Quarkonia measurements with ALICE at the LHC

Magdalena MalekB for the ALICE collaboration

aInstitut de Physique Nucléaire d’Orsay (IPNO) - France
CNRS: UMR8608 - IN2P3 - Université Paris Sud - Paris XI

Abstract

In this paper, we summarize the perspectives on quarkonia detection in the ALICE experiment at the CERN LHC, both in the dielectron and dimuon decay channels.

1. Introduction

Quarkonia production in heavy ion collisions is considered to be one of the most powerful tools to probe the quark-gluon plasma (QGP) formation. In fact, the in-medium behavior of the J/ψ was proposed to test whether deconfinement has occurred. It was predicted that in a deconfined medium, color screening dissolves the c̅c bound state [1]. This result provided a strong motivation for experimental studies of quarkonia production at SPS and RHIC.

ALICE (A Large Ion Collider Experiment) [2, 3, 4] is the experiment dedicated to the study of heavy ion collisions in the unprecedented energy regime of the LHC (Large Hadron Collider) collider. Its goal is to study the properties of deconfined matter: the Quark Gluon Plasma (QGP).

The LHC will collide Pb-Pb at $\sqrt{s_{NN}} = 5.5$ TeV opening up new perspectives in the QGP study. To extract information about the QGP from Pb-Pb collisions, the comparison to less complex systems, for which deconfinement effects are not expected, is mandatory. The LHC will deliver p-p collisions ($\sqrt{s_{NN}}=14$ TeV) and p-Pb collisions ($\sqrt{s_{NN}} = 8.8$ TeV) providing a solid baseline for the Pb-Pb system.

The ALICE detector is composed of a central barrel system ($|\eta|<0.9$), a muon spectrometer (-4.0 < $\eta$ < -2.5) and several small additional detectors. Quarkonia will be measured in ALICE via the dielectron channel at midrapidity and via the dimuon channel at forward rapidity. In the following, we report on a selection of results from analyses which are being prepared on simulations.

2. Quarkonia detection in the dielectron channel

The measurement of electron pairs in the ALICE central barrel is provided by the combination of several detectors that are described here, as seen by a particle travelling out from the interaction point:

- Inner Tracking System (ITS) [5] allows 3-D reconstruction of the primary vertex, secondary vertex finding, and particle identification via $dE/dx$. It is composed of three subsystems of two layers each: the Silicon Pixel Detector, the Silicon Drift Detector and the Silicon Strip Detector.
• Time Projection Chamber (TPC) \cite{6}, optimized for large multiplicity environments, allows track finding, momentum measurement, and charged hadron identification via $dE/dx$. The detector has an inner radius of 0.9 m, an outer radius of 2.5 m and a length of 5.1 m. The momentum resolution for the track reconstruction, including TPC and ITS information, is expected to be better than 2\% for $p_t < 20$ GeV/c.

• Transition Radiation Detector (TRD) \cite{7} allows electron identification and also provides fast triggering. Electron identification is provided by the TRD for momenta larger than 1 GeV/c. This detector is made of 18 longitudinal supermodules, 6 radial layers, and 5 stacks along the beam axis.

The expected early statistic collected by ALICE for quarkonia measurements is summarized in Table 1. These numbers correspond to $10^6$ s data taking period of central (10\% most central) Pb-Pb collisions at a luminosity of $5 \times 10^{26}$ cm$^{-2}$s$^{-1}$ and for a charged particle multiplicity density $dN_{ch}/d\eta = 3000$. The invariant mass resolution for the quarkonia was studied in the full simulation. The reconstructed peaks were fitted by a Gaussian and the invariant mass resolution for the $J/\psi$ ($\Upsilon$) is found to be 30 (90) MeV/$c^2$. The analysis showed that the $J/\psi$ signal can be reconstructed up to $p_t = \unit[10]{GeV/c}$.

| state | S(x10$^{3}$) | B(x10$^{3}$) | S/B | S/$\sqrt{S+B}$ |
|-------|-------------|-------------|-----|----------------|
| $J/\psi$ | 121.1 | 88.2 | 1.4 | 265 |
| $\Upsilon$ | 1.3 | 0.8 | 1.6 | 28 |
| $\Upsilon'$ | 0.46 | 0.8 | 0.6 | 13 |

Table 1: Expected signal rates (S), background (B), signal-to-background ratios and significance, in the dielectron channel, for charmonia and bottomonia states integrated over full acceptance with an interval of $\pm 1.5\sigma$ around each resonance mass for Pb-Pb collisions. All yields correspond to annual data taking ($10^6$ s) at a luminosity of $5 \times 10^{26}$ cm$^{-2}$s$^{-1}$.

3. Quarkonia detection in the dimuon channel

The detection of muon pairs in the forward rapidity region is provided by the muon spectrometer \cite{8}. This detector contains a set of absorbers: a front absorber, a muon filter, a beam shielding and an absorber against the LHC background. The goal of these absorbers is to suppress hadron and electron background. The tracking system that allows the muon trajectory reconstruction is composed of five tracking stations with two detector planes each. The dipole magnet with a field integral of 3 Tm along the beam axis provides the bending power to measure the momenta of muons. Two trigger stations provide a fast electronic signal for the trigger selection of muon events. The $p_t$ cut of 1 (2) GeV/c applied to single muons allows charmonia (bottomonia) detection down to zero transverse momenta. The invariant mass resolution for the $J/\psi$ ($\Upsilon$) is expected to be around 70 (100) MeV/$c^2$. The high-$p_t$ reach for the $J/\psi$ is expected to be around 20 GeV/c. The expected quarkonia signal and background yields, and the corresponding signal-to-background ratios and significance for the 5\% most central collisions are presented in Table 2.
4. Prompt and secondary $J/\psi$

In addition to prompt $J/\psi$ and $\psi'$, also those from B decays have to be taken into account. The contribution of $J/\psi$ ($\psi'$) from B decay is about 22 (39) % of the total $J/\psi$ ($\psi'$) yields. To separate the prompt $J/\psi$’s from the secondary ones, dielectron pairs with a displaced vertex must be identified. In fact, the $J/\psi$ originating from B decay are produced at large distances (several hundred of microns) from the primary vertex. The vertexing capabilities of the ITS allow to apply this method in the central barrel. This analysis is not expected to be performed in the forward rapidity region because the muon spectrometer does not provide vertexing capabilities at present.

5. Suppression studies

Two extreme suppression scenarios were studied. The first one characterized by a high critical deconfinement temperature at $T_c = 270$ MeV [9] and the second one using $T_c = 190$ MeV [10]. The ratios of the resonance rates over those for beauty as a function of the number of participants were studied to check the detector ability to distinguish between different suppression scenarios. It was shown [3] that the error bars for $J/\psi$ and $\Upsilon$ to open beauty ratio are small enough to distinguish between these two suppression scenarios.

6. Quarkonia polarization

Quarkonia polarization measurements should allow to distinguish different production mechanisms, since different models predict different polarizations. Quarkonia polarization can be reconstructed from the angular distribution of the decay products (dimuons or dielectrons) in the quarkonia rest frame. It has been predicted that an increase of $J/\psi$ polarization may be expected if the QGP is formed [11].

It is expected that a measurement of the $J/\psi$ and $\Upsilon$ polarization (integrated over centrality) will be possible after an annual data taking of Pb-Pb collision. It can be seen in Fig. 1 that the background subtraction is mandatory to obtain a correct estimation of the $J/\psi$ polarization.

7. Summary

We presented an overview of the ALICE perspectives for quarkonia physics. We conclude that the quarkonia are interesting tools to probe the properties of the strongly-interacting medium.

| state | S(x10^3) | B(x10^3) | S/B | S/√S + B |
|-------|----------|----------|-----|----------|
| $J/\psi$ | 130      | 680      | 0.20| 150      |
| $\psi'$ | 3.7      | 300      | 0.01| 6.7      |
| $\Upsilon$ | 1.3      | 0.8      | 1.7 | 29       |
| $\Upsilon'$ | 0.35     | 0.54     | 0.65| 12       |
| $\Upsilon''$ | 0.20     | 0.42     | 0.48| 8.1      |

Table 2: Expected signal rates (S), background (B), signal-to-background ratios and significance, in the dimuon channel, for charmonia and bottomonia states for annual running time of Pb-Pb collisions at a luminosity of $5 \times 10^{26}$ cm$^{-2}$s$^{-1}$. The yields correspond to an interval of ±2σ around the resonance mass.
formed in heavy ion collisions. The ALICE detector can measure quarkonia in the dielectron and dimuon channels in different rapidity domains. It can detect quarkonia down to $p_t = 0$ in both channels. The excellent tracking, vertexing and particle identification capabilities of ALICE will allow us to explore this very rich topic. It is believed that the large statistics of quarkonia expected at the LHC and the experimental capabilities of the ALICE detector will help to clarify the quarkonia production picture that is still today one of the most discussed topics in heavy-ion physics.

References

[1] T. Matsui and H. Satz, Phys. Lett. B178 (1986) 416.
[2] ALICE Collaboration, Physics Performance Report Volume I, J. Phys. G30 (2003) 1517.
[3] ALICE Collaboration, Physics Performance Report Volume II, J. Phys. G32 (2006) 1295.
[4] ALICE Collaboration, JINST 0803 (2008) S08002.
[5] ALICE Collaboration, Technical Design Report of Inner Tracking System, CERN/LHCC 1999-12.
[6] ALICE Collaboration, Technical Design Report of Time Projection Chamber, CERN/LHCC 2000-01.
[7] ALICE Collaboration, Technical Design Report of Transition Radiation Detector, CERN/LHCC 2001-21.
[8] ALICE Collaboration, Technical Design Report of Dimuon Forward Spectrometer, CERN/LHCC 1999-22.
[9] W.M. Alberico, A. Beraudo, A. De Pace, A. Molinari, Phys. Rev. D72 (2005) 114011.
[10] C. Y. Wong, [arXiv:hep-ph/0507084v1].
[11] B. L. Ioffe, D. E. Kharzeev, Phys. Rev. C68 (2003) 061902.