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## Multiplicity of charged particles in Pb–Pb collisions at SPS energies

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**Abstract.** The multiplicity of charged particles in the central rapidity region has been measured by the NA57 experiment in Pb–Pb collisions at the CERN SPS at two beam momenta: 158 A GeV/c and 40 A GeV/c. The value of  $dN_{ch}/d\eta$  at the maximum has been determined and studied as a function of centrality within the range covered by NA57 (about 55% most central part of the inelastic cross section). The central rapidity multiplicity varies roughly linearly with the number of wounded nucleons (participants) and increases approximately logarithmically with the centre of mass energy.

## 1. Introduction

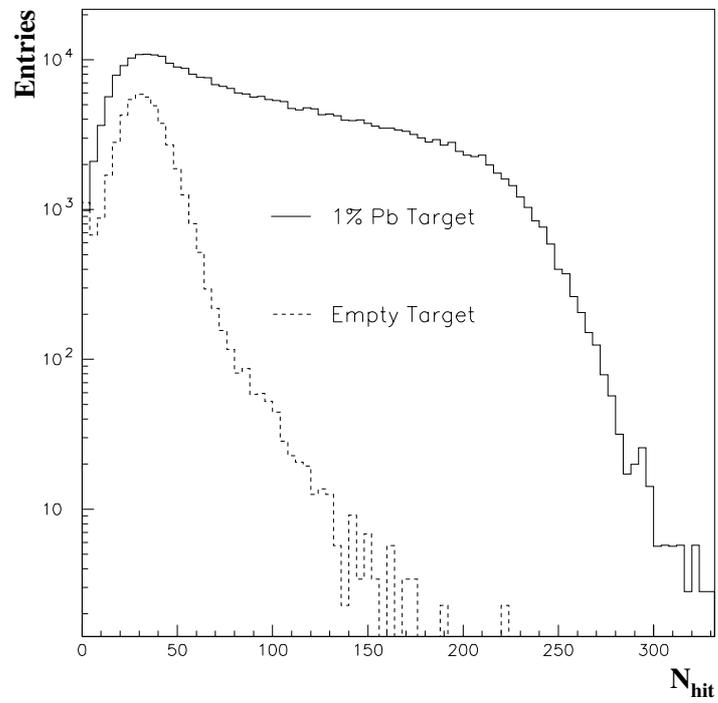
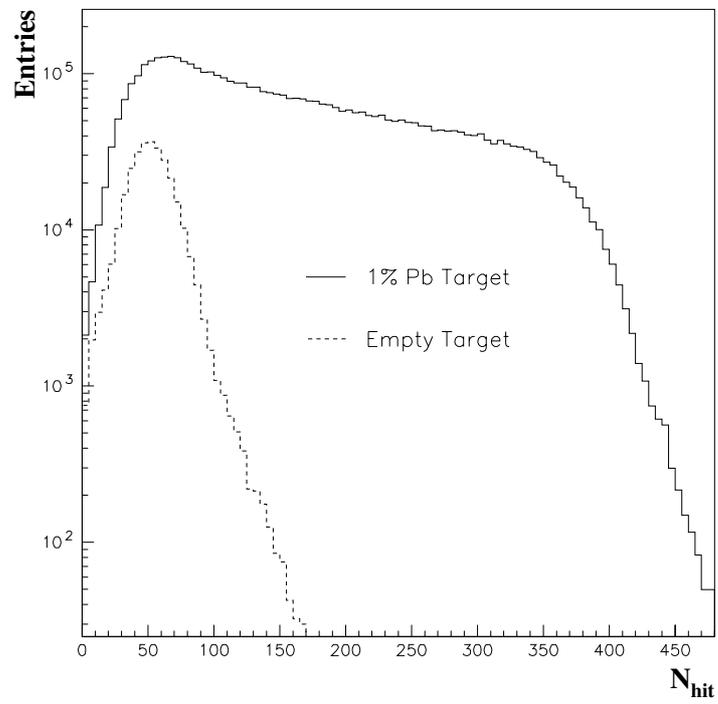
The NA57 experiment samples the event multiplicity with a dedicated Microstrip Silicon Detector (MSD). The MSD multiplicity is used for the off-line estimate of the collision centrality as expressed by the number of nucleons participating in the primary interactions [1]. This allows us to study the production of strange particles in Pb–Pb collisions as a function of the collision centrality [2]. Here we concentrate our attention on the evaluation of the central rapidity charged particle multiplicity as characterized by its maximum pseudorapidity density  $dN_{ch}/d\eta|_{max}$ , which is independent of the details of the acceptance and for this reason very convenient for comparison between different experiments. Our measurements at both energies cover a centrality range corresponding to about 55% most central Pb-Pb collisions.

## 2. Multiplicity reconstruction

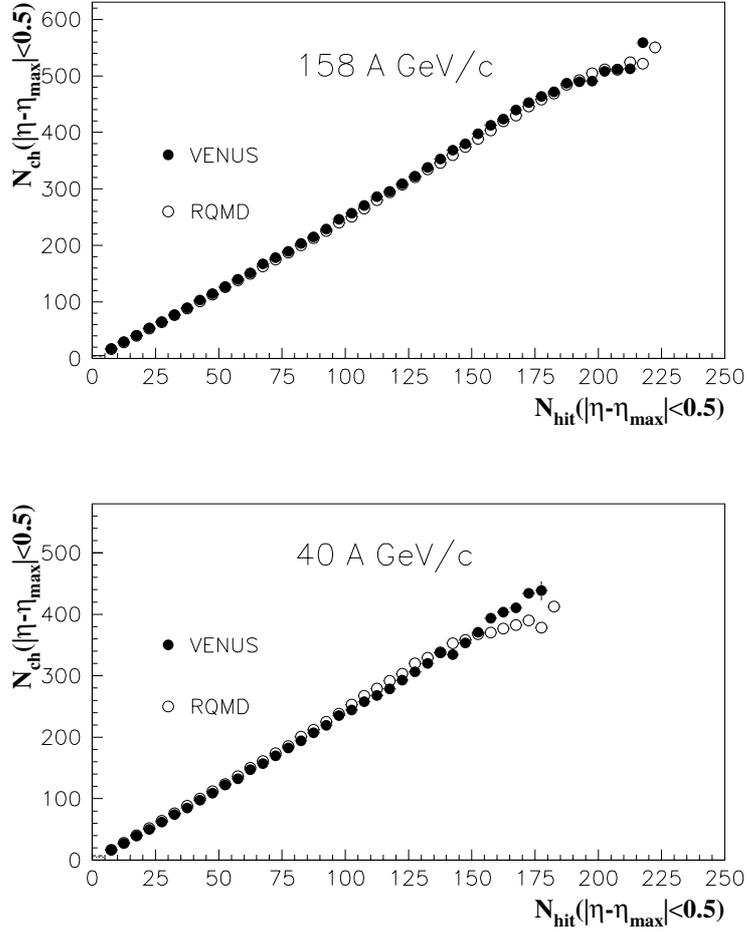
The NA57 experimental set-up and multiplicity reconstruction procedure are described elsewhere [3]. Here we recall only the main steps of the multiplicity analysis. The strips of the MSD detector provide analogue signals proportional to the energy deposited by the crossing particles. Once the MSD is properly calibrated, the detector charged particle multiplicity ( $N_{hit}$ ) is evaluated using an algorithm which takes into account the total energy contained in each of the clusters. This quantity is corrected for uncorrelated background hits (estimated from the *beam-trigger* data), mostly due to  $\delta$  rays. The  $N_{hit}$  distribution corresponding to the pseudorapidity range  $2.0 < \eta < 4.0$  for the 158 A GeV/c is shown in figure 1 (top). The empty target contribution (about 6 %), concentrated at relatively low multiplicity, is subtracted from the data subsequently. In the same figure 1(bottom) the corresponding distribution for the 40 A GeV/c ( $1.9 < \eta < 3.6$ ) is also shown. In order to obtain the charged particle multiplicity for the full azimuthal range ( $N_{ch}$ ) a geometrical correction must be applied. This is determined by tracing Pb-Pb events generated by VENUS [4] (and/or RQMD [5]) through a GEANT [6] simulation of the apparatus. In this way charge sharing, secondary interactions,  $\gamma$  ray conversions and particle decays are accounted for. Also an extrapolation from  $p_t = 30 - 40$  MeV/c down to  $p_t = 0$  is performed.

The charged particle distribution produced in a restricted range of pseudorapidity  $\eta$  can be obtained by selecting only the strips covering the corresponding acceptance. We indicate by  $N_{hit}(|\eta - \eta_{max}| < 0.5)$  and  $N_{ch}(|\eta - \eta_{max}| < 0.5)$  the hit and the total (corrected) charged particle multiplicity measured in one unit of  $\eta$  around maximum of the distribution,  $\eta_{max}$  (correspondingly 2.4 and 3.1 for 40 and 158 A GeV/c beam momenta). In figure 2 the correlation between these two quantities is shown for both beam momenta and the two Monte Carlo generators used.

As expected, the correction factor leading from  $N_{hit}(|\eta - \eta_{max}| < 0.5)$  to  $N_{ch}(|\eta - \eta_{max}| < 0.5)$



**Figure 1.** Hit multiplicity distribution at 158 A GeV/ $c$  (top) and 40 A GeV/ $c$  (bottom). The empty target contribution is also shown.



**Figure 2.** Correlation between charged particle multiplicity and hit multiplicity in one unit of pseudorapidity around central rapidity for 158 A GeV/c (top) and 40 A GeV/c (bottom) simulated data.

is not sensitive to the event generator type (the maximum difference does not exceed 2%) used in the GEANT simulation.

The peak value,  $dN/d\eta|_{max}$  can be obtained by applying a small correction factor  $f$  to  $N_{ch}(|\eta - \eta_{max}| < 0.5)$ , corresponding to the ratio between the peak and the average value of  $dN/d\eta$  in the central  $\eta$  unit. The widths of the  $dN/d\eta$  distributions, known from measurements done by other experiments (for example [7]), show only a weak dependence on centrality. This allows us to use the same value of  $f$  for the whole centrality range spanned by NA57. Assuming a Gaussian shape of the  $dN_{ch}/d\eta$  distribution and taking an average of the reported  $\sigma$ 's we have estimated  $f = 1.02$  at 158 A GeV/c and  $f = 1.03$  at 40 A GeV/c .

### 3. Collision centrality classes

#### 3.1. 158 A GeV/c data

The distribution of  $N_{ch}$  (in the full acceptance), shown in figure 3, is used to determine the centrality of events, given by the number of participants, defined as the number of nucleons subject to at least one primary inelastic collision (called *wounded nucleons* [8]). The procedure



**Table 1.** Average  $dN/d\eta|_{max}$  and  $\langle N_{wound} \rangle$  as a function of centrality (158 A GeV/c ). The errors are statistical only.

% of $\sigma_{inel}$	$\langle dN/d\eta _{max} \rangle$	$\langle N_{wound} \rangle$	r.m.s
0 – 5	$478 \pm 10$	$349 \pm 1$	30
5 – 10	$388 \pm 9$	$293 \pm 2$	33
10 – 15	$324 \pm 9$	$245 \pm 3$	30
15 – 20	$266 \pm 8$	$201 \pm 3$	28
20 – 25	$217 \pm 7$	$165 \pm 3$	25
25 – 30	$180 \pm 7$	$136 \pm 4$	22
30 – 35	$149 \pm 6$	$114 \pm 4$	20
35 – 45	$106 \pm 5$	$81 \pm 5$	20
45 – 50	$71 \pm 4$	$51 \pm 5$	14

**Table 2.** NA57 standard centrality classes (158 A GeV/c). The errors are statistical only.

% of $\sigma_{inel}$	$\langle N_{wound} \rangle$	r.m.s	% of empty target
0 – 5	$349 \pm 1$	28	0.0
5 – 11	$290 \pm 2$	36	0.0
11 – 23	$209 \pm 3$	37	0.0
23 – 40	$121 \pm 4$	30	0.9
40 – 53	$62 \pm 4$	18	17.0

of extracting the average number of wounded nucleons,  $\langle N_{wound} \rangle$ , for a given multiplicity range, has been described in detail in [1], where  $N_{ch}$  was allowed to be proportional to a power of the number of wounded nucleons:  $N_{ch} \propto N_{wound}^\alpha$ . The data are well described with  $\alpha = 1.0$ , as can be seen in figure 3 (top).

The inelastic Pb–Pb cross section, obtained from the Glauber model, is  $\sigma_{inel}^{Glauber} = 7.26$  barn. The trigger cross section measured from the trigger rate, the incoming flux and the target thickness is  $\sigma_{trig}^{exp} = 4.15 \pm 0.11$  barn, consistent with the Glauber-Wounded Nucleon Model (G-WNM) fit. This corresponds to the trigger cross section fraction of 57 %. For the purpose of this study we divide the data into nine centrality classes (see table 1) covering the 50 % most central inelastic cross section. In table 1 we report for each centrality class the average  $\langle dN/d\eta|_{max} \rangle$ , the average number of wounded nucleons  $\langle N_{wound} \rangle$  (calculated with  $\alpha = 1.0$ ) and the r.m.s. of their distribution. In the standard NA57 analysis of the strange particle production, the centrality dependence is studied using only five, broader centrality classes [2]. The corresponding values of  $\langle N_{wound} \rangle$  and the r.m.s. of the distributions in these classes are given in table 2 together with the empty target contribution, as discussed in the previous section.

### 3.2. 40 A GeV/c data

The distribution of  $N_{ch}$  (figure 3 bottom) has been fitted using the same procedure as for the 158 A GeV/c data, but excluding from the fit a slightly wider low multiplicity region ( $N_{ch} < 110$ ). As the value  $\alpha = 1.0$  gives a poor fit the value  $\alpha = 1.10$  was adopted instead.

The measured trigger cross section is  $\sigma_{trig}^{exp} = 4.07 \pm 0.11$  barn, corresponding to about 56% of

**Table 3.** Average  $dN/d\eta|_{max}$  and  $\langle N_{wound} \rangle$  as a function of centrality (40 A GeV/c ). The errors are statistical only.

% of $\sigma_{inel}$	$\langle dN/d\eta _{max} \rangle$	$\langle N_{wound} \rangle$	r.m.s
0 – 5	$348 \pm 10$	$350 \pm 1$	27
5 – 10	$275 \pm 9$	$298 \pm 1$	31
10 – 15	$225 \pm 8$	$250 \pm 2$	29
15 – 20	$185 \pm 7$	$208 \pm 3$	27
20 – 25	$150 \pm 6$	$173 \pm 4$	24
25 – 30	$122 \pm 6$	$143 \pm 4$	22
30 – 35	$97 \pm 5$	$117 \pm 5$	20
35 – 45	$69 \pm 4$	$86 \pm 5$	19
45 – 50	$46 \pm 3$	$61 \pm 5$	15

**Table 4.** NA57 standard centrality classes (40 A GeV/c ). The errors are statistical only.

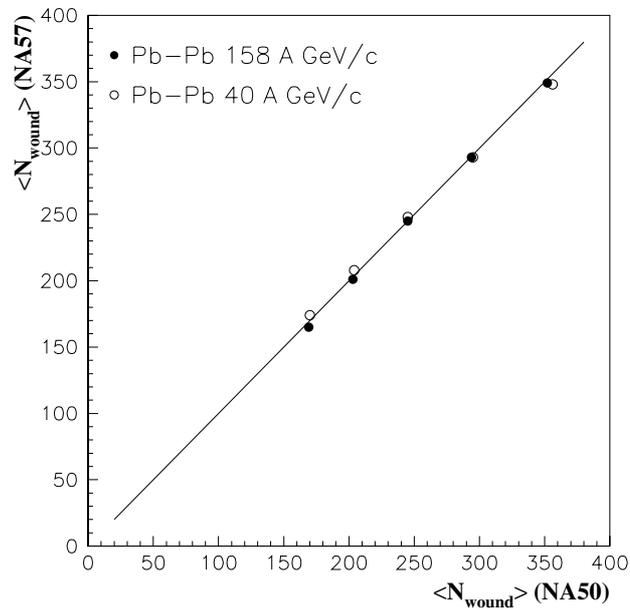
% of $\sigma_{inel}$	$\langle N_{wound} \rangle$	r.m.s	% of empty target
0 – 5	$346 \pm 1$	31	0.0
5 – 11	$292 \pm 1$	41	0.0
11 – 23	$208 \pm 4$	44	0.0
23 – 40	$119 \pm 5$	36	8.5
40 – 53	$57 \pm 5$	24	32.0

the inelastic cross section. This value is also consistent with the G-WNM fit. As in case of 158 GeV/c we divide the data into nine centrality classes as shown in table 3. The centrality classes used for strange particle analysis at 40 A GeV/c are given in table 4. Note that the average numbers of wounded nucleons in the centrality classes are not identical at the two energies due to small systematic effects in the data analysis.

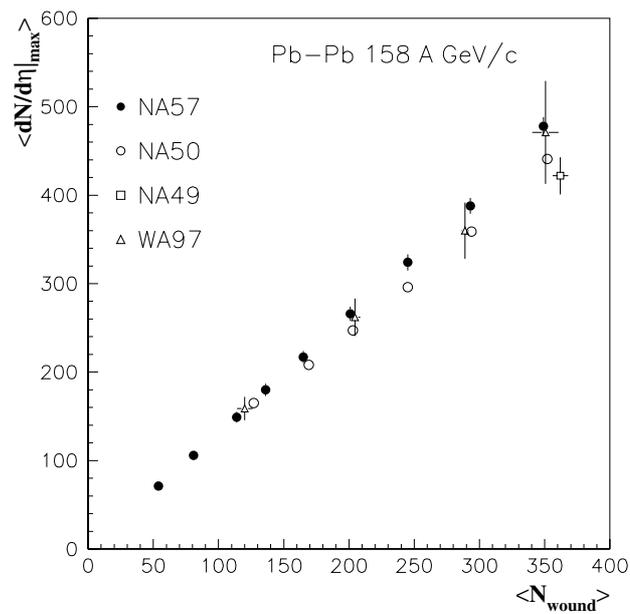
#### 4. Comparison with other experiments

A comparison between the number of participants as determined by NA57 and NA50 [9] is shown in figure 4 for both beam energies and common centrality classes. The agreement is very good as the maximum deviation between the  $\langle N_{wound} \rangle$  values of the two experiments (in the common centrality range) does not exceed 3%. In figure 5 the values of  $\langle dN/d\eta|_{max} \rangle$  from table 1 are compared with those measured by NA50 [9] at 158 A GeV/c. There is a good overall agreement but some differences appear in the most central classes, while the value of  $\alpha = 1.02 \pm 0.02(\text{stat}) \pm 0.06(\text{syst})$  found by NA50 is compatible with a linear correlation between  $N_{wound}$  and  $N_{ch}$  as in our case. The NA49 peak value of  $dN/d\eta|_{max}$  for charged hadrons (only for the 5% most central events) was calculated [10] by using the published results on rapidity and transverse momentum spectra of identified hadrons [7]. The resulting value (the square symbol) is a little below our measurement and slightly shifted in  $\langle N_{wound} \rangle$ .

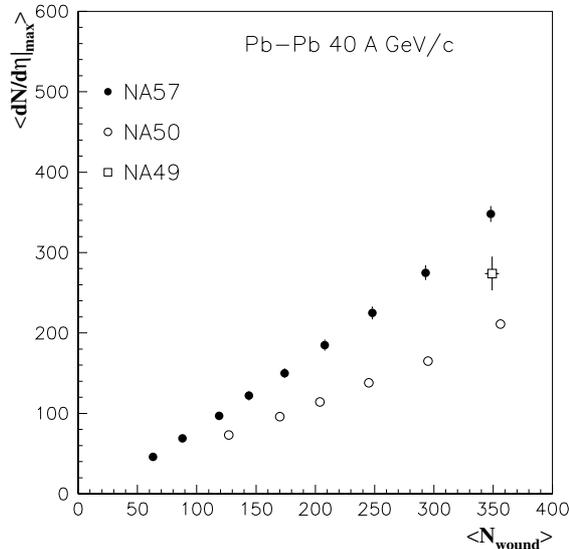
The NA57 multiplicity data have been also compared to those evaluated from the negative particle multiplicity ( $h^-$ ) measured by the WA97 experiment [11]. The resulting values, plotted in the same figure 5, show a good agreement with NA57. Figure 6 shows a comparison of the



**Figure 4.** Comparison between the number of participants as determined by NA57 and NA50, for 158 A GeV/ $c$  and 40 A GeV/ $c$  data. The full line is a diagonal corresponding to a perfect agreement. The error bars are not seen as they are smaller than the symbols.



**Figure 5.**  $\langle dN/d\eta|_{\text{max}} \rangle$  as a function of the average of participants for the 158 A GeV/ $c$  data. The errors bars, where not shown, are contained within the symbols.



**Figure 6.**  $\langle dN/d\eta|_{max} \rangle$  as a function of the average of participants for the 40 A GeV/c data. The error bars, where not shown, are contained within the symbols.

NA57, NA50 and NA49 multiplicities measured at 40 A GeV/c (WA97 has not measured  $h^-$  yields at this beam momentum). Now we observe a clear disagreement between our results and those of NA50; for the most central class there is a factor 1.7 between the corresponding  $dN/d\eta|_{max}$  values. This discrepancy can be seen already at the level of the  $N_{wound} - N_{ch}$  correlation; we obtain good fits (see figure 3) with the values of  $\alpha$  in the range  $1.09 < \alpha < 1.12$  while NA50 reports a value of  $\alpha = 1.02 \pm 0.02(\text{stat}) \pm 0.06(\text{syst})$ . The only NA49 point [10] (most central 7 %) lies in the middle between the NA57 and NA50 values.

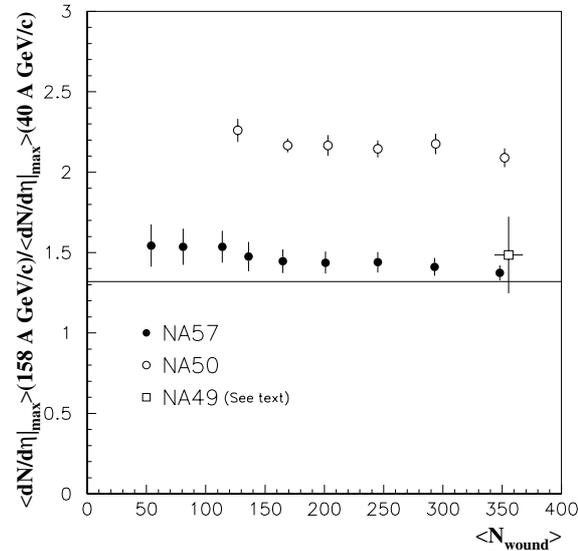
In figure 7 the ratio between  $\langle dN_{ch}/d\eta|_{max} \rangle$  at 158 A GeV/c and 40 A GeV/c is plotted as a function of  $\langle N_{wound} \rangle$ .

In p-p collisions, the charged particle multiplicity at mid-rapidity is found to scale approximately as logarithm of the centre mass energy [12]. Assuming the same dependence to hold in Pb-Pb collisions one would expect the ratio of 1.31, which is indicated by a horizontal line in figure 7. The NA57 values are only slightly above this prediction while the NA50 ratios are in the range 2.13 – 2.38. The NA49 point (averaged between the two centrality ranges of 5 and 7 %) is in good agreement with our measurement.

## 5. Conclusions

We have measured the multiplicity of charged particles in Pb-Pb collisions at the two beam momenta, 158 A GeV/c and 40 A GeV/c, in the pseudorapidity ranges  $2.0 < \eta < 4.0$  and  $1.9 < \eta < 3.6$ , respectively. The multiplicity distributions are well described by a generalized Glauber-Wounded Nucleon Model, where  $N_{ch} \propto N_{wound}^\alpha$ . The value of  $\alpha$  is compatible with 1.0 at 158 A GeV/c, but slightly larger ( $\alpha = 1.10$ ) at 40 A GeV/c.

The value of  $dN_{ch}/d\eta$  at the maximum has been studied as a function of centrality over the 50% most central range covered by NA57. At 158 A GeV/c a good agreement is observed with the values determined by extrapolation of the WA97 results on negative particles. The NA50 values tend to fall slightly below our measurements, especially for the most central classes. The single (most central) NA49 point is also slightly below our measurement. The situation at 40



**Figure 7.** Ratio between  $\langle dN/d\eta|_{max} \rangle$  at 158 A GeV/c and 40 A GeV/c as a function of the participants ( $N_{wound}$ ) as measured by NA57 (black circles), NA50 (open circles) and NA49 (open square). The horizontal line corresponds to a simple logarithmic scaling.

A GeV/c is quite different, as the disagreement between our measurement and that of NA50 becomes unacceptably large, pointing to some unresolved systematic errors present at the lower beam momentum. There is nevertheless no disagreement in the determination of  $\langle N_{wound} \rangle$  in the common centrality classes of the two experiments as seen in figure 4.

Finally, we find that the charged particle multiplicity at central rapidity is quite close to a logarithmic scaling with the center of mass energy. This finding is confirmed by the NA49 result but clearly incompatible with the NA50 measurement.

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