CP Violation in Non-Leptonic Hyperon Decays at the Tau-Charm Factory

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Abstract

CP violation in non-leptonic $\Lambda$ and $\Xi$ decays is explored at the Tau-Charm Factory from a phenomenological model-independent point of view. Bounds for a CP-odd observable at the level of SM predictions could be achievable in a 1 year run with monochromators.

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AT THE TAU-CHARM FACTORY

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CP violation in non-leptonic Λ and Ξ decays is explored at the Tau-Charm Factory from a phenomenological model-independent point of view. Bounds for a CP-odd observable at the level of SM predictions could be achievable in a 1 year run with monochromators.

1. NON-LEPTONIC HYPERON DECAYS

1.1 Phenomenology

Hyperons (Y) decay mainly non-leptonically to a baryon (B) plus a pion. This decay ($J^P = \frac{1}{2}^+ \rightarrow \frac{1}{2}^+ \otimes 0^-$) is described by two components one $S$ wave (parity violating) and one $P$ wave (parity conserving).

In the helicity formalism [1], the invariant amplitude for this process can be written in a model independent way as:

$$A \propto F_\lambda P_{\frac{1}{2}^+}(\phi, \theta, 0),$$

where ($\theta, \phi$) are the spherical angles of the final baryon momentum in the hyperon rest frame, $M$ the spin of the hyperon, $\lambda$ the helicity of the final baryon, and $F_\lambda$ the two helicity decay amplitudes, related to the partial waves through

$$S = \frac{1}{\sqrt{2}}(F_+ + F_-),$$

$$P = \frac{1}{\sqrt{2}}(F_+ - F_-)$$

The transition rate is proportional to

$$R(\hat{\omega}_Y, \hat{\omega}_B) = 1 + \gamma \hat{\omega}_Y \cdot \hat{\omega}_B + (1 - \gamma)(\hat{\omega}_Y \cdot \hat{B})(\hat{\omega}_B \cdot \hat{B}) + \alpha(\hat{\omega}_Y \times \hat{\omega}_B) \cdot \hat{B} + \beta(\hat{\omega}_Y \times \hat{\omega}_B) \cdot \hat{B}$$

$$\alpha^2 + \beta^2 + \gamma^2 = 1$$

where $\hat{B}$ is a unit vector in the direction of the final baryon momentum, and $\hat{\omega}_Y$ and $\hat{\omega}_B$ are unit vectors in the directions of the hyperon and final baryon spins, respectively. Notice that $\alpha$ is the degree of longitudinal polarization of the final baryon if the hyperons are not polarized, as well as an asymmetry decay constant whereas $\beta$ is related to the transverse polarization of the final baryon.
Squaring the invariant amplitude, it is straightforward to relate $F_\alpha$ to $\alpha$, $\beta$ and $\gamma$:

\[
\alpha = \frac{|F_+|^2 - |F_+|^2}{|F_+|^2 + |F_+|^2} = \frac{2\Re(S^*P)}{|S|^2 + |P|^2},
\]

(4.1)

\[
\beta = \frac{2\Im(F_+^*F_-)}{|F_+|^2 + |F_+|^2} = \frac{2\Im(S^*P)}{|S|^2 + |P|^2},
\]

(4.2)

and

\[
\gamma = \frac{2\Re(F_+^*F_-)}{|F_+|^2 + |F_+|^2} = \frac{|S|^2 - |P|^2}{|S|^2 + |P|^2}.
\]

(4.3)

According to the properties of the helicity decay amplitudes under $C$ and $P$ transformations, the decay parameters and the decay widths for the hyperon and its antihyperon should be related in the following way, assuming CP conservation:

\[
\alpha_Y = -\alpha_Y,
\]

(5.1)

\[
\beta_Y = -\beta_Y,
\]

(5.2)

\[
\gamma_Y = \gamma_Y,
\]

(5.3)

\[
\Gamma_Y = \Gamma_Y.
\]

(5.4)

1.2 Standard Model predictions and present experimental values

In the Standard Model, a small amount of CP violation is allowed in non-leptonic hyperon decays, mainly through penguin diagrams with box diagrams at higher orders. There are large uncertainties in the SM predictions due to the difficulty in evaluating the quark operator expected values in hadronic bound states. The present range of predictions for the most common CP-odd observables is \[2\]

\[
|A_Y| \equiv \frac{|\alpha_Y + \alpha_Y|}{|\alpha_Y - \alpha_Y|} \sim 10^{-5} - 5 \times 10^{-4}
\]

(6.1)

\[
|B_Y'| \equiv \frac{|\beta_Y + \beta_Y|}{|\beta_Y - \beta_Y|} \sim 10|A_Y| \sim 10^{-4} - 5 \times 10^{-3}
\]

(6.2)

\[
|B_Y| \equiv \frac{|\beta_Y + \beta_Y|}{|\beta_Y - \beta_Y|} \sim 100|A_Y| \sim 10^{-3} - 5 \times 10^{-2}
\]

(6.3)

\[
|\Delta_Y| \equiv \frac{|\Gamma_Y - \Gamma_Y|}{|\Gamma_Y + \Gamma_Y|} \sim 0.1|A_Y| \sim 10^{-6} - 5 \times 10^{-5}
\]

(6.4)

where model independent considerations have been taken into account to estimate (6.2), (6.3) and (6.4).

From the experimental point of view, $A_Y$ is easier to measure because there is no need to analyze final baryon polarizations, but, on the contrary, $B_Y$ is more sensitive to test CP violations. The best determination of a CP-odd parameter in the hyperon decays, at present has been obtained by PS185 with 86000 events giving $A_\Lambda = -0.025 \pm 0.019$ \[3\].
On the other side, the experimental values for the $\beta$'s are very small, increasing the difficulty of measuring the observables $B$ and $B'$. A double self-analyzing decay chain, such as

$$\Xi^- \rightarrow \Lambda \pi^- \rightarrow p\pi^-\pi^-$$  \hspace{1cm} \text{(7)}$$

has been proposed to measure $\beta_\Xi$ \cite{4}, \cite{5} where the $p$ acts as a spin analyzer for the $\Lambda$.

Of course, very large data samples and a very clean systematic free environment are required. These are precisely the working conditions of the $\tau cF$ running at the $J/\Psi$ energy.

2. THE TAU-CHARM FACTORY CAPABILITIES

High statistics can be reached at the $\tau cF$ working at the $J/\Psi$ energy. The $J/\Psi$ resonance is very narrow and this implies that the excitation curve is dominated by the beam spread of the machine. The $e^+e^-$ visible cross-section can be computed from the mass, the total width and the branching ratio to electrons, taking into account the radiative corrections and convoluting the result with a gaussian collision energy spread $\sigma(E)$ \cite{4} (Fig. 1). In order to achieve a narrow beam energy spread, the use of monochromators has been explored. In the nominal configuration, the $\tau cF$ has an expected luminosity of $L = 6 \times 10^{32}\text{cm}^{-2}\text{s}^{-1}$ at the $J/\Psi$ peak whereas in the monochromators scheme the expected luminosity at the $J/\Psi$ is $L = 4 \times 10^{32}\text{cm}^{-2}\text{s}^{-1}$ \cite{8}. The production rates, for an $10^7$ efficient year, can be computed using the $J/\Psi \rightarrow \Xi\Xi$, $J/\Psi \rightarrow \Lambda\Lambda$, $\Xi \rightarrow \Lambda\pi$ and $\Lambda \rightarrow p\pi$ branching ratios from \cite{6}, obtaining the values quoted in Table 1.

<table>
<thead>
<tr>
<th>events/year</th>
<th>without monochromators $\sigma(E) = 1.3\text{ MeV}$</th>
<th>with monochromators $\sigma(E) = 0.1\text{ MeV}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$J/\Psi$</td>
<td>$1.3 \times 10^{10}$</td>
<td>$8 \times 10^{10}$</td>
</tr>
<tr>
<td>$\Lambda\Lambda$</td>
<td>$1.8 \times 10^{7}$</td>
<td>$11 \times 10^{7}$</td>
</tr>
<tr>
<td>$\Xi\Xi$</td>
<td>$2.4 \times 10^{7}$</td>
<td>$14 \times 10^{7}$</td>
</tr>
<tr>
<td>$\Lambda\Lambda \rightarrow p\bar{p}\pi\pi$</td>
<td>$7.2 \times 10^{6}$</td>
<td>$42 \times 10^{6}$</td>
</tr>
<tr>
<td>$\Xi\Xi \rightarrow \Lambda\Lambda\pi \rightarrow p\bar{p}\pi\pi\pi$</td>
<td>$9.6 \times 10^{6}$</td>
<td>$56 \times 10^{6}$</td>
</tr>
</tbody>
</table>
All the angles are referred to the mother particle rest frame.

\[ \text{FN} = \% \text{, F; F;} = 5 \]

\[ (Y_1 B_1) \rightarrow \{ (E_A (E_A) (A, 1, A) (A, 2)} \]

\[ (8.1) \]

Polarization. The amplitudes for each subprocess are

\[ A (J/\Psi (M) \rightarrow \Xi (\lambda_\Xi) \Xi (\lambda_\Xi)) \propto A_{\lambda_\Xi} D_{\lambda_\Xi}^\lambda \]

\[ (8.2) \]

with

\[ (Y, B) \in \{ (\Xi, \Lambda), (\Xi, \bar{\Lambda}), (\Lambda, \bar{\Lambda}), (\lambda, \bar{\lambda}) \} \]

\[ (8.3) \]

and

\[ |F_{\pm}|^2 = \frac{1 \pm \alpha_{\gamma}}{2}, \quad F_{\pm} F_{\mp} = \frac{\gamma_{\gamma} \pm i\beta_{\gamma}}{2}. \]

(8.4)

All the angles are referred to the mother particle rest frame.

Figure 1: \( J/\Psi \) visible cross-section for different values of the collision energy spread \( \sigma(E) \)

On the other hand, \( e^+ e^- \) collisions provide a hyperon-antihyperon state with well-defined quantum numbers \( (J = 1) \) thus allowing very clear two branches correlations. Finally, a high resolution detector with large angular coverage permits a good measurement free of systematics.

3. THE DECAY CHAINS FOR \( \Xi \) and \( \Lambda \) PAIRS PRODUCED AT THE \( J/\Psi \)

The cross-section for these processes can be evaluated using the helicity formalism. The \( J/\Psi \) is described by a density matrix, \( \rho \), which contains information about the beam polarization. The amplitudes for each subprocess are

\[ A (J/\Psi (M) \rightarrow \Xi (\lambda_\Xi) \Xi (\lambda_\Xi)) \propto A_{\lambda_\Xi} D_{\lambda_\Xi}^\lambda \]

\[ (8.1) \]

with

\[ (Y, B) \in \{ (\Xi, \Lambda), (\Xi, \bar{\Lambda}), (\Lambda, \bar{\Lambda}), (\lambda, \bar{\lambda}) \} \]

\[ (8.3) \]

and

\[ |F_{\pm}|^2 = \frac{1 \pm \alpha_{\gamma}}{2}, \quad F_{\pm} F_{\mp} = \frac{\gamma_{\gamma} \pm i\beta_{\gamma}}{2}. \]

(8.4)

All the angles are referred to the mother particle rest frame.
3.1 $e^+e^- \rightarrow J/\Psi \rightarrow \Xi^+ \Xi^- \rightarrow \Lambda\bar{\Lambda}\pi^+\pi^- \rightarrow p\bar{p}\pi^+\pi^-\pi^-$

The amplitude for the whole process is the product of the amplitudes of each subprocess, summing up over intermediate helicities. The cross-section is the sum over final helicities of the product of the total amplitude times its complex conjugate:

$$
\frac{d\sigma(J/\Psi \rightarrow \Xi^+ \Xi^- \rightarrow p\bar{p}\pi^+\pi^-\pi^-)}{d\Omega_\Xi d\Omega_\Lambda d\Omega_p d\Omega_\pi} \propto \sum_M \sum_{M'} \rho_{MM'} \times \sum_{\lambda_+} \sum_{\lambda_-} \sum_{\lambda_\Lambda} \sum_{\lambda_\pi} A_{\lambda_+ \lambda_- \lambda_\Lambda \lambda_\pi} A_{\lambda_+ \lambda_- \lambda_\Lambda \lambda_\pi}^* \frac{F_{\lambda_+}^{\Xi^+} F_{\lambda_-}^{\Xi^-}}{F_{\lambda_+}^{\Lambda} F_{\lambda_-}^{\Lambda}} \frac{|F_{\lambda_\pi}^\Lambda|^2}{|F_{\lambda_\pi}|^2}
$$

The expansion of this expression is several pages long, and it will be omitted. The point is that $\alpha_\Xi$ and $\beta_\Xi$ contribute independently to different terms whereas there is no information available on $\beta_\Lambda$ or $\beta_\bar{\Lambda}$ because $F_{\lambda_\Lambda}^\Lambda$ and $F_{\lambda_\bar{\Lambda}}^\Lambda$ appear only in absolute value. This is just a consequence of the fact that in a double hyperon decay only the polarization of the first hyperon is analyzed.

3.2 $e^+e^- \rightarrow J/\Psi \rightarrow \Lambda\bar{\Lambda} \rightarrow p\bar{p}\pi\pi$

In this case there are only contributions from the $\alpha$ parameters of the $\Lambda$ decays, and the expanded formula is more sizeable. If $e^+e^-$ beams are prepared to be longitudinally polarized with polarization degrees $P_L^+ \psi$ and $P_L^-\psi$, respectively, then

$$
\frac{d\sigma(J/\Psi \rightarrow \Lambda\bar{\Lambda} \rightarrow p\bar{p}\pi\pi)}{d\Omega_\Lambda d\Omega_p d\Omega_\pi} \propto
\frac{1}{2} |A_{++}|^2 (1 + P_L^+ P_L^-) \sin^2 \theta_\Lambda \{1 - \alpha_\Lambda \alpha_\bar{\Lambda} [\cos \theta_p \cos \theta_p - \sin \theta_p \sin \theta_p \cos (\phi_p - \phi_\pi)]\}
+ \frac{1}{4} |A_{+-}|^2 (1 + P_L^+ P_L^-) (1 + 2 \cos^2 \theta_\Lambda) \{1 + \alpha_\Lambda \alpha_\bar{\Lambda} \cos \theta_p \cos \theta_p
+ \alpha_\Lambda \alpha_\bar{\Lambda} \sin^2 \theta_p \sin \theta_p \cos (\phi_p + \phi_\pi)]
+ 2 P_L^+ P_L^- \cos \theta_\Lambda \{\alpha_\Lambda \cos \theta_p + \alpha_\bar{\Lambda} \cos \theta_\pi\}
$$

\[ (10) \]

$$
- \frac{1}{\sqrt{2}} \text{Re}[A_{++}^* A_{+-}] \sin \theta_\Lambda \{1 + P_L^+ P_L^- \cos \theta_\Lambda \alpha_\Lambda \alpha_\bar{\Lambda} [\cos \theta_p \sin \theta_p \cos \phi_p + \cos \theta_p \sin \theta_p \cos \phi_\pi]
+ P_L^+ P_L^- \alpha_\Lambda \sin \theta_p \cos \phi_\pi + \alpha_\bar{\Lambda} \sin \theta_p \cos \phi_\pi]\}
$$

$$
- \frac{1}{\sqrt{2}} \text{Im}[A_{++}^* A_{+-}] \sin \theta_\Lambda \{1 + P_L^+ P_L^- \cos \theta_\Lambda \alpha_\Lambda \alpha_\bar{\Lambda} [\cos \theta_p \sin \phi_p + \alpha_\Lambda \sin \theta_p \sin \phi_\pi]
+ P_L^+ P_L^- \alpha_\Lambda \cos \theta_p \sin \phi_\pi + \alpha_\bar{\Lambda} \cos \theta_p \sin \phi_\pi]\}
$$

5
Parity conservation in the $J/\Psi$ strong and electromagnetic decay has been taking into account, resulting the relationships (11) and allowing only two independent helicity decay amplitudes,

$$A_{++} = A_{--}, \quad A_{+-} = A_{-+}$$

(11)

Notice that if the beams are not longitudinally polarized ($P_+^L P_-^L = 0$) then only the combination $\alpha_\Lambda \alpha_{\bar{\Lambda}}$ is available, unless $\Im[A_{++} A_{-+}]$ is different from zero.

### 3.3 Extracting the information

These angular distributions can provide different and independent measurements of decay parameter products. The combinations of decay parameters which are available can be isolated decomposing the differential cross-sections into a spherical harmonic basis, the momenta of the distributions being

$$T_{i_1 i_2 i_3 i_4 m_1 m_2 m_3 m_4}^{m} (\Xi) = \langle Y^*_{m_1} (\Omega_\Xi) Y^*_{i_1 m_1} (\Omega_\Lambda) Y^*_{i_2 m_2} (\Omega_\bar{\Lambda}) Y^*_{i_3 m_3} (\Omega_p) Y^*_{i_4 m_4} (\Omega_p) \rangle,$$

(12.1)

$$T_{i_1 i_2 i_3 m_1 m_2}^{m} (\Lambda) = \langle Y^*_{m_1} (\Omega_\Lambda) Y^*_{i_1 m_1} (\Omega_p) Y^*_{i_2 m_2} (\Omega_p) \rangle$$

(12.2)

Table 2: Independently measurable decay parameter combinations in the $\Lambda \bar{\Lambda}$ and $\Xi \Xi$ channels.

<table>
<thead>
<tr>
<th>$J/\Psi$ Decay channel</th>
<th>Beam polar.</th>
<th>Measured parameter combinations</th>
<th>Measured parameters</th>
<th>CP odd observables</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Lambda \bar{\Lambda}$</td>
<td>NO</td>
<td>$\alpha_\Lambda \alpha_{\bar{\Lambda}}$</td>
<td>$\alpha_\Lambda \alpha_{\bar{\Lambda}}$</td>
<td>$A_\Lambda$ (requires ext. data)</td>
</tr>
<tr>
<td>$\Lambda \Lambda$</td>
<td>YES</td>
<td>$\alpha_\Lambda, \alpha_{\bar{\Lambda}}, \alpha_\Lambda \alpha_{\bar{\Lambda}}$</td>
<td>$\alpha_\Lambda, \alpha_{\bar{\Lambda}}$</td>
<td>$A_\Lambda$</td>
</tr>
<tr>
<td>$\Xi^- \Xi^+$</td>
<td>NO</td>
<td>$\alpha_{\Xi^+}, \alpha_{\Xi^-}, \alpha_{\Xi^+} \alpha_{\Xi^-}$</td>
<td>$\alpha_{\Xi^+}, \alpha_{\Xi^-}$</td>
<td>$A_{\Xi^-}$</td>
</tr>
<tr>
<td>$\Xi^- \Xi^+$</td>
<td>YES</td>
<td>As without polarisation plus $\alpha_{\Xi^+}, \alpha_{\Xi^-}, \alpha_{\Xi^+} \alpha_{\Xi^-}$</td>
<td>$\alpha_{\Xi^+}, \alpha_{\Xi^-}$</td>
<td>$A_{\Xi^-}$</td>
</tr>
</tbody>
</table>

These momenta are connected with the observed ones in a very systematic way through an acceptance matrix, where both experimental and analysis cuts are included. Besides, a direct exploration of the expanded formulas also helped in the identification of the useful distributions. The result is summarized in Table 2.
3.4 Induced polarizations

To understand the role of the different decay parameters and angular combinations it is useful to study the polarization induced in the particles produced at each decay.

The degree of polarization vector of the hyperon pairs produced at the $J/\Psi$, in $e^+e^-$ collisions of longitudinally polarized beams, can be expressed as:

$$\vec{P}_B = -\frac{\sqrt{2} R_{A+} R_{A-}}{|A_+ A_-|^2} \sin \theta_\Xi \cos \theta_\Xi \vec{\tau} + \vec{P}_{\text{beams}} \left\{ \cos \theta_\Xi \vec{\tau} - \sqrt{2} R_{A+} R_{A-} \sin \theta_\Xi \vec{x} \right\}$$

(13)

where $P_{\text{beams}} = (P^L_\Xi + P^L_\Xi)/(1 + P^L_\Xi P^L_\Xi)$ is the longitudinal degree of polarization of the beams, $\vec{x} = (\vec{e}^+ \times \vec{\Xi} \times \vec{\Xi})/\sin \theta_\Xi$ is a unit vector contained in the plane of production and orthogonal to the $\Xi$ direction and $\vec{\tau} = (\vec{e}^+ \times \vec{\Xi})/\sin \theta_\Xi$ is a unit vector transverse to the plane of production.

On the other hand, the hyperon decay rate can be written as

$$R(\Lambda \to B\pi) \propto 1 + \alpha_\Lambda \vec{P}_\Lambda \cdot \vec{B}$$

(14)

taking into account that the density matrix for a spin $1/2$ state is fully determined by its polarization according to:

$$\rho_{\lambda\nu} = \begin{pmatrix} 1 + P^\lambda_Y & P^\nu_Y - i P^\rho_Y \\ P^\nu_Y + i P^\rho_Y & 1 - P^\rho_Y \end{pmatrix}$$

(15)

Finally from Eq. (3) it is easy to realize that the hyperon decay polarizes the final baryon producing a state described by the polarization vector:

$$\vec{P}_B = \frac{1}{1 + \alpha_\Lambda \vec{P}_\Lambda \cdot \vec{B}} \left[ (\alpha_\Lambda + \vec{P}_\Lambda \cdot \vec{B}) \vec{B} + \beta_\Lambda (\vec{P}_\Lambda \times \vec{B}) - \gamma_\Lambda \vec{B} \times (\vec{B} \times \vec{P}_\Lambda) \right]$$

(16)

Summarizing, if the $e^+e^-$ beams are longitudinally polarized then the $\Xi$'s coming out in a certain direction, determined by their polar angle $\theta_\Xi$ respect to the beam, will have, at least a longitudinal component of polarization, $P^L_\Xi \propto P_{\text{beams}}$, so that it is possible to select an angular range of $\theta_\Xi$ (e.g. the forward region) and obtain a polarized sample. Consequently, using Eqs. (13) and (16), the $\Lambda$ sample from the decay of these $\Xi$'s will have a transverse component of polarization, along $\vec{y}_\Lambda = (\vec{\Xi} \times \vec{\Lambda})/|\vec{\Xi} \times \vec{\Lambda}|$. This induced polarization, $\vec{P}_T$, is proportional to $P_{\text{beams}} \beta (\vec{\Xi} \times \vec{\Lambda})$. Hence, the angular distribution of the protons from the decay of these $\Lambda$'s will have a component:

$$R^T(\theta_p^*) = 1 + \alpha_\Lambda \vec{P}_T \cdot \vec{p} = 1 + k P_{\text{beams}} \alpha_\Lambda \beta_\Xi (\vec{\Xi} \times \vec{\Lambda}) \cdot \vec{p}, \quad \text{where} \quad \cos \theta_p^* = \vec{y}_\Lambda \cdot \vec{p}$$

(17)

In this way it is possible, studying single decay branch distributions, to obtain $\beta_\Xi$ from $R^T(\theta_p^*)$, and compute $B_\Xi$ comparing $R^T(\theta_p^*)$ and $R^T(\theta_p^*)$.

If the beams are not polarized then the $\Xi$'s are produced with no longitudinal polarization. They could have a component of polarization transverse to their plane.
of production but it would be proportional to $\frac{\mathcal{A}_+^* \mathcal{A}_-}{|\mathcal{A}_+^*|}$, whose value has never been measured and will not be considered. Anyway, one can always use the recoiling $\Xi'$s to select a sample of polarized $\Xi$'s. For this purpose a polarized subsample of $\Xi$’s is chosen accepting only the events where the $\Xi$'s decay to $\Lambda$'s with a particular orientation. Then the degree of polarization of the $\Xi$’s will be $P^{\Xi}_E \propto \alpha_\Xi (\Xi \cdot \Lambda) = -\alpha_\Xi (\Xi \cdot \bar{\Lambda})$. Applying the same arguments that in the previous case, the parameter combination $\alpha_\Xi \alpha_\Lambda \beta_\Xi$ is measurable studying the distribution of $(\Xi \cdot \bar{\Lambda})(\Xi \times \bar{\Lambda}) \cdot \hat{p}$, and interchanging the roles of $\Xi \leftrightarrow \bar{\Xi}$ and $\Lambda \leftrightarrow \bar{\Lambda}$ then $\alpha_\Xi \alpha_\Lambda \beta_\Xi$ can also be measured. In this way the CP-odd observable $B_\Xi$ can be computed even without beam polarization.

4. THE MONTE CARLO SIMULATION

To evaluate the possibilities of the Tau-Charm Factory for observing CP-violation through the hyperons decays, a detailed Monte Carlo simulation has been developed. The event generator for the $\Xi\Xi$ has been built directly from Eq. (9) including all the correlations between the different decays. The event generator for the $\Lambda \bar{\Lambda}$ is built from the corresponding equation including also all the correlations. The angular distributions are affected by the detector resolution and acceptance. In the Monte Carlo simulation we have included the effects of the angular acceptance, $|\cos(\theta_{LAB})| \leq 0.9$, the threshold of minimum pion momenta that the drift chamber will be able to measure, $p_\pi \geq 50$ MeV/c, and in the $\Lambda \bar{\Lambda}$ case we have requested that the two primary decay vertices are inside the drift chamber, as a triggering element to enhance the hyperon-antihyperon events [4].
Figure 3: Distribution of reconstructed mass and momenta of $\Lambda$ and $\Xi$ both in $5 \times 10^6$ $J/\psi \rightarrow \Xi\Xi$ and $J/\psi \rightarrow \Lambda\Lambda$ events.

The most important element in the measurement of these kinds of events is the drift chamber, its resolution for the $\tau cF$ detector [7] was described by:

$$\Delta \left( \frac{1}{p_T} \right) = \left( 0.003 \oplus \frac{0.003}{\beta p_T} \right) \text{GeV}^{-1},$$

$$\Delta(\phi) = 4 \times 10^{-4} \text{ rad},$$

$$\Delta(\theta) = \sin^2 \theta \times 2.25 \times 10^{-3} \text{ rad}. \quad (18)$$

Figure 2a shows the detector effects on the simplest angular distribution, $\theta_\Lambda$ in the $J/\psi \rightarrow \Lambda\Lambda$ channel, with beam polarization present. To avoid systematic errors we can only impose symmetrical analysis cuts and/or apply geometrical acceptance corrections MC-independent. The comparison of generated and reconstructed data after detector effects and analysis cuts is shown in Fig. 2b, for the same angular distribution.

In Fig. 3, the distribution of reconstructed mass and momenta of $\Lambda$ and $\Xi$ are presented, both for the $J/\psi \rightarrow \Xi\Xi$ and $J/\psi \rightarrow \Lambda\Lambda$ cases, showing the excellent detector resolution and the event identification power of these distributions.
4.1 $\Lambda\bar{\Lambda}$ channel

The mean decay length at laboratory for the $\Lambda$'s produced in the $J/\Psi \rightarrow \Lambda\bar{\Lambda}$ events is 7.595 cm, quite inside the drift chamber, allowing a good radial acceptance for the primary vertices (33.5%). The analysis cuts used were: symmetrical selections in the polar angle of the $\Lambda$, $|\cos\theta_\Lambda| \leq 0.85$, and in the polar angle of the protons in the rest frame of the $\Lambda$, $|\cos\theta_p| \leq 0.85$. The former is to be safe from angular acceptance cuts, and the latter is to get rid of low momentum pions without spoiling the shape of the distributions (low momentum pions go out in the opposite direction to the boost of the $\Lambda$'s).

4.1.1 Case without longitudinal beam polarization

The only hyperon decay parameters combination available without beam polarization is $\alpha_\Lambda\alpha_{\bar{\Lambda}}$. The most sensitive angular correlations to $\alpha_\Lambda\alpha_{\bar{\Lambda}}$ are the Forward-Backward asymmetries of proton and antiproton angles in their corresponding mother particle rest frames (Fig. 4a and 4b):

$$\langle FB(\theta_p)\rangle_{\cos\theta_p} = k_{FB}\alpha_\Lambda\alpha_{\bar{\Lambda}} \cos\theta_p,$$  
\hspace{5cm} (19.1)

$$\langle FB(\theta_p)\rangle_{\cos\theta_p} = k_{FB}\alpha_\Lambda\alpha_{\bar{\Lambda}} \cos\theta_p,$$  
\hspace{5cm} (19.2)

with $k_{FB}$ a constant depending on the ratio $|A_{+\pm}/A_{++}|$ and on the symmetrical analysis cuts. With 1 year data with (without) monochromators the Tau-Charm Factory could reach sensitivities of

$$\frac{\Delta m}{m} = \frac{\Delta\alpha_\Lambda\alpha_{\bar{\Lambda}}}{\alpha_\Lambda\alpha_{\bar{\Lambda}}} = 0.5\%\ (1.3\%).$$  
\hspace{5cm} (20)

Introducing $\alpha_\Lambda$ as an external input, from one hypothetical independent experiment with negligible uncertainties, a sensitivity of $\Delta A_\Lambda \sim 5 \times 10^{-3}$ would be achievable using these correlations.

4.1.2 Case with longitudinal beam polarization

If the beams are longitudinally polarized it is possible to measure $\alpha_\Lambda$ and $\alpha_{\bar{\Lambda}}$, and therefore $A_\Lambda$, from the Forward-Backward asymmetry in the production angle, $\theta_\Lambda$, for an specific decay angle, $\theta_p$, involving in this way only one branch at a time (Fig. 4c and 4d):

$$\langle FB(\theta_\Lambda)\rangle_{\cos\theta_p} = P_{\text{beams}}k_{FB}\alpha_{\Lambda}\alpha_{\bar{\Lambda}} \cos\theta_p,$$  
\hspace{5cm} (21.1)

$$\langle FB(\theta_\Lambda)\rangle_{\cos\theta_p} = P_{\text{beams}}k_{FB}\alpha_{\Lambda}\alpha_{\bar{\Lambda}} \cos\theta_p,$$  
\hspace{5cm} (21.2)

with $k_{FB}'$ being another computable constant.

The sensitivity to $A_\Lambda$ for a comparison of both distributions, assuming a realistic 40% polarization degree for the beams [8], with one year data using the monochromators scheme is

$$\Delta A_\Lambda \sim 3 \times 10^{-3},$$  
\hspace{5cm} (22)

where a dependence of the sensitivity with the number of events and the beams polarization $\Delta A_\Lambda \propto \sqrt{N_{\text{beams}}}^{-1}$ has been taken into account to scale from the Monte Carlo ($N_{MC}^{MC} = 5 \times 10^6 \rightarrow N_{MC}^{MC} = 42 \times 10^6$ and $P_{\text{beams}}^{MC} = 100\% \rightarrow P_{\text{beams}}^{MC} = 40\%$).
Figure 4: Angular correlations measuring $\alpha_A$ and $\alpha_{\Lambda}$ in the process \( J/\Psi \rightarrow \Lambda\bar{\Lambda} \). $\theta_A(\theta_\bar{A})$ are the decay angles of $\Lambda \rightarrow p\pi^-$ ($\bar{\Lambda} \rightarrow \bar{p}\pi^+$) in the $\Lambda(\bar{\Lambda})$ rest frame and $\theta_A$ is the angle between the $\Lambda$ and the $e^-$ beam.

4.2 \( \Xi\Xi \) channel

In this channel no vertex cuts are required. The symmetrical analysis cuts applied are: $|\cos \theta_\Xi| \leq 0.76$, $|\cos \theta_{\bar{\Xi}}| \leq 0.93$ and $|\sin \phi_p| \geq 0.5$. The last cut whose purpose is to select the events with $\Lambda$ pions energetic enough to be measurable by the drift chamber, is rather severe decreasing the statistics by a big factor ($\sim 1/15$). Other possibilities are under study.

As already explained, with these $\Xi\Xi$ events $A_\Lambda$ and $A_{\Xi}$ can be measured, but also $B'_{\Xi}$ is observable and it is much more sensitive to CP violations, so in these paper we will present only details for the evaluation of this magnitude.

5 million Lambda events with 100% Beam Polarization
4.2.1 Case without longitudinal beam polarization

Without polarization we have to study two branches correlations to measure $B'_\Xi$. In fact in all the terms of the differential cross section for this process the $\beta_\Xi$ parameter appears always combined, at least with two other decay parameters. A good distribution to evaluate $\beta_\Xi$ is the asymmetry of the triple correlation product $[(\Xi \times \Lambda) \cdot \vec{p}]$ versus $(\vec{\Xi} \cdot \vec{\Lambda})$ (and the symmetric one interchanging the roles of $\Xi \to \Xi$ and $\Lambda \to \Lambda$):

$$\langle LR(\phi_p) \rangle_{\cos \theta_\Lambda} = k_{LR} \alpha_\Xi \alpha_\Lambda \beta_\Xi \cos \theta_\Lambda,$$  \hspace{1cm} (23.1)

$$\langle LR(\phi_p) \rangle_{\cos \theta_\Lambda} = -k_{LR} \alpha_\Xi \alpha_\Lambda \beta_\Xi \cos \theta_\Lambda,$$  \hspace{1cm} (23.2)

where $LR$ is the Left-Right asymmetry of the proton production referred to the plane of production of the $\Lambda$ in the $\Xi$ rest frame (Fig. 5a), and $k_{LR}$ is a constant that can be computed from the the ratio $|A^+ / A^-|$ and the analysis cuts. $B'_\Xi$ can be obtaining comparing these two distributions. Assuming the same value for $\alpha_\Xi \alpha_\Lambda$ and $\alpha_\Xi \alpha_\Lambda$ the sensitivity to this CP-odd observable with one year's data with monochromator optics would be

$$\Delta B'_\Xi \sim 4.5 \times 10^{-3} - 10^{-2},$$ \hspace{1cm} (24)

where the value $4.5 \times 10^{-3}$ is the expected limit one can reach improving the present selections to achieve the optimal acceptance for this kind of events (close to 70%).

4.2.2 Case with longitudinal beam polarization

Once the beams are polarized, the $B'_\Xi$ can be obtaining comparing distributions that involve only one branch at a time, decreasing the possible sources of systematic errors. A good way is to observe (Fig. 5b) the following asymmetries:

$$\langle LR(\phi_p)FB(\theta_\Xi) \rangle_{\sin \theta_\Lambda} = P_{\text{beams}} k'_{LR} \alpha_\Xi \alpha_\Lambda \beta_\Xi \sin \theta_\Lambda,$$  \hspace{1cm} (25.1)

$$\langle LR(\phi_p)FB(\theta_\Xi) \rangle_{\sin \theta_\Lambda} = -P_{\text{beams}} k'_{LR} \alpha_\Xi \alpha_\Lambda \beta_\Xi \sin \theta_\Lambda$$ \hspace{1cm} (25.2)

For a 40 % longitudinal beam polarization the sensitivity provided by one year's data with monochromator optics would be, with the same remarks than for the previous case:

$$\Delta B'_\Xi \sim 3 \times 10^{-3} - 9 \times 10^{-3}.$$ \hspace{1cm} (26)

4. CONCLUSIONS

In this paper it has been shown that the study of the hyperon decay parameters in the $J/\Psi \to \Xi^- \Xi^+$ and $J/\Psi \to \Lambda \Lambda$ systems at the Tau-Charm Factory, could become a very interesting alternative to explore CP violation. In fact it has been shown that several CP-odd parameters can be studied for different hyperon systems and each one using many different and independent distributions, that will be affected by different systematic effects. Special consideration deserve the possibility to study $B'_\Xi$ with a Tau-Charm Factory including monochromator optic and large longitudinal beam polarization. The option to build such an accelerator complex has been studied in detail [8] with very optimistic conclusions, and once operational it would allow to reach the level of sensitivity required to check the Standard Model predictions for $B'_\Xi$. 

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Figure 5: Angular correlations measuring $\beta_{\Xi}/(\beta_{\Xi})$ in the process $J/\Psi \rightarrow \Xi^{-} \Xi^{+} \rightarrow \Lambda \Lambda \pi^{+} \pi^{-} \rightarrow ppp^{+} \pi^{+} \pi^{-} \pi^{-}$ (a) without and (b) with beams polarization.
Table 3: Sensitivities on the CP-odd observables in $J/\psi \to \Lambda\Lambda$ and $J/\psi \to \Xi^-\Xi^+$ with $8 \times 10^{10}$ $J/\psi$ events ($\approx 1$ year with monochromators).

<table>
<thead>
<tr>
<th>$J/\psi$ Decay channel</th>
<th>Beams Polarization</th>
<th>Measured CP-odd parameters</th>
<th>SM predictions</th>
<th>$\tau cF$ sensitivities</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Lambda\Lambda$</td>
<td>NO</td>
<td>$A_{\Lambda}$ (requires ext. data)</td>
<td>$10^5 - 5 \times 10^{-4}$</td>
<td>$5 \times 10^{-3}$</td>
</tr>
<tr>
<td>$\Xi^-\Xi^+$</td>
<td>YES</td>
<td>$A_{\Xi}$</td>
<td>$10^{-5} - 5 \times 10^{-4}$</td>
<td>$\leq 10^{-3}$ (40% polarization)</td>
</tr>
<tr>
<td></td>
<td>NO</td>
<td>$A_{\Xi}$</td>
<td>$10^{-5} - 5 \times 10^{-4}$</td>
<td>$\approx 10^{-3}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$A_{\Xi}$</td>
<td>$10^{-4} - 5 \times 10^{-3}$</td>
<td>$\approx 5 \times 10^{-3}$</td>
</tr>
</tbody>
</table>

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