Parametrization of T and CPT violation in $B^0 \rightarrow c\bar{c}K^0$ (interference)

MITP Workshop on T violation and CPT tests in neutral-meson systems

Pablo Villanueva-Pérez IFIC- Universitat de València

Outline

- Interference in the Weisskopf-Wigner Approximation
- Time Reversal Violation analysis for $B^0 \to c\bar{c}K^0$
- Parametrization T and CPT violation

WEISSKOPF-WIGNER APPROXIMATION

Weisskopf-Wigner Approach

- Goal of this presentation $\longrightarrow$ discuss a paremetrization in an interfering system ($oscillation \times decay$).
- Approach to the problem: Weisskopf-Wigner Approach (WWA). Other approaches? Open system formulation?
- In this presentation only WWA is going to be discussed.
- WWA approximations:

$$|\psi\rangle = a(t)|B^0\rangle + b(t)|\bar{B}^0\rangle + c(t)|f_1\rangle + d(t)|f_2\rangle + \ldots$$

1. At $t = 0$ only $a(t)$ or $b(t)$ are different from 0.
2. We are only interested in the B^0 and $\bar{B}^0$ system, not the final states. Therefore we only compute the values of $a(t)$ or $b(t)$.
3. The time t of our study is much larger than the strong-interaction time scale.

Oscillations $B^0 \leftrightarrow \bar{B}^0$

- The Hamiltonian of the system is not hermitian.

$$i\frac{d}{dt}\begin{pmatrix}\psi_1\\ \psi_2\end{pmatrix} = \begin{pmatrix}M_{11} & M_{12}\\ M_{21} & M_{22}\end{pmatrix} - \frac{i}{2}\begin{pmatrix}\Gamma_{11} & \Gamma_{12}\\ \Gamma_{21} & \Gamma_{22}\end{pmatrix}$$

- Simmetry constrains:

Symmetry	Matrix elements condition
CPT	$M_{11} = M_{22}$ and $\Gamma_{11} = \Gamma_{22}$
CP	$M_{11} = M_{22}$, $\Gamma_{11} = \Gamma_{22}$, $M_{21} = e^{i2\epsilon} M_{12}$, and $\Gamma_{21} = e^{i2\epsilon}\Gamma_{12}$
T	$M_{21} = e^{i2\epsilon} M_{12}$, and $\Gamma_{21} = e^{i2\epsilon}\Gamma_{12}$

- Hamiltonian eigenstates:

$$\frac{p}{q} \equiv \sqrt{\frac{M_{12}^* - \frac{i}{2}\Gamma_{12}^*}{M_{12} - \frac{i}{2}\Gamma_{12}}}$$

$$|B_L\rangle = p\sqrt{1-z}|B^0\rangle + q\sqrt{1+z}|\bar{B}^0\rangle$$
$$|B_H\rangle = p\sqrt{1+z}|B^0\rangle - q\sqrt{1-z}|\bar{B}^0\rangle$$

$$z \equiv \frac{(M_{11}-M_{22}) - \frac{i}{2}(\Gamma_{11}-\Gamma_{22})}{2\sqrt{(M_{12}-\frac{i}{2}\Gamma_{12})(M_{12}^*-\frac{i}{2}\Gamma_{12}^*) + \frac{1}{4}(M_{11}-M_{22}-\frac{i}{2}(\Gamma_{11}-\Gamma_{22}))}}$$

Oscillations $B^0 \leftrightarrow \bar{B}^0$

- In terms of the ϵ and δ parameters

$$\frac{q}{p} \equiv \frac{1-\epsilon}{1+\epsilon} \qquad z \equiv 2\delta \qquad \left|\frac{q}{p}\right|^2 \approx 1 - Im\frac{\Gamma_{12}}{M_{12}}$$

- For the neutral *B* mesons $\left|\frac{q}{p}\right| \approx 1$ is a good approximation it's not like that for the neutral K mesons $\longrightarrow$ introduces subtleties.
- We derive:
  - If $\left|\frac{q}{p}\right| \neq 1$ we have T and CP violation, but CPT conserved.
  - If $z \neq 0$, CP and CPT are violated, but T is conserved.
- Constrains of the parameters due to CP, T and CPT.

	CPT		$\not{CPT}$		
	CP,T	$\not{CP},\not{T}$	$\not{CP},T$	$CP,\not{T}$	$\not{CP},\not{T}$
$\lvert q/p \rvert$	$=1$	$\neq 1$	$=1$	$=1$	$\neq 1$
z	$=0$	$=0$	$\neq 0$	$=0$	$\neq 0$

Decays for the $B^0\bar{B}^0$ system

- The time evolved states are

$$|B^0(t)\rangle = (g_+(t) + z g_-(t))|B^0\rangle - \sqrt{1-z^2}\frac{q}{p} g_-(t)|\bar{B}^0\rangle \ ,$$
$$|\bar{B}^0(t)\rangle = (g_+(t) - z g_-(t))|\bar{B}^0\rangle - \sqrt{1-z^2}\frac{p}{q} g_-(t)|B^0\rangle \ .$$

- Where

$$g_\pm(t) = \frac{1}{2}(e^{-i\omega_H t} \pm e^{-i\omega_L t})$$

$\omega_{H/L} \equiv$Complex eigenvalues

- To introduce the decay we define

$$A_f \equiv \langle f|T|B^0\rangle$$
$$\bar{A}_f \equiv \langle f|T|\bar{B}^0\rangle$$

$$\lambda_f \equiv \frac{q}{p}\frac{\bar{A}_f}{A_f} = \left|\frac{q}{p}\right|\left|\frac{\bar{A}_f}{A_f}\right| e^{-i\phi}$$

- λ_f is a CP parameter in the interference ($\mathrm{oscillation} \times decay$) if f is a CP eigenstate:
  - $|\frac{q}{p}| \neq 1$ is a CP and T violation signal in the oscillation.
  - $|A_f| \neq |\bar{A}_f|$ is a signal of direct CP and CPT violation if f is a CP eigenstate, in the approximation of no FSI (only one amplitude).
- Is there any parameter like λ_f which can directly interpreted as a T or CPT violating parameter in the interference?

DIRECT OBSERVATION OF TIME REVERSAL VIOLATION

Phys.Rev.Lett. 109 (2012) 211801

TRV in unstable system searches

Decay TRV searches

CP: $B^0 \to K^+\pi^-$, R_1 ; $\bar{B}^0 \to K^-\pi^+$, R_2

CPT ⟷

$K^-\pi^+ \to \bar{B}^0$, R_1 ; $K^+\pi^- \to B^0$, R_2

$$\left|\frac{\bar{A}_f}{A_f}\right|$$

Unable to perform the T test:

- Preparation of the initial state.
- The strong processes will swamp the feeble weak processes.

Mixing TRV searches $\left|\frac{q}{p}\right|$

$K^0 \to \bar{K}^0$, $B^0 \to \bar{B}^0$ —CPT→ $K^0 \to \bar{K}^0$, $B^0 \to \bar{B}^0$

CP ↓

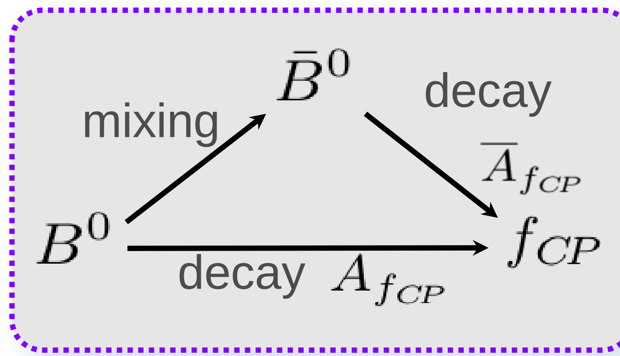
$\bar{K}^0 \to K^0$, $\bar{B}^0 \to B^0$

T ↘ $\bar{K}^0 \to K^0$, $\bar{B}^0 \to B^0$

CPLEAR

A test of CP and T simultaneously.
If CP is conserved and T violated this observable is 0.

Interference TRV searches



$$\lambda_f$$

CPV time dependent (TD) studies:

- There are no exchanges $t \leftrightarrow -t$ and $|in> \leftrightarrow |out>$.
- Assumes CPT invariance and $\Delta\Gamma = 0$.

Foundations of the analysis

A GENUINE and DIRECT evidence of TRV would mean an experiment that, considered by itself, clearly shows TRV INDEPENDENT of, and UNCONNECTED to, the results of CPV.

T – Violation means Asymmetry under the interchange

- *in ⇄ out states* ⟶ *Experimentally tricky*
- *t ⇄ -t*

Quantum (EPR) entanglement at B-factories

- The initial state can be written in any combination of B states

Bañuls & Bernabeu, PLB464, 117 (1999)

Υ(4S) decay yields an entangled state of *B* mesons

$$|i\rangle = 1/\sqrt{2}\left[B^0(t_1)\overline{B}^0(t_2) - \overline{B}^0(t_1)B^0(t_2)\right]$$
$$= 1/\sqrt{2}\left[B_+(t_1)B_-(t_2) - B_-(t_1)B_+(t_2)\right]$$

Flavor tag: e.g. B semileptonic decay to $l^+ X$ ($l^- X$) projects $B^0(\bar{B}^0)$ ⇒ $\bar{B}^0(B^0)$ tag

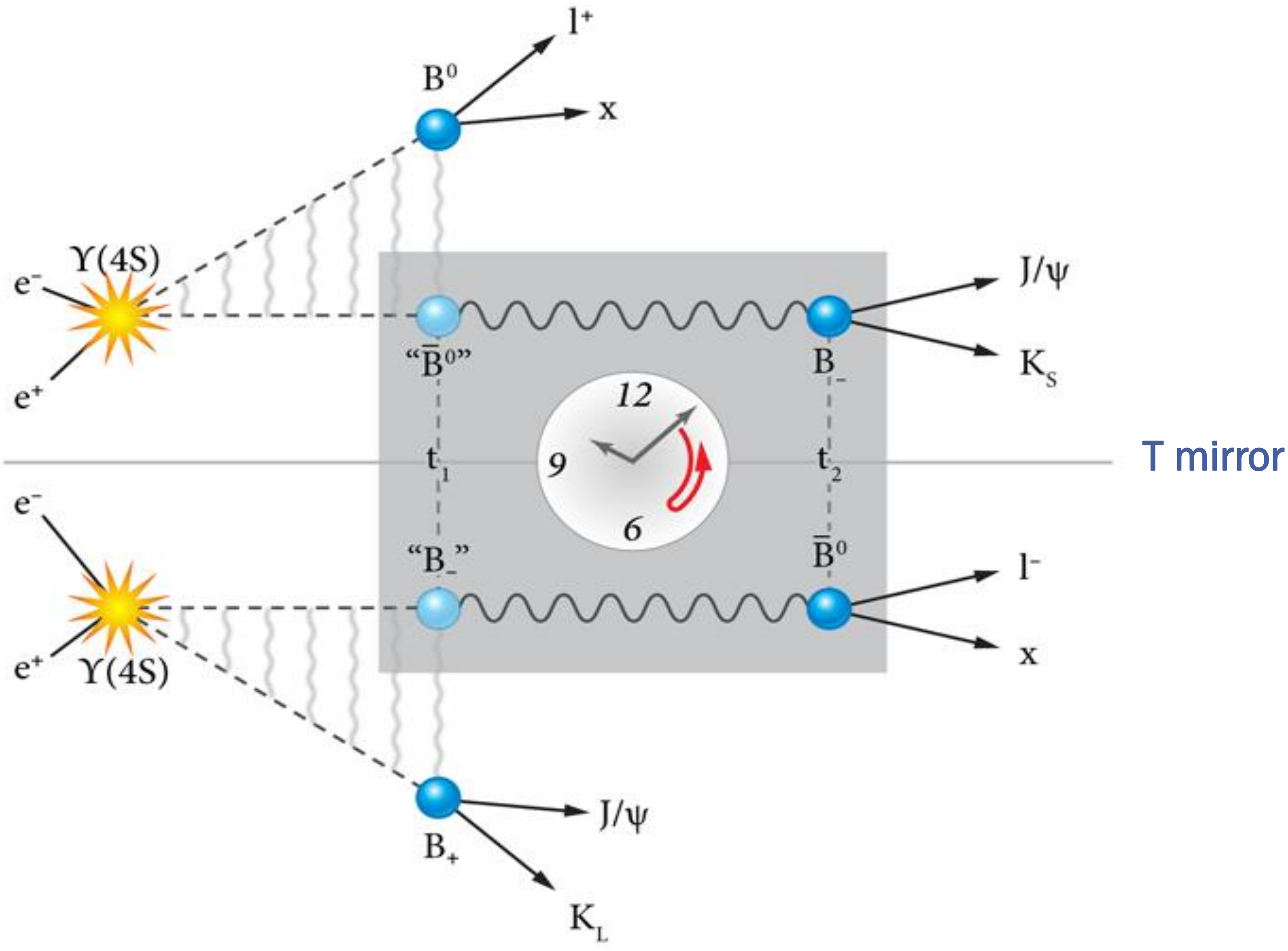
CP tag: B_+ decay to $J/\psi K_L$ projects ⇒ B_- tag ("CP-odd")
B_- decay to $c\bar{c}K_S$ projects ⇒ B_+ tag ("CP-even")

J. B., F. M-V, P. V-P, JHEP (2012).

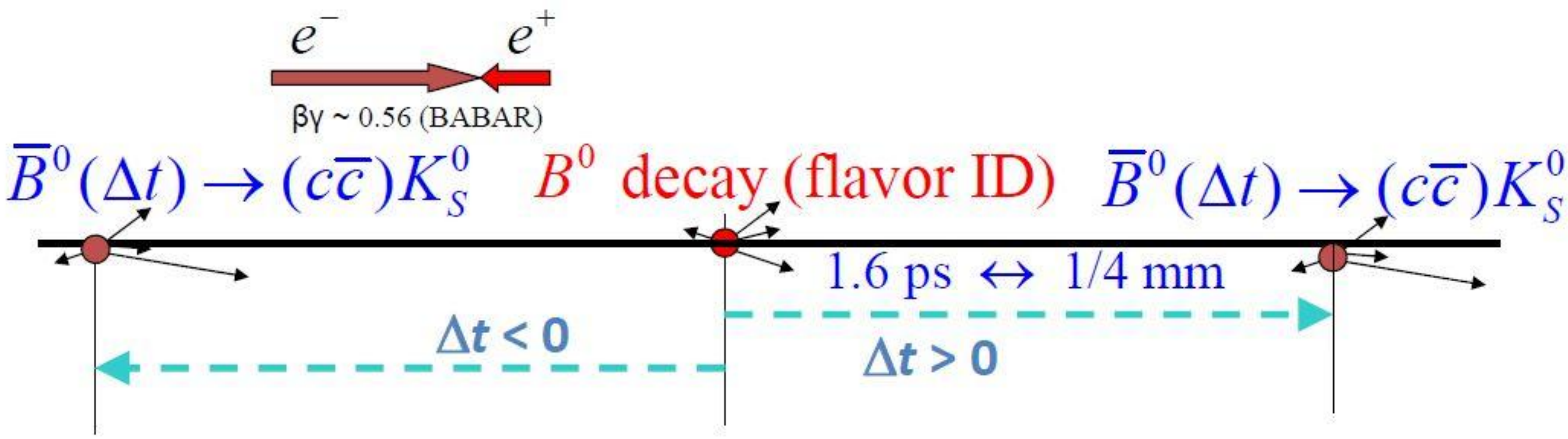
B_+, B_- are not necesarilly CP-eigenstates of the neutral B-system, only under certain phase convention and assumptions:

- No Direct CP violation.
- Neglecting CP violation in the neutral Kaon sector.

TRV in the evolution of the *B*-meson



TRV in the evolution of the B meson



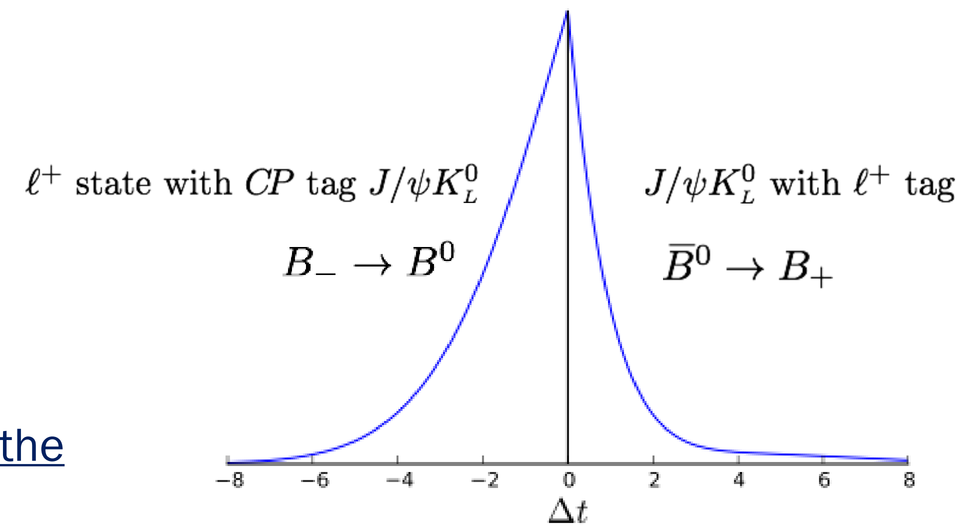
- In B factory CP violation canonical analysis, we define

$$\Delta t = t_{CP} - t_{flav} \simeq \Delta z / \beta\gamma c$$

Signed decay time difference

- If Δt<0, we can exchange the roles of the two B's in above picture

$$\Delta t = \pm \Delta\tau$$



Expected Dt distribution, e.g. J/yK_L, l^+ X

T-conjugated processes

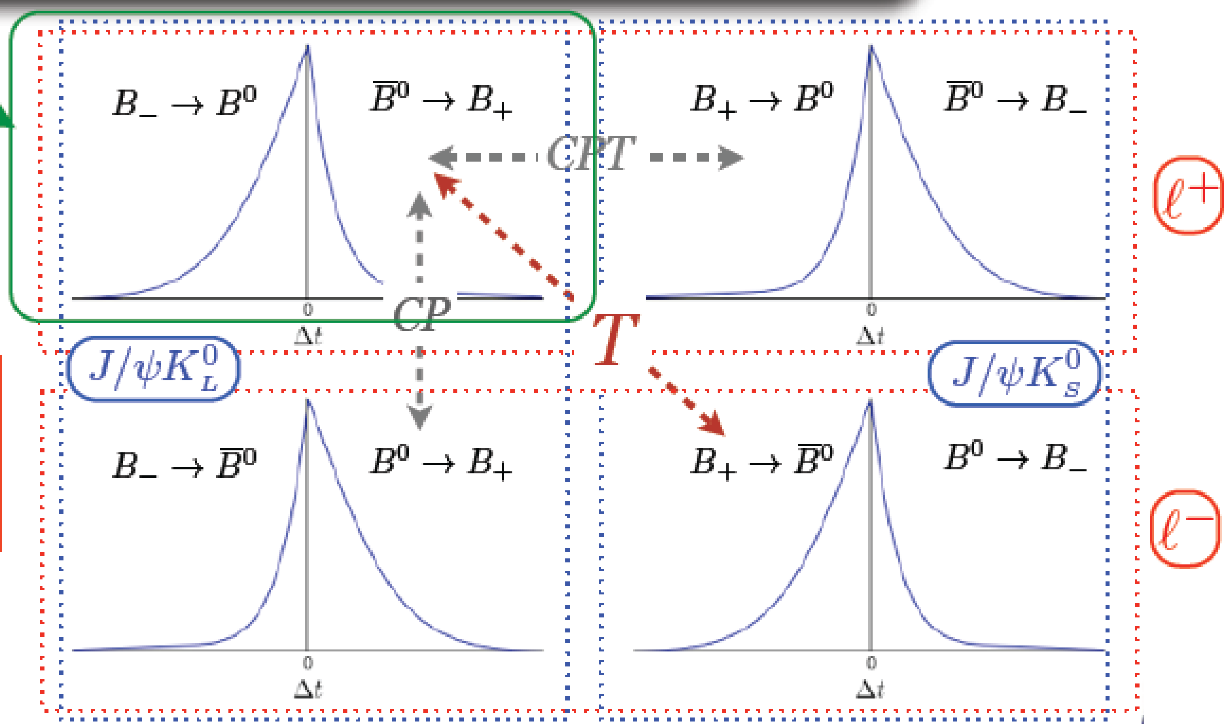
Define processes of interest and their T-transformed counterparts

JHEP08 (2012) 064

Reference (X,Y)		T-Transformed	
$B^0 \to B_+$	$(\ell^-, J/\psi K_L^0)$	$B_+ \to B^0$	$(J/\psi K_S^0, \ell^+)$
$B^0 \to B_-$	$(\ell^-, J/\psi K_S^0)$	$B_- \to B^0$	$(J/\psi K_L^0, \ell^+)$
$\overline{B}^0 \to B_+$	$(\ell^+, J/\psi K_L^0)$	$B_+ \to \overline{B}^0$	$(J/\psi K_S^0, \ell^-)$
$\overline{B}^0 \to B_-$	$(\ell^+, J/\psi K_S^0)$	$B_- \to \overline{B}^0$	$(J/\psi K_L^0, \ell^-)$

(X,Y) is the reconstructed final states (tag, reco.)

...and similar for CP, CPT



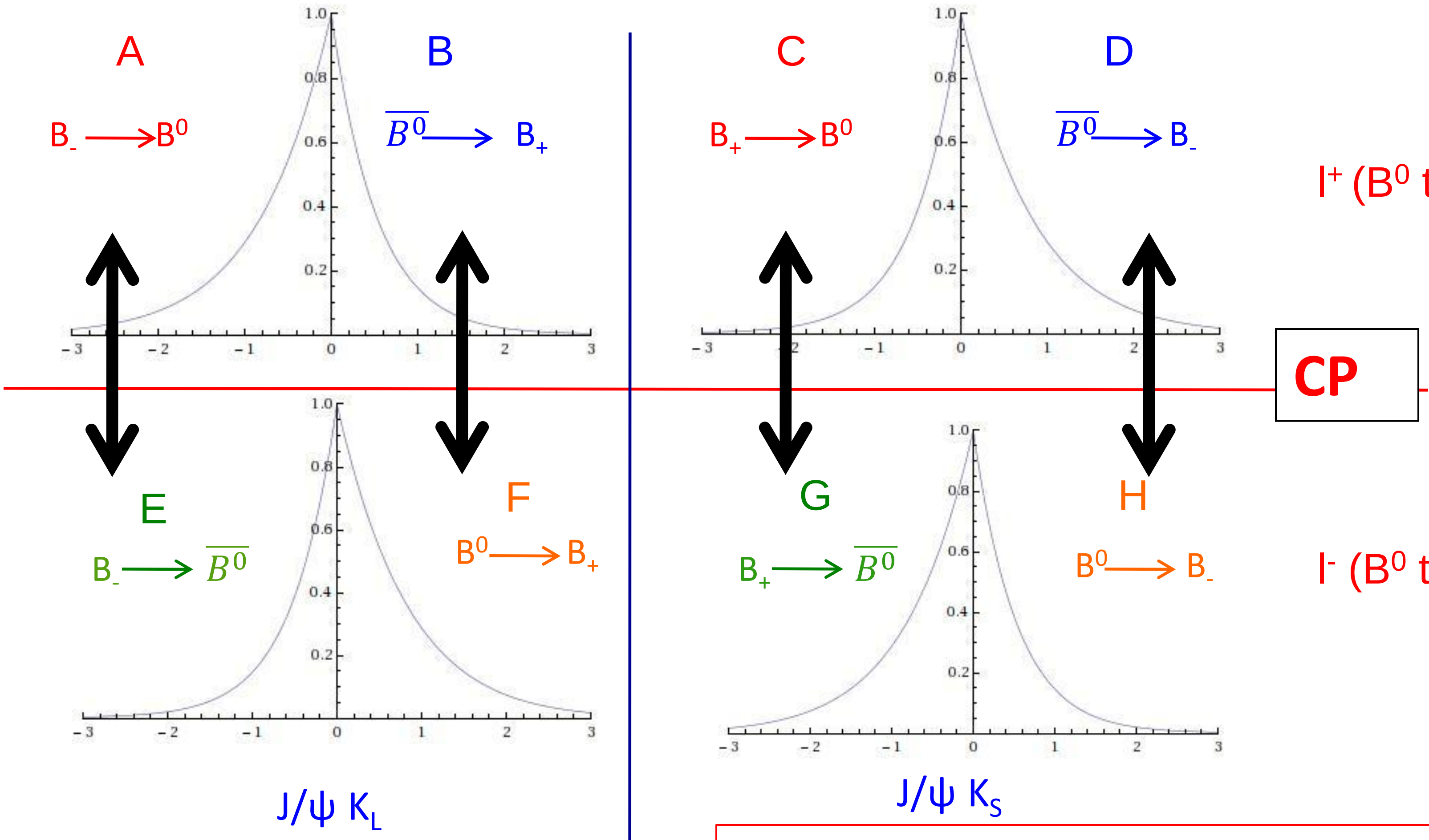
In total we can build:

- 4 independent T comparisons
- 4 independent CP comparisons
- 4 independent CPT comparisons

T implies comparison of:
1) Opposite Δt sign
2) Different reco states (ψK_S v. ψK_L)
3) Opposite flavor states (B^0 v. $\overline{B}^0$)

Discard odd effect t↔-t

CP-conjugated processes

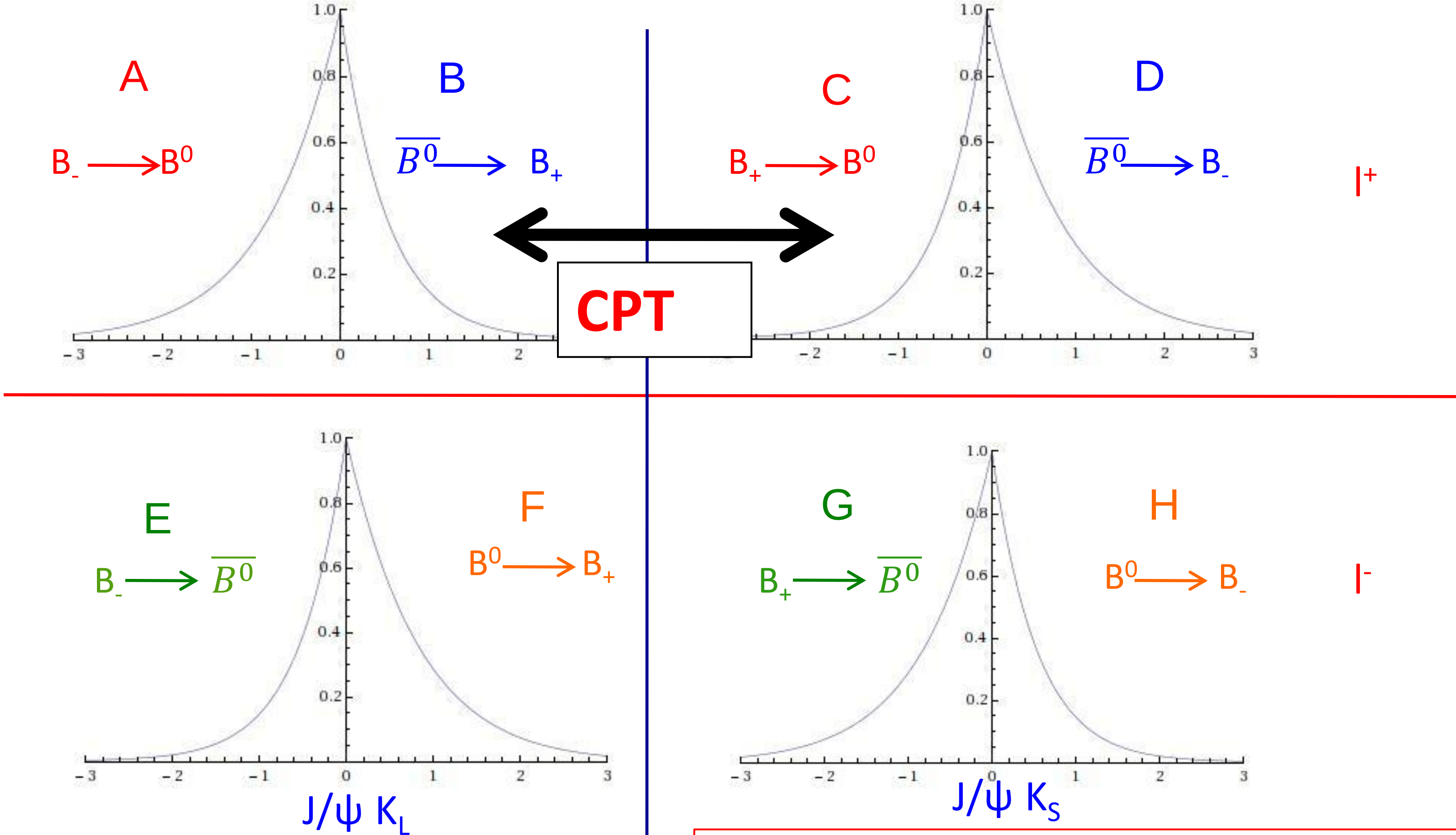


A, B, C, D —CP→ E, F, G, H

CP implies comparison of:

1) Same Δt sign.
2) Same reco states (only $J/\Psi K_S$ or $J/\Psi K_L$).
3) Opposite tag states (B^0 vs $\bar{B}^0$).

CPT-conjugated processes



A		D
B	CPT →	C
F		G
H		E

CPT implies comparison of:

1) Opposite Δt sign.
2) Different reco states ($J/\Psi K_S$ vs. $J/\Psi K_L$).
3) Same tag states (only B^0 or $\bar{B}^0$).

Signal parameters

$$g^{\pm}_{\alpha,\beta}(\Delta\tau) \propto e^{-\Gamma\Delta\tau}\{1 + S^{\pm}_{\alpha,\beta}\sin(\Delta m_d \Delta\tau) + C^{\pm}_{\alpha,\beta}\cos(\Delta m_d \Delta\tau)\}$$

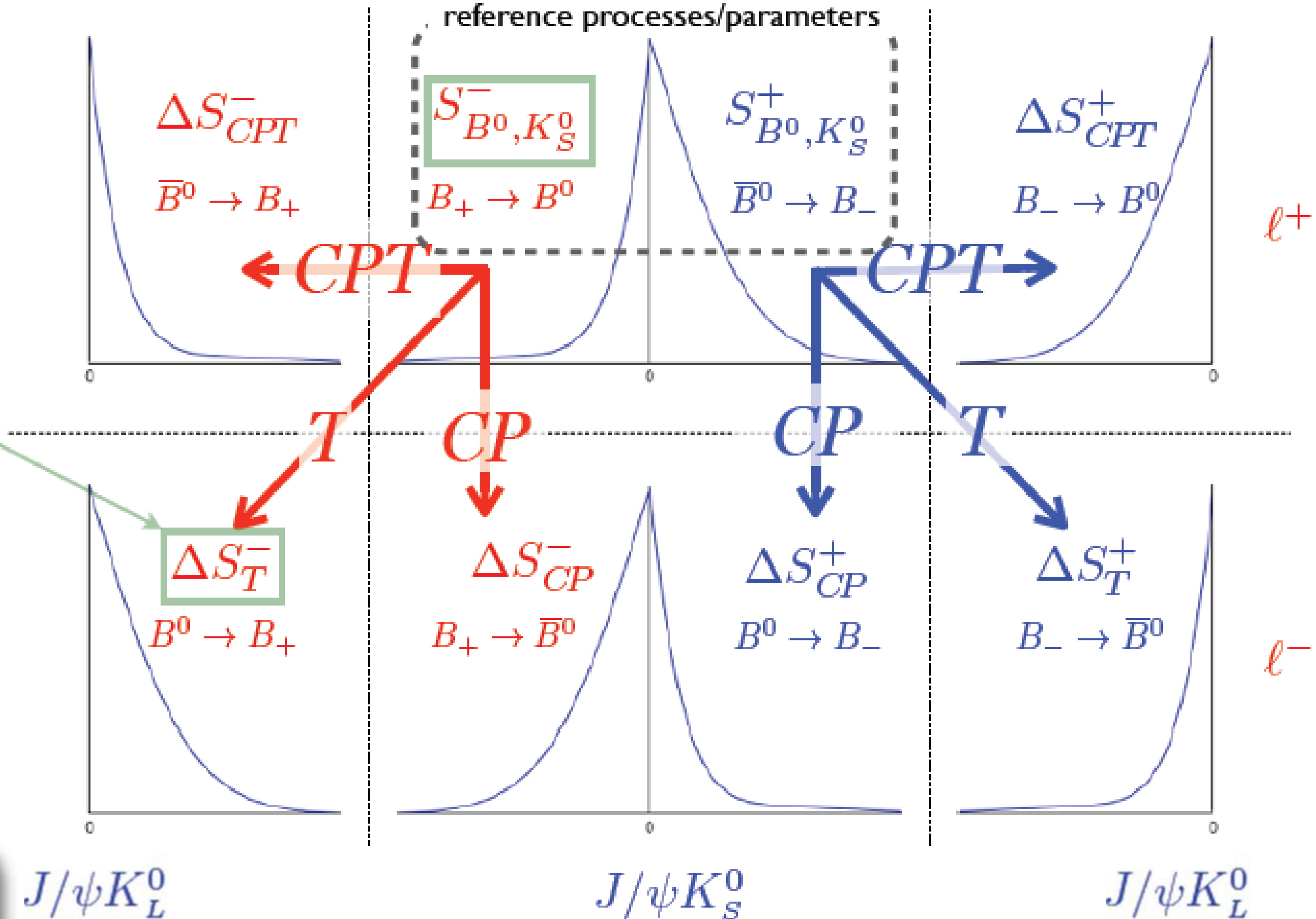
Assumes $\Delta\Gamma = 0$

$$\Delta t = t_{CP} - t_{flav} = \begin{cases} +\Delta\tau & \text{for "flavor tag"} \\ -\Delta\tau & \text{for "CP tag"} \end{cases}$$

$$\alpha \in \{B^0, \bar{B}^0\}; \quad \beta \in \{K^0_S, K^0_L\}$$

Prediction from CPV

Parameter	Value
$S^+_{B^0,K^0_S}$	0.7
$\Delta S^+_T = S^-_{\bar{B}^0,K^0_L} - S^+_{B^0,K^0_S}$	−1.4
$\Delta S^+_{CP} = S^+_{\bar{B}^0,K^0_S} - S^+_{B^0,K^0_S}$	−1.4
$\Delta S^+_{CPT} = S^-_{B^0,K^0_L} - S^+_{B^0,K^0_S}$	0.0
$S^-_{B^0,K^0_S}$	−0.7
$\Delta S^-_T = S^+_{\bar{B}^0,K^0_L} - S^-_{B^0,K^0_S}$	1.4
$\Delta S^-_{CP} = S^-_{\bar{B}^0,K^0_S} - S^-_{B^0,K^0_S}$	1.4
$\Delta S^-_{CPT} = S^+_{B^0,K^0_L} - S^-_{B^0,K^0_S}$	0.0
$C^+_{B^0,K^0_S}$	0.0
$\Delta C^+_T = C^-_{\bar{B}^0,K^0_L} - C^+_{B^0,K^0_S}$	0.0
$\Delta C^+_{CP} = C^+_{\bar{B}^0,K^0_S} - C^+_{B^0,K^0_S}$	0.0
$\Delta C^+_{CPT} = C^-_{B^0,K^0_L} - C^+_{B^0,K^0_S}$	0.0
$C^-_{B^0,K^0_S}$	0.0
$\Delta C^-_T = C^+_{\bar{B}^0,K^0_L} - C^-_{B^0,K^0_S}$	0.0
$\Delta C^-_{CP} = C^-_{\bar{B}^0,K^0_S} - C^-_{B^0,K^0_S}$	0.0
$\Delta C^-_{CPT} = C^+_{B^0,K^0_L} - C^-_{B^0,K^0_S}$	0.0



For T Violation

in the interference $\Delta S^+_T \neq 0$, $\Delta S^-_T \neq 0$

in the decay $\Delta C^+_T \neq 0$, $\Delta C^-_T \neq 0$

T AND CPT PARAMETRIZATION

Coherent system

- Initial state at the $\Upsilon(4S)$:

$$|\Upsilon(4S)(t_1,t_2)\rangle = \frac{1}{\sqrt{2}}\left[|B^0(t_1)\rangle|\bar{B}^0(t_2)\rangle - |\bar{B}^0(t_1)\rangle|B^0(t_2)\rangle\right]$$

- Using this initial state we obtain the decay rate:

$$|\langle f_1 f_2|\Upsilon(4S)(\Delta t)\rangle|^2 \quad \propto e^{-\Gamma|\Delta t|} \quad \left[D^{\pm}_{f_1,f_2} cosh(\frac{\Delta\Gamma\Delta t}{2}) + C^{\pm}_{f_1,f_2} cos(\Delta m \Delta t)\right.$$
$$\left. E^{\pm}_{f_1,f_2} sinh(\frac{\Delta\Gamma\Delta t}{2}) + S^{\pm}_{f_1,f_2} sin(\Delta m \Delta t)\right]$$

  - Where:

$$\Delta m = Re(\omega_H) - Re(\omega_L) \qquad \Delta\Gamma = 2i\left[Im(\omega_H) - Im(\omega_L)\right] \qquad \Delta t = t_2 - t_1$$

- Note for Δt exchange ($\Delta t \leftrightarrow -\Delta t$) is equivalent to $f_1 \leftrightarrow f_2$.
- From the 4 experimental samples we can extract the 8 intensities.

Intensity parameters

$B_{\rm flav}$	$D^{\pm}_{\alpha,CP}$
B^0	$1/2\{\vert A_{\ell+}\vert^2\vert A_{CP}\vert^2\vert p/q\vert^2[1+\vert\lambda_{CP}\vert^2-4Re(\lambda_{CP})Re(\lambda_{\ell+})+2Re(z)Re(\lambda_{CP})-2Im(z)Im(\lambda_{CP})]\}$
$\overline{B}^0$	$1/2\{\vert\bar{A}_{\ell-}\vert^2\vert A_{CP}\vert^2[1+\vert\lambda_{CP}\vert^2-4Re(\lambda_{CP})Re(\bar{\lambda}_{\ell-})-2Re(z)Re(\lambda_{CP})-2Im(z)Im(\lambda_{CP})]\}$

	$C^{\pm}_{\alpha,CP}$
B^0	$1/2\{\vert A_{\ell+}\vert^2\vert A_{CP}\vert^2\vert p/q\vert^2[-1+\vert\lambda_{CP}\vert^2-4Im(\lambda_{CP})Im(\lambda_{\ell+})-2Re(z)Re(\lambda_{CP})+2Im(z)Im(\lambda_{CP})]\}$
$\overline{B}^0$	$1/2\{\vert A_{\ell-}\vert^2\vert A_{CP}\vert^2[1-\vert\lambda_{CP}\vert^2+4Im(\lambda_{CP})Im(\bar{\lambda}_{\ell-})+2Re(z)Re(\lambda_{CP})+2Im(z)Im(\lambda_{CP})]\}$

	$\pm s_{\alpha,CP}$
B^0	$\pm\vert A_{\ell+}\vert^2\vert A_{CP}\vert^2\vert p/q\vert^2[\vert\lambda_{CP}\vert^2\lambda_{\ell+}-\lambda^*_{CP}+\lambda^*_{\ell+}-\vert\lambda_{CP}\vert^2 z]$
$\overline{B}^0$	$\pm\vert\bar{A}_{\ell-}\vert^2\vert A_{CP}\vert^2[\bar{\lambda}_{\ell-}-\lambda_{CP}+\vert\lambda_{CP}\vert^2\bar{\lambda}^*_{\ell-}+z]$

$$E^{\pm}_{f_1,CP}\equiv\mp Re(s_{f_1,CP}) \qquad S^{\pm}_{f_1,CP}\equiv\pm Im(s_{f_1,CP})$$

CP parameters

- Approximations:
  - The only approximation used $\Delta B \Delta Q$ rule

$$\lambda_{\ell^+} = \bar{\lambda}_{\ell^-} = 0$$

- *CP* parameters ($\ell^+ \leftrightarrow \ell^-$):

$$\begin{aligned}
\Delta S^+_{CP} &\equiv S^+_{\ell^-,K_S} - S^+_{\ell^+,K_S} \\
&= |A_{K_S}|^2 \Big\{ -Im(\lambda_{K_S})\Big(|A_{\ell^-}|^2 + |A_{\ell^+}|^2\Big|\frac{p}{q}\Big|^2\Big) + Im(z)\Big(|A_{\ell^-}|^2 + |A_{\ell^+}|^2\Big|\frac{p}{q}\Big|^2|\lambda_{K_S}|^2\Big)\Big\} \\
&\approx |A_{K_S}|^2 \Big\{ -Im(\lambda_{K_S})\Big(|A_{\ell^-}|^2 + |A_{\ell^+}|^2\Big|\frac{p}{q}\Big|^2\Big)\Big\}
\end{aligned}$$

$$\begin{aligned}
\Delta C^+_{CP} &\equiv C^+_{\ell^-,K_S} - C^+_{\ell^+,K_S} \\
&= \frac{|A_{K_S}|^2}{2}\Big\{\Big(|A_{\ell^-}|^2 + |A_{\ell^+}|^2\Big|\frac{p}{q}\Big|^2\Big)\Big(1 - |\lambda_{KS}|^2 + 2Re(z)Re(\lambda_{K_S})\Big) \\
&\quad +2Im(z)Im(\lambda_{K_S})\Big(|A_{\ell^-}|^2 - |A_{\ell^+}|^2\Big|\frac{p}{q}\Big|^2\Big)\Big\} \\
&\approx \frac{|A_{K_S}|^2}{2}\Big\{\Big(|A_{\ell^-}|^2 + |A_{\ell^+}|^2\Big|\frac{p}{q}\Big|^2\Big)\Big(1 - |\lambda_{KS}|^2\Big)\Big\}
\end{aligned}$$

T parameters

- T parameters ($\ell^+ \leftrightarrow \ell^-$, $K_S \leftrightarrow K_L$, $\Delta t \leftrightarrow -\Delta t$):

$$
\begin{aligned}
\Delta S_T^+ &\equiv S^-_{\ell^-,K_L} - S^+_{\ell^+,K_S} = -(S^+_{\ell^-,K_L} + S^+_{\ell^+,K_S}) \\
&= \left(|A_{\ell-}|^2|A_{K_L}|^2 Im(\lambda_{K_L}) - |A_{\ell+}|^2\left|\frac{p}{q}\right|^2|A_{K_S}|^2 Im(\lambda_{K_S})\right) \\
&\quad -Im(z)\left(|A_{\ell-}|^2|A_{K_L}|^2 - |A_{\ell+}|^2\left|\frac{p}{q}\right|^2|A_{K_S}|^2|\lambda_{K_S}|^2\right) \\
&\approx \left(|A_{\ell-}|^2|A_{K_L}|^2 Im(\lambda_{K_L}) - |A_{\ell+}|^2\left|\frac{p}{q}\right|^2|A_{K_S}|^2 Im(\lambda_{K_S})\right)
\end{aligned}
$$

$$
\begin{aligned}
\Delta C_T^+ &\equiv C^-_{\ell^-,K_L} - C^+_{\ell^+,K_S} \\
&= \frac{1}{2}\left\{\left[|A_{\ell-}|^2|A_{K_L}|^2(1-|\lambda_{K_L}|^2) + |A_{\ell+}|^2\left|\frac{p}{q}\right|^2|A_{K_S}|^2(1-|\lambda_{K_S}|^2)\right]\right. \\
&\quad \left.+2Re(z\lambda^*_{K_L})|A_{\ell-}|^2|A_{K_L}|^2 + 2Re(z\lambda_{K_S})|A_{\ell+}|^2\left|\frac{p}{q}\right|^2|A_{K_S}|^2\right\} \\
&\approx \frac{1}{2}\left\{|A_{\ell-}|^2|A_{K_L}|^2(1-|\lambda_{K_L}|^2) + |A_{\ell+}|^2\left|\frac{p}{q}\right|^2|A_{K_S}|^2(1-|\lambda_{K_S}|^2)\right\}
\end{aligned}
$$

CPT parameters

- *CPT* parameters ($K_S \leftrightarrow K_L$, $\Delta t \leftrightarrow -\Delta t$):

$$\begin{aligned}\Delta S^{+}_{CPT} &\equiv S^{-}_{\ell+,K_L} - S^{+}_{\ell+,K_S} = -(S^{+}_{\ell+,K_L} + S^{+}_{\ell+,K_S}) \\ &= -|A_{\ell+}|^2\left|\frac{p}{q}\right|^2\Big\{|A_{K_L}|^2 Im(\lambda_{K_L}) + |A_{K_S}|^2 Im(\lambda_{K_S}) \\ &\quad -Im(z)\Big(|A_{K_L}|^2|\lambda_{K_L}|^2 + |A_{K_S}|^2|\lambda_{K_S}|^2\Big)\Big\}\end{aligned}$$

$$\begin{aligned}\Delta C^{+}_{CPT} &\equiv C^{-}_{\ell+,K_L} - C^{+}_{\ell+,K_S} = C^{+}_{\ell+,K_L} - C^{+}_{\ell+,K_S} \\ &= \frac{1}{2}|A_{\ell+}|^2\left|\frac{p}{q}\right|^2\Big\{|A_{K_L}|^2(|\lambda_{K_L}|^2 - 1) - |A_{K_S}|^2(|\lambda_{K_S}|^2 - 1) \\ &\quad -2\Big(|A_{K_L}|^2 Re(z\lambda_{K_L}) - |A_{K_S}|^2 Re(z\lambda_{K_S})\Big)\Big\}\end{aligned}$$

TRV analysis approximations

- We have assumed:
  - $\Delta\Gamma = 0$: $\left|\frac{q}{p}\right| = 1$
  - No direct CP violation:

$$\begin{cases} |A_{\bar{f}}| &= |\bar{A}_f| \\ |A_f| &= |\bar{A}_{\bar{f}}| \end{cases} \xrightarrow{f \equiv CP \text{ eigenstate}} \left\{ |A_{CP}| = |\bar{A}_{CP}| \right.$$

  - Neglect CP violation in the Kaon sector:

    $c\bar{c}K_S$ is a *CP-odd eigenstate*

    $J/\psi K_L$ is a *CP-even eigenstate*

  - We can choose a phase convention where:

CP tag: B_+ decay to $J/\psi K_L$ projects $\Rightarrow$ B_- CP-odd state
B_- decay to $c\bar{c}K_S$ projects $\Rightarrow$ B_+ CP-even state

$$\lambda_{K_S} \equiv \eta_{K_S}\lambda_{CP} = -\eta_{K_L}\lambda_{CP} = -\lambda_{K_L} \qquad \eta_{K_L} = -\eta_{K_S} = 1$$

CP, T, CPT parameters

CP

$$\Delta S^{+}_{CP} \propto \left\{2Im(\lambda_{CP}) + Im(z)\left(1+|\lambda_{CP}|^2\right)\right\}$$
$$= 2\left(Im(\lambda_{CP}) + Im(z)\right)$$
$$\Delta C^{+}_{CP} \propto \left(1-|\lambda_{CP}|^2\right) - 2Re(z)Re(\lambda_{CP})$$
$$= -2Re(z)Re(\lambda_{CP})$$

T

$$\Delta S^{+}_{T} \propto 2Im(\lambda_{CP}) - Im(z)\left(1-|\lambda_{CP}|^2\right)$$
$$= 2Im(\lambda_{CP})$$
$$\Delta C^{+}_{T} \propto (1-|\lambda_{CP}|^2) + Re(z\lambda^{*}_{CP}) - Re(z\lambda_{CP})$$
$$= -2Im(z)Im(\lambda_{CP})$$

CPT

$$\Delta S^{+}_{CPT} \propto 2Im(z)|\lambda_{CP}|^2 = 2Im(z)$$
$$\Delta C^{+}_{CPT} \propto -2Re(z\lambda_{CP})$$

With this approximation:

- z is the only CPT parameter.
- $CP \times T \times CPT$ leaves the initial process invariant.

CPT test in the interference

- First CPT test in transitions:
  - Neglecting CP violation in the Kaon sector.
  - No direct CP violation.
  - The parameter in the WWA is just *z (No direct CP violation)*.

- Options to increment the precission:
  - Use other channels which are exactly CP eigenstates:
    - Decays to vector-vector states and perform an angular analysis.
  - Other options?
  - Studies in other neutral systems?

CONCLUSIONS

Conclusions for discussion

- Parameters for T and CPT have been presented in the time evolution of the *B* meson, in the WWA framework.

- The parameters with the approximation obtained for the PRL publication are shown.

Danke schön