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Abstract. KASCADE-Grande is a large detector array for observations of the energy spectrum as well as the chemical composition of cosmic ray air showers up to primary energies of 1 EeV. The multi-detector arrangement allows to measure the electromagnetic and muonic components for individual air showers. In this analysis, the reconstruction of the all-particle energy spectrum is based on the size spectra of the charged particle component. The energy is calibrated by using Monte Carlo simulations performed with CORSIKA and high-energy interaction models QGSJet, EPOS and SIBYLL. In all cases FLUKA has been used as low-energy interaction model. In this contribution the resulting spectra by means of different hadronic interaction models will be compared and discussed.

1. Introduction
The physical properties of the all-particle energy spectra of primary cosmic rays in the knee region is greatly important for testing theoretical hypotheses of the cosmic ray origin, acceleration and propagation. The aim of KASCADE-Grande is to examine the iron-knee, which presents the end of the bulk of cosmic rays of galactic origin, in the cosmic ray energy spectrum. It has been investigated at around 10^{17} eV by KASCADE-Grande observations [1]. In general, the interpretation of the measurements requires reliable numerical simulations of extensive air showers (EAS) to obtain physical properties of the shower including primary particles. A large uncertainty in those simulations arises from the models which describes the hadronic interactions. In this contribution, model predictions for different hadronic interactions are therefore investigated how their features influence the energy estimation.

The KASCADE-Grande array covering an area of 700×700 m^2 is optimized to measure extensive air showers up to primary energies of 1 EeV [2]. It comprises 37 scintillation detector stations located on a hexagonal grid with an average spacing of 137 m for the measurements of the charged shower component. Each of the detector stations is equipped with plastic scintillator sheets covering a total area of 10 m^2. Full efficiency for the shower size is reached at the number of charged particles of around 10^6, which approximately corresponds to a primary energy of 10^{16} eV. The limit at high energies is due to the restricted area of the Grande array.

2. Hadronic interaction models
For the air shower simulations the CORSIKA [3] program has been used, applying different hadronic interaction models. The response of all detector components is taken into account using the GEANT package. The predicted observables at ground level, such as e.g. the number of electrons, muons and hadrons are then compared to the measurements.

FLUKA [4] (E $<$ 200 GeV) model has been used for hadronic interactions at low energies. High-energy interactions were treated with different models QGSJET-II-2 [5], EPOS 1.99 [6] and SIBYLL 2.1 [7]. Showers initiated by primary protons and iron nuclei have been simulated. The simulations covered the energy range of 10^{14} - 3×10^{18} eV with zenith angles in the interval 0° - 42°. The spectral index in the simulations was -2 and for the analysis it is accordingly weighted to a slope of -3. The simulated events are analyzed by the same procedure as the experimental data, in order to avoid biases by pattern recognition and reconstruction algorithms.

3. Data analysis
Data presented here were taken from December 2003 to October 2009 and it corresponds to the total measured time of 1173 days, where all components of KASCADE and KASCADE-Grande were operating without failures in data acquisition. The cuts on the fiducial area and zenith angles smaller than 40° result in approximately $2\cdot10^6$ events for the following analysis.

The shower size, i.e. the total number of charged particles in the shower [2], per individual event is corrected for attenuation in the atmosphere by the Constant Intensity Cut (CIC) method. To determine the correlation between the number of charged particles and the primary energy, the Monte-Carlo simulations were used, where the angular range of 17° - 24° was selected, based on different hadronic interaction models. The correlation of the primary energy as a function of the number of charged particles is plotted in the left panel of Fig. 1 for the assumption of primary protons and iron, respectively, as well as for the different interaction models. Under the assumption of a linear dependence in logarithmic scale: $\lg E = a + b\cdot\lg(N_{ch})$ and a particular primary composition, the fitting is applied in the range of full trigger and reconstruction efficiencies. The energy calibration depends on simulations, i.e. interaction models, so that the fits are performed individually and the resulting coefficients of the calibration for the three models are compiled in Table 1.

Table 1. Coefficients of the energy calibration functions.

Models	a(H)	b(H)	a(Fe)	b(Fe)
QGSJET-II-2	1.23	0.93	1.75	0.90
EPOS 1.99	1.39	0.92	1.56	0.94
SIBYLL 2.1	1.03	0.96	1.67	0.92

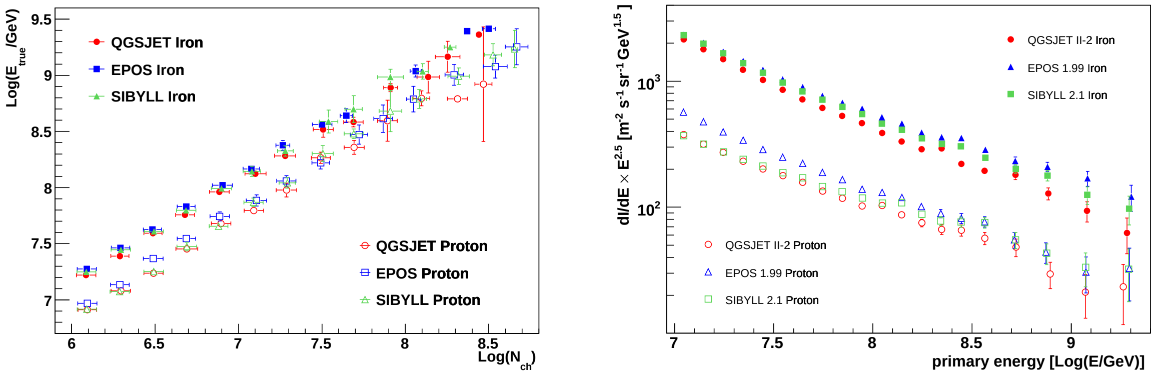

Figure 1. Calibration functions for assumed pure proton and iron primaries for the observable N_{ch} (left). Reconstructed all-particle energy spectra from KASCADE-Grande shower size for assuming proton and iron composition, based on different hadronic interaction models QGSJET-II-2, EPOS 1.99 and SIBYLL 2.1 (right).

The right panel of Fig. 1 shows the all-particle energy spectra obtained after applying the energy reconstruction functions, based on the assumption of iron and proton for QGSJET-II-2, EPOS 1.99 and SIBYLL 2.1 models, where the bin to bin fluctuations are not yet corrected for. The spectral slopes of all three models show slightly different tendencies over whole energy ranges, however relatively similar dependences on the assumption of primary masses and all spectra present similar distributions. Regarding the intensity, the spectrum of EPOS 1.99 leads to higher flux (10-15%) compared to QGSJET-II-2. This is due to the fact that the EPOS 1.99 model predicts less charged particles for a fixed primary energy, so that it assigns higher flux. For the SIBYLL 2.1, it is interesting to remark that assuming protons is close to QGSJET-II-2, assuming iron is close to EPOS 1.99. In general, the resulting all-particle energy spectra of three different interaction models show that they can not be described by a single power-law. A detailed discussion of the all-particle energy spectrum based on QGSJET-II-2 can be found in Ref. [8].

4. Selecting primary mass group

Air showers induced by heavier cosmic ray primaries develop earlier in the atmosphere due to their larger cross section for interacting with air nuclei, and the higher nucleon number leads to relatively larger muon number at ground level. Therefore, the fraction of muons to all charged particles at observation level characterizes the primary mass, i.e. electron-rich showers are generated by light primary nuclei and electron-poor showers by heavy nuclei, respectively. Since KASCADE-Grande measures the particle numbers well after the shower maximum, the measured showers were separated into electron-poor and electron-rich events representing heavy

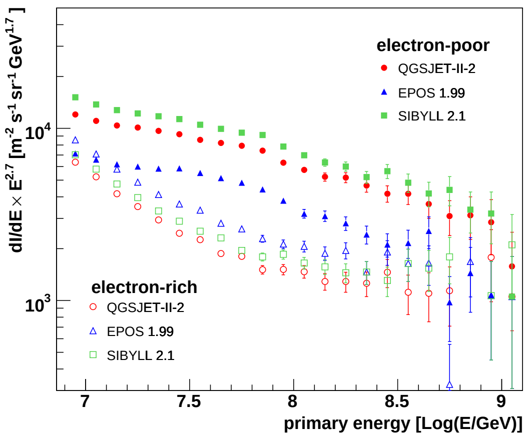

Figure 2. Reconstructed energy spectra of the electron-poor and electron-rich components, based on different hadronic interaction models QGSJET-II-2, EPOS 1.99 and SIBYLL 2.1.

and light mass groups. For this approach, the shower size ratio $Y_{CIC} = logN_\mu/logN_{ch}$ is used to separate the events, where N_μ and N_{ch} are the muon and the charged particle numbers corrected for attenuation effects in the atmosphere by the CIC method. Figure 2 shows the energy spectra of electron-rich and electron-poor reconstructed by using the Y_{CIC} selection, where the corresponding values of Y_{CIC} to the three models are applied. The optimal separation value between light and heavy mass groups is $Y_{CIC} = 0.84$ for QGSJET-II-2 and SIBYLL 2.1, while 0.86 for EPOS 1.99. Even though different hadronic models would bring some different Y_{CIC} parameters, the shape and structures of the resulting energy spectra of these mass components present a similar tendency for three different interaction models. In the spectrum of the electron-poor events (i.e. the spectrum for heavy primaries), a knee-like feature shows up at about 90 PeV for all three cases. Further detailed analyses are currently being performed.

5. Conclusion

The influences of the different hadronic interaction models on the reconstructed all-particle energy spectrum were investigated by performing the reconstructed charged particle shower size method, based on simulations with the hadronic interaction models QGSJET-II-2, EPOS 1.99 and SIBYLL 2.1. For the all-particle energy spectrum, the flux differences of EPOS 1.99 and SIBYLL 2.1 with respect to QGSJET-II-2 are about 15% and less than 10%, respectively. The spectral shapes are in reasonable agreement for the three interaction models.

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