# CANGAROO-III: Status report

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for the CANGAROO team

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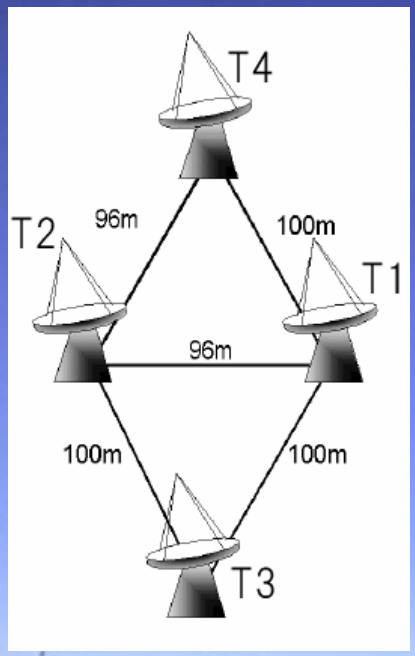
Towards a Network of Atmospheric Cherenkov Detectors VII,
April 27-29, 2005, École Polytechnique

# CANGAROO team

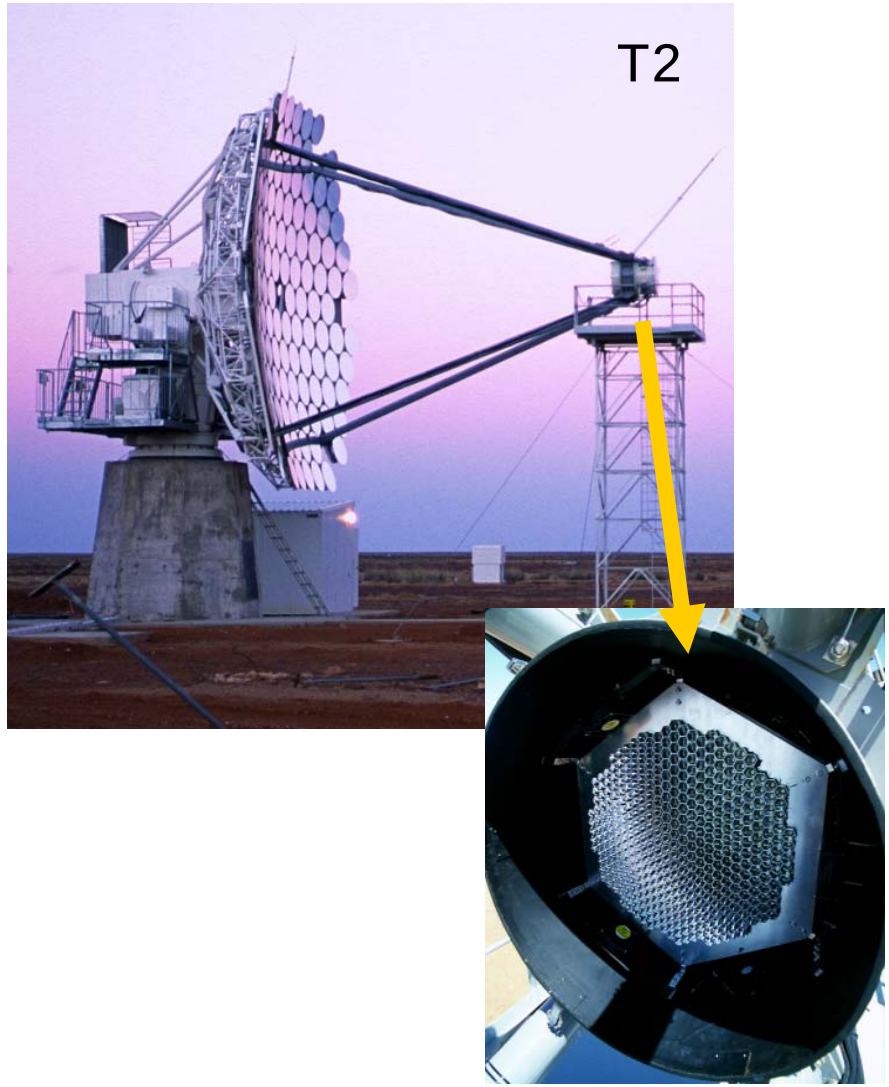
- University of Adelaide 
- Australian National University 
- Ibaraki University 
- Ibaraki Prefectural University 
- Konan University 
- Kyoto University 
- STE Lab, Nagoya University 
- National Astronomical Observatory of Japan 
- Kitasato University 
- Shinshu University 
- Institute of Space and Astronautical Science 
- Tokai University 
- ICRR, University of Tokyo 
- Yamagata University 
- Yamanashi Gakuin University 

# Woomera: 2004 March

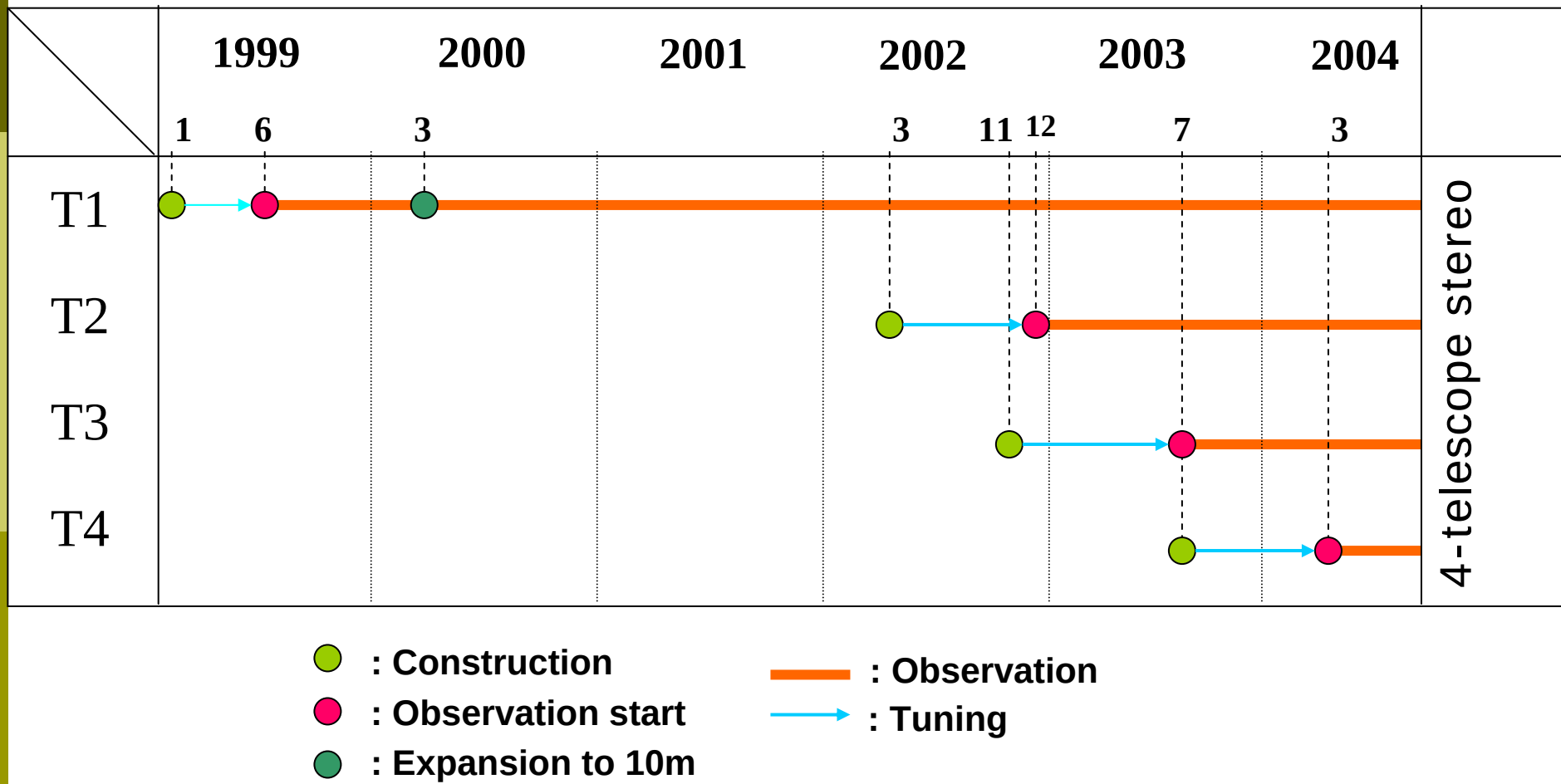



# Basic specifications of telescopes

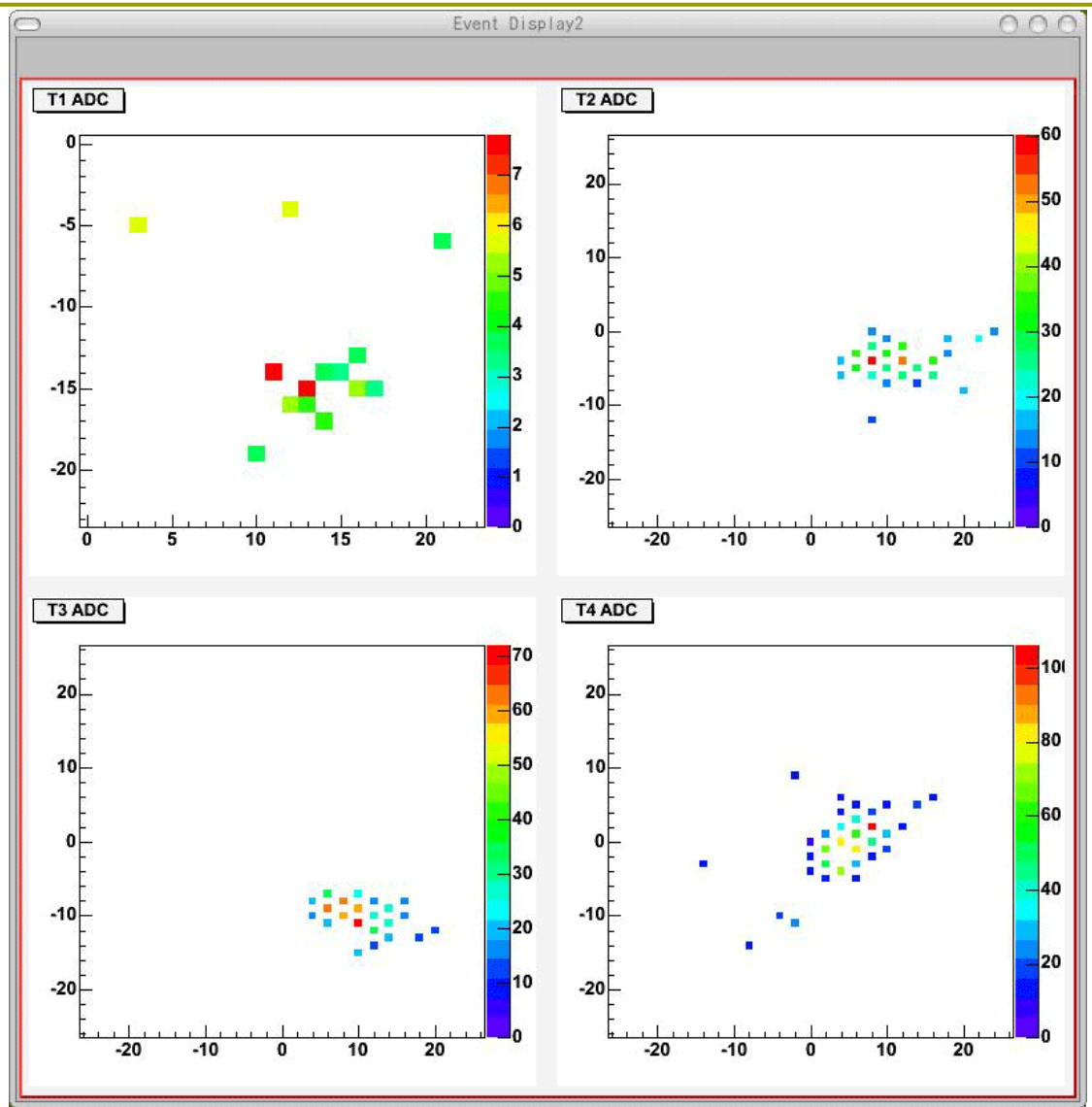
- Location:
  - 31°06'S, 136°47'E
  - 160m a.s.l.
- Telescope:
  - 114× 80cmϕ FRP mirrors (57m$^2$, Al surface)
  - 8m focal length
  - Alt-azimuth mount
- Camera:
  - T1: 552ch (2.7° FOV)
  - T2,T3,T4: 427ch (4° FOV)
- Electronics:
  - TDC+ADC



# Construction of CANGAROO-III



# Sample of 4-fold stereo events



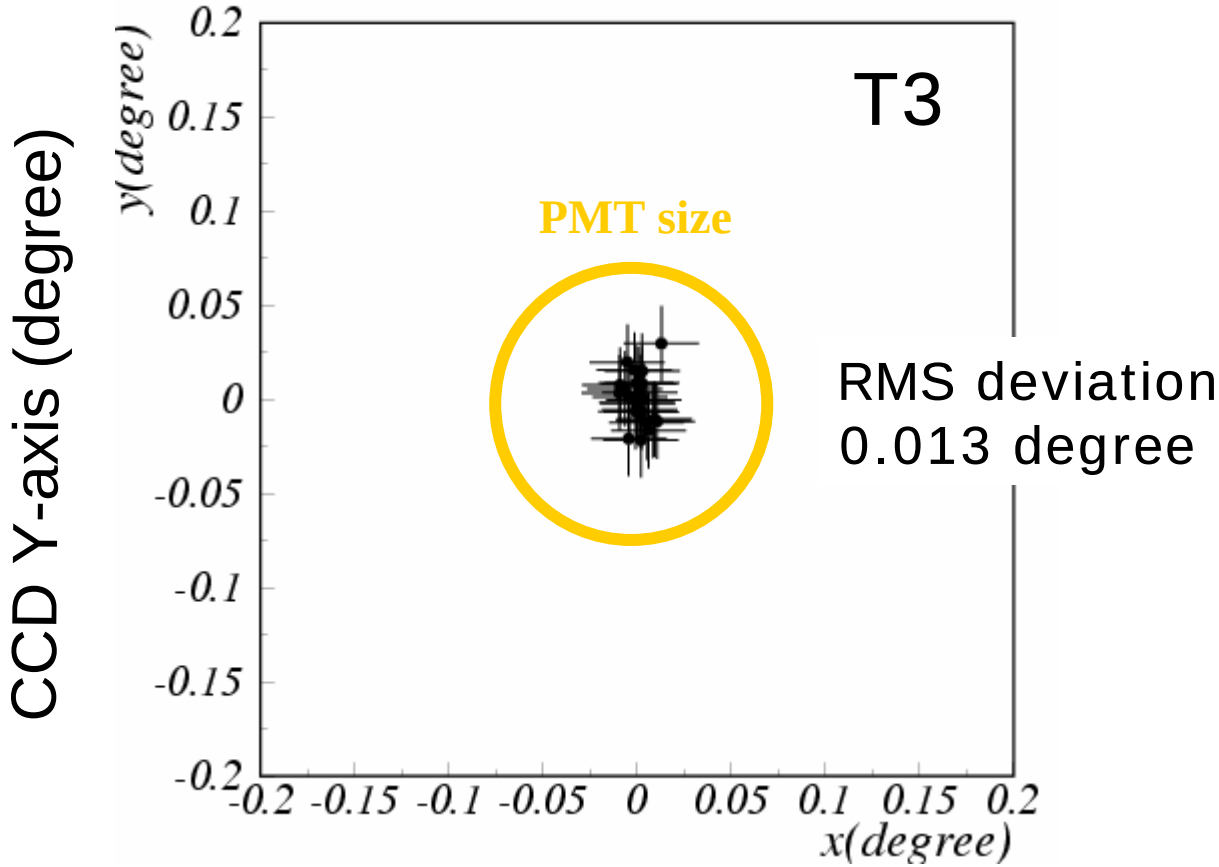

Data:
2004
March

# Stereo analysis: still underway & in progress

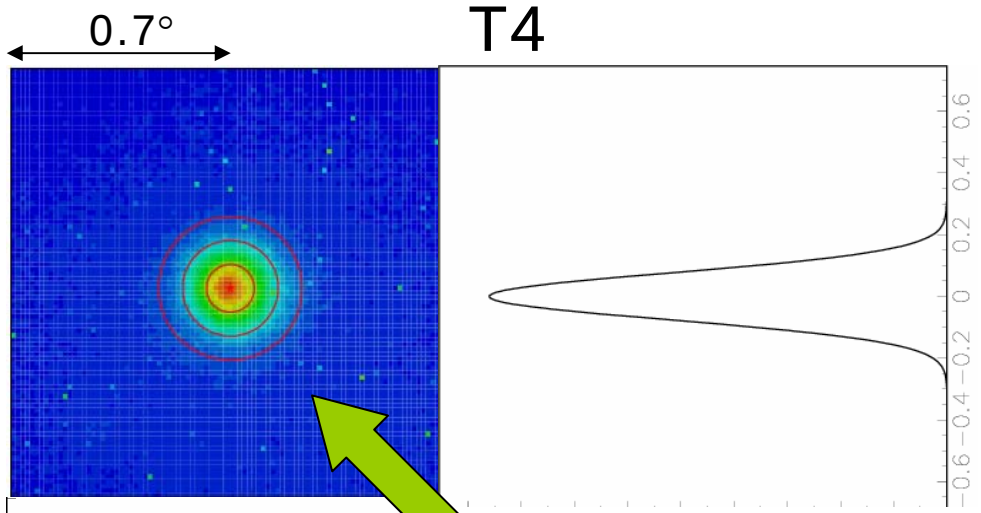
- Inconsistency with H.E.S.S results on some sources
  ⇒ New observations with CANGAROO III
  Efforts for advanced analysis procedures
- Measure more optical parameters
  - CCD measurements of spotsizes and stars
- Use muons for calibration
  - Tune Monte Carlo simulation
- Use the Crab as the standard candle
  - Flux obtained with Monte Carlo simulation is compared with those reported by other groups
- Independent teams within the collaboration are working:
  - Hereafter, referred to as Teams A, B, C ...
  - Results, especially detections, are double-checked

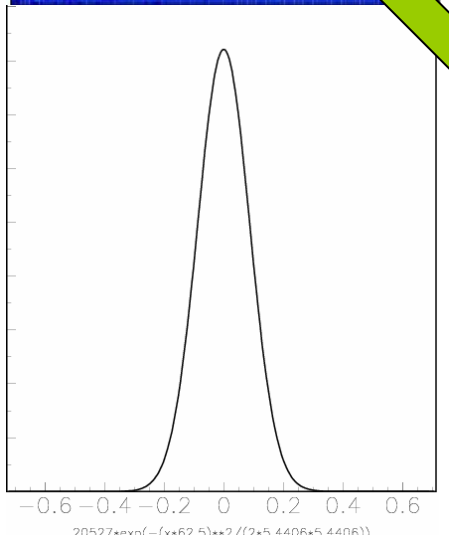
# Star tracking

Star position error observed by a CCD camera



# Spot size




Point Spread Function (FWHM)

T1: 0.20°

T2: 0.21°

T3: 0.14°

T4: 0.16°

(measured at construction time)

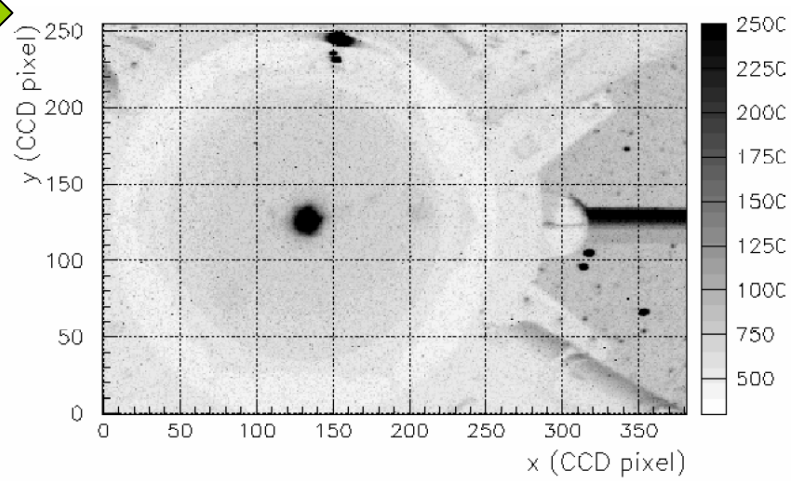
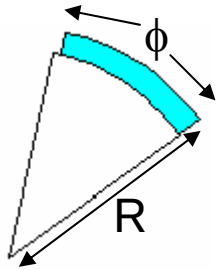



Image of a star on camera observed by a CCD camera

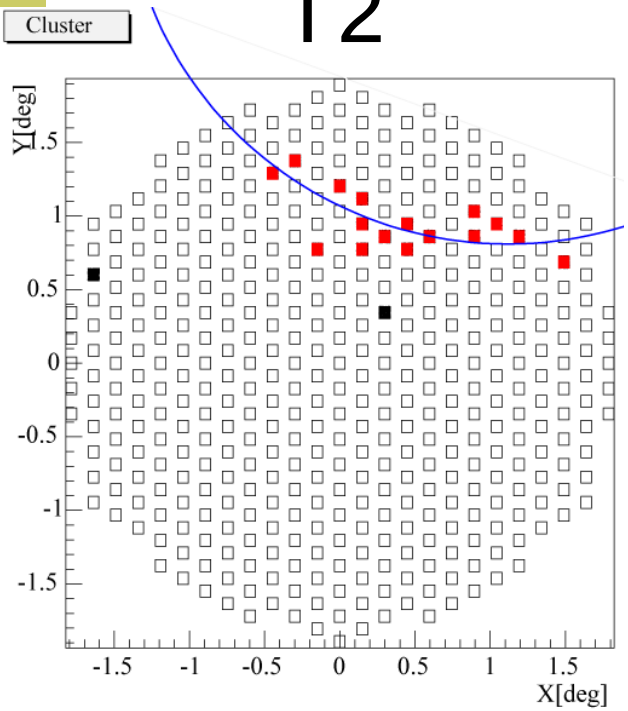
# Muon events (1)

- Selected by
  1) clustering
  2) R×ϕ (arc length) >2deg•rad
  3) Small $\chi^2$ (good fit)

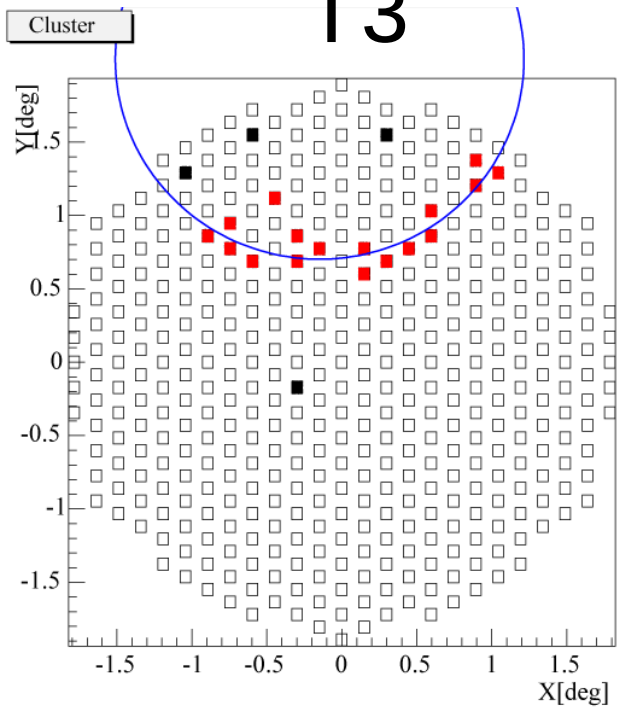



Data: 2004 March

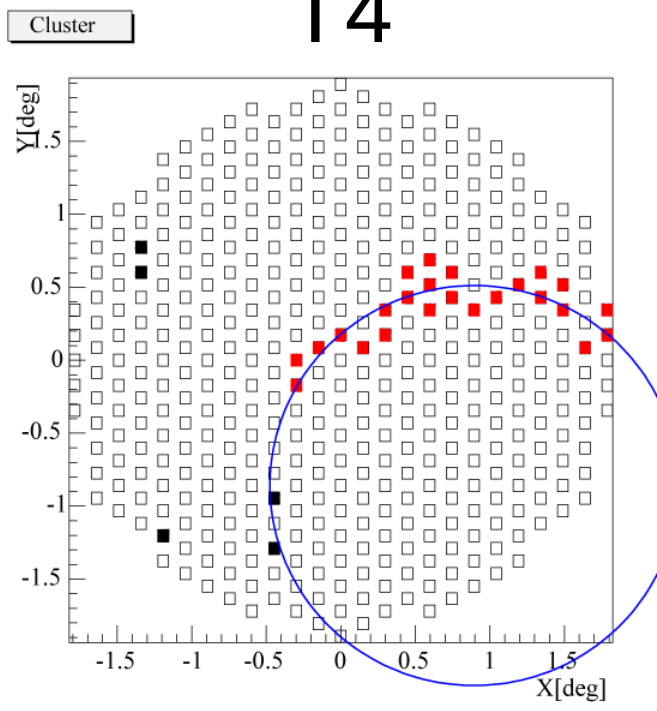
T2




T3



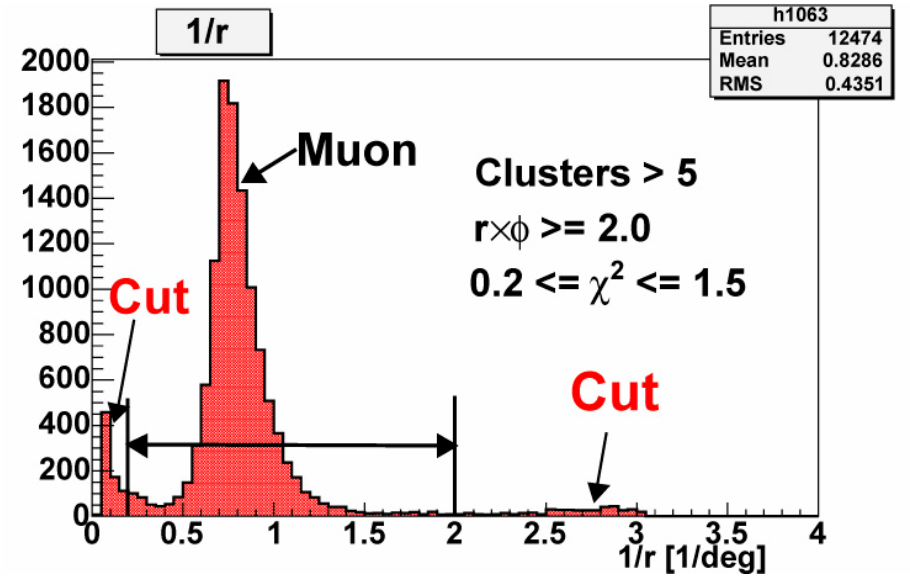

T4

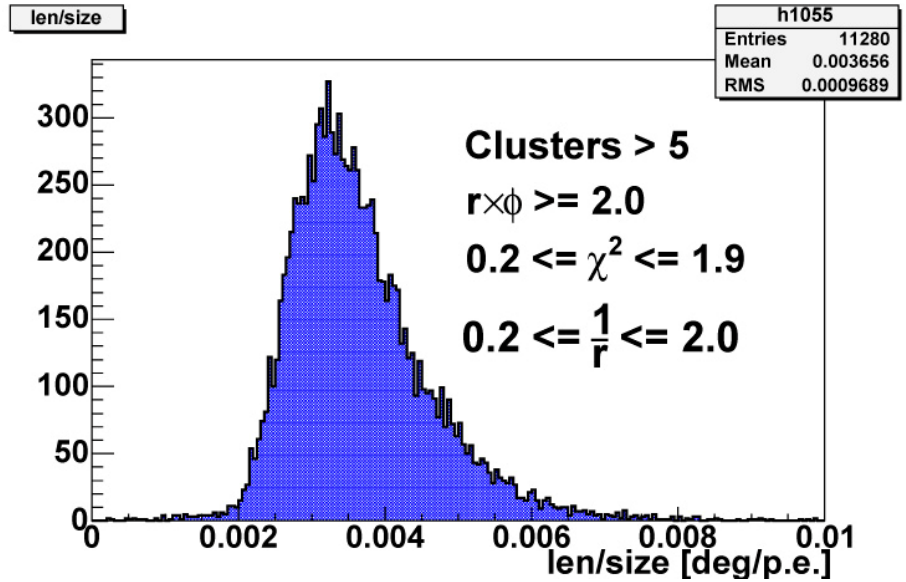


# Muon events (2)

- T4 $r[m] \approx 8 \tan\theta_C$

  on the focal plane




Curvature Distribution

Length/size Distribution

1-7GeV : 1/r >= 1.0 [1/deg]
> 7GeV : 1/r < 1.0 [1/deg]

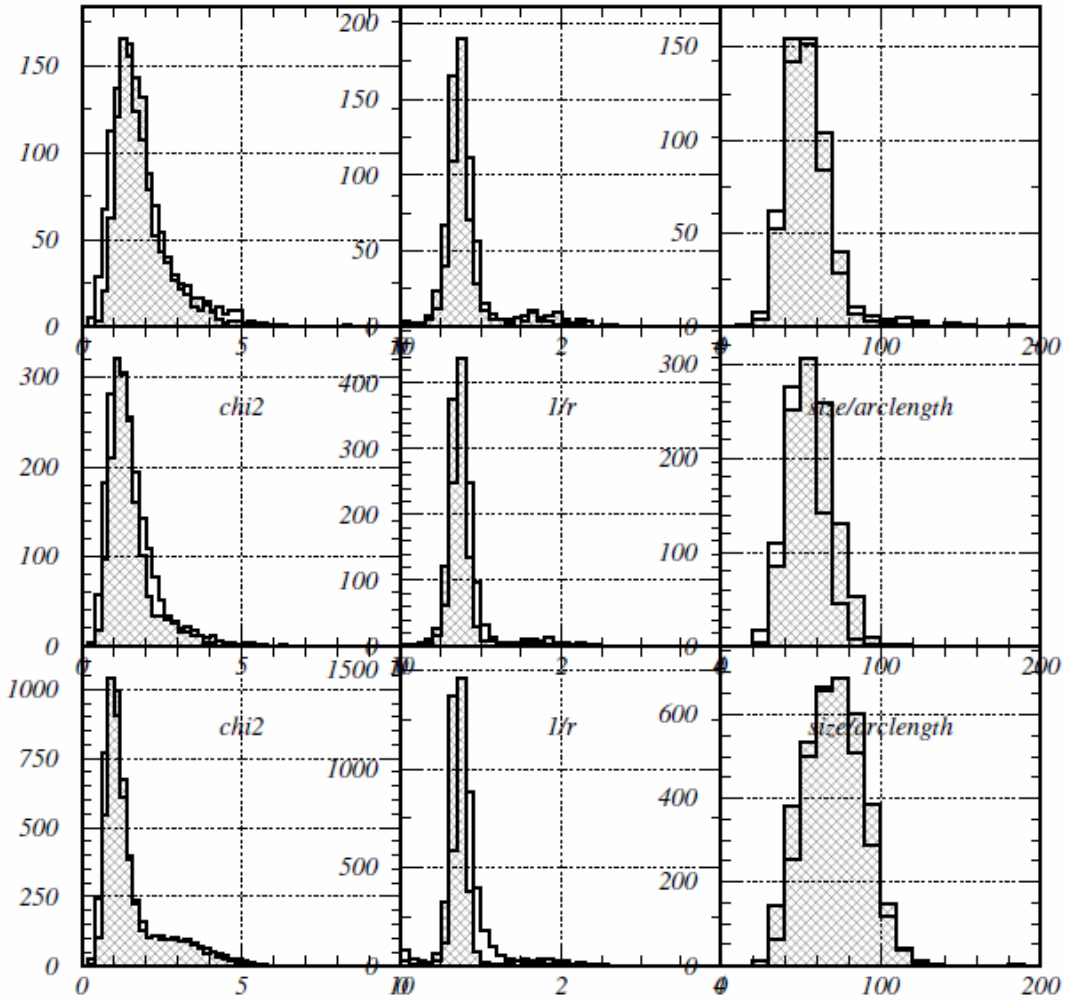
Monte Carlo simulation

# Muon parameters compared with Monte Carlo

T2

T3

T4




$\chi^2$ 1/r size/arclength

Histogram: data

Hatched: M.C.

$\chi^2$: for ring fitting

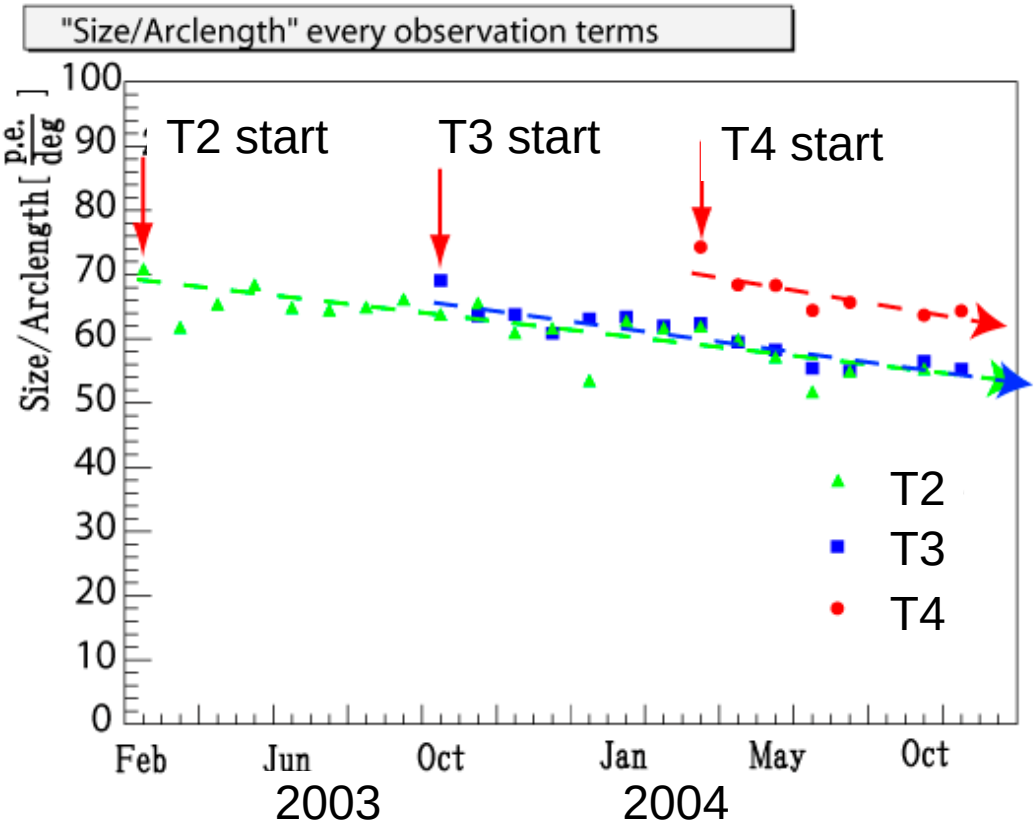
(sensitive to spot size)

r: curvature radius

(~0.8 for $v/c$=1)

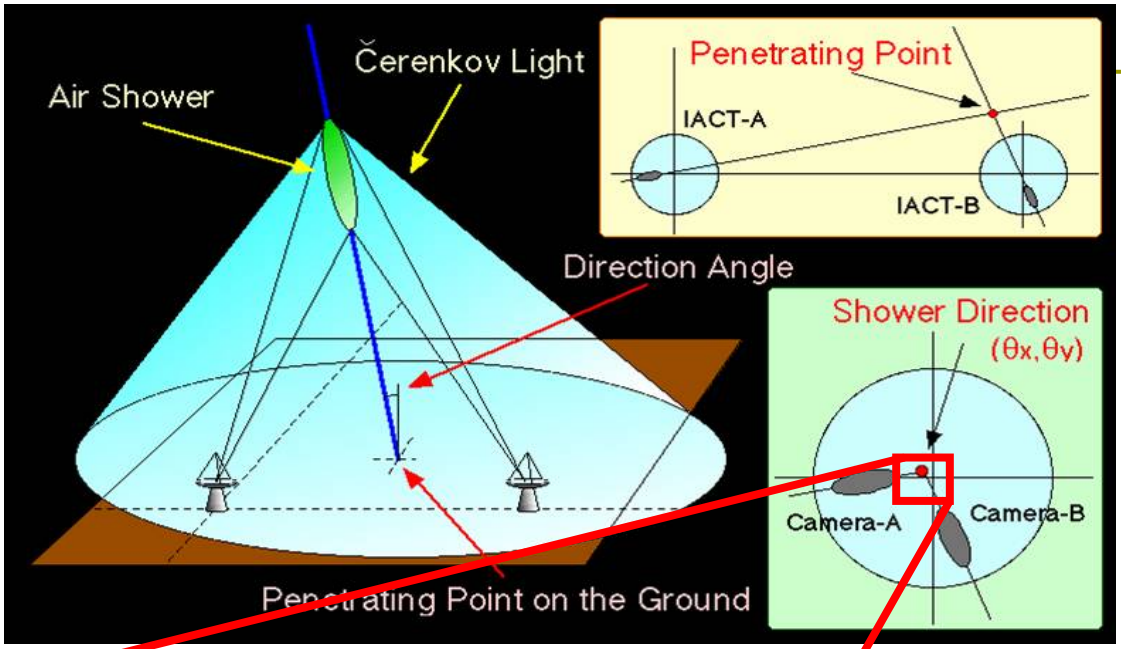
Size/arclength $\propto$ total light collection efficiency

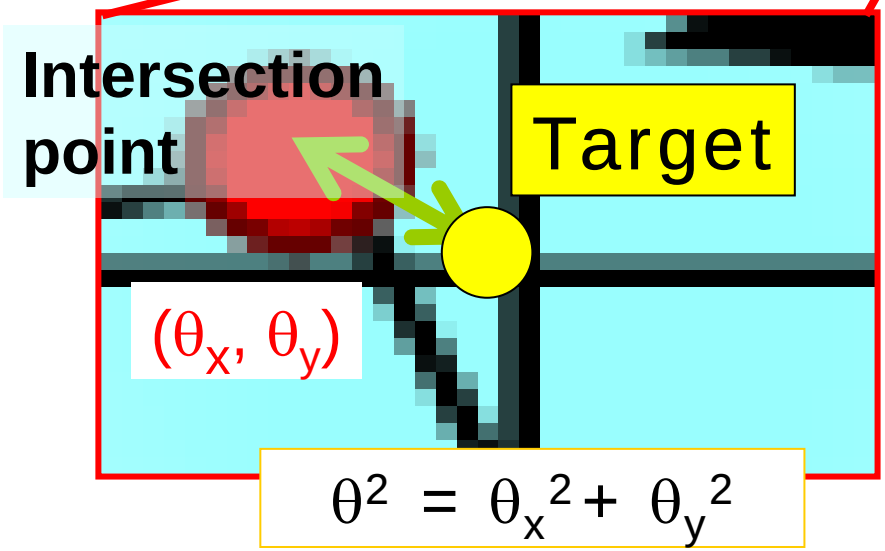
# Time variation of Size/Arclength




- Monitor of total light conversion efficiency
- Gradually, *Size/Arclength* is decreasing (~5% / year)
- Mirror degradation due to dust etc.

# Stereo observation



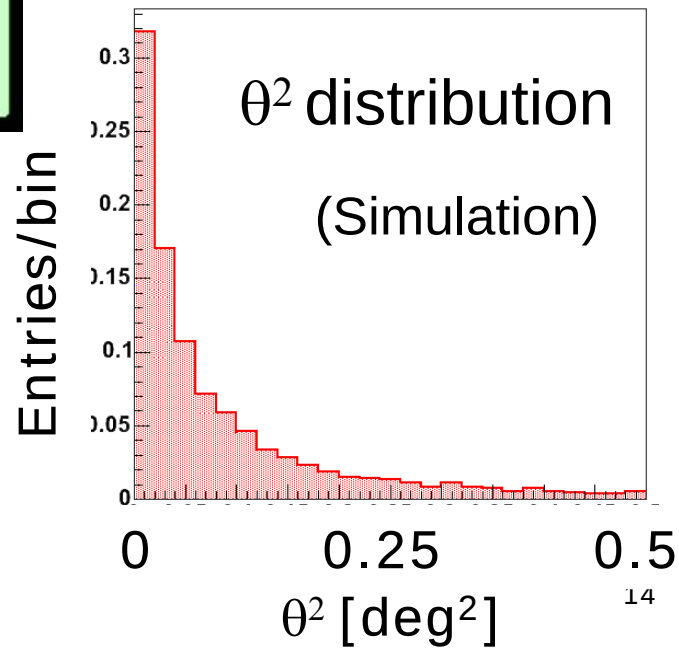

Angular resolution

0.25deg → 0.1 deg

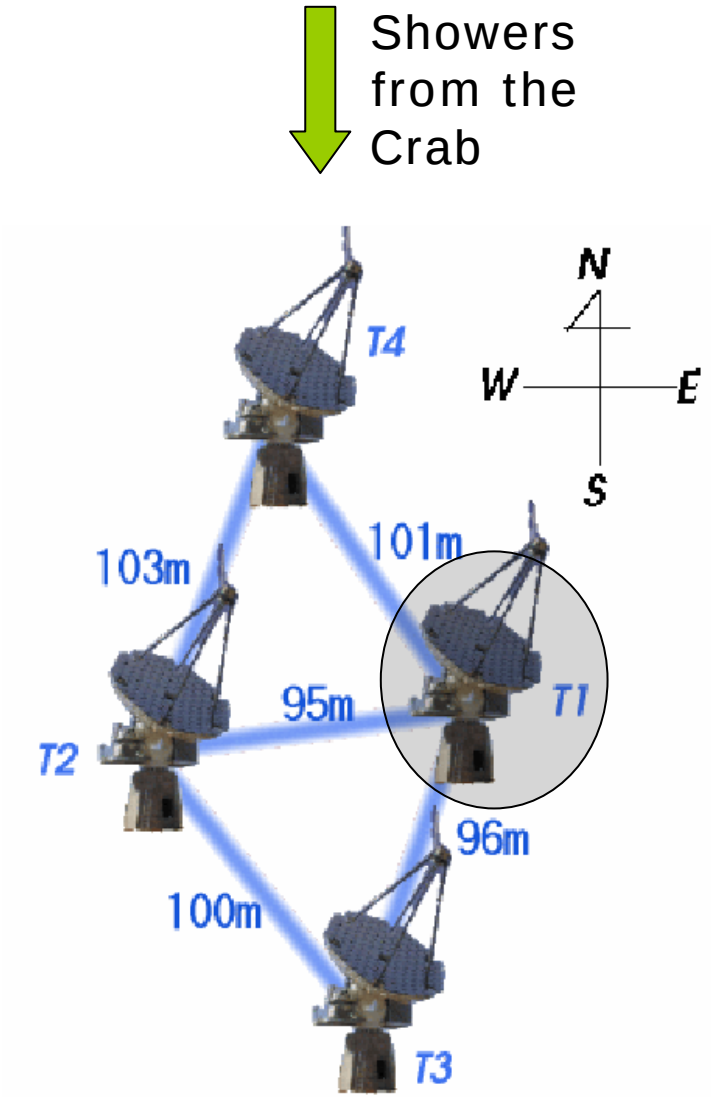
Energy resolution

30% → 15%

Better S/N (no local muons)

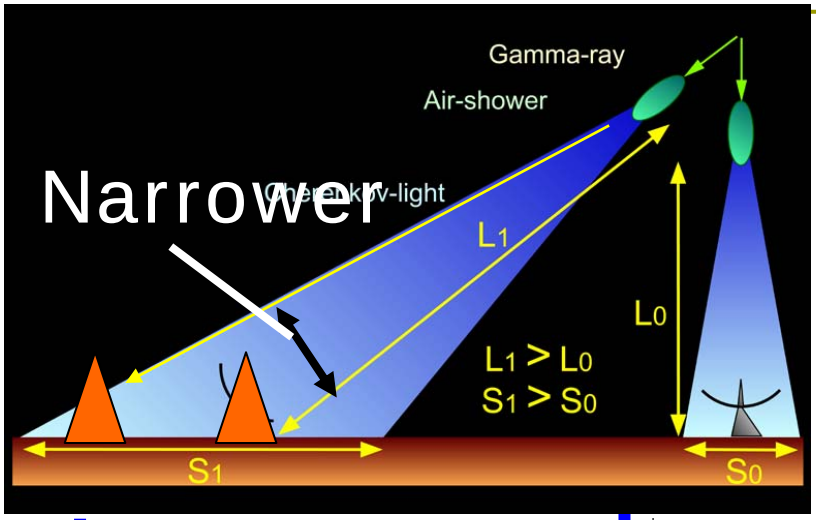


# Unfortunate situation for the Crab



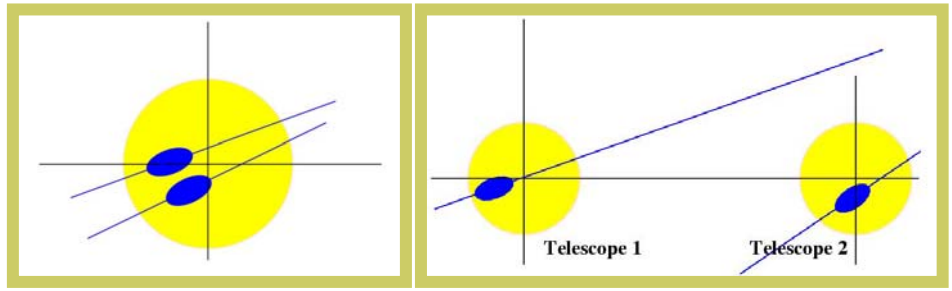

- The oldest T1 has higher energy threshold and bad efficiency for stereo observation
- Only T2/T3/T4 are used for stereo analysis
- Stereo baseline becomes short for the Crab observation at large zenith angles

# Large zenith angle observation of the Crab

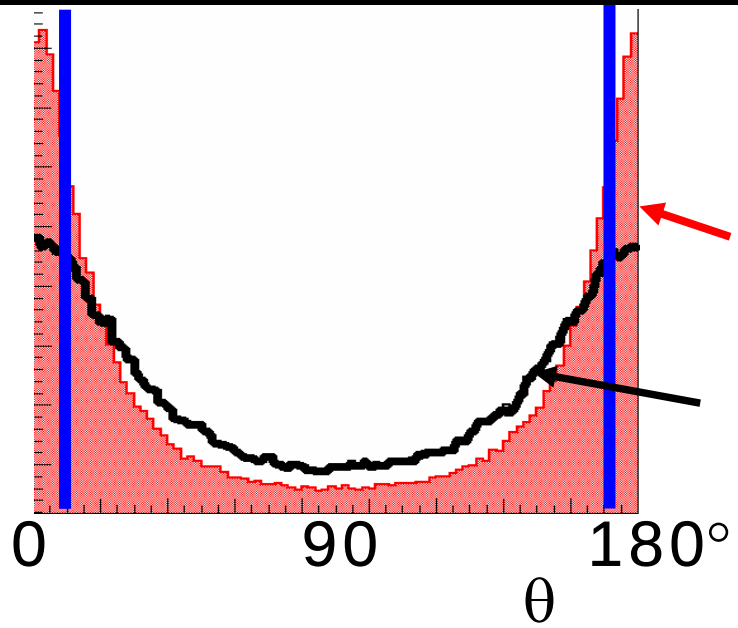



Higher energy threshold ~1TeV

Bad intersection accuracy

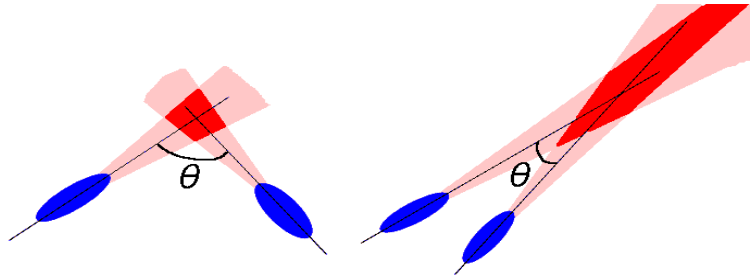



Far core→small angle→bad accuracy




h~30°

h~60°



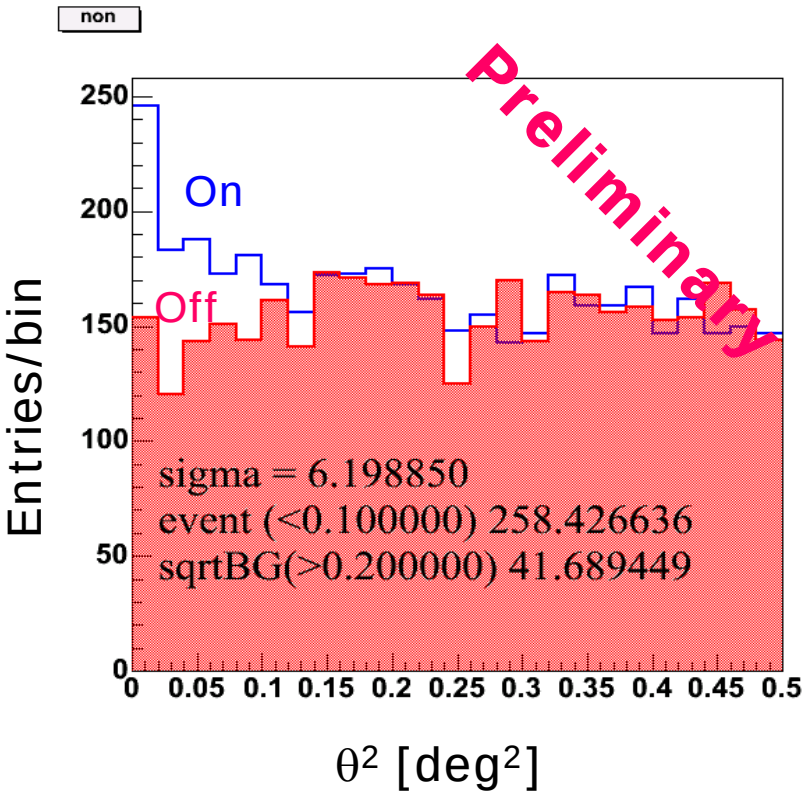

Accept 15°<θ<165° only

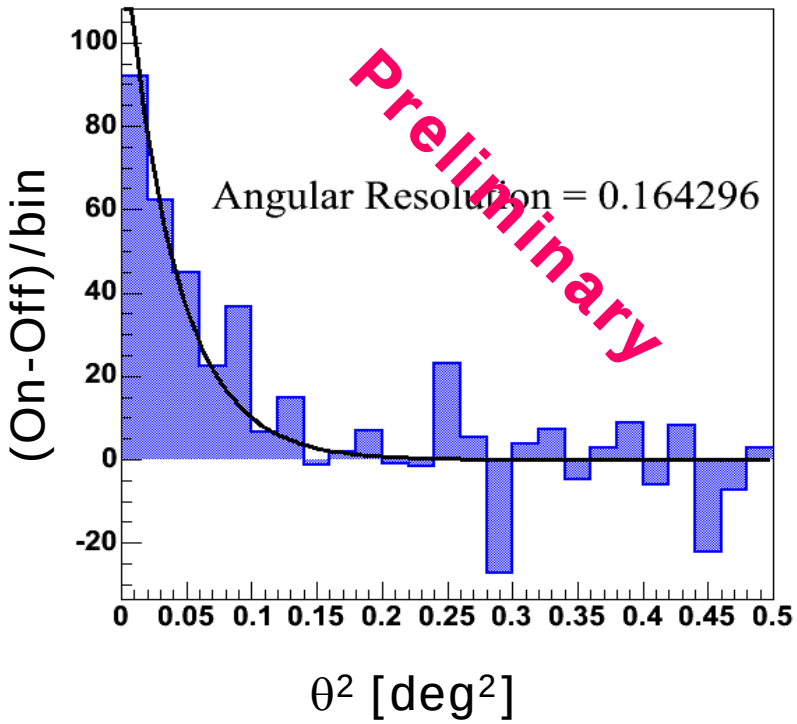
# Crab signal (1)

Team “A”

(simple square cuts)

Nov 2003




Sigma : 6.19

Excess : 258±42 event

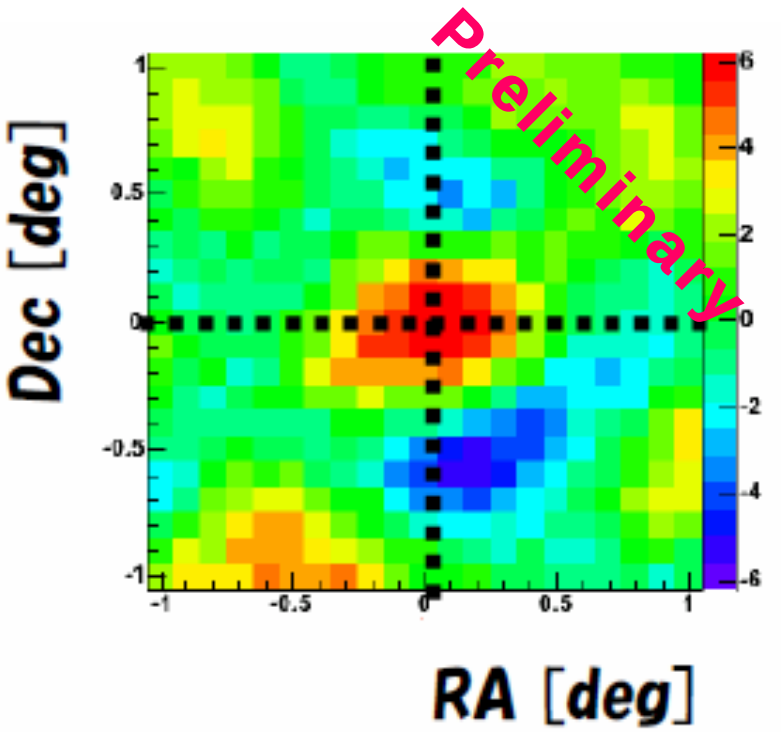
Angular Resolution : 0.16° (HWHM)

- T2 & T3
- ON 7.5hr
- OFF 7.0hr

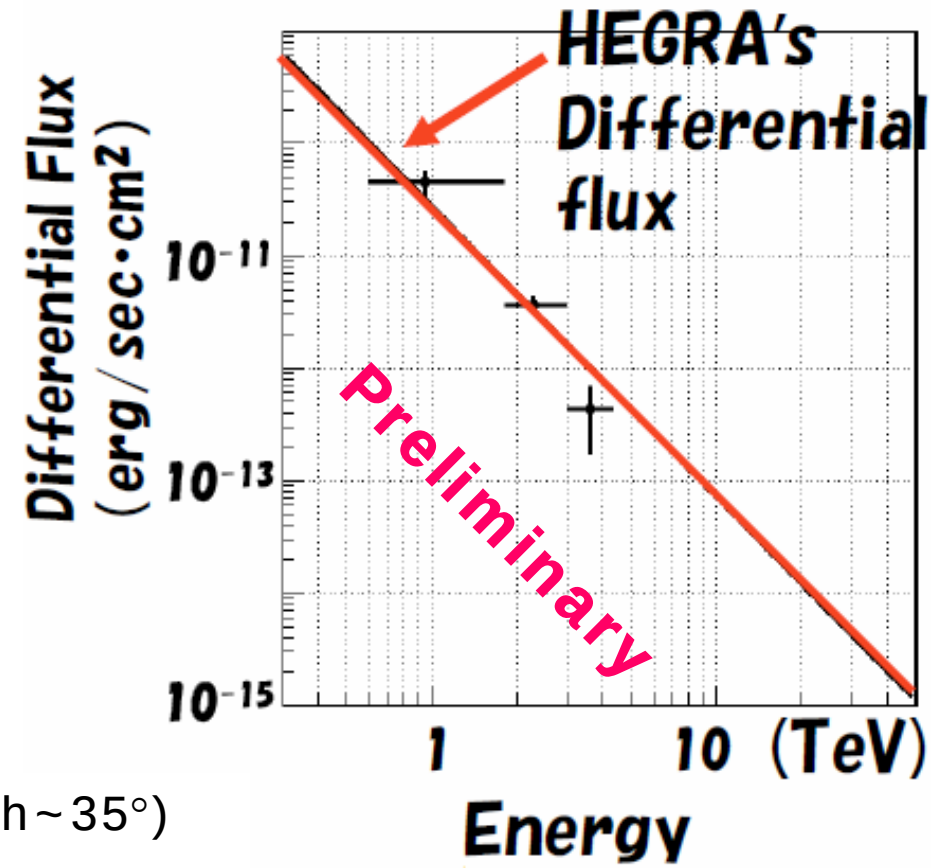
# Crab signal (2)

Team “A”

- Significance map




- Differential flux



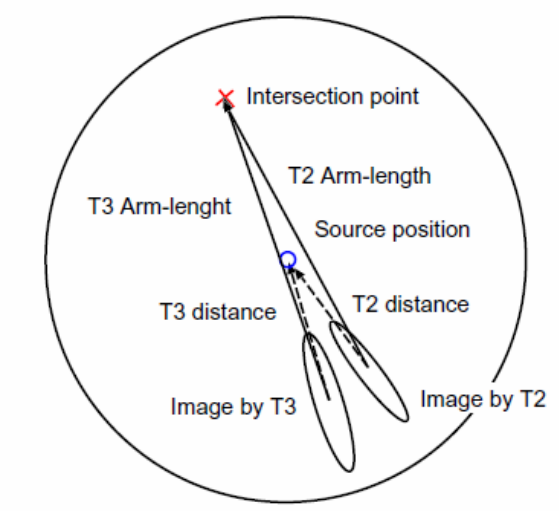

Angular resolution for the Crab (h~35°)

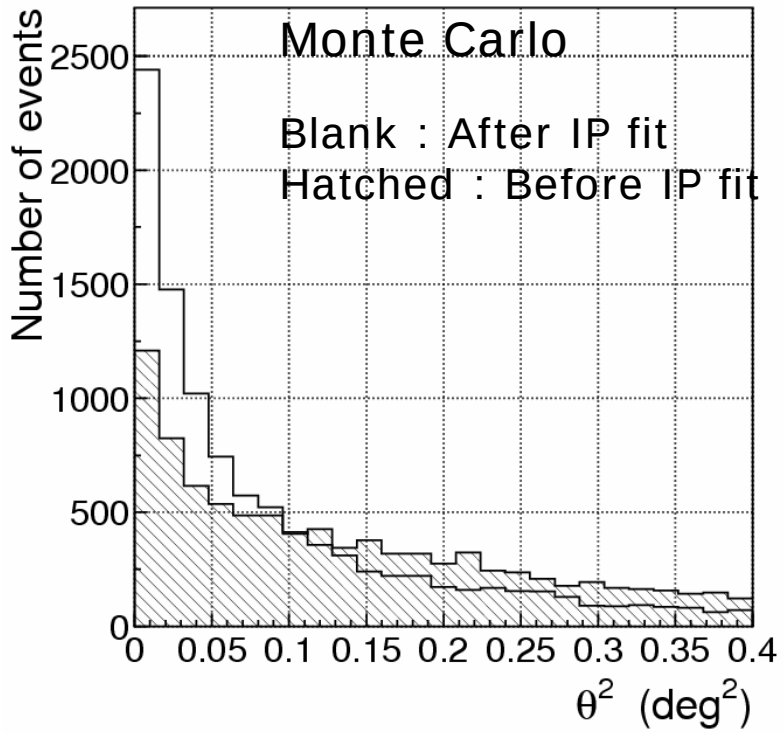
~0.17° (RA) / 0.14 ° (Decl)

# IP constraint fit

$$\chi^2 \equiv \sum_{\text{Telescopes}} \left[ \left( \frac{\text{Width}(x,y)}{\sigma_w} \right)^2 + \left( \frac{\text{Armlength}(x,y) - \langle \text{Armlength} \rangle}{\sigma_{ARM}} \right)^2 \right]$$

Search intersection point (IP) by minimizing $\chi^2$ so that width along shower axis to be minimum and armlength to be near the expected value (<Armlength>=0.75, Mesh size 0.025°)



# γ/h separation by Fisher discriminant

- Linear combination of image parameters ($x_i$)

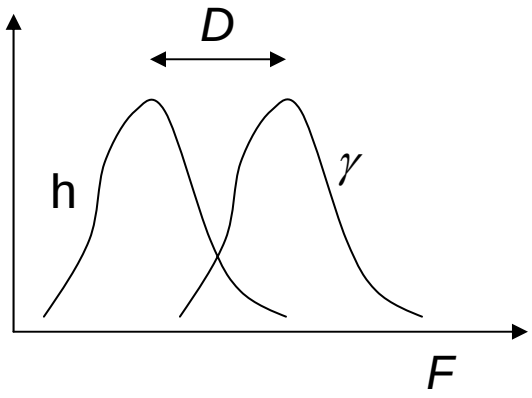
$$F \equiv \sum_i \alpha_i x_i$$

- Difference between signal (γ) and background (h)

$$D \equiv \langle F_\gamma \rangle - \langle F_h \rangle$$

- Determine $\alpha_i$ which maximize separation (solvable using correlation matrix)

$$S \equiv \langle D \rangle^2 / \langle (D - \langle D \rangle)^2 \rangle$$




- With calculated $\alpha_i$ for a known source, the (appropriately normalized) combination *F* could be the "Fisher discriminant" for other sources.

- We use *widths* and *lengths* of multiple telescopes for image parameters.

R.A. Fisher, Annals of Eugenics, 7 (1936) 179

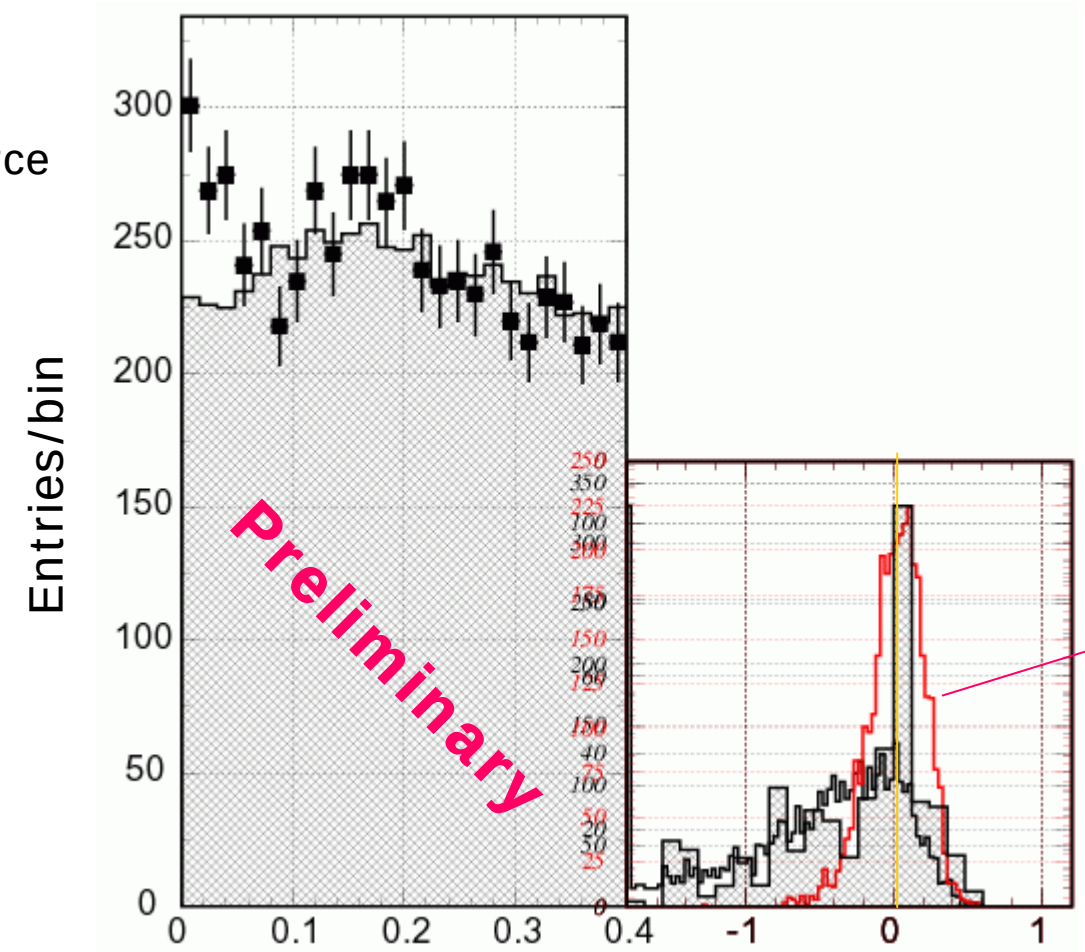
# Crab signal (3)

Team “B”

(with IP fit & Fisher D.)

Points: On-source

Hatched: Off-source



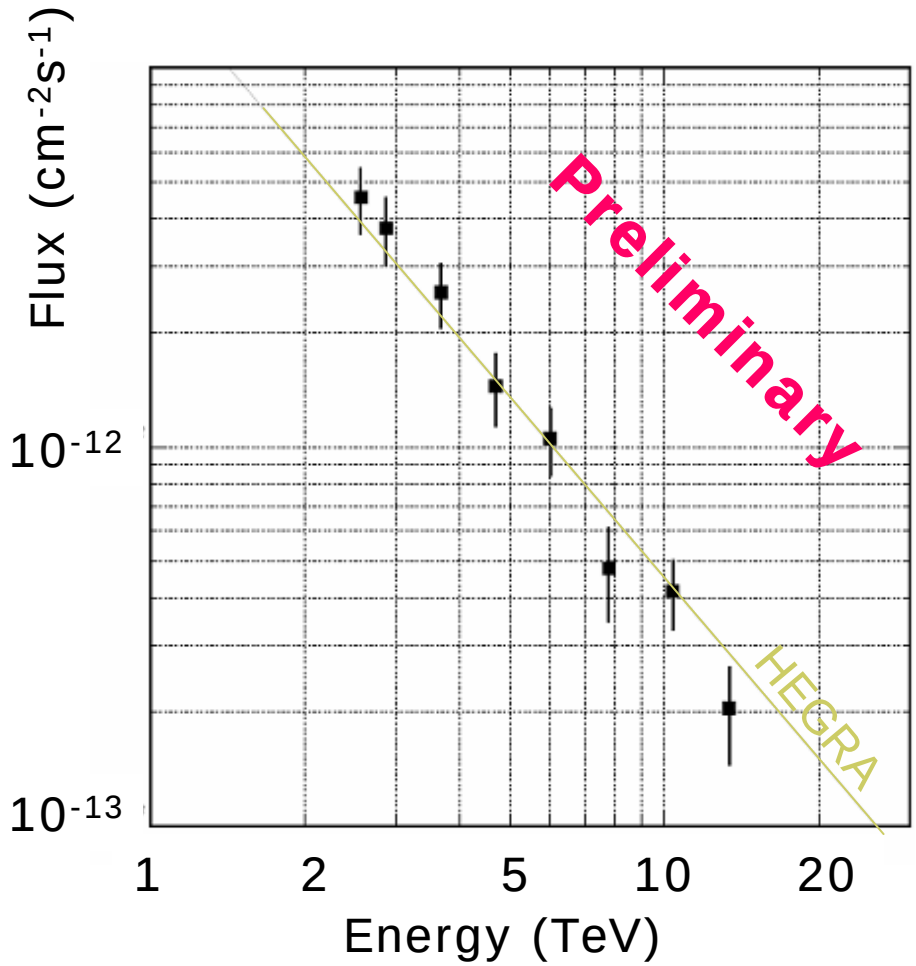

•T2 & T3

•890 min (Dec.2003)

# Crab spectrum

Team “B”

(with IP fit & Fisher D.)




- T2 & T3
- 890 min (Dec.2003)

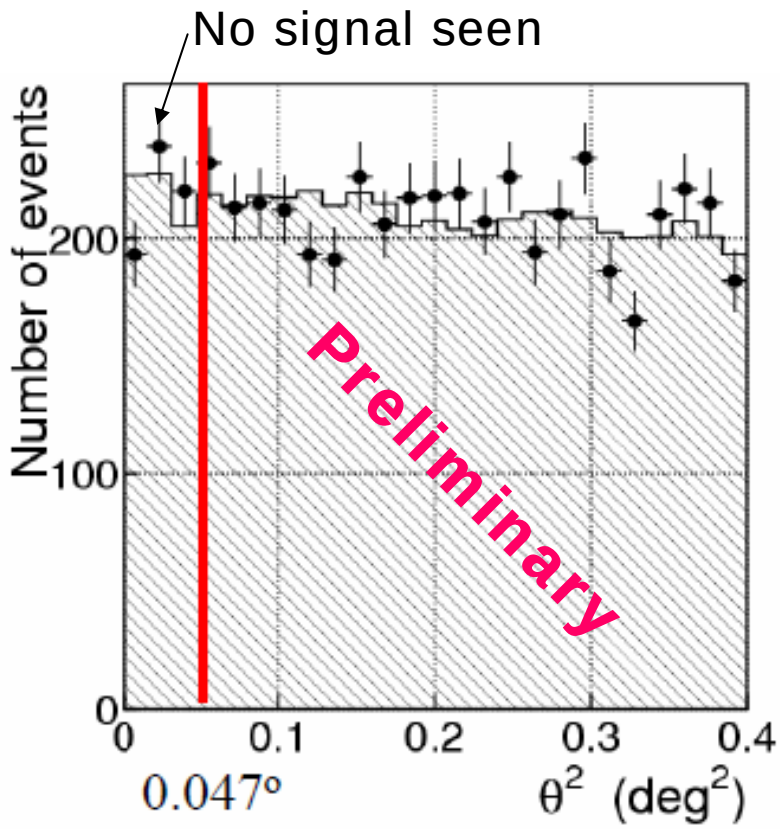
# Cen A: the nearest AGN

S. Kabuki


Near infrared image
2MASS
1.2-2.17μm

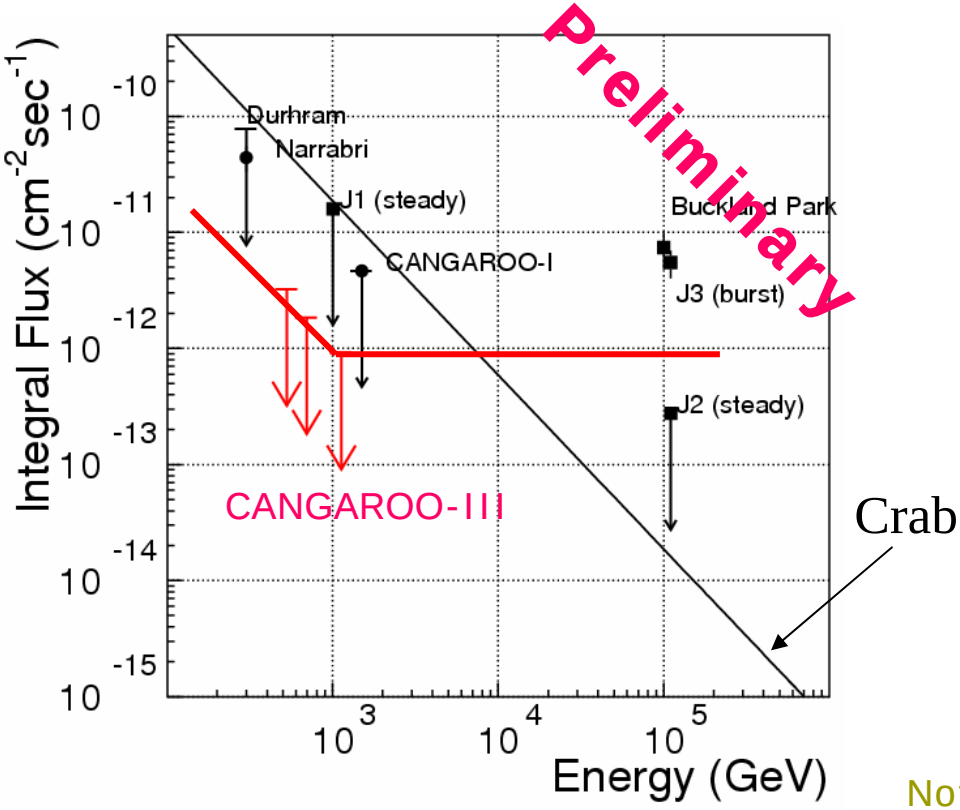

- Elliptical
- Radio galaxy
- Fanaroff-Riley type I
- "Misaligned" BL Lac (~ 60°)
- Distance 3.5 Mpc (z=0.00183)

| Observation term | Observation time (T2-T3) | Observation time (T2-T4) | Average zenith angle |
|---|---|---|---|
| 15 – 28 Mar 2004 | 603 min | 414 min | 17 degree |
| 15 – 28 Apr 2004 | 444 min | 468 min | 17 degree |
| Total | 1047 min | 882 min | |



# Cen A: flux limit

S. Kabuki



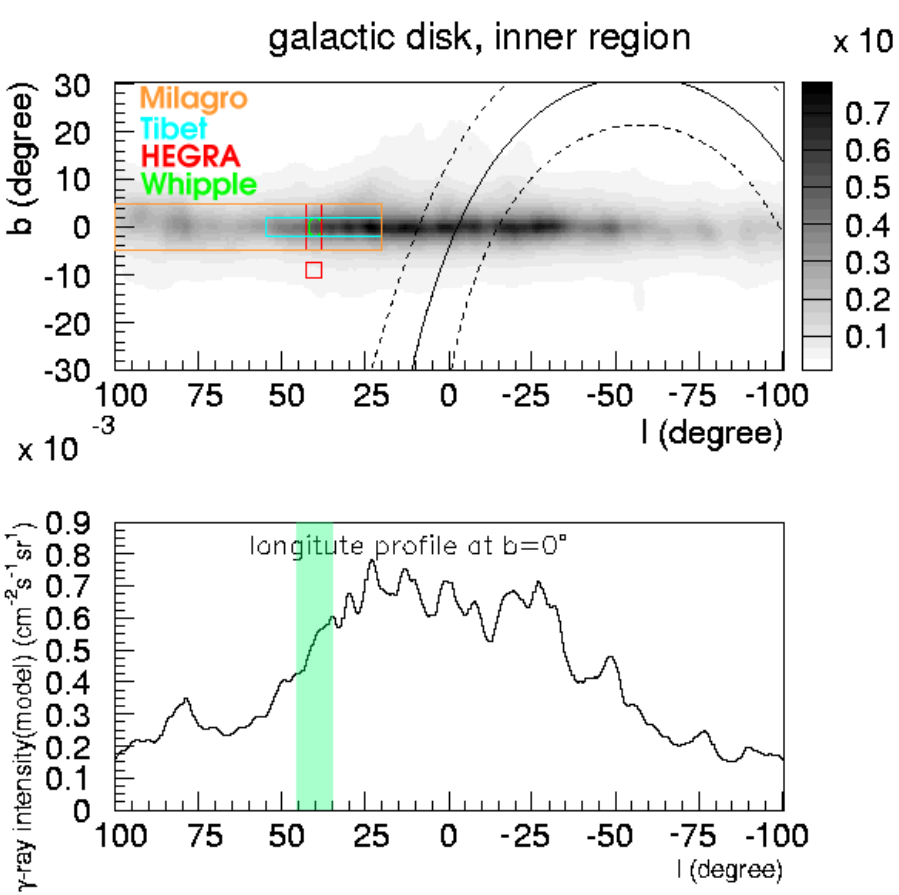

Upper limit:

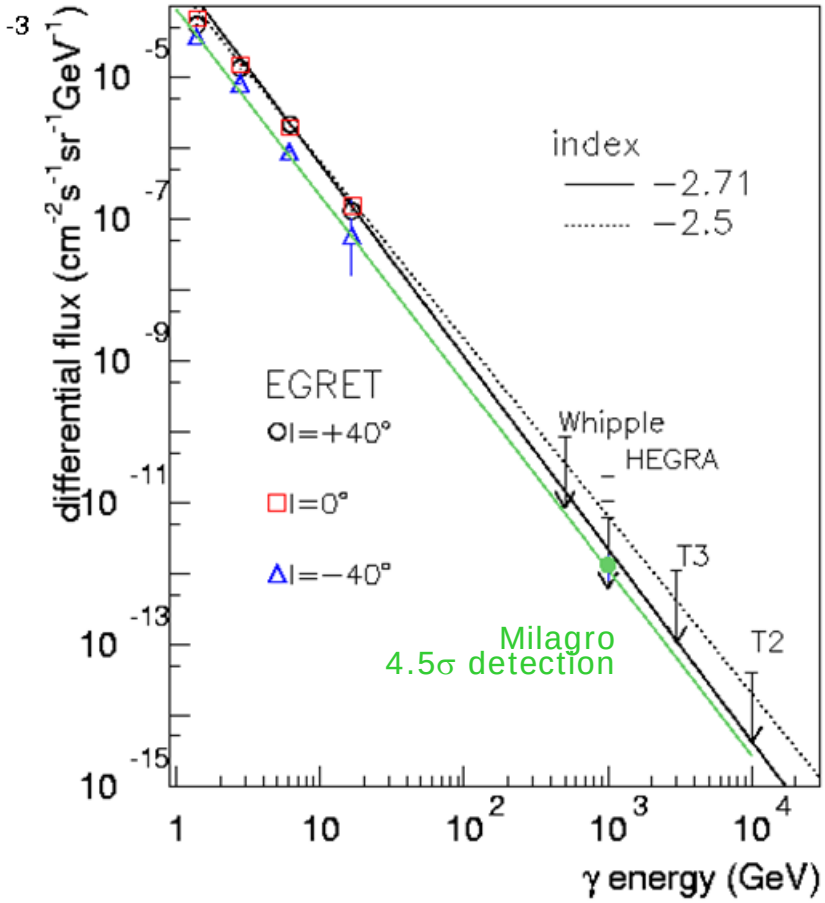
~7% Crab

| Energy bin (GeV) | 530 | 700 | 1120 |
|---|---|---|---|
| 2 σ upper limit flux ($\times 10^{-12}$cm$^{-2}$sec$^{-1}$) | 3.2 | 1.8 | 0.9 |

Note that this is a highly variable source, and the TeV claim in 70's was based on observations during its flaring activity.

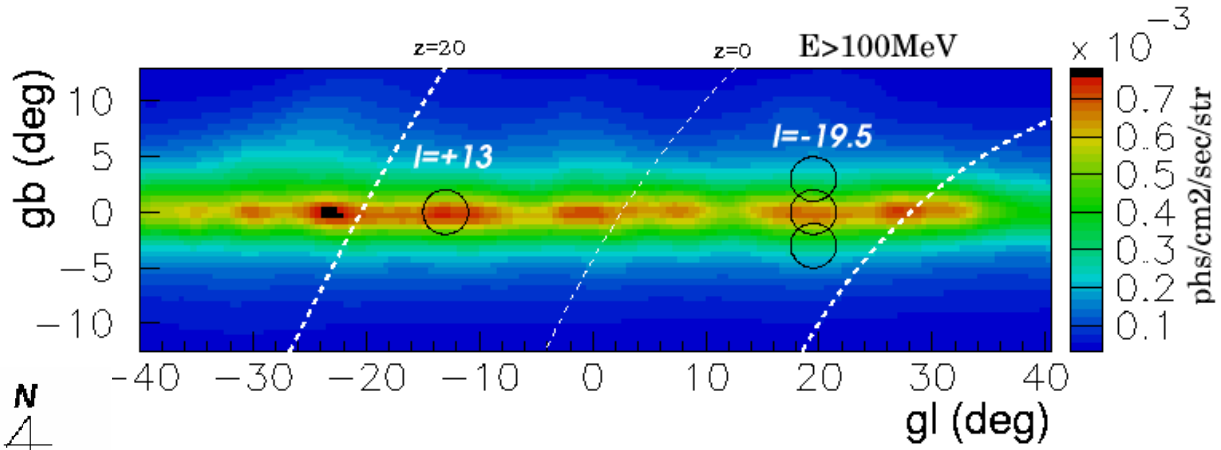
# Galactic diffuse emission

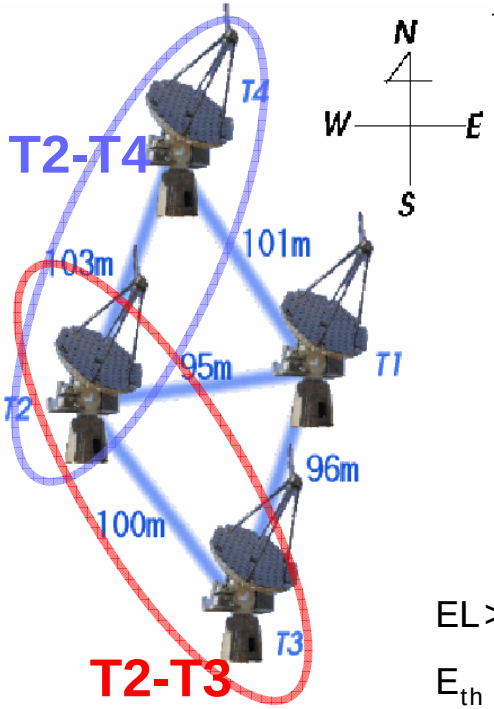


# Observation of the Galactic disk

M. Ohishi




EL>45deg

$E_{th}$ ~600 GeV

***l=-19.5*** 2004Jun

(Obs.time in minutes)

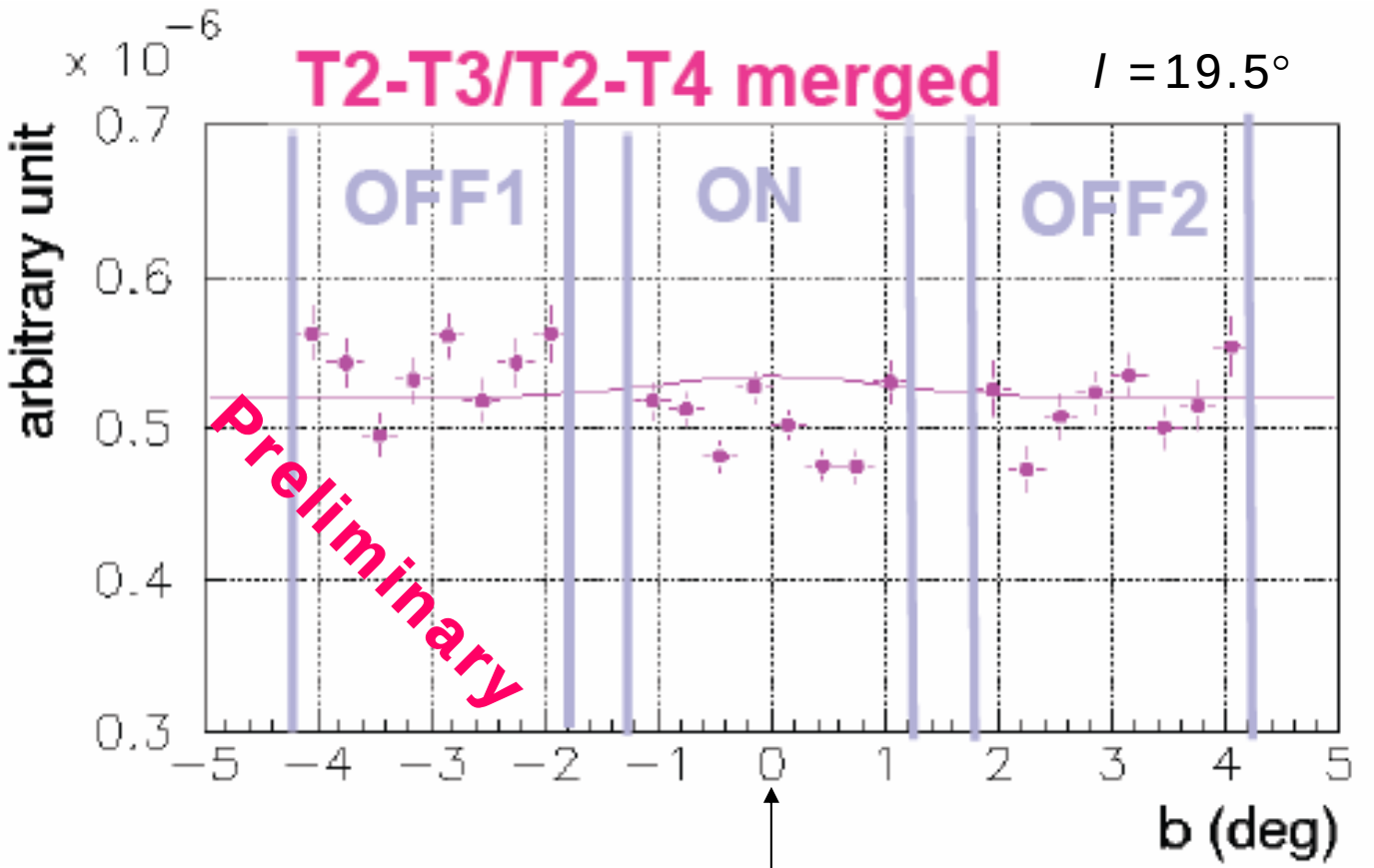
| Obs.term | tel.pair | ***b=0°*** | ***b=-3°*** | ***b=+3°*** |
|---|---|---|---|---|
| 2004Jun | T2-T3 | 635.3 | 322.3 | 292.9 |
| 2004Jun | T2-T4 | 380.0 | 201.9 | 192.5 |

***l=+13*** 2004Jun/Aug

| Obs.term | tel.pair | **ON** | **OFF** |
|---|---|---|---|
| 2004Jun | T2-T3 | 289.6 | 340.0 |
| 2004Jun | T2-T4 | 199.5 | 270.0 |
| 2004Aug | T2-T3 | 224.9 | 183.6 |
| 2004Aug | T2-T4 | 280.0 | 85.7 |

# Galactic disk scan result

M. Ohishi

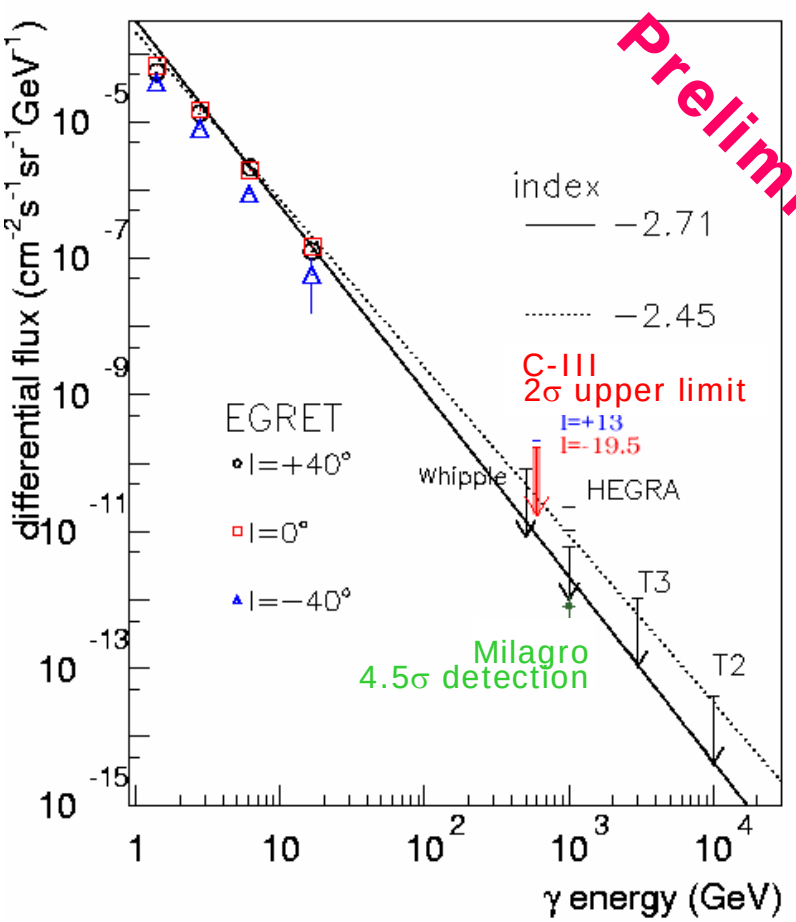


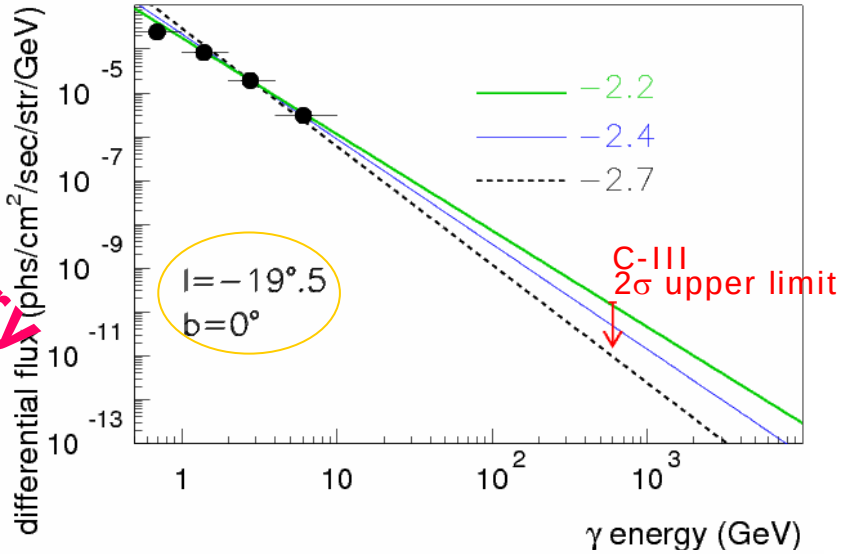

No excess at the disk!

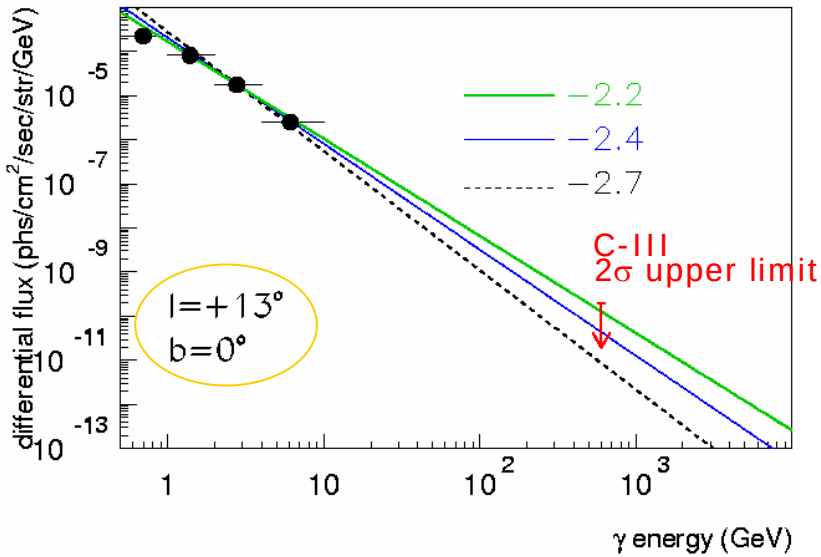
(expected $\sigma \sim 1$deg)

M. Ohishi, preliminary

# Galactic diffuse emission: upper limit



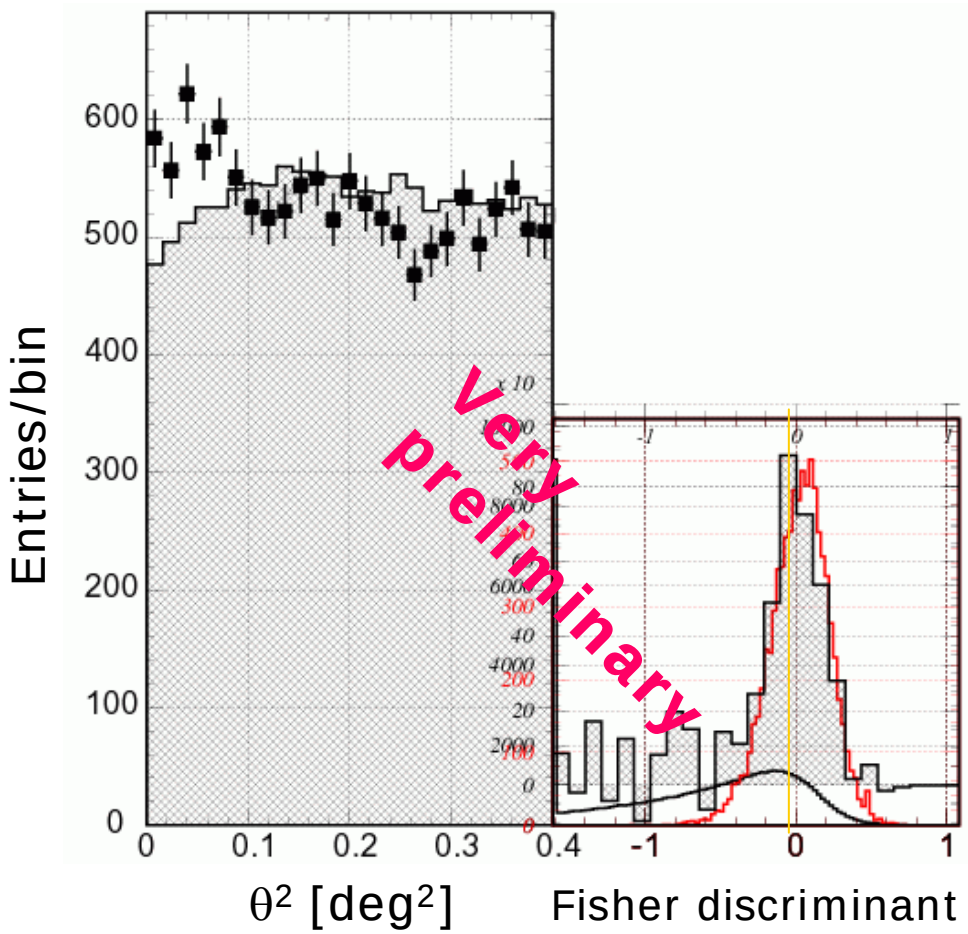



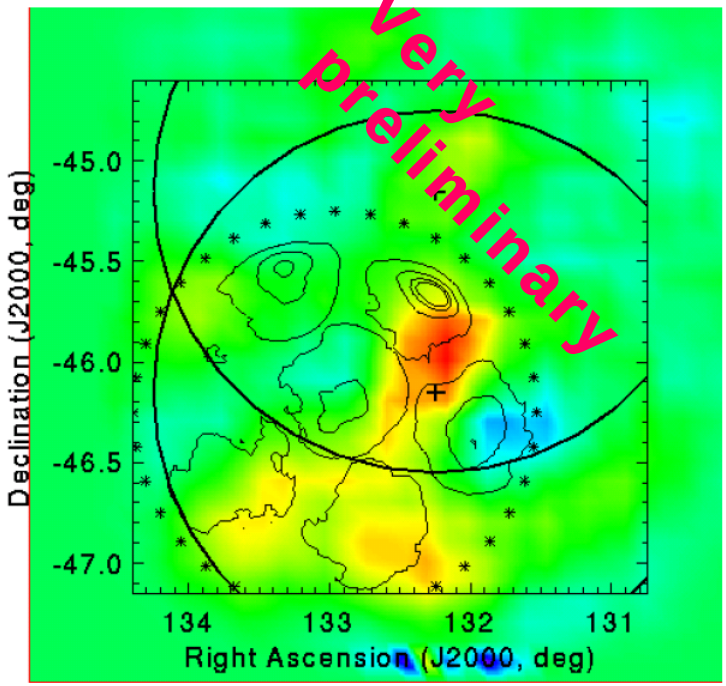

CANGAROO-III: syst.error included

Other TeV obs: Cygnus regions

# SNR RX J0852.0-4622

Team “B”



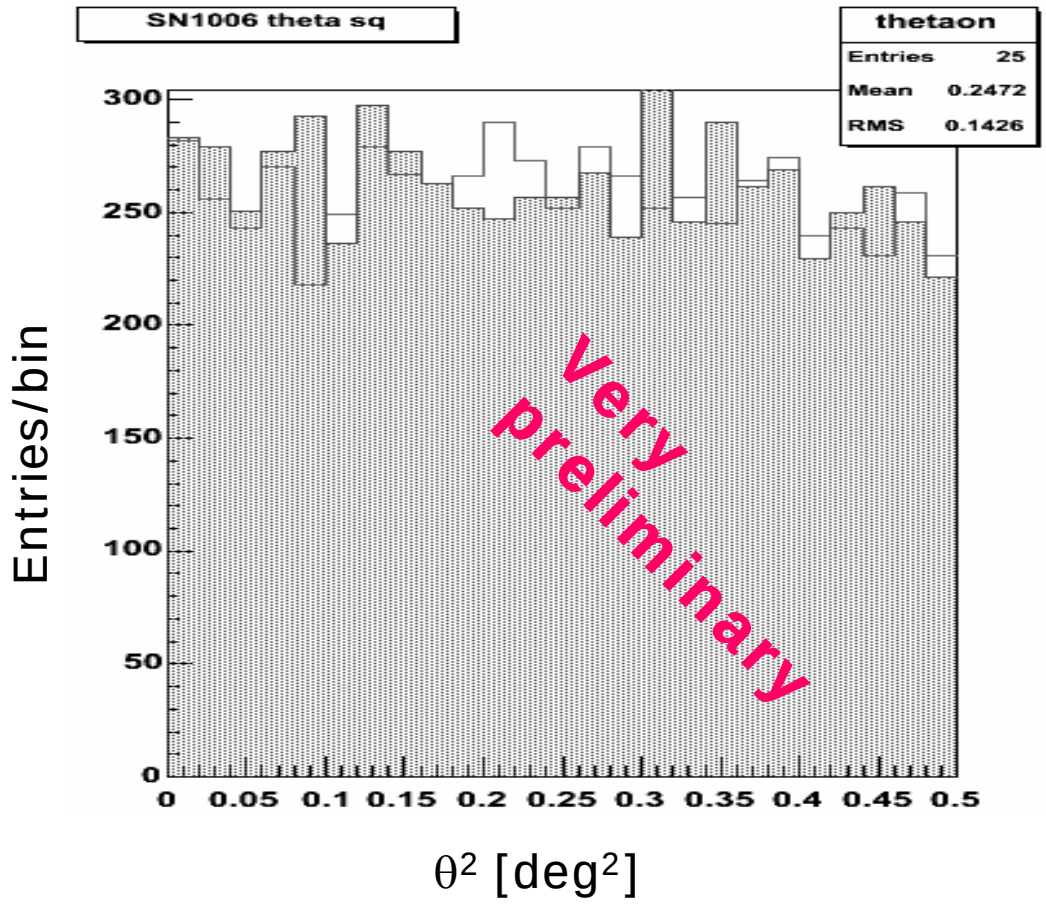

- T2 & T3
- 1204min (Jan.15-Feb.24, 2004)

Fisher D. set at the Crab level

For single telescope observations, see Katagiri et al., ApJ 619 (2005) L163

# SN1006

Team “A”




Blank: CANGAROO-I hot spot

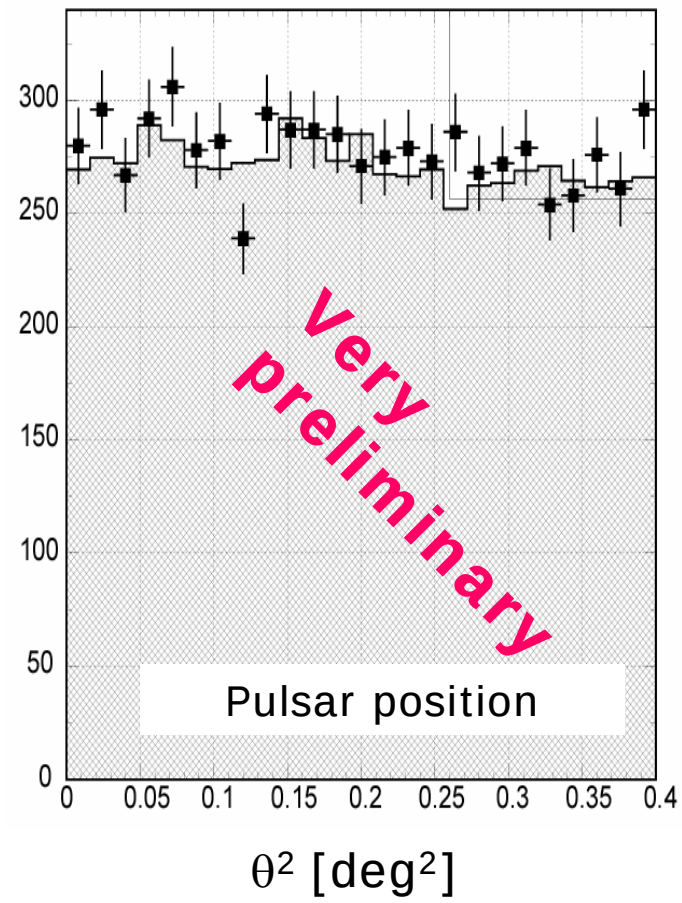
Hatched: Off-source

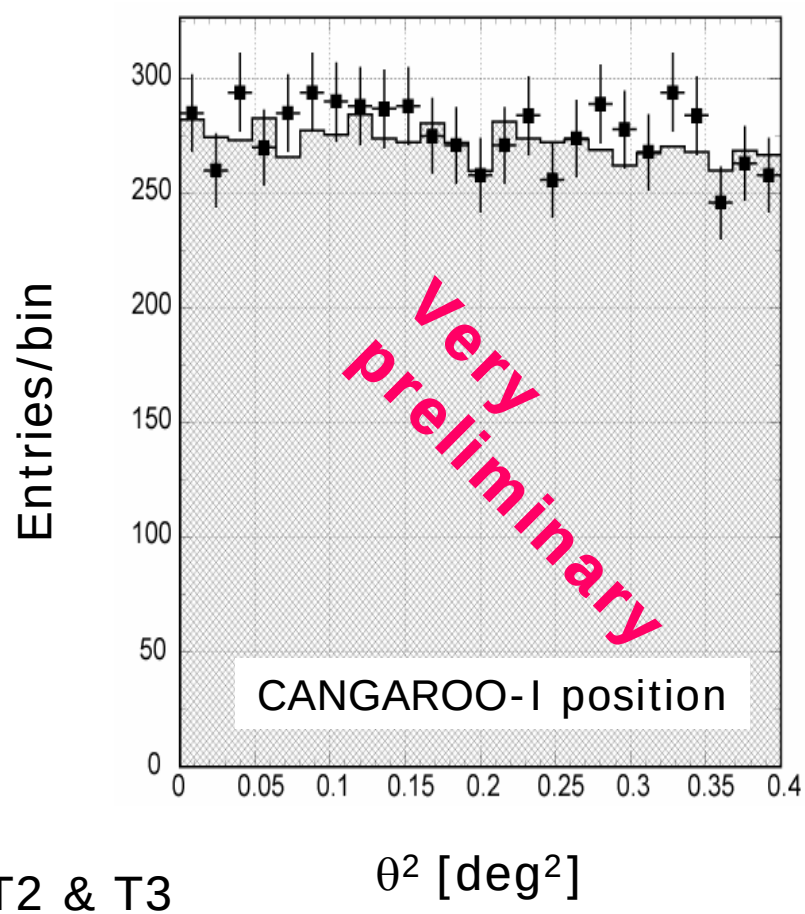
- T2 & T3
- ON 1954min
- OFF 1606min (May 14-26, 2005)

Square cuts at the Crab level

# Vela pulsar

Team “B”



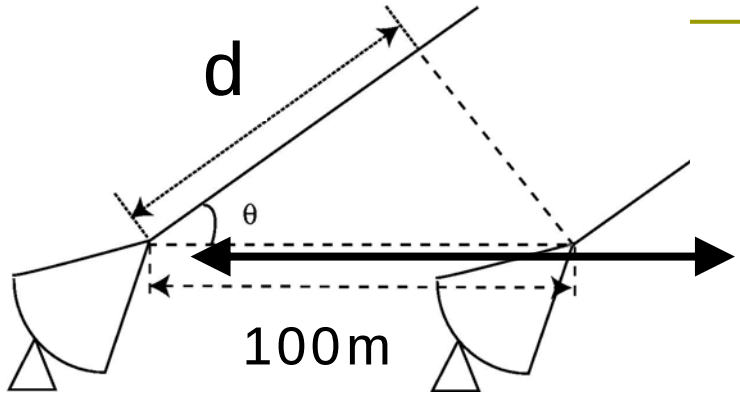




Fisher D. set at the Crab level

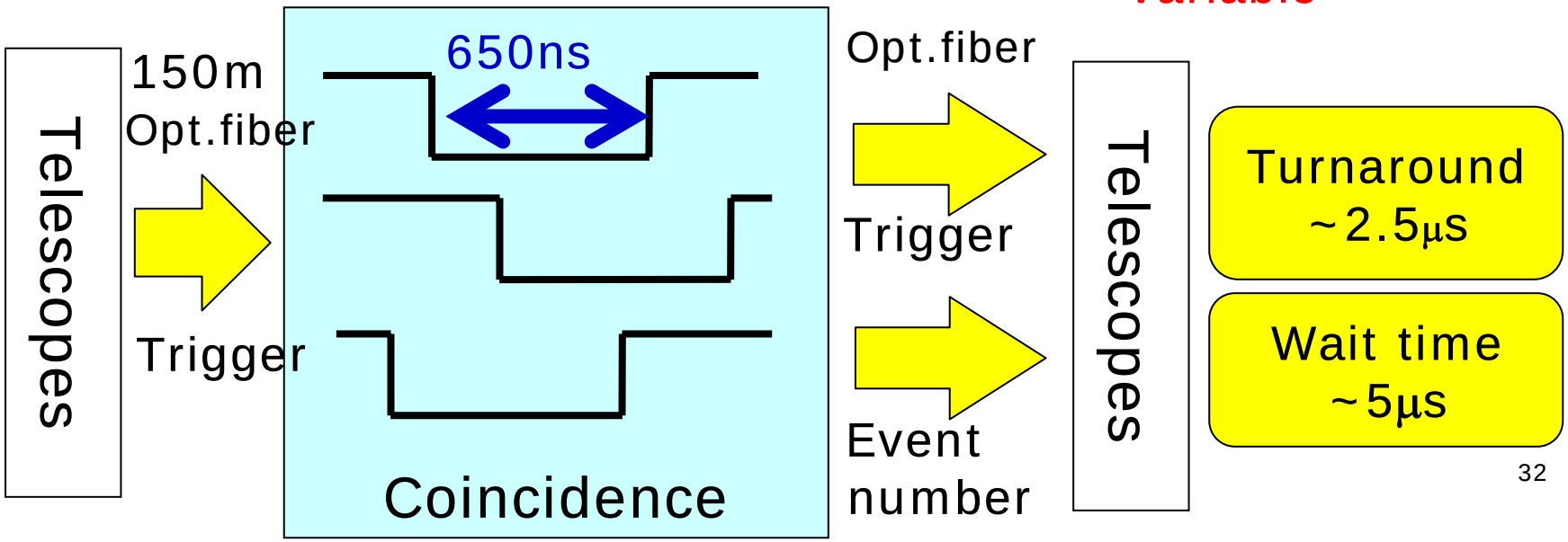
- T2 & T3
- 1311min (Jan.17-Feb.25, 2004)

# Global trigger system

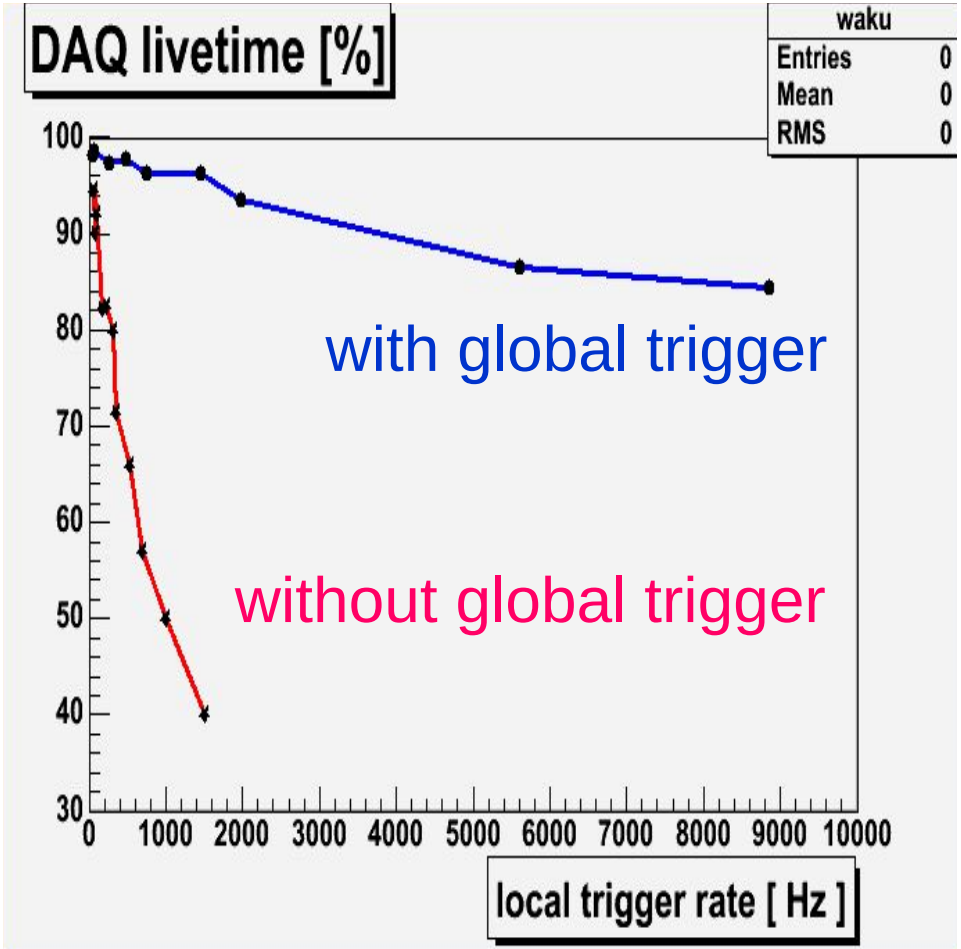
- Before: “software trigger”
  - Each telescopes triggered independently
- Now: “hardware stereo”
  - Requires at least 2 telescopes
- If no coincidence ⇒ Reset
  - Dead time ×1/100

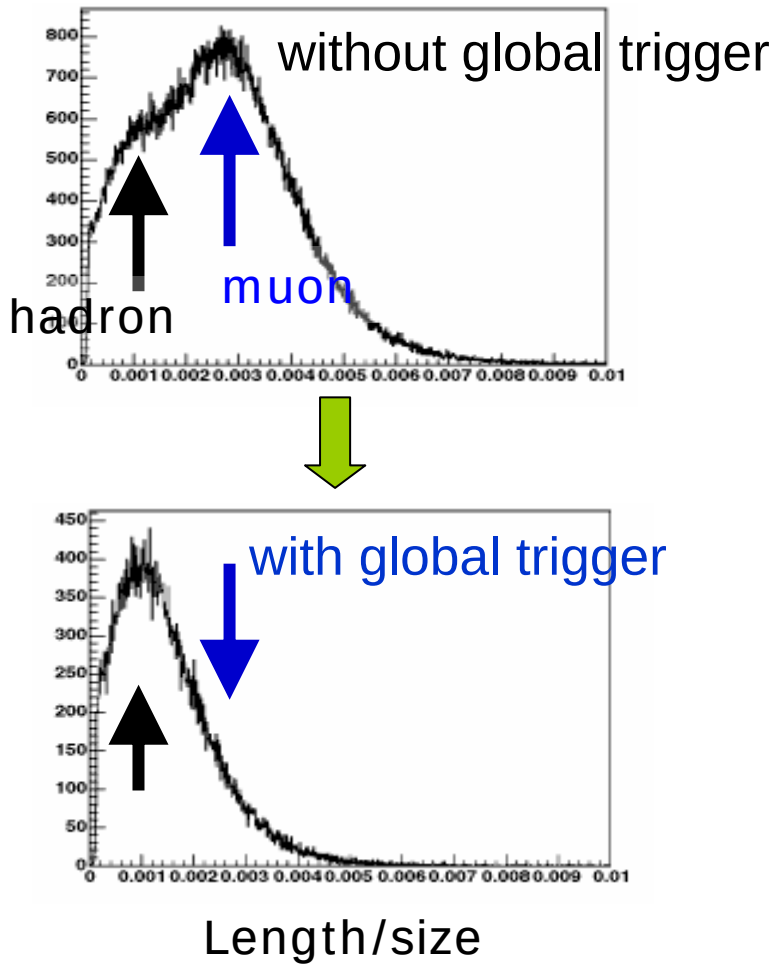



$\Delta t = d/c$ < 500ns
variable



# Effect of global triggers




Muon events are removed!

# Summary

- We have been carrying out 4-telescope stereo observations of sub-TeV gamma-rays since 2004 March. Now we have incorporated a global trigger system to reduce muons.
- Stereo analyses are being developed using muons for calibration, and the energy spectrum of the Crab is consistent with other results.
- Preliminary results on Cen A and the Galactic disk show no gamma-ray signal. SNR RX J0852.0-4622 appears as extended source, and the morphological study is progressing.
- Observations of SN1006 and Vela pulsar were made by using CANGAROO III telescopes. Very preliminary analyses appear to show no significant signals, which may suggest upper limits lower than the CANGAROO-I fluxes obtained several years ago.

End