DIRECT OBSERVATION OF TIME REVERSAL VIOLATION

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Representing the BaBar Collaboration

DISCRETE 2012

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Outline

- **Introduction**
  - TRV in stable and unstable systems
  - Foundations of the analysis
- **Analysis Procedure**
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  - Signal description and fitting strategy
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- **Summary and interpretation**
  - Contours
  - Significance and asymmetries
- **Conclusions**

J. P. Lees et al. Phys. Rev. Lett. 109, 211801 (2012)

PHYSICAL REVIEW LETTERS

Published two weeks ago!!

Observation of Time-Reversal Violation in the B^0 Meson System

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PARTICLE PHYSICS

Time's arrow in B mesons

A cornerstone of theoretical particle physics — the idea that not all processes run in the same way forwards in time as they do backwards — has been observed directly for the first time.

Members of the BaBar Collaboration trawled data from their experiment (pictured), which ran at the SLAC National Accelerator Laboratory in Menlo Park, California, from 1999 to 2008. The researchers identified B-meson decay chains that were time reversals of each other, and a comparison of the decay rates revealed a strong asymmetry. Earlier experiments have caught hints of time-reversal violation but failed to distinguish it clearly from violations of other fundamental symmetries.

Phys. Rev. Lett. 109, 211801 (2012)

For a longer story on this research, see go.nature.com/258vei

640 | NATURE | VOL 491 | 29 NOVEMBER 2012

The Economist

The arrow of time

To the relief of physicists, time really does have a preferred direction

Sep 1st 2012 | from the print edition

TIME seems to flow inexorably in one direction. Superficially, that is because things deteriorate with age—and this, in turn, is because there are innumerably fewer ways to arrange particles in an orderly fashion than in a jumbled mess. Any change in an existing arrangement is therefore likely to increase its disorder. Dig a little deeper, though, and time's arrow becomes mysterious. A particle cannot, by itself, become.........

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Time-reversal asymmetry in particle physics has finally been clearly seen

Bertram M. Schwarzschild

November 2012, page 16

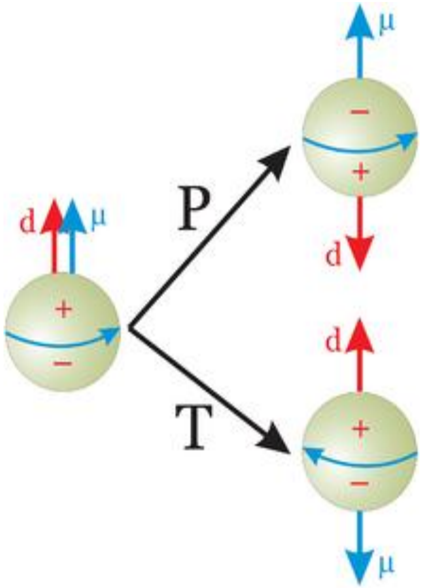
DIGITAL OBJECT IDENTIFIER

http://dx.doi.org/10.1063/PT.3.1774

INTRODUCTION

Time Reversal Violation (TRV)

- Time Reversal in stable systems
  - A non-zero value of a T-odd observable in a stationary state, e.g, dipole moment of an elementary particle or an atom.
  - In an oscillation a difference in the probability of a→b from b→a at a given time, e.g., $\nu_e \to \nu_\mu$ vs. $\nu_\mu \to \nu_e$ experiment proposed for the neutrino factories with muon storage ring.



- Time Reversal in unstable systems
  1. Reversal of motion ($t \to -t$).
  2. |in>↔|out> exchange.

discard → ~~Odd effects $t \to -t$~~

→ Experimentally tricky!

CP violation mechanisms		T violation mechanisms
• Decay • Mixing • Mixing×Decay	⟷ CPT	• Decay • Mixing • Mixing×Decay

TRV in unstable systems

- 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

Unable to perform the T test:

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

- Mixing TRV searches

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

CPT →

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

CP ↓ **T** ↘

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

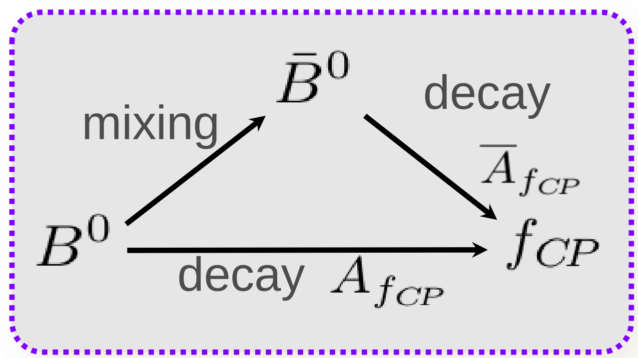
=

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

CPLEAR
4σ evidence

A test of CP and T simoultaneously.
If CP is conserved and T violated or viceversa this observable is 0.

- Interference TRV searches



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

- Ingredients: M. C. Bañuls and J. Bernabeu, Phys. Lett. B 464, 117 (1999); Nucl. Phys. B 590, 19 (2000).
  - EPR entanglement produced by the decay of the $\Upsilon(4S)$.

$$|i>= 1/\sqrt{2}[B^0(t_1)\bar{B}^0(t_2) - \bar{B}^0(t_1)B^0(t_2)]$$
$$= 1/\sqrt{2}[B_+(t_1)B_-(t_2) - B_-(t_1)B_+(t_2)]$$

B_+, B_- projected by → $J/\psi K_L$, $J/\psi K_S$

  - Quantum Mechanics.

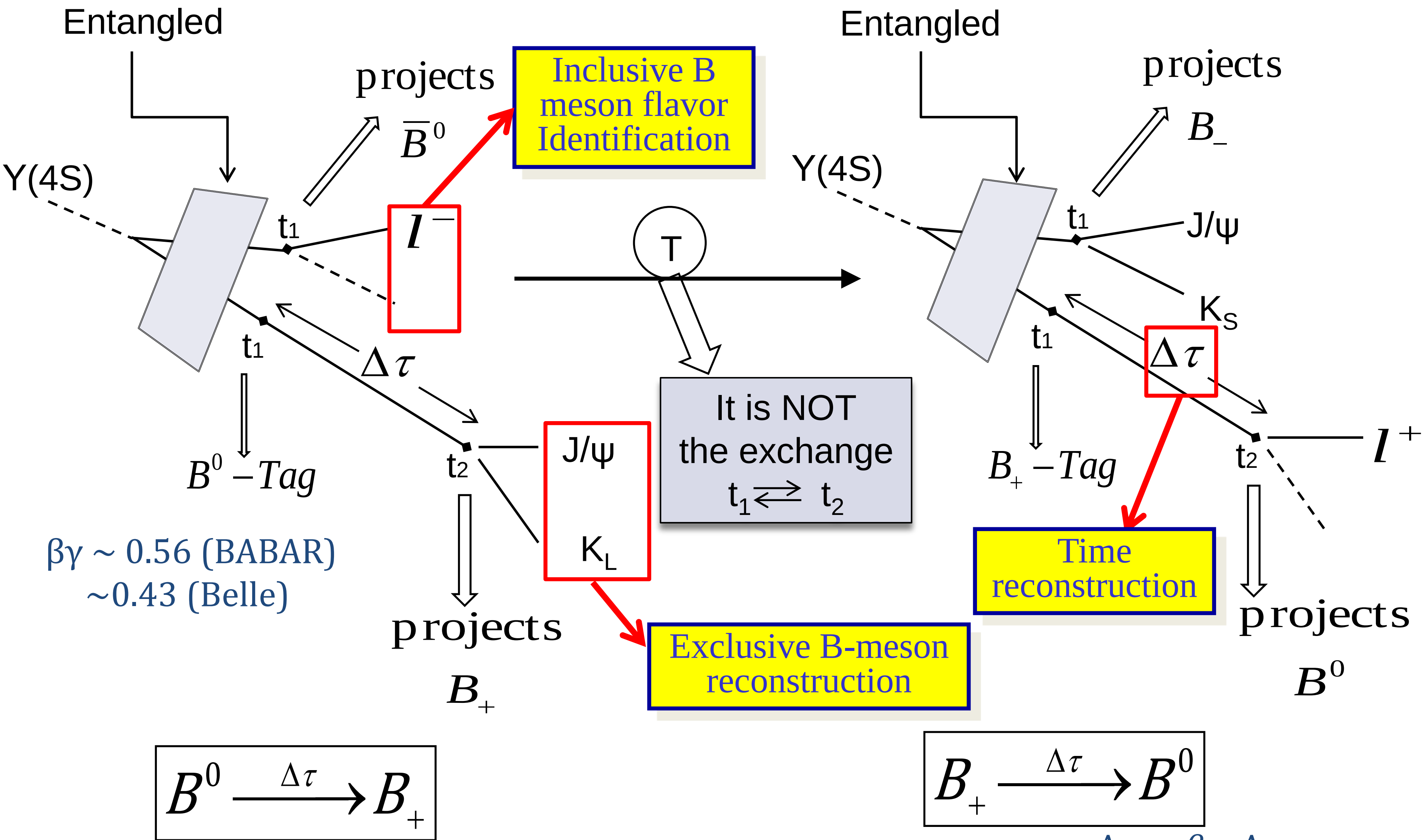
$$\Delta\tau = t_Y - t_X > 0$$

Reference: Physical Process
(X,Y): Reconstructed Final States

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

l^+ and l^- project over the B flavor, i.e., B^0 and $\bar{B}^0$ respectively

Foundations of the analysis

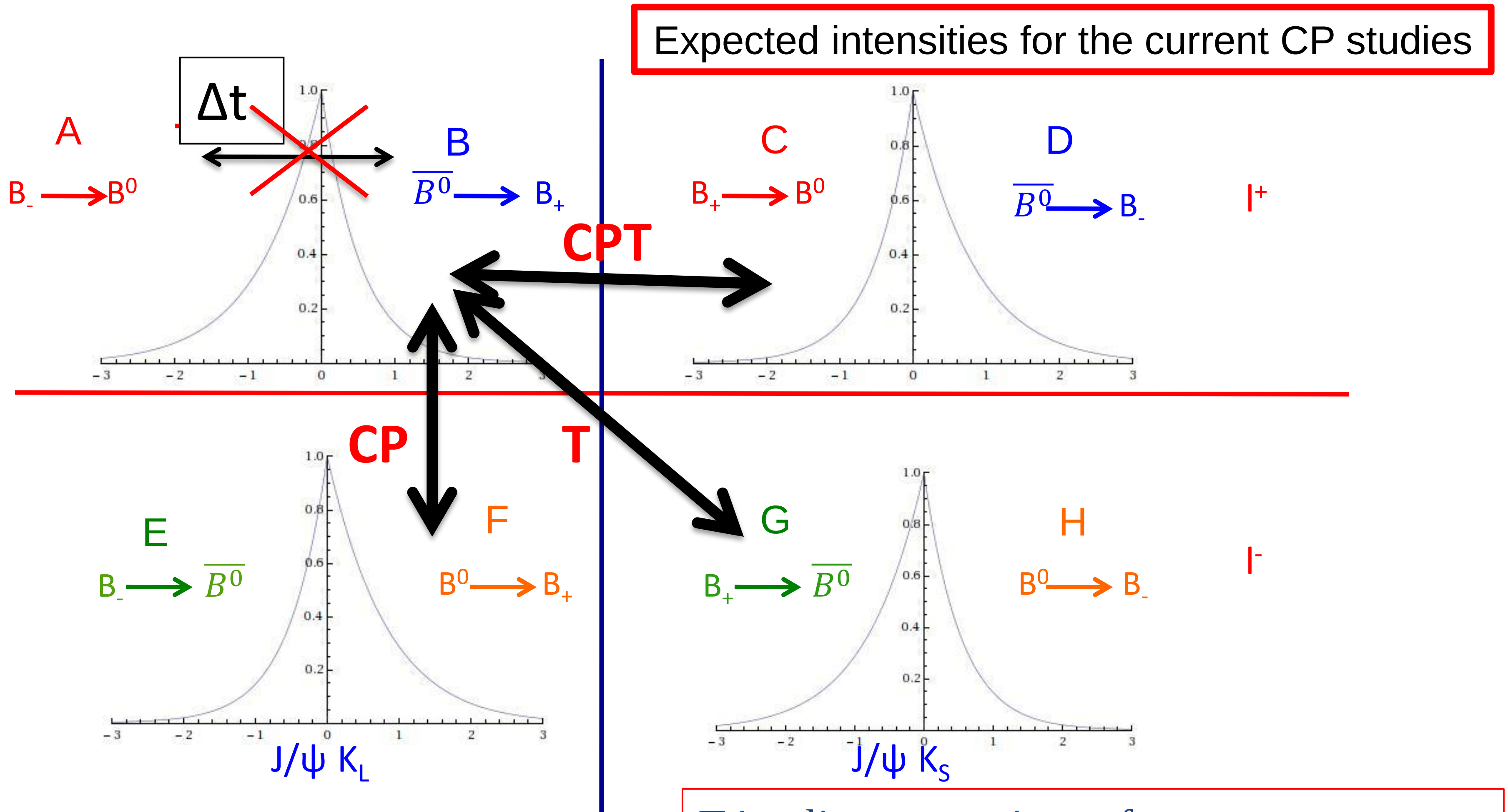


$\Delta z = \beta\gamma c \Delta\tau$

$< \Delta z > \sim 250\mu m$ (BABAR)

Bernabeu, Martinez-Vidal and Villanueva-Perez
JHEP 1208 (2012) 064

Foundations of the analysis



In total we can build:

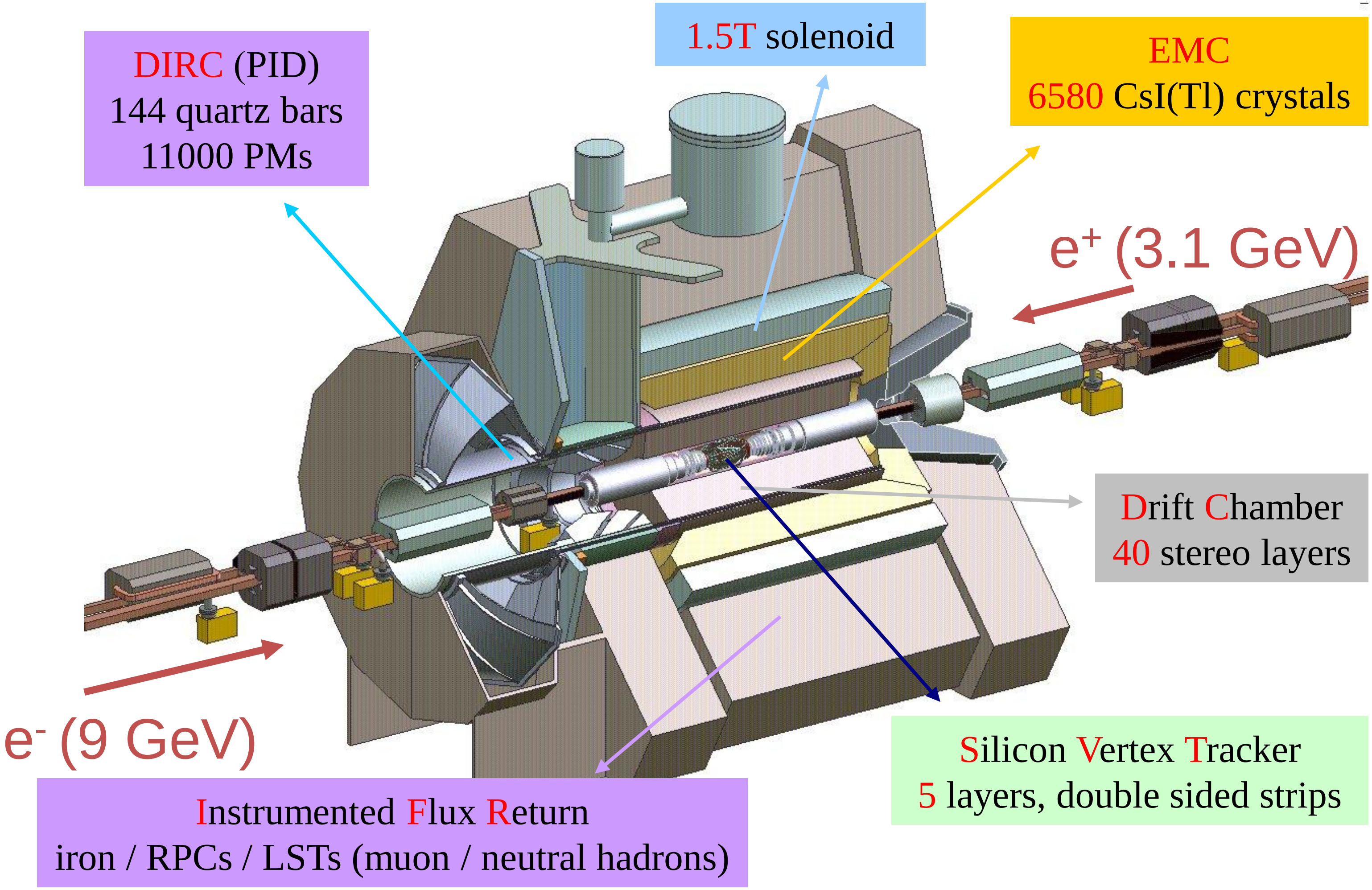
- 4 Independent T comparisons.
- 4 Independent CP comparisons.
- 4 Independent CPT comparisons.

T implies comparison of:

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

ANALYSIS PROCEDURE

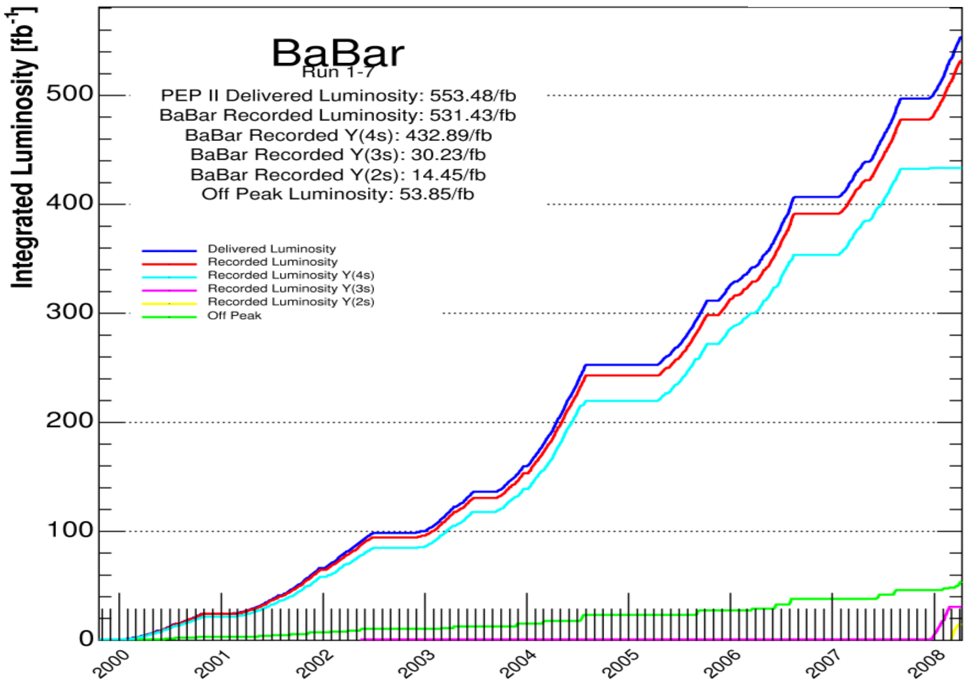
BaBar detector

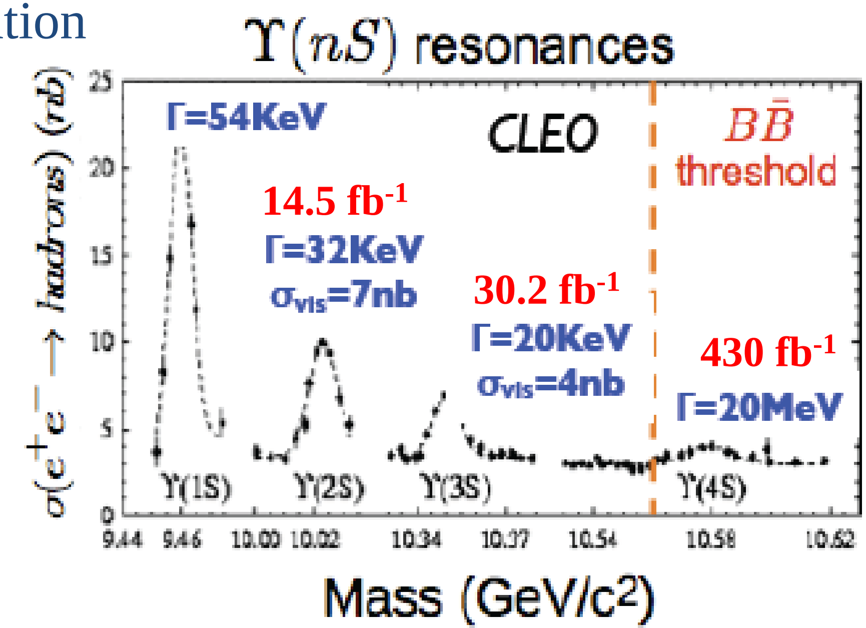


- Asymmetric B-factory: E_{cms} = 10.58 GeV $\quad e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\bar{B}$
- Performed a wide range of flavor physics results in B, Charm and τ sectors
- General purpose detector in e^+e^- environment: precision tracking, photon/electron detection, particle ID, muon/K_L identification. Very stable over the 9 years of operation

Data Set

- 530 fb^{-1} recorded in the 9 years of operation





54 fb^{-1} Off-Υ(nS)
4 fb^{-1} above Υ(4S)

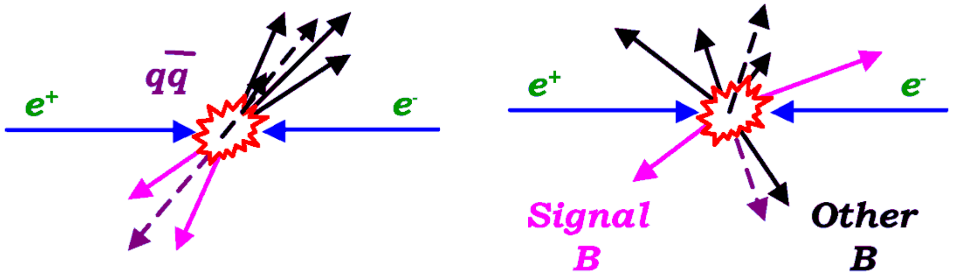
Decays used for the analysis:

- $c\bar{c}K_S$: $B^0 \to J/\psi K_S$, $B^0 \to \psi(2S)K_S$, $B^0 \to \chi_{c1}K_S$
- $c\bar{c}K_L$: $B^0 \to J/\psi K_L$
- B_{flav}: $B^0 \to D^*\pi(\rho, a_1)$, $B^0 \to J/\psi K^{*0}$
- Control sample $c\bar{c}K^\pm$ and $J/\psi K^{*+}$, e.g., $B^+ \to J/\psi K^+$, $B^+ \to \psi(2S)K^+$, $B^+ \to J/\psi K^{*+}$

- ≈ 470×10^6 BB (0.5×Belle)
- ≈ 690×10^6 cc
- ≈ 500×10^6 $\tau^+\tau^-$
- ≈ 1.2×10^8 Υ(3S) (7×Belle+Cleo)
- ≈ 1.0×10^8 Υ(2S) (0.5×Belle+Cleo)

Backgrounds and B characterization

- Veto significant/potentially dangerous B decay backgrounds
  - Depends strongly on B decay channel under study
- Suppress continuum $e^+e^- \rightarrow q\bar{q}$ (q=u,d,s,c) background using
  - Angular distribution: B flight direction
  - Event shape variables:
    - Background: "jetty"
    - Signal: almost at rest



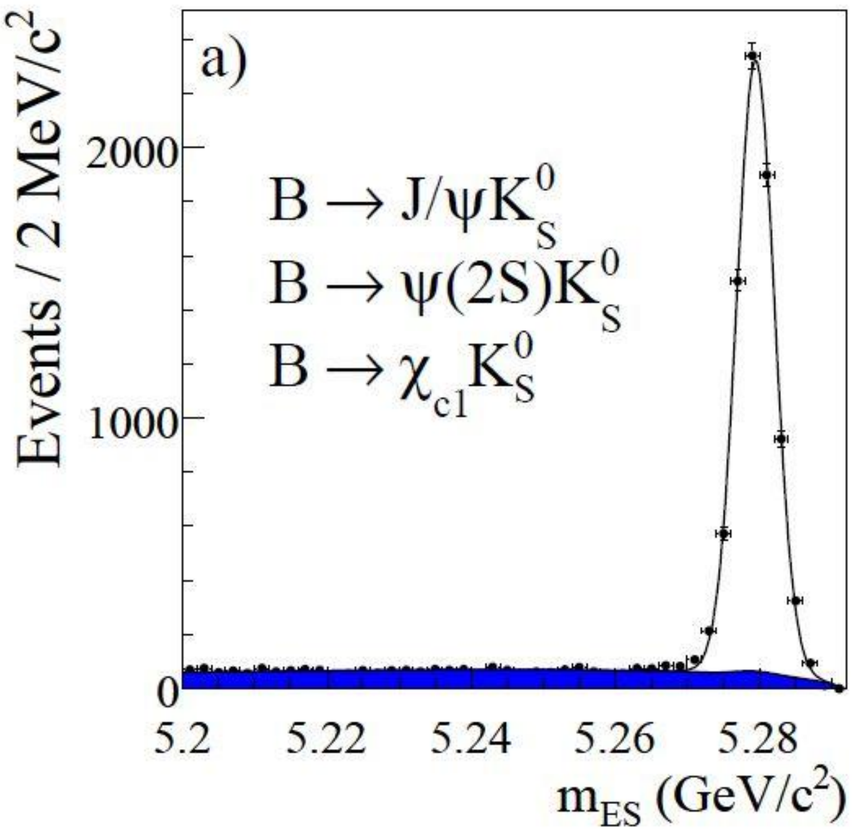
- Characterize B candidates using
  - Beam constrained mass: $m_{ES} = \sqrt{E^{*2}_{beam} - |\vec{p}^{*}_{B}|^2}$
    - B mesons produced almost at rest

$$E^*_B = E^*_{beam} \qquad p^*_B \sim 300\,\mathrm{MeV}/c$$

    - Resolution ~3 MeV dominated by beam energy spread
  - Energy difference: $\Delta E = E^*_B - E^*_{beam}$
    - Energy of B candidate almost equal to half beam energy
    - Resolution ~10-50 MeV depends on neutrals in final state
- Select best B candidates (based on invariant masses of daughter particles)

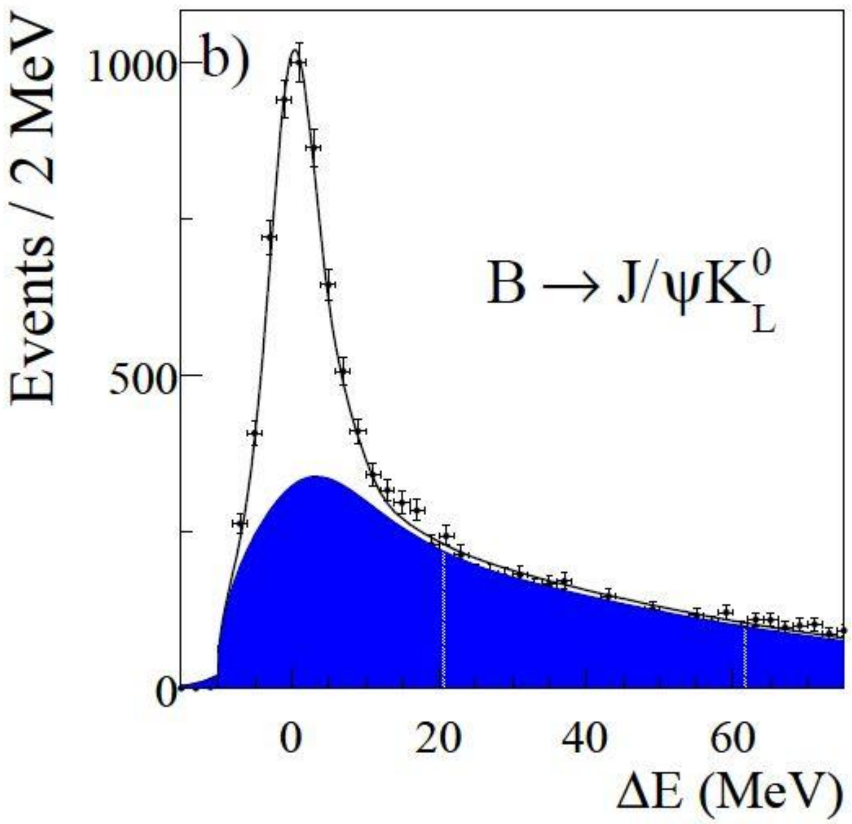
$c\bar{c}K_S$ and J/ψK_L samples composition

$c\bar{c}K_S$ sample



7796 events
Purity: 87% to 96%

$J/\psi K_L$ sample



5813 events
Purity: ~56%

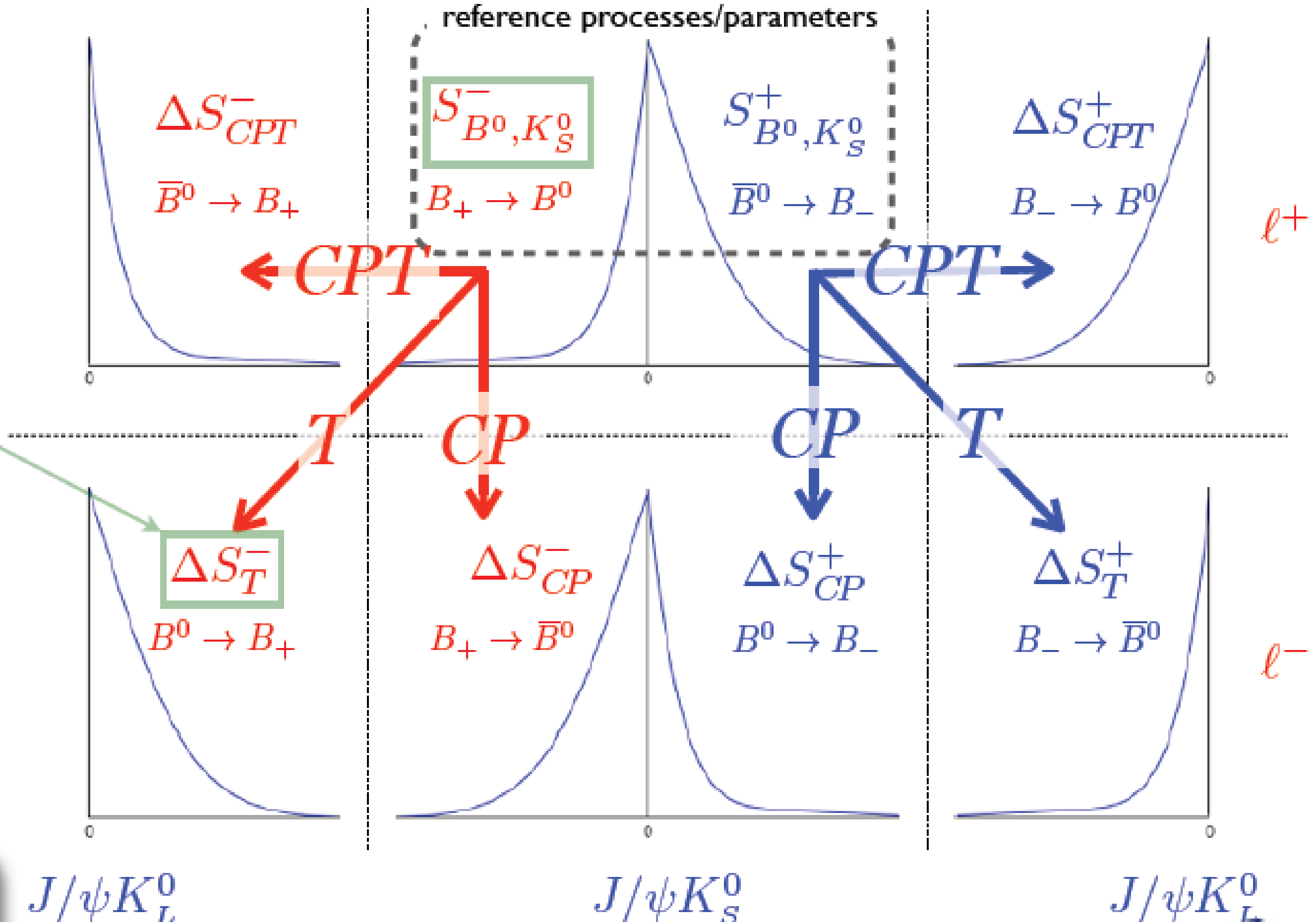
Signal parameters

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

$$\Delta t = t_{CP} - t_{flav} = \begin{cases} +\Delta\tau & \text{for "flavor tag"} \\ -\Delta\tau & \text{for "CP tag"} \end{cases} \qquad \alpha \in \{B^0, \bar{B}^0\}; \quad \beta \in \{K^0_S, K^0_L\}$$

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 $\Delta C^+_T \neq 0$, $\Delta C^-_T \neq 0$

Signal model

- Signal PDF

Step function   Resolution function

$$H_{\alpha,\beta}(\Delta t) \propto g^{+}_{\alpha,\beta}(\Delta t_{true}) \times \mathrm{H}(\Delta t_{true}) \otimes \Re(\delta t;\sigma_{\Delta t})$$

Flavor tagged events (+)

$$+ \quad g^{-}_{\alpha,\beta}(-\Delta t_{true}) \times \mathrm{H}(-\Delta t_{true}) \otimes \Re(\delta t;\sigma_{\Delta t})$$

$$\delta t = \Delta t - \Delta t_{\mathrm{true}}$$

CP tagged events (–)

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

- Fit has to unfold $\Delta t_{true}>0$ and $\Delta t_{true}<0$ events (mixed due to limited time resolution), to obtain **8 sets of S, C parameters**

$2\ \Delta t\ (\Delta t > 0, \Delta t < 0)$ × $2\ flav\ (B^0, \bar{B}^0)$ × $2\ CP\ (K_S, K_L)$

- Flavor misID fractions *w* (not shown here) dilute the S,C parameters by a factor (1-2*w*)
- In practice, we directly fit to the T-, CP- and CPT-violating parameters

  $\Delta S_T^{\pm}, \Delta C_T^{\pm}$ $\Delta S_{CP}^{\pm}, \Delta C_{CP}^{\pm}$ $\Delta S_{CPT}^{\pm}, \Delta C_{CPT}^{\pm}$
- In canonical CP violation studies (assume CPT and $\Delta\Gamma$=0), one single S, C set
  - In SM, S~ sin2β= 0.679±0.020 (HFAG winter'12) and C~0

Fitting strategy

- From the B_{flav} sample we extract the time resolution parameters and the wrong flavor ID fractions which are exported to the CP ($c\bar{c}K_S, J/\psi K_L$) sample.
- Perform simultaneous unbinned ML fit to B^0, $\bar{B}^0$, $c\bar{c}K_S$, and $J/\psi K_L$ for $\Delta t > 0$ and $\Delta t < 0$ events.
- Normalize PDF simultaneously for $B^0, \bar{B}^0$ and $\Delta t > 0$ and $\Delta t < 0$ and independently for $c\bar{c}K_S$, $J/\psi K_L$.
- Obtain the 8 sets of S, C parameters, and from these, define T, CP and CPT violating parameters ΔS, ΔC.

Complete results

Group	Parameter	Final result	SM expected val.
T	ΔS_T^+	$-1.37 \pm 0.14 \pm 0.06$	-1.4
	ΔS_T^-	$1.17 \pm 0.18 \pm 0.11$	1.4
	ΔC_T^+	$0.10 \pm 0.14 \pm 0.08$	$0.$
	ΔC_T^-	$0.04 \pm 0.14 \pm 0.08$	$0.$
CP	ΔS_{CP}^+	$-1.30 \pm 0.11 \pm 0.07$	-1.4
	ΔS_{CP}^-	$1.33 \pm 0.12 \pm 0.06$	1.4
	ΔC_{CP}^+	$0.07 \pm 0.09 \pm 0.03$	$0.$
	ΔC_T^-	$0.08 \pm 0.10 \pm 0.04$	$0.$
CPT	ΔS_{CPT}^+	$0.16 \pm 0.21 \pm 0.09$	$0.$
	ΔS_{CPT}^-	$-0.03 \pm 0.13 \pm 0.06$	$0.$
	ΔC_{CPT}^+	$0.14 \pm 0.15 \pm 0.07$	$0.$
	ΔC_{CPT}^-	$0.03 \pm 0.12 \pm 0.08$	$0.$
REF.	$S_{\ell^+,K_S^0}^+$	$0.55 \pm 0.09 \pm 0.06$	0.7
	$S_{\ell^+,K_S^0}^-$	$-0.66 \pm 0.06 \pm 0.04$	-0.7
	$C_{\ell^+,K_S^0}^+$	$0.01 \pm 0.07 \pm 0.05$	$0.$
	$C_{\ell^+,K_S^0}^-$	$-0.05 \pm 0.06 \pm 0.03$	$0.$

Systematic uncertainties

Systematic source	ΔS_T^+	ΔS_T^-
misID flavour	0.02	0.02
Δt resolution function	0.02	0.05
Outlier's scale factor	0.01	-0.01
m_{ES} parameters	0.01	0.00
ΔE parameters	0.02	0.02
K_L systematics	0.03	0.03
Differences between B_{CP} and B_{flav}	0.02	0.02
Background effects	0.03	0.04
Uncertainty on fit bias from MC	0.01	0.08
Detector and vertexing effects.	0.01	0.04
$\Delta\Gamma \neq 0$ effects	0.00	0.00
External physics parameters	0.00	0.01
Normalization effects	0.01	0.01
Total Systematics	0.06	0.11

Similar procedure to ***B. Aubert et al.*** **PRD 79, 072009 (2009)**

SUMMARY

AND

INTERPRETATION

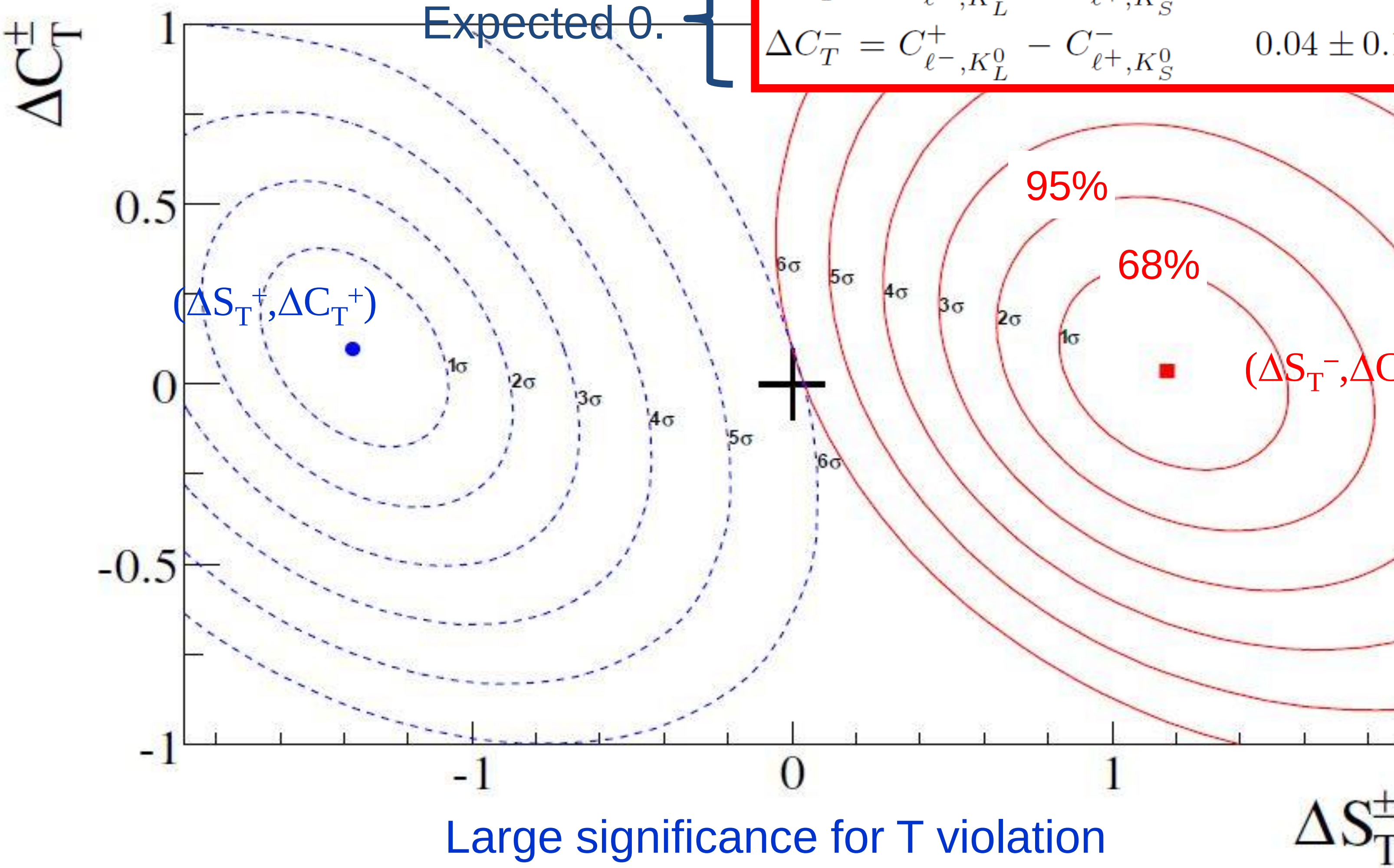
Interpretation of the results

***BABAR* PRL 109, 211801 (2012)**

Expected ±1.4

Expected 0.

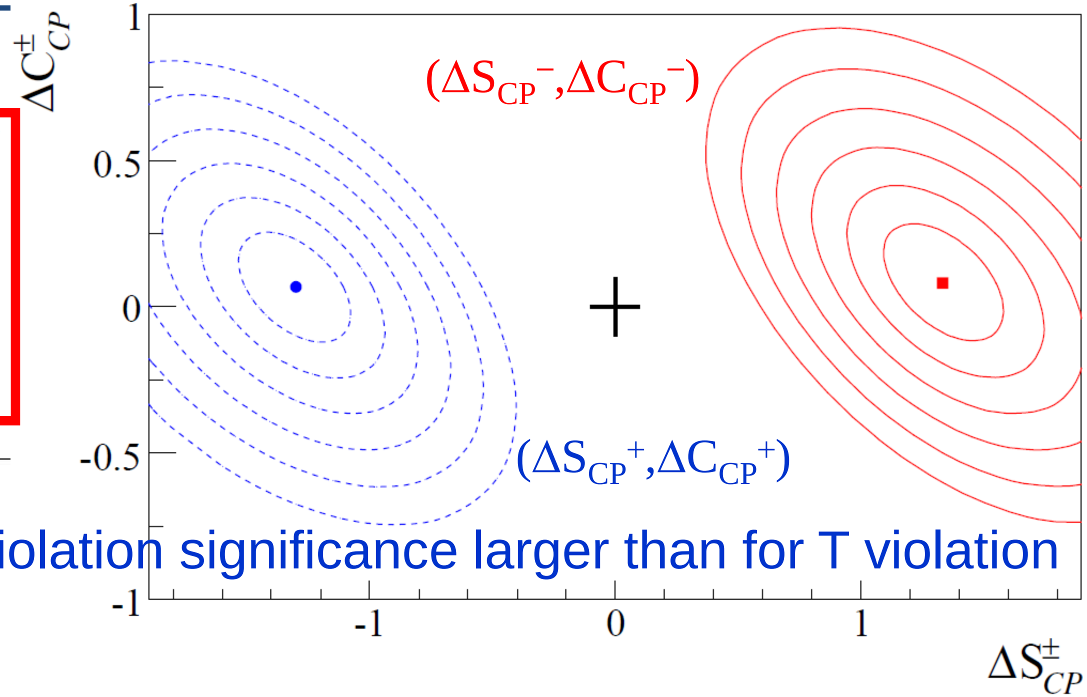
$\Delta S_T^+ = S^-_{\ell^-,K_L^0} - S^+_{\ell^+,K_S^0}$		$-1.37 \pm 0.14 \pm 0.06$
$\Delta S_T^- = S^+_{\ell^-,K_L^0} - S^-_{\ell^+,K_S^0}$		$1.17 \pm 0.18 \pm 0.11$
$\Delta C_T^+ = C^-_{\ell^-,K_L^0} - C^+_{\ell^+,K_S^0}$		$0.10 \pm 0.14 \pm 0.08$
$\Delta C_T^- = C^+_{\ell^-,K_L^0} - C^-_{\ell^+,K_S^0}$		$0.04 \pm 0.14 \pm 0.08$



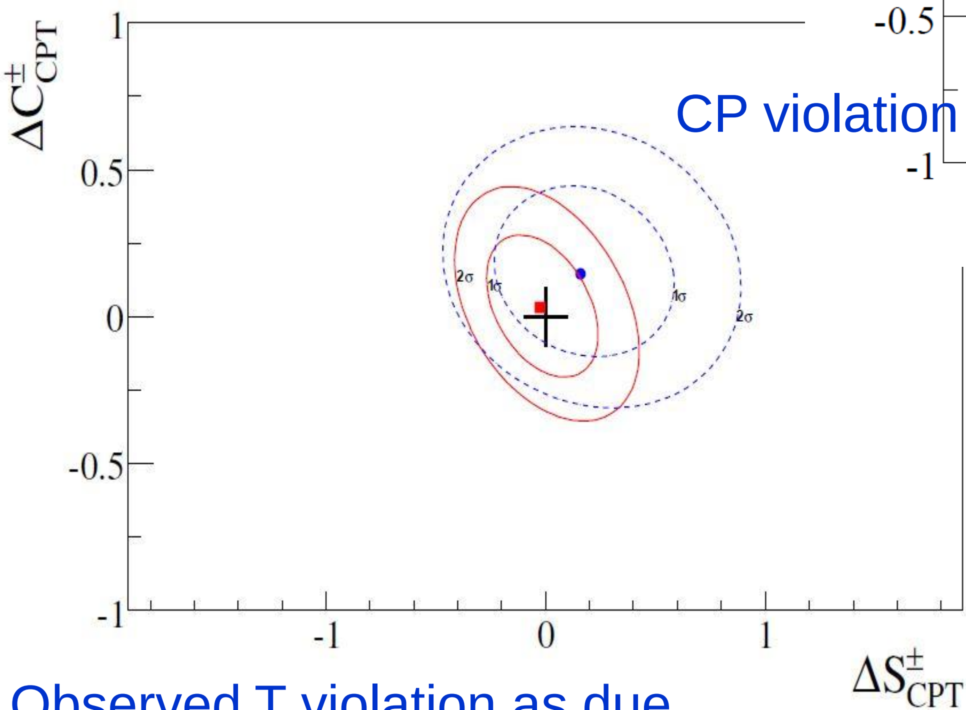
Large significance for T violation

Interpretation of the results

$\Delta S^{+}_{CP} = S^{+}_{\ell-,K^0_S} - S^{+}_{\ell+,K^0_S}$	$-1.30 \pm 0.11 \pm 0.07$
$\Delta S^{-}_{CP} = S^{-}_{\ell-,K^0_S} - S^{-}_{\ell+,K^0_S}$	$1.33 \pm 0.12 \pm 0.06$
$\Delta C^{+}_{CP} = C^{+}_{\ell-,K^0_S} - C^{+}_{\ell+,K^0_S}$	$0.07 \pm 0.09 \pm 0.03$
$\Delta C^{-}_{CP} = C^{-}_{\ell-,K^0_S} - C^{-}_{\ell+,K^0_S}$	$0.08 \pm 0.10 \pm 0.04$



CP violation significance larger than for T violation



$\Delta S^{+}_{CPT} = S^{-}_{\ell+,K^0_L} - S^{+}_{\ell+,K^0_S}$	$0.16 \pm 0.21 \pm 0.09$
$\Delta S^{-}_{CPT} = S^{+}_{\ell+,K^0_L} - S^{-}_{\ell+,K^0_S}$	$-0.03 \pm 0.13 \pm 0.06$
$\Delta C^{+}_{CPT} = C^{-}_{\ell+,K^0_L} - C^{+}_{\ell+,K^0_S}$	$0.14 \pm 0.15 \pm 0.07$
$\Delta C^{-}_{CPT} = C^{+}_{\ell+,K^0_L} - C^{-}_{\ell+,K^0_S}$	$0.03 \pm 0.12 \pm 0.08$

Observed T violation as due to compensate CP violation

Significance of T violation

1. We obtain the likelihood value of the fit to S, C for the 8 independent samples (Standard Fit).
2. We repeat the fit, reassembling the parameters for T-conjugated processes, to forbid T violation.
3. Significance of T violation evaluated from the difference of the likelihood values.
4. Raw asymmetries and fit projections can be now plotted in the standard way.

T invariance
$\Delta S_T^+ = 0$
$\Delta S_T^- = 0$
$\Delta S_{CP}^+ = \Delta S_{CPT}^+$
$\Delta S_{CP}^- = \Delta S_{CPT}^-$
$\Delta C_T^+ = 0$
$\Delta C_T^- = 0$
$\Delta C_{CP}^+ = \Delta C_{CPT}^+$
$\Delta C_{CP}^- = \Delta C_{CPT}^-$

$$\Delta\chi^2 = -2(\ln L_{No\_T\_Violation} - \ln L)$$

$$\Delta\nu = 8$$

5. CP, and CPT significance is evaluated similarly.
6. Using Gaussian approximation, we evaluate the change of likelihood in 1σ systematic variation.

$$m_j^2 = -2[\ln L(q_j, o_j) - \ln L(p_0)] / s_{stat,j}^2$$

7. We take the max{m_j^2} and we divide our significance (s^2) by (1+ max{m_j^2})

Asymmetries

- Example of asymmetry building for T-Violation:

$H^{\pm}_{\alpha,\beta}(\Delta t)$ is the intensity for each sample with Δt>0 and all experimental effects.

$$A_T(\Delta t) \equiv \frac{H^{-}_{l^-,K_L}(\Delta t) - H^{+}_{K_S,l^+}(\Delta t)}{H^{-}_{l^-,K_L}(\Delta t) + H^{+}_{K_S,l^+}(\Delta t)} \approx \frac{\Delta C_T^{+}}{2}\cos\Delta m\Delta t + \frac{\Delta S_T^{+}}{2}\sin\Delta m\Delta t$$

$\approx 0.$

$\approx \pm 1.4$

Where:

$$H^{\pm}_{\alpha,\beta}(\Delta t) = H_{\alpha,\beta}(\pm\Delta t)\mathrm{H}(\Delta t)$$

Assuming no experimental effects

- We build an asymmetry for these four reference transitions:

$$\overline{B}^0 \to B_- \qquad \overline{B}^0 \to B_+ \qquad B_+ \to B^0 \qquad B_- \to B^0$$

T raw asymmetries + significance

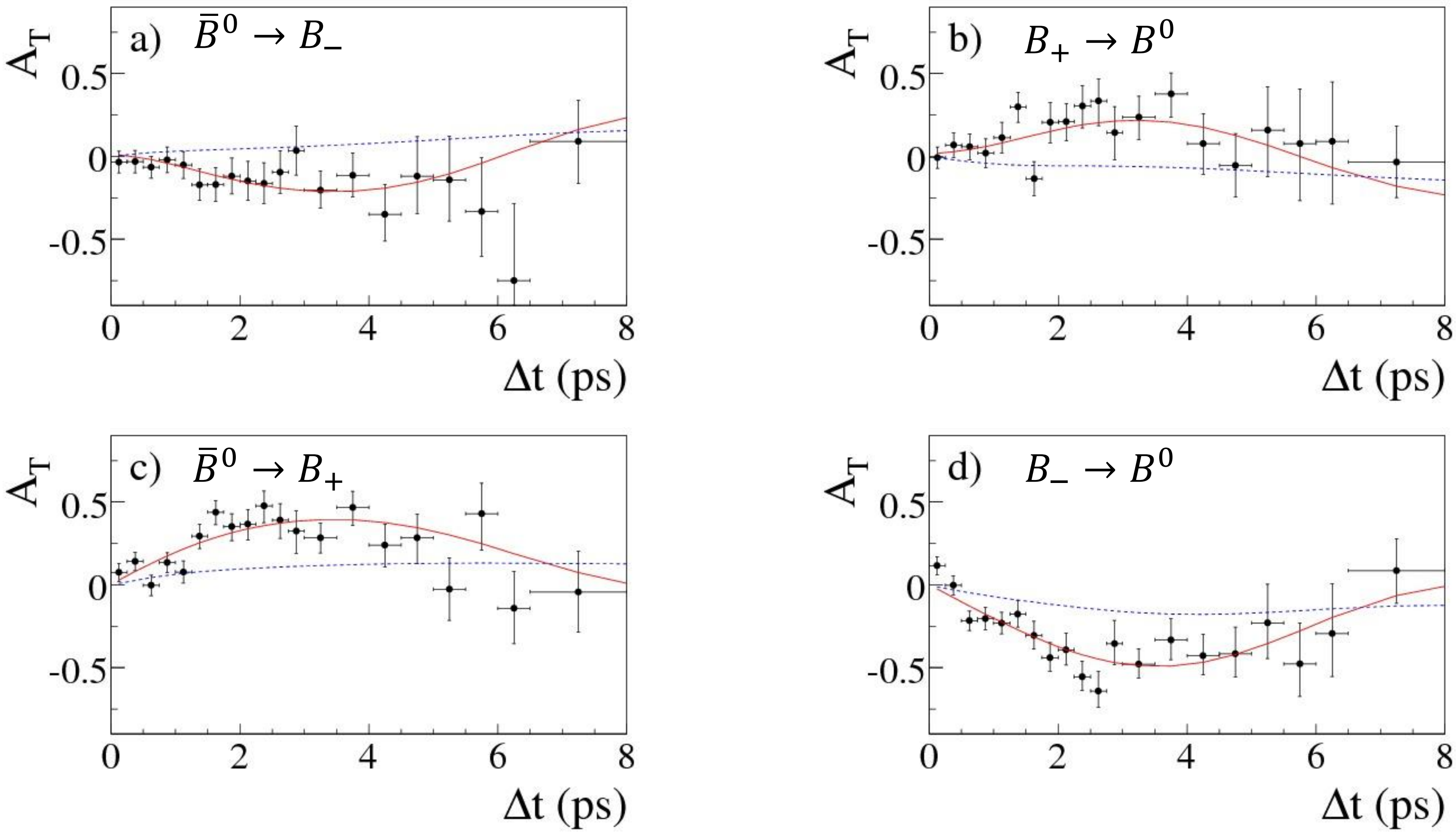
Significance test

$s^2_{NoT} = 226$ ⇒ 14σ

$s^2_{NoCP} = 307$ ⇒ 16.6σ

$s^2_{NoCPT} = 5$ ⇒ 0.33σ

Stat. and Syst. $\Delta\nu=8$



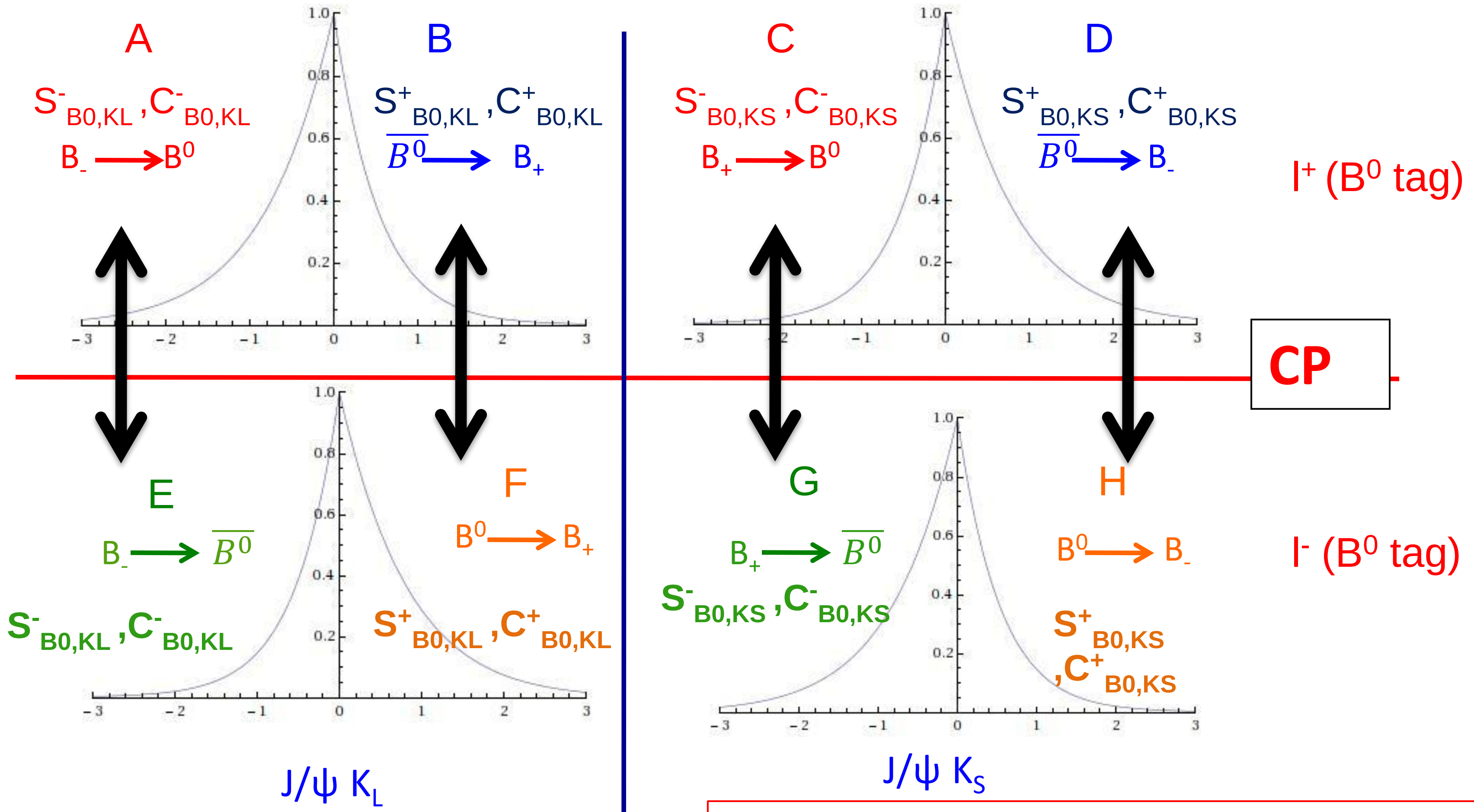
CONCLUSIONS

Conclusions

- We have measured T-violating parameters in the time evolution of neutral-B mesons.
- These parameters have been measured:
  - Directly: without exp. connection to CP and CPT.
  - Genuinely: exchanging *in-states* and *out-states*.
- We observe a large deviation of T invariance at 14σ level.
- Our result is consistent with CP-violating measurements assuming CPT invariance.
- This constitutes the first direct observation of Time Reversal Violation (not related to CP), in the evolution of the neutral-B mesons.

BACK-UP

($S^{\pm}$, $C^{\pm}$) parameters and CP asymmetries

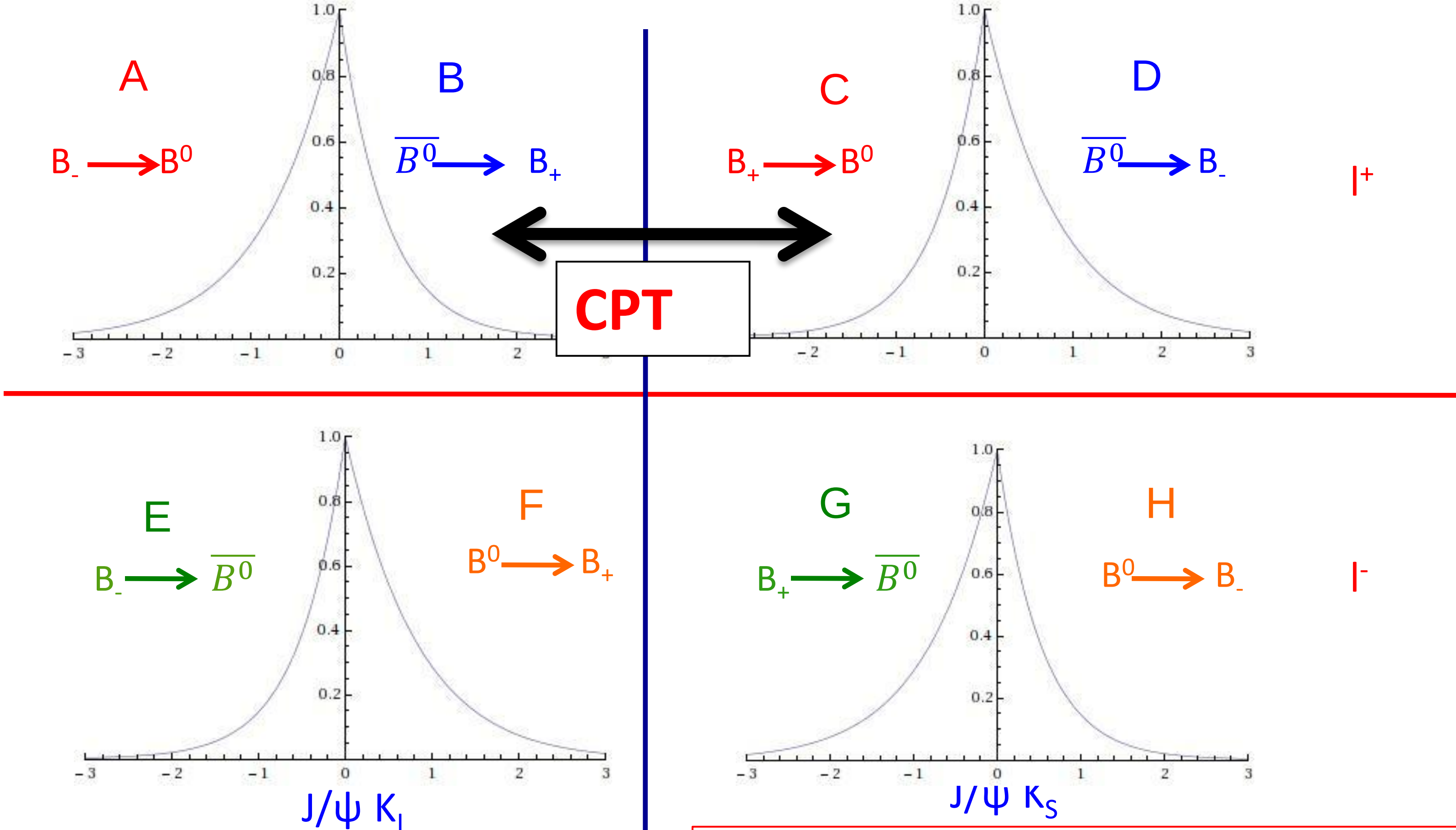


A, **B**, **C**, **D** —**CP**→ **E**, **F**, **G**, **H**

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 $\bar{B}^0$).

$(S^{\pm}, C^{\pm})$ parameters and CPT asymmetries



A		D
B	CPT →	C
F		G
H		E

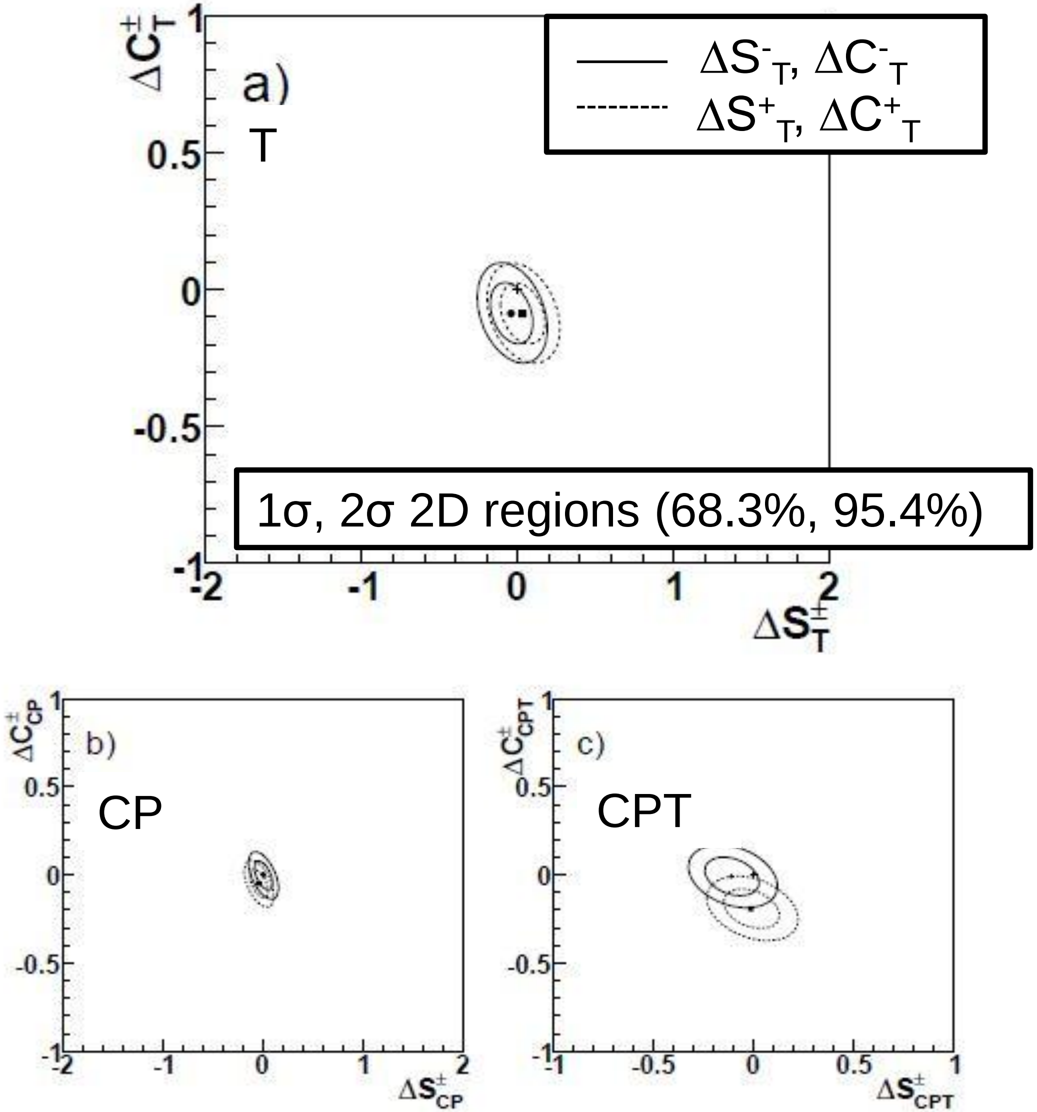
CPT implies comparison of:

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 $\bar{B}^0$).

Fitting Fit results (Control Data Sample)

ccK$^{\pm}$ as J/ψK_S
J/ψK^{*+} as J/ψK_L

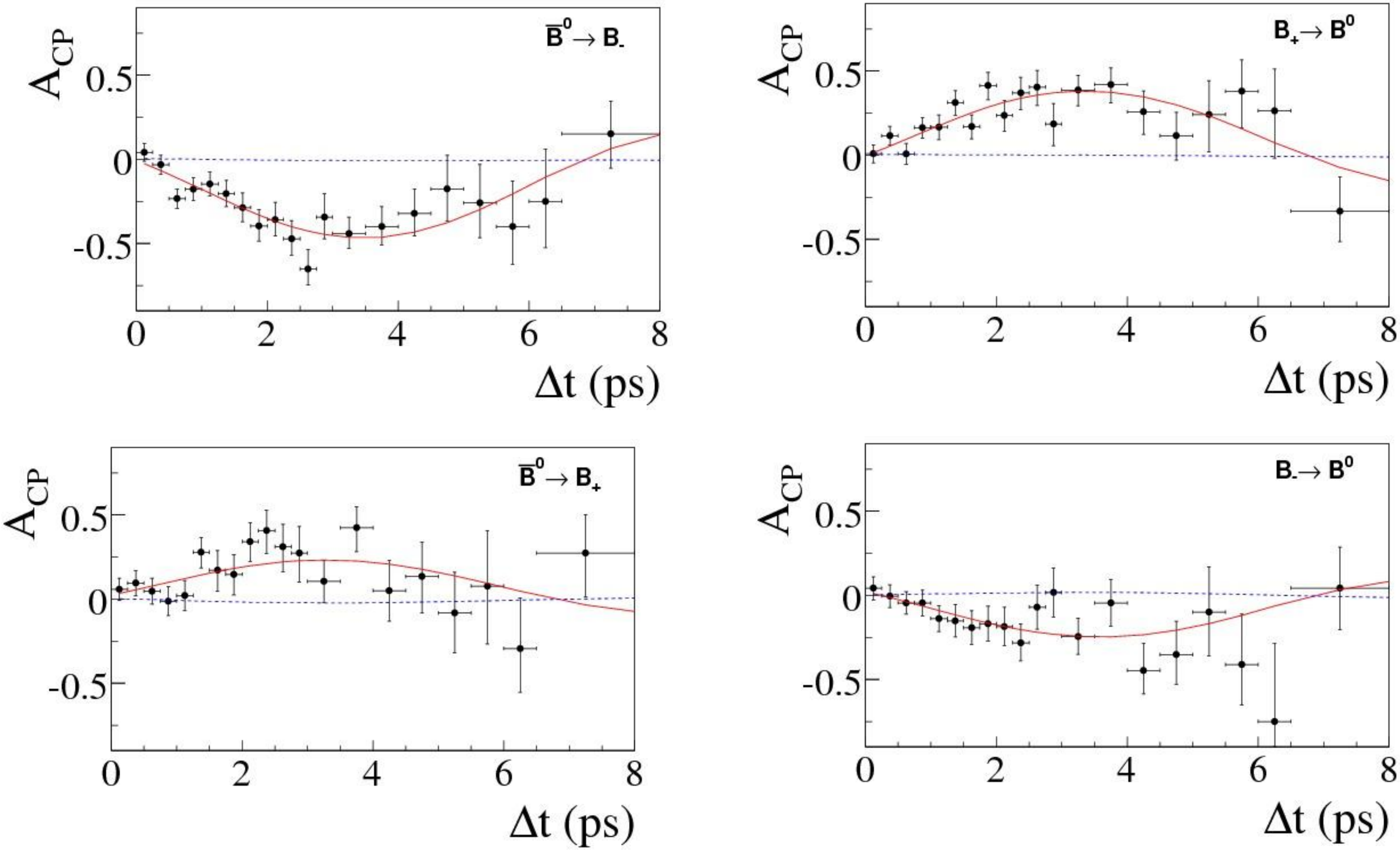
Parameter	Value
$\Delta C^{-}_{\rm CP}$	0.036 ± 0.050
$\Delta C^{-}_{\rm CPT}$	-0.0042 ± 0.068
$\Delta C^{-}_{\rm T}$	-0.0405 ± 0.073
$\Delta C^{+}_{\rm CP}$	-0.0044 ± 0.049
$\Delta C^{+}_{\rm CPT}$	-0.1586 ± 0.070
$\Delta C^{+}_{\rm T}$	-0.0237 ± 0.073
$\Delta S^{-}_{\rm CP}$	0.088 ± 0.054
$\Delta S^{-}_{\rm CPT}$	-0.1035 ± 0.083
$\Delta S^{-}_{\rm T}$	0.041 ± 0.089
$\Delta S^{+}_{\rm CP}$	0.041 ± 0.053
$\Delta S^{+}_{\rm CPT}$	0.030 ± 0.086
$\Delta S^{+}_{\rm T}$	0.155 ± 0.094
$C^{-}_{\rm B^0,K^0_S}$	0.025 ± 0.032
$C^{+}_{\rm B^0,K^0_S}$	0.038 ± 0.031
$S^{-}_{\rm B^0,K^0_S}$	-0.0072 ± 0.038
$S^{+}_{\rm B^0,K^0_S}$	-0.0002 ± 0.038



CP raw asymmetries(CP Data Sample)

No CP violation
Experimental data

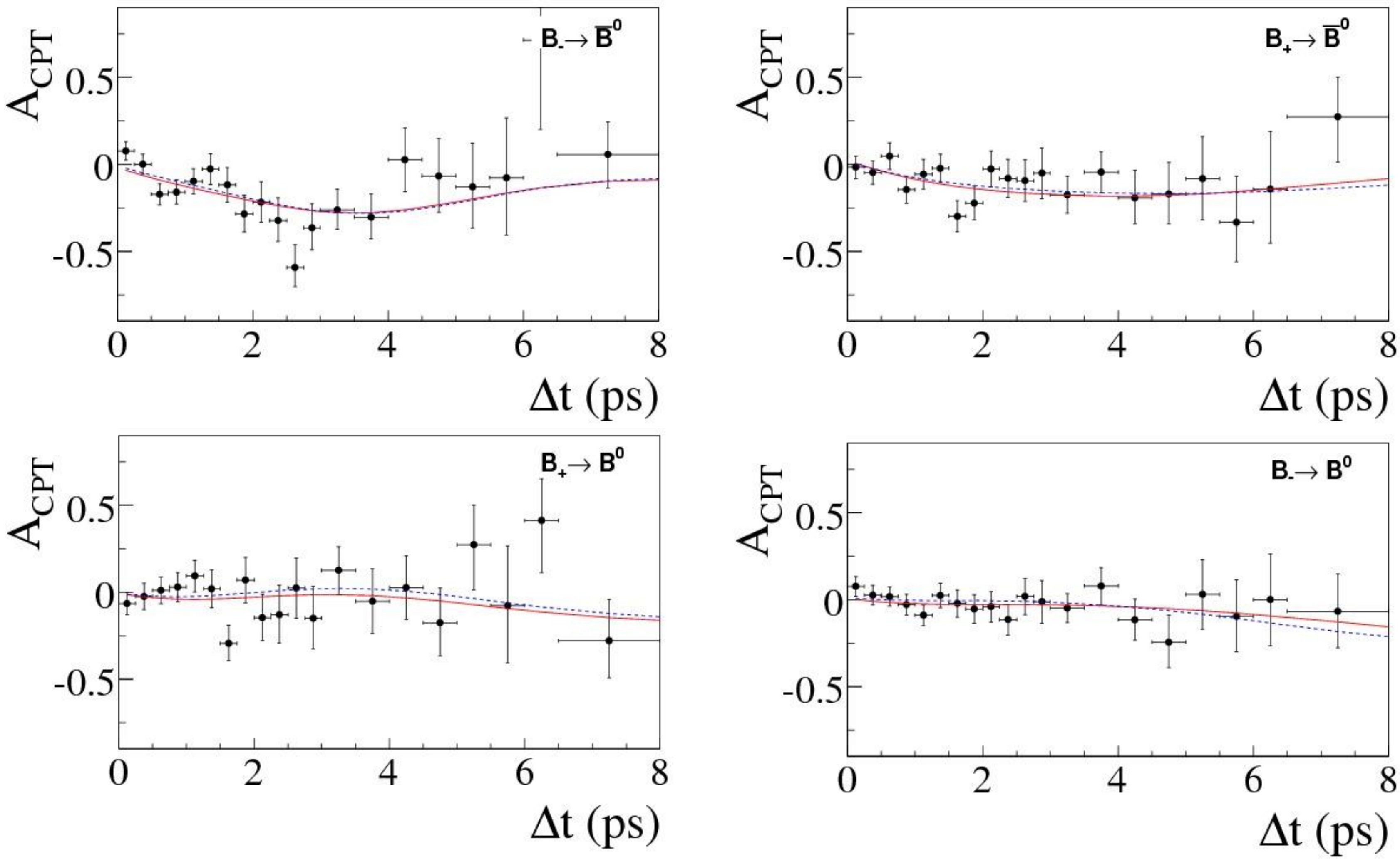
Signal region:
$5.27 < m_{ES} < 5.29$ GeV/c^2
$|E| < 0.010$ GeV



CPT raw asymmetries(CP Data Sample)

No CPT violation
Experimental data

Signal region:
$5.27 < m_{ES} < 5.29\ GeV/c^2$
$|E| < 0.010$ GeV



$(S^{\pm}, C^{\pm})$-$(\Delta S^{\pm}, \Delta C^{\pm})$ parameters: approx. expected values

$(\Delta S^{\pm}, \Delta C^{\pm})$ parameters

Param.	Expected Value	Param.	Expected Value
$S^{+}{}_{B0,KS}$	0.7	$C^{+}{}_{B0,KS}$	0.
$S^{-}{}_{B0,KS}$	-0.7	$C^{-}{}_{B0,KS}$	0.
$\Delta S^{+}{}_{T}$	-1.4	$\Delta C^{+}{}_{T}$	0.
$\Delta S^{-}{}_{T}$	1.4	$\Delta C^{-}{}_{T}$	0.
$\Delta S^{+}{}_{CP}$	-1.4	$\Delta C^{+}{}_{CP}$	0.
$\Delta S^{-}{}_{CP}$	1.4	$\Delta C^{-}{}_{CP}$	0.
$\Delta S^{+}{}_{CPT}$	0.	$\Delta C^{+}{}_{CPT}$	0.
$\Delta S^{-}{}_{CPT}$	0.	$\Delta C^{-}{}_{CPT}$	0.

E.g. T is violated:

If $\Delta S^{+}{}_{T} \neq 0$, $\Delta S^{-}{}_{T} \neq 0 \rightarrow$ T is violated in the interference

If $\Delta C^{+}{}_{T} \neq 0$, $\Delta C^{-}{}_{T} \neq 0 \rightarrow$ T is violated in the decay