A DETERMINATION OF THE β PARAMETER AS A TEST OF T-INVARIANCE IN THE CHARGED DECAY MODE OF THE Λ HYPERON

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The β parameter of $\Lambda \rightarrow p + \pi^-$ have been measured. We obtain $\beta = -0.13 \pm 0.07$, in agreement with time reversal invariance. The Λ polarization in $\pi^- + p \rightarrow \Lambda + K^0$ at 1.03 GeV/c and 1.06 GeV/c is also given.

We have performed an experiment to determine the decay parameters α, β and γ in the decay

$$\Lambda \rightarrow p + \pi^- \tag{1}$$

by studying the asymmetry in the decay of polarized Λ and the subsequent scattering of the decay proton in a carbon-plate spark chamber. The β parameter is of particular importance as a test of T-invariance in this decay. We present in table 1 a preliminary value for this parameter based on about 60% of the final expected statistics of the experiment. Our value is in agreement with the previous determinations by Cronin and Overseth [1], and Overseth and Roth [2], also given in table 1. It is also consistent with the value derived from the experimentally determined pion-nucleon phase shifts in the $I = \frac{1}{2}$ state [3], assuming T-invariance and the $\Delta I = \frac{1}{2}$ rule.

Table 1
Result of this experiment compared with results of previous experiments and with the predicted value.

Experiment	β
This experiment	-0.13 ± 0.07
Cronin and Overseth [1]	$+0.18 \pm 0.24$
Overseth and Roth [2]	-0.10 ± 0.07
Weigthed average	-0.10 ± 0.05
Predicted, assuming T-invariance and $\alpha = 0.63$	-0.07 ± 0.02

If s and p are the s- and p-wave amplitudes in the process (1), the decay parameters are defined as [4]:

$$\alpha = 2\,\mathrm{Re}\,(s^* p)/(|s|^2 + |p|^2)\,;$$
$$\beta = 2\,\mathrm{Im}\,(s^* p)/(|s|^2 + |p|^2)\,;$$
$$\gamma = (|s|^2 - |p|^2)/(|s|^2 + |p|^2)\,.$$

The polarization $\boldsymbol{P}_{\mathrm{p}}$ of the proton in the lambda rest system is then given in terms of these parameters

$$\boldsymbol{P}_{\mathrm{p}} = \frac{(\alpha + \boldsymbol{P}_\Lambda \cdot \hat{\boldsymbol{q}})\hat{\boldsymbol{q}} + \beta[\boldsymbol{P}_\Lambda \times \hat{\boldsymbol{q}}] + \gamma[\hat{\boldsymbol{q}} \times [\boldsymbol{P}_\Lambda \times \hat{\boldsymbol{q}}]]}{1 + \alpha\, \boldsymbol{P}_\Lambda \cdot \hat{\boldsymbol{q}}} \tag{2}$$

in which $\hat{\boldsymbol{q}}$ is a unit vector along the proton direction, and $\boldsymbol{P}_\Lambda$ is the polarization of the decaying Λ.

The Λ are produced in the reaction

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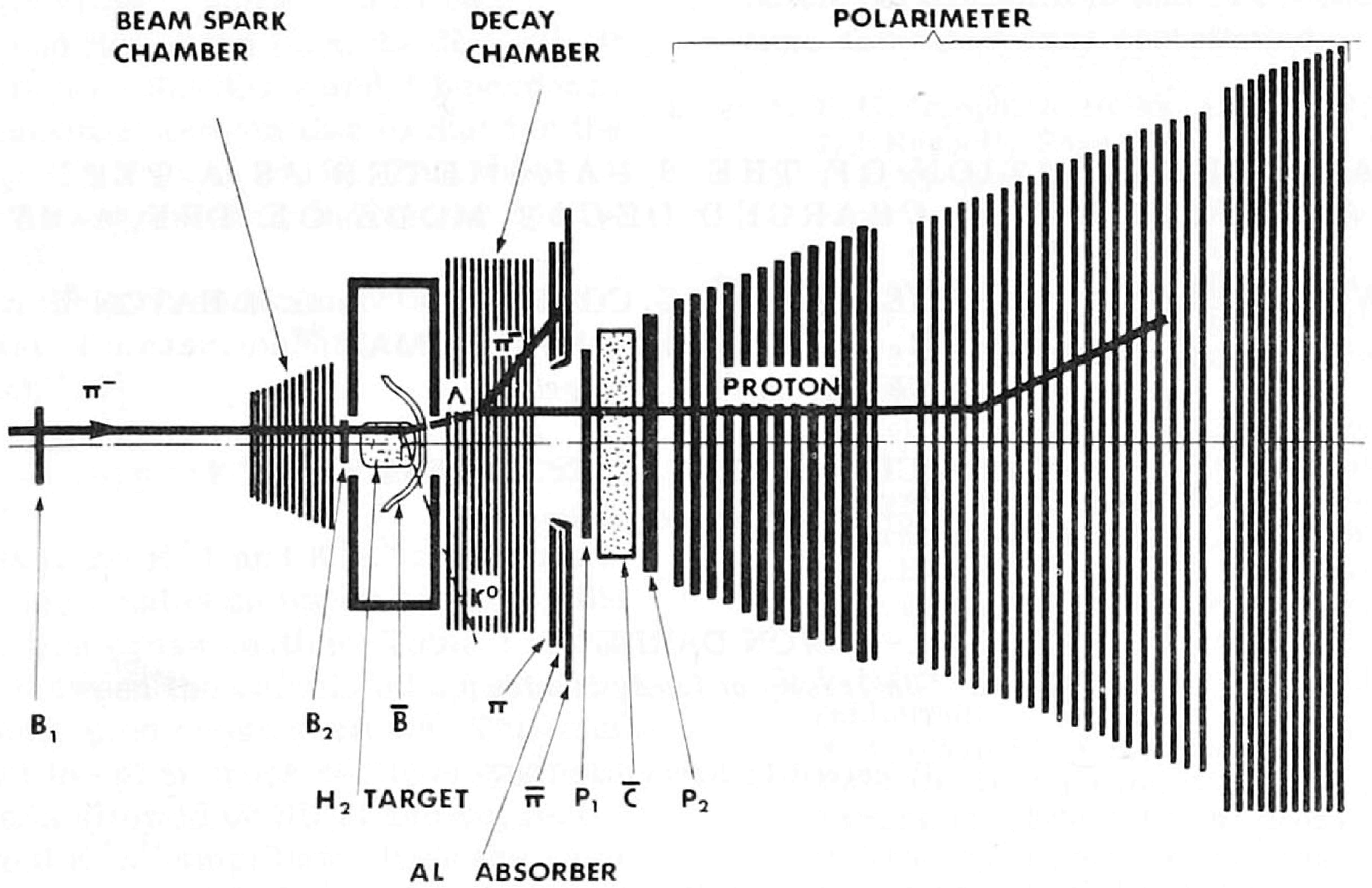

Fig. 1. Apparatus to measure the polarization of the protons from Λ decay through proton-carbon scattering. The Λ are produced in hydrogen. The counters π and $\bar{\pi}$ select low-energy decay pions, $P_1P_2\bar{C}$ select decay protons. The polarimeter consists of carbon plate spark chambers. The tracks are photographically recorded with 90° stereo.

$$\pi^- + p \rightarrow \Lambda + K^0 \qquad (3)$$

using π^- of 1.03 and 1.06 GeV/c momentum from the CERN PS. At this energy the reaction is known to produce highly polarized Λ [5].

A diagram of the *experimental apparatus* is shown in fig. 1. The beam, momentum analysed to about ±1%, is defined by two counters B_1 and B_2, and the beam track is recorded in the thin-foil beam spark chamber. It then impinges on the liquid hydrogen target, 8 cm long. The cup-shaped antocoincidence counter $\bar{B}$ rejects non-reacting beam particles and reactions with charged secondaries. To increase the event rate this counter is situated as close as possible to the hydrogen target, inside the vacuum tank. The disintegration of the Λ is observed in the thin-foil decay chamber. A large-angle track (normally the decay pion) is required to trigger the scintillation counter π but not to have enough range to traverse the 6 mm aluminium absorber and trigger the anticoincidence counter $\bar{\pi}$. The absorber and both counters have a 22 cm diameter hole through which a small-angle particle (normally the decay proton) can pass and trigger the counters P_1P_2. Cases in which the small-angle track is a high-velocity particle (for example, in background reactions due to K^0 decay or electron pairs) are rejected by the water threshold Čerenkov counter $\bar{C}$ in anticoincidence. The particle then enters the polarimeter, a spark chamber array with graphite plates of 5 - 16 cm thickness, totalling 100 g/cm^2.

The experiment is designed to select events in which Λ are produced with high energy and decay with a high-energy proton and a low-energy pion in the laboratory system. In this configuration the transverse proton polarization in the laboratory is particularly sensitive to the β parameter, and the long range of the proton favours scattering in the polarimeter.

The trigger rate for the spark chambers with this counter configuration was ~ 32 per 10^7 incoming π^-. In the couse of the experiment 430 000 photographs were taken of which approximately 60% contained a V event. Of these, about 7% showed a small angle track with a scatter in the polarimeter of more than 3^o in projection. These events were then manually measured on a digitized measuring table.

The *dominant background* among the V events is expected to come from π^- charge exchange. In this reaction either an electron pair produced by one of the $\pi^0\gamma$-rays or a two-prong star produced by the neutron could simulate the Λ decay. The probability for γ-ray or neutron conversion is however very small, since the amount of material between the anticoincidence counter and the end of the decay spark chamber is only 0.29 g/cm^2, including an effective 0.8 mm insensitive layer of the anticoincidence counter $\overline{B}$. It is also very unlikely than an electron pair will have the large opening angle which is required for the V decay by our triggering geometry and that it is not rejected by the Čerenkov anticoincidence counter $\overline{C}$. The number of pictures with a V-event originating from π^- charge exchange is therefore small. Since most of them will be eliminated in the kinematical analysis, the contribution of this process to the final sample of events is negligible.

In another possible background reaction, the V event could be due to the decay of the K^0 in the reaction (3) rather than to that of the Λ. However, a Monte Carlo calculation of this process shows that the combined effect of the threshold Čerenkov counter $\overline{C}$, and the anticoincidence counter $\overline{\pi}$ render this background insignificant.

As an independent test that the majority of our events is due to Λ decay we have measured the lifetime for a sample for which the triggering efficiency could be reliably calculated. We obtain a value of $(2.43 \pm 0.07) \times 10^{-10}$ s which compares well with the world average.

The *reconstruction* of the measured events was carried out with a combined geometry and kinematics programme which fitted the measured spark positions to the hypothesis for the events. The above arguments permitted us to restrict ourselves to the only hypothesis of Λ production on hydrogen and subsequent decay. The range information for the proton from the carbon spark chamber is not included at this stage, but is used later to determine the inelasticity in the scattering process. The kinematic fit under these conditions is of the 1-C type, but degenerates to a 0-C fit when the production and decay planes coincide. In addition to the "normal" solution this analysis usually yielded parasitic solutions in most of which either the proton or the decay pion had very low energy. In about 50% of the measured events either the kinematics programme found no solutions, or the solutions found were not consistent with the trigger requirements, and with the observed minimum range of the decay proton in the range chamber. These events have been omitted from our present analysis, but we expect that most of them can be recovered by remeasurement and programme developments. As shown later, the provisional omission of this class of events does not introduce a bias in the determination of β.

We have *analysed* the experiment in terms of the asymmetry parameters β and α and the average Λ polarization $\overline{P}_\Lambda$, by maximizing the likelihood function, i.e. the product of the probability densities for the events. 7377 measured events contribute to this likelihood function. In $\sim 91\%$ of these, the interpretation was unambiguous. For these, only that part of the probability density needs to be taken into account, which depends on the parameters β, α and $\boldsymbol{P}_\Lambda$:

$$(1+\alpha\, \boldsymbol{P}_\Lambda \cdot \hat{\boldsymbol{q}})\ (1+S\boldsymbol{n}\cdot \boldsymbol{P}_\mathrm{p}^\mathrm{o}(\beta, \alpha, P_\Lambda)) \qquad (4)$$

In this expression S is the analysing power of the proton-carbon scattering, $\boldsymbol{P}_\mathrm{p}^\mathrm{o}$ is the polarization of the proton in its rest system, and $\hat{\boldsymbol{n}}$ is the normal to the scattering plane [‡]. For the events in which several configurations gave a fit to the measurements and satisfied the triggering requirements, each configuration gives to the probability density for the event a contribution which is the product of the a-priori probability density for the configuration to occur and the probability that the configuration will give the measured sparks.

From the position of the maximum in the likelihood function, we obtain for β the result of table 1, using an analysing power of carbon which is derived individually for each event from the compilation of Peterson [6], and the reconstructed proton energy, scattering angle and inelasticity. The corresponding value for $\alpha = 0.63 \pm 0.03$, is also in good agreement with the result of Overseth and Roth. The average polarisation of the Λ was found to be $\overline{P}_\Lambda = 0.77 \pm 0.03$.

To test the sensitivity of the result to the assumptions about the analysing power, we have also carried out the analysis for different values of an analysing power, independent of proton energy, angle and inelasticity. The result of this test for β, α and P_Λ is shown in fig. 2, together with the value obtained using Peterson's analysing power, and the results of Overseth and Roth for β and α. The errors given in fig. 2 (and table 1) are statistical. As can been seen from fig. 2, β is very insensitive to the analysing power, while for more precise determinations of α and P_Λ more reliable data on the analysing power would be desirable.

An *instrumental asymmetry* or a biased selection of the events would influence the experimental result in β only if it introduces a correlation between the production and scattering plane of the event. This correlation can arise only as the combination of two asymmetries, giving a pre-

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[‡] For simplicity we have in our present analysis neglected the small difference between $\boldsymbol{P}_\mathrm{p}^\mathrm{o}$ and the polarization $\boldsymbol{P}_\mathrm{p}$, eq. (2), in the Λ rest frame.

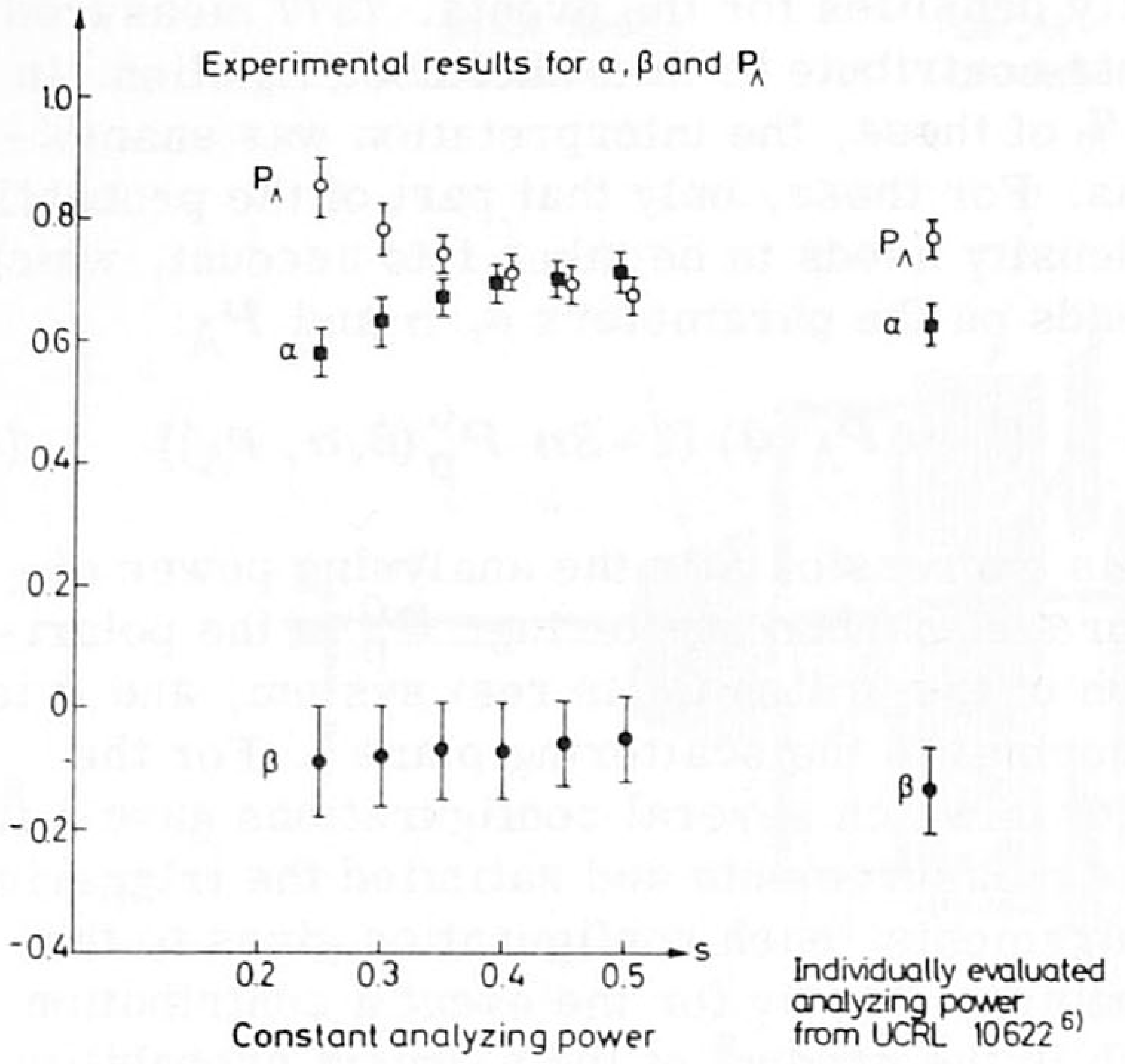

Fig. 2. β, α and P_Λ derived from an experiment assuming (left) a constant average analysing power and (right) an analysing power assigned individually to each event according to the proton energy at the scattering point, the scattering angle and the inelasticity, using ref. 6.

ferred azimuth for the normal to the production plane and for the scattering point. The corresponding distributions of our events deviate from uniformity by less than 5% and the ensuing effect on β would be less than 0.005.

In contrast, the determination of α and γ from the scattering asymmetry towards or away from the beam axis is influenced in first order by any variation of the detection efficiency of the spark chamber with the distance from the axis or the angle of the track relative to the spark chamber planes. α and γ are therefore much more sensitive to these biases.

In our analysis we have taken the Λ polarization to be constant over our angular acceptance. We have in an independent analysis of a larger sample, which also includes events without proton scattering, determined αP_Λ as a function of the c.m. production angle Θ^*_Λ from the up-down asymmetry of the decay proton (fig. 3). The smooth dependence of P_Λ on Θ^*_Λ justifies the assumption P_Λ = const.

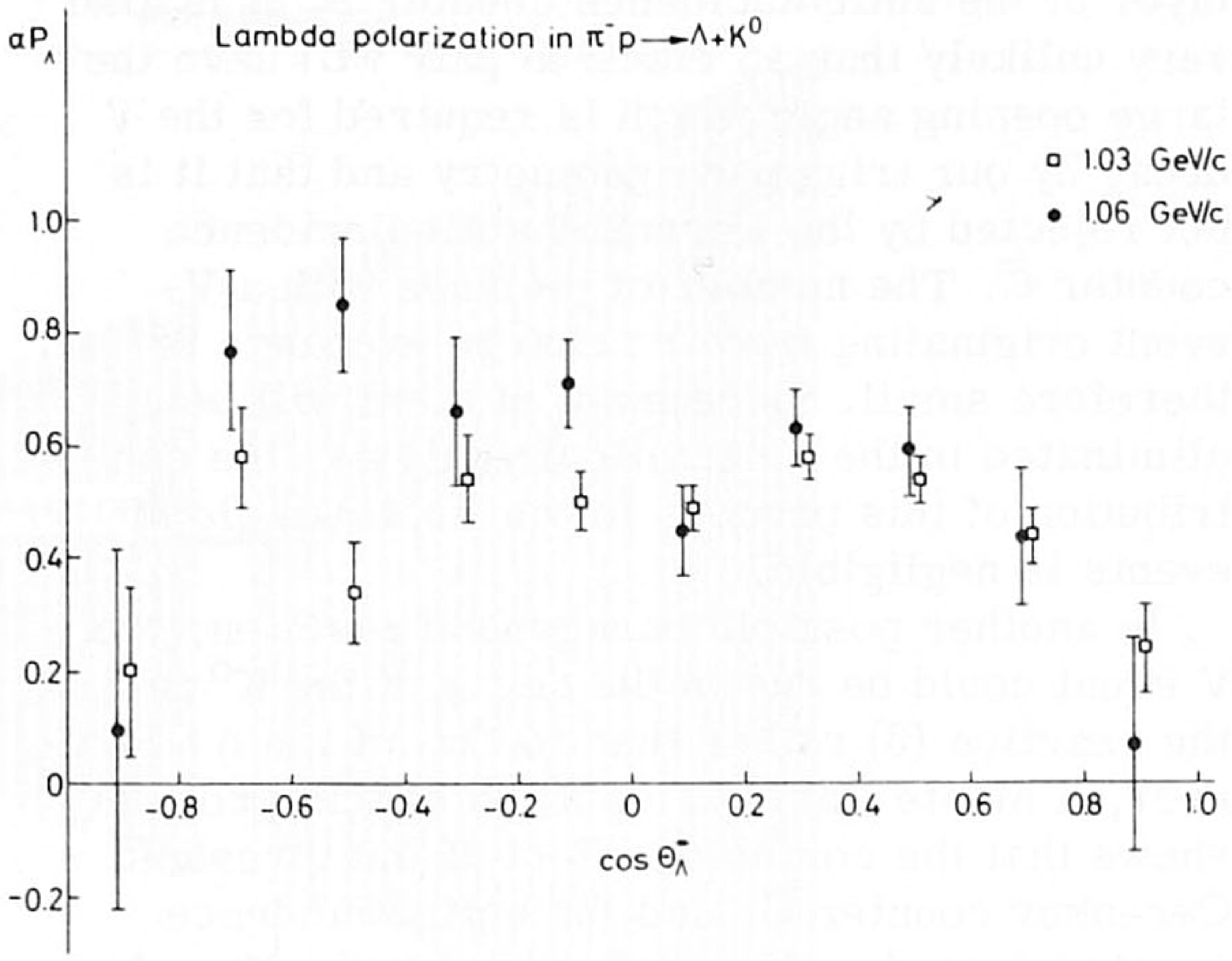

Fig. 3. Λ polarization in the reaction $\pi^- + p \rightarrow \Lambda + K^0$ at 1.03 GeV/c and 1.06 GeV/c. The figure gives $\alpha \cdot P_\Lambda$ versus Θ^*_Λ. Θ^*_Λ is the angle of the Λ in the production centre of momentum.

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