B02: ニュートリノ精密測定にむけた原子核乾板開発

原子核乾板製造設備によって可能になる実験計画

宇宙ガンマ線精密観測計画 GRAINE

電子対飛跡の精密測定システム開発

(中村悠哉　博士論文『エマルション望遠鏡によるガンマ線天体の高解像度撮像』の一部)

PTEP EDITOR'S CHOICE
Y.Nakamura et al, PTEP, 2021,12
JPS Hot Topics
https://jpsht.jps.jp/article/2.007.html

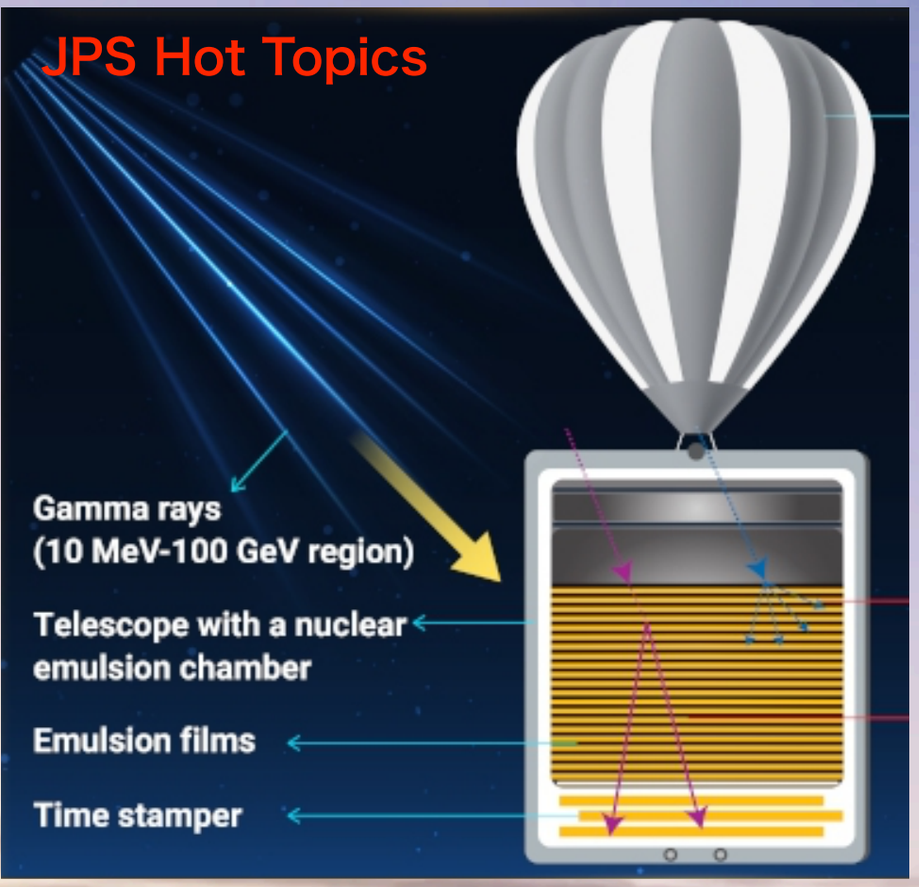
代打報告　六條宏紀

GRAINE Project

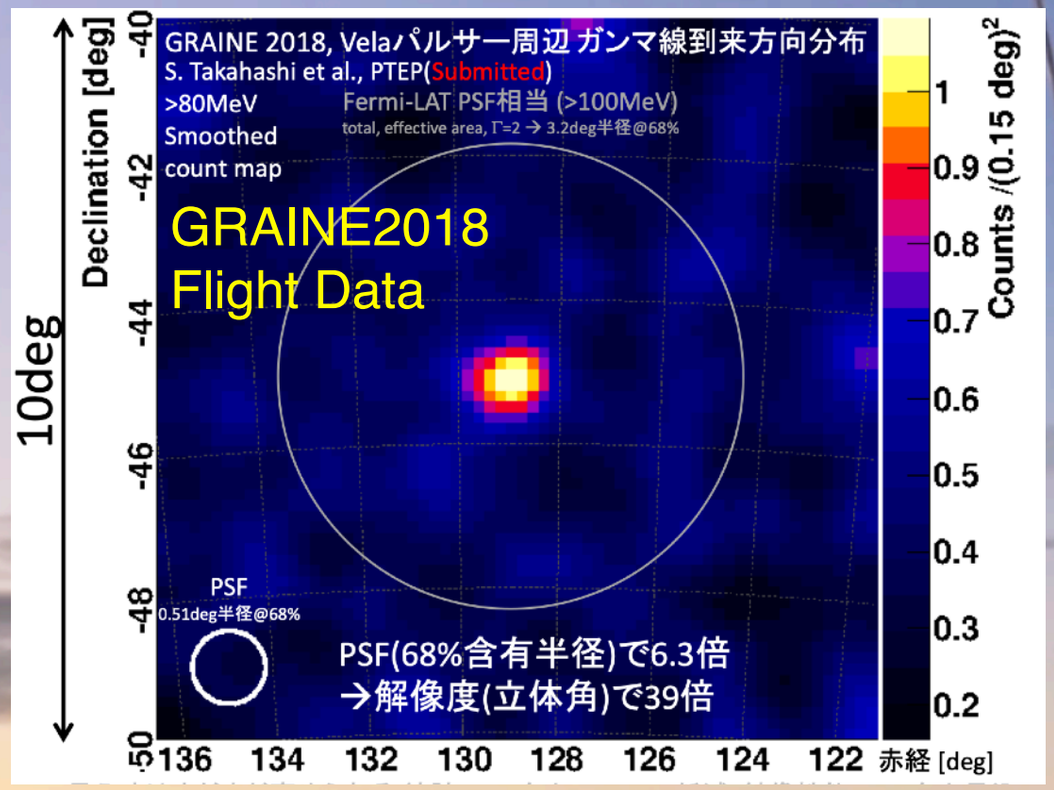
Cosmic γ-ray Observation in sub-GeV/GeV using Balloon-borne Nuclear Emulsion Telescope

PI: S.Aoki(Kobe)

photo:
GRAINE 2018
Balloon Experiment
2018.4.26 @ AUS



✓ **Detection of Vela pulsar**
✓ **Highest Imaging (0.5°, >80MeV)**



Scientific Balloon Launch provided by ISAS/JAXA

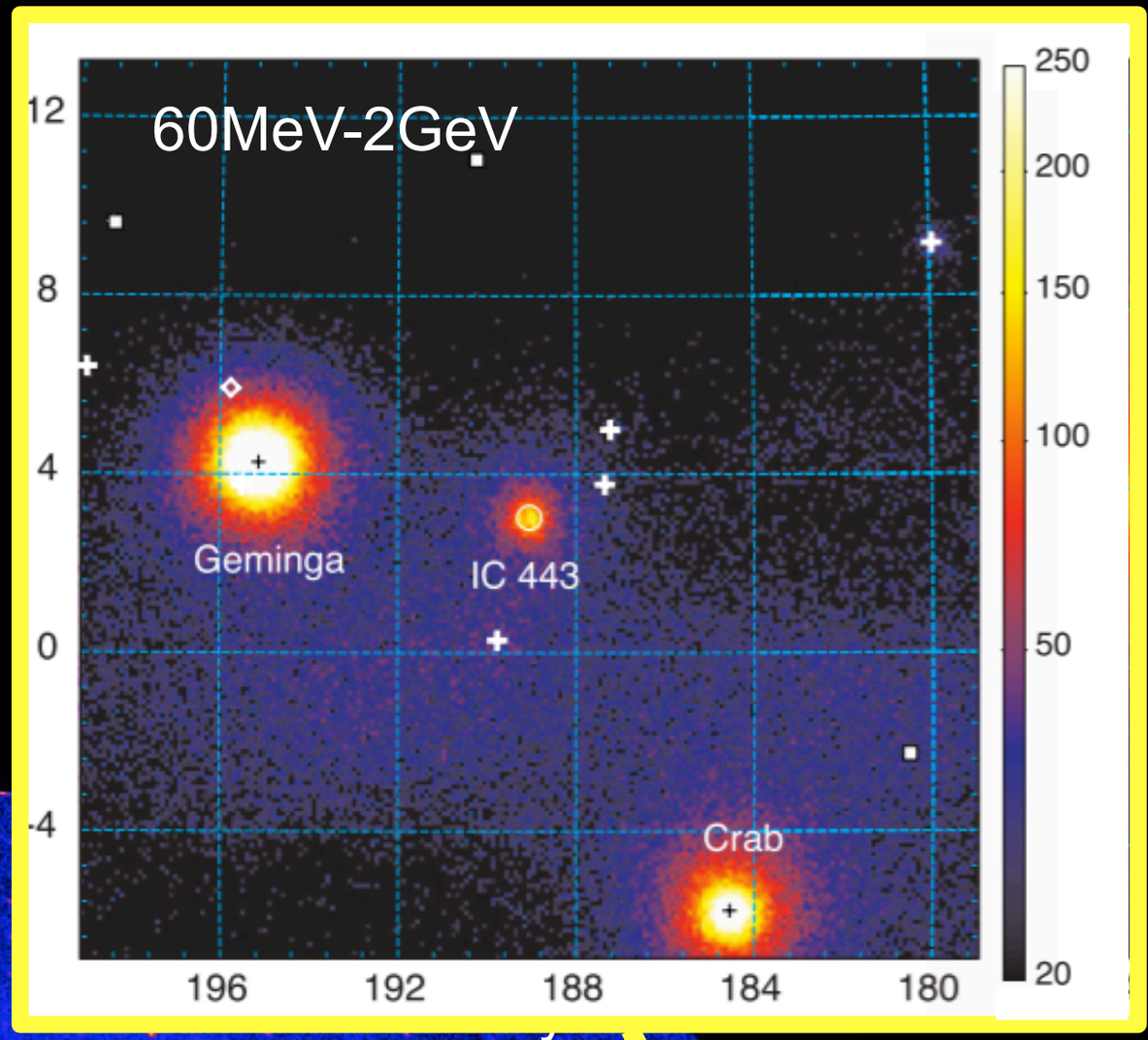
衛星では実現できない
次世代ガンマ線望遠鏡
世界最大口径(~10倍)
世界最高解像度(~100倍)
世界初偏光有感(前例無)

→ **Large-scale GRAINE-Next in 2023 (approved by JAXA)**

Gamma-ray Observation (sub-GeV/GeV region)

	Telescope	Detected sources
1990-2001	EGRET spark chamber	271
2008-	Fermi-LAT SSD tracker	>5000

All-Sky Map
via gamma-ray
above 1 GeV

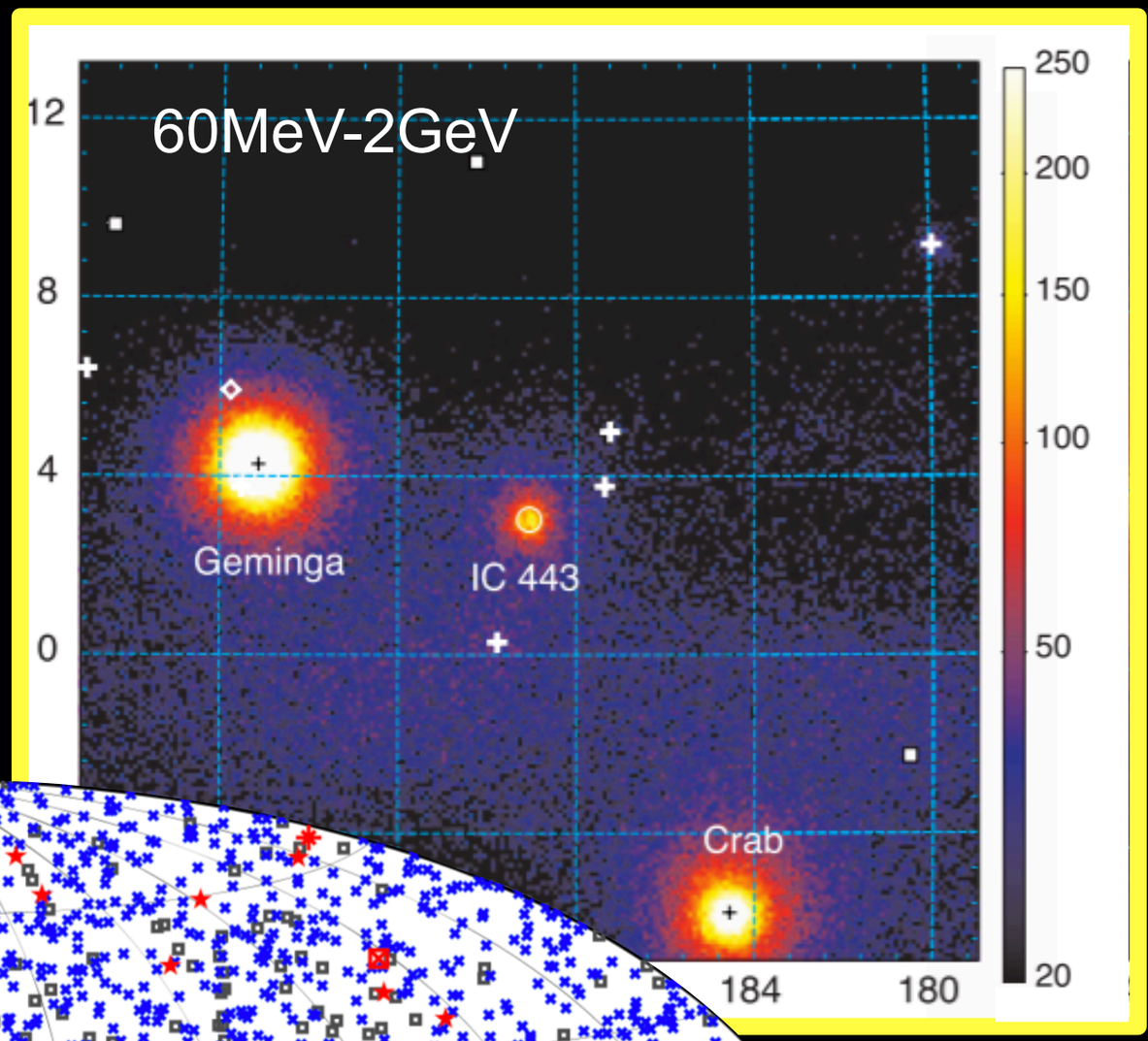


Galactic plane

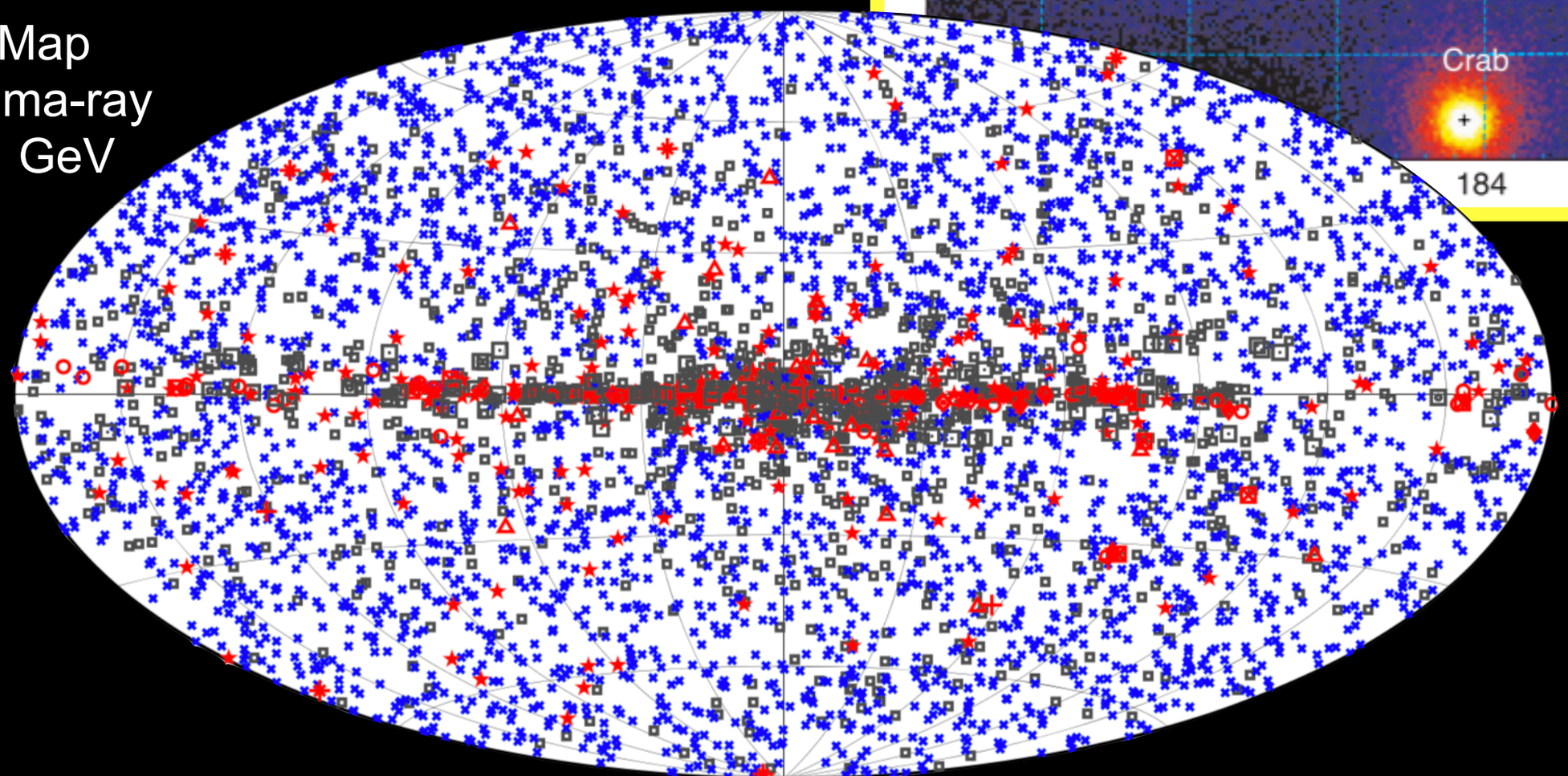
Galactic center

Gamma-ray Observation (sub-GeV/GeV region)

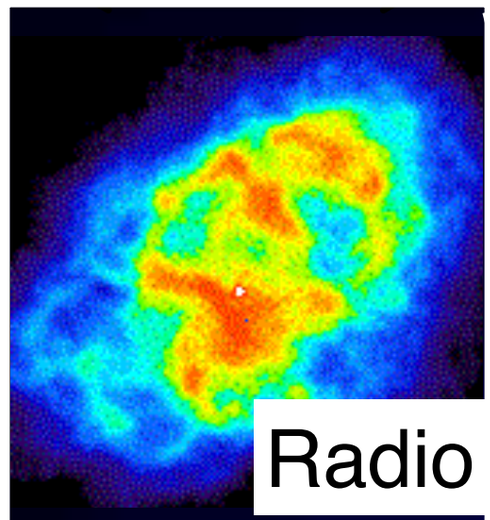
	Telescope	Detected sources
1990-2001	EGRET spark chamber	271
2008-	Fermi-LAT SSD tracker	>5000



All-Sky Map
via gamma-ray
above 1 GeV



Imaging performance of telescopes (Angular resolution)


Radio


Infrared


Visible


X ray

Crab Nebula
（M1:SN1054）

0.1度

γ ray >1GeV
(Fermi-LAT)

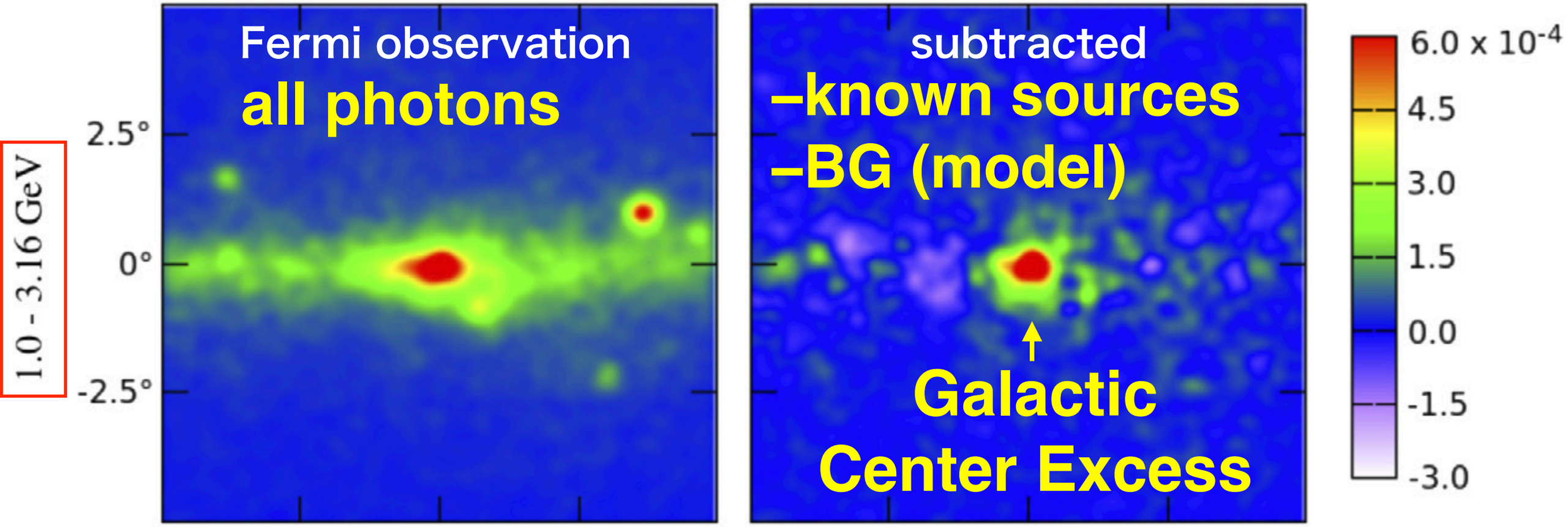
0.1度

月の大きさ
程度にボケる

角度分解能が
圧倒的に不足！！

Unsolved issues in gamma-ray observation

• Unknown gamma-ray emission in the galactic center region



Annihilation of DM？ unresolved astrophysical object？

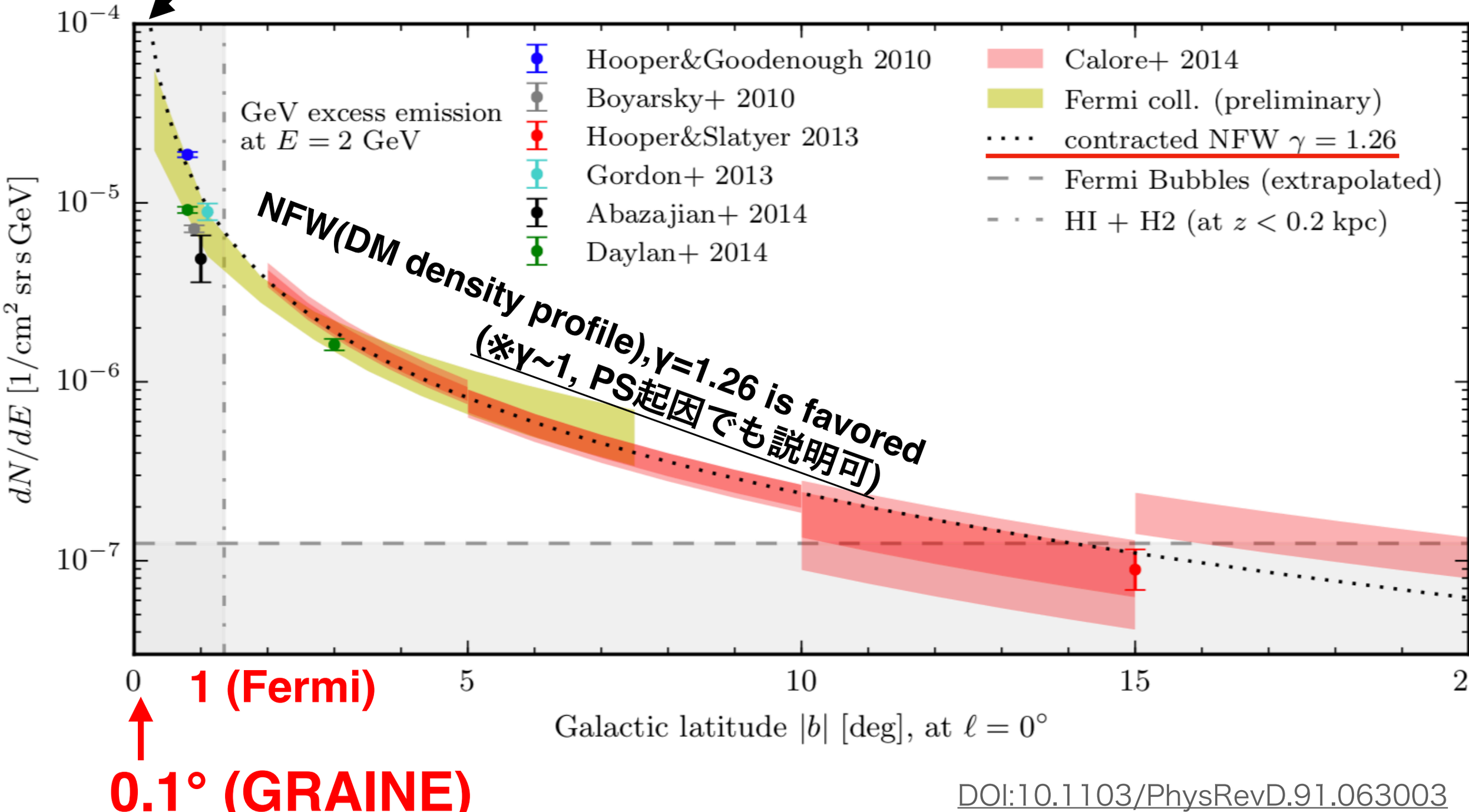
Understanding spacial distribution is important for model verification
⇄limited by the current angular resolution (1 deg.)

GRAINE realizes high-resolution observation
at the galactic center region (<0.1 deg.)

GeV-γ excess Observation near the galactic center

Differential Flux for each distance (b) from the center

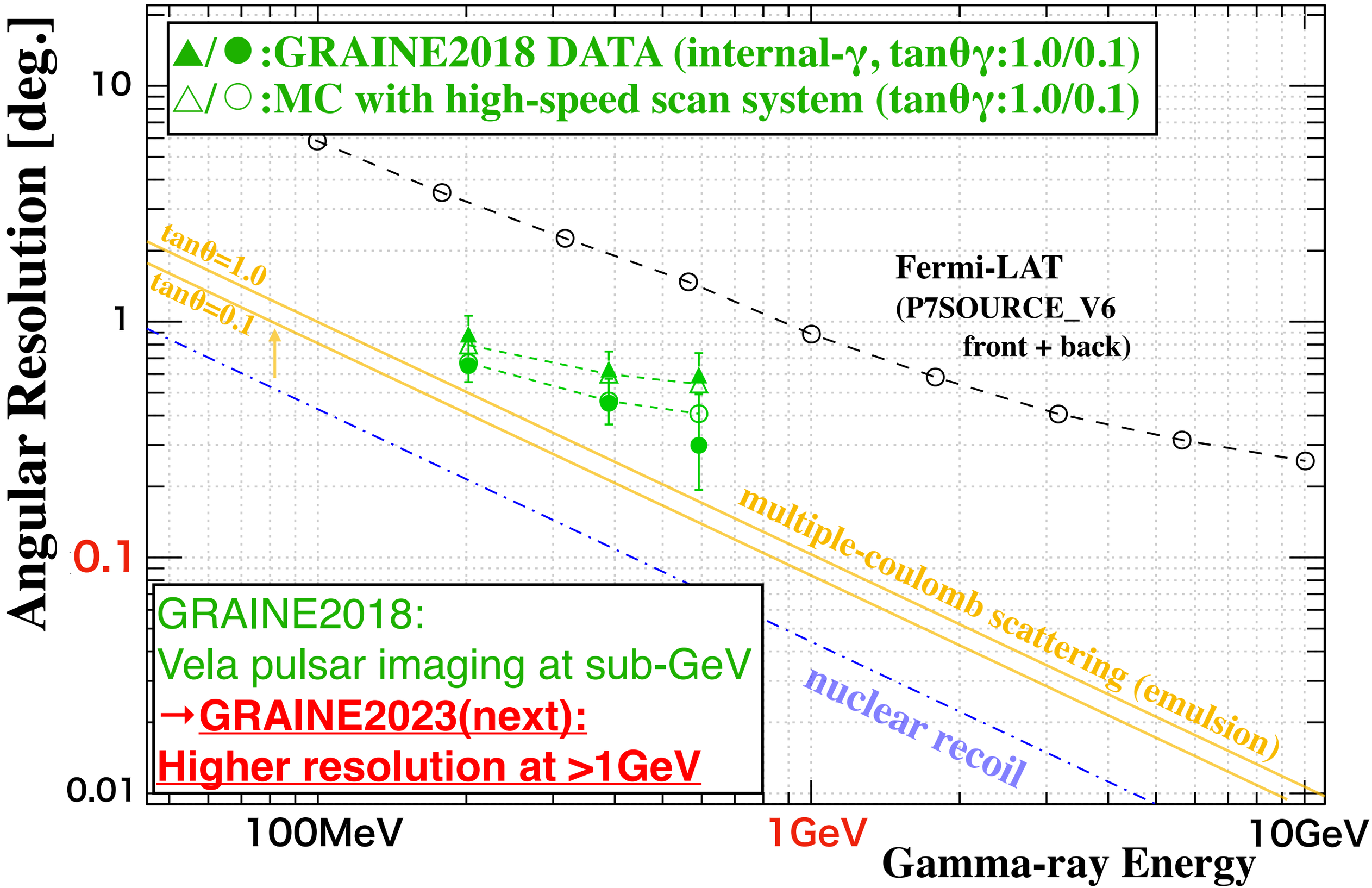
Density increases sharply near the center
→ Gamma Radiation increases



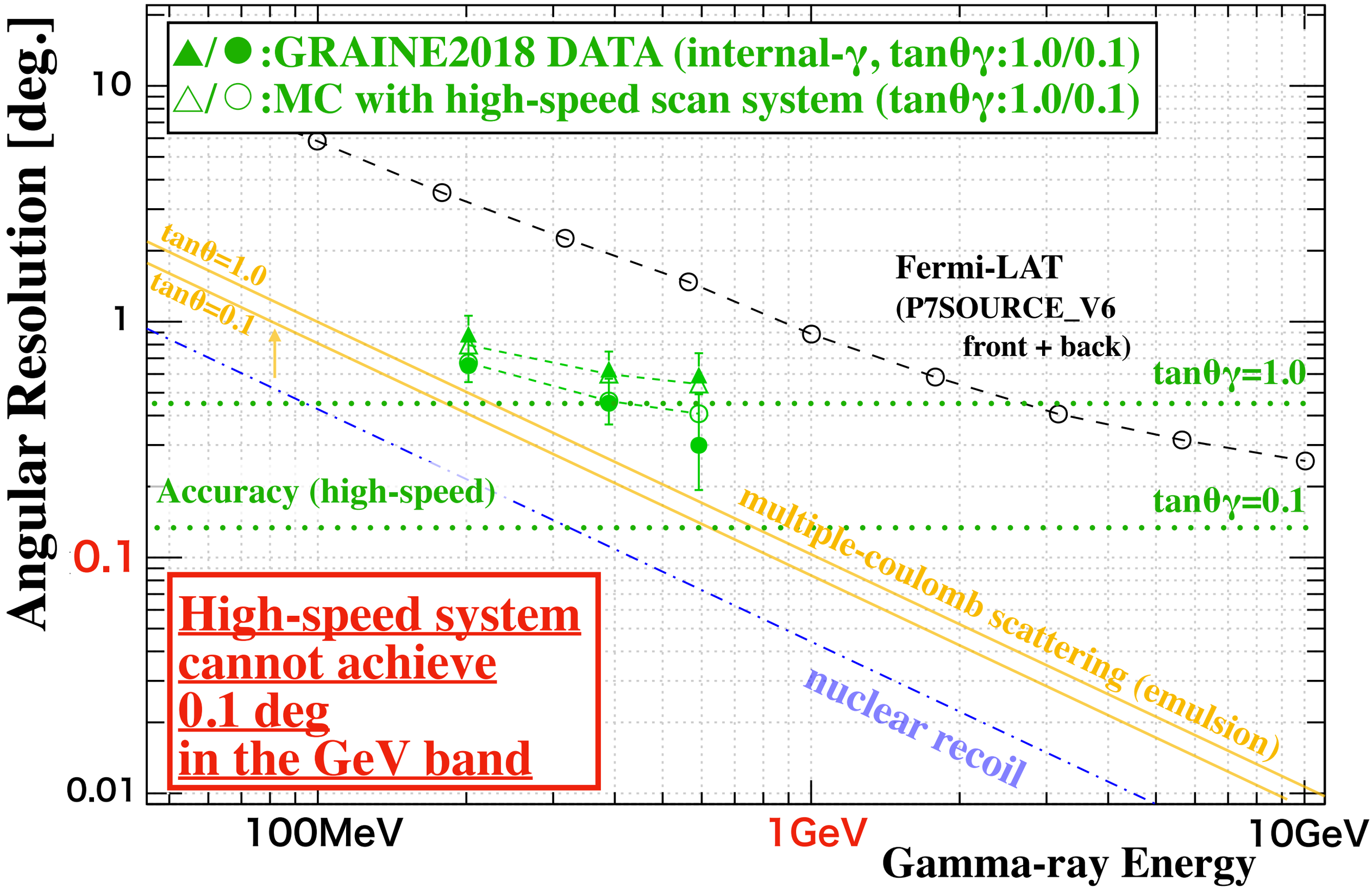
0.1° (GRAINE)

DOI:10.1103/PhysRevD.91.063003

Angular Resolution for Gamma Ray

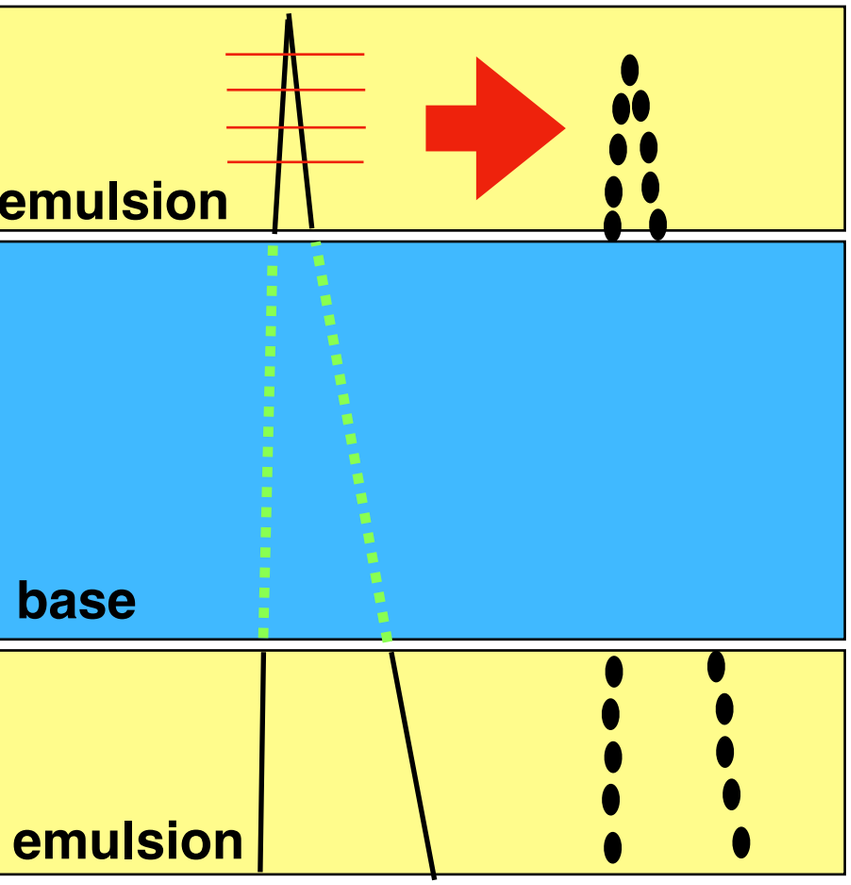


Angular Resolution for Gamma Ray

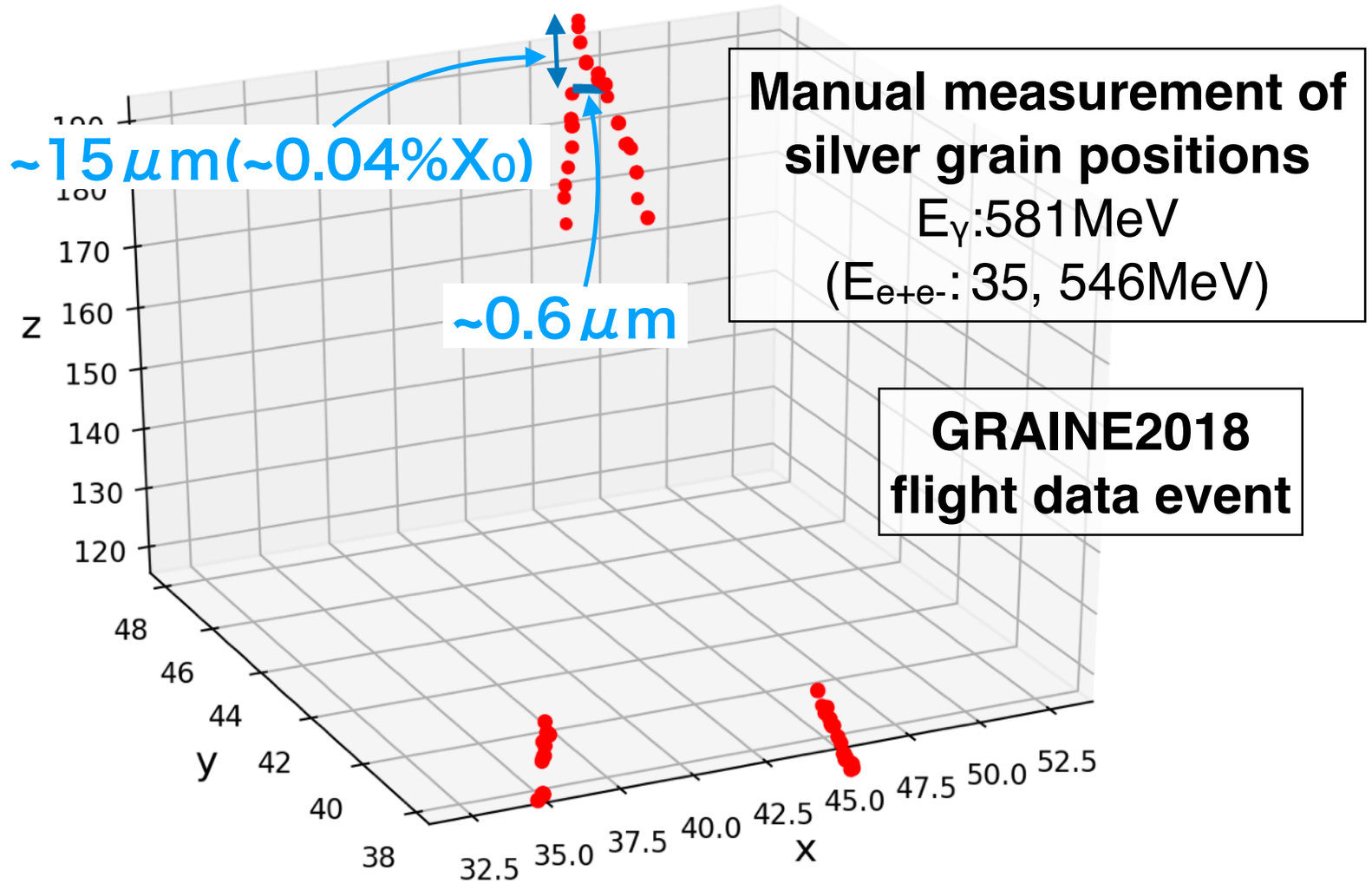


Precise measurement of electron pair track

<u>High-speed scanning</u>
Detects straight lines from hit information in 16 layers



<u>Precise scanning</u>
Measures 3D positions of each silver grain to maximize the information contained in Emulsion



Manual measurement of silver grain positions
E_γ:581MeV
(E_{e+e-}: 35, 546MeV)

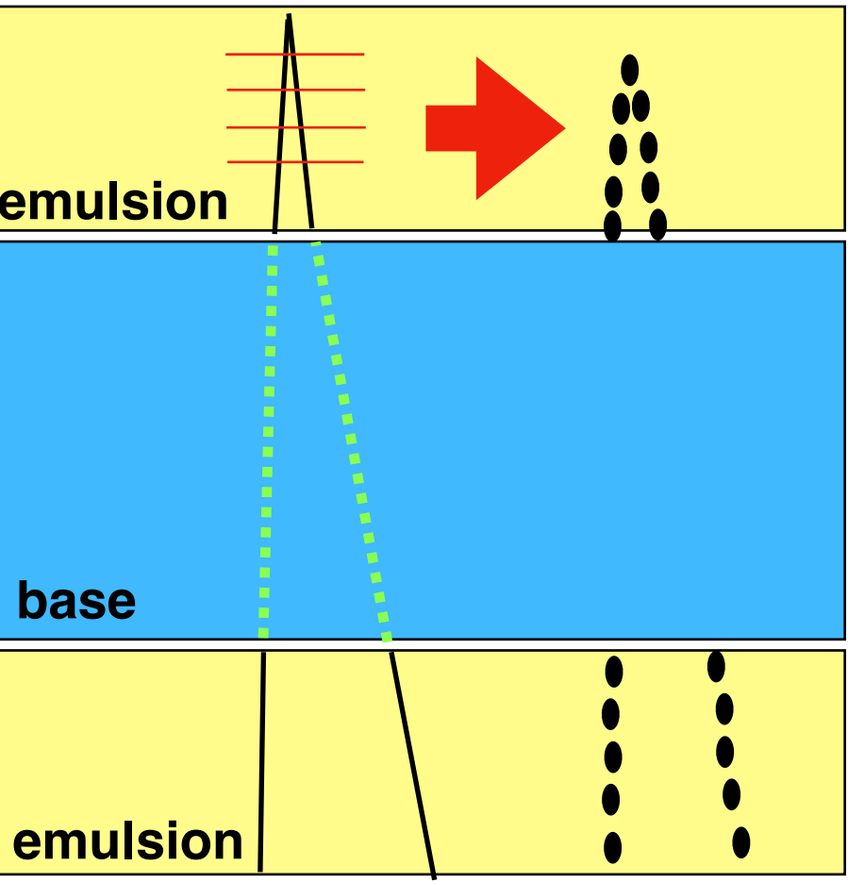
GRAINE2018 flight data event

<u>Expected to improve angular resolution (x1.5-3)</u>

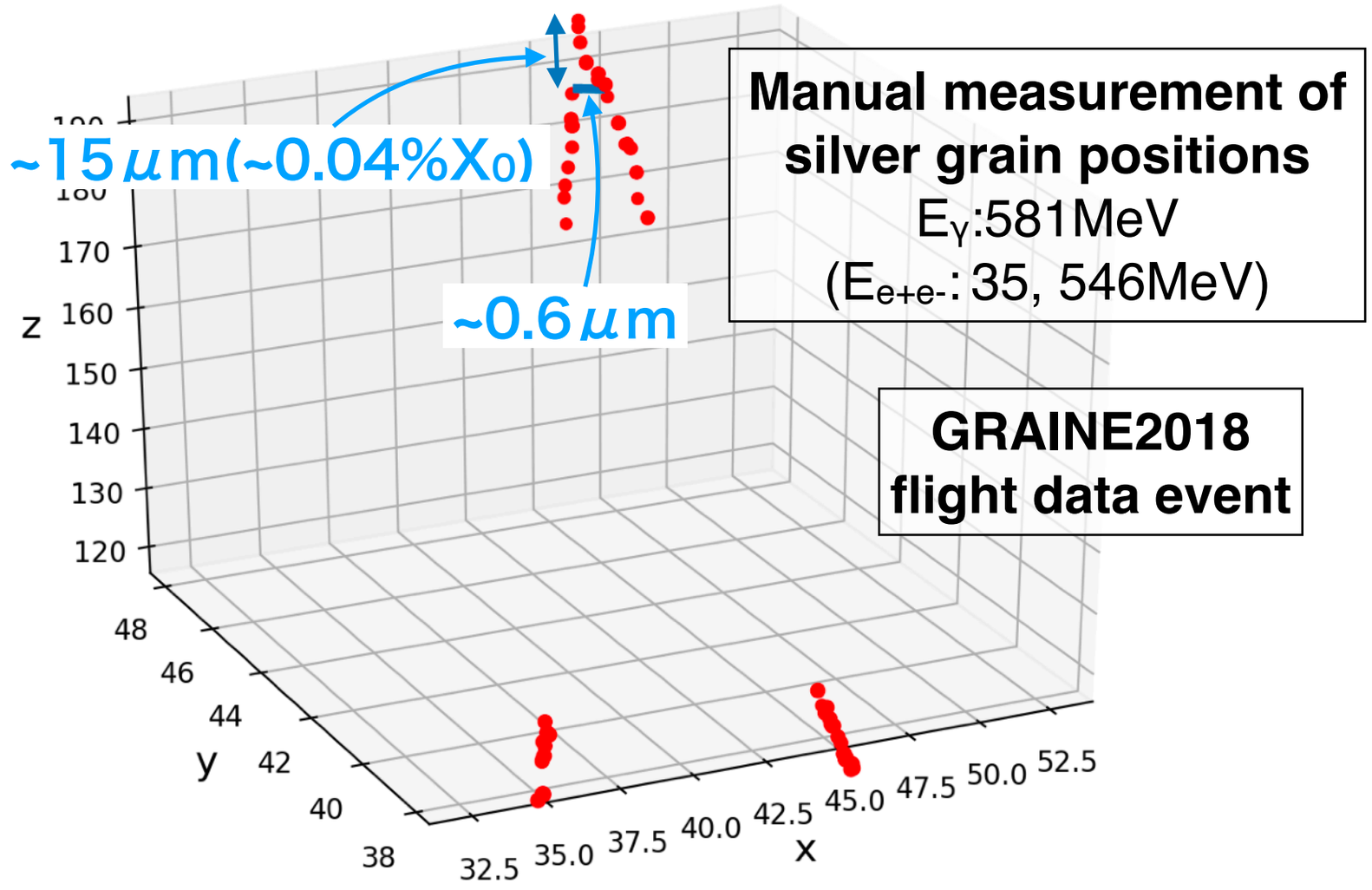
(Demonstration is already proven in beam test+manual meas.)

Precise measurement of electron pair track

<u>High-speed scanning</u>
Detects straight lines from hit information in 16 layers



<u>Precise scanning</u>
Measures 3D positions of each silver grain to maximize the information contained in Emulsion



Manual measurement of silver grain positions
E_γ:581MeV
(E_{e+e-}: 35, 546MeV)

GRAINE2018 flight data event

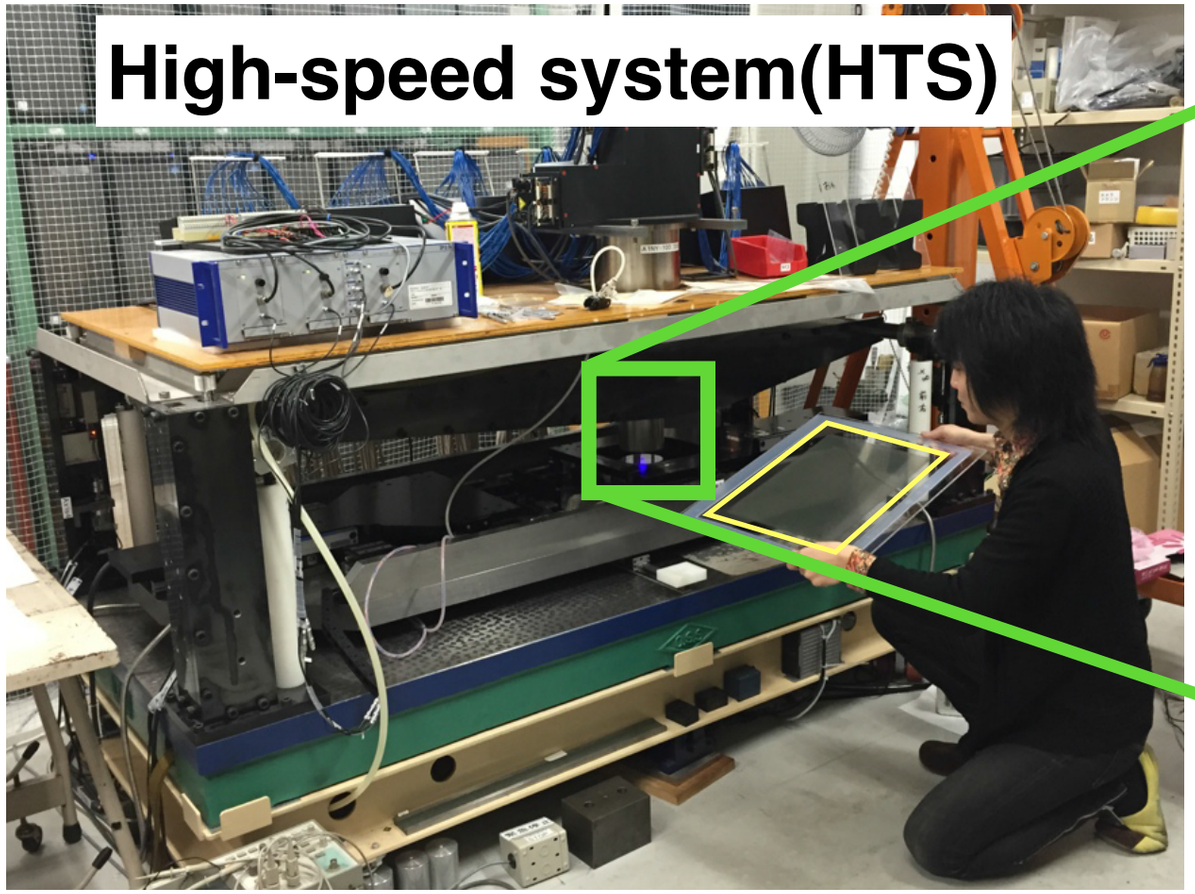
<u>Expected to improve angular resolution (x1.5-3)</u>

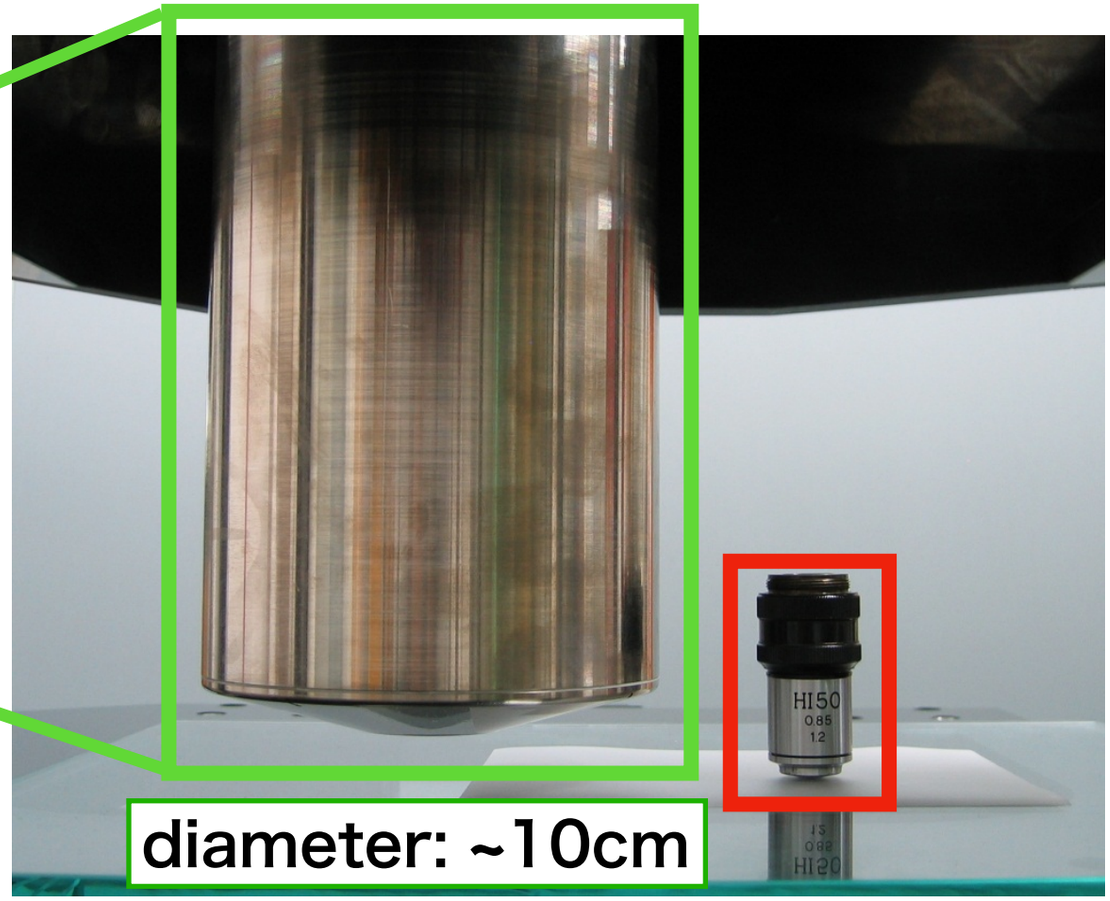
(Demonstration is already proven in beam test+manual meas.)

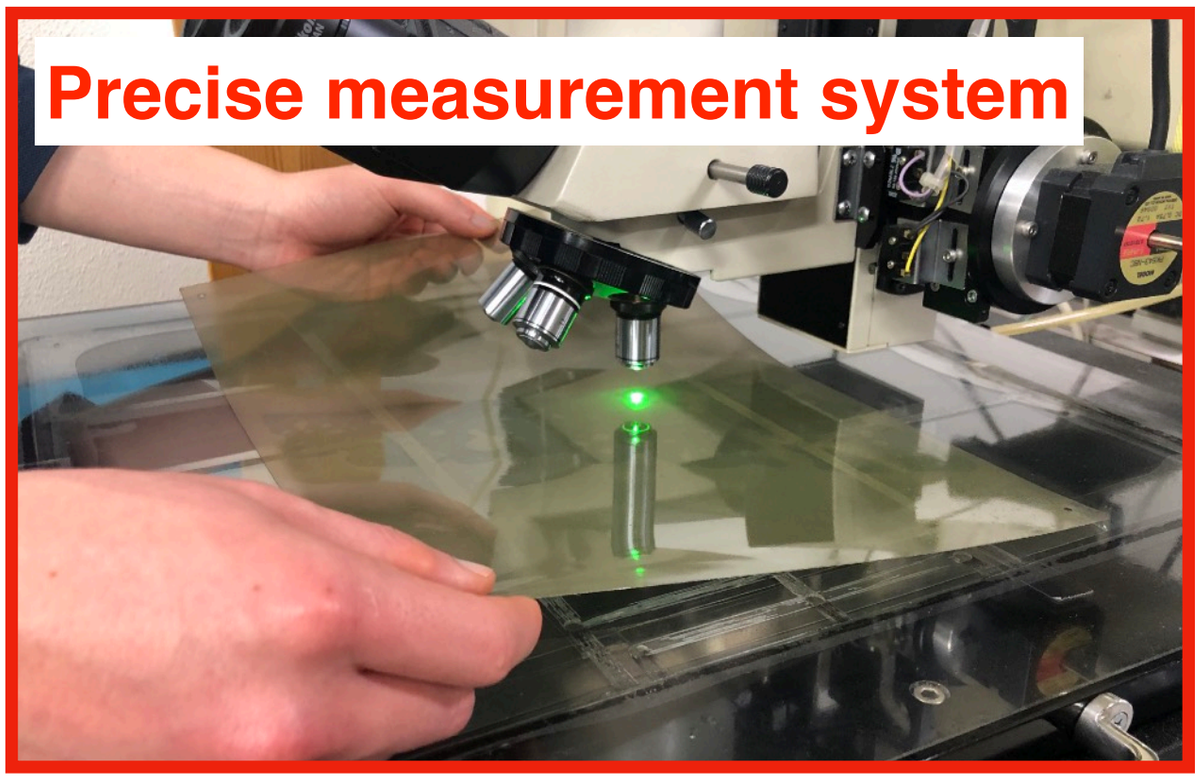
e-pair event selection (high-speed scan)
→Event-by-event Re-analysis(precise scan)

Development (for high statistics, large area telescope) :
Automation & Combined analysis scheme

Microscope for precise measurement

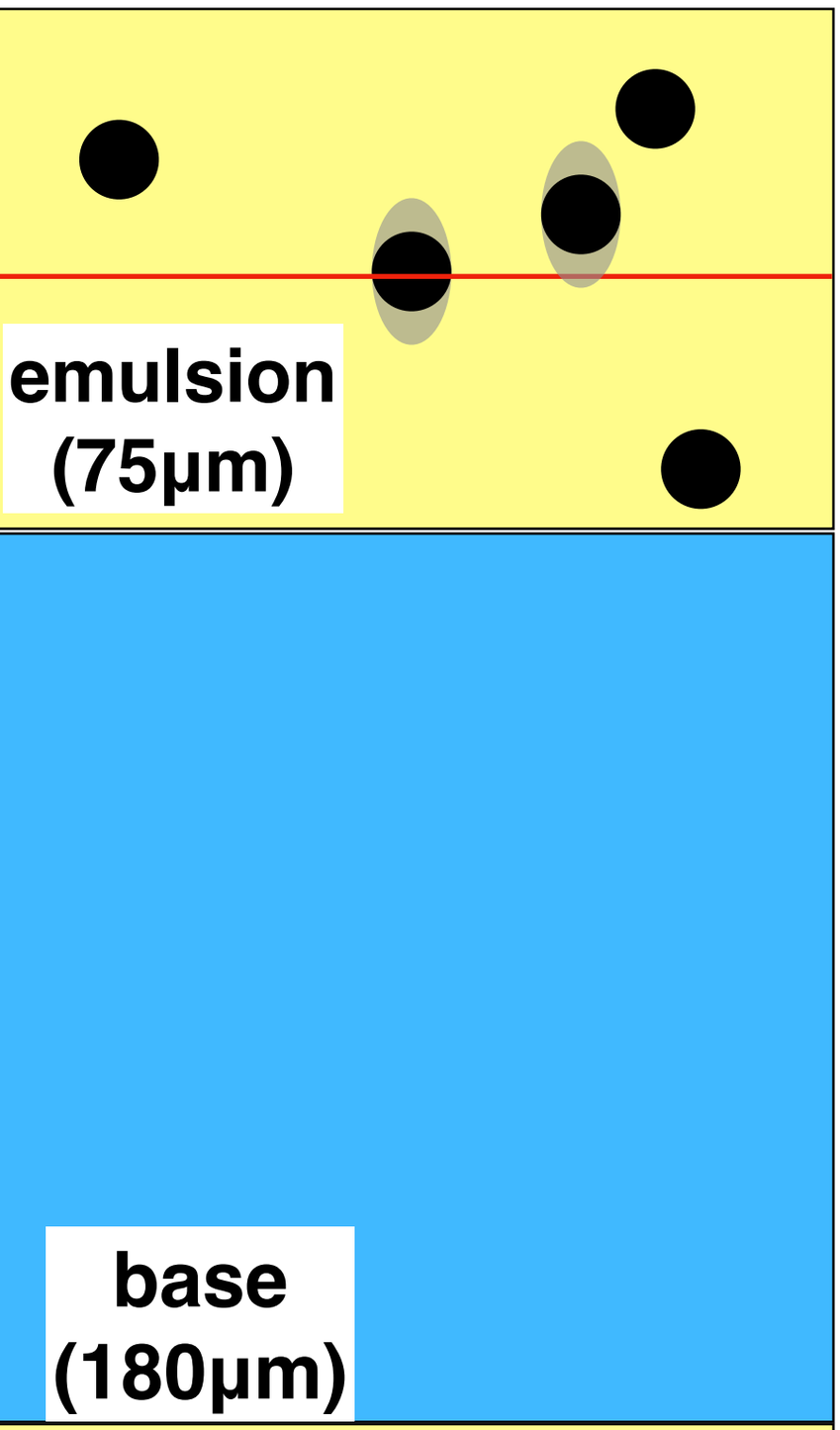




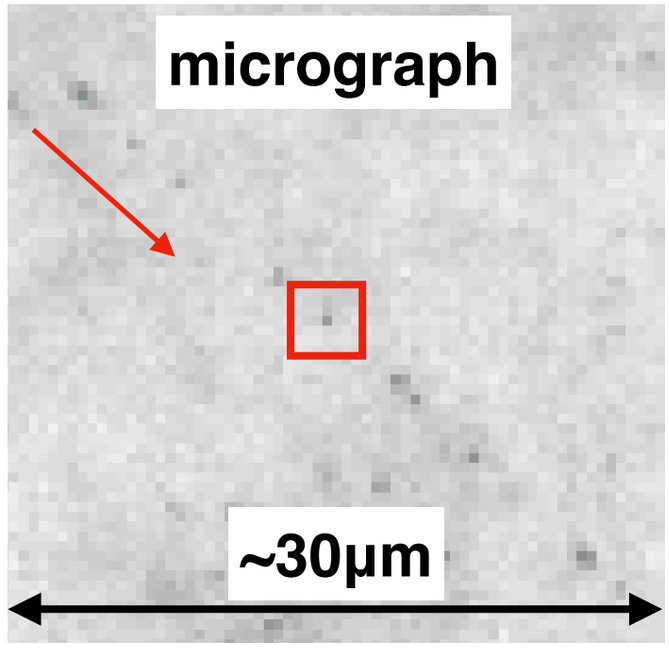


The FoV is narrow, but higher resolution microscope

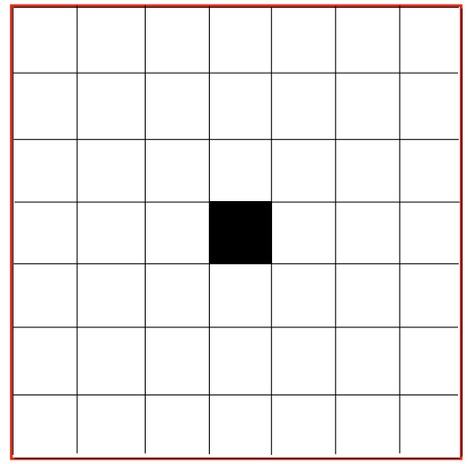
Development of automated measurement of silver grain positions ~Tomographic image acquisition, XY position measurement~.



High-speed(0.45μm/pixel)

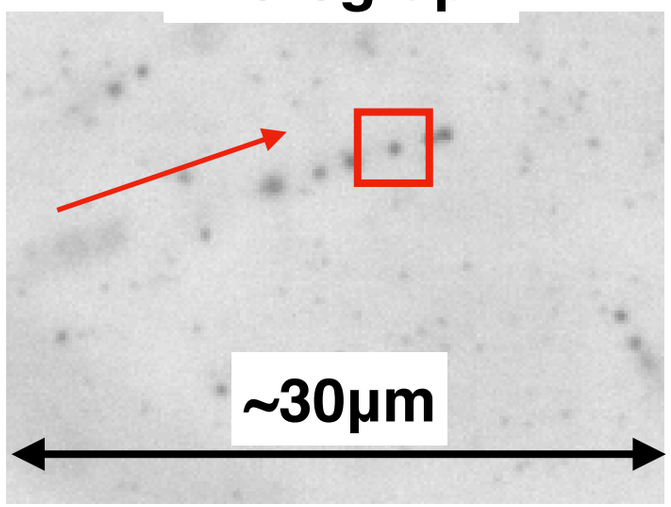


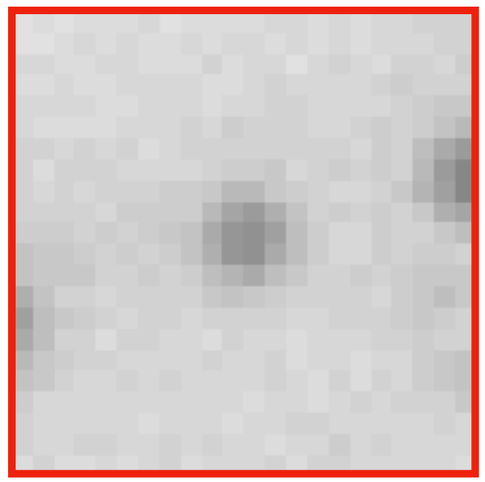
binarization



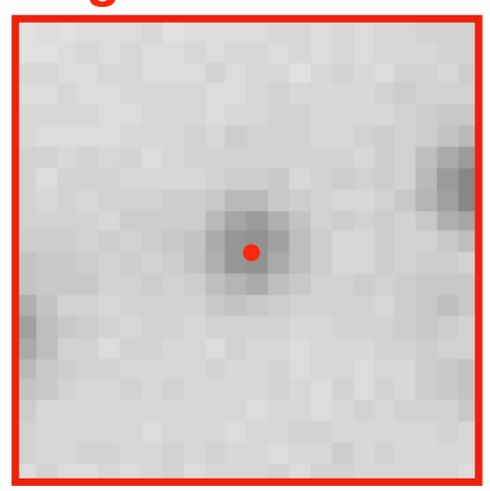
Precision(0.15μm/pixel)

micrograph

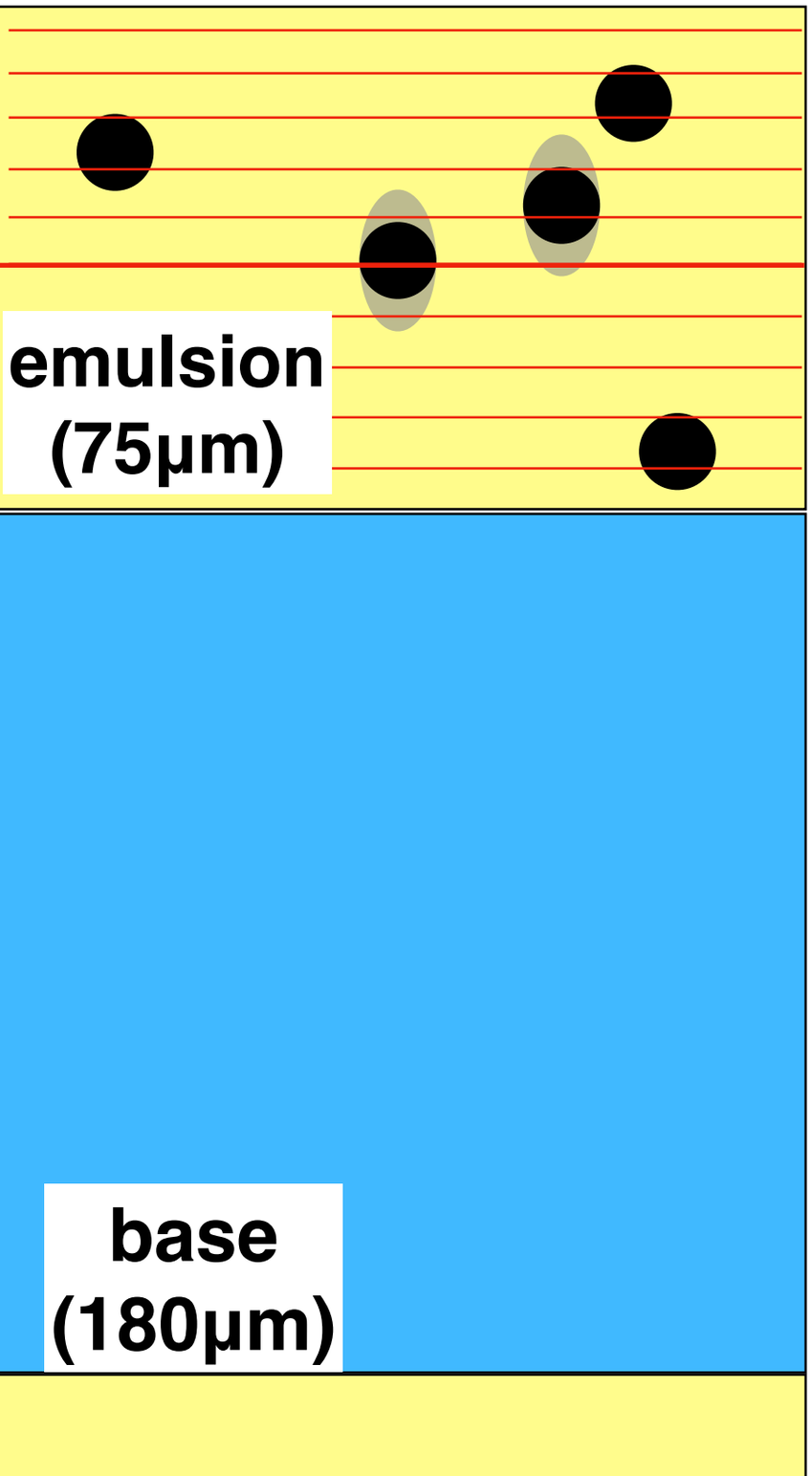




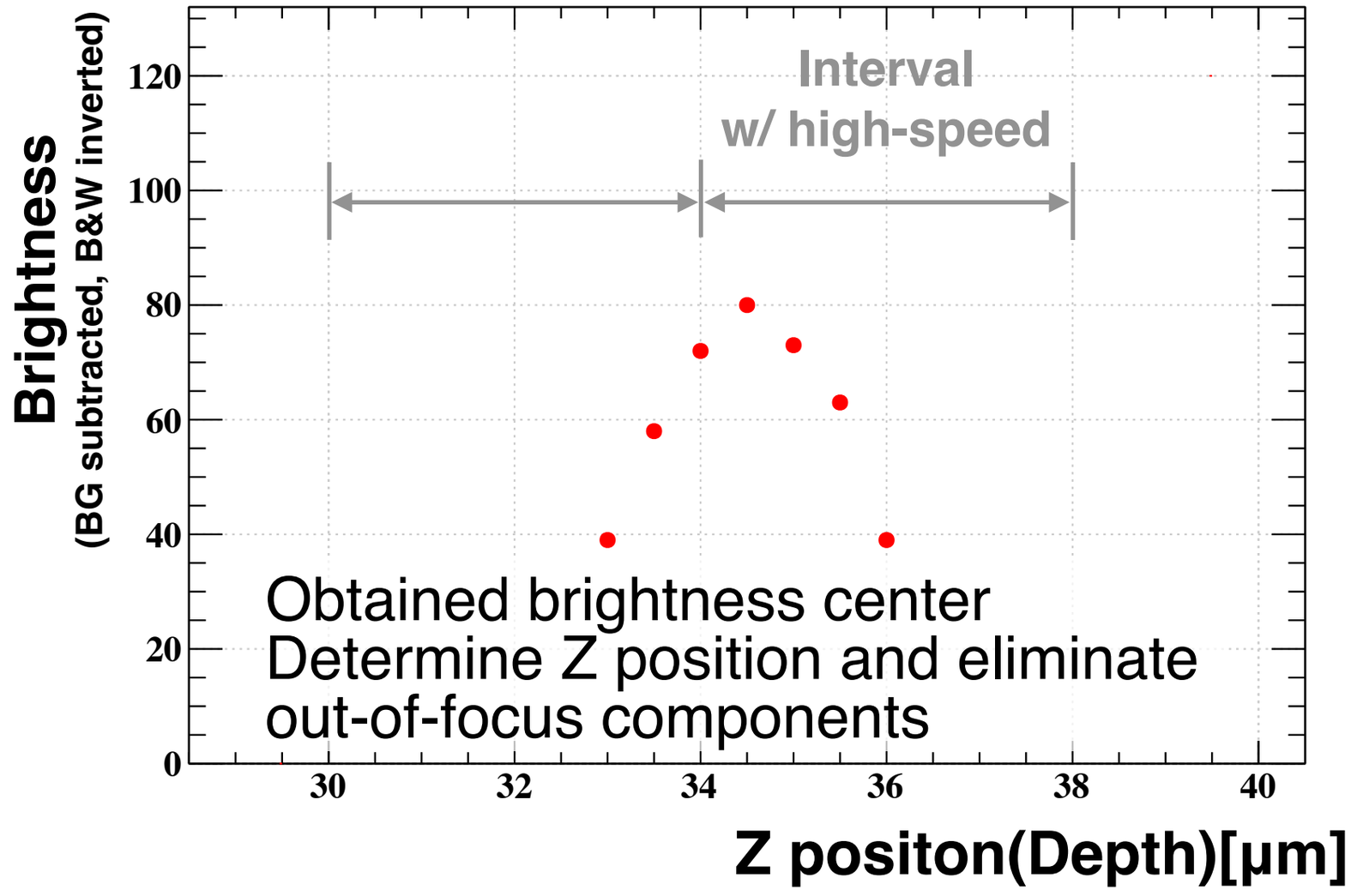
Brightness center



Development of automated measurement of silver grain positions ~Continuous image acquisition, Z-position measurement~.

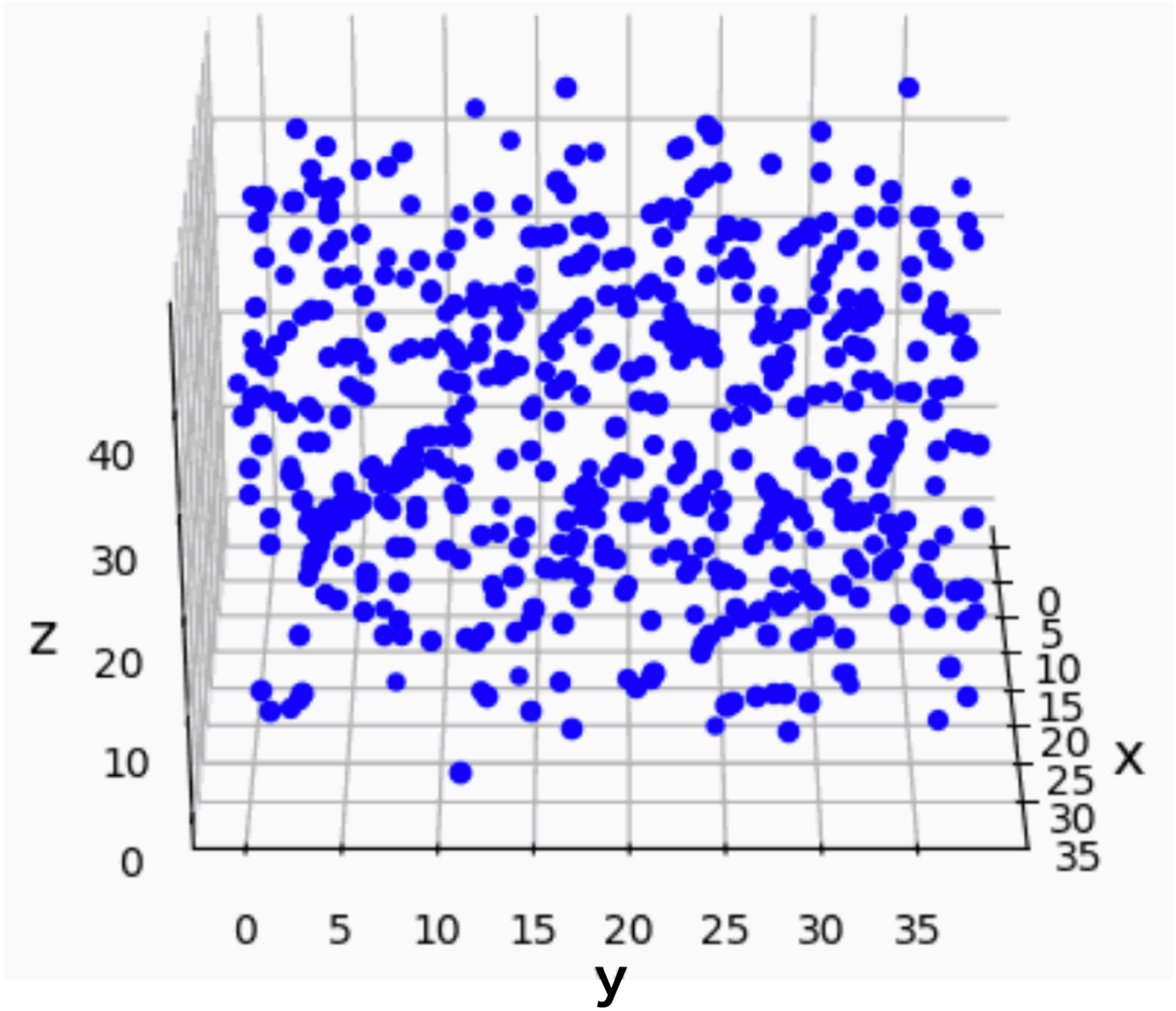


Captures tomographic images at 0.5-μm intervals (⇄High speed: ~4-μm intervals)



Development of automated measurement of silver grain positions

-Result of automatic 3D position measurement-

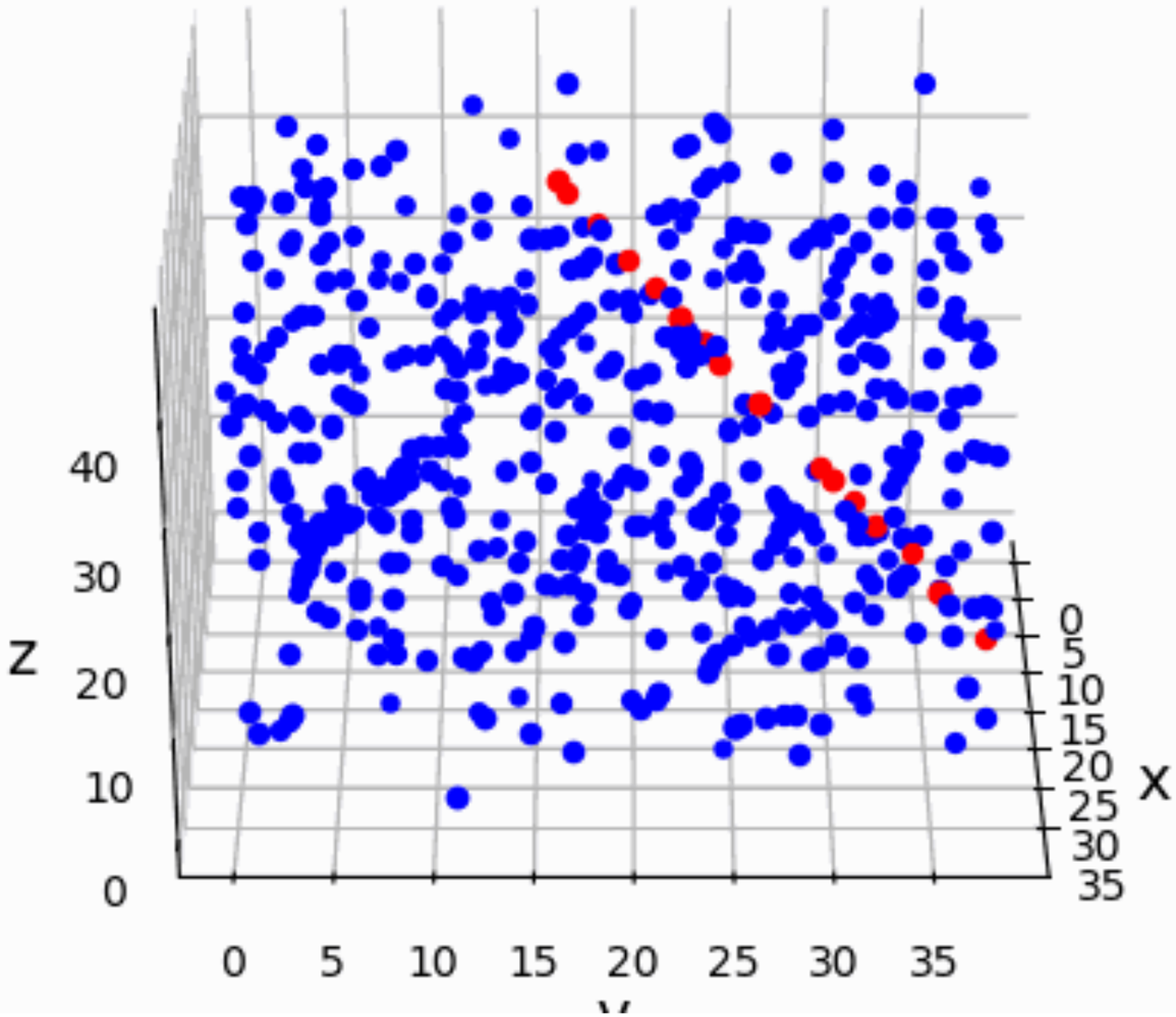


528 grains/~38*38*50 μm³
consistent with expected value from manual measurement

The 3D coordinates of silver grains in the emulsion layer can be automatically obtained from the continuous tomographic image.

Development of automated measurement of silver grain positions

-Result of automatic 3D position measurement-



Red:High-momentum track
selected from
high-speed scanning data

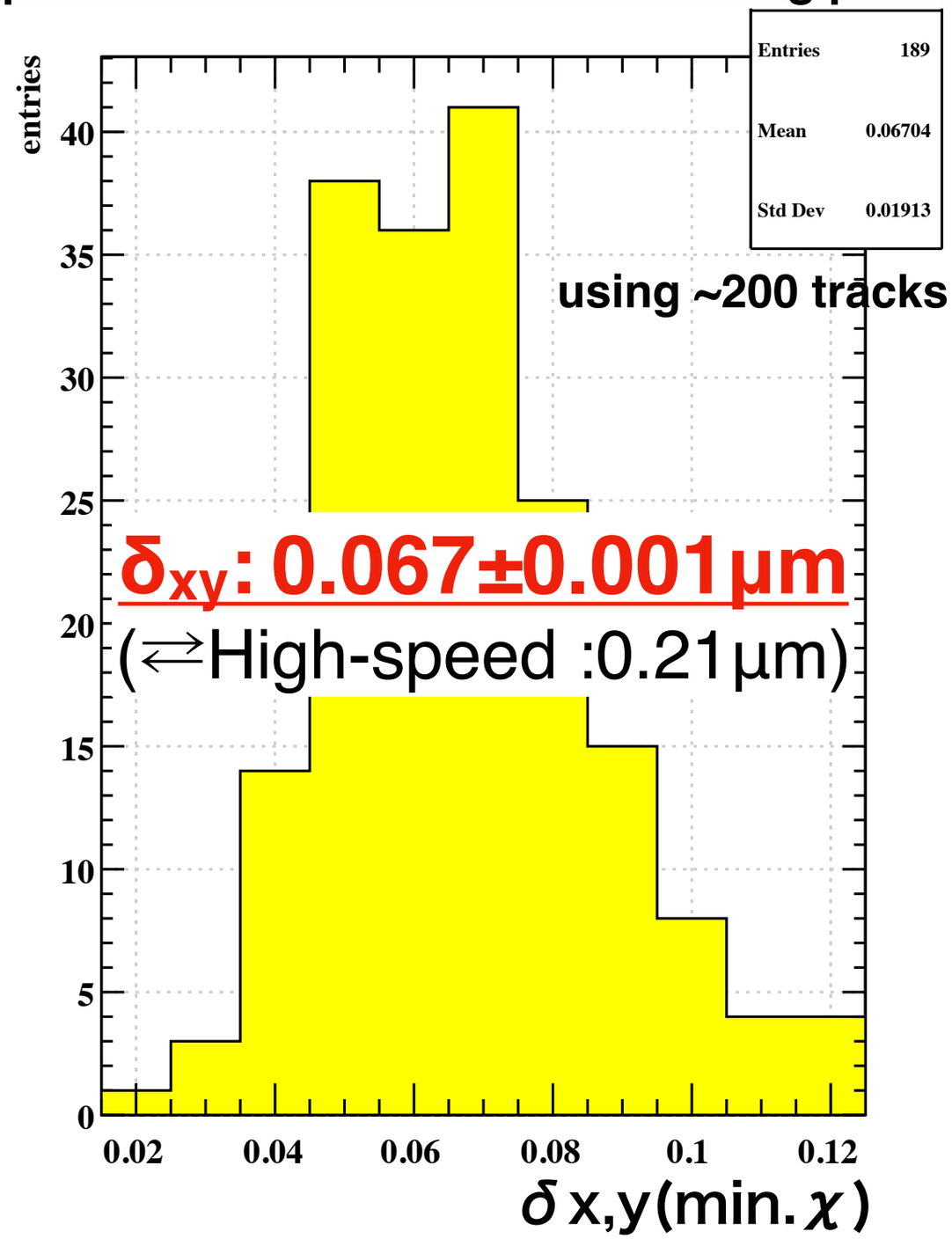
The 3D coordinates of silver grains in the emulsion layer can be automatically obtained
from the continuous tomographic image.

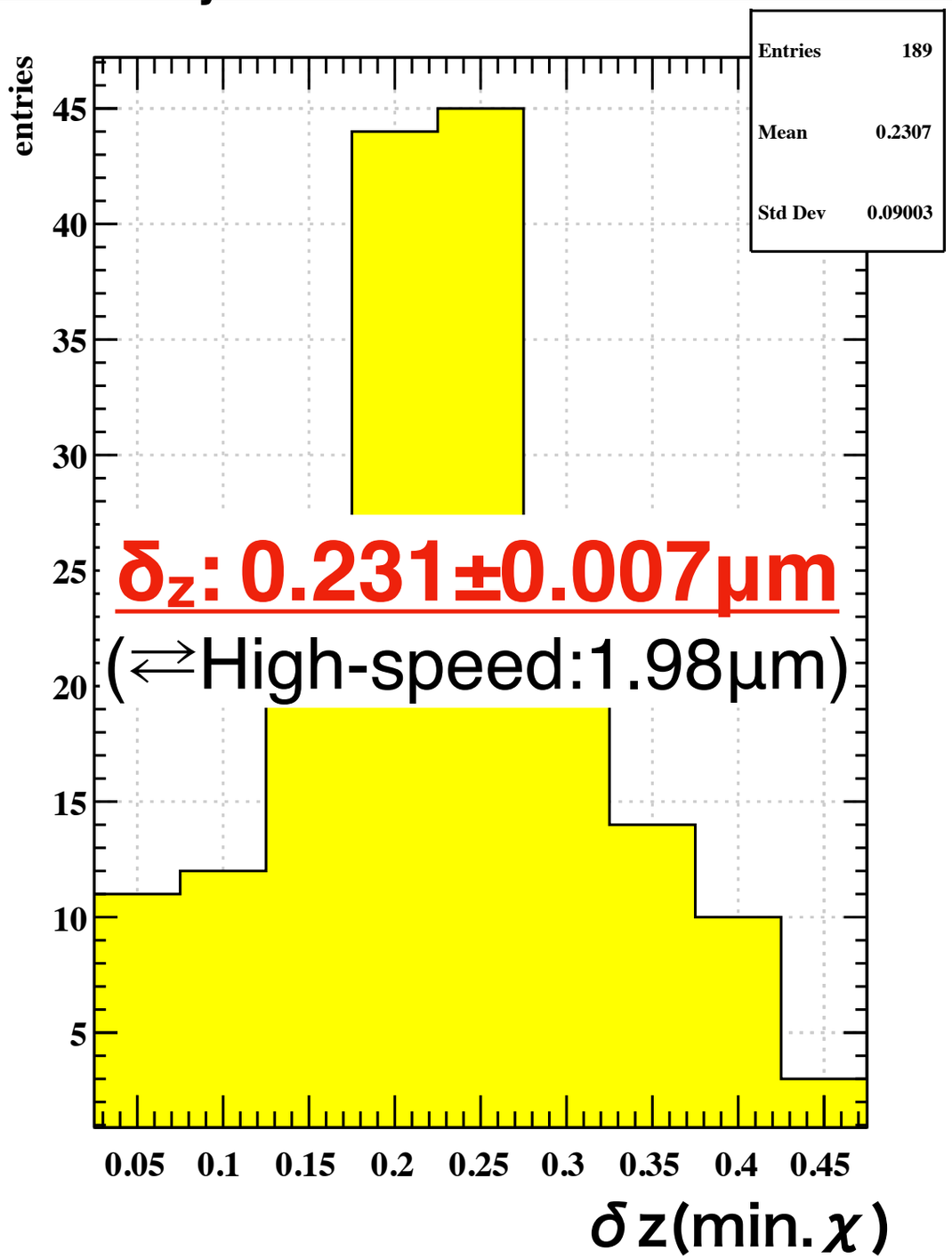
→Evaluate position accuracy using high momentum tracks

Development of automated measurement of silver grain positions

-Result of resolution of 3D position measurement-

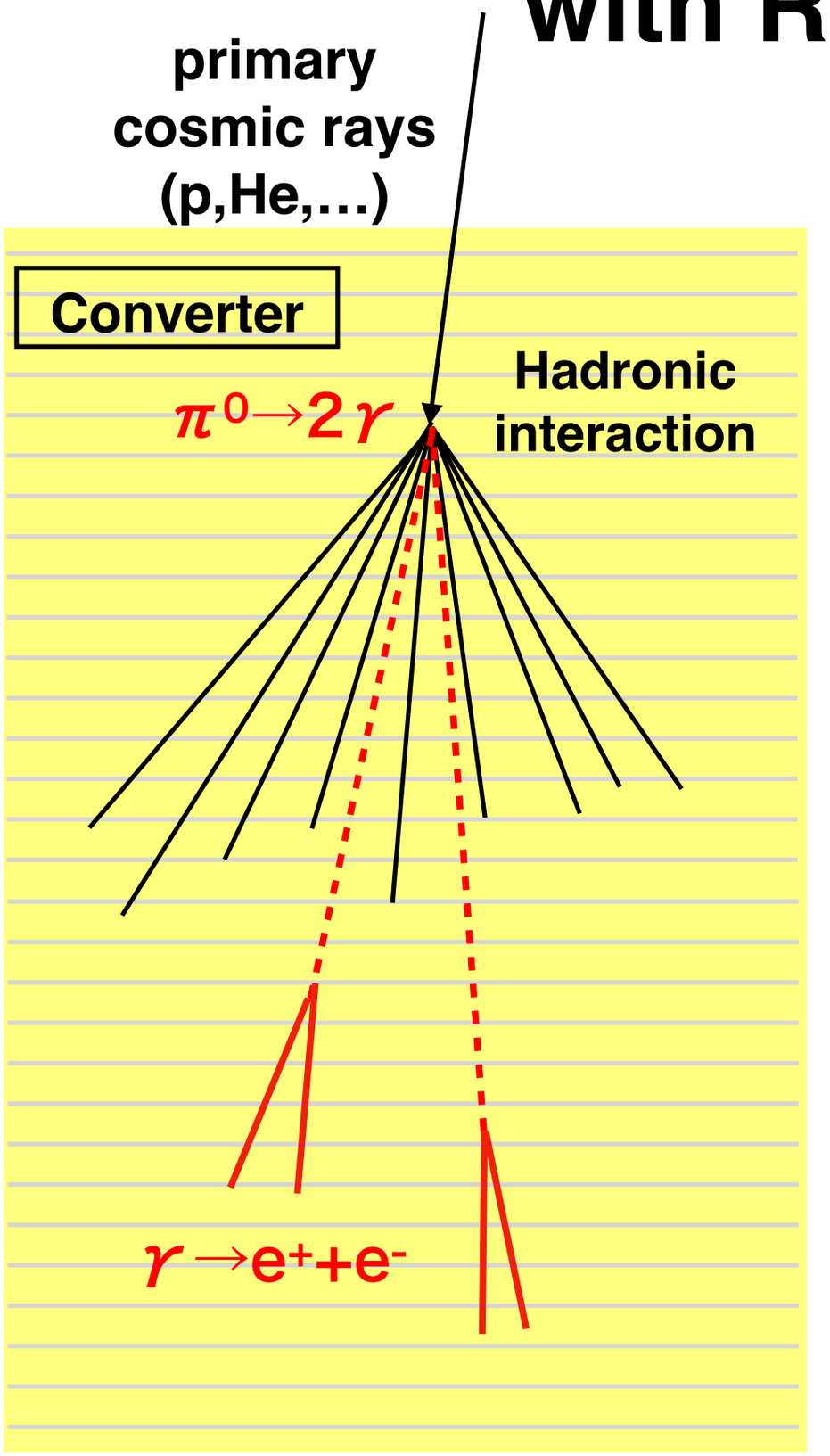
Compare data with simulations assuming position accuracy and estimate measurement accuracy





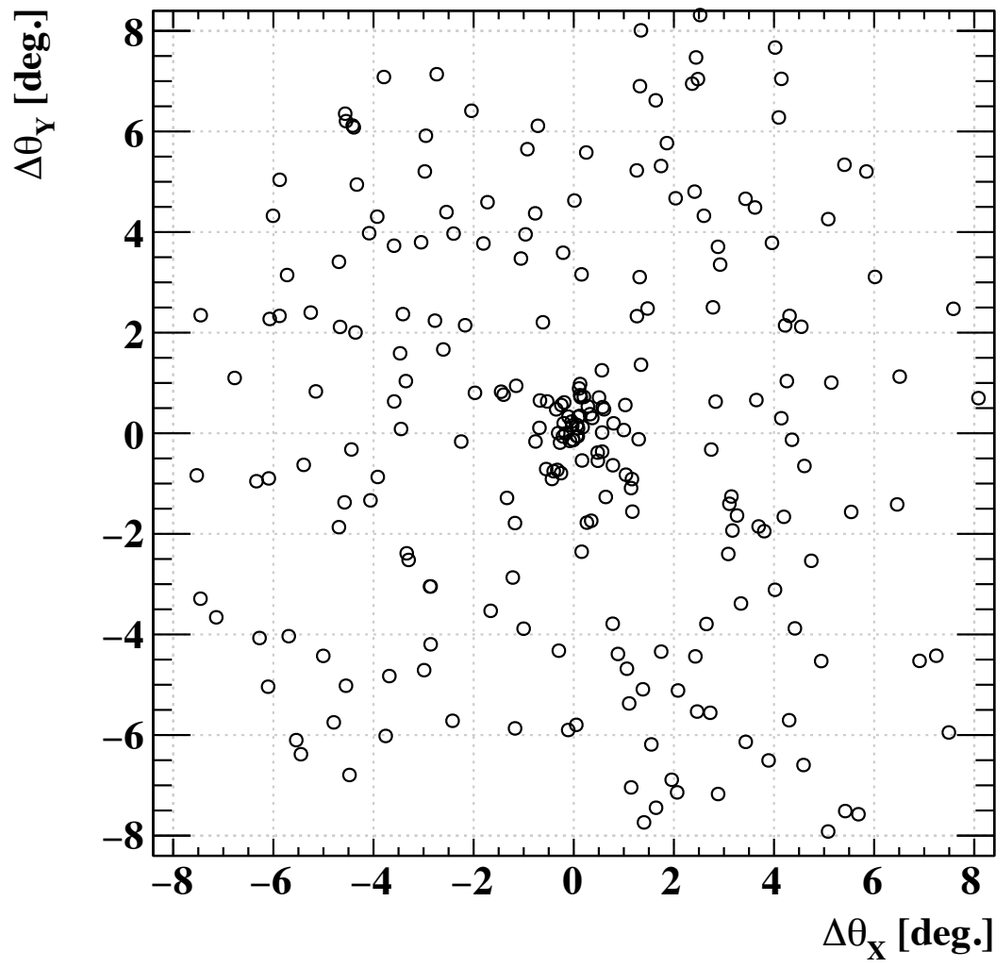
Achieved automation of precise 3D position measurement of silver grains
(measurement accuracy improved by ~1 order of magnitude)

Evaluation of gamma-ray angular resolution with Re-analysis scheme



Using flight data γ-rays from GRAINE2018

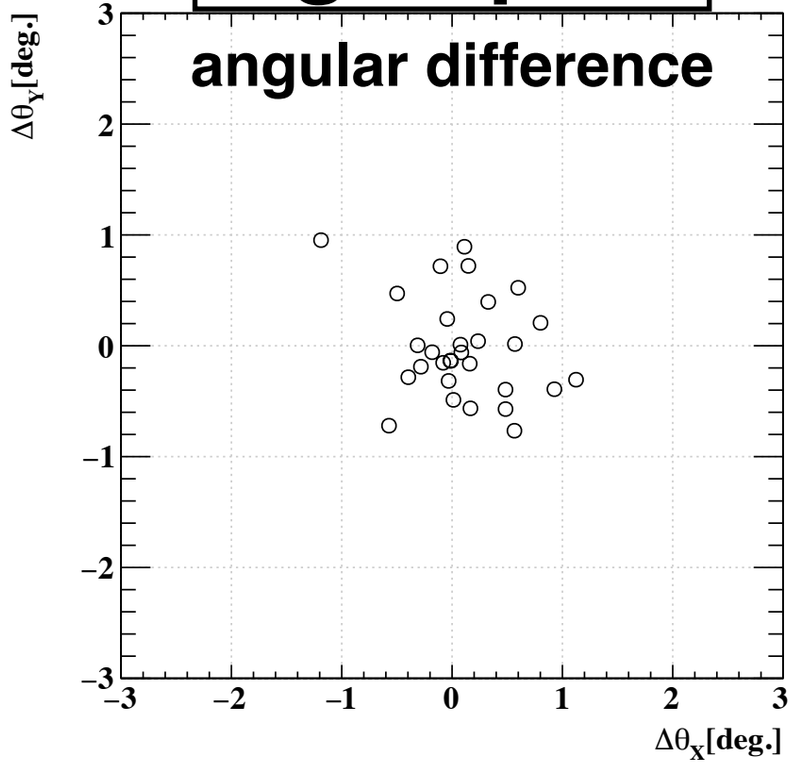
Angular difference distribution (high speed scan data)
E_γ:500-700MeV、$\tan\theta_\gamma$:0.8-1.0

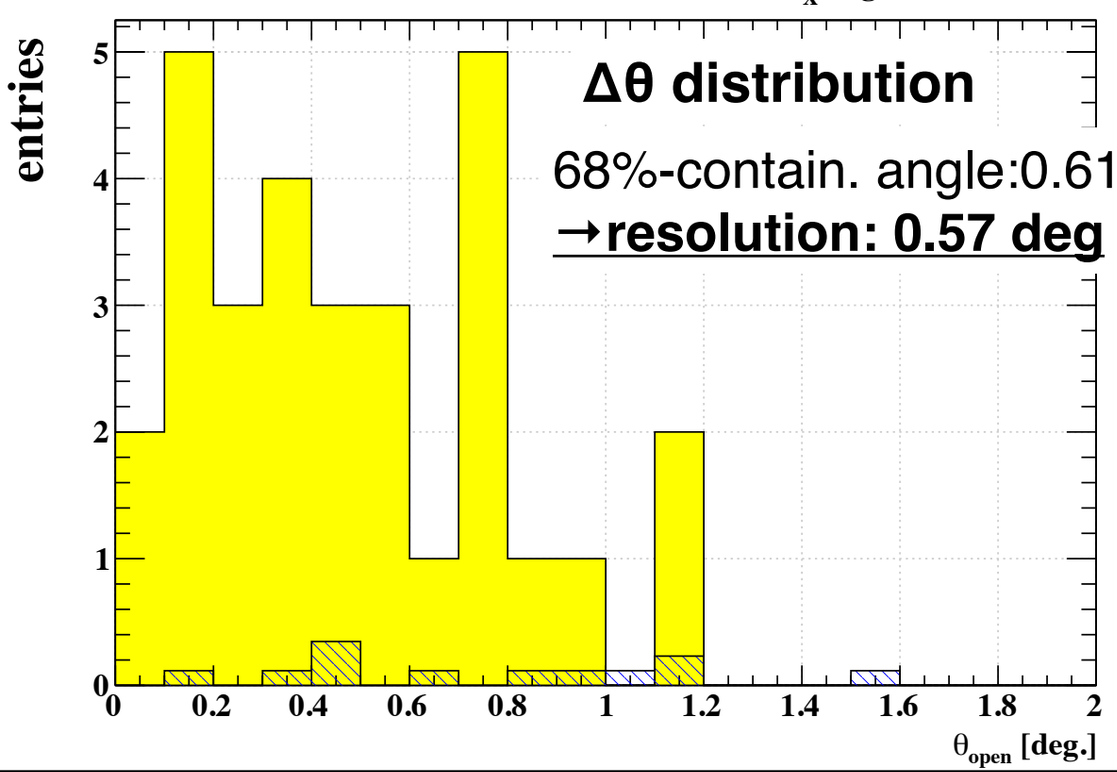


Randomly selected 30 event in signal region
(Estimated contamination BG: 1.4 events)
and Re-analysis the angle w/ Precise scan

Result of gamma-ray angular resolution w/ Re-analysis (high-speed & precision)

High-speed

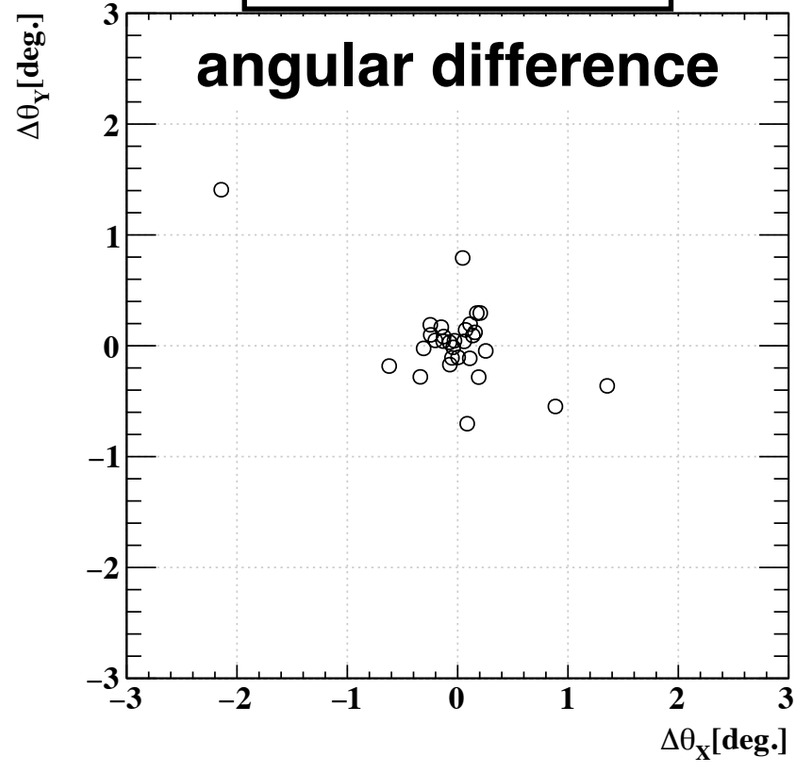


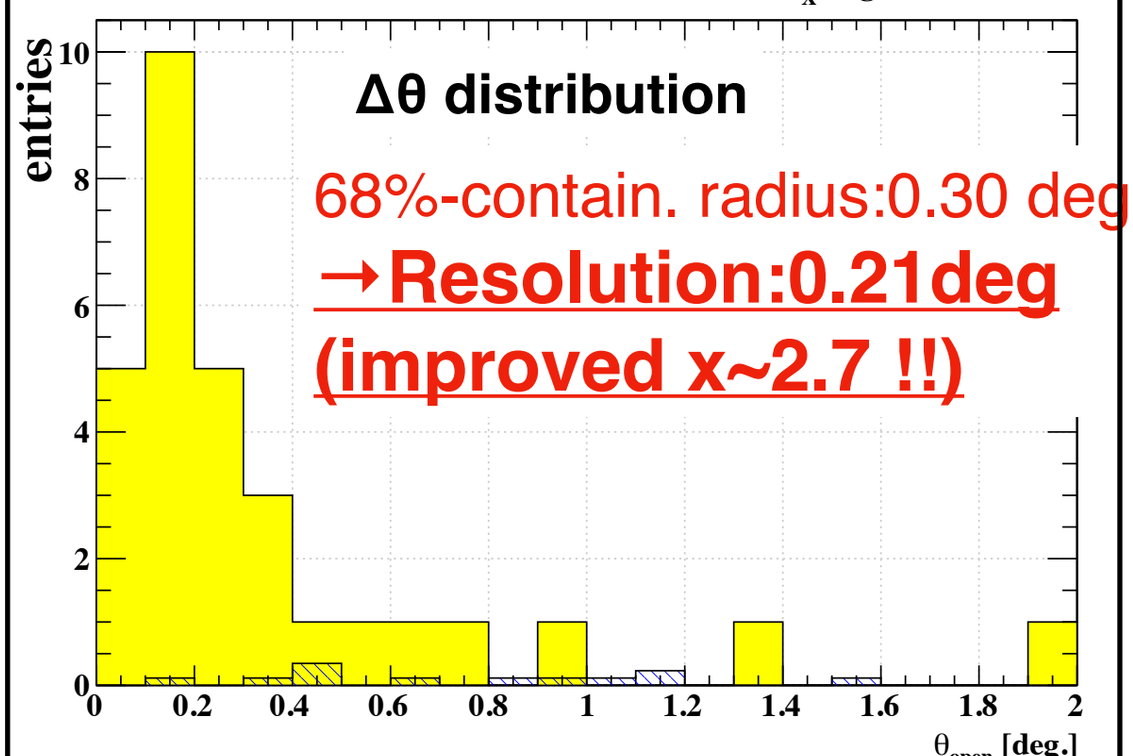


68%-contain. angle:0.61deg

→resolution: 0.57 deg

Precision



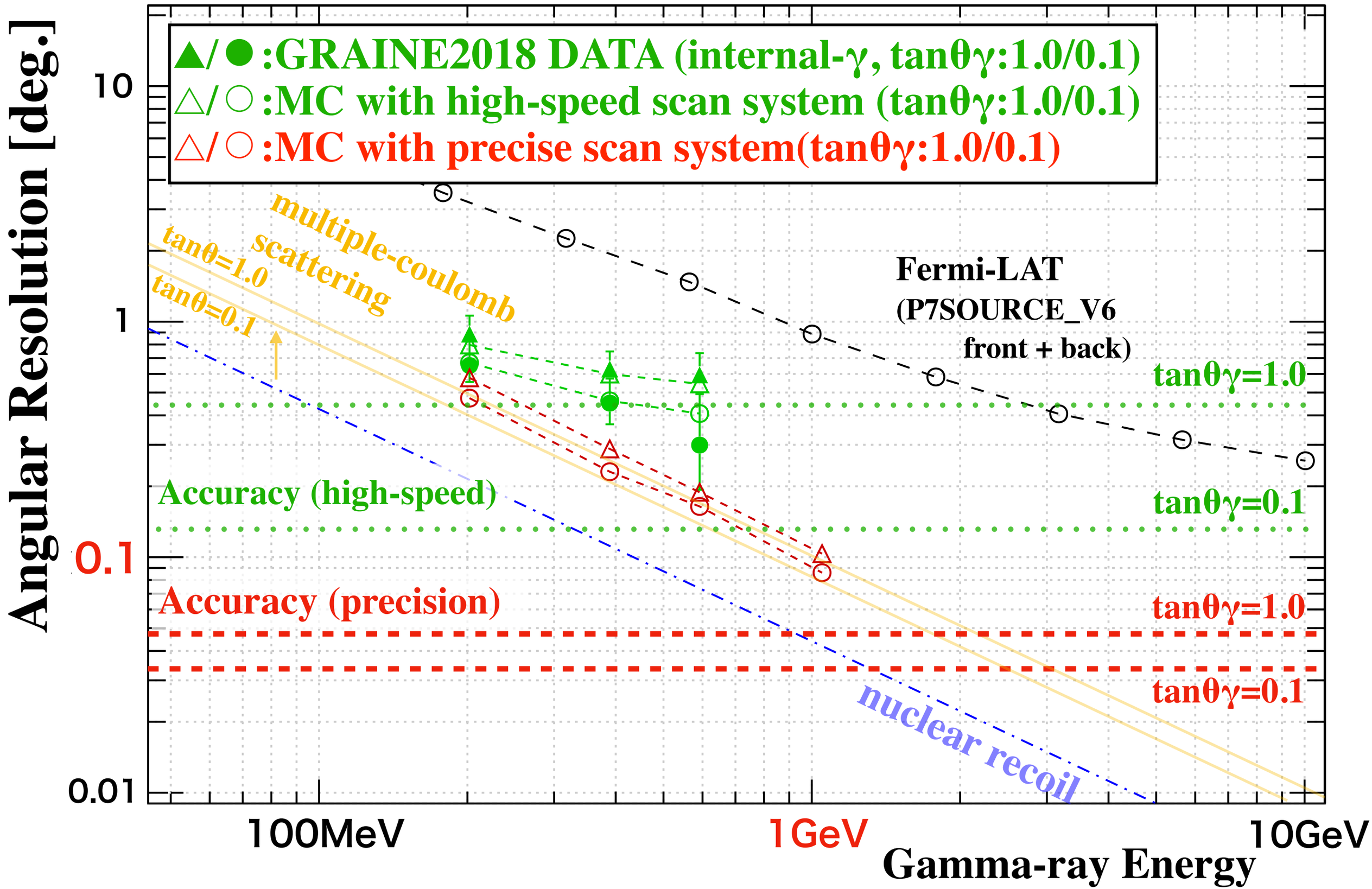


68%-contain. radius:0.30 deg

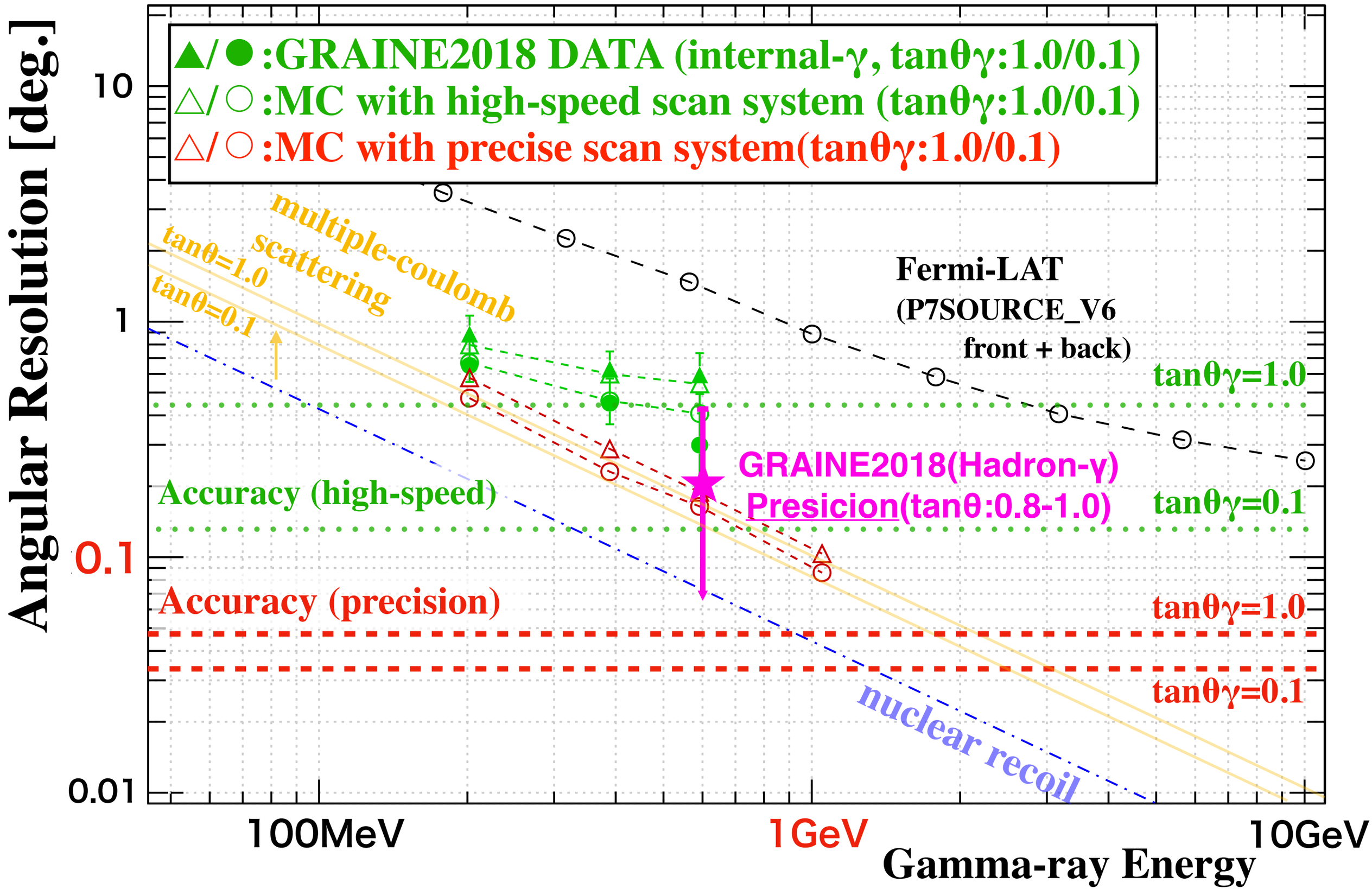
→Resolution:0.21deg

(improved x~2.7 !!)

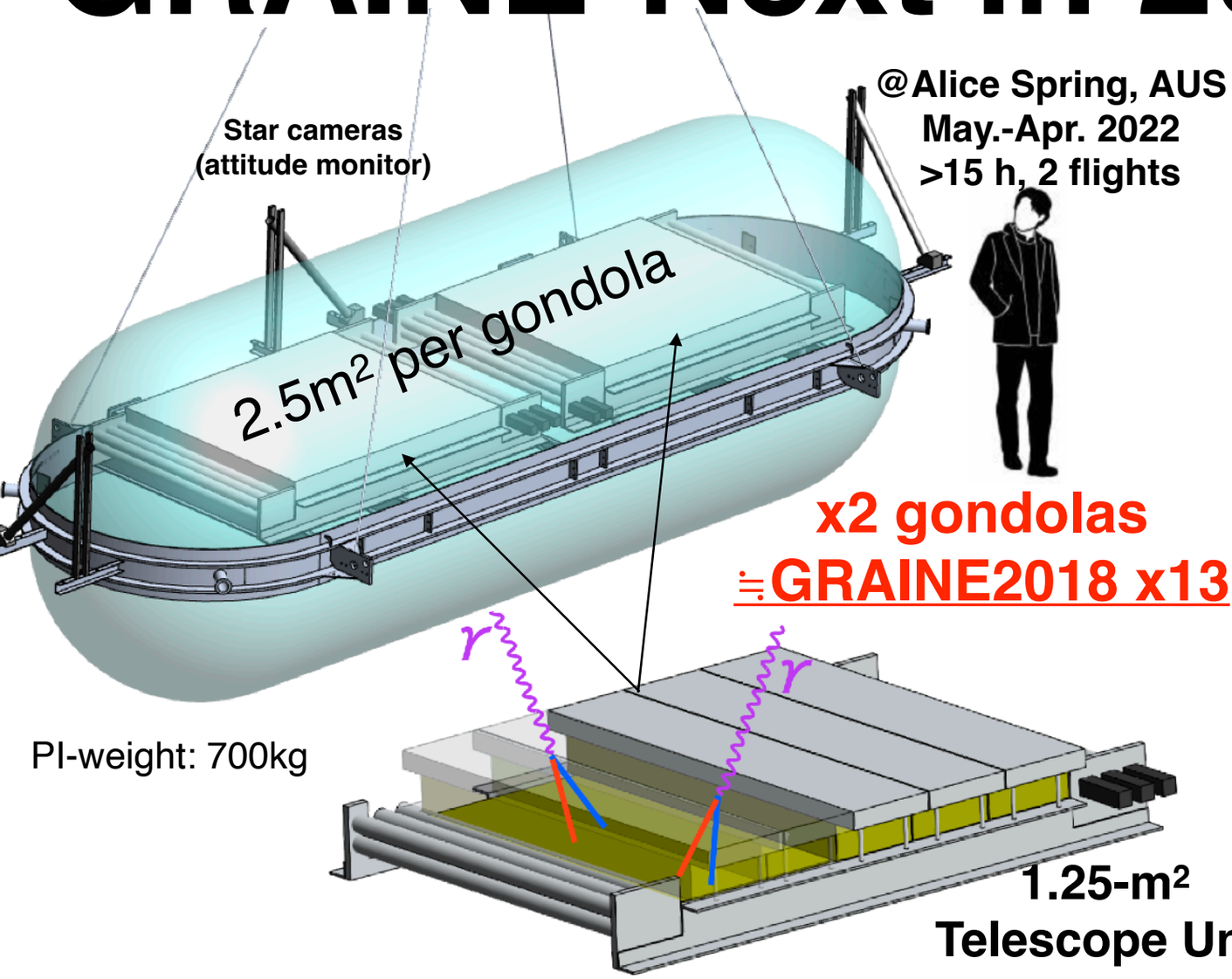
Gamma-ray angular resolution w/ Re-analysis (high-speed & precision)



Gamma-ray angular resolution w/ Re-analysis (high-speed & precision)



GRAINE-Next in 2023 (approved)



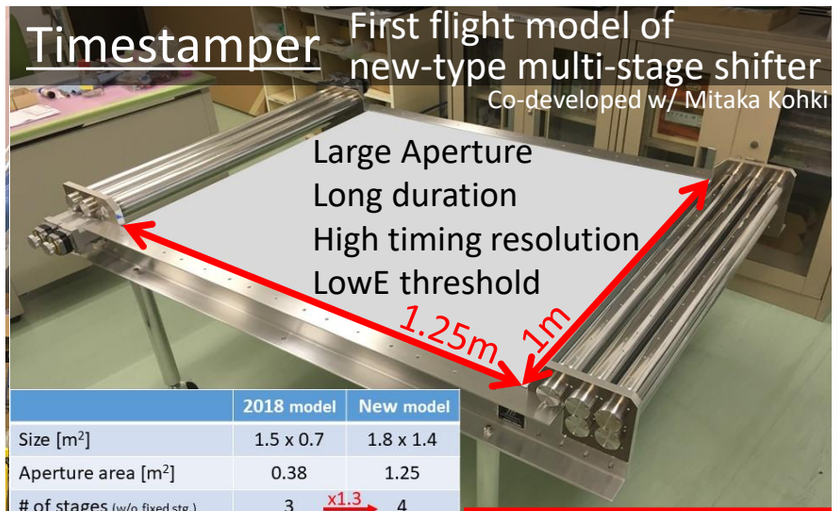
@Alice Spring, AUS
May.-Apr. 2022
>15 h, 2 flights

x2 gondolas
≒GRAINE2018 x13

- Commissioning towards scientific observation
- The world's largest aperture GeV gamma-ray telescope
- High-resolution imaging of Vela in GeV region
- Observation of Gal. center region (diffuse, point sources)
- Survey for transient sources (~2 events/flight is expected)

Timestamper

First flight model of new-type multi-stage shifter
Co-developed w/ Mitaka Kohki



	2018 model		New model
Size [m²]	1.5 x 0.7		1.8 x 1.4
Aperture area [m²]	0.38		1.25
# of stages (w/o fixed stg.)	3	x1.3 →	4
Gap [mm] ()内は最終段間	1 (0.5)	x1/2 →	0.5
Weight [kg]	65		80
Weight w/ 1.25m²-ap [kg]	214	x1/2.7 →	80

~1/3 weight per area
cf. 2018 model

Pressure vessel gondola

Film Production

& Improvement of developing solution

Summary

- Developed a system to automatically measure the three-dimensional coordinates of silver particles in emulsion.
  Achieved positioning accuracy ~1 order better than high speed system
  δ_{xy}=0.067μm、δ_z=0.231μm

  Angular Res. of <0.1 degree achievable with 1-1.5 GeV gamma rays

- Reanalysis of γ-ray angles by precision measurements for GRAINE2018 flight data due to hadron reactions

  Result. **0.21 deg. @**E_γ:500-700MeV, $\tan\theta_\gamma$:0.8-1.0
  Achieved ~2.7x improvement compared with high-speed system

  (Precise measurement minimizes electromagnetic scattering
  →Angular resolution improvement in sub-GeV
  and polarization measurement are realized)

GRAINE 2023 with large-area x precision measurements will start high-resolution observations of galactic centers, etc.