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Higgs boson production in UHECR interactions with air nuclei

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We study the production of Higgs bosons through vacuum excitation due to a fraction of interaction energy transfer to vacuum during UHECR interactions with air nuclei. A model is developed for hadronic interaction based on the algorithm of the GENCL code of the UA5 experiment of CERN by incorporating the process of Higgs boson production due to vacuum excitation. We consider the high energy muon multiplicity as a probe for production of Higgs boson. It is found that this mechanism is significant starting from $E_P \sim 10^{18}$ eV.

1. Introduction

The standard model (SM) Higgs boson is yet to be discovered by the on-going particle physics experiments. It is expected that this particle will be discovered at the Fermilab Tevatron [1] or at the CERN Large Hadron Collider (LHC) [2]. A good theoretical description of the precision electoweak data within the SM requires the Higgs boson to be lighter than about 200 GeV [3]. In this report we try to manifest the idea that, in Ultra High Energy Cosmic Rays (UHECR) interactions with air nuclei there is a possibility that the vacuum becomes locally hot, bubbles are formed by phase transition, Higgs bosons are produced and decay very fast to heavy fermion pairs. This effect appears in a very rapid increase of the multiplicity of heavy fermion pairs with energy. The possibility of vacuum excitation or bubble formation depends on the fraction of the total energy of collision (centre of mass energy) that goes to local vacuum. This faction of energy is not known [4]. In the following sections we have discussed this aspect in the context of excessive production of heavy fermions with energy in UHECR interactions.

2. Production of Higgs boson through vacuum excitation

We develop a model [5] for Higgs bosons production using the theoretical formalism of vacuum excitation that is based on thermofield theory [4] followed by decay of Higgs bosons to very high energy muons. Thus the very high energy muons produced at the very first collision bears the signature of Higgs production [5]. We therefore incorporate this effect in the conventional hadronic cascade simulation program developed based on the GENCL code of UA5 experiment [6] of CERN. In this analysis we assume that, the fractions of interaction energy (f_e) that may go to vacuum excitation or bubble formation are 0.0, 0.01, 0.02, ..., 0.5 and the interaction and decay processes in the atmosphere are simulated only for hadrons (π, K, and N) and muons above 0.01 TeV, 0.1 TeV and 1 TeV [5]. The Monte-Carlo simulation program developed for the first p-air interaction is run for primary energies of proton from $E_p = 10^{15}$ to 10^{20}eV and for different fractions of energy transfer to bubble formation f_e (0.0 - 0.5). It is found that the average Higgs boson number $< n_H >$ increases with increasing bubble energy E_b and this trend can be expressed as,

$$< n_H >= n_0 (E_b)^{\gamma}, \qquad (1)$$

where $n_0 = 2.45 \pm 0.04$ and $\gamma = 0.99 \pm 0.004$. Here the average value is calculated from 5000 p-air interactions. The resulting muon multiplicity distributions for 5000 showers for different E_p and f_e are compared with the corresponding simulations with $f_e = 0$. In order to derive the signature of Higgs boson production, muon multiplicity distributions for muon energy thresholds of 0.01 TeV, 0.1 TeV and 1 TeV are selected as the probes. As shown in the figure 1, the muon multiplicity distributions for primary energies 10^{19}eV and 10^{20}eV and for f_e = 0.3 and 0.5 are compared with f_e = 0 for different muon threshold energies. It is observed that, the distinction between muon multiplicity distributions increases and multiplicity distributions move towards larger multiplicity side for increasing primary energy and fraction of energy transfer for a particular value of muon threshold energy. Similarly as the muon threshold energy increases, the separation between muon multiplicity distributions for $f_e \neq 0$ and $f_e = 0$ becomes more and more distinct and also the distributions with $f_e = 0$ moves towards lower multiplicity side gradually. This indicates that with the rise of primary energy E_p and the fraction of energy transfer f_e, very high energy muon or prompt muon multiplicity increases considerably, pointing to the possibility of Higgs signature.

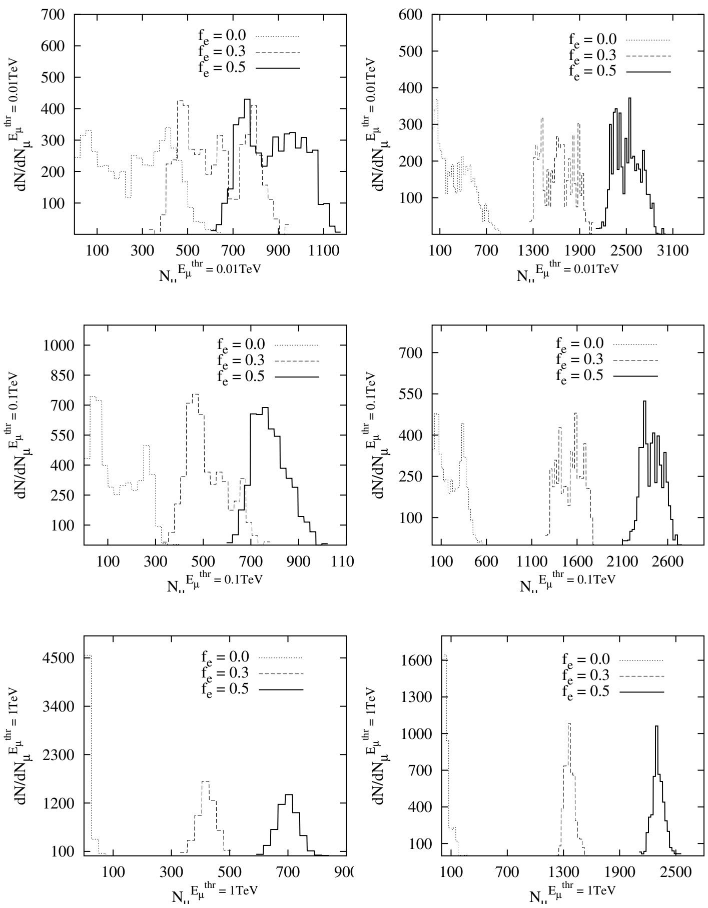

Figure 1. Muon multiplicity distributions at first interaction level for 5000 proton induced showers for different fractions of energy transfer. The data is taken for muon threshold energies (E_μ^{thr}) 0.01TeV, 0.1TeV and 1TeV. The panel of the figures on the left hand side is for primary energy (E_P) 10^{19}eV and on the right hand side is for 10^{20}eV respectively.

In figure 2(a) we have shown the variation of average muon number with bubble energy for different threshold energies of muon. It is clear from this figure that the average muon number increases remarkably with the increase of the value of the bubble energy for all values of the muon threshold energies. On the other hand the difference in average muon number decreases for different muon threshold energies as the bubble energy is increasing and at a considerable high value of bubble energy this difference vanishes. Exactly same observation can be made also from the figure 2(b) which gives a plot between primary energy of the cosmic rays particle and the average muon number observed from Higgs bosons decay that are produced during interaction with air nuclei for a fraction of energy transfer f_e = 0.3. From these observations it can be inferred that at higher values of bubble energies or primary energies (as the bubble energy increases with the increase of the primary energy for a particular fraction of energy transfer to vacuum) the number of prompt muon increases considerably (that is at these energies, only prompt or very high energy muons dominate the total muon flux) and that is why at higher values of bubble energies or primary energies the average muon multiplicities are almost independent of muon threshold energies, indicating possible signature of Higgs production in these interactions.

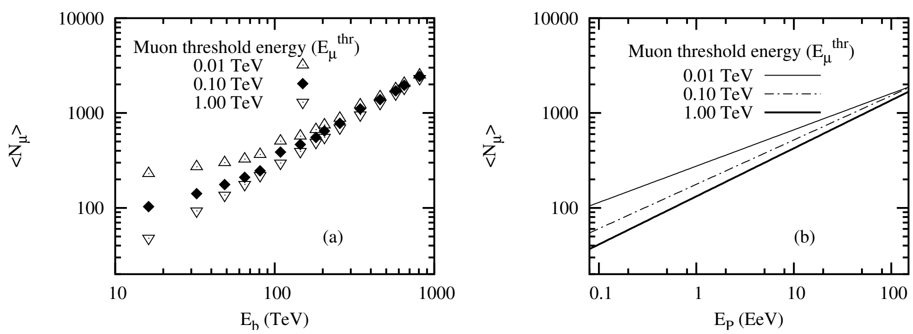

Figure 2. (a) Average muon number at the first interaction level versus bubble energy for different muon energy thresholds. (b) Variation of average number of muons with primary energy of cosmic rays particle at the first interaction level for different muon threshold energies and for the fraction of energy transfer f_e = 0.3. Data is taken from 5000 proton induced showers.

The significance of our mechanism is studied by using the equation,

$$\chi^2 = \sum_{i=1}^{n} \frac{\{(N_\mu^{f_e \neq 0})_i - (N_\mu^{f_e = 0})_i\}^2}{(N_\mu^{f_e = 0})_i} \tag{2}$$

where $N_\mu^{f_e \neq 0}$ is the number of muons at $f_e \neq 0$ and $N_\mu^{f_e = 0}$ is the same at $f_e = 0$. The result of this study is shown in figure 3. It is found from this study that, the Higgs boson production mechanism is significant from $E_P \sim 10^{18}$eV for all fractions of energy transfer $f_e \geq 0.1$. For further higher energies this mechanism gives significant contributions starting from much lower values of f_e.

3. Concluding remarks

It should be pointed out that, other possible sources of high energy excessive muon multiplicity are the semi-leptonic decays of hadrons containing heavy quarks, most notably charm and bottom. It is reported in [7] that charm contribution to the atmospheric muon flux becomes dominant over the conventional contribution at energies of about 10^5 GeV. FREJUS Collaboration [8] has recently reported enhanced muon flux in TeV energy range, indicating that perhaps prompt muon flux from charm decay is larger than expected in the standard

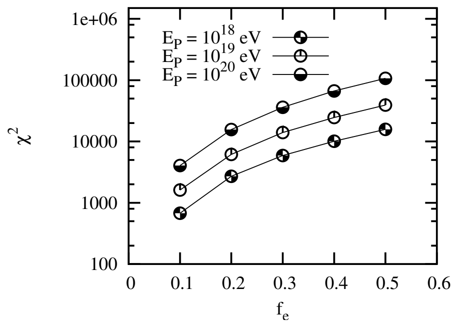

Figure 3. Dispersion of muon multiplicity distributions for different $f_e \neq 0$ from $f_e = 0$.

atmospheric neutrino and muon calculation. Most recently the LEP working group for Higgs boson searches [9] reported that the SM Higgs boson is expected to decay via $b\bar{b}$ (main channel, the branching ratio is 74% for a mass of 115 GeV) and $c\bar{c}$ with 4% branching ratio besides decays to $\tau^+\tau^-$, WW^* and gg channels. So it can be expected that bottom and charmed mesons from Higgs boson also contribute to the prompt muon and neutrino fluxes or to the excessive muon and neutrino multiplicity with energy, besides from the conventional bottom and charmed mesons produced in the cosmic rays interactions with air nuclei. However to disentangle Higgs contributions to prompt muon flux from the charmed or other heavy particles contributions, the study of transverse momentum distributions spectra of muons would be helpful. The muons from Higgs bosons will obviously follow high p_T distributions than from other sources because of the mechanism we reported here. A further study will shed more light over the subject of prompt flux in connection with its source and nature.

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