DISCUSSION

Sandweiss: The comment is that in the events $\Sigma^+\overline{\Sigma^+}$ that we observed there were 12 identified, and in 11 of those the antiparticle went forward and the particle went backward in agreement with these results.

Cool: May I ask if there is an appreciable amount of production of $\overline{\Xi^-}$ with additional mesons?

Montanet: At 3 GeV/c we cannot produce a π in addition to the $\Xi\bar{\Xi}$ pair. At 3.6 and 4 GeV/c, the results are far from complete, but the preliminary results tell us that there is certainly not an appreciable amount of such π production.

Sandweiss: In answer to Dr. Cool's question: In the charged Σ events we seem to find about 15% charged Σ pairs with an extra π^0, but again, in agreement with the others no cascades with extra π's at 3.3 GeV.

Gregory: As Montanet mentioned all the data are not analysed but we have started the scanning on the 4 GeV and there is one $\overline{\Xi^-}\pi^-\Xi^0$ event.

STRANGE PARTICLE CORRELATIONS IN HIGH ENERGY PION-NUCLEON COLLISIONS

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I. INTRODUCTION

We report here results based on 127 selected V^0 pairs produced by π^- of 6, 11 and 18 GeV/c in hydrogen-like (or free neutron-like) collisions in the Ecole Polytechnique 1 m heavy liquid bubble chamber [1] filled with a mixture 86% propane—14% Fréon CF_3Br (by volume). Due to the large size (300 litres) of our BC our efficiency to detect both V^0's of a pair is greater than that obtained in previous [2] studies made using the CERN 32 cm HBC and the Dubna 24 litre propane BC. Choosing events in which both neutral strange particles are visible enables us to study the correlations of the two strange particles produced in a given interaction and to study separately the behaviour of the K_1^0's from the reactions:

$$\pi^- + \text{nucleon} \rightarrow K^0 + \bar{K}^0 + n\pi + \text{nucleon}$$
(hereafter " $K\bar{K}$ ")

and $\pi^- + \text{nucleon} \rightarrow K^0 + Y^0 + n\pi$ (hereafter " YK ")

II. BUBBLE CHAMBER AND BEAM

Characteristics of the bubble chamber and the π-beams are summarized in Table I. The BC was about 100 m from the fast flip aluminium target in the CERN PS. The beam momentum was defined by the PS field, two bending magnets, and associated collimators.

TABLE I

E.P.B.C.	π^-BEAM			
Useful volume: $100 \times 52 \times 48$ cm^3.	Momenta GeV/c	$\Delta p/P$	Contamination $\mu + e$	Number of useful pictures
Magnetic field: 17,5 k gauss. (uniform to 10%) Stereoscopic angle: 27°	6.1	±4%	~5%	28,000
Liquid composition: C_3H_8 86%, CF_3Br 14% by volume.	11.6	±2%	~4%	7,000
Density: 0.55. Radiation length: 52 cm.	18.1	±2%	~4%	20,000

Since the target flip time (and thus the PS beam energy) was adjusted so that the pions were emitted at momenta close to the kinematical limit, the K^- and $\bar{p}$ contamination was negligible. The muon contamination was about 5% at all three beam momenta. The beam intensity was set to 4 or 5 pions per photo.

III. ANALYSIS

1. Scanning and measurements

The photos were scanned for interactions of beam tracks producing two V^0's. In order to be selected such a primary interaction had to be compatible with a π^- proton or a π^- neutron collision, i.e., to present at most one (forward) proton and as many negative as positive secondaries, or one extra negative. After measurement, an interaction was rejected if either V^0 or the system of the two V^0's was kinematically inconsistent with coming from a beam pion-nucleon interaction, or if after V^0 identification more than one baryon was present among the secondaries.

About half the selected interactions occurred on free protons present in propane. The other half occurred on quasi-free nucleons in nuclei. We estimate the contamination of interactions in which two nucleons participated is less than 20%. We calculate that Fermi motion of the struck nucleon would not appreciably perturb the V^0 production kinematics at these beam momenta.

2. V^0 identification

Each measured V^0 was fitted by a least squares analysis to K^0, Λ^0 and $\bar{\Lambda}^0$ assumptions [3]. Identification of the V^0 decay tracks as π^+ or proton, π^- or antiproton through ionization, visible stopping point, visible track length *vs* momentum, or δ ray emission was used to remove some of ambiguities. Care was taken to resolve (K^0 or Λ^0) ambiguities symmetrically with (K^0 or $\bar{\Lambda}^0$) ambiguities. Finally each surviving V^0 was classified into one of the categories: K^0, Λ^0, (K^0 or Λ^0), (K^0 or $\bar{\Lambda}^0$), $\bar{\Lambda}^0$.

Since the number of $\bar{\Lambda}^0$'s in these photos is negligible we have assumed the (K^0 or $\bar{\Lambda}^0$) ambiguous cases are K^0s. Some 2/3 of the (K^0 or Λ^0) ambiguous cases are in fact Λ^0's as can be seen from Fig. 1. This conclusion is confirmed by the fact that the number of (K^0 or $\bar{\Lambda}^0$) ambiguous cases is much smaller than the number of (K^0 or Λ^0). Since we took care to resolve the (K^0 or $\bar{\Lambda}^0$) ambiguities symmetrically with the (K^0 or Λ^0), and since the K^0 has spin zero, we should have as many K^0's decaying into (K^0 or $\bar{\Lambda}^0$) ambiguous configurations as into (K^0 or Λ^0).

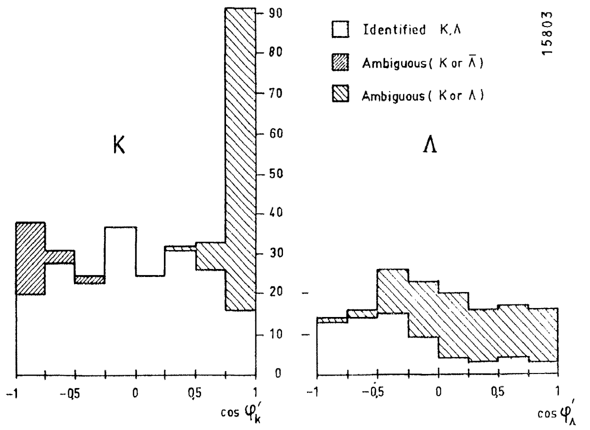

Fig. 1 Cos Φ' where Φ' = polar angle of positive decay track with respect to V^0 line of flight in V^0 rest system. V^0's produced at all three beam momenta are summed here.

As Fig. 1 shows, a simple cut-off in the angle of the positive decay track with respect to the line of flight of the K^0 in its rest system ($\cos\phi'_K < 0.75$) leaves a sample of K^0's not appreciably contaminated by wrongly identified Λ^0's and which still contains 87.5% of the total number of K^0's. In addition this sample is unbiased with respect to the production process.

No such simple cut-off is available for the Λ^0's (see Fig. 1), and the identified Λ^0 category is strongly biased in energy. Fortunately, as discussed above, if we take as Λ^0's all the V^0's which are either identified Λ^0's or ambiguous (K^0 or Λ^0) the resulting sample is little contaminated by K^0's (about 10% at 6 GeV beam momentum, 20% at 18 GeV). This K^0 contamination can be subtracted out statistically by subtracting out the (K^0 or $\bar{\Lambda}^0$) events treated as Λ^0's, leaving a sample or Λ^0's unbiased in energy and pure except for statistical fluctuations.

Selected $K^0\bar{K}^0$ *pairs* are thus those events in which both K^0's have $\cos\phi'_K < 0.75$ (about 76% of the total number of $K^0\bar{K}^0$ pairs).

Selected $K^0\Lambda^0$ *pairs* are thus those events with the K^0 having $\cos\phi'_K < 0.75$ and the Λ^0 either identified or ambiguous. Background of $K^0\bar{K}^0$ pairs in the

$K^0\Lambda^0$ lot is subtracted out statistically by subtracting the contribution of the $K^0(K^0$ or $\overline{\Lambda^0})$ pairs with the ambiguous V^0 treated as a Λ^0.

Each V^0 was individually weighted to take into account detection loss due to decay outside the BC, interaction in the liquid and confusion with electron-positron pairs. The product of the weights of the two V^0's from a given interaction was taken as the weight of the event.

Table II summarizes the data and gives an indication of the detection efficiency of the BC. At 6 GeV, most event weights are less than 1.2. At 18 GeV they can reach 2 or 3. The last column indicates the $K^0\overline{K^0}$ contamination present in the $K^0\Lambda^0$ category, before subtraction. This contamination has been subtracted out from the " $K\Lambda$ " histograms given below.

TABLE II

General statistics

		6.1 GeV	11.6 GeV	18.1 GeV
$K^0\overline{K^0}$	observed	22	11	13
	corrected	24.8	16.9	19.3
$K^0\Lambda^0$	observed	49	7	25
	corrected	60.6	11.9	44.4
$K^0(\overline{K^0}\Lambda^0)$	observed	4	0	4
	corrected	4.9	0	9.7

After weighting each event and subtracting out the K^0 contamination from our sample of Λ^0's, we find no evidence of forward-backward asymmetry in the Λ^0 decay. $(F-B)/(F+B) = -0.05 \pm 0.11$.

IV. RESULTS

Tables III and IV give the arithmetic means of the various distributions shown below, as well as the mean charged multiplicities of the $K^0\overline{K^0}$ and $K^0\Lambda^0$ producing jets.

Fig. 2 shows the interaction CMS longitudinal momentum distributions of the K^0's and Λ^0's from $K^0\Lambda^0$ pairs.

TABLE III

Mean values for $K^0\overline{K^0}$ production

	6.1 GeV	11.6 GeV	18.1 GeV
$\langle m \rangle$	1.6	1.7	3.8
$\langle p_{KT} \rangle$ GeV/c	0.41	0.65	0.40
$\langle p^*_K \rangle$ GeV/c	0.60	0.83	0.82
$\langle p^*_{KL} \rangle$ GeV/c	0.31	0.62	0.30
$\langle p_{(\overset{*}{K}K)L} \rangle$ GeV/c	0.62	1.24	0.60
$\langle Q_{KK} \rangle$ GeV	0.30	0.31	0.41

The Λ^0's tend to go backward in the interaction CMS but all p^*_L are roughly equally probable from the maximum kinematically possible backward to somewhat forward. Thus large momentum transfers from target nucleon to Λ^0 are not rare (see Fig. 3 showing $M = \sqrt{-\Delta^2_{p\Lambda}}$ where:

$$\Delta^2_{p\Lambda} = (E_p - E_\Lambda)^2 - (\mathbf{P}_p - \mathbf{P}_\Lambda)^2$$

The longitudinal component of the momentum of the $K\overline{K}$ system and of the $K\Lambda$ system is shown in Fig. 4 $(p_{(\overset{*}{K}\Lambda)L} = p^*_{KL} + p^*_{\Lambda L})$. The $K\overline{K}$ system tends to go forward in the CMS although there is some indication of a small momentum backward group at 18 GeV. The $K\Lambda$ system tends to go backwards but is most often nearly at rest in the CMS.

TABLE IV

Mean values for Λ^0K^0 production

	6.1 GeV	11.6 GeV	18.1 GeV
$\langle m \rangle$	1.3	2.2	2.7
$\langle p_{KT} \rangle$ GeV/c	0.40	0.49	0.63
$\langle p_{\Lambda T} \rangle$ GeV/c	0.37	0.69	0.55
$\langle p^*_K \rangle$ GeV/c	0.77	0.85	1.06
$\langle p^*_\Lambda \rangle$ GeV/c	0.83	1.40	1.41
$\langle p^*_{KL} \rangle$ GeV/c	0.37	0.08	0.61
$\langle p^*_{\Lambda L} \rangle$	−0.56	0.01	−1.20
$\langle p_{(\overset{*}{K}\Lambda)L} \rangle$ GeV/c	−0.19	0.09	−0.69
$\langle Q_{K\Lambda} \rangle$ GeV	0.61	0.98	0.99

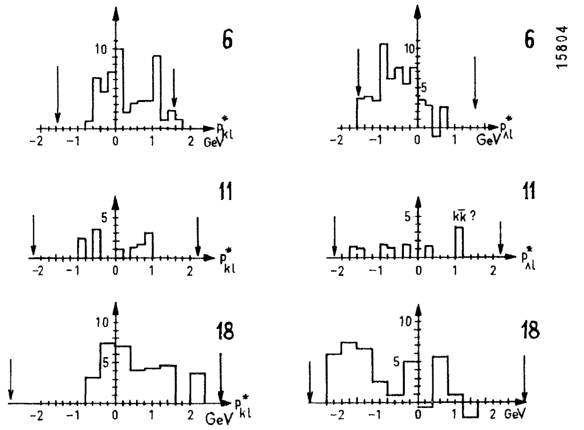

Fig. 2 π-P CMS longitudinal momentum distributions for the K^0's and Λ^0's of K^0 Y^0 pairs. Arrows show kinematical limits. The event marked "$K\bar{K}$?" at 11 GeV is a K^0 ($\bar{K}^0$ or Λ^0) event with large weight which is probably really a $K\bar{K}$ pair, but happens by a statistical fluctuation not to be subtracted out by a corresponding $\bar{K}^0$ (K^0, or $\bar{\Lambda}^0$) event.

The relative energy of the two K^0's in $K\bar{K}$ production tends to be quite small (Fig. 5 shows $Q_{KK} = \sqrt{(E_{K1}+E_{K2})^2-(\mathbf{P}_{K1}+\mathbf{P}_{K2})^2}-2M_K$). In nearly all of our $K\bar{K}$ events, Q_{KK} is less than 0.6 GeV, for nearly half the events Q_{KK} is less than 0.2 GeV, whereas the kinematical limit of Q_{KK} for 6 GeV is 1.6 GeV, for 18 GeV it is ~4 GeV. The distribution of Q_{KK} does not vary significantly with beam momentum. Also the $p^*_{(KK)L}$ distribution (Fig. 4) is the same (within our rather large statistical errors) for $Q_{KK}>0.2$ GeV and $Q_{KK}<0.2$ GeV.

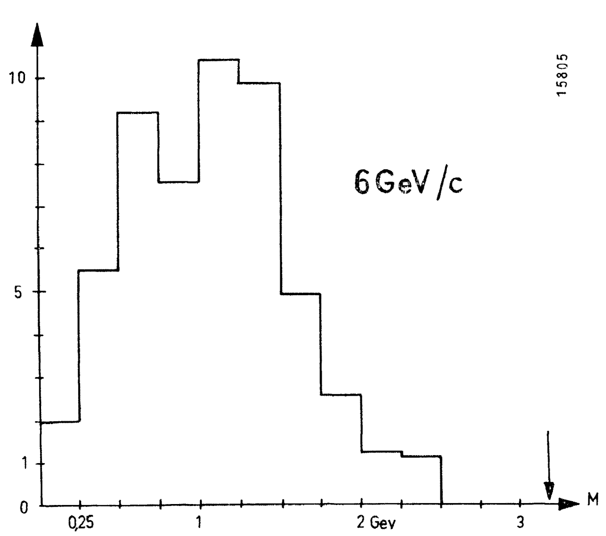

Fig. 3 Proton to Λ 4-momentum transfer $M = \sqrt{-\Delta^2_{p\Lambda}}$ where

$$\Delta^2_{p\Lambda} = (E_p-E_\Lambda)^2-(\mathbf{P}_p-\mathbf{P}_\Lambda)^2.$$

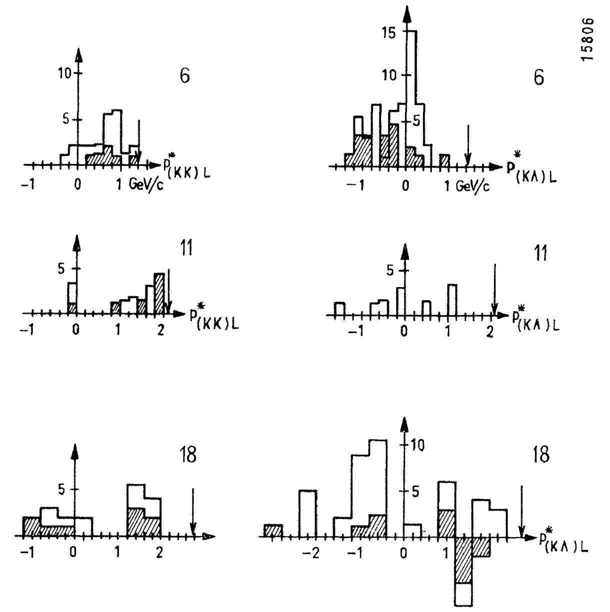

Fig. 4 Longitudinal component of πP CMS momentum of the $K\bar{K}$ and $K\Lambda$ system:

$$p^*_{(KK)L} = p^*_{K_1L}+p^*_{K_2L},\quad p_{(K\Lambda)L} = p^*_{KL}+p^*_{\Lambda L}.$$

Arrows show kinematical limits, shaded events have $Q_{kk}<0.2$ GeV (or $Q_{k\Lambda}<0.2$ GeV.)

The $Q_{K\Lambda}$ of the $K^0\Lambda^0$ system (Fig. 6) tends also to be small relative to its kinematical limit, but only about half of our events have $Q_{K\Lambda}$ less than 0.6 GeV, some 20% have $Q_{K\Lambda}<0.2$ GeV.

Our preliminary data on the correlations among the strange particles and the pions of low multiplicity

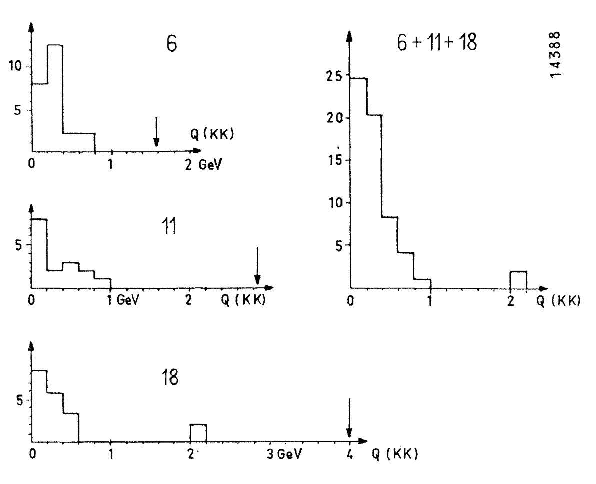

Fig. 5 Relative energy (Q_{KK}) of the two K^0's of a $K^0\bar{K}^0$ pair

$$Q_{KK} = \sqrt{(E_{K_1}+E_{K_2})^2-(\mathbf{P}_{K_1}+\mathbf{P}_{K_2})^2}-2M_K$$

jets at 6 GeV are shown in Figs. 7 and 8. The $Q_{K^0\pi^+}$ distribution for the $K\Lambda$ jets (Fig. 7) shows a peak near the K^* mass of 885 MeV which the $Q_{K^0\pi^-}$-distribution does not show. (This is in agreement with the assignment of isotopic spin 1/2 to the K^*.) There is no striking evidence for K^* or $\overline{K^*}$ production in the $K\overline{K}$ jets (Fig. 8). Some evidence of peaking about the Y_1^* mass (1385 MeV) is visible in our preliminary $Q_{\Lambda\pi}$ distributions (Fig. 7).

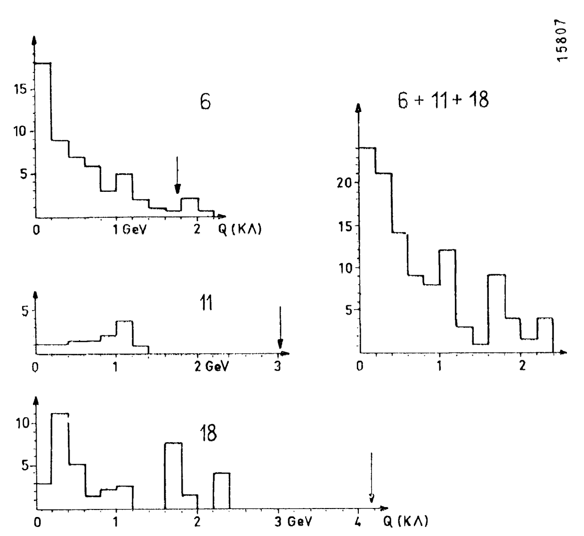

Fig. 6 Relative energy ($Q_{K\Lambda}$) of the two V^0's of a $K^0\Lambda^0$ pair

$$Q_{K\Lambda} = \sqrt{(E_K+E_\Lambda)^2-(\mathbf{P}_K+\mathbf{P}_\Lambda)^2}-M_K-M_\Lambda$$

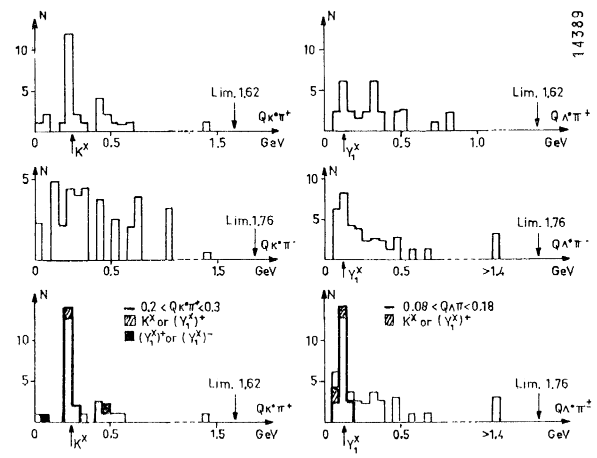

Fig. 7 Relative energy (Q_{KK} or $Q_{\Lambda\pi}$) of V^0 and outgoing pion of jet

$$Q_{K\pi} = \sqrt{(E_K+E_\pi)^2-(\mathbf{P}_K+\mathbf{P}_\pi)^2}-M_K-M_\pi$$

If there are for example two π^+ from a given jet two boxes appear in the $Q_{K^0\pi^+}$ histogram.

The lowest histogram is "enhanced ", i.e. if a particle "resonates " in one combination all the other combinations using it are suppressed.

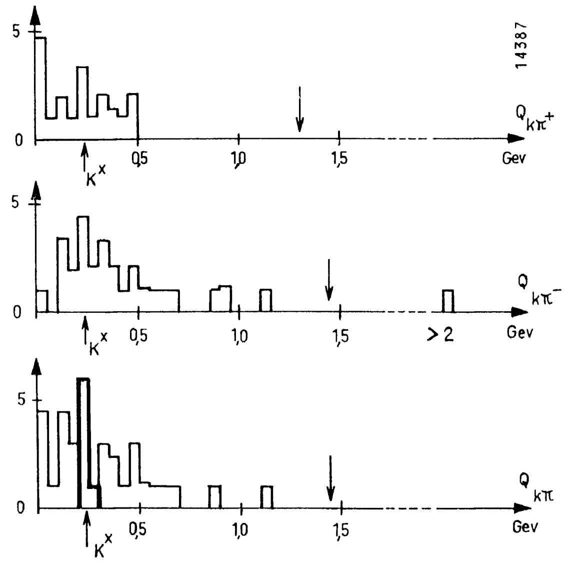

Fig. 8 as Fig. 7 but for the K^0's of $K^0\overline{K^0}$ pairs.

V. DISCUSSION

1. Baryon kinematics

The Baryon goes backwards in the interaction CMS, therefore neither $K^0\Lambda^0$ nor $K^0\overline{K^0}$ production at these energies is a purely statistical process.

Fig. 2 verifies the well-known [2)] fact that the Λ^0's tend to go backwards in the CMS.

That the nucleon in $K\overline{K}$ jets tends also to go backwards, follows essentially from the facts that the $K\overline{K}$ pair tends to go forward and that the mean pion multiplicity is not large. More than 80% of the nucleons would go backwards at 6 and 11 GeV (~60% at 18 GeV) even if the system formed by all of the jet particles except the $K\overline{K}$ pair decayed isotropically into two bodies: the nucleon in one direction and all of the pions together in the opposite direction.

2. π or K exchange

The backward peaking of the Baryon suggests that " glancing " collisions play an important role in high energy pion-nucleon interactions. In a simple model the interaction is pictured as taking place through the exchange of a single virtual particle between the " pion vertex " and the " nucleon vertex " as indicated in Fig. 9.

The square of four-momentum transferred between the two vertices is expected to have small negative values [4)], consequently the momentum of the system

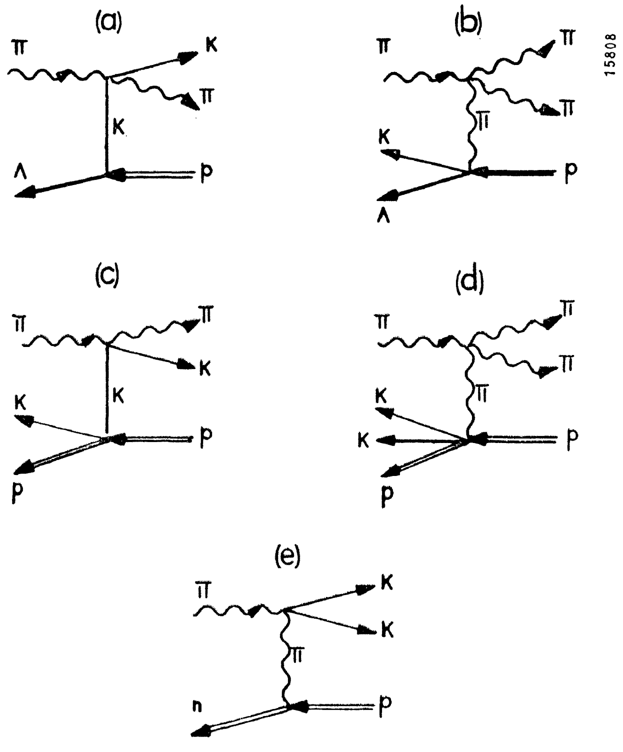

Fig. 9 Schematic diagrams illustrating some possible "peripheral" models of πP collisions producing $K\Lambda$ or $K\bar{K}$ pairs.

of all particles emitted at one vertex should tend to be as close as possible to the corresponding incident particle momentum.

Some groups of our events agree qualitatively with each of the models shown in Fig. 9, but none of the models seems to explain all the general features of the data.

One is tempted to interpret the backward peaking of the Λ^0's and the forward peaking of the K^0's in $K\Lambda$ production by predominance of model a.

This model would not seem to be dominant, however, since the K^0's longitudinal momenta (Fig. 2) are smaller on the average than would be expected if they were emitted isotropically from the pion vertex. Also small momentum transfers are not dominant (Fig. 3).

The fact that the K^0's from $K\Lambda$ pairs are emitted predominantly forward in the CMS would seem to contradict model b.

K-exchange in $K\bar{K}$ production (model c) should give more backward K's and larger Q values for the KK system than observed (Fig. 5).

These conclusions could be weakened of course by the presence of extra pions at the two vertices. For example if a diffraction-like scattering were predominant in graphs a) or c) one might expect the K^0's to have predominantly small $p_L{}^*$.

The longitudinal momentum for the $K\bar{K}$ system is predominantly forward (Fig. 4) contrary to model d. Some events especially at 11 GeV are in good agreement with model e but the longitudinal momenta of the $K\bar{K}$ system are too small for this model to be predominant unless some pions are emitted along with the two K's.

3. Q_{KK} and $Q_{K\Lambda}$

The Q_{KK} distribution (Fig. 5) seems independent of available CMS energy (i.e. beam momentum). Events with $Q_{KK} < 0.2$ GeV have $p^*_{(KK)L}$ distribution (Fig. 4) similar to that for $Q_{KK} > 0.2$ GeV. This apparent independence of Q_{KK} from the production kinematics is evidence of a strong correlation between the K^0s of $K^0\overline{K^0}$ pairs. It is tempting to attribute this correlation to a low energy $K\bar{K}$ interaction, or to a resonant state of mass ~ 1.1 GeV which could decay into a $K_1^0K_1^0$ pair [*].

It is not, however, necessary to invoke a $K\bar{K}$ resonance to explain our data. The baryon is known to go strongly backwards in the CMS, thus the target nucleon (or nucleon plus created pions) could retain such a large fraction of the available CMS energy and momentum that little phase space be left for relative energy of the two K^0's. Further study is in progress of the jets associated with the V^0 pairs in hope of shedding light on this point.

In contrast to the $K\bar{K}$ case, the $Q_{K\Lambda}$ distribution does depend on beam momentum, also small $Q_{K\Lambda}$ tends to be associated with jets of many pions and large $Q_{K\Lambda}$ with low multiplicity jets (in fact we have three events consistent with *no* pions being created along with the $K\Lambda$ pair).

4. K^* and Y_1^*

The presence of a peak in our $Q_{K^0\pi^+}$ distribution (Fig. 7) at a mass consistent with the K^* mass (885 MeV) and the absence of such a peak in our

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[*] For spin 0 and mass 1.05 GeV the decay into $\pi+\pi$ (if allowed) would be favoured by phase space alone by about a factor 3 over the decay into $K+\bar{K}$. For spin 2, mass 1.05 the factor would be about 250 for spin 2, mass 1.1 GeV about 60.

$Q_{K^0\pi^-}$-distribution (which peak should not occur if the K^* has isotopic spin ½) is evidence of K^0 production via K^{*+} in $K\Lambda$ jets. Since the " background " in the $Q_{K^0\pi^+}$ distribution might include K^0's from K^{*0} decay, it would seem that a very large fraction of $K\Lambda$ production at 6 GeV occurs via K^*.

There is evidence of a peak in $Q_{\Lambda\pi^-}$, perhaps also in $Q_{\Lambda\pi^+}$ at a mass consistent with the Y_1^* mass (1385 MeV). We have found only 4 events out of 29 which might be examples of simultaneous production of K^{*+} and Y_1^*.

We see no evidence of peaking in the K^* mass region of our $Q_{K^0\pi^+}$ and $Q_{K^0\pi^-}$ distributions for the K^0's produced in $K^0\overline{K^0}$ pairs (Fig. 10). Note, however, that we cannot distinguish K^0's from $\overline{K^0}$'s so the " background/peak " ratio should be relatively larger here than for the K^0's from $K\Lambda$ pairs.

TO SUM UP

(i) We confirm [2)] that the Λ^0's are peaked backwards in the CMS but with longitudinal momentum distributed roughly uniformly from slightly forward to the maximum kinematically possible backwards.

(ii) Analysis of our $K^0\overline{K^0}$ events gives evidence of similar backward peaking of the nucleon in $K\overline{K^0}$ jets.

(iii) CMS longitudinal and transverse momentum distributions show little difference in the behaviour of the K^0's from $K^0\overline{K^0}$ pairs and those from K^0Y^0 pairs. Both tend to go forward in the CMS but small momenta are most probable.

(iv) The main features of our data cannot be explained by phase space alone, nor by any single naive peripheral model.

(v) The K^0's of $K^0\overline{K^0}$ tend to come off together with ~50% chance of relative energy $Q_{KK}<0.2$ GeV, $^1/_8$ ($^1/_{50}$) of the energy available in the CMS at 6 GeV (18 GeV) beam energy. The Q_{KK} distribution is approximatively independent of beam energy.

(vi) Preliminary data on correlations among the strange particles and the pions of the $K^0\Lambda^0$ producing jets show evidence for K^{*+} and Y_1^* production by 6 GeV π^-. We see no evidence for K^* production in $K^0\overline{K^0}$ producing jets.

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