First results from the ALICE experiment

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The results from first series of measurements performed by the ALICE experiment at the LHC are presented. These measurements include the charged-particle pseudorapidity densities, multiplicity distributions and transverse momentum spectra obtained by analysing the data collected in 2009 and 2010 in proton-proton collisions at three different center-of-mass energies of 0.9, 2.36, and 7 TeV. The results are compared to previous proton-antiproton data and to model predictions.

1. INTRODUCTION

The energy density expected to be reached in PbPb collisions at the LHC will be of the order of a few tens GeV/fm^3. Under these conditions, a deconfined state of quarks and gluons, the quark-gluon plasma, is expected to be formed. A Large Ion Collider Experiment (ALICE) [1] at CERN is a general-purpose heavy ion experiment designed to study the physics of this new state of matter. However, these studies cannot be effectively performed without having a reliable "hadronic reference". All the measurements that will be done by ALICE in heavy ion collisions will have to be compared with the corresponding, properly scaled, proton-proton results. Also, it is important to check if the models that successfully described the particle production in "elementary" collisions at lower energies still do so when extrapolated to the LHC energy domain. Finally, one might expect something completely new (like some kind of collective effects at the partonic level) to happen in *pp* collisions at these new LHC energies. For this, we would need to study all the observables as the function of multiplicity. Which, in turn, requires good multiplicity measurements.

The description of the ALICE detectors can be found in [1]. As for the first *pp* runs in 2009 and 2010, the most important detectors are the Inner Tracking System (ITS), the Time

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Projection Chamber (TPC), the Time-Of-Flight detector (TOF) (all covering the pseudorapidity range $|\eta| < 0.9$), and the muon spectrometer (MUON) (with the pseudorapidity coverage $-4 < \eta < -2.5$). All these detectors are fully installed and operational.

The triggering for the first collisions is essentially minimum bias. At least one charged particle is required in about 8 units of pseudorapidity covered by the two innermost pixel layers of the ITS (with the pseudorapidity windows of $|\eta| < 2.0$ and $|\eta| < 1.4$), respectively) and the two scintillating rings of the V0A and the V0C detectors (with the coverage of $2.8 < \eta < 5.1$ and $-3.7 < \eta < -1.7$). A special single-muon trigger is also implemented for triggering the muon spectrometer, and it is read out in coincidence with the general minimum-bias trigger. The coincidence with the beam pickup counters, which can be done in several logical combinations, allows for accepting special control triggers used for the background estimations.

We have taken data at three energies: 0.9 TeV, 2.36 TeV, and 7 TeV. At 0.9 and 2.36 TeV we consider two event classes: inelastic (INEL) and non-single-diffractive (NSD). The corresponding corrections for the triggering efficiency are done by tuning the MC event class fractions to match the UA5 [2], E710 [3], and CDF [4] data, and using PYTHIA 6.4.14 and 6.4.21 [5, 6], tune D6T [7], and PHOJET 1.12 [8] Monte Carlo models to assess the effects of different kinematics. At 7 TeV, we use the hadron-level event class definition, requiring at least one charged particle in a pseudorapidity window $|\eta| < 1$.

2. THE FIRST PHYSICS RESULTS

2.1. Charged-particle pseudorapidity density and multiplicity distributions.

The first multiplicity measurements in ALICE were done with the two inner most pixel layers of the ITS. ALICE has published the charged-particle pseudorapidity ($\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta$) densities and multiplicity distributions obtained for the INEL and NSD events in pp collisions at 0.9 TeV, 2.36 TeV, and 7 TeV [9–11]. The results were found to be consistent with UA5 $p\bar{p}$ data at 0.9 TeV [12, 13], and also with CMS pp data at 0.9 and 2.36 TeV [14] (for the NSD events).

The obtained multiplicity distributions fit well to a single negative binomial distribution, and the distribution for the INEL events tends to have more events with low multiplicity than the NSD events do. The dependence of $\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta$ on the collision energy $\sqrt{s}$ is well described by the power-law function ($\sim s^{0.1}$) [11]. This increase with $\sqrt{s}$ is systematically bigger than predicted by several PYTHIA tunes and PHOJET.

2.2. Mid-rapidity anti-proton to proton ratio.

This measurement provides an important piece information for the theoretical discussion over the question: what carries the baryon number? The models postulating that the baryon number is carried by valence di-quarks, predict the $\bar{p}/p$ ratio should be 1 at the LHC energies. Other models involve special configurations of gluonic field, the so called "string junctions", that may also be related to the baryon number (see, for example, the references in [15]). In these models, the $\bar{p}/p$ ratio does not reach 1 even at the LHC energies.

ALICE has performed this measurement and has added two important points to the $\bar{p}/p$ excitation function, at 0.9 TeV and 7 TeV. At 7 TeV, the measured value of $\bar{p}/p$ is $0.990 \pm 0.006 \pm 0.014$ (the first error is statistical, the second is systematic), which is consistent with 1. The ratio has also been studied as the function of the transverse momentum. It has been found that the models with string junctions systematically underestimate the data, especially at 0.9 TeV [15].

Altogether, these results put a strong constraint on the association between the string junctions and the baryon number.

2.3. Bose-Einstein correlations with charged pions.

The Bose-Einstein correlations of identical pions are a well known tool to evaluate the size and the space-time evolution of the emitting system. ALICE has measured the corresponding correlation function in pp collisions at 0.9 TeV as the function of $q_{\mathrm{inv}} = |\mathbf{p}_1 - \mathbf{p}_2|$ ($\mathbf{p}_1$ and $\mathbf{p}_2$ being the momenta of the pions in a pair) [16].

The radius of the emitting system grows with the event multiplicity, consistently with the measurements by other experiments. At the same time, it stays approximately constant as the function of the absolute value of the difference between the transverse momenta of the pions in a pair, $k_{\mathrm{T}} = |\mathbf{p}_{1,\mathrm{T}} - \mathbf{p}_{2,\mathrm{T}}|/2$, which is different from the previous observations. We also report a significant systematic uncertainty inevitably affecting all these measurements. This systematic uncertainty comes from the assumption about the shape of the "base line", which is, likely, not to be flat in pp, as it is often assumed.

2.4. Particle production and transverse-momentum spectra.

The charged-particle transverse-momentum spectrum measured by ALICE in the pseudorapidity window $|\eta| < 0.8$ [17] fits well to the modified Hagedorn function. At the transverse momenta $p_{\mathrm{T}} > 3$ GeV/c, the shape of the spectrum is somewhat better described by the power-law function. The comparison to the PHOJET and different PYTHIA tunes shows that none of these Monte Carlo models gives a reasonable description of the data.

We also compare this spectrum with the ones measured by other experiments (UA1, ATLAS, and CMS, see the references in [17]). ALICE's spectrum is harder. This has been understood as the consequence of the narrower pseudorapidity window that is used by ALICE.

A rather strong test of the available models can be performed by looking at the correlation between the mean p_{T} and the multiplicity. It turns out that none of the used Monte Carlo models is able to simultaneously reproduce the measured correlation [17] and the multiplicity distributions reported in [10].

Up to the moment of presenting these results (August 2010), ALICE has also obtained the transverse-momentum spectra of identified particles ($\pi^{\pm}$, $K^{\pm}$, $p^{\pm}$, ϕ, K^0_{S}, Λ^0, $\bar{\Lambda}^0$, and $\Xi^{\pm}$) in proton-proton collisions at 900 GeV. The charged particle identification is done by combining the $\mathrm{d}E/\mathrm{d}x$ measurements in the ITS and TPC with the time-of-flight information provided by the TOF detector. The ϕ-mesons are reconstructed in the $\phi \to K^+K^-$ channel using the invariant mass method. The K^0_{S} and the strange baryons are identified by their V0 and cascade decay topology. The comparison with different PYTHIA tunes and the PHOJET shows that all the Monte Carlo models significantly underestimate the production of the strange particles. For example, the spectrum of the K^0_{S} at transverse momenta larger than ~ 1 GeV/c is underestimated by a factor of ~ 2 (see Fig. 1), and by a factor of ~ 3 for the Λ^0 (see Fig. 2). This discrepancy is smaller in the case of the ϕ.

Quite a few items in ALICE's physics programme require the detection of resonances, the K^{*0} and ϕ in particular. These resonances are clearly seen by our detectors and their parameters (mass and width) are consistent with the corresponding PDG values.

The π^0 and η mesons can be detected in ALICE by means of double γ-conversion reconstruction in TPC and ITS, and also using the calorimeters, PHOton Spectrometer (PHOS) and ElectroMagnetic CALorimeter (EMCAL). The reconstruction of the γ conversions is also used for a precise mapping of the material distribution in the detectors.

2.5. Jets and high-p_{T} particle correlations.

ALICE is also capable of reconstructing the jets and measuring the jet spectra. The collaboration is working on the correlations between the leading (high-p_{T}) particles and other particles in the event. Once the leading particles are defined and isolated, one can study the properties of the underlying event, which is sensitive to the soft-component and multi-parton interactions. Our data show significantly stronger contribution from underlying events than what is predicted by the usual Monte Carlo models, especially when the momentum of the leading particle is below 10 GeV/c.

2.6. Heavy-flavour particle measurements.

With the statistics that we have at the moment of the conference ($\sim 1.5 \times 10^8$ minimum bias pp events at 7 TeV), we can already see clear signals of J/ψ and D mesons. The subsequent extraction of the p_{T} spectra of these particles has started.

In the mid-rapidity region of ALICE, we can measure the J/ψ spectrum reconstructed in the e^+e^- decay channel. In the forward rapidity region, the same spectrum can also be obtained in the $\mu^+\mu^-$ decay channel, using the MUON spectrometer (see Fig. 3).

The D meson family can be reconstructed in several decay channels. The D^0 meson is easily detected in the Kπ decay channel. In addition to D^0's, we also reconstruct the charged D mesons in the K$\pi\pi$ channel, and even the charged D* mesons in the $\mathrm{D}^0\pi$ channel, as shown in Fig. 4. All the signals can be extracted in momentum bins and up to $p_{\mathrm{T}} \sim 15$ GeV/c at least.

We are also investigating the possibilities to study the charm and beauty production using the the semi-leptonic decay channels. Currently, in the mid-rapidity part of ALICE, we identify the electrons by the energy loss in the TPC. Soon, the Transition Radiation Detector and the PHOS and EMCAL will start contributing to the identification, which will then extend the accessible p_{T} range. Special measures are taken to suppress the background from the γ conversions: selection the tracks having bigger impact parameters and having a cluster attached at the inner-most layer of the ITS, and subtracting from the final spectrum the electron spectrum associated with the reconstructed γ's.

In the MUON spectrometer, the single muon spectrum is corrected for the contribution of muons coming from other than heavy-flavour particle decays, using detailed Monte Carlo simulations with PYTHIA. The resulting spectrum is then separated into the charm and beauty contributions by fitting to the spectral shapes provided by pQCD calculations.

3. CONCLUSIONS

The ALICE experiment has successfully started taking and analyzing data recorded at 0.9, 2.36, and 7 TeV in pp collisions at LHC. The obtained first results are valuable for better understanding the mechanisms of particle production at the LHC energies. These results are also important as the reference for ALICE's main stream studies that will start in nucleus-nucleus collisions at the end of this year.

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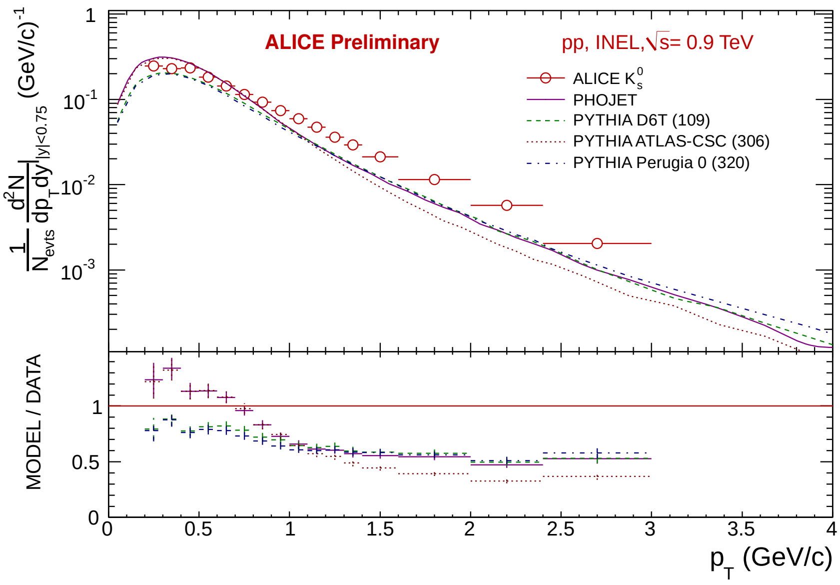

Figure 1. The transverse-momentum spectrum for the K^0_S measured in INEL *pp* collisions and compared with different PYTHIA tunes and with the PHOJET.

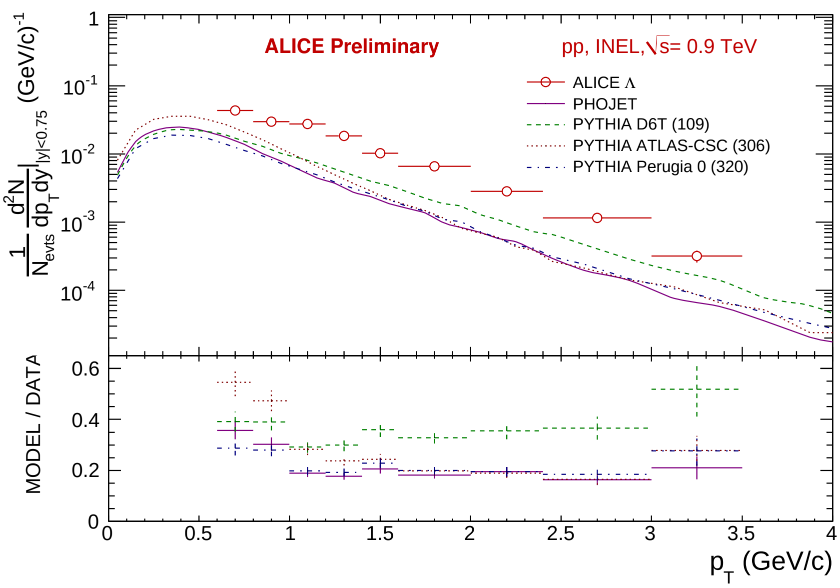

Figure 2. The transverse-momentum spectrum of the Λ^0 measured in INEL *pp* collisions and compared with different PYTHIA tunes and with the PHOJET.

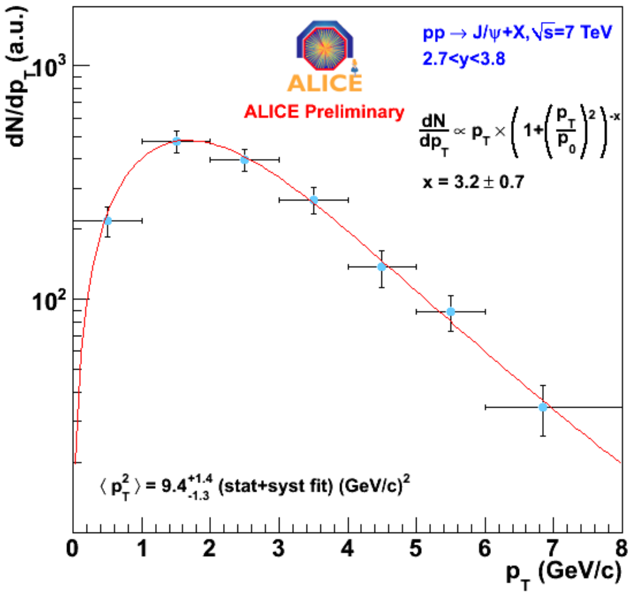

Figure 3. The transverse-momentum spectrum of J/ψ measured by the ALICE MUON spectrometer in the $\mu^+\mu^-$ decay channel.

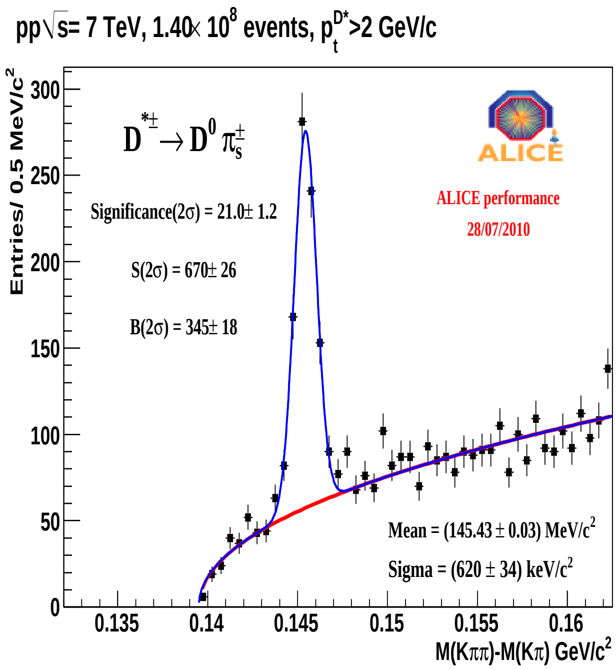

Figure 4. The invariant mass spectrum of charged D^* mesons identified by the ALICE ITS, TPC, and TOF detectors in the $D^0\pi$ decay channel.

FIGURE CAPTIONS

Fig. 1: The transverse-momentum spectrum for the K_S^0 measured in INEL pp collisions and compared with different PYTHIA tunes and with the PHOJET.

Fig. 2: The transverse-momentum spectrum of the Λ^0 measured in INEL pp collisions and compared with different PYTHIA tunes and with the PHOJET.

Fig. 3: The transverse-momentum spectrum of J/ψ measured by the ALICE MUON spectrometer in the $\mu^+\mu^-$ decay channel.

Fig. 4: The invariant mass spectrum of charged D* mesons identified by the ALICE ITS, TPC, and TOF detectors in the D$^0\pi$ decay channel.