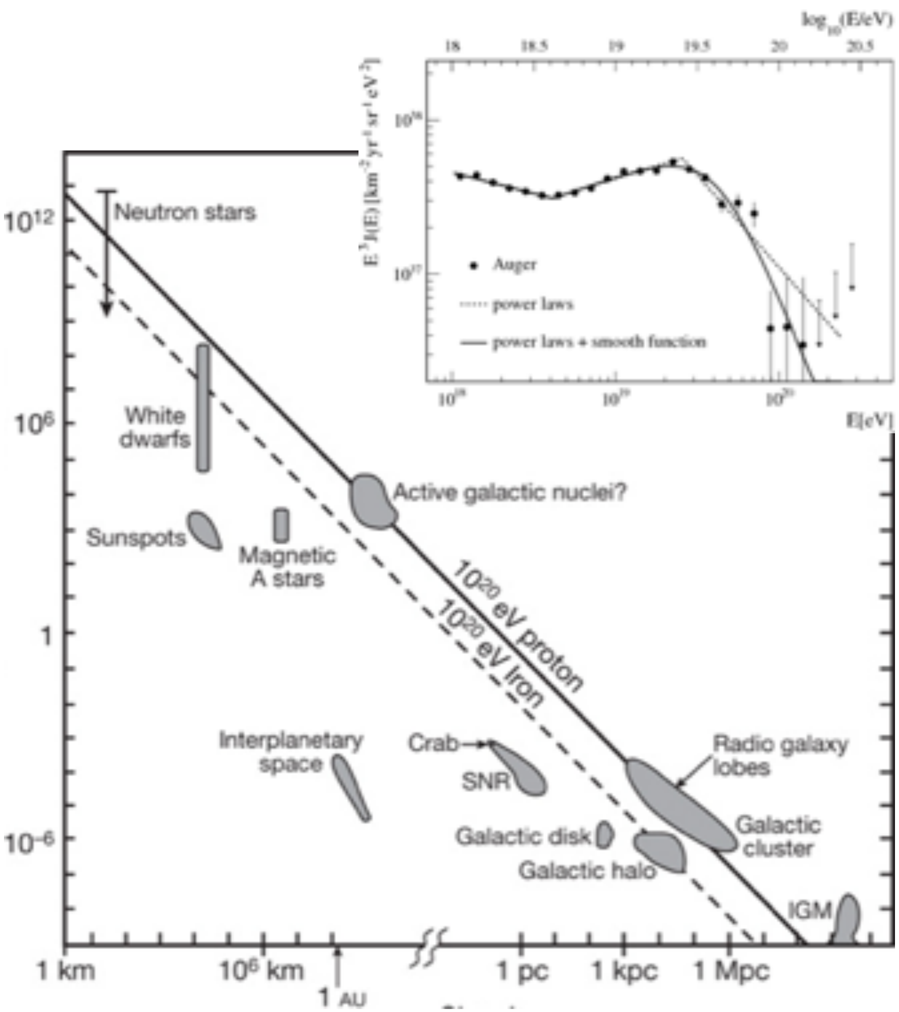



- Keys to the measurement
  - Azimuthal angular resolution
    - transverse track length and multiple scattering
  - Intrinsic modulation of the detector!

# Blazars and Origin of the UHECRs

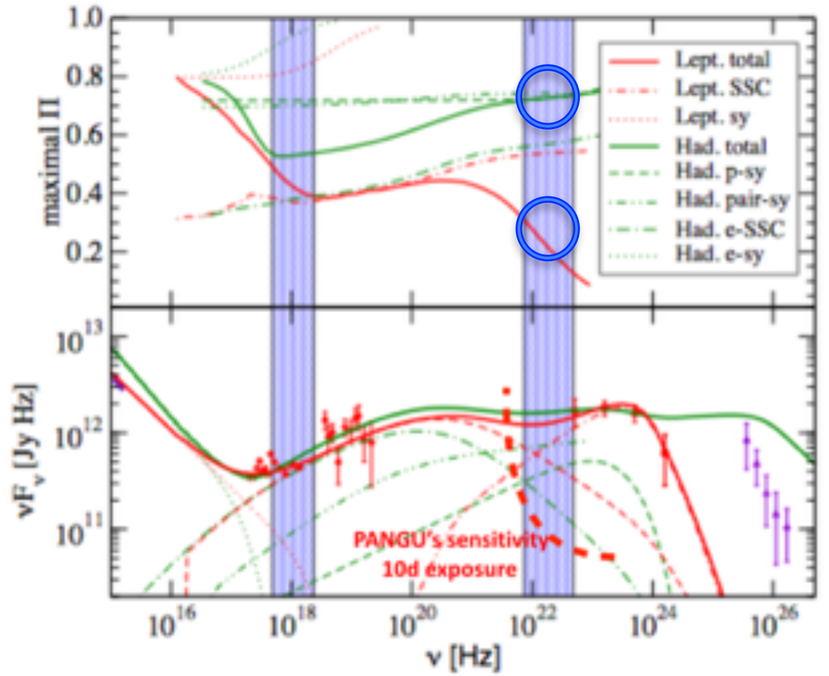
**Standard hypothesis: shocks in hadronic jets of Active Galactic Nuclei**



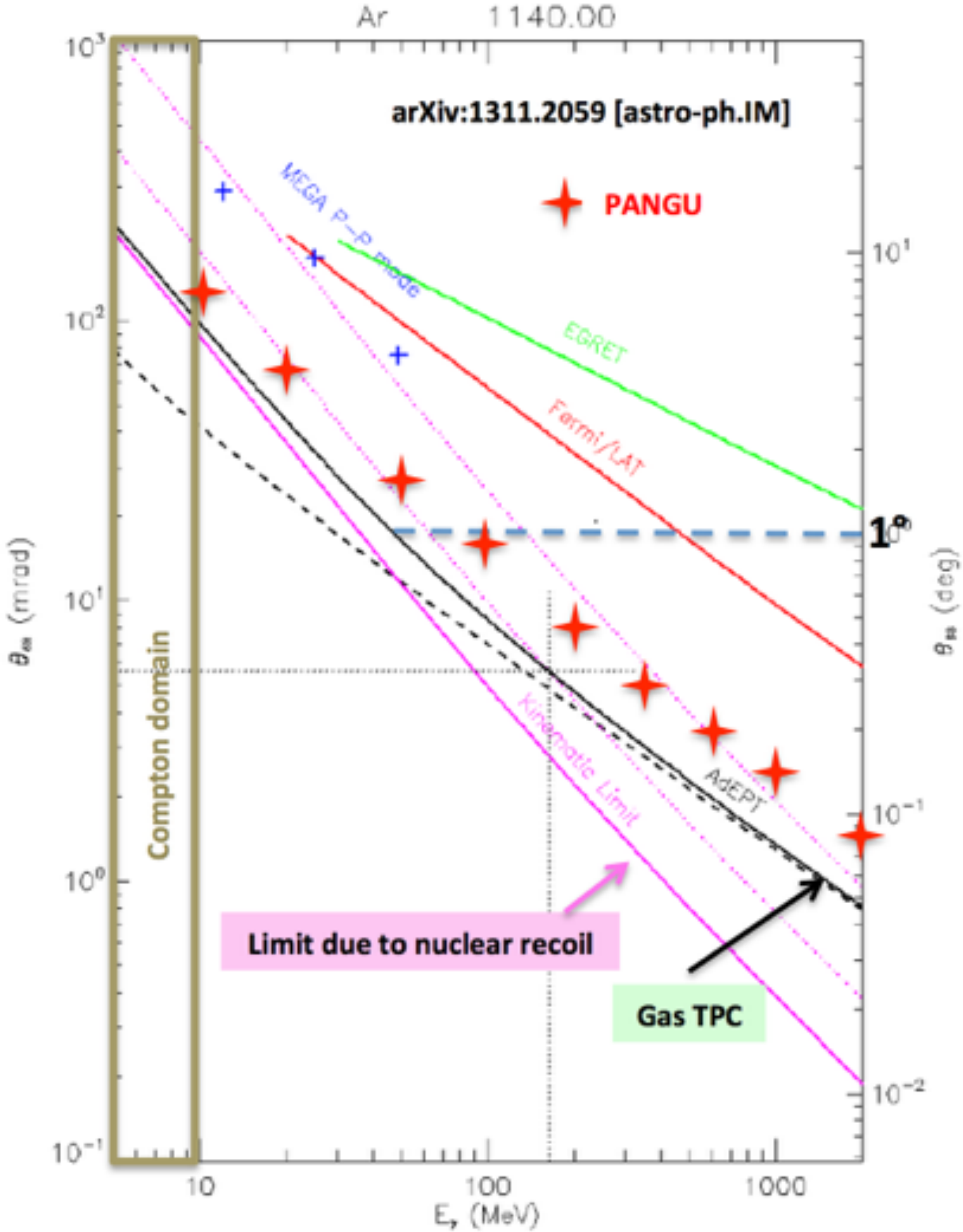

- **Jet spectra can be reproduced by leptonic or hadronic models**
  - **Only hadronic models predict neutrinos and high polarization in sub GeV range.**

**➠ PANGU observations of blazars flares**

**Assume fully ordered magnetic field, measurable in the near IR**

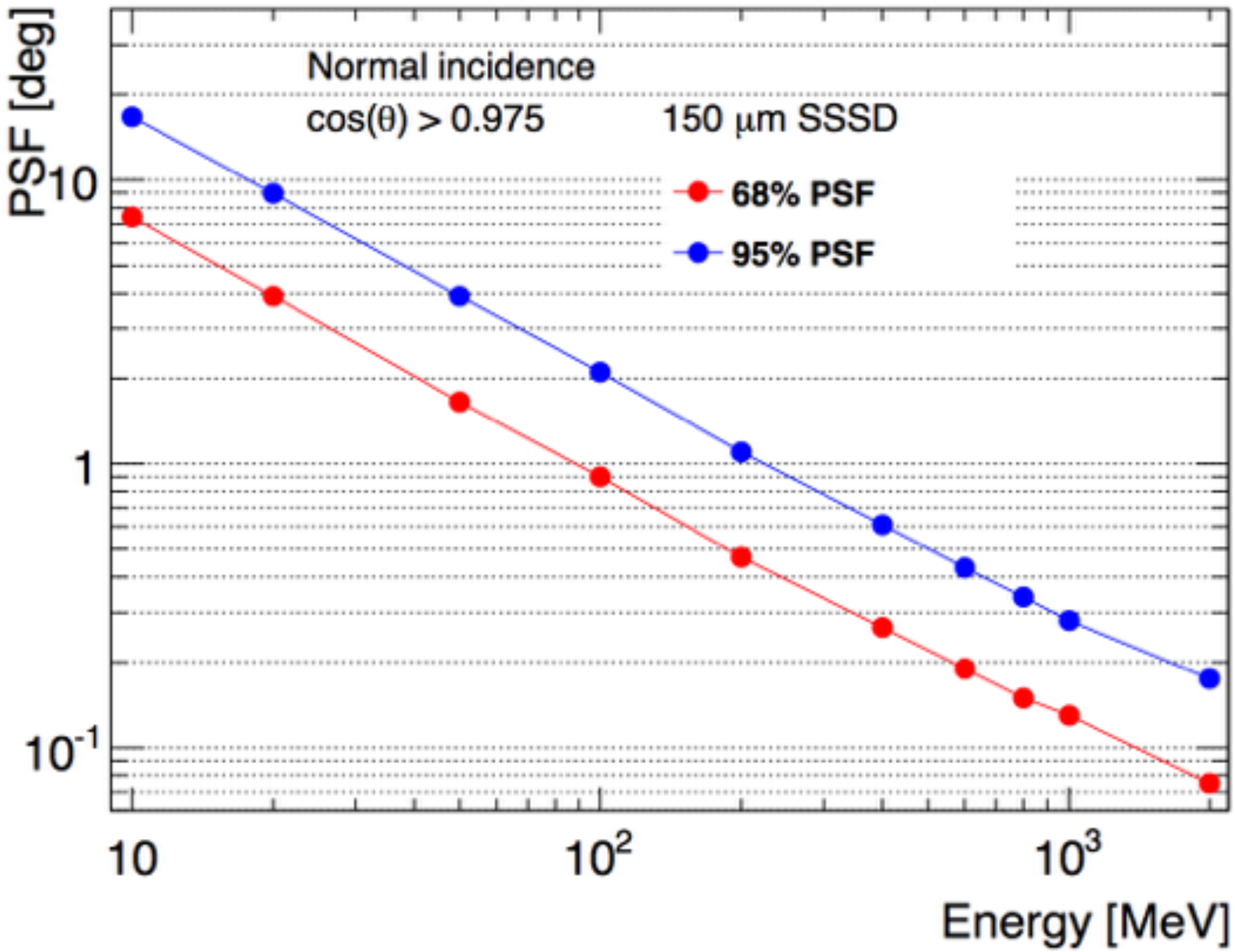



Zhang & Böttcher, 2013

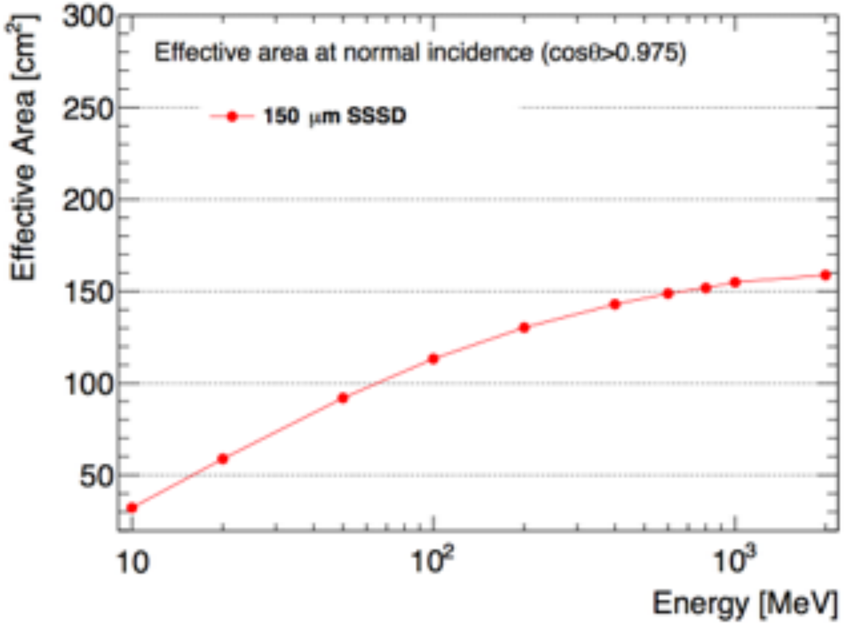


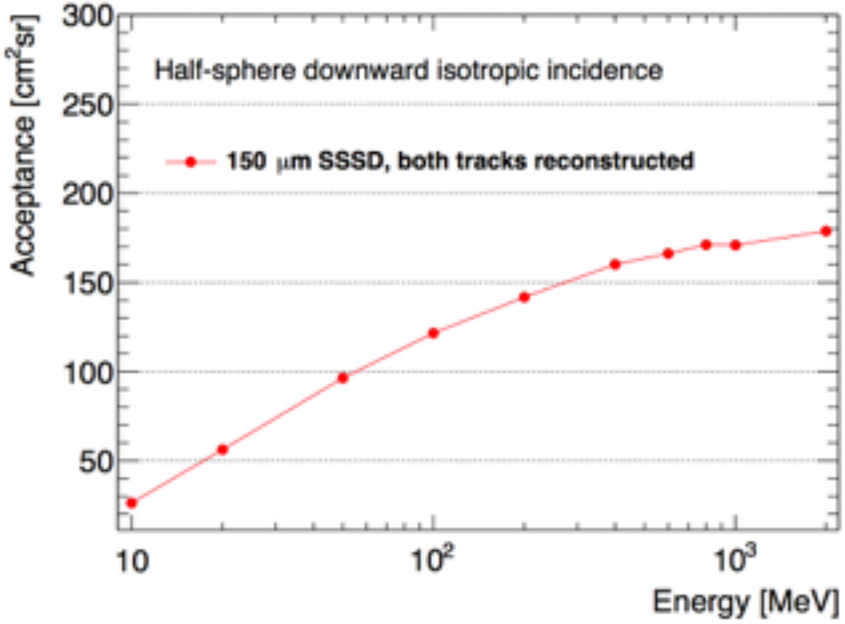
Ar 1140.00
arXiv:1311.2059 [astro-ph.IM]
PANGU
MEGA P-P mode
EGRET
Fermi/LAT
1°
Compton domain
Kinematic Limit
AdEPT
Limit due to nuclear recoil
Gas TPC
θ (mrad)
θ (deg)
E (MeV)

# Point Spread Function

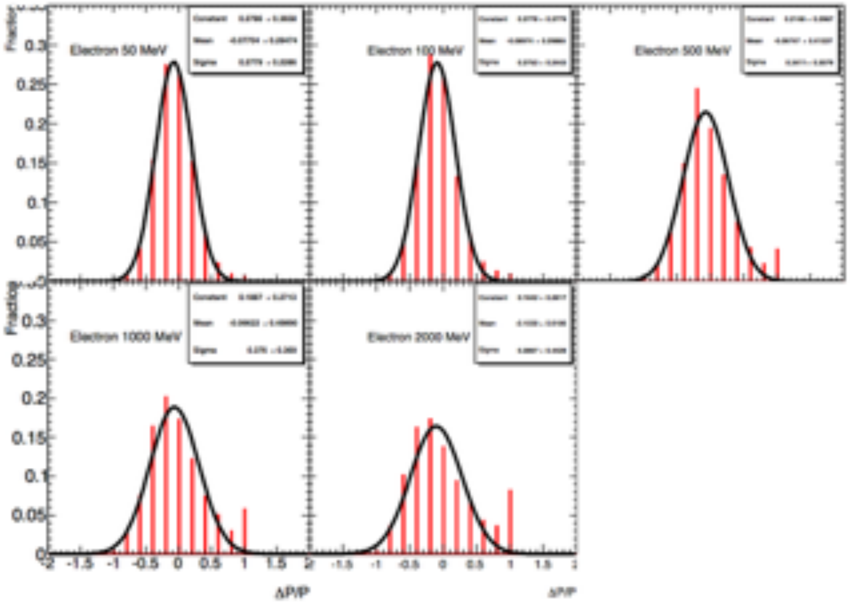


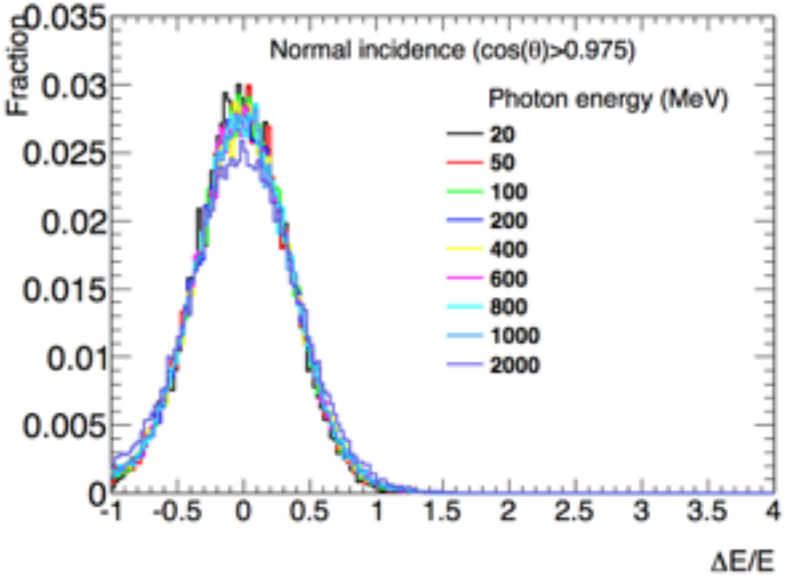
# Effective area and acceptance



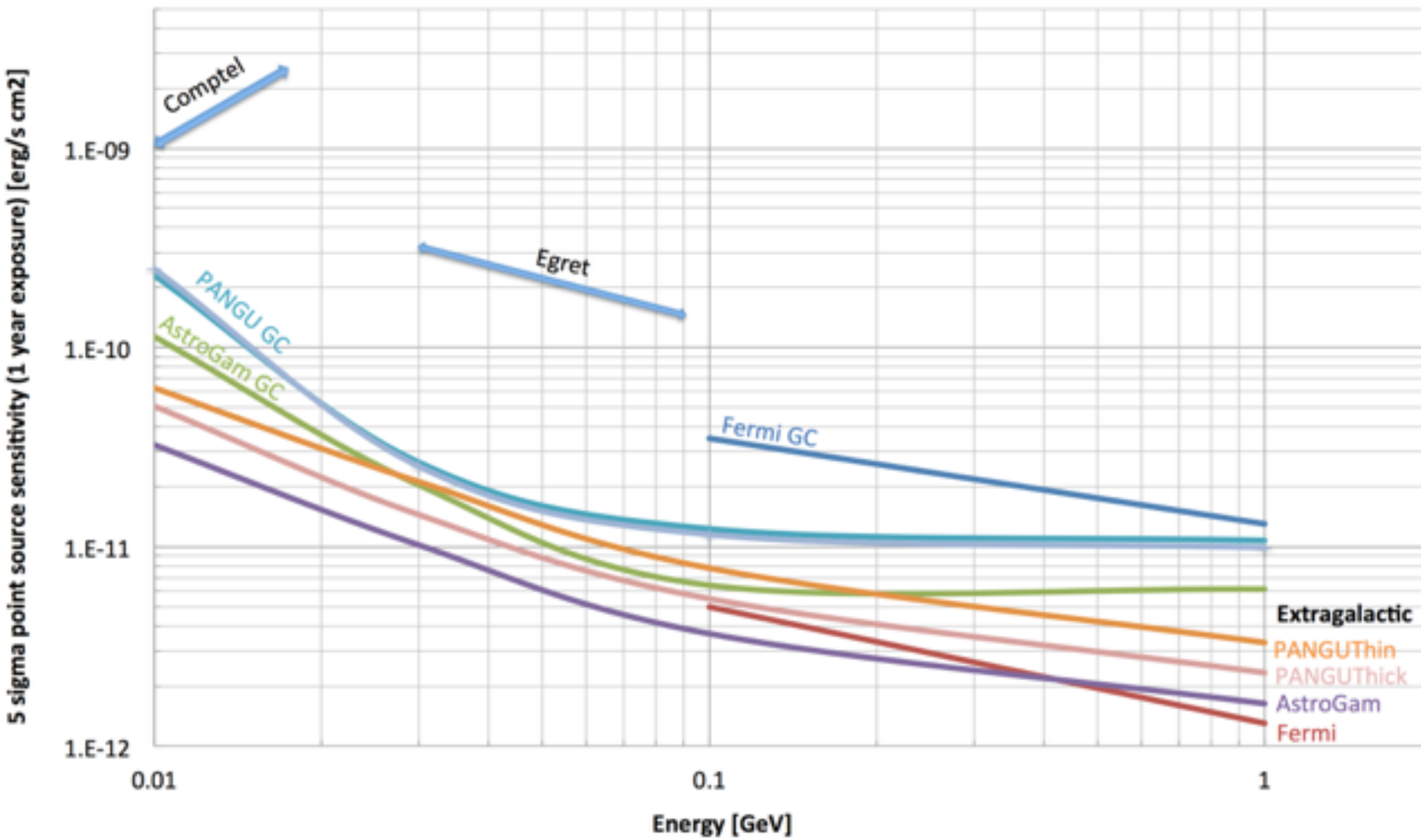



# Energy resolution

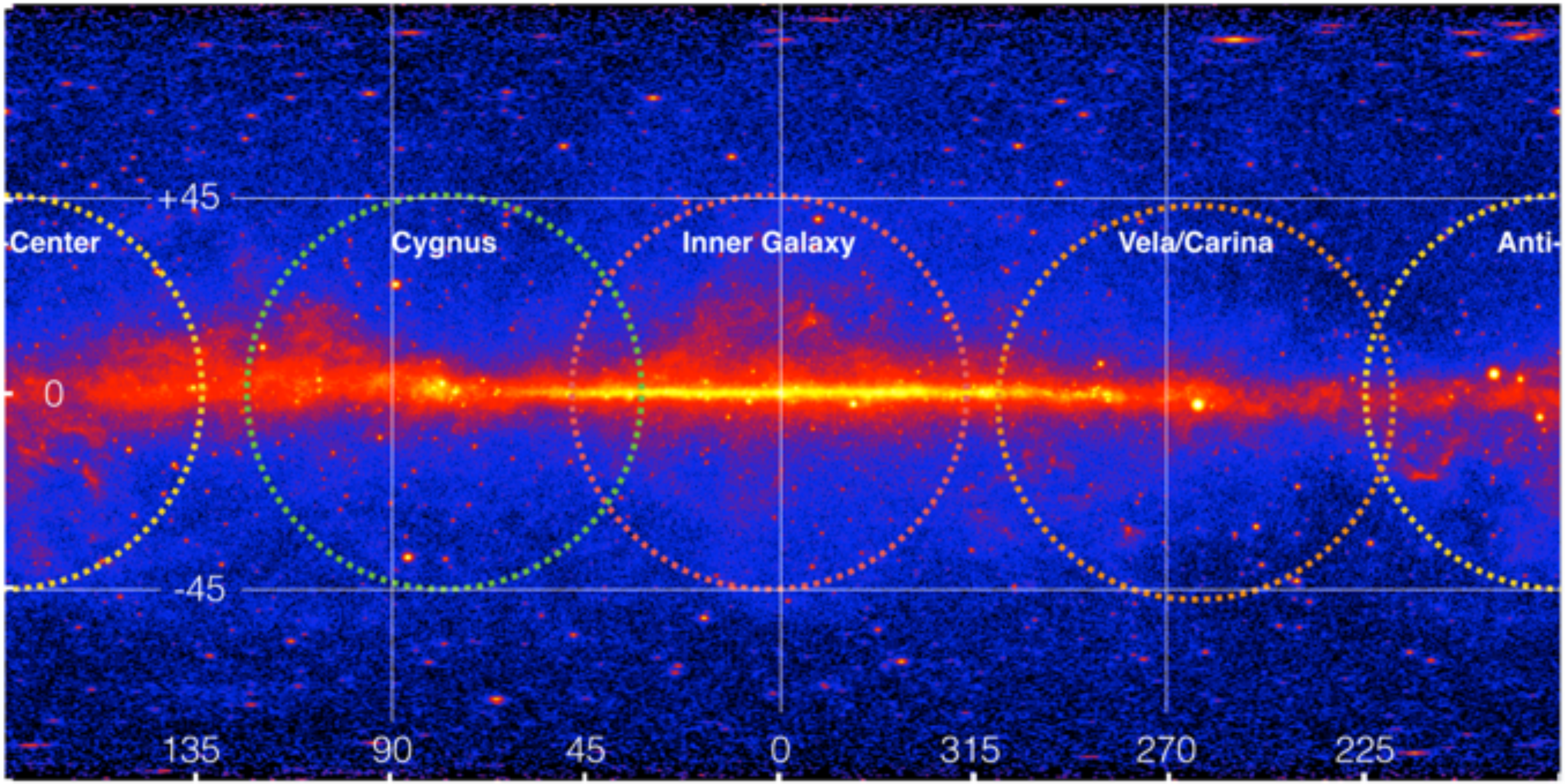


# Sensitivity comparison of PANGU and Fermi



# Observation mode of PANGU



# Comparison with DAMPE and Fermi

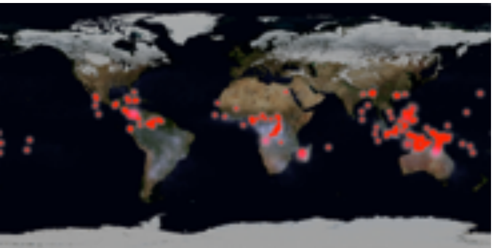
| | PANGU | DAMPE | Fermi-LAT |
|---|---|---|---|
| γ工作能区(GeV) | 0.01-10 | $5 – 10^4$ | 0.1 - 1000 |
| γ 能量分辨 (%) | 40@0.1GeV | 1.5 @100 GeV | 10@100GeV |
| γ 角分辨 (deg) | 1.0@0.1GeV | 0.2 @10 GeV | 3.0@0.1GeV |
| 重量 | 300 kg | 1900 kg | 4300 kg |

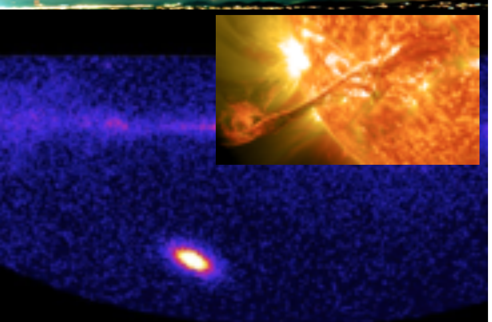
| Mission parameter | Requirement |
|---|---|
| **Energy band** | 10 MeV-10GeV |
| **Field of view with nominal effective area** | 1 steradian (45° opening)<br>Design: π steradian (60° opening) |
| **Maximum field of view** | 2π steradian |
| **Point source sensitivity**<br>(Galactic centre) | $10^{-11}$ erg/s cm$^2$ (>100 MeV, 1 year eff. exposure)<br>$10^{-10}$ erg/s cm$^2$ (10 MeV, 1 year eff. exposure) |
| **Angular resolution**<br>(normal incidence) | 1 degree (100 MeV)<br>0.2 degree (1 GeV) |
| **Polarisation sensitivity** | Amplitude: 20% for $10^4$ events<br>Direction: 45 degrees for $10^4$ events |
| **Absolute event reconstructed time tagging accuracy** | 10 micro-seconds |
| **Energy resolution** | 30-50% |
| **Detector alignment calibration** | < 10 micro-meters |
| **Attitude reconstruction accuracy** | < 1 arcmin (X – optical - axis)<br>< 0.5 arcmin (Y/Z axis) |
| **Replanning capability (TOO)** | < 1 working day |
| **Mission duration** | 3.5 years, extendable to 10 years |
| **Scientific telemetry** | 10 Mbit/s |

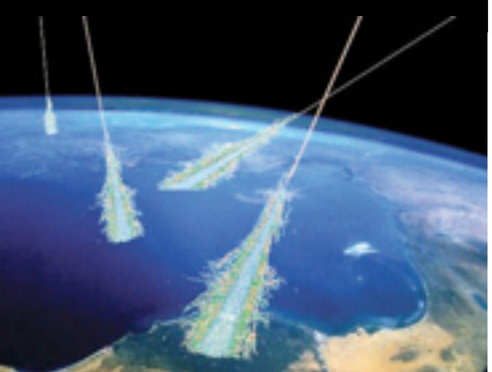
# Conclusions

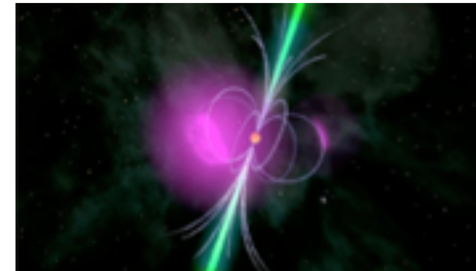
- **PANGU is an *unique and timely opportunity* for high energy astrophysics. It will resolve and monitoring the sub-GeV sky with unprecedented spatial resolution, separating diffuse gamma-ray emission from point sources**
  - **PANGU science is not "incremental science", it will lead to fundamental discoveries and understanding.**
- **PANGU is synergic with DAMPE, HERD, CTA, Gamma-400, LHAASO 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**

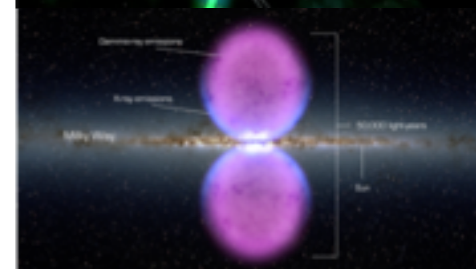
# Thank You!

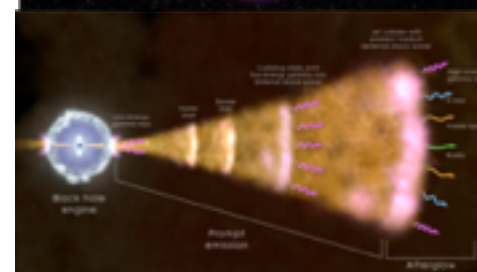












## Welcome to join!