GRAINE project

γ-ray observations by balloon-borne emulsion telescope with a high angular resolution, polarization sensitivity and large-aperture-area

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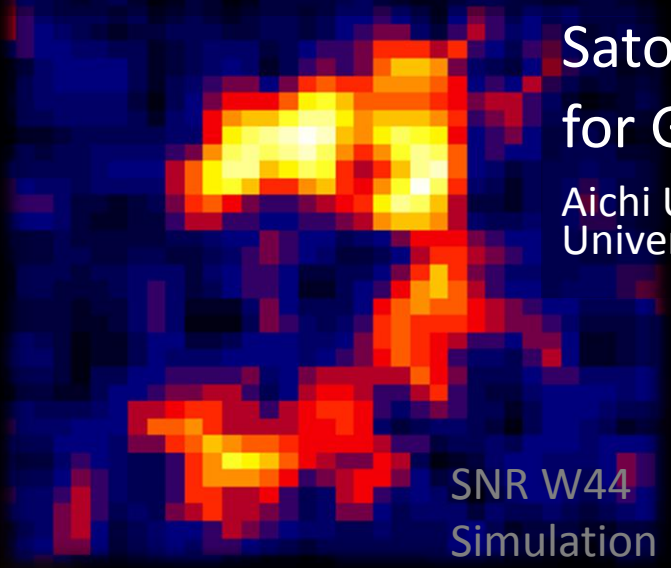
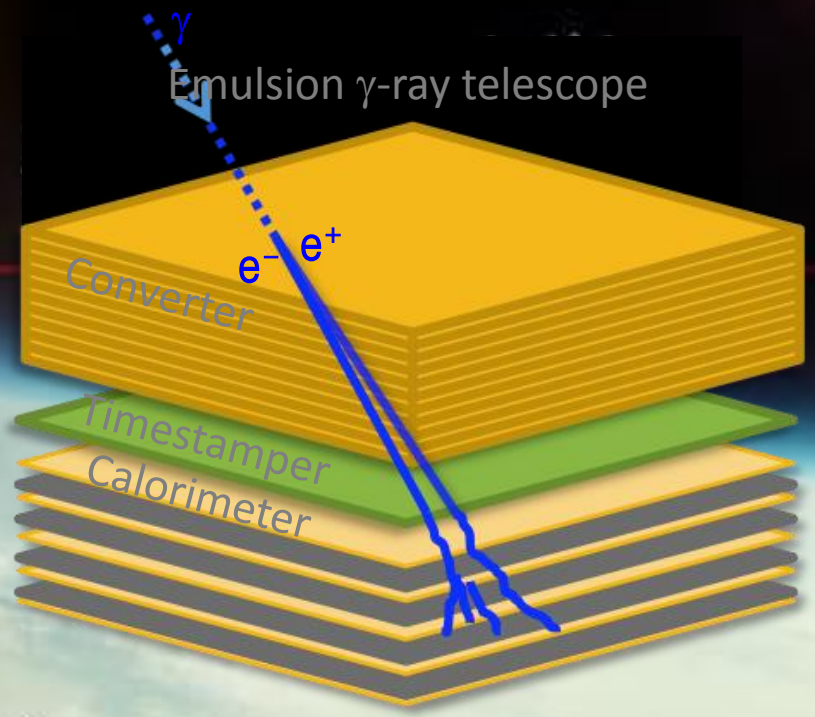
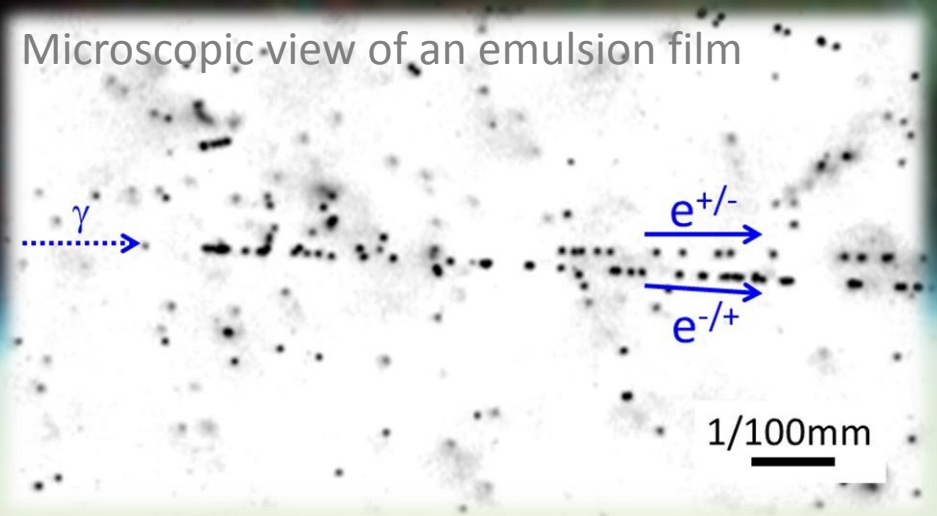
for GRAINE collaboration, PI: S. Aoki (Kobe Univ.)

Aichi University of education, ISAS/JAXA, Kobe University, Nagoya University, Okayama University of science, Utsunomiya University



SNR W44
Simulation





BG photo : GRAINE2011, JAXA scientific ballooning (taken by NHK)

Fermi's Five-year View of the Gamma-ray Sky (>1GeV)

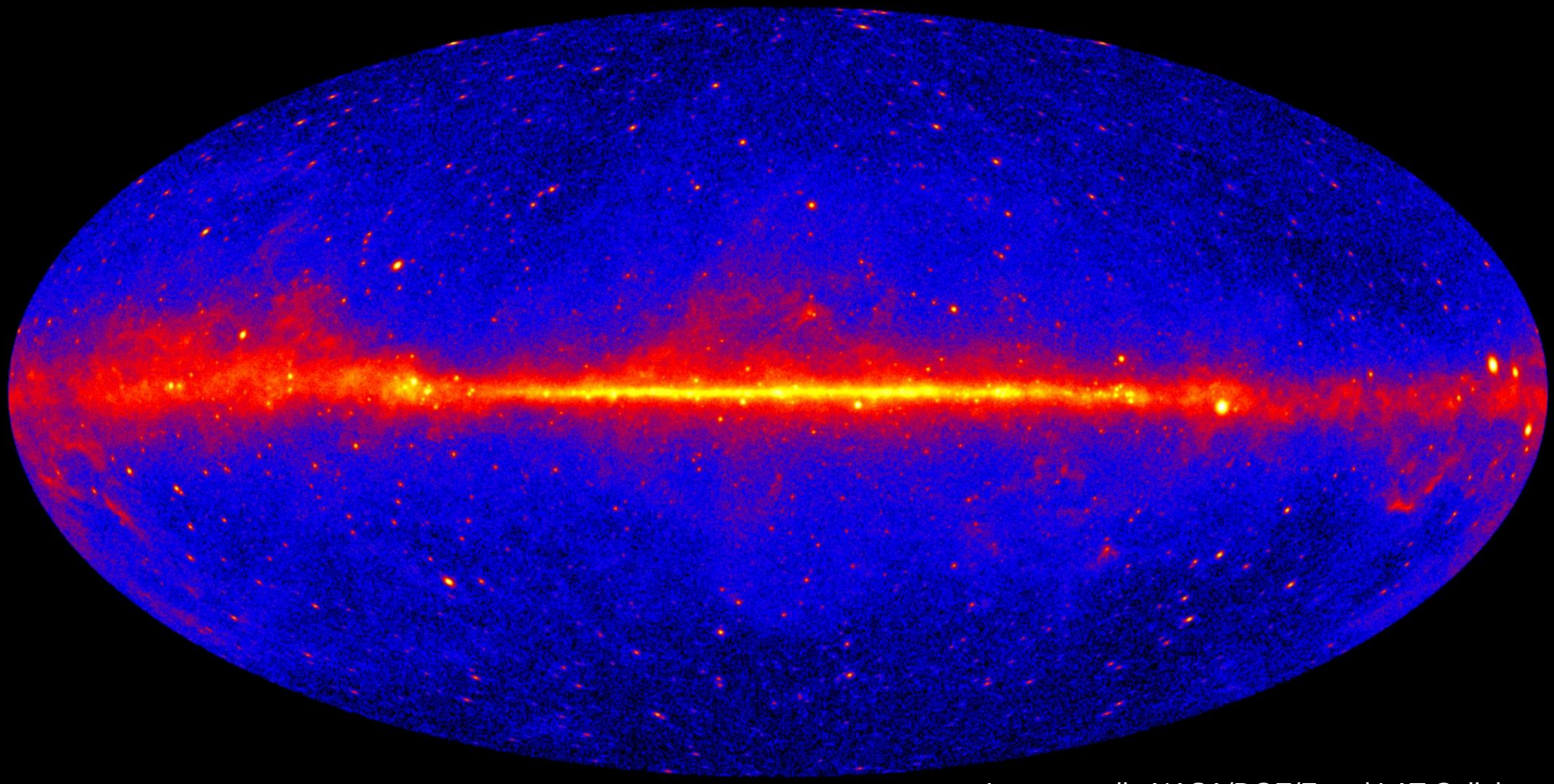
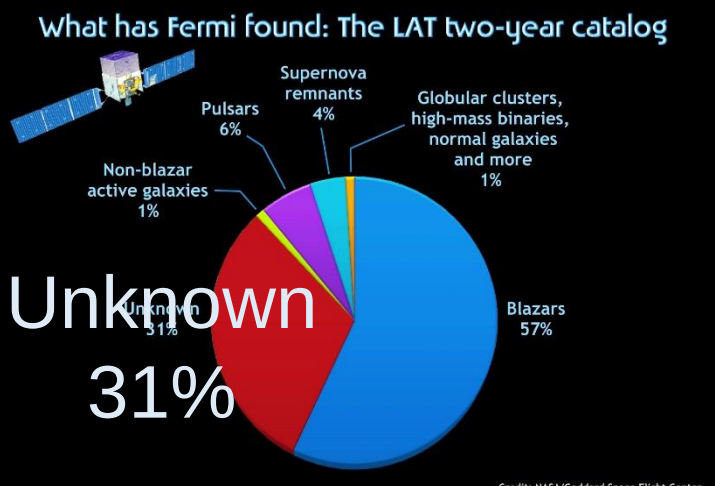


Image credit: NASA/DOE/Fermi LAT Collaboration

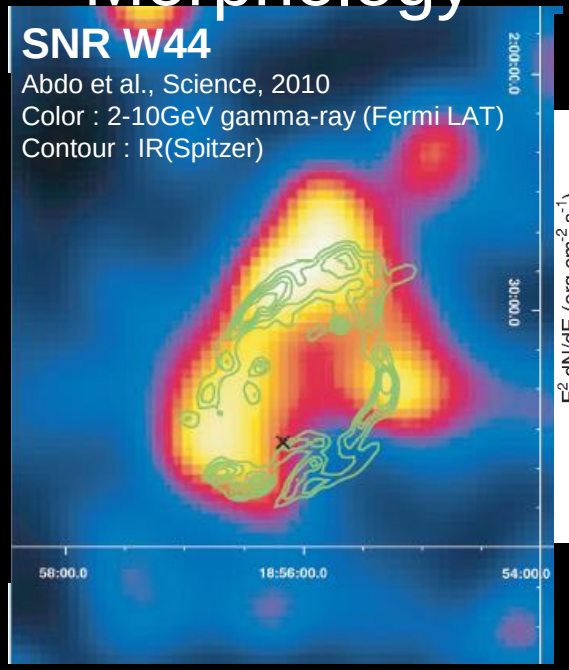
>3000 sources (3FGL)

Un-ID

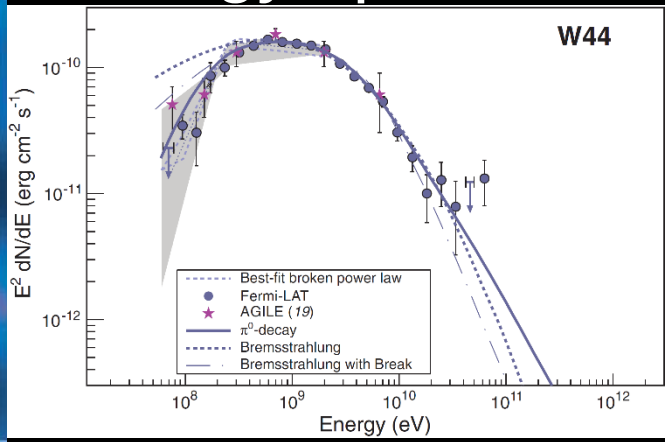


Unknown 31%

Morphology



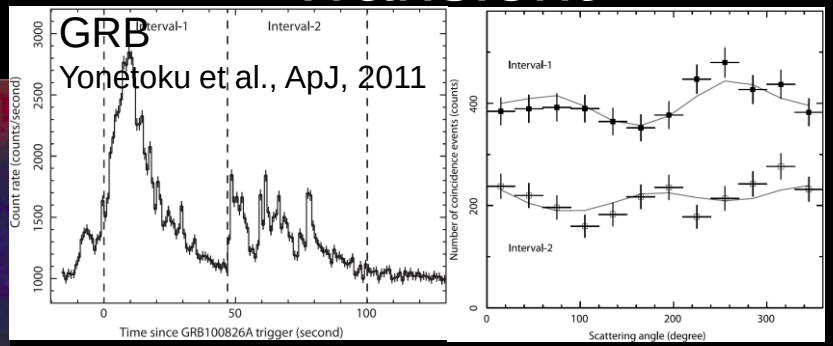
Energy spectrum

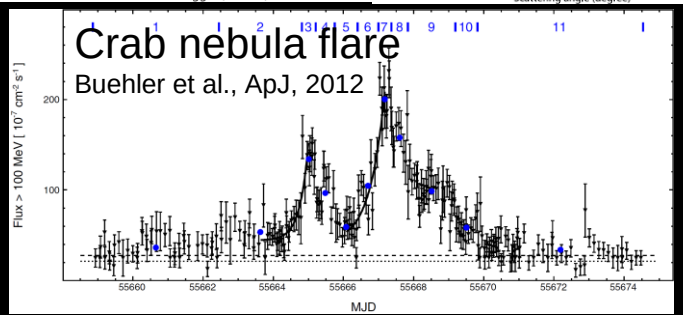


M. Ackermann et al. Science, 2013

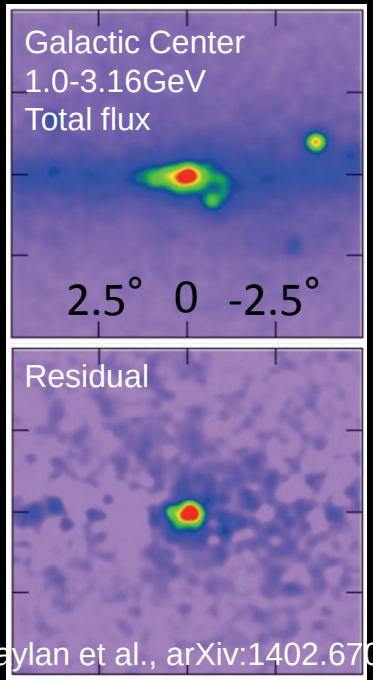
Polarization

Transient





Dark matter



T.Daylan et al., arXiv:1402.6703v1

Nuclear emulsion

Microscopic view
10micron

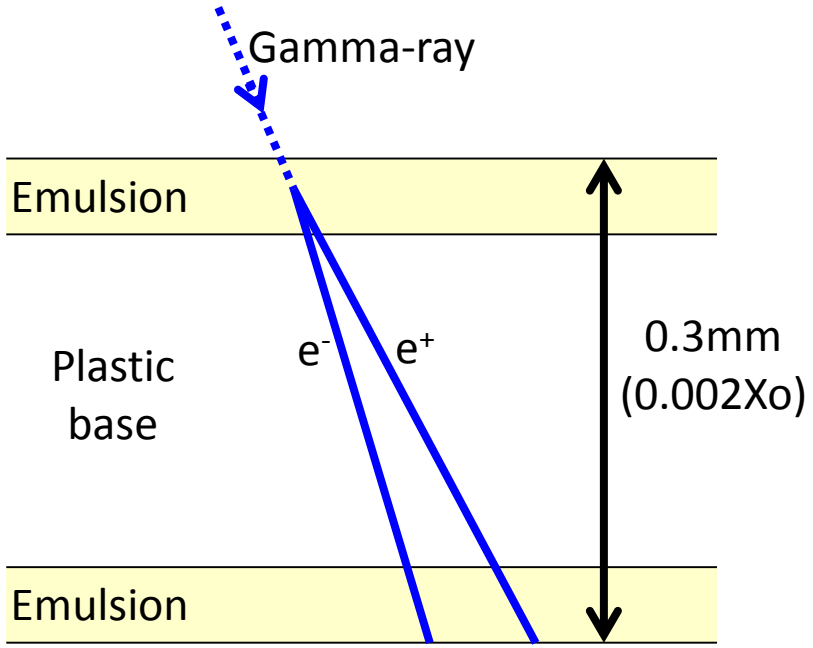
Intrinsic position accuracy ~60nm

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

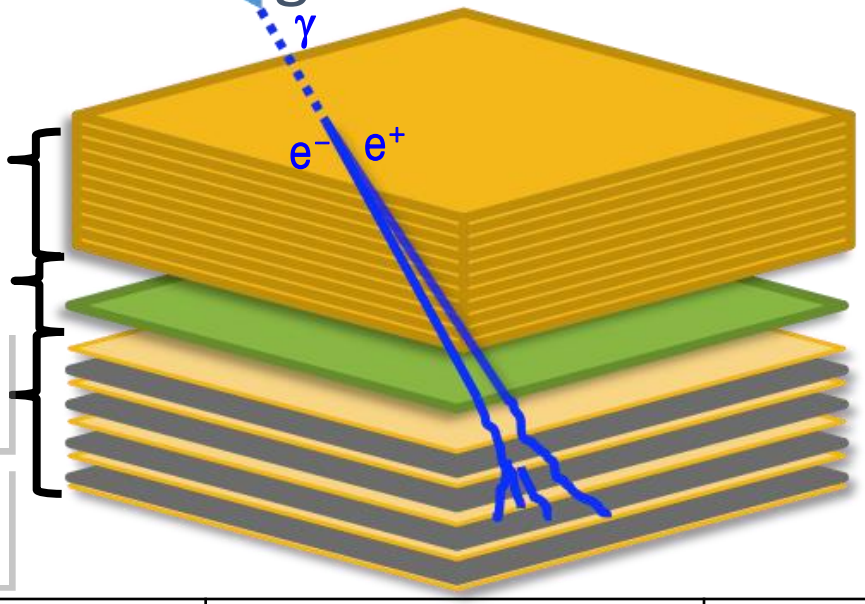
Gamma-Ray Astro-Imager with Nuclear Emulsion

Converter
Emulsion + Copper foil

Timestamper
Multi-stage shifter

Calorimeter
Emulsion + metal plate

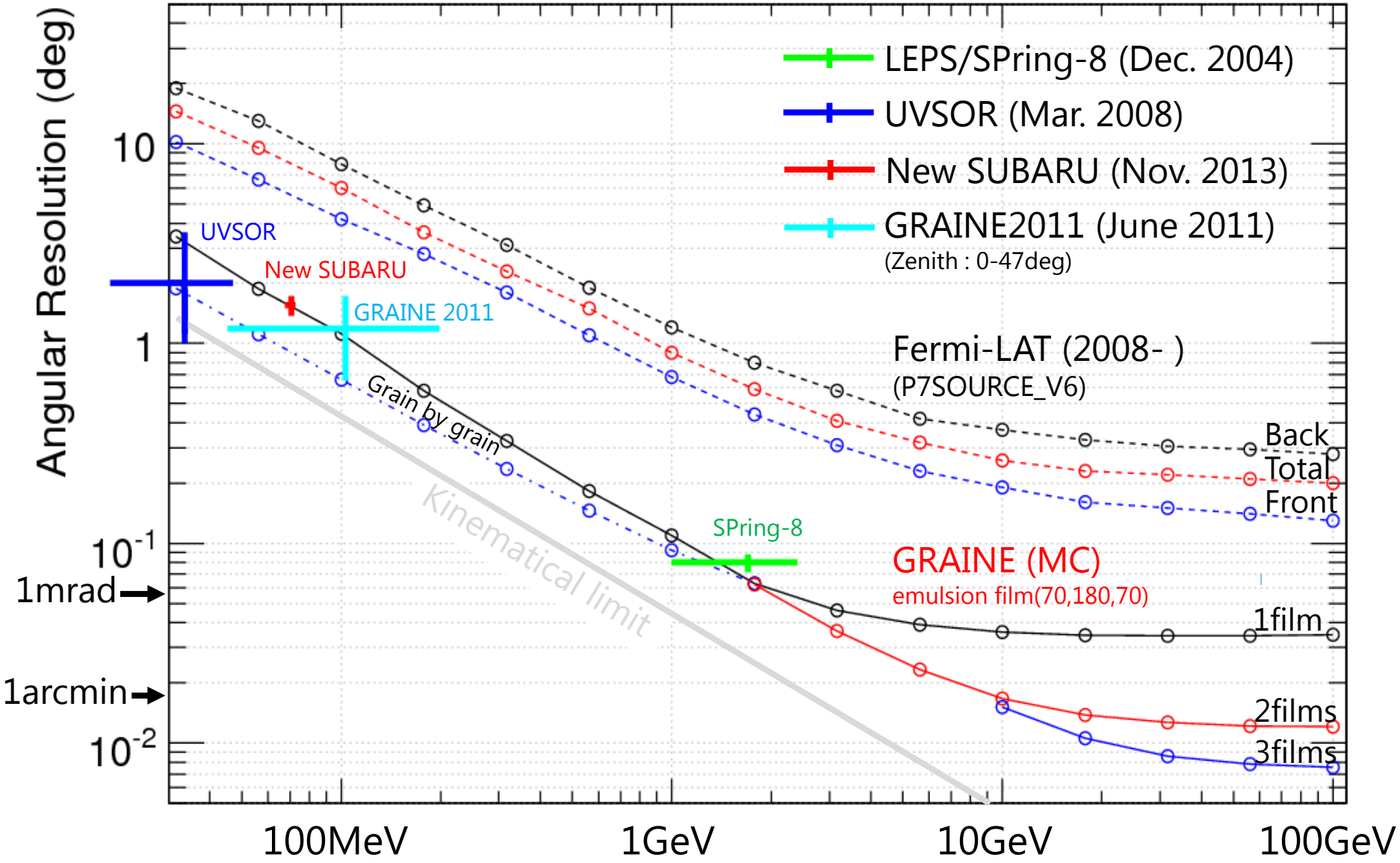
Attitude monitor
Star camera



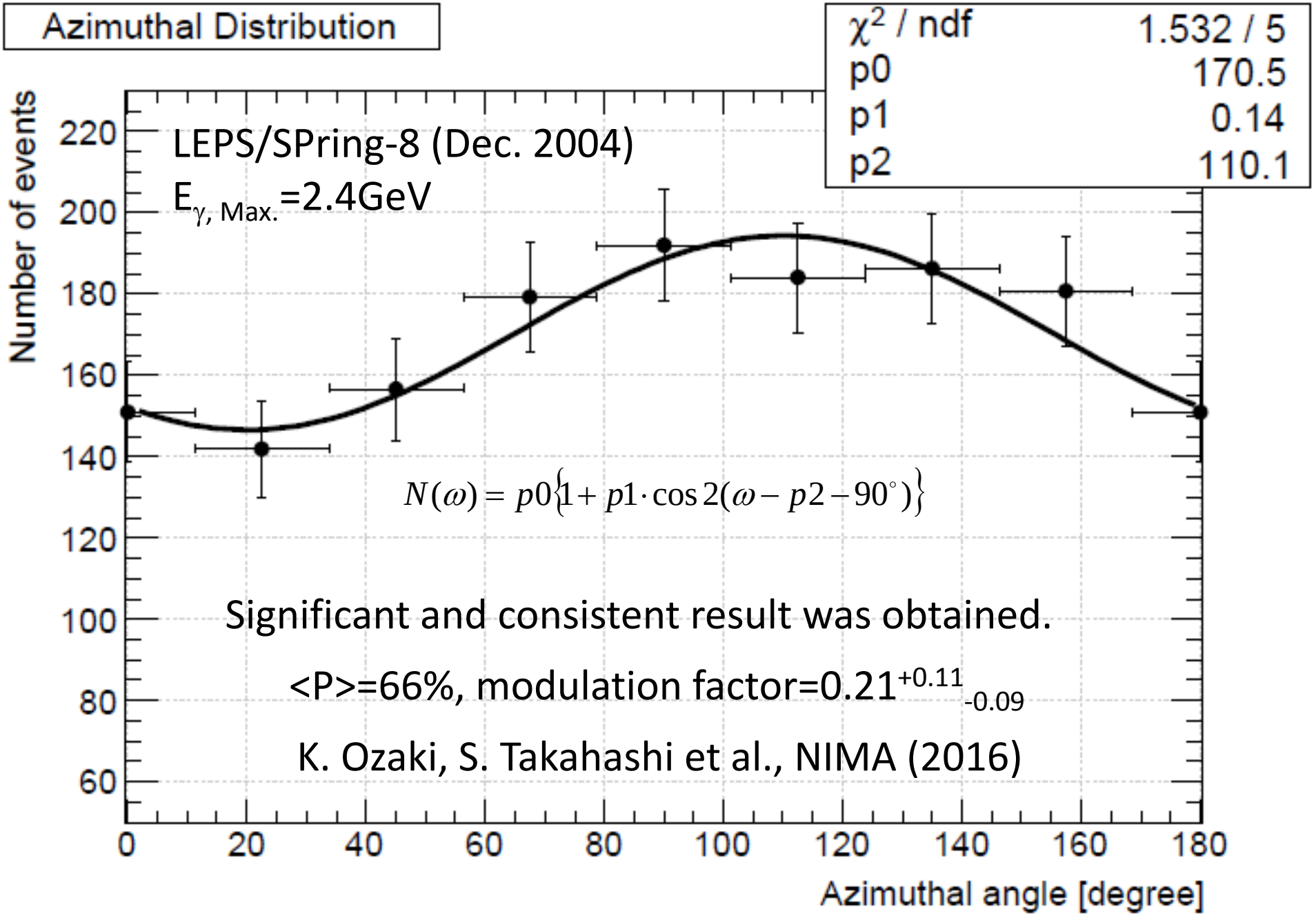
＊ $10m^2 * \varepsilon_{trans} * \varepsilon_{conv} * \varepsilon_{det}$

	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	---		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



Polarization sensitivity



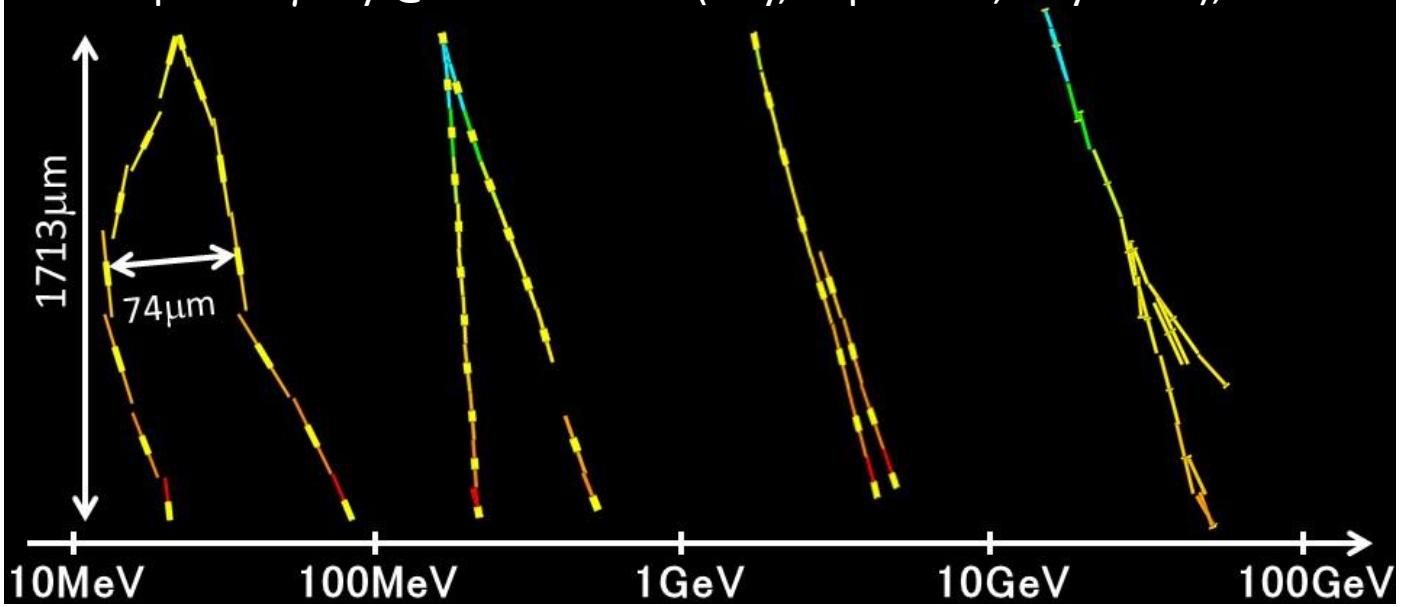
Significant and consistent result was obtained.

<P>=66%, modulation factor=$0.21^{+0.11}_{-0.09}$

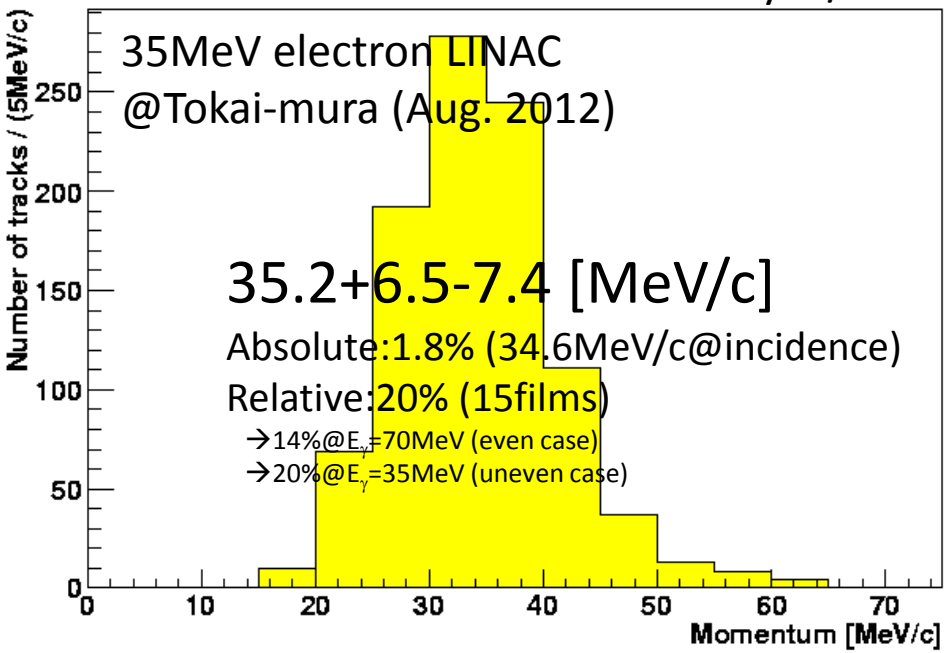
K. Ozaki, S. Takahashi et al., NIMA (2016)

Energy range

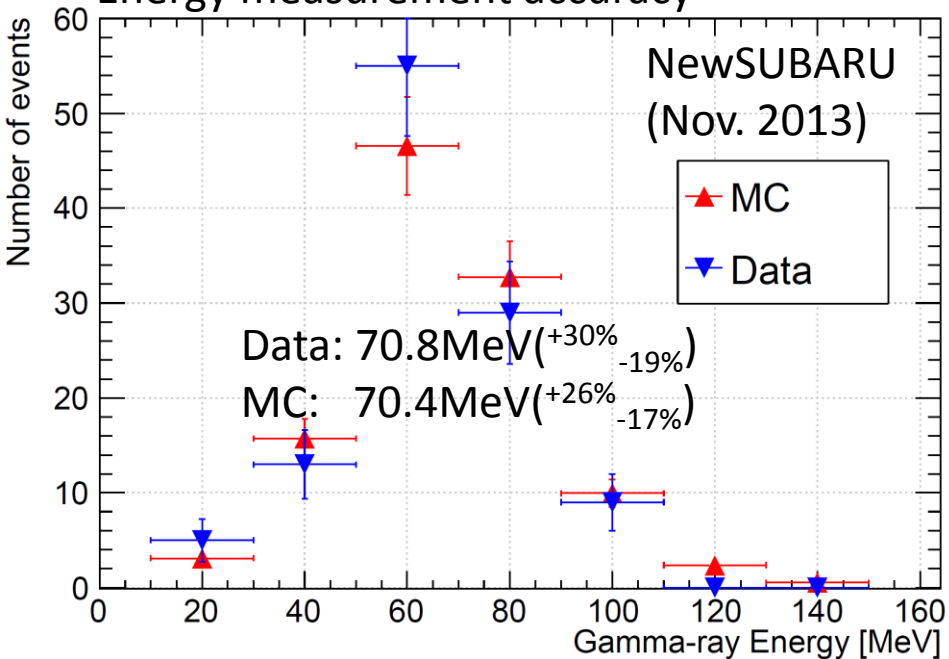
Atmospheric γ-ray @Mt. Norikura (July, Sep. 2007, July 2013), et al.



Momentum measurement accuracy w/MCS



Energy measurement accuracy

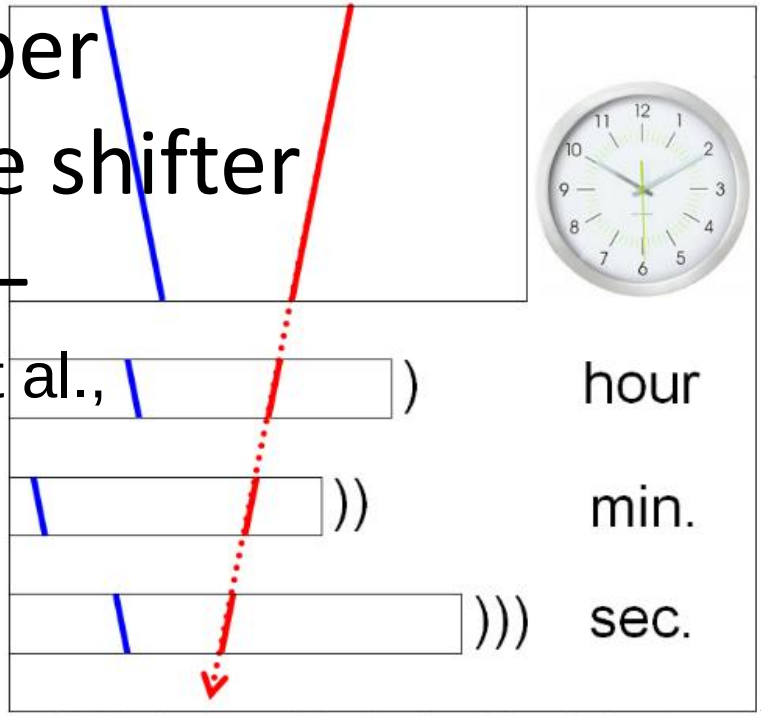


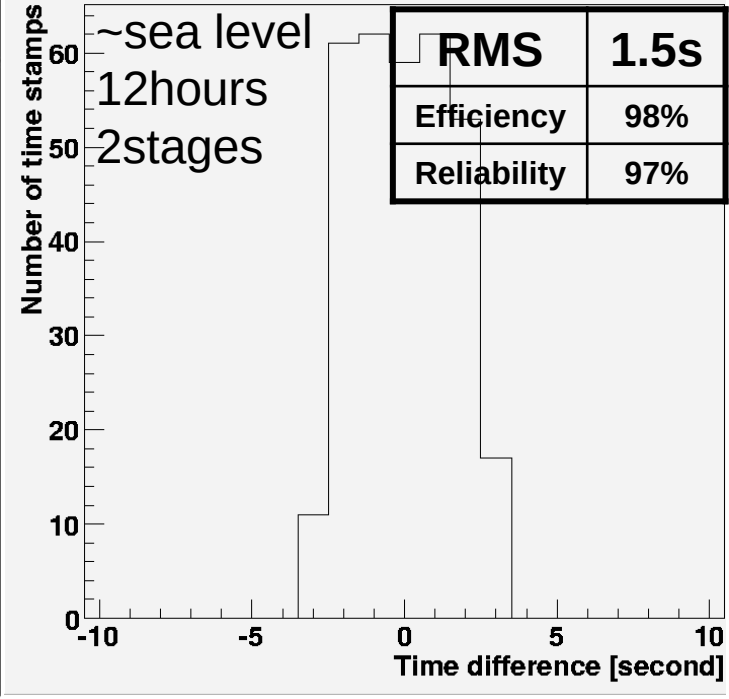
Timestamper

Multi-stage shifter

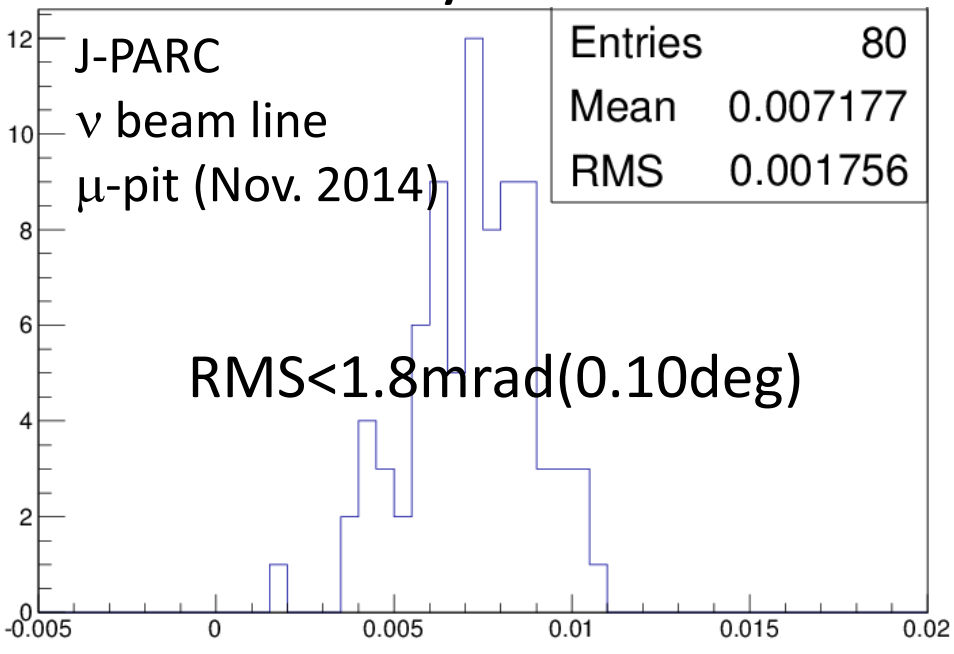
June 2007–

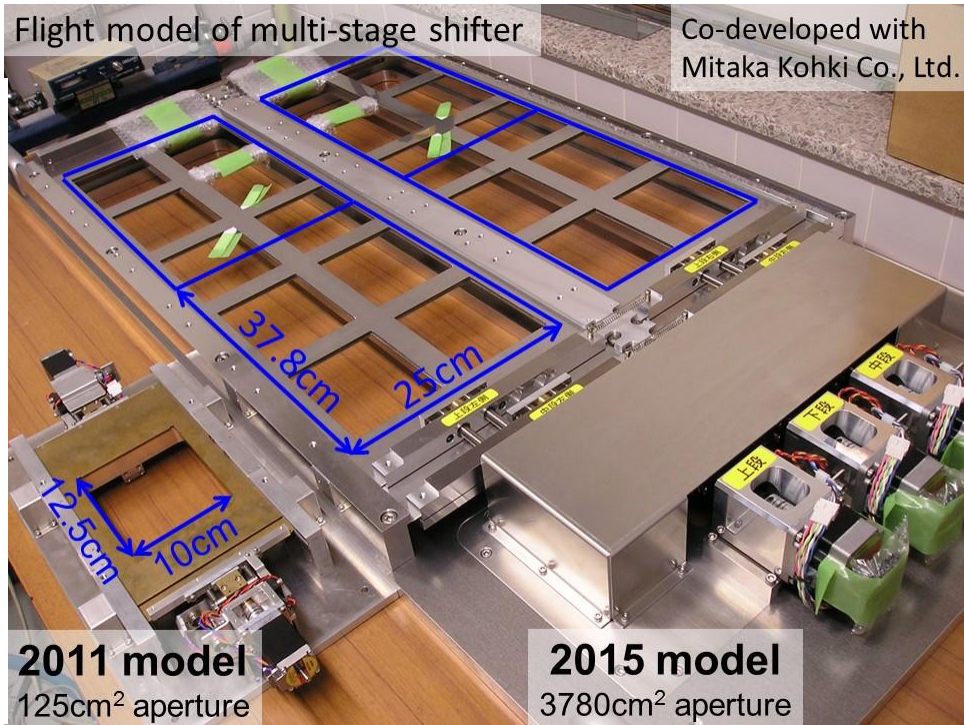
S.Takahashi et al., NIMA(2010)





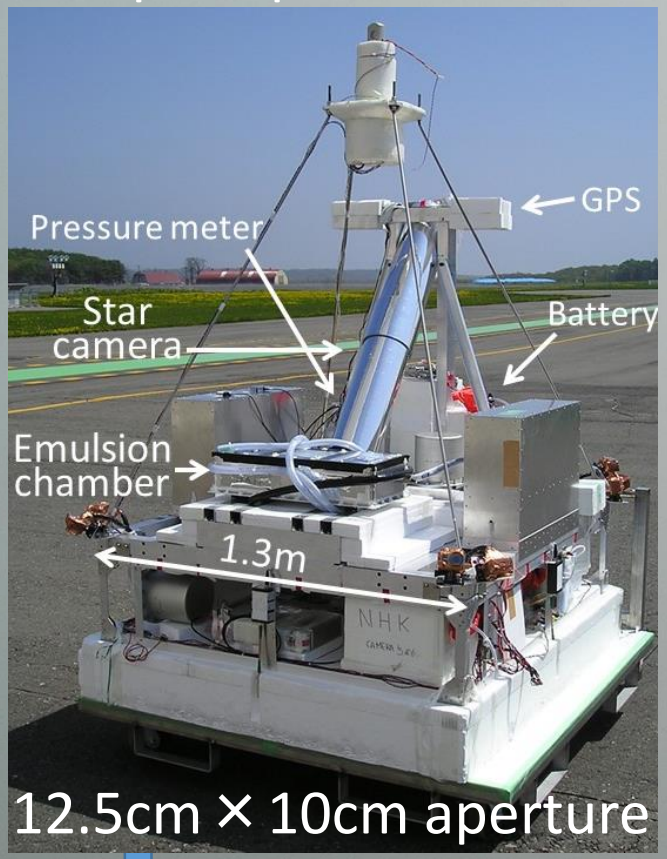
Flatness study





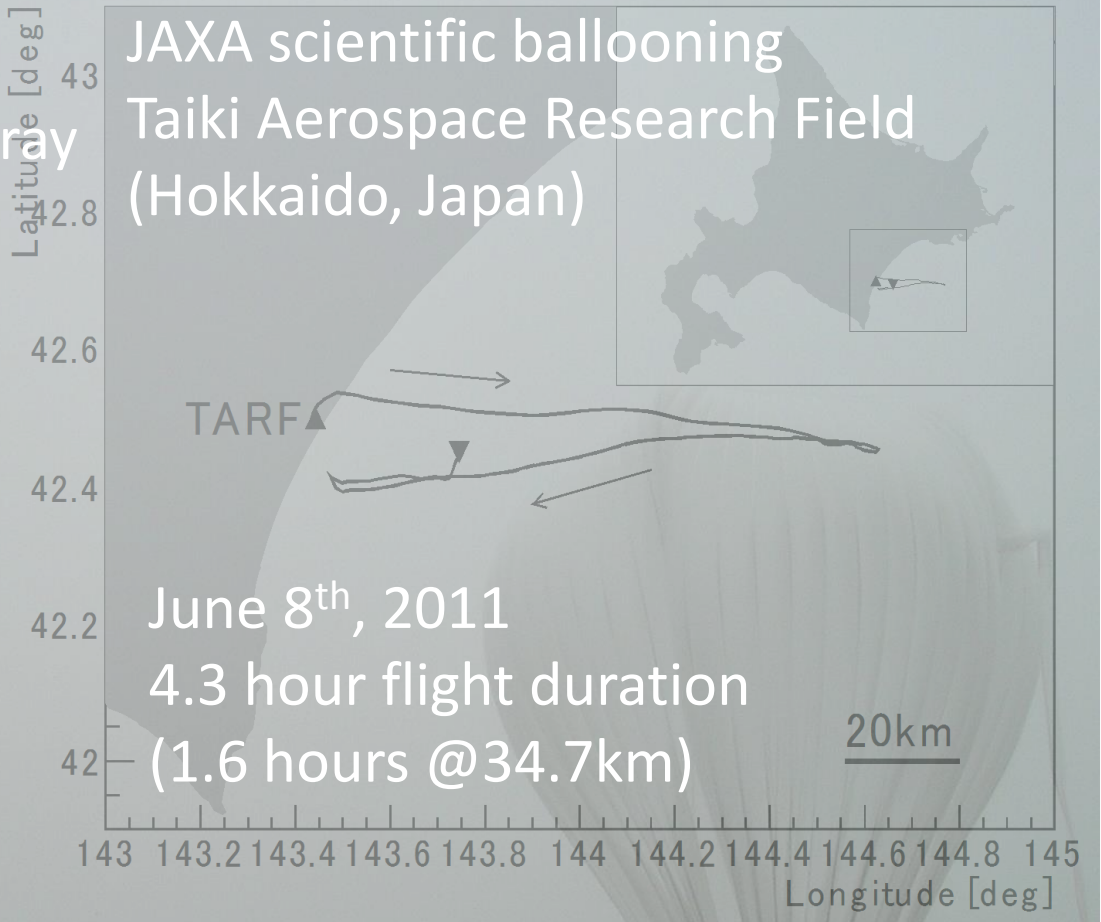
GRAINE 2011

First balloon-borne emulsion γ-ray telescope experiment



12.5cm × 10cm aperture

JAXA scientific ballooning
Taiki Aerospace Research Field
(Hokkaido, Japan)

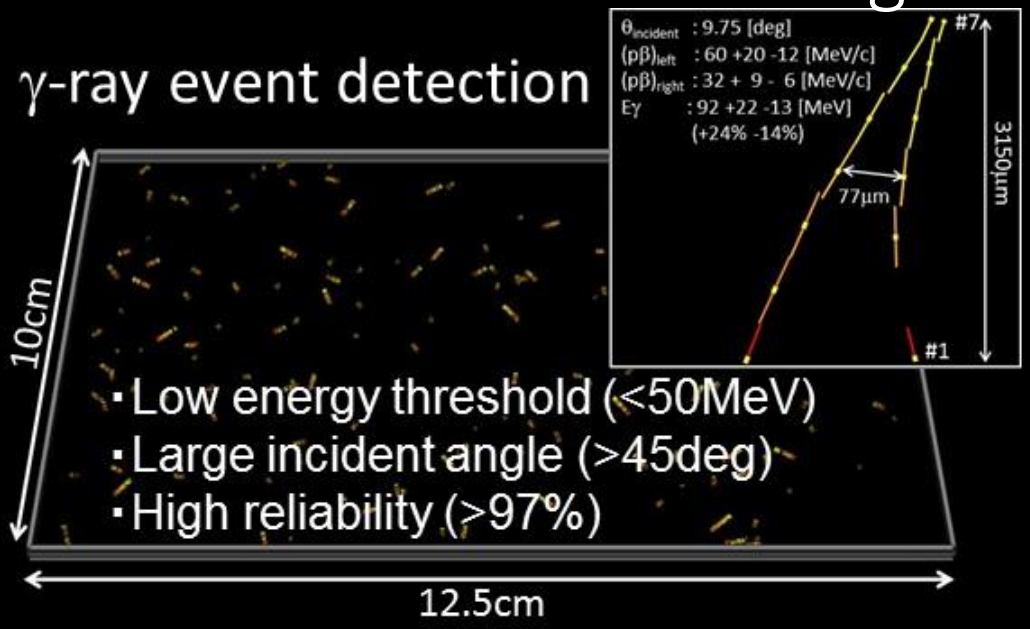


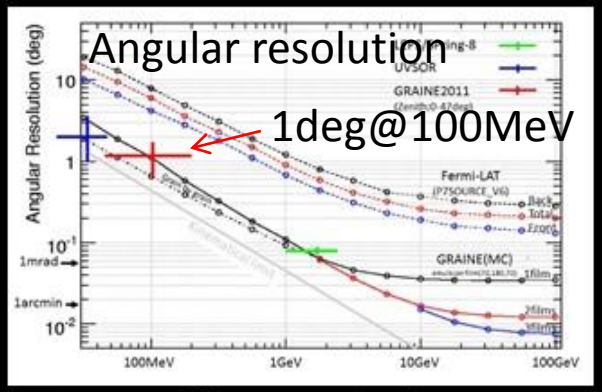
June 8th, 2011
4.3 hour flight duration
(1.6 hours @34.7km)

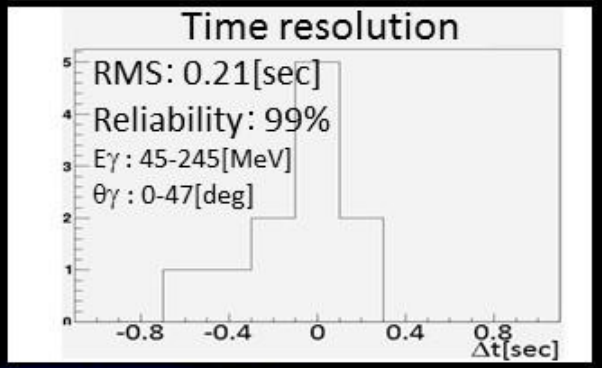
First balloon-borne experiment
Feasibility test

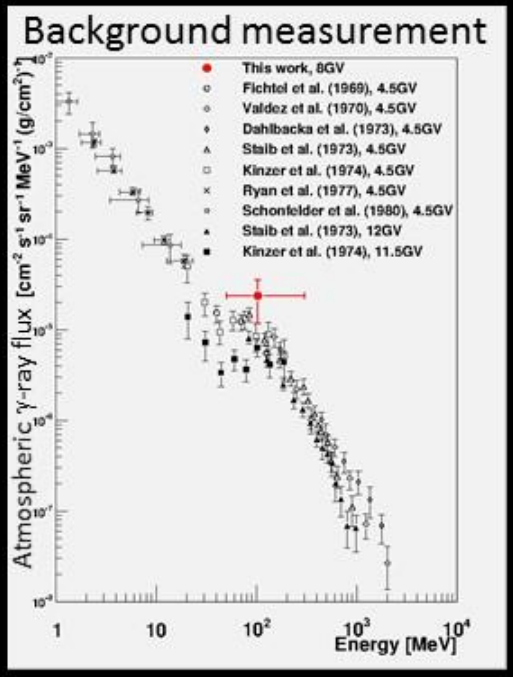
GRAINE 2011 Flight data analysis

γ-ray event detection

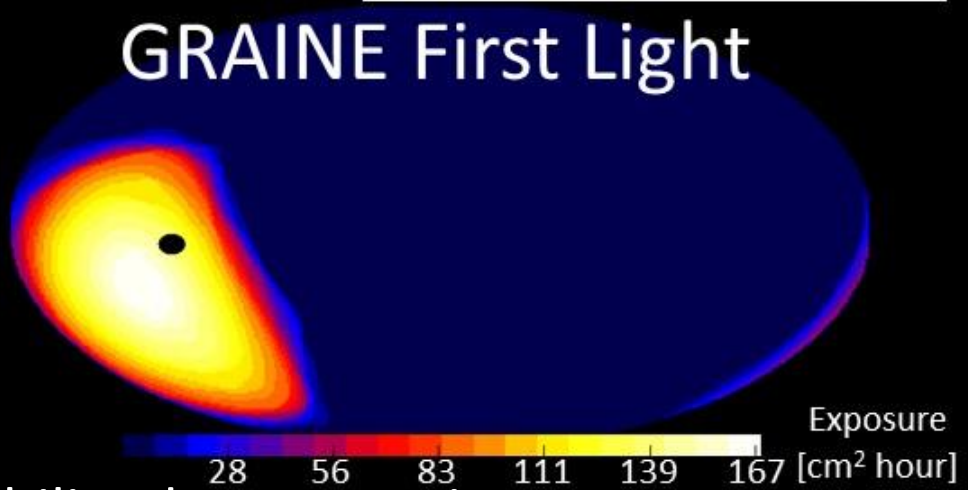








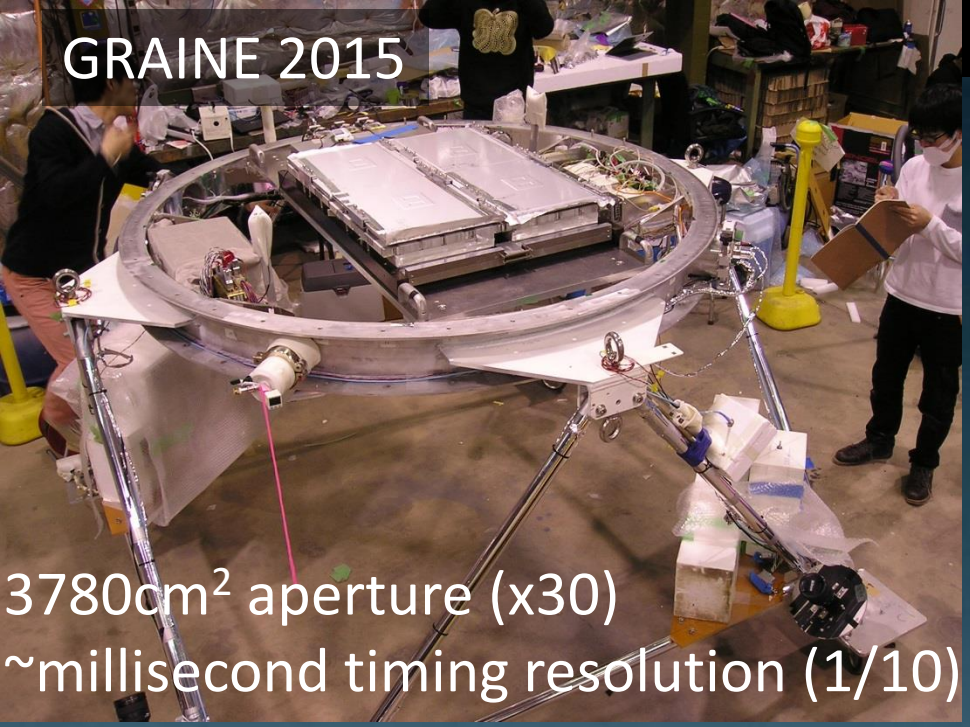
GRAINE First Light



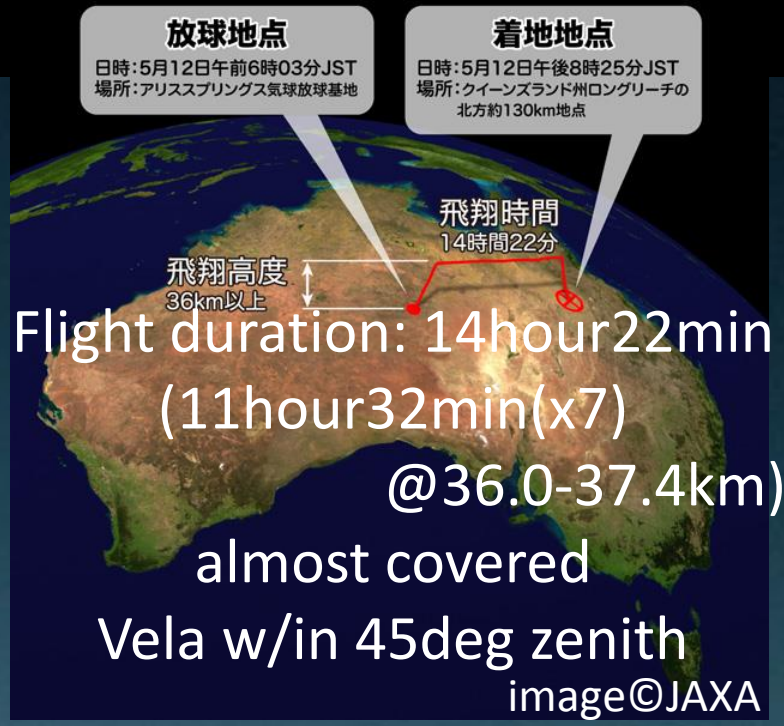
Feasibility demonstration

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

GRAINE 2015



3780cm^2 aperture (x30)
~millisecond timing resolution (1/10)



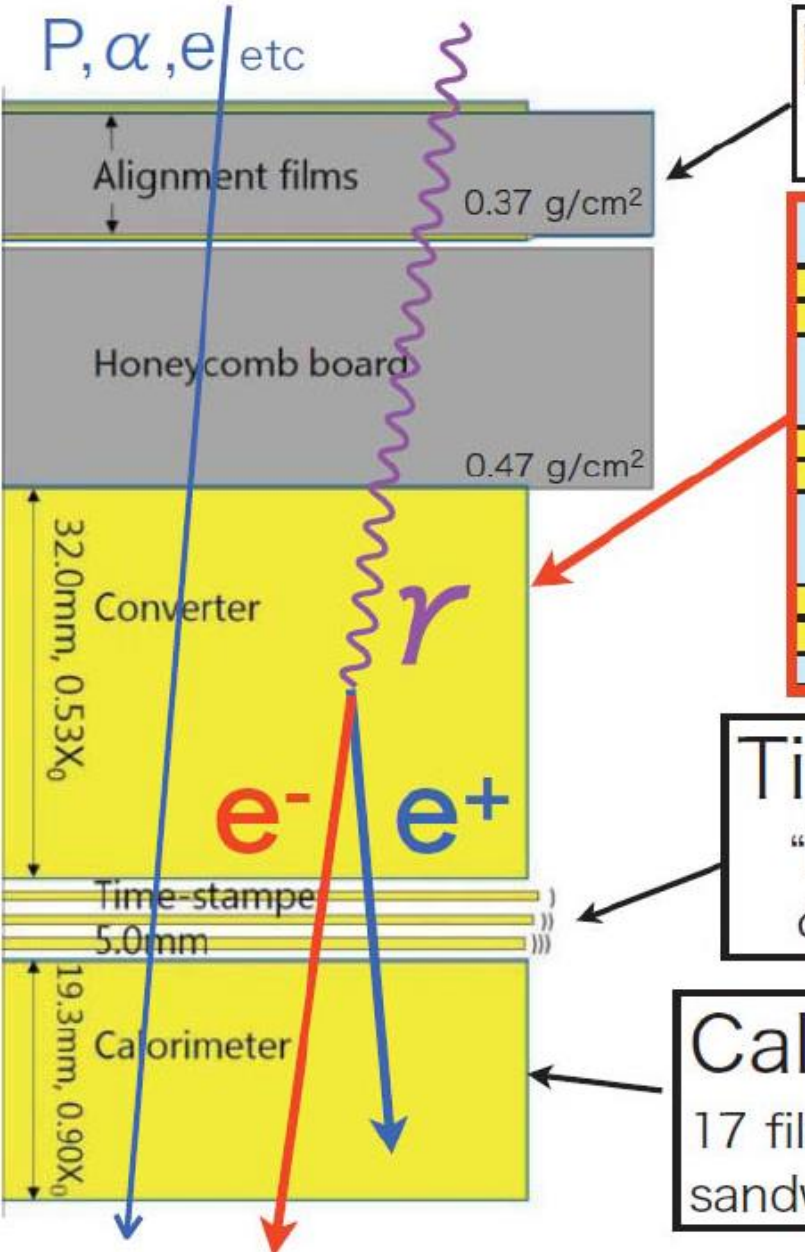
Flight duration: 14hour22min
(11hour32min(x7)
@36.0-37.4km)
almost covered
Vela w/in 45deg zenith
image©JAXA

Launched, 6:33 12th May 2015
Design, various improvements & preparations
Establishment of a scheme & flow of the experiment in Australia
Demonstration of overall performance

Image©JAXA

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

GRAINE-2015 Detector



Flatness alignment films

Al honeycomb +3 films

Converter

base 180 μm
emulsion 70 μm (double sides)

100 films(Thickness:32mm)
0.53 X_0 , $\varepsilon_{conv.}$ = 34%

Time stamper

"Multi-stage shifter" (3 stages)
δt = 0.5 s (Vela obs. mode: 0.01s)

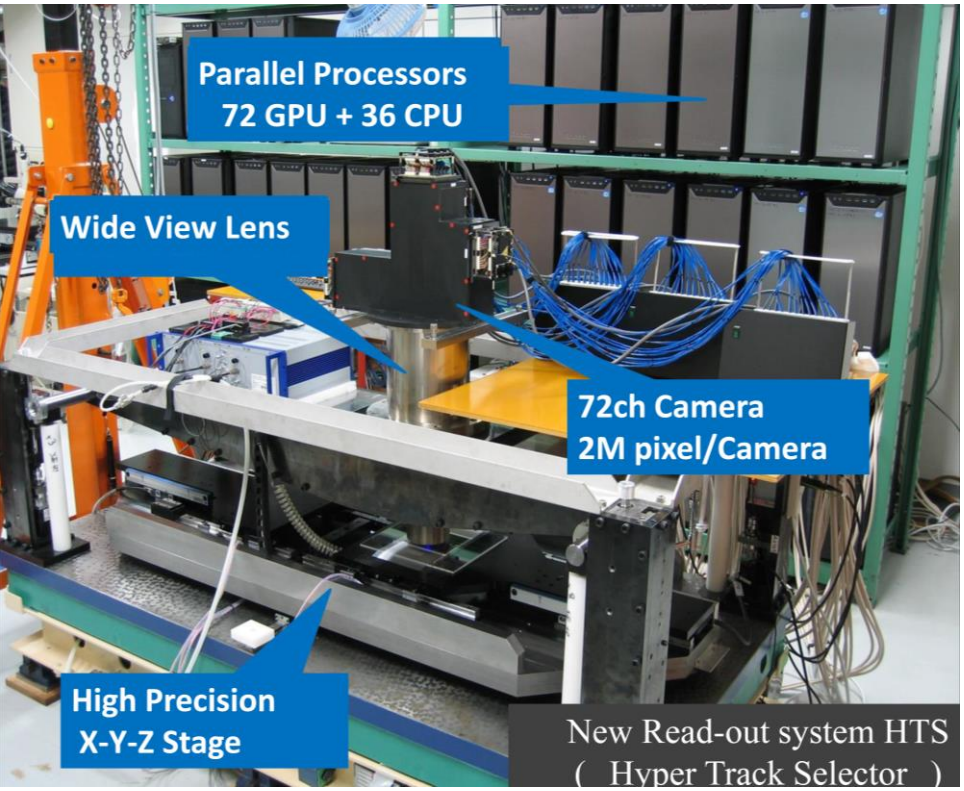
Calorimeter

17 films+16 SUS plates(1mm thick)
sandwich structure, thickness19.3mm, 0.90 X_0

Emulsion track read-out

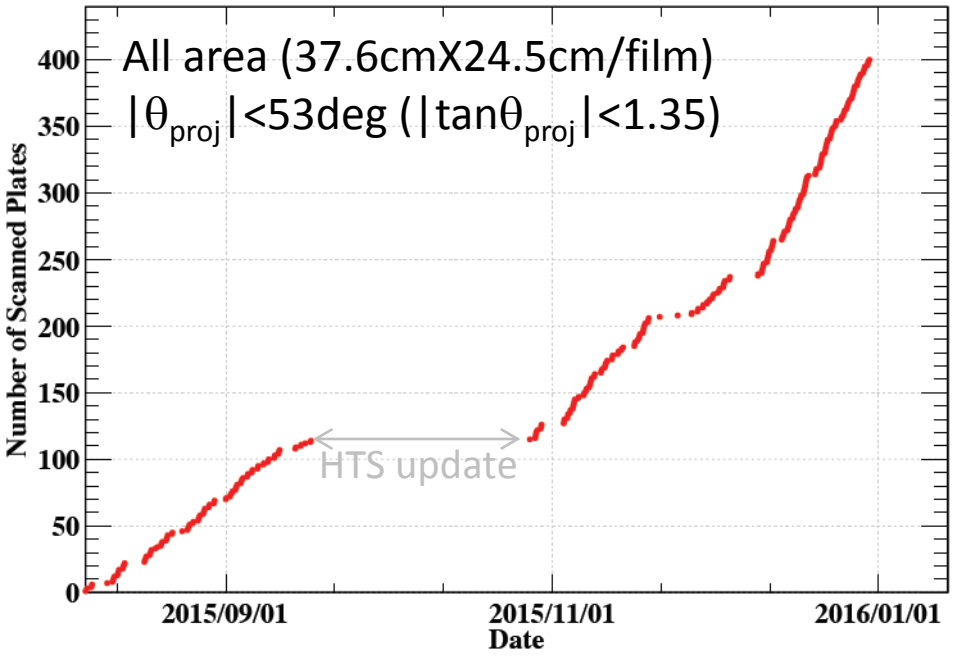
After film development, surface treatment, thickness tuning, scanning parameter tuning

Emulsion read-out system
Hyper Track Selector @ Nagoya U



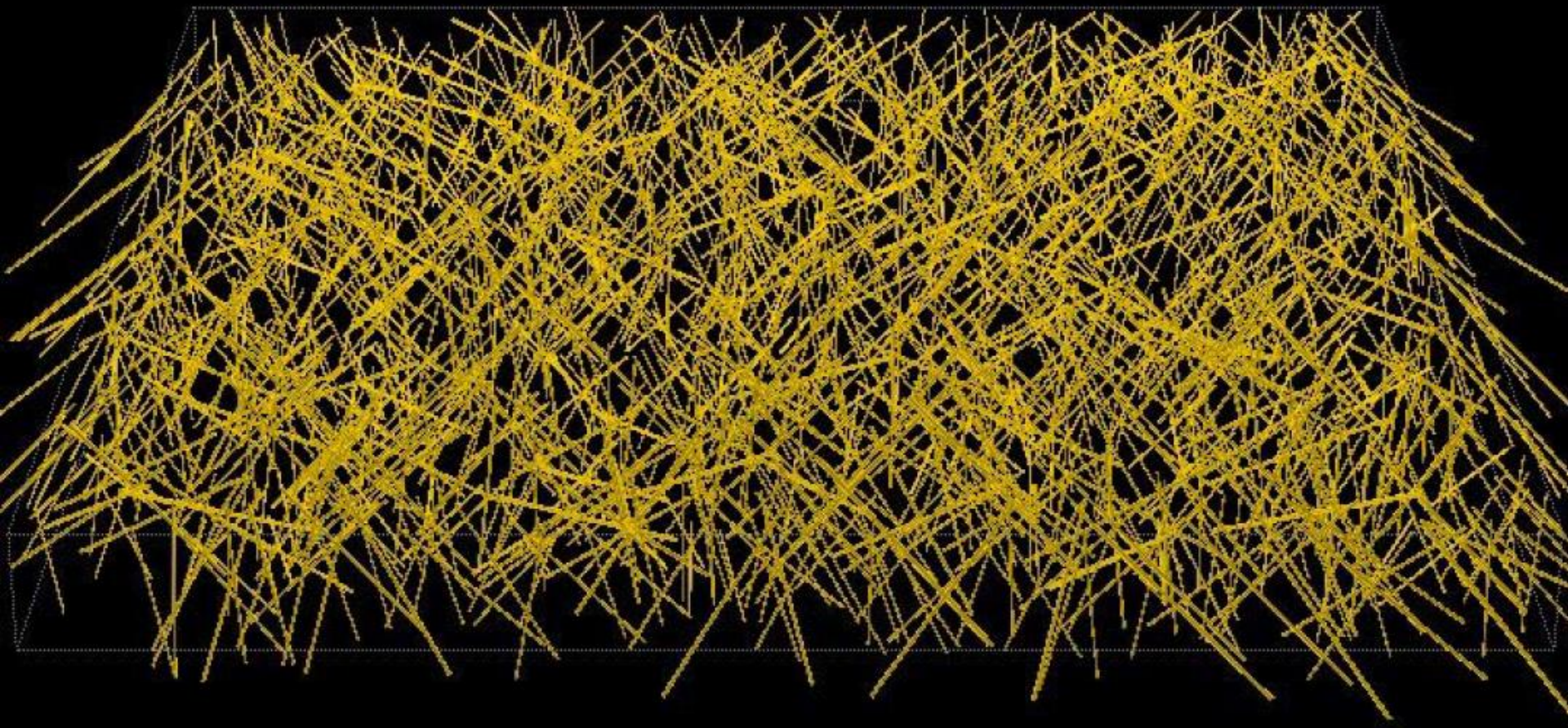
First practical scanning

Scanning progress



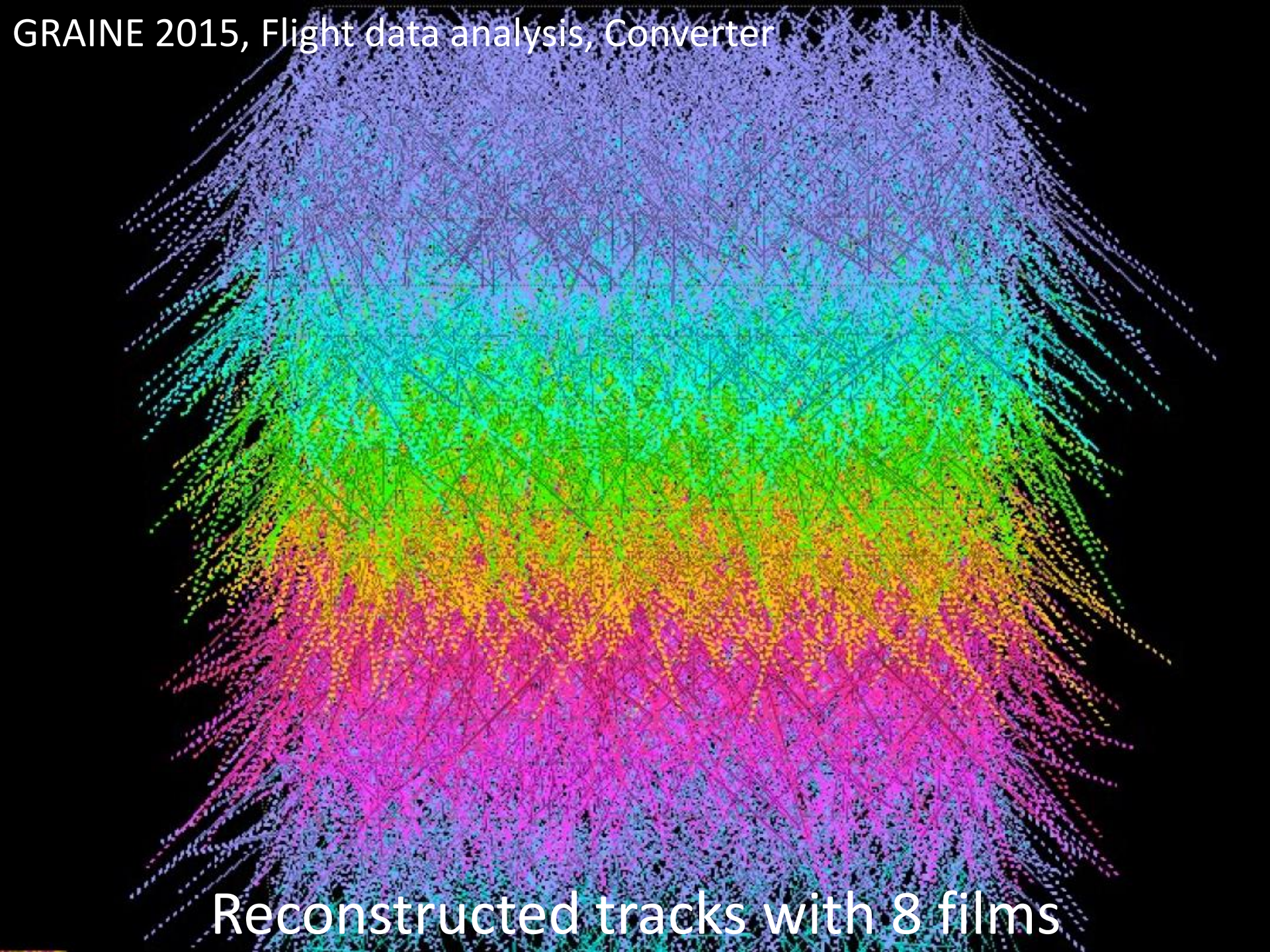
Completed for all films
(432films, 41m^2(film area basis))
-Converter 100 films x 4units
-Timestamper 8 films x 4units

GRAINE 2015, Flight data analysis, Converter



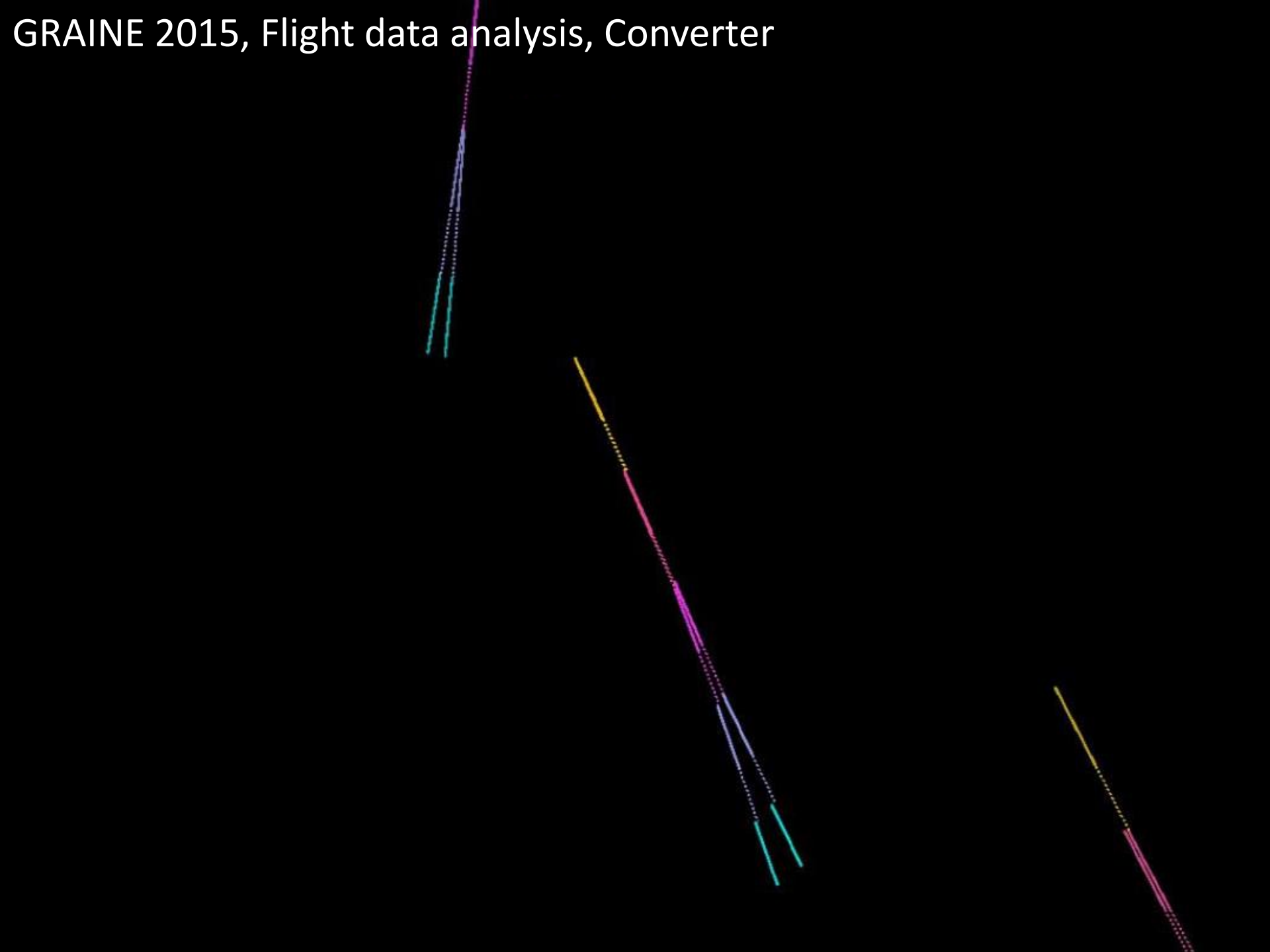
2 mm x 2 mm of single film
density ~400 tracks/mm^2

GRAINE 2015, Flight data analysis, Converter



Reconstructed tracks with 8 films

GRAINE 2015, Flight data analysis, Converter



GRAINE 2015, Flight data analysis, Converter

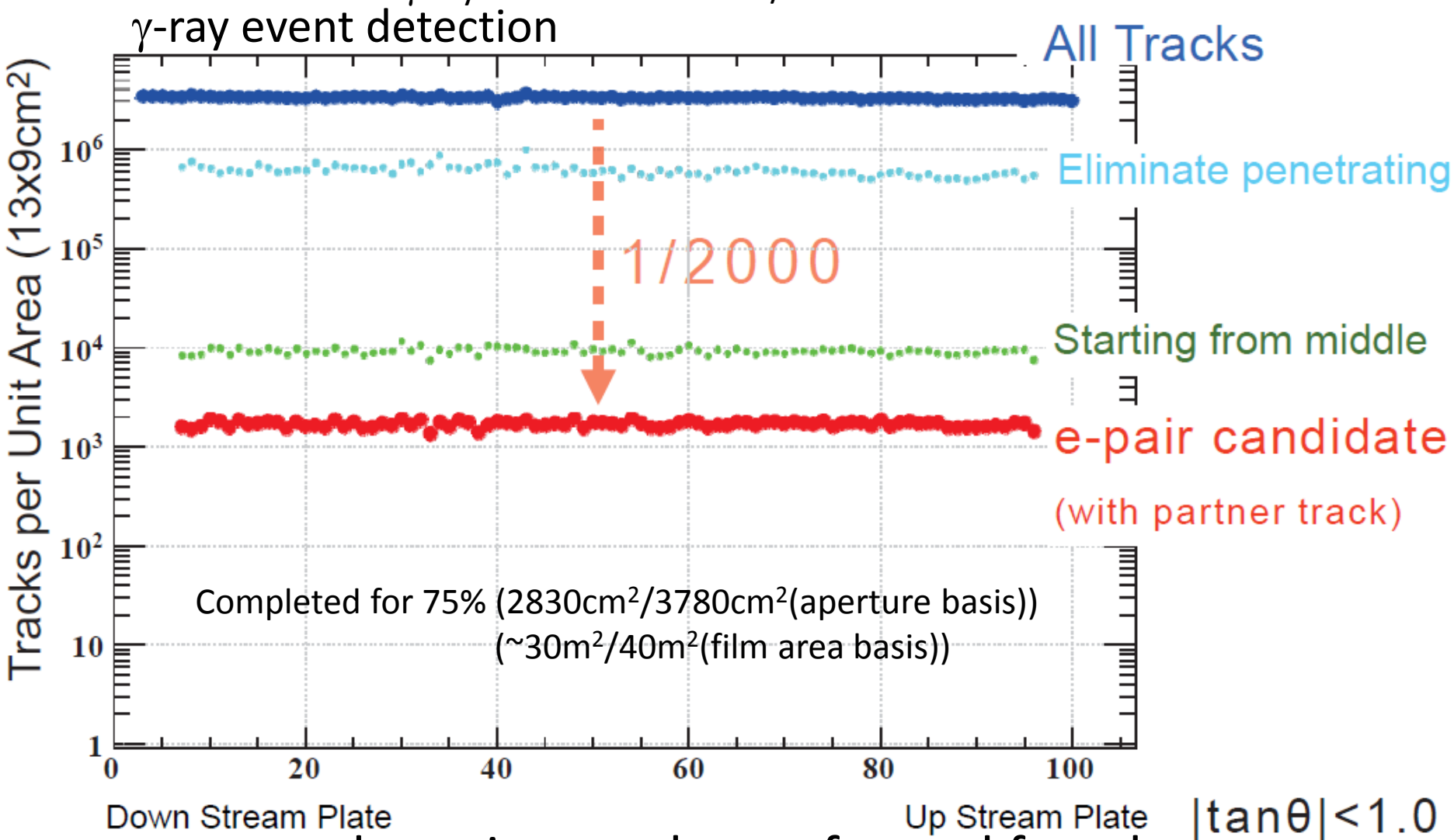
GRAINE 2015, Flight data analysis, Converter

Achieved improvements

-Emulsion film S/N ratio X~20, data size ~1/20

-Track finding inefficiency in a single film ~1/10

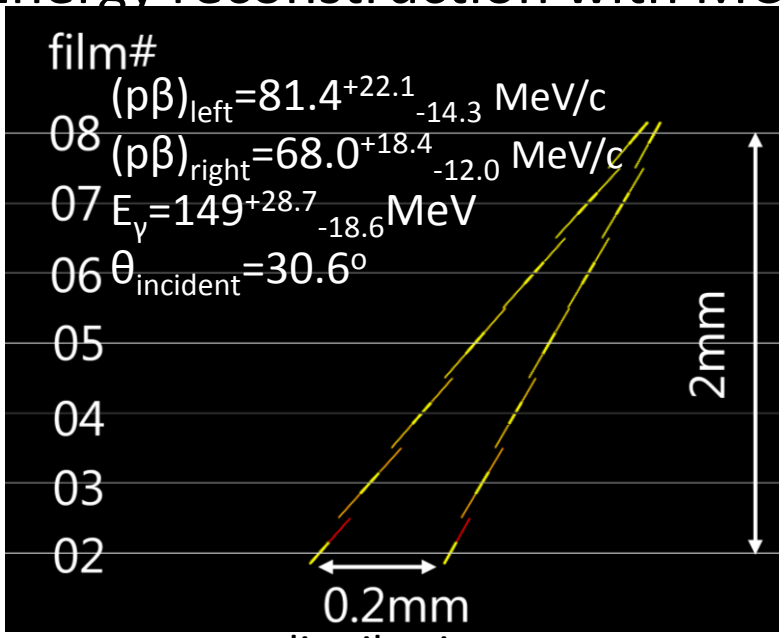
-Reduction load for γ-ray event detection ~1/200



γ-ray event detection can be performed for a large area.

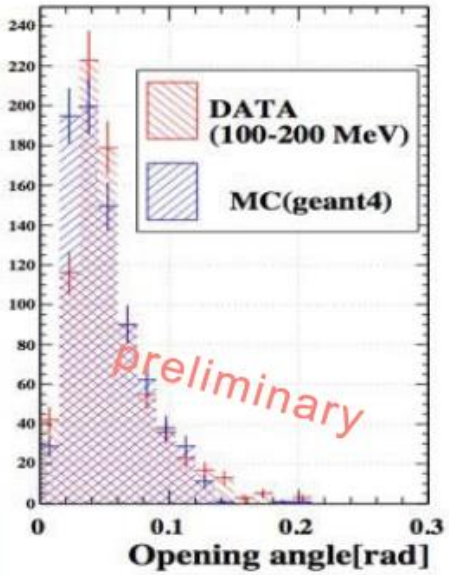
GRAINE 2015, Flight data analysis, Converter

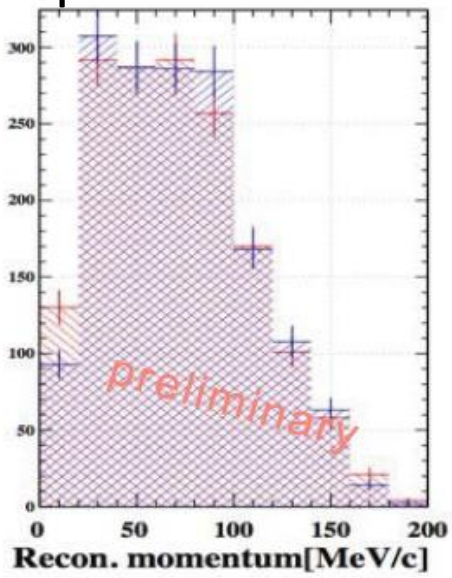
Energy reconstruction with MCS



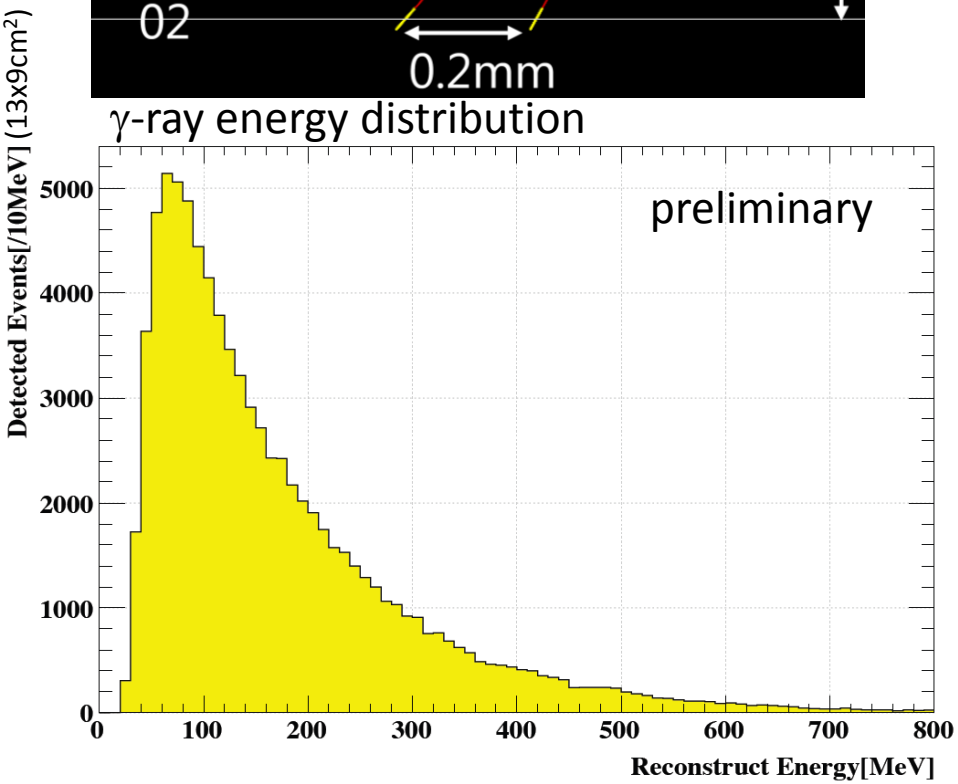
e-pair kinematics

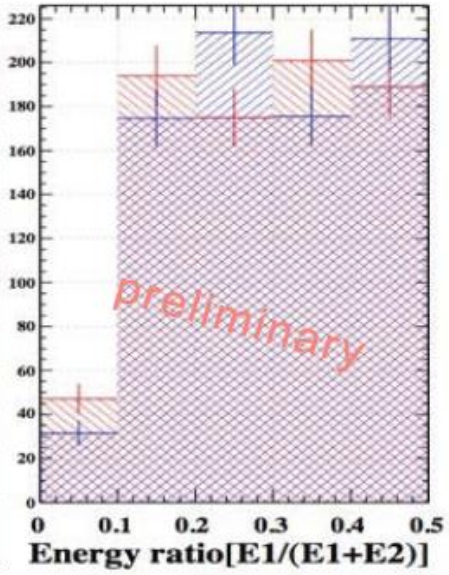
Data-MC comparison

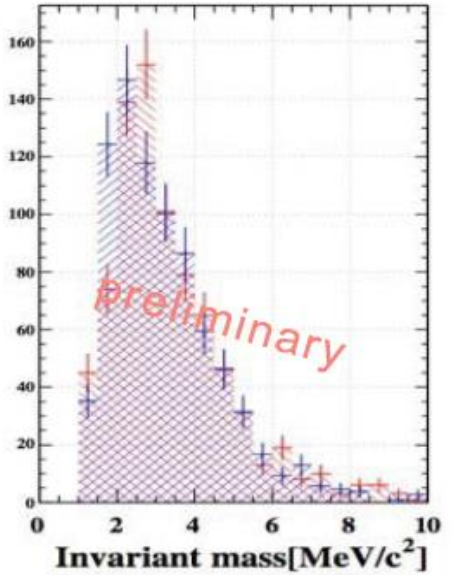




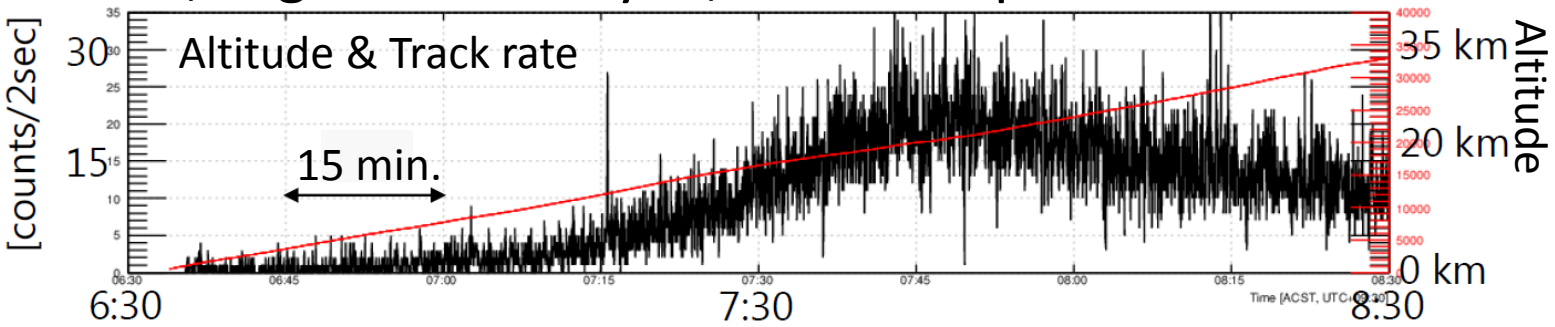
γ-ray energy distribution

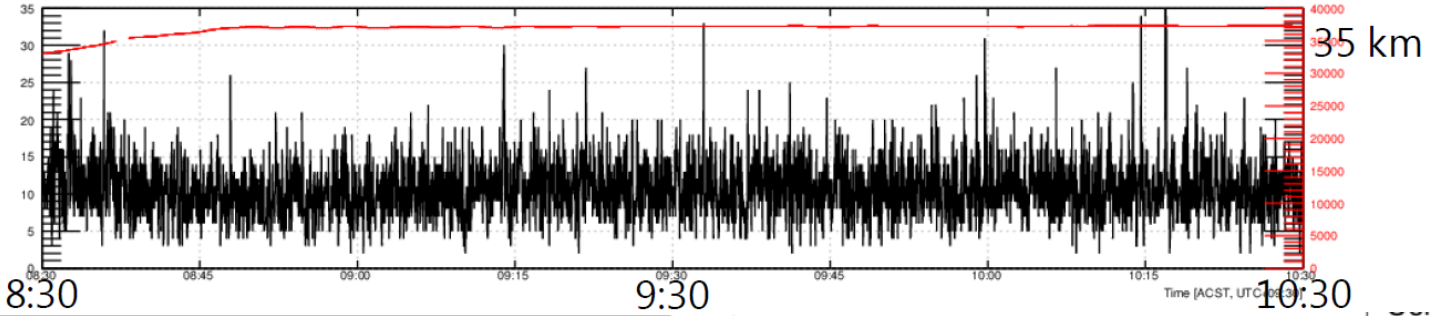


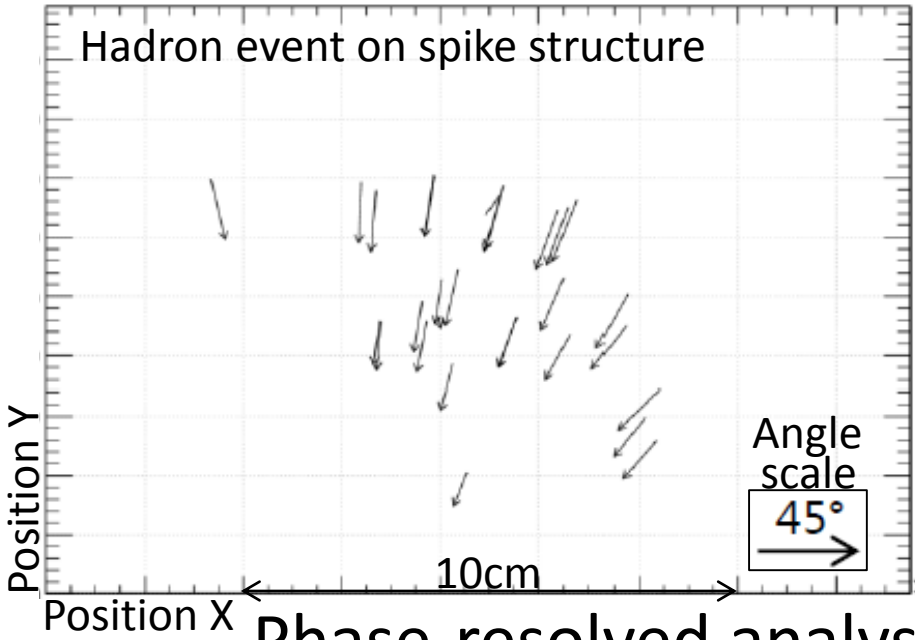


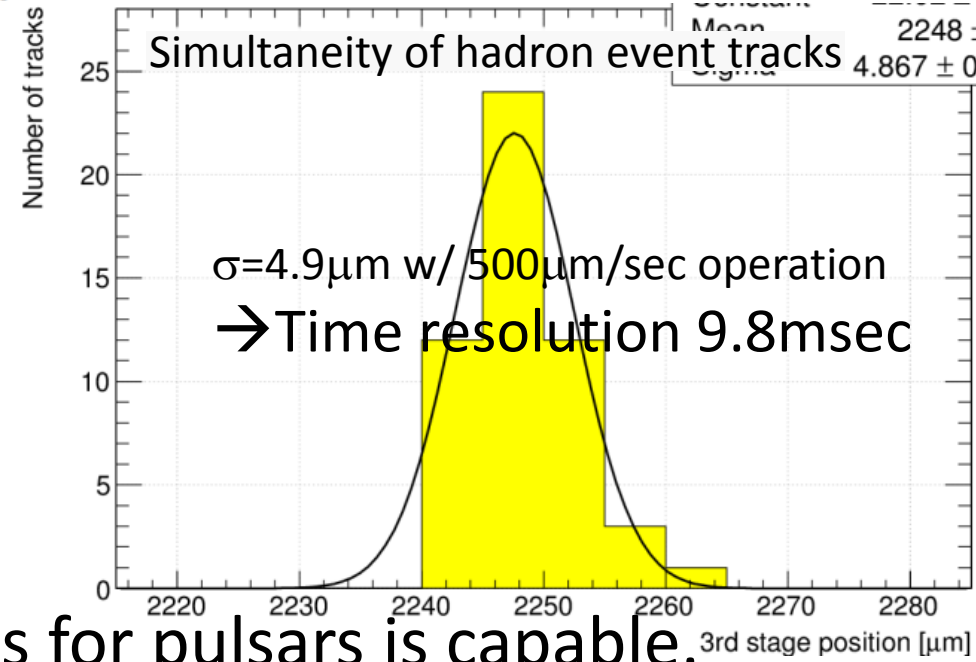


GRAINE 2015, Flight data analysis, Timestamper







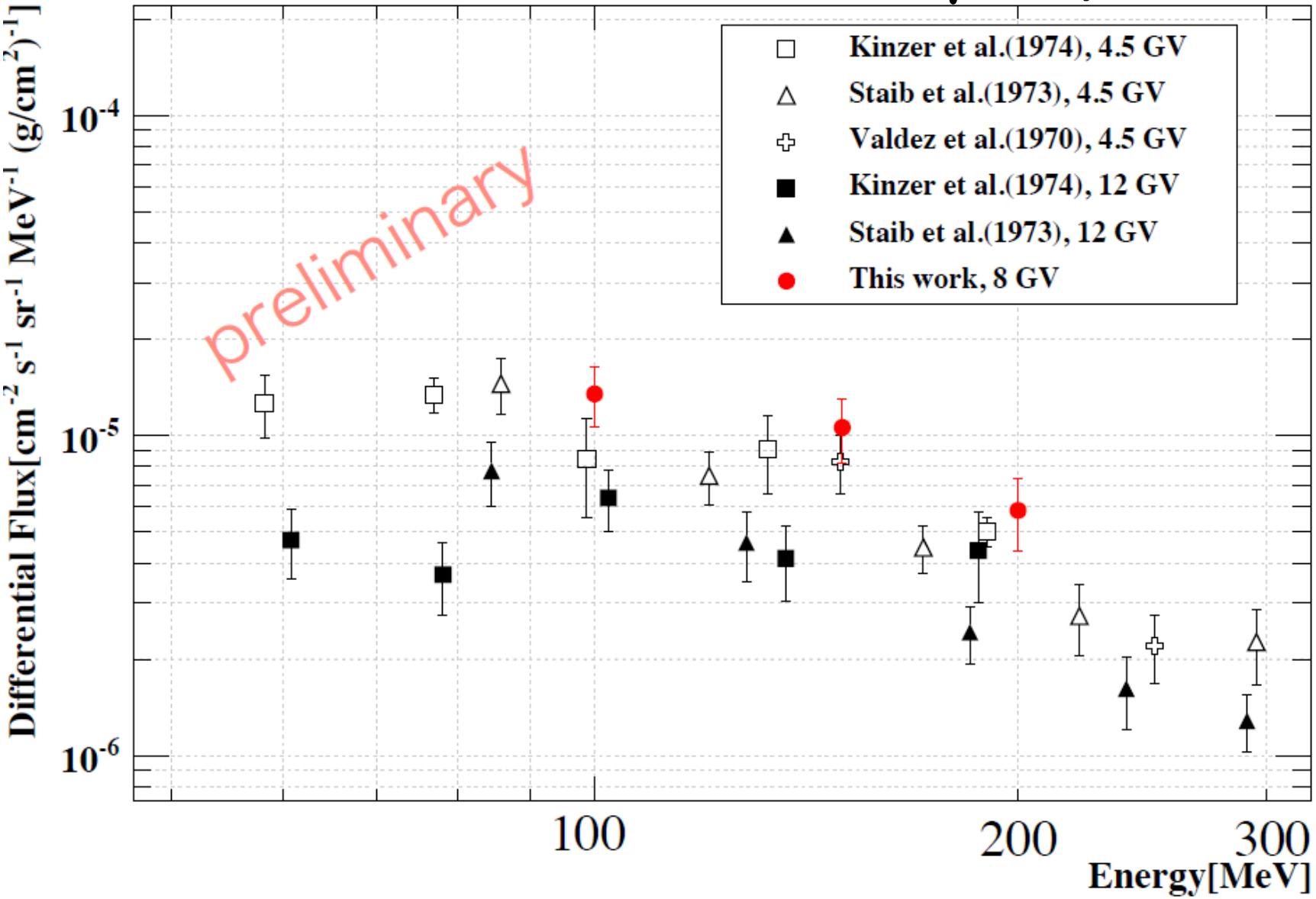


Phase-resolved analysis for pulsars is capable.

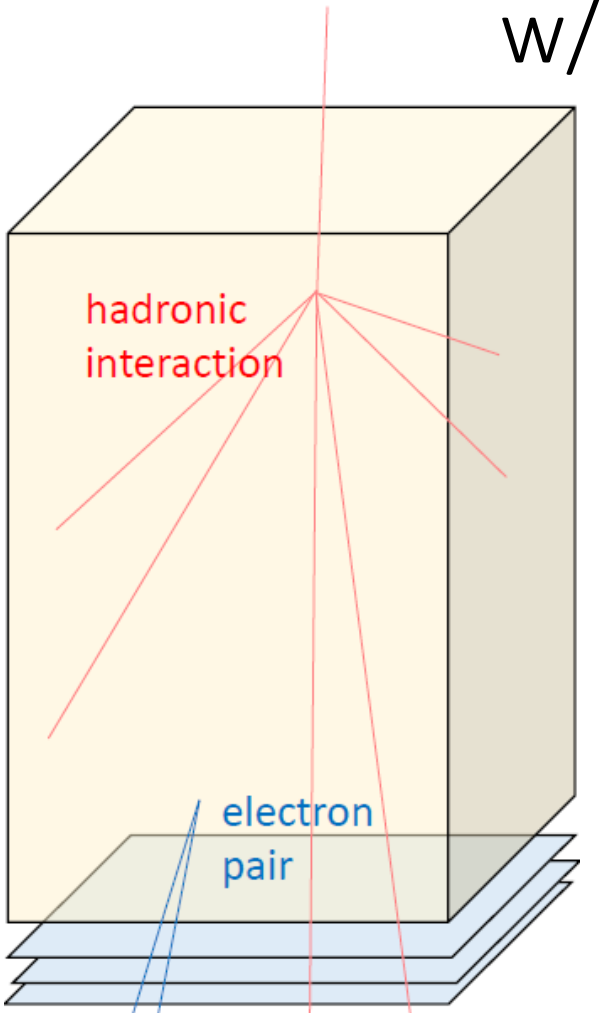
e.g. 89msec period of Vela pulsar

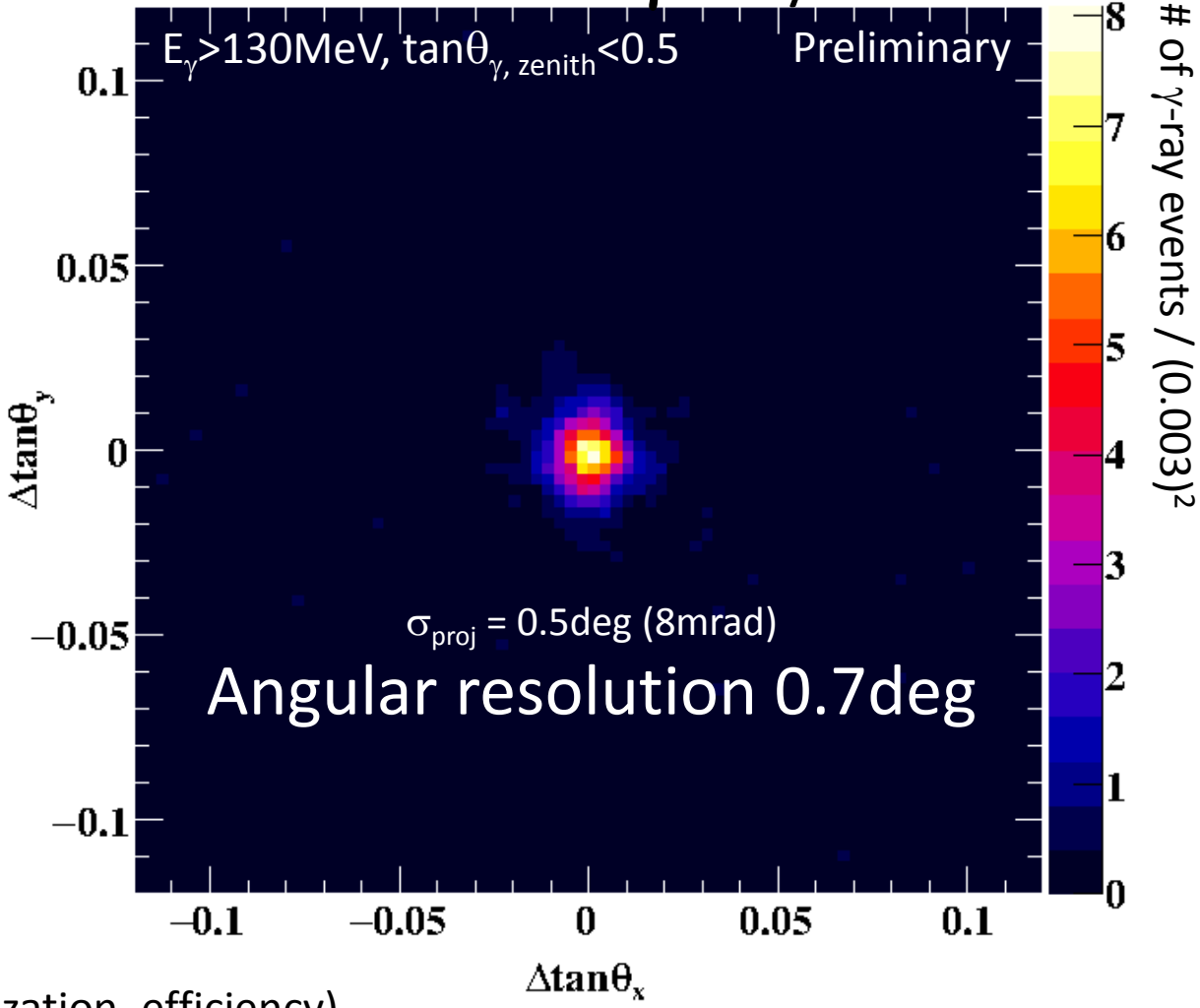
GRAINE 2015, Flight data analysis, Converter+Timestamper

Measurement of atm. γ-ray flux



γ-ray imaging performance w/ hadron induced γ-ray events





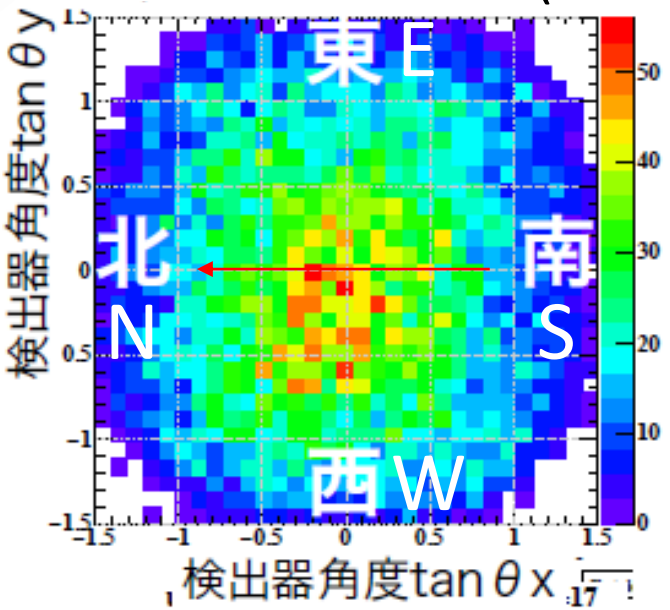
Calibration sorce
(direction, timing, energy, polarization, efficiency)

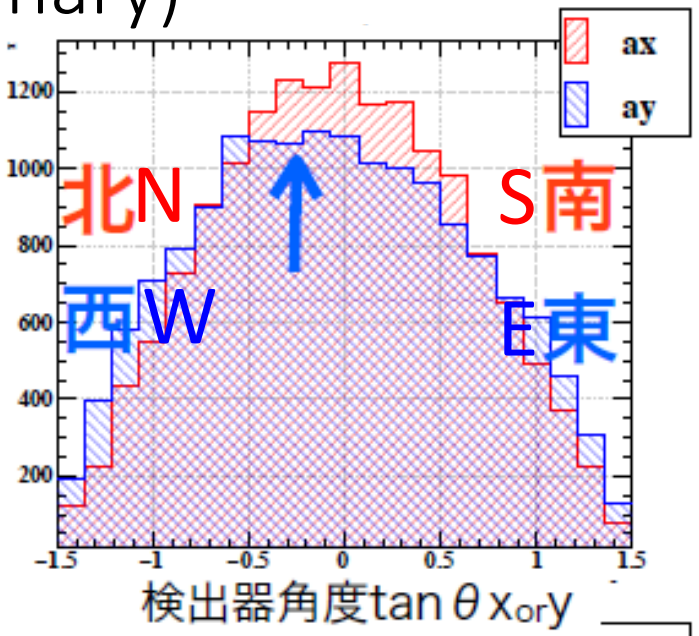
High γ-ray imaging performance was being obtained.

GRAINE 2015, Flight data analysis, Converter+Timestamper+Attitude

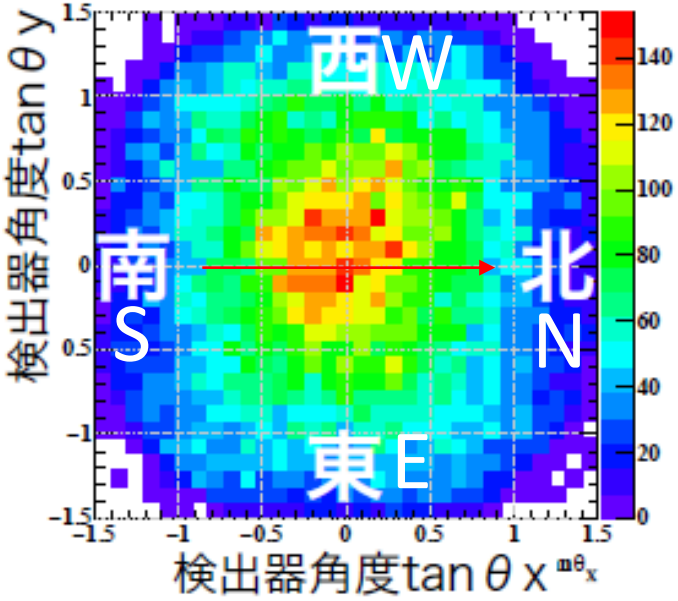
East-west effect (Preliminary)

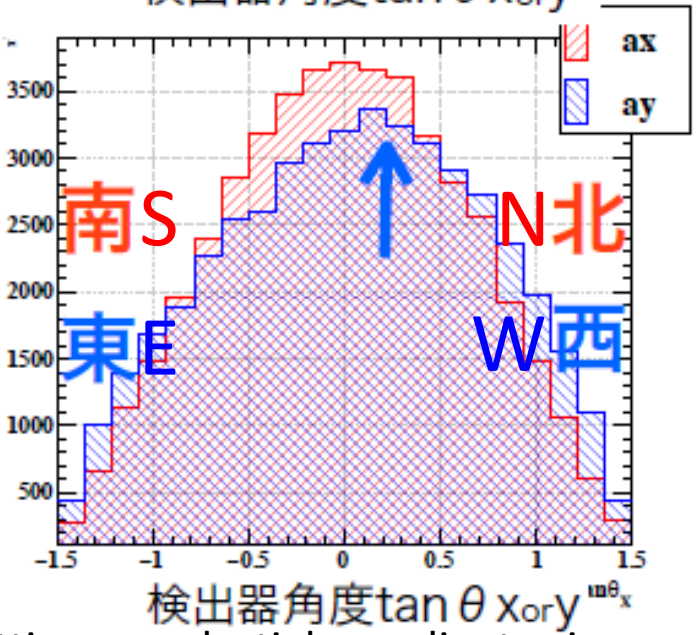
検出器軸が北向きの時





検出器軸が南向きの時





γ-ray plotting on celestial coordinates is ongoing.

GRAINE Scientific observation roadmap

2018

Alice Springs
>~1m^2 aperture, >~36hours flight duration
<~10g/cm^2 altitude
Commissioning flight

2021-

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

-Scientific model establishment
(size, weight)
-Flight duration
-Performance demonstration
-Scientific obs. starting

Vela pulsar
Polarization observation (<50%)

Pioneering polarization observation for high energy γ-rays

SNR W44 (<200MeV, >200MeV)
Precise spectrum measurement
High resolution imaging

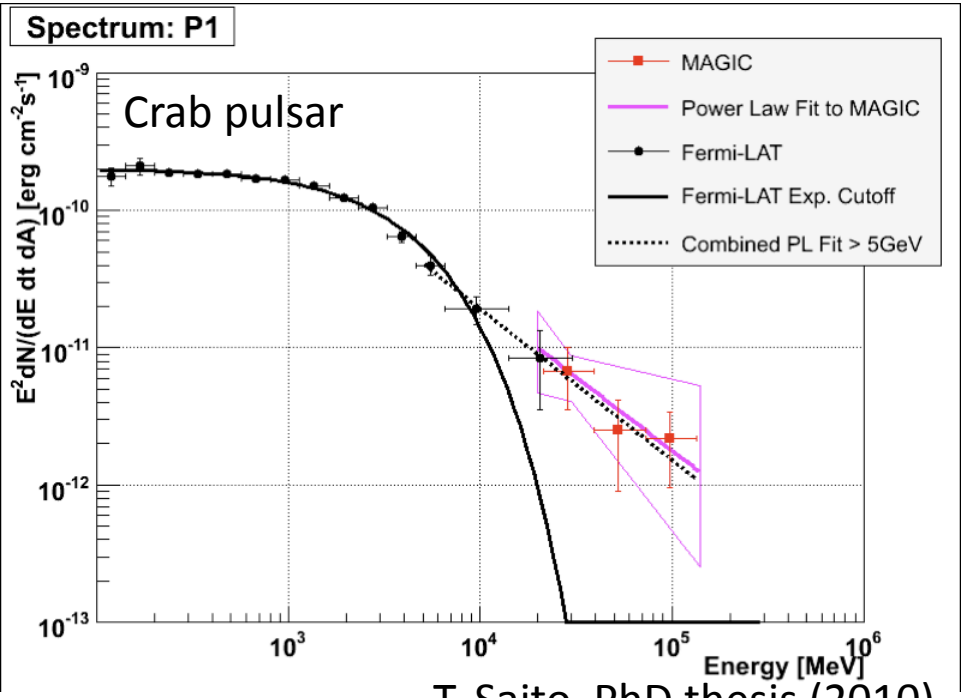
Studying cosmic ray sources

Galactic Center
Obs. with ~arcmin resolution

Resolving GeV γ-ray excess at galactic center

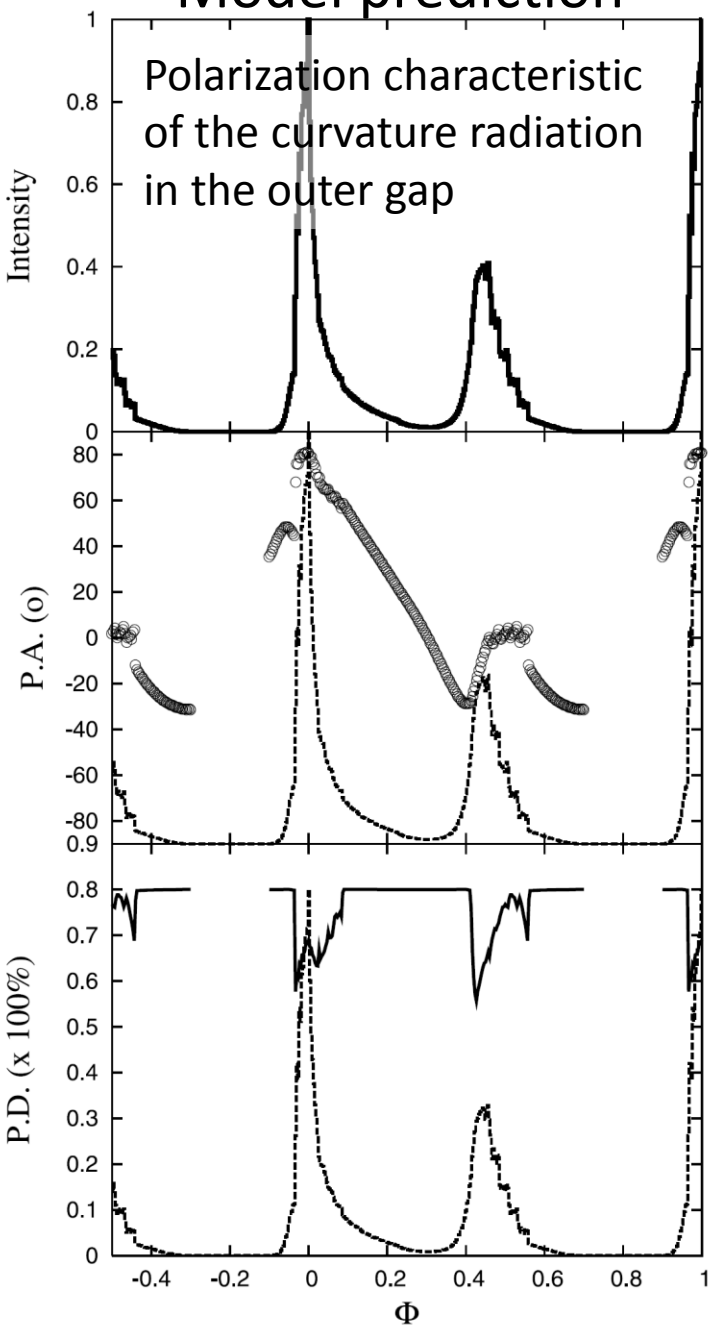
Pioneering polarization observation for high energy γ-rays
Approaching emission mechanism

Pulsars, AGNs, Flares, GRBs



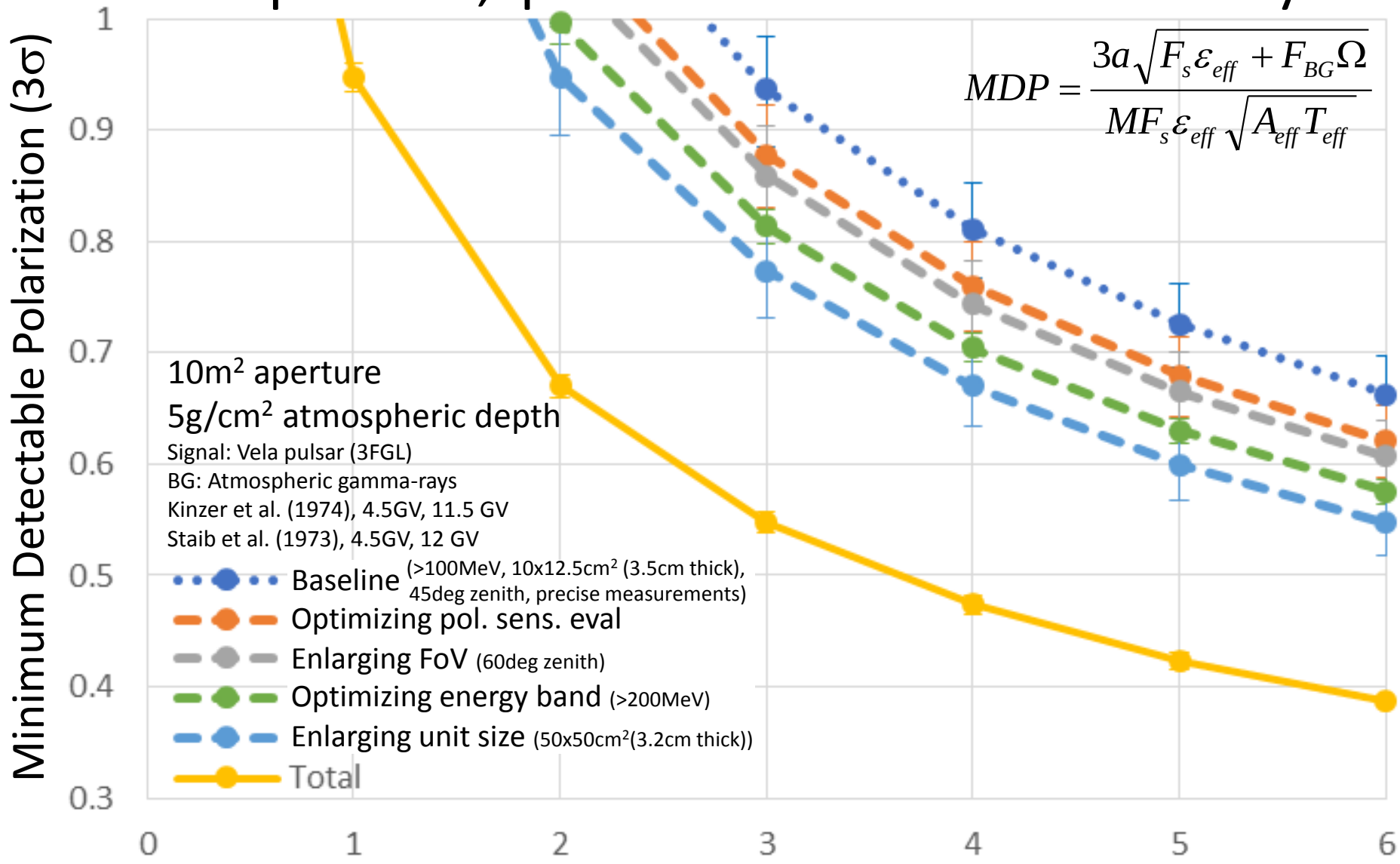
T. Saito, PhD thesis (2010)

Model prediction



J.Takata and H.-K.Chang, ApJ, 670:677-692, 2007

Vela pulsar, polarization sensitivity



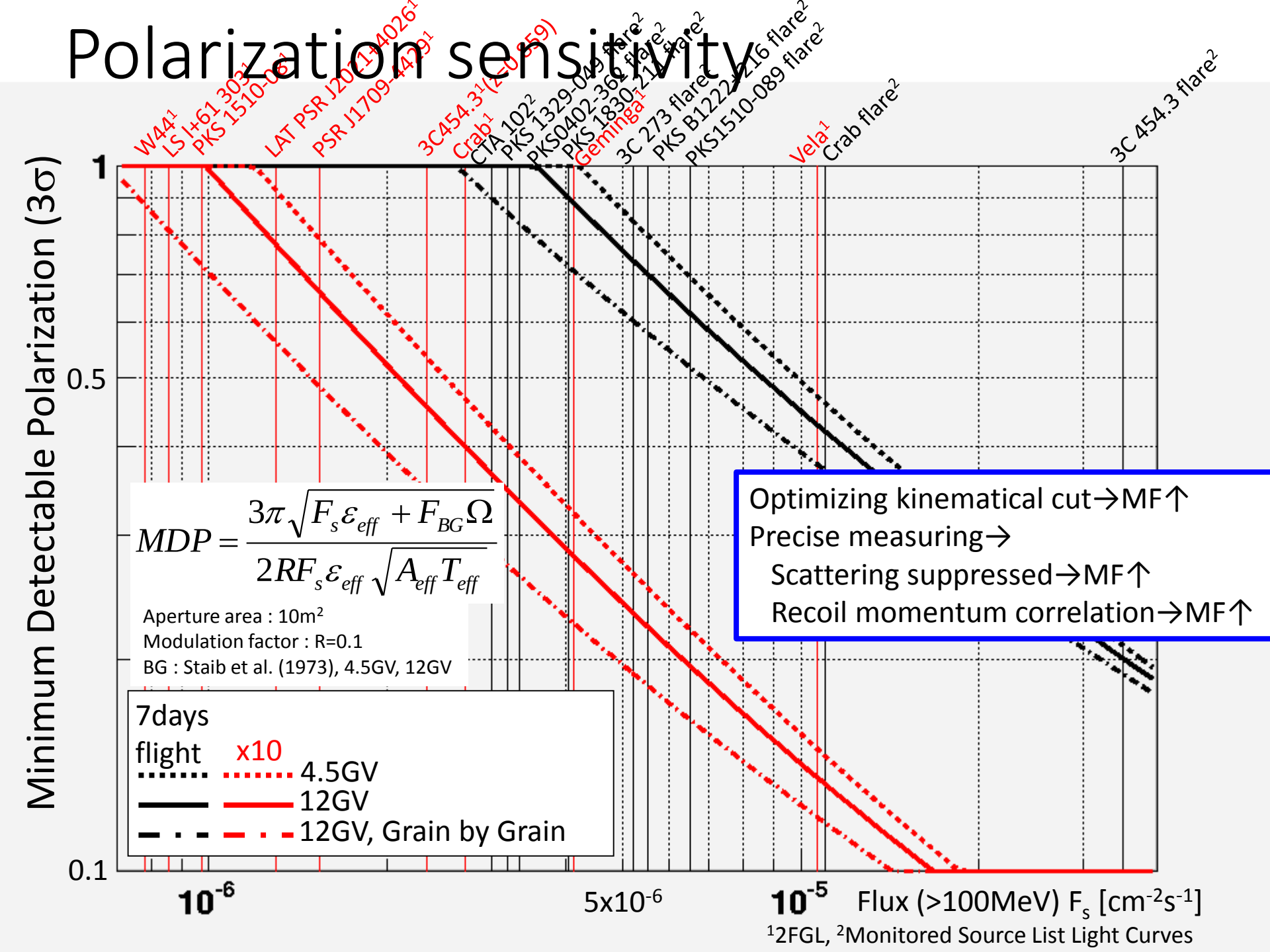
Alice Springs

Apr. 15th, 19:39(ACST) culmination, 21.6deg zenith

16:24–22:54 (6.5h/cross) w/in 45deg zenith, 14:58 – 24:20(9.4h/cross) w/in 60deg zenith

# of crosses of a source in a field of view of the telescope with diurnal rotation (roughly corresponding to flight days)

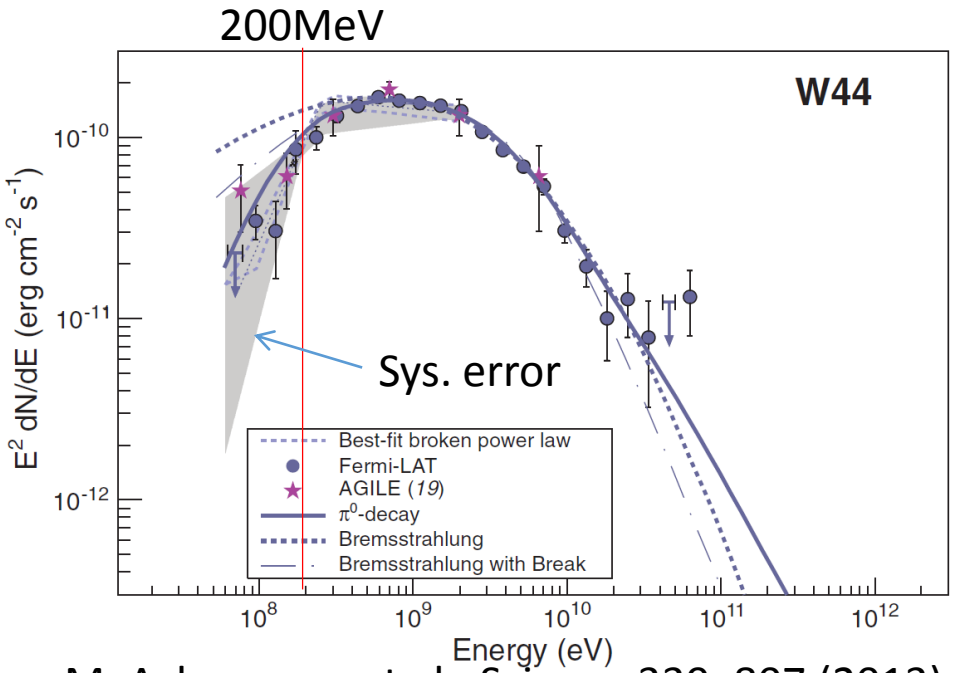
Polarization sensitivity



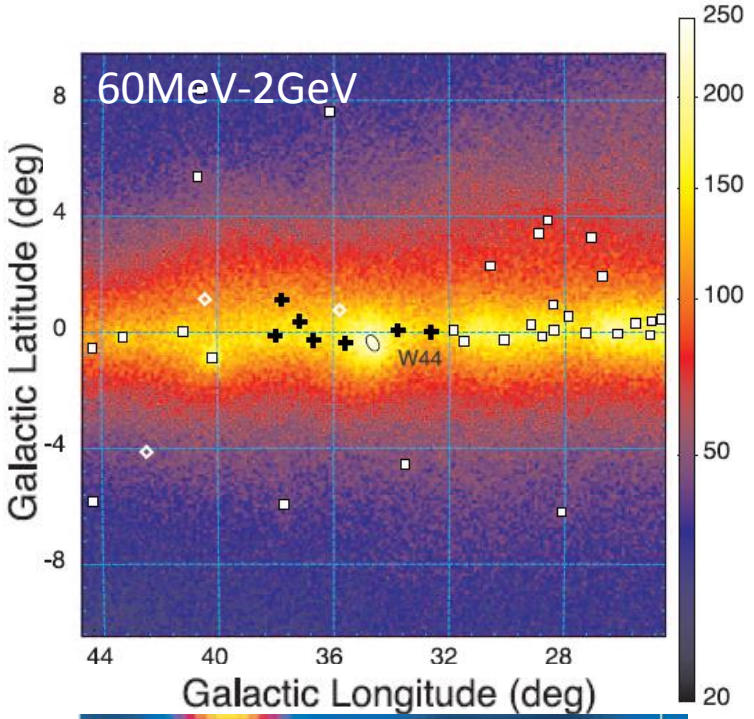
[1]2FGL, [2]Monitored Source List Light Curves

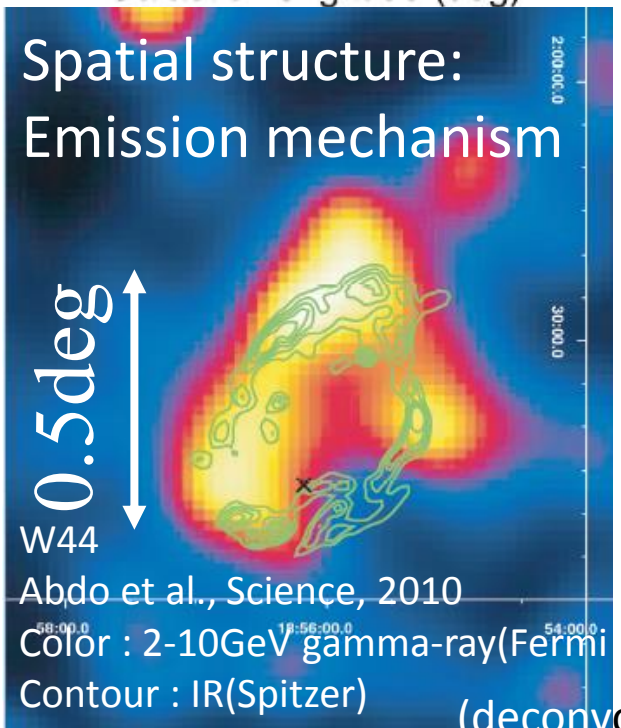
π^0 emission: Direct evidence of proton acceleration

SNRs



M. Ackermann et al., Science 339, 807 (2013)

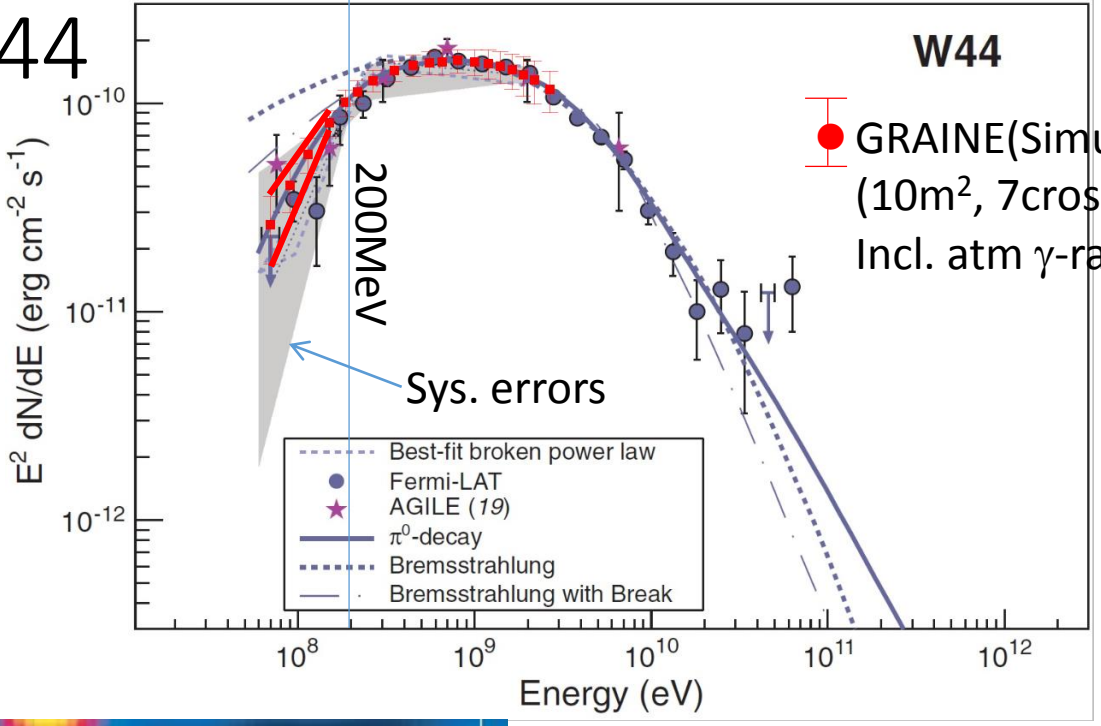




<200MeV, precise spectrum measurements with suppressed systematic errors

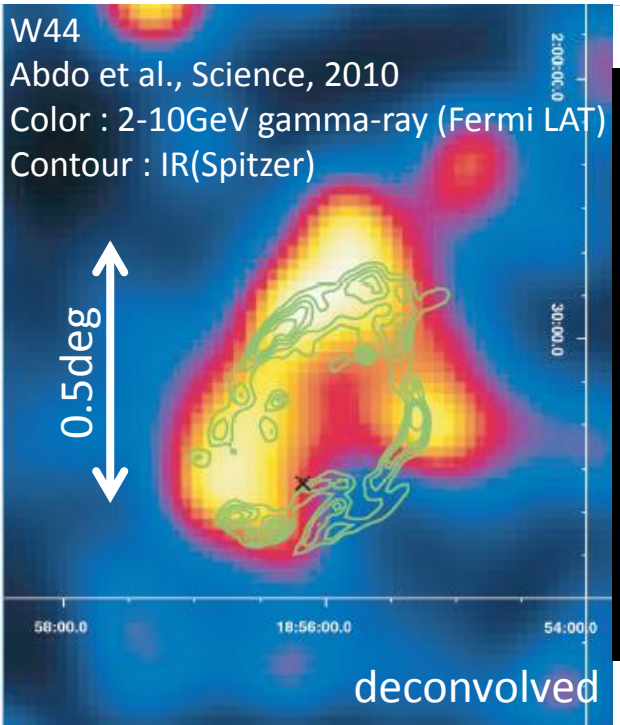
>200MeV, investigating spatial structure

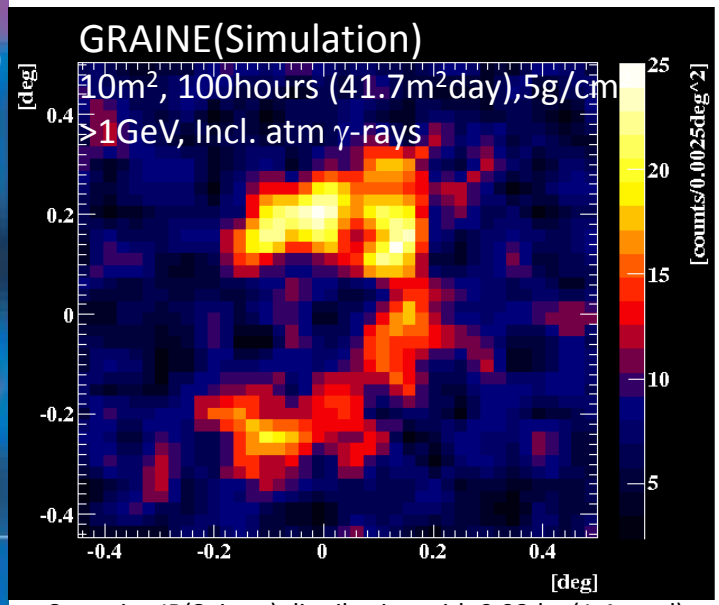
W44



GRAINE(Simulation)
(10m², 7crossX10, 5g/cm²,
Incl. atm γ-rays)

<200MeV
Precise spectral measuring
with suppressed systematic errors



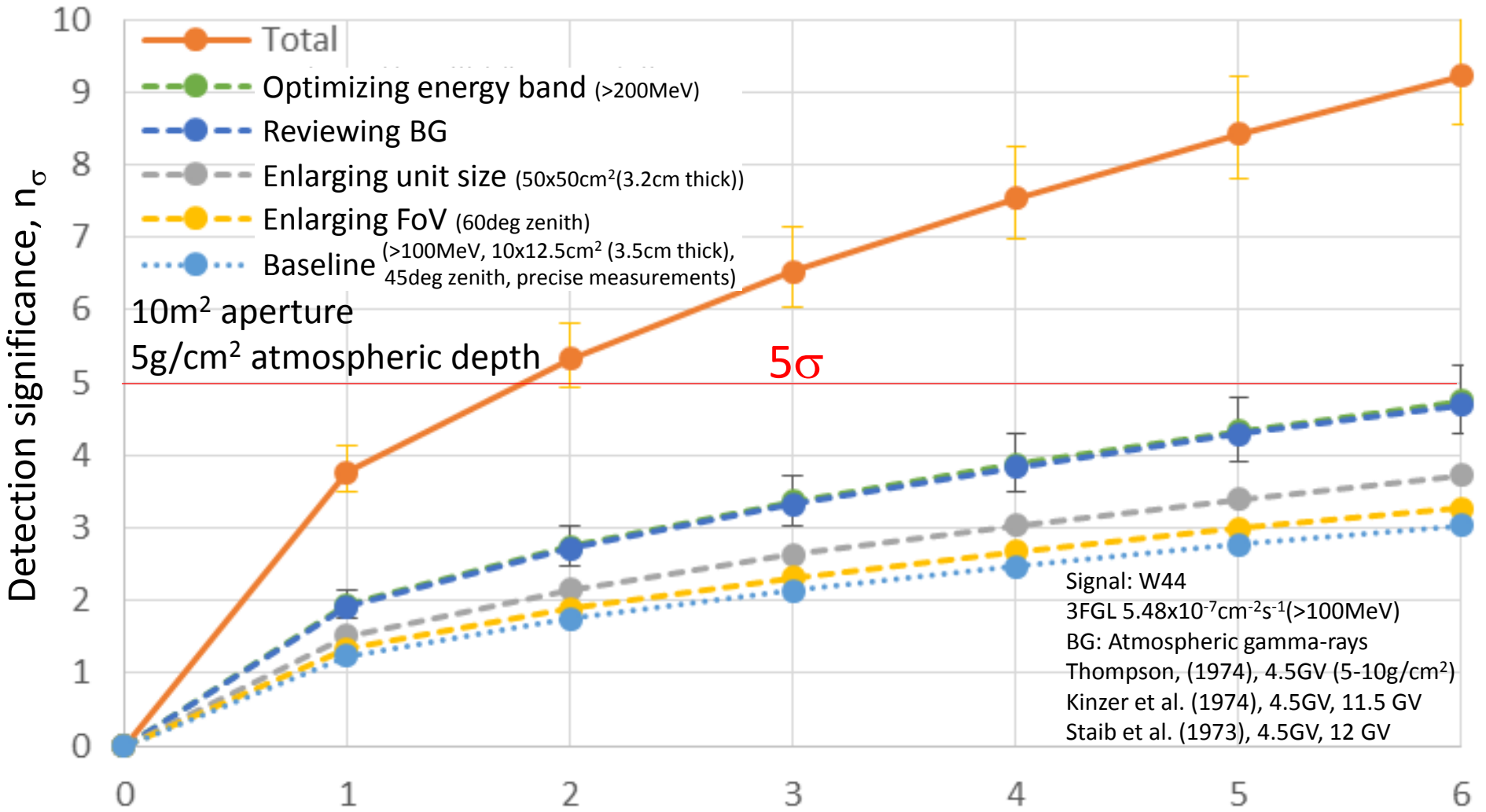


Smearing IR(Spitzer) distribution with 0.08deg(1.4mrad)
Considering atmospheric gamma-ray(>1GeV) as BG

>200MeV
Investigating spatial structure

W44 detection sensitivity

$$n_\sigma = \frac{N_s}{\sqrt{N_{BG}}}$$



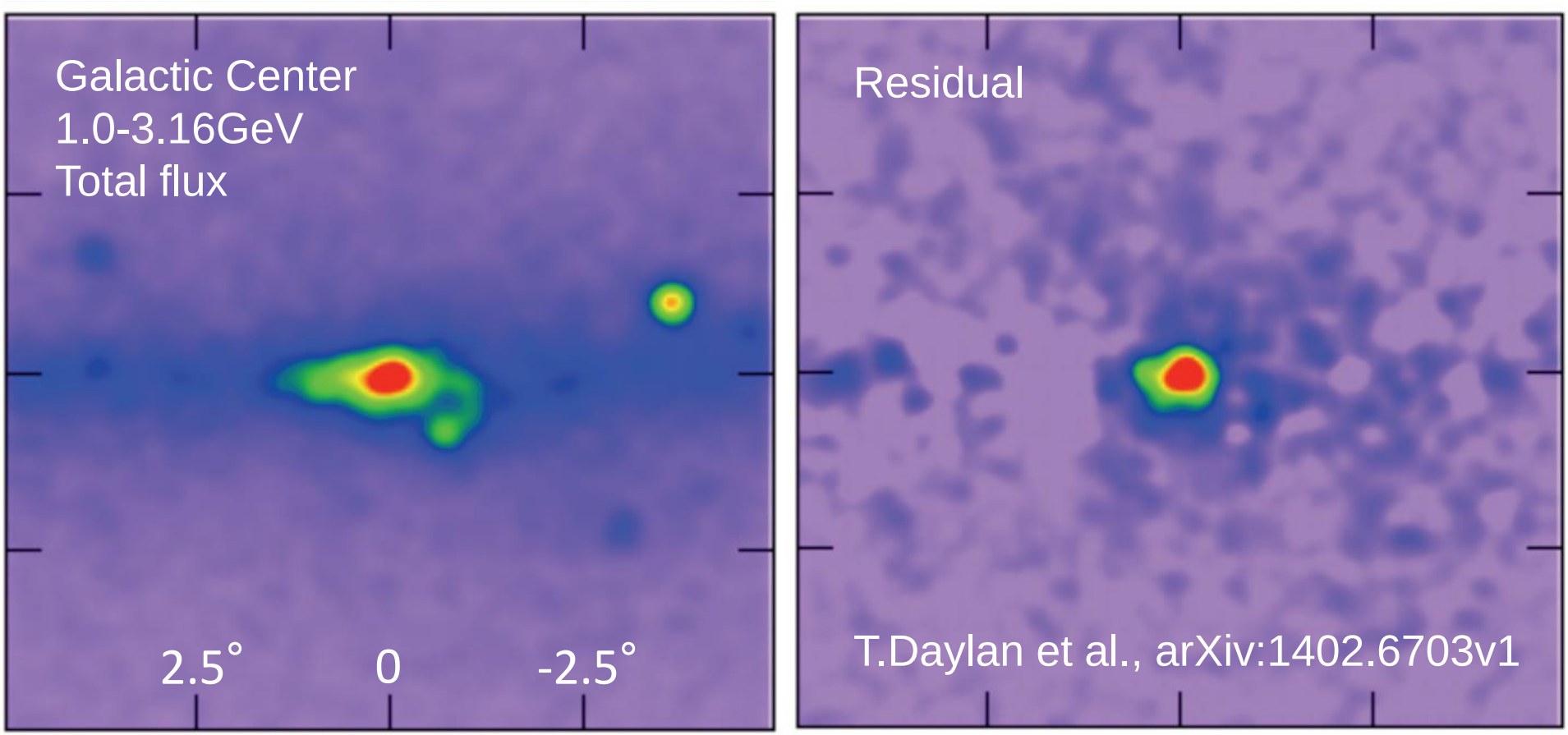
# of crosses of a source in a field of view of the telescope with diurnal rotation (roughly corresponding to flight days)

Alice Springs

Apr. 15th, 6:04(ACST) culmination, 25.1deg zenith

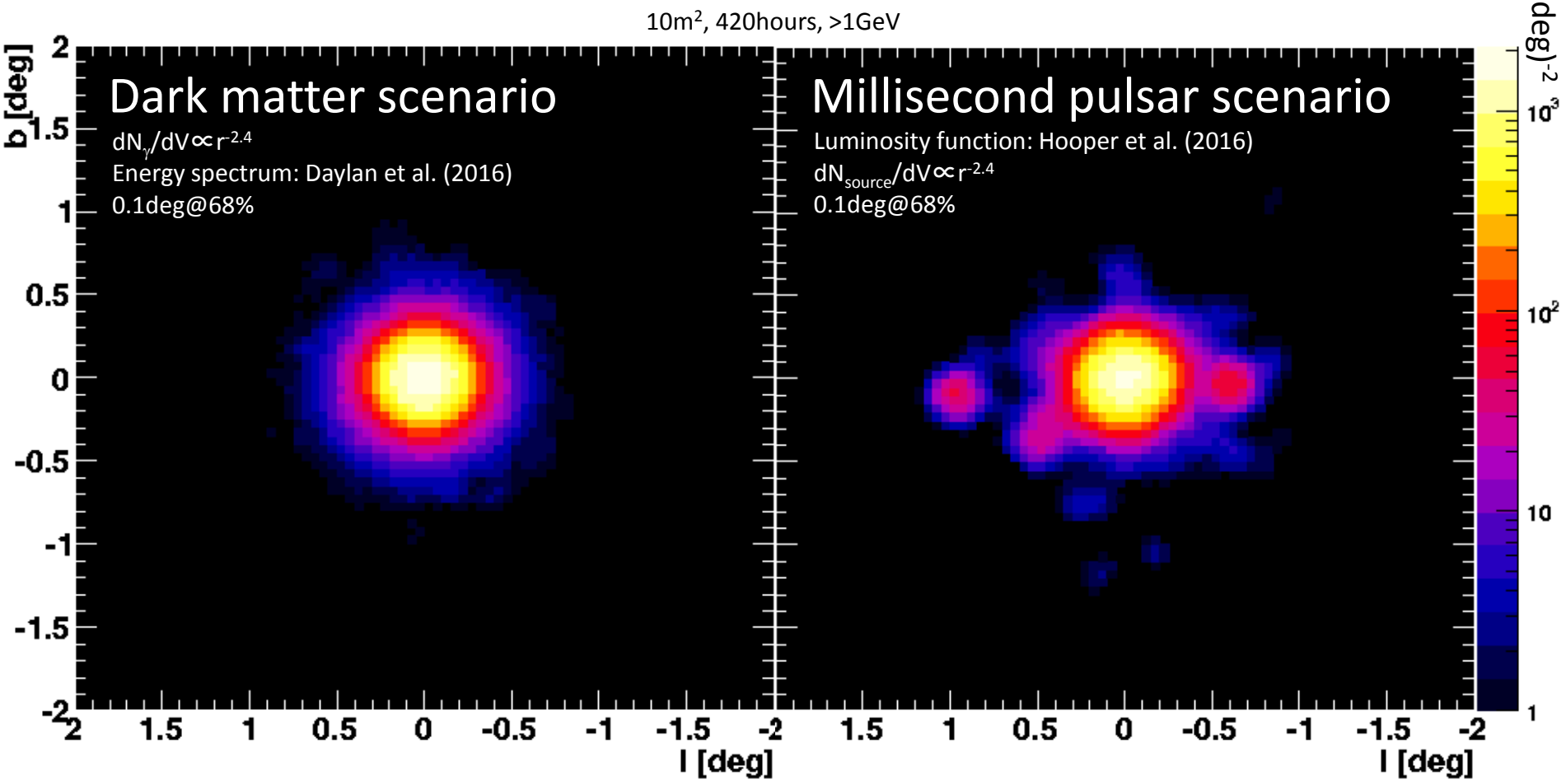
3:27–8:42 (5.25h/cross) w/in 45deg zenith, 2:19 – 9:49(7.5h/cross) w/in 60deg zenith

GeV γ-ray excess at galactic center region

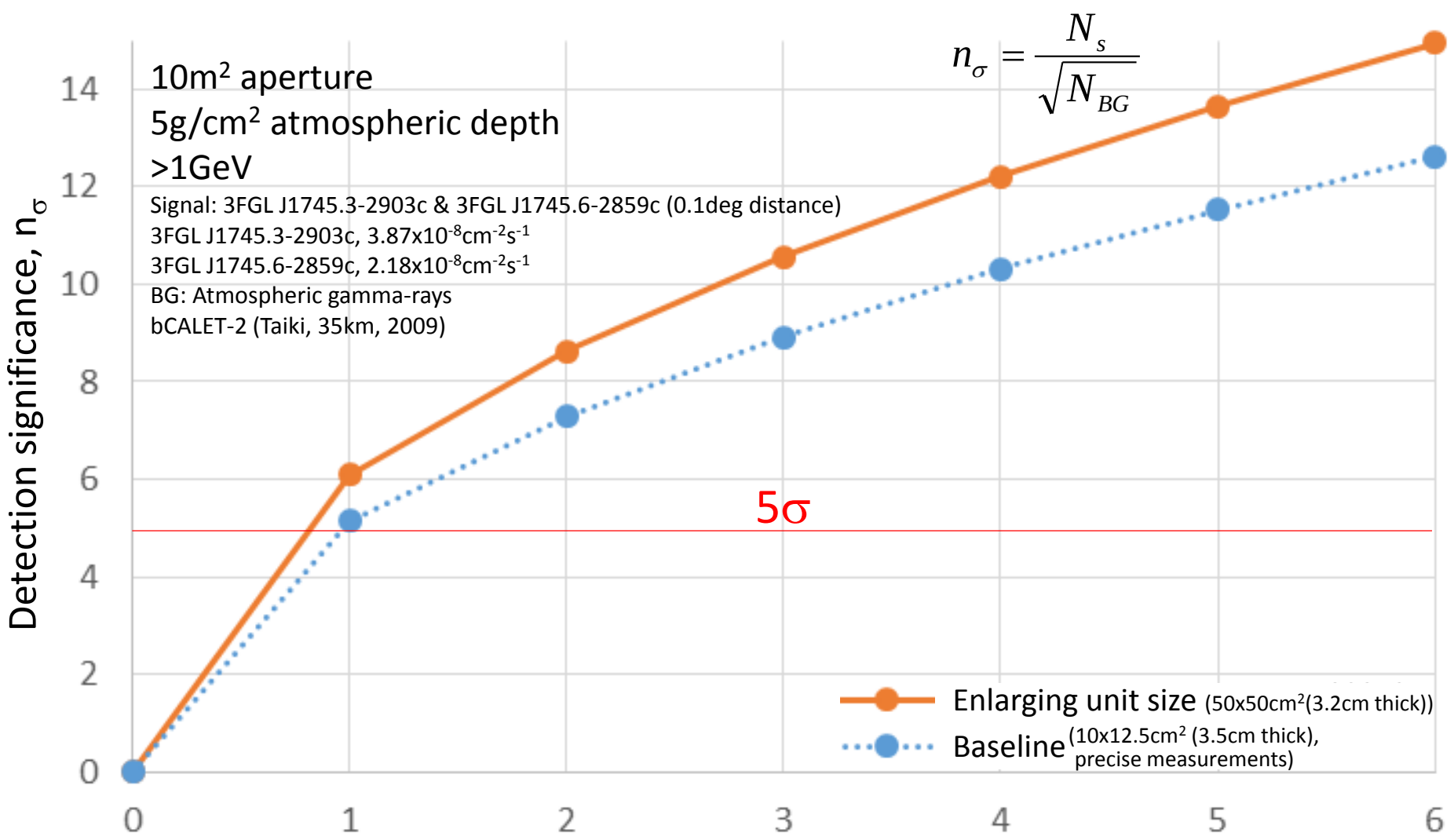


GeV γ-ray observations at galactic center region with ~arcmin resolution

Simulation of GeV γ-ray excess at galactic center region w/ high angular resolution



Galactic center region, detection sensitivity



Alice Springs

Apr. 15th, 4:53(ACST) culmination, 5.3deg zenith

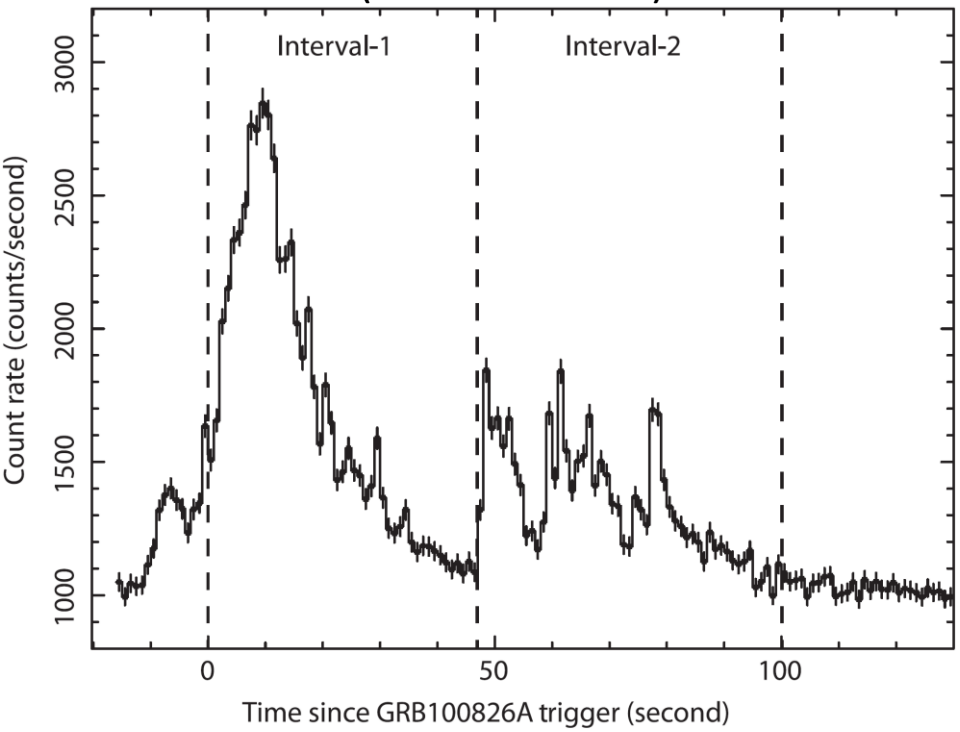
1:31–8:16 (6.75h/cross) w/in 45deg zenith

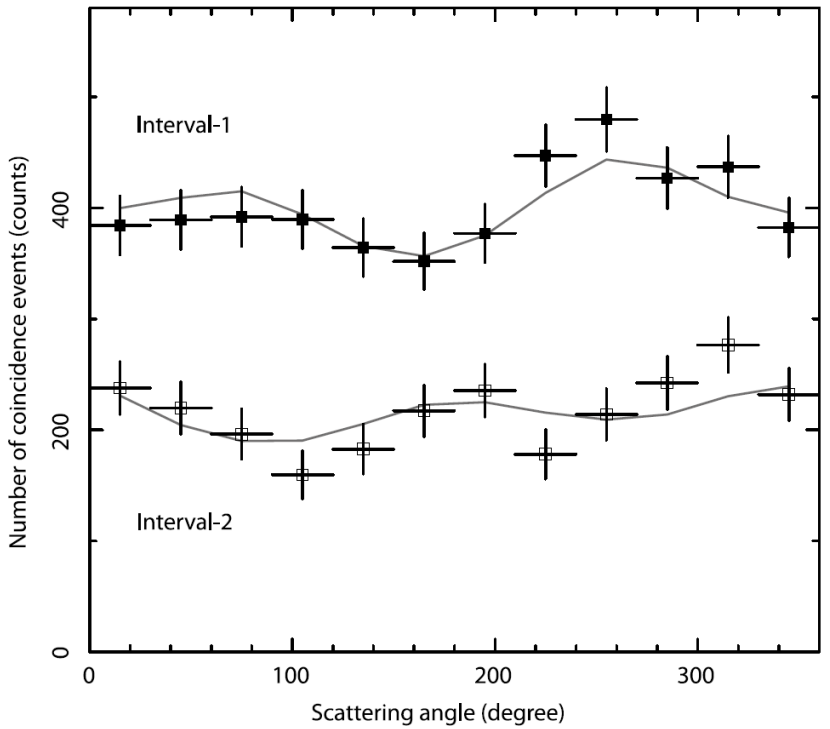
of a source in a field of view of the telescope with diurnal rotation (roughly corresponding to flight days)

N_{signal}=132, N_{BG}=78 @ 6 crosses

Test of fundamental symmetries beyond the Planck scale

IKAROS-GAP (70keV-300keV)





Yonetoku et al., ApJ, 2011

Scale of CPT violation (rotation angle of pol. vector)

$$d\theta \simeq \xi p^2 dt / M_{Pl}$$

Constraint from GRB pol. obs. by GAP

$$|\xi| < O(10^{-15})$$

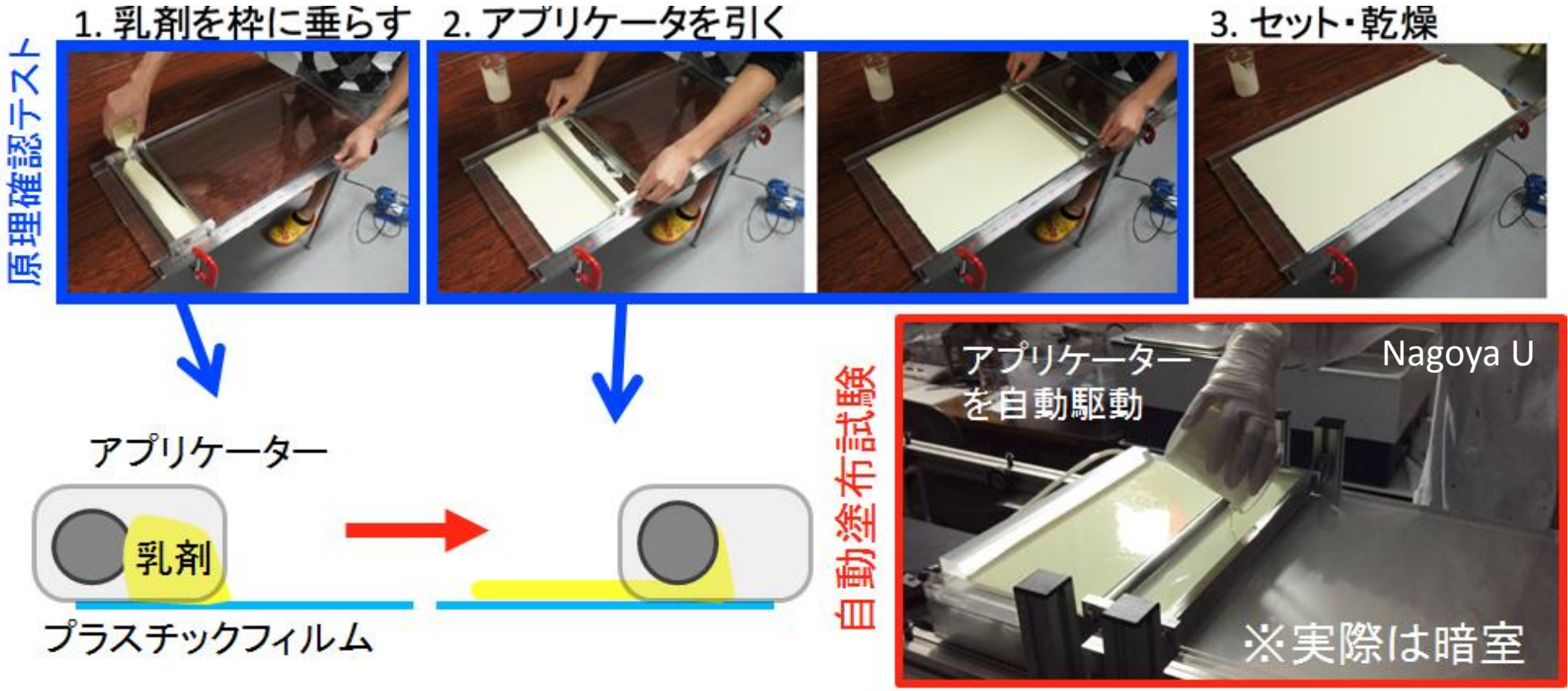
K.Toma et al., PRL 109, 241104 (2012)

By polarization observation for **high energy γ-rays** (e.g. > 100 MeV) from **distant AGNs and GRBs** by emulsion γ-ray telescope, **much strict** (five order of magnitude better) **validation** of CPT symmetry can be performed.

Improvements and preparations for scientific balloon-borne experiments

Emulsion film production

Automatic emulsion gel pouring



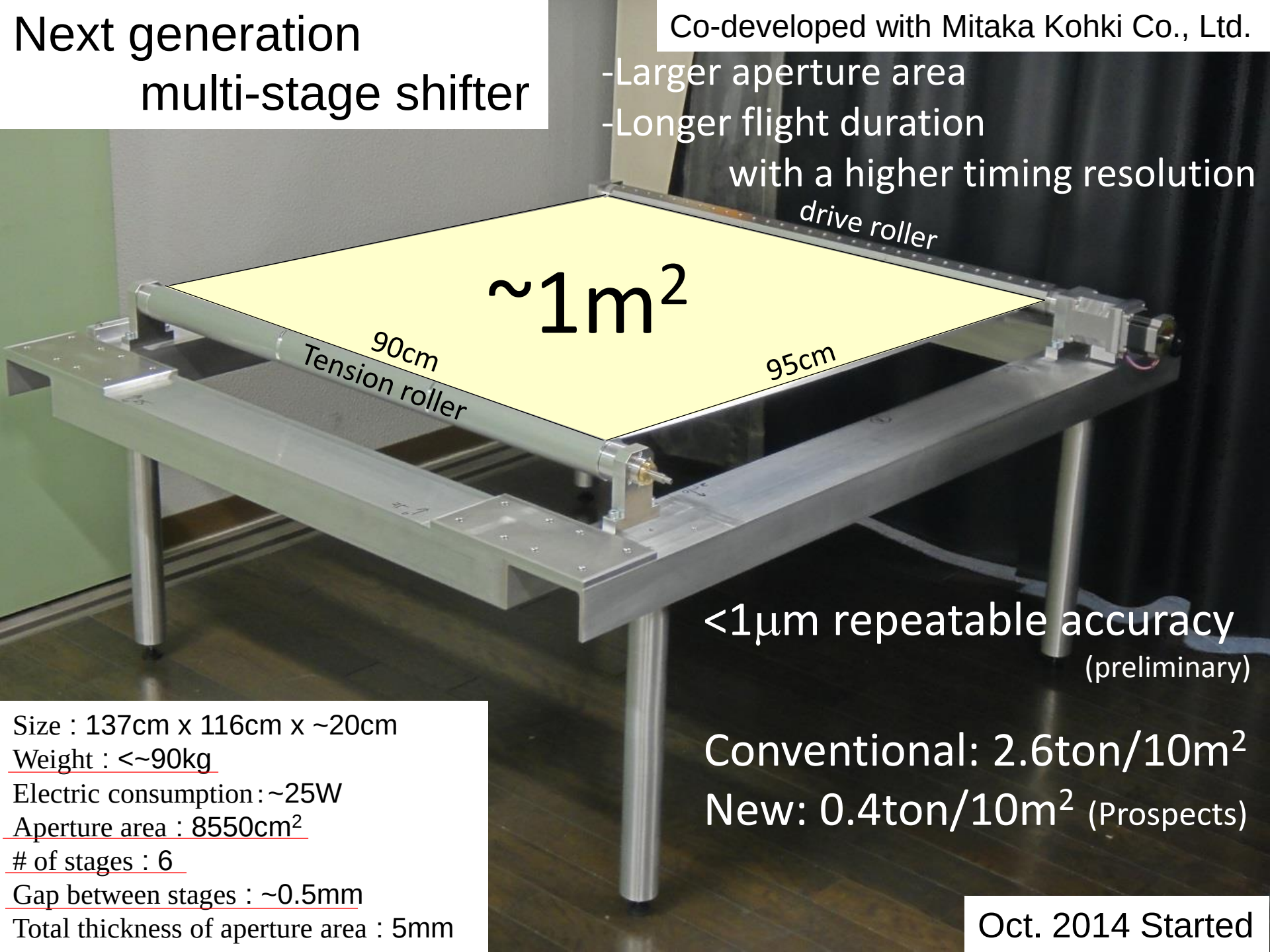
アプリケーターによる自動フィルム成形システム
膜厚相当の隙間を設けたステンレス製のヘッドをフィルム面に沿ってスライドさせ、均質な塗布を実現する

Quite uniform and mass-producible emulsion film production can be performed.

Next generation multi-stage shifter

Co-developed with Mitaka Kohki Co., Ltd.

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



<1μm repeatable accuracy
(preliminary)

Conventional: 2.6ton/10m²
New: 0.4ton/10m² (Prospects)

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

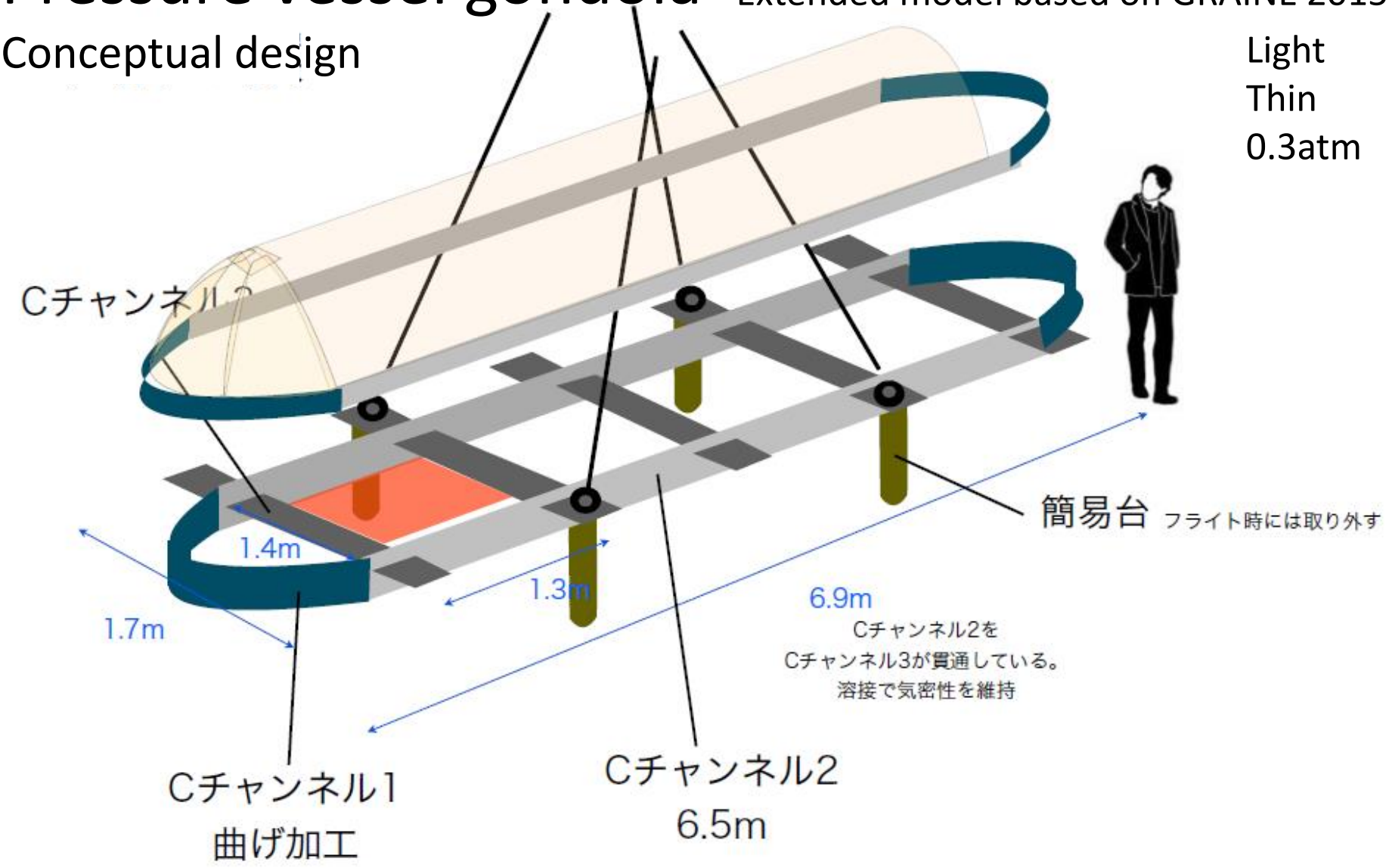
Oct. 2014 Started

Pressure vessel gondola

Extended model based on GRAINE 2015

Conceptual design

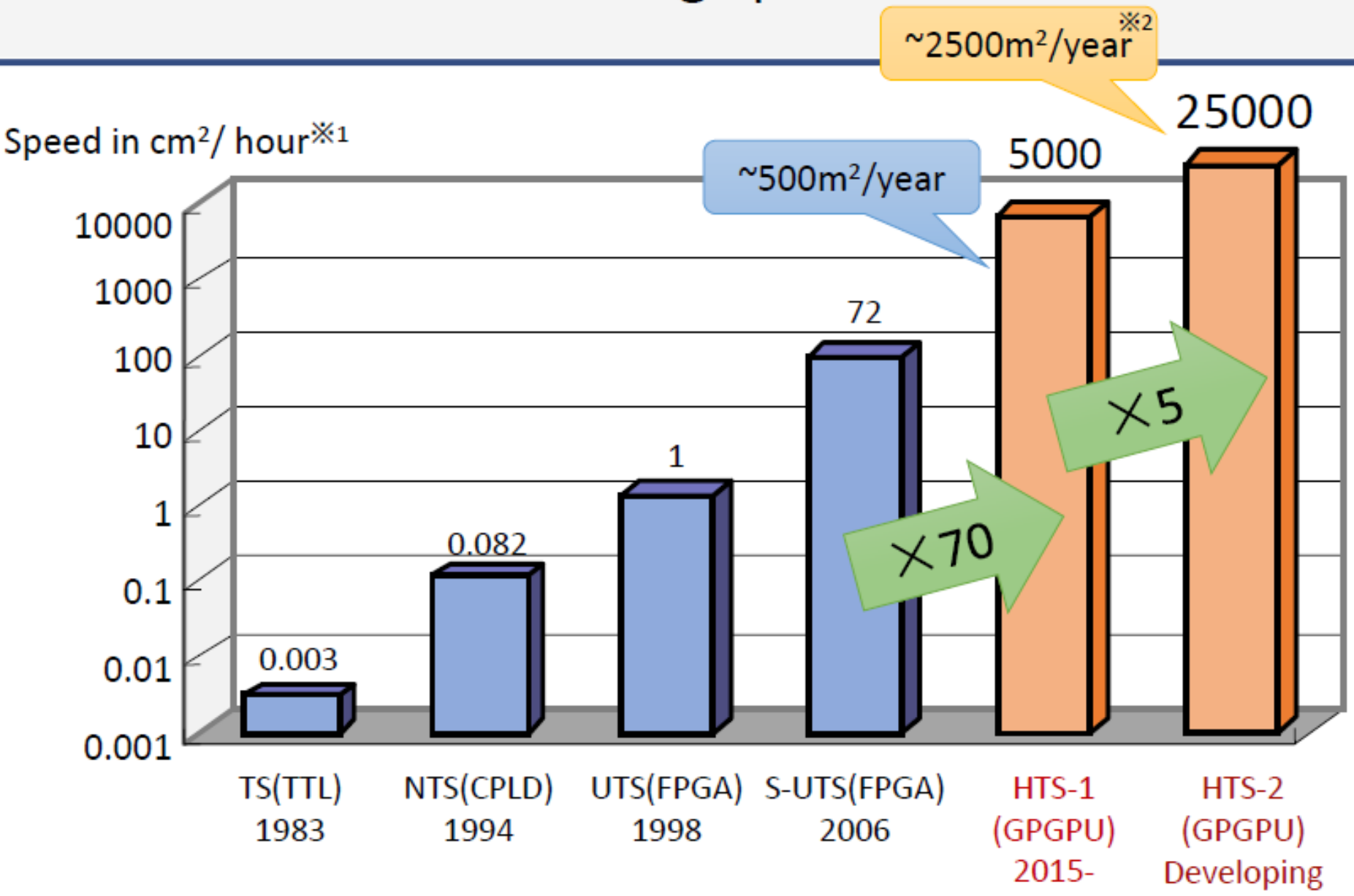
Light
Thin
0.3atm



5m^2 (4units) aperture area
w/ a single pressure vessel gondola (~250kg weight)

※1 Area of emulsion layer
※2 Area of the films with 24 hour shift

Evolution of the Scanning Speed



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