

GRAINE project : Cosmic Gamma-ray Observation with Balloon-Borne Emulsion Telescope

Shigeki Aoki for GRAINE collaboration

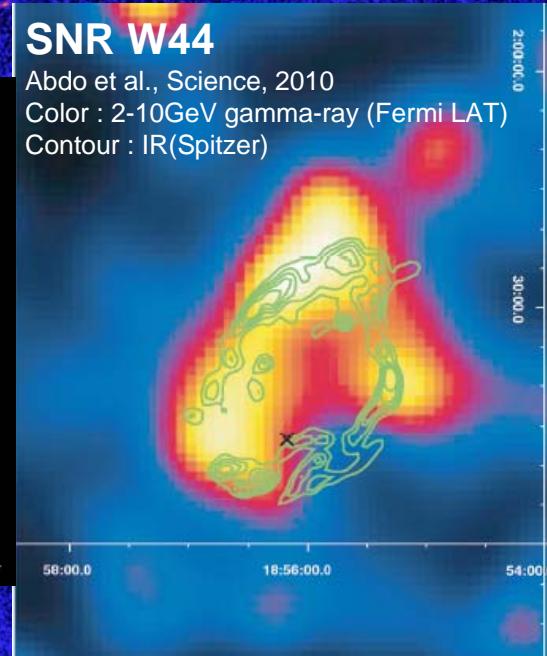
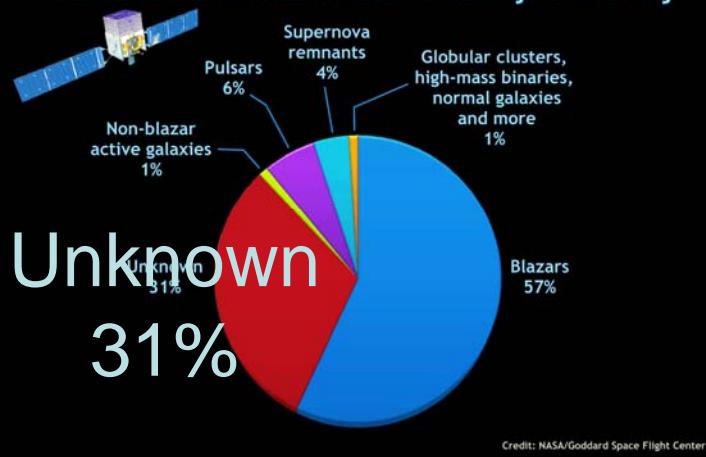
Shigeki Aoki(1), Kaname Hamada(2), Toshio Hara(1), Katsumi Ishiguro(3), Atsushi Iyono(4), Keiki Kamada(1), Hiroaki Kawahara(3), Nobuko Kitagawa(3), Koichi Kodama(5), Ryousuke Komatani(3), Masahiro Komatsu(3), Motoaki Miyanishi(3), Fukashi Mizutani(1), Saki Mizutani(1), Kunihiro Morishima(3), Naotaka Naganawa(3), Tatsuhiro Naka(3), Ryo Nakagawa(1), Yuji Nakatsuka(3), Mitsuhiro Nakamura(3), Toshiyuki Nakano(3), Kimio Niwa(3), Keita Ozaki(1), Hiroki Rokujo(3), Takashi Sako(3), Yoshitaka Saito(5), Osamu Sato(3), Yoshihiro Sato(6), Atsumu Suzuki(1), Kazuya Suzuki(3), Satoru Takahashi(1), Keisuke Tamura(2), Ikuo Tezuka(6), Junya Yoshida(3) and Tetsuya Yoshida(2)

(1)Kobe University, (2)ISAS/JAXA, (3)Nagoya University, (4)Okayama University of science, (5)Aichi University of education, (6)Utsunomiya University



Fermi two-year all-sky map ($E_{\gamma} > 1 \text{ GeV}$)

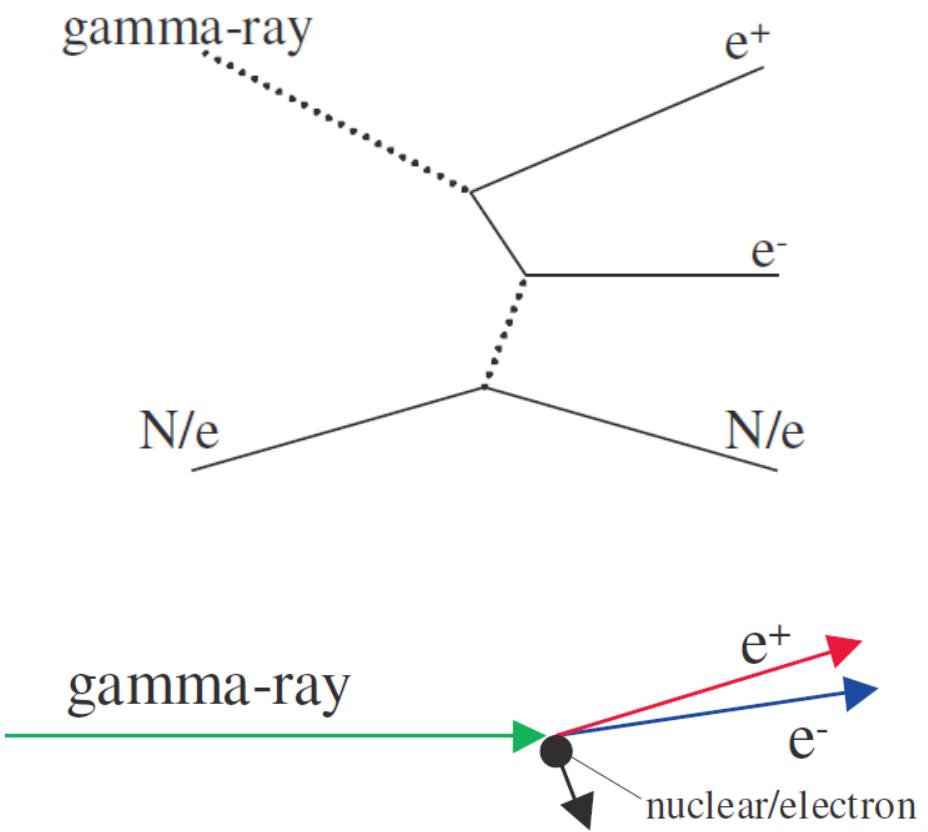
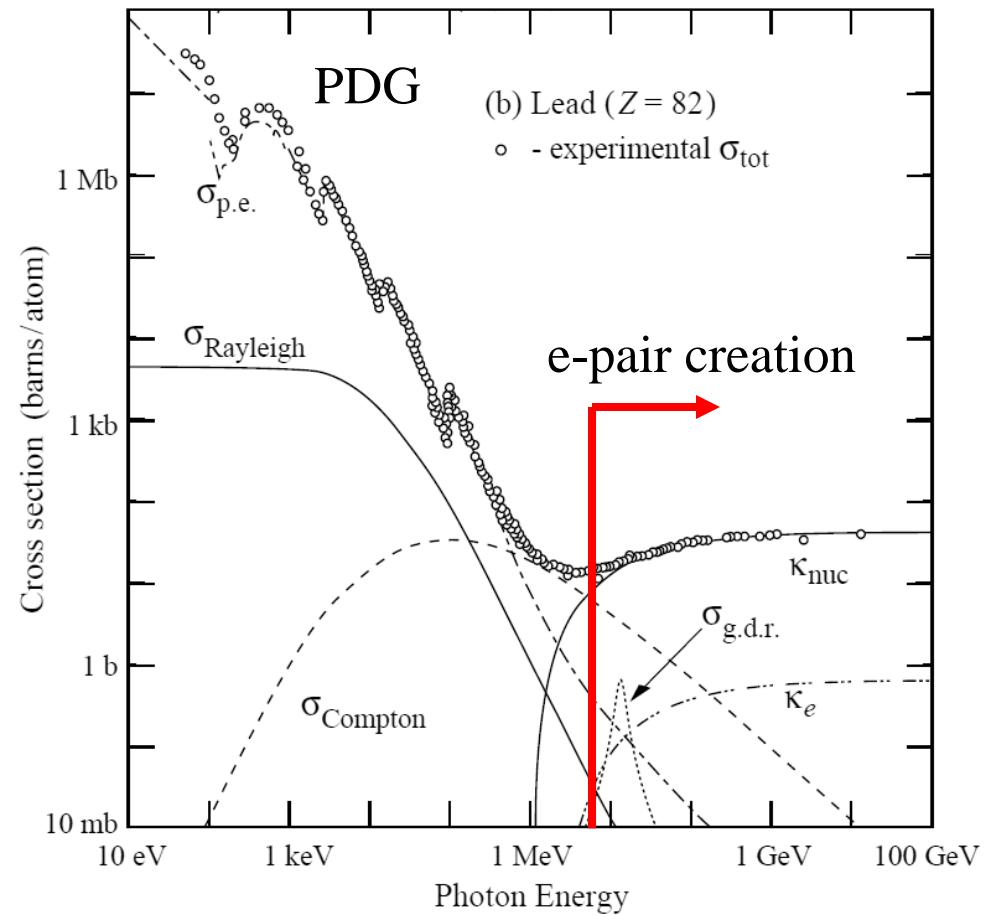
What has Fermi found: The LAT two-year catalog



Credit: NASA/DOE/Fermi/LAT Collaboration

1873 sources

Detection principle of high energy gamma-ray

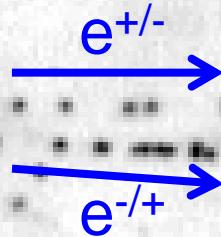


Arrival direction, timing, energy, polarization

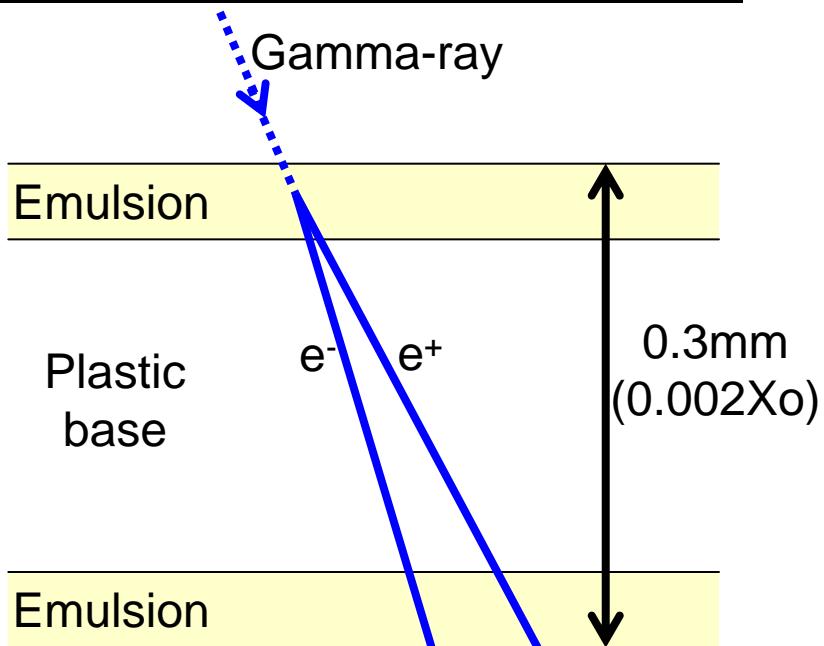
Nuclear emulsion

Microscopic view
10micron

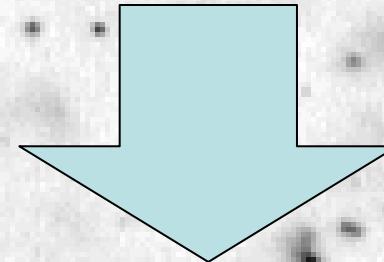
Gamma-ray


$e^{+/-}$
 $e^{-/+}$


Cross sectional view of an emulsion film



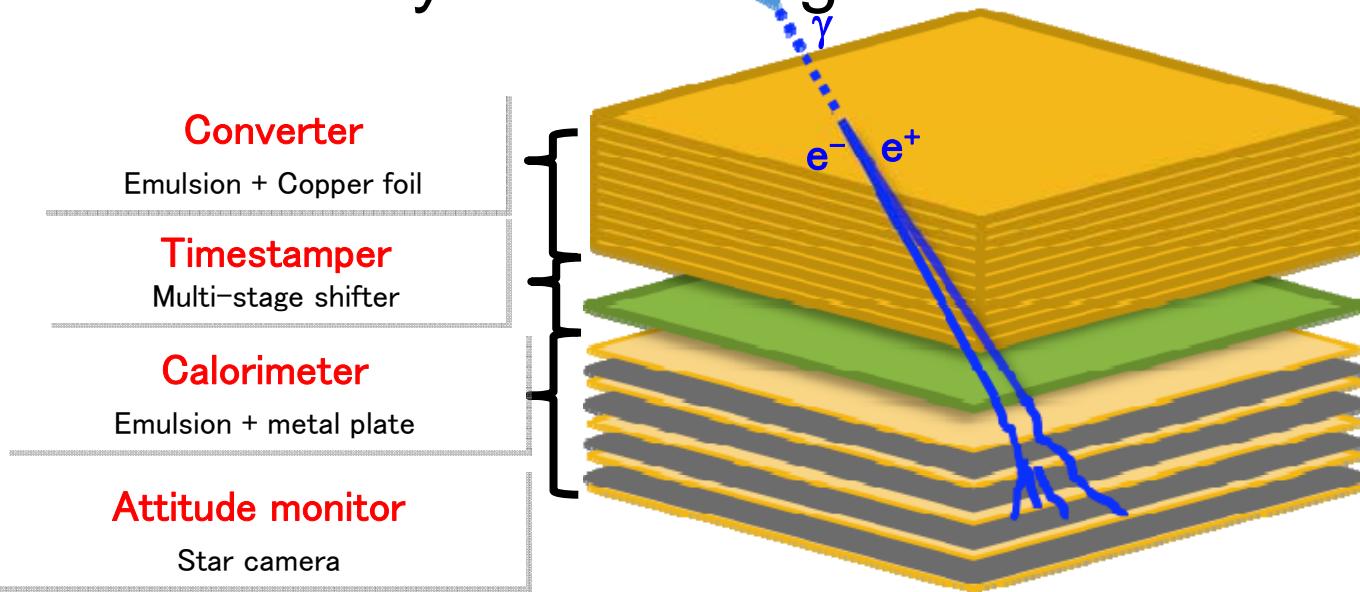
Powerful tracking device
>High spatial resolution : ~1micron
>Small radiation length : 0.002X₀



High angular resolution for gamma-ray
Sensitive to gamma-ray polarization

GRAINE

Gamma-Ray Astro-Imager with Nuclear Emulsion

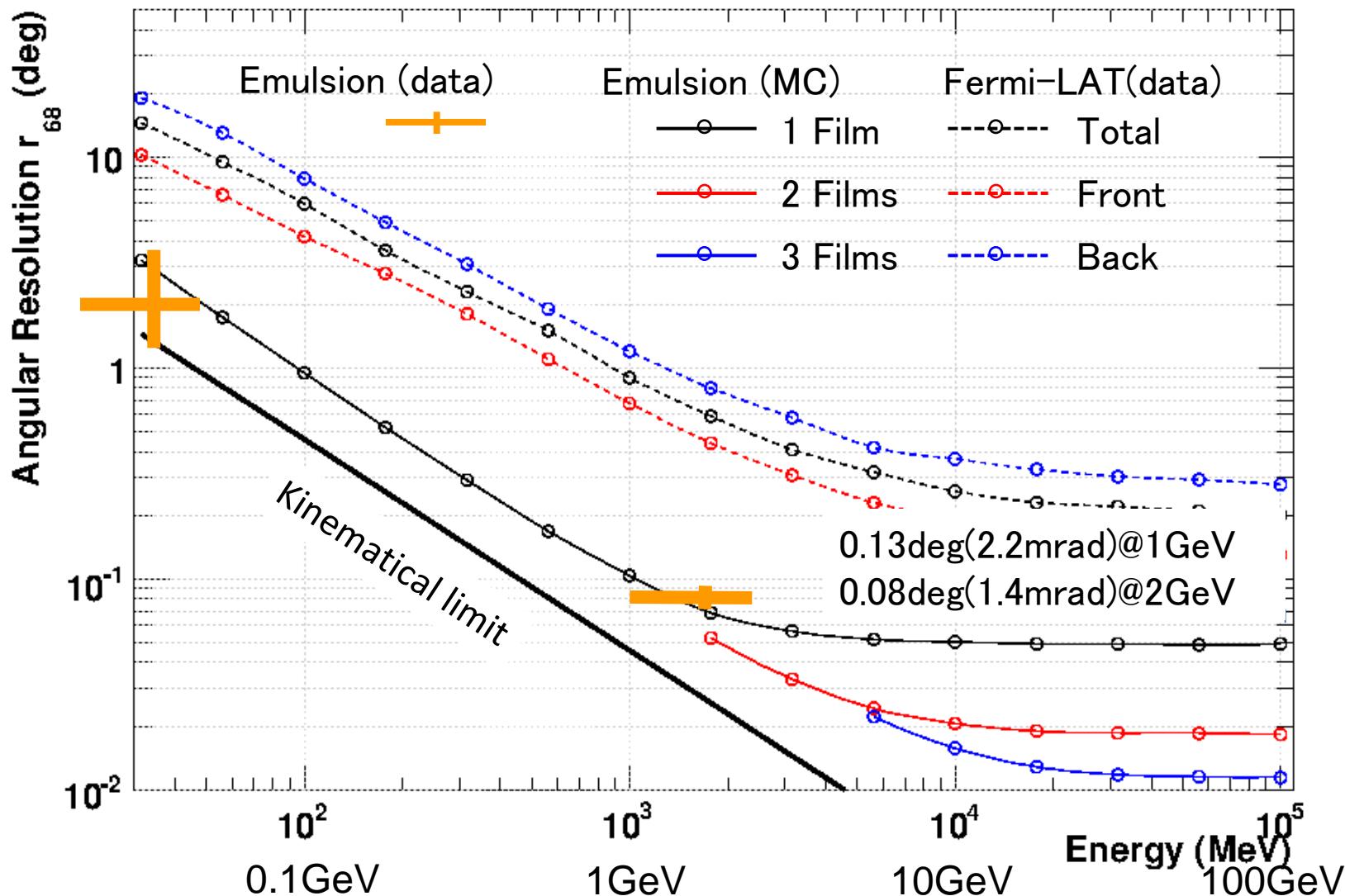


* $10m^2 * \epsilon_{trans} * \epsilon_{conv} * \epsilon_{det}$

	Fermi LAT	GRAINE
Angular resolution @100MeV	6.0deg (105mrad)	$\xrightarrow{x1/7}$ 0.93deg (16mrad)
@1GeV	0.90deg (16mrad)	$\xrightarrow{x1/9}$ 0.10deg (1.7mrad)
Energy range	20MeV – 300GeV	10MeV – 100GeV
Polarization sensitivity	No	Yes
Effective area @ 100MeV	$0.25m^2$	$\xrightarrow{x8}$ $2.1m^2 *$
@ 1GeV	$0.88m^2$	$\xrightarrow{x3}$ $2.8m^2 *$
Dead time	$26.5 \mu \text{ sec}$ (readout time)	Dead time free

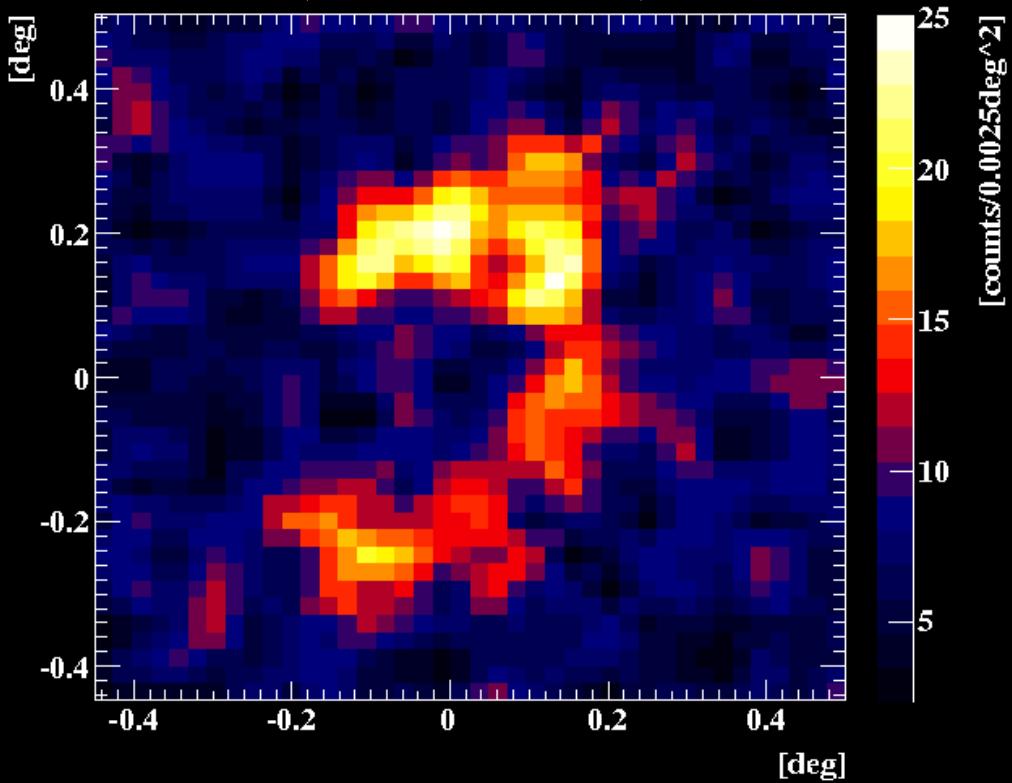
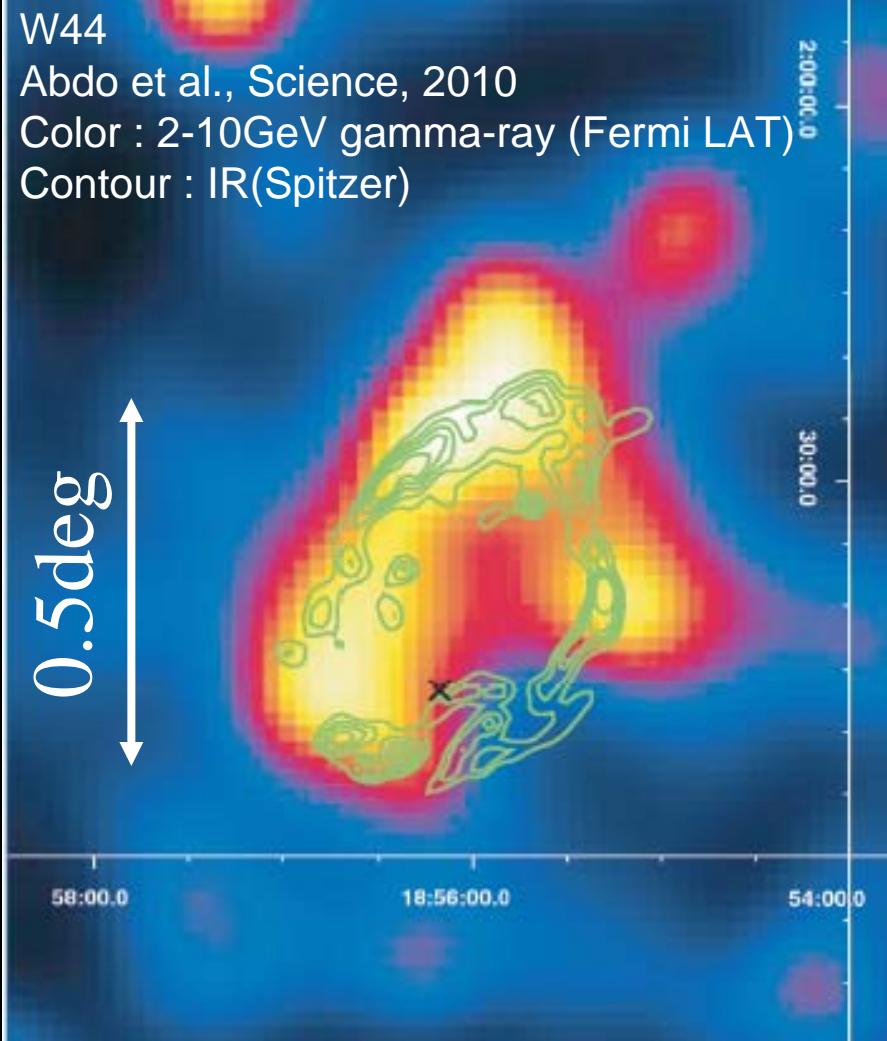
Angular Resolution

PSF at normal incidence



High resolution imaging

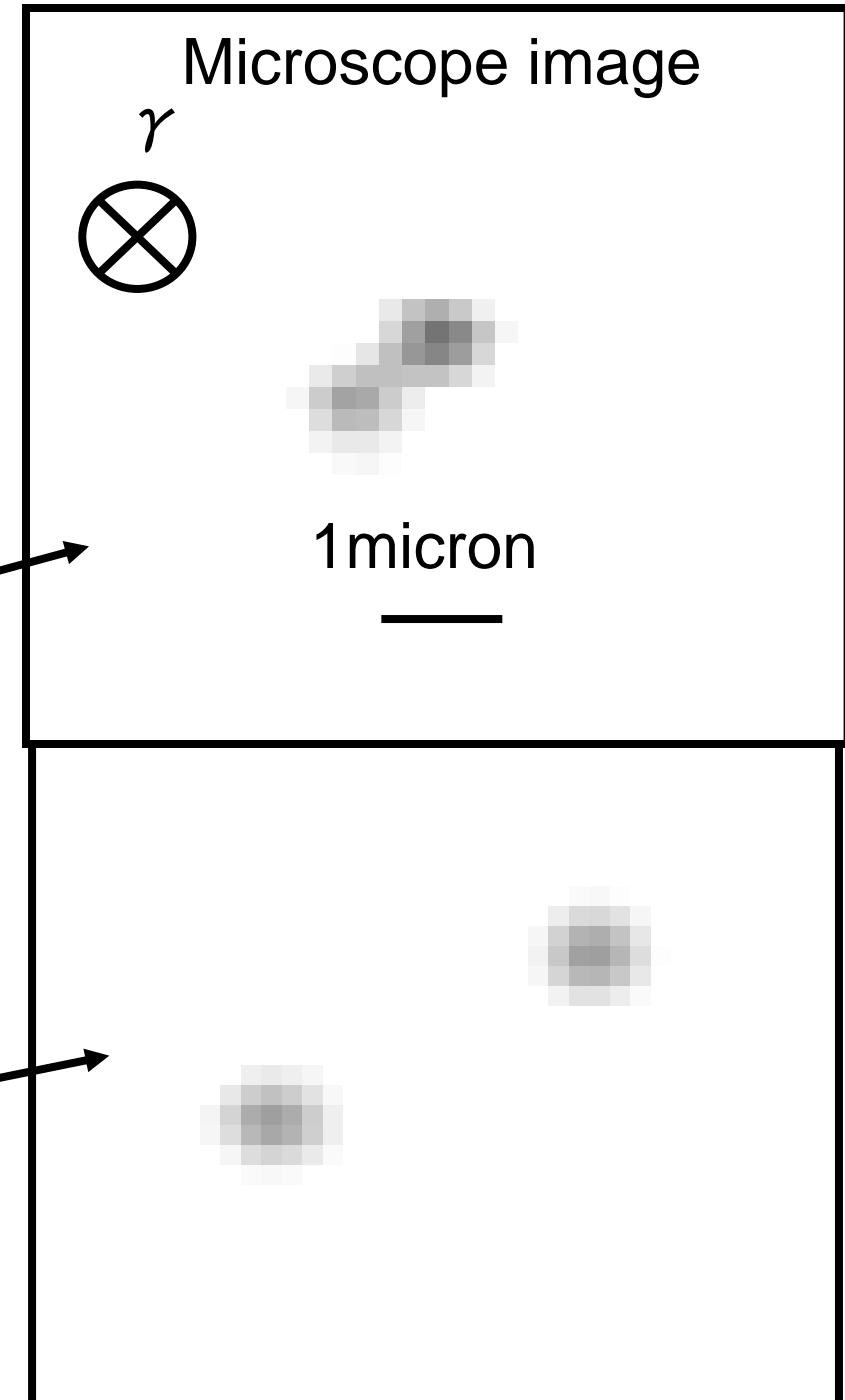
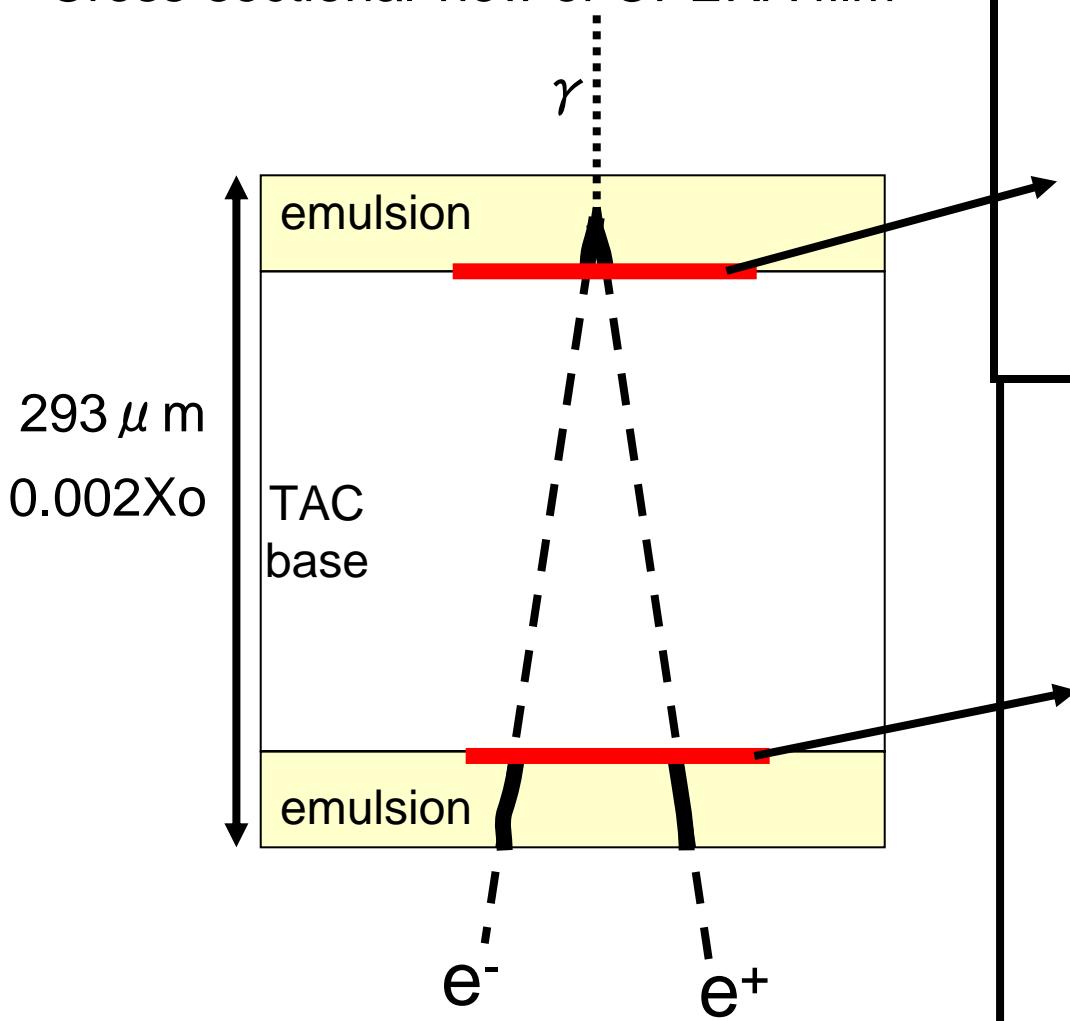
GRAINE
(Simulation)



- 3 flights ($41.7 \text{ m}^2 \text{ days}$)
- $> 1 \text{ GeV}$
- Smearing IR(Spitzer) distribution with $0.08 \text{ deg} (1.4 \text{ mrad})$
- Considering atmospheric gamma-ray ($> 1 \text{ GeV}$) as BG

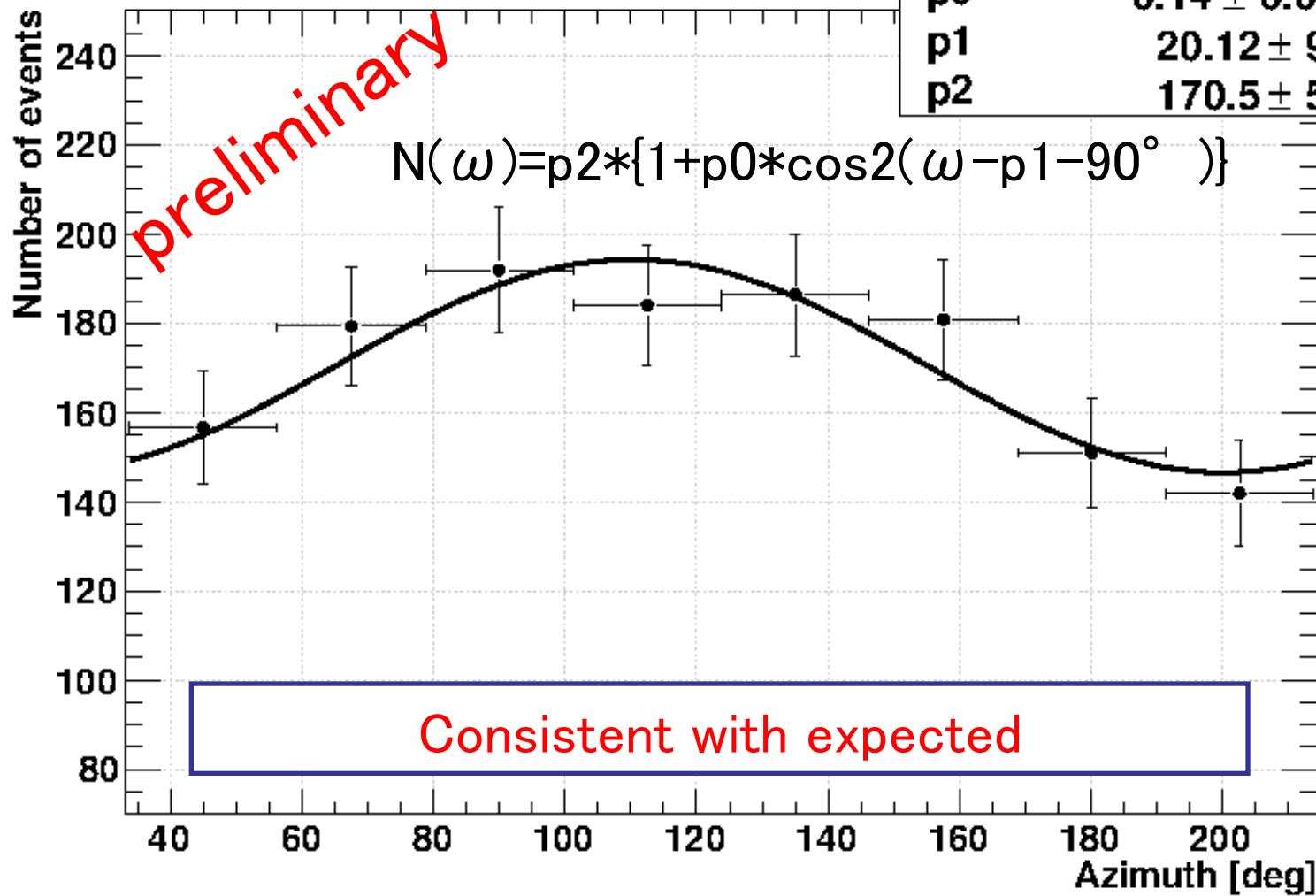
Polarization measurement

Cross-sectional view of OPERA film



Polarization sensitivity

Azimuthal Distribution



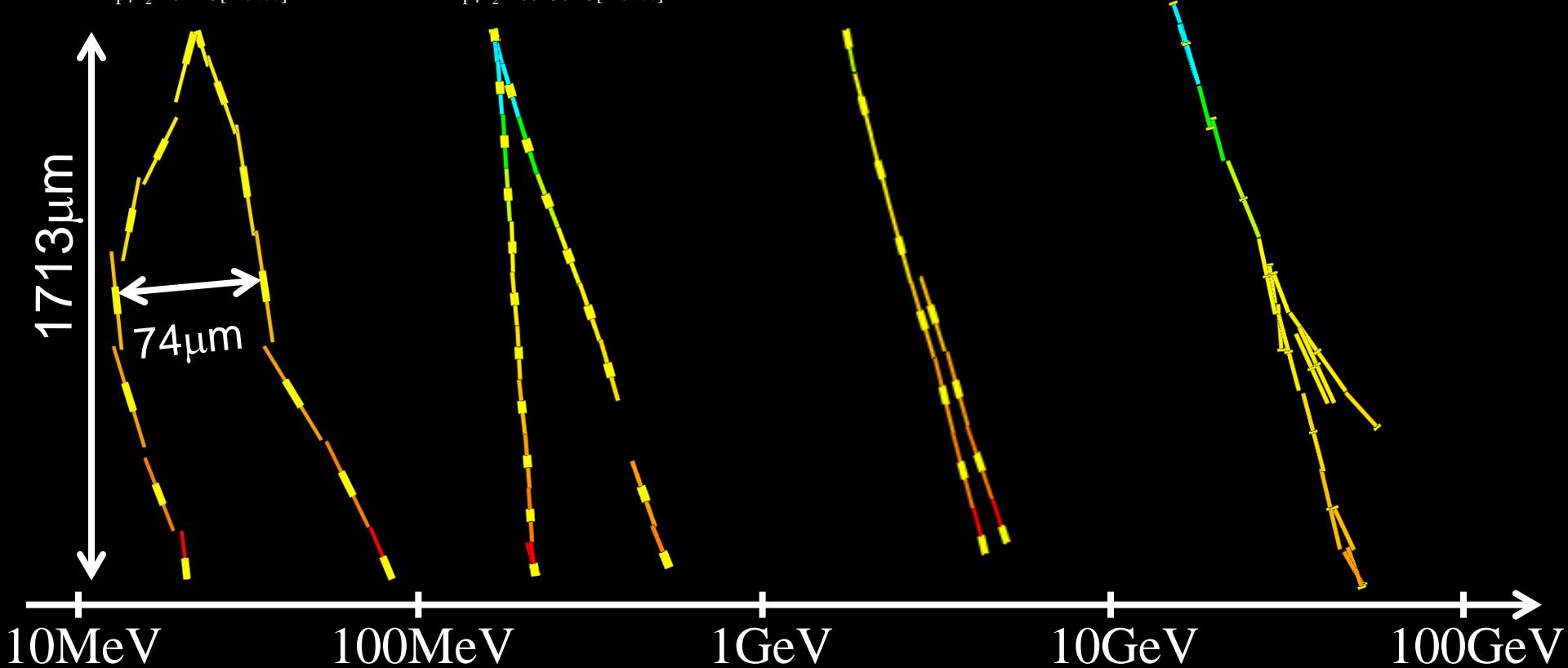
Energy range

LCS gamma-ray beam
@ UVSOR
Event ID : 221 2314379
 $E=28+6\cdot4[\text{MeV}]$
 $p\beta_1=13+4\cdot2[\text{MeV}/c]$
 $p\beta_2=15+4\cdot3[\text{MeV}/c]$

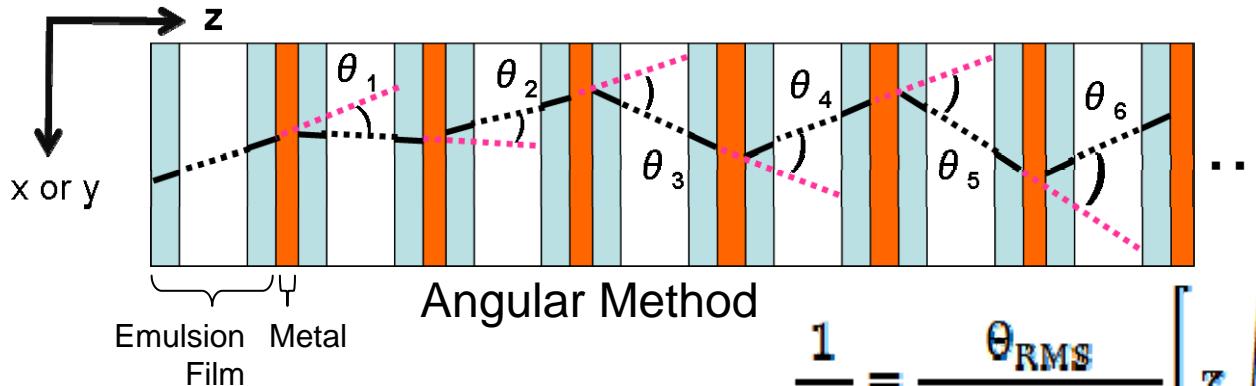
Atmospheric gamma-ray
@ Mt. Norikura
Event ID : 131 3741965
 $E=150+38\cdot15[\text{MeV}]$
 $p\beta_1=50+12\cdot7[\text{MeV}/c]$
 $p\beta_2=100+36\cdot13[\text{MeV}/c]$

LCS gamma-ray beam
@ SPring-8

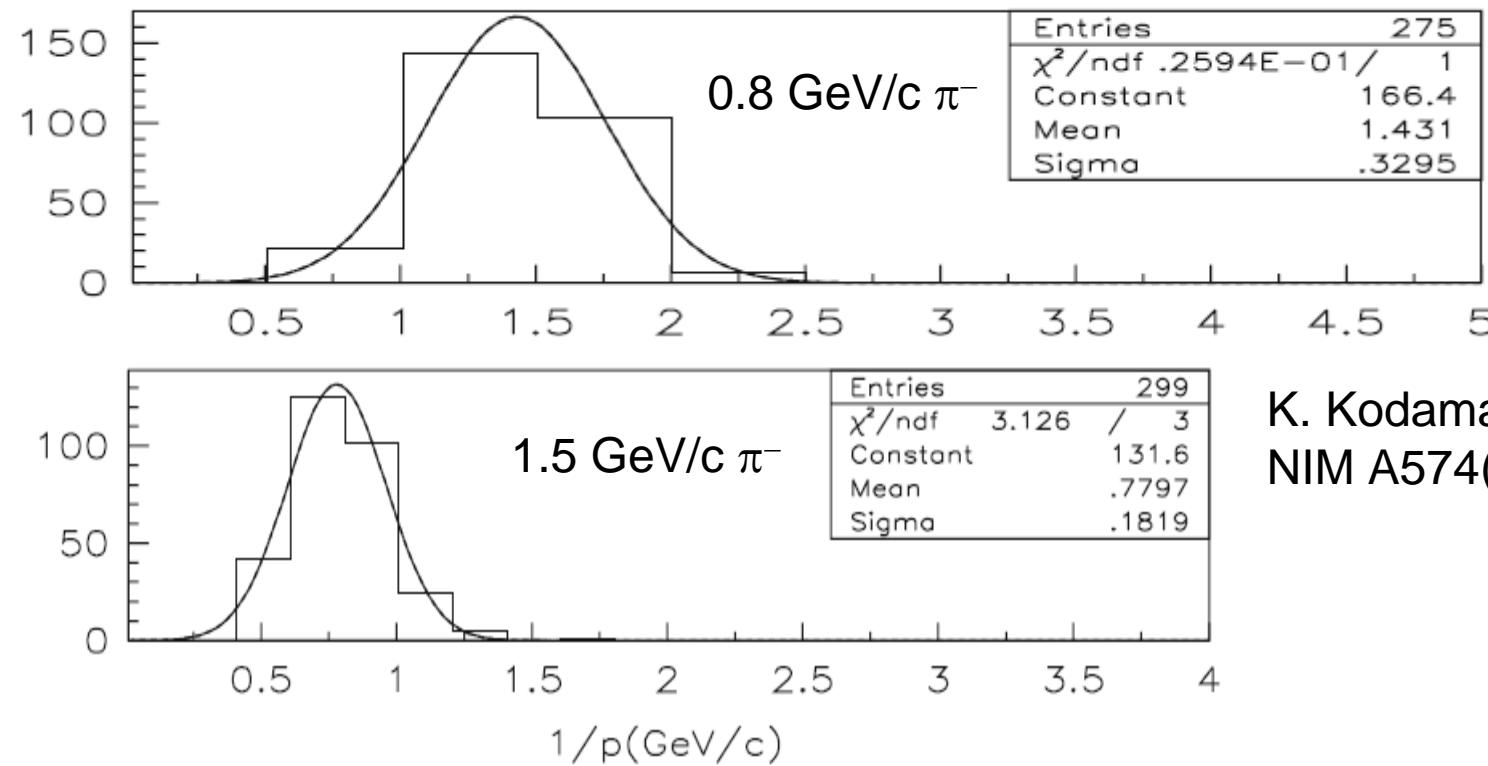
Atmospheric gamma-ray
@ balloon flight (MSC)



Momentum Measurement by MCS



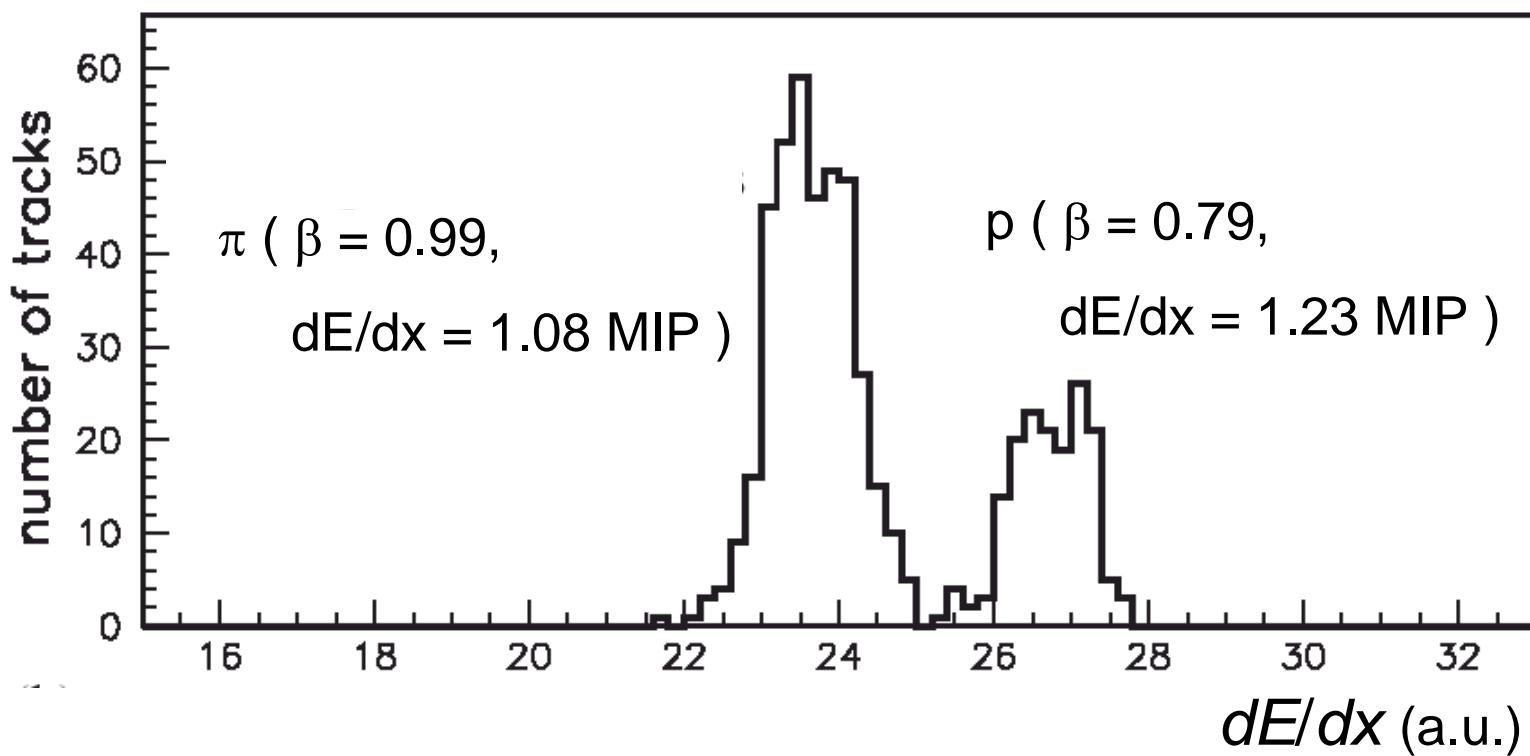
$$\frac{1}{p\beta} = \frac{\theta_{\text{RMS}}}{13.6 \text{ MeV/c}} \left[z \sqrt{\frac{x}{X_0}} \left(1 + 0.038 \ln \left(\frac{x}{X_0} \right) \right) \right]^{-1}$$



K. Kodama et al.
NIM A574(2007) pp.192-198

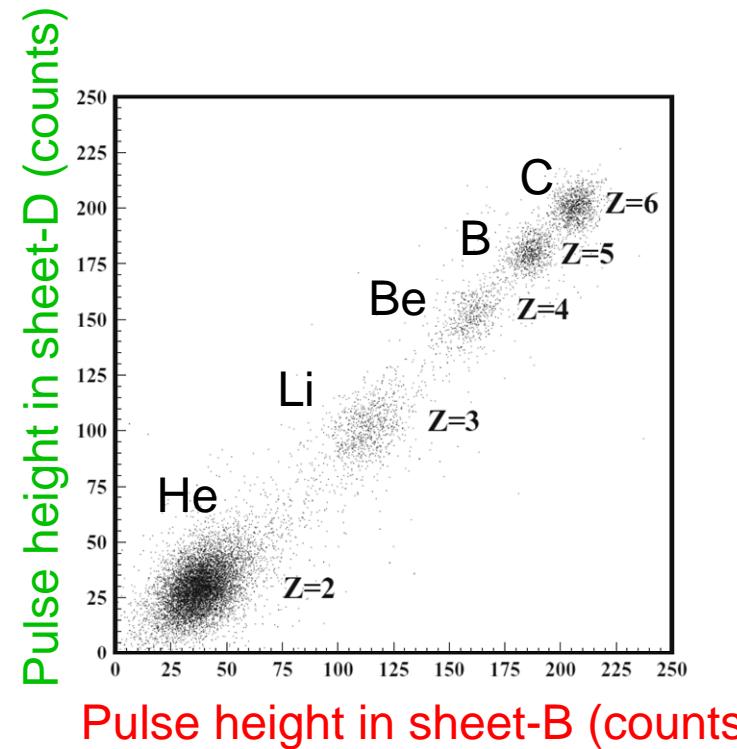
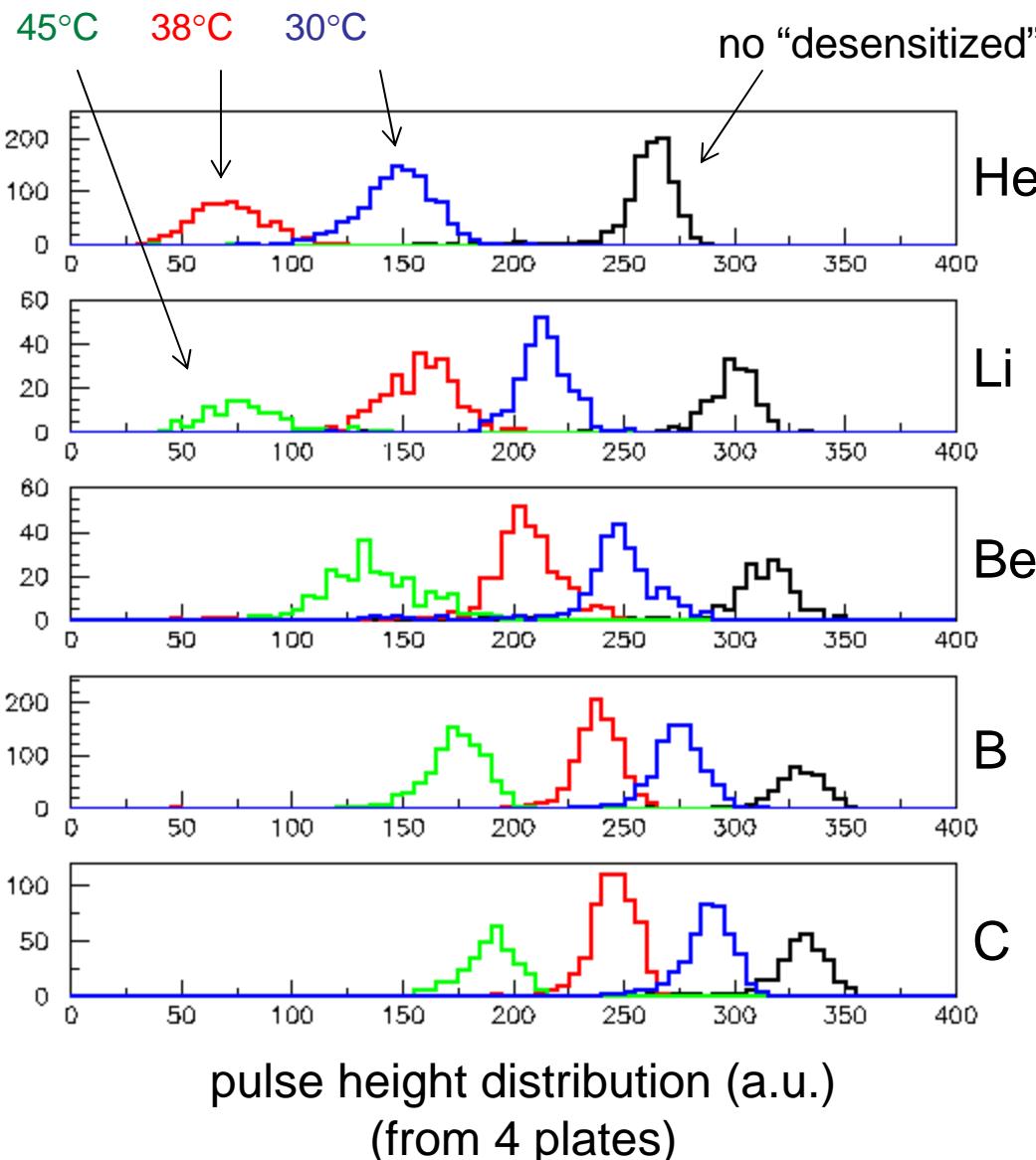
dE/dx measurement (p-id)

“OPERA film” \times KEK-PS 1.2 GeV/c beam (29 films)



dE/dx measurement (Z -id for nuclei)

"desensitized" operation (98% RH 3days)

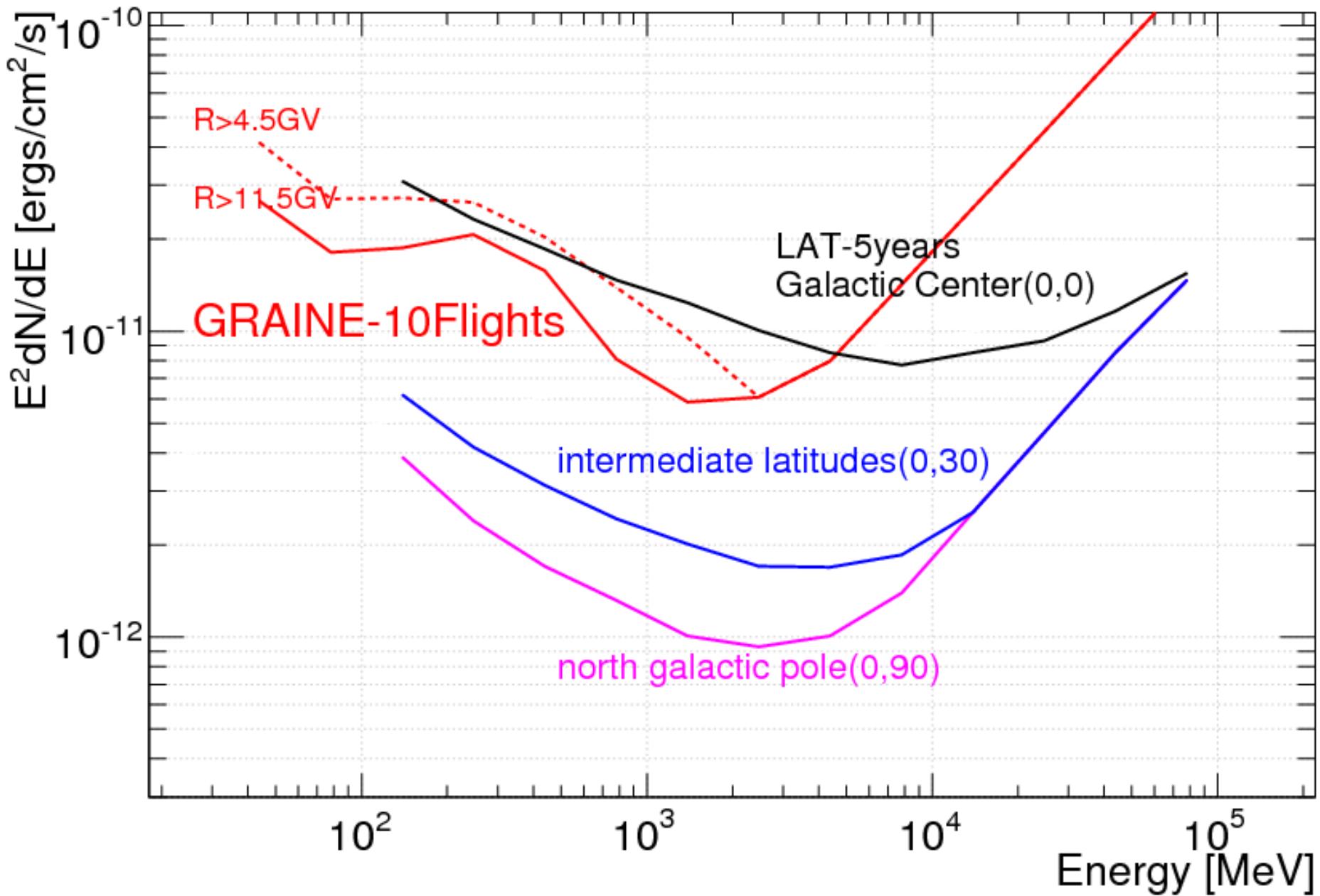


T. Toshito et al.,
NIM A556 (2006) pp.482-489
Phys. Rev. C75 (2007) 054606

GRAINE roadmap

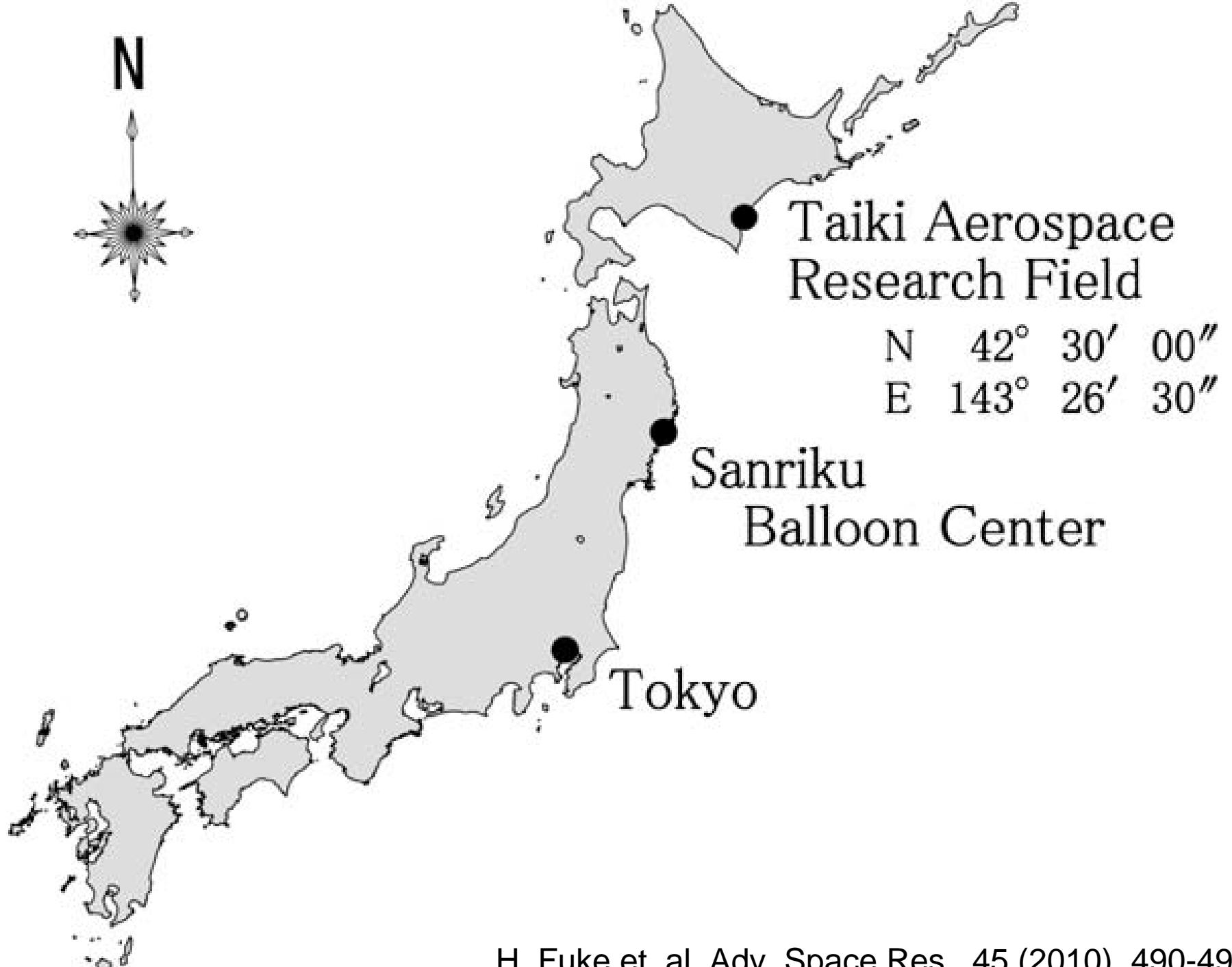
- 8th/June/2011, TARF, JAXA Scientific Ballooning,
12.5cm x 10cm aperture area, 4.3hours (1.6hours@35km) flight duration
 - Working test for each element
 - Connection test between elements
 - Measurement of atmospheric gamma-rays
- 2014(Planned), Alice Springs, JAXA International Scientific Ballooning
2500cm² aperture area, 1 day flight duration
 - Overall test by detecting known gamma-ray source
 - Observation with highest imaging resolution
- 2015-
10m² aperture area, 7days flight duration
 - Starting scientific observation

Differential Sensitivity



GRAINE roadmap

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12.5cm x 10cm aperture area, 4.3hours (1.6hours@35km) flight duration
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Taiki Aerospace Research Field

Pacific Ocean

Airstrip (L 1,000m)

Sliding Launcher on
Rails (L 460m)

Meteorological
Equipments

Balloon Operation
Building

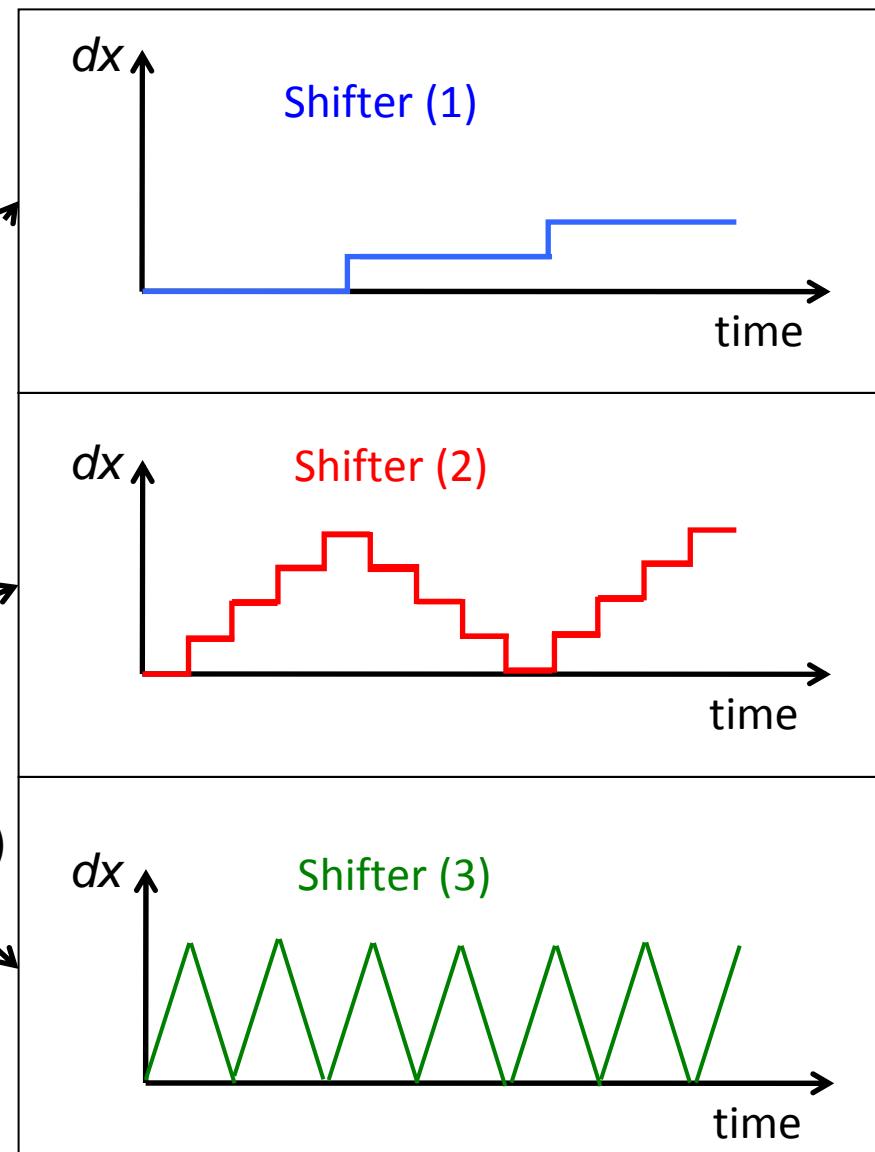
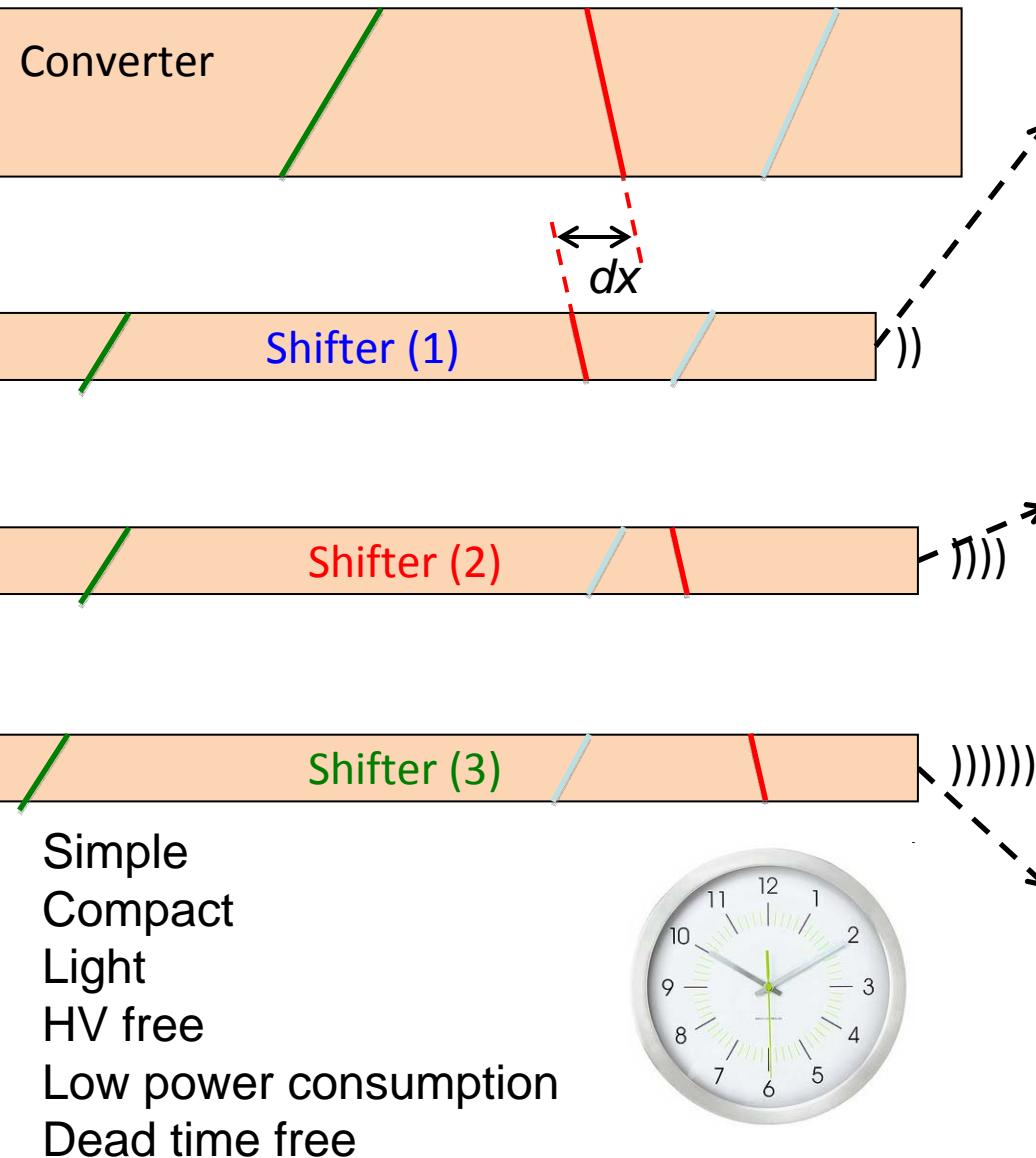
Handling Area ($\phi 140m$)

Hangar
(W30m, H35m, L83m)



Multi-stage shifter (time stamper)

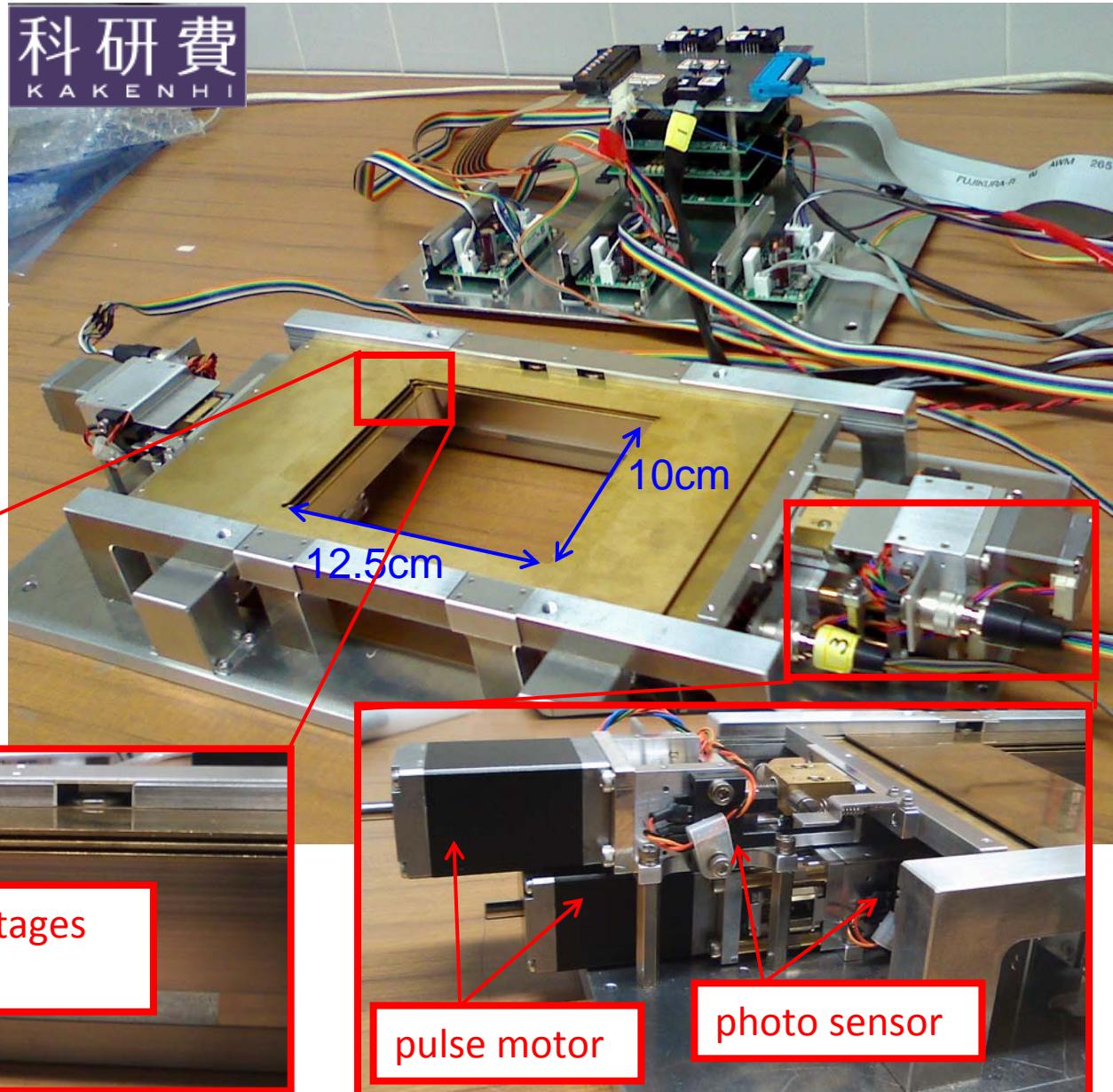
S. Takahashi et al.
NIM A620(2010) pp.192-195

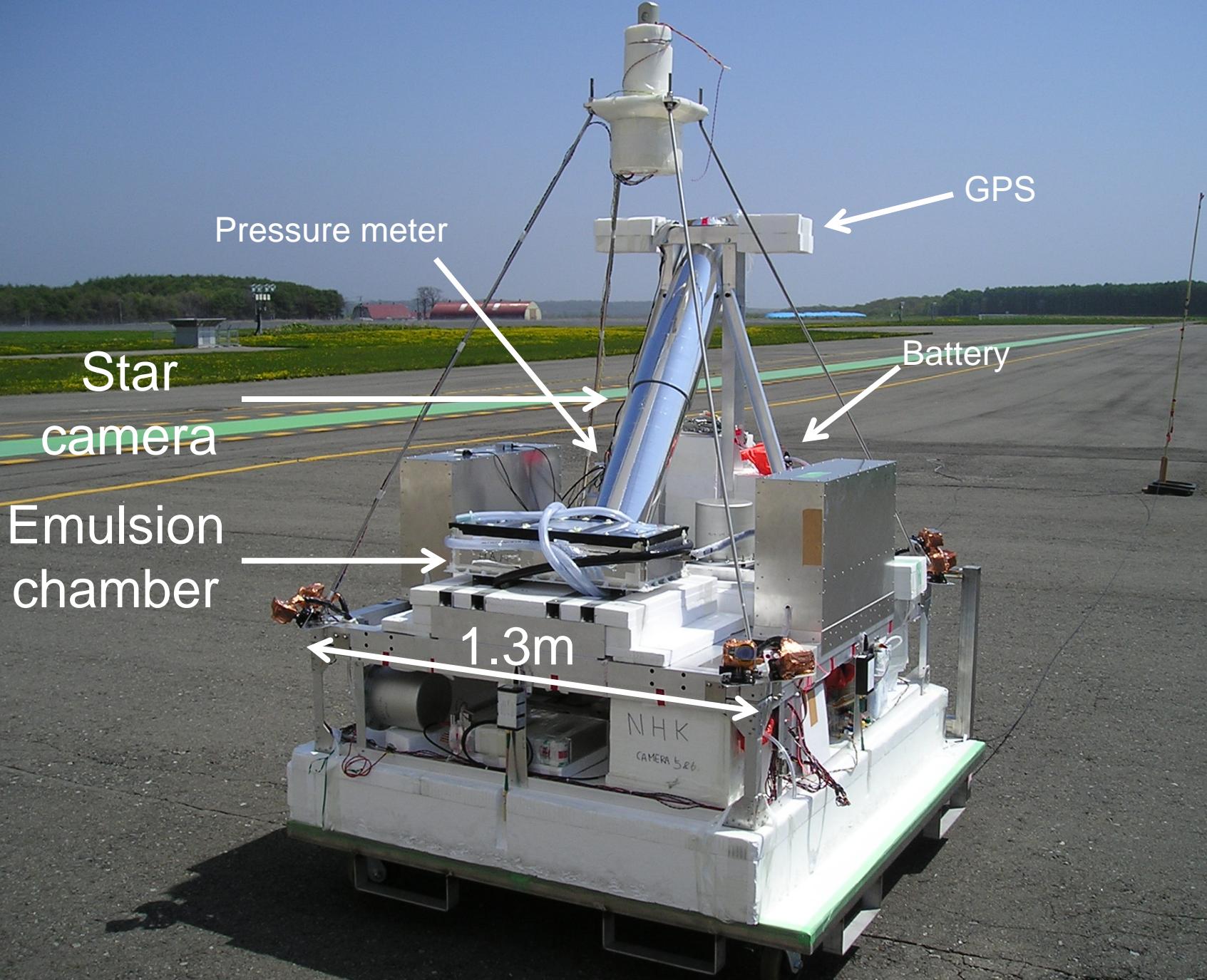


Multi-stage Shifter (Time Stamper)

Co-developed with
Mitaka Kohki Co., Ltd.

Weight : 5 kg
Power Cons.: 20 W
Reproducibility: 1 μ m





TARF

8th June 2011

5:05



Flight path



42.5°

43°

Level flight (34.7km)

7:14~8:50

20km

145°

9:36



Altitude [km]

42°

43°

40

30

20

10

0

143

143.5

144

144.5

145

Longitude [°]

8:50

5:05

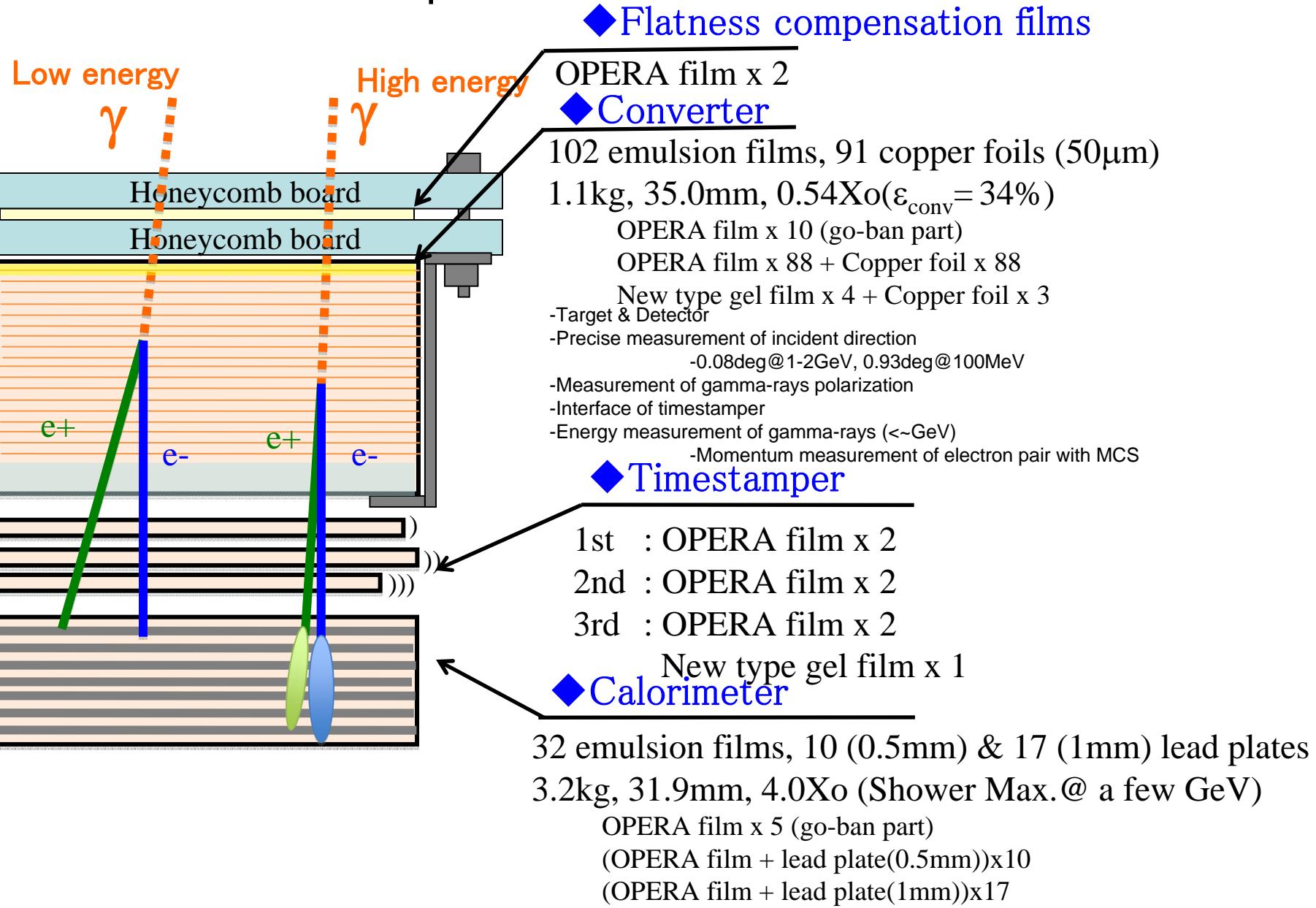
9:24

7:14

Duration : 4.3hours
Level : 1.6hours

Emulsion chamber

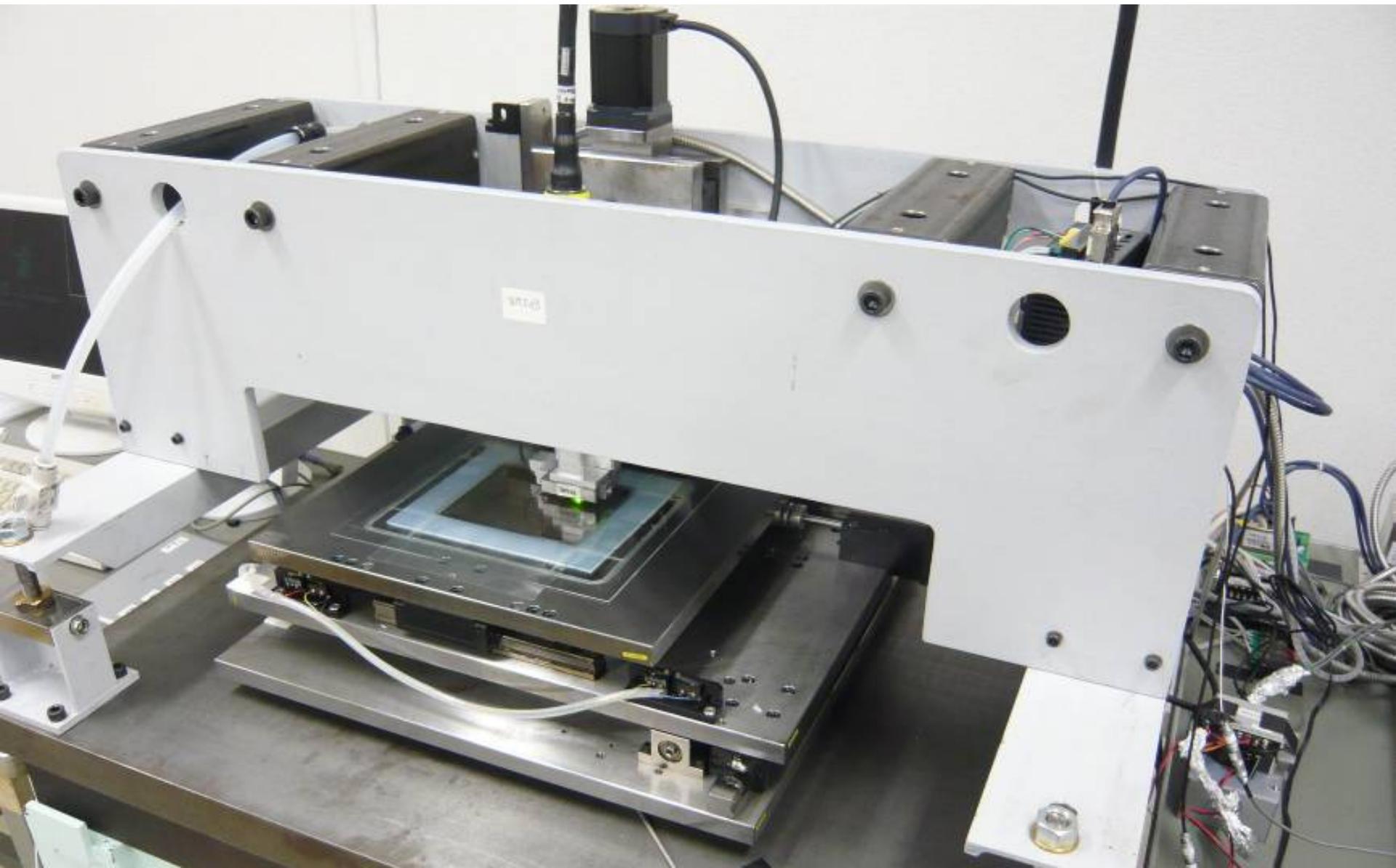
Aperture area : 12.5cm x 10cm



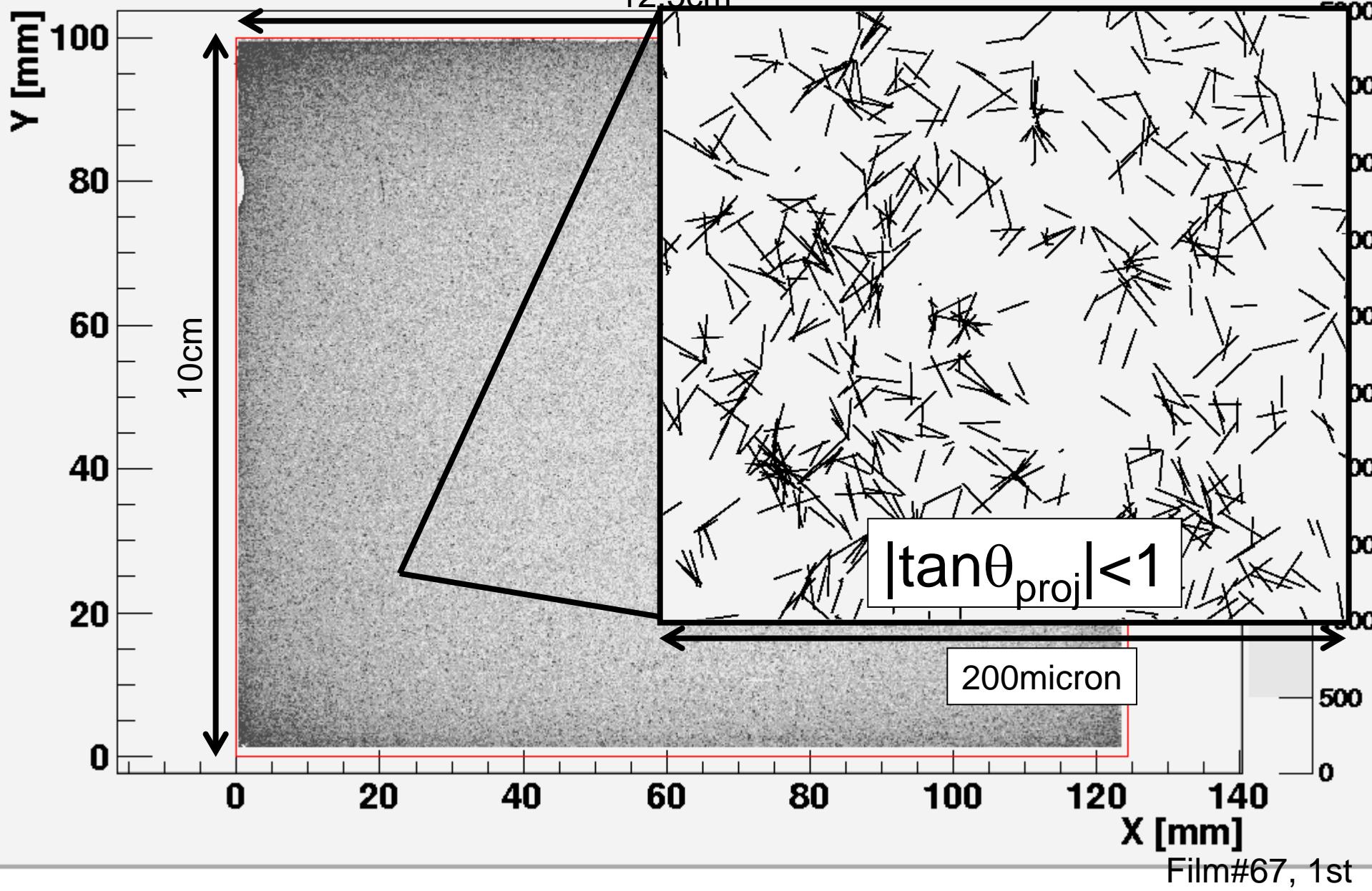
Automated Emulsion Scanning System

“ S-UTS ”

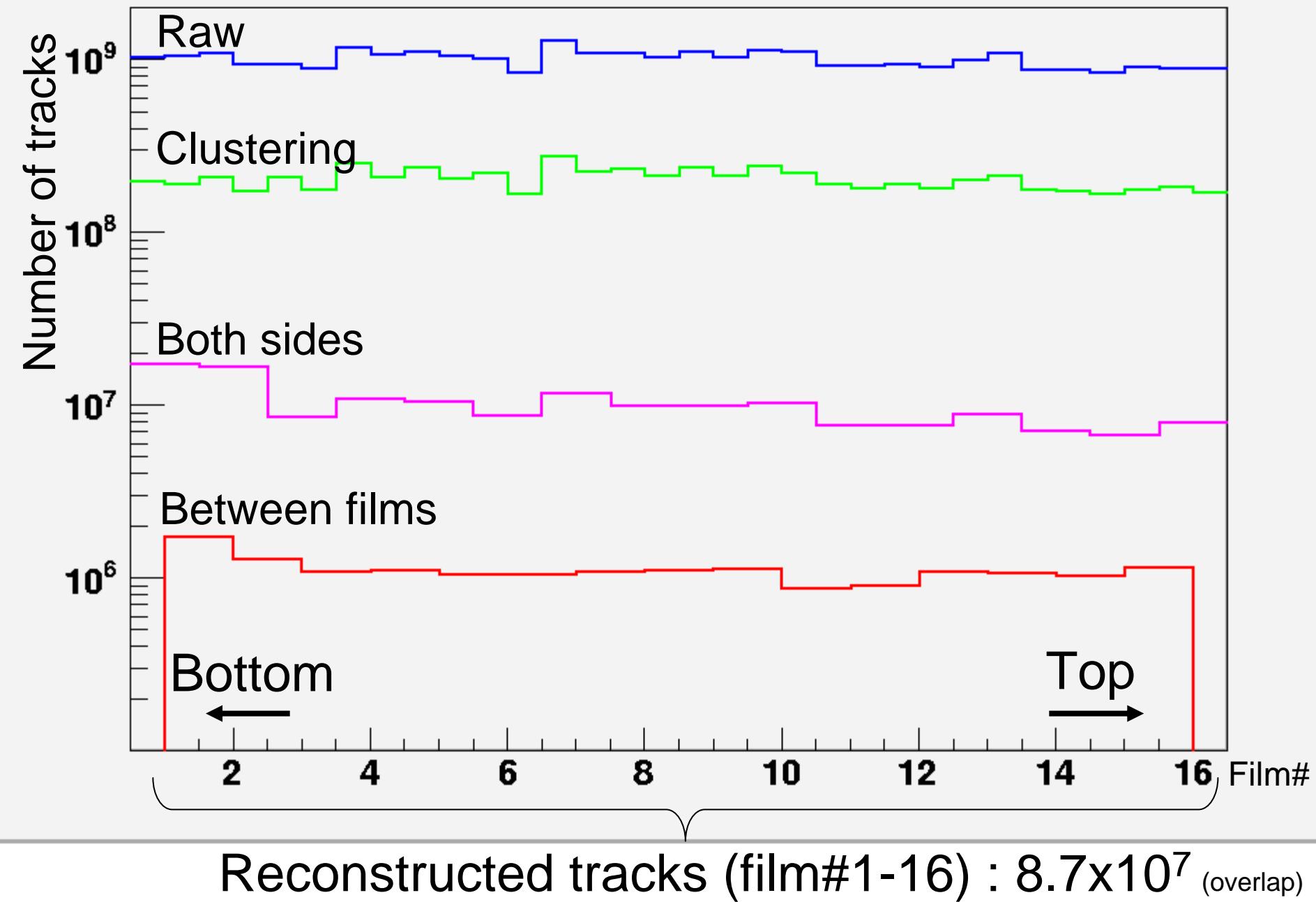
Nagoya Univ.



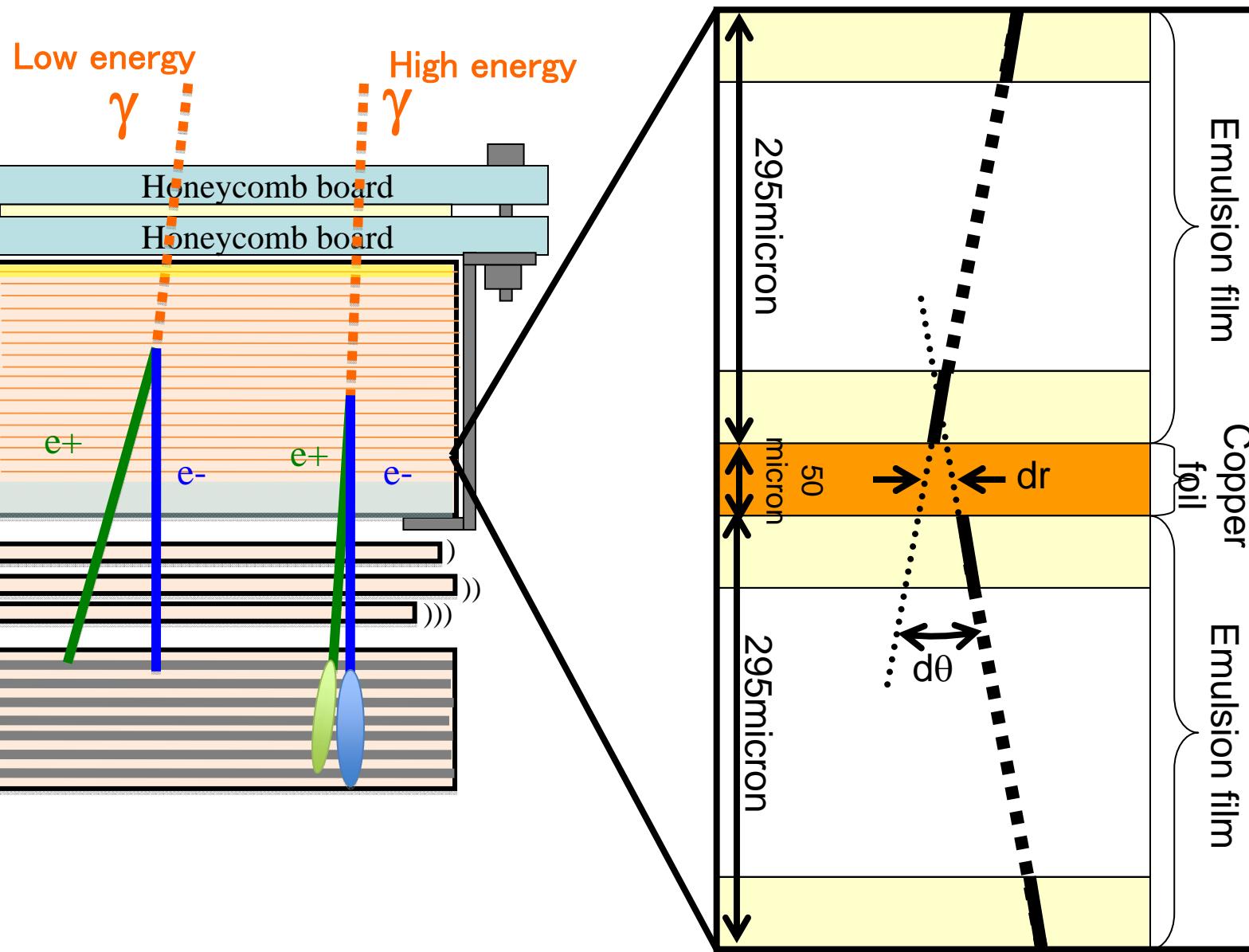
Number of tracks: 8.0×10^8



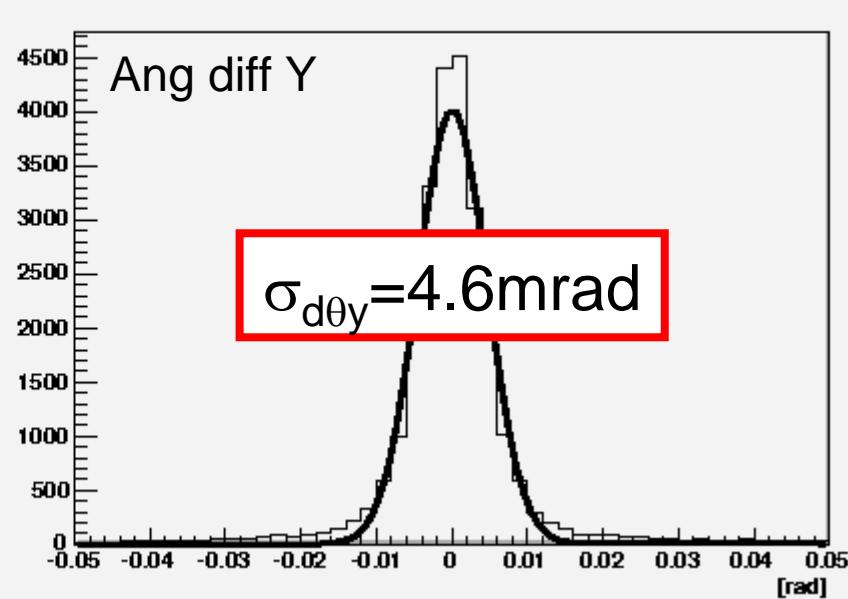
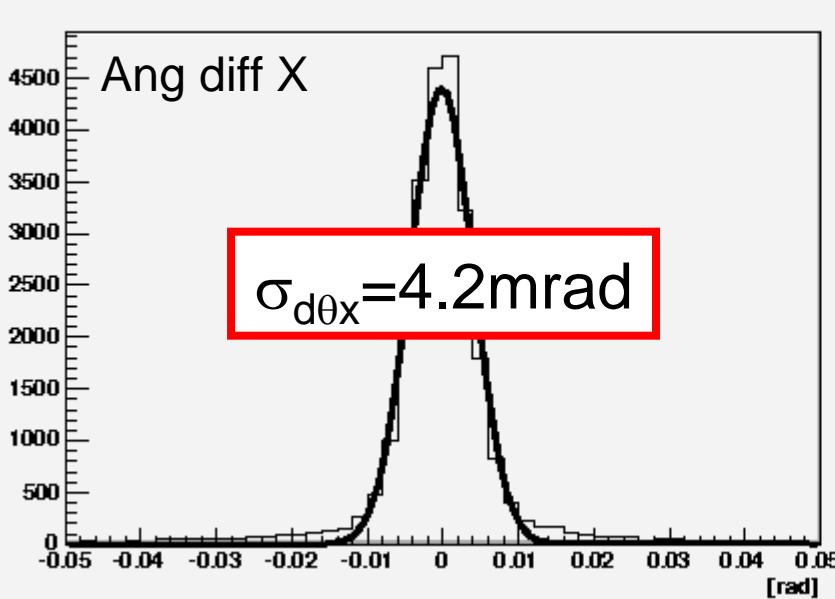
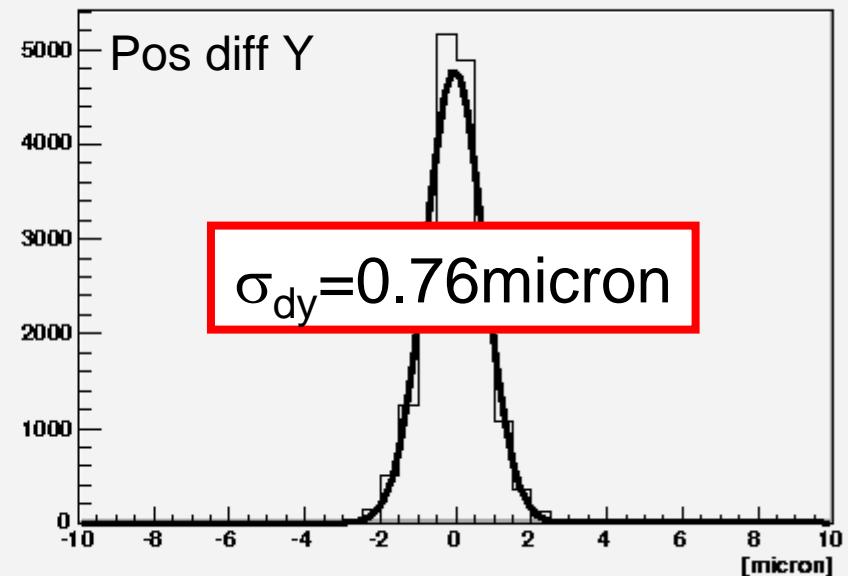
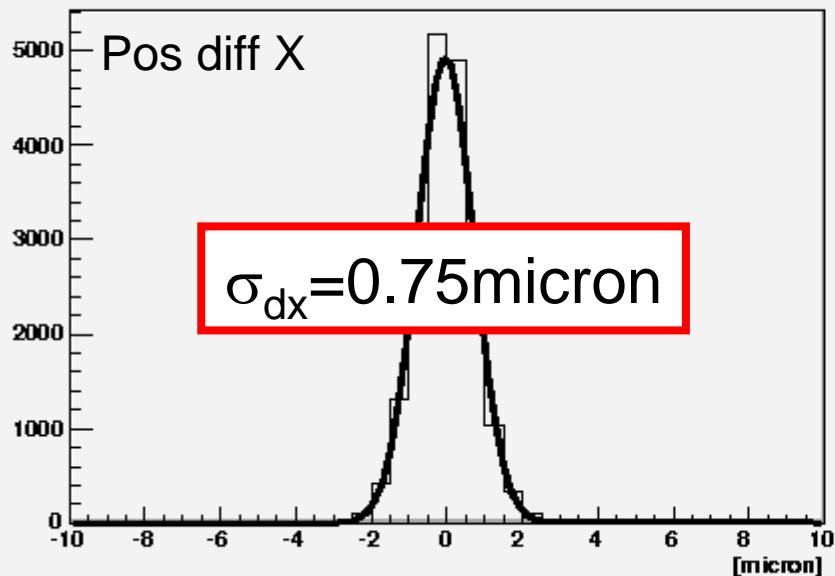
Track reconstruction



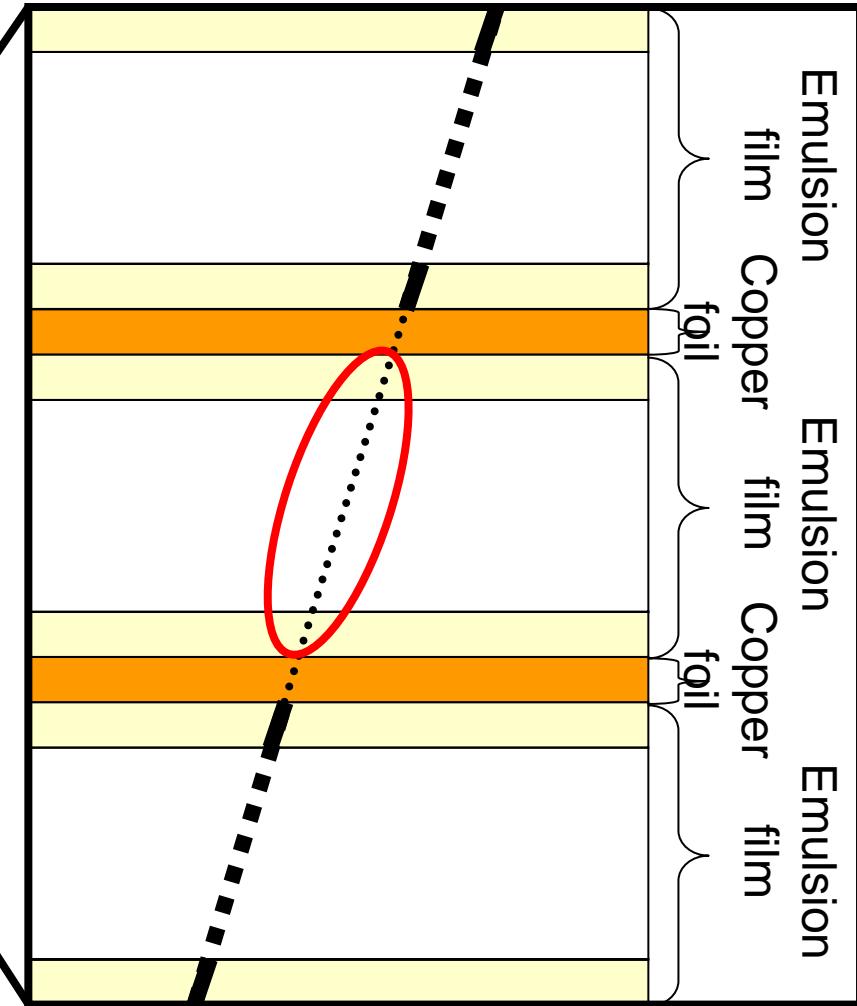
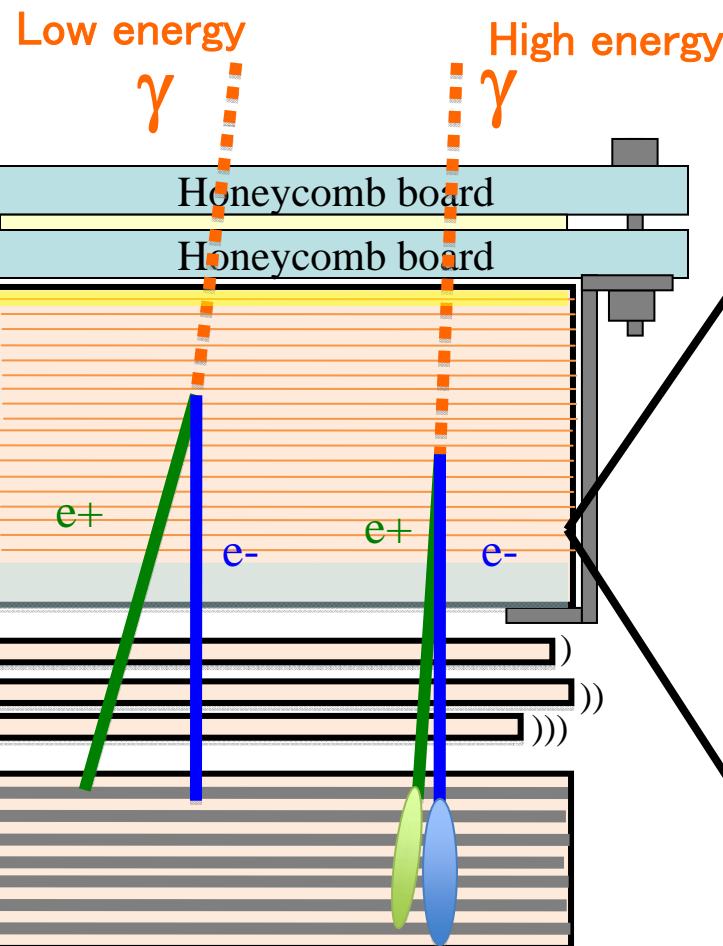
Connection accuracy



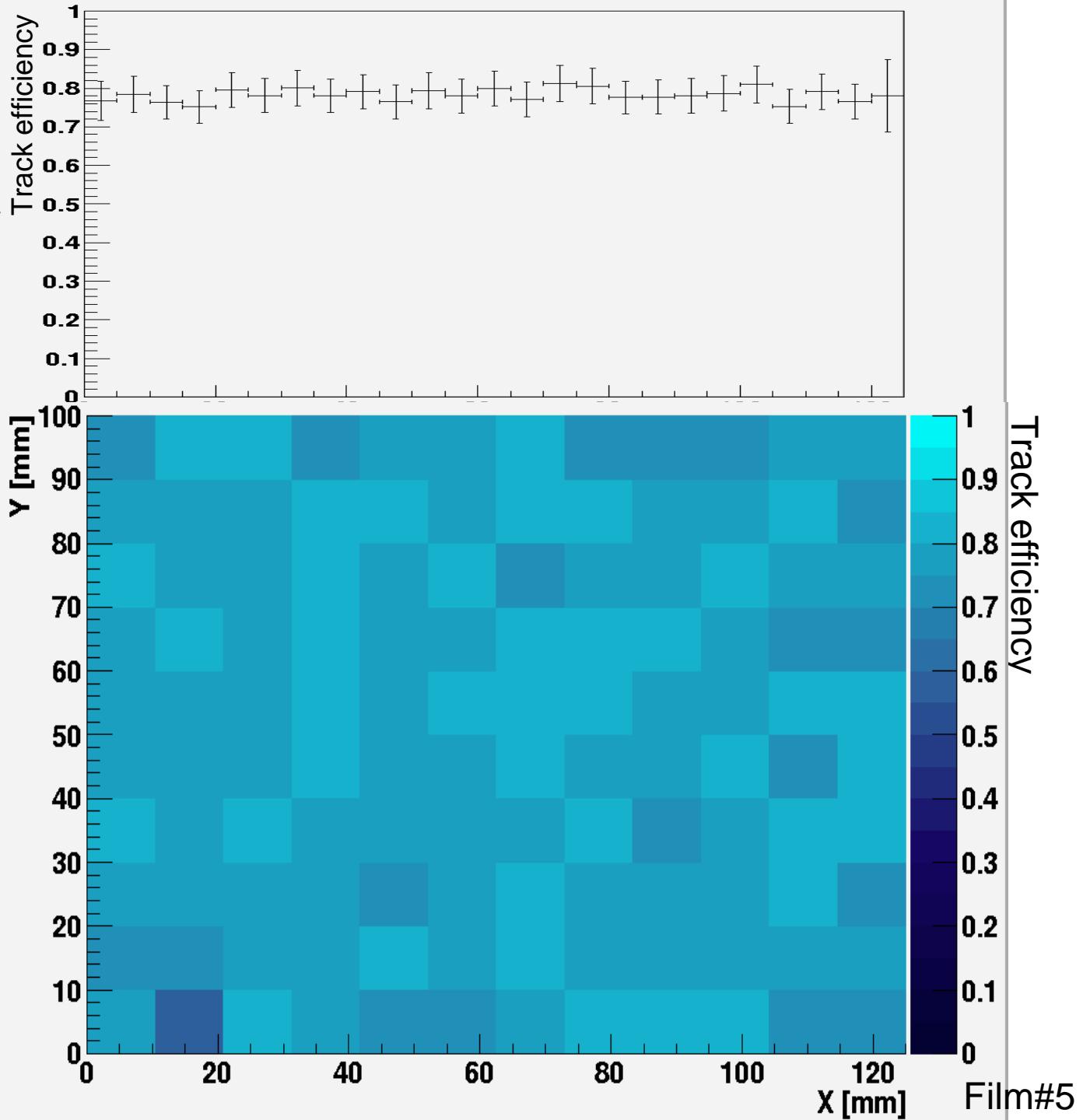
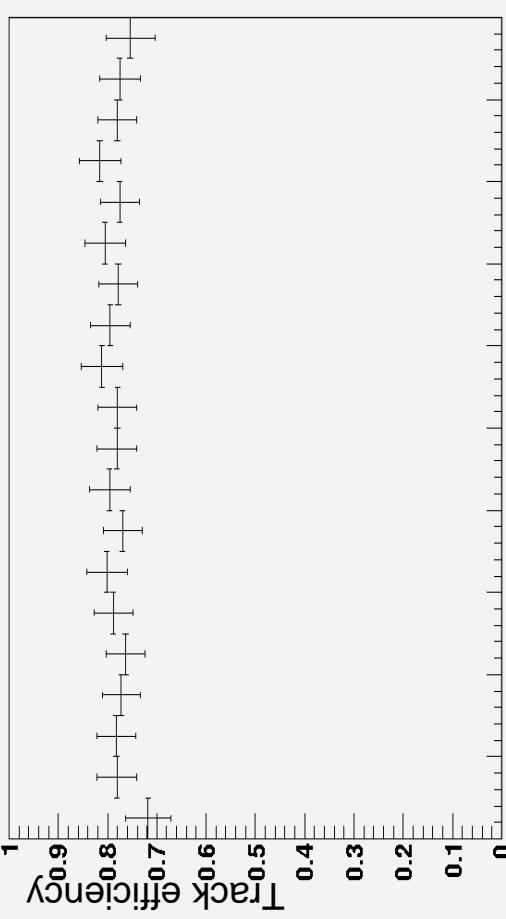
Connection accuracy



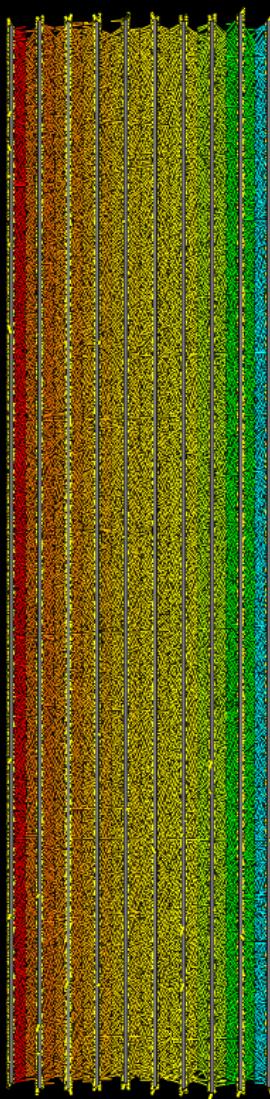
Track efficiency



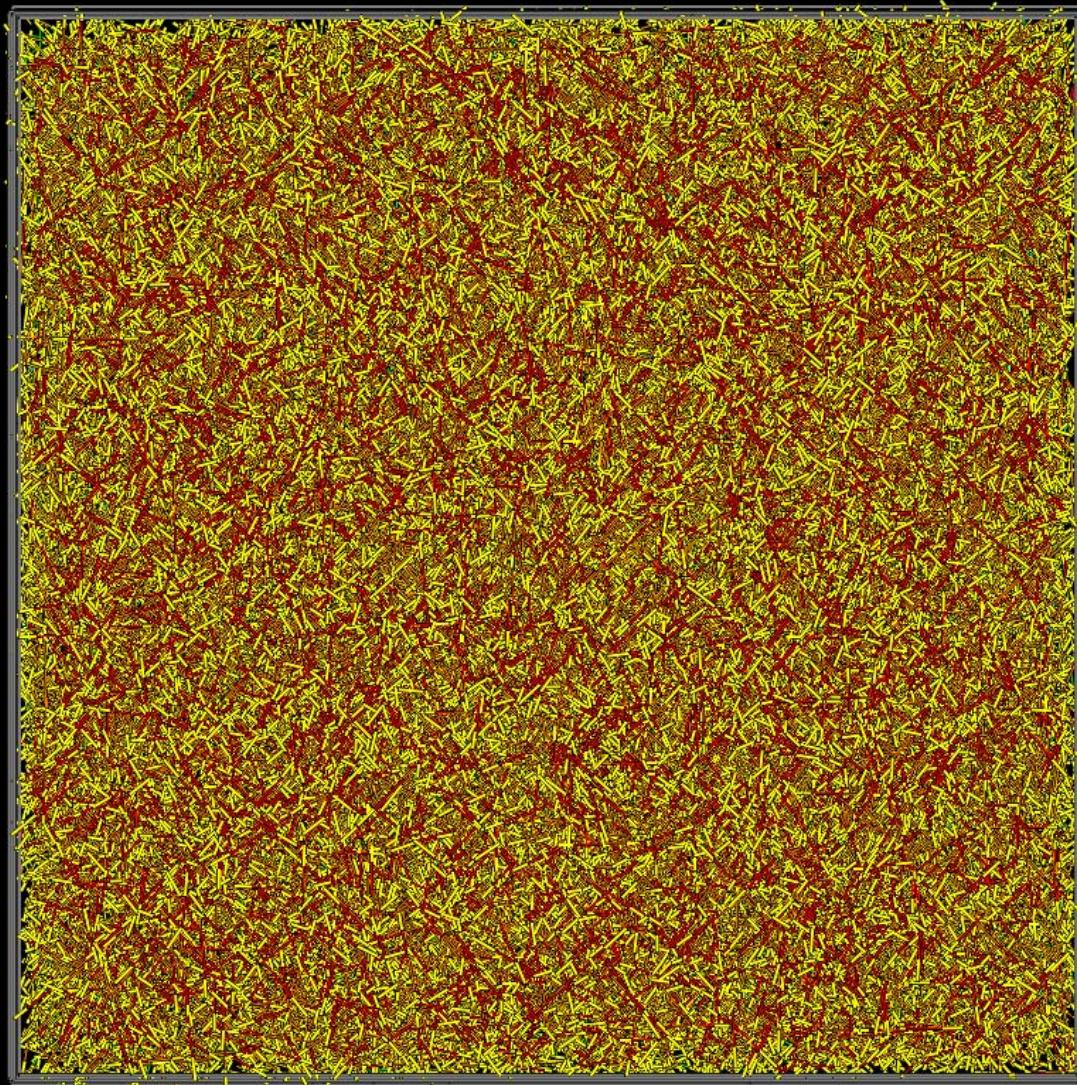
Track efficiency



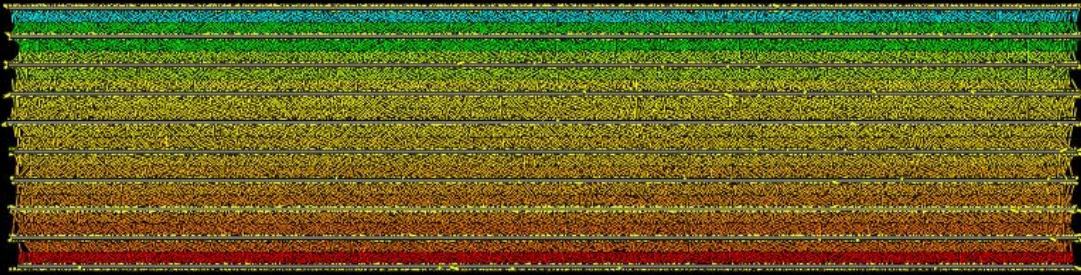
Z

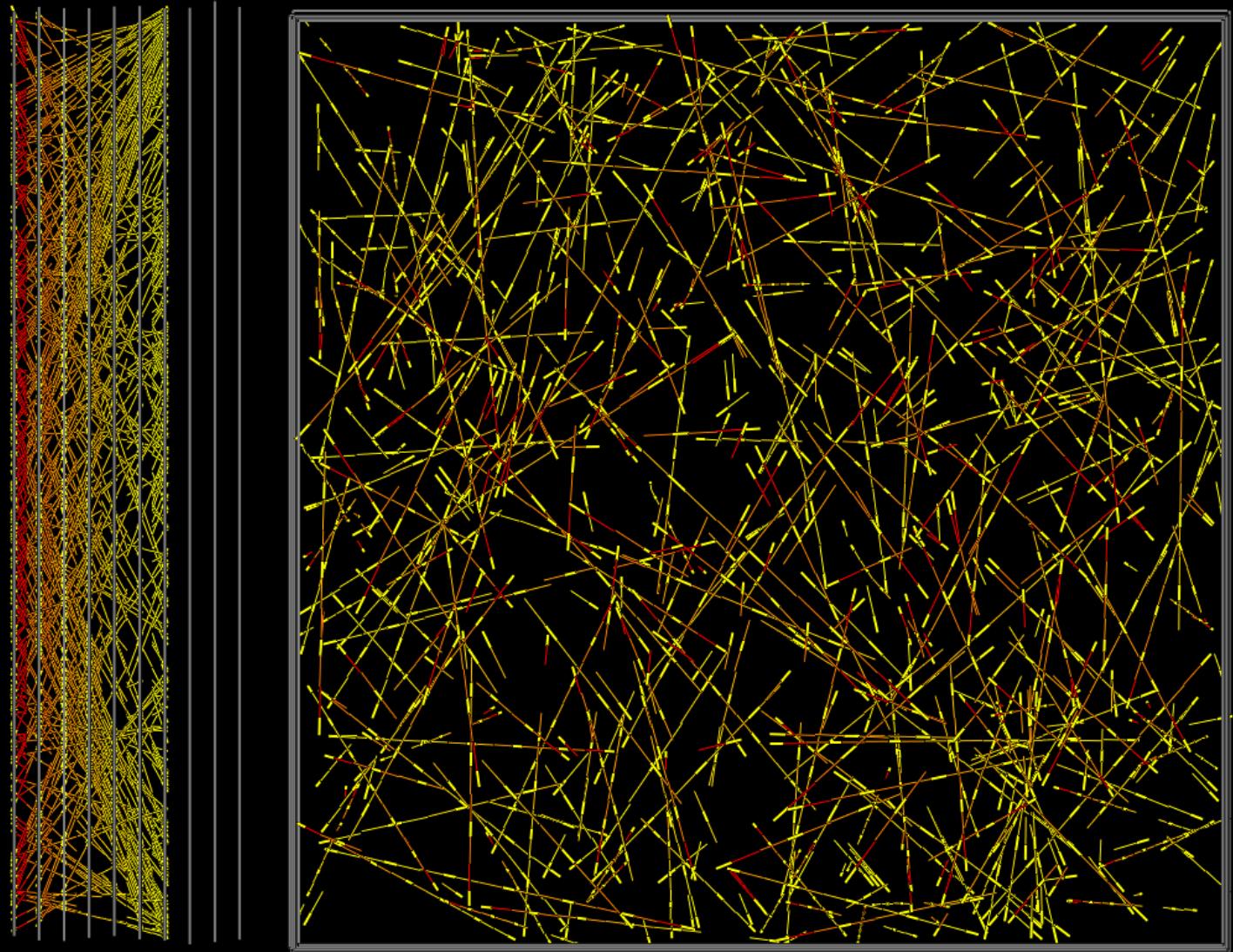


Y



(5mm)² x 10films X
2x10⁴tracks

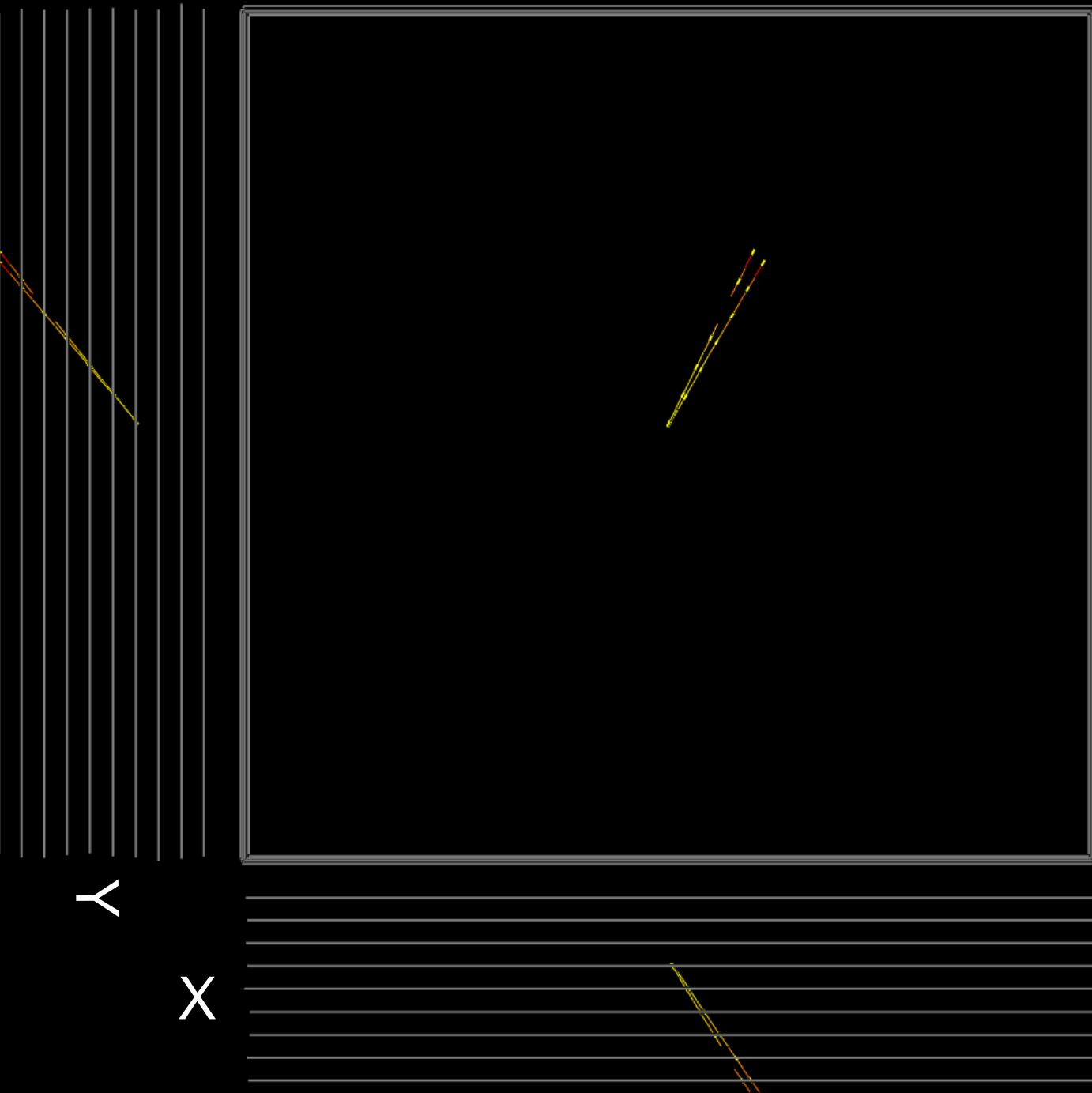




Y

X

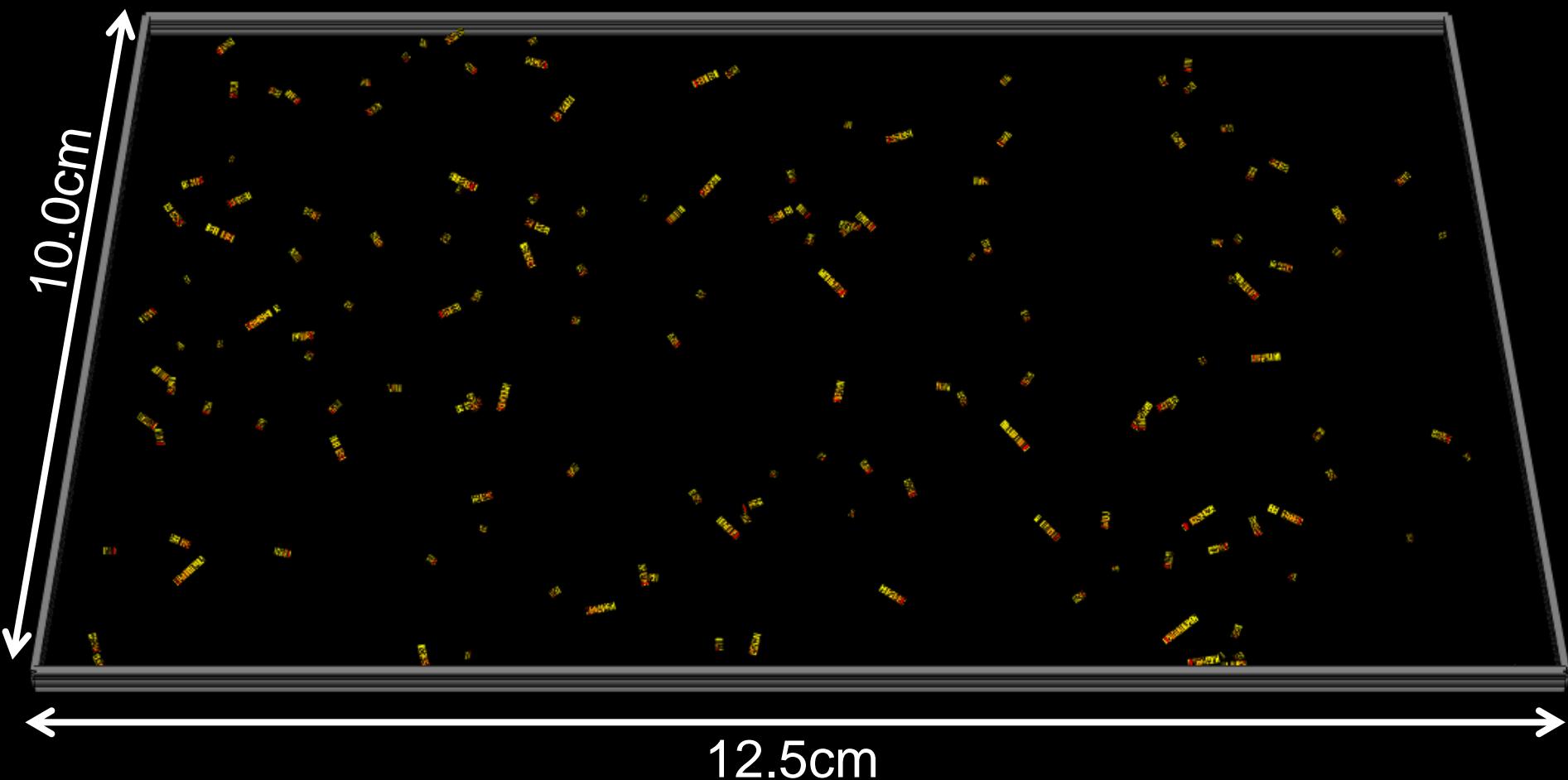
Z



Z

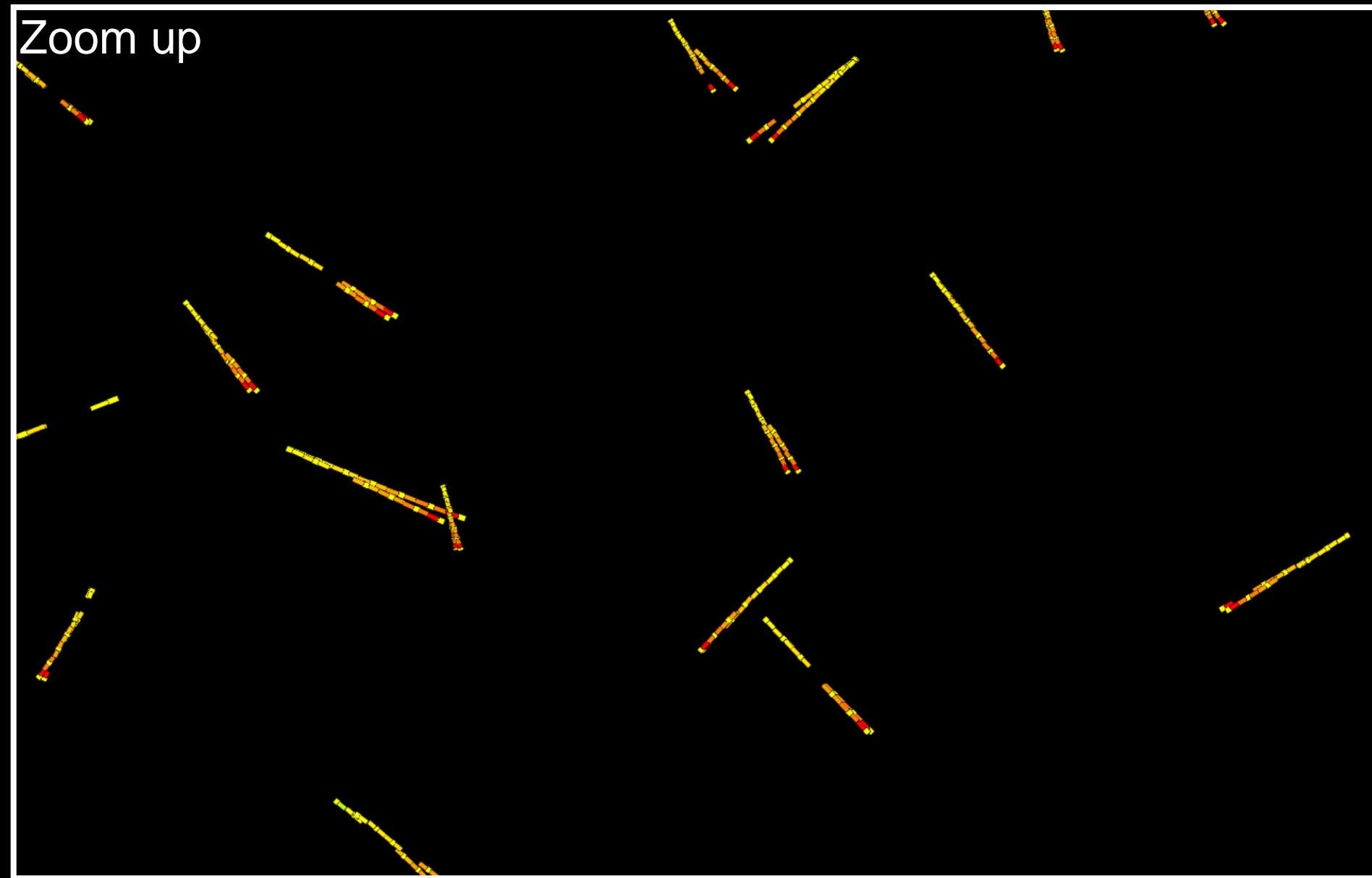
X

Y



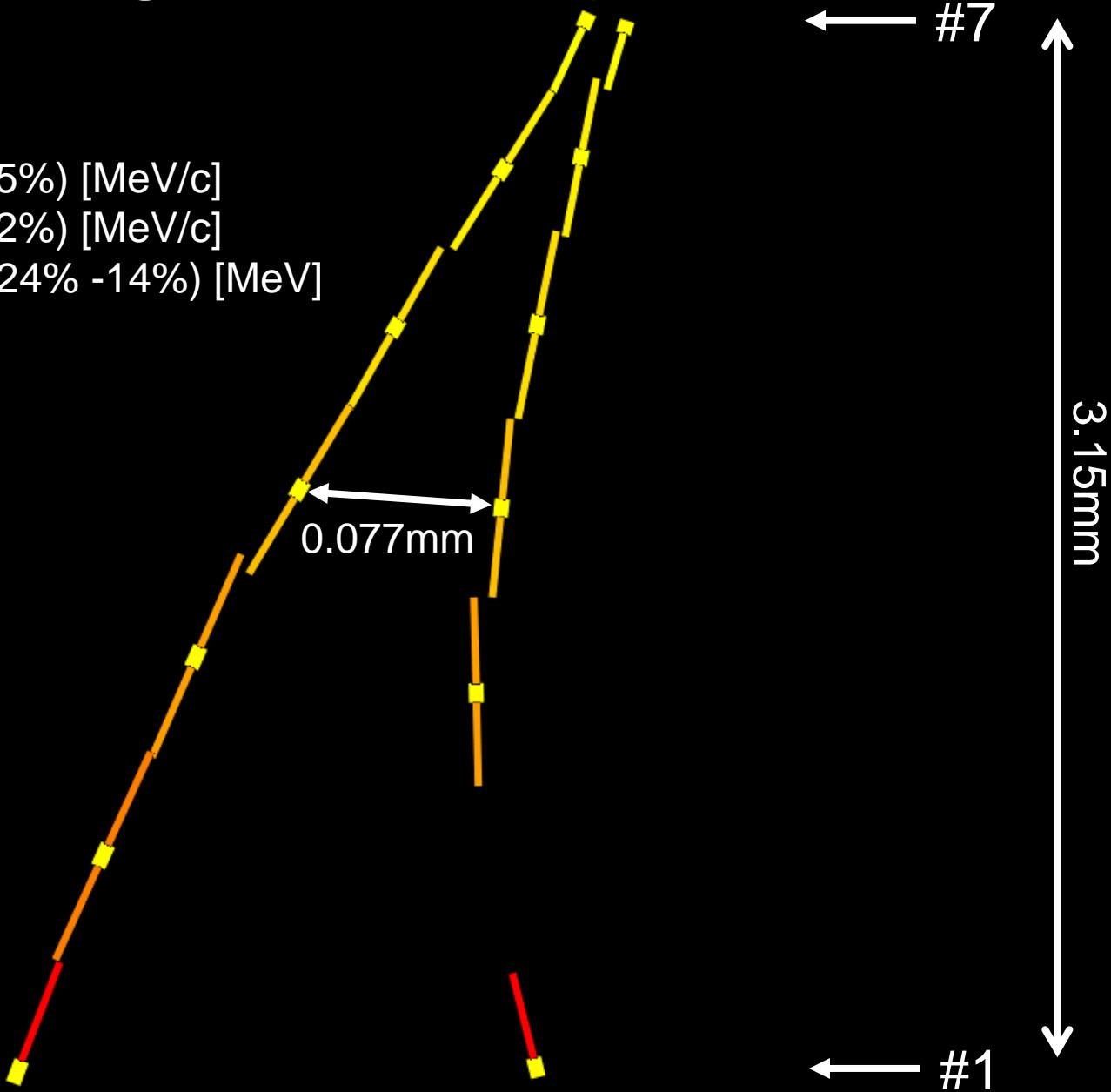
153events
Reliability 97%

Zoom up

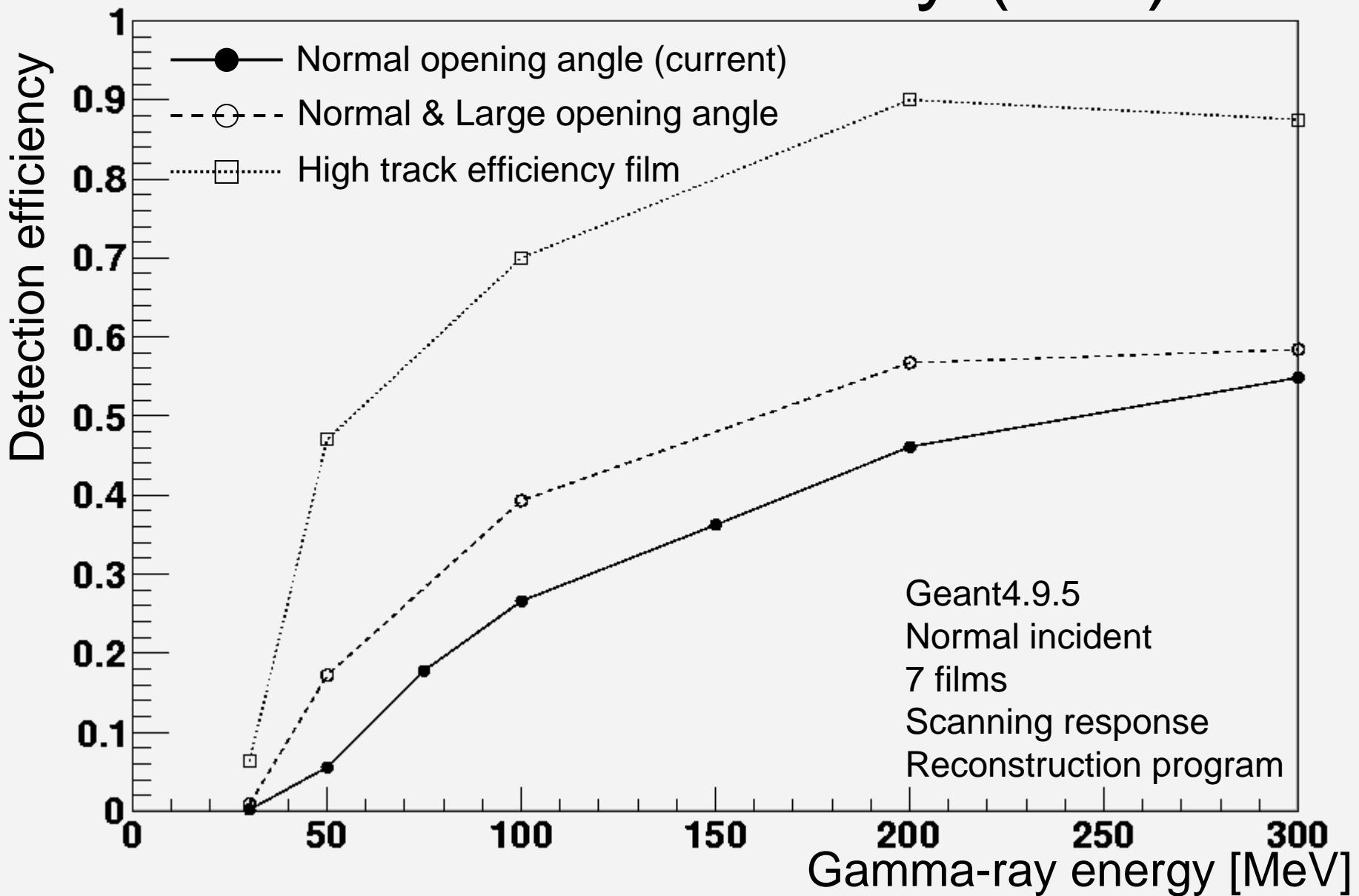


One of gamma-ray events

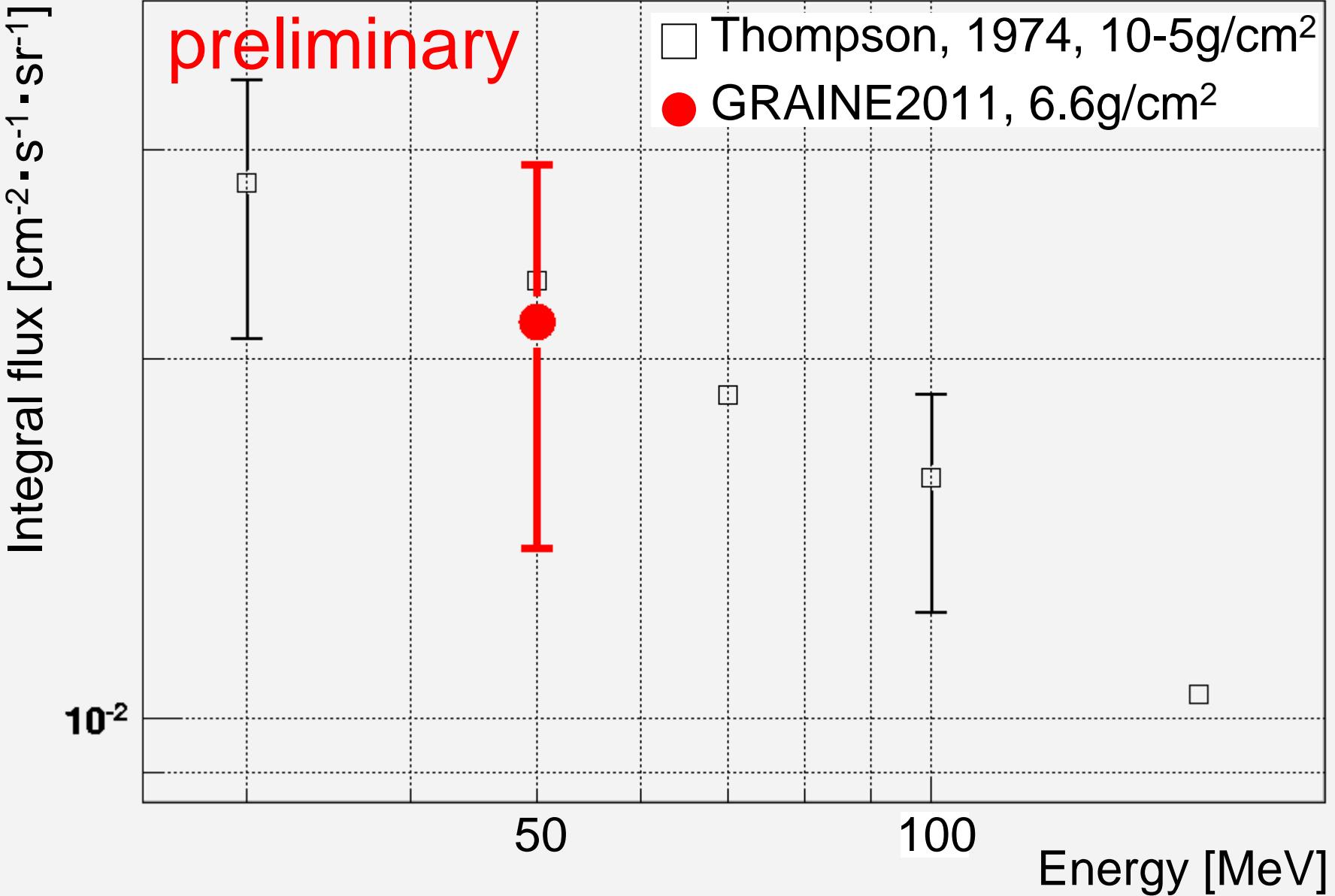
Event : 71 6923485
Start : #7
 θ_{incident} : 9.748 [deg]
 $(p\beta)_{\text{left}}$: 60 +20 -12 (25%) [MeV/c]
 $(p\beta)_{\text{right}}$: 32 + 9 - 6 (22%) [MeV/c]
 E_γ : 92 +22 -13 (+24% -14%) [MeV]



Detection efficiency (MC)



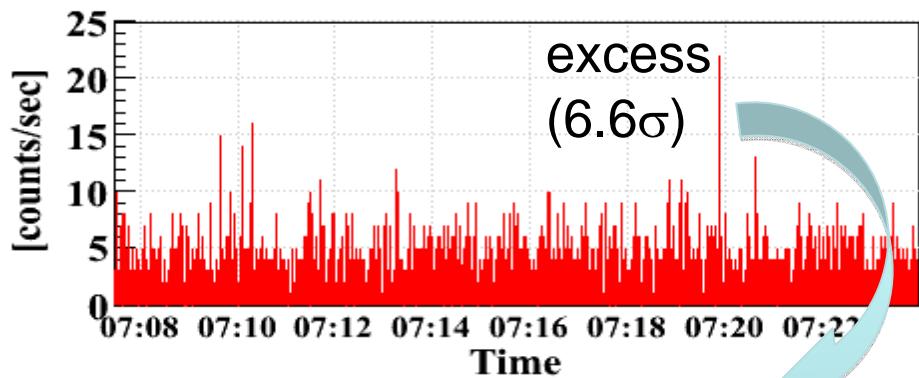
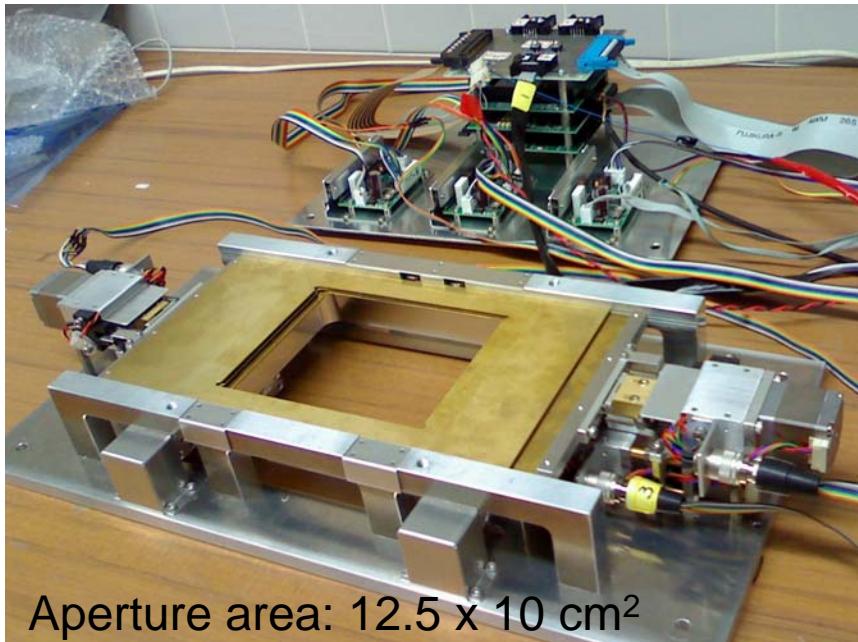
Atmospheric gamma-ray flux@35km



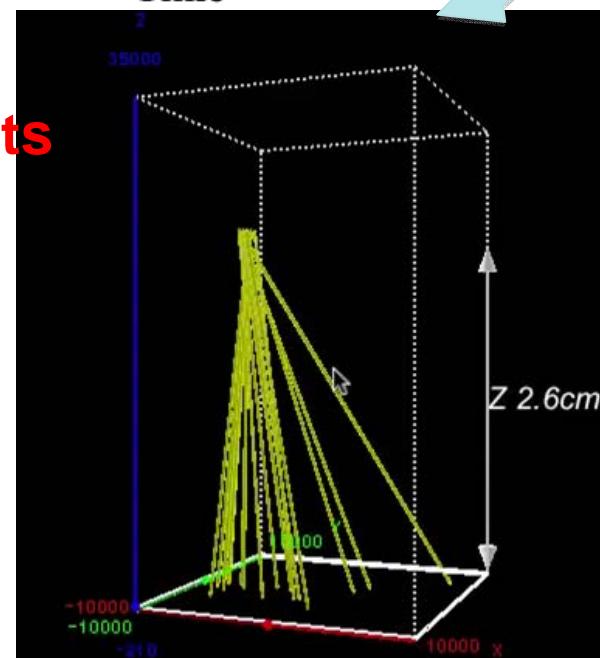
Establishment of timestamp technique @GRAINE2011

H.Rokujo, et al., NIM A, 701 (2013)

“Multi-stage shifter” 1st model Track rate mesurement @35km



Detection of
hadron events



- Correct operation during whole observation time
- Giving time info. to all penetrating tracks
- Detection of hadron shower tracks by timing and 3-D spatial analysis
- Time resolution: 0.15 sec

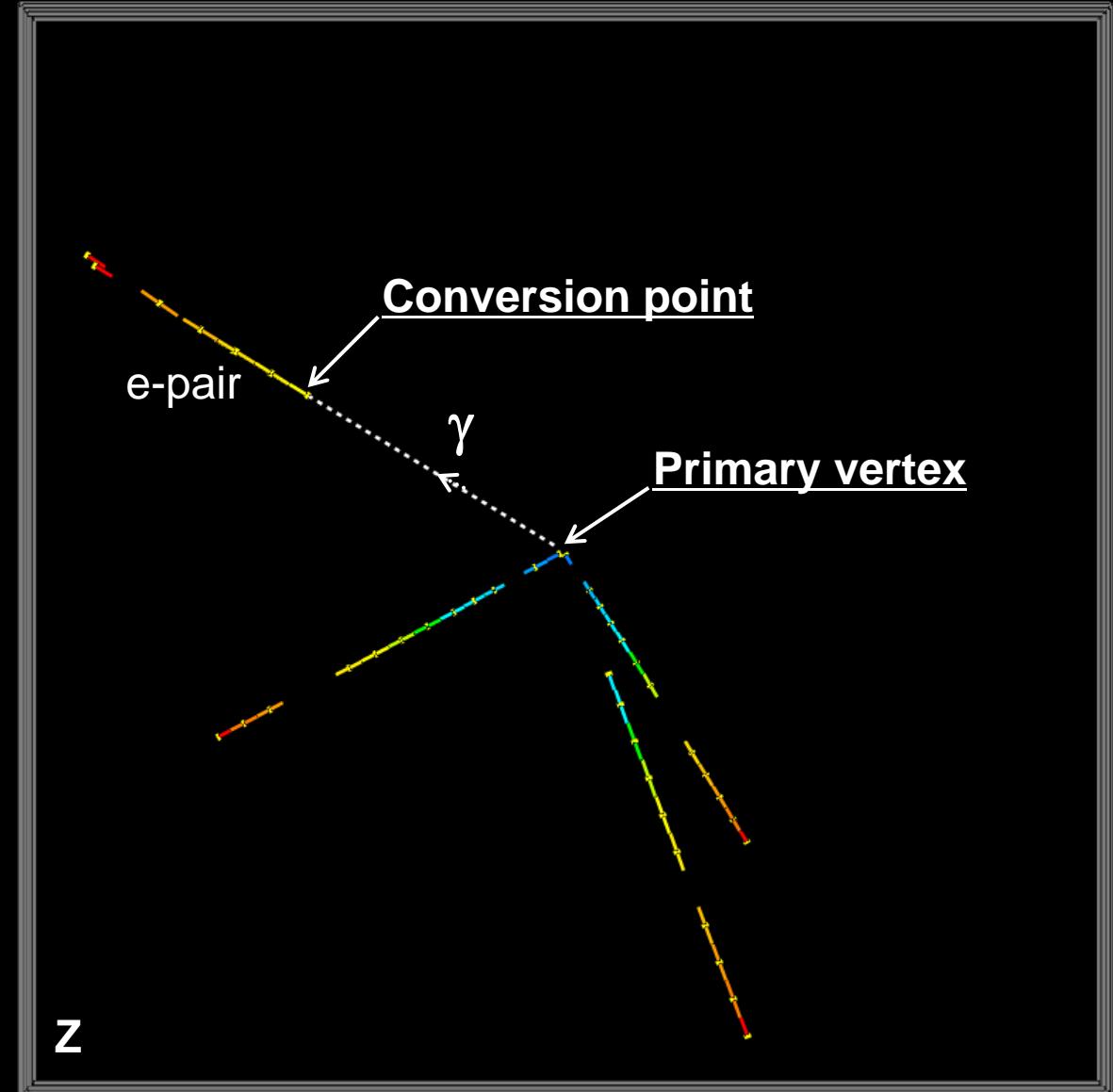
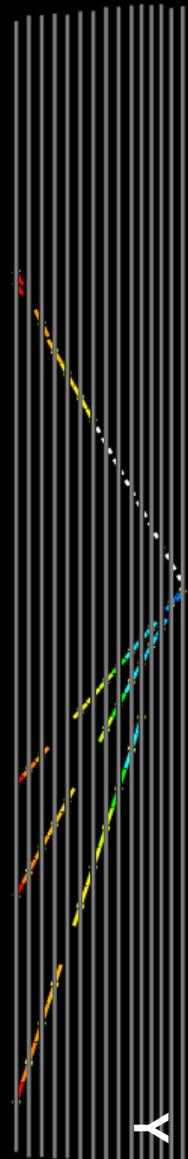
Ev : 2438038

7:18:34.5 (JST)

$\Delta t = \pm 0.5\text{s}$

1.2cm x 1.2cm

x 16films

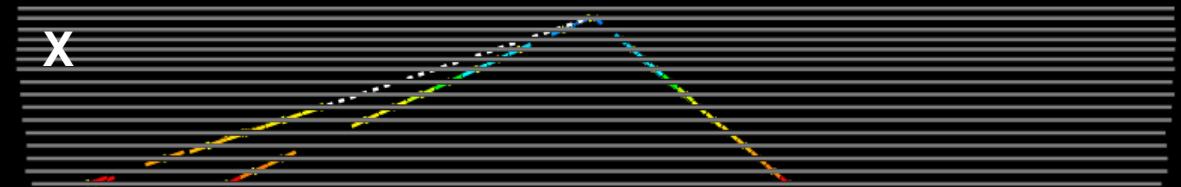


Pointing accuracy

$\Delta\theta_{\text{space}} : 0.65\text{deg} (0.0114\text{rad})$

$E_\gamma : 45+33-10 [\text{MeV}]$

$\theta_\gamma : 46.61 [\text{deg}]$





- **Optics Filter**

Schneider Optics B+W091

- **Camera Lens**

Nikon AF Nikkor 85mm F1.4D

- diameter: 60.7mm
- focal length: 85mm

- **CCD Camera**

HAMAMATSU C3077-79

(near-IR camera)

- pixels: 640×480

- **CPU board**

ADVANTECH PCM-3362

- CPU: Intel Atom N450 1.66GHz

- **Video Capture board**

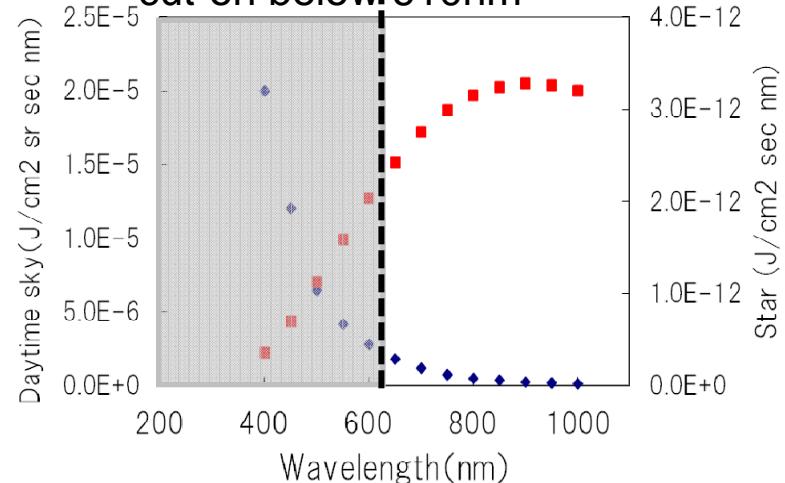
Sensory Frame Grabber Model 311

- ADC : 8bit
- Frame rate: 30FPS

- **SSD(128GB)**

TOSHIBA SSDN-ST128H

Optics filter
cut-on below 610nm



◆ : Daytime sky BG (Dietz et al., 2002)

■ : Star spectrum (M-type:3200K)

Field of View:

5.9deg(H) \times 4.5deg(V)

Limiting magnitude : 6

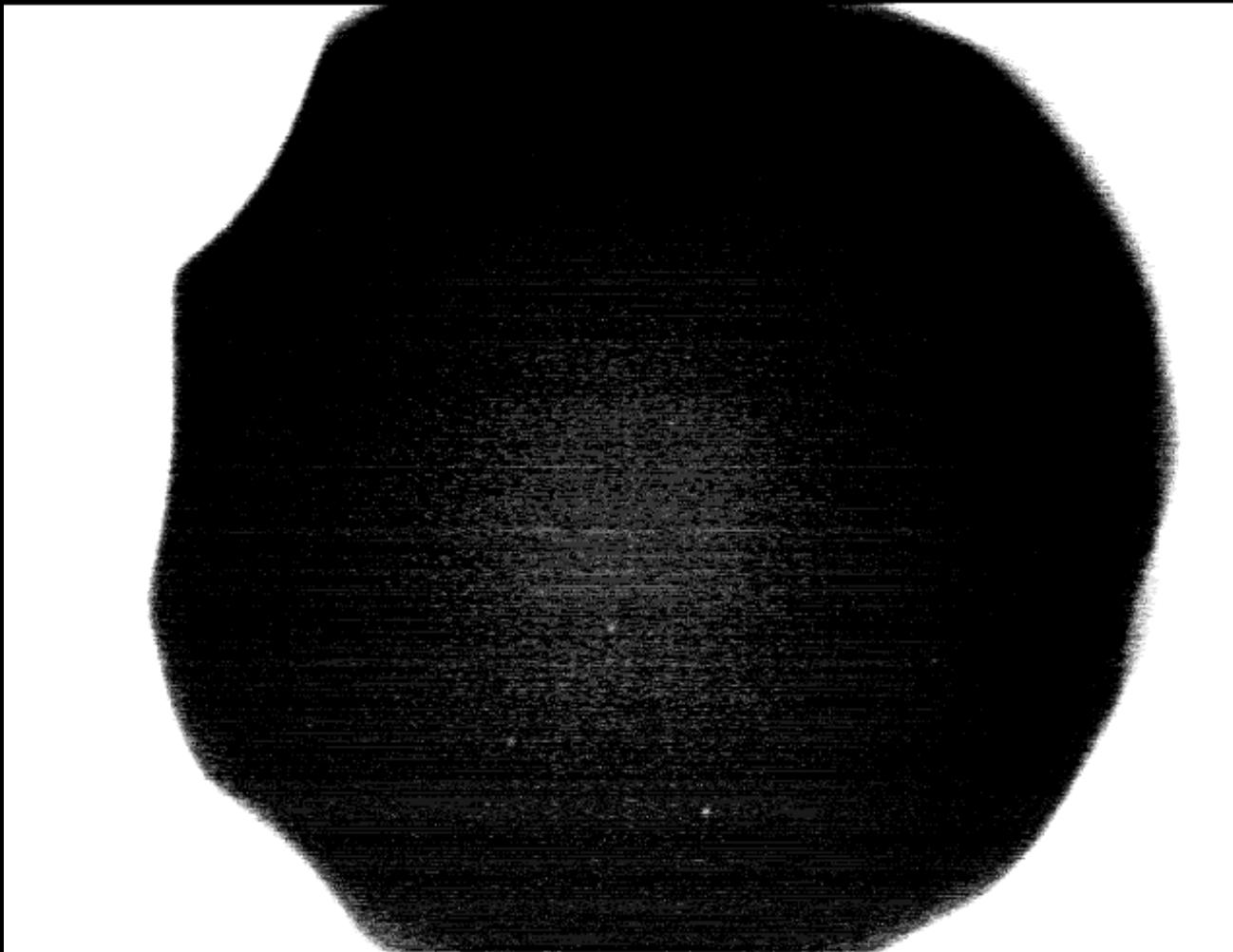
Monitoring accuracy : 0.16mrad



K.Ozaki, et al., Proc. of Balloon
Sympo., isas12-sbs-022 (in Japanese)

Image data on Level Flight

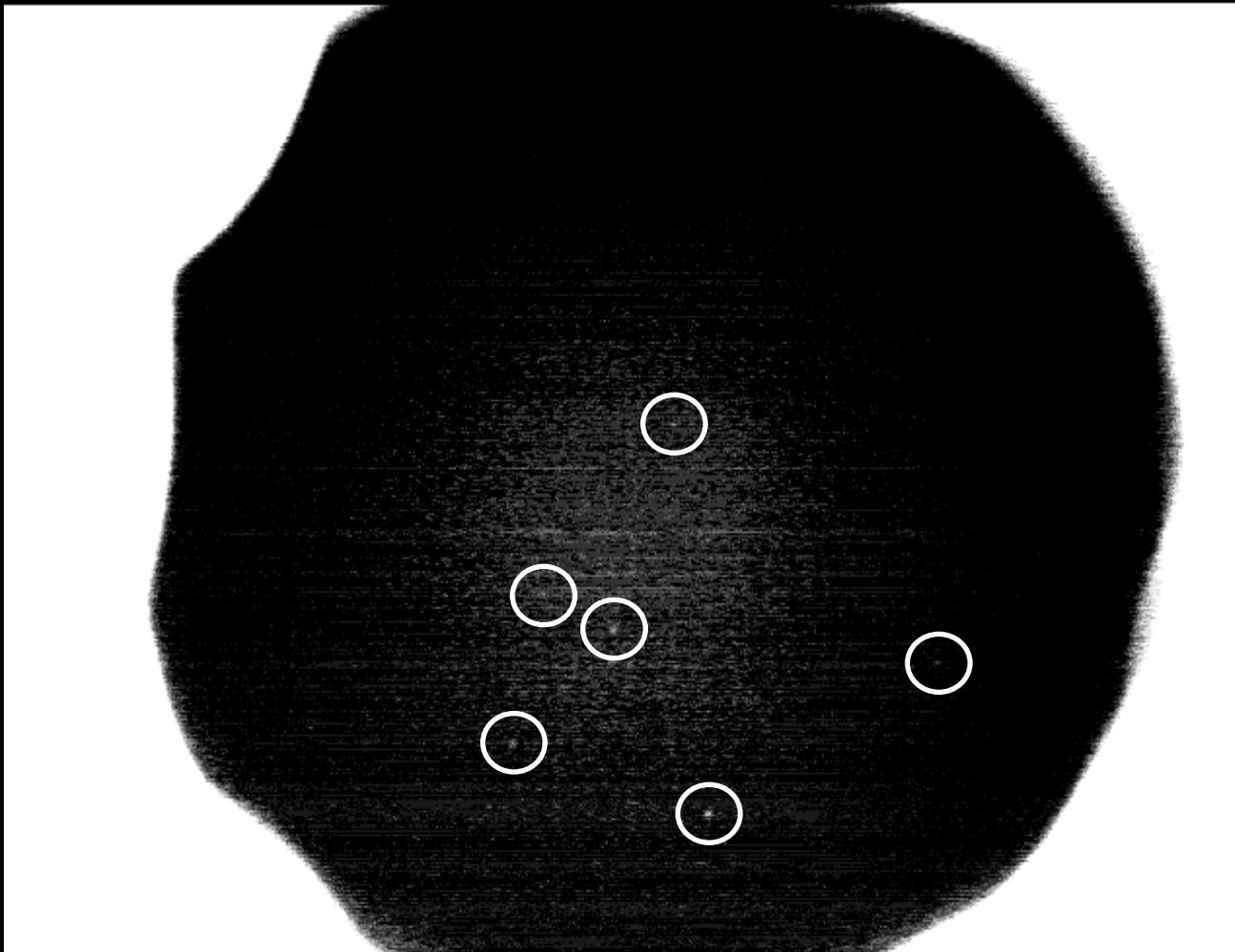
time: 8:11:00.16 (@Altitude 34.6km)



Because of stray light reflected on hood, outer region was saturated.

Image data on Level Flight

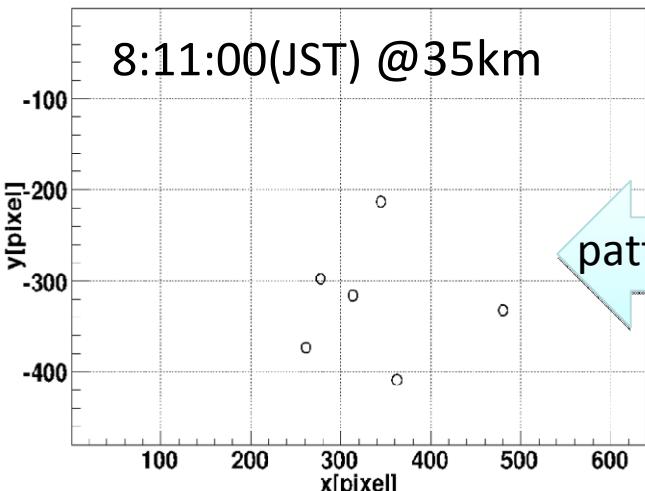
time: 8:11:00.16 (@Altitude 34.6km)



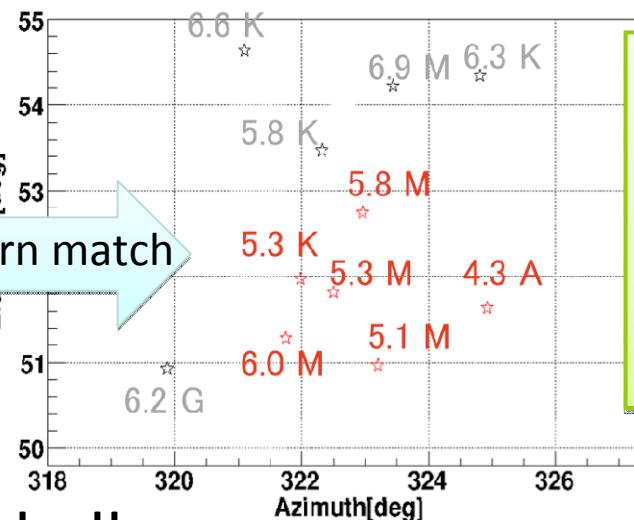
6 stars were detected.

Attitude analysis

Daytime star camera view



Star catalog data



K. Ozaki et al.,
Proc. of Balloon Sympo.,
isas12-sbs-022

Working rate: 74 %

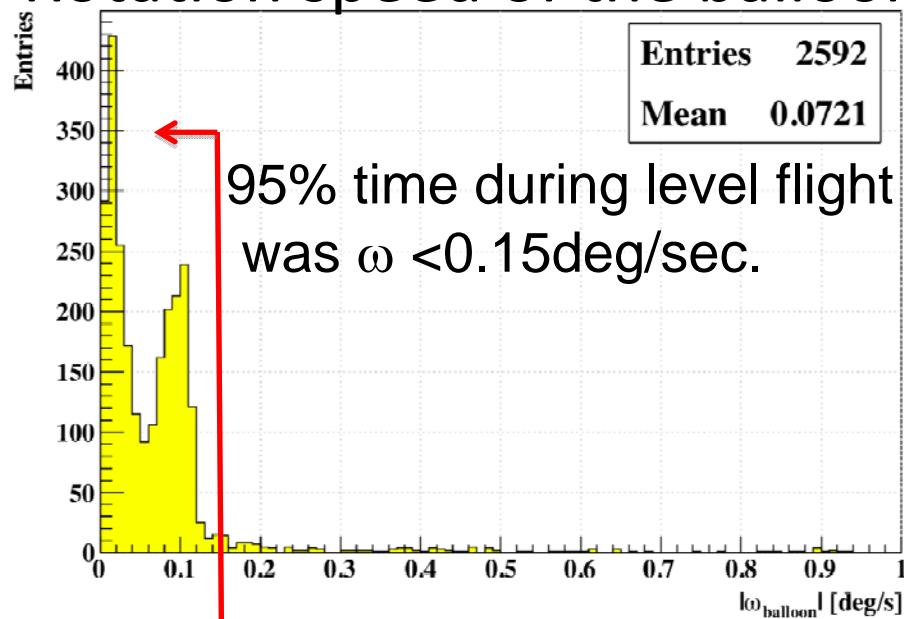
Monitoring

accuracy: < mrad

Elevation < 0.25mrad

Azimuth < 0.44mrad

Rotation speed of the balloon

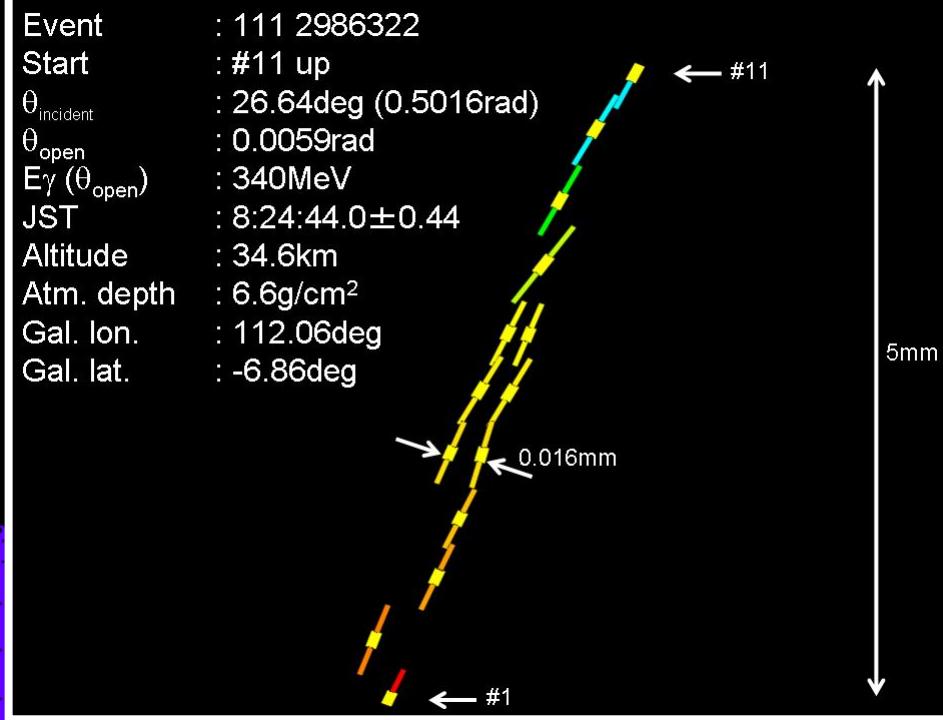
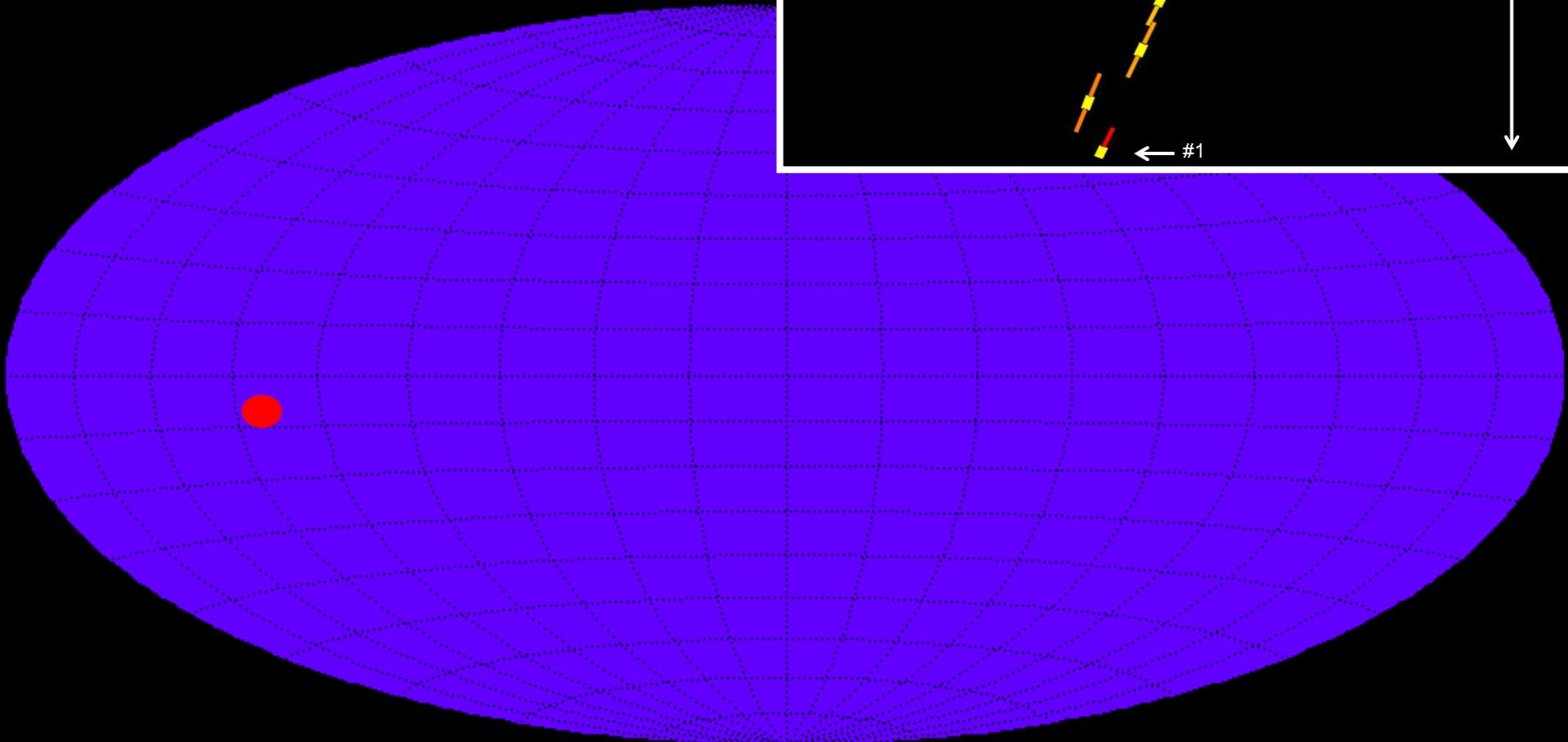


It is important to decide telescope attitude to celestial coordinate better than emulsion angular resolution(0.08deg).

We confirmed attitude decision accuracy was $<\omega \sigma_t$
 $< 0.02\text{deg}$.

GRAINE

First Light



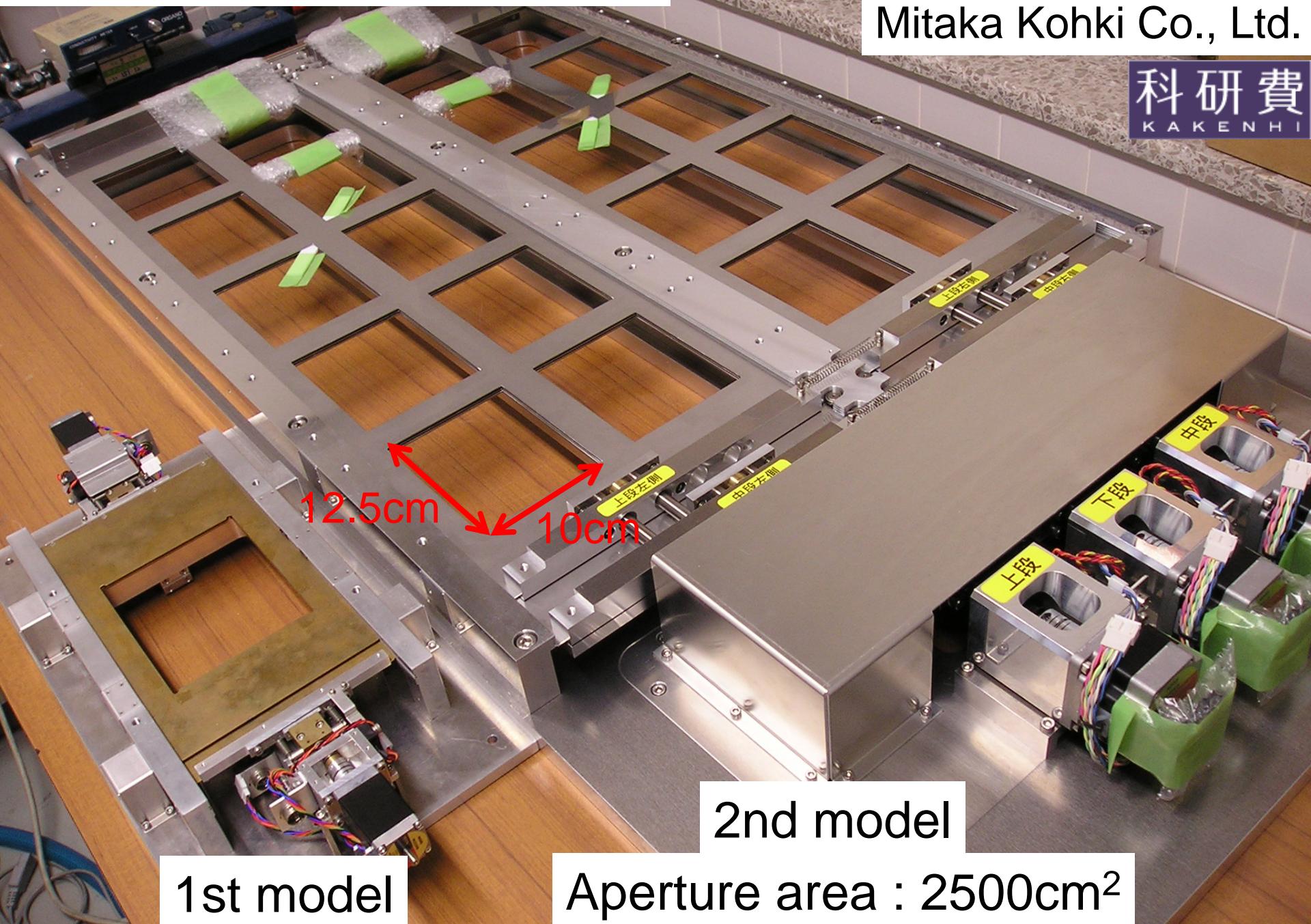
GRAINE roadmap

- 8th/June/2011, TARF, JAXA Scientific Ballooning,
12.5cm x 10cm aperture area, 4.3hours (1.6hours@35km) flight duration
 - Working test for each element
 - Connection test between elements
 - Measurement of atmospheric gamma-rays
- 2014(Planned), Alice Springs, JAXA International Scientific Ballooning
2500cm² aperture area, 1 day flight duration
 - Overall test by detecting known gamma-ray source
 - Observation with highest imaging resolution
- 2015-
10m² aperture area, 7days flight duration
 - Starting scientific observation

Flight model of multi-stage shifter

Co-developed with
Mitaka Kohki Co., Ltd.

科研費
KAKENHI



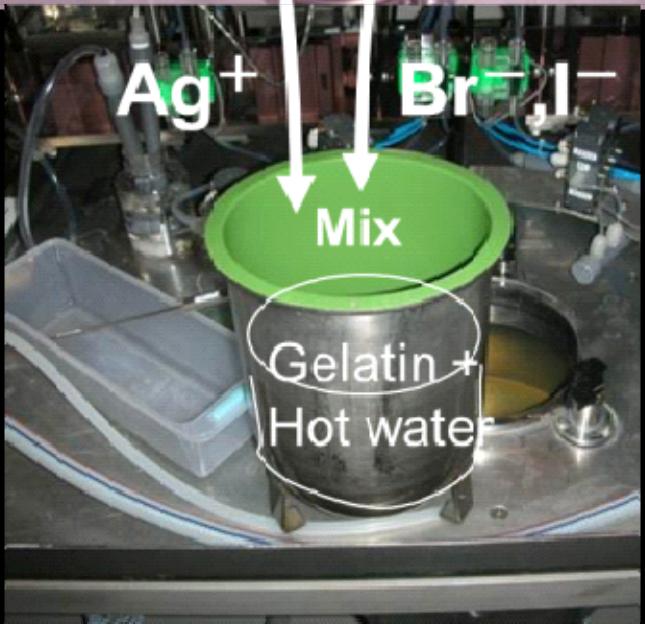
1st model

2nd model

Aperture area : 2500cm²

Emulsion production

Fuji Janet Co., Ltd., Nagoya Univ.



Gelatin1/4, Na type, Fe x 2, MIP (XAA, 20deg, 40min)

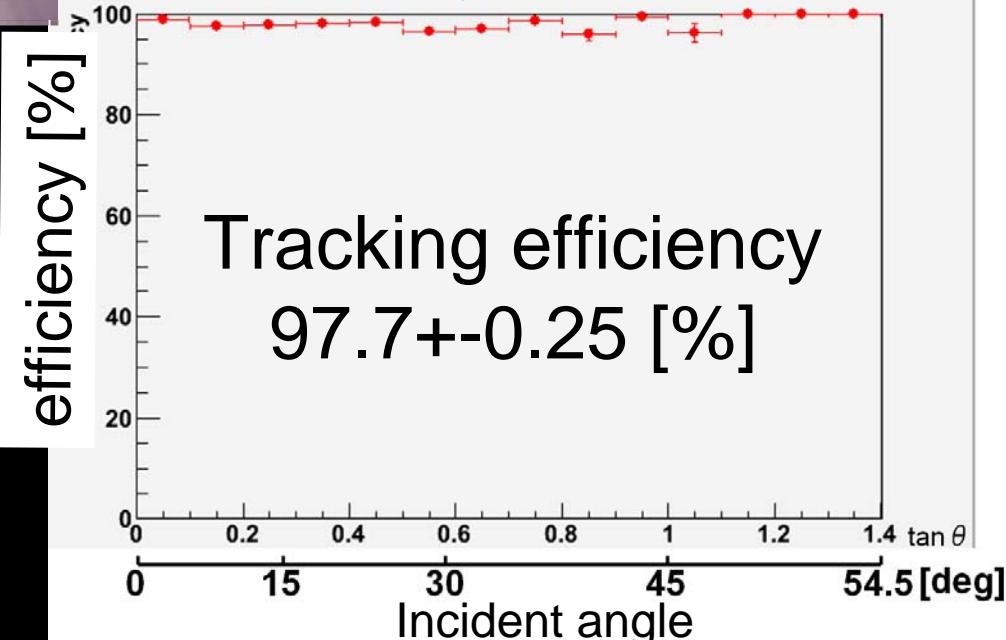
New type

GD=86.1+-4.7
FD=2.9+-0.9

OPERA type

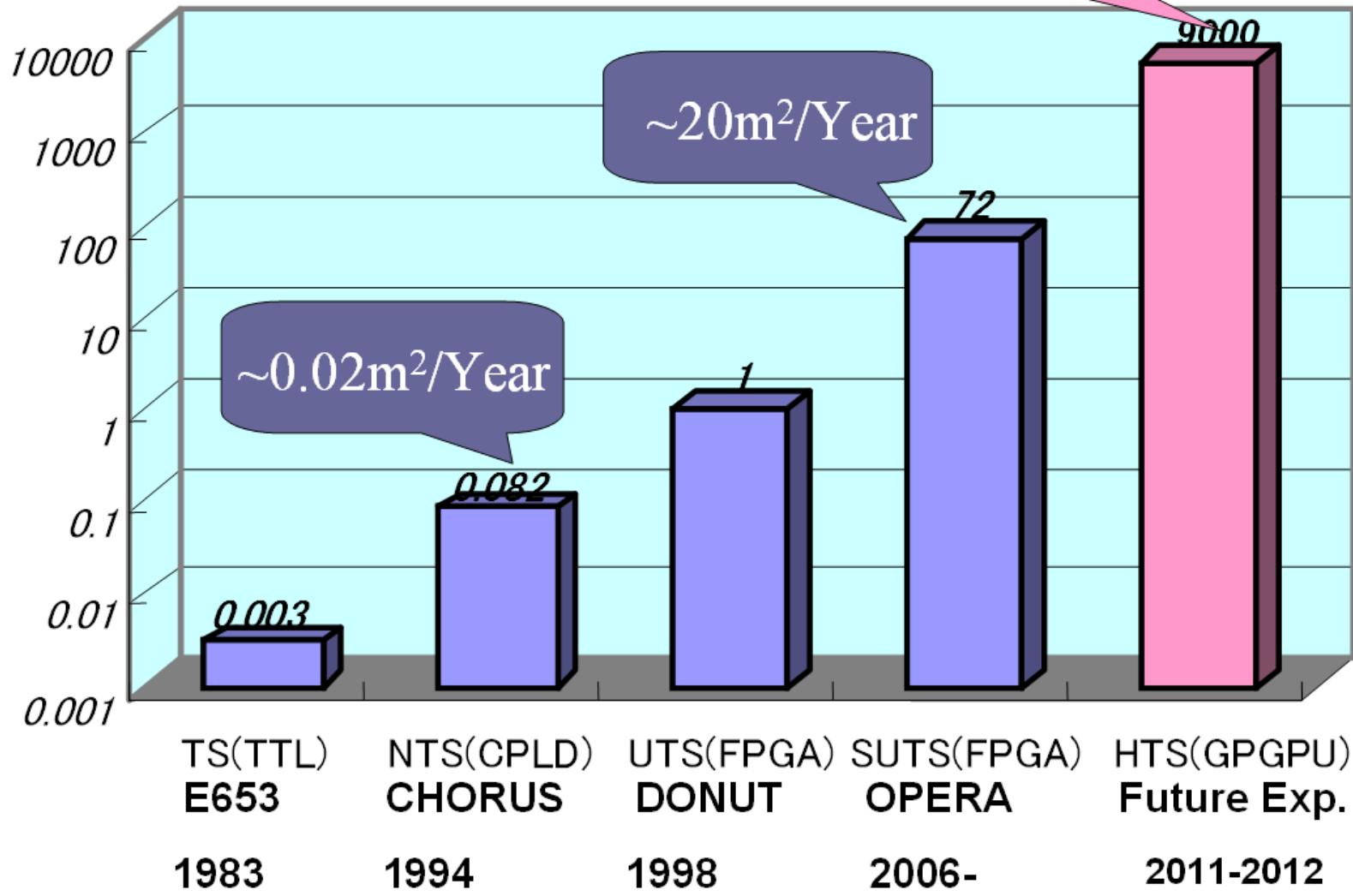
GD=34.8+-0.6
FD=3.7+-0.4

efficiency Evaluated by K. Kamada (Kobe Univ.)



Evolution of the Scanning Speed

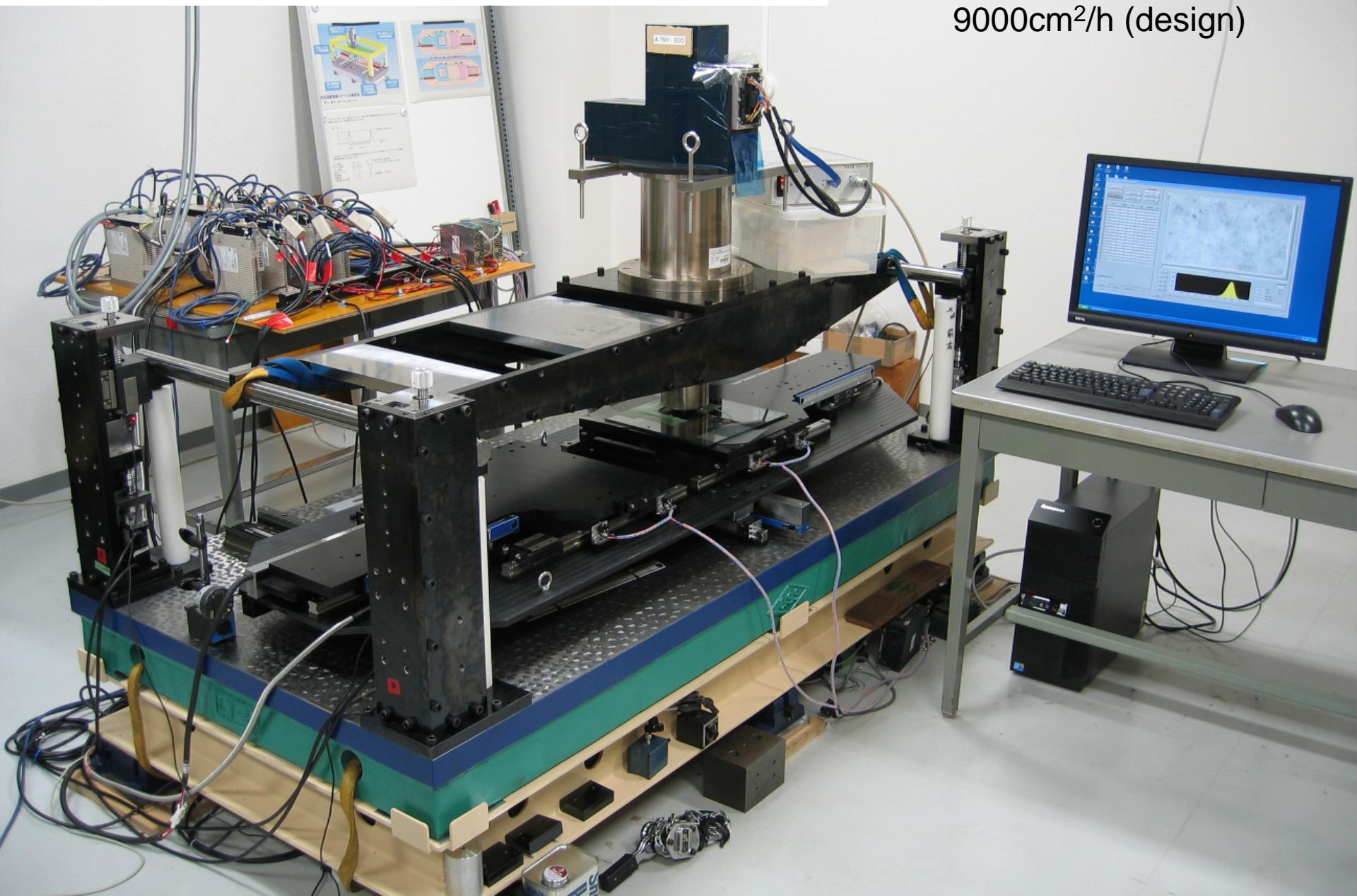
Speed in cm²/h



Automated emulsion read-out system (Nagoya Univ.)

Hyper-TS: Next Generation Read-out system

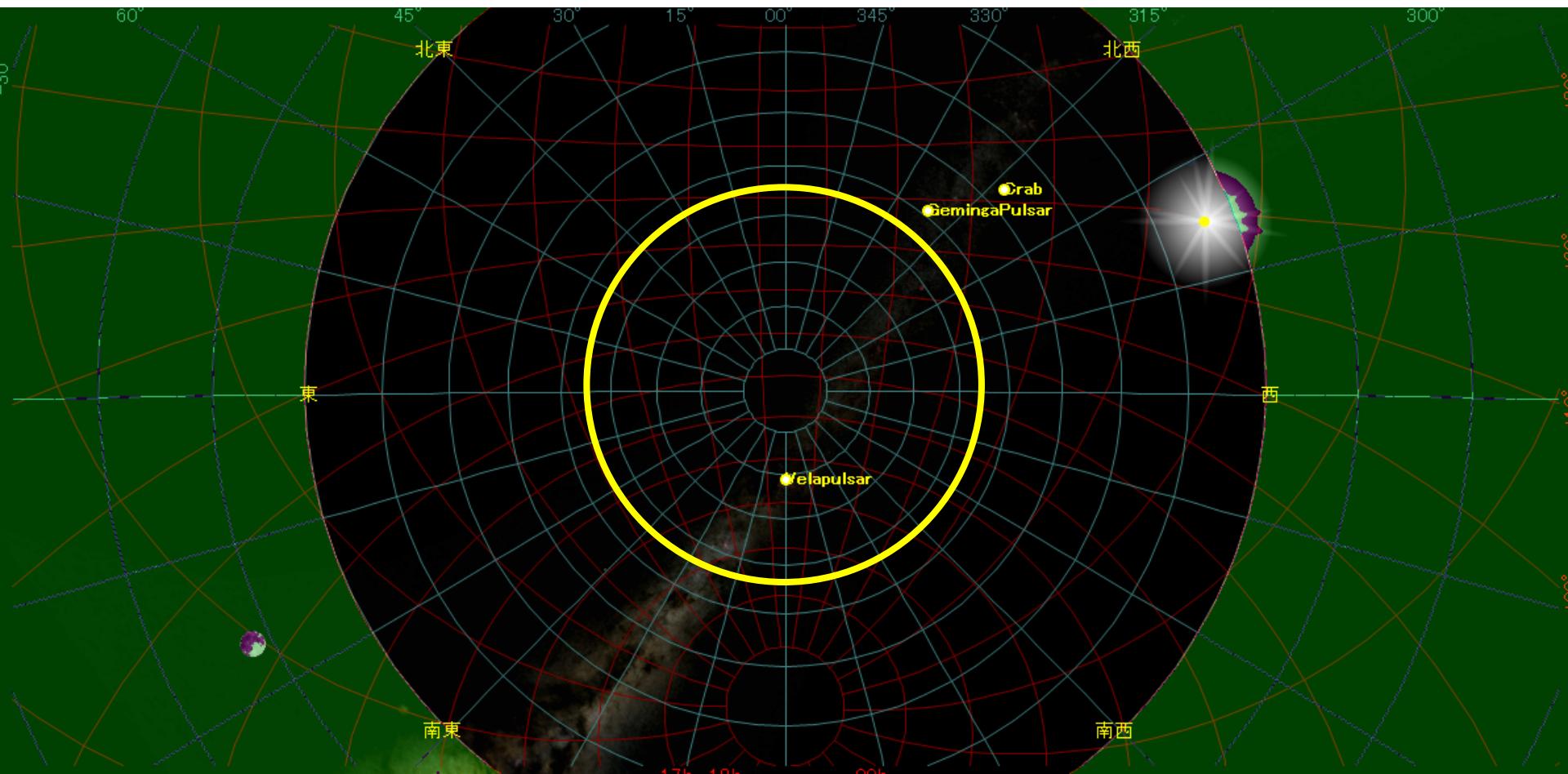
Scanning speed
9000cm²/h (design)





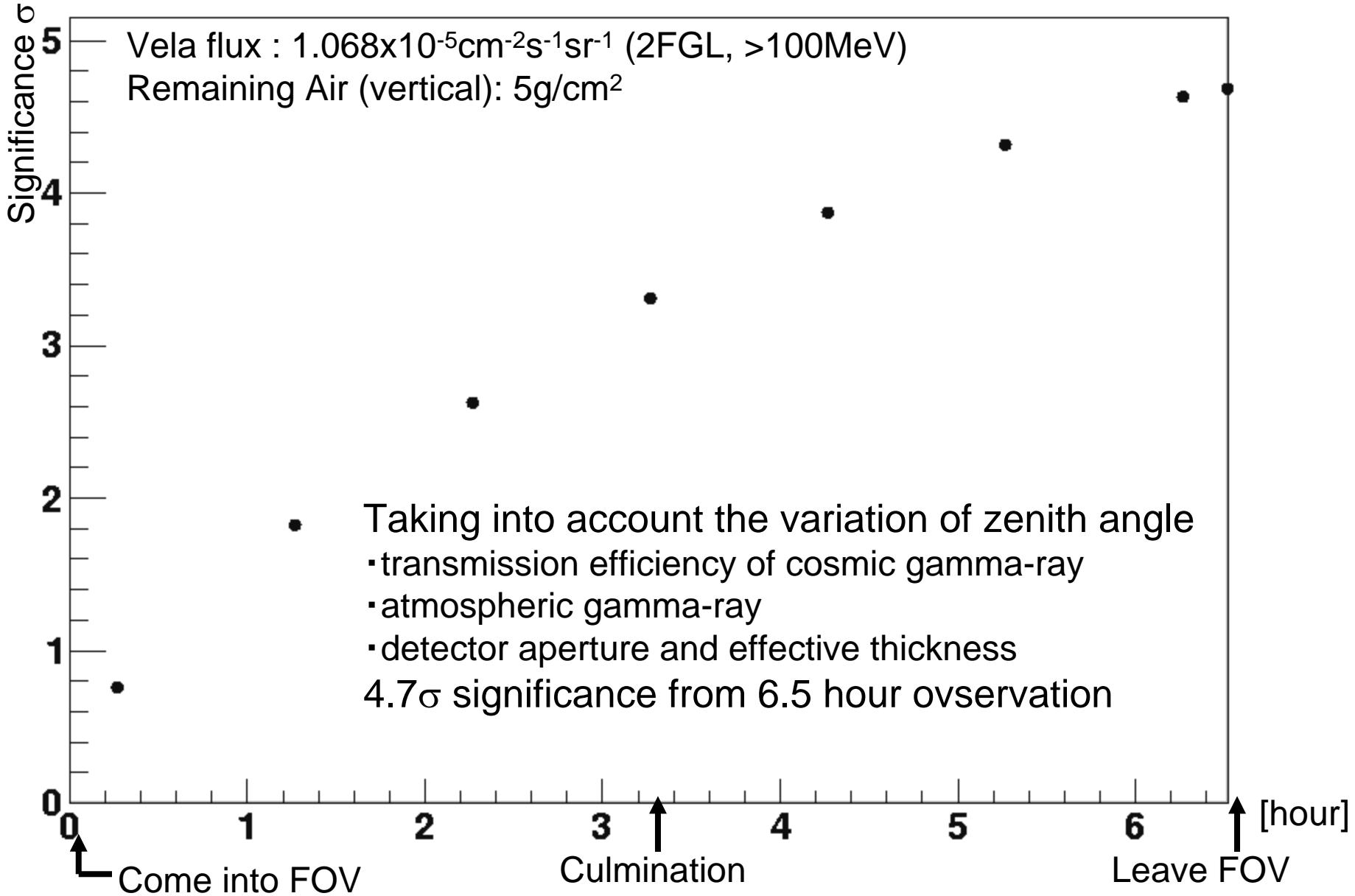
Flight duration ~1day

Vela

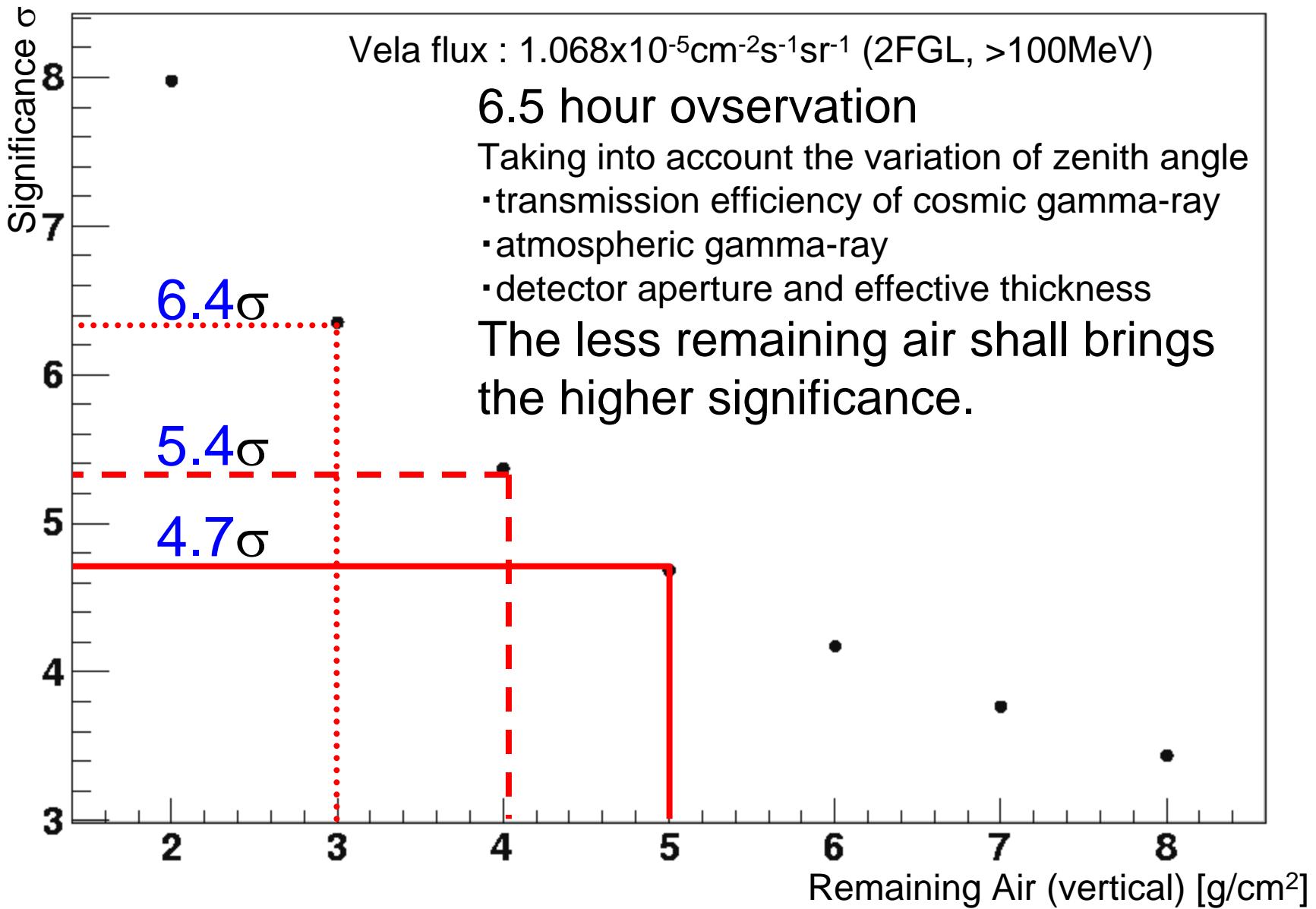


Alice Springs 2014/May/15, Culmination 17:09(NT), In FOV 6.5hours (13:53-20:24)
Lat.: $-23^{\circ} 40'$
Lon.: $133^{\circ} 50' E$

Significance vs. Exposure Time



Significance vs. Remaining Air Thickness

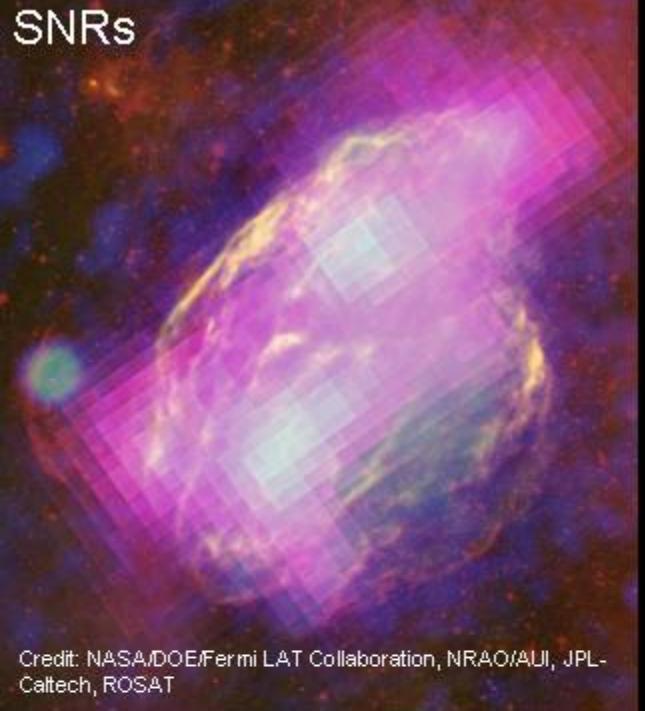


2013

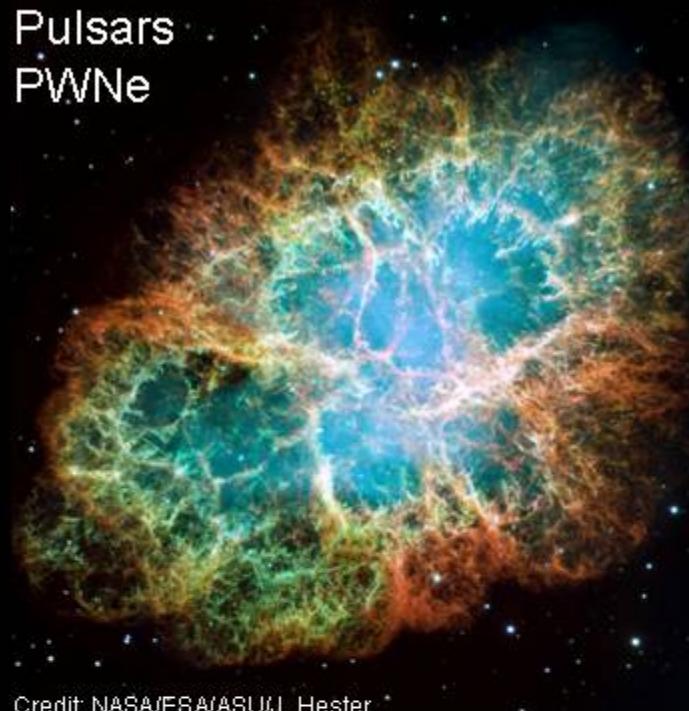
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Emulsion film : Established 2nd flight model									Film production		
Multi-stage shifter : Low T&P test, Assembling, Flight ready											
Star camera : Design, Test, Assembling, Flight ready											
2014											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Stacking & Assembling										

- -Sep/2013, emulsion film for 2nd flight model will be established.
- -Sep/2013, multi-stage shifter will be ready for the the flight.
- -Sep/2013, star camera will be ready for the flight.
- Oct/2013-Jan/2014, emulsion film production
- Feb-Apr/2014, stacking and assembling
- May/2014, 2nd flight model will be ready for the flight.

SNRs



Pulsars PWNe



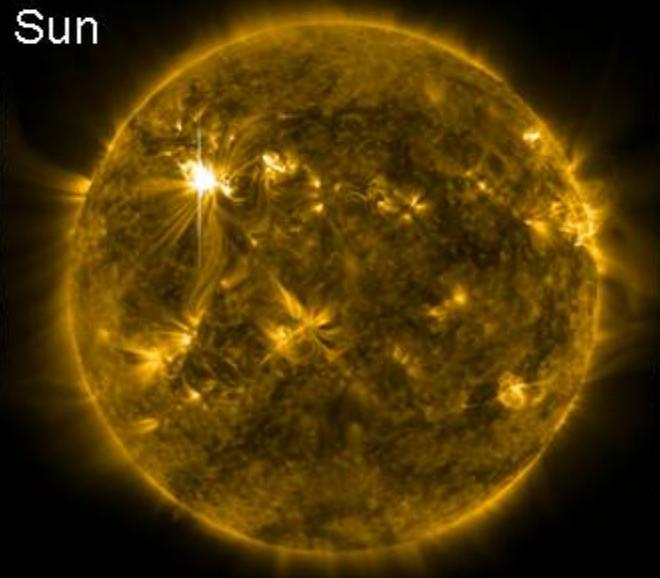
AGNs



GRBs



Sun



Dwarf Galaxies



SNRs

Pulsars

AGNs

PWNs

Subject

- Galactic cosmic-rays origin, acceleration and propagation
- Galactic high energy objects
 - Pulsar, PWN, SNR, Magnetar, X-ray binary, Globular cluster
- Extragalactic cosmic-rays origin, acceleration and propagation
- Extragalactic high energy objects
 - AGN, GRB, cluster of galaxy, starburst galaxy
- Cosmological research by using gamma-rays from AGNs and GRBs
- Search for gamma-rays from annihilation/decay of dark matter from galactic center and dwarf galaxy

Credit: NASA/DOE/Fermi LAT Collaboration, NRAO/AUI/JPL, Caltech, ROSTAT

Credit: NASA/DOE/Fermi LAT Collaboration, Capella Observatory, and Ilana Fearn, Tim Cornwell, and Ron Bess (CSIRO/ATNF), R. Morganti (ASTRON), and N. Junkes (MPFR)

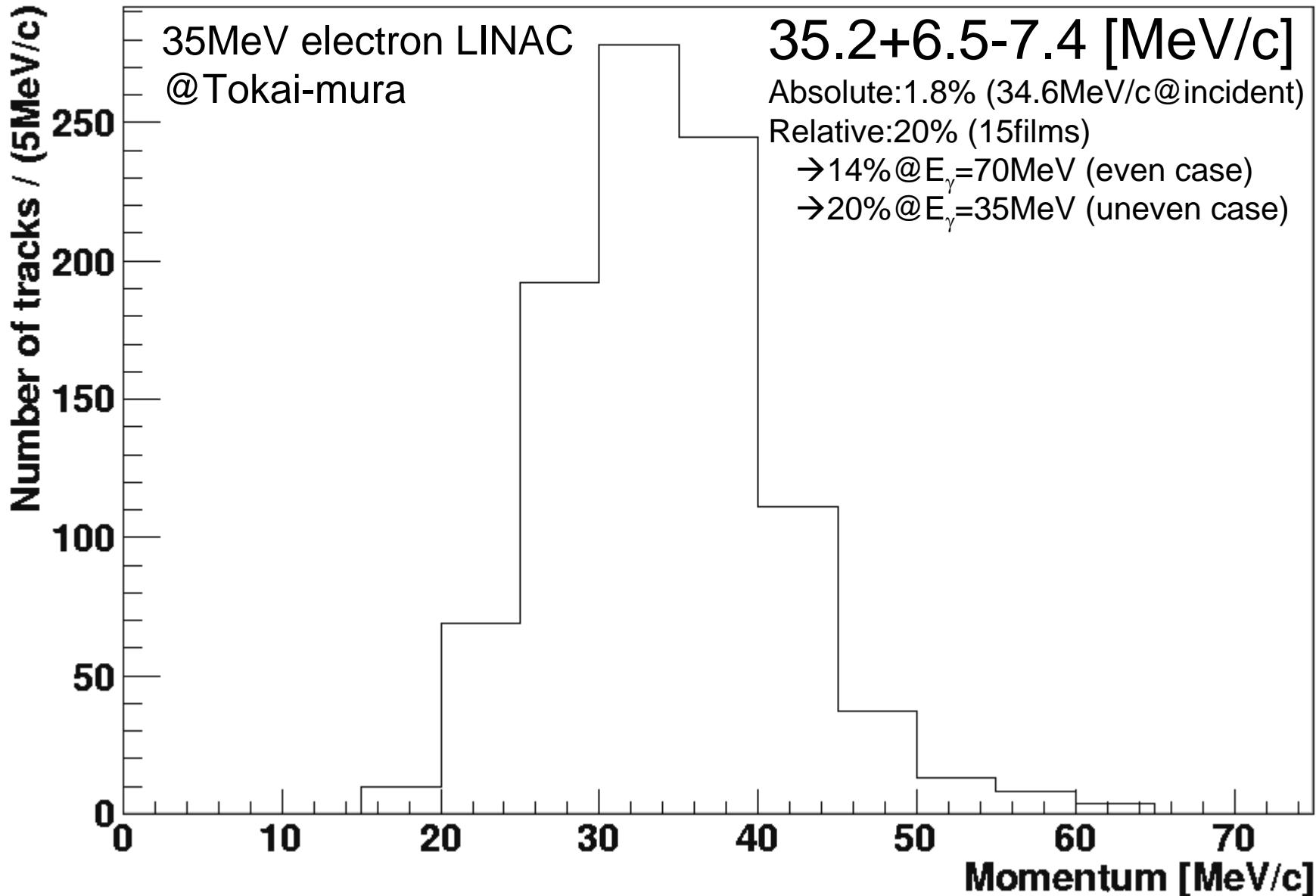
Credit: NASA/Sonoma State University/Aurore Simonnet

Summary and Outlook

- Promoting GRAINE project
- Performed balloon experiment in 2011
- Demonstrated emulsion gamma-ray telescope with flight data
- Measured atmospheric gamma-ray
- Preparing for planned balloon experiment at Alice Springs in 2014

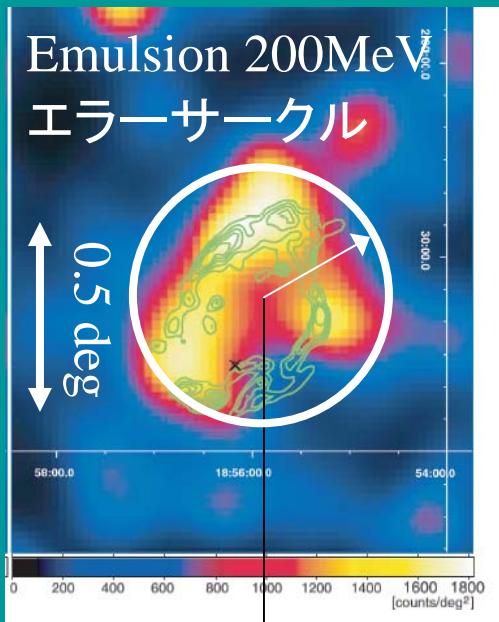
backup

Momentum measurement with multiple coulomb scattering for gamma-ray energy reconstruction

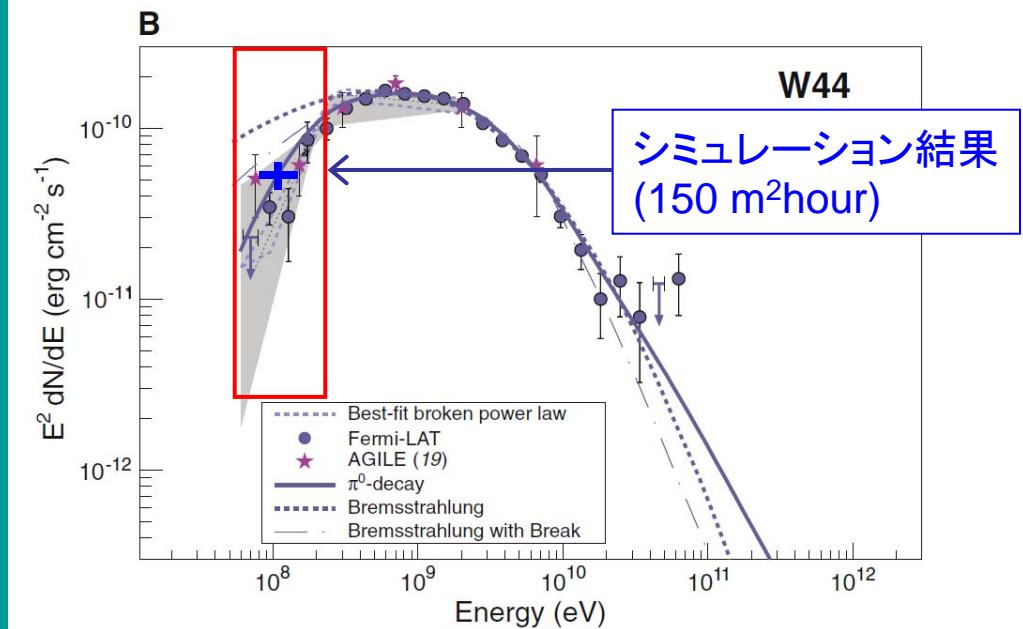


SNR W44

放射起源に迫る上で200MeV以下が重要



Fermi 200MeV
エラーサークル



M. Ackermann *et al.*
Science **339**, 807 (2013);
DOI: 10.1126/science.1231160