Event-by-event search for charge-neutral fluctuations in Pb-Pb collisions at 158 AGeV

Madan M. Aggarwal
Department of Physics, Panjab University, Chandigarh-160014, India
(For the WA98 Collaboration)

Abstract. Results from the analysis of data obtained from the WA98 experiment at the CERN SPS have been presented. Some events have been filtered which show photon excess in limited $\eta - \phi$ zones within the overlap region of the charged particle and photon multiplicity detectors.

Keywords. Disoriented chiral condensate, centauro/anticentauro events, Fluctuations

PACS Nos 2.0

Charged-neutral fluctuations have been one of the predicted signals for chiral symmetry restoration in heavy-ion collisions at ultra-relativistic energies Refs. [1-7]. It is hoped that the extreme energy densities residing inside the spatial region between receding baryonic slabs shortly after a heavy ion collision may provide the physical conditions necessary for the formation of a chiral condensate aligned in a direction different from the true vacuum. It has been predicted that the chiral field relaxes to the true vacuum in such domains emitting coherent pions. The coherent pion emission by domains of such Disoriented Chiral Condensates (DCCs) within the collision volume results in large fluctuations in the ratio of neutral to charged pions in those domains. The observed Centauro and Anti-Centauro events in cosmic ray collisions [8] may be due to the formation of large domains of DCCs.

Recently DCC formation has been investigated by the Minimax experiment in $p - \bar{p}$ collisions at the Tevatron energy [9] and by the NA49 experiment [10] at the CERN SPS but no conclusive evidence for DCC formation was observed. The WA98 experiment has also studied the correlated neutral to charged particle fluctuations globally [11] and by the Discrete Wavelet Transform (DWT) technique [12] in Pb-Pb collisions at 158 AGeV and upper limits on DCC formation have been reported. In this paper we present first results on an event-by-event search for charged-neutral fluctuations in limited $\eta - \phi$ phase space regions.

Results are based on the Pb-Pb collision data at 158 AGeV taken by the WA98 experiment at the CERN SPS, under zero magnetic field conditions, during the 1996 run time. In the present investigation we have used the distribution of photons measured by the Photon Multiplicity Detector (PMD) and that of charged particles measured by the Silicon Pad Multiplicity Detector (SPMD). The PMD, placed at 21.5 meters downstream of the target, consisted of plastic scintillator pads of varying sizes, arranged inside 28 box modules, placed behind $3X_0$ thick lead converter plates [13]. The energy deposited in each pad due to preshowering was measured by a CCD camera system and was digitized. The clusters of neighbouring affected pads were used to count the number of hits on the PMD. Those
clusters with ADC values greater than or equal to three times that of the minimum ionising track were regarded as photon-like hits and will be referred to as photon hits \((N_\gamma)\) throughout this paper. The photon counting efficiency was found to be 68% to 73% for central and peripheral events, respectively. In the present analysis, the data from 22 central cameras covering the pseudorapidity region of \(2.9 < \eta < 4.2\) has been used. The SPMD, consisted of 22 radial and 46 azimuthal segments in each of the quadrants and covered the pseudorapidity region of \(2.35 < \eta < 3.75\). The detection efficiency of the SPMD was 99%. The Midrapidity Calorimeter (MIRAC) placed at 24 m downstream of the target measured the flow of transverse energy \((E_T)\) emanating from the collision. \(E_T\) is used to characterize the event centrality.

We study the fluctuations in the neutral pion fraction \((f)\)

\[
f = \frac{N_{\pi^0}}{N_{\pi^0} + N_{\pi^\pm}} \approx \frac{N_\gamma/2}{N_\gamma/2 + N_{ch}}
\]

which should follow a probability distribution of the type:

\[
P(f) = \frac{1}{2\sqrt{f}}
\]

for emission from DCC domains.

We have confined ourselves to the study of events having photon excess in azimuthal patches within the overlap zone of the PMD and the SPMD. For these patches, the purity of the photon sample observed by the PMD is higher than those for normal patches due to the depleted flux of charged particles.

We have analysed a set of 196K events, corresponding to the top 15% of the minimum bias cross-section, as determined from the transverse energy \((E_T)\) measured by the MIRAC. The events are analyzed for fluctuations in the neutral pion fraction \((f)\) in the \(\eta - \phi\) phase space region on an event-by-event basis. In this paper an attempt has been made to identify anticentauro type events. Such events are characterised by an excess of gammas over the number of charge particles in certain \(\eta - \phi\) domains. Since the location of these domains is not known it is essential to extend our search over the whole range of \(\phi\) values. In our method we choose a particular azimuthal window, \(\Delta \phi\), in the pseudorapidity region, \(2.9 < \eta \leq 3.75\). We scan the entire azimuthal range from 0° to 360° in order to search for a patch having maximum value of \(f\) which will be referred to as \(f_{max}\). This scan is performed by successive 2° rotations of the \((\Delta \eta - \Delta \phi)\) patch. To minimize the statistical fluctuations, a patch with maximum \(f\) value in an event was required to have at least 40 \(\gamma\)'s corresponding to a 15% statistical error.

Results have been compared with simulated events obtained using the VENUS 4.12 event generator [14]. These events were processed through the WA98 detector setup using GEANT 3.21. The output of these processed simulated events is analysed in a similar manner as data and is referred to as \((V+G)\). The statistical significance of the above results is obtained by comparing the results with those from mixed events. Mixed events are obtained by randomly mixing photons and charged particles independently while keeping the \(N_\gamma - N_{ch}\) correlation intact and also taking proper care of the two track resolution.

An event displaying PMD hits (filled circles) and SPMD hits (open squares) within the overlap \(\eta - \phi\) zone (obtained by using the method described above) is shown in Figure 1. A patch of \(\Delta \phi = 90°\) in azimuth is also marked. It is seen that in this domain the number
Figure 1. Plot showing photon hits (PMD) and charged particle hits (SPMD) in an azimuthal plane. The marked 90° patch corresponds to $f_{\text{max}} = 0.77$.

Figure 2. $f_{\text{max}}$ distributions for 60° patch for Data (solid histogram), Mixed Events (dashed histogram) and V+G (dotted histogram).
Table 1. No. of events, per 10 K, with neutral pion fraction $f_{\text{max}} > 0.55$ in data, VENUS+GEANT and Mixed Events for $40^\circ$, $60^\circ$, and $90^\circ$ patch sizes for different centrality bins selected by the MIRAC.

| Event Type     | Sample | No. of events | $\Delta \phi=40^\circ$ | $\Delta \phi=60^\circ$ | $\Delta \phi=90^\circ$ |
|---------------|--------|---------------|-------------------------|-------------------------|-------------------------|
| Top 5%        | Data   | 84K           | 185.9±4.7               | 16.8±1.4                | 0.9±0.3                 |
|               | V+G    | 13K           | 0.7±0.7                 | $\approx 0^*$          | $\approx 0^*$           |
|               | EvtMix | 83K           | 37.8±2.1                | 1.9±0.5                 | 0                       |
| Top 5-10%     | Data   | 78K           | 325.0±6.5               | 69.3±3.0                | 2.7±0.6                 |
|               | V+G    | 8K            | 1.2±1.2                 | 1.2±1.2                 | $\approx 0^*$           |
|               | EvtMix | 77K           | 109.3±3.8               | 14.8±1.4                | 0.4±0.2                 |
| Top 10-15%    | Data   | 34K           | 317.1±9.5               | 158.6±6.7               | 12.3±1.9                |
|               | V+G    | 6K            | 1.5±1.5                 | 3.0±2.1                 | $\approx 0^*$           |
|               | EvtMix | 30K           | 120.0±6.3               | 56.9±4.3                | 1.6±0.7                 |

* The number of events have been estimated, for a similar statistics as in the data, assuming a gaussian distribution for $f$ as in Fig. 2 for V+G events.

of charged particles is only 12 as compared to 84 photons which corresponds to $f_{\text{max}} = 0.77$ in this event. Figure 2 shows histograms of the maximum value of $f$, obtained in an event, for Data, Mixed Events, and V+G for a domain size of $\Delta \phi = 60^\circ$. It is seen that the $f_{\text{max}}$ distribution for the data extends to much larger values than mixed events and (V+G) events. A similar trend was observed for lower centrality intervals (i.e., top 5 - 10 % and top 10 - 15 % events). This analysis was also carried out for 40$^\circ$ and 90$^\circ$ patch sizes. Table 1 lists the number of events per 10 K, corresponding to $f_{\text{max}} > 0.55$ for various values of azimuthal windows (i.e., $40^\circ$, $60^\circ$, and $90^\circ$) for three centrality bins with at least 40 $\gamma$’s in a domain. The results for simulated V+G events and generated mixed events for different centralities and patch sizes are also listed in the table for comparison. We see that events with $f_{\text{max}} > 0.55$ are more frequent in data as compared to those seen in mixed events and in V+G events. The fraction of these events decreases significantly as we increase the patch size. Furthermore, the fraction of these events increases significantly with decrease in centrality. Figure 3 exhibits the azimuthal distribution of patches having $f_{\text{max}} > 0.55$ in data in the top 15 % central events for a $60^\circ$ patch. It is seen that these patches are more or less uniformly distributed in azimuth.

To test the authenticity of these events the immediate preceding and succeeding events in the data have been checked for the same $\eta - \phi$ patch and the neutral pion fraction ($f$) was calculated for the same patch size. The distribution of these $f$ values is shown by the dashed line in Figure 4. The cut of $N_{\gamma} > 40$ has also been used here. In Figure 4 we also show, for comparison, the neutral pion fraction for patches having $f_{\text{max}} > 0.55$ (solid line) with $N_{\gamma} > 40$. It is seen that the dashed curve has its peak around 0.35 and it shows a behaviour similar to that of generic events. It means that events with $f_{\text{max}} > 0.55$ are special events, having large non-statistical charged-neutral fluctuations. In this sense, these events closely resemble the anti-centaurio type events found in cosmic experiments [8].

In summary, we have found events with large charged-neutral fluctuations in our data which show $f_{\text{max}} > 0.55$ in certain $\Delta \phi$ domains. These domains are uniformly distributed...
Event by event...

**Figure 3.** $\phi$ distribution of the patches having $f_{\text{max}} > 0.55$ for 60° domain in the top 15% of events.

**Figure 4.** Neutral pion fraction ($f$) distributions for events having $f_{\text{max}} > 0.55$ (solid line) and for preceding and succeeding events (dashed line) for 60° patch having $N_\gamma > 40$. 

*Pramana – J. Phys.*, 5
in azimuth. The fraction of such events are much larger in the data as compared to those seen in the mixed events and V+G events. The percentage of these events increases significantly with decreasing patch size. Also the fraction of such events increases significantly as we decrease the centrality. This is the first time that anticentauro type events have been observed in heavy ion collisions in an accelerator based experiment.

References

[1] A.A. Anselm and M.G. Ryskin, Phys Lett. B266 (1991) 482.
[2] J.D. Bjorken, K.L. Kowalski, C.C. Taylor, "Baked Alaska", SLAC-PUB-6109, 1993.
[3] J.P. Blaizot and D. Diakonov, Phys Lett. B315 (1993) 226.
[4] K. Rajagopal and F. Wilczek, Nucl. Phys. B399 (1993) 395; Nucl. Phys. B404 (1993) 577.
[5] S. Gavin et al., Phys. Rev. Lett. 72 (1994) 2143.
[6] S. Digal, R. Ray, S. Sengupta and A.M. Srivastava, Int. J. Mod. Phys. A15 (2000) 2269
[7] M. Asakawa, H. Minaka and B. Muller, e-print, nucl-th/0011031 Dec. 2001.
[8] C.M.G. Lattes et al., JACEE Collaboration, Phys. Rep. 65 (1980) 151.
[9] T.C. Brooks et al., Minimax collaboration Phys. Rev. D61 (2000) 032003.
[10] H. Appelshauser et al., NA49 collaboration, Phys. Lett. B459 (1999) 679.
[11] M.M. Aggarwal et al., WA98 collaboration, Phys. Lett. B420 (1998) 169.
[12] M.M. Aggarwal et al., WA98 collaboration, Phys. Rev. C64 (2001) 011901 R.
[13] M.M. Aggarwal et al., WA98 collaboration, Nucl. Instr. Meth. Phys. Res. A424 (1999) 395.
[14] K. Werner, Phys. Rep. 232 (1993) 87.