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Meson Spectra in p + p Collisions at LHC

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Abstract

The p + p (proton + proton) collisions are important to understand particle production mechanism in partonic collisions and are also used as baseline for heavy ion collisions. We present systematic study of meson spectra in p + p collisions at LHC energies ($\sqrt{s}$ = 0.9, 2.76 and 7.0 TeV). We also studied the transverse mass (m_T) spectra of pion and kaon for p + p collisions at all above mentioned energies. In an earlier study [1], it was shown that all the mesons produced in p + p and d + Au collisions at $\sqrt{s_{NN}}$ = 200 GeV follow m_T scaling while in Au + Au collisions at same energy the mesons with strange and charm quark contents do not follow m_T scaling which can be attributed to medium modifications. Here we fit all pion spectra with Hagedorn distribution and extract all the output parameters from the fitting. Then we fit kaon spectra using m_T scaling with the help of those extracted fitting parameters along with a normalizing factor. We observed that m_T scaling in case of kaon is valid in p + p collisions at LHC energies. The normalizing factor of kaon with respect to pion (K/π) is almost constant in all energies . This study is important for the observation of strangeness enhancement in heavy ion collisions, which is an important probe of quark gluon plasma (QGP). It is also used as a baseline for the study of medium modifications in heavy ion collisions. Kaon spectra provides a unique opportunity to identify new flavor and CP violating interactions beyond the Standard Model (SM).

Keywords: LHC, Hagedorn Function, Meson Spectra.

1. Introduction

The Large Hadron Collider (LHC) [2] is a particle collider located at CERN, near Geneva, Switzerland. It is world's largest and highest energy particle accelerator. The LHC is built in the old Large Electron Positron (LEP) collider tunnel which is of circumference approximately 27 Km. There are four large experiment detectors located around the LHC beam pipe. Two of them, CMS and ATLAS, are general multi-purpose detectors and are placed diagonally opposite corners of the LHC. These two experiments aim for exploring the Higgs sector, possible new physics as well as performing the measurements of the standard model parameters. The LHC-b experiment is a dedicated experiment for studying B-Physics. The ALICE experiment is designed to study the quark gluon plasma in the heavy ion collisions. Here we take the p + p collisions data from CMS (Compact Muon Solenoid) experiment [3] in various center of mass energies to perform our study on meson spectra.

The meson spectra provide insight into the particle production mechanism [4] and interaction in the hadronic and Quark Gluon Plasma (QGP) phases. The detailed study of systematics of meson spectra is also important because it acts as an ingredient for estimating the hadronic decay backgrounds in the photon, single lepton and dilepton

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spectra. Measurements of transverse momentum spectra for particles emerging from p + p collisions are used as a baseline to which similar measurements from heavy ion collisions are compared. In addition, several observations from p + p collisions, such as the p_T spectra with particle mass are interesting in their own right. WA80 collaboration [5] found that the spectral shapes of pion (π) and eta (η) mesons are identical when plotted as a function of m_T. This property is known as m_T scaling and has been extremely useful to obtain the unknown meson spectra. In this work, we used m_T scaling to obtain the spectra of kaon from a given pion spectrum. We parameterize pion spectra first and then obtained the spectra of kaon using m_T scaling. The agreement of the m_T scaled and experimental data shapes are excellent in case of kaon and their fitted relative normalization gives ratio of kaon to pion m_T spectra. These ratios are useful to obtain the hadronic decay contribution in photonic and leptonic channels but also point to the quantitative changes in the dynamics of the heavy ion collision over p + p collisions.

2. Methodology

In this section, we describe the fitting procedure using m_T scaling, but before that we give an idea about the fit function used in our analysis. Hagedorn proposed this distribution function [6] to describe the data of invariant cross section of hadrons as a function of p_T over a wide range (0.3–10 GeV/c). The PHENIX collaboration [7–9] has used the modified form of this function to give a good description of pion spectra in wide p_T range. This formula has been extensively used for p + p, d + Au and Au + Au collisions [1] which in terms of m_T is given by:

$$E\,[d^3N/dp^3] = A\,[\exp(-am_T - bm_T^2) + m_T/p_0]^{-n} = f_\pi\,[p_T^2 + m_\pi^2]^{1/2} \quad (1)$$

which is close to an exponential form at low P_T or m_T and a pure power law form at high P_T or m_T. f_π is the pion fit function, m_π is the rest mass of pion and A, a, b, p_0 and n are the fit parameters. Then we obtain the spectra of kaon ($K^\pm$) using pion fit function as:

$$E\,[d^3N/dp^3] = S\,f_K\,[p_T^2 + m_K^2]^{1/2} \quad (2)$$

where f_K is the kaon fit function, m_K is the rest mass of kaon ($K^\pm$). The factor S is the relative normalization of the kaon m_T spectrum to the pion m_T spectrum which we obtain by fitting the experimentally measured kaon spectrum. We use pion fit function to obtain the m_T spectra of kaon ($K^\pm$).

Here we use all the data of pion and kaon from the CMS experiment [2] at LHC [1]. Both the data of pion and kaon are taken within the unity rapidity range (i.e., $|y| < 1.0$) of CMS detector. The errors on the data are quadratic sums of statistical and uncorrelated systematic errors wherever available.

Table 1. Hagedorn fitting parameters at different center of mass energies

Fitting Parameters	Center of mass energy(√s) 0.9 TeV	2.76 TeV	7.0 TeV
A	22.91 ± 0.98	25.03 ± 2.33	34.64 ± 3.10
a	0.307 ± 0.105	0.025 ± 0.002	0.001 ± 0.0002
b	0.421 ± 0.078	0.1003 ± 0.051	0.201 ± 0.12
p_0	0.568 ± 0.014	2.392 ± 1.269	1.145 ± 0.42
n	6.54 ± 0.02	10.40 ± 0.34	11.07 ± 0.52

3. Results and Discussions

Figure 1 shows the (average) invariant yield of charged pion ($\pi^\pm$) and charged kaon ($K^\pm$) as a function of (m_T – m) for p + p collision at $\sqrt{s}$ = 900 GeV. It is convenient to replace m_T by (m_T – m) for comparing particles of different masses and also to include collective effects. Figure 2 and Figure (3) shows the (average) invariant yields of $\pi^\pm$, $K^\pm$ as a function of (m_T–m) for p+p collision at $\sqrt{s}$ = 2.76 TeV and 7 TeV respectively. Here we have used the average yields of charged pion and charged kaon in our case.

In case of pion, the solid line is the modified Hagedorn function curve which is used to fit the pion data. The corresponding fit parameters of pion are given in Table 1. Here in the fitting, the parameters "a" and "b" governs the lower m_T region and the parameters "p_0" and "n" governs the higher m_T region, the parameter "A" is an adjusting parameter in both the cases. In case of kaon, the solid line is obtained from pion fit function using m_T scaling; the relative normalization has been used to fit the kaon spectra. The relative normalization for kaons are given in Table 2.

Table 2. Relative normalization (S) of kaon w.r.t. pion (K/π) at different center of mass energies

Center of mass(√s) energies	Relative Normalization (S) of kaon w.r.t pion (K/π)
0.9 TeV	0.406 ± 0.003
2.76 TeV	0.393 ± 0.003
7.0 TeV	0.370 ± 0.003

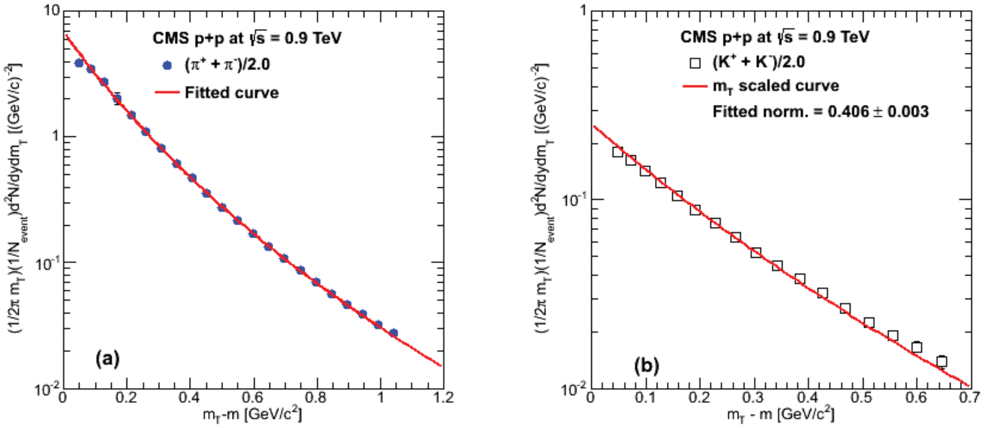

Figure 1. The invariant yield of (a) pion $(\pi^+ + \pi^-)/2$ and (b) kaon $(K^+ + K^-)/2$ as a function of $(m^T - m)$ for p + p collisions at $\sqrt{s} = 0.9$ TeV.

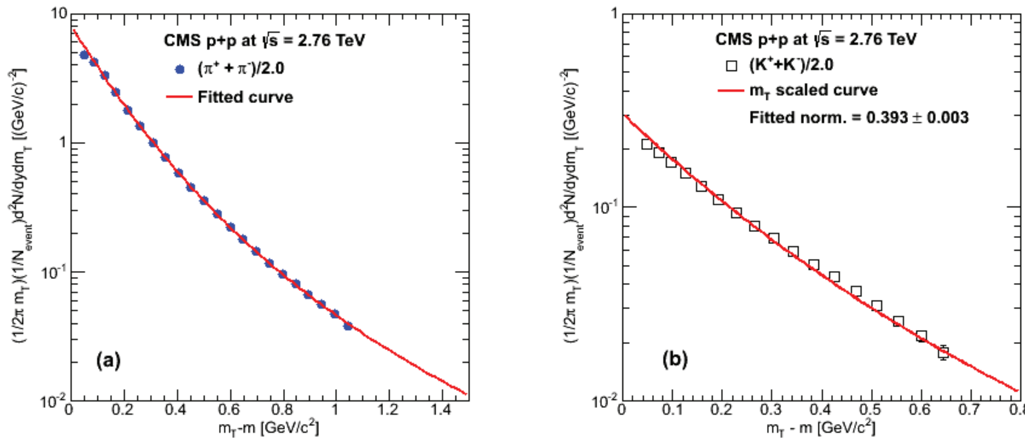

Figure 2. The invariant yield of (a) pion $(\pi^+ + \pi^-)/2$ and (b) kaon $(K^+ + K^-)/2$ as a function of $(m^T - m)$ for p + p collisions at $\sqrt{s} = 2.76$ TeV.

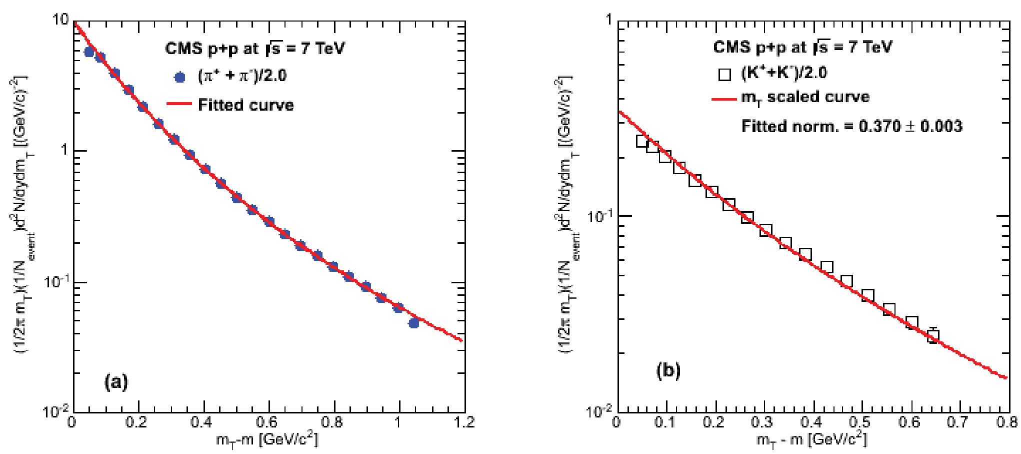

Figure 3. The invariant yield of (a) pion $(\pi^+ + \pi^-)/2$ and (b) kaon $(K^+ + K^-)/2$ as a function of $(mT - m)$ for p + p collisions at $\sqrt{s} = 7.0$ TeV.

Here we observe that, there is a good agreement between the m_T scaled and experimental data shape of kaon. So we can say that m_T scaling is valid in case of p + p collisions at LHC. The values of relative normalization (S) of kaon (K/π) are almost constant throughout all the LHC energies. But if we strictly observe, then we will find that the relative normalizations of kaon (K/π) are decreasing with the increasing of center of mass energies (√s).

4. References

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