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EXPERIMENTAL POSSIBILITIES AT LEAR FOR
TESTING CP INVARIANCE IN HYPERON DECAYS

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ABSTRACT

Following the suggestion originally made by L.L. Chau and by J.F. Donoghue et al. to use hyperon decays in order to study milliweak CP violation outside the K^0 system, an example of a possible survey experiment is presented. Asymmetries at the level of 10^{-3} - 10^{-4} can be measured in the reaction $p\bar{p} \rightarrow \Lambda\bar{\Lambda}$. Such a study can be done at LEAR with an internal gas-jet target. Systematic errors are considered and design criteria for the detector are given.

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1. INTRODUCTION

In 1964 Christenson et al. [1] discovered evidence that CP is violated in K^0 decay. More than 20 years later, still no system other than K^0 has exhibited CP or T violation. All the CP results in K^0 decay can be described by a single parameter $|\varepsilon|$, already measured in the 1964 experiment. The origin of the observed violation of CP is still not known, but it is one of the fundamental questions in particle physics. The phenomenon of CP violation is probably a key toward the deeper understanding of elementary particles, and in particular could provide essential tests of the Standard Model. It is thus crucial to search for the same phenomenon in systems other than those of K^0 meson decays, and hyperons would seem to be one of the most interesting candidates [2]. Hyperon decays provide tests of CP violation which appear promising as signals of the possible milliweak $\Delta S = 1$ CP non-conservation. Signals of order 10^{-4} are expected in many models, including the Standard Model, and this is not far beyond present experimental limits. In particular, asymmetry measurements in $p\bar{p} \rightarrow \Lambda\bar{\Lambda}$ can be the most suitable way of doing CP-violation studies outside the K^0 system [3]. Such a study can be carried out at LEAR with an internal gas-jet target, and for this a survey experiment is proposed [4].

2. PHYSICS

All the results on K^0 decays can be explained by the superweak mechanism [5]. The milliweak CP-violating $\Delta S = 1$ effects, which are parametrized by ε' in the K^0 system (until now, only one non-null result for ε' is obtained [6]), could be observed in the non-leptonic decays of hyperons. As an example, we can use the $\Lambda\bar{\Lambda}$ system [3], although similar considerations hold for Σ and Ξ decays. The CP violation arises from an interference between different amplitudes (S- or P-wave or/and $I = 1/2$, $I = 3/2$ final states). For the decays $\Lambda \rightarrow p\pi^-$ and $\Lambda \rightarrow n\pi^0$, the amplitudes can be

characterized by their absolute value, by a CP-violating phase Φ due to weak interactions, and by a phase δ which arises from strong interactions.

For the Λ decay we have

$$S = S_{1/2} \exp i(\delta_{1/2}^S + \Phi_{1/2}^S) + S_{3/2} \exp i(\delta_{3/2}^S + \Phi_{3/2}^S) ,$$

$$P = P_{1/2} \exp i(\delta_{1/2}^P + \Phi_{1/2}^P) + P_{3/2} \exp i(\delta_{3/2}^P + \Phi_{3/2}^P) ,$$

but for the $\bar{\Lambda}$ decay,

$$\bar{S} = - S_{1/2} \exp i(\delta_{1/2}^S - \Phi_{1/2}^S) - S_{3/2} \exp i(\delta_{3/2}^S - \Phi_{3/2}^S) ,$$

$$\bar{P} = P_{1/2} \exp i(\delta_{1/2}^P - \Phi_{1/2}^P) + P_{3/2} \exp i(\delta_{3/2}^P - \Phi_{3/2}^P) ,$$

where S (P) is the S-wave (P-wave) parity-violating (-conserving) amplitude. Both amplitudes contribute to the decay matrix element,

$$M = S + P \vec{\sigma} \cdot \vec{q} .$$

Because the final-state π -nucleon phase shifts δ are different, CP-violating effects exist and can be isolated by comparing Λ and $\bar{\Lambda}$ decays. The simple measurement of CP violation is the rate difference Δ ,

$$\Delta = \frac{\Gamma(\Lambda \rightarrow p\pi^-) - \Gamma(\bar{\Lambda} \rightarrow \bar{p}\pi^+)}{\Gamma(\Lambda \rightarrow p\pi^-) + \Gamma(\bar{\Lambda} \rightarrow \bar{p}\pi^+)} = -2 \frac{S_{3/2}}{S_{1/2}} \sin(\delta_{3/2}^S - \delta_{1/2}^S) \sin(\Phi_{3/2}^S - \Phi_{1/2}^S)$$

in the limit of S-wave dominance and to leading order. Using experimental values,

$$\Delta \approx 10^{-2} \sin(\Phi_{3/2}^S - \Phi_{1/2}^S) .$$

This rate difference is thus suppressed both by the $\Delta I = 1/2$ rule and by the smallness of strong phase shifts δ . An alternative is to compare the decay asymmetry parameter α for the two decays. Neglecting the $I = 3/2$ final state, the CP-violating effect is

$$A = \frac{\alpha + \bar{\alpha}}{\alpha - \bar{\alpha}} = \sin(\Phi_{1/2}^S - \Phi_{1/2}^P) \sin(\delta_{1/2}^P - \delta_{1/2}^S) \\ \approx 0.1 \sin(\Phi_{1/2}^S - \Phi_{1/2}^P) .$$

A still more difficult parameter to measure is β , which is related to the polarization of the final baryon. The CP-violating effect can be given by

$$B' = \frac{\beta + \bar{\beta}}{\alpha - \bar{\alpha}} = \sin(\Phi_{1/2}^S - \Phi_{1/2}^P) \quad \text{or} \quad B = \frac{\beta + \bar{\beta}}{\beta - \bar{\beta}} = \frac{B'}{\tan(\delta_{1/2}^P - \delta_{1/2}^S)} ,$$

where the $I = 3/2$ final state is still neglected. Here it is clear that B' is the optimal signal. Other possibilities with a polarized beam and/or a polarized target could also be envisaged. Estimates of $\beta + \bar{\beta}$ are of a few 10^{-4} in the Kobayashi-Maskawa (KM) model, and this provides an example of an effect that could be much larger than ϵ' but very hard to measure. If we use χ to denote the strength of the $\Delta S = 1$ CP violation, we find

$$B' = \chi , \\ A = \chi \sin(\delta_{1/2}^P - \delta_{1/2}^S) \approx 1/10\chi , \\ \Delta = \chi \sin(\delta_{3/2}^S - \delta_{1/2}^S) S_{3/2}/S_{1/2} \approx 1/100\chi .$$

Appendix A shows how these quantities are related to the KM matrix elements. More detailed predictions given by Donoghue et al. [3] for the KM model [7], the Weinberg-Higgs model [8], and the left-right symmetric model [9] are quoted in Table 1. Because of many theoretical uncertainties, these numbers should be taken as only rough guides. The superweak mechanism, which contributes to ΔS

= 2 CP-violating effects only, of course gives no effect. Thus -- and this by itself could be a very important result of the experiment -- the observation of CP violation in hyperon decays would imply that CP non-conservation is a milliweak and not a superweak phenomenon. The rough magnitude of the effect, would, if present, provide a discrimination between theories. In addition, the hyperon system is very rich and many effects (SU3 structure, isospin, etc.) can be studied.

3. ASYMMETRIES

If we return to the production reaction $p\bar{p} \rightarrow \Lambda\bar{\Lambda}$, we can see how these previous decay parameters translate into CP asymmetries. In the centre-of-mass system,

$$\bar{p}(k) + p(k) \rightarrow \bar{\Lambda} + \Lambda \rightarrow \bar{p}(\bar{p}) + \pi^+(\bar{q}) + p(p) + \pi^-(q) ,$$

where k is the initial proton or antiproton momentum, p and $\bar{p}$ are the final proton and antiproton momenta, and q and $\bar{q}$ are the final pion momenta. Consider the triple product

$$A = \vec{k}(\vec{p}\wedge\vec{q} - \vec{\bar{p}}\wedge\vec{\bar{q}}) = -\vec{k} \wedge (\vec{p} + \vec{q})(\vec{\bar{p}} + \vec{\bar{q}}) ,$$

where A is CP-violating. This asymmetry just counts the number of protons and antiprotons above and below the production plane defined by $\vec{k} \wedge (\vec{p} + \vec{q})$. Integrating the asymmetry A over the decay angular distribution $D(\theta, \bar{\theta})$, defined as

$$D(\theta, \bar{\theta}) = (1/16\pi^2)$$

$$\times [1 + P(\alpha \cos \theta_Y + \bar{\alpha} \cos \bar{\theta}_Y) + \alpha\bar{\alpha}\epsilon_{ij}C_{ij} \cos \theta_i \cos \bar{\theta}_j] ,$$

where P and C_{ij} are the Λ or $\bar{\Lambda}$ polarization and the spin correlations, respectively (Λ and $\bar{\Lambda}$ will be produced with equal polari-

zation normal to the production plane); $\theta = (\theta, \varphi)$ and $\bar{\theta} = (\bar{\theta}, \bar{\varphi})$ are the decay angles in the Λ and $\bar{\Lambda}$ rest frames, we obtain

$$\tilde{A} = [N_{p,up} + N_{\bar{p},up} - N_{p,down} - N_{\bar{p},down}] / N_{evts} ,$$

$$\tilde{A} = 1/2 P(\alpha + \bar{\alpha}) .$$

Therefore the counting asymmetry $\tilde{A}$ provides a way of measuring possible CP-violating effects at a $p\bar{p}$ machine. The other signal possibilities can also be linked to other asymmetries [3]. It is important to note that background processes cannot generate this asymmetry, so that the measurements of $\tilde{A}$ are free from background-induced systematic errors. This procedure is better than comparing separate measurements of α and $\bar{\alpha}$. The measurement of $\tilde{A}$ is done at each value of the polarization $P = P(s, t)$, where s and t are the usual Mandelstam variables. In order to avoid the smearing of the CP signal when the summation includes positive and negative polarization terms, it is better to introduce the number

$$\tilde{N} = [N_{p,up} + N_{\bar{p},down} - N_{p,down} - N_{\bar{p},up}] / N_{evts} ,$$

and to consider the ratio $\tilde{A}/\tilde{N} = (\alpha + \bar{\alpha})/(\alpha - \bar{\alpha})$, without forgetting that the higher the $P(s, t)$ the smaller the error on $\tilde{A}/\tilde{N}$.

4. EXPERIMENTAL APPARATUS

As first noticed by the PS185 Collaboration [4], the best way to study CP-violating asymmetries in the $\Lambda\bar{\Lambda}$ system is to use a thin internal target in LEAR (Super-LEAR in the collider mode can be a very interesting alternative). The rising cross-section of the reaction in the field of LEAR momenta means that we have to work at high momenta, and therefore the interesting physics is located in the forward cone. Thus the experimental set-up should be particularly well designed in its forward part. Figure 1 shows the polar diagram of the reaction $p\bar{p} \rightarrow \Lambda\bar{\Lambda}$ at 2 GeV/c.

4.1 The H₂ jet target in LEAR

The use of an internal target

- will provide the very high luminosity needed by such an experiment; in the Antiproton Collector (ACOL) era, a luminosity of $10^{31} \text{ cm}^{-2} \text{ s}^{-1}$ should be obtained, giving very high statistics;
- will reduce the systematic errors related to the secondary interactions of the Λ , $\bar{\Lambda}$, and decay products in the target;
- will allow a good vertex definition, which will be very useful in the geometrical and kinematical reconstruction of the event, and in particular will minimize errors in the location of p and $\bar{p}$ relative to the production plane. In addition, the very small $\Delta p/p$ of the internal $\bar{p}$ beam is of great importance for the kinematical reconstruction.

The target we propose could be similar to the gas-jet target used by the R704 experiment at the CERN Intersecting Storage Rings (ISR) (fig. 2). With a density of 8×10^{13} atoms per cm^2 and with 10^{10} circulating $\bar{p}$, the luminosity will be of the order of $10^{31} \text{ cm}^{-2} \text{ s}^{-1}$. With a thicker target, even higher luminosities can be achieved.

4.2 The detector

The detection set-up should accommodate the very high rates corresponding to a high luminosity (total rate: 10^6 to 10^7 particles per second; useful event rate: $\gtrsim 10^7$ events per day). Therefore, to be able to handle such high trigger and acquisition rates the different detectors, including their readout, should be fast.

In order to have the smallest possible errors on the directions of the final baryon or antibaryon relative to the production plane, we have also to put effort into achieving a very precise tracking throughout the whole acceptance region (backward π), and especially in the forward part. This reconstruction will

require a magnetic analysis. The limit of precision is given by the multiple scattering, in particular in the vacuum pipe.

The apparatus should identify the final p and $\bar{p}$. A Cherenkov counter can fulfil this function. Because space is restricted, the apparatus should be compact even for maximum acceptance.

All these requirements could be fulfilled by a detector of the JETSET type [10], which is a general-purpose detector with a ' 4π ' compact geometry and high-rate devices:

- a fast ring-imaging Cherenkov counter (RICH) (identification and trigger);
- silicon microstrips and straw chambers (tracking);
- scintillators or scintillator fibres (trigger);
- a bismuth germanium oxide (BGO) calorimeter.

A superconducting solenoid gives the magnetic field. This detector is shown schematically in fig. 3. It is designed to measure $K_S^0 \bar{K}_S^0$ and $K^+ K^- K^+ K^-$ final states, and is not perfectly adapted to measuring asymmetries in Λ and $\bar{\Lambda}$ decays. A dedicated detector of a similar kind would be more suitable.

4.3 Trigger and acquisition

The high rates and the relative complexity of the events make it necessary to have several trigger levels. Fast processors shared between the acquisition and the kinematical reconstruction can speed up the analysis and avoid the handling of a too large quantity of tapes. Difficult or delicate events (those at the boundary of the production plane, or problematic ones) can be flagged for a more precise off-line analysis.

Systematic errors coming from the trigger (trigger bias for some peculiar topology, for example) should be reduced according to the required precision of the asymmetry measurement. The final baryon or antibaryon signature is essential in the trigger, so we need a good knowledge of the efficiency map of the Cherenkov counter.

4.4 Rates and background

4.4.1 Rates

The number of events which are needed to obtain an asymmetry A up to n standard deviations is given by

$$N_{\text{evts}} = n^2 / A^2 .$$

If, for example, we try to measure $A = 10^{-4}$ to 3 st. dev., we need $N_{\text{evts}} = 9 \times 10^8 \approx 10^9$. With a luminosity $L = 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$, a production cross-section $\sigma = 40 \text{ } \mu\text{b}$, and a global acceptance $\varepsilon = 30\%$, giving about 10^7 events per day, we have to run for approximately 100 days.

In fact, for high $\bar{p}$ momenta (1.8-2.0 GeV/c), the production cross-section of the reaction $p\bar{p} \rightarrow \Lambda\bar{\Lambda}$ (shown in fig. 4) is of the order of 100 μb (40 μb for the $p\pi^-\bar{p}\pi^+$ decay channel). In this region, the geometrical acceptance for the JETSET detector is about 20%, with or without the magnetic field. More precisely, and with the magnetic field, the acceptance values ε are as follows:

20%	at	2.0 GeV/c ,
17%	at	1.8 GeV/c ,
6%	at	1.6 GeV/c .

With a better design of the forward part, this acceptance can be increased to 40-50% at 2.0 GeV/c. A global acceptance of 30% and a luminosity of $10^{31} \text{ cm}^{-2} \text{ s}^{-1}$ give a rate of 120 events per second for a total $p\bar{p}$ rate of about 3×10^5 events per second. The problem of requiring very high statistics is the *fundamental limitation of the experiment*.

4.4.2 Background

Background reactions such as $p\bar{p} \rightarrow p\pi^-\bar{p}\pi^+$ are not dangerous as far as the asymmetry is concerned. They cannot fake a spurious

asymmetry if CP is conserved in strong interactions, and we believe in this statement. But the other hyperon production reactions such as $p\bar{p} \rightarrow \bar{\Lambda}\Sigma^0$ or $\Lambda\bar{\Sigma}^0$ can simulate the $p\bar{p} \rightarrow \Lambda\bar{\Lambda}$ reaction if the γ from Σ^0 or $\bar{\Sigma}^0$ decay escape detection. A very efficient electromagnetic calorimeter (BGO) and a precise kinematical reconstruction should greatly reduce this background. Corrections from this cascade process can be calculated. Further studies are necessary to clarify these points. It is also still possible to work just below the $\Lambda\bar{\Sigma}^0$ threshold (1.65 GeV/c) but with less statistics. However, we should still have to have the best signal-to-background ratio in order to avoid analysing useless events.

5. EXPERIMENTAL ASYMMETRIES

We have first the intrinsic asymmetries of the experiment. The $\bar{\Lambda}$ are forward-produced in the c.m. system; for an experiment at LEAR they are also forward-produced in the lab. system but are more forward-peaked than the Λ . The corresponding baryon or antibaryon is therefore similarly peaked. (For an experiment at Super-LEAR in the collider mode, the situation is more symmetric in this respect: the Λ and $\bar{\Lambda}$ are produced back-to-back in the lab. frame.) In addition, the interactions of particle and antiparticle with matter (vacuum pipe, detectors) are also not symmetric, mainly because of the particle-antiparticle annihilation process.

Apart from these intrinsic asymmetries, we also have asymmetries coming from the different parts of the apparatus (trigger, efficiencies, geometrical position errors, magnetic field, etc.). Note that we have no problems with the monitoring or the normalization, because we measure the Λ and $\bar{\Lambda}$ decay products simultaneously.

5.1 Asymmetries coming from the beam or the target

The beam-cooling process leads to a beam divergence of a few milliradians at the target position. This and the target spatial

extension (less than 1 cm^3) give uncertainties in the angular measurements. The target dimensions should be the smallest possible but still be compatible with reasonable working conditions.

5.2 Asymmetries coming from the detector

5.2.1 Trigger asymmetries

These asymmetries were briefly mentioned in subsection 4.3.

5.2.2 Secondary interactions

The secondary interactions and the multiple scattering of Λ , $\bar{\Lambda}$, or decay products in the jet target, the vacuum pipe, and the counters are the cause of the main limitation on a precise measurement. The Λ and $\bar{\Lambda}$ secondary interactions in the target are minimized by the use of a gas-jet target. The small-angle scattering gives final errors inside $\Delta\theta$, which is the important cut on θ ($\bar{\theta}$), i.e. the angle between the baryon (antibaryon) and the normal to the production plane in the Λ ($\bar{\Lambda}$) rest frame. This θ or $\bar{\theta}$ cut is imposed in order to reject events where the baryon or antibaryon is at the boundary of the production plane. The decay products are charged and give essentially multiple scattering in the vacuum pipe and in the detectors. This is the most dangerous effect because a large number of events can be discarded by the $\Delta\theta$ cut. If it is technically possible to reduce the transverse beam dimensions (i.e. to bypass the apparatus at the initial cooling stage when the beam is large, and then work with a very small beam) so as to have a small beam pipe, this problem of multiple scattering of the decay products can be overcome by recording events where the hyperons decay outside the beam pipe. Moreover, in this case the geometrical acceptance is increased by a factor of 2 to 3. The large-angle scattering of Λ , $\bar{\Lambda}$, or decay products can be filtered out by the reconstruction program or even by multiplicity criteria at the trigger level.

5.2.3 Counter efficiencies

To first order the asymmetry is not affected by counter inefficiency because we work on the basis of a well-reconstructed event. If one of the particles is missing or is misidentified, the event is lost. To higher order, there can be an effect on the asymmetry if, for some reason, the inefficiencies lead to more baryons or antibaryons up than down, or vice versa. As for the trigger bias asymmetries, this effect should be investigated in more detail. In any case a good knowledge of the efficiency map of the detectors is required.

5.2.4 Asymmetries coming from the kinematical reconstruction

In the kinematical reconstruction of the momenta p_p and $p_{\bar{p}}$ and of the production plane in the Λ and $\bar{\Lambda}$ rest frames, the statistical errors, due to the experimental resolution of the detectors, and the systematic errors, due to the position errors of the different parts of the apparatus, are essential for estimating the cuts on the kinematical variables and in particular on θ and $\bar{\theta}$. When θ or $\bar{\theta}$ belongs to the range $(\pi/2 - \Delta\theta)$ to $(\pi/2 + \Delta\theta)$ the event is rejected and no spurious effect is introduced into the measurement of $\tilde{A}$. The angular errors coming from the beam divergence or the target extension can be absorbed in these cuts, and for many events, also the errors due to the hyperon spin precession in the magnetic field. In order to have the control of these spin-precession-induced errors and also, of course, to have precise momenta measurements, we need a high-quality and well-known magnetic field.

5.2.5 Radiative decays

The radiative decay $\Lambda \rightarrow p\pi^-\gamma$ occurs with a branching ratio [11] of about 10^{-3} . In this case, the γ can be detected by an electromagnetic calorimeter (such as the BGO calorimeter foreseen for the JETSET experiment) and the event is then rejected. Only a small fraction of the γ escape detection. As for the detection of

the γ from the $\bar{\Sigma}\Lambda$ and $\Sigma\bar{\Lambda}$ events, high efficiency is very important for the low-energy γ .

6. CONCLUSIONS

It is very important to search for CP violation in the $\Lambda\bar{\Lambda}$ system, and it seems feasible to measure counting asymmetries at the level of a few 10^{-4} . At present, the LEAR machine equipped with a gas-jet target offers the best possibility for carrying out this work.

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Table 1
CP-violating asymmetries

	Model			
	Superweak	KM (Stand. Model)	Weinberg- Higgs	Left-right symmetric
Asymmetry	$\chi = 0$	$\chi \approx 20\epsilon$	$\chi \approx \epsilon$	$\chi \approx 1/10\epsilon$
Δ	0	-5.4×10^{-7}	-7.8×10^{-6}	0
A	0	-0.5×10^{-4}	-2.5×10^{-5}	-1.1×10^{-5}
B	0	3.0×10^{-3}	1.6×10^{-3}	7.0×10^{-4}
B'	0	3.7×10^{-4}	2.0×10^{-4}	8.0×10^{-5}

APPENDIX A

Λ AND $\bar{\Lambda}$ DECAYS IN THE KOBAYASHI-MASKAWA MODEL

In the standard electroweak theory, the interactions of leptons and hadrons with the gauge bosons W^+ and W^- are described by a Lagrangian of the type

$$g(l_\lambda + h_\lambda)W^\lambda$$

where

$$l_\lambda = \sum_i \bar{l}_i \gamma_\lambda (1-\gamma_5) v_i ,$$

$$h_\lambda = \sum_{ij} \bar{u}_i V_{ij} \gamma_\lambda (1-\gamma_5) d_j ,$$

where l and h are the lepton and the hadron part respectively; l_i and v_i are the lepton fields; u_i and d_i are the quark fields; and V_{ij} is the Kobayashi-Maskawa quark-mixing matrix. In the Standard Model with three quark doublets:

$$u_i = (u, c, t) ,$$

$$d_i = (d, s, b) ,$$

$$l_i = (e, \mu, \tau) ,$$

and

$$V = \begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix} .$$

As an example, the non-leptonic decay $K \rightarrow \pi\pi$ corresponding to the transition $s \rightarrow u + \bar{u} + d$ is governed by the product $V_{us} \cdot V_{ud}^*$. A 3×3 unitary matrix V has, in general, three angles and six phases; however, by a change of the phase of the quark fields, this can be reduced to a single phase δ which could be the origin of CP

violation in the weak interactions. An interesting parametrization of the KM matrix is

$$V = \begin{bmatrix} C_1 & S_1 C_3 & S_1 S_3 \\ -S_1 C_2 & C_1 C_2 C_3 - S_2 S_3 e^{i\delta} & C_1 C_2 S_3 + S_2 C_3 e^{i\delta} \\ -S_1 S_2 & C_1 S_2 C_3 + C_2 S_3 e^{i\delta} & C_1 S_2 S_3 - C_2 C_3 e^{i\delta} \end{bmatrix}$$

where $C_i = \cos \theta_i$ and $S_i = \sin \theta_i$.

Note:

- i) CP violation is due to δ only.
- ii) As a corollary, there is no CP violation from the Cabibbo matrix.
- iii) The smallness of the CP-violating effect ($\epsilon \approx 10^{-3}$) is due to the hierarchy amongst the quark generations because the non-diagonal terms for the heavy quarks are small. The values of the matrix elements $|V_{ij}|$ are determined from the experimental transitions, in particular in the semileptonic decays.

Example : $|V_{ud}|$: $0^+ \rightarrow 0^+ \beta$ -decays,

$|V_{us}|$: strange-particle decays,

$|V_{cb}|$: $B \rightarrow \text{Dev}$ decays.

The decay amplitudes for $\Lambda \rightarrow p\pi$ and $\bar{\Lambda} \rightarrow \bar{p}\pi$ are obtained from the matrix elements V_{ij} . The contributing quark diagrams are shown in fig. A.1. From them, we can derive

$$A(\Lambda \rightarrow p\pi) = V_{us} V_{ud}^* A_1' + V_{cs} V_{cd}^* A_2' ,$$

$$\bar{A}(\bar{\Lambda} \rightarrow \bar{p}\pi) = V_{us}^* V_{ud} A_1' + V_{cs}^* V_{cd} A_2' ,$$

where

$$A_1' = a' + b' + c' + e' ,$$

$$A_2' = e' .$$

The partial rate difference Δ comes directly from the above expressions:

$$\Delta = \frac{\text{BR}(\Lambda \rightarrow p\pi) - \text{BR}(\bar{\Lambda} \rightarrow \bar{p}\pi)}{\text{BR}(\Lambda \rightarrow p\pi) + \text{BR}(\bar{\Lambda} \rightarrow \bar{p}\pi)}$$

$$= \frac{4S_2 S_3 \sin \delta C_1 C_2 C_3 \text{Im}(A_1' A_2'^*)}{(|A|^2 + |\bar{A}|^2) S_1^{-2}},$$

where $\sin \delta$ is the CP-violating part. Experimentally, $S_2 S_3 \sin \delta \approx 10^{-3} - 10^{-4}$ (depending on the top mass m_t), which is a small value. In addition,

$$\frac{\text{Im}(A_1' A_2'^*)}{(|A|^2 + |\bar{A}|^2) S_1^{-2}} \approx \text{Im}(a_{1/2} a_{3/2}) / |a_{1/2}|$$

is suppressed by the $\Delta I = 1/2$ rule. The magnitude of Δ is thus very small ($\approx 10^{-6}$), and it is better to consider the other asymmetries $\alpha + \bar{\alpha}$ and $\beta + \bar{\beta}$, neither of which are suppressed by this rule.

Figure captions

- Fig. 1 : Polar diagram of the Λ and $\bar{\Lambda}$ momentum distributions in the reaction $p\bar{p} \rightarrow \Lambda\bar{\Lambda}$ with a $\bar{p}$ beam of 2 GeV/c [4]. The elliptic curve gives, at the same time, the probability distribution of Λ and $\bar{\Lambda}$ decays in space (lower scale). The dashed lines show the limiting cones of the decay protons (antiprotons).
- Fig. 2 : Top view of the jet target to be installed at LEAR by the JETSET Collaboration. This target is very similar to the one used by the R704 experiment.
- Fig. 3 : Side view of the JETSET detector as proposed in CERN/PSCC/86-23.
- Fig. 4 : The cross-section of the reaction $p\bar{p} \rightarrow \Lambda\bar{\Lambda}$ and the geometrical acceptance ε versus the $\bar{p}$ momentum in the lab. system. The circles and the right-hand scale correspond to the acceptance.
- Fig. A.1 : Quark diagrams in the $\Lambda \rightarrow p\pi^-$ decay. The diagrams (see text) corresponding to $\bar{\Lambda} \rightarrow \bar{p}\pi^+$ can be obtained by replacing $u, d, s,$ and c by $\bar{u}, \bar{d}, \bar{s},$ and $\bar{c}$; $V^* \rightarrow V$ and $V \rightarrow V^*$.

Fig. 1

Fig. 2

- GAS JET (direction into paper)
- ▤ SILICON MICRO-STRIP TRACKER (barrel: 3 z layers
end-cap: 3 x+y layers)
- ▥ STRAW CHAMBER (barrel: 8 z layers
end-cap: 4 x+y layers)
- ▧ FAST RICH (liquid C_6F_{14} radiator)
- ▨ BGO ELECTROMAGNETIC CALORIMETER (photodiode readout)
- ▩ SUPERCONDUCTING SOLENOID (6 Tesla)
- FLUX RETURN (restricted to top and
bottom sides of detector)
- ▬ TRIGGER SCINTILLATION COUNTERS

Fig. 3

Fig. 4

Fig. A.1