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

高橋 覚 (神戸大)

for GRAINE collaboration

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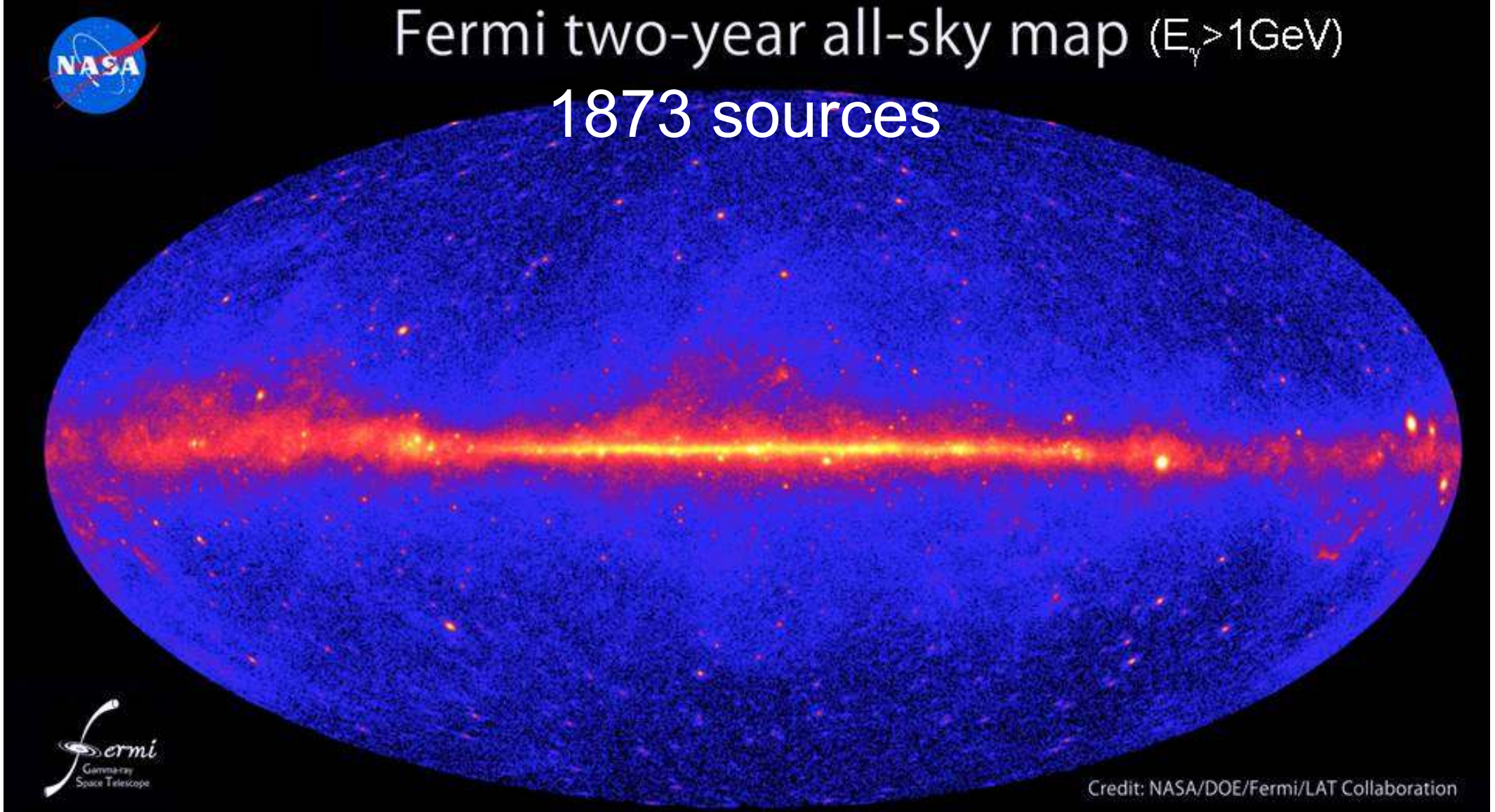
(1)Kobe University, (2)ISAS/JAXA, (3)Nagoya University, (4)Okayama University of science, (5)Aichi University of education, (6)Utsunomiya University

PI : 青木 茂樹 (神戸大)

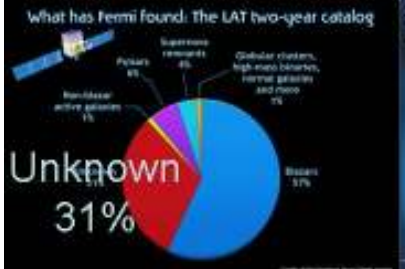
Fermi two-year all-sky map (E_γ>1GeV)

1873 sources

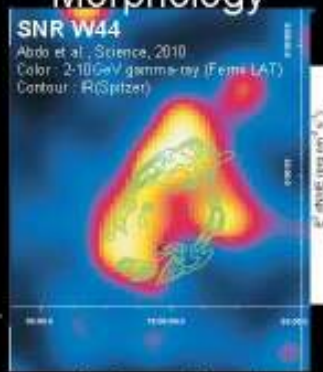


Credit: NASA/DOE/Fermi/LAT Collaboration

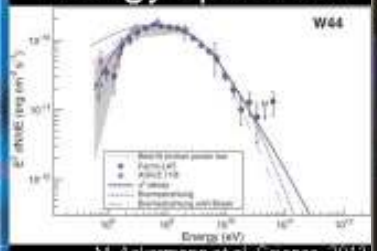
Un-ID



Morphology



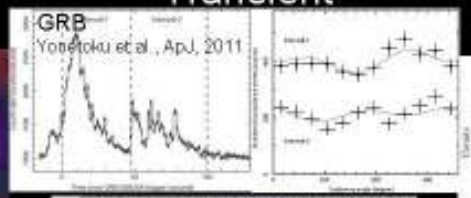
Energy spectrum

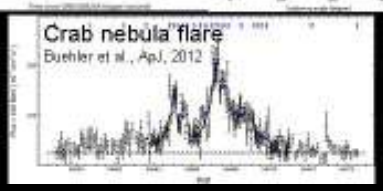


M. Ackermann et al. Science, 2013

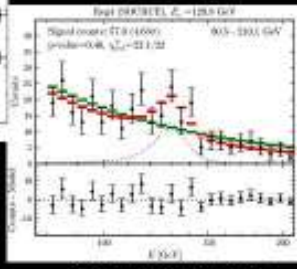
Polarization

Transient



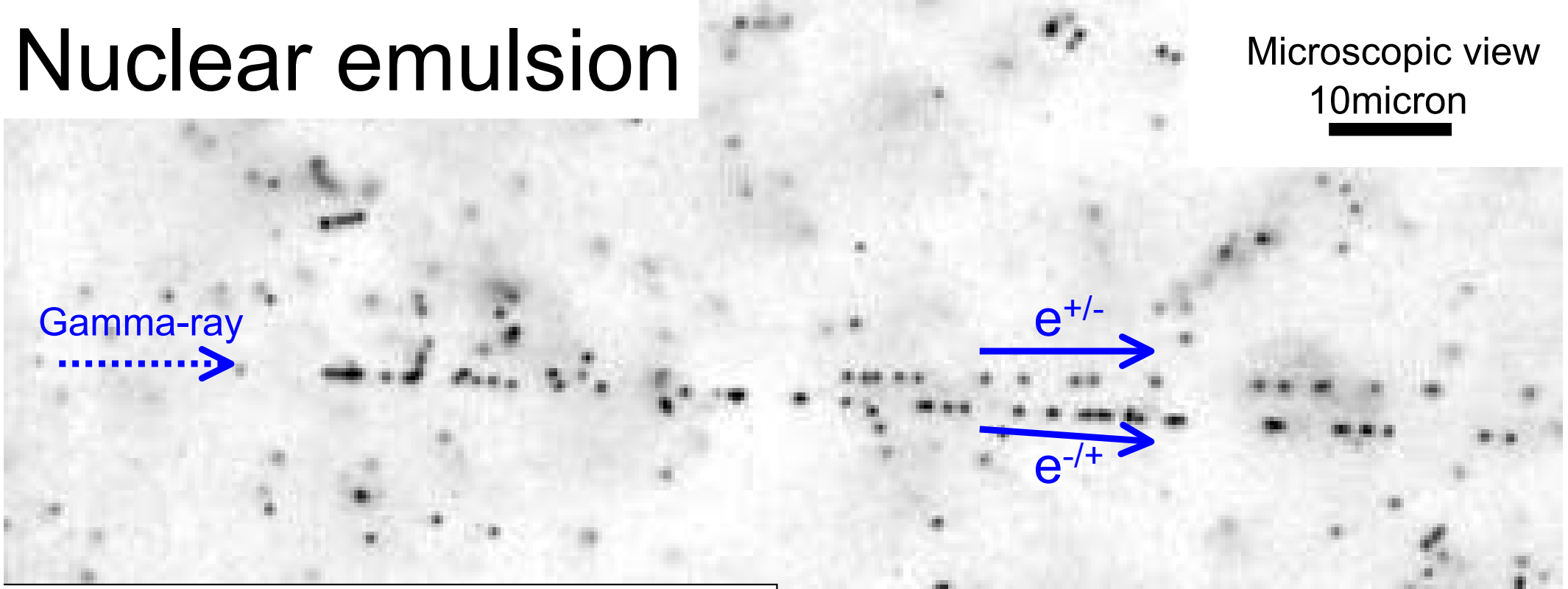


Dark matter

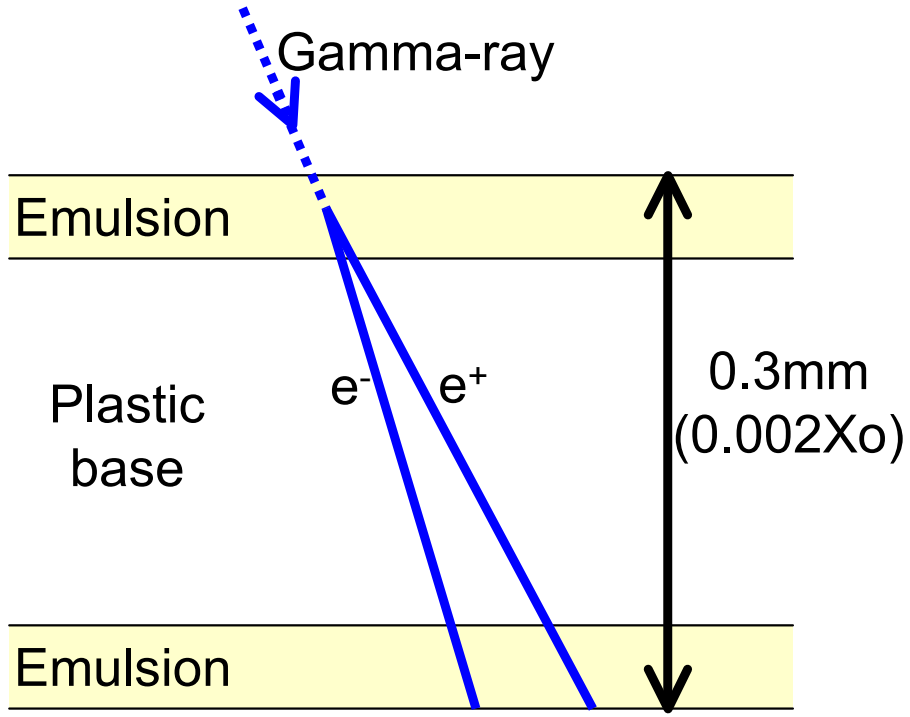


Gamma-ray line
Weniger, JCAP, 2012

Nuclear emulsion



Cross sectional view of an emulsion film



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

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

GRAINE

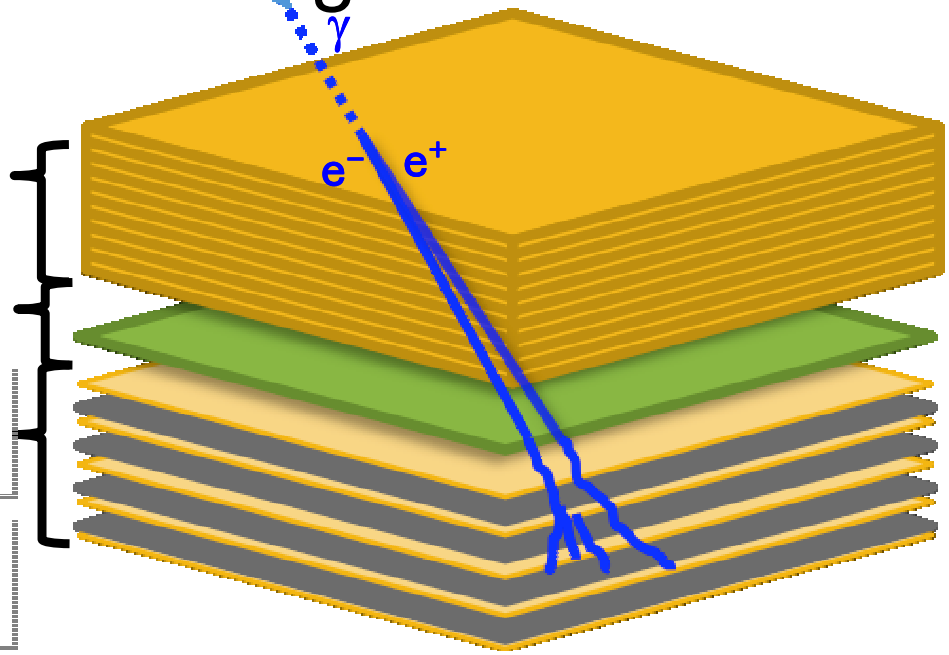
Gamma-Ray Astro-Imager with Nuclear Emulsion

Converter
Emulsion + Copper foil

Timestamper
Multi-stage shifter

Calorimeter
Emulsion + metal plate

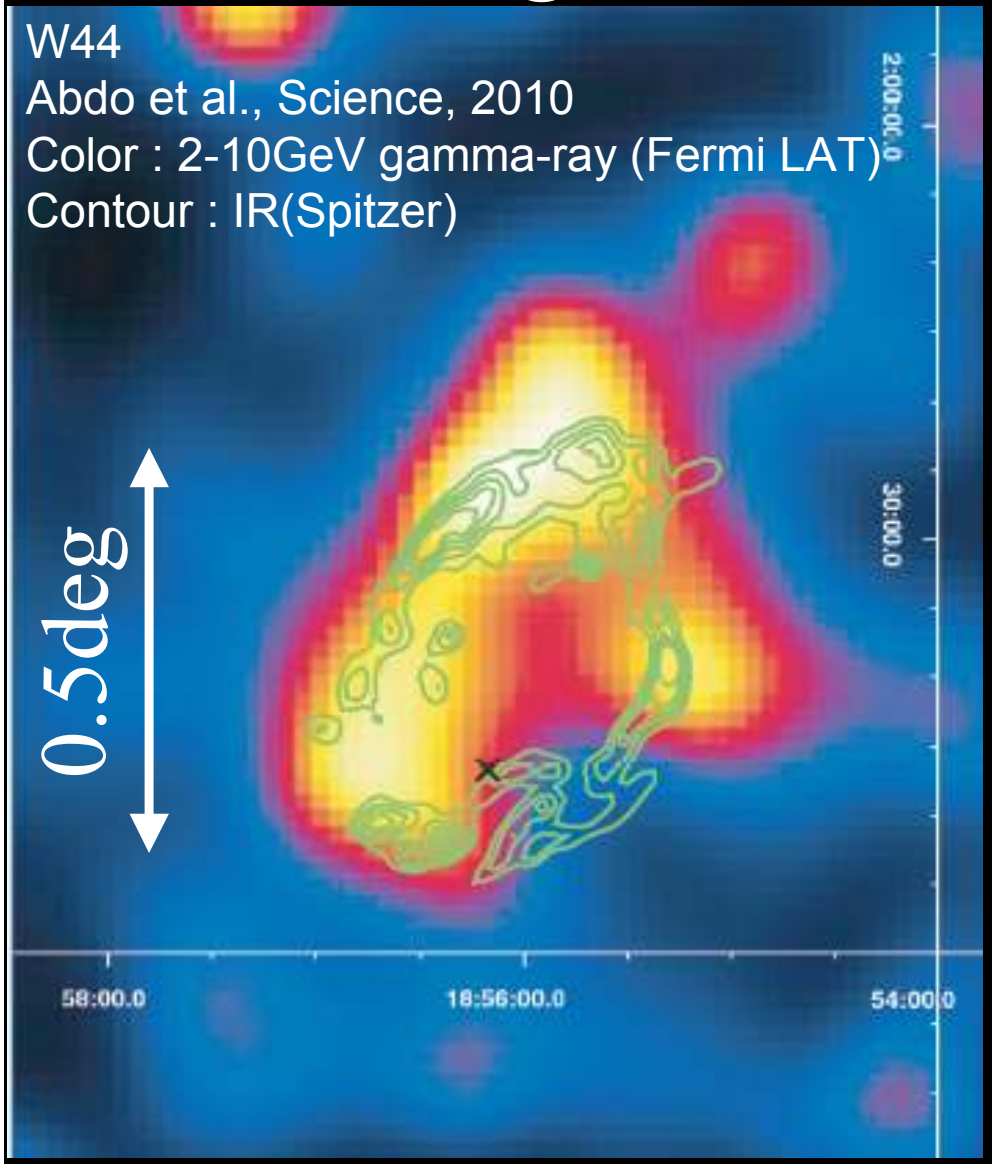
Attitude monitor
Star camera



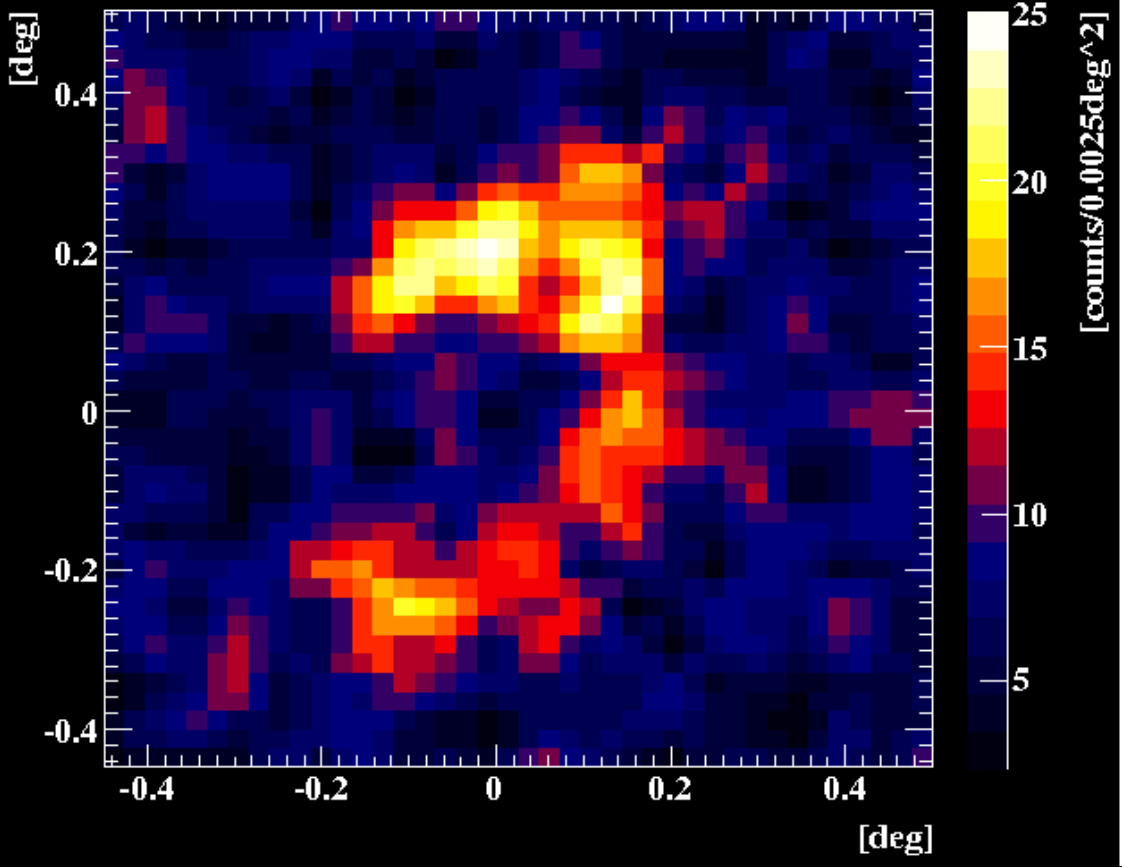
＊ $10m^2 * \varepsilon_{trans} * \varepsilon_{conv} * \varepsilon_{det}$

	Fermi LAT		GRAINE
Angular resolution @100MeV	6.0deg (105mrad)	x1/6 →	1.0deg (17mrad)
@1GeV	0.90deg (16mrad)	x1/9 →	0.1deg (1.7mrad)
Energy range	20MeV – 300GeV		10MeV – 100GeV
Polarization sensitivity	No		Yes
Effective area @ 100MeV	$0.25m^2$	x8 →	$2.1m^2$ ＊
@ 1GeV	$0.88m^2$	x3 →	$2.8m^2$ ＊
Dead time	26.5 μ sec(readout time)		Dead time free

High resolution imaging



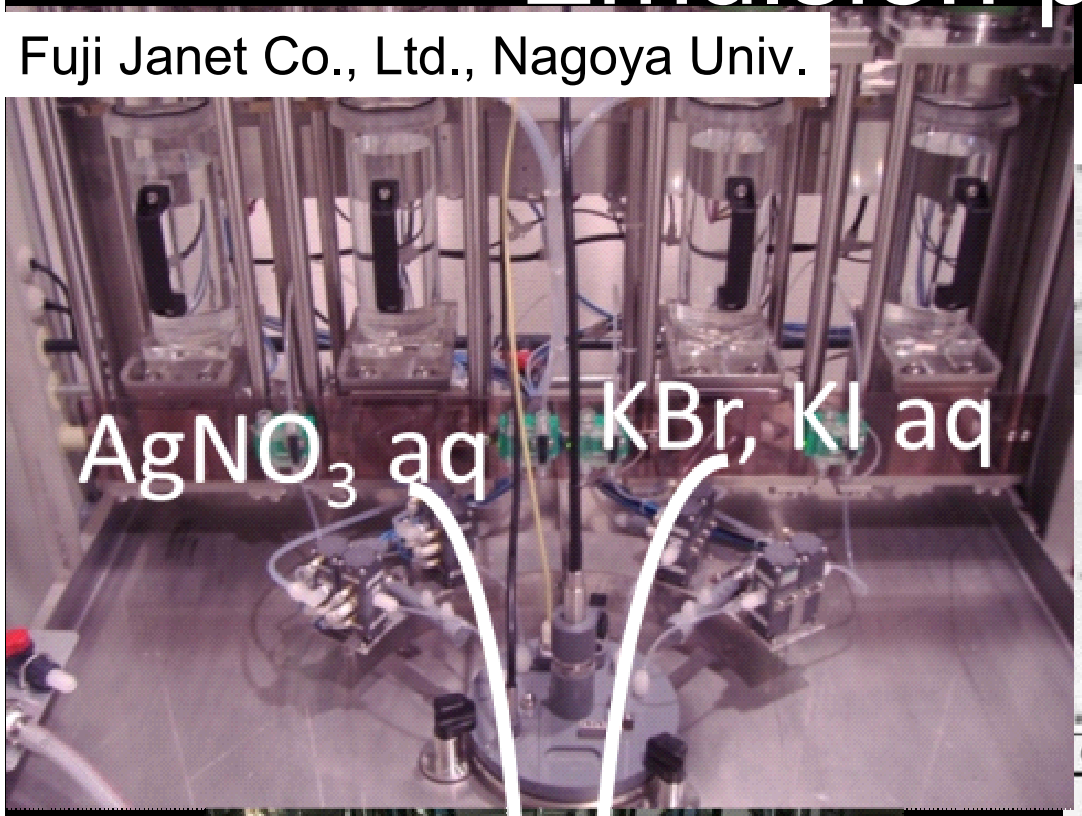
GRAINE (Simulation)

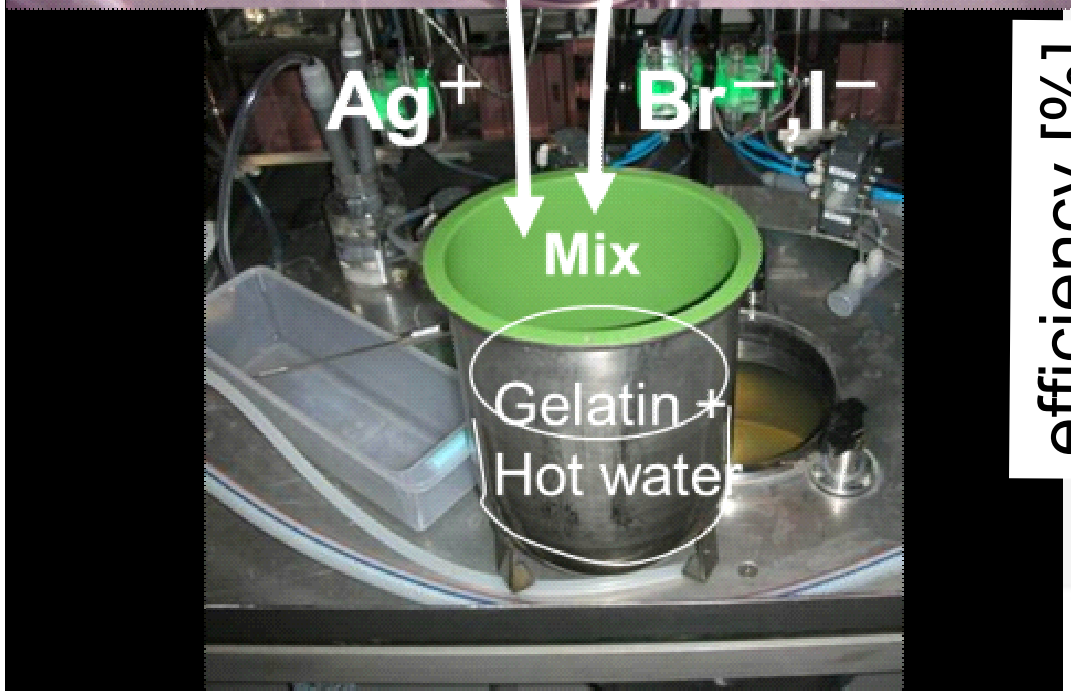


- **3flights** (41.7m^{2}days)
- >1GeV
- Smearing IR(Spitzer) distribution with 0.08deg(1.4mrad)
- Considering atmospheric gamma-ray(>1GeV) as BG

Emulsion production

Fuji Janet Co., Ltd., Nagoya Univ.

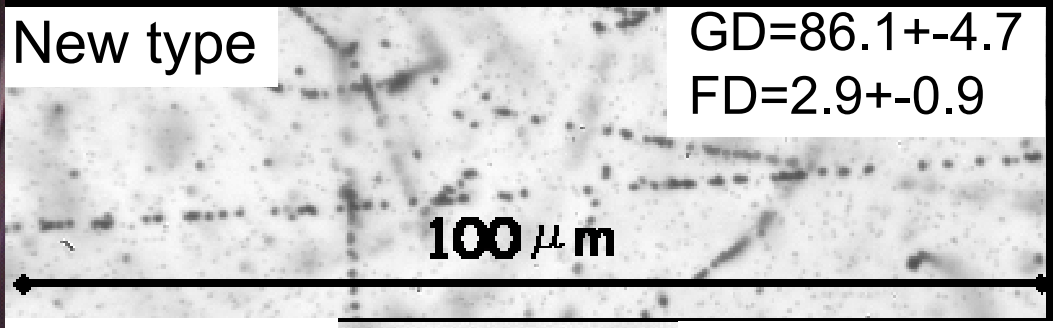




Gelatin1/4, Na type, Fe x 2, MIP (XAA, 20deg, 40min)

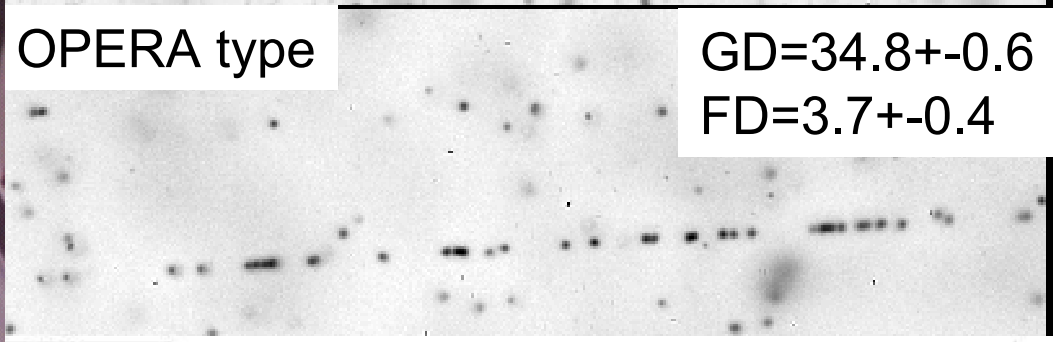
New type

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



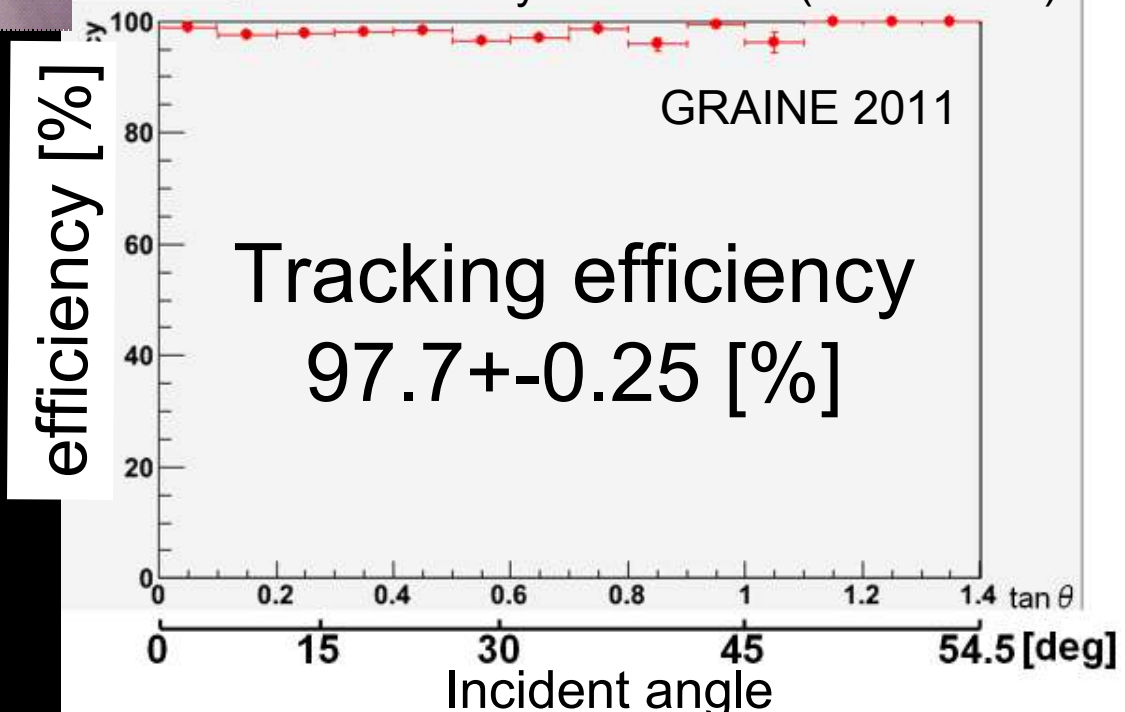
OPERA type

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



efficiency

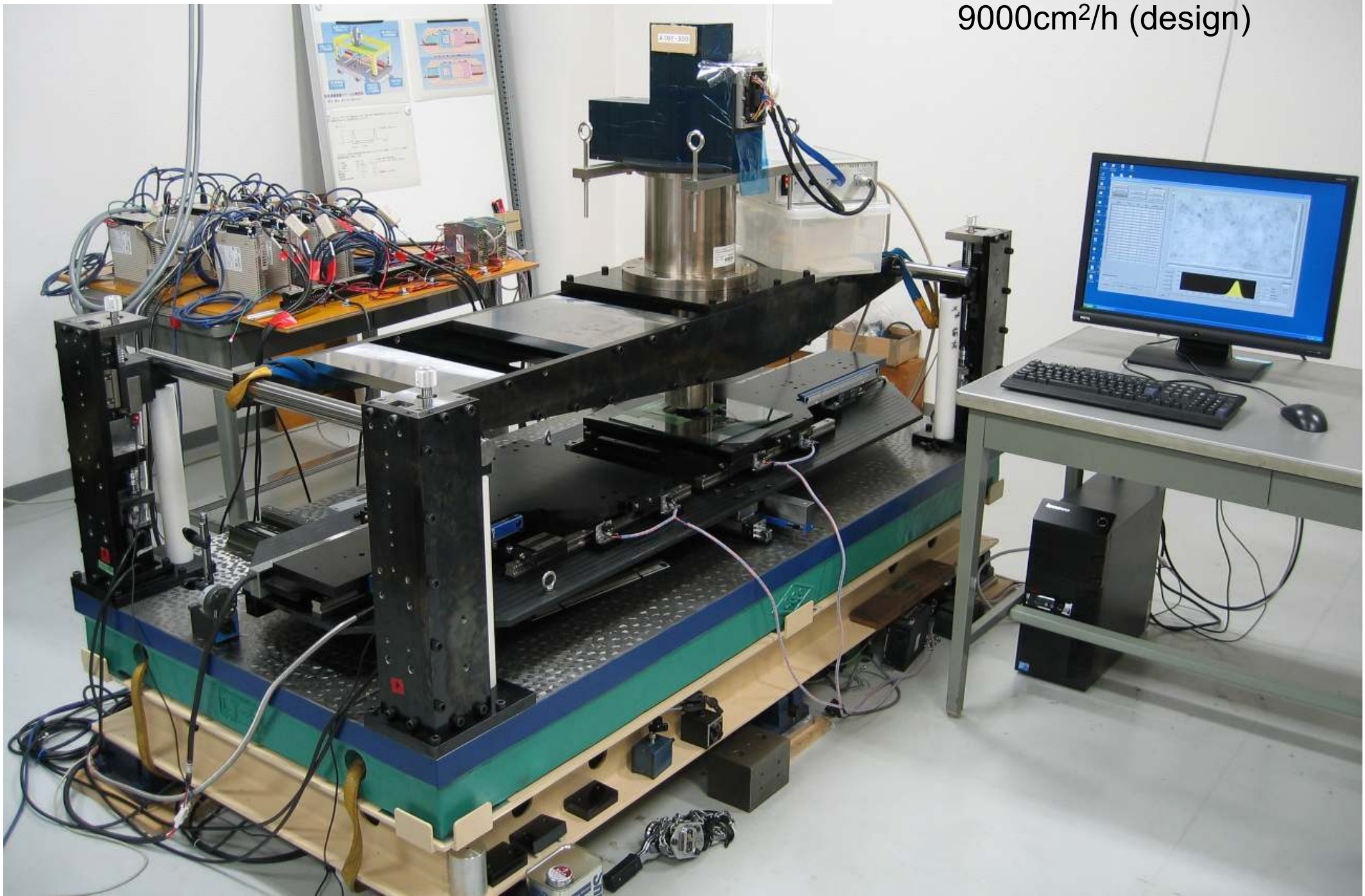
Evaluated by K. Kamada (Kobe Univ.)



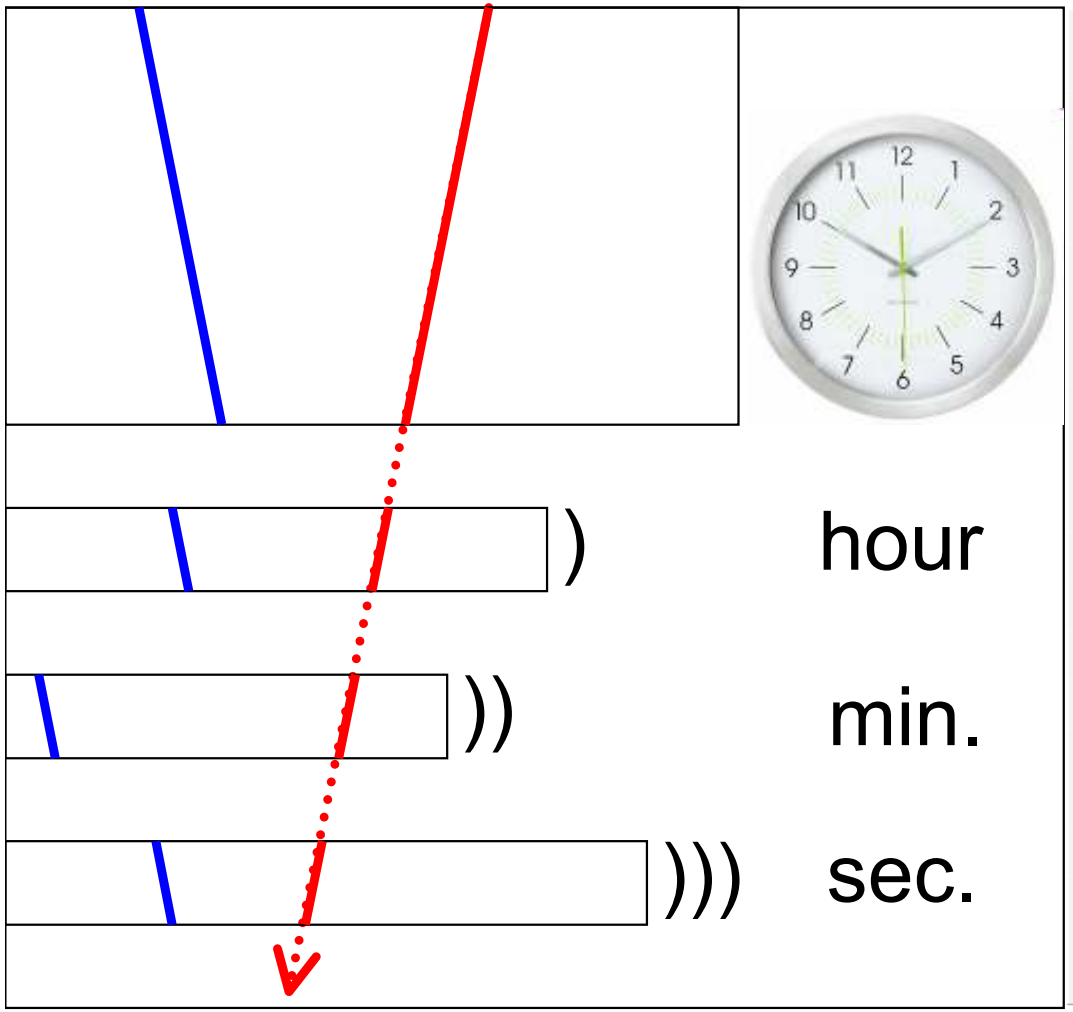
Automated emulsion read-out system (Nagoya Univ.)

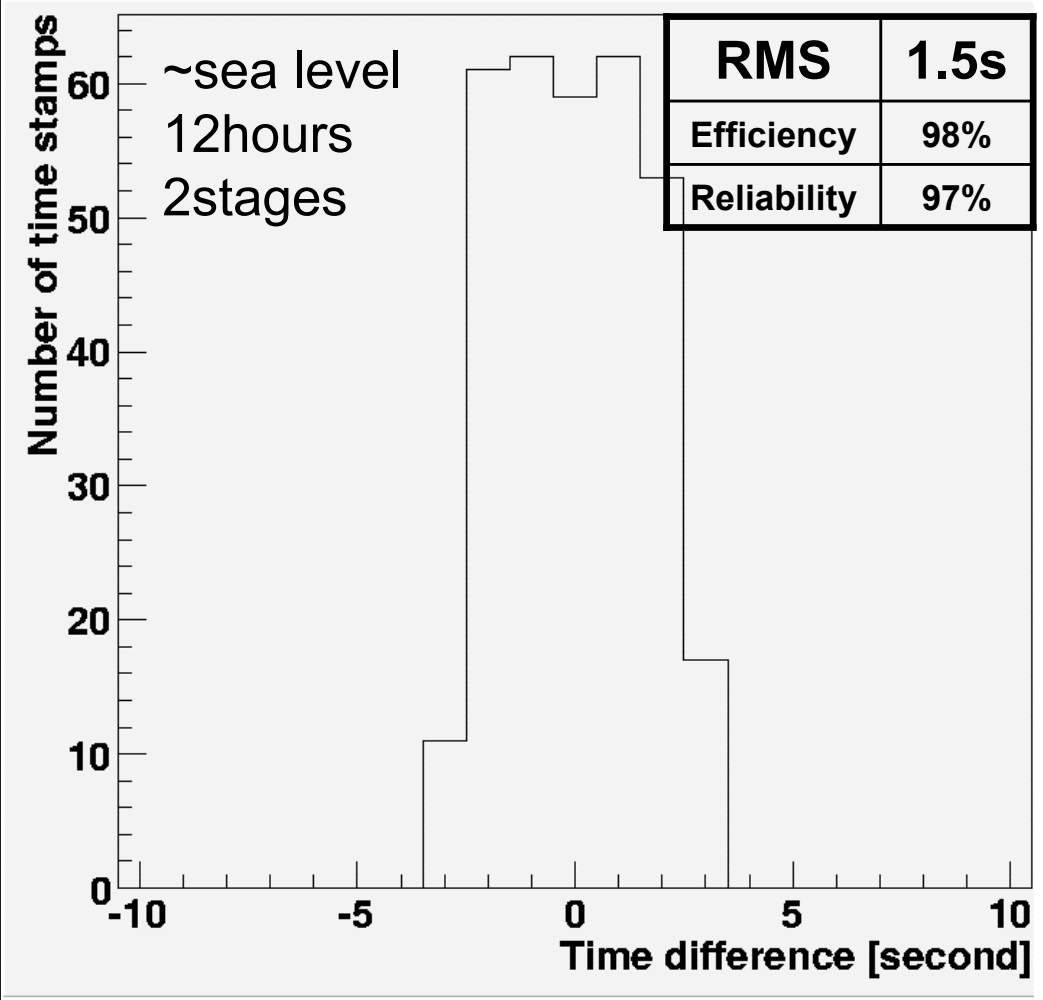
Hyper-TS: Next Generation Read-out system

Scanning speed
9000cm^2/h (design)



Multi-stage shifter





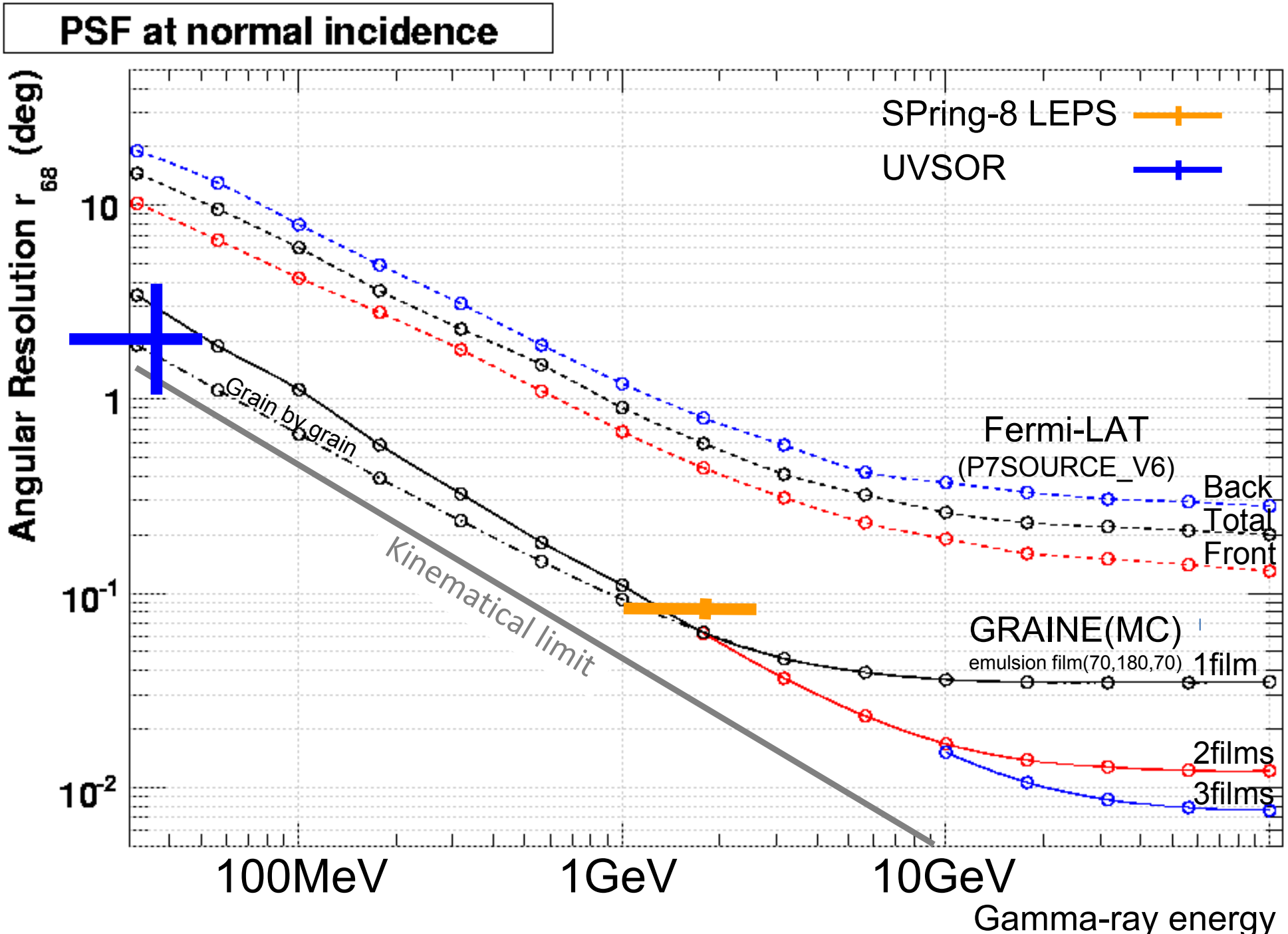
S.Takahashi et al., Nucl. Instr. And Meth. A, 620 (2010) 192-195

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

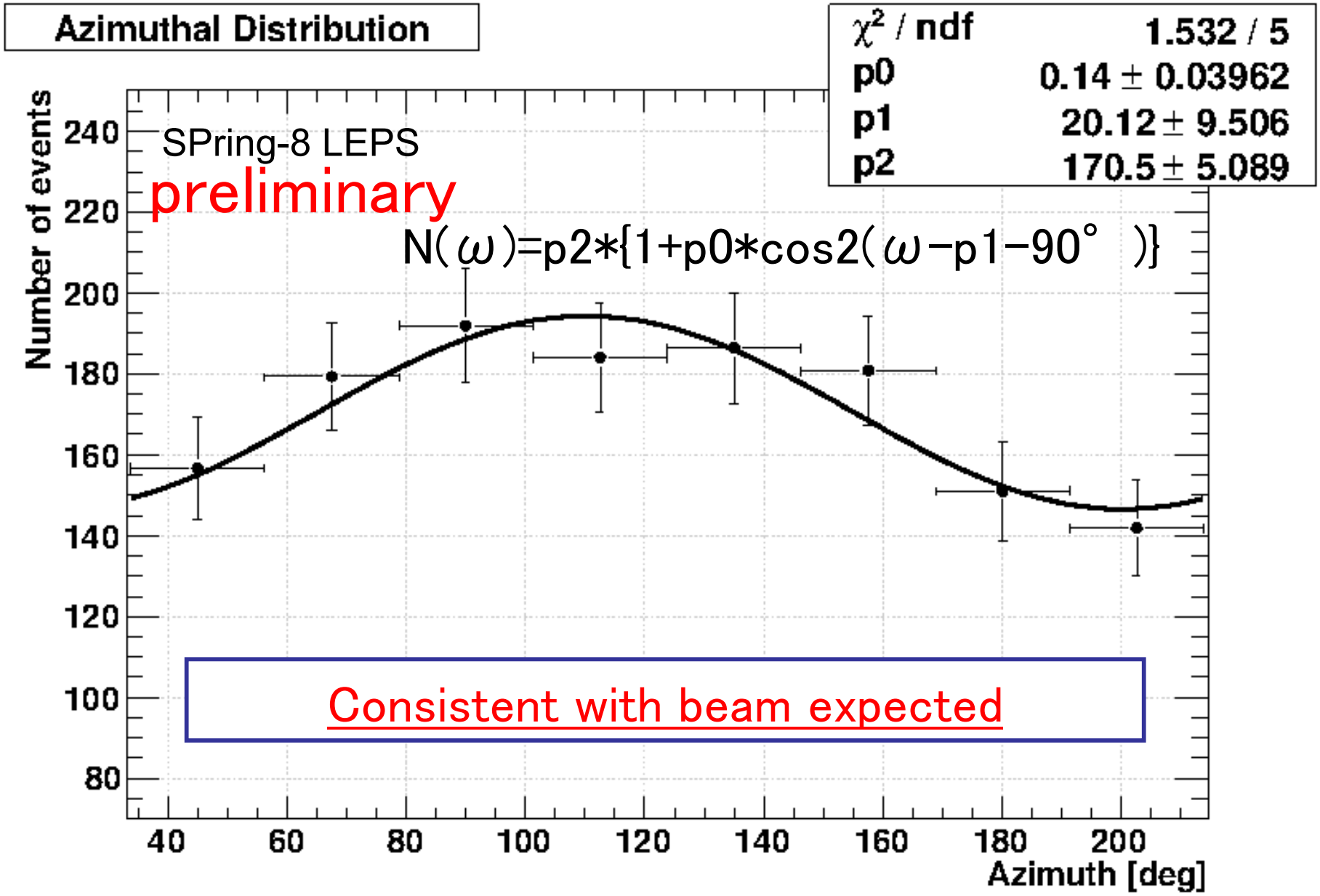
→ Low P threshold, High reliability, High efficiency, Large scale

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

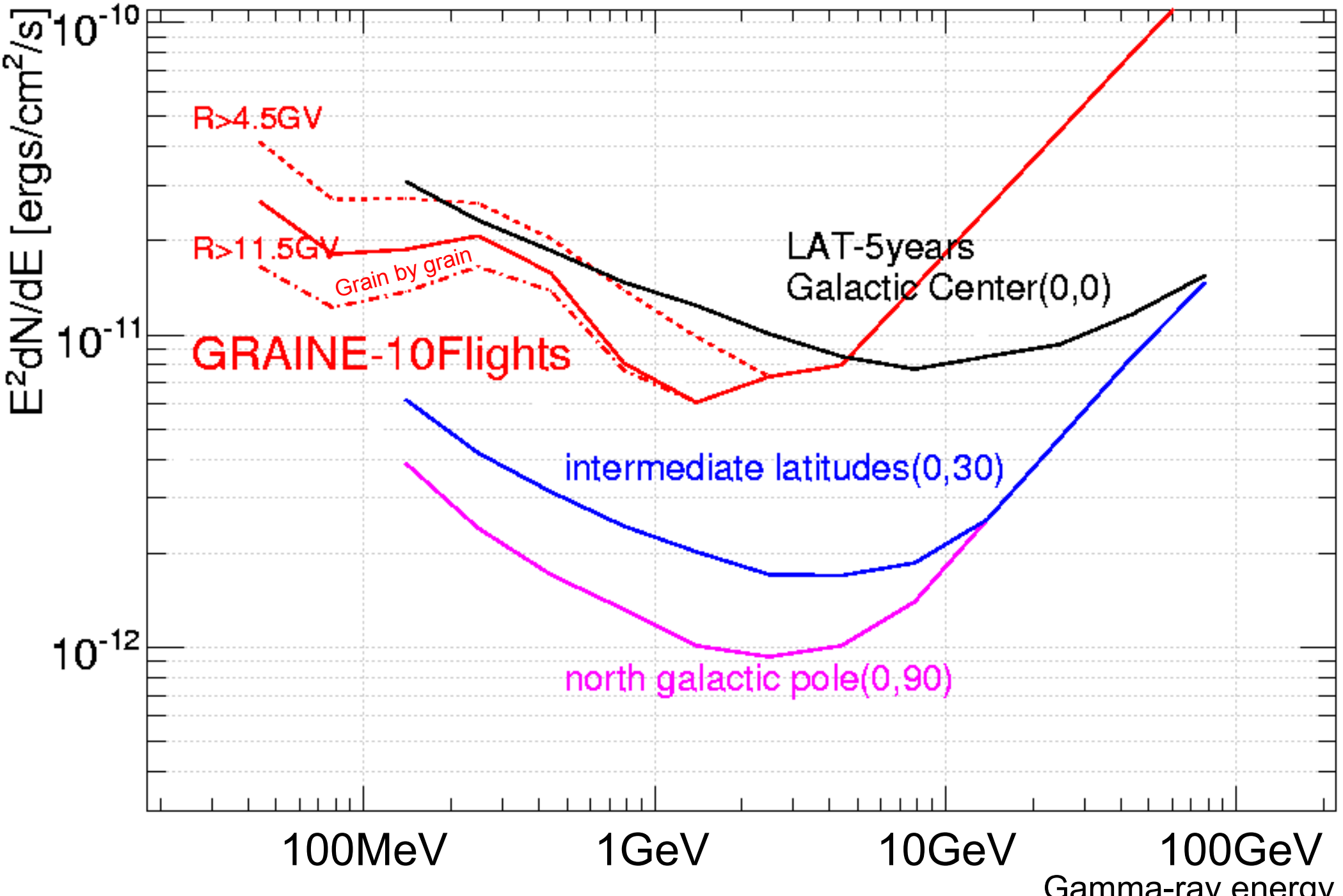
Angular resolution



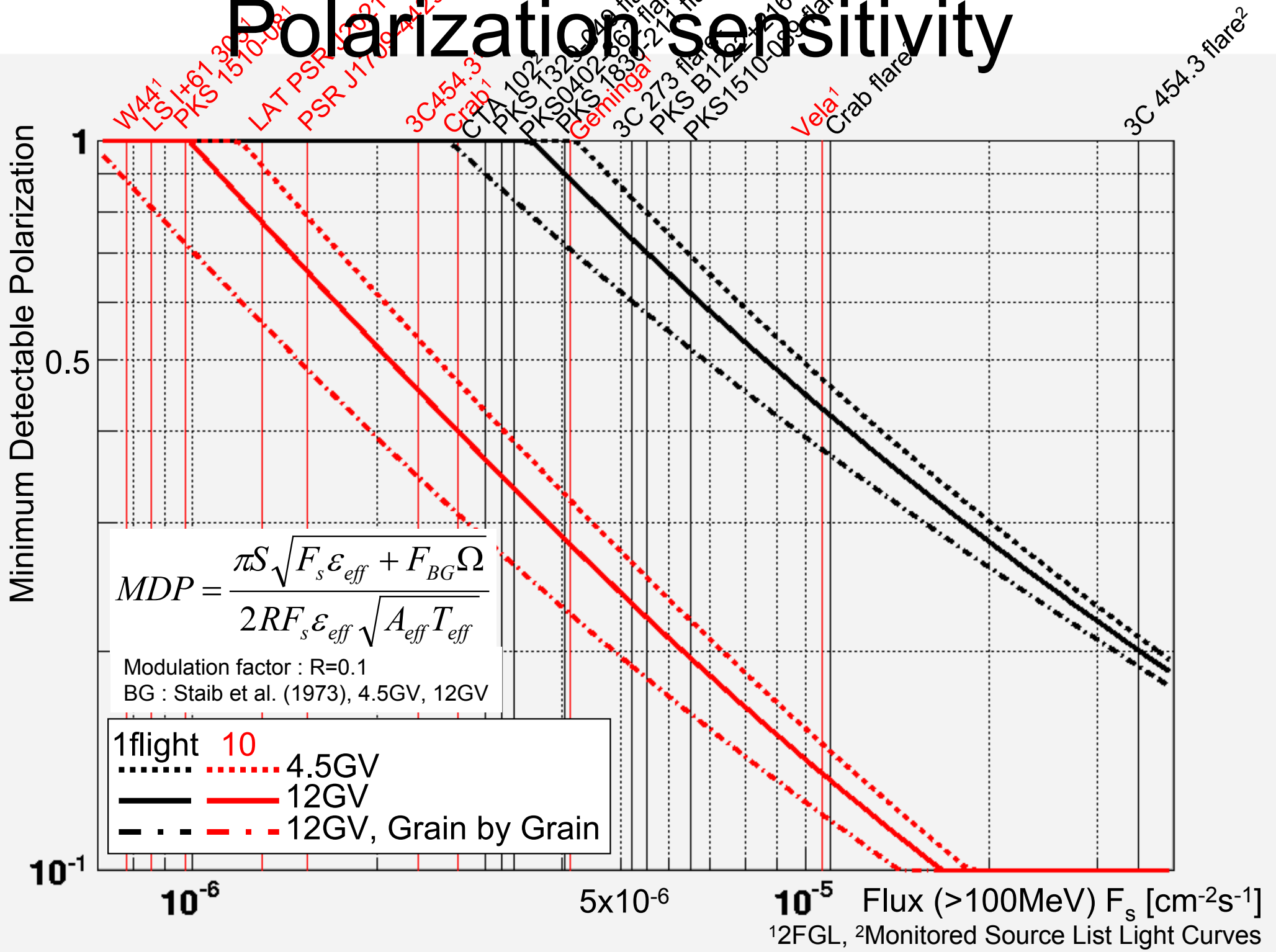
Polarization sensitivity



Source sensitivity



Polarization sensitivity



GRAINE roadmap

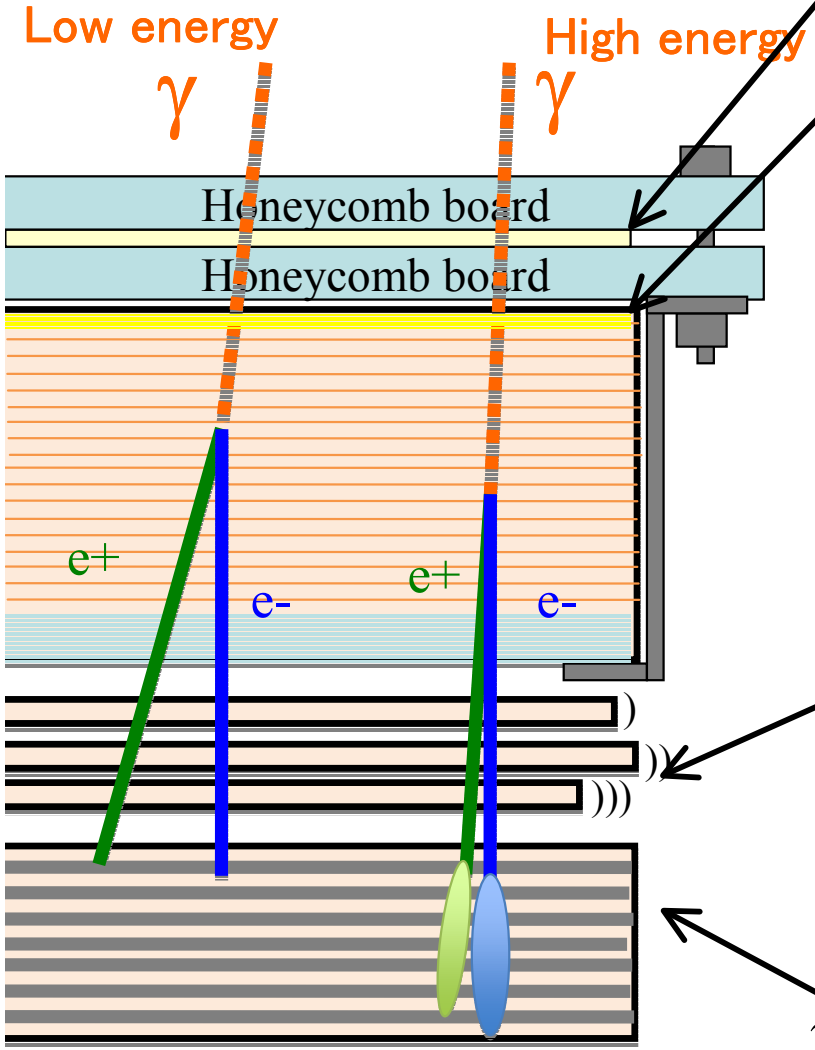
- 8th/June/2011, TARF, JAXA Scientific Ballooning, PI : S. Aoki (Kobe Univ.)
  12.5cm x 10cm aperture area, 4.3hours (1.6hours@35km) flight duration
  - Working test for each component
  - Connection test between components
  - Measurement of atmospheric gamma-rays

- 2014(Planned), Alice Springs, JAXA International Scientific Ballooning
  2500cm^2 aperture area, 1 day flight duration
  - Overall test by detecting known gamma-ray source
  - Observation with highest imaging resolution

- 2015-
  10m^2 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 (50μm)

1.1kg, 35.0mm, 0.54Xo(ε_{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

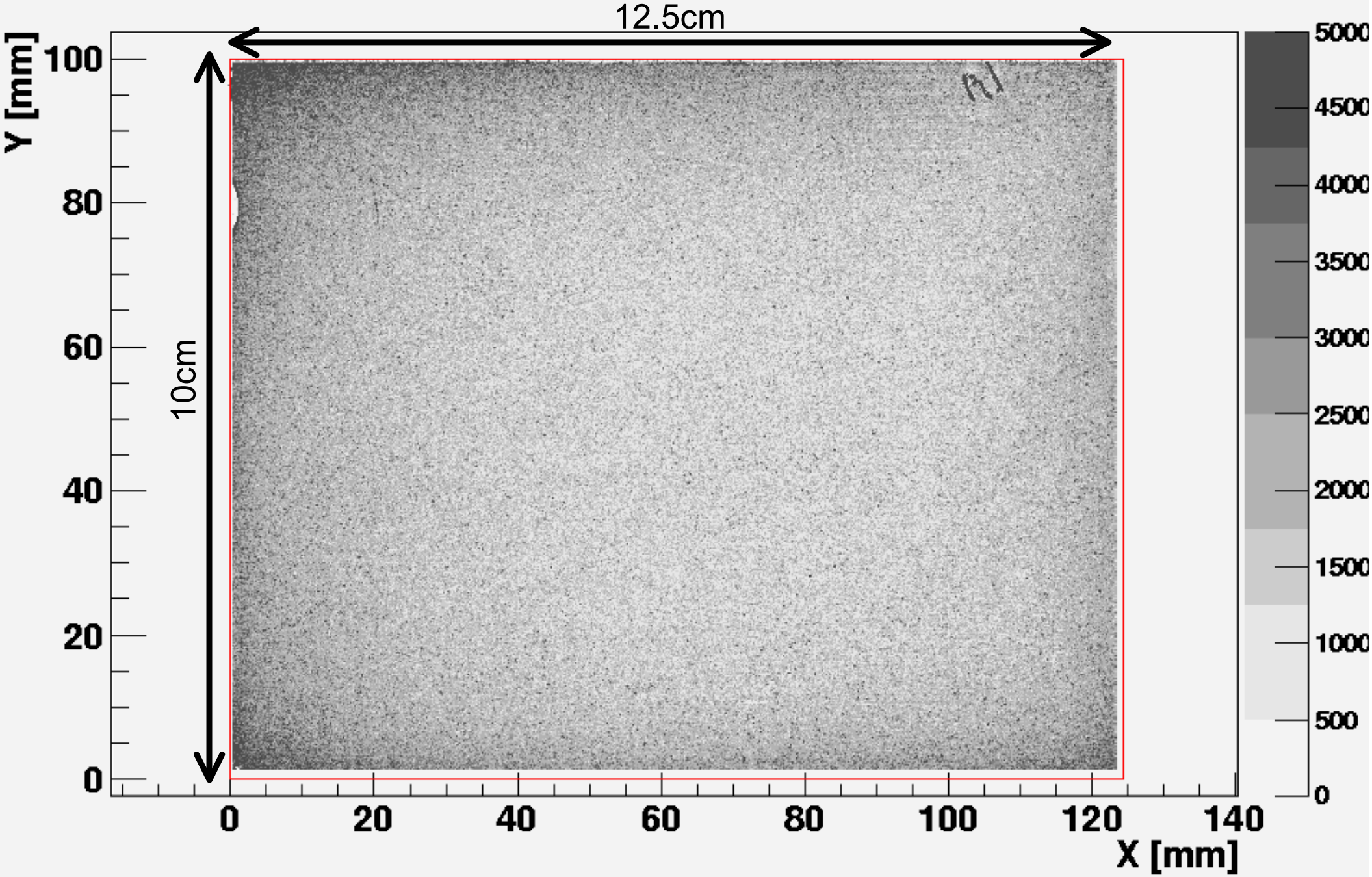
3.2kg, 31.9mm, 4.0Xo (Shower Max.@ a few GeV)

OPERA film x 5 (go-ban part)

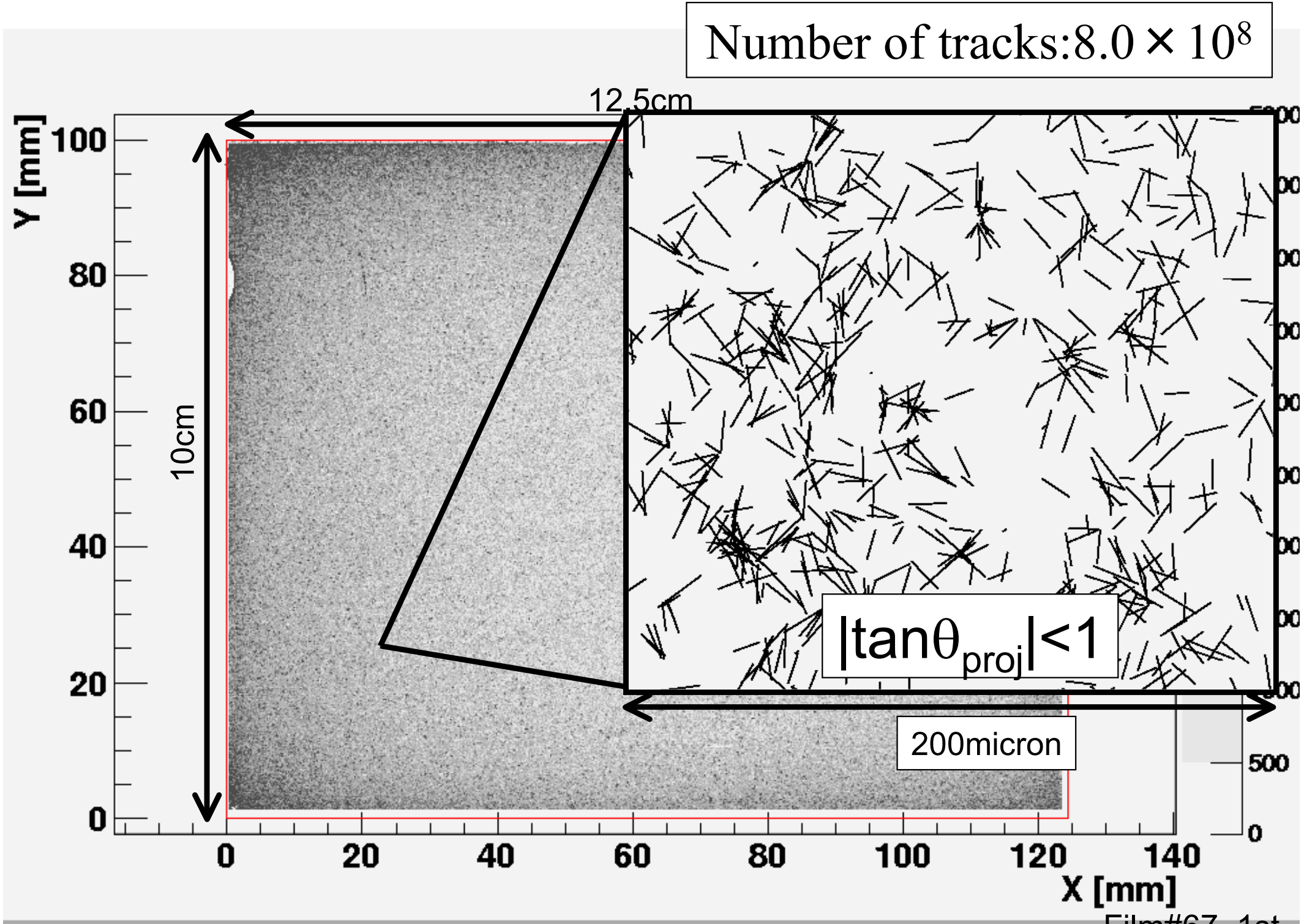
(OPERA film + lead plate(0.5mm))x10

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

Number of tracks:8.0×10^8

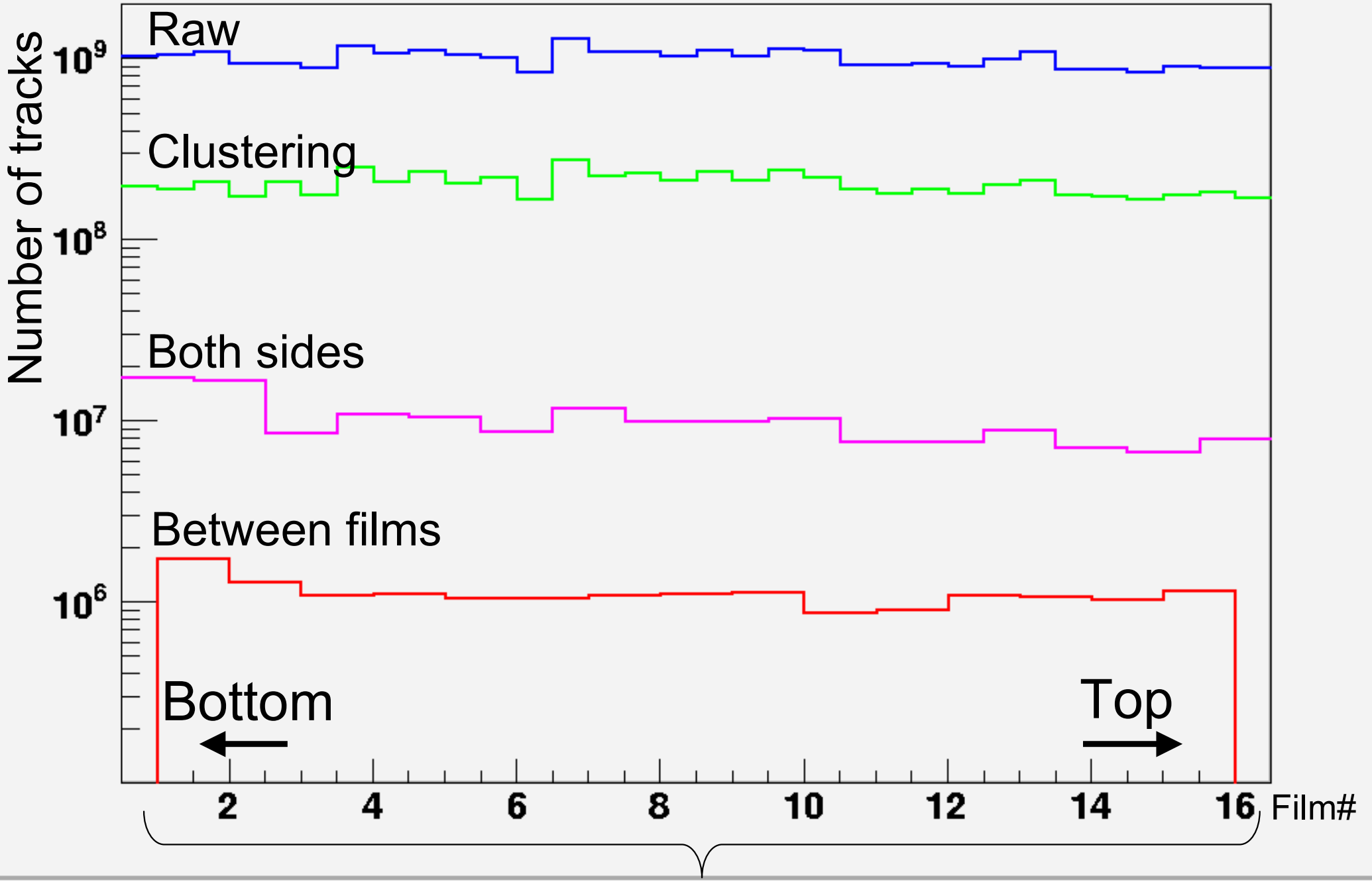


Film#67, 1st

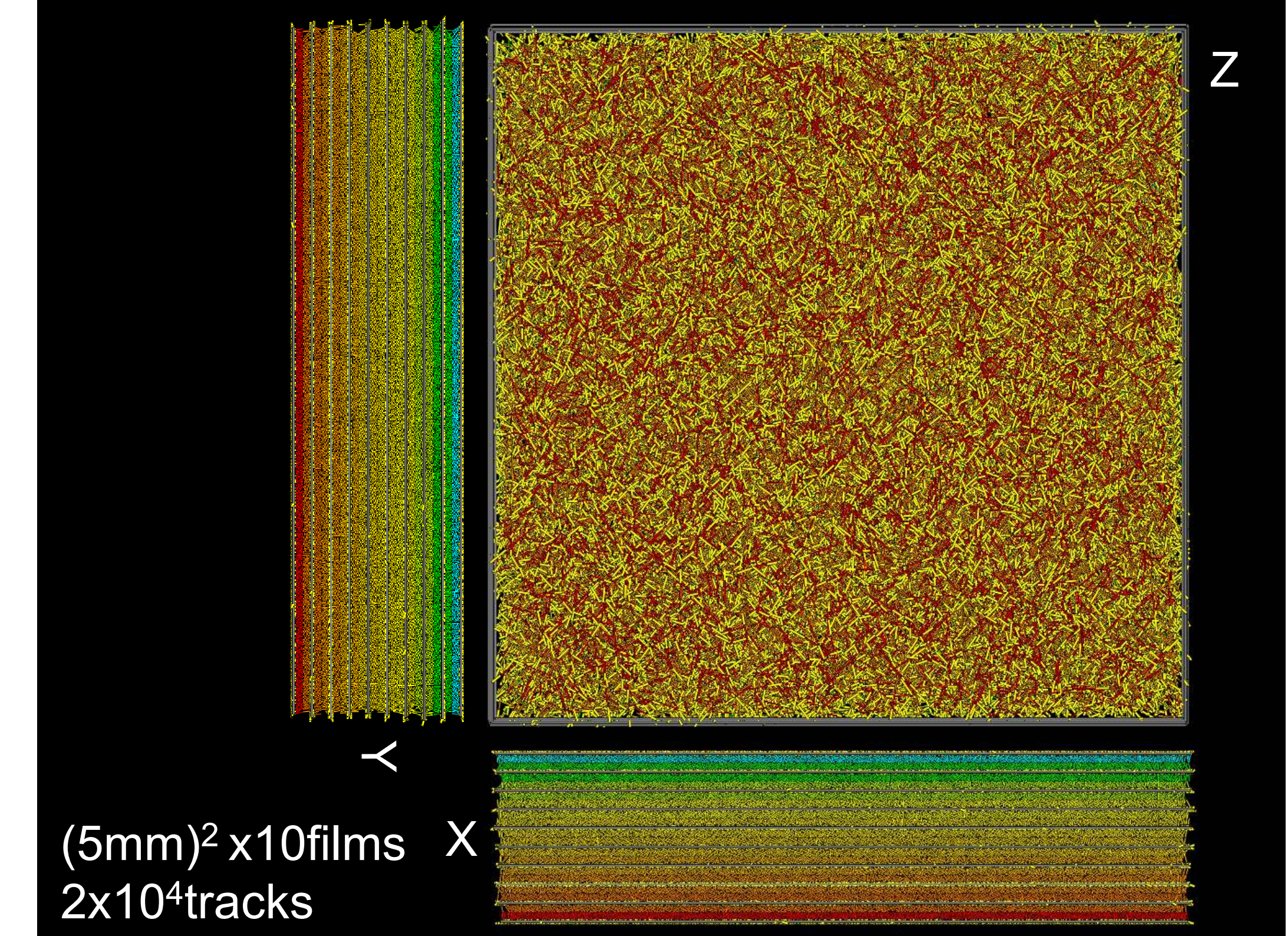

Number of tracks:8.0 × 10^8
12.5cm
10cm
200micron
|tanθproj|<1
Y [mm]
X [mm]
0
20
40
60
80
100
120
140
500

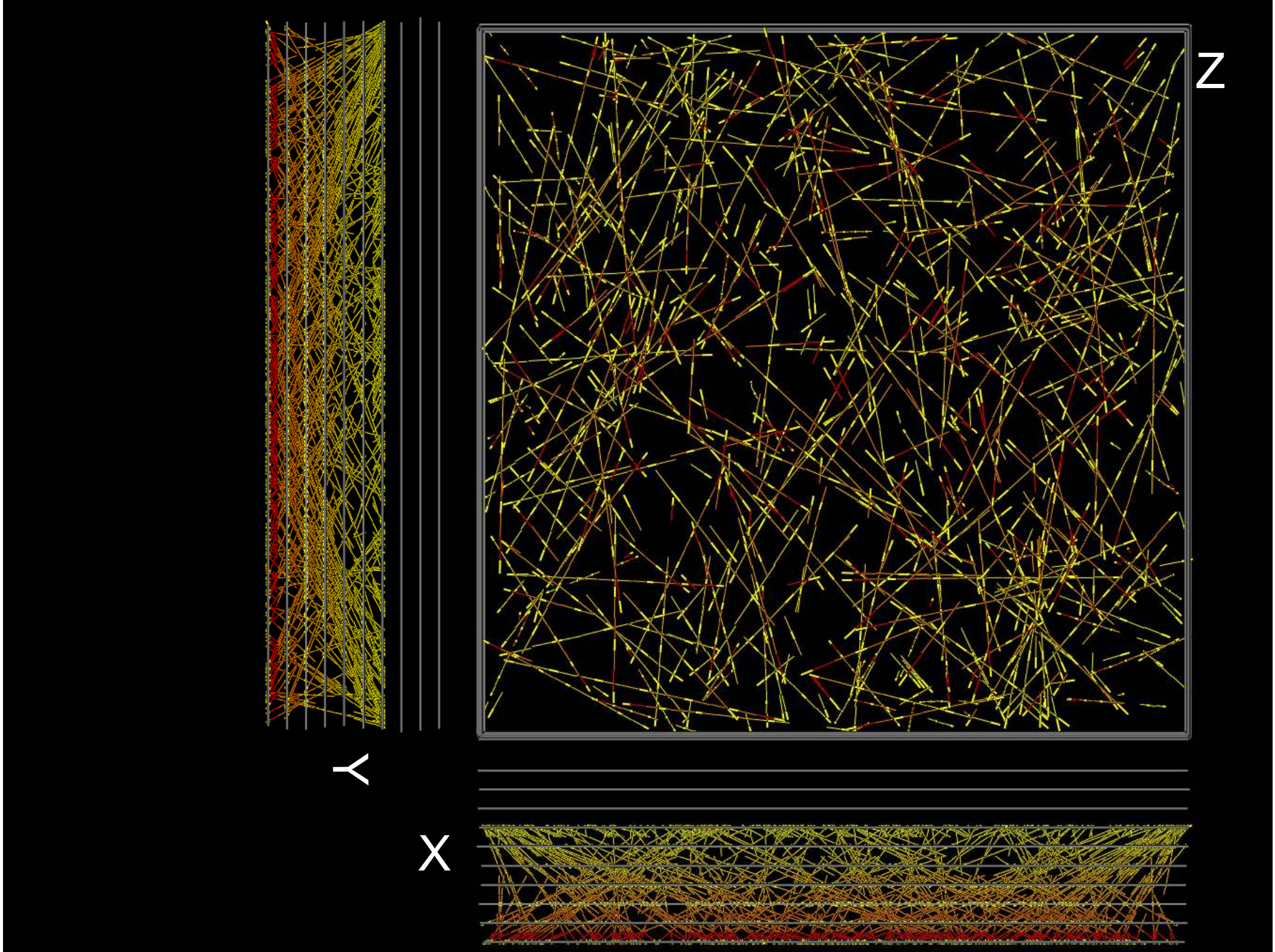
Film#67, 1st

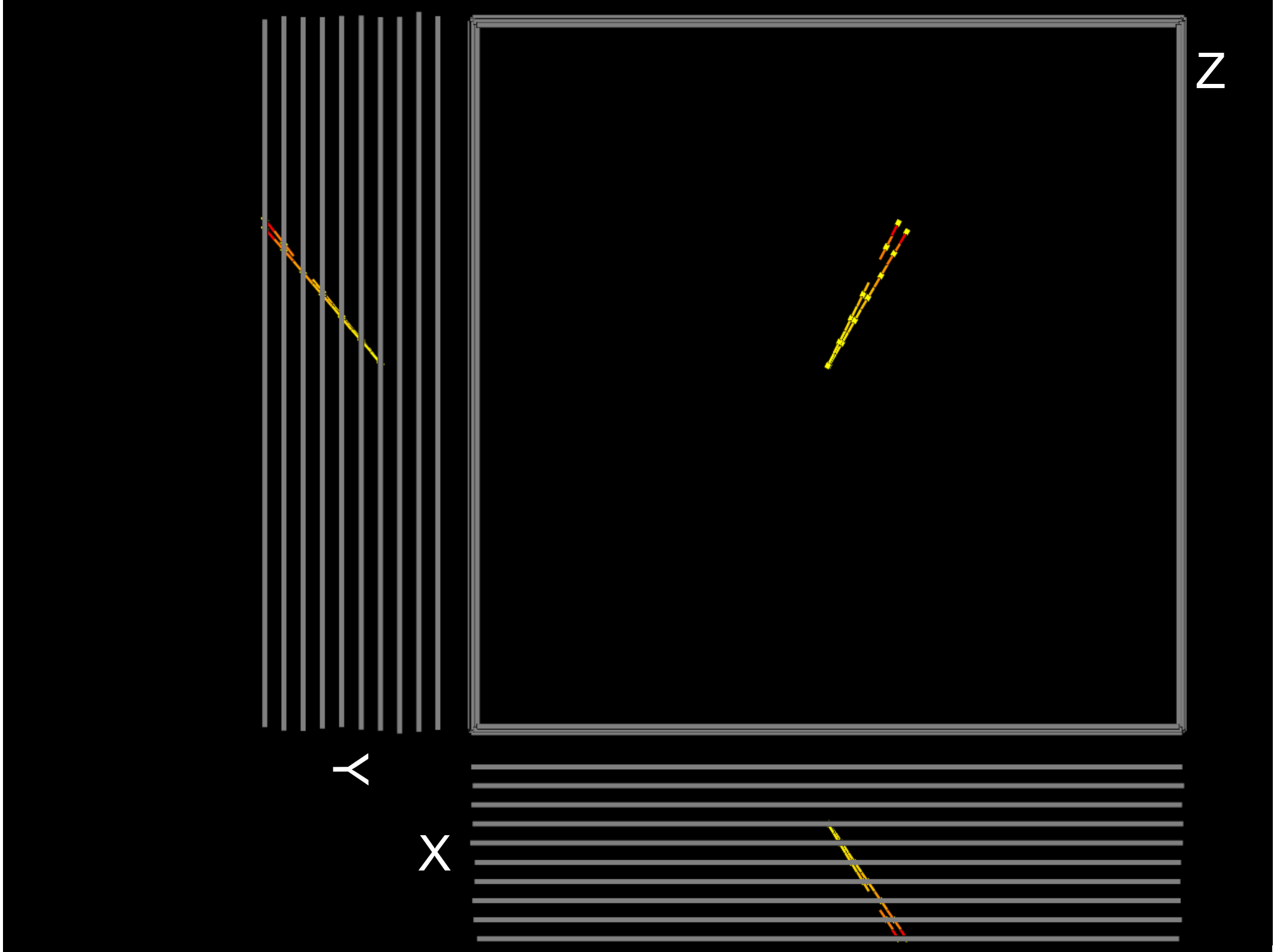
Track reconstruction

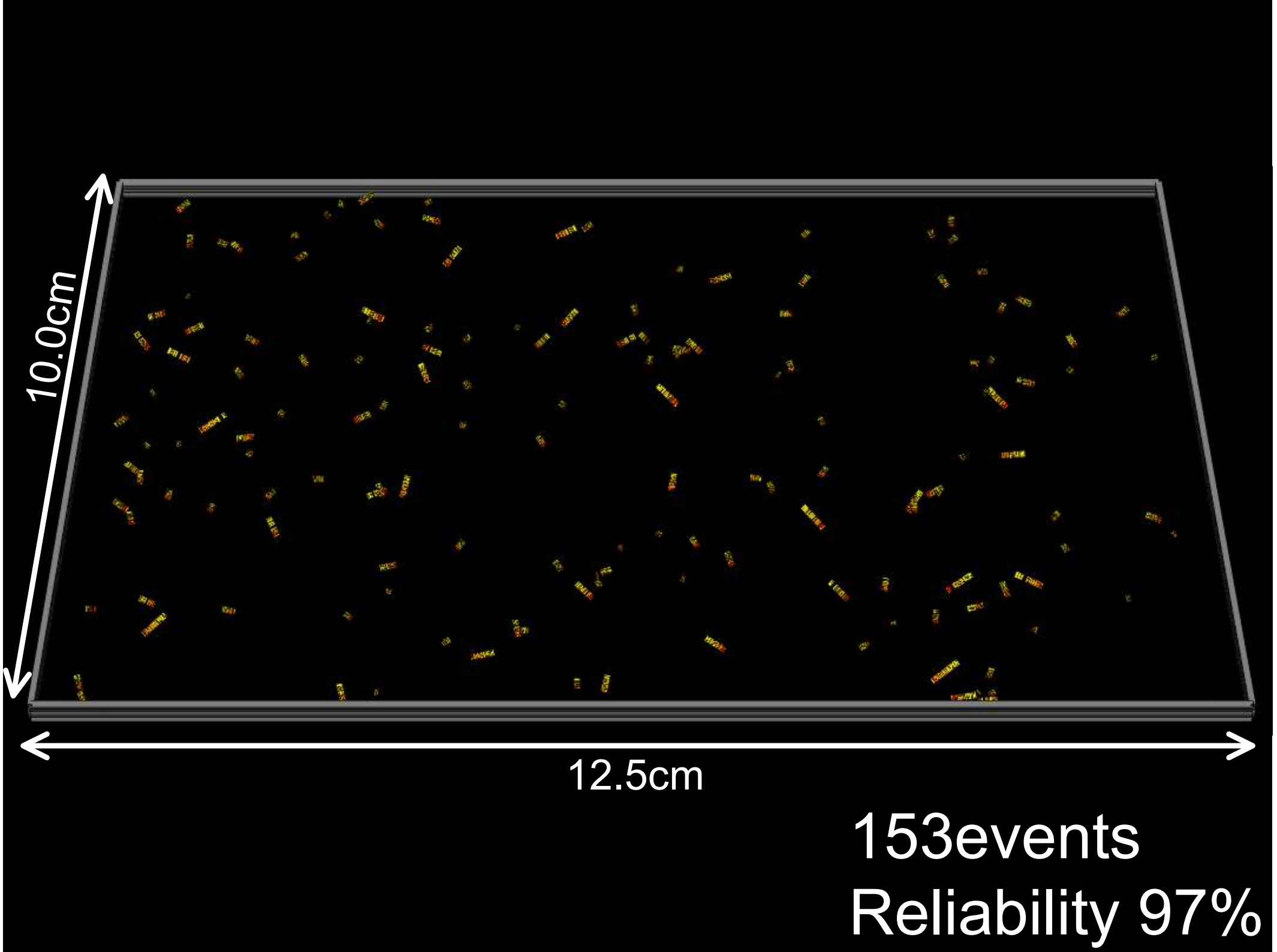


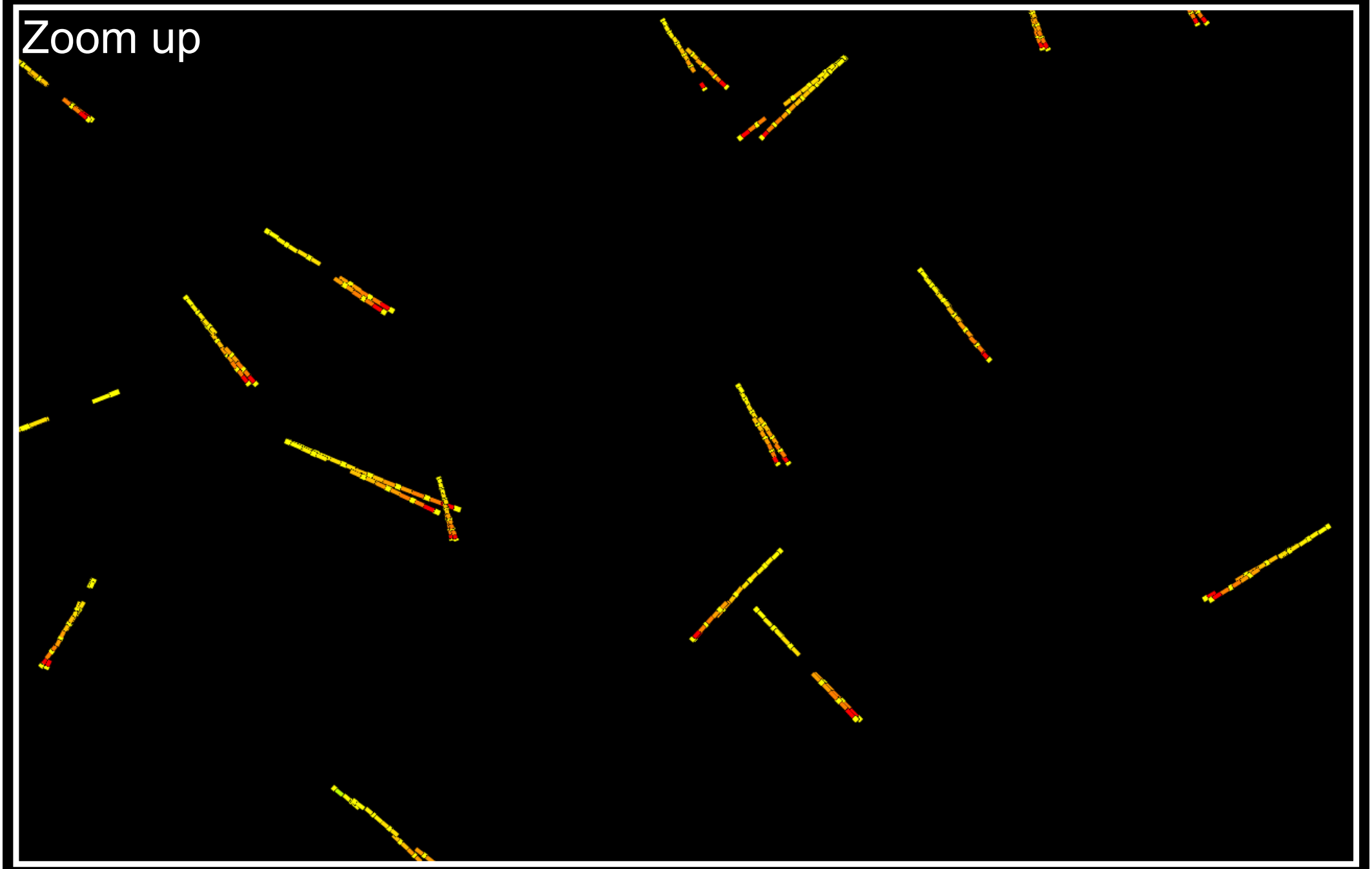
Reconstructed tracks (film#1-16) : 8.7×10^7 (overlap)


Z
Y
X
(5mm)^2 x10films
2x10^{4}tracks


Z
Y
X

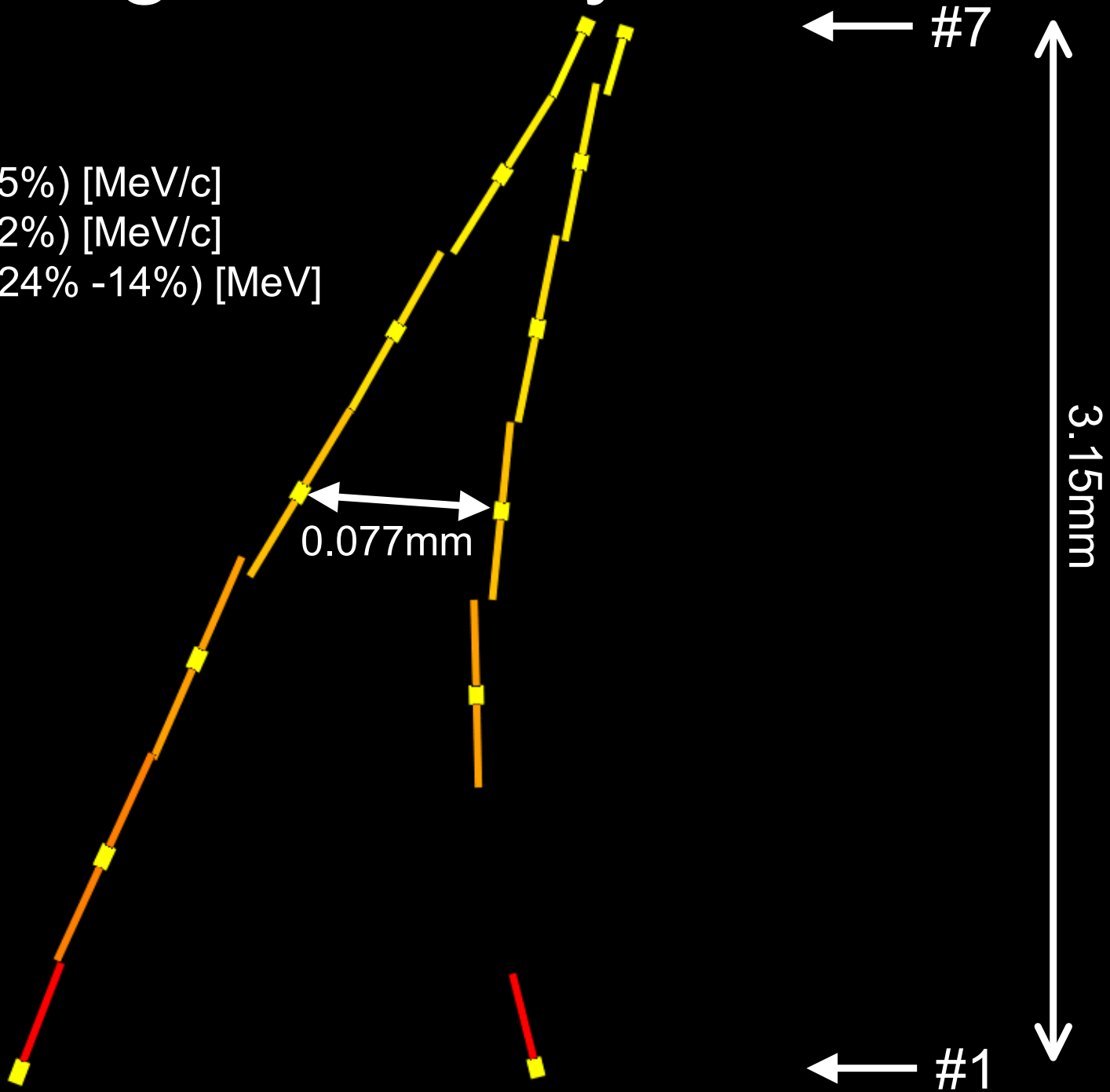

Z
Y
X


10.0cm
12.5cm
153events
Reliability 97%


Zoom up

One of gamma-ray events

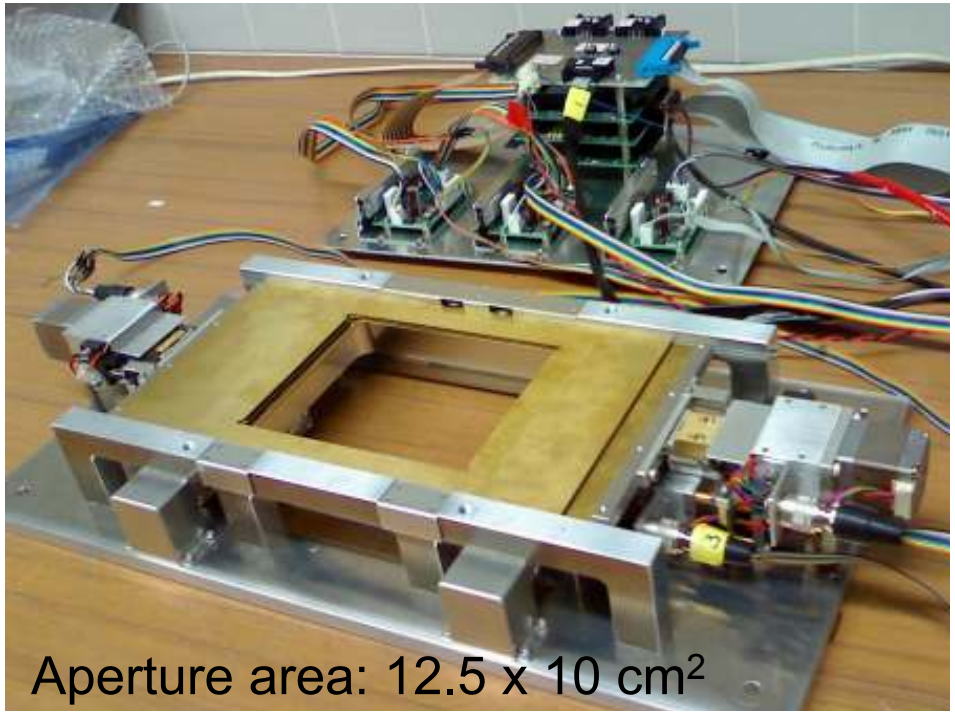
Event : 71 6923485
Start : #7
$\theta_{incident}$: 9.748 [deg]
$(p\beta)_{left}$: 60 +20 -12 (25%) [MeV/c]
$(p\beta)_{right}$: 32 + 9 - 6 (22%) [MeV/c]
$E\gamma$: 92 +22 -13 (+24% -14%) [MeV]



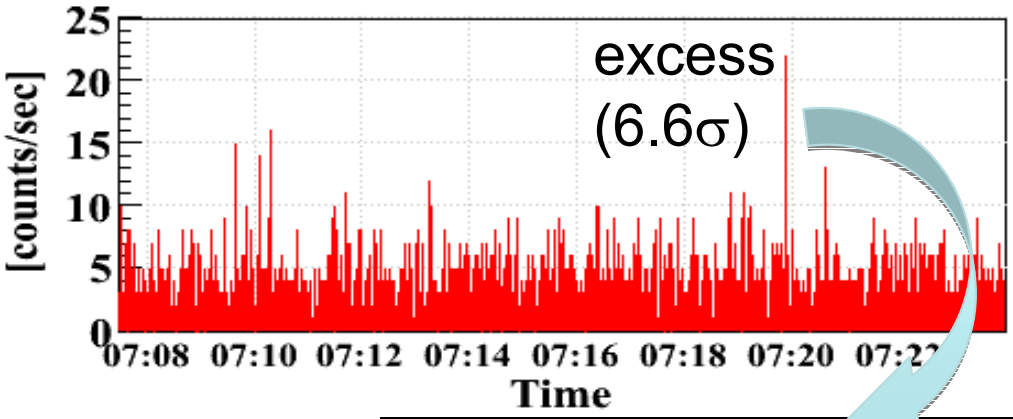
Establishment of timestamp technique @GRAINE2011

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

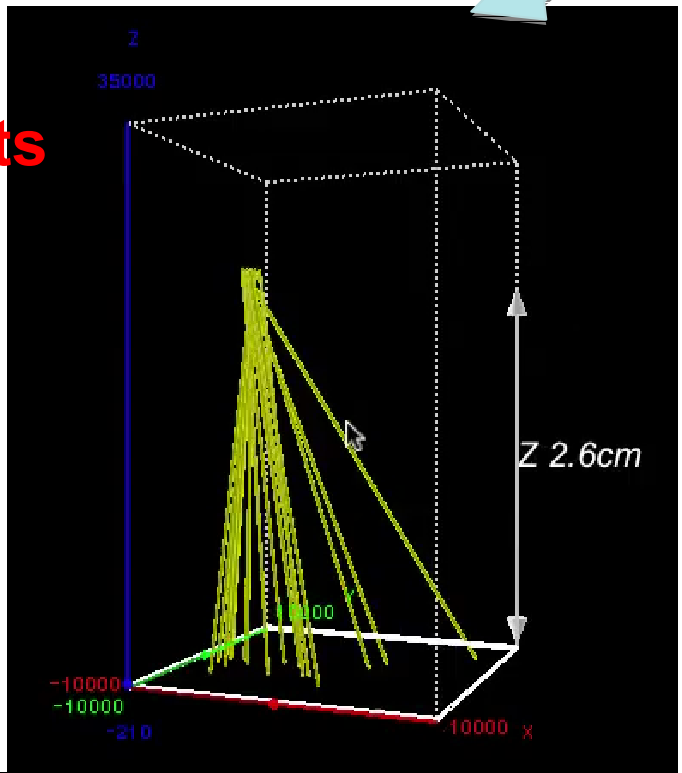
"Multi-stage shifter" 1st model



Track rate mesurement@35km



Detection of hadron events



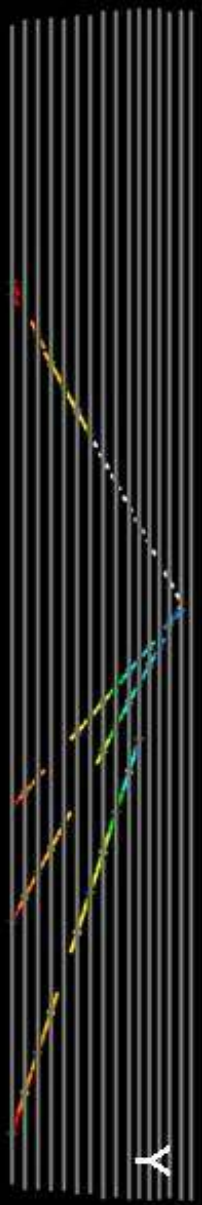
- Correct operation during whole observation time
- Giving time info. to all penetrating tracks
- Detection of hadron shower tracks by timing and 3-D spatial analysis
- Time resolution: 0.15 sec

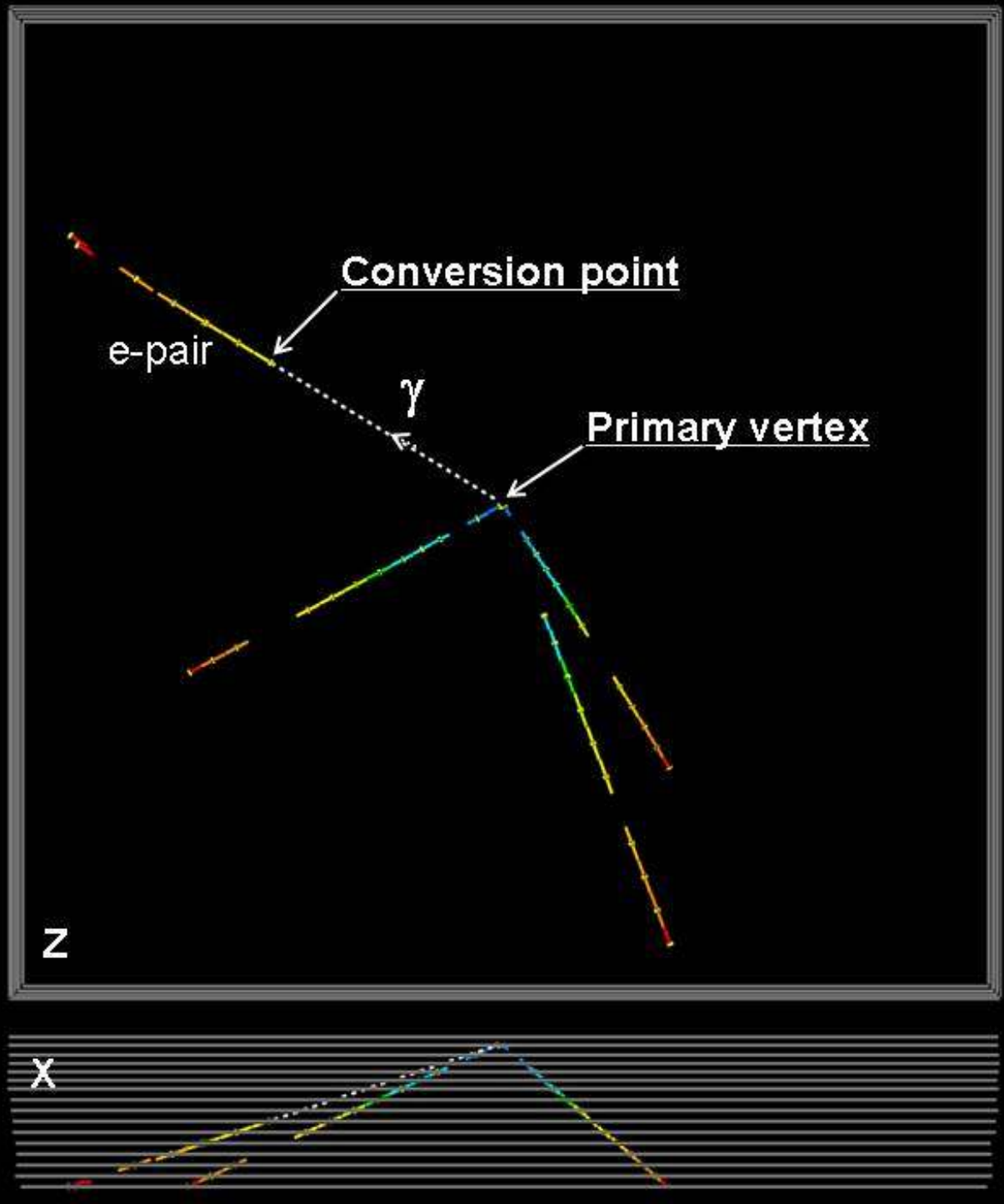
Hadron induced event

Ev : 2438038
Eγ : 45+33-10[MeV]
θγ : 46.61[deg]
7:18:34.5 (JST)

Δt=+-0.5s
Convergence

1.2cm x 1.2cm
x 16films





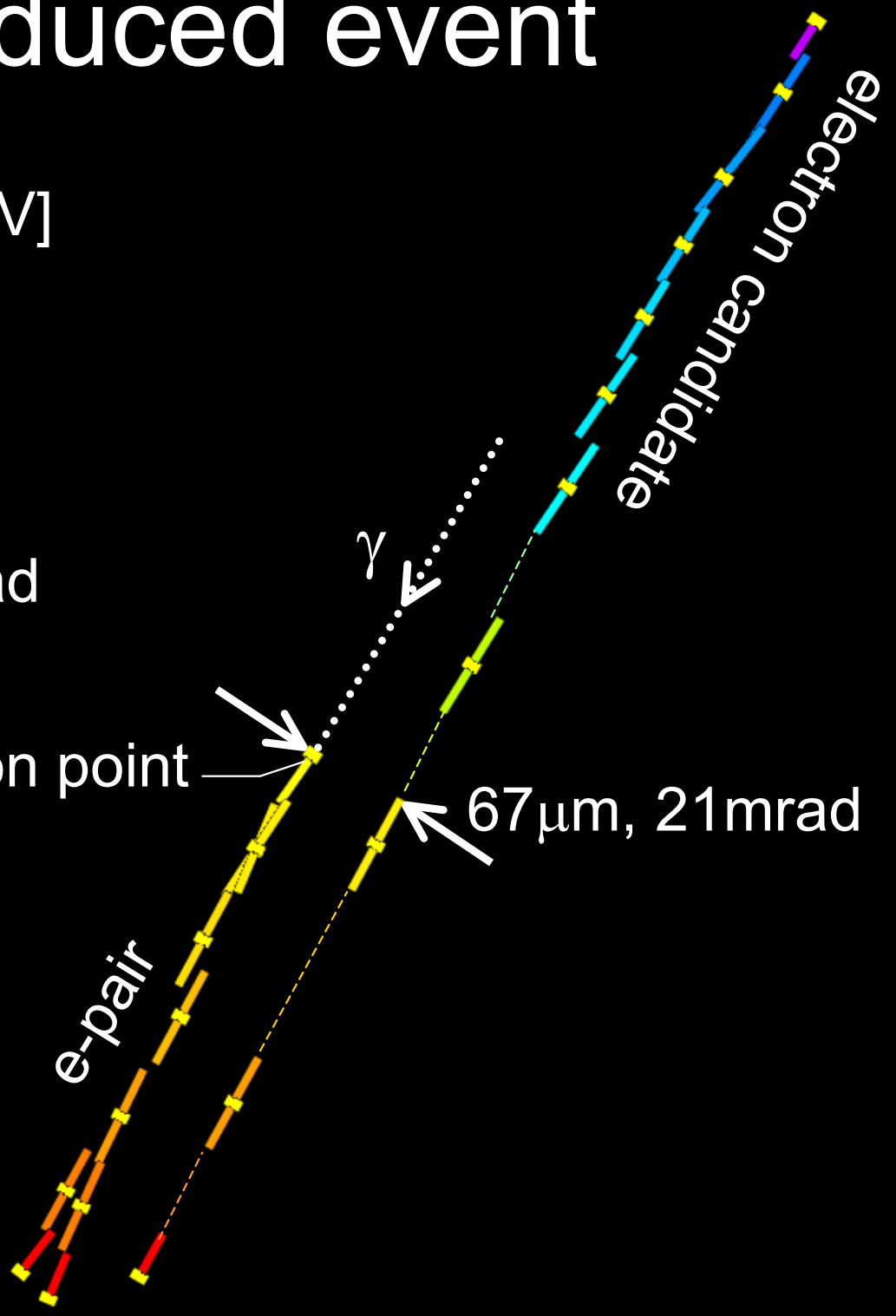
Pointing accuracy

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

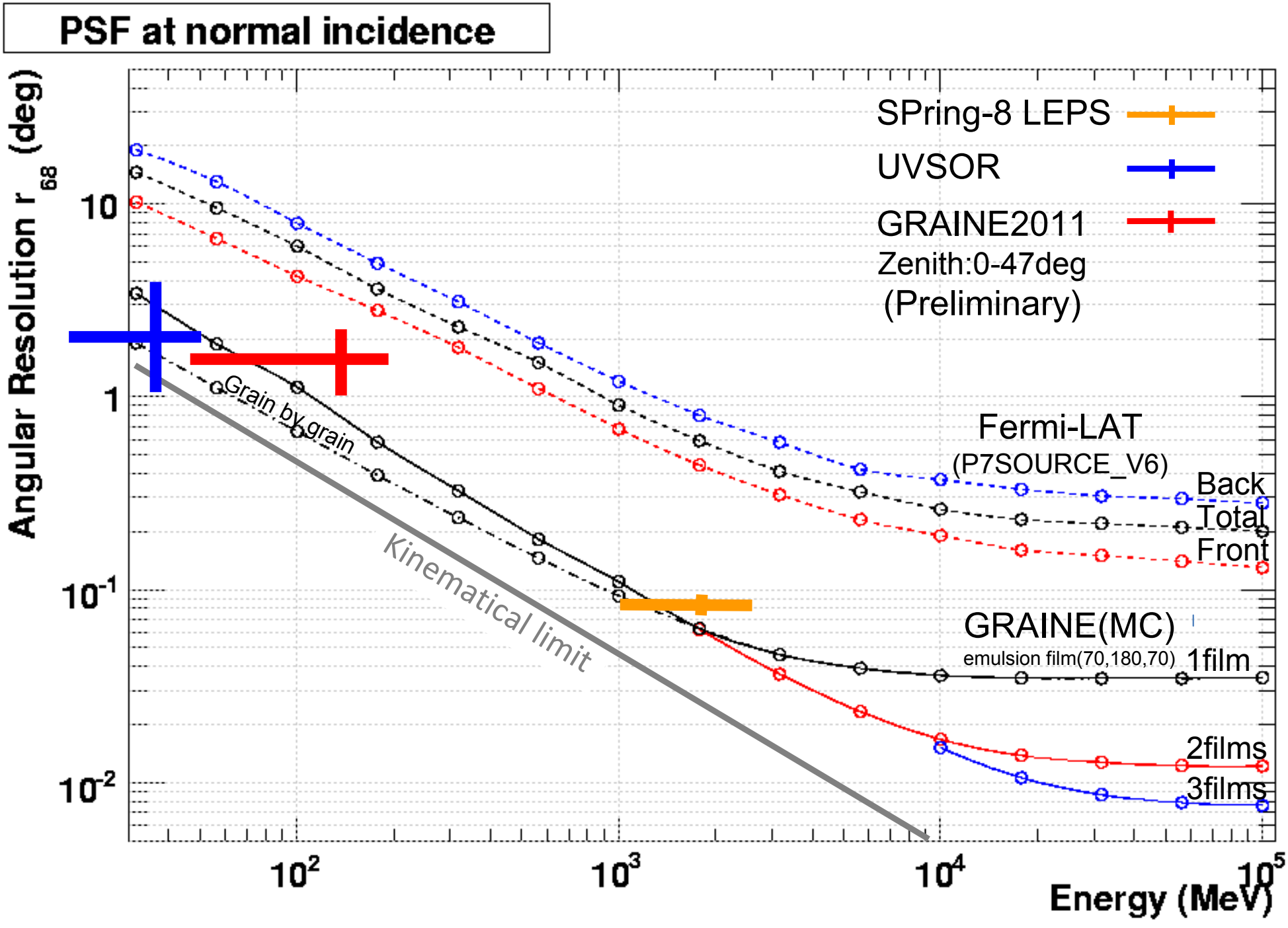
Electron induced event

Ev : 7797344
Eγ : 100+64-23 [MeV]
θγ : 38.96 [deg]
8:15:52.9 (JST)

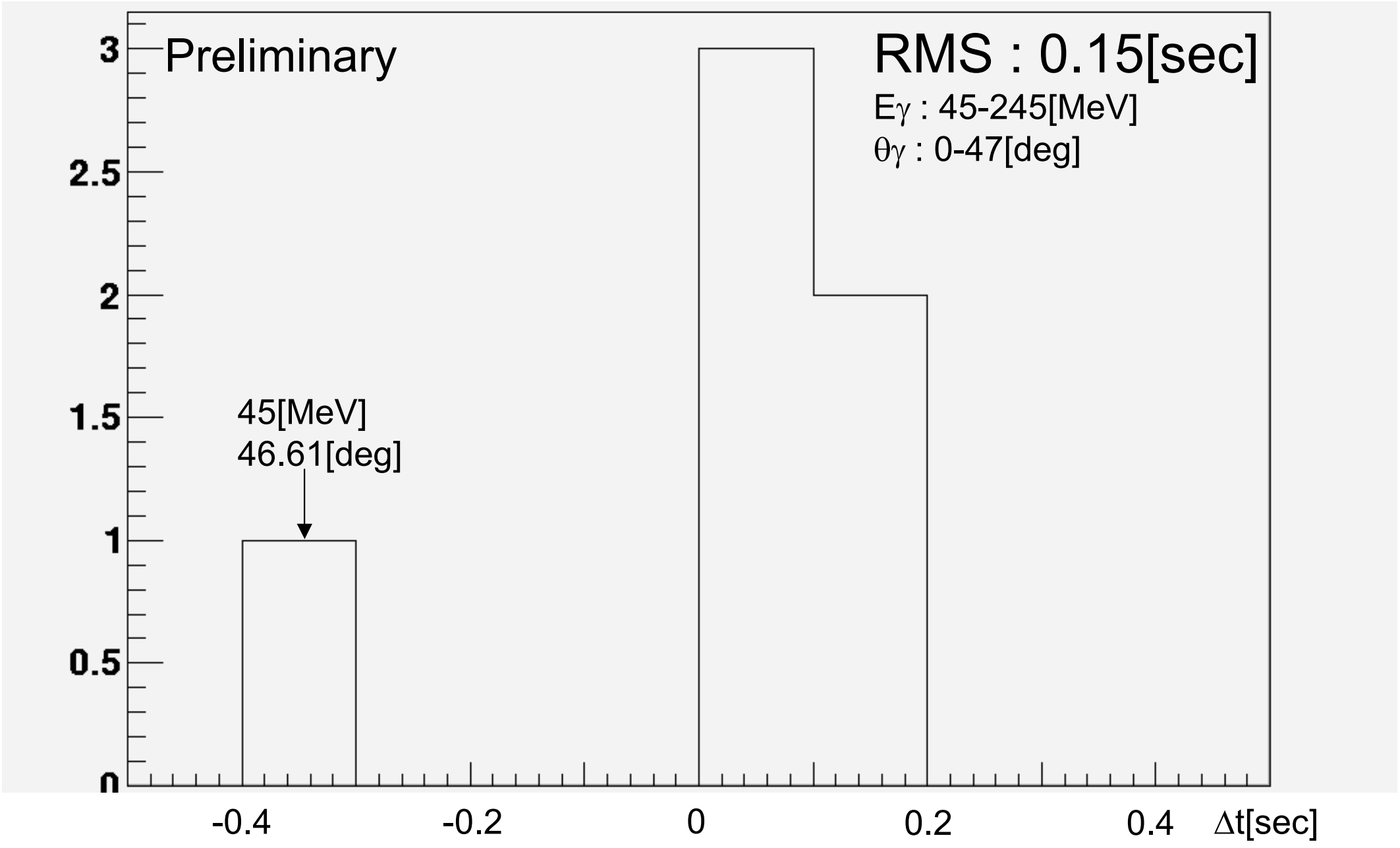
Δt=+-0.5s
Δr<1mm, Δθ<60mrad



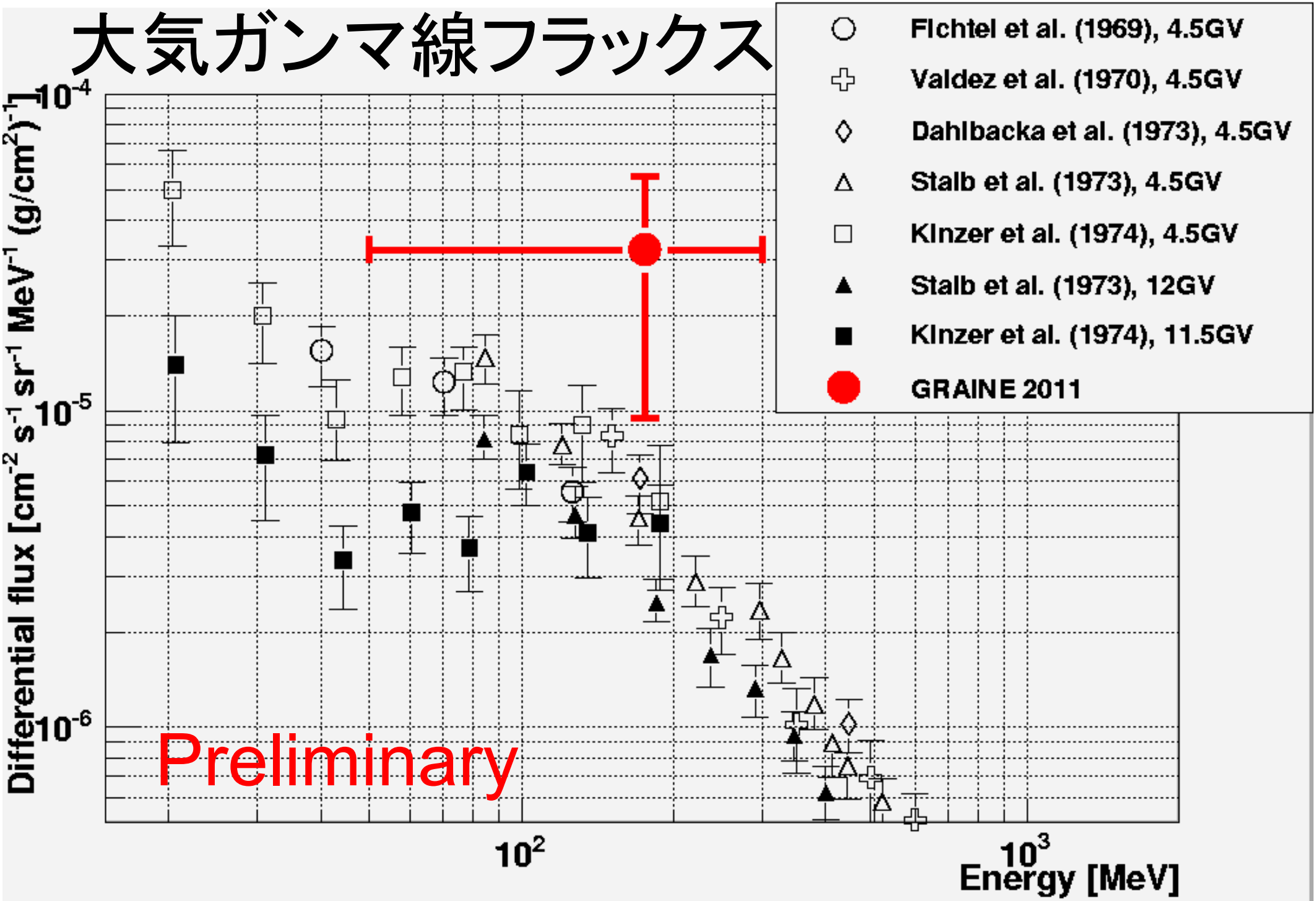
Angular resolution



Gamma-ray timing accuracy



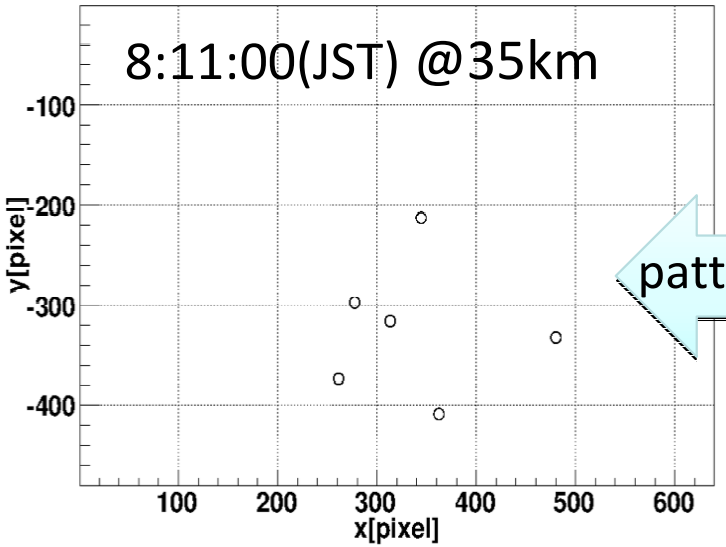
大気ガンマ線フラックス



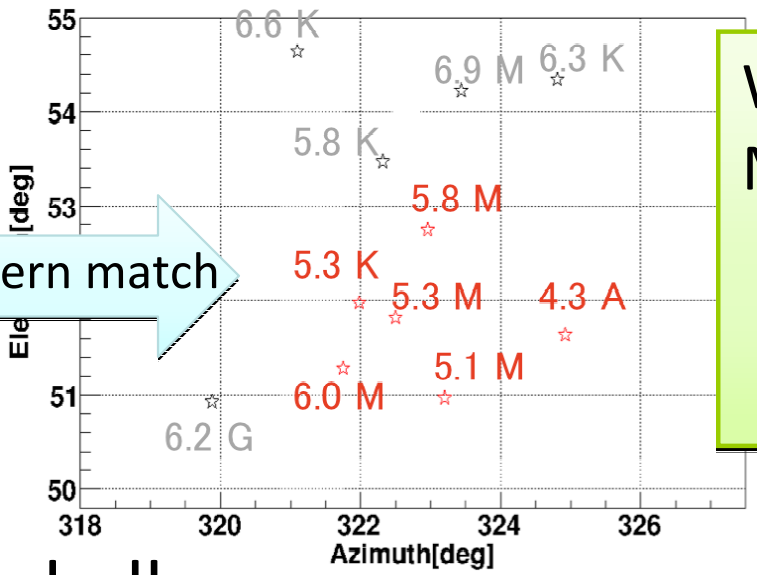
Attitude analysis

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

Daytime star camera view



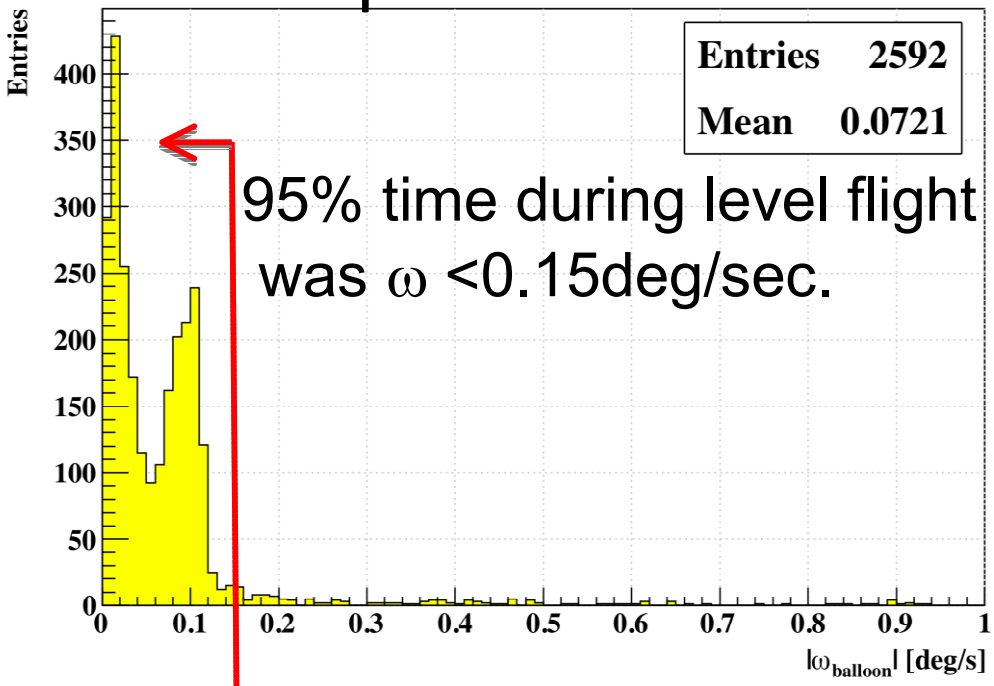
Star catalog data



pattern match

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

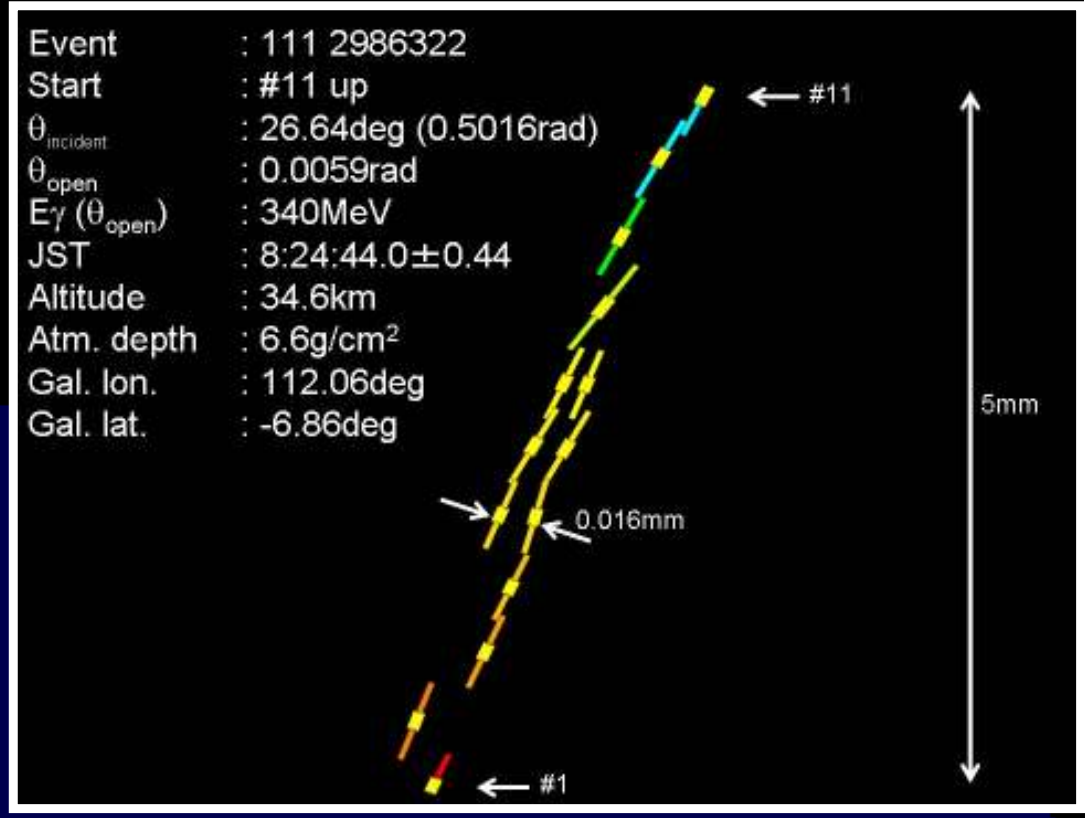
Rotation speed of the balloon

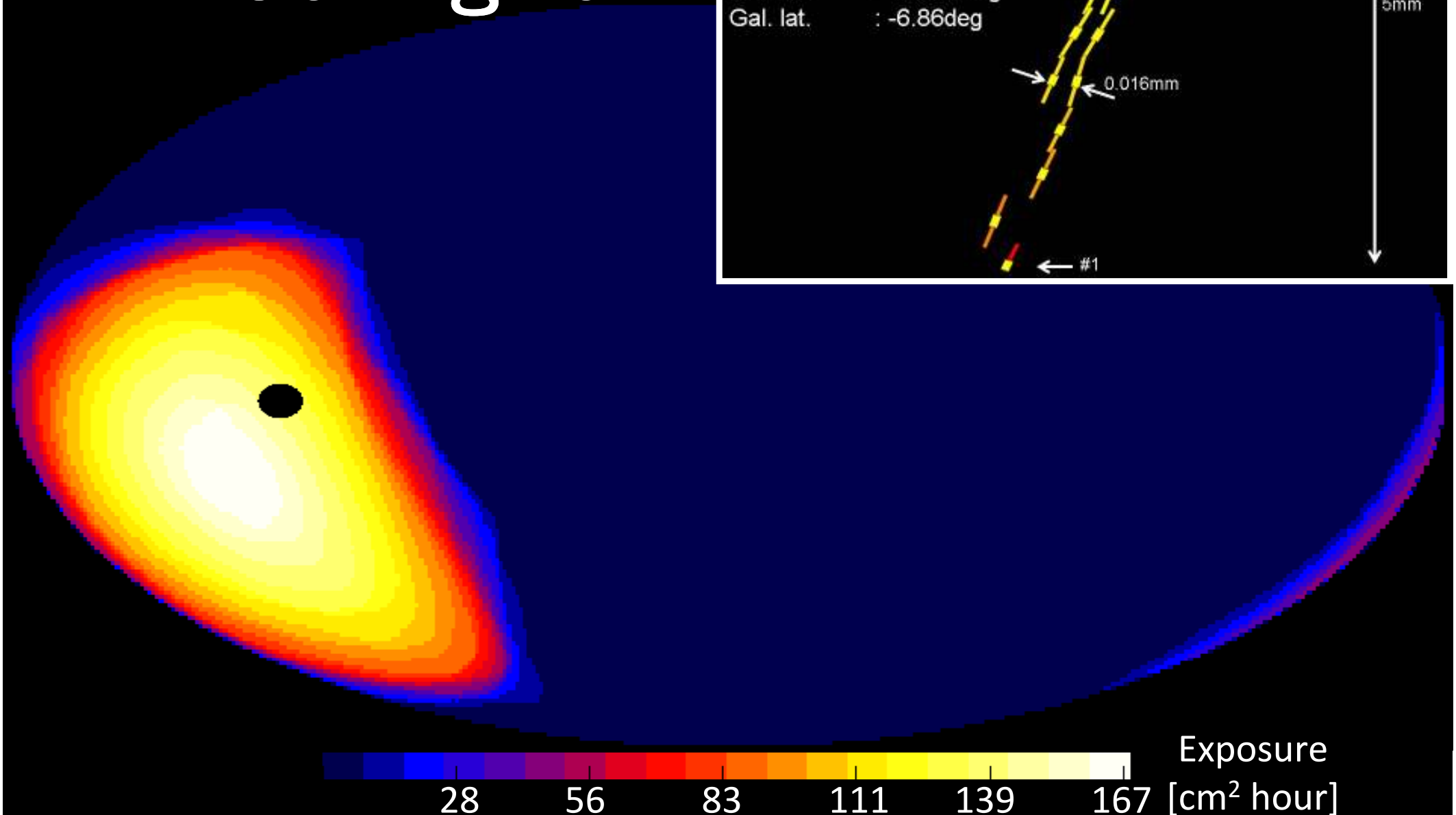


It is important to decide telescope attitude to celestial coordinate better than emulsion angular resolution(0.08deg).

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

GRAINE First Light





GRAINE roadmap

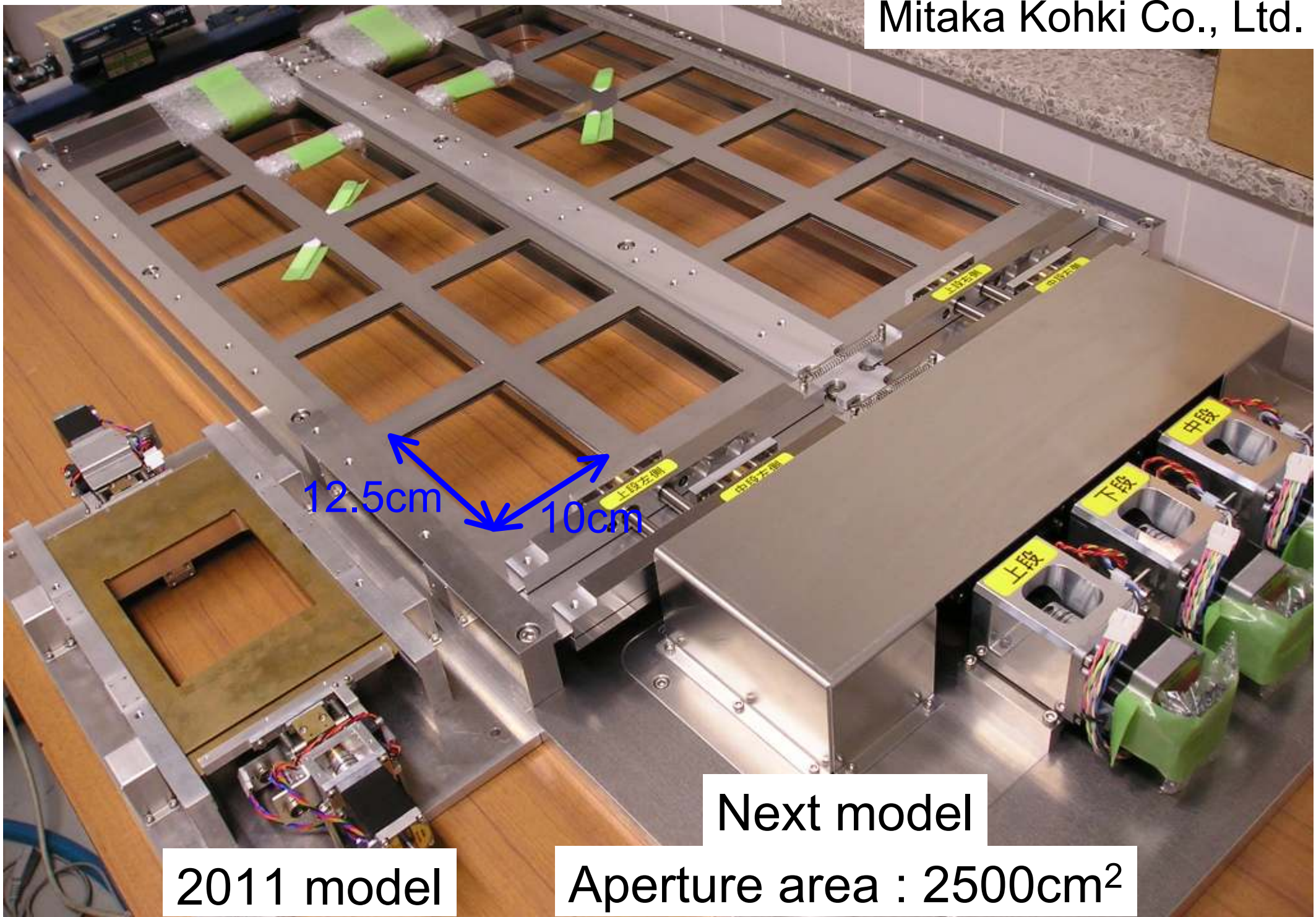
- 8th/June/2011, TARF, JAXA Scientific Ballooning, PI : S. Aoki (Kobe Univ.)
  12.5cm x 10cm aperture area, 4.3hours (1.6hours@35km) flight duration
  - Working test for each component
  - Connection test between components
  - Measurement of atmospheric gamma-rays

- 2014(Planned), Alice Springs, JAXA International Scientific Ballooning
  2500cm^2 aperture area, 1 day flight duration
  - Overall test by detecting known gamma-ray source
  - Observation with highest imaging resolution

- 2015-
  10m^2 aperture area, 7days flight duration
  - Starting scientific observation

Flight model of multi-stage shifter

Co-developed with
Mitaka Kohki Co., Ltd.



2011 model

Next model

Aperture area : 2500cm^2