IL NUOVO CIMENTO Vol. 34 C, N. 2 Marzo-Aprile 2011
DOI 10.1393/ncc/i2011-10839-4

Colloquia: WISH2010

Particle production in pp collisions at 900 GeV and 7 TeV with ALICE

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(ricevuto il 17 Dicembre 2010; approvato il 29 Dicembre 2010; pubblicato online il 30 Marzo 2011)

Summary. — The ALICE experiment started studying pp collisions at the end of 2009. Pions, kaons, protons are identified using the excellent identification capability of the central barrel detectors over a wide momentum range, at central rapidity ($|y| < 0.5$). The ALICE detectors were designed to perform such a study by using the energy-loss dependence on momentum in the lower and intermediate p_t region and the time-of-flight measurement in the higher p_t region. Moreover, the kaon yield is also measured reconstructing the kaon decays through their kinks topology. A comparison between ALICE measurements and Monte Carlo predictions (using several models) is also reported focusing on the features of the observed p_t spectra.

PACS 13.85.-t – Hadron-induced high- and super-high-energy interactions (energy > 10 GeV).

1. – Introduction

The study presented here is based on the excellent particle identification capability of the ALICE detector applied for the first pp collisions at $\sqrt{s} = 900\,\text{GeV}$.

The ALICE detector is a dedicated heavy-ion experiment [1,2], designed to cope with the high particle multiplicities expected in central lead-lead collisions at $\sqrt{s} = 5.5\,\text{TeV}$. The central barrel (midrapidity) detectors of ALICE consist of a six-layer silicon detector (ITS), located 3.9–48.9 cm from the beam axis, a Time Projection Chamber (TPC) at 85–250 cm, a Transition Radiation Detector (TRD) for electron identification at 290–368 cm (not used in this analysis), and a Time-Of-Flight (TOF) detector at 370–399 cm. The detectors are located in a solenoidal magnetic field of $B = 0.5\,\text{T}$.

We report pion, kaon and proton identified via several independent techniques: specific energy loss, $\mathrm{d}E/\mathrm{d}x$, information from the ITS and/or the TPC, and TOF information at higher p_t. The combination of these methods provides particle identification over a transverse momentum range of $0.2\,\text{GeV}/c < p_t < 2.5\,\text{GeV}/c$. Charged kaons, identified via the "kink" topology of their weak decay in the TPC, provide a complementary measurement over a similar p_t range. All reported particle yields are for primary particles, meaning those directly produced in the collision including the products of strong and electromagnetic decays but excluding products from the weak decays of strange particles.

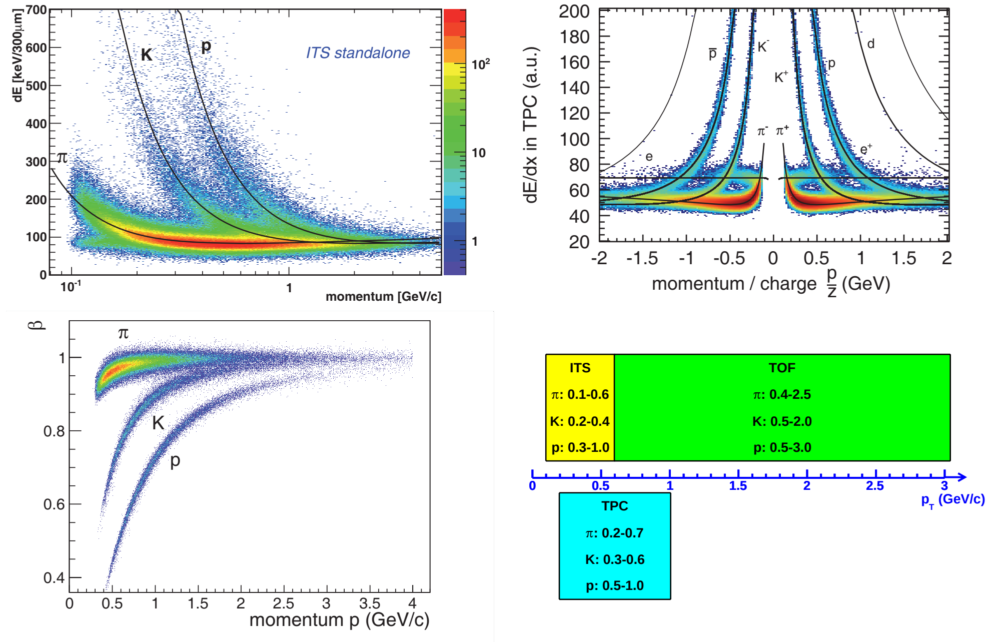

Fig. 1. – dE/dx *vs.* momentum and β *vs.* momentum plots for the ALICE subdetector (top, ITS and TPC; bottom, TOF) in the central barrel ($|\eta| < 0.9$). A sketch on the performance of combined Particle IDentification (PID) is also shown for $0.1 < p_t < 3\,\mathrm{GeV}/c$.

The data presented were collected during the commissioning of the LHC at CERN in the fall of 2009 with pp collisions. The energy of each beam was 450 GeV (*i.e.* injection energy). The collider has run with 4×4 bunches per beam, resulting in two-bunch crossing (BC) per beam circulation period (89 μs) at the ALICE interaction point. The remaining two bunches were passing through the ALICE detector and served to estimate the contribution of beam-gas interactions. The average rate was a few events per s and pile-up within one bunch crossing was, therefore, negligible. The analysis is based on a sample of ~ 300000 inelastic pp collisions.

2. – Particle identification performance: ITS, TPC, TOF

The PID (Particle IDentification) performance is one of the distinctive features of the ALICE experiment. The presence of many detectors partially or fully devoted to this task allows to identify particles in a wide range of momenta. The main performances of the central barrel detectors are presented in this section with the usual methods while other techniques are discussed in the following one.

The inner detector, ITS [3], tracks particles after few centimeters from the interaction point and it provides the information on the dE/dx for the track till very low momenta (namely 100 MeV/c). In fig. 1, upper left, the mean dE/dx for the sample of ITS standalone tracks is shown together with the parametrization of the Bethe-Bloch curve.

In the intermediate momentum region the TPC [4] represents the ideal detector to separate the different species. It provides a dE/dx measurement and the tracks release energy for a very long path length. The particle identification is based on the specific

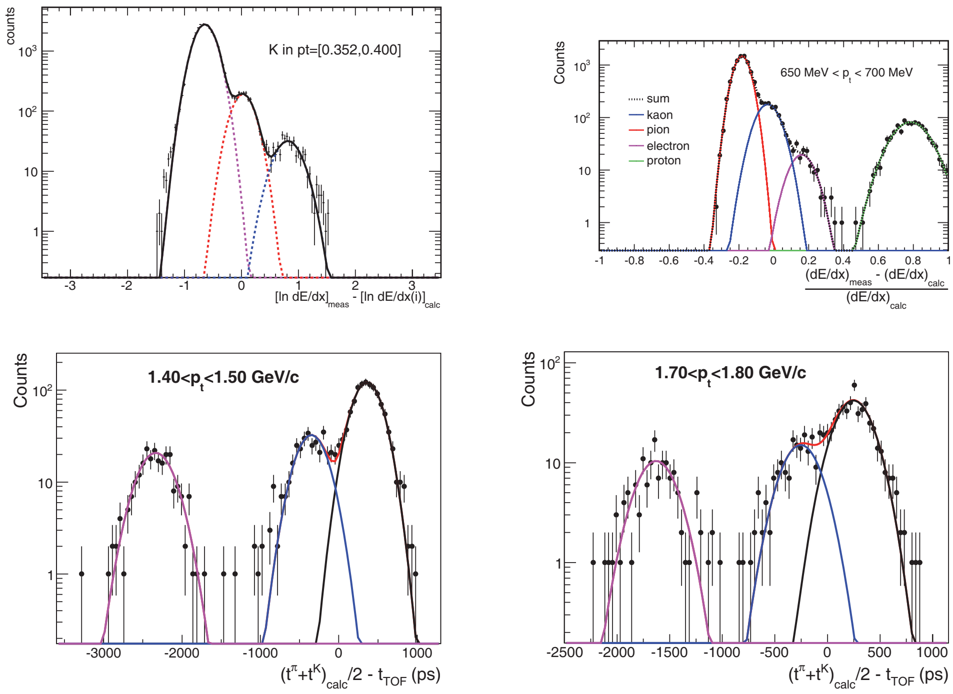

Fig. 2. – dE/dx distribution at lower momenta obtained with the ITS (top-left). dE/dx distribution at intermediate momenta obtained with the TPC (top-right). Arrival time distribution at higher momenta obtained with the TOF. The choice of a proper variable was tuned in order to improve the Gaussian response: t^{π}_{calc} and t^{K}_{calc} are the expected times for pion and kaon hypotheses, respectively; t_{TOF} is the time measured by the TOF (bottom).

energy deposit of each particle in the gas of the TPC, shown in fig. 1, upper right, as a function of momentum separately for positive and negative charges. The solid lines show the parameterization of the Bethe-Bloch curve.

Particles reaching the TOF system [5] are identified by measuring simultaneously their momentum and velocity. From the reconstructed flight path L and the measured time of flight t_{TOF}, the velocity $\beta = L/t_{TOF}$ is obtained, as displayed in fig. 1, as a function of the momentum p at the vertex. The width of the bands reflects the observed overall time-of-flight resolution of about 180 ps, which depends on the TOF timing signal resolution, on the accuracy on the reconstructed flight path and on the uncertainty on the event start time, t^0_{ev}. In particular, this last contribution is related to the uncertainty in establishing the absolute time of the collision that in 2009, due to the finite size of the bunches, had been fluctuating with respect to the nominal time signal from the LHC with a σ of about 140 ps. To reduce this uncertainty, which contributes in a significant way to the observed overall time-of-flight resolution, the TOF information itself is used to determine t^0_{ev} in events having at least three tracks with an associated TOF signal.

The number of pions, kaons and protons in a given p_t and rapidity interval is determined, for the ITS case, by fitting the distributions of the track-by-track difference between the logarithm of the measured and calculated energy deposit, fig. 2 (top-left).

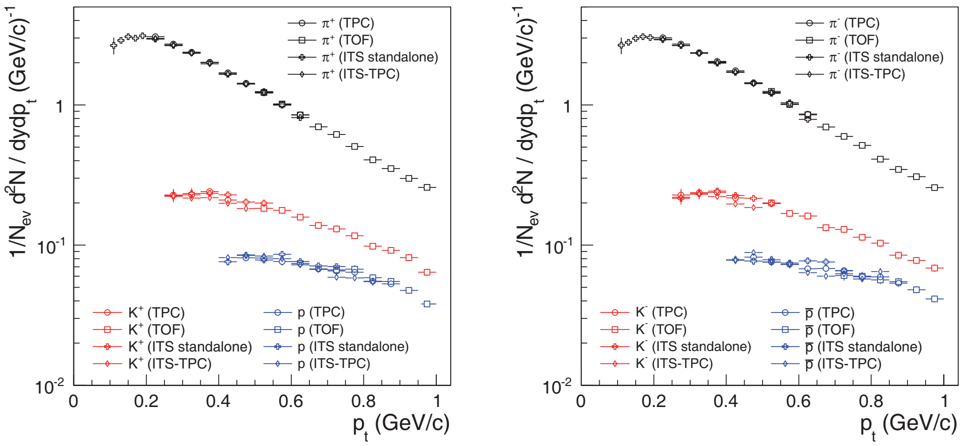

Fig. 3. – Transverse momentum spectra for $|y| < 0.5$ of positive (left) and negative (right) hadrons for the three detector analyses.

A similar approach was used also for the TPC analysis and an example of the dE/dx distribution in a specific p_t bin is shown in fig. 2 (top-right).

The yields in the TOF case are obtained from the simultaneous fit of the distribution of the time difference S between the measured t_{TOF} and the average between the calculated time for pions and kaons

$$S = (t^{\pi} + t^{K})_{calc}/2 - t_{TOF}.$$

The distribution of the variable S is reported in fig. 2 (bottom) for different transverse momentum bins and for positive particles.

Combining the results from various pid techniques a yield spectrum is obtained in the range from 0.2 GeV/c to 2.5 GeV/c. Figure 3 shows a comparison between the results of the analysis from the different detectors. The spectra are normalized to inelastic collisions and the differences of the analyses with the three detectors are of the order of few percents (less than the systematic errors).

3. – Particle identification performance: TPC with kink and HMPID

In this section, the determination of the yields of charged kaons identified by their weak decay (kink topology) inside the TPC detector is described. This procedure allows an extension of the study of kaons to intermediate momenta, on a track-by-track level, although in the present case the p_t reach is limited by statistics. The kinematics of the kink topology, measured as a secondary vertex with one mother and one daughter track of the same charge, allows the separation of kaon decays from the main source of background kinks coming from charged pion decays. The main decay channels for kaons are the two-body decays given below together with their branching ratios:

$$K^{\pm} \rightarrow \mu^{\pm} + \nu_{\mu} \qquad \text{(BR 63.55\%)}, \tag{1}$$

$$K^{\pm} \rightarrow \pi^{\pm} + \pi^{0} \qquad \text{(BR 20.66\%)}. \tag{2}$$

Three-body decays with one charged daughter track (BR 9.87%) as well as three-body decays into three charged pions (BR 5.6%) are also detected.

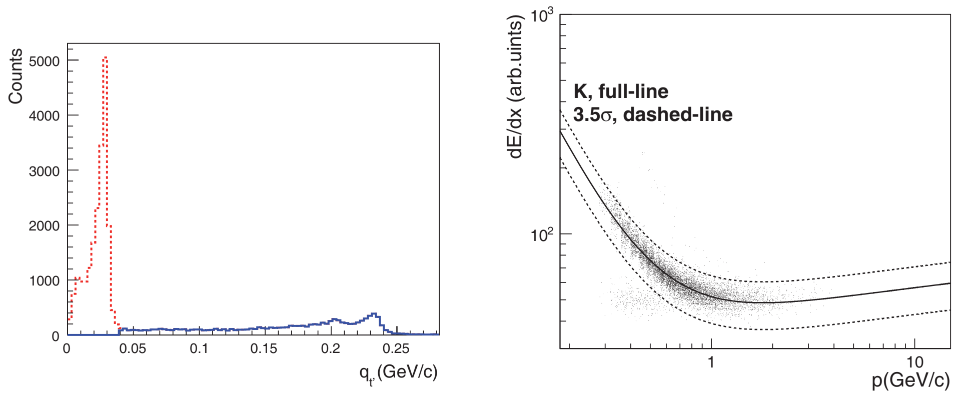

Fig. 4. – $q_{t'}$ distribution of daughter tracks with respect to mother momentum (left). dE/dx of kaon-kins as a function of the mother momentum (selection criteria applied).

The transverse momentum of the daughter with respect to the mother's direction ($q_{t'}$) has for the two-body decay to $\mu+\nu_\mu$ an upper limit of 236 MeV/c for kaons and 30 MeV/c for pions. The corresponding upper limit for the two-body decay $K^\pm \rightarrow \pi^\pm + \pi^0$ is 205 MeV/c. All three limits can be seen as peaks in fig. 4 (left) showing the $q_{t'}$ distribution of all measured kinks inside the selected volume and rapidity range $|y| < 0.7$. Selecting kinks with $q_{t'} > 40$ MeV/c removes the majority of π-decays. At this stage, we have a rather clean sample of kaons as demonstrated in fig. 4 (right) showing the dE/dx *vs.* the mother momentum. Most of the tracks are within a 3.5σ band with respect to the corresponding Bethe-Bloch line of kaons.

The kaons spectra obtained with various techniques, also including kinks and K_s^0 spectra, are compared in fig. 5 (left). The very good agreement demonstrating that all

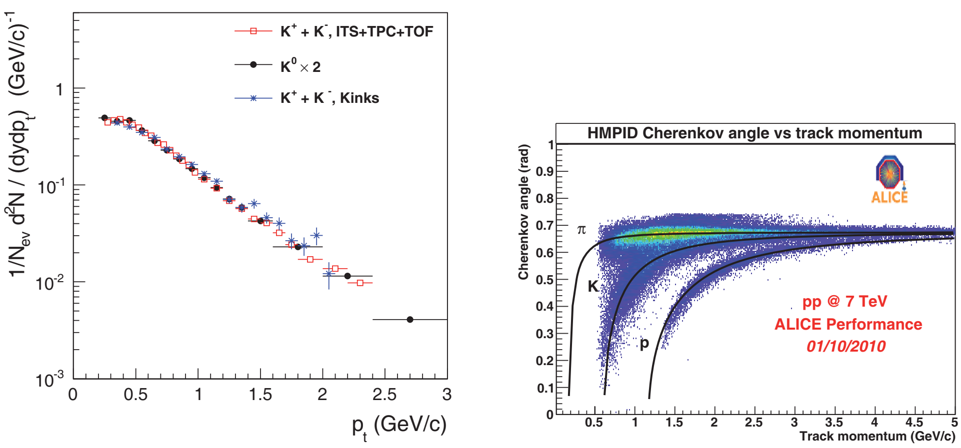

Fig. 5. – Left: comparison of charge kaon spectra obtained from the ITS-TOF-TPC combined technique, from kink topology and K_s^0 spectrum. Right: Cherenkov angle measured by HMPID *vs.* momentum.

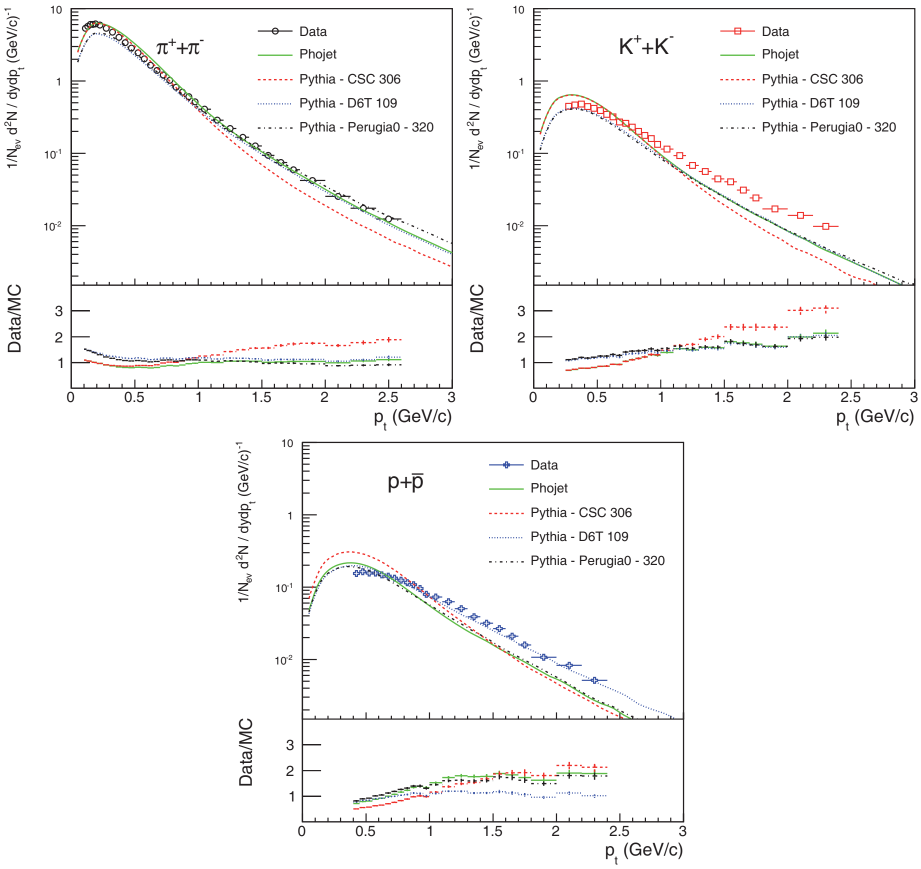

Fig. 6. – Comparison of pions, kaons and protons spectra (both charges combined) with various tunes of event generators.

the relevant efficiencies are well under control, allowed us to combine the spectra in order to cover the full momentum range.

Figure 5 also shows a preliminary plot of the HMPID [6] performances in pp collisions at $\sqrt{s} = 7\,\mathrm{TeV}$. Even if the HMPID acceptance does not cover all the azimuthal and pseudorapidity range of the other detectors it provides an independent measurement of the three species, very useful to control systematics in the high-p_t region and so to extend the identification at higher momenta.

4. – Particle spectra

QCD-inspired models are used as event generators to simulate the experimental results. Figure 6 shows a comparison of the measured pion, kaon and proton spectra with several tunes of the PYTHIA event generator [7] and with PHOJET [8]. It is interesting to note that while the PYTHIA tunes Perugia0 [9], CSC 306 [10] and D6T [11] give a reasonable description of the unidentified charged hadron spectra [12], they show large deviations from the measured identified hadron spectra. Especially the kaon spectra are poorly described: the measured p_t-spectrum falls more slowly with increasing p_t than the event-generators predict. Also the proton spectrum is not well reproduced. All tunes fail in the low-p_t range, only the tune D6T agrees in the high-momentum range.

5. – Conclusion

The first identified spectra for pp collisions at $\sqrt{s} = 900\,\text{GeV}$ with the ALICE detector have been shown demostrating the PID performances of several systems.

It was shown how the several subdetectors (ITS, TPC and TOF) at midrapidity allow to perform the measurement of identified particle spectra in a complementary way. The availability of complementary and independent PID techniques (K_s^0 and $K^{\pm}$-kinks) allowed to demonstrate that systematic uncertainties are under control in all the momentum range we have considered.

In the beginning of 2010 ALICE has also started to collect pp data at $\sqrt{s} = 7\,\text{TeV}$. The large-statistics data sample collected for such collisions allowed us to reach very fast a very good performance in particle identification and the analysis of charge particle spectra is ongoing. Finally, these first studies and results also represent an important reference for the incoming PbPb collisions where we also expect excellent capabilities in particle identification.

REFERENCES

[1] Carminati F. *et al.* (ALICE), *J. Phys. G*, **30** (2004) 1517.
[2] Alessandro B. *et al.* (ALICE), *J. Phys. G*, **32** (2006) 1295.
[3] Aamodt K. *et al.* (ALICE), *JINST*, **3** (2008) S08002.
[4] Alme J. *et al.*, *Nucl. Instrum. Methods A*, **622** (2010) 316.
[5] Akindinov A. *et al.*, *Nuovo Cimento B*, **124** (2009) 235.
[6] ALICE, *CERN/LHCC*, 98-19 (1998) 1.
[7] Sjostrand T., Mrenna S. and Skands P. Z., *JHEP*, **05** (2006) 026.
[8] Engel R., Ranft J. and Roesler S., *Phys. Rev. D*, **52** (1995) 1459.
[9] Skands P. Z., 0905.3418 (2008).
[10] Moraes A. (ATLAS), ATLAS-Note, ATL-COM-PHYS-2009-119 (2009).
[11] Albrov M. G. *et al.* (Tev4LHC QCD Working Group), arXiv:hep-ph/0610012 (2006).
[12] Aamodt K. *et al.* (ALICE), *Phys. Lett. B*, **693** (2010) 53.