The Compact Muon Solenoid Experiment
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CMS results on heavy ion physics

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Abstract

We present a summary of recent heavy ion results with the CMS detector at the LHC, including several topics of interest to the study of quark matter.

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CMS RESULTS ON HEAVY ION PHYSICS

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Abstract. We present a summary of recent heavy ion results with the CMS detector at the LHC, including several topics of interest to the study of quark matter.

1 Introduction

The experiments at the LHC have reported new results in pp, pA, and AA collisions over the past years. This proceeding briefly presents the most interesting results from the CMS Collaboration on quark matter. The Compact Muon Solenoid is a general purpose detector very well suited for the study of heavy ion collisions, its detailed description can be found in [1]. First heavy ion collisions occurred in CMS on 7 November 2010, and after almost ten years of operation we have published nearly one hundred heavy ion papers and have also shown a number of recent preliminary results. All of the CMS heavy ion papers can be found at the CMS website [2].

2 Soft probes in heavy ion collisions with the CMS detector

Soft probes, i.e. particles with low transverse momentum p_T , allow us to see the global picture of heavy ion collisions.

The pseudorapidity distributions of charged hadrons in pPb collisions at nucleon-nucleon center-of-mass energies $\sqrt{s_{NN}} = 5.02$ and 8.16 TeV were presented [3]. The particle densities per participant nucleon are compared to similar measurements in other experiments, $\sqrt{s_{NN}}$ -dependences for pp, pA, AA collisions follow power laws.

The almost hermetic coverage of the CMS detector was used to measure the distribution of transverse energy, E_T , over 13.2 units of pseudorapidity η [4].

Long-range ($2 < |\Delta\eta| < 4$), near-side (azimuthal angle $\Delta\phi \approx 0$) angular correlations were observed with the CMS detector in high multiplicity pp [5] and pPb [6] collisions (as well as in PbPb [7]) — so-called “ridge”-effect. One of the possible interpretation of the “ridge”-effect is the interplay of independent elliptical and triangular harmonics [8] (with HYDJET++ Monte-Carlo generator [9]).

Measurements of two- and multi-particle angular correlations in pp collisions were presented as a function of charged-particle multiplicity [10]. For high-multiplicity pp events, a mass ordering is observed for the values of charged hadrons (mostly pions), K_S^0 , and $\Lambda/\bar{\Lambda}$, with lighter particle species exhibiting a stronger azimuthal anisotropy signal below the transverse momentum $p_T \approx 2$

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GeV/ c . These observations are similar to those seen in pPb and PbPb collisions [11], and support the interpretation of a collective origin for the observed long-range correlations in high-multiplicity pp collisions.

The elliptic azimuthal anisotropy coefficient v_2 was measured for charm and strange hadrons in pPb collisions collected by the CMS experiment at $\sqrt{s_{NN}} = 8.16$ TeV [12]. A significant positive v_2 signal from long-range azimuthal correlations is observed for all particle species in high-multiplicity pPb collisions. The results suggest that charm quarks have a smaller v_2 than the lighter quarks, probably reflecting a weaker collective behavior.

Azimuthal correlations of charged particles in XeXe collisions at $\sqrt{s_{NN}} = 5.44$ TeV were studied [13]. The magnitude of the v_2 coefficients for XeXe collisions is larger than those found in PbPb collisions for the most central collisions. This is attributed to a larger fluctuation component in the lighter colliding system. Hydrodynamic models that consider the Xe nuclear deformation [14] are able to better describe the $v_2[\text{XeXe}]/v_2[\text{PbPb}]$ ratio in central collisions than those assuming a spherical Xe shape — see Figure 1.

Figure 1: Centrality dependence of the spectrum-weighted second v_2 , third v_3 , and fourth v_4 harmonic coefficients from two-particle correlations method for $0.3 < p_T < 3.0$ GeV/ c for XeXe and PbPb collisions. The lower panels show the ratio of the results for the two systems. Theoretical predictions from Ref. [14] are compared to the data (filled area) [13].

3 Hard probes in heavy ion collisions with the CMS detector

Hard probes, i.e. particles with large p_T and/or high mass, are of crucial importance for quark matter studies.

The cross sections for $\Upsilon(1S)$, $\Upsilon(2S)$, and $\Upsilon(3S)$ production in PbPb and pp collisions at $\sqrt{s_{NN}} = 5.02$ TeV have been measured [15]. The nuclear

modification factors, R_{AA} , derived from the PbPb-to-pp ratio of yields for each state, are studied as functions of meson rapidity and transverse momentum, as well as PbPb collision centrality. The yields of all three states are found to be significantly suppressed, and compatible with a sequential ordering of the suppression — see Figure 2. No sign of $\Upsilon(3S)$ was found.

Figure 2: Invariant mass distribution of muon pairs in PbPb collisions, for the kinematic range of muon pair transverse momentum $p_T(\mu^+\mu^-) < 30$ GeV/ c and rapidity $|y(\mu^+\mu^-)| < 2.4$. The results of the fits to the data are shown as solid lines. The dashed lines are the result of the fits (solid line). In order to show the suppression of all three Υ states, the amplitudes of the corresponding peaks are increased above those found in the fit by the inverse of the measured R_{AA} for the corresponding Υ meson [15].

Jet production in PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV was studied with the CMS detector [16]. For the most peripheral PbPb collisions, good agreement of the dijet momentum balance distributions with pp data and reference calculations at the same collision energy is found, while more central collisions show a strong imbalance of leading and subleading jet transverse momentum attributed to the jet-quenching effect. The dijets in central collisions are found to be more unbalanced than the reference, for leading jet transverse momentum up to the highest values studied [17]. A redistribution of energy from small to large angles from the jet axis is observed for PbPb relative to pp events, with the most pronounced effect seen for central collisions [18]. The energy flow within the jet is modified by shifting the momentum away from the jet axis out to large relative angular distances such that in central PbPb collisions, the ratio of the jet shapes in PbPb to pp collisions approaches a value of two.

The differential yields of charged particles within $|\eta| < 1$ are measured using XeXe collisions at $\sqrt{s_{NN}} = 5.44$ TeV [19]. The yields are reported as functions of collision centrality and $p_T = 0.5 - 100$ GeV/ c . A previously reported p_T

spectrum from pp at $\sqrt{s} = 5.02$ TeV [20] is used for comparison after correcting for the difference in center-of-mass energy. The nuclear modification factors using this reference, R_{AA}^* , are constructed and compared to previous measurements and theoretical predictions. In head-on collisions, the R_{AA}^* has a value of 0.17 in the p_T range of 6–8 GeV/ c , but increases to approximately 0.7 at 100 GeV/ c . Above ≈ 6 GeV/ c , the XeXe data show a notably smaller suppression than previous results for PbPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV [21] when compared at the same centrality (i.e., the same fraction of total cross section). However, the XeXe suppression is slightly greater than that for PbPb in events having a similar number of participating nucleons.

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- [1] CMS Collaboration, JINST **3** S08004 (2008) S08004.
- [2] <http://cms-results.web.cern.ch/cms-results/public-results/publications/HIN/>
- [3] CMS Collaboration, J. High Energy Phys. **01** (2018) 045.
- [4] CMS Collaboration, Phys. Rev. **C 100** (2019) 024902.
- [5] CMS Collaboration, J. High Energy Phys. **09** (2010) 091.
- [6] CMS Collaboration, Phys. Lett. **B 718** (2013) 795.
- [7] CMS Collaboration, J. High Energy Phys. **07** (2011) 076.
- [8] G. Eyyubova et al., Phys. Rev. **C 91** (2015) 064907.
- [9] I. Lokhtin et al., Comp. Phys. Comm. **180** (2009) 779.
- [10] CMS Collaboration, Phys. Lett. **B 765** (2017) 193.
- [11] CMS Collaboration, Phys. Lett. **B 724** (2013) 213.
- [12] CMS Collaboration, Phys. Rev. Lett. **121** (2018) 082301.
- [13] CMS Collaboration, Phys. Rev. **C 100** (2019) 044902.
- [14] G. Giacalone et al., Phys. Rev. **C 97** (2018) 034904.
- [15] CMS Collaboration, Phys. Lett. **B 790** (2019) 270.
- [16] CMS Collaboration, Phys. Rev. **C 84** (2011) 024906.
- [17] CMS Collaboration, Phys. Lett. **B 712** (2012) 176.
- [18] CMS Collaboration, J. High Energy Phys. **05** (2018) 006.
- [19] CMS Collaboration, J. High Energy Phys. **10** (2018) 138.
- [20] CMS Collaboration, Eur. Phys. J. **C 72** (2012) 1945.
- [21] CMS Collaboration, J. High Energy Phys. **04** (2017) 039.