IS THE RIDDLE OF THE HYPERON POLARIZATIONS SOLVED?

(J. SOFFER HYPERON99, FNAL)

- A RAPID TOUR OF THE HYPERON POLARIZATION DATA

- SOME THEORETICAL IDEAS FOR SINGLE SPIN ASYMMETRIES (P_Y, A_N) IN INCLUSIVE PRODUCTION

  - FRAGMENTATION REGION

    SEMI CLASSICAL ARGUMENTS

    REGGE TYPE MODELS

  - HARD SCATTERING REGION

    NEW IDEAS IN THE QCD PARTON MODEL

A RAPID TOUR OF THE HYPERON POLARIZATION DATA

SEVERAL FACTS AND FIRST Λ POLARIZATI[ON]
DISCOVERED IN 1976 AT FNAL BY STUDYING
HYPERONS PRODUCED BY 300 GeV/c PROTONS ON
Be TARGET

$$p \, Be \to \Lambda^{\uparrow} X$$

COULD ESTABLISH THAT ($0.3 < x_F < 0.9$, $p_T \leq$ [illegible]
FRAGMENTATION REGION [illegible]

- Λ HAS A LARGE NEGATIVE POL. P_Λ $\vec{n} = \frac{\vec{p}_{in} \times \vec{p}_\Lambda}{|\vec{p}_{in} \times \vec{p}_\Lambda|}$
- ITS MAGNITUDE ↗ WITH p_T

LATER FIND

- P_Λ IS PRETTY MUCH ENERGY IND! FROM 12 GeV/c TO ISR ENERGIES!

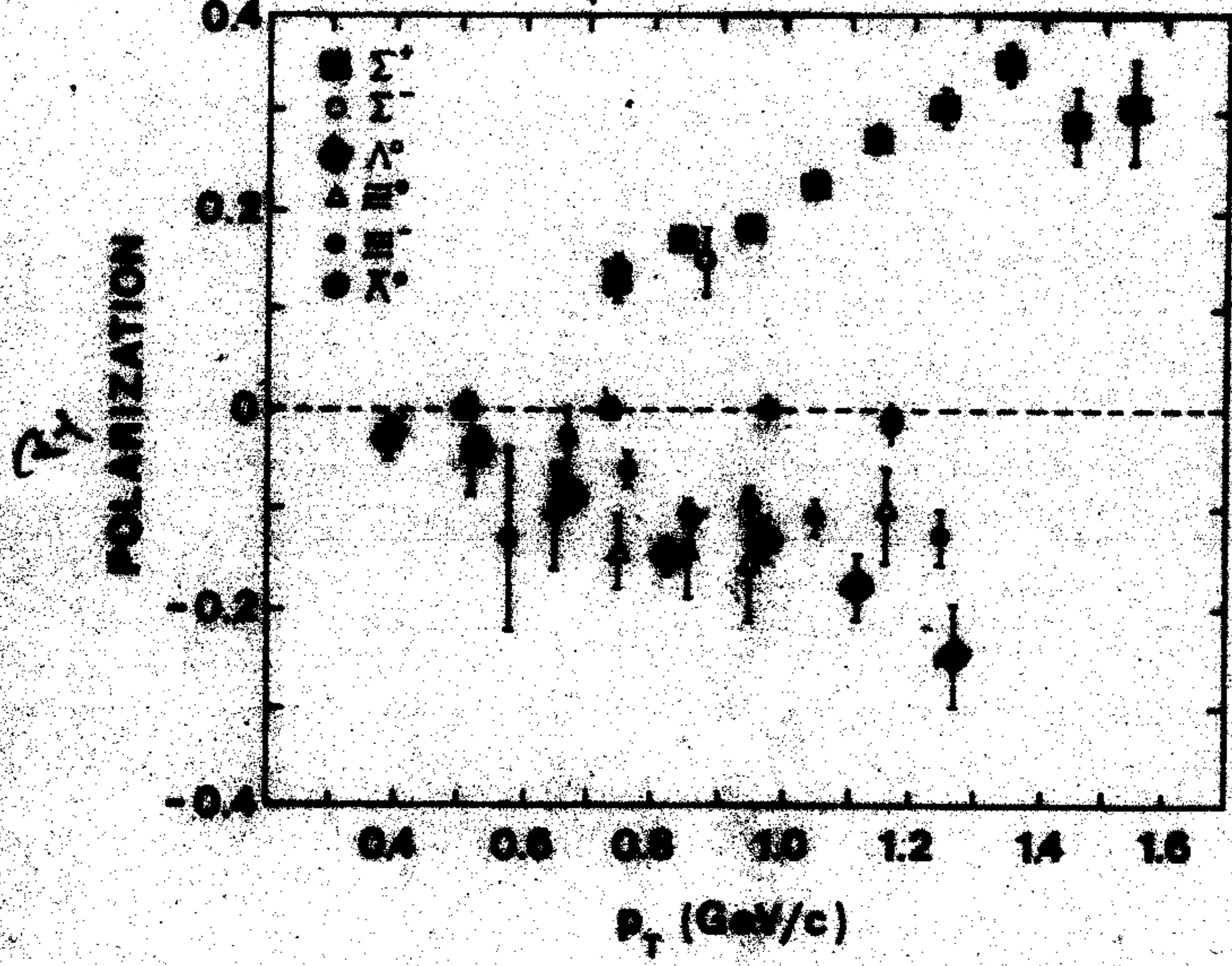
OVER LAST 20 YEARS LOTS OF DATA HAVE BEEN ACCUMULATED AND IN PARTICULAR WE KNOW

- VERY WELL THE Λ SPECTRUM $E \frac{d\sigma}{d^3p}(x, p_T)$
- P_Λ SATURATES AT LARGE p_T ($p_T \sim$ [illegible])
- $pp \to \Sigma^{+\uparrow} X$ P_Σ IS OPPOSITE SIGN
- $pp \to p^{\uparrow} X$ $P_p = 0$
- \+ OTHER FACTS (Ξ^0, Ξ^-, ----) A YET.

(FOR A NICE REVIEW SEE L. PONDROM PHYS. REP. 122 (1985) + K. HELLER IN [illegible] CONF. PROC.

\+ THE PUZZLE OF THE ANTI-HYPERONS
$P_{\bar\Lambda} \neq 0$ BUT $P_{\bar\Lambda} = 0$, $P_{\Xi^-} \approx P_{\bar\Xi}$, $P_{\Sigma^-} \approx P_{\bar\Sigma}$,
$P_{\Sigma} \neq 0$ BUT $P_{\bar\Sigma} = 0$

WHAT A CHALLENGE FOR THEORY!



$p + N \to Y +$

FNAL
400 GeV

Phys. Rev. Lett. 58, 855 (1987)

P_Λ EXTENDS TO LARGE p_T

LUNDBERG ET AL. PHYS. REV. D40, 3557 (1989)

400 GeV/c

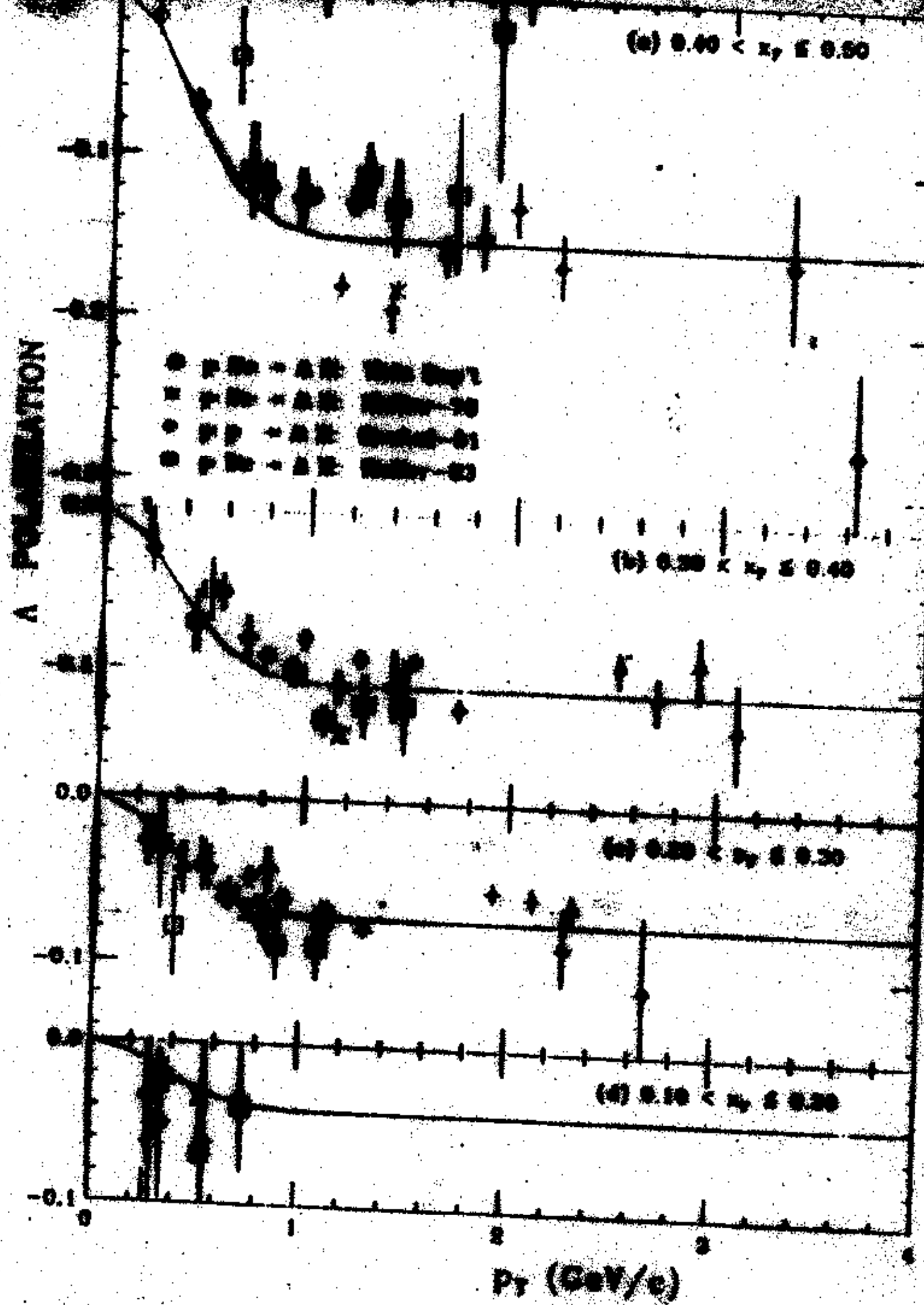


FIG. 5. Inclusive Λ polarization as a function of p_T with x_F restricted to each of the four ranges indicated in (a)–(d). The data plotted are from this experiment and Refs. 3, 23, and 24. All four experiments used the same spectrometer and measurement techniques. Errors when not shown are smaller than the points. The lines are ...

Alternate functi
taining the x_F dep
represents the dat
consistent with th
quirement that th
tor linear in p_T i
this latter requirem

$P_y = (C_1 x_F + \ldots$

It was tried and χ
of this experiment
of the three experi
Some additiona
[illegible] p
data of Ref. 24 in
[illegible]
$\chi^2/N_{DF} = 42.$
$\chi^2/N_{DF} = 63.$
[illegible] "goodness
linear function in
The dependence
target material h
sults.[24-26] All e
the polarization
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tion of Cu and P
the [illegible]
data are shown as
evidence that the
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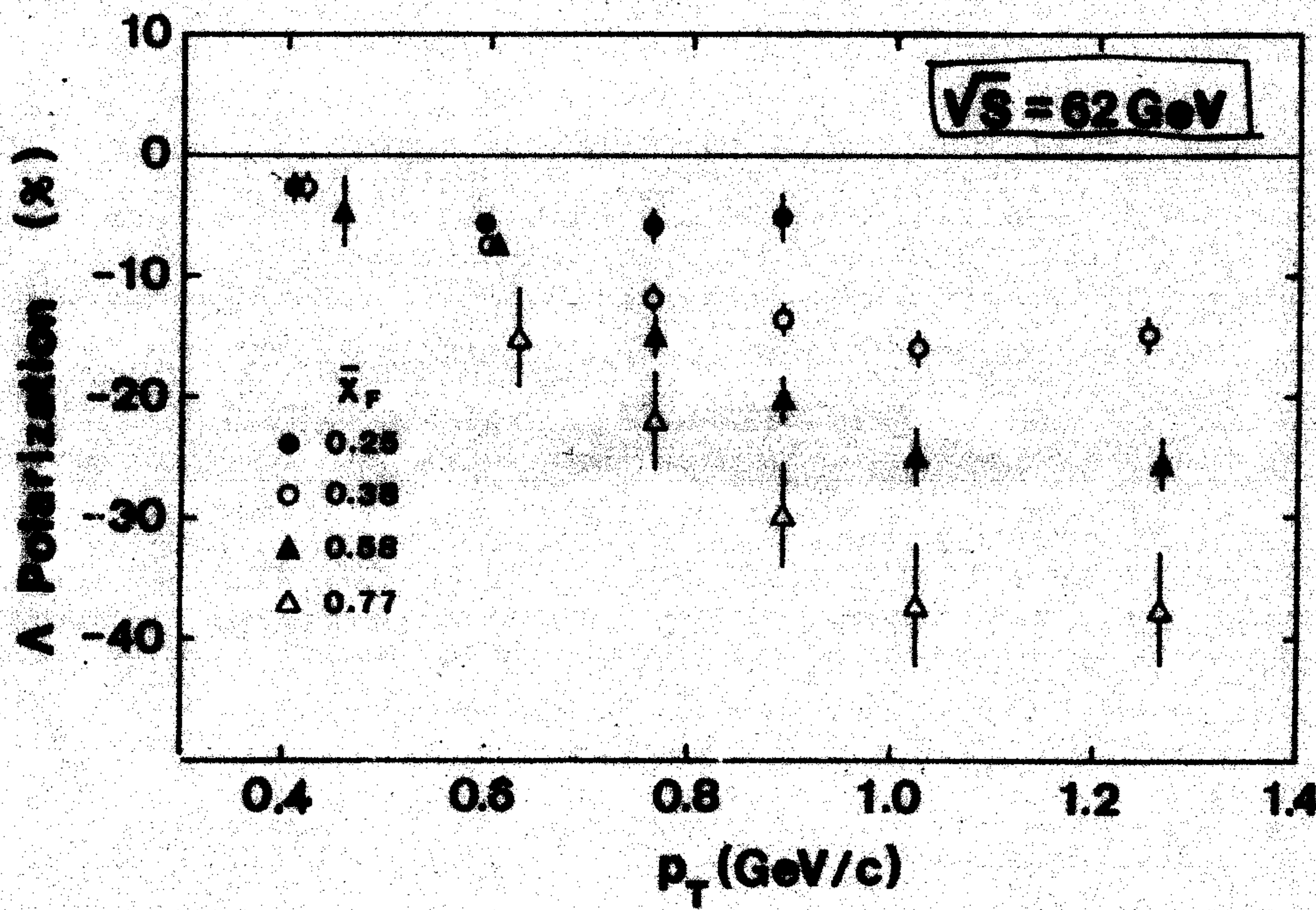
VI. PC



Λ Polarization (%)
10
0
-10
-20
-30
-40
√s = 62 GeV
$\bar{x}_F$
● 0.25
○ 0.35
▲ 0.56
△ 0.77
0.4
0.6
0.8
1.0
1.2
1.4
p_T (GeV/c)

pp → Λ X

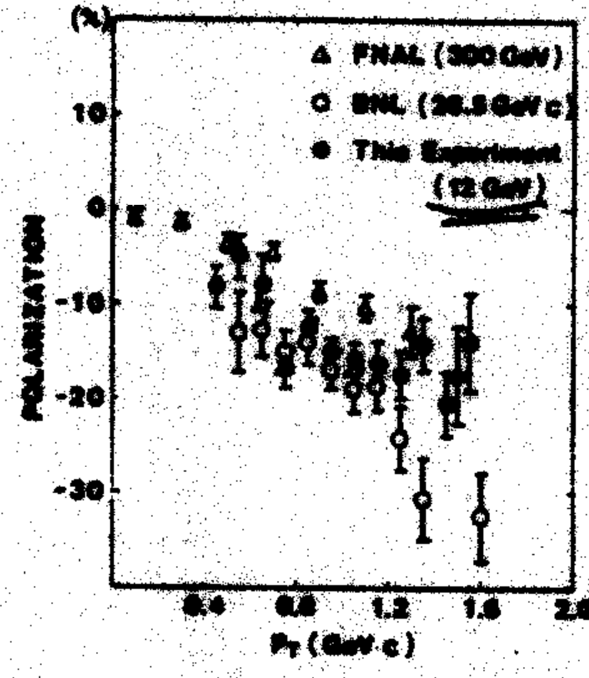


FIG. 3. The p_T dependence of Λ^0 polarization at 12 GeV in comparison with higher-energy data.

space limitations of the experimental area.

The acceptance $A(\cos\theta_i)$ was calculated with a hybrid Monte Carlo program by using the same Λ^0 momentum and decay point that were obtained from real data. The angular distribution corrected for the acceptance was fitted by a linear function of $\cos\theta_i$, and αP_i was obtained from the slope of the straight line. The efficiencies of the trigger counters were measured in the course of data taking and they proved to be sufficiently high. The local efficiencies of each chamber plane were determined by track reconstruction. The drift cells of the DC's in the neutral-beam path had few percent lower efficiencies as compared with other cells because of the intense neutral-particle background. The local efficiencies of the chambers were taken into account in the

FIG. 4.
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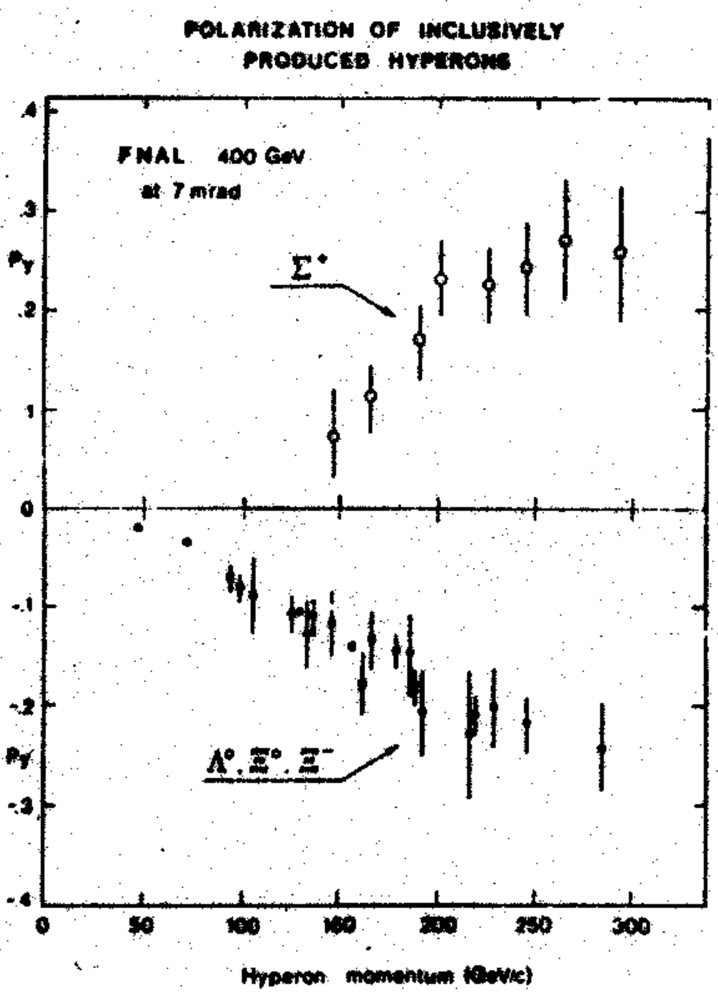


Fig. 6a

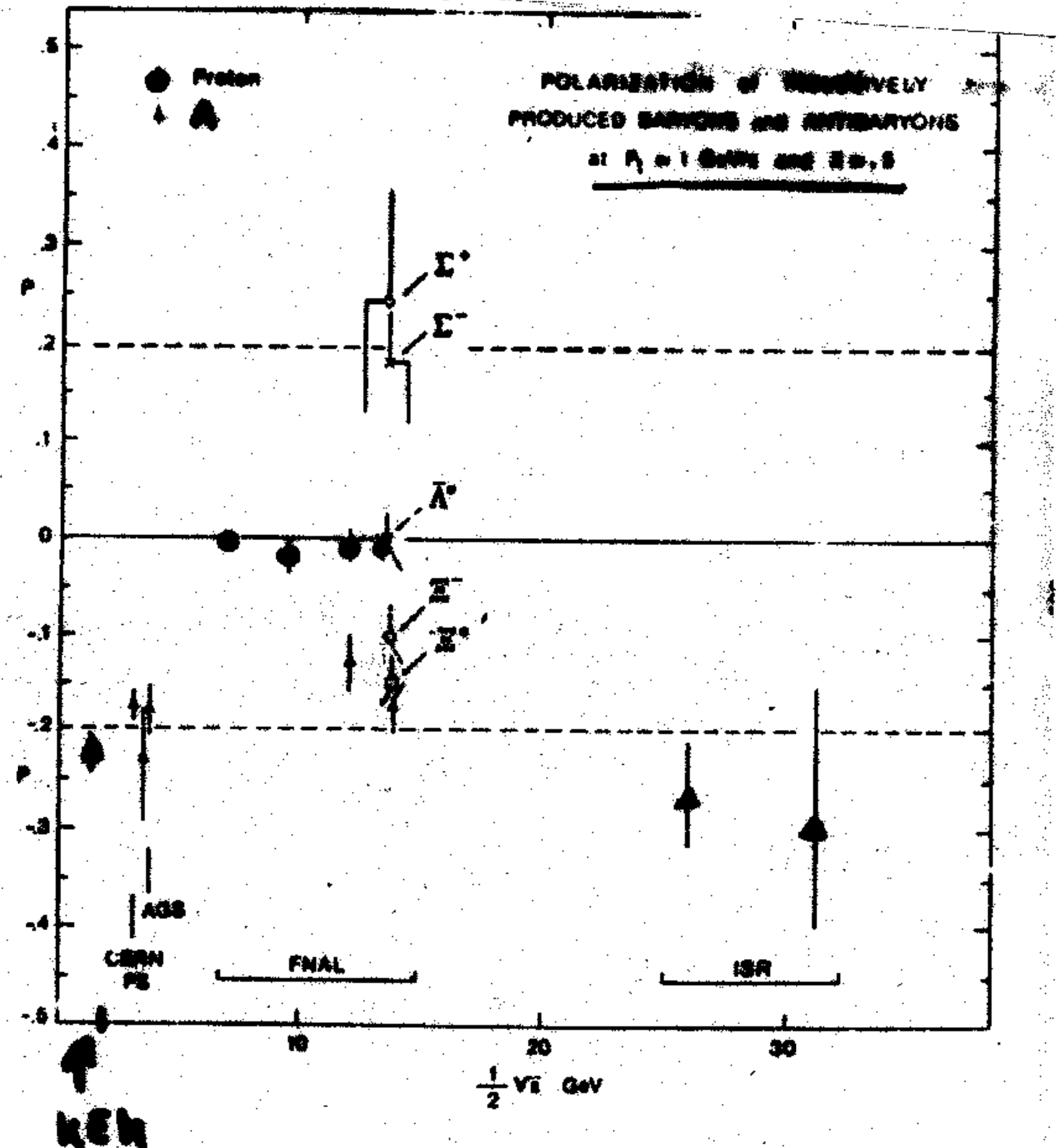


Fig. 6b

in $pp \to p^{\uparrow}X$ NO EFFECT !

A. Morelos et al. PRL 71, 2172 (1993)

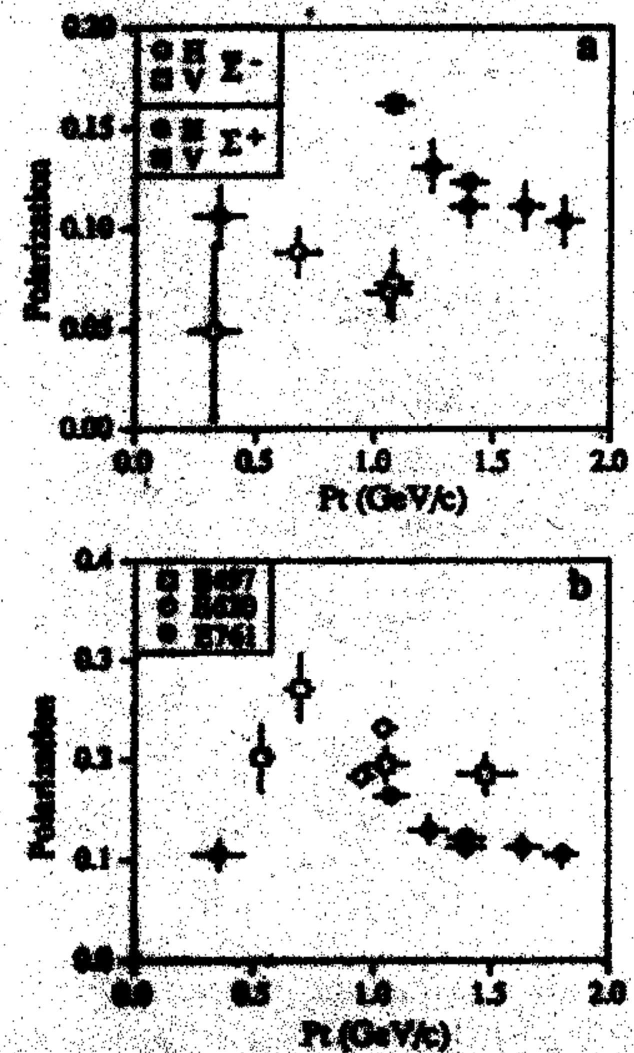
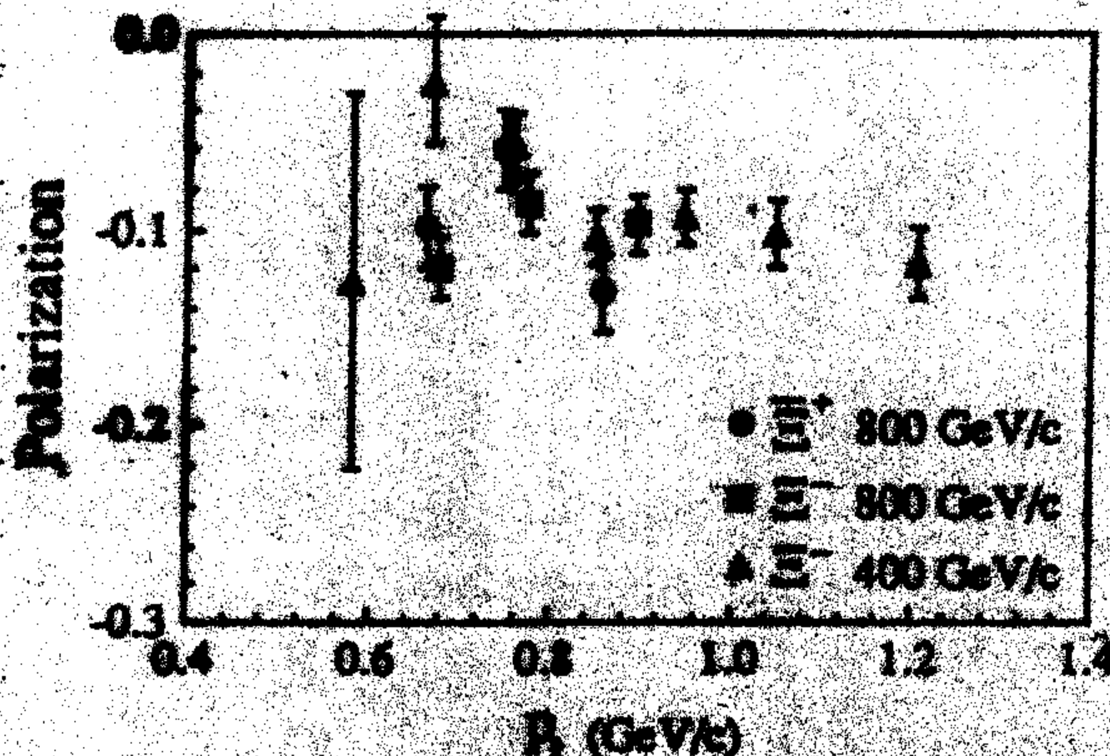


FIG. 1. (a) Comparison of polarizations for Σ^+ and Σ^- as a function of p_t from this experiment. (b) Polarization of Σ^+ as a function of p_t and comparison with previous measurements at 400-GeV incident proton energy. Note that the E620 data are from production on a Be target. The others are a Cu target. All of these data are in the range $0.47 < x_F < 0.53$.

P. M. Ho et al. PRL 65, 1713 (199



. 4. Comparison of the Ξ^+ and Ξ^- polarization from periment with that of the Ξ^- data taken at 400 GeV/*c* production angle of 5 mrad. (See Ramsika *et al.*, Ref.

SOME THEORETICAL IDEAS FOR SINGLE SPIN ASYMMETRIES (P_Y, A_N) IN ONE PARTICLE INCLUSIVE PRODUCTIO[N]

CONSIDER $a + b \to c^{\uparrow} + X$

$$P_c(\sqrt{s}, x_F^c, p_T^c) = \frac{d\sigma_c^{\uparrow} - d\sigma_c^{\downarrow}}{d\sigma_c^{\uparrow} + d\sigma_c^{\downarrow}} = \frac{\mathrm{Im}(f_+ f_-^*)}{d\sigma}$$

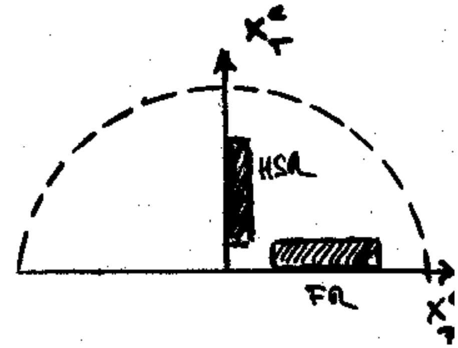
$x_F^c = 2p_L^c/\sqrt{s}$

(SAME FOR $a^{\uparrow} + b \to c + X$, CALL A_N)

↑ NEED FLIP AND PHASE DI[FFERENCE]

P_c OR $A_N \neq 0$ NON TRIVIAL ⇒ HIGH COHERENCE IN MANY EXCL. CHANN[ELS]

TWO DIFFERENT KINEMATIC REGIONS



α) FRAGMENTATION REGION (FR)

i.e. $0.3 \leq x_F^c \leq 0.8$,

$x_T^c = 2p_T^c/\sqrt{s}$ $\quad x_T^c \leq 0.1 - 0.15$

β) HARD SCATT. REGION (HSR)

i.e. $x_F^c \sim 0$,

$x_T^c \geq 0.15$

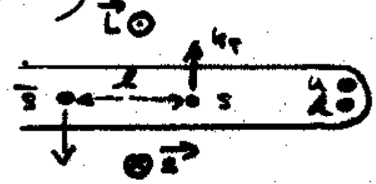
WE EXPECT DIFFERENT DYNAMICS AT WORK

- MOST OF THE HYPERON DATA ARE IN THE FR

FR I) SEMI CLASSICAL ARGUMENTS (NO PHASE)

a) LUND MODEL (PHYS. REP. 97 1983, 31)

IN THE FRAGMENTATION $p \to \Lambda$
s QUARK IS PRODUCED IN COLOR
FLUX TUBE WITH COMPENSATION
MECHANISM FOR $k_T \neq 0$, SINCE
$\vec{J} = \vec{L} + \vec{S}$ IS CONSERVED AND $|\vec{L}| \propto k_T l$



PREDICTS $P_\Lambda < 0$ IF ASSUME SU(6) OK, i.e. $\vec{S}_s = \vec{S}_\Lambda$
((ud) S-STATE)

MOREOVER P_Λ GROWS WITH k_T

AND $P_\Sigma > 0$ FROM SU(6) BECAUSE (uu) or (dd) p-STATE

OK QUALITATIVELY BUT WHAT ABOUT Λ, Σ SPECTRUM?

IT'S IMPORTANT TO DESCRIBE $d\sigma$ AS WELL

e.g. Λ AND Ξ HAVE SAME P BUT VERY $\neq$ $d\sigma$

MOREOVER IS THIS SIMPLE PICTURE CORRECT?

IF SO, s AND $\bar{s}$ SHOULD MOVE INTO OPPOSITE DIRECTIONS. BY LOOKING AT FINAL STATE $K^+\Lambda$ THE DIRECTION OF K^+ GIVES DIRECTION OF $\bar{s}$ AND SHOULD SEE $P_\Lambda \neq 0$ ONLY WHEN K^+ AND Λ ARE IN OPPOSITE HEMISPHERE

E766 AT BNL (27.5 GeV/c)

EXTENSIVE STUDIES OF EXCLUSIVE CHANNELS

$pp \to p\Lambda K^+\pi^+\pi^-\pi^+\pi^-, \dots$ (PRL 76, 22, 1996)
(PRL 82, 5213, 1999)

AND FOUND GENERAL TREND OF P_Λ IN AGREEMENT WITH INCLUSIVE CASE

$$P_\Lambda(x_F, p_T) = (-0.443 \pm 0.037)\, x_F\, p_T$$

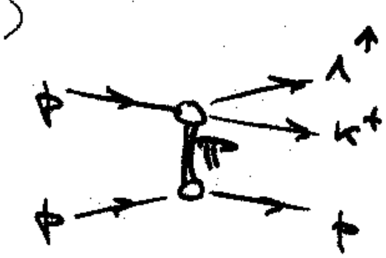
<u>BUT</u> NO SUCH CORRELATION BETWEEN DIRECTION OF K^+ AND P_Λ

WHAT TO CONCLUDE?

IT SEEMS THAT THIS HAS TO BE INVESTIGATED FURTHER AT HIGHER ENERGY

THERE IS A "SLIGHT" INDICATION FOR SUCH A CORRELATION AT ISR ENERGY $\sqrt{s} = 63$ GeV (HENKES et al. PL B283, 1992, 155) WHERE A LARGE NEGATIVE P_Λ (−60%) HAS BEEN OBSERVED IN THE SIMPLE EXCLUSIVE CHANNEL $pp \to (K^+\Lambda)p$
(CONSISTENT WITH E690 at $\sqrt{s} \simeq 40$ GeV)

P_Λ COULD BE RELATED TO A DIFFRACTIVE MECHANISM WITH $I\!P$ EXCHANGE ??

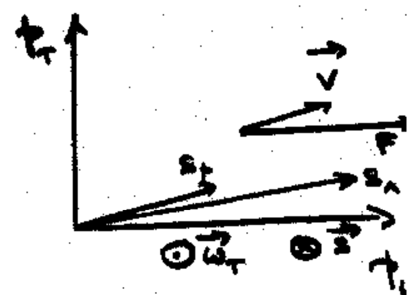


$\Rightarrow$ NO ENERGY DEP.

b) THOMAS PRECESSION (DE GRAND, MIETTINEN, PRD 24 2419, 1981)
+ PRD 32, 2445 1985

IN THE FRAGMENTATION $p \to \Lambda$ s QUARK IS ACCELERATED WITH $\vec{F}$ (UNSPECIFIED) SO GET T.P. $\vec{\omega}_T \sim \vec{F} \times \vec{v}$

WANT TO MINIMIZE THE ENERGY $\vec{\omega}_T \cdot \vec{s}$



SO AGAIN PREDICTS $P_\Lambda < 0$

MOREOVER PREDICTS SIGN DIFF. BETWEEN $pp \to \Lambda^\uparrow X$ AND $K^-p \to \Lambda X$ BECAUSE NOW s QUARK COMING FROM K^- IS DECCELERATED

HOWEVER $P_{K^- \to \Lambda} \simeq -2\, P_{p \to \Lambda}$, SO NEED A SCHEME MORE INVOLVED WITH SEVERAL PARAMETERS

S. K. Gourlay et al. 176 GeV/c

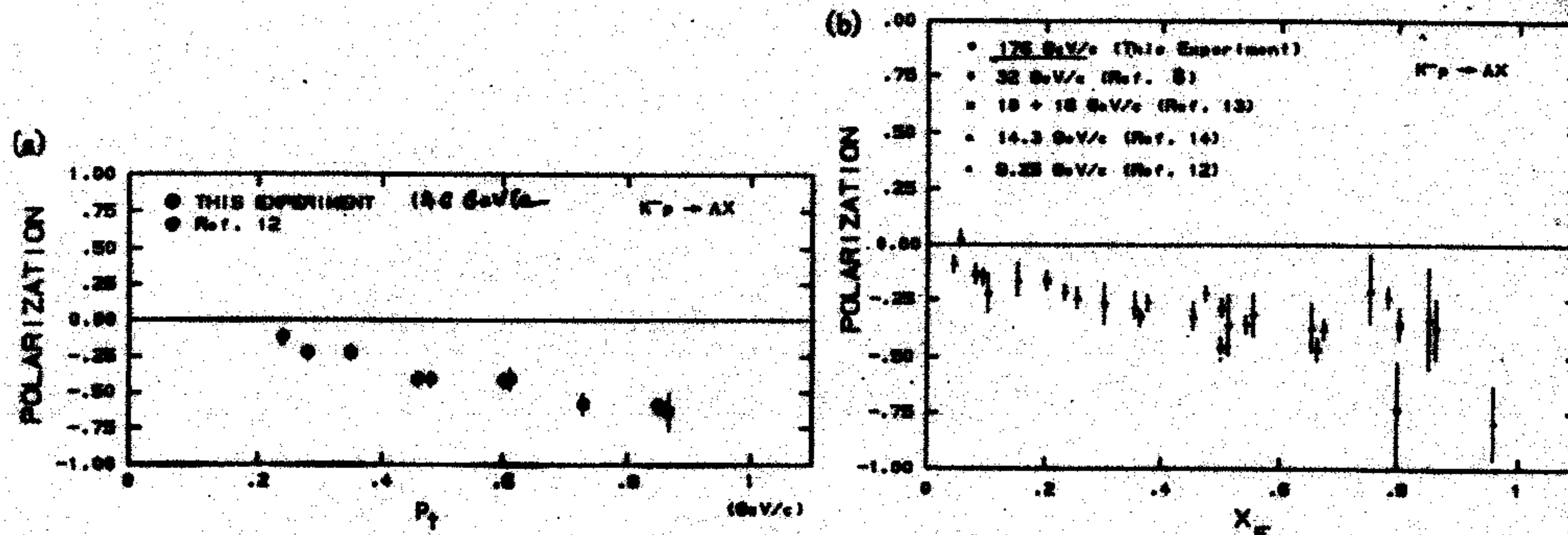


FIG. 5. (a) Lambda polarization from $K^- + p \rightarrow \Lambda + x$ and the 8.25-GeV/c data of Ref. 12 plotted vs p_t. (b) Lambda polarization from $K^- + P \rightarrow \Lambda + x$ and the data from Refs. 13 and 14 plotted vs x_F.

$$\vec{n} = \vec{p}_\Lambda \times \vec{p}_{beam}$$

vides a test of the use of SU(6) wave functions and the as- predicted asymmetry is

TABLE II. Spin-observable predictions using method of Degrand and Miettinen (Ref. 4).

	Reaction	P	DATA	A	D_{NN}	Reference
VVS	$p\to\Lambda$	$-\epsilon$	•	0 ⇐ FAILS	0 ⇐ FAILS	1, 2, and 17
VVS	$p\to\Sigma^+$	$\frac{1}{3}\epsilon+\frac{2}{3}\delta$	•	$\frac{2}{3}(\epsilon+\delta)$	$\frac{2}{3}$	6
VVS	$p\to\Sigma^0$	$\frac{1}{3}\epsilon+\frac{2}{3}\delta$		$\frac{2}{3}(\epsilon+\delta)$ ⇐ FAILS	$\frac{2}{3}$ ⇐	7
VSS	$p\to\Sigma^-$	$\frac{2}{3}\epsilon'-\frac{1}{6}\delta'$	•	$-\frac{1}{3}\epsilon'-\frac{1}{18}\delta'$	$-\frac{2}{9}$	8
VSS	$p\to\Xi^-$	$-\frac{1}{3}\epsilon'-\frac{2}{3}\delta'$	•	$-\frac{1}{3}\epsilon'-\frac{2}{9}\delta'$	$\frac{1}{9}$	10
VSS	$p\to\Xi^0$	$-\frac{1}{3}\epsilon'-\frac{2}{3}\delta'$	•	$\frac{2}{3}\epsilon'+\frac{4}{9}\delta'$	$-\frac{2}{9}$	9
VSS	$p\to\pi^+$ or K^+			$\frac{2}{3}(\epsilon+\epsilon')$ ⇐ FAILS		28
VSS	$p\to\pi^-$ or K^0			$-\frac{1}{3}(\epsilon+\epsilon')$ ⇐		27 and 28
VSS	$K^-\to\Lambda$	ϵ'	•			5
VSS	$K^+\to\bar{\Lambda}$	ϵ'	•			29
VSS	$K^-\to\Sigma^-$, Σ^0, or Σ^+	$-\frac{1}{3}\epsilon'-\frac{2}{3}\delta'$				
VSS	$K^-\to\Xi^-$	$\frac{2}{3}\epsilon'-\frac{1}{6}\delta'$	•			24
VSS	$\pi^+\to\Lambda$	$-\frac{1}{2}\delta'$				
VSS	$\pi^-\to\Lambda$	$-\frac{1}{2}\delta'$	•			30
EXPT Pω0	$p\to\Omega^-$	0 ⇐ ok				
EXPT −7%	$\Lambda\to\Omega^-$	$\frac{5}{6}(\epsilon-\delta+\lambda)\not\Rightarrow 0$		$(\lambda=0)$		
EXPT −7%	$\Xi^0\to\Omega^-$	$\frac{5}{6}(\delta'-\epsilon'+\lambda)\Rightarrow -\frac{5}{4}\epsilon$ ⇐ FAILS				

POSITIVITY CONSTRAINTS FOR $\uparrow p\,\uparrow p \to \uparrow\Lambda X$

(M.G. DONCEL and A. MÉNDEZ, PHYS. LETT. B41 (1972) 83)
(THIS REACTION IS DESCRIBED IN TERMS OF SEVEN SPIN OBS.)

LET'S CONSIDER THREE TRANSVERSE SPIN OBSERVABLES

P_Λ — Λ POLARIZATION

A_N — ANALYZING POWER (OR LEFT-RIGHT ASYM.)

D_{NN} — DEPOLARIZATION PARAMETER (SPIN TRANSFER)

POSITIVITY YIELDS THE FOLLOWING CONSTRAINTS WHICH MUST BE SATISFIED FOR ANY KINEMATIC POINT $(x_F, p_T, \sqrt{s})$

① $1 + D_{NN} \geq |P_\Lambda + A_N|$

② $1 - D_{NN} \geq |P_\Lambda - A_N|$

GIVEN D_{NN} ONE CAN FIND THE ALLOWED REGION IN THE PLANE P_Λ, A_N (AND VICE VERSA)

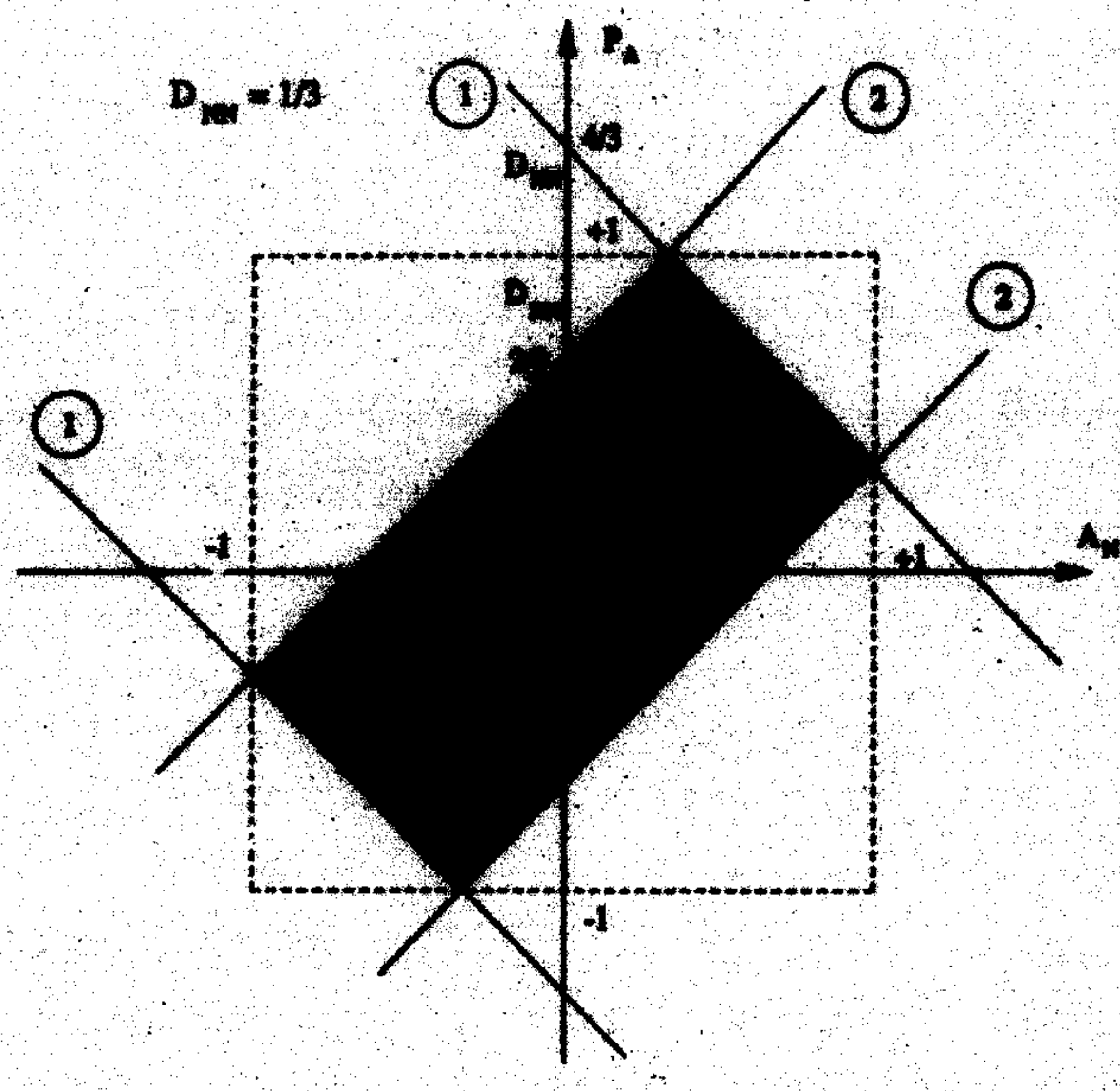
SEE GRAPHS FOR THREE VALUES $D_{NN} = 0, 1/3, 1/2$

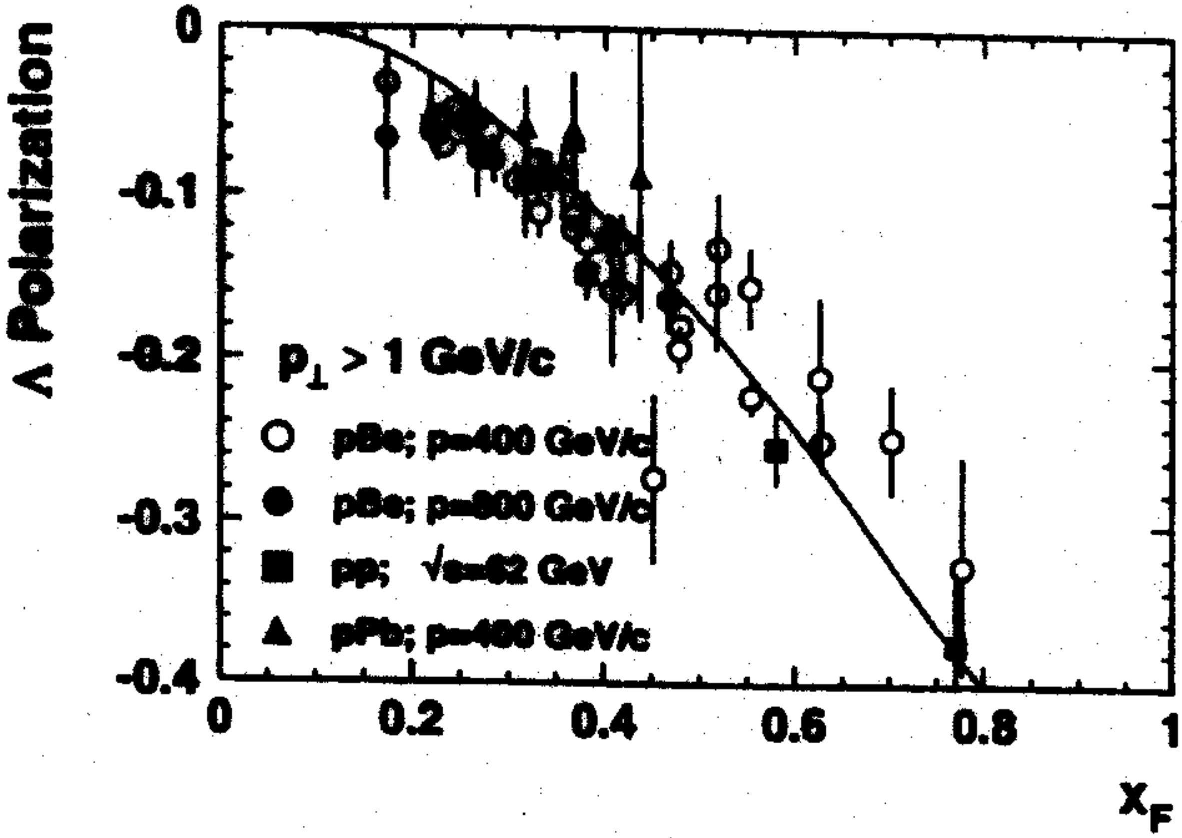
FOR $D_{NN} < 0$ SAME REGION BUT MUST EXCHANGE P_Λ AND A_N. IF $D_{NN} \to 1 \Rightarrow P_\Lambda$ AND $A_N \to 0$

E704 SATISFIES POSITIVITY

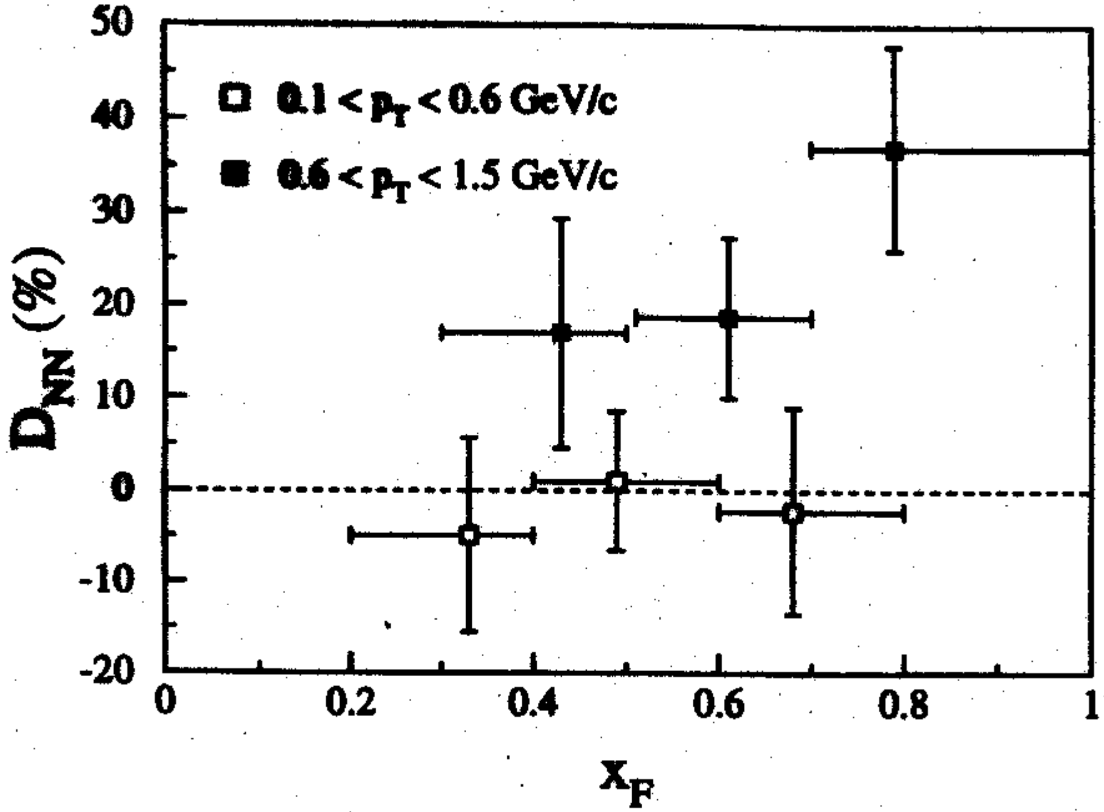
FOR EXAMPLE AT $p_T \sim 1$ GeV/c $x_F \sim 0.8$

$D_{NN} \sim 1/3$ AND THEY HAVE $A_N \sim -10\%$, $P_\Lambda \sim -30\%$


$D_{NW} = 1/3$
P_A
A_N
4/3
+1
-1
+1
-1
1
1
2
2

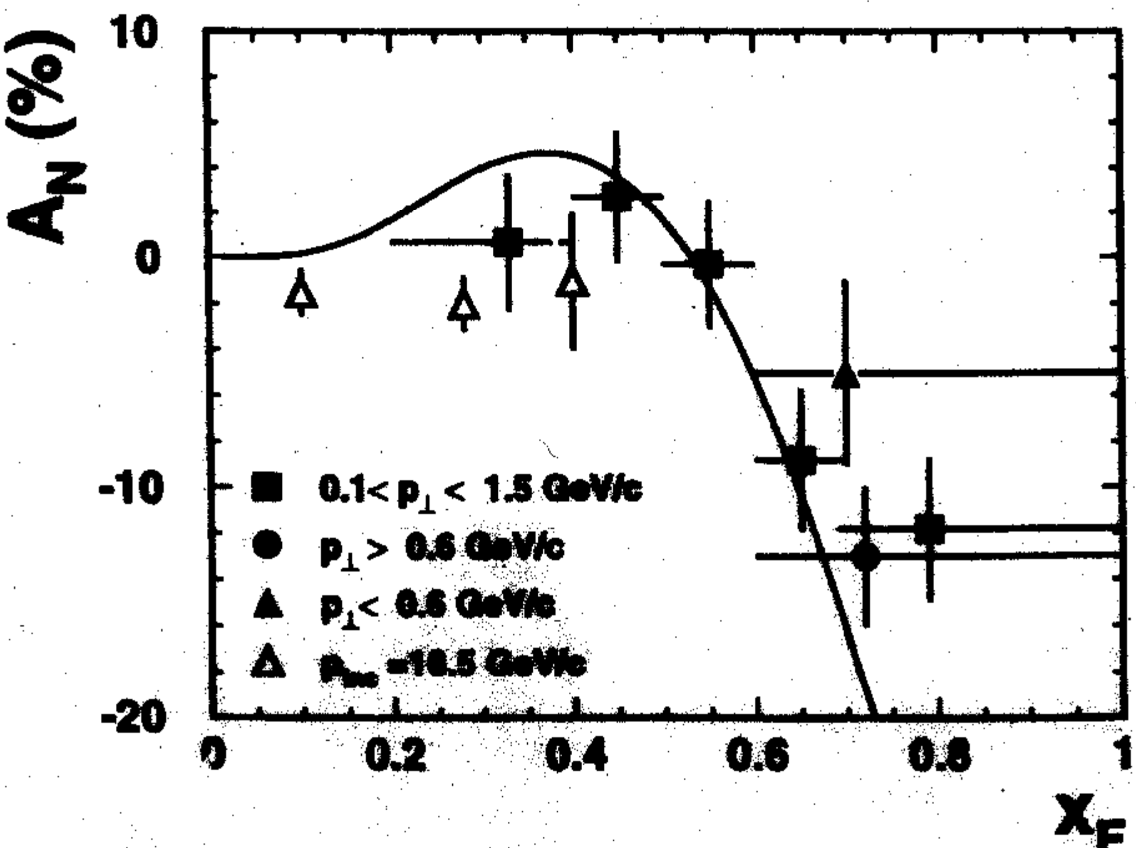


Λ Polarization
0
-0.1
-0.2
-0.3
-0.4
0
0.2
0.4
0.6
0.8
1
x_F
$p_\perp$ > 1 GeV/c
pBe; p=400 GeV/c
pBe; p=800 GeV/c
pp; √s=62 GeV
pPb; p=400 GeV/c



E704

PRL 78 4003 (1997)



E704

PRL 75 3073 (1995)

2) BERLIN MODEL (BOROS, LIANG, MENG, PRD 51, 1995, 4867
PRL 79, 1997, 3608)

THEY ARGUE THAT THE EXISTENCE OF $A_N \neq 0$ IN PION INCLUSIVE PROD. IS A STRONG INDICATION FOR ORBITING VALENCE QUARKS IN POL. PROTON.

SO THE ORBITAL MOTION SHOULD BE TAKEN INTO ACCOUNT WITH THE FOLLOWING S.C. PICTURE

- HADRON IS POLARIZED $\rightleftarrows$ ITS VALENCE QUARKS ARE POLARIZED
- SURFACE EFFECT : ONLY VALENCE QUARKS KEEP INFORMATION OF POLARIZATION

DIRECT FORMATION IN INCLUSIVE PION PROD.

$$q_v^a(\uparrow) + q_s^{\bar{a}} \rightarrow \text{MESON}$$

ARE "GOING LEFT" DOWNSTREAM

up → left
down → right

SO IN $p^{\uparrow} p \rightarrow \pi^+ X$ SINCE $\pi^+ = (u_v \bar{d}_s)$

ONE SHOULD HAVE $A_N > 0$

IN $p^{\uparrow} p \rightarrow \pi^- X$ SINCE $\pi^- = (d_v \bar{u}_s)$

ONE SHOULD HAVE $A_N < 0$

MOREOVER THEY ASSUME

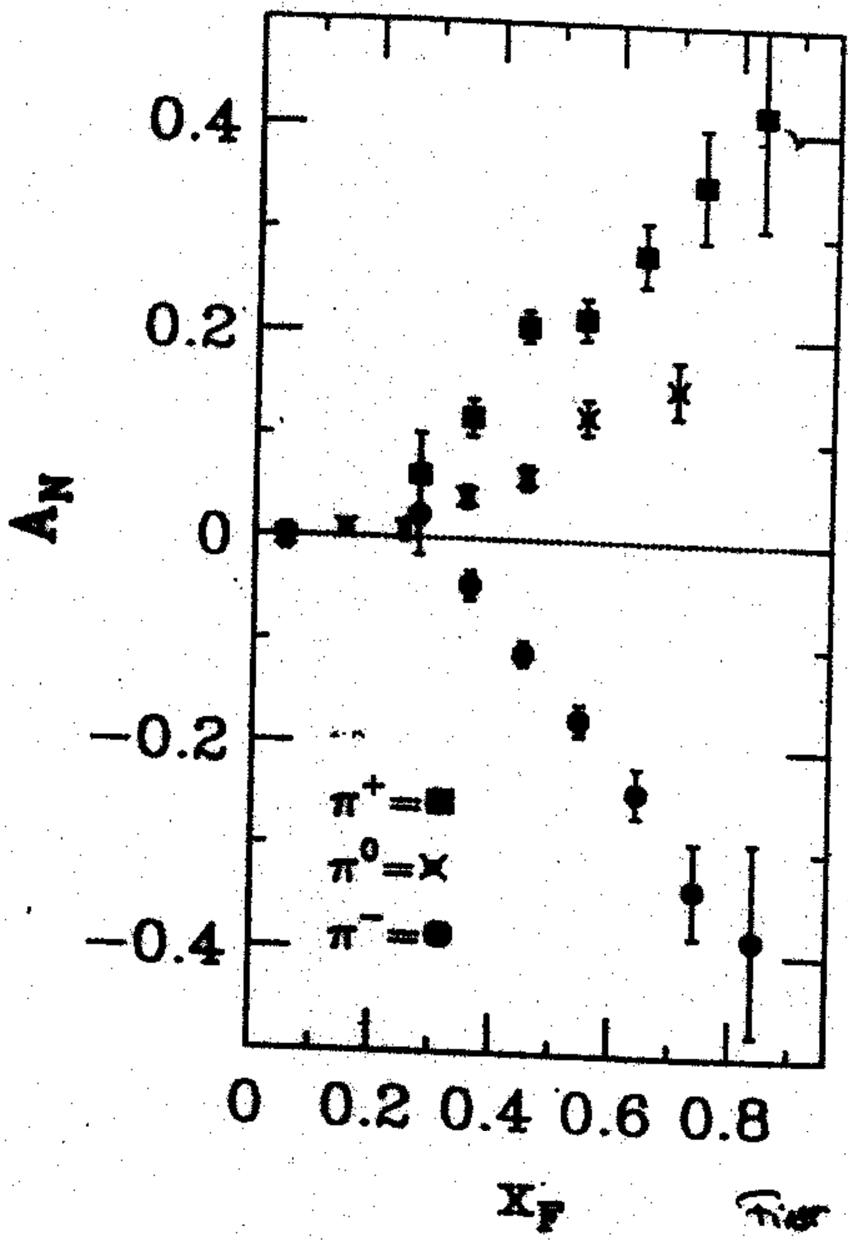
- x_F OF h PRODUCED IS x OF $q_v^{\uparrow}$ POL.
- $\Delta q_T = \Delta q$ AND GET APPROXIMATELY

$$A_N(\pi^+) \sim \Delta u_v(x_F)$$

$$A_N(\pi^-) \sim \Delta d_v(x_F)$$

NO SPECTRUM , NO p_T DEPENDENCE

$2\sigma_0 A_N^0 = \sigma_+ A_N^+ + \sigma_- A_N^-$ (isospin relation)



First in CERN Courier March 91 !!

FIG. 4

Later D.L. Adams et al. PL B264 (1991) 462

(E704 FNAL) p↑ 200 GeV

These reactions can be used as polarimeters at H.E. !!

OTHER CONSEQUENCES

? $A_N(K^+) = A_N(\pi^+)$ $K^+ = (u_v \bar{s})$

? $A_N(K^-) = 0$ $K^- = (s \bar{u}_s)$

(OR) $A_N(K_s^0) = A_N(\pi^-)$ $K_s^0 = (d_v \bar{s})$

? $A_N(\bar{K}_s^0) = 0$ $\bar{K}_s^0 = (s \bar{d}_s)$

AND MORE FOR POL. NEUTRON TARGETS

$$A_N(p n^\uparrow \to \pi^\pm) = A_N(p^\uparrow p \to \pi^\mp)$$

$x_F < 0$ $x_F > 0$

$$A_N(p n^\uparrow \to \pi^0) = A_N(p^\uparrow p \to \pi^0)$$

FOR HYPERON INCLUSIVE PRODUCTION

$$p^\uparrow + p \to \Lambda + X$$

THREE POSSIBILITIES OF DIRECT FORMATION

(a) $(u_v d_v)^P + (s_s)^T \to \Lambda$ DOMINATES $x_F > 0.6$

(b) $(u_v)^P + (d_s s_s)^T \to \Lambda$ " $x_F \sim 0.4$ $A_N >$

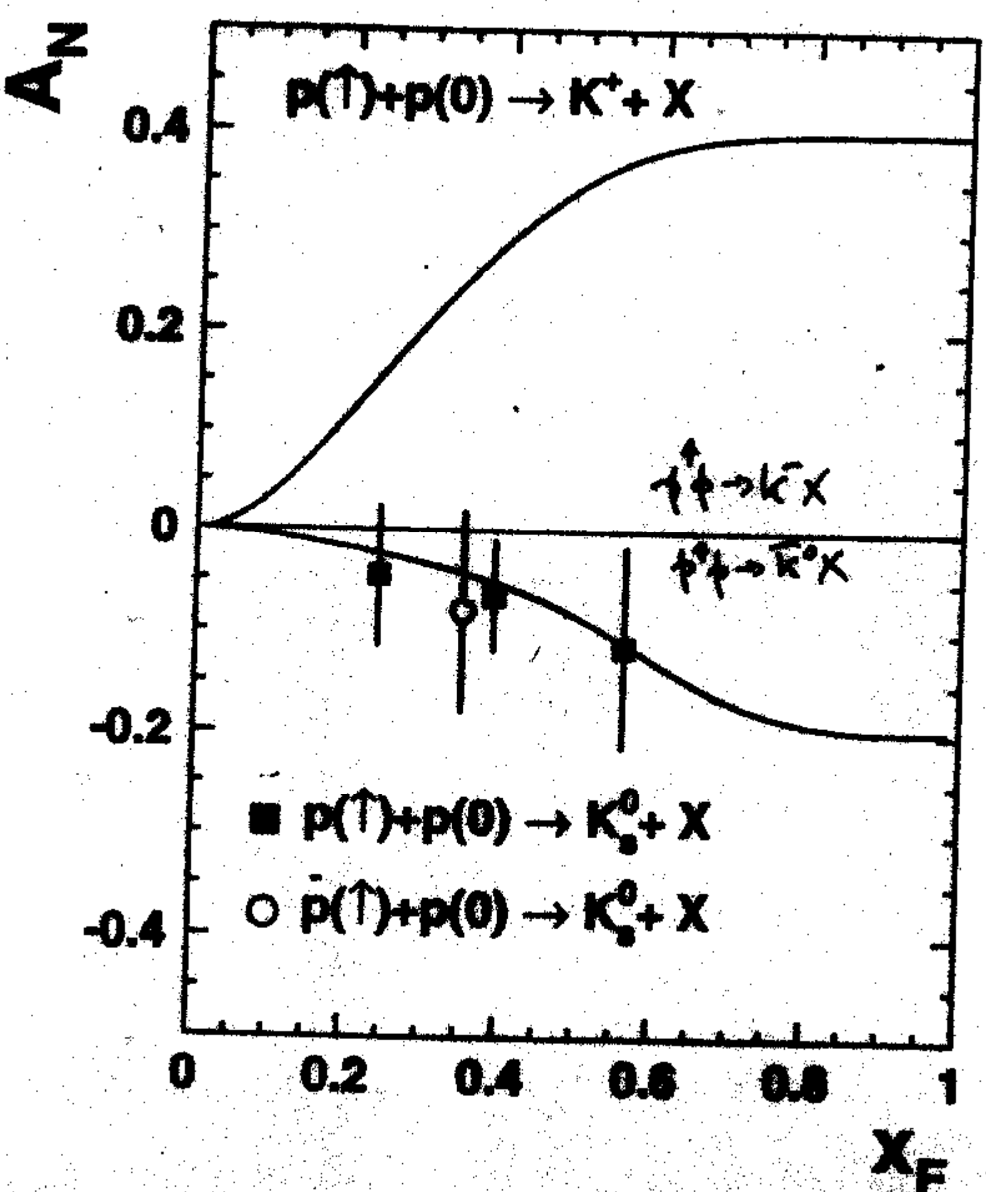
(c) $(d_v)^P + (u_s s_s)^T \to \Lambda$ $A_N <$

BUT (a) IS ASSOCIATED TO $(u_v)^P + (\bar{s}_s)^T \to K^+$
OR $(u_v)^P + (\bar{d}_s)^T \to \pi^+$

SO K^+ OR π^+ "GOING LEFT" SO Λ GOING RIGHT

$A_N < 0$

NOT FULLY CONVINCING AND WHAT ABOUT OTHER HYPERONS (ANTI HYPERONS) !?



E704
200 GeV/c

Fig 2

-65
results

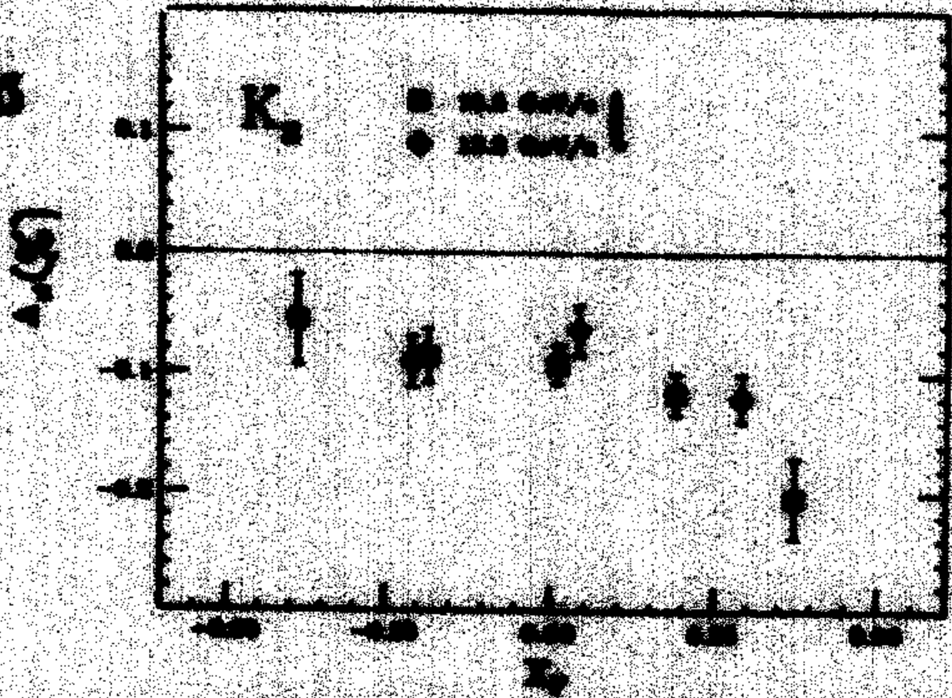


FIG. 3. [illegible] for K^0_S [illegible] function of Feynman x [illegible]

K^0_S

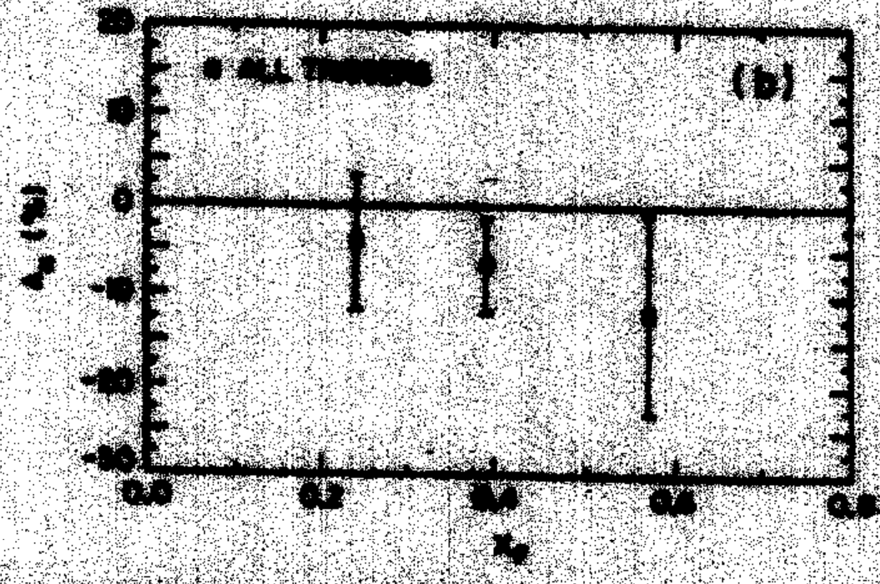


Figure 3.7 [illegible]

E 704
200 GeV/c

NO ENERGY
DEPENDENCE

BALESTRA et al. Phys. Rev. Lett. 83 1534 (1999)

$\vec{p}p$ AT 3.67 GeV/c

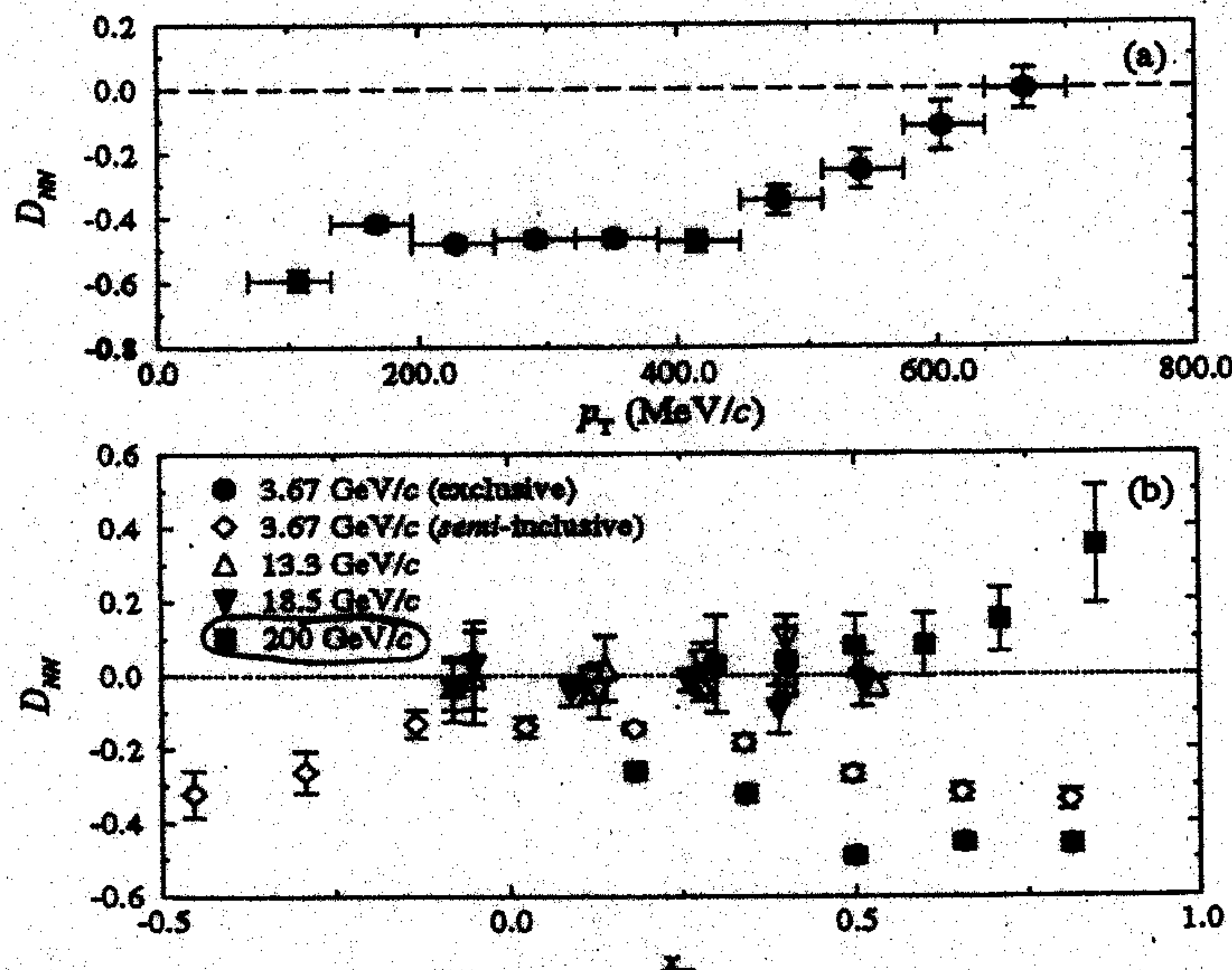
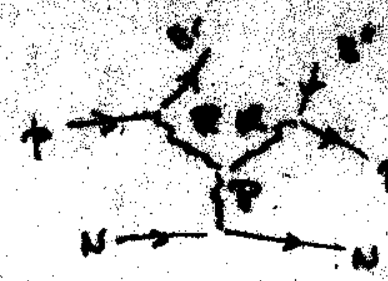


FIG. 3. (a) Measured D_{NN} values vs. transverse momentum transfer for the *exclusive* $\vec{p}p \rightarrow pK^+\vec{\Lambda}$ reaction. The horizontal error bars reflect the width of the p_T bins analyzed. The vertical error bars reflect statistical uncertainties only. (b) D_{NN} as a function of x_F for the present *exclusive* Λ production and for *inclusive* Λ production at various higher incident momenta from Refs. [14,15]. Also shown for comparison are the *semi*-inclusive results from the present data.

II) REGGE TYPE MODELS (NON QCD [illegible]

a) THE MILANO MODEL ([illegible], [illegible], [illegible] PL B [illegible], 199[illegible], [illegible])

BASED ON A TRIPLE - REGGE EXCHANGE MECHANISM FOR HYPERON PRODUCTION



+ RESONANCE INTERFERENCE

NEED TO CONSIDER THREE PRODUCTION MECHANISMS

GET A FAIRLY GOOD DESCRIPTION OF THE SPECTRUM

AND P_Λ BUT NOT SO WELL FOR P_Σ.

PROBABLY HARD TO EXTEND TO OTHER HYPERON (Ξ^-, Ξ^0, ...) BUT WORKS ALSO FOR A_N IN π PRODUCTION

b) THE ONE - PION EXCHANGE MODEL (S.S., N.TÖRNQVIST PRL 68, 1992, 909)

WE ASSUME FRAGMENTATION IS DOMINATED BY A REGGEIZED ONE - PION EXCHANGE SO $pp \to K\Lambda X$

AND NEED TO INTEGRATE OVER KAON PHASE SPACE

NEED $\frac{d\sigma}{dt}$ OF BINARY $\pi p \to K\Lambda$ IN RES. REGION UP TO 10 GeV OR SO.

$\sigma_{tot}(\pi p)$

OFF SHELL PION PROPAGATOR

PREDICTS ABSOLUTE NORMALISATION OF $d\sigma$ WHICH HAS SCALING

GO TO P_Λ AND RELATE IT TO P OF THE BINARY

GET REASONABLE DESCRIPTION AND FIND FROM LOW ENERGY THAT $P_\Lambda \simeq - P_{\Sigma^+}$

CAN EXTEND TO A_N IN PION PRODUCTION

BUT NO WAY TO EXTEND IT TO $K^- p \to \Lambda K$

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essentially no role in the x_F or p_T dependence of the polarization.

In order to elucidate the origin of the sign of the polarization we recall in schematic form eq. (19) of ref. [9]:

$$\Delta\sigma \propto g_{\Sigma\Lambda\pi} g_{\Sigma^*\Lambda\pi} \beta^{\pi\Sigma^*}_{++} \beta^{\pi\Sigma^{**}}_{+-} , \qquad (10)$$

where we have highlighted the coupling-constant dependence of the dominant term. Now SU(3) symmetry implies that $g_{\Sigma\Lambda\pi}$ and $g_{\Sigma^*\Lambda\pi}$ have opposite signs [9], while duality implies that the two Regge residues, β, have the same signs and thus the overall sign for the Λ^0 polarization is negative. In the case Σ^+ production the Regge residues are the same but the relevant couplings, g, have the same signs and thus the overall sign is positive; for Σ^- some cancellation occurs but the dominant contribution is as for Σ^+.

In fig. 5 our results for the Λ^0 polarization are shown as a function of p_T for various values of x_F compared with the experimental data [11,18]. Over the range of x_F presented (for lower values the model is not applicable and at higher values the data are too inaccurate to permit serious comparison) one sees the more-or-less linear variation of the polarization seen experimentally [2].

In fig. 6 the same comparison with data [19] is made for Σ's. Here agreement is not so good, however in the present calculation we have not yet taken into account the contribution of the $\Lambda(1405)$ which decays 100% into $\Sigma\pi$, a full calculation will be presented in ref. [16]. As for $\bar{\Lambda}^0$ polarization, our model, being based on fragmentation, is naturally consistent

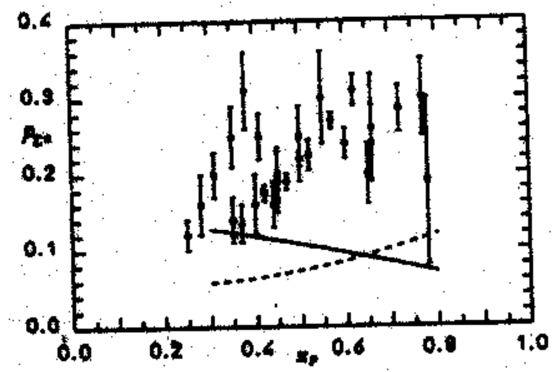

Fig. 6. Our results for the Σ^+ (continuous) and Σ^- (dashed) polarization compared with the data, ○ and ● respectively (for $p_T > 0.5$ GeV/c, see ref. [19]).

with the negligible value observed experimentally [20].

As is clearly seen from figs. 5 and 6 we have been able to give a rather satisfactory explanation of the large polarization observed at high p_T for the hyperons (Λ^0 and $\Sigma^{0,\pm}$). One might wonder if this mechanism would not give similar results for the proton polarization which is known to be negligible [21]. Little thought is required to realize that the Regge model can easily explain this result. Indeed the leading Regge exchange in this region is well known to be the diffractive, pomeron singularity which will lead to domination by the direct production channel, thus suppressing any possible polarization. No calculation has been attempted for Ξ production [22] since it would require a rather elaborate extension of the Regge model. One might worry that the mechanism responsible for Ξ polarization might in some way distort our predictions for the Λ^0 case. However, since the production cross section for Ξ in this kinematical region is between one and two orders of magnitude smaller we can safely neglect this possibility.

We note that with the rather obvious extension to pion production (i.e., by including the baryon resonances coupling to the ρ and ω trajectories) one could hope to explain the not unrelated π^0 asymmetry [23]; this we intend to examine in a future publication.

In conclusion we would like to stress that we have produced a full explanation of the hitherto puzzling results in hyperon polarization entirely in terms of well-known and familiar aspects of hadron dynamics without recourse to ad hoc assumptions as to the

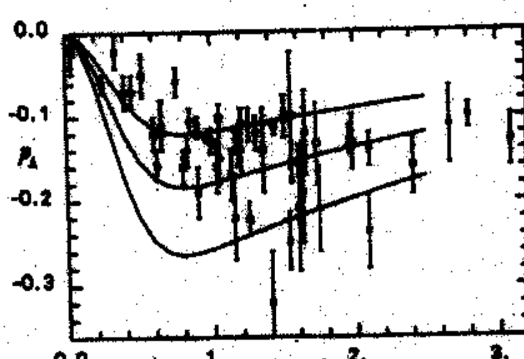

Fig. 5. Our results for the Λ^0 polarization as a function of p_T for x_F=0.40, 0.55, 0.70 (upper, middle and lower curves respectively) compared with the data (●, □, ×) of refs. [11,18].

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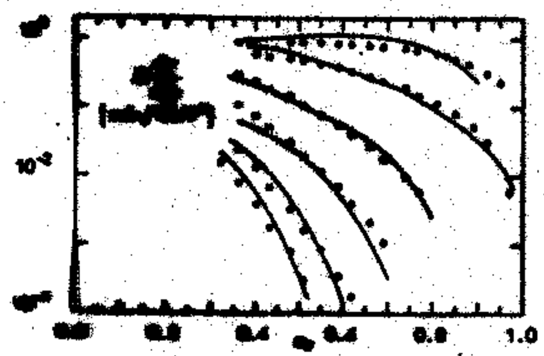

Fig. 2. The triple-Regge prediction of the Λ^0 cross section compared to the data of ref. [11], the curves from top to bottom refer to θ_{lab} = 0.5, 2, 4, 6, 8.1, 10 mrad.

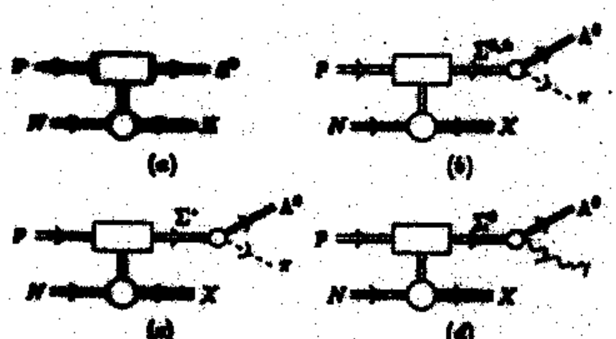

Fig. 3. The production channels for $pN \to \Lambda^0 + X$: (a) direct production; (b), (c) intermediate baryon dissociation contributions ($\Sigma^{0,+}$, Σ^*) and (d) Σ^0 electromagnetic decay contribution.

(a) $p+p \to \Lambda^0 + X$ (direct production),

(b) $p+p \to \Sigma^{0,+} + X$
$\quad \hookrightarrow \Lambda^0 + \pi$,

(c) $p+p \to \Sigma^* + X$
$\quad \hookrightarrow \Lambda^0 + \pi$,

(d) $p+P \to \Sigma^0 + X$
$\quad \hookrightarrow \Lambda^0 + \gamma$.

The first of which leads only to unpolarized Λ's, while interference between the second and third can give rise to polarization by virtue of the fact that the amplitude for the second is purely imaginary (since $m_\Sigma < m_\Lambda + m_\pi$) and that of the third is real (since $m_{\Sigma^*} > m_\Lambda + m_\pi$). The fourth process should also contribute to the polarization owing to the intermediate Σ^0 being polarized via an analogous mechanism. In the case of Σ production there will be a direct channel such as (a) for $\Sigma^{0,+}$ only, i.e., the first step of (b); an off-shell contribution from an intermediate Λ^0 analogous to (b); an on-shell contribution as in (c); but clearly no such electromagnetic contribution as (d).

In order to illustrate the underlying physics, in fig. 4, we display the contributions of the various subchannels. We wish to underline that the contributions of channels (b) and (c) are comparable in magnitude to that of the direct production throughout the range of p_T, a vital precondition for large polarization. Indeed there is some experimental evidence that direct Λ^0 production may be somewhat suppressed [17]; this would, of course, slightly enhance the polarization effects we obtain.

It is now a rather simple exercise to calculate the desired polarizations through the introduction of the relevant baryon propagators and couplings as dictated by SU(6) and the known decay widths and branching ratios. Indeed we should stress that at this point there are no free parameters; the polarization dependence (in particular the sign) is now completely determined by the spin structure of the SU(6) wave functions, as list of relevant Regge residues for spin-flip and non-flip amplitudes may be found in ref. [9]. Indeed those parameters used in the model are only relevant to the unpolarized cross-section behaviour, in particular the overall normalization G_0 cancels in the polarization and the two "slope" parameters are common to all four mechanisms and thus play

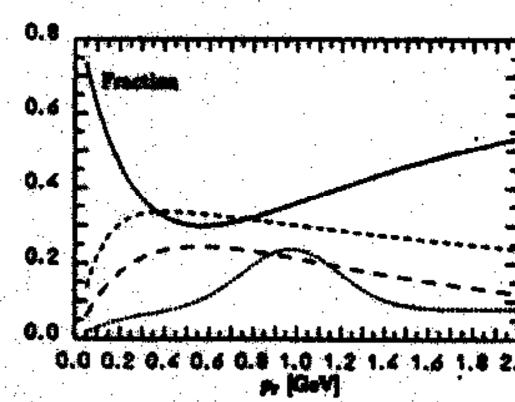

Fig. 4. The estimated fractional contribution of the different mechanisms as a function of p_T for x_F=0.5; direct (continuous), $\Sigma^{0,+}$ (dotted), Σ^* (short dashed) and Σ^0 electromagnetic decay (long dashed).

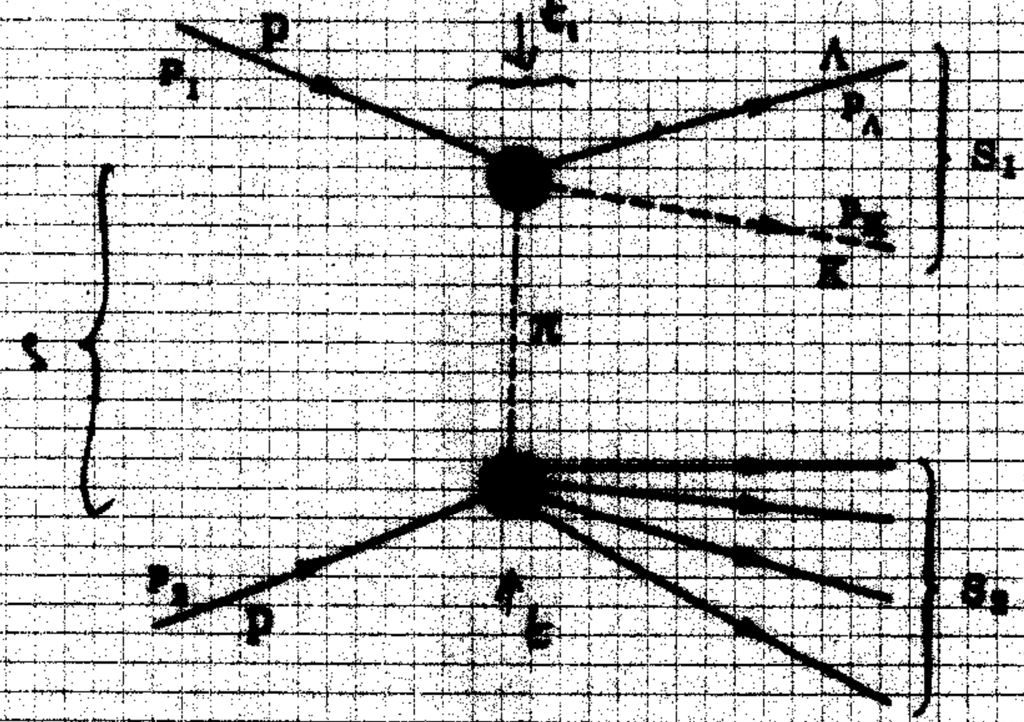

Fig. 1

$s_1 << s$

$s_2 \sim s$

t SMALL, π IS ALMOST ON MASS SHELL

T.S., N. TÖRNQVIST, Phys. Rev. Lett. 37, 907(1976)

ASS

1.6

's at 5 GeV/c.
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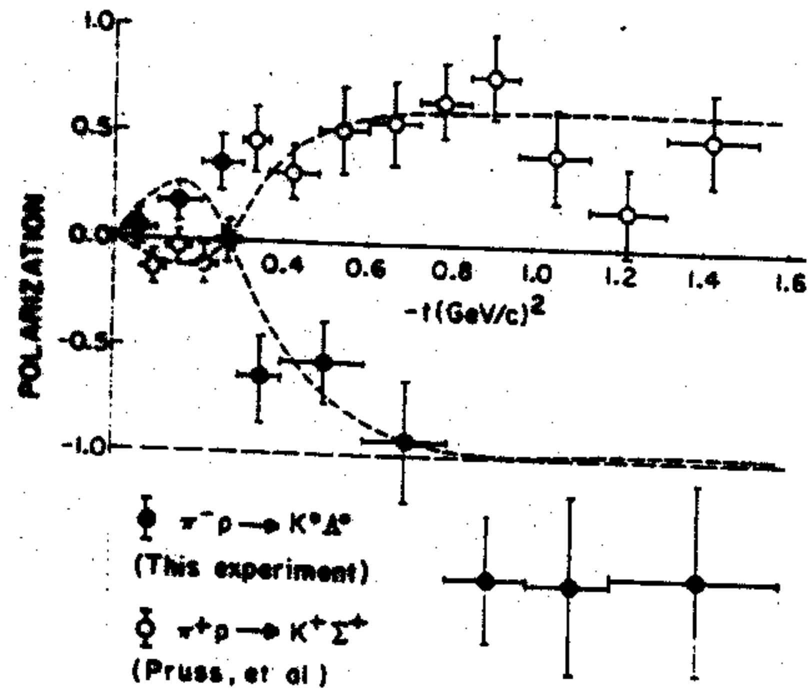
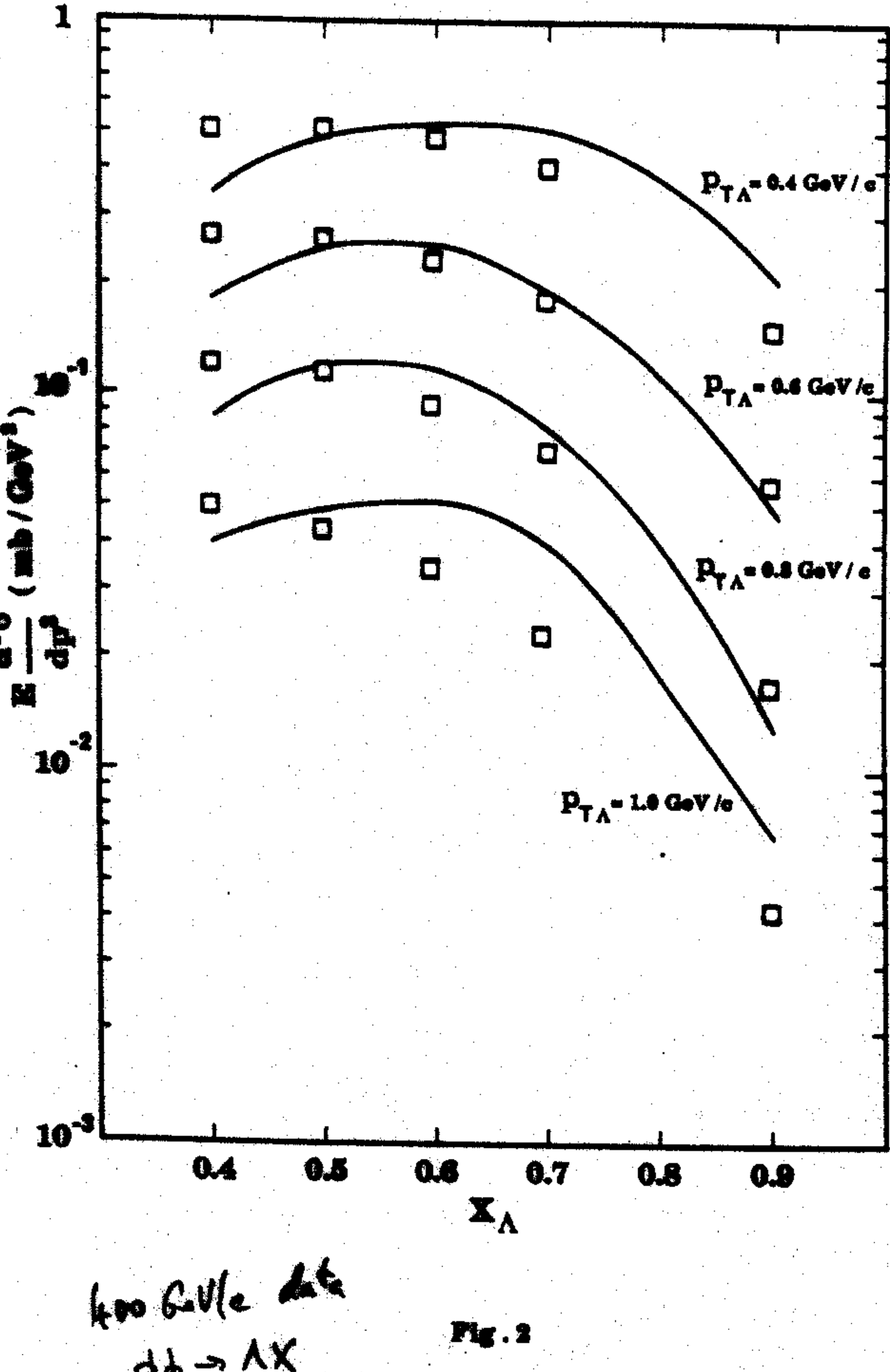


Fig. 3. Polarization in $\pi^- p \to K^0 \Lambda^0$, measured in this experiment, and in $\pi^+ p \to K^+ \Sigma^+$, from ref. [3].

Table 1
Polarization in $\pi^- p \to K^0 \Lambda^0$ at 5 GeV/c

$-t$ Interval $(GeV/c)^2$	Polarization
0.01 – 0.10	0.04 ± 0.08
0.10 – 0.20	0.17 ± 0.09
0.20 – 0.30	0.36 ± 0.14
0.30 – 0.40	−0.63 ± 0.20
0.40 – 0.60	−0.56 ± 0.20
0.60 – 0.80	−0.92 ± 0.30
0.80 – 1.0	−1.57 ± 0.30
1.0 – 1.2	−1.59 ± 0.42
1.2 – 1.6	−1.55 ± 0.45

that this was due to systematic measurement errors was carefully investigated. Monte Carlo calculations showed that only small acceptance corrections to the measured values of the polarization were required (less than 0.01 at all values of t). Events with more than one recoil chamber track could be fitted to the 4C production ...



1
10^{-1}
10^{-2}
10^{-3}
$E\frac{d^3\sigma}{dp^3}$ (mb / GeV^2)
$p_{T\Lambda}$= 0.4 GeV / c
$p_{T\Lambda}$= 0.6 GeV / c
$p_{T\Lambda}$= 0.8 GeV / c
$p_{T\Lambda}$= 1.0 GeV / c
0.4
0.5
0.6
0.7
0.8
0.9
X_Λ
400 GeV/c data
$pp \to \Lambda X$

Fig. 2

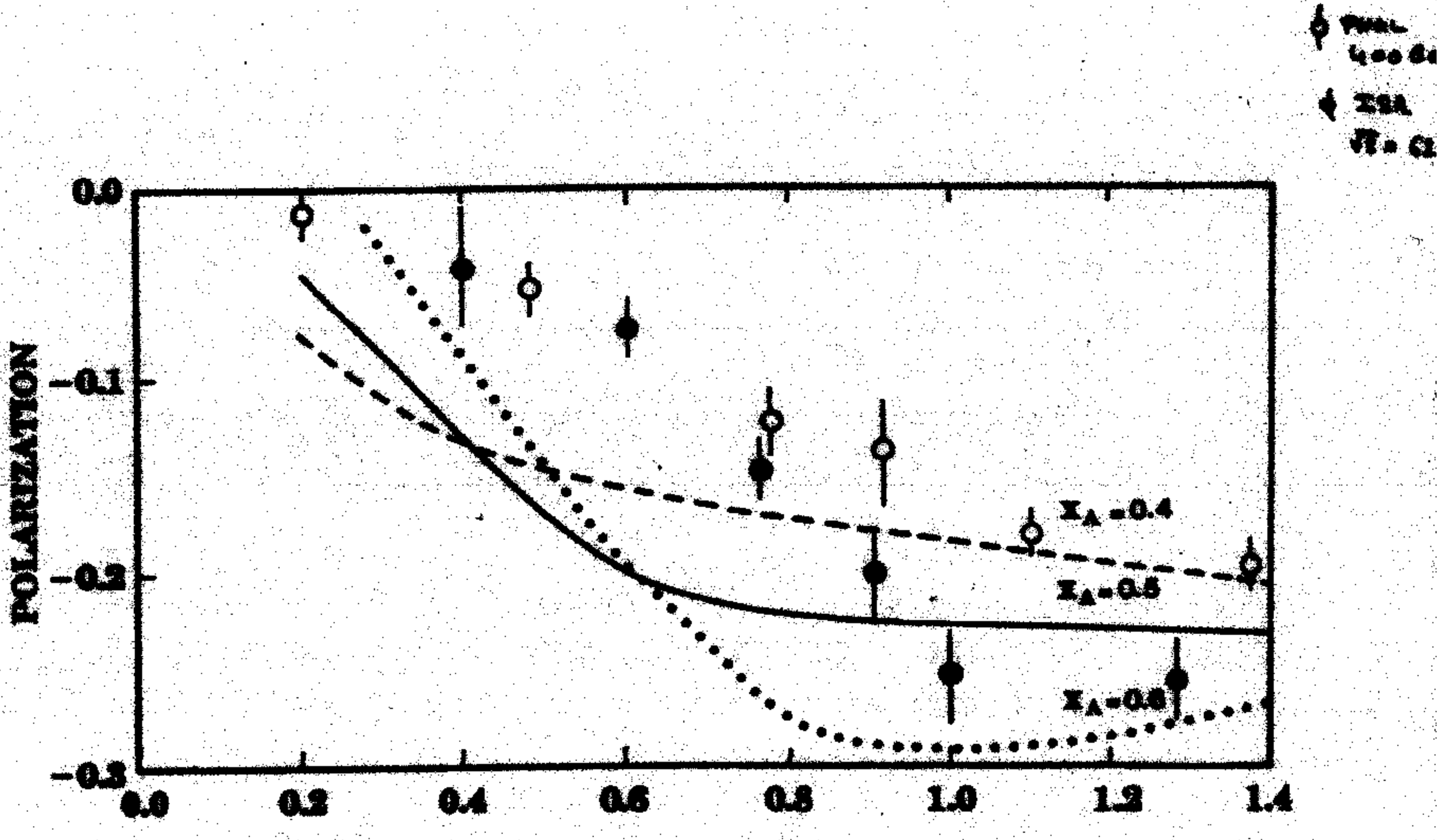

POLARIZATION
0.0
-0.1
-0.2
-0.3
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
x_Λ =0.4
x_Λ =0.5
x_Λ =0.6
$P_{T\Lambda}$ (GeV/c)

Fig. 3

HSR|

NEW IDEAS FOR TRANSVERSE POLAR. IN QCD PARTON MODEL

THE HARD SCATT. REGION INVOLVES SHORT DISTANCE PROCESSES

NAIVELY AND IN QCD TWIST-2 $A_N \sim \frac{\alpha_s m_q}{p_T}$

SO ONE EXPECTS $A_N \sim 0$ { FLIP → m_q; IMAGINARY PART AND PHASE DIFF → α_s }

HOWEVER NOT NECESSARILY

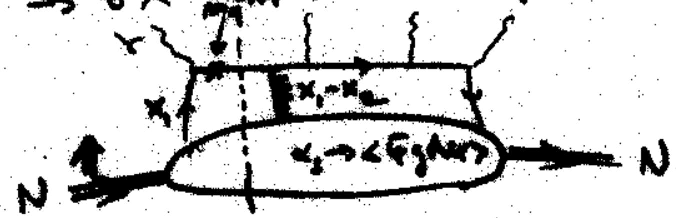
THE CASE IF CONSIDER TWIST-3 CONTRIBUTIONS

INTRODUCE QUARK-GLUON CORRELATORS (NON-LOCAL

A NEW STRUCTURE FUNCTION (A. EFREMOV, O. TERYAEV PL 150B, 1985, 383)

THE SIMPLEST SITUATION

is $\gamma N^{\uparrow} \to \gamma X$ $\frac{1}{x_1 + i\varepsilon} = P\frac{1}{x_1} + i\pi\delta(x_1)$



$$A_N \sim \frac{M\, b(x_1, x_2)}{p_T}$$

$b(x_1, x_2)$ MUST BE EXTRACTED FROM DATA

FOR $p^{\uparrow}p \to \Lambda^{\uparrow}X$ OR $p^{\uparrow}p \to \pi X$ NEED TO INTRODUCE THE FRAGMENTATION FUNCTIONS

D_q^{Λ} OR D_q^{π} IN ADDITION.

VERY LITTLE DATA IN THIS REGION AND THE SITUATION IS UNCLEAR

200 GeV/c $p^{\uparrow}p \rightarrow \gamma X$

(=== 2 q-g correlation hypothesis)

E704

PL B 345 (1995) 569

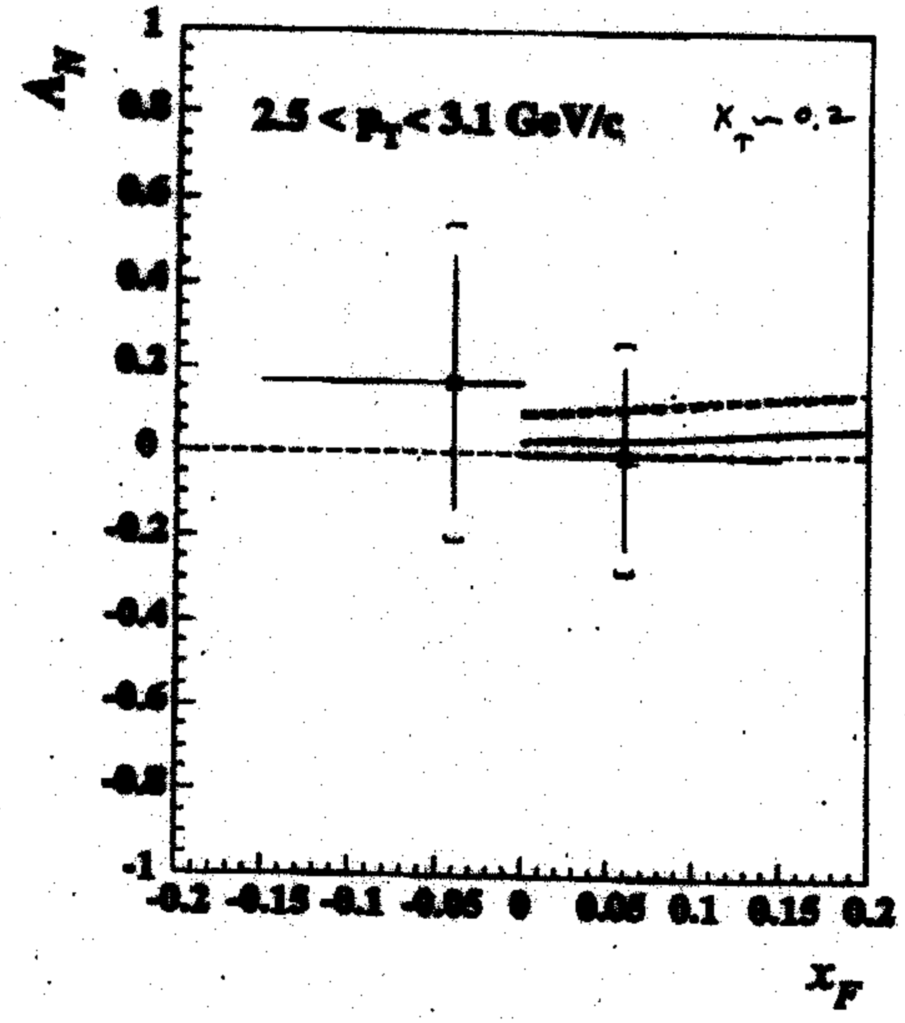
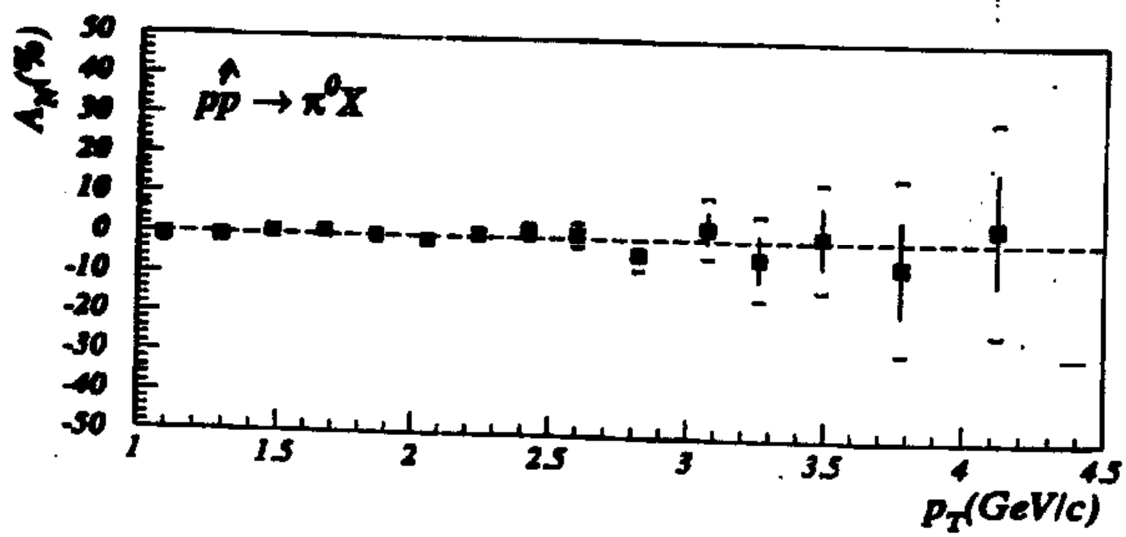
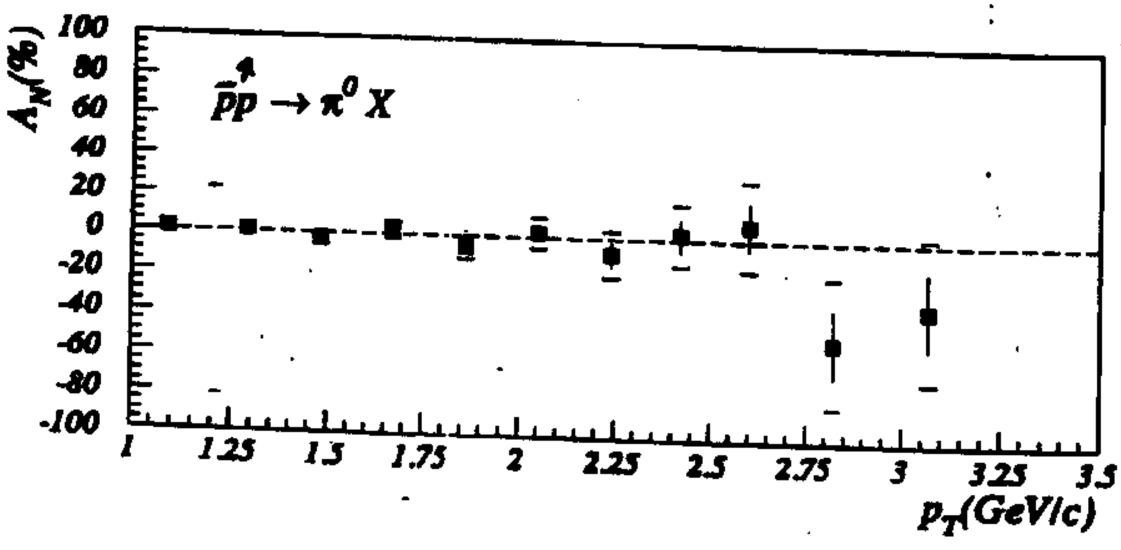


Figure 5

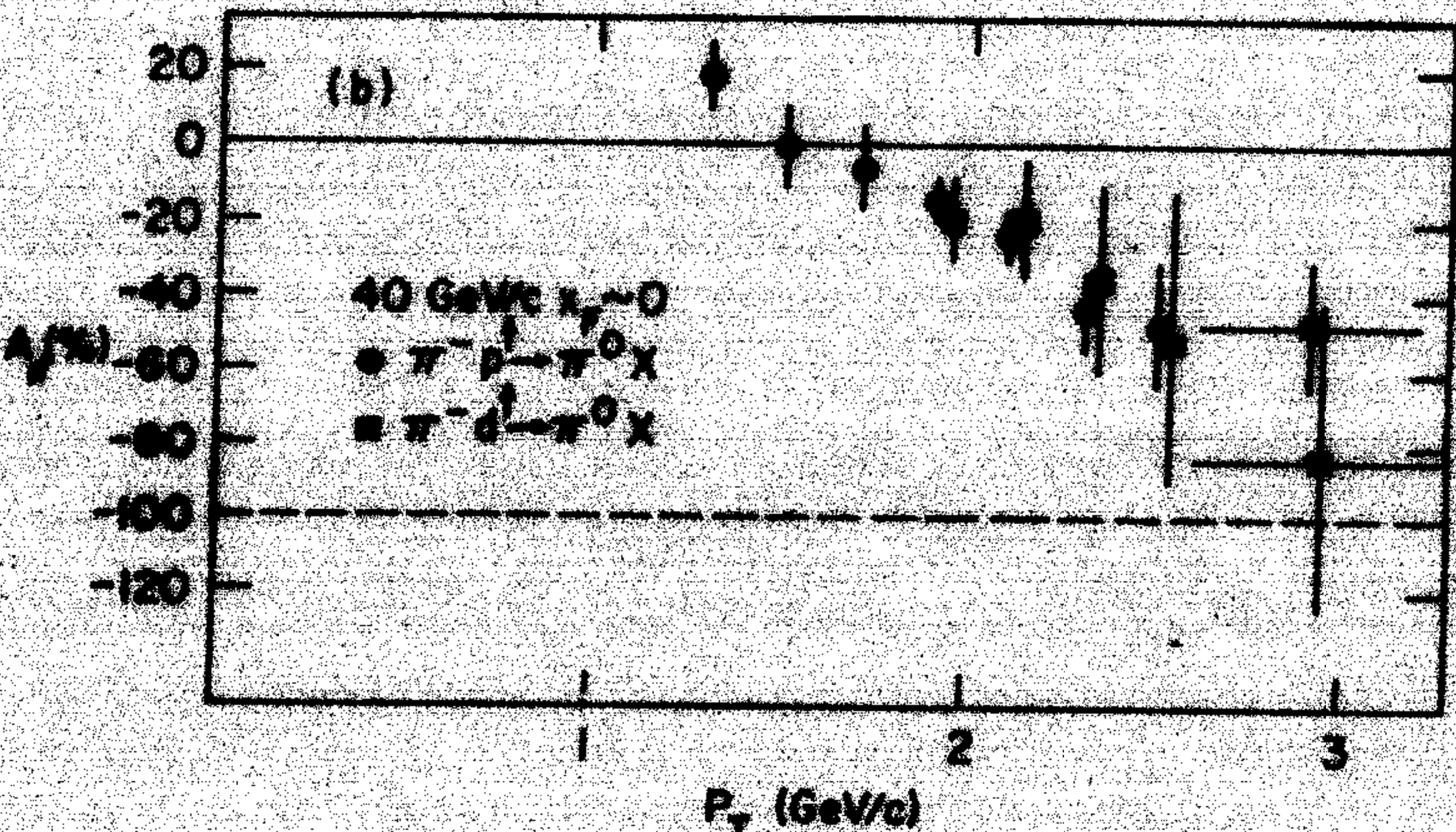
Phys. Rev. D53 4747 (1996) E704

200 GeV/c





V.P. APOKIN et al. PHYS. LETT. 243B, 461 (1990)



SERPUKHOV DATA

THE PUZZLING SITUATION OF HYPERON (ANTI-HYPERON) POLARIZATIONS IN HADRON COLLISIONS IS A VERY IMPORTANT ISSUE OF HIGH ENERGY PHYSICS, WE OUGHT TO UNDERSTAND

I WISH I KNEW THE RELEVANT PHYSICAL PICTURE, IF ANY, WHICH ACCOUNTS FOR ALL THESE FEATURES

RJ (PRIVATE CONVERSATI
1995)