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Upper limits on the isotropic gamma ray / cosmic ray ratio from the Grapes III experiment at Ooty

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Abstract. We have attempted to determine the isotropic gamma-ray / cosmic ray ratio using the very large area ($560m^2$) and packed muon detector operating with the EAS array at Ooty in southern India. The showers with their cores incident within the area of the EAS array but with no associated penetrating track in the muon detectors, classified as muon-poor showers, have been considered as primary gamma-ray initiated shower candidates. We have obtained upper limits on the flux of isotropic gamma-rays over the energy region from 20 TeV to 500 TeV. A conservative upper limit on the ratio, I_{gamma}/I_{CR} of $1*10^{-3}$ at 90% C.L., over the energy region, 100 TeV to 500 TeV, has been placed.

1 Introduction

It is important to estimate the gamma ray intensity apart from the total cosmic ray intensity in all energy ranges for various studies in astrophysics. In the VHE/UHE region, it can be estimated by looking at the excess of intensity from the direction of a point source which has been confirmed by observations at other wave lengths, if the astronomical object exists at relatively short distance. Gamma rays coming from sources at cosmological distances, such as distant AGN's, and gamma rays due to cosmological origin are expected to arrive isotropically. In several tens of TeV region, the isotropic gamma ray flux is expected to be higher as a result of cascading from interactions of extremely high energy cosmic rays with the cosmic microwave background radiation by the Bottom-Up model (Halzen et al, 1990) or the Top-Down model (Aharonian et.al., 1992). Though, it is experimentally very difficult to distinguish gamma-rays from cosmic rays with ground based observations, recently upper limits have been placed by several groups which seem to question the validity of such models in the several tens of TeV to several tens of PeV energy range (Matthews et al 1991, Karle et al 1995, Aglietta et al 1996, Chantell et al 1997).

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2 Detectors

The GRAPES III air shower experiment is located at Ooty in southern India (N 11.4, E 76.7 and 2200m altitude). It is observing 2 components of air showers, the electro-magnetic component and the muon component, to study cosmic gamma rays and particles in the several tens of TeV to several tens of PeV energy range. About 250 electron detectors (scintillation counters) are arranged in a 8m span hexagonal dense array. The scintillation counter consists of a 5cm thickness, $1m^2$ area plastic scintillator viewed by a 5cm diameter photo-multiplier. The counting rate of each detectors are monitored continuously.

The muon detectors are arranged in the form of 16 modules with the cluster located towards the northern edge of the electron detector array. Total muon detection area is $560m^2$. A muon module consists of 232 proportional counters (cross-sectional area 10cm x 10cm and length of 6m) arranged in 4 layers separated by 15cm thick concrete layers under 2m thickness concrete absorber giving $35m^2$ detection area for muons > 1GeV.

The triggering condition is any 10 detectors out of 120 detectors at center of array. The trigger rate is about 13Hz.

3 Data Analysis

We analyzed data observed in last one year, from March 2000 to April 2001. The electron-magnetic component data are used for estimation of primary cosmic ray energy and core location of air shower. The muon component data are used to select candidate of gamma ray primary.

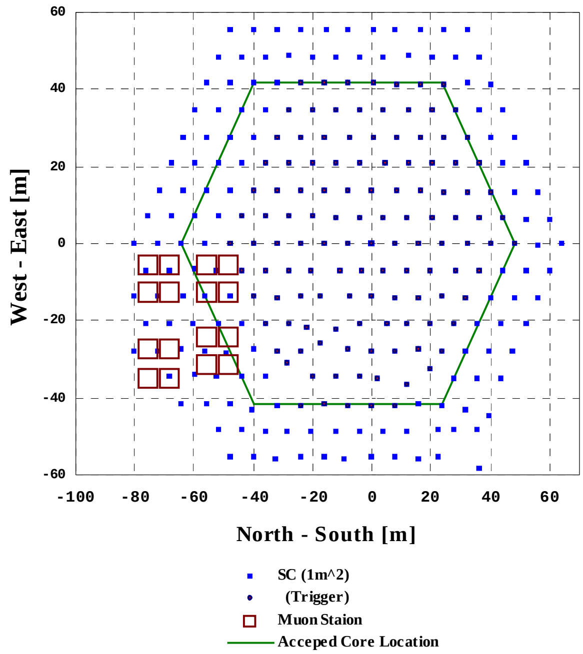

Fig.1 Ooty Air Shower Array

3.1 Electro-magnetic component For the electro-magnetic component analysis, the following criteria were used for off-line shower selection for this work:

(a) Total number of detected particles > 30.
(b) Detected particles by outer most two rings < 35% of total detected particles.
(c) Air shower core should be inside a hexagonal area as shown in Fig. 1.
(d) Zenith angle < 25 degs.
(e) Total number of detected particle > 30.

The core location, arrival direction, total number of detected particles for electro-magnetic component were determined for these showers. The core location is estimated by particle weighted center of higher most 7 scintillation detectors. The arrival direction is estimated by fitting a conical air shower front to the timing data. Detected number of particles fluctuate quite lot for small air shower. To avoid larger air shower contamination that real location is outside of array we used cut (b). This effect was tested by semi-Monte Carlo simulation through the GENAS program(Ver 2.2, K.Kasahara & S. Torii 1990). (Fig. 2a, 2b)

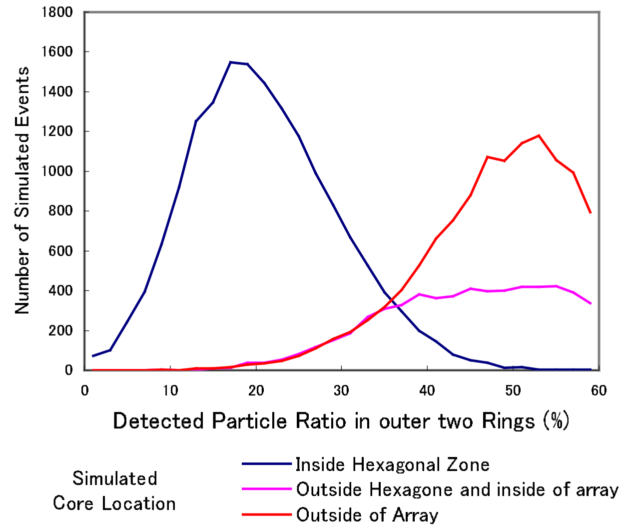

Fig.2a Contamination of "outside" Events

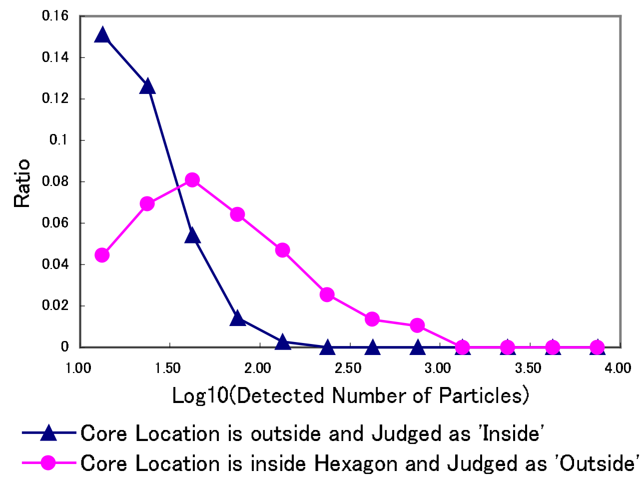

Fig.2b Effect of cut(b) See text.

3.2 Muon component: For the muon component analysis, the detected muon number has been estimated from the observed muon tracks in the 4 layers of the detector whose direction must match with the direction of the air shower arrival direction determined from data on the electro-magnetic component. We use any 3 layers coincidence out of 4 layers. The number of detected muons depends on the air shower primary energy, distance from the core to the muon detector, and the muon detection area. In the Ooty air shower array, typically several muons can be detected for total number of detected particles 100, distance from muon detector to core 40m. Though Muon data recording gate width is 10microsec per event, we used 3.5microsec software gate to reduce chance muons. The muon counting rate, unrelated to air shower trigger, is ~3900/module/sec for any 3-fold coincidences. So, conservatively, the average number of muons due to chance coincidence is estimated to be ~0.07 per event for all muon detectors.

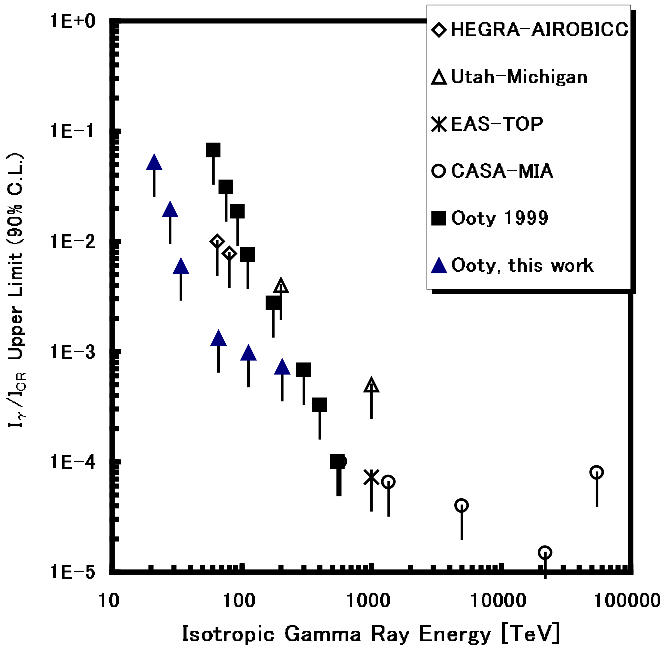

Fig.3 Upper Limit of Isitropic

4 Simulation and Calculation

It has been known for a long time that gamma ray induced air showers are muon-poor compared to particle/nucleus induced showers due to much less number of hadronic interactions. Monte Carlo simulations with CORSIKA (Ver 5.62, Dieter Heck 2000) show that 2 to 3% muons are expected from gamma ray induced air shower compared to proton induced showers for same primary energy. Since typical events observed by the Ooty air shower array have 0 to several tens of muons, we have classified no-muon detected air showers as muon-poor events. We have calculated the upper limit on the ratio of gamma ray flux to all cosmic ray flux using these muon-poor events as the candidates for gamma ray induced showers. First, we estimated median energy of primary cosmic ray for each detected particles bin. We did not find clear difference of detected number of particles between proton primary and gamma-ray primary for 10 to a few 100 TeV energy rage. Same time we got number of muons for each shower and we estimated probability of muon less shower by gamma primary for each distance bin from the center of muon detectors.

5 Discussion and Conclusion

Upper limit on the ratio of gamma ray flux to the cosmic ray flux is given by:

$$\frac{I_{gamma}}{I_{CR}} \leq \frac{N_{muon-poor}(90\%C.L.)}{N_{all}} \cdot \frac{1}{e_{gamma}} \cdot \frac{1}{1-\cdot n_{chance}}$$

where $N_{muon\text{-}poor}$(90%C.L.) is a 90% confidence level upper limit on the number of muon-poor air showers assuming Poisson distribution, N_{all} is the total number of air showers, e_{gamma} is the efficiency to detect gamma ray induced air showers as muon-poor air showers, n_{chance} is the average number of muons due to chance coincidence. The result is shown in Fig. 3 and compared with the upper limits given by other groups.

Present work improves the I_{gamma}/I_{CR} upper limit given by the HEGRA group for the 50 - 100 TeV region by almost one order. The Ooty result gives most strict upper limit for the 20 – 500 TeV region.

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