SOFT AND HARD INTERACTIONS IN $P\bar{P}$ COLLISIONS AT $
abla S = 1800$ AND 630 GEV

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Soft proton-antiproton interactions are selected from events collected with the CDF minimum-bias trigger at $\sqrt{s} = 1800$ and 630 GeV. The analysis of their properties compared at the two energies reveals important and unexpected invariances.

1 Introduction

This paper describes an attempt to address the problem and the study of the properties of genuine soft interactions. These are identified as a subsample of proton antiproton interactions collected with the CDF minimum bias trigger. In the analysis a splitting procedure of the full minimum bias sample in two subsamples, one highly enriched in soft interactions and the other enriched in hard interactions, is applied. The two subsamples are analysed separately through the compared measures of some inclusive distributions and final state correlations at different c.m.s. energies. The results evidence some interesting unobserved properties of the isolated soft sample and, in particular, a remarkable unpredicted invariance of some of the measured correlations and spectra between 630 and 1800 GeV.

2 Experimental Procedure

The experiment has been performed with the CDF detector at the Fermilab Tevatron Collider. The CDF apparatus has been described elsewhere; here only the parts of the setup utilized for the present analysis are discussed.

Data were collected with a minimum bias trigger during Run 1A, 1B, 1C (1800 GeV) and 1C (630 GeV). For the present measure the charged tracks detected in the Central Tracking Chamber (CTC) have been used. The CTC is a drift chamber covering a $\eta$ interval of about three units with full efficiency for $|\eta| \leq 1$ and $p_t \geq 0.4$ GeV/c. The transverse energy flux was measured in the full calorimeter system, globally covering from -4.2 to 4.2 in $\eta$.

About 3,300,000 triggers were collected at $\sqrt{s} = 1800$ GeV in three different run periods (run 1A+1B+1C) and 2,600,000 at $\sqrt{s} = 630$ GeV (run 1C).
For each event a careful selection of the tracks was applied to remove the main sources of background and reconstruction mismatching. In order to ensure full CTC efficiency only tracks with $p_t \geq 0.4$ GeV/c and $|\eta| \leq 1.0$ were accepted. Given the above cuts the charged track multiplicity, throughout our analysis, is defined by the number of selected CTC tracks in each event. The mean $p_t$ of the event is defined as the sum of the $p_t$ of all the measured tracks divided by their number.

We define soft interaction any event in which no cluster of a minimum transverse energy of 1.1 GeV is observed in $|\eta| \leq 4.2$. Clusters of towers in the Central and End-Plug Calorimeters were reconstructed via the jet-finding cone algorithm with radius in $\eta, \phi$ of 0.7. With the above selection a cluster may consist of a seed tower of $E_T > 1$ GeV and an adjacent tower of at least 0.1 GeV. Calorimeter cluster finding has been checked and corrected for energy losses in the calorimeter cracks with a track cluster algorithm. The total Min-Bias sample was splitted in a soft ( events with no clusters) and in a hard sample ( events with at least 1 cluster ).

3 Data Analysis

Some inclusive distributions, namely multiplicity and transverse momentum distributions, are examined first. The comparison of the multiplicity distributions at 1800 and 630 GeV for the full MB sample, plotted in KNO variable (not shown in figure), exhibits a weak violation of the KNO scaling as it is expected in a limited phase space region. The same comparison is made for the soft and hard samples separately and the results are shown in Fig. 1. The ratios of the overstanding distributions are plotted in the bottom part of each plot in Figs. 1. A remarkable superposition of the distributions at the two energies is observed for the soft sample, suggesting that the KNO scaling violation in the full sample comes from the hard component.

The transverse momentum distributions, examined separately for the three samples, full MB, soft and hard, at the two energies ( not shown in figure ) show a steeper slope of the soft $p_t$ distribution with respect to the full MB and to the hard samples. This is expected as it merely reflects the absence of events with high $p_t$ jets. The soft $p_t$ distributions, when plotted at each single multiplicity at the two cms energies of 1800 and 630 GeV, overlap in value and slope; in other words they are c.m.s. energy invariant. This is shown in Fig. 2 for the full MB and for the soft samples where the distributions at the two energies are superimposed; only plots of event multiplicities of 5 and 10 are shown for brevity. This result is completely unexpected and suggests that in purely soft interactions the number of produced (charged)
particles is the only global variable of the event changing with $\sqrt{s}$.

The correlation between mean $p_t$ and charged multiplicity is known since its first observation by UA1 [3] and successively investigated at the ISR [4] and at the Tevatron Collider energies [5], but its theoretical explanation is still not completely known. Our results are summarized in Fig. 3 for the MB and the soft samples.

To be noted is the good superposition of the plots at the two energies for the soft sample, keeping in mind the limited purity of the enriched sample. Still to be noted is the weak but clear rise of the $p_t$ in this sample. This rise, which is stronger in the low multiplicity region, is not due to the hard interaction contamination that only affects the high multiplicity region.

Event-by-event fluctuations on the mean $p_t$ have been shown to be a valid tool to investigate the collective behaviour of soft multibody production. In slightly different ways this tool has been applied to analyze experimental data [6,7,8]. Following the approach of [6], the dispersion of the mean event $p_t$ is defined for each multiplicity by:

$$D_m (\bar{p}_t) = \frac{\langle \bar{p}_t^2 \rangle_m - \langle \bar{p}_t \rangle_m^2}{\langle \bar{p}_t \rangle_{\text{sample}}}$$  \hspace{1cm} (1)

Brackets $\langle \rangle$ indicate average over all events with a given multiplicity $m$, while $\bar{p}_t$ is here the mean $p_t$ of the event defined above.
The dispersion $D$ is expected to decrease with increasing multiplicity and to converge to zero when $m \to \infty$ if only pure statistical fluctuations are present. Conversely, an extrapolation to a non-zero value would indicate the presence of non statistical fluctuations from event to event in the $\langle p_T \rangle_{ev}$. This indeed is what was found in $^6$ and, in different ways, in $^7,^8$. In Fig. 4 the result of the present measure of the dispersion from Eq. (1) as a function of the inverse multiplicity for the full minimum bias sample is shown. Data points deviate from linearity at high multiplicity, particularly at $\sqrt{s} = 1800$ GeV. The separate analysis of the dispersion versus multiplicity for the soft sample, shown in the same figure, confirms that this effect is related to the contribution of the jet production which, as discussed in $^9$, increases the event-by-event fluctuations.

In this sample the points drop at high multiplicity (multiplicity $\gtrsim 10$). This effect, which was not observed in $^6$, cannot lead to the conclusion of an extrapolation different from zero at infinite multiplicity.
Figure 3. Mean transverse momentum vs multiplicity at 1800 and 630 GeV. Here the $\langle p_t \rangle$ is computed as the sum of the $p_t$ of all the measured tracks at the given multiplicity divided by their number.

Figure 4. Dispersion of the mean event $p_t$ as a function of the inverse multiplicity for the full MB and the soft samples at 1800 and 630 GeV. At the bottom of each plot, the ratio of the two curves at the two energies is shown.

4 Conclusions

Minimum bias events are separated in a soft and a hard interaction sample. Comparing their behaviours at two c.m.s. energies, we obtain the following
- The multiplicity distributions of soft interactions follow the KNO scaling going from $\sqrt{s} = 630$ to 1800 GeV and its $p_t$ distributions at fixed multiplicity are energy invariant.

- The dependence of the mean $p_t$ on multiplicity shows a small rise even in the soft sample where any hard parton interaction is at least strongly suppressed. The remarkably good invariance with energy, when considering the limited purity of the sample (which only affects the medium-high multiplicities) derives from the result quoted above.

- The dependence of the dispersion of the $\langle p_t \rangle_{ev}$ on the inverse multiplicity shows a non-linear behaviour which was not previously observed. The weak rise at multiplicity greater than $\sim 10$ is essentially due to the presence of hard parton interactions.

In the same multiplicity region the slope of the dispersion in the soft sample allows to exclude a non-zero extrapolation at infinite multiplicity.

In all the distributions and correlations studied the soft subsample is compatible with the hypothesis of invariance with the c.m.s. energy, which is a relevant and new result.

References