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Production of $K^{\pm}$ charged particles spectra with cosmic ray models simulation

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The purpose of this analysis is to conduct a simulation study and evaluate the performance of a few hadronic interaction models in the production of $K^{\pm}$ charged particles measured by the ALICE experiment in proton-proton collisions at $\sqrt{s} = 900$ GeV using modified Hagedorn function with embedded transverse flow velocity. Simulation models in this analysis are widely used to describe the propagation of cosmic air showers in the atmosphere. Among the employed hadronic interaction models, we present results from the EPOS-LHC, Pythia, QGSJETII-04, and Sibyll models, as they are widely used and able to achieve good agreement with experimental data. Up to about 1.3 GeV/c, EPOS-LHC and Sibyll show a good prediction of the data, while Pythia, QGSJETII-04 underestimate the data over the entire energy range.

Keywords: Air shower simulation; hadronic interactions; cosmic rays; strange hadrons; proton-proton collisions

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1. Introduction

The hadron production process is considered as important in the interaction and propagation of cosmic ray particles in the atmosphere. In addition, hadron production is being used in nuclear and particle physics. Therefore, further studies of the related parameters such as the transverse momentum (p_T), rapidity (y) and pseudo-rapidity (η), yield, and angular distributions can be used in event generators processes (i.e. interaction, correlation, hadronization of partons, and final state effects [1]). The study of transverse momentum spectra in heavy ion collision has been widely considered as an important approach to further understanding the properties of medium effect, including final state effects, yield, and spectral shape of hadrons [2, 3].

Furthermore, many statistical theoretical models such as Tsallis distributions [4, 5], Blast-wave model [6], and Erlang distribution [7], have been used to study the transverse momentum spectra of charged particles. Additionally, these models can be used to fit the data and extract some physical quantities such the transverse flow velocity $< \beta >$, kinetic freezeout temperature T_0, and effective temperature T_{eff}, etc. by incorporating additional functions such as the Hagedorn function with transverse flow [8, 9], which are very useful parameters to help us understand the interacting system at different stages.

In this paper, we conduct a simulation study with four hadron production models and compare the results to the measurement of charged kaons in pp collisions at 900 GeV by the ALICE experiment [10]. In addition, we use the Hagedorn function with the embedded transverse flow velocity to fit the data and extract some parameters such as T_0 and $< \beta_T >$.

2. Methodology and models

The transverse momentum distributions (p_T) of $K^{\pm}$ have been reported by many high-energy experiments, and at different energies, such as the ALICE experiment where charged particles are produced at $\sqrt{s} = 900$ GeV in the transverse momentum range between 0.1 and 2.5 GeV/c and pseudorapidity of $\eta < 0.5$ [10]. Our aim in this work is to analyze the p_T distributions of $K^{\pm}$ using Monte Carlo simulations and compare them to the experimental data from ALICE. Several hadronic interaction models are used in the simulation such as EPOS-LHC, Pythia, QGSJETII-04, and Sibyll. An overview of these models is given below:

EPOS-LHC: EPOS is a parton simulation model that uses a multiple scattering quantum mechanical approach widely used by many particle accelerators. The model is also widespread in simulating the hadronic interactions of high-energy cosmic rays. The simple parton model using the theory of Reggie-Gribov is the basis of the model, and the interactions in soft, semi-hard, and hard scattering are described with the exchange Pomerons. The model was upgraded to EPOS-LHC to account for the energy of the LHC, which considers data with a transverse momentum up to several GeV/c [12].

PYTHIA: The Pythia8 model is a simulation model that is based on partons interaction and parton showers, and it uses the Lund string fragmentation model for hadronization [13–15]. It is widely used to describe the proton-proton interactions in high-energy particle collisions, where many physics processes are considered such as QCD scattering (diffractive, elastic, electroweak,

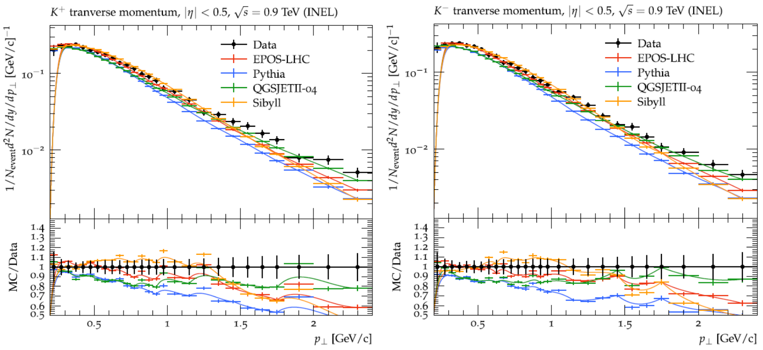

Figure 1: Transverse momentum spectra p_T of the positive and negative charged kaons ($K^{\pm}$ produced in pp collision at 900 GeV. Colorful lines represent the data from the simulation models as shown in the legend, while experimental data points are presented with black circles. The ratio between the simulation and data is also presented in the lower panel.

hard, and soft), and top quark production. Several versions are available of this model, and we use PYTHIA8.309 in our simulation [16], and it will called later PYTHIA.

QGSJETII-04 is an event generator built upon the quark-gluon string and Gribov Reggoen theories [17, 18]. A cutoff threshold is considered to distinguish between soft and hard interactions, which simultaneously contribute to the QGSJET model. Elastic scattering originates from soft interactions and accounts for a non-perturbative parton cascade. On the other hand, the exchange of a pair of soft Pomerons leads to the production of a "semi-hard" Pomeron with a parton ladder [19]. The effect of Pomerons is dominant at high energies producing a huge number of interactions.

Sibyll: This model is commonly used in the simulation of the hadronic interactions of high-energy cosmic rays, which requires a detailed description of cosmic ray particles and their propagation in the atmosphere [20]. SYBILL2.3d used the dual parton model (DMP) [21], mini-jet model [22, 23], and the Lund Monte Carlo algorithms [24, 25] to account for the soft interactions and particle hadronization. For simplicity, the model will be called Sibyll in the rest of the paper.

Furthermore, the modified Hagedorn function is used to fit the p_T spectra of $K^{\pm}$ [8, 11]:

$$\frac{d^2N}{N_{ev}dp_Tdy} = 2\pi p_T C \left(1 + <\gamma_T> \frac{m_T - p_T <\beta_T>}{nT_0}\right)^{-n}, \tag{1}$$

where C is the normalization constant, T_0 is the kinetic freezeout temperature, β_T is the average flow velocity. Such fit is useful to extract several parameters such as the kinetic freeze-out temperature (T_0) and average transverse flow velocity (β_T), and compare them between the data and simulations.

3. Results and discussion

In this section, we compare the transverse momentum distributions of $K^{\pm}$ charged particles obtained from Monte Carlo simulations to the experimental data from the ALICE experiment in the p_T range of (0.1–2.5) GeV/c and pseudorapidity $|\eta| < 0.5$ in pp collisions at $\sqrt{s} = 900$ GeV. In Figure 1, the experimental data is plotted in solid black markers, while the predictions of the simulation models EPOS-LHC, Pythia, QGSJETII-04, and Sibyll are shown in lines with different

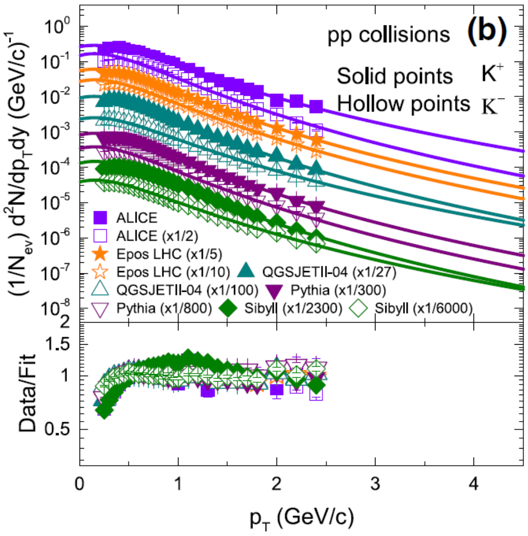

Figure 2: Result of the fit function on the transverse momentum spectra of charged kaons produced in pp collision at 900 GeV obtained from experimental and simulation data. Filled and empty markers represent positive and negative kaons, respectively, while colored lines show the fit results using Eq. 1.

colors, red, blue, green, and orange colors, respectively. Error bars in simulation models represent the statistical uncertainties, while they represent statistical and systematic uncertainties added in quadrature in the experimental data. Furthermore, the lower panel of the figure is added to present the ratio of the spectra between simulation and data. It can be seen from Figure 1 that, up to about 1.4 GeV/c and within error bars, EPOS-LHC and Sibyll show a good description of the data, while QGSJETII-04 and Pythia underestimate the data over the entire energy range. QGSJETII-04 shows a better prediction for K^{-}.

The results of the fit curves with Equation 1 on the transverse momentum distribution of charges kaon particles are shown in Figure 2, We find the Hagedorn function fits the experimental data very well. The ratio between the data and the fit function results, in the lower panel, is around unity except below 0.5 GeV/c. Additionally, we can extract the transverse flow velocity $< \beta_T >$ and freezeout temperature T_0 from the free parameters of the fit function. It is useful to conduct the analyses for other charged particles such as $\pi^{\pm}$ and $pp^{\cdot}$ and study the dependence of these parameters on the mass of the particles.

4. Conclusions and outlook

A prediction of the transverse momentum spectra of kaon charges particles, obtained from a few simulation models (i.e. EPOS-LHC, Pythia, QGSJETII-04, and Sibyll), is compared to measured data from the ALICE experiment. The analysis is conducted in a transverse momentum window of $p_T = 0.1 - 2.5$ GeV/c at $\sqrt{s} = 900$ GeV and pseudorapidity $\eta < 0.5$ in pp collisions. We observed that EPOS-LHC and Sibyll models were able to reproduce the kaon spectra up to about 1.3 GeV/c. On the other hand, an underestimation of the data is found in the case of QGSJETII-04 and Pythia, with increasing discrepancy with larger p_T. In addition, the Hagedorn function is used to fit transverse momentum spectra and showed a good agreement except below 1.5 GeV/c. The transverse flow velocity and freezeout temperature can be extracted from the free parameters of the fit function and can be used in future analyses for comparison with results from other charged particles.

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