Charged-Particle Pseudorapidity Density Distributions from \( \text{Au + Au} \) Collisions at \( \sqrt{s_{\text{NN}}} = 130 \text{ GeV} \)

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The charged-particle pseudorapidity density \( dN_{ch}/d\eta \) has been measured for \( \text{Au + Au} \) collisions at \( \sqrt{s_{\text{NN}}} = 130 \text{ GeV} \) at RHIC, using the PHOBOS apparatus. The total number of charged particles produced for the 5% most-central \( \text{Au + Au} \) collisions for \( |\eta| \leq 5.4 \) is found to be \( 4200 \pm 470 \). The evolution of \( dN_{ch}/d\eta \) with centrality is discussed, and compared to model calculations and to data from proton-induced collisions. The data show an enhancement in charged-particle production at midrapidity, while in the fragmentation regions, the results are consistent with expectations from \( pp \) and \( pA \) scattering.

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The data for \( dN_{ch}/d\eta \) at midrapidity (\( |\eta| < 1 \)) for the most central \( \text{Au + Au} \) collisions at \( \sqrt{s_{\text{NN}}} = 56 \) and 130 GeV [1] are in reasonable agreement with the predictions of a number of models including HIJING [3], a saturation model (EKRT) [4], and purely hadronic models (e.g., LUCIFER [5,6]). The centrality dependence of \( dN_{ch}/d\eta \) at midrapidity has also been measured [7,8]. These latter results suggest some deviation from both the HIJING and EKRT model predictions, although they are in broad agreement with the results of calculations by Kharzeev and Nardi [9].

An extension of the measurements of \( dN_{ch}/d\eta \) data beyond midrapidity, for a range of impact parameters, is necessary to further constrain models. It is also of interest to determine whether the observed scaling of the charged-particle yield with \( N_{\text{part}} \) at midrapidity is modified at large values of \( \eta \) where, in proton-nucleus (\( pA \)) collisions [10–12], rescattering, stopping, and target fragmentation influence the shape of the \( dN_{ch}/d\eta \) distributions. In order to address these questions, we have used the PHOBOS apparatus to measure the charged-particle pseudorapidity density \( dN_{ch}/d\eta \) from \( \text{Au + Au} \) collisions at \( \sqrt{s_{\text{NN}}} = 130 \text{ GeV} \) over the range \( |\eta| < 5.4 \).

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The PHOBOS experiment at RHIC largely consists of several arrays of silicon pad detectors. The details of the experimental arrangement are described in Ref. [13]. The procedures used for event selection, the determination of the collision-vertex position, event centrality, and the estimation of \(N_{\text{part}}\), have been described in Refs. [1,8]. The specific elements of the experiment used in the current measurement and the analysis procedures leading to \(dN_{\text{ch}}/d\eta\) are described below.

The data samples included in the current analysis were taken at a collision energy of \(\sqrt{s_{NN}} = 130\) GeV. The collision vertices were confined to a region within \(\pm 10\) cm of the nominal beam crossing and center of the apparatus \((z = 0)\). At midrapidity, charged particles were detected, and their energy deposition measured, with an octagonal array of pad detectors approximately 1 m long (the “octagon”) that surrounds the thin-walled Be beam pipe. The octagon subtends the full azimuthal range, except for regions where sensors that would interrupt the acceptance for the tracking spectrometers and vertex finding detectors are removed. For collision vertices within \(|z| < 10\) cm, the pseudorapidity coverage of the octagon is complete for \(|\eta| \leq 3.2\). Six rings of silicon pad detectors, placed at distances of \(|z| = 1, 2,\) and \(5\) m, detected particles in pseudorapidity ranges of \(3 \leq |\eta| \leq 4, 4 \leq |\eta| \leq 4.7,\) and \(4.7 \leq |\eta| \leq 5.4\), respectively. Thus, for collisions within the 20 cm long region in the center of the experiment, there are no significant gaps in the \(\eta\) coverage from one subdetector to the next. The total numbers of pads in the octagon and rings are \(11,040\) and \(3,072\), respectively.

Two complementary methods were used to analyze the pseudorapidity distribution data. The first method (“hit counting”) uses the segmentation of the multiplicity detector. After merging of signals in neighboring pads, in cases where a particle travels through more than a single pad, the deposited energy was corrected for the angle of incidence, so that all tracks originating from the collision vertex possess a common average value of the deposited energy (\(\Delta E = 80\) keV). Pads containing more than 75% of this value were counted as occupied. This requirement largely suppresses hits from background and from secondary particles not originating from the primary collision vertex. Then, for a given value of \(\eta\) and bin \(i\) in collision centrality, the number of hit pads \(N(\eta, i)\) was corrected for the effects of multiple occupancy, where more than one particle travels through a given pad, as well as for contributions from the remaining secondary particles, absorption in the beam pipe, and weak decays of primary particles. The probability \(P(N)\) of \(N\) particles passing through a given pad was assumed to be Poisson distributed. The mean occupancy \(\mu(\eta, i)\) was then determined from the ratio of occupied to unoccupied pads in a range of \(\eta\) for each centrality bin. As a check, the occupancy was also determined from the energy-deposition spectra, where a fitting procedure was used to determine the relative contribution to the total energy deposition of one or more particles. Maximum values of approximately 1.6 particles per hit pad were obtained for the most central collisions at midrapidity.

To account for effects or biases not treated in the above analysis procedures, a final correction was deduced from GEANT [14] simulations of the detector response using events from the HIJING [3], RQMD [15], and VENUS [16] event generators. The ratio between the simulated, occupancy-corrected \(dN_{\text{ch}}/d\eta\) distributions and the known “truth” distributions formed this last set of corrections, which ranged up to 15% in the octagon and up to 50% in the rings. These background correction factors, dependent upon both \(\eta\) and centrality bin, were applied to the occupancy-corrected data, yielding \(dN_{\text{ch}}/d\eta\). The final results obtained using both occupancy determination methods were in good agreement.

In the second (“analog”) method, the pseudorapidity distribution was extracted directly from the energy deposition \(\Delta E(\eta)\) in the multiplicity detectors, which was transformed into \(dN_{\text{ch}}/d\eta\) using the results of Monte Carlo simulations. The average energy per track (\(\Delta E_{\mu}\)) was determined as a function of \(\eta\) using particles from HIJING events, passed through the GEANT simulation of the detector. The fraction of primary particles \(f_{\text{prim}}(\eta)\) was determined from the same simulations. Then, \(dN_{\text{ch}}/d\eta = \frac{\Delta E(\eta) f_{\text{prim}}(\eta)}{\Delta E_{\mu}(\eta) \Delta \eta}\). Although the two methods are significantly different, they yield results that differ generally by \(\leq 5\%\) throughout the range in \(\eta\), well within the systematic uncertainties (see below), which are approximately 10%.

The systematic uncertainty in the occupancy correction for the hit-counting analysis was obtained by comparing the results from the full analysis chain using Poisson-derived occupancy corrections with those derived from the measured \(\Delta E\) spectra. The average deviations are less than 3%, yielding a partial systematic error of \(\approx 3\%\) at midrapidity. The systematic uncertainties from the Monte Carlo simulations have been estimated by using different assumptions in the GEANT simulation, as well as different event generators, including RQMD [15] and VENUS [16]. The variations observed in the derived background corrections are between 4% and 8%, suggesting a total systematic uncertainty of approximately 10%. The systematic errors in the analog analysis arise from uncertainties in the Monte Carlo simulations, and in the absolute energy calibrations of the silicon-pad detectors. The latter are approximately 5%, yielding a total systematic error for the analog method of approximately 10%, similar to that for the hit-counting method.

Our final results are presented in Figs. 1(a)–1(f), which show the error-weighted average values of \(dN_{\text{ch}}/d\eta\) from the two procedures for six different centrality bins. The error bars represent a convolution of the estimated systematic errors in the different analyses. The different centrality bins are denoted by the corresponding fraction of the estimated total cross section \(\sigma_{\text{tot}}\) based on the observed fraction \(\sigma_{\text{obs}} = (0.97 \pm 0.03)\sigma_{\text{tot}}\), as well as by the deduced average number of participant nucleons \(\langle N_{\text{part}}\rangle\). The
present analyses give values of $dN_{ch}/d\eta|_{\eta<1}$ that are in
good agreement from the independent analysis presented in [8]. For example, for the 6% most central collisions, we
find $dN_{ch}/d\eta|_{\eta<1} = 547 \pm 55$, compared to $580 \pm 25$
from Ref. [8].

The integral over $|\eta| < 5.4$ of the distributions, $N_{ch}^{tot}$,
plotted in Fig. 2(a) as a function of centrality, is a direct
measure of the total entropy produced in the collisions.
Predictions of its magnitude have varied by as much as
a factor of 2 [17]. With increasing $<N_{part}>$, the observed
values of $N_{ch}^{tot}$ change smoothly from 910 $\pm$ 100 for the
40%–45% centrality bin to 4200 $\pm$ 470 for the 3% most
central collisions. Per participant pair, these numbers cor
respond, respectively, to 21.8 $\pm$ 2.6 and 23.7 $\pm$ 2.7, com
pared with the $pp$ and $p\bar{p}$ nondiffractive total charged
particle multiplicity of 18.5 $\pm$ 0.7 [18]. The uncertainties
contain a contribution in quadrature from the systematic
errors in $<N_{part}>$ which range from approximately 3%
to 5% [8]. The predictions of the HIJING model repro
duce the general trend of the $N_{ch}^{tot}$ centrality dependence,
but systematically underpredict the observed values by
10%–15%.

The shapes of the pseudorapidity distributions evolve
gradually with increasing centrality, as shown in
Figs. 1(a)–1(f). For all centrality bins, there is a plateau
region between $-2 < \eta < 2$, followed by a rapid dropoff
towards larger pseudorapidities. A more detailed study
of the centrality dependence of the shape is given in

Figs. 2(b)–2(f) and Fig. 3(a). In Figs. 2(b)–2(f), the
$N_{part}$ dependence of $dN_{ch}/d\eta$ normalized per participant
pair $<N_{part}/2>$ is plotted for five pseudorapidity bins
ranging from $|\eta| < 1$ to $5 < |\eta| < 5.4$. Also plotted are
data from $pp$ [19] and $p\bar{p}$ [20] collisions, scaled as
described below, as open circles, and predictions from the
HIJING model as solid lines. The statistical uncertainties
are small and the systematic uncertainties are comparable
to those described above. Figure 3(a) shows the pseudora
pidity distribution for peripheral (35%–45%) and central
(0%–6%) Au $+$ Au collisions, scaled by the respective
$<N_{part}/2>$.

For all pseudorapidity bins in Figs. 2(b)–2(f), the data
evolve smoothly from the most peripheral to the most cen
tral collisions. As seen in Figs. 2(b), 2(c), and 3(a), central
collisions yield a 10%–15% higher $dN_{ch}/d\eta$ per partici
pant in the plateau region, compared to peripheral events.
This difference between central and peripheral collisions
changes character between $|\eta| = 3$ and 4, beyond which a
higher yield per participant is found in peripheral colli
sions. In the highest 1.5 units of pseudorapidity, as is
observed in $pA$ collisions [10–12], the scaled charged-
particle density actually falls with $N_{part}$, being reduced by
nearly a factor of 2 for $|\eta| > 5$. Qualitatively, the changes
in the distributions from peripheral to central collisions in
the fragmentation regions are similar to those observed in \( pA \) collisions [10–12].

Finally, Fig. 3(b) shows a comparison between \( dN_{ch}/d\eta/\langle N_{\text{part}} \rangle/2 \) from 0%–6% central Au + Au collisions (data points) and scaled data from \( pp \) and \( p\bar{p} \) collisions (grey band). The \( pp/p\bar{p} \) distribution was obtained by scaling the measured \( dN_{ch}/d\eta \) distributions from \( pp \) collisions at \( \sqrt{s} = 53 \text{ GeV} \) and \( p\bar{p} \) collisions at \( \sqrt{s} = 200 \) and 546 GeV [19,20] horizontally by \( y_{\text{max}}(130 \text{ GeV})/y_{\text{max}}(\sqrt{s}) \), where \( y_{\text{max}}(\sqrt{s}) = \ln(\sqrt{s}/m_p) \), and vertically using the parametrization of \( dN/d\eta |_{|\eta|<1} \) from [20]. This empirical scaling is chosen such that the extrapolation of three sets of \( pp \) or \( p\bar{p} \) data are confined within the grey band on Fig. 3(b). The grey band gives an estimate of the uncertainty of this extrapolation procedure.

The scaled \( dN_{ch}/d\eta \) is found to be higher in central Au + Au collisions than in \( pp/p\bar{p} \) over the full pseudorapidity range out to \( |\eta| = 4 \), with the largest excess observed in the central plateau region. This is in contrast with the HIJING prediction (solid curve), which shows an excess in Au + Au collisions only for \( |\eta| \leq 2–3 \). A possible origin of this qualitative difference is suggested by the AMPT model of Zhang et al. [21]. In this model, the initial state parton distribution is obtained as in HIJING, but is followed by a parton cascade [22], string fragmentation, and hadronic rescattering using a relativistic transport model [23]. This model reproduces the excess in particle production at higher pseudorapidities seen in Au + Au collisions relative to \( pp/p\bar{p} \). Furthermore, predictions of \( dN_{ch}/d\eta \) in a completely hadronic framework (e.g., LUCIFER) [6] are very similar to those of the AMPT calculations, and are also in good agreement with the data for the most central collisions. These observations suggest that effects in the hadronic phase, e.g., rescattering, should be taken into account to provide a full description of the data. A comparison of the predicted centrality dependence of the full distributions from these models with the data would also be of interest. Further insight will be gained from future RHIC data, which should include more precise reference data from \( pp \) collisions, as well as nucleus-nucleus data at different collision energies. These results will provide a basis for separating the effects of new phenomena from conventional hadronic physics.

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[14] GEANT Detector Description and Simulation Tool v. 3.21, CERN.