Recent Bottomonium measurement in pp, p–Pb and Pb-Pb collisions

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Bottomonium measurement in the heavy-ion collisions provide a useful tool to study both initial-state effects on heavy-quark production and final-state interactions between heavy quarks and the deconfined medium, quark-gluon plasma (QGP). At the LHC, bottomonium production has been measured in pp, p–Pb and Pb–Pb collisions at various centre-of-mass energy per nucleon. This manuscript reports the recent bottomonium measurements.

Many theoretical model have been proposed for quarkonium production in pp collisions: the colour singlet model (CSM), the colour evaporation model(CEM) and the most recent effective field theory, nonrelativistic QCD (NRQCD). None of the existing models fully describe the quarkonium production. The polarisation constrains quarkonium production mechanisms to test the current knowledge of QCD. The NLO calculations predict small polarisation for Υ(1S) and Υ(2S) states, but a strong transverse polarisation for Υ(3S) at high p_T, whereas in ICEM (k_T-factorization approach) model there is no significant differences in polarizations among the $\Upsilon(nS)$ states. The ALICE, CMS, LHCb measured the bottomonium polarizations and the polarizations parameter are consistent with zero within the uncertainties in both HE and CS frames [2]. The Υ(nS)/Υ(1S) yields ratio decreases as a function of multiplicity observed by the CMS collaboration and suggested the connection with the underlying event(UE). The modification of the UE for bottomonium states in pp collisions have been studied by ATLAS collaboration. Fig. 1 shows the strong difference in the multiplicity of the UE for different $\Upsilon(nS)$ states [1].

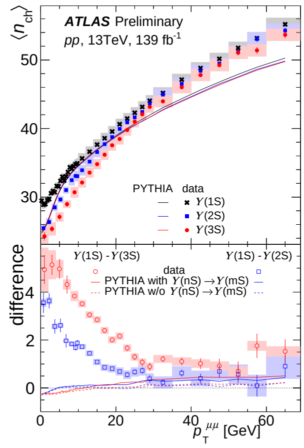

FIG. 1: The mean number of charged particles as function of $p_{\rm T}$ for $\Upsilon(nS)$

The azimuthal anisotropic "elliptic" flow is usually quantified in terms of the second harmonic coefficient (v_2) of the Fourier decomposition of the azimuthal particle distribution. The strong azimuthal correlations are measured among particles emitted over a wide range of rapidity in Pb–Pb collisions at the LHC experiments. These correlations are thought to arise from the creation of a strongly interacting QGP medium that shows nearly ideal hydrodynamic behaviour. Similar long-range correlations have been measured in high multiplicity events in pp and p–Pb collisions. Positive v_2 of J/ψ value has been reported in p–Pb collisions by the CMS and ALICE experiment indicating that heavy flavour quarks may also be thermalized in this lighter system. However, collective flow behaviour is not found for Υ(nS) in Pb–Pb collisions. The v_2 of Υ(1S) is consistent with zero within the uncertainties in p–Pb collisions [3]. Regardless

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of the system size, it is found that the bottomonium v_2 is consistent with zero and hints of different behaviour for charmonia and bottomonia production mechanism.

The modification of J/ψ production at LHC energies with respect to the binary-scaled yield in pp collisions has been explained as an interplay of the suppression and the regeneration mechanisms commonly studied using the nuclear modification factor ($R_{\rm AA}$). For bottomonium states, $R_{\rm AA}$ measurements have been reported by the LHC and RICH experiments. The results show significant suppression of Υ(1S) mesons in heavy ion collisions, while the Υ(2S) meson are even more suppressed. The zero v_2 suggest negligiable regeneration in bottomonium sector. Recenty, the Υ(3S) meson is observed for the first time in Pb–Pb collisions by the CMS experiment [4] and the amount of suppression is found to be stronger than for the Υ(2S) meson as shown in Fig. 2. The $R_{\rm AA}$ of Υ(2S) and Υ(3S) are found to be decrease gradually towards more central collision. Combined with previous LHC measurements, the new CMS results reveal the sequential suppression of Υ(1S), Υ(2S), and Υ(3S) mesons in heavy ion collisions. The larger data samples expected in Run 3 and Run 4, together with improved detector performance and measurement techniques, will significantly improve the bottomonium measurements with extended kinematic coverage.

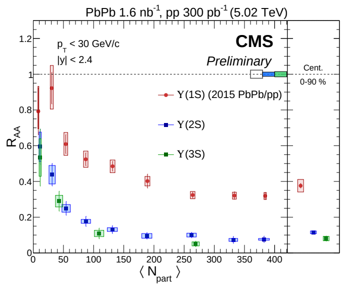

FIG. 2: The $R_{\rm AA}$ for $\Upsilon(nS)$ as function of $\langle N_{\rm part}\rangle$ where the $\langle N_{\rm part}\rangle$ is average number of participating nucleons in Pb–Pb collisions for the given centrality interval.

References

[1] ATLAS-CONF-2022-023
[2] Phys. Rev. **D 99** (2019) 3, 034007
[3] CMS-PAS-HIN-21-001
[4] CMS-PAS-HIN-21-007