CORSIKA Simulation for Massive Quarks in Hadronic Showers

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Introduction

- Heavy quark contents in extensive air showers (EAS) of ultra-high energy cosmic ray (UHECRs) primaries can contribute more to the shower profile at detector level.
- Previous studies [1] on the EAS simulations for heavy quarks like charmed mesons or D-mesons have shown change of shower profile due to charged and neutral D-mesons decay to muons, electrons, photons and neutrinos.
- In this work, we study the influence of charmed mesons on the production of muons and electrons+photons using CORSIKA Monte Carlo simulation for the proton primaries within energy 10^{18} eV to $10^{19.2}$ eV. We also show the neutrino contents of the shower.

CORSIKA Simulation

- CORSIKA (**CO**smic **R**ay **S**imulations for **KA**scade) [2] is a detailed Monte Carlo program of the development of EAS in the atmosphere.
- CORSIKA 7.7410 package is used for the EAS simulation. SIBYLL2.3d [3] and GHEISHA 2002d [4] models were used for high energy and low energy hadronic interactions respectively.
- Simulations were done in two ways as:
  - **With charm production**, selected the charmed option in the CORSIKA compile file.
  - **Without charm production**, remove the charmed option in the CORSIKA compile file and selected SIBCHM False in the input parameters file.

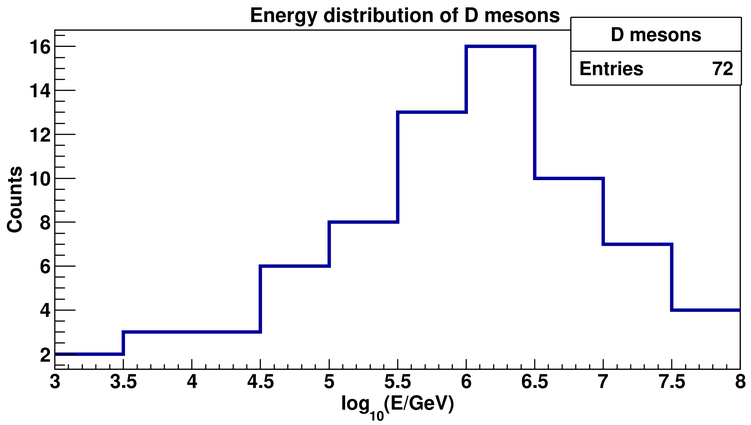
Simulation Parameters

- The primary energy range is divided into six logarithmic bins with an interval of 0.2. Some input parameters of the simulation and events generated in each bin are as follows:

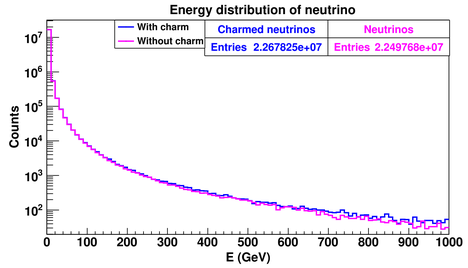
Parameter Name	Value
Primary Particle	Proton (14)
Primary Energy	10^{18} – $10^{19.2}$ eV
Energy Slope	-2.7
Zenith Angle	20°
Observation Level	Sea Level
First Interaction(From sea Level)	1 km

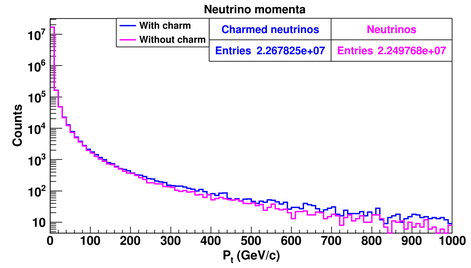
Energy bin (eV)	No. of Events
10^{18} – $10^{18.2}$	100
$10^{18.2}$ – $10^{18.4}$	46
$10^{18.4}$ – $10^{18.6}$	20
$10^{18.6}$ – $10^{18.8}$	10
$10^{18.8}$ – 10^{19}	4
10^{19} – $10^{19.2}$	2

D-Mesons Distribution

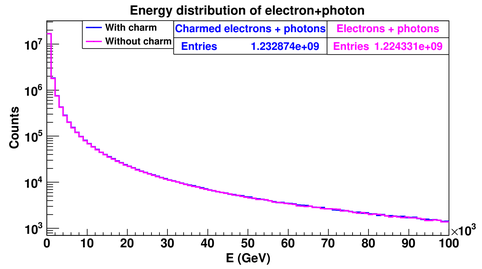


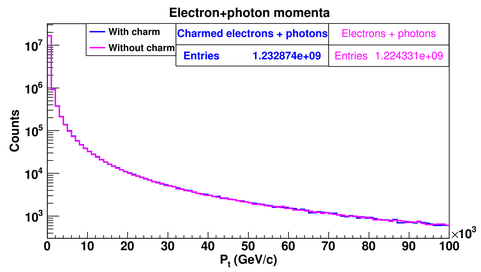
Neutrinos Distribution



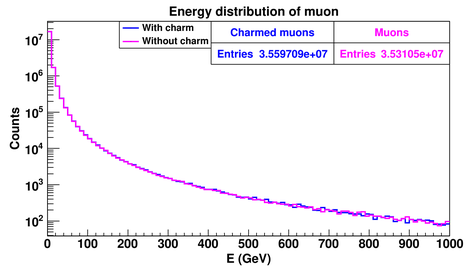


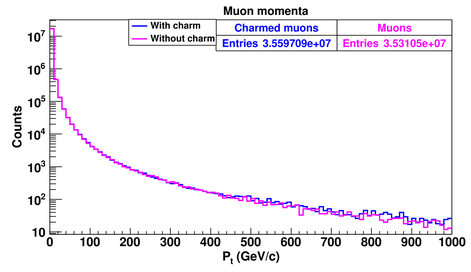
Electrons+photons Distribution





Muons Distribution





Summary & Discussions

- Using CORSIKA simulation, we studied the EAS contents specifically muons, electrons and photons for primary UHE protons considering production of D-mesons.
- From the simulation, we also found the neutrino contents for the EAS showers. With charmed meson OFF, we found the ratio $\nu_e + \bar{\nu_e} : \nu_\mu + \bar{\nu_\mu} : \nu_\tau + \bar{\nu_\tau}$ as $1 : 23 : 0$ where as for charmed meson ON, the ratio becomes $1 : 23 : 1.6 \times 10^{-4}$. The appearance of ν_τ is due to the 5% branching ratio decay mode of D_s mesons.
- For the above study, we used the SIBYLL2.3d and GHEISHA 2002d models. In the future, we will use other models to have a check on the results.

References

[1] P.W. Gaemers, *Charm particle production in High Energy Cosmic Ray Showers using CORSIKA*, PhD. thesis, Netherlands (2016).

[2] D. Heck, J. Knapp, J.N. Capdevielle, G. Schatz, T. Thouw, Report FZKA 6019, Forschungszentrum Karlsruhe(1998).

[3] R.S. Fletcher, T.K. Gaisser, P. Lipari, and T. Stanev, *Phys. Rev.* **D50** (1994) 5710; J. Engel, T.K. Gaisser, P. Lipari, and T. Stanev, *Phys. Rev.* **D46** (1992) 5013.

[4] H. Fesefeldt, Report **PITHA-85/02** (1985), RWTH Aachen, available from: http://cds.cern.ch/record/162911/files/CM-P00055931.pdf