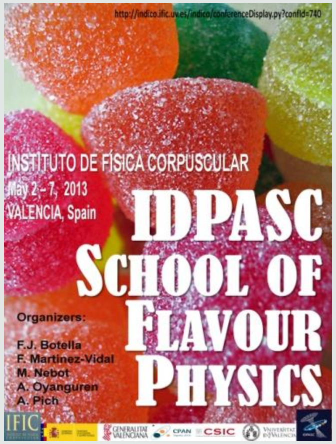


IDPASC SCHOOL OF FLAVOUR PHYSICS

IFIC, 2-7 May 2013

Time Reversal Violation for Entangled Neutral Mesons

José Bernabéu
IFIC-Valencia

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………

PARTICLE PHYSICS

Time's arrow in B mesons

SLAC NATL ACCELERATOR LAB.

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

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

Bertram M. Schwarzschild

November 2012, page 16

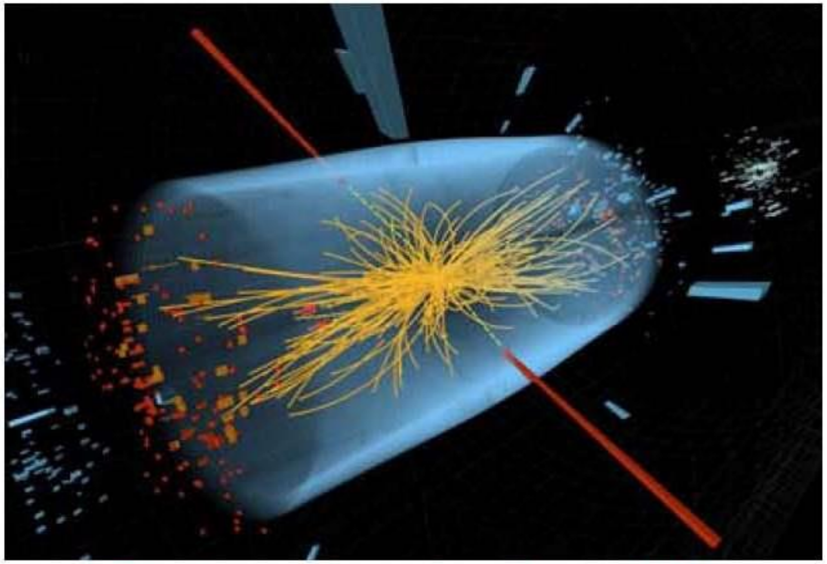
DIGITAL OBJECT IDENTIFIER

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

PHYSICS WORLD REVEALS ITS TOP BREAKTHROUGHS FOR 2012

http://physicsworld.com/cws/article/news/2012/dec/14/physics-world-reveals-its-top-10-breakthrough.

CERN discovers Higgs-like boson



One of many proton–proton collisions at CMS

Majorana fermions

Looking for Majorana fermions in a solid

Time-reversal violation

"To the BaBar collaboration for making the first direct observation of time-reversal violation by measuring the rates at which the B^0 meson changes quantum states."

Mainly based on

- For B's in B-Factories

- CONCEPT→ M.C. Bañuls, J.B., PLB (1999), NPB (2000);

  scrutinized by L. Wolfenstein, IJMP(1999); H. Quinn, JPCS(2009); V. Rubakov; T. Nakada; F. Botella, …

  "it would appear to be a true TRV effect"

- METHOD, DEFINITE PROPOSAL & SIMULATION →
  J.B., F. Martínez-Vidal, P. Villanueva-Pérez, JHEP (2012)

- EXPERIMENTAL RESULT→
  BABAR Collaboration, PRL (2012),
  with View Point by Michael Zeller

- For K's in Φ-Factory

- J.B., A. Di Domenico, P. Villanueva-Pérez, NPB (2012)

Reprinted from

PHYSICS LETTERS B

Physics Letters B 464 (1999) 117–122

CP, T and CPT versus temporal asymmetries for entangled states of the B_d-system

M.C. Bañuls [a,1], J. Bernabéu [b,2,3]

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N-H
ELSEVIER

OUTLINE

- Symmetries in the Laws of Physics
- Universe t-Asymmetry, the “Arrow of Time”
- Is it possible to search for TRV in unstable systems?
- EPR-Entanglement: Flavour-Tag, CP-Tag
- The Decay as a Filtering Measurement
- Genuine Observables in B-factories: not needing $\Delta\Gamma$
- T-violating parameters
- CPV, TRV, CPTV Asymmetries
- Foundations of the Experimental Analysis
- T raw asymmetries & Significance, from BABAR
- Conclusion

SYMMETRIES IN THE LAWS OF PHYSICS

- ”Microscopic” Symmetry Violations.
- T-Violation exists in the Standard Model or any field theoretic extension.
- All field theories with Lorentz invariance have CPT symmetry

➡ Automatic connection between CP-violation ⟷ related T-violation

- T and CPT described by ANTIUNITARY rather than unitary operators, introducing many intriguing subtleties.

➡ Observed CP-Violation ⟹ T should be violated as well: Is it observed?

T - Violation means Asymmetry under

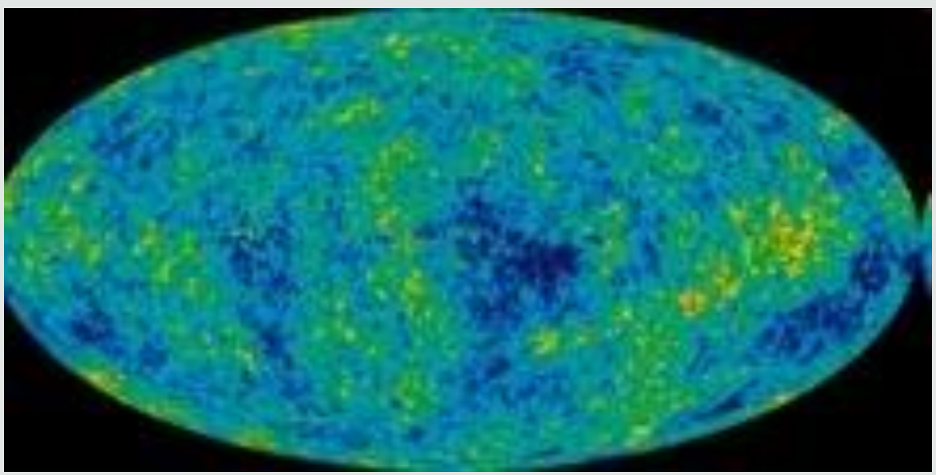
Interchange in ⇆ out states

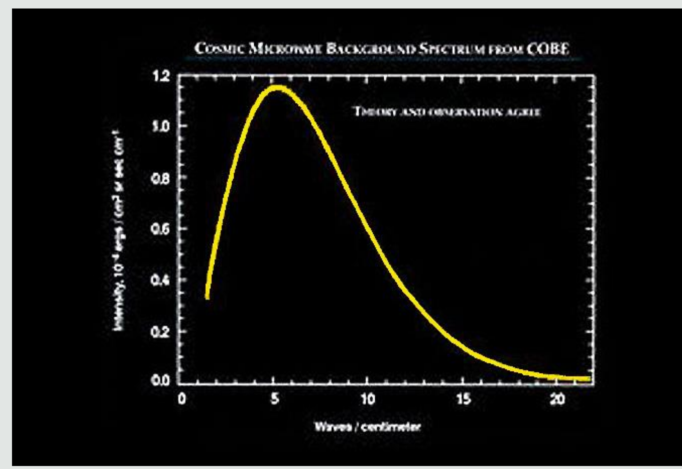
- Effects in particle physics odd under t ⇆ -t are not necessarily T-violating.
- t- asymmetries can occur in theories with exact T- symmetry: Universe Time’s Arrow

UNIVERSE t - ASYMMETRY

- No doubt Universe is expanding, even accelerating ⟶ asymmetry t ⇆ -t
- BUT this is perfectly compatible with laws of physics that are TR symmetric
- This t-asymmetry is due to the initial condition of <u>our</u> Universe ⟶ Inflation?
- Similar to the fact that in <u>our</u> Universe we have a privileged reference frame

  ⟷ CMB radiation with same temperature





- BUT this is not a violation of Lorentz invariance of the laws of physics

THE "ARROW OF TIME"

- t-asymmetry in complex systems
- Nature of Thermodynamics ⟶ (Eddington)
  Time's Arrow is a property of ENTROPY alone

Time is asymmetric with respect to the amount of order in an isolated system.

- Unsolved problem?

Is quantum wave function collapse related to the thermodynamic arrow of time?

- In particle physics,

Particle Decay is an example of a time-asymmetric process:

The irreversible character of $P \longrightarrow 1 + \ldots + n$ is not related to T-violation.
In fact, it looks like it prevents a true test of T-symmetry in unstable systems [Wolfenstein, Quinn]

- Any connection between the Universe t-asymmetry and the "arrow of time"?

Probably YES, saying that the initial condition was improbable: more ordered.

- But none of these t-asymmetries is a test of TRV:

the "Arrow of Time" is NOT Time Reversal Violation.

DIRECT EVIDENCE FOR TIME REVERSAL VIOLATION

- A direct evidence for TRV would mean an experiment that, considered by itself, clearly shows TRV INDEPENDENT of, and unconnected to, the results for CPV

- No existing result up to now had clearly demonstrated TRV in this sense. Two types of experiments can do it:

1) A non-zero expectation value of a T-odd operator for a non-degenerate stationary state $\longrightarrow$ Electric Dipole Moment: P-odd, C-even, T-odd

It can be generated by either

- Strong T-violation $\longrightarrow$ θ-term $\epsilon_{\mu\nu\varsigma\sigma} F^{\mu\nu} F^{\varsigma\sigma}$ [Peccei & Quinn], or
- Weak T-violation

2) in $\leftrightarrows$ out: $S_{f,i} \longrightarrow S_{-i,-f}$ transition.

The Kabir asymmetry $K^0 \rightarrow \overline{K}^0$ *vs.* $\overline{K}^0 \rightarrow K^0$ has been measured by CP-LEAR with non-vanishing value and a significance of 4 σ. But the interpretation of this observable as evidence for TRV is controversial...

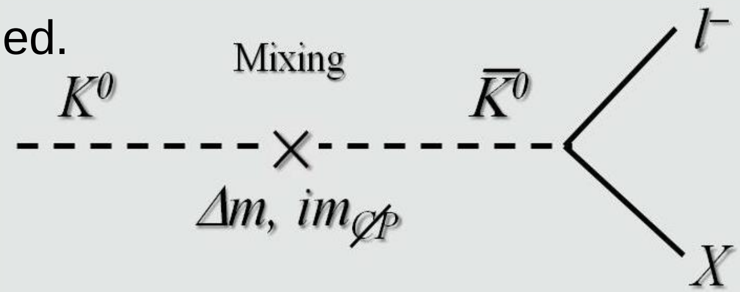
CAN TR BE TESTED IN UNSTABLE SYSTEMS?

THE FACTS

- Taking as Reference $K^0 \to \overline{K}^0$ and calling (X,Y) the observed decays at times t_1 and t_2, with $\Delta t \equiv t_2 - t_1 > 0$, the CP, T and CPT transformed transitions are

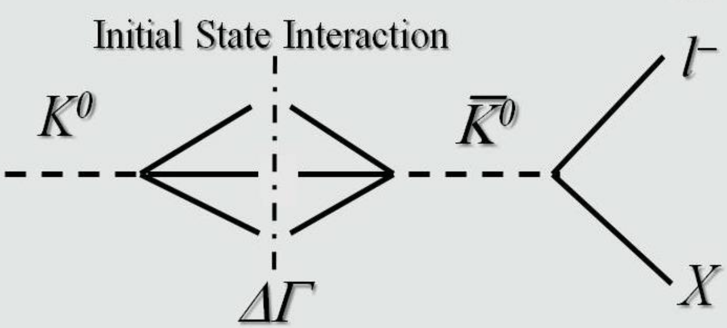
Transition	$K^0 \to \overline{K}^0$	$\overline{K}^0 \to K^0$	$\overline{K}^0 \to K^0$	$K^0 \to \overline{K}^0$	$K^0 \to \overline{K}^0$
(X,Y)	(l^-, l^-)	(l^+, l^+)	(l^+, l^+)	(l^-, l^-)	(l^-, l^-)
Transformation	Reference	CP	T	CPT	Δt

➡ No way to separate T and CP if T were defined.



- T-operator is not defined for **decaying** states: its time reverse is not a physical state.
- The Kabir asymmetry NEEDS the interference of CP mixing with the "initial state interaction" to generate the effect, directly proportional to ΔΓ.

The decay plays an essential role



- The time evolutions of $K^0 \to \overline{K}^0$ and $\overline{K}^0 \to K^0$ are equal, the asymmetry is time independent.
- In the WW approach, the entire effect comes from the overlap of non-orthogonal K_L, K_S states. If the **stationary** states were orthogonal ➡ no asymmetry.
- L. Wolfenstein: "it is not as direct a test of TRV as one might like".

EPR-ENTANGLEMENT: FLAVOUR-TAG

- Are the previous arguments ruling out all tests of T symmetry for particles that decay?
  NO, if $\Delta\Gamma$ is not needed $\Rightarrow$ interference with x without mixing (flavour-CP decays)

- The opportunity arises [M.C. Bañuls, J.B.] from the Quantum Mechanical Entanglement imposed by the EPR correlation:
  one can have SEPARATE tests of CP, T and CPT!

- $B^0 - \overline{B}^0$ EPR-Entanglement imposed by Particle Identity:

  $B^0, \overline{B}^0$ are two states of a unique (complex) field

- The two states connected by C, so that C$\mathscr{P}$ = + [$\mathscr{P}$: permutation operation].

- In neutral meson factories, $B^0 - \overline{B}^0$ produced by Y (4S)-decay: J=1, S=0 ➡

L=1 ➡ C= - ➡ **$\mathscr{P}$= -, antisymmetric wave function** ↔

$$\Upsilon \to B^0\,\overline{B}^0 \qquad\qquad |i\rangle = \frac{1}{\sqrt{2}}\left[B^0(t_1)\overline{B}^0(t_2) - \overline{B}^0(t_1)B^0(t_2)\right]$$

where the states 1 and 2 are defined by the time of their decay with $t_1 < t_2$.
Time evolution (including the Mixing $B^0 \to \overline{B}^0$) preserves $B^0\,\overline{B}^0$ terms only.

➡ Perfect for Flavour-Tag: The observation of $B^0 \to l^+$, for example, at time t_1, tells us that the complementary (still living) state is $\overline{B}^0$ at t_1, and, once the state is prepared at t_1 , we have single state time evolution for $t_1 < t < t_2$.

EPR-ENTANGLEMENT: CP-TAG

- BUT the INDIVIDUAL STATE of each neutral meson is NOT DEFINED BEFORE its collapse as a filter imposed by the observation of the decay of its orthogonal partner!

- One can rewrite $|i\rangle$ in terms of any other pair of **orthogonal** states of the individual neutral B-mesons:

Consider B_+ and B_-, where B_- is filtered by the decay $J/\Psi\ K_+$, K_+ being the neutral K-meson decaying $K_+ \to \pi\pi$, and B_+ is the orthogonal to B_-, not connected to $J/\Psi\ K_+$

⇨ **automatic transfer of information.**

We may call the preparation of the initial state at t_1, using the filter imposed by a first observation of one of these decays, a “CP-tag”, although $B_\pm$ are not CP-eigenstates of B’s necessarily.

The same entangled state of the system can be rewritten

$$|i\rangle = \frac{1}{\sqrt{2}}\left[B_+(t_1)B_-(t_2) - B_-(t_1)B_+(t_2)\right]$$

THE DECAY AS A FILTERING MEASUREMENT

- The decay is irreversible (a misfortune for T-symetry), but

“Virtue shines in the misfortunes”
ARISTOTLE

- Is the Decay projecting a definite state of the B (the Virtue)?

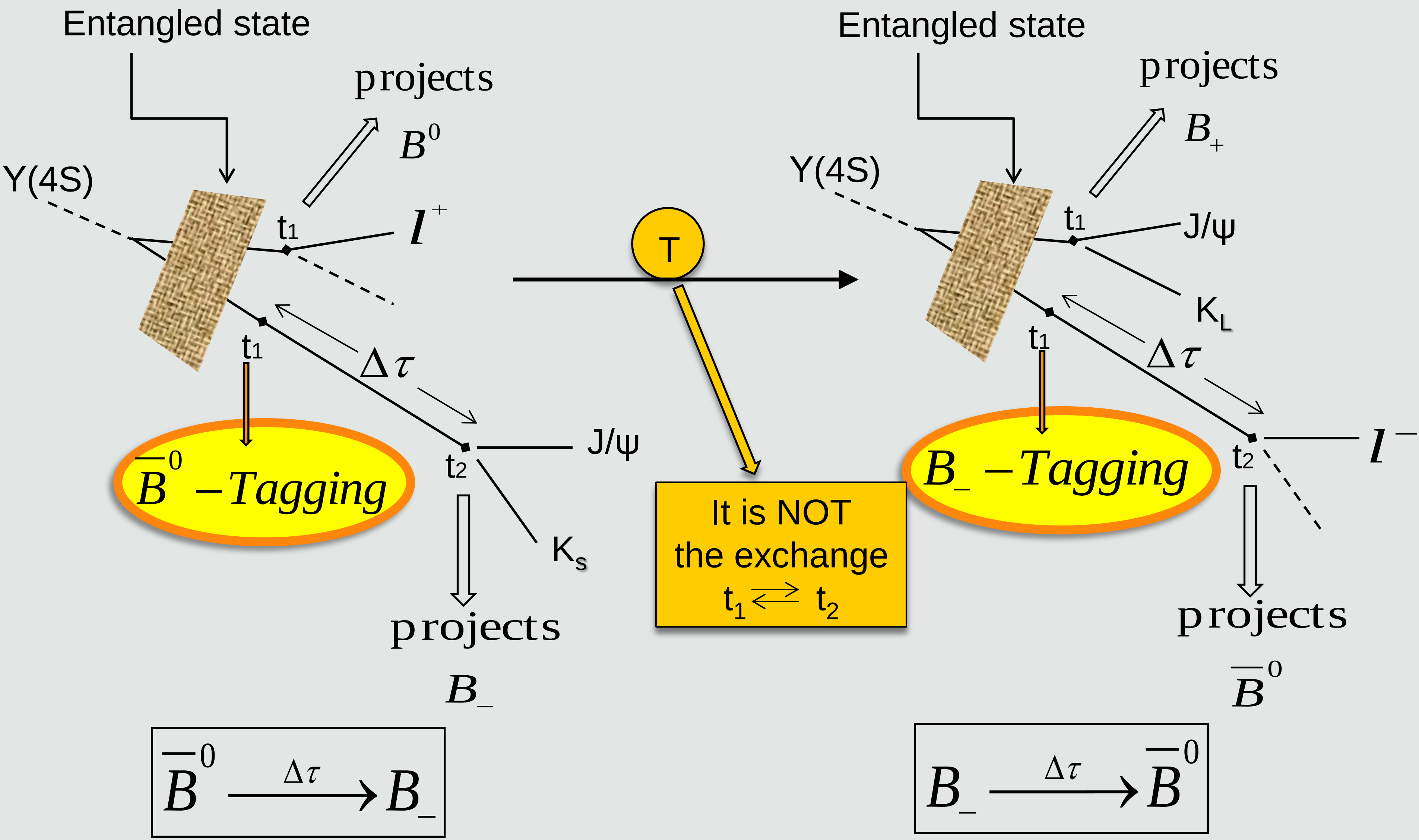
- A decay product with definite flavour, for example l^+, projects B^0, implying the Flavour Tag $\overline{B}^0$ for the living partner.

- For a definite CP eigenstate decay product, for example $J/\Psi\ K_L$, the condition to filter a definite state is [J.B., F. Martinez, P. Villanueva] that the decay amplitude has a single weak phase. This B state is called B_+.

- **Einstein-Podolsky-Rosen correlation** →
a “CP-Tag” prepares the orthogonal state B_- for the living partner.
What is B_- experimentally? The state filtered by $J/\Psi\ K_S$ decay product.

- B_+, B_- are not necessarilly CP-eigenstates of the neutral B-system

WHAT IS T-TRANSFORMATION EXPERIMENTALLY?



GENUINE OBSERVABLES NOT NEEDING ΔΓ

- We may proceed to a partition of the complete set of events into four categories, defined by the tag in the first decay at t_1: B_+ , B_- , B^0 or $\overline{B}^0$ so we have 8 different Decay-Intensities at our disposal as functions of $\Delta\tau = t_2 - t_1 \rangle 0$

- Each of these 8 processes

$$I_i(\Delta\tau) \sim e^{-\Gamma\Delta\tau}\{ C_i \cos(\Delta m \Delta\tau) + S_i \sin(\Delta m \Delta\tau) + C'_i \cosh(\Delta\Gamma\Delta\tau) + S'_i \sinh(\Delta\Gamma\Delta\tau) \}$$

- For a genuine test of a symmetry, one has to compare the I_i (Δt) of a transition and its transformed. For the case of T: in <=> out

- Careful: Up to now, for CPV analyses in B-factories, BABAR & BELLE had assumed CPT-invariance and $\Delta\Gamma = 0$:

⇨ Then Δt ⇆ -Δt exchange, which is NOT T-operation, [M.C.Bañuls, J.B.] implies T symmetry.

⇨ Only 2 independent Intensities to be compared, if CP ~T ~Δt are connected.

⇨ Alternatively, one may establish $S_i \neq 0$ for a single transition. Δt-asymmetric.

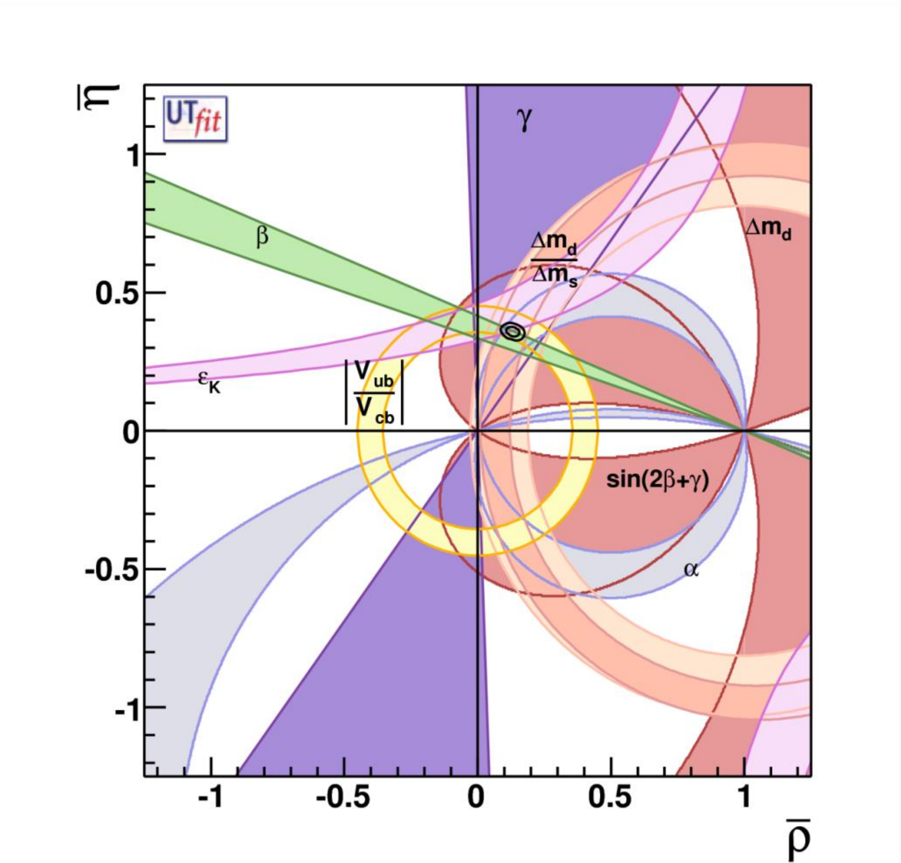
INTERLUDE: CP-Violation in Standard Model

- In the Standard Model, charged weak interactions among quarks are codified in a 3 X 3 unitarity matrix: the **CKM Mixing Matrix**.
- The existence of this matrix conveys the fact that the quarks which participate to weak processes are a linear combination of mass eigenstates
- The unitarity conditions can be represented by triangles in the complex plane.
- For the B-Bbar system, the unitarity triangle is given by

$$V_{ud}V_{ub}^{*} + V_{cd}V_{cb}^{*} + V_{td}V_{tb}^{*} = 0$$

- Flavour Mixing and CP-Violation are described with high precision in the SM:

$S_i \sim \sin(2\beta) = 0.67 \pm 0.02$



GENUINE OBSERVABLES NOT NEEDING ΔΓ

- 1) Take $B_0 \rightarrow B_+$ as the Reference transition and call (X,Y) the observed decays at times t_1 and t_2. The CP, T and CPT transformed transitions are

Transition	$B^0 \rightarrow B_+$	$\overline{B}^0 \rightarrow B_+$	$B_+ \rightarrow B^0$	$B_+ \rightarrow \overline{B}^0$	$B_- \rightarrow \overline{B}^0$
(X,Y)	$(l^-, J/\Psi K_L)$	$(l^+, J/\Psi K_L)$	$(J/\Psi K_S, l^+)$	$(J/\Psi K_S, l^-)$	$(J/\Psi K_L, l^-)$
Transformation	Reference	CP	T	CPT	Δt

Exercise: Check that the 4 processes are experimentally independent and that Δt-exchange (in the same experimental "sample") X ⇆ Y is NOT equiv. to a symmetry

- 2)Take $B^0 \rightarrow B_-$ as the Reference transition. The CP, T and CPT transformed transitions are

Transition	$B^0 \rightarrow B_-$	$\overline{B}^0 \rightarrow B_-$	$B_- \rightarrow B^0$	$B_- \rightarrow \overline{B}^0$	$B_+ \rightarrow \overline{B}^0$
(X,Y)	$(l^-, J/\Psi K_S)$	$(l^+, J/\Psi K_S)$	$(J/\Psi K_L, l^+)$	$(J/\Psi K_L, l^-)$	$(J/\Psi K_S, l^-)$
Transformation	Reference	CP	T	CPT	Δt

➡ A second Asymmetry for each of the 3 transformations can be built!

- 3) Select (Y,X) from 1) as Reference.
- 4) Select (Y,X) from 2) as Reference.
- Only QM EPR-Entanglement and time resolution assumed.

➡ 4 Model-Independent Asymmetries for CP
⊕
4 Model-Independent Asymmetries for T

T-VIOLATING PARAMETERS

- Asymmetries in time dependent decay rates for any pair of T-conjugated transitions would be apparent through differences between $S^{\pm}_{\alpha,\beta}$ or $C^{\pm}_{\alpha,\beta}$
- Example:

  A significant difference between the $S^{+}_{\ell^+,K_S}$ and $S^{-}_{\ell^-,K_L}$ coefficients implies observation of T violation.
- In the standard model these coeficients are related as a consequence of CPT invariance and $\Delta\Gamma = 0$ [J.B., M.C.Bañuls]

$$S = S^{+}_{l^+,K_S} = -S^{+}_{l^-,K_S} = -S^{-}_{l^+,K_S} = S^{-}_{l^-,K_S} = -S^{+}_{l^+,K_L} = S^{+}_{l^-,K_L} = S^{-}_{l^+,K_L} = -S^{-}_{l^-,K_L} \approx 0.7$$

$$C = C^{+}_{l^+,K_S} = -C^{+}_{l^-,K_S} = C^{-}_{l^+,K_S} = -C^{-}_{l^-,K_S} = C^{+}_{l^+,K_L} = -C^{+}_{l^-,K_L} = C^{-}_{l^+,K_L} = -C^{-}_{l^-,K_L} \approx 0$$

- Any non-vanishing value of the asymmetry parameters

$$\Delta S^{+}_{\mathrm{T}} = S^{-}_{\ell^-,K_L} - S^{+}_{\ell^+,K_S}$$
$$\Delta S^{-}_{\mathrm{T}} = S^{+}_{\ell^-,K_L} - S^{-}_{\ell^+,K_S}$$

$$\Delta C^{+}_{\mathrm{T}} = C^{-}_{\ell^-,K_L} - C^{+}_{\ell^+,K_S}$$
$$\Delta C^{-}_{\mathrm{T}} = C^{+}_{\ell^-,K_L} - C^{-}_{\ell^+,K_S}$$

measures T violation in the time evolution between the two decays.

GENUINE CPV-ASYMMETRIES

$$A_{CP,1} = \frac{\Gamma\left(l^-, J/\Psi K_L\right) - \Gamma\left(l^+, J/\Psi K_L\right)}{+}$$

Δt

- $$A_{CP,2} = \frac{\Gamma\left(l^-, J/\Psi K_S\right) - \Gamma\left(l^+, J/\Psi K_S\right)}{+}$$

$$A_{CP,3} = \frac{\Gamma\left(J/\Psi K_L, l^-\right) - \Gamma\left(J/\Psi K_L, l^+\right)}{+}$$

Δt

$$A_{CP,4} = \frac{\Gamma\left(J/\Psi K_S, l^-\right) - \Gamma\left(J/\Psi K_S, l^+\right)}{+}$$

GENUINE TRV-ASYMMETRIES

$$A_{T,1} = \frac{\Gamma\left(l^-, J/\Psi K_L\right) - \Gamma\left(J/\Psi K_S, l^+\right)}{+}$$

$$A_{T,2} = \frac{\Gamma\left(l^-, J/\Psi K_S\right) - \Gamma\left(J/\Psi K_L, l^+\right)}{+}$$

$$A_{T,3} = \frac{\Gamma\left(J/\Psi K_L, l^-\right) - \Gamma\left(l^+, J/\Psi K_S\right)}{+}$$

$$A_{T,4} = \frac{\Gamma\left(J/\Psi K_S, l^-\right) - \Gamma\left(l^+, J/\Psi K_L\right)}{+}$$

Δt ($A_{T,1} \leftrightarrow A_{T,3}$)

Δt ($A_{T,2} \leftrightarrow A_{T,4}$)

GENUINE CPTV-ASYMMETRIES

$$A_{CPT,1} = \frac{\Gamma\left(l^-, J/\Psi K_L\right) - \Gamma\left(J/\Psi K_S, l^-\right)}{+}$$

Δt

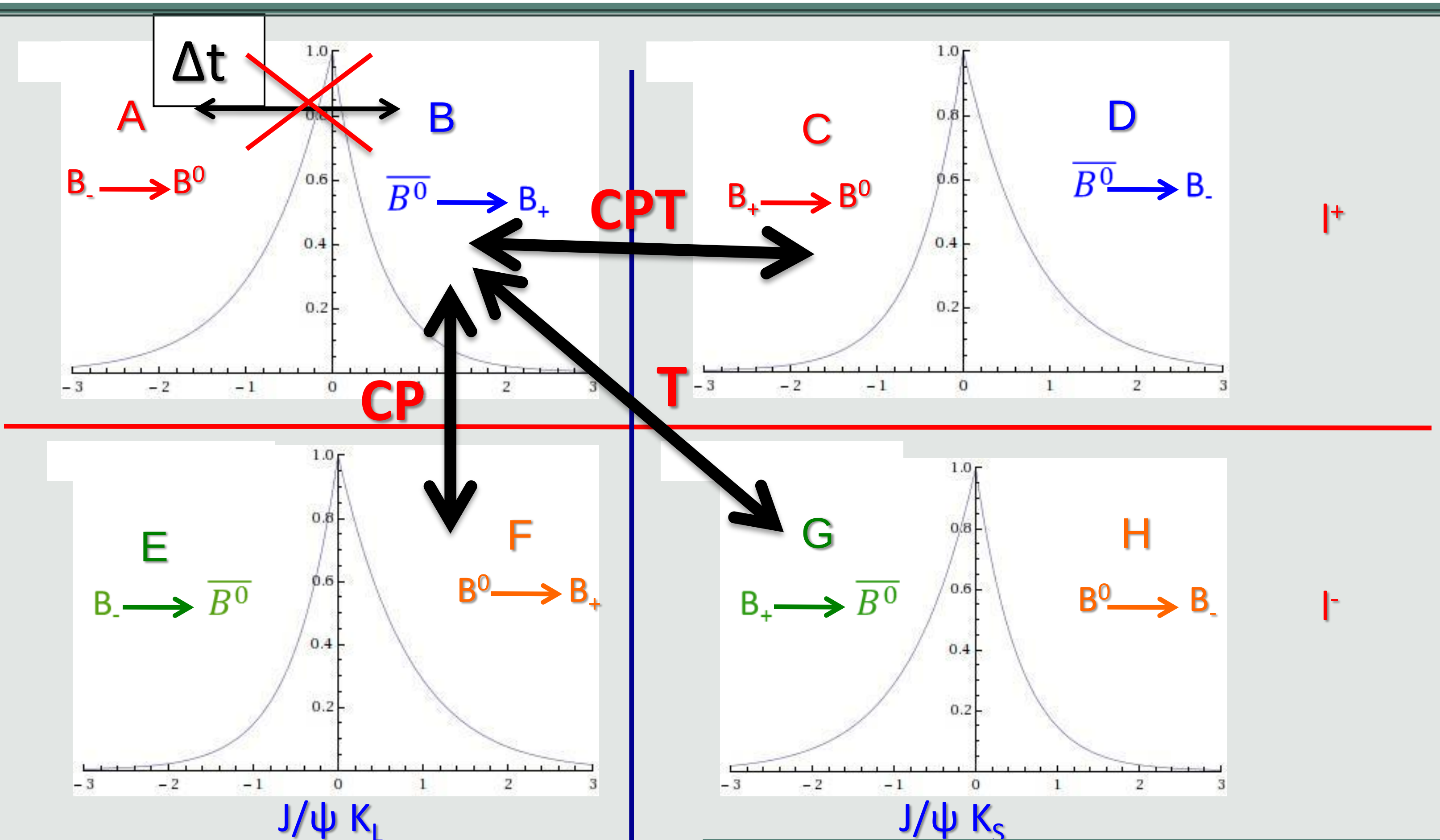
$$A_{CPT,2} = \frac{\Gamma\left(l^-, J/\Psi K_S\right) - \Gamma\left(J/\Psi K_L, l^-\right)}{+}$$

$$A_{CPT,3} = \frac{\Gamma\left(l^+, J/\Psi K_L\right) - \Gamma\left(J/\Psi K_S, l^+\right)}{+}$$

Δt

$$A_{CPT,4} = \frac{\Gamma\left(l^+, J/\Psi K_S\right) - \Gamma\left(J/\Psi K_L, l^+\right)}{+}$$

FOUNDATIONS OF THE ANALYSIS



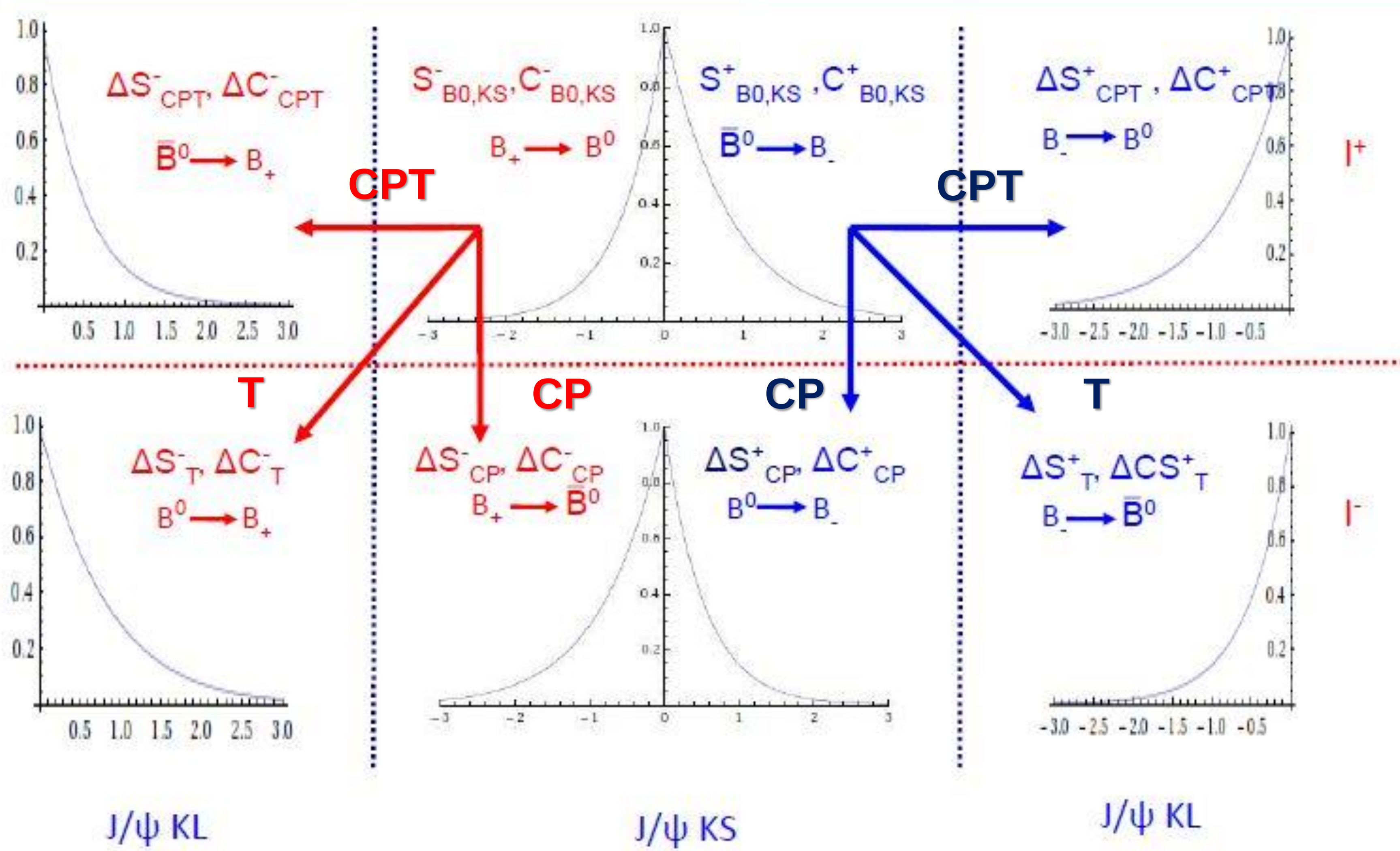
In total we can build:

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

T implies comparison of:

1) "Opposite Δt sign", i.e. , in ↔ out
2) Different CP states ($J/\Psi K_S$ vs. $J/\Psi K_L$)
3) Opposite flavour states $\left(B^0 \; vs. \; \overline{B}^0 \right)$

ΔS± , ΔC± parameters

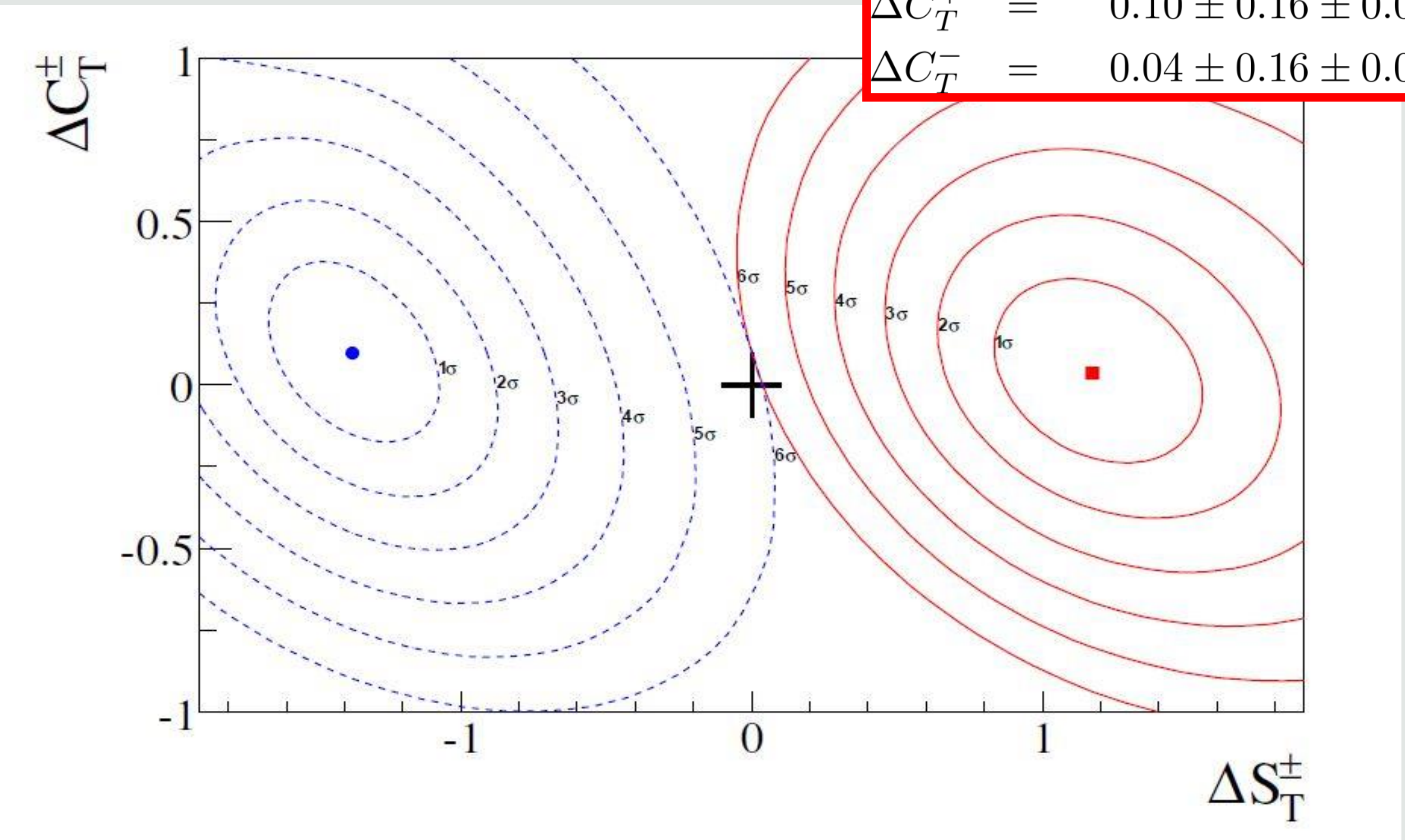


EXPERIMENTAL RESULTS

Parameter	Final result	SM expected val.
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^-	$0.04 \pm 0.14 \pm 0.08$	$0.$
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^-	$0.08 \pm 0.10 \pm 0.04$	$0.$
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}^-	$0.03 \pm 0.12 \pm 0.08$	$0.$
$S_{\ell^+,K_S^0}^+$	$0.55 \pm 0.09 \pm 0.06$	0.7
$S_{\ell^+,K_S^0}^-$	$-0.66 \pm 0.06 \pm 0.04$	-0.7
$C_{\ell^+,K_S^0}^+$	$0.01 \pm 0.07 \pm 0.05$	$0.$
$C_{\ell^+,K_S^0}^-$	$-0.05 \pm 0.06 \pm 0.03$	$0.$

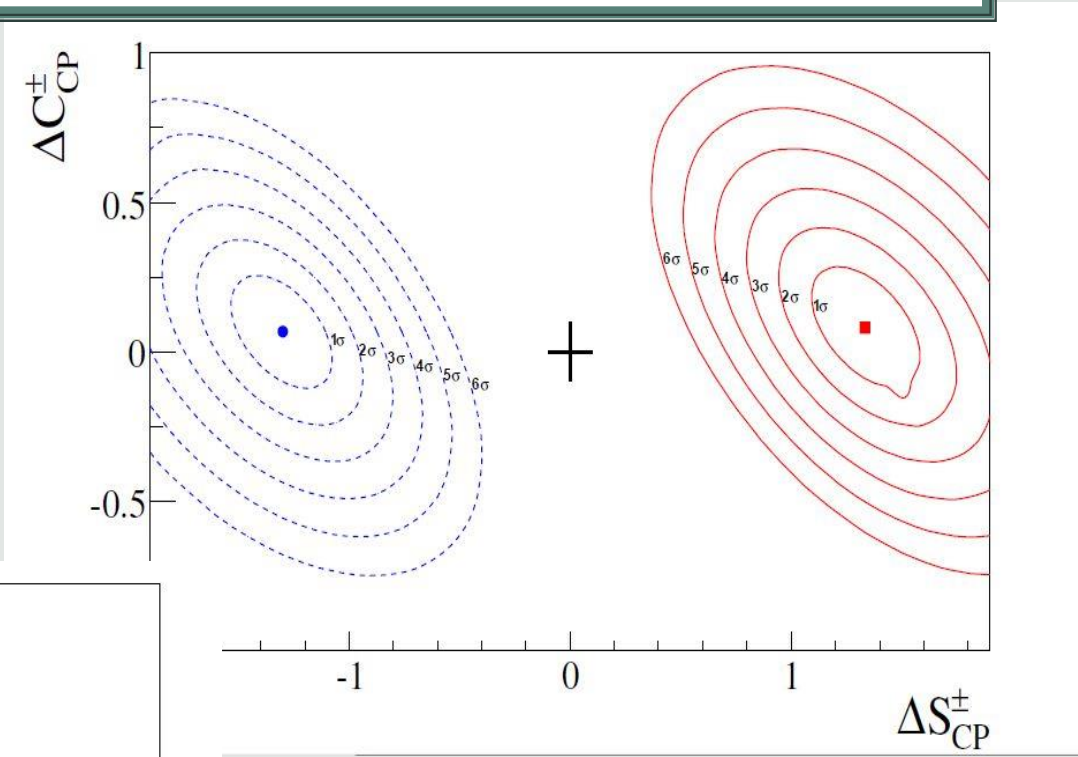
INTERPRETATION OF THE RESULTS

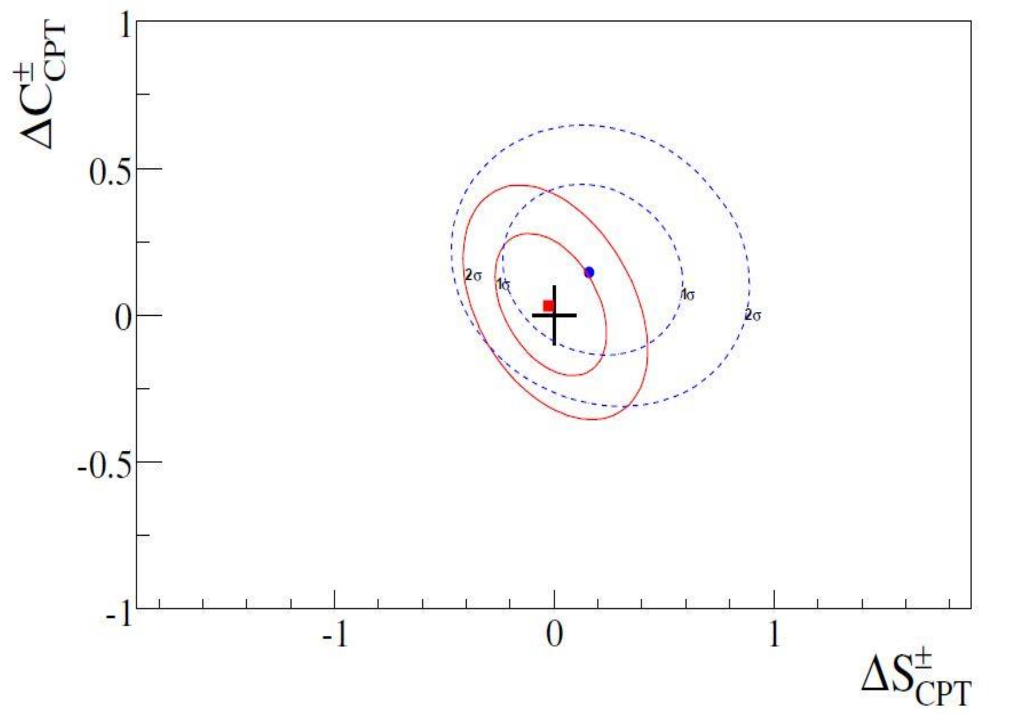
$$\Delta S_T^+ = -1.37 \pm 0.14 \pm 0.06$$
$$\Delta S_T^- = 1.17 \pm 0.18 \pm 0.11$$
$$\Delta C_T^+ = 0.10 \pm 0.16 \pm 0.08$$
$$\Delta C_T^- = 0.04 \pm 0.16 \pm 0.08$$



INTERPRETATION OF THE RESULTS

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



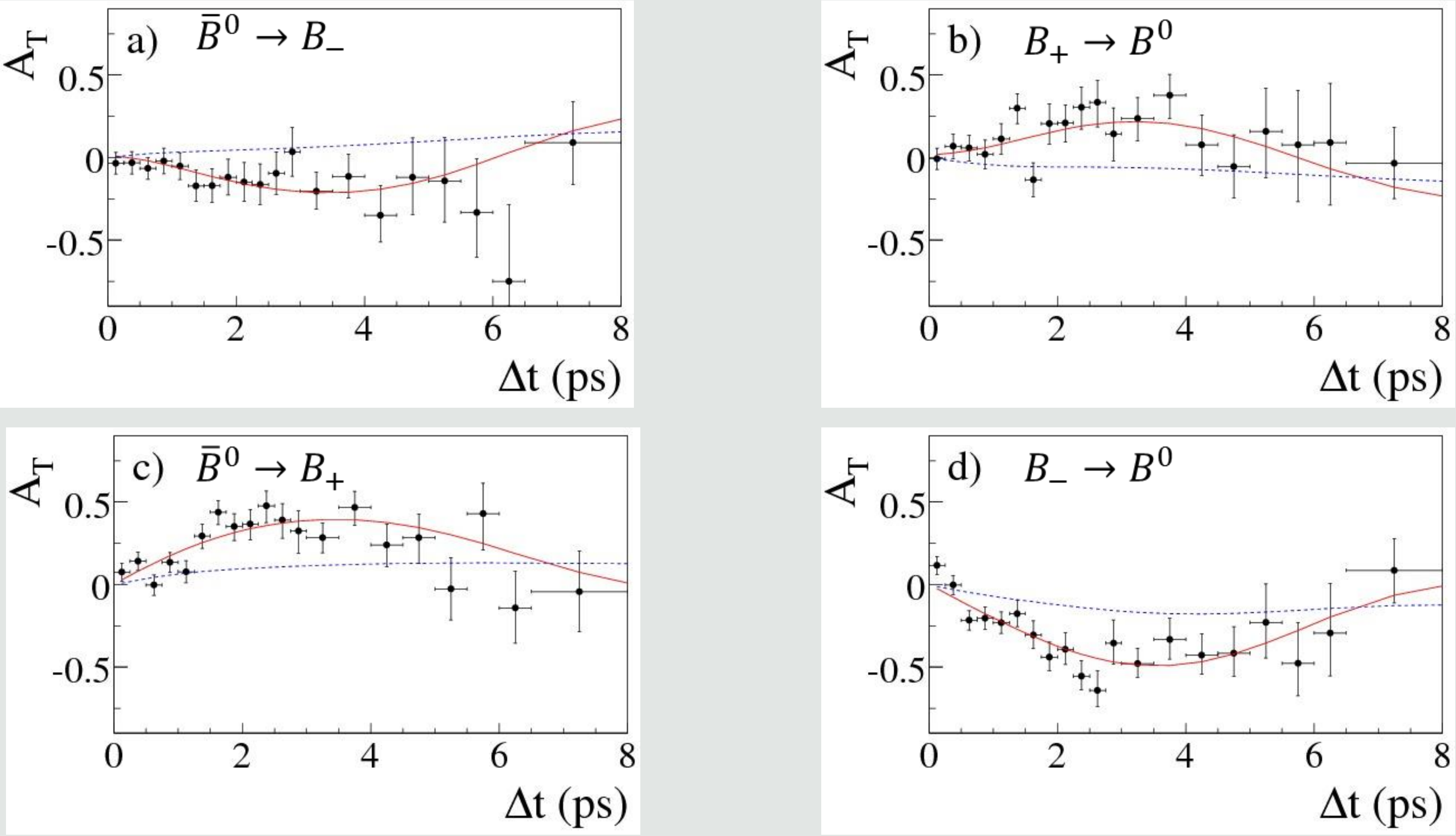


$$\Delta S^{+}_{CPT} = 0.16 \pm 0.20 \pm 0.09$$
$$\Delta S^{-}_{CPT} = -0.03 \pm 0.13 \pm 0.06$$
$$\Delta C^{+}_{CPT} = 0.15 \pm 0.17 \pm 0.07$$
$$\Delta C^{-}_{CPT} = 0.03 \pm 0.14 \pm 0.08$$

T RAW ASYMMETRIES & SIGNIFICANCE

$s^2_{NoT} = 226$	14σ
$s^2_{NoCP} = 307$	16.6σ
$s^2_{NoCPT} = 5$	0.33σ

Stat. only $\Delta\nu$=8



CONCLUSION

- Observed t-Asymmetries, like the Arrow of Time, are not T-violating:

  Genuine TRV means Asymmetry under in $\leftrightarrows$ out

- **Unique opportunity for unstable systems: EPR-Entanglement between the two neutral mesons in B, and Φ, factories $\longrightarrow$ Information transfer.**

- Flavour-CP Channels $\longrightarrow$ 8 different Decay-Intensities.

In appropriate combinations,

4 Genuine independent Asymmetries for each: CP, T, CPT

2 Independent Asymmetry parameters for each CP, T, CPT

- T-violating parameters in the time evolution of a neutral B meson, between flavour and CP decay times, have been measured by BABAR.

- **BABAR observes a large deviation of T invariance at 14 σ level, far more than needed to declare a Discovery.**

- The results are consistent with CPT invariance in the time-evolution of the $B^0 - \overline{B}^0$ system, connecting CPV and TRV in DIFFERENT transitions.

- **This is the first direct observation of Time Reversal Violation in the time evolution of any system.**

This Discovery was made possible thanks to the spectacular quantum properties of EPR <u>entangled</u> states:

"The reality of two entangled B's is much more than the sum of two separate B local realities"

THANK YOU VERY MUCH

FOR YOUR ATTENTION

$B_{-} \underrightarrow{\Delta\tau} \overline{B}^0$

$\rightarrow c\bar{c}s$