CHARGE FLUCTUATIONS IN $\pi^+ p$ AND $K^+ p$ COLLISIONS*

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It reports on charge fluctuations in $\pi^+ p$ and $K^+ p$ collisions at 250 GeV/c. The dependence of these fluctuations on the size of rapidity window and on the multiplicity are presented systematically. The results are compared with those obtained from current theoretical expectations for a hadronic gas, a QGP phase, a stochastic model and a PYTHIA simulation.

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The newly introduced event-by-event charge fluctuations [1] are supposed to be a feasible signal for a QGP phase transition. There are two kinds of measures for the fluctuations. One is net charge fluctuation and another is charge ratio fluctuation. The direct measure of *net charge* fluctuations is the variance of net charge $\delta Q^2 = \langle Q^2\rangle - \langle Q\rangle^2$, where $Q = Q^+ + Q^-$, $Q^+ = n^+$, $Q^- = -n^-$, Q^+ and Q^- are positive and negative charges and n^+ and n^- are the numbers of corresponding particles. The average is over all events in the sample. In order to reduce the volume fluctuations due to the variation of impact parameter, *charge ratio* $R = n^+/n^-$ fluctuations are recommended in [1] and the corresponding measure is

$$D(R) = \langle n_{\rm ch}\rangle \cdot \delta R^2, \tag{1}$$

where $\delta R^2 = \langle R^2\rangle - \langle R\rangle^2$ is the variance of the charge ratio and $n_{\rm ch} = n^+ + n^-$. In the high multiplicity limit, the above two measures are approximately connected by the relation $D(R) \approx 4\frac{\delta Q^2}{\langle n_{\rm ch}\rangle}$ where the correction in leading order of multiplicity is $1/\langle n_{\rm ch}\rangle$. Hence, the D-measure in terms of net charge

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fluctuations is defined as

$$D(Q) = 4\frac{\delta Q^2}{\langle n_{\rm ch}\rangle}. \tag{2}$$

If charge is randomly assigned (+1 or -1 with equal probability) to each particle within the acceptance, the variance of net charge is $\langle n_{\rm ch}\rangle$ and $D(Q)$ will be 4. The theoretical predictions [1] for the D-measure in a QGP phase range from 0.75 to 1, while they are about 3 to 4 for a hadronic gas.

In accounting for charge conservation in a large rapidity range and a non-zero net charge due to non-negligible baryon stopping, two correction factors [2],

$$C_y = 1 - \frac{\langle n_{\rm ch}\rangle_{\Delta y}}{\langle n_{\rm ch}\rangle_{\rm total}}, \quad C_\mu = \frac{\langle n^+_{\Delta y}\rangle^2}{\langle n^-_{\Delta y}\rangle^2}, \tag{3}$$

are applied to the D-measures of Eq. (3) and (4):

$$\tilde{D} = \frac{D}{C_y C_\mu}. \tag{4}$$

The preliminary data from current relativistic heavy ion experiments [3–6] with limited acceptance indicate consistently that the measured value of $D(Q)$ in a narrow central rapidity window is slightly smaller than that of the stochastic scenario and can be reproduced by hadronic gas with resonance decay. It is differ markedly from that expected for a QGP phase. However, it is still not clear if this is mainly caused by nucleus-nucleus effects, *e.g. rescattering* [7].

Furthermore, the D-measures in terms of the charge ratio and the net charge fluctuations show very different multiplicity dependence [6] and their corrected versions $\tilde{D}$ have different rapidity dependence [8]. Which is the better record of charge fluctuations and whether the corrections, Eq. (5), are proper is still under investigation.

Up to now, the charge fluctuations have not been well estimated in hadron-hadron collisions, where the full acceptance in a wider rapidity region allow a clear observation on the charge fluctuations in different rapidity windows. Here, we present D and $\tilde{D}$ measures in different central rapidity intervals and for different multiplicities in π^+p and K^+p collisions at 250 GeV/c, with excellent momentum resolution over the full 4π acceptance. A total of 44 524 non-single-diffractive events is obtained after all necessary rejections. The selection of the data is described in detail in [9]. Secondary interactions are suppressed by a visual scan and the requirement of charge balance, γ conversion near the vertex by electron identification.

The $D(Q)$-measure in central rapidity windows from $|y|<y_{\rm cut}=\delta y/2 = 0.25$ to δy=6 is presented in Fig.1(a), where the solid points are the NA22

data and the open circles correspond to the results from the PYTHIA generator [10] (this convention will be kept in all the following figures). The open triangles correspond to random charge assigned to each particle in the window. The latter is 4, as expected, no matter how small the multiplicity is in very narrow rapidity intervals. This shows that the accuracy of event-by-event analysis hardly depends on event multiplicity and thus can be useful even for low multiplicity cases [11].

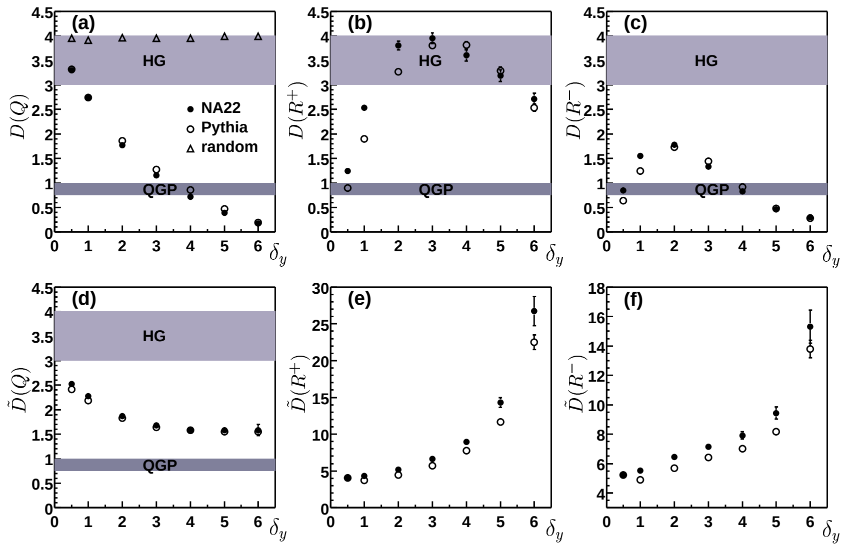

Fig. 1. The dependence of (a) $D(Q)$, (b)$D(R^+)$, (c)$D(R^-)$, (d) $\tilde{D}(Q)$, (e)$\tilde{D}(R^+)$ and (f) $\tilde{D}(R^-)$ on the size of the central rapidity window $|y| < \delta y/2$.

The first experimental point in Fig. 1(a) at $|y| < 0.25$ is in the band theoretically expected for hadronic gas and is comparable with those of STAR and PHENIX, which are about 3.1 to 3.9 with $|\eta| < 0.5$ to 0.75 for STAR [5] and 3.66 with $|\eta| < 0.35$ for PHENIX [6]. So charge fluctuations in relativistic heavy ion collisions in a narrow central rapidity window is close to that of h–h collisions. With the widening of rapidity window, the experimental data keep decreasing from the band theoretically expected for a hadronic gas to that expected for a QGP, and even below. After taking the charge conservation in large rapidity windows and the baryon stopping into account, its corrected version is presented in Fig. 1(d). It stays between the bands for a hadronic gas and for a QGP. There is a good saturation in large central rapidity windows [1], which means that the long range correlations caused by charge conservation has been well deduced from the measure.

The event-by-event fluctuations defined as Eq. (1) have been shown to be related to the correlations [11] between Q^+ and Q^-. It can be seen from Fig. 1(b) that in this experiment the data of event-by-event charge fluctuations in small rapidity windows develop a peak, indicating clearly the existence of short range charge correlations. This kind of correlations has been suggested in Ref. [12] to explain the even and odd multiplicity distributions in different rapidity windows [13].

Due to the positive charge of the initial-state particles in NA22 and PYTHIA, the average number of positively charged particles is higher than that of negatively charged ones, as is also the case in heavy ion experiments [6]. This asymmetry effect becomes large in the large rapidity windows and causes the fluctuations in the charge ratio $R^+ = n^+/n^-$ and $R^- = n^-/n^+$ not to be a simple inverse relation. Therefore, we present the D-measures in terms of the charge ratios R^+ and R^- in Figs. 1(b), (c), (e) and (f) separately, where, according to the definitions of charge ratio above, events with $n^- = 0$ and $n^+ = 0$ have been excluded from the analysis of R^+ and R^- respectively.

It can be seen from the figures that both $D(R^+)$ and $D(R^-)$ first increase with increasing rapidity window to a maximum and then decrease. From $\delta y = 2$ to $\delta y = 5$, the $D(R^+)$-measure falls into the band of a hadronic gas. The $D(R^-)$-measure has much lower a value in comparison to $D(R^+)$ and passes through the band of QGP.

From the mere observation, whether the measures stay in the range theoretically predicted for a hadronic gas or not, we still can not judge which one is better in measuring the charge fluctuations. It is interesting to see how those measures are in recording the *change* of charge fluctuations with multiplicity in different rapidity windows from early published results of NA22 [13], where the multiplicity dependency has been studied in different rapidity windows, and the characteristic phenomena appear only in large enough windows, *e.g.* $|y| < 2.5$.

In Fig. 2, the dependence of $D(Q)$, $D(R^+)$ and $D(R^-)$ on multiplicity is presented for two rapidity windows, $|y| < 2.5$ (upper rows) and 3 (lower rows). From the results, the following can be observed: *(i)* First of all, all plots show multiplicity dependence. This is different from the results of PHENIX, where such a dependence is seen only for $D(R^+)$ [6]. *(ii)* For $|y| < 2.5$, the data on $D(Q)$ are separated at large even and odd multiplicities, consistent with former even–odd multiplicity distributions [13]. However, because of the large errors, this separation is not so clear in the charge ratio measurements. For $|y| < 3$, the separation turns out to be more clear for all, $D(Q)$, $D(R^+)$ and $D(R^-)$, and the fluctuations in odd multiplicities are larger than those in even ones. The $D(Q)$ have almost equal separation distance for all multiplicities, while the $D(R^+)$ have large distance for low multiplicities and the $D(R^-)$ have large distance for large multiplicities with very big errors for odd multiplicities.

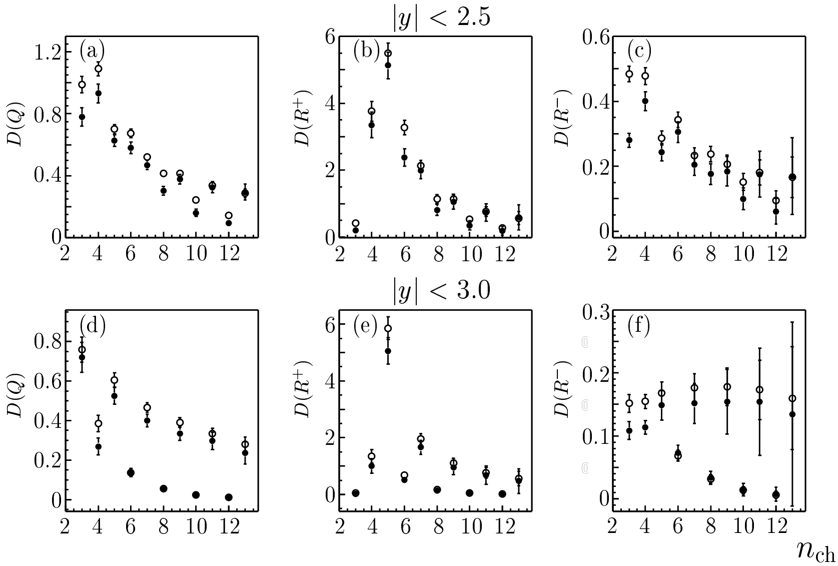

Fig. 2. The dependence of $D(Q)$, $D(R^+)$ and $D(R^-)$ on multiplicity for $|y| < 2.5$ (upper row) and $|y| < 3$ (lower row).

The results can be summarized as follows: The net charge and charge ratio fluctuations both have strong rapidity dependence. The corrected net charge event-by-event fluctuations well measure the correlations between the positive and negative charge in short rapidity range. The $\tilde{D}(R^+)$ and $\tilde{D}(R^-)$ are always above the band for the hadronic gas and keep increasing with the size of rapidity windows. The net charge and charge ratio fluctuations both have multiplicity dependence. The net charge fluctuation measure has a better record in different charge fluctuations of even and odd multiplicities than the charge ratio ones do. PYTHIA can reproduce the net charge and charge ratio fluctuations in different rapidity intervals and for different multiplicities.

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