

GRAINE計画：

気球搭載型大口径エマルジョン望遠鏡による
10MeV-100GeVガンマ線の高解像度・偏光観測

高橋 覚 (神戸大)

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), Ryoussuke 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), Emi Shibayama(1), Takuya Shiraishi(3), Atsumu Suzuki(1), Kazuya Suzuki(3), Satoru Takahashi(1), Keisuke Tamura(2), Syuichi Tawa(1), Ikuo Tezuka(6), Junya Yoshida(3), Tetsuya Yoshida(2) and Masahiro Yoshimoto(2)

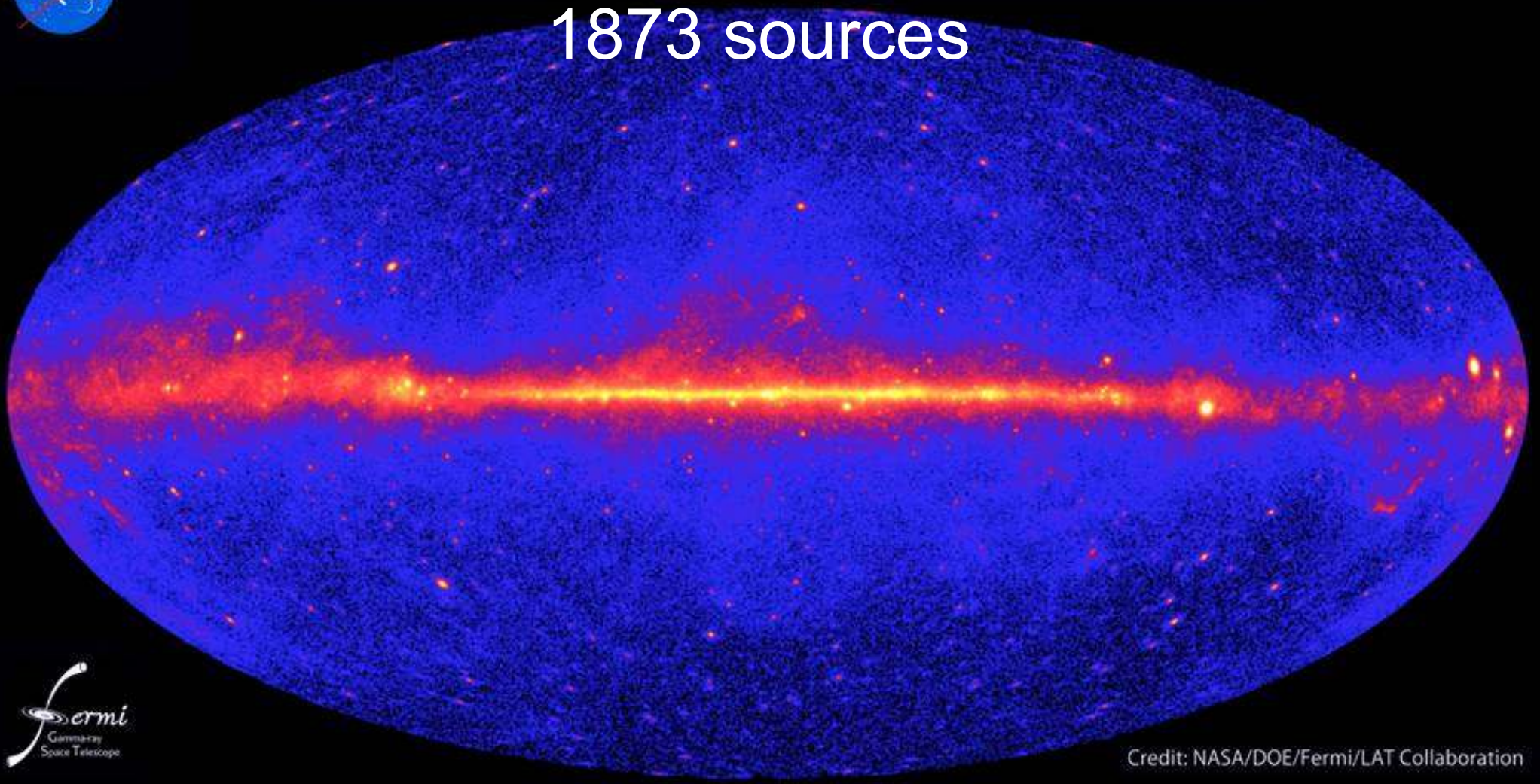
(1)Kobe University, (2)ISAS/JAXA, (3)Nagoya University, (4)Okayama University of science,
(5)Aichi University of education, (6)Utsunomiya University

PI : 青木 茂樹 (神戸大)



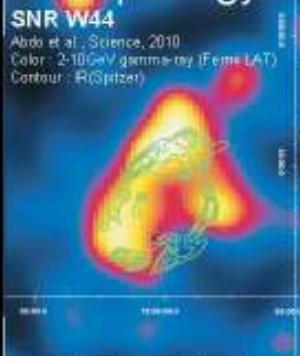
Fermi two-year all-sky map ($E_\gamma > 1\text{GeV}$)

1873 sources

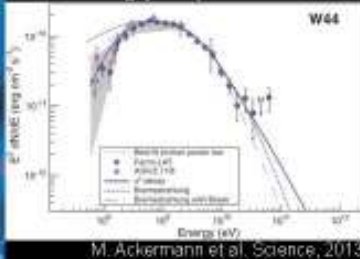


Credit: NASA/DOE/Fermi/LAT Collaboration

Morphology



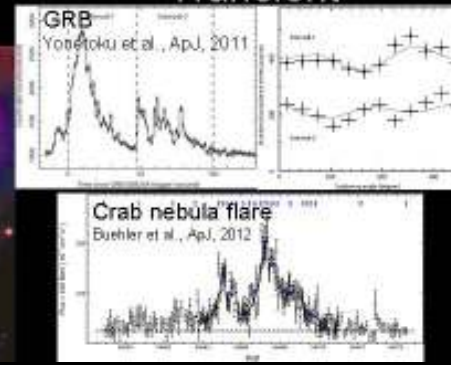
Energy spectrum



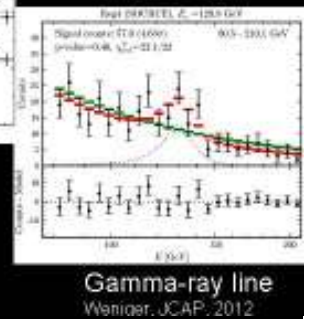
Polarization



Transient

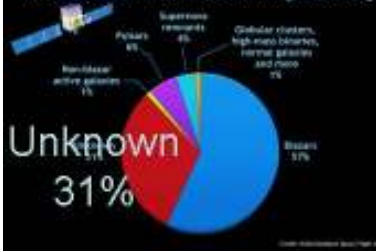


Dark matter



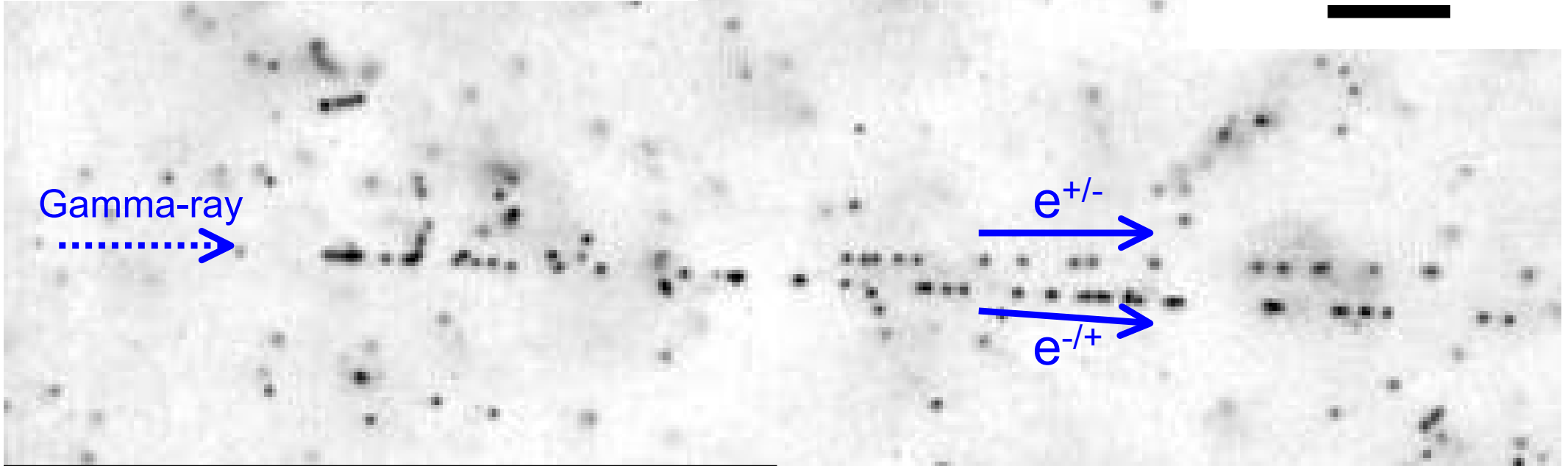
Un-ID

What has Fermi found: The LAT two-year catalog

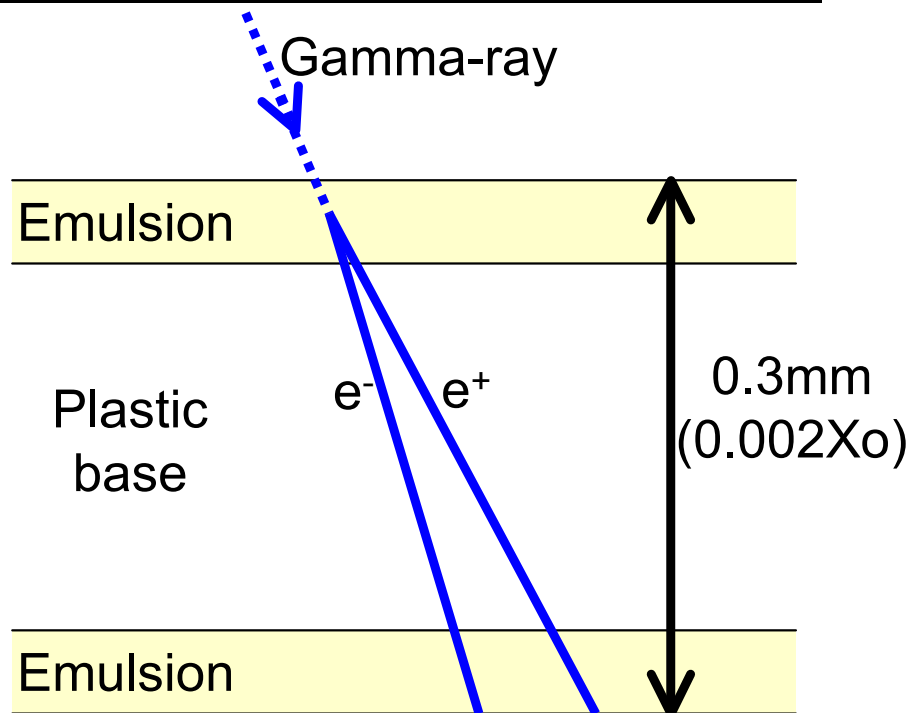


Nuclear emulsion

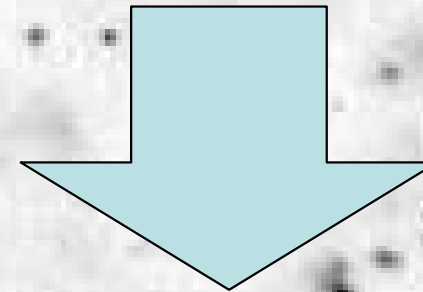
Microscopic view
10micron



Cross sectional view of an emulsion film



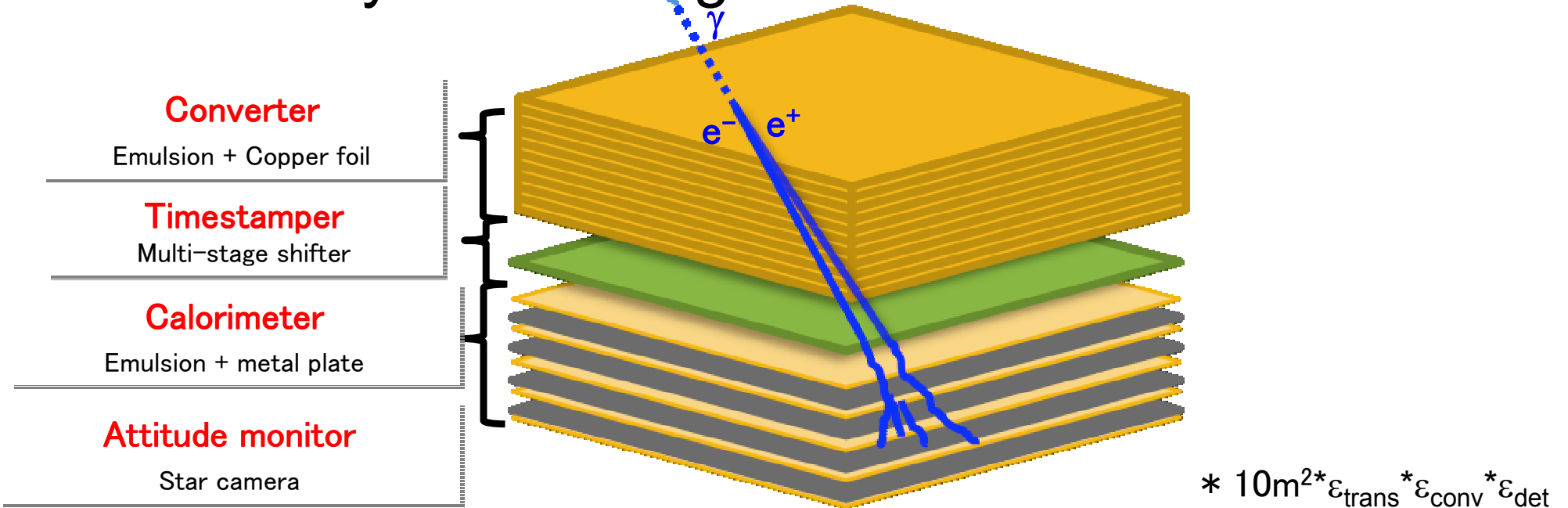
Powerful tracking device
>High spatial resolution : $\sim 1\text{micron}$
>Small radiation length : $0.002X_0$



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

GRAINE

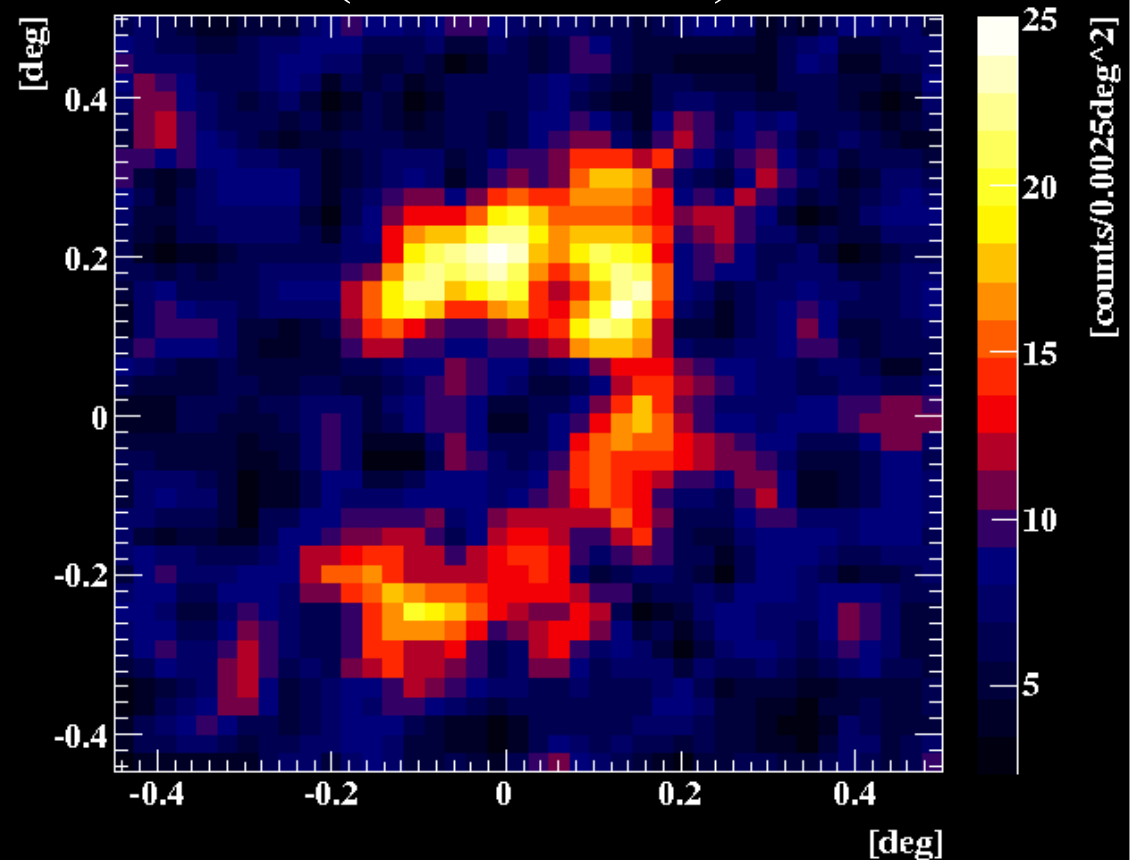
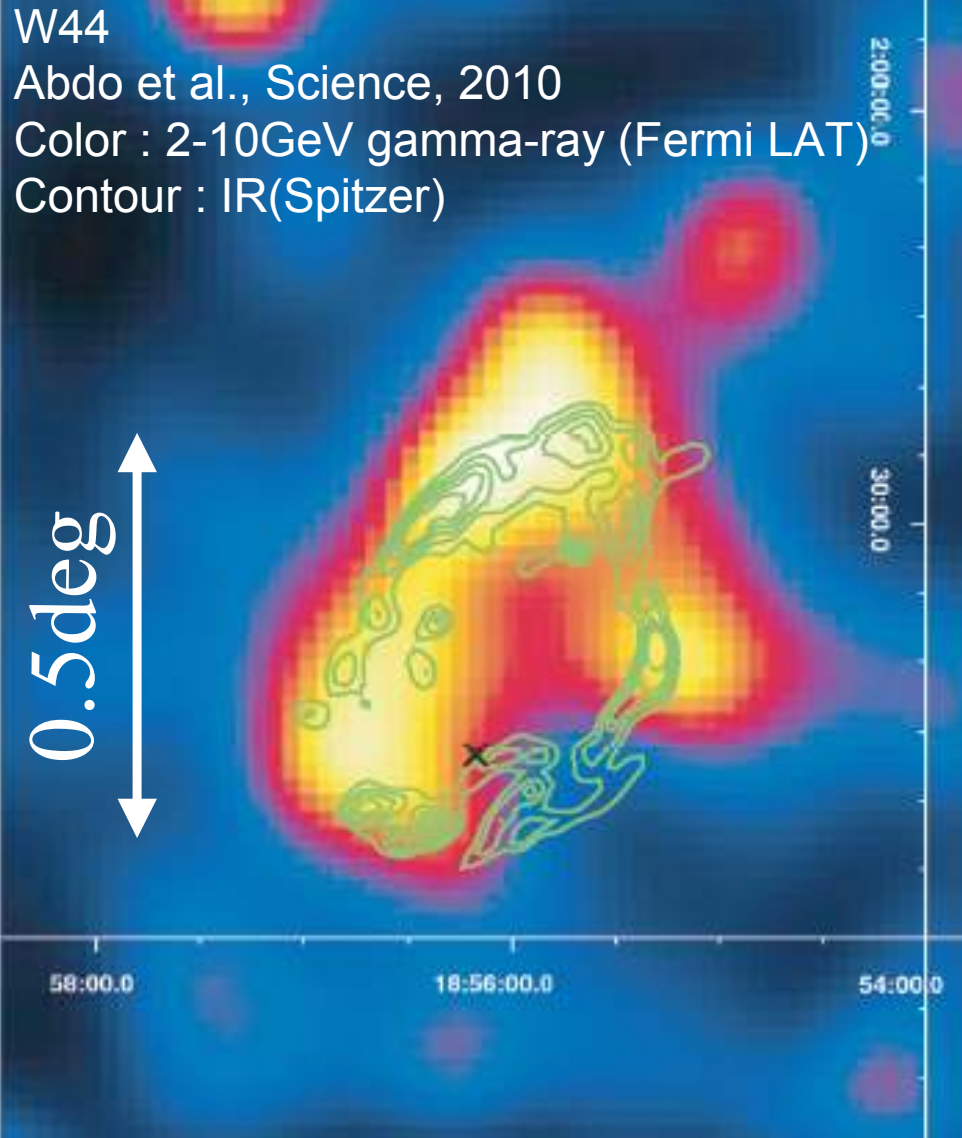
Gamma-Ray Astro-Imager with Nuclear Emulsion



	Fermi LAT	GRAINE
Angular resolution @100MeV	6.0deg (105mrad)	1.0deg (17mrad)
@1GeV	0.90deg (16mrad)	0.1deg (1.7mrad)
Energy range	20MeV – 300GeV	10MeV – 100GeV
Polarization sensitivity	No	Yes
Effective area @ 100MeV	0.25m ²	2.1m ² *
@ 1GeV	0.88m ²	2.8m ² *
Dead time	26.5 μ sec _(readout time)	Dead time free

High resolution imaging

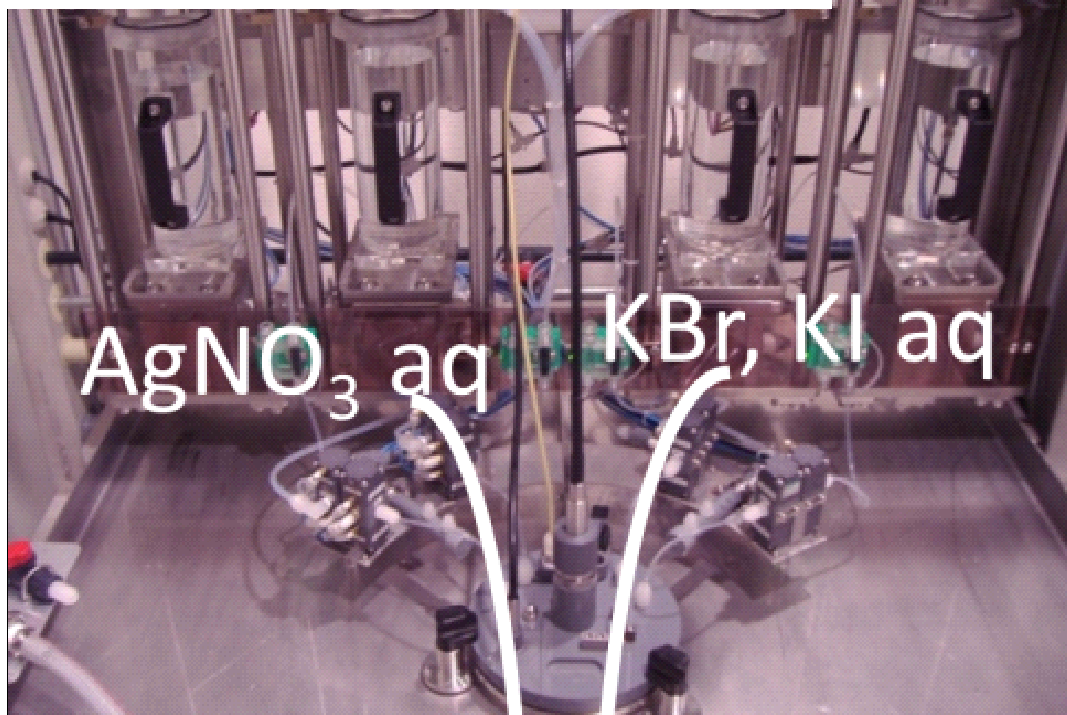
GRAINE (Simulation)



- **3 flights** (41.7m²days)
- >1GeV
- Smearing IR(Spitzer) distribution
with 0.08deg(1.4mrad)
- Considering atmospheric gamma-ray(>1GeV) as BG

Emulsion production

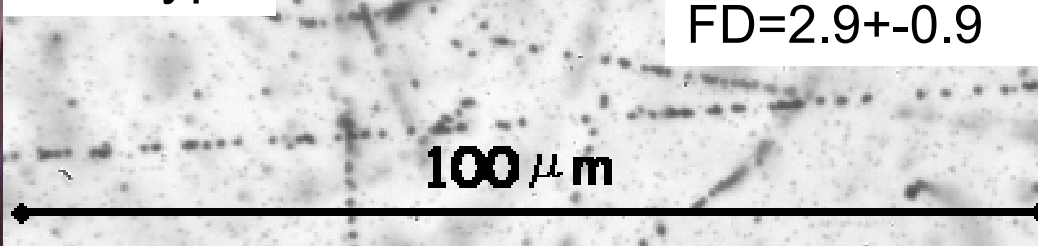
Fuji Janet Co., Ltd., Nagoya Univ.



Gelatin 1/4, Na type, Fe x 2, MIP (XAA, 20deg, 40min)

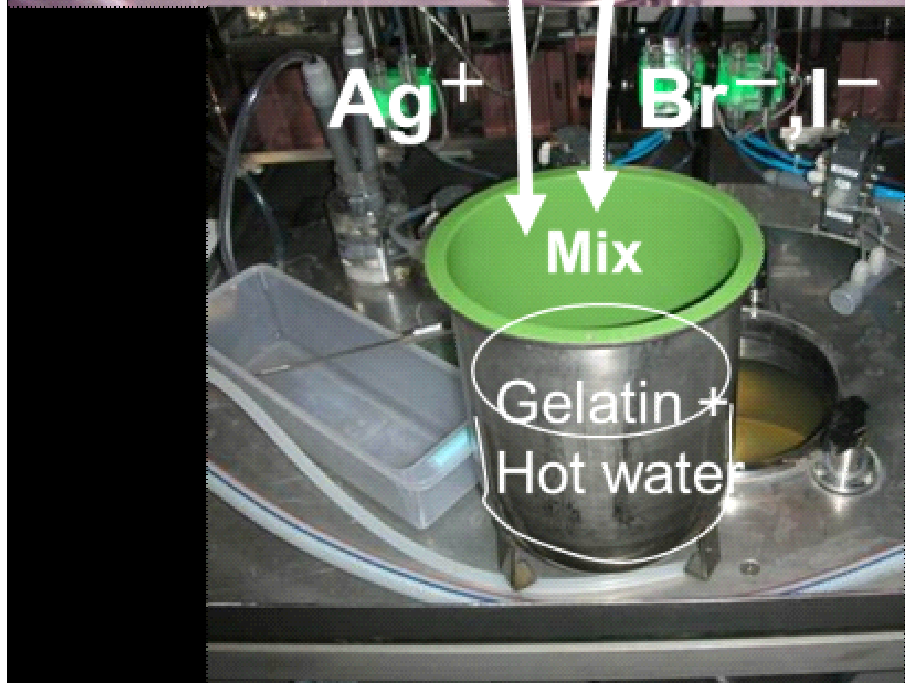
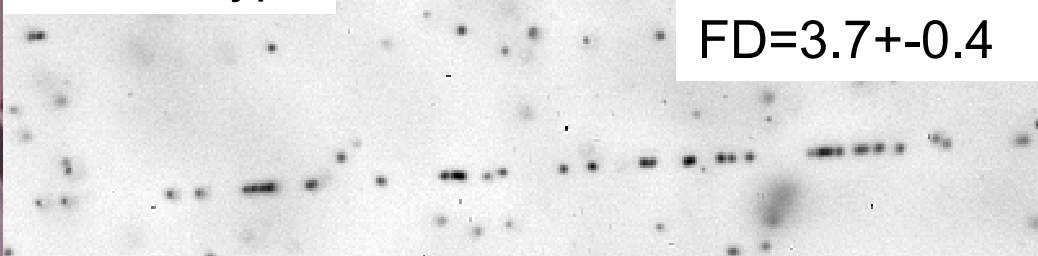
New type

GD=86.1±4.7
FD=2.9±0.9

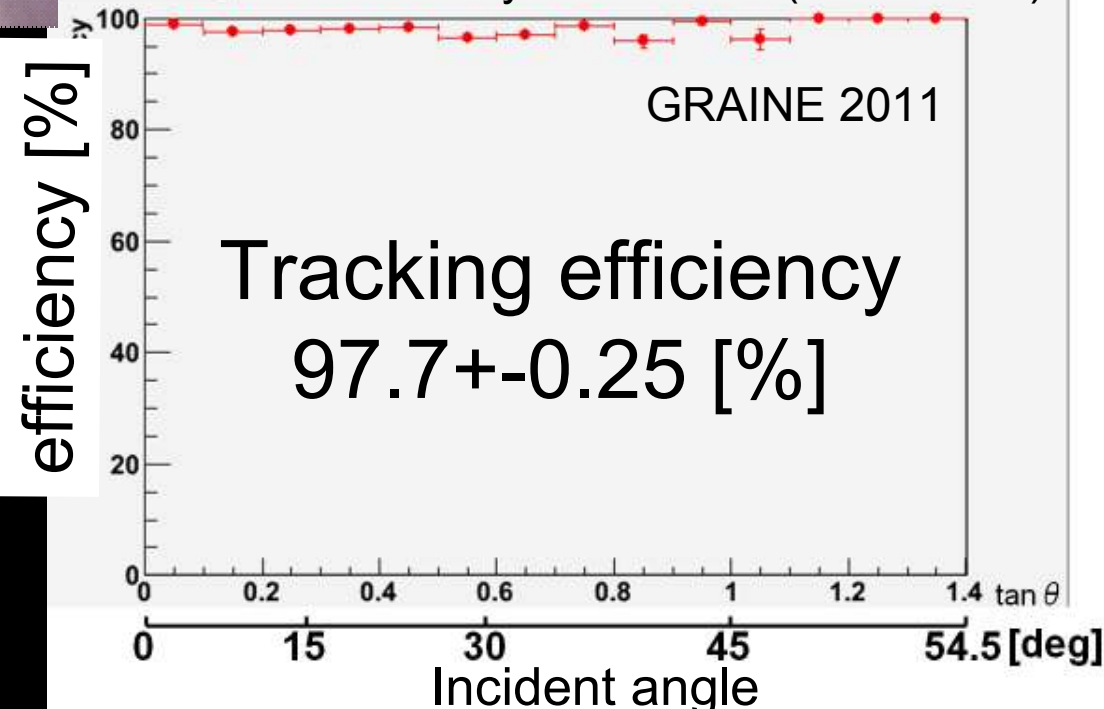


OPERA type

GD=34.8±0.6
FD=3.7±0.4



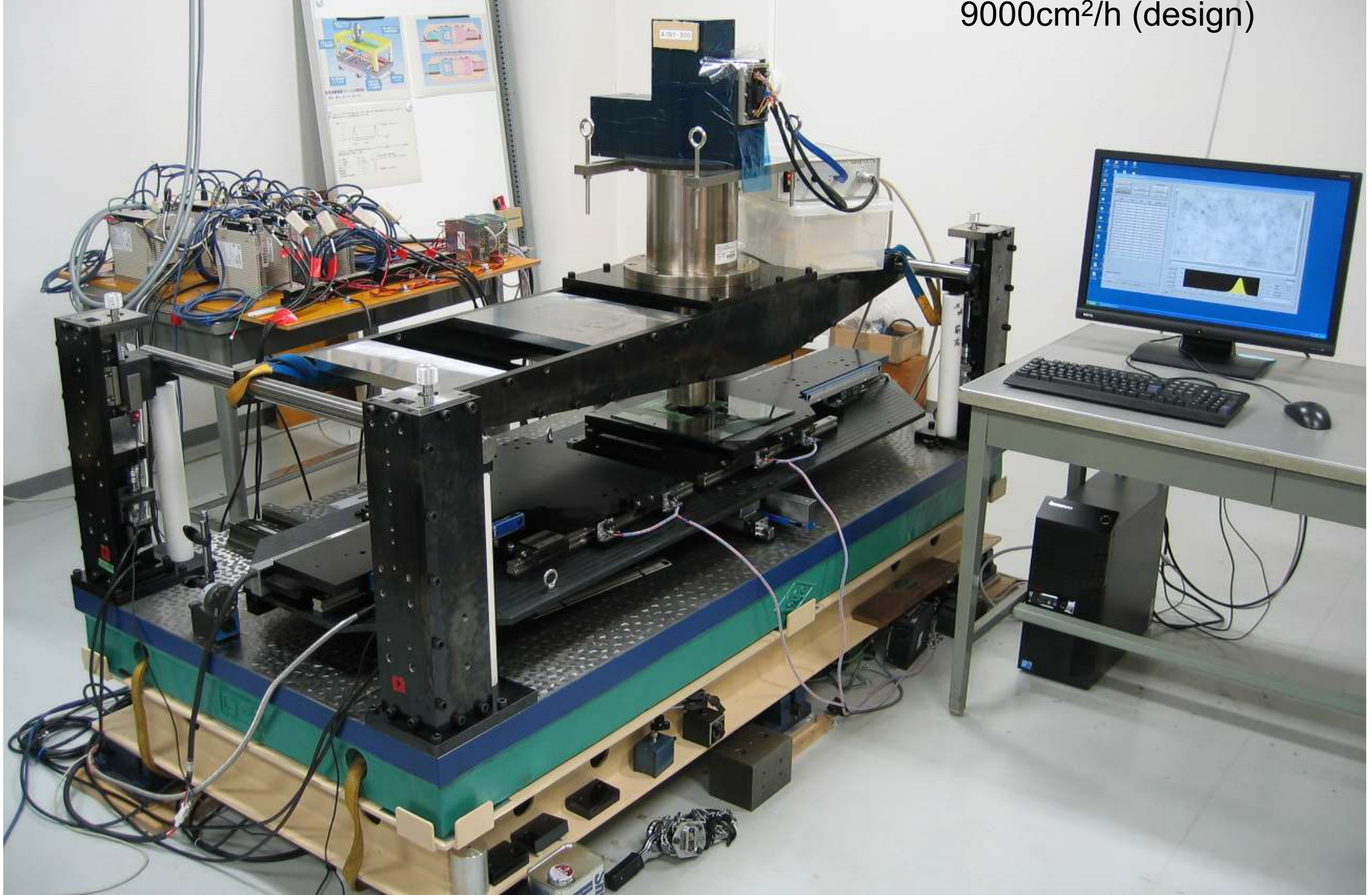
efficiency Evaluated by K. Kamada (Kobe Univ.)



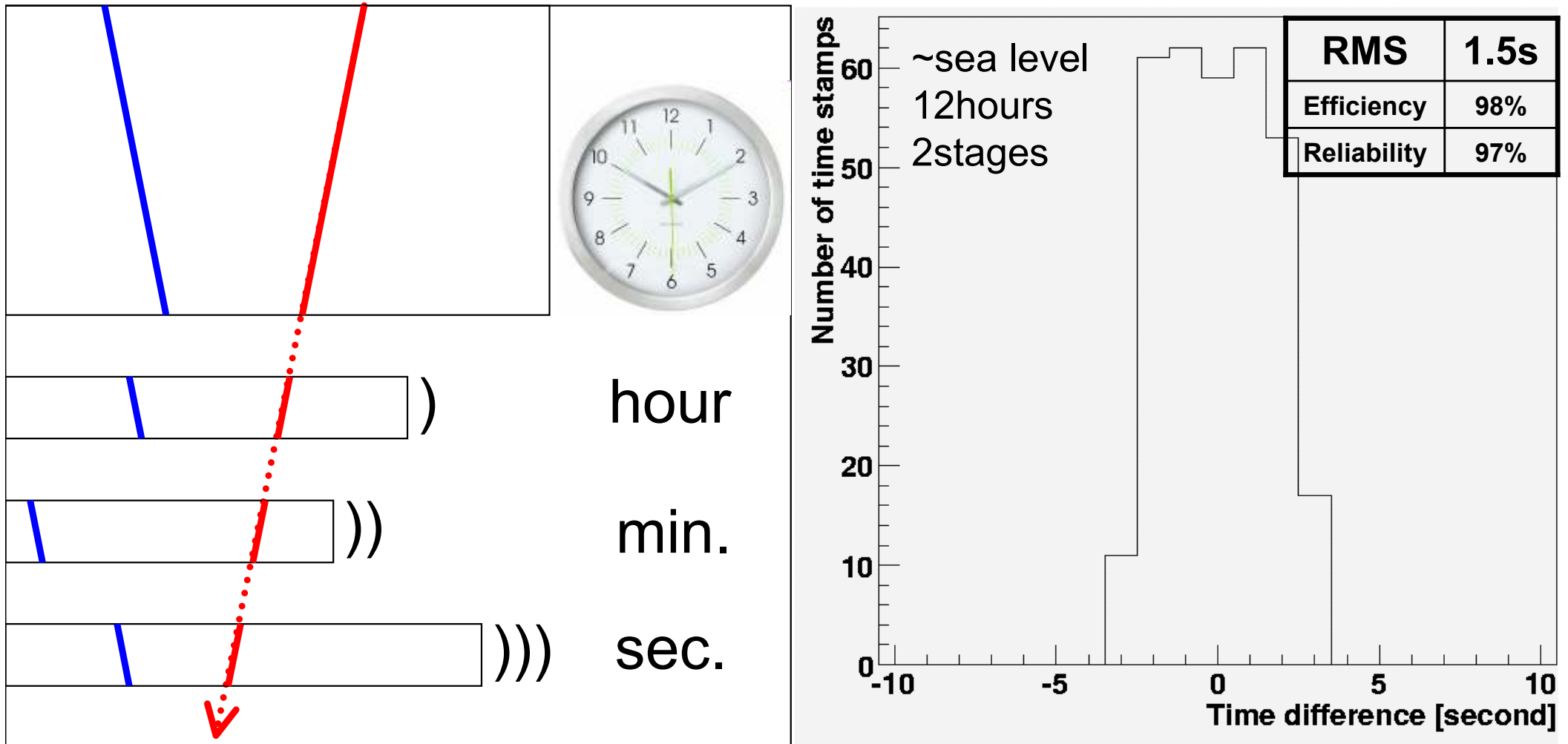
Automated emulsion read-out system (Nagoya Univ.)

Hyper-TS: Next Generation Read-out system

Scanning speed
9000cm²/h (design)



Multi-stage shifter



S.Takahashi et al., Nucl. Instr. And Meth. A, 620 (2010) 192-195

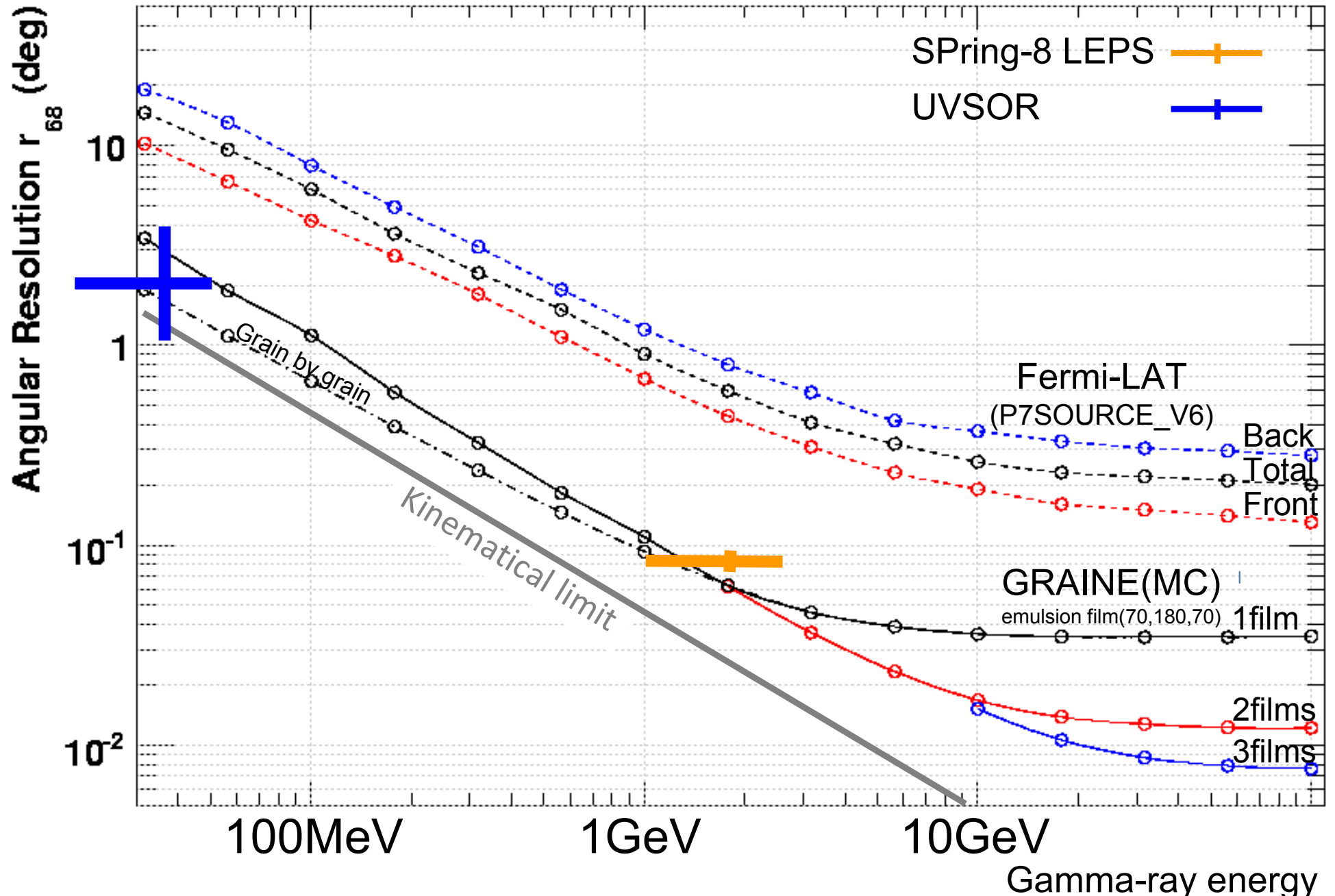
Consists of emulsion films with Small R.L., High pos & ang resolution

→ Low P threshold, High reliability, High efficiency, Large scale

Simple component, Compact, Light, HV free, Low power consumption, Dead time free

Angular resolution

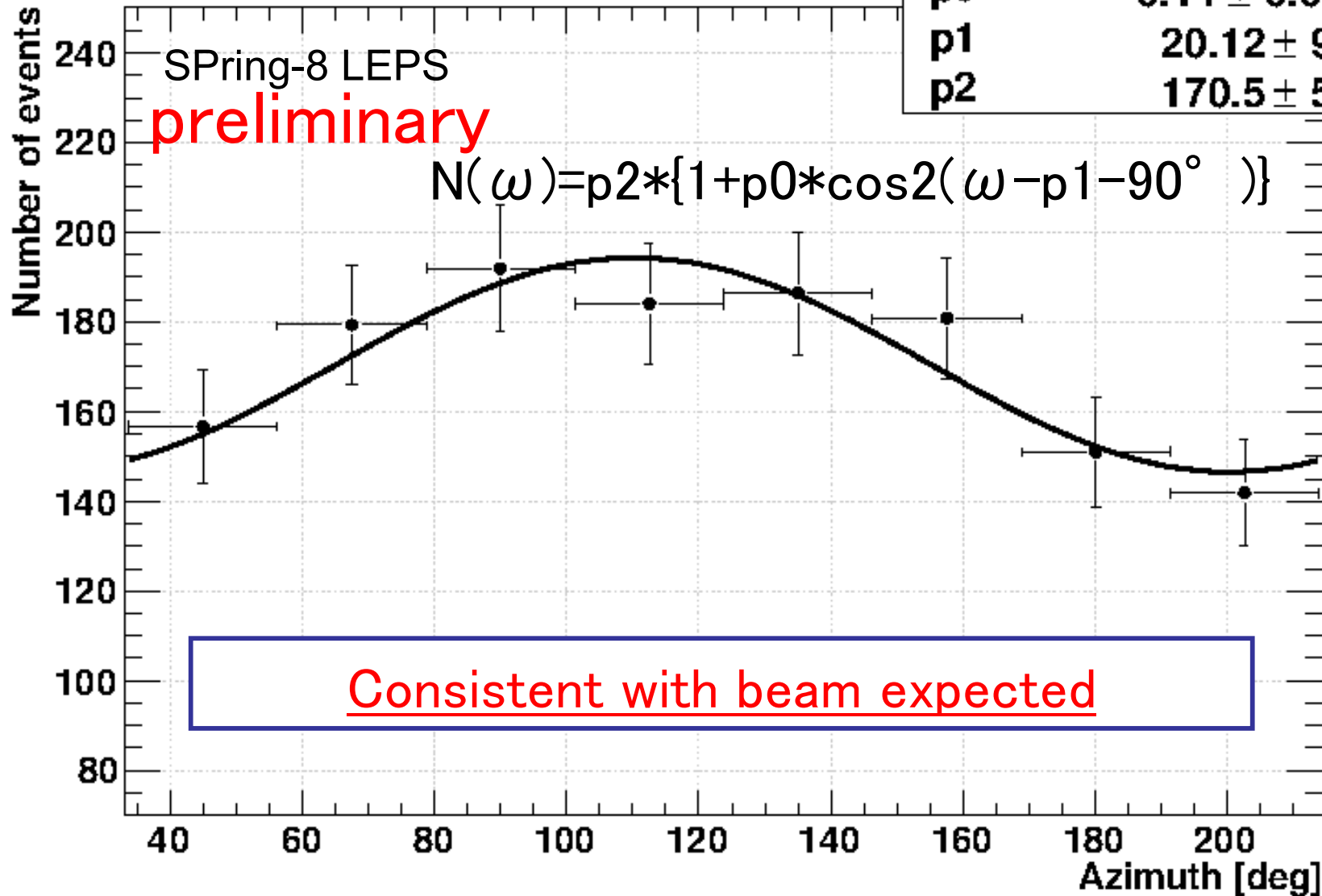
PSF at normal incidence



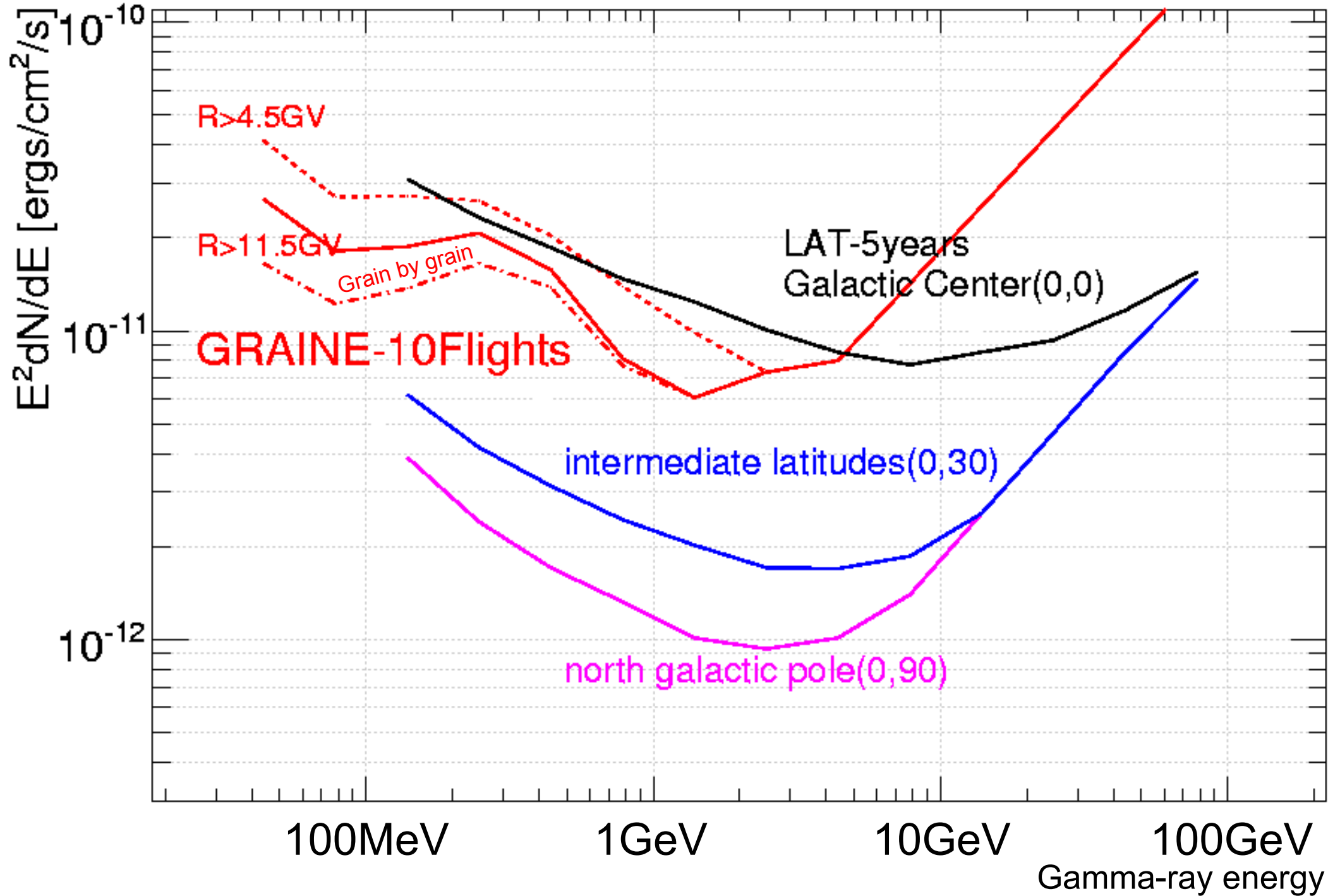
Polarization sensitivity

Azimuthal Distribution

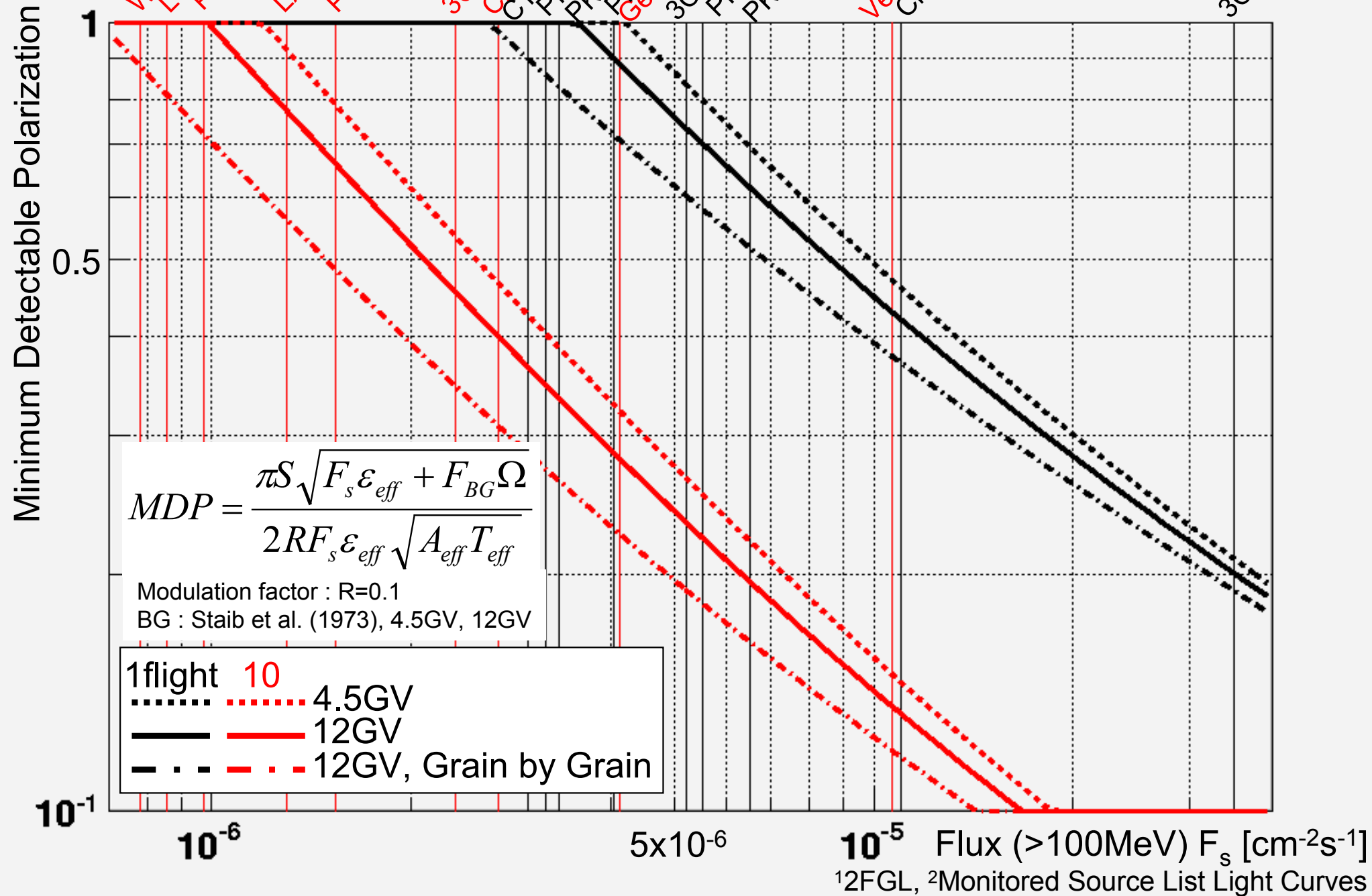
χ^2 / ndf	1.532 / 5
p0	0.14 ± 0.03962
p1	20.12 ± 9.506
p2	170.5 ± 5.089



Source sensitivity



Polarization sensitivity



GRAINE roadmap

- 8th/June/2011, TARF, JAXA Scientific Ballooning, PI : S. Aoki (Kobe Univ.)
12.5cm x 10cm aperture area, 4.3hours (1.6hours@35km) flight duration
 - Working test for each component
 - Connection test between components
 - 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

Emulsion chamber

Aperture area : 12.5cm x 10cm

◆ Flatness compensation films

OPERA film x 2

◆ Converter

102 emulsion films, 91 copper foils (50 μ m)

1.1kg, 35.0mm, 0.54Xo ($\epsilon_{\text{conv}} = 34\%$)

OPERA film x 10 (go-ban part)

OPERA film x 88 + Copper foil x 88

New type gel film x 4 + Copper foil x 3

-Target & Detector

-Precise measurement of incident direction

-0.08deg@1-2GeV, 0.93deg@100MeV

-Measurement of gamma-rays polarization

-Interface of timestamper

-Energy measurement of gamma-rays (<~GeV)

-Momentum measurement of electron pair with MCS

◆ Timestamper

1st : OPERA film x 2

2nd : OPERA film x 2

3rd : OPERA film x 2

New type gel film x 1

◆ Calorimeter

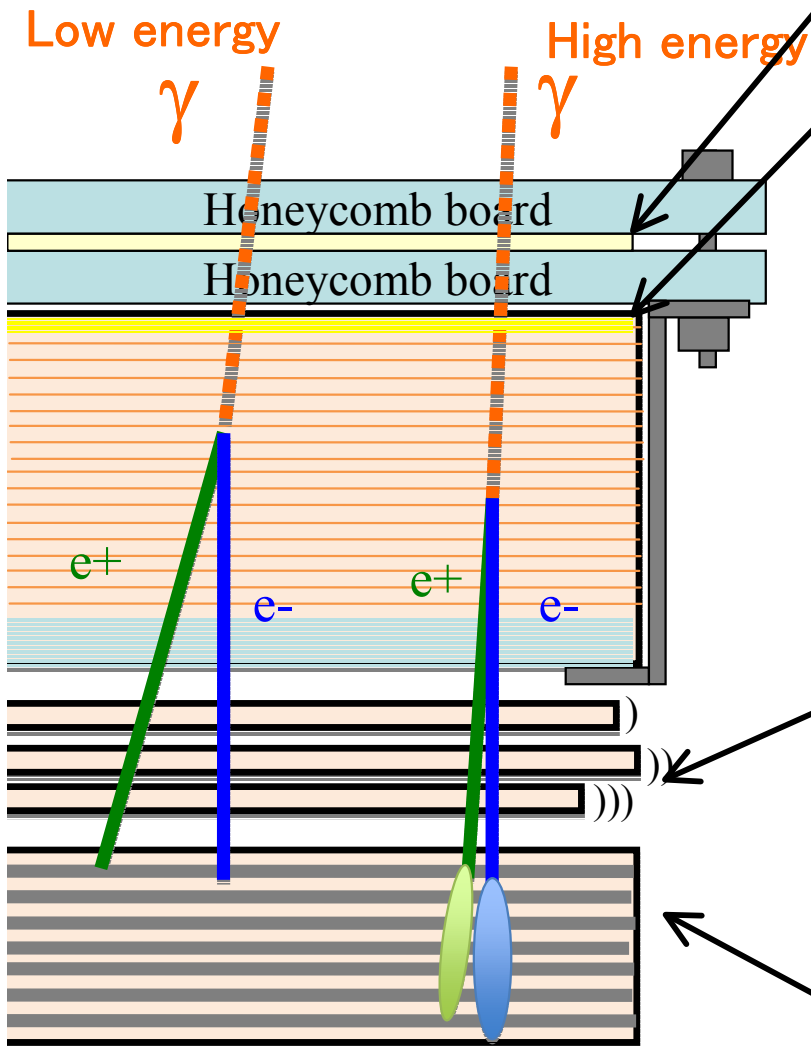
32 emulsion films, 10 (0.5mm) & 17 (1mm) lead plates

3.2kg, 31.9mm, 4.0Xo (Shower Max.@ a few GeV)

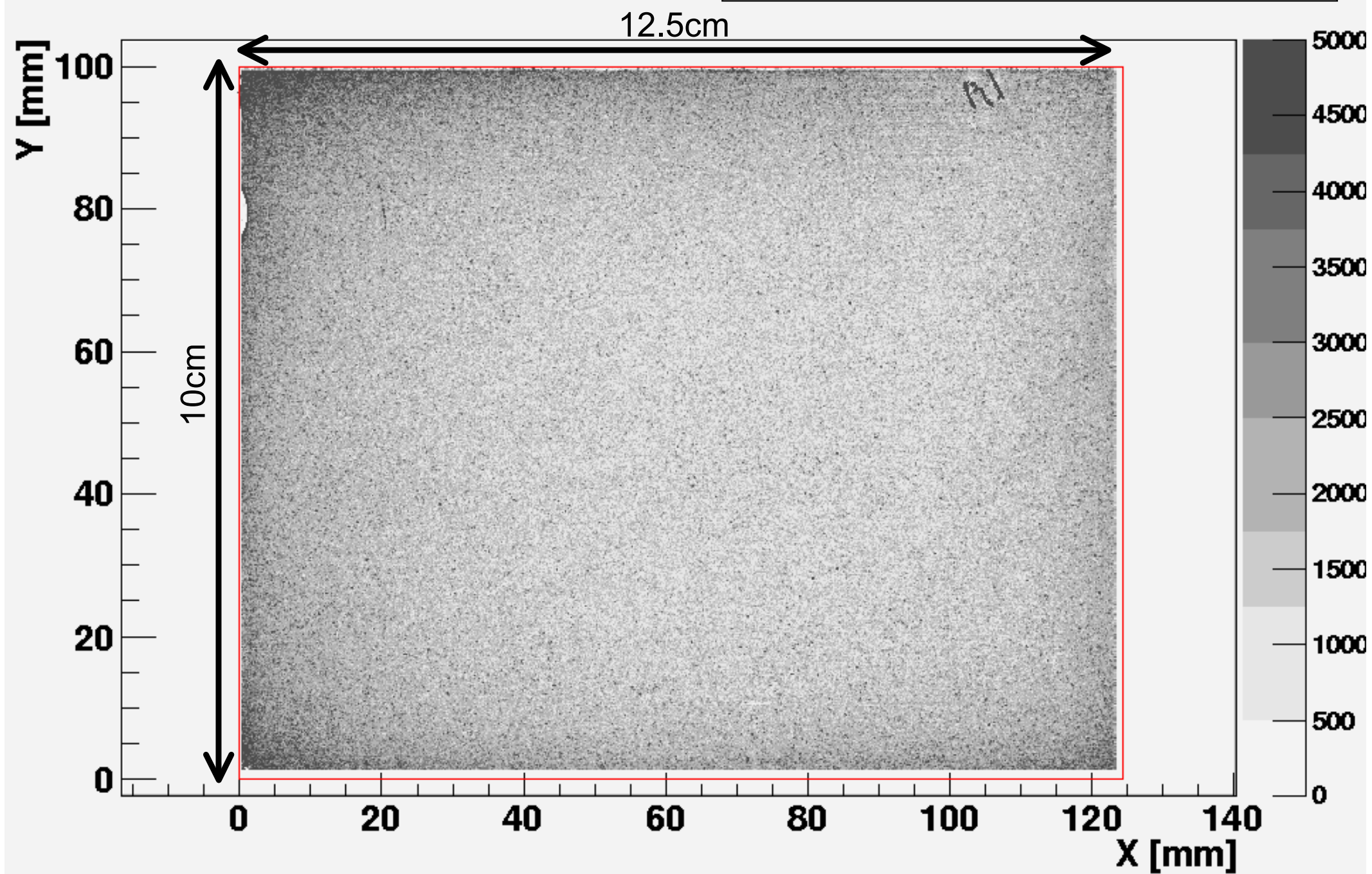
OPERA film x 5 (go-ban part)

(OPERA film + lead plate(0.5mm))x10

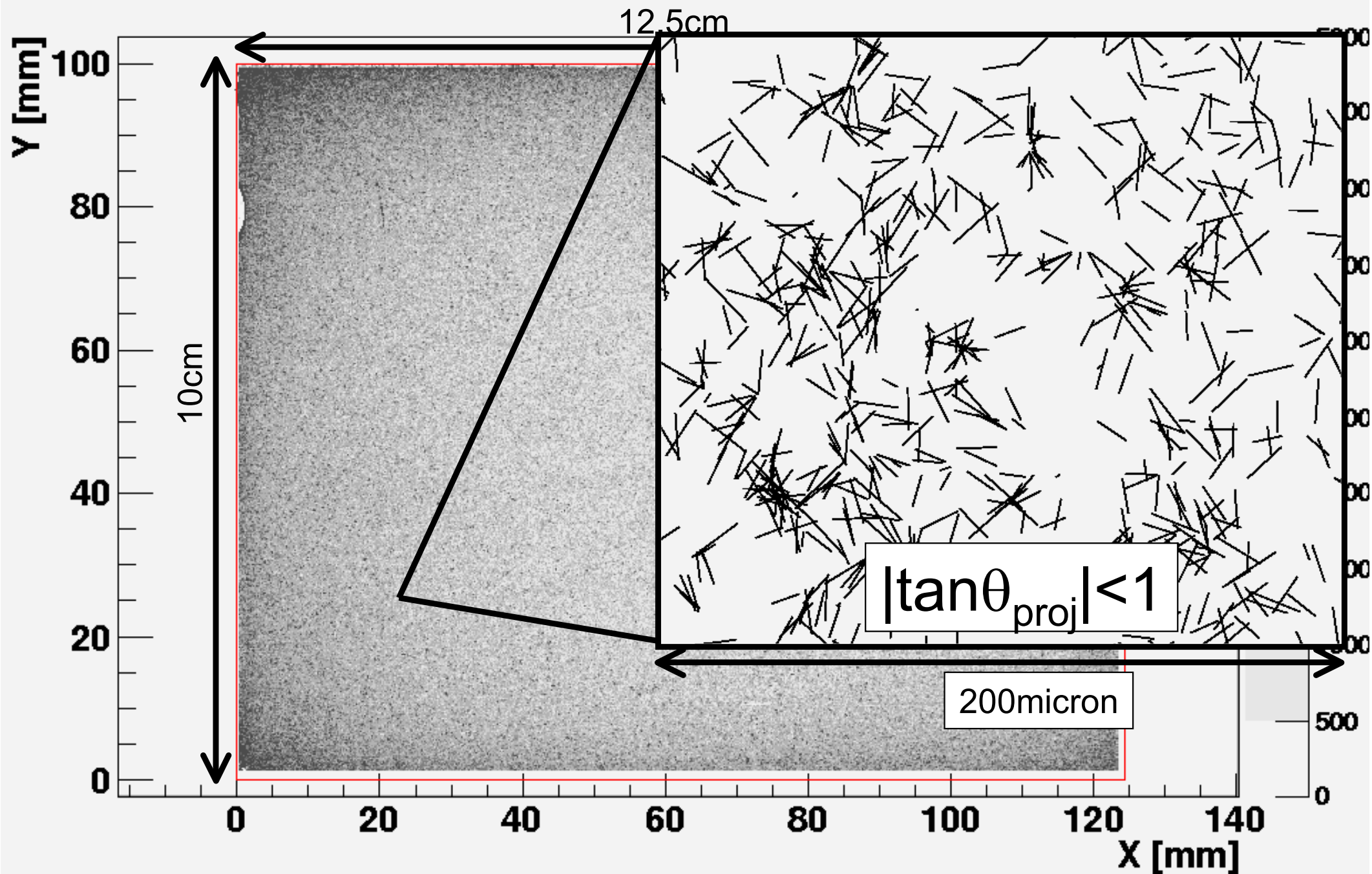
(OPERA film + lead plate(1mm))x17



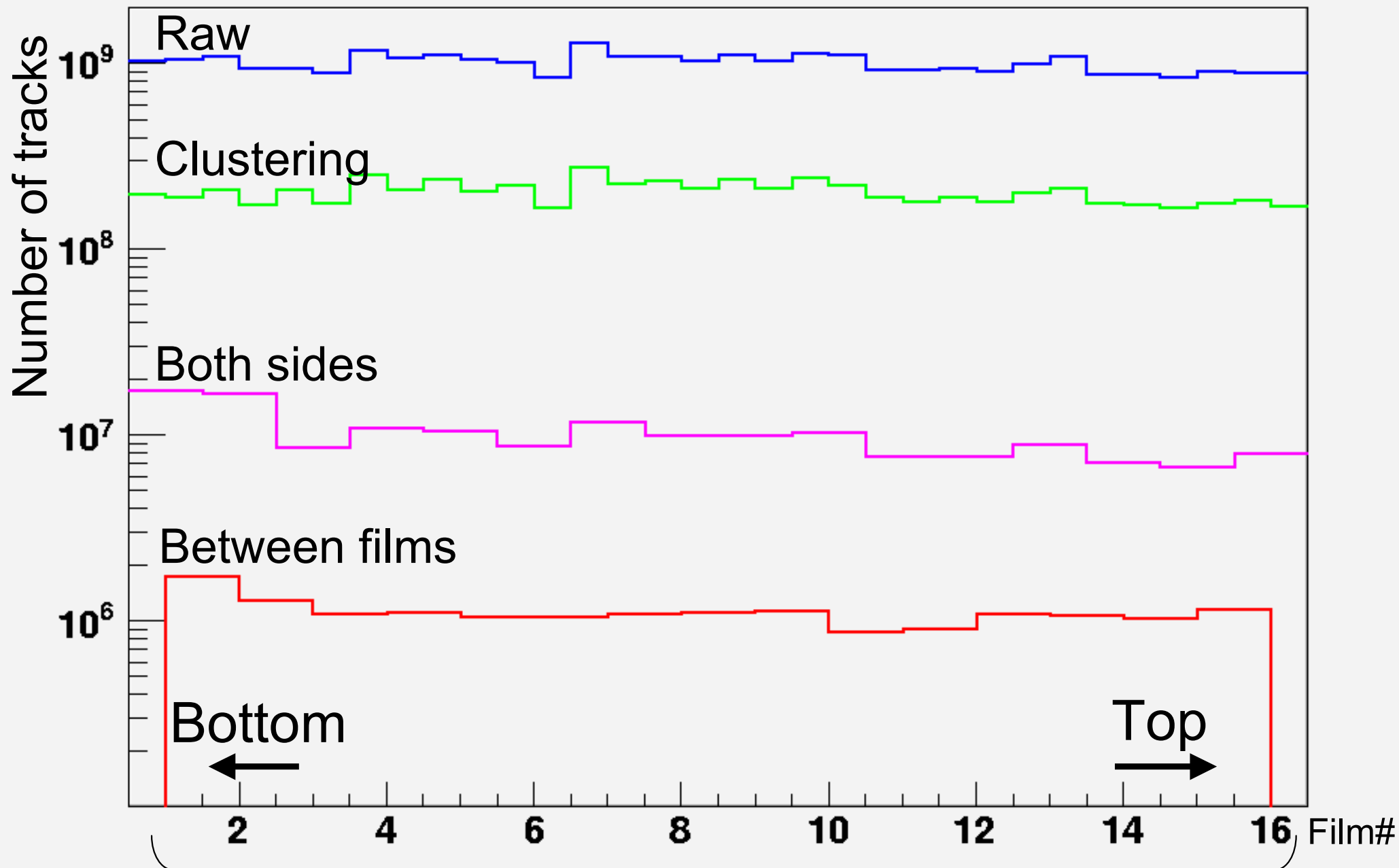
Number of tracks: 8.0×10^8



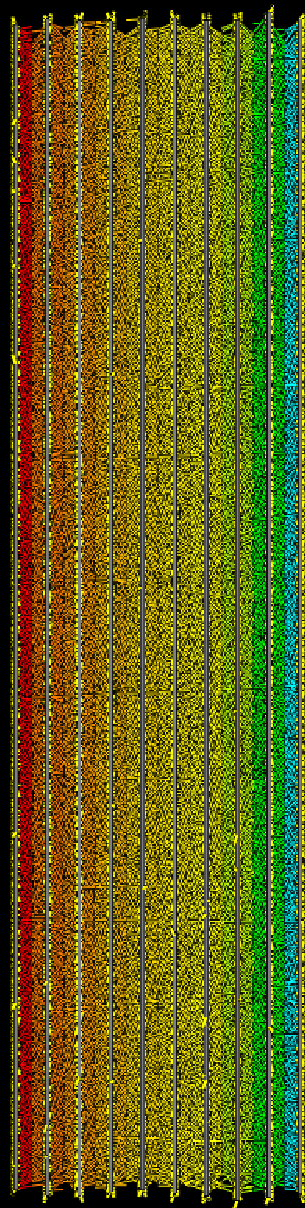
Number of tracks: 8.0×10^8



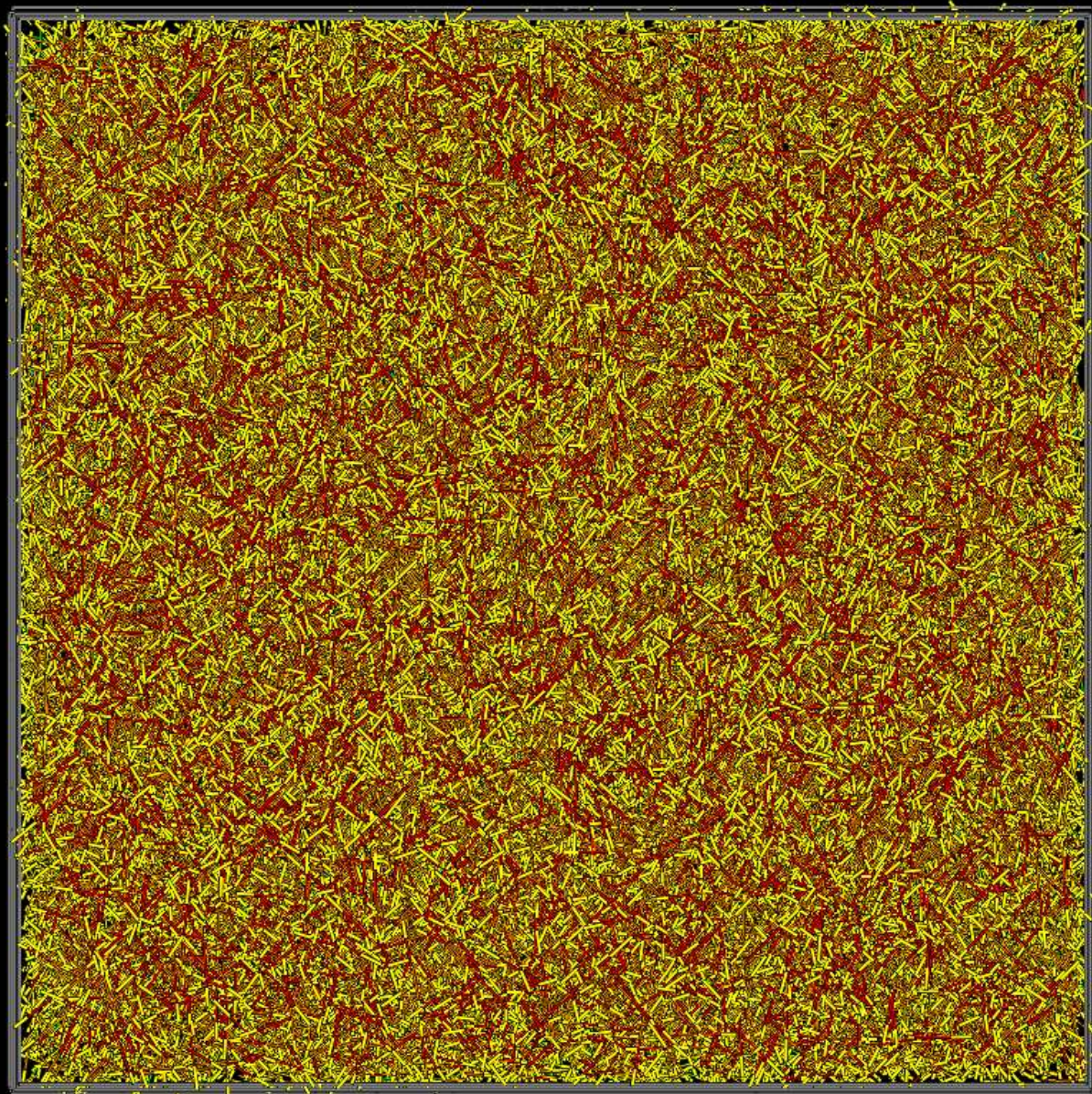
Track reconstruction



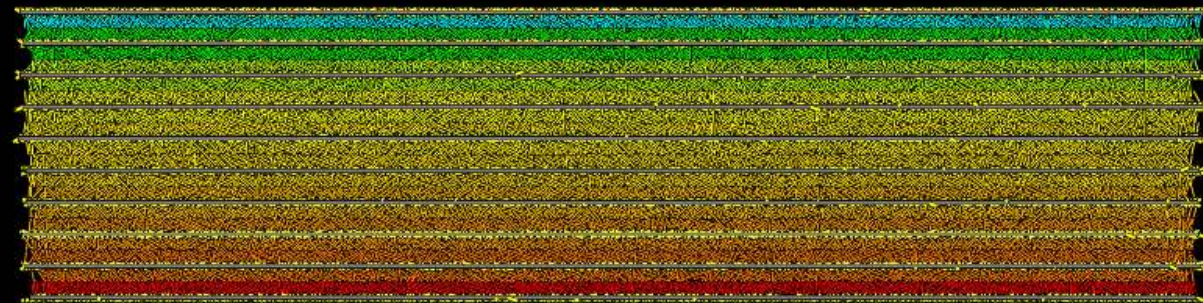
Reconstructed tracks (film#1-16) : 8.7×10^7 (overlap)



Y

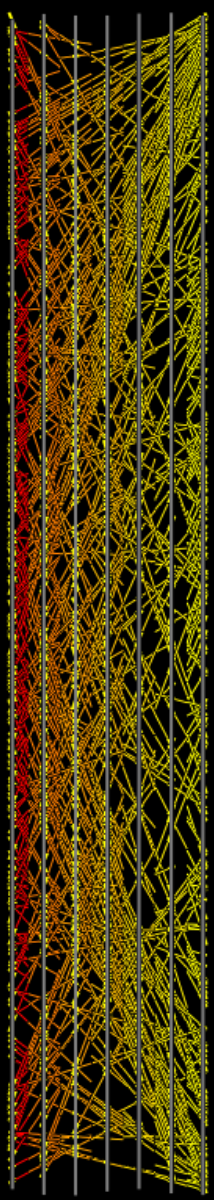


Z

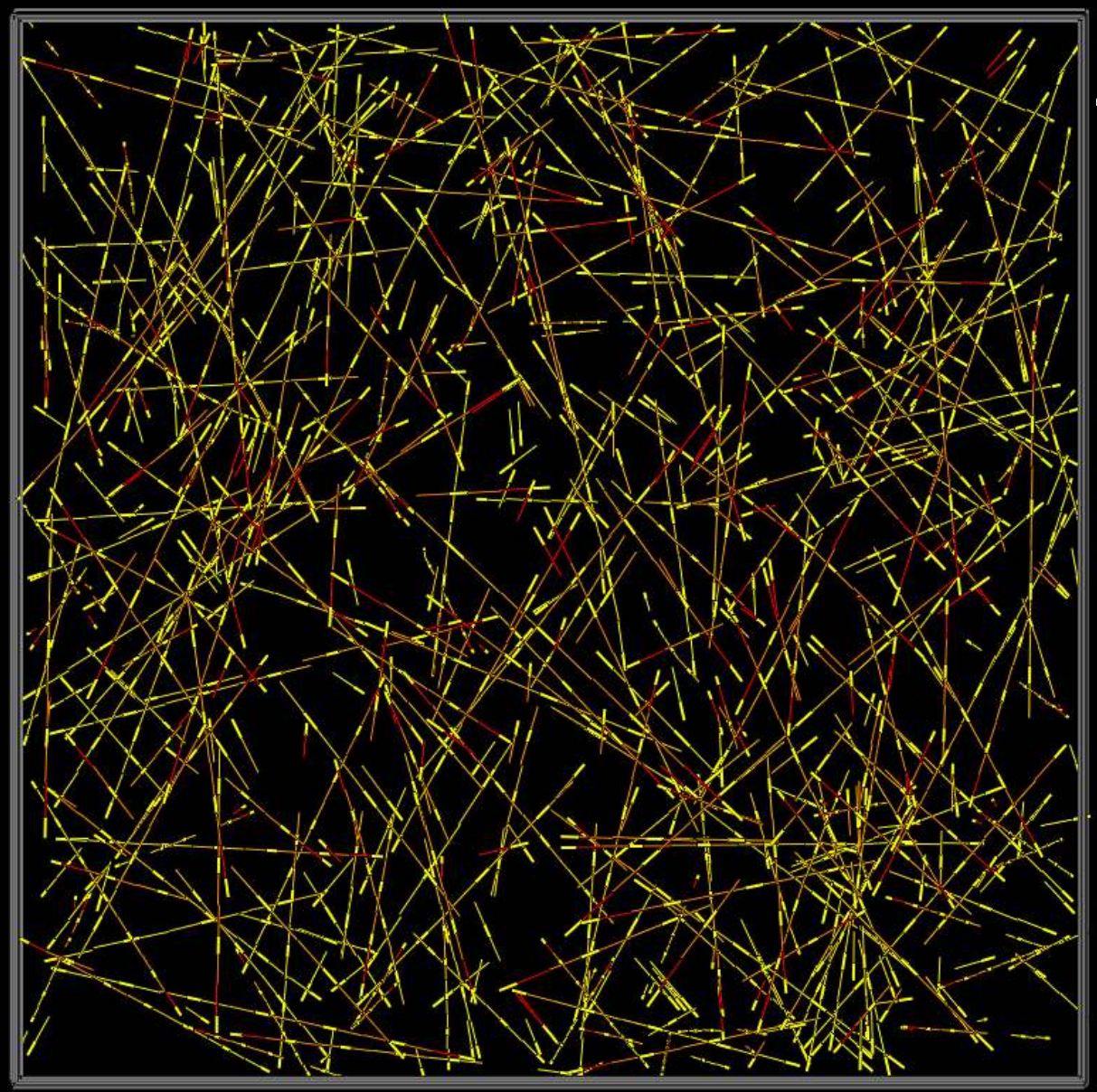


X

$(5\text{mm})^2 \times 10\text{films}$
 $2 \times 10^4\text{tracks}$

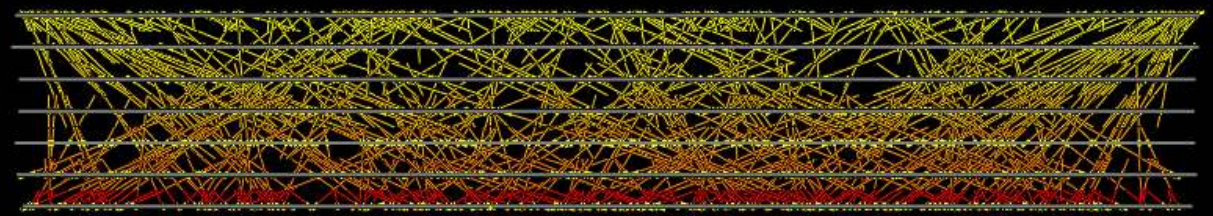


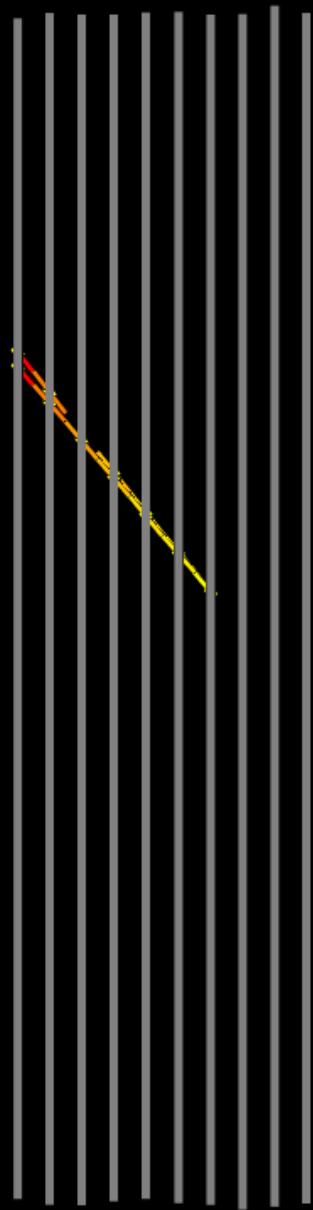
Y



Z

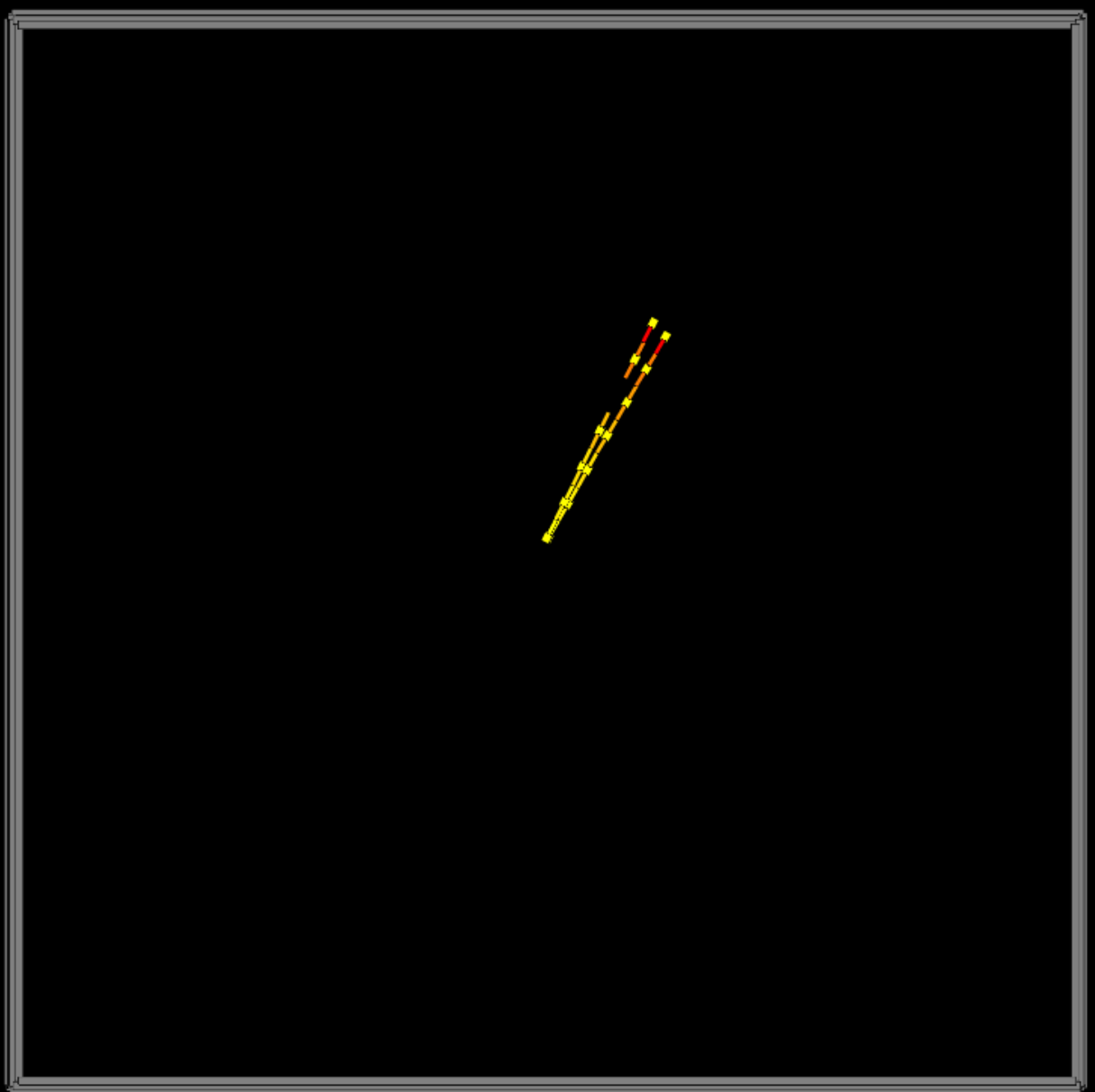
X



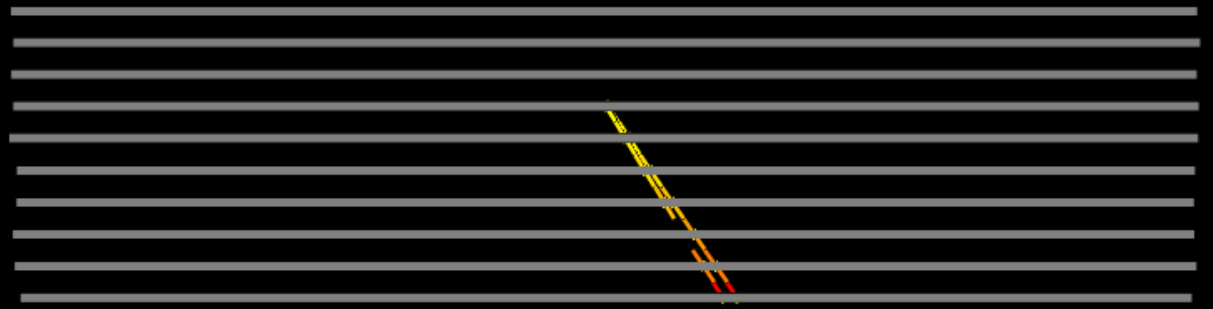


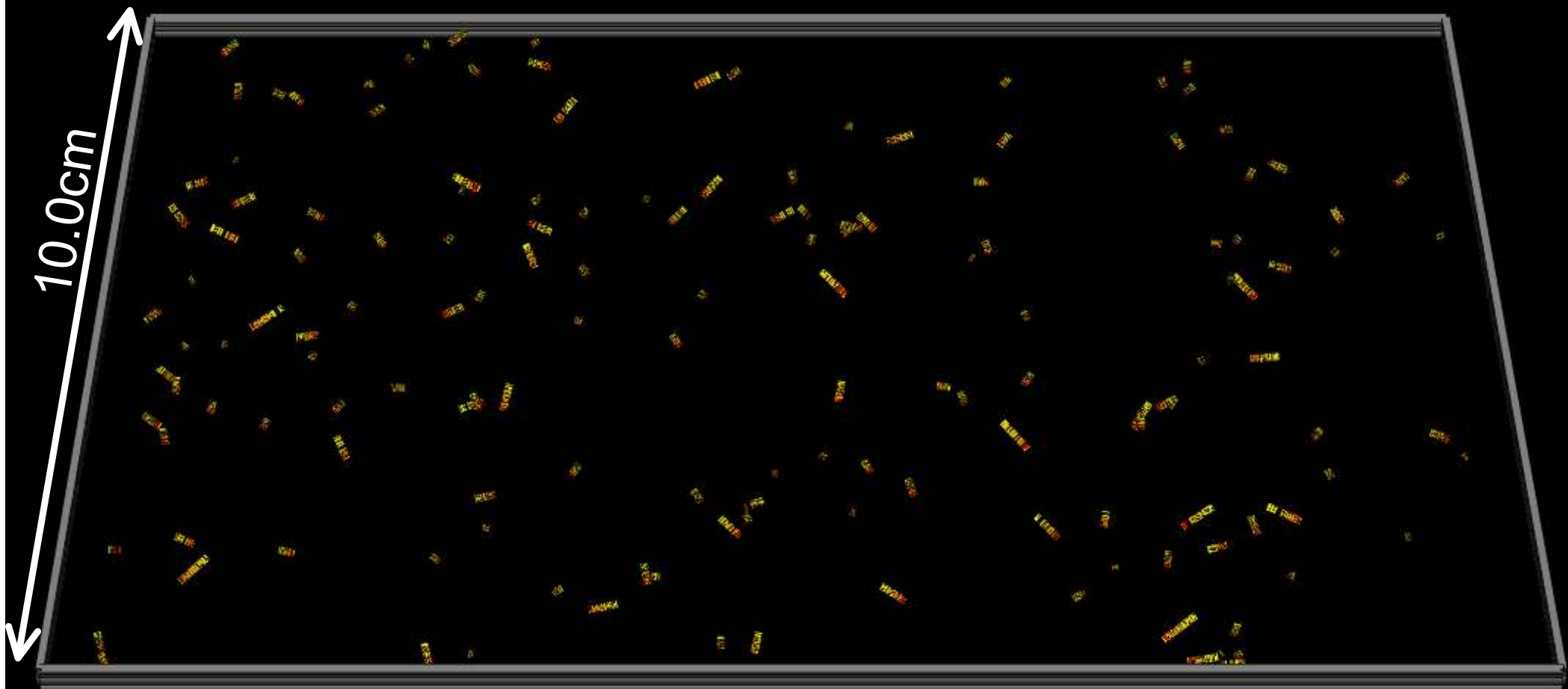
Y

X



Z

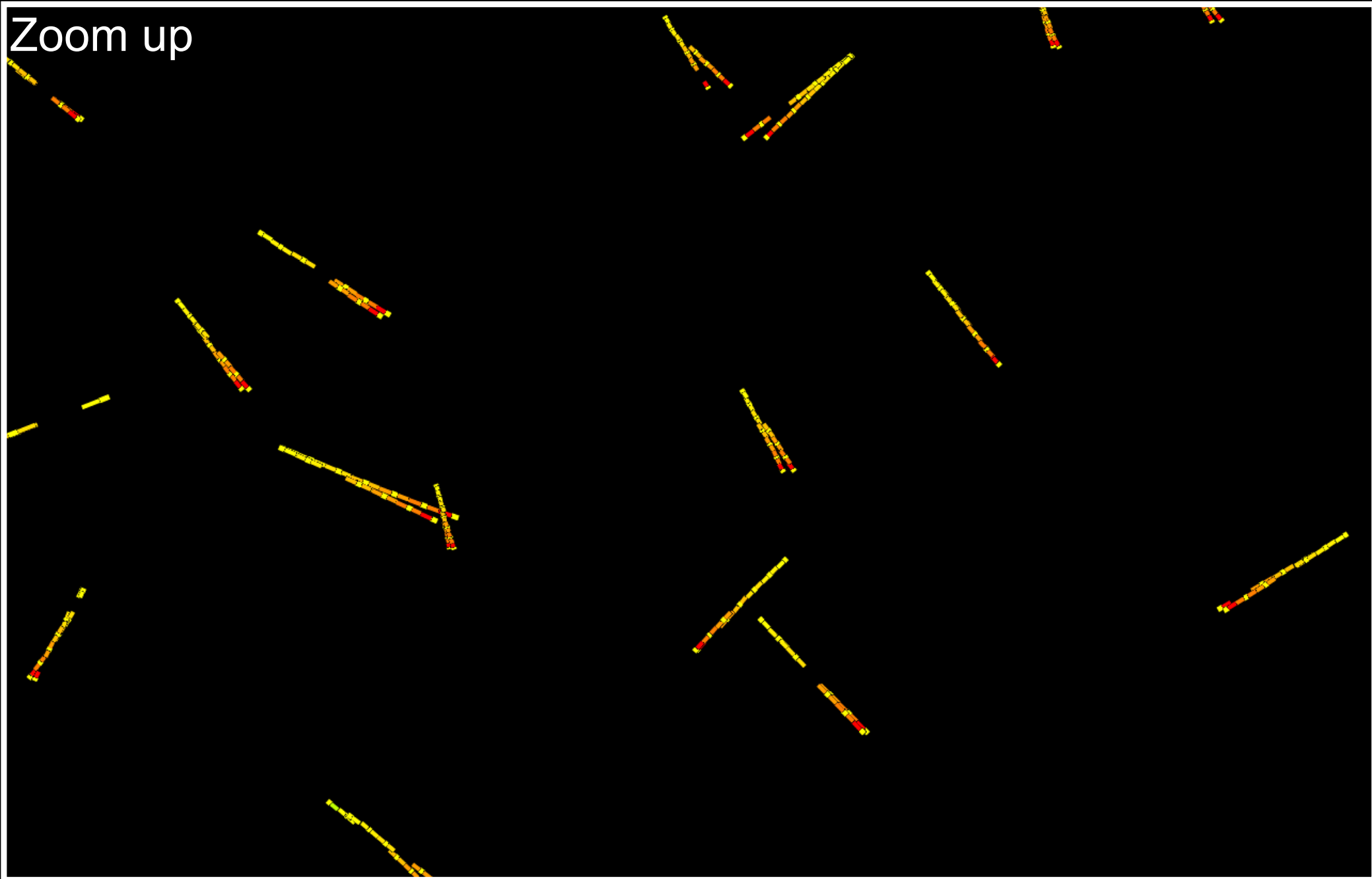




12.5cm

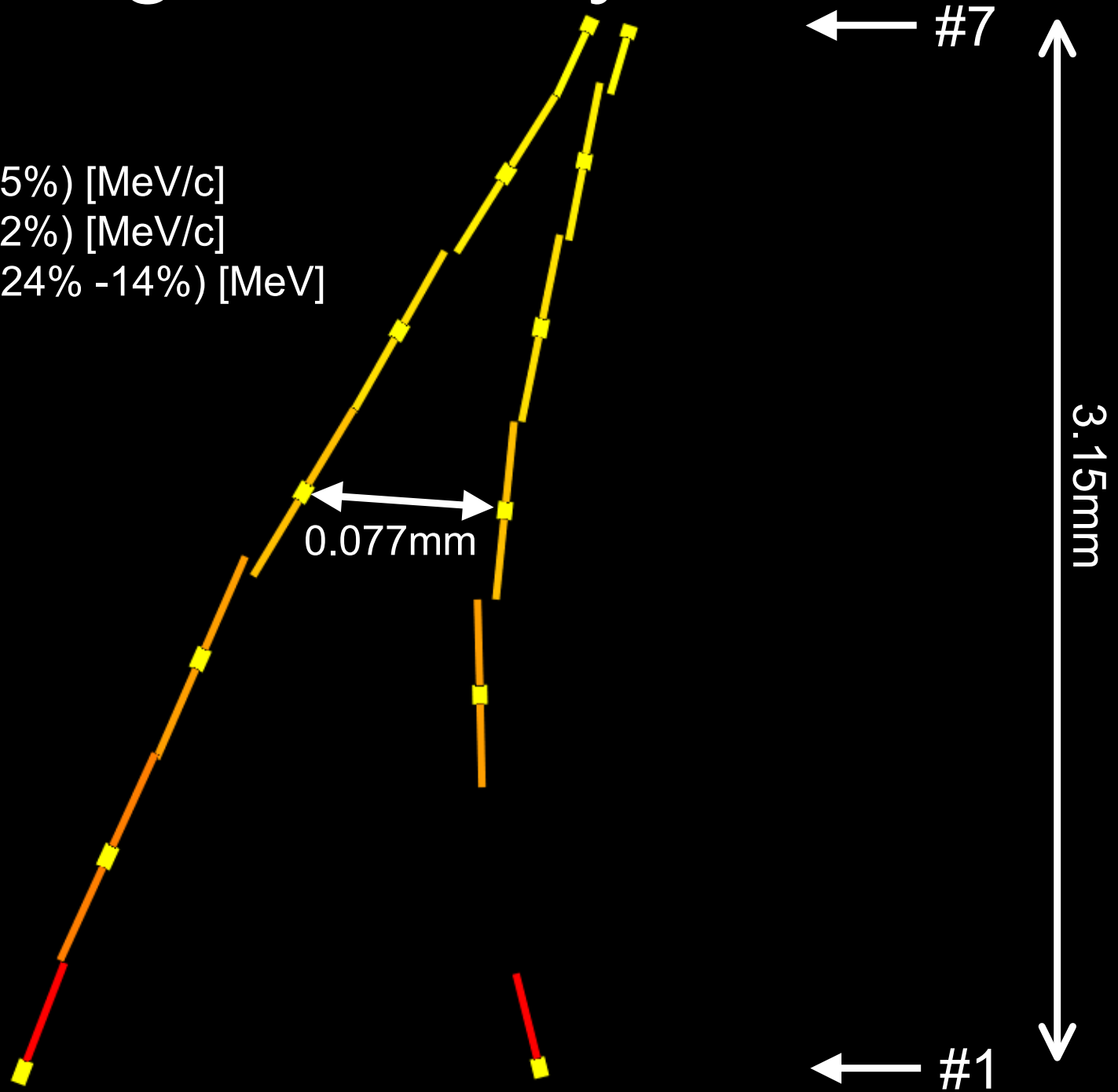
153events
Reliability 97%

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]

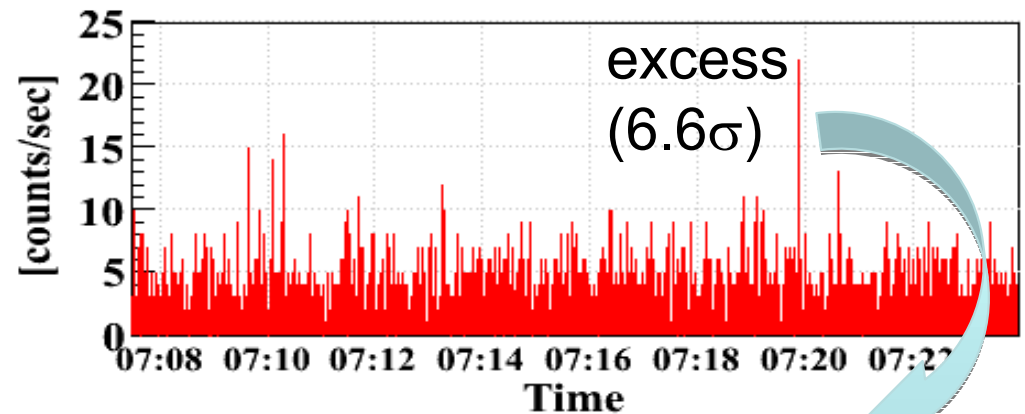
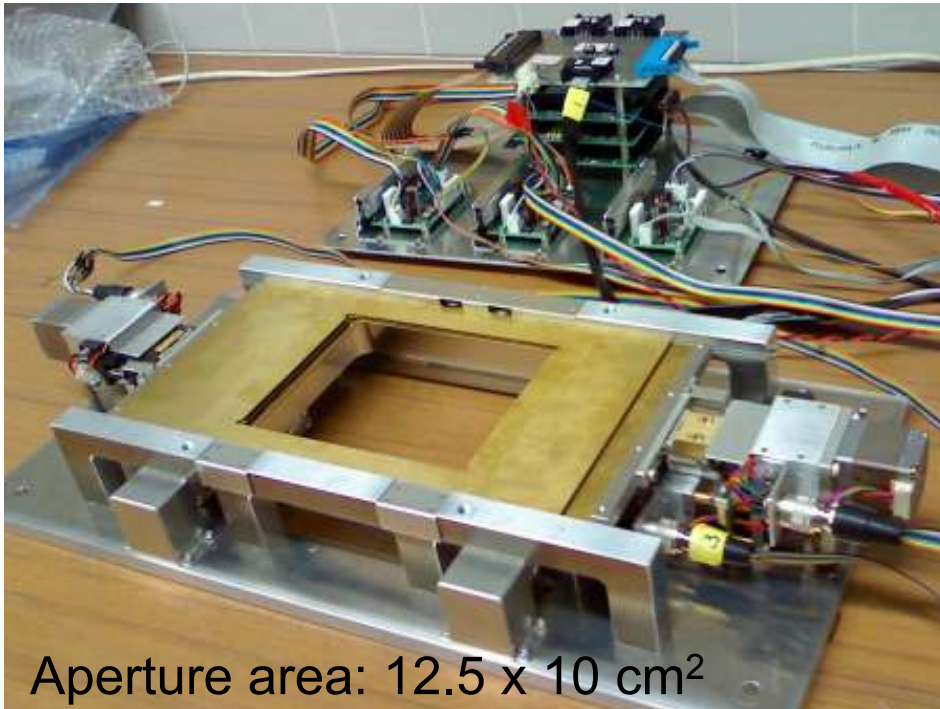


Establishment of timestamp technique

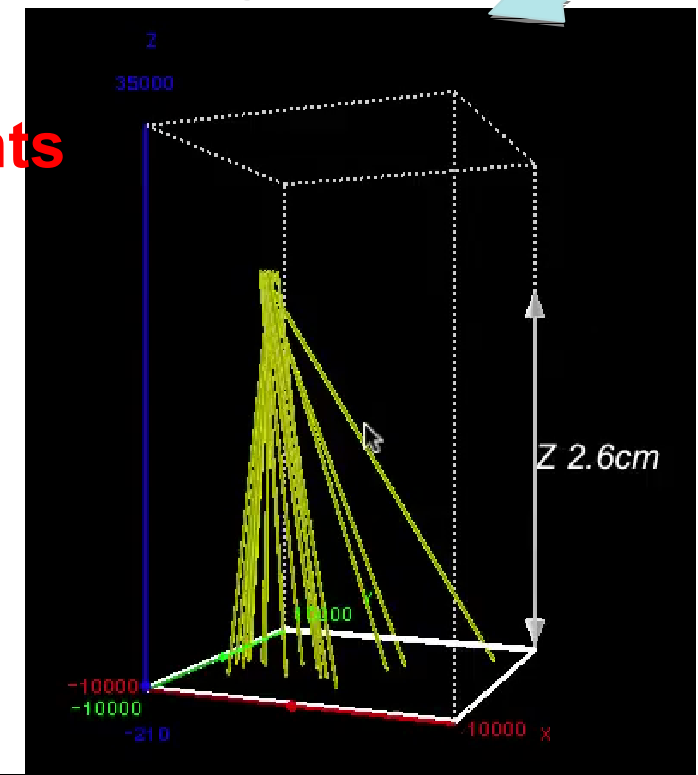
H.Rokujo, et al., NIM A, 701 (2013)

@GRAINE2011

“Multi-stage shifter” 1st model Track rate measurement@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

Hadron induced event

E_ν : 2438038

E_γ : 45^{+33}_{-10} [MeV]

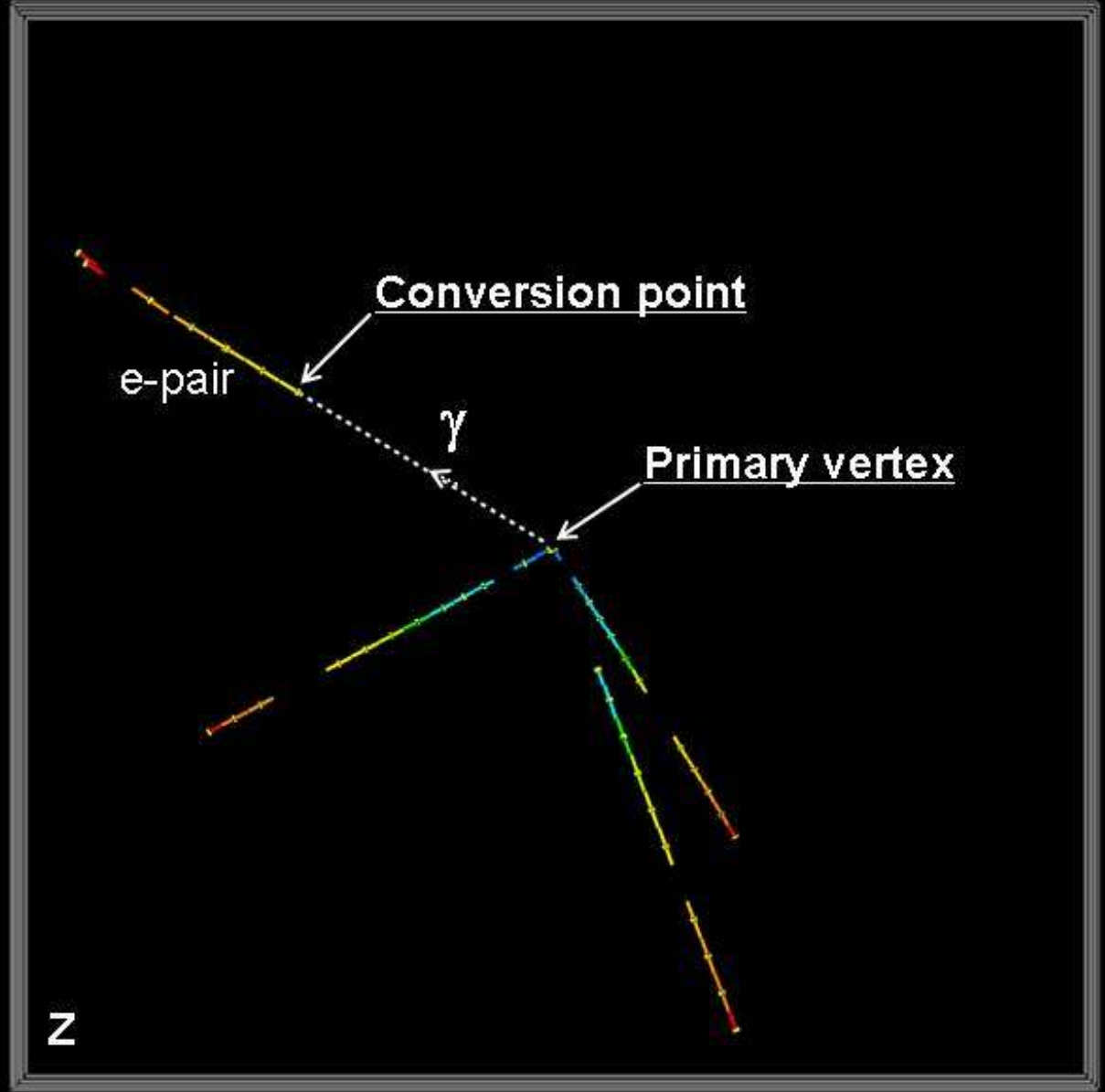
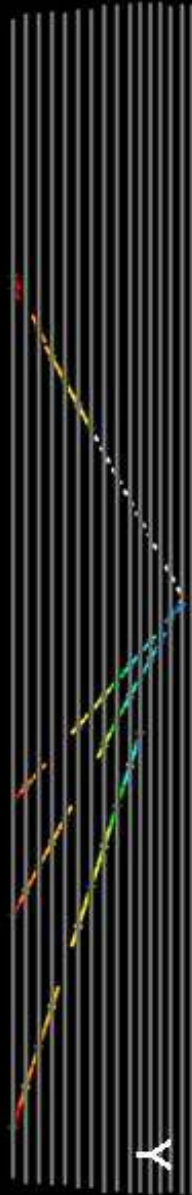
θ_γ : 46.61[deg]

7:18:34.5 (JST)

$\Delta t = \pm 0.5$ s

Convergence

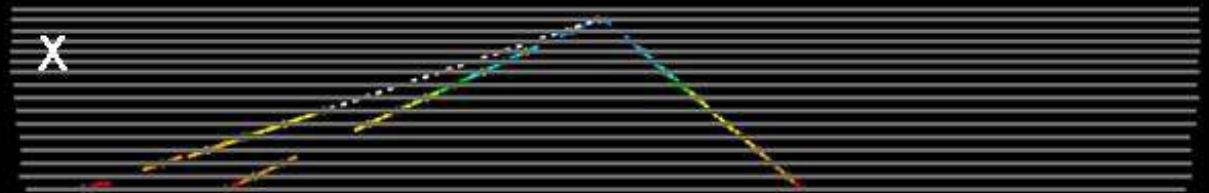
1.2cm x 1.2cm
x 16films



Pointing accuracy

$\Delta\theta_{\text{space}}$: 0.65deg

(0.0114rad)



Electron induced event

E_ν : 7797344

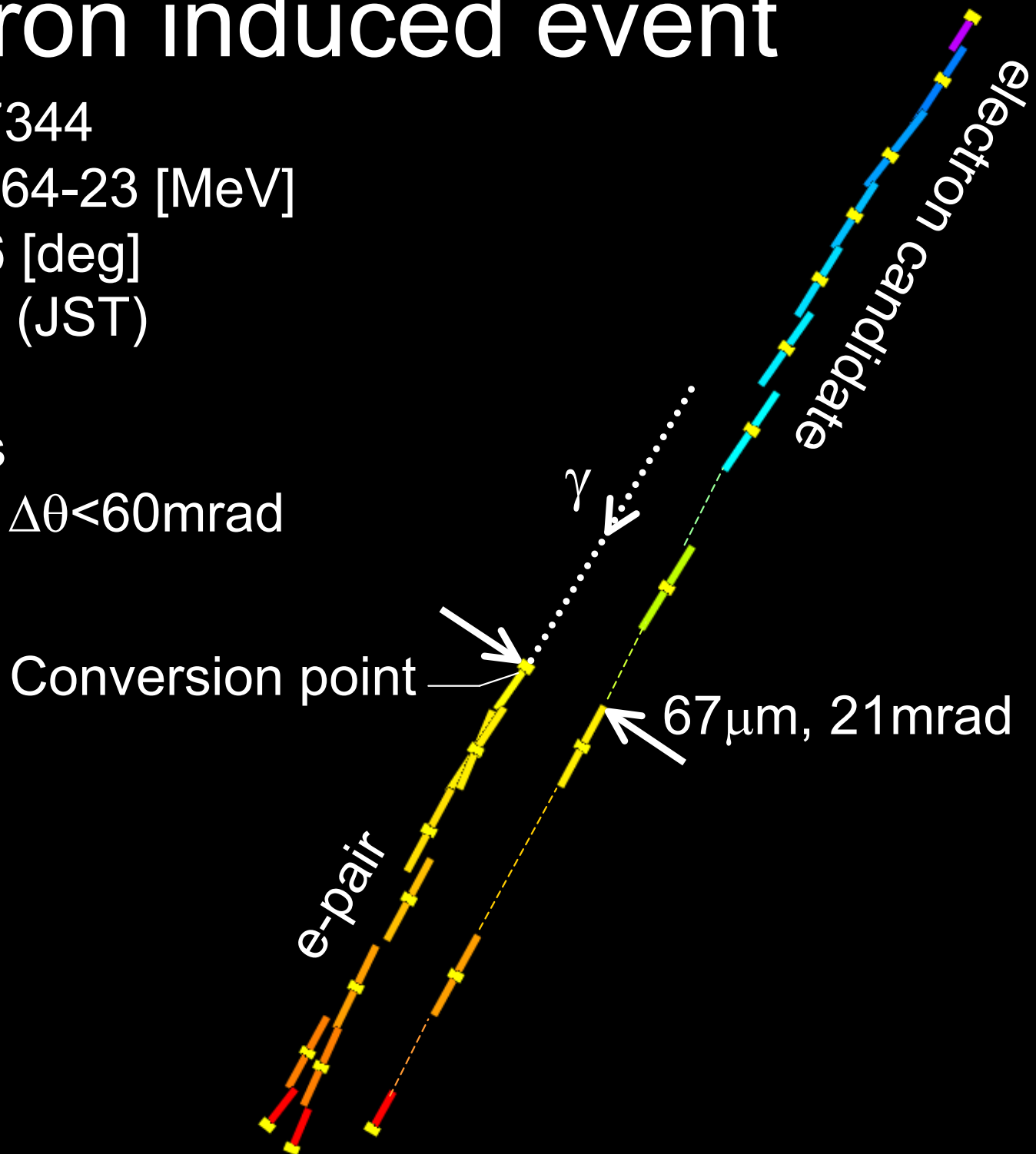
E_γ : 100+64-23 [MeV]

θ_γ : 38.96 [deg]

8:15:52.9 (JST)

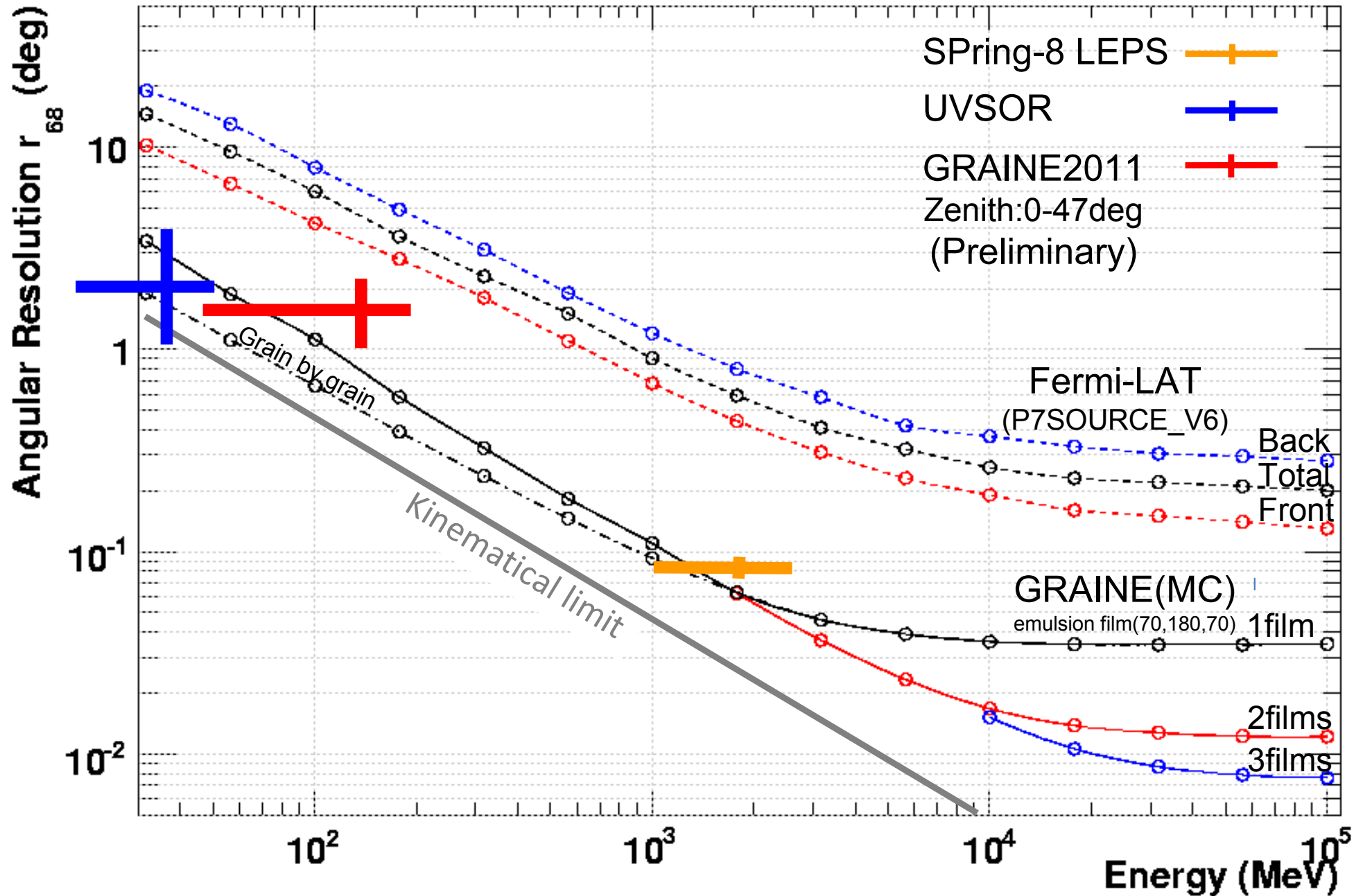
$\Delta t = \pm 0.5$ s

$\Delta r < 1$ mm, $\Delta\theta < 60$ mrad

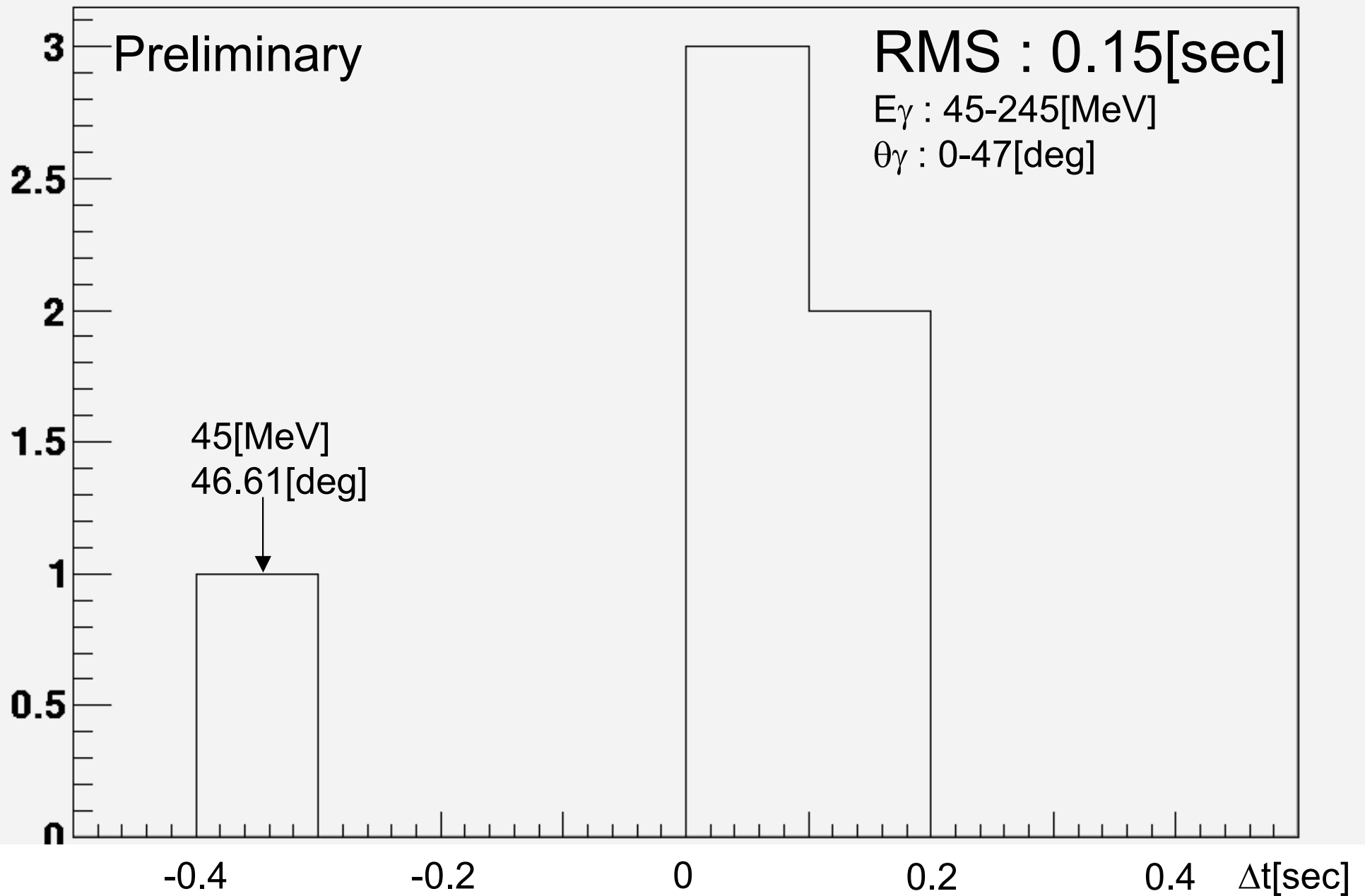


Angular resolution

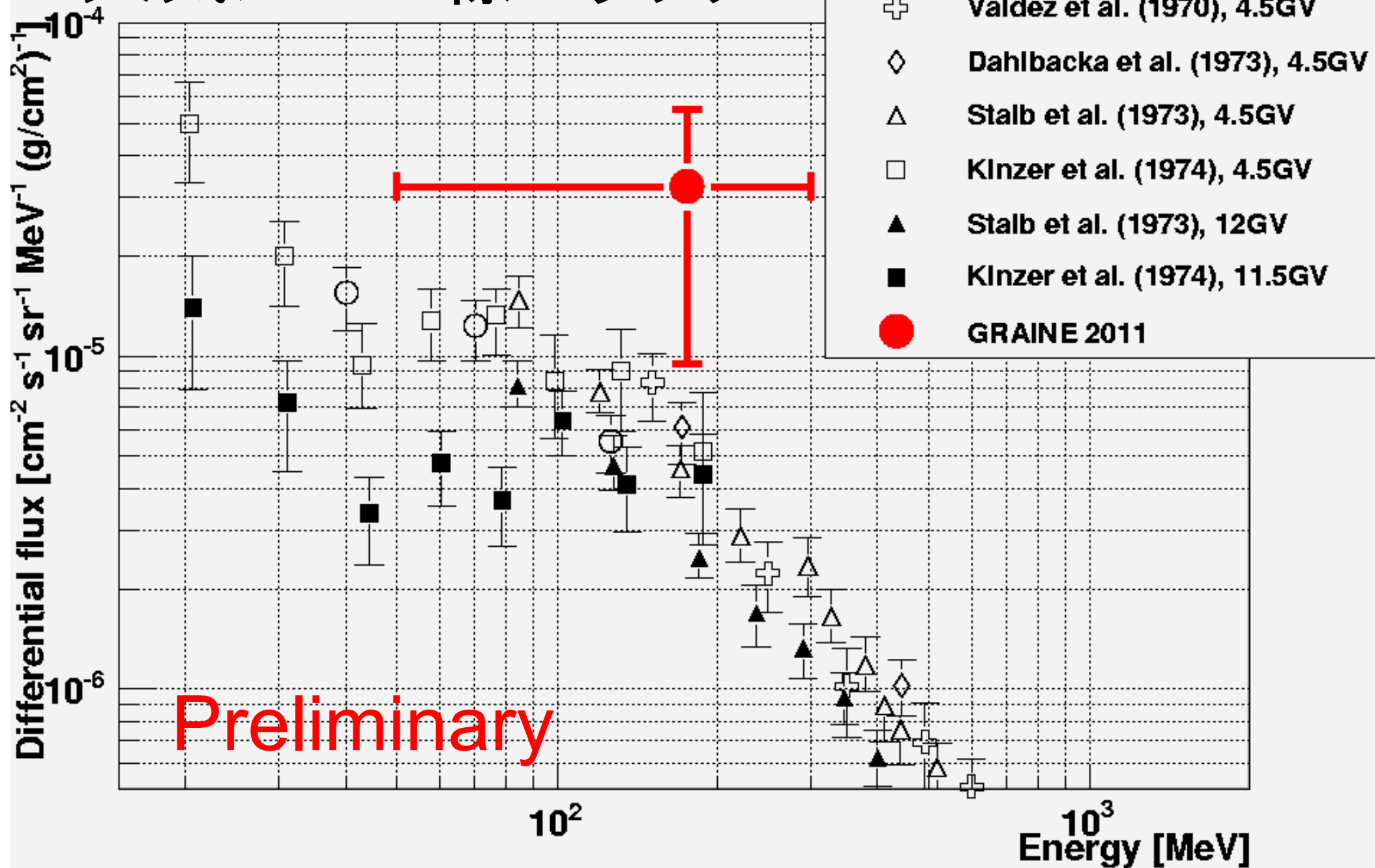
PSF at normal incidence



Gamma-ray timing accuracy



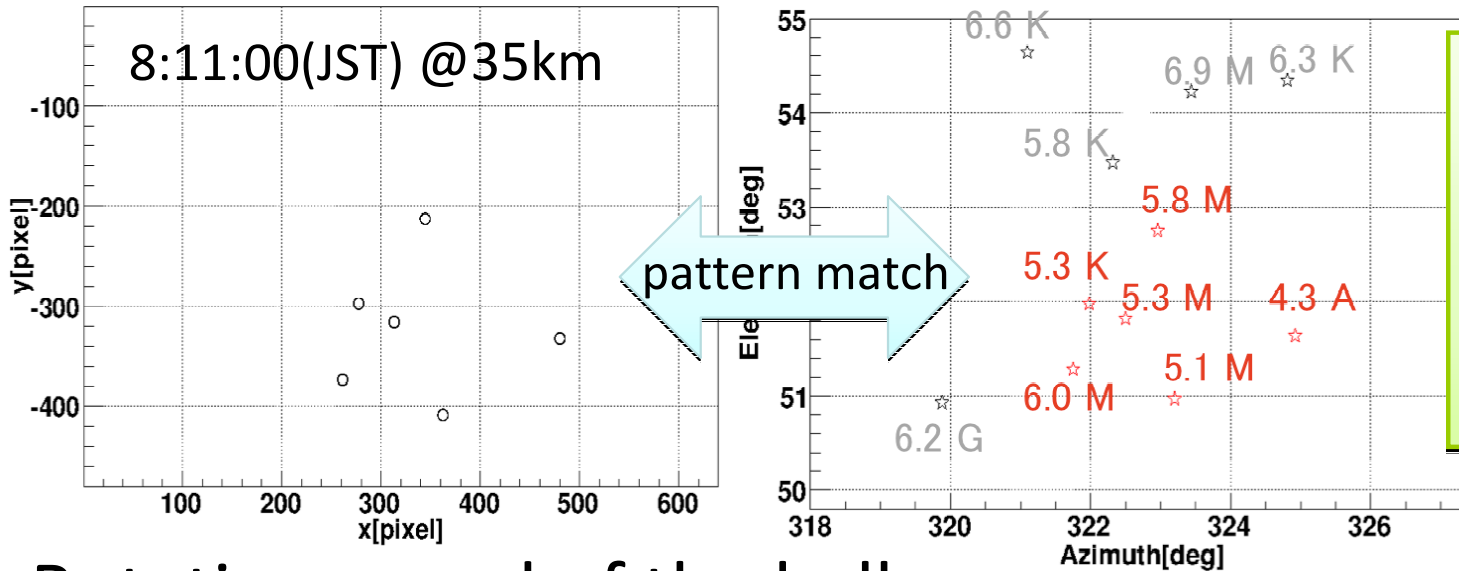
大気ガンマ線フラックス



Attitude analysis

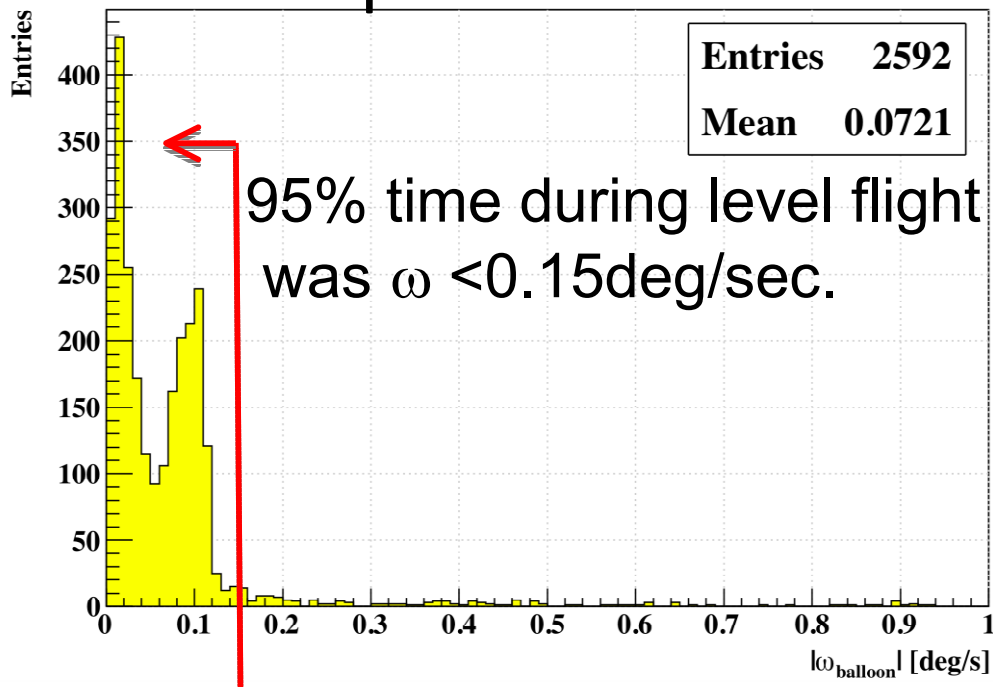
Daytime star camera view

Star catalog data



Working rate: 74 %
Monitoring
accuracy: < mrad
Elevation < 0.25mrad
Azimuth < 0.44mrad

Rotation speed of the balloon



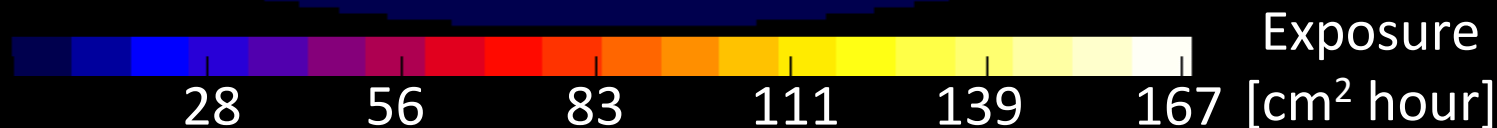
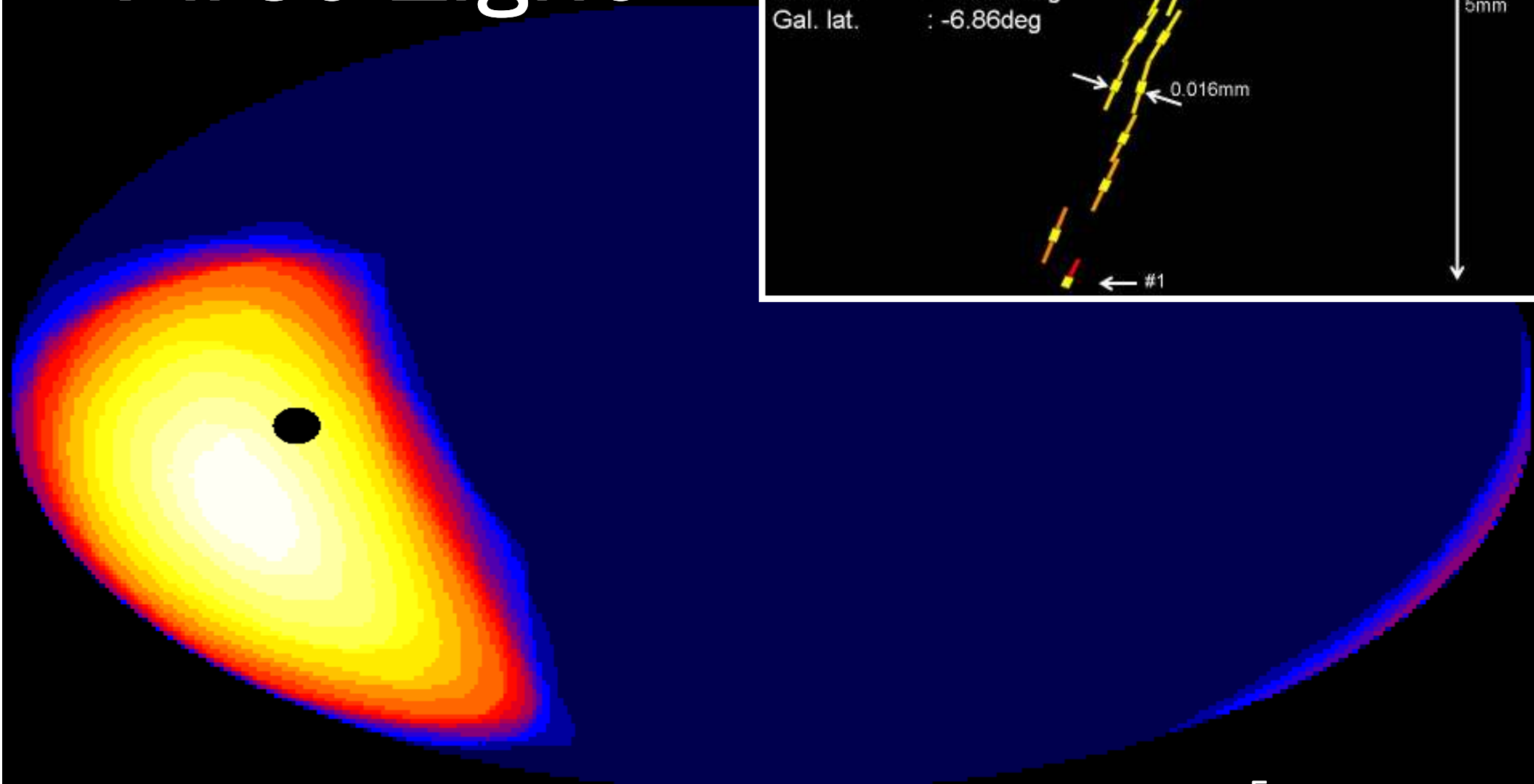
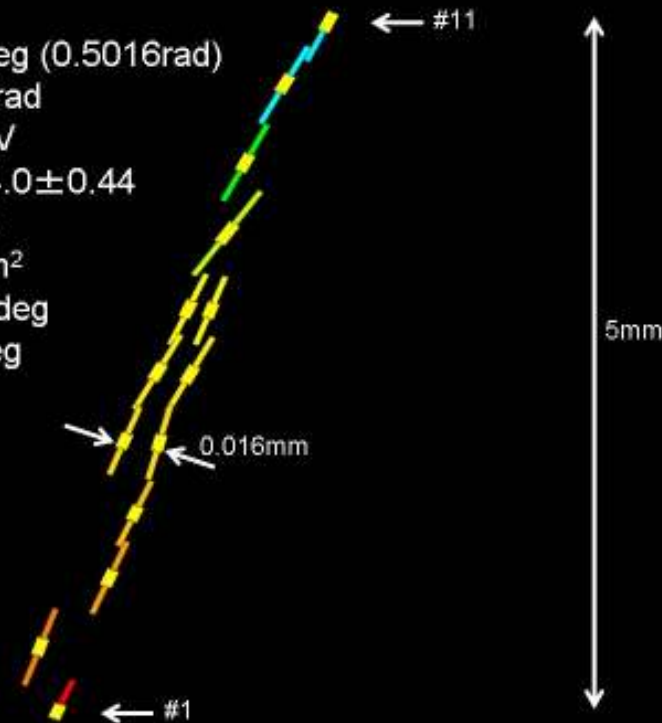
It is important to decide telescope attitude to celestial coordinate better than emulsion angular resolution(0.08deg).

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

GRAINE

First Light

Event : 111 2986322
Start : #11 up
 θ_{incident} : 26.64deg (0.5016rad)
 θ_{open} : 0.0059rad
 $E_{\gamma}(\theta_{\text{open}})$: 340MeV
JST : 8:24:44.0 \pm 0.44
Altitude : 34.6km
Atm. depth : 6.6g/cm²
Gal. lon. : 112.06deg
Gal. lat. : -6.86deg

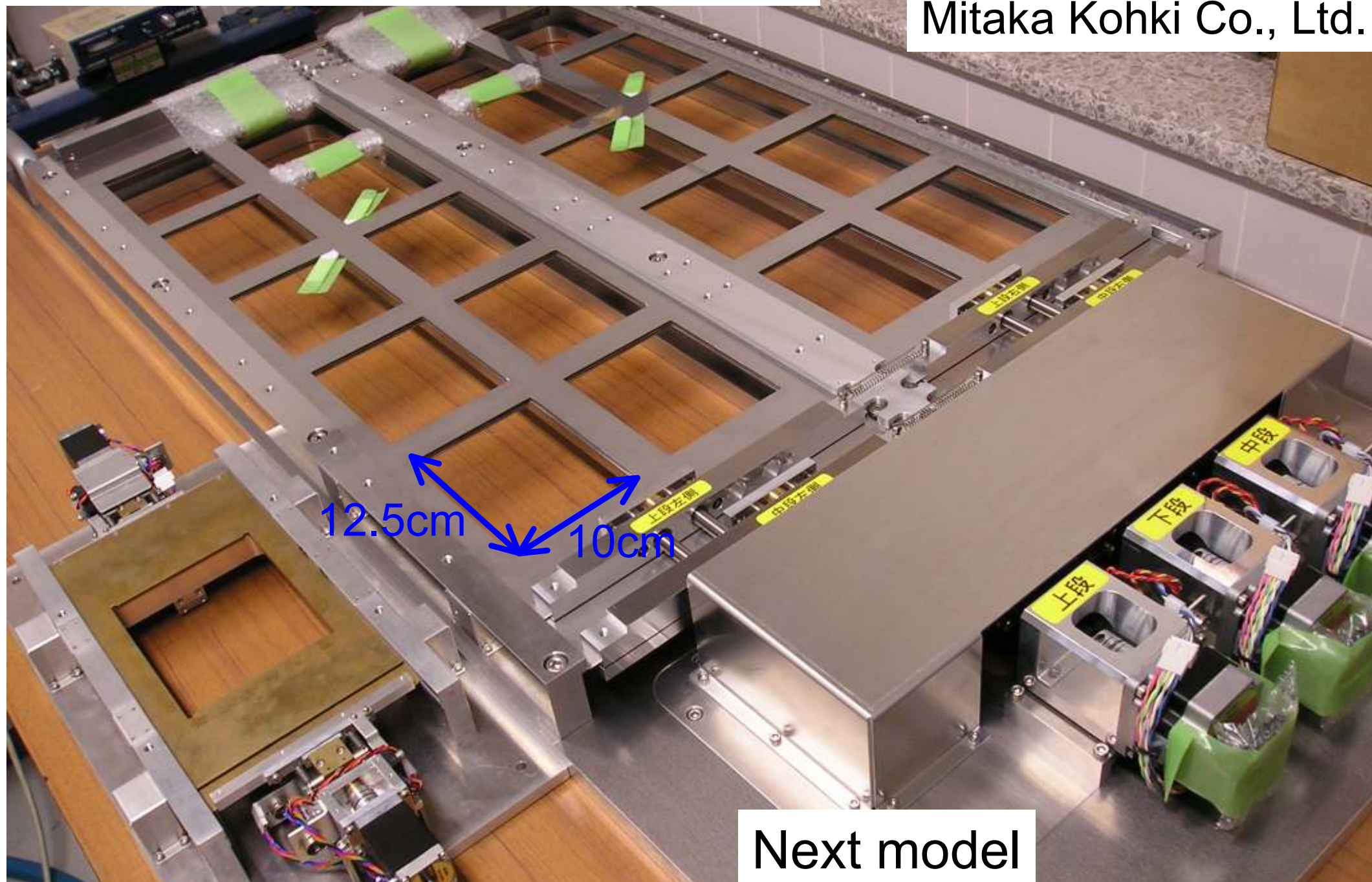


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Flight model of multi-stage shifter

Co-developed with
Mitaka Kohki Co., Ltd.



12.5cm
10cm

Next model

2011 model

Aperture area : 2500cm²