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Statistical Properties of the Final State as a Function of The Average Event P_t in Minimum-Bias Interactions

V.Bolognesi, M.M.Deninno, D.Di Nuzzo,
I.Fiori, N.Moggi, F.Rimondi, S.Zucchelli

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1 Introduction

The present note describes a preliminary attempt to a systematic study of minimum bias event structure.The purpose is a comparative analysis of various variables describing the average statistical properties of the softly produced multibody final state as a function of the same reference variable. Results from the two available energies, 1800 and 630 GeV, are compared. Comparison is also made with results from high E_t triggers data in order to investigate how to characterize the different production mechanisms.

Let us try to better explain the goal of these studies. Soft hadron interactions neither are compellingly described by any of the attempted theoretical model, nor by direct QCD approach, since at such low momentum transfer, one is definitely in the non pertubative regime. The large amount of experimental data available on these interactions, which mainly cover the center of mass energy range below the Tevatron energy, gives detailed information on many features of the inelastic soft hadron interactions. Nevertheless the few recognized regularities in these data, like the log(s) scaling of the inclusive distributions and the approximate KNO scaling, still do not give a compelling picture of all the features of the low p_t multibody production and the production mechanisms remain unexplained. Moreover the known experimental data do not tell anything about the evolution from soft to hard parton interactions. Performing a comparative, systematic analysis of the behaviour of some general features of the soft interactions as a function of the same reference variable and the comparison at different energies, we try to evidentiate some specific characteristics of these interactions and their modifications when hard interactions onset.

In the preliminary results presented in this note we used as reference variable the average event p_t which is defined as:

$$\overline{p_t} = \frac{1}{n}\sum_{j=1}^{n} \mid p_t \mid_j \qquad (1)$$

where n is the event multiplicity and $\mid p_t \mid_j$ the transverse momentum of the j^{th} track. Unless otherwise stated they are both measured in the $\mid \eta \mid \leq 1$ and $p_t \geq$ 0.4 GeV/c intervals as described below.

This variable, involving the transverse momentum and the multiplicity of the events, is significantly connected to the dynamics of the event and to its origin from soft or hard parton interactions.

Three global variables have been analysed as a function of the above average event p_t:

- the normalized event multiplicity;
- the strength of the short range pseudorapidity correlation;
- the mean number of K^0 plus Λ^0 in the event.

The detailed definition of each of these quantities will be given in the following.

2 Experimental data and selection procedure

The results presented here come from large samples of minimum-bias triggers recorded during three different data taking periods: the 1988/89 run (about 280,000 triggers), the run 1A (about 299,000 triggers) and the run 1C (about 250,000 triggers at $\sqrt{s}$=630 GeV). In addition one sample of about 13,500 events at $\sqrt{s}$=1800 GeV from "JET_20" and "JET_50" have been analyzed.

Only tracks measured by the CTC have been used. The almost standard event and track selection has been applied [1, 2, 3, 4]. In order to reject multiple interactions, events with two primary vertexes in a 60 cm interval have been rejected. To ensure a good event acceptance in the CTC, the event vertex has been required to be in $\pm$ 60 cm from the origin of the coordinate system. The CTC track selection requires three dimensional tracks with an impact parameter less than 0.5 and the distance between the event vertex and the extrapolated Z0 of the track less than 5 cm.

Finally, in order to ensure a full CTC tracking efficiency, only tracks with $p_t > 0.4$ GeV/c and $\mid \eta \mid \leq 1$ have been accepted.

3 Analysis

The fig.1 shows a scatter plot where, for each event in the sample, in the orizontal scale is plotted the average event p_t as defined in (1) and in the vertical scale the event multiplicity. The latter quantity is given by the number of tracks counted by the CTC in the above mentioned p_t and η regions, divided by the mean value of the multiplicity distribution.

Fig.2 shows the profile of the scatter plot, that is the average scaled multiplicity of the events laying in each slice of 0.2 GeV/c size of the $\langle p_t \rangle$. The result of fig.2 was already presented [4], but we would like to add a few comments on it.

The low mean multiplicity tail above event $\langle p_t \rangle$ 1.5 GeV/c does not mean that high $\langle p_t \rangle$ events all have lower multiplicities than at low $\langle p_t \rangle$, but it is merely a consequence of the steaply decreasing population of the scatter plot of fig.1 for increasing of both $\langle p_t \rangle$ and $\langle n/\bar{n} \rangle$ and of the limited η interval observed. In other words it simply says that high $\langle p_t \rangle$ high multiplicity events, which would rise the tail to higher values, have too low cross section to be recorded by the minimum bias trigger.Would we be able to attenuate the sovrasting number of low $\langle p_t \rangle$ events, which largely dominate the minimum bias and the total inelastic $p\bar{p}$ cross-section, we should see appearing the rare high $\langle p_t \rangle$ high multiplicity events which are obscured in the minimum bias trigger and in the fig.1 plot. To check this in fig.3 it is shown the same scatter plot of fig.1 filled with events coming from "JET_20" and "JET_50" triggers. These events populate the middle high $\langle p_t \rangle$ - $\langle n/\bar{n} \rangle$ region of the plot. The profile is shown in fig.4 (open squares). The Minimum Bias data of fig.2 (full circles) are superimposed for comparison. It is worth to note that the steply increasing part of the curve of fig.4 contains only about the 23% of the events. They are mainly events which have jet activity at large η with a few low p_t tracks in the CTC and they might be affected by trigger threshold inefficiency and by few residual cosmic ray triggers.

The fig. 5 contains the superposition of the profile plots of minimum bias events from two different energies $\sqrt{s} = 1800$ GeV and $\sqrt{s} = 630$ GeV. It is remarkable that, with the normalized multiplicity scale used, the two plots at the two different energies are almost equal. In particular there is a good overlapping of the peak values.

How can these results be reproduced by the current soft interaction simulators? In order to check this point three sets of Monte Carlo data have been generated. Two samples of about 57,000 and about 14,000 events have been generated with MB1 generator at 1800 and 630 GeV respectively. One sample of about 45,000 events has been generated with Pythia. The MB1 data have been simulated through the detector and fully reconstructed [1]

A comparison with MB1 reconstructed data is shown in fig.6. The full circles are the average multiplicities from 1800 GeV data (the same of fig.2) and superimposed, open circles, are the average multiplicities as computed by the Monte Carlo at the same energy. The full triangles show the average multiplicities computed by the Monte Carlo at 630 GeV. As it can be seen the Monte Carlo reproduces the shapes of the experimental curves, but not the mean multiplicity values and, what is even more important, it does not reproduce the energy invariance of the peak position. Pythia generated data, not shown in the figure, are in stronger desagreement with the experimental data.

The results shown in figures 1-5 are obtained using tracks in the limited phase space region $p_t > 0.4$ GeV/c and $\mid \eta \mid \leq 1$. Of course this is not a measurement of the true $\langle p_t \rangle$ and $\langle n/\bar{n} \rangle$. In order to extimate the effects of the limited phase space analyzed and to verify that it does not introduce important distorsions on the shape of the above curves we did the following. Using data from run 1988/89, in which the VTPC chamber could measure the true multiplicity (but not the p_t) in a η interval $\pm$ 2.5, we took as a measure of the $\langle p_t \rangle$ of the event the sum of the E_t measured in the calorimeter (central and plug) divided by the number of tracks measured by the VTPC. The result is shown in fig.7 (star points). For comparison the same curve as in fig.2 is also shown in the plot (full circles). It can be seen that the VTPC data are traslated toward lower $\langle E_t \rangle$ values but they have the same shape of the CTC data.

To get an idea of how this plot should appear when plotting the true $\langle n/\bar{n} \rangle$ and $\langle p_t \rangle$ in the full phase space we use the MB1 Monte Carlo data. The open

[1] MB1 is a fenomenological Monte Carlo for minimum biased inelastic events. Properties of the final state hadrons are adjusted to reproduce the average charged multiplicity, the charged multiplicity distribution, the transverse momentum distribution, and pseudorapidity distribution tuned on the CERN-ISR and SPS energies and extrapolated to the Tevatron Energy. An averaged charged multiplicity is calculated with a fitted formula. The charged multiplicity for the event is generated with a parametrized KNO distribution function.Then the total multiplicity is set. Particle types are decided randomly with pre-set fractions on particle-by-particle base. Transverse masses ($=\sqrt{Pt^2 + m^2}$) for all the particles are generated according to a power form. Afterwards, transverse momenta are readjusted to give a vanishing total transverse momentum. Pseudo rapidities are generated with a properly parametrized distribution. Finally, if the generated event has too much energy or if the missing mass of it is too small, the event is not recorded and program starts again. MB1 has been an official CDF/OFFLINE software package till offline version 4.6 For more information refer to the memo GENMB1.MEM in C$DOC.

diamonds of fig.7 show the $\langle n/\bar{n}\rangle$ versus $\langle p_t\rangle$ computed in the full phase space using the generated MB1 events.

In fig. 8 the transverse average energy as measured by the calorimeters and the VTPC is plotted as a function of the average transverse momentum as measured by the CTC. The two variables are clearly linearly related in the region between about 0.7 and 2.0 GeV. The region below 0.7 GeV is not taken into account because it is at the limit of sensitivity of the plug calorimeter.

3.1 Two Particle Pseudorapidity Correlations

The two particle pseudorapidity correlation measures the tendency of pairs of particles in a multiparticle final state to be emitted close by in rapidity, within a range of 1 or 2 units. The correlation function is defined by:

$$\mathrm{C}(\eta_1,\eta_2) = \rho''(\eta_1,\eta_2) - \rho'(\eta_1)\rho'(\eta_2) \tag{4}$$

where:

$$\rho'(\eta) = \frac{1}{\sigma}\frac{\mathrm{d}\sigma}{\mathrm{d}\eta} = \frac{1}{\mathrm{N}}\frac{\Delta \mathrm{n}}{\Delta\eta}$$
$$\rho''(\eta_1,\eta_2) = \frac{1}{\sigma}\frac{\mathrm{d}^2\sigma}{\mathrm{d}\eta_1\mathrm{d}\eta_2} = \frac{1}{\mathrm{N}}\frac{\Delta \mathrm{n}_{12}}{\Delta\eta_1\Delta\eta_2}$$

are the single and two particle pseudorapidity densities, Δn is the number of tracks in $\Delta\eta$, Δn_{12} is the number of pairs in $\Delta\eta_1$ and $\Delta\eta_2$, and N is the number of events. Function (4) differs from zero if the joint production of pairs of particles differs from the independent production of two particles with the same pseudorapity values. In order to minimize the effects of the detector acceptance and track reconstruction efficiency, the reduced correlation function is used:

$$\mathrm{R}(\eta_1,\eta_2) = \mathrm{C}(\eta_1,\eta_2)/\rho'(\eta_1)\rho'(\eta_2) \tag{5}$$

In order to measure the strength of the correlation, the behaviour of $\mathrm{R}(\eta_1,\eta_2)$ is examined at fixed values of η_2, as a function of η_1. In this way the correlation effect appears as a peak in the correlation function at $\eta_1 \simeq \eta_2$. The height of the peak is slightly independent from the value of η_2, at least when η_2 moves in a 0.5 pseudorapidity range. The correlation strength can then be measured by averaging the peak values of the correlation function at $\eta_1 = \eta_2$ for various values of η_2. This quantity has been measured using CTC tracks in $\Delta\eta = \pm\, 1$. With the form defined in equation (4), the correlation function (4) is normalized to $\langle n(n-1)\rangle$ - $\langle n\rangle^2$ where $\langle n\rangle$ is the average multiplicity of the analyzed event sample. Hence also $\mathrm{R}(\eta_1, \eta_2)$ defined as in equation (5) contains an implicit dependence on the mean multiplicity of the event set analyzed. So to compare the strength of the correlation at different event $\langle p_t\rangle$ we renormalize the function R dividing it by the value of its integral over the overall $\Delta\eta_1\Delta\eta_2$ interval. The results are plotted in fig. 9 as a function of $\langle p_t\rangle$. In the same figure are shown the data at $\sqrt{s}$ 1800 GeV (black points) and at 630 GeV (open triangles).

The correlation exhibits an oscillation for event $\langle p_t\rangle$ below 0.6 GeV/c, due to the flipping to negative sign of the normalization factor of the first point, then it has a smooth behaviour with a shallow minimum around 0.9 - 1.0 GeV/c. The agreement between the 1800 GeV and 630 GeV is really good. In particular both energies show the oscillation at low $\langle p_t\rangle$ and the minimum around 1 GeV/c. In fig. 10 is shown the short range correlation for high E_t triggers superimposed to the 1800 GeV minimum bias data. The jet trigger data rise with increasing $\langle p_t\rangle$ with a steeper slope than minimum bias data. Previous preliminary measurements of this correlation were done in CDF [4, 5].

3.2 K^0 and Λ^0 Production

We discuss now the production of V^0 as a function of the $\langle p_t\rangle$ of the event. The K^0 short and the Λ^0, decaying before entering the CTC, can be detected looking for couples of opposite sign off-vertex CTC tracks converging to a secondary vertex. The standard off-line module described in [6] and track segments from the CTCS bank has been used to search for K^0 and Λ^0 in our data samples. Fig. 11 shows the average number of V^0 (K^0 plus Λ^0) per event divided by the average number of V^0 in the sample as a function of the event $\langle p_t\rangle$. This plot is the profile of a scatter plot obtained in the same way as described for fig.1. That is: each entry of the scatter plot is defined by the $\langle p_t\rangle$ of the events and by its number of V^0 divided by the mean number of V^0 in the analyzed sample. With this normalization the effects of V^0 finding inefficiency are minimized. One can see in fig.11 the results for $\sqrt{s}$ = 1800 GeV (full circles) compared with the data at 630 GeV (open triangles). The behaviour of the average number of V^0 shows a rapid increase for low values of $\langle p_t\rangle$, reaches a maximum around 1 GeV/c and then falls down up to $\langle p_t\rangle$ around 1.5 GeV/c. For higher p_t the curve seems to be flat within large errors. There is a clear analogy with the behaviour of the average charged multiplicity apart for the flat tail that, for the V^0 , seems to start at a lower $\langle p_t \rangle$ and to be at a higher level, with respect to the maximum, than for charged tracks. As well as for the charged tracks, there is a quite good agreement between 1800 and 630 GeV data.

In fig. 12 the mean number of V^0 as a function of the event $\langle p_t \rangle$ for the 1800 GeV minimum bias data is compared with the same quantities extracted from the jet trigger sample. As for the average multiplicity, the mean number of V^0 for the jet trigger shows a flat behaviour for high $\langle p_t \rangle$ at a level correspondent, within the large errors of the minimum bias data, to the flat tail of these latter. Finally in Fig. 13 a comparison with Monte Carlo data is shown. Only about 10,000 events of the entire Monte Carlo MB1 sample have also the V^0 reconstructed. Even with the limited statistic the MB1 data give a very rough reproduction of the shape of the experimental data, but no quantitative agreement with the data points.

4 Conclusions

The analysis of the dependence of the average normalized multiplicity, and of the normalized mean number of V^0 per event as a function of the event $\langle p_t \rangle$ shows the following features:
- a rapid increase with increasing $\langle p_t \rangle$ up to a $\langle p_t \rangle$ of about 0.8 - 1.1 GeV/c, followed by a descent and flatten tail above $\langle p_t \rangle$ 1.5 - 2.0 GeV/c. This region of event $\langle p_t \rangle$ around 0.8 - 1.1 GeV/c corresponds to the maximum of the event $\langle p_t \rangle$ distribution and contains about the 31% of the events (this percentage becomes 99% if the interval is extended from 0.4 to 1.5 GeV/c). That is in this small region lays a large part of the total inelastic $\bar{p}p$ cross-section.

- Both for the multiplicity and the V^0 plots the two curves at 1800 and 630 GeV are almost overlapping, showing a full agreement in the shape of the event $\langle p_t \rangle$ dependence. In particular there is a nice coincidence in the position and the value of the peak.

- The data from jet triggers, that show an event $\langle p_t \rangle$ distribution shifted to above 1 GeV/c with respect to the minimum bias, have an average normalized mean multiplicity and a normalized mean number of V^0 per event almost flat as a function of the event $\langle p_t \rangle$ above 1.5 GeV/c. The level of the plateau, while for the mean number of V^0 is almost correspondent to the flat tail of the minimum bias data, for the average normalized multiplicity sets at a higher level than the correspondant flat part of the minimum bias data.

- The pseudorapidity correlations, which for the minimum bias have a nearly flat behaviour for event $\langle p_t \rangle$ above 0.6 GeV/c and with a good superposition between 1800 and 630 GeV, show a rise, in the high E_t data, well above their value in the minimum bias. It should be noticed that the high E_t data have still high statistic for event $\langle p_t \rangle$ around and above 1.5 GeV/c, where mimum bias have been averaged over a large $\langle p_t \rangle$ range.

In summary, the scaling of our plots with energy for the minimum bias data, might suggest that soft interactions goes through a specific condition, characterized by an event average p_t that, measured in our limited phase space is around 1 GeV/c, independent from energy and with high cross section. With increasing event $\langle p_t \rangle$ hard parton scattering sets on and the events show average properties which stay flat or increase as a function of the event $\langle p_t \rangle$. The connection between the two production mechanisms is still unclear.

References

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[4] CDF Coll. - F.Rimondi. XXIV International Symposium on Multiparticle Dynamics, Vietri sul Mare, Italy, Sept. 12-19, 1994 (CDF/PUB/MIN_BIAS/PUBLIC/2879).

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[6] G.Apollinari, J.P.Berge, J.Skarha, "K0LM Module Testing" CDF note 2886, 1994 (CDF/ANAL/BOTTOM/PUBLIC/2886).

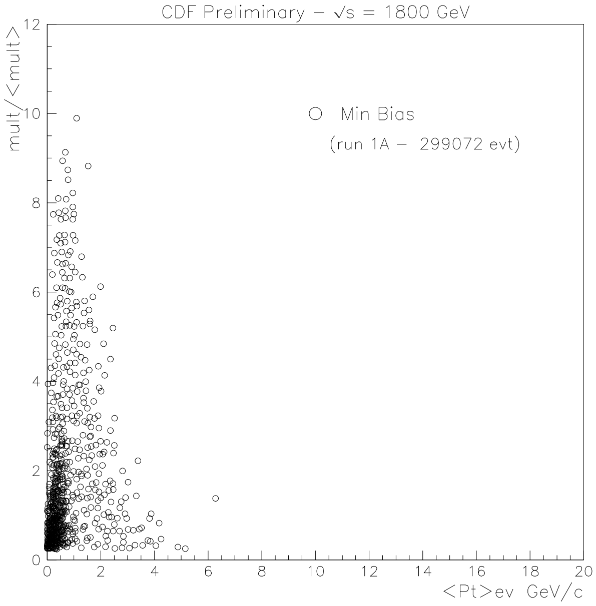

Figure 1: Scatter plot of minimum bias events at 1800 GeV from run 1A. The variable on the horizontal axis is the event average pt. On the vertical one there is the event charged multiplicity normalized to the total average multiplicity of the sample of events. Both variables are measured by the CTC.

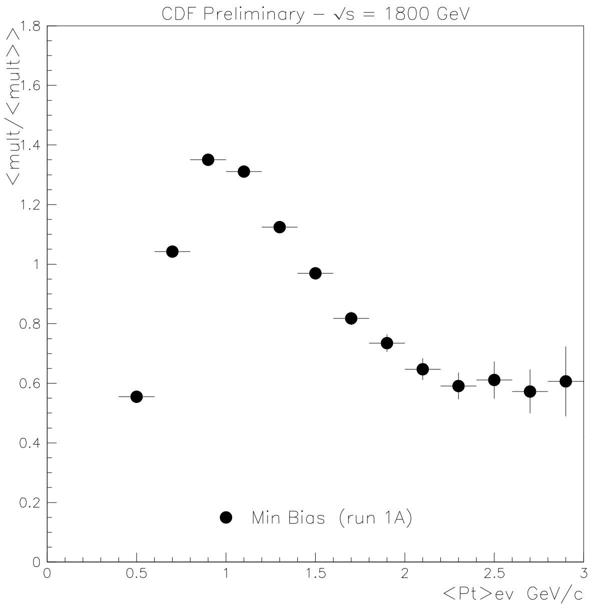

Figure 2: Profile of the Fig. 1 scatter plot obtained using 0.2 GeV/c slices in pt. The plot clearly shows a maximum at around 1 GeV/c. In this region is concentrated the maximum production of minimum bias events.

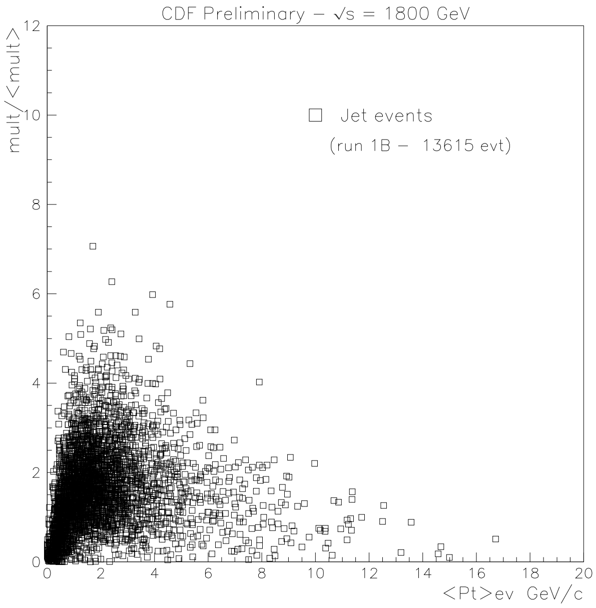

Figure 3: Scatter plot of high p_t events at 1800 GeV from run 1A. This sample of events was selected from JET_20 and JET_50 triggers. On the vertical axis there is the event multiplicity normalized to the total average multiplicity of these events.

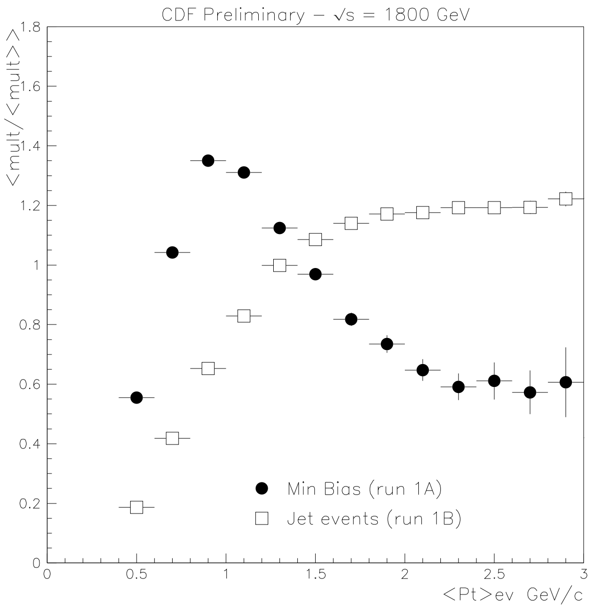

Figure 4: Superposition of profile plots from minimum bias and high p_t events at 1800 GeV. It is clearly visible the different behaviour of the two kinds of events.

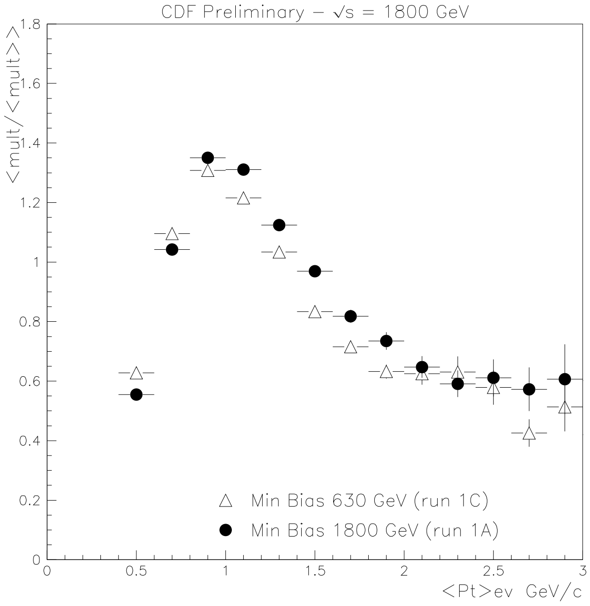

Figure 5: Superposition of profile plots of average multiplicity versus average event pt from minimum bias events at 630 and 1800 GeV. To be remarked that the data from two different energies shows exactly the same behaviour as function of the average event pt.

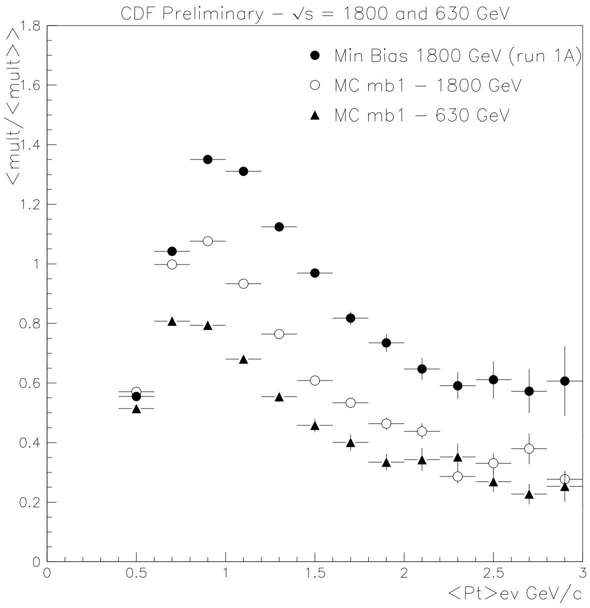

Figure 6: Average multiplicity from 1800 GeV minimum bias data in comparison with Monte Carlo simulation at 630 and 1800 GeV.

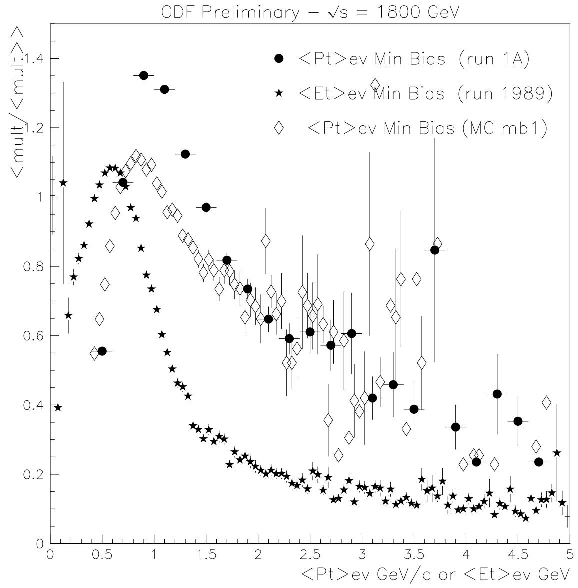

Figure 7: Average multiplicity distribution as function of the average transverse energy , obtained by dividing the calorimeter energy by the VTPC multiplicity, in comparison with the same distribution obtained by using the CTC . The two curves look shifted , but not distorted. This indicates that the CTC doesn't measure the true transverse momentum but something proportional to it. Black dots are from MonteCarlo simulation in the full phase space.

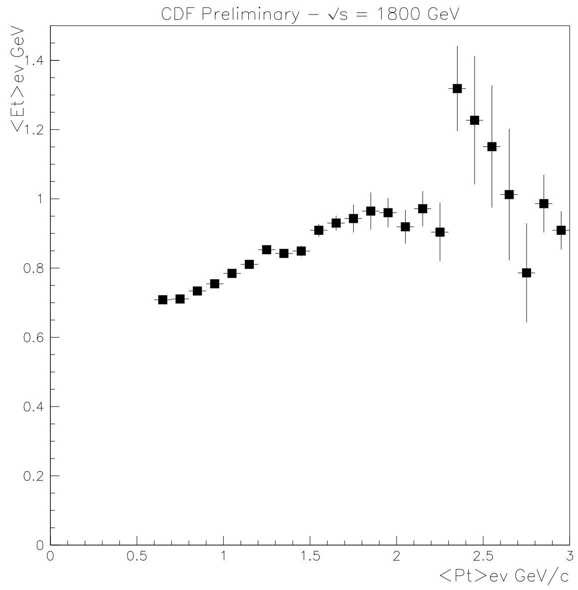

Figure 8: Plot of average transverse energy as measured with the calorimeter (central plus plug) and VTPC versus average transverse momentum as measured by the CTC. There is a direct proportionality between these two variables in the range of interest.

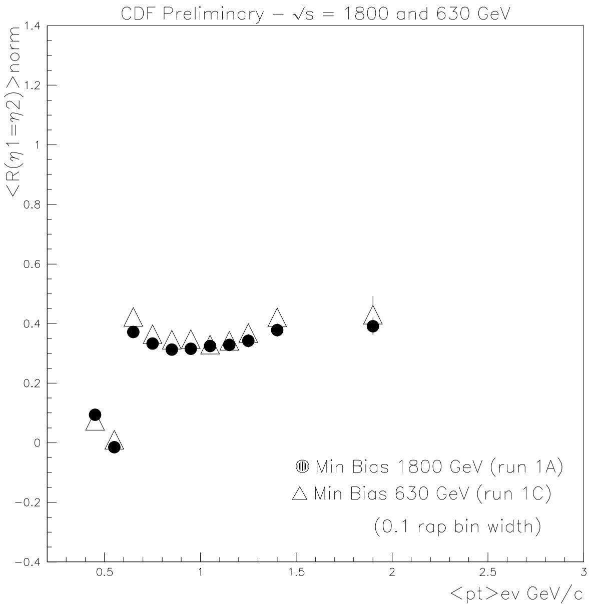

Figure 9: Comparison of short range correlation at 1800 and 630 GeV in the center of mass for minimum bias events. Once again the behaviour of the correlation as function of the average event pt is quite similar at the two different energies.

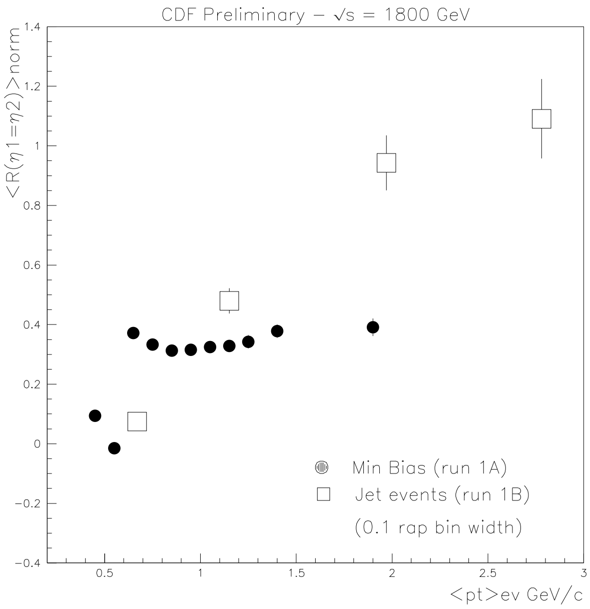

Figure 10: Behaviour of the short range correlation at 1800 GeV in the center of mass for minimum bias and JET trigger events.

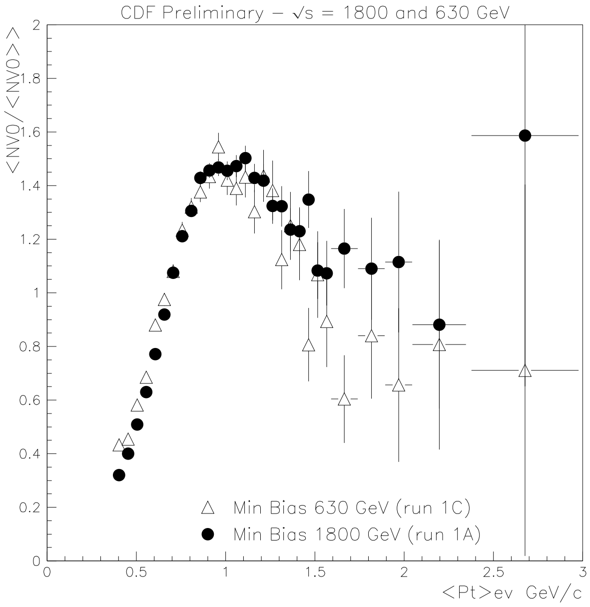

Figure 11: **Strange particle production in minimum bias. The average number of V0 events is plotted as function of the average event pt for two different energies.**

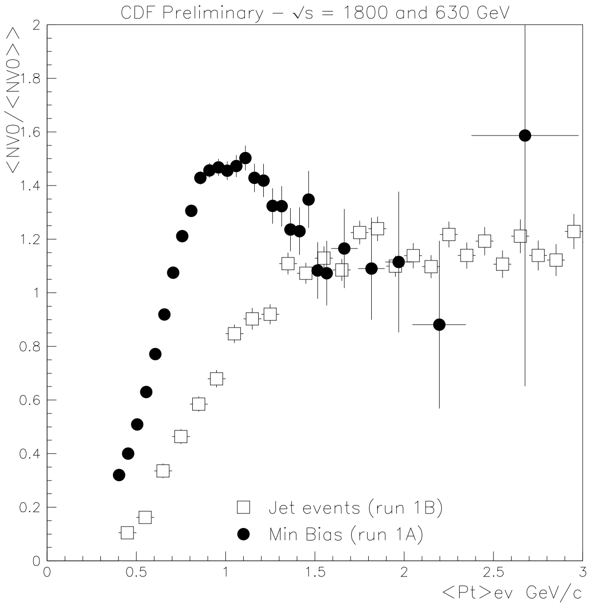

Figure 12: **Comparison of average number of V0 events produced at 1800 GeV in minimum bias events and in JET trigger events as function of the average event pt.**

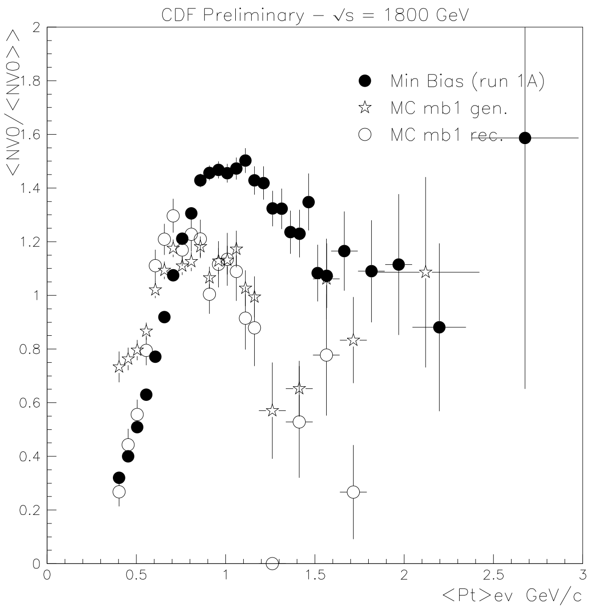

Figure 13: **Strange particles production in minimum bias events. Data at 1800 GeV are to be compared with Monte Carlo simulated and fully reconstructed data.**