Determination of the number of wounded nucleons in Pb+Pb collisions at 158 $A\,\mathrm{GeV}/c$

Presented by N. Carrer for the WA97 and NA57 collaborations:

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The charged particle multiplicity distributions measured with the WA97 and the NA57 multiplicity detectors in $\mathrm{Pb}+\mathrm{Pb}$ collisions at 158 $A\,\mathrm{GeV}/c$ have been analyzed in the framework of the Wounded Nucleon Model (WNM). We obtain a good description of the data within the centrality range of our samples. This allows us to make use of the measured multiplicities to estimate the number of wounded nucleons of the collision.

1. Introduction

The centrality of the collision is a fundamental parameter in the study of heavy–ion reactions since, for a given colliding system and beam energy, it determines the volume and the energy density of the fireball. In heavy–ion experiments the centrality is usually estimated by measuring one or more of the following observables: charged particle multiplicity (N_{ch}), transverse energy (E_T), energy deposited in a zero degree calorimeter (E_{ZDC}). The WA97 and NA57 experiments estimate the centrality using the charged particle multiplicity measured over the pseudorapidity range $2 < \eta < 4$.

The Glauber model [7] provides a simple geometrical interpretation of a collision between nuclei. In this model the projectile nucleons traverse the target nucleus in a straight line and can undergo several collisions with the nucleons of the target. The assumption is made that although the nucleon becomes excited (*wounded*) as a result of consecutive collisions, it remains essentially a nucleonic state and thus it interacts with the same cross section as the original nucleon. In addition, the main WNM [2] assumption is that the average multiplicity in a collision is proportional to the number of wounded nucleons (N_{part}). The WNM has proven to be successful in describing proton–nucleus ($\mathrm{p} + \mathrm{A}$) interactions [1]. In this paper we shall study to which extent this proportionality also holds in $\mathrm{Pb} + \mathrm{Pb}$ reactions. Such a scaling law has already been shown to work for E_T [3] in $\mathrm{Pb} + \mathrm{Pb}$ collisions.

2. Multiplicity measurement

The NA57 and WA97 experiments have similar layouts. These are described respectively in Ref. [4] and [5]. A $158\,A\,\mathrm{GeV}/c$ lead beam is incident on a lead target with a thickness corresponding to 1% of the $\mathrm{Pb} + \mathrm{Pb}$ interaction length. Scintillator petals, placed at 10 cm from the target and covering the pseudorapidity range $1 < \eta < 2$, provide a fast estimate of the multiplicity which is used at trigger level. For a more detailed study of the centrality of the collisions, the multiplicity of charged particles is measured by two planes of silicon micro-strip detectors (MSD), positioned respectively 19.8 cm and 54.5 cm downstream of the target. Each plane consists of three independent arms. The strip dimensions were chosen so as to keep the occupation numbers as uniform as possible. With this geometry, the first and the second plane cover the pseudorapidity region $1.88 < \eta < 2.99$ and $2.87 < \eta < 4.00$ respectively.

In order to obtain the charged particle multiplicity distribution in the pseudorapidity range $2 < \eta < 4$, the contribution due to interactions in the air or other materials along the beam line (*empty target* contamination) was subtracted from the MSD data. Then the hit multiplicity on the MSD detectors (M_{raw}) was corrected for delta–rays and background hits, geometrical acceptance, detector response (efficiency, double hits, charge sharing between contiguous strips), secondary interactions and gamma rays conversions.

The empty target contamination was subtracted using data samples collected without the target. In NA57 an effort was made to reduce this contribution in order to collect a sample of more peripheral events. The empty target contamination was $\simeq 17\%$ of the triggered events for WA97 and $\simeq 6\%$ for NA57. The delta–ray contribution to the measured multiplicity comes mainly from the passage in air of lead ions which traverse the set–up while the MSD is integrating the signals of a triggered event. This contribution

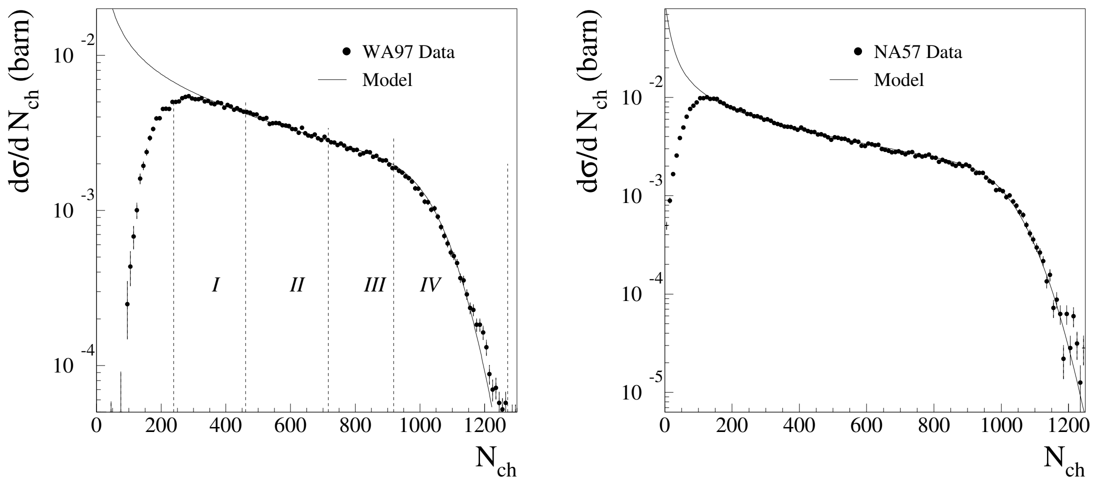

Figure 1. Fit of the multiplicity distributions with the Wounded Nucleon Model for the WA97 (left) and NA57 (right) experiments.

amounts to about 2.5% of the maximum multiplicity for WA97 and to 0.7% for NA57. The systematic error due to the uncertainty on the number of beams traversing the apparatus during the integration time of the MSD is included in the analysis. All the other corrections have been computed via a Monte Carlo simulation.

Due to the partial azimuthal coverage of the pseudorapidity region $2 < \eta < 4$, the multiplicity distribution, corrected for the aforementioned contributions, is smeared due to fluctuations inherent in the experimental sampling process. This contribution to the dispersion has been evaluated by studying the relative multiplicity fluctuations between the two MSD planes. We assume the two planes to give independent measurements of N_{ch} since they cover two practically non–overlapping pseudorapidity intervals symmetric around midrapidity.

3. Wounded Nucleon Model fit to the data

We describe the multiplicity distribution in the framework of the WNM. We assume that the average charged particle multiplicity is proportional to the number of wounded nucleons, computed from the Glauber model [2]: $\langle N_{ch} \rangle = qN_{part}$. The only physical inputs to the model are the density distribution of the nucleons inside the nucleus and the nucleon–nucleon cross section. Since we are interested in non–diffractive particle production we use the nucleon–nucleon inelastic cross section $\sigma_{in} = 30\,\mathrm{mb}$. The nuclear density distribution has been parameterized by a Woods–Saxon function with parameters taken from Ref. [6].

The average number of wounded nucleons for a given impact parameter $\mathbf{b}$ is [3]:

$$\langle N_{part}(\mathbf{b})\rangle = A\int T_A(\mathbf{s})\,\{1-[1-T_B(\mathbf{s}-\mathbf{b})\sigma_{in}]^B\}\mathrm{d}^2\mathbf{s}$$
$$+B\int T_B(\mathbf{s}-\mathbf{b})\,\{1-[1-T_A(\mathbf{s})\sigma_{in}]^A\}\mathrm{d}^2\mathbf{s}, \qquad (1)$$

where $T_{A,B}$ are the thickness functions [7] of the target (A) and projectile (B) nuclei and the integration variable $\mathbf{s}$ spans the plane perpendicular to the collision axis.

For a fixed impact parameter the dispersion of the number of charged particles is given by the formula:

$$\sigma^2_{N_{ch}} = q^2\sigma^2_{N_{part}} + N_{part}\sigma^2_q + (\sigma^{exp}_{N_{ch}})^2, \qquad (2)$$

where $\sigma_{N_{part}}$ is the dispersion of the number of wounded nucleons and σ_q is the dispersion of the number of charged particles per wounded nucleon. $\sigma_{N_{part}}$ has been evaluated via a Monte Carlo implementation of the Glauber model. According to $\mathrm{p+p}$ data up to ISR energies, the dispersion σ_q is proportional to the charged particle multiplicity [8], *i.e.* $\sigma_q = aq$, where $a \simeq 1$ at SPS energies in the pseudorapidity range $2 < \eta < 4$ [9,10]. The last term in equation (2) is the experimental sampling dispersion discussed previously.

The differential inelastic $\mathrm{Pb+Pb}$ cross section $\mathrm{d}\sigma^{\mathrm{Pb+Pb}}_{\mathrm{in}}/\mathrm{dN_{ch}}$ can be written as:

$$\frac{\mathrm{d}\sigma^{\mathrm{Pb+Pb}}_{\mathrm{in}}}{\mathrm{dN_{ch}}}(N_{ch}) = \int \mathrm{d}\mathbf{b}\,[1-\mathrm{P}(0,\mathbf{b})] \times \frac{1}{\sqrt{2\pi}\sigma_{\mathrm{N_{ch}}}}\,\exp\left\{-\frac{(\mathrm{N_{ch}} - \mathrm{q}\,\langle \mathrm{N_{part}}(\mathbf{b})\rangle)^2}{2\sigma^2_{\mathrm{N_{ch}}}}\right\}, \qquad (3)$$

where $[1-P(0,\mathbf{b})]$ is the probability of having at least one inelastic collision.

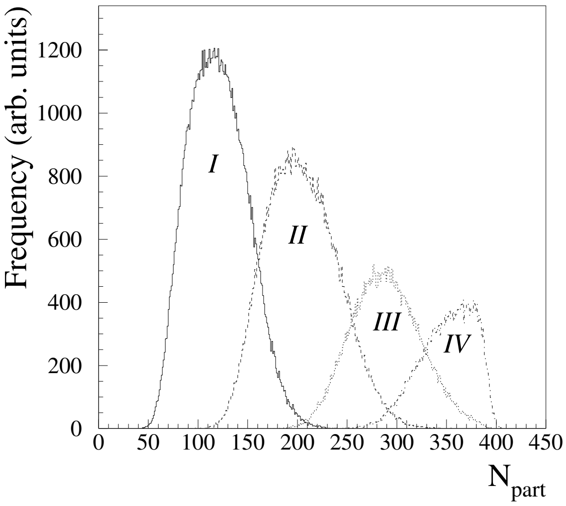

Figure 2: Distribution of the number of wounded nucleons in the four WA97 multiplicity bins.

Figure 1 shows the WNM fit to the corrected WA97 and NA57 charged particle multiplicity distributions in the range $2 < \eta < 4$. We fitted simultaneously both the proportionality constant q and the absolute normalization. We indicate the value of the trigger cross section extracted from the fit normalization as σ^{fit}_{trig}. The parameters of the fit of $\mathrm{d}\sigma/\mathrm{dN_{ch}}$ are shown in table 1, where the quoted errors include both statistical (first error) and systematics (second error) contributions. The fitted trigger cross section for the WA97 experiment is compatible with the estimated experimental value of about the 40% of the total $\mathrm{Pb+Pb}$ inelastic cross section. In the NA57 experiment the trigger cross section was measured with a 3% precision and its value $\sigma^{\mathrm{exp}}_{\mathrm{trig}} = (4.29 \pm 0.12)$ barn is in agreement with the value obtained from the WNM fit. Figure 1 also shows the four centrality classes used in the analysis of the

WA97 experiment [11]. Figure 2 shows the distribution of the number of wounded nucleons for each multiplicity bin according to the fit. The first multiplicity bin has been corrected for the effect of the centrality trigger. The average values of N_{part} together with the FWHM values of their distributions are listed in table 2.

4. Conclusions

We have presented the charged particle multiplicity measurements performed by the WA97 and NA57 experiments in the pseudorapidity range $2 < \eta < 4$. The Wounded Nucleon Model provides a good description of the multiplicity distributions both with respect to the shape and to the absolute normalization of the spectra. This allowed us to estimate the number of wounded nucleons in Pb + Pb collisions. The extended centrality range of the NA57 data sample should allow us to have a sizable statistics of events down to $N_{part} = 40 \div 50$. This will make possible to reach within the Pb + Pb system the same number of wounded nucleons characteristic of central S + S collisions.

Table 1
Parameters of the fit.

	WA97	NA57
q	$2.70 \pm 0.03 \pm 0.08$	$2.62 \pm 0.03^{+0.02}_{-0.05}$
σ^{fit}_{trig} (barn)	$3.14 \pm 0.09^{+0.11}_{-0.12}$	$4.42 \pm 0.14^{+0.15}_{-0.07}$
χ^2/d.o.f.	2.05	1.50

Table 2
Average N_{part} and FWHM of the distribution for the four WA97 multiplicity classes.

	Bin 1	Bin 2	Bin 3	Bin 4
$\langle N_{part} \rangle$	$120.1^{+5.7}_{-6.1}$	$204.6^{+4.1}_{-4.4}$	$289.0^{+2.5}_{-2.9}$	$350.6^{+0.9}_{-1.1}$
FWHM	79.7	90.3	81.3	72.1

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