ELSEVIER

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NUCLEAR PHYSICS B
PROCEEDINGS
SUPPLEMENTS

Study of the c.r. composition and interaction at $E_0 = 10 - 100$ TeV from the observation of H.E. muons and atmospheric Cherenkov Light in EAS

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In the energy region 10 - 100 TeV both the c.r. composition from direct measurements and the cross section for high energy secondary production in the very forward region for p-air interactions are rather uncertain. Contemporaneous measurements of the total energy and of the threshold energy/nucleon of the primary particle can be provided by the atmospheric Cherenkov light and high energy muons. These measurements are performed by the combined operation of the Cherenkov array of the EAS-TOP experiment on the surface (810 gcm^2 atmospheric depth) and of the LVD experiment in the underground Gran Sasso Laboratories (3300 m w.e.; $E_\mu^{th} = 1.3$ TeV) leading to the measurement of $< N_\mu > (E_\mu > 1.3$ TeV, $E_0)$ in the given energy range. The combined operation of the experiments and preliminary results are reported.

1. Introduction

At cosmic ray primary energies of the order of 10 TeV typical observables at ground level are the Cherenkov Light (C.L.) produced in atmosphere by the secondary electrons of Extensive Air Showers (EAS) and high energy muons.

The contemporaneous measurement of these two quantities provides the unique possibility in ground based cosmic ray experiments of obtaining information on the total energy E_0 and on the minimum energy per nucleon of the primary ($E_\mu^{th} \propto E_0/A$).

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Such measurements [1] are among the main aims of the correlated operation between the EAS-TOP experiment (Campo Imperatore, 2005 m a.s.l.) and the detectors running in the deep underground Gran Sasso Laboratories (1100 m rock coverage: $E_\mu^{th} = 1.3 TeV$).
The experiment provides:
a) a measurement of $< N_\mu >$ ($E_\mu \geq 1.3$ TeV) for high energy muons and fixed primary proton energy for $x = E_{sec}/E_0 > 0.1$: at $E_0 \approx 10 TeV$ only proton primaries contribute to TeV muons. This allows to check the models used in H.E. hadron interactions that differentiate in the region $x > 0.1$ and it is important for the interpretation of deep underground muon measurements, the p-air cross section for secondary production being not directly measured in this energy range.
b) a study of the p/helium ratio at $30 \leq E_0 \leq 100 TeV$ which is quite controversial from direct measurements [2,3]. Helium primaries contribute to the TeV muons flux above $E_0 \simeq 30 TeV$, carbon primaries above $E_0 \simeq 80 TeV$.

2. The data and the analysis

LVD is a Large Volume Detector [4] of liquid scintillator counters interleaved with limited streamer tubes in a compact geometry that combines high tracking capabilities (angular resolution 4 mrad) with good energy loss measurements located in the underground Gran Sasso Laboratories. In the present analysis one tower is considered for a total area of 78 m^2.
EAS-TOP [5] is a multicomponent EAS array located at 2005 m a.s.l. 23 deg. above the zenith of the LVD detector, the two experiments being separed by 1100 m of rock.
The Cherenkov array of the EAS-TOP experiment [6] consists of eight telescopes 60-80 m apart from each other. Each telescope loads a multianode photomultiplier on the focal plane of a parabolic mirror for the detection of Cherenkov images [7] and two wide angle detectors realized with 7 photomultipliers (d = 6.8 cm each) on the focal plane of a parabolic mirror 0.5 m^2 and 40 cm focal length for a field of view (f.o.v.) of 12.5 degrees.
The Cherenkov measurements are performed on clear moonless nights with the telescopes pointing to the sky with the optical axis parallel to the EAS-TOP - LVD direction. Due to the lack of direct link between the two experiments, the coincident events are extracted a posteriori on the basis of the absolute time differences with a resolution of 1 μs.
The data have been collected in 97 h of running time with 3 telescopes between June and December 1997. The rate of coincidences is $\approx$ 1 ev/h per telescope.
The Cherenkov events are identified by the coincidence, in a time window of 30 nsec, between any two photomultipliers having the same geometrical position on the focal plane of the two different mirrors on the same telescope . The trigger threshold is $N_{phe}^{th} = 200$ photoelectrons corrisponding to $E_0^{th} \approx 10 TeV$; the trigger rate is 5 Hz/telescope.
The number of photoelectrons detected on each photomultiplier is obtained from the charge measurement of the anode output after subtraction of the mean value of the ADC pedestals obtained from the data every 300 seconds. The absolute gain of the photomultipliers has been measured by the single photoelectron calibration with an accuracy of $\Delta G/G \approx 10\%$. The overall error on the number of photoelectrons has been obtained by comparing the number of photoelectrons (N_A, N_B) detected on two different mirrors as shown in figure 1. For the whole data set and $N_{phe} \simeq 1000$ the error on the photoelectron counting on individual channels, assuming $\sigma_{N_A} \simeq \sigma_{N_B}$, is $\Delta N_{phe}/N_{phe} \simeq 13\%$.
In this preliminary analysis the conversion to the primary energy is obtained from the number of photoelectrons (N_{phe}) detected on the two mirrors ($A = 1 m^2$): $E_0 = \frac{N_{phe}}{\epsilon A \rho_c}$; ρ_c is the photon density derived from the C.L. lateral distribution for primary protons at the EAS-TOP atmospheric depth assuming a mean distance R = 80 m from the shower axis [8], $\epsilon = 15\%$ being the quantum efficiency of the photomultipliers integrated over the C.L. spectrum.
To reduce the systematics related to the loss of light when the triggering photomultipliers are at the edges of the f.o.v. the present analysis has

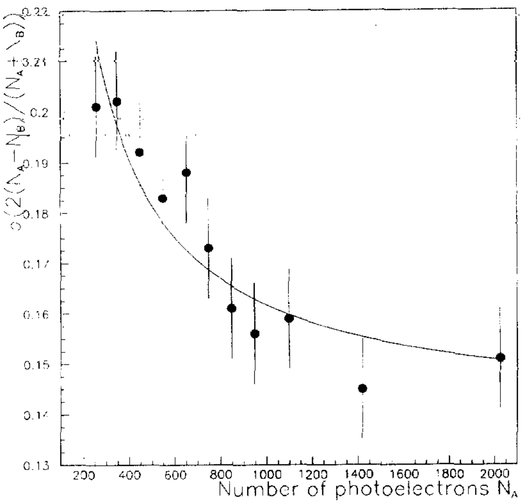

Figure 1. Dependence of the standard deviation of the distribution of $\frac{2(N_A-N_B)}{(N_A+N_B)}$ on the detected number of photoelectrons (2 photomultipliers, 1 night of measurement).

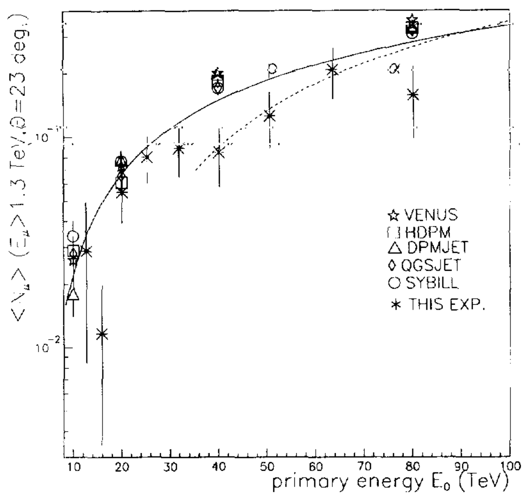

Figure 2. $< N_\mu >$ measured by the combined operation between the EAS-TOP Cherenkov array and the LVD experiment. The continuous and dotted lines show the results of Forti et al. [9].

been limited to the coincident events having both the central photomultipliers fired . The f.o.v is thus reduced to 5 deg. and the choice reduces the statistics from 394 to 87 coincident events. Such events are divided in intervals of primary energy and for each bin the ratio between the number of coincidences with LVD and the total number of Cherenkov events normalized to the acceptances of the two apparatuses is obtained. Since all coincident events have $N_\mu \approx 1$, the given ratio represents the measurement of $< N_\mu > (E_\mu > 1.3\ TeV, E_0)$, 1.3 TeV being the "effective" muon energy threshold for muon counting at the LVD depth.

3. Results and conclusions

Fig.2 shows the behaviour of $< N_\mu >$ versus E_0 compared with the results of the calculations of Forti et al. [9] for a beam of pure protons and pure alfa particles together with the expectations of $< N_\mu > (E_\mu > 1.3\ TeV)$ for different models and primary protons obtained through the CORSIKA code.
Such preliminary data confirm the general trend of expectations over the whole 10 - 100 TeV energy range.

A reduction of errors (statistic + systematic) at a level $\leq 10\%$ is necessary to measure the muon yield with the accuracy required to determine the proton contribution in the 10 TeV energy range (discrimination between different models) and possibly to identify the primary helium contribution around 50 TeV. The measurement can thus provide a good connection between direct and EAS observation of high energy cosmic rays.

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