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PHOTOPRODUCTION OF $K^+\Lambda$ AND $K^+\Sigma^0$ FROM HYDROGEN FROM 5 to 16 GeV*

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ABSTRACT

Cross sections for the reactions $\gamma p \rightarrow K^+\Lambda$ and $\gamma p \rightarrow K^+\Sigma^0$ have been measured at four-momentum transfer squared (-t) from 0.005 to 2 GeV^2, at photon energies 5, 8, 11, and 16 GeV. For $-t > 0.2$ GeV^2 each of the K^+ cross sections are about 1/3 of the π^+n photoproduction cross section, having nearly the same energy and momentum transfer dependence. The K^+ cross sections fall off at small $|t|$, however, in contrast to the sharp forward spike seen in π^+n; this leads to a disagreement with an SU(3) prediction for $-t < 0.1$ GeV^2. The ratio of $K^+\Sigma^0$ to $K^+\Lambda$ cross sections is typically between 0.5 and 1.0.

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Cross sections for the reactions $\gamma p \rightarrow K^+\Lambda$ and $\gamma p \rightarrow K^+\Sigma^0$ were measured simultaneously with $\gamma p \rightarrow \pi^+ n$ using the SLAC 20-GeV magnetic spectrometer.[1] This extends work done previously at other laboratories in the few GeV range.[2-5] The experimental apparatus has been described previously[6].

The measured K^+ yields were corrected for K^+ decay, detection inefficiencies in the shower counter, range hodoscope, and Čerenkov counters, absorption in detectors, dead time and accidental coincidences, and empty target yields. The errors given in the figures and table reflect only the counting statistics folded with a 5% error to account for fluctuating systematics. In addition, there is an overall uncertainty in normalization of ± 10%.

Cross sections were obtained by measuring K^+ yields produced by photons near the end point of the bremsstrahlung spectrum. For each event, a missing mass was calculated for a photon energy equal to the bremsstrahlung end point energy. The yield as a function of missing mass then has a step at the Λ mass plus a second step, beginning at the Σ^0 mass. The shape of the steps is a reflection of the bremsstrahlung spectrum[7] and the variation of the cross section with energy, folded with the finite experimental resolution. The resolution was accurately determined from the step in the $\pi^+ n$ reaction measured at the same time; it was typically 0.04 GeV^2 (standard deviation), in units of missing mass squared, compared to a separation of 0.18 GeV^2 between the Λ and Σ^0 steps. The position of the Λ and Σ^0 steps was computed from the measured position of the $\pi^+ n$ step which agreed with the position expected from the calibration of the beam and spectrometer momenta to better than 0.3%. The cross sections were obtained by least-squares fitting the height of the Λ and Σ^0 steps. To represent background processes a polynomial in missing mass squared was included beginning at the threshold for $\gamma p \rightarrow K^+\Lambda\pi^0$.

The results of the cross section measurements are given in Figs. 1 and 2. Both K reactions fall exponentially for $-t > 0.5\ \text{GeV}^2$ approximately as $e^{(3.0 \pm 0.2)t}$, similar to the $\gamma p \to \pi^+ n$ cross sections. At smaller $|t|$, the K^+ cross sections become flat in t and then decreases as -t goes towards zero, markedly different from $\pi^+ n$, where a sharp spike was seen for $-t < m_\pi^2$.

The energy dependence of the cross section at fixed t is conveniently parameterized by,

$$\frac{d\sigma}{dt} = \beta(t)\,(s - M^2)^{2\alpha(t) - 2} \qquad (1)$$

where M is the proton mass, s the square of the cm energy and β is a function only of t. The values of α obtained for $\gamma p \to K^+\Lambda$, using only the cross sections at 8, 11, and 16 GeV, are shown in Fig. 1b; α remains close to zero and thus defies interpretation as a single dominant Regge trajectory with a normal slope of 1 GeV^{-2}.

The total cross sections for $K^+\Lambda$ and $K^+\Sigma^0$ photoproduction can be approximated by integrating the forward differential cross sections, neglecting the large $|t|$ regions which presumably contribute a few percent or less. This gives

$$\sigma_{tot} = \frac{(6 \pm 1)}{k^2}\,\mu b \qquad (2)$$

(k is the lab photon energy in GeV) for each process, the Λ cross section tending to be slightly higher than the Σ^0 cross section. Our Λ cross section ties on well with the values obtained by the DESY bubble chamber group,[2] Eq. (2) being valid down to k = 1.5 GeV. The Σ^0 cross section does not tie on well; the bubble chamber group observed only three events in the range k = 2.0 - 5.8 GeV, a factor of four less than expected from Eq. (2).

The forward $\pi^+ n$ data have been fitted by theoretically assuming the pion to conspire at t = 0 with a trajectory of opposite parity[8,9] as well as by assuming evasive π exchange interfering with other conspiring mechanisms.[10,11,12] In the case of the K^+ reactions, the smallness of the cross sections at small $|t|$ allows good fits to the data with either evasion or conspiracy for K^+ exchange.[9] Frøyland[13] has fitted the $K^+\Lambda$ cross section with an evasive K^+ trajectory and a conspiring K-P cut.

The $K^+\Sigma^0$ cross section, however, requires an additional trajectory. If K^+ exchange were the only contribuiton to both $K^+\Lambda$ and $K^+\Sigma^0$ photoproduction, the coupling constants

$$\frac{g^2_{K\Lambda n}}{4\pi} = 16.0 \pm 2.5 , \qquad \frac{g^2_{K\Sigma n}}{4\pi} = 0.3 \pm 0.5 \tag{3}$$

calculated using dispersion relations,[14] would give a Σ^0/Λ ratio of less than 0.1 which disagrees with the data. Hence some other exchange must contribute significantly, at least to the $K^+\Sigma^0$ reaction. In order to fit the Σ^0/Λ ratio as well as the $K^+\Lambda$ cross section, Ball et al.,[8] included an evasive K^* trajectory along with a conspiring K^+ exchange. By varying the amount of K^* exchange, they fit the ratio near $t = -.3$ and predict a fall off as t goes from $-.05$ to zero, due to the vanishing of the K^* exchange at $t = 0$. The data are consistent with such a fall off, but do not provide a stringent test.

SU(3) predicts the following relation among photoproduction amplitudes:[15]

$$\sqrt{2}\, A(\pi^+ n) = -\sqrt{3}\, A(K^+\Lambda) - A(K^+\Sigma^0) \quad . \tag{4}$$

Letting ϕ be the unknown phase between the $K^+\Lambda$ and $K^+\Sigma^0$ amplitudes, we have the following relation among cross sections

$$2\,\frac{d\sigma}{dt}(\pi^+ n) = 3\,\frac{d\sigma}{dt}(K^+\Lambda) + \frac{d\sigma}{dt}(K^+\Sigma^0) + 2\cos\phi\,\sqrt{3\,\frac{d\sigma}{dt}(K^+\Lambda)\,\frac{d\sigma}{dt}(K^+\Sigma^0)}\ . \tag{5}$$

Previous photoproduction data[4] between 3.4 and 4 GeV for $0.2 < -t < 0.8\ \text{GeV}^2$ give values for $|\cos\phi|$ less than unity. The values of $\cos\phi$ calculated from our data are shown in Fig. 2b. The data are consistent with the SU(3) relation Eq. (4) except for small $|t|$, where the violation is simply related to the fact that the K^+ cross sections fall off while the π^+ increases.

The ratio of $K^+\Sigma^0$ to $K^+\Lambda$ photoproduction has been predicted using the quark model plus SU(6).[16,17] For baryon spin flip, as required by angular momentum conservation for photoproduction at zero degrees, $R = \frac{d\sigma}{dt}(K^+\Sigma^0) \Big/ \frac{d\sigma}{dt}(K^+\Lambda) = 1/27$ is predicted, while for arbitrary mixtures of spin flip and spin non-flip, the prediction $R \leq 1/3$ is obtained. Neither of these predictions agree with the data. An $SU(6)_W$ model,[18] however, predicts a ratio in good agreement with the data by including the 405 dimensional representation which is not present in the quark model.

The vector dominance model relates $K^+\Lambda$ photoproduction to the processes $V^0 p \to K^+\Lambda$ were $V^0 = \rho^0, \omega, \phi$. Unfortunately, these processes cannot be observed and need not, in general, have the same rates as the measurable processes $K^- p \to V^0\Lambda$. Davier[19] has discussed this point and compared the 5 GeV data with the K^-p data of R. Ammar et al;[20] he finds a factor of two or more discrepancy if one assumes the rate for $V^0 p \to K^+\Lambda$ to be the same as for $K^- p \to V^0\Lambda$. If the vector dominance model is valid this implies that the rate $V^0 p \to K^+\Lambda$ is considerably larger than that for $K^- p \to V^0\Lambda$. This result is similar to that found in comparing $\gamma p \to \pi^- \Delta^{++}_{1236}$ to $\pi^+ p \to V^0 \Delta^{++}$ where also the rate for $V^0 p \to \pi^- \Delta^{++}$ must be larger than that for the crossed reaction $\pi^+ p \to V^0 \Delta^{++}$, if vector dominance is valid.[6]

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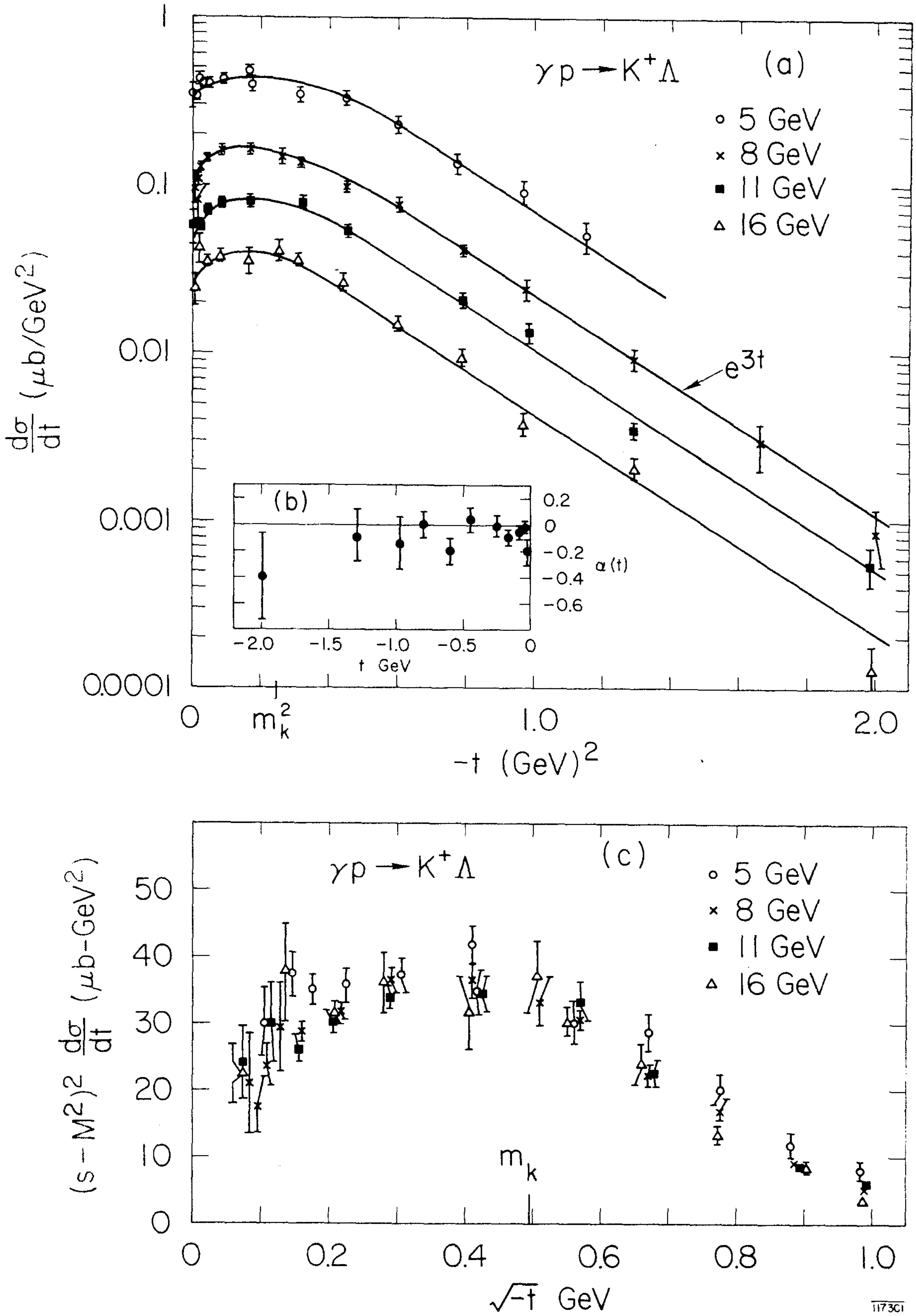
TABLE I

5 GeV			8 GeV			11 GeV			16 GeV		
$-(t-t_0)$ GeV^2	$\frac{d\sigma}{dt}(K^+\Lambda)$ $\mu b/GeV^2$ $t_0 = -.0108$	$\frac{d\sigma}{dt}(K^+\Sigma^0)$ $\mu b/GeV^2$ $t_0 = -.0161$	$-(t-t_0)$ GeV^2	$\frac{d\sigma}{dt}(K^+\Lambda)$ $\mu b/GeV^2$ $t_0 = -.0064$	$\frac{d\sigma}{dt}(K^+\Sigma^0)$ $\mu b/GeV^2$ $t_0 = -.0096$	$-(t-t_0)$ GeV^2	$\frac{d\sigma}{dt}(K^+\Lambda)$ $\mu b/GeV^2$ $t_0 = -.0046$	$\frac{d\sigma}{dt}(K^+\Sigma^0)$ $\mu b/GeV^2$ $t_0 \approx -.0068$	$-(t-t_0)$ GeV^2	$\frac{d\sigma}{dt}(K^+\Lambda)$ $\mu b/GeV^2$ $t_0 = -.0031$	$\frac{d\sigma}{dt}(K^+\Sigma^0)$ $\mu b/GeV^2$ $t_0 = -.0046$
0.0002	0.34 ± 0.06	---	0.0005	0.094 ± 0.033	---	0.0011	0.057 ± 0.013	---	0.0022	0.024 ± 0.005	---
0.004	0.333 ± 0.022	0.173 ± 0.033	0.0029	0.079 ± 0.018	---	0.0074	0.070 ± 0.014	---	0.0158	0.042 ± 0.008	---
0.010	0.425 ± 0.038	0.176 ± 0.057	0.0050	0.105 ± 0.014	---	0.020	0.058 ± 0.005	0.044 ± 0.008	0.039	0.035 ± 0.002	0.024 ± 0.003
0.020	0.398 ± 0.025	0.151 ± 0.035	0.010	0.130 ± 0.030	0.039 ± 0.014	0.040	0.071 ± 0.004	0.044 ± 0.008	0.078	0.040 ± 0.002	0.036 ± 0.003
0.039	0.405 ± 0.031	0.241 ± 0.045	0.020	0.127 ± 0.006	0.081 ± 0.012	0.080	0.079 ± 0.004	0.063 ± 0.006	0.162	0.035 ± 0.003	0.045 ± 0.007
0.079	0.424 ± 0.030	0.213 ± 0.046	0.039	0.141 ± 0.005	0.082 ± 0.008	0.165	0.080 ± 0.006	0.081 ± 0.013	0.26	0.041 ± 0.0030	0.046 ± 0.007
0.157	0.473 ± 0.032	0.15 ± 0.05	0.080	0.161 ± 0.009	0.094 ± 0.015	0.32	0.078 ± 0.007	0.046 ± 0.012	0.31	0.0335 ± 0.0023	0.031 ± 0.005
0.163	0.394 ± 0.039	0.44 ± 0.10	0.16	0.161 ± 0.012	0.138 ± 0.022	0.46	0.053 ± 0.005	0.053 ± 0.011	0.44	0.0264 ± 0.0033	0.028 ± 0.009
0.305	0.341 ± 0.037	0.35 ± 0.09	0.25	0.147 ± 0.016	0.126 ± 0.027	0.79	0.0203 ± 0.0019	0.018 ± 0.004	0.60	0.0149 ± 0.0015	0.013 ± 0.004
0.44	0.325 ± 0.033	0.26 ± 0.08	0.31	0.135 ± 0.006	0.094 ± 0.009	1.0	0.0133 ± 0.0018	0.0009 ± 0.0032	0.79	0.0094 ± 0.0010	0.0056 ± 0.0019
0.59	0.228 ± 0.025	0.14 ± 0.05	0.44	0.098 ± 0.008	0.090 ± 0.016	1.3	0.0036 ± 0.0004	0.0031 ± 0.0009	1.0	0.0038 ± 0.0006	0.0032 ± 0.0013
0.76	0.134 ± 0.020	0.12 ± 0.05	0.60	0.076 ± 0.007	0.068 ± 0.017	2.0	0.00056 ± 0.00014	0.00007 ± 0.00022	1.3	0.0021 ± 0.0003	0.0016 ± 0.0007
0.96	0.092 ± 0.016	0.040 ± 0.036	0.77	0.041 ± 0.003	0.046 ± 0.008				2.0	0.00013 ± 0.00005	0.00018 ± 0.00011
1.14	0.050 ± 0.011	0.026 ± 0.025	0.97	0.024 ± 0.003	0.014 ± 0.008						
			1.28	0.0091 ± 0.0013	0.0080 ± 0.0035						
			1.65	0.0029 ± 0.0009	0.0013 ± 0.0021						
			2.0	0.00086 ± 0.00032	0.0006 ± 0.0006						

LIST OF FIGURES



γp → K⁺Λ
(a)
5 GeV
8 GeV
11 GeV
16 GeV
e^3t
dσ/dt (μb/GeV²)
1
0.1
0.01
0.001
0.0001
0
m_k²
1.0
2.0
-t (GeV)²
(b)
0.2
0
-0.2
-0.4
-0.6
α(t)
-2.0
-1.5
-1.0
-0.5
0
t GeV
γp → K⁺Λ
(c)
5 GeV
8 GeV
11 GeV
16 GeV
(s-M²)² dσ/dt (μb-GeV²)
50
40
30
20
10
0
m_k
0
0.2
0.4
0.6
0.8
1.0
√-t GeV
1173C1

Fig. 1

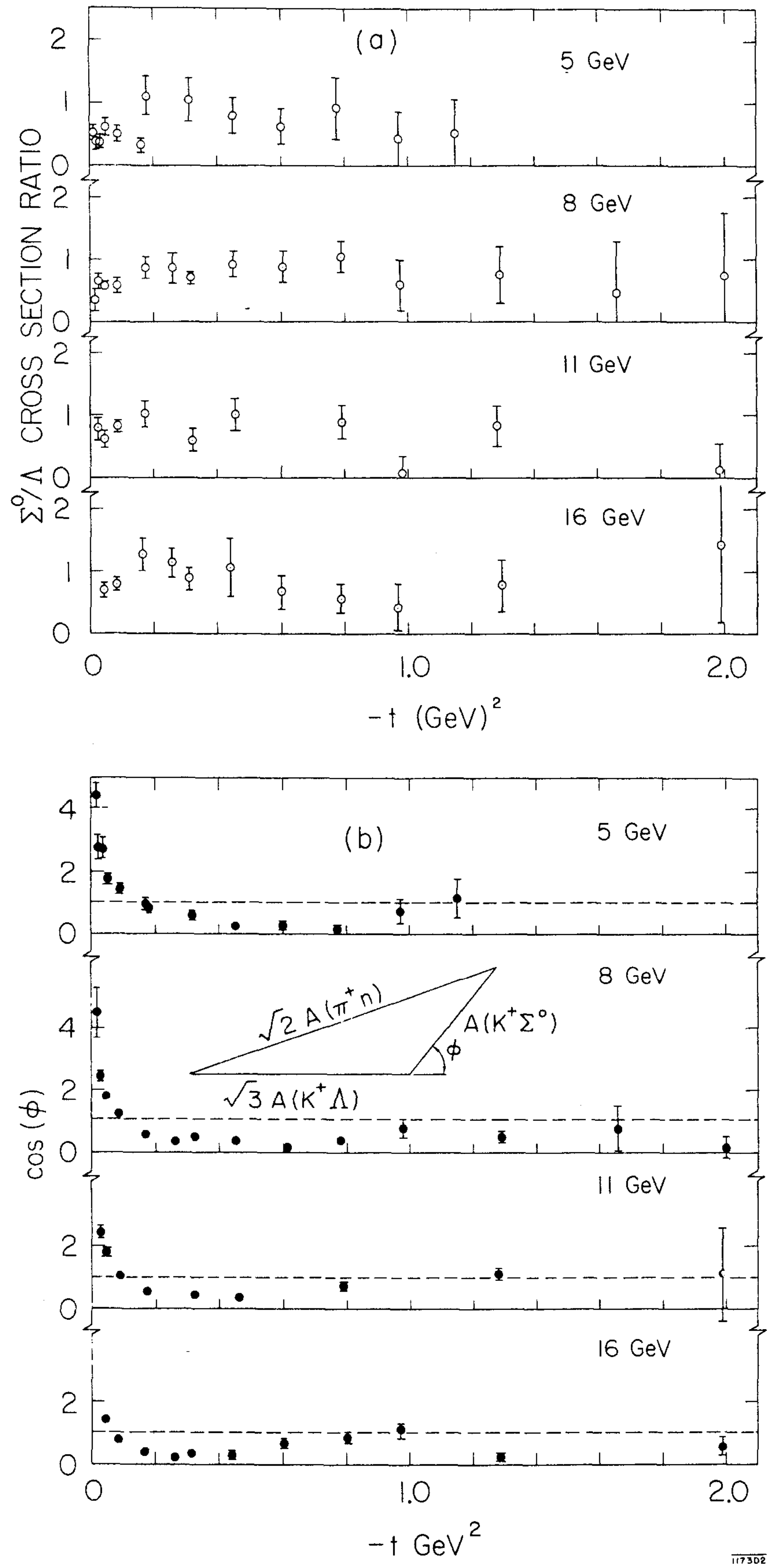

(a)
5 GeV
8 GeV
11 GeV
16 GeV
Σ°/Λ CROSS SECTION RATIO
−t (GeV)²
(b)
5 GeV
8 GeV
11 GeV
16 GeV
√2 A(π⁺n)
A(K⁺Σ°)
√3 A(K⁺Λ)
cos(φ)
−t GeV²
1173D2

Fig. 2