# Simulation of Atmospheric Neutrino Fluxes with CORSIKA

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## Abstract

The three dimensional Monte Carlo simulation code CORSIKA is used to calculate the fluxes of atmospheric neutrinos with the hadronic interaction models DPMJET, VENUS, and UrQMD. For this purpose the original CORSIKA is extended by a parametrization of the solar modulation and a microscopic calculation of the directional dependence of the geomagnetic cut-off functions. A precise description for the geography of the Earth has been included by a digital elevation model, tables for the local magnetic field in the atmosphere, and various atmospheric models for different geographic latitudes and annual seasons. The neutrino fluxes obtained are compared with other calculations.

## 1. Introduction

After the experimental results of Super-Kamiokande have established the atmospheric neutrino anomaly with high statistical accuracy [5,6], it is now the turn of theoretical calculations to provide precise neutrino fluxes needed in the analysis of the neutrino oscillation parameters. Neutrino fluxes have been calculated by various groups. A recent overview and comparison of the results can be found in Ref. [7]. This paper presents a full three dimensional simulation for atmospheric muon and neutrino fluxes using the standard air shower simulation code CORSIKA [8]. The actual attempt includes a complete description of the geographical parameters of the Earth.

## 2. CORSIKA and its extensions

CORSIKA has been designed for the simulation of extensive air showers with energies around $10^{15}$ eV. In order to simulate atmospheric particle fluxes induced by low energy primary particles, the version 6.000 of CORSIKA has been

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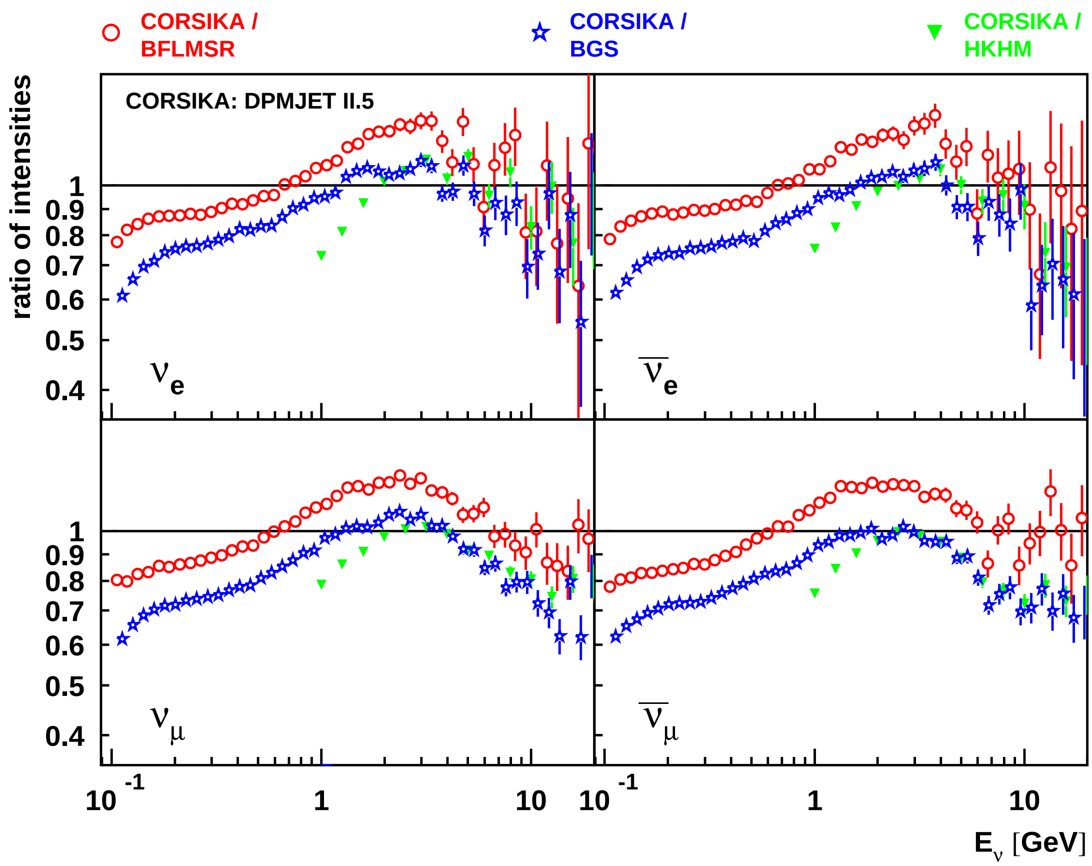


**Fig. 1.** The vertical differential intensities of the different neutrino flavors in Kamioka, displayed as the ratio between the CORSIKA results using DPMJET as hadronic interaction model and the calculations of BGS [1,2], HKHM [9], and BFLMSR [3].

extended by a precise calculation of the geomagnetic cut-off and a parametrization of the solar modulation. For the calculation of atmospheric neutrino fluxes a digital elevation model of the Earth, tables for the local magnetic field in the atmosphere, and various atmospheric models for different climatic zones and annual seasons have been added, too. Details about these extensions and results of tests with atmospheric muon fluxes can be found in Ref. [11].

## 3. Calculation of atmospheric neutrino fluxes for Kamioka

The simulation of atmospheric neutrino fluxes for Kamioka is split in two separate calculations. The downward going neutrinos are simulated locally for Kamioka, while the upward going neutrinos are calculated from primary particles distributed over the entire Earth and only neutrinos passing in a circle of 1000 km distance from Kamioka are used in the further analysis.

Fig. 1 shows the results of CORSIKA using DPMJET II.5 [10] as hadronic

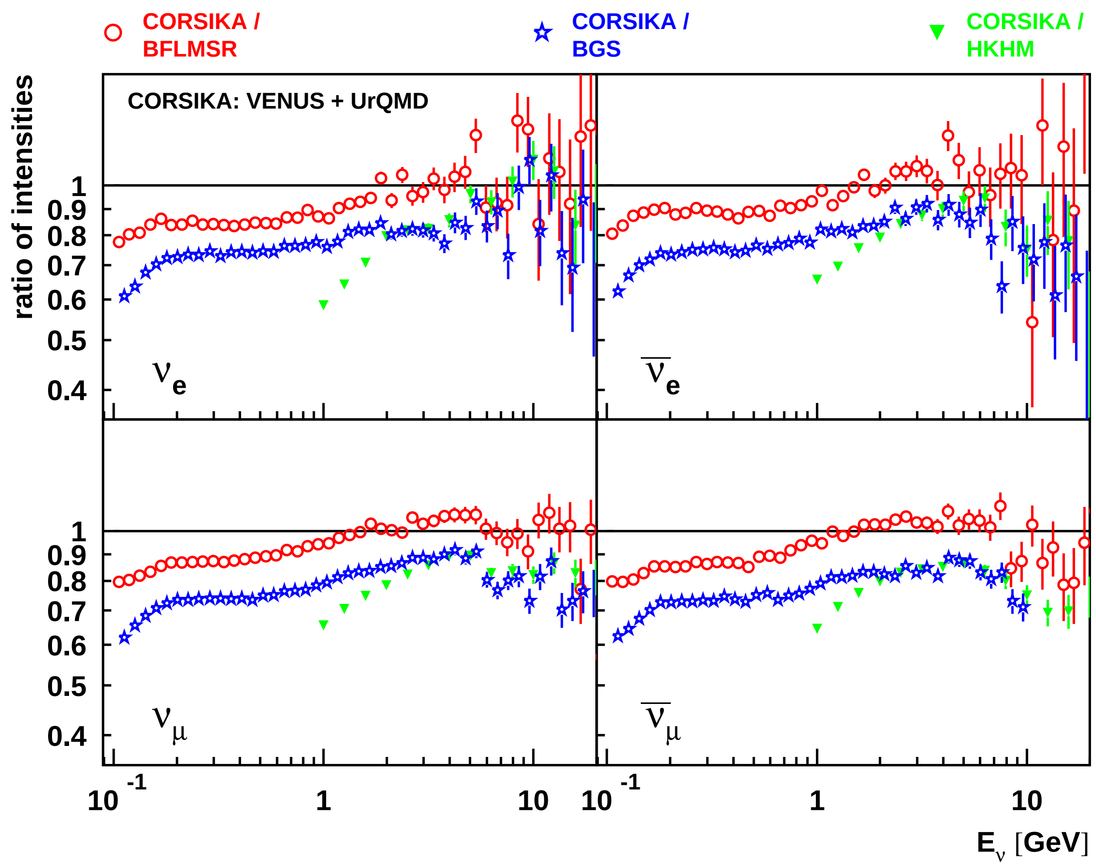


**Fig. 2.** The vertical differential intensities of the different neutrino flavors in Kamioka. Shown is the ratio between the CORSIKA results using VENUS + UrQMD as hadronic interaction model and the calculations of BGS [1,2], HKHM [9], and BFLMSR [3].

interaction model, and Fig. 2 shows the corresponding results using VENUS 4.125 [12] + UrQMD 1.1 [4]. The energy threshold between VENUS and UrQMD is set to $E_{Lab} = 80\,\mathrm{GeV}$. The results are compared with calculations of Barr, Gaisser, and Stanev (BGS) [1,2]; Honda et al. (HKHM) [9]; Battistoni et al. (BFLMSR) [3]. Fig. 3 displays the directional dependence of the neutrino fluxes in Kamioka.

## 4. Conclusion

CORSIKA has been used for a precise calculation of atmospheric neutrino fluxes. The fluxes obtained are lower than the results of one dimensional calculations of BGS and HKHM, but comparable to the results of the three dimensional calculation of BFLMSR. Further results and detailed comparisons may be found in Ref. [11].

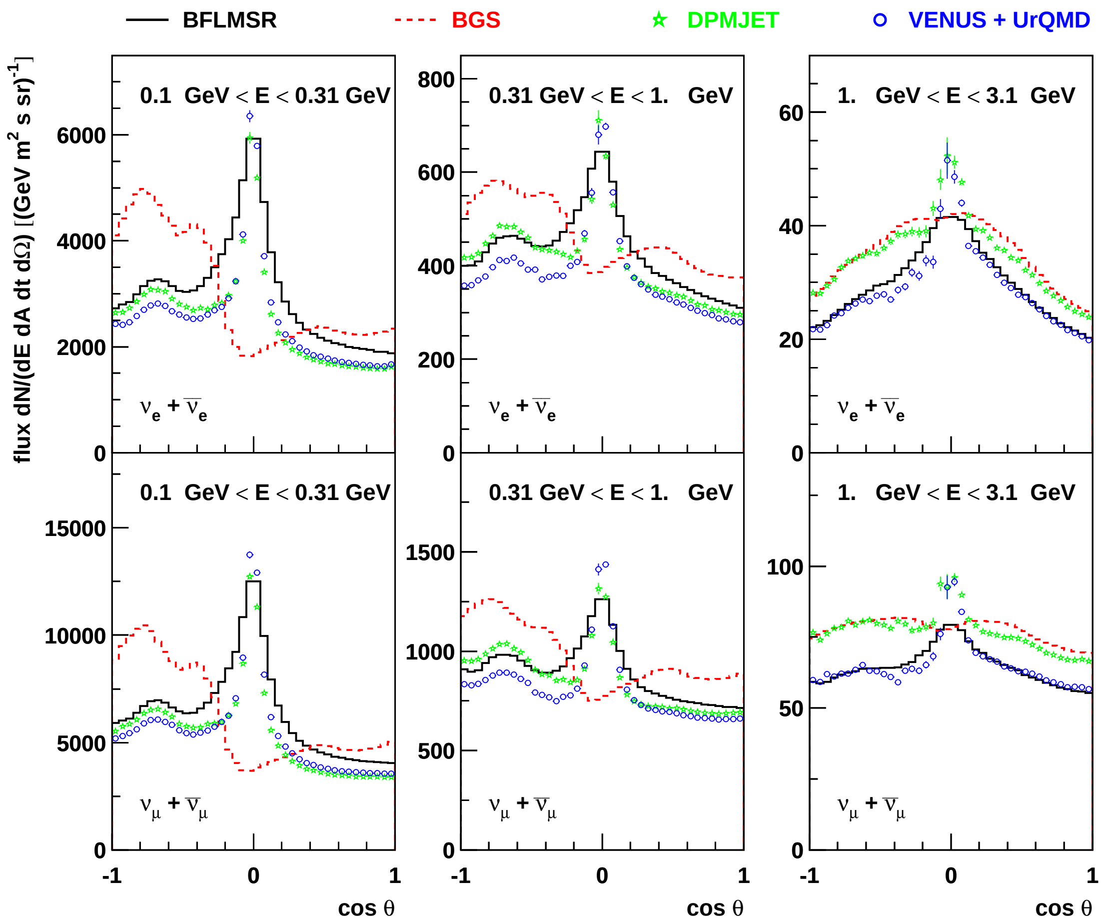


**Fig. 3.** The zenith angle dependence of the neutrino intensities in Kamioka as calculated by CORSIKA with DPMJET and with VENUS + UrQMD in comparison with the calculations of BFLMSR [3] and BGS [1,2].

## 5. References


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