Multiplicity Dependence of $J/\psi$ Production and QCD Dynamics in $p + p$ Collisions at $\sqrt{s} = 13$ TeV

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At very high centre-of-mass energies, the interacting objects in $p + p$ collisions are quarks and gluons. It is believed that there are multiple interactions between the partons in a single $p + p$ event. Now-a-days the multiplicity dependent study in $p + p$ collisions has gathered considerable interest in the scientific community. According to several theoretical calculations, high gluon participation in the the hadronic collisions is the cause for high-multiplicity particle production. If the interaction is hard enough (large $p_T$ transfer), the multiple interactions of partons lead to production of heavy particles like $J/\psi$. Recently, a linear increase of the relative $J/\psi$ yield with charged particle multiplicity is observed in $p + p$ collisions in different experimental results. In the present work, we have studied the contribution of quarks and gluons to the multiplicity dependence of $J/\psi$ production using pQCD inspired model, PYTHIA8 tune 4C at $\sqrt{s} = 13$ TeV by measuring relative $J/\psi$ yield and relative $\langle p_T \rangle$ of $J/\psi$ as a function of charged particle multiplicity for different hard-QCD processes. We have estimated a newly defined ratio, $r_{pp} = \frac{<p_T>_{pp}}{<p_T>_{MB}}$ to understand the $J/\psi$ production in high-multiplicity $p + p$ collisions. For the first time we attempt to measure the nuclear modification factor like observables ($R_{pp}$ and $R_{ep}$) in $p + p$ collisions to understand the possibility of a system formation in high-multiplicity $p + p$ collisions.

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I. INTRODUCTION

Development of novel theoretical models to understand quarkonia production mechanism in hadronic collisions is one of the challenging tasks in high energy particle physics. Many theoretical models like, Color Singlet, non-relativistic QCD (NRQCD) and the Color Evaporation Model try to explain the heavy-flavour production in hard processes [1, 2]. There have been dedicated efforts [3, 4] in understanding the production cross section and polarisation of $J/\psi$ by taking the inputs from recent LHC measurements [5, 6, 7]. At the LHC, the event multiplicity dependence of charmonium production is of great interest to the scientific community and thought to provide the event structure in $p + p$ collisions in terms of interplay between soft and hard collisions. Recently, ALICE experiment has measured the relative $J/\psi$ yield, $\frac{dN_{J/\psi}/dy}{<dN_{J/\psi}/dy>}$ as a function of relative charged particle multiplicity density, $<dN_{ch}/dy>$ [8]. It is observed that the relative $J/\psi$ yield increases faster than linear as compared to relative charged particle multiplicity both in mid-rapidity as well as in forward rapidity [9]. There have been many theoretical models [10, 11] to explain this behaviour. QCD-inspired model, PYTHIA8 reproduces the results quantitatively well, where multiple partonic interaction (MPI) is an important ingredient. In our previous work [12], we have explored this for different centre-of-mass energies by considering MPI with color-reconnection (CR) and without color-reconnection (No-CR).

For the production of charmonium, formation of $c$ and $\bar{c}$ is treated as a perturbative process and their coalescence to form a bound-charmonium state as a non-perturbative process. Since the mass of charm quark ($m_c = 1.275$ GeV) is high enough, it makes the expansion parameter small. Therefore, we can apply perturbative QCD (pQCD) for $c\bar{c}$ production [13]. It has been suggested by many theoretical models that the major contribution of the $J/\psi$ events in hadronic collisions can mainly be from the following mechanisms [14]:

- Fusion of light quarks ($u, d, s$) and anti-quarks ($\bar{u}, \bar{d}, \bar{s}$) pairs into a $J/\psi$ ($q\bar{q} \rightarrow c\bar{c}$)
- Fusion of heavy charmed quarks ($c$) to produce a $J/\psi$
- Fusion of light quarks ($u, d, s$) to produce a virtual gluon, which then decays into a $c\bar{c}$ pair ($q\bar{q} \rightarrow g^* \rightarrow c\bar{c}$)
- Fusion of two gluons to produce a virtual gluon which then decays into a $c\bar{c}$ state ($gg \rightarrow c\bar{c}$)

In addition to the above processes, recently, people argue that there is a substantial contribution in $J/\psi$ production from MPIs. One of the most important ingredient of PYTHIA8 is that, specifically one can study the contribution of QCD processes like $gg \rightarrow c\bar{c}$ and $q\bar{q} \rightarrow c\bar{c}$ to $J/\psi$ production. As PYTHIA8 is one of the best models to describe the production of relative yield of inclusive $J/\psi$ versus charged particle multiplicity [15], it allows us to study this observable from different hard-processes. In this work, we have extended the study performed in Ref [17] to $gg \rightarrow c\bar{c}$ and $q\bar{q} \rightarrow c\bar{c}$ hard-QCD processes along with the contribution of MPIs.

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ALICE experiment has performed the $p_T$ and multiplicity dependence study of $J/\psi$ production in $p+p$ collisions [13]. It is shown that $J/\psi$ is produced more in high-multiplicity and high-$p_T$ regions. In this paper, we have studied the softening and hardening of the $p_T$-spectra of $J/\psi$ in different multiplicity classes with respect to MB using PYTHIA8. This type of study has been done only for light-flavor particles in experiments so far [19], because of limited statistics for heavy-flavour particles. The present study will help to understand the difference in production mechanisms of $J/\psi$ from light-flavor particles. In particular, in order to see the contribution of $J/\psi$ production from $q\bar{q} \rightarrow c\bar{c}$, $q\bar{q} \rightarrow c\bar{c}$ and MPI, it is better to study the $p_T$ dependence of $J/\psi$ production for different charged particle multiplicity bins. According to MPI, $J/\psi$ can be formed from first $2 \rightarrow 2$ hard collisions as well as subsequent semi-hard collisions [20]. So, the hard $gg \rightarrow c\bar{c}$ and $q\bar{q} \rightarrow c\bar{c}$ will produce high-$p_T J/\psi$, whereas MPI contains high-$p_T J/\psi$ (hard) as well as low-$p_T J/\psi$ (semi-hard). Therefore, the $<p_T>$ as a function of charged particle multiplicity can clear the view of hard and semi-hard contributions of MPI to $J/\psi$ production.

The physics of high-multiplicity events in $p+p$ collisions at LHC energies is a topic of intense research to the scientific community now-a-days. In the high multiplicity $p+p$ collisions, many interesting results have been found [21-24], where a possible formation of a deconfined medium [21-23] is under discussion. The charged particle multiplicity measured in high-multiplicity $p+p$ collisions at $\sqrt{s} = 7$ TeV exceeds the charged particle multiplicity for peripheral Cu+Cu collisions at $\sqrt{s_{NN}} = 200$ GeV [22]. Therefore, $p+p$ collisions at $\sqrt{s} = 13$ TeV must be more interesting to look for heavy-ion-like phenomena in $p+p$ collisions. So, now the question arises whether the high multiplicity $p+p$ collisions exhibit heavy-ion like behaviour or not? The best way to answer this question is to study the observables of high-multiplicity $p+p$ collisions and have a direct comparison.

In Ref. [20], a new variable, $r_{AA} = \frac{<p_T^2>_{AA}}{<p_T^2>_{pp}}$, has been proposed to understand the $J/\psi$ production in heavy-ion collisions in SPS, RHIC and LHC energies. In this paper, we have studied this in different multiplicity classes in $p+p$ collisions to compare the similarity between the system created in heavy-ion collisions and high-multiplicity $p+p$ collisions. We have used the modified formula for $p+p$ collisions as $r_{pp} = \frac{<p_T^2>_{+u^{-}b u n}}{<p_T^2>_{+u^{-}a b n}}$, where $<p_T^2>_{+u^{-}b u n}$ and $<p_T^2>_{+u^{-}a b n}$ are the averaged transverse momentum squared for $J/\psi$ in $i^{th}$ multiplicity classes and MB events, respectively. Another most important observable to study the system created in heavy-ion collisions is nuclear modification factor ($R_{AA}$) which is defined as the ratio of invariant yield in A+A collisions with respect to invariant yield in $p+p$ collisions multiplied by average number of collisions, $<N_{col}>$. $R_{AA} < 1$ indicates that there is a medium modification. Here, we introduce a similar ratio in $p+p$ collisions to understand the possibility of existence of any kind of heavy-ion like system in high-multiplicity events.

The paper is organised as follows. Section II presents Event generation and Analysis methodology. Results are discussed in the Section III which is divided into four subsections, (A) Multiplicity dependence of $J/\psi$ in hard-QCD Processes (B) Transverse momentum and Multiplicity dependence of $J/\psi$ production (C) Multiplicity dependence of $r_{pp}$, and (D) nuclear modification factors like ratios are discussed. Finally in Section IV we summarise our work highlighting major observations and outlook.

II. EVENT GENERATION AND ANALYSIS METHODOLOGY

To simulate the study of multiparticle interaction in $p+p$ collisions, PYTHIA program is widely used as a high-energy Physics event generator. In this work, PYTHIA 8.215 version is used. PYTHIA8 is coded in C++ and has major upgrade over PYTHIA6 which is, the incorporation of Multi-Parton Interaction (MPI) scenario, where heavy-flavor quarks can be produced through 2 → 2 hard sub-processes. Detailed explanation on PYTHIA8 Physics processes can be found in Ref. [27]. In this paper, we have used 4C tuned PYTHIA8 [28] (Tune:pp = 5, in this scheme, modified multiparton interactions parameters give a higher and more rapidly increasing charged pseudorapidity plateau, for better agreement with some early key LHC numbers). We have included the MPI-based scheme of Colour Reconnection (ColourReconnection:reconnect = on) of PYTHIA8.

In our study, we have simulated inelastic, non-diffractive component of the total cross section for all hard QCD processes (HardQCD:all=on), which includes the production of heavy quarks. Besides these processes, we have also simulated leading order processes for heavy quark production, namely, $gg \rightarrow c\bar{c}$, $q\bar{q} \rightarrow c\bar{c}$ (HardQCD:gg2ccbar=on and HardQCD:qqbar2ccbar=on), separately. A cut on transverse momentum, $p_T = 0.5$ GeV/c (using PhaseSpace:THatMinDiverge) is used to avoid the divergences of QCD processes in the limit $p_T \rightarrow 0$. In order to have quarkonia (here charmonia is of interest) production, Charmonium:all flag in PYTHIA8 is included, which allows quarkonia production through NRQCD framework [29-31]. Measurement of $J/\psi$ production is done in the dimuon channel and thus we have specifically decayed $J/\psi$ to the dimuon channel and measured the yield of the reconstructed particles by defining an external decay mode. This helps in comparing the observations directly with the experimental data.

We have generated 1600 million events for $p+p$ collisions at $\sqrt{s} = 13$ TeV using PYTHIA8.2 for hard QCD processes, 100 million events each for $gg \rightarrow c\bar{c}$ and $q\bar{q} \rightarrow c\bar{c}$ processes. $J/\psi$ are reconstructed via dimuon channel ($J/\psi \rightarrow \mu^{+} + \mu^{-}$). The charged particle multiplicity yield, which is defined as $N_{ch}/<N_{ch}>$, is measured at midrapidity ($|y| < 1.0$), where $N_{ch}$ is the
mean of the charged particle multiplicity in a particular bin and \(<N_{ch}>\) is the mean of the charged particle multiplicity in minimum-bias events. The relative \(J/\psi\) yield is measured in forward rapidity \((2.5 < y < 4.0)\) using the following relation:

\[
\frac{Y_{J/\psi}}{<Y_{J/\psi}>} = \frac{N_{J/\psi}^i N_{ext}}{N_{total}^i N_{ext}}
\]

(1)

where, \(N_{J/\psi}^i\) and \(N_{ext}^i\) are the number of \(J/\psi\) and number of events in \(i^{th}\) multiplicity bin, respectively. \(N_{total}^i\) and \(N_{ext}\) are the total number of \(J/\psi\) produced and total number of minimum-bias events, respectively. As the frequency of lower multiplicity events is higher, the bin width is taken smaller at lower multiplicity and then subsequently higher to maximize the statistics at high multiplicity bins.

The statistical uncertainties are calculated in each multiplicity bin for both relative charged particle multiplicity \((N_{ch}/<N_{ch}>\) and relative \(J/\psi\) yield \((N_{J/\psi}/<N_{J/\psi}>\)). Uncertainty in \(N_{ch}\) measurement is given by the ratio of RMS value of the charged particle multiplicity and square root of the number of charged particles in that bin \((N_{RMS}/\sqrt{N_{ch}^{bin}})\). The ratio between RMS value of the minimum-bias (MB) charged particle multiplicity and square root of the number of minimum-bias charged particles \((N_{RMS}^{MB}/\sqrt{N_{MB}})\) gives the uncertainty in \(<N_{ch}>\). The uncertainty to measure the number of \(J/\psi\) particles is simply \(\sqrt{N_{J/\psi}}\). These uncertainties are propagated using standard error propagation formula to estimate the uncertainties in relative charged particle multiplicity as well as in relative \(J/\psi\) yield.

The mean transverse momentum, \(<p_T>\) of \(J/\psi\) is calculated for each multiplicity bin and corresponding error is given by the ratio of standard deviation and square root of the number of entries in that bin \((\sigma/\sqrt{N_{bin}})\).

### III. RESULTS AND DISCUSSION

To check the compatibility of PYTHIA8 with the experimental data we have compared \(J/\psi\) production between data and PYTHIA8 in same kinematic range. Fig. 1 and Fig. 2 show the comparison of \(J/\psi\) production cross-section as a function of \(p_T\) and rapidity \((y)\) respectively between data and PYTHIA for minimum-bias events. The open symbols represent the data obtained by ALICE experiment [32] and the solid circles show the results from PYTHIA8 model at \(\sqrt{s}=13\) TeV. The lower panels of the figures show the ratio between data and model. It is observed that PYTHIA8 explains the data very well. For one low-\(p_T\) bin \((p_T \sim 0.5\) GeV/c\), the deviation is larger and for two high-\(p_T\) bins \((p_T \sim 24\) GeV/c and \(p_T \sim 28\) GeV/c\), deviation is around 64% and 23%, respectively. The deviations in higher \(p_T\) bins are due to lack of statistics. These bins with large uncertainties have been omitted in Fig. 1. However, bins with larger deviations are comparable with data within uncertainties. Furthermore, the rapidity spectra are very well reproduced by MC data with less than 1% deviation from experimental data. These measurements provide us the
boost to study the quarkonia production using PYTHIA8 in \( p + p \) collisions at the LHC energies.

**A. Multiplicity dependence of \( J/\psi \) in hard-QCD Processes**

From the first measurement of \( J/\psi \) as a function of multiplicity, there have been constant efforts to understand the underlying Physics. It is expected that the linear increase of \( J/\psi \) with event multiplicity is the cause of participation of higher number of gluons [33]. It is also believed that a major contribution of \( J/\psi \) comes from semi-hard collisions in addition to first hard \( 2 \rightarrow 2 \) collisions [20]. To explore the effect of gluon and quark contributions on quarkonia production in \( p + p \) collisions, we have studied different processes of \( J/\psi \) production in PYTHIA8 at \( \sqrt{s} = 13 \) TeV for different multiplicity classes. The left panel of Fig. 3 shows the relative \( J/\psi \) yield as a function of charged particle multiplicity for different processes such as, \( gg \rightarrow c\bar{c}, q\bar{q} \rightarrow c\bar{c} \) and inclusive hard processes. It is observed that all the processes are comparable up to \( N_{ch} \sim 20-30 \) and for \( N_{ch} \gtrsim 30 \) the contributions from \( gg \rightarrow c\bar{c}, q\bar{q} \rightarrow c\bar{c} \) become negligible compared to the inclusive hard processes. One of the main reasons behind this is the dominance of MPI at high multiplicity events. The right panel of Fig. 3 supports this statement as we can see the relative \( J/\psi \) yield to increase linearly with number of MPIs.

![Graph showing multiplicity dependence of J/psi](image)

**FIG. 3:** (Color online) Left panel: Relative yield of \( J/\psi \) as a function of charged particle multiplicity. Different symbols are for different hard processes of PYTHIA8. Right panel: Relative yield of \( J/\psi \) as a function of number of multi-parton interactions for inclusive hard processes using PYTHIA8. The vertical lines in data points are the statistical uncertainties.

Figure 4 shows relative mean transverse momentum, \( <p_{T}> \) of \( J/\psi \) for different hard processes of PYTHIA8 as a function of charged particle multiplicity. It is observed that relative \( <p_{T}> \) increases with multiplicity. It indicates that more harder \( J/\psi \) are produced for higher multiplicity classes. However, for \( gg \rightarrow c\bar{c} \) and \( q\bar{q} \rightarrow c\bar{c} \) the rate of increase is much faster than that of inclusive hard processes. We found that up to \( N_{ch} \sim 20-30 \) the contributions to \( <p_{T}> \) mainly come from the processes: \( gg \rightarrow c\bar{c} \) and \( q\bar{q} \rightarrow c\bar{c} \) and for \( N_{ch} \gtrsim 30 \) the rate of increase of \( <p_{T}> \) is slower for inclusive hard processes than that of other two. This may be due to the dominance of MPIs (which contributes to semi-hard \( J/\psi \) also) over hard processes at higher multiplicity classes. It is also observed that the relative \( <p_{T}> \) of \( J/\psi \) in \( gg \rightarrow c\bar{c} \) process dominates over \( q\bar{q} \rightarrow c\bar{c} \) at highest multiplicity class. It indicates that at very high-multiplicity \( p + p \) collisions the contribution of gluons are more than the quarks to produce harder \( J/\psi \) particles. The relative \( <p_{T}> \) of the \( J/\psi \) in inclusive hard processes shows a slightly increasing behaviour as a function of \( N_{ch} \) unlike the saturation of relative \( <p_{T}> \) in \( p-Pb \) collisions as observed by ALICE experiment [34], which needs further investigation.

![Graph showing mean transverse momentum](image)

**FIG. 4:** (Color online) Relative mean transverse momentum of \( J/\psi \) is presented as a function of charged particle multiplicity for different hard processes of PYTHIA8. Different symbols are for different processes. The vertical lines in data points are the statistical uncertainties.

For the completeness and for a clear view of the observed pictures, it is worth studying the relative hardness versus relative softness. Although, there is no such type of experimental study available, we have tried to study this using PYTHIA8. This is shown in the Fig 5. Figure 5 shows the relative \( <p_{T}> \) of charged particles (softness) as a function of relative \( <p_{T}> \) of \( J/\psi \) (hardness).

It can be clearly seen from the figure that with an increase of around 3 units of \( <p_{T}> \) of \( N_{ch} \) with respect to MB, there is only increase of around 0.1 unit for \( J/\psi \) compared to MB for inclusive hard-QCD processes and only around 0.5 for \( gg \rightarrow c\bar{c} \) and \( q\bar{q} \rightarrow c\bar{c} \) processes. So, the \( <p_{T}> \) of charged particle increases much more faster compared to \( <p_{T}> \) of \( J/\psi \).
The whole fact indicates that as we go from low to high multiplicity events in pp collisions at $\sqrt{s} = 13$ TeV, we study a newly defined nuclear modification factor for the transverse momentum $r_{pp}$:

$$r_{pp} = \frac{\langle p_T^2 \rangle_{i}^{ch\text{bin}}}{\langle p_T^2 \rangle_{MB}},$$

where $\langle p_T^2 \rangle_{i}^{ch\text{bin}}$ and $\langle p_T^2 \rangle_{MB}$ are the averaged transverse momentum squared for $J/\psi$ in $i^{th}$ multiplicity class and minimum biased events, respectively. Figure 7 shows the $r_{pp}$ of $J/\psi$ as a function of relative charge-particle multiplicity. It is observed that $r_{pp}$ increases with increasing multiplicity. To understand the results we need to compare it with the results obtained in heavy-ion collisions. Reference [26] shows that the $r_{AA}$ (which is defined as $\frac{\langle p_T^2 \rangle_{AA}}{\langle p_T^2 \rangle_{pp}}$) values are different for different collision energies in heavy-ion collisions. It is found that $r_{AA} > 1$ for SPS,
multiplicities $r_{AA} \sim 1$ for RHIC and $r_{AA} < 1$ for LHC in midrapidity region. The reason behind these are: at SPS almost all the measured $J/\psi$ are produced via initial hard processes and the increase with centrality arises from the Cronin effect and the leakage effect [36]. But at RHIC and LHC, regeneration plays an important role. At RHIC regeneration and initial hard processes cancel each and we get $r_{AA} \sim 1$. Whereas at LHC, regeneration dominates and we get decreasing $r_{AA}$ with centrality. We observe that for $p+p$ collisions $r_{pp}$ values show a trend similar to SPS heavy-ion results. This indicates that even at highest centre-of-mass energy and for highest multiplicity classes of $p+p$ collisions, regeneration effect is negligible and initial hard processes dominate in $J/\psi$ production.

In summary, multiplicity dependent study of the transverse momentum ($p_T$) spectra of $J/\psi$ has been performed using 4C tuned PYTHIA8 MC event generator in $p+p$ collisions at $\sqrt{s} = 13$ TeV. The $J/\psi$ are reconstructed via dimuon channel at forward rapidity ($2.5 < y < 4.0$). In this work, we have tried to understand the $J/\psi$ production mechanism as a function of multiplicity as well as $p_T$. Relative $J/\psi$ yields are measured as a function of charged particles for different hard-QCD processes. Also, relative $<p_T>$ is measured as a function of charged particle multiplicity for different hard processes. The ratio of $<p_T>$ between $i^{th}$ multiplicity class and minimum biased events, which is defined as $r_{pp}$, is measured as a function of relative charged particle multiplicity. For the first time, we attempt to measure $R_{pp}$ and $R_{cp}$ in $p+p$ collisions. Following are the observations from the current study:

- Up to $N_{ch} \simeq (20 - 30), J/\psi$ are mainly produced via $gg \rightarrow c\bar{c}$ and $q\bar{q} \rightarrow c\bar{c}$ and for $N_{ch} \gtrsim 30$ the contribution from MPI dominates. This leads to a decrease in $<p_T>$ of inclusive $J/\psi$ with respect to MB as a function of $N_{ch}$.
- The higher $J/\psi$ production for inclusive hard-QCD processes compared to $gg \rightarrow c\bar{c}$ and $q\bar{q} \rightarrow c\bar{c}$ pro-

\[ R_{cp} = \frac{<N_{ch}>_{0-5}}{<N_{ch}>_{80-170}} \frac{(dN/N_{ext}dp_T)_{80-170}}{(dN/N_{ext}dp_T)_{0-5}}, \]

which are similar to the nuclear modification factors $R_{AA}$ and $R_{cp}$ in heavy-ion collisions. Here, $<N_{ch}>_{80-170}, <N_{ch}>_{0-5}$ and $<N_{ch}>_{MB}$ are the average charged particle multiplicity for $(80-170), (0-5)$ multiplicity classes and MB events, respectively. In case of MPI, $p+p$ collisions are no more a $2 \rightarrow 2$ process rather it can be treated as multiple collisions. Since MPIs are proportional to $N_{ch}$ we take $<N_{ch}>$ as the scaling factor to measure the $R_{pp}$ and $R_{cp}$ for $p+p$ collisions. Right upper panel of Fig. 8 shows the $p_T$-spectra of $J/\psi$ for highest $(80-170)$ multiplicity class and MB events scaled with corresponding $<N_{ch}>$ values. Lower panel shows the $R_{pp}$ as defined in Eq. 3. 10% suppression is observed for $p_T < 2$ GeV/c. For mid-$p_T$ region: 2-6 GeV/c, $R_{pp}$ values are unity and increases rapidly in the high-$p_T$ region: $p_T > 6$ GeV/c. Since $R_{pp}$ (or $R_{AA}$) is directly related to the particle energy loss in the medium, this indicates that low-$p_T J/\psi$ particles loose their energy due to MPIs but there is no effect on high-$p_T J/\psi$. Since there is a hint of suppression at low-$p_T$ region it will be interesting to measure the $R_{pp}$ in experiments. So that, one can conclude about the observables like $R_{AA}(or \ R_{pp})$. This can reveal whether the suppression is arising due to MPIs or heavy-ion like system in $p+p$ collision. The $R_{cp}$ is consistent with unity up to $p_T < 4$ GeV/c and increases at high-$p_T$ similarly as $R_{pp}$.

IV. SUMMARY

To understand the possibility of formation of a system in high-multiplicity events in $p+p$ collisions at $\sqrt{s} = 13$ TeV, we define two variables [37]:

\[ R_{pp} = \frac{<N_{ch}>_{MB}}{<N_{ch}>_{80-170}} \frac{(dN/N_{ext}dp_T)_{80-170}}{(dN/N_{ext}dp_T)_{MB}}, \]

\[ R_{cp} = \frac{<N_{ch}>_{0-5}}{<N_{ch}>_{80-170}} \frac{(dN/N_{ext}dp_T)_{80-170}}{(dN/N_{ext}dp_T)_{0-5}}, \]
cesses indicates that MPI plays an important role for events with $N_{ch} \gtrsim 20$.

- It is found that $gg \rightarrow c\bar{c}$ dominates over the $q\bar{q} \rightarrow c\bar{c}$ towards higher multiplicities.
- From the $p_T$-spectra of $J/\psi$ for different multiplicity classes, we found that harder $J/\psi$ are produced as we go towards the higher multiplicities.
- $\tau_{pp}$ shows similar increasing nature with multiplicity as it was found at SPS for heavy-ion collisions. This tells us that $J/\psi$ is produced from initial hard processes.
- $R_{pp}$ shows 10% suppression for $p_T < 2$ GeV/c. However, there is no suppression observed in case of $R_{cp}$ measurements. It will be very interesting to measure these quantities in experimental data.

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