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Electric charge fluctuations in central Pb+Pb collisions at 20, 30, 40, 80 and 158 AGeV

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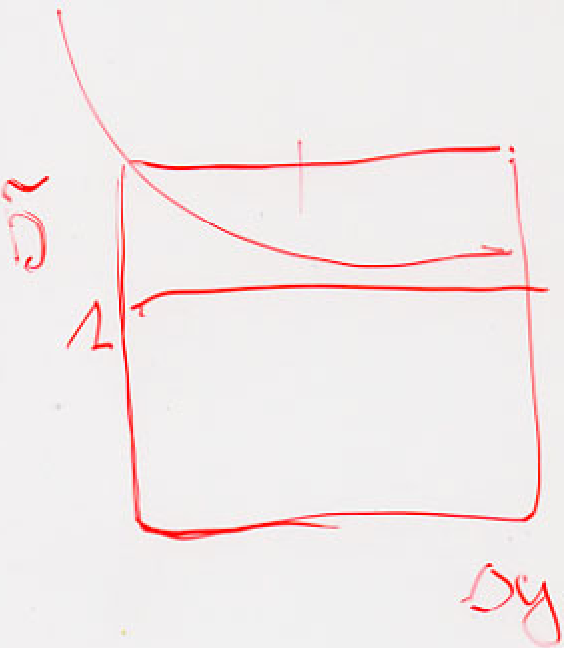
1. INTRODUCTION
2. THE MEASURES OF CHARGE FLUCTUATIONS
3. EXPERIMENTAL SET-UP
4. DATA, ANALYSIS AND ERRORS
5. RESULTS AND DISCUSSION

THE BASIC MEASURE:

$$\Delta\Phi_q \equiv \Phi_q - \Phi_{GCC}$$



ACCEPTANCE PARAMETRIZATION:

$$p_T(\phi) = \frac{1}{A + \left(\frac{D \pm \phi}{C}\right)^6} + B$$

	20AGeV				30AGeV				40AGeV				80AGeV				158AGeV			
y	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
-0.5									0	0	23	4	0	0	35	-10	0	-1	63	-8
-0.3					0	0	25	-7	0	0	30	7	0	0.07	40	-10	0	0	57	-10
-0.1	0	-1	32	-7	0	0	31	-8	0	0	38	10	0	0.07	46	-10	0	0.09	63	-13
0.1	0	0	34	-8	0	0	40	-8	0	0	43	8	0	0.05	52	-12	0	0.08	67	-4
0.3	0	0	41	-8	0	0	44	-8	0	0	46	7	0	0	58	-7	0	0.08	65	-3
0.5	0	-0.05	47	-8	0	0	46	-7	0	0	40	0	0	-1	29	-2	0	0.05	27	0
0.7	0	-0.1	50	-7	0	0	42	0	0	0	22	0	0	0.05	26	0	0	0	35	0
0.9	0	-0.3	53	-3	0	0	35	-10	0	0	34	6	0	0.08	35	0	0	0.1	41	0
1.1	0	-0.2	38	-10	0	0	39	-13	0	0	46	15	0.3	0.1	67	-27	0.34	0.43	109	0
1.3	0	-0.1	42	-12	0	0	44	-14	0	0	52	15	0.3	0.3	75	-15	0.36	0.43	100	0
1.5	0	0	43	-8	0	0	55	-21	0	0.1	58	20	0.3	0.27	85	0	0.55	0.4	100	0
1.7	0	0	51	-18	0	0.08	62	-2	0	0.08	72	0	0.3	0.18	75	0	0.6	0.4	88	0
1.9	0	0	63	-4	0	0.08	67	0	0	0.08	68	0	0.45	0.15	70	0	0.61	0.35	73	0
2.1	0	0	62	0	0	0.05	61	0	0	0.09	60	0	0.5	0.12	50	0	0.73	0.34	55	0
2.3	0	0	57	0	0.6	0.05	57	0	0.5	0.08	50	0	0.75	0.08	50	0	1.7	0.28	60	0
2.5	0.7	0	54	0	0.6	0	46	0	0.6	0.05	40	0	2.2	0.08	50	0	2.8	0.25	60	0
2.7	0.7	0	41	0	1	0	33	0	1.5	0.05	35	0	3.2	0.08	45	0	5	0.2	57	0
2.9	1.5	0	30	0	2.7	0	32	0					4.5	0.08	45	0	7	0.15	60	0
3.1													5.5	0	45	0	7	0.1	70	0

TABLE II: Values of the parameters A, B, C and D of the acceptance curves for different energies and rapidity intervals.

acceptance and which is centred at the maximum of the rapidity distribution of the accepted particles (the position of the maximum is X, X, X, X, and X for 20, 30, 40, 80 and 158 *A*GeV, respectively). This range is devided into 20 bins of the same size (0.115 at the 30 and 40 *A*GeV and 0.12 at the 80 and 158 *A*GeV). The two medial sections make up the smallest rapidity intervall, the four medial sections the next bigger one and so on. This pocedure is illustrated in Fig. 3 for 158 *A*GeV data.

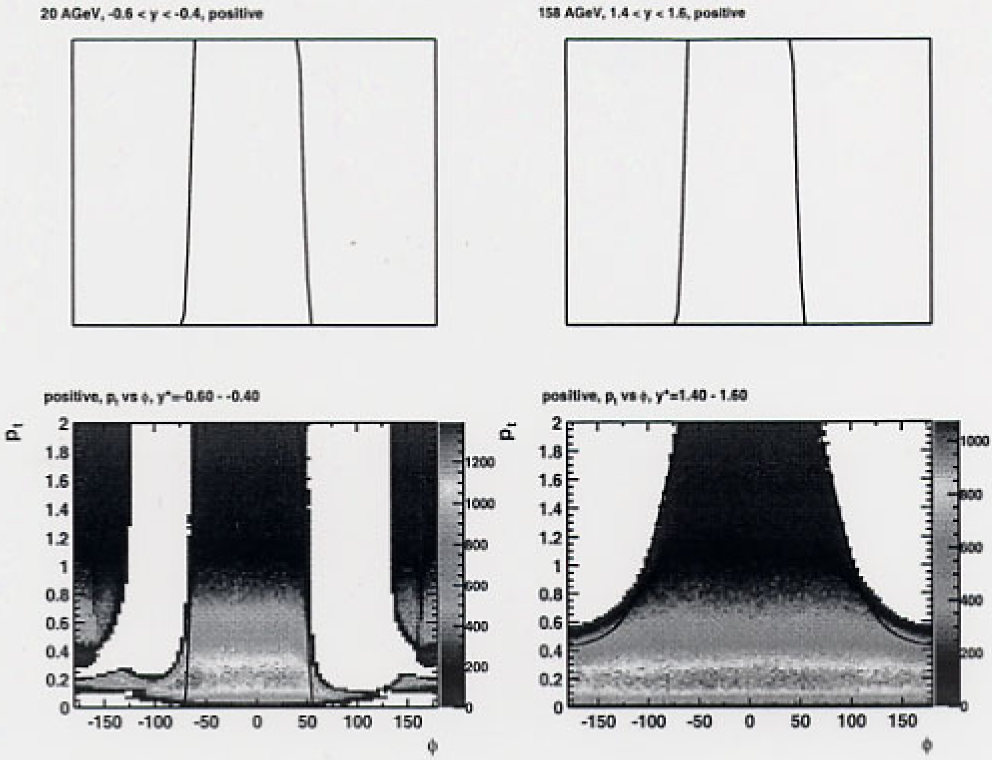


FIG. 2: An illustration of the acceptance used for the analysis in the p_T-ϕ-plane for $-0.6 < y < -0.4$ and $1.4 < y < 1.6$ at 20 and 158 AGeV.

For each event the positively and negatively charge particles which fall into each rapidity interval and the corresponding p_T-ϕ acceptance are counted and using these numbers the values of $\Delta\Phi_q$ are calculated.

C. Errors

The statistical error of $\Delta\Phi_q$ is calculated by dividing the whole sample of events into 10 subsamples and calculating $\Delta\Phi_q$ for each subsample separately. The dispersion (D) of the obtained $\Delta\Phi_q$ values divided by $\sqrt{9}$ has been taken as the statistical error. The systematic errors of $\Delta\Phi_q$ are estimated by varying track quality cuts. The values of $\Delta\Phi_q$ are calculated for two additional sets of cuts, more and less restrictive in comparison to standard cuts. The difference of these two values is considered as the systematic error. The statistical errors are much smaller than the systematic ones. Therefore in all figures

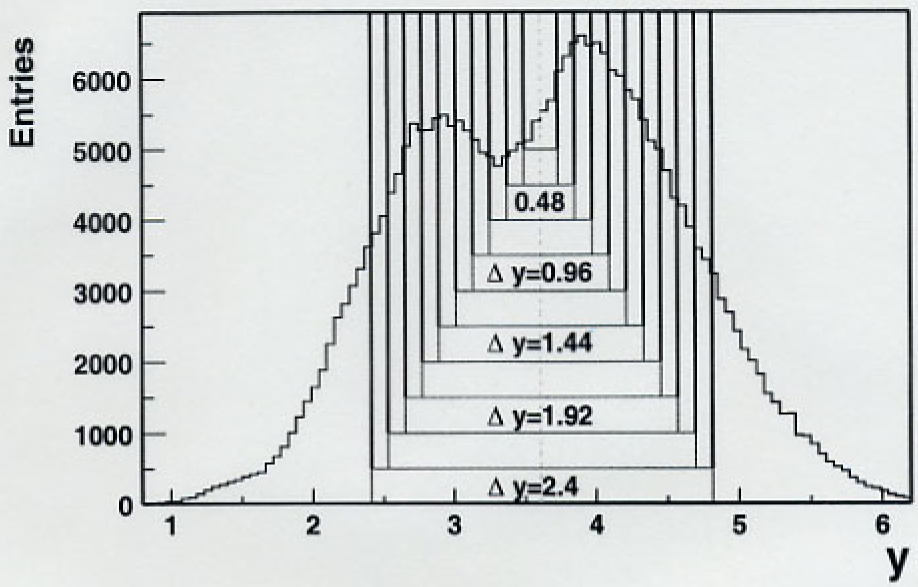


FIG. 3: The rapidity distribution of accepted particles in central Pb+Pb collisions at 158 AGeV and its subdivision into rapidity intervals. In the backward- and midrapidity region the acceptance of the detectors are not homogeneous. Therefore a big part of these regions are not used in the analysis.

only the systematic errors are shown.

V. RESULTS AND DISCUSSION

A simple measure of charge fluctuations is the width of the net-charge ($Q = N_+ - N_-$) distribution. As an example this distribution for central Pb+Pb collisions at 158 AGeV is shown in Fig. 4. This distributions is compared to the net-charge distribution obtained using mixed events (dashed line in Fig. 4), which is significantly broader that the net-charge distribution obtained from the data. The differences are due to the charge conservation which correlates positively and negatively charged particles in the data, but not in the mixed events. Insensitive to this correlation is the measure $\Delta\Phi_q$ (see Sec. II).

The dependence of $\Delta\Phi_q$ on the width of the rapidity interval Δy is shown in Fig. 5 for central Pb+Pb collisions at 20, 30, 40, 80 and 158 AGeV. Note that experimental points

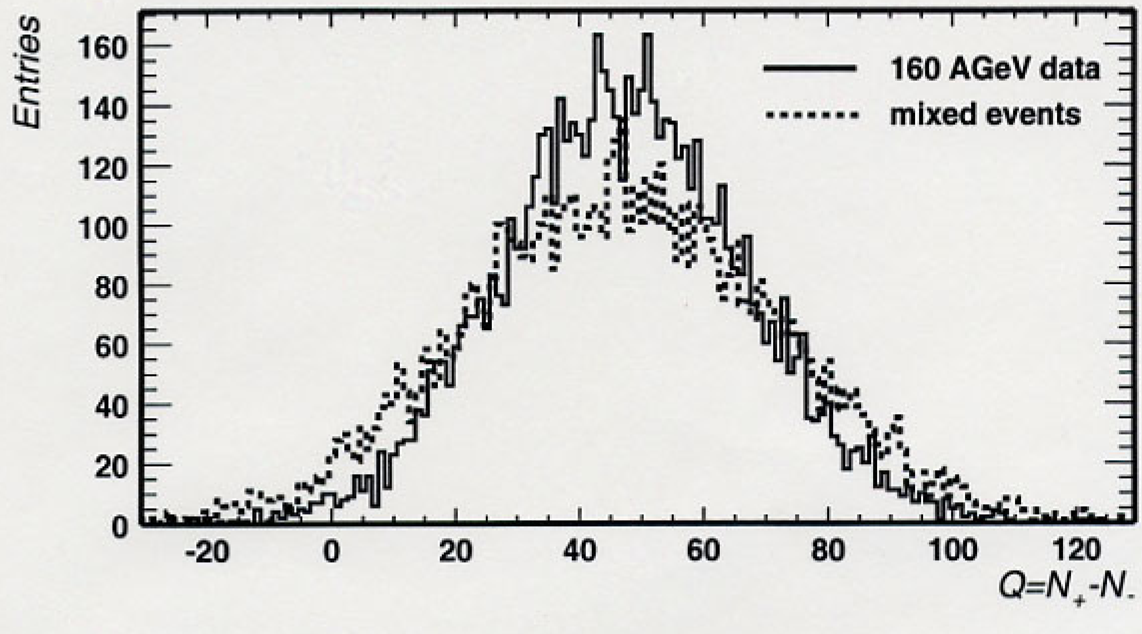


FIG. 4: The distribution of the net-charge for central Pb+Pb collisions at 158 AGeV (solid line) and the corresponding distribution obtained for mixed events (dashed line).

for a given energy are correlated as the data used for narrow rapidity intervals are included in the broader intervals. The measured values of $\Delta\Phi_q$ are close to 0, $\mid \Delta\Phi_q \mid \tilde{<} 0.05$. They are significantly larger than the value expected for QGP fluctuations ($\Delta\Phi_q \approx -0.5$ [8, 16]). However, the values for $\Delta y < 1$ are significantly smaller than zero. In order to study the energy dependence of this suppression effect the $\Delta\Phi_q$ values for $\Delta y \approx 0.47$ are plotted versus $\sqrt{s_N}$ in Fig. 6. One observes a monotonic increase of $\Delta\Phi_q$ with $\sqrt{s_{NN}}$. This effect is not seen for large rapidity intervals, see Fig. 7. The numerical values of $\Delta\Phi_q$ for $\Delta y \approx 0.47$ and $\Delta y \approx 2.35$ are given in the Table III.

/* -0.0234772 20 -0.024765 30 -0.016458 -0.03950555 -0.0527562 1.2

-0.023101510355395 20 -0.027626127249 30 -0.02428647242254 -0.051309889 - 0.03569144367 3.0 */ For an interpretation the results should be compared to model predictions.

A simple QGP model was proposed in [5]. In this model the ratio of up-, down-, anti up- and anti down-quarks and gluons in equilibrium is calculated under the assumption of zero baryo-chemical potential and providing zero quark masses. Assuming entropy and

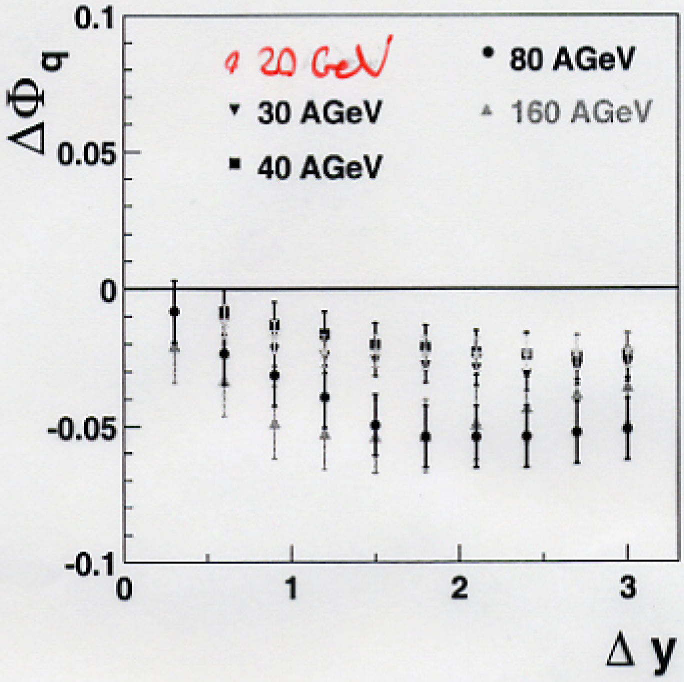


FIG. 5: The values of $\Delta\Phi_q$ at the energies 20, 30, 40, 80 and 158 AGeV.

$\Delta\Phi_q$	20 AGeV	30 AGeV	40 AGeV	80 AGeV	160 AGeV
$\Delta y = 3$	-0.023±0.006±0.0	-0.028±0.0±0.002	-0.024±0.008±0.0	-0.051±0.011±0.0	-0.036±0.013±0.0
$\Delta y = 1.2$	-0.023± 0.006± 0.0	-0.025±0.0±0.016	-0.016±0.008±0.0	-0.040±0.011±0.0	-0.053±0.013±0.0

TABLE III: $\Delta\Phi_q$ for $\Delta y = 3.00$ and $\Delta y = 1.2$ at 20, 30, 40, 80 and 158 AGeV. The first error is systematic the second statistical.

net charge conservation during the evolution from the QGP to the final hadron state in each rapidity interval the number of pions (N) and their net charge is calculated. The number of charged pions is taken to be $N_{ch} = \frac{2}{3} \cdot N$ based on isospin symmetry. Using this model it was shown that the electric charge fluctuations in the QGP are much smaller than in the hadron gas (see Fig. 8) [5, 8].

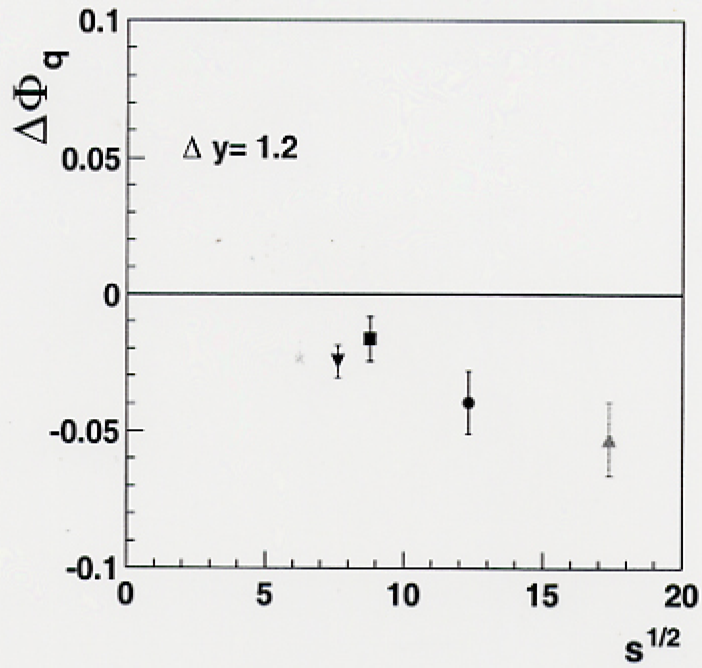


FIG. 6: An energy scan of the $\Delta\Phi_q$ values for small rapidity interval $\Delta y \approx 0.47$.

However this model is not complete. A large fraction of pions originates from decays of resonances [15]. This effect is expected to lead to a distortion of the charge fluctuations established in the hadronic stage. To quantify this effect a simple model was proposed. Here we sketched its basic assumptions, a detailed description can be found in [16].

From the total number of produced final state pions the entropy of the system is calculated. This entropy is attributed to the early stage QGP treated as an ideal gas of massless quarks and gluons. The Bose-Einstein- and Fermi-Dirac-statistics are used to calculate equilibrium numbers of quarks and gluons. The rapidity distribution of these partons is centered at $y = 0$ and it is assumed to be Gaussian shaped with $\sigma = 0.8$. For the calculations of charge fluctuations the rapidity interval $-3 < y < 3$ is divided into several (10 and 20) bins and in each bin the entropy of the inlying partons and the net-charge is calculated. This entropy is attributed to ideal gas of ρ-mesons. The numbers of ρ^+-, ρ^-- are ρ^o-mesons in each bin are calculated assuming that $\frac{1}{3}$ of all ρ-mesons are neutral. Further on, all ρ-mesons decay isotropically into two pions. The rapidity distribution of the pions is divided into 20 bins and the number of positively and negatively charged pions in each bin is counted and use for the $\Delta\Phi_q$ calculation. The results of this model

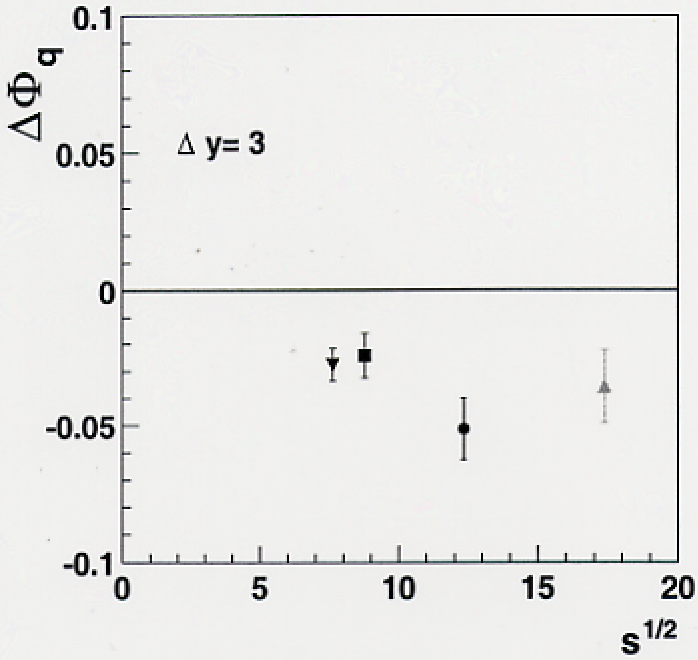


FIG. 7: An energy scan of the $\Delta\Phi_q$ values for large rapidity interval $\Delta y \approx 2.35$.

FIG. 8: The values of $\Delta\Phi_q$ obtained in the QGP model.

are shown in Fig. 9. The vertical bars indicate the difference between the $\Delta\Phi_q$ values obtained by dividing the rapidity distribution of the partons into 10 and into 20 bins.

As expected the decays of resonances strongly distort the initial QGP fluctuations. The value of $\Delta\Phi_q$ increases from values between -0.2 and -0.5 (Fig. 8) to values typical for a gas of pions correlated only by global charge conservations, $\Delta\Phi_q = 0$. This model shows that the distribution of charged particles which arise after hadronization and which may carry informations on prehadronic state is strongly distorted by the decay of resonances. This may explain why the data does not show the suppression of the charge fluctuations naively expected in the case of QGP creation.

The influence of resonance decays on charge fluctuations depends on the size of the considered rapidity interval. If it is much bigger than the typical rapidity difference of the daugh-

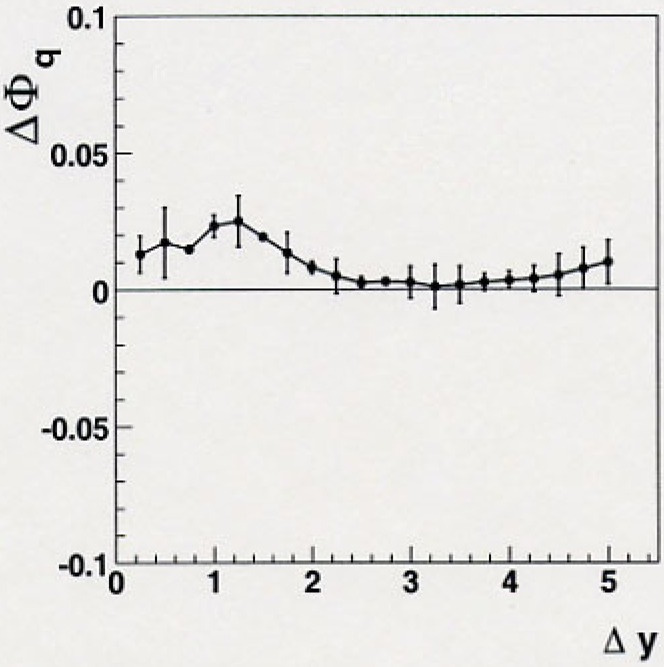


FIG. 9: The values of $\Delta\Phi_q$ obtained in the QGP+ρ-gas model.

ter particles, the charge within the interval will not be changed by the decay and therefore the charge fluctuations should not be affected by the decay of resonances. Whereas, if the considered rapidity interval is small, a large fraction of daughter particles will drop out of the interval and the initial net-charge will be significantly changed. The mean rapidity difference of two pions originated from decays of a $\rho(770)$-meson is bigger than 1 unit of rapidity. Therefore in order to minimize the decay effect the rapidity interval should be much bigger than 1. However, this constraint is difficult to fulfill. At SPS and lower energies the rapidity distribution of all produced particles is not much broader than 1. A rapidity interval which is big enough to neglect the influence of resonances decays would contain all particles. This would fix the net-charge in the interval ($Q = 2 \cdot A$, A is the atomic number of the colliding nucleus) and therefore the charge would not fluctuate. Thus at SPS energies measured charge fluctuations are not sensitive to the initial QGP fluctuations. However at very high energies where the rapidity distribution of produced particles is significantly broader than 1 the charge fluctuations may be a valid signature of QGP creation.