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Nuclear Physics B (Proc. Suppl.) 70 (1999) 509–511

NUCLEAR PHYSICS B
PROCEEDINGS
SUPPLEMENTS

Study of Horizontal Air Showers from *EAS-TOP* : a possible tool for UHE neutrino detection?

THE EAS-TOP COLLABORATION*

Presented by G. Navarra [a]

[a]Dipartimento di Fisica Generale dell' Università, Torino, and I.N.F.N., Torino, Italy

Horizontal Air Showers, i.e. events observed at "quasi" horizontal incidence, are studied from *EAS-TOP* at Campo Imperatore (National Gran Sasso Laboratories). The "reality" of such events as due to deeply penetrating particles is discussed from the experimental point of view.

We deduce:

- the measurement of the HE muon flux at $E_\mu = 20\ TeV$:

$F_\mu(> 20\ TeV) = (1.3 \pm 0.4) \times 10^{-11} cm^{-2}s^{-1}sr^{-1}$,

- the upper limit to the extraterrestrial HE neutrino flux:

$I_\nu(> 10^5 GeV) < 5.2 \times 10^{-9} cm^{-2}s^{-1}sr^{-1}$.

The possibility to develop the technique for UHE ν detection is discussed.

1. Introduction

A program to exploit the detection of Extensive Air Showers recorded at very large zenith angles (HAS) for the study of high energy penetrating particles, either produced in the atmosphere(μ) and of cosmic origin (ν), is developed by the *EAS-TOP* array [1] at Campo Imperatore (2000 m a.s.l.) above the underground Gran Sasso Laboratories. The array includes detectors of UHE cosmic rays ($E_0 = 10^{13} \div 10^{16}$ eV) through different EAS components.

The electromagnetic detector is made of 35 modules of plastic scintillators (10 m^2 each) distributed over an area of $\sim 10^5\ m^2$ [2] on the slope of *Mount Aquila* (average slope $\simeq 15°$). The triggering condition for the events under discussion is provided by the firing of a subarray made of 6 (or 7) contiguous modules, the central one recording the largest number of particles. The energy threshold is set at 30 % of the energy loss of a vertical minimum ionizing particle (*m.i.p.*). Arrival directions are measured from the time of flight technique with accuracy 0.8° for vertical incidence.

The μ-detector is a tracking module (140 m^2 area) made of 18 layers of streamer tubes and 9 layers of iron absorbers (13 cm thick). The readout is performed on orthogonal x and y views. The energy threshold for vertical incidence is $\approx 1 GeV$ and the angular resolution 0.6°[3].

2. Angular distribution

At zenith angles $\theta > 65°$ an excess of events (HAS) is observed above the rate of EAS as expected from their attenuation length in the atmosphere [4–6] (Fig.1). As a confirmation of the anomalous arrival direction of HAS we notice the absence of events from the direction of the sky shaded by the top of the mountain on

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*M.Aglietta[1,2], B.Alessandro[2], P.Antonioli[3], F.Arneodo[4], V.S.Berezinsky[4], L.Bergamasco[2,5], M.Bertaina[2,5], C.Castagnoli[1,2], A.Castellina[1,2], A.Chiavassa[2,5], G.Cini Castagnoli[2,5], B.D'Ettorre Piazzoli[6], G.Di Sciascio[6], W.Fulgione[1,2], P.Galeotti[2,5], A.Z.Gazizov[Y], P.L.Ghia[1,2], M.Iacovacci[6], G.Mannocchi[1,2], C.Morello[1,2], G.Navarra[2,5], O.Saavedra[2,5], G.C.Trinchero[1,2], P.Vallania[1,2], S.Vernetto[1,2], C.Vigorito[2,5]. [1]*Istituto di Cosmo-Geofisica del CNR, Torino, Italy,* [2]*Istituto Nazionale di Fisica Nucleare, Torino, Italy,* [3]*Istituto Nazionale di Fisica Nucleare, Bologna, Italy,* [4]*INFN, Laboratorio Nazionale del Gran Sasso, L' Aquila, Italy,* [5]*Dipartimento di Fisica Generale dell' Università, Torino, Italy,* [6]*Dipartimento di Scienze Fisiche dell' Università and INFN, Napoli, Italy,* [7]*Institute of Physics of the Belarussian Academy of Sciences, Belarus*

PII S0920-5632(98)00485-X

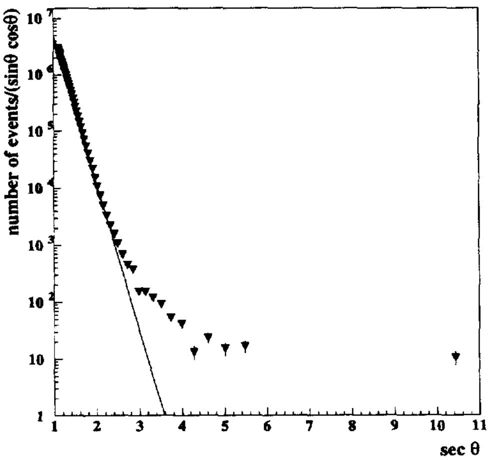

Figure 1. The zenith angle distribution of EAS as measured by the EAS-TOP array.

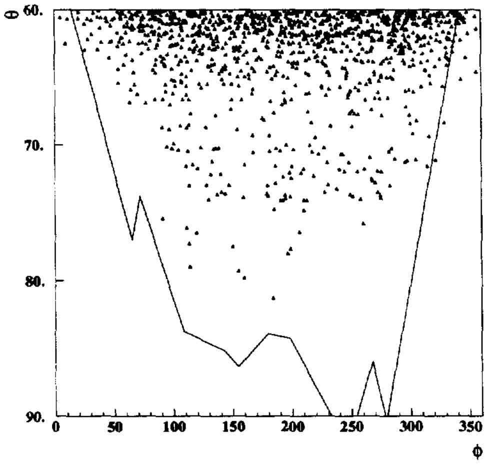

Figure 2. Arrival directions of EAS and the mountain profile seen by EAS-TOP.

which the array is located (Fig.2). Further, by comparing the arrival directions as reconstructed by the e.m. and muon detectors we study the angular resolution of the shower array for very inclined events. From the $\Delta\theta$ distribution between the reconstructed directions of the e.m. and muon detectors in a subset of events with $\theta \geq 65°$ and $N_\mu > 1$, a cut in the e.m. reconstruction ($\chi^2 \leq 1$/d.f. with $\epsilon > 85\%$) has been choosen, and the systematic deviations have been obtained. Applying such corrections, the amount of events due to the contamination from reconstruction errors in the e.m. detector, for any cut of θ above 70°, is less than 30%. The comparison of the zenith angles as obtained by the two detectors is shown for this subset of events in Fig. 3. The existence of events with $\theta \geq 75°$, which cannot be explained by errors in the angular reconstruction is confirmed.

Moreover the dependence of the barometric effect on the zenith angle clearly shows that at $sec\theta$ 2 a non-attenuated component dominates over the c.r. hadronic flux. This is shown in Fig.4 where the barometric coefficient is seen to follow the expected $sec\theta$ dependence, deviating above $\approx 60°$.

3. The data and results

In this analysis we use only events with $\theta \geq 75°$, for which the contamination from cosmic ray hadron showers is ≈ 1 %. In 986 observation days we have 37 events: 12 of them with energy losses in the 6 (or 7) triggering scintillators larger than $\Delta E_{min} = 32.8$ MeV (corresponding to 4 vertical *m.i.p.*).

The acceptance of the EAS array has been calculated as a function of the EAS primary energy (E_{EAS}), the production height above the observation level (x), the triggering requirement (ΔE_{min}), and the zenith angle (θ). The fluctuations in the shower development and the transition effect in the scintillators have been included.

By assuming that all observed events are produced by muon interactions, which is their natural interpretation, we derive the UHE muon flux $S_\mu(> E_{\mu_0})$. All muons are assumed to be originated by meson decays following a spectrum:

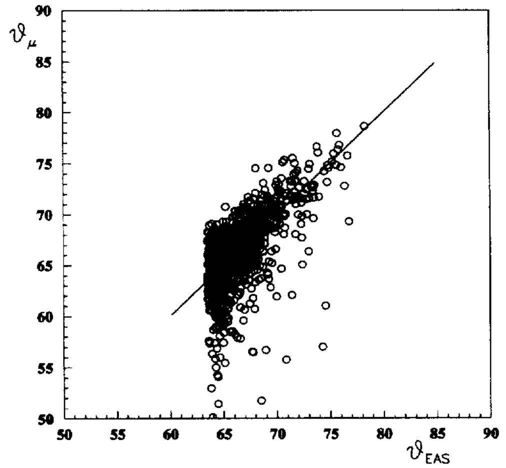

Figure 3. Scatter plot of the event directions obtained by the e.m. and muon detectors.

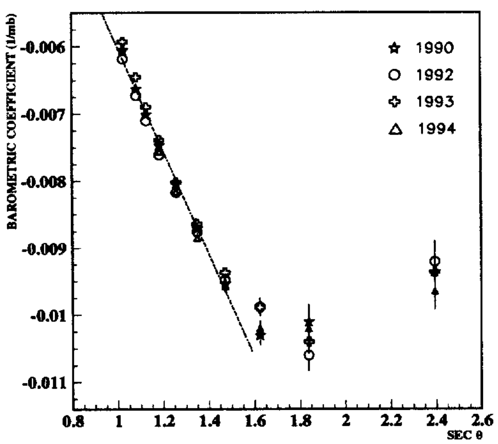

Figure 4. Barometric coefficient for different zenith angles measured by *EAS-TOP*.

$S_\mu(E_\mu) \propto E_\mu^{-\gamma}/\cos\theta$ with $\gamma = 3.73$. Using the rate of events with $\Delta E_{min} = 32.8$ MeV (the corresponding μ–primary median energy beeing $\approx 20\ TeV$) we obtain:

$$S_\mu(> 20\ \text{TeV}) = 1.3 \times 10^{-11}\ \text{cm}^{-2}\ \text{s}^{-1}\ \text{sr}^{-1} \quad (1)$$

with statistical error 30% and systematic errors $\approx$ 15%. This is well consistent with the underground measurements [7].

Since all such events can be explained by muon interactions, we can derive upper limits to the flux of other penetrating particles as neutrinos.

For the shape of neutrino spectrum $I_\nu(E_\nu)$ we use the calculations of ref. [8] for the $\nu_\mu + \bar{\nu}_\mu$ fluxes from AGNs accompanied by the corresponding ν_e and $\bar{\nu}_e$ fluxes. The differential νN cross-sections are calculated using the *Eichten et al.* [9] parameterization of the quark distributions in nucleons with the extrapolation for very small x, described in ref. [10].

By using, as upper limit to the number of observed events, $n = 2.3$ for 90% c.l., we obtain:

$$I_\nu(> 10^5 GeV) < 5.2 \times 10^{-9}\ \text{cm}^{-2}\text{s}^{-1}\text{sr}^{-1}. \quad (2)$$

This shows that studies of HAS provide significant informations on the UHE ν-fluxes. The collecting areas necessary to approach the predicted fluxes are $\approx (10 \div 20)\times$ the *EAS-TOP* one. In any case such areas should be realized without losses of accuracies of the detectors.

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