Heavy lepton pair production in nucleus-nucleus collisions at LHC energy - a case study

Sarbani Majumder*
Center for Astroparticle Physics & Space Science,
Block-EN, Sector-V, Salt Lake, Kolkata-700091, INDIA

Introduction

Dilepton production in high energy heavy-ion collisions have been shown to be an excellent observable for studying various dynamical aspects of the evolution of the system formed in heavy-ion collisions [1]. With the starting of the heavy-ion collision program at Large Hadron Collider (LHC) a value of $\sqrt{s_{NN}} = 5.5$ TeV is planned to reach in Pb + Pb collisions. At these energies we expect significant production of the third generation lepton, the τ-leptons. It is expected that the τ production would not be masked by the huge hadronic background production due to its large mass (~ 1.77 GeV). In this present work we try to provide a baseline for the experimental searches by presenting a case study of $\tau^+\tau^-$ pair production for central Pb+Pb collisions at mid-rapidity for $\sqrt{s_{NN}} = 5.5$ TeV.

Sources of Tau lepton pairs

The main processes for $\tau^{\pm}$ pair production is by quark and anti-quark annihilation via intermediary photon, Z and Higgs bosons. The matrix element for the process $q\bar{q} \rightarrow \tau^+\tau^-$ via Z is given by,

$$M_Z = \frac{g^2}{4cos^2\theta_w}\frac{1}{(q^2 - {m_z}^2)}[\bar{v}(p_2)\Gamma_q u(p_1)] [\bar{u}(k_1)\Gamma_\tau v(k_2)] \tag{1}$$

with

$$\Gamma_q = \gamma^\mu(c_V^q - c_A^q\gamma_5) \tag{2}$$

and

$$\Gamma_\tau = [\gamma_\mu - \frac{q_\mu\gamma_\nu q^\nu}{{m_z}^2}][c_V^\tau - c_A^\tau\gamma_5] \tag{3}$$

The matrix element for the photon mediated process is given by:

$$M_\gamma = \frac{e_q e}{q^2}[\bar{v}(p_2)\gamma^\mu u(p_1)][\bar{u}(k_1)\gamma_\mu v(k_2)] \tag{4}$$

Finally, the matrix element for the Higgs mediated process is:

$$M_H = \frac{m_q m_\tau}{v^2(s - m_H^2)}[\bar{v}(p_2)u(p_1)][\bar{u}(k_1)v(k_2)] \tag{5}$$

where (p_1, p_2) and (k_1, k_2) are initial state and final state momenta respectively and $v(\sim 246$ GeV [?]) is the vacuum expectation value of Higgs field. Values of the parameters we have used are: $M_\tau = 1.78$ GeV, $m_Z = 91$ GeV, $m_H = 120$ GeV, $sin\theta_w = 0.234$, $c_A^q = 0.5$, $c_V^q = 0.19$, $c_A^\tau = -0.5$ and $c_V^\tau = -0.03$.

Drell-Yan and Thermal production

The production of Drell-Yan Tau lepton from pp collision is obtained by folding the partonic cross section (σ_q) by the parton distribution functions (PDF). In the present work CTEQ5M PDF's have been taken for the evaluation of the DY contributions. The dilepton yield from leading order DY process in Pb+Pb collisions is obtained as follows:

$$\frac{dN}{dM^2dy} = \frac{N_{coll}(b)}{\sigma_{\rm in}^{pp}} \times \frac{d\sigma^{pp}}{dM^2dy} \tag{6}$$

where $N_{coll}(b)$ is the number of binary nucleon nucleon collisions at an impact parameter b. We have taken $\sigma_{\rm in}^{pp} = 60$ mb and $b = 3.6$ fm corresponding to $0-5\%$ centrality at $\sqrt{s_{\rm NN}} =$ 5.5 TeV.

*Electronic address: sarbanimajumder@gmail.com

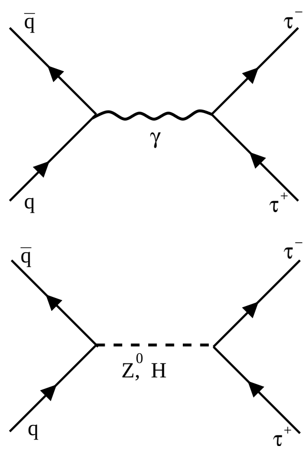

FIG. 1: Feynman diagrams for heavy dilepton production.

The thermal production of $\tau^+\tau^-$ can be obtained by convolution of the elementary cross section mentioned above by the thermal distribution of the participating thermal quarks. The space time evolution of the system has been studied by using ideal relativistic hydrodynamics with longitudinal boost invariance [2] and cylindrical symmetry. We assume that the system reaches equilibration at a proper time $\tau_i = 0.08$ fm/c after the collision. The initial temperature, T_i is taken to be 700 MeV and is calculated assuming the hadronic multiplicity (dN/dy)$\sim$ 2100. Eos have been taken from [3] and [4] for partonic and hadronic phase respectively. The crossover temperature (T_c) is taken to be 175 MeV.

Results and discussion

To figure out the thermal contributions from QGP one can adopt the following procedure: *thermal contributions=contributions from heavy ion collision minus $N_{coll}\times$contributions from pp collisions* where N_{coll} is the number of nucleon-nucleon interactions in the nuclear collisions at a given centrality. We observe that the ratio is above unity for the mass range of 4 to 6 GeV. This indicates that one should be able to extract

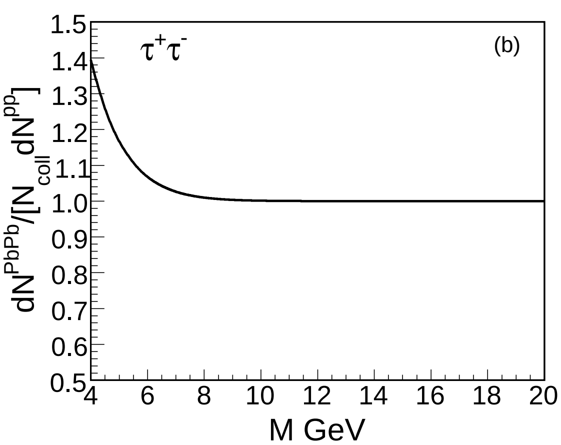

FIG. 2: The ratio $\frac{dN^{PbPb}}{dMdy}$ / $[N_{coll}\frac{dN^{pp}}{dMdy}]$ is shown, here $\frac{dN^{PbPb}}{dMdy}$ is the sum of the thermal and DY contribution; $\frac{dN^{pp}}{dMdy}$ is the DY contribution from *pp* collision, and $N_{coll} = 1369$ for Pb+Pb collisions at $\sqrt{s_{\rm NN}} = 5.5$ TeV.

a clear information of thermal contribution from partonic source at LHC energies using heavy lepton pair measurement within the mass window of 4 to 6 GeV.

Acknowledgments

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