Quark participants and global observables

Pawan Kumar Netrakanti and Bedangadas Mohanty
Variable Energy Cyclotron Centre, Kolkata 700064, India
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We show that the centrality dependence of charged particle and photon pseudorapidity density at midrapidity along with the transverse energy pseudorapidity density at SPS and RHIC energies scales with the number of participating constituent quarks. The number of charged particles and transverse energy per participant constituent quark is found to increase with increase in beam energy.

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I. INTRODUCTION

One of the challenges in relativistic heavy ion collisions is to measure and study the large number of particles produced in such reactions. Measurement of particle density and transverse energy density in rapidity is a convenient way to describe particle production in heavy ion collisions. The pseudorapidity density \(dN/d\eta\) and transverse energy pseudorapidity density \((dE_T/d\eta)\) at mid-rapidity is found to increase with increase in centrality of the reaction at SPS and RHIC energies \[1, 2, 3, 4\]. This has been claimed to be understood using a simple geometrical picture of collision. At SPS energies, it was found that the number of charged particles and transverse energy per participant constituent quark is found to increase with increase in centrality of the reaction at SPS and RHIC energies \[1, 2\]. This has been claimed to be understood using a simple geometrical picture of collision. At SPS energies, it was found that the particle production scales with the number of participating nucleons \(N_{part}\),

\[
\frac{dN}{d\eta} \propto N_{part}^{\alpha} \tag{1}
\]

The value of \(\alpha\) for photons and charged particles at SPS energies were found to be 1.12 \(\pm\) 0.03 and 1.07 \(\pm\) 0.05 respectively \[1, 2\]. While that for \(E_T\) is 1.08 \(\pm\) 0.06. Within the quoted systematic errors the value of \(\alpha\) is similar for both photons, charged particles and transverse energy. The value of \(\alpha\) indicates a deviation from the picture of a naive wounded nucleus model \((\alpha = 1)\).

At RHIC energies, it was found that the contribution from hard processes had a major role in understanding particle production \[3\]. The centrality dependence of charged particle pseudorapidity density \(dN_{ch}/d\eta\) was explained using the following relation,

\[
\frac{dN_{ch}}{d\eta} \propto \beta N_{part} + (1 - \beta) N_{coll} \tag{2}
\]

where the parameter \(\beta\) is the relative fraction of particles produced in soft collisions, and \((1 - \beta)\) is the relative fraction produced in hard collisions. It was observed that the fraction of the hadron multiplicity originating from hard processes at centre of mass energy \(\sqrt{s}\) 56 GeV was 22\% and that at 130 GeV was 37\%. However this fraction does not increase much for 200 GeV, thereby bringing in some inconsistency with such an approach. This is because one expects the relative contribution from hard process to increase with increase in collision energy.

Another approach is to consider that the nucleus-nucleus collision is a superposition of constituent quarks collisions. Such a model has been used to show that the centrality dependence of charged particle pseudorapidity density at midrapidity for RHIC energies is proportional to the number of participating constituent quarks \(N_{q-part}\) \[3\].

In this brief report, we shall address the following aspects using the constituent quark model. (a) Does the above scaling of charged particle pseudorapidity density with number of participating constituent quarks holds good for other global observables like photon pseudorapidity density \(dN_{\gamma}/d\eta\) and transverse energy pseudorapidity density \(dE_T/d\eta\) \? (b) Is such a scaling also observed at SPS energies ?

In the next section, we briefly describe the calculation of number of participating nucleons and number of quark participants for various centre of mass energies. In section III, we present the results and finally we summarize in section IV.

II. CALCULATION OF \(N_{N-part}\) AND \(N_{q-part}\)

The mean number of nucleon and quark participants is calculated in a similar manner as in Ref. \[3\]. A Wood - Saxon nuclear density profile as given below, is used for our calculations,

\[
n_A(r) = \frac{n_0}{1 + exp[(r - R)/d]} \tag{3}
\]

with parameters \(n_0 = 0.17 \text{ fm}^{-3}\), \(R=(1.12A^{1/3} - 0.86A^{-1/3})\text{fm}\), \(d=0.54\text{fm}\). The \(N_{N-part}\) for nucleus-nucleus (AB) collisions is calculated using the relation,

\[
N_{part,AB} = \int d^2s T_A(\vec{s}) \{1 - [1 - \sigma_{NN}T_B(\vec{s} - \vec{b})/B]^B\} \tag{4}
\]

\[
+ \int d^2s T_B(\vec{s}) \{1 - [1 - \sigma_{NN}T_A(\vec{s} - \vec{b})/A]^A\}
\]
where \( T(b) = \int_{-\infty}^{+\infty} dz n_A(\sqrt{b^2 + z^2}) \), is the thickness function which is defined as the probability for having a nucleon-nucleon (NN) collision within the transverse area element \( db \) when one nucleon is situated at an impact parameter \( b \) relative to another nucleon. We use the inelastic NN cross section \( \sigma_{NN} = 30 \text{ mb}, 41 \text{ mb}, 42 \text{ mb} \) at \( \sqrt{s} = 17.3 \text{ GeV}, 130 \text{ GeV}, 200 \text{ GeV} \) respectively. In a similar manner the \( N_{q-part} \) is also calculated keeping in mind, the density was changed to three times that of the nucleon density (\( n_q = 3n_0 = 0.51 \text{ fm}^{-3} \)). The cross sections are also changed in accordance with \( \sigma_{qq} = \sigma_{NN}/9 = 3.33 \text{ mb}, 4.55 \text{ mb}, 4.66 \text{ mb} \) for 17.3 GeV, 130 GeV, 200 GeV respectively [6]. The sensitivity of the results to choice of \( \sigma_{qq} \) has already been discussed in Ref. [6] hence not done in this work.

III. RESULTS

Figure 1 shows the \( \langle dN_{ch}/d\eta \rangle/N_{N-part} \), \( \langle dN_{\gamma}/d\eta \rangle/N_{N-part} \) and \( \langle dE_T/d\eta \rangle/N_{N-part} \) as a function of centrality at SPS energy. The lower panel shows the values for per nucleon participant. The error bars shown are the systematic errors. The data taken are from the WA98 experiment [27]. It is observed that the values of the observables per nucleon participant increases as one goes from peripheral collisions to central collisions. Whereas it remains fairly constant for the case of quark participants. It may also be noted that the values for charged particles and photons are of similar order.

Figure 2 shows the \( \langle dN_{ch}/d\eta \rangle/N_{N-part} \), and \( \langle dN_{\gamma}/d\eta \rangle/N_{N-part} \), and \( \langle dE_T/d\eta \rangle/N_{N-part} \) as a function of centrality for \( \sqrt{s} = 130 \text{ GeV} \) and \( \langle dN_{ch}/d\eta \rangle/N_{N-part} \) for \( \sqrt{s} = 200 \text{ GeV} \) at RHIC. The lower panel shows the values for per quark participant. The error bars shown are the systematic errors. The data taken are from the PHENIX [3] and PHOBOS experiments [4]. Similar to the case of SPS energy, here also the values of the observables per nucleon participant increases as one goes from peripheral collisions to central collisions. While it remains fairly constant for the case of quark participants. The differences between \( \langle dN_{ch}/d\eta \rangle/N_{N-part} \) or \( \langle dN_{ch}/d\eta \rangle/N_{q-part} \) at \( \sqrt{s} = 130 \text{ GeV} \) and \( \text{200 GeV} \) is not much. However there is a general trend of increase in value of \( \langle dN_{ch}/d\eta \rangle/N_{q-part} \) and \( \langle dE_T/d\eta \rangle/N_{q-part} \) with increase in \( \sqrt{s} \).

IV. SUMMARY

We find that the particle multiplicity density and transverse energy density scales linearly with the number of constituent quark participants for SPS and RHIC energies.
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