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TRANSVERSE MOMENTUM DISTRIBUTIONS OF HADRONS PRODUCED IN αα AND αp COLLISIONS AT THE CERN INTERSECTING STORAGE RINGS

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ABSTRACT

The inclusive production of charged hadrons has been measured in αα and αp collisions at nucleon-nucleon c.m. energies ($\sqrt{s_{nn}}$) of 31 and 44 GeV, respectively, for transverse momenta p_T up to 5 GeV/c in the central rapidity (y) region. At high p_T the yields are consistent with being 4 times and 16 times higher than the ones in pp interactions at y = 0, for αα and αp interactions respectively. However, an enhancement over these factors, as expected from an earlier FNAL experiment, cannot be ruled out.

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1. INTRODUCTION

The target mass (A) dependence of the production of hadrons with large transverse momenta (p_T) was first measured by the Chicago-Princeton (CP) Collaboration at FNAL for collisions of 200-400 GeV protons with nuclei [1,2]. It was expected that for the rare hard interactions no shadowing would occur, and consequently that at large p_T the production would be proportional to A^1. However, when the A-dependence of the invariant cross-section $E(d^3\sigma/dp^3)$ was parametrized as $A^{\alpha(p_T)}$ it was found that the power $\alpha(p_T)$ grows to values larger than 1.0 for p_T larger than 2 GeV/c.

This "anomalous nuclear enhancement" was later confirmed in other experiments [3] and triggered many speculations from the theoretical side. The formation of big bags, or collective effects, rescattering of partons, contributions from the Fermi motion of nucleons, and other possible mechanisms have been discussed [4].

Clearly more experimental information is needed in order to reveal the mechanism responsible for the anomalous enhancement. One of the motivations for studying $\alpha\alpha$ and αp collisions in the CERN Intersecting Storage Rings (ISR) with the Split Field Magnet (SFM) detector derived from the unique possibility of measuring the momenta of charged particles over a solid angle close to 4π. It was hoped that the characteristics of the charged secondaries associated with a large-p_T trigger track could provide a clue to the anomalous enhancement.

In this letter we will present the inclusive invariant cross-sections for charged particle production for p_T up to 5 GeV/c and the ratio of pions to all charged hadrons for p_T greater than 3 GeV/c. Results of the study of the associated event structure will be reported in a forthcoming paper.

2. THE EXPERIMENT

The energy of the α beams in the ISR was 63.0 GeV (15.8 GeV/nucleon) and that of the proton beams 31.5 GeV. The centre-of-mass energies ($\sqrt{s}$) were 124.6 and 88.1 GeV or, in the average nucleon-nucleon subsystems ($\sqrt{s_{nn}}$), 31.2 and 44.0 GeV for $\alpha\alpha$ and αp interactions, respectively.

The luminosities were: 3.1×10^{28} cm^{-2} s^{-1} ($\alpha\alpha$); and 7.4×10^{29} cm^{-2} s^{-1} (αp) [5]. The data presented here were obtained with an integrated luminosity of 2.2×10^{33} cm^{-2} ($\alpha\alpha$) and 4.3×10^{34} cm^{-2} (αp). The luminosity was measured at small angles with respect to the outgoing beams by monitor counters, which were calibrated once for αp and once for $\alpha\alpha$ collisions by the van der Meer method [6].

The experiment was done at the SFM detector. This detector is a general-purpose spectrometer, capable of analysing momenta of charged particles over close to 4π sr and of identifying particles in limited regions of phase space. The magnet produces a field volume of 30 m^3 with a maximum strength of 1 T. By means of multiwire proportional chambers (MWPCs) more than 85% of all charged particles are detected in normal inelastic interactions. The details of this apparatus have been described elsewhere [7].

Two different trigger procedures have been used. The low-p_T data ($p_T < 2$ GeV/c) were obtained with a minimum bias trigger, which requires at least one track candidate anywhere in the detector. One track candidate is defined by the coincidence of at least three pairs of wire planes. The event samples contained 37,000 $\alpha\alpha$ and 27,000 αp inelastic interactions.

For the large-p_T data ($p_T > 2$ GeV/c), two independent trigger regions were set up at polar angles of 45° with respect to the beams near the horizontal plane (azimuthal angle ϕ between ±15°). The trigger decision was made in two steps by means of signals from the MWPCs. The first decision requires one track candidate in one of the trigger regions. The second decision uses signals from groups of 16 neighbouring vertical wires and requires fixed coincidence patterns (trigger roads) between different planes corresponding to tracks with lower curvature. Thus tracks with higher curvature are rejected ($p_T < 1.5$ GeV/c). Two gas Čerenkov counters filled with freon-12 at atmospheric pressure detect pions with total laboratory momenta above 3.8 GeV/c. Starting from a sample of 0.4×10^6 (1.0×10^6) large-p_T triggers on tape for $\alpha\alpha$ (αp) interactions, 12,000 (44,000) events with a track having p_T higher than 2 GeV/c were obtained.

The momentum resolution Δp is $0.004\ p^2$ (with p in units of GeV/c) in the trigger regions. The acceptance of the trigger regions, including the efficiency for track finding, was determined by a Monte Carlo simulation. The error in the absolute normalization of the cross-sections, which is due to the luminosity measurement, is estimated to be smaller than 10% based on the stability of results obtained in repeated measurements with pp beams.

3. RESULTS

The measured invariant cross-sections $d^2\sigma/\pi dy dp_T^2$ as a function of p_T are shown in figs. 1a to 1d for positive and negative tracks separately, and compared with results obtained by the British-Scandinavian (BS) Collaboration for pp interactions at the same $\sqrt{s_{nn}}$ [8].

All kinematic quantities are given in the nucleon-nucleon centre-of-mass system. The mean rapidities (y) selected by the large-p_T trigger are indicated; they differ by 0.2 units for positive and negative tracks going into the same trigger region owing to the opposite curvature of the tracks in the magnetic field. Both rapidity windows Δy are about 0.5 units wide. Corresponding y intervals have been selected for the minimum-bias events in the off-line analysis. In the case of αp collisions, the two trigger regions are not symmetrical with respect to $y = 0$, contrary to pp and $\alpha\alpha$ collisions, since the proton-nucleon centre of mass moves with a rapidity of -0.35 in the direction of the proton beam.

With increasing p_T, the cross-sections for αp interactions decrease more quickly on the α-side (positive y) than on the proton side (negative y), for negative as well as for positive tracks (figs. 1a and 1b). The production cross-sections for pp interactions used for the comparison were measured at different y in the range 0 to 1. At $\sqrt{s} = 44$ GeV no systematic dependence on y can be seen in the pp data. At $\sqrt{s} = 31$ GeV the BS data exhibit a clear y dependence -- the cross-sections decrease with increasing y at high p_T.

The invariant cross-sections were fitted to a function of the form

$$A \exp(-ap_T) + B \exp(-bp_T) \qquad (1)$$

in the range $0.3 < p_T < 4$ GeV/c. The fitted parameters are given in table 1. The measured ratios of pions to all hadrons of the same charge

$$F_\pi^\pm(p_T) = N(\pi^\pm)/N(h^\pm) \qquad \text{for } p_T > 3 \text{ GeV/c} \tag{2}$$

are listed in the last column of table 1. Particle discrimination was only possible for p_T above 3 GeV/c, corresponding to the minimum laboratory momentum of 3.8 GeV/c which pions need in order to produce light in the Čerenkov counters. Within the available p_T range no statistically significant change of the particle ratios were observed, so the average ratio in the interval $3 < p_T < 4.5$ GeV/c is quoted. These particle ratios are within the errors compatible with the ones measured in pp and pd interactions [2], apart from a slight increase of the fraction of positive heavy particles in αα collisions.

4. DISCUSSION

For αp interactions the yield of particles was found to be higher on the proton side than on the α side. Since the absolute values of y of the trigger particle are lower on the proton side than on the α side, this result may be attributed to a decrease of the invariant cross-sections with increasing y. However, such a strong dependence on y is in contrast to the weak dependence on y of the BS pp data at $\sqrt{s} = 44$ GeV and may therefore be a nuclear effect.

For a better comparison of the yields of produced particles in αp and αα interactions with the yield in pp interactions, we show in fig. 2 the cross-section ratios $R^\pm(\alpha p/pp)$ and $R^\pm(\alpha\alpha/pp)$. The ratio $R^+(\alpha p/pp)$, for instance, is defined as

$$R^+(\alpha p/pp) = \frac{d^2\sigma^+/dydp_T(\alpha p)}{d^2\sigma^+/dydp_T(pp)} , \tag{3}$$

taken at the same $\sqrt{s_{nn}}$ and at the nearest y. The solid lines in figs. 2a and 2b were obtained by calculating the ratio as

$$R^\pm(\alpha p/pp) = \sum_i 4^{\alpha_i^\pm(p_T)} F_i^\pm , \tag{4}$$

where $F_i^\pm$, the relative amount of $\pi^\pm$, $K^\pm$, and $p^\pm$ [cf. eq. (2)], and $\alpha_i^\pm(p_T)$ were taken from ref. [2], neglecting a potential energy dependence of $\alpha_i(p_T)$ and the known small energy dependence of F_i and possibile isospin effects. The naive expectation -- a factor of 4 -- is indicated by a dotted line. The ratio rises from about 3 at low p_T to a value close to 4 at higher p_T. In the overlap region in p_T this is consistent with the results of two other experiments at the ISR, which have measured the π^0 production [9,10]. It should be noted here that the precise determination of $\alpha_i(p_T)$ in the FNAL experiment was made possible by the use of very heavy targets. The expected enhancement in αp interactions is 20% above 4 for p_T = 4 GeV/c, whilst uncertainties in the absolute normalization of the cross-sections are of the order of 10%. (The error bars in the figures indicate only the statistical errors.)

For $\alpha\alpha$ interactions, the naive expectation for the ratio $R^{\pm}(\alpha\alpha/pp)$ is 16 -- corresponding to 4 × 4 independently interacting nucleon pairs (dotted line in figs. 2c and 2d). The curve corresponds to the square of the ratio $R^{\pm}$ for αp (eq. 4). The ratio to the BS pp data at y = 0 increases from 10 to slightly above 16. With respect to the cross-sections at y = 0.6, a rather significant enhancement over the factor of 16 is observed. Unfortunately, the pp data at y = 0.6 have only been measured up to p_T = 2.6 GeV/c. In addition, recent results from the Axial Field Spectrometer Collaboration indicate that the two high-p_T pp data points at y = 0.6 may be inconsistent [11]. An enhancement of the ratio $R^0_\pi(\alpha\alpha/pp)$ over the factor of 16 at high p_T has been found by the two other experiments at the ISR [9,10].

Our results are consistent with a value of 16 for $R^{\pm}(\alpha\alpha/pp)$ and a value of 4 for $R^{\pm}(\alpha p/pp)$ at p_T higher than 1 GeV/c. However, an enhancement over these factors, of a size expected by extrapolation from the FNAL experiment, is not significantly ruled out; relatively small variations of the pp and $\alpha\alpha$ cross-sections as a function of the rapidity y -- as indeed observed for αp interactions -- could render the ratios consistent with such an enhancement.

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Table 1

Centre-of-mass energy per average nucleon-nucleon collision $\sqrt{s_{nn}}$, average rapidity $\langle y \rangle$, fitted parameters [eq. (1)], and pion fraction $F_{\pi}^{\pm}$ [eq. (2)] for the inclusive production of positive (h^+) and negative (h^-) hadrons by $\alpha\alpha$ and αp interactions

	$\sqrt{s_{nn}}$ (GeV)	$\langle y \rangle$ $\Delta y = 0.5$	A $\left(\frac{10^{-27}\ cm^2\ c^3}{GeV^2}\right)$	a $\left(\frac{GeV}{c}\right)^{-1}$	B $\left(\frac{10^{-27}\ cm^2\ c^3}{GeV^2}\right)$	b $\left(\frac{GeV}{c}\right)^{-1}$	$F_{\pi}^{\pm}$ $3 < p_T < 4.5$ GeV/c
$\alpha\alpha \to h^+$	31.2	±0.83	1816	6.14	208.0	3.64	0.43 ± 0.03
$\alpha\alpha \to h^-$	31.2	±0.63	1721	5.86	102.0	3.59	0.77 ± 0.04
$\alpha p \to h^+$	44.0	−0.48	583	5.72	19.6	3.11	0.59 ± 0.02
$\alpha p \to h^+$	44.0	+1.18	527	5.85	33.5	3.47	0.54 ± 0.02
$\alpha p \to h^-$	44.0	−0.28	548	5.69	7.0	2.97	0.72 ± 0.02
$\alpha p \to h^-$	44.0	+0.98	547	5.81	15.6	3.36	0.83 ± 0.02

Figure captions

Fig. 1 : Invariant cross-sections $d^2\sigma/\pi dyd(p_T^2)$ in units of mb GeV^{-2} c^3 as a function of p_T for

αp collisions, positive (a) and negative (b) tracks;

$\alpha\alpha$ collisions, positive (c) and negative (d) tracks.

The lines through the points correspond to the fitted functions (see text and table 1). The cross-sections are compared with pp data (lower points) from ref. [8].

Fig. 2 : The ratios [cf. eq. (3)] of invariant cross-sections in αp and $\alpha\alpha$ collisions to the ones in pp collisions as a function of p_T:

a) αp collisions, positive tracks;

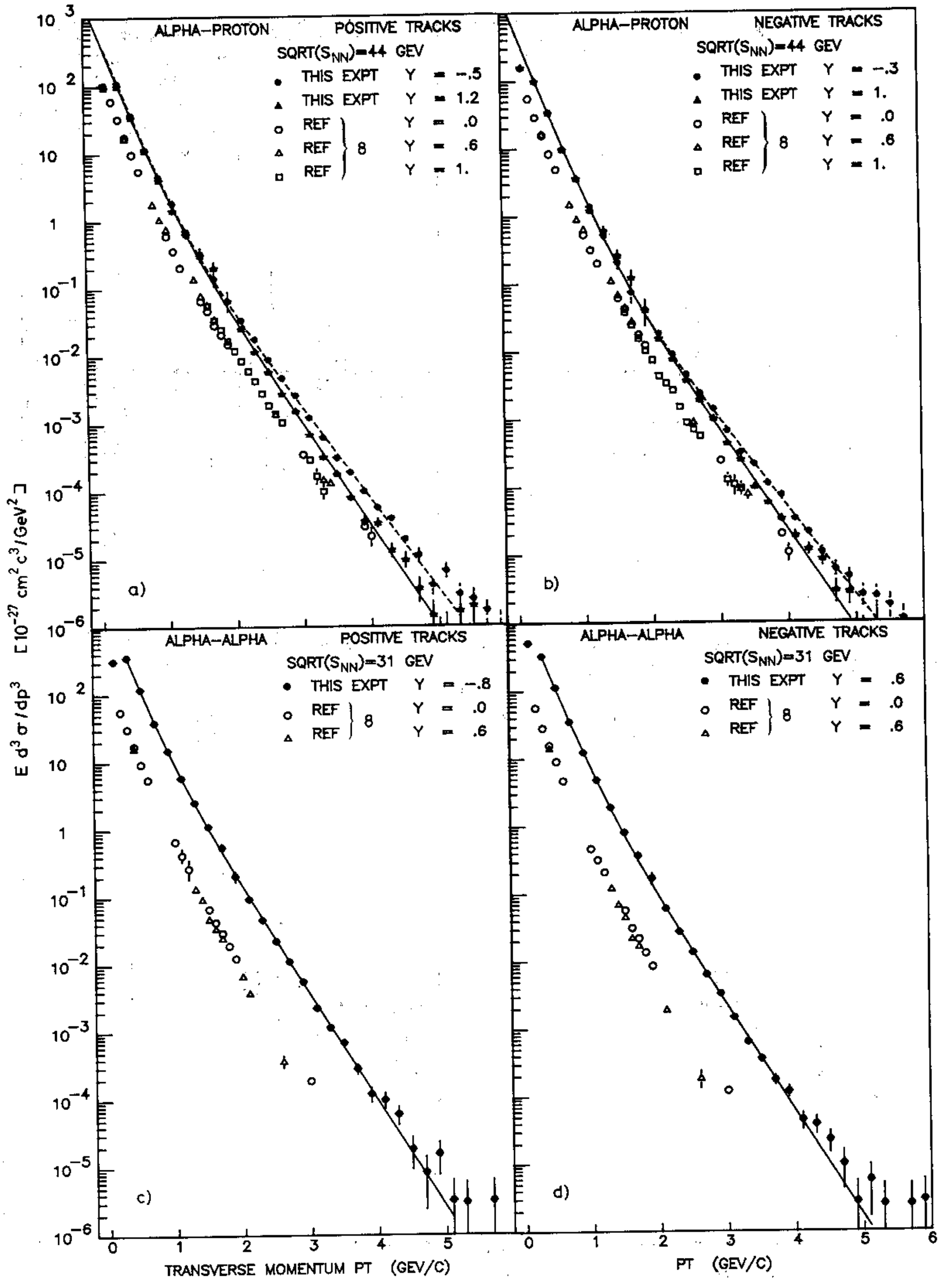
b) αp collisions, negative tracks.

Solid lines: expected ratio [eq. (4)]:

c) $\alpha\alpha$ collisions, positive tracks;

d) $\alpha\alpha$ collisions, negative tracks.

Solid line: the square of the ratio as defined in eq. (4).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REF 8 Y = .6
REF Y = 1.
a)
ALPHA-PROTON NEGATIVE TRACKS
SQRT(S_NN)=44 GEV
THIS EXPT Y = -.3
THIS EXPT Y = 1.
REF Y = .0
REF 8 Y = .6
REF Y = 1.
b)
ALPHA-ALPHA POSITIVE TRACKS
SQRT(S_NN)=31 GEV
THIS EXPT Y = -.8
REF 8 Y = .0
REF Y = .6
c)
ALPHA-ALPHA NEGATIVE TRACKS
SQRT(S_NN)=31 GEV
THIS EXPT Y = .6
REF 8 Y = .0
REF Y = .6
d)
E d³σ/dp³ [10⁻²⁷ cm²c³/GeV²]
TRANSVERSE MOMENTUM PT (GEV/C)
PT (GEV/C)

Fig. 1

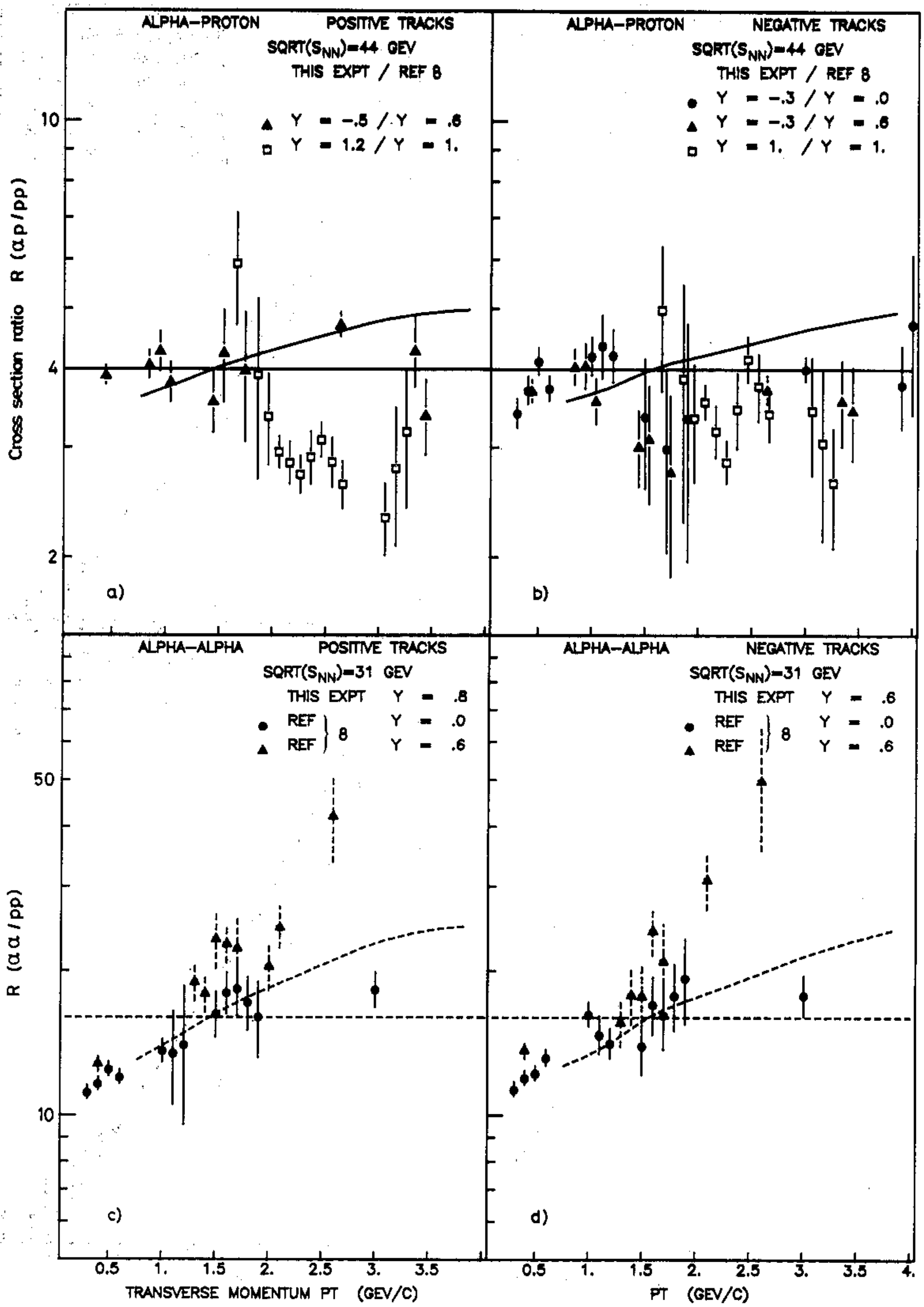
ALPHA-PROTON
POSITIVE TRACKS
SQRT(S_NN)=44 GEV
THIS EXPT / REF 8
Y = -.5 / Y = .6
Y = 1.2 / Y = 1.
a)
ALPHA-PROTON
NEGATIVE TRACKS
SQRT(S_NN)=44 GEV
THIS EXPT / REF 8
Y = -.3 / Y = .0
Y = -.3 / Y = .6
Y = 1. / Y = 1.
b)
Cross section ratio R (αp/pp)
ALPHA-ALPHA
POSITIVE TRACKS
SQRT(S_NN)=31 GEV
THIS EXPT Y = .6
REF Y = .0
REF 8 Y = .6
c)
ALPHA-ALPHA
NEGATIVE TRACKS
SQRT(S_NN)=31 GEV
THIS EXPT Y = .6
REF Y = .0
REF 8 Y = .6
d)
R (αα/pp)
TRANSVERSE MOMENTUM PT (GEV/C)
PT (GEV/C)

Fig. 2