Charged Multiplicities at SPS and RHIC and consequences for $J/\psi$ suppression

A. CAPELLA, D. SOUSA
Laboratoire de Physique Théorique,
Université de Paris-Sud, Bâtiment 210, F-91405 Orsay Cedex, France

Hadron multiplicities in nucleus–nucleus interactions are calculated in the Dual Parton Model and its dependence on the number of collisions and the number of participants is analyzed. Shadowing corrections are calculated as a function of impact parameter and the multiplicity per participant as a function of centrality is found to be in agreement with experiment at SPS and RHIC energies. The obtained results are used to compute the $J/\psi$ suppression in a comover approach.

1 Charged Multiplicities in the Dual Parton Model

In the Dual Parton Model (DPM) the charged multiplicity per unit rapidity in a symmetric collision is given by

$$
\frac{dN_{ch}^{AA}}{dy}(y,b) = n_A(b) \left[ N_{\mu}^{qq-p-q_{\mu}^T} (y) + N_{\mu}^{q_{\mu}^T-q_{q}^T} (y) + (2k-2)N_{\mu}^{q_s-\bar{q_s}} \right] + 
\left( n(b) - n_A(b) \right) \left( 2k \frac{N_{\mu}^{q_s-\bar{q_s}} (y)}{2k} \right)
$$

(1)

Here $P$ and $T$ stand for the projectile and target nuclei, $n(b)$ is the average number of binary collisions and $n_A(b)$ the average number of participants of nucleus $A$. These quantities can be computed in a Glauber model. $k$ is the average number of inelastic collisions in $pp$ and $\mu(b) = kn(b)/n_A(b)$ is the total average number of collisions suffered by each nucleon.

In the DPM each inelastic collision leads to two strings and the total number of strings is $2kn$. The charged multiplicity produced by a single string is obtained by a convolution of momentum distribution functions and fragmentation function, and it depends on $\mu$ due to energy conservation. We see from (1) that the multiplicity is given by a linear combination of $n_A$ and $n$ with coefficients which depend on the impact parameter $b$ (via $\mu(b)$).
Shadowing corrections in Gribov theory are universal, i.e. they apply both to soft and hard processes. They are closely related to the size of diffractive production and, thus, are controlled by triple Pomeron diagrams. The reduction of the multiplicity resulting from shadowing corrections has been computed in. These corrections are negligible at SPS energies but at RHIC energies they reduce the multiplicity by 40 to 50%.

We present the results obtained at two different energies: $\sqrt{s} = 17.3$ and 130 GeV. The corresponding non-diffractive cross-sections are $\sigma_{ND} = 26$ and 33 mb, respectively. We take $k = 1.4$ and 2.0 corresponding to $dN_{pp}^{ND}/dy = 1.56$ and 2.72. The result in absence of shadowing at $\sqrt{s} = 17.3$ is shown in Fig 1 (a) (solid line). We obtain a mild increase of the multiplicity per participant consistent with the results of the WA98 Collaboration. This increase gets stronger with increasing energies. As we pointed out before, shadowing corrections are negligible at SPS energies but their effect is large at RHIC. Unfortunately, shadowing corrections have a rather large uncertainty at RHIC energies. Two alternative calculations of shadowing lead to the results at $\sqrt{s} = 130$ GeV shown by the solid lines in Fig 1 (b). Clearly, with the larger values of the shadowing corrections we obtain a quantitative agreement with the PHENIX data.

Note that our calculations refer to $dN/dy$ while the first RHIC measurements refer to $dN/d\eta$. The latter is, of course, smaller at mid rapidities. This difference is negligibly small as SPS where the laboratory pseudo-rapidity variable is used. However, at $\sqrt{s} = 130$ GeV where $\eta_{cm}$ is used instead, their ratio can be as large as 1.3.

2 $J/\psi$ suppression

Now we are going to use these multiplicities, computed in the framework of DPM, to determine the $J/\psi$ suppression in the comovers approach. In this model, the $J/\psi$ survival probability is the product of two factors $S_{abs}(b, s) \cdot S_{co}(b, s)$. The first factor represents the suppression due to nuclear absorption of the $c\bar{c}$ pair. Its expression, given by the probabilistic Glauber model, is well known. It contains a parameter, the absorptive cross-section $\sigma_{abs}$. The second factor $S_{co}(b, s)$ represents the suppression resulting from the interaction with comovers. Its expression depends on the averaged interaction cross-section $\sigma_{co}$ and on the value of the multiplicity at
Experimentally, the ratio of $J/\psi$ over DY is plotted as a function of either $E_T$ or the energy of the zero degree calorimeter $E_{ZDC}$. $E_T$ is the transverse energy of neutrals deposited in the NA50 calorimeter, located in the backward hemisphere $(1.1 < y_{lab} < 2.3)$. Using the proportionality between $E_T$ and multiplicity, we have

$$E_T(b) = \frac{1}{2} q N_{y_{col}}^c(b) .$$

Here the multiplicity of comovers is determined in the rapidity region of the NA50 calorimeter. The energy of the zero degree calorimeter is defined as

$$E_{ZDC}(b) = [A - n_A(b)]E_{in} + \alpha n_A(b)E_{in} ,$$

Here $n_A$ is the number of participants, $A - n_A$ the number of spectators, and $E_{in} = 158$ GeV is the beam energy. The last term represents the small fraction of wounded nucleons and/or fast secondaries that hit the ZD Calorimeter. The values of $q$ and $\alpha$ are obtained, respectively, from a fit of the tails of the $E_T$ and $E_{ZDC}$ distributions. With the obtained values, the measured $E_T - E_{ZDC}$ correlation is well reproduced.

We see from Eqs. (2) and (3) that, in order to describe the centrality dependence of the $J/\psi$ suppression, it is paramount to have a good description of the $b$ dependence of $N_{y}^c$ – both in the rapidity region of the dimuon trigger and in the one of the $E_T$ calorimeter. In the latter we obtain an scaling in the number of participants, i.e. we recover the wounded nucleon model.

The model allows to compute the ratio $J/\psi$ over DY versus either $E_T$ or $E_{ZDC}$ from peripheral collisions up to the knee of the $E_T$ or $E_{ZDC}$ distributions. To go beyond it, we have to introduce the fluctuations responsible for the tail of the $E_T$ and $E_{ZDC}$ distributions (Eqs. (3) and (4) give only the average values at each $b$). They have been introduced in the model by multiplying $N_{y_{DT}}^c(b)$ in Eq. (3) by $F(b) = E_T/E_T(b)$, where $E_T$ is the measured value of the transverse energy. Likewise, for the suppression versus $E_{ZDC}$ we multiply $N_{y_{DT}}^c(b)$ by $n_A(E_{ZDC})/n_A(b)$ where $n_A(E_{ZDC})$ is obtained from Eq. (4): $n_A(E_{ZDC}) = (AE_{in} - E_{ZDC})/E_{in}(1 - \alpha)$.

The results are presented in Fig. 2 and compared with the NA50 data. We see that from peripheral collisions up to the knee of the $E_T$ distribution, the data are well described. However, beyond the inflexion point at the knee, the decrease in the data is sharper than in the model. Note, however, that the data beyond the knee are obtained with the so-called minimum bias (MB) analysis. Only the ratio $J/\psi$ over MB is measured and it is multiplied by a theoretical ratio DY/MB. In the model used by NA50, this ratio is essentially flat beyond the knee – due to the fact that the tail of the $E_T$ distribution of hard (DY) and soft (MB) processes is assumed to be the same. The behaviour of the MB NA50 data beyond the knee can be explained by the combined effects of a small decrease of the hadronic $E_T$ in the $J/\psi$ event sample (due to the $E_T$ taken by the $J/\psi$ trigger), together with the sharp decrease of the $E_T$ distributions in this tail region. This phenomenon does not affect the (true) ratio $J/\psi$ over DY (obtained in the NA50 standard analysis), but does affect the one obtained by the so-called minimum bias analysis.

The results of the model as a function of $E_{ZDC}$ are presented in Fig. 2 (b). The centrality dependence of the $J/\psi$ suppression is reasonably well reproduced except for the broad bump centered at $E_{ZDC} \sim 12$ TeV. No such structure is seen in the $E_T$ distribution at the same $b$ ($E_T \sim 85$ GeV). Note that the suppression beyond the knee ($E_{ZDC} \lesssim 5$ TeV) is well reproduced by the model. This was to be expected since the tail of the $E_{ZDC}$ distribution is not affected by
Figure 2: a): Ratio $J/\psi$ over DY versus $E_T$ compared to NA50 data. The full curve is the theoretical prediction with $E_T$ fluctuations and the dashed line contains $E_T$ fluctuations and the $E_T$ loss induced by the $J/\psi$ trigger. b): Ratio $J/\psi$ over DY versus $E_{ZDC}$ compared to preliminary results presented by NA50. The full line is obtained computing for each $b$, the value of $E_{ZDC}$ and the value of the ratio $R$, taking into account fluctuations and changing the normalization by a factor 0.94. In both figures the dotted line is the NA50 absorption model, fitting pA and SU. The used parameters are $\sigma_{abs}=4.5$ mb, $\sigma_{co}=1$ mb, $q=0.62$, $\alpha=0.076$ and $N_f=1.15 fm^{-2}$.

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