ICRR Seminar
2013/June/25

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

Shigeki Aoki for GRAINE collaboration

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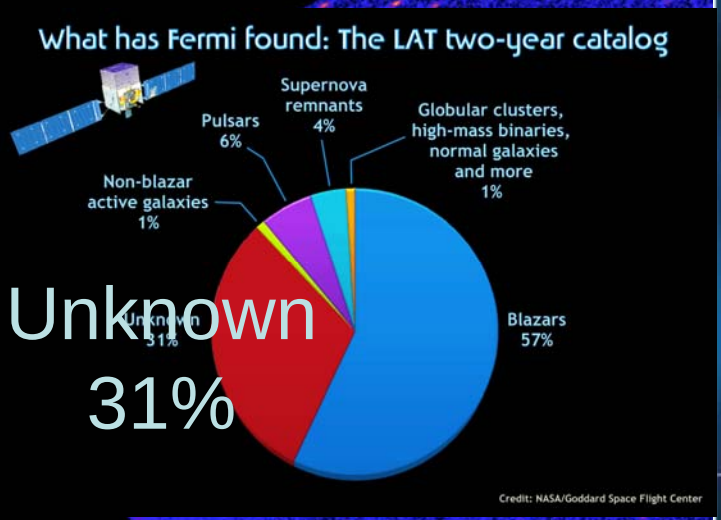
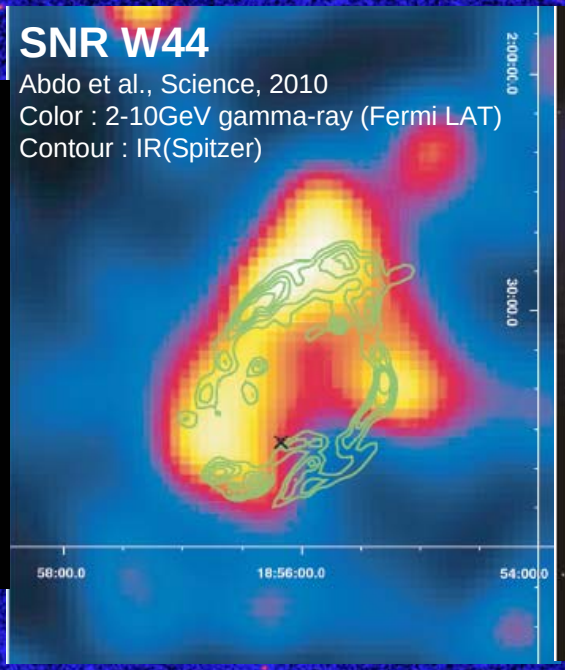
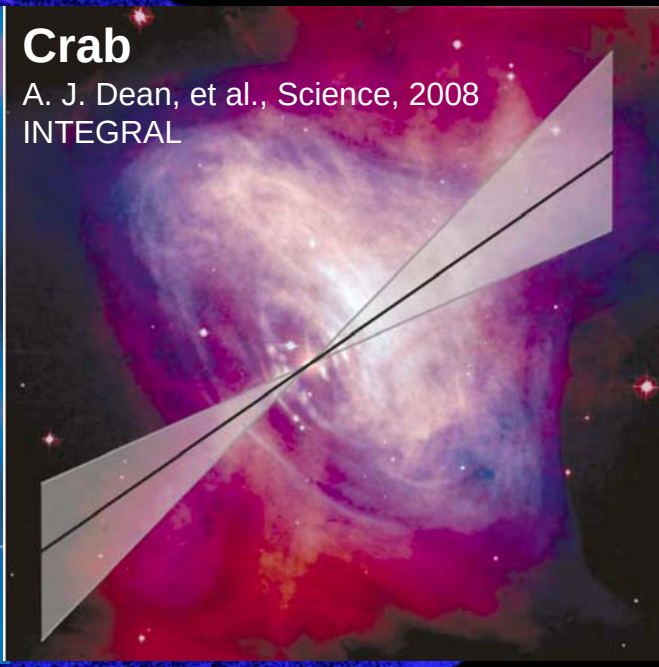
(1)Kobe University, (2)ISAS/JAXA, (3)Nagoya University, (4)Okayama University of science, (5)Aichi University of education, (6)Utsunomiya University

Fermi two-year all-sky map (E_γ>1GeV)



Unknown 31%

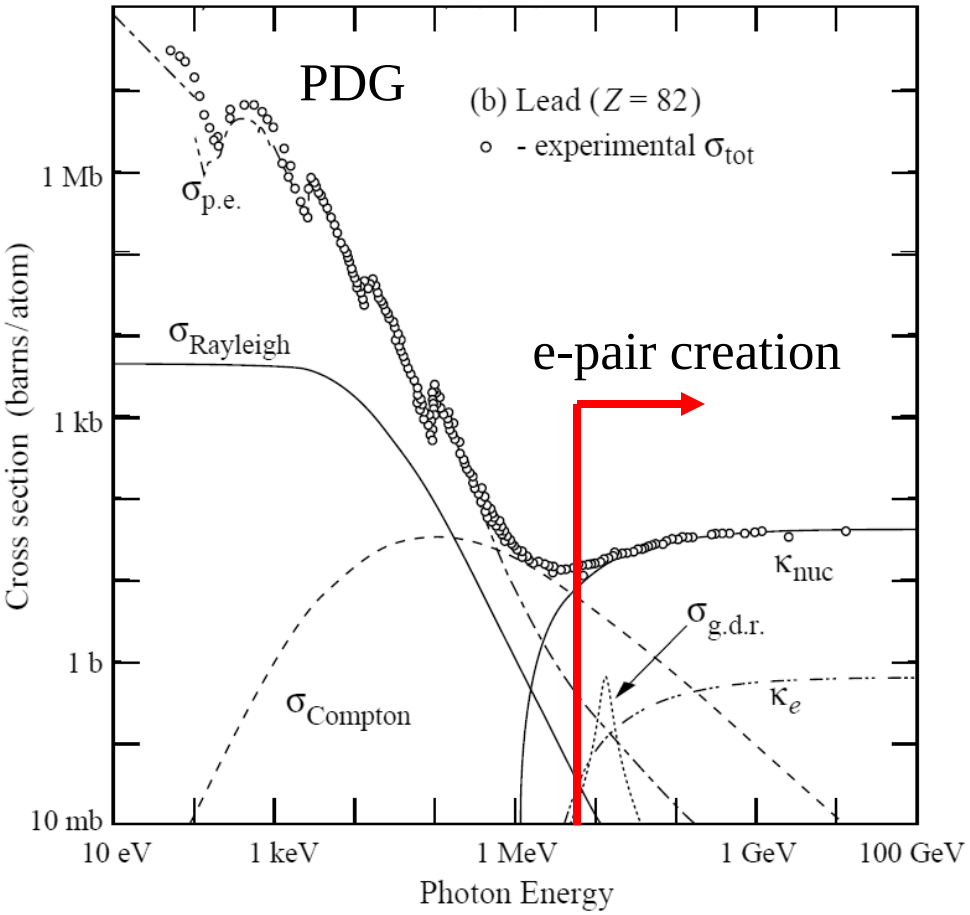


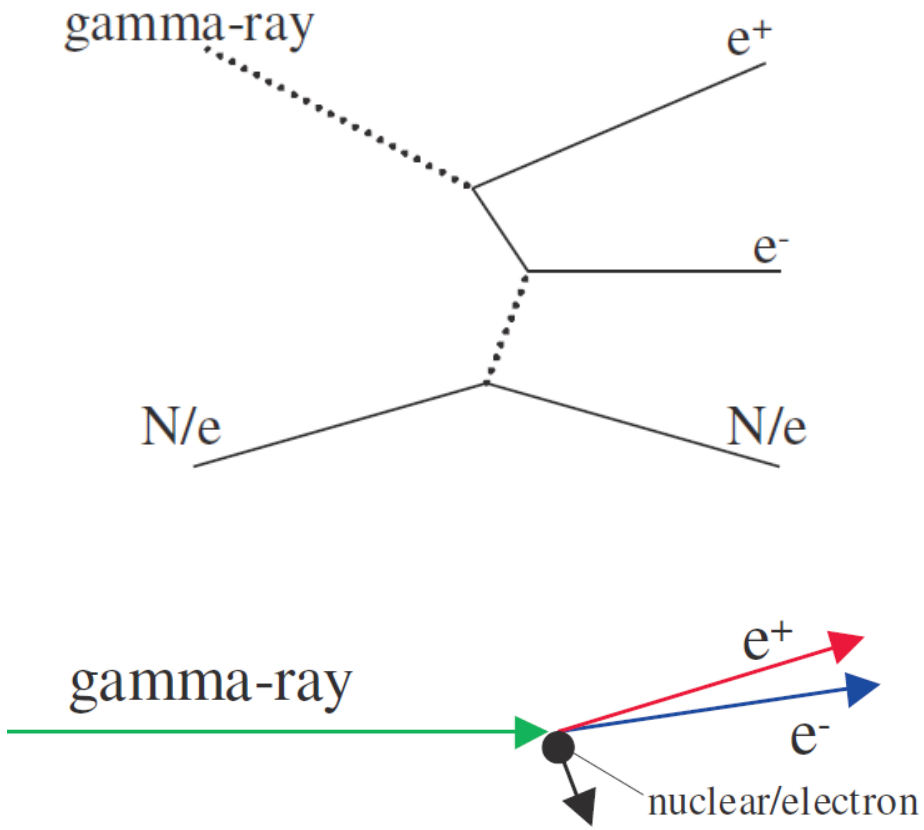


Credit: NASA/DOE/Fermi/LAT Collaboration

1873 sources

Detection principle of high energy gamma-ray





Arrival direction, timing, energy, polarization

Nuclear emulsion

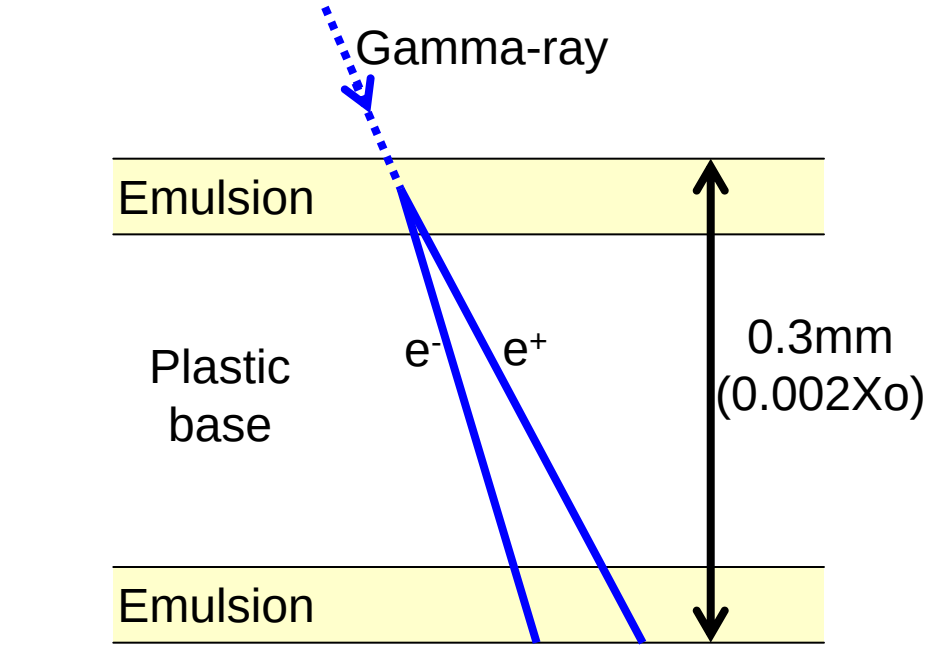
Microscopic view
10micron

Gamma-ray

$e^{+/-}$

$e^{-/+}$

Cross sectional view of an emulsion film

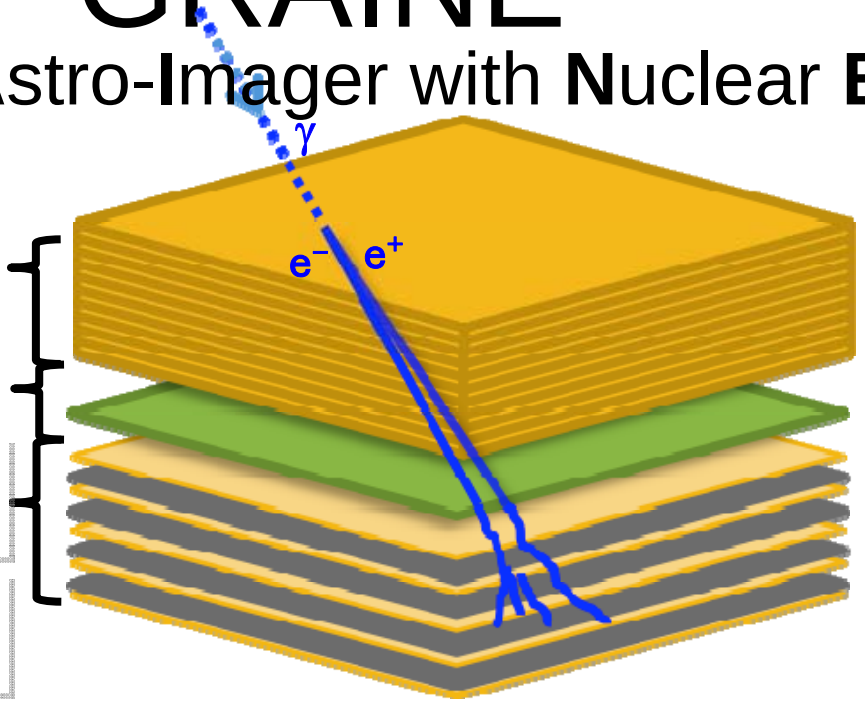


Powerful tracking device
>High spatial resolution : ~1micron
>Small radiation length : 0.002Xo

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

GRAINE

Gamma-**R**ay **A**stro-**I**mager with **N**uclear **E**mulsion



Converter
Emulsion + Copper foil

Timestamper
Multi-stage shifter

Calorimeter
Emulsion + metal plate

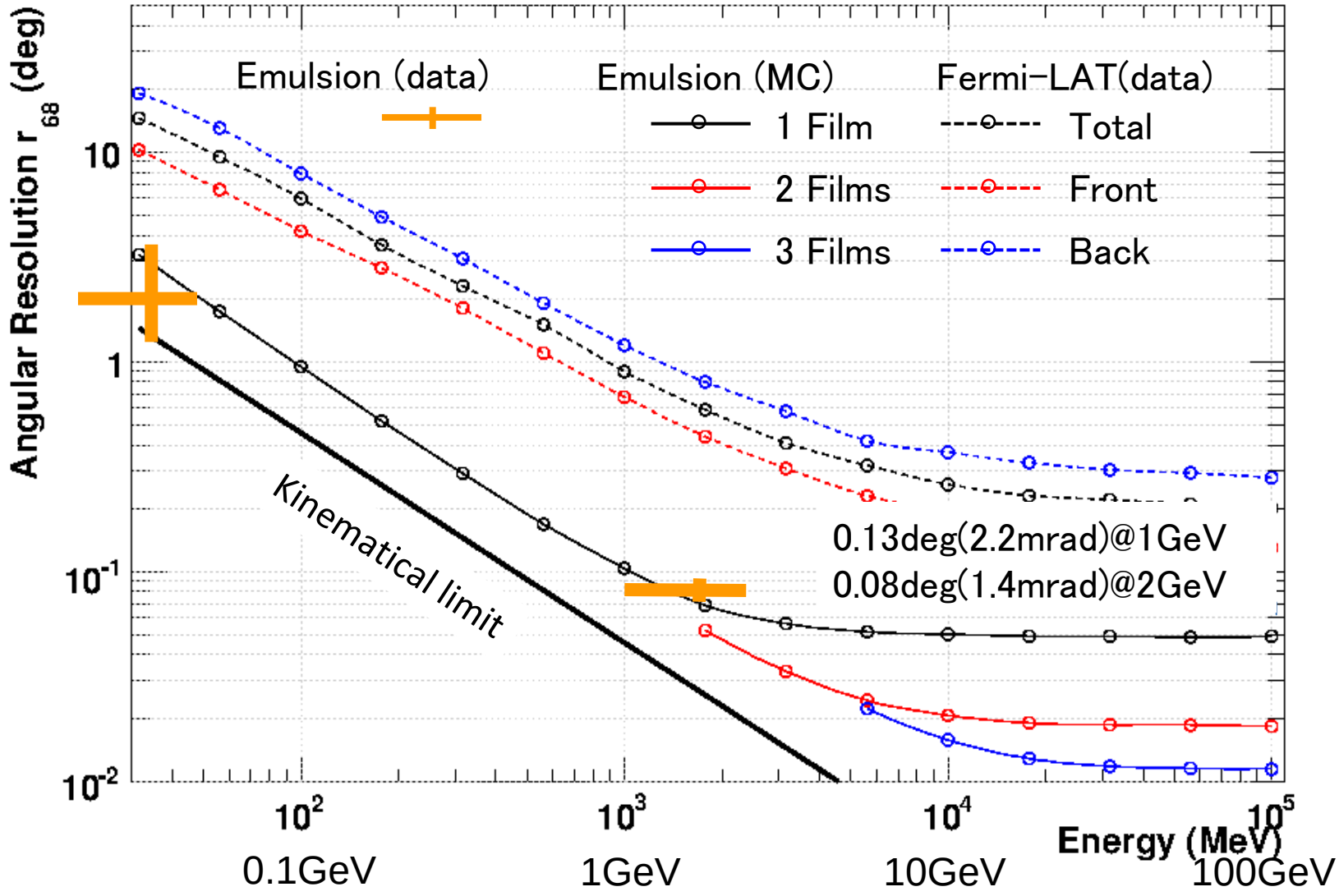
Attitude monitor
Star camera

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

	Fermi LAT		GRAINE
Angular resolution @100MeV	6.0deg (105mrad)	x1/7 →	0.93deg (16mrad)
@1GeV	0.90deg (16mrad)	x1/9 →	0.10deg (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

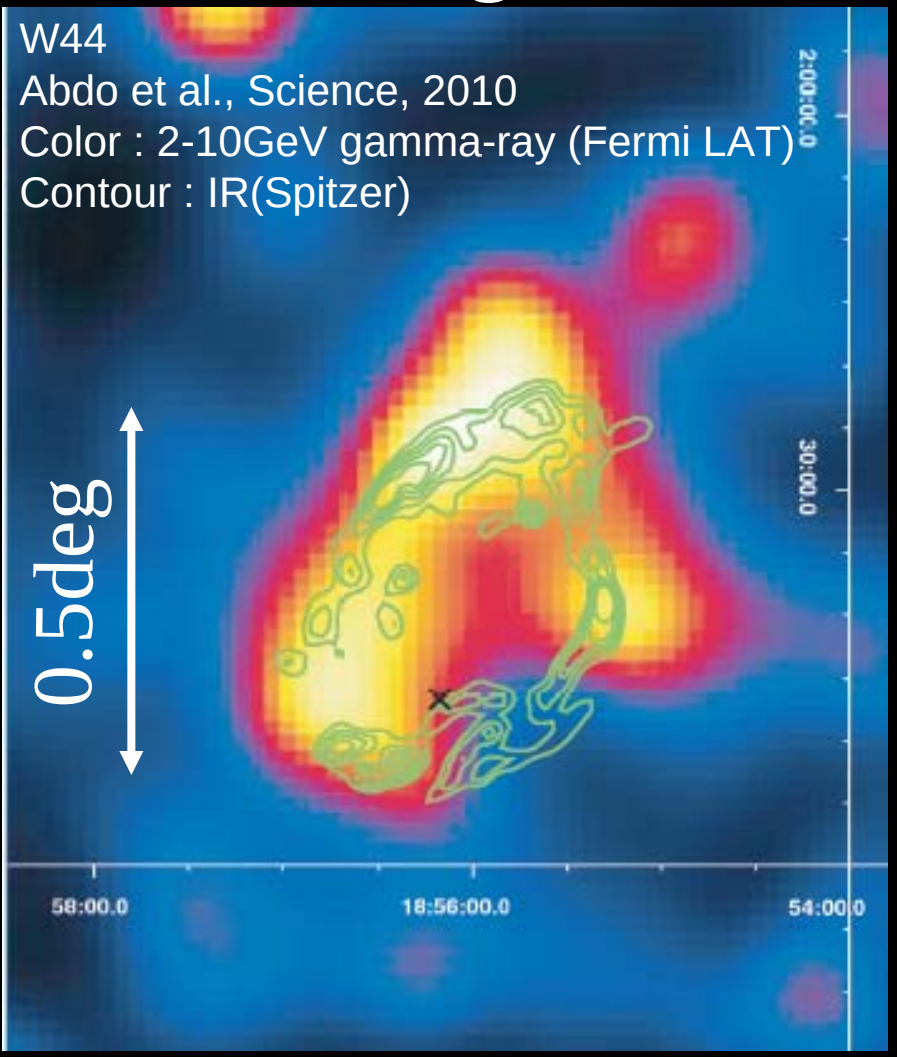
Angular Resolution

PSF at normal incidence

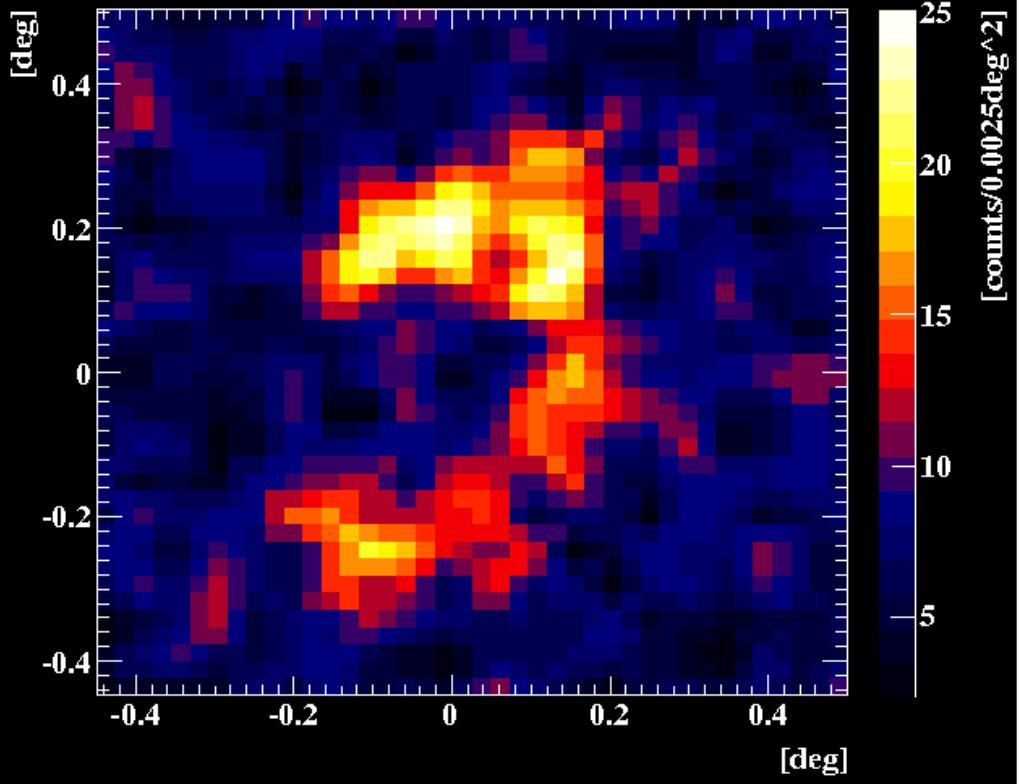


* http://www.slac.stanford.edu/exp/glast/groups/canda/lat_Performance.htm

High resolution imaging

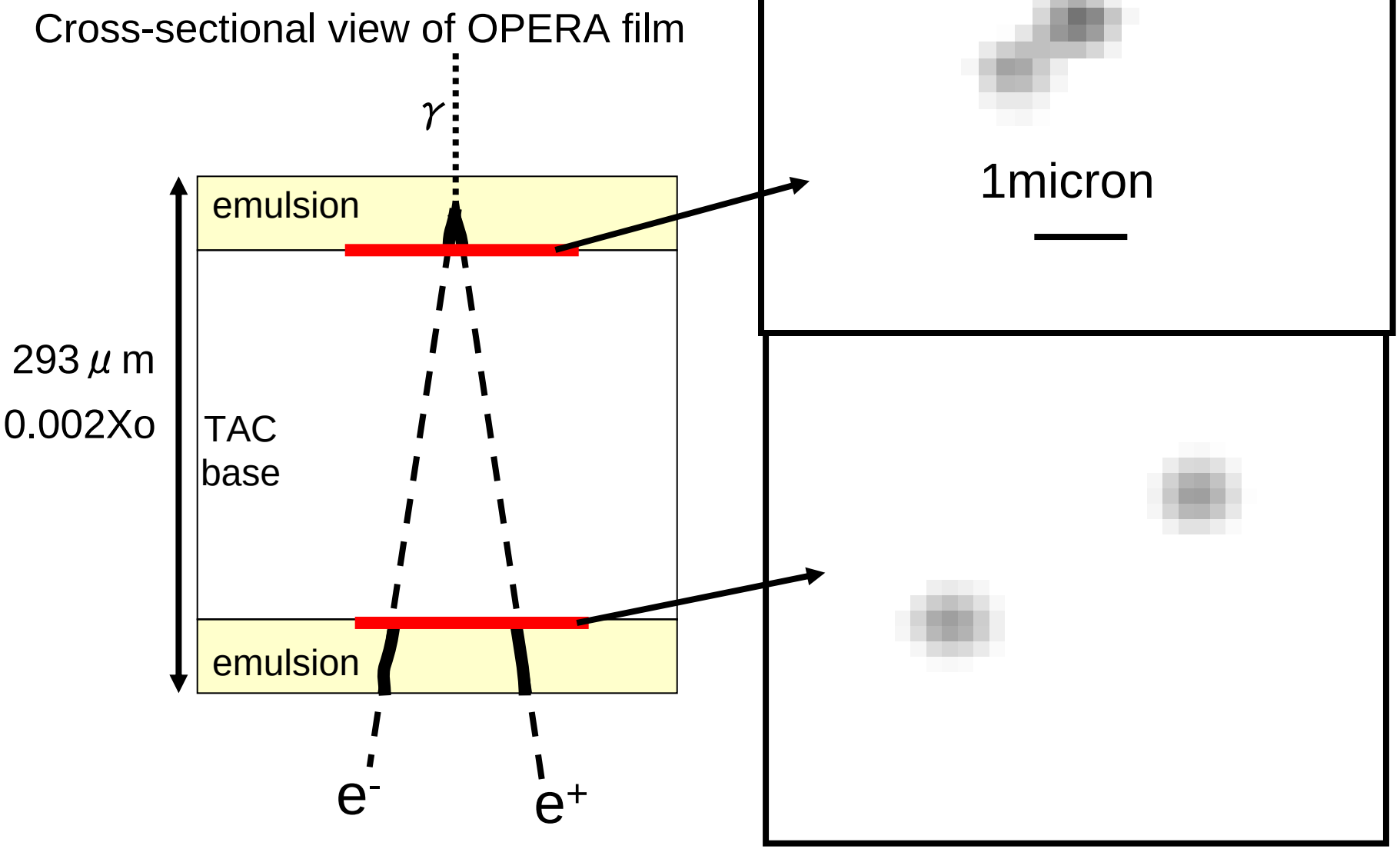


GRAINE (Simulation)

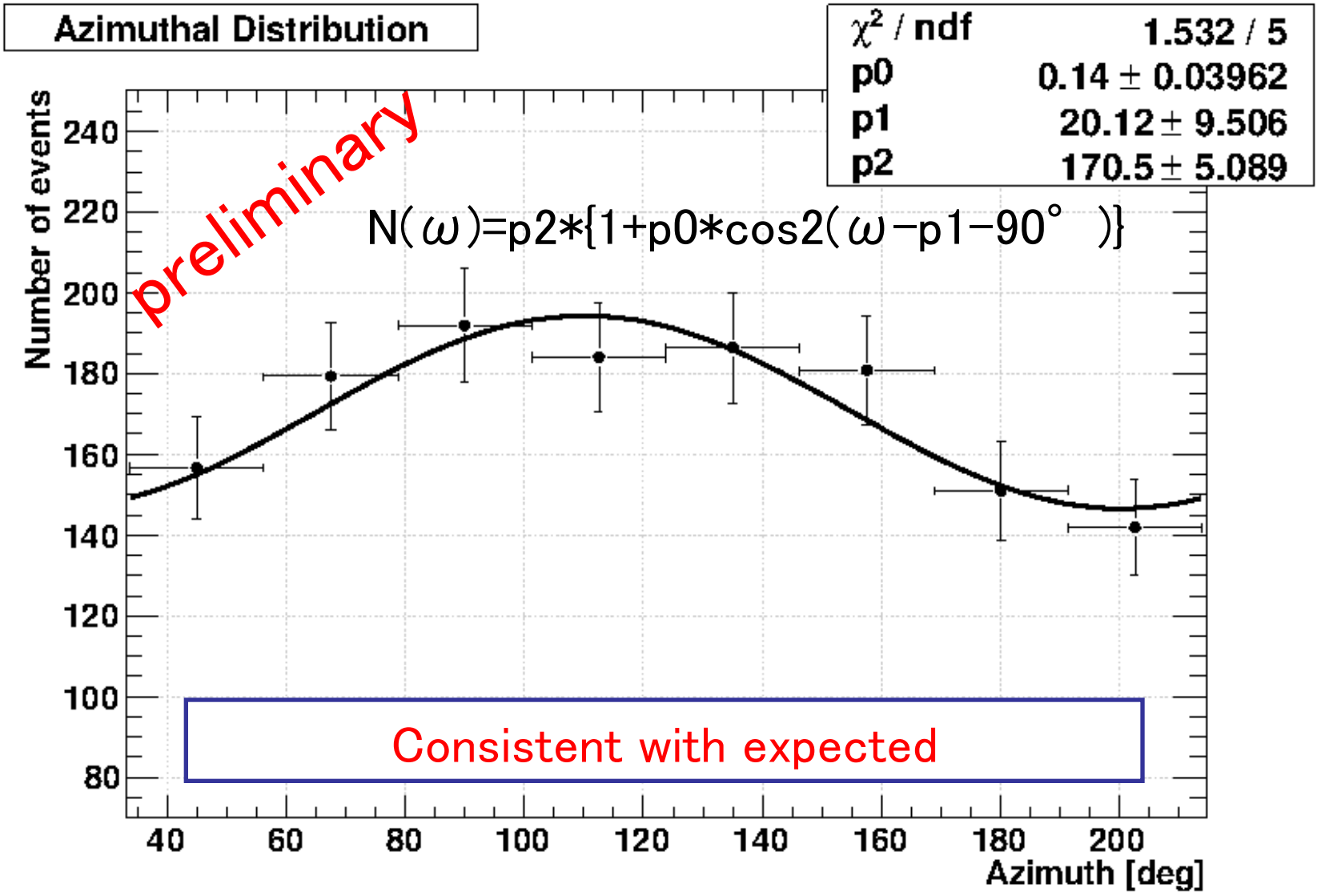


- **3flights** (41.7m^{2}days)
- >1GeV
- Smearing IR(Spitzer) distribution with 0.08deg(1.4mrad)
- Considering atmospheric gamma-ray(>1GeV) as BG

Polarization measurement



Polarization sensitivity



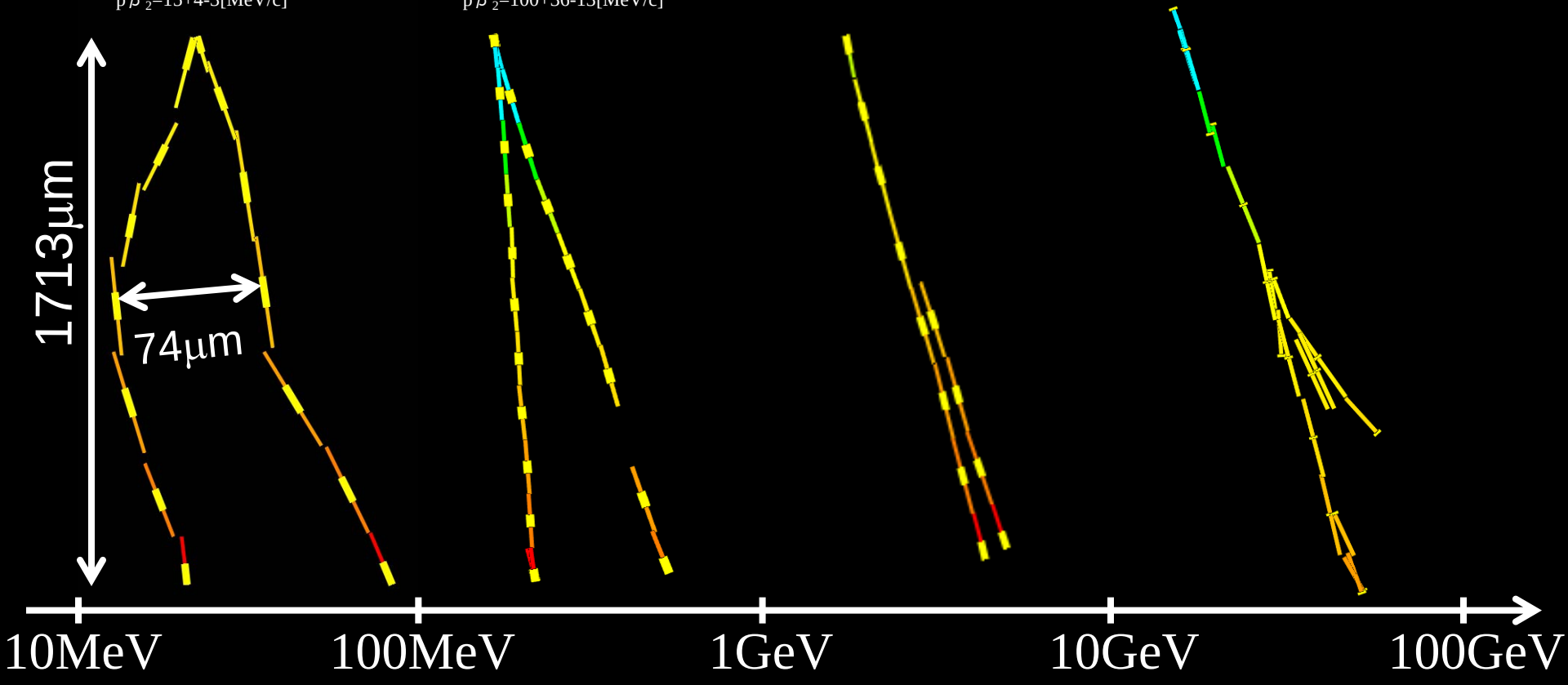
Energy range

LCS gamma-ray beam
@ UVSOR
Event ID : 221 2314379
E=28+6-4[MeV]
pβ $_1$=13+4-2[MeV/c]
pβ $_2$=15+4-3[MeV/c]

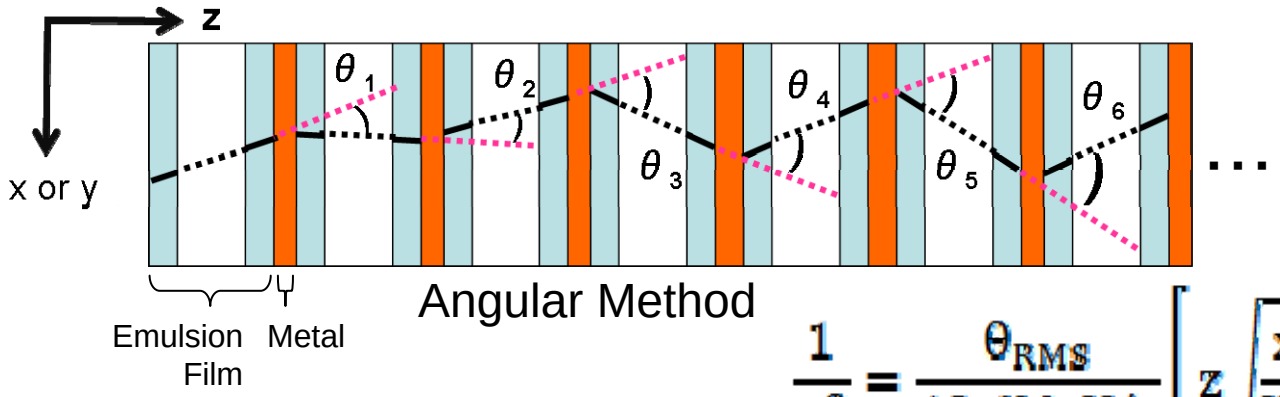
Atmospheric gamma-ray
@ Mt. Norikura
Event ID : 131 3741965
E=150+38-15[MeV]
pβ $_1$=50+12-7[MeV/c]
pβ $_2$=100+36-13[MeV/c]

LCS gamma-ray beam
@ SPring-8

Atmospheric gamma-ray
@ balloon flight (MSC)

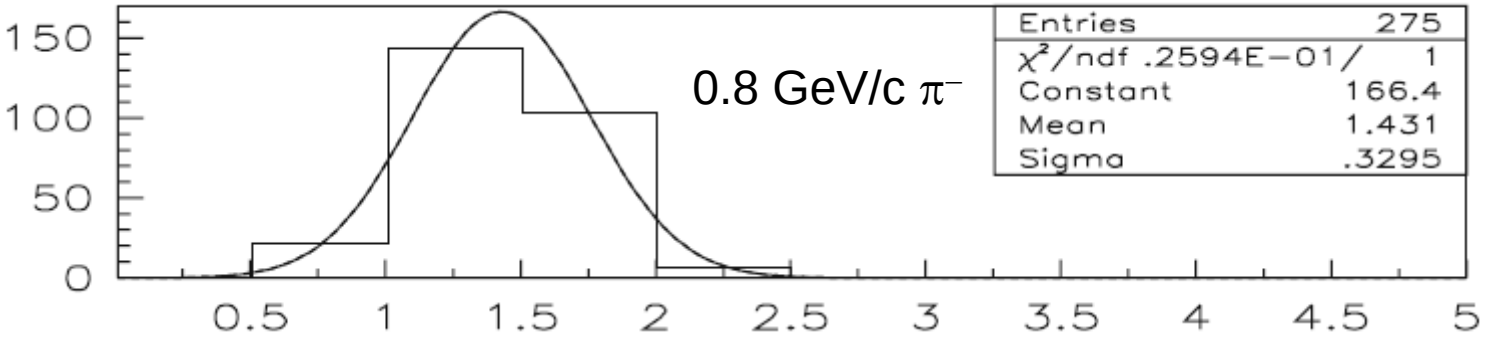


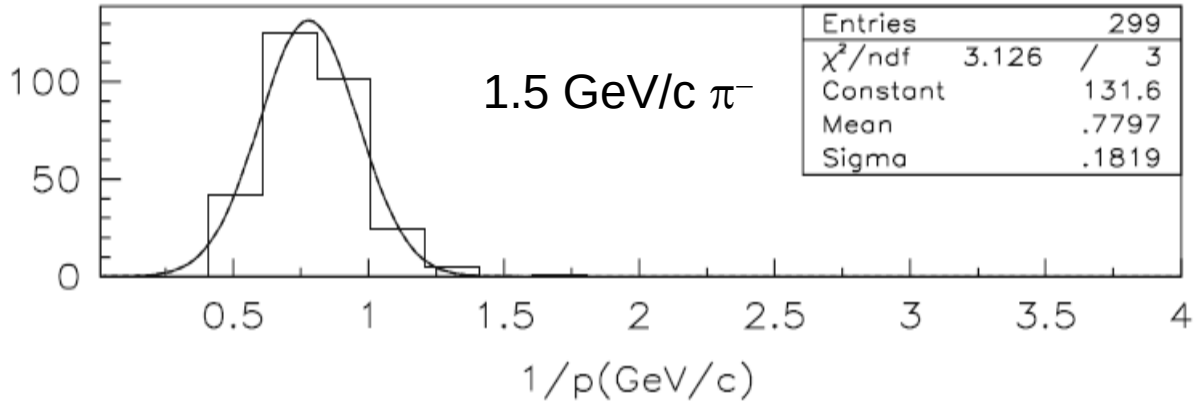
Momentum Measurement by MCS



Angular Method

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

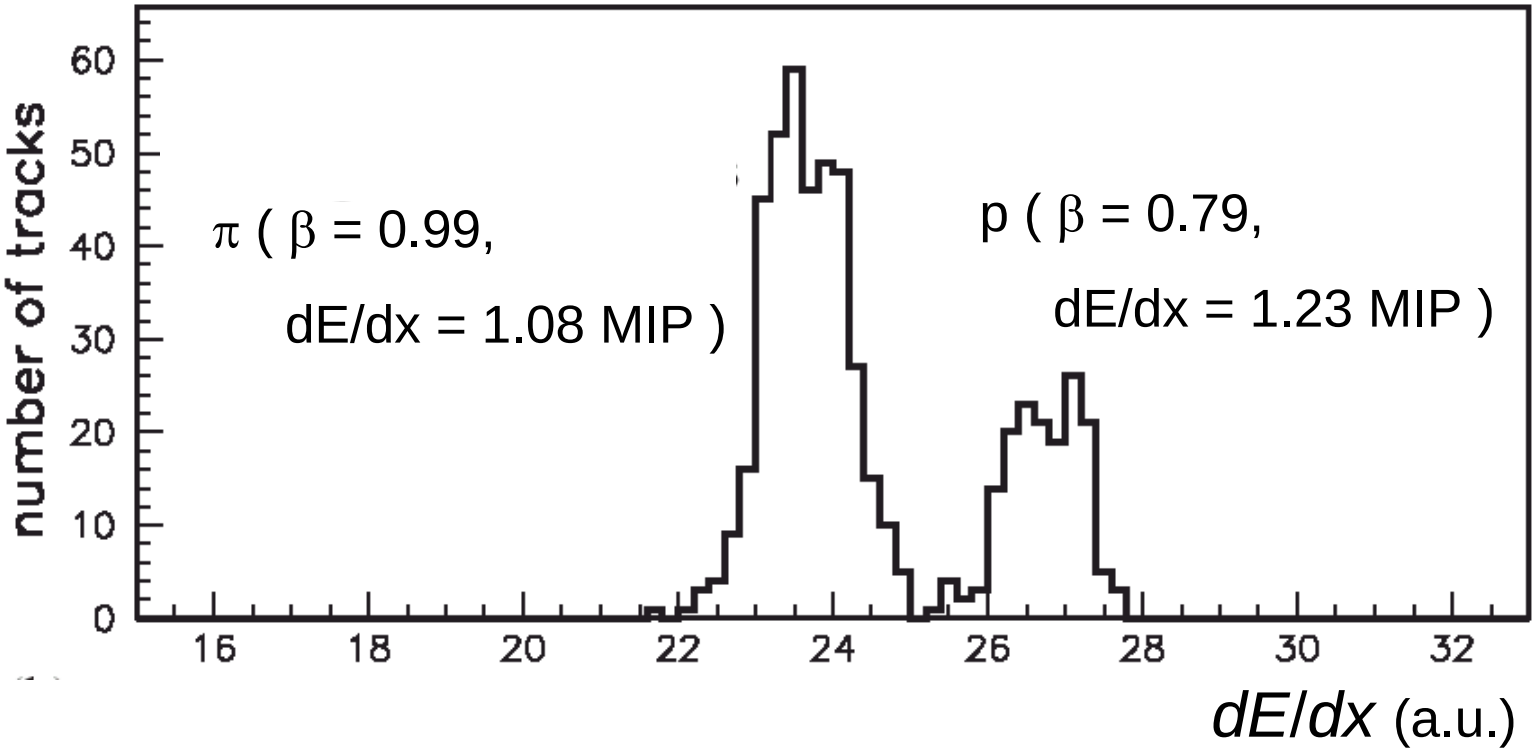




K. Kodama et al.
NIM A574(2007) pp.192-198

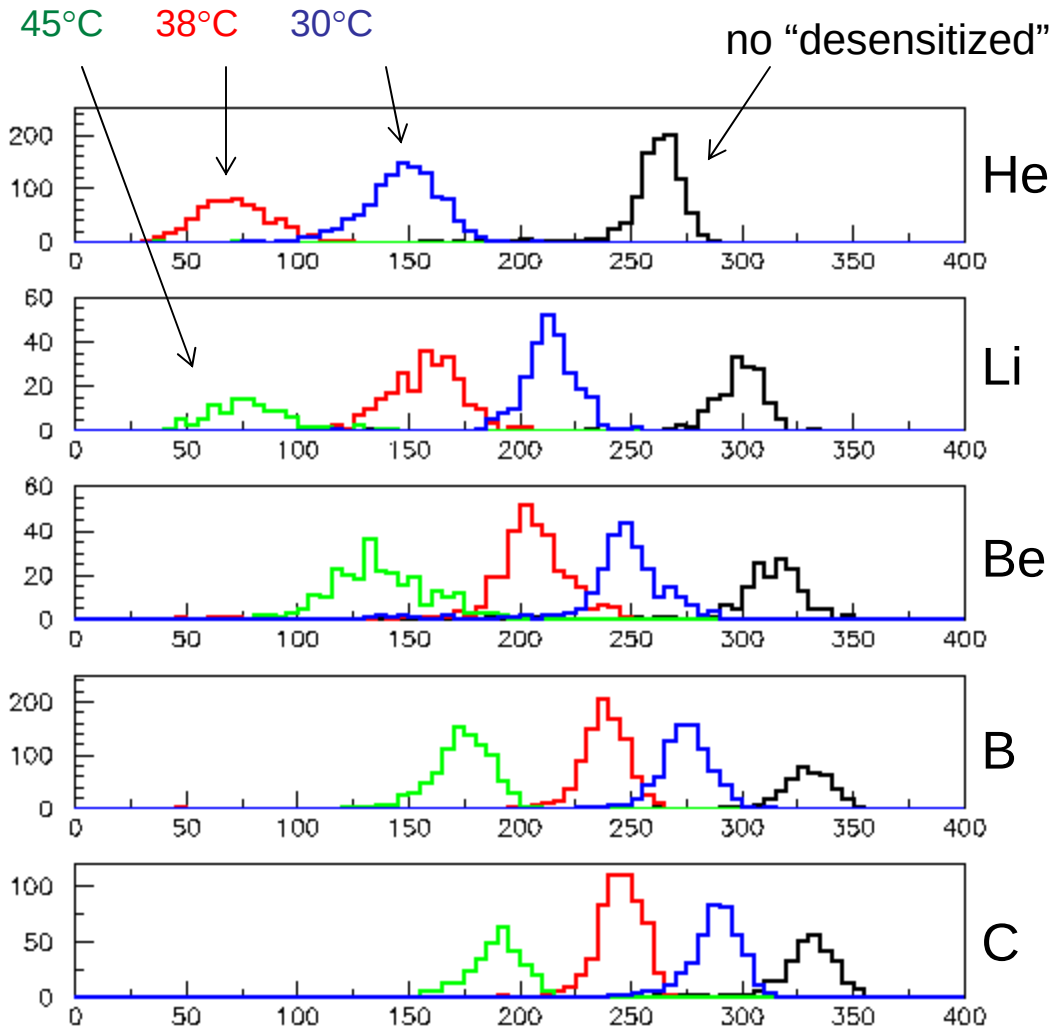
dE/dx measurement (p-id)

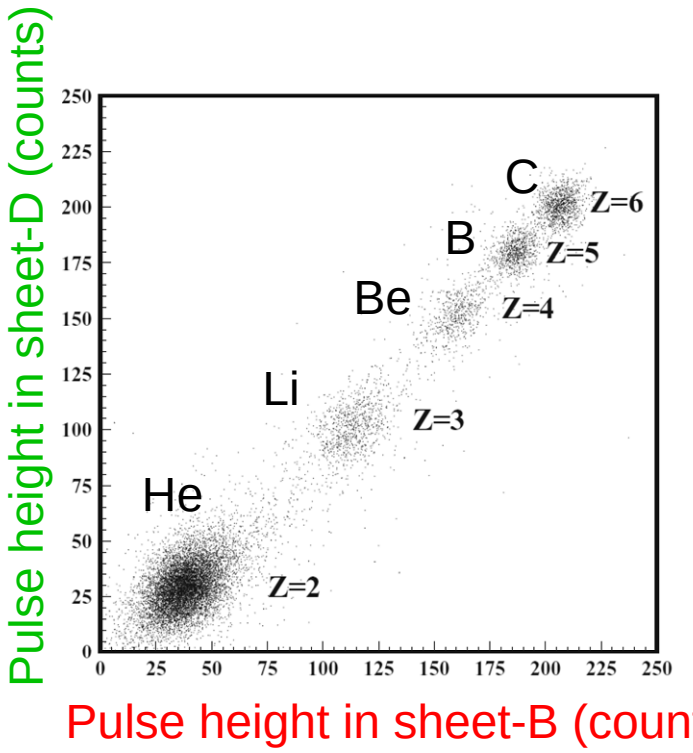
“OPERA film” × KEK-PS 1.2 GeV/c beam (29 films)



dE/dx measurement (*Z*-id for nuclei)

"desensitized" operation (98% RH 3days)





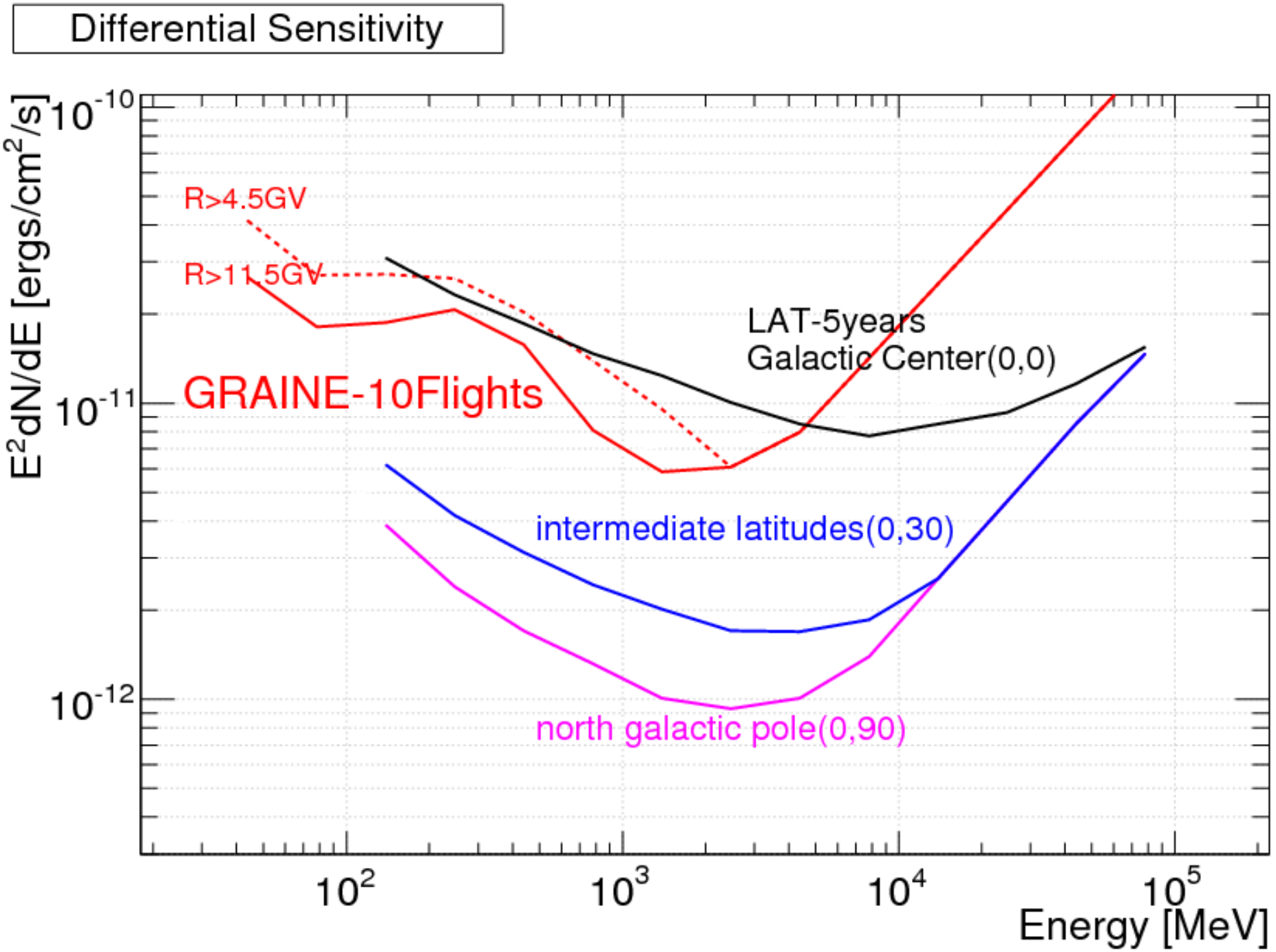
T. Toshito et al.,
NIM A556 (2006) pp.482-489
Phys. Rev. C75 (2007) 054606

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
  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


Differential Sensitivity
E^2dN/dE [ergs/cm^2/s]
10^{-10}
10^{-11}
10^{-12}
R>4.5GV
R>11.5GV
GRAINE-10Flights
LAT-5years
Galactic Center(0,0)
intermediate latitudes(0,30)
north galactic pole(0,90)
10^2
10^3
10^4
10^5
Energy [MeV]

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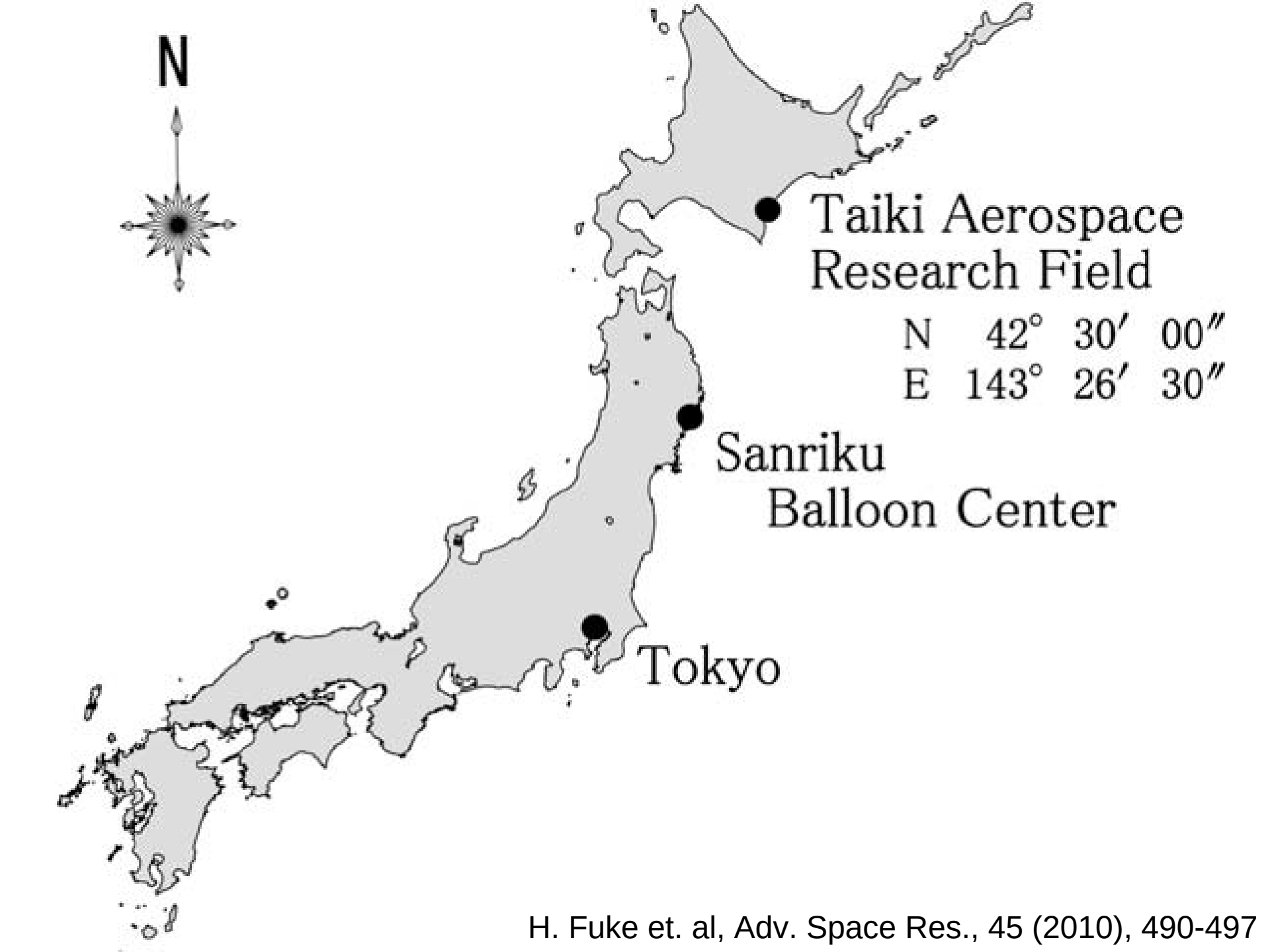
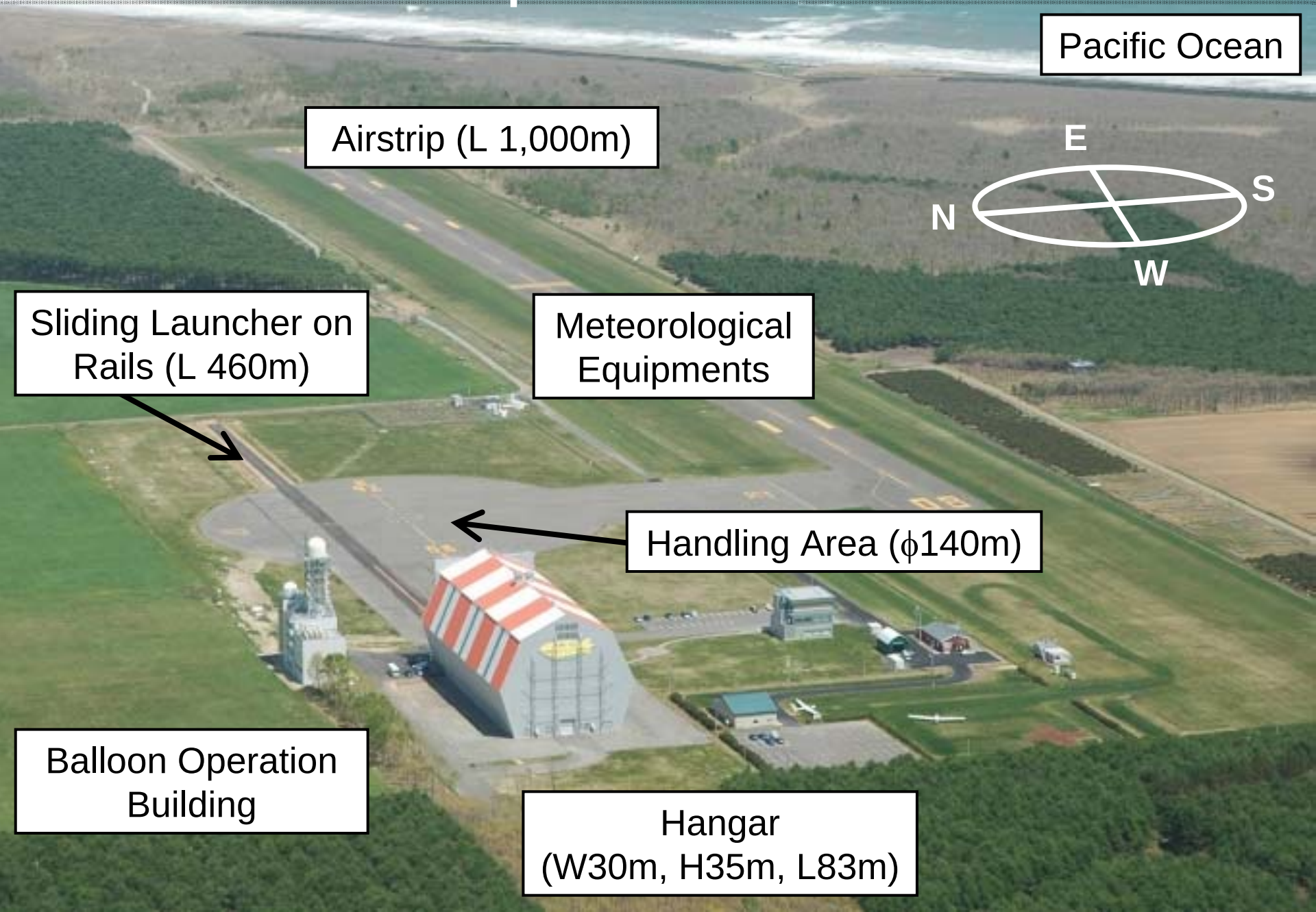


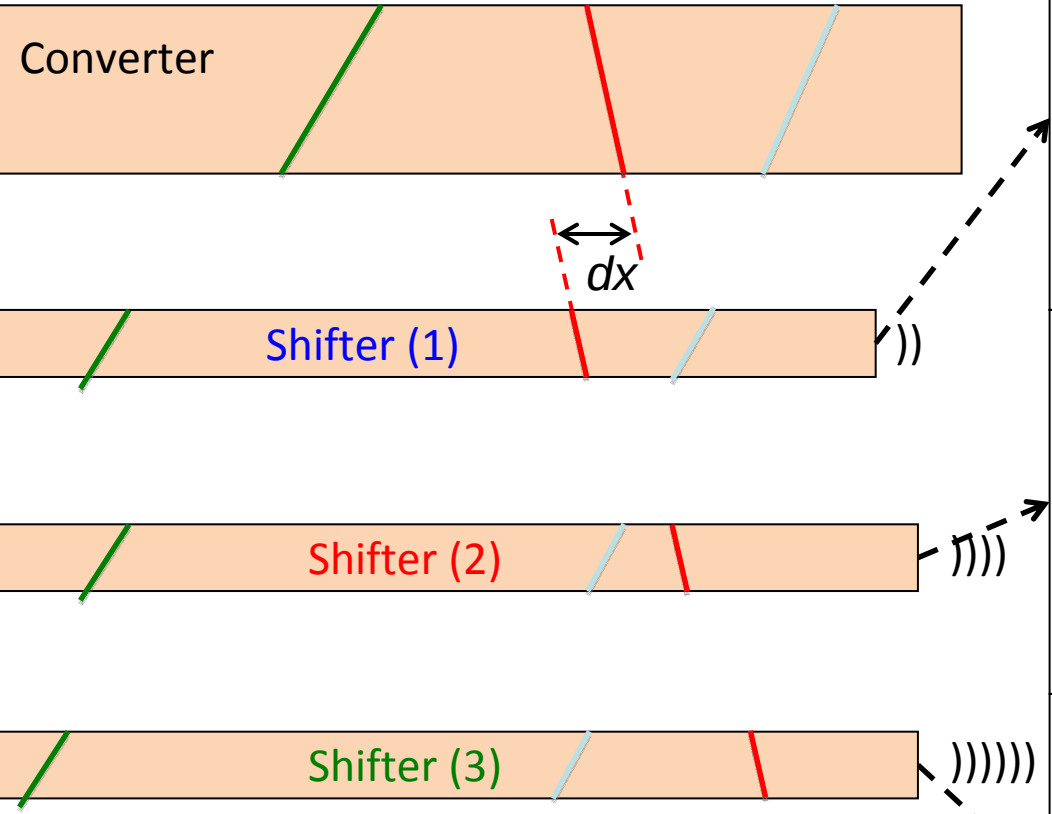
H. Fuke et. al, Adv. Space Res., 45 (2010), 490-497

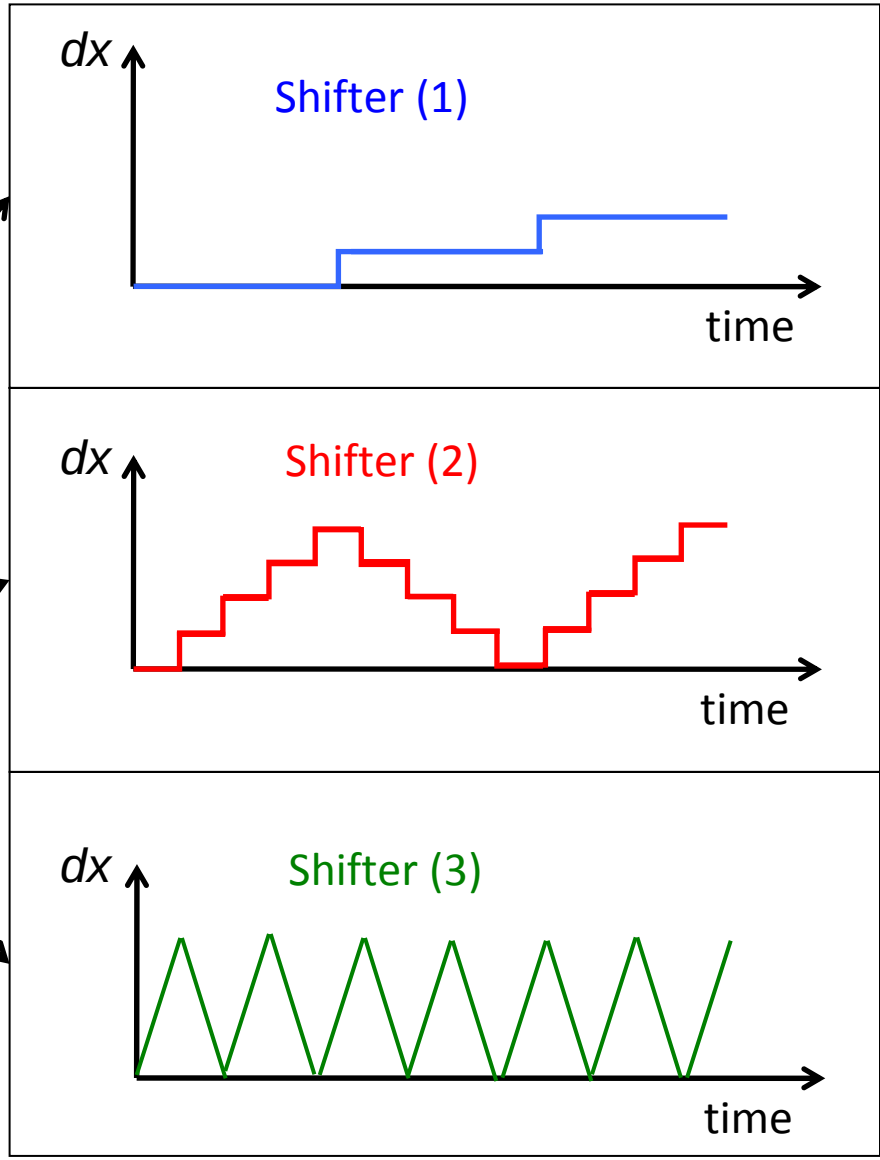
Taiki Aerospace Research Field



Multi-stage shifter
(time stamper)

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



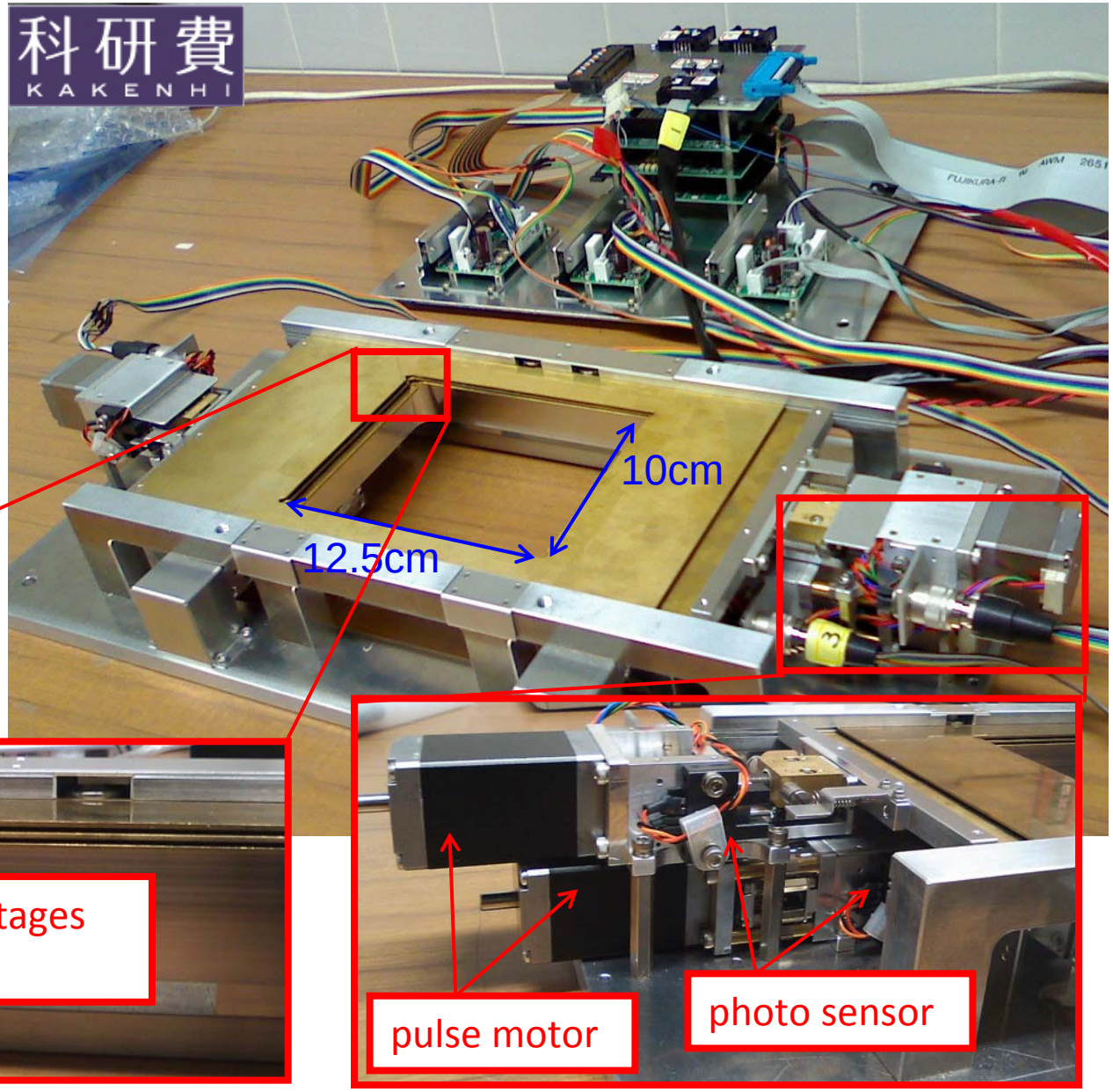


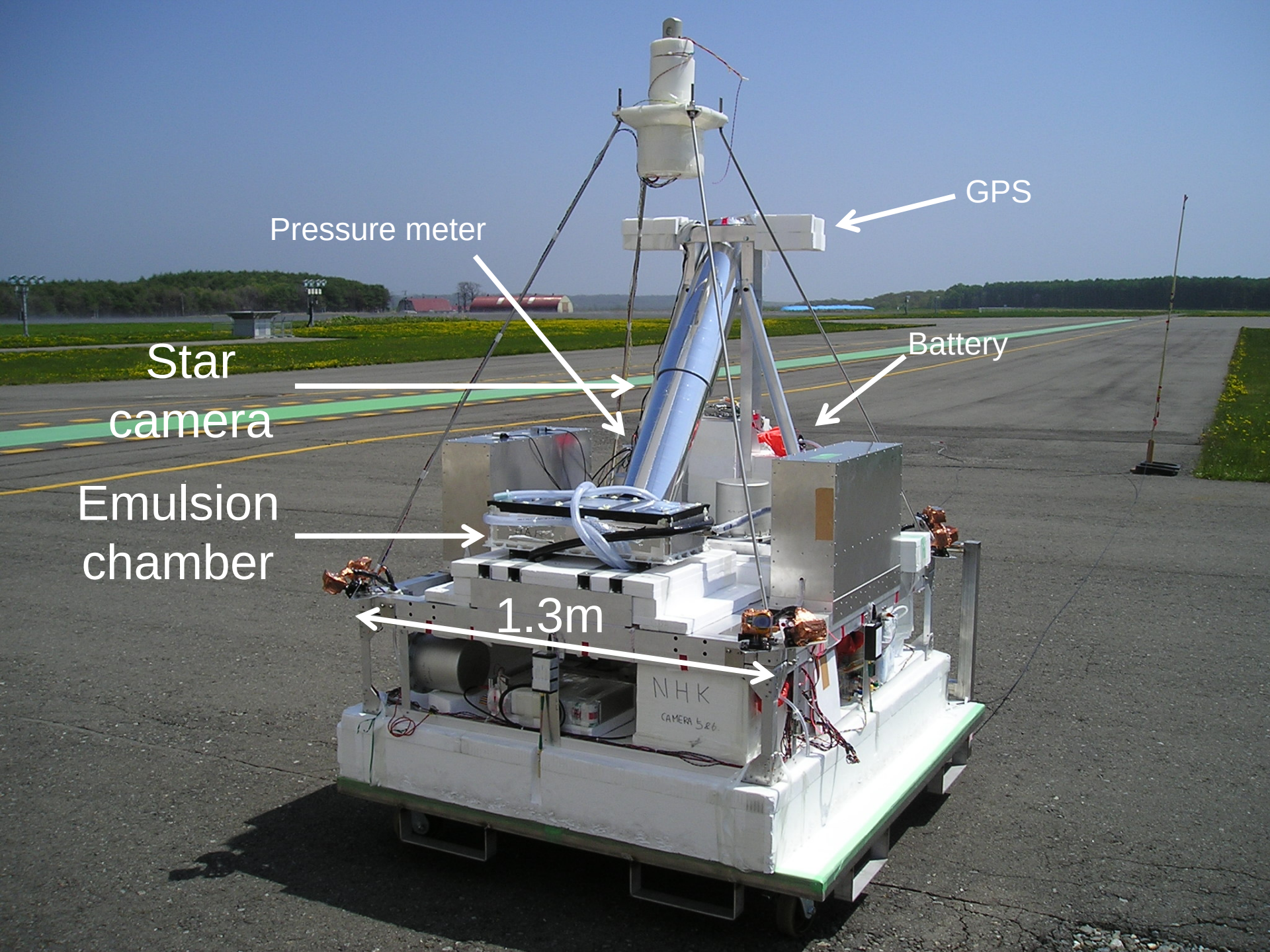
Simple
Compact
Light
HV free
Low power consumption
Dead time free

Multi-stage Shifter (Time Stamper)

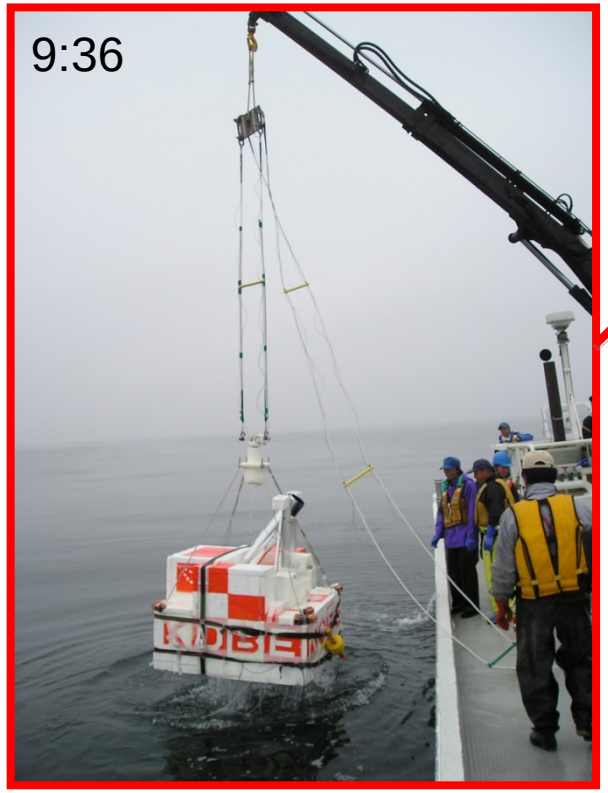
Co-developed with
Mitaka Kohki Co., Ltd.

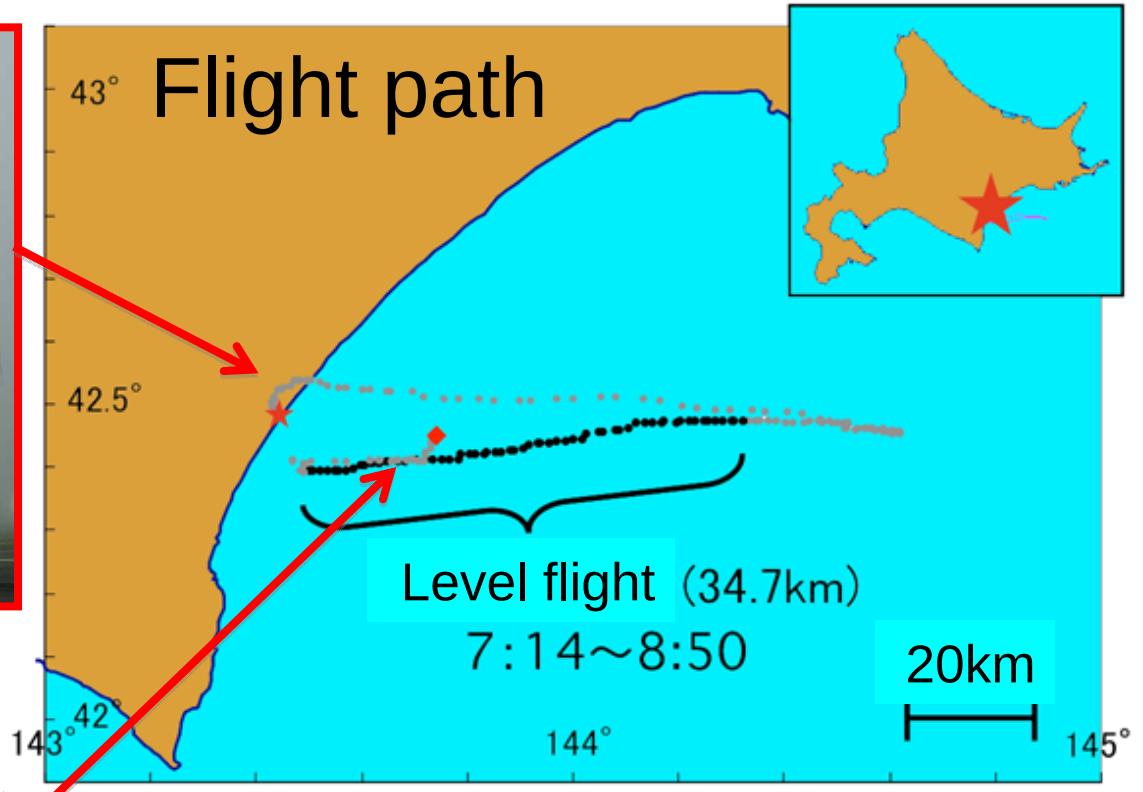
Weight : 5 kg
Power Cons.: 20 W
Reproducibility: 1μm

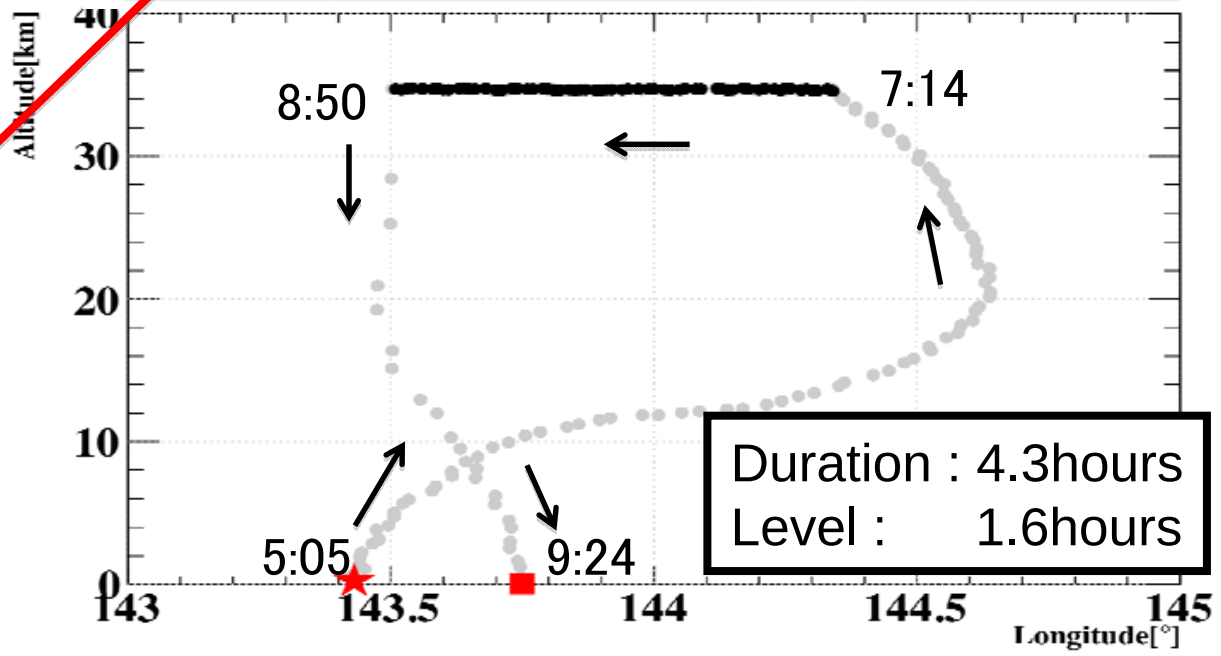



GPS
Pressure meter
Battery
Star camera
Emulsion chamber
1.3m
NHK
CAMERA 5&6


TARF
8th June 2011
5:05

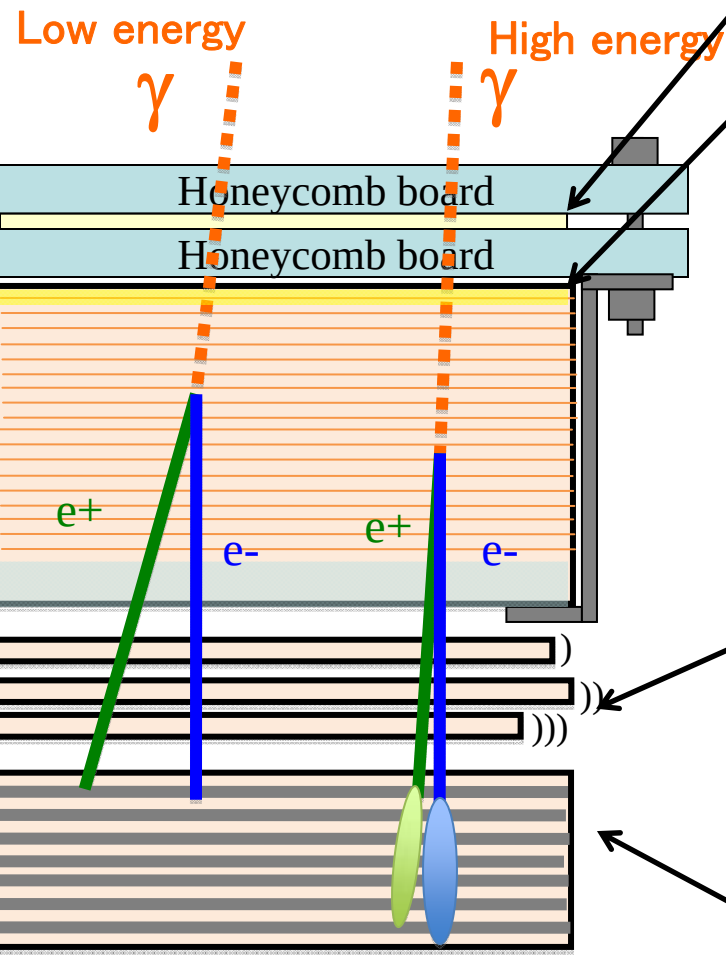

9:36


Flight path
43°
42.5°
42°
143°
144°
145°
Level flight (34.7km)
7:14~8:50
20km


8:50
7:14
5:05
9:24
Duration : 4.3hours
Level : 1.6hours
0
10
20
30
143
143.5
144
144.5
145
Longitude[°]

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)

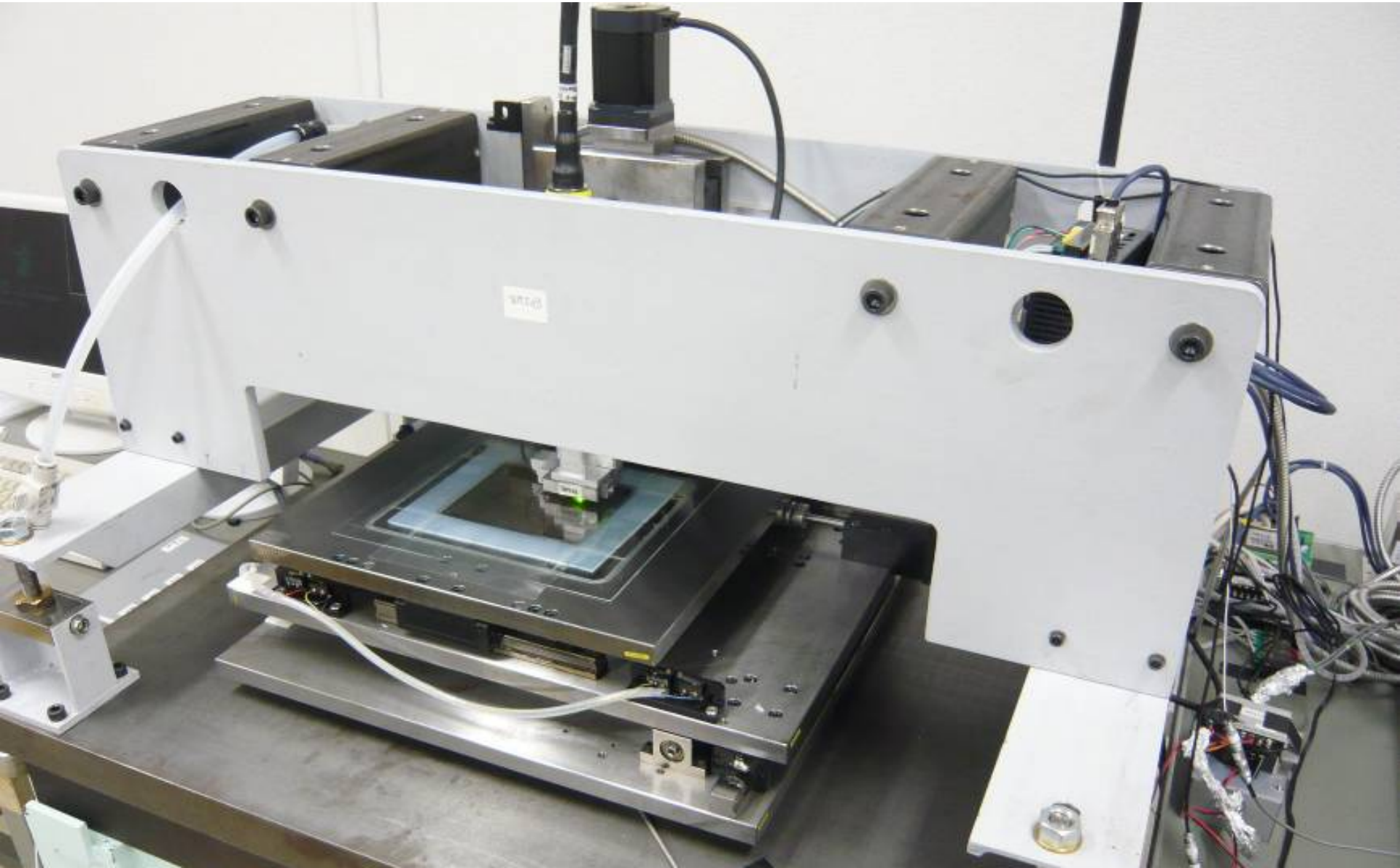
(OPERA film + lead plate(0.5mm))x10

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

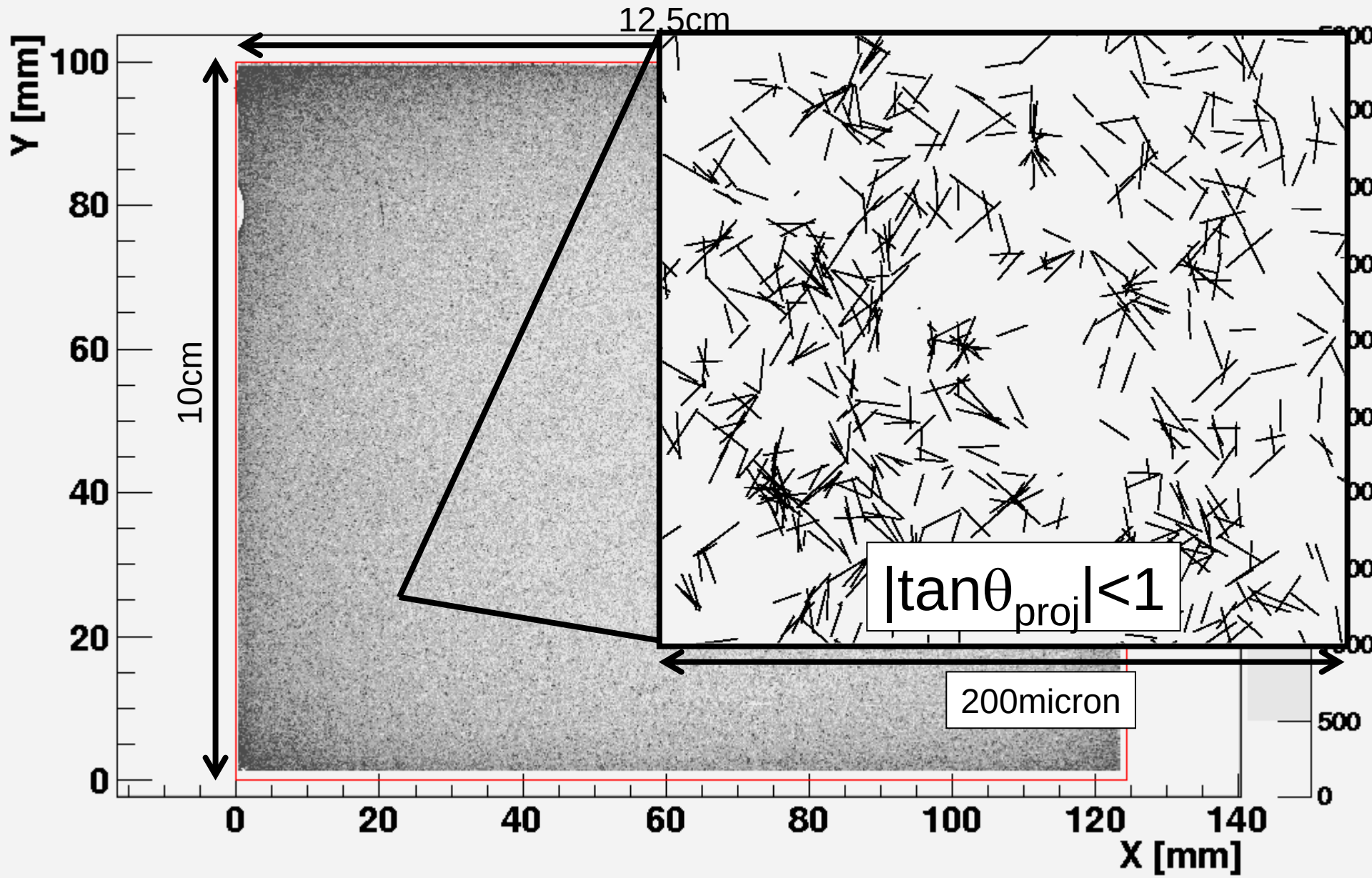
Automated Emulsion Scanning System

“ S-UTS ”

Nagoya Univ.

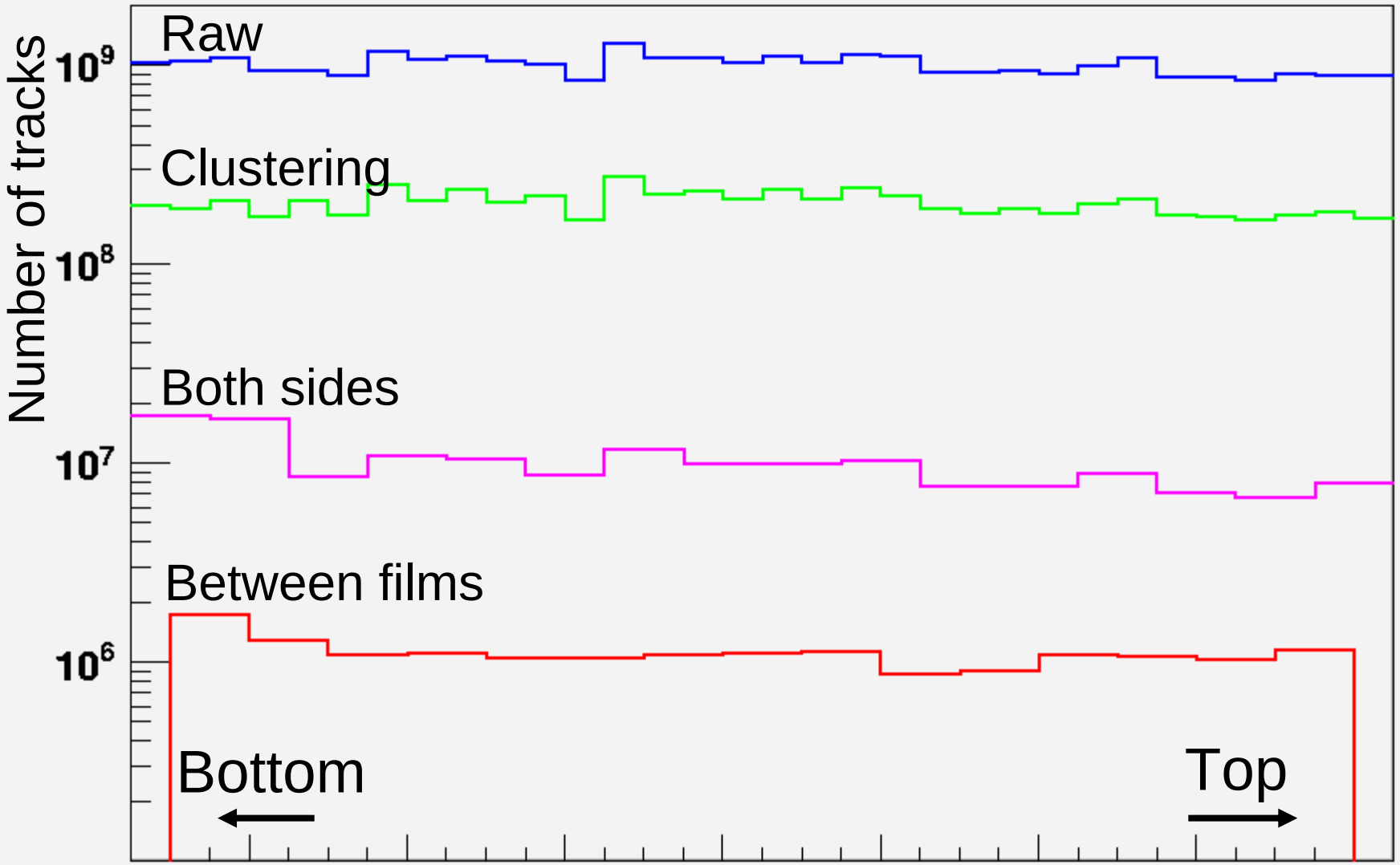


Number of tracks:8.0×10^8



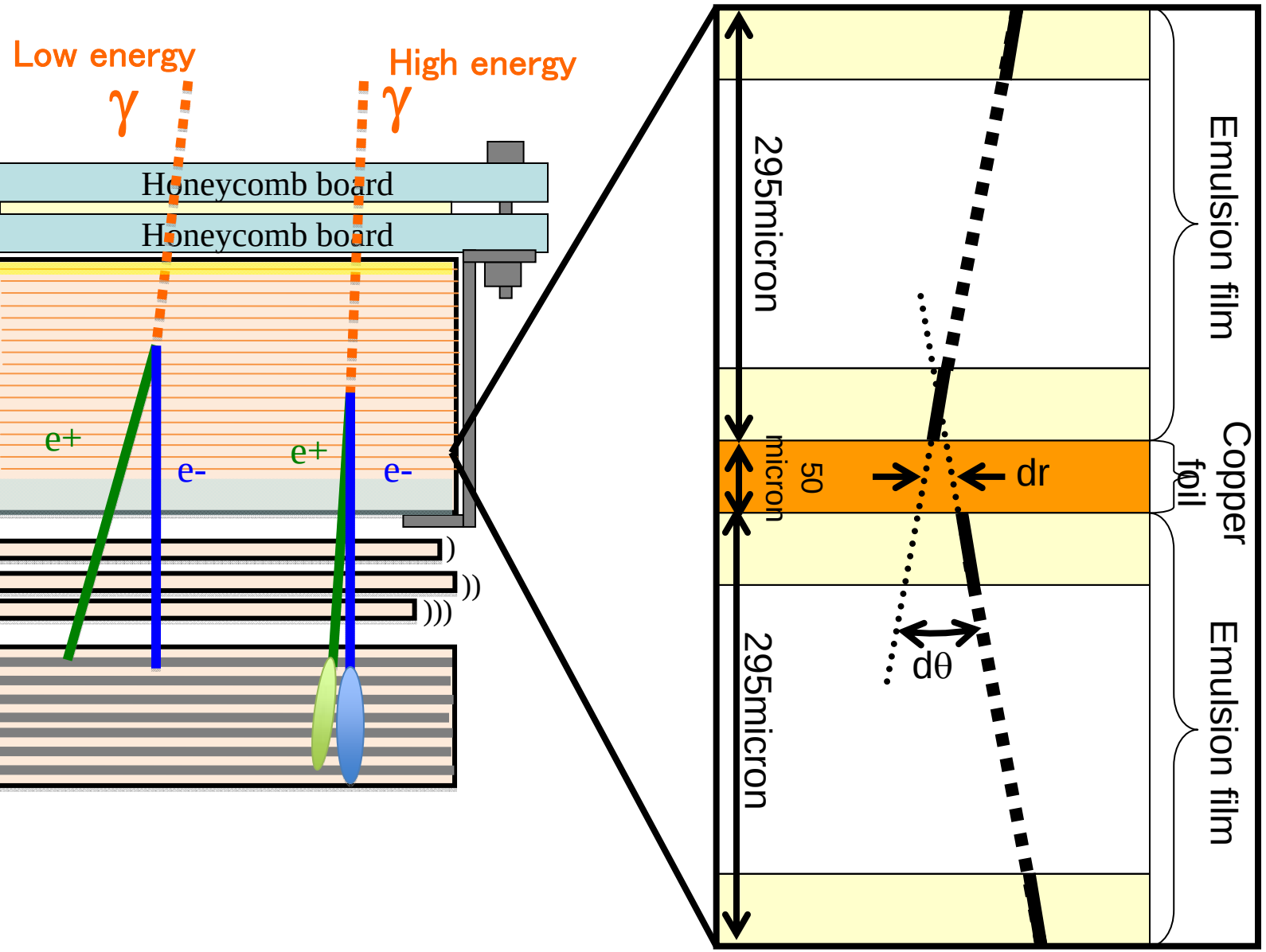
Film#67, 1st

Track reconstruction



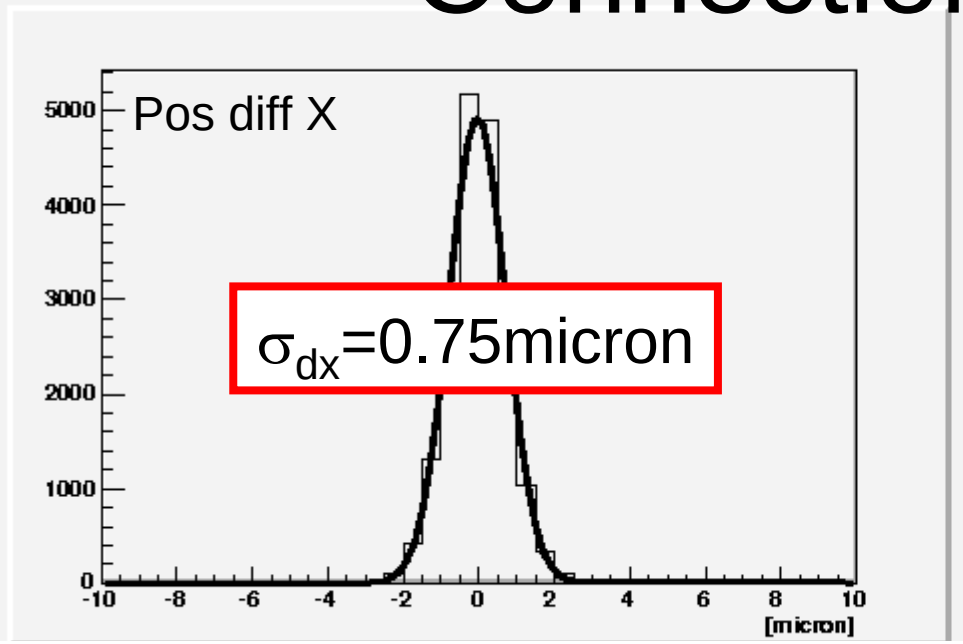
Reconstructed tracks (film#1-16) : 8.7×10^7 (overlap)

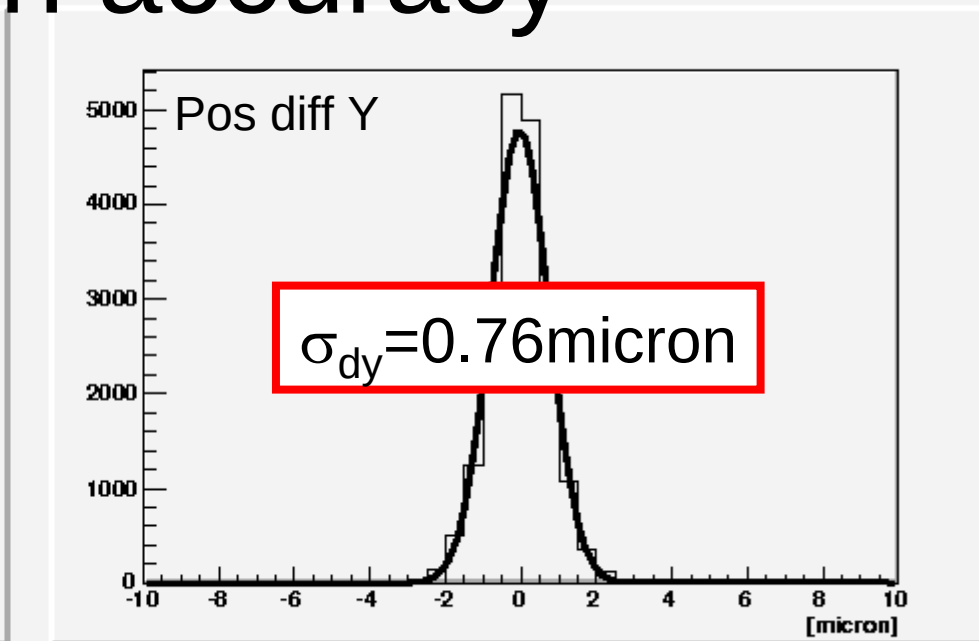
Connection accuracy

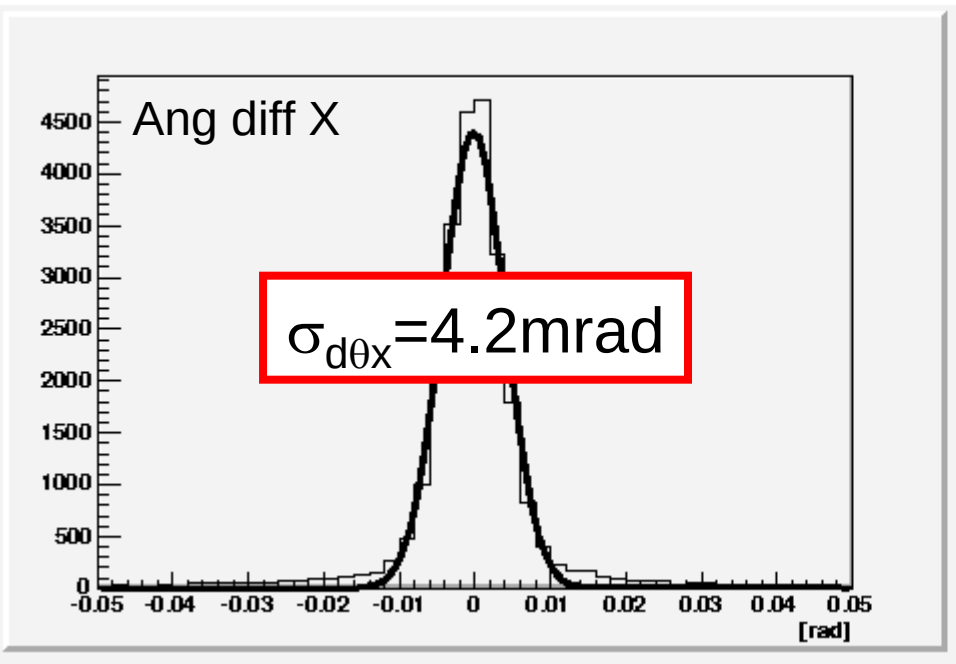


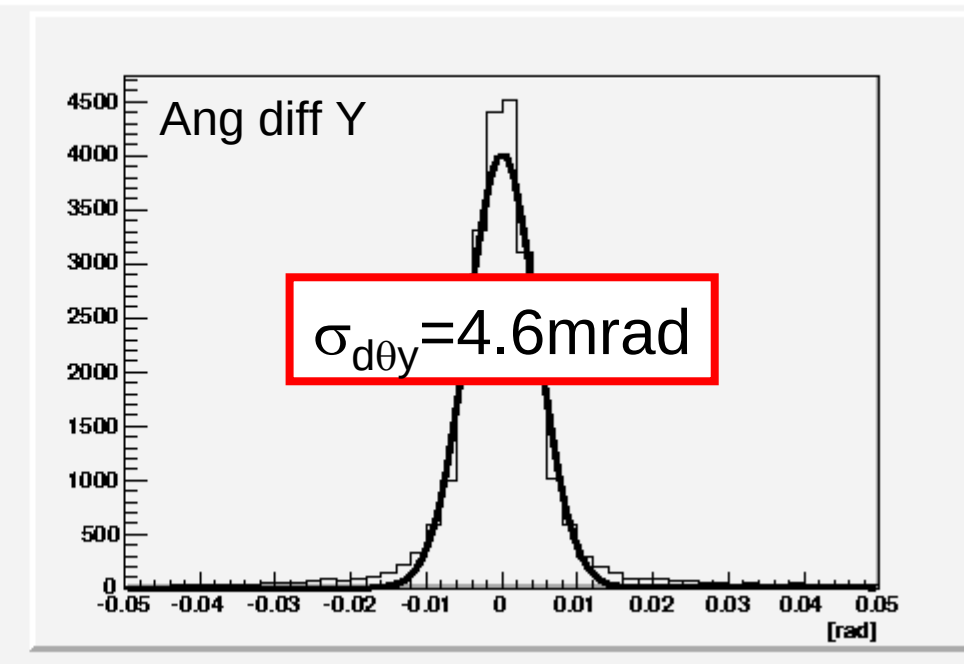
Connection accuracy

Film#12-13
tanθ<0.1

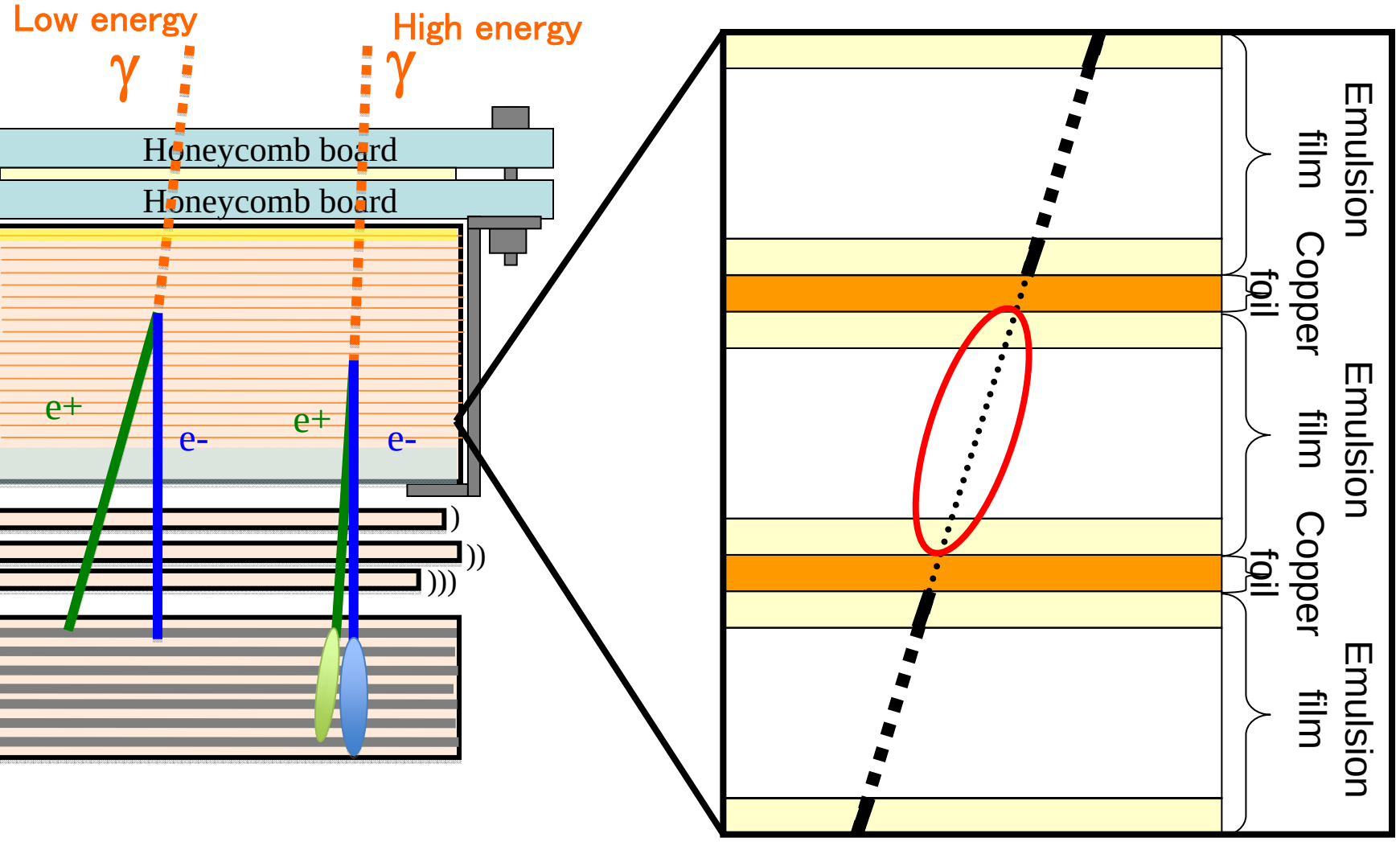




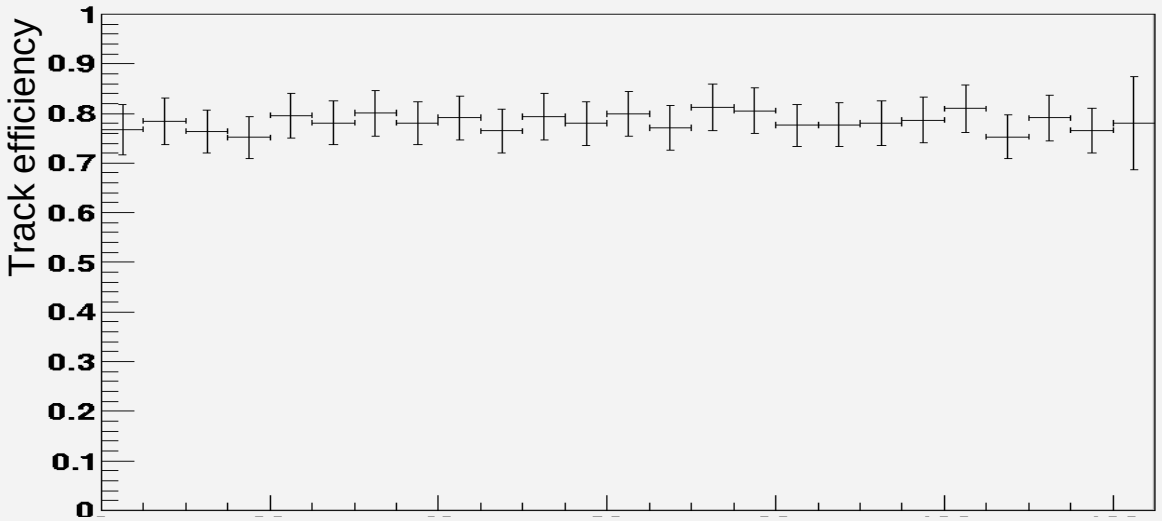


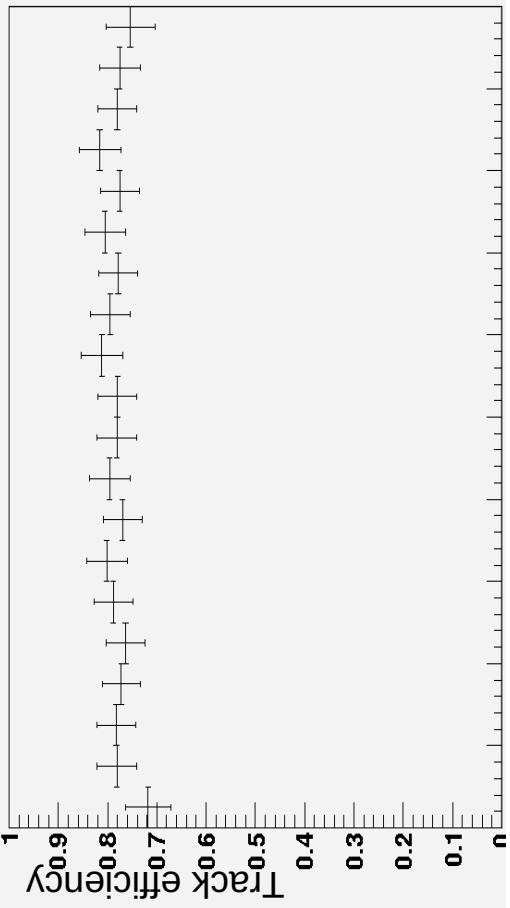


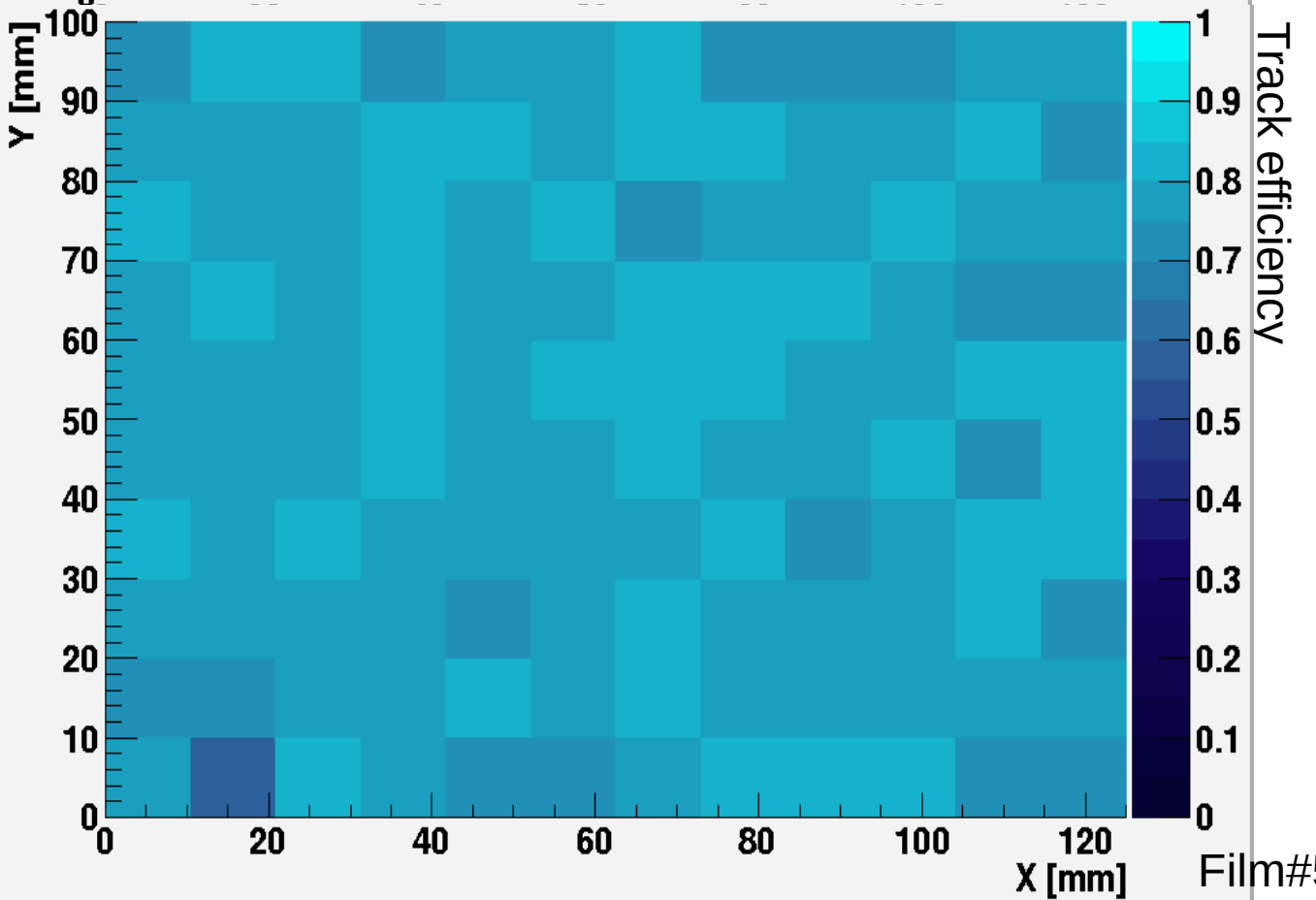
Track efficiency



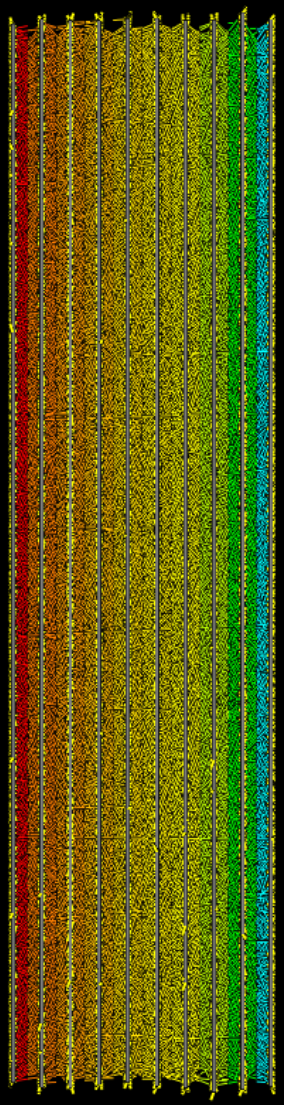
Track efficiency

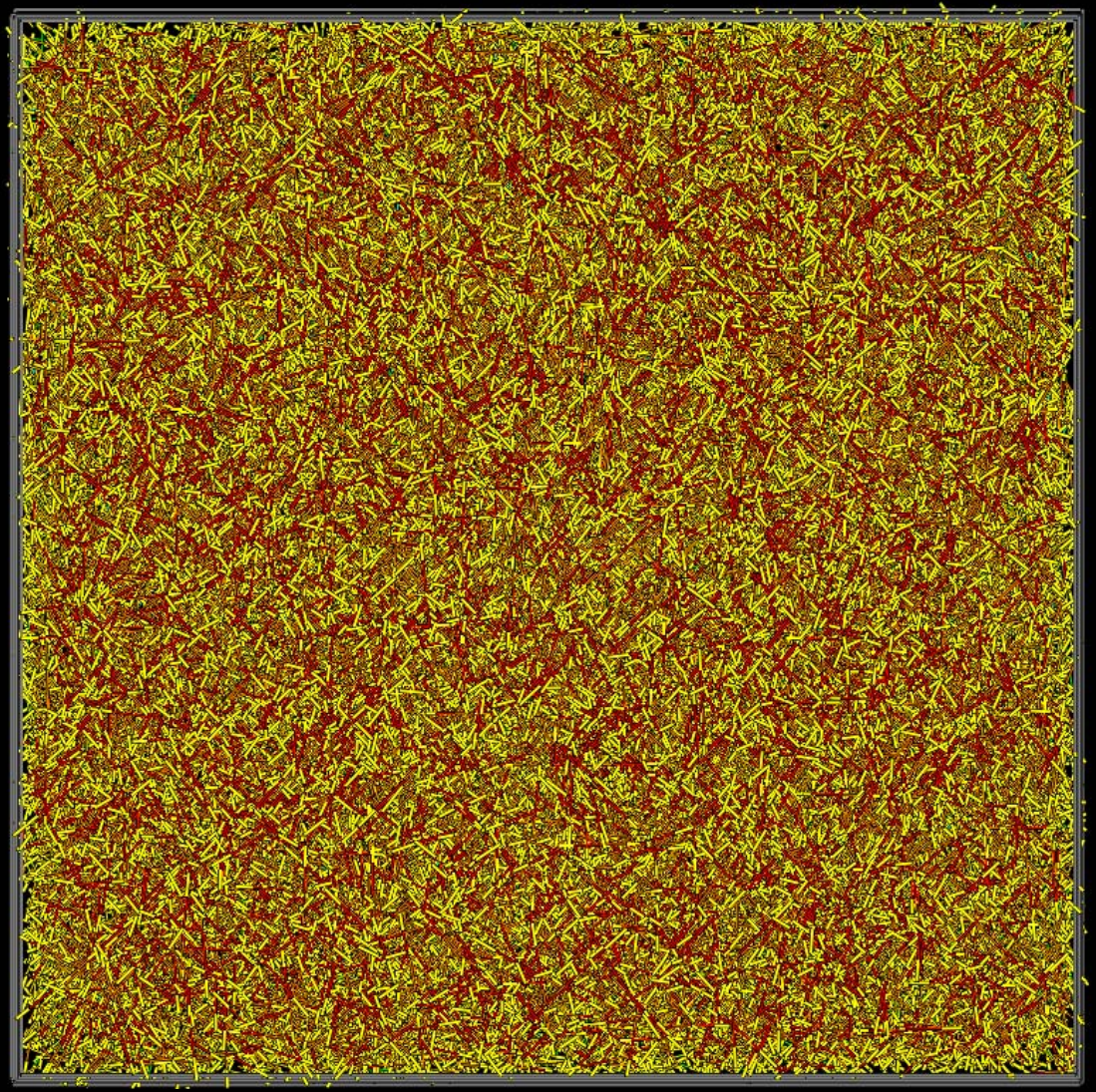






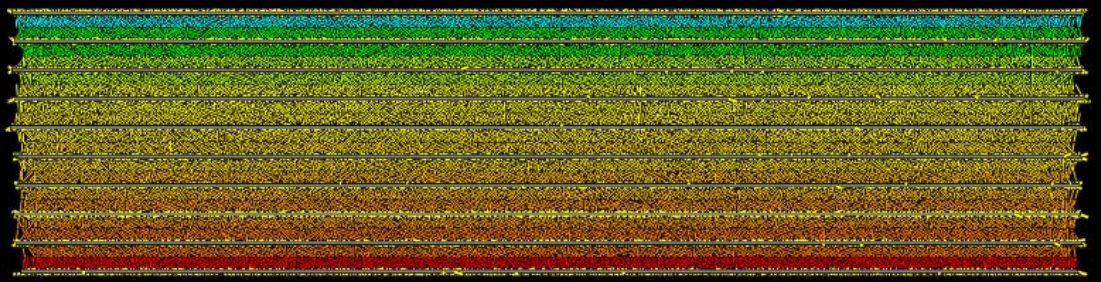
Film#5





Z

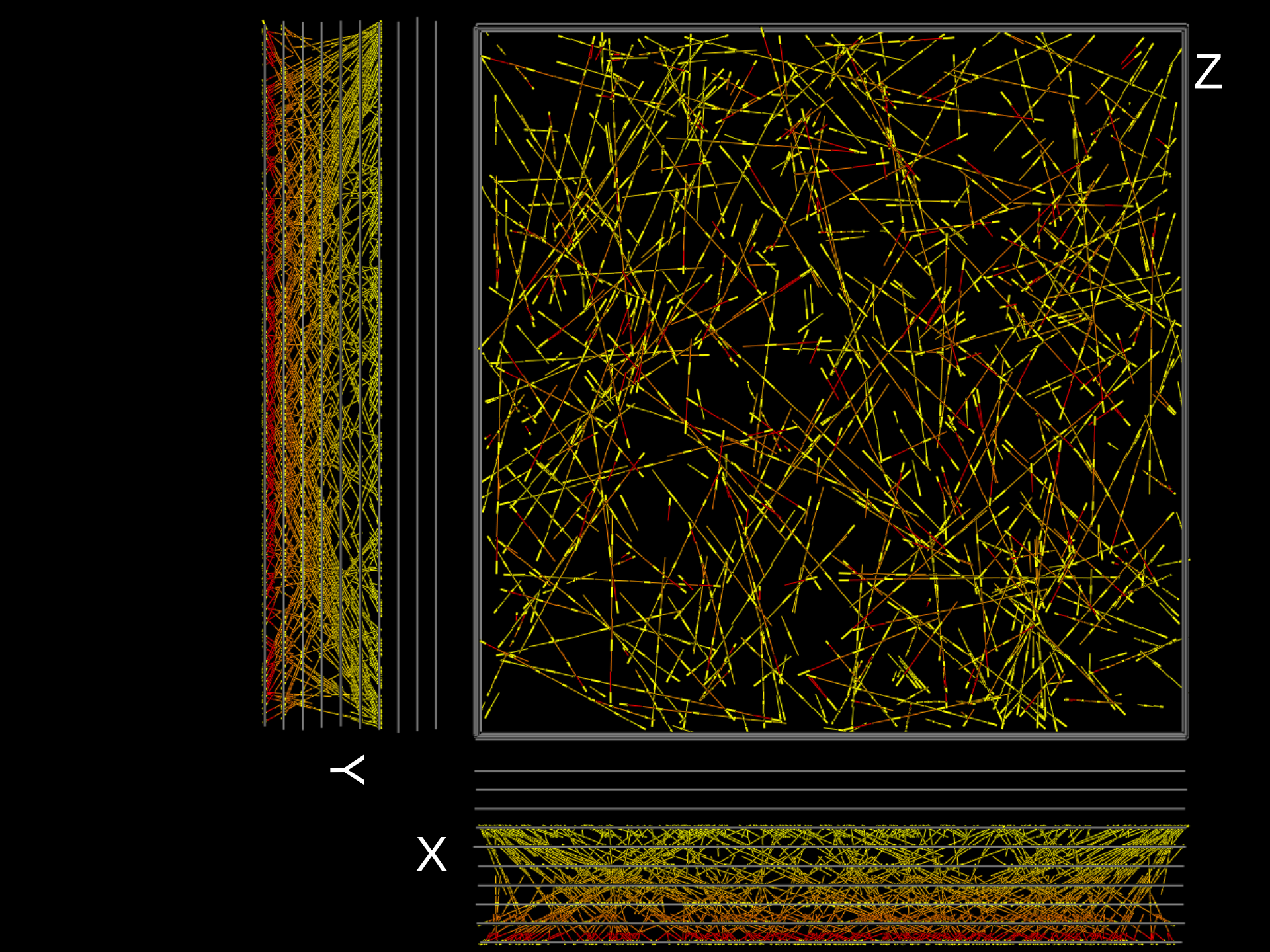
Y

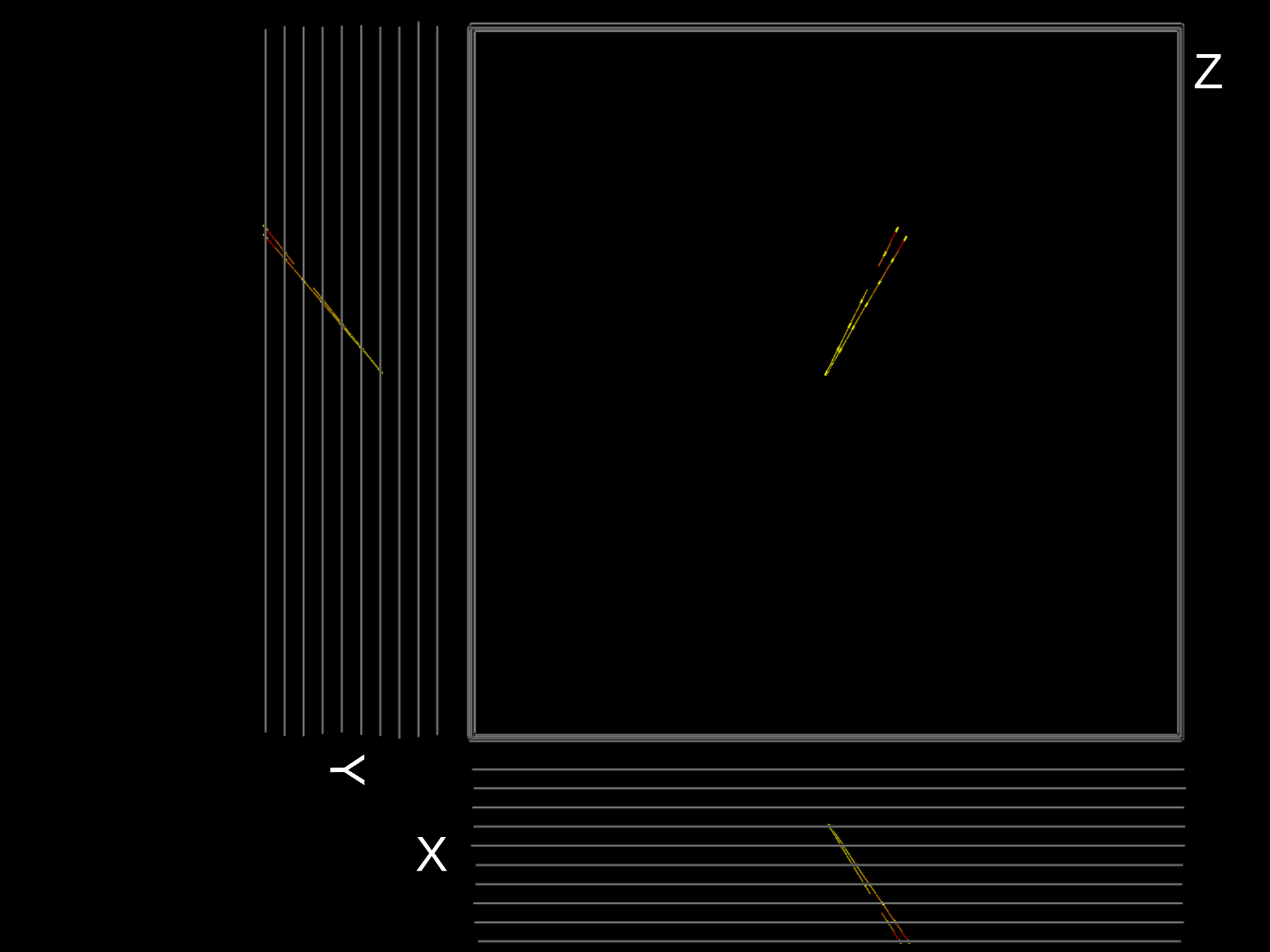


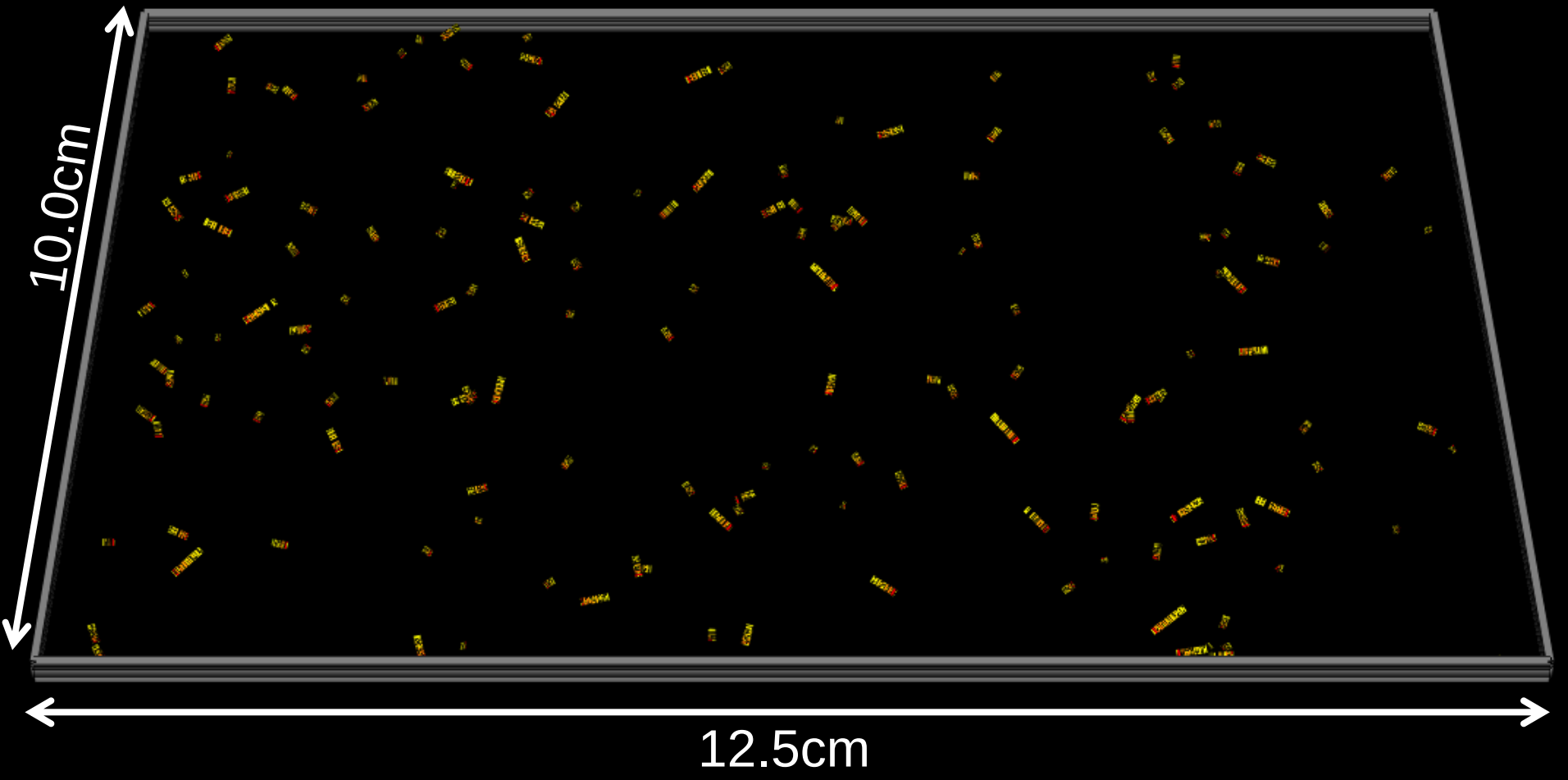
X

$(5mm)^2$ x10films

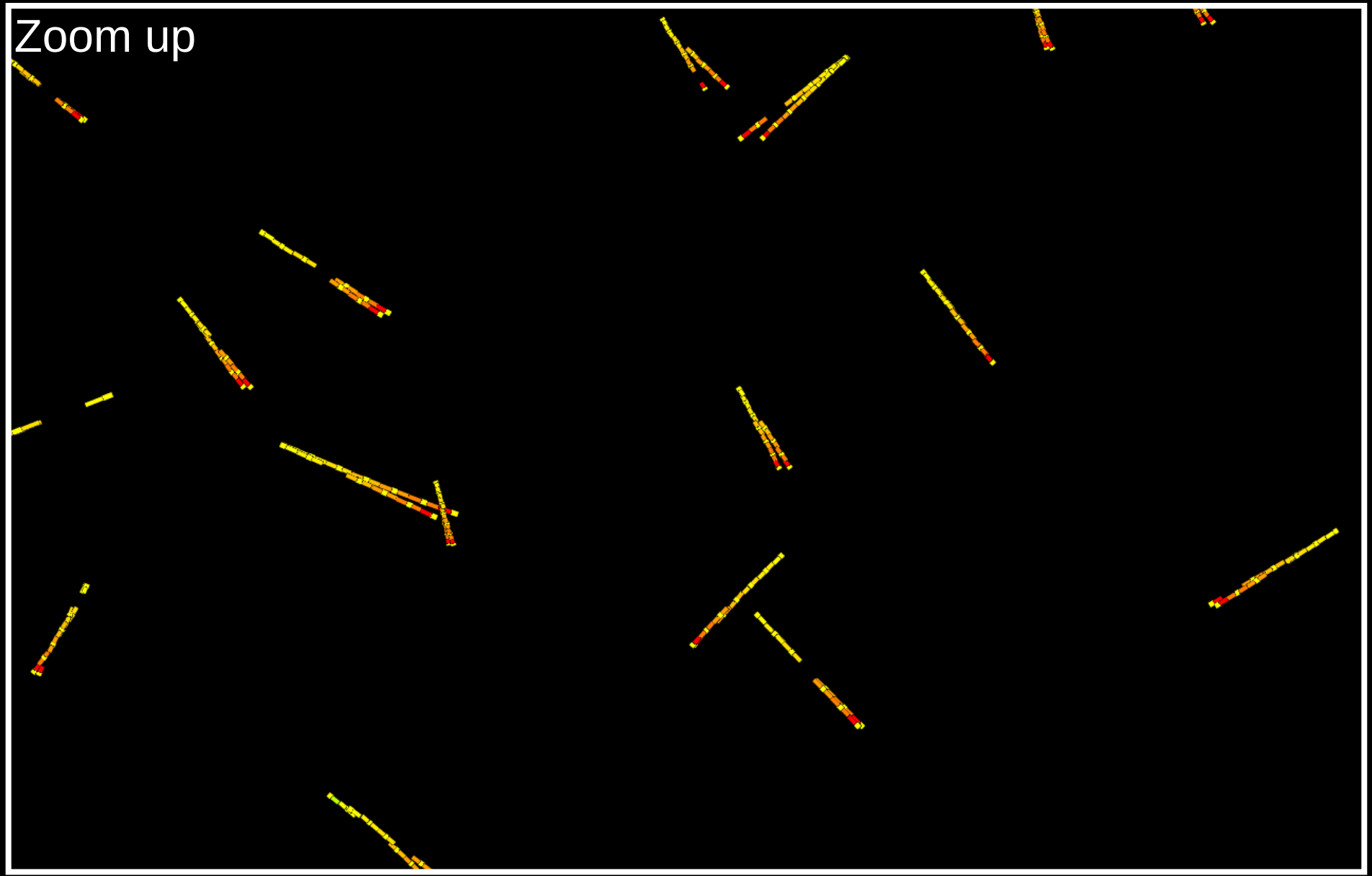
$2x10^4$tracks


Z
Y
X


Z
Y
X

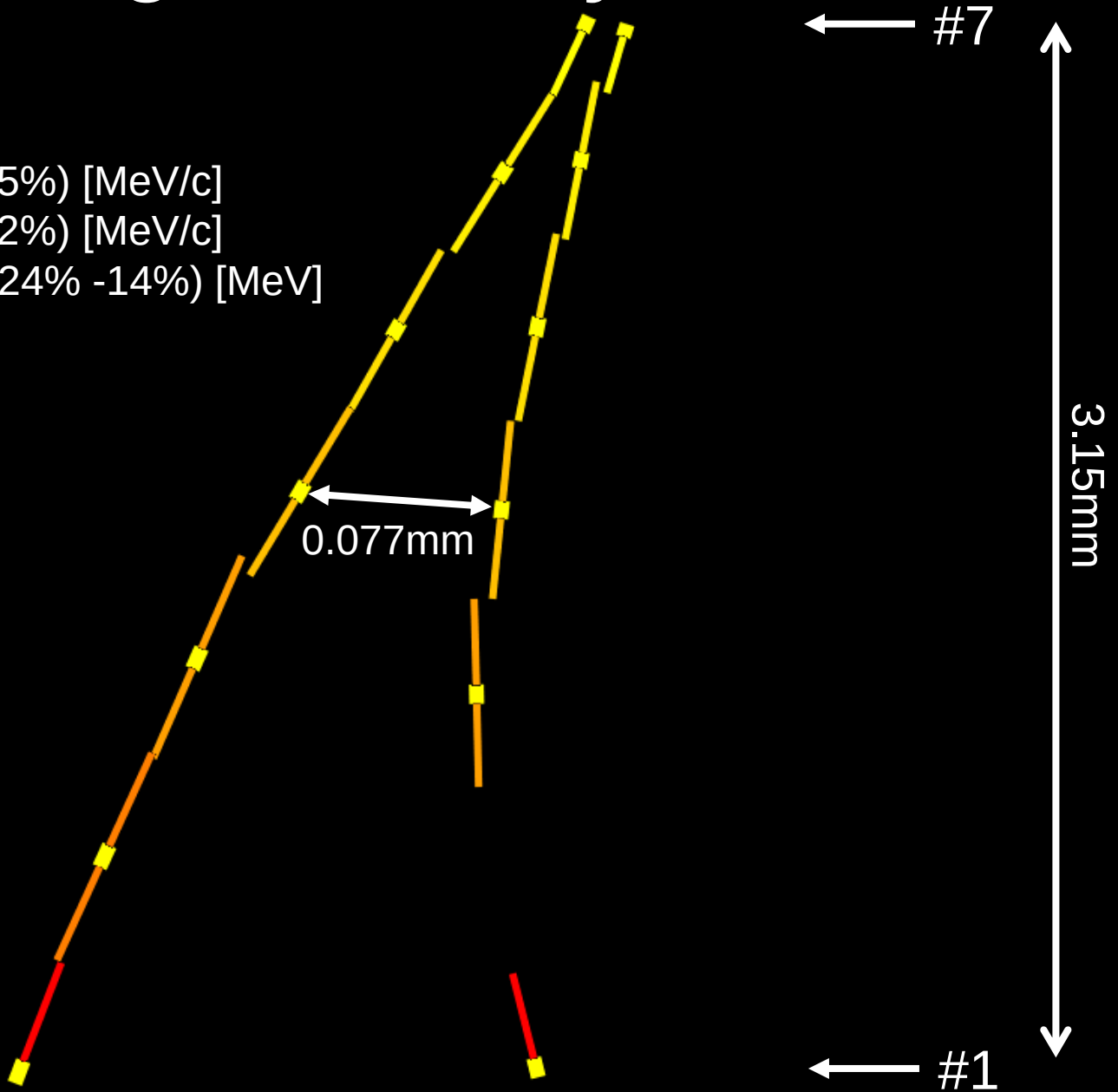


153events
Reliability 97%

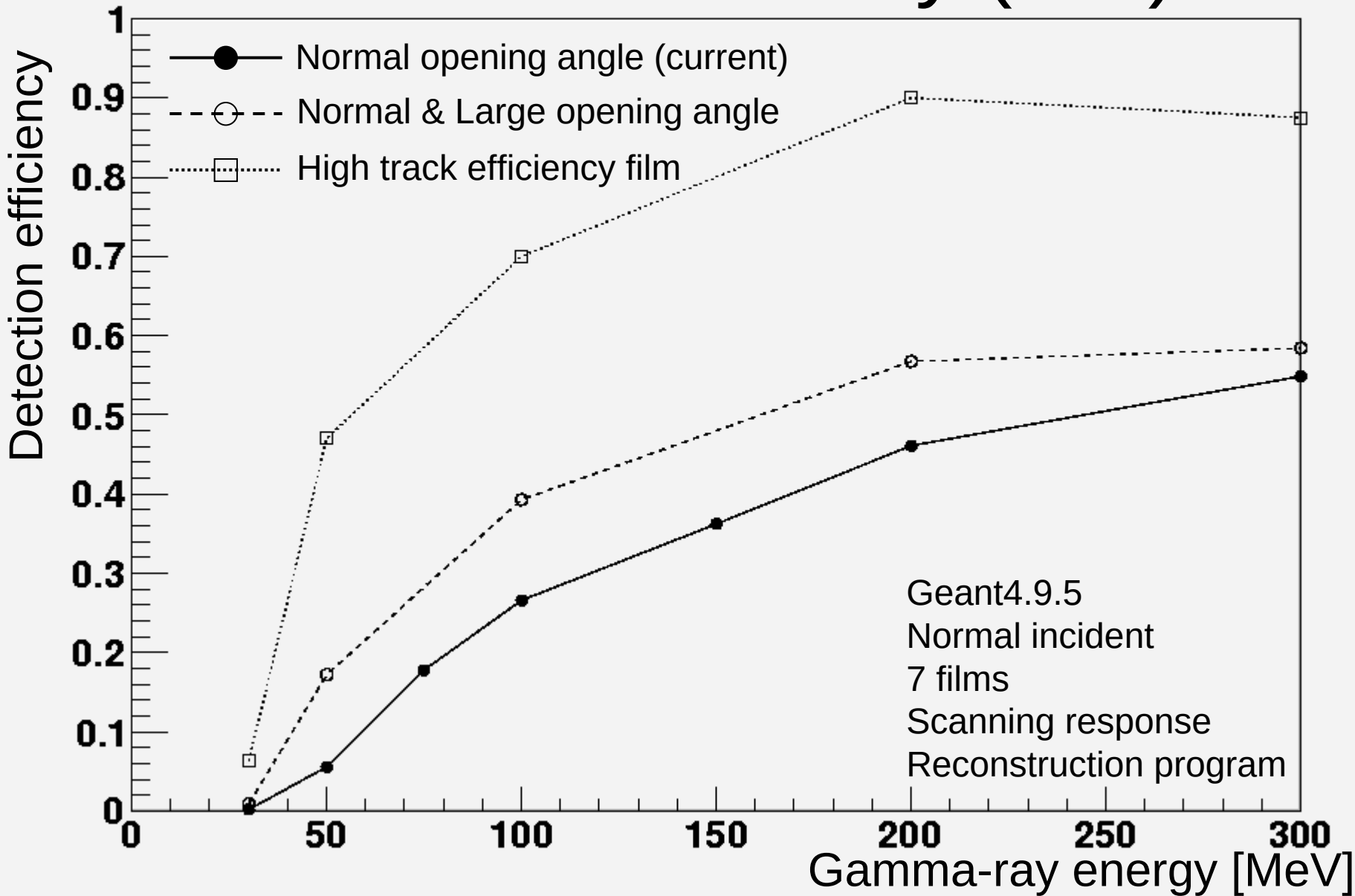

Zoom up

One of gamma-ray events

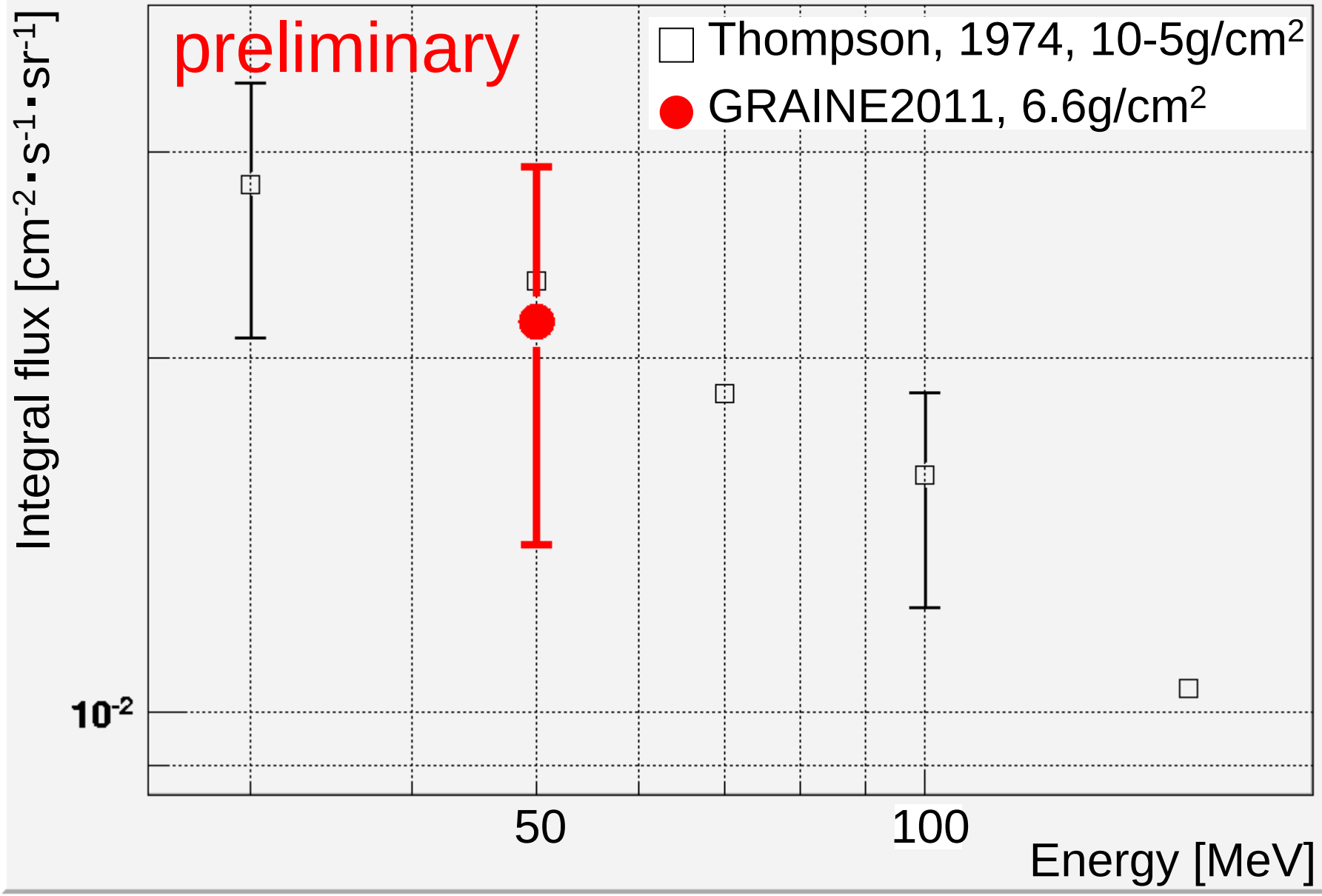
Event : 71 6923485
Start : #7
$\theta_{incident}$: 9.748 [deg]
$(p\beta)_{left}$: 60 +20 -12 (25%) [MeV/c]
$(p\beta)_{right}$: 32 + 9 - 6 (22%) [MeV/c]
$E\gamma$: 92 +22 -13 (+24% -14%) [MeV]



Detection efficiency (MC)



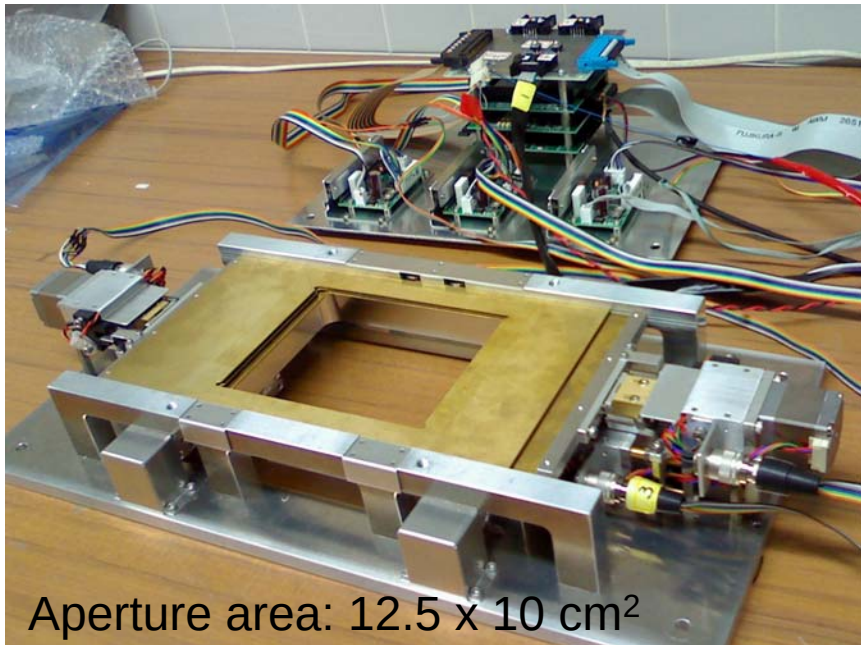
Atmospheric gamma-ray flux@35km



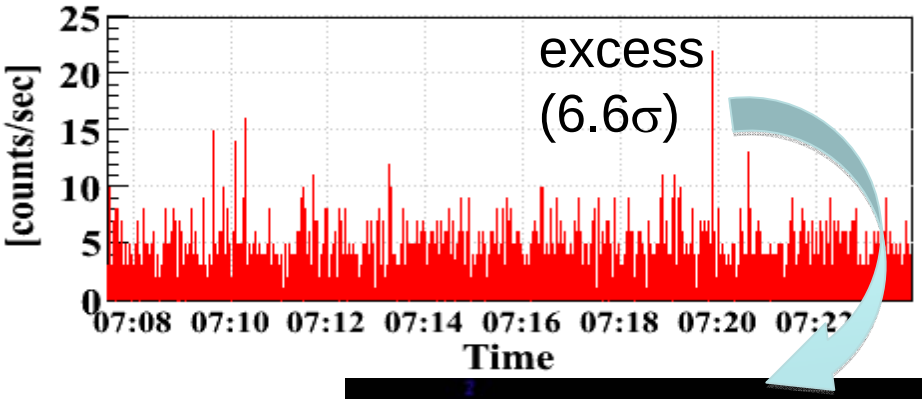
Establishment of timestamp technique @GRAINE2011

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

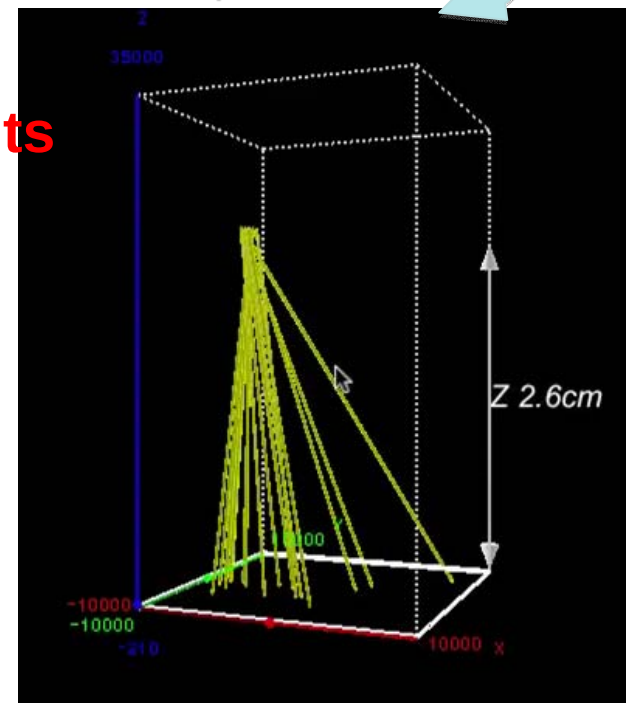
"Multi-stage shifter" 1st model



Track rate mesurement@35km

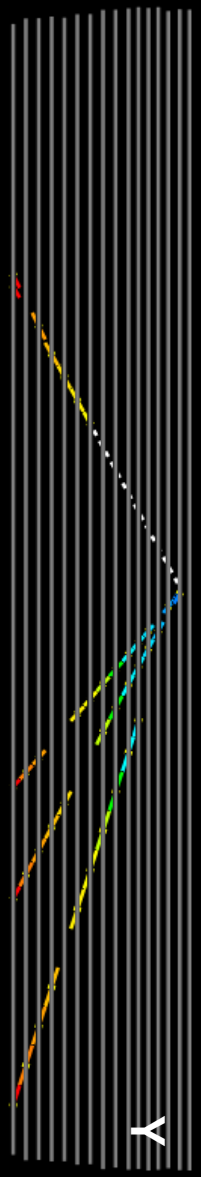


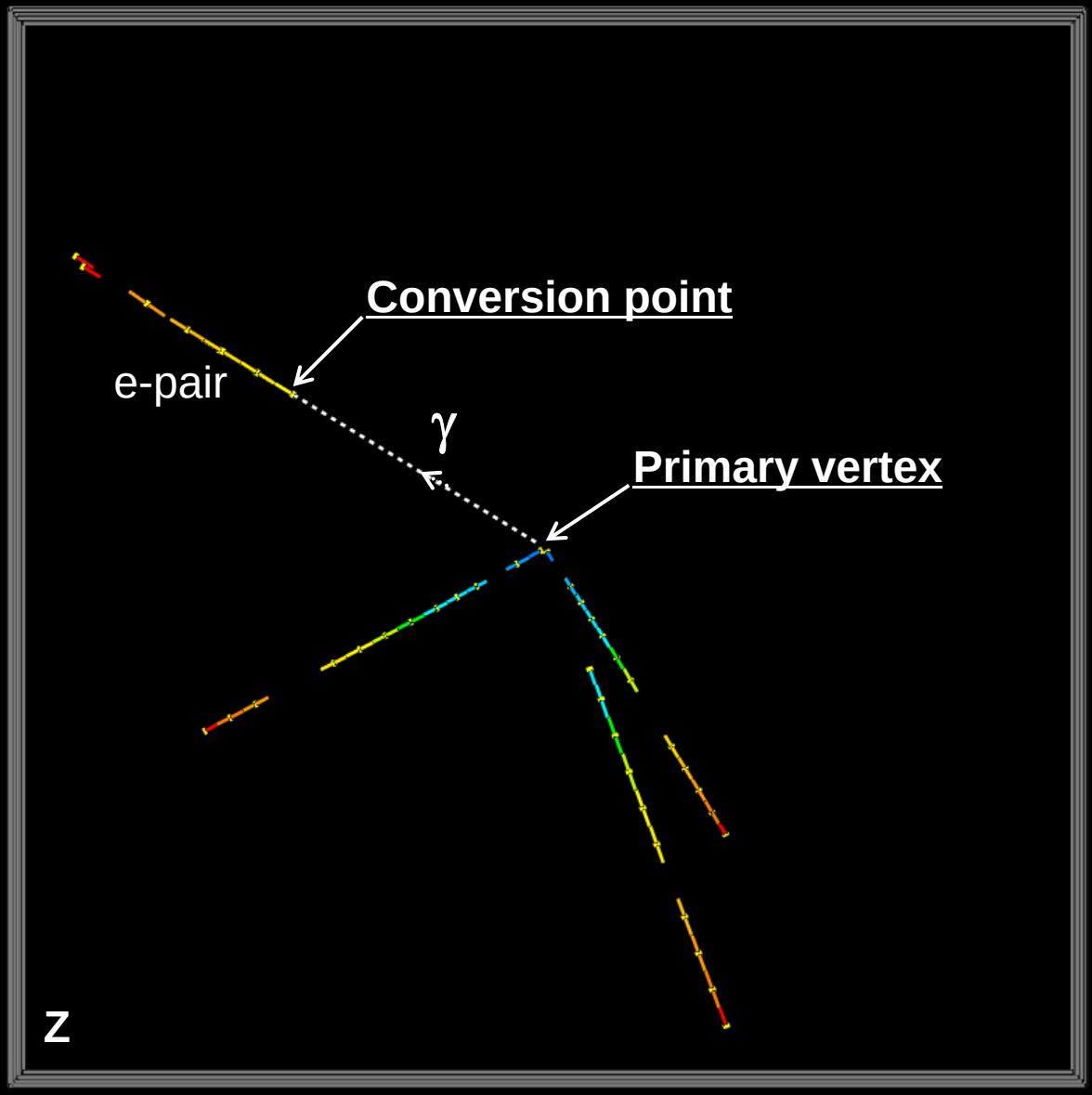
Detection of hadron events



- 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

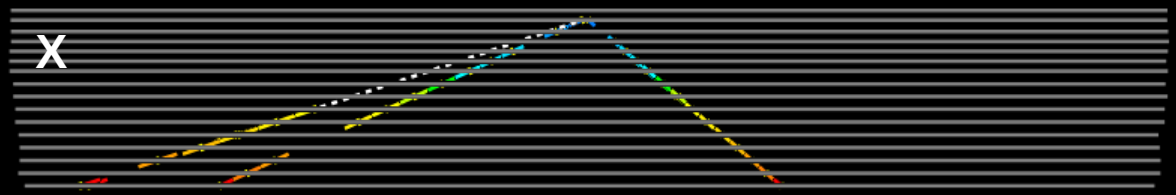
Ev : 2438038
7:18:34.5 (JST)
Δt=+-0.5s
1.2cm x 1.2cm
x 16films





Pointing accuracy

$\Delta\theta_{space}$: 0.65deg (0.0114rad)
Eγ : 45+33-10 [MeV]
θγ : 46.61 [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**

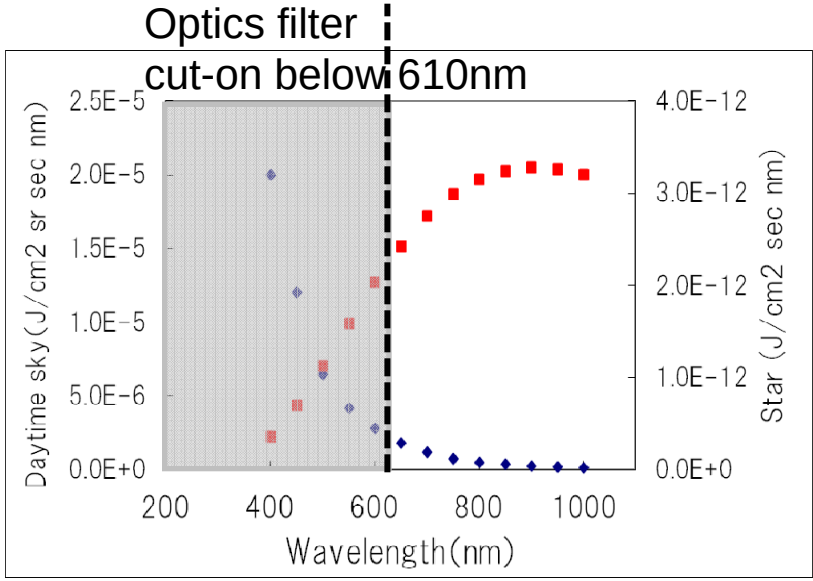
  ADVANTECH PCM-3362
  - CPU：Intel Atom N450 1.66GHz

- **Video Capture board**

  Sensory Frame Grabber Model 311
  - ADC ：8bit
  - Frame rate：30FPS

- **SSD(128GB)**

  TOSHIBA SSDN-ST128H



◆：Daytime sky BG（Dietz et al., 2002）

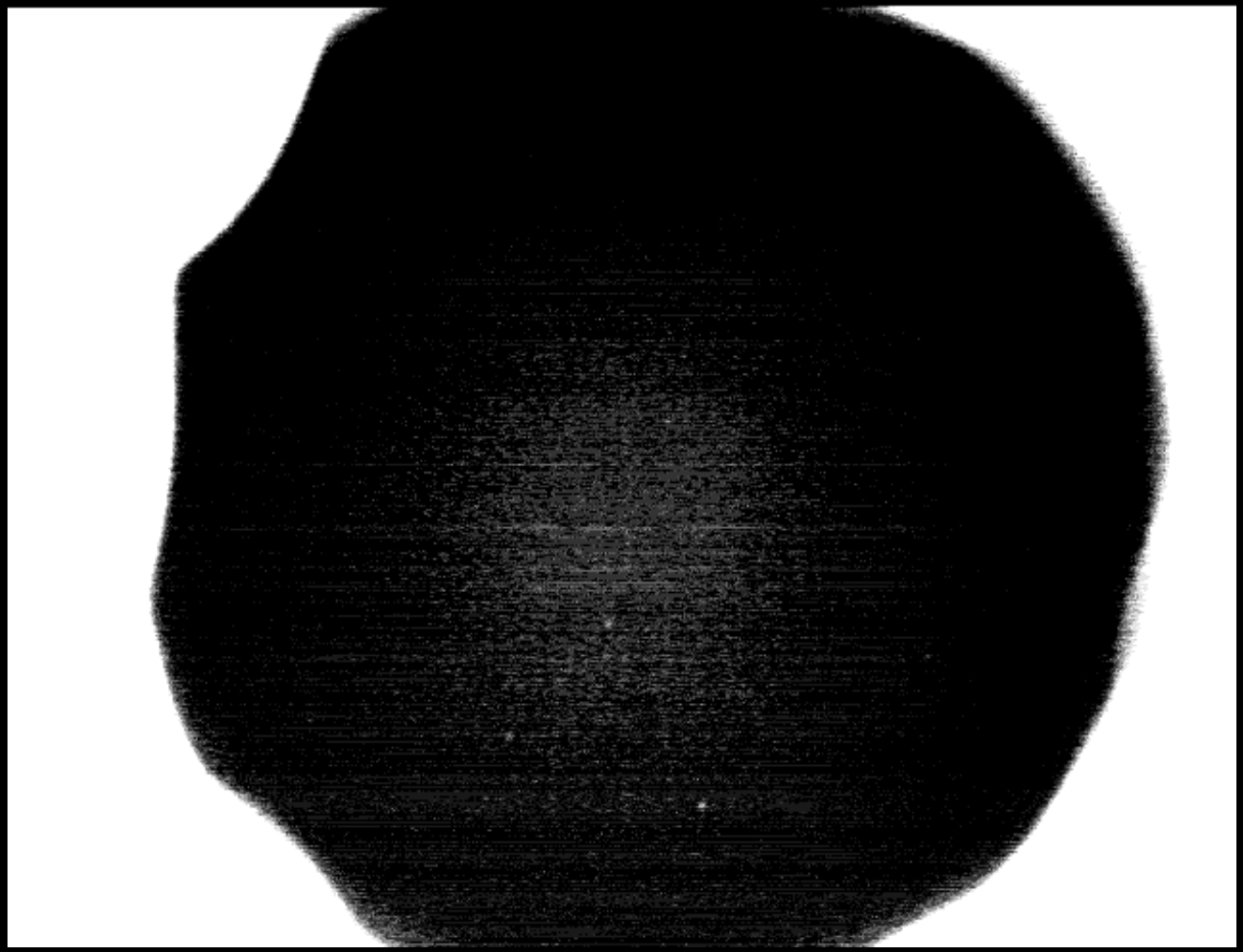
■：Star spectrum（M-type:3200K）

Field of View：
5.9deg(H)×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

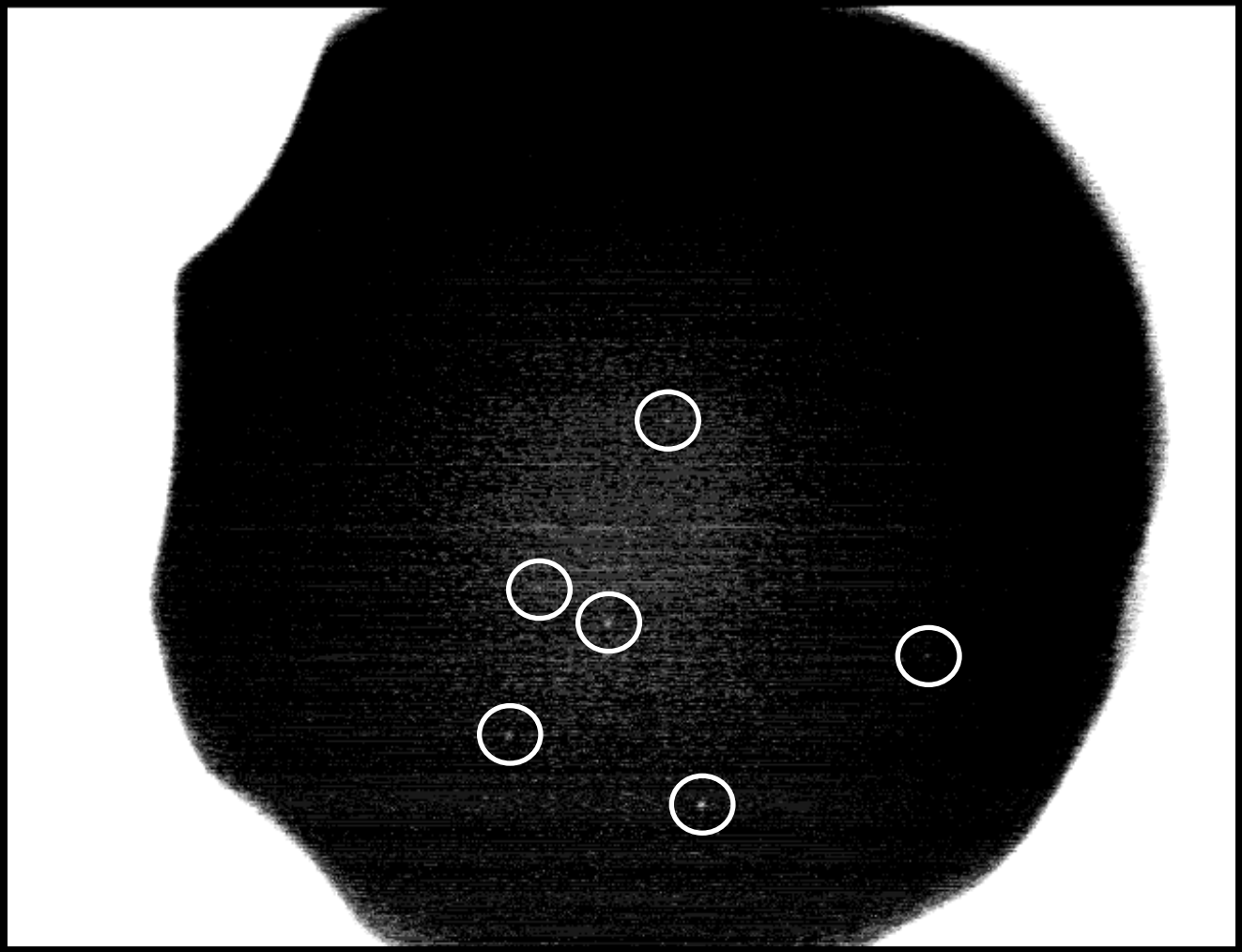
time: 8:11:00.16 (@Altitude 34.6km)



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

Image data on Level Flight

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

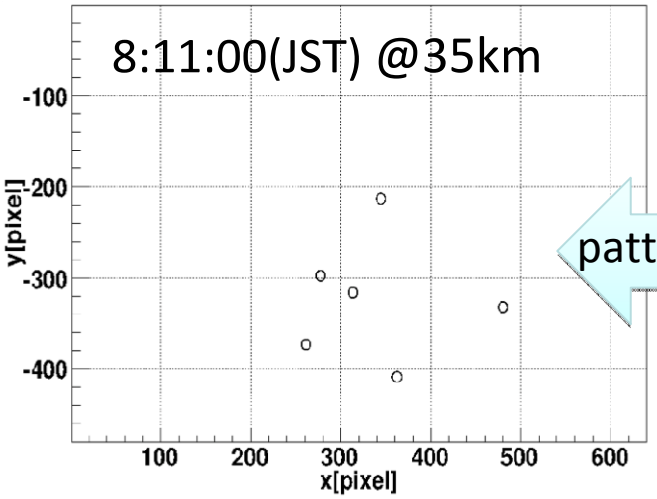


6 stars were detected.

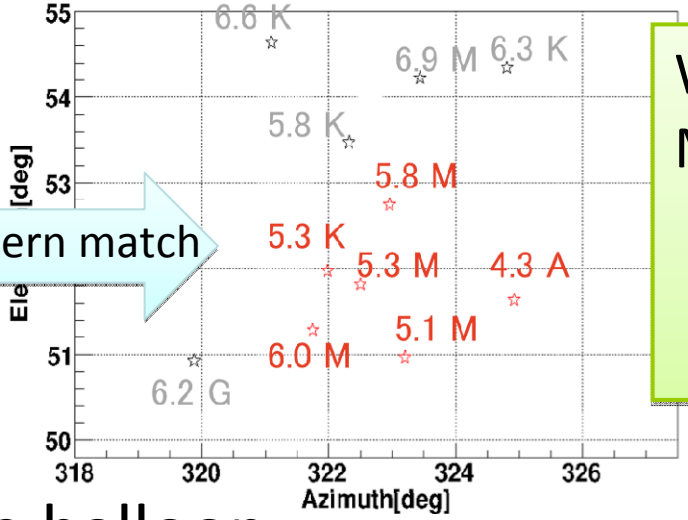
Attitude analysis

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

Daytime star camera view



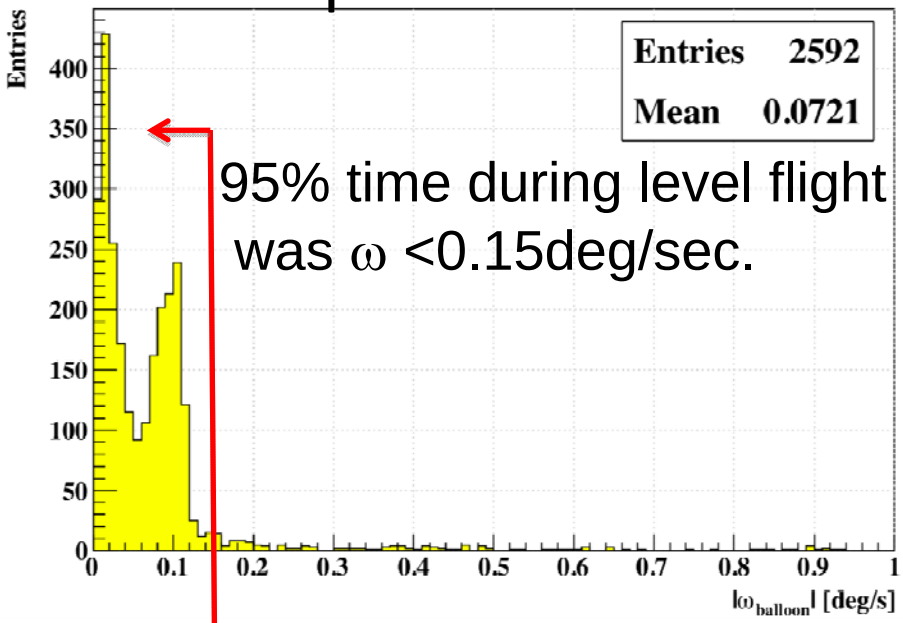
Star catalog data



pattern match

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

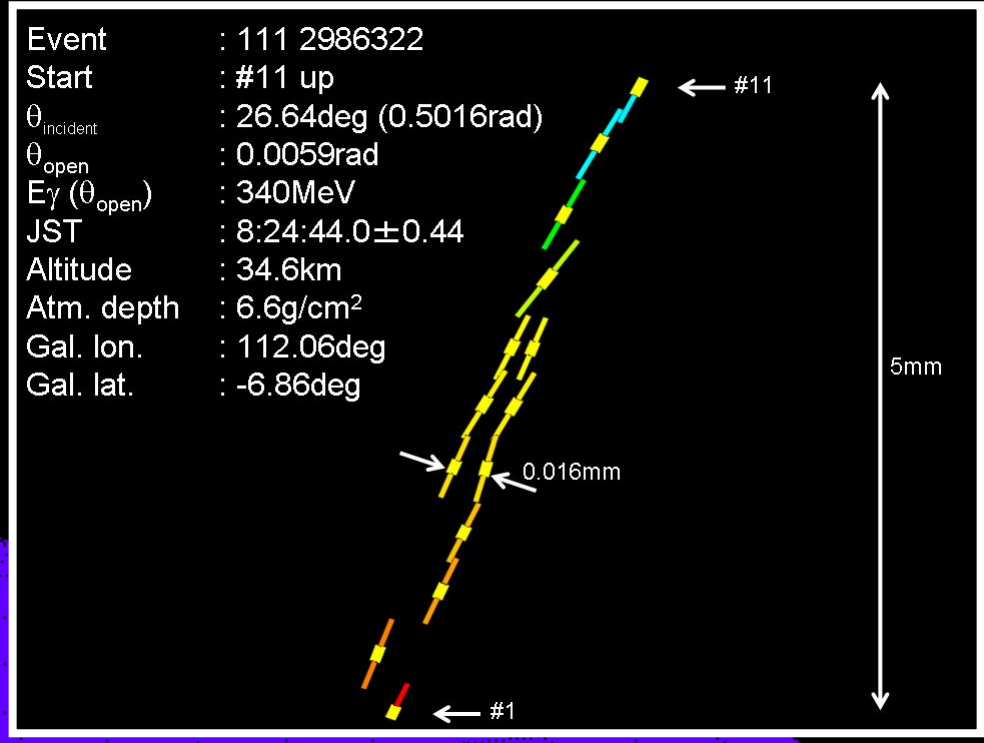
Rotation speed of the balloon

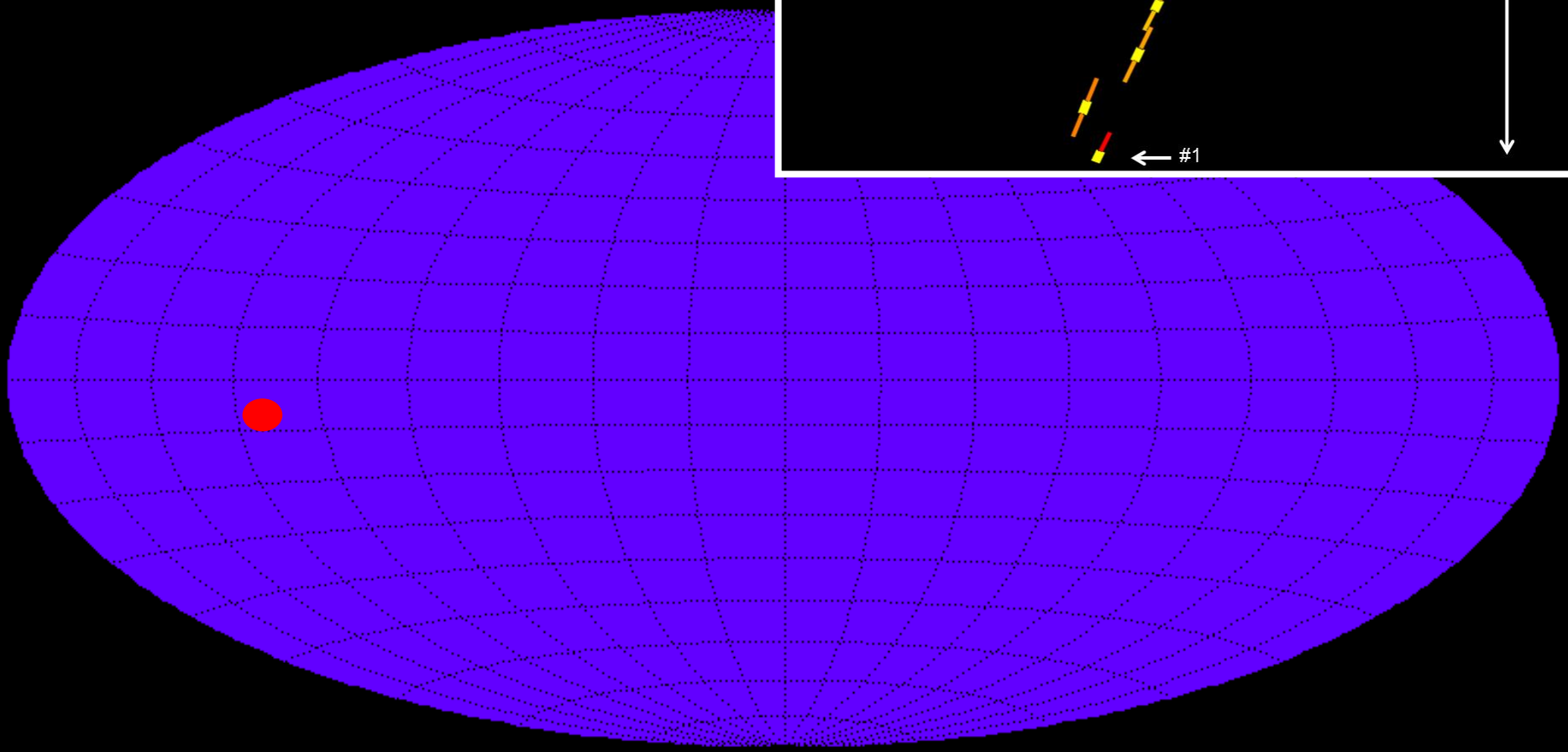


It is important to decide telescope attitude to celestial coordinate better than emulsion angular resolution(0.08deg).

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

GRAINE First Light



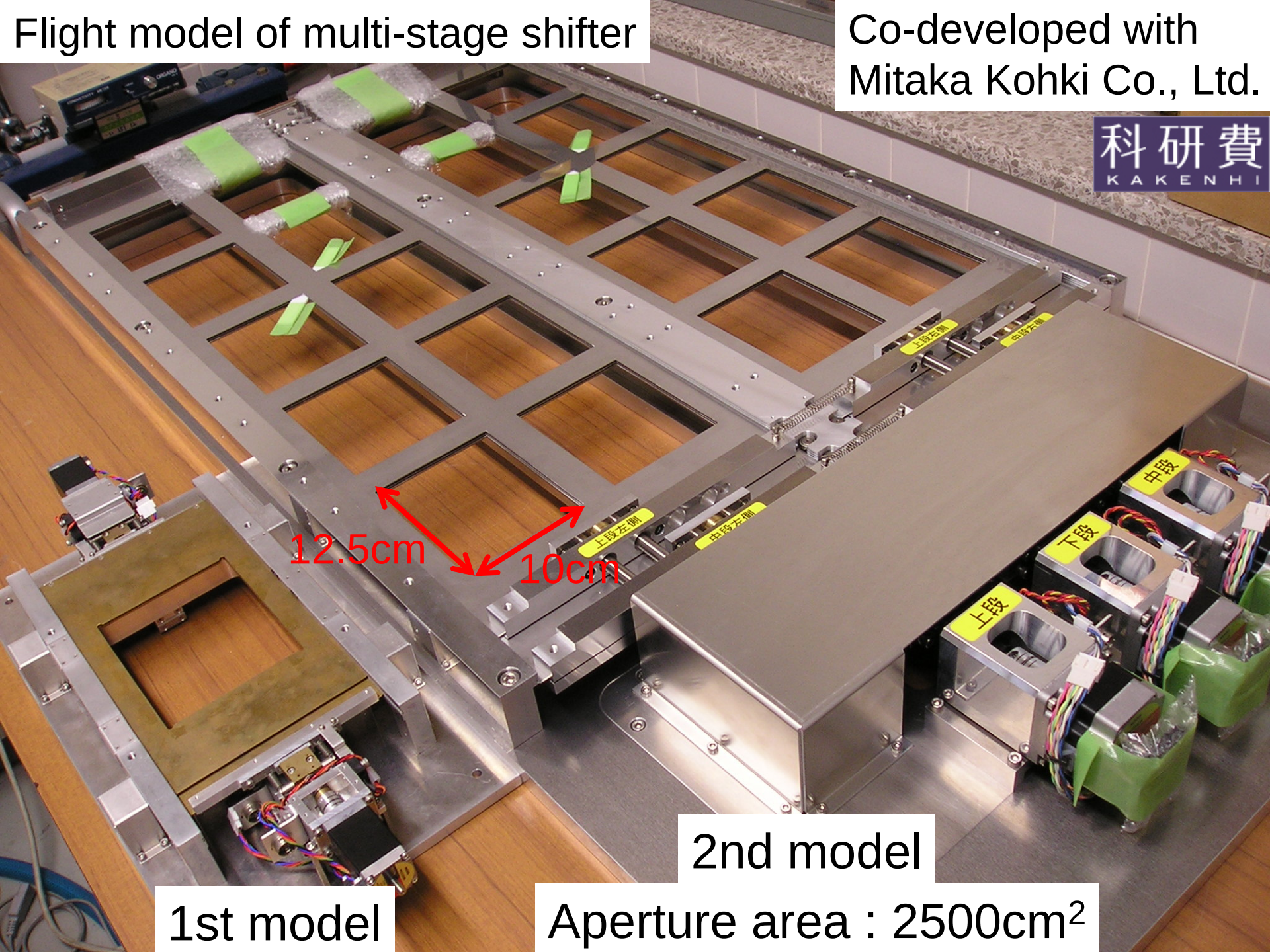


GRAINE roadmap

- 8th/June/2011, TARF, JAXA Scientific Ballooning,
  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

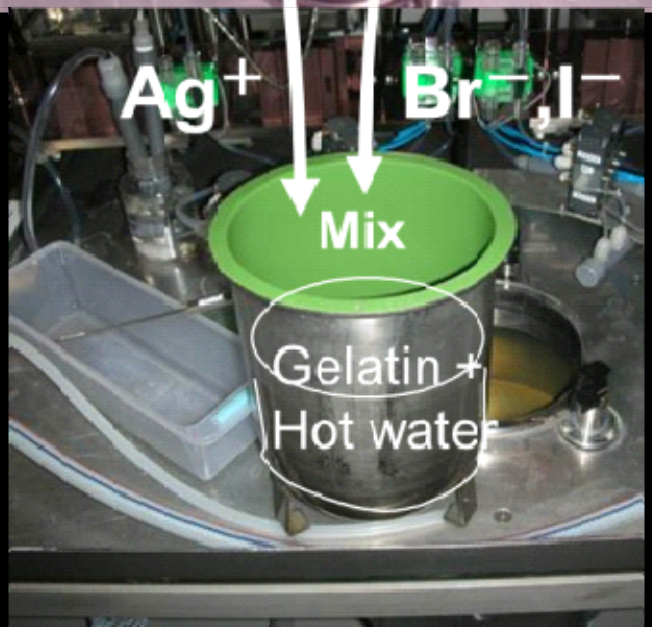
- 2014(Planned), Alice Springs, JAXA International Scientific Ballooning
  2500cm^2 aperture area, 1 day flight duration
  - Overall test by detecting known gamma-ray source
  - Observation with highest imaging resolution

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

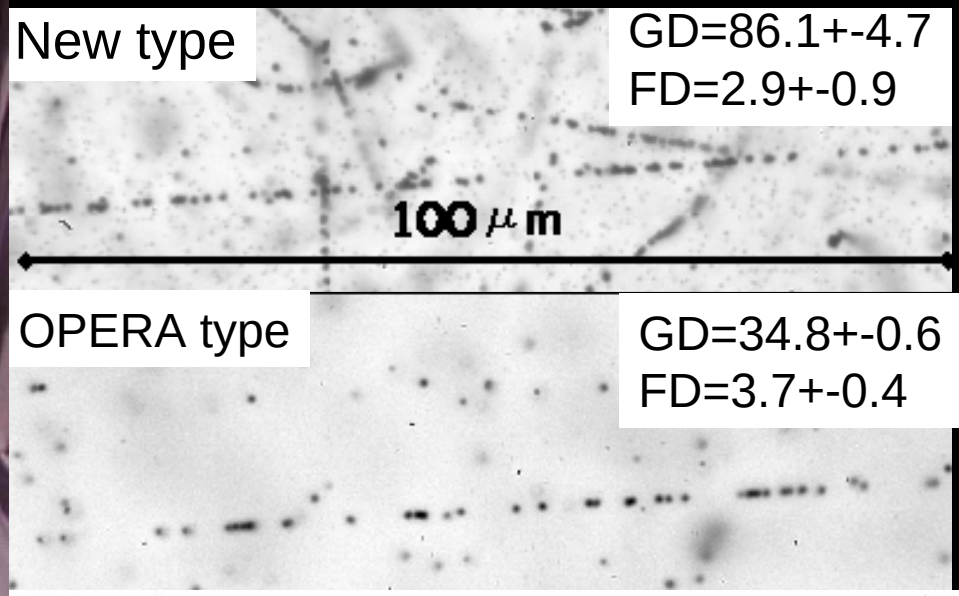

Flight model of multi-stage shifter
Co-developed with
Mitaka Kohki Co., Ltd.
科研費
KAKENHI
12.5cm
10cm
上段左側
中段左側
上段
下段
中段
2nd model
1st model
Aperture area : 2500cm²

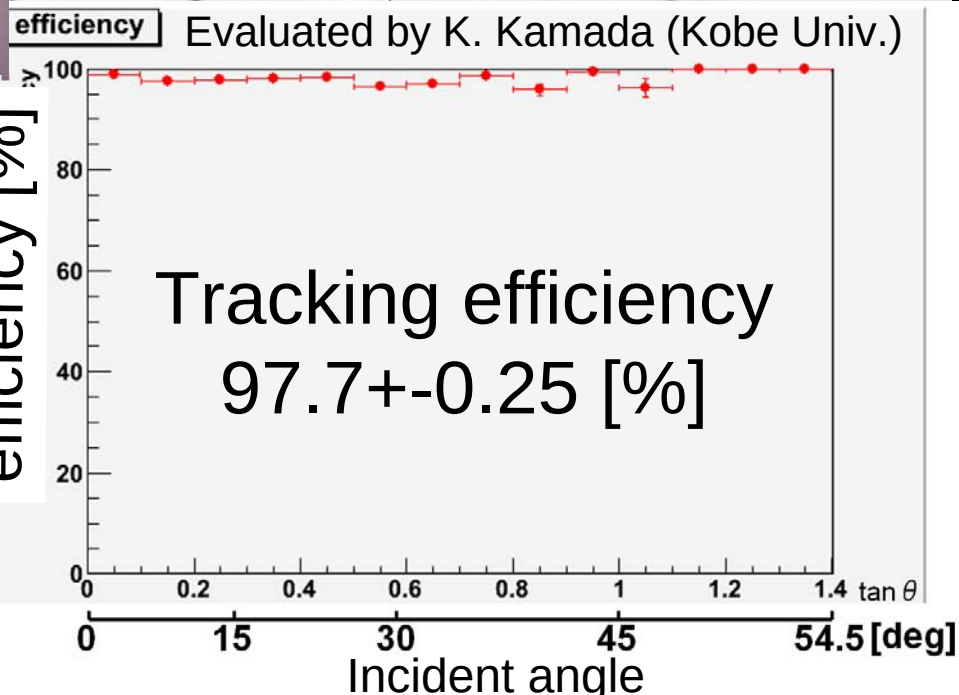
Emulsion production

Fuji Janet Co., Ltd., Nagoya Univ.

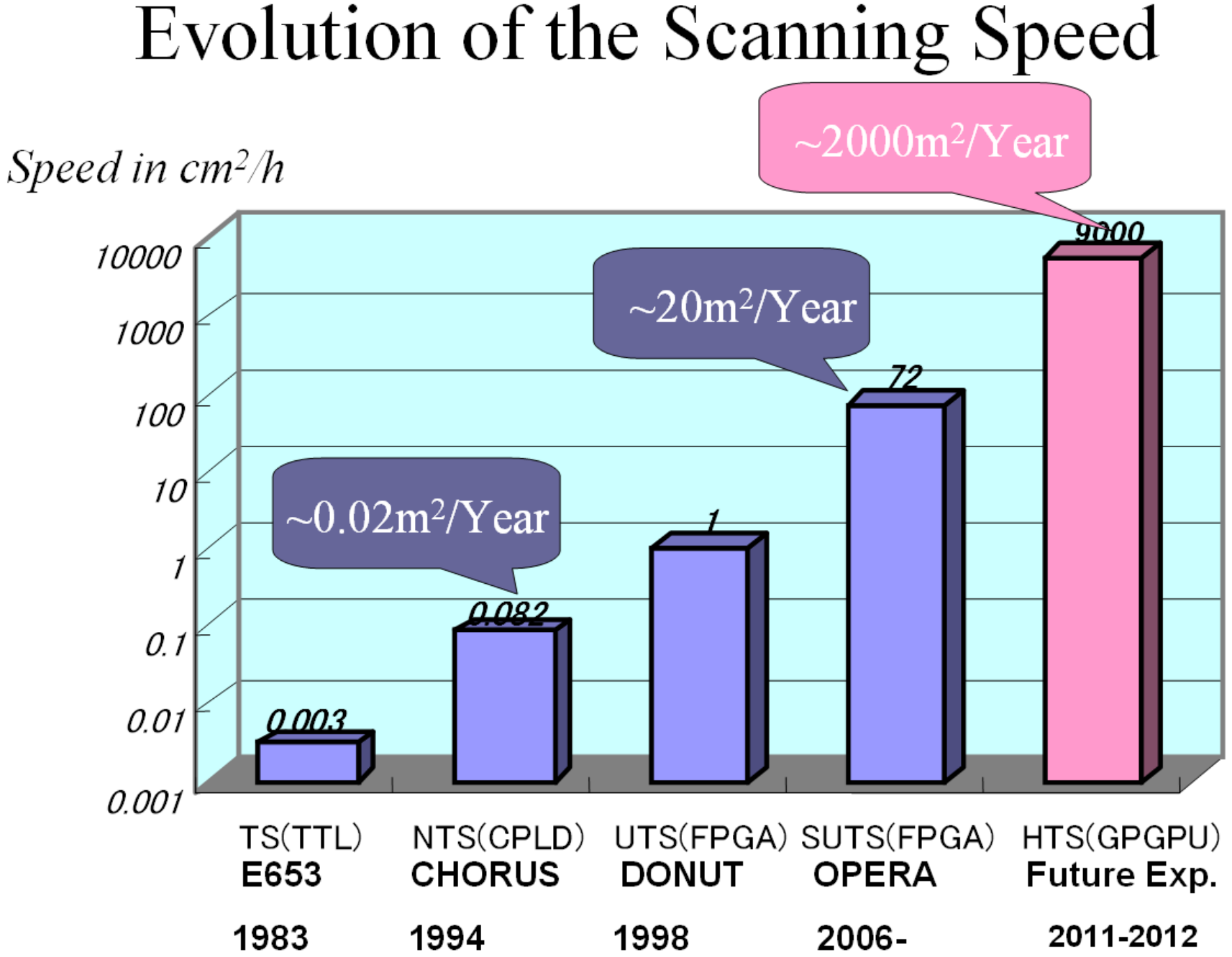


Gelatin1/4, Na type, Fe x 2, MIP (XAA, 20deg, 40min)





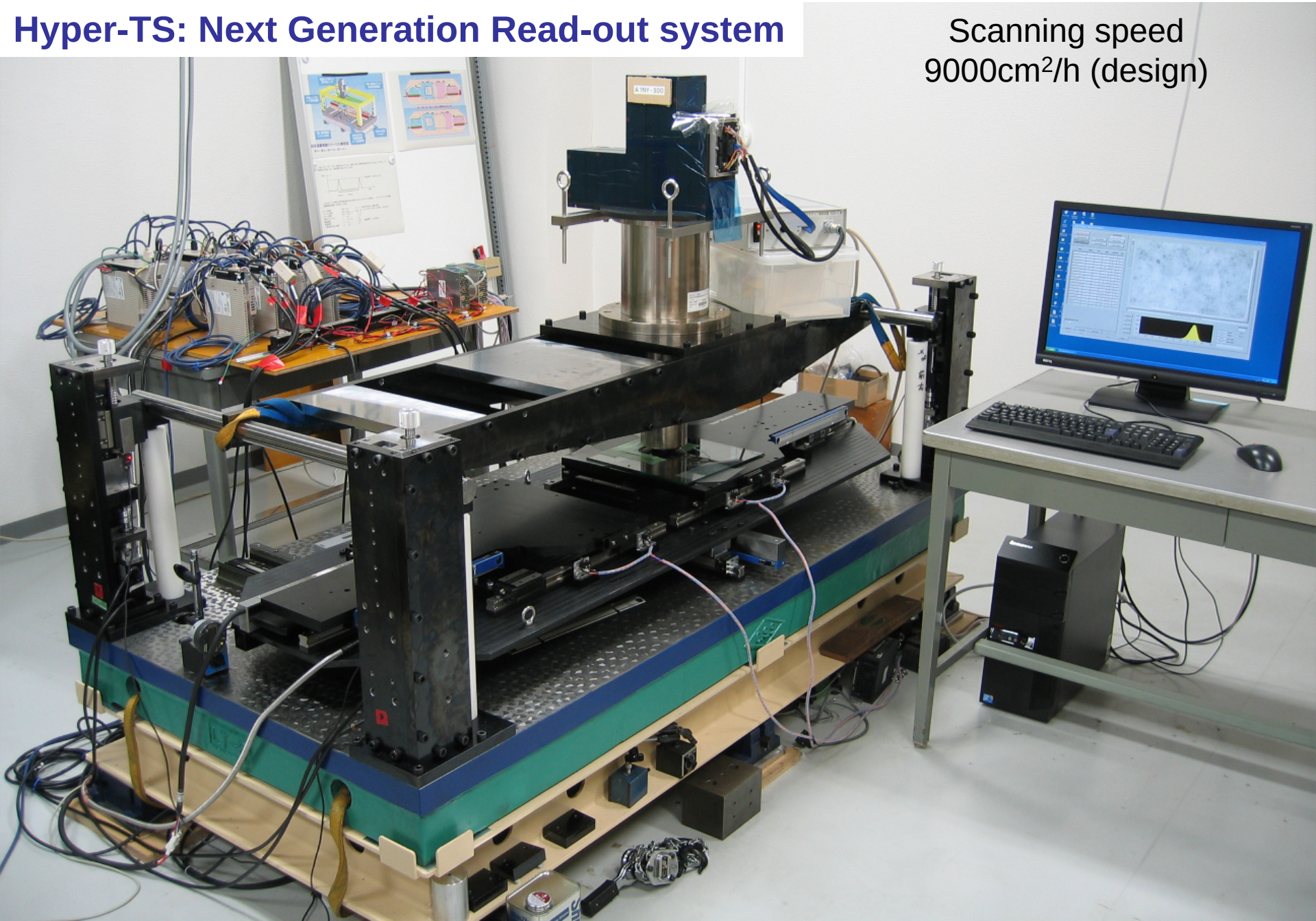
Automated emulsion read-out system (Nagoya Univ.)



Automated emulsion read-out system (Nagoya Univ.)

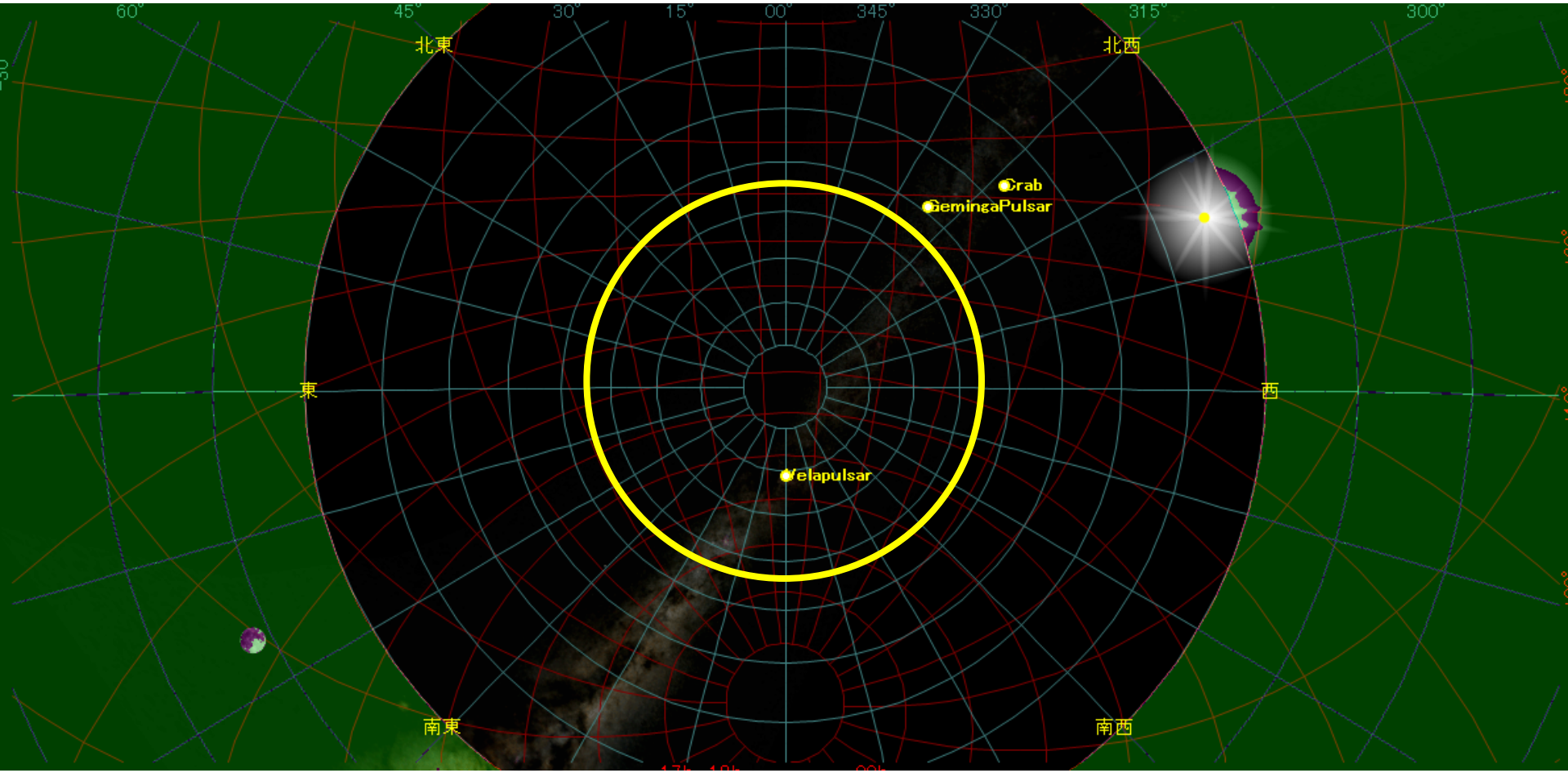
Hyper-TS: Next Generation Read-out system

Scanning speed
9000cm^2/h (design)



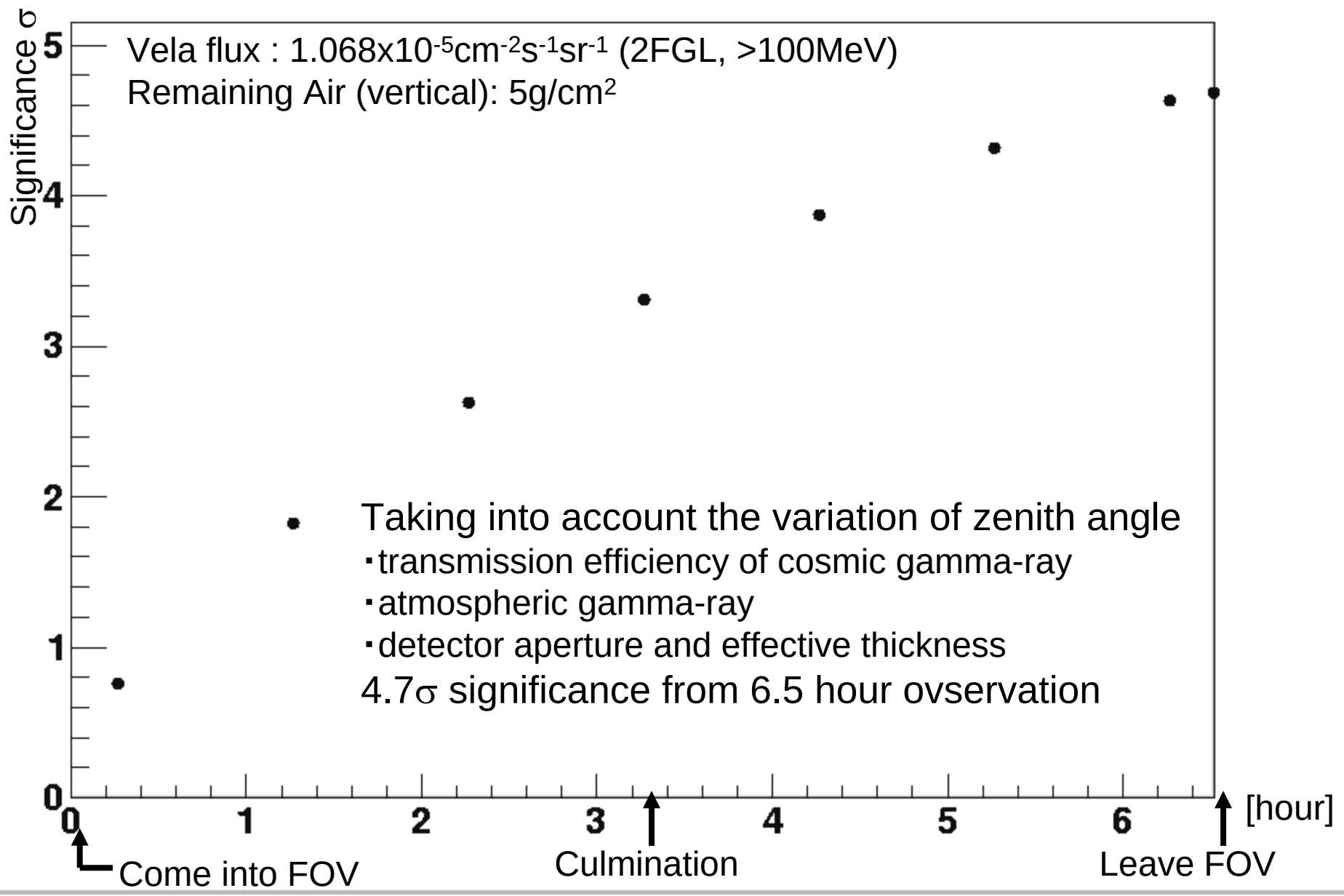
Flight duration ~1day

Vela

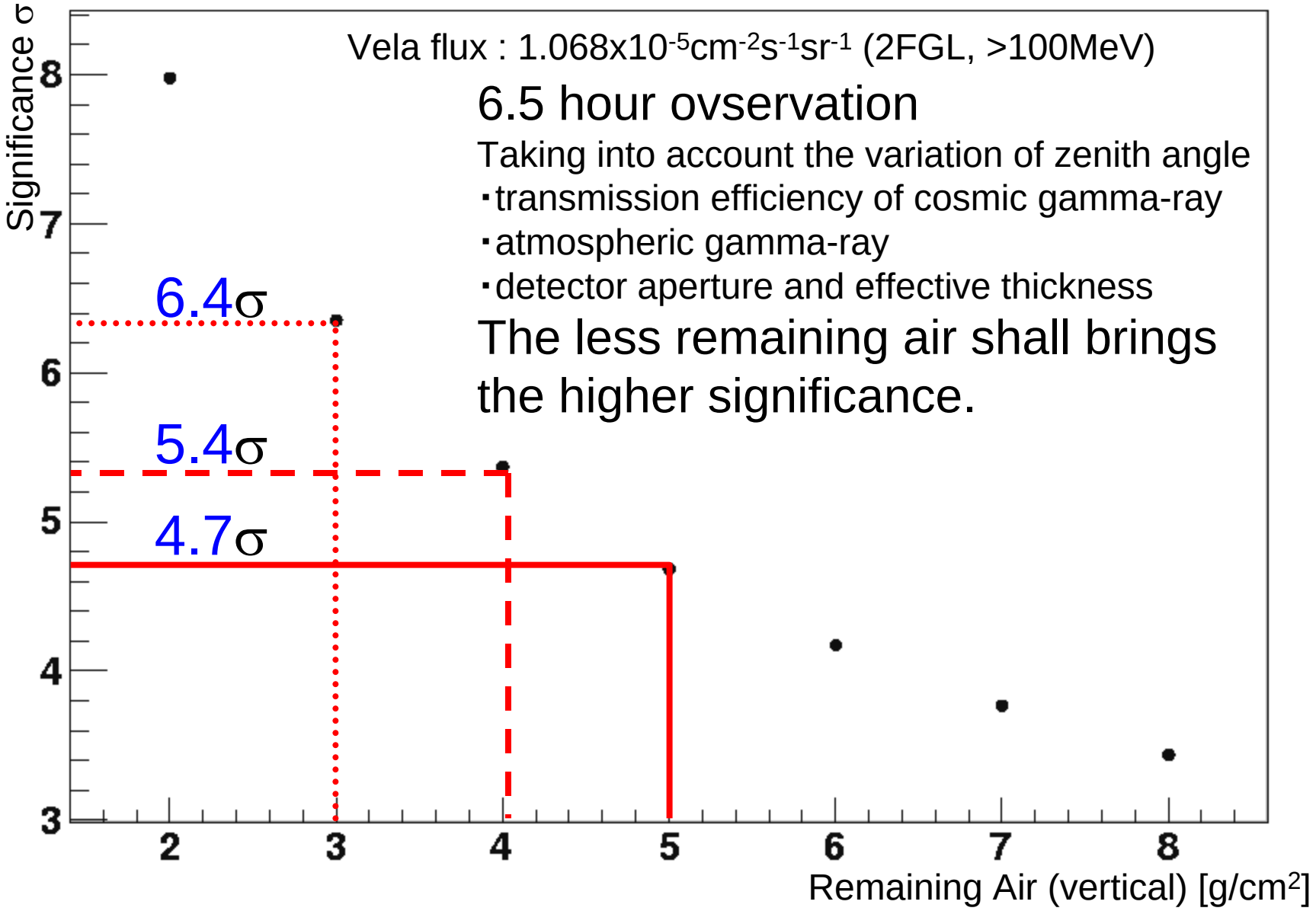


Alice Springs　2014/May/15,　Culmination 17:09(NT), In FOV 6.5hours (13:53-20:24)
Lat.: -23° 40’　(-0:30(JST))
Lon.: 133° 50’ E

Significance vs. Exposure Time



Significance vs. Remaining Air Thickness

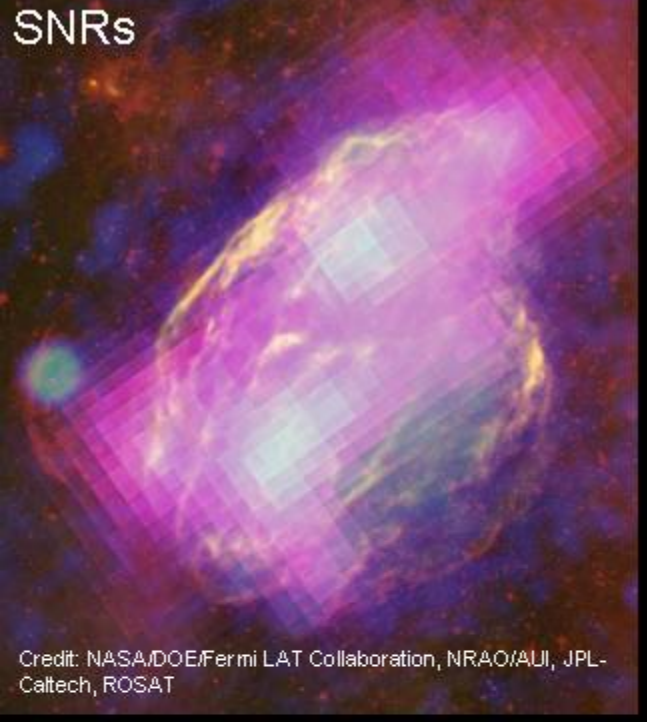


2013											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Emulsion film : Established 2nd flight model									Film production		
Multi-stage shifter : Low T&P test, Assembling, Flight ready											
Star camera : Design, Test, Assembling, Flight ready											

2014											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Stacking & Assembling										

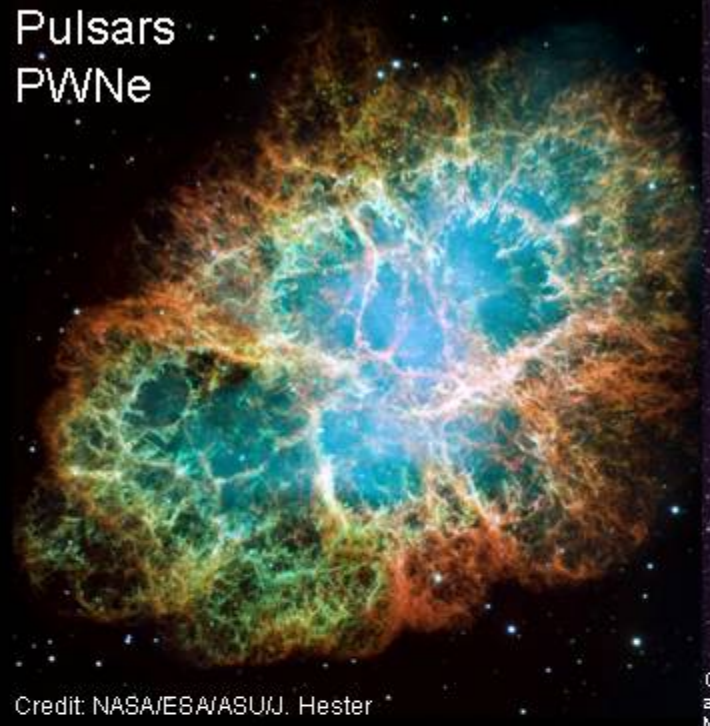
- -Sep/2013, emulsion film for 2nd flight model will be established.
- -Sep/2013, multi-stage shifter will be ready for the the flight.
- -Sep/2013, star camera will be ready for the flight.
- Oct/2013-Jan/2014, emulsion film production
- Feb-Apr/2014, stacking and assembling
- May/2014, 2^{nd} flight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

SNRs



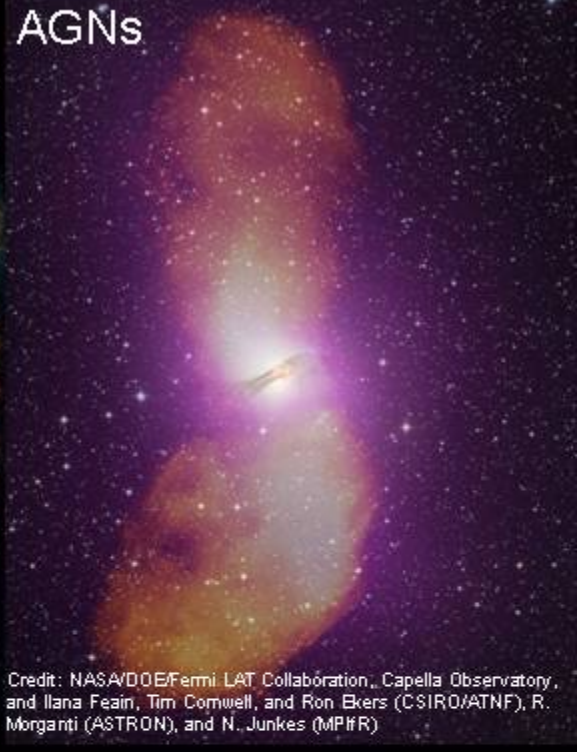
Credit: NASA/DOE/Fermi LAT Collaboration, NRAO/AUI, JPL-Caltech, ROSAT

Pulsars
PWNe



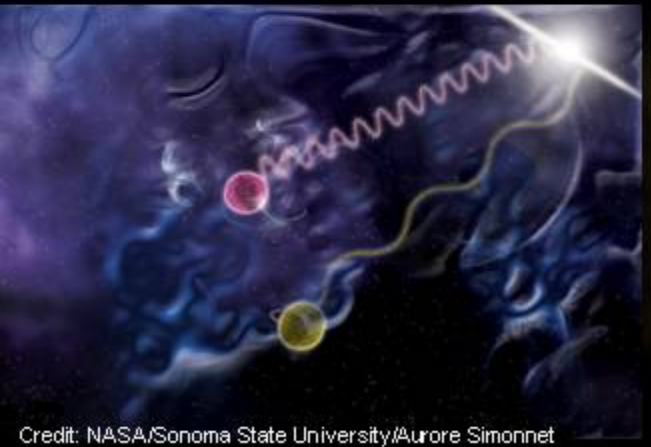
Credit: NASA/ESA/ASU/J. Hester

AGNs



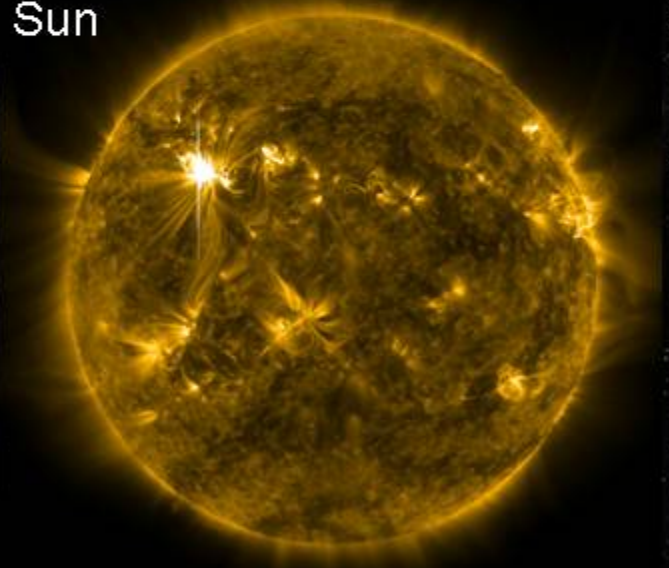
Credit: NASA/DOE/Fermi LAT Collaboration, Capella Observatory, and Ilana Feain, Tim Cornwell, and Ron Ekers (CSIRO/ATNF), R. Morganti (ASTRON), and N. Junkes (MPIfR)

GRBs



Credit: NASA/Sonoma State University/Aurore Simonnet

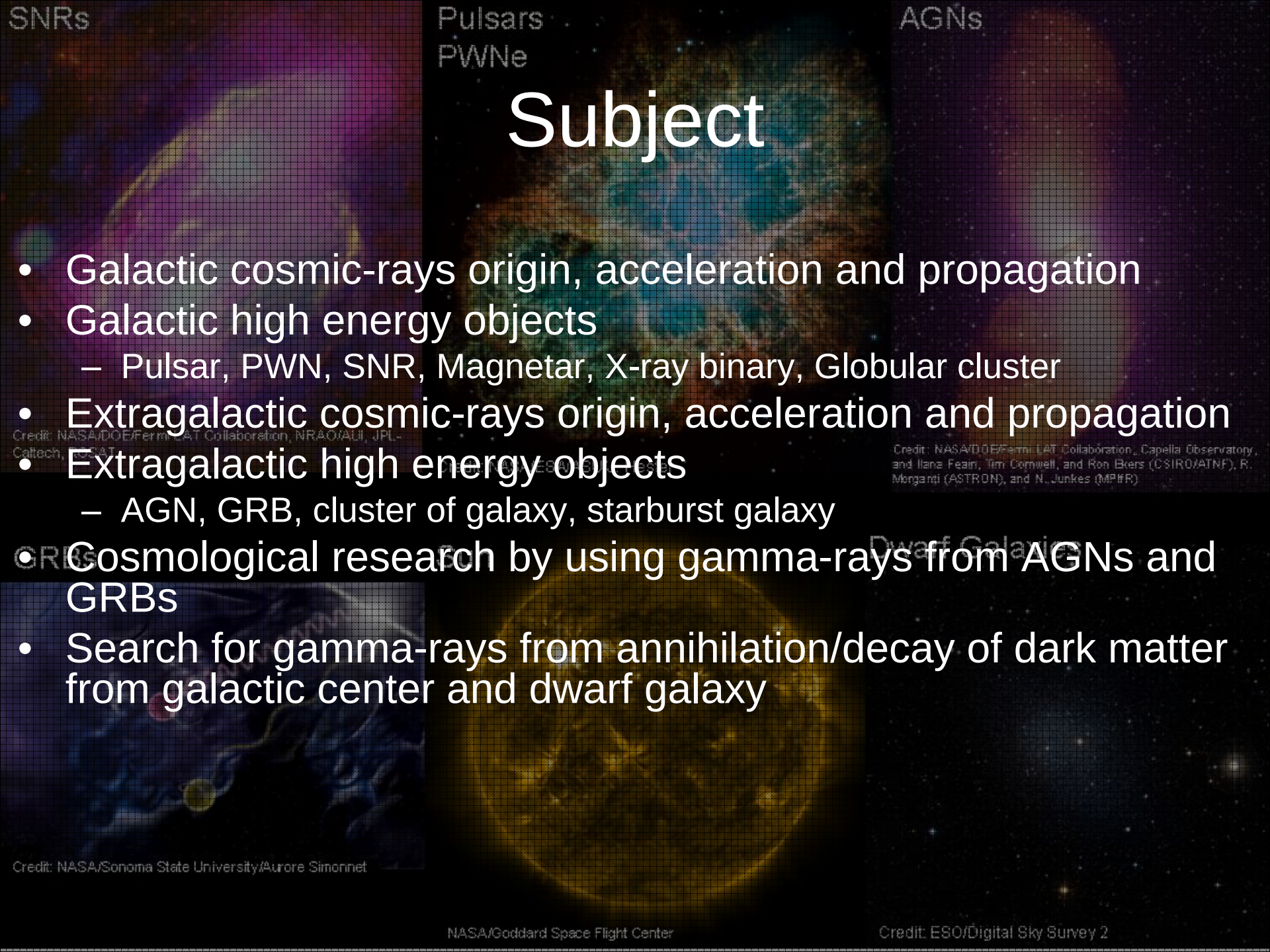
Sun



NASA/Goddard Space Flight Center

Dwarf Galaxies

Credit: ESO/Digital Sky Survey 2



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

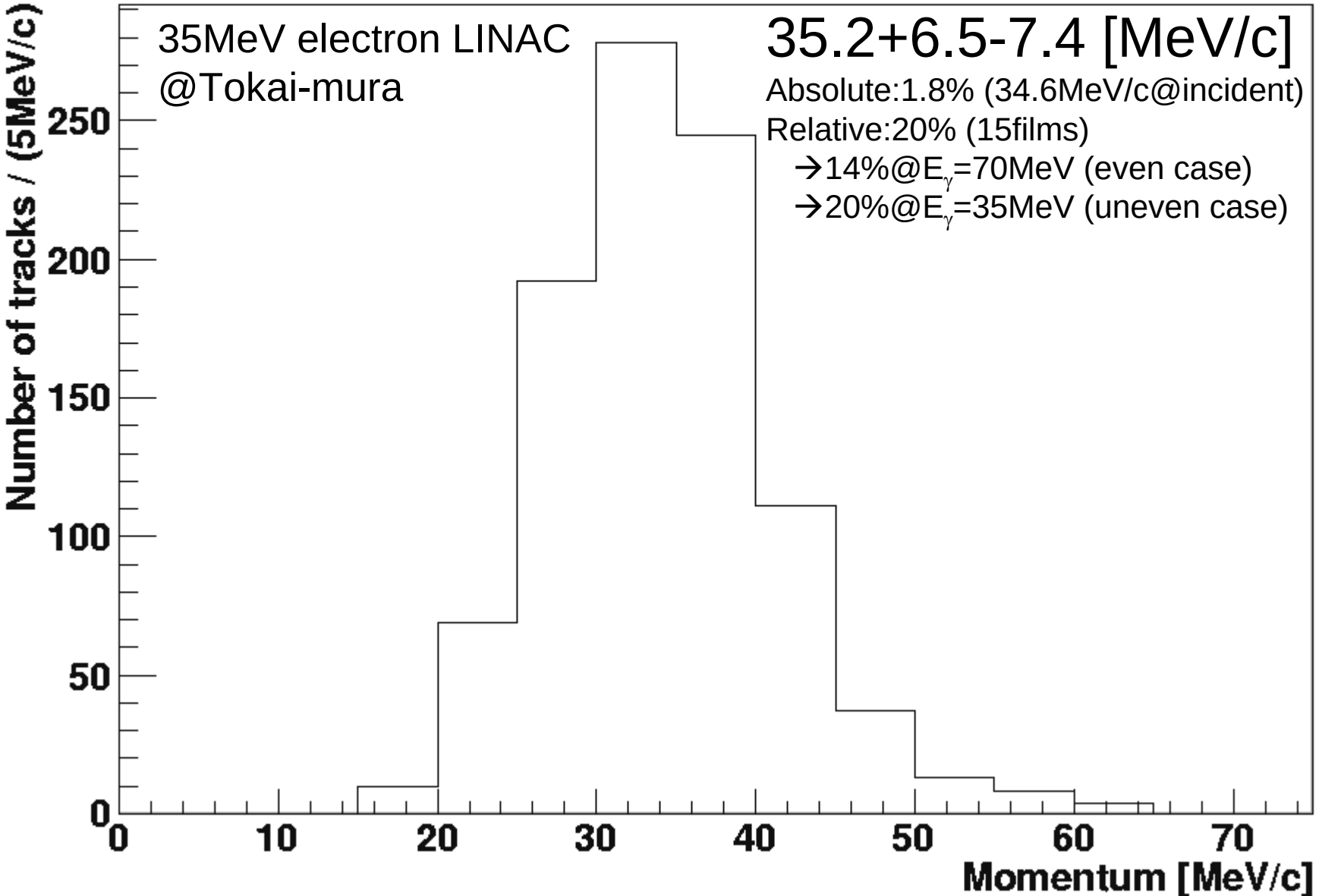
Summary and Outlook

- Promoting GRAINE project
- Performed balloon experiment in 2011
- Demonstrated emulsion gamma-ray telescope with flight data
- Measured atmospheric gamma-ray

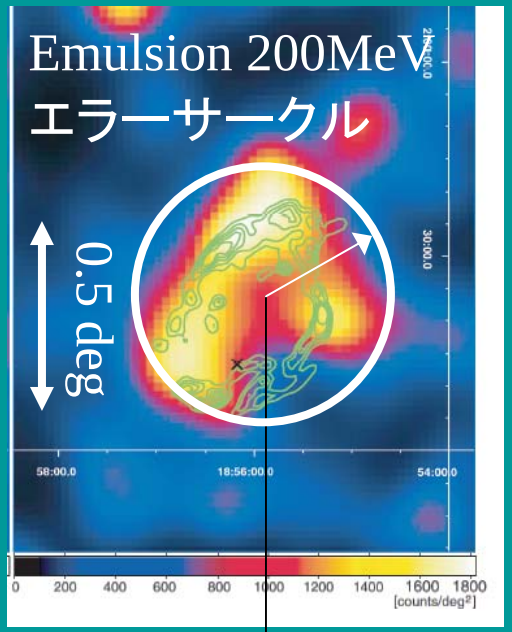
- Preparing for planned balloon experiment at Alice Springs in 2014

backup

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

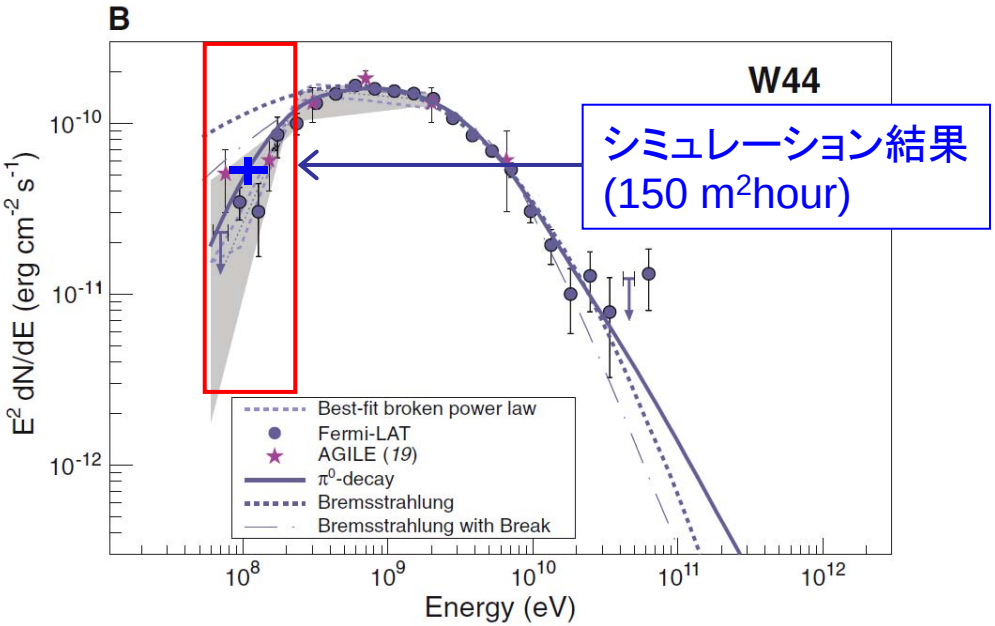


SNR W44



Fermi 200MeV
エラーサークル

放射起源に迫る上で200MeV以下が重要



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