GRAINE:
sub-GeV/GeV gamma-ray observation using a balloon-borne telescope equipped with nuclear emulsion films

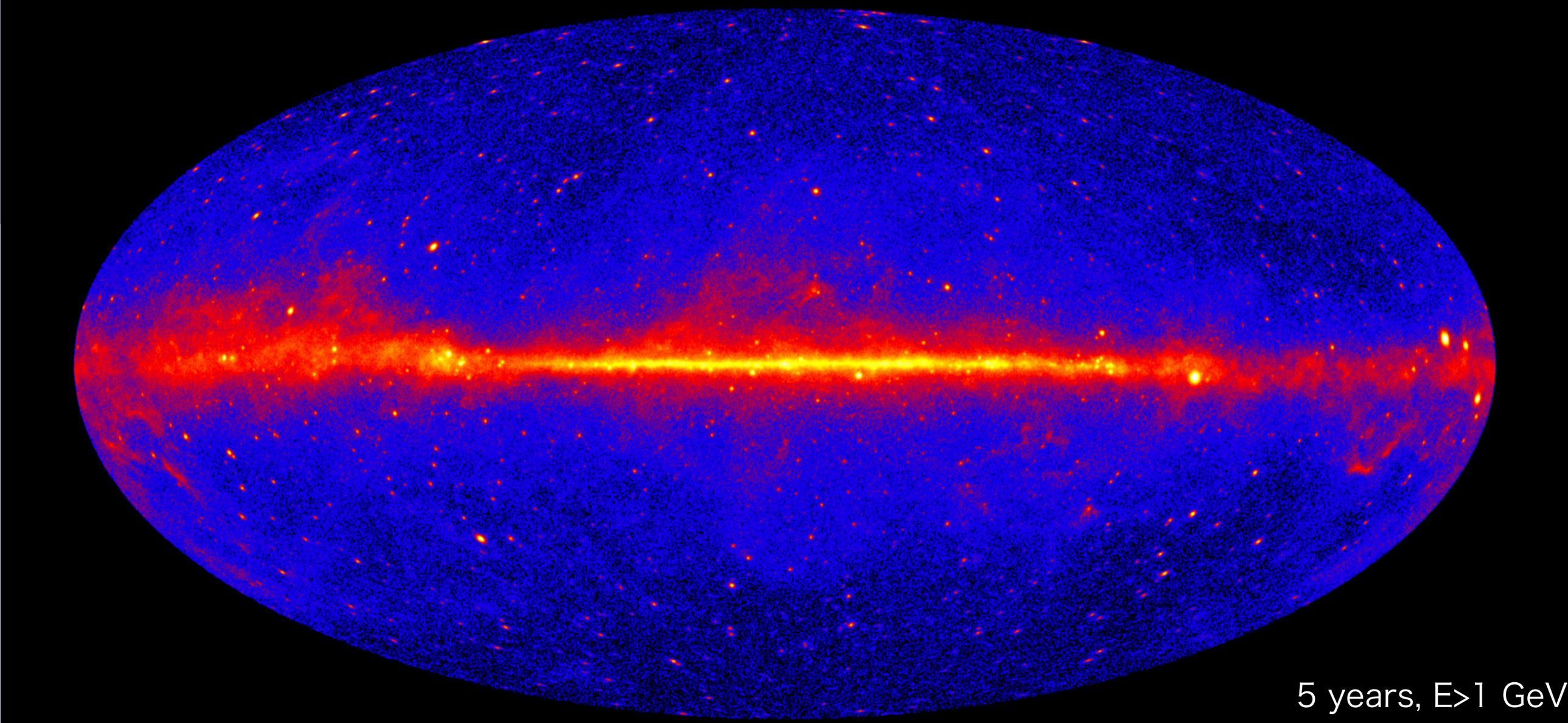
Nagoya University, KMI
Yuya Nakamura
for GRAINE Collaboration

launching in GRAINE2023 at Australia

Cosmic Gamma ray(sub-GeV,GeV)

	Telescope	detected sources
1990-2001	EGRET	271
2008-	**Fermi-LAT**	**>7000**

- **Revealing the high-energy astronomical phenomena**(Black hole, pulsar, etc)
- **Ripple effect for many fields** (w/ Gravitational waves, neutrino)



5 years, E>1 GeV

Cosmic Gam

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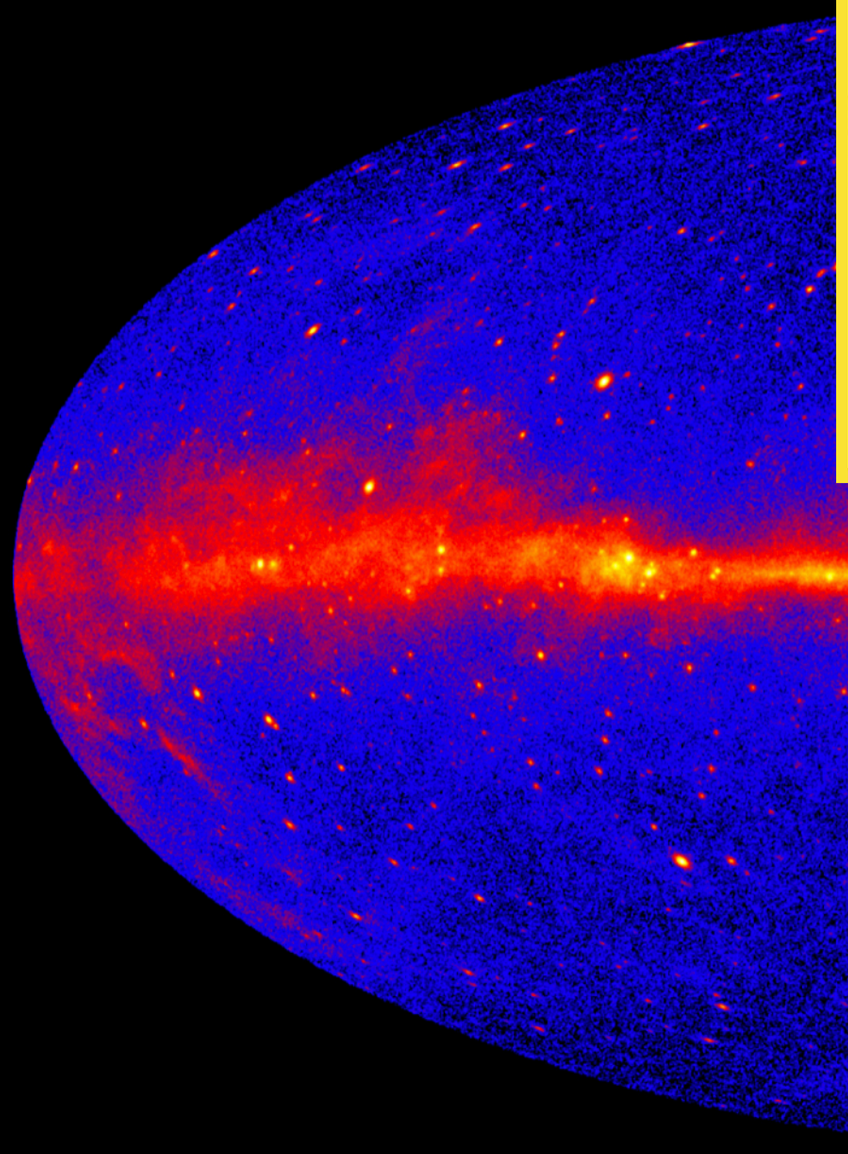
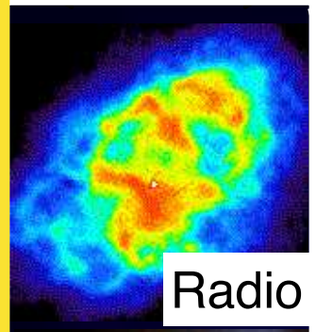
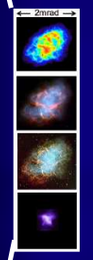




Imaging Performance of Fermi-LAT

γ ray >1GeV
(Fermi-LAT)

Crab Nebula
(M1:SN1054)



0.1°

0.1°

Same scale

All objects are blurred with the size of the moon!!

5 years, E>1 GeV

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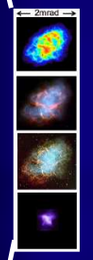

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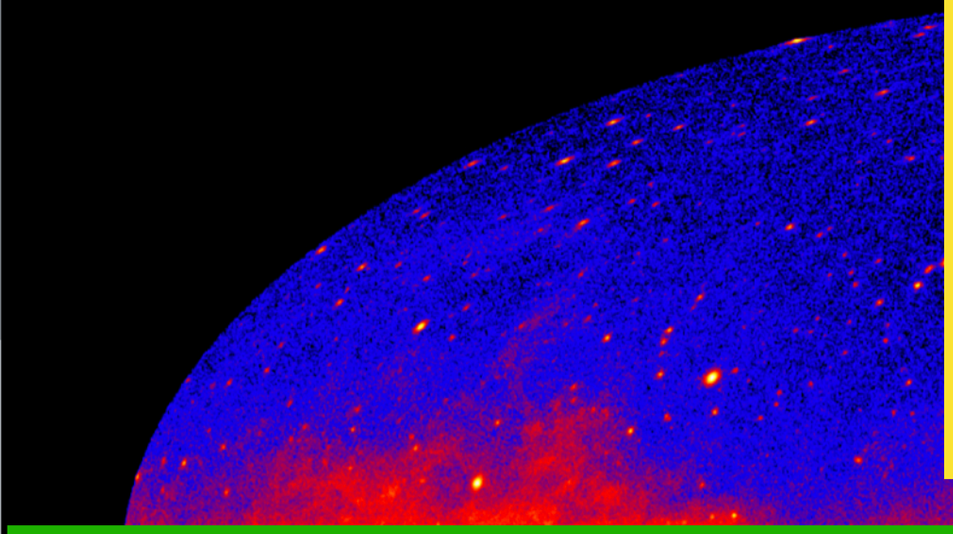
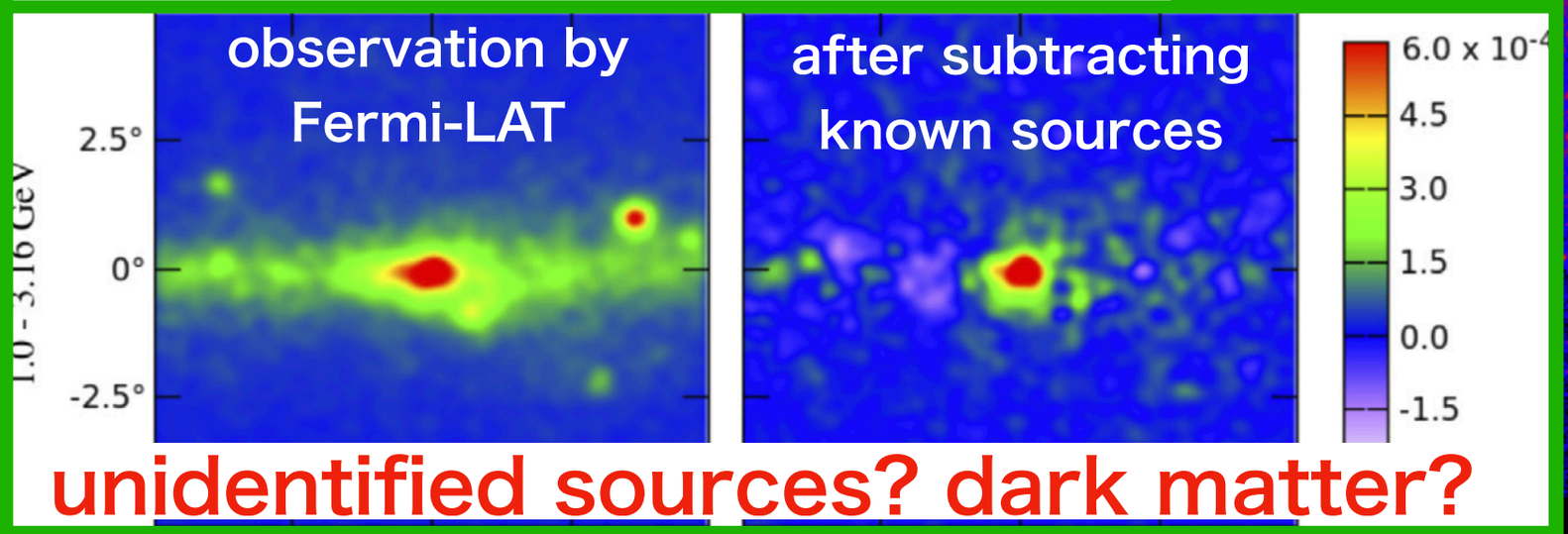


unknown γ-ray excess at GC



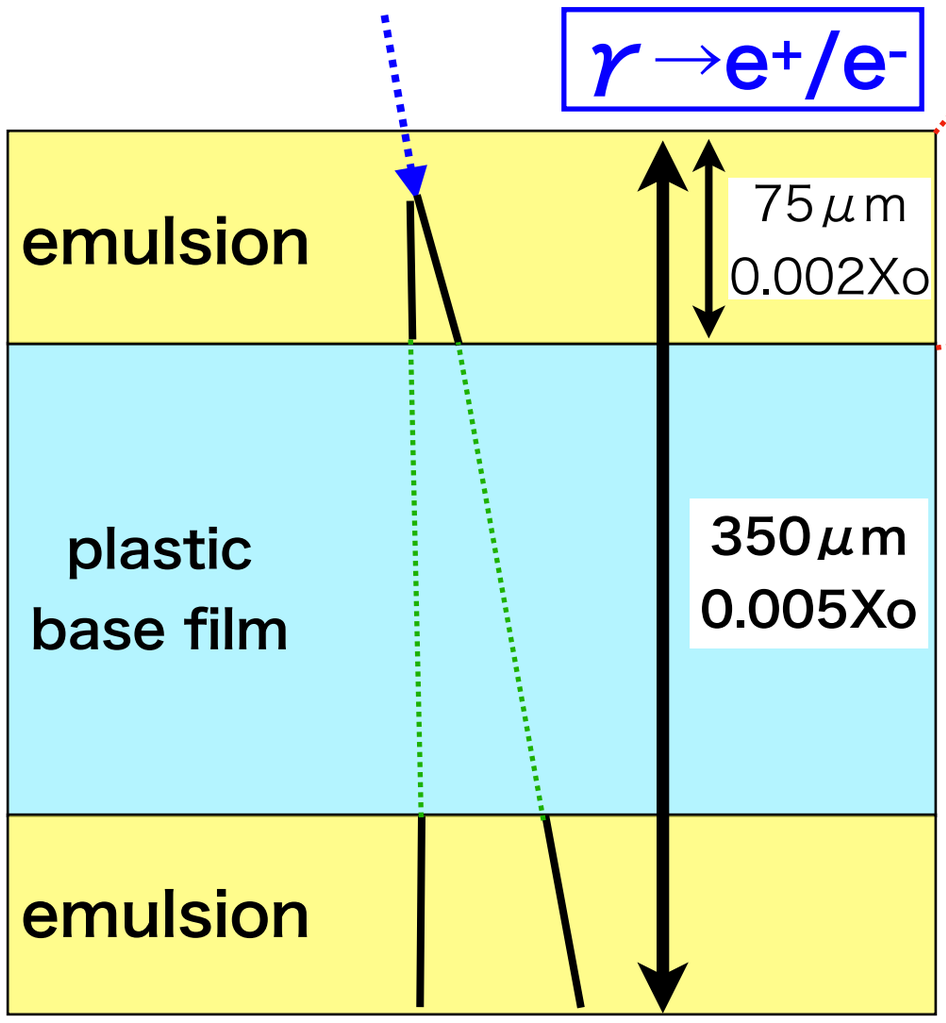
unidentified sources? dark matter?

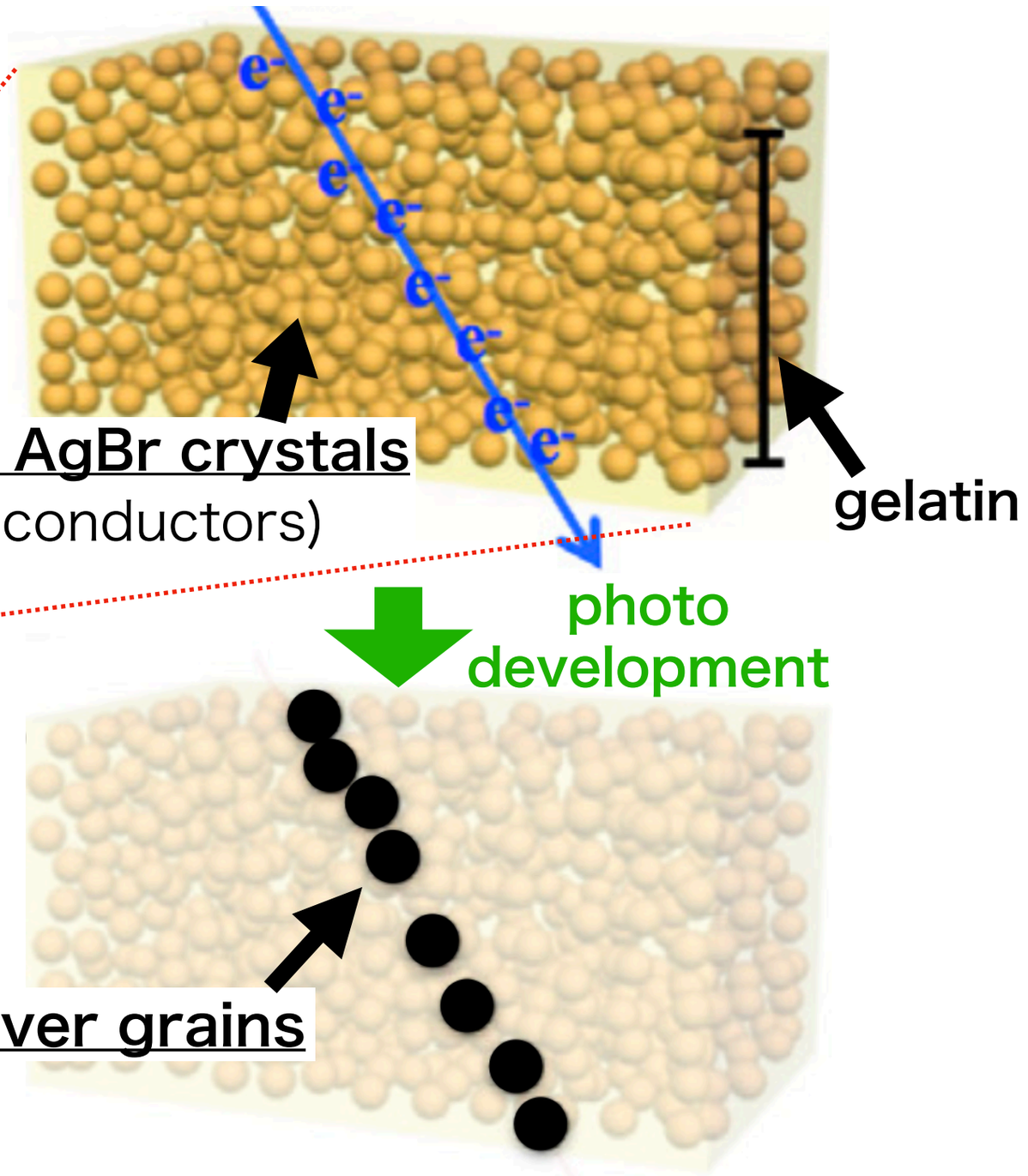
Improvement of the angular resolution is needed

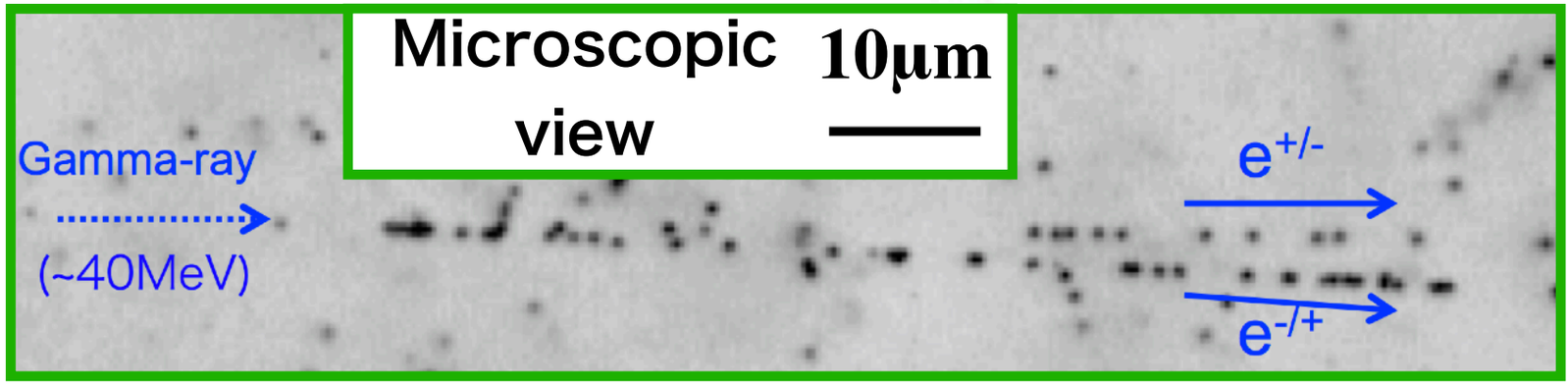
5 years, E>1 GeV

Detector: Nuclear emulsion film

cross sectional view
of the emulsion film

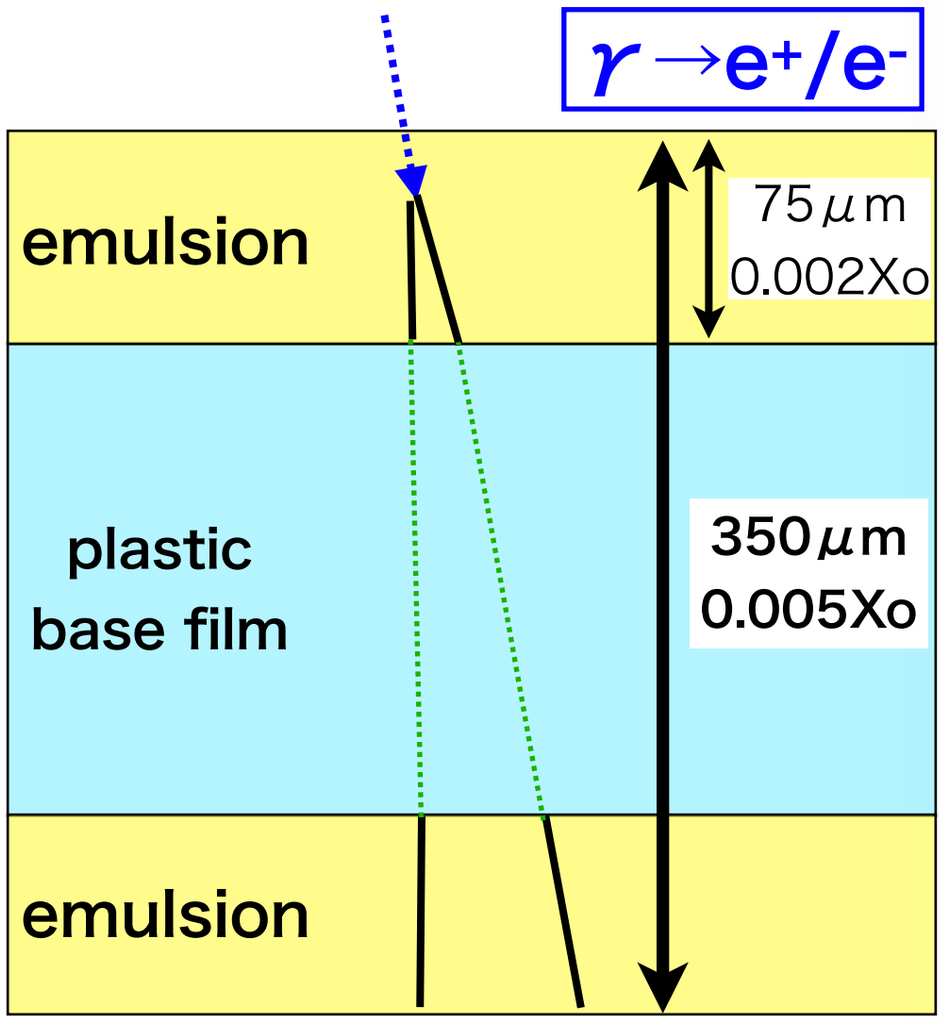






Detector: Nuclear emulsion film

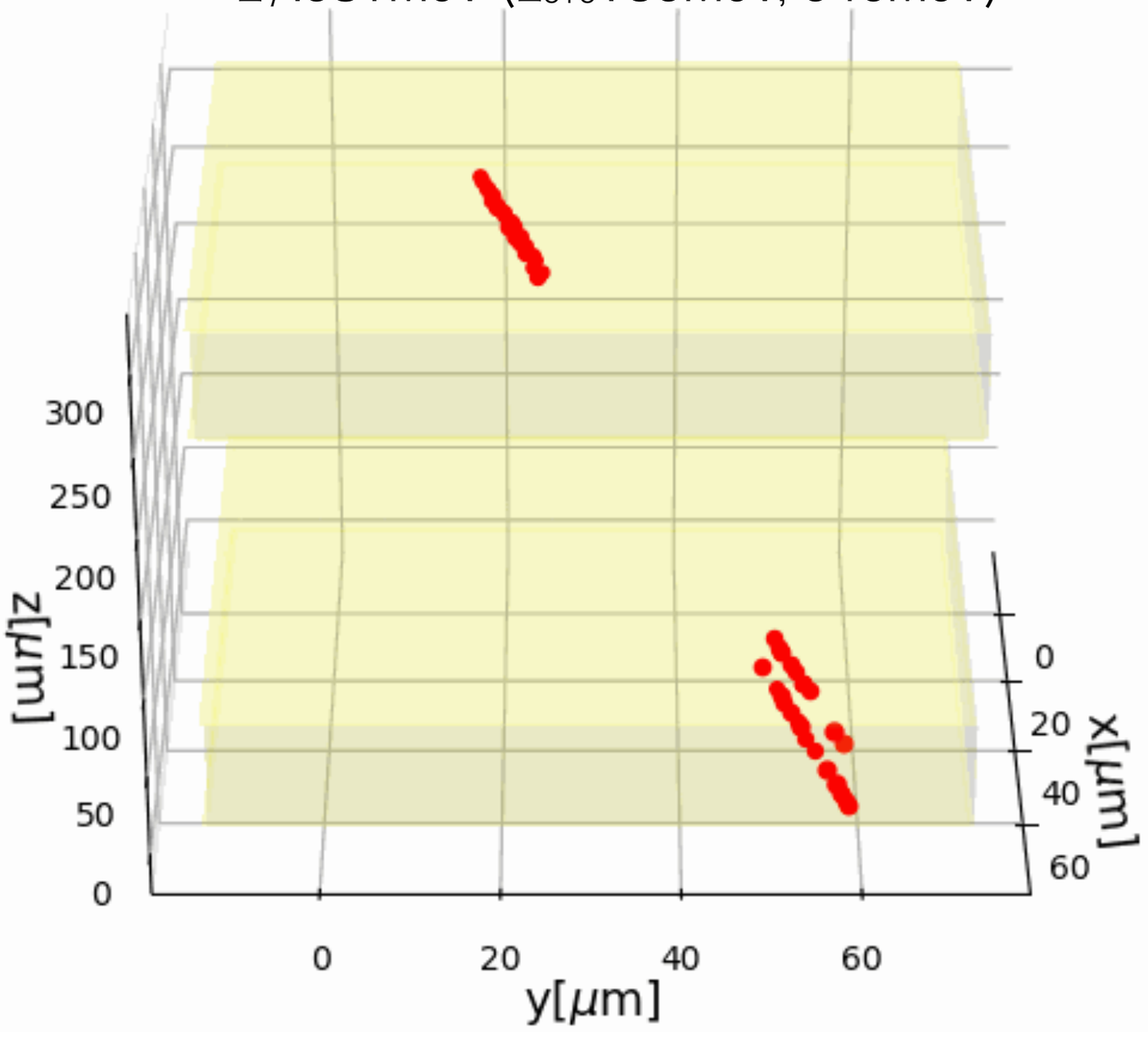
cross sectional view
of the emulsion film



Scanning system: analog to digital

3-D position of silver grains

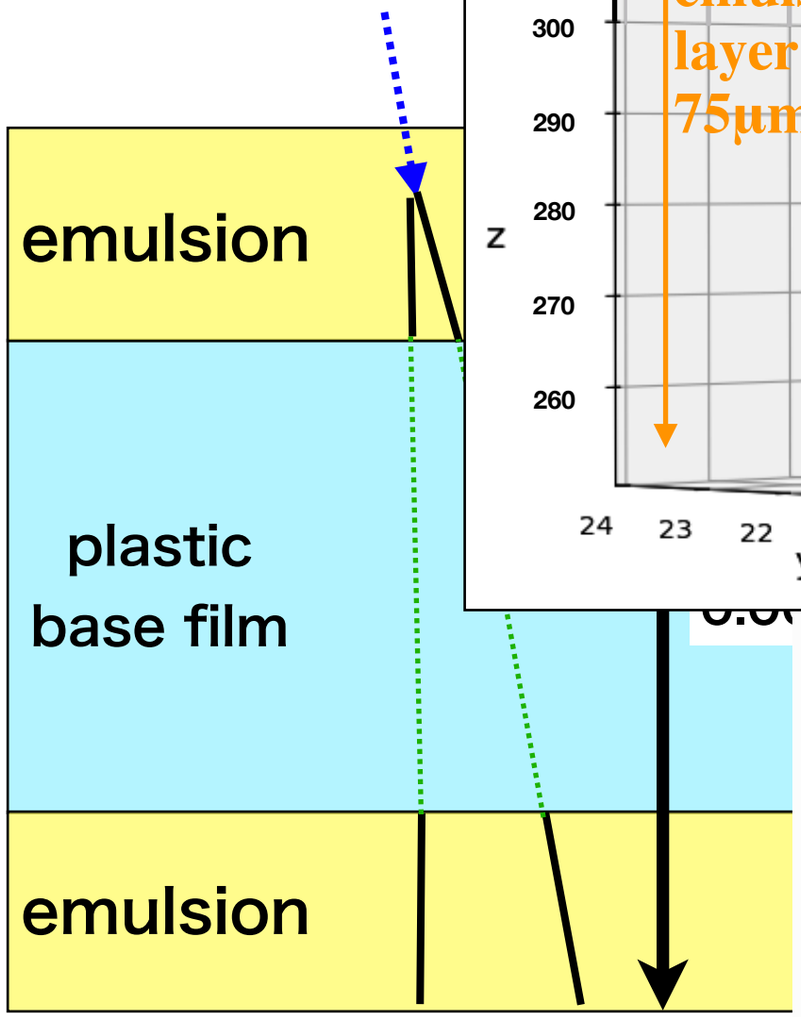
E_γ:581MeV (E_{e+e-}: 35MeV, 546MeV)

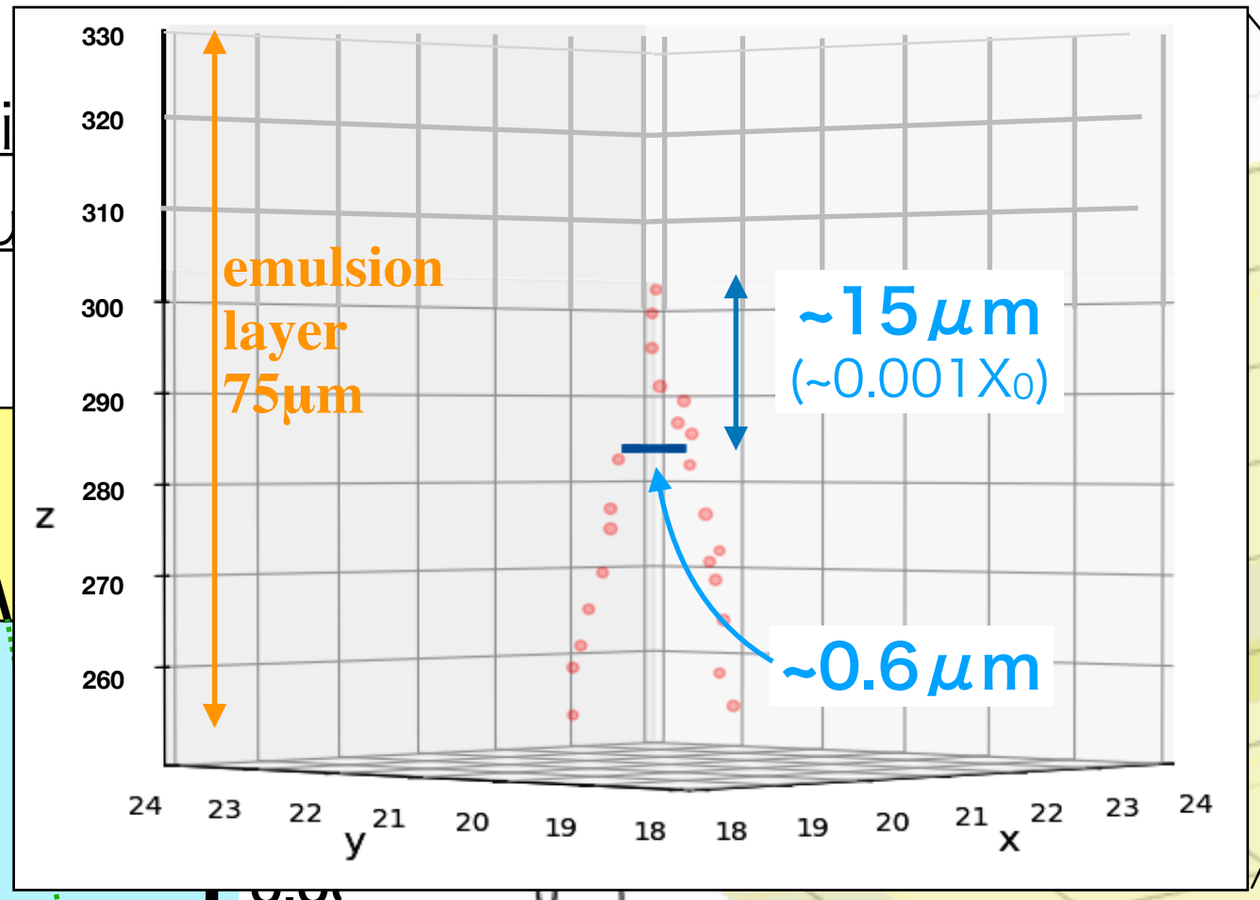


Detector: Nuclear emulsion film

cross secti

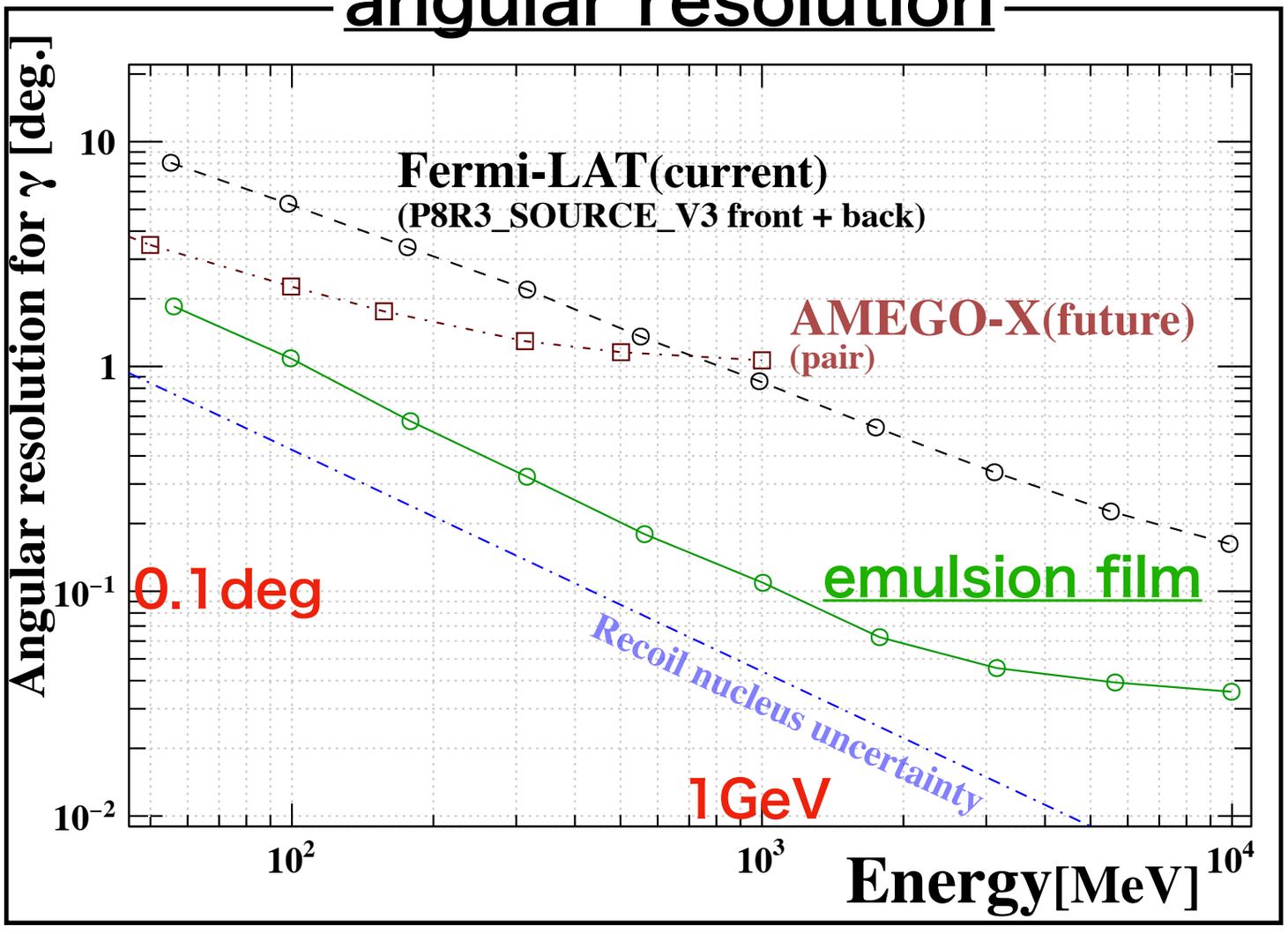
of the emu





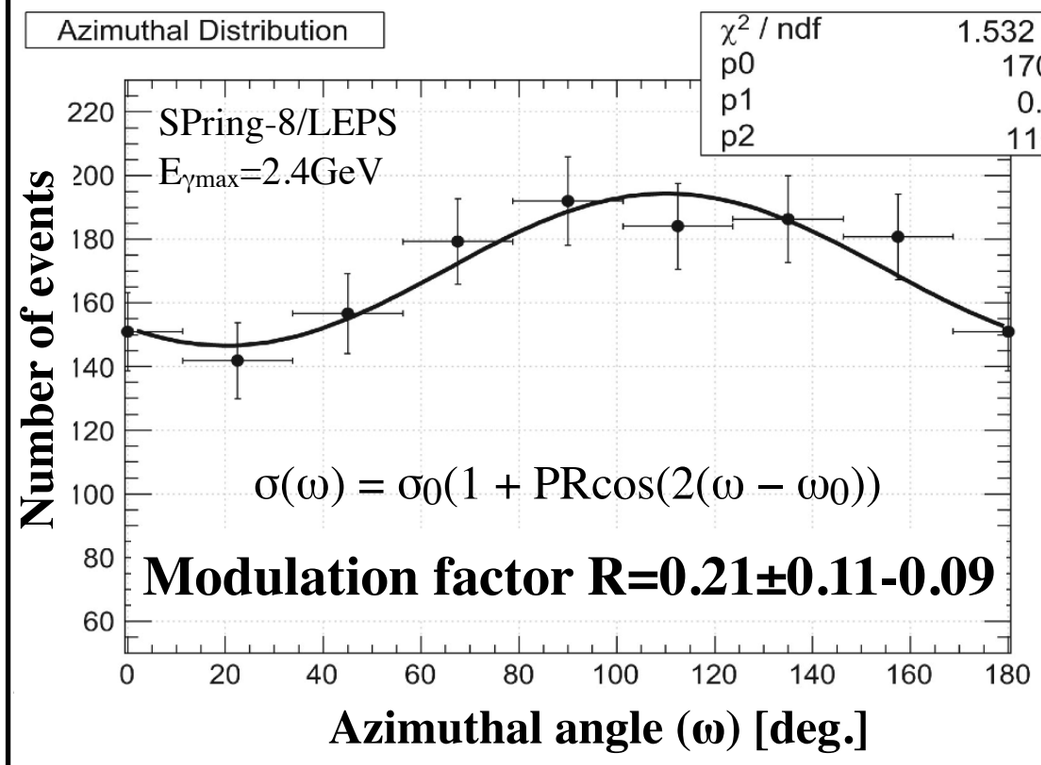
Performance for gamma-rays

angular resolution



polarization sensitivity

(result of a 2.4 GeV beam experiment)



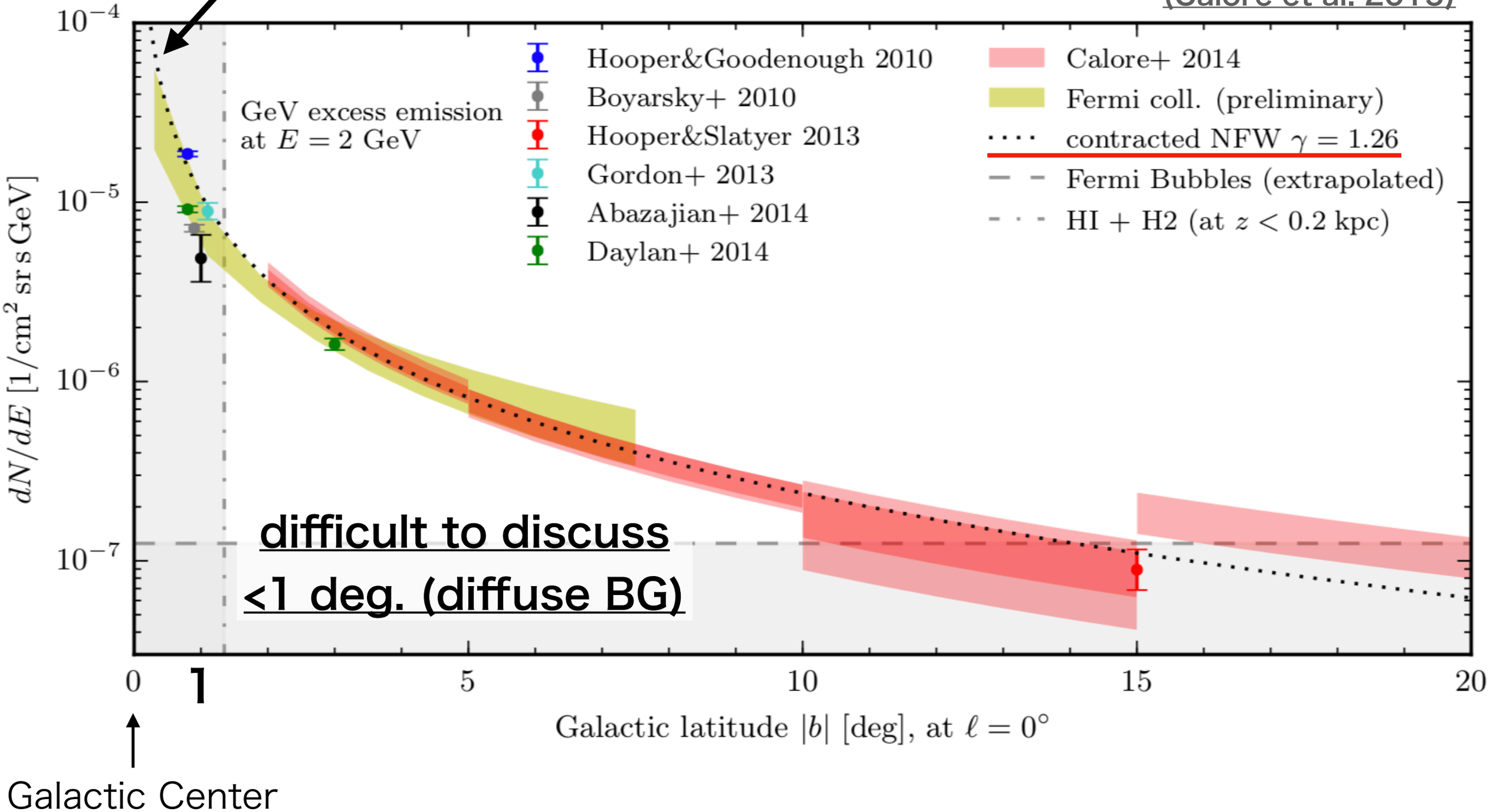
high angular resolution, polarization sensitivity

Galactic Center GeV Excess

Radial profile (latitude dependency of the Excess flux)

DM scenario? (NFW, γ=1.26？)

(Calore et al. 2015)



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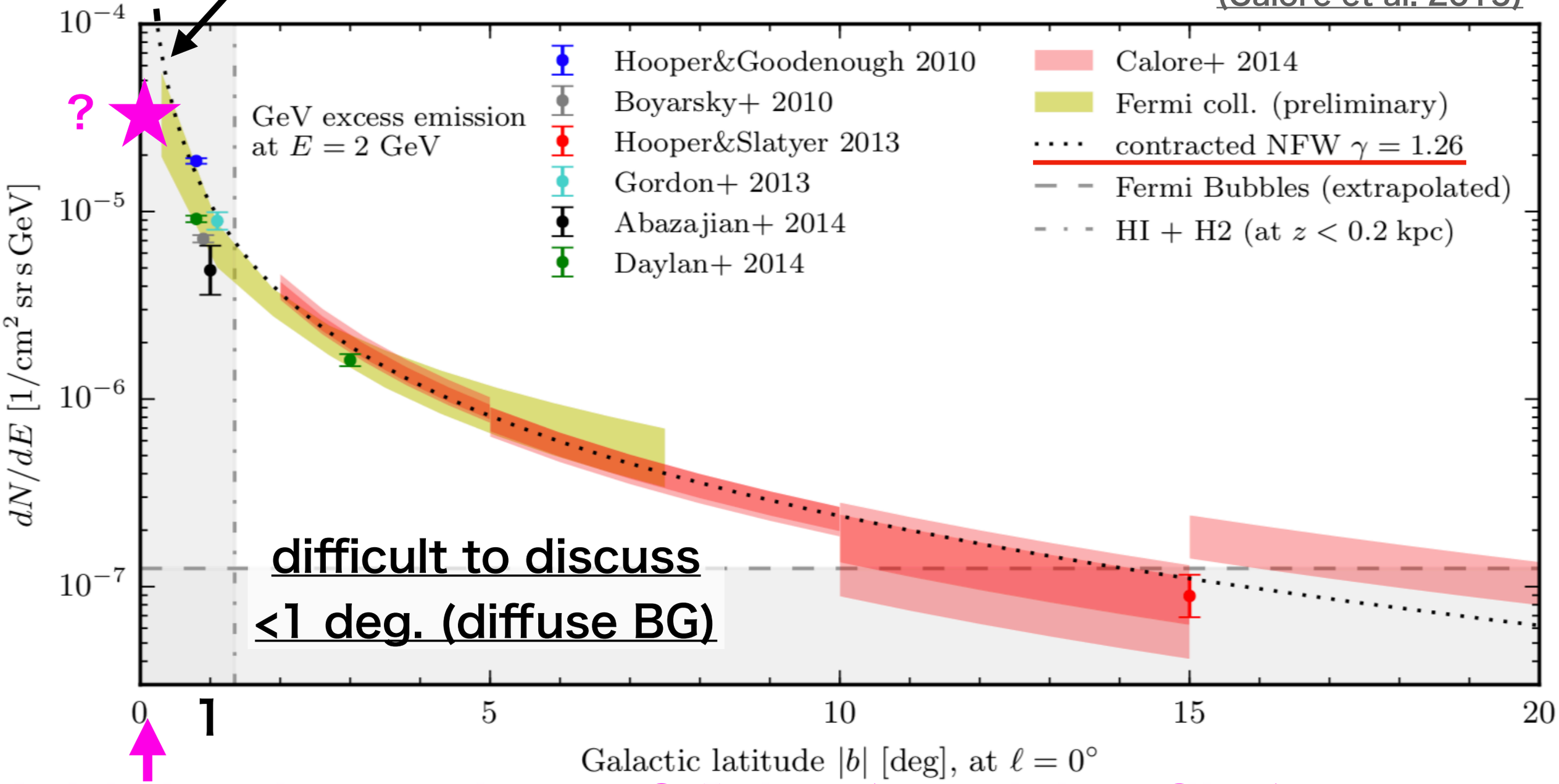
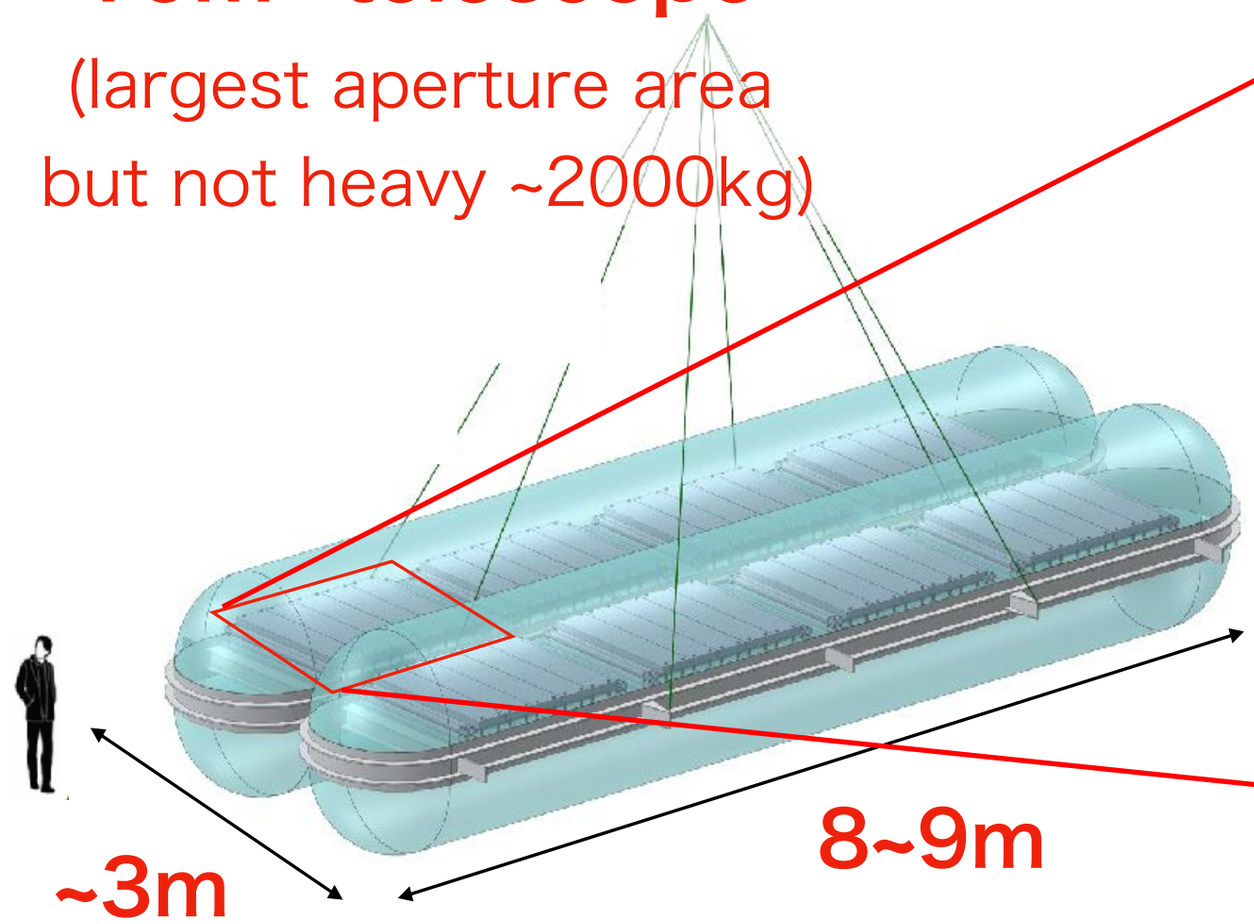


Add the data point at 0.1deg.(emulsion film)

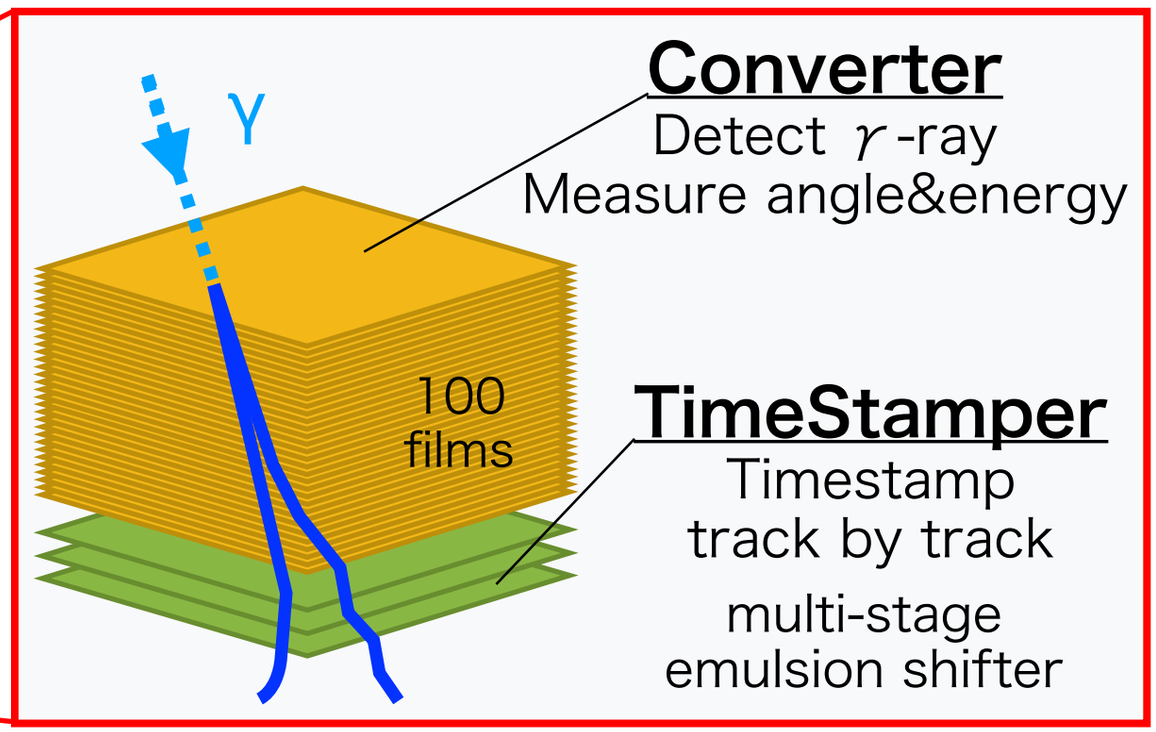
GRAINE project

Cosmic gamma-ray observation
w/ balloon-borne emulsion gamma-ray telescope

Balloon-borne
10m² telescope
(largest aperture area
but not heavy ~2000kg)



emulsion gamma-ray telescope



Altitude Monitor
(star camera)

GRAINE project

Prototype Phase

2004- Technology development

2011 1st Balloon experiment
(0.01m² @Japan w/ JAXA**)**

Demonstration phase

2015 2nd Balloon experiment
(0.38m²@Australia w/ JAXA**)**

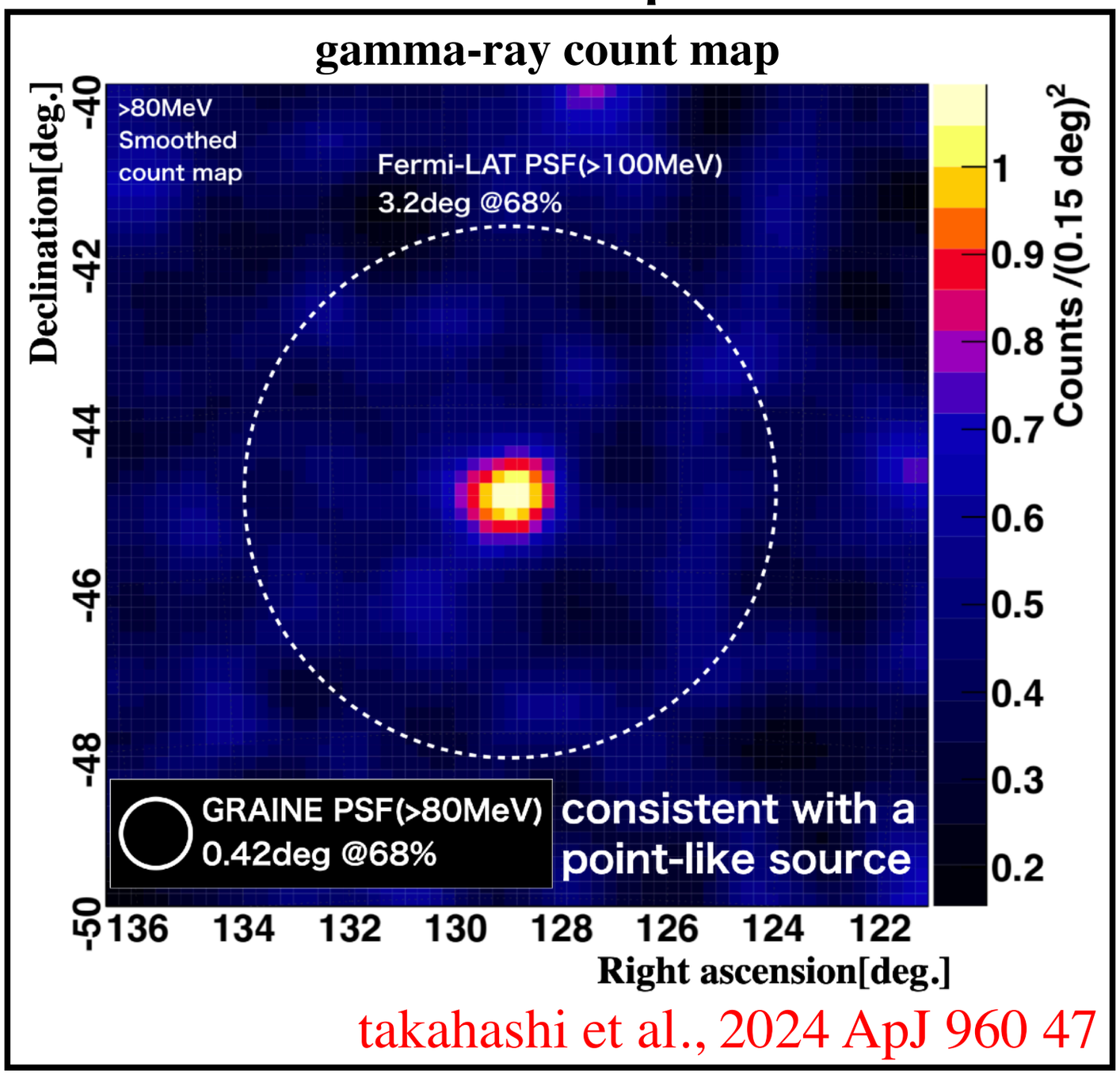
2018 3rd Balloon experiment
(0.38m²@Australia w/ JAXA**)**

Scientific phase

2023 4th Balloon experiment
(2.5m²@Australia w/ JAXA**)**

2027? 5th Balloon experiment

Observation for the Vela pulsar in the 2018 experiment



takahashi et al., 2024 ApJ 960 47

Imaging with the highest resolution in sub-GeV

Preliminary predictions for GRAINE2023 observations

Gal. Center (0.1°)

Significance >1GeV

15σ
12
9
6
3

Assuming a dark matter scenario (NFW, γ=1.26) Calore et al. 2015

No excess (known astronomical sources)

Vela pulsar

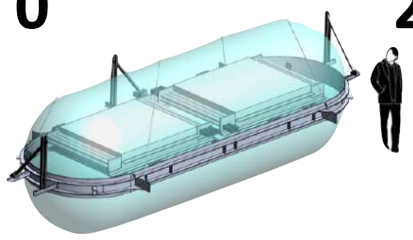
Minimum Detectable Polarization (>0.1GeV)

3 σ
2 σ
90%
70
50
30

Theoretical prediction
Alice K. H. et al. 2017

0 2.5 5 7.5 10 12.

Telescope Area x 1-day Flight [m·flight]



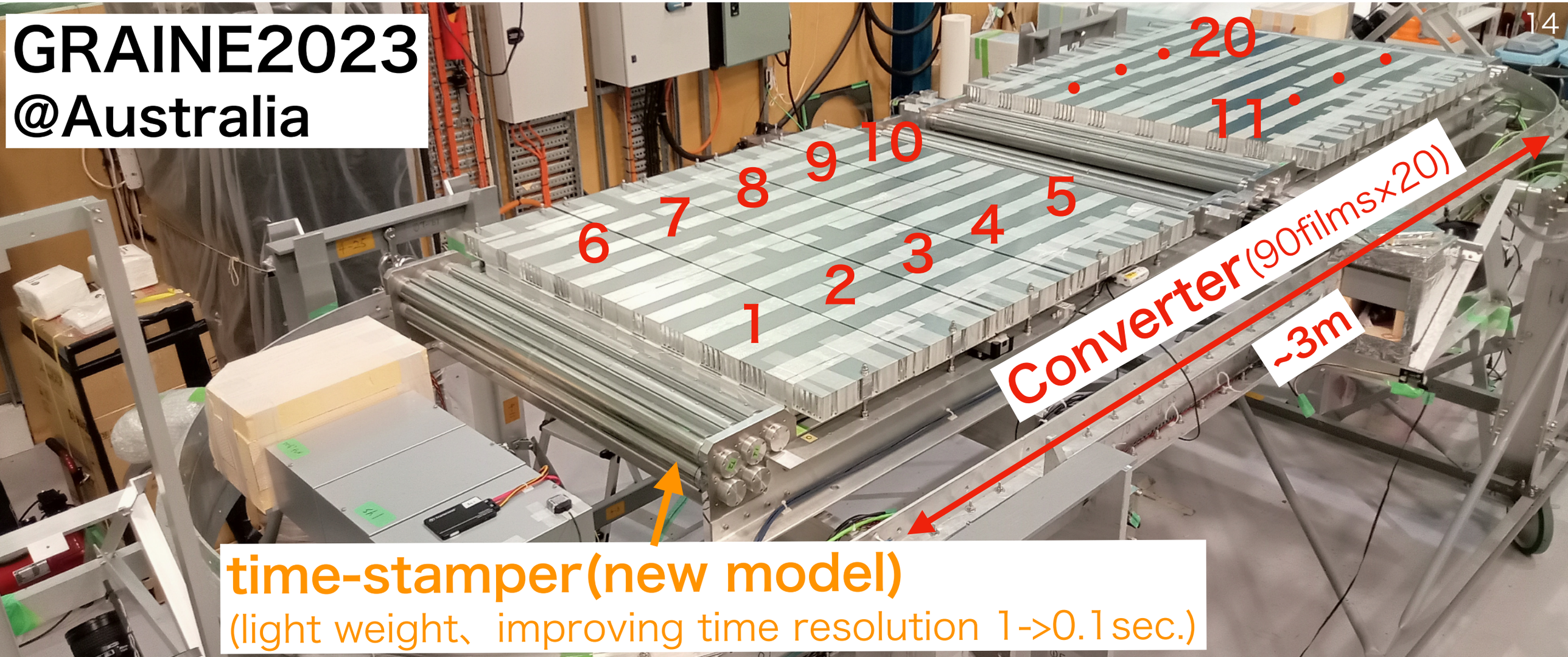
2.5 m²

GRAINE 2023

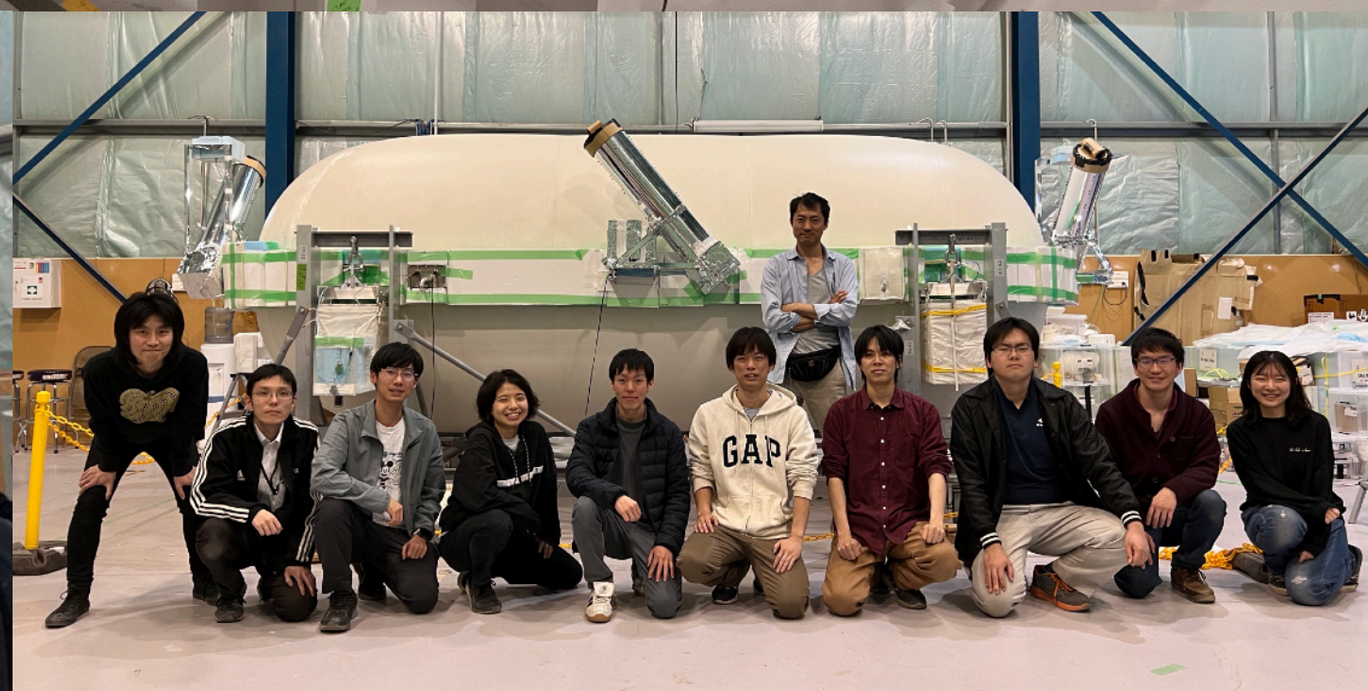
full scale model(10m²)

if 1 week flight:
MDP(2σ,3σ)=15%,23%

GRAINE2023 @Australia

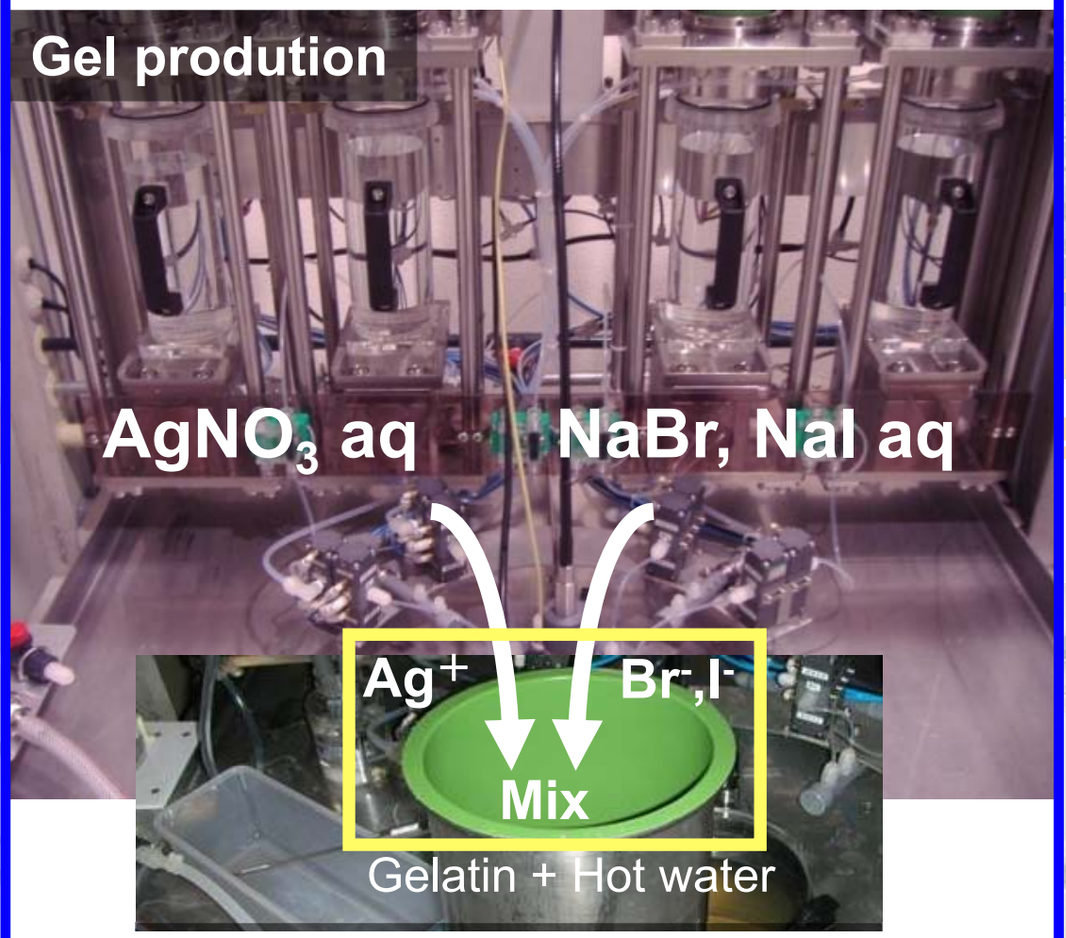


pressure vessel gondola



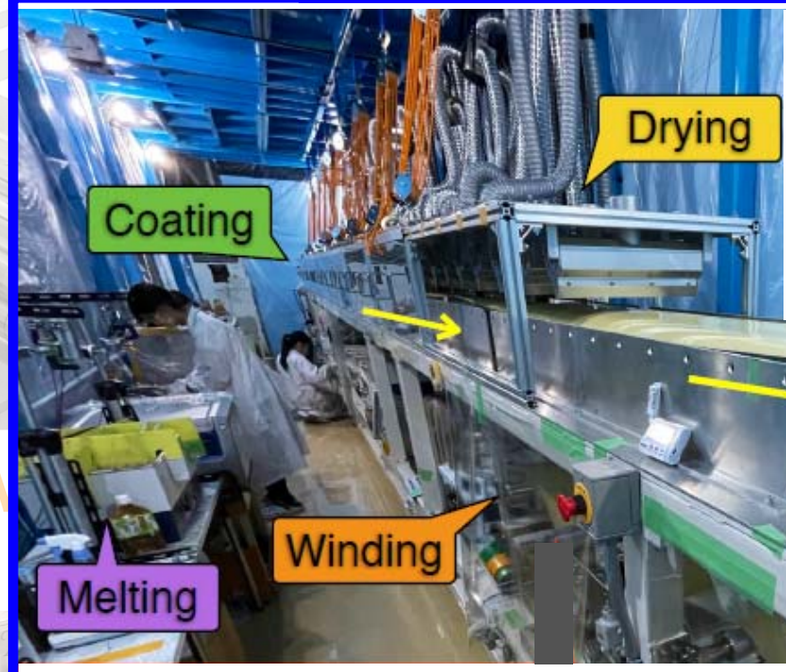
GRAINE2023 @Australia

Emulsion gel production

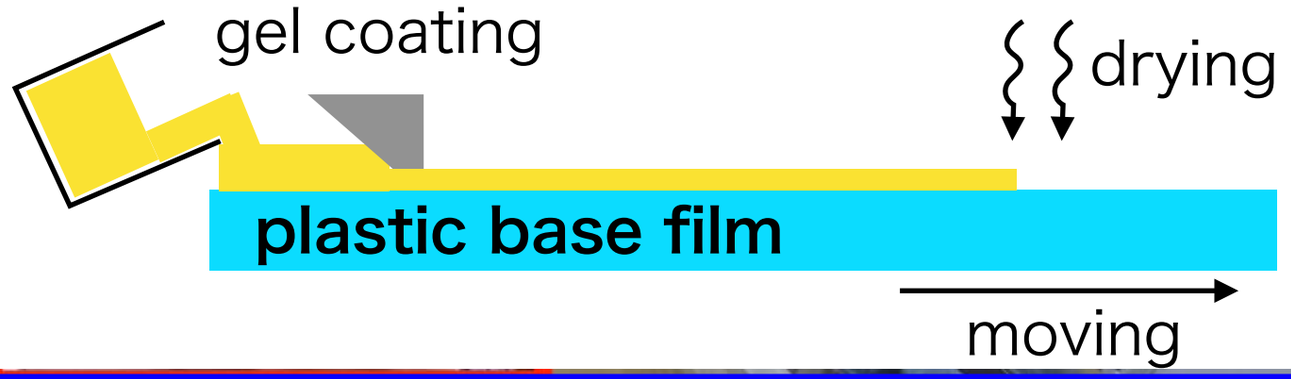


2021- :30 times larger machine is running

Emulsion film coating



2021 May.-
Automatic roll-to-roll emulsion film coating system
(Real production in the dark room)



Emulsion film production facilities are in our lab. at Nagoya University

pressure vessel gondola

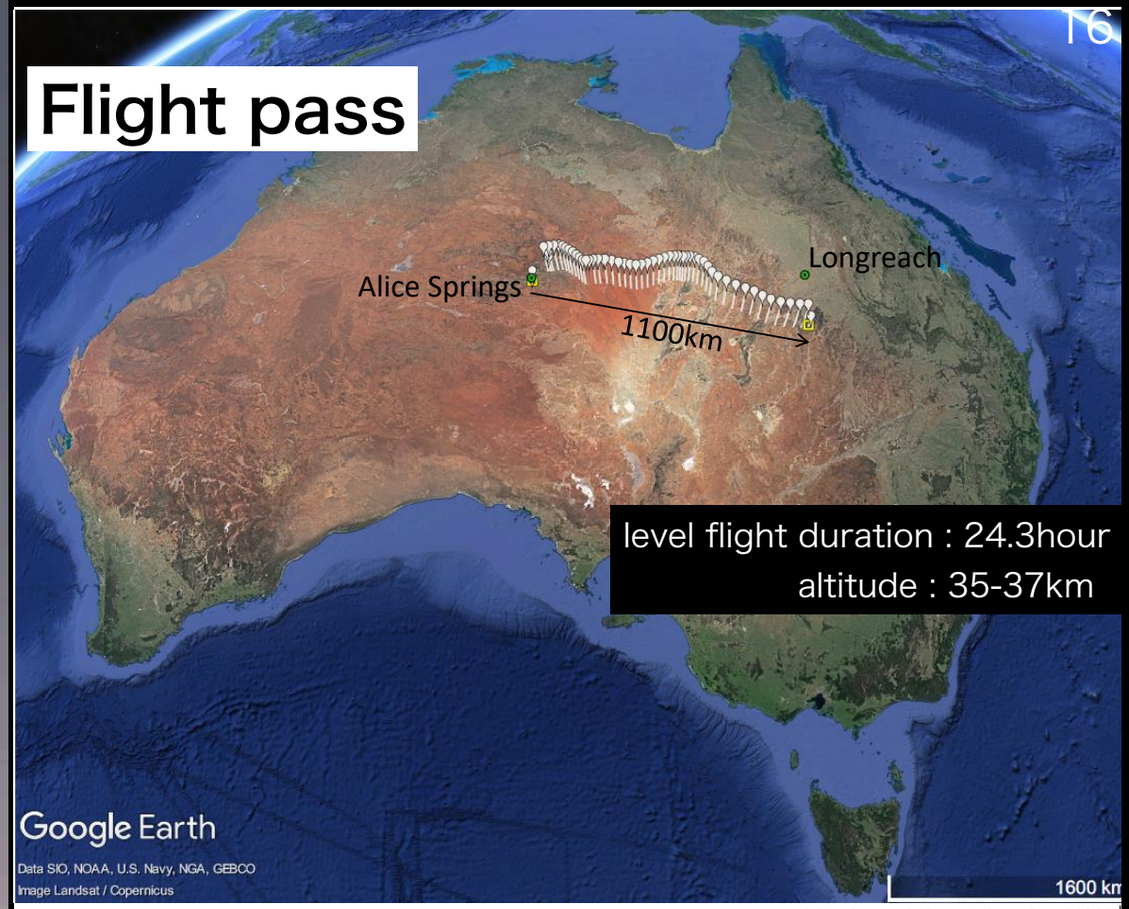
Launching on Apr. 30th, 6:32am

Balloon was successfully released by the JAXA team

Our gondola

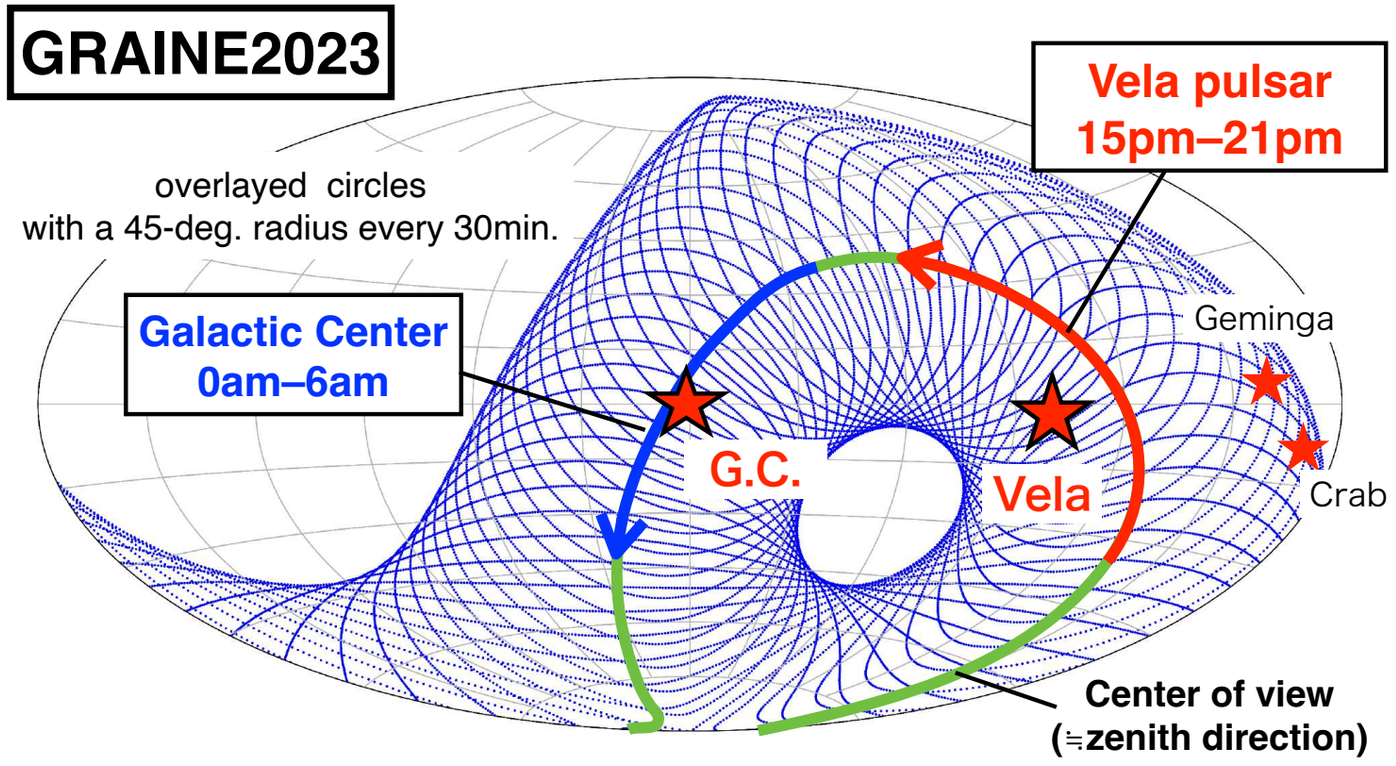
photo by JAXA

Flight pass

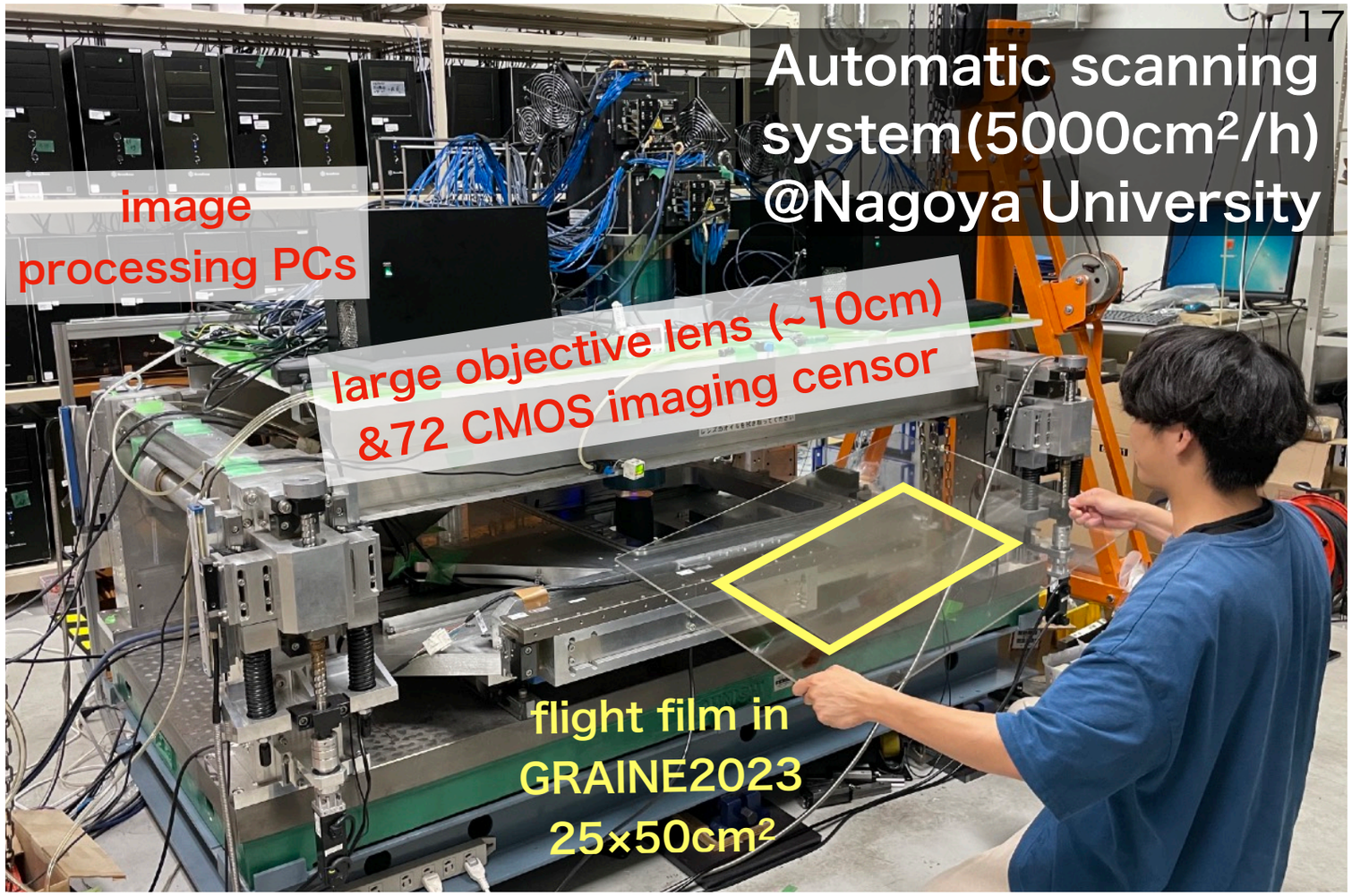


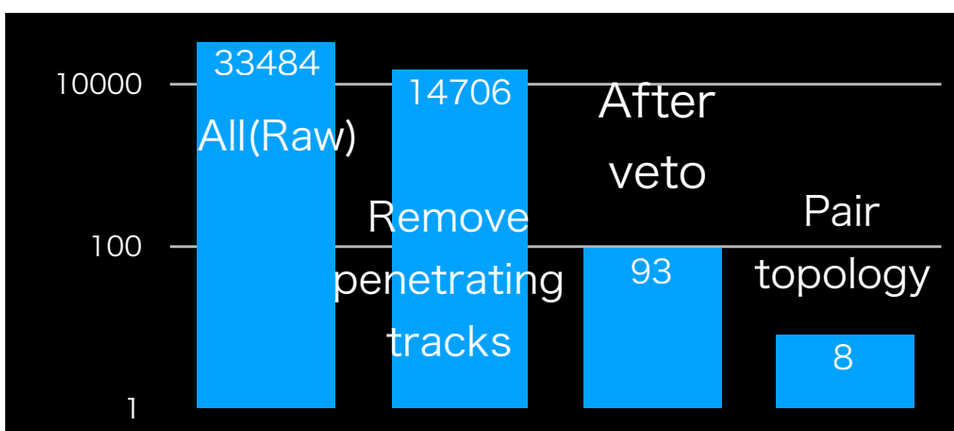
altitude and time taken by JAXA

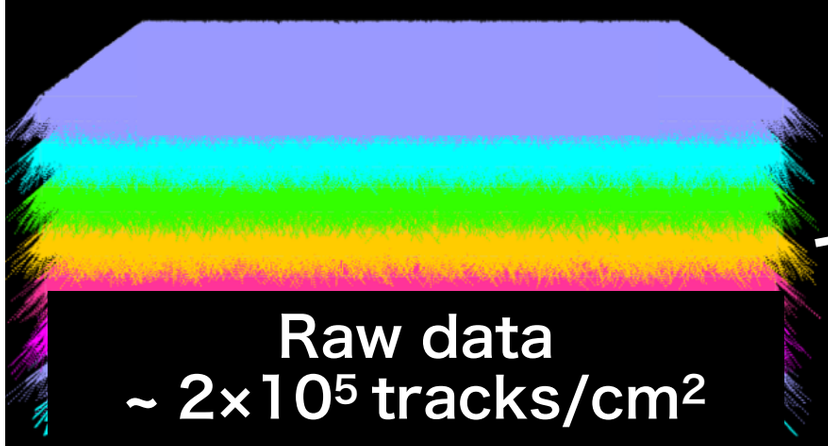
Celestial regions observed by the Emulsion Telescope (FoV ±45°)



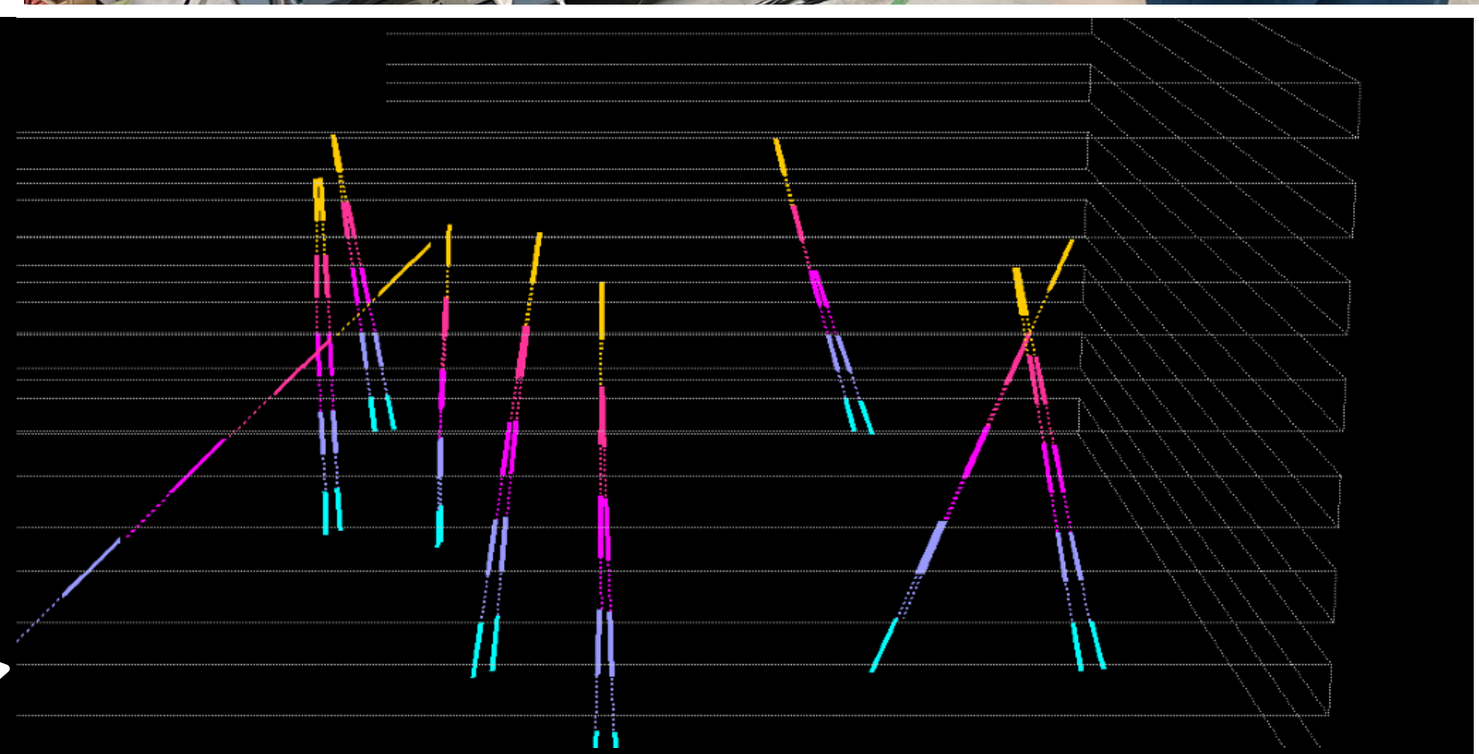
Data taking w/ the high-speed emulsion scanning system







Raw data
~ 2×10^5 tracks/cm²

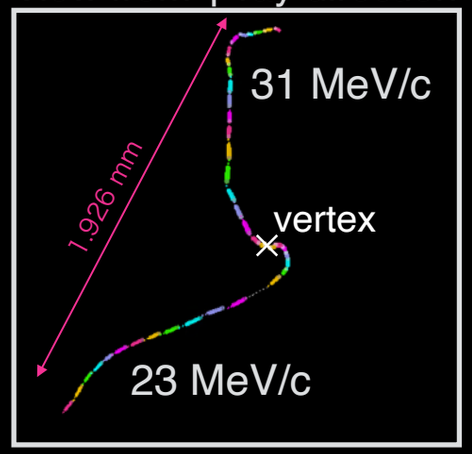


>10^7 γ-ray events have been detected

Detected “e-pair” event topologies

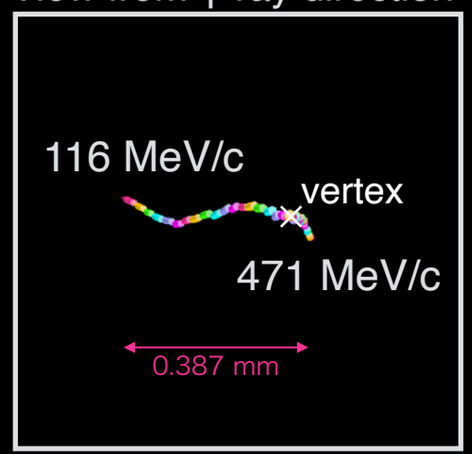
unit 10
start_pl 25
gid 6915973
θ_zenith 29.6°
θ_open 5.17°
E_gamma
$54_{\pm 19}$ MeV

View from γ-ray direction

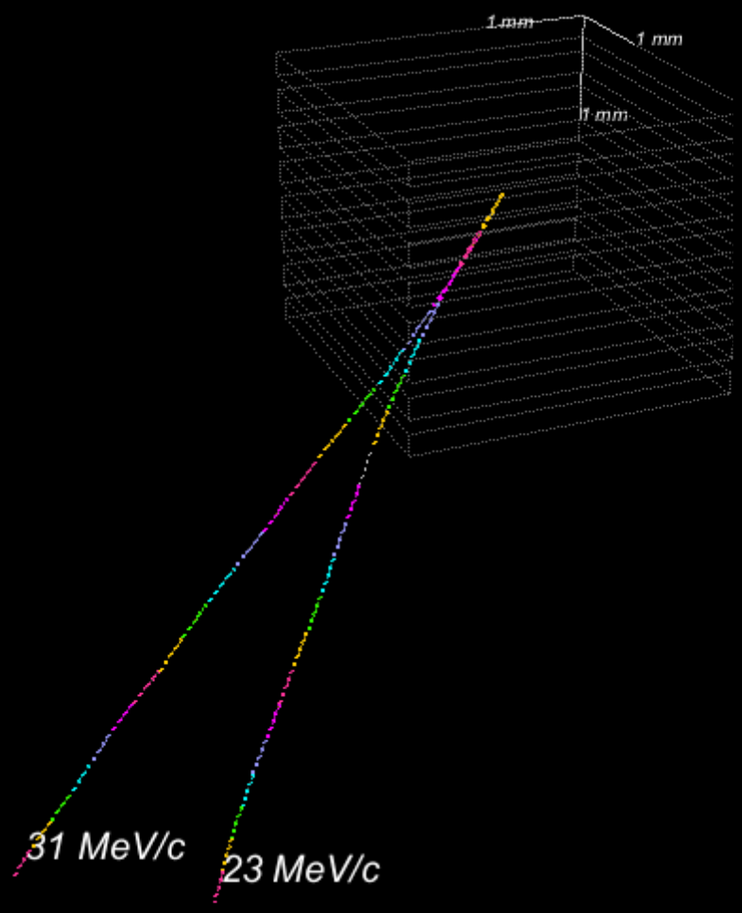


unit 10
start_pl 25
gid 8237284
θ_zenith 30.5°
θ_open 1.36°
E_gamma
$587_{\pm 204}$ MeV

View from γ-ray direction



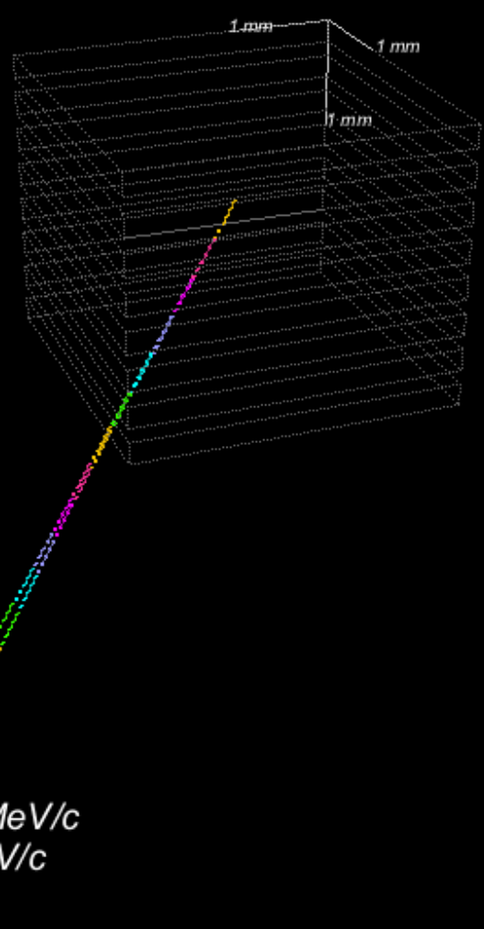
1mm



Angular difference
→Track momentum

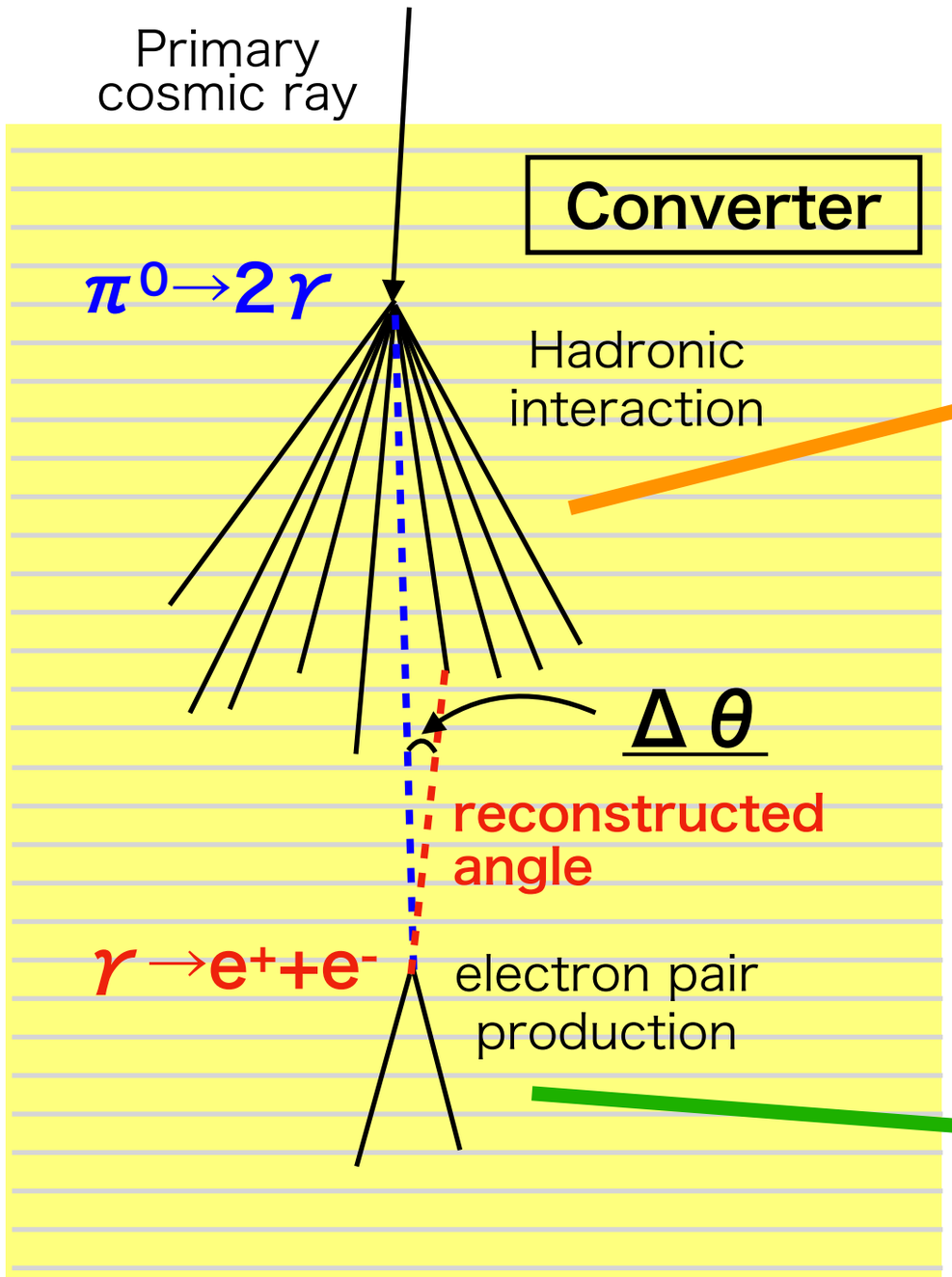
$$\theta_{RMS} = \frac{13.6}{P}\sqrt{x/X_0}$$

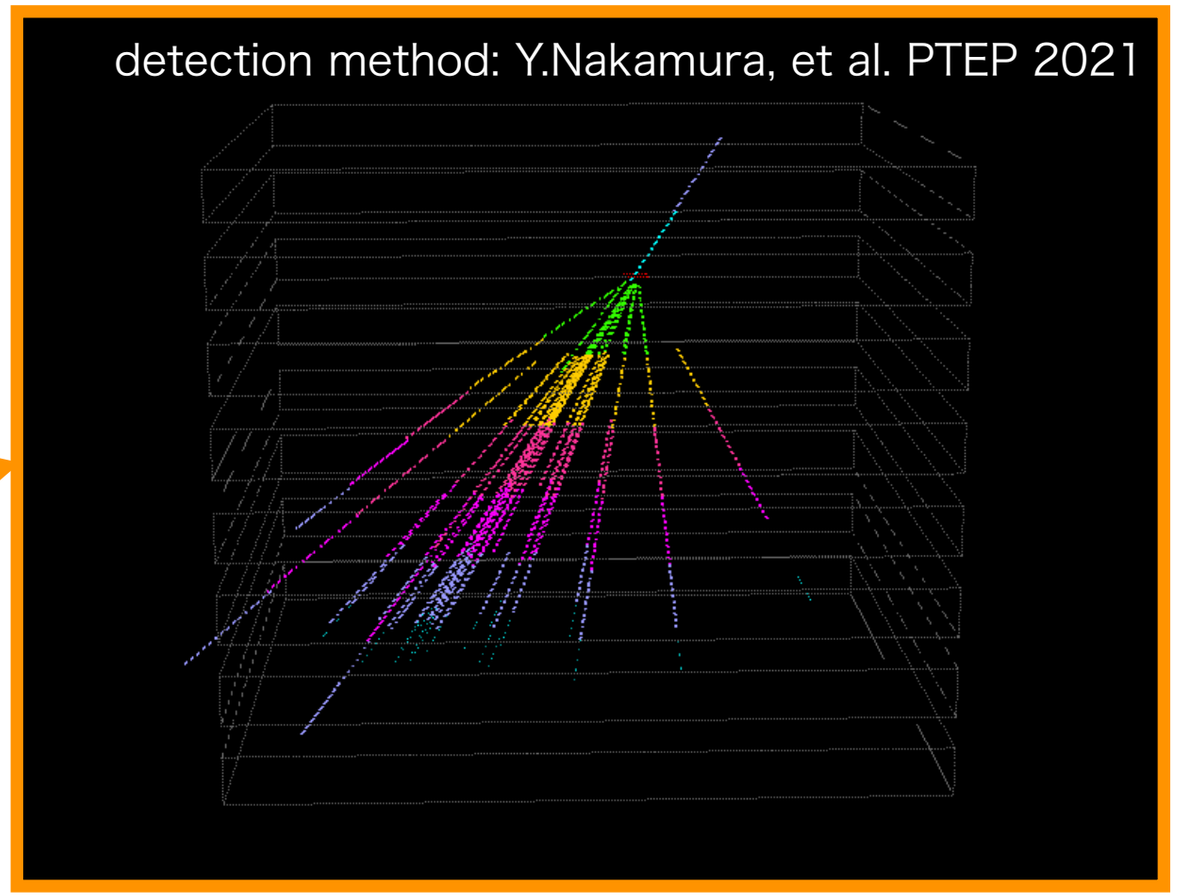
lower momentum
-> larger ang. diff.



Performance of the angular measurement

① Internal calibration source

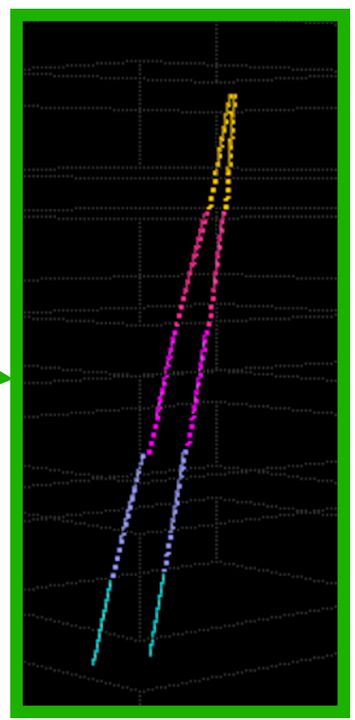




multiplicity >10($\tan\theta_\gamma$<1.0)

1.3×10⁴ events

(searched with 156 films)



incident angle ($\tan\theta_\gamma$): 0.0-1.0

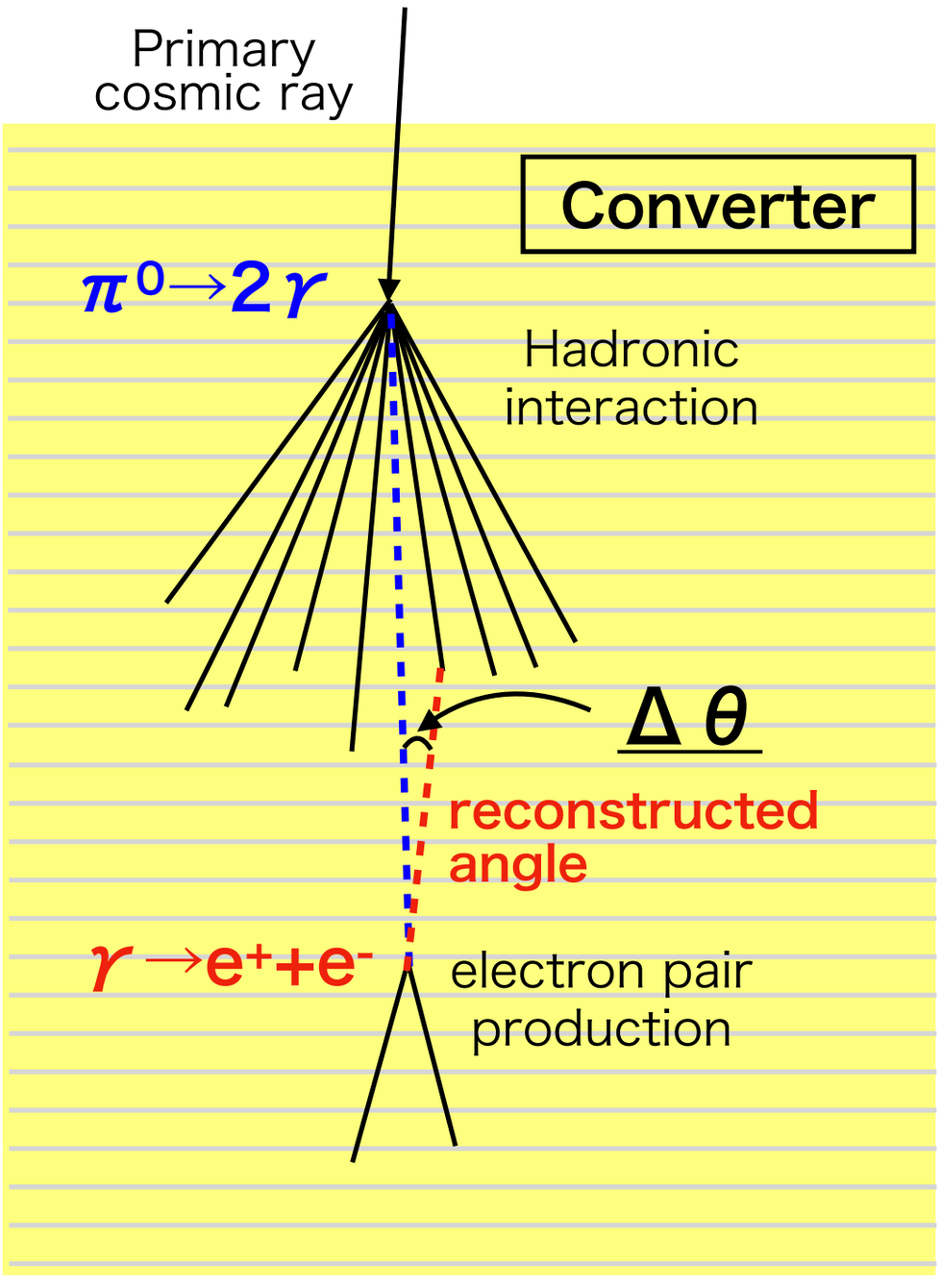
energy range: 100-400MeV

6.8×10⁶ events

(searched with 140 films)

Performance of the angular measurement

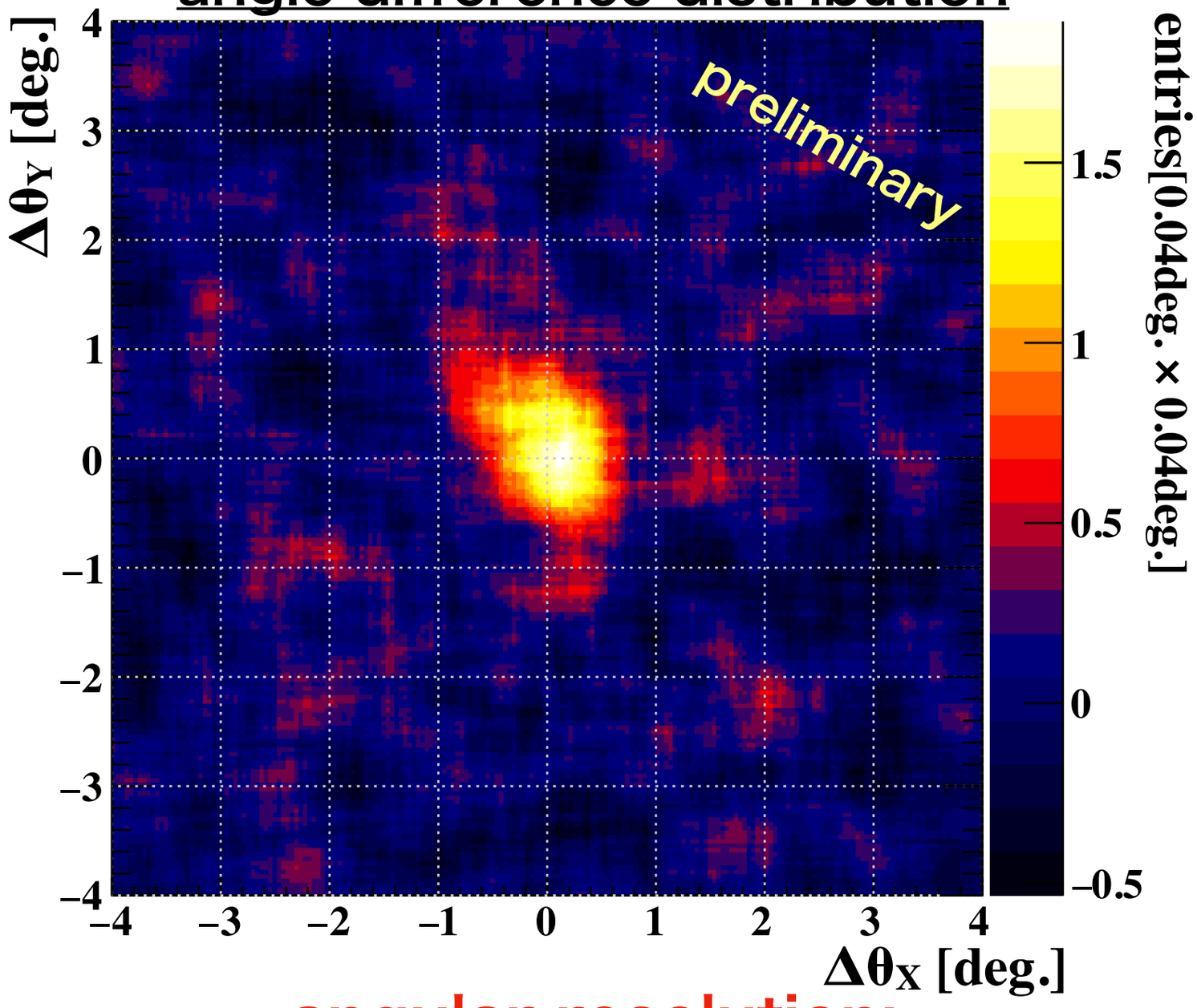
① Internal calibration source



Uncertainty of the expected direction: ~0.3deg.

after subtracting random BG
and smoothing

angle difference distribution



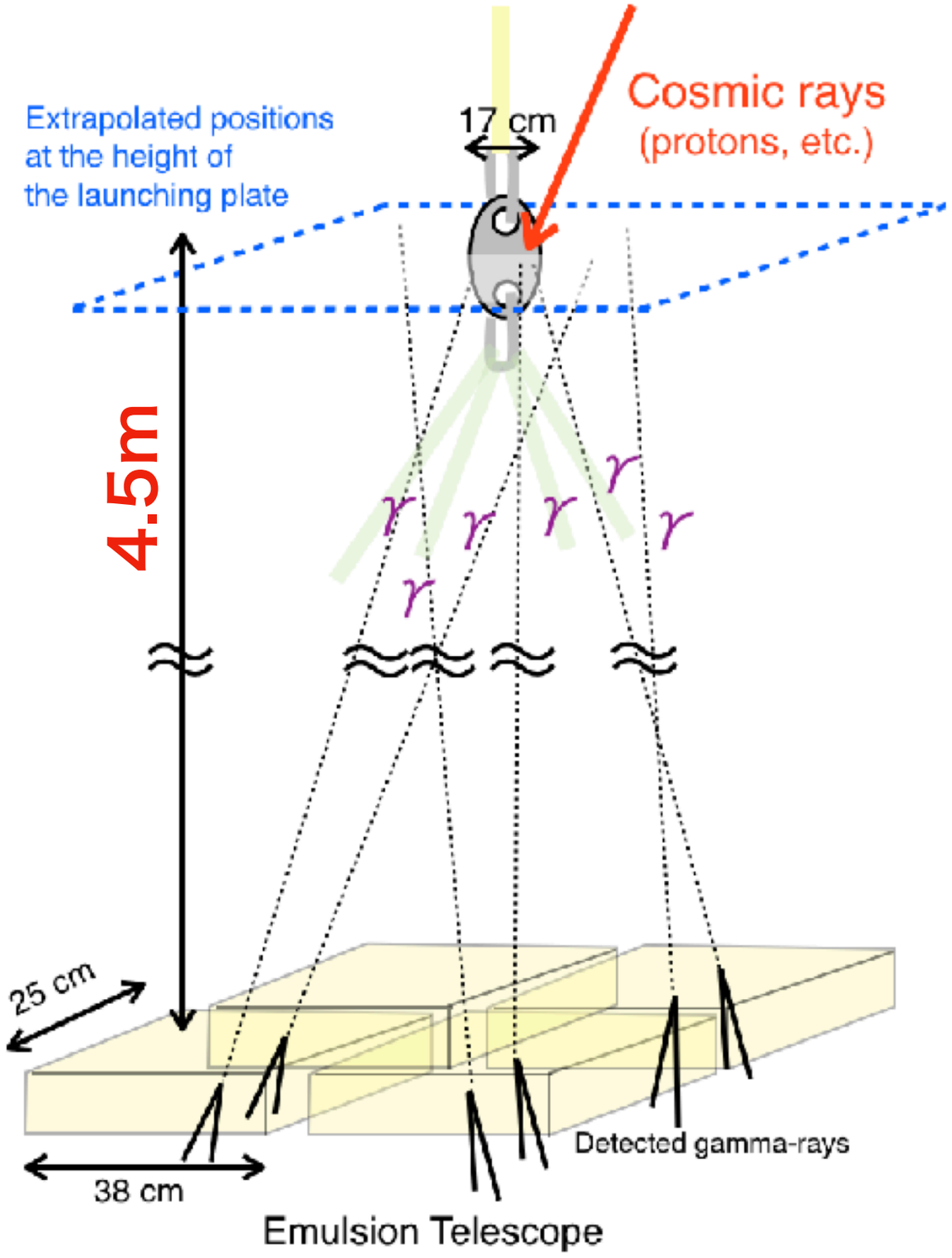
angular resolution:

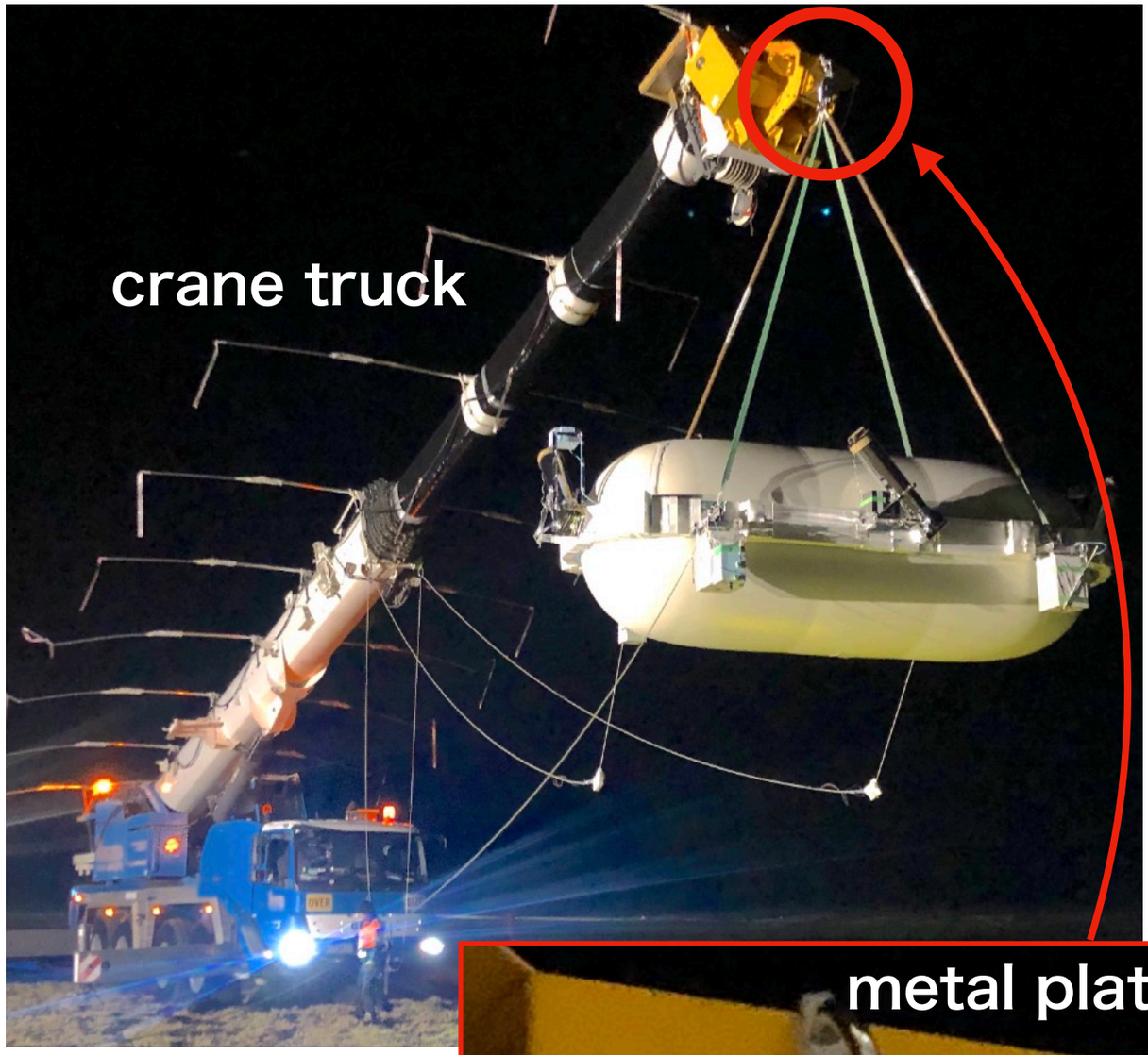
0.64±0.12deg.($E_{ave.}$ ~250MeV)

(expected value: 0.65deg.)

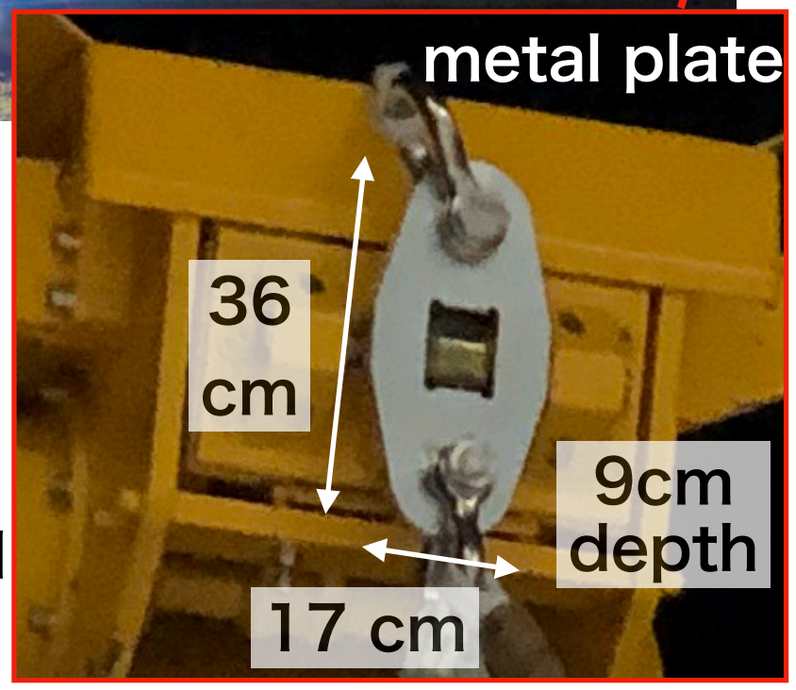
Performance of the angular measurement

② External calibration source





connecting
our gondola and
the balloon



Performance of the angular measurement

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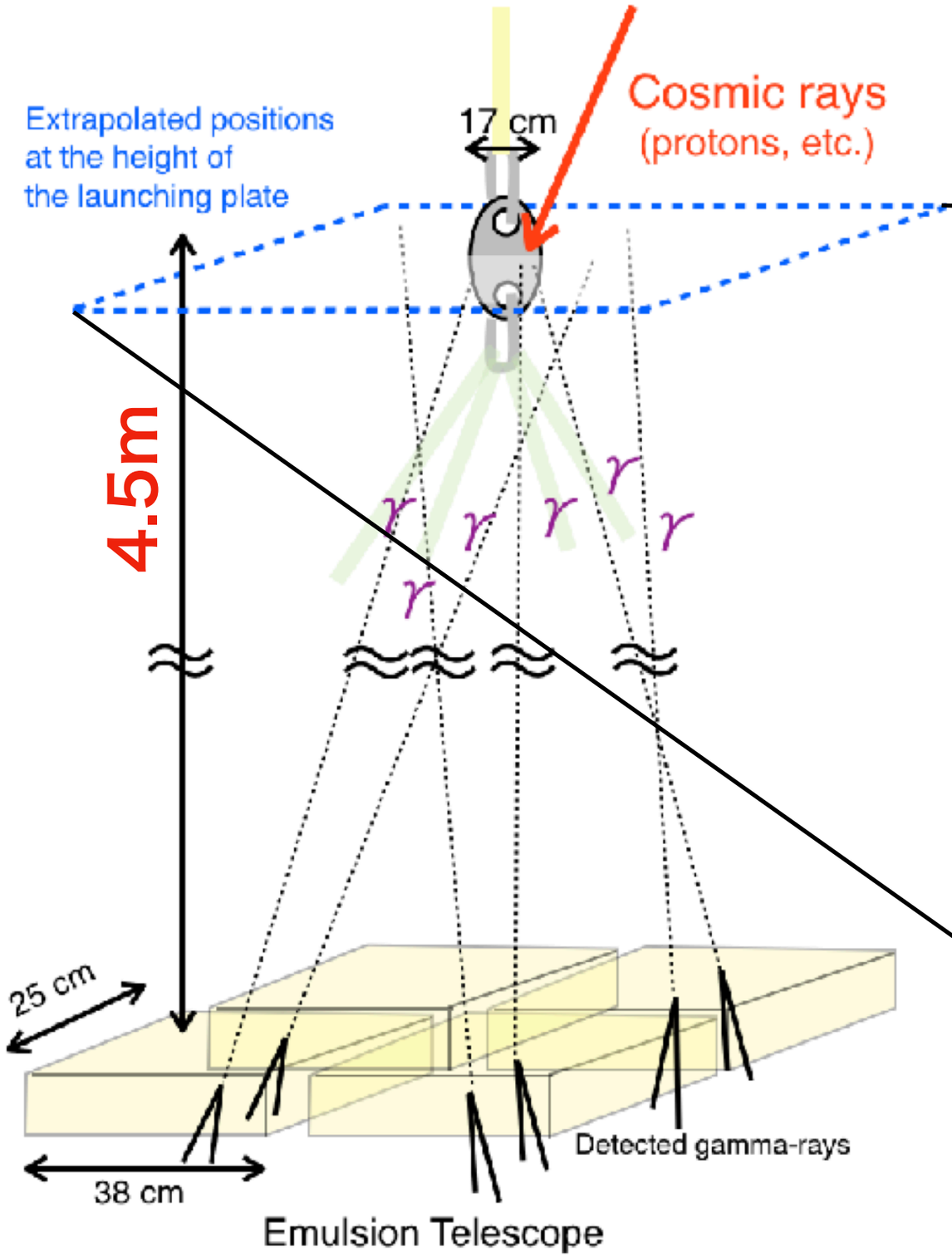
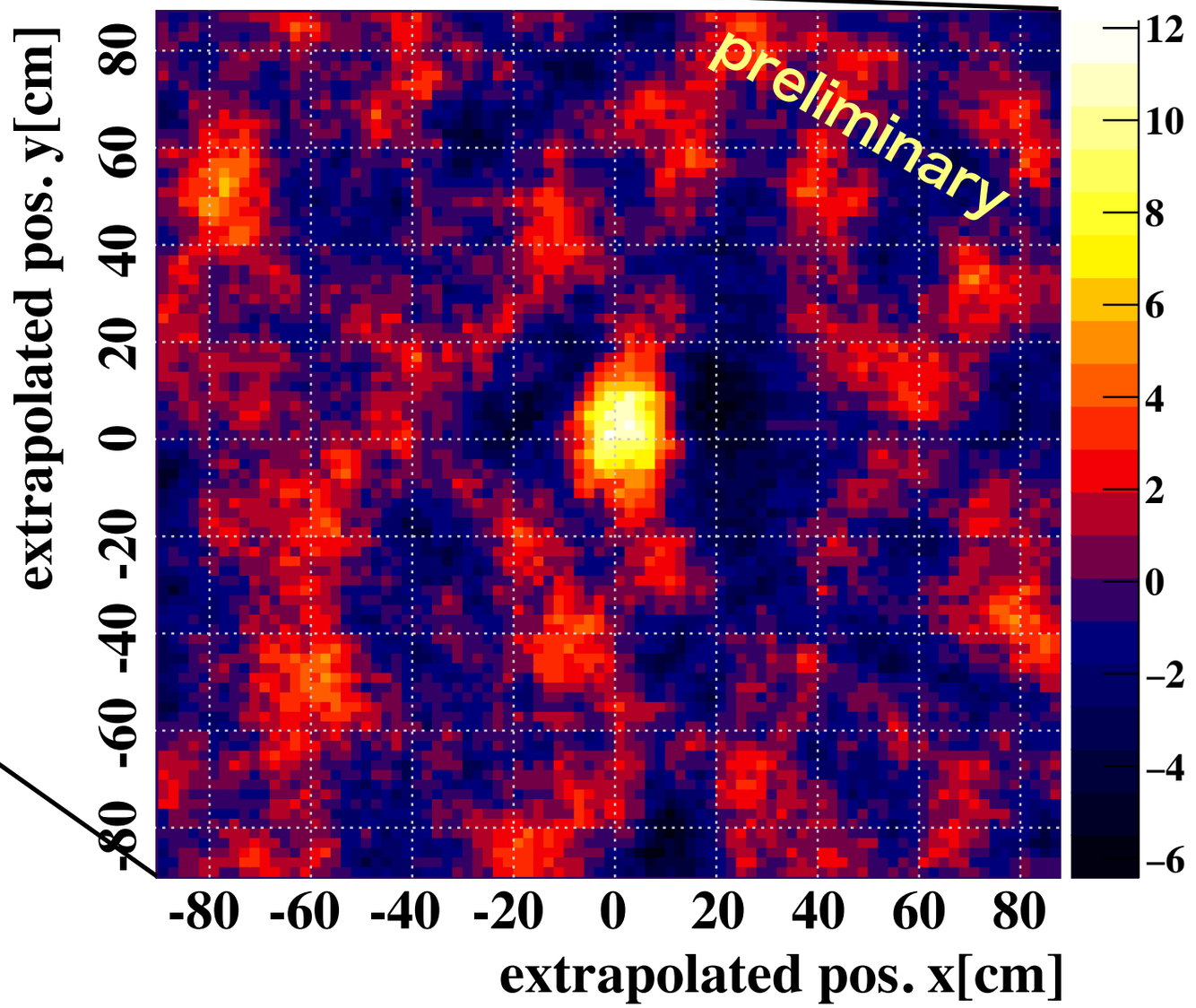
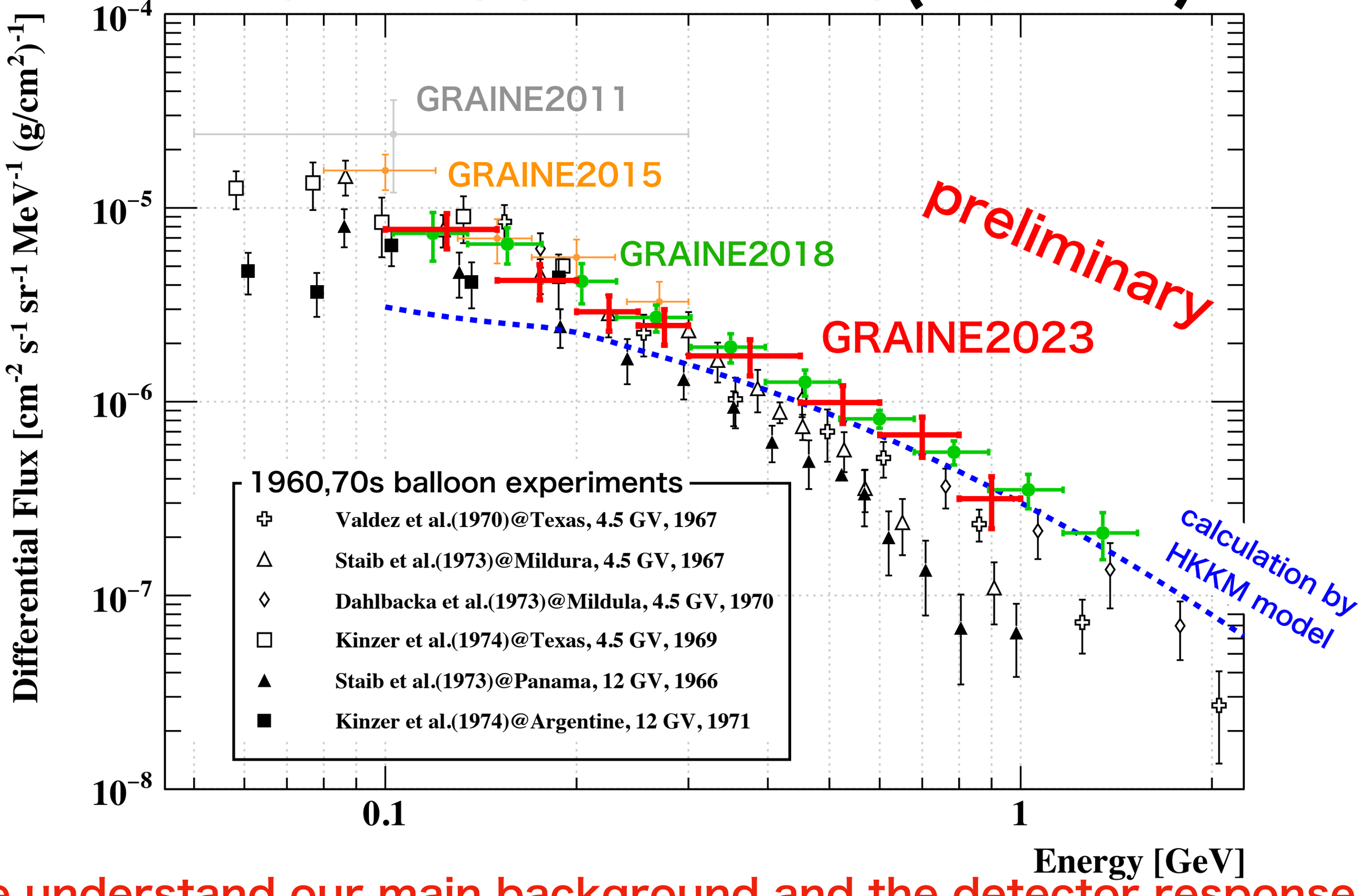


after subtracting random BG
and smoothing

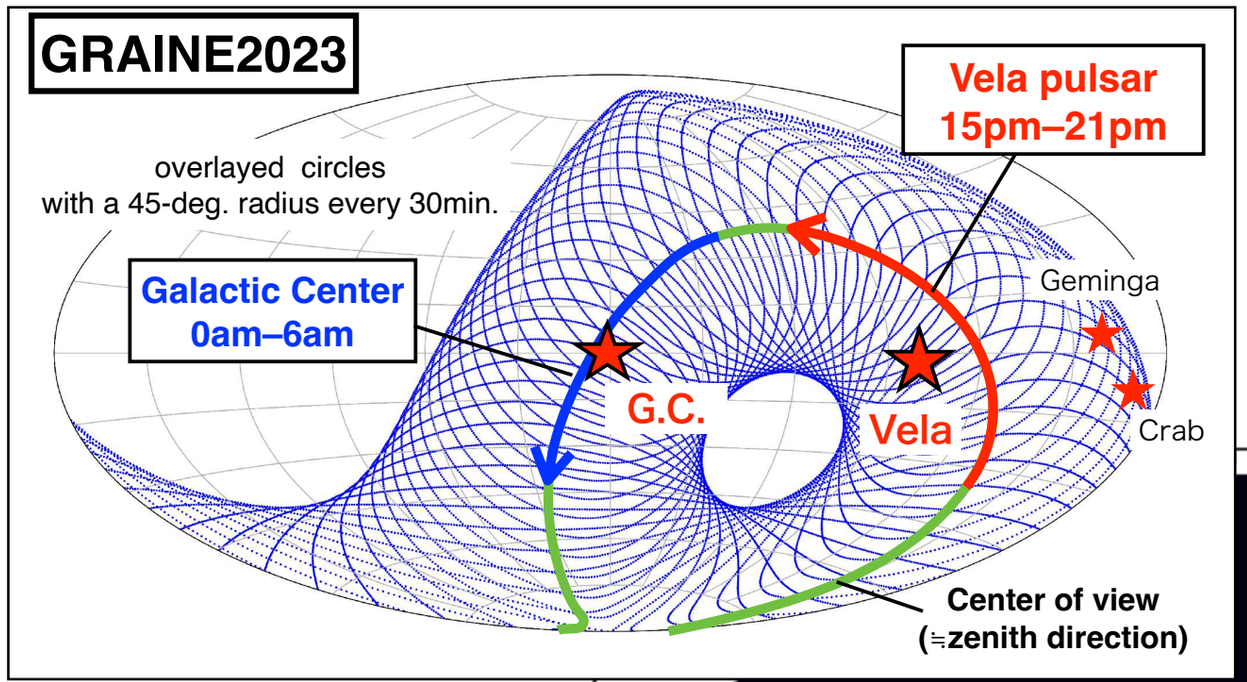


Atmospheric gamma-ray observation at the balloon attitude(~36km)

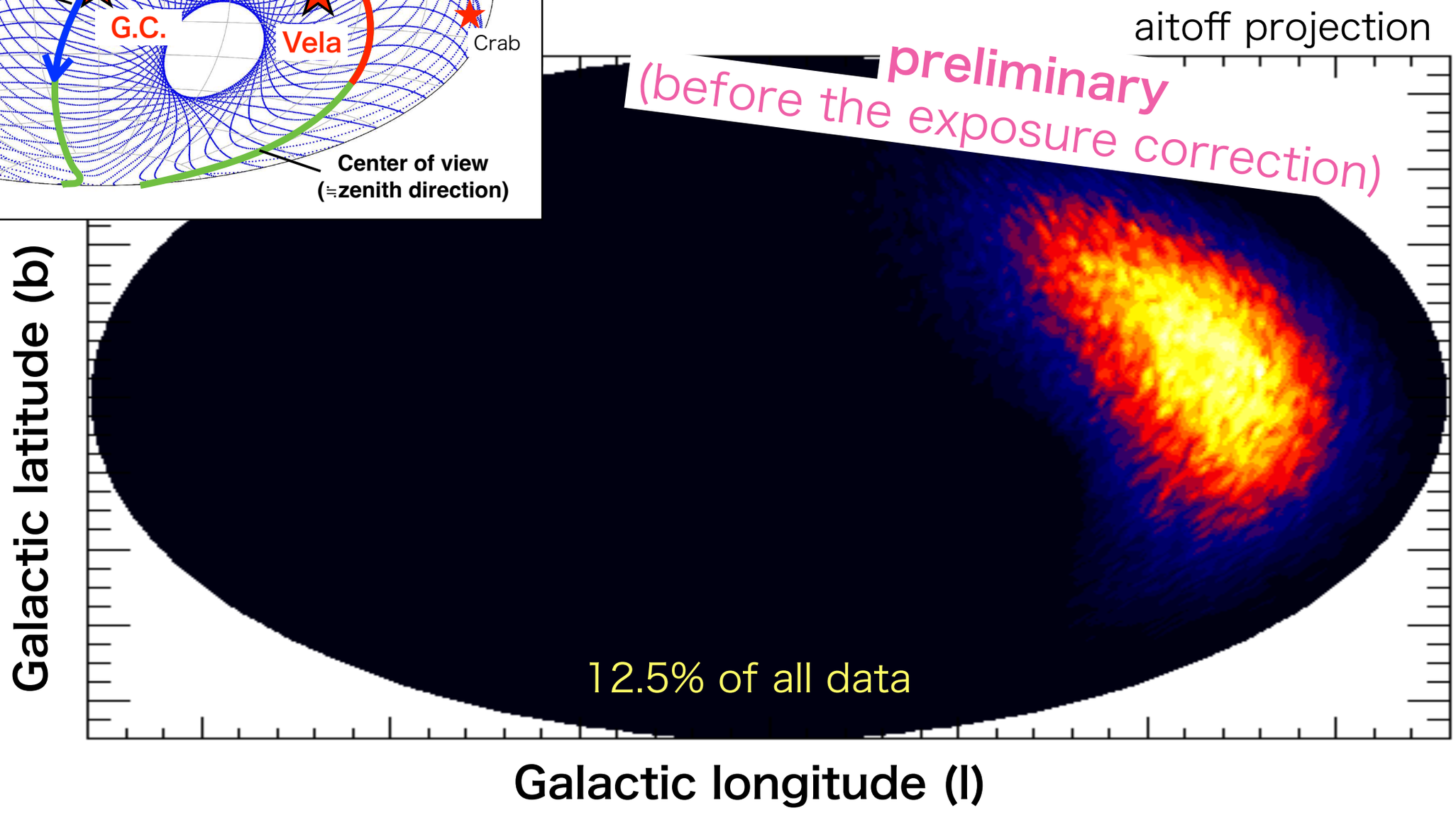


We understand our main background and the detector response

Arrival direction of γ-ray in the galactic coordinate



Combined analysis(angle, time, attitude)



Analysis for the sources(GC,Vela) is ongoing

Summary

Prototype Phase

2004- Technology development

2011 1st Balloon experiment
(0.01m² @Japan w/ JAXA**)**

Demonstration phase

2015 2nd Balloon experiment
(0.38m²@Australia w/ JAXA**)**

2018 3rd Balloon experiment
(0.38m²@Australia w/ JAXA)

Scientific phase

2023 4th Balloon experiment
(2.5m²@Australia w/ JAXA**)**

2027? 5th Balloon experiment

GRAINE project : Cosmic γ-ray observation w/ the high angular resolution & the polarization sensitivity

We conducted 4th balloon experiment in 2023
Starting of the scientific observation

- Observation of the G.C. region w/ the highest resolution
- Trying to measure the polarization of the pulsar

Analysis in GRAINE2023 is ongoing now

-Basic performances are well consistent with the expected values
-Observed atmospheric γ-ray is consistent with the previous experiments
-Analysis for the astronomical sources is ongoing

In the future, we want to conduct repeatedly balloon experiments with larger aperture area / longer flight duration