Upper Limit on the Diffuse Gamma Ray Flux Using Air Shower Observations at Ooty

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Abstract

We have attempted to determine diffuse gamma ray flux using very large area (560m^2) and compact muon detectors operating with GRAPES-3 air shower array. The showers with their cores incident within the EAS array but with no associated penetrating track in the muon detectors are classified as muon-poor showers. These are considered candidates for gamma ray initiated showers. 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_γ/I_{CR} of 3×10^{-4} at 90% C.L., over the energy region, 100 TeV to 500 TeV, has been placed.

1. Introduction

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 [4] or the Top-Down model[2]. Though, it is experimentally very difficult to distinguish gamma-rays from cosmic rays with ground based observations, 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 [1][2][3][5][7][8].

pp. 2273–2276

2. Experiment

The GRAPES-3 air shower experiment is located at Ooty in southern India (N 11.4, E 76.7 and 2200m altitude). It is observing two components of air showers, the electro-magnetic component and the muon component, to study cosmic gamma rays and particles in 10TeV to several tens of PeV energy range. 257 electron detectors (1m^2 area plastic scintillator, 5cm thickness) are arranged in a 8m span hexagonal dense array.

The muon detectors are arranged in the form of 16 well packed modules with the cluster Total muon detection area is 560m^2 consists of 232 proportional counters (cross-sectional area 10cm×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 electron detectors out of 120 detectors at center of array. The trigger rate is about 13Hz.

3. Data Analysis

We analyzed data observed from March 2000 to December 2001. The electro-magnetic component data are used for estimation of primary cosmic ray energy, core location and arival direction of air shower. The muon component data are used to select candidate of gamma ray primary. We analyzed total 5.9×10^8 events.

3.1. Electro-magnetic component

For the electro-magnetic component analysis, we used two stages of analysis method. First, we got total number of detected charged particles($\Sigma n_p(ob)$) and estimated shower core location as center of gravity of highest most 7 scintillation detectors. For relatively large shower ($\Sigma n_p(ob) > 70$), we used maximum likelihood method to estimate size, age and core location[10]. For small showers NKG function fitting is not suitable. Estimated shower size has too large error due to detection fluctuation. When we estimate primary particle energy, shower size is better parameter compare with total number of detected charged particles if size estimation is good. So we used shower size for primary particle energy estimation $Ne > 10^4$ and used Ne(ob) for smaller shower. Under this condition we selected following showers. (a) Air shower core should be inside a hexagonal area as shown in fig.1.. (b) Zenith angle < 25 degs.

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

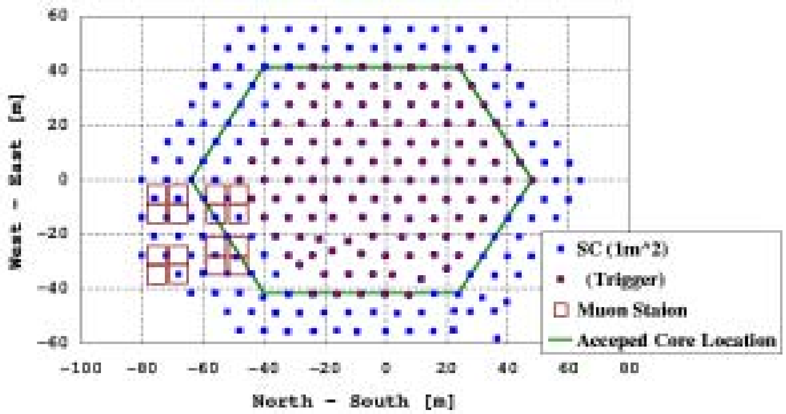

Fig. 1. GRAPES-3 Air Shower Array

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. We got the detection efficiency for any 3 layers out of 4 layers $> 99\%$ for penetrating particles using layer efficiency, $> 98\%$. Estimation of number of muons is quite accurate especially for small number of detected muons. The number of detected muons depends on the air shower primary energy, distance from the core and the 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. Average number of chance muon is estimated as 0.07 per event. Muon lateral density distribution gives optimum data collection area.

4. Simulation and Calculation

Monte Carlo simulations with CORSIKA (Ver 5.62[6]) show that 2 to 3% muons are expected from gamma ray induced air shower compared to the 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 range. 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 for efficiency correction.

5. Discussion and Conclusion

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

$$\frac{I_\gamma}{I_{CR}} \le \frac{N_{muonpoor}(90\%C.L.)}{N_{all}} \frac{1}{e_\gamma} \frac{1}{1-n_{chance}}$$

where $N_{muonpoor}$(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_γ is the efficiency to detect gamma ray induced air showers as muon-poor air showers, nchance is the average number of muons due to chance coincidence. The result is shown in fig.2. and compared with the upper limits given by other groups. The Ooty result gives most strict upper limit for the 20 - 500 TeV region.

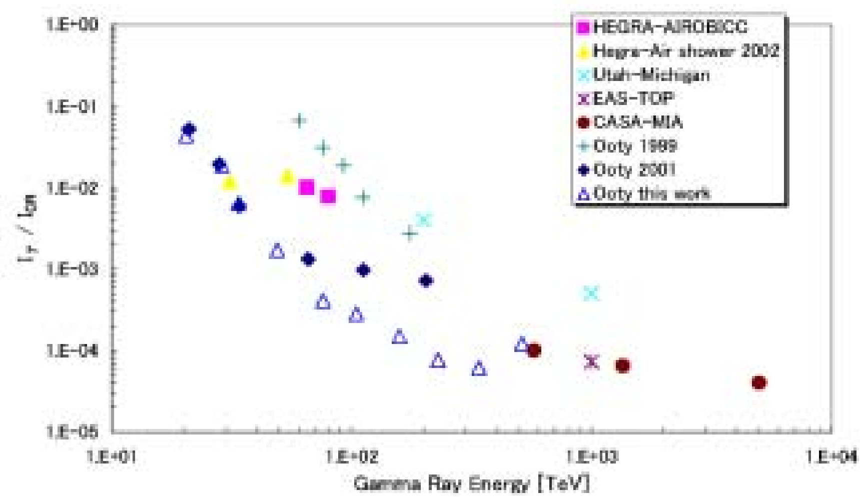

Fig. 2. Upper Limit of Isotropic Gamma Ray

6. References

1. Aglietta M. et al. 1996, Astropart. Phys. 6, 71
2. Aharonian F.A. et al. 1992, Phys. Rev. D 46, 4188
3. Chantell M.C. et al. 1997, Phys. Rev. Lett. 79, 1805
4. Halzen A.F. et al. 1990, Phys. Rev. D 41, 342
5. Hayashi Y. et al. 2001, 27th ICRC, 2385
6. Heck D. et al. 1998, FZKA 6019, Forschungszentrum Karlsruhe
7. Karle A. et al. 1995, Phys. Lett. B 347, 161
8. Matthews J. et al. 1991, ApJ 375, 202
9. Sasano M. et al. 1999, 26th ICRC
10. Tanaka H. et al. 2003, 28th ICRC