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SOFT AND HARD INTERACTIONS IN $P\bar{P}$ COLLISIONS AT $\sqrt{S} = 1800$ 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 [1]; 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 η interval of about three units with full efficiency for $|\eta| \leq 1$ and $p_t \geq 0.4$ GeV/c. The tranverse energy flux was measured in the full calorimeter system, globally covering from -4.2 to 4.2 in η.
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 af all the measured tracks divided by their number.

We define *soft* interaction any event in which no cluster of a minimum tranverse 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 η, ϕ 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 [2]. 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)

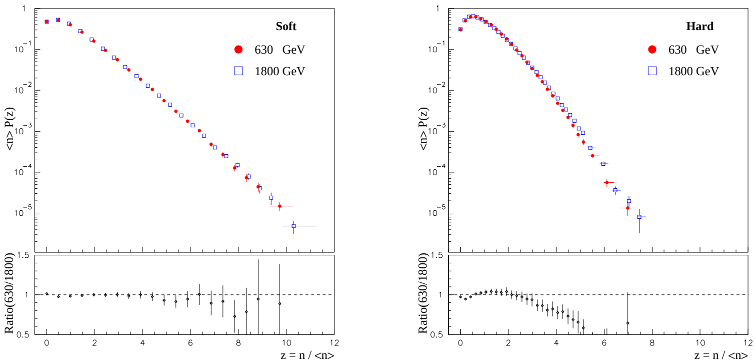

Figure 1. Multiplicity distributions for the *soft* and the *hard* samples at 1800 and 630 GeV; data are plotted in KNO variables. On the bottom of each plot, the ratio of the two distributions at the two energies is shown.

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 duet 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:

$$D_m\left(\bar{p}_t\right) = \frac{\langle \bar{p}_t^2 \rangle_m - \langle \bar{p}_t \rangle_m^2}{\langle p_t \rangle_{sample}} \qquad (1)$$

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.

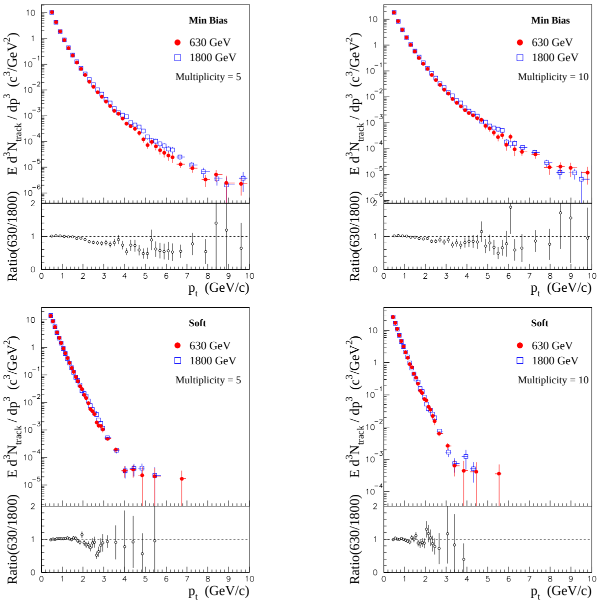

Figure 2. Transverse momentum distributions at fixed multiplicity (multiplicity = 5, 10) for the full MB and Soft samples at 1800 and 630 GeV. At the bottom of each plot the ratio of the two above distributions is shown.

The dispersion D is expected to decrease with increasing multiplicity and to converge to zero when $m \to \infty$ if only pure statistical fluctuactions 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.

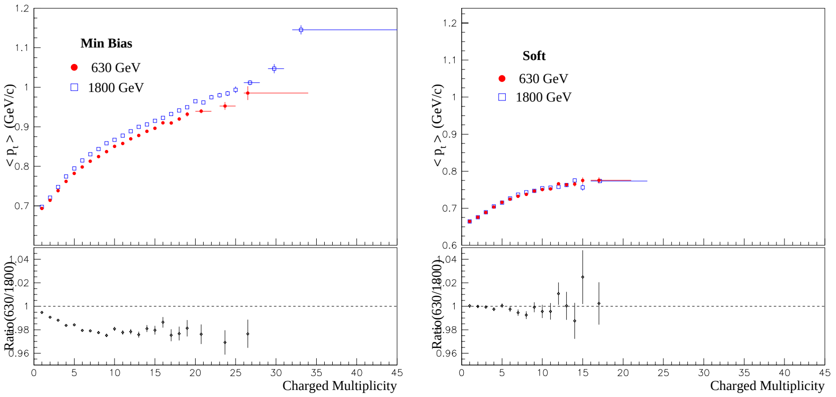

Figure 3. Mean transverse momentum vs multiplicity at 1800 and 630 GeV. Here the $\langle p_t \rangle$ is computed as the sum of the p_t of all the measured tracks at the given multiplicity divided by their number

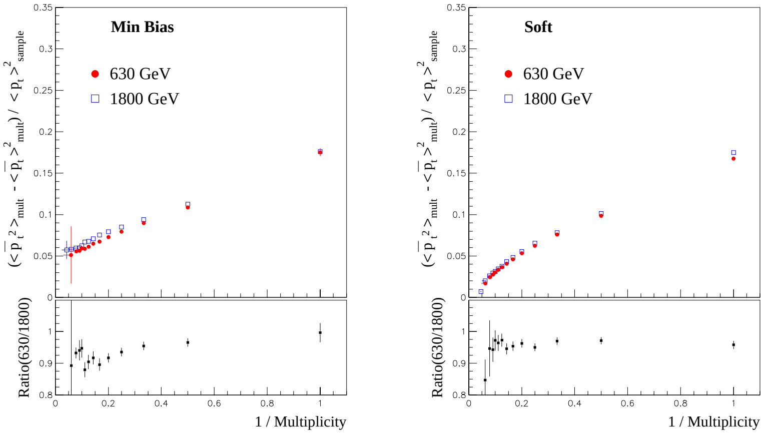

Figure 4. Dispersion of the mean event p_t as a function of the inverse multiplicity for the full MB and the *soft* samples at 1800 and 630 GeV. At the bottom of each plot, the ratio of the two curves at the two energies is shown.

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 results.

- 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 ∼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.

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