Spectra of Charged Pions, Kaons, and Protons Identified via Tracker Energy Loss from CMS

Ferenc Siklér[1] for the CMS Collaboration

[1]Wigner RCP, Budapest, Hungary

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Measured spectra of identified charged hadrons produced in pp collisions at $\sqrt{s} = 0.9$, 2.76, and 7 TeV are presented in the transverse momentum range $p_{\mathrm{T}} \approx 0.1$–1.7 GeV/$c$ at midrapidity ($|y| < 1$). The charged pions, kaons, and protons are identified using the measured energy loss in the silicon tracker and other track information. The fully corrected primary p_{T} spectra and integrated yields are compared to various tunes of the Pythia6 and Pythia8 event generators. The average p_{T} for pions, kaons, and protons increases rapidly with the mass of the hadron and the event charged-particle multiplicity, independent of the center-of-mass energy.

1 Introduction

The study of particle production in hadronic collisions has a long history in high energy physics, nuclear physics, and cosmic-ray physics. The measurement of particle spectra is important for studying the scaling properties of particle production and to test predictions of models and Monte Carlo event generators. Details of the analysis can be found in [1].

2 Data analysis

The CMS detector is described in [2]. Particle reconstruction is bounded by the acceptance of the tracker, while particle identification capabilities are limited to $p < 0.16$ GeV/c for electrons, $p < 1.20$ GeV/c for pions, $p < 1.05$ GeV/c for kaons, and $p < 1.70$ GeV/c for protons. The physics results will be presented in the range $-1 < y < 1$. The statistical uncertainties of the measurement are negligible.

The selected event sample is corrected to a well-defined particle-level selection to ease comparison with generator-level predictions. In this study a double-sided (DS) selection was chosen. It is close to the actual hardware trigger and software selections: at least one particle with $E > 3$ GeV on each side ($-5 < \eta < -3$ and $3 < \eta < 5$). According to several Pythia tunes, the overall efficiency of this double-sided selection to the total inelastic cross-section is about 66-72% (0.9 TeV), 70-76% (2.76 TeV), and 73-78% (7 TeV). Mostly non-diffractive events are selected, but a smaller fraction of single- or double-diffractive events are accepted as well.

The special tracking and the agglomerative vertex-reconstruction algorithm used in the analysis are the same as for the previous papers on unidentified spectra [3, 4] which provides high reconstruction efficiency with low background rate.

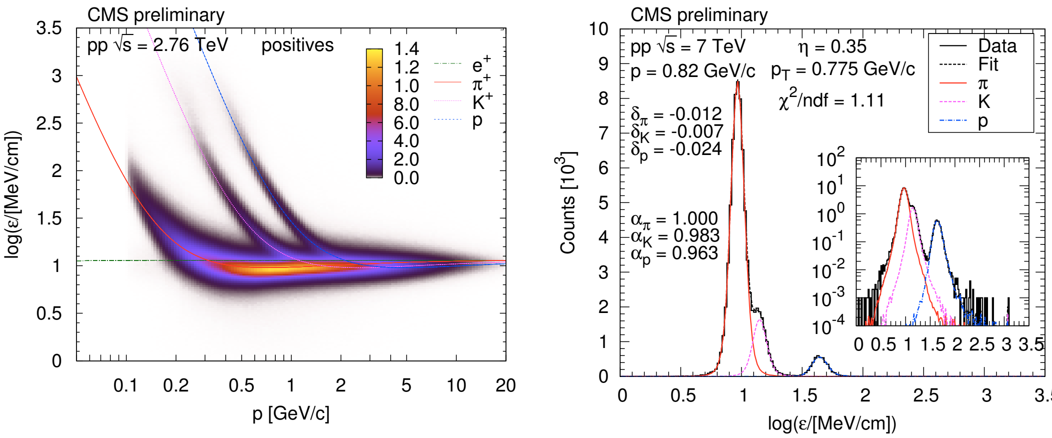

Figure 1: Left: Distribution of $\log \varepsilon$ values as a function of total momentum p in case of the 2.76 TeV dataset, for positives particles. Right: Example $\log \varepsilon$ distribution for the 7 TeV inclusive dataset. The curves are the results of template fits.

The silicon layers are thin and the individual energy deposits are not Gaussian-distributed but show a long tail of higher values. The energy loss of charged particles in silicon can be approximated by a simple analytical model [5]. It gives the probability density $p(y|\varepsilon, l)$ of energy deposit y, if the *most probable energy loss rate* ε at a reference path length of l_0, and the path length l inside the silicon are known. In this analysis the model is used in connection with maximum likelihood estimation to calibrate the gain of the detector elements, in our case the readout chips, and is applied to the energy loss rate estimation of tracks (Fig. 1). For details see [1].

3 Results

In previously published measurements of unidentified and identified particles, the following form of the Tsallis-Pareto-type distribution [6, 7] was used:

$$\frac{d^2N}{dy dp_{\mathrm{T}}} = \frac{dN}{dy} \cdot C \cdot p_{\mathrm{T}} \left[1 + \frac{(m_{\mathrm{T}} - m)}{nT}\right]^{-n}$$

where C is a normalization constant, and $m_{\mathrm{T}} = \sqrt{m^2 + p_{\mathrm{T}}^2}$. The above formula is a useful parametrization of the data for extrapolating the spectra to $p_{\mathrm{T}} = 0$ and for obtaining $\langle p_{\mathrm{T}} \rangle$ and dN/dy.

The fully corrected transverse momentum distributions of positive and negative hadrons (pions, kaons, protons) are shown in Fig. 2, plotted with fits to the Tsallis-Pareto parametrization. Comparisons to Pythia tunes show that tunes D6T and 4C are systematically below or above the spectra, whereas Z2 is generally closer to the measurements (except for low-p_{T} protons). The ratios of oppositely charged particles are around one as expected for pair-produced particles at midrapidity.

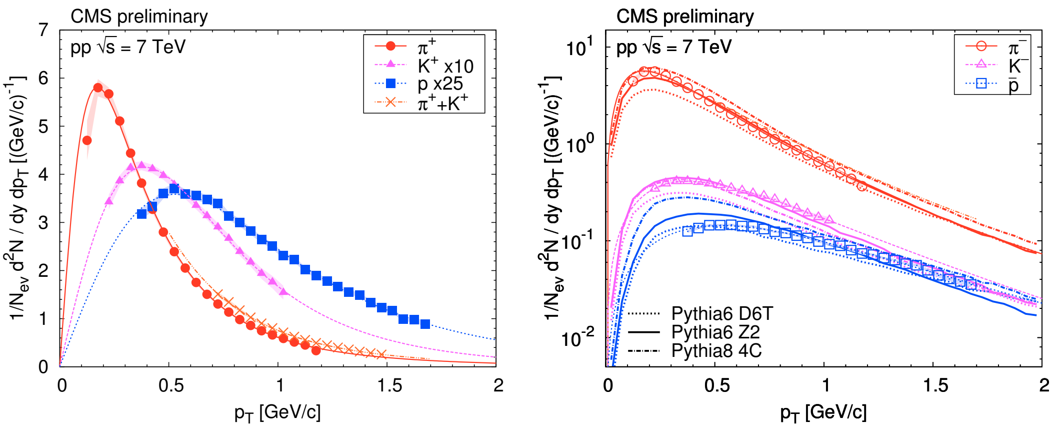

Figure 2: Transverse momentum distributions of identified charged hadrons (pions, kaons, protons) in the range $|y| < 1$, for positives (left) and negatives (right), at $\sqrt{s} = 7$ TeV. Kaons and protons are scaled as shown. Fits to Eq. (3) or predictions of Pythia tunes are superimposed.

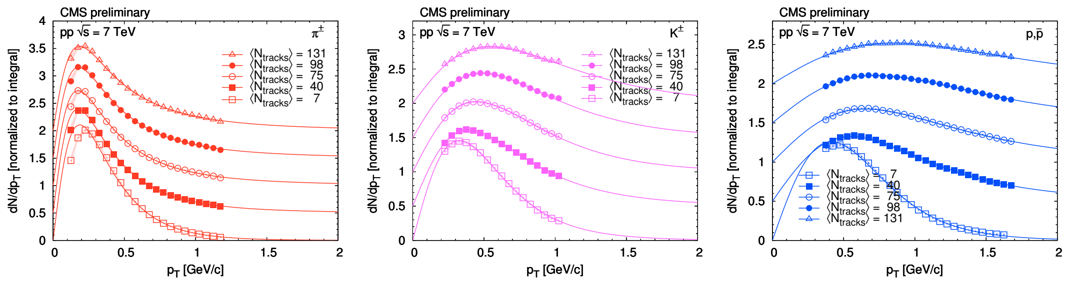

Figure 3: Normalized transverse momentum distributions of charged pions, kaons, protons in a few representative multiplicity classes, in the range $|y| < 1$, at $\sqrt{s} = 7$ TeV, fitted to the Tsallis-Pareto parametrization (solid lines). For visibility, the values with increasing multiplicity are successively shifted by 0.5 units along the vertical axis.

The study of the multiplicity dependence of the various observables considered here is motivated by the intriguing hadron correlations observed in pp collisions at high track multiplicities [8]. To this end, 12 event classes are defined, according to the number of reconstructed particles. In order to facilitate comparisons with models, the corresponding true track multiplicity in the range $|\eta| < 2.4$ (N_{tracks}) was determined from models. Normalized transverse momentum distributions of identified charged hadrons in selected multiplicity classes, in the range $|y| < 1$, at $\sqrt{s} = 7$ TeV are shown in Fig. 3. In case of pions the distributions are remarkably similar, in practice independent of $\sqrt{s}$ and multiplicity. For kaons and protons there is a clear evolution as the multiplicity increases.

Ratios of particle yields as a function of multiplicity in $|\eta| < 2.4$ reveal that K/π and p/π ratios are flat as a function of N_{tracks}. The universality of $\langle p_{\text{T}} \rangle$ and particle ratios versus track

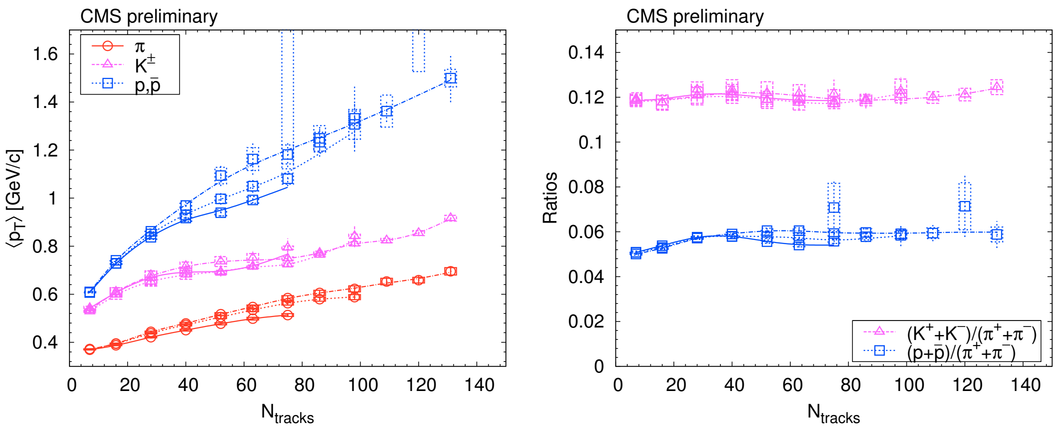

Figure 4: Left: Average transverse momentum of identified charged hadrons (pions, kaons, protons) in the range $|y| < 1$, for all particle types. Right: Ratios of particle yields. Both plots are given as a function of particle multiplicity in $|\eta| < 2.4$.

multiplicity, independent of the collision energy, is demonstrated in Fig. 4.

4 Summary

Measured spectra of identified charged hadrons produced in pp collisions at $\sqrt{s} = 0.9$, 2.76, and 7 TeV were presented. The obtained p_{T} spectra and integrated yields were compared to models. The multiplicity dependence of the rapidity-density and the average transverse momentum indicates that particle production at LHC energies is strongly correlated with event multiplicity rather than with the center-of-mass energy of the collision. This correlation can have a common deeper reason: at TeV energies, the characteristics of particle production in hadronic collisions are constrained by the amount of initial parton energy that is available in any given collision.

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