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Examination of Xmax anisotropy for the next generation Ultra-high energy cosmic rays observation

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Abstracrt : Estimation of the mass composition in ultra-high energy cosmic rays is essential to understand their origin and generation mechanism.Recent experiments are expected to discover anisotropy of the mass composition in ultra-high energy cosmic rays.Anisotropy analysis of mass composition using Xmax is currently being performed, but the problem is that the statistics of cosmic rays with Xmax information is limited. For the next generation experiments, it is important to know how much statistics should be accumulated to find Xmax anisotropy.Therefore, in this analysis, we examine of Xmax anisotropy search for ultra-high energy cosmic rays under various conditions for the case where there is a difference in Xmax in the reported anisotropy.

Motivation

We tried Mass composition analysis of ultra-high energy cosmic rays for each arrival direction.Fig. 1 shows the sky map and plotted real data. Fig.2 shows the comparison of mass composition between HotSpot and Background.But,The statistics observed in the Hotspot are not sufficient to find / evaluate to the Xmax anisotropy.

How much more observations is needed to obtain Xmax anisotropy?

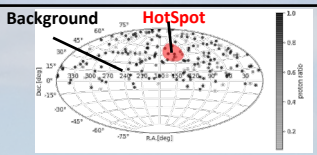


Fig. 1: The Sky map and plotted real data (Energy >10EeV)

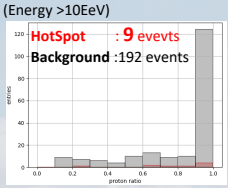


Fig. 2: comparison of mass composition

Purpose

Estimate the statistics needed to evaluate Xmax anisotropy by simulating the following four assumptions.

1. The angular scale of the Xmax anisotropy is identical to the energy anisotropy (= HotSpot).
2. The distribution of Xmax in the whole sky is assumed to be unified in global sky,and **the particle of excess in HotSpot is assumed to be one type of particle.**
3. The energy distribution of the arriving particle follows the function of the TA spectrum.
4. The development of air showers can be evaluated with MC.

Analysis

We Determine the attributes of inside and outside on the HotSpot, energy index and the composition with probability according to the assumptions. **We choiced "Auger mixed composition" (Fig 3) assumed as global composition and We choiced "TA Energy spectrum"(Fig. 4) as Enegy spectram.** Then Randomly select Xmax from the database (2000 candidates) according to the attributes.Database is consist of 3 energy index levels and 5 type of the nucleus for composition with MC. **We use Hadron Interaction model with EPOS LHC.**Calculate the p-value by comparing the Xmax distributions of inside and outside of the HotSpot every 1 event aquire from database.And Repeat until the two distributions are separated by some significance (>3σ).

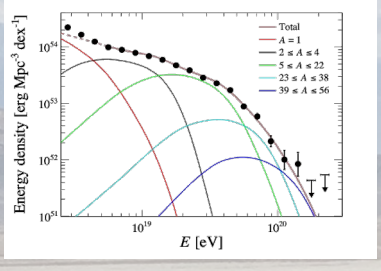


Fig. 3: Energy density obtained with the best fit parameters of the benchmark scenario[1]

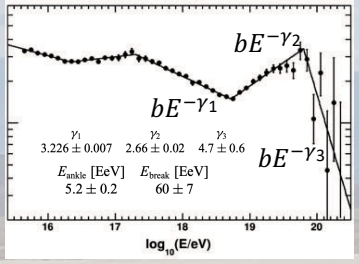


Fig. 4: Energy spectra presented by the TA Collaboration at the 34th International Cosmic Ray Conference (ICRC 2015) [2]

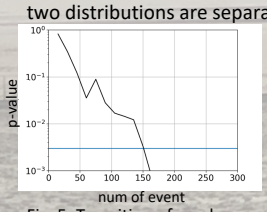


Fig. 5: Transition of p-value relative to number of events

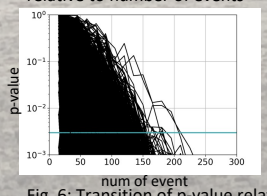


Fig. 6: Transition of p-value relative to number of events(1000times)

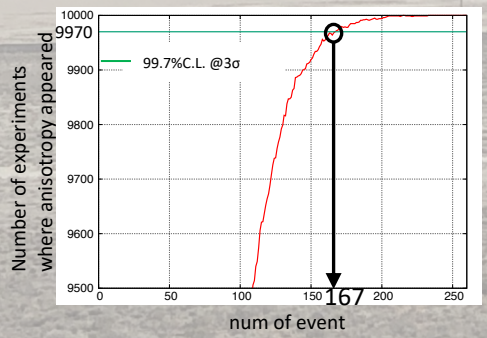


Fig. 7: Number of events that significantly separate the Xmaxdistributions of the two regions

Fig. 5 shows the result of calculate the p-value.This figure means Then,We consider Fig. 5 is the result of one experiment. And Repeat 10000 times(Fig. 6) to find how many times separate by some significance at 3σ.This is equivalent to finding the number of Xmax observations required for a sufficient difference in the Xmax distribution to appear in 10000 experiments.

And Estimate the number of observed events that can detect a sufficient difference in the Xmax distribution with a probability of 3σ(99.7%) . **This means it is the statistic required to find Xmax anisotropy .**

Fig. 7 shows the relationship between nun of event and Number of experiments where anisotropy appeared.

In this figure excess particles in the HotSpot region is assumed as proton. The distribution is significantly separated by about **167** events

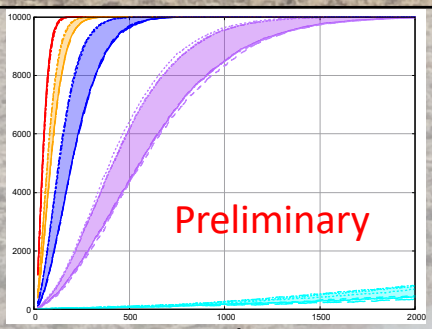
Result

We also analyzed in the case HotSpot excess particle is He,CNO,Si,Fe.

And also changed **broken power law** withn the error, and changed Hadron Interaction model to **QGSJET II-04**.

Fig. 8 shows the result of changing

- HotSpot excess particle
- broken power law
- changed Hadron Interaction model to QGSJET II-04



	EPOS LHC	QGSJET II-04
proton :	161~167 events	155~160 events
He :	245~251 events	319~329 events
CNO :	1412~1486 events	1986~2000 events
Si :	10000 events and more	10000 events and more
Fe :	470~481 events	665~694 events

Fig. 8: Number of events that significantly separate the Xmax distributions of the two regions

References

[1] Auger ,PHYSICAL REVIEW LETTERS 125, 121106 (2020)

[2] Valerio Verzi1,*, Dmitri Ivanov2,*, and Yoshiki Tsunesada **PTEP 2017**,12A103