TRANSVERSE MOMENTUM SPECTRA FOR CHARGED PARTICLES
AT THE CERN PROTON ANTIPROTON COLLIDER

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Submitted for publication in Physics Letters

(PAPER I)

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Abstract

We have measured transverse momentum spectra up to 10 GeV/c for charged particles produced centrally in proton-antiproton collisions at 540 GeV in the centre of mass at the CERN collider. Our results are compared with data at ISR energies and with the predictions of a QCD model. The charged particle spectrum shows a clear dependence on charged track multiplicity.

I. Introduction

The UAl detector has been presented several times¹⁾²⁾ and will be described in detail elsewhere. In this paper we present transverse momentum spectra for charged particles produced in $\bar{p}p$ collisions at $\sqrt{s} = 540$ GeV. The data have been obtained by track curvature measurement in the central detector, using magnetic field settings of 0.56 and 0.28 Tesla. No particle identification has been attempted.

II. Trigger and luminosity

We have analysed about 48000 events at 0.56 Tesla and about 39000 events at 0.28 Tesla. The events were taken with a low bias trigger defined by two hodoscopes subtending angular regions from 12 to 56 mrad with respect to each beam arm. The final spectra are based on the 0.56 Tesla data, for which the corresponding integrated luminosity, provided by the collider operation team from beam profile and bunch intensity measurements, is $(1 \pm 0.25) \times 10^{30}$ cm⁻² after correction for our dead-time.

The 0.28 Tesla data have been used to check the validity of our momentum reconstruction and acceptance correction procedures.

III. Charged particle reconstruction

Charged particles are detected by the "central detector" which is a cylinder of 5.8 m length and 2.3 m diameter containing 6 modules of drift chambers equipped with image readout. Particle trajectories are measured in space every centimetre. All wires are parallel to the uniform magnetic field so that coordinates in the curvature plane are given by drift time and wire position while the third coordinate is given by current division.

At the time of data taking, our detector was only partially equipped with electronics. Nevertheless the track finding efficiency of our reconstruction programs is high and has been estimated by physicist scanning as 92 (± 2)% in the full detector and 97 (± 1)% in the three quadrants with the best

acceptance. Association with the primary vertex is uncertain for $\sim 6\%$ of the tracks.

Acceptance losses have been estimated by assuming flat physical distributions in azimuthal angle around the beams and in rapidity. Regions with less than 50% acceptance have been excluded from the p_t spectra and have been compensated by an overall geometric scale factor. Otherwise each track has been weighted by an acceptance factor which depends on its charge, transverse momentum, rapidity and azimuthal angle.

The absolute and relative positions of the detector wire planes have been determined by detailed survey measurements during construction and after installation, giving an accuracy throughout the detector volume of better than ± 0.3 mm in the electron drift direction. Drift velocity, drift angle and angular correction parameters have been determined by auto-calibration procedures^{1f)} applied to clean track samples. First order corrections have been made for time-slewing effects and for the dependence of current division measurements on pulse height. The r.m.s. dispersion of the circle fits in the curvature plane is $\sim 280\mu\text{m}$ and the current division coordinate has an r.m.s. accuracy of $\sim 2.3\%$ of the wire length.

We have considered several sources of contamination of the p_t spectrum, especially at high p_t where resolution is limited and the cross-section is low :

a) The steeply falling spectrum is flattened by random measurement errors ($\Delta p_t/p_t^2 \approx 0.02$) and systematic effects (a study of zero-field tracks shows a mean unbiased distortion of the sagitta $\sim 200\mu\text{m}$).

We have applied a correction assuming a gaussian resolution function of $1/p_t$. For the 0.56 Tesla data the cross-section is typically reduced by about 10% at $p_t=5$ GeV/c and about 40% at $p_t=10$ GeV/c. After correction the p_t spectra obtained at 0.28 and 0.56 Tesla agree within 15% up to 5 GeV/c.

b) Particle decays may give rise to contamination at high p_t by artificially increasing apparent track momenta. This effect is limited by strict track quality cuts and has been shown by Monte Carlo studies to be negligible at 5 GeV/c and less than 30% at 10 GeV/c.

c) Overlap of tracks and bad reconstruction may also generate a high P_t tail. All tracks above $p_t = 5$ GeV/c have been systematically studied on a

Megatek display giving an estimate of $17(\pm 7)\%$ for the proportion of doubtful tracks accepted by our cuts. A sample of tracks with $3 < p_t < 5$ GeV/c was similarly studied and produced $< 3\%$ of doubtful tracks.

IV. Inclusive p_t spectrum

Figure 1 shows the invariant cross-section for unidentified charged particles as a function of p_t between 0.3 GeV/c and 10 GeV/c in the rapidity interval $|y| < 2.5$. A total inelastic cross-section of 40 mb has been assumed.

Figure 2 shows the same data with a fitted curve of the following empirical form :

$$E \frac{d^3\sigma}{d^3p} = A p_{t0}^n / (p_t + p_{t0})^n$$

This parametrisation describes the data well over the entire range of p_t . Table I gives the values of A , p_{t0} and n together with the average transverse momentum, assuming validity of the parametrisation below $p_t = 0.3$ GeV/c. It is also shown that the power n , for fixed p_{t0} , does not depend very much on the chosen p_t region.

A comparison of our data with ISR results³⁾ at $\sqrt{s} = 53$ and 63 GeV (fig. 1) shows that our spectrum is considerably flatter, even at rather low values of p_t . At $p_t = 10$ GeV/c the cross-section has increased by about three orders of magnitude. Table I gives the parameters of our fit for ISR data. From $\sqrt{s} = 63$ GeV to $\sqrt{s} = 540$ GeV the average p_t has increased from 357 to 424 MeV/c.

In fig. 1, the inclusive p_t spectra at collider and ISR energies are compared with the predictions of a recent QCD model⁴⁾. In addition to standard QCD hard scattering and parton fragmentation processes⁵⁾, this model includes radiation (mostly gluons) off the initial and final state partons⁶⁾. It is shown in reference 4 that the initial state gluon bremsstrahlung gives an important contribution at collider energies. Figure 1 shows that we obtain an excellent description of our data and of the difference with respect to ISR energies. The results of fitting our empirical parametrisation to a QCD prediction up to $p_t = 40$ GeV/c at $\sqrt{s}=540$ GeV are shown in table I.

V. Multiplicity dependence of the p_t spectrum

In figure 3, the p_t spectrum is shown separately up to 6 GeV/c for three bands of charged particle multiplicity in the rapidity range $|y| < 2.5$, expressed as the number of particles per unit of rapidity ($N/\Delta y$), and corrected for geometrical acceptance as previously described. The three spectra are normalised to the full inclusive cross-section at $p_t=0$ GeV/c.

Systematic checks have revealed no significant multiplicity-dependent biases in acceptance, p_t errors or track finding efficiency. We therefore conclude that the p_t spectrum becomes flatter as the multiplicity increases, and that this trend occurs even at low values of p_t . This is confirmed in more detail, for multiplicities up to $N/\Delta y \sim 12$, in table II, which gives fitted values of A and n, for fixed p_{t0} , as a function of multiplicity, and also by figure 4 which shows the variation of mean p_t with multiplicity. At very high multiplicities ($N/\Delta y > 12$) the mean p_t no longer increases; this could possibly be a kinematic effect due to saturation of the available centre-of-mass energy. At low multiplicities ($N/\Delta y \sim 2$) our mean p_t measurements are in good agreement with data at ISR and FNAL energies^{3a,8,9)}.

The increase of $\langle p_t \rangle$ as a function of multiplicity has been suggested by cosmic ray measurements of Lattes et al⁷⁾. At even higher energies they have found that the p_t spectrum flattens dramatically with increasing event complexity.

VI. Summary

We have measured the inclusive charged particle p_t spectrum up to 10 GeV/c and have fitted this spectrum over the full p_t range with a simple empirical form. A QCD model gives a good description of our data and of the rise in cross-section from ISR energies. The p_t spectrum flattens with increasing charged multiplicity but the mean p_t is compatible with ISR values for the same number of particles per rapidity unit.

Acknowledgements

We should like to thank the members of the CERN Accelerator Divisions for their work in commissioning the SPS Collider and providing the collisions which have yielded this physics. We are extremely grateful to the CERN management and staff who have supported the UA1 experiment so generously, and extend these warm thanks to the following external sources of financial support :

Fonds zur Forderung der Wissenschaftlichen Forschung, Austria.

Valtion luonnontieteellinen toimikunta, Finland.

Institut National de Physique Nucléaire et de Physique des Particules and
Institut de Recherche Fundamentale (CEA), France.

Bundesministerium für Forschung und Technologie, Germany.

Istituto Nazionale di Fisica Nucleare, Italy.

Science and Engineering Research Council, United Kingdom.

Department of Energy, USA.

A great deal of understanding was demanded of all these bodies in order that we could realise the UA1 detector on the timescale required. Our technical and engineering colleagues in the collaborating institutes provided the untiring support needed to build UA1 ; without their efforts we would have nothing to report, and we deeply acknowledge their work. Thanks are also due to the following people who have worked with the collaboration in the preparation and data collection on the runs described here, D. Cline, G. Petrucci, P. Queru, M. Steuer, H. Verweij and R. Wilson.

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Table Captions

Table 1. Fit parameters of $E d^3 \sigma / d^3 p = A p_{t0}^n / (p_t + p_{t0})^n$:

- a) for UA1 data at $\sqrt{s} = 540$ GeV
- b) for ISR data at $\sqrt{s} = 63$ GeV
- c) for QCD prediction at $\sqrt{s} = 540$ GeV

Quoted errors are purely statistical. Projected (marginal) errors are given for p_{t0} and n since they are highly correlated.

Table 2. Fit parameters of $E d^3 \sigma / d^3 p = A p_{t0} / (p_t + p_{t0})^n$ at $\sqrt{s}=540$ GeV for different bands of charged track multiplicity. The fits were made for the region $0 < p_t < 6$ GeV/c, with p_{t0} fixed at 1.30

TABLE I

Data	P_t interval used GeV/c	A $10^{-2} \frac{cm}{GeV^2 c}$	P_{t0}	n	$\langle p_t \rangle$ GeV/c	χ^2	Degrees of Freedom
This work	0.3 - 10	$0.47 \pm .01$	$1.30 \pm .20$	$9.14 \pm .90$	$.424 \pm .001$	51	52
	0.3 - 2	$0.46 \pm .01$	1.30 fixed	$9.14 \pm .02$	$.424 \pm .001$	29	32
	2 - 10	$0.37 \pm .06$	1.30 fixed	$8.99 \pm .15$	$.435 \pm .012$	20	19
Alper et al ($\sqrt{s}=63$ GeV)	0.1 - 2.0	$0.28 \pm .01$	1.30 fixed	$10.7 \pm .03$	$.340 \pm .002$	59	18
		$0.22 \pm .01$	1.83 ± 1.24	13.3 ± 6	$.356 \pm .002$	11	17
QCD calculation	2 - 40		1.30 fixed	8.33			
			0.80	8.02			

TABLE II

$n/\Delta y$	$\langle n/\Delta y \rangle$	A $10^{-2} \text{ cm}^{-2} \text{ GeV}^{-2} \text{ c}^{-2}$	n	$\langle p_t \rangle$ GeV/c	χ^2	Degrees of freedom
0.6 - 1	0.8	$.009 \pm .001$	$11.02 \pm .20$	.325	44	32
1 - 2	1.5	$.042 \pm .001$	$10.41 \pm .08$	.352	61	42
2 - 3	2.5	$.063 \pm .001$	$10.17 \pm .05$	.363	77	44
4 - 5	4.9	$.066 \pm .001$	$9.45 \pm .05$	.404	49	45
7 - 8	7.5	$.040 \pm .001$	$8.87 \pm .05$	.444	45	45
9 - 10	9.5	$.024 \pm .001$	$8.64 \pm .06$	.462	42	44
12 - 14	12.8	$.011 \pm .0004$	$8.48 \pm .08$	.476	38	45
14 - 16	14.9	$.004 \pm .0002$	$8.67 \pm .14$	.459	54	43
> 16	18.2	$.003 \pm .0002$	$8.55 \pm .17$	.469	44	41

Figure Captions

Fig. 1. The invariant cross-sections as a function of transverse momentum for :

- a) UA1 data at $\sqrt{s}=540$ GeV for charged hadrons in the rapidity interval $|y| < 2.5$
- b) ISR data at $\sqrt{s}=63$ GeV for π^0 at 90° and charged hadrons at 90° and 50° .
- c) QCD predictions at $\sqrt{s}=540$ GeV and $\sqrt{s}=63$ GeV for π^0 at 90° .

Fig. 2. The invariant cross-sections as a function of transverse momentum for hadrons ($\sqrt{s}=540$ GeV) compared to a fitted curve of the form

$$E d^3 \sigma / d^3 p = A p_{t0}^n / (p_t + p_{t0})^n.$$

Fig. 3. The invariant cross-sections as a function of transverse momentum for charged hadrons ($\sqrt{s} = 540$ GeV) for three bands of charged track multiplicity in the interval $|y| < 2.5$ (normalised to the full cross-section at $p_t = 0$ GeV/c).

Fig. 4. The mean transverse momentum of charged hadrons ($\sqrt{s}=540$ GeV) as a function of charged track multiplicity in the rapidity interval $|y| < 2.5$ [Error bars are purely statistical. Systematic effects from acceptance and fitting procedures could alter the $\langle p_t \rangle$ scale by up to 10 MeV/c. Points without error bars give the global average of p_t as a function of the mean number of charged particles per unit of rapidity at FNAL ISR and collider energies].

Fig. 1

Fig. 3

Fig. 4