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Status of the ALICE experiment and first results on heavy flavour production

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Abstract

The ALICE experiment is the LHC detector mainly dedicated to the study of the Quark Gluon Plasma (QGP) in Pb-Pb collisions. The detector has started the data taking less than one year ago, delivering immediately relevant results. An overview of the first physics results obtained in the first six month of running of the experiment will be summarized, giving special emphasis to heavy flavour measurements.

Heavy flavours are ideal probes to explore both the formation and properties of the QGP, since they experience the full collision history and are expected to be copiously produced at LHC, much more than at any other collider. With ALICE we will measure heavy flavours down to small transverse momentum, combining hadronic and leptonic channels, both at central and forward rapidity. In particular, in the central rapidity region, it is possible to exclusively reconstruct open charm mesons and baryons via hadronic decay channels. Furthermore, the good identification of electrons allows to measure the production both of charmonium and open beauty.

First results from p-p collisions at 7 TeV will be shown, including the clear signals of open and hidden charm hadrons reconstructed at ALICE. These data provide interesting insight into QCD processes in a new energy regime, are important as a baseline for the Pb-Pb program and demonstrate the potential for heavy flavour cross section measurements with the ALICE detector.

ALICE, status, heavy flavour, first results

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1. Introduction

ALICE (A Large Ion Collider Experiment) is the LHC experiment mainly dedicated to the detection and the determination of the properties of the Quark Gluon Plasma (QGP) formed in heavy ion collisions. Since the startup of LHC, high statistics data have been collected with proton-proton collisions at the three energies available, namely 900 GeV, 2.36 TeV and 7 TeV, to perform various physics analysis. In this paper we describe the physics results obtained so far from these data samples. In particular, in section 2 the detector, its performance and the data samples collected are described. In section 3 the outcome of the charged particle multiplicity measurement and the analysis of charged hadrons transverse momentum spectra are summarized. Section 4 will be focused on heavy flavours, starting with motivations and concluding with the experimental results achieved at 7 TeV.

2. ALICE: set up and data taking

The ALICE detector is composed by a central barrel, embedded in a magnetic field of 0.5 T, where tracking, vertexing and Particle IDentification are performed, and a muon arm, where muons are reconstructed and identified. The experimental setup of the experiment is described in detail in [1]. Although its design is optimized for Pb-Pb collisions and the main physics program concentrates on heavy ions, the proton-proton program is rich and ambitious. The p-p data, in fact, not only represent the necessary baseline to understand the heavy ion results, but have a great interest per se. Among the relevant topics, physics at high multiplicity and heavy flavour measurements can be cited. Moreover, the studies on minimum bias collisions and the underlying event will provide significant input to theoretical models and Monte Carlo generators.

2.1. Tracking, vertexing and PID

In the reconstruction of the primary and secondary vertices, the Inner Tracking System is playing a leading role. It is the detector closer to the interaction point and is composed by three different technologies: Silicon Pixel (SPD), Silicon Strip (SSD), Silicon Drift (SDD). The alignment procedure, described in [2], has been carried out using both cosmic tracks and tracks from p-p collisions. For example, the residual misalignment in the SPD is less than 10 µm, achieving a spatial resolution of 14 µm, very close to the design specification. The primary interaction vertex is reconstructed event by event by extrapolating the tracks to the intersection region, fitting the position of the vertex and constraining it to the measured average intersection profile. The resolution achieved is less than 100 µm even in low multiplicity events. In addition, the resolution of the track impact parameter is of the order of few hundreds of µm for very low momentum tracks, improving when the track momentum increases and reaching 80 µm for tracks with momentum of 1 GeV. Primary vertex and impact parameter resolutions are both important features to discriminate tracks coming from secondary vertices displaced only by few tens of microns from the interaction vertex

The heart of the tracking is the Time Projection Chamber, described in [3]. It is the biggest ever built and it has been designed to reconstruct more than 15000 primary tracks in central Pb-Pb collisions. The calibration was ready before the first data taking in November 2009, exploiting cosmic ray tracks crossing the detector. The momentum resolution achieved is less than 1% for tracks with p < 1 GeV/c, confirmed by the measurement of the K^0 mass peak, while the tracking is well under control for tracks with momentum up to 10 GeV/c.

One of the ALICE peculiarities is the Particle IDentification: different particle species can be very well distinguished by three different detectors in different and complementary momentum regions. The TPC identifies particles with intermediate momenta thanks to the energy loss in its volume, managing to distinguish even anti-tritons. The Time Of Flight and the ITS are able to distinguish charged hadrons down to 0.1 GeV/c (the latter) and up to 3.5 GeV/c (TOF).

2.2. Data taking

The data collection has started the 23rd of November 2009 with p-p collisions at 900 GeV. Since then, the following data sets (minimum bias events) have been collected, at the three energies made available by the machine:

- 7×10^6 events at 900 GeV
- 3×10^4 events at 2.36 GeV
- 8×10^8 events at 7 TeV (statistics available on August 1st).

The detectors used for issuing the minimum bias trigger are the SPD and the segmented scintillator counter VZERO, as described in [1,4]. The 0.9 TeV and 7 TeV data were collected triggering on one track anywhere in the eight units of pseudorapidity covered by the two trigger detectors. This is realized requiring at least one hit in the SPD, combined in logical or with one signal in the VZERO counters. For the data taking at 2.36 TeV, the VZERO was switched off and the trigger provided only by the SPD, i.e. one track in |?| <2, in coincidence with the signal of two beam pick up counters.
Combining these triggers with the background rejection techniques described in [5], the remaining background is of the order of 10^{-4} to 10^{-5}, while the efficiency is more than 90%.

3. First experimental results

The first physics results have been obtained already a few hours after the first recorded event, but more detailed analyses have been carried out to characterize the LHC collisions and study the energy dependence of the observables. Among the relevant topics, the multiplicity of charged particles, the transverse momentum spectrum of hadrons and the Hanbury-Brown and Twiss correlation led to publications and are here summarized.

3.1. Multiplicity of charged particles

The pseudorapidity density and the multiplicity distribution of primary charged tracks have been measured in a new energy domain, using all the available data sets. The aim of the study is to determine one of the global characteristics of p-p collisions, providing constraint to models and input to event generators: currently, the theoretical predictions depend strongly on the model and the fine tuning of the event generator.

In these analyses, the charged multiplicity is measured from the track segments (called "tracklets") reconstructed by correlating hits in the two SPD layers, as described in [5,6]. The details of the analysis and the description of the systematic uncertainties are in [6,7] .

In general, it has been observed that the models underestimate the particle production in p-p collisions and the disagreement between data and Monte Carlo increases with increasing energy. In particular, the relative increase of charged particle pseudorapidity density with respect to vs = 900 GeV is summarized in fig 1.

The shape of the measured multiplicity distribution has not been reproduced by any of the models and tunes used for this analysis.

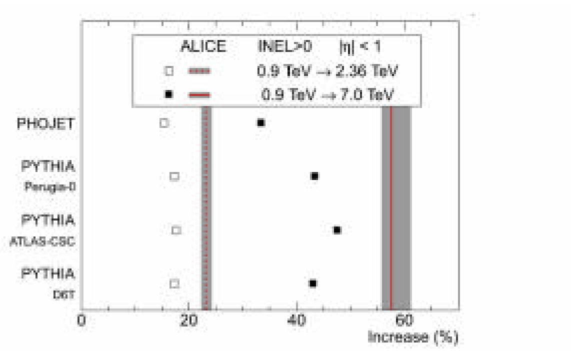

Figure 1: Relative increase of the charged-particle pseudorapidity density, for inelastic collisions with at least one charged particle in the acceptance, for vs = 0.9 – 2.36 TeV and vs = 2.36 – 7 TeV, with different generators and tuning. The lines correspond to the ALICE measurements [7].

3.2. Transverse momentum spectrum

The inclusive charged particle differential transverse momentum yield has been measured in p-p collisions at vs = 900 GeV, in the central rapidity region [8]. The track momentum range is $0.15<p_T<10$ GeV/c, where both hard and soft processes are supposed to contribute to particle production. In addition, the correlation between transverse momentum and charged particles multiplicity has been measured. This measurement is useful to characterize the p-p collisions and to provide constraints to generators such as PYTHIA and PHOJET. The events used for this study belong to two different classes: inelastic (INEL) and non-single-diffractive (NSD), while only the tracks reconstructed in the TPC and extrapolated to the ITS, in the rapidity region |?|<0.8, are selected.

The transverse momentum distribution has been compared to the data recently published by ATLAS [9] and CMS [10]: the agreement is good below 1 GeV/c, while the ALICE spectrum is harder for higher momenta. A similar behavior can be observed comparing the data from ALICE and from the UA1 collaboration in collisions at the same energy. These discrepancies are most likely [8] due to the different pseudorapidity acceptances.

Furthermore, as shown in fig. 2, the measured transverse momentum distribution has been compared to the predictions of different generators. The Perugia-0 and D6T tunes of PYTHIA give a good description of the spectral shape, but they underestimate by about 20% the yield. On the other hand, PHOJET and the ATLAS-CSC tune of PYTHIA provide a better description of the charged track multiplicity but fail in reproducing their p_T spectrum.

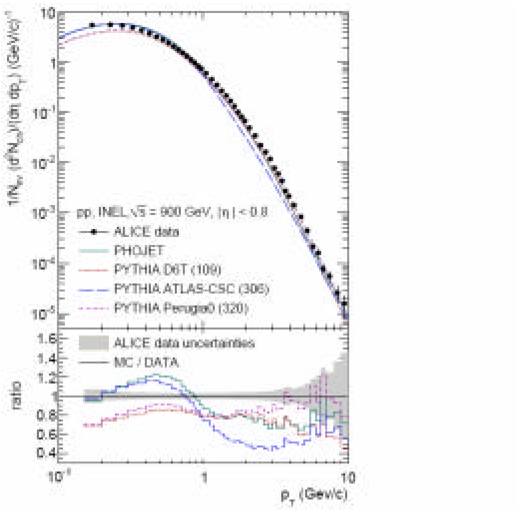

Figure 2: Top: Comparison of the primary charged particle differential yield in INEL collisions to results from PHOJET and PYTHIA. Bottom: Ratio between Monte Carlo simulations and data. [8].

3.3. Hanbury-Braun and Twiss correlation

The basic idea of this technique is to use the Bose-Einstein correlation between two pions (identical bosons) in order to get information about the space-time evolution of the source emitting the pions. The measured two-particle correlation functions $C(q_{inv})$ were fitted by a Gaussian function which accounts for the Bose-Einstein enhancement for pair of pions with small momentum difference:

$$C(q_{inv}) = [1 + l \exp(-R_{inv}^2 q_{inv}^2)]$$

where ? describes the correlation strength, R_{inv} the Gaussian HBT radius, q_{inv} the quadri-momentum difference.

The HBT radius has been correlated with the charged particles multiplicity of the event: an increase of the HBT radius with multiplicity is observed, consistent with the systematic trend measured in hadron-hadron collisions with vs > 50 GeV. On theother hand, a surprise comes out looking at the dependence of the HBT radii on the mean transverse momentum of the pions pair (k_T), that should provide information about the collective flow of the bulk system. In contradiction with what has been found by other experiments, no k_T dependence is observed (fig. 3). This discrepancy can be explained by a different baseline shape assumption and a different average multiplicity in the considered collisions, see discussion in [11].

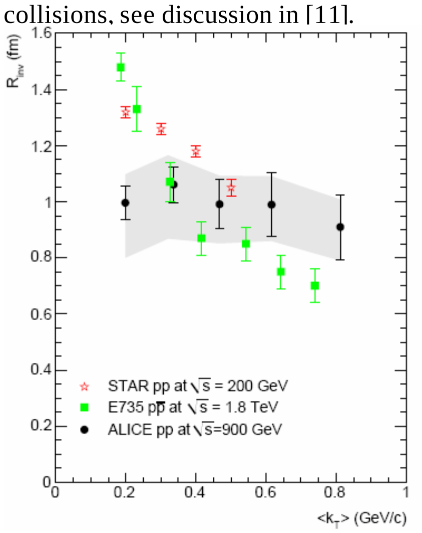

Figure 3: One dimensional Gaussian HBT radius as a function of the transverse momentum k_T (full dots), compared to other RHIC and Fermilab data. Results taken from [11] .

4. Charm and beauty in ALICE

Heavy flavours are ideal probes for the QGP formation and the determination of its properties. They are created in the initial hard collision, experiencing the full collision history. Furthermore, measuring the open charm and beauty will facilitate the understanding of the energy loss by partons crossing the hot and dense medium formed in Pb-Pb collisions. The energy loss is predominantly due to gluon emission and is influenced by color effects (the Casimir factor), which causes the gluons to radiate more energy than the quarks, and by the quark mass (dead cone effect). Thus, the open beauty hadrons are expected to be less quenched than the open charm ones, which are expected to be less quenched that light hadrons.

The proton-proton collisions will provide the necessary baseline to understand the Pb-Pb results and will allow to measure charm and beauty cross sections, to be compared with the perturbative QCD predictions in a new energy domain attained with collisions at the LHC.

Heavy flavours will be abundantly produced at the LHC: the cross section of charm and beauty are expected to increase, respectively, by a factor 20 and 100 with respect to RHIC [12].

ALICE is able to reconstruct charm and beauty both in the central and in the forward rapidity regions and through different decay channels, thanks to its excellent tracking performance, to the vertex and impact parameter precision and to the particle identification capability. The measurements in preparation are: exclusive reconstruction of open charm mesons and baryons via hadronic decay channels, measurement of electrons and muons from heavy flavour decays as well as reconstruction of charmonium and bottomonium from lepton pairs.

4.1. Open charm

The open charm mesons (D^0, D^+, D^*, D_s) and baryon (?$_c$) are exclusively reconstructed by exploiting hadronic decay channels in 2-4 charged particle final states. This is done by identifying their decay vertices, which are typically displaced by few hundreds of micrometers from the interaction vertex Not only is the decay length of these particles very small, but also the combinatorial background is high already in p-p collisions, making the measure particularly challenging.

The analysis schema is the following: all the charm candidates are formed by combining tracks with proper charge signs. Then topological cuts are applied to separate the signal from the combinatorial background. The raw signal is extracted by fitting the resulting invariant mass spectrum. The D meson yield is then extracted by applying the needed corrections for efficiencies, acceptance and feed-down from beauty mesons.

An example is the analysis of the D^0 ? Kp. In this case, all the pairs of tracks with a large impact parameter are selected, then requiring that the D^0 candidate points to the primary vertex. About $1.4x10^8$ p-p events at vs = 7 TeV have been analyzed so far and D^0 decaying in two charged prongs has been seen (fig. 4) with a statistical significance greater than 20. Also D^+ and D* have been seen with a similar significance (see R. Bala and Y. Wang contributions), while the D^0 in its four charged prongs decay channel has been seen with lower significance.

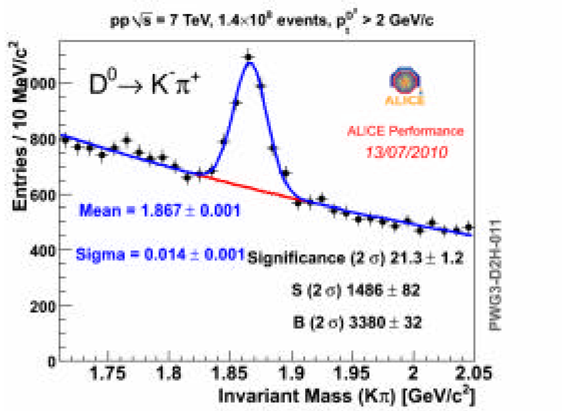

Figure 4: Invariant mass spectrum for candidates D^0? Kp in p-p collisions at vs = 7 TeV, after the selections described in the text.

4.2. Heavy flavour electrons

The inclusive heavy flavour cross section can be computed using the muons at forward rapidity (see N. Bastid contribution) and electrons in the central barrel: their spectrum is, in fact, dominated by the contribution from charm and beauty at high transverse momentum The particle identification is essential in this analysis, in order to provide a pure sample of electrons. The main source of contamination is due to pions.

The selection strategy is based on TPC and TOF. The tracks identified as pions, kaons and protons in the latter are rejected. After this first cleaning of the sample, the electrons are identified by the energy loss in the TPC. In the resulting sample, the pion contamination is estimated to be smaller than 50% for pt<4 GeV/c. The first transverse momentum spectrum for p-p collisions at vs = 7 TeV can be found in fig. 5. Another ingredient for the electron identification is the Transition Radiation Detector: at the moment, the PID calibration is ongoing.

Analyzing the electrons, also open beauty can be identified. Again, the rejection of the pions becomes crucial to eliminate most of the background. Then, a cut on impact parameter is expected to reduce the background coming from charm and gamma conversions. Collecting a number of events corresponding to a nominal year of data taking (10^9 p-p and 10^7 central Pb-Pb collisions) the measurement will be feasible with relative statistical error <5% up to p_T = 13 GeV/c.

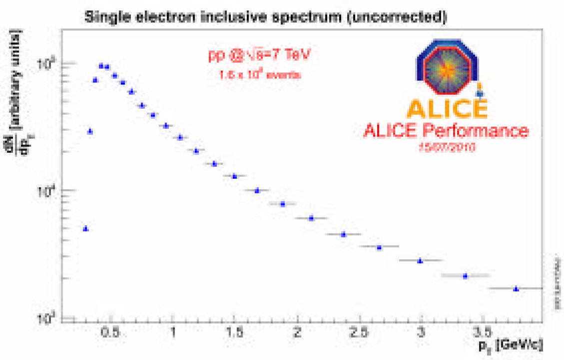

Figure 5: Single electron inclusive spectrum, not corrected for efficiencies and acceptance, and not unfolded in p_T. Obtained from $1.6x10^8$ p-p collisions events at vs =7 TeV.

4.3. Hidden charm

The *J/?* dissociation in Pb-Pb collisions is one of the most important signatures of QGP formation [13]. Significant questions are left without an answer from RHIC analysis: the *J/?* suppression was the same as measured at the SPS, while it was predicted to be higher. Several theoretical models have tried to explain this observation, but only the LHC data will give a clear solution to the puzzle. In the p-p collisions, the measurement is interesting not only as a reference for the heavy ion data, but per se: in fact, none of the models available manages to describe simultaneously the polarization and the production of this particle.

In ALICE, the measure is possible using both muons at forward rapidity (see N. Bastide contribution) and electrons. In the central barrel, the *J/?* is identified in its electronic channel and the reconstruction is based on the invariant mass analysis of positively identified e^+e^- pairs, where the electron identification strategy described in the previous section is used. The measurement allows us to reach small values of transverse momenta. The first result with p-p collisions at vs = 7 TeV is shown in fig 6, where a fit with a Crystal Ball function [14] has been performed. Without any trigger, we expect some 500 *J/?* in the electron channel for 10^9 minimum bias events, enough for a significant analysis.

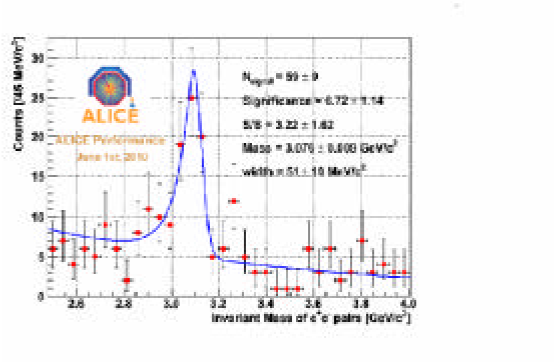

Figure 6: Invariant mass of selected electron-positron pairs, the peak around the *J/?* mass is fitted with an exponential function plus a Crystal Ball. Obtained from 10^8 p-p collisions at vs =7 TeV.

5. Conclusions

The ALICE detector is in a good shape and ready to achieve all the physics goals. The global characteristics of p-p collisions, such as the charged track multiplicity and the particle transverse momentum spectrum, have been determined. The heavy flavours program has just started, giving its first promising results.

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