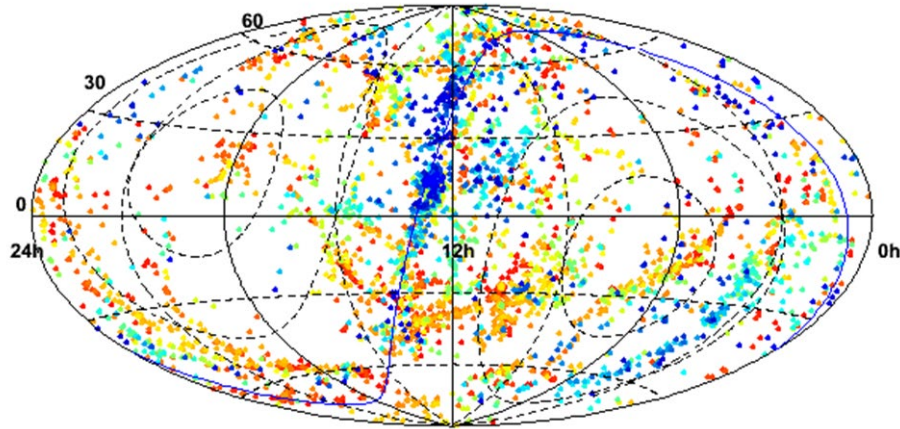


**Anisotropy search in the Ultra High Energy Cosmic
Ray Spectrum in the Northern Hemisphere
using latest data obtained with Telescope Array
surface detector**

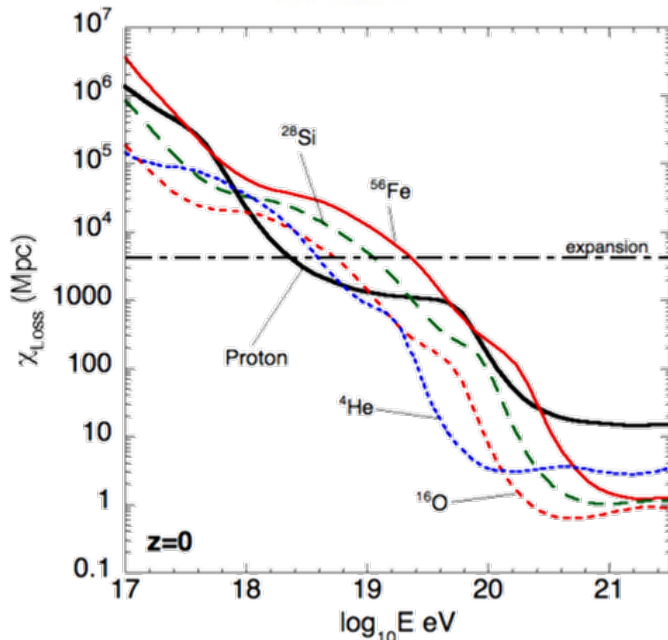
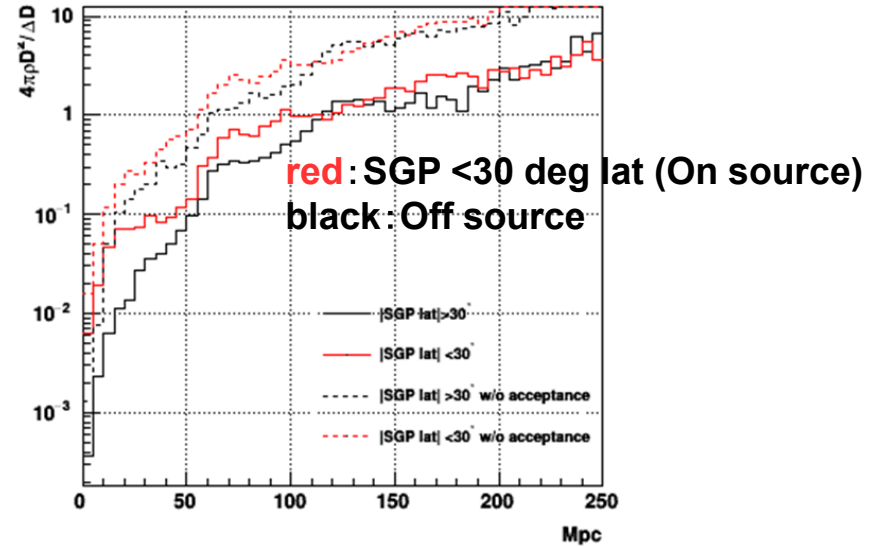
**Toshiyuki Nonaka
Institute for Cosmic Ray Research,
University of Tokyo
for The Telescope Array Collaboration**

Matter distribution and anisotropy

2MRS catalogue : objects <75Mpc



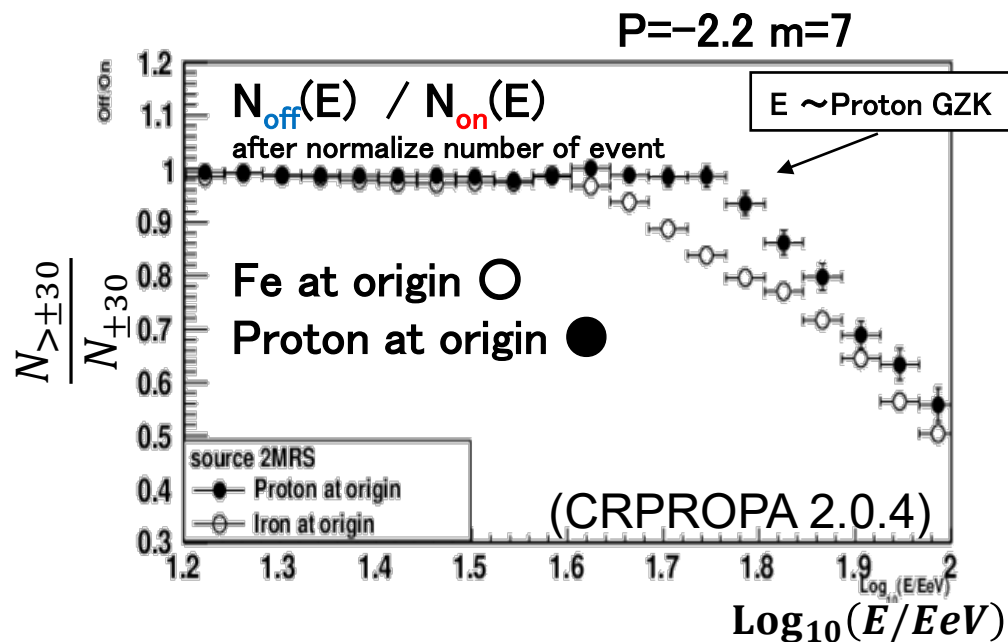
Relative amount of objects
(in 2MRS, catalogue's efficiency is corrected)



- Distance distribution of matter is different between direction of **SGP**, and not SGP.
 - Spectrum should reflect energy loss process.
 - Spectrum shape's difference should emerge (More distance → More attenuation)

How the difference will be seen?

- Flux simulation were done assuming source distribution is proportional to the number of galaxy.
- Ratio of normalized flux between two sky areas is displayed
- The sky areas are $\text{SGPLatitude} < \pm 30$ and $> \pm 30$



Simulation were done both Iron(at origin) case and Proton case. Vertical axis is the ratio of normalized flux from out side of SGP region where number of galaxy is less.

There are feature

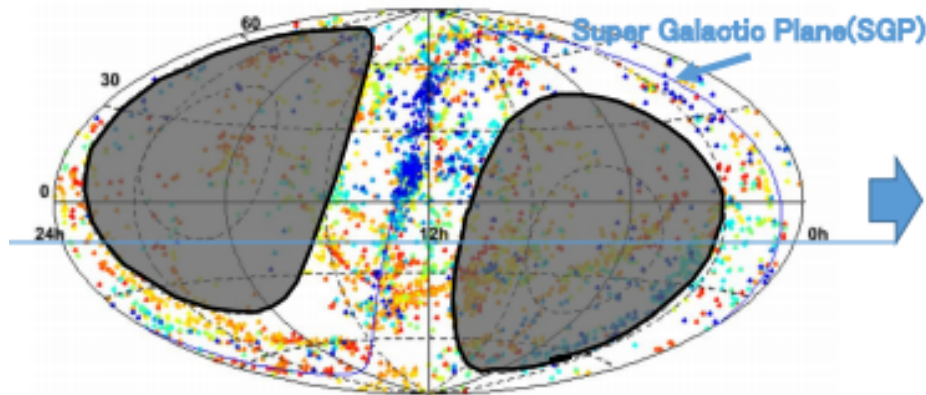
$N_{>\pm 30}$ shows

✓ Early break

✓ More attenuation at high energy than $N_{\pm 30}$

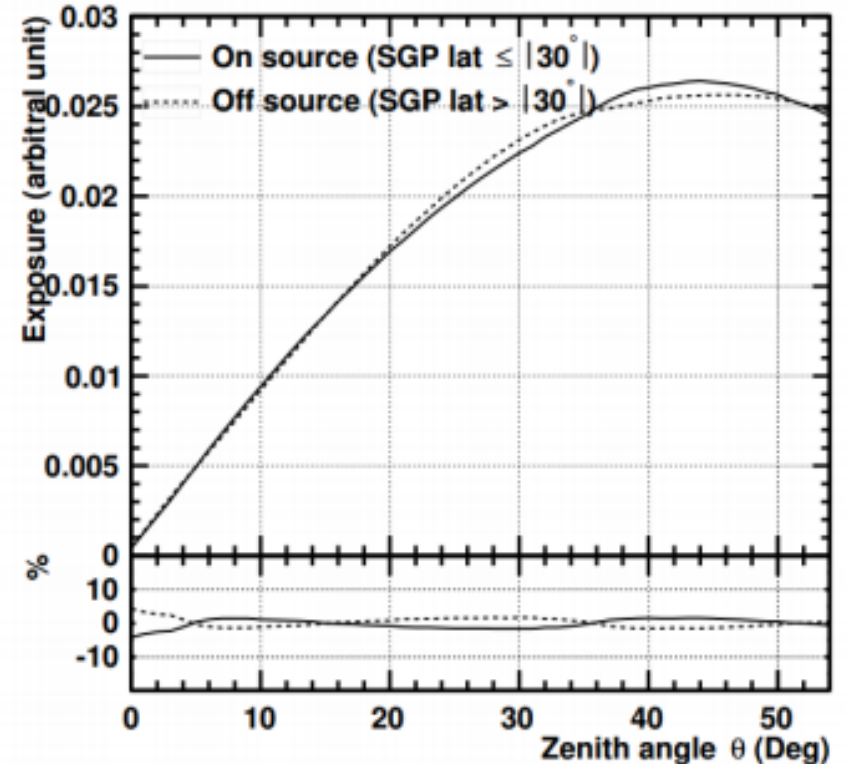
Analysis

TA Field of View (dec $> -15^\circ$)

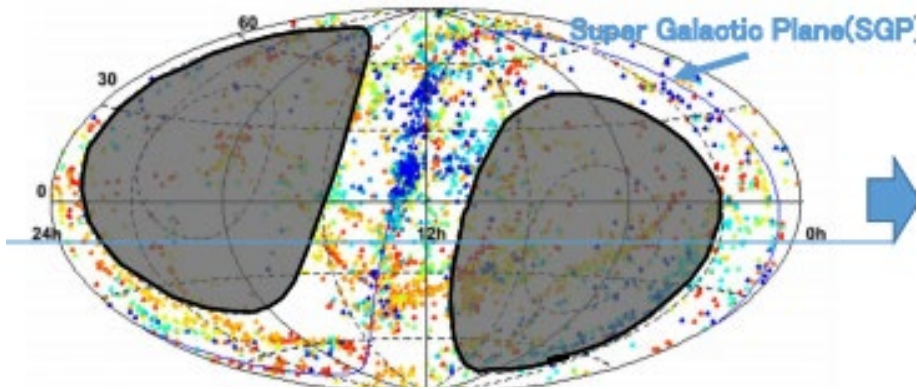


SGP latitude $\leq |30^\circ|$ (On source)
SGP latitude $> |30^\circ|$ (Off source)
Fraction in Exposure (52% vs 48%)

Zenith angle distribution of Exposure



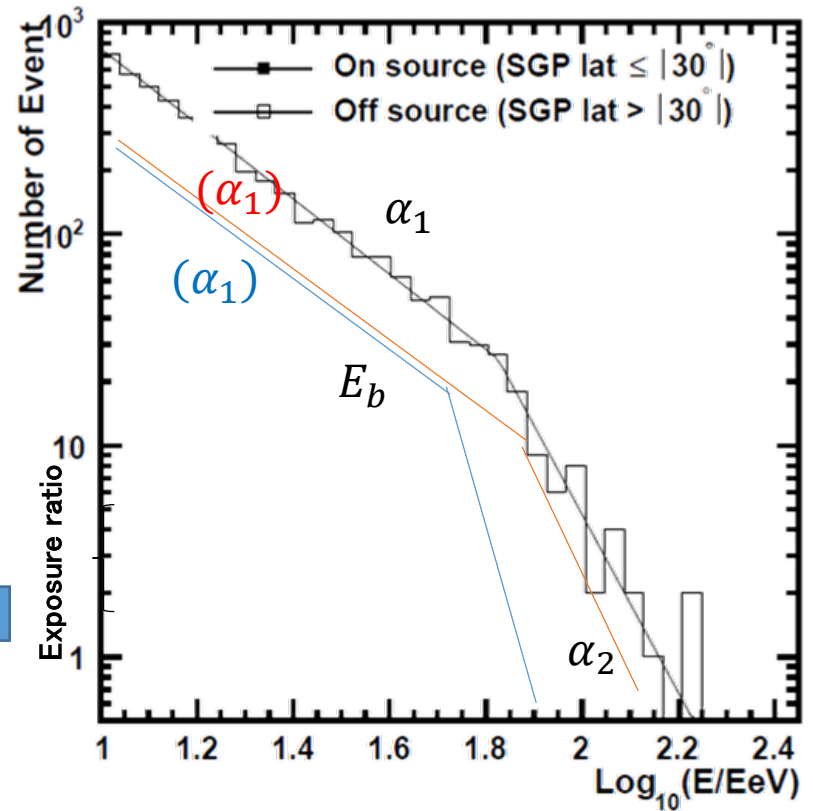
- As a first step using “Super Galactic Plane” as a target of sky division
- Simple shape of “On”/”Off” sky area.
- Condition of Observation is identical.



SGP latitude $<|30^\circ|$ | (On source)
 SGP latitude $>|30^\circ|$ | (Off source)
 Fraction in Exposure (52% vs 48%)

α_1 : Power law index at lower energy
 α_2 : index at higher energy
 E_b : Break energy (EeV)

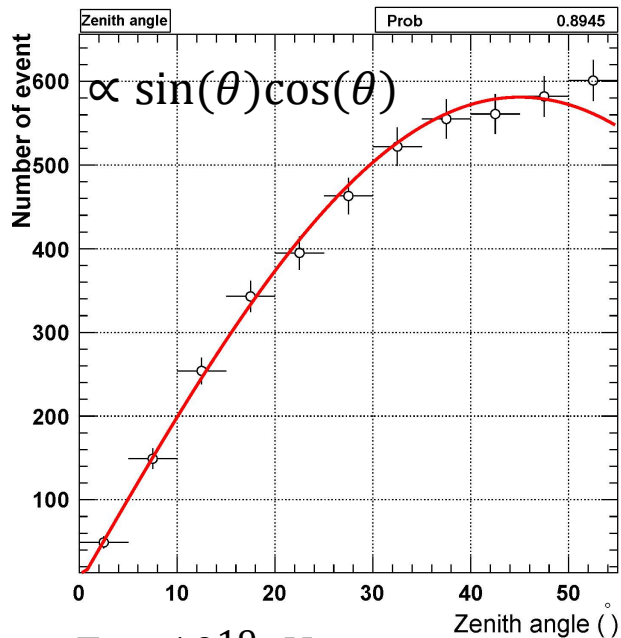
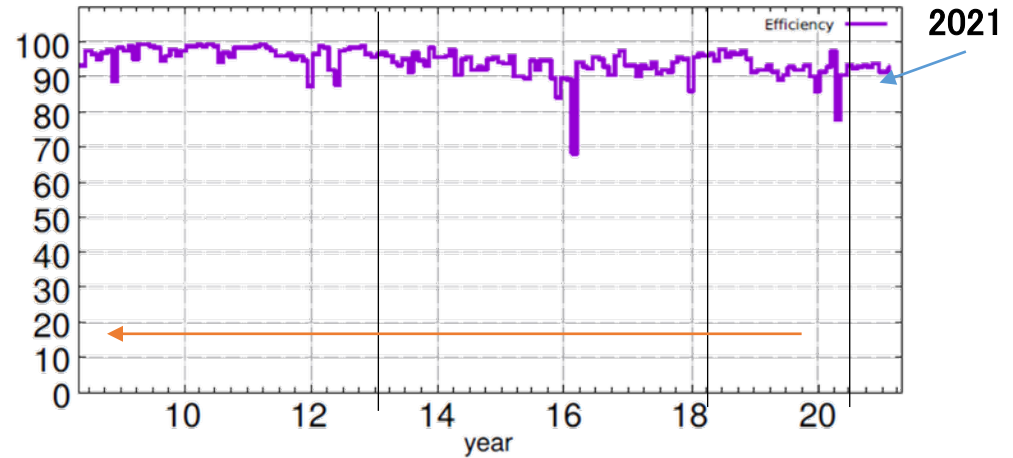
(Energy distribution)



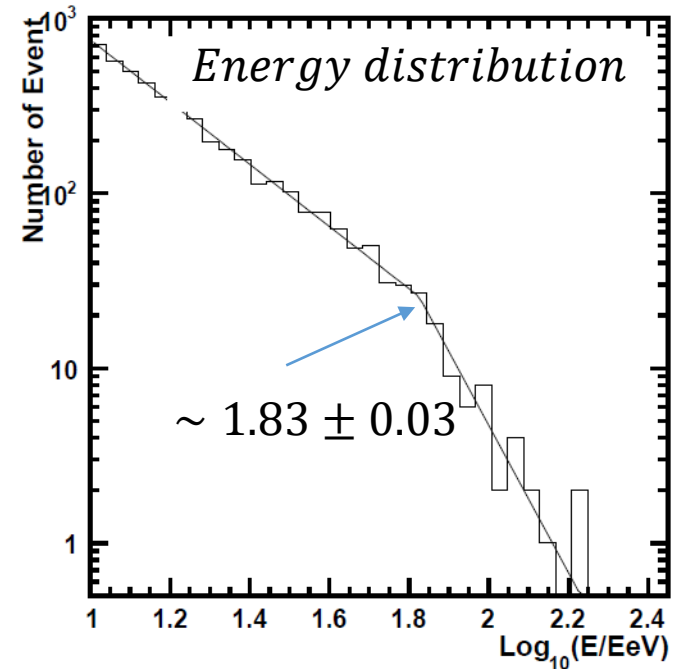
$$E_b^{off} = \frac{N_{off}(E \geq E_b^{off})}{N_{all}(E \geq E_b^{off})}$$

Data

- 12 yr data
 - 2008/05/11 – 2020/05/11
 - Efficiency $\sim 95\%$
 - Zenith angle $0^\circ \sim 55^\circ$
 - Energy $E \geq 10^{19} \text{eV}$
- Trigger efficiency $\sim 100\%$*

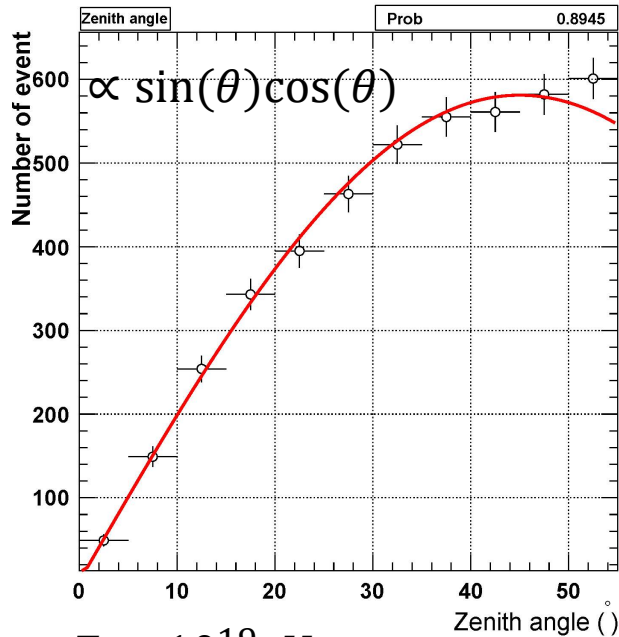
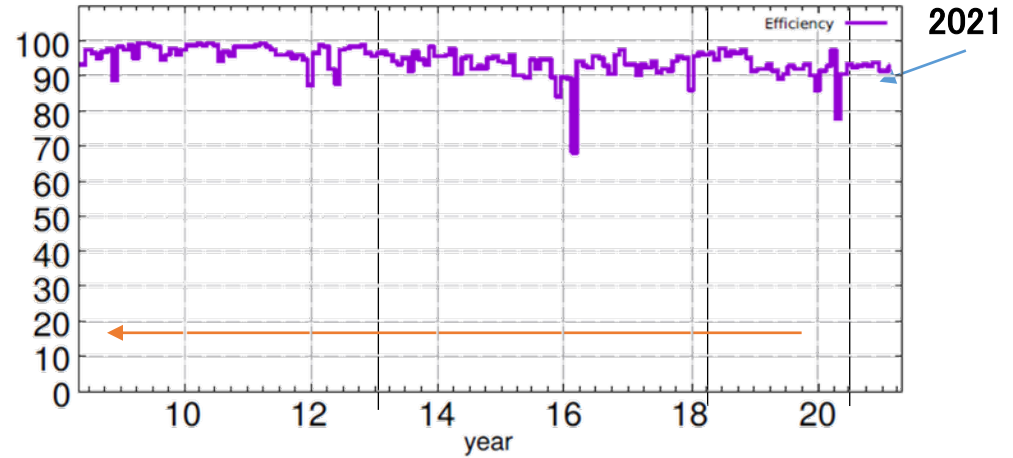


$E > 10^{19} \text{eV}$,
 \rightarrow *Trigger efficiency $\sim 100\%$*

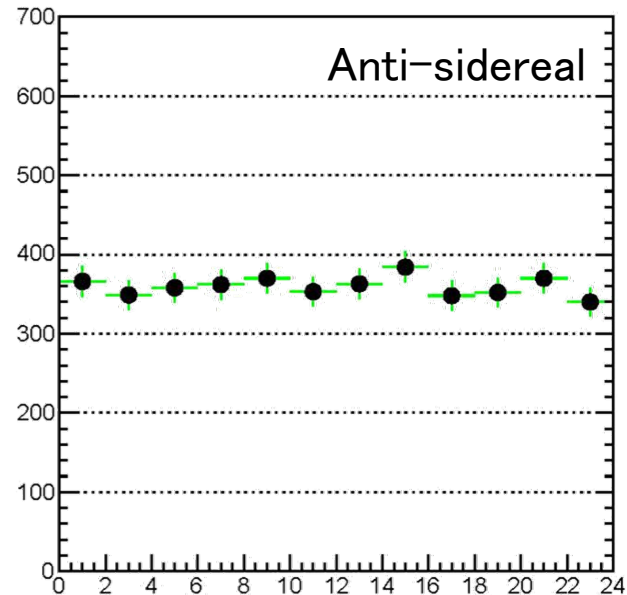


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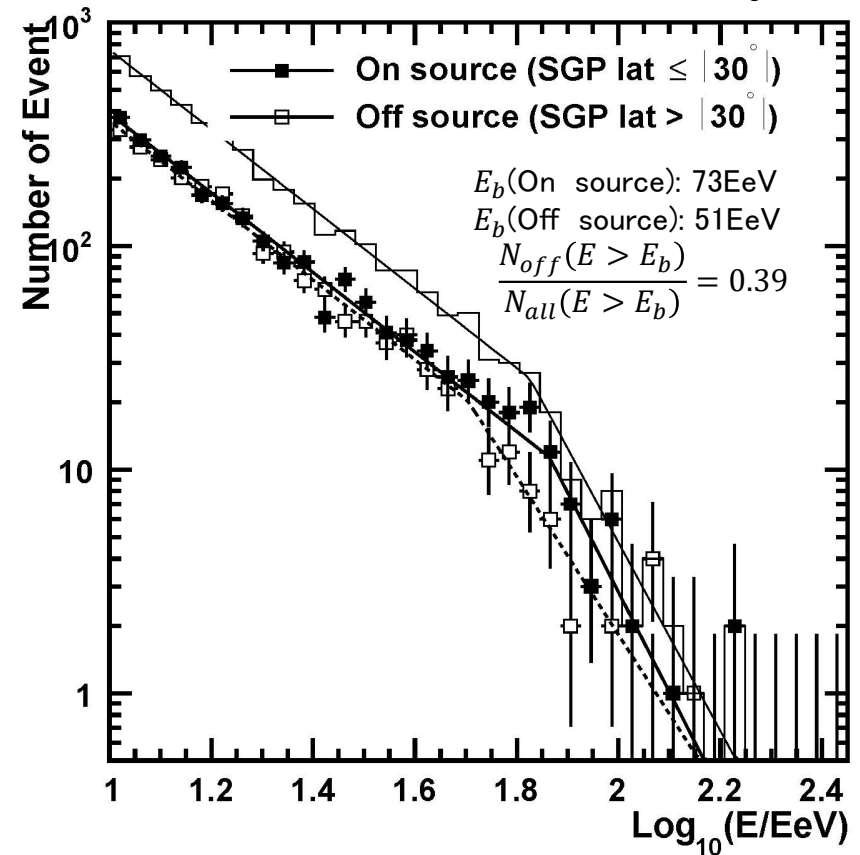
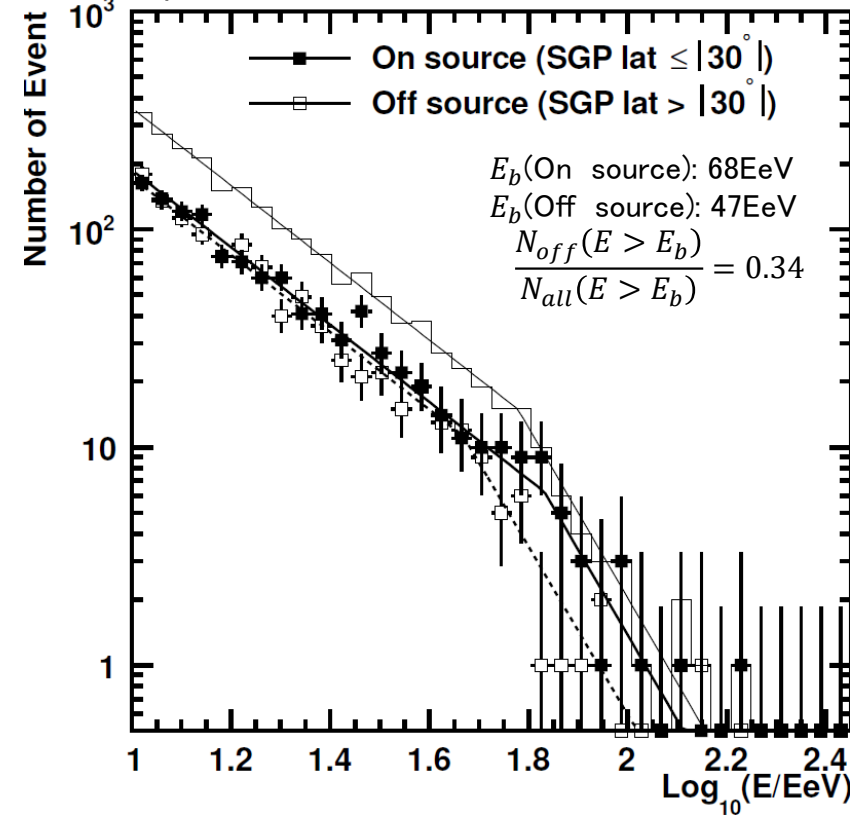


Energy distribution 5yr, 12yr data

Observed Energy distribution
Broken power low fit

5year

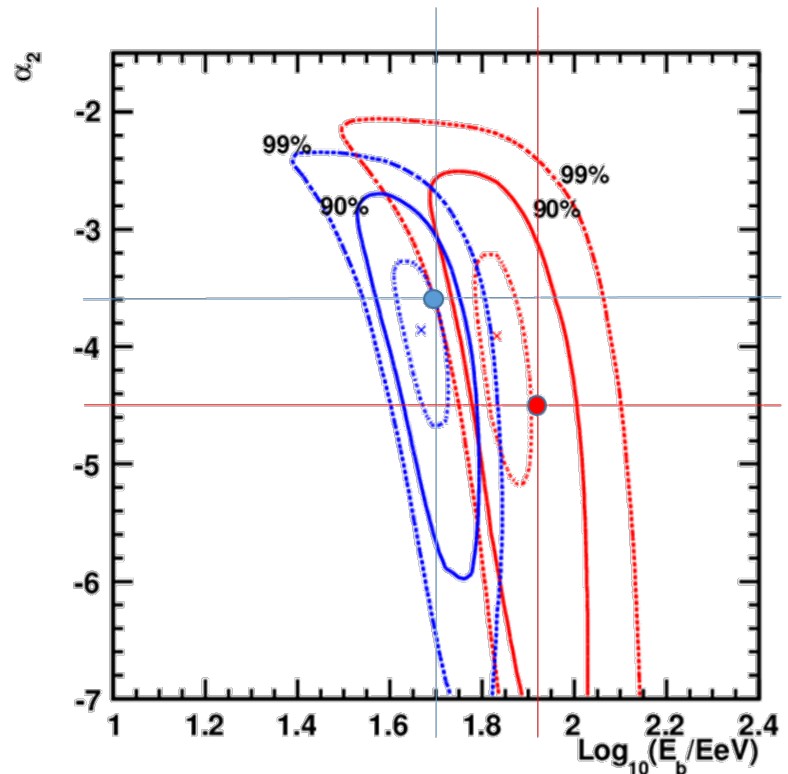
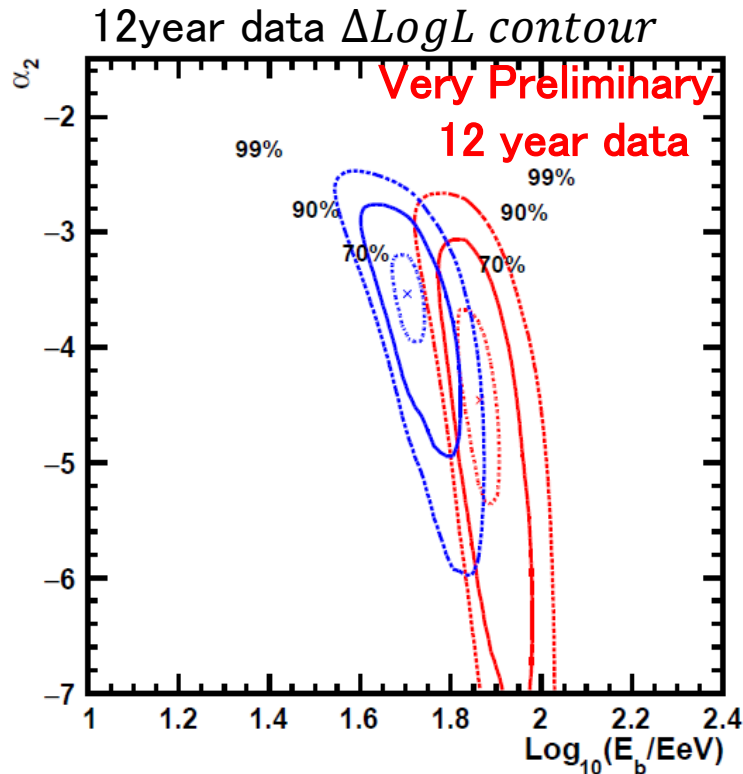
12year



Area	C_o	α_1	$\log_{10}(E_b/EeV)$	α_2
All	$2.14^{+0.34}_{-0.30} \times 10^{+4}$	$-1.775^{+0.053}_{-0.053}$	$1.778^{+0.040}_{-0.068}$	$-3.91^{+0.64}_{-0.66}$
On source	$(1.1128 \times 10^{+4})$	(-1.775)	$1.832^{+0.069}_{-0.041}$	$-3.91^{+0.70}_{-1.26}$
Off source	$(1.0286 \times 10^{+4})$	(-1.775)	$1.668^{+0.052}_{-0.053}$	$-3.86^{+0.58}_{-0.82}$

Area	C_o	α_1	$\log_{10}(E_b/EeV)$	α_2
All	$4.519^{+0.458}_{-0.433} \times 10^{+4}$	$-1.778^{+0.036}_{-0.034}$	$1.825^{+0.026}_{-0.033}$	$-4.20^{+0.49}_{-0.52}$
On source	$(2.349 \times 10^{+4})$	(-1.778)	$1.865^{+0.036}_{-0.042}$	$-4.46^{+0.77}_{-0.90}$
Off source	$(2.169 \times 10^{+4})$	(-1.778)	$1.705^{+0.054}_{-0.028}$	$-3.54^{+0.34}_{-0.42}$

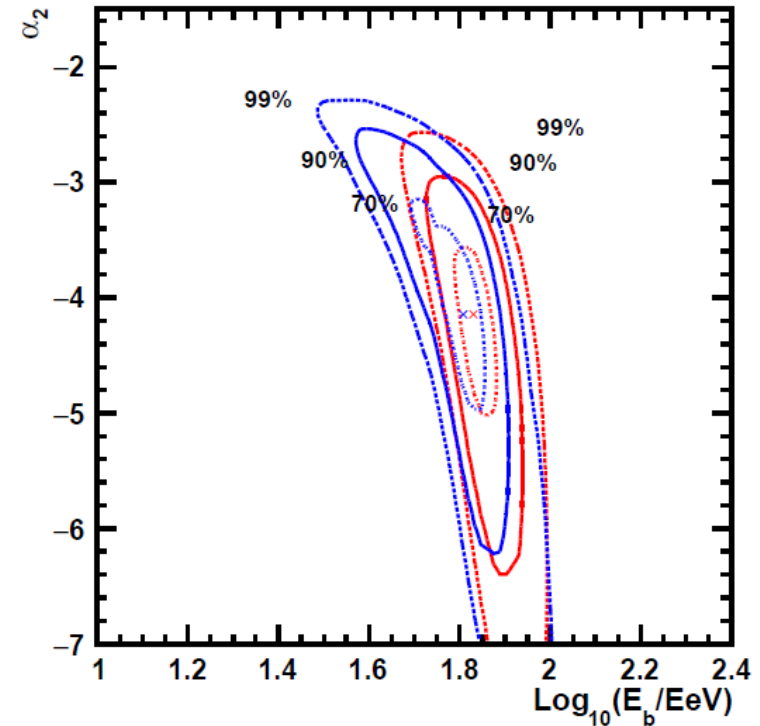
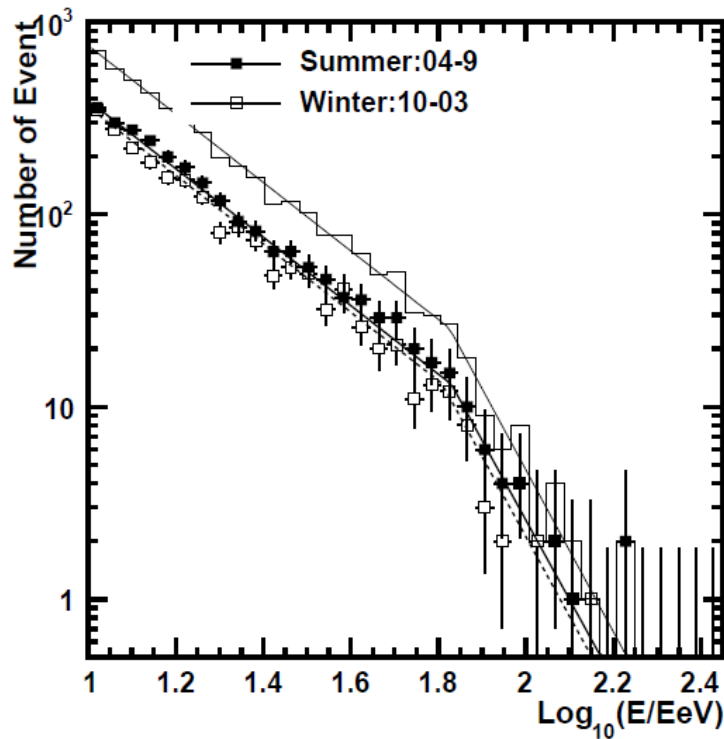
Comparison between 5 year and 12 year



Estimated brak energy and slope are consistent with first 5 year and 12 year data
Contour have shurinked it's area due to increase of statistics
Still we see same difference early dificit at off source

Effect of atmospheric condition

Summer data vs Winter data

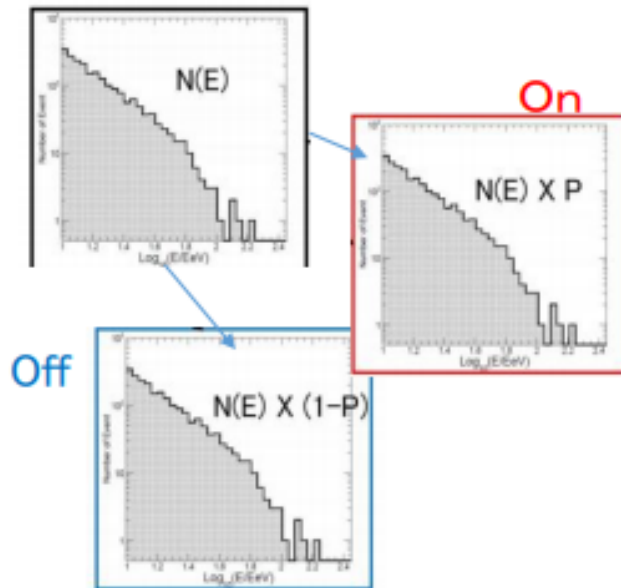


- Data is divided into Summer and Winter. (no directional information)
- The difference of the spectrum shape is negligibly small .

Estimation of chance probability

Procedure of calculation

- Shuffle events to **On** source and **Off** source with binominal probability based on exposure fraction.

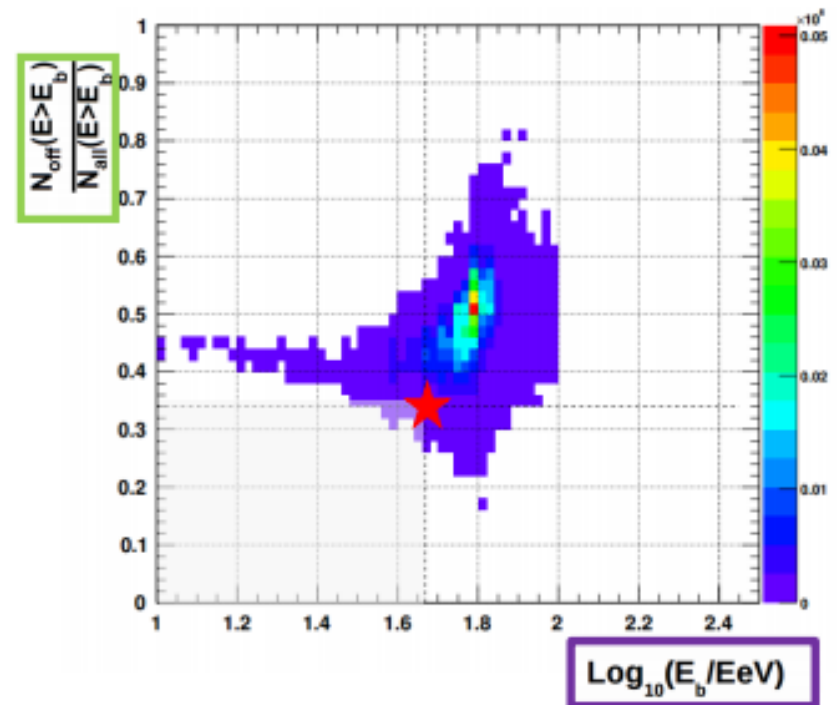


- Obtain $\text{Log}_{10}(E_b/E\text{eV})$ and $\frac{N_{\text{off}}(E>E_b)}{N_{\text{all}}(E>E_b)}$ with same procedure at each trial.
- Repeat and count how many times smaller $\text{Log}_{10}(E_b/E\text{eV})$ $\frac{N_{\text{off}}(E>E_b)}{N_{\text{all}}(E>E_b)}$ is observed.

★ Data

$$\text{Log}_{10}(E_b/E\text{eV}) = 1.67$$

$$\frac{N_{\text{off}}(E>E_b)}{N_{\text{all}}(E>E_b)} = 0.34$$



$$P = 6.2 \times 10^{-4} \quad (3.2 \sigma)$$

Summary

- The difference in energy distribution was evaluated between two sky areas in northern hemisphere.
 - One of the sky area is Super-Galactic latitude **within $\pm 30^\circ$** (On source) and the other is Super-Galactic latitude ***out side of $\pm 30^\circ$*** (Off source).
 - The simulation suggests that the cosmic ray energy distribution will differ at high energy end. The distribution from Off source area shows early breake at high energy end.
 - The shape of observed cosmic ray energy distribution above 10^{19} eV was examined using Telescope array surface detectors.
 - The trend of the difference in energy distribution (3.2σ with 5 year data) was analyzed with 12 years of data.
 - 12 years data, the maximum likelihood value is within the confidence region of the 5-year data.
-