SLAC-PUB-1202
(T-E)
March 1973

Near 90° Scattering in the Channels $\bar{K}^0 p \to \pi^+ \Lambda^0$, $\bar{K}^0 p \to \pi^+ \Sigma^0$ and $K_L^0 p \to K_S^0 p$ from 1.0 to 7.5 GeV/c*

G.W. Brandenburg, W.B. Johnson, D.W.G.S. Leith, J.S. Loos,**
J.A.J. Matthews, F.C. Winkelmann+ and R.J. Yamartino++

Stanford Linear Accelerator Center
Stanford University
Stanford, California 94305

Abstract

Differential cross sections for center of mass scattering angles near 90° are presented for the reactions $\bar{K}^0 p \to \pi^+ \Lambda^0$, $\bar{K}^0 p \to \pi^+ \Sigma^0$ and $K_L^0 p \to K_S^0 p$ in the momentum interval 1.0 to 7.5 GeV/c. The energy dependences of these cross sections are found to be equally well described by the parameterizations: $\left(\frac{d\sigma}{d\Omega}\right)_{90^\circ} \propto s^{-n}$ or $\left(\frac{d\sigma}{d\Omega}\right)_{90^\circ} \propto e^{-bp_\perp}$.

(Submitted to Physics Letters)

---

*Work supported by the U.S. Atomic Energy Commission
**Now at Duke University, Durham, North Carolina
+Now at Lawrence Berkeley Laboratory, Berkeley, California
++Now at Purdue University, Lafayette, Indiana

Since the first large angle measurements of pp elastic scattering [1], there has been growing interest in the possibility of probing the structure of hadrons at small distances using purely hadronic reactions [2]. Recently parton models [3,4] have made these speculations quantitative, providing numerous predictions for both large angle elastic and two body scattering cross sections. Initial comparisons [3,4] of these models with elastic data indicate that agreement is found even at quite low energies, and suggest that similar comparisons be made for inelastic two body reactions.

In this letter cross sections at 90° are presented for the reactions $\overline{K}^o p \rightarrow \pi^+ \Lambda^o$, $\overline{K}^o p \rightarrow \pi^+ \Sigma^o$ and $K^o_L p \rightarrow K^o_S p$ in the momentum interval 1.0 to 7.5 GeV/c. These data result from an ~ 30 event/μb exposure of the SLAC 40-inch (1 meter) hydrogen bubble chamber to a K^o_L beam.

General experimental details have been presented previously [5]. Events are accepted with confidence levels > 1%. The separation of ambiguous Λ^o and Σ^o events discussed elsewhere [6], results in a residual contamination of Σ^o events in the Λ^o sample estimated to be ~ 5 ± 5% for the present data. Contamination of the Σ^o events from misidentified $\Lambda^o \pi^+ \pi^o$ final states is $\lesssim$ 10% below 2.5 GeV/c but $\lesssim$ 6% for data above this beam momentum. Similarly, the inclusion of $K^o_S \pi^+ n$ or $K^o_S \pi^o p$ final states in the $K^o_L p \rightarrow K^o_S p$ data is estimated to be $\lesssim$ 2%.

Corrections have been applied for small azimuthal losses (< 8%), for scanning losses (~ 8%), for neutral decay modes of the K^o_S and Λ^o, and for losses resulting from finite K^o_S and Λ^o decay volumes (average correction factors vary from ~ 1.05 to ~ 1.10 for K^o_S decays and from ~ 1.05 to 1.85 for Λ^o decays between 1.0 and 7.5 GeV/c). The quoted cross section uncertainties include in quadrature the uncertainties in the K_L^o beam momentum spectrum ($\lesssim 4\%$), in the azimuthal loss correction ($\lesssim 2\%$), and in the scanning efficiency ($\lesssim 2\%$). An overall normalization uncertainty of $\sim 10\%$ has not been included.

The 90^o differential cross sections for our $\overline{K}^o p \rightarrow \pi^+\Lambda^o$, $\overline{K}^o p \rightarrow \pi^+\Sigma^o$ and $K_L^o p \rightarrow K_S^o p$ data are shown in fig. 1. For comparison, cross sections for the reaction $\pi^- p \rightarrow \pi^o n$ [7] are also plotted in this figure. Numerical values for our data are recorded in table 1.

The striking feature of all four cross sections in fig. 1 is their rapid decrease in magnitude with increasing energy. Parameterizing the cross sections with the power law form:

$$\left(\frac{d\sigma}{d\Omega}\right)_{90^o} = \frac{A}{s^n} \qquad (1)$$

the data are fitted in several intervals in s, the center of mass energy squared, to obtain the energy dependence for the parameter "n" shown in fig. 2.* At a given energy, the values of n for the K induced reactions are consistent with equality, but are smaller than the corresponding results for the $\pi^- p \rightarrow \pi^o n$ reaction, where $n = 9.3 \pm 0.4$ and $n = 10.7 \pm 0.8$ for data above 2 and 2.5 GeV/c respectively. Values for similar momentum intervals for the K induced reactions are recorded in table 2. All four

*In evaluating the parameter "n" in the overlapping momentum intervals 2.5 to 3.5 GeV/c and 2.5 to 7.5 GeV/c, maximum likelihood and χ^2 minimization techniques were used respectively. However, the 2.5 to 3.5 GeV/c interval was treated as one bin in the χ^2 fit to the larger region; this results in the two values of n being substantially independent.

reactions indicate that the parameter "n" increases within the momentum interval ~ 1.5 to ~ 7.5 GeV/c.

The form of eq. (1) is motivated by recent parton model predictions for the power law dependence of 90° elastic cross sections. In particular, the parton exchange model of Blankenbecler, Brodsky and Gunion [4] obtains a general result for two body scattering:

$$\left(\frac{d\sigma}{dt}\right) = \frac{\pi}{qq'}\left(\frac{d\sigma}{d\Omega}\right) = \frac{f(\cos\theta)}{s^{m}} \qquad (2)$$

where $f(\cos\theta)$ is specified for each reaction, and q, q' are the center of mass momenta in initial and final states. At high energies this is equivalent to the parameterization of eq. (1)** where $n = m-1$. For meson-baryon scattering, assuming dipole and monopole form factors for the proton and mesons respectively, this model yields the energy dependence $m = 8$, shown as the curve in fig. 2. The K induced reactions are in agreement with this prediction; a recent π^{+} photoproduction result [8] and the $\pi^{-}p \rightarrow \pi^{0}n$ data [7] prefer slightly larger values of m than predicted.

Comparisons with other features of this model [4] have also been made; the results for the angular dependence of our data about 90° are shown in fig. 3. The parton exchange model predictions are given by the curves in this figure. The data are observed to be in qualitative agreement with the predictions, $K_{L}^{0}p \rightarrow K_{S}^{0}p$ being more asymmetric than either Λ or Σ reactions, but higher energy data are desirable. The comparison of the 90° cross sections for $K_{L}^{0}p \rightarrow K_{S}^{0}p$ and $\pi^{-}p \rightarrow \pi^{0}n$ is less

---

**For the present reactions this approximation is quite good for laboratory momenta $\gtrsim 2.5$ GeV/c (see fig. 2).

favorable however, yielding:

$$\left(\frac{d\sigma}{d\Omega}\right)_{90^\circ} (K_L^o p \rightarrow K_S^o p) \Bigg/ \left(\frac{d\sigma}{d\Omega}\right)_{90^\circ} (\pi^- p \rightarrow \pi^o n) \approx 1/3,$$

(see fig. 1) in contrast to the predicted value [4] of ~ 1/18.

We have also parameterized the data with an exponential dependence on transverse momentum:

$$\left(\frac{d\sigma}{d\Omega}\right)_{90^\circ} = B\ e^{-bp_\perp} \qquad (3)$$

where $p_\perp$ is simply the center of mass momentum, q', for 90° scattering. This parameterization, shown as the dashed curves in fig. 1, describes the data equally as well as the power law dependence of eq. (1). Values of b evaluated in two momentum intervals are recorded in table 2.***

Our motivation for comparing eq. (3) to the data stems from Orear's [9] successful description of large angle pp elastic data with this form. We note that an exponential dependence of $p_\perp$ also provides a good description of inclusive single particle cross sections [10] for transverse momenta in the region spanned by the present data (see table 1). For inclusive production, the exponential dependence on transverse momentum is often ascribed to the "thermodynamic" nature of strong interactions [11]. We conjecture that this may also determine the energy dependence of two body scattering cross sections near 90°. Therefore, assuming that the invariant cross section for two particle scattering near 90° is given by

***For $\pi^- p \rightarrow \pi^o n$ values of $b = 12.8 \pm 0.6$ and $b = 14.2 \pm 1.0$ are obtained for data above 2 and 2.5 GeV/c respectively.

the product of the inclusive single particle cross sections, we obtain:+

$$\left(\frac{d\sigma}{d\Omega}\right) \mathrel{\dot{\propto}} e^{-(b_1+b_2)p_\perp} \qquad (4)$$

where $p_\perp$ is now directly related to the energy of the two body reaction, and b_1, b_2 are the appropriate slopes for single particle inclusive production at 90^o. These slopes are essentially independent of energy [10] but may differ by $\sim 2\ (\mathrm{GeV}/c)^{-1}$ for different particle masses. Taking representative values [12], we expect $b_1+b_2 \sim 8.5$ and 10.5 for Kp and πp reactions respectively. This result does agree in magnitude with the present analysis (see table 2 and fig. 2). The predictions of eq. (4) for the angular dependence around 90^o, although symmetric in this parameterization, are also observed to be in qualitative agreement with the data (see fig. 3). However, higher statistics experiments are clearly required to better determine the relationship between single particle inclusive distributions and two body cross sections near 90^o.

In conclusion, differential cross sections for 90^o production in the non-diffractive channels $\bar{K}^o p \to \pi^+\Lambda^o$, $\bar{K}^o p \to \pi^+\Sigma^o$ and $K^o_L p \to K^o_S p$ are observed to be in agreement with the dependences: $\left(\frac{d\sigma}{d\Omega}\right)_{90^o} \mathrel{\dot{\propto}} s^{-7}$ or $\left(\frac{d\sigma}{d\Omega}\right)_{90^o} \mathrel{\dot{\propto}} e^{-9p_\perp}$ suggested by a parton exchange model, and inclusive single particle spectra respectively.

We would like to thank R. Blankenbecler and M. Davier for helpful

---

+More generally $\left(\frac{d\sigma}{d\Omega}\right)_{90^o} \mathrel{\dot{\propto}} F(x_1 \approx 0,\ p_{\perp_1})\ F(x_2 \approx 0,\ p_{\perp_2} = p_{\perp_1})$ where the $F(x,p_\perp)$ are the appropriate invariant structure functions for single particle inclusive production. Interestingly, a similar relation is implied by the parton exchange model, ref. [4].

discussions, and G. Luste, K. Moriyasu, and W. Smart for their contribution to the earlier parts of the experiment. We also acknowledge the assistance provided by R. Watt and the crew of the SLAC 40-inch bubble chamber, by J. Brown and the scanning and measuring staff at SLAC, and by D. Johnson for data handling.

Table 1

Differential Cross Sections at 90°

	P_{LAB} (GeV/c)	q' (GeV/c)	$\left(\frac{d\sigma}{d\Omega}\right)_{90^\circ}^{(a)}$ (μb/sr)	$\left(\frac{d\sigma}{dt}\right)_{90^\circ}^{(a)}$ ($\mu b/GeV^2$)
$K_L^o p \to K_S^o p$	1.0 - 1.5	0.523 - 0.696	133 ± 19.8	1104 ± 165
	1.5 - 2.0	0.696 - 0.840	35.6 ± 5.60	190 ± 29.9
	2.0 - 2.5	0.840 - 0.965	10.0 ± 2.32	38.6 ± 8.96
	2.5 - 3.5	0.965 - 1.179	4.52 ± 0.84	17.4 ± 3.24
	3.5 - 5.0	1.179 - 1.444	$0.43 \pm^{0.30}_{0.19}$	$0.79 \pm^{0.55}_{0.35}$
	5.0 - 7.5	1.444 - 1.803	< 0.43 (b)	< 0.051 (b)
$\overline{K}^o p \to \pi^+ \Lambda^o$	1.0 - 1.5	0.539 - 0.695	172 ± 24.4	1413 ± 200
	1.5 - 2.0	0.695 - 0.832	133 ± 14.3	713 ± 76.6
	2.0 - 2.5	0.832 - 0.954	39.6 ± 6.17	154 ± 24.1
	2.5 - 3.5	0.954 - 1.165	13.2 ± 2.26	36.5 ± 6.25
	3.5 - 5.0	1.165 - 1.429	$1.01 \pm^{0.71}_{0.44}$	$1.87 \pm^{1.31}_{0.81}$
	5.0 - 7.5	1.429 - 1.789	$0.54 \pm^{0.55}_{0.31}$	$0.65 \pm^{0.66}_{0.37}$
	7.5 - 10.0	1.789 - 2.089	< 0.18	< 0.15
$\overline{K}^o p \to \pi^+ \Sigma^o$	1.0 - 1.5	0.488 - 0.650	78.6 ± 16.2	699 ± 144
	1.5 - 2.0	0.650 - 0.792	24.9 ± 6.48	141 ± 36.8
	2.0 - 2.5	0.792 - 0.917	14.3 ± 3.84	58.3 ± 15.7
	2.5 - 3.5	0.917 - 1.133	9.25 ± 1.90	26.4 ± 5.43
	3.5 - 5.0	1.133 - 1.402	$0.83 \pm^{0.68}_{0.42}$	$1.57 \pm^{1.29}_{0.79}$
	5.0 - 7.5	1.402 - 1.766	< 0.15	< 0.18

(a) Determined in the interval $-0.2 \leq \cos\theta^* \leq 0.2$

(b) Upper bounds correspond to 85% confidence limit (1.9 events when no events were observed)

Table 2

Model Parameters from Fits to the 90° Cross Sections:

$$\left(\frac{d\sigma}{d\Omega}\right)_{90^\circ} = A/s^n \text{ and } \left(\frac{d\sigma}{d\Omega}\right)_{90^\circ} = B\ e^{-bp_\perp}$$

Parameter	P_{LAB} (GeV/c)	Reaction		
		$K_L^o p \rightarrow K_S^o p$ [a]	$\overline{K}^o p \rightarrow \pi^+ \Lambda^o$	$\overline{K}^o p \rightarrow \pi^+ \Sigma^o$ [a]
n	1.5 - 7.5	6.3 ± 0.4	6.2 ± 0.4	4.8 ± 0.5
	2.5 - 7.5	8.5 ± 1.2	7.4 ± 1.4	8.1 ± 1.4
b $(GeV/c)^{-1}$	1.5 - 7.5	8.0 ± 0.6	8.3 ± 0.5	6.0 ± 0.6
	2.5 - 7.5	10.2 ± 1.5	9.5 ± 2.0	9.7 ± 1.7

(a) For these reactions the cross sections in the momentum interval 5-7.5 GeV/c was taken equivalent to 1 ± 1 events although no events were seen.

REFERENCES

[1] G. Cocconi, V.T. Cocconi, A.D. Krish, J. Orear, R. Rubenstein, D.B. Scarl, W.F. Baker, E.W. Jenkins and A.L. Read, Phys. Rev. Letters 11 (1963) 499.

[2] T.T. Wu and C.N. Yang, Phys. Rev. 137 (1965) B708; H.D.I. Abarbanel, S.D. Drell and F.J. Gilman, Phys. Rev. Letters 20 (1968) 280; M.M. Islam and J. Rosen, Phys. Rev. Letters 22 (1969) 502; S.M. Berman and M. Jacob, Phys. Rev. Letters 25 (1970) 1683; G. Cocconi, Nuovo Cimento 57A (1968) 837.

[3] S.M. Berman, J.D. Bjorken and J.B. Kogut, Phys. Rev. D4 (1971) 3388; D. Horn and M. Moshe, Nucl. Phys. B48 (1972) 557; D. Cline, F. Halzen and M. Waldrop, Univ. of Wisconsin preprint (1972).

[4] J.F. Gunion, S.J. Brodsky and R. Blankenbecler, Phys. Letters 39B (1972) 649; 42B (1972) 461; SLAC preprint SLAC-PUB-1183 (1973).

[5] G.W. Brandenburg, W.B. Johnson, D.W.G.S. Leith, J.S. Loos, G.J. Luste, J.A.J. Matthews, K. Moriyasu, W.M. Smart, F.C. Winkelmann and R.J. Yamartino, Phys. Rev. Letters 30 (1973) 145; Nucl. Phys. B45 (1972) 397; Phys. Rev. D7 (1973) 708.

[6] R.J. Yamartino, Ph.D. thesis, Stanford University (1973).

[7] A.S. Carroll et al., Phys. Rev. 177 (1969) 2047; J.E. Nelson et al., LBL preprint LBL-1027 (1972); R.K. Yamamoto et al., MIT preprint (1972); W.S. Brockett et al., Phys. Rev. Letters 26 (1971) 527.

[8] R.L. Anderson, B. Gottschalk, D.B. Gustavson, H.J. Halpern, R. Prepost and D.H. Tompkins, SLAC preprint SLAC-PUB-1178 (1973).

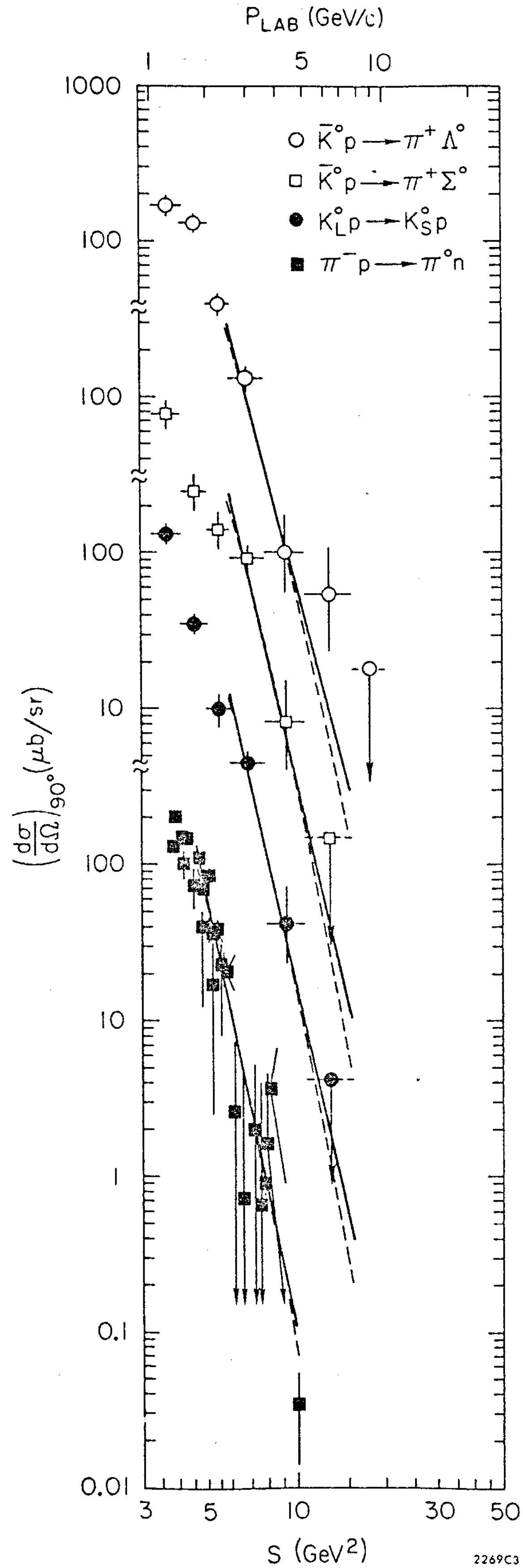
[9] J. Orear, Phys. Rev. Letters 12 (1964) 112.

[10] J.C. Sens, Oxford Conference Report (1972); M. Jacob, XVI International Conference on High Energy Physics Report, CERN preprint Ref. Th. 1570-CERN (1972).

[11] W.R. Frazer, L. Ingber, C.H. Mehta, C.H. Poon, D. Silverman, K. Stowe, P.D. Ting and H. Yesian, Rev. Mod. Phys. 44 (1972) 284; R. Hagedorn, Nuovo Cimento 56A (1958) 1027.

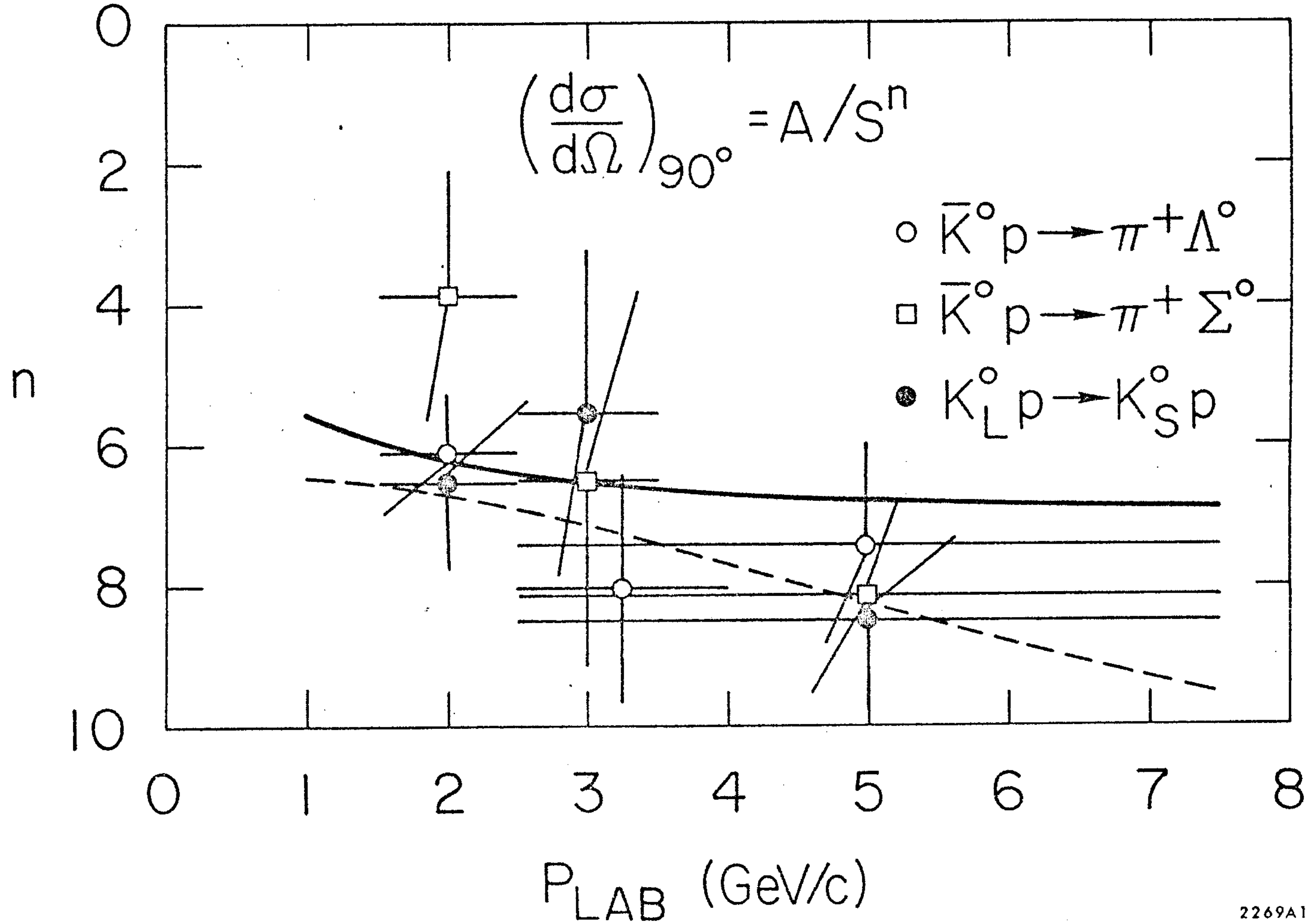
[12] U. Idschok, P. Kobe, H.J. Mück, B. Wessels, V. Blobel, H. Fesefeldt, B. Hellwig, D. Mönkemeyer, F. Selonke, G.W. Brandenburg, H. Franz, W. Richter, W. Schrankel and B. Schwarzschild, Univ. of Bonn preprint (1972); British Scandinavian Collab., B. Alper *et al*., preprint (1972).

LIST OF FIGURES



P_{LAB} (GeV/c)
1
5
10
1000
100
100
100
10
100
10
1
0.1
0.01
$\bar{K}^\circ p \to \pi^+ \Lambda^\circ$
$\bar{K}^\circ p \to \pi^+ \Sigma^\circ$
$K_L^\circ p \to K_S^\circ p$
$\pi^- p \to \pi^\circ n$
$\left(\frac{d\sigma}{d\Omega}\right)_{90^\circ} (\mu b/sr)$
3
5
10
30
50
S (GeV²)
2269C3

Fig. 1



$\left(\frac{d\sigma}{d\Omega}\right)_{90°} = A/S^n$
○ $\bar{K}^\circ p \rightarrow \pi^+ \Lambda^\circ$
□ $\bar{K}^\circ p \rightarrow \pi^+ \Sigma^\circ$
● $K_L^\circ p \rightarrow K_S^\circ p$
n
0
2
4
6
8
10
0
1
2
3
4
5
6
7
8
P_{LAB} (GeV/c)
2269A1

Fig. 2

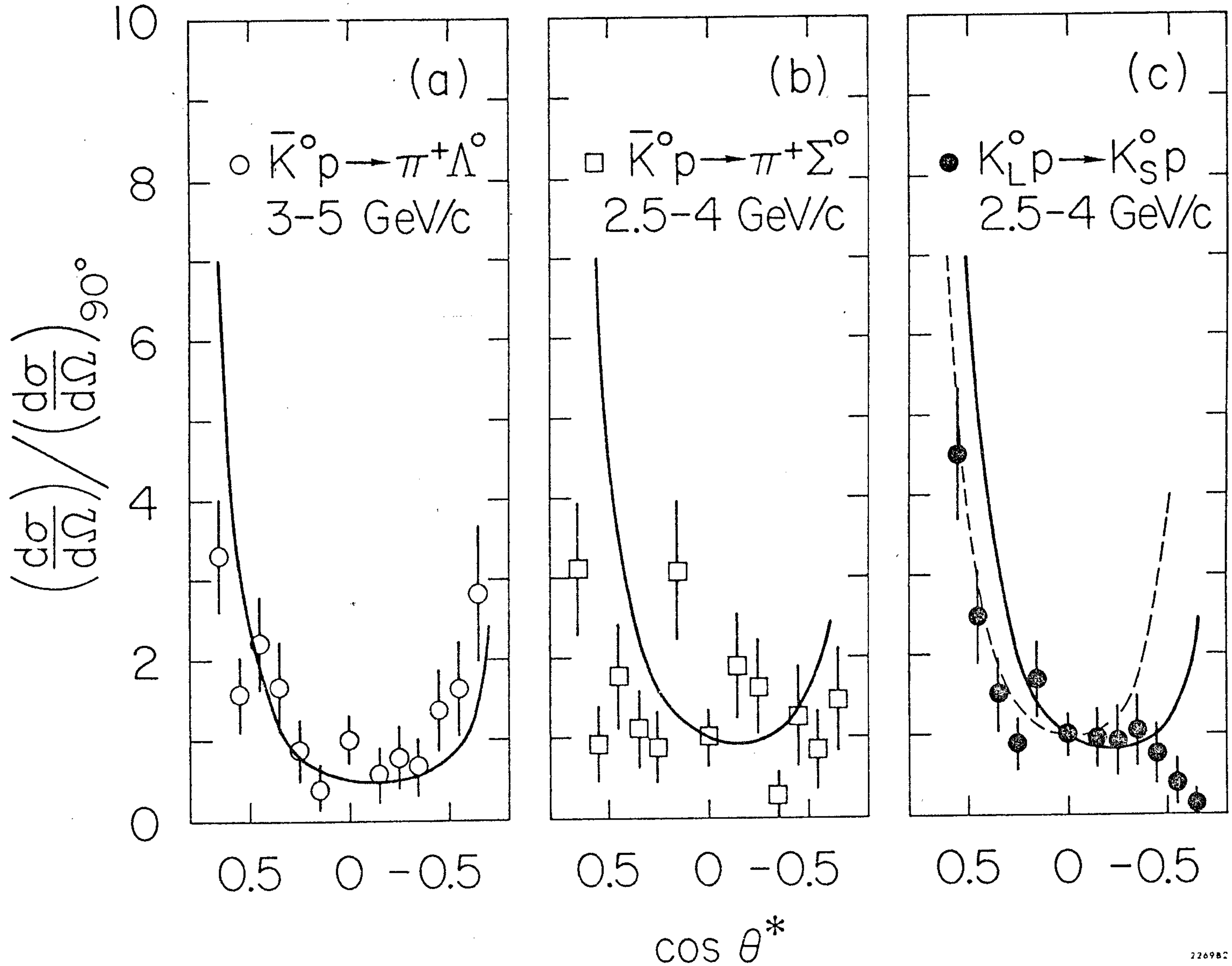

10
8
6
4
2
0
$\left(\frac{d\sigma}{d\Omega}\right) / \left(\frac{d\sigma}{d\Omega}\right)_{90°}$
(a)
$\bar{K}^\circ p \to \pi^+\Lambda^\circ$
3-5 GeV/c
(b)
$\bar{K}^\circ p \to \pi^+\Sigma^\circ$
2.5-4 GeV/c
(c)
$K_L^\circ p \to K_S^\circ p$
2.5-4 GeV/c
0.5 0 -0.5
0.5 0 -0.5
0.5 0 -0.5
cos θ^*
226982

Fig. 3