TARGET 2.2 – a hadronic interaction model for studying inclusive muon and neutrino fluxes

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Abstract

We present a new version of the hadronic interaction model TARGET which includes a model for baryon pair production, an explicit simulation of target nucleons, and updated leading baryon distributions. As an example for a typical application the inclusive muon flux prediction calculated with TARGET is compared to recent L3 measurements.

1. Introduction

The Monte Carlo event generator TARGET [12],[9] is ideally suited to investigate the role of hadronic particle production in atmospheric neutrino and muon flux calculations. In contrast to more sophisticated models such as DPMJET [16] and FLUKA [10] it is based on parametrizations of accelerator data and a minimum number of additional model assumptions. TARGET is designed to optimally simulate particle production in phase space regions important for inclusive neutrino and muon flux predictions [8]. Due to its intrinsic simplicity TARGET is a very flexible model that can be easily tuned to existing and new data.

In the following we summarize improvements recently implemented in the code (TARGET version 2.2) and compare it with the measurement of the inclusive atmospheric muon flux by the L3 Collaboration [17]. The previous version of the model, TARGET 2.1, is described in [9] and compared to other models in [14].

2. New features in TARGET

TARGET as an event generator primarily intended for calculation of lepton fluxes in the GeV energy range is constructed to simulate all relevant physics processes of nucleon-, pion- and kaon-air interactions in the energy range from 1 to several 100 GeV. In this energy range the production of baryon-antibaryon pairs, such as p-$\bar{p}$, is kinematically suppressed. However, it becomes increasingly

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important at high energy. To make the high-energy extrapolation more reliable we implemented the simulation of baryon-antibaryon pair production. Fig. 1 shows the TARGET results on the mean antiproton production multiplicity in p-air collisions. The data points are measurements from p-p collisions. The small shift of the threshold energy between the TARGET curve and the p-p data is due to the Fermi motion of the nucleons in the nucleus. In addition the total multiplicity is slightly higher in p-air collisions since, on average, more than one target nucleon participates in the scattering, sharing the total energy available. The momentum distribution of the nucleons is sampled using an updated version of the inclusive differential cross section given in [11].

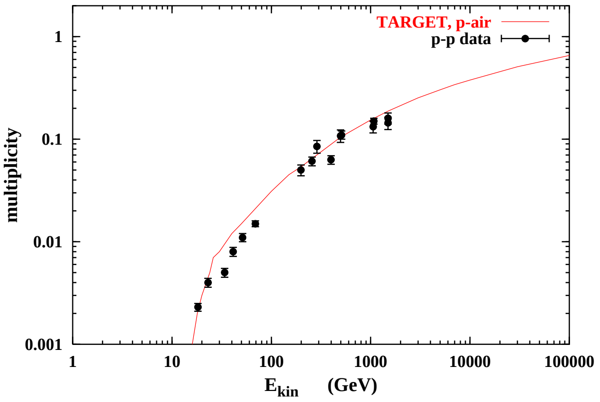

Fig. 1. Antiproton production multiplicity – TARGET results are compared to p-p data [1].

For tuning TARGET to forthcoming data from virtually 4π acceptance experiments such as HARP [2] the simulation of target fragmentation effects is needed. Previously only leading nucleon production was considered in p/n-air collisions, however, accounting for the participating nucleon recoil energy. In the new version of TARGET both the participating target nucleons and the associated slow (diffractive) pion production are simulated, employing the same distributions as used for leading particle production. In addition, improved parametrizations of the leading proton and neutron distributions were implemented. A comparison of the leading nucleon distribution in p-air collisions to NA49 data on 158 GeV p-p collisions [5] is shown in Fig. 2. The NA49 data were slightly rescaled to ensure that the sum of protons and neutrons equals unity. As expected the leading proton distribution is somewhat harder in p-p collisions than p-air interactions. In Fig. 2 the model is compared with p-Be data at 24 GeV [6], finding good agreement.

3. Inclusive atmospheric muon flux at high energy

A comparison of TARGET predictions to the low-energy muon flux measurement of CAPRICE98 [4] can be found in [3]. Here we will compare the new version of TARGET to L3 data [17].

One important input to any such calculation is the primary cosmic ray spectrum. In Ref. [13] different primary flux measurements are compared and a

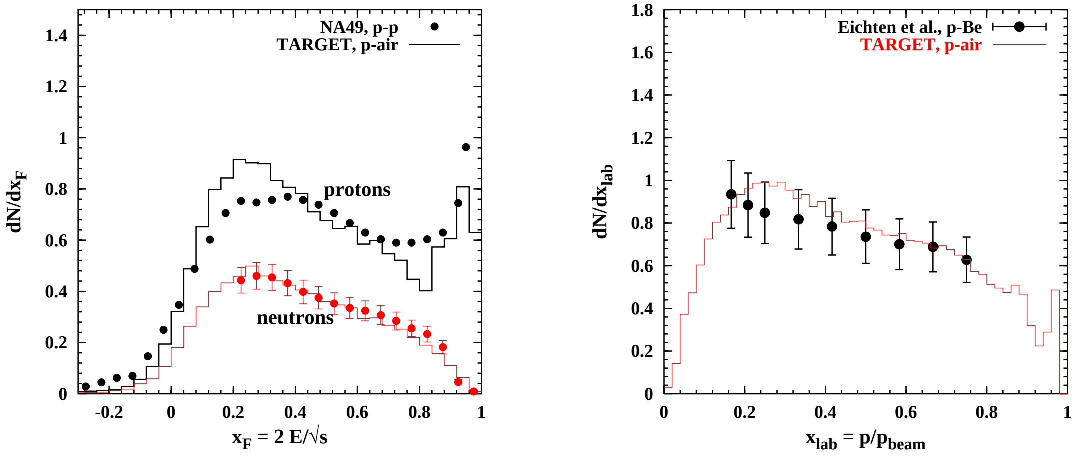

Fig. 2. Comparison of TARGET predictions to different measurements of nucleon distributions (see text).

flux parametrization, covering a wide energy range, is given. The results discussed in the following are based on this parametrization and have to be rescaled if one adopts, for example, the CAPRICE98 flux measurement [4]. Fig. 3. shows

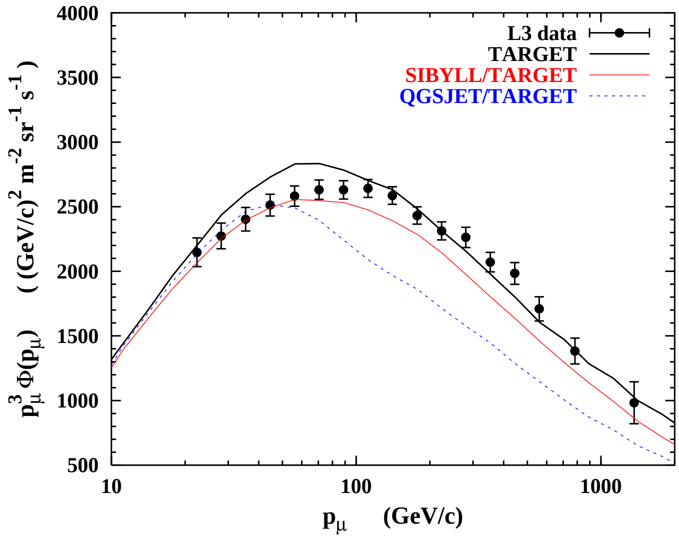

Fig. 3. Comparison of inclusive muon flux predictions to L3 data [17]. Shown are calculations using QGSJET 98 [15], SIBYLL 2.1 [7] and TARGET as high-energy hadronic interaction model.

muon flux predictions obtained with different model combinations together with L3 data. In the simulations all interactions at energies below 200 GeV were simulated with TARGET. The curves labeled SIBYLL and QGSJET refer to simulations in which TARGET was replaced by the respective model for collisions at higher energies. Therefore one expects the differences due to the interaction models to be fully visible only at energies greater than $\sim 100\,\mathrm{GeV}$. It is known that QGSJET gives a good description of the muon production in extensive air showers (EAS) in the primary energy range $10^{14} - 10^{16}$ eV. Furthermore, SIBYLL predicts in general fewer muons in EAS than QGSJET. However, in the case of inclusive muon production different regions of the secondary particle phase space are important and the situation is the opposite.

4. Conclusions

Inclusive muon flux measurements provide important cross checks of the reliability of hadronic interaction models. They are complementary to muon measurements in EAS. The comparison with L3 data shows that the TARGET model gives a good description of the inclusive high-energy muon flux. SIBYLL 2.1 provides a similarly good description of the L3 data.

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