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A STUDY OF THE REACTION $\pi^+ p \rightarrow \Sigma^+ K^+$ IN THE REGION OF THE $\Delta(1920)$

G. Borreani and G. E. Kalmus

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Submitted to the XIVth International
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Berkeley, California

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ABSTRACT

XIVth International Conference on High Energy Physics, 1968

A Study of the Reaction $\pi^+ p \rightarrow \Sigma^+ K^+$ in the Region of the Λ (1920)

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Berkeley, California

Preliminary results including cross-sections, angular distributions, and polarizations will be presented for the channel $\pi^+ p \rightarrow \Sigma^+ K^+$ at incident pion momenta of 1.35, 1.43, and 1.68 BeV/c. A discussion of the partial wave amplitudes present in the channel will also be given.

(Submitted title by George Kalmus was A Study of the Strange Particle Channels in the $\pi^+ p$ Interactions in the Region of the Λ (1920)).

I. INTRODUCTION

We are reporting preliminary results of an exposure of 1.35, 1.44 and 1.68 BeV/c π^+ mesons in the L.R.L. 72" Bubble Chamber. This exposure represents about half of the eventual data in the experiment, another 3 momenta are currently being taken in the Berkeley 25" Bubble Chamber. A total of 130 000 pictures were taken divided approximately equally between the three momenta. The analysis of the data is not yet complete, in particular more work on the partial wave decomposition of the amplitude is still in progress.

II. EXPERIMENTAL DETAILS

A. Exposure

The film at 1.35, 1.44 and 1.68 BeV/c contained approximately 0.45, 0.6 and 0.6 μb equivalents respectively, within our fiducial cuts.

B. Scanning and Measuring

The entire film was scanned twice for the events $\pi^+ p \rightarrow \Sigma^+ K^+$ with $\Sigma^+ \rightarrow p\pi^\circ$ or $\Sigma^+ \rightarrow n\pi^+$. The events found were measured using the COBWEB on-line Franckenstein system and put through the Fog-Cloudy-Fair system for reconstruction, constraining and plotting. The fitting procedure consisted of a two-vertex simultaneous fit (at the production and Σ^+ decay verteces) as well as single vertex fits at the two verteces. About 2% of the film spread evenly throughout the exposure, was scanned for beam tracks, using the same criteria as below in III, a). An estimate based on a delta ray

count was made to obtain the μ contamination of the beam.

III. RESULTS

Table I shows the number of events found at each energy which satisfy the following cuts:

a) Beam track is within acceptable angular and momentum limits

b) Σ^+ is > 0.3 c.m. long and lives $\leq$ 3 lifetimes

c) Σ^+ decay angle in the lab is > 10° for the $\Sigma^+ \rightarrow \pi^+ n$ decay mode and > 5° for the $\Sigma^+ \rightarrow p\pi^\circ$ mode

d) Event is within fiducial volume

Since cuts b, c, and Σ^+ momentum dependent, each event was weighted to take into account these two cuts, as well as the possibility of the Σ^+ leaving the chamber before decaying. The weighted number of events is also given in the Table.

Figure 1. Shows the cross-sections obtained by this experiment at the three momenta together with cross-sections in this energy range given in the literature.[1] The quoted errors on our points are 1.5 x statistical to take into account some uncertainties in the normalization. Work is continuing to reduce these uncertainites. Our cross-sections were obtained using only the weighted $\Sigma^+ K^+$, $\Sigma^+ \rightarrow \pi^+ n$ events, and correcting by the ratio of 100/47.2 [2] to account for the $\Sigma^+ \rightarrow p\pi^\circ$ decays. The reason for doing this rather than using all our decays was because the angular cut in the laboratory is much more severe for $\Sigma^+ \rightarrow p\pi^\circ$ and also the greater difficulty of finding these events. This manifested itself in a definite bias for $\Sigma^+ \rightarrow p\pi^\circ$ events where the proton is near the

plane containing optic axis of the camera and direction of the Σ^+. This same bias was not present for the $\Sigma^+ \rightarrow \pi^+ n$ events.

Figure 2. Shows the integral distribution of the Σ time of flight. The data points include all event; the line represents the best fit, which was done by maximum likelihood applying fiducial volume cuts and a minimum Σ length cut of 5 mm. Our best fit gives a value for the Σ lifetime of $(.814 \pm .034)\ .10^{-10}$ sec. compared with the World Average of $(.810 \pm .013) \times 10^{-10}$ sec.[2]

Figure 3. Shows the angular distribution of the weighted and unweighted events obtained using only the $\Sigma^+ \rightarrow \pi^+ n$ events.

Figure 4. Shows the polarization as a function of angle for the $\Sigma^+ \rightarrow p\pi^\circ$ events.

Figure 5. Shows the values of expansion coeffients A1/A0 etc. of the Legendre polynomials fitted to the distributions shown in Fig. 3. Where the expression $d\sigma/d\Omega = \lambda\!\!\!^{-2} \sum_{m=o} A_m P_m (\cos\theta)$ has been used, and the coefficients have been normalized by dividing by $A_0 = \sigma/4\pi\lambda\!\!\!^{-2}$.

Figure 6. Shows the values of the expansion coefficients B1/A0, B2/A0 etc. of the 1st associated Legendre series when fitted to the polarization distribution shown in Fig. 4. $(d\sigma/d\Omega)\ \vec{P} = \hat{n}\ \lambda\!\!\!^{-2} \sum_{n=1} B_n P'_n (\cos\theta)$.

IV. DISCUSSION

A complete partial wave analysis, using the program VWAVE developed by Smart,[3] is in progress. In this paper we report the results obtained in fitting to a small selection of partial wave combinations.

In order to get a qualitative feeling for the amplitudes present we examine the A coefficients plotted in Fig. 5, and compare them with

tables of such coefficients given in the literature (see for example Tripp[4]).

1. Since a 6th order fit appears to be satisfactory at all energies the absence of higher coefficients is immediately interpreted as absence of waves higher than G7.[5]

The presence of the A_6 term at the two higher momenta indicates that there must be an amplitude F7 and/or an interference term F5 F7. Due to the Minami ambiguity the opposite parity terms (G7 and D5 G7) cannot be distinguished from the above until we examine the polarization data. However G7 and F7 cannot be both present because this in general would produce a non zero A_7 through their interference. Any of the above terms can account also for the non zero A_2 and A_4 coefficients.

2. The presence of a large A_3 term at all energies requires at least one interference term between two amplitudes of different parities. A_3 coefficient can be produced by terms S1F5, S1F7 or P3D3 or P3D5. However P3D5 would also produce a large A1 not observed, whereas P3D3 would imply interference terms like D3F7 which would induce a large A_5 not observed. The other terms that produce A_3, D5F5 and D5F7 would also require large A5 and/or A1. In conclusion we are left with S1F5, S1F7 and their Minami ambiguous P1D5, P1G7.

Since it is known that there is an F7 resonance in this region we have started off from the simplest assumption i.e. that at each energy there is only one of the possible amplitude combinations given above present, and that the F7 amplitude is important. This leads us to the simplest initial guesses:

1) S1, F7
2) S1, F5, F7

More refined guesses can be inferred assuming, as before, an F7 amplitude of the size required by A_6 and trying to reproduce, besides A3, also the small A5 observed. More waves may be then required to produce cancellation of the arising A_1 contributions. We are thus lead to the following combinations:

3) S1, D3, F7

4) S1, P1, D5, F7

5) S1, P3, D5, F7

We started with the above five amplitudes and extended our search for a good fit using the program VWAVE.

The inputs to the program are the angular distributions, polarization and cross-sections at each energy. Background amplitudes are parameterized in the form $T = (A + Bk)\, e^{i\,(C+Dk)}$. Resonant amplitudes are parameterized as $T = \frac{\frac{1}{2} e^{i\varphi} (\Gamma_e \Gamma_r)^{1/2}}{E_R - E - i\Gamma/2}$ where k is the incident c.m. momentum, Γ_e and Γ_r are the partial width into the elastic and $\Sigma^+ K^+$ channel, E_R the mass of the resonance, Γ the total width and φ the phase. The energy dependence of the partial widths has been approximated as

$$\Gamma_i \;\alpha\; \left[\frac{k_i^2}{k_i^2+x^2}\right]^{\ell_i} \frac{k_i}{E}$$

as given by Glashow and Rosenfeld.[6] k_i and ℓ_i are the momentum and orbital angular momentum of the decay products of the resonance in the ith channel. We have used x = 350 MeV.

The parameters A, B, C, D, $(x_e\, x_r)^{1/2} = \left[(\Gamma_e\, \Gamma_r)^{1/2}/\Gamma\right]$, Γ, E_R and φ could either be varied or set equal to constants (including zero).

Since the amount of data available is rather limited the number of free parameters that may be determined is also not large.

Table II shows some of the hypotheses tried together with their χ^2 and confidence levels. For resonant amplitudes we used fixed masses and widths as given by Donnachie, et al.[7] i.e.:

$$P3,\ E_R = 1688 \quad \Gamma = 280 \text{ MeV}$$

$$D3,\ E_R = 1691 \quad \Gamma = 270 \text{ MeV}$$

$$D5,\ E_R = 1954 \quad \Gamma = 310 \text{ MeV}$$

$$F7,\ E_R = 1946 \quad \Gamma = 220 \text{ MeV}$$

We wish to emphasize again that the results given in Table II are <u>not</u> a complete set, and that they should only be used as indications of what combinations of amplitudes do account for the data and which do not. It is quite likely that other sets of amplitudes not yet tried will also give satisfactory fits.

We should like to thank Dr. Wesley M. Smart for the use of his program "VWAVE" without which our results would be even more preliminary than they are.

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*Work done under the auspices of the U.S. Atomic Energy Commission

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3. W. M. Smart, Phys. Rev. 169, 1330 (1968).
4. R. D. Tripp, "Baryon Resonances", Rendiconti della Scuola Internationale di Fisica Enrico Fermi, p. 122, Academic Press 1966.
5. The χ^2 probabilities for a 6th degree order fit are respectively 7.5%, 93%, 98% at 1.35, 1.44, 1.68 GeV/c. The lower probability at 1.35 GeV/c is mainly due to the dip in the angular distribution at $\cos\theta_k = 0.65$. Although the probability is considerably improved for a 8th degree fit at this stage we do not interpret it as sufficient indication of a G9 wave.

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Table I.

	No. of $\pi^+ p \rightarrow \Sigma^+ K^+$, $\Sigma^+ \rightarrow \pi^+ n$ (Cut)	No. of $\pi^+ p$ $\Sigma^+ K^+$, $\Sigma^+ \rightarrow \pi^+ n$ (Weighted)	No. of $\pi^+ p$ $\Sigma^+ K^+$, $\Sigma^+ \rightarrow p\, \pi^\circ$ used in the Polarization Measurement
1.34 BeV/c	256	333.7	218
1.44 BeV/c	277	365.6	204
1.68 BeV/c	212	277.4	127

Table II.

S1	P1	P3	D3	D5	F5	F7	# of Free Parameters	Degrees of Freedom	χ^2	Confidence Level
Con						Res	3	52	143.9	$< 10^{-7}$
E.D.						Res	5	50	114.3	$< 10^{-7}$
E.D.					Con	Res	7	48	92.3	6×10^{-5}
Con			Res			Res	5	50	116.8	10^{-7}
E.D.			Res			Res	7	48	108.5	3×10^{-7}
Con	Con			Con		Res	7	48	105.1	1.1×10^{-6}
E.D.		Con		Con		Res	9	46	62.7	.048
Con		Con		Res		Res	7	48	65.5	.045
E.D.		Con		Res		Res	9	46	57.5	.118
Con		Res		Res		Res	7	48	60.7	.102
Con	Con	Con		Res		Res	9	46	58.4	.102
Con	Con	Con				Res	7	48	76.6	.004
E.D.	Con	Con		Res		Res	11	44	49.0	.284
E.D.		Con				Res	5	48	64.0	.059
E.D.		Res				Res	7	48	59.1	.130
E.D.				Res		Res	7	48	88.1	2×10^{-4}
Con			Res	Res		Res	7	48	80.8	.001
Con				Con		Res	5	50	101.0	10^{-5}

Key: Con - means background amplitude with B=D=0, A and C are left free.

E.D.- means background amplitude with A,B,C,D left free.

Res - means resonant amplitude of fixed mass and width as given in reference 7, φ and $(x_e\ x_r)^{1/2}$ are left free.

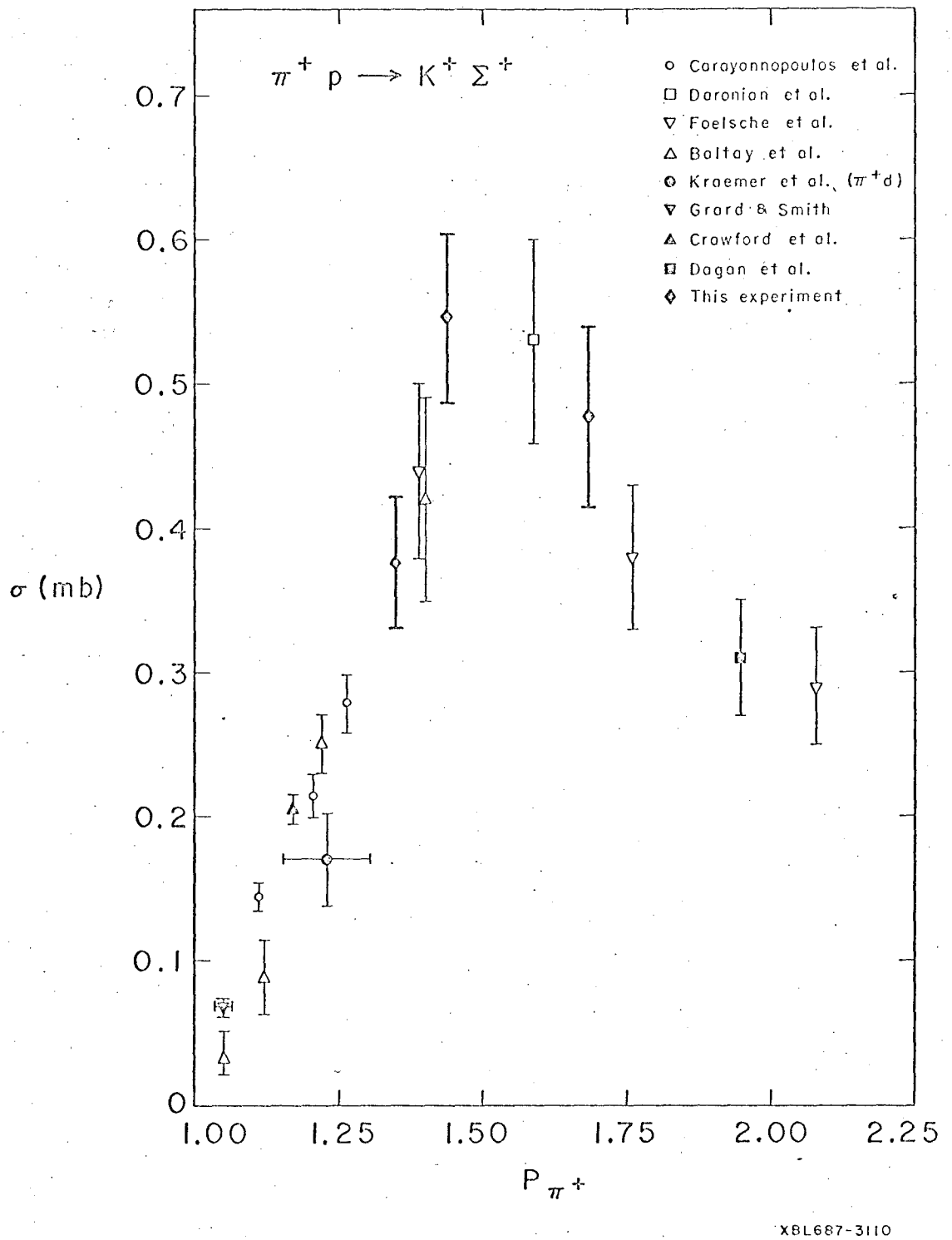
$\pi^+ p \longrightarrow K^+ \Sigma^+$
Carayonnopoulos et al.
Daronian et al.
Foelsche et al.
Baltay et al.
Kraemer et al. ($\pi^+ d$)
Grard & Smith
Crawford et al.
Dagan et al.
This experiment
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
σ (mb)
1.00
1.25
1.50
1.75
2.00
2.25
P_{π^+}
XBL687-3110

Fig. 1

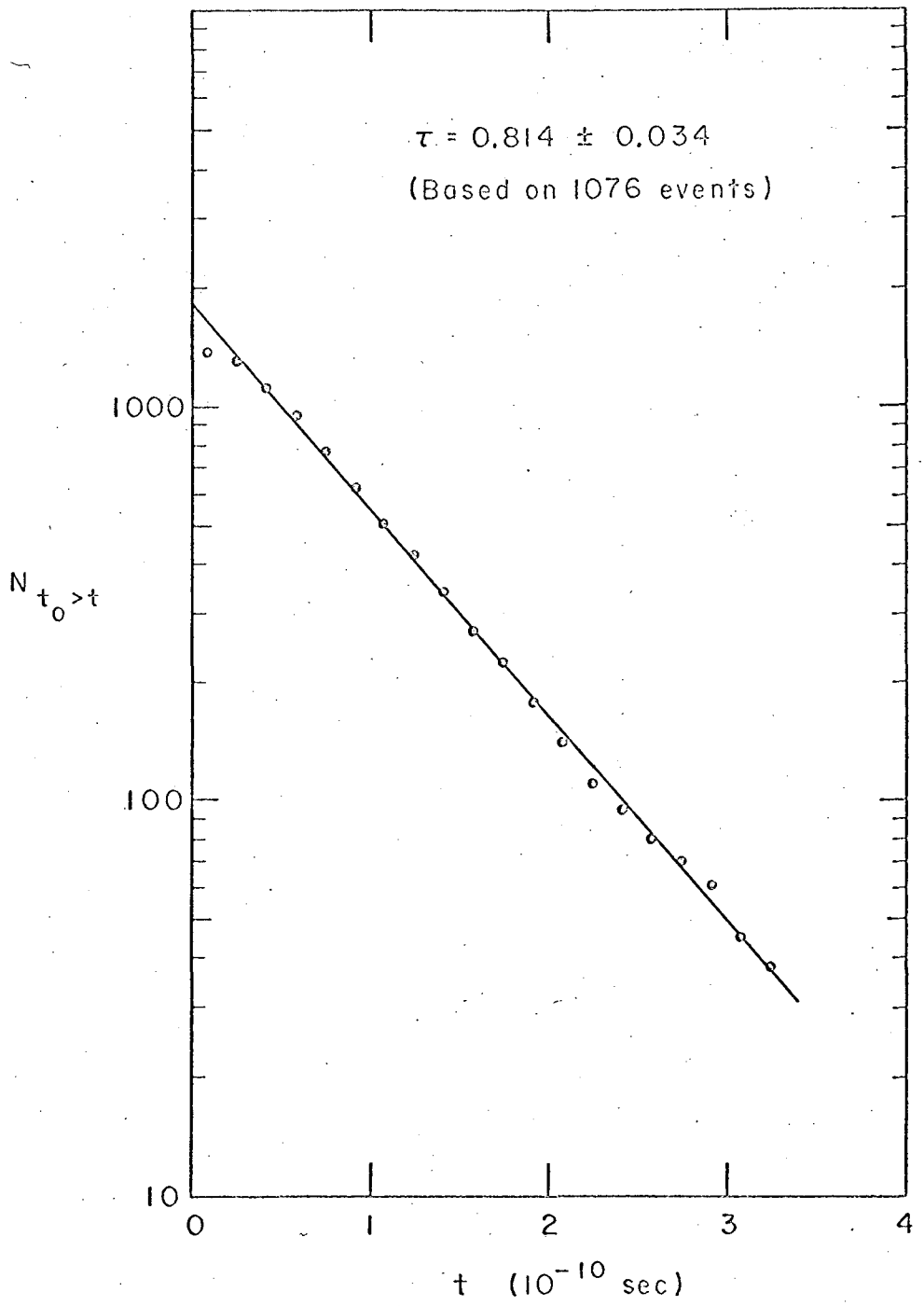

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Fig. 2

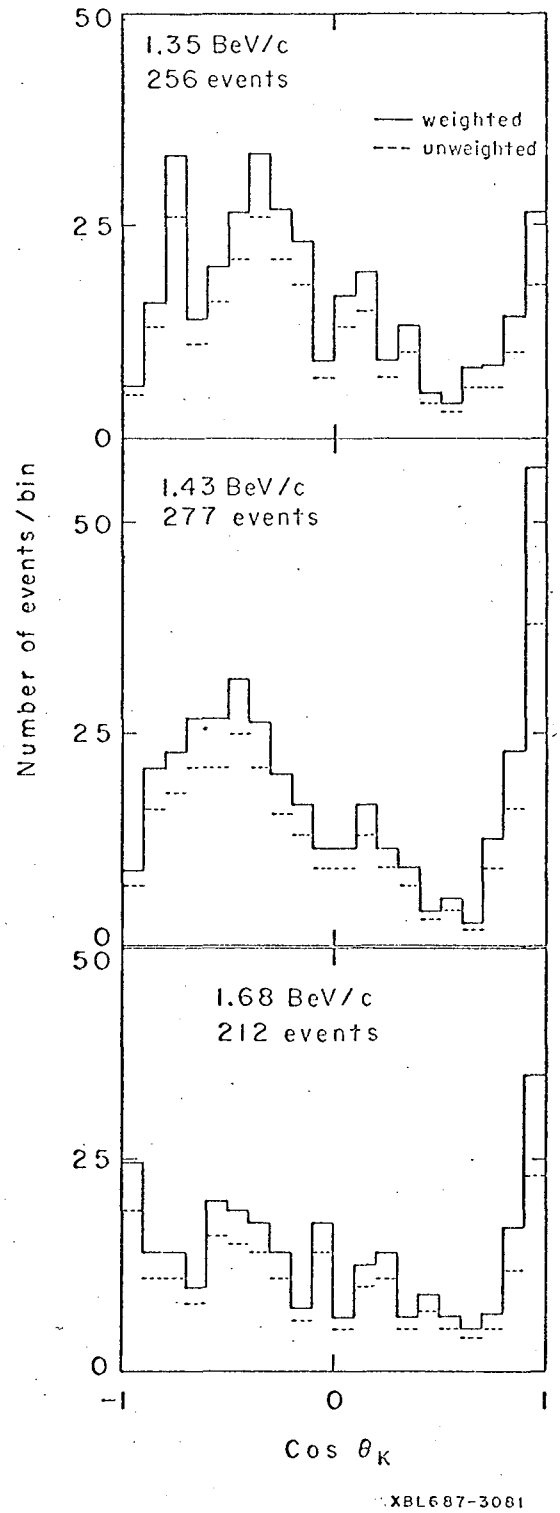
1.35 BeV/c
256 events
weighted
unweighted
1.43 BeV/c
277 events
1.68 BeV/c
212 events
Number of events / bin
50
25
0
-1
0
1
Cos θ_K
XBL687-3081

Fig. 3

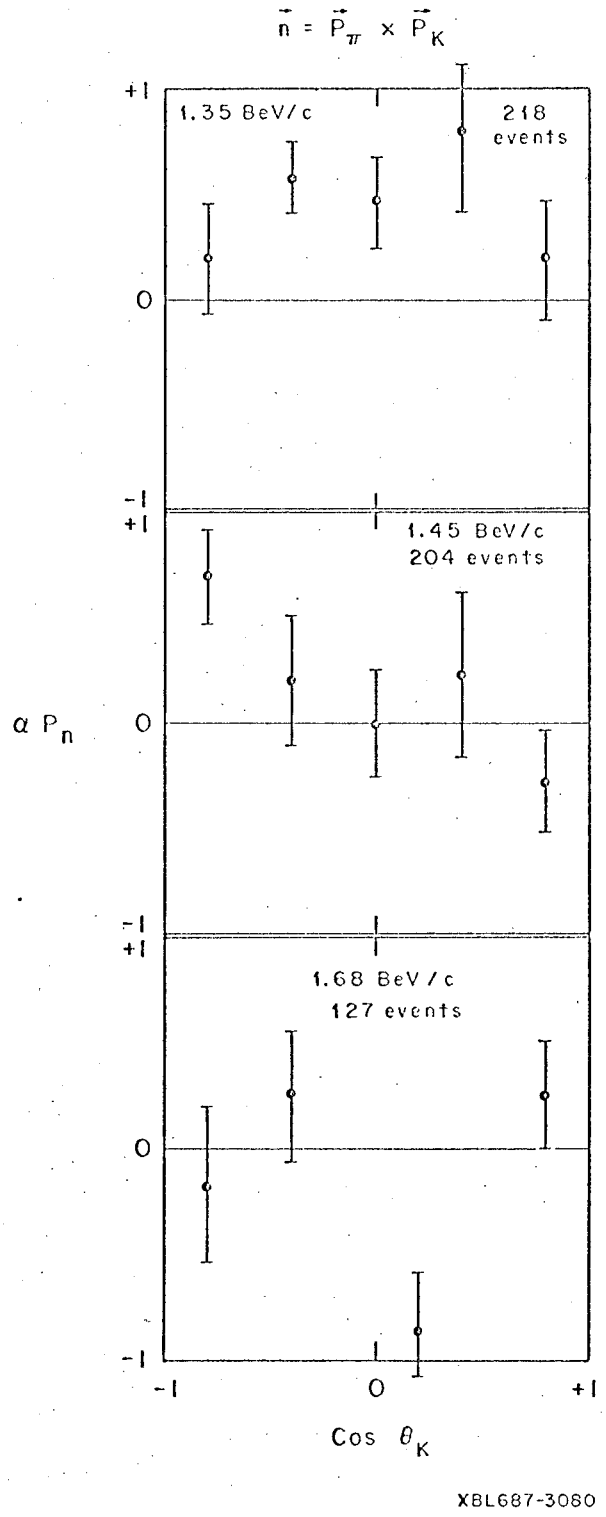
$\vec{n} = \vec{P}_\pi \times \vec{P}_K$
1.35 BeV/c
218 events
1.45 BeV/c
204 events
1.68 BeV/c
127 events
αP_n
+1
0
-1
Cos θ_K
XBL687-3080

Fig. 4

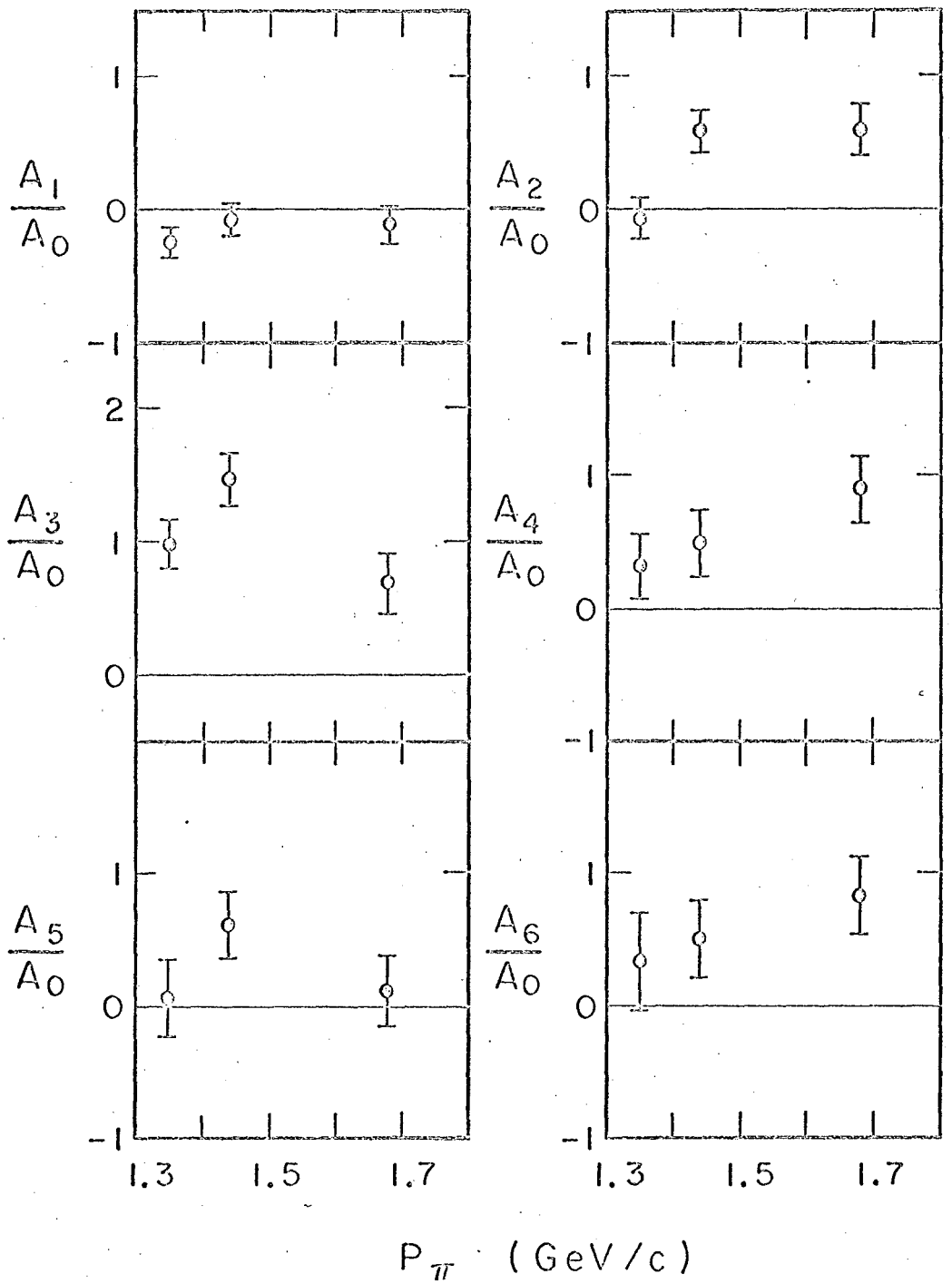

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Fig. 5

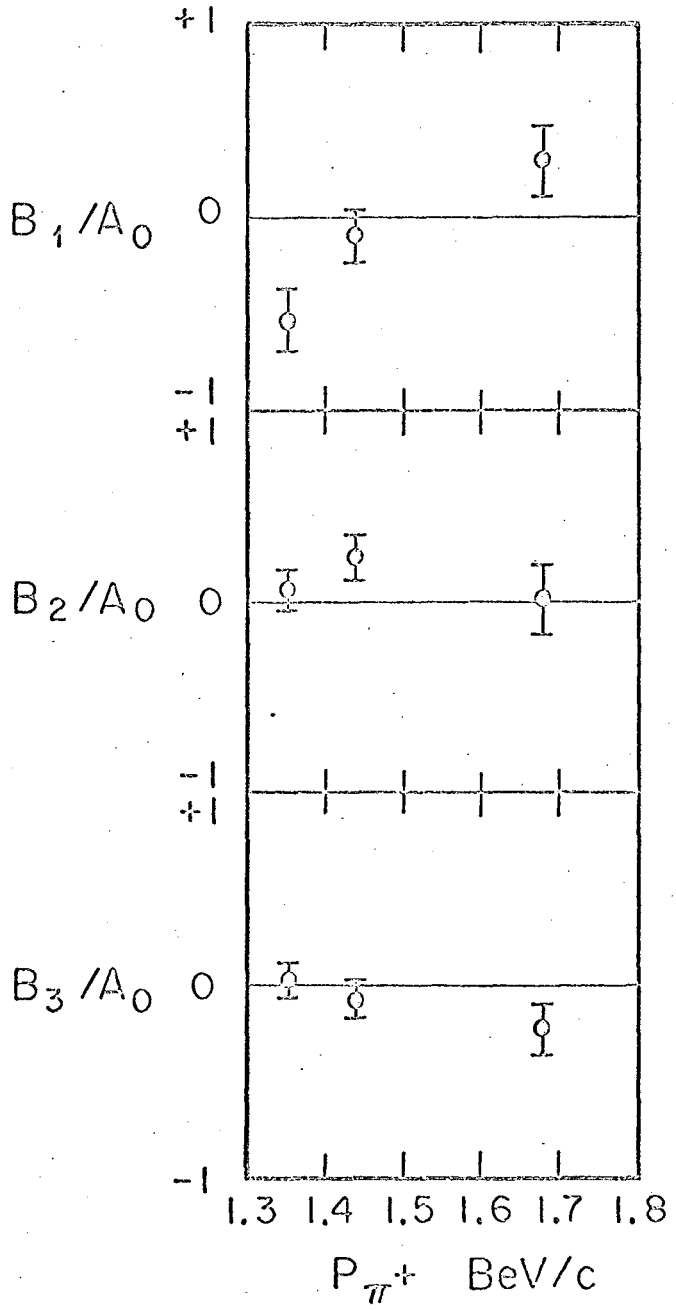

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Fig. 6