PRAMANA — journal of physics | © Indian Academy of Sciences | Vol. 60, No. 5 May 2003 pp. 1059–1065

# Pseudorapidity distributions of charged particles in Pb–Pb collisions at super proton synchrotron energies from the NA50 experiment

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**Abstract.** We present the measurements of charged particle pseudorapidity distributions $dN_{ch}/d\eta$ performed by the NA50 experiment in Pb–Pb collisions at the CERN SPS. Measurements were done at incident energies of 40 GeV ($\sqrt{s} = 8.77$ GeV) and 158 GeV ($\sqrt{s} = 17.3$ GeV) per nucleon over a broad impact parameter range. The multiplicity distributions are studied as a function of centrality using the number of participating nucleons ($N_{part}$), or the number of binary nucleon–nucleon collisions ($N_{coll}$). Their values at midrapidity exhibit a linear scaling with $N_{part}$ at both energies. Particle yield increases approximately by a factor of 2 between $\sqrt{s} = 8.77$ GeV and $\sqrt{s} = 17.3$ GeV.

**Keywords.** Relativistic heavy-ion collisions; pseudorapidity distributions; multiparticle production; silicon multiplicity detectors.

**PACS No. 25.75**

## 1. Introduction

The multiplicity of charged particles produced in heavy-ion collisions is a global variable that is essential for their characterization, because it quantifies to which extent the incoming beam energy is released to produce new particles. It may help constrain different models of particle production, and quantify the relative importance of soft versus hard processes in the particle production mechanisms at different energies. In this respect, an important test for models of particle production in heavy-ion reactions is the study of its scaling properties with respect to both the number of participant nucleons ($N_{part}$) and the number of binary collisions ($N_{coll}$). Another information relevant for constraining particle production models is provided by the study of the scaling of charged particle multiplicity versus $\sqrt{s}$.

The pseudorapidity distributions of charged particles in Pb–Pb collisions at the CERN SPS have been measured with the multiplicity detector of the NA50 experiment at beam energies 40 GeV and 158 GeV per nucleon. In this paper the particle density at mid-rapidity ($dN/d\eta|_{max}$) and the yield per participant pair are studied versus the centrality of the collision, at both energies, using values of $N_{part}$ and of $N_{coll}$ calculated in the framework of the Glauber model, in order to enrich the pattern outlined by the results of other experiments at the super proton synchrotron (SPS) and at relativistic heavy-ion collider (RHIC).

## 2. Experimental setup and data taking conditions

The NA50 apparatus [1] consists of a muon spectrometer, equipped with three centrality detectors (a zero degree calorimeter, an electromagnetic calorimeter and a multiplicity detector) and specific devices for beam tagging and interaction vertex identification. The analyzed data were collected during special runs at low beam intensity using the minimum bias (MB) trigger, which requires a non-zero energy deposit in the ZDC. Data collected at two different SPS Pb beam energies, namely 158 and 40 GeV, are analyzed.

The multiplicity and the angular distribution of charged particles are measured in a wide acceptance window by a silicon strip multiplicity detector (MD) [2–4]. In this analysis the determination of the centrality of the collision is obtained first, by means of the zero degree calorimeter (ZDC) [5] which measures the energy $E_{\text{ZDC}}$ of the spectator nucleons travelling in the forward direction and second, by the electromagnetic calorimeter (EMCAL) which measures the neutral transverse energy $E_{\text{T}}$ in the pseudorapidity range $1.1 < \eta < 2.3$.

## 3. Centrality selection and model calculations

The aim of our analysis is to study the properties of $\mathrm{d}N_{\text{ch}}/\mathrm{d}\eta$ distributions in Pb–Pb collisions as a function of centrality using two independent centrality estimators, namely, the forward energy $E_{\text{ZDC}}$ and the transverse energy $E_{\text{T}}$. To allow a comparison of the results obtained with these two different variables, centrality intervals have been defined in terms of fractions of the inelastic cross-section which was calculated from the minimum bias (MB) $\mathrm{d}N/\mathrm{d}E_{\text{ZDC}}$ and $\mathrm{d}N/\mathrm{d}E_{\text{T}}$ distributions.

The limits of each centrality class have been fixed so as to have classes with a width corresponding to 5% of the total inelastic cross section $\sigma_{\text{inel}}$. When the 5% class would have been too narrow with respect to the $E_{\text{ZDC}}$ or $E_{\text{T}}$ resolution thus giving rise to possible biases in the centrality selection, a class with a width corresponding to $10\% \cdot \sigma_{\text{inel}}$ has been defined. In this way, six centrality classes have been defined for both centrality estimators. For the data sample collected at 40 GeV per nucleon incident energy, due to the bad resolution of the ZDC at such a low beam energy, only the analysis with the $E_{\text{T}}$ based centrality selection has been performed.

For each centrality interval, the average values of $N_{\text{part}}$ and $N_{\text{coll}}$ have been estimated in the framework of the Glauber model with the Woods–Saxon nuclear density parametrization and assuming that $E_{\text{T}}$ is proportional to the number of participants and $E_{\text{ZDC}}$ to the number of projectile spectators. Smearing effects due to the experimental resolution of the calorimeters have also been included in our calculation.

## 4. Event analysis

The data analysis has been performed both in the centrality classes defined by $E_{\text{T}}$ and in the ones defined by $E_{\text{ZDC}}$, according to the following procedure. First some quality cuts ensuring rejection of beam pile-up and out of target interaction events have been applied to the data sample. Then in each centrality class the raw $\mathrm{d}N_{\text{ch}}/\mathrm{d}\eta$ distribution has been calculated. Finally, the primary $\mathrm{d}N_{\text{ch}}/\mathrm{d}\eta$ distribution has been obtained by subtracting the delta electron contribution and then by correcting for secondary processes. Gamma conversions and other processes of secondary particle production or primary particle decay have been evaluated with a complete Monte Carlo simulation based on the VENUS 4.12 event generator and on the GEANT 3.21 package for track propagation and detector response simulation. We estimate the overall systematic error on the evaluated multiplicity to be below 8% for the data collected at 158 GeV/nucleon and about 10% for the 40 GeV/nucleon sample.

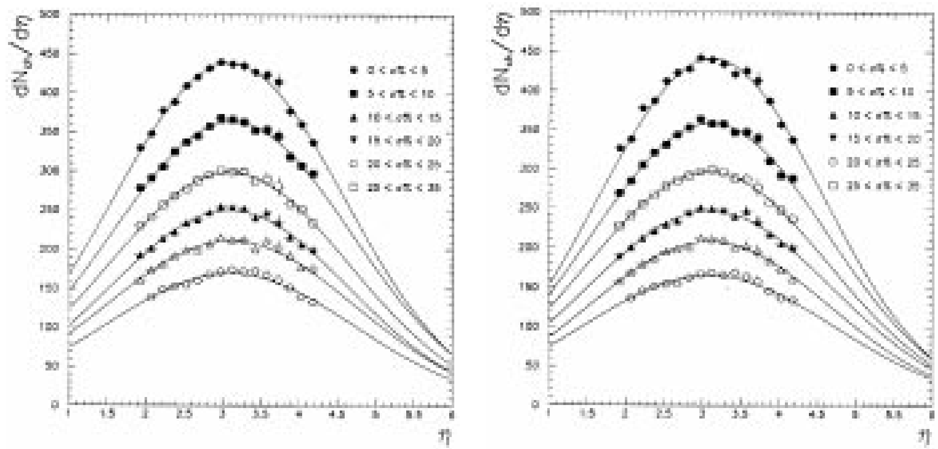

**Figure 1.** Pseudorapidity distributions of charged particles in 158 GeV/nucleon Pb–Pb collisions obtained using $E_{\mathrm{ZDC}}$ (left plot) and $E_{\mathrm{T}}$ (right plot) as centrality estimators. Gaussian fits are superimposed.

## 5. Data analysis

### 5.1 *Pseudorapidity distributions*

The pseudorapidity distributions of the primary charged particles for the different centrality classes have been calculated following the procedure outlined above.

The $\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta$ distributions thus obtained have been fitted with Gaussians, to obtain an estimate of the charged particle pseudorapidity density at the peak ($\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta|_{\mathrm{max}}$), of the peak position ($\eta_{\mathrm{max}}$) and of the Gaussian width ($\sigma_{\mathrm{Gaus}}$). We emphasize that, thanks to the wide $\eta$ coverage ($\sim$2.2 units) approximately symmetric around the peak, we do not need to fix the mid-rapidity point $\eta_{\mathrm{max}}$ at the theoretical value. Instead, we leave it as a free parameter of the fit.

The results of the fits for the 158 GeV data sample with the two independent centrality selections are shown in figure 1. They are in very good agreement. The maximum difference between the corresponding $\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta|_{\mathrm{max}}$ values amounts to $\simeq$2.5%. The mid-rapidity values resulting from the Gaussian fits are compatible with the value $\eta_{\mathrm{max}} \simeq 3.1$ extracted from VENUS. The width of Gaussian fits to $\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta$ for both centrality estimators ($\sigma_{\mathrm{Gaus}} \simeq 1.55$) shows a slightly decreasing behavior with increasing centrality. This narrowing of the shape of the particle pseudorapidity distributions with increasing centrality can be associated with the higher degree of stopping reached in the interaction.

In figure 2, the particle pseudorapidity distributions obtained for the data collected at 40 GeV per nucleon beam energy are shown. The $\eta_{\mathrm{max}}$ value expected from VENUS is 2.47 and is compatible with our results. The width of the Gaussians ($\sigma_{\mathrm{Gaus}} \simeq 1.3$) is lower than the one observed for the 158 GeV data sample, reflecting the fact that the available phase space in rapidity increases with the center-of-mass energy. Furthermore, also for this data sample, the fitted values of $\sigma_{\mathrm{Gaus}}$ suggest a decrease of the width of the $\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta$ distributions with increasing centrality.

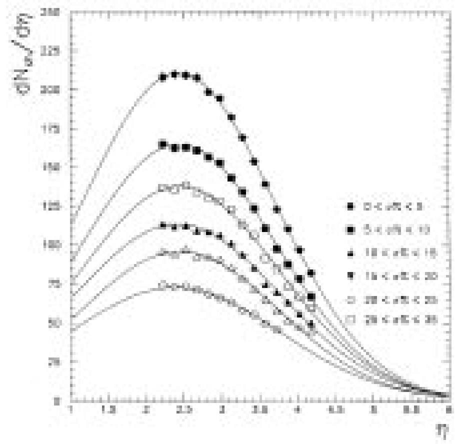

**Figure 2.** Pseudorapidity distributions of charged particles in 40 GeV/nucleon Pb–Pb collisions obtained using $E_{\mathrm{T}}$ as centrality estimator.

### 5.2 *Centrality dependence of particle production*

To evaluate the centrality dependence of particle production, the scaling behavior of $\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta\,|_{\max}$ as a function of the number of participant nucleons $N_{\mathrm{part}}$ has been parametrized with the usual power law behavior:

$$\left(\frac{\mathrm{d}N_{\mathrm{ch}}}{\mathrm{d}\eta}\right)_{\max} \propto N_{\mathrm{part}}^{\alpha}.$$

The value of the scaling exponent for the 158 GeV/nucleon data sample results to be $\alpha = 1.00 \pm 0.01(\mathrm{stat.}) \pm 0.04(\mathrm{syst.})$ with both the $E_{\mathrm{T}}$ and the $E_{\mathrm{ZDC}}$ centrality selections, as can be seen in figure 3. This value of $\alpha$ is in agreement with the wounded nucleon model assumption that the average multiplicity in a collision is proportional to the number of participant (wounded) nucleons.

It has to be stressed that the value of the exponent $\alpha$ is strongly dependent on the value of $\langle N_{\mathrm{part}}\rangle$ and may vary significantly as a consequence of slight variations of $\langle N_{\mathrm{part}}\rangle$.

A fit with the power law $\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta\,|_{\max} \propto N_{\mathrm{coll}}^{\beta}$ has also been performed, obtaining for the exponent the values $\beta = 0.74$ and 0.76 with $E_{\mathrm{ZDC}}$ and $E_{\mathrm{T}}$ centrality selections, respectively. Therefore, we can conclude that $N_{\mathrm{part}}$ is well-suited to describe the scaling of particle production with the centrality of the collision and that a scaling like $N_{\mathrm{coll}}$ is not observed at this energy.

Finally, a fit with the function $\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta\,|_{\max} = A \times N_{\mathrm{part}} + B \times N_{\mathrm{coll}}$ has been done, in order to verify the possible presence of a term proportional to the number of collisions. The results of the fits for both centrality selections lead to values of $B$ compatible with zero, indicating that the contribution from hard processes to charged particle production is negligible at this energy.

The data sample collected at 40 GeV per nucleon has also been fitted with $N_{\mathrm{part}}^{\alpha}$, leading to $\alpha = 1.02 \pm 0.02(\mathrm{stat.}) \pm 0.06(\mathrm{syst.})$, which is compatible with the value found at 158 GeV per nucleon.

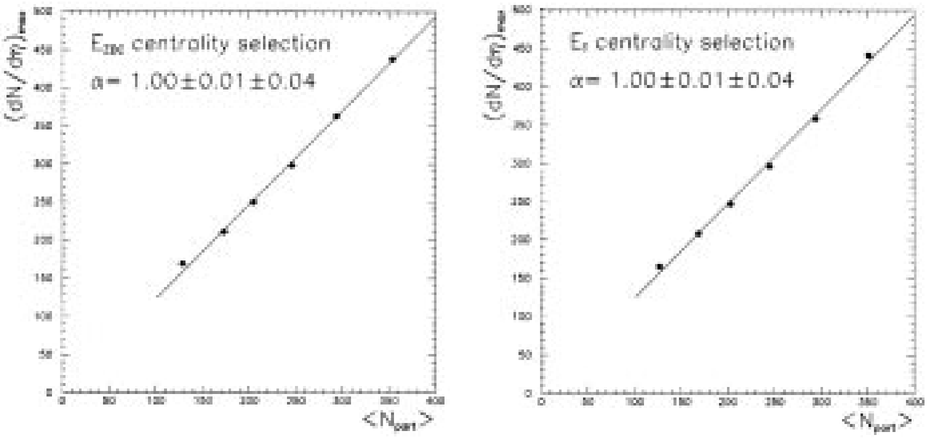


**Figure 3.** Pseudorapidity density of $N_{ch}$ at mid-rapidity as a function of the number of participants ($N_{part}$) in 158 GeV per nucleon Pb–Pb collisions with the two independent centrality selections. Power-law fits are superimposed.

### 5.3 *Energy dependence of charged particle production*

In order to study the energy dependence of charged particle production and to compare our results with the ones obtained for other colliding systems, we have calculated the charged particle pseudorapidity density at mid-rapidity per participant pair. In particular, at 158 GeV per nucleon for the 0–5% centrality range we obtain: $dN_{ch}/d\eta|_{max}/(0.5\langle N_{part}\rangle) = 2.49 \pm 0.03(\text{stat.}) \pm 0.20(\text{syst.})$, which is the average of the values obtained with the $E_T$ and $E_{ZDC}$ centrality selections. The systematic error accounts for the 8% systematic uncertainty on the multiplicity evaluation.

At 40 GeV per nucleon, for the 0–5% centrality range we obtain: $dN_{ch}/d\eta|_{max}/(0.5\langle N_{part}\rangle) = 1.18 \pm 0.03(\text{stat.}) \pm 0.17(\text{syst.})$. The large systematic error bar is due to both the 10% systematic error on the multiplicity and the uncertainty ($\approx 10\%$) on the evaluation of $\langle N_{part}\rangle$ for the most central band.

It is important to point out that the yield per participant pair is strongly dependent on the $N_{part}$ calculation, and therefore the comparison of our results with other experiments, which may use different models for the evaluation of $N_{part}$, is very delicate.

## 6. Conclusions

The charged particle pseudorapidity distributions $dN_{ch}/d\eta$ have been studied as a function of the number of participant nucleons $N_{part}$ and of binary nucleon–nucleon collisions $N_{coll}$ in Pb–Pb collisions at two different beam energies, namely 158 GeV per nucleon ($\sqrt{s} = 17.2$ GeV) and 40 GeV per nucleon ($\sqrt{s} = 8.66$ GeV).

The maximum of the $dN_{ch}/d\eta$ distributions has been estimated by means of Gaussian fits. The results obtained indicate a steep increase of particle production at SPS energies, which amounts to approximately a factor of 2 when going from $\sqrt{s} = 8.66$ GeV to 17.2 GeV.

The charged particle pseudorapidity density at mid-rapidity scales as $N_{\text{part}}^{\alpha}$ with $\alpha = 1.00 \pm 0.01(\text{stat.}) \pm 0.04(\text{syst.})$ at 158 GeV per nucleon beam energy, in agreement with the wounded nucleon model predictions. The presence of a contribution scaling like $N_{\text{coll}}$ is not observed, so that hard processes seem to play a negligible role in charged particle production at 158 GeV per nucleon. A similar scaling with $\alpha = 1.02 \pm 0.02 \pm 0.06$ is observed for the data at 40 GeV per nucleon where no contribution from hard processes is expected.

**Acknowledgements**

This work was supported in part by the Polish State Committee for Scientific Research, project no. 2P03B03319.

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