CERN LIBRARIES, GENEVA

CM-P00064251

SYSTEMATIC STUDY OF $K\pi$ PRODUCTION IN THE REACTION $K^+p \rightarrow K_S^0\pi^+p$:
TECHNIQUE AND MEASUREMENTS AT 10 GeV/c

R. Baldi, T. Böhringer, P.A. Dorsaz, V. Hungerbühler,
M.N. Kienzle-Focacci, M. Martin, A. Mermoud, C. Nef and
P. Siegrist

University of Geneva, Switzerland

and

CERN, Geneva, Switzerland

ABSTRACT

A two-arm spectrometer for simple event topologies is described. Its main characteristics are: i) large solid-angle acceptance for the forward emitted particles, owing to the absence of magnetic-momentum analysis; ii) high-resolution time-of-flight measurement of the recoil proton, in the momentum transfer range $0.05 < |t| < 1 \text{ (GeV/c)}^2$; and iii) high data-taking rate and on-line pattern recognition.

The apparatus has been used for a systematic study of the $K\pi$ system produced in the reaction $K^+p \rightarrow K_S^0\pi^+p$ at 10 GeV/c. We present the results in terms of spherical harmonics moments of the $K\pi$ -decay angular distribution.

Geneva - 5 October 1977

(Submitted to Nuclear Physics B)

1. INTRODUCTION

The aim of this experiment is the detailed investigation of $K\pi$ production in the reaction

$$K^\pm p \rightarrow K_S^0 \pi^\pm p \quad \text{with} \quad K_S^0 \rightarrow \pi^+ \pi^- . \quad (1)$$

We have built a spectrometer with the object of obtaining high statistics in this channel, as well as in other channels with similar topologies. In this first of two papers we describe the apparatus, its performance, and the method of analysis, in detail. We then present our results in terms of moments of the $K\pi$ -decay angular distribution in the t -channel helicity frame, which we determine both as a function of $K\pi$ mass and of momentum transfer t .

In the second paper [1] we then study the physical implications. In particular, we perform an amplitude analysis of $K\pi$ production through the $K^*(890)$ and $K^*(1420)$ mass region and discuss the exchange mechanism responsible for production of these resonances.

2. THE SPECTROMETER

The spectrometer has been designed to measure events signed by a slow recoil proton at large laboratory angle and $1 V^0 + 1$ charged track in the forward direction. This topology corresponds to the reactions

$$\begin{aligned} K^\pm p &\rightarrow (K_S^0 \pi^\pm) p , & K_S^0 &\rightarrow \pi^+ \pi^- \\ K^+ p &\rightarrow (\bar{\Lambda} p) p , & \bar{\Lambda} &\rightarrow \bar{p} \pi^+ \\ K^- p &\rightarrow (\Lambda \bar{p}) p , & \Lambda &\rightarrow p \pi^- \\ \pi^\pm p &\rightarrow K_S^0 K^\pm p , & K_S^0 &\rightarrow \pi^+ \pi^- \\ pp &\rightarrow \Lambda K^+ p , & \Lambda &\rightarrow p \pi^- \\ \bar{p} p &\rightarrow \bar{\Lambda} K^- p , & \bar{\Lambda} &\rightarrow \bar{p} \pi^+ . \end{aligned} \quad (2)$$

The spectrometer is capable of operating in an unseparated beam of either polarity and of recording simultaneously K^- , π^- , and p -induced reactions. As the main aim of the experiment is kaon physics, incident K 's are given priority over π 's and p 's, in order to accept these comparatively rare events with small dead-time

loss: this is achieved by a two-level trigger in conjunction with a buffer memory. The π^- and p-induced triggers are then recorded as by-products, with a lower priority.

Other topologies are also obtained as by-products, corresponding, for example, to the reactions

$$\begin{aligned} K^+p &\rightarrow K^+K^+K^-p \\ K^+p &\rightarrow K^+K_S^0K_S^0p \quad \text{with both } K_S^0 \rightarrow \pi^+\pi^- . \end{aligned} \quad (3)$$

2.1 Principle of the spectrometer

The apparatus consists of the following parts (Fig. 1):

- a beam spectrometer, to measure identity, direction and momentum of the incident particle;
- a recoil proton arm to identify the recoil proton, and to measure the direction and momentum;
- a forward arm to measure the directions of the forward emitted particles.

No magnet is used and therefore the forward particle momenta are not measured. The kinematics can be completely reconstructed for events with one forward track and a seen V^0 [2C fit, reactions (2)], three forward tracks, or one forward track and two seen V^0 's [both 1C fits, reactions (3)]. In addition to the kinematical constraints there are geometrical constraints, such as the requirement of a minimum separation between production and decay vertex of the V^0 , or coplanarity of the V^0 decay with the production vertex.

The absence of a magnet has the disadvantage of a limitation on the topologies given above; it has the advantages of a large acceptance, of limited information necessary per event, and of simplified pattern recognition and geometrical reconstruction programs. This allows a high data-recording rate, and fast event processing, indispensable for obtaining the desired statistics.

2.2 Beam and target

The experiment has been operating in the d_{31} beam at the CERN PS. At a momentum of 10 GeV/c, and with a momentum bite of $\pm 1.4\%$ for the positive beam and

$\pm 2.4\%$ for the negative beam, the intensity was typically 2.4×10^6 positive particles, and 0.35×10^6 negative particles per 420 msec burst at the experimental target.

The beam momentum is measured by making use of an intermediate horizontal focus with a chromaticity of $5 \text{ mm}/\% \Delta p/p$. Two scintillation hodoscopes H_0 and H'_0 , with 6 vertical overlapping elements each, record the position of the trajectory near the intermediate focus. The momentum measurement is calibrated by closing the momentum slit to 0.1% and moving it across a band of $\pm 1.5\%$. As an example, Fig. 2 gives the distribution of hits in H_0 and H'_0 , for a narrow slit centred at $p_0 - 1\%$, p_0 , and $p_0 + 1\%$. The momentum resolution, deduced from such calibrations, is $\Delta p/p = 0.2\%$.

The direction of the incident particle is measured by four hodoscopes H_1 to H_4 , two of them with horizontal and two with vertical elements, before the hydrogen target. The angular resolution of the incident track is $\pm 0.54 \text{ mrad}$, mainly due to the element size and geometry of the hodoscopes.

Four threshold Čerenkov counters C_1 to C_4 are used for particle identification: two 3 m counters, filled with hydrogen at 7.5 atm, are sensitive to pions, and two 1 m counters, filled with isobutane at 6.5 atm, are sensitive to pions and kaons. The beam composition $K/\pi/p$ is $1.9\%/97\%/1.1\%$ for negative polarity, and $2.1\%/25\%/73\%$ for positive polarity, at a primary beam energy of $26 \text{ GeV}/c$. The contamination of the K sample, owing to inefficiencies, dead-time, accidentals and δ -rays, is negligible for the negative beam, and amounts to 2% by pions and 4% by protons in the positive beam.

The beam is focused on a 53 cm long liquid-hydrogen target of 4 cm diameter. The beam size at the focus is 20 mm horizontally and 24 mm vertically (FWHM). The beam is positioned close to the side wall of the target, in order to reduce multiple scattering of the recoil proton, which traverses on the average 1 cm of liquid hydrogen. The target vacuum vessel has a carefully designed geometry, with thin mylar windows on the side of the proton arm (250μ), and the forward arm (500μ).

2.3 Forward arm; multiwire proportional chambers

The forward arm consists of four multiwire proportional chambers (MWPC), each with two perpendicular sense wire planes. The first chamber downstream from the target has a fiducial area of $512 \times 512 \text{ mm}^2$, while that of the three following chambers is $1280 \times 1280 \text{ mm}^2$. The first and third chamber measure horizontal (x) and vertical (z) coordinates, the second and fourth chamber are rotated by 15° (u-v coordinates), in order to remove ambiguities. The forward arm accepts tracks up to about 33° with respect to the beam axis.

The construction parameters are the following: sense wires have diameter 20μ and spacing 2 mm . For each sense-wire plane there is a separate set of two high-voltage planes, made of 50μ wires with spacing 1 mm . The high-voltage gap of 6 mm is kept constant by support wires and spacers.

The gas used is the "magic" mixture, consisting of 79% argon, 14% isobutane, 0.3% freon 13B1 and 7% methylal. The chambers are operated at about -4000 V .

The read-out of all wires is in parallel: each wire is connected to a pre-amplifier mounted on the chamber frame. The signals then travel through 60 m long twisted pairs to line receivers, followed by one-shot delays and flip-flop memories.

The angular resolution, due to the geometrical accuracy of the MWPCs, is about $\pm 0.3 \text{ mrad}$. Multiple scattering in hydrogen, air, and the MWPCs ($L/L_{\text{rad}} = 0.0073$) dominates for tracks slower than 4 GeV/c .

The MWPC efficiency depends on particle flux. Outside the beam and support-wire regions, the efficiency was 95 to 98%. In the beam region, for a flux density of the order of $10^6 \text{ particles/cm}^2 \text{ sec}$ typical for the positive beam, the efficiency drops to about 60% (Fig. 3). The inefficiency is limited to the region where the flux is high and does not extend to the whole length of the sense wires going through the beam. It is therefore related to a space-charge effect rather than to electronics dead-time.

The support lines of the sense-wire planes are fixed at a potential of -1000 V . They produce an inefficiency of about 50% in a 4 mm wide band. We observed no loss of efficiency due to the support wires of the high-voltage planes.

2.4 Recoil proton arm; time-of-flight counter

The recoil proton arm consists of a large time-of-flight scintillator (T) for the momentum determination, a range system of scintillators and absorbers for proton identification, and of three MWPCs identical to the ones used in the forward arm for direction measurements [the range system is not used in the analysis of the 2C channels (2)]. The axis of the proton arm is at 59.5° with respect to the beam. The geometry of the proton arm determines essentially the acceptance in $K\pi$ mass (Fig. 4).

Time of flight is measured between a start counter S in the beam line in front of the target, and the stop counter T of dimensions $150 \times 150 \text{ cm}^2$, at a distance of 1.9 m from the target. Both S and T counters are each viewed by 4 photomultipliers, giving 4 independent time-of-flight measurements. The start and stop signals are fed, on the one hand, into a commercial time-digitizer circuit; on the other hand, their pulse height is also recorded in ADCs. The four time-of-flight measurements are then averaged, and a correction depending on the average pulse height in the S and T counters is applied. These corrections have been determined empirically using elastic events. The proton time of flight is then obtained after correction for the distance between the S counter and the interaction vertex, and finally the proton momentum at the production vertex is deduced from the time of flight, taking into account the energy loss along the proton path.

The time resolution has been measured in the production set-up using elastic events. From incident momentum and recoil angle the expected time of flight can be calculated and compared with the measured value. Alternatively, the incident and forward track can be used to predict time of flight of the recoil particle, which is compared with the measured value. From these distributions we can then derive the time resolution, shown in Fig. 5, which is found to depend on proton momentum. A typical value is 200 psec at $p = 500 \text{ MeV}/c$, corresponding to a momentum resolution of 2%.

The MWPCs in the proton arm are of the same construction as those in the forward arm. However, a less expensive read-out system is used. As one expects only one particle in the proton arm, it is possible to encode 256 consecutive

sense wires into 16 groups of 16 wires each. Each sense-wire signal is then fed into two electronic channels: one channel gives the number of the group, the second gives the wire number within the group. The number of electronics channels required is thus reduced by a factor of eight.

At low rate (less than a few kilocycles) and for single tracks, the efficiency of this system is the same as for parallel read-out. It drops, however, with increasing accidental rate in the chambers, as it is difficult to remove ambiguities due to multitracks in one segment of 256 wires. It is mainly for this reason that the efficiency per track of the MWPCs in the proton arm drops to about 70% in the highest intensity runs.

The accuracy of the recoil proton direction is determined primarily by the multiple scattering in hydrogen and air. The average amount of material traversed is $L/L_{\text{rad}} = 0.005$, corresponding to an angular resolution of 4.3 mrad for 500 MeV/c protons.

3. TRIGGER AND DATA ACQUISITION SYSTEM

The trigger and data-acquisition system (Fig. 6) consists of the following parts:

- a) A first-level trigger, derived from the scintillation and Čerenkov counter signals, available after 600 nsec. It generates gates for the hodoscope and time-of-flight signals, and a strobe for the MWPCs.
 - b) Memories prior to transfer. They are CAMAC ADCs, TDCs, pattern units and scalars. The MWPCs have two memories: a parallel memory on each wire, followed by one CAMAC compatible coding unit per MWPC plane. These give in 2 to 3 μsec the number of wire clusters, their coordinate and size.
 - c) A second-level trigger. It is derived from the information of the beam hodoscopes, and of the MWPC coding units, and initializes the transfer to the computer.
 - d) A PDP 11/45 for data acquisition and partial event processing between bursts.
 - e) An IBM 1800 for tape writing and on-line checking of the whole equipment.
- IBM 1800 and PDP 11/45 are linked through a CAMAC buffer memory.

3.1 The first-level trigger

The first-level trigger condition is:

$$M = B \cdot C \cdot T \cdot SAT \cdot \bar{A} ,$$

where B is the coincidence of the beam telescope counters ($B = B_0 B_1 B_3 \bar{A}_0 S_1 S_2 S_3 S_4$). $\bar{A}_0$ is an anti-halo counter and S_i are the four time-of-flight start signals.

The Čerenkov-coincidence C identifies the beam particle: $C = C_1 C_2 C_3 C_4$ for a π , $C_1 \bar{C}_2 C_3 \bar{C}_4$ for a K, and $\bar{C}_1 \bar{C}_2 \bar{C}_3 \bar{C}_4$ for a p. The π and p signals can be pre-scaled before the first-level trigger.

T is a coincidence of the four time-of-flight stop signals. In order to reduce the time jitter due to the large counter size, the time average of pairs of photomultipliers looking at opposite sides of the counter are used: $T = (T_{13} \text{ average}) \cdot (T_{24} \text{ average})$. The resulting time jitter is less than 2 nsec and allows rejection of $\beta = 1$ particles.

SAT is a threshold on the sum of the amplitudes of the four stop signals, to remove minimum ionizing particles in the proton arm.

$\bar{A} = \bar{A}_1 \cdot \bar{A}_2$ is an anti-beam telescope with rough momentum analysis downstream from the target. It rejects non-interacting beam particles without suppressing interaction products emitted in the beam region with a lower momentum.

3.2 The second-level trigger

The second-level trigger N is a coincidence of four flip-flop outputs, each corresponding to a specific condition:

$$N = M \cdot H \cdot F \cdot P ,$$

where M is the first-level trigger;

H is a condition on the beam hodoscopes requiring at least one hit in each of the hodoscopes H_1 to H_4 .

F is a condition on the number of forward tracks. For each plane of the forward MWPCs, a lower and upper limit on the number of clusters can be set, as well as lower and upper limits on the total number of clusters in all x-u and z-v planes. The F rejection is overridden for kaon- and antiproton-induced events.

P is a condition on the MWPCs in the proton arm, requiring at least one hit in two x- and in two z-planes. This is the minimum condition for the reconstruction of a proton track.

If not all the conditions are met, the event is rejected and the whole electronics reset.

3.3 PDP 11/45 and IBM 1800

If the second-level decision is yes, transfer to the PDP 11/45 starts. The following data blocks are transferred successively:

- a) Scalers, pattern units, ADCs and TDCs (28 16-bit words).
- b) MWPC coding units (64 words).

The total transfer time is about 370 μ sec. The events are first stored in the 24K memory of the PDP 11/45, at a maximum rate of 225 events per burst.

The transfer of 225 events gives a dead-time of about 20% for a 400 msec burst. This represents too high a loss for the relatively rare kaon-induced events. To avoid this loss, pion- or proton-induced triggers are inhibited while an event is being transferred to the PDP 11/45. The rare kaon or antiproton-induced events, however, are inhibited only for the time necessary for transferring the first data block, i.e. for about 100 μ sec. After this time, the first block is reset, and a new event can again be accepted. It will be stored in the first block normally, and in the parallel flip-flop memories of the MWPCs, waiting for the coding units to be liberated. The resulting dead-time for such high-priority events is thus reduced to a few per cent.

In the 2.2 to 2.4 sec between bursts, the PDP does a partial processing of all events. It consists of pattern recognition and track reconstruction in the forward MWPCs, of decoding the information of the matrix read-out of the proton chambers, and of checking the hodoscope signals.

Events with more than one track in the last four hodoscope planes are rejected. Also events where the proton track cannot be reconstructed because of ambiguities in the matrix read-out are rejected. The track reconstruction in the forward arm is the main part of the on-line processing. For an average of about

3 reconstructed tracks/event, this requires about 10 msec/event. As forward track reconstruction is a major part of the complete geometrical event reconstruction, we have been able to reduce the off-line processing by approximately a factor of two.

As soon as the events are processed by the PDP, they are transferred via a 256-word CAMAC buffer memory to the IBM 1800, used for tape writing and for technical checks. The technical monitoring is performed by a sampling program, consisting of five overlays which are running cyclically. Each has a specific task: analysis of the detectors in the beam line (hodoscopes, Čerenkov counters, spot size, etc.), the forward MWPCs (distribution of hits, efficiency, etc.), the proton MWPCs, the time-of-flight system (TDC and ADC distributions), and the results of the reconstruction by the PDP (track parameters, χ^2). The results in the form of histograms are displayed continuously.

4. DATA ANALYSIS

4.1 Event identification

Events corresponding to the reaction (1) are identified by their geometry and kinematics. The geometry cuts select candidates with the correct topology: i) a successfully reconstructed single track in the proton arm due to a recoil particle, and ii) a (1 charged + seen V^0)-topology in the forward arm. The V^0 -decay vertex must be at least 27 mm downstream from the production vertex. We allow for the possibility of one additional accidental track.

Next, we use momentum conservation to calculate the unmeasured momentum magnitudes of the three forward particles. We then calculate the two kinematic constraints of the reaction, which can be chosen as the over-all energy balance ΔE of the reaction

$$\Delta E = E_{\text{inc}} + m_p - E_{\text{recoil}} - \sum_{i=1}^3 E_i \quad (4)$$

(where E_i are the forward particle energies) and the effective mass of the V^0 . These two constraints must be satisfied within wide limits: $|\Delta E| < 20$ MeV and $450 < M_{K^0} < 550$ MeV.

Events satisfying these criteria are processed by a kinematical 2C fit, and accepted if $P(\chi^2) > 5\%$. The successfully fitted events are further required to have forward momentum $p > 300$ MeV/c. This cut eliminates events suffering from large multiple scattering in the target. Finally we require $M_{\pi p} > 1.4$ GeV in order to remove a small background due to excitation of the target nucleon in $K^\pm p \rightarrow K^0 \Delta^{\pm+}$. Note that this reaction is already suppressed by the spectrometer geometry and by the requirement of a single track in the proton detector.

The resulting sample contains 46450 events corresponding to the $K^+ p \rightarrow K_S^0 \pi^+ p$ reaction, and 17960 events in the $K^- p \rightarrow K_S^0 \pi^- p$ channel.

4.2 Background

The quality of the sample can be demonstrated by displaying the distribution of the kinematical constraints ΔE and M_{K^0} , calculated with the unfitted quantities only (Fig. 7). Interpolation of the tails of the M_{K^0} distribution under the K^0 -mass peak gives a background of about 2%. Alternatively, we can estimate the amount of background by inspecting the shape of the $P(\chi^2)$ distribution. The excess of events at small $P(\chi^2)$ is also of the order of 2%.

The most likely source of background is the reaction

$$K^\pm p \rightarrow K_S^0 \pi^\pm \pi^0 p, \quad (5)$$

with a π^0 in addition to the (1 charged + seen V^0)-topology. This reaction is diffractive and has a large cross-section. We have estimated the expected contamination of the data by this channel using a Monte Carlo program. We find a value which is indeed consistent with the observed one.

4.3 Resolutions

The energy balance is satisfied to ± 3.5 MeV. This small value is due to the fact that any inaccuracy in the incident momentum is carried over into inaccuracies of the absolute momenta of the forward particles. The energy balance is insensitive, in first order, to the resulting shift in longitudinal momentum. The K^0 -mass resolution is ± 7 MeV. These widths are in good agreement with Monte Carlo calculations incorporating the resolutions of the individual detectors.

The resolution in $K\pi$ mass is mass dependent: at the mass of the $K^*(890)$, $K^*(1420)$ and $K^*(1780)$ resonances, it is ± 7 , 8.5 , and 10 MeV, respectively. The t resolution depends essentially on the accuracy of the time-of-flight measurement: typical values are ± 0.005 at $t = -0.1$ $(\text{GeV}/c)^2$ and ± 0.02 at $t = -0.4$ $(\text{GeV}/c)^2$. We monitor the stability of the system by continuously recording elastic events during the data-taking periods.

4.4 Acceptance

The acceptance for production of a $K\pi$ system as a function of mass and momentum transfer is essentially determined by the proton arm, while the acceptance as a function of decay angles is given by the forward arm.

The $K\pi$ -mass acceptance extends from threshold up to about 2.4 GeV at an incident momentum of 10 GeV/c (Fig. 4). The azimuthal aperture of the recoil detector limits the over-all acceptance to a maximum of 17% . This does, of course, not introduce any bias in the $K\pi$ -decay angular distribution.

The absence of a momentum-analysing magnet allows a large forward solid angle of 0.3 sr. The forward arm acceptance is limited only by the size of the MWPCs, and by chamber inefficiency in the beam region.

We have done detailed acceptance calculations by the Monte Carlo method, in order to present the data in corrected form, normalized to the production cross-section. In particular, the calculation takes into account:

- a) the geometry of the entire set-up;
- b) the efficiency of the MWPCs;
- c) absorption and decay of the incoming kaon, and of the outgoing pions, including the energy dependence.

In addition, the Monte Carlo program includes the effects of the cuts on kinematic variables to remove background, as discussed above:

- d) forward particle momentum $p > 300$ MeV/c;
- e) πp effective mass $M_{\pi p} > 1.4$ GeV.

The Monte Carlo program generates events for fixed values of the production variables $M_{K\pi}$ and t , as a function of the $K\pi$ -decay angles $(\cos \theta, \phi)$ in the Gottfried-Jackson frame. The acceptance is obtained simply from the ratio of

events accepted by the apparatus to events generated, as a function of the four kinematical variables. As an example, we show in Fig. 8 the $(\cos \theta, \phi)$ -acceptance of the $K^*(890)$ [$0.84 < M_{K\pi} < 0.94$ GeV] and the $K^*(1420)$ [$1.36 < M_{K\pi} < 1.5$ GeV] in the t range $0.05 < |t| < 1$ (GeV/c)². The general shape of the distribution is determined essentially by geometry and MWPC inefficiency.

As a check of the Monte Carlo calculations, we have compared the measured distributions of K^0 -decay angles and lifetime to those generated by Monte Carlo. There is good agreement between the two.

4.5 Cross-section normalization

The Monte Carlo acceptance calculation (Section 4.4) accounts for efficiencies depending on the configuration of each event. In order to obtain absolute cross-sections we have to correct, in addition, for the following configuration-independent effects:

	Efficiency	
	<u>K⁺ beam</u>	<u>K⁻ beam</u>
i) incident particle identification	0.94	1.0
ii) hodoscope efficiency	0.83	0.90
iii) dead-time losses	0.96	0.99
iv) efficiency of time-of-flight system	0.88	0.95
v) accidentals in beam anticounters A ₁ , A ₂	0.92	0.98
vi) track reconstruction efficiency:		
proton arm	0.67	0.75
forward arm	0.87	0.94
vii) cuts on event geometry	0.93	0.93
viii) cuts on event kinematics	0.93	0.93

To determine the normalization of the data, we have selected two independent samples of particularly homogeneous quality for each beam polarity. We obtain consistent results and estimate the systematic error of the cross-section scale to be about 10%. Correcting finally for the branching ratio $B(K^0 \rightarrow K_S^0 \rightarrow \pi^+\pi^-) = 0.344$, we obtain the following sensitivity of the experiment [in the $K^*(890)$ region]:

$$\begin{aligned}
 &329 \text{ measured events}/\mu\text{b} \quad \text{for} \quad K^+p \rightarrow K^0\pi^+p \\
 &138 \text{ measured events}/\mu\text{b} \quad \text{for} \quad K^-p \rightarrow \bar{K}^0\pi^-p .
 \end{aligned}$$

5. THE MEASUREMENTS

Here we present our data on the reactions $K^\pm p \rightarrow K_S^0 \pi^\pm p$ at 10 GeV/c incident momentum. Figure 9 shows the $K_S^0 \pi^\pm$ mass spectra in the full range of momentum transfer t accepted in this experiment, $0.05 < |t| < 1.0$ (GeV/c)². The solid-line histograms show the uncorrected data, while the points with error bars represent the spectra after correction for the acceptance of the spectrometer. The spectra are clearly dominated by production of the $K^*(890)$ and $K^*(1420)$ resonances above a very low level of non-resonant background.

The high statistics allows the determination of the spherical harmonics moments of the $K\pi$ decay angular distribution as a function of $K\pi$ mass and as a function of t in the mass regions corresponding to $K^*(890)$ and $K^*(1420)$ production, both for the K^+ and K^- induced reactions.

5.1 Determination of the moments

In a given bin of production variables M, t we expand the $K\pi$ -decay angular distribution $I(\theta, \phi)$ as

$$I(\theta, \phi) = N \sum_{J, M} \langle Y_J^M \rangle Y_J^M(\theta, \phi) , \quad (6)$$

where N is the number of events (or the cross-section) in the M, t bin considered. The spherical harmonics moments $\langle Y_J^M \rangle$ are obtained by inversion:

$$N \langle Y_J^M \rangle = \int I(\theta, \phi) Y_J^M(\theta, \phi) d\Omega . \quad (7)$$

In this analysis, we take θ, ϕ to be the angles of the K^0 in the t -channel helicity frame (Gottfried-Jackson frame). In this reference frame, parity conservation in the production process implies the symmetry:

$$I(\theta, \phi) = I(\theta, 2\pi - \phi) , \quad (8)$$

or in terms of the moments

$$\langle Y_J^{-M} \rangle = (-1)^M \langle Y_J^M \rangle \quad \text{and} \quad \langle \text{Im } Y_J^M \rangle = 0 . \quad (9)$$

This property allows one to rewrite $I(\theta, \phi)$ in the form

$$I(\theta, \phi) = N \sum_{J, M \geq 0} \epsilon_J^M \langle \text{Re } Y_J^M \rangle \text{Re } Y_J^M(\theta, \phi) \quad (10)$$

with

$$\epsilon_J^M = \begin{cases} 1 & \text{for } M = 0 \\ 2 & \text{for } M \neq 0 \end{cases}$$

where the sum now extends over positive values of M only. For ease of notation, we will omit from now on the Re sign in front of Y_J^M .

The measured angular distribution $\tilde{I}(\theta, \phi)$ is distorted by the acceptance of the spectrometer $A(\theta, \phi)$:

$$\tilde{I}(\theta, \phi) = A(\theta, \phi) \cdot I(\theta, \phi) . \quad (11)$$

The measured moments $\langle \tilde{Y}_J^M \rangle$ of the distribution $\tilde{I}(\theta, \phi)$ are related to the true moments $\langle Y_J^M \rangle$ of $I(\theta, \phi)$ by a set of linear equations:

$$\langle \tilde{Y}_J^M \rangle = \sum_{J', M' \geq 0} A_{JJ'}^{MM'} \langle Y_{J'}^{M'} \rangle . \quad (12)$$

The correlation coefficients $A_{JJ'}^{MM'}$ are determined by the acceptance function $A(\theta, \phi)$ in the following way:

$$A_{JJ'}^{MM'} = \int Y_J^M(\theta, \phi) \cdot A(\theta, \phi) \cdot Y_{J'}^{M'}(\theta, \phi) d\Omega \quad (13)$$

and they can be calculated by the Monte Carlo method.

We note that the number of equations (12) is determined by the complexity of the shape of the acceptance, while the number of unknown moments depends on how many waves are present in the reaction. We found that the acceptance is well represented by a set of moments with $0 \leq J \leq 8$ and $0 \leq M \leq J$. In practice, we solve therefore an overdetermined system of 45 equations by a least-squares fit. The number of moments fitted depends on the mass interval studied.

5.2 The moments as a function of mass

We calculate the moments $N \langle Y_J^M \rangle$ of the angular distribution of the K^0 in the t -channel helicity (Gottfried-Jackson) frame. Figures 10 to 13 show the mass dependence of the moments, in the t interval $0.1 < |t| < 0.4$ (GeV/c)². In this

restricted range we expect the different amplitudes to have similar t dependence. The normalization is such that $N\langle Y_0^0 \rangle = d\sigma/dM$, i.e. the cross-section within this t range.

The moments in Figs. 10-11 have been obtained from a fit with $J_{\max} = 4$ and $M_{\max} = 2$ to the set of equations (12). A good fit is obtained in the mass region up to 1.6 GeV without the introduction of any higher moments into the fit. We further search for moments with higher M or J by fitting all terms up to $J_{\max} = 4$, $M_{\max} = 4$, and up to $J_{\max} = 6$, $M_{\max} = 2$, respectively. The moments with $M = 3$ and 4, shown in Figs. 12-13, are negligible compared to the dominant moments, implying that the $K^*(1420)$ is predominantly produced with helicity $\lambda = 0, 1$ and that $\lambda = 2$ is negligible. Also the moments $J = 5$ and 6 do not show any significant signal (Figs. 12-13). The lower moments are stable with respect to the particular choice of $J_{\max}$ and $M_{\max}$. We conclude that S-, P-, and D-waves with helicity zero and one suffice to describe the data in the mass range up to 1.6 GeV.

The moments in the higher mass region $1.5 < M < 2.2$ GeV have been published previously [2]. They give clear evidence for production of the $K^*(1780)$ resonance with spin-parity $J^P = 3^-$.

5.3 The moments as a function of t

In Figs. 14-17 we give the t dependence of the moments in the mass regions of the $K^*(890)$ ($0.84 < M < 0.94$ GeV) and the $K^*(1420)$ ($1.34 < M < 1.50$ GeV). The terms $\langle Y_J^M \rangle$ up to $J_{\max} = 4$, $M_{\max} = 2$ have been included in the fits. Figures 18 and 19 show the higher moments in the $K^*(1420)$ region, obtained from fits with $J_{\max} = 4$, $M_{\max} = 4$ and with $J_{\max} = 6$, $M_{\max} = 2$. Again, these moments are consistent with zero. The data are normalized such that $N\langle Y_0^0 \rangle = d\sigma/dt$, the differential cross-section within the mass interval.

5.4 Conclusions

We have measured $K\pi$ production by K^+ and K^- beams in the non-charge-exchange reactions (1). The statistics obtained are an order of magnitude larger than in previous experiments at the same energy. The dependence on mass $M_{K\pi}$ and momentum transfer t of the moments $N\langle Y_J^M \rangle$ of the $K\pi$ decay angular distribution has been determined. Investigation of the significant moments shows that the mass region up

to 1.6 GeV can be described by S-, P-, and D-waves with helicity zero and one. A detailed amplitude analysis and study of production mechanism is the subject of Refs. 3 and 4 and of the following paper.

Acknowledgements

We gratefully acknowledge the hospitality and technical assistance of CERN, as well as the loan of equipment by the EP Division. We thank the Fonds National Suisse for support of the project. We thank the technicians of the University of Geneva for expert assistance, and A. Delavy for help with computing. We thank A.D. Martin, B. Morel and B. Schrempp for many useful discussions on the analysis of the data.

REFERENCES

- 1) A.D. Martin et al., Amplitude and natural-parity-exchange analysis of $K^{\pm}p \rightarrow (K\pi)^{\pm}p$ data at 10 GeV/c, following paper.
- 2) R. Baldi et al., Phys. Letters 63B (1976) 344.
- 3) R. Baldi et al., Amplitudes and exchange mechanisms for K^* resonances produced by the reactions $K^{\pm}p \rightarrow K^{*\pm}p$ at 10 GeV/c, submitted to Phys. Letters.
- 4) A. Mermoud, Mesure et analyse en ondes partielles de la production du système $K^0\pi$ dans la réaction $K^{\pm}p \rightarrow (K_S^0\pi^{\pm})p$ à 10 GeV/c, Ph.D. thesis, University of Geneva (1977).

Figure captions

- Fig. 1 : Experimental layout.
- Fig. 2 : Distribution in the hodoscopes H_0 and H'_0 for different incident momenta.
- Fig. 3 : Inefficiency of the first and third forward MWPCs in the beam region, measured in runs at high intensity ($10^6/\text{cm}^2 \text{ sec}$) and low intensity ($10^5/\text{cm}^2 \text{ sec}$).
- Fig. 4 : Kinematics of the recoil proton. The frame in full line indicates the region of full acceptance where the whole length of the target is seen by the proton arm. The dotted line indicates regions of partial acceptance.
- Fig. 5 : Resolution of the time-of-flight system.
- Fig. 6 : Trigger logic and organization of the data acquisition.
- Fig. 7 : Distribution of the kinematical constraints ΔE and M_{K^0} , as calculated from the unfitted quantities.
- Fig. 8 : The total acceptance in per cent for the $K^*(890)$ and $K^*(1420)$ as a function of $(\cos \theta, \phi)$ in the Gottfried-Jackson frame.
- Fig. 9 : a) $K_S^0 \pi^+$ and b) $K_S^0 \pi^-$ effective mass spectrum, for $0.05 < |t| < 1 \text{ (GeV/c)}^2$. The spectrum is shown before (histogram) and after (points with error bars) acceptance correction. A constant factor of 5.8, due to the azimuthal aperture of the proton detector, is not included in the correction.
- Fig. 10 : The moments $N\langle Y_J^M \rangle$ of the $K_S^0 \pi^+$ decay angular distribution as a function of $K\pi$ mass, in the t interval $0.1 < |t| < 0.4 \text{ (GeV/c)}^2$.
- Fig. 11 : The moments $N\langle Y_J^M \rangle$ of the $K_S^0 \pi^-$ decay angular distribution as a function of $K\pi$ mass, in the t interval $0.1 < |t| < 0.4 \text{ (GeV/c)}^2$.
- Fig. 12 : The higher moments $M = 3, 4$ and $J = 5, 6$ for $K_S^0 \pi^+$ as a function of mass, in the t interval $0.1 < |t| < 0.4 \text{ (GeV/c)}^2$.
- Fig. 13 : The higher moments $M = 3, 4$ and $J = 5, 6$ for $K_S^0 \pi^-$ as a function of mass, in the t interval $0.1 < |t| < 0.4 \text{ (GeV/c)}^2$.
- Fig. 14 : The moments $N\langle Y_J^M \rangle$ as a function of t , in the $K^{*+}(890)$ region ($0.84 < M_{K\pi} < 0.94 \text{ GeV}$).

- Fig. 15 : The moments $N\langle Y_J^M \rangle$ as a function of t , in the $K^{*-}(890)$ region
($0.84 < M_{K\pi} < 0.94$ GeV).
- Fig. 16 : The moments $N\langle Y_J^M \rangle$ as a function of t , in the $K^{*+}(1420)$ region
($1.34 < M_{K\pi} < 1.50$ GeV).
- Fig. 17 : The moments $N\langle Y_J^M \rangle$ as a function of t , in the $K^{*-}(1420)$ region
($1.34 < M_{K\pi} < 1.50$ GeV).
- Fig. 18 : The higher moments $M = 3, 4$ and $J = 5, 6$ as a function of t , in the
 $K^{*+}(1420)$ region.
- Fig. 19 : The higher moments $M = 3, 4$ and $J = 5, 6$ as a function of t , in the
 $K^{*-}(1420)$ region.

Fig. 1

DISTRIBUTION IN HODOSCOPES HO VERSUS HO'

RUN 2531

P INCIDENT = P NOMINAL - 1 PERCENT

	1	2	3	4	5	6	7	8	9	10	11
1 1	0	2	5	21	34	0	0	0	0	0	0
2 1	0	1	5	161	88	0	0	0	0	0	0
3 1	0	5	111	414	40	1	0	0	0	0	0
4 1	0	5	406	314	19	0	1	0	0	0	0
5 1	0	47	548	71	4	1	0	0	0	0	0
6 1	0	153	229	5	0	0	0	0	0	0	0
7 1	0	45	22	1	0	0	0	0	0	0	0
8 1	0	1	0	0	0	0	0	0	0	0	0
9 1	0	0	0	0	0	0	0	0	0	0	0
10 1	0	0	0	0	0	0	0	0	0	0	0
11 1	0	0	0	0	0	0	0	0	0	0	0

P INCIDENT = P NOMINAL

	1	2	3	4	5	6	7	8	9	10	11
1 1	0	0	0	0	0	0	0	0	0	0	0
2 1	0	0	0	0	1	0	0	0	0	0	0
3 1	0	0	0	0	1	1	5	14	0	0	0
4 1	0	0	0	0	0	8	185	67	0	0	0
5 1	0	0	0	1	5	153	259	27	1	0	0
6 1	0	0	0	0	53	567	115	6	0	0	0
7 1	0	0	0	4	376	308	15	2	0	0	0
8 1	0	0	0	85	489	15	0	0	0	0	0
9 1	0	0	0	64	50	0	0	0	0	0	0
10 1	0	0	0	0	0	0	0	0	0	0	0
11 1	0	0	0	0	0	0	0	0	0	0	0

P INCIDENT = P NOMINAL + 1 PERCENT

	1	2	3	4	5	6	7	8	9	10	11
1 1	0	0	0	0	0	0	0	0	0	0	0
2 1	0	0	0	0	0	0	0	0	0	0	0
3 1	0	0	0	0	0	0	0	0	0	0	0
4 1	0	0	0	0	0	0	0	0	0	0	0
5 1	0	0	0	0	0	0	0	1	0	1	0
6 1	0	0	0	0	0	0	0	1	8	84	6
7 1	0	0	0	0	0	0	2	5	172	136	6
8 1	0	0	0	0	0	0	4	178	284	33	0
9 1	0	0	0	0	0	1	104	406	63	8	0
10 1	0	0	0	0	0	28	313	54	0	0	0
11 1	0	0	0	0	0	4	11	0	0	0	0

Fig. 2

Fig. 3

Fig. 4

Fig. 5

a) Trigger logic

b) Data flow

Fig. 6

Fig. 7

Fig. 8

Fig. 9

Fig. 10

Fig. 11

Fig. 12

Fig. 13

Fig. 14

Fig. 15

Fig. 16

Fig. 17

Fig. 18

Fig. 19