

Balloon-borne Emulsion Gamma-ray Telescope

GRAINE project

Gamma-Ray Astro-Imager with Nuclear Emulsion

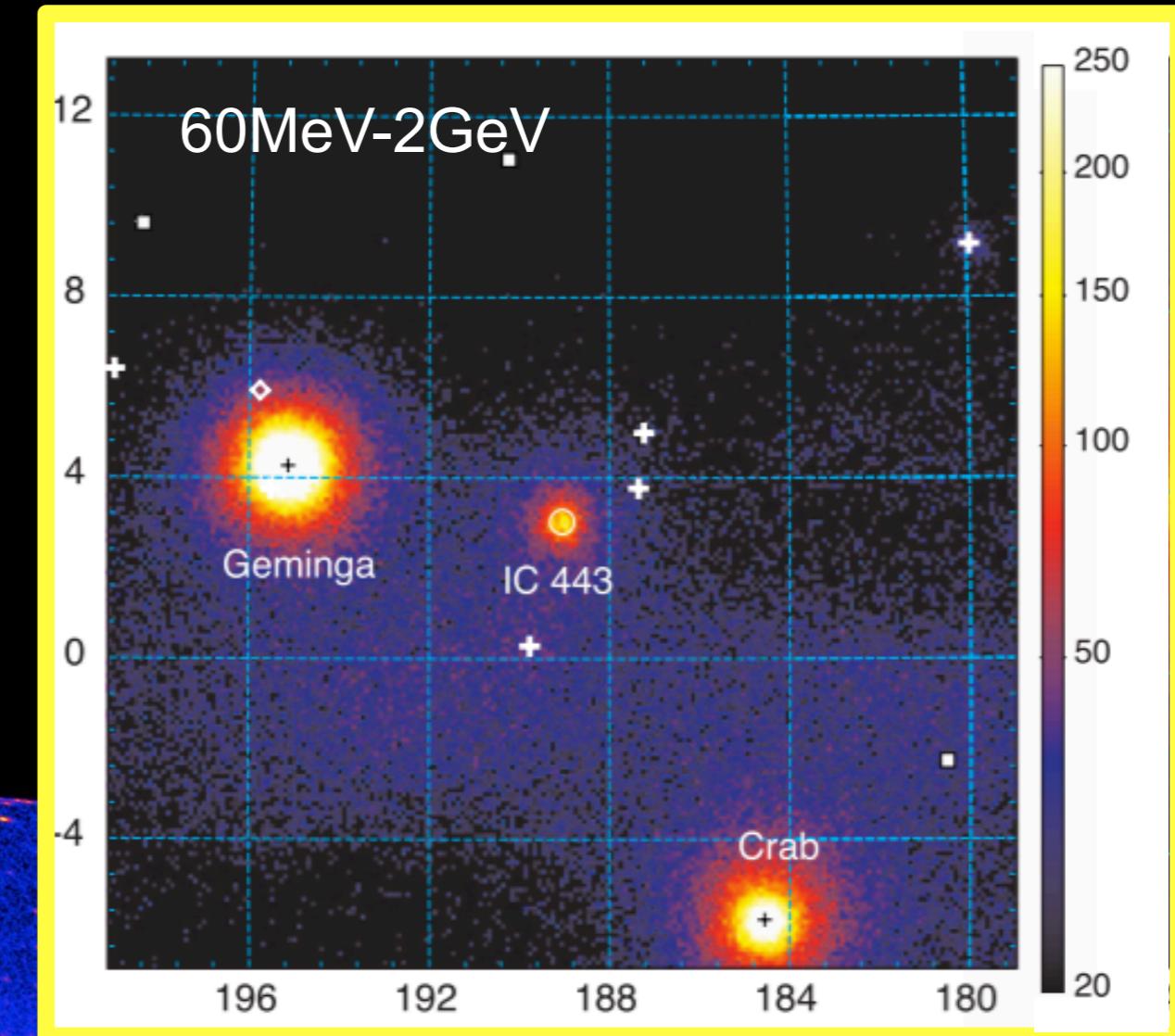
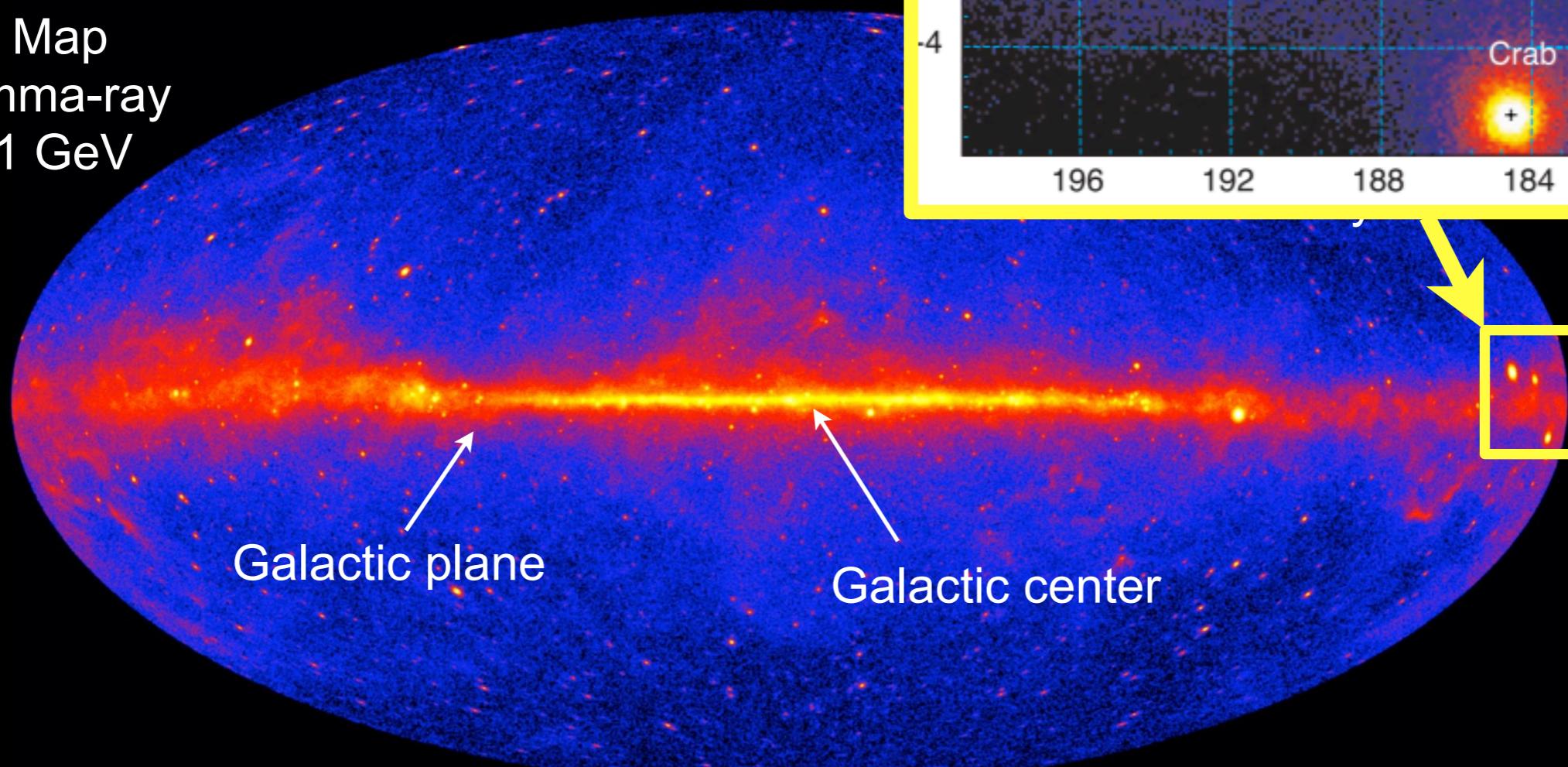
Measurements of Hadronic
Interactions using Nuclear Emulsion

Hiroki ROKUJO (Nagoya Univ.)
for GRAINE collaboration

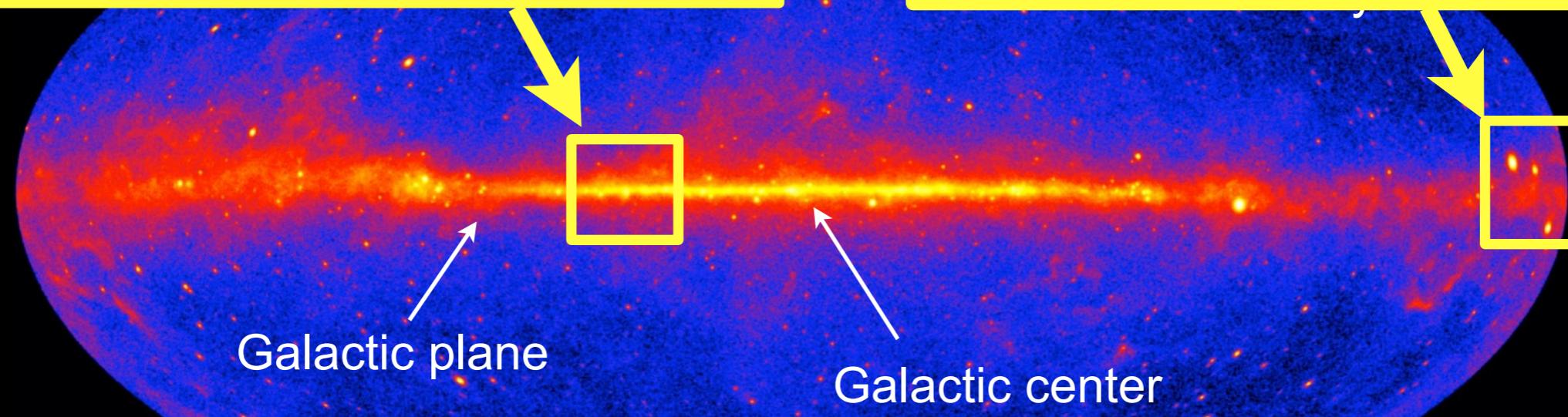
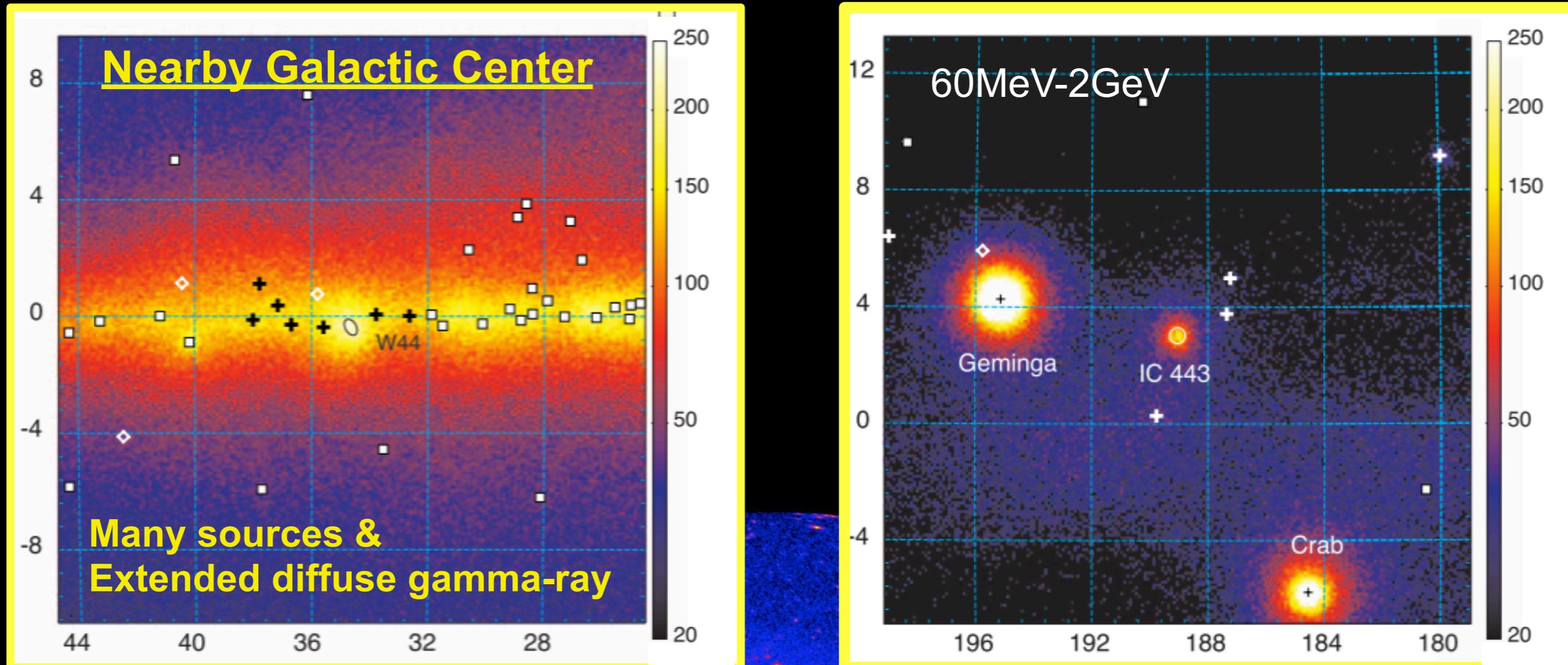
Gamma-ray Observation (GeV/sub-GeV region)

	Telescope	Detected sources
1990-2001	EGRET spark chamber	271
2008-	Fermi-LAT SSD tracker	>3000

All-Sky Map
via gamma-ray
above 1 GeV



Gamma-ray Observation (GeV/sub-GeV region)



High-statistic → **NEXT: Precise Observation**

Nuclear Emulsion

Microscopic view
10micron

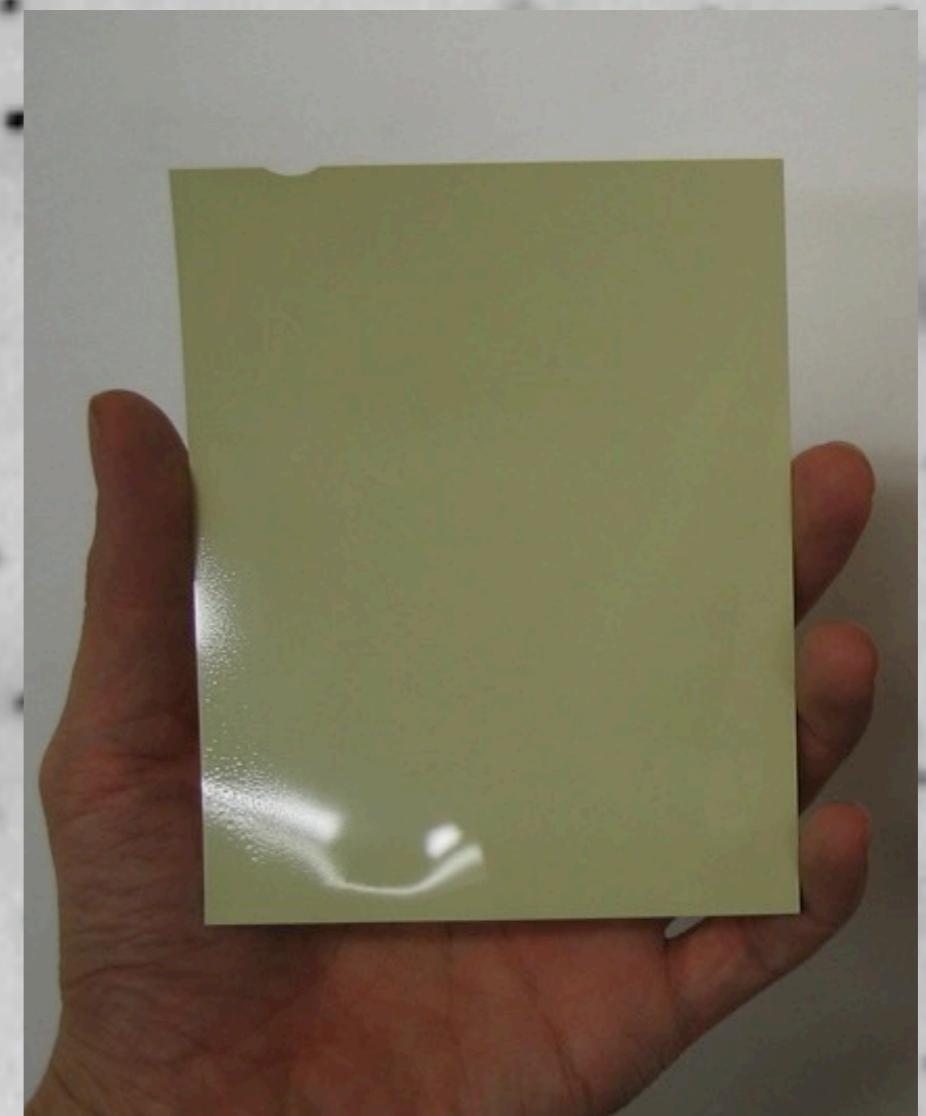
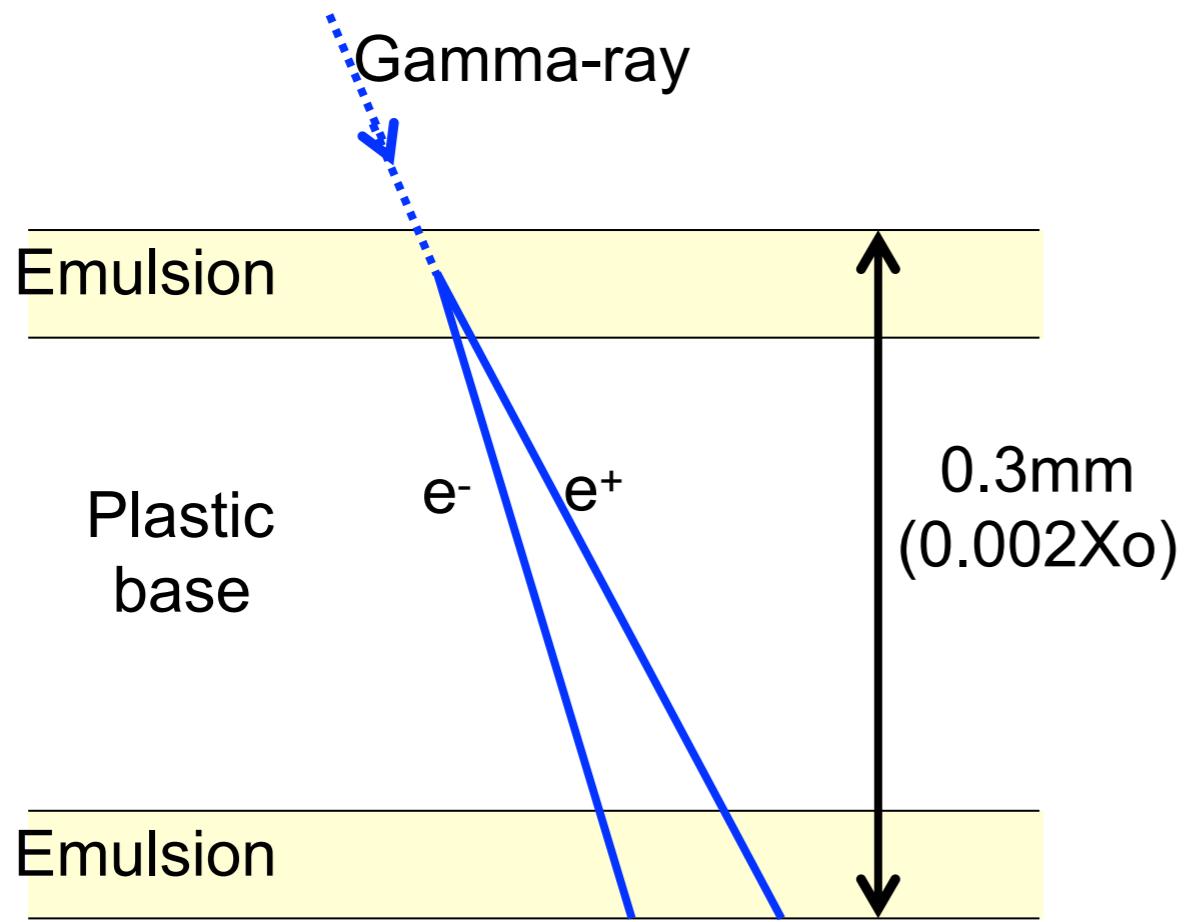
Gamma-ray



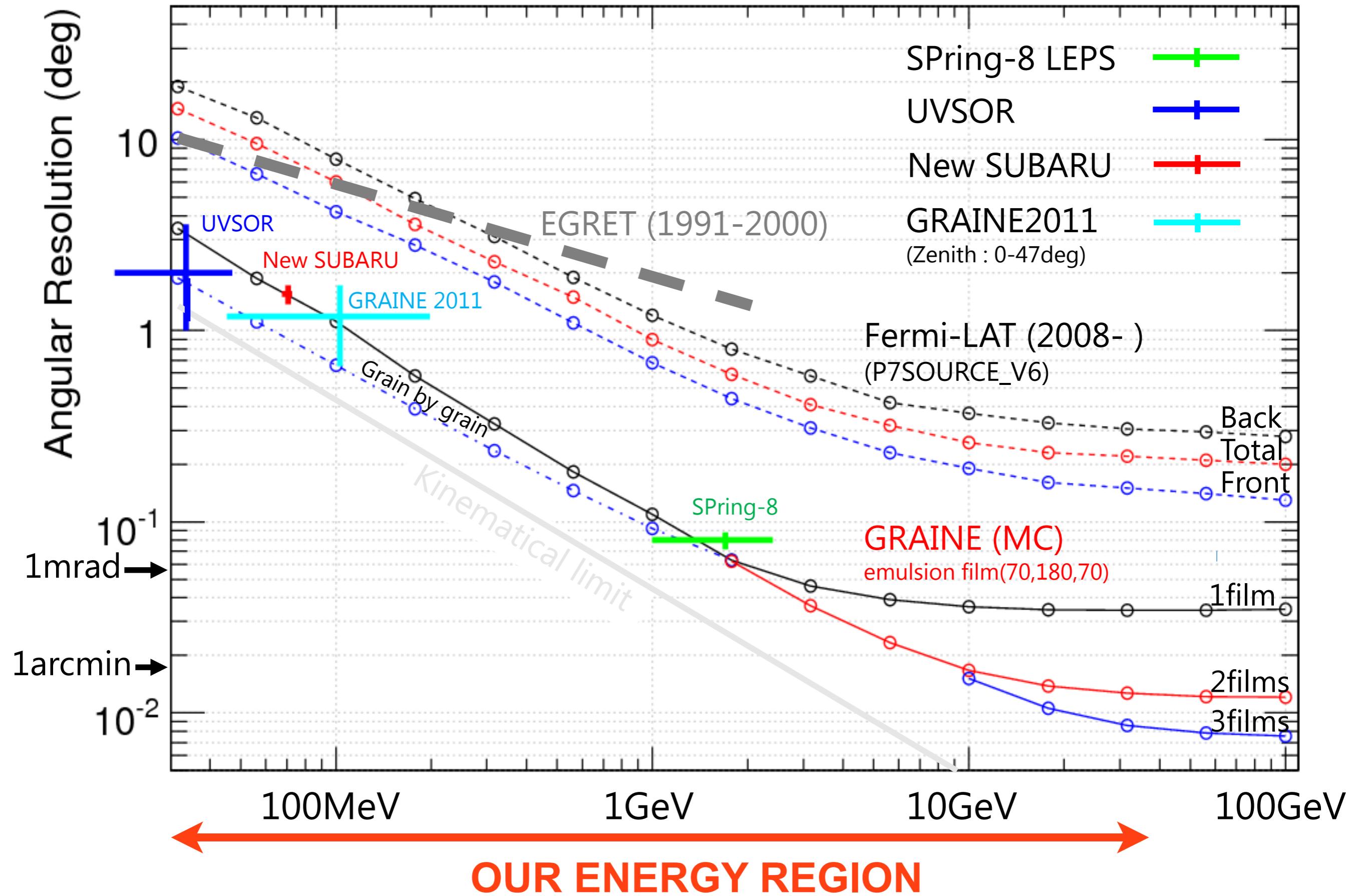
$e^{+/-}$

$e^{-/+}$

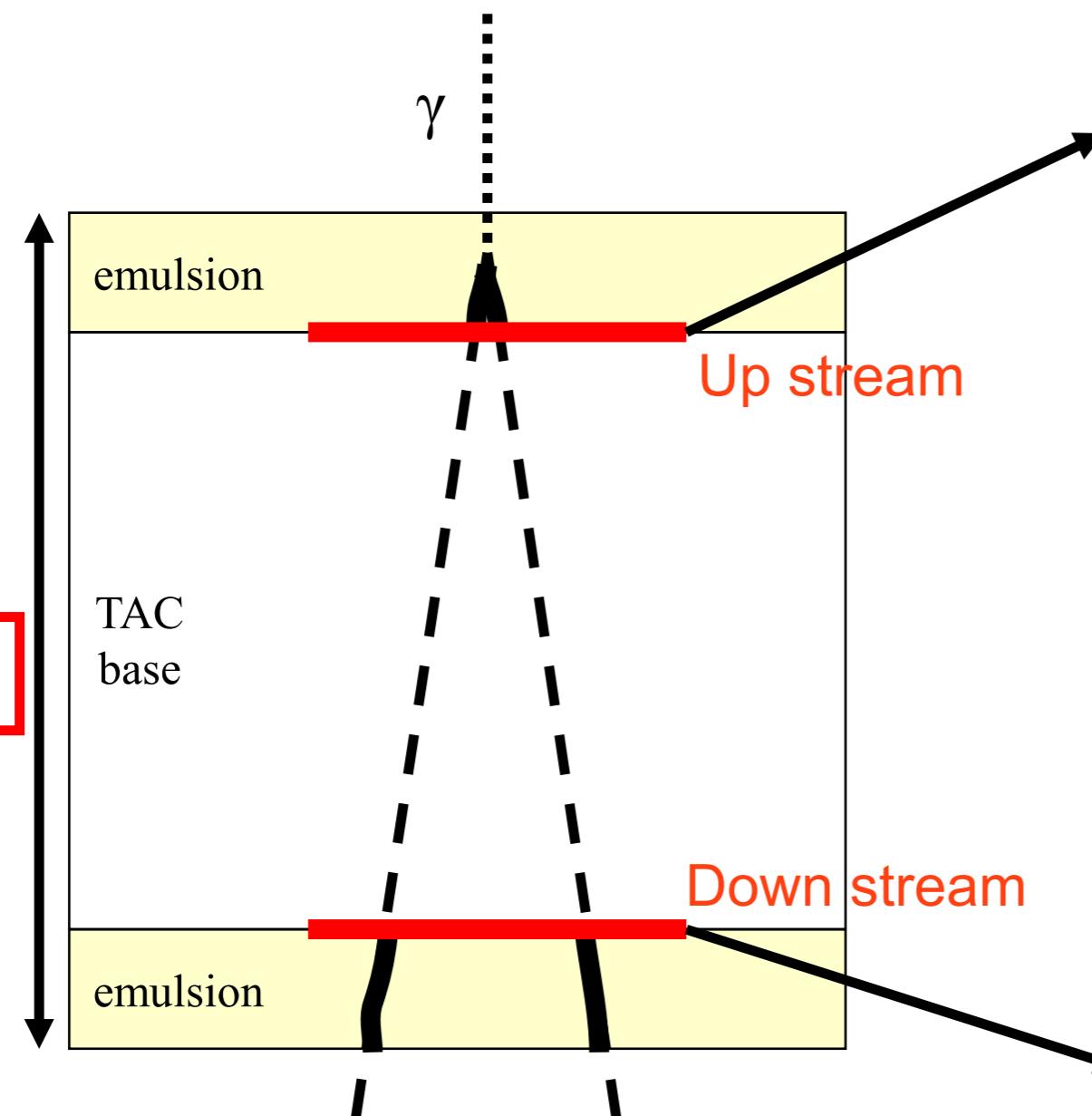
Cross sectional view of a plate



Angular Resolution for Gamma Ray



Polarimetry



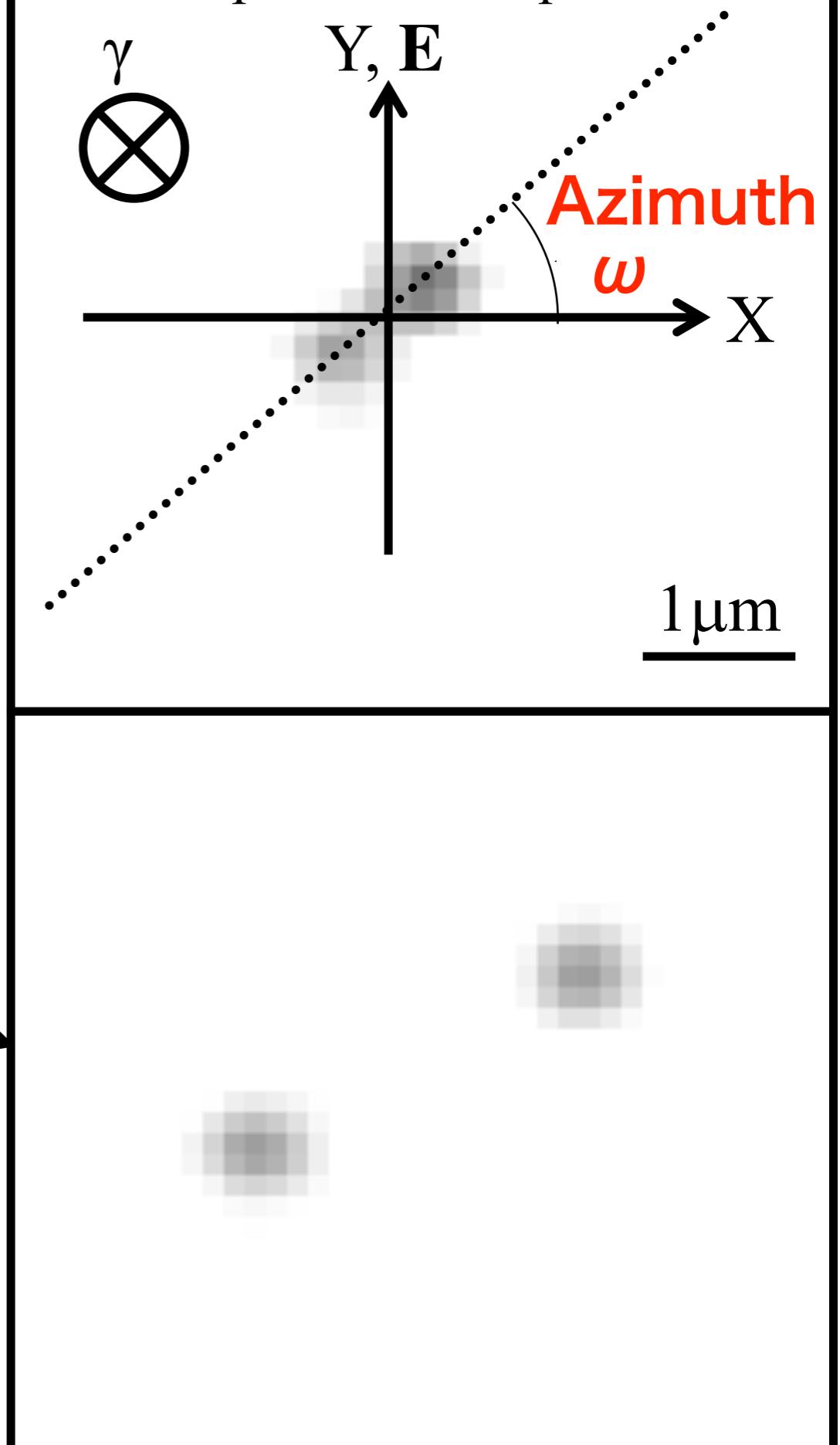
$$\sigma(\omega) = \sigma_0 \{ 1 + P \cdot A \cdot \cos 2(\omega - \pi/2) \}$$

P : degree of polarization

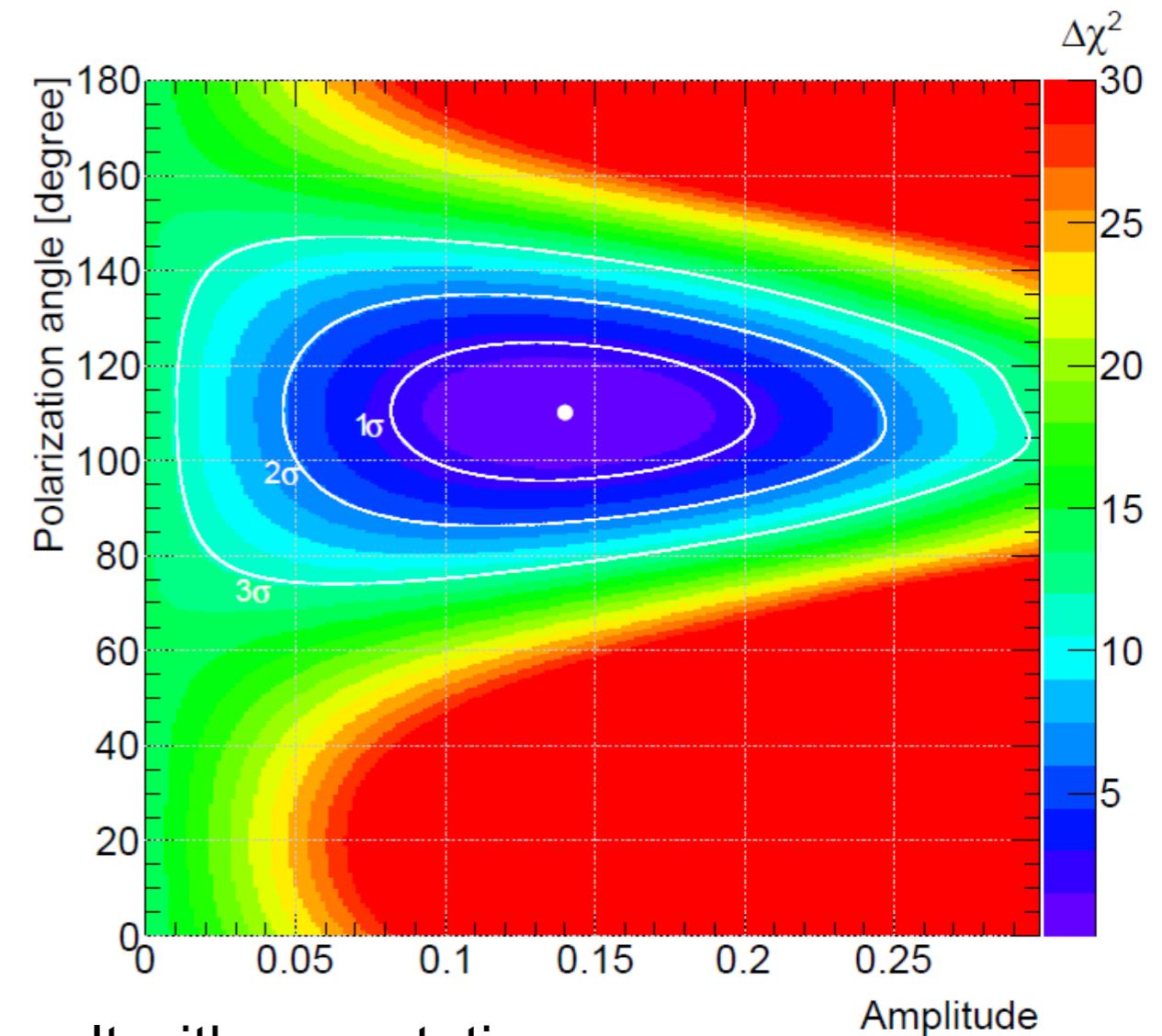
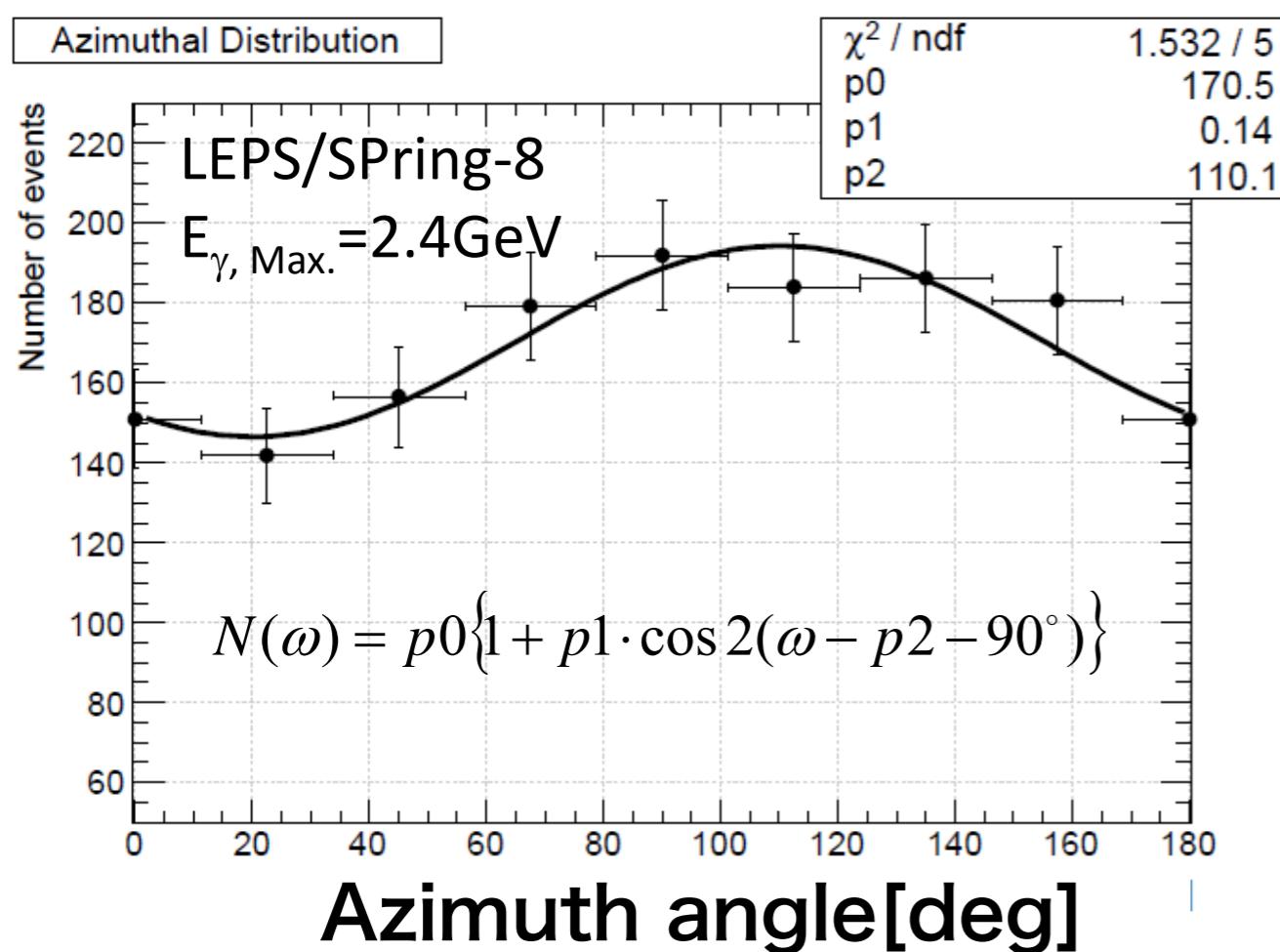
ω : Azimuth

A : Amplitude (0.1 – 0.3)_{depending on the kinematics}

Microscopic view of a pair creation



Polarization measurement with accel. γ -ray beam



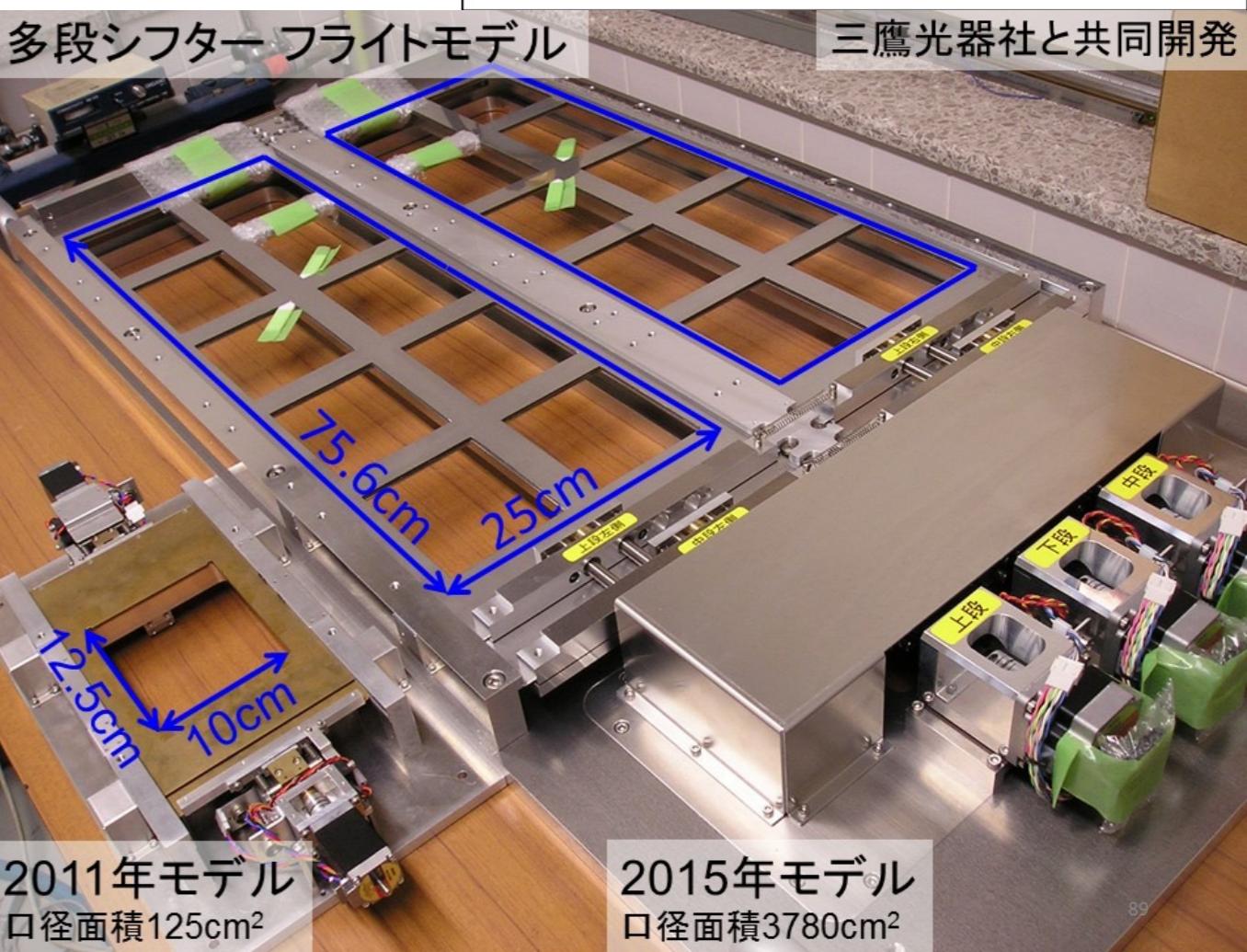
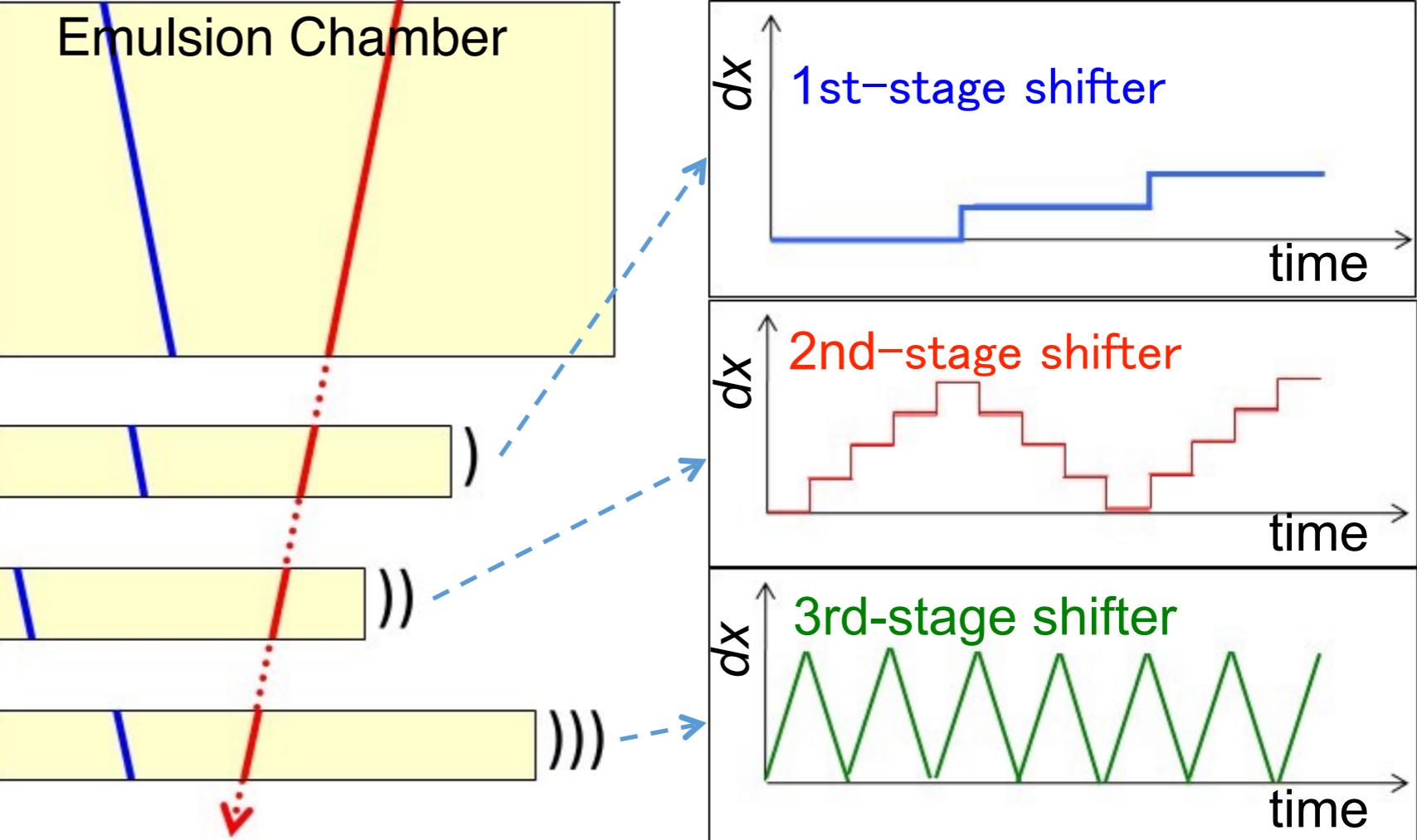
Significant & consistent result with expectation.

$\langle P \rangle = 66\%$, modulation factor = 0.21 ± 0.09

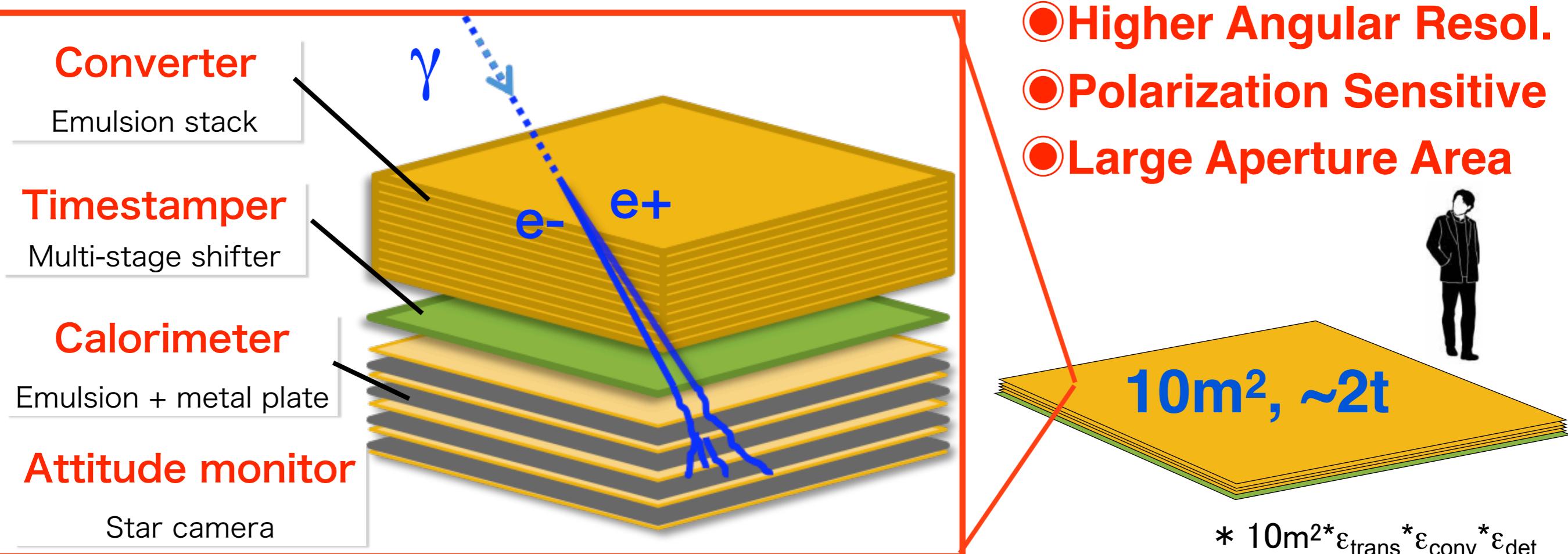
New technique for GRAINE Multi-stage Shifter (Time stamper)

Consisting of emulsion film.
Low momentum threshold~10MeV/c
High reliability & efficiency
Enlargeable
Simple, compact, light weight, high-vol. free,
low consumption, dead-time free

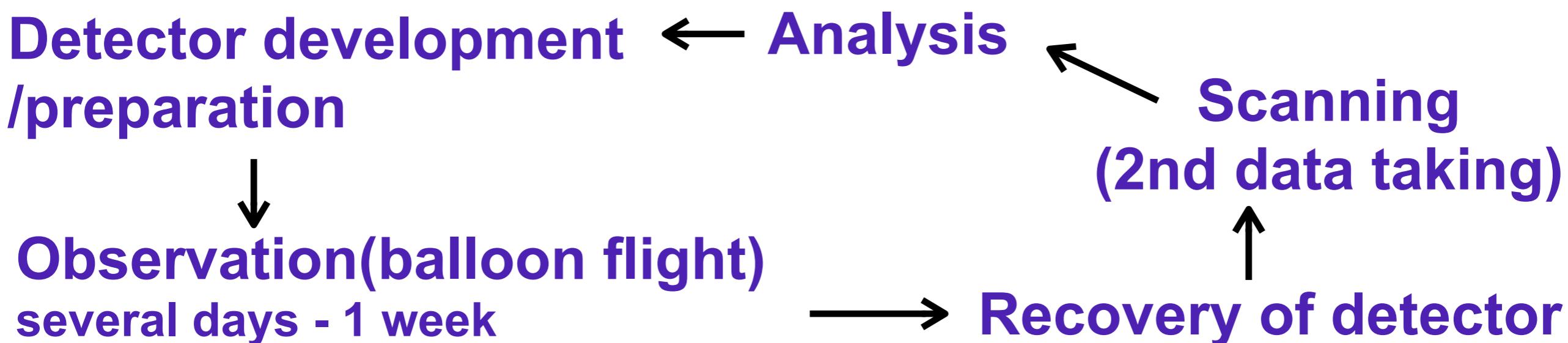
S. Takahashi et al.
NIM A620(2010) pp.192-195



Emulsion gamma-ray Telescope



Flow of experiment



GRAINE project

2004– Development on ground

S.Takahashi et al. NIMA 620, 192 (2010)
K.Ozaki et al. NIMA 833, 165 (2016)

2011(Jun.) 1st Balloon-Exp.

- Checking Feasibility

H.Rokujo et al. NIMA 701, 127 (2013).

S.Takahashi et al. PTEP 2015 043H01

2015(May.) 2nd Balloon-Exp.

- establishment of experimental flow
- demonstration of detector

K.Ozaki et al., JINST 10, P12018 (2015)

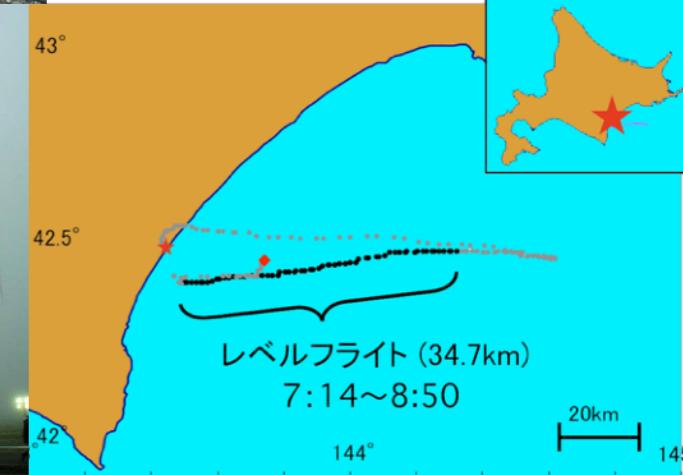
S.Takahashi et al. PTEP 2016, 073F01

+ in prep. (technical paper)



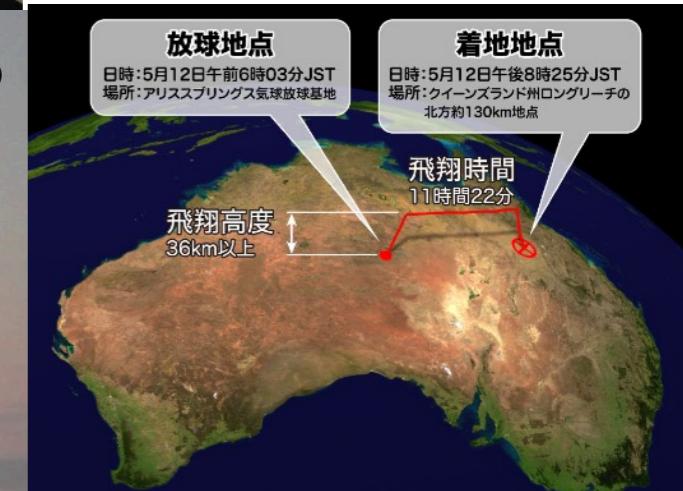
GRAINE 2011

Aperture : 0.013m²
1.6 h@35km



GRAINE 2015

Aperture : 0.38m²
11.5 h@36-37km



Prepare

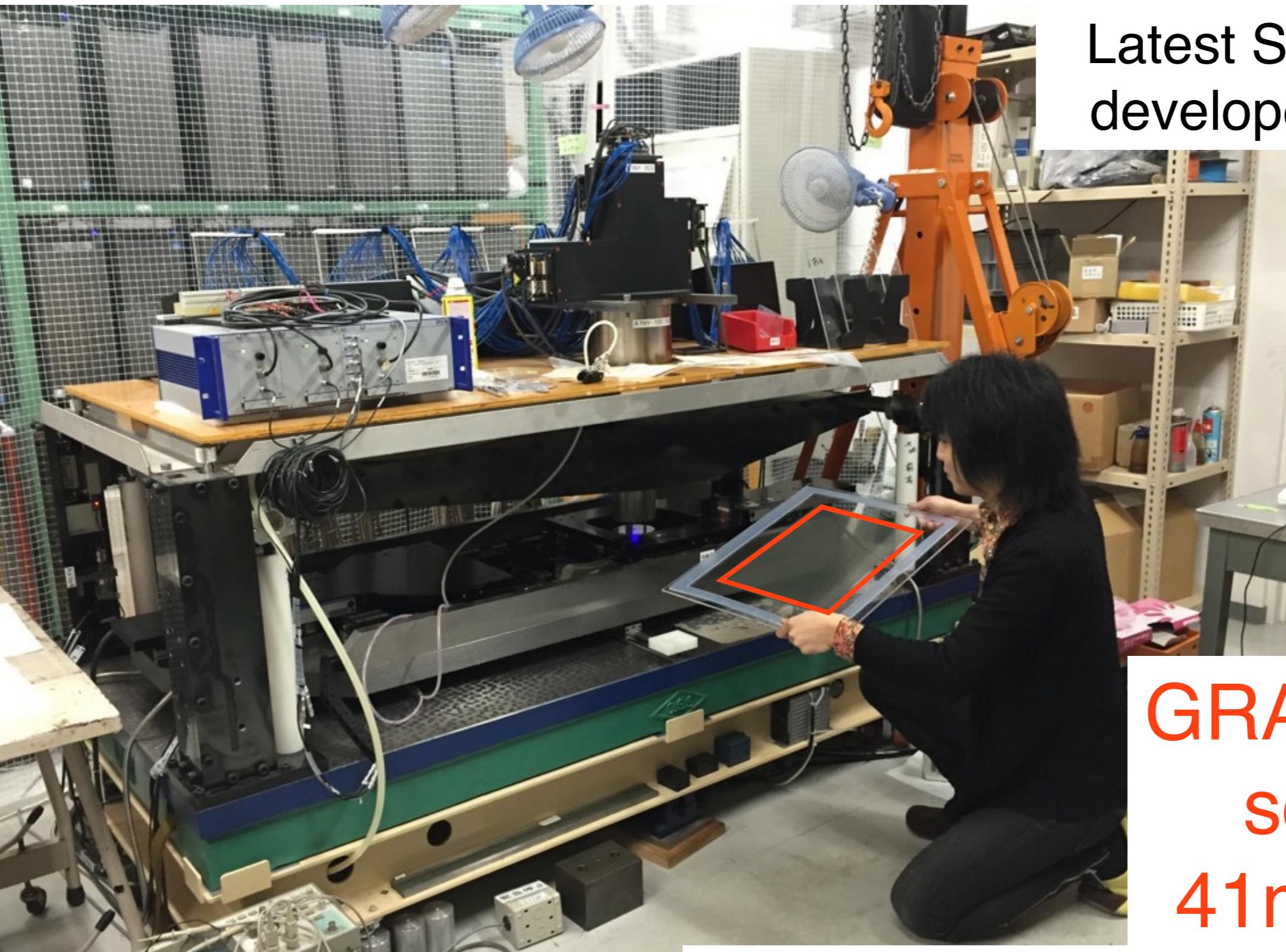
2018(Apr.) 3rd Balloon-Exp.

- Celestial source detection

2021- Start scientific

observation w/10m²

2nd-Data taking by Scanning System

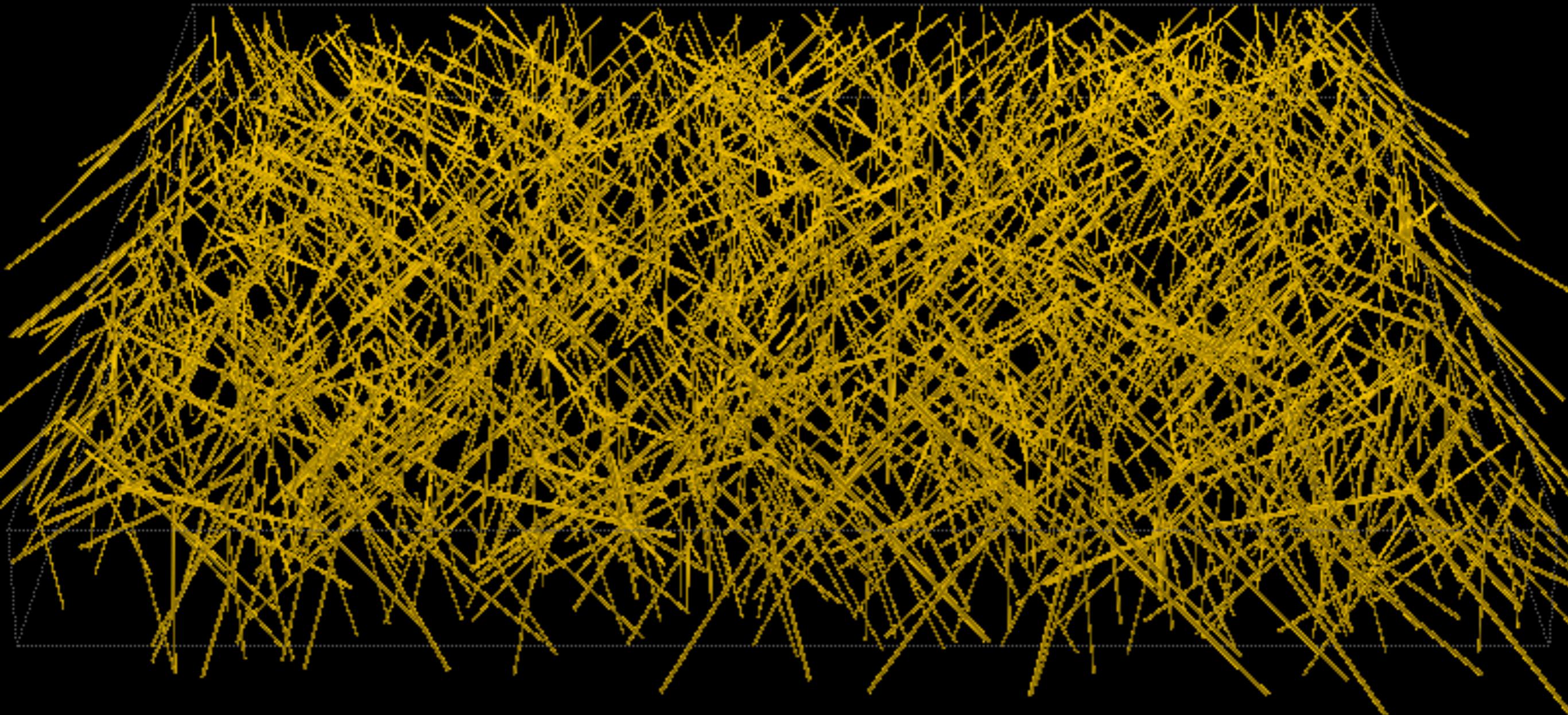


Latest System “HTS”
developed in Nagoya

GRAINE 2015
scanned
 41m^2 in total

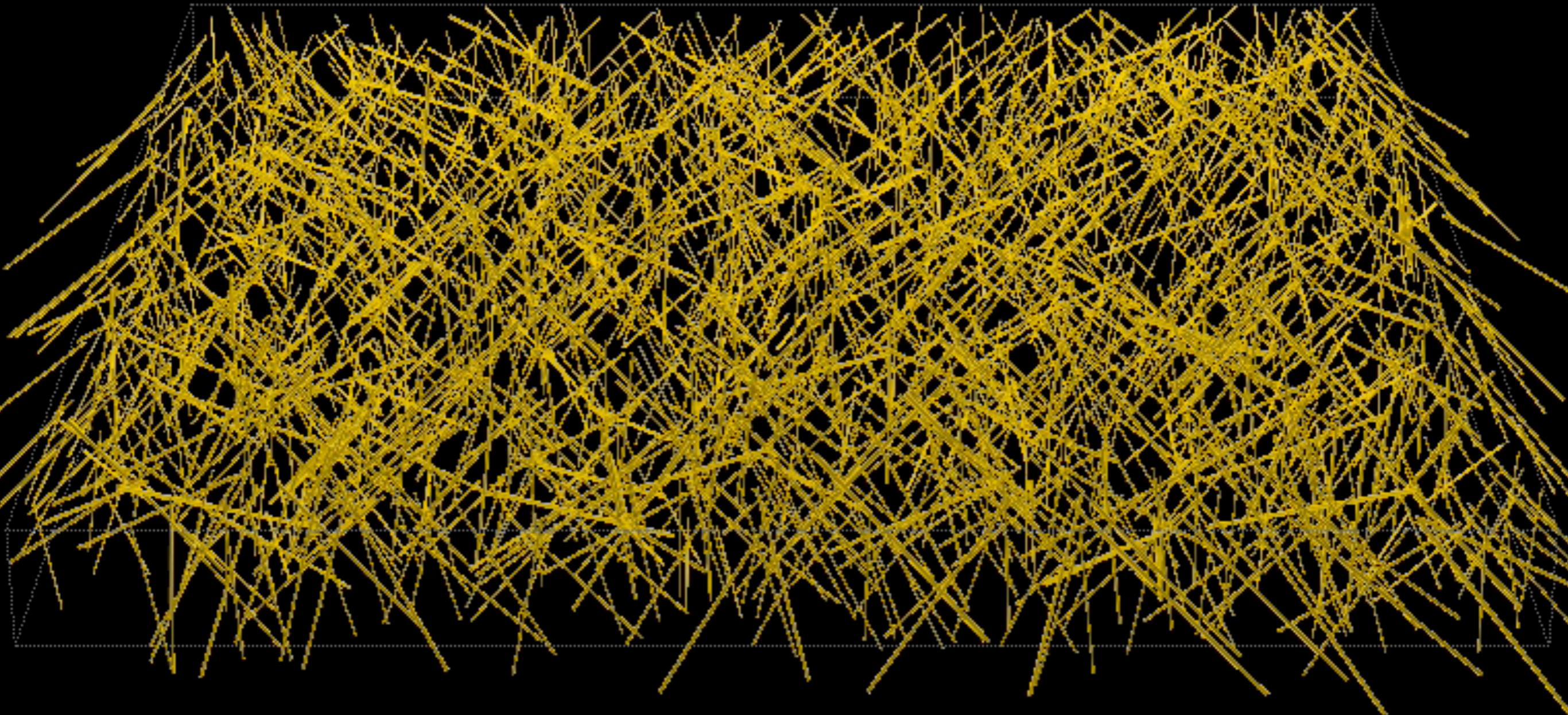
current speed $4000\text{ cm}^2/\text{h}$
→ $25000\text{cm}^2/\text{h}$ by next generation system

Flight data



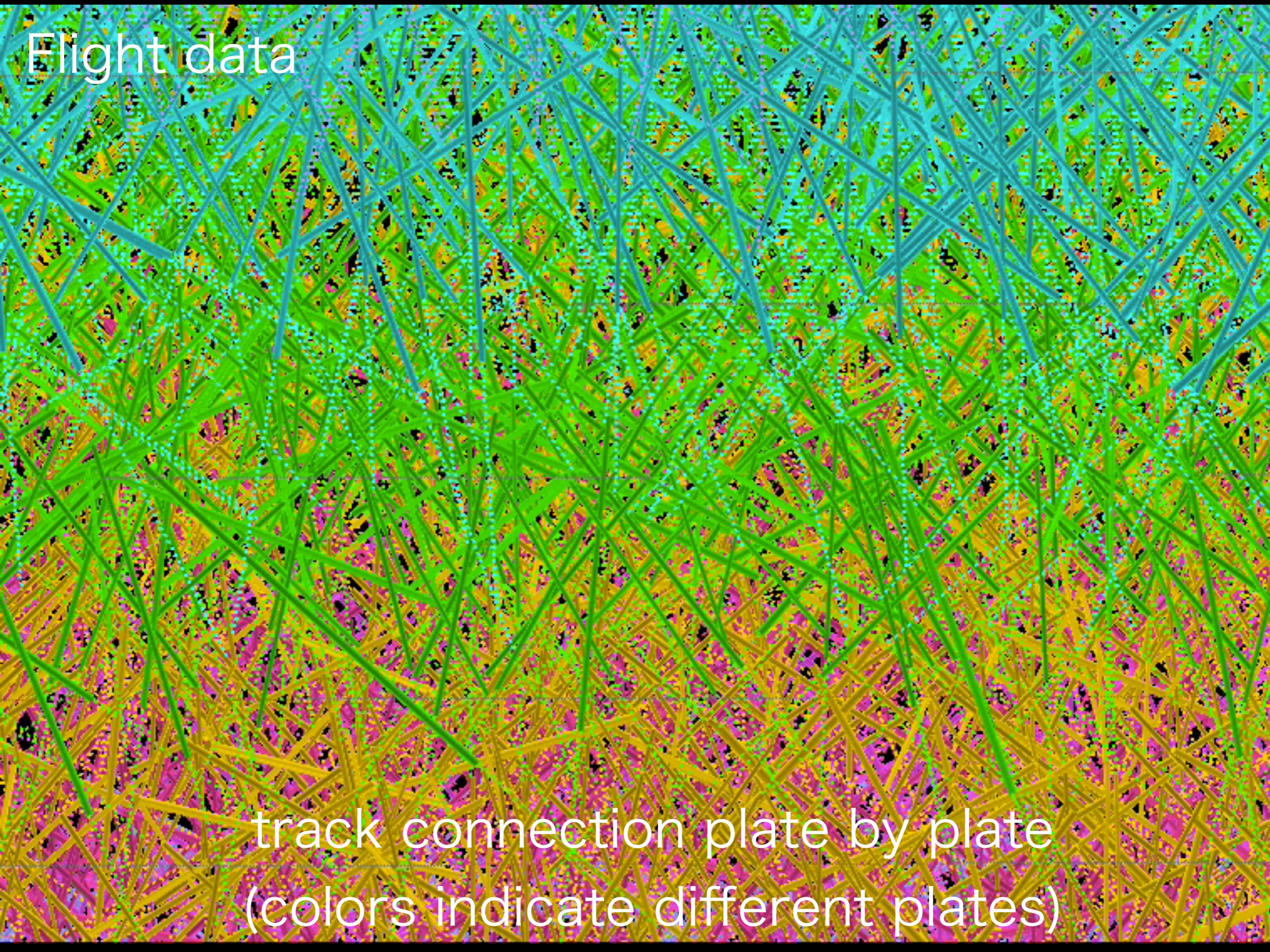
2 mm x 2 mm of single film

Flight data



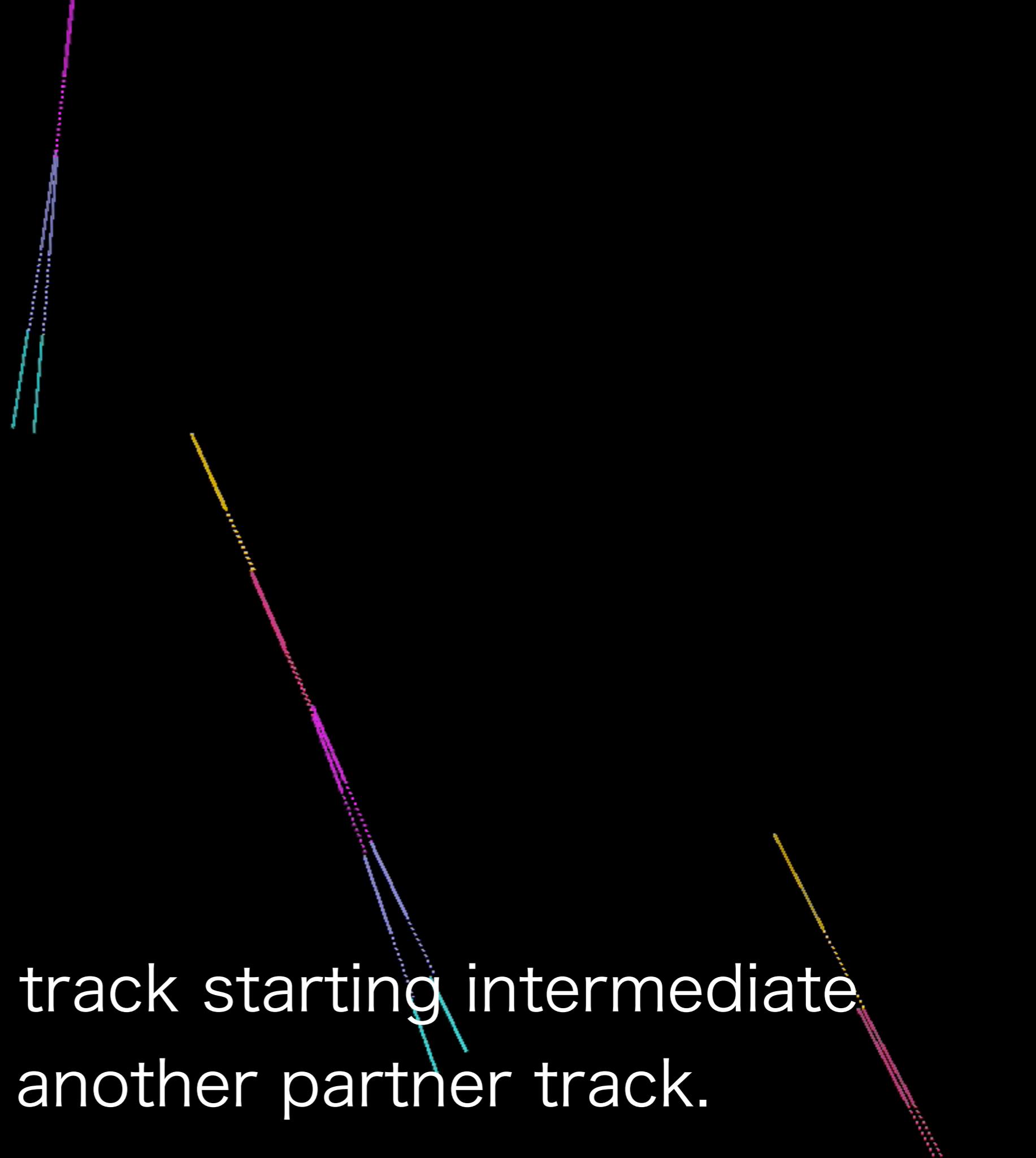
emulsion film records all charged particles.
density ~400 tracks/mm²

Flight data



track connection plate by plate
(colors indicate different plates)

Flight data

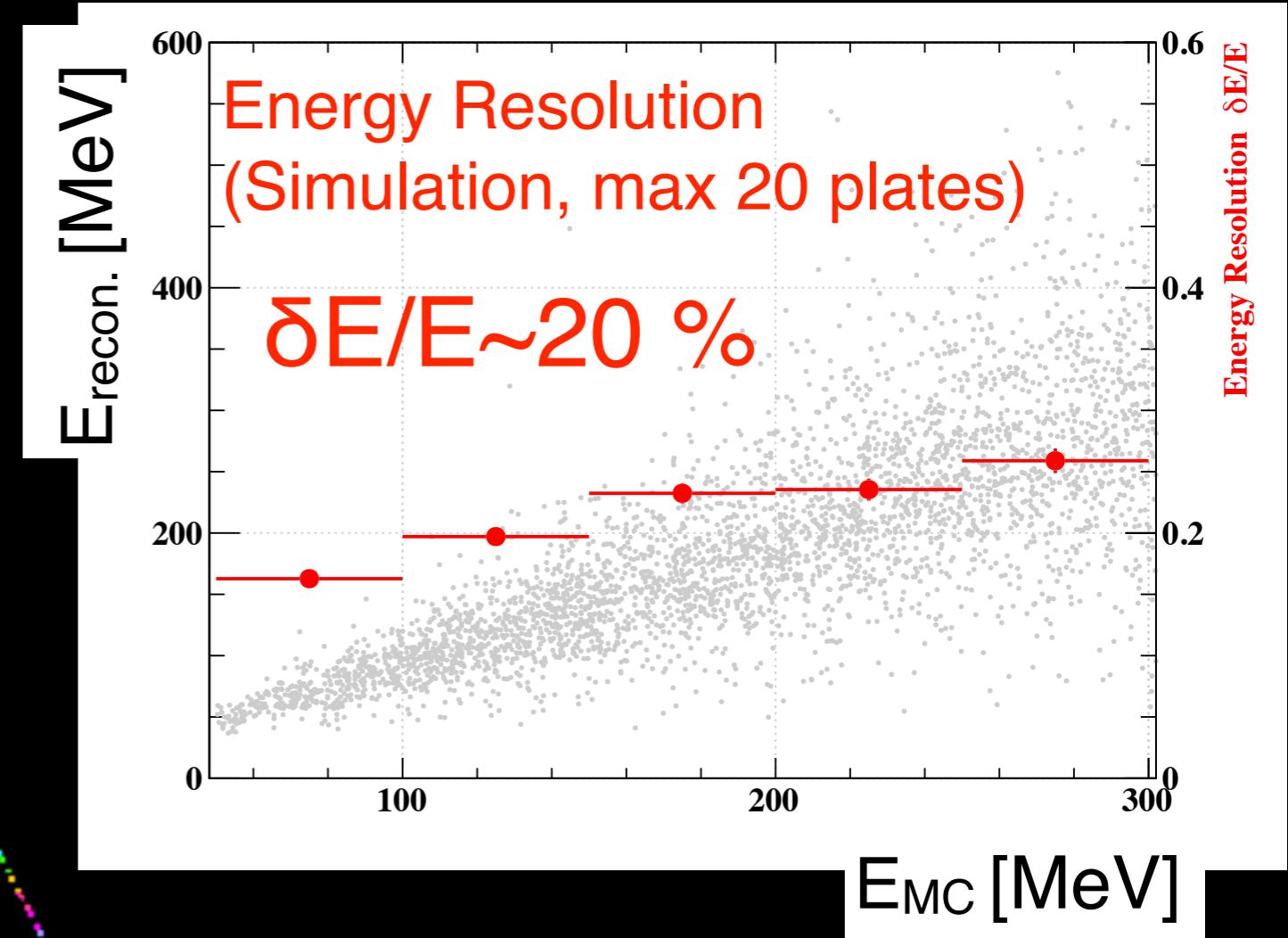


selecting track starting intermediate
with another partner track.

Flight data

Track 1
Momentum:
46 MeV/c (Recon.)

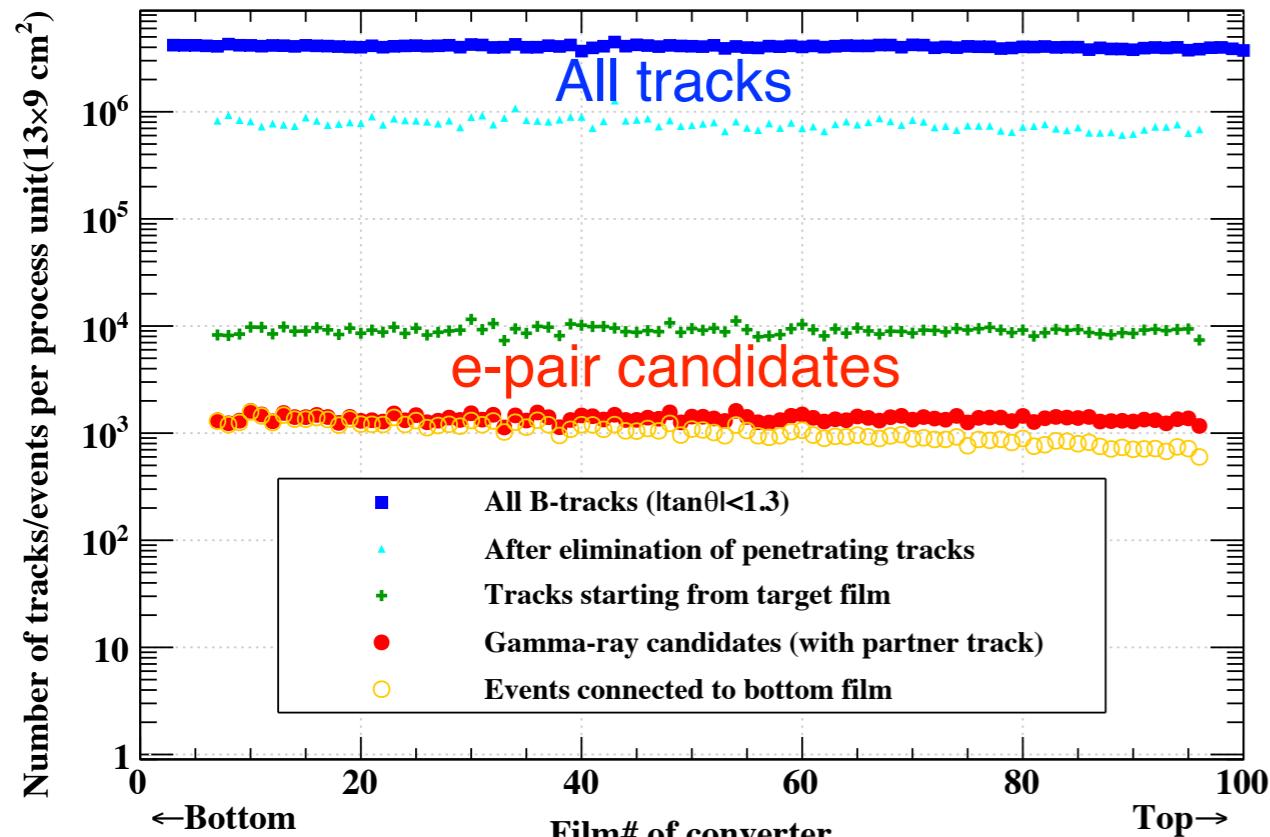
Track 2
Momentum:
129 MeV/c (Recon.)



Gamma-ray Energy:
176 MeV (Recon.)

Recent Progress of GRAINE

Automatic Selection for the whole chamber

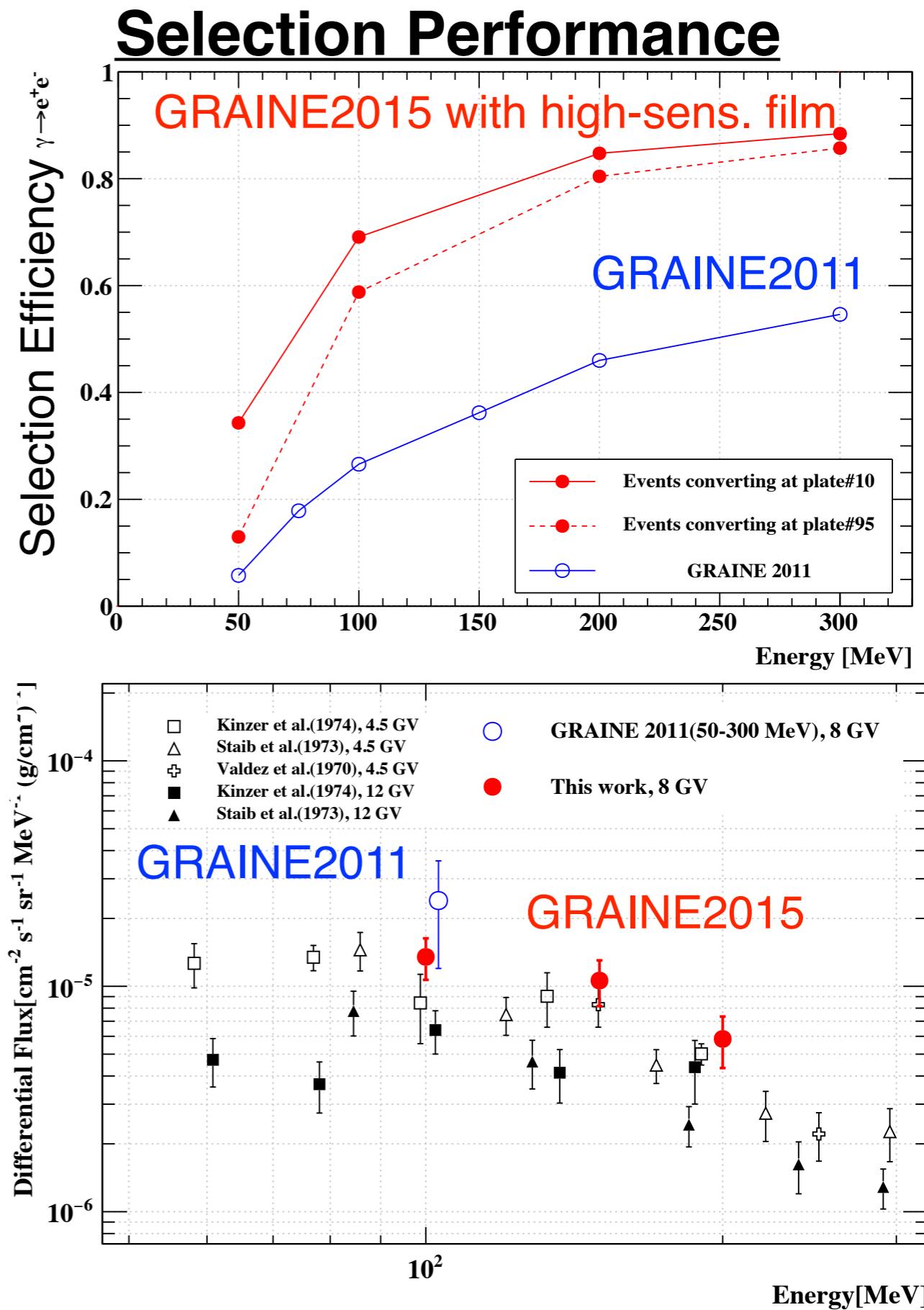


Detected event number

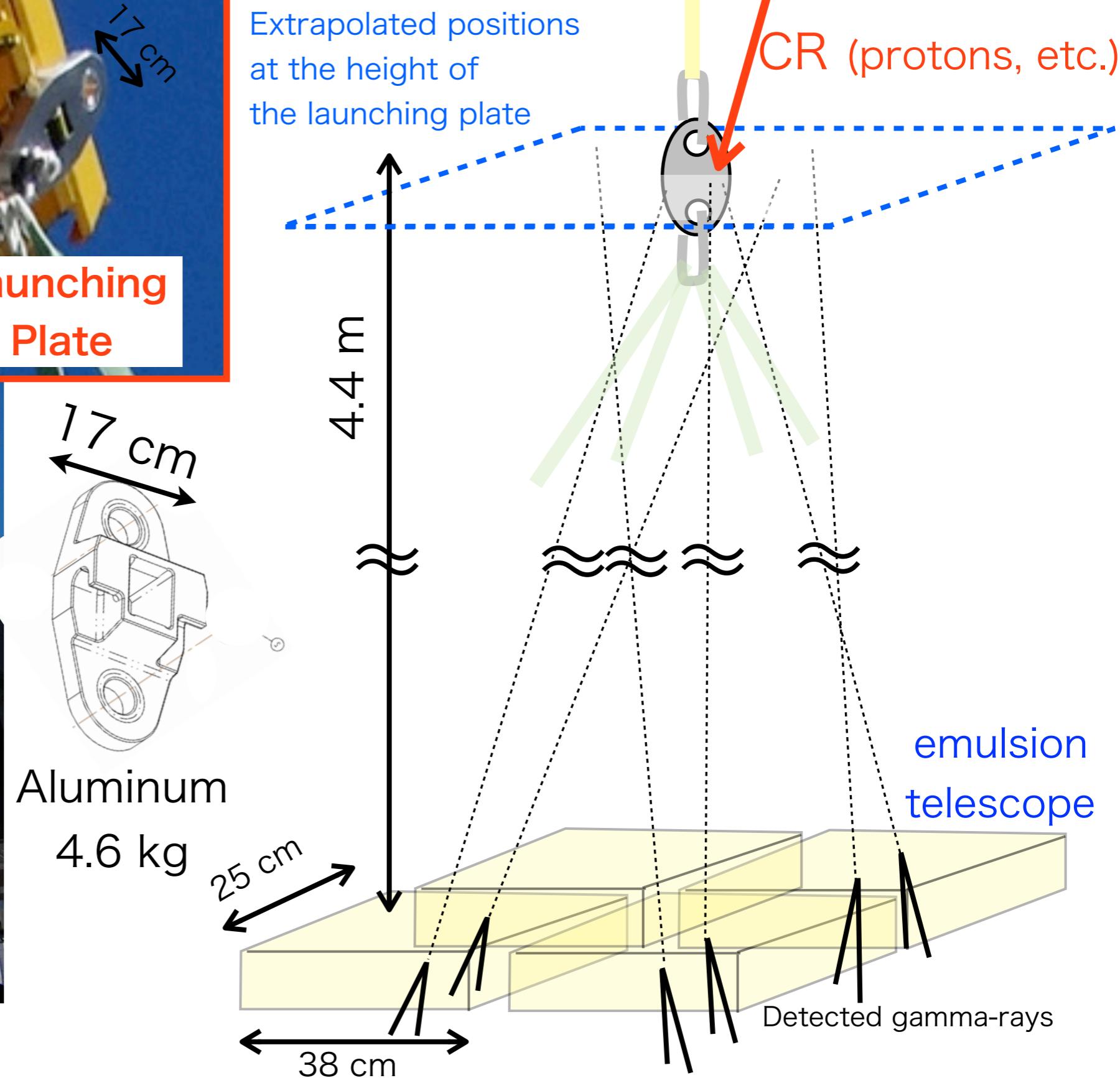
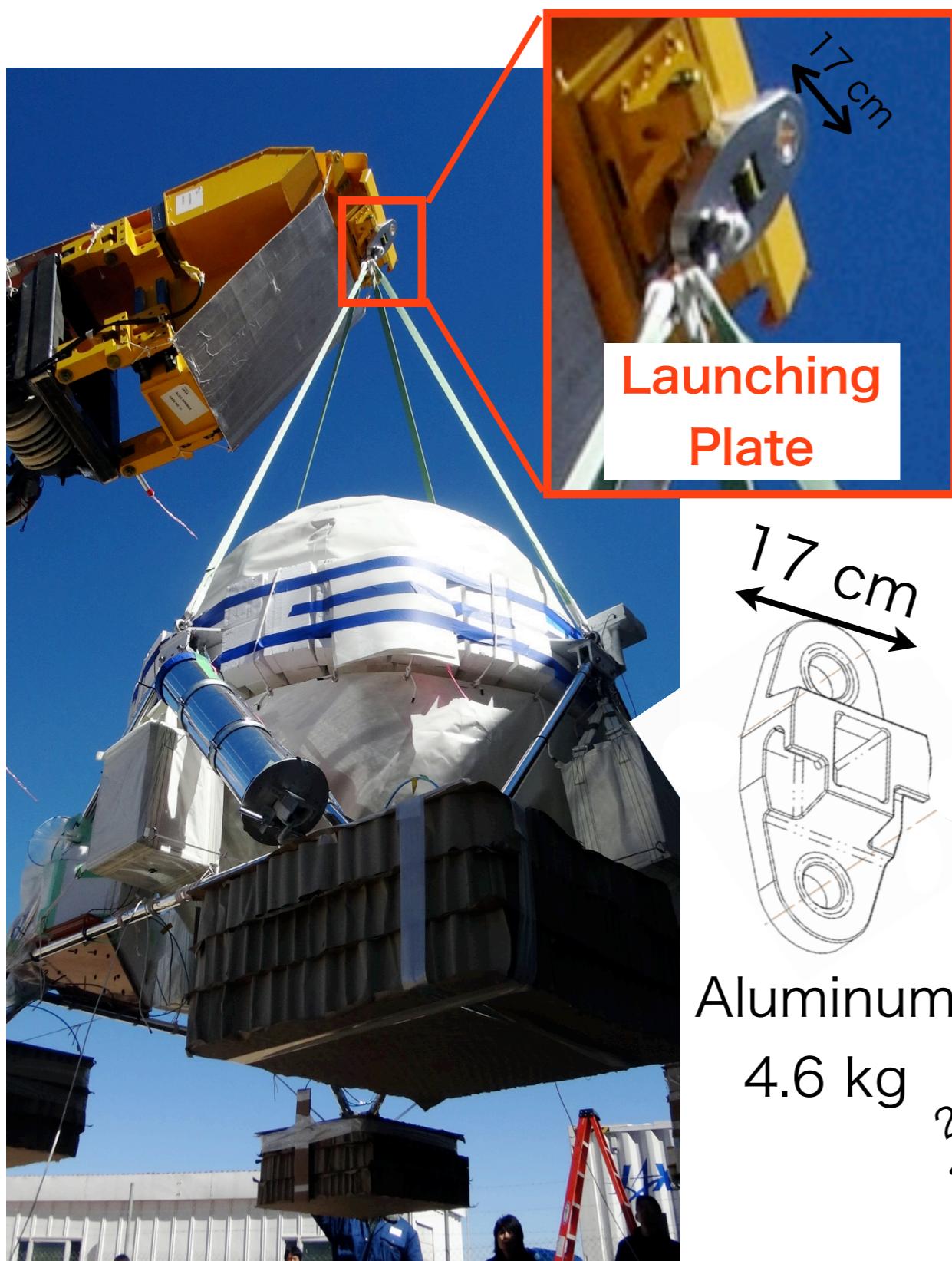
GRAINE2011
157 events
reliability 98%
partial analysis

\rightarrow **GRAINE2015**
 $\sim 10^6$ events
reliability 95%
almost full analysis (~75%)

BG measurement
(atmospheric gamma rays)

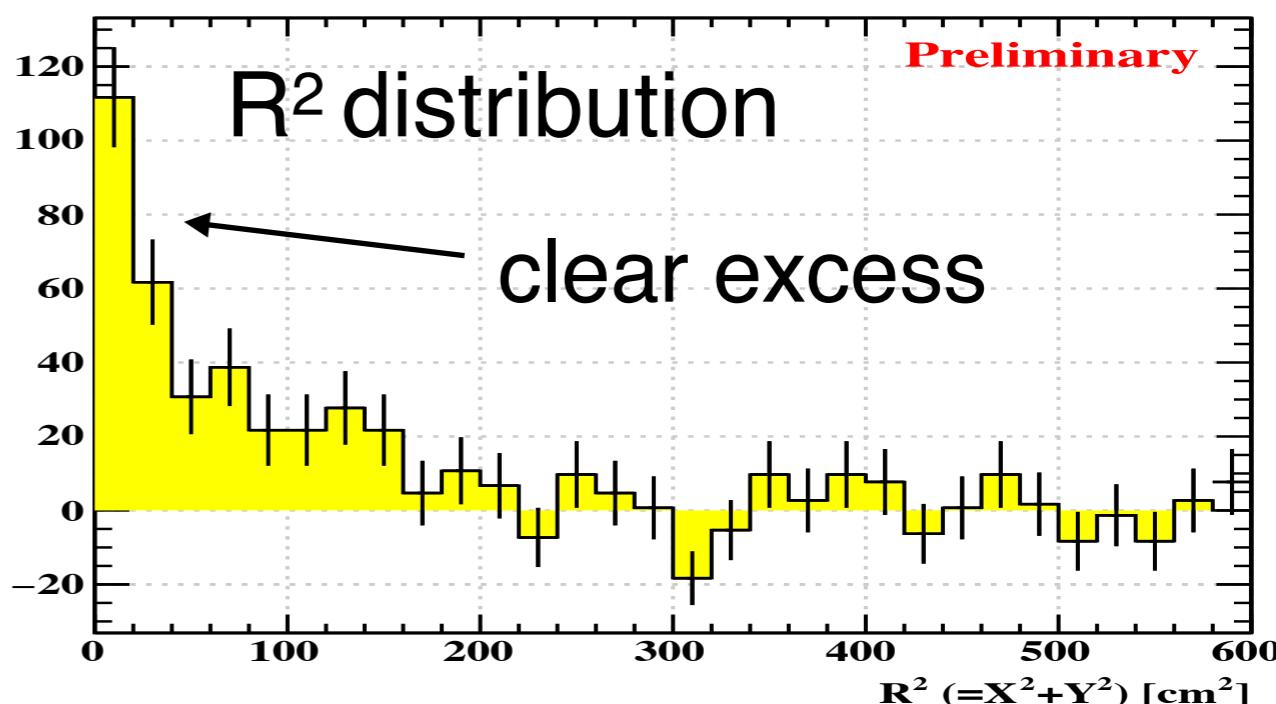
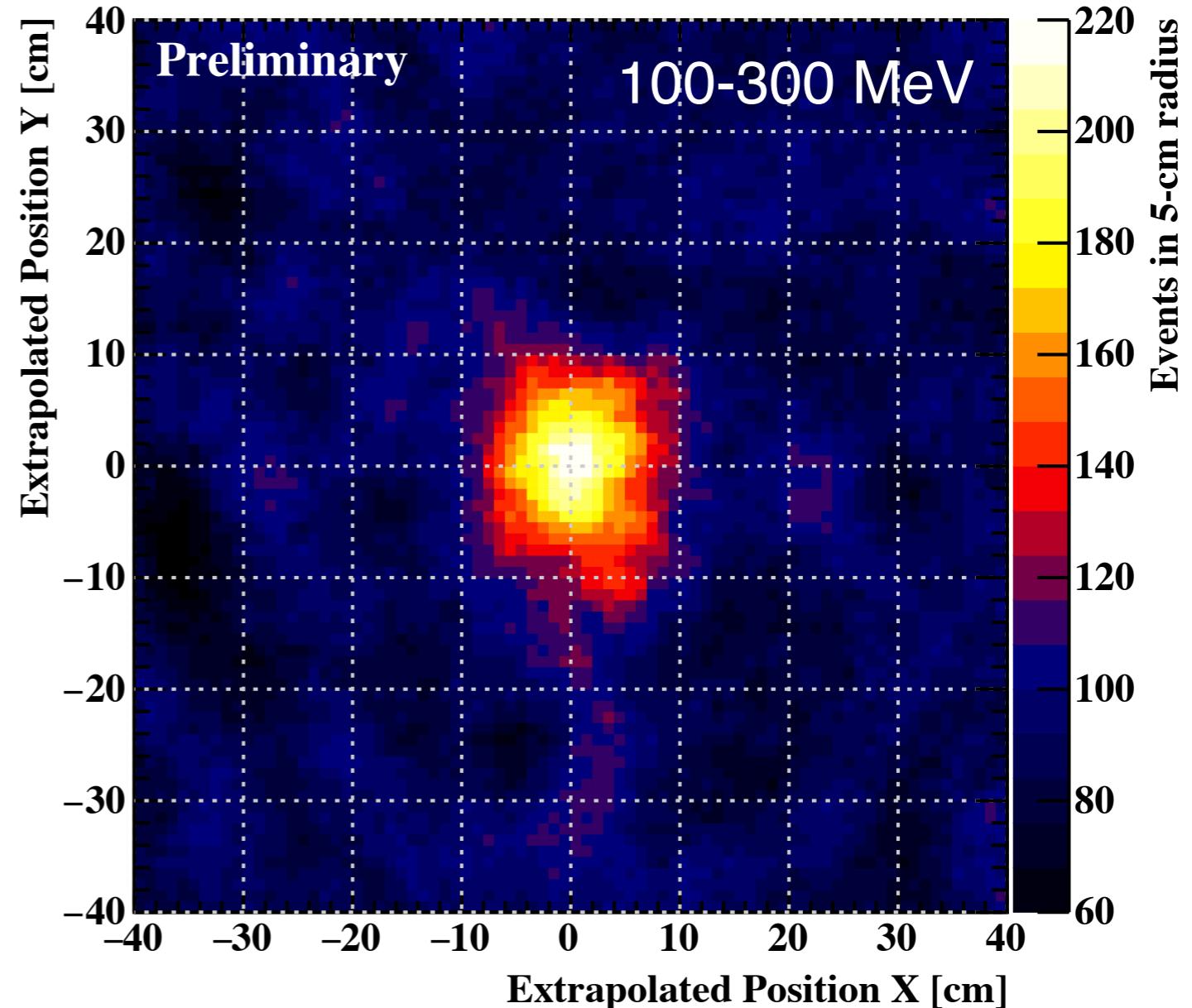
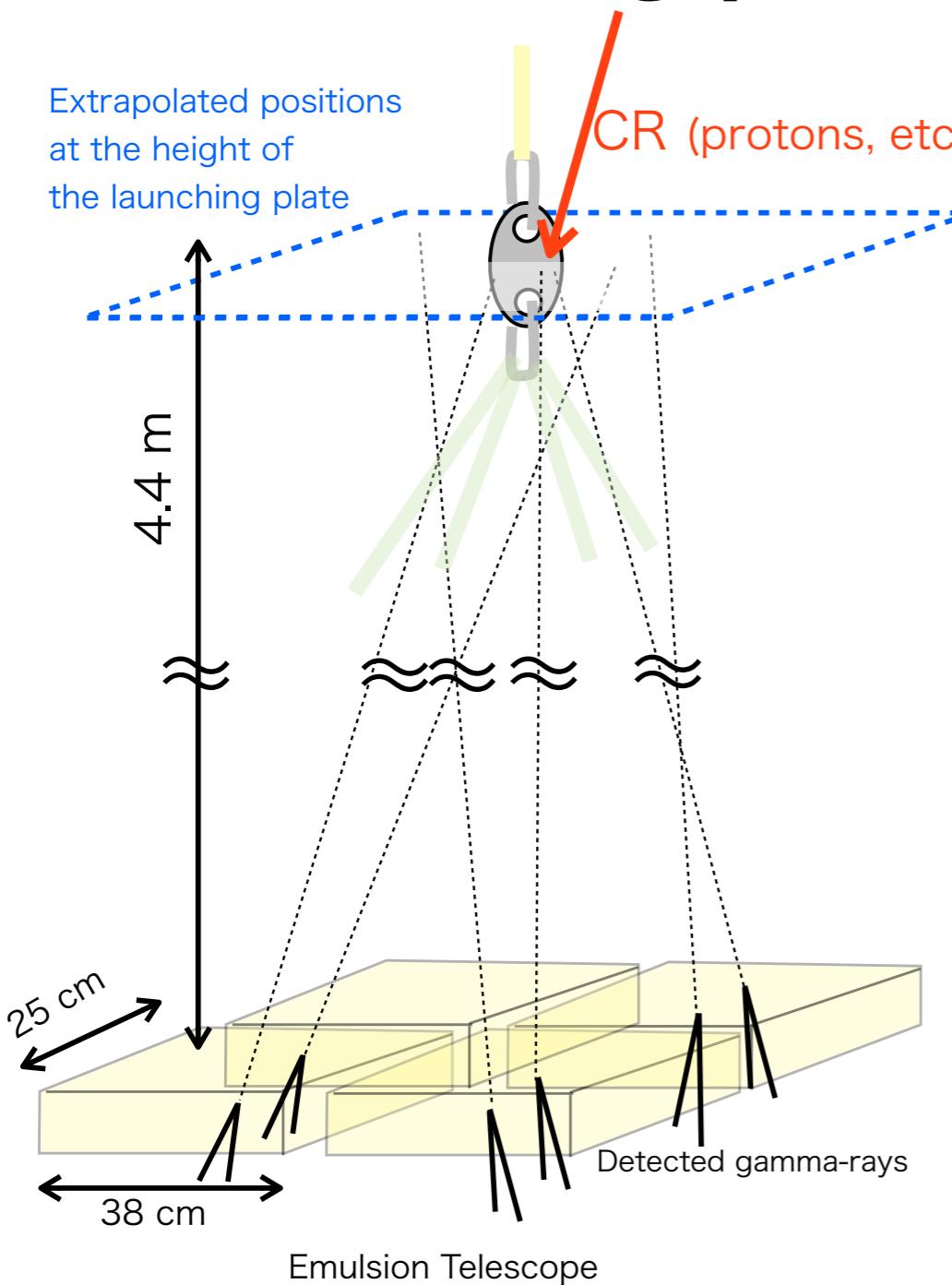


Demonstration of Gamma-ray Imaging during Balloon Observation



Gamma-ray Image of the launching plate

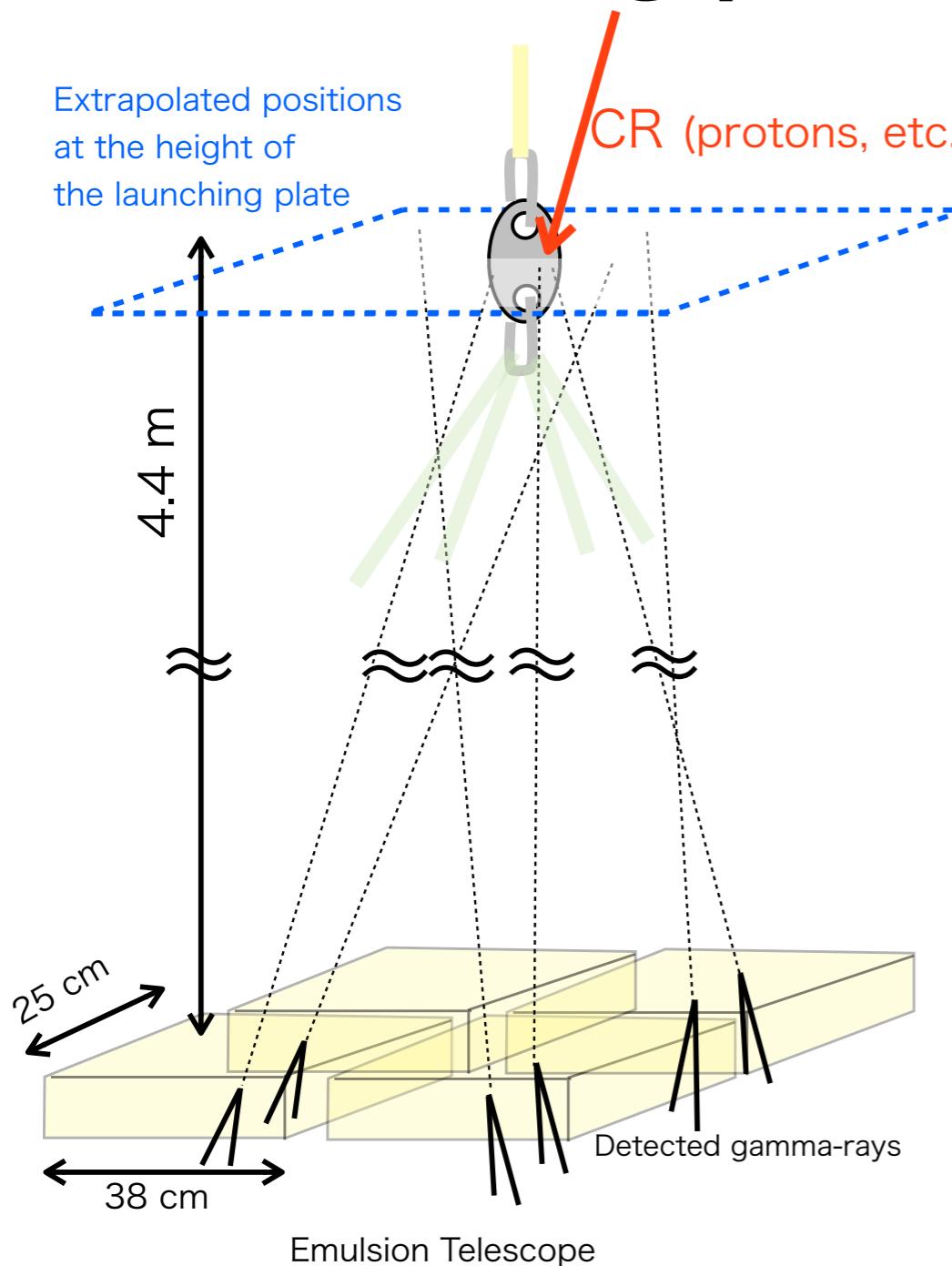
H.Rokujo, et al. in prep.



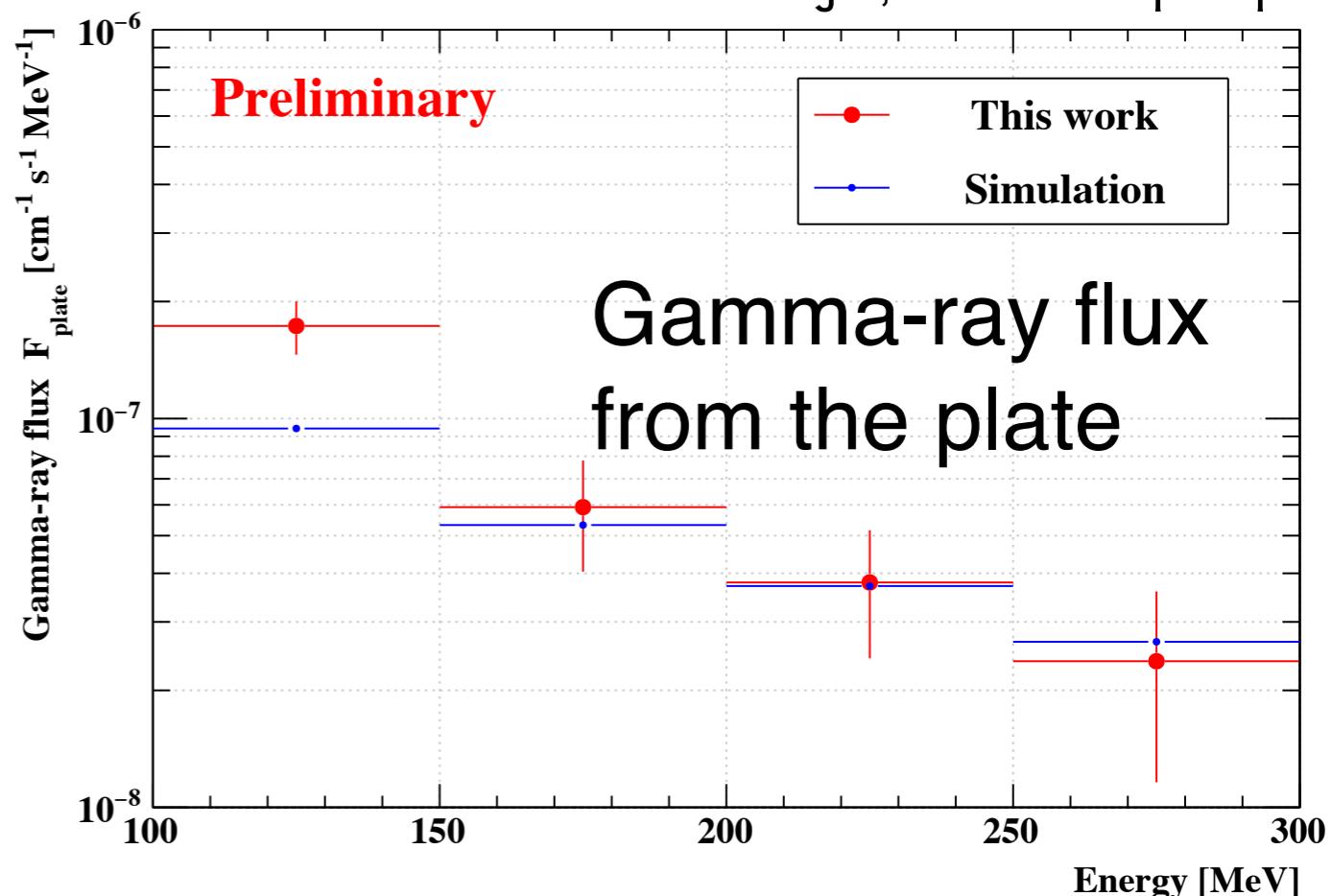
This result is the first demonstration with the whole of enlarged area.
(So far, with a small area using accel. beam)

Gamma-ray Image of the launching plate

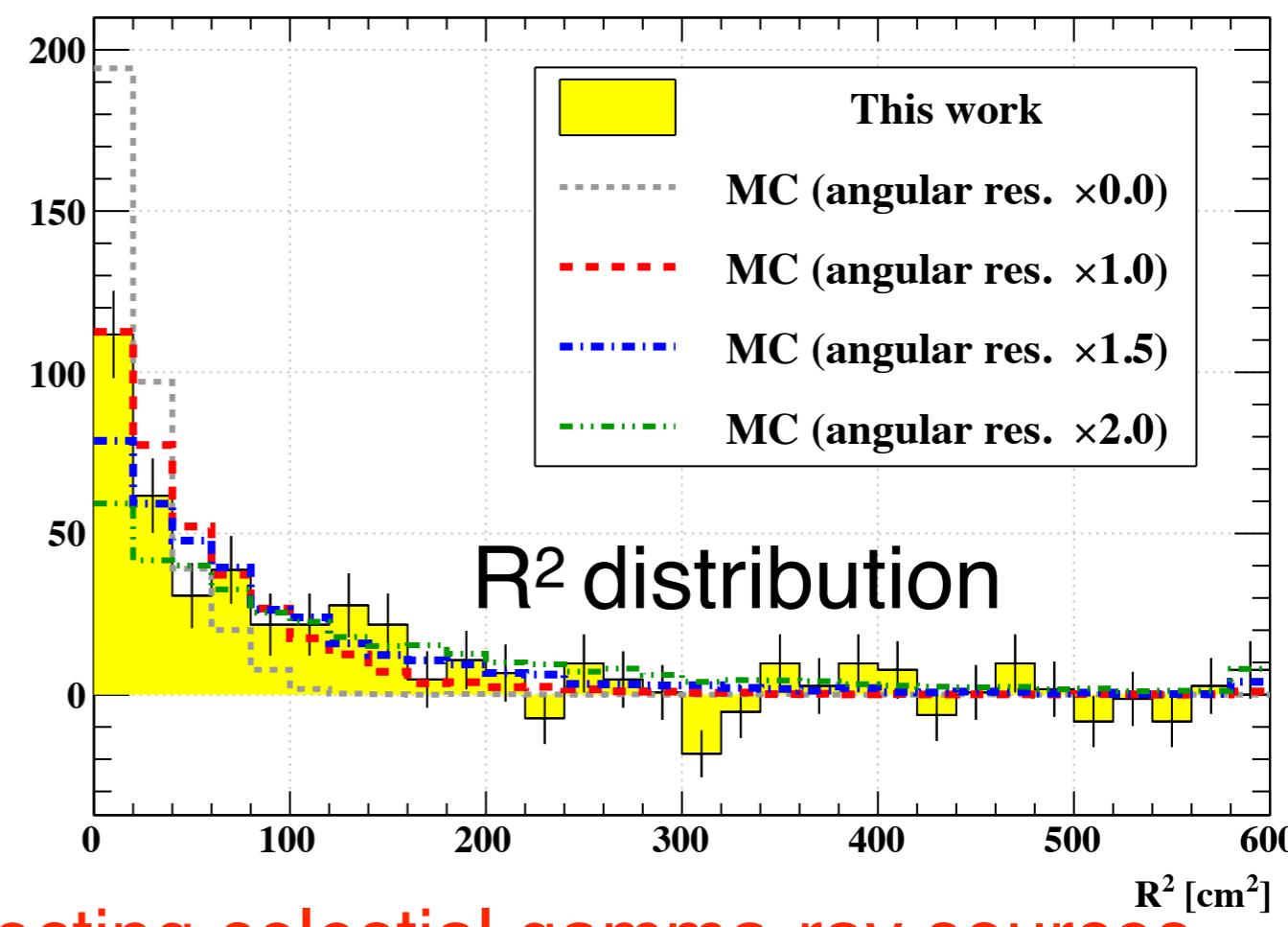
H.Rokujo, et al. in prep.



Emulsion telescope has
good observation performance.
→ Next: overall demonstration by detecting celestial gamma-ray sources

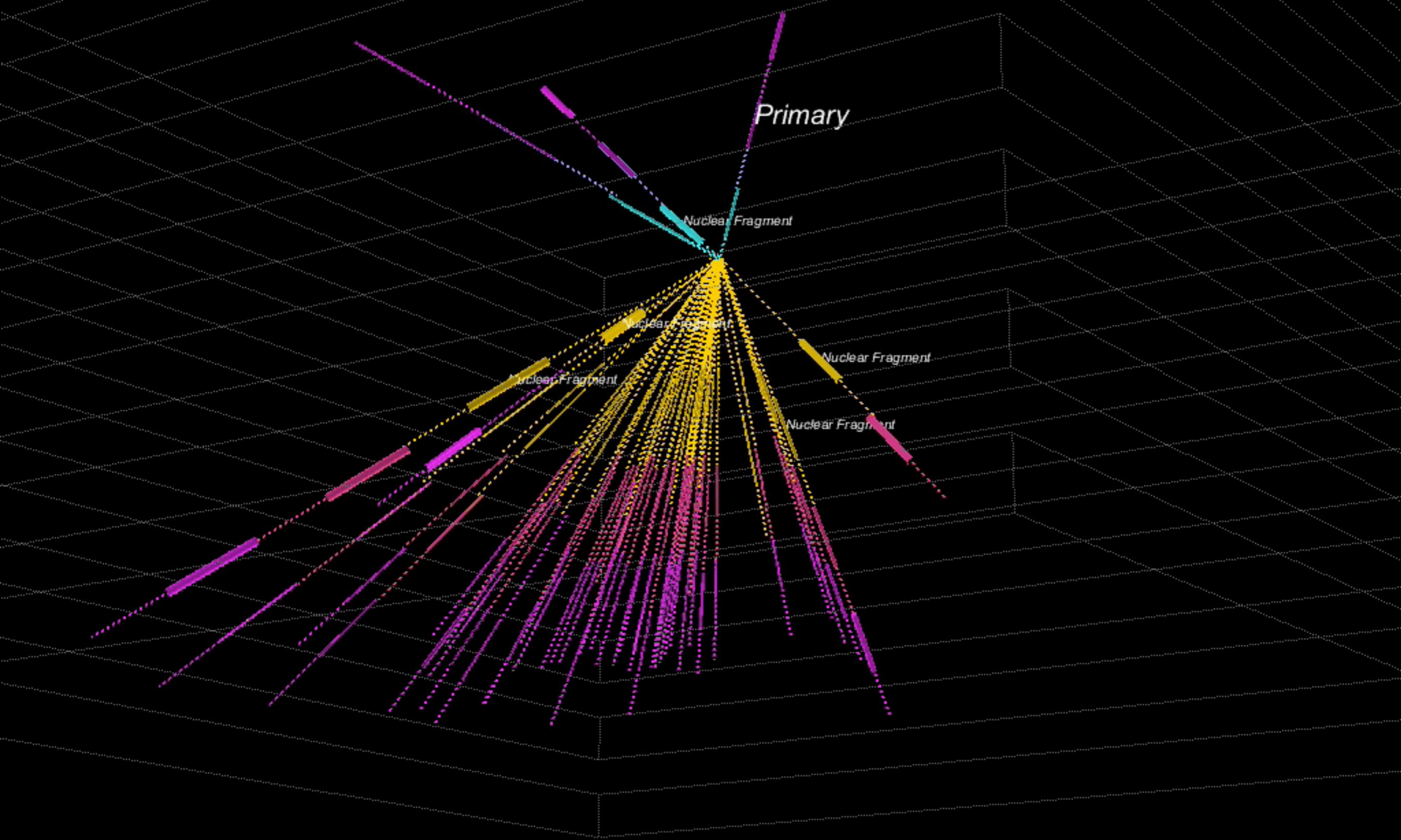


Gamma-ray flux
from the plate

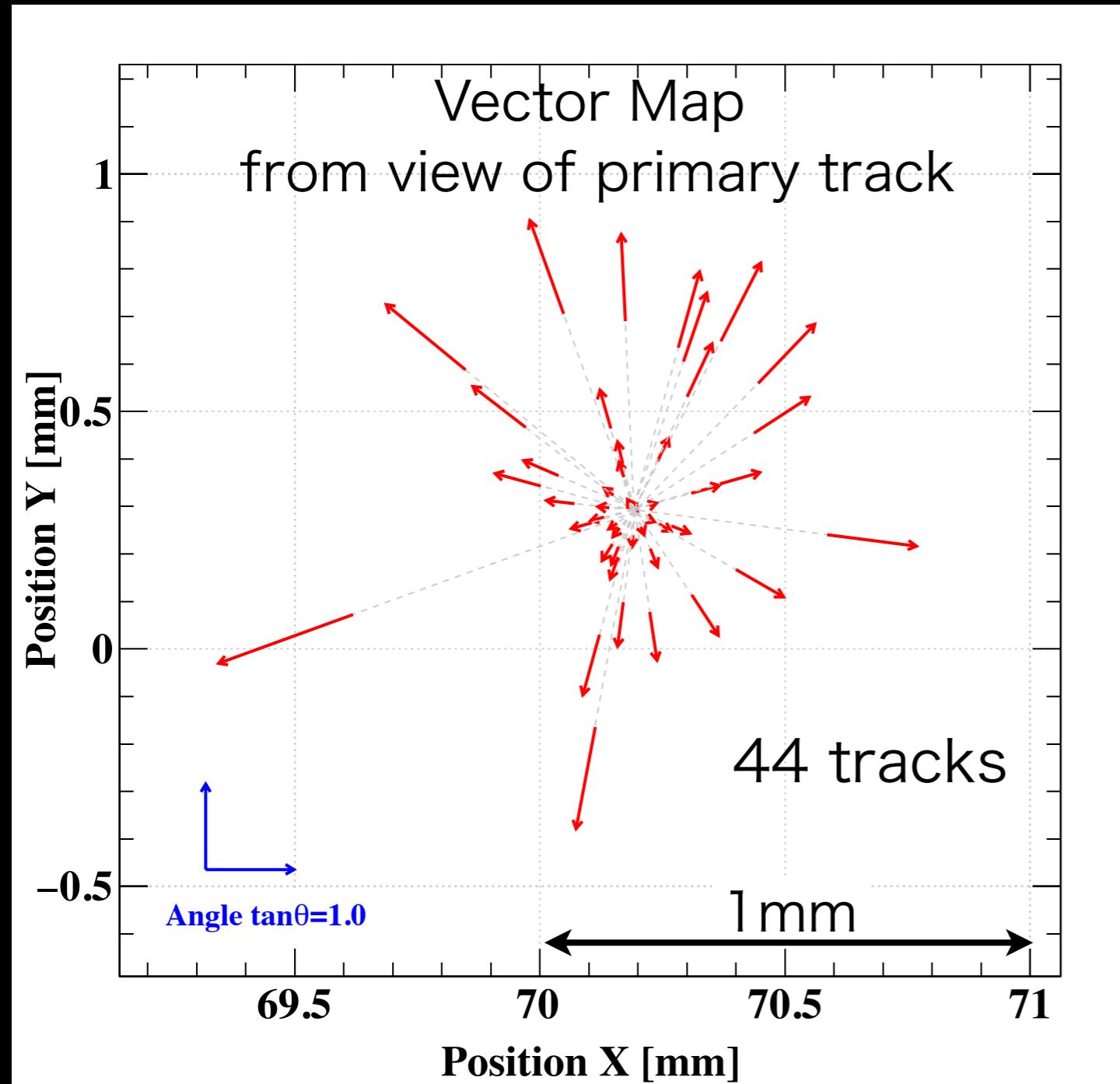


R^2 distribution

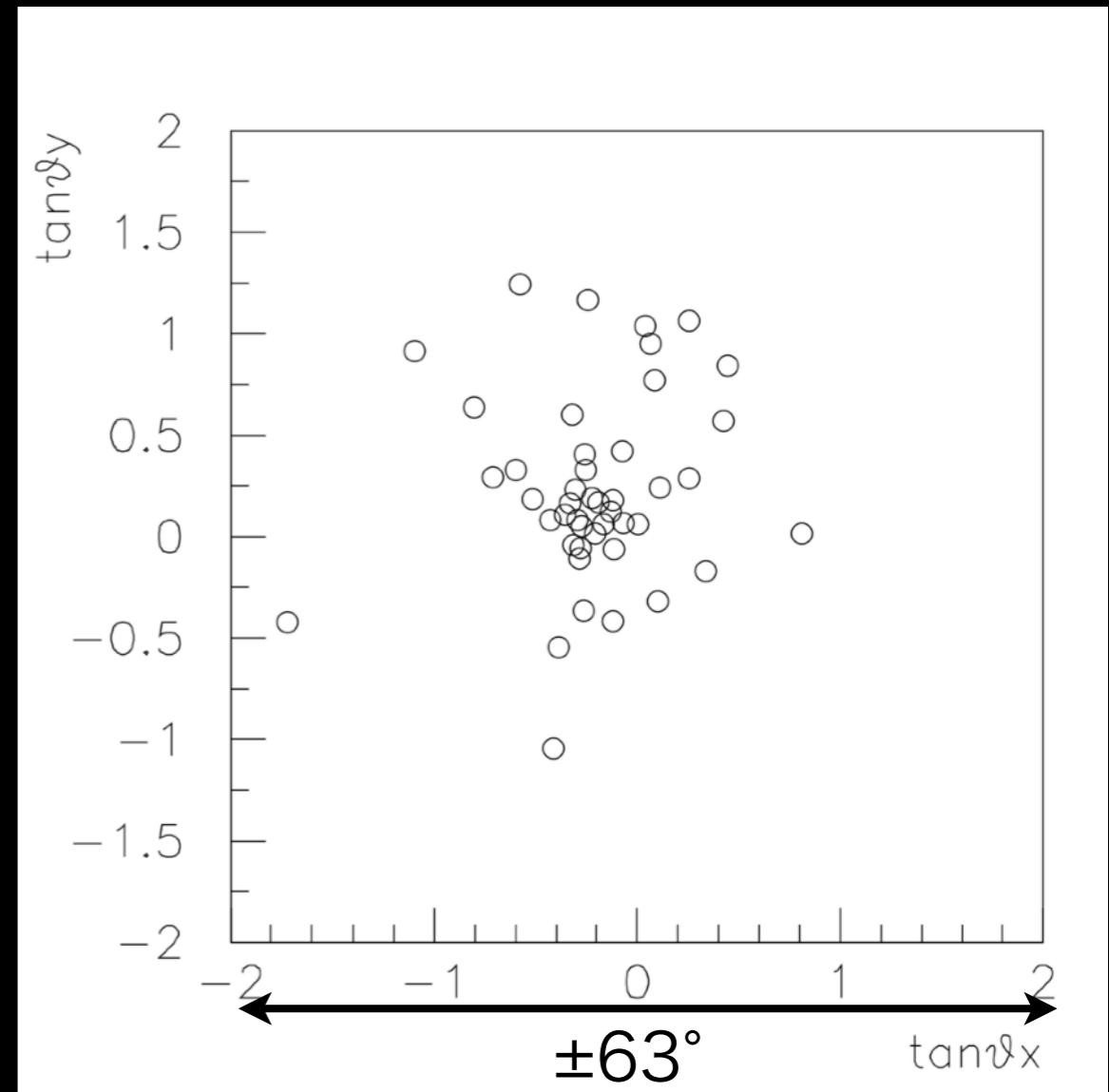
An Example of Hadron Int. Detected in the GRAINE 2015 Chamber



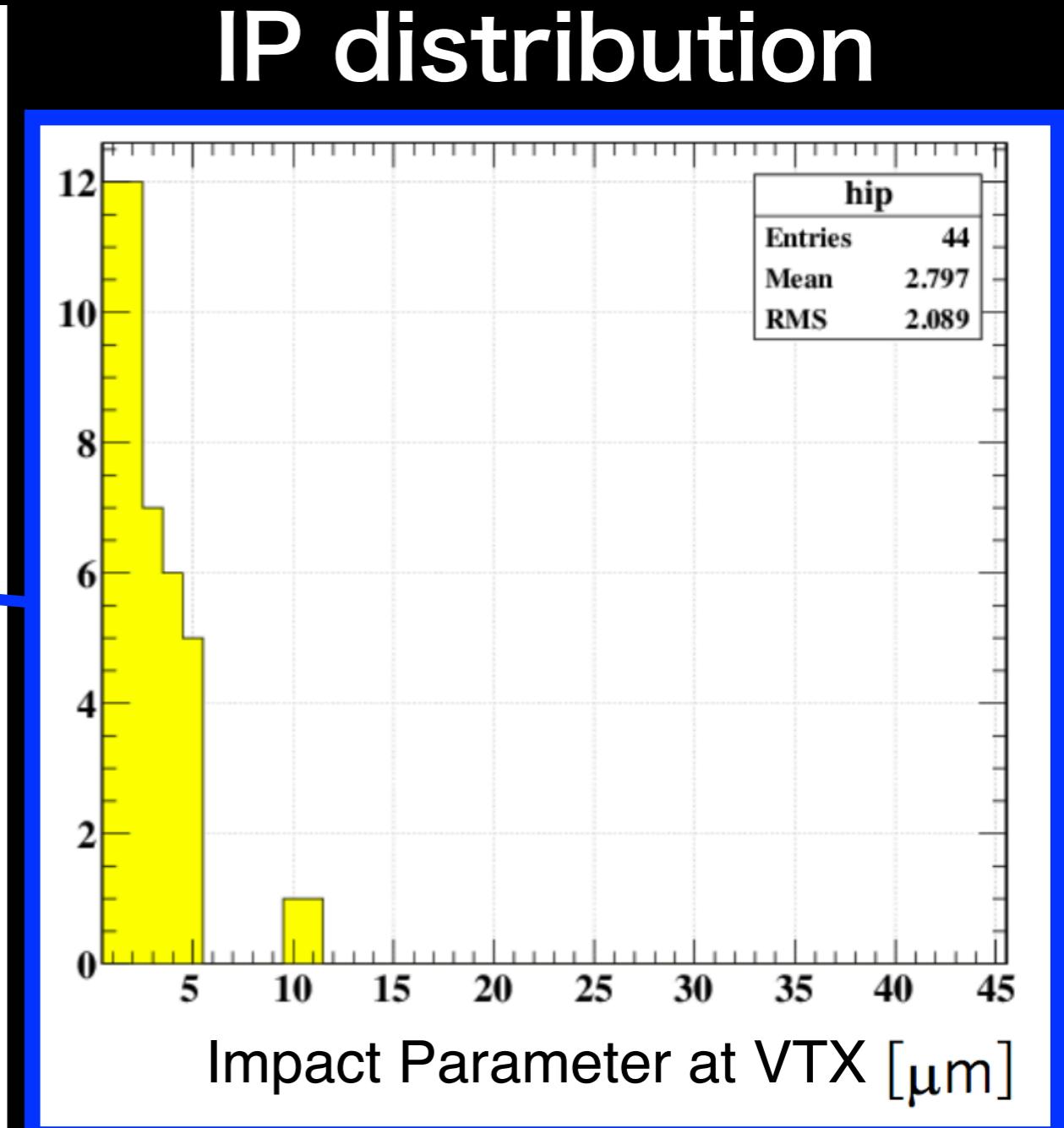
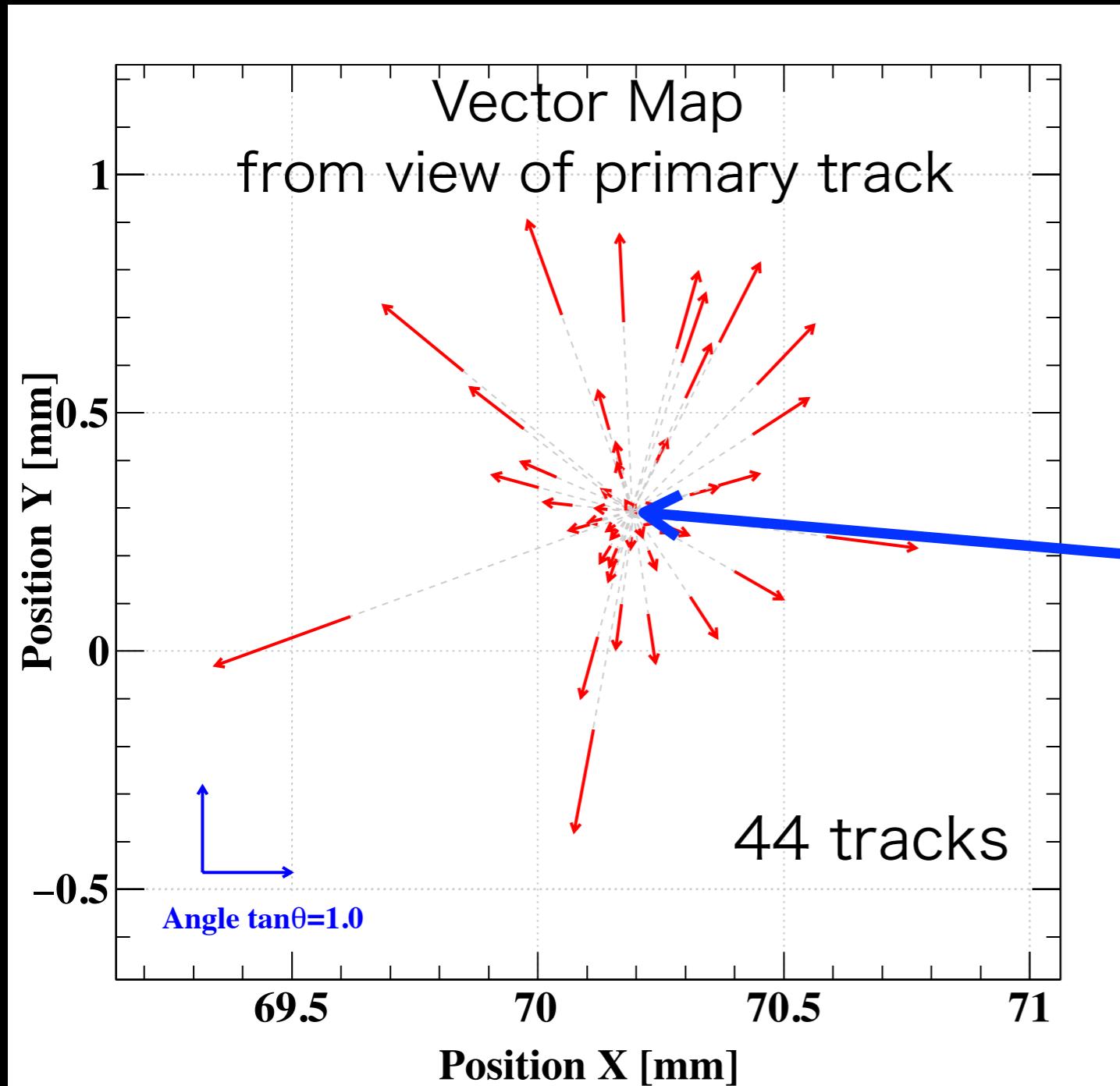
An Example of Hadron Int. Detected in the GRAINE 2015 Chamber



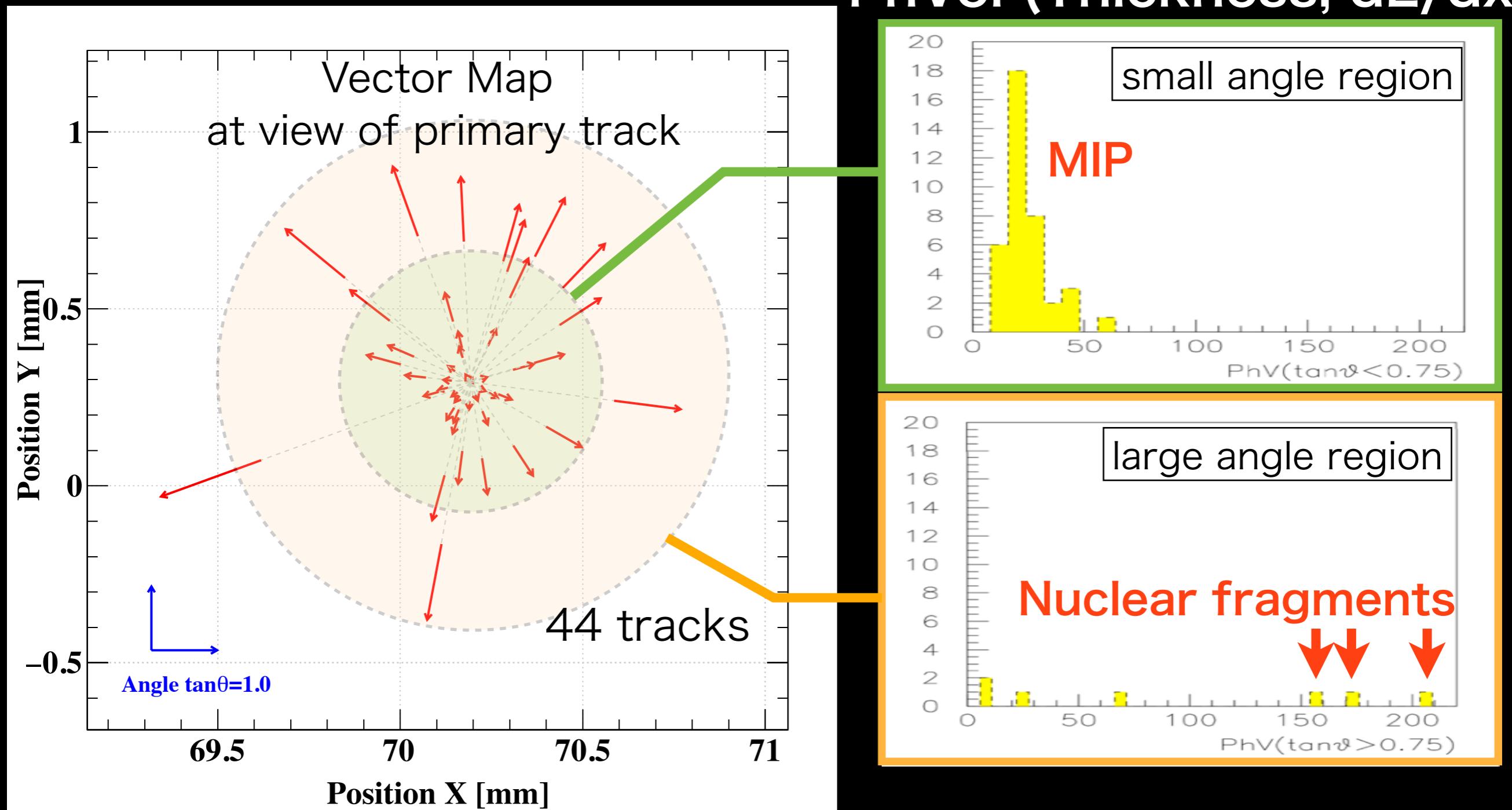
Angular distribution



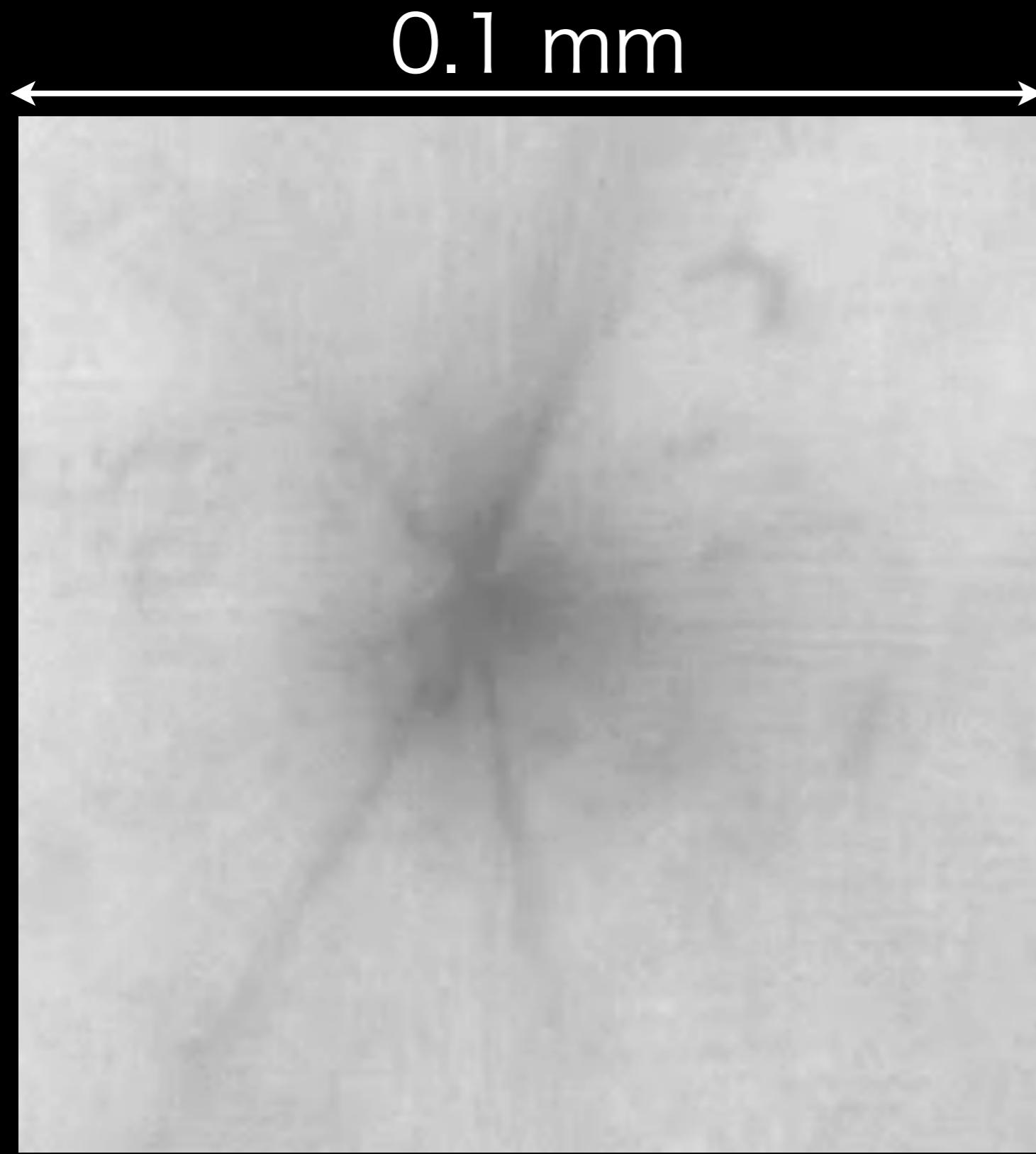
An Example of Hadron Int. Detected in the GRAINE 2015 Chamber



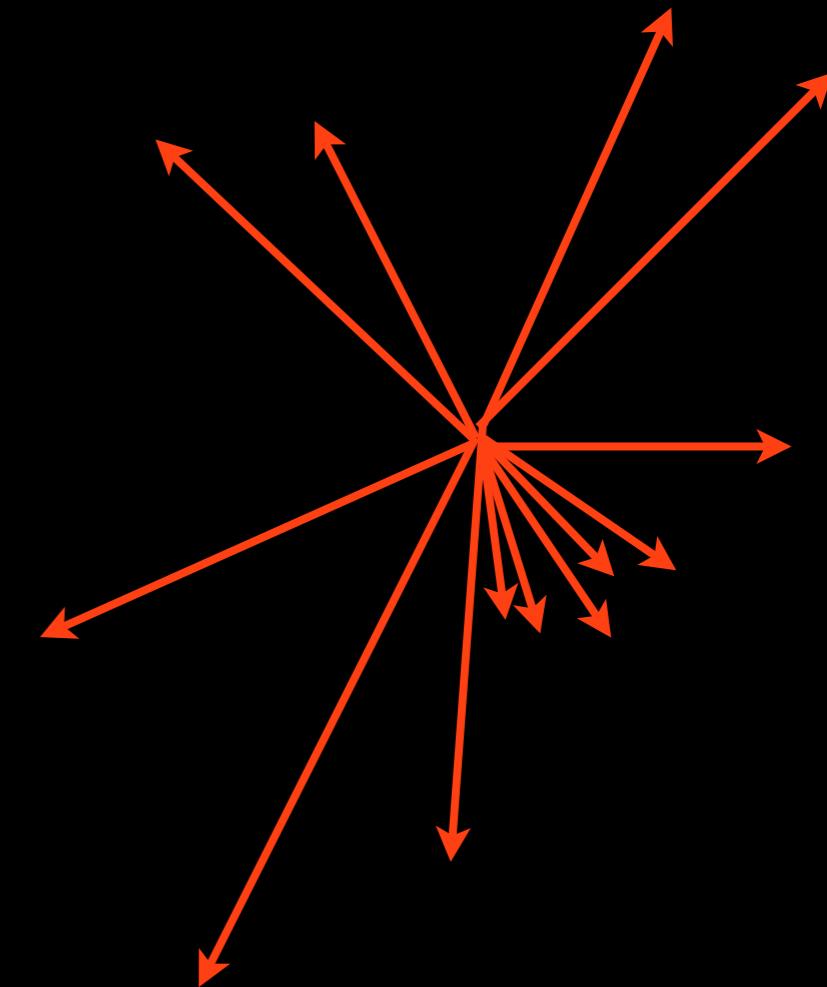
An Example of Hadron Int. Detected in the GRAINE 2015 Chamber



Microscopic view around VTX

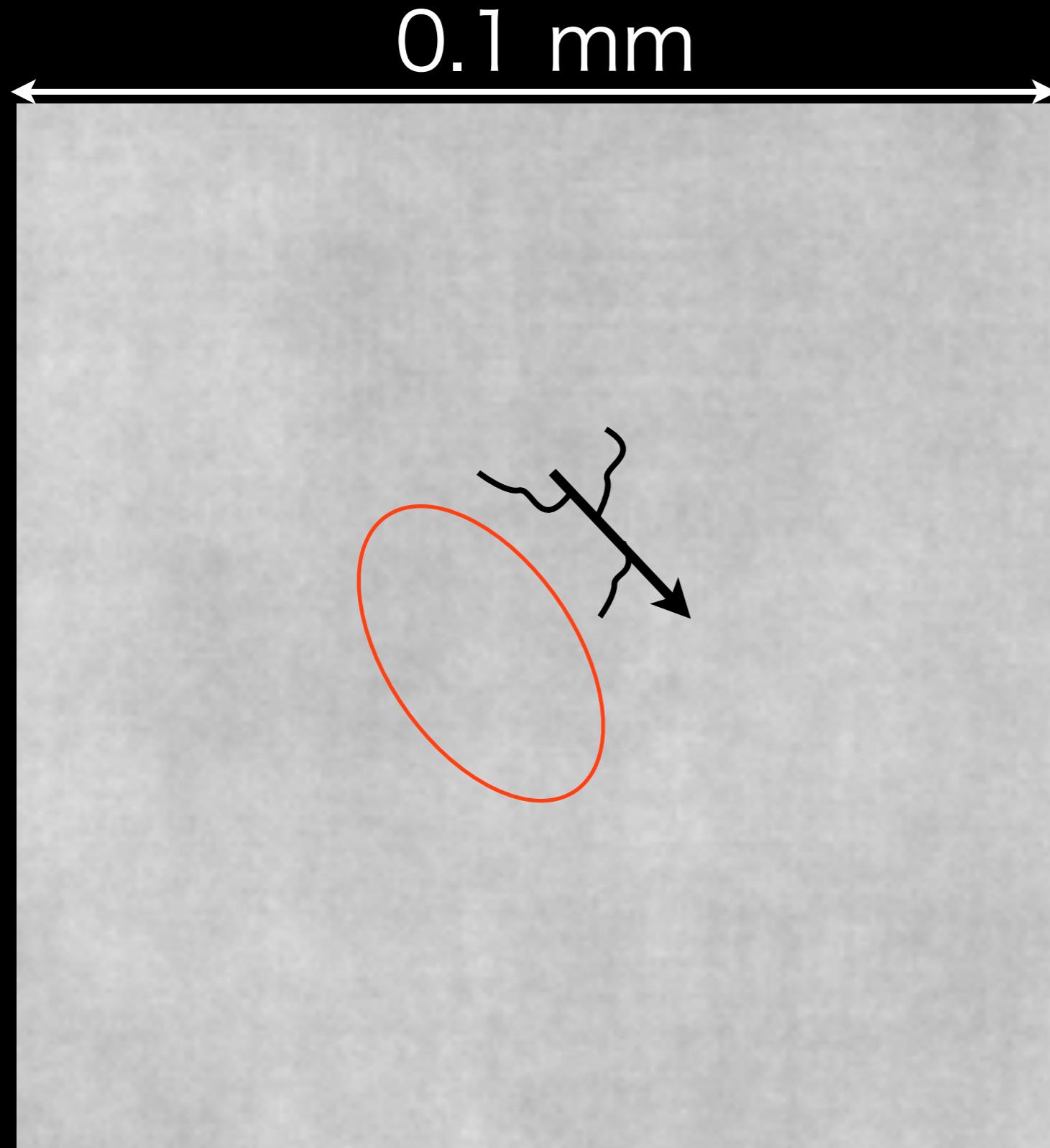


VTX in emulsion layer



2ndry&
nuclear fragments

Microscopic view of primary track



Primary track
has δ -rays

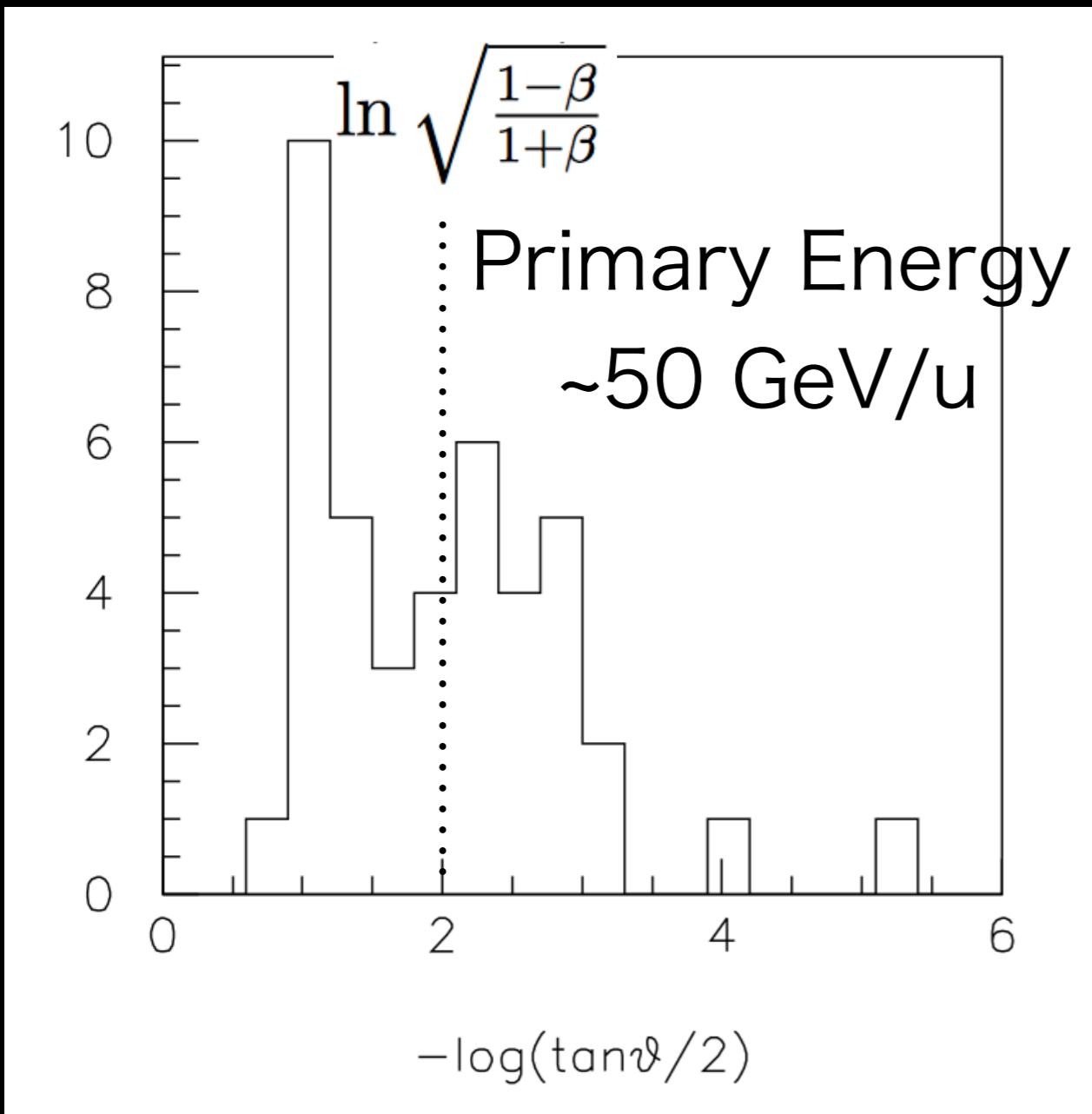


A small diagram on the right shows a red wavy line with an arrow pointing downwards and to the right, representing a secondary particle track. To its right, the chemical symbols C, N, and O are listed.

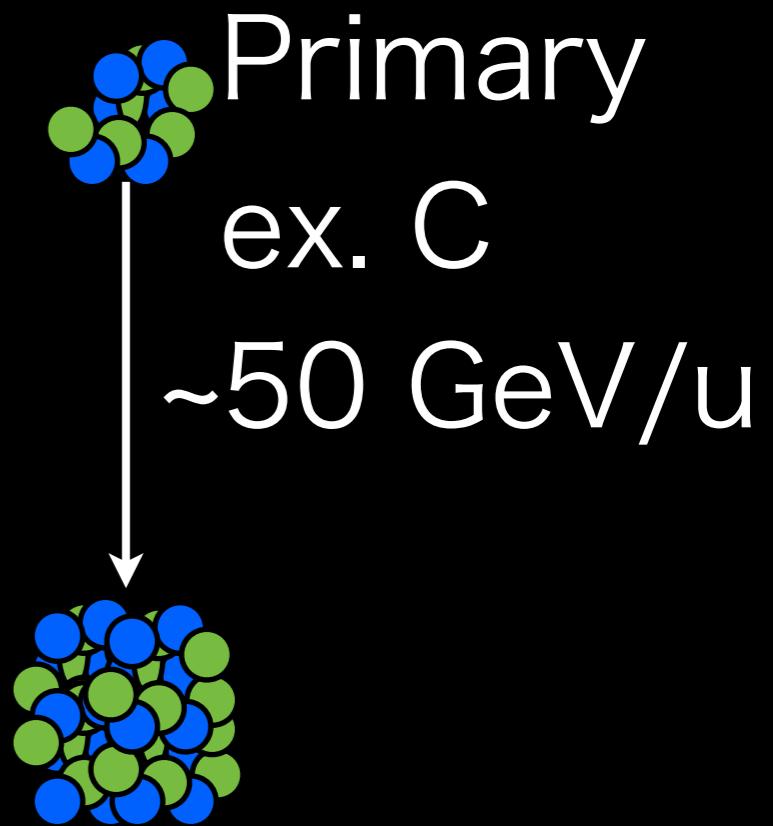
charge can be
determine by δ ray counting

Imagine this interaction from emulsion data

pseudo-rapidity distribution
(the lab. frame)

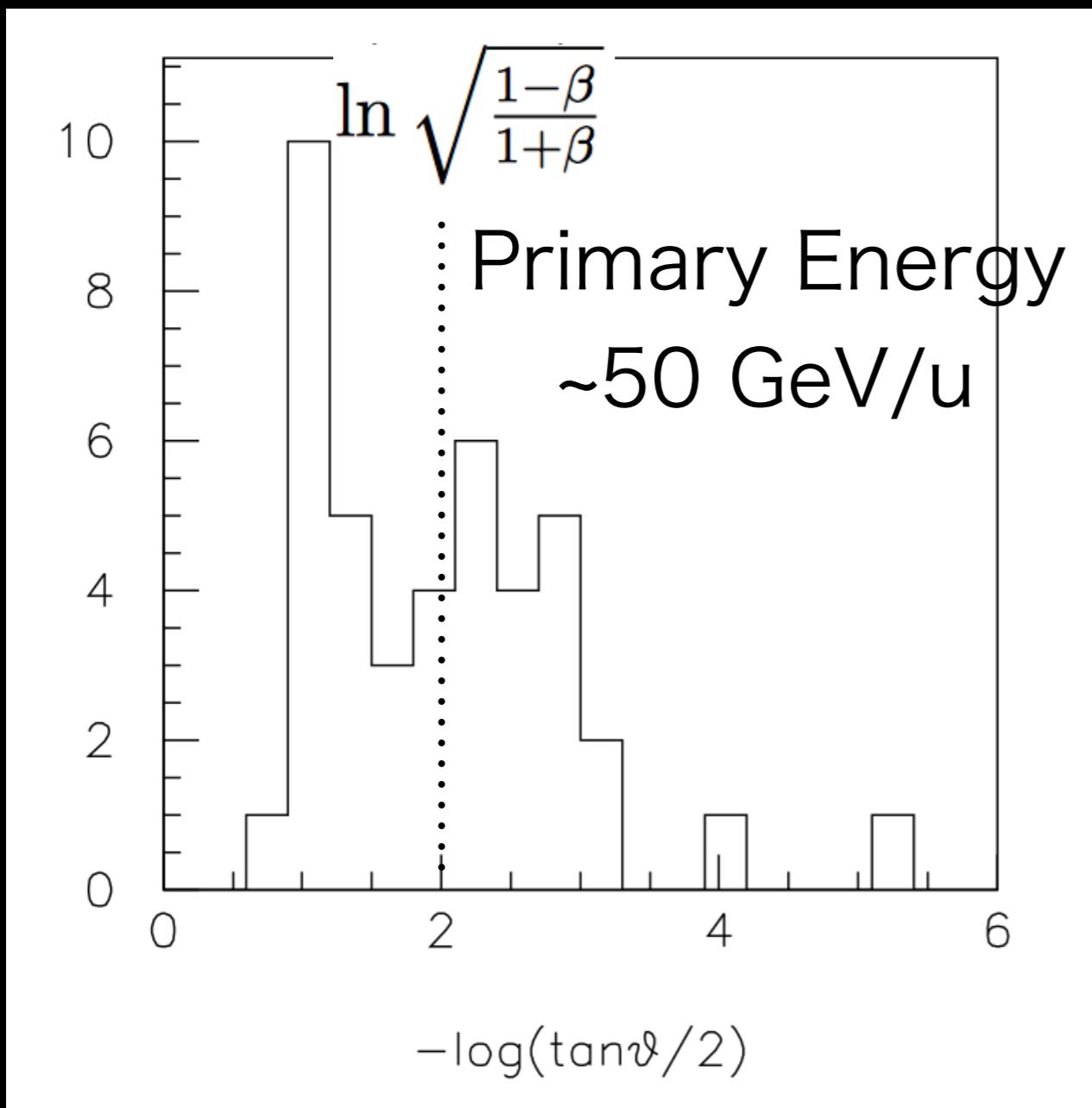


Target
ex. Ag



Imagine this interaction from emulsion data

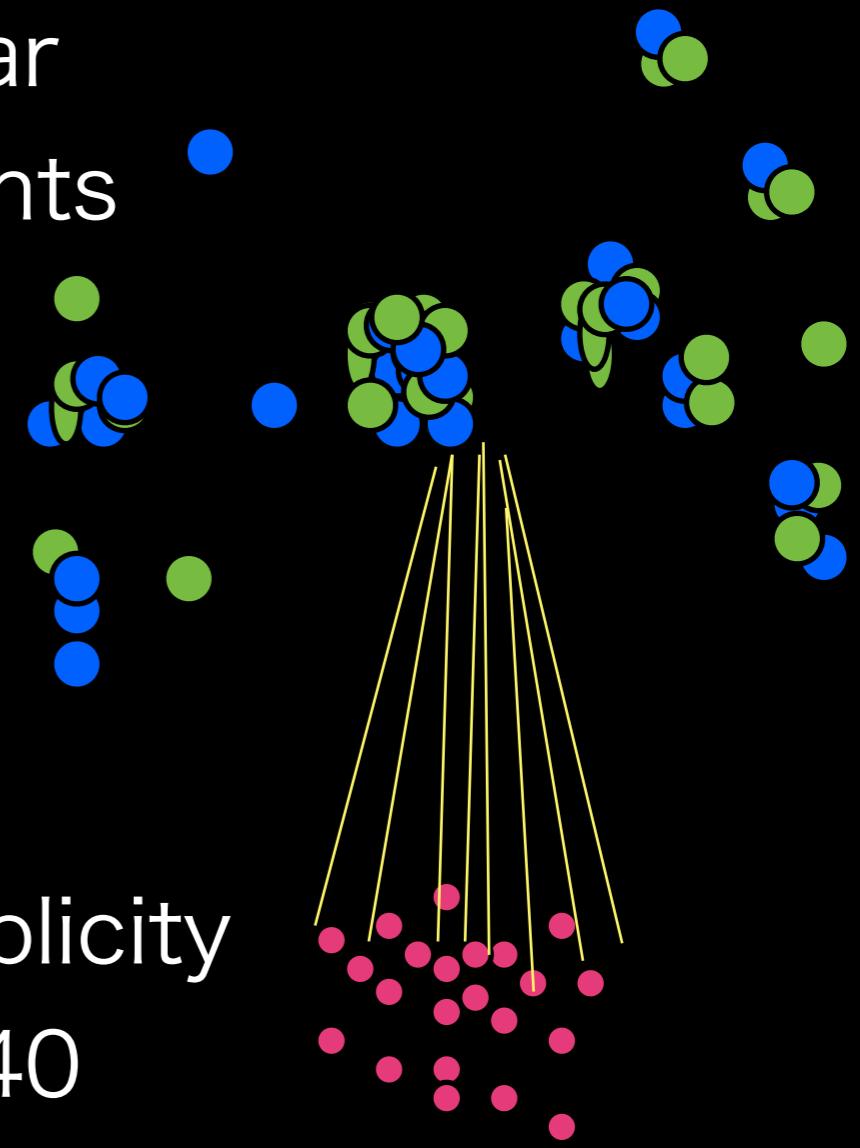
pseudo-rapidity distribution
(the lab. frame)



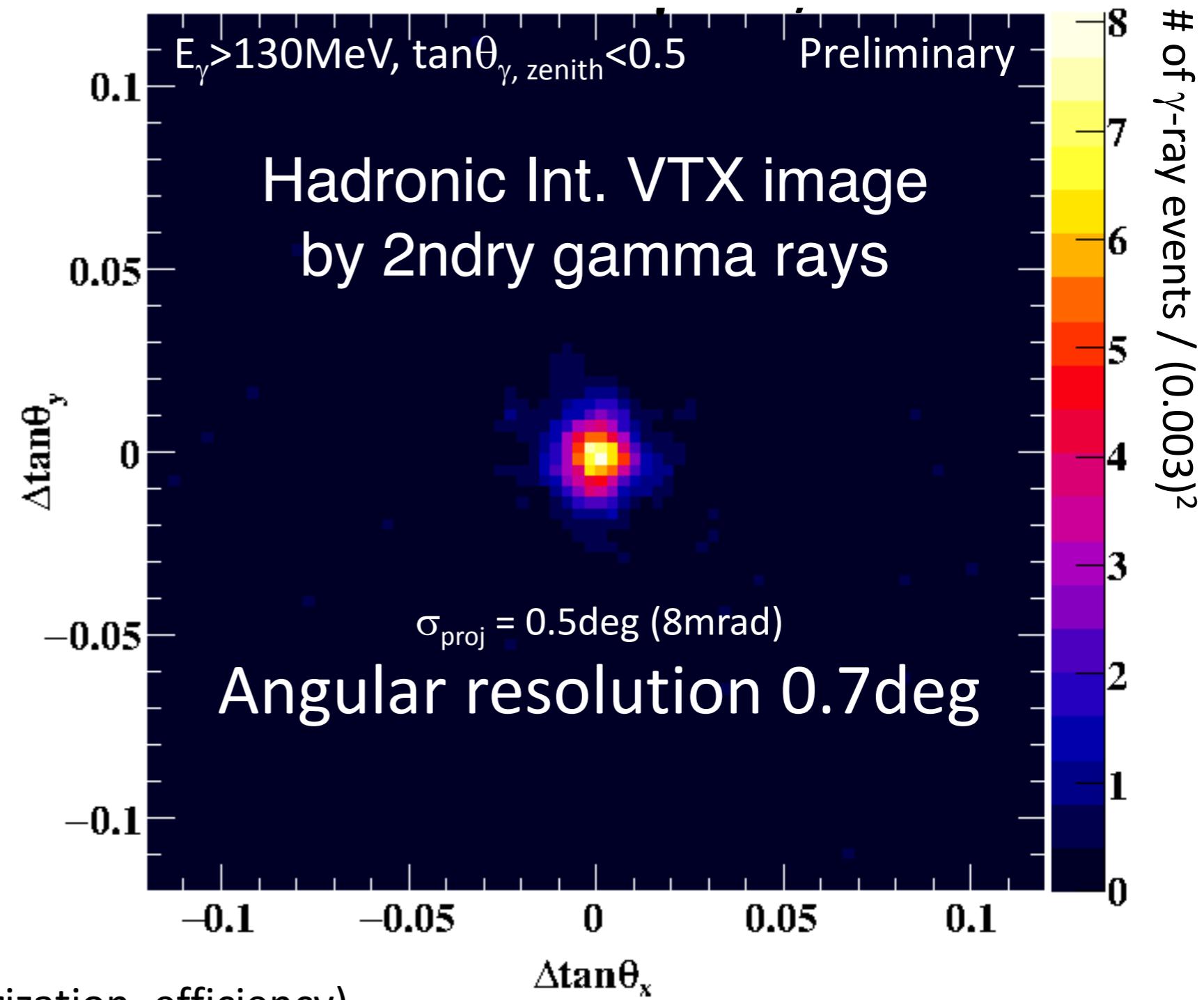
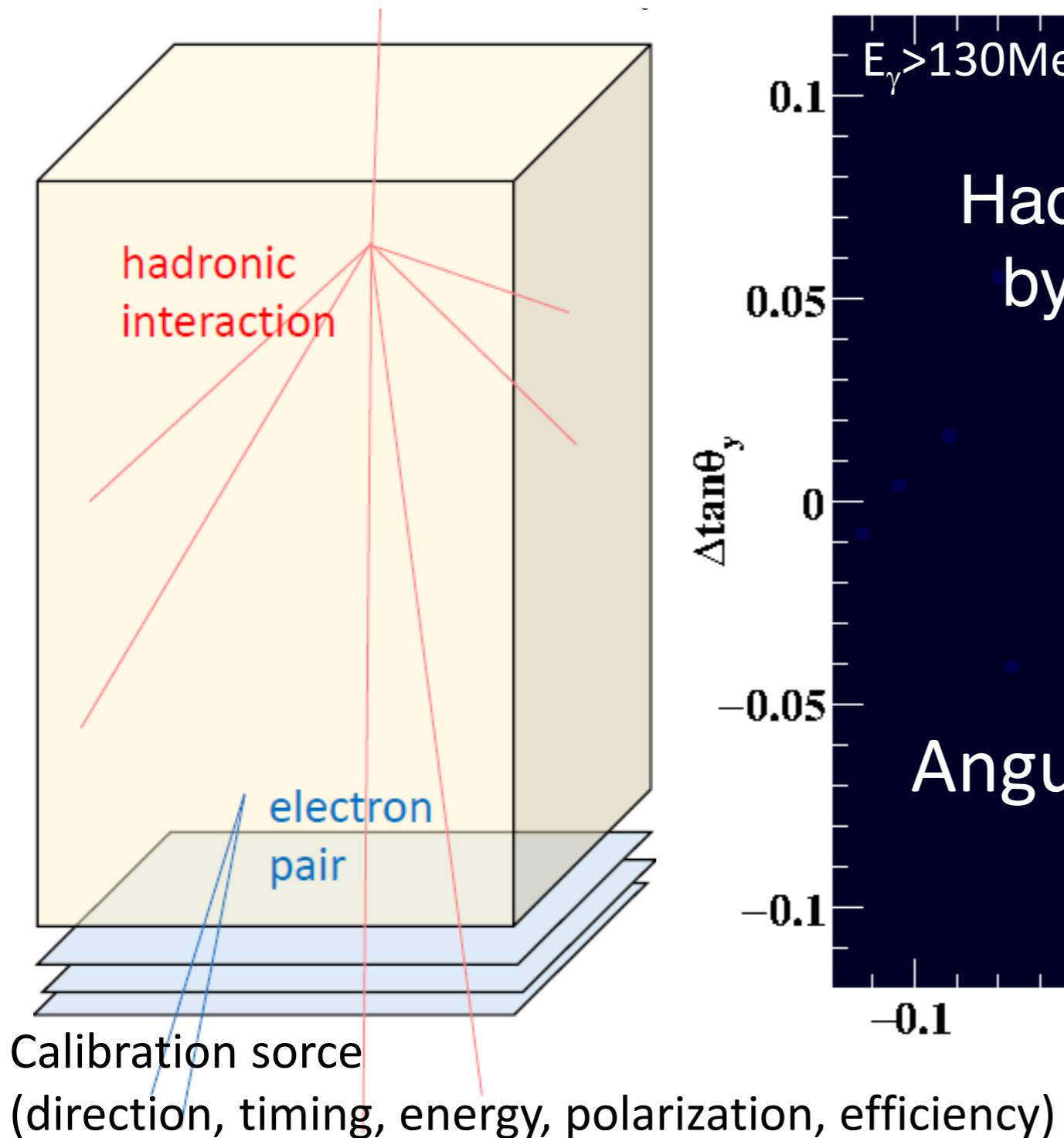
Nuclear
fragments

multiplicity

~40

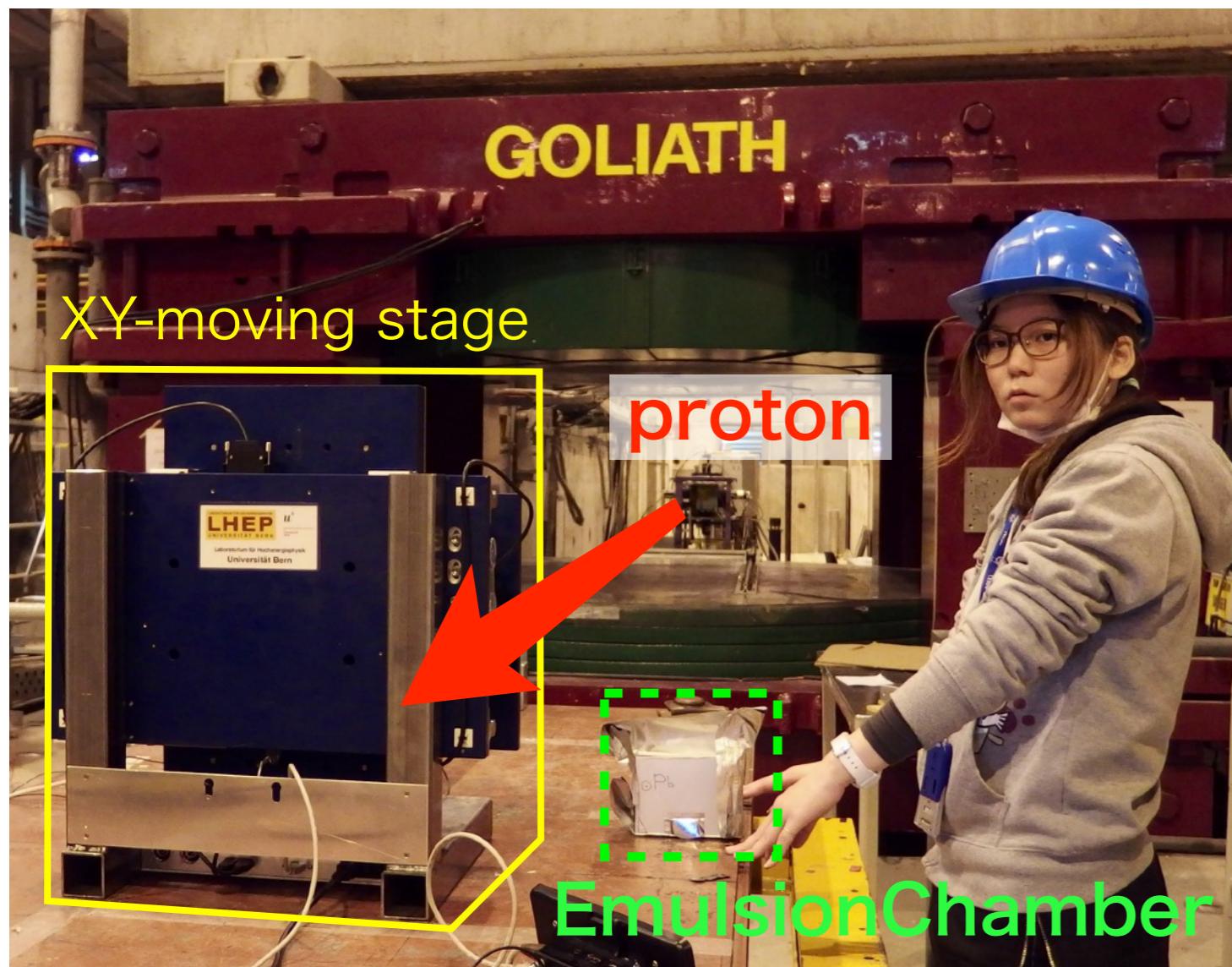


Calibration source for gamma-ray telescope

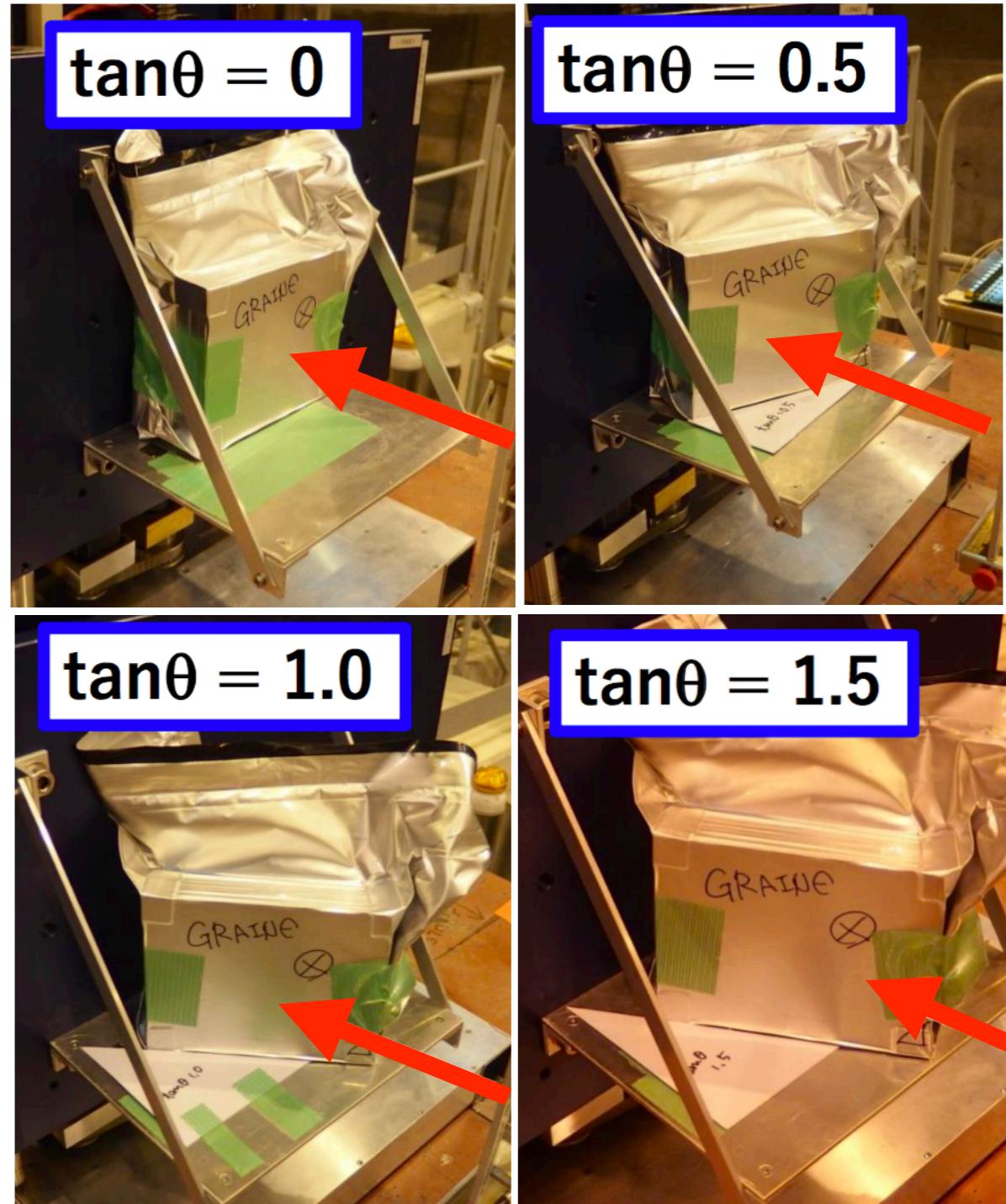


High γ -ray imaging performance is being obtained.

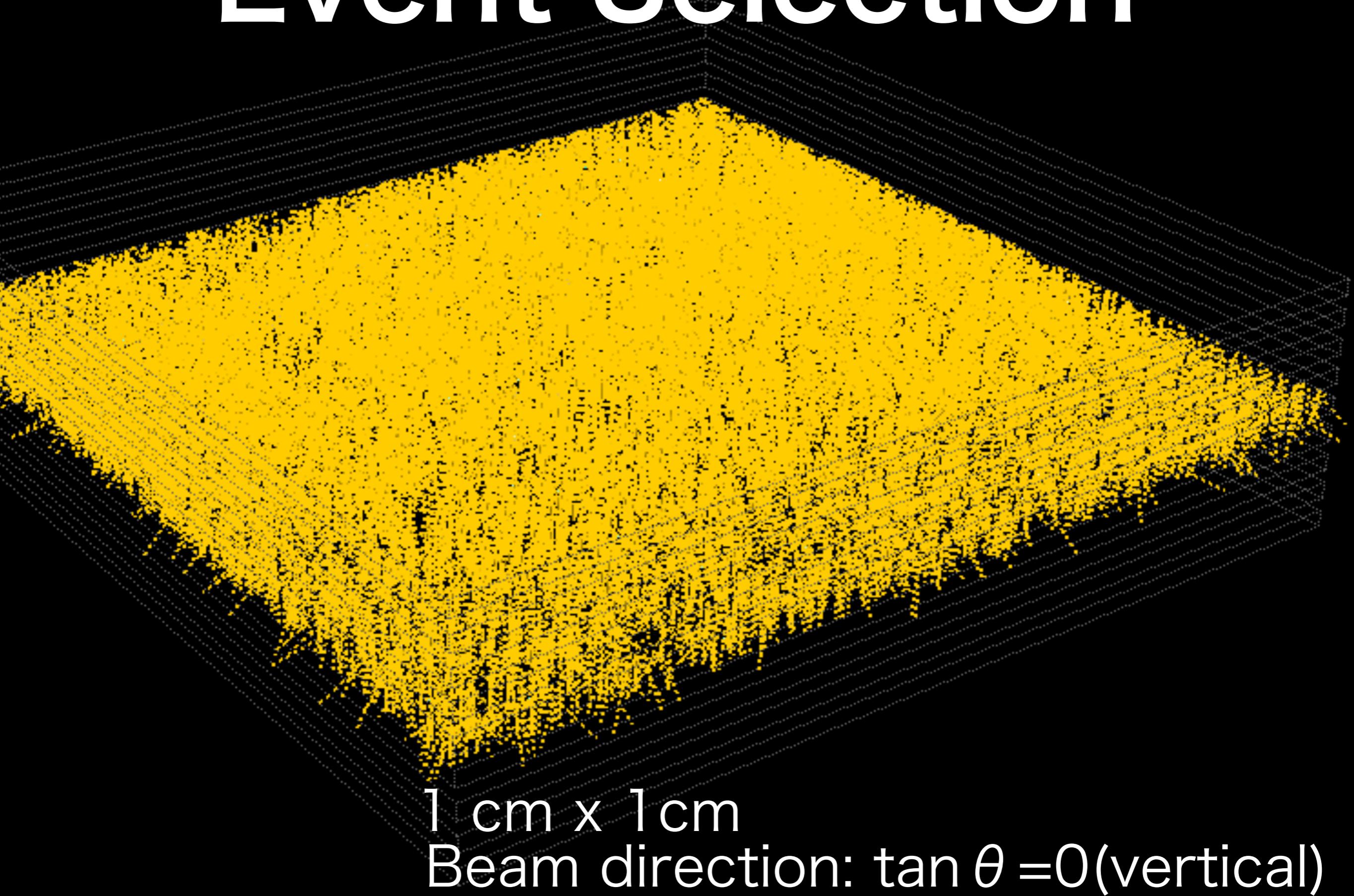
Beam Test @CERN SPS/PS for Calibration of Hadronic int. Detection



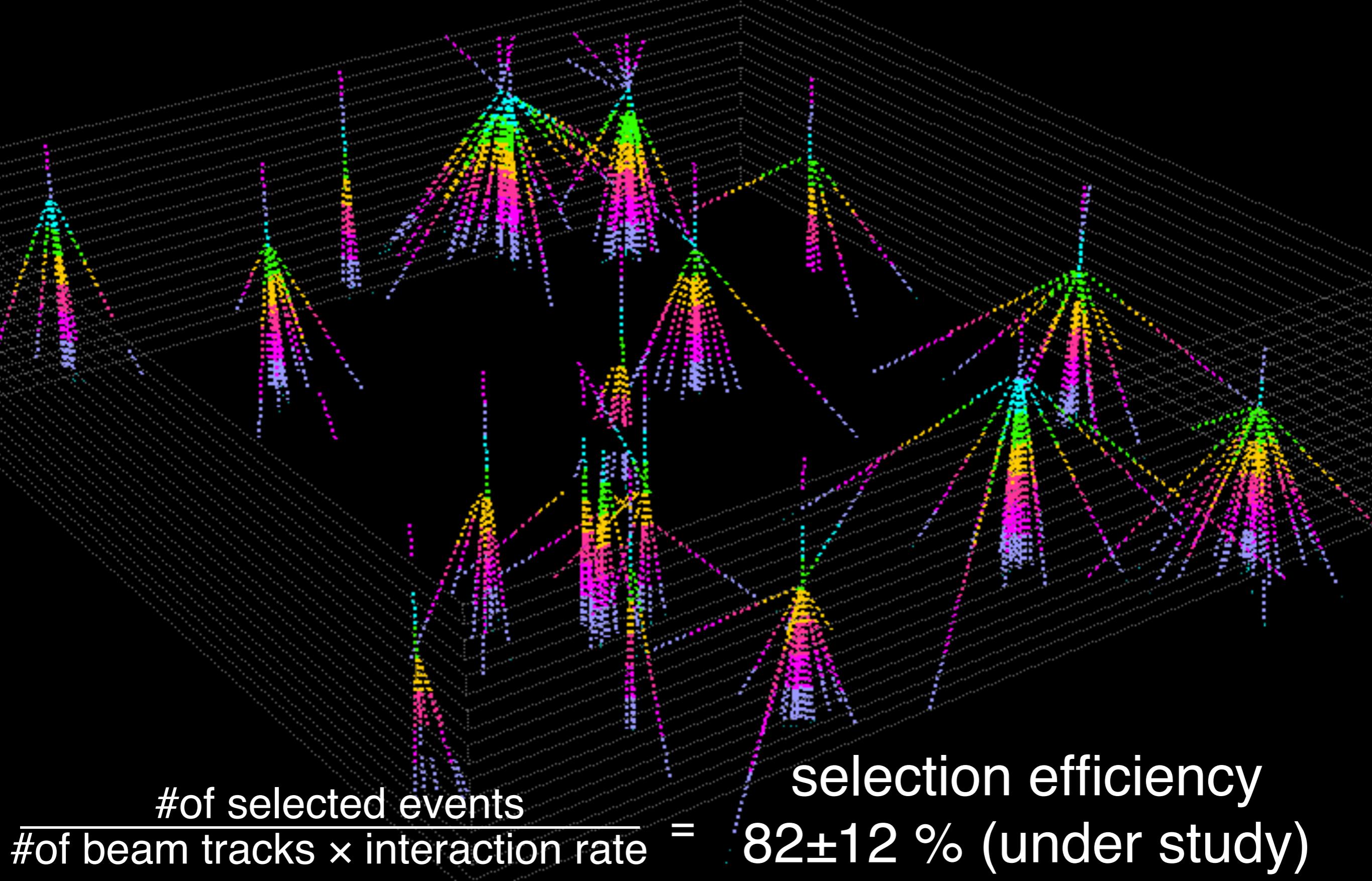
p	400 GeV	@SPS	Nov.2016
π^-	8 GeV	@PS	Aug.2017



Event Selection

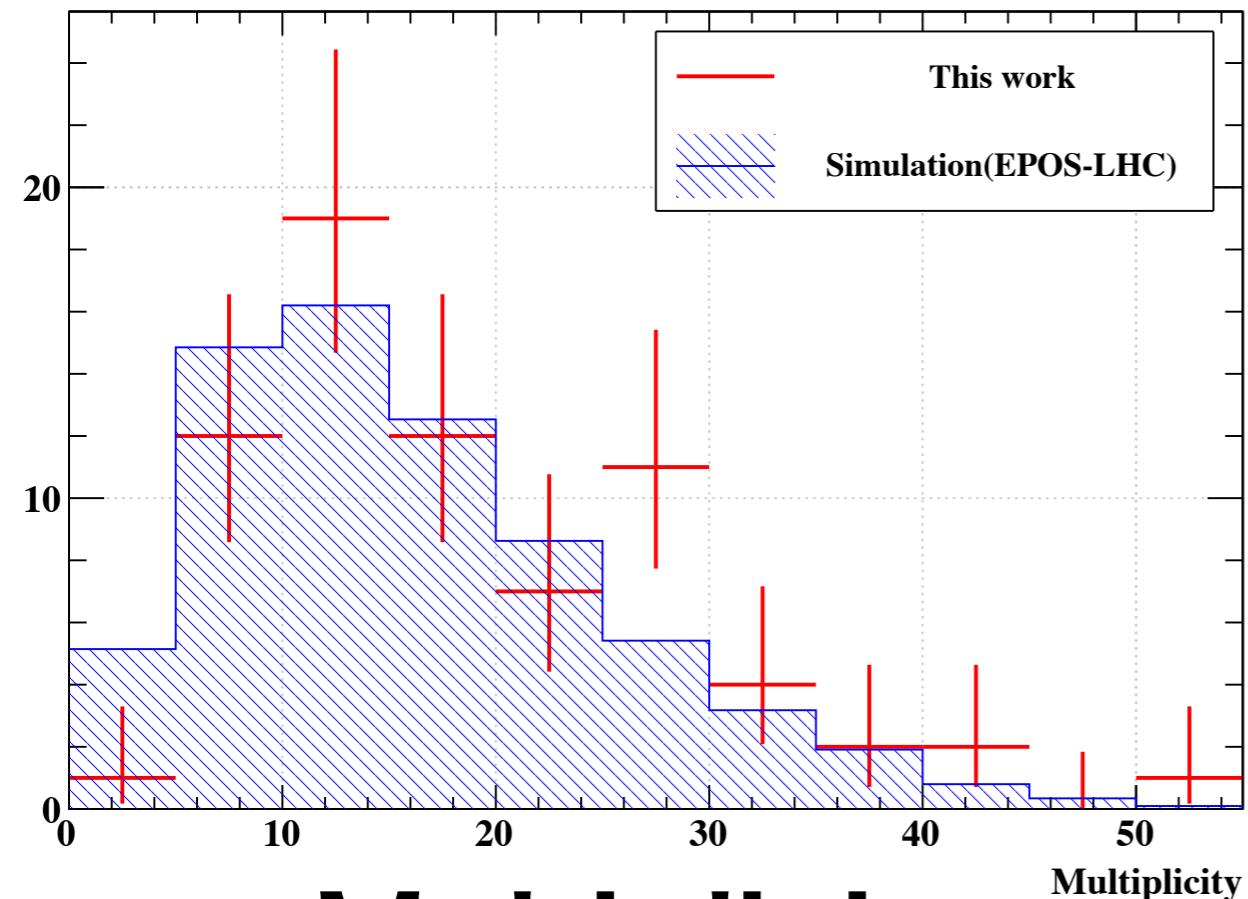


Event Selection

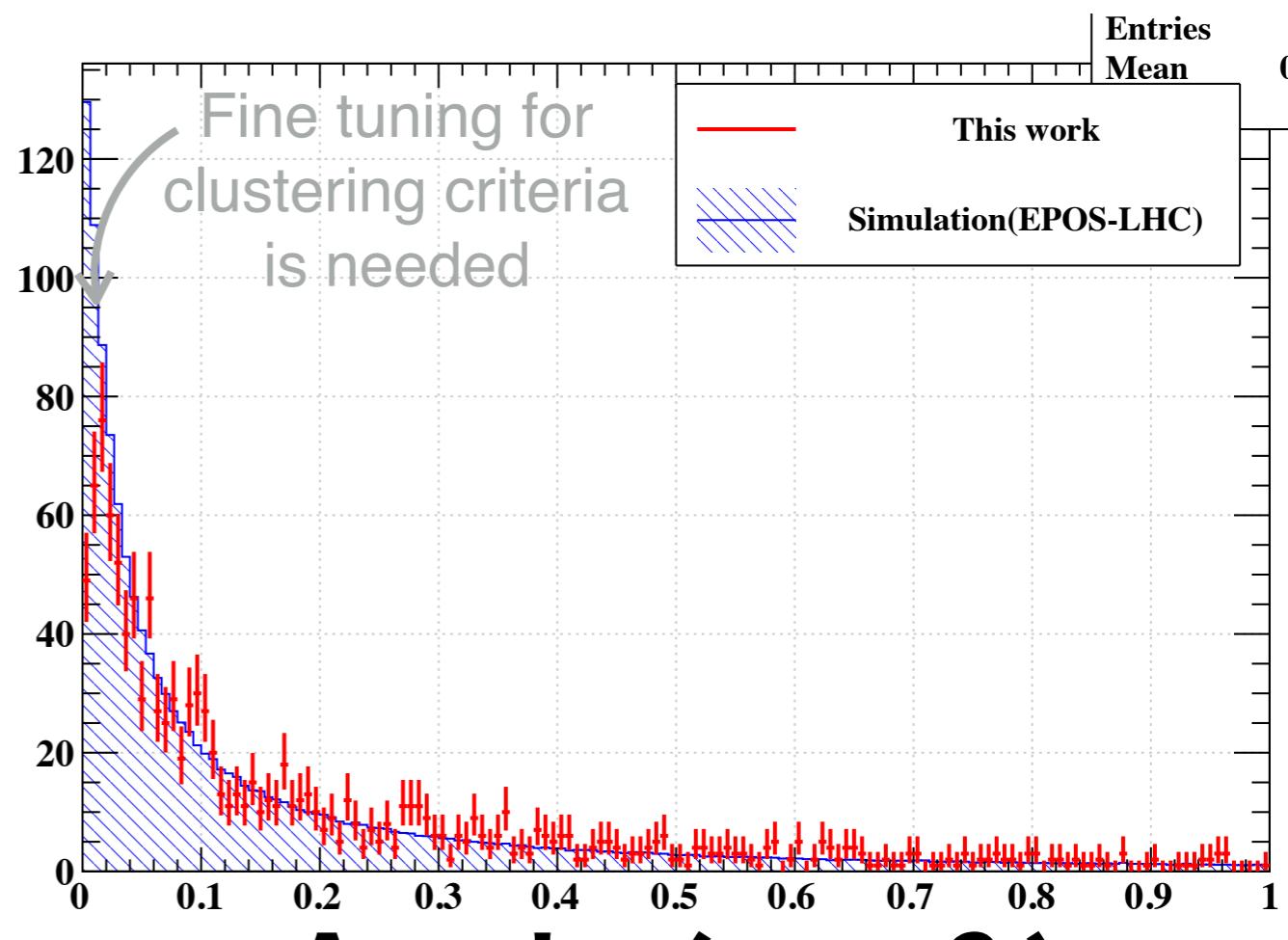


Comparison with Post-LHC Int. Model

Minimum bias measurement with nuclear emulsion



Multiplicity
(preliminary)

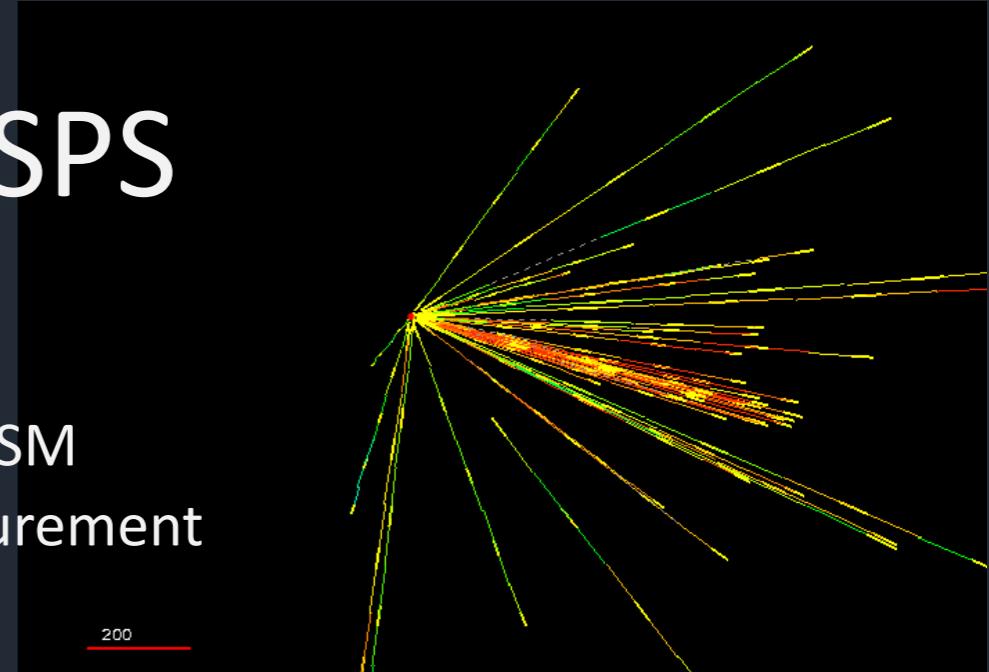


Angle ($\tan \theta$)
(preliminary)

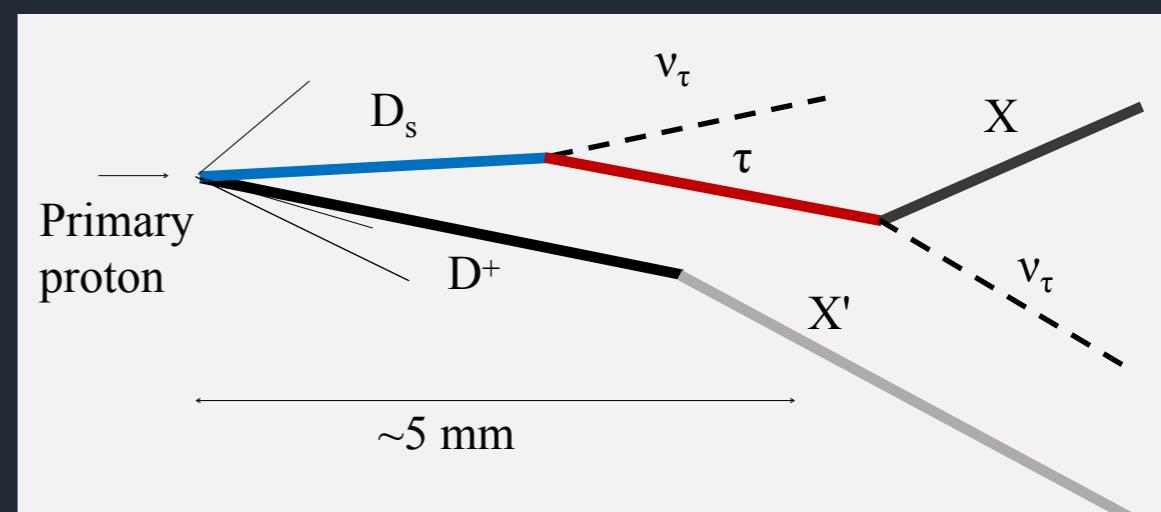
this is the first data of comparison between emulsion
measurement and Post-LHC Int. Model.

The DsTau project at the CERN SPS

- **Physics motivations**
 - Tau neutrinos are among the less known particles in the SM
 - Large systematic uncertainties in the cross section measurement
 - Precision measurement of $\nu\tau$ CC cross section
 - Test of lepton universality in $\nu\tau$ CC interactions
 - Also important for future neutrino experiments, e.g. DUNE, Hyper-K
- **DsTau goals**
 - Improve knowledge of $\nu\tau$ production: systematic uncertainties $\sim 50\% \rightarrow \sim 10\%$
 - Re-evaluation of the cross section from DONUT
 - Essential input for future $\nu\tau$ experiment, e.g. SHiP
- **Method**
 - Detect double-kink topology within a few mm
 - Measure differential production cross section of Ds mesons
- **Status of the project**
 - Lol submitted in Feb. 2016 \rightarrow positive feedback
 - Proton beam tests in Nov. 2016, May 2017
 - **Proposal submitted in Aug. 2017 (SPSC-P-354)**
 - <https://cds.cern.ch/record/2281295?ln=ja#>



ν_τ source:
 $D_s^+ \rightarrow \tau^+ \nu_\tau \rightarrow X \nu_\tau \bar{\nu}_\tau$
 $D_s^- \rightarrow \tau^- \bar{\nu}_\tau \rightarrow X \bar{\nu}_\tau \nu_\tau$



Summary

- **GRAINE project**
 - Precise observation by balloon-borne emulsion gamma-ray telescope
 - High angular resolution, Polarization sensitive, Large effective area
 - SNR, Galactic center/plane, un-ID sources, Polarimetry, Burst events
- **2015-Balloon experiment in AUS**
 - Flight, Scanning, and Analysis were established.
 - Demonstrated gamma-ray imaging performance @100-300 MeV
 - Cosmic ray interaction events were observed in GRAINE chamber ($\sim 10^5$ events.). Good calibration source for gamma-ray observation.
- **Trial of minimum bias measurement for 400 GeV proton int.**
 - Multiplicity & angular distributions seem consistent with Post-LHC model
- **Several working groups in emulsion users start hadron interaction measurements (DsTau project etc.)**