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Do the state-of-the-art simulation codes explain emulsion chamber data at mountain altitude ?

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Experimental data observed by emulsion chambers at Pamir and Chacaltaya are compared with simulation calculations using CORSIKA program employing VENUS and HDPM for high energy hadronic interactions. Although these models are considered to be based on modern theory and are widely-accepted as standard simulation codes, it is shown that no models can explain many characteristics observed in the experiments.

1. INTRODUCTION

We have been shown that the characteristics of cosmic-ray families observed by Pamir and Chacaltaya emulsion chambers are not fully explained by smoothly extrapolating those of hadronic interactions so far obtained by accelerator experiments [1]. The above argument is based on the comparison of experimental data with simulation calculations using phenomenological UA5 algorithm for atmospheric nuclear interactions [2].

However we often encounter criticism that we emulsion community should use newer simulation codes which have some theoretical background and are widely-accepted in oder to make the argument convincing, though newer simulation codes for high energy nuclear interaction do not always reproduce the existing accelerator data.

CORSIKA [3], one of the-state-of-the-art simulation codes, is a well-organized and detailed Monte Carlo program for extensive air showers developed for KASCADE experiment and is opened to the researchers.

In the present paper we use CORSIKA code for calculations of ordinary high energy cosmic-ray families. experimental data and also with calculations using purely phenomenological model so far we used.

2. SIMULATION CALCULATIONS

Here we use three different simulation codes for calculations of atmospheric families.

1) UA5air : simplified and modified phenomenological UA5 algorithm to hadron-Air interactions, so far we used. For the atmospheric propagation we use algorithm formulated by T.Shibata [4].

2) CORSIKA+VENUS : air shower simulation program CORSIKA5.20 employing VENUS4.12 for atmospheric nuclear interactions.

3) CORSIKA+HDPM : CORSIKA5.20 employing HDPM for atmospheric nuclear interaction.

Detection probability of hadrons in the chamber is assumed to be 0.7 and hadron energy is transformed into visible energy using k_γ-distribution in h-C interaction obtained by modified UA5 algorithm in 1) and by VENUS4.12 in 2) and 3).

The energy of primary cosmic-rays are sampled from the spectrum formulated by Nicolsky [5].

3. HADRON AND GAMMA FAMILIES

3.1. Family flux

Fig.1 shows integral spectrum of gamma-ray component of family energy,ΣE_γ. Here, the detection threshold energy is taken to be 4 TeV. Experimental data gives family intensity as $I(\geq 100TeV) \sim 0.37m^{-2}y^{-1}sr^{-1}$. Although different simulation code gives different family intensity, all the simulated data gives still $3 \sim 4$ times higher intensity than observations. The result indicates that the energy dissipation of the atmospheric interaction is stronger than that assumed in the simulation calculations.

3.2. Hadron-rich events

Hadron-rich nature of the events are well seen in a correlation diagram on the number of detected hadrons, N_h, and energy fraction of hadron

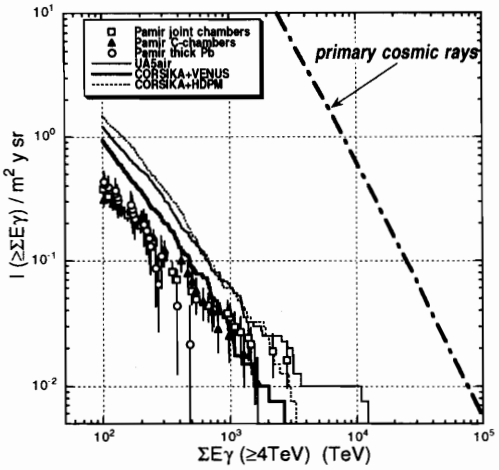

Figure 1. Integral spectrum of ΣE_γ of families observed by Pamir chambers.

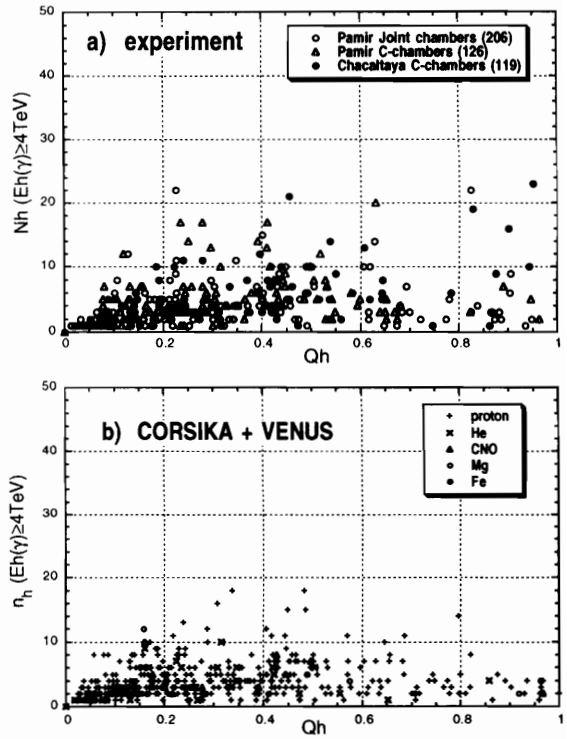

Figure 2. Diagram on the number of detected hadrons, N_h, and energy fraction of hadron component, Q_h, in a family for the events $100 \leq \Sigma(E_\gamma + E_h^{(\gamma)}) < 1000TeV$. a) experimental data and b) simulated data using CORSIKA+VENUS.

component in a family ,$Q_h \equiv \Sigma E_h^{(\gamma)}/\Sigma(E_\gamma + E_h^{(\gamma)})$. In Fig.2 we show those for experimental data (a) and for simulated data using CORSIKA+VENUS (b). Hadron-rich events (Centauro-species) which are distributed in the region of $N_h \geq\sim 10$ and $Q_h \geq\sim 0.6$ in the experimental data are scarcely seen in the simulated events. The other two models give almost same results as in Fig.2b. Thus we can conclude that the Centauro-like events are not due to superposed fluctuation of ordinary nuclear interactions during passage through the atmosphere.

3.3. Correlation between hadrons and gamma-rays

Fig.3 shows a distribution on relative distance, R_{min}, between a hadron and its nearest neighbouring showers in a family. One can see that there exist clear excess over simulated almost flat distribution in the region of $R_{min} \leq 1mm$ in the experimental data. The anomalous correlation between hadrons and gamma-rays is often seen as very collimated shower-clusters, named 'mini-clusters', in which both hadrons and gamma-rays are included. 'Mini-clusters' are indicating an existence of particle production with very small p_t, $< p_t >= 10 \sim 20MeV/c$.

4. EAS-TRIGGERED FAMILIES

In the experiment combined with emulsion chamber and EAS array [6], which has been carried out on Mt. Chacaltaya, we can detect both atmospheric families and air-showers at the same time. We have calculated, for the combined experiment, atmospheric families and accompanied air-shower size, N_e, using above three simulation

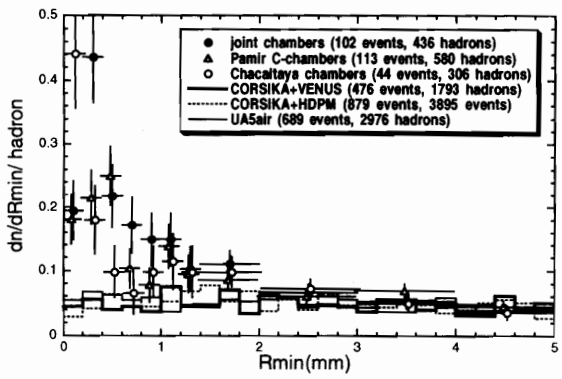

Figure 3. Distribution of relative distance, R_{min}, between a hadron and its nearest neighbouring showers in a family.

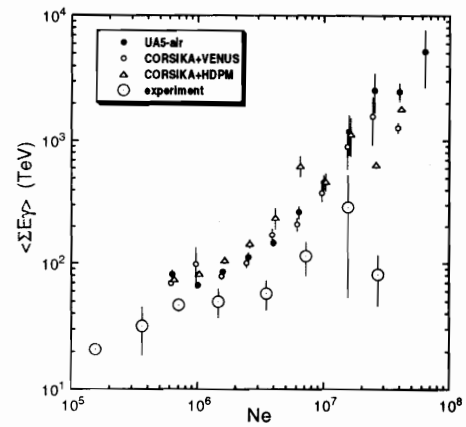

Figure 4. Diagram on air-shower size, N_e, and average energy sum, $< \Sigma E_\gamma >$, of associated atmospheric families.

codes. In Fig.4 we show a diagram on N_e and average energy sum, $< \Sigma E_\gamma >$, of associated atmospheric families. Here the average is calculated for the events of $\Sigma E_\gamma \geq 10TeV$. Detection threshold energy is taken to be 2 TeV. As is seen in the figure, N_e-dependence of family energy in three simulation calculations are almost identical. The experimental data, however, shows systematically smaller family energy than simulated data in the region of N_e larger than $\sim 5 \times 10^6$. The result again indicates that the energy dissipation is much strong in the atmospheric interactions than in the assumed nuclear interactions.

5. SUMMARY

Atmospheric families are simulated using three different simulation codes, purely phenomenological one (using UA5 algorithm) and newer ones (using CORSIKA employing VENUS and HDPM). Although the newer models are considered to be based on modern theory and are accepted as a standard simulation code, the characteristics of the atmospheric families simulated using those code are not much different from those obtained by phenomenological model. And none of the three simulation calculations satisfactorily explain the experimental characteristics of the observed atmospheric families.

The author would like to express his sincere thanks to CORSIKA development group for free use of the simulation codes. The calculation was carried out using IBM RS/6000 SP at the Computer Center of Kinki University.

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Lining material tests for the AUGER PROJECT surface detector

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We are trying to obtain a suitable material to compose the lining of a water Cerenkov tank for the surface detector, part of a hybrid detector of the Auger Project. Results of tests were compared with DuPont 1073Tyvek^{TM} and obtained a reasonable performance for (PVC+$BaSO_4$) material.

1. Introduction

A hybrid detector proposed to the Pierre Auger Project is an array with water Cerenkov tanks and mirrors to observe fluorescence light in the atmosphere, both produced by particles of Cosmic Radiation entering in the atmosphere and multiplicating through. The main aim of the Pierre Auger Project is to detect Extensive Air Shower with energy $E > 10^{19}$ eV and particular interest to increase the statistics for $E \sim 10^{20}$ eV, where GZK cut-off could exist.

Our contribution to the engineering phase of the Pierre Auger Project is restricted to a search for a convenient reflective material. For that purpose we measured the reflection of some commercially available materials and a specially made PVC+$BaSO_4$ material, under request and recipes to SANSUY S/A - IND. DE PLÁSTICOS, a Brazilian plastic industry.

First, we did measurements of relative diffuse reflection on dry materials, using a PERKIN-ELMER, Lambda 9 - series 1645 - UV/VIS/NIR Spectrometer, part of IFGW/UNICAMP facilities. In a second step, a flexible tank full of tap water, lined by (PVC+$BaSO_4$) or DuPont 1073Tyvek was used. Also measurements of transmitance was done for both materials and we found that no transmitted signal was observed for the PVC bag, then this one is sufficiently shielded against external light effect on the Cerenkov light produced inside the tank.

2. Measurements

Figures 1 shows the beforehand mentioned measurements of dry materials. As the Cerenkov light produced inside the tank by Cosmic-Ray particles is in a ultraviolet region, we disregard several other tested materials, for instance TiO_2. Some other tested material, mainly thermoluminescent materials (Teflon+$BaSO_4$:Eu or Teflon+Mg_2SiO_4) showed relative diffuse reflection greater than 100%. This could be caused by Eu, that is the essential luminescent chemical element, taking into account that the reference material of the spectrophotometer for the diffuse relative reflection measurements is an Al plate painted with $BaSO_4$, as is written in the spectrometer's manual. From these results and observations we decided to concentrate the measurements in the (PVC+$BaSO_4$) material, testing many combinations of chemical elements concentrations and thickness of the sheets.

Afterwards we measured the signal of cosmic-ray particles (mainly muons) in a water tank, first with (PVC+$BaSO_4$) and after with DuPont 1073Tyvek bags, working as lining material. The tank has diameter=1.2m, height=1.3m, filled with $\approx$ 1,500 liters of tap water and provided with a photomultiplier Phillips XP2040 optically coupled to a plexiglas base. A pair of plastic scintillators, with different sizes was located over the tank. Following preliminary observations, calibrations and measurements, we moved one of the plastic scintillators to be under the water tank, in a vertical line linking the upper scintillator, the tank and the lower (smaller) scintillator, ex-