Ref.TH.1897-CERN

LINE REVERSAL, SU(3), AND EXCHANGE DEGENERACY IN $K^{\pm}N$ CHARGE EXCHANGE AT 4 GeV/c

F. Elvekjaer and R.C. Johnson *)

CERN - Geneva

A B S T R A C T

New differential cross-section data for $K^+n \to K^0p$ and $K^-p \to \bar{K}^0n$ at 4 GeV/c are studied. The SU(3) octet sum rule is well satisfied and the ρ quantum number exchange is shown separately to obey SU(3) well. The observed breaking of line-reversal equality is shown to be too big to be accounted for by the s channel helicity non-flip amplitudes alone, and a possible mechanism of exchange-degeneracy breaking in the flip amplitude is pointed out.

---

*) On leave from Durham University, England.

Ref.TH.1897-CERN
5 July 1974

Counter measurements of differential cross-sections $\sigma(K^{\pm})$ for the $K^{\pm}N$ charge-exchange ($K^{\pm}$CEX) reactions $K^{+}n \to K^{0}p$ and $K^{-}p \to \bar{K}^{0}n$ at $p_L = 3,4,6$ GeV/c have become available recently [1]. The $K^{\pm}$CEX processes are connected by line-reversal and proceed by exchange of ρ and A_2 quantum numbers. The new data represent the first detailed study of both reactions in one experiment. Consequently they offer the possibility of a realistic analysis of exchange-degeneracy (EXD) breaking and related questions - an analysis less plagued than usual by doubts about relative normalizations.

The majority by a factor of more than two of the $K^{\pm}$CEX events [1] is at 4 GeV/c, and so we concentrate at this energy. Figure 1 shows

$$\sigma_{\pm} \equiv \frac{1}{2}\left\{\sigma(K^{-}) \pm \sigma(K^{+})\right\} \tag{1}$$

as a function of t. Measurements at two of the t values are adjusted within their errors to make them more consistent with smooth extrapolations through neighbouring values ; the results are not sensitive to this.

Also shown in Fig. 1 is the well-known combination [2]

$$\sigma_{0} \equiv \frac{1}{2}\left\{\sigma(\pi) + 3\,\sigma(\eta)\right\} \tag{2}$$

of differential cross-sections for $\pi^{-}p \to \pi^{0}n$, ηn interpolated from data at 3.7 [3], 4.0 [4], 3.67, 3.8, and 4.83 [5] GeV/c. The good agreement

$$\sigma_{+} = \sigma_{0} \tag{3}$$

is evidence that at this energy, whatever combination of Regge poles and cuts constitute ρ and A_2 exchange, each obeys SU(3) octet symmetry in coupling to two pseudoscalar mesons [2].

In fact for $-0.05 \gtrsim t \gtrsim -0.4\ (\mathrm{GeV}/c)^2$ satisfaction of Eq. (3) tests SU(3) for only the dominant flip amplitude. Figure 2(a) illustrates this point, showing the decomposition

$$\sigma(\pi) = \sigma_N + \sigma_F \tag{4}$$

of the $\pi^- p$ CEX cross-section into s channel helicity flip (σ_F) and non-flip (σ_N) components according to a typical analysis of $\pi^- p \to \pi^0 n$ with finite-energy sum rule (FESR) constraints [6].

For the ρ exchange a more detailed test of SU(3) is possible. The prediction for the amplitudes is that

$$\rho(KN) = -\rho(\pi N)/\sqrt{2} \quad , \tag{5}$$

and on this basis Fig. 2(b) compares an effective pole parametrization of $\rho(\pi N)$ [6] with recent $K^{\pm}N$ FESR integrals, evaluated at cut-off $p_L = 1.5$ GeV/c [7]. The agreement is excellent in the region of interest, $-t \lesssim 1.1\ (\mathrm{GeV}/c)^2$.

A model of EXD ρ and A_2 Regge poles predicts line-reversal symmetry, $\sigma_- = 0$. Let us now consider the origin of the breaking of the line-reversal equality (LRB) illustrated in Fig. 1, and seen similarly at $p_L = 3$ and 6 GeV/c at a comparable level - i.e., about 30%, measured by $\frac{1}{2}|\sigma_-|/\sigma_+$ [1]. Recall that LRB is observed also in hypercharge exchange (HCEX) reactions at these energies and apparently up to 14 GeV/c [8], although bubble-chamber data for $K^{\pm}$ CEX at 12 GeV/c are consistent with $\sigma_- = 0$ [9]. In each case, at any rate at smaller $|t|$, we have

$$\sigma(\mathit{Real}) > \sigma(\mathit{Rotating}) \tag{6}$$

in the EXD Regge pole language, which here means $\sigma_- < 0$.

A widely-advocated model of amplitude systematics generates LRB through effects in s channel helicity non-flip amplitudes. Single flip amplitudes are supposed to be correctly described by simple EXD Regge poles, or equivalent dual absorptive terms [for reviews and references, see, e.g., Ref. 10)]. The origin is the empirical features of πN scattering where the flips amplitude $\rho_{+-}(\pi N)$ is accurately Regge pole-like at current energies [11]. The success of SU(3) [Eqs. (3) and (5)] strongly suggests similar Regge behaviour for $\rho_{+-}(KN)$.

However, evidence for the state of the A_2 single flip is unclear. Model fits to older data on $K^{\pm}$ CEX and to related processes [reviewed in, e.g., Refs. 10) and 12)] are consistent with Regge pole-like, EXD, SU(3) symmetric flip amplitudes. But the FESR for $K^{\pm}N$, while as we see [Fig. 2(b)] giving impressive confirmation for the ρ, predict an A_2 exchange which is completely different - at any rate near the upper end of the phase-shift region, $p_L \approx 1.5$ GeV/c [7]. For the SU(3) related $K^*_{V,T}$ exchanges the available FESR results are not completely consistent [13], but (with some symmetry breaking) the LRB in the non-flip-dominated HCEX reactions is naturally accommodated within the scheme [8].

In resonance production reactions where single-flip dominance is indicated, Fox and Quigg [10] have emphasized the lack of evidence for smaller LRB in flip than in non-flip, but here relative normalization is a big difficulty.

A feature of the newer and more accurate $K^{\pm}$CEX data in Fig. 1 is the large size of σ_- with its suggestion of a turnover near $t = 0$. With over-all flip dominance expected, the immediate suspicion is that, contrary to the above popular model, LRB here is <u>not</u> confined solely to the non-flip amplitude. Confirmation of this suspicion is immediate, as follows.

Using the SU(3) relation Eq. (5) established by the $K^{\pm}N$ FESR to calculate $\rho(KN)$ (both flip and non-flip), the data $\sigma_{\pm}$ determine the A_2 non-flip amplitude T in modulus and phase, <u>under the model assumption that the A_2 flip amplitude is a simple Regge pole-like term, EXD with ρ_{+-}</u>.

If the common ρ-A_2 EXD Regge pole trajectory is $\alpha(t)$, we obtain the equations

$$\sigma_+ = |T|^2 + \frac{1}{2}\sigma_N + \sigma_F/(1-\cos\pi\alpha) , \qquad (7)$$

$$\sigma_- = \sqrt{2\sigma_N} \cdot |T| \cdot \cos\theta \, , \qquad (8)$$

where σ_N and σ_F are $\pi^- p$ CEX non-flip and flip cross-sections as in Eq. (4). By hypothesis, ρ and A_2 are orthogonal in s channel helicity flip and so do not contribute to σ_-. Through Eq. (7), σ_+ determines $|T|$. Then from Eq. (8) the LRB σ_- gives the projection of T onto ρ_{++}, measured by $\cos\theta$. There is a two-fold ambiguity in the solution since $\cos\theta = \cos(-\theta)$.

Figure 3(a) shows $|T|$ as a function of t for two typical choices of $\alpha(t)$ [6),11),14)]. The solution is sensitive to $\alpha(t)$ which vanishes near $t = -0.55$ $(\mathrm{GeV}/c)^2$. This is the only place where possible ρ' terms are important in the flip amplitude. As a result, we find large uncertainties at $t = -0.45$ $(\mathrm{GeV}/c)^2$ and -0.55 $(\mathrm{GeV}/c)^2$, although the solution on each side interpolates smoothly. In Figure 3(a) [as in Fig. 2(a)] σ_N and σ_N are calculated from the fit of Ref. 6) but other comparable fits [e.g., 14)] to $\pi^- p$ CEX give almost identical results. The error bars correspond to those on the $K^\pm$ CEX data [1)]. The dip-bump structure near $t = -0.1$ to -0.2 $(\mathrm{GeV}/c)^2$ is caused by the rapid drop of σ_N and rapid rise of σ_F with increasing $|t|$.

In Fig. 3(b), where $\cos\theta$ is plotted, the failure of the model is evident - over a range of t, $|\cos\theta|$ is bigger than unity. The SU(3) assumption is tested, and credible minor adjustments to σ_N and σ_F, and indeed to $\alpha(t)$, do not save the situation [*)]. The LRB shown by the data is too big to be explained by the model, i.e., by non-flip amplitudes alone. Moreover, the discrepancy in Fig. 3(b) is largest where the flip amplitudes are largest [compare, e.g., Fig. 2(a)]. Therefore, it is reasonable to infer that in $K^\pm$ CEX at 4 GeV/c, contrary to popular belief, <u>there is a substantial breaking of EXD between the ρ and A_2 in the s channel helicity flip amplitude</u>.

---

*) E.g., at $t = -0.25$ $(\mathrm{GeV}/c)^2$, for $\alpha(t) = 0.55 + t$, to reduce $|\cos\theta|$ from 2.4 to 1.0 requires $|T|^2 > \sigma_+$; or else an increase of σ_N by a factor of about 6 to 8.

The present analysis offers no direct clues to the mechanism of flip EXD breaking. The size of flip correction necessary between $t \approx -0.1\ (\mathrm{GeV}/c)^2$ and $t \approx -0.4\ (\mathrm{GeV}/c)^2$ can be bounded by assuming it to be (anti) parallel to the EXD term, when an effect of order 15% in amplitude is estimated.

One notes that high-energy measurements of $\sigma(\pi)$ [15] and $\sigma(\eta)$ [16] show standard Regge pole energy-dependences for the dominant flip amplitudes in $0 > t \gtrsim -0.5\ (\mathrm{GeV}/c)^2$, consistent with parallel ρ and A_2 trajectories in this region, where the A_2 is displaced downward by $\Delta\alpha \approx 0.1$ or so. Such an "α breaking" of pole EXD gives the obtuse angle between ρ and A_2 flip components necessary for $\sigma_- < 0$, and gives the order of magnitude about right [17].

With this mechanism the flip part of the LRB σ_- then vanishes at $t = 0$ and $t \approx -0.55\ (\mathrm{GeV}/c)^2$. It is interesting to note here that, according to Fig. 1, $\sigma_-(t=0)$ is roughly the same size as $\sigma_-(t \approx -0.55\ (\mathrm{GeV}/c)^2)$. The mechanism also predicts a persistent effect at high energies in $K^\pm$ CEX, and, with a phase for T closer to EXD $(\theta > 0)$ it contributes to polarizations small and negative in $K^- p \to \bar{K}^o n$, and larger and positive in $K^+ n \to K^o p$. This agrees with available data [18] and other indications [19].

To summarize, some immediate features of accurate new $K^\pm$ CEX data at $p_L = 4$ GeV/c are as follows.

(i) They are consistent with SU(3) octet symmetry for helicity flip ρ and A_2 quantum number exchange. There is new separate evidence from FESR for SU(3) couplings of the ρ quantum number in both flip and non-flip.

(ii) The sizeable breaking of line-reversal symmetry is not consistent with the standard model which blames the s channel helicity non-flip amplitude while supposing that the flip amplitude is EXD and Regge pole-like. A model of α broken EXD poles may work for the flip amplitude.

Data at 3 and 6 GeV/c from the same experiment [1] have lower statistics and larger errors rendering conclusions correspondingly less certain. The satisfaction of the SU(3) sum rule Eq. (3) [2] is good at 6 GeV/c but poorer at 3 GeV/c. The success of Eq. (5) points to the A_2

as the culprit, consistent with the anomalous A_2 FESR results [7]. A detailed analysis of A_2 exchange will be presented elsewhere [20].

We conclude with the traditional plea for more accurate data. $K^{\pm}$ CEX polarizations near 4 GeV/c to complement the cross-sections are obviously of prime interest.

ACKNOWLEDGMENTS

We thank Alan Irving, Alan Martin and Chris Michael for their comments.

REFERENCES

1) R. Diebold et al., Phys.Rev.Letters 32B, 904 (1974).

2) V. Barger and D. Cline, Phys.Rev. 156, 1522 (1967).

3) P.A. Borgeaud, Thesis, Saclay report number CEA-R-4037, 1970, unpublished ;
O. Guisan et al., Phys.Letters 18, 200 (1965).

4) J. Hladky et al., Phys.Letters 31B, 475 (1970).

5) P. Sonderegger et al., Phys.Letters 20, 75 (1966) ;
M.A. Wahlig and I. Manelli, Phys.Rev. 168, 1515 (1968).

6) V. Barger and R.J.N. Phillips, Phys.Rev. 187, 2210 (1969).

7) F. Elvekjaer and B.R. Martin, Nuclear Phys.B 75, 388 (1974).

8) A.C. Irving, A.D. Martin and V. Barger, Nuovo Cimento 16A, 573 (1973) ;
V. Barger and A.D. Martin, Phys.Letters 39B, 379 (1972).

9) P. Astbury et al., Phys.Letters 23, 396 (1966) ;
A. Firestone et al., Phys.Rev.Letters 25, 958 (1970).

10) G.C. Fox and C. Quigg, Ann.Rev.Nuclear Science 23, 219 (1973) ;
C.B. Chiu, Ann.Rev.Nuclear Science 22, 255 (1972) ;
C. Michael, Proc. XVI International Conference High Energy Physics, Batavia (1972) and Proc. Fourth International Conference High Energy Collisions (ed. J.R. Smith), report RHEL-72-001 (1972) ;
R.J.N. Phillips, Proc. Amsterdam International Conference on Elementary Particles (eds. A.G. Tenner and M.J.G. Veltman), North Holland (1971) ;
H. Harari, Proc.International Conference Duality and Symmetry in Hadron Physics (ed. E. Gotsman), Jerusalem, Weizmann Science (1971).

11) F. Halzen and C. Michael, Phys.Letters 36B, 367 (1971) ;
V. Barger and F. Halzen, Phys.Rev. D6, 1918 (1972).

12) J.S. Loos and J.A.J. Matthews, Phys.Rev. D6, 2463 (1972) ;
J.A.J. Matthews, SLAC-PUB-1123, 1972, unpublished ;
B. Schrempp and F. Schrempp, Meribel talk, 1974.

13) R.D. Field and J.D. Jackson, Phys.Rev. D4, 693 (1971) ;
L.G.F. Vanryckeghem, Oxford preprint (1974) ;
R.C.E. Devenish, C.D. Froggatt and B.R. Martin (to be published).

14) J.W. Coleman and R.C. Johnson, Phys.Rev. D7, 3386 (1973).

15) V. Bolotov et al., Nuclear Phys. B73, 365 (1974) ;
A. Barnes et al., Caltech/LBL preprint, London Conference paper 378/1046 (1974).

16) V. Bolotov et al., Nuclear Phys. B73, 387 (1974) ;
W.D. Apel et al., Serpukhov preprint, London Conference contribution (1974) ;
A. Barnes et al., Caltech/LBL preprint, London Conference paper 379/1045 (1974).

17) P.R. Auvil et al., Phys.Letters 31B, 303 (1970).

18) W. Beusch et al., Phys.Letters 46B, 477 (1973).

19) F. Elvekjaer and R.C. Johnson, CERN preprint TH. 1845 (1974) ;
A.D. Martin, C. Michael and R.J.N. Phillips, Nuclear Phys. B43, 13 (1972).

20) F. Elvekjaer and R.C. Johnson, CERN preprint TH.1899 (1974).

FIGURE CAPTIONS

Fig. 1 : Cross-section combinations $\sigma_{\pm}$ defined in Eqs. (1) and (2) plotted on a linear scale against t. As described in the text the data are smoothed : at $t = -0.04\ (\mathrm{GeV}/c)^2$ the value of $\sigma(K^-)$ is decreased to the limit of its quoted experimental error, and $\sigma(K^+)$ is similarly increased ; at $t = -0.45\ (\mathrm{GeV}/c)^2$ $\sigma(K^+)$ is increased to its upper error limit. Included are values of σ_0 defined in Eq. (2) to test the Barger-Cline sum rule, Eq. (3).

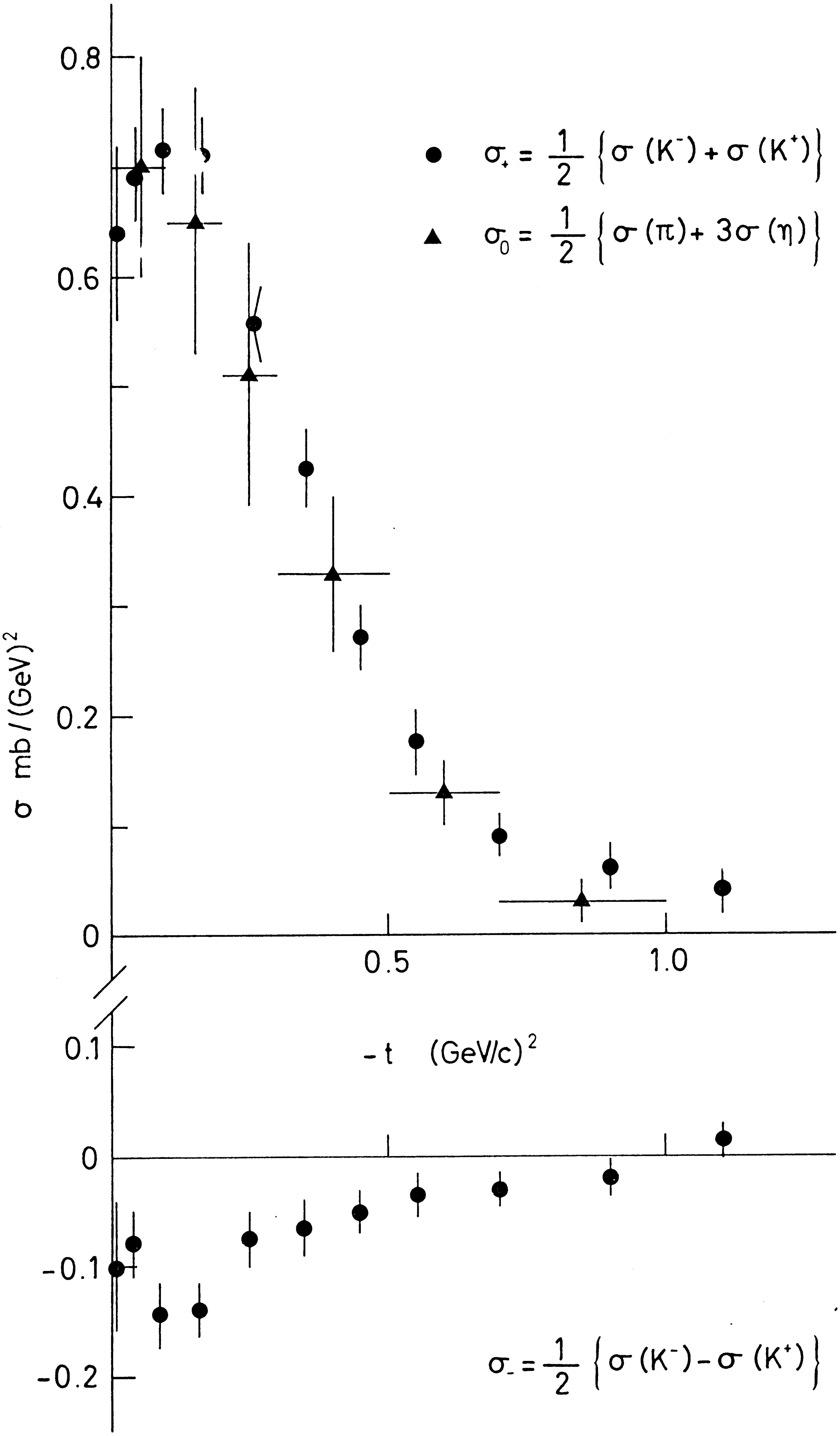
Fig. 2 : (a) Cross-section components σ_N and σ_F defined in Eq. (4), plotted on a linear scale. From Ref. 6).

(b) Comparison between FESR integrals (bands) for ρ quantum number exchange in $K^{\pm}N$ scattering [from Ref. 7)] and the high-energy contribution (dashed line) of Regge ρ amplitudes for πN scattering [from Ref. 6)] scaled by the SU(3) factor $-1/\sqrt{2}$ as in Eq. (5). Precisely, the amplitudes whose imaginary parts are integrated are (in the usual notation) $\rho_{++} \approx A + \nu B$, $\rho_{+-} \approx A$, and units are $\hbar = c = \mathrm{GeV} = 1$. See Ref. 7) for full details.

Fig. 3 : (a) Values of $|T|$ for two choices of $\alpha(t)$. The trajectory $\alpha(t) = 0.5 + 0.9\ t$ reproduces well the phase of ρ_{+-} at $p_L = 6$ GeV/c [see Fig. 4 of Michael's Oxford Conference talk, Ref. 10)], and $\alpha(t) = 0.55 + t$ is the ρ pole trajectory used in FESR fits, Refs. 6) and 14).

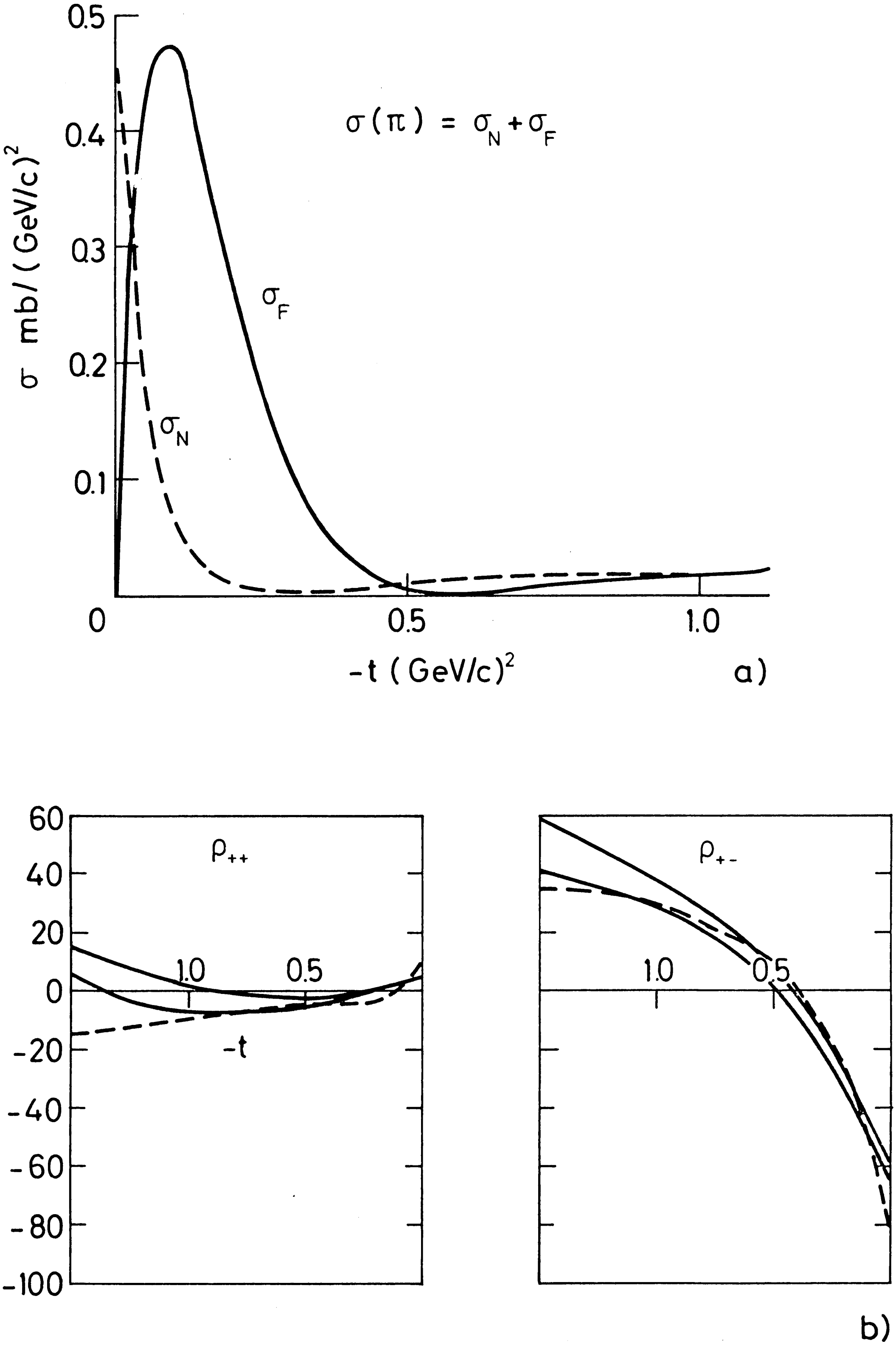
(b) Values of $\cos\theta$ for the same two choices of $\alpha(t)$.

In both cases, points are joined by hand-drawn curves.



0.8
0.6
0.4
0.2
0
0.1
0
-0.1
-0.2
0.5
1.0
σ mb / (GeV)^2
- t (GeV/c)^2
$\sigma_+ = \frac{1}{2}\{\sigma(K^-) + \sigma(K^+)\}$
$\sigma_0 = \frac{1}{2}\{\sigma(\pi) + 3\sigma(\eta)\}$
$\sigma_- = \frac{1}{2}\{\sigma(K^-) - \sigma(K^+)\}$

FIG. 1



0.5
0.4
0.3
0.2
0.1
0
σ mb/ (GeV/c)^2
σ(π) = $\sigma_N + \sigma_F$
σ_F
σ_N
0.5
1.0
-t (GeV/c)^2
a)
60
40
20
0
-20
-40
-60
-80
-100
ρ_{++}
1.0
0.5
-t
ρ_{+-}
1.0
0.5
b)

FIG. 2

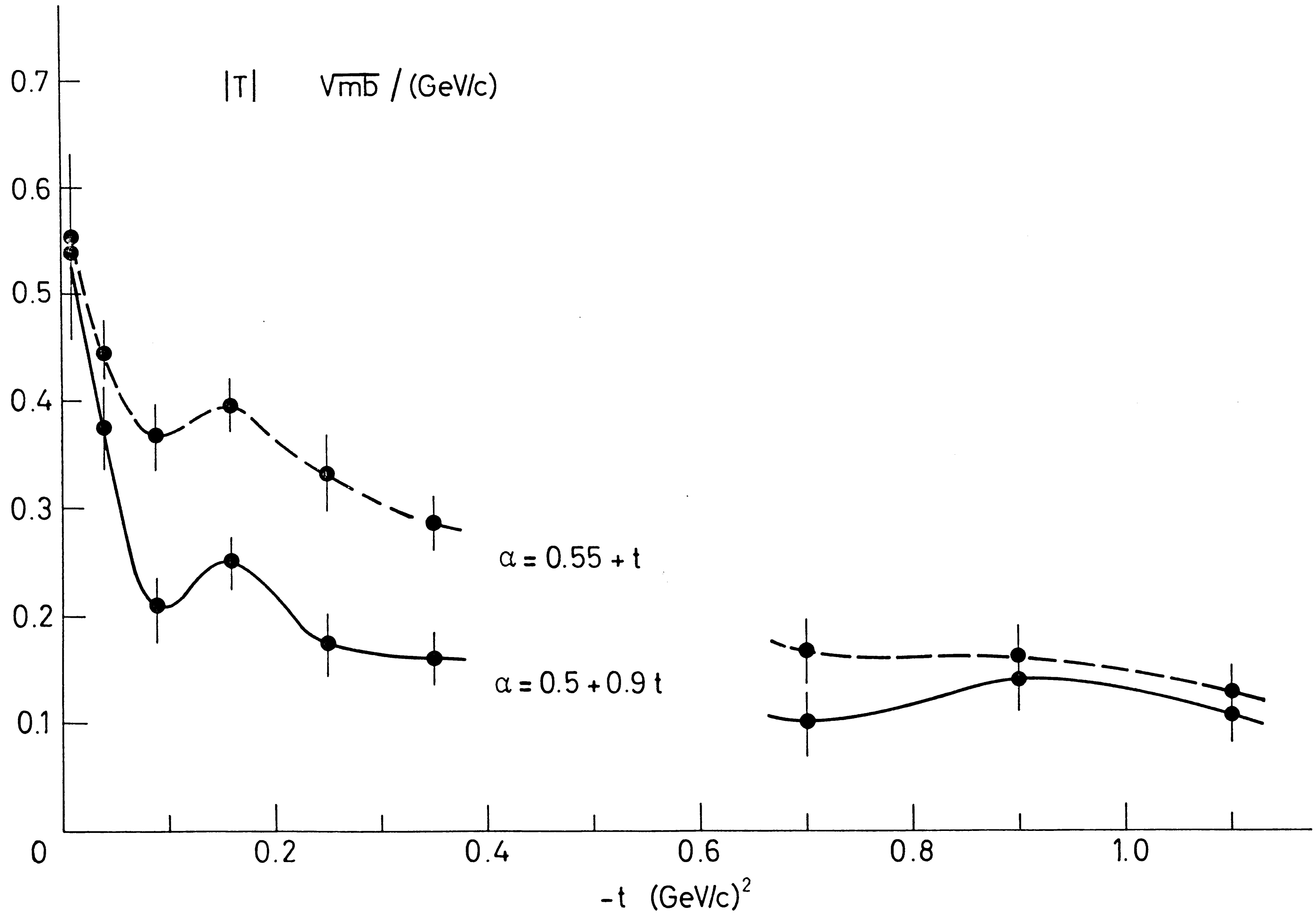


FIG. 3 (a)

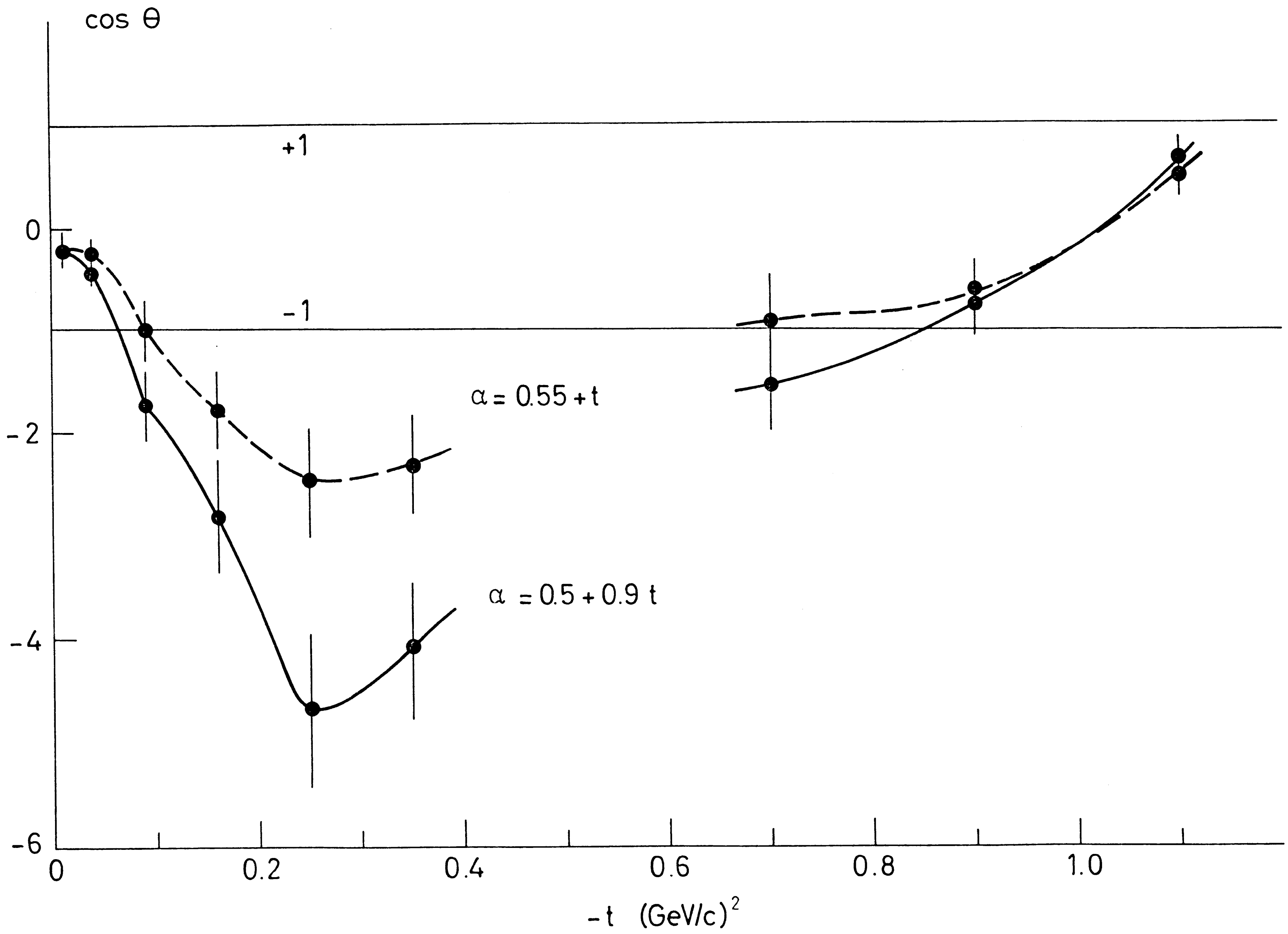


FIG. 3 (b)