

Very high energy gamma-ray observations of the galactic plane with the CANGAROO-III telescopes

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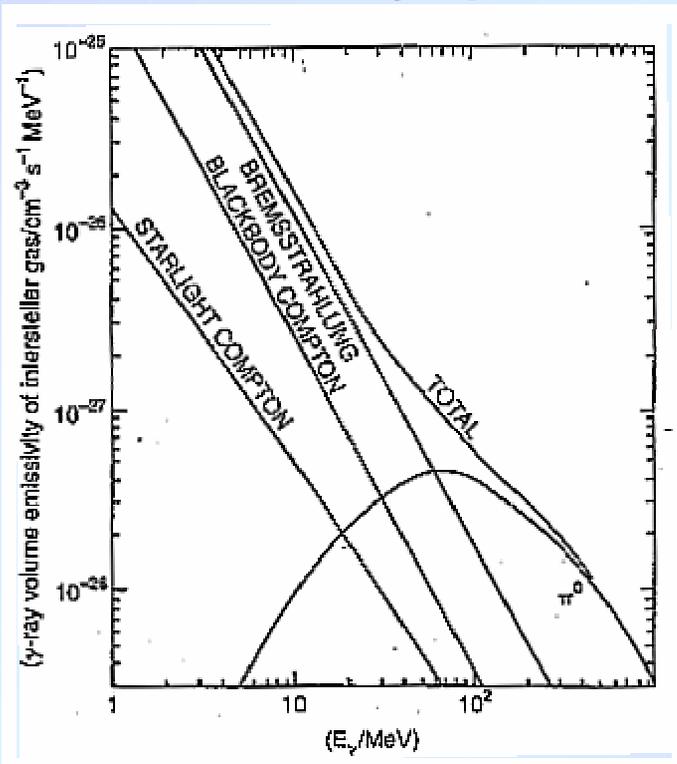
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- Observation of the galactic plane with the CANGAROO-III telescopes in 2004 Jun/Aug
- Analysis of the diffuse component
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Motivation for the VHE observation of the galactic plane(1)

gamma-ray emission processes

- ✓ Cosmic ray **proton** – matter $pp \rightarrow \pi^0 \rightarrow 2\gamma$ neutral pion decay
- ✓ Cosmic ray **electron** – matter Bremsstrahlung
- ✓ Cosmic ray **electron** – photons Inverse Compton

Gamma-ray spectrum



EGRET diffuse emission model input parameters

- target matter(HI,HII,H₂) distribution ← radio obs.
- cosmic ray spectrum(e/p) ← measurement at Solar vicinity
- spatial distribution of cosmic-ray intensity
← Assumption that it correlate with the distribution of the matter with correlation length r

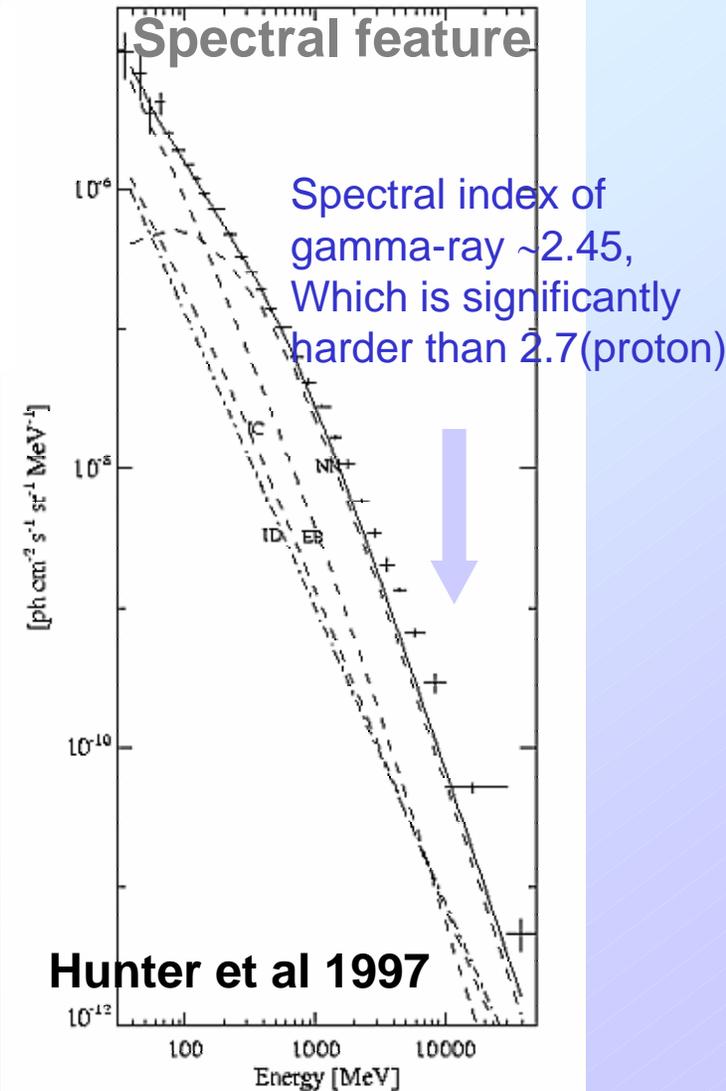
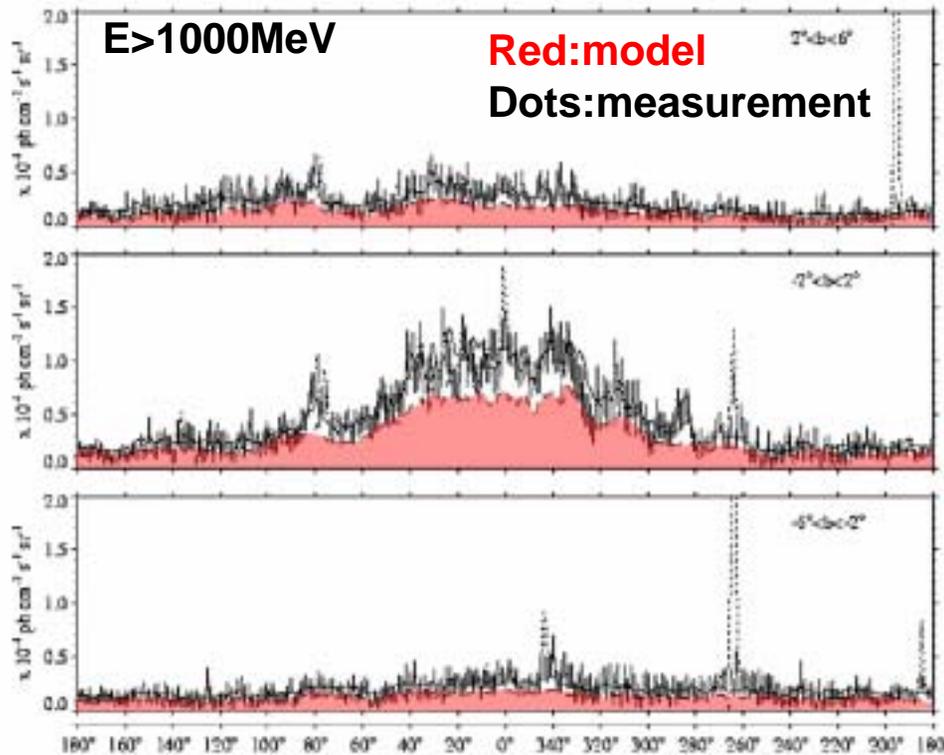
Only **two** free parameters in the model:

$$X=N(H_2)/W_{CO}, \text{ Correlation length } r$$

Motivation for the VHE observation of the galactic plane(2)

EGRET GeV observation of the galactic plane

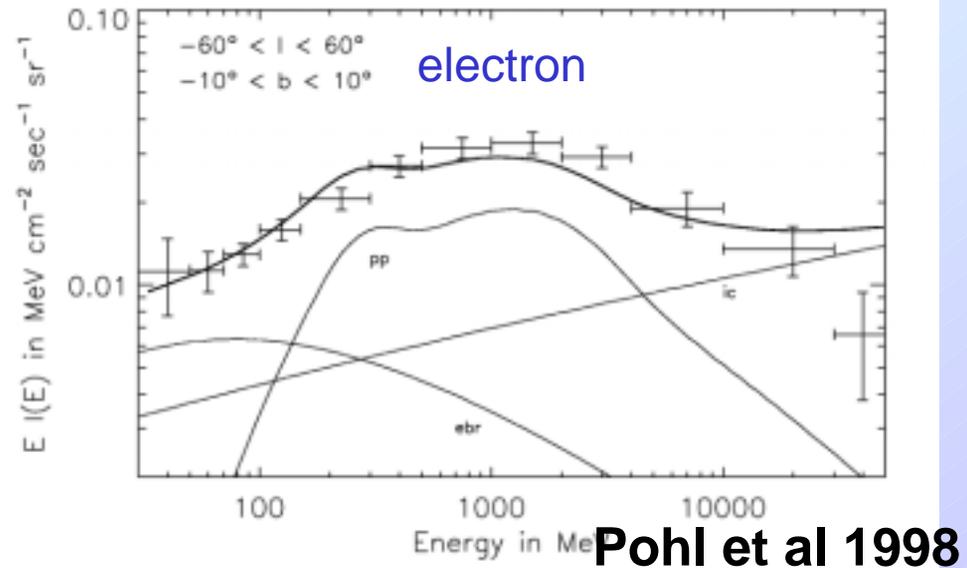
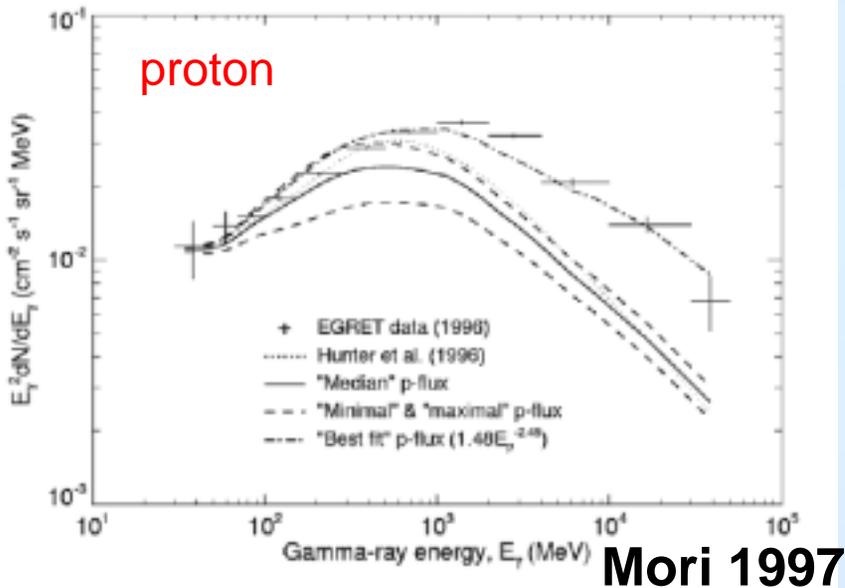
- The EGRET diffuse model well reproduced the measurement in MeV region both for spatial/spectral feature
- As for high energy ($E > 1 \text{ GeV}$) region, the measurement shows $\sim 60\%$ excess respect to the model prediction.



Hypotheses to explain “GeV excess”

Parameter validity in the EGRET diffuse model:

- ✓ Kinematics of π^0 is not understood with required accuracy?
- ✓ Cosmic-ray proton spectrum (index -2.7) is not suitable as Galactic average?
- ✓ Contribution of inverse Compton component may be underestimated?

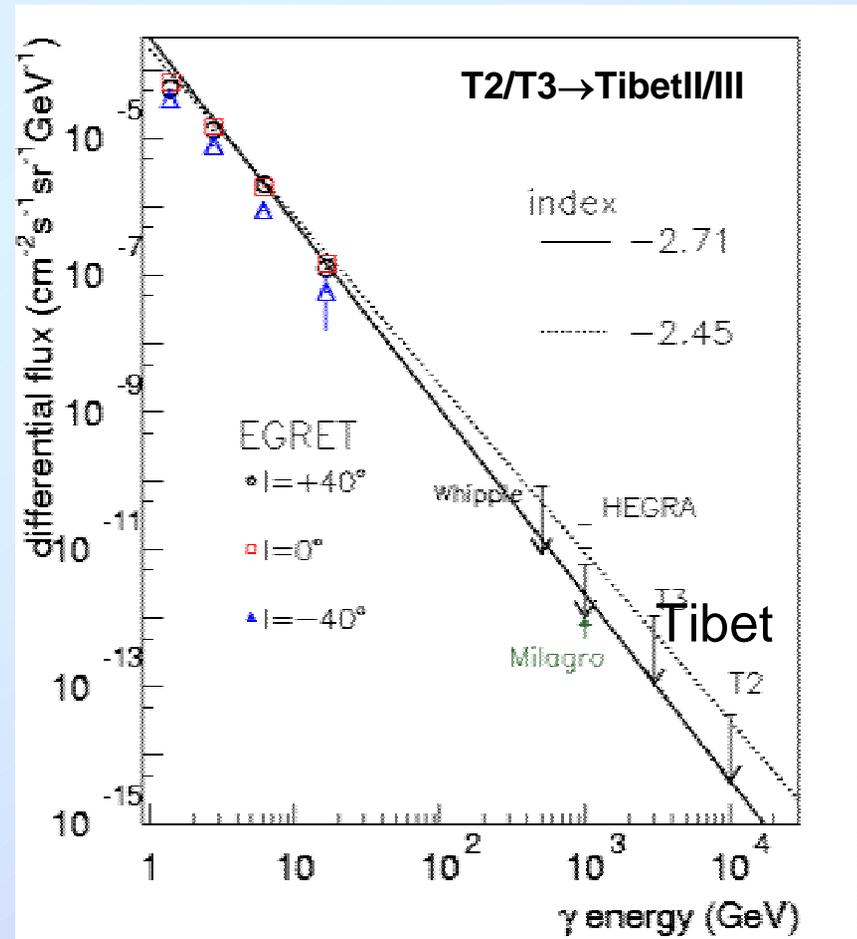
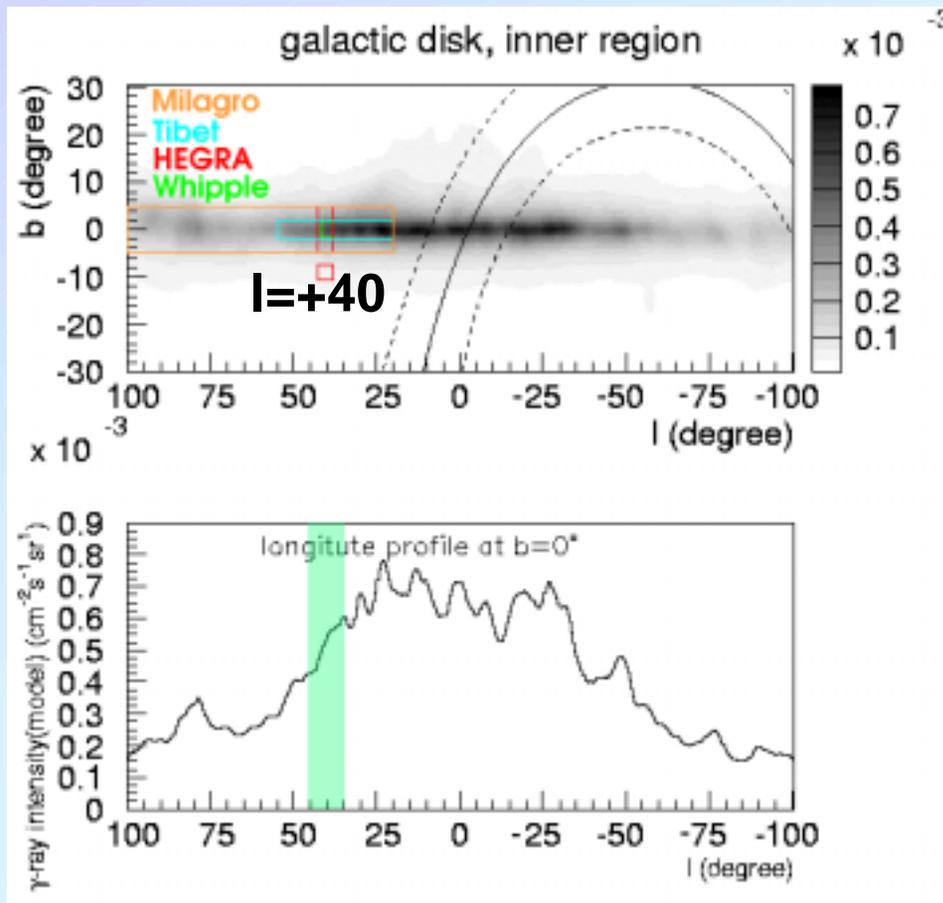


Or,

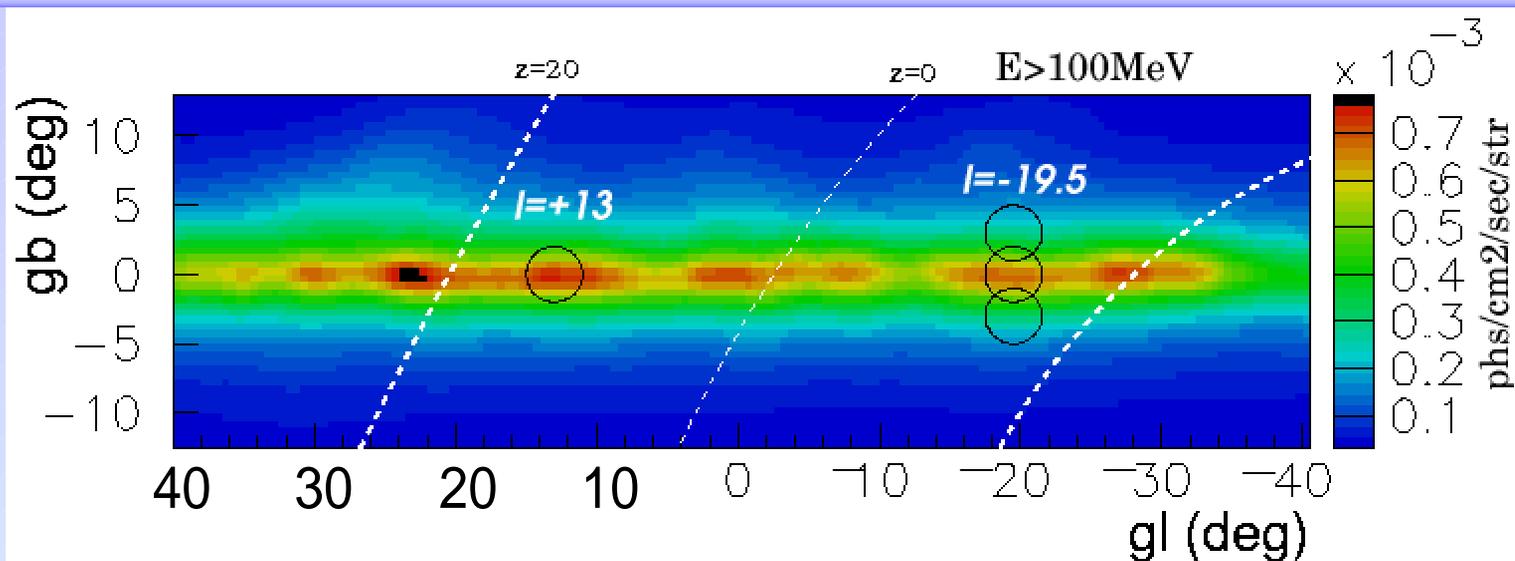
- ✓ GeV excess may be originated by superimposition of weak point sources which cannot be resolved by the EGRET angular resolution..

Past VHE observations and results of the galactic plane

- EGRET energy band – up to 30GeV. Measurement at TeV region verify that the hard(-2.45) spectrum is maintained up to more high energy region.
- Fine angular resolution (~ 10 arcmin) achieved by the IACT may bring the discovery of unknown point sources.



Observation of the galactic plane with the CANGAROO-III telescopes(1)

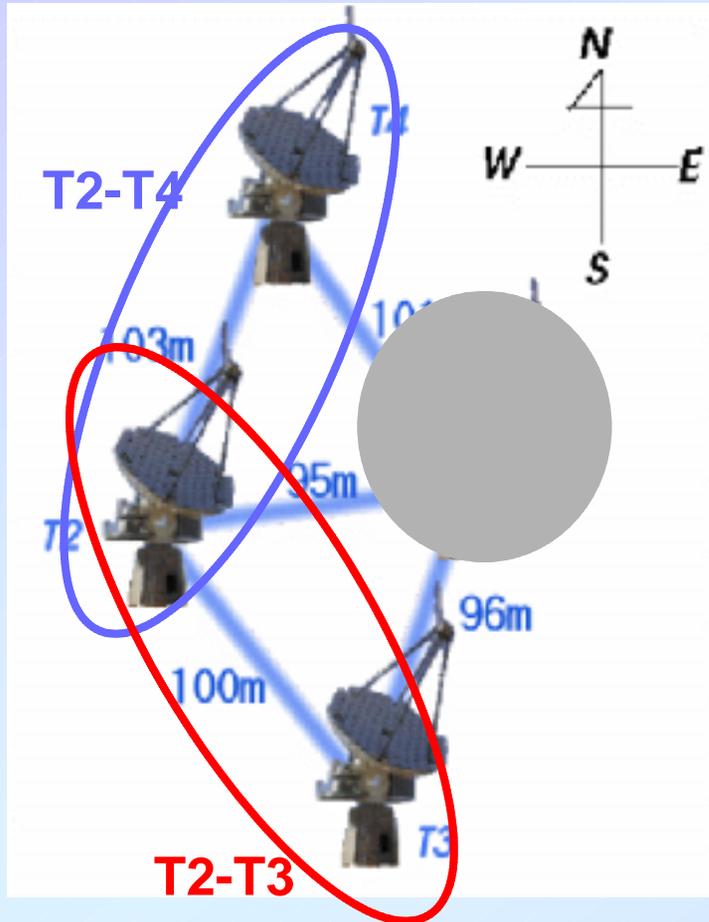


Selection criteria of the observed points

1. Coincident with local maximum of the EGRET diffuse model
2. Minimum zenith angles at the CANGAROO site is less than 20 deg
3. No bright stars in the FOV
4. No known TeV point sources in the FOV

→ Selected region: $(l,b)=(-19^{\circ}.5, 0^{\circ}.0)$, $(+13^{\circ}.0, 0^{\circ}.0)$

Observation of the galactic plane with the CANGAROO-III telescopes(2)



Net obs.time

$l = -19^\circ.5$ 2004Jun

<i>Obs.term</i>	<i>tel.pair</i>	$b=0^\circ$	$b=-3^\circ$	$b=+3^\circ$
2004Jun	T2-T3	10.6h	5.4h	4.9h
2004Jun	T2-T4	6.3h	3.4h	3.2h

$l = +13^\circ$ 2004Jun/Aug

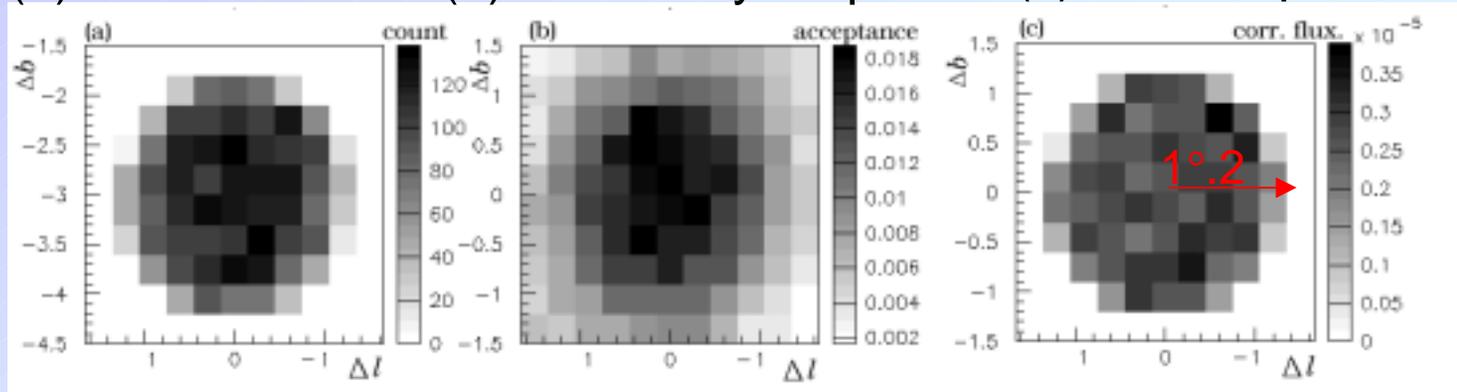
<i>Obs.term</i>	<i>tel.pair</i>	ON	OFF
2004Jun	T2-T3	4.8h	5.7h
2004Jun	T2-T4	3.3h	4.5h
2004Aug	T2-T3	3.7h	3.1h
2004Aug	T2-T4	4.7h	1.4h

EL>45°, energy threshold : ~600GeV

Analysis of the diffuse component(1)

Acceptance correction

(a) Event count (b) Sensitivity map (c) Flux map



(a) (b) (c)

$$N_{count}(l_i, b_j) / S_{eff}(l_i, b_j) / T = F(l_i, b_j)$$

➤ As for this truly extended source (*source size > field of view*)

$$I = \sum_{i=1}^{N_1} \sum_{j=1}^{N_2} F(l_i, b_j) / \Delta\Omega$$

➤ Comparison of “averaged” gamma-ray-like event flux between ON and OFF region

$$l = -19^\circ.5$$

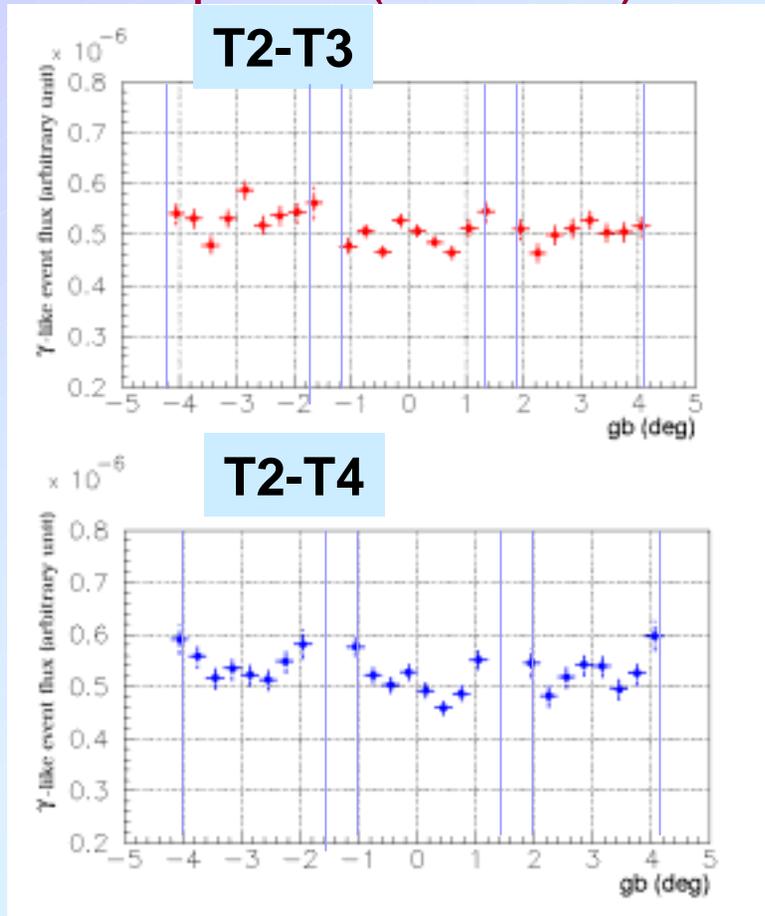
$$I(b=0) - \frac{I(b=-3) + I(b=+3)}{2}$$

$$l = +13^\circ$$

$$I(ON) - I(OFF)$$

Analysis of the diffuse component(2)

Gamma-ray like event
Latitude profile($l=-19.5$)



Cf. EGRET measured profile:
Gaussian $1\sigma \sim 1.0$ deg

✓ $|l-19^{\circ}.5| < 0^{\circ}.75$,
 b interval : $0^{\circ}.3$
Vertical bar ← stat. err. 1σ

✓ Normalization of the regions
← number of proton-like
events

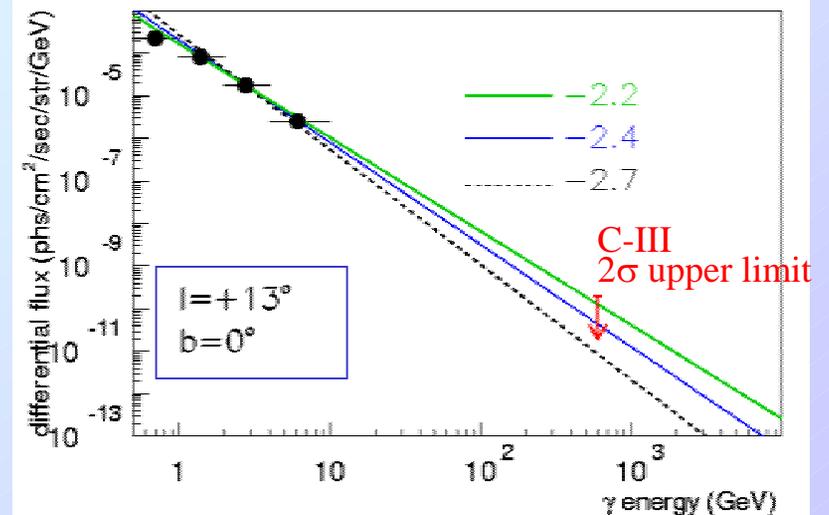
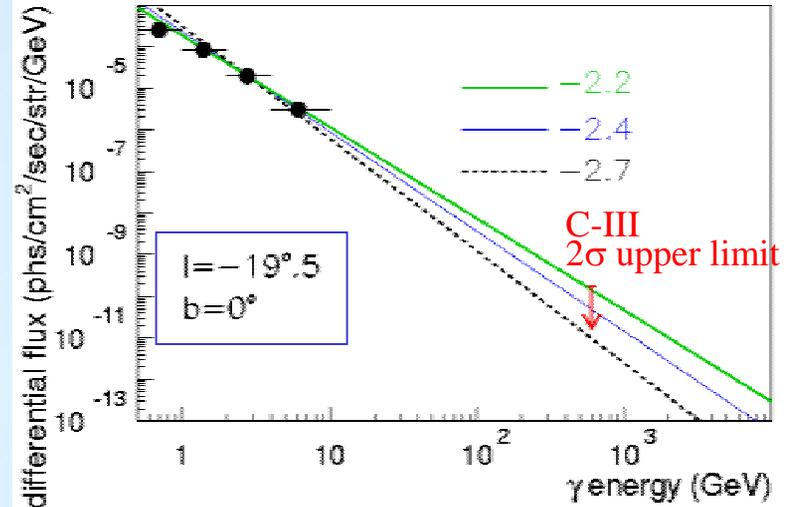
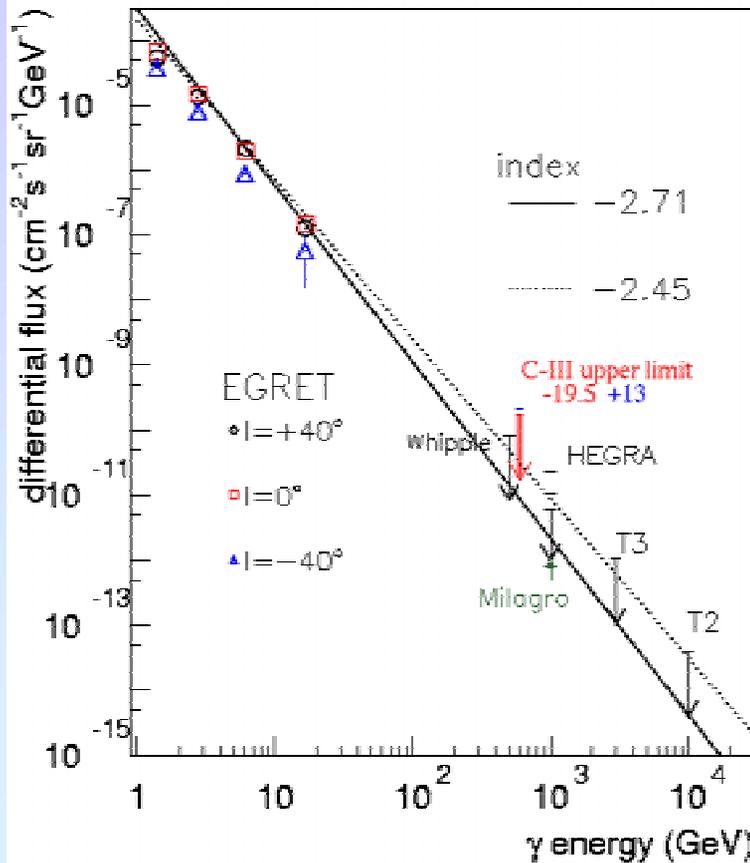
➤ No significant excess associated
with the plane was found both
for $l=-19.5$ and $l=+13$.



2σ flux upper limit can be
obtained from this measurement.
(systematic error is also
considered here.)

Analysis of the diffuse component(3)

2 σ flux upper limit for the diffuse component

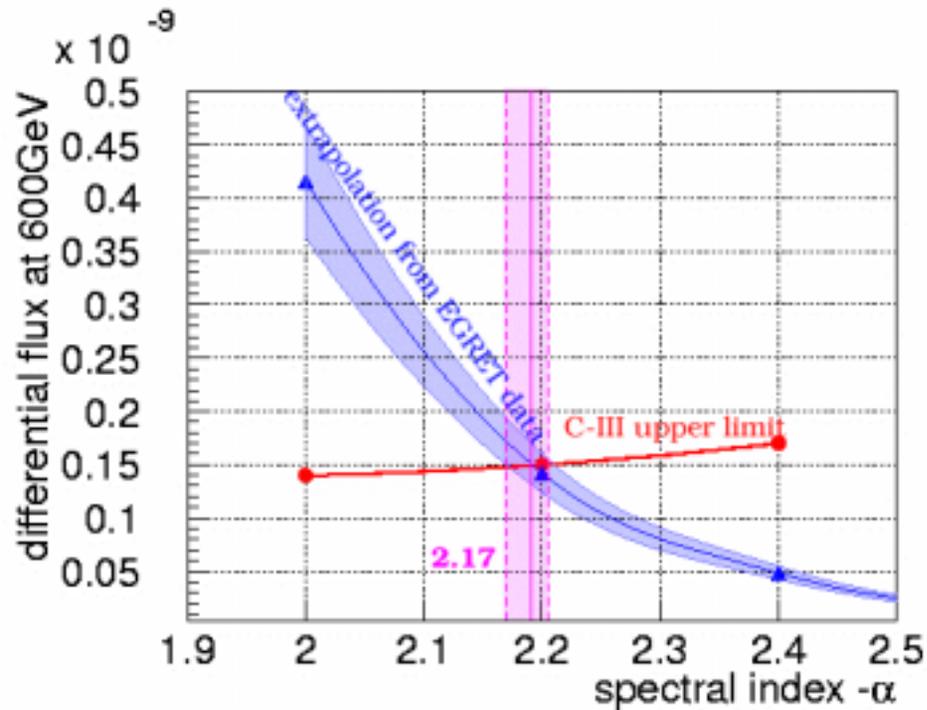


Comparison with other VHE results

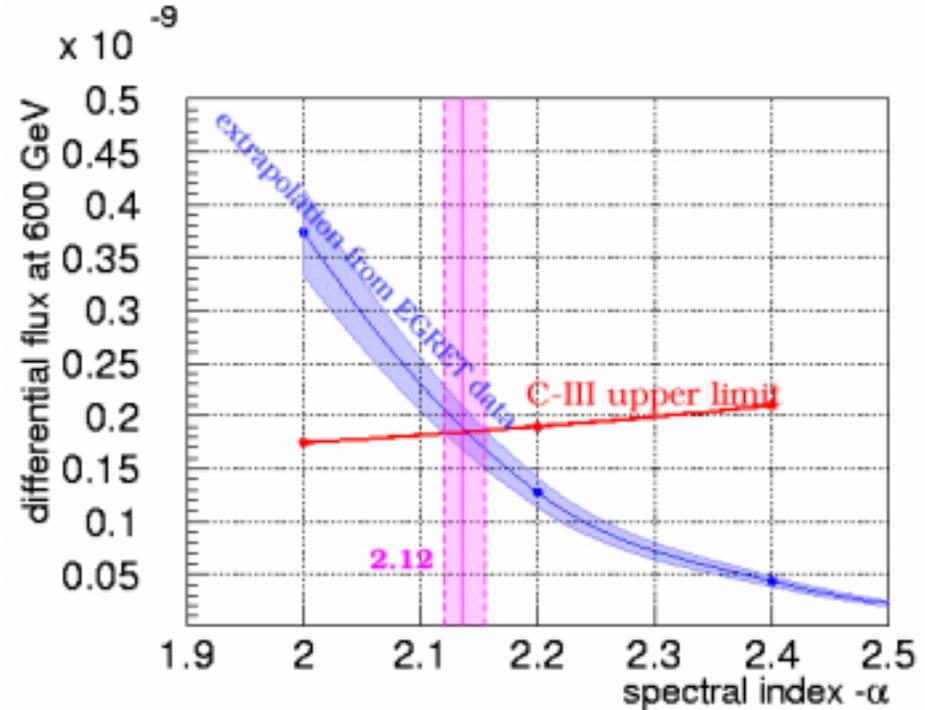
C-III \rightarrow systematic error included

Upper limits for the diffuse component –limitation to the spectral index

$l = -19.5^\circ$



$l = +13^\circ$

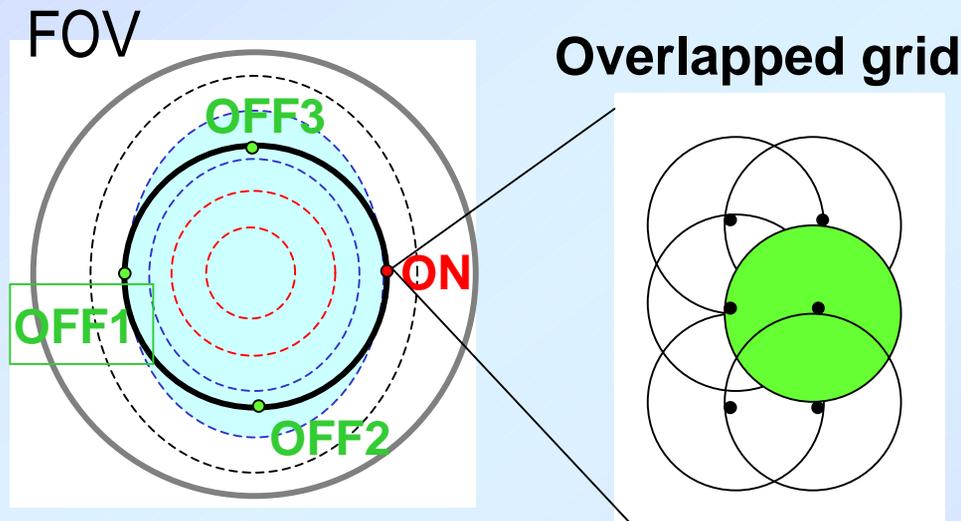


➤ Spectral index lower limit is determined so that extrapolation from EGRET measurement point does not conflict with the C-III upper limit

$l = -19.5^\circ : 2.17$ $l = +13^\circ : 2.12$

Survey analysis the unknown point sources(1)

- In the case $FOV \gg$ source size, “OFF” region can be chosen within the FOV (cf. wobble obs.)
- Grid search within the field of view was performed
(This analysis method is based on the work by HEGRA (Aharonian 1998)).
- OFF position should be chosen to be at the point where sensitivity in the FOV is almost same as the ON



$$\text{significance} = \frac{N_{ON} - \beta N_{OFF}}{\sqrt{N_{ON} + \beta^2 N_{OFF}}}$$

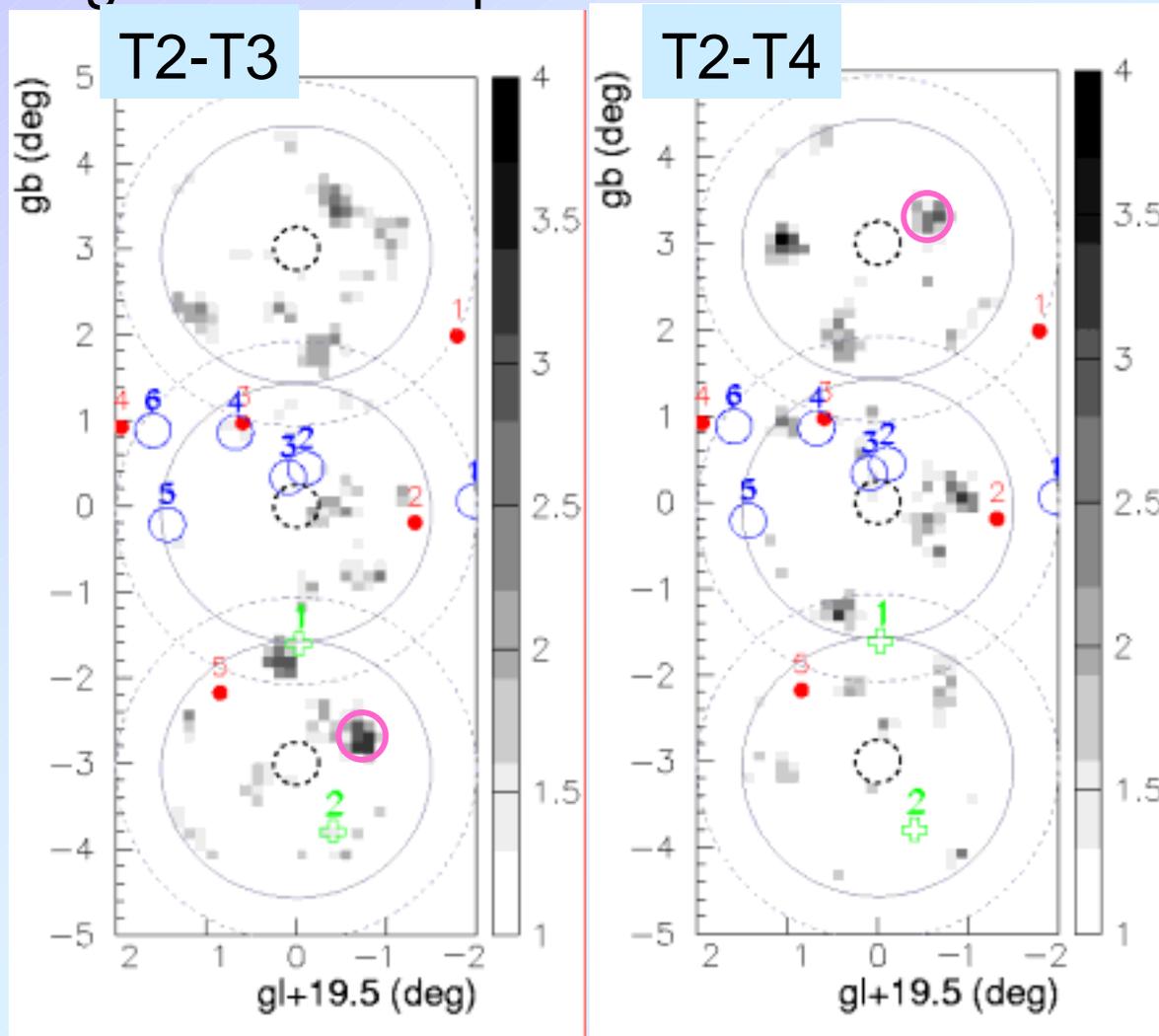
(in this case $\beta=1$)

- interval $0^\circ.125$
- collection radius $0^\circ.25$
- Number of grid point: 454

C-III angular resolution of this observation: $\sim 0^\circ.17$ R.M.S.

Survey analysis for the unknown point sources(2)

Significance map



Red point : pulsars
Blue circle : SNRs
Green cross : EGRET point sources

Max.significance

T2-T3: 3.3σ

T2-T4: 3.8σ

Isotropic MC

T2-T3 3.1σ

T2-T4 3.5σ

No significant source ($>4\sigma$) was found

Typical 2σ flux upper limit:
~20% Crab

Summary

➤ Inner region of the galactic plane ($l=-19.5$, $l=+13$) was observed with the CANGAROO-III stereoscopic system with 600GeV energy threshold. These regions have not been observed in VHE region so far.

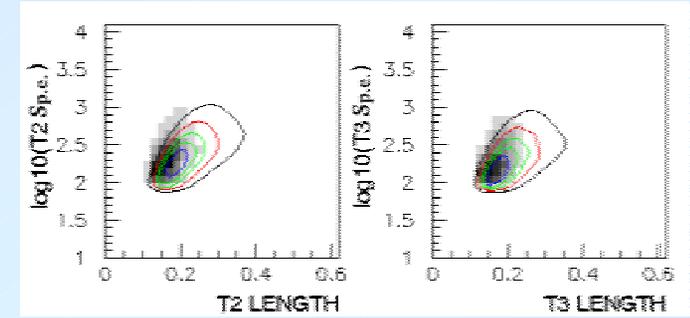
➤ As for the diffuse component, no significant excess was found both for the $l=-19.5/l=+13$ regions. Combining EGRET observed points and flux upper limit imposed by the CANGAROO-III, gamma-ray spectral index limit is obtained to be -2.17 and -2.12 for $l=-19.5$, $l=+13$ respectively.

➤ As for the point source survey for $l=-19.5$ region, no significant (4σ) point source was found in the field of view. Typical upper limit flux is $\sim 20\%$ Crab level.

-like event selection by image parameters

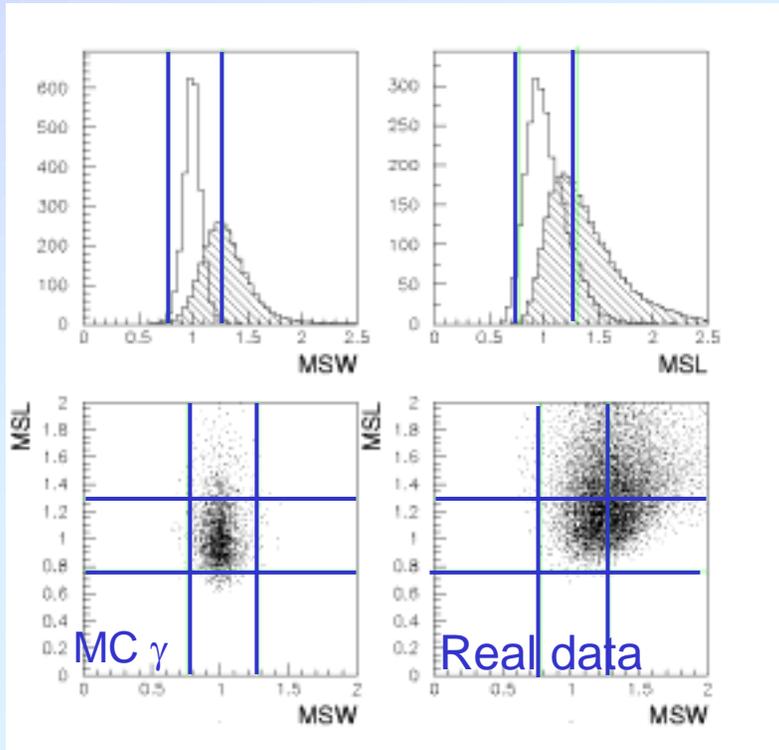
➤ Number of image parameters ← num. Of tel.

1. Conventional square cut
2. Mean Scaled parameter cut
(energy dependence correction included)



Blank:MC

Hatched:Real



➤ Definition of Mean Scaled parameters

Mean Scaled WIDTH(MSW):

$$MSW \equiv \frac{1}{n} \sum_{i=1}^n w_i / \langle w \rangle_i^k$$

i : Tel. ID, k : $S_{p.e.}$ bin number

n : number of telescopes=2

$\langle w \rangle_i^k$: averaged WIDTH of i th telescope whose Sp.e. comes in k th bin

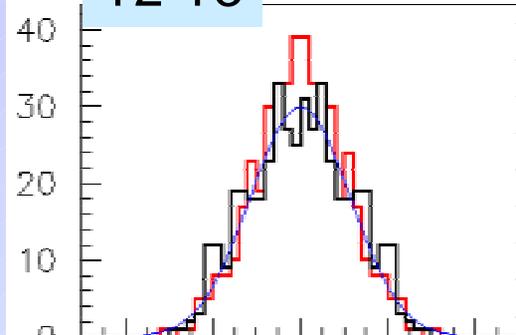
MSL is derived in the same way.



Point source survey :significance distribution

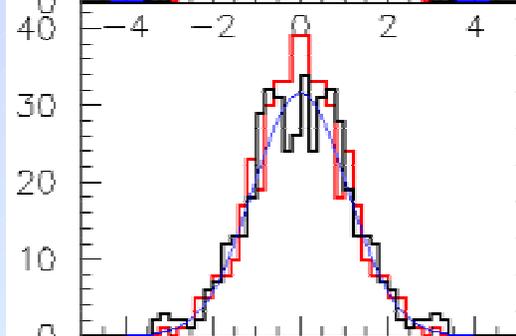
Red:isotropic MC Black:Real data

T2-T3



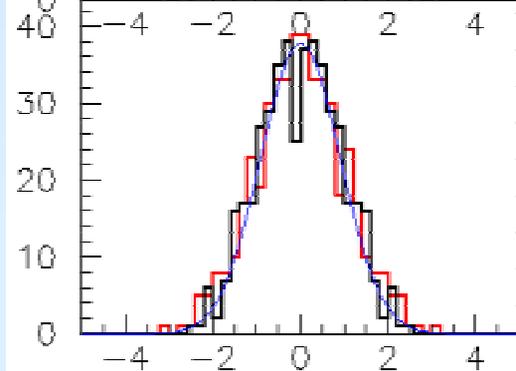
Real data: Gaussian fit
mean 0.002
sigma 1.15 0.04

$$\chi^2 / \text{DOF} = 0.86$$



mean 0.003
sigma 1.08 0.04

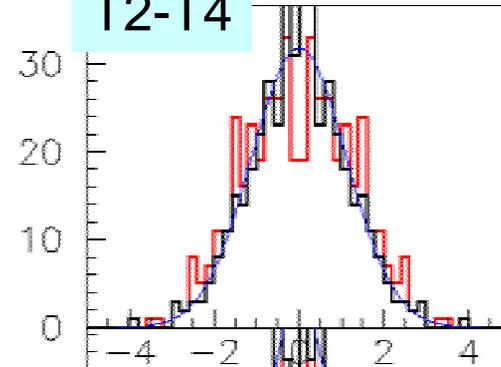
$$\chi^2 / \text{DOF} = 0.84$$



mean 0.004
sigma 0.91 0.03

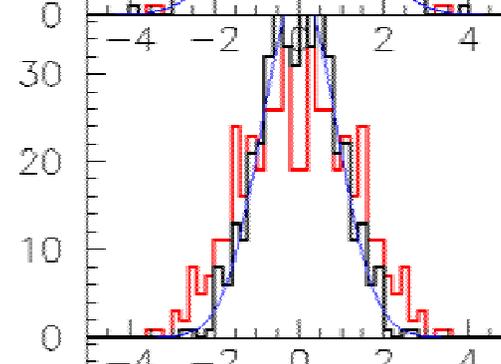
$$\chi^2 / \text{DOF} = 0.96$$

T2-T4



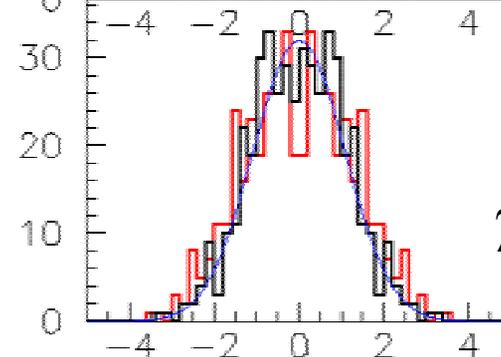
mean 0.001
sigma 1.13 0.05

$$\chi^2 / \text{DOF} = 0.83$$



mean 0.003
sigma 0.88 0.03

$$\chi^2 / \text{DOF} = 2.21$$



mean 0.002
sigma 1.08 0.04

$$\chi^2 / \text{DOF} = 1.40$$