MAXIMUM PARTICLE DENSITIES
IN RAPIDITY SPACE OF π^+p , K^+p AND pp COLLISIONS AT 250 GeV/c

NA22 Collaboration^(*)

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ABSTRACT

In a study of π^+p , K^+p and pp collisions at $\sqrt{s} = 22$ GeV in the European Hybrid Spectrometer (EHS), the maximum charged particle density per given rapidity interval is found to rise linearly with charged particle multiplicity, independent of beam particle type and practically independent of energy between 22 and 900 GeV. An anomalous π^+p event is found with 10 particles within the very narrow rapidity interval $\Delta y = 0.098$.

In connection with hot hadronic matter and heavy ion collisions, the interest has increased in high density fluctuations in rapidity space. The UA5 Collaboration had presented events with 15 or more charged particles produced within $1/2$ unit of pseudo-rapidity [1] (see also [2-4]). This observation has led to the suggestion [5] that such spectacular spikes might be the result of the formation in the primary hadron-hadron collision of a "hot-spot" of matter, possibly in the quark-gluon phase. On the other hand, it has turned out that events with such particle densities can, in fact, be generated by the UA5 Monte-Carlo program at a comparable rate, so that these spikes are more or less what one would expect on the basis of the observed multiplicity and rapidity distribution, together with clustering [2,3].

Nevertheless, inspired by the observation of large fluctuations and the need for a "calibration" for heavy ion collisions, we have looked for spike-like events in an experiment (NA22) performed at CERN. In this experiment the European Hybrid Spectrometer (EHS) is used, equipped with the Rapid Cycling Bubble Chamber (RCBC) as a vertex detector and exposed to a 250 GeV/c tagged, positive, meson enriched beam. In data taking, a minimum bias interaction trigger has been used. The experimental set-up and the trigger conditions are described in ref. [6], where details pertaining to the topological cross sections and charged multiplicity distributions for 250 GeV/c π^+p , K^+p and pp interactions can be found. The rapidity dependence of negative and all-charged multiplicities in this experiment is discussed in ref. [7].

Events are accepted when the reconstructed topology and the charge balance are correct. Except for slow protons, all particles are assigned the pion mass. Our samples consist of 37 127, 44 587 and 7366 inelastic π^+p , K^+p and pp events, respectively.

We determine the maximum track density $(\Delta n/\Delta \eta)_{\max}$ within an event by scanning with a fixed (pseudo-) rapidity window $\Delta \eta$ across the full η range. The average of this quantity, $\langle (\Delta n/\Delta \eta)_{\max} \rangle$ over all events of given total charge multiplicity n_{ch} , is given in fig. 1(a) as a function of n_{ch} for our π^+p data at $\sqrt{s} = 22$ GeV and compared to the UA5 data at 540 GeV [4]. In both cases, the pseudo-rapidity window is $\Delta \eta = 0.5$. In UA5, $\langle (\Delta n/\Delta \eta)_{\max} \rangle$ is found to be roughly proportional to n_{ch} and independent of energy between 200 and 900 GeV.

Our data support this observation of approximate energy independence in the range of n_{ch} , available in our experiment and extend it to the much wider energy range 22-900 GeV. Furthermore, they confirm the approximately linear dependence of $\langle (dn/d\eta)_{max} \rangle$ on n_{ch} .

In fig. 1(b), we compare our results for π^+p , K^+p and pp collisions at 22 GeV, but now with a window of $\Delta\eta = 0.1$. The maximum track density is larger for the smaller $\Delta\eta$, but remains linear in n_{ch} . Fits to the form $\langle (\Delta n/\Delta\eta)_{max} \rangle = a + bn_{ch}$ in the range $8 \leq n_{ch} \leq 20$ result in the parameters given in table 1. Within errors, they are the same for π^+p , K^+p and pp collisions.

TABLE 1

The parameters obtained in the fits of the π^+p , K^+p and pp data at 250 GeV/c by a function $\langle (\Delta n/\Delta\eta)_{max} \rangle = a + bn_{ch}$ (for $\Delta\eta = 0.1$, $8 \leq n_{ch} \leq 20$).

	a	b	χ^2/ND
π^+p	7.77 ± 0.12	1.04 ± 0.01	40/5
K^+p	8.03 ± 0.11	1.02 ± 0.01	17/5
pp	8.56 ± 0.30	0.97 ± 0.03	1/5

Our data, combined with the UA5 data thus show that the maximum charged particle density per given pseudo-rapidity interval is indeed rising linearly with the charged particle multiplicity, independent of beam particle identity and practically independent of energy in a very large energy range.

To be able to compare to UA5 results, we have restricted ourselves to pseudo-rapidity. EHS allows us to use rapidity y , more naturally connected to the problem of hot hadronic matter. In studying $\langle (\Delta n/\Delta\eta)_{max} \rangle$ we have found several events with very high local particle density in very narrow pseudo-rapidity intervals. Prompted by this observation, we now look for the distribution of events having a maximum density of n charged particles inside a small c.m. rapidity interval $\Delta y = 0.1$. Fig. 2 indicates that the number N of such events in our samples decreases exponentially with increasing n with the same rate

for π^+p , K^+p and pp collisions. Fits by an exponential form $dN/dn = a \cdot \exp(-bn)$ result in the same values for the exponential slope, i.e. 2.22 ± 0.05 , 2.28 ± 0.05 and 2.17 ± 0.10 for π^+p , K^+p and pp reactions, respectively. The results of the fits for π^+p and pp data are shown as straight lines in fig. 2. Existing low p_t models can reproduce this "background" behaviour.

TABLE 2

Track parameters of charged particles in the anomalous event (momenta in GeV), particles 8 to 17 are in the spike. The momentum component p_x is in the beam direction, p_y and p_z transverse to it.

n	y	p_t	p_x	p_y	p_z	Charge	Particle
1	-1.694	0.389	0.829	0.386	-0.055	1	-
2	-1.068	0.168	0.855	-0.142	0.090	1	π
3	-0.605	0.183	1.445	-0.123	0.136	1	π
4	-0.505	0.472	3.410	0.467	0.064	-1	π/e
5	-0.454	0.147	1.480	-0.129	0.070	1	π
6	-0.321	0.313	2.866	0.075	0.304	1	-
7	-0.267	0.523	4.773	0.510	0.116	-1	π
8	-0.242	0.039	1.310	-0.038	-0.007	-1	π
9	-0.215	0.051	1.380	-0.038	0.033	1	-
10	-0.205	0.536	5.200	0.114	-0.524	1	π/K
11	-0.201	0.135	1.828	0.129	-0.040	-1	π
12	-0.181	0.122	1.784	-0.080	0.093	-1	π
13	-0.165	0.295	3.187	-0.293	0.034	1	-
14	-0.155	0.181	2.253	0.180	-0.020	-1	-
15	-0.154	0.110	1.756	-0.013	0.109	-1	π
16	-0.153	0.329	3.536	-0.326	0.048	-1	-
17	-0.144	0.183	2.300	-0.140	-0.118	1	π
18	0.077	0.261	3.686	-0.247	-0.083	-1	π
19	0.272	0.084	2.469	0.075	-0.039	1	-
20	0.438	0.298	5.894	-0.182	0.236	-1	π
21	0.512	0.146	3.885	-0.127	-0.071	1	-
22	0.942	0.300	9.809	0.245	-0.174	1	-
23	1.084	0.335	12.396	-0.296	0.156	-1	π/K
24	1.439	0.278	15.154	-0.088	0.264	1	π
25	1.561	0.300	18.206	0.296	0.049	1	π
26	2.452	0.192	31.882	0.120	0.150	-1	-

However, one of the π^+p events is incompatible with the smooth trend of our data in fig. 2. The event has 10 charged particles within

$\Delta y = 0.098$, i.e. a local density of 100 particles per unit of rapidity, much more than observed in the events by the UA5 Collaboration at ~ 25 times our c.m. energy. From an extrapolation of the exponential fall-off in fig. 2, only 10^{-3} events with 10 tracks in $\Delta y = 0.1$ would be expected in our combined samples, while we find one. This probability increases to $\sim 3 \cdot 10^{-3}$ if a rapidity window $\Delta y = 0.2$ is used instead.

The anomalous event is one of 20 events with $n_{ch} = 26$ in our π^+p , K^+p and pp samples and corresponds to a production cross section of $0.2 \mu b$. Its interaction vertex is perfectly seen in the center of RCBC and all 26 tracks are well measured in the bubble chamber or reconstructed in the downstream spectrometer. The charged particles carry 57% of the total available energy. About half of the neutral energy is recovered in the gamma detectors.

A two-dimensional plot of azimuthal angle ϕ versus c.m. rapidity y for all charged tracks in the event is shown in fig. 3(a), its projection onto the rapidity axis in fig. 3(b). The spike is seen at a small negative y value. It is not associated with jet production in any obvious way. The particles in the spike are randomly distributed in the azimuthal angle ϕ about the beam direction (fig. 3(a)). The average transverse momentum for all charged particles in the event and for the particles in the spike is about the same and amounts to $0.25 \text{ GeV}/c$. The total charge of the 10 particles in the $\Delta y < 0.1$ interval equals to -2 . The effective mass of the 10 particles is only $2.46 \text{ GeV}/c^2$. The track parameters are given in table 2.

From 10 particles in the spike, 5 have been unambiguously identified as pions in the spectrometer. With masses of the other 5 particles not identified, we cannot exclude the possibility of at least some of them not being pions and therefore having a rapidity different from that of the spike. This possibility is less likely for π^+p sample where the spike is observed. Estimates based on model calculations indicate that possible kaon admixture would reduce the statistical significance of the spike to a few times 10^{-3} .

On the other hand, if all particles in the spike are pions, its interpretation is not obvious. In the beginning, we have mentioned the suggested interpretation [5] of large fluctuations in rapidity density as a "hot-spot" of matter in the quark-gluon phase. The existence of such spikes is also predicted in another approach [8], interpreting coherent hadron production analogous to Cherenkov radiation. This approach has been stimulated by the observation of (statistically insignificant) spikes in the pseudo-rapidity distribution of secondary charged particles in three cosmic ray events at energies of 10^{13} , 10^{15} and 10^{16} eV. According to ref. [8], this process of gluon radiation by a valence quark of the initial hadron is, however, expected to be seen at much higher energies and at large transverse momenta.

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FIGURE CAPTIONS

- Fig. 1 The maximum track density $(\Delta n/\Delta\eta)_{\max}$ within an event, averaged over all events with given charge multiplicity n_{ch} , as a function of n_{ch} . In subfigure 1(a), the π^+p data at $\sqrt{s} = 22$ GeV are compared to pp data at 540 GeV [4], the pseudo-rapidity window is $\Delta\eta = 0.5$. In subfigure 1(b), π^+p , K^+p and pp data at 22 GeV are compared to each other, the window is $\Delta\eta = 0.1$.
- Fig. 2 The distribution of number N of events with a maximum of n charged particles inside 0.1 unit of rapidity for K^+p , π^+p and pp collisions at $\sqrt{s} = 22$ GeV. The straight lines correspond to fits of the π^+p and pp data to exponentials, with the slope parameter given in the text.
- Fig. 3 (a) Scatter plot of azimuthal angle ϕ versus cm rapidity y for all secondary charged particles in the anomalous π^+p event.

(b) Projection of the scatter plot onto the rapidity axis.

Fig. 1

Fig. 2

Fig. 3