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Measurement of hadron composition in charged jets from pp collisions with the ALICE experiment

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Abstract

We report the first measurement of charged pion, kaon and (anti-)proton production in jets from hadron colliders. The measurement was carried out with the ALICE detector using 2×10^8 minimum bias pp collisions at a centre-of-mass energy of $\sqrt{s} = 7$ TeV at the LHC. We present the π, K and p transverse momentum (p_{T}) spectra, as well as the spectra of the reduced momentum ($z^{\mathrm{ch}} \equiv p_{\mathrm{T}}^{\mathrm{track}}/p_{\mathrm{T,jet}}^{\mathrm{ch}}$), in charged jets of p_{T} between 5–20 GeV/c. The measurement is compared to Monte Carlo calculations.

Keywords: Pion/kaon/proton; Identified hadron production; Jet; Fragmentation

1. Introduction

Jets are phenomenological objects constructed to represent partons originating from hard scattering processes. Recently, neutral fragments in jets have been studied by the CDF Collaboration [1]. However, knowledge of jet fragmentation to charged hadrons currently is only constrained by data from e^+e^- colliders [2,3]. The particle identification (PID) capabilities of the ALICE experiment [4] at the LHC with sophisticated statistical techniques allow to identify charged pions, kaons and (anti-)protons in jets at hadron colliders for the first time.

The Time Projection Chamber (TPC) [5] is the main PID device of ALICE with the specific energy loss ($\mathrm{d}E/\mathrm{d}x$) resolution in pp collisions of 5–6%. The measurement presented here

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[1] A list of members of the ALICE Collaboration and acknowledgements can be found at the end of this issue.

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follows the same analysis strategy as the previous ALICE measurement of the inclusive charged particle production in charged jets [6] and explores in addition the TPC performance limit for the challenging PID in jets.

2. Analysis details

This analysis is based on a minimum bias (MB) data sample of 2×10^8 pp collisions at a centre-of-mass energy of $\sqrt{s} = 7$ TeV collected with the ALICE detector. Charged tracks of transverse momentum $p_{\mathrm{T}}^{\mathrm{track}} > 0.15$ GeV/c in the pseudo-rapidity range $|\eta^{\mathrm{track}}| < 0.9$ are reconstructed with the ALICE Inner Tracking System (ITS) and the TPC. They are then grouped into charged jets with the anti-k_{T} algorithm implemented in the FastJet [7] package and with a resolution parameter $R = 0.4$. Charged jets of transverse momentum $p_{\mathrm{T,jet}}^{\mathrm{ch}}$ in three regions 5–10, 10–15, 15–20 GeV/c are studied separately. The uncorrected differential yields of π, K and p in the jets are extracted using the TPC dE/dx information. The results are corrected for detectors effects, including tracking efficiency, track p_{T} resolution, jet p_{T} resolution, secondary particle and muon (fake pion) contamination. These corrections are based on the inclusive measurement in [6] taking into account particle species dependent effects. The following discussions focus on the method of the PID in jets.

The uncorrected differential yields of π, K and p are provided by the TPC Coherent Fit [8] which is a fitting program analysing the two-dimensional distribution of the TPC dE/dx signal vs. particle momentum (p). It determines the raw differential particle yields in p_{T} from 0.15 GeV/c to above 20 GeV/c with an accuracy on average better than 10% for the ALICE data in pp collisions. This method is based on the observation that the mean and width of the dE/dx distribution as well as the fractions of different particle species are all continuous functions of the particle momentum. Using models of dE/dx distributions, denoted as $s_k(p;\boldsymbol{\theta})$ with a set of *a priori* unknown parameters $\boldsymbol{\theta}$, for particle species k as a function of the particle momentum, a log-likelihood function l is built with additional parameters f_{ki} for the fraction of species k at momentum bin i. The expression for l reads

$$l = \sum_i l_i \left[\sum_k f_{ki} s_k(p_i;\boldsymbol{\theta}) \right], \tag{1}$$

where l_i is the log-likelihood function for the momentum bin i. The functional form of the particle fraction f_{ki} is not known, but a continuity condition in the particle momentum can be imposed by adding a regularisation term to Eq. (1) such that f_{ki} is only allowed to deviate statistically from the interpolated value from neighbouring momentum bins

$$l = \sum_i l_i \left[\sum_k f_{ki} s_k(p_i;\boldsymbol{\theta}) \right] + \sum_{k,i} l_{ki}^{\mathrm{reg}}(f_{ki}), \tag{2}$$

where the regularisation strength for each particle species and momentum bin contributes equally.[2] The parameters $\boldsymbol{\theta}$ and f_{ki} are determined using the maximum likelihood estimation with the full log-likelihood function (2) from the dE/dx vs. p distribution. This single optimisation procedure drives *coherently* the full-range constraint on the dE/dx models as well as the constraint on the particle fractions, performing the calibration of dE/dx and the particle yield extraction simultaneously.

[2] The regularisation term l_{ki}^{reg} is derived from a Gaussian likelihood and therefore has a proper statistical interpretation.

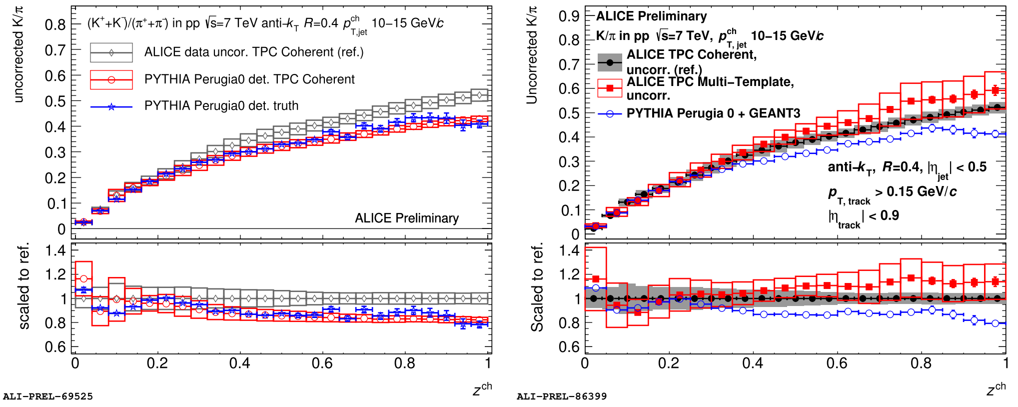

Fig. 1. Uncorrected K/π ratio for charged jet constituents as a function of $z^{\mathrm{ch}} \equiv p_{\mathrm{T}}^{\mathrm{track}}/p_{\mathrm{T,jet}}^{\mathrm{ch}}$ from data and MC (PYTHIA Perugia0). *Left*: uncorrected results from data and MC by the TPC Coherent Fit compared to the detector level MC truth. *Right*: uncorrected results from data by the TPC Coherent Fit and the TPC Multi-Template Fit compared to the detector level MC truth. The error bars are statistical errors and the error boxes represent systematic errors.

The challenge in PID using $\mathrm{d}E/\mathrm{d}x$ at high particle momentum ($p > 4$ GeV/c) is that the particle fractions are very sensitive to the mean of the $\mathrm{d}E/\mathrm{d}x$ distribution. For the ALICE pp collision data, the K–p separation is about 5% at high momentum, and consequently a 1‰ $\mathrm{d}E/\mathrm{d}x$ bias can induce a 2% bias in the particle fraction. Extensive examination of the systematics in the TPC Coherent Fit has therefore been performed, including the $\mathrm{d}E/\mathrm{d}x$ model uncertainties, the stability against the change of the $\mathrm{d}E/\mathrm{d}x$ quality, the possible particle species dependence of $\mathrm{d}E/\mathrm{d}x$ (which turns out to be negligible), and mostly critically, the jet p_{T} dependence of $\mathrm{d}E/\mathrm{d}x$ which is caused by an enhanced track density in jets.[3] The last source of systematics is specific to this analysis with respect to the general case of the identified particle production in inclusive MB data sample. The TPC Coherent Fit performs the $\mathrm{d}E/\mathrm{d}x$ calibration for different $p_{\mathrm{T,jet}}^{\mathrm{ch}}$ data samples separately and it was found that in these jet p_{T} regions the $\mathrm{d}E/\mathrm{d}x$ increases by 0.3% per 5 GeV/c $p_{\mathrm{T,jet}}^{\mathrm{ch}}$ increase. Because with the TPC Coherent Fit the $\mathrm{d}E/\mathrm{d}x$ parameters are automatically adjusted for each $p_{\mathrm{T,jet}}^{\mathrm{ch}}$ sample, no error arises from this effect. As a further verification of the systematic errors, the method is applied in an identical way also to Monte Carlo (MC) samples (PYTHIA [9] Perugia0 [10] tune) with the full ALICE detector simulation and reconstruction. As is shown in Fig. 1 (*left*), the uncorrected K/π ratio extracted by the TPC Coherent Fit from the MC sample is consistent with the detector level MC truth. In the same figure, the uncorrected ratio from data is also shown; it can be seen that MC deviates from the data beyond the systematic errors.

The TPC Coherent Fit is further cross-checked with an independent method – the TPC Multi-Template Fit, which generates templates of TPC $\mathrm{d}E/\mathrm{d}x$ distributions with the particle fractions as the only unknown parameters after predetermination of the $\mathrm{d}E/\mathrm{d}x$ distributions. In this method, the $\mathrm{d}E/\mathrm{d}x$ response up to intermediate momentum is determined in detail with pure particles selected from MB data samples via the TPC $\mathrm{d}E/\mathrm{d}x$, the Time-Of-Flight (TOF) signal and the decay products of $\mathrm{K}_{\mathrm{S}}^{0}$, Λ and γ. The response at high momentum is determined by the $\mathrm{d}E/\mathrm{d}x$

[3] This effect is quantitatively verified from an independent study using electron–positron pairs from γ-conversions and a realistic track density profile in jets provided by PYTHIA [9].

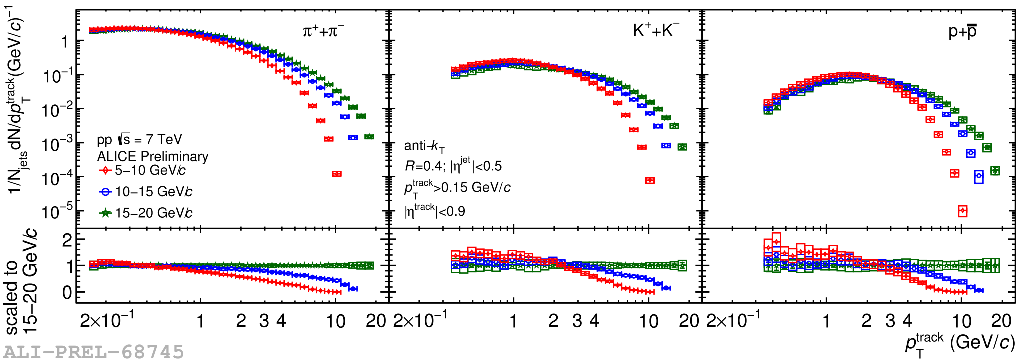

Fig. 2. Corrected p_T-spectra of π (*left*), K (*middle*) and p (*right*) in charged jets from pp collisions at 7 TeV. The spectra are shown for three different charged jet p_T ranges indicated by the legend.

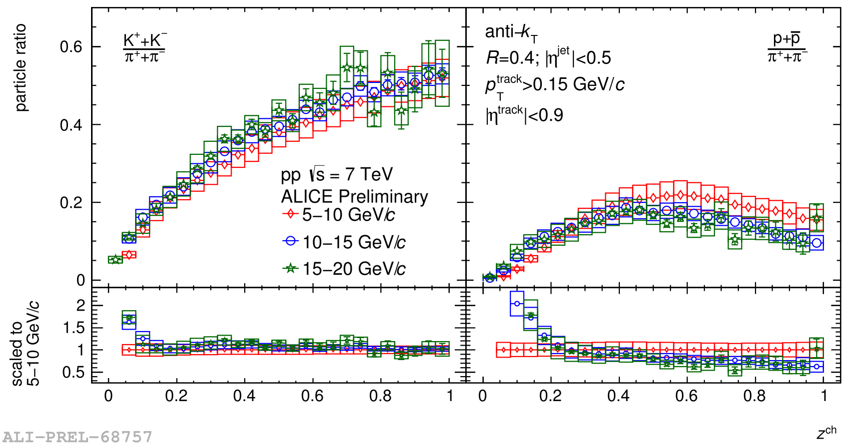

Fig. 3. K/π and p/π ratios as a function of z^{ch} for charged jet constituents from pp collisions at 7 TeV.

model fitting to the pure samples; the particle fractions are estimated by minimising the difference between the template and the data. The two methods have different sources of systematic uncertainties and, as shown in Fig. 1 (*right*), the results by both methods are consistent within the estimated systematic errors.

3. Results

The fully corrected p_T-differential yields per jet of π, K and p in charged jets are shown in Fig. 2 for the three jet p_T intervals. They drop over 3–4 orders of magnitude with increasing particle p_T. Larger $p^{ch}_{T,jet}$ gives rise to higher yields for high p_T particles, the ordering being reversed at around 0.4 (2) GeV/c for π (K and p).

The particle ratios K/π and p/π in charged jets as a function of the reduced momentum $z^{ch} \equiv p^{track}_T / p^{ch}_{T,jet}$ are shown in Fig. 3. The monotonic increase of the K/π ratio to 0.5–0.6 shows that the strangeness fraction in jets increases with z^{ch}, while the maxima of the p/π ratio at $0.5 < z^{ch} < 0.6$ indicate that leading baryon production in jets is suppressed. Comparing the

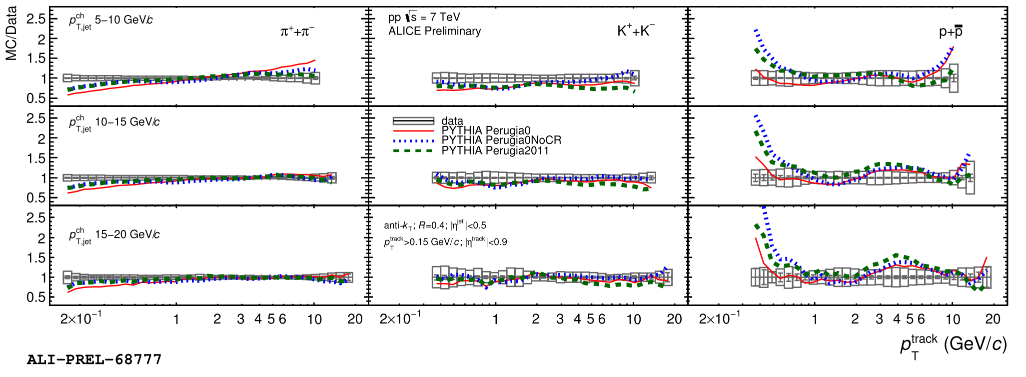

Fig. 4. Data-PYTHIA comparison for the particle p_T-spectra in charged jets from pp collisions at 7 TeV.

particle ratios for different jet p_T, we observe a z^{ch}-scaling at $z^{ch} > 0.2$ for K/π among $p_{T,jet}^{ch}$ 5–10, 10–15, 15–20 GeV/c and for p/π between 10–15 and 15–20 GeV/c.

The results are compared in Fig. 4 to three sets of PYTHIA [9] tunes, Perugia0, Perugia0NoCR (*CR* stands for *colour reconnection*) and Perugia2011 [10]. PYTHIA describes the p_T-spectra better at large $p_{T,jet}^{ch}$ for high p_T particles. The best agreement is obtained for kaons while PYTHIA undershoots (overshoots) low p_T pions (protons). The data are reproduced in general within 30% accuracy except for the low p_T protons for which the deviation goes up beyond 100% at around 0.4 GeV/c. In addition, PYTHIA reproduces the maxima of the proton spectra but fails to describe the width and the high p_T slope. Furthermore, of the tunes tested here, Perugia0NoCR gives the best description of the kaon spectra at $p_{T,jet}^{ch}$ 5–10 and 10–15 GeV/c.

4. Conclusions

We have presented the first measurement of jet fragmentation to charged hadrons at hadron colliders from ALICE. The yields of π, K and p in charged jets from pp collisions are extracted with advanced PID techniques. The results show that the strangeness fraction increases with z^{ch} while the leading baryon production is suppressed at high z^{ch}. PYTHIA simulations are able to reproduce the data within 30% accuracy with increasing tension at low p_T.

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