EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN/EP 86-123
10 September 1986

MULTIPLICITY DEPENDENCE OF TRANSVERSE MOMENTUM SPECTRA IN pp, $\bar{p}$p, dd AND $\alpha\alpha$ COLLISIONS AT ISR ENERGIES

A. Breakstone[1(*)], R. Campanini[3], G. Claesson[7], H.B. Crawley[1],
M. Cuffiani[3], G.M. Dallavalle[4], M.M. Deninno[3], K. Doroba[8], D. Drijard[4],
F. Fabbri[3], A. Firestone[1], M.A. Faessler[4], H.G. Fischer[4], H. Floege[6],
S.Y. Fung[4(**)], H. Frehse[4(***)], S. Garpman[7], W. Geist[2], L. Gesswein[6],
G. Giacomelli[3], R. Gokieli[8], M. Gorbics[1], M. Gorski[4], C. R. Gruhn[2],
P. Hanke[6], M. Heiden[2], W. Herr[4], D. Isenhower[1], T. J. Ketel[4],
E. E. Kluge[6], J. W. Lamsa[1], T. Lohse[4], I. Lund[7], R. Mankel[5], W. T. Meyer[1],
T. Nakada[6(+)], I. Otterlund[7], M. Panter[4(++)], H. Pugh[2], A. Putzer[6],
K. Rauschnabel[5], B. Rensch[6], F. Rimondi[3], M. Schmelling[5], L. Schroeder[2],
G.P. Siroli[3(+++)], R. Sosnowski[8], E. Stenlund[7], T.J.M. Symons[2],
M. Szczekowski[8], R. Szwed[8], O. Ullaland[4], R. Walczak[8], D. Wegener[5],
and M. Wunsch[6]

1 Ames Laboratory, Ames, Iowa, USA
2 Nucl. Science Div., Lawrence Berkeley Lab., Berkeley, CA, USA
3 Dip. di Fisica dell'Università and INFN, Bologna, Italy
4 CERN, European Organization for Nuclear Research, Geneva, Switzerland
5 Inst. für Physik der Universität, Dortmund, Germany
6 Inst. für Hochenergiephysik der Universität, Heidelberg, Germany
7 Division of Cosmic and Subatomic Physics, Univ. of Lund, Sweden
8 Univ. and Inst. for Nuclear Research, Warsaw, Poland

Submitted to Physics Letters B

(*) Department of Physics, University of Hawaii, USA
(**) Univ. of California, Riverside, USA
(***) CDC, Zürich, Switzerland
(+) SIN, Villigen, Switzerland
(++) Univ. of Karlsruhe, Germany
(+++) Univ. of Maryland, College Park, Maryland, USA

3218P/GMD/ed

ABSTRACT

We analyze the variation of the average transverse momentum, $<p_T>$, with the multiplicity of charged particles produced in pp, $\bar{p}p$, dd and $\alpha\alpha$ collisions at ISR energies. An increase of $<p_T>$ with increasing particle density $\rho = \Delta n/\Delta y$ for charged particles produced in the central region is observed. The energy dependence of this effect and its dependence on the type of colliding particles are discussed.

1. INTRODUCTION

The experimental results obtained in the last decade at the CERN ISR and at lower energies showed that the transverse momenta, p_T, of particles produced in hadron-hadron collisions are concentrated at low values, and that, at low p_T, the p_T distributions depend only weakly on energy and on the type of incident particles. Recent experiments at the CERN proton-antiproton collider at a centre of mass energy $\sqrt{s}$ = 540 GeV [1] and at the highest ISR energy, $\sqrt{s}$ = 62 GeV [2] have shown that there is an increase of the mean transverse momentum $<p_T>$ with the number of charged particles produced per unit rapidity, $\rho = \Delta n/\Delta y$, in the central region of rapidity and that the increase becomes larger as $\sqrt{s}$ increases. A number of possible explanations for this observation have been proposed [3-5] in the context of geometrical models, of thermodynamical models, of mini-jets (semi hard scattering), etc. In thermodynamical models the average p_T is a measure of the temperature, while the central particle density is a measure of the entropy density. The study of $<p_T>$ versus ρ may yield information on possible phase transitions. In geometrical models high multiplicity events occur preferentially at small impact parameters and correspond to higher temperatures and thus have larger average transverse momentum. Due to lack of phase space, the increase of $<p_T>$ should slow down at a certain value of ρ, dependent on energy. The high p_T region is essentially thought to arise from constituent scattering, which should yield particles in a characteristic jet structure and higher multiplicities. Thus at higher p_T we should have higher multiplicities. As the energy increases the proportion of hard scattered events increases and hence the slope of the dependence of $<p_T>$ on ρ should increase. The full comprehension of the phenomenon requires precise data at different energies, comparison of different types of collisions as well as analyses of related phenomena.

In this paper we present the results of an analysis of charged particle production in proton-proton, antiproton-proton, deuteron-deuteron and alpha-alpha interactions at nucleon-nucleon centre of mass energies of $\sqrt{s_{NN}}$ = 62 and 31 GeV. Preliminary results on this subject were already presented [6].

2. EXPERIMENTAL

The experiment was performed at the CERN Intersecting Storage Rings (ISR) using the Split Field Magnet (SFM) detector. The magnetic volume of the detector (with a maximum field strength of 1 Tesla) was filled with Multiwire Proportional Chambers. The momenta of charged particles were measured in nearly the full solid angle. The performance of the detector is described in previous publications [7]. Table 1 gives the details of the available data. Note that the statistics for pp data are about an order of magnitude larger than for the other data.

This experiment used a "minimum bias" trigger, which essentially required the presence of at least one candidate charged track in the detector. This trigger accepted ~ 95% of the inelastic cross section. The events were reconstructed with the standard SFM chain of computer programs (an older version was used for the $p\bar{p}$ and some pp data). A good vertex fit, defined by a minimum of two charged tracks, was required for each event. This reduced the acceptance to about 90% of the inelastic cross section.

A number of selection criteria were applied to the data:

(a) The interaction vertex was required to be in the overlap region of the two colliding beams. This condition is particularly important for $\bar{p}p$ interactions, where backgrounds from beam-gas and beam-wall interactions were high. Only 15,000 $\bar{p}p$ interactions were obtained with the minimum bias trigger discussed above; these events came from about one million triggers; the other 68,000 interactions were obtained with a quasi-minimum bias trigger, which required at least one forward and one backward track. It was checked that the two triggers gave the same results after the requirement of a good vertex fit.

(b) Tracks were accepted if the relative precision in the measurement of their momenta was $\Delta p/p < 0.8$.

(c) In order to reduce further some background from mismeasured tracks, only particles with $p_T < 2.5$ GeV/c were used.

Furthermore, events with less than four tracks are not considered for this analysis, in order to reduce the contribution of diffractive processes.

3. ANALYSIS

Fig. 1 shows the uncorrected transverse momentum distributions for events with low (4-6) and high (> 12) multiplicities of charged particles produced in the central rapidity region ($|y| < 1.5$) for $\alpha\alpha$ and dd interactions at a centre of mass energy $\sqrt{s}_{NN} = 31$ GeV. The data follow an approximate exponential behaviour for $0.2 < p_T < 0.8$ GeV/c, while at larger values of p_T the distributions flatten out; there are substantial losses for $p_T < 0.15$ GeV/c [8]. It is apparent that the curves at lower multiplicities are steeper than the ones at higher multiplicities. Moreover, the largest differences involve medium and high p_T values.

The average transverse momentum, $<p_T>$, was evaluated for the Δn charged tracks remaining after the previously mentioned cuts ($p_T < 2.5$ GeV/c and $\Delta p/p < 0.8$), in the rapidity interval $-1.5 < y < 1.5$. Furthermore, we applied a low p_T cut ($p_T > 0.15$ GeV/c) in order to reduce the effects of acceptance losses. The quantity $<p_T>$ may be computed using two methods.

In the first method we perform a fit of the measured p_T distributions in the range $0.3 < p_T < 0.8$ GeV/c to an exponential form

$$\frac{dn}{dp_T^2} = A\, e^{-bp_T} \quad . \tag{1}$$

The average transverse momentum is then given by

$$<p_T> = 2/b \quad . \tag{2}$$

In the second method one computes algebraically the mean values of p_T. The value of $<p_T>$ corresponding to a given Δn (Δn is the number of central particles having $p_T < 2.5$ GeV/c and $\Delta p/p < 0.8$) is then calculated using only those particles that, among the Δn, have $p_T > 0.15$ GeV/c. This gives a lower statistical error, but yields values of $<p_T>$ slightly larger than (2) because of losses of tracks at small p_T (fig. 1). This second method is nevertheless useful for the analysis of the variations of $<p_T>$ versus particle density $\rho = \Delta n/\Delta y$ and for the comparison of the average transverse momenta for particles produced in different initial states. The two methods are not exactly equivalent, since the second takes into account contributions from the high p_T tail.

4. RESULTS

Fig. 2 shows the average transverse momenta of charged particles produced in the central region of rapidity ($|y| < 1.5$) versus the observed charged multiplicity density in the same central region. The average transverse momentum was computed algebraically in the range $0.15 < p_T < 2.5$ GeV/c. Therefore $<p_T>$ is overestimated and the absolute $<p_T>$ scale is affected by a systematic shift of about 20% for all multiplicities. In fact, we estimate that the average p_T should be:
(a) reduced by about 18% because of the cut at $p_T = 0.15$ GeV/c,
(b) increased by less than 1% because of the cut at 2.5 GeV/c and
(c) decreased by 2% because of some background in the interval $2 < p_T < 2.5$ GeV/c. We have also estimated that acceptance losses in the central region reduce the average multiplicity by about 30%.

All the data in fig. 2 exhibit an increase of the average transverse momentum with increasing charged particle density ρ. The increase is, within errors, equal for pp and $\bar{p}p$ (the slight difference between the absolute values is due to the different versions of the reconstruction program); the pp data at $\sqrt{s} = 31$ GeV have a smaller rate of increase than at 62 GeV; at 31 GeV the $\alpha\alpha$ data [9] have a larger increase than dd and pp. The increase could be non-linear for pp and $\bar{p}p$, for which the dependence seems to weaken for $\rho > 4$-5 [10].

The p_T distributions in fig. 1 indicate that the dependence of the average transverse momentum on charged multiplicity density should be enhanced if one uses data with $p_T > 0.3$ GeV/c. This is indeed so, as shown in fig. 3.

The average transverse momenta computed on the basis of exponential fits to the p_T distributions in the region $0.3 < p_T < 0.8$ GeV/c with $|y| < 2$ are shown in fig. 4 for pp and $\bar{p}p$ interactions at $\sqrt{s} = 62$ GeV.

The pp sample (240,000 events) was reconstructed with exactly the same version of the SFM chain of programs as that used for $\bar{p}p$. The data of fig. 4 show that $\bar{p}p$ and pp at $\sqrt{s}$ = 62 GeV are equal within errors. Notice also that the absolute value has a smaller systematic error compared to that shown in fig. 2.

In conclusion, we have observed an increase of the average transverse momentum with charged multiplicity density in the central rapidity region at ISR energies for pp, $\bar{p}p$, dd and $\alpha\alpha$ collisions. The increase is the same for pp and $\bar{p}p$ collisions. At $\sqrt{s}$ = 31 GeV the rate of increase for $\alpha\alpha$ collisions is larger than that for dd, which is comparable with that for pp. The amount of increase for pp collisions at ISR energies rises with c.m. energy. The magnitude of the effect at the ISR is considerably smaller than at the CERN $\bar{p}p$ collider, where there is still a sizeable energy dependence [11].

Acknowledgements

This experiment was greatly helped by contributions from the SFM Detector Group. We are indebted to the ISR Experimental Support Group. We would also like to thank N. Rivoire for her important help. The Dortmund and Heidelberg groups were supported by a grant from the Bundesministerium für Forschung und Technologie of the Federal Republic of Germany. The Ames group was supported by the United States Department of Energy under contract W-7405-eng-82. The Bologna group was supported in part by MPI (60%) grants of the Italian Ministry of Education. One of us (M.A.F.) thanks the Deutsche Forschungsgemeinschaft for a Heisenberg fellowship.

REFERENCES

[1] G. Arnison et al., Phys. Lett. 118B (1982) 167.

[2] A. Breakstone et al., Phys. Lett. 132B (1983) 463.

[3] L. Van Hove, Phys. Lett. 118B (1982) 138.

[4] S. Barshay, Phys. Lett. 127B (1983) 129.

[5] M. Jacob, CERN preprint, CERN/TH 3515 (1983).

[6] A. Breakstone et al., Multiplicity dependence of transverse momentum spectra at ISR energies, Int. EPS Conf., Bari (1985).

[7] M. Della Negra et al., Nucl. Phys. B127 (1977) 1;

W. Bell et al., Nucl. Instr. & Meth. 156 (1978) 111.

[8] R. Hagedorn, Rivista Nuovo Cimento 6 (1983) 1.

[9] W. Bell et al., Zeit. für Physik C27 (1985) 191.

[10] ABCDHW Collaboration, Multiplicity dependence of the average transverse momentum and of the particle size in pp interactions at $\sqrt{s}$ = 31, 44 and 62 GeV, XXIIIrd Int. Conf. on High Energy Phys., Berkeley CA, USA (1986).

[11] F. Ceradini, Proceedings of the Int. EPS Conf., Bari (1985).

TABLE 1

Details of the event samples used for the present analysis. The centre of mass energy, $\sqrt{s_{NN}}$, is the nucleon-nucleon c.m. energy. The last column gives the nominal magnetic field strength in the SFM detector.

Interaction	$\sqrt{s_{NN}}$ (GeV)	Number of events ($\times 10^3$)	Magnetic field (Tesla)
pp	62	816	1
$p\bar{p}$	62	83	1
pp	31	1400	0.5
$\alpha\alpha$	31	74	1
dd	31	117	1

FIGURE CAPTIONS

Fig. 1 Transverse momentum distributions for low (4-6) and high (> 12) multiplicities of charged particles produced in the central region of rapidity, $|y| < 1.5$, of αα and dd collisions at $\sqrt{s}_{NN} = 31$ GeV.

Fig. 2 The average transverse momentum of charged particles (with $0.15 < p_T < 2.5$ GeV/c) produced in the central region of rapidity ($|y| < 1.5$) plotted versus charged particle multiplicity density. The graph shows data for pp and $p\bar{p}$ interactions at $\sqrt{s} = 62$ GeV and for pp, dd and αα interactions at $\sqrt{s} = 31$ GeV per nucleon. The cuts applied to the data are described in the text.

Fig. 3 Data as in fig. 2, but using the p_T range $0.3 < p_T < 2.5$ GeV/c.

Fig. 4 The average transverse momentum for charged particles produced in the central region ($|y| < 2$) for pp and $\bar{p}p$ interactions at $\sqrt{s} = 62$ GeV computed using a parametrization of the form of eq. (1).

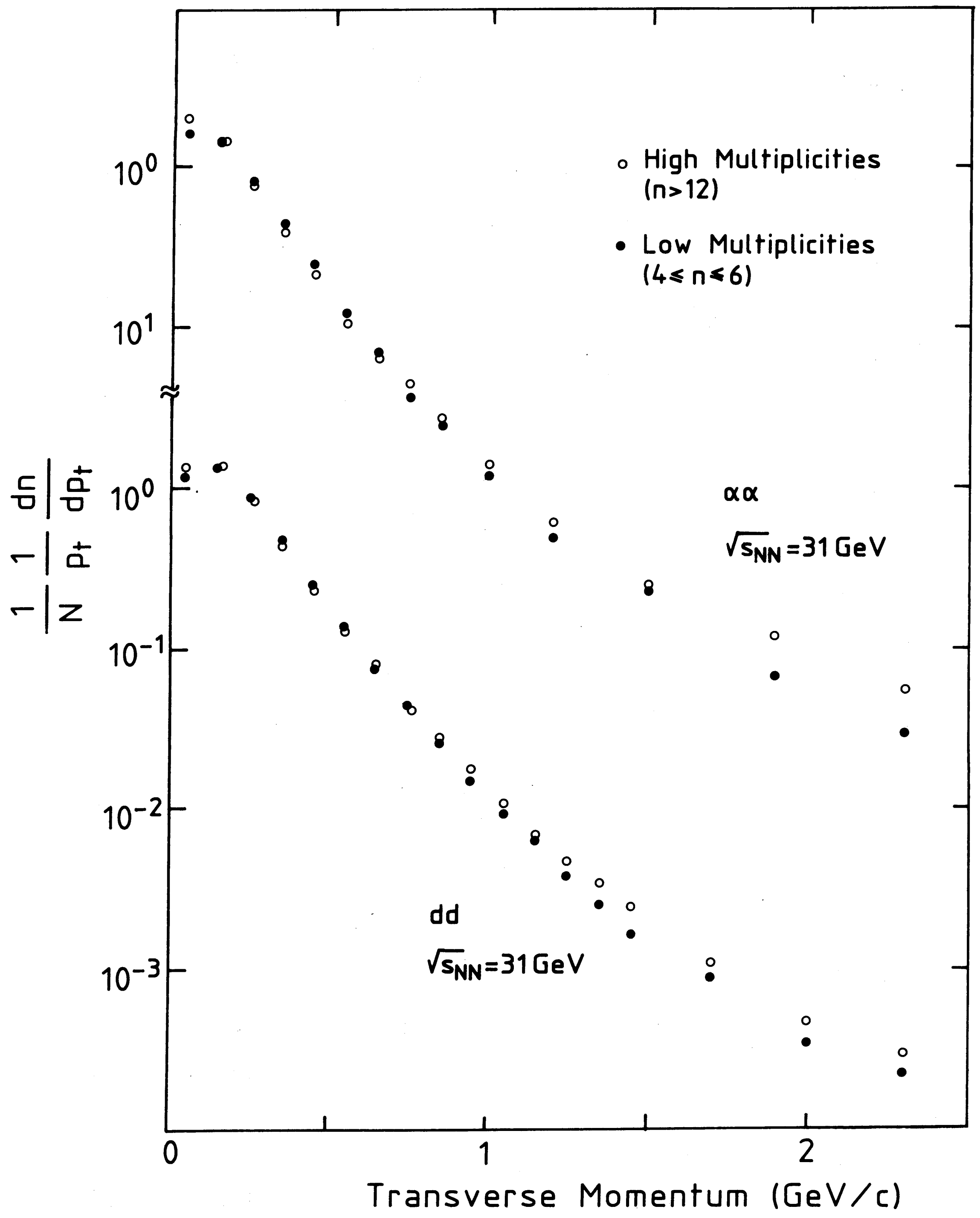
10^0
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
$\frac{1}{N}\frac{1}{p_t}\frac{dn}{dp_t}$
○ High Multiplicities (n>12)
● Low Multiplicities ($4 \leq n \leq 6$)
αα
$\sqrt{s_{NN}}$ = 31 GeV
dd
$\sqrt{s_{NN}}$ = 31 GeV
0
1
2
Transverse Momentum (GeV/c)

Fig. 1

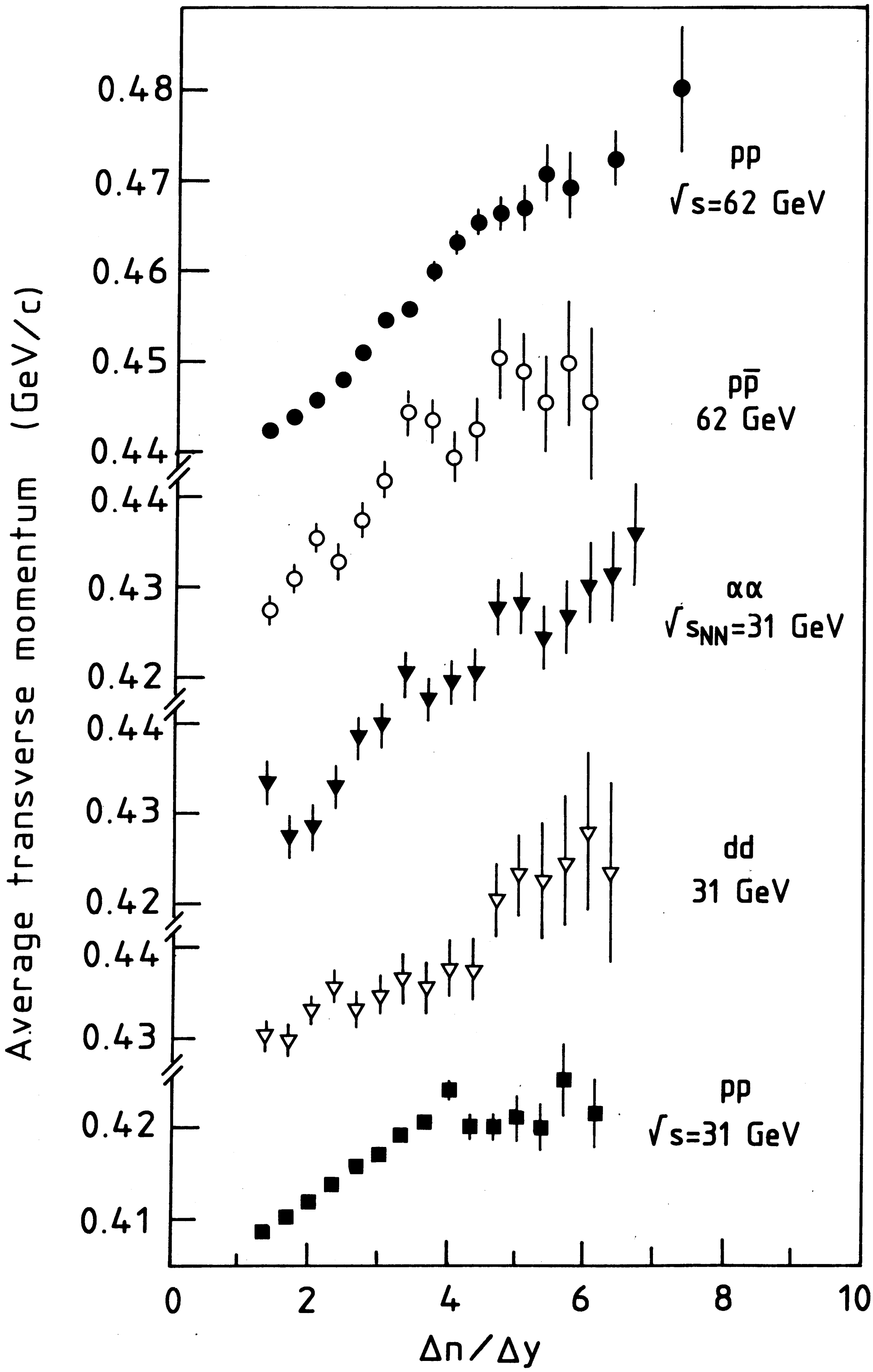
Average transverse momentum (GeV/c)
0.48
0.47
0.46
0.45
0.44
0.44
0.43
0.42
0.44
0.43
0.42
0.44
0.43
0.42
0.41
pp
√s=62 GeV
pp̄
62 GeV
αα
√s_NN=31 GeV
dd
31 GeV
pp
√s=31 GeV
0
2
4
6
8
10
Δn/Δy

Fig. 2

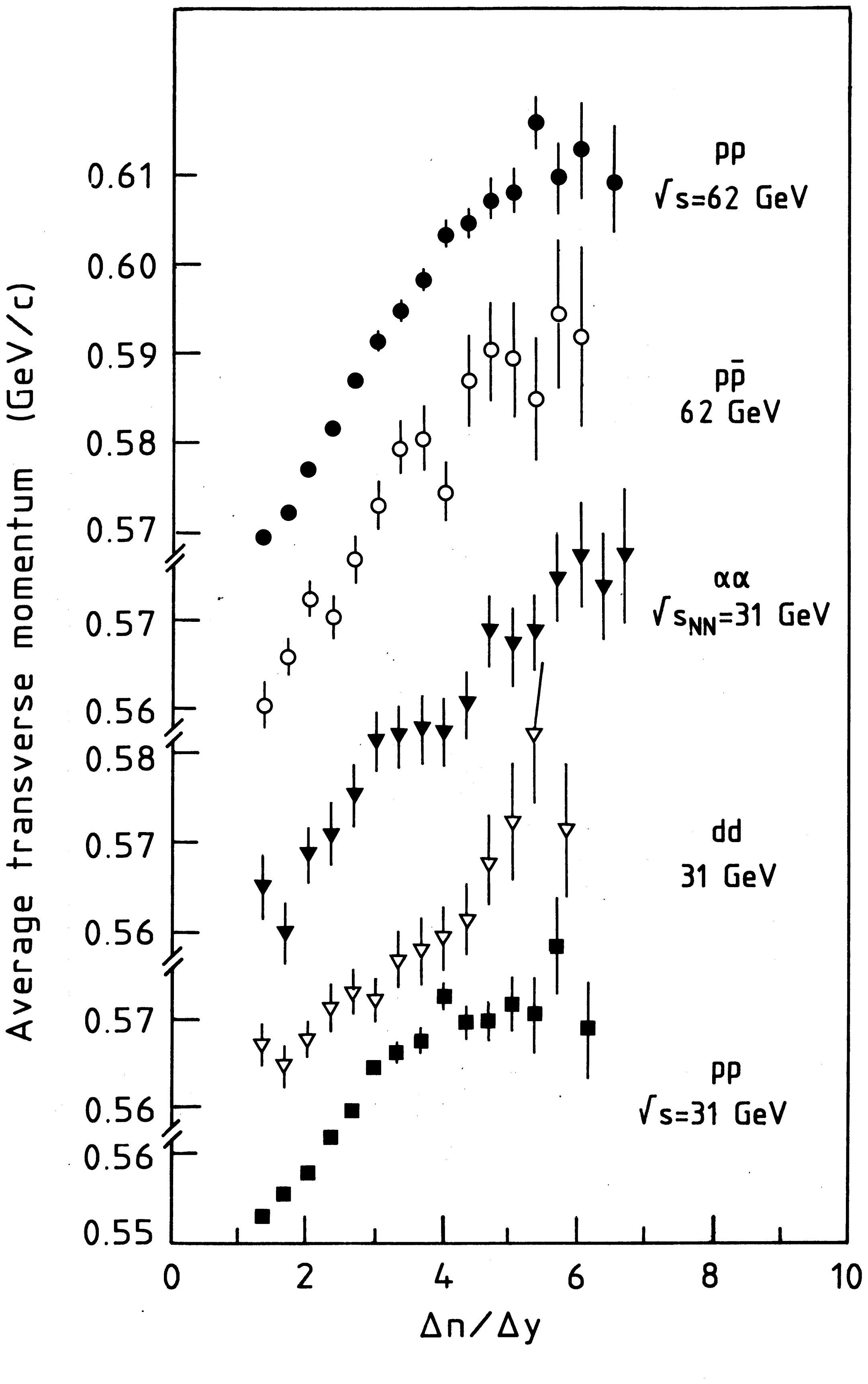
pp
√s=62 GeV
pp̄
62 GeV
αα
√s_NN=31 GeV
dd
31 GeV
pp
√s=31 GeV
Average transverse momentum (GeV/c)
Δn/Δy
0.61
0.60
0.59
0.58
0.57
0.57
0.56
0.58
0.57
0.56
0.57
0.56
0.56
0.55
0
2
4
6
8
10

Fig. 3

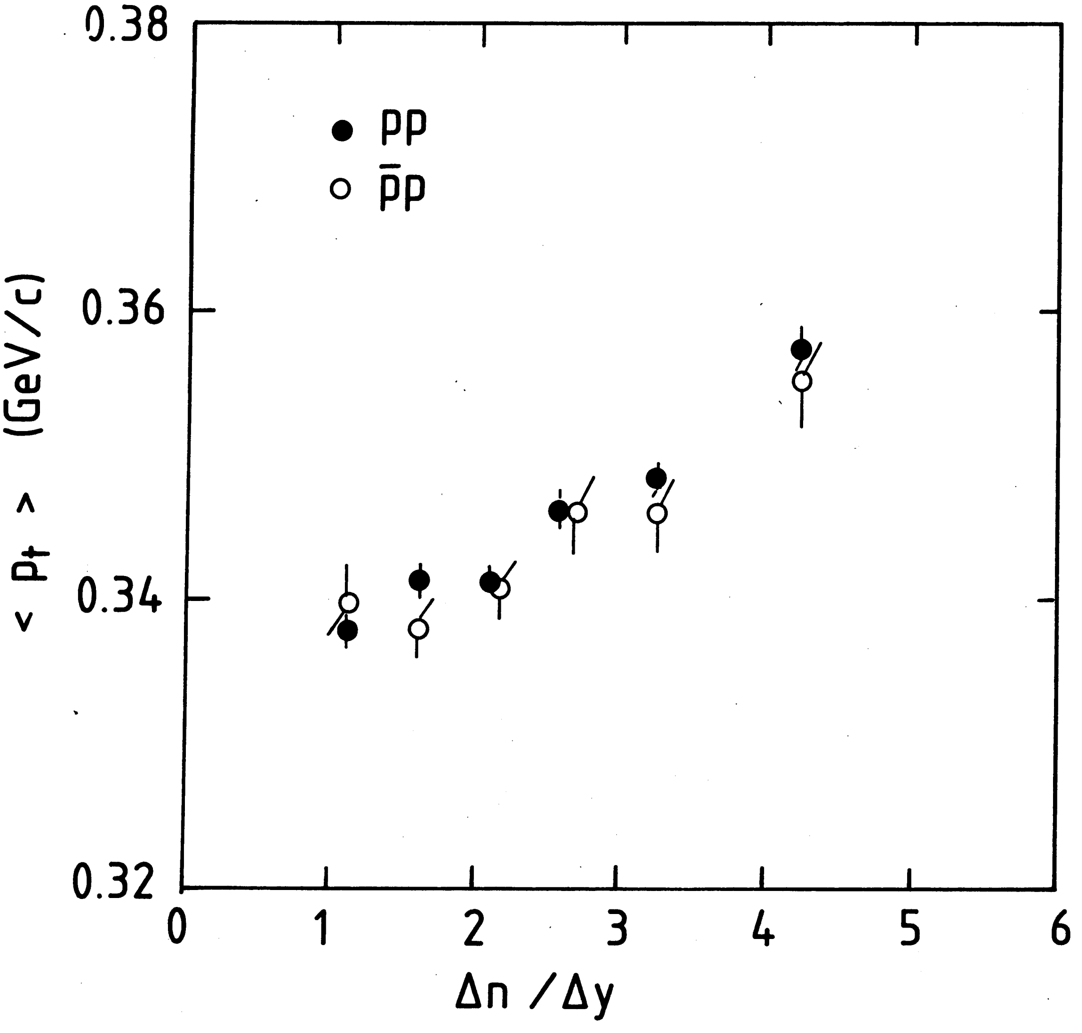

Fig. 4