Baryon anti-baryon annihilation effect on strange baryons production & apparent strangeness enhancement at SPS energy

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A deconfined medium of quarks and gluons, the quark gluon plasma (QGP) is produced in heavy ion collisions at relativistic energies. One of the signatures of the QGP formation is the "strangeness enhancement" which reflect itself as relative enhancement of strange over non-strange particles. Indeed a non-monotonic energy dependence was observed in K/π ratios at CERN SPS. Besides that, an apparent signature of strangeness enhancement was also observed in the baryon sector in $\bar{\Lambda}/\bar{p}$ ratios. While K and π can be produced from resonance decays, $\bar{\Lambda}$ and $\bar{p}$ are rather considered cleaner probe for strangeness enhancement because later are both anti-particles which are solely produced from collisions as well because of their high mass, resonance contributions are relatively less particularly at SPS energy.

Strangeness production is in general favoured in the partonic medium because of abundant production of strange and anti-strange quarks from gluon-gluon fusion. This may cause a relative enhancement in strange particle production over non-strange particles after the hadronization. However, it is to be remembered, particularly at the SPS energy range where the baryon density is high, post-hadronization effects can also modify the yields of the particles in a way that it mimics the signatures of strangeness enhancement. Particularly, for $\bar{\Lambda}$ and $\bar{p}$ baryon anti-baryon(B$\bar{\text{B}}$)-annihilation can have significant effect.

In this work we investigate how B$\bar{\text{B}}$-annihilation can impact Λ-$\bar{\Lambda}$ production in the final state, as well as, its effect on $\bar{\Lambda}/\bar{p}$ ratios at SPS energy range. We use UrQMD (Ultra-relativistic Quantum Molecular Dynamics) hadronic transport model to simulate Pb+Pb collisions with and without incorporating the $B\bar{B}$-annihilation in the final state. The annihilation cross section in UrQMD is parameterized as per the Eq. 1.

$$\sigma_{ann}^{\mathrm{p\bar{p}}} = \sigma_0^{\mathrm{N}} \frac{s_0}{s}[\frac{A^2 s_0}{(s-s_0)^2 + A^2 s_0} + B], \quad (1)$$

where σ_0^{N} = 120 mb, s_0 = 4m$_N^2$, A = 50 MeV and B = 0.6. [1]. For strange baryons, annihilation cross section is scaled by a correction factor based on Additive Quark Model (AQM) which suppresses the annihilation probability for strange baryons and anti-baryons. The parameters in the model are constrained to reproduce inclusive yields of particles in the data. For this study, we generated about a million Pb+Pb UrQMD events in impact parameter range 0 < b < 3.4 fm at $\sqrt{s_{NN}}$ = 6.27 GeV, 7.62 GeV, 8.77 GeV, 12.3 GeV and 17.3 GeV with and without incorporating the B$\bar{\text{B}}$ annihilation.

We first study the effect of B$\bar{\text{B}}$ annihilation on the average transverse mass ($\langle m_T \rangle$- m$_0$) of Λ and $\bar{\Lambda}$ as a function of $\sqrt{s}$. It is interesting to note, although Λ and $\bar{\Lambda}$ have same mass, their $\langle m_T \rangle$- m$_0$ exhibit difference in magnitude and the difference is seen to increase with the decrease in beam energy or increase in net baryon-density. In Fig. 1, we present UrQMD results for $\langle m_T \rangle$- m$_0$ for Λ and $\bar{\Lambda}$ as a function of $\sqrt{s}$ together with the data points from NA49 and STAR. UrQMD calculations also show a similar trend in the difference in magnitude of $\langle m_T \rangle$- m$_0$ for Λ and $\bar{\Lambda}$. This observed split in the magnitude of $\langle m_T \rangle$- m$_0$ for Λ and $\bar{\Lambda}$ is understood as an effect of B$\bar{\text{B}}$ an-

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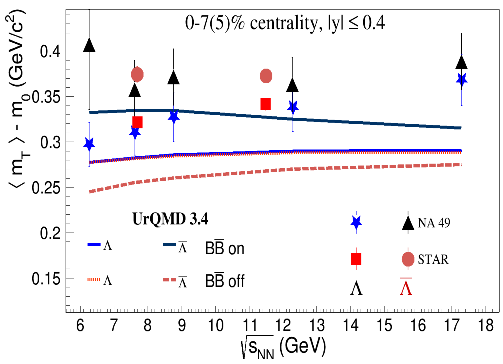

FIG. 1: Energy dependence of mean transverse mass, $\langle m_T \rangle$ - m_0, at mid-rapidity($|y| < 0.5$) for Λ and $\bar{\Lambda}$ in central Pb+Pb collisions at $\sqrt{s_{NN}} = 6.27$ to 17.3 GeV from UrQMD with $B\bar{B}$ annihilation and without $B\bar{B}$ annihilation. UrQMD calculations are compared with central Pb+Pb collisions at $\sqrt{s_{NN}} = 6.27$ to 17.3 from NA49 [2] and STAR results from central Au+Au collisions at $\sqrt{s_{NN}} =$ 7.7 and 11.5 GeV

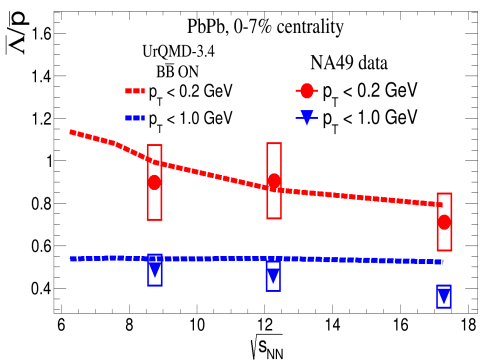

FIG. 2: $\bar{\Lambda}/\bar{p}$ ratios with $B\bar{B}$ annihilation in UrQMD and compared it with feed-down corrected NA49 data points at low p_T and inclusive p_T for central (0-7%) PbPb collisions.

nihilation where the low momenta $\bar{\Lambda}$s have annihilated more compared to Λs. This leads to a lowering of low p_T yields of $\bar{\Lambda}$ while keeping the high p_T yields nearly unaltered, resulting in a hardening of $\bar{\Lambda}$'s p_T-spectra and systematically higher values of average $\langle m_T \rangle$-m_0 for $\bar{\Lambda}$. This difference in the $\langle m_T \rangle$- m_0 between Λ and $\bar{\Lambda}$ reduces with increasing $\sqrt{s}$ as the effect of $B\bar{B}$ annihilation gradually weakens with decreasing baryon density. It is also interesting to note that UrQMD calculations without $B\bar{B}$ annihilation also show a difference in the magnitudes of $\langle m_T \rangle$- m_0 for Λ and $\bar{\Lambda}$ but with an opposite trend i.e, $\langle m_T \rangle$- m_0 of Λ is systematically higher than $\bar{\Lambda}$. In absence of $B\bar{B}$ annihilation, this split in $\langle m_T \rangle$- m_0 can be explained taking into account different energy thresholds of Λ and $\bar{\Lambda}$ production in hadronic interaction channels. Particularly $\bar{\Lambda}$ has higher energy threshold than Λ.

Finally, we calculate $\sqrt{s}$ dependence of $\bar{\Lambda}/\bar{p}$ ratios with and without $B\bar{B}$ annihilation, as shown in Fig. 2, where NA49 data points are also included. We used feed-down corrected NA49 data and a BlastWave fit to extract yields in different p_T-ranges. We find that $\bar{\Lambda}/\bar{p}$ ratios are indeed sensitive to $B\bar{B}$ annihilation and its impact depend strongly on the kinematic selection, in particular, to the choice of p_T-range. We observe that in low p_T range ($p_T < 0.2$ GeV/c) $\bar{\Lambda}/\bar{p}$ ratios achieve maximum and it exceeds unity for the lowest collision energy. This trend for $\bar{\Lambda}/\bar{p}$ enhancement in the UrQMD model is qualitatively similar to data and somehow expected, because, annihilation cross-sections of $\bar{\Lambda}$ is less than $\bar{p}$ which result in more suppression of $\bar{p}$ yield in the final state compared to $\bar{\Lambda}$, leading to an enhancement in $\bar{\Lambda}/\bar{p}$ ratios.

It is to be noted that the enhancement in $\bar{\Lambda}/\bar{p}$ ratios both in data and model calculation is only observed at low-p_T but for inclusive p_T ratios are almost flat with $\sqrt{s}$. From this study, it may be inferred that the observed enhancement in $\bar{\Lambda}/\bar{p}$ ratios in data could also be an effect of $B\bar{B}$ annihilation.

References

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[2] C. Alt et al., (NA49 Collaboration) Phys. Rev. C 78, 034918 (2008).