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High-mass dimuon resonances in Pb-Pb collisions at 5.5 TeV in CMS

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Abstract

The measurement of the charmonium (J/ψ, ψ') and bottomonium (Υ, Υ', Υ'') resonances and Z^0 boson in nucleus-nucleus collisions provides crucial information on high density QCD matter. The observation of anomalous suppression of J/ψ at the CERN-SPS and RHIC is well established but the clarification of some important questions requires equivalent studies of the Υ family, only possible at LHC energies. The Z^0 boson will be produced for the first time in heavy-ion collisions at the LHC and, since its dominant production channel is through $q\bar{q}$ fusion, it is an excellent probe of the nuclear modification of quark distribution functions. This paper reports the capabilities of the CMS detector to study quarkonium and Z^0 production in Pb-Pb collisions at 5.5 TeV, through the dimuon decay channel.

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1 Introduction

Heavy Ion Collisions at the LHC will explore regions of energy and particle density significantly beyond those reachable at RHIC. The charmonium studies in heavy-ion collisions at the SPS and at RHIC revealed a significant *anomalous* suppression in Pb-Pb and Au-Au collisions at $\sqrt{s_{NN}}$ = 17.3 GeV [1] and 200 GeV [2], respectively. At the LHC energies, the Υ family will become accessible with much larger cross sections [3] and may answer some unresolved questions on the interpretation of the quarkonium suppression data. Heavy quarks are produced mainly via gluon-gluon fusion, which is sensitive to saturation of the gluon density at low-x in the nucleus (Colour Glass Condensate). Quarkonium production cross sections in Pb-Pb collisions at the LHC will, thus, give information relevant to the study of the partonic medium and of the initial-state modifications of the nuclear parton distribution functions.

At the high collision energies of LHC, the cross section for processes with Q^2 >(50 GeV)^2 is large enough for detailed systematic studies. Z^0 production proceeds predominantly through the $q\bar{q}$ channel. Hence, it provides a unique opportunity to study the modifications of quark distributions in the nucleus at high $Q^2 = m^2{}_{Z^0}$ [4]. The CMS detector [5] is designed to identify and precisely measure muons over a large energy and rapidity range and is well suited to study quarkonium and Z^0 production in their dimuon decay channel.

This work presents the expected capabilities of CMS to measure the heavy-quarkonia and Z^0 cross sections, versus centrality, rapidity (y) and transverse momentum ($p_{\rm T}$), in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.5 TeV, via their dimuon decay channel. The dimuon mass resolution, the signal over background ratio and the expected yields as a function of $p_{\rm T}$, y, and centrality in one-month Pb-Pb running are presented [6].

2 Simulation of signal and backgrounds for quarkonia and Z^0

The signal and background dimuons for quarkonium studies are obtained from realistic distributions: NLO pQCD for heavy-quark production processes [7] and HIJING [8] for the soft background. The quarkonium production cross sections per nucleon-nucleon collision are calculated to NLO using the color evaporation model (CEM) [7], taking account of shadowing effects, whereas the Z^0 production cross section per nucleon-nucleon collision is calculated using PYTHIA6.409 [9]. The Pb-Pb cross sections are obtained by scaling the per nucleon cross section with A^2, where $A = 208$. A main source of background in the dimuon invariant mass spectrum is combinatorial muon pairs from the decays of charged pions and kaons (which represent about 90% of the total produced charged particles), simulated using input $d^2N/dp_{\rm T}dy$ distributions from HIJING, for multiplicities $\frac{dN_{ch}}{d\eta}\ |_{\eta=0}$ = 2500 and 5000 (lower and upper limit) in the 0–5% most central Pb-Pb collisions. Another source of background is due to muons from open heavy flavour (D,B) meson decays. The expected average multiplicities for signal high mass dimuon resonances per head-on Pb-Pb collision at $\sqrt{s}$=5.5 TeV are: J/ψ: 0.034; ψ': 6.2×10^{-4}; Υ: 2.1×10^{-4}; Υ': 5.6×10^{-5}; Υ'': 3.0×10^{-5}; and Z^0: 4.8×10^{-5}. The corresponding values for "minimum bias collisions" are: 6.3×10^{-3}; 1.3×10^{-4}; 3.8×10^{-5}; 1.0×10^{-5}; 5.7×10^{-6}; and 8.9×10^{-6}. The number of dimuons from D,B meson decays, per head-on Pb-Pb collision, (with shadowing) is 150 from charm and 5 from beauty. The values for "minimum bias collisions" are five times smaller.

2.1 Dimuon Reconstruction and analysis

The CMS detector response to muons is parametrised by 2 dimensional (p, η) acceptance and trigger tables. The track is accepted or rejected according to the heavy-ion dimuon trigger criteria. The J/ψ and Υ acceptances were calculated as a function of p_T for $|\eta| < 2.4$. The J/ψ acceptance increases with $p_{\rm T}$, flattening out at $\sim$ 15% for $p_{\rm T} \geq$ 12 GeV/c, whereas the Υ acceptance starts at $\sim$40% and flattens out at $\sim$ 15% for $p_{\rm T} > 4$ GeV/c. The $p_{\rm T}$-integrated acceptance (within $|\eta| < 2.4$) is about 1.2% for the J/ψ, 26% for the Υ and 58% for the Z^0. The dimuon reconstruction algorithm used in the heavy-ion analysis is a modification of the regional track finder and is based on the muons seeded by the muon stations and on the knowledge of the primary vertex. The dependence of the Υ reconstruction efficiency on the Pb-Pb charged-particle multiplicity was obtained from a full GEANT simulation using the Υ signal dimuons embedded in HIJING events. Figure 1 shows the Υ efficiency and purity as a function of the charged-particle density. In the central barrel, the dimuon reconstruction efficiency remains above 80% for all multiplicities. The purity decreases slightly with increasing $\frac{dN_{ch}}{dy}\ |_{y=0}$ but also stays above 80% even at multiplicities as high as $\frac{dN_{ch}}{dy}\ |_{y=0}$ = 6500. About 5×10^7 Pb-Pb collisions were simulated with the fast simulation software of CMS, as described in [3, 6]. Muons passing the acceptance tables are combined to form pairs and each pair is weighted according to the trigger and reconstruction efficiencies (dependent on the momentum, pseudorapidity, purity and event multiplicity), as determined with the full simulation. The different

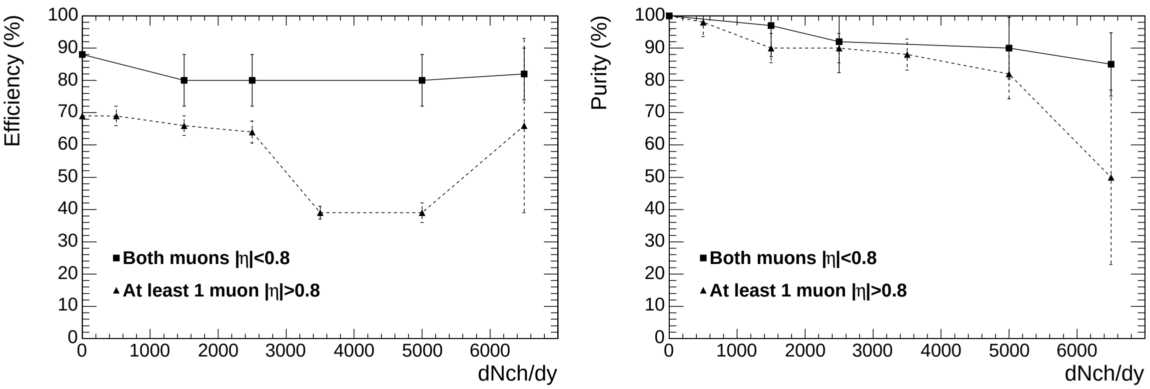

Figure 1: Υ reconstruction efficiency (left) and purity (right) as a function of the Pb-Pb charged particle rapidity density $\frac{dN_{ch}}{dy}\ |_{y=0}$.

quarkonium resonances appear on top of a continuum due to the random pairing of muons from decays of pions, kaons, charm mesons and bottom mesons. The background of uncorrelated muon pairs is determined from the like-sign muon pairs mass distribution and subtracted from the opposite-sign dimuon mass distribution, giving us a better access to the quarkonium decay signals, as shown in Fig. 2 for $\frac{dN_{ch}}{d\eta}\ |_{\eta=0}= 5000$ and $|\eta| < 2.4$. The dimuon mass resolution is about 1% of the quarkonium mass: 35 MeV/c^2 at the J/ψ mass and 86 MeV/c^2 at the Υ mass.

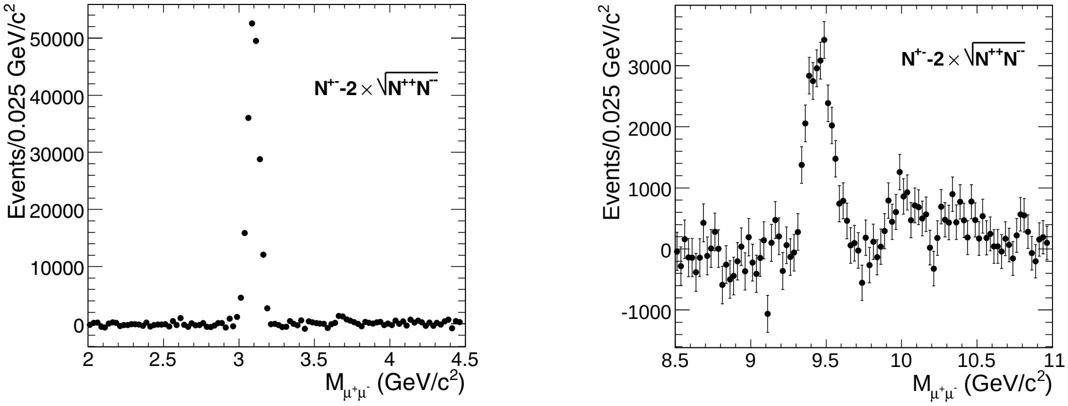

Figure 2: Signal dimuon mass distributions in the J/ψ (left) and Υ (right) mass regions, as expected after one month of Pb-Pb running (0.5 nb^{-1}) for $\frac{dN_{ch}}{d\eta}\ |_{\eta=0}= 5000$ and $|\eta| < 2.4$, assuming no quarkonium suppression.

Figure 3 shows the expected dimuon mass distribution from Z^0 dimuon decays and from several background sources (heavy flavours, Drell-Yan, pion and kaon decays, and mixed origins). A clear signal from $Z^0 \rightarrow \mu^+\mu^-$ decays is seen, of about 11 000 events within $M_Z \pm 10$ GeV/c^2, with less than 5% background.

3 Summary

CMS can reconstruct the charmonium and bottomonium resonances, via their dimuon decay channel, with large acceptances, high efficiencies, good purity and a very good dimuon mass resolution, even in the case of exceptionally high multiplicities. The large acceptance in CMS will enable detailed studies of the nuclear quark distribution functions in a kinematic regime never probed before.

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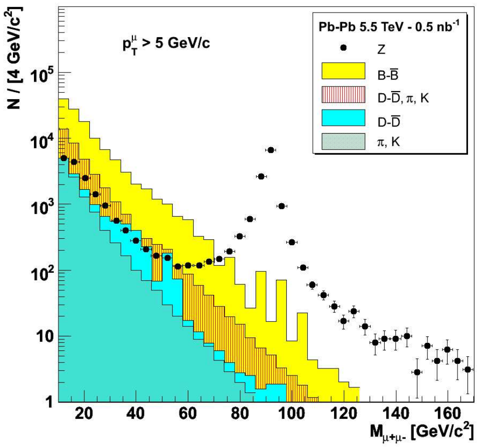

Figure 3: Expected $Z^0 \rightarrow \mu\mu$ signal and combinatorial dimuon background, for $p_{\mathrm{T}}^{\mu} > 5$ GeV/c and $|\eta^{\mu}| < 2.4$, after one month of Pb-Pb running (0.5 nb^{-1} integrated luminosity)

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