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Limits on the Isotropic γ-ray / Cosmic ray Ratio in the Ultra High Energy region from the EAS Experiment at Ooty

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Abstract

We have attempted to determine the isotropic γ-ray / cosmic ray ratio using the very large area($560m^2$) 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 γ-ray initiated shower candidates. We have obtained upper limits on the flux of isotropic γ-rays over the energy region from 50 TeV to 550 TeV. A conservative upper limit on the ratio, I_γ / I_{CR} of $3*10^{-3}$ at 90% C.L., over the energy region, 200 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

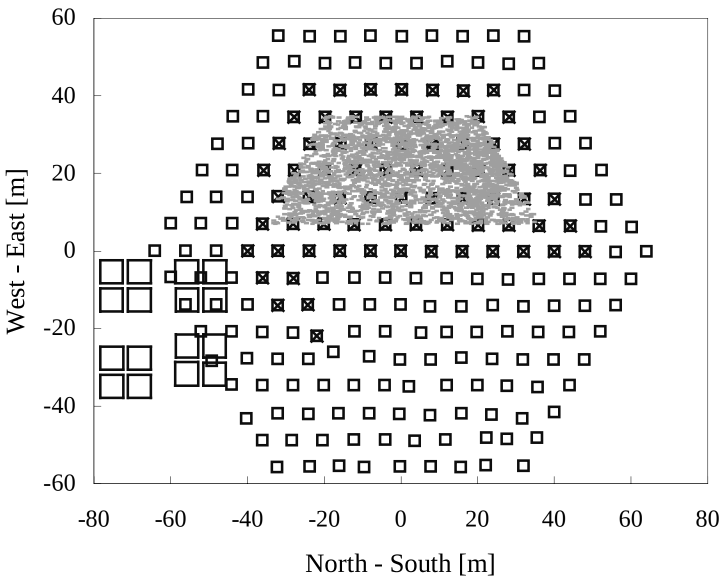

Figure 1: The arrangement of EAS array
□ :$1m^2$ S.C.(used detectors for this analysis are crossed mark)
□ :Muon detector ($35m^2$)

several tens of PeV energy range (Matthews et al 1991, Karle et al 1995, Aglietta et al 1996, Chantell et al 1997).

2 Detector:

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. 217 electron detectors (scintillation counters) are arranged within 64m of the Centre 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 photomultiplier. 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.

3 Data Analysis:

The Ooty Air Shower Array started data taking with 100 scintillation counters and 16 muon modules from April 1998 onwards with a trigger rate ~10Hz. We have analyzed 4-1/2 months data (April-September 1998) using signals from 80 scintillation counters which were operating satisfactorily and gave stable vaules for single particle calibration. In this analysis, the electro-magnetic component data are used to estimate the air shower energy and core location, and the muon component data are used to select potential candidates for gamma ray primaries.

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

(a) Total number of hit scintillation counters >=15.
(b) Out of the higher most 4 scintillation counters, outer most ring detector <=1.
(c) Sum of the particles of 4 scintillation counters >= 10 particles.
(d) Out of higher most 6 scintillation counters, except the farthest, diameter <= 30m.

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 5 scintillation counters. The arrival direction is estimated by fitting a conical air shower front to the timing data. Additional selection criteria were placed on the analysed showers as follows:

(a) Core should be inside a trapezoid area as shown in Fig. 1.
(b) Zenith angle < 25 degs.

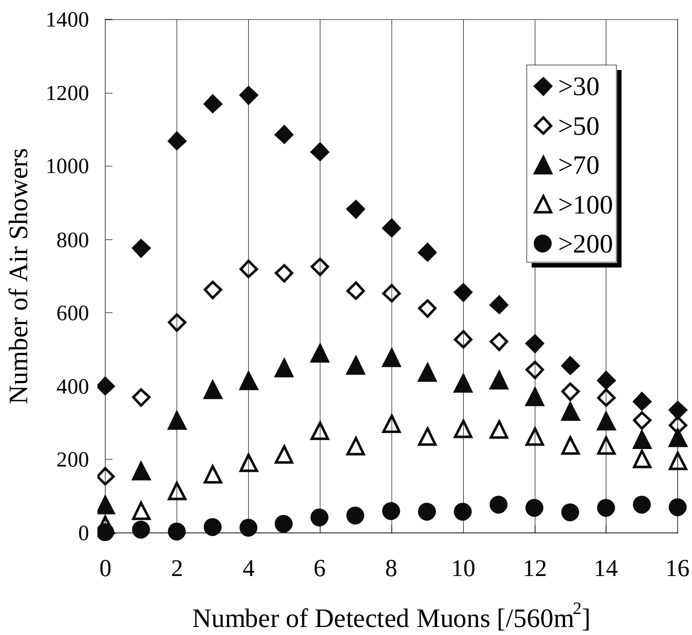

Figure 2: Multiplicity distribution of muons

(c) Total number of detected particle is a cut parameter (>30, ----, >1300) related to energy.
(d) Distance from the center of the Muon Station-0 center to the core is a cut parameter (<30m, <90m) related to the muon lateral distribution.

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. 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 particle >30, distance from muon detector to core < 30m. Muon data recording gate width is 5microsec per event, and the muon count rate, unrelated to air shower trigger, is ~3300/module/sec for 4-fold coincidences. So, conservatively, the average number of muons due to chance coincidence is estimated to be ~0.25 per event for all muon detectors. In Fig.2, we show the muon multiplicity distributions for different shower size groups classified by detected particle number.

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 COSMOS (Ver 4.92, K. Kasahara 1995) show that less than 5% 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 estimate primary energy distribution and its median value by semi-Monte Carlo simulation through the GENAS program (Ver 2.2, K. Kasahara & S. Torii 1990), using the same criteria for electron detectors and event selection for both gamma ray and nucleus. Second, we input these energy distribution data and core location distribution data into the Monte Carlo simulation (COSMOS Ver 4.92) to simulate gamma ray induced air showers including trigger effect and errors in estimation of core position. Using these results, we estimate the efficiency with which gamma ray induced air showers can be observed as muon-poor events. Observation data and simulation results are shown in Table.

Table : Observation data and simulation results(<30m)

No. of Detected Electron [particle]	>30	>50	>70	>100	>200	>300
Median Energy for γ [TeV]	61	76	93	112	175	227
Median Energy for CR [TeV]	47	62	78	99	145	208
No. of Air Shower	17239	12966	9946	7024	3169	1994
No. of Mu-poor Air Shower	400	154	75	21	1	0
No. of Mu-poor U.L.(90%C.L.)	433	174	87	28	3.9	2.3
Muon Detection Ratio for gamma [%]	2.7	3.0	3.4	3.8	4.7	5.3
Muon Detection Ratio By chance [%]	23	23	23	23	23	23
ε_γ [%]	75	75	74	74	73	73
Upper Limit for I_γ / I_{CR} (90% C.L.)	6.7E-02	3.1E-02	1.9E-02	7.6E-03	2.8E-03	2.0E-03

5 Discussion and Conclusion:

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

$$\frac{I_\gamma}{I_{CR}} \leq \frac{N_{muon-poor}(90\%C.L.)}{N_{all}} \cdot \frac{1}{\varepsilon_\gamma} \cdot \left(\frac{E_{CR}}{E_\gamma}\right)^{-\alpha}$$

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, ε_γ is the efficiency to detect gamma ray induced air showers as muon-poor air showers, E_{CR} is the median cosmic ray energy, $E\gamma$ is the median gamma ray energy, and α is the power-law spectral index for the primary energy spectrum. The result is shown in Fig. 3 and compared with the upper limits given by other groups.

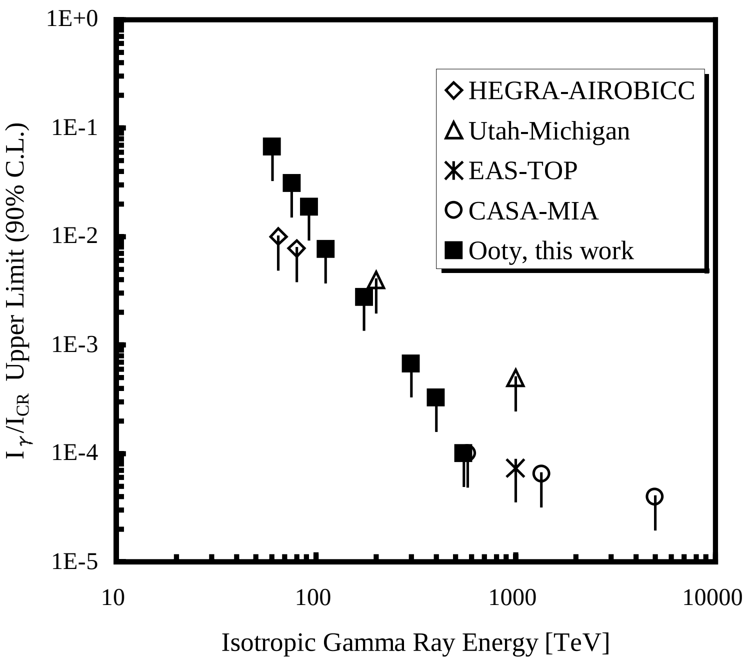

Figure 3: Upper limit of gamma ray/Icr for various group.

It is seen from the Figure that the Ooty result from the present work doesn't improve the I_γ / I_{CR} upper limit given by the HEGRA group for the 50 - 100 TeV region. However, for the 200 - 550 TeV region, the Ooty result gives a more strict upper limit. In very near future, the number of electron detectors in the GRAPES III array will increase to 217 and the gate width for the muon detectors will be decreased from 5microsec to ~3microsec. These developments will make it possible for us to place a better upper limit on the I_γ / I_{CR} ratio for both the lower energy region as well as the higher energy range.

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