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Experimental EAS data relevant to underground physics: the EAS size spectrum and the rate of HAS as a limit to the astrophysical ν-flux.

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The recent data on the EAS size spectrum, and on the rate of 'Horizontal Air Showers' (HAS), as detected by the EAS-TOP experiment at Campo Imperatore (LNGS), are presented. Their implications for the interpretation of underground muon data, and for UHE neutrino astronomy are discussed.

1. INTRODUCTION

In this paper we will briefly discuss two aspects of the EAS results from the EAS-TOP experiment at Campo Imperatore (Gran Sasso Laboratory) relevant for the interpretation of underground data and for planning future large underground detectors.

a) The interpretation of muon data recorded deep underground requires the normalization to the cosmic ray energy spectrum. At primary energies E_0>100 TeV, this is obtained from the EAS size spectrum measured at the surface by EAS arrays, and with this size spectrum all interpretations have to be consistent. We present here the EAS size spectrum in the range $N_e=10^5$-10^7 particles as measured by EAS-TOP at the atmospheric depth of 800 g cm^{-2}. A possible interpretation of such spectrum from the extrapolation of the direct measurements of the different c.r. components, performed at lower energies, is discussed.

b) New projects are under development in connection with UHE neutrino astronomy, following the suggested ν-fluxes from AGNs. EAS arrays with good angular resolutions can provide interesting results in the field, and in this context we discuss the HAS recorded by EAS-TOP, and derive an upper limit to the UHE diffuse ν- flux.

The EAS-TOP array [1] is located at Campo Imperatore (2000 m a.s.l.), above the underground laboratories. It consists of detectors of the different EAS components, namely:
i) e.m.: 35 modules of plastic scintillators (10 m^2 each) distributed over an area of ~10^5 m^2 [2];
ii) muon-hadron: 140 m^2 calorimeter, 920 g/cm^2 thick, made of 9 iron layers, seen by limited-streamer and quasi-proportional tubes for muon tracking and hadron calorimetry [3];
iii) Cerenkov: 8 telescopes with imaging devices (multipixel photomultipliers), 4 of them in operation [4];
iv) radio: 3 radio antennas operating in the MHz wavelength region [5].
We are essentially discussing here the results of the e.m., and partially of the muon detectors.

2. THE EAS SIZE SPECTRUM

The shower sizes and core locations of individual events are obtained (by means of a χ^2 fit) from the number of particles recorded by

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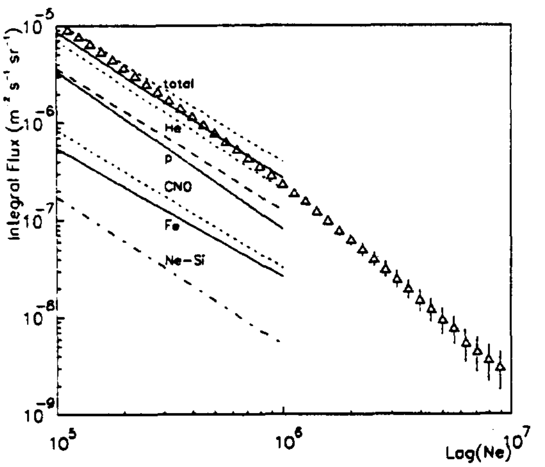

Fig . 1 The experimental EAS size spectrum and the expected one from the extrapolations of the lower energy data; the error band corresponding to 1 s.d. error of the measured helium spectrum is also shown (dotted line)

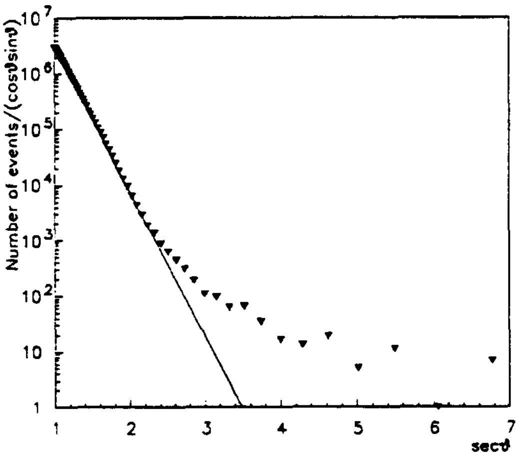

Fig. 2 The measured zenith angle distribution of detected EAS.

each scintillator module for all events having their cores inside the array. The resolution $\Delta N_e/N_e$, deduced from simulations including all experimental inaccuracies, is <20% for $N_e > 10^5$ (reconstructions procedures and accuracies are discussed in ref. [2]).

Fig.1 shows the experimental size spectrum for vertical incidence. The steepening of the spectrum is clearly seen at $N_e \sim 10^6$ particles. The power law indexes of the size spectrum obtained through fits in the shower size ranges $5.2 < \mathrm{Log}N_e < 5.7$ and $6.2 < \mathrm{Log}N_e < 6.7$ are respectively $\gamma_1 = 1.67 \pm 0.01$ and $\gamma_2 = 2.09 \pm 0.1$. The intensity above $\mathrm{Log}\ N_e = 5.2$ is $I = (5.39 \pm 0.06)\ 10^{-6}\ m^{-2}\ s^{-1}\ sr^{-1}$ [6].

As a first approach, we compare such measured N_e spectrum with that expected from the extrapolations of the spectra of the c.r. components, obtained from direct measurements at lower energies. These data are taken for protons and Helium from ref. [7], and for heavier primaries from ref. [8].

The conversion from primary energy to shower size is obtained by means of the interaction model and the propagation of the cascades in the atmosphere included in the Monte Carlo program HEMAS [9].

The results of such comparison are reported in fig.1, where it is clearly shown that the extrapolated fluxes (that we call Σ model), at least up to the 'knee' of the primary spectrum, where such extrapolation is meaningful, explains fairly well the measured size spectrum.

3. HAS: LIMITS ON THE DIFFUSE ν-FLUXES.

At zenith angles $\theta > 65^0$ an excess of events is observed above the rates of EAS as expected from their attenuation length in the atmosphere ($\Lambda = 220$ g cm^{-2}, fig. 2) [10],[11].

The natural interpretation of such events is that they are expected to be due to the interactions (mostly bremsstrahlung) of UHE muons that penetrate deep in atmosphere. However the possibility of exploiting such Horizontal Air Showers for UHE neutrino astronomy has also been discussed [12].

A crucial constraint for such an experiment is that these 'horizontal events' have to be selected on the basis of arrival direction measurements only, with a limited contamination from the large background of hadron c.r. showers (the e.m. detector of EAS-TOP is recording events above 70^0 at a rate of ~1 ev day^{-1} against a total number of internal trigger of 1.5 10^5 day^{-1}). The arrival directions of individual events for the EAS e.m. detector is measured from the time of flight technique, and the reconstruction accuracy for 'usual' showers is checked by the observation of the shadow of the moon on the primary cosmic ray flux [13]. In a previous paper [11] we have shown that the 'anomalous' arrival direction of such fraction of showers is confirmed by different approaches, namely:

- the measured arrival direction accuracy for the very inclined events ($\Delta\theta \sim 1.5^0$ for $\theta > 60^0$);

- the lack of events from the direction of the sky masked by the top of the mountain on which the array is located;
- the agreement of the arrival direction reconstructed by the e.m. and the muon detector (for which the direction is obtained with a tracking technique).

In 258.3 analyzed days, 34 events with $\theta_{e.m.} > 75^0$ (the strict selection used in this first analysis) have been recorded. 18, 10 and 4 of them show energy losses in the 6 (or 7) triggering scintillators larger respectively than 8.2, 16.4 and 32.8 MeV.

The calculation of the expected rate requires good knowledge of:
a) the acceptance of the EAS array for these very inclined directions;
b) the transition effects in the scintillators (mainly gamma ray conversions and delta rays);
c) the fluctuations in the shower development.

A detailed comparison of the experimental and expected rates from muon interactions and of the EAS phenomenology will be presented elsewhere. The general consistency of such interpretation can be inferred from the fact that all events accumulate quite near the threshold, as expected from the steepness of the atmospheric muon energy spectrum (power law index $\gamma \sim 3.7$).
At this stage we want just take in account the 4 events that survive 32.8 MeV cut in the energy loss in all the triggering scintillator modules.
The EAS development has been calculated following the quoted HEMAS code and a shape of longitudinal development as suggested in ref. [14]. The acceptance area has been evaluated by a simulation wich takes into account points a,b and c. To give an indication, with the 32.8 MeV energy loss threshold, the effective area at $\theta = 75^0$, for $N_e = 10^{-5}$, is $A_{eff} \sim 2.8 \cdot 10^4$ m^2, depending on zenith angle as $(\cos\theta)^{2.3}$.
The processes taken into account are:

i) $\nu_\mu + N \Rightarrow$ hadrons + x
ii) $\nu_e + N \Rightarrow$ e + hadrons
iii) $\bar{\nu}_e + N \Rightarrow W^- \Rightarrow$ hadrons (Glashow resonance, $E_0 = 5.6 \cdot 10^6$ GeV))

The cross sections are from ref. [15]. The upper limits to the UHE diffuse ν-fluxes that can thus be obtained at 90% c.l., with the quoted 4 candidate, i.e. without any background substraction, are:

i) $\Phi \nu_\mu$ (>10^4 GeV) < 10^{-6} cm^{-2}s^{-1}sr^{-1}
ii) $\Phi \nu_e$ (>10^4 GeV) < 3.8 10^{-7} cm^{-2}s^{-1}sr^{-1}
iii) $\Phi \bar{\nu}_e$ (>5.6$10^6$ GeV) < 1.6 10^{-10} cm^{-2}s^{-1}sr^{-1}

If we substrat the 4 events, that are explained from the muon interactions, we obtain:
$\Phi \bar{\nu}_e$ (>5.6$10^6$ GeV) < 5.5 10^{-11} cm^{-2}s^{-1}sr^{-1} .

These limits are a factor 50÷100 higher than the diffuse $\nu_\mu + \bar{\nu}_\mu$ fluxes calculated from AGNs by different authors ([16], but show the potentialities of the EAS technique in the field and, at least in the UHE region, represent the best experimental limit, obtained so far by direct measurements, to the $\bar{\nu}_e$ diffuse flux .

REFERENCES

1) M. Aglietta et al. (EAS-TOP coll.), Il Nuovo Cimento, 9C, 262 (1986)
2) M. Aglietta et al. (EAS-TOP coll.), Nuclear Instruments and Methods, A277, 23 (1989) and A336, 310-321 (1993)
3) M.Aglietta et al. (EAS-TOP coll.), Il Nuovo Cimento, 15C, 735 (1992)
4) M.Aglietta et al. (EAS-TOP coll.), Il Nuovo Cimento, 15C, 357 (1992)
5) C. Castagnoli et al., Proc. 23rd ICRC, 1,233 (Calgary, 1993)
6) EAS-TOP Coll., Proc. 23rd ICRC, 4,247 (Calgary, 1993)
7) Jacee Coll., (T.H. Burnett et al.), Ap. J. 349 (1990) L25, and (K. Asakimori et al.), Proc. 22nd ICRC, 2 (Dublin, 1991), 57
8) CRN Coll. (D. Muller et al.), Ap. J., 374 (1991), 356
9) C. Forti et al., Phys Rev., D 42 (1990) 3668
10) E. Bohm and M. Nagano, J. Phys. A, 6 (1973) 1262; M. Nagano et al., J Phys. G, 12(1989) 69
11)EAS-TOP Coll., Proc. 23rd ICRC, 4,255 (Calgary, 1993)
12) V.S. Berezinsky and A. Yu. Smirnov, Astrophys. Space Sci, 32 (1975) 461; V. S. Berezinsky et al., Sov. J. Nucl. Phys., 43 (1986) 406; E. Zas et al., Astroparticle Physics, 1 (1993) 297
13) M. Aglietta et al., "High Energy Gamma-Ray Astronomy", AIP Conference Proc. 220 (Ann. Arbor 1990) 145
14) E. J. Fenyves et al., Phys. Rev. D, 37 (1988) 649
15) "Astrophysics of Cosmic Rays", North Holland V. L. Ginzburg ed. (1990)
16) F. W. Stecker et al., Proc. Workshop "High Energy Neutrino Astrophysics" (Honolulu, 1992), 1; A. P. Szabo and R. J. Protheroe, ib., 24