Angular resolution of GRAPES-3 Experiment

Akitoshi Oshima
(National Astronomical Observatory of Japan)

Collaborators
- India (Tata Institute of Fundamental Research)
- Japan (Osaka City University)

GRAPES-3 Experiment

- Main goal
  - Composition and energy spectrum of primary cosmic rays at knee region
  - Search for gamma ray point sources > 10TeV
  - Diffuse gamma ray > 10TeV
  - Anisotropy of cosmic rays due to solar activity

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Extensive air shower array in the world

KASKADE

ARGOYBJ

Tibet ASy

Telescope Array

Chakartaya

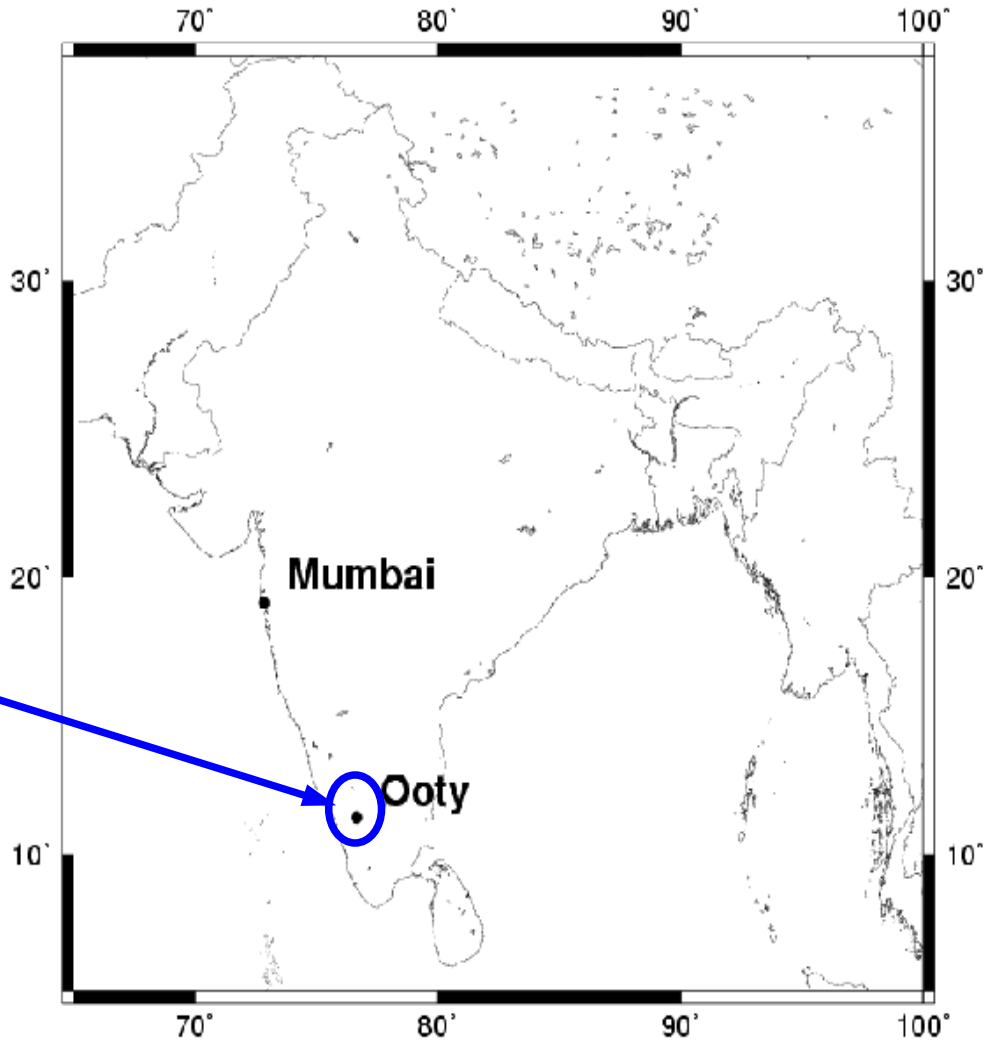
GRAPES-3

Pier Auger

and many others...

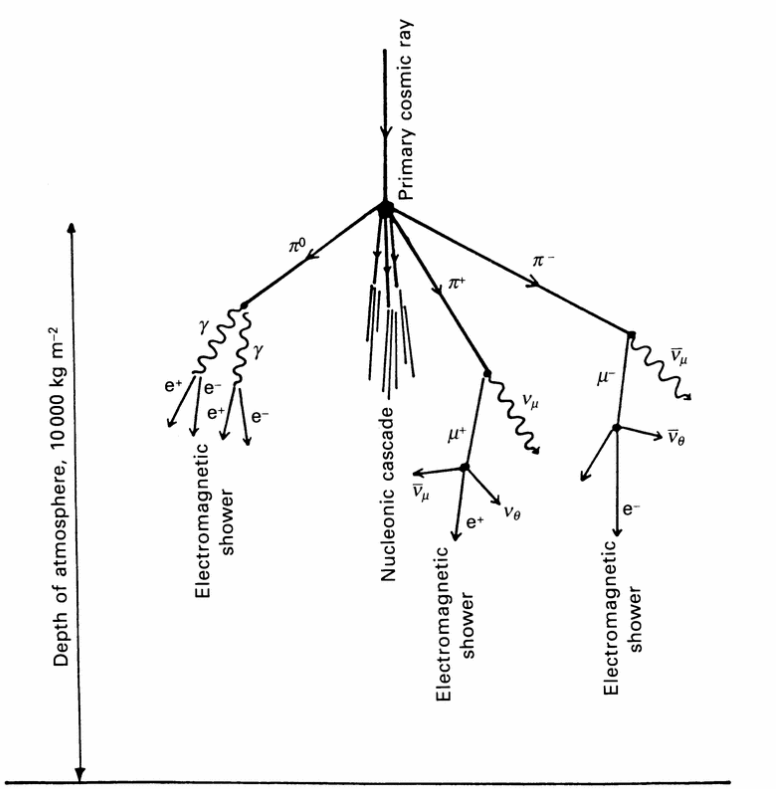
Experiment

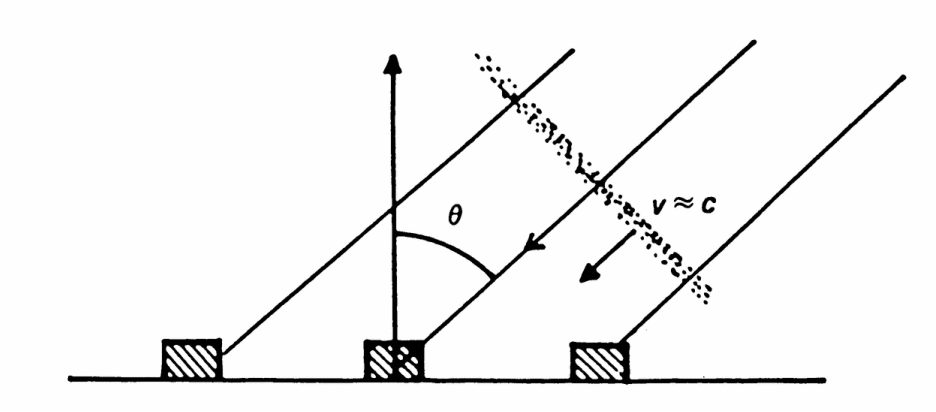
- Collaborator
  - TIFR (India)
  - OCU (Japan)
- Place
  - Ooty, Tamil Nadu
  - 76.7E, 11.4N
  - 2200m asl.
- EAS array
  - scintillation detectors
  - Electromagnetic component
- Muon detectors
  - Proportional counters

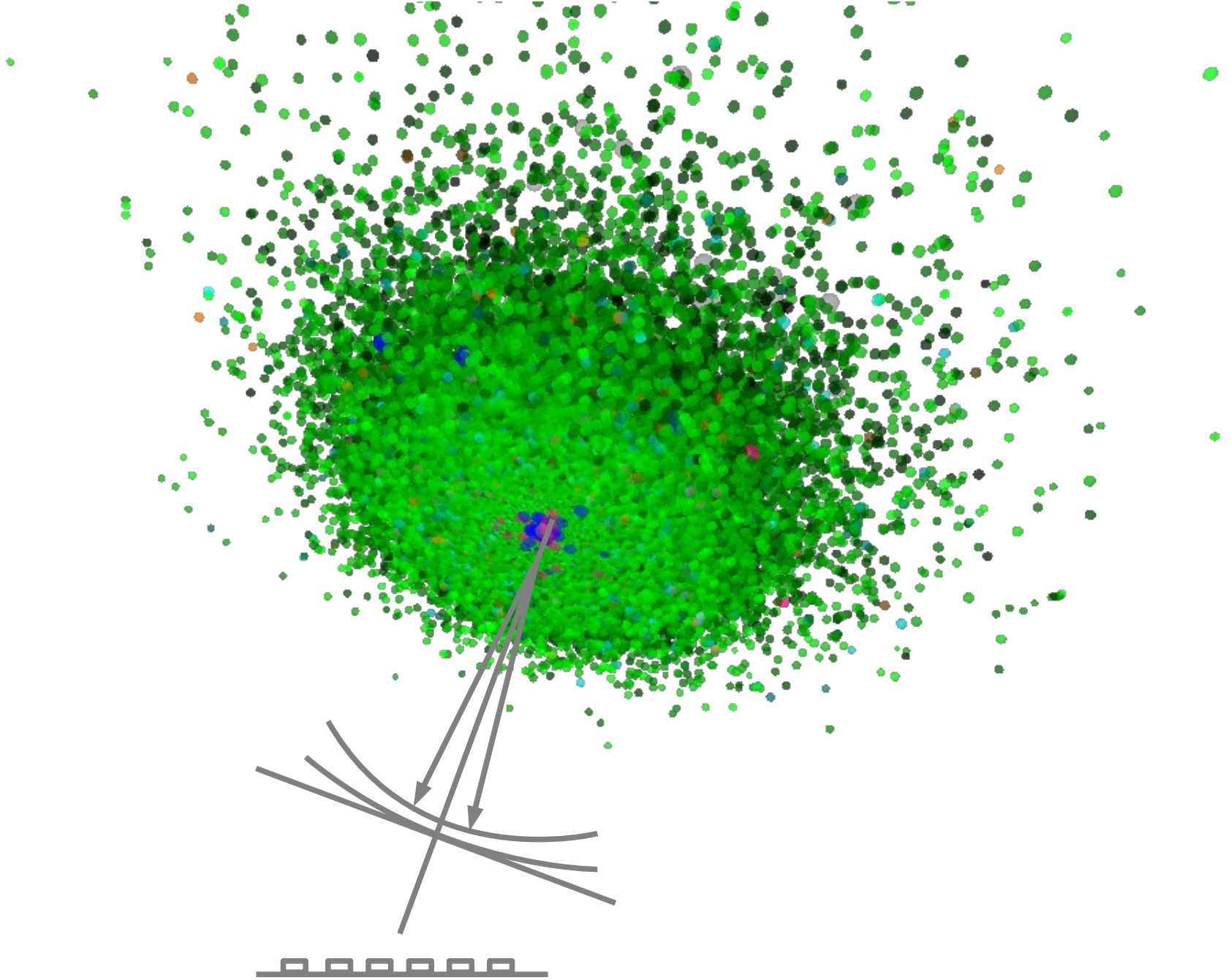


Air Shower Experiment

- Extensive cascade of secondary particles and electromagnetic radiation produced in the atmosphere when a primary cosmic ray enters the earth atmosphere.
- Hadronic cascade and electromagnetic cascade component.

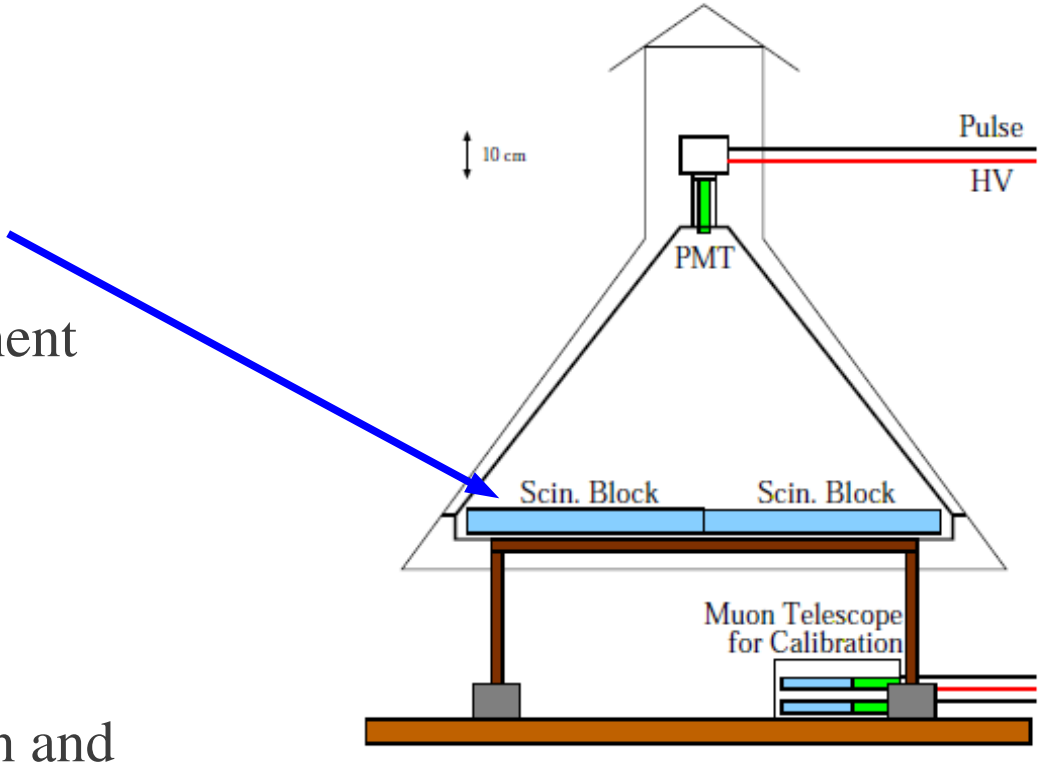






Scintillation detectors

- Arrangement
  - Hexagonal with 8m span
- Scintillator
  - Plastic scintillator
  - 1m x 1m x 5cm
- Electromagnetic component
- Information
  - ADC
  - TDC
- single particle calibration and timing calibration
  - Portable muon telescope
  - ~40days cycle



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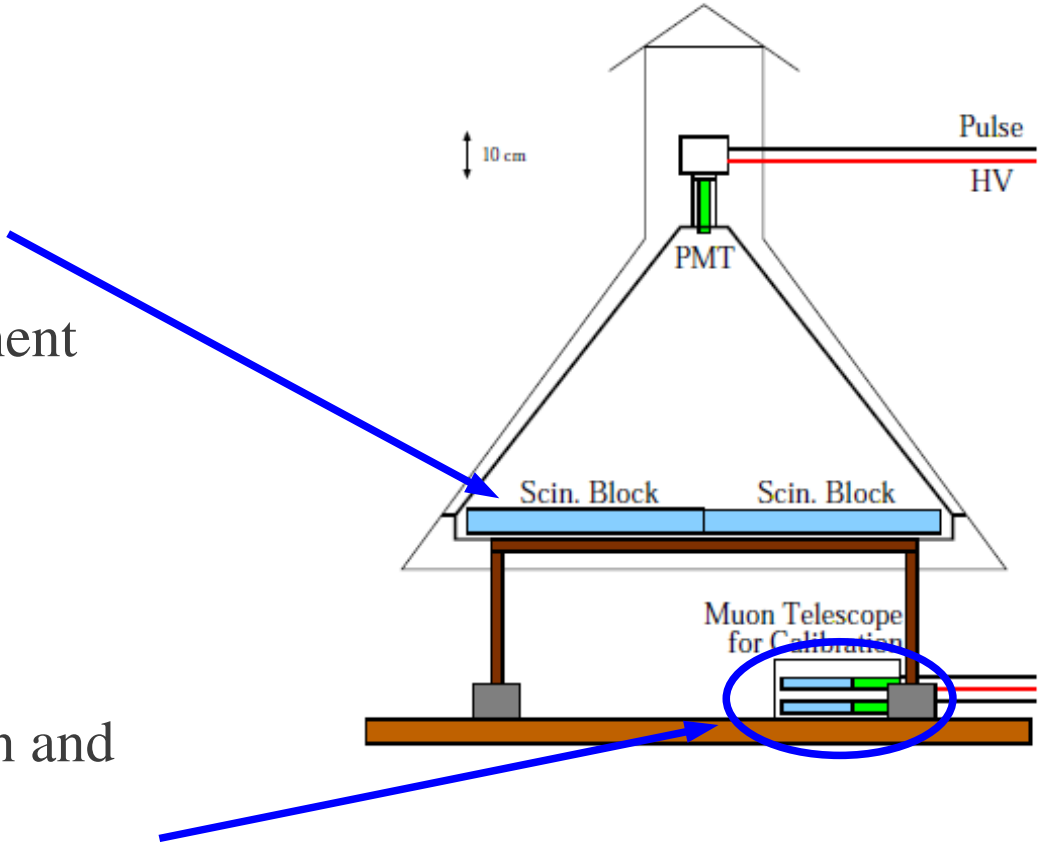

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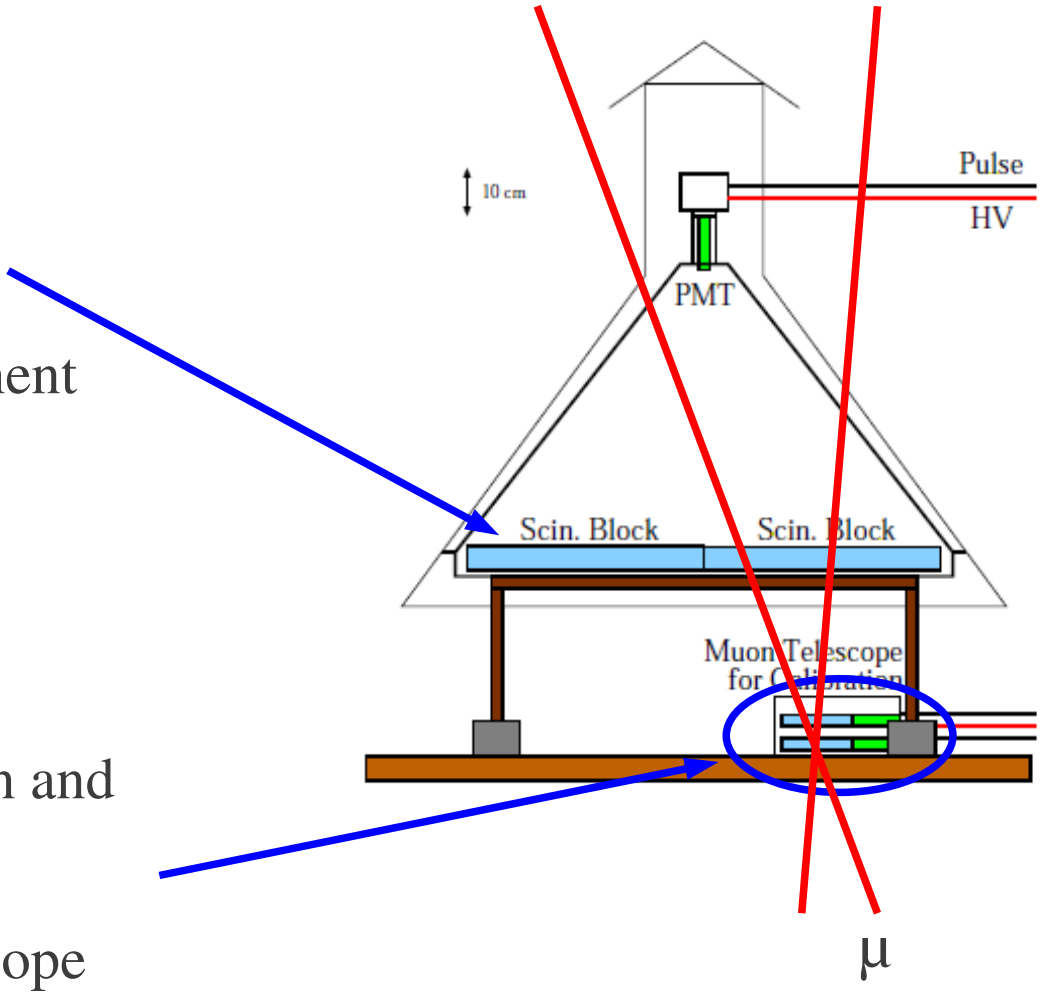

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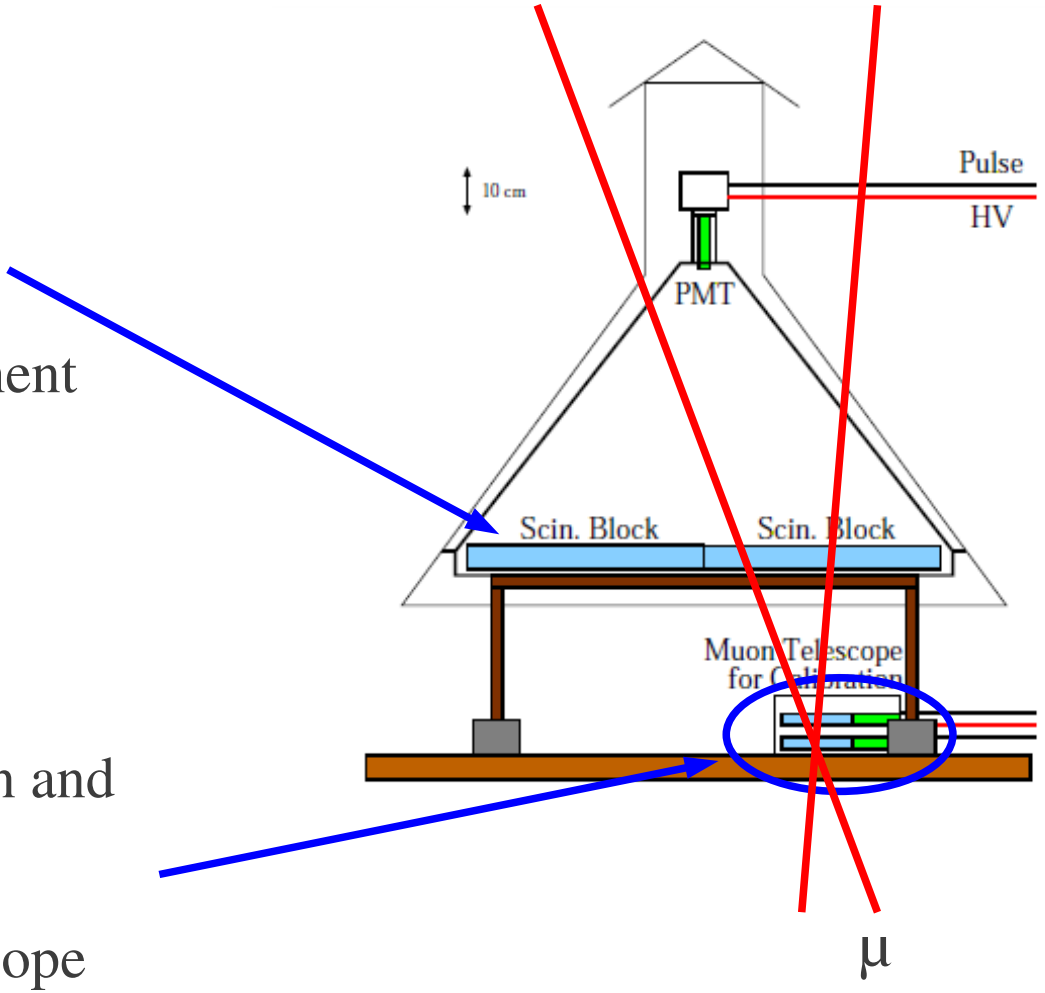
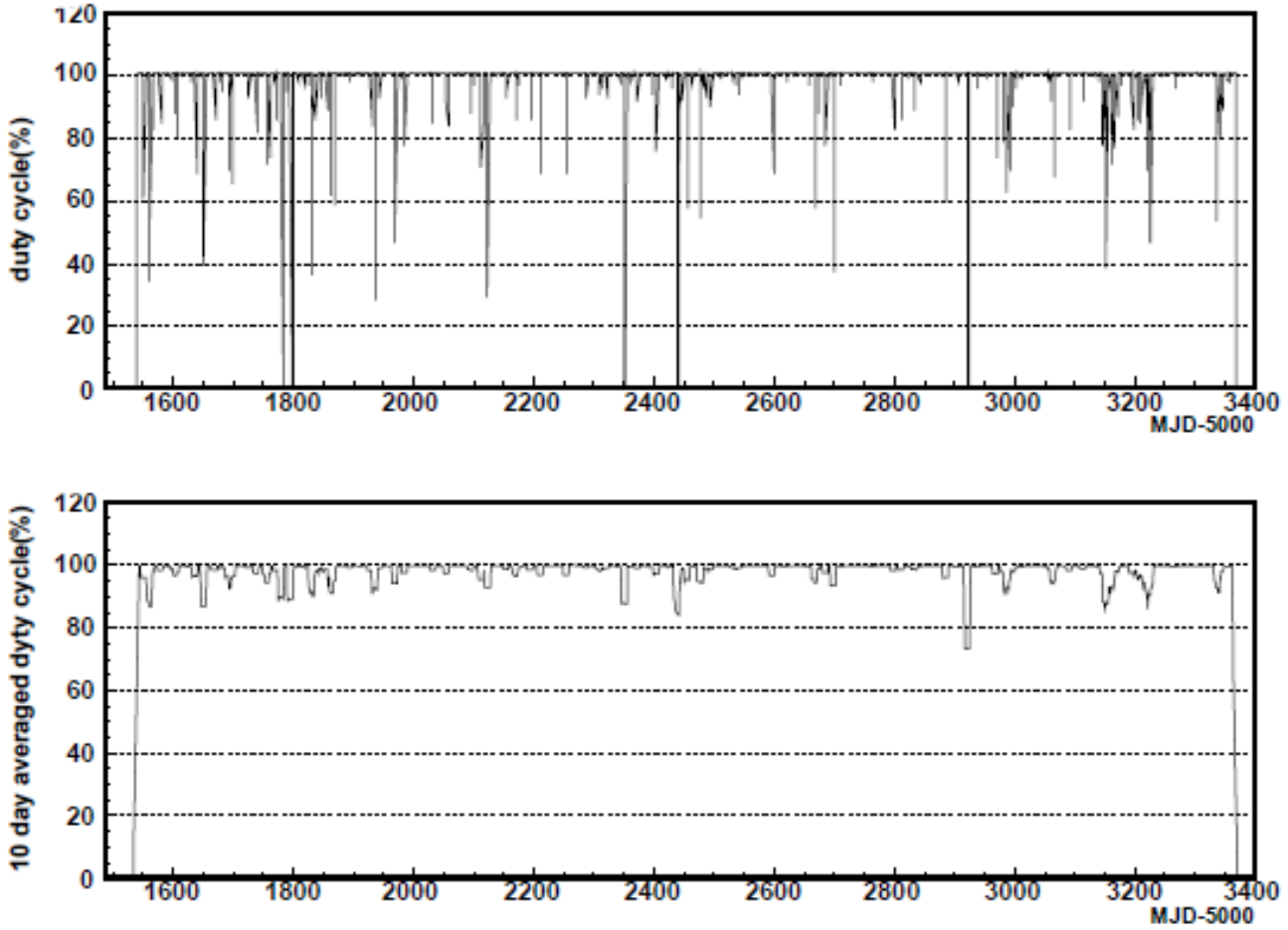


History of Angular resolution of GRAPES-3

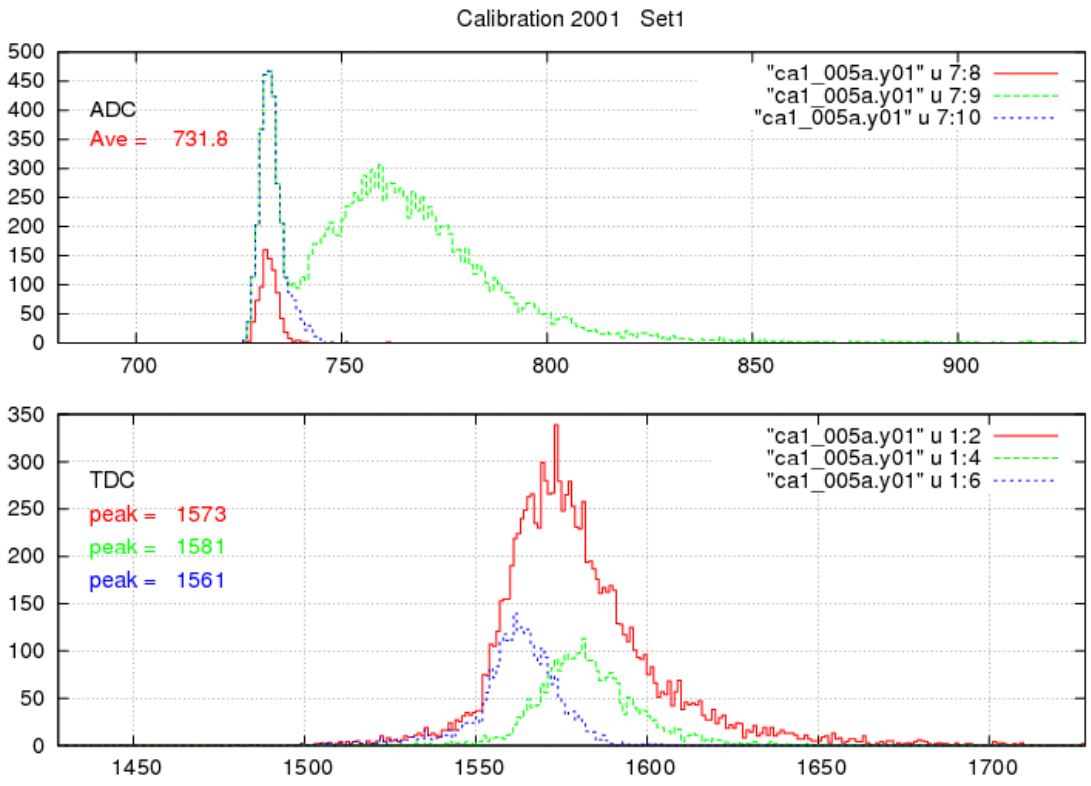
- Improving the angular resolution
  - Moon shadow could not be seen clearly (till few years ago)
  - Timing offset was the key to improve resolution
    - Temperature variation of signal cable?
    - Temperature variation of circuit?
  - Timing offset is measured once in about 40days
- Getting angular resolution(2000-2003)
  - Even-odd method
  - Right-left method
  - Moon and Sun shadow

GRAPES-3 operation (2000-2003)



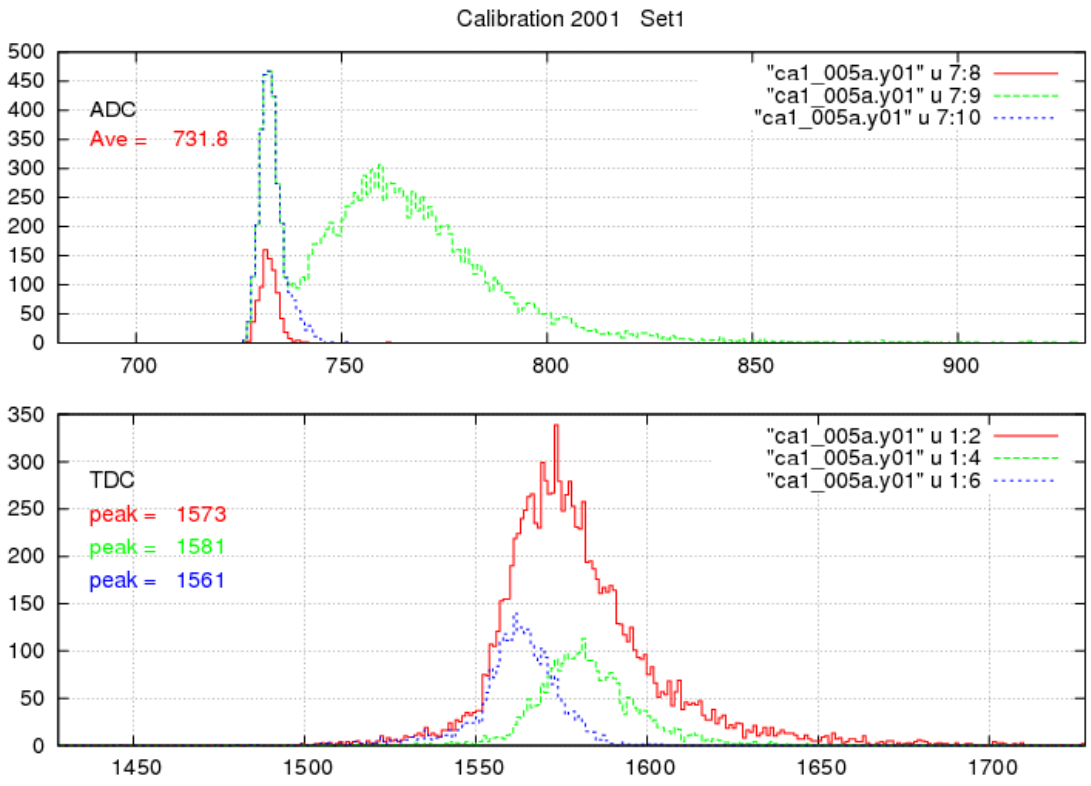
- GRAPES-3 can monitors the sky 24hr.
- Many known TeV gamma ray candidates exist in the field of view.

Timing offset (TDC0)



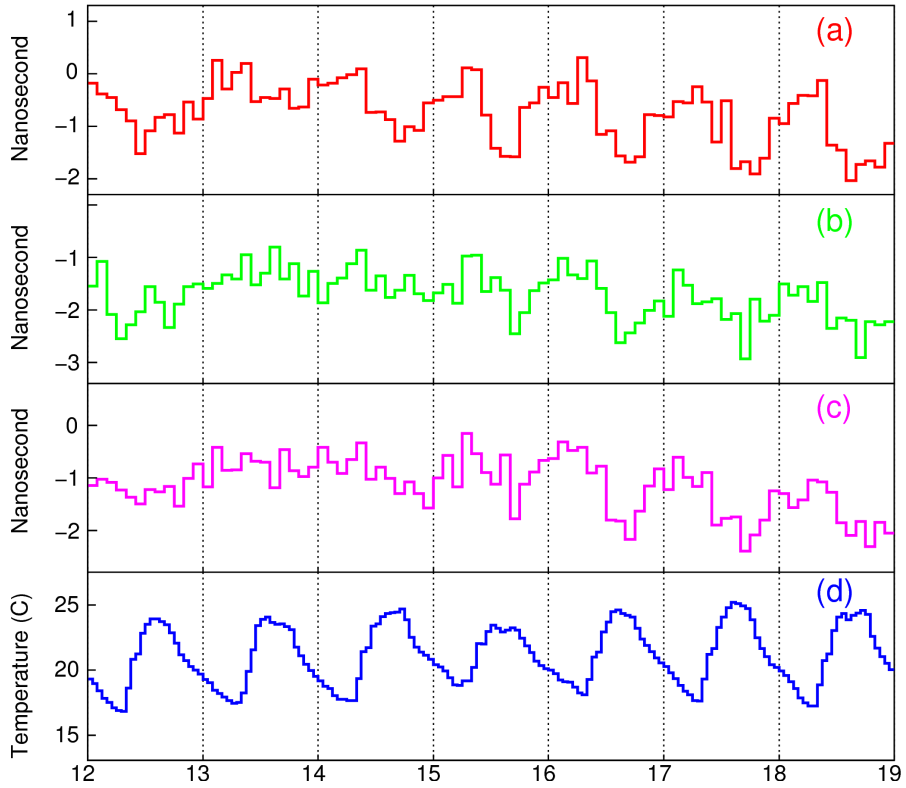
- Timing offset is measured once in 40days
- Measured with the portable muon telescope

Timing offset (TDC0)



→ Recent detailed analysis on TDC0 will be presented by P.K.Mohanty

Variation of timing offset



Ch001

Ch003

Ch005

Temperature

- All detectors have its specific timing offset
- Variation comes from where?

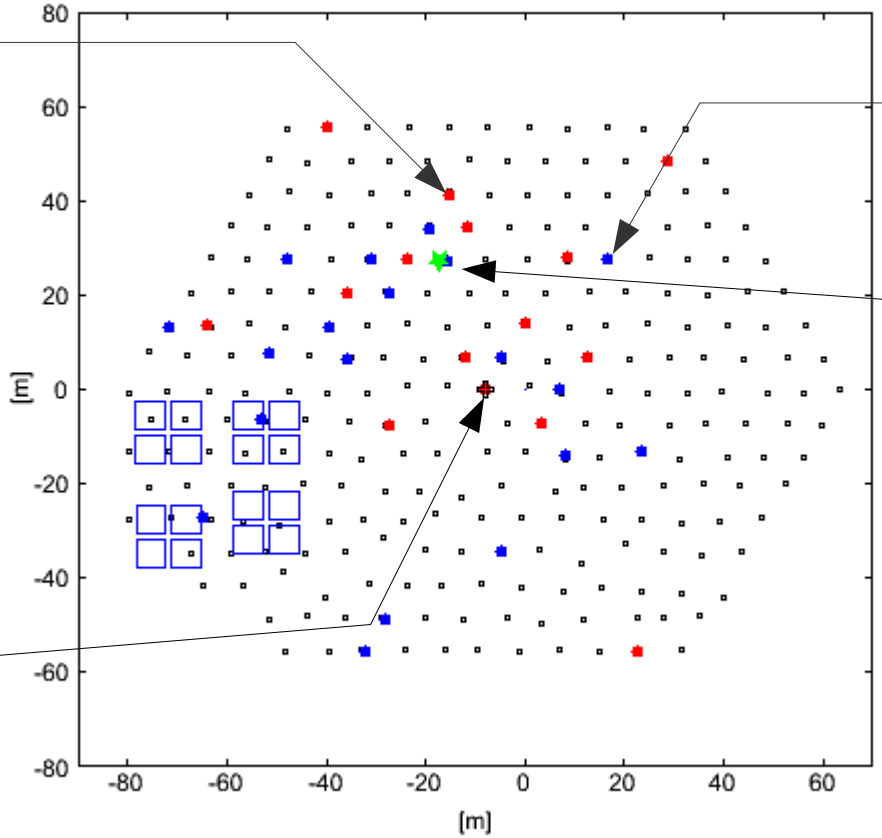
Even odd method

Detector in Even array

Detector in Odd array

Shower core

Center of the array

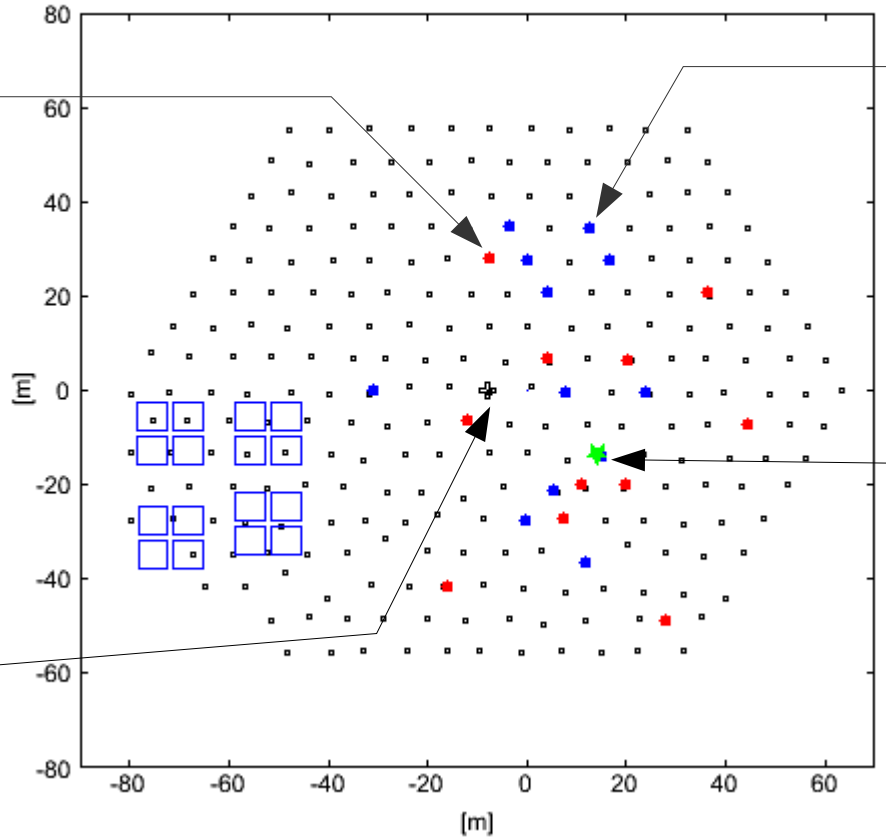


- Divide the array into two sub array
- Each array covers the same area with half number of detectors

Even odd method

Detector in Even array

Detector in Odd array

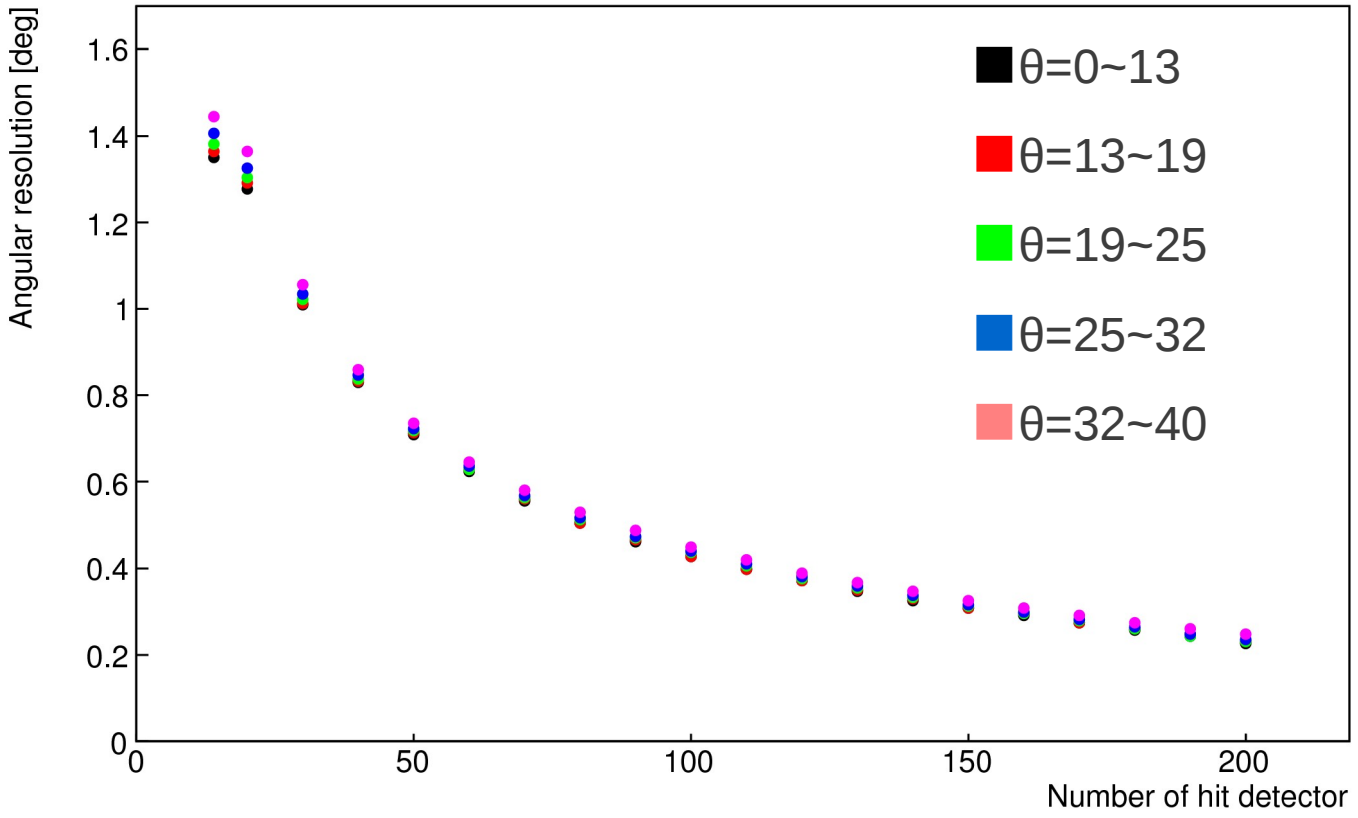


Shower core

Center of the array

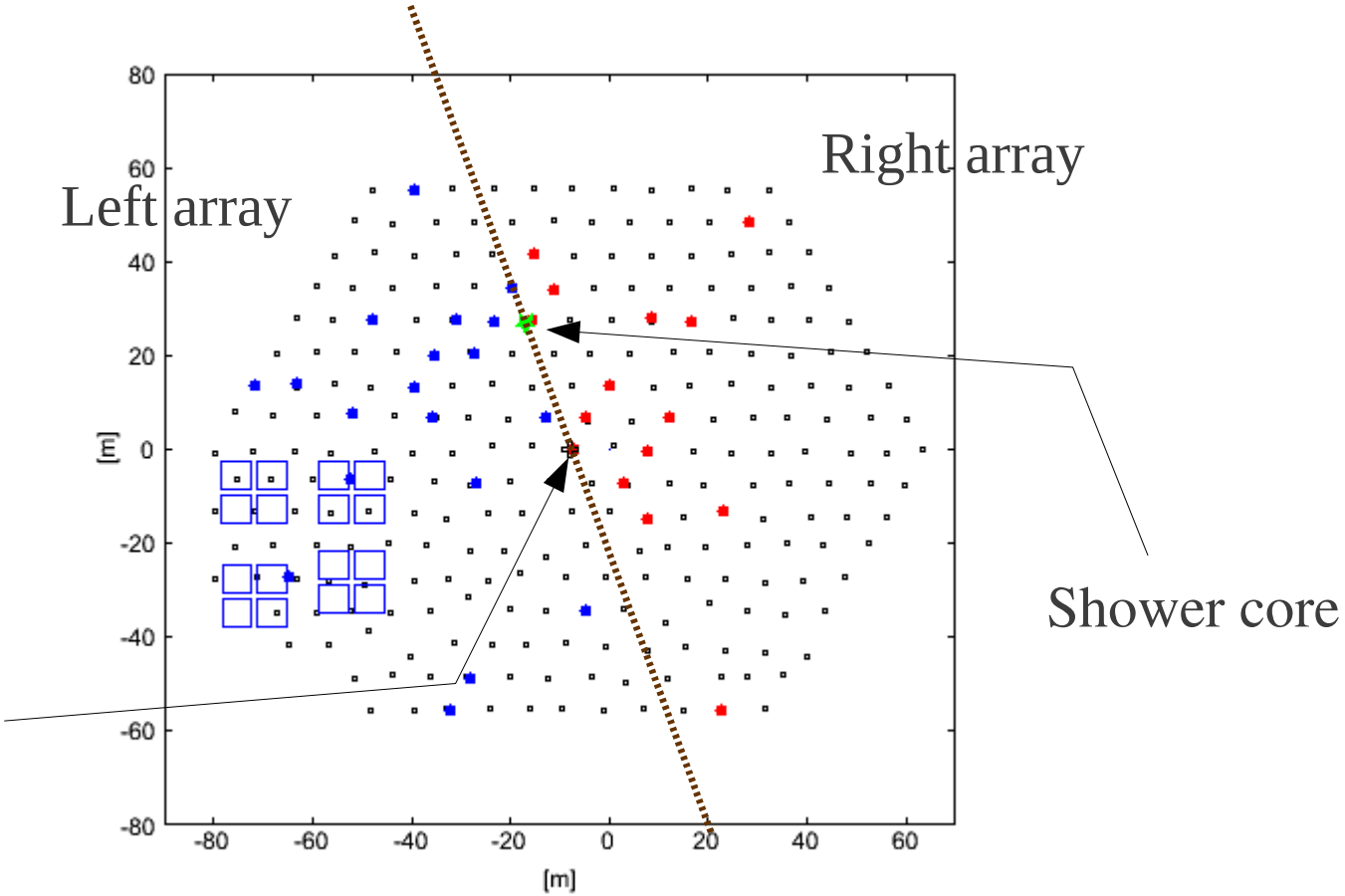
- Divide the array into two sub array
- Each array covers the same area with half number of detectors

Angular resolution (Even odd method)



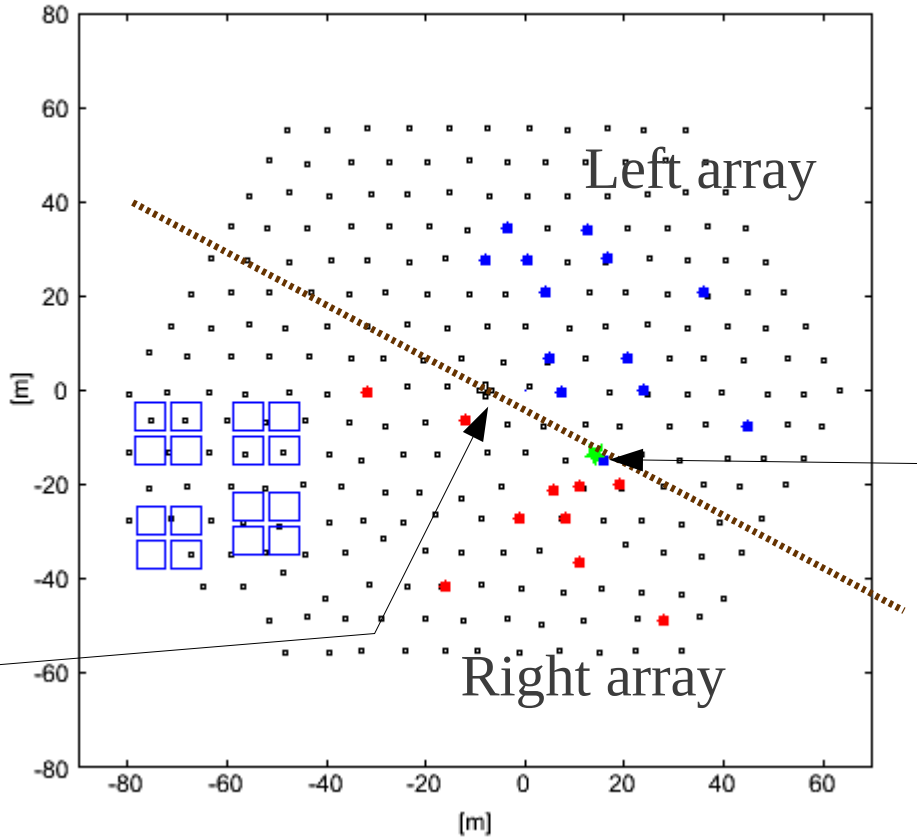
- Constant in different zenith angle
- Better angular resolution with large number of detectors

Right left method



- Split the array into right and left array
- Each array covers half the area with half number of detectors

Right left method

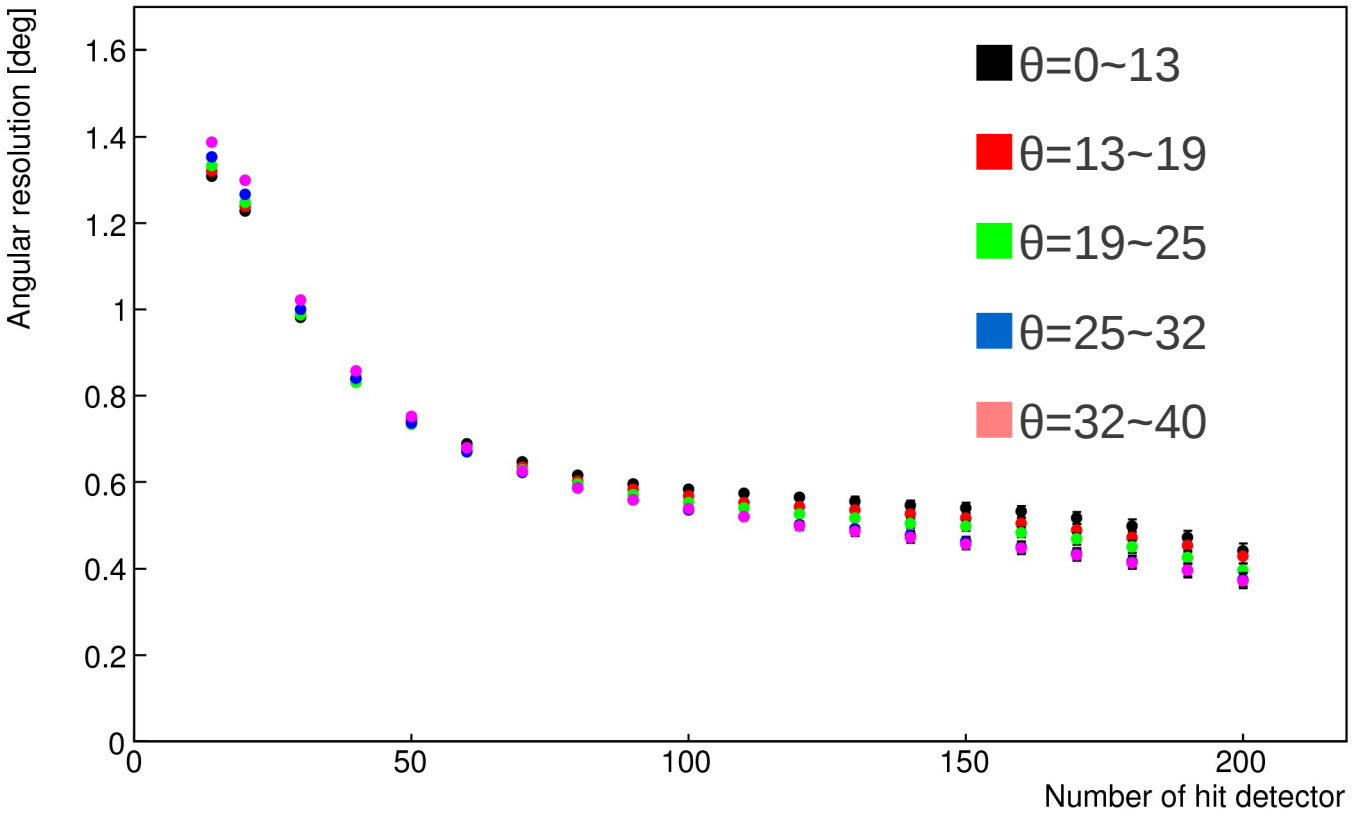


Shower core

Center of the array

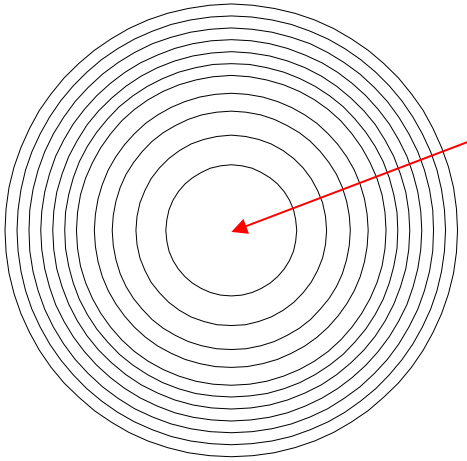
- Split the array into right and left array
- Each array covers half the area with half number of detectors

Angular resolution (Right left method)



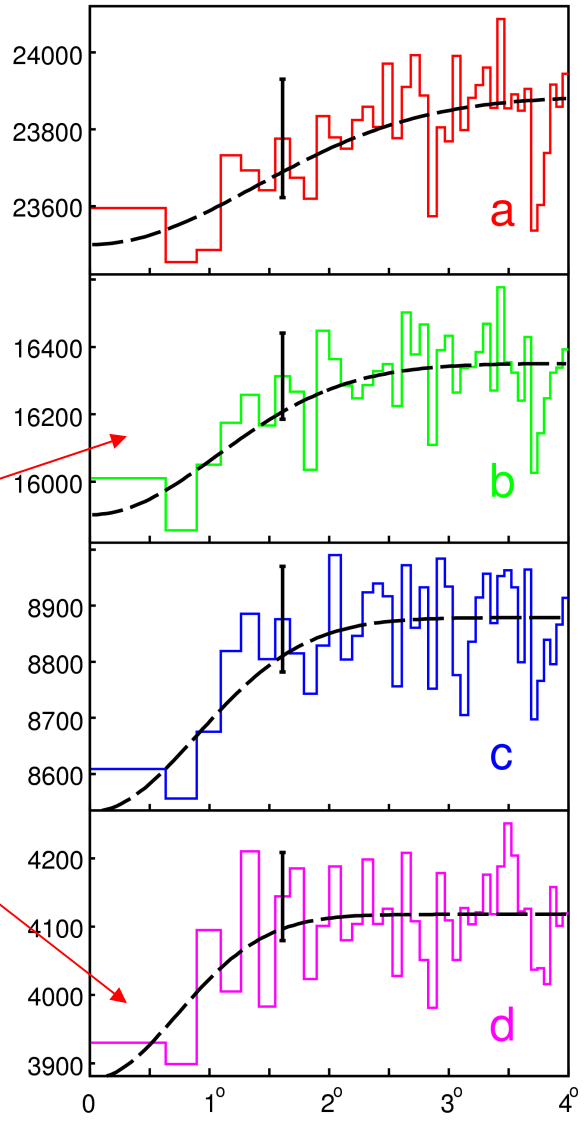
- Angular resolution is changing in different zenith angle
- Fitting effect? Cone fitting

Moon shadow



Moon or Sun

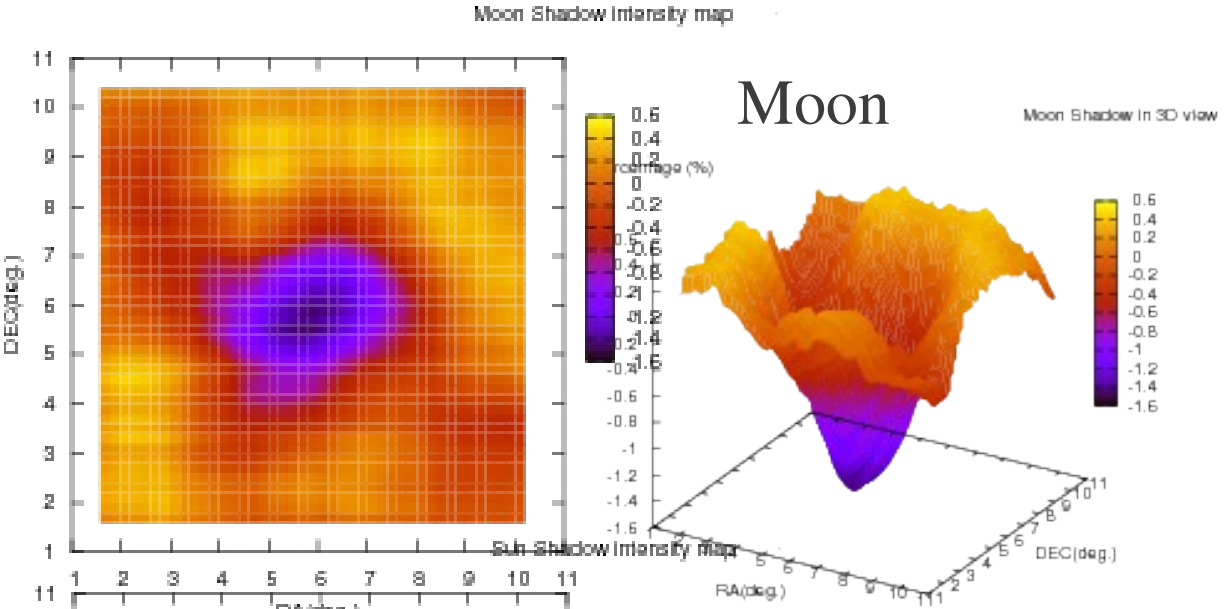
Radius~0.25°

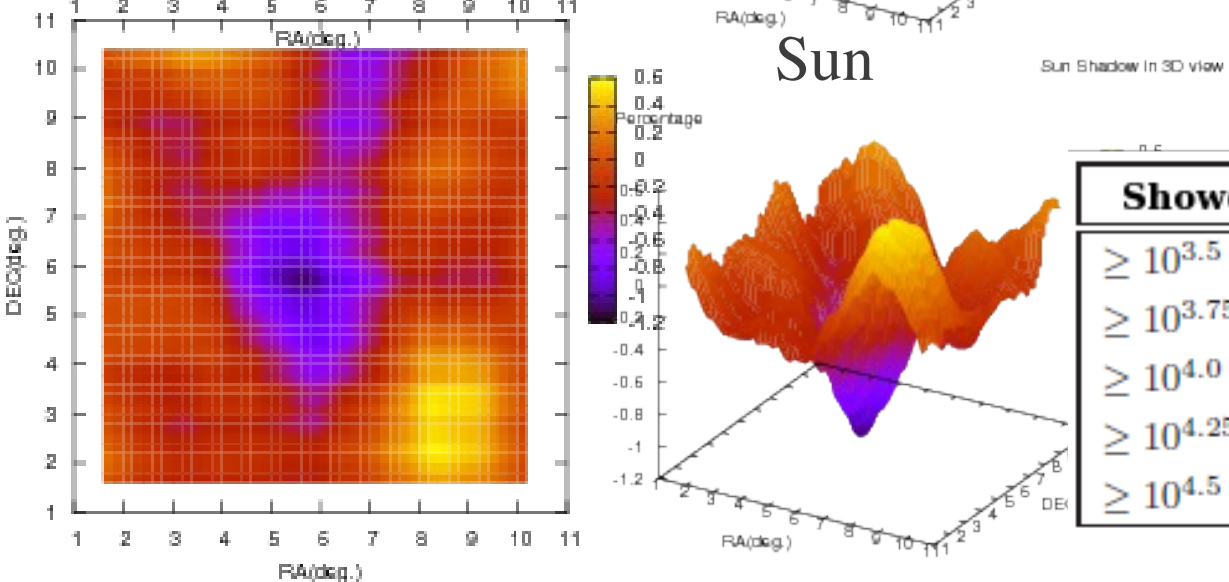


Deficit of the count of cosmic rays due to shadow

Moon and sun shadow can be seen with good angular resolution.

Moon and Sun shadow





Shape of the shadow

↓ assumption

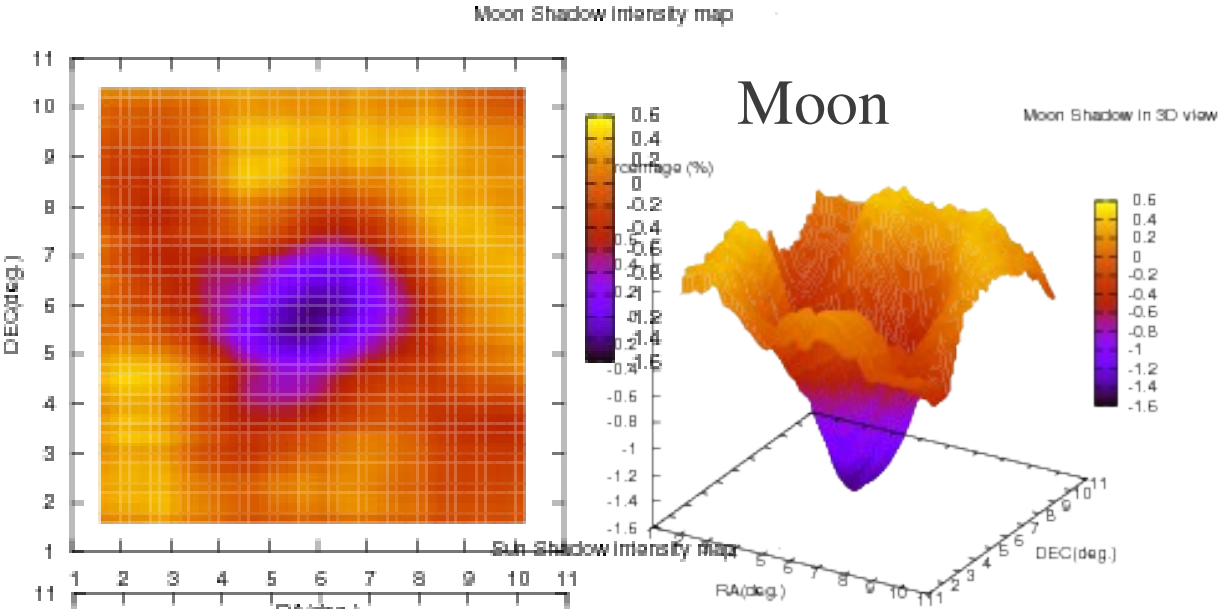
2D gaussian distribution

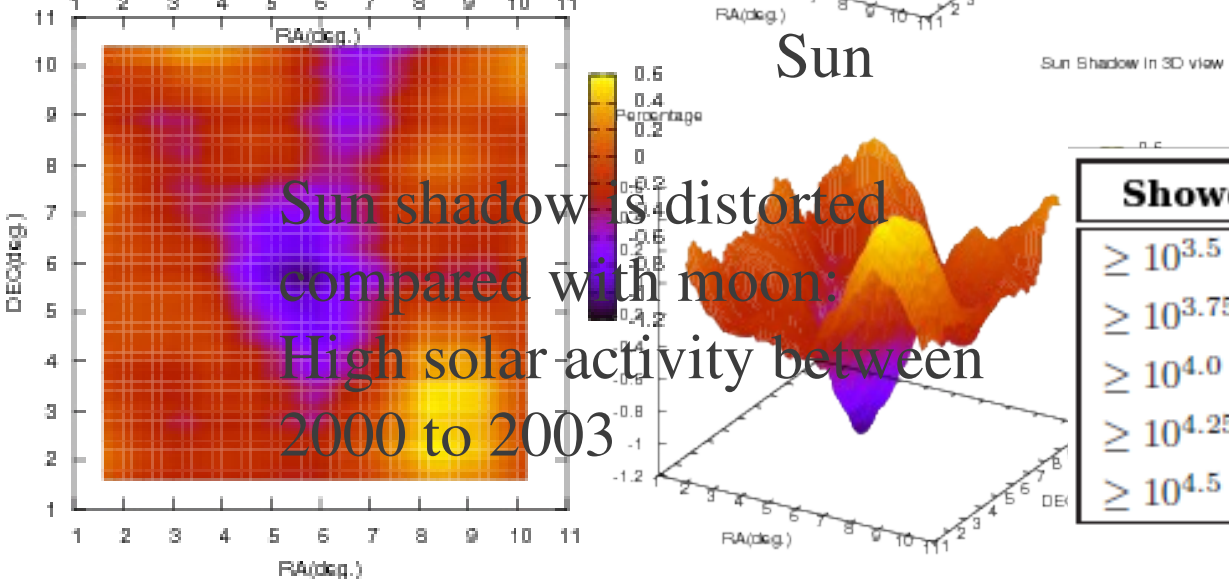
↓

Angular resolution from Moon shadow

Shower size (N_e)	Ang. resolution	Error
$\geq 10^{3.5}$	1.07°	0.13°
$\geq 10^{3.75}$	0.89°	0.12°
$\geq 10^{4.0}$	0.73°	0.10°
$\geq 10^{4.25}$	0.61°	0.09°
$\geq 10^{4.5}$	0.50°	0.10°

Moon and Sun shadow





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Angular resolution from Moon shadow

Sun shadow is distorted compared with moon: High solar activity between 2000 to 2003

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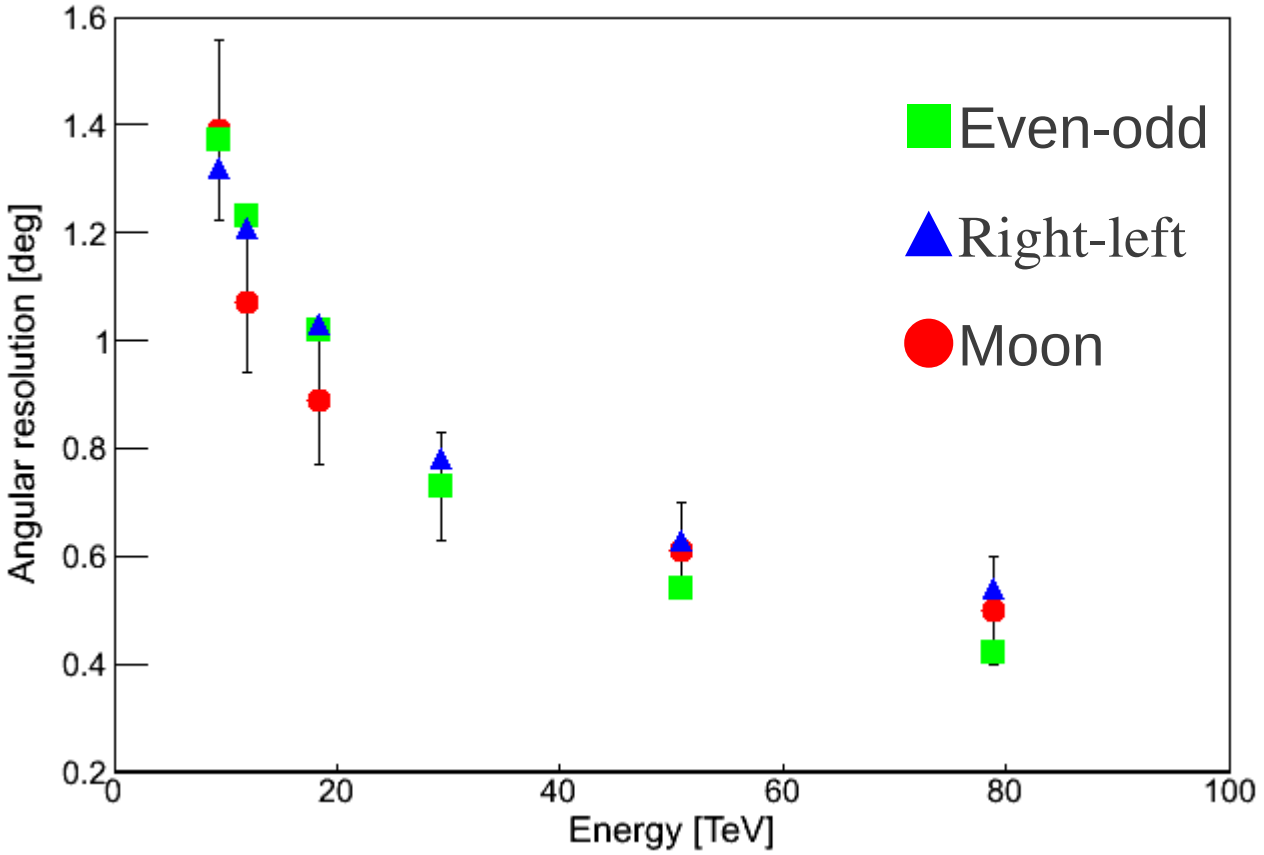
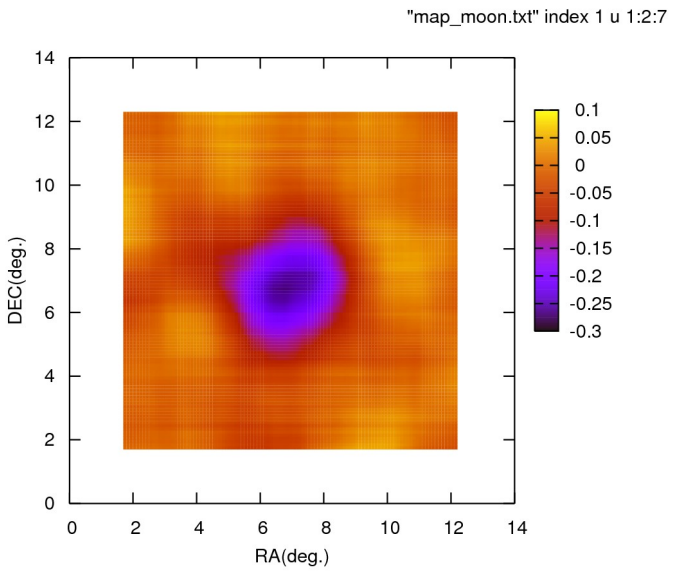
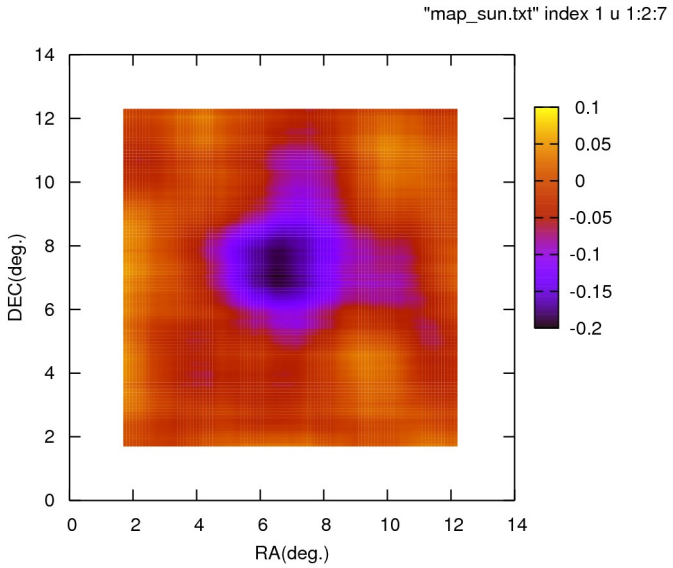
Angular resolution of GRAPES-3



Recent analysis(7years data)



Moon



Sun

- Data: 2000 – 2006 (7years data)
- Moon and Sun are detected clearly

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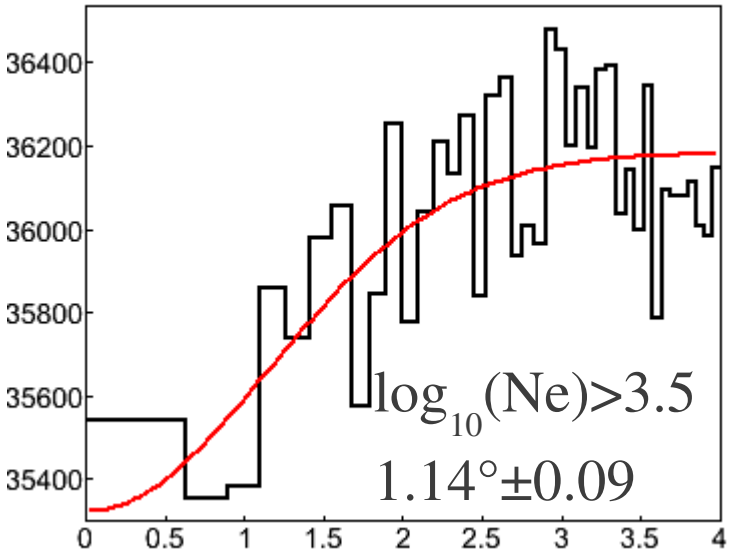

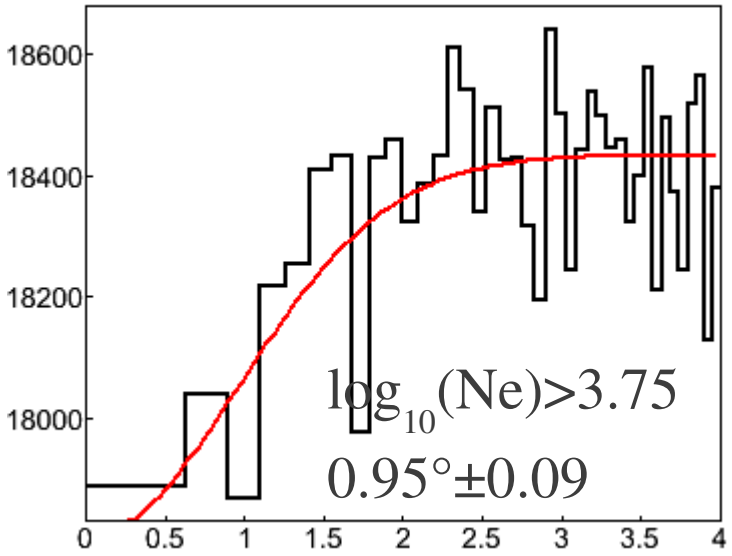

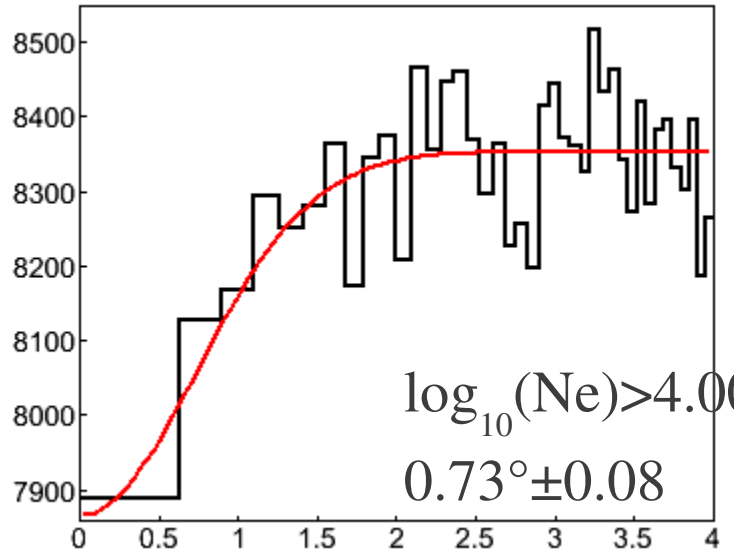

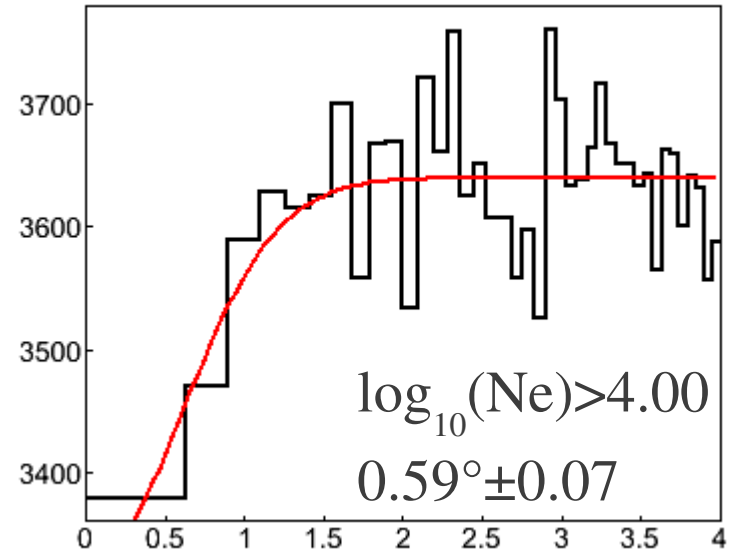

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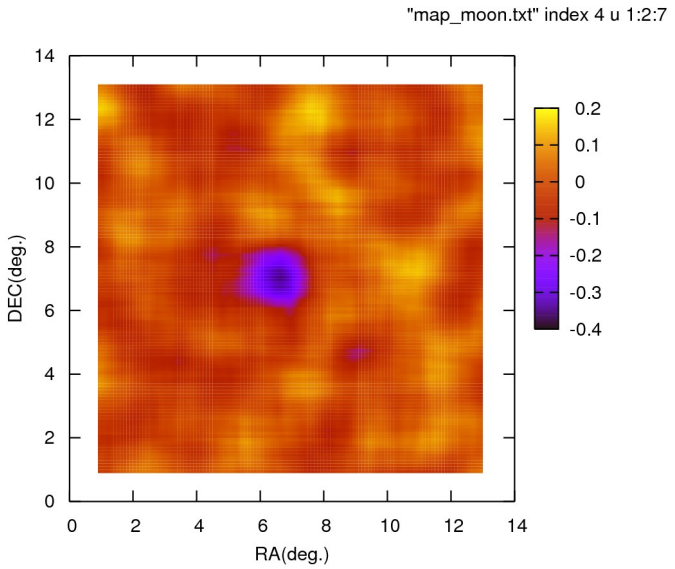

Moon

Summary

- Angular resolution
  - Data 2000-2003 analyzed
  - Three different methods were used
  - Even-odd, right-left, Moon shadow
  - $0.5° > 80\text{TeV}$
- Data updated
  - Data 2000-2006 analyzed
  - Moon and Sun shadow detected clearly