Transverse Momentum Spectra of Charged Particles
in $p\bar{p}$ Collisions at $\sqrt{s} = 630$ GeV

G.Bocquet, A.Norton, H.Q.Wang¹
CERN, CH-1211 Geneva 23, Switzerland

V.Karimäki, R.Kinnunen, M.Pimiä, J.Tuominiemi
*Research Institute for High Energy Physics and Department of Physics,
University of Helsinki, Siltavuorenpenger 20C, FIN-00170 Helsinki, Finland*

C.Albajar
Universidad Autonoma C-XI, Cantoblanco, 28049 Madrid, Spain

J.P.Revol², P.Sphicas, K.Sumorok, C.H.Tan, S.Tether
MIT, Cambridge, MA 02139, USA

B.Buschbeck, H.Dibon, P.Lipa, M.Markytan, N.Neumeister
*Institut für Hochenergiephysik, Österreichische Akademie der Wissenschaften,
Nikolsdorfergasse 18, A-1050 Vienna, Austria*

Abstract

We have analysed a sample of 2.36 million minimum bias events produced in $p\bar{p}$ collisions at $\sqrt{s} = 630$ GeV in the UA1 experiment at the CERN collider. We have studied production of charged particles with transverse momenta (p_T) up to 25 GeV/c. The results are in agreement with QCD predictions. The rise of $\langle p_T \rangle$ with charged particle multiplicity may be related to changing production of low p_T particles.

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¹Visitor from Wuhan, China

²Now at CERN, Geneva, Switzerland

1. Introduction

In this paper results are given from analysis of UA1 minimum bias data. From a single collider run at $\sqrt{s}=630$ GeV in 1987 (integrated luminosity = $65\mu b^{-1}$) a high statistics sample of 2.36 Million minimum bias events was recorded.

The analysis extends the maximum coverage of the p_T distribution of charged hadrons from 10 GeV/c^[1] to 25 GeV/c. The p_T distribution is compared with QCD and the dependence on charge, rapidity and particle multiplicity is investigated.

2. Data Sample

All the data discussed in this paper were recorded with a trigger^[2] requiring one or more particles in either forward arm. The trigger acceptance exceeds $(96\pm 2)\%$ of the full non-single diffractive inelastic cross-section. The detector element relevant for this analysis is the Central Detector, CD^[3]. It consists of drift chambers which measure the momenta of charged particles in a magnetic field in the pseudorapidity interval $|\eta| < 3.0$. The field of the dipole magnet, usually set at 0.7T was lowered to 0.21T for a small set of data in order to study systematic effects in the response of the CD. The other detector elements are described elsewhere^[4].

Background events from beam-gas were easily eliminated offline by additional trigger timing cuts and by requirement of a good collision vertex. The average luminosity during the run was about $10^{27} cm^{-2} s^{-1}$ and the contribution from double interactions in the same trigger interval is therefore negligible.

After background contamination cuts, reconstruction in the CD resulted in a sample of 2.36×10^6 events with at least two charged tracks, including about 2% of residual beam-gas events with no reconstructed primary vertex. An additional 2% of events contain more than one vertex identified as primary by our software algorithm; further study has shown that these arise mainly from confusion between a genuine primary vertex and a nearby secondary vertex. The present analysis is confined to the remaining sample of 2.29×10^6 events with a single reconstructed primary vertex, but we have checked that the spectra presented here are not significantly modified if the tracks from multi-vertex events are included.

3. Inclusive Charged Hadrons

In order to minimize biases with this high statistics data sample, a recalibration of the CD (geometrical and drift parameters) was carried out with a new technique using data with two opposite magnetic field settings (± 0.7 T). In parallel the measurement of the coordinate along the wires by current division was recalibrated using the data.

Figure 1: Inclusive p_T distribution of charged particles and fitted function

For the p_T spectra, primary tracks were selected with good fit chisquares in both projections, > 30 hits and a ratio of seen/expected hits $> 40\%$. These cuts minimise contamination from fake tracks and ensure a sufficiently good momentum resolution ($dp/p \approx 20\%$ at $p_T = 25$ GeV/c). Corresponding tables of acceptance weights in (p, θ, ϕ) were generated by a single track Monte Carlo, incorporating frequency distributions for gaps (missing hits or groups of hits) from a model fitted to the data. Tracks in local regions with acceptance below 20% were excluded and a global correction applied. The analysis has been repeated with different acceptance and quality cuts to check the stability of the results.

Fig. 1 shows the acceptance-corrected p_T distribution for charged particles in the interval $|\eta| < 3$ at $\sqrt{s} = 630$ GeV, compared to previous UA1 measurements at $\sqrt{s} = 540$ GeV^[1].

4. Functional Form of the p_T Distribution

In previous analyses, a functional form inspired by QCD and first introduced by UA1^[1] has been used to fit the p_T spectrum:

$$E \frac{d^3\sigma}{dp^3} = \frac{A p_T^{0n}}{(p_T + p_T^0)^n}.$$

As stressed by Hagedorn^[5], p_T^0 and n are highly correlated when fitted over a limited range of p_T . In this analysis it is possible to reduce the correlation by fitting over the full measured range of p_T from 0.18 to 25 GeV/c, giving the result $n = 8.91 \pm 0.13$ and $p_T^0 = 1.32 \pm 0.05$. This fit was tuned to give a chisquare per degree of freedom (χ^2/NDF) = 1 by folding an extra uncertainty of 4.3% in addition to the statistical error. This gives a realistic relative weighting for all p_T bins, and the same uncertainty has been included in all subsequent fits. The reference fit is shown in Fig.1 and the consistency in different p_T regions is illustrated in Table 1, fixing respectively p_T^0 and n at their nominal values from the reference fit.

Table 1: Parameters of fits to p_T distribution in different p_T regions

	p_T^0 fixed (=1.32)			n fixed (=8.9)		
	A	n	χ^2/NDF	A	p_T^0	χ^2/NDF
$p_T > 0.18$	3.65 ± 0.02	8.90 ± 0.04	1.00	3.65 ± 0.02	1.32 ± 0.02	1.00
$p_T > 2.00$	3.64 ± 0.06	8.89 ± 0.08	0.98	3.64 ± 0.04	1.31 ± 0.05	0.94
$p_T > 3.00$	3.57 ± 0.09	8.81 ± 0.12	1.12	3.67 ± 0.06	1.36 ± 0.09	1.11
$p_T > 5.10$	3.30 ± 0.23	8.52 ± 0.25	1.46	3.81 ± 0.13	1.67 ± 0.27	1.54

5. Systematic Check of the p_T Spectrum

All p_T spectra have been corrected for acceptance and also for smearing due to finite resolution of the transverse momentum measurement. As a cross-check the p_T spectrum was measured using a small sample (80k) of events with the lower magnetic field of 0.21 T. The smearing correction is significant above $p_T \approx 10$ GeV/c where the corrected distribution for a field of 0.21T (0.7T) is below the uncorrected one by a factor $\approx 6(1.5)$; at $p_T = 15$ GeV/c the corresponding factors are $\approx 7.5(2.5)$. At low field the smearing correction is much larger but the corrected distribution is in reasonable agreement with the higher field results (Table 2).

As a further check of systematic effects the p_T spectrum has been fitted separately for opposite magnetic fields (roughly equal samples $\approx 0.8 \times 10^6$ events each) for which the drift angle also changes sign (about ± 25 degrees) (Table 2).

Table 2: Parameters of fits to p_T for different field and charge

	B[T]	p_T^0 [GeV/c]	n	χ^2/NDF
before smearing	0.21	1.32 (fixed)	8.81 ± 0.1	4.4
after smearing	0.21	1.32 (fixed)	9.14 ± 0.1	2.1
	+0.7	1.31 ± 0.015	8.9 (fixed)	1.03
	-0.7	1.32 ± 0.015	8.9 (fixed)	1.08
Q -ve	± 0.7	1.320 ± 0.015	8.9 (fixed)	0.98
Q +ve	± 0.7	1.317 ± 0.015	8.9 (fixed)	0.96

6. Dependence of p_T Spectrum on Charge and Pseudo-Rapidity

In Fig. 2, the invariant cross section is shown separately as a function of p_T for positive and negative particles. There is no evidence for different behaviour, and the fitted p_T^0 for $n = 8.9$ (fixed) is given in Table 2.

Figure 2: p_T spectra for positive and negative particles and fitted functions

Fig. 3 shows the p_T spectrum in five different bands of pseudo-rapidity, with fitted curves for $n = 8.9$ (fixed). There is no clear dependence on pseudo-rapidity (Table 3).

Table 3: Parameters of fits to p_T as a function of η

$ \eta $	A	p_T^0	χ^2/NDF
$0.0 \rightarrow 0.6$	3.28 ± 0.03	1.28 ± 0.02	1.2
$0.6 \rightarrow 1.2$	3.18 ± 0.02	1.27 ± 0.01	0.7
$1.2 \rightarrow 1.8$	3.25 ± 0.03	1.30 ± 0.02	1.0
$1.8 \rightarrow 2.4$	3.38 ± 0.02	1.37 ± 0.01	0.7
$2.4 \rightarrow 3.0$	2.98 ± 0.08	1.20 ± 0.07	1.3

Figure 3: p_T spectra in different pseudo-rapidity bands and fitted functions

7. Comparison with QCD

Borzumati et al^[6] have found good agreement of earlier UA2 and CDF data with a next to leading order QCD calculation for π/K production, using hadronization from experimental data. They have recently extended their calculation^[7] to higher p_T and a comparison with the present data is given in Fig. 4. The three curves correspond to different choices of the renormalisation scale. There is good agreement for $p_T > 3$ GeV/c, where the QCD calculation is more reliable, for a renormalisation scale of $p_T/2$.

Figure 4: p_T spectrum compared with QCD

8. Dependence of Mean p_T on Charged Multiplicity

As pointed out by Hagedorn^[5], the definition of $\langle p_T \rangle$ in a steeply falling spectrum with experimental losses at low p_T is somewhat arbitrary, and care is needed in comparing different experimental results. In this analysis $\langle p_T \rangle$ has been computed analytically from the functional form, assuming extrapolation to $p_T = 0$, as

$$\langle p_T \rangle = \frac{2p_T^0}{n-3}.$$

Even then the scale of $\langle p_T \rangle$ depends on the fitting technique and two extremes have been tried, with n fixed and with p_T^0 fixed.

In Fig. 5 the dependence of $\langle p_T \rangle$ on the charged track multiplicity per unit of pseudo-rapidity is shown for both cases. The $\langle p_T \rangle$ increases with multiplicity, with no evidence of saturation over the measured range. There is a systematic error of about $\pm 12\%$ on the multiplicity scale, estimated by recomputing the multiplicity for different acceptance cuts. The corrected systematic error bars for three different regions are indicated in Fig. 5.

Figure 5: Dependence of mean p_T on charged track multiplicity

The curves fitted to the p_T spectra for different multiplicity regions tend to be parallel at higher p_T , as illustrated in Table 4 for $p_T > 2.2$ GeV/c where p_T^0 is constant within errors for fixed $n = 8.9$; below 2.2 GeV/c there is a significant increase of p_T^0 with multiplicity, and the fit chisquares are poorer. This suggests that the rise of $\langle p_T \rangle$ with multiplicity occurs because there are relatively fewer particles at low p_T in the high multiplicity events. The effect may then be associated with changing production of lower p_T particles, best represented by variation of p_T^0 , accompanied by a constant higher p_T component.

Table 4: Parameters of fits to p_T as a function of n_{ch}

$n_{ch}/(\Delta\eta = 1)$	$p_T^0(0.2 \leq p_T < 2.2)$	χ^2/NDF	$p_T^0(2.2 \leq p_T)$	χ^2/NDF
0.00 $\rightarrow$ 2.12	1.18 ± 0.04	2.70	1.25 ± 0.10	1.06
4.27 $\rightarrow$ 6.40	1.31 ± 0.05	4.68	1.27 ± 0.11	1.54
11.73 $\rightarrow$ 13.87	1.51 ± 0.06	3.70	1.32 ± 0.19	0.99
14.93 $\rightarrow$ 21.33	1.52 ± 0.07	1.46	1.41 ± 0.33	1.15

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