Balloon-borne Emulsion Gamma-ray Telescope

GRAINE project

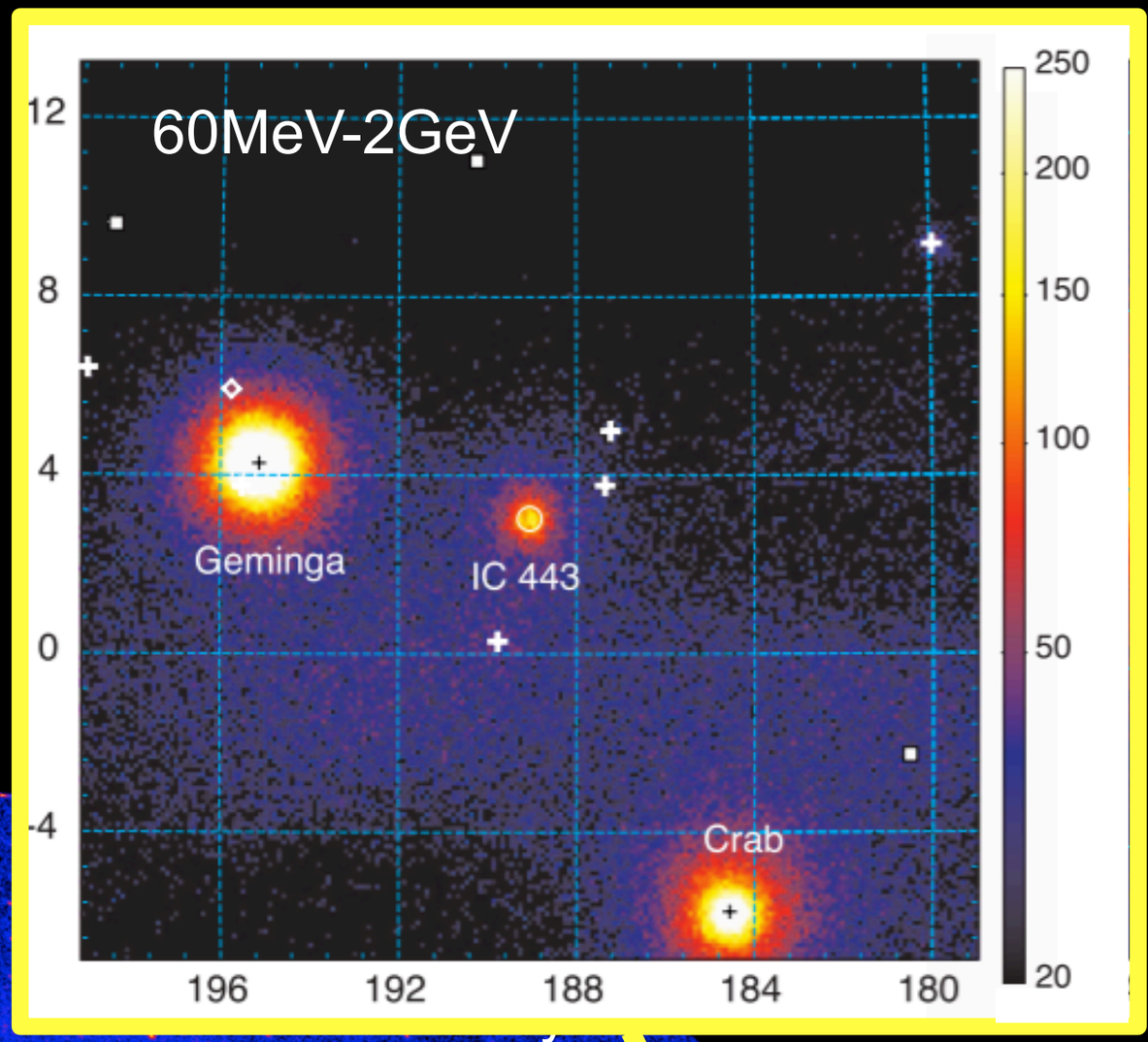
Gamma-Ray Astro-Imager with Nuclear Emulsion

Hiroki ROKUJO (Nagoya Univ.)
for GRAINE collaboration

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

	Telescope	Detected sources
1990-2001	EGRET spark chamber	271
2008-	Fermi-LAT SSD tracker	>3000

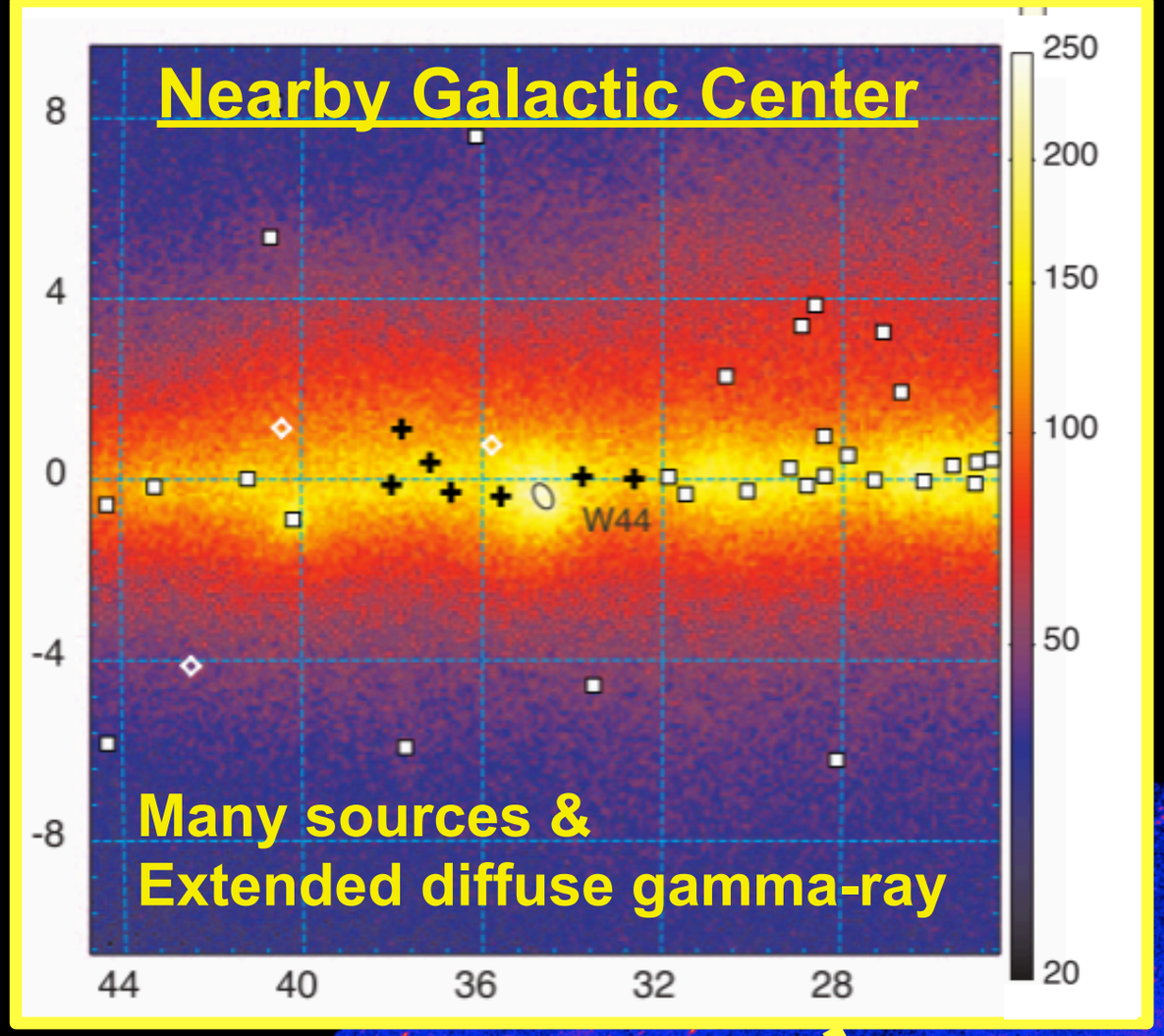
All-Sky Map via gamma-ray above 1 GeV

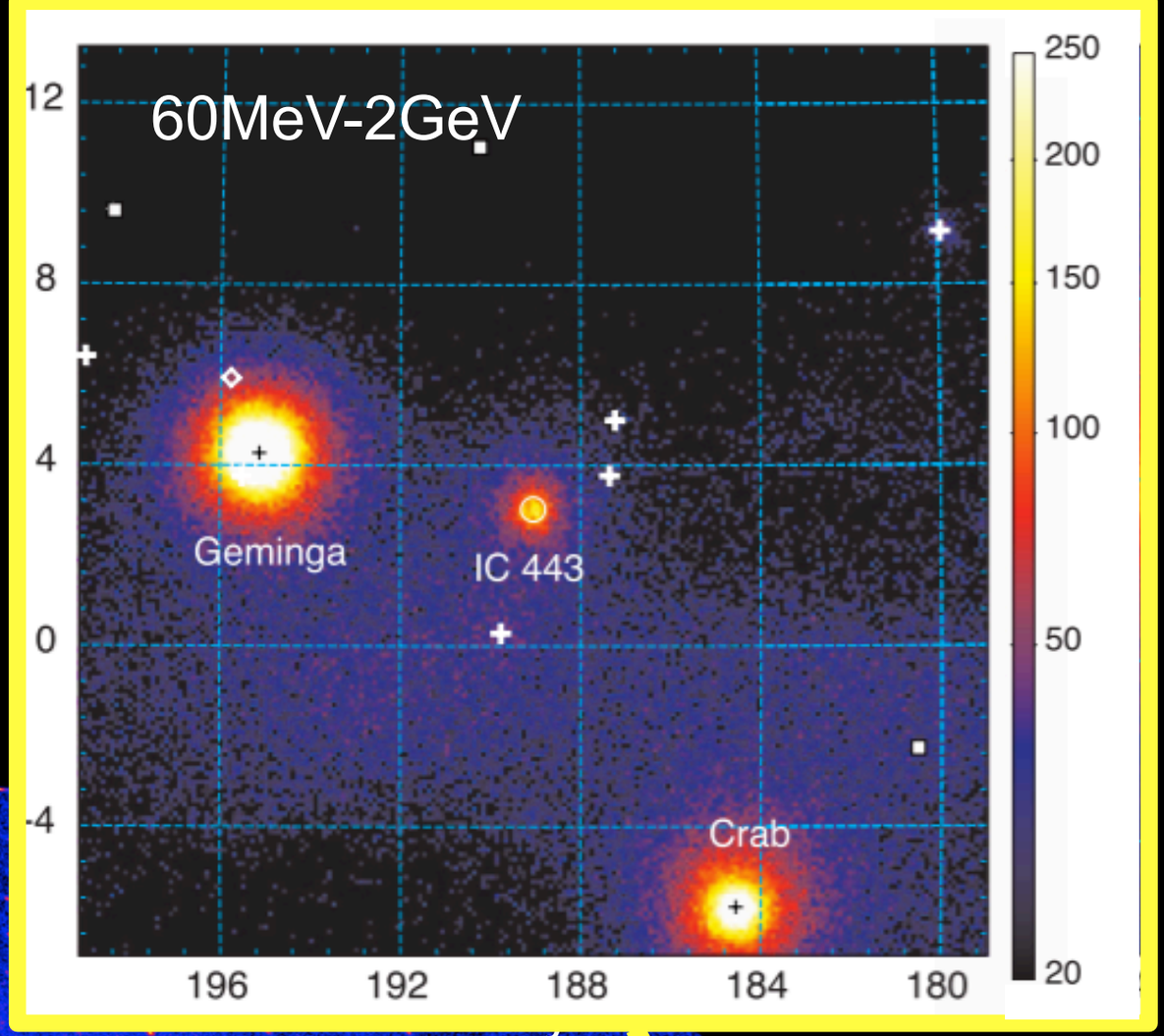


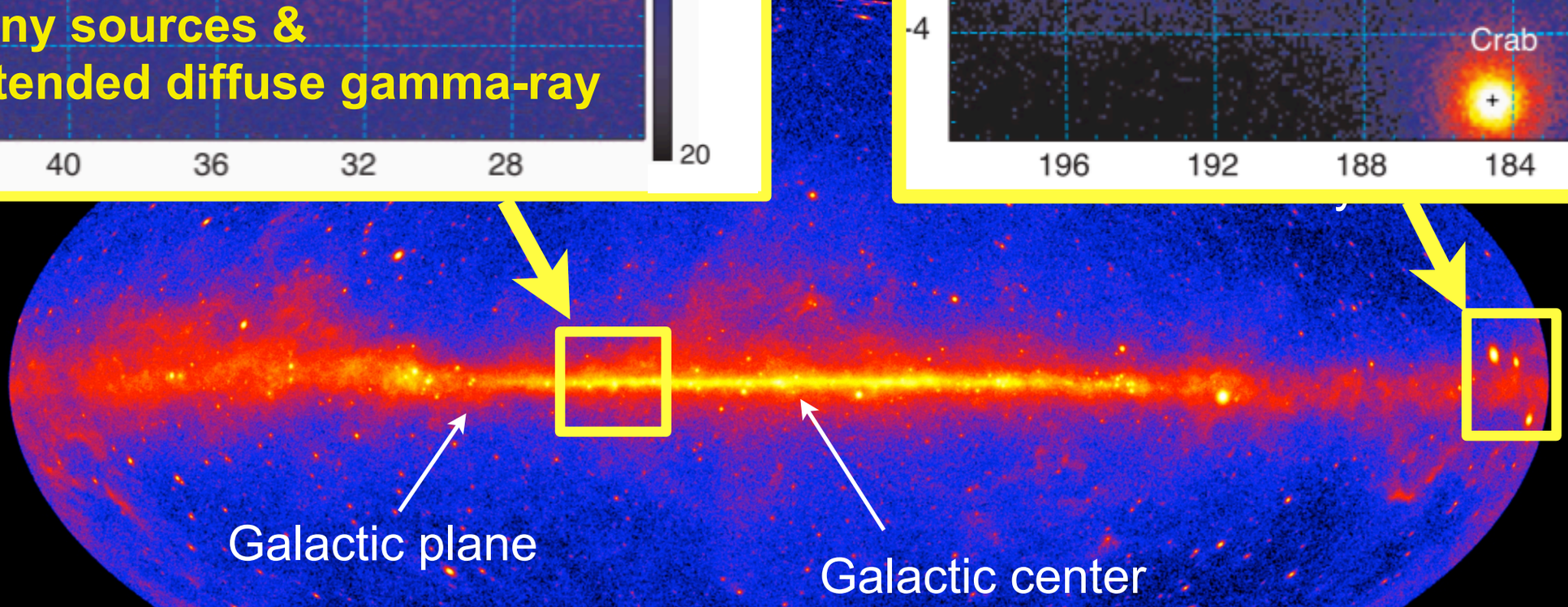
Galactic plane

Galactic center

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







High-statistic → NEXT: Precise Observation

Nuclear Emulsion

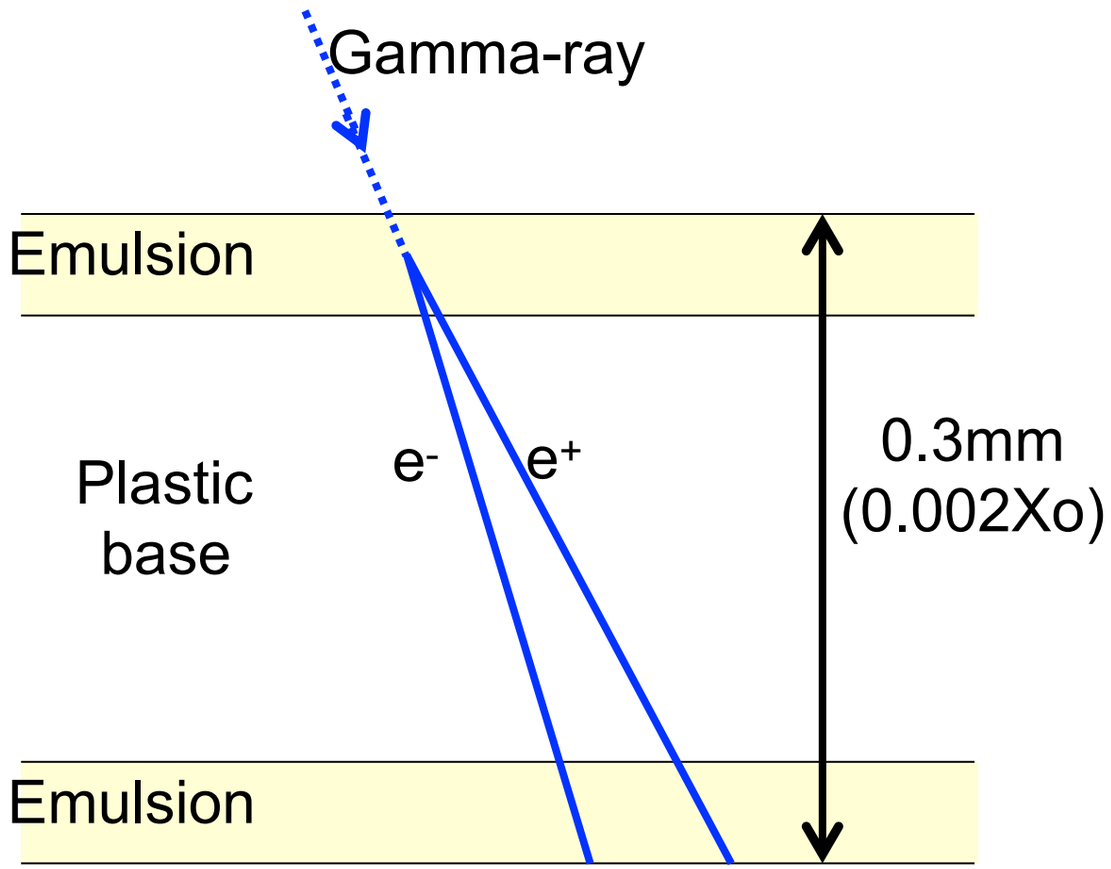
Microscopic view
10micron

Gamma-ray

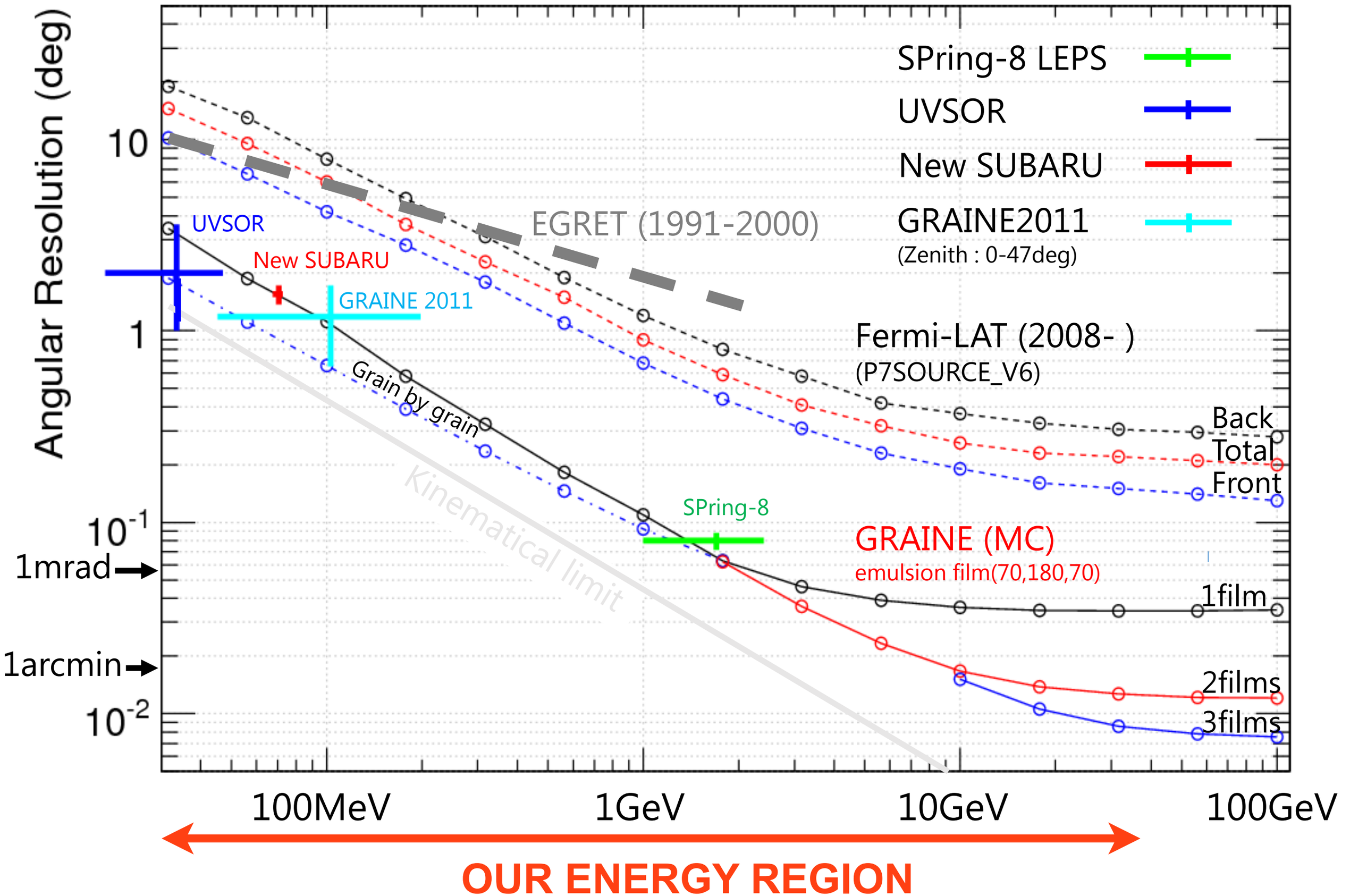
$e^{+/-}$

$e^{-/+}$

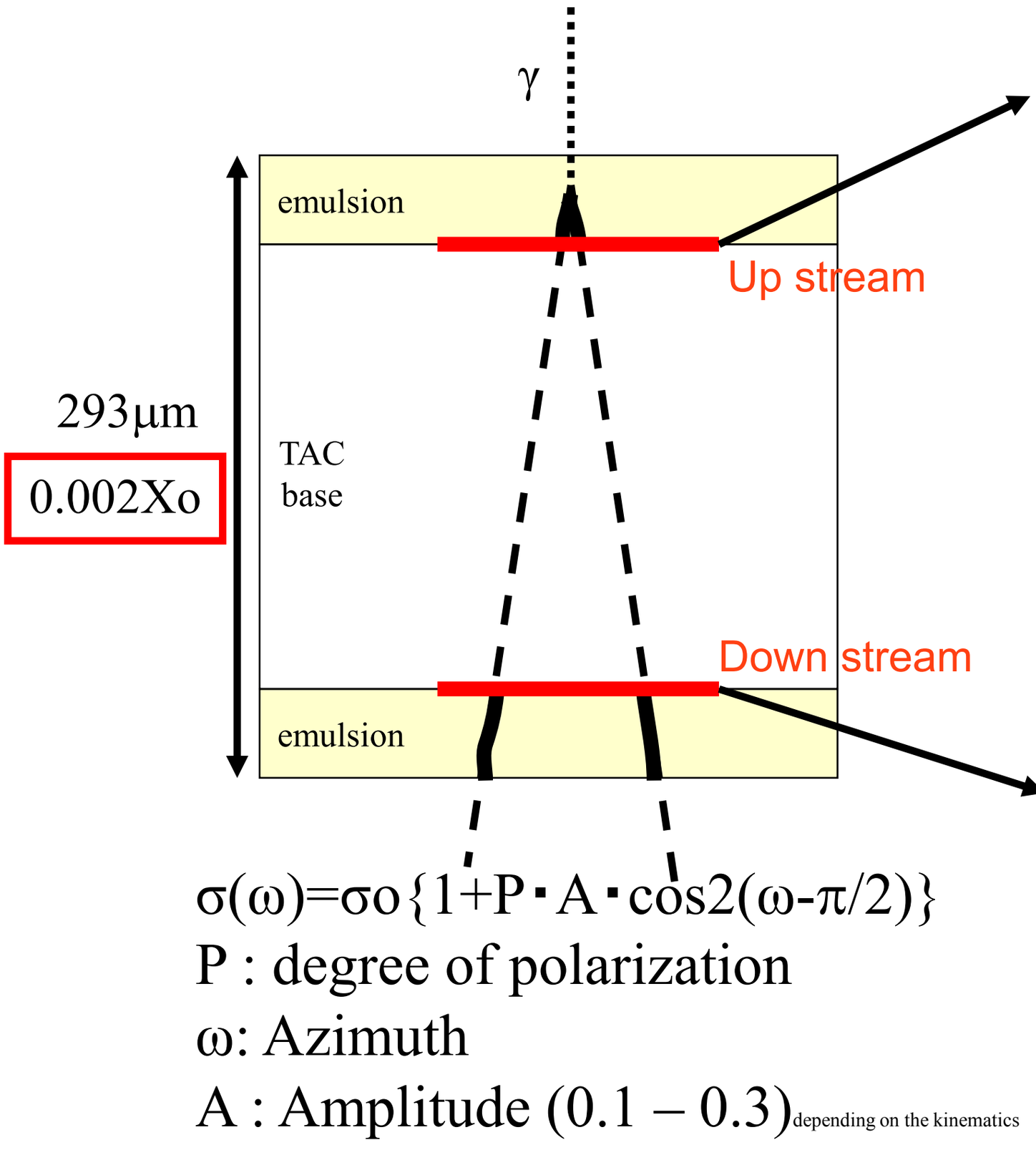
Cross sectional view of a plate

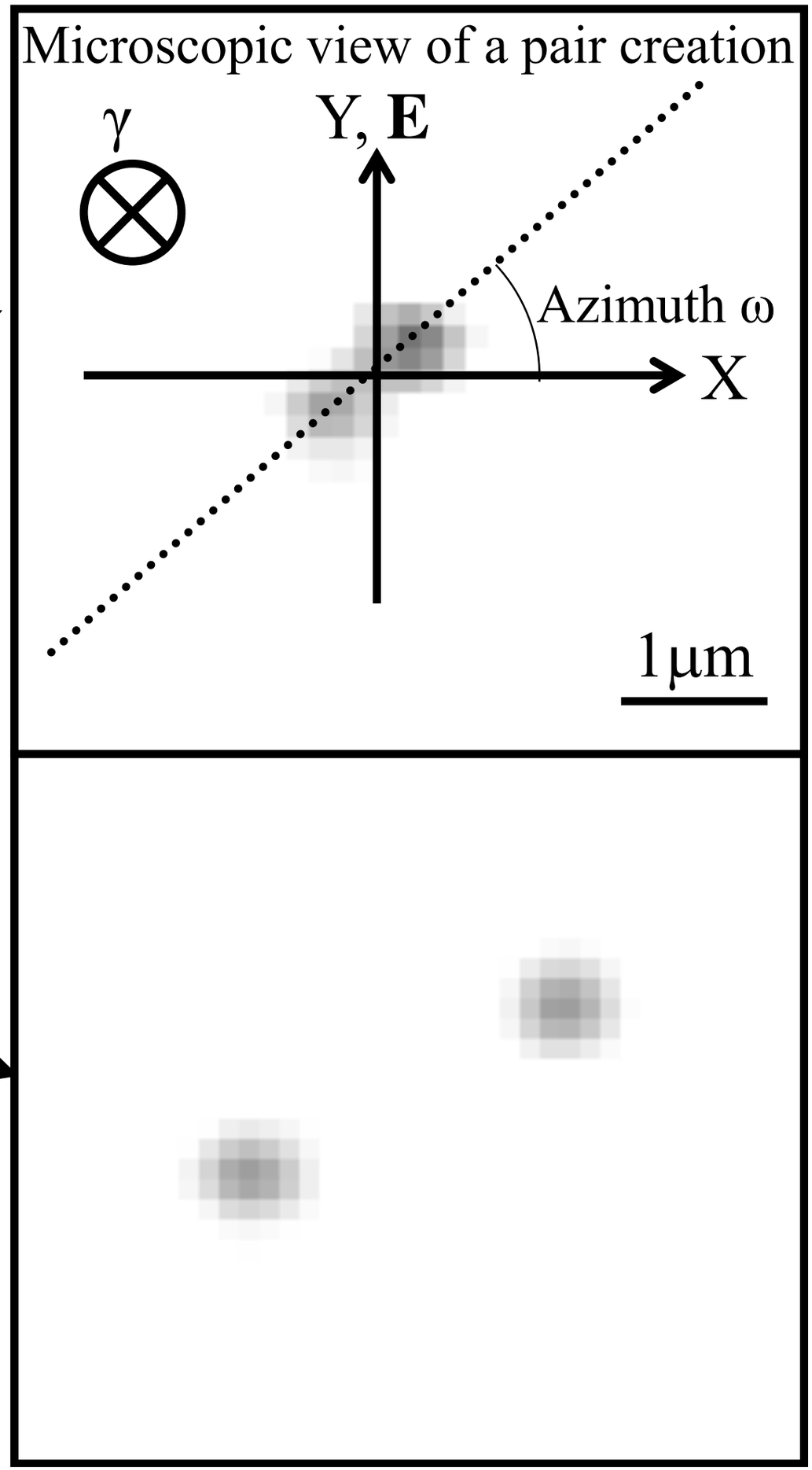


Angular Resolution for Gamma Ray



Polarimetry





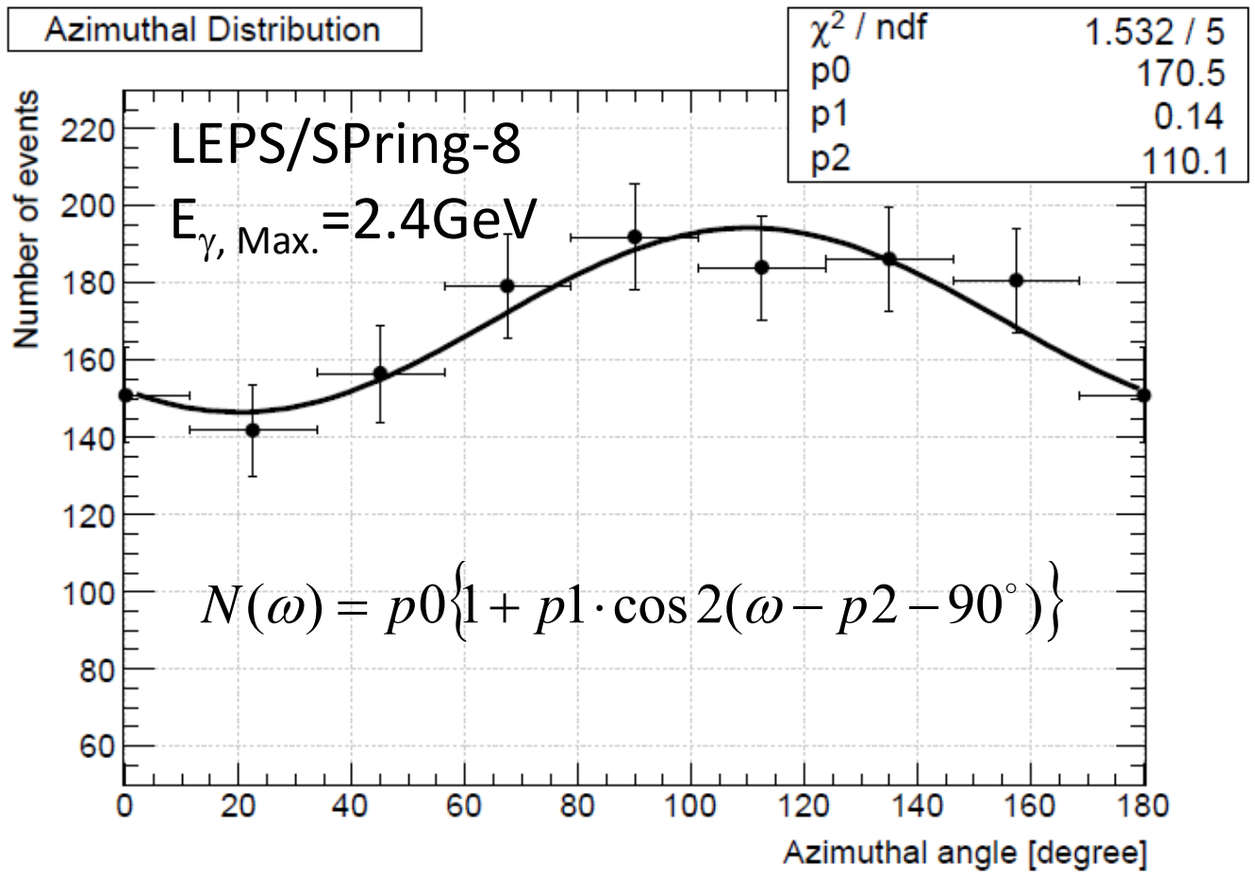
$$\sigma(\omega)=\sigma o\{1+P\cdot A\cdot \cos 2(\omega-\pi/2)\}$$

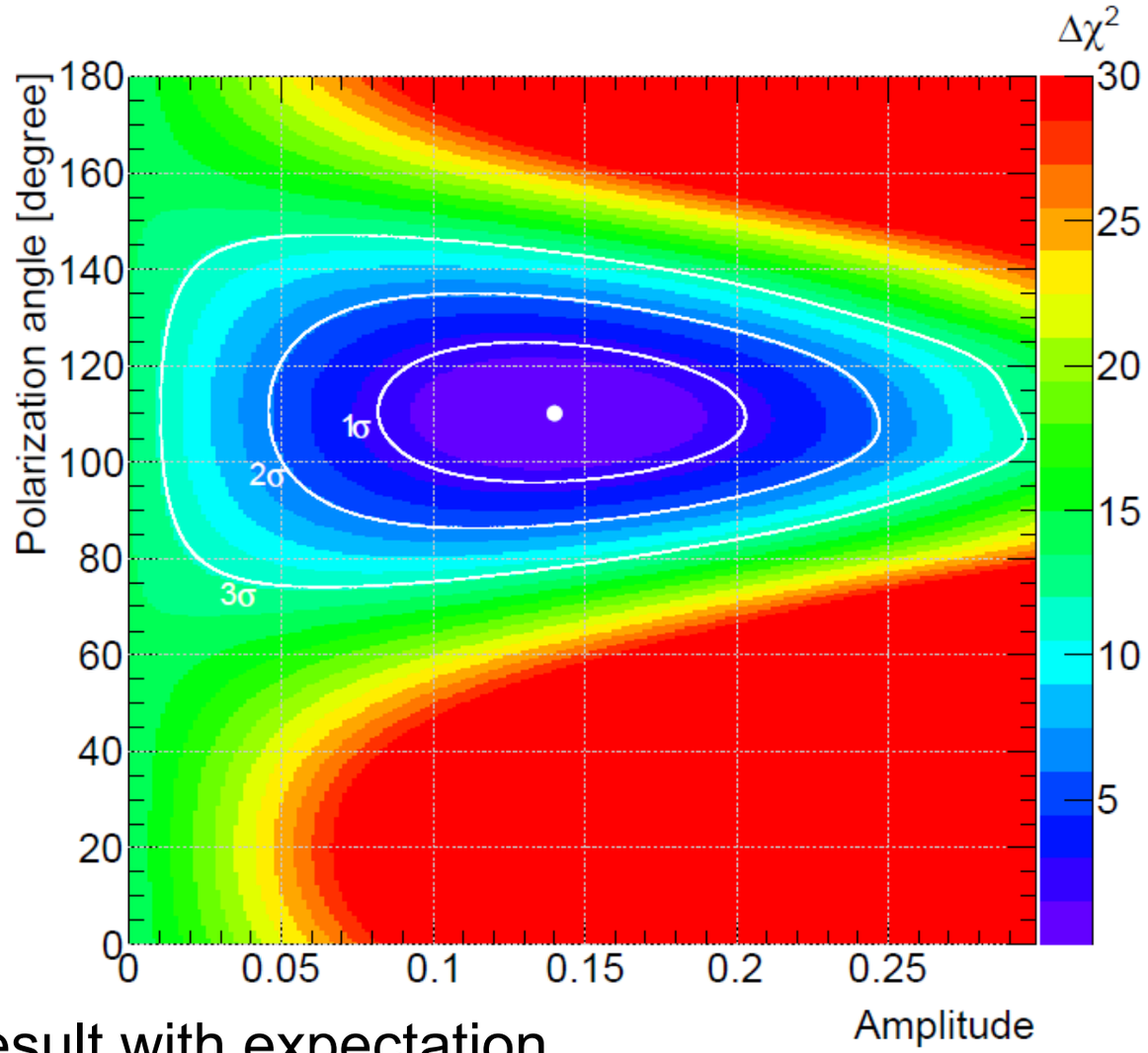
P : degree of polarization

ω: Azimuth

A : Amplitude (0.1 – 0.3)$_{\text{depending on the kinematics}}$

Polarization measurement with accel. γ-ray beam





Significant & consistent result with expectation.

<P>=66%, modulation factor = 0.21+-0.09

K. Ozaki, et al., NIM A 833, 11(2016)165

New technique for GRAINE

Multi-stage Shifter (Time stamper)

Consisting of emulsion film.

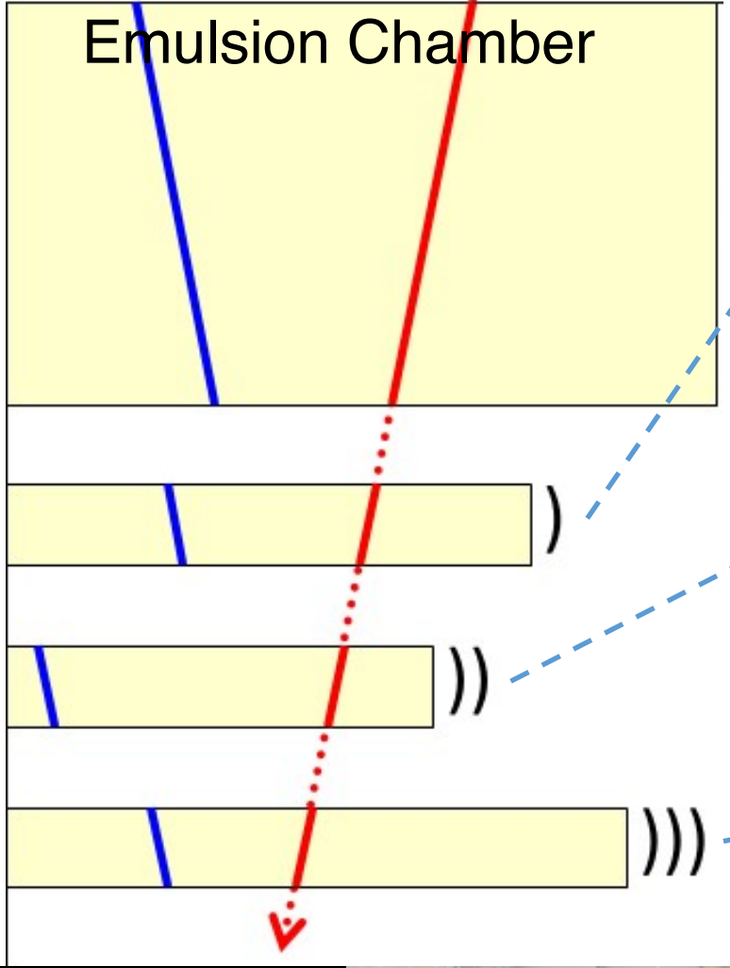
Low momentum threshold~10MeV/c

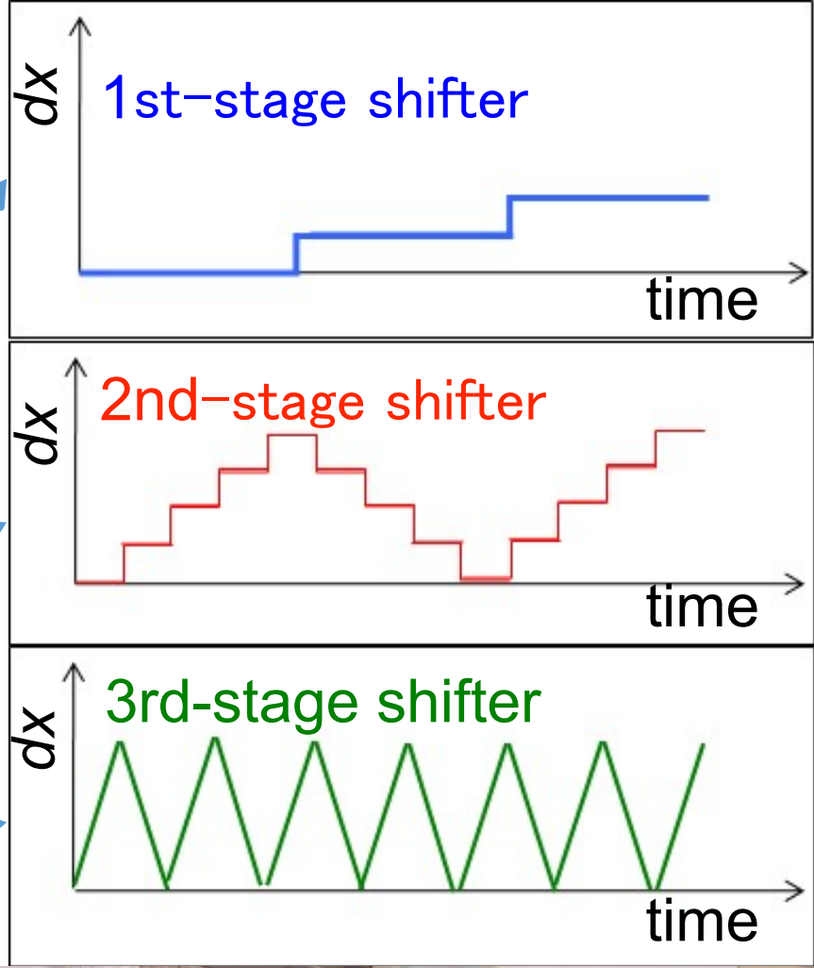
High reliability & efficiency

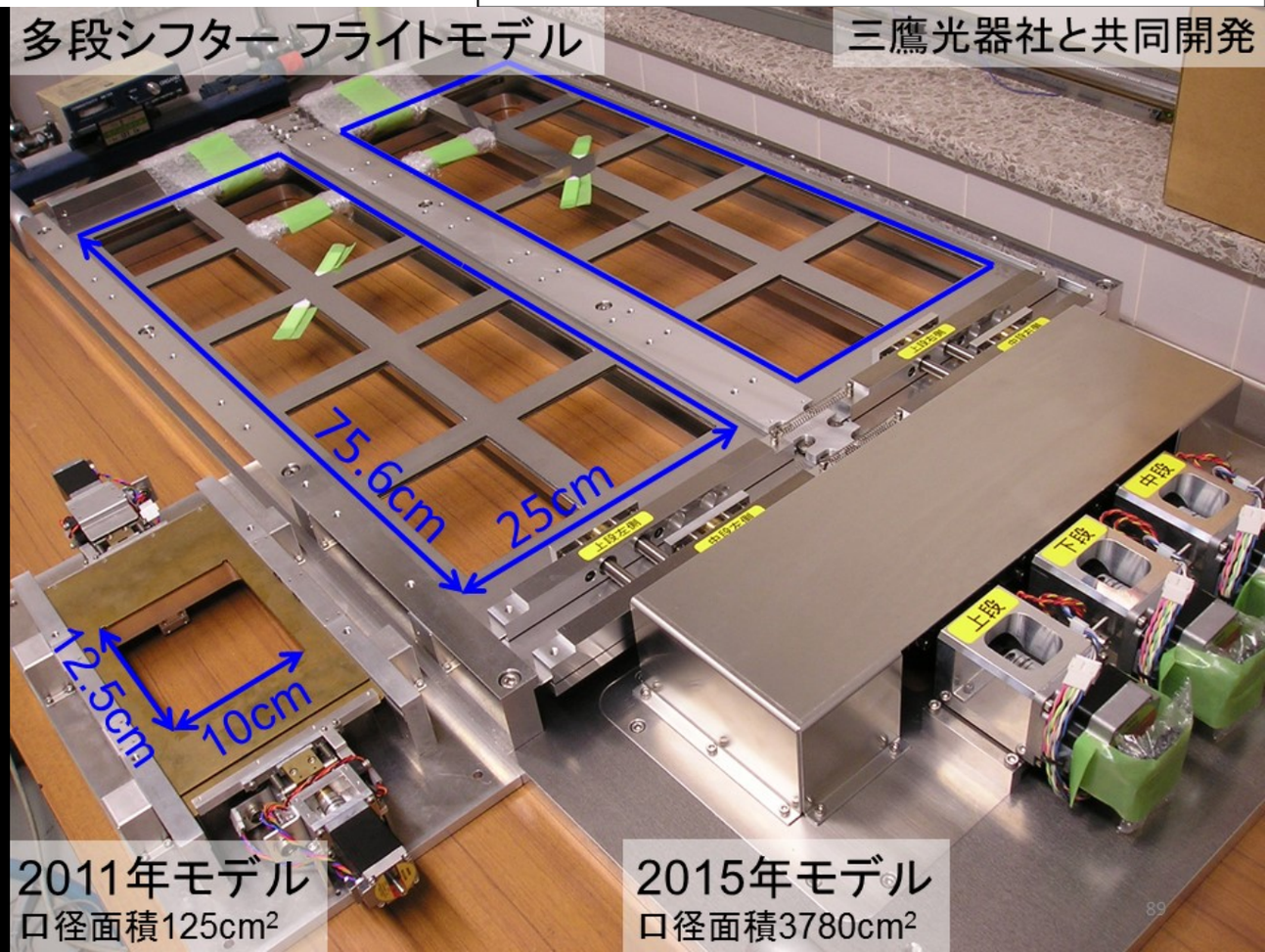
Enlargeable

Simple, compact, light weight, high-vol. free, low consumption, dead-time free

S. Takahashi et al.
NIM A620(2010) pp.192-195







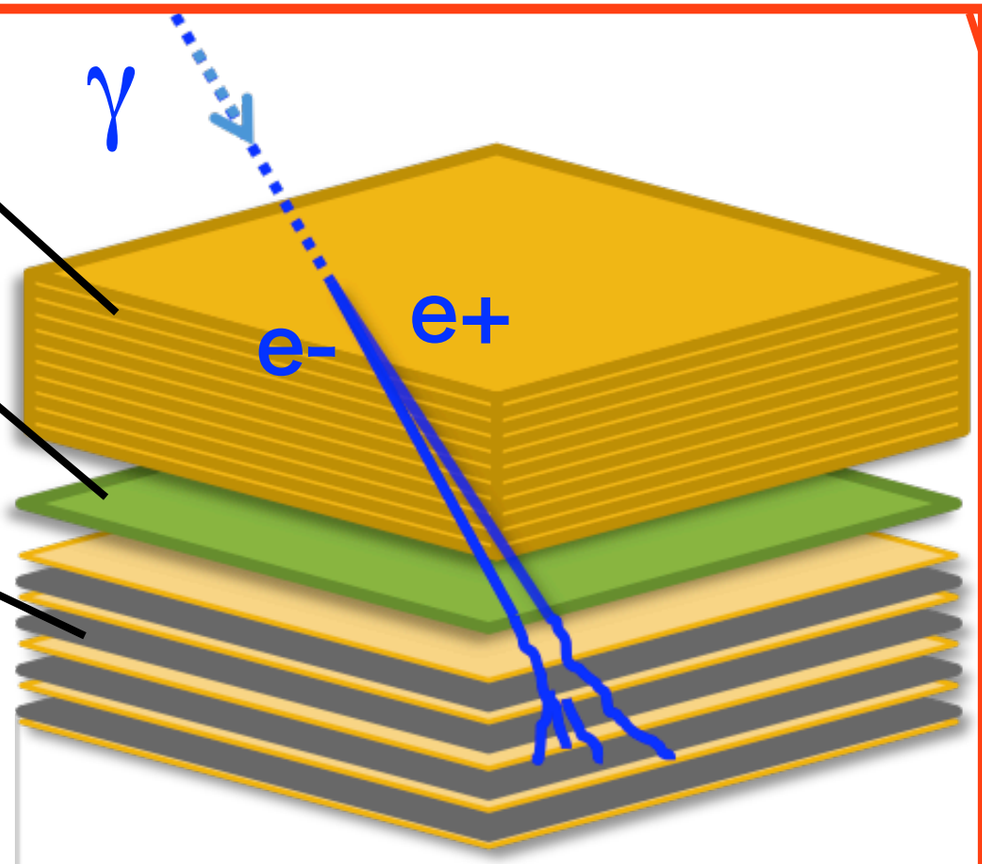
Emulsion Gamma-ray Telescope

Converter
Emulsion stack

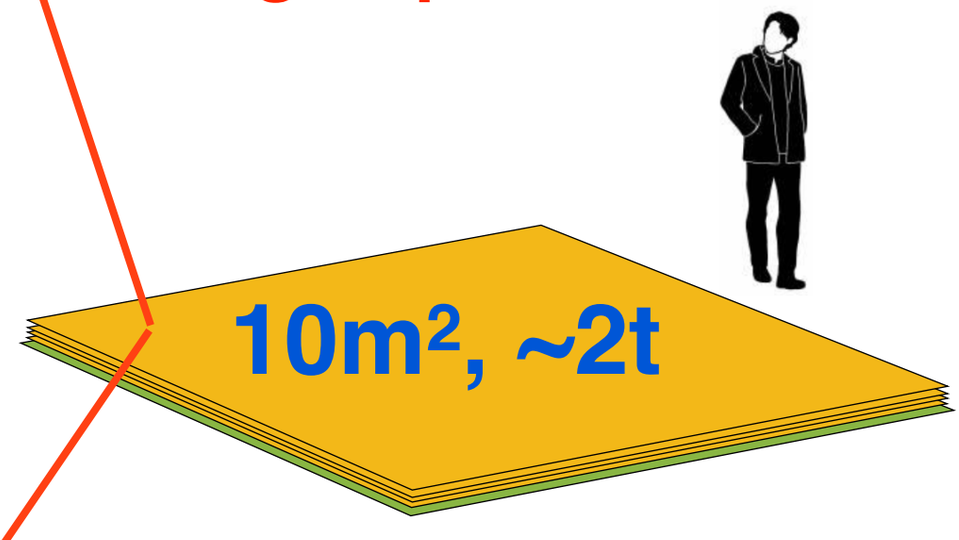
Timestamper
Multi-stage shifter

Calorimeter
Emulsion + metal plate

Attitude monitor
Star camera



- **Higher Angular Resol.**
- **Polarization Sensitive**
- **Large Aperture Area**



＊ $10m^{2}*\varepsilon_{trans}*\varepsilon_{conv}*\varepsilon_{det}$

Flow of experiment

Detector development /preparation

↓

Observation(balloon flight)
several days - 1 week

→ **Recovery of detector**

↑

Scanning (2nd data taking)

↖

Analysis

← **Detector development /preparation**

GRAINE project

2004– Development on ground

S.Takahashi et al. NIMA 620, 192 (2010)
K.Ozaki et al. NIMA 833, 165 (2016)

2011(Jun.) 1st Balloon-Exp.

- Checking Feasibility

H.Rokujo et al. NIMA 701, 127 (2013).
S.Takahashi et al. PTEP 2015 043H01

2015(May.) 2nd Balloon-Exp.

- establishment of experimental flow
- demonstration of detector

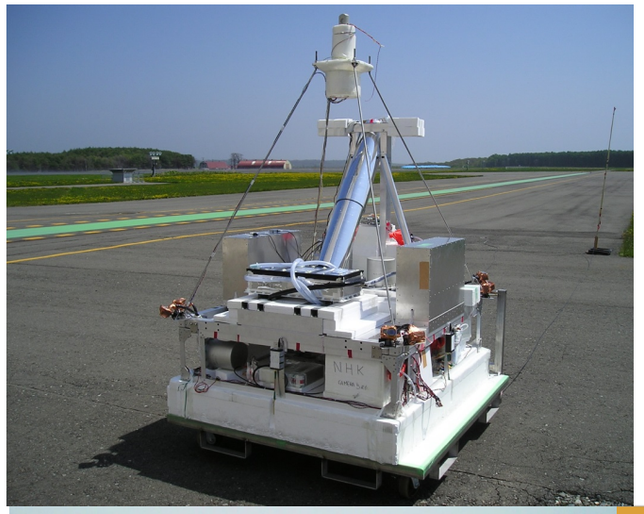
K.Ozaki et al., JINST 10, P12018 (2015)
S.Takahashi et al. PTEP 2016, 073F01
H,Rokujo et al., PTEP (submitted)

Under Preparation

2018(Apr.) 3rd Balloon-Exp.

- Celestial source detection

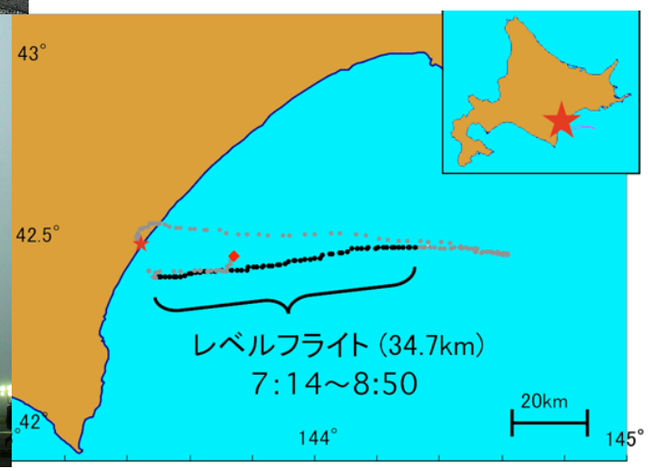
2021- Start scientific observation w/10m²



GRAINE 2011

Aperture：0.013m²

1.6 h@35km

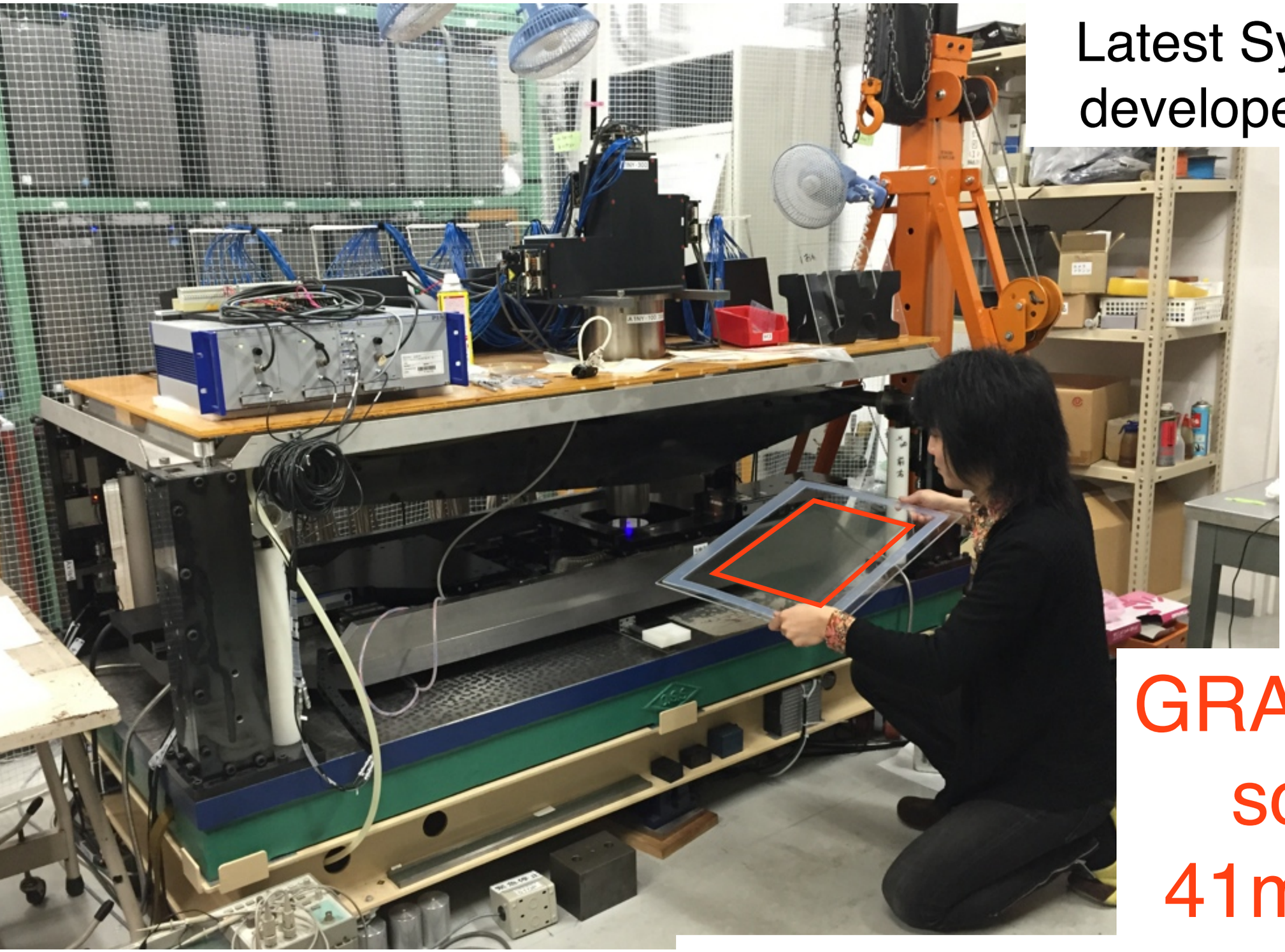


GRAINE 2015

Aperture：0.38m²

11.5 h@36-37km

Data taking by Scanning System

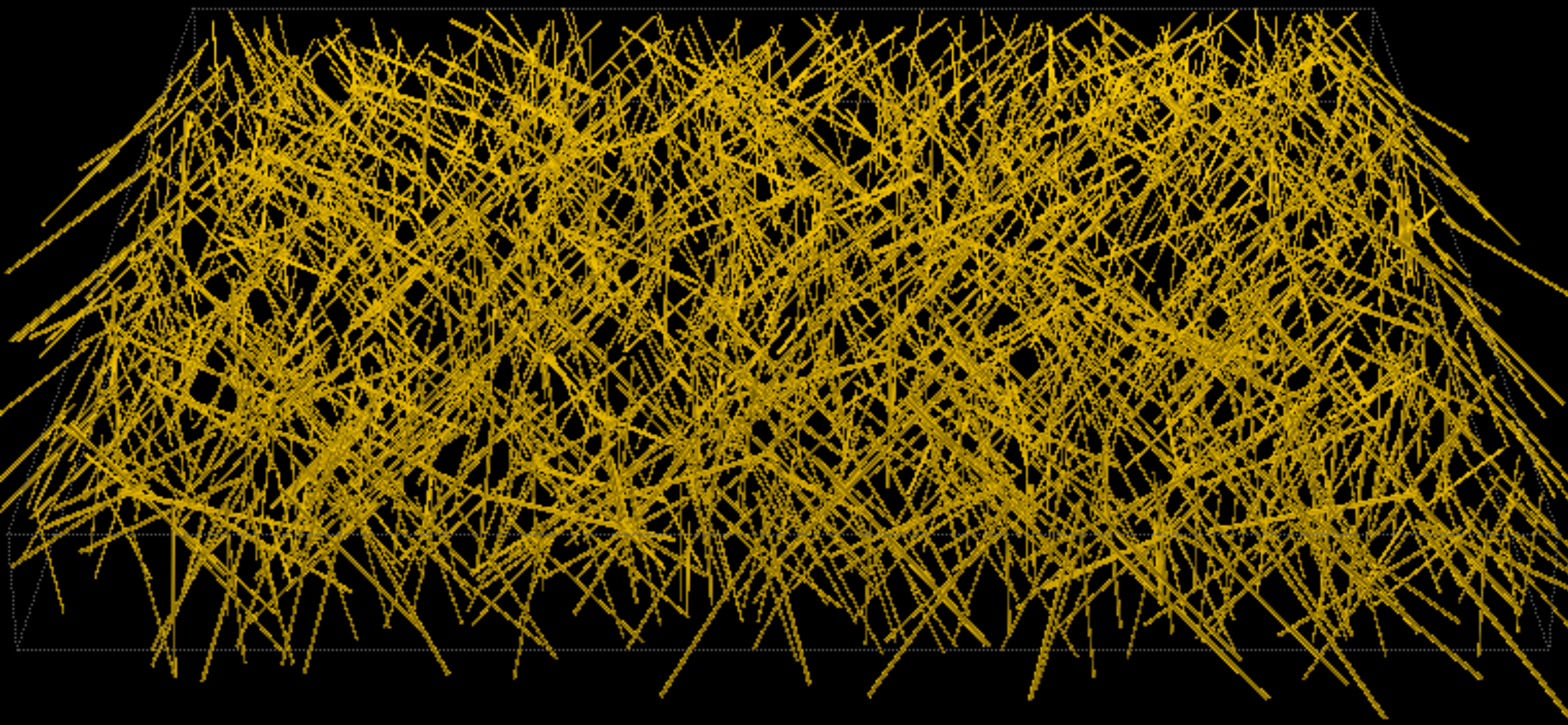


Latest System “HTS”
developed in Nagoya

GRAINE 2015
scanned
41m² in total

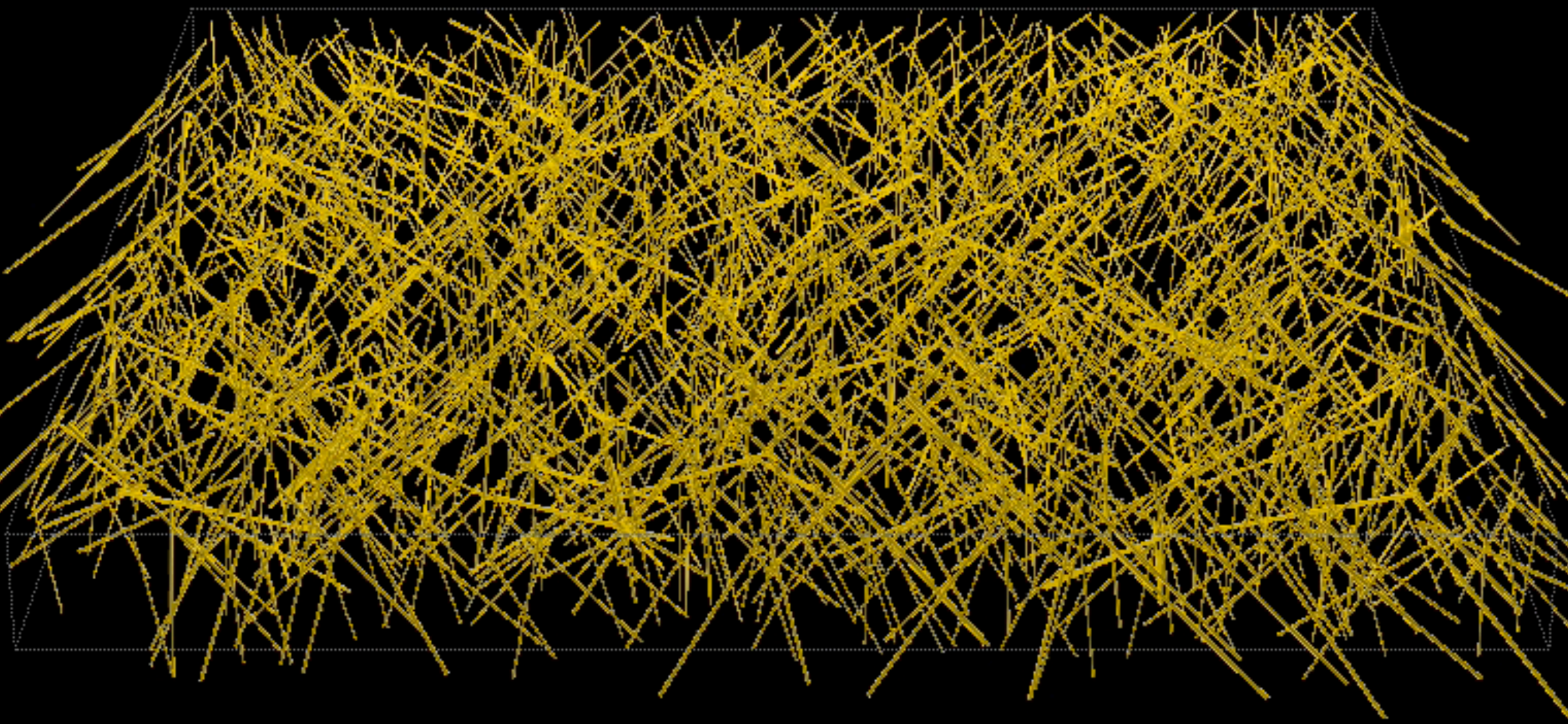
current speed 4000 cm²/h
→25000cm²/h by next generation system

Flight data



2 mm x 2 mm of single film

Flight data



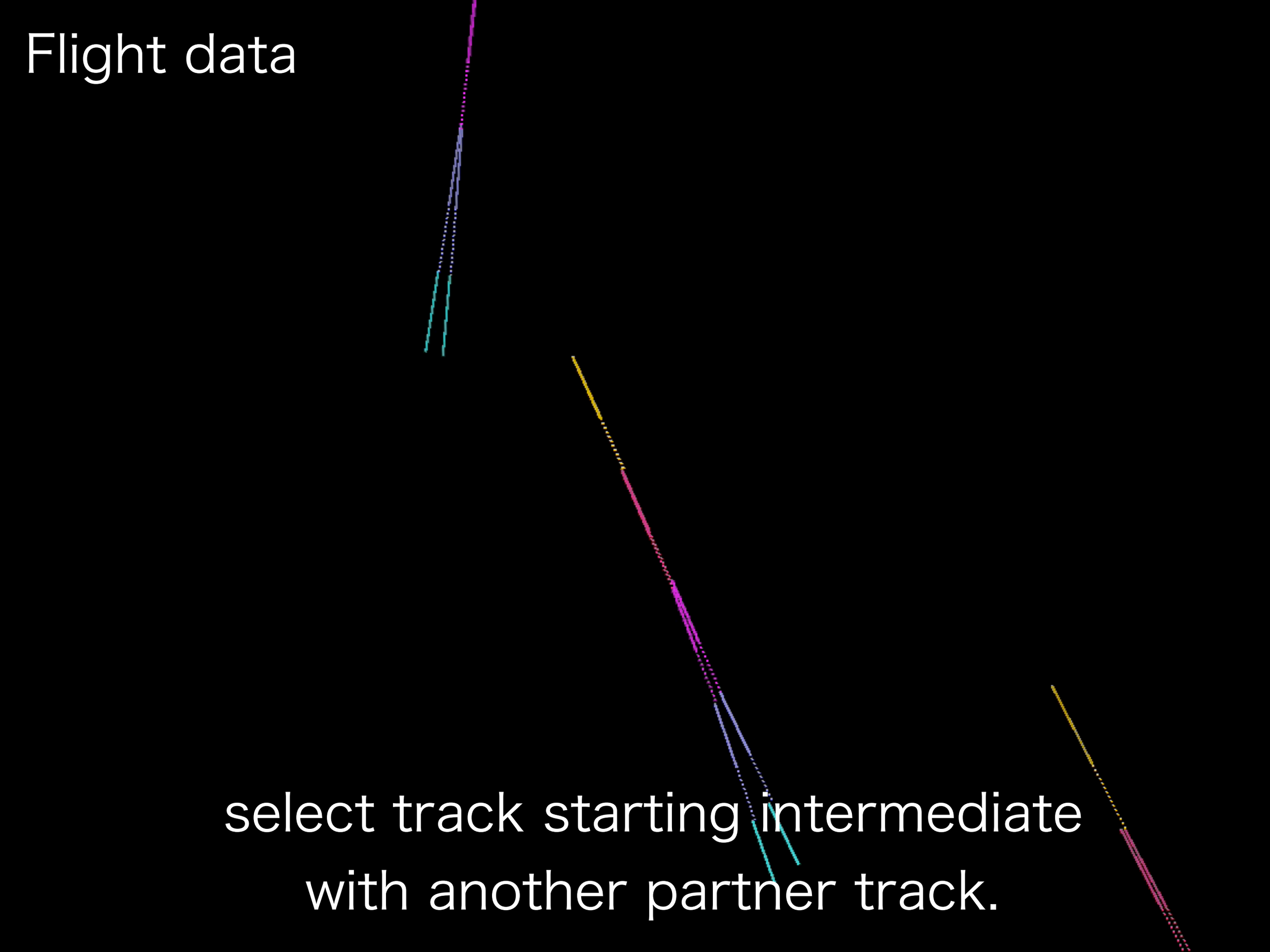
emulsion film records all charged particles.

density ~400 tracks/mm^2

Flight data

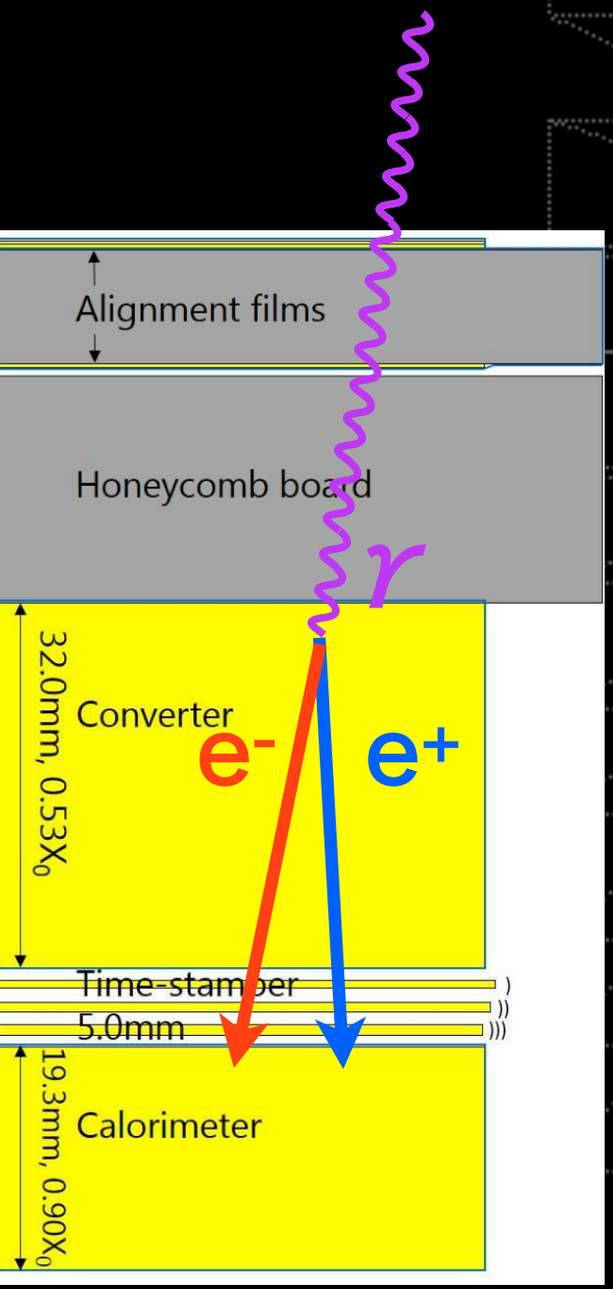
track connection plate by plate
(colors indicate different plates)

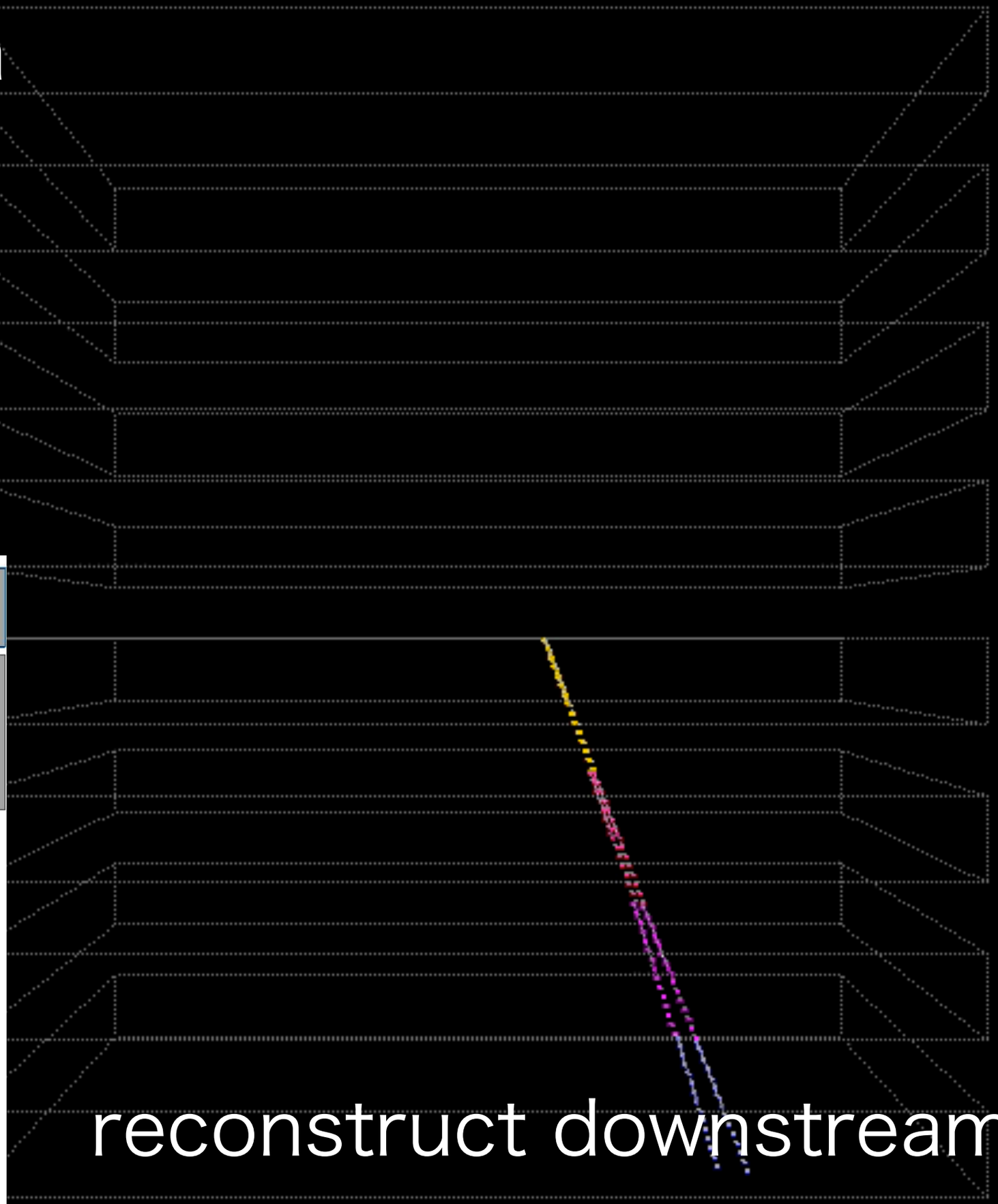
Flight data



select track starting intermediate
with another partner track.

Flight data





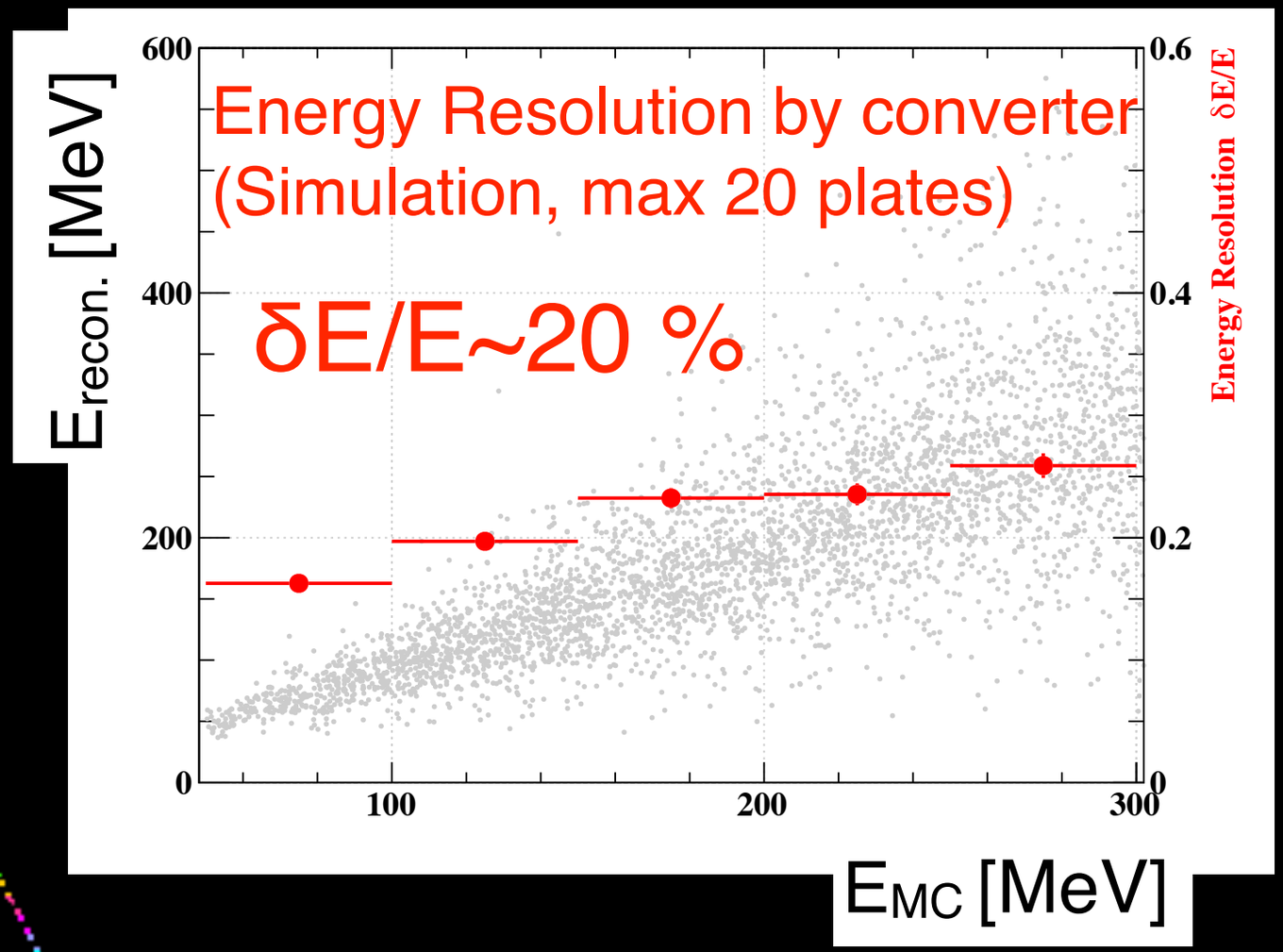
reconstruct downstream tracks

(Follow down for 95 plates in this event)

Flight data

Track 2
Momentum:
129 MeV/c (Recon.)

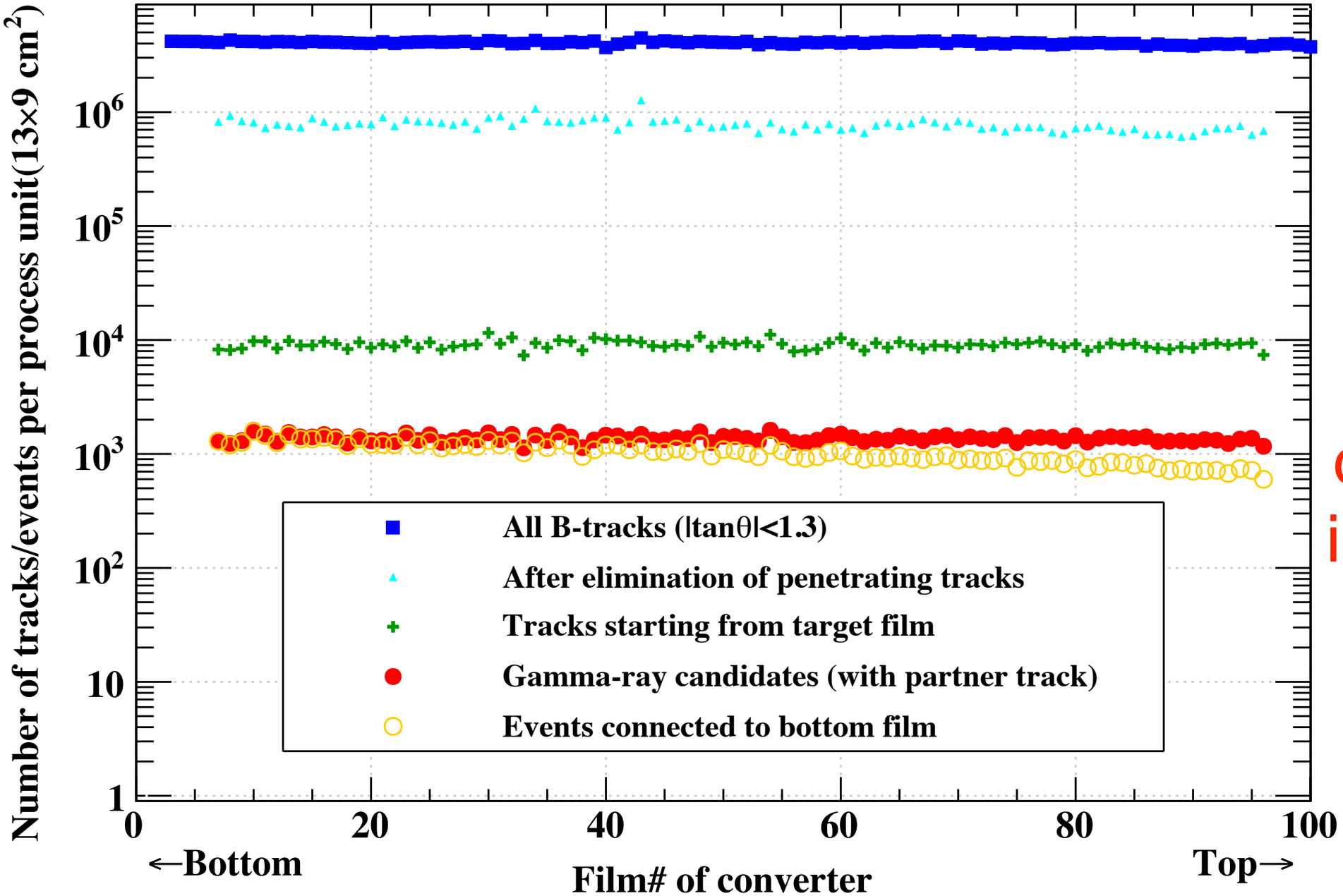
Track 1
Momentum:
46 MeV/c (Recon.)



Gamma-ray Energy:
176 MeV (Recon.)

Recent Progress of GRAINE

▪Automatic γ→e+e− Selection for the whole of the chamber



All tracks

e-pair candidates in each film

Detected event number

GRAINE2011

157 events

reliability 98%, partial analysis

x10000

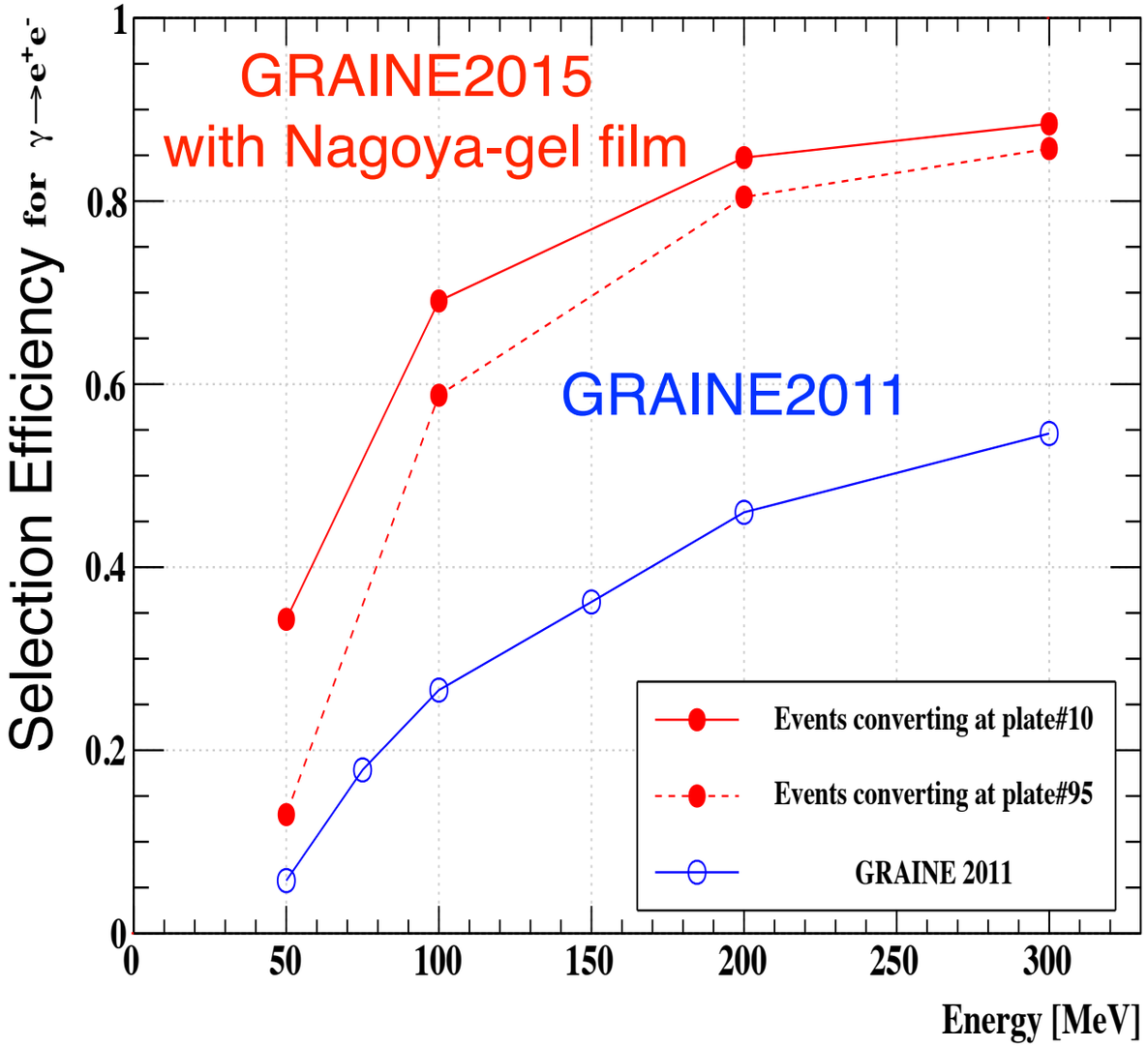
GRAINE2015

~10^6 events

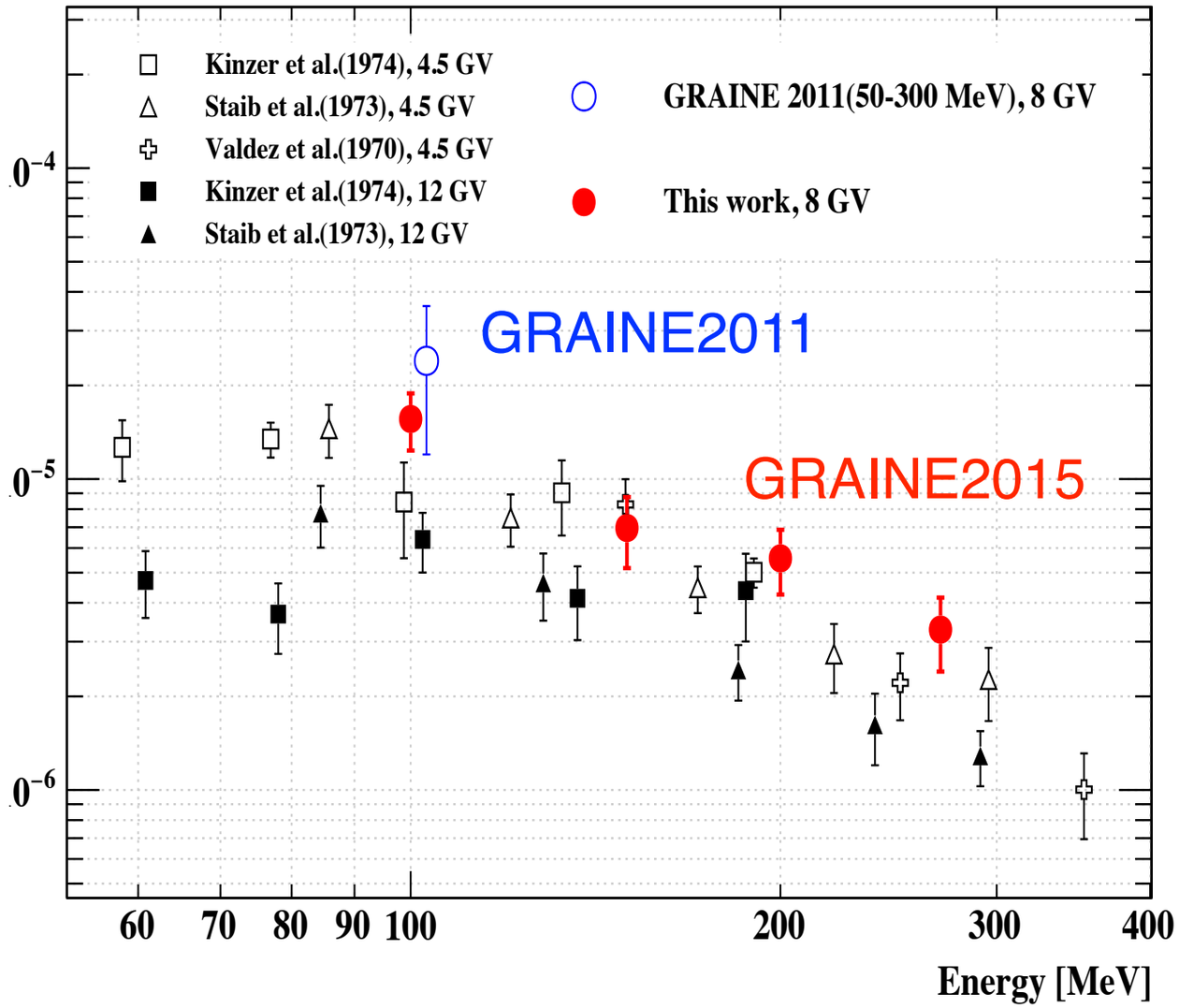
reliability 95%, almost full analysis (~75%)

Recent Progress of GRAINE

▪Selection Performance(MC)

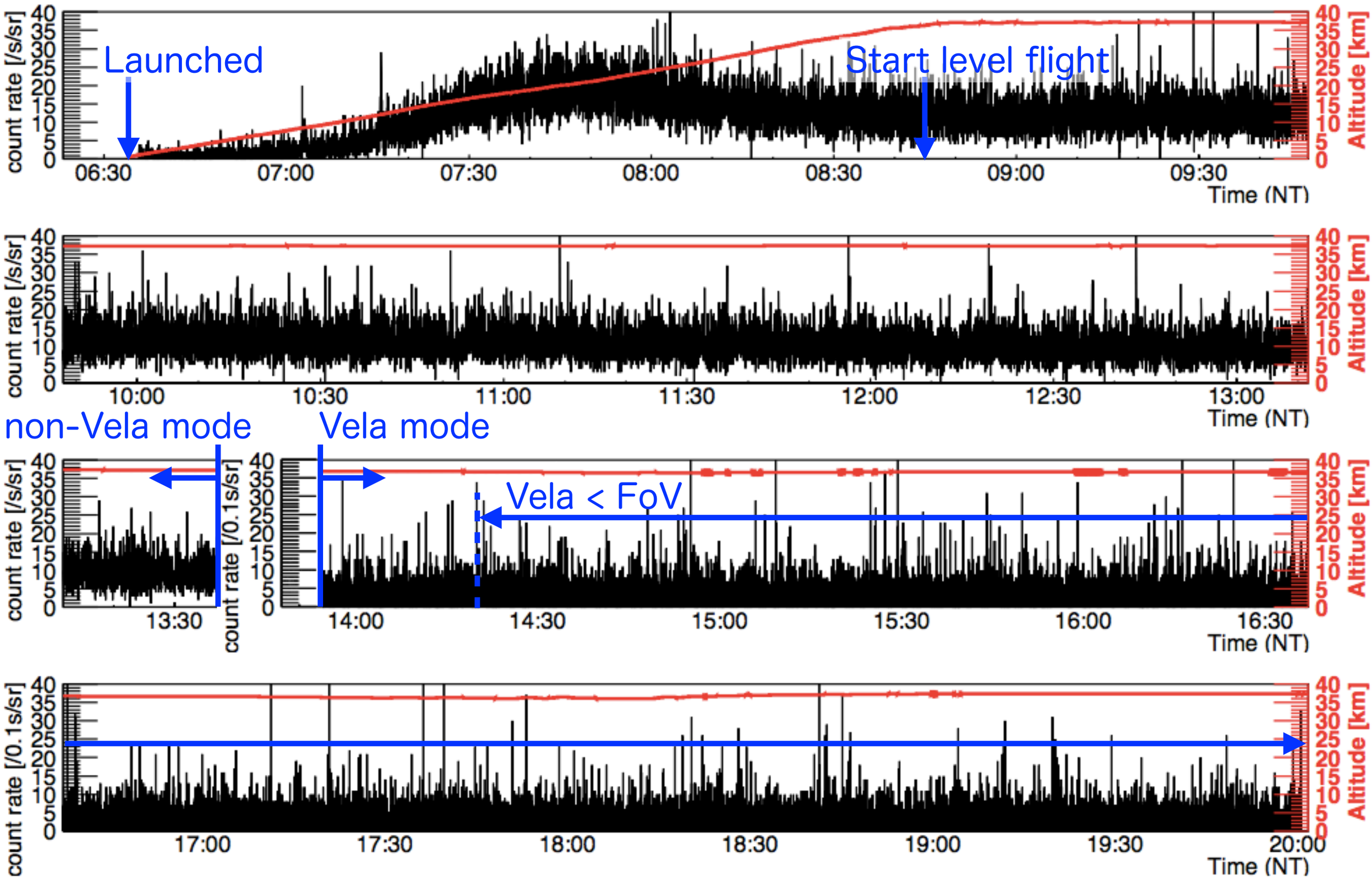


▪BG Flux Measurement (atmospheric gamma rays)

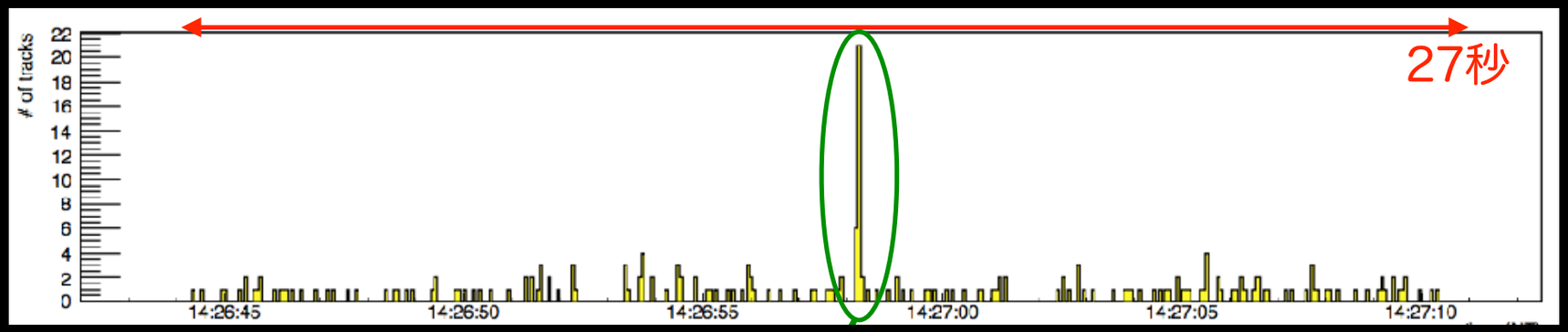


F.Mizutani (Kobe Univ.)

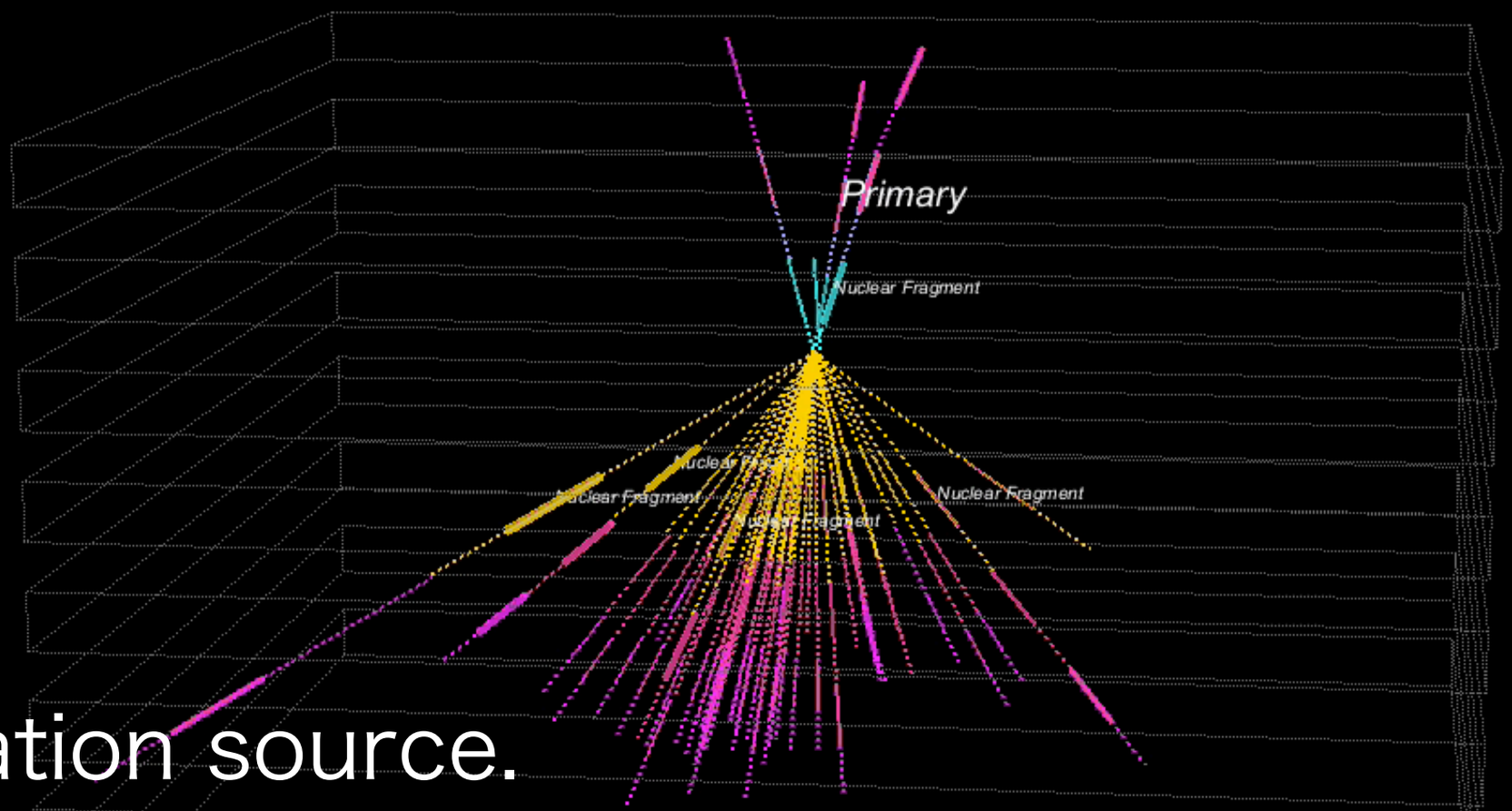
Count Rate of Cosmic Ray



Trigger of Hadronic Interaction Event by Timing Information



3 mm x 3mm.



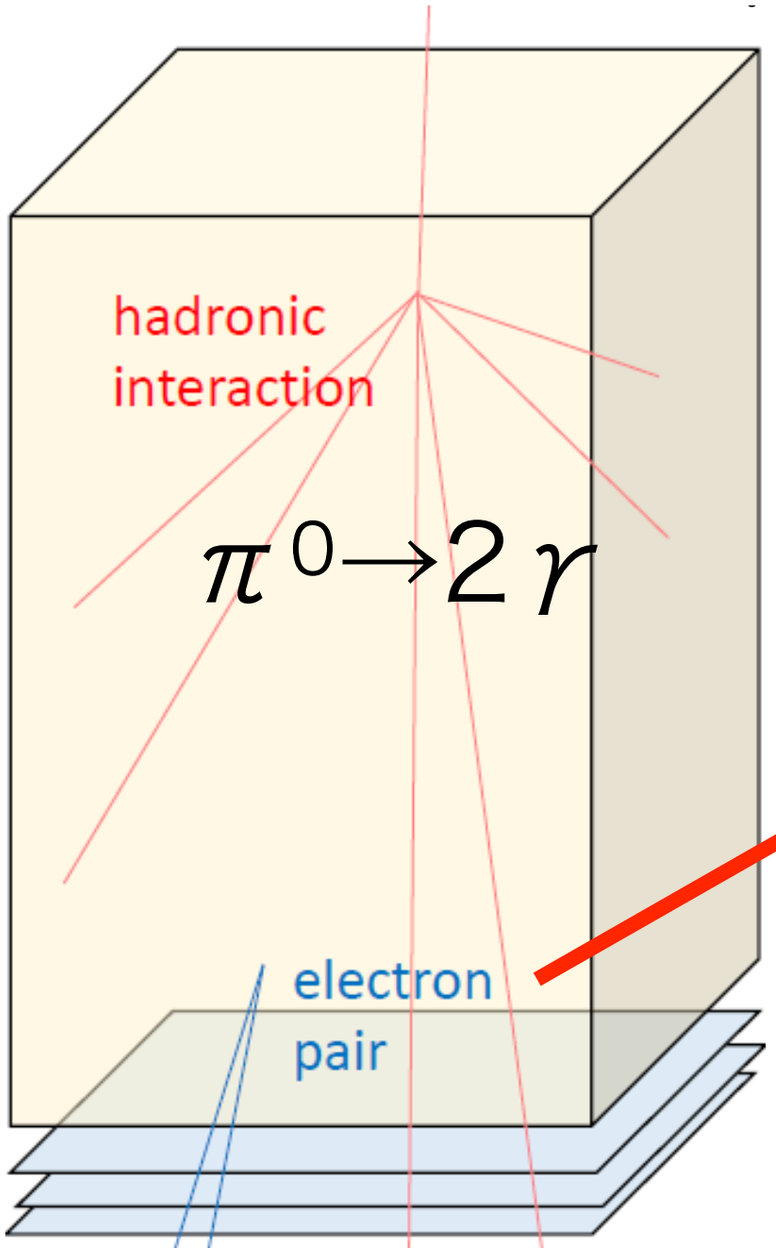
For timing calibration source.

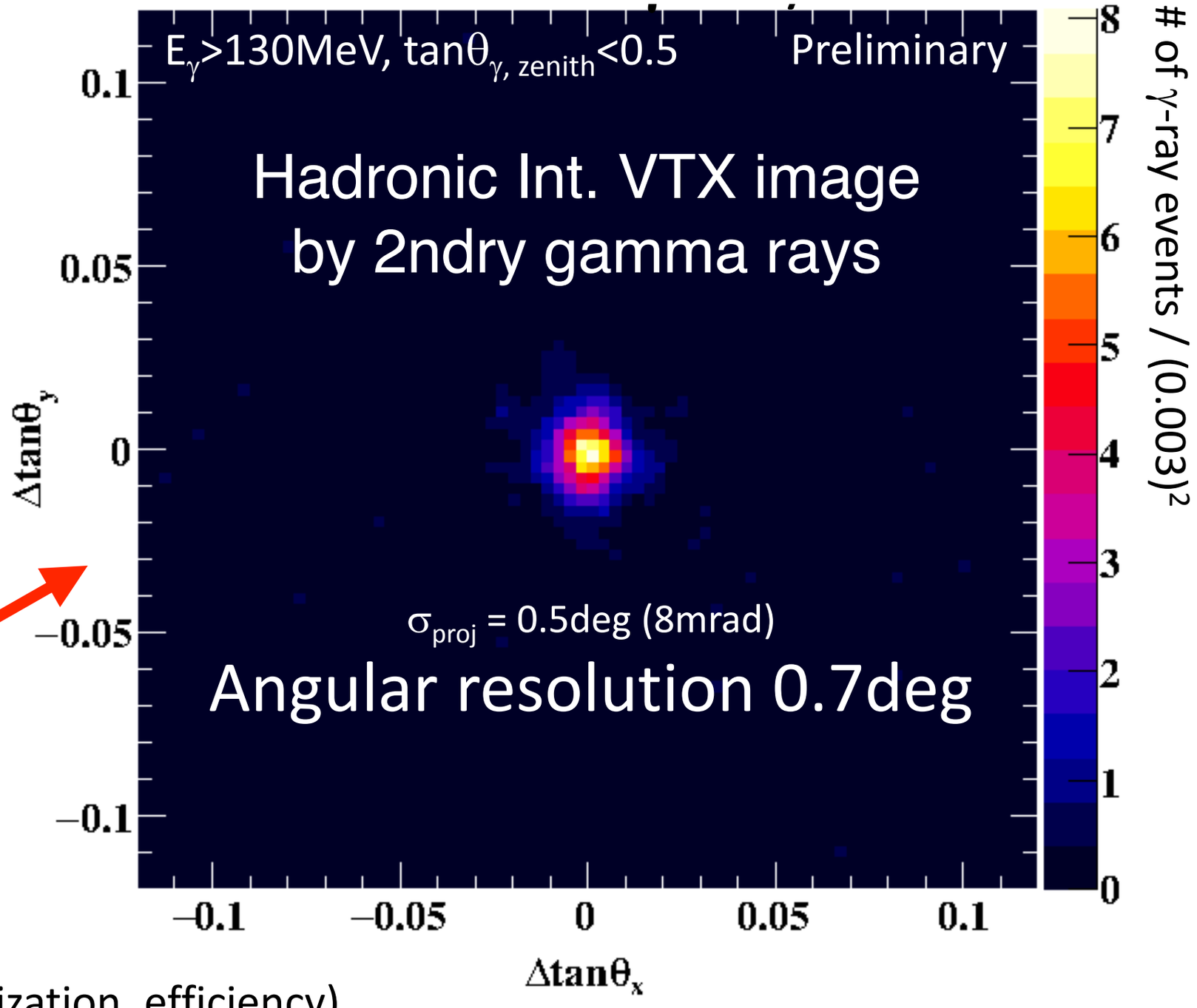
→Time resolution : 9.5 msec @ E>500MeV

26 msec @ E<200MeV

H.Kawahara (Nagoya Univ.)

Calibration source for gamma-ray telescope

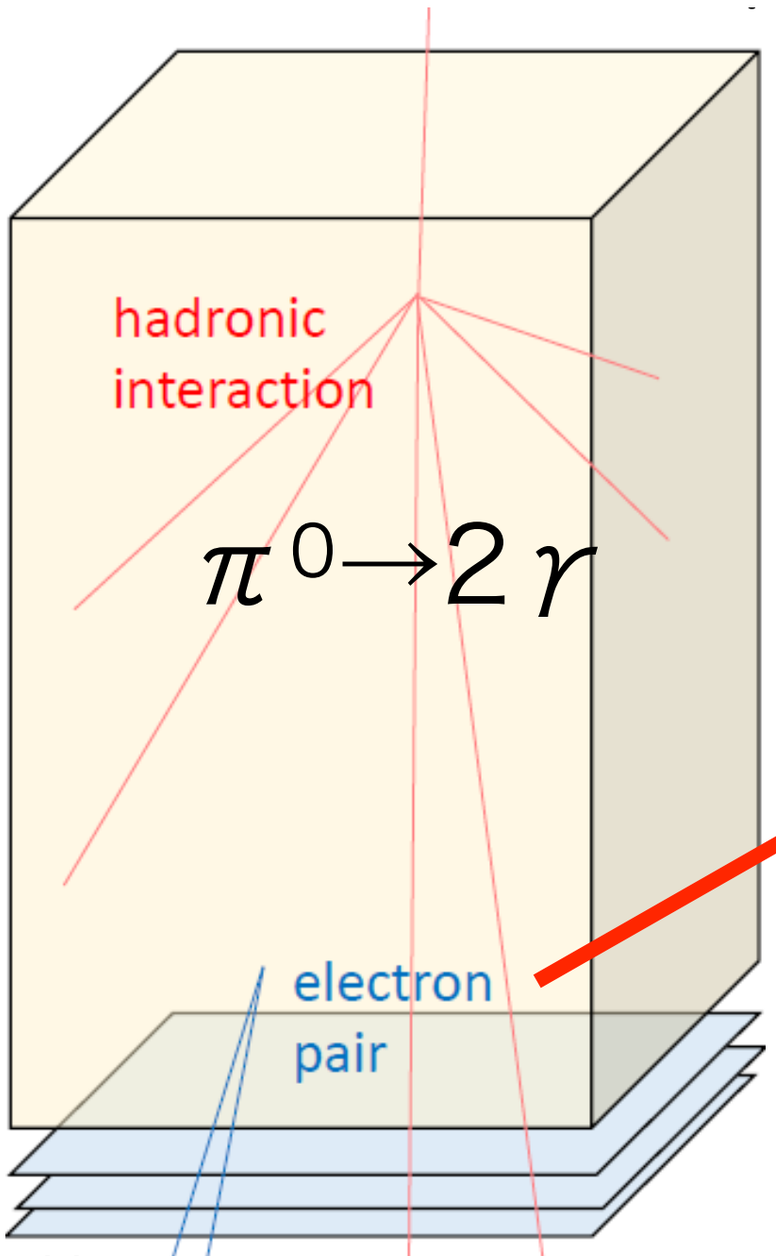


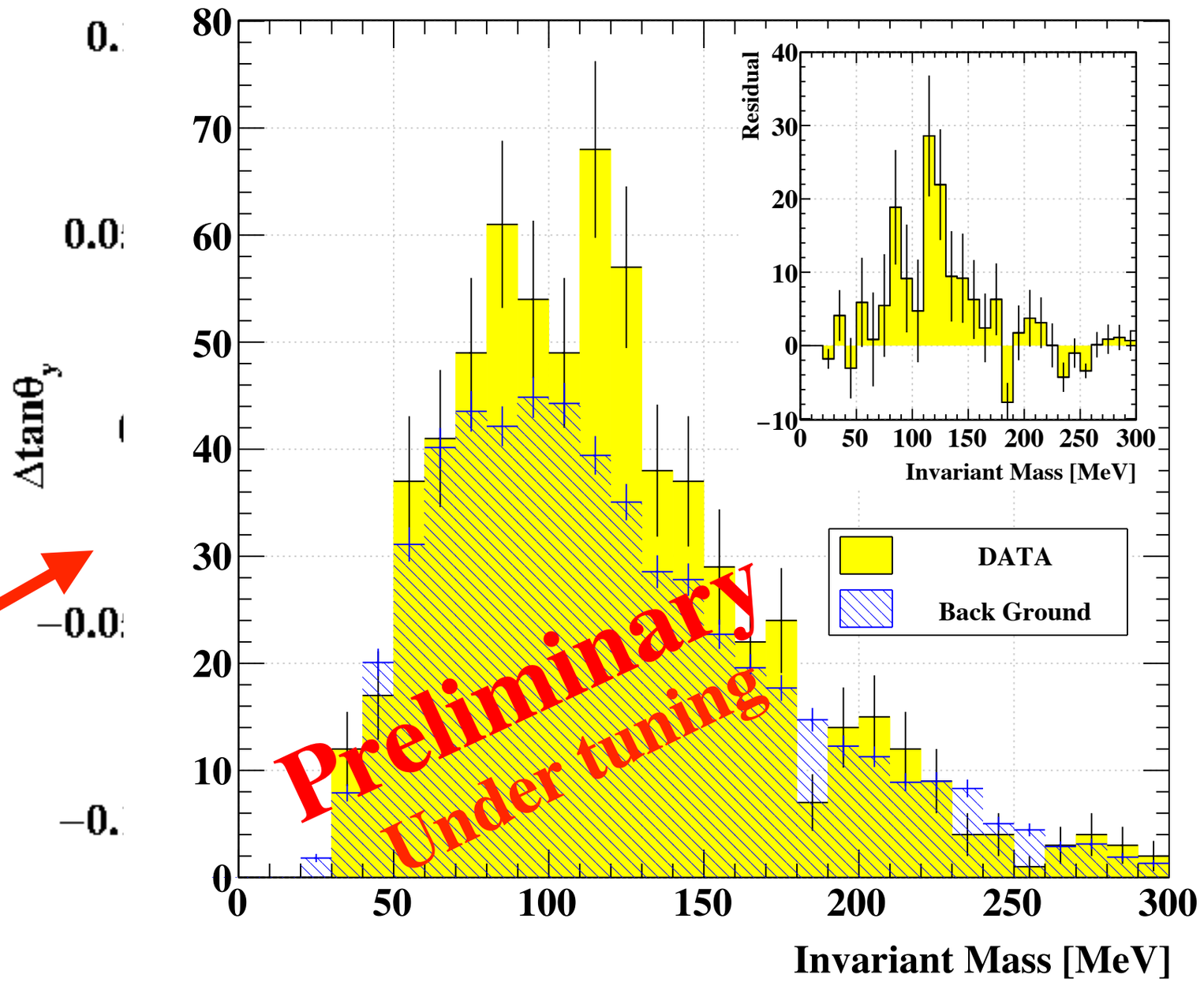


Calibration sorce
(direction, timing, energy, polarization, efficiency)

High γ-ray imaging performance is being obtained.

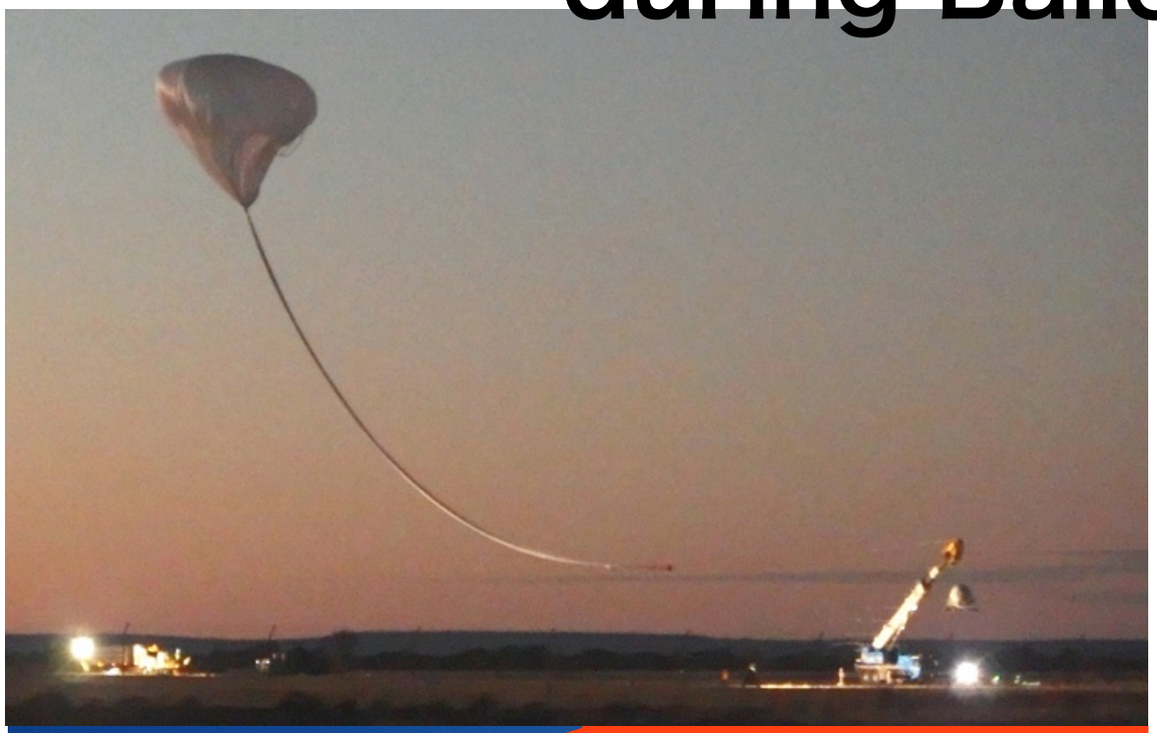
Calibration source for gamma-ray telescope

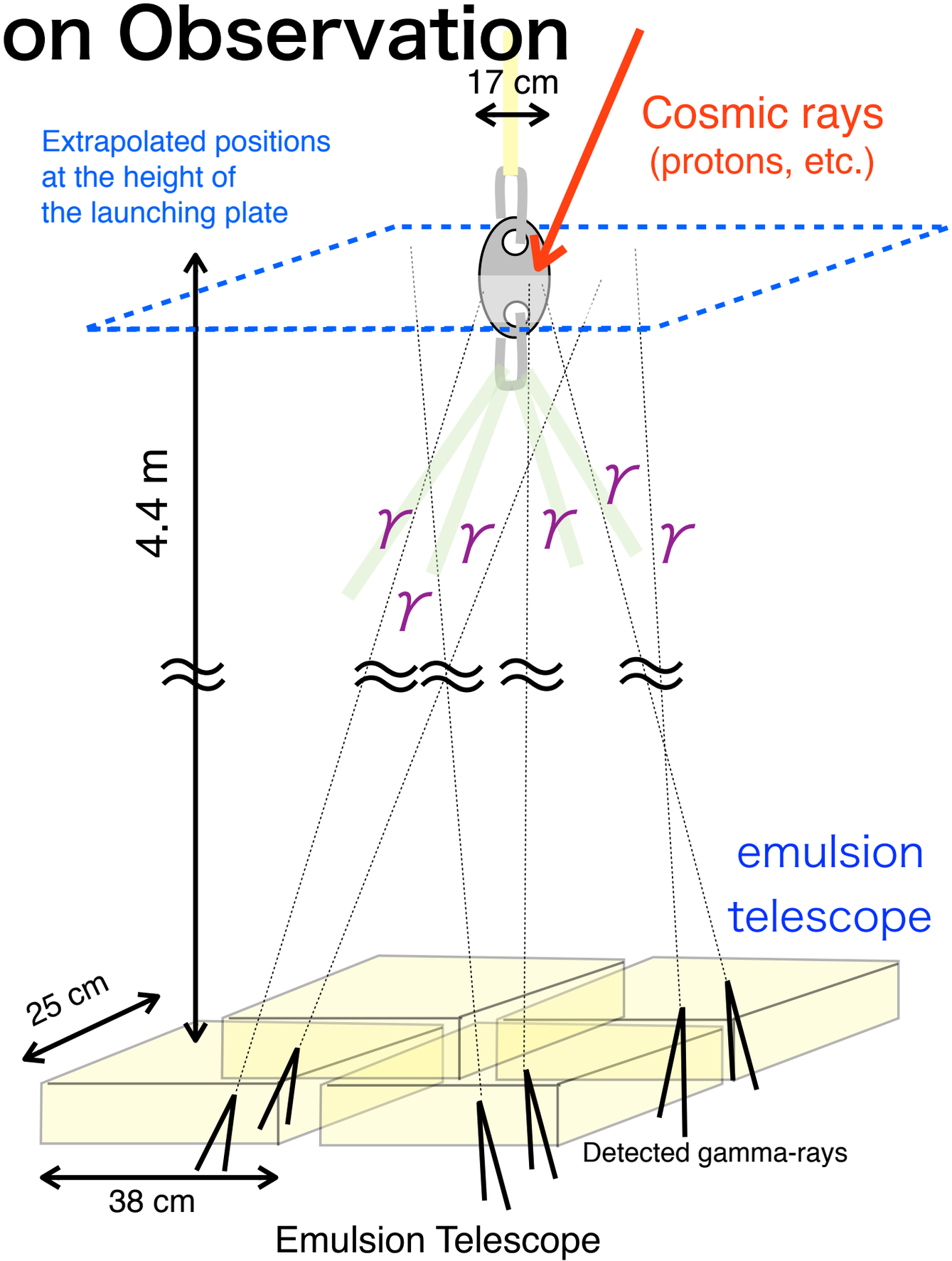




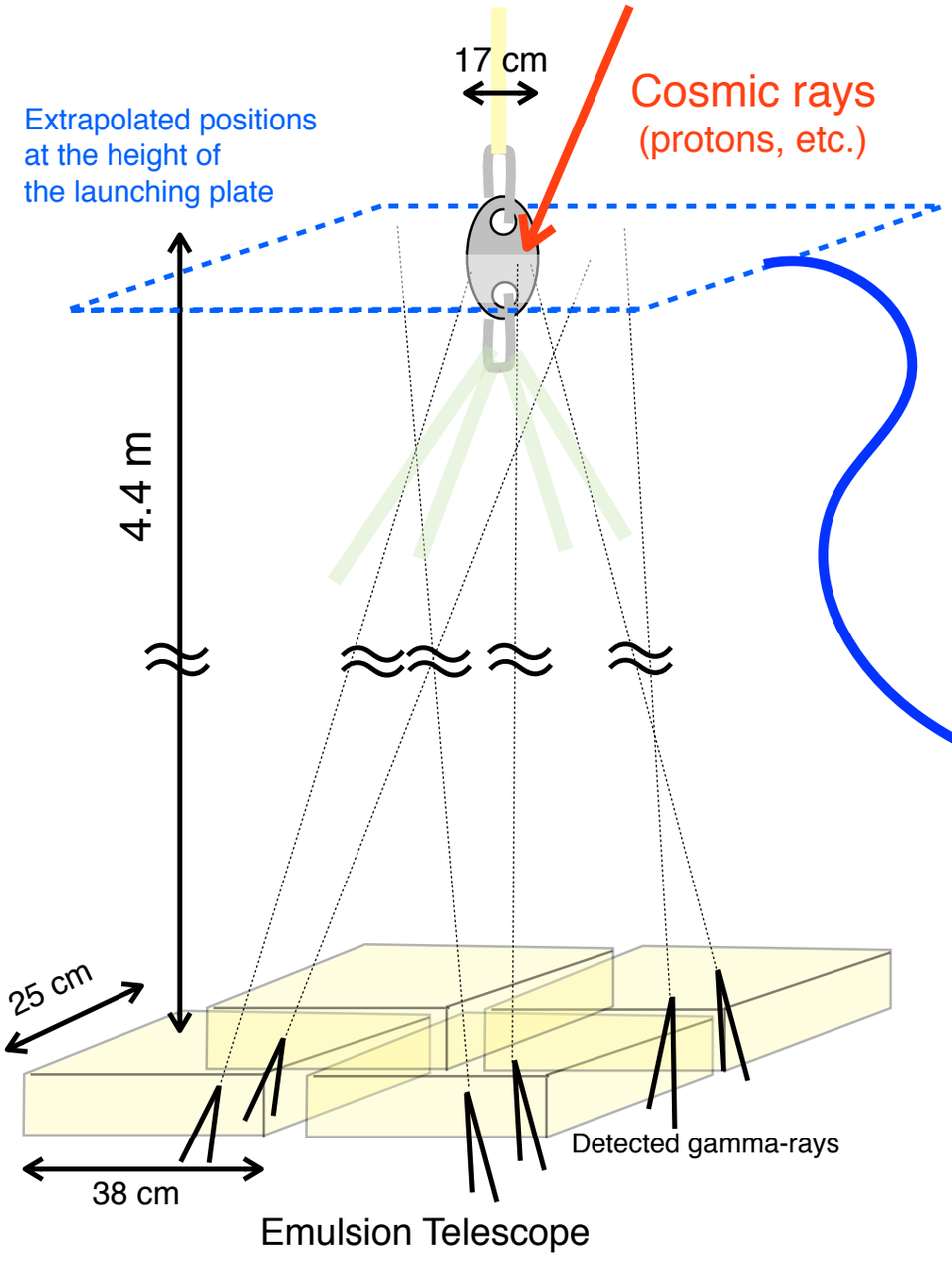
Calibration sorce
(direction, timing, energy, polarization, efficiency)

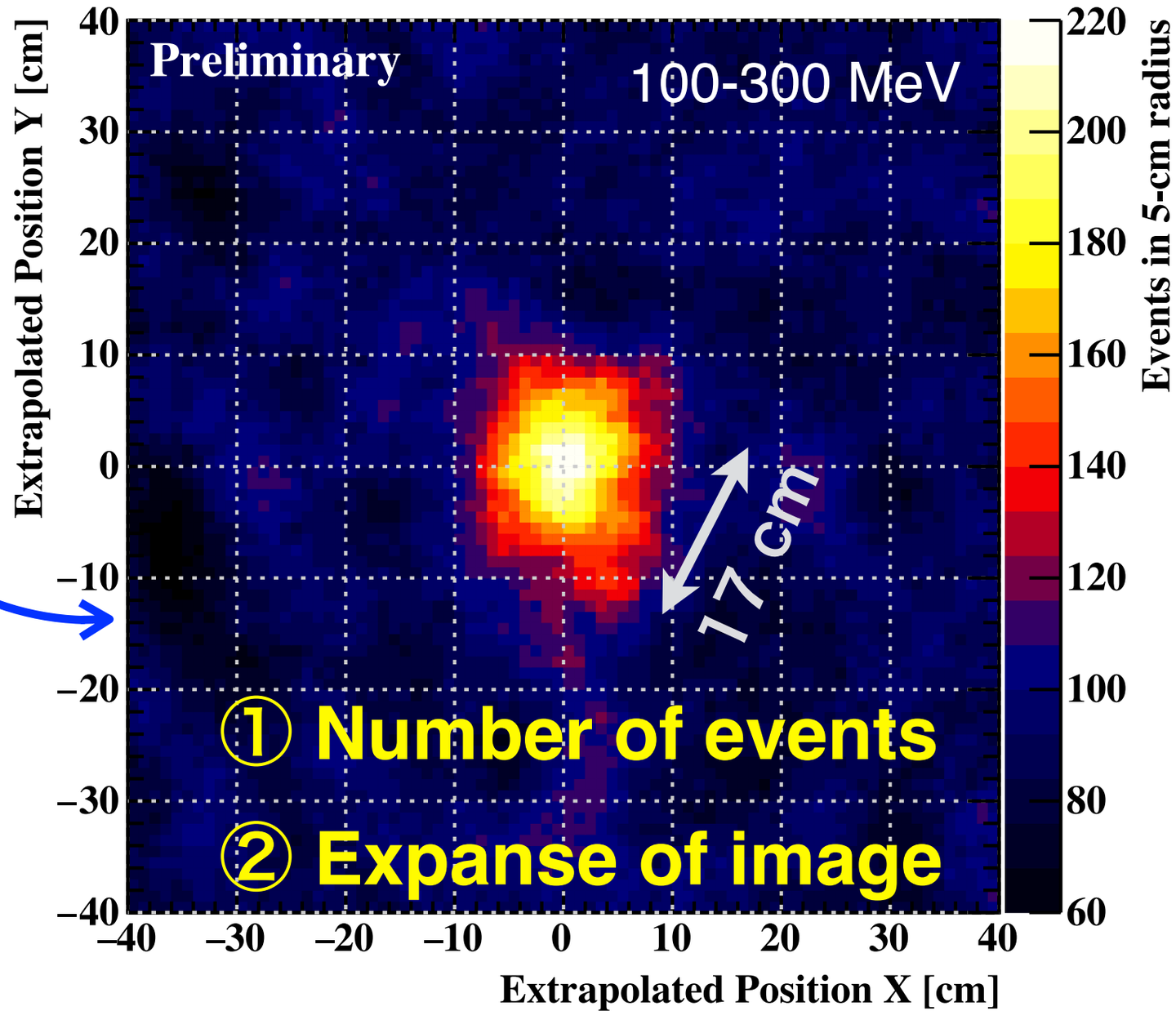
Demonstration of Gamma-ray Imaging during Balloon Observation





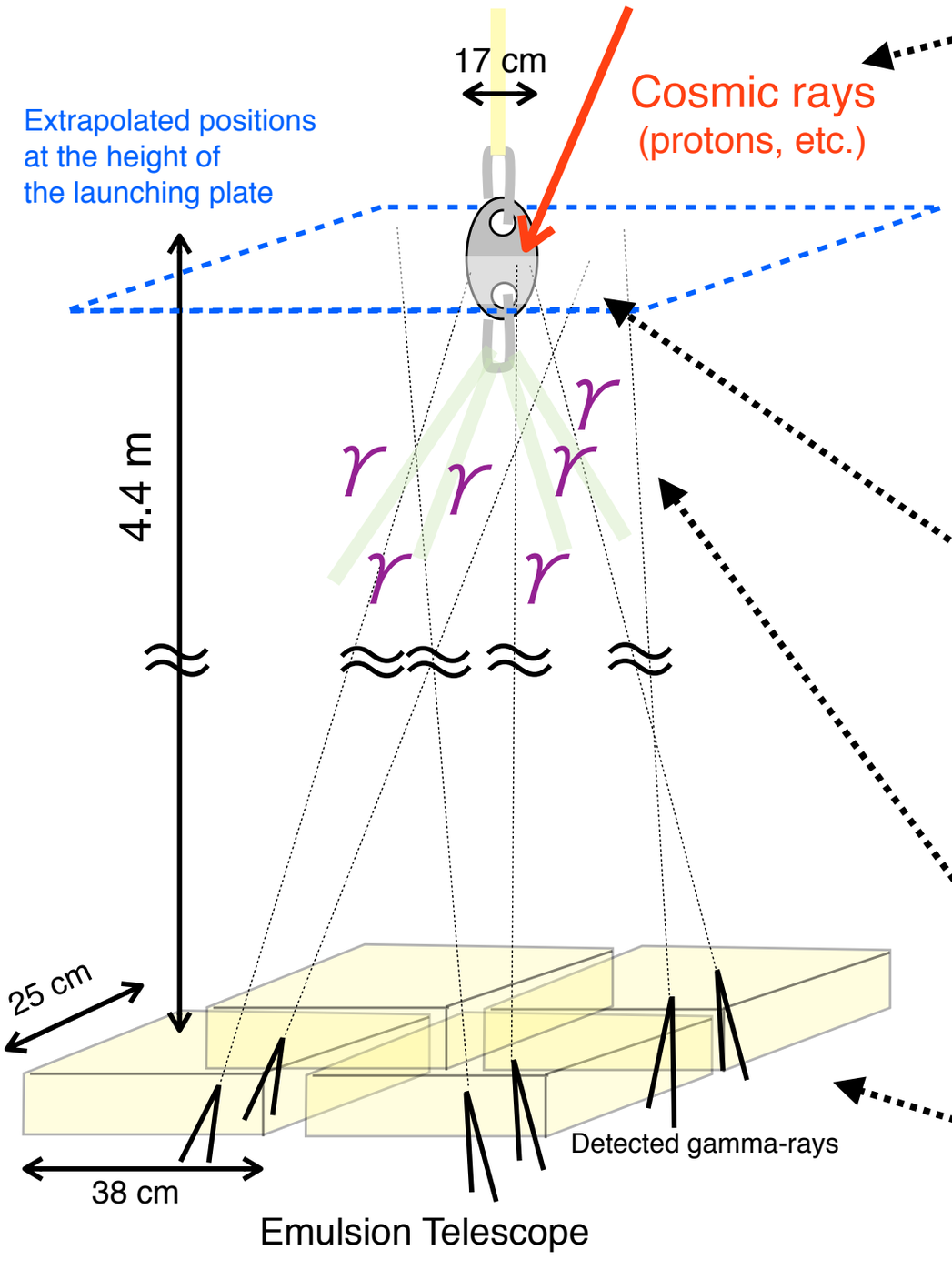
Result of gamma-ray imaging of launching plate





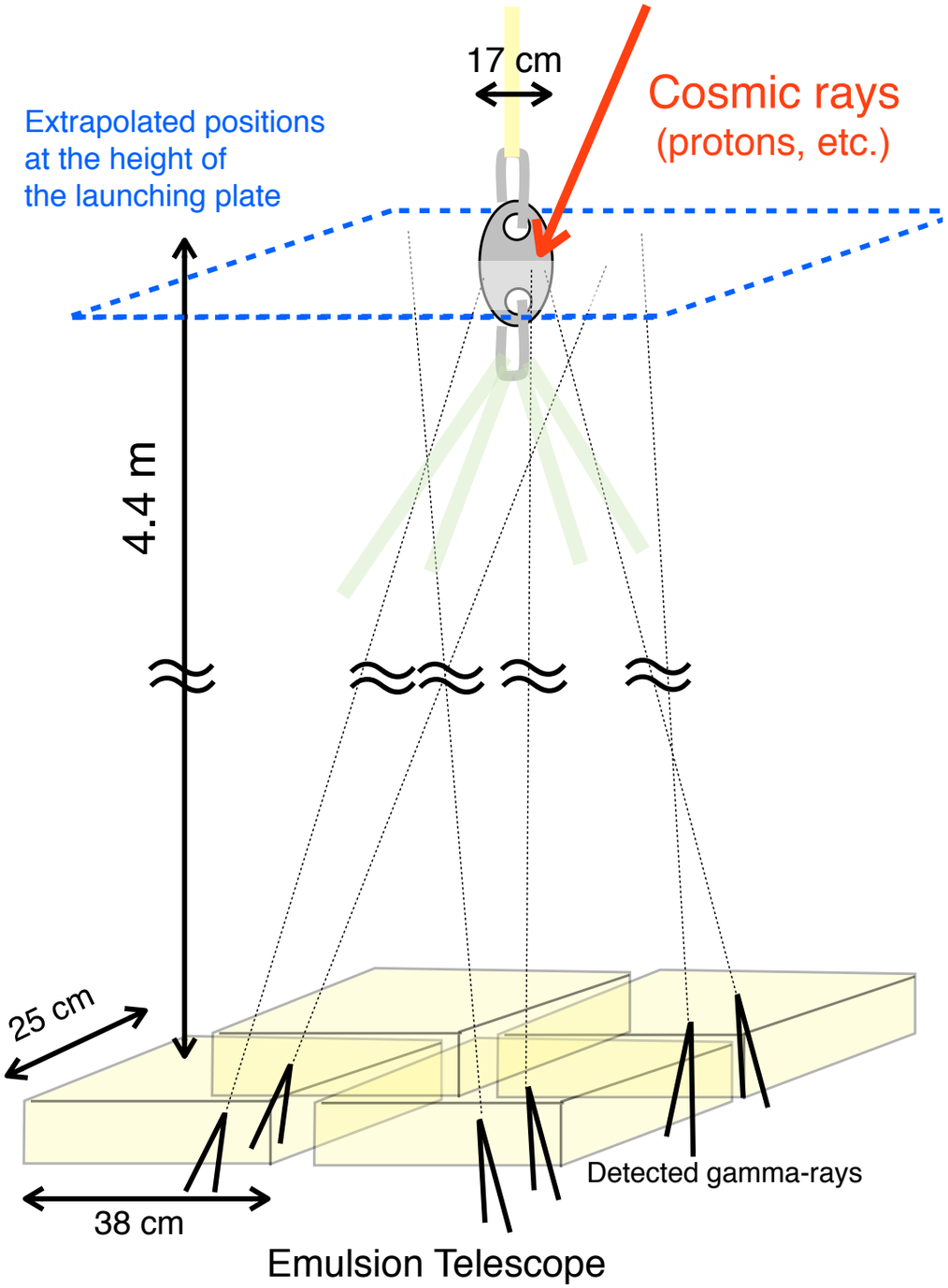
the first demonstration of gamma-ray imaging of external gamma-ray source with balloon-borne emulsion telescope

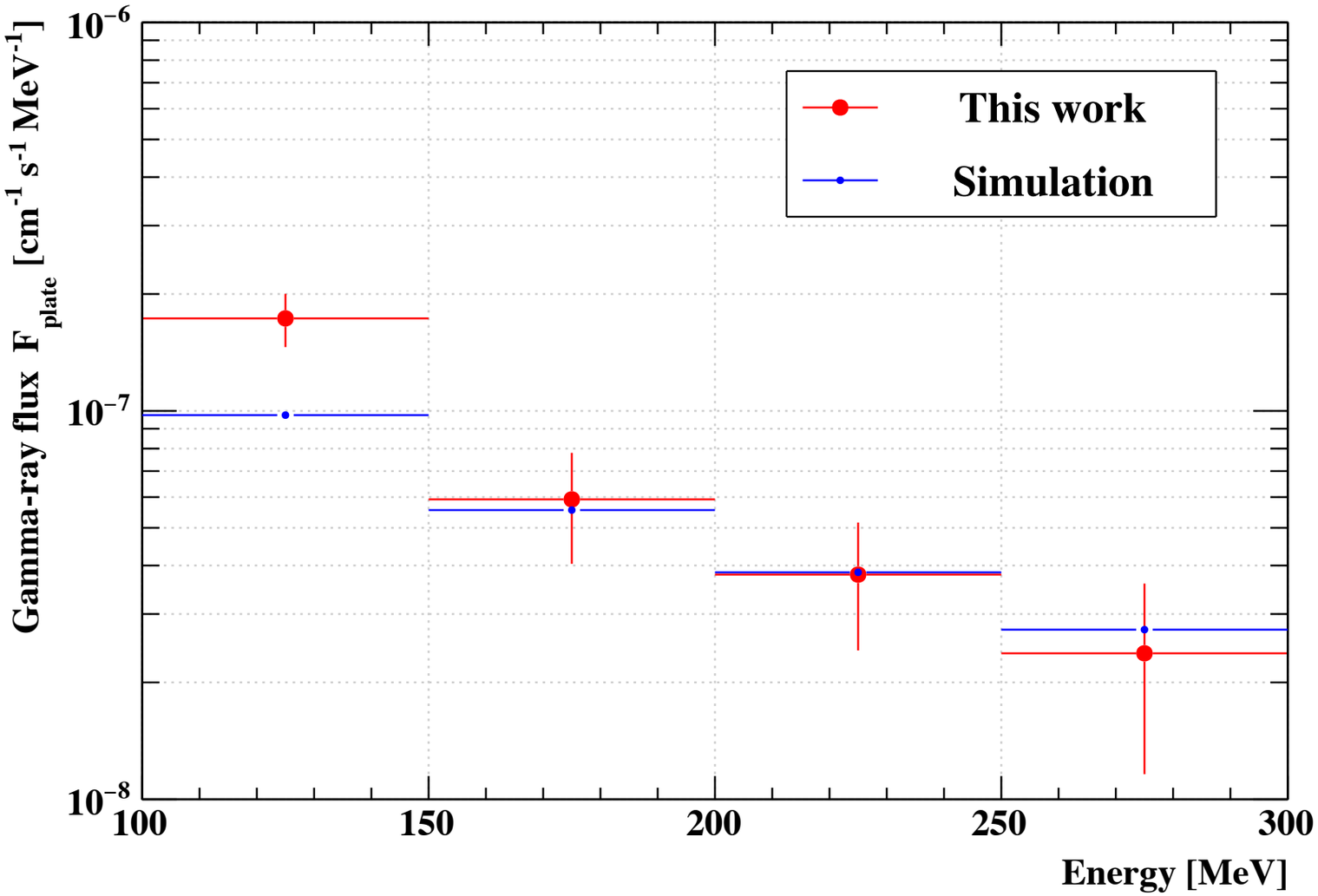
MC simulation



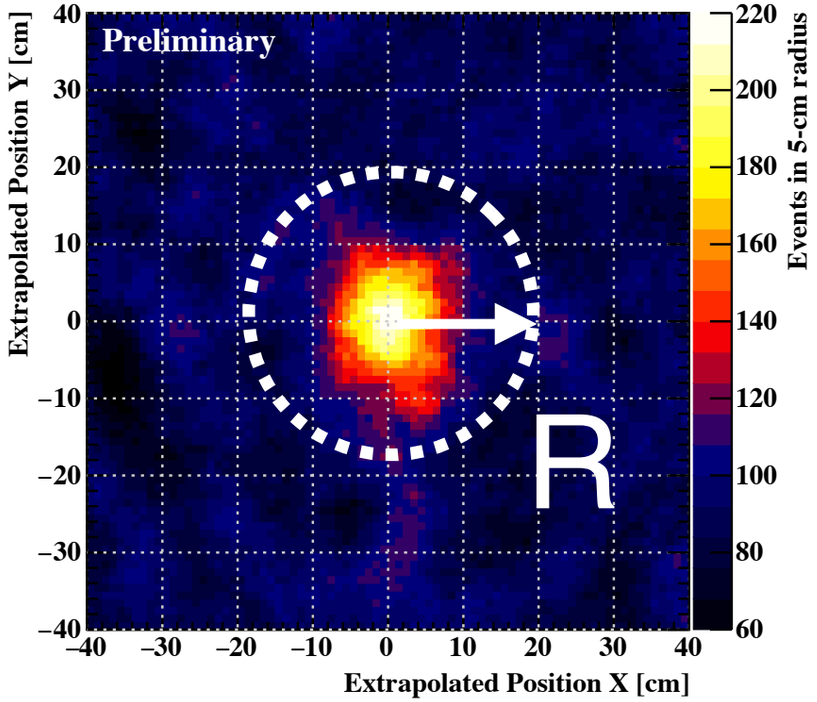
- Incident particles
  - P, α, $e^{-/+}$, γ
  - 37 km @ Australia, Alice Springs
  - Spectrum, Zenith angle distributions calculated by HKKM model (thanks to M.Honda)
- Target
  - Launching plate (Al)　4.6 kg
  - Shackles (Fe) 3.1 kg　x 2
- Geant4.10.01, QGSP_BERT
- Output gamma-ray data
  - Positions, angles, energies at detector

① Gamma-ray Flux From Launching plate

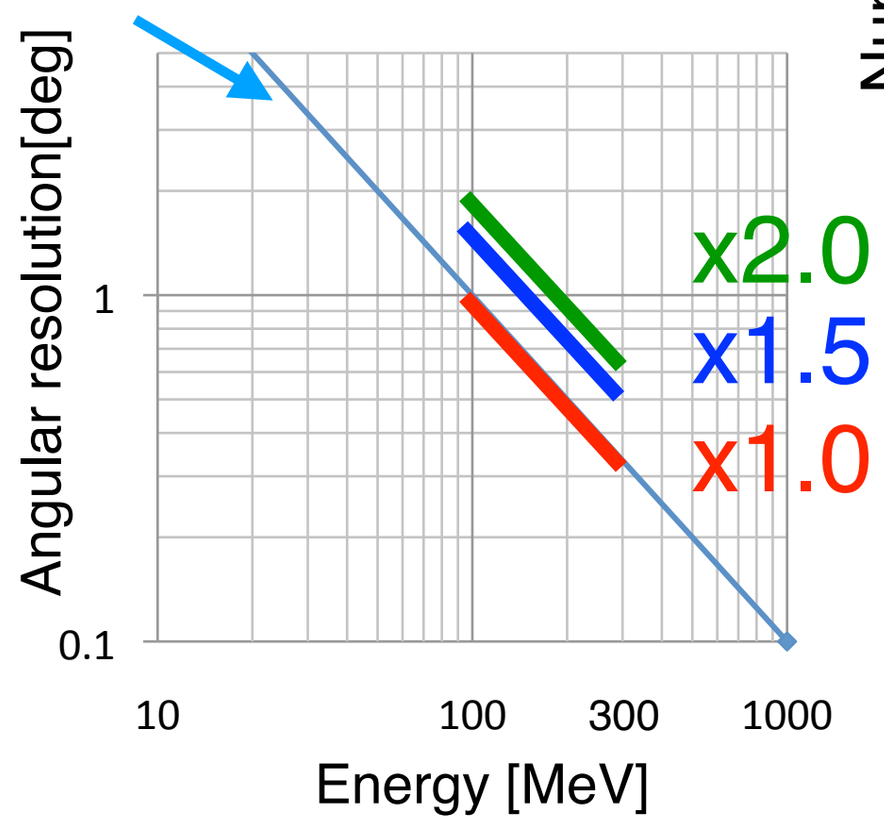




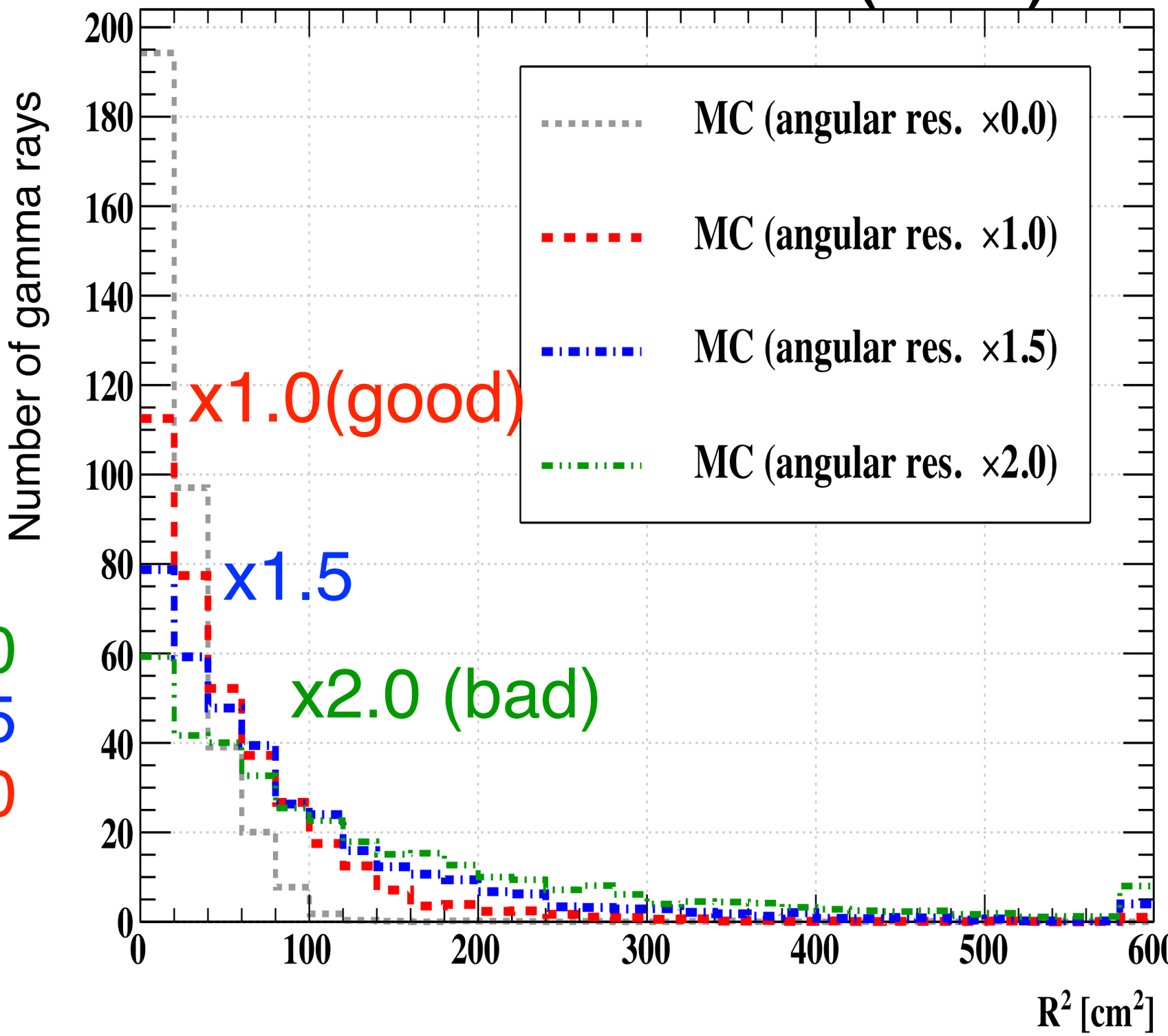
② Expanse of gamma-ray image



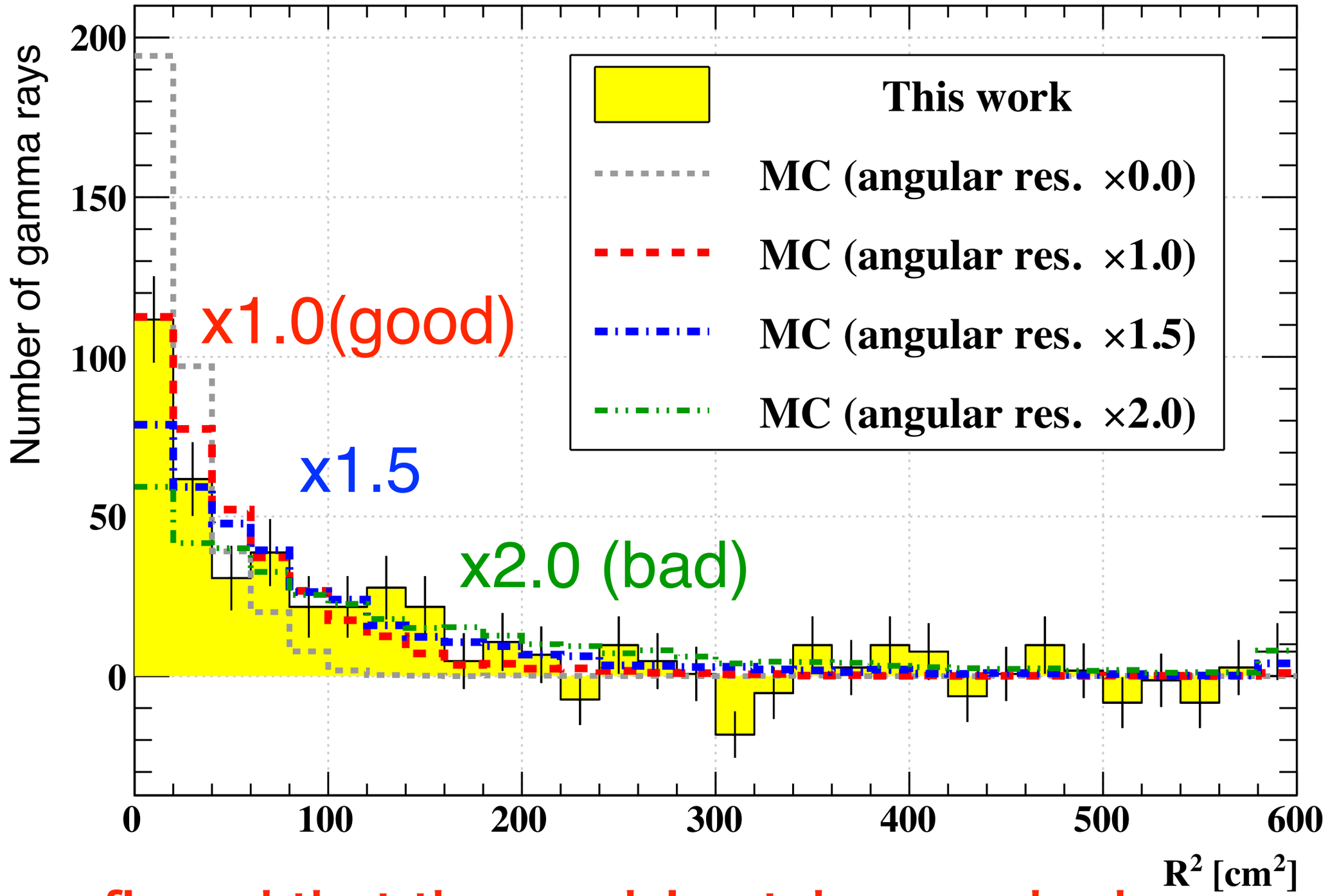
Expected angular resolution



R² distribution (MC)



② Expanse of gamma-ray image



we confirmed that the emulsion telescope had an excellent angular resolution in the 100–300-MeV energy region during the observation, as expected.

GRAINE2015

- Aperture area 3780cm^2 [×30] (“high-sensitive film”, total area 48m^2)
- Flight time 14.4hour (11.5hour@36.0–37.4km) [×7]
- Established balloon exp. scheme & flow @ Australia
- Total read out area 41m^2 by HTS (First large scale trial)
- S/N ratio of “high-sensitive film” [×20] ⇒ Data size reduced [×1/20]
- Tracking efficiency of single film (.78 ➔ .97.7) ⇒ inefficiency [×1/10]
- Data reduction load to detect gamma-ray event [×1/200]
- Data processed overall effective aperture area 2830cm^2 (total area 30m^2)
- Pointing accuracy of gamma-ray ≲ 1.0deg
- Time resolution 9.8 msec [×1/10]
- Limiting magnitude of the Star Camera 6.1 ➔ 7.5

Much improved from GRAINE2011

GRAINE Scientific observation roadmap

2018, Demonstration

Alice Springs
~0.4m^2 aperture
~18hours flight duration
<~5g/cm^2 altitude

Approved by JAXA

Vela pulsar detection, Imaging, phase resolved analysis
Galactic diffuse & Geminga detection/indication

2021–, Scientific flight

Alice Springs
10m^2 aperture
>~36hours flight duration
<~10g/cm^2 altitude

Funded by JSPS

Vela pulsar
Polarization observation (<50%)
→ Pioneering polarization observation for high energy γ-rays

SNR W44 (<200MeV, >200MeV)
Precise spectrum measurement
High resolution imaging
→ Studying cosmic ray sources

Galactic Center
Obs. with ~arcmin resolution
→ Resolving GeV γ-ray excess at galactic center

Test of fundamental symmetries beyond the Planck scale

Transient sources
Obs. w/ high sensitivity
& high photon stats
→ Studying transient sources & w/ ones

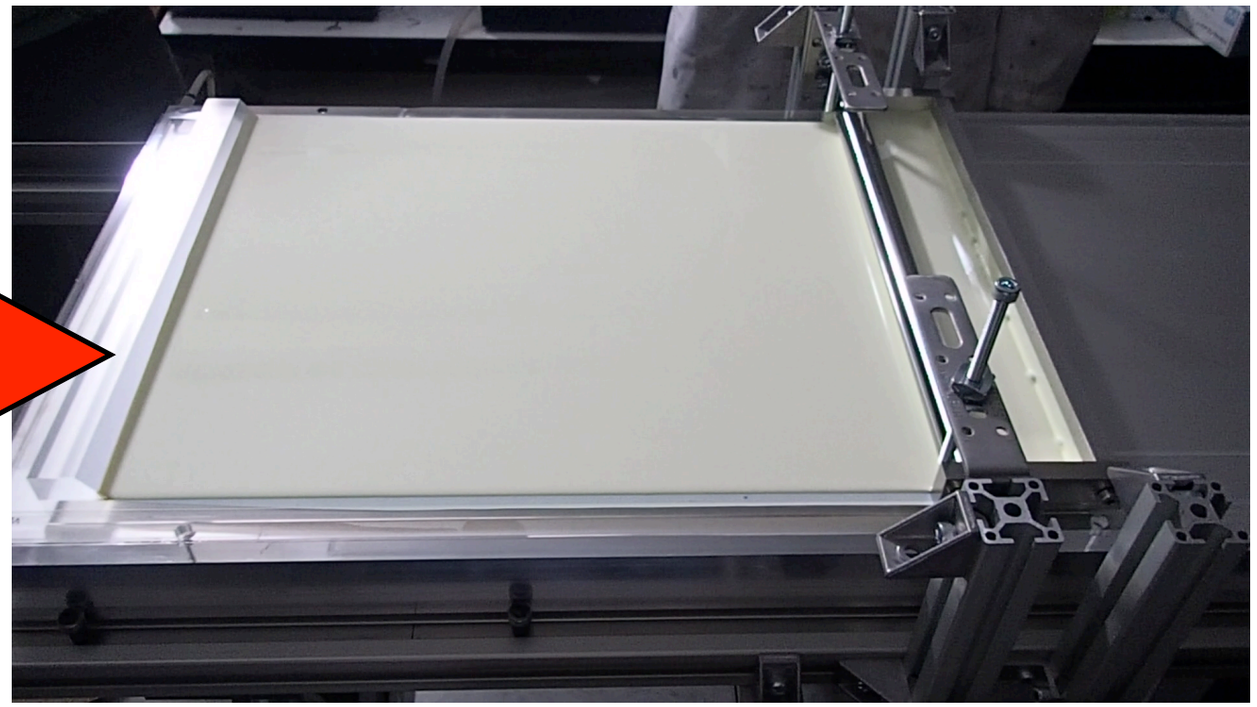
Search for γ-ray correlation with Giant Radio Pulses from pulsars
Search for GeV γ-ray Pair Halo → Constraints on IGMF

Emulsion Film Production

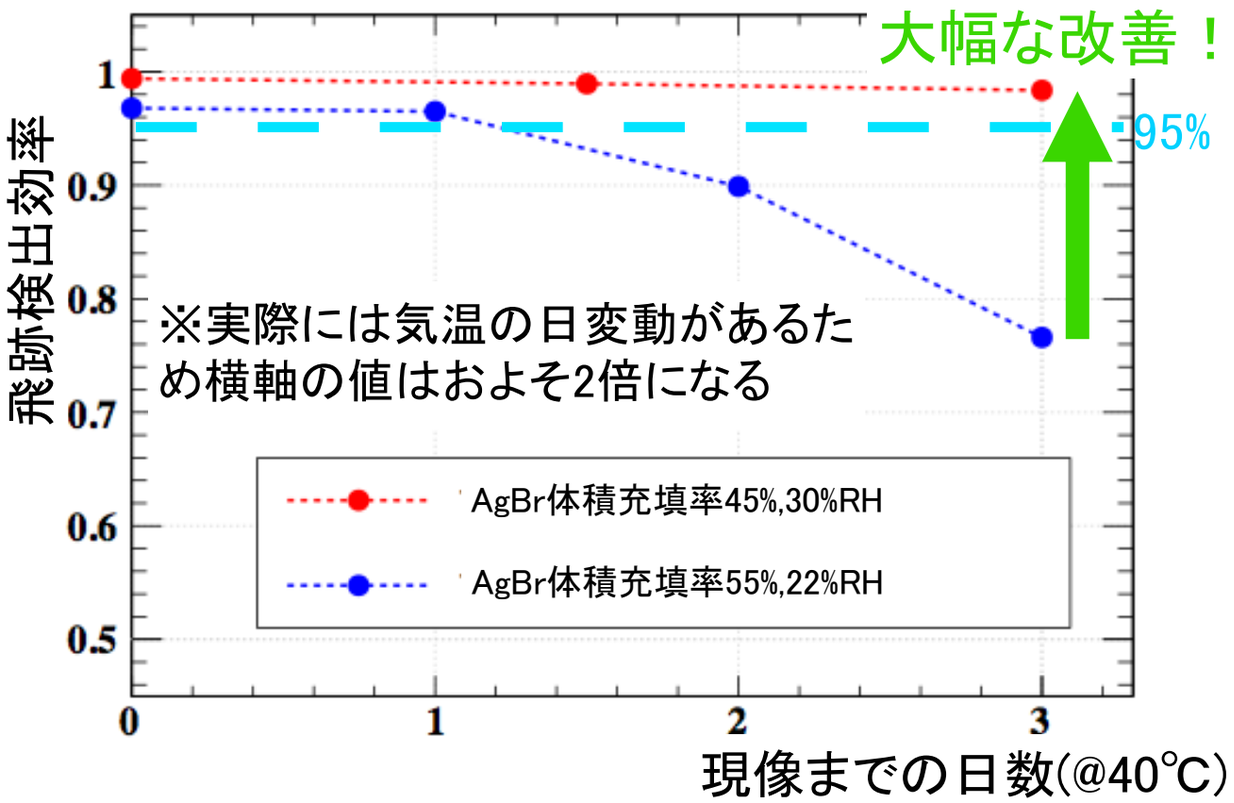
Nagoya Univ.

Conventional

New (under development)



We are constructing faster and more uniform film production.



Study for the performance of emulsion is updated day by day.

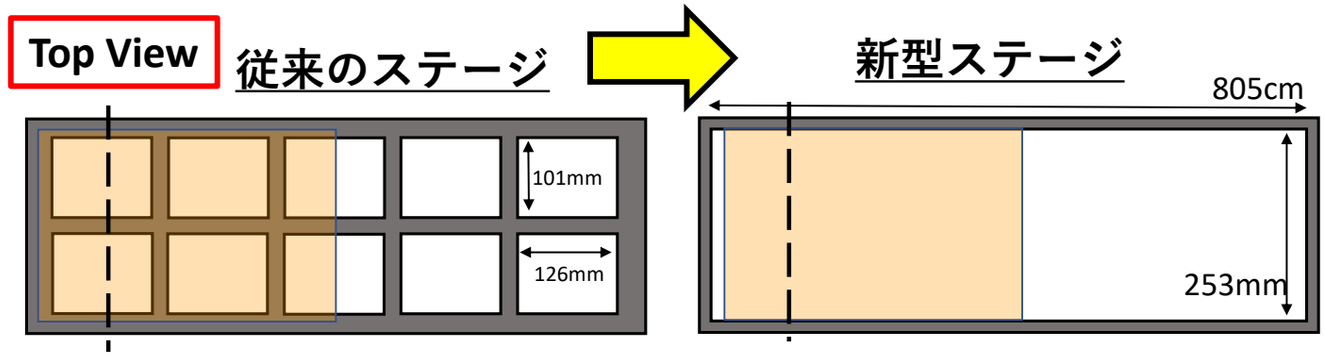
We install emulsion films which has better long-term stability to GRAINE 2018.

Kobe Univ.

Multi-stage Shifter

GRAINE2018 Model

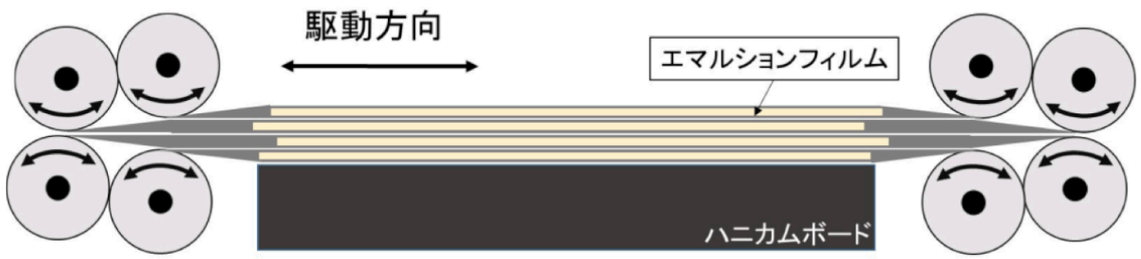
recovered in GRAINE 2015.



reducing the materials of the stage
to increase the low momentum track efficiency.

GRAINE2021 Model

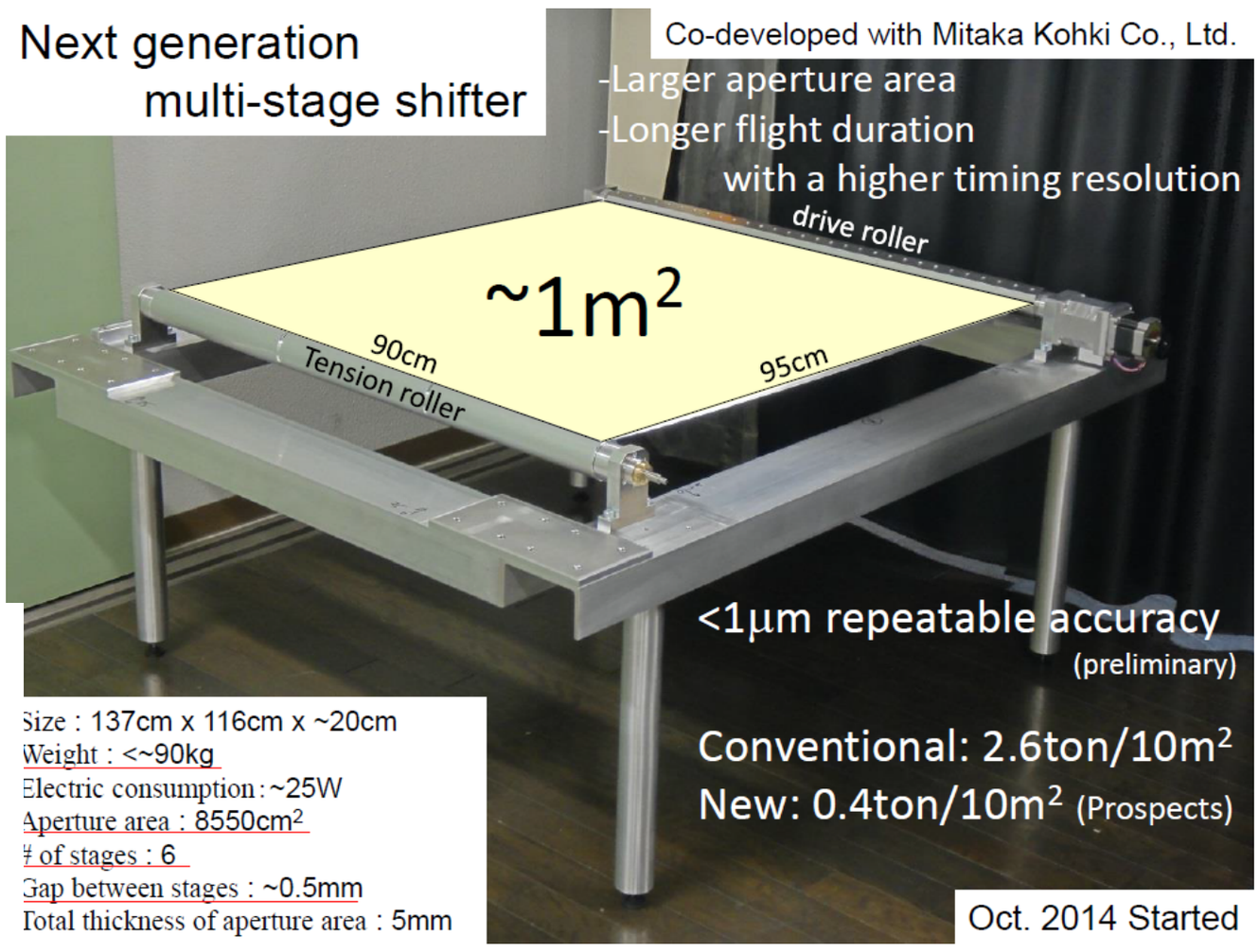
light-weight multi-stage shifter unit.



Next generation
multi-stage shifter

Co-developed with Mitaka Kohki Co., Ltd.

-Larger aperture area
-Longer flight duration
with a higher timing resolution



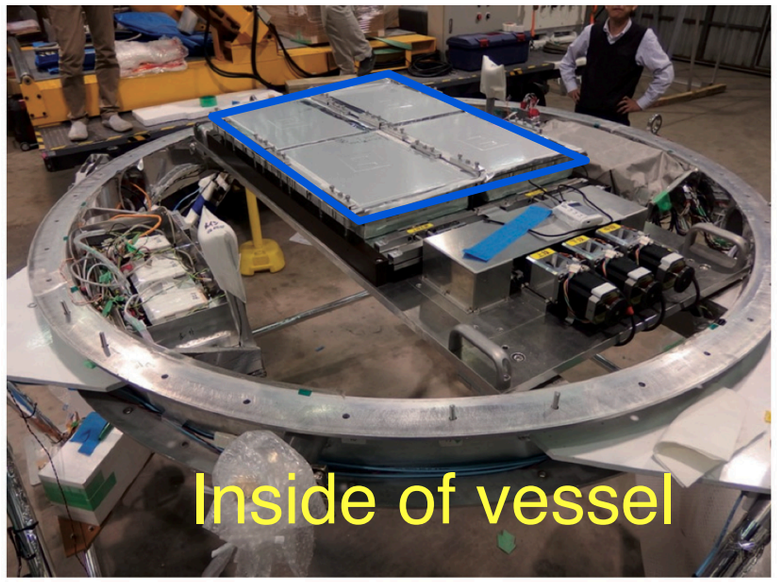
Size : 137cm x 116cm x ~20cm
Weight : <~90kg
Electric consumption : ~25W
Aperture area : 8550cm²
# of stages : 6
Gap between stages : ~0.5mm
Total thickness of aperture area : 5mm

we plan to set 8 units on the balloon gondola

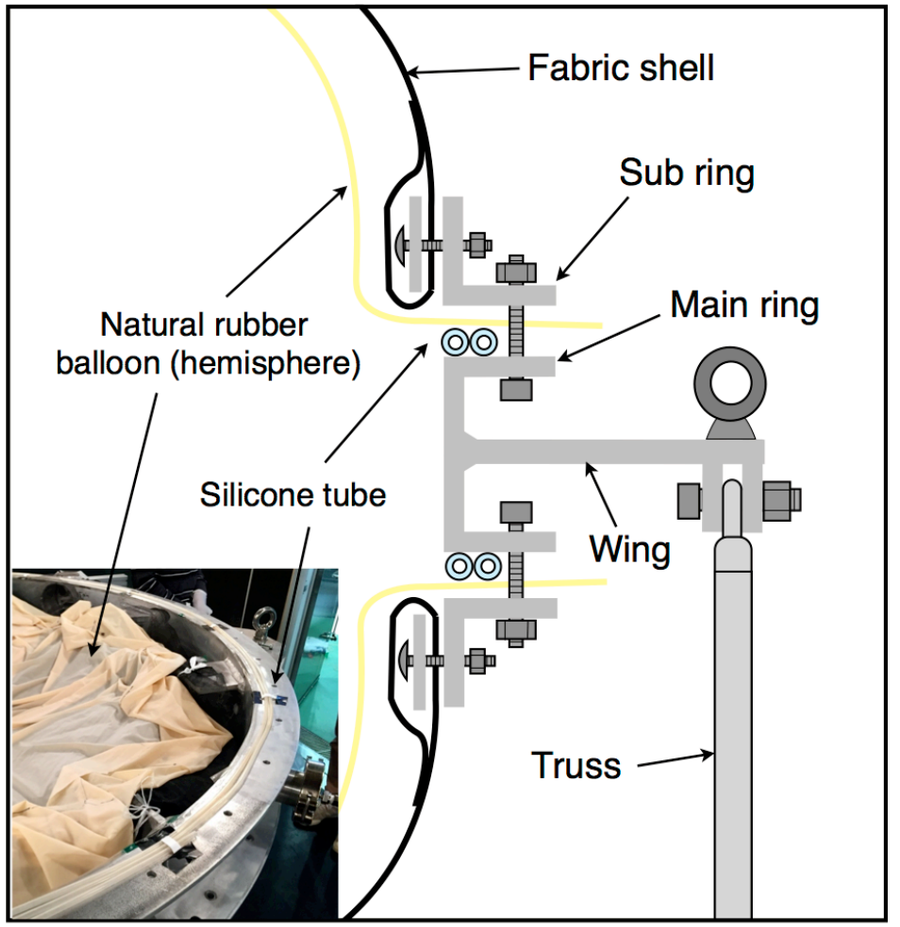
Pressure Vessel Gondola

Nagoya Univ.

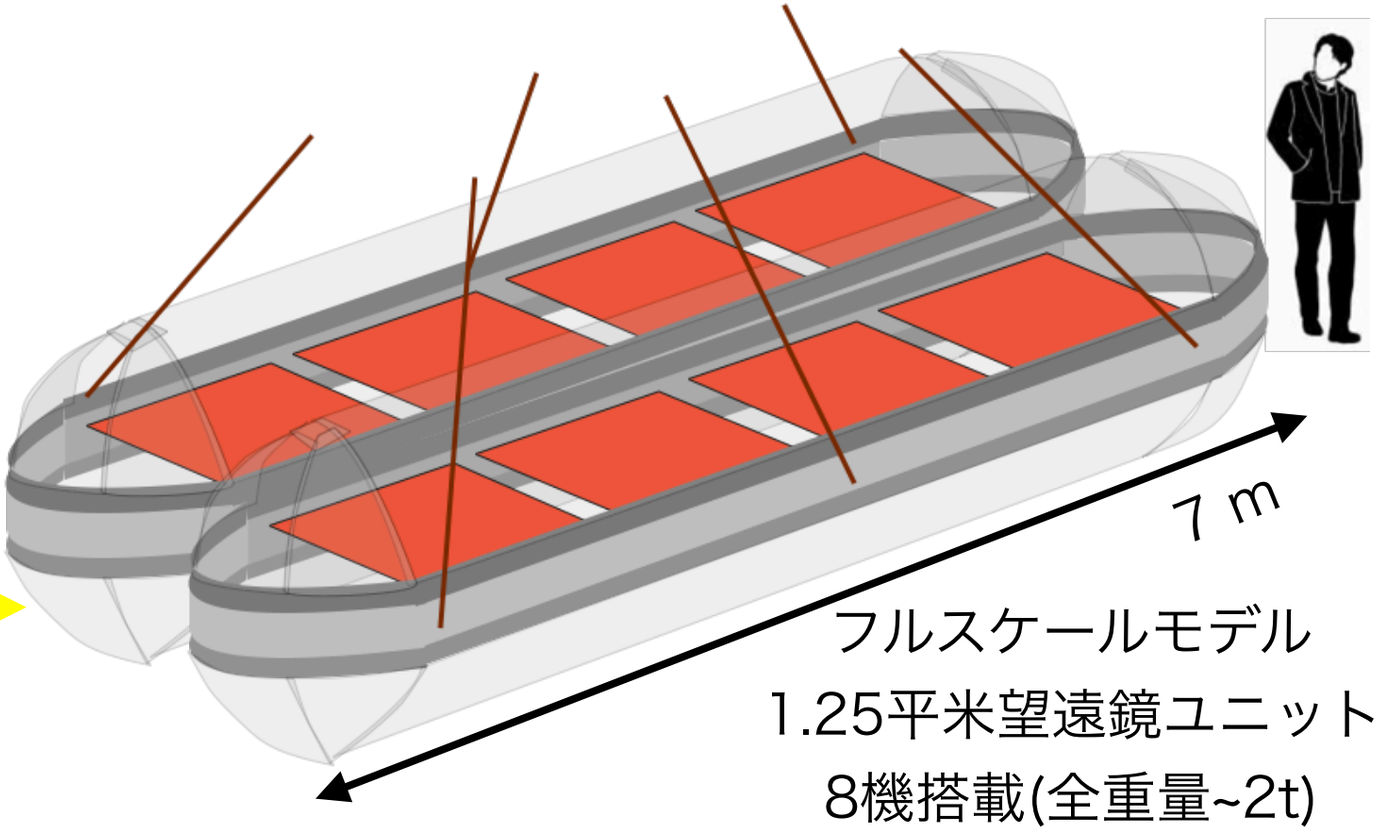
To keep vacuum-packed
emulsion chambers
at observation altitudes



2015年モデル(球型)
GRAINE2015使用



2018年モデル(繭型)
GRAINE2018使用予定



フルスケールモデル
1.25平米望遠鏡ユニット
8機搭載(全重量~2t)

Summary & Prospects

- **GRAINE project**
  - Precise observation by balloon-borne emulsion gamma-ray telescope
  - High angular resolution, Polarization sensitive, Large effective area
- **2015-Balloon experiment in AUS**
  - Flight, Scanning, and Analysis were established.
  - Achieved 9.8 ms of time resolution by multi-stage shifter.
  - Demonstrated gamma-ray imaging performance @100-300 MeV as expected
- **Prospects**
  - GRAINE2018 (scheduled in next April.)
    - The goal is confirming the overall performance by detecting a celestial gamma-ray source(Vela pulsar).
  - GRAINE2021:
    - Start Scientific Observations with 10-m^2 Telescope
    - Polarimetry, SNR, Galactic center, un-ID sources, Burst events