PROCEEDINGS OF SCIENCE

Heavy flavour and Quarkonium measurements with ALICE at the LHC

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ALICE is the LHC experiment dedicated to the study of heavy-ion collisions. The main purpose of ALICE is to investigate the properties of a state of deconfined nuclear matter, the Quark Gluon Plasma. Heavy flavour measurements will play a crucial role in this investigation. The physics programme of ALICE has started by studying proton-proton collisions at unprecedented high energies. We present the first results on open heavy flavour and quarkonia in proton-proton collisions at $\sqrt{s}$=7 TeV measured by the ALICE experiment at both mid- and forward-rapidities.

35th International Conference of High Energy Physics
July 22-28, 2010
Paris, France

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1. Introduction

In ultra-relativistic heavy-ion collisions, we aim to investigate the properties of nuclear matter under extreme conditions of temperature and pressure which are expected to lead to the creation of deconfined partonic matter, the Quark Gluon Plasma (QGP). With the objective of studying the QGP, heavy-ion collisions were studied at the CERN SPS and are currently under investigation at RHIC at BNL. Their investigation, at unprecedented high energies, has just started at the Large Hadron Collider (LHC) at CERN.

While several observables have been proposed to characterize the QGP, the study of heavy quark (c and b) production is thought to be one of the most powerful probes. Indeed, heavy quarks should probe the medium since the initial phases of its formation. The strong interaction with the high-density QCD matter results in an energy-loss whose underlying mechanisms are still under investigation. The study of the production of heavy quark and anti-quark bound states (quarkonia), J/ψ, ψ' ($c\bar{c}$), Υ(1S), Υ(2S) and Υ(3S) ($b\bar{b}$) is particularly interesting. It was first proposed that quarkonium resonances will dissociate by color screening in the QGP [1], thus a suppression of quarkonium production in nucleus-nucleus collisions compared to proton-nucleus collisions was predicted as a signature of the QGP formation. Later, it was also proposed that additional quarkonium production mechanisms, such as statistical hadronization [2] or quark and anti-quark recombination in the QGP [3], could add to the prompt production by initial hard scattering. In this case an enhanced production of quarkonium resonances will be observed in nucleus-nucleus collisions. The regeneration scenarios are expected to be important for the charmonium states at LHC energies.

The study of heavy flavour and quarkonium production in proton-proton (p-p) collisions is an integral part of the ALICE physics program. In addition to provide the necessary reference for Pb-Pb data, the p-p measurement will constrain the different production models. After a brief presentation of the used apparatus we present the first results on open heavy flavour and quarkonia in proton-proton collisions at $\sqrt{s}$=7 TeV measured by the ALICE experiment at both mid- and forward-rapidities.

2. The ALICE experiment at the LHC

ALICE is a general-purpose heavy-ion experiment designed to study the physics of strongly interacting matter and the QGP in nucleus-nucleus collisions at the LHC. The detector is designed to cope with the highest particle multiplicities anticipated for Pb-Pb collisions (dN_{ch}/dy up to 8000). ALICE has been successfully taking data since November 2009, with the first Pb-Pb collisions recorded on November 7$^{\text{th}}$ 2010.

The detector consists of a central part, which measures hadrons, electrons and photons, and of a forward spectrometer to measure muons. The central part, which covers polar angles from 45° to 135° over the full azimuth, is embedded in the L3 solenoidal magnet. It consists of various tracking detectors and particle identification arrays among which are the Inner Tracking System (ITS), a cylindrical Time-Projection Chamber (TPC) [4], a Transition Radiation Detector (TRD) and a Time Of Flight (TOF) detector. The forward muon arm covers polar angles from 171° to 178°.

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Several smaller detectors (ZDC, FMD, V0...) for global event characterization and triggering are located at forward-backward angles. More details can be found in [5].

3. Data samples

The ALICE experiment collected data in p-p collisions at $\sqrt{s}$=7 TeV from March 2010 to November 2010. Two main event types were recorded by ALICE, minimum-bias events and events with at least one triggered muon. The former requires either one signal in the Silicon Pixel Detector (SPD) or in one of the two scintillator vertex detectors (V0), in coincidence with a beam-beam counter. The latter requires an additional signal in the forward muon spectrometer trigger system. Further background rejection was applied offline to reject beam-gas and beam-halo events. While for the analyses of central detector data only the minimum bias events were used, both types were used for those of the muon spectrometer data.

The results presented here correspond to the analysis of 140 M (110 M) minimum bias events for the mid-rapidity open-charm (J/ψ) analysis. At forward rapidity, the single-muon and quarkonium analyses are based on 4.7 M muon triggered events.

4. Open heavy flavour

The charm (c) and bottom (b) quarks production cross-sections can be measured in ALICE at both mid- and forward-rapidities. At mid-rapidity, they can be measured with hadronic decays or semi-leptonic decays ($e^{\pm}$) of heavy flavour hadrons. At forward-rapidity, the semi-leptonic $\mu^{\pm}$ decay method is used. The analysis techniques and expected performances in both p-p and Pb-Pb collisions have been thoroughly studied in [6].

Several D mesons have already been observed in p-p collisions at $\sqrt{s}$=7 TeV. The D^0 has been reconstructed in the decay channel $D^0 \rightarrow K^-\pi^+$, down from p_T=1 GeV/c up to 12 GeV/c as well as in the four prong decay $D^0 \rightarrow K^-\pi^+\pi^-\pi^+$ for $p_T > 3$ GeV/c. The D^+ is observed for $p_T > 2$ GeV/c in its three prong decay channel $D^+ \rightarrow K^+\pi^-\pi^+$. Finally, the D^{*+} is measured by reconstructing the topology of the decay $D^{*+} \rightarrow D^0\pi_s^+$ followed by $D^0 \rightarrow K^-\pi^+$. The D^* has been observed differentially for 2 GeV/c $< p_T <$ 18 GeV/c. More details on these analyses can be found in another contribution to these proceedings [7].

The corrected single electron distribution has been measured up to $p_T = 4$ GeV/c for $|\eta| < 0.8$. Tracking is performed in the ITS and TPC and the crucial electron identification is performed using the TPC and TOF signals. Better electron identification up to a momenta of about 15 GeV/c will be achieved with the TRD. The EMCAL will also play an important role in this range of momenta and higher. Further details can be found in another contribution to these proceedings [8].

The extraction of the heavy-flavour contribution from the single muon spectra requires the subtraction of three main sources of background: a) muons from the decay-in-flight of light hadrons (decay muons); b) muons from the decay of hadrons produced in the interaction with the front absorber (secondary muons); c) punch-through hadrons. The last contribution can be efficiently subtracted by requiring the matching of the tracks with the trigger. Due to the lower mass of the parent particles, the background muons have a softer transverse momentum than the heavy-flavour muons. They dominate for low transverse momentum and are negligible ($\sim 3\%$) for $p_T > 2$ GeV/c.

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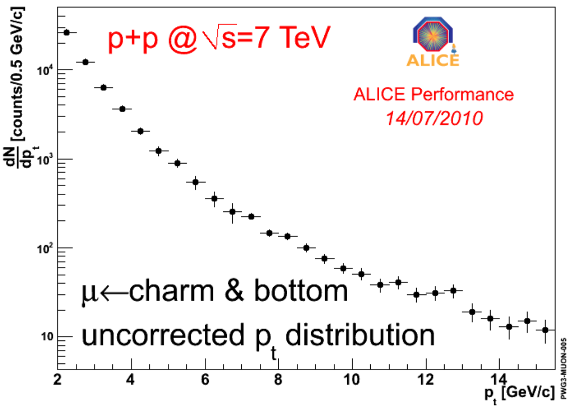

Figure 1: Uncorrected Single muon transverse momentum distribution in proton-proton collisions at 7 TeV.

In the latter region, the main source of background consists of decay muons ($\sim 25\%$), which have been subtracted by means of simulations. Figure 1 shows the resulting uncorrected transverse momentum distribution of single muons coming from heavy flavour hadrons decays in the $2 < p_T < 16$ GeV/c and $-4.0 < \eta < -2.5$ acceptance region.

5. Quarkonia

Quarkonium measurements can be performed in ALICE at both mid- and forward-rapidities in the di-electron and di-muon decay channels, respectively. The analysis techniques and expected performances in both p-p and Pb-Pb collisions have been thoroughly studied in [6].

The J/ψ is observed for $|\eta| < 0.9$ GeV/c in the e^+e^- invariant mass distribution. The electrons are tracked in the ITS and TPC and identified using the energy loss in the TPC. A drastic improvement of the mid-rapidity J/ψ analysis will be achieved by using the TOF signal and specially the TRD for the electron identification. More information can be found in another contribution to these proceedings [9].

The J/ψ is also measured for $-3.8 < \eta < -2.7$ in the $\mu^+\mu^-$ decay channel. The muons are reconstructed with the ALICE forward muon spectrometer and at least one of them is required to match with the muon trigger system in order to reduce the combinatorial background. The J/ψ signal is extracted in seven p_T bins from 0 to 8 GeV/c by fitting the invariant mass distribution with the sum of a Gaussian for the J/ψ signal and an exponential for the background. Acceptance and efficiency corrections as a function of p_T are computed using realistic Monte-Carlo simulations of the detector response. The corrected J/ψ transverse momentum distribution in arbitrary units is shown in figure 2.

We calculate the J/ψ $< p_T^2 >$ from a fit to the corrected transverse momentum distribution using the functional form first proposed in [10] and also used by several earlier experiments. The fit function as well as the resulting distribution is shown in figure 2. We obtain $< p_T^2 >= 9.4^{+1.4}_{-1.3}$ GeV/c^2. The quoted uncertainties are statistical and systematics due to the fit function. Further systematics uncertainties are under evaluation. Figure 3 shows the $< p_T^2 >$ as a function of the collision energy. The expected hardening of the J/ψ spectrum is observed in the increase of

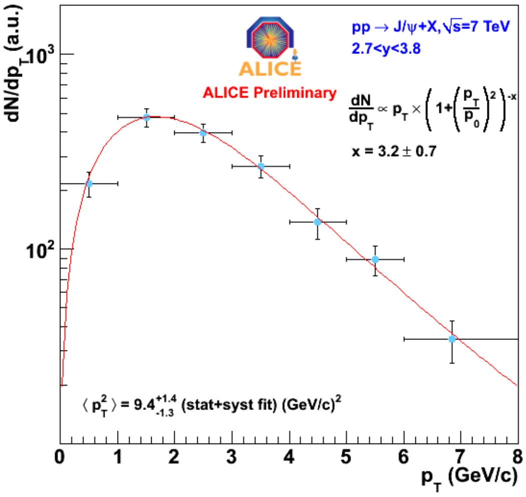

Figure 2: Acceptance and efficiency corrected J/ψ transverse momentum distribution.

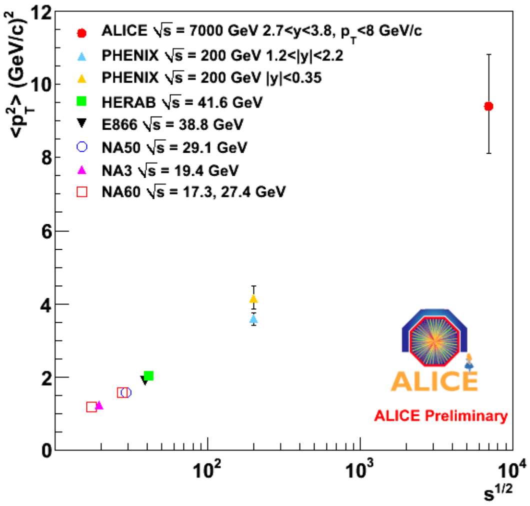

Figure 3: $J/\psi < p_T^2 >$ as a function of $\sqrt{s_{\rm NN}}$.

$< p_T^2 >$ with $\sqrt{s}$. Furthermore, the linear increase of $< p_T^2 >$ with $\log\sqrt{s}$ seems to hold up to LHC energies.

6. Conclusion

We have shown the first results on open heavy flavour and quarkonium production in p-p collisions at $\sqrt{s}$=7 TeV measured with the ALICE experiment at the LHC. This first measurements have revealed the ALICE potential in the heavy flavour physics sector. It has also contribute to understand and prepare the detector for the studies of the forthcoming Pb-Pb data at $\sqrt{s_{\rm NN}}$=2.76 TeV.

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