Analysis of Discrete Symmetries in b-Baryon Decays

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Motivation and Introduction I

- Modern Particle Physics is well described by gauge field theories which are built on fundamental principles, the most important ones being Lorentz Invariance, Unitarity and Hermiticity.
- An immediate consequence of these principles is the famous CPT theorem which stipulates that any physical system and its CPT-conjugate one have identical physical laws.
- On another side, CPT theorem supposes that, if CP symmetry is violated, Time Reversal (TR) is no longer a good symmetry and this mathematical feature represents only an *indirect violation* of TR symmetry.
- However some experiments performed recently at CERN and Fermilab have shown a clear signal of direct TR violation in the $K^0 - \bar{K}^0$ system.

Motivation and Introduction II

- More precisely, the prediction of the size of the violation in these weak decays is strongly model dependent, which stimulates people to search for signals of new physics(*NP*), beyond the standard model (*SM*).
- For example, the decays involving the transition $b \longrightarrow s$ present CPV parameters, like the $B^0 - \bar{B}^0$ mixing phase and the transverse polarization of spinning decay products of Λ_b, which are very small in *SM* predictions, but are considerably enhanced in other models.
- In particular, recent signals of *NP* have been claimed in B decays: the CP violating phases of $B \longrightarrow K\pi$ and $B_s \longrightarrow \phi J/\psi$ may be considerably greater than predicted by *SM*.

Motivation and Introduction III

- Λ_b decays are suggested as new sources of *CPV* and *TRV* parameters, especially in view of the abundant production of this resonance in the forthcoming $LHC - b$ experiment.
- Lastly the *CPT* theorem, valid for local field theories, has been tested to a great precision in the neutral kaon decay, but not in other situations: for example, it has never been checked in decays involving the b-quark, furthermore a meaningful size of uncertainty remains in $K^{\pm} \to \pi^{\pm}\pi^{0}$.
- The aim of the our present work is to check some model independent tests of *TRV*, *CPV* and *CPT* invariance in hadronic Λ_b decays of the type

  $$\Lambda_b \to \Lambda V$$

  V denoting a $J^P = 1^-$ resonance, either the J/ψ or a light vector meson, like ρ^0, ω etc.

Motivation and Introduction IV

- The Parametrization is done by means of the spin density matrix (*SDM*) of the angular distributions and the polarizations of the decay products.
- Then we studied the behavior of these observable under *CP* and *T*, singling out those which are sensitive to *T*, *CP* and *CPT* violations.
- Our approach resembles the one proposed by Lee and Yang many years ago, to use hyperon decays for the same tests.
- We are applying this model to see some asymmetries parameters in some particular channels

$$\Lambda_b \rightarrow \Lambda J/\psi$$

and

$$\Lambda_b \rightarrow \Lambda\rho^0\,(\omega)$$

Kinematical properties of $\Lambda_b \to \Lambda V$ decays I

WE studied the kinematical properties of decays $\Lambda_b \to \Lambda V$ by the Jacob-Wick helicity formalism.

Helicity formalism has some advantages:

- Helicity, $\lambda = \frac{\vec{\sigma}.\vec{p}}{|\vec{p}|}$, depends on spin $\vec{s}$ and momentum $\vec{p}$ of the particle and does not depend on its orbital angular momentum $\vec{\ell}$, so it is rotationally invariant.
- We can work easily in the rest frame of resonances.

It is more convenient to define a frame of three mutually orthogonal unit vectors

$$\vec{e}_z = \vec{n} = \frac{\vec{p}_p \times \vec{p}_b}{|\vec{p}_p \times \vec{p}_b|}; \quad \vec{e}_x = \frac{\vec{p}_p}{|\vec{p}_p|}; \quad \vec{e}_y = \vec{e}_z \times \vec{e}_x$$

Kinematical properties of $\Lambda_b \to \Lambda V$ decays II

Here $\vec{p}_p$ and $\vec{p}_b$ are, respectively, the proton momentum and the Λ_b momentum. If produced by means of strong interactions then Λ_b is polarized along $\vec{n}$. Therefore we choose the quantization axis along $\vec{e}_z = \vec{n}$.

Λ_b being transversally polarized, its polarization value is given by $\vec{\mathcal{P}}^{\Lambda_b} = \langle \vec{S}_{\Lambda b} \cdot \vec{e}_z \rangle$. Let M_i be the Λ_b spin projection along $\vec{e}_z$ axis and, are respectively the helicity values of Λ and V . Conservation of total angular momentum leads to four possible values for the pair $(\lambda_1, \lambda_2) = (1/2, 0),\ (1/2, 1),\ (-1/2, -1),\ (-1/2, 0)$.

Kinematical properties of $\Lambda_b \to \Lambda V$ decays III

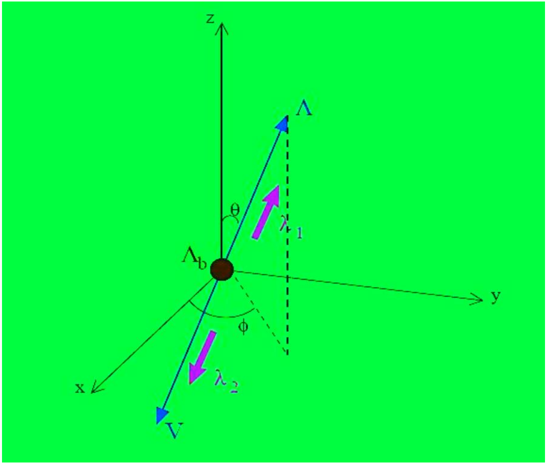

Figure: Λ_b decay in its transversity frame

Kinematical properties of $\Lambda_b \to \Lambda V$ decays IV

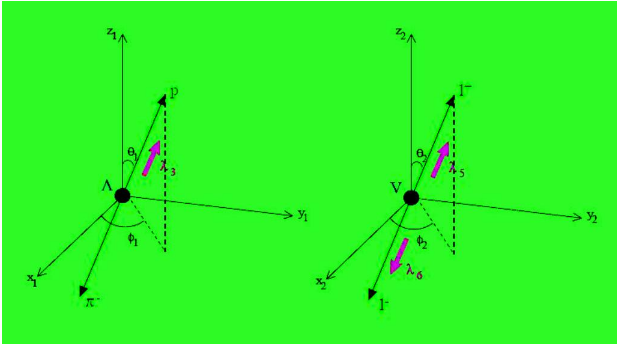

Figure: Helicity frames for Λ and vector meson

Kinematical properties of $\Lambda_b \to \Lambda V$ decays V

We define the Spin Density Matrix (SDM) for Λ_b as:

$$\rho^{\Lambda_b} = \frac{1}{2}\left(1 + \vec{\mathcal{P}}^{\Lambda_b} \cdot \vec{\sigma}\right)$$

where $\vec{\sigma} = (\sigma_x,\ \sigma_y,\ \sigma_z)$ are the Pauli spin matrices.
In the rest frame of Λ_b the components of its polarization vector are

$$P_z^{\Lambda_b} = \frac{1}{2}\left(\rho_{++}^{\Lambda_b} - \rho_{--}^{\Lambda_b}\right), \quad P_x^{\Lambda_b} = \Re\left(\rho_{+-}^{\Lambda_b}\right), \quad P_y^{\Lambda_b} = -\Im\left(\rho_{+-}^{\Lambda_b}\right)$$

$\rho_{MM'}^{\Lambda_b}$ are the matrix elements of ρ^{Λ_b} ; $M, M' = \pm$ denoting the values of the third component of the Λ_b spin along the quantization axis. ρ^{Λ_b} verifies the normalization condition

$$Tr\left(\rho^{\Lambda_b}\right) = \left(\rho_{++}^{\Lambda_b} + \rho_{--}^{\Lambda_b}\right) = 1$$

Kinematical properties of $\Lambda_b \to \Lambda V$ decays VI

Intermediate resonance states, Λ and V , can be described by a density-matrix named ρ^f whose analytic expression is given by standard quantum-mechanical relations:

$$\rho^f = \mathcal{T}^\dagger \rho^{\Lambda_b} \mathcal{T}$$

where $\mathcal{T}$ is the transition-matrix related to the S-matrix by $S = 1 + i\mathcal{T}$. After summing over the initial polarizations of $M, \ M'$ of Λ_b and taking into account the angular momentum conservation, the helicity formalism gives us

$$\rho^f_{\lambda\lambda'\chi\chi'} = \frac{1}{4\pi} \left\{ \begin{array}{c} A_{\lambda,\lambda-\chi} A^*_{\lambda',\lambda'-\chi} \left(1 + 4\chi P_1^{\Lambda_b}\right) \delta_{\chi,\chi'} \\ +2A_{\lambda,\lambda'-\chi} A^*_{\lambda,\lambda'+\chi} \left(P_2^{\Lambda_b} + 2i\chi P_3^{\Lambda_b}\right) \delta_{\chi,-\chi'} \end{array} \right\}$$

Kinematical properties of $\Lambda_b \to \Lambda V$ decays VII

where

$$A_{\lambda,\lambda'-\chi} = 4\pi \left(\frac{m_b}{|\vec{p}_b|}\right) \langle J, M; \lambda, \lambda' - \chi \,|\mathcal{T}|\, J, M\rangle$$

is the helicity amplitude and by angular momentum conservation

$$\chi = \lambda_1 - \lambda_2 = \pm\frac{1}{2};\ \chi' = \lambda_1' - \lambda_2' = \pm\frac{1}{2}$$

The final decay amplitude, $\mathcal{A}^f\left(M_i, \lambda_{1,}\lambda_2\right)$, for the process of sequence decays $\Lambda_b(M_i) \to \Lambda(\lambda_1)V(\lambda_2) \to p\pi^-\ell^+\ell^-(h^+h^-)$ can be factorized according to the three decay amplitudes $A_0(M_i)$, $A_1(\lambda_1)$ and $A_2(\lambda_2)$. It includes all the possible intermediate states, so that a sum over the helicity states (λ_1, λ_2) is performed:

$$\mathcal{A}^f\left(M_i, \lambda_{1,}\lambda_2\right) = \sum_{\lambda_1,\lambda_2} A_0(M_i)A_1(\lambda_1)A_2(\lambda_2).$$

Kinematical properties of $\Lambda_b \to \Lambda V$ decays VIII

The decay probability, $d\sigma$, depending on the amplitude, $\mathcal{A}^f\,(M_i, \lambda_{1,}\lambda_2)$, takes the form,

$$d\sigma \propto \sum_{M_i, M_i'} \rho^{\Lambda_b}_{MM'} \mathcal{A}^f \mathcal{A}^{f*}$$

The helicity asymmetry parameter, α_{AS} for Λ_b is given by

$$\alpha_{AS} = \frac{\left|A_{\frac{1}{2},0}\right|^2 + \left|A_{-\frac{1}{2},-1}\right|^2 - \left|A_{-\frac{1}{2},0}\right|^2 - \left|A_{\frac{1}{2},1}\right|^2}{\left|A_{\frac{1}{2},0}\right|^2 + \left|A_{-\frac{1}{2},-1}\right|^2 + \left|A_{-\frac{1}{2},0}\right|^2 + \left|A_{\frac{1}{2},1}\right|^2}$$

The Weak Decay Helicity Amplitude I

On the dynamical side, both tree and penguin diagrams are involved in the evaluation of the Hadronic Matrix Elements(*HME*). Heavy Quark effective theory is extensively used for the calculation of *HME*.
In tree approximation, the effective interaction Hamiltonian, $\mathcal{H}^{eff}$, can be written as,

$$\mathcal{H}^{eff} = \frac{G_F}{\sqrt{2}} V_{qb} V_{qs}^{*} \sum_{i=1}^{10} C_i \left(m_b\right) O_i \left(m_b\right)$$

where $C_i \left(m_b\right)$ are the Wilson Coefficients and the operators, $O_i \left(m_b\right)$ can be understood as local operators which govern the weak interaction of quarks in the given decay. They can be written as

$$O_i = \left(\bar{q}_\alpha \Gamma_{i1} q_\beta\right) \left(\bar{q}_\mu \Gamma_{i2} q_\nu\right)$$

The Weak Decay Helicity Amplitude II

where Γ_{ij} denotes the gamma matrices.
By using the Factorization assumption one can get the helicity amplitude for the decay $\Lambda_b \to \Lambda V\ (1^-)$ as

$$A_{(\lambda,\lambda')} = \frac{G_F}{\sqrt{2}} f_V E_V \langle \Lambda \left| \bar{s}\gamma_\mu \left(1-\gamma_5\right) b \right| \Lambda_b \rangle_{(\lambda,\lambda')} \left\{ V^T_{CKM} C^T_i - V^P_{CKM} C^P_i \right\}$$

where f_V and E_V are the decay constant and energy of Vector meson. $V^{T,P}_{CKM} = V_{qb} V^*_{qs}$ are the CKM matrix elements for the tree and penguin diagrams while $C^{T,P}_i$ are Wilson Coefficients. The baryonic matrix

The Weak Decay Helicity Amplitude III

element $\mathcal{M}^{\Lambda_b}_{(\lambda,\lambda')} \equiv \langle \Lambda \left| \bar{s}\gamma_\mu \left(1-\gamma_5\right) b \right| \Lambda_b \rangle_{(\lambda,\lambda')}$ is calculated by using the Heavy Quark Effective Theory(HQET), read as

$$
\begin{aligned}
\mathcal{M}^{\Lambda_b}_{\frac{1}{2},0} &= -\frac{\left|\vec{P}_V\right|}{E_V}\left(\frac{m_{\Lambda_b}+m_\Lambda}{E_\Lambda+m_\Lambda}\xi^-\left(\omega\right)+2\xi_2\left(\omega\right)\right) \\
\mathcal{M}^{\Lambda_b}_{-\frac{1}{2},-1} &= \frac{1}{\sqrt{2}}\left(\frac{\left|\vec{P}_V\right|}{E_\Lambda+m_\Lambda}\xi^-\left(\omega\right)+\xi^+\left(\omega\right)\right) \\
\mathcal{M}^{\Lambda_b}_{\frac{1}{2},1} &= \frac{1}{\sqrt{2}}\left(\frac{\left|\vec{P}_V\right|}{E_\Lambda+m_\Lambda}\xi^-\left(\omega\right)-\xi^+\left(\omega\right)\right) \\
\mathcal{M}^{\Lambda_b}_{\frac{1}{2},0} &= \frac{\left|\vec{P}_V\right|^2}{E_V\left(E_V+m_\Lambda\right)}\xi^-\left(\omega\right)+\xi^+\left(\omega\right)
\end{aligned}
$$

The Weak Decay Helicity Amplitude IV

where $\left|\vec{P}_V\right|$ and E_V are the momentum and energy of vector meson in the rest frame of Λ_b, given as

$$\left|\vec{P}_V\right| = \frac{\sqrt{\left[m_{\Lambda_b}^2 - (m_V + m_\Lambda)^2\right]\left[m_{\Lambda_b}^2 - (m_V - m_\Lambda)^2\right]}}{2m_{\Lambda_b}}$$

$$E_V = \frac{m_{\Lambda_b}^2 + m_V^2 - m_\Lambda^2}{2m_{\Lambda_b}}, \text{ and } E_\Lambda = \frac{m_{\Lambda_b}^2 + m_\Lambda^2 - m_V^2}{2m_{\Lambda_b}}$$

The Weak Decay Helicity Amplitude V

and the form factors $\xi^{\pm}(\omega) = \xi_1(\omega) \pm \xi_2(\omega)$ are defined for convenience. While the form factors $\xi_{1,2}(\omega)$ are evaluated in terms of heavy quark effective form factors $F_i's$ as

$$\begin{aligned} \xi_1(\omega) &= \frac{1}{2}\left[2F_1(\omega) + F_2(\omega) + F_3(\omega)\left(1 + \frac{m_{\Lambda_b}}{m_\Lambda}\right)\right] \\ \xi_2(\omega) &= \frac{1}{2}F_2(\omega) \end{aligned}$$

We have calculated these form factors of $\Lambda_b \to \Lambda J/\psi$, there numerical values corresponding to $\omega = 1.857$ the invarient velocity for J/ψ, are

$$F_1(\omega) = 1.44812, \quad F_2(\omega) = 0.03609, \quad F_3(\omega) = 0.175$$

and

$$\xi_1(\omega) = 1.99501, \quad \xi_2(\omega) = 0.018046$$

The Weak Decay Helicity Amplitude VI

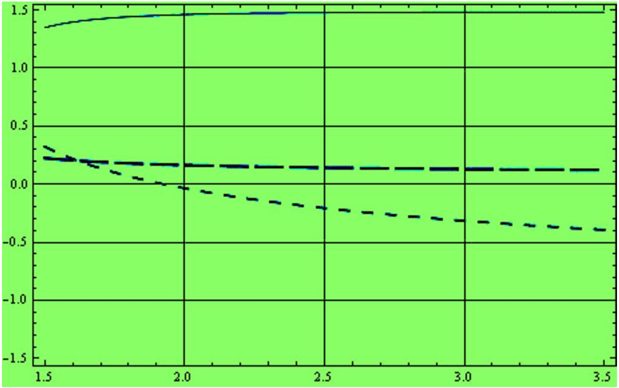

Figure: Farm Factors F_1 solid curve, F_2 short-dashed curve and F_3 long-dashed curve

The Weak Decay Helicity Amplitude VII

For $\Lambda_b \to \Lambda J/\psi$, the Branching ratio is 0.86×10^{-4} , which is inaccordance with experimental value $(4.7 \pm 2.1 \pm 1.9) \times 10^{-4}$.The helicity asymmetry parameter α_{AS} gives the value 28.4%.

Polarizations and Angular Distributions I

Parity violation in Λ_b weak decays into Λ, V necessarily leads to a polarization process of the two intermediate resonances Λ and V. In order to determine the vector-polarization of each resonance, a new set of axis is defined as

$$\vec{e}_L = \frac{\vec{p}_p}{|\vec{p}_p|}; \quad \vec{e}_z = \vec{n} = \frac{\vec{p}_p \times \vec{p}_b}{|\vec{p}_p \times \vec{p}_b|}; \quad \vec{e}_N = \vec{e}_z \times \vec{e}_L; \quad \vec{e}_T = \vec{e}_L \times \vec{e}_N$$

In this new frame, the vector-polarization of any resonance defined in

the original Λ_b frame can be written as:

$$\vec{\mathcal{P}}^i = P_L \vec{e}_L + P_T \vec{e}_T + P_N \vec{e}_N$$

where $i = \Lambda$ or V and P_L, P_N, P_T are longitudinal, normal and transverse polarizations of the decay resonance.

Polarizations and Angular Distributions II

It is worth noticing that the basis vectors $\vec{e}_L$, $\vec{e}_N$ and $\vec{e}_T$ have the following properties according to parity and TR: *P-odd,T-odd; P-odd,T-odd* and *P-even, T-even* respectively, while the polarization-vector $\vec{\mathcal{P}}$ is P-even and T-odd. So using these properties we can get $P_L = P - odd, T - even$, $P_N = P - odd, T - even$ and $\mathbf{P}_T = P - even, \mathbf{T} - \mathbf{odd}$.

The angular distribution of the decay products, $W(\theta, \phi)$, can be deduced from the SDM, according to the formulae

$$W(\theta, \phi) = Tr\left(\rho^f_{\lambda\lambda'\chi\chi'}\right)$$

Taking into account $\rho^f_{\lambda\lambda'\chi\chi'}$, we get

$$W(\theta, \phi) = \frac{1}{4\pi}\left(G_W + \Delta G_W P_1^{\Lambda_b}\right)$$

Polarizations and Angular Distributions III

where

$$
\begin{aligned}
G_W &= \left|A_{\frac{1}{2},0}\right|^2 + \left|A_{-\frac{1}{2},-1}\right|^2 + \left|A_{-\frac{1}{2},0}\right|^2 + \left|A_{\frac{1}{2},1}\right|^2 \\
\Delta G_W &= 2\left(\left|A_{\frac{1}{2},0}\right|^2 + \left|A_{-\frac{1}{2},-1}\right|^2 - \left|A_{-\frac{1}{2},0}\right|^2 - \left|A_{\frac{1}{2},1}\right|^2\right)
\end{aligned}
$$

The polarization vectors of the resonance states can be evaluated as

$$
\vec{P}^i = \frac{Tr\left(\rho^f_{\lambda\lambda'\chi\chi'} \cdot \vec{s}^i\right)}{Tr\left(\rho^f_{\lambda\lambda'\chi\chi'}\right)} = \frac{Tr\left(\rho^f_{\lambda\lambda'\chi\chi'} \cdot \vec{s}^i\right)}{W\left(\theta, \phi\right)}
$$

so

$$
W\left(\theta, \phi\right)\vec{P}^i = Tr\left(\rho^f_{\lambda\lambda'\chi\chi'} \cdot \vec{s}^i\right)
$$

Polarizations and Angular Distributions IV

where $\vec{s} \equiv (s_x, s_y, s_z)$ denotes the spin vector operator of the resonance state.
The components of the polarization vector of Λ are given as

$$\begin{aligned}
W(\theta,\phi)\, P_L^{\Lambda}(\theta,\phi) &= \frac{1}{4\pi}\left(G_L^{\Lambda} + \Delta G_L^{\Lambda} P_1^{\Lambda_b}\right) \\
W(\theta,\phi)\, P_T^{\Lambda}(\theta,\phi) &= \frac{1}{4\pi}\left(G_T^{\Lambda} P_2^{\Lambda_b} + \Delta G_T^{\Lambda} P_3^{\Lambda_b}\right) \\
W(\theta,\phi)\, P_N^{\Lambda}(\theta,\phi) &= \frac{1}{4\pi}\left(G_N^{\Lambda} P_2^{\Lambda_b} + \Delta G_N^{\Lambda} P_3^{\Lambda_b}\right)
\end{aligned}$$

Polarizations and Angular Distributions V

where

$$
\begin{aligned}
G_L^{\Lambda} &= \frac{1}{2}\left(\left|A_{\frac{1}{2},0}\right|^2 - \left|A_{-\frac{1}{2},-1}\right|^2 - \left|A_{-\frac{1}{2},0}\right|^2 + \left|A_{\frac{1}{2},1}\right|^2\right) \\
\Delta G_L^{\Lambda} &= \left|A_{\frac{1}{2},0}\right|^2 - \left|A_{-\frac{1}{2},-1}\right|^2 + \left|A_{-\frac{1}{2},0}\right|^2 - \left|A_{\frac{1}{2},1}\right|^2 \\
G_T^{\Lambda} &= -2\Im\left(A_{\frac{1}{2},0}A^*_{-\frac{1}{2},0} + A_{\frac{1}{2},1}A^*_{-\frac{1}{2},-1}\right) \\
\Delta G_T^{\Lambda} &= 2\Re\left(A_{\frac{1}{2},0}A^*_{-\frac{1}{2},0} - A_{\frac{1}{2},1}A^*_{-\frac{1}{2},-1}\right) \\
G_N^{\Lambda} &= 2\Re\left(A_{\frac{1}{2},0}A^*_{-\frac{1}{2},0} + A_{\frac{1}{2},1}A^*_{-\frac{1}{2},-1}\right) \\
\Delta G_N^{\Lambda} &= -2\Im\left(A_{\frac{1}{2},0}A^*_{-\frac{1}{2},0} - A_{\frac{1}{2},1}A^*_{-\frac{1}{2},-1}\right)
\end{aligned}
$$

Polarizations and Angular Distributions VI

Similarly one can get the components of the polarization vector of V as

$$
\begin{aligned}
W(\theta,\phi)\, P_L^{\Lambda V}(\theta,\phi) &= \frac{1}{4\pi}\left(G_L^V + \Delta G_L^V P_1^{\Lambda_b}\right) \\
W(\theta,\phi)\, P_T^{V}(\theta,\phi) &= \frac{1}{4\pi}\left(G_T^V P_2^{\Lambda_b} + \Delta G_T^V P_3^{\Lambda_b}\right) \\
W(\theta,\phi)\, P_N^{V}(\theta,\phi) &= \frac{1}{4\pi}\left(\Delta G_T^V P_2^{\Lambda_b} - G_T^V P_3^{\Lambda_b}\right)
\end{aligned}
$$

Polarizations and Angular Distributions VII

where

$$
\begin{aligned}
G_L^{\Lambda} &= -2\left(\left|A_{-\frac{1}{2},-1}\right|^2 + \left|A_{\frac{1}{2},1}\right|^2\right) \\
\Delta G_L^{\Lambda} &= \left|A_{-\frac{1}{2},-1}\right|^2 - \left|A_{\frac{1}{2},1}\right|^2 \\
G_T^{\Lambda} &= -2\sqrt{2}\Im\left(A_{\frac{1}{2},1}A^*_{\frac{1}{2},0} - A_{-\frac{1}{2},-1}A^*_{-\frac{1}{2},0}\right) \\
\Delta G_T^{\Lambda} &= 2\sqrt{2}\Re\left(A_{\frac{1}{2},1}A^*_{\frac{1}{2},0} + A_{-\frac{1}{2},-1}A^*_{-\frac{1}{2},0}\right)
\end{aligned}
$$

Parametrization of Observables I

we can write a model independent parametrization, based on the previous formulae, of the angular distribution, of the polarization of Λ and V. In particular, we describe such observables in terms of a minimum number of independent parameters. The formulae of the angular distribution and of the polarization of Λ can be rewritten as

$$
\begin{aligned}
W(\theta, \phi) &= \frac{1}{4\pi} G_W \left(1 + 2\alpha_W P_1^{\Lambda_b}\right) \\
\vec{\mathcal{P}}^{\Lambda} &= \frac{1}{1 + 2\alpha_W P_1^{\Lambda_b}} \left(C_L \vec{e}_L + C_T \vec{e}_T + C_N \vec{e}_N\right)
\end{aligned}
$$

Parametrization of Observables II

with

$$\begin{aligned}
\alpha_W &= \frac{\Delta G_W}{2G_W} \\
C_L &= B_L\left(1 + 2\alpha_L P_1^{\Lambda_b}\right) \\
C_T &= B_T\left(P_2^{\Lambda_b} + 2\alpha_T P_3^{\Lambda_b}\right) \\
C_N &= B_N\left(P_2^{\Lambda_b} + 2\alpha_N P_3^{\Lambda_b}\right)
\end{aligned}$$

where

$$\begin{aligned}
B_L &= \frac{G_L^{\Lambda}}{G_W}; \quad B_T = \frac{G_T^{\Lambda}}{G_W}; \quad B_N = \frac{G_N^{\Lambda}}{G_W}; \\
\alpha_L &= \frac{\Delta G_L^{\Lambda}}{2G_L^{\Lambda}}; \quad \alpha_T = \frac{\Delta G_T^{\Lambda}}{2G_T^{\Lambda}}; \quad \alpha_N = \frac{\Delta G_N^{\Lambda}}{2G_N^{\Lambda}}
\end{aligned}$$

One can get similar correlations for Vector meson.

TRV, CPV and CPT Tests I

Now we illustrate properties of the above observables under discrete transformations and indicate the violation of these parameters under discrete transformations.

Time reversal violation: The rotationally invariant helicity amplitudes transform under time reversal (TR) in such a way that

$$A_{\lambda,\lambda'}A^*_{-\lambda,-\lambda'} \longrightarrow A^*_{\lambda,\lambda'}A_{-\lambda,-\lambda'}$$

This fallows from the anti-unitarity character of TR and from the fact that helicity invariance under TR.

Then the transverse polarizations $P_T^{\Lambda}(\theta,\phi)$, $P_T^{V}(\theta,\phi)$ and B_T change sign under TR. So non-zero value of any of these observables will be the signature of direct TRV. These observable are promising for possible effects of New Physics.

TRV, CPV and CPT Tests II

CP-Violation: The CP transformation causes, according to the usual phase conventions

$$A_{\lambda,\lambda'} \rightarrow -\bar{A}_{-\lambda,-\lambda'}$$

where the barred amplitude refers to the $\bar{\Lambda}_b$ decay. For detecting possible CP violation we define the following asymmetry parameters

$$\begin{aligned} R_W &= \frac{G_W - \bar{G}_W}{G_W + \bar{G}_W}, \quad R_L = \frac{B_L + \bar{B}_L}{B_L - \bar{B}_L} \\ R_T &= \frac{B_T + \bar{B}_T}{B_T - \bar{B}_T}, \quad R_N = \frac{B_N - \bar{B}_N}{B_N - \bar{B}_N} \\ \gamma_W &= \frac{\alpha_W + \bar{\alpha}_W}{\alpha_W - \bar{\alpha}_W}, \quad \gamma_L = \frac{\alpha_L + \bar{\alpha}_L}{\alpha_L - \bar{\alpha}_L} \\ \gamma_T &= \frac{\alpha_T + \bar{\alpha}_T}{\alpha_T - \bar{\alpha}_T}, \quad \gamma_N = \frac{\alpha_N + \bar{\alpha}_N}{\alpha_N - \bar{\alpha}_N} \end{aligned}$$

TRV, CPV and CPT Tests III

Any non-zero value of the above defined ratios would be a CP violating asymmetry parameter. All the above parameters are even under time reversal, therefore they can be applied to test for the invariance of CPT theorem and possibly are the signature of New Physics.

For details see for Example:

- E. D. Salvo and Z. J. Ajaltouni: arXiv:0805.4171.
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Summary and Conclusions

- The general analysis is completely model independent and also independent of final state interactions.
- It is important to note that the TRV tests based on Λ_b polarization are similar to those proposed by Lee and Yang for hyperon decays. However in our case we may also consider the polarization correlations, which provide a TRV test independent of the polarization of the parent resonance.
- The observables considered in the our work are very sensitive to New Physics. These quantities have been considered even more convenient than $B^0 - \bar{B}^0$ mixing phases.
- In the forthcoming LHC run, these asymmetry parameters will be analyzed to great precision, which will enhance our understanding of the nature of discrete symmetries.