TA Anisotropy Summary

Eiji Kido

for the Telescope Array Collaboration

Outline

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  - Hotspot
  - Correlation with LSS
  - Anisotropy in energy spectrum
  - Correlation with nearby AGNs
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Telescope Array Collaboration

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5 countries, ~120 collaborators

FD station

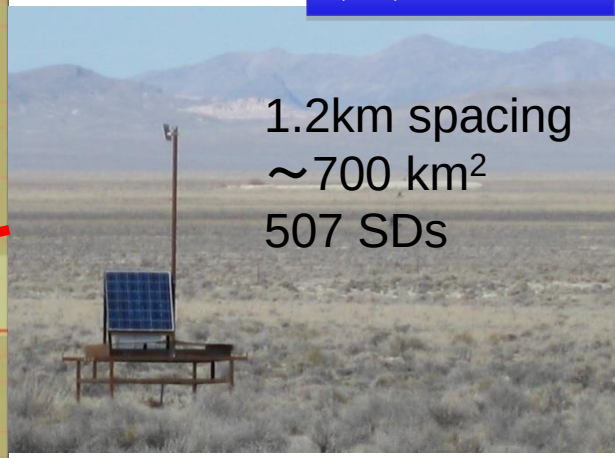
MDFD

Utah, USA
- lat. 39.30°N, long. 112.91°W

TALE
SD array

SD array

Surface Detector
(SD)



CLF

LRFD

28km

BRFD

Fluorescence Detector
(FD) station

FD station

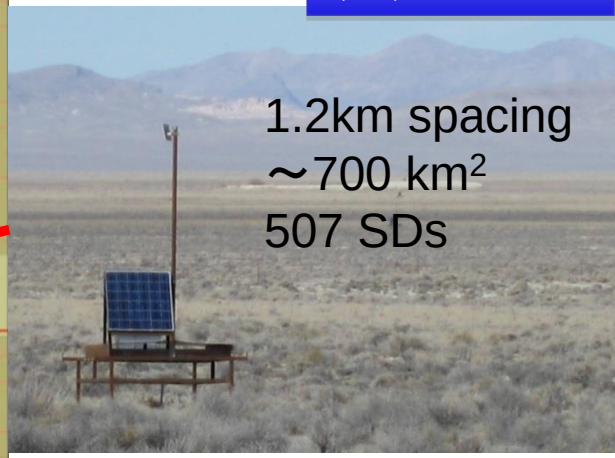
MDFD

Utah, USA
- lat. 39.30°N, long. 112.91°W

TALE
SD array

SD array

Surface Detector
(SD)



CLF

LRFD

28km

BRFD

Fluorescence Detector
(FD) station

TA SD & FD Full operation : **7 years** from 2008 May

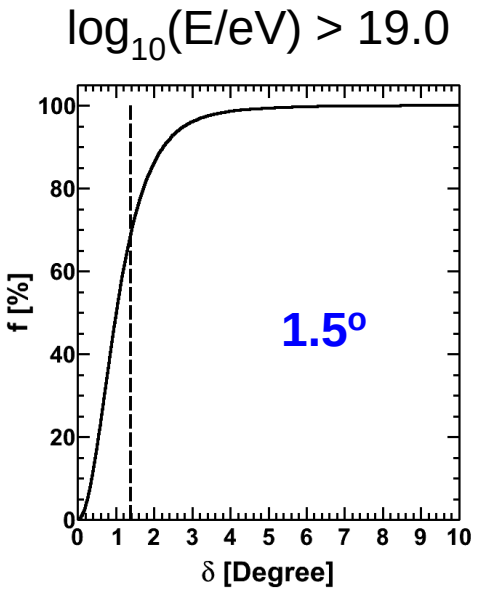
SD statistics～10×(FD statistics)

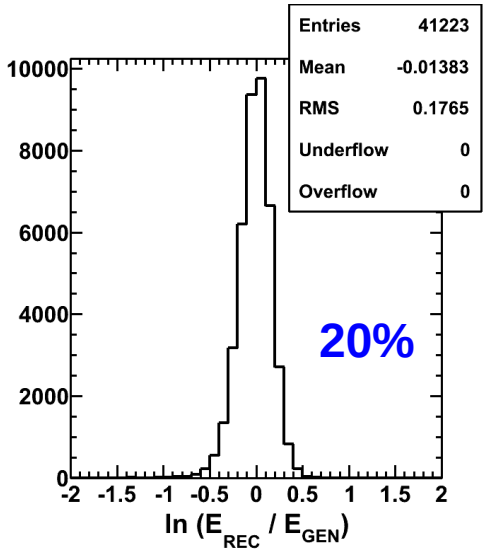
FD observes only moon less night

Anisotropy is studied using SD data

Data Set for anisotropy studies

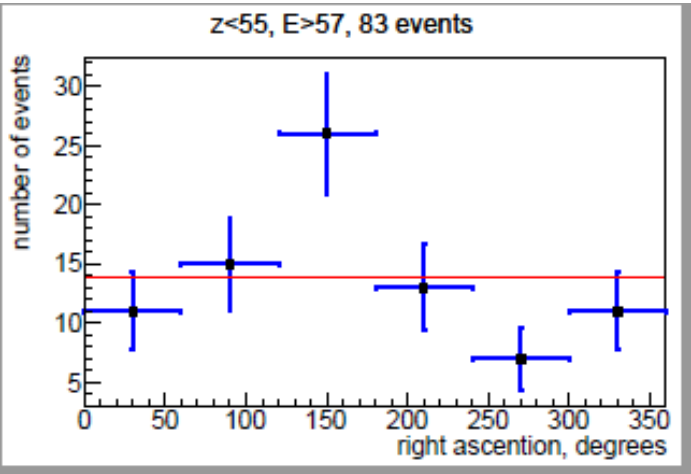
- SD data (2008 May 12 - 2015 May 11)
- Zenith angle < 55 (deg.)
- E > 10 EeV 2996 events, E > 40 EeV 210 events, E > 57 EeV 83 events
- Energy resolution～20%
- Angular resolution: better than 1.5 (deg.)

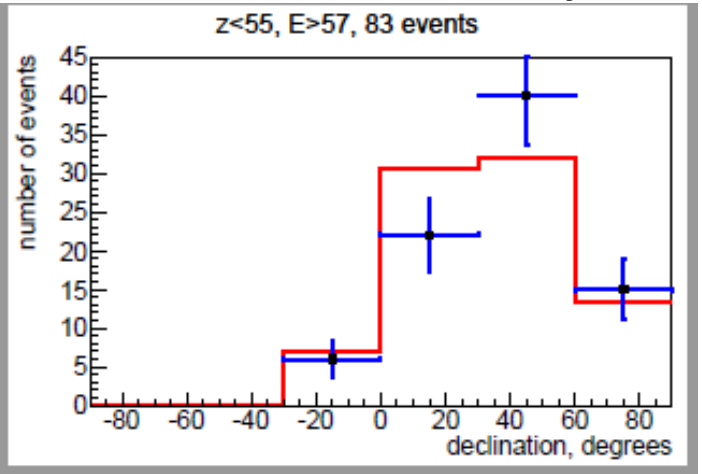


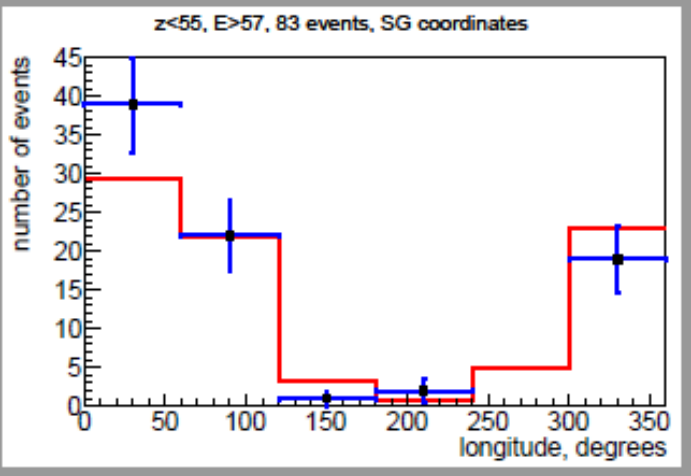


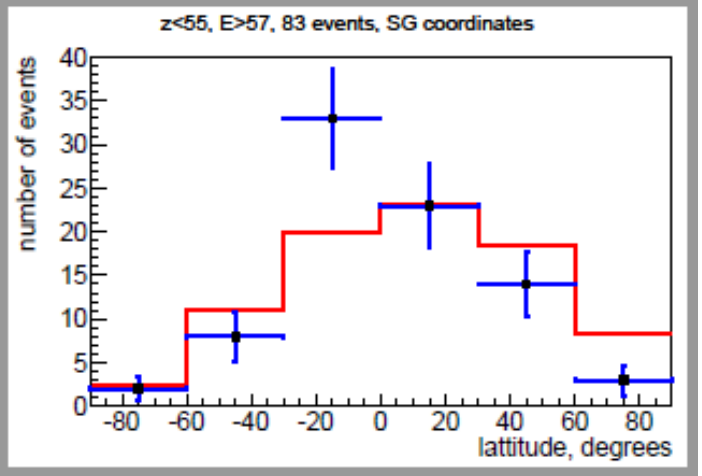
Distribution of arrival directions

ICRR 2015 Tinyakov









E > 10 and 40 EeV
Probabilities using
K-S test: p > 0.12
Isotropic

→
Show the results
mainly on
E > 57 EeV

E > 57 EeV
Probabilities using
K-S test

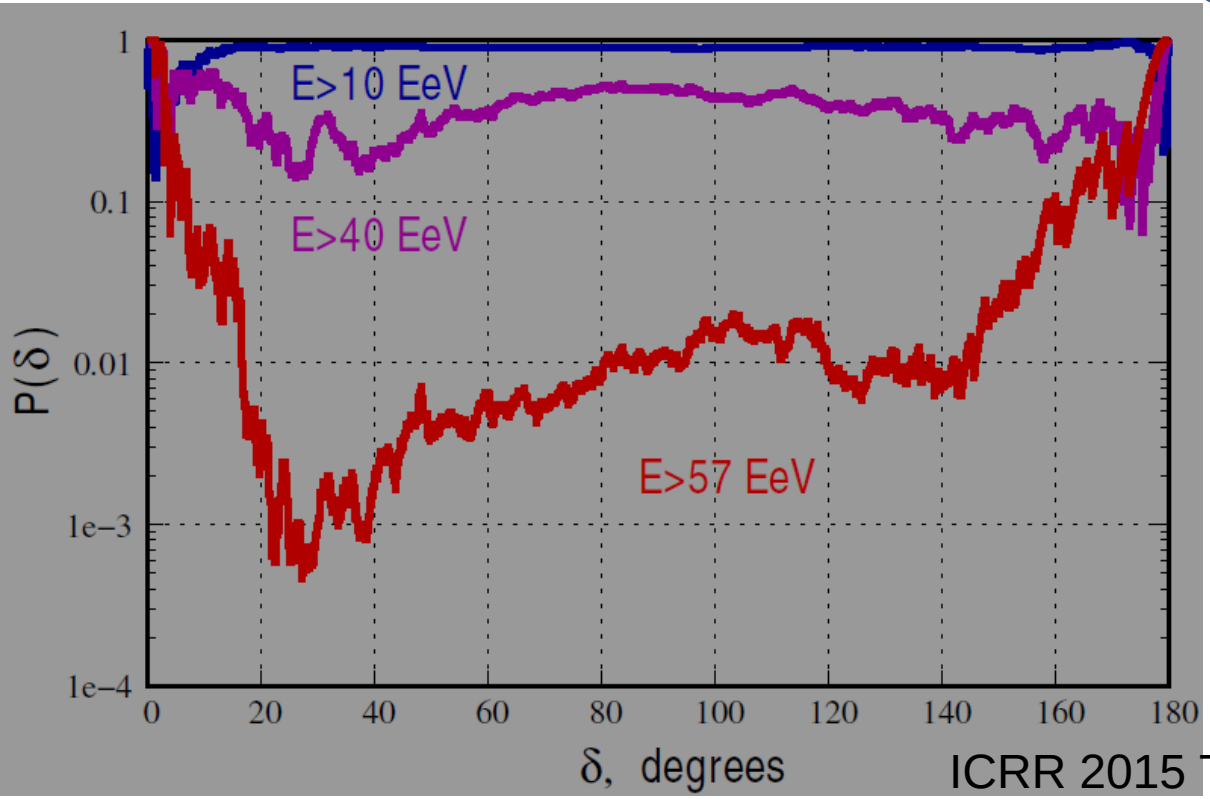
Frame	longitude	latitude
Equatorial:	0.07	0.04
Supergalactic:	0.01	0.03

Results of anisotropy studies

Autocorrelation

Number of pairs < δ (deg)
is evaluated from isotropy.

Chance probability

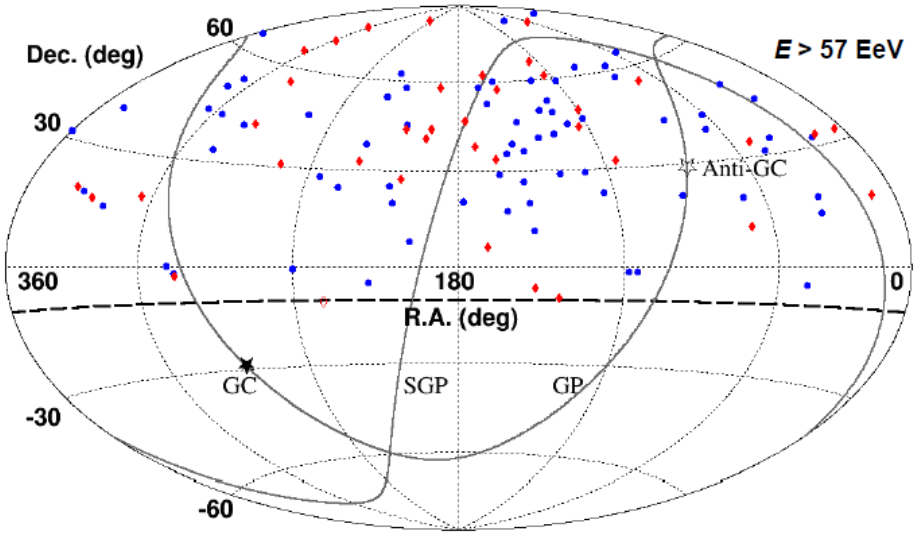


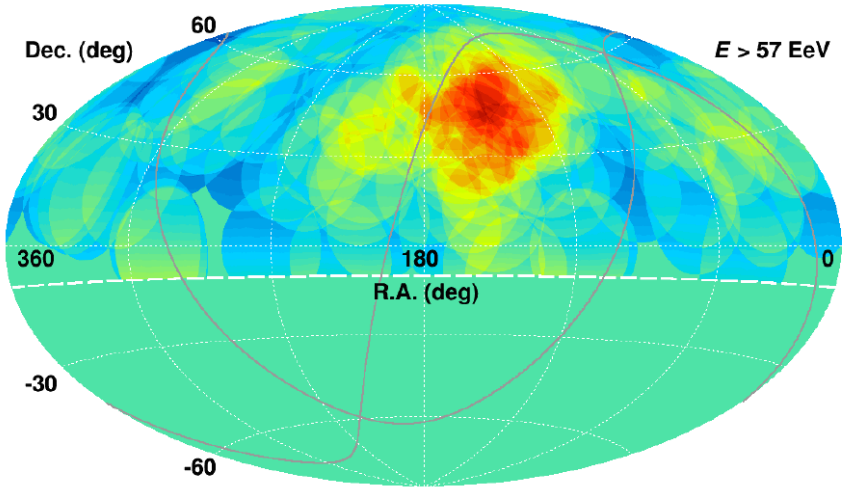
Compatible with isotropy
at E > 10 EeV and E > 40 EeV

Chance probability ～ 0.1%
(pre-trial)
at around δ～20-30 (deg.)
at E > 57 EeV

Updated Hotspot analysis

Oversampling using 20 deg. radius circles





Blue: 5 year data (published in *ApJL 790, L21 (2014)*)
Red: 6 and 7 year data (37 events)

Equatorial coordnate
ICRR 2015 Kawata

- Loose cut data, **7 year** data 109 events (Zenith angle < 55 (deg.))
- Max significance: RA 148.4 (deg.) Dec 44.5 (deg.) ("Hotspot")

  Observed: 24 events, isotropy: 6.88 events → Significance: 5.1σ (Li-Ma)
- Chance probability to exceed 5.1σ in the exposure: **3.4σ (0.037 %)** (post-trial)

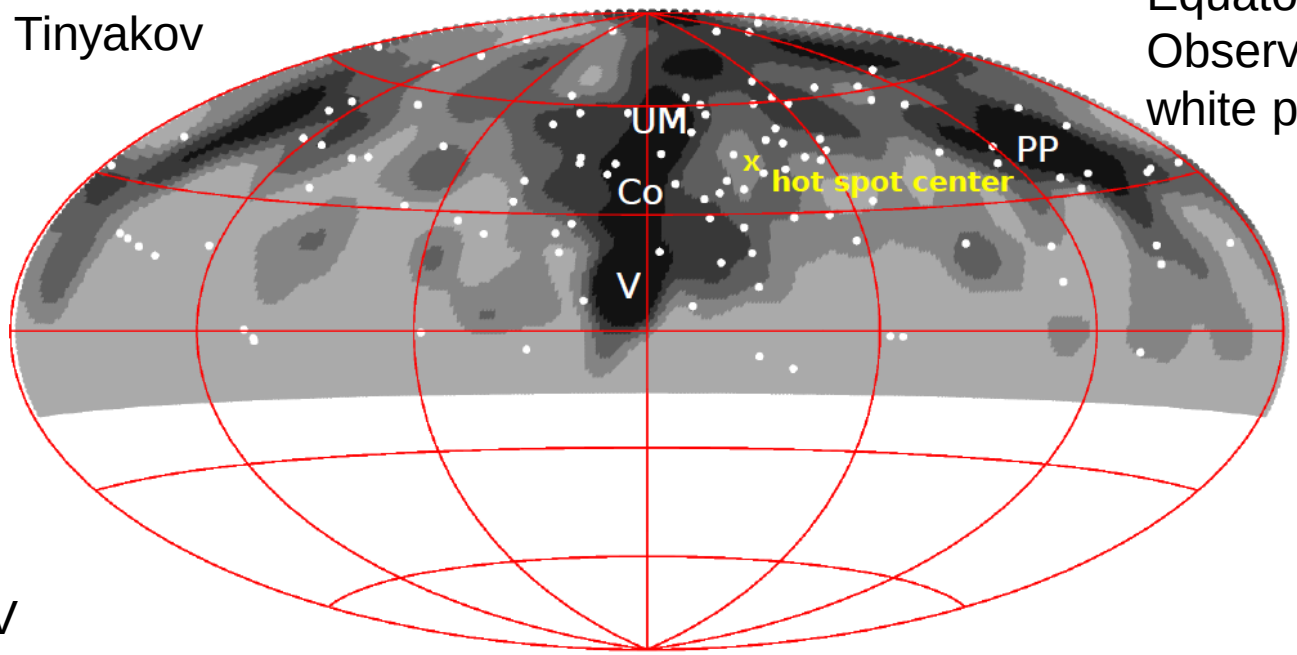
  (15, 20, 25, 30, 35 (deg.) radius circles are searched.)

3.4σ (0.037 %) was also obtained in **5 year** data in *ApJL 790, L21 (2014)*

Correlation with LSS

ICRR 2015 Tinyakov

Equatorial coordinate
Observed events:
white point

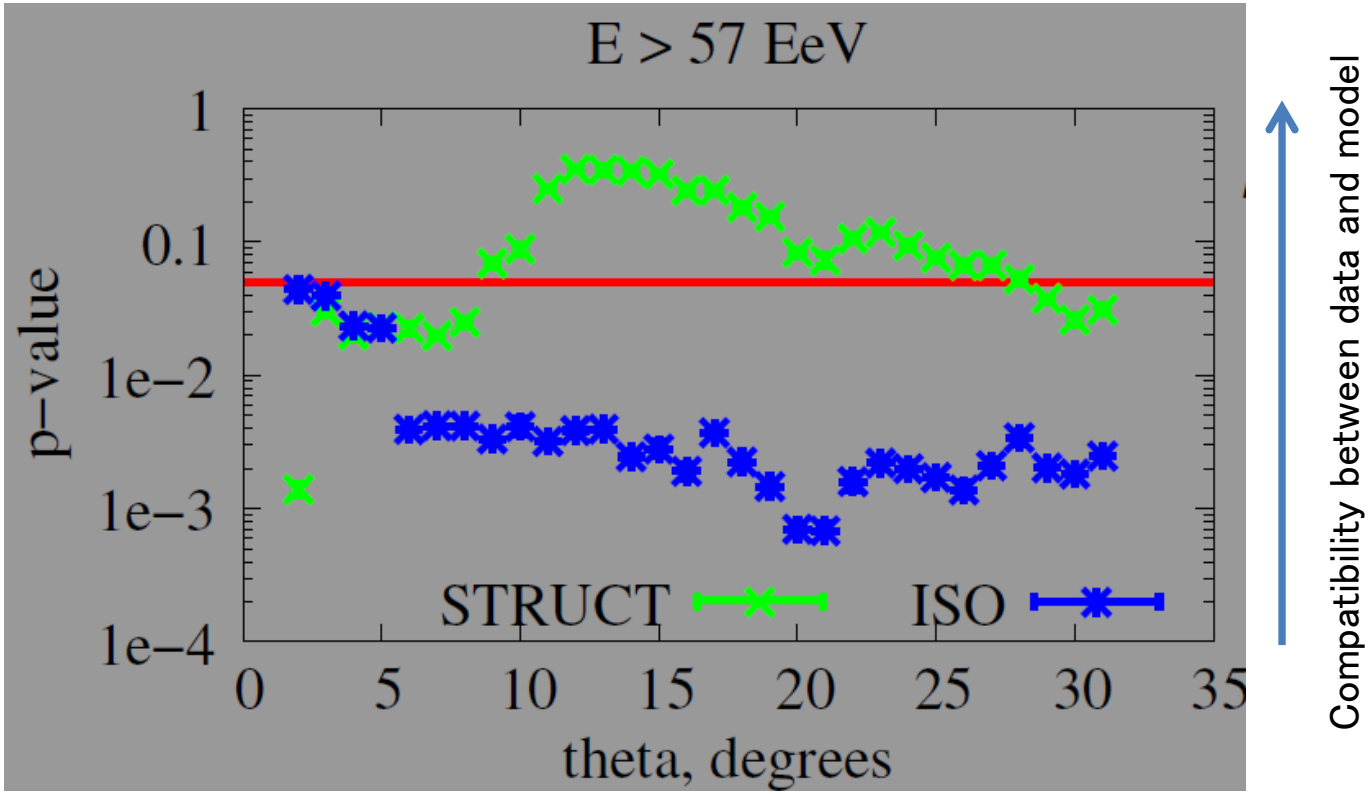


E > 57 EeV
Smearing angle 6 (deg.)

Expected flux is calculated from
1) 2MASS XSCz catalog, 109000 galaxies with $K_{mag} < 12.5$ within 250 Mpc
2) Gaussian smoothing of the angular with Θ.
3) Energy loss of Protons with CMB/IRB

Data is compared with the model flux
using K-S test as a function of Θ.

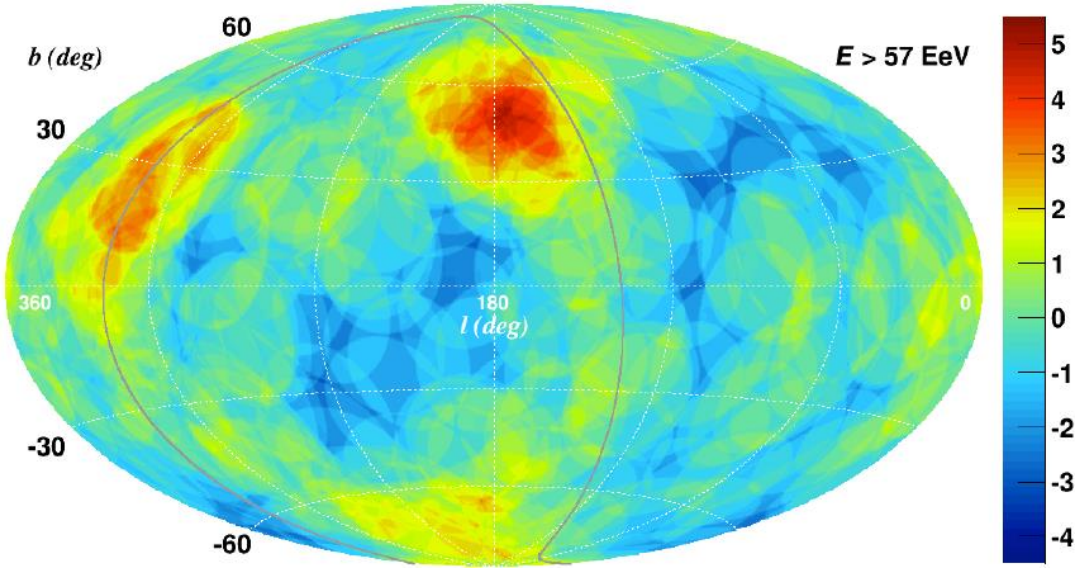
Compatibility with LSS and isotropy



ICRR 2015 Tinyakov

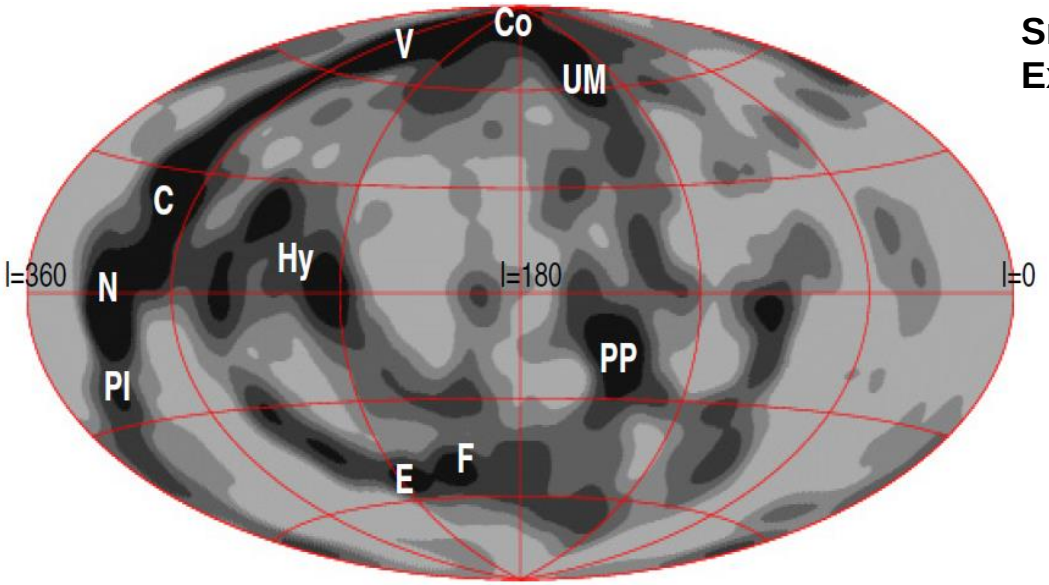
- Compatible with LSS
- Compatibility with isotropy is low ～a few × 0.1 % (pre-trial) for large smearing angles (> 5 deg.)

Hotspot analysis for the whole sky (Galactic coordinate)



E > 57 EeV
TA 6 years 87 events
Auger 10 years157 events
(No correction of Energy scale is applied.)

→ Over-density around the super Galactic plane in the future?



Smearing angle: Θ_s = 6°, E > 57 EeV
Expected flux distribution

C: Centaurus supercluster (60 Mpc); Co: Coma cluster (90 Mpc); E: Eridanus cluster (30 Mpc); F: Fornax cluster (20 Mpc); Hy: Hydra supercluster (50 Mpc); N: Norma supercluster (65 Mpc); Pl: Pavo-Indus supercluster (70 Mpc); PP: Perseus-Pisces supercluster (70 Mpc); UM: Ursa Major (20 Mpc); and V: Virgo cluster (20 Mpc).

Other anisotropy studies

- Anisotropy in energy spectrum
  - Comparison between 2 energy spectra
  - “On source”: within 30 (deg.) from super-galactic plane

  → **∼3.2σ difference** between 2 energy spectra
- Correlation with nearby AGNs
  - Same catalog (VCV) and same parameters (3.1° angular scale , $z \leqq 0.018$, $E > 57$ EeV) are used as Pierre Auger. (Spectrum data set (zenigh angle < 45 (deg.)) is used.)
  - **24** events are correlated with nearby AGNs out of **64** events →**chance probability: 1.2 %**
- Search for EeV protons of Galactic origin
  - 1-3 EeV: **data is compatible with isotropy**
  - **Upper limit of $(N_{Data} - N_{MC})/N_{MC}$** ($N_{MC}$: number of events from isotropic MC)

    → fraction of Galactic proton < ∼1% at 90% C.L.

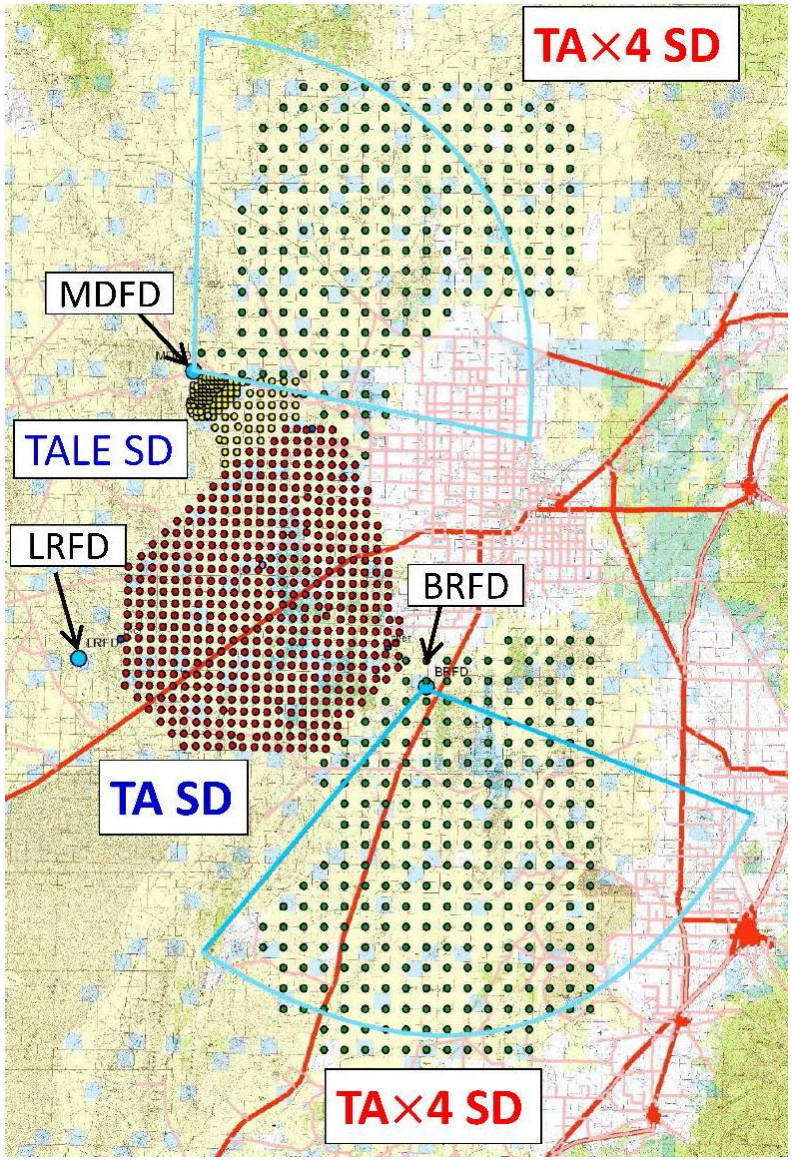
Summary and Conclusions

- Chance probability of the hotspot for 7 years remains **3.4σ** as for 5-year initial sample.
- Significance of anisotropy is still not enough for the definite conclusion.

→ The extension project TAx4 is in progress.

Plan: collect ～19 year TA SD data until 2020

TAx4 experiment



500 SDs, 2.08 km spacing

covers

~3x TA SD (about 2100 km^2)

Total about 4x TA SD 3000 km^2

(full operation:2017 Dec -)

→ ～ 12 year TA SD

～ 7 year TA SD from the extension

→～19 year TA SD data until 2020

2015 April approved

Back Up

Anisotropy in energy spectrum

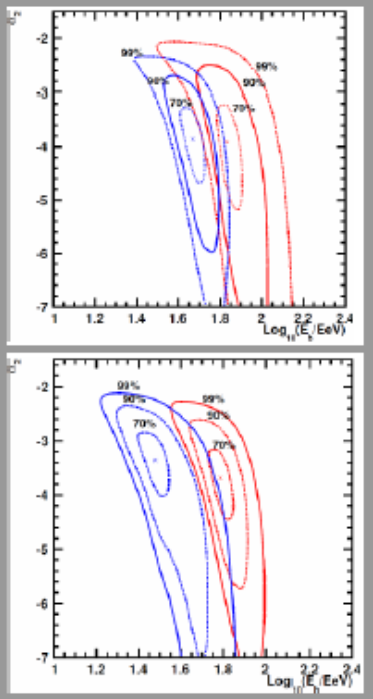
T. Nonaka, P1CR 233, Jul. 30

Strategy:

- Split the event set into “on-source” and “off-source” parts
- compare the “on-source” and “off-source” energy spectra

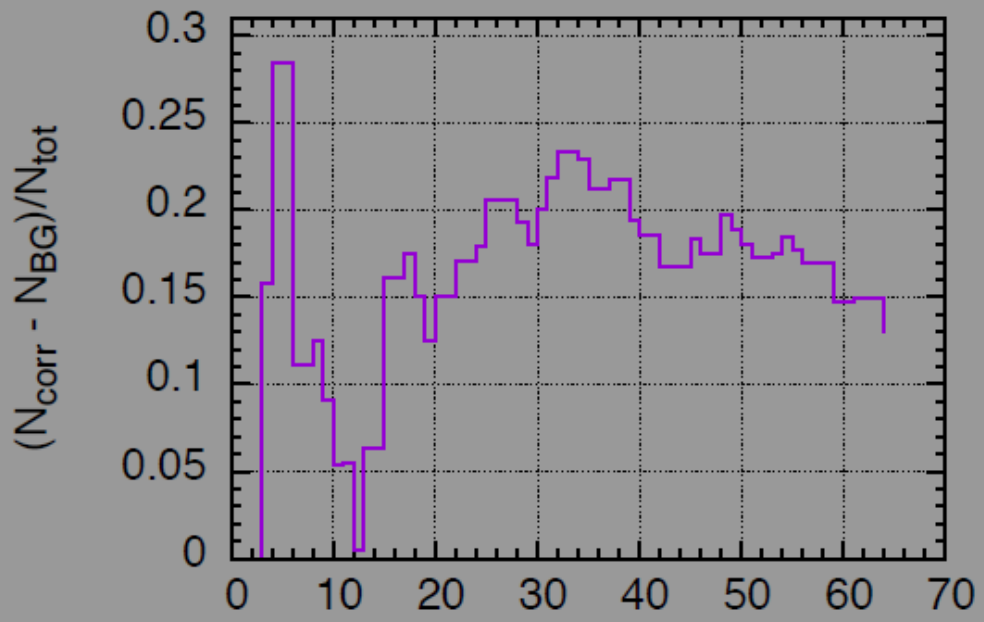
Two analyses:

- “On-source” = within 30° from Supergalactic plane
  $\Longrightarrow \sim 3.2\sigma$ difference
- “On-source” = within 11° from VCV AGNs
  $\Longrightarrow \sim 2.4\sigma$ difference



CORRELATION WITH NEARBY AGN

- For compatibility with previous TA studies use the "spectrum" data set: strict cuts, $\theta_z < 45°$, $E > 57$ EeV, 7 years = 64 events
- Putative sources: AGN from VCV catalog with $z < 0.018$ (472 objects)



The fractional excess of correlating events $(N_{\rm corr} - N_{\rm bg})/N_{\rm tot}$.

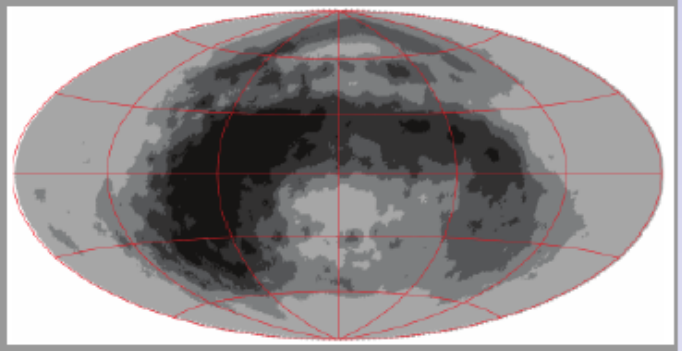
- Within 3.1° from AGNs there are 24 correlating events; for 1 event $P(1) = 0.2415$; p-value $= P(24) = 0.012$

Search for EeV protons of Galactic origin

Motivation:

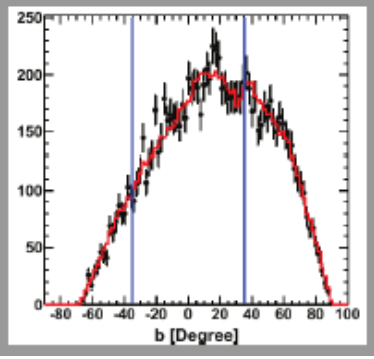
D. Ivanov, P2CR 858, Aug. 1

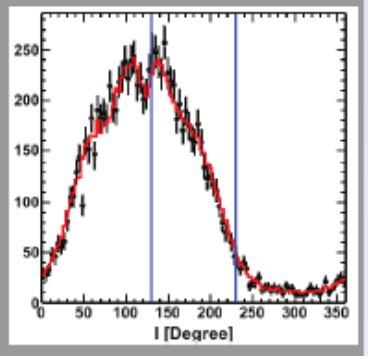
- At the transition from ballistic to diffusive regime ($E \sim 1$ EeV), one can predict the proton flux from galactic sources in a *model-independent way*. It is *strongly anisotropic*.
- Comparing to observed flux, the proton component may be constrained.



Results:

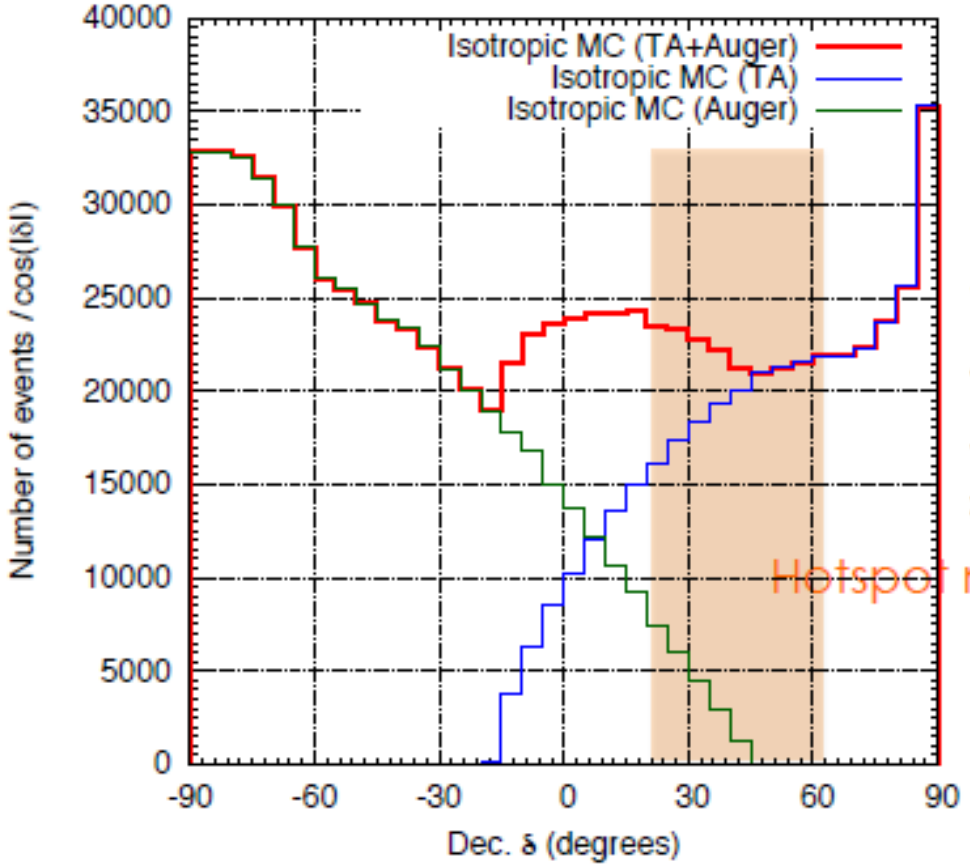
- fraction of Galactic protons in EeV cosmic rays is $\lesssim 1\%$ at 90% CL.

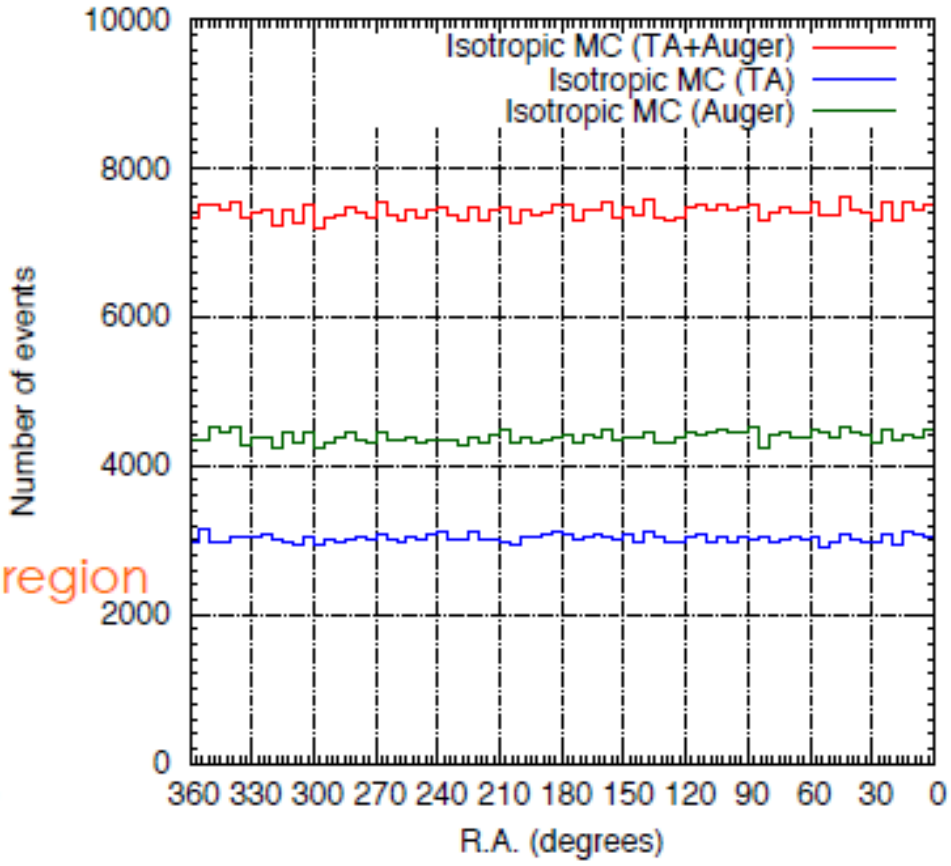




MC Background (TA+PAO)
Dec. and R.A. distribution

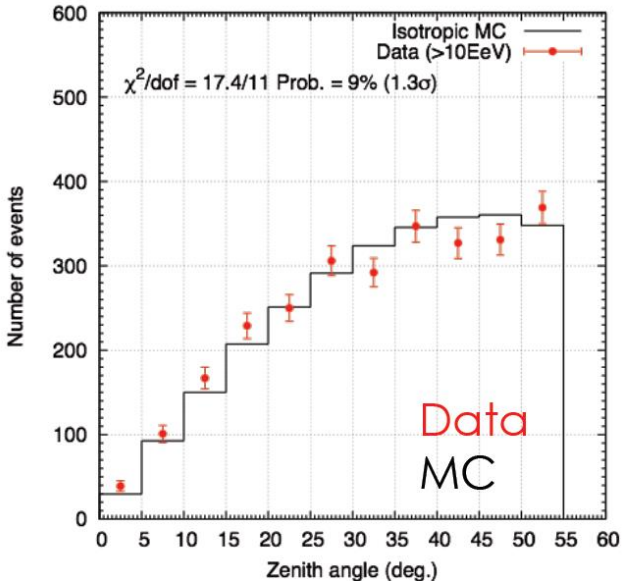
A uniform distribution according to the TA+Auger geometrical exposure (sinθ cosθ random) .

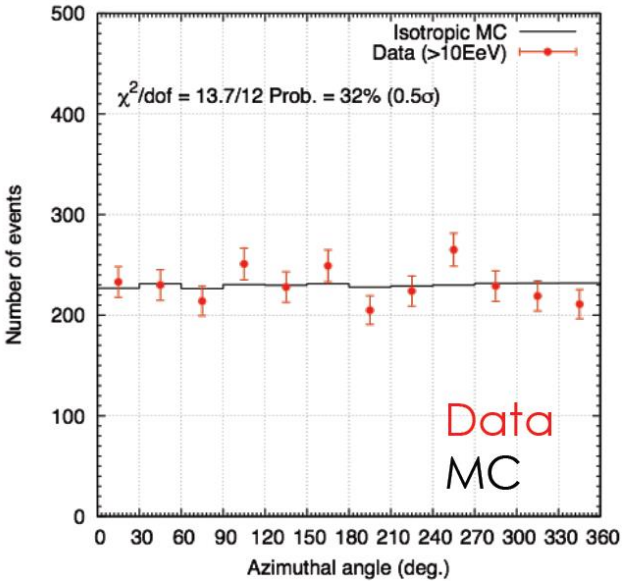




Total 534,000 events

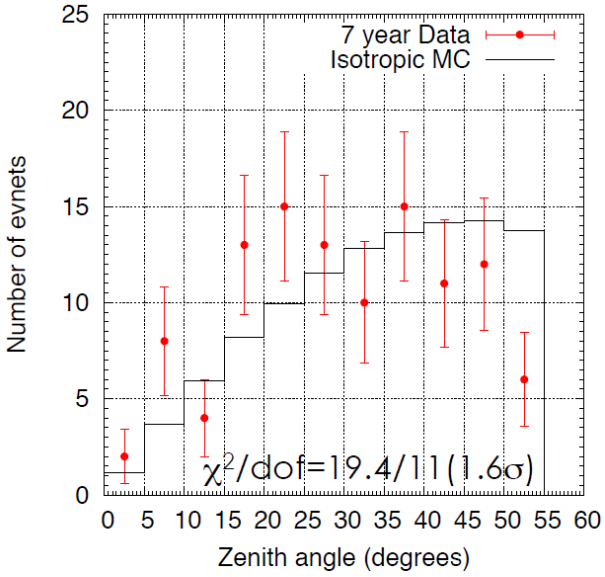
Data/MC comparison E > 10 EeV

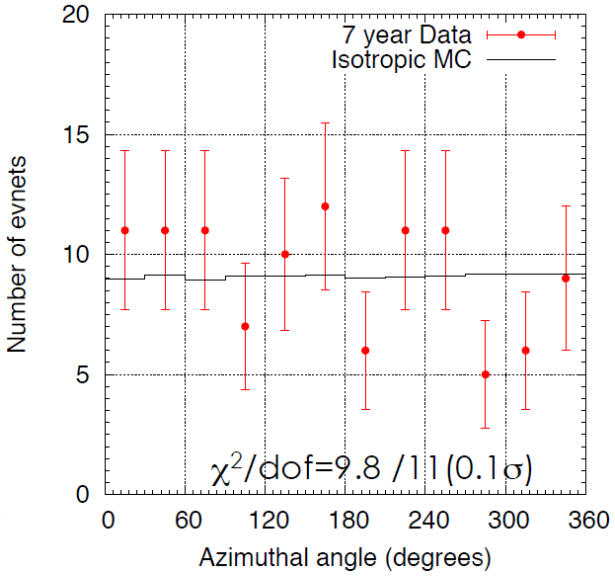




Control sample
KS probability > 0.09

Data/MC comparison E > 57 EeV





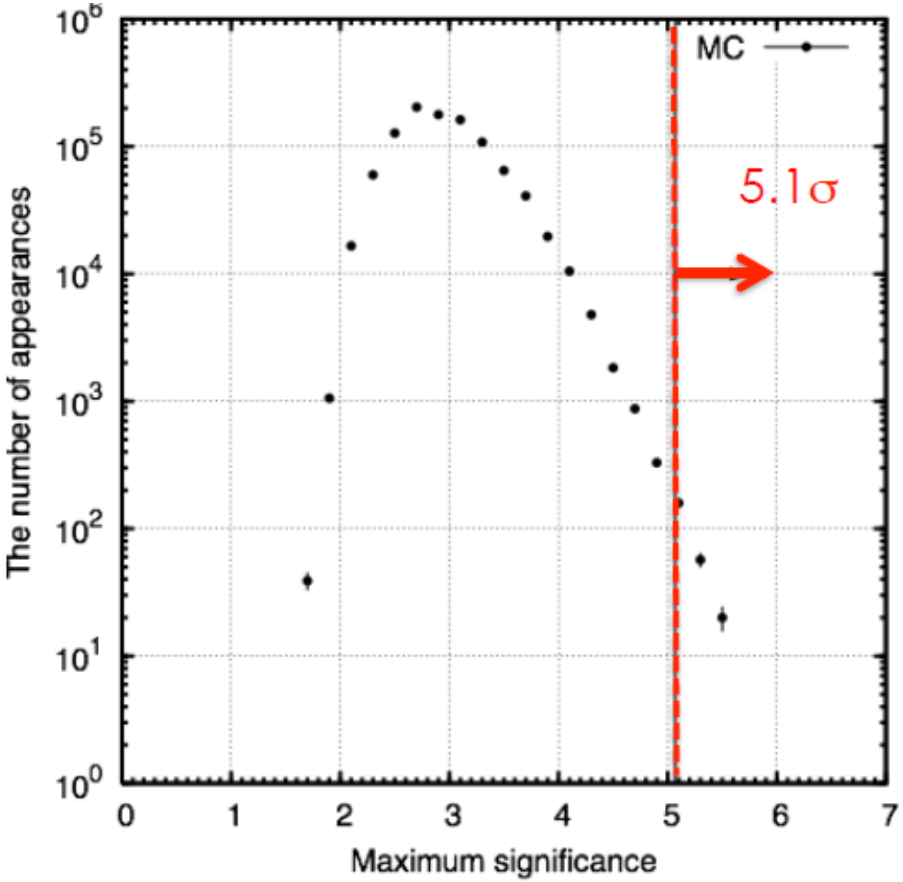
Control sample
KS probability > 0.09

Chance probability

Random 109 events assuming isotropy (TA geometrical exposure)

Adopt same analysis & create significance maps (by five oversampling radius : 15, 20, 25, 30, 35 deg.)

Search for maximum significance in the FoV



Repeat 1 million times
How many >5.1σ ?

P = 367 / 1,000,000 trials
= 3.7×10^{-4} (3.4σ)