Pseudorapidity Distributions of Charged Particles in d + Au and p + p Collisions at $\sqrt{s_{_{NN}}} = 200$ GeV

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Abstract. The measured pseudorapidity distributions of primary charged particles are presented for d + Au and p + p collisions at $\sqrt{s_{_{NN}}} = 200$ GeV over a wide pseudorapidity range of $|\eta| \leq 5.4$. The results for d + Au collisions are presented for minimum-bias events and as a function of collision centrality. The measurements for p + p collisions are shown for minimum-bias events. The ratio of the charged particle multiplicity in d + Au and p + A collisions relative to that for inelastic p + p collisions is found to depend only on $\langle N_{part} \rangle$, and it is remarkably independent of collision energy and system mass. The deuteron and gold fragmentation regions in d + Au collisions are in good agreement with proton nucleus data at lower energies.

Multiplicity distributions of charged particles provide a fundamental measure of the ultra-relativistic collisions now experimentally accessible at RHIC. The particle densities are sensitive to the relative contribution of "soft" processes, involving the longer length scales associated with non-perturbative QCD mechanisms, and "hard" partonic processes. The PHOBOS collaboration has measured charged particle production over a broad range of pseudorapidity $|\eta| \leq 5.4$ at several energies $\sqrt{s_{_{NN}}} = 19.6$, 56, 130 and 200 GeV. We have found that the particle multiplicity in the mid-rapidity region of central Au+Au collisions changes smoothly as a function of $\sqrt{s_{_{NN}}}$ and that the total charged particle production scales with number of participants [1, 2]. For a given centrality, the distributions are found to scale with energy according to the "limiting fragmentation" hypothesis [3]. Kharzeev et al. [4]

attempt to describe these experimental observations in terms of the properties of the initial state as opposed to the dynamics of the final state. The multiplicity measurements of d + Au collisions at $\sqrt{s_{NN}}$ = 200 GeV presented in this paper as function of collision centrality should help clarify the reaction dynamics in heavy ion collisions.

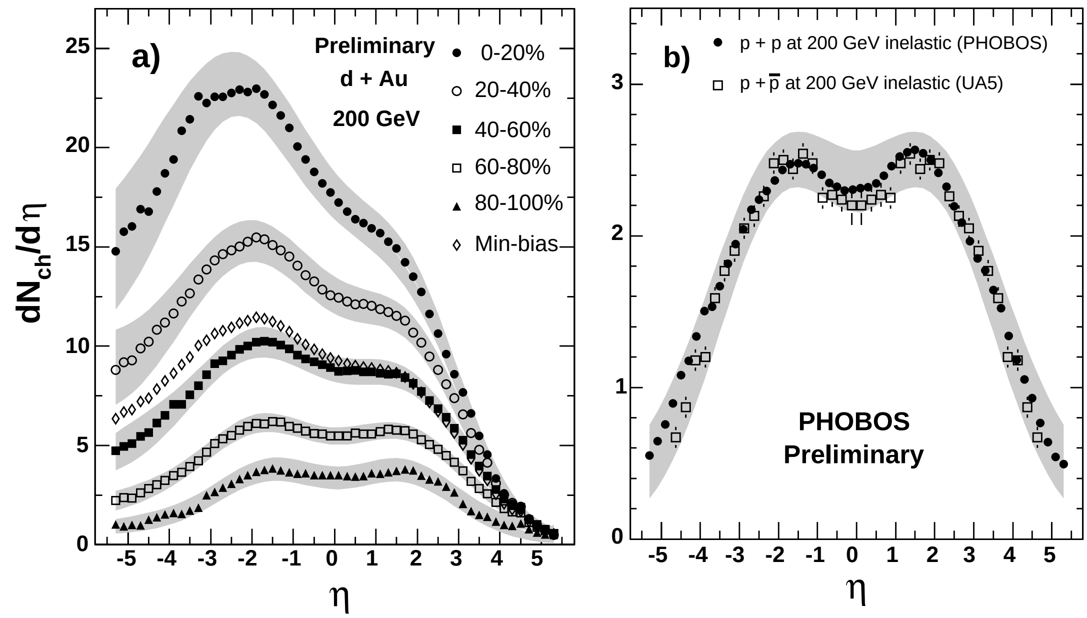

Figure 1. Panel a): Centrality dependence of $dN_{ch}/d\eta$ distributions for $\sqrt{s_{NN}}$ = 200 GeV d + Au collisions for five centrality bins. Shaded bands represent 90% confidence level errors. The minimum bias distribution [5] is shown as open diamonds. Panel b): Comparison of $dN_{ch}/d\eta$ distributions from inelastic p + p and p + p̄ collisions at the same energy, $\sqrt{s_{NN}}$ = 200 GeV.

In this paper, we report on the measurement of charged particle pseudorapidity distributions for d + Au and p + p collisions at $\sqrt{s_{NN}}$ = 200 GeV. The data for p + p collisions are presented for minimum-bias events. The results for d + Au collisions as a function of collision centrality (0-20%, 20-40%, 40-60%, 60-80% and 80-100%) are compared to p + A measurements at lower energies. The multiplicity array used in d + Au and p + p collisions is the same as that for Au + Au collisions at $\sqrt{s_{NN}}$ = 200 GeV. Details about the detector setup and multiplicity reconstruction can be found in Ref. [5].

Figure 1a) shows the pseudorapidity distributions of primary charged particles measured for d + Au collisions at $\sqrt{s_{NN}}$ = 200 GeV in five centrality bins over a wide range of pseudorapidity $|\eta| \leq 5.4$. The systematic errors are shown as gray bands. The statistical errors are negligible. The pseudorapidity is evaluated in the nucleon-nucleon center-of-mass frame; a negative pseudorapidity corresponds to the fragmentation region of the gold nucleus. The asymmetry in the pseudorapidity distributions decreases as the collisions become less central, reaching near symmetry for the most peripheral bin. A detailed study of the minimum-bias distribution (open diamonds) and a comparison to the saturation approach as well as microscopic models can be found in Ref. [5]. Figure 1b) shows the comparison of the pseudorapidity distributions of inelastic p + p collisions measured by PHOBOS to inelastic p + p̄ collisions measured by UA5 [6] at the same energy, $\sqrt{s_{NN}}$ = 200 GeV. The integrated primary charged particle multiplicity in the measured region for inelastic p + p collisions is $N^{ch}_{|\eta|\leq 5.4} = 19.9 \pm 2.2$(syst), and we estimate that the total charged particle multiplicity in this reaction is $N^{ch} = 20.6 \pm 2.3$(syst).

Figure 2a) shows the variation of R_A with the total number of participant

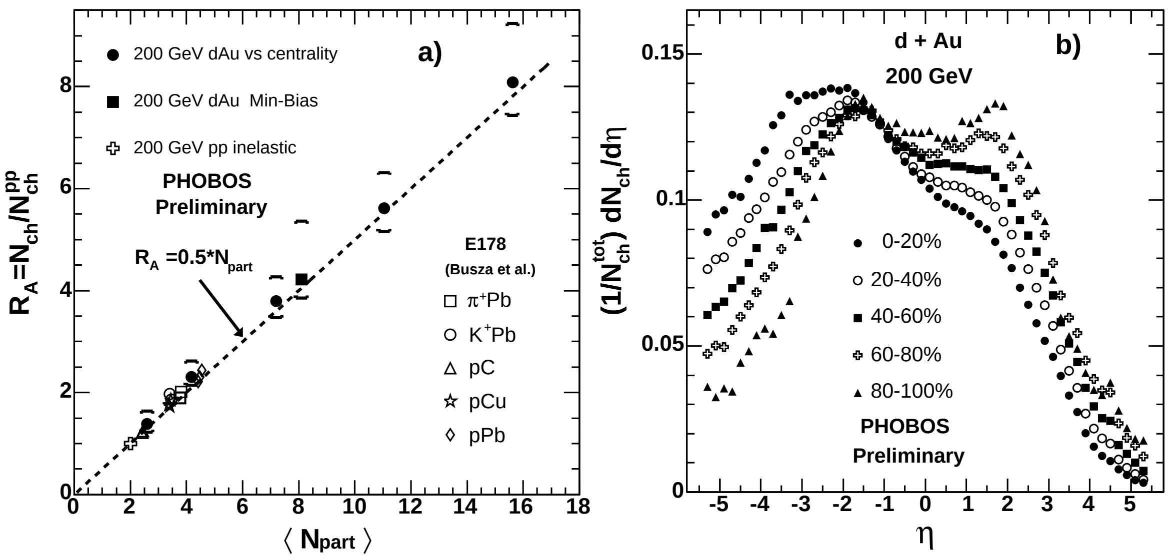

Figure 2. Panel a): The ratio $\mathrm{R_A} = \mathrm{N_{ch}}/\mathrm{N_{ch}^{pp}}$ as a function of the total number of participant nucleons $\langle N_{part}\rangle$ for different collision systems. The pCu, pPb, π^+Pb collisions are for $\sqrt{s_{NN}}$ = 19.4, 13.7 and 9.69 GeV, and the $\mathrm{K^+}$Pb for $\sqrt{s_{NN}}$ = 13.7 and 9.69 GeV. The brackets indicate the systematic errors on the ratio $\mathrm{R_A}$. The dashed line represents the linear relation $\mathrm{R_A} = \frac{1}{2}\langle N_{part}\rangle$. Panel b): Illustration of the dependence of the $\mathrm{dN_{ch}}/\mathrm{d}\eta$ shapes as a function of collision centrality. The distributions are normalized to the estimated total charged particle multiplicity.

nucleons $\langle N_{part}\rangle$ for different collision systems. Here $\mathrm{R_A}$ is the ratio of the integrated total charged particle multiplicity for pC, pCu, pPb, π^+Pb, $\mathrm{K^+}$Pb (taken from Ref. [7]) and dAu collisions to the integrated total charged particle multiplicity for inelastic p + p collisions at the same energy, $\sqrt{s_{NN}}$. The results show that the linear dependence of $\mathrm{R_A}$ on $\langle N_{part}\rangle$, $\mathrm{R_A} = \frac{1}{2}\langle N_{part}\rangle$, observed at lower energies in pA collisions [8] also holds for d+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV. Figure 2b) illustrates the dependence of the $\mathrm{dN_{ch}}/\mathrm{d}\eta$ shapes as a function of collision centrality. The distributions are normalized to the estimated total charged particle multiplicity. The results show how particle production moves towards negative η with increasing centrality.

Figure 3 shows the pseudorapidity distributions of charged particles in d + Au collisions for centrality bin 50-70% (panels a and b) in comparison to a compilation of world data on p + Emulsion (Em) collisions at five energies, and for centrality bin 40-50% compared to p + Pb collisions [7] (panels c and d). The two centrality bins were selected in order to match $\langle N_{part}\rangle$ between d + Au, p + Em, and p + Pb collisions. The corresponding normalization of the $\mathrm{dN_{ch}}/\mathrm{d}\eta$ for d + Au and p + Em collisions requires a ratio of $\langle \mathrm{N_{part}(dAu)}\rangle/\langle \mathrm{N_{part}(pEm)}\rangle$=1.6. However, a ratio of $\langle \mathrm{N_{part}(dAu)}\rangle/\langle \mathrm{N_{part}(pPb)}\rangle$=1.83 is required for the d + Au and p + Pb comparison, if the data are to correspond to the same number of nucleons interacting with the nucleus. In order to compare the pseudorapidity distribution in the gold direction, the pseudorapidity η is shifted to $\eta + \mathrm{y_{target}}$ and the same procedure is applied in the deuteron fragmentation region, where η is shifted to $\eta - \mathrm{y_{beam}}$. The results presented in Figure 3 in panels a) and b) reveal remarkably good agreement between the fragmentation regions of the deuteron from d + Au collisions and of the proton from p + Em collisions at different energies. The overlapping region between the fragmentation regions of the deuteron and proton extends to lower η with increasing collision energy. The same phenomenon is observed in the fragmentation regions of the gold direction from d + Au collisions and the Em direction from p + Em collisions. A similar conclusion can be made from the comparison of more central d + Au collisions and p + Pb data shown in panels c) and d).

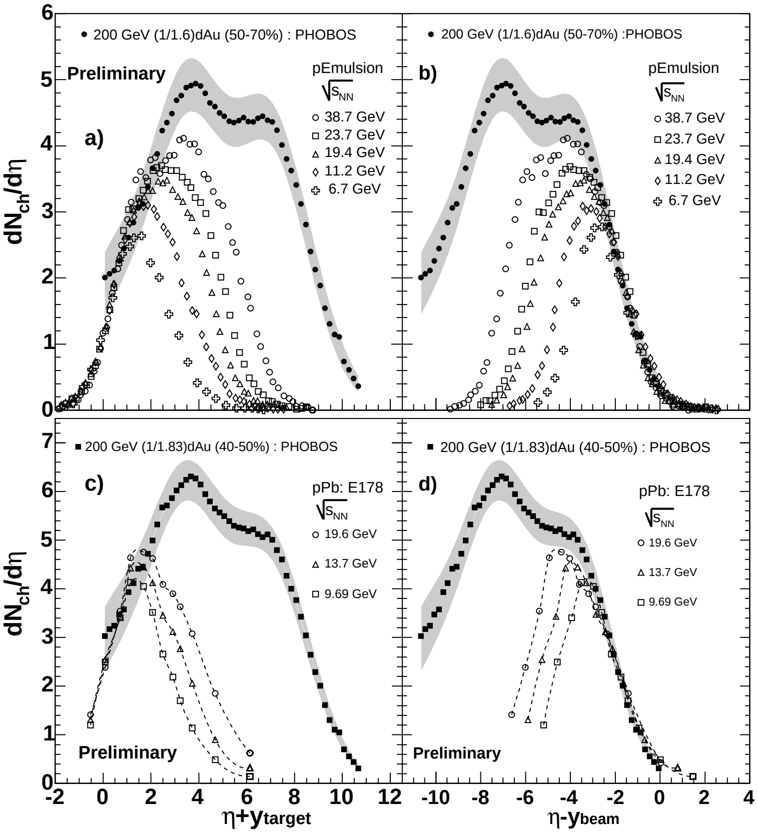

Figure 3. Panel a): Comparison of the pseudorapidity distribution of charged particles for d + Au collisions at $\sqrt{s_{NN}}$ = 200 GeV for centrality bin 50-70% with compilation of world data on p + Em collisions at five energies. The η measured in center-of-mass system has been shifted to $\eta + \mathrm{y}_{\mathrm{target}}$ in order to study the fragmentation regions in the gold/Emulsion direction. Panel b): similar to panel a) but shifted to $\eta - \mathrm{y}_{\mathrm{beam}}$ in order to study the fragmentation regions in the deuteron/proton direction. Panels c) and d): the same as panels a) and b) but for more central d + Au collisions and compared to p + Pb collisions at three energies (for more details see text).

In summary, the pseudorapidity distributions of charged particles have been measured for d + Au and p + p collisions at $\sqrt{s_{NN}}$ = 200 GeV. The results for d + Au collisions have been presented for five centrality bins and for minimum-bias events. The ratio of primary charged particle multiplicity in d + Au and p + A collisions relative to that for inelastic p + p collisions is found to depend only on $\langle N_{part} \rangle$, and it is remarkably independent of collision energy and system mass. The normalized distributions in d + Au collisions show how particle production moves towards negative η with increasing centrality. The fragmentation region in the deuteron (gold) direction of d + Au collisions is in good agreement with the fragmentation region in the proton (nucleus) direction of p + nucleus collisions.

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[1] Back B B *et al* 2002 *Phys. Rev. Lett.* **88** 022302
[2] Back B B *et al* 2002 *Phys. Rev.* **C65** 031901
[3] Back B B *et al* 2003 *Phys. Rev. Lett.* **91** 052303
[4] Kharzeev D *et al* 2001 *Phys. Lett.* **B507** 121 and 2001 *Phys. Lett.* **B523** 79
[5] Back B B *et al* 2003 *Preprint* nucl-ex/0311009 (submitted to 2003 *Phys. Rev. Lett.*)
[6] Alner G J *et al* 1986 *Z. Phys.* **C33** 1
[7] Elias J E *et al* 1980 *Phys. Rev.* **D22** 13
[8] Busza W 1977 *Acta Phys. Pol.* **B8** 333