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

Dipanwita Dutta for CMS Collaboration

Nuclear Physics Division, Bhabha Atomic Research Centre, Trombay, Mumbai, India 400085

E-mail: dutta.dipa@gmail.com

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. Z^0 bosons will be produced for the first time in heavy-ion collisions at the LHC and, since their dominant production channel is through $q\bar{q}$ fusion, it is an excellent probe of the nuclear modification of quark distribution functions. The capabilities of the CMS detector to study the quarkonia and Z^0 boson production in Pb-Pb collisions at 5.5 TeV through the dimuon decay channel, are reported.

1. Introduction

Heavy Ion Collisions at the LHC will explore the region of energy and particle density significantly beyond those reachable at RHIC and hence give rise to qualitatively new probes. The charmonia studies in heavy-ion collisions at the SPS and at RHIC reveals a factor of $\sim$2–3 *anomalous* suppression in Pb-Pb and AuAu collisions at $\sqrt{s_{NN}} = 17.3$ GeV [1] and 200 GeV [2], respectively. Only part of the suppression observed at RHIC can be explained by calculations including shadowing and cold nuclear matter absorption effects. At the LHC energies the Υ family will become accessible with much larger cross-sections [3] and may answer some unresolved questions of quarkonia suppression. 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). Quarkonia cross-sections in Pb-Pb collisions at the LHC will thus give information of both the partonic medium as well as initial-state modifications of the nuclear parton distribution functions.

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

In this work 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 are presented. The dimuon mass resolutions, 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 physics and background for Quarkonia and Z^0

The signal and background dimuons for quarkonia 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 color evaporation model (CEM) [7] taking account of shadowing effect where as Z^0 production cross-sections per nucleon-nucleon collision are calculated using PYTHIA6.409 [9]. The Pb-Pb cross sections are obtained by scaling the per nucleon cross section with A^2, where $A = 208$. The two main sources of background in the dimuon invariant mass spectrum are: (1) Combinatorial muon pairs from the decays of **charged pions and kaons** which represent about 90% of the total produced charged particles and 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. (2) Another source of background is due to muons from **open heavy flavour** (D,B) meson decays. The expected average multiplicities N_{PbPb} for signal high mass dimuon resonances per head-on (min-bias) Pb-Pb collisions at $\sqrt{s}$=5.5 TeV are : $J/\psi \to \mu\mu$: 0.034 (6.3×10^{-3}); $\psi' \to \mu\mu$: 6.2×10^{-4} (1.3×10^{-4}); $\Upsilon \to \mu\mu$: 2.1×10^{-4} (3.8×10^{-5}), $\Upsilon' \to \mu\mu$: 5.6×10^{-5} (1.0×10^{-5}); $\Upsilon'' \to \mu\mu$: 3.0×10^{-5} (5.7×10^{-6}) and $Z^0 \to \mu\mu$: 4.8×10^{-5} (8.9×10^{-6}). The heavy-quark background expected per head-on (minimum bias) Pb-Pb collisions with shadowing are: $N_{PbPb}(c\bar{c})$= 150 (26) and $N_{PbPb}(b\bar{b})$= 5 (1).

2.1. Dimuon Reconstruction and analysis

The CMS detector response to muons are 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 acceptance of J/ψ and Υ is studied as a function of p_T for $|\eta| < 2.4$. J/ψ acceptance increases with $p_{\rm T}$, flattening out at $\sim$ 15% for $p_{\rm T} \geq$ 12 GeV/c. whereas Υ acceptance starts at $\sim$40% and remains constant at $\sim$ 15% for $p_{\rm T} > 4$ GeV/c. The $p_{\rm T}$-integrated acceptance is about 1.2% for the J/ψ and 26% for the Υ and $p_{\rm T}$ integrated acceptance for Z^0 is 58%. 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 charged-particle density. In the central barrel, the dimuon reconstruction efficiency remains above 80% for all multiplicities whereas 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 generated with the fast MC, as described

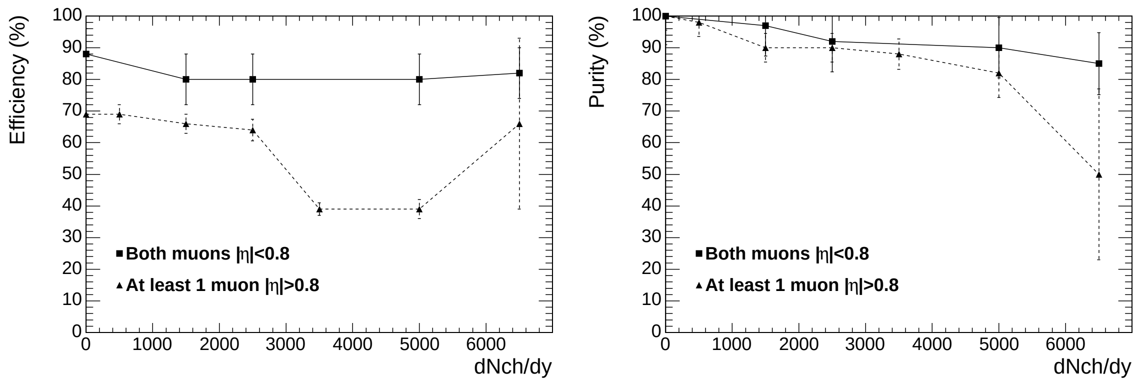

Figure 1. Υ reconstruction efficiency (left) and purity (right) as a function of the Pb-Pb charged particle rapidity density $\frac{dN_{ch}}{dy}|_{y=0}$.

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) determined with the full simulation. The different quarkonia resonances appear on top of a continuum due to the various sources of decay muons: $\pi + K$, charm and bottom decays. The background of uncorrelated muon pairs, which contribute to the like-sign muon pairs mass distribution, are subtracted from the opposite-sign dimuon mass distribution, giving us a better access to the quarkonia decay signals as shown in Figure 2 for $\frac{dN_{ch}}{d\eta}|_{\eta=0}= 5000$ and $|\eta| < 2.4$. In the *full* pseudorapidity range, the dimuon mass resolution is about 1% of the quarkonium mass: 35 MeV at the J/ψ mass and 86 MeV at the Υ mass.

Figure 3 shows the expected dimuon mass distribution from signal Z^0 and backgrounds from heavy flavour, Drell-Yan, hadronic decays from π and K and mixed orgin. A clear signal from $Z^0 \rightarrow \mu^+\mu^-$ decays is seen, 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 (26% for the Υ and 1.2% for the J/ψ), high efficiencies ($\sim$80%), good purity ($\sim$90%) and a very good dimuon mass resolution (54 MeV at the Υ mass), when both muons are detected in the central barrel ($|\eta| < 0.8$), even in the case of exceptionally high multiplicities ($\frac{dN_{ch}}{d\eta}|_{\eta=0}\approx 5000$). The large acceptance

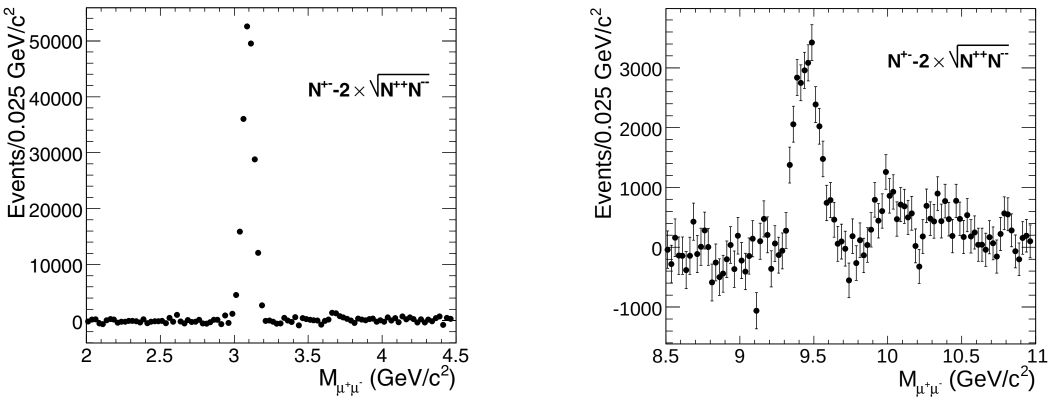

Figure 2. Signal dimuon mass distributions in the J/ψ (left) and Υ (right) mass regions, as expected after one month of Pb-Pb running (0.5 nb^{-1}) for $\frac{dN_{ch}}{d\eta}\ |_{\eta=0}= 5000$ and $|\eta| < 2.4$ assuming no quarkonia suppression.

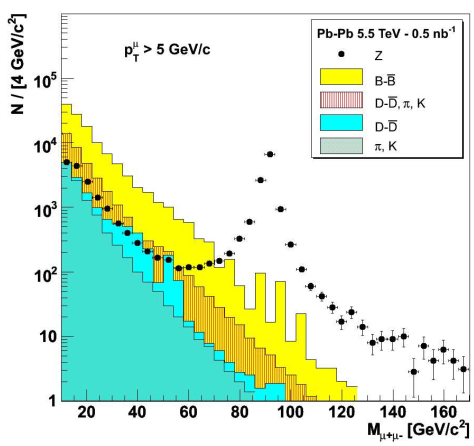

Figure 3. Expected $Z^0 \rightarrow \mu\mu$ signal and combinatorial dimuon background, $p_{\mathrm{T}}^{\mu} > 5$ GeV/c and $|\eta^{\mu}| < 2.4$ after one month of Pb-Pb running (0.5 nb^{-1})

in CMS will allow for detailed studies of the nuclear quark distribution functions in a kinematic regime never probed before.

References

[1] M. C. Abreu *et al.* (NA50 Collaboration), Phys. Lett. B477, 28 (2000).
[2] A. Adare (PHENIX Collaboration), Phys. Rev. Lett. 98 232301(2007).
[3] CMS PTDR: Addendum on High Density QCD with Heavy Ions, D d'Enterria et al. J. Phys. G. Nucl. Part. Phys. 34 (2007) 2307-2455.
[4] R. Vogt, Phys. Rev. C64, 044901 (2001).
[5] The CMS Physics Technical Design Report, Vol.I CERN/LHCC 2006-001.
[6] M. Bedjidian and O. Kodolova, CMS Note 2006/089, 2006.
[7] M. Bedjidian, hep-ph/0311048 (2003).
[8] X. N. Wang and M. Gyulassy, Phys. Rev. D44, 3501 (1991).
[9] Torbjrn Sjstrand, Leif Lnnblad, Stephen Mrenna, PYTHIA6.32 Physics and Manual.