24th Rencontres de Blois

Particle Physics and Cosmology

Heavy Flavour and QCD parallel session

May 29th, 2012

CPV in $b\to s$ penguins and T,CPT violation at BABAR and BELLE

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OUTLINE

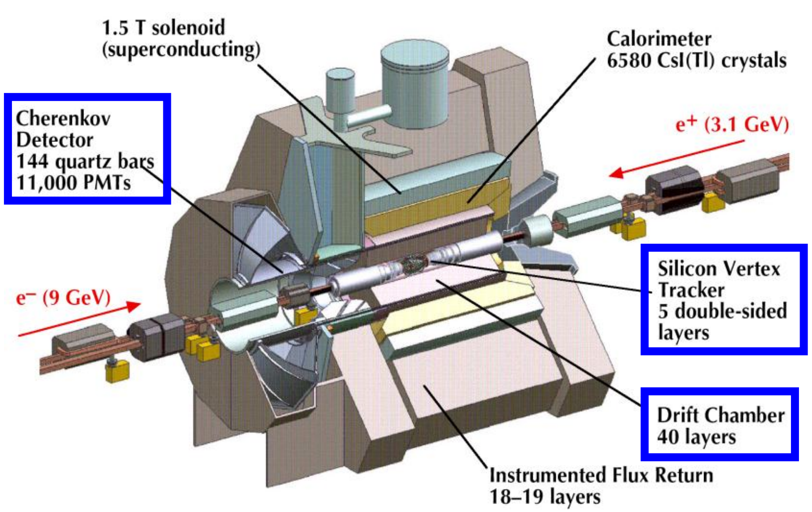
- Introduction: B factories, datasets , and analyses method
- Direct observation of time reversal violation NEW!
- Search for time-dependent CPT violation
- Study of rare $b \to s$ penguin decays
  - $B \to KKK$ CPV analyses and over the Dalitz plot
    - $B^0 \to K^0_S K^0_S K^0_S$, $B^0 \to K^0_S K^+ K^-$, $B^+ \to K^0_S K^0_S K^+$, $B^+ \to K^+ K^+ K^-$
  - $B \to K^{(*)} l^+ l^-$

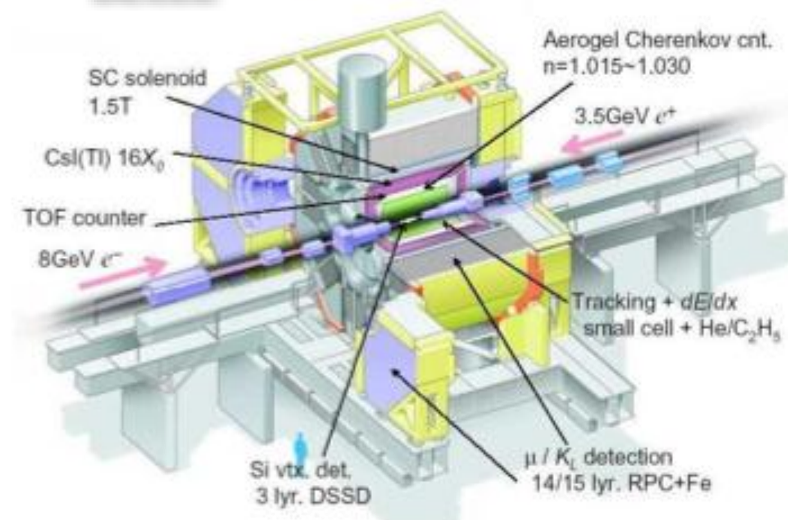
The Beauty factories

$e^+e^- \rightarrow \Upsilon(4s) \rightarrow B\bar{B}$ $B^0\bar{B}^0$ (coherent state) , or B^+B^- with $\beta\gamma$~0.5

BABAR experiment
PEPII, SLAC, USA

Belle experiment
KEKB, KEK, Japan





3.1 GeV e^+ and 9 GeV e^- beams

3.5 GeV e^+ and 8 GeV e^- beams

$\int$ Ldt~433 fb^{-1}@Υ(4S), 550 fb^{-1} total (Off, Υ(ns))

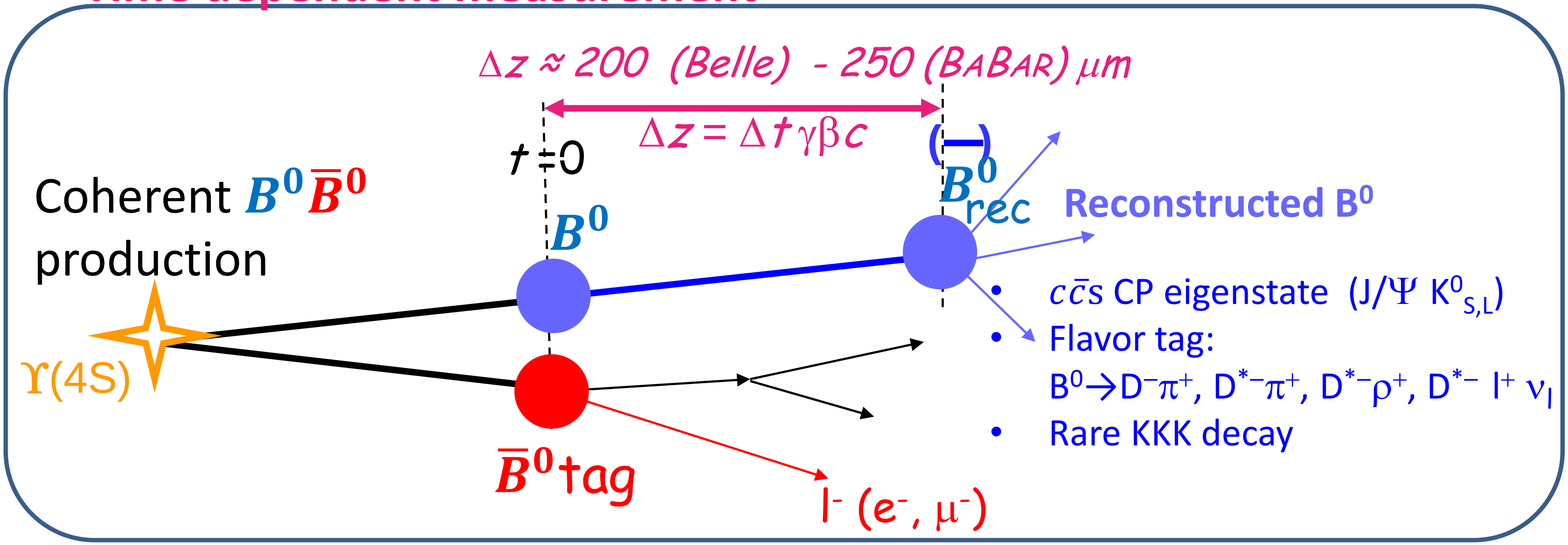
$\sim 470\ M\ B\bar{B}$, all used in analyses shown here

711 fb^{-1}@Υ(4S), > 1 ab^{-1} total (Off, Υ(ns))

$\sim 772\ M\ B\bar{B}$, $535\ M\ B\bar{B}$ used in CPT analysis

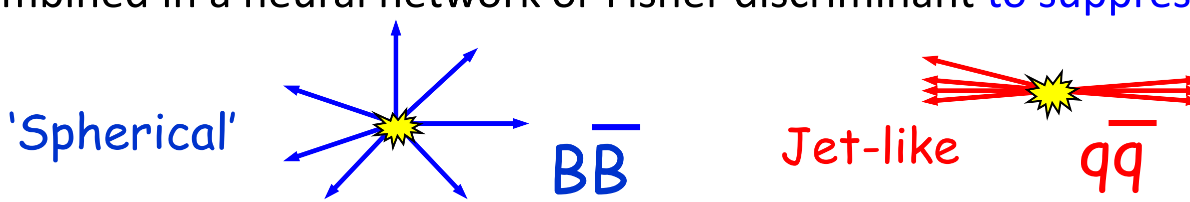
Analyses methods

Time dependent measurement



- Kinematical identification with
  - $m_{ES} = \sqrt{E_{beam}^{*2} - p_B^{*2}}$ (Beam energy substituted mass)
  - $\Delta E = E^*_B - E^*_{beam}$ (Energy difference)

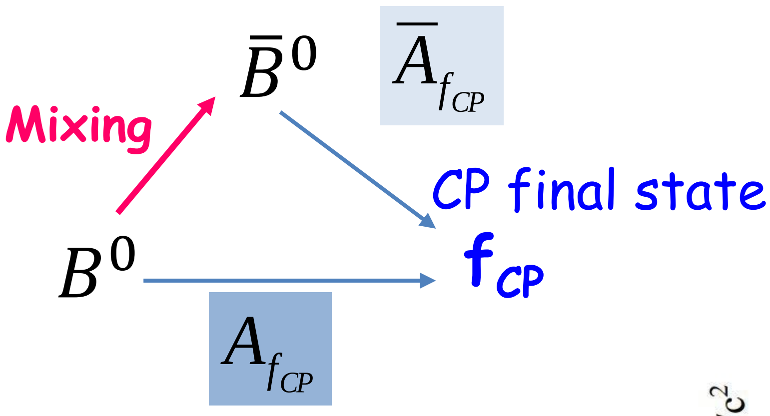
- Event-shape variables combined in a neural network or Fisher discriminant to suppress jet-like continuum events

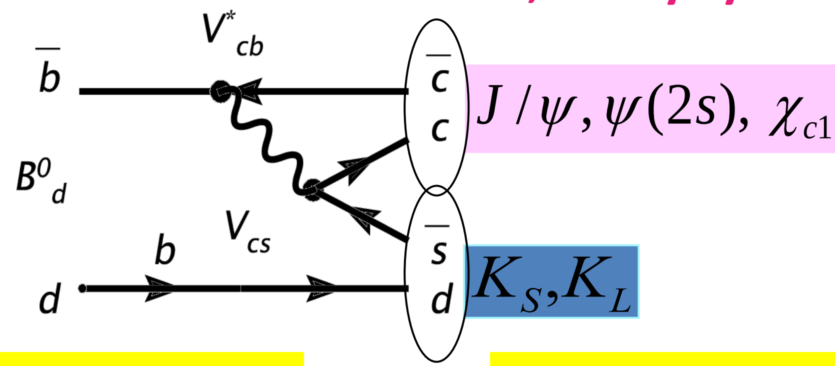


Direct observation of time reversal violation (1)

Preliminary result, shown for the first time at FPCP (last week), by Pablo Villanueva-Pérez

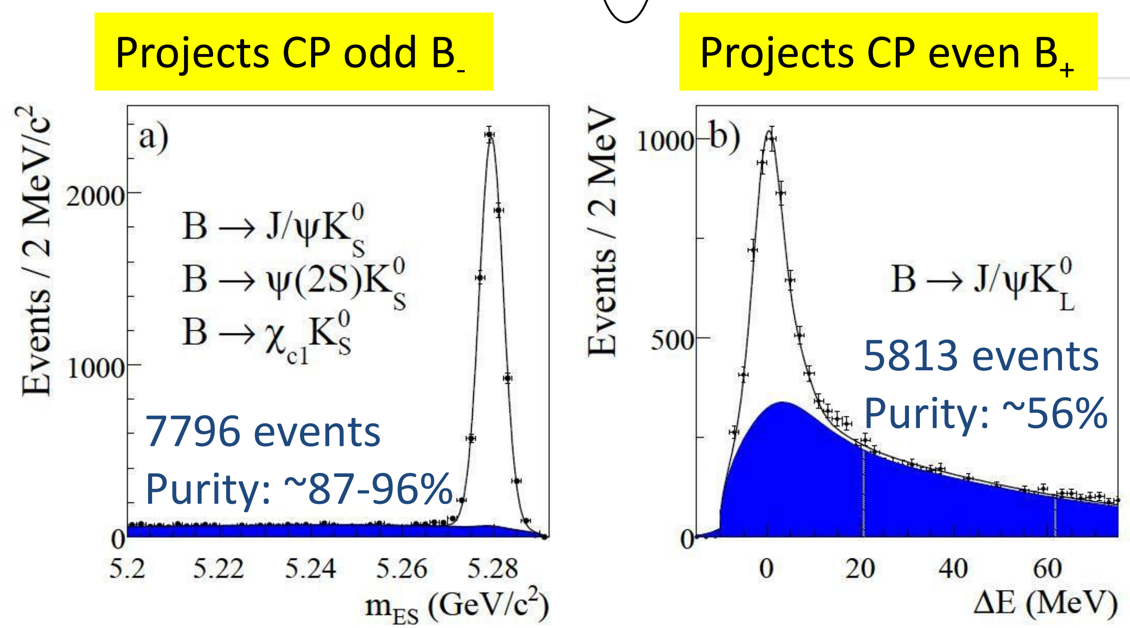
First direct observation of Time Reversal Violation, in any system.





If CPT is true, T violation is expected as CP violation is observed in the interference between decay with/without B^0 mixing. But it had never been measured before.

First direct observation of T violation ! with also CP and CPT measurements.



BABAR Preliminary

Direct observation of time reversal violation (2)

EPR entanglement from Y(4S)

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

Semileptonic decay projects:
B^0 *with* l^+, $\bar{B}^0$ *with* l^-

$J/\Psi K_L$ *projects CP even* $B_+ = \frac{1}{\sqrt{2}}[B^0 + \bar{B}^0]$

$J/\Psi K_S$ *projects CP odd* $B_- = \frac{1}{\sqrt{2}}[B^0 - \bar{B}^0]$

Final state (X, Y), one B^0 or $\bar{B}^0$, and one CP state B_+ or B_-, with decay time $t_X<t_Y$

Physical process / Reco Final state Reference (X,Y)		Physical process / Reco Final state T transformed (X,Y)	
$B^0 \to B_+$	l^-, J/Ψ K_L	$B_+ \to B^0$	J/Ψ K_S, l^+
$B^0 \to B_-$	l^-, J/Ψ K_s	$B_- \to B^0$	J/Ψ K_L, l^+
$\bar{B}^0 \to B_+$	l^+, J/Ψ K_L	$B_+ \to \bar{B}^0$	J/Ψ K_S, l^-
$\bar{B}^0 \to B_-$	l^+, J/Ψ K_S	$B_- \to \bar{B}^0$	J/Ψ K_L, l^-

4 independent T comparisons (as 4 CP and 4 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 $\bar{B}^0$).

Direct observation of time reversal violation (3)

Signal model

Assumes $\Delta\Gamma_d$ =0 but does NOT assume CPT

(for perfect time reconstruction: formula needs to be corrected for time resolution)

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

$$\alpha \in \{B^0, \bar{B}^0\};\ \beta \in \{K_S, K_L\}$$

$$\Delta t = t_{CP} - t_{flav}$$

The signal model has 8 different sets of S, C parameters

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

To be compared to the usual CPV studies : one single set

$$g_{\alpha,\beta}(\Delta t) \propto e^{-\Gamma|\Delta t|}\{1 \pm [\eta_f S\sin(\Delta m_d \Delta t) + C\cos(\Delta m_d \Delta t)]\}$$

Assumes $\Delta\Gamma_d$ =0 and CPT

In SM and CKM formalism: S ~ sin 2β (BABAR) = sin 2ϕ_1(Belle) ~ 0.7

Fit Method:

1. **Simultaneous ML fit to B^0, $\bar{B}^0$, $c\bar{c}K_S$, and $J/\psi K_L$ for Δt >0 and Δt <0 events.**
2. **Obtain the 8 sets of S, C parameters, and from these, we define T, CP and CPT violating parameters ΔS, ΔC.**

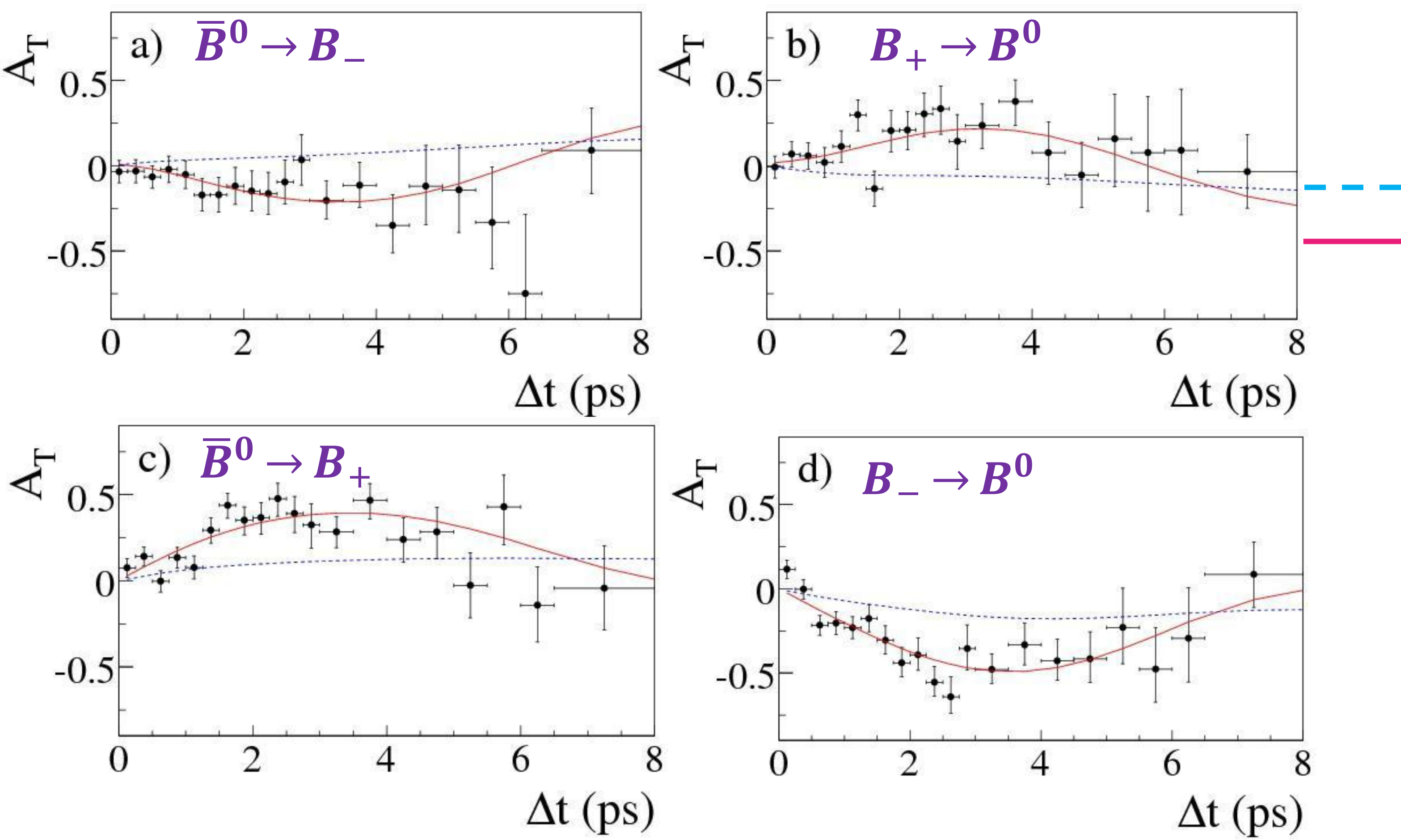
Direct observation of time reversal violation (4)

Illustrative : 4 independent T violating asymmetries

Include experimental reconstruction effects.

Neglecting reconstruction effects : $A_T \approx \frac{1}{2}\left[\Delta S_T{}^{\pm}\sin(\Delta m\,|\Delta t|) + \Delta C_T{}^{\pm}\cos(\Delta m\,|\Delta t|)\right]$

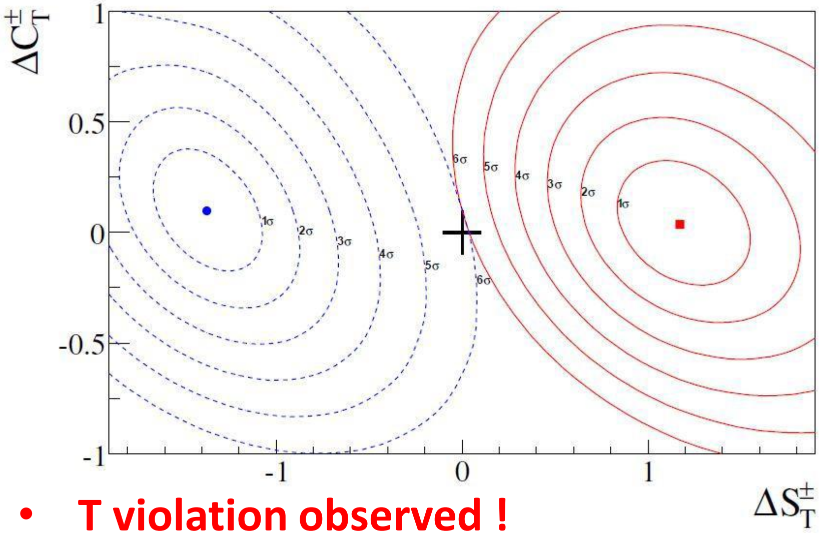
BABAR Preliminary



Direct observation of time reversal violation (5)

BABAR Preliminary

-2 ln ΔL scan with systematics included



- **T violation observed !**
- **Due to CP violation** in the interference between the decay with/wo B mixing (ΔS ≠0), but not directly in the decay (ΔC consistent with 0).
- **No CPT violation seen**

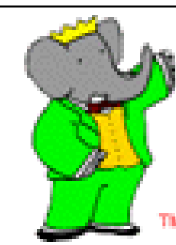
T violation seen with 14 σ significance

CP violation seen with 16.6 σ significance

No CPT violation: 0.33 σ significance

BABAR Preliminary

Parameter	Result
$\Delta S_T^+ = S^-_{\ell^- X, J/\psi K_L^0} - S^+_{\ell^+ X, c\bar{c}K_S^0}$	$-1.37 \pm 0.14 \pm 0.06$
$\Delta S_T^- = S^+_{\ell^- X, J/\psi K_L^0} - S^-_{\ell^+ X, c\bar{c}K_S^0}$	$1.17 \pm 0.18 \pm 0.11$
$\Delta C_T^+ = C^-_{\ell^- X, J/\psi K_L^0} - C^+_{\ell^+ X, c\bar{c}K_S^0}$	$0.10 \pm 0.16 \pm 0.08$
$\Delta C_T^- = C^+_{\ell^- X, J/\psi K_L^0} - C^-_{\ell^+ X, c\bar{c}K_S^0}$	$0.04 \pm 0.16 \pm 0.08$
$\Delta S_{CP}^+ = S^+_{\ell^- X, c\bar{c}K_S^0} - S^+_{\ell^+ X, c\bar{c}K_S^0}$	$-1.30 \pm 0.10 \pm 0.07$
$\Delta S_{CP}^- = S^-_{\ell^- X, c\bar{c}K_S^0} - S^-_{\ell^+ X, c\bar{c}K_S^0}$	$1.33 \pm 0.12 \pm 0.06$
$\Delta C_{CP}^+ = C^+_{\ell^- X, c\bar{c}K_S^0} - C^+_{\ell^+ X, c\bar{c}K_S^0}$	$0.07 \pm 0.09 \pm 0.03$
$\Delta C_{CP}^- = C^-_{\ell^- X, c\bar{c}K_S^0} - C^-_{\ell^+ X, c\bar{c}K_S^0}$	$0.08 \pm 0.10 \pm 0.04$
$\Delta S_{CPT}^+ = S^-_{\ell^+ X, J/\psi K_L^0} - S^+_{\ell^+ X, c\bar{c}K_S^0}$	$0.16 \pm 0.20 \pm 0.09$
$\Delta S_{CPT}^- = S^+_{\ell^+ X, J/\psi K_L^0} - S^-_{\ell^+ X, c\bar{c}K_S^0}$	$-0.03 \pm 0.13 \pm 0.06$
$\Delta C_{CPT}^+ = C^-_{\ell^+ X, J/\psi K_L^0} - C^+_{\ell^+ X, c\bar{c}K_S^0}$	$0.15 \pm 0.17 \pm 0.07$
$\Delta C_{CPT}^- = C^+_{\ell^+ X, J/\psi K_L^0} - C^-_{\ell^+ X, c\bar{c}K_S^0}$	$0.03 \pm 0.14 \pm 0.08$



Search for time dependent CPT violation (1)

BELLE

PRD 85, 071105(R) (2012) $\quad$ **535 $M\ B\overline{B}$**

Measurement of CPT violating z parameter and $\Delta\Gamma_d/\Gamma_d$

Im(**z**) and /or Re (**z**) ≠ 0 ⇔ CPT violation in $B^0 - \bar{B}^0$ mixing

Mass eigenstates:

$|B_L\rangle = p\sqrt{1-\boldsymbol{z}}\,|B^0\rangle + q\sqrt{1+\boldsymbol{z}}\,|\overline{B^0}\rangle$ $\qquad \Delta\Gamma_d = \Gamma_H - \Gamma_L$

$|B_H\rangle = p\sqrt{1+\boldsymbol{z}}\,|B^0\rangle - q\sqrt{1-\boldsymbol{z}}\,|\overline{B^0}\rangle$ $\qquad \Gamma_d = (\Gamma_H + \Gamma_L)/2$

Flavor tag one B meson using semileptonic decay and reconstruct second B meson into CP or flavor final states:

- $c\bar{c}s$ CP eigenstates : $J/\Psi\ K^0_{S,L}$
- Flavor state : $B^0 \rightarrow D^-\pi^+$, $D^{*-}\pi^+$, $D^{*-}\rho^+$, $D^{*-}\ l^+\ \nu_l$

Previous BABAR and Belle measurements use dilepton events (2 semileptonic decays).
Most precise previous measurement from BABAR with 232 M $B\bar{B}$:
« Search for T, CP, and CPT violation in $B^0\bar{B}^0$ mixing with inclusive Dilepton events » PRL 96, 251802 (2006).

This new Belle measurement improves the overall precision by factors of 1.3 to 2.0 for all parameters.

Search for time dependent CPT violation (2)

BELLE

Δt distribution with CP and CPT violation, applies to any neutral B decay

$$P(\Delta t, f_{rec}, f_{tag}) = \frac{\Gamma_d}{2} e^{-\Gamma_d|\Delta t|} \times$$

$$\left[\frac{|a_+|^2 + |a_-|^2}{2} \cosh\frac{\Delta\Gamma_d}{2}\Delta t - Re(a_+ a_-^*) \sinh\frac{\Delta\Gamma_d}{2}\Delta t + \frac{|a_+|^2 - |a_-|^2}{2} \cos\Delta m_d \Delta t - Im(a_+ a_-^*) \sin\Delta m_d \Delta t\right]$$

$$a_+ = \bar{A}_{tag} A_{rec} - A_{tag}\bar{A}_{rec};$$

$$a_- = \sqrt{1 - z^2}\left(\frac{p}{q} A_{tag} A_{rec} - \frac{q}{p}\bar{A}_{tag}\bar{A}_{rec}\right) + z\left(\bar{A}_{tag} A_{rec} + A_{tag}\bar{A}_{rec}\right)$$

$$A_{tag} = \langle f_{tag}|H_d|B^0\rangle;\ \bar{A}_{tag} = \langle f_{tag}|H_d|\bar{B}^0\rangle;\ A_{rec} = \langle f_{rec}|H_d|B^0\rangle;\ \bar{A}_{rec} = \langle f_{rec}|H_d|\bar{B}^0\rangle;$$

Simultaneous ML fit of Δt distributions for different decay modes to extract main physics parameters : **Re (z), Im (z), $\Delta\Gamma_d/\Gamma_d$** and τ_{B^0}, τ_{B^+}, Δm_d, $|\lambda_{CP}|$, $\arg(\lambda_{CP}\eta_{CP})$

With $\lambda_{CP} = \frac{q}{p} \times \frac{A(B^0 \to f_{CP})}{A(\bar{B}^0 \to f_{CP})}$ and Im $(\eta_{CP}\lambda_{CP})$~$\sin(2\phi_1)=\sin(2\beta)$

B_{rec} decay modes (events counts)	Sensitive mainly to
$J/\psi K^0_S$ (7,713) $J/\psi K^0_L$ (10,966)	Re(z) and $\Delta\Gamma_d/\Gamma_d$
$D^-\pi^+$ (39,366) ; $D^{*-}\pi^+$ (46,292) $D^{*-}\rho^+$ (45,913) ; $D^{*-} l^+\nu_l$ (383,818)	Im (z)

Search for time dependent CPT violation (3)

$$\mathcal{R}e(z) = [+1.9 \pm 3.7(\text{stat}) \pm 3.3(\text{syst})] \times 10^{-2},$$
$$\mathcal{I}m(z) = [-5.7 \pm 3.3(\text{stat}) \pm 3.3(\text{syst})] \times 10^{-3},$$
$$\Delta\Gamma_d/\Gamma_d = [-1.7 \pm 1.8(\text{stat}) \pm 1.1(\text{syst})] \times 10^{-2},$$

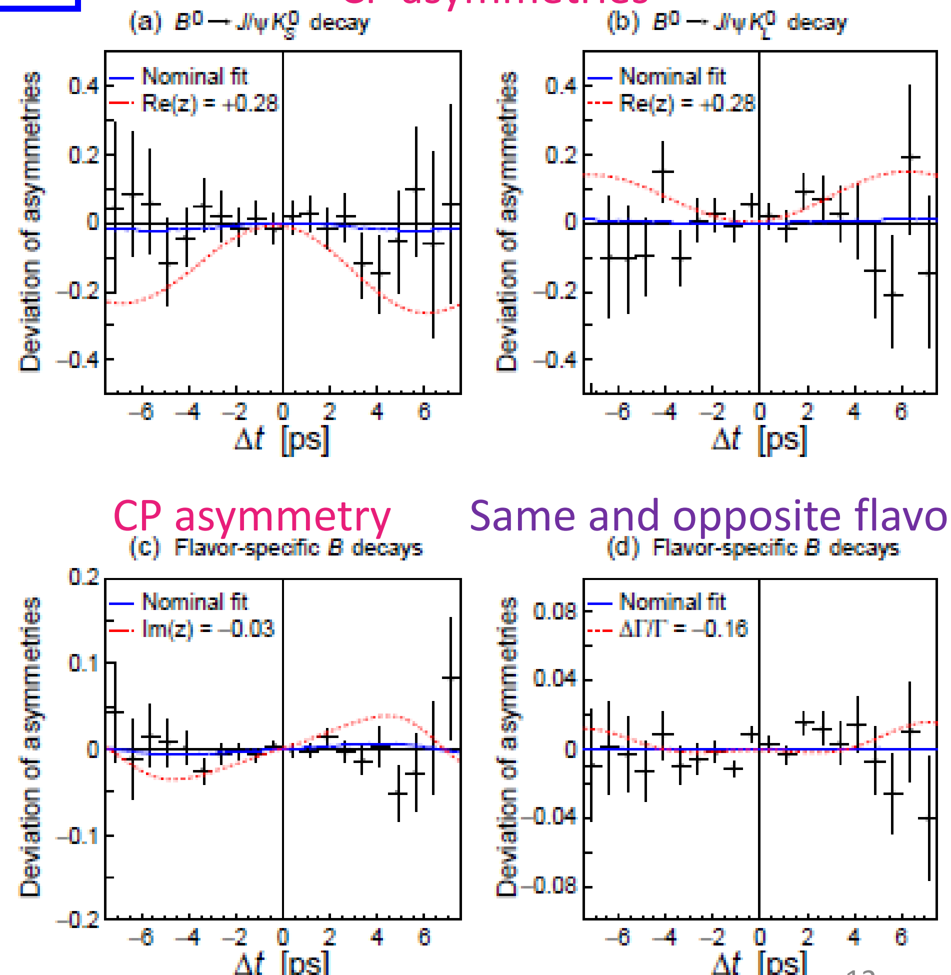
PRD 85, 071105(R) (2012)

Consistent with zero

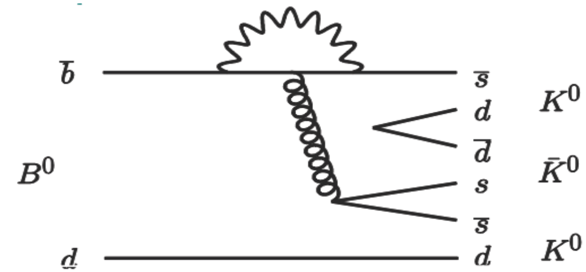
Systematic errors

Source	$\delta(\mathcal{R}e(z))$	$\delta(\mathcal{I}m(z))$	$\delta(\Delta\Gamma_d/\Gamma_d)$
Vertex reconstruction	0.008	0.0028	0.009
Δt-resolution function	0.003	0.0004	0.002
Tag-side interference	0.028	0.0006	0.001
CSD effect	0.004	0.0008	0.003
Fit bias	0.012	0.0013	0.005
Signal fraction	0.004	0.0002	0.002
Background Δt shape	0.005	0.0001	0.002
Others	0.001	< 0.0001	0.002
Total	0.033	0.0033	0.011

CP asymmetries



B→KKK decays



- Modes dominated by penguin diagram : sensitive to new physics
- Related to measurement of $\sin(2\beta_{eff})$
- Study of Dalitz plot structure : also look for controversial resonance f_X (1500), wide structure in K^+K^- mass seen in past $B^0 \to K^0_S K^+ K^-$ and $B^+ \to K^+ K^+ K^-$ BABAR and Belle measurements. Found unnecessary according to new analyses shown here.

1) $B^0 \to K^0_S K^0_S K^0_S$

PRD 85, 054023 (2012)

« Amplitude analysis and measurement of the time-dependent CP asymmetry »

- First results on Dalitz plot structure in this final state (time integrated)
- Improved measurement of time CP-violation parameters in this decay.

2) $B^0 \to K^0_S K^+ K^-$, $B^+ \to K^0_S K^0_S K^+$, $B^+ \to K^+ K^+ K^-$

arXiv:1201.5897v2 [hep-ex] Accepted by PRD

« Study of CP violation in Dalitz plot analyses»

- First ever Dalitz plot of $B^+ \to K^0_S K^0_S K^+$

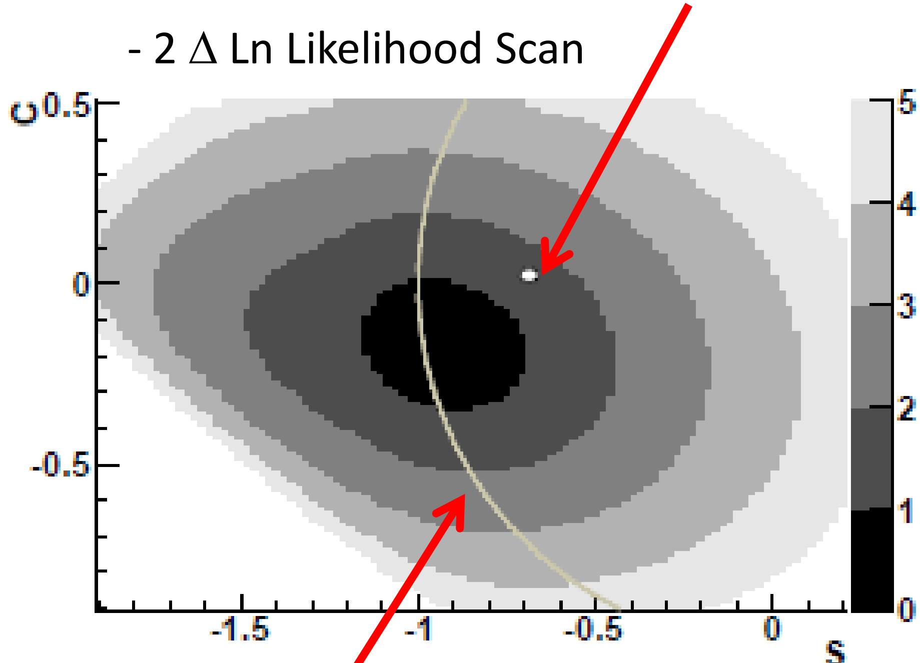
PRD 85, 054023 (2012)

$B^0 \to K^0_S K^0_S K^0_S$

- CP eigenstate so CPV study possible without looking at Dalitz plot
- 3 $K^0{}_S \to \pi^+\pi^-$ or (2 $K^0{}_S \to \pi^+\pi^-$ and 1 $K^0{}_S \to \pi^0\pi^0$)
- Fit finds 200 ± 15 signal events among 505 candidates
- Time Dependent CP analysis : CP conservation excluded at 3.8 σ

First evidence for CPV in this mode

BABAR $B^0 \to c\bar{c}K^{(*)}$ Value



~ sin(2β^{eff})

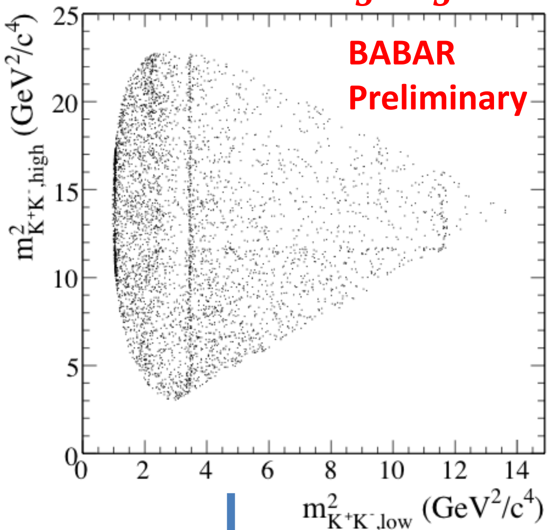
$$\mathcal{S} = -0.94\,^{+0.24}_{-0.21},$$
$$\mathcal{C} = -0.17 \pm 0.18$$

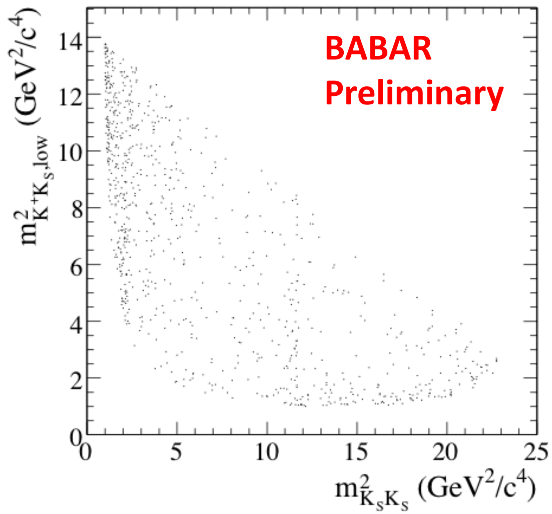
Physical boundary

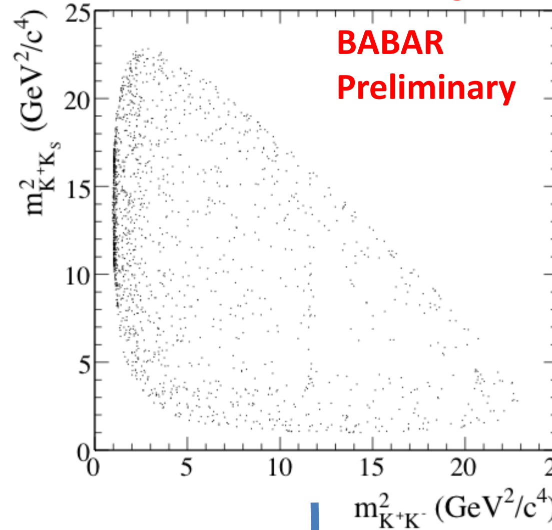
N(sig) ~ 5300 — $B^+ \rightarrow K^+K^0{}_SK^0{}_S$

N(sig) ~ 600 — $B^+ \rightarrow K^+K^0{}_SK^0{}_S$

N(sig) ~ 1400 — $B^0 \rightarrow K^+K^-K^0{}_S$





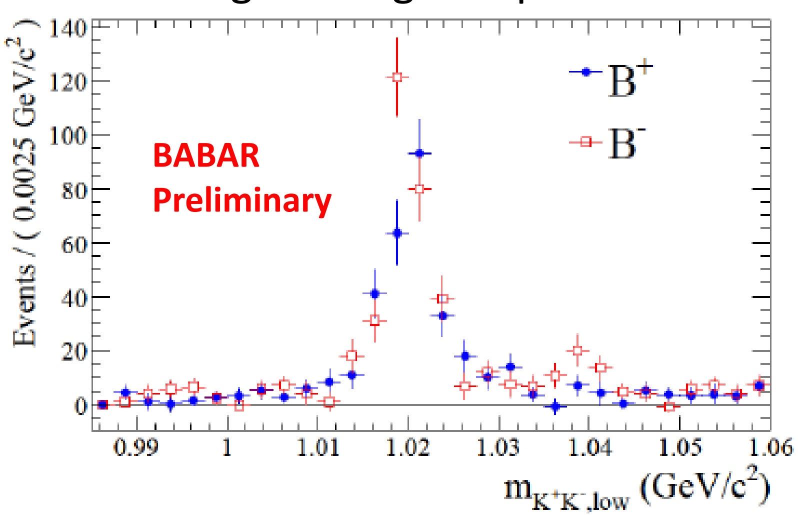


BABAR Preliminary

$B^+ \rightarrow \phi K^+$: A_{CP}=(12.8 ±4.4 ±1.3)% ; zero excluded at 2.8 σ, SM predicts ~(0-4.7)%

$B^0 \rightarrow \phi K_S$: (charmonium β=21.4 ± 0.8 deg)

Signal weighted plot



Component	β_{eff} (deg)	$A_{CP}(=-C)(\%)$
$\phi(1020)K^0_S$	$21 \pm 6 \pm 2$	$-5 \pm 18 \pm 5$
$f_0(980)K^0_S$	$18 \pm 6 \pm 4$	$-28 \pm 24 \pm 9$
Other	$20.3 \pm 4.3 \pm 1.2$	$-2 \pm 9 \pm 3$

arXiv:1201.5897v2 [hep-ex] Accepted by PRD

BABAR Preliminary

$A_{CP} \sim \eta_{CP} \sin(2\beta^{eff}) \times \sin(\Delta m \Delta t)$

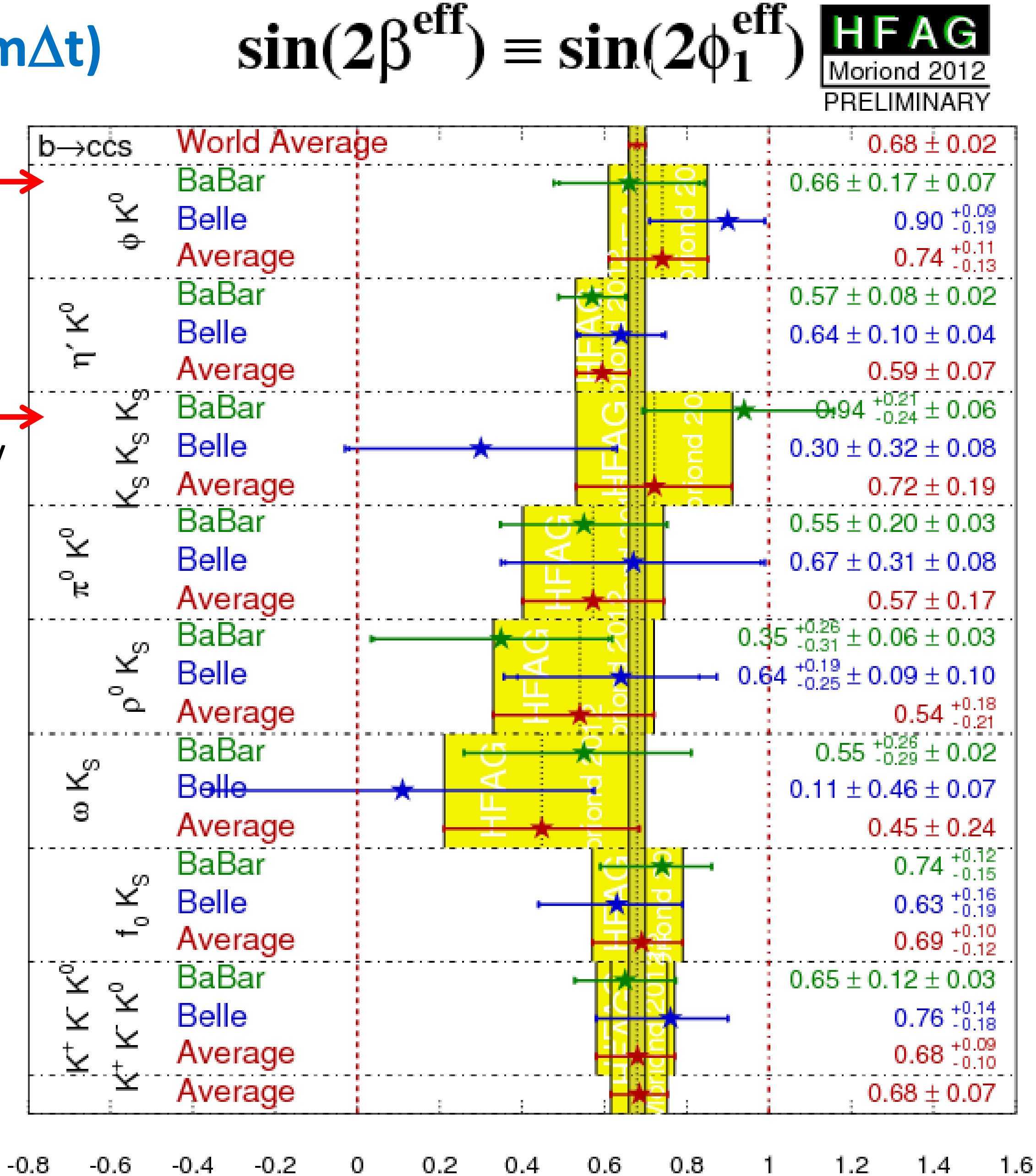
$\sin(2\beta^{eff}) \equiv \sin(2\phi_1^{eff})$

ϕK^0 clean theoretically

New results shown in this talk

$K^0{}_S\, K^0{}_S\, K^0{}_S$ clean theoretically

BABAR Preliminary

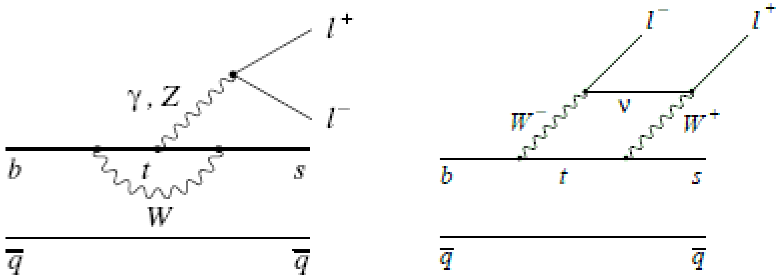


Study of B→ $K^{(*)}l^+l^-$ decays

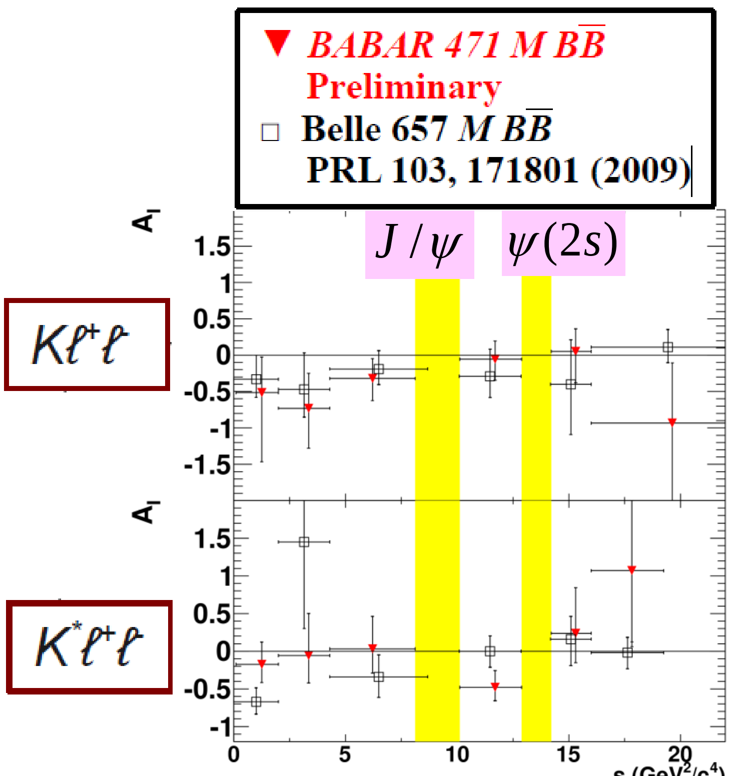
Preliminary

Very sensitive to new physics

arXiv:1204:3933v1 [hep-ex] submitted to PRD



$K_s e^+e^-$, $K^+e^+e^-$, $K_s\mu^+\mu^-$, $K^+\mu^+\mu^-$,
$K^{*+}(\rightarrow K_s\pi^+)e^+e^-$, $K^{*0}(\rightarrow K^+\pi^-)e^+e^-$,
$K^{*+}(\rightarrow K_s\pi^+)\mu^+\mu^-$, $K^{*0}(\rightarrow K^+\pi^-)\mu^+\mu^-$



Measurements versus ***s*** in good agreement with SM and with Belle, CDF, LHCb:

- Partial Branching Fractions
- CP asymmetries
- Lepton Flavor ratio

$\ell^+\ell^- = e^+e^-, \mu^+\mu^-$
$s \equiv (m_{\ell+\ell-})^2$

$$A_I^{K^{(*)}} \equiv \frac{\mathcal{B}(B^0 \to K^{(*)0}\ell^+\ell^-) - r_\tau \mathcal{B}(B^+ \to K^{(*)+}\ell^+\ell^-)}{\mathcal{B}(B^0 \to K^{(*)0}\ell^+\ell^-) + r_\tau \mathcal{B}(B^+ \to K^{(*)+}\ell^+\ell^-)}$$

Isospin asymmetry: at low dilepton masses, isospin asymmetries are negative as seen by Belle, the combined BABAR/Belle $K^{(*)}\ell^+\ell^-$ result indicates ~3σ effect

Conclusions

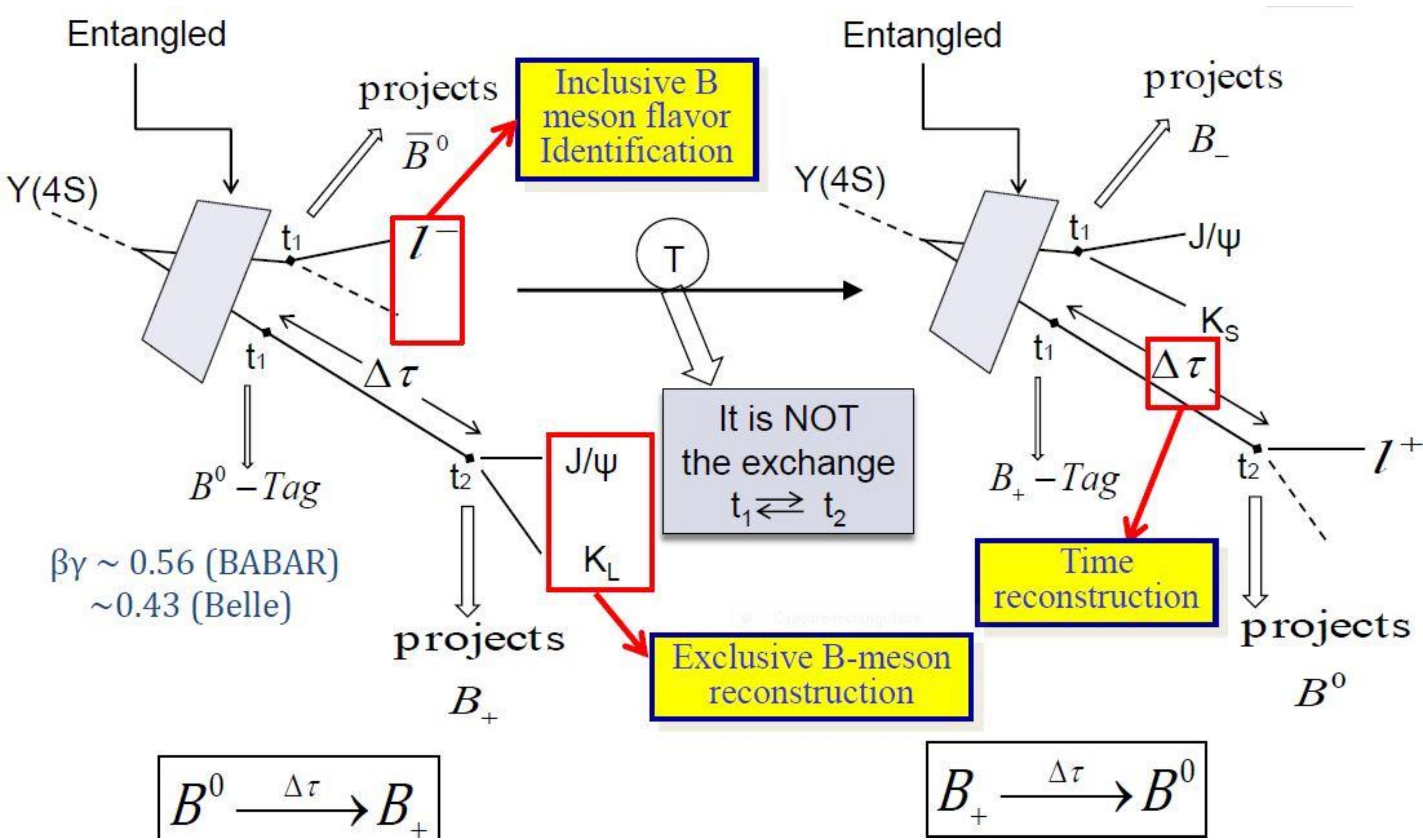
- **First direct observation of time reversal violation, in any system.**

T violation observed with a 14 σ significance (BABAR preliminary, paper to be submitted soon) due to CP violation in the interference (B^0 decay with/wo mixing). Different from CPLEAR - **Physics Letters B 444 (1998) 43** - for which T and CP violation in $K^0\overline{K}^0$mixing can not be distinguished. No hint of CPT violation, that can be measured as well.

- New search for time-dependent CPT violation published by Belle. Most accurate measurement of CPT violating z parameter in $B^0\overline{B}^0$ mixing and $\Delta\Gamma_d/\Gamma_d$, all consistent with zero.

- Recent BABAR (preliminary and published) results on rare b→s penguin decays to search for new physics.
  - Analyses of B^+ and $B^0 \rightarrow$ K K K decays over the Dalitz plot, and time dependent CP violation measurements.
    - First evidence of time-dependent CP Violation in $B^0 \rightarrow K^0_S K^0_S K^0_S$
    - Most precise measurement of $\beta^{eff}(\phi K_S) = \phi_1^{eff}(\phi K_S) = 21\pm6\pm2$ degrees
    - Indication of direct CP violation in $B^+ \rightarrow \phi K^+$ at $2.8\ \sigma$, larger than SM prediction.
  - Analysis of the electroweak penguin decays $B \rightarrow K^{(*)} l^+ l^-$. No new physics observed.

BACK-UP



Entangled
projects
Inclusive B meson flavor Identification
$\overline{B}^0$
Y(4S)
t_1
l^-
T
t_1
$\Delta\tau$
$B^0 - Tag$
t_2
J/ψ
K_L
It is NOT the exchange $t_1 \rightleftarrows t_2$
βγ ~ 0.56 (BABAR) ~0.43 (Belle)
projects
B_+
Exclusive B-meson reconstruction
$B^0 \xrightarrow{\Delta\tau} B_+$
Entangled
projects
B_-
Y(4S)
t_1
J/ψ
K_S
t_1
$\Delta\tau$
$B_+ - Tag$
t_2
l^+
Time reconstruction
projects
B^0
$B_+ \xrightarrow{\Delta\tau} B^0$

Significance of T violation only stat.

T invariance	CP invariance	CPT invariance
$\Delta S^+_{\rm T} = 0$	$\Delta S^+_{\rm CP} = 0$	$\Delta S^+_{\rm CPT} = 0$
$\Delta S^-_{\rm T} = 0$	$\Delta S^-_{\rm CP} = 0$	$\Delta S^-_{\rm CPT} = 0$
$\Delta S^+_{\rm CP} = \Delta S^+_{\rm CPT}$	$\Delta S^+_{\rm T} = \Delta S^+_{\rm CPT}$	$\Delta S^+_{\rm T} = \Delta S^+_{\rm CP}$
$\Delta S^-_{\rm CP} = \Delta S^-_{\rm CPT}$	$\Delta S^-_{\rm T} = \Delta S^-_{\rm CPT}$	$\Delta S^-_{\rm T} = \Delta S^-_{\rm CP}$
$\Delta C^+_{\rm T} = 0$	$\Delta C^+_{\rm CP} = 0$	$\Delta C^+_{\rm CPT} = 0$
$\Delta C^-_{\rm T} = 0$	$\Delta C^-_{\rm CP} = 0$	$\Delta C^-_{\rm CPT} = 0$
$\Delta C^+_{\rm CP} = \Delta C^+_{\rm CPT}$	$\Delta C^+_{\rm T} = \Delta C^+_{\rm CPT}$	$\Delta C^+_{\rm T} = \Delta C^+_{\rm CP}$
$\Delta C^-_{\rm CP} = \Delta C^-_{\rm CPT}$	$\Delta C^-_{\rm T} = \Delta C^-_{\rm CPT}$	$\Delta C^-_{\rm T} = \Delta C^-_{\rm CP}$

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.

$$\Delta\chi^2 = -2(\ln L_{No\_T\_Violation} - \ln L)$$
$$\Delta\nu = 8$$

5. CP, and CPT significance is evaluated similarly.
6. Using Gaussian approximation, we evaluate the change of likelihood in 1σ systematic variation.
$$m_j^2 = -2[\ln L(q_j, o_j) - \ln L(p_0)] / s^2_{stat,j}$$
7. We take the max$\{m_j^2\}$ and we devide our significace (s^2) by (1+ max$\{m_j^2\}$)

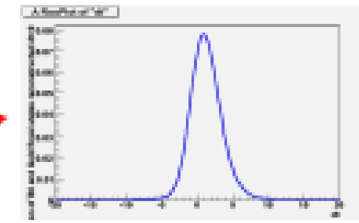
Signal model description

- General Signal PDF for the 8 intensities

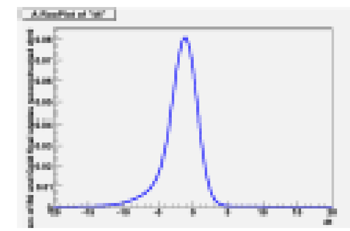
$\Delta t_{true} = t_{CP} - t_{flav}$

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

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



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



where

H(Δt)≡ Heaviside function

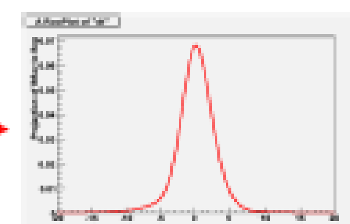
$\alpha \in \{B^0, \bar{B}^0\}$; $\beta \in \{K_S, K_L\}$ $\quad \mathcal{R}(\delta t, \sigma_{\Delta t}) \equiv$ resolution function

- The signal model has 8 different sets of S, C parameters

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

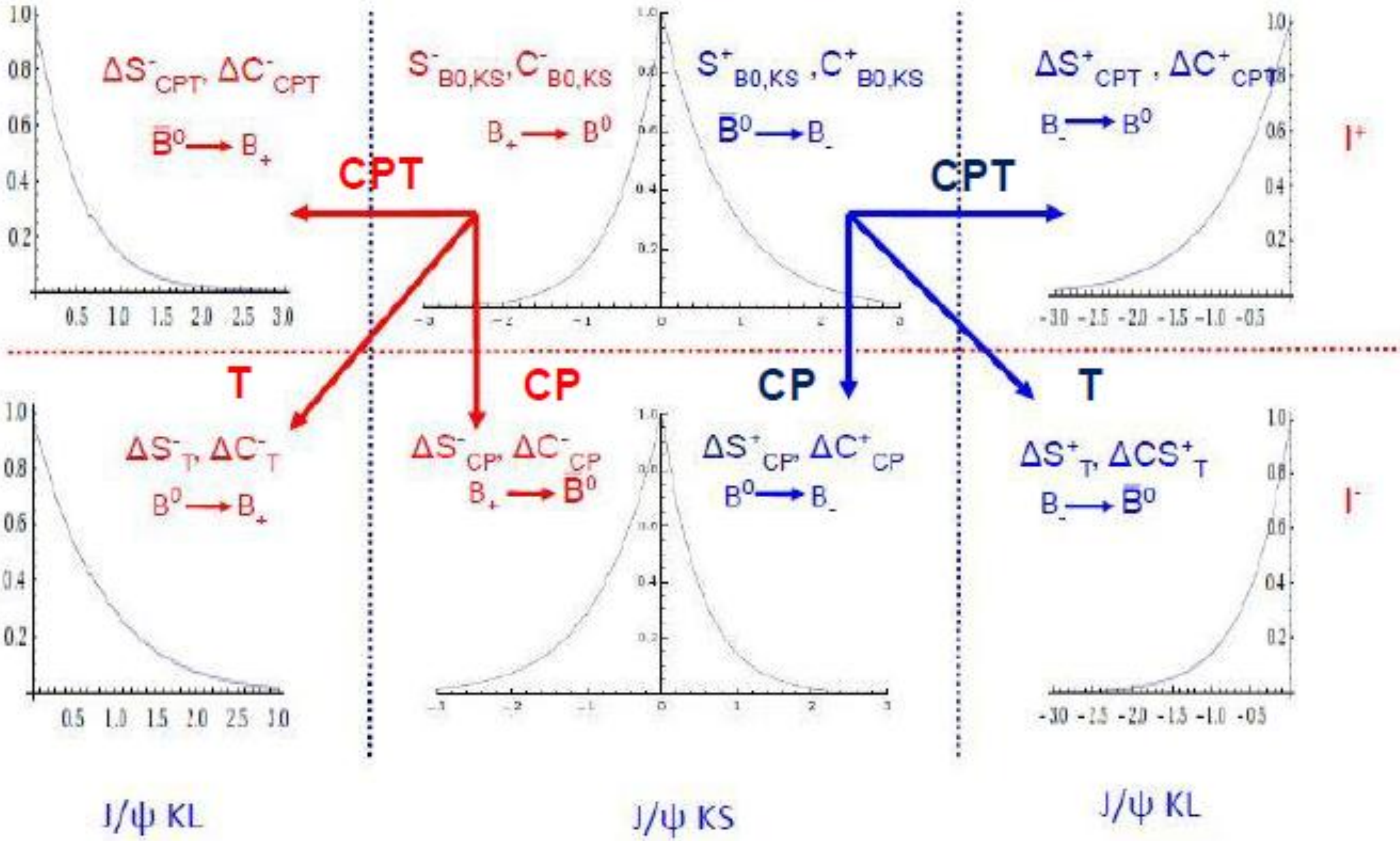
- To be compared to the usual CPV studies: 1 single set

$$g_{\alpha,\beta}(\Delta t) \propto e^{-\Gamma|\Delta t|}\{1 \pm [\eta_f S \sin(\Delta m_d \Delta t) + C\cos(\Delta m_d \Delta t)]\}$$



Assumes CPT and $\Delta\Gamma = 0$

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

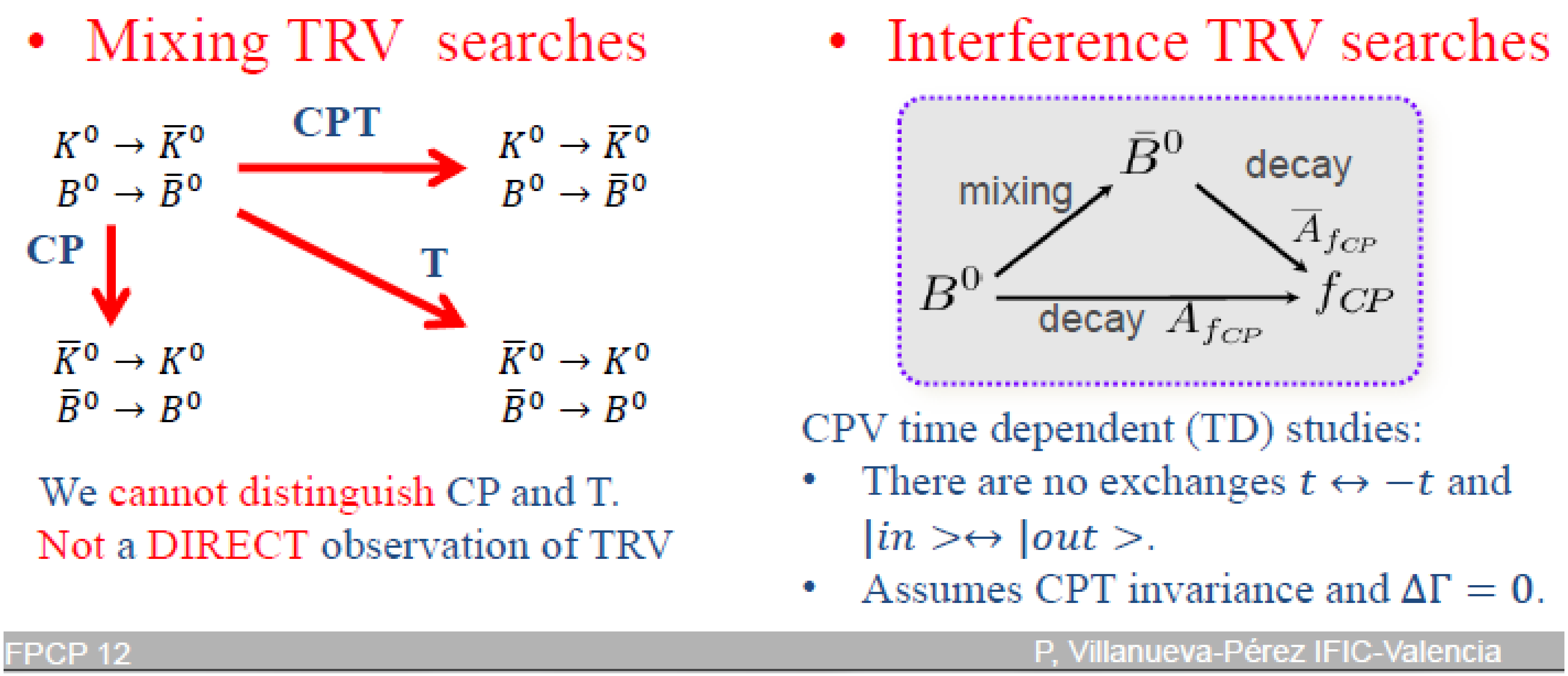


Systematic uncertainties

Systematic source	ΔS_T^+	ΔS_T^-
misID flavour	0.019	0.019
Δt resolution function	0.02	0.05
Outlier's scale factor	0.012	-0.013
m_{ES} parameters	0.012	0.0018
ΔE parameters	0.017	0.017
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	0.010	0.08
Detector and vertexing effects.	0.011	0.04
$\Delta\Gamma \neq 0$ effects	0.004	0.003
External physics parameters	0.005	0.006
Normalization effects	0.012	0.009
Total Systematics	0.06	0.11

CPLEAR - **Physics Letters B 444 (1998) 43** - used $K^0 \to \overline{K}^0$ versus $\overline{K}^0 \to K^0$, so CP and T are experimentally identical since CP [$K^0 \to \overline{K}^0$]=$\overline{K}^0 \to K^0$ = T [$K^0 \to \overline{K}^0$]

Same as measurements of |q/p| with dileptons (flavor oscillations), i.e. |q/p| is a CP and T violating parameter (in the $B^0\overline{B}^0$mixing), so we cannot conclude from it if the effect is T or CP, or both.



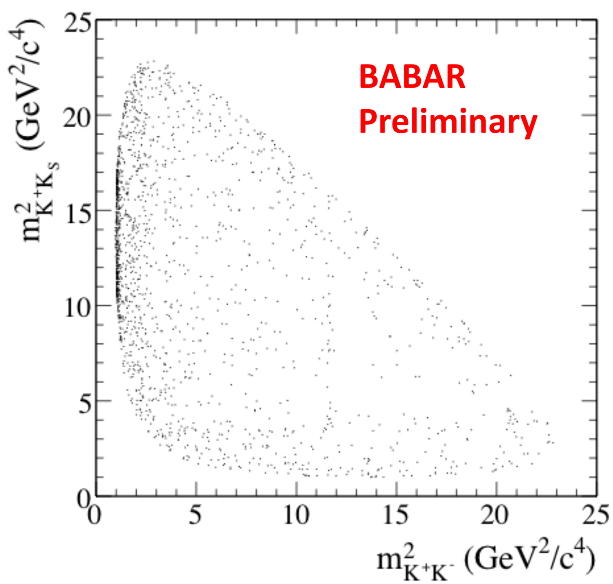
Dalitz plot analysis

$$\mathcal{A} \equiv \mathcal{A}(B \to KKK; m_{12}, m_{23}) = \sum_j a_j F_j(m_{12}, m_{23})$$

$$a_j = c_j(1 + b_j)e^{i(\phi_j + \delta_j)}$$
$$\bar{a}_j = c_j(1 - b_j)e^{i(\phi_j - \delta_j)}$$

F_j are resonant or nonresonant lineshapes: relativistic Breit-Wigner, spin-factors, etc.

From isobar coefficients can derive: partial branching fractions, A_{CP} (= $-2b/(1+b^2)$), β_{eff} (= $\beta + \delta$), etc.



N(sig) ~ 1400

$B^0 \to K^+K^-K^0{}_S$

$B^0 \to K_s^0 K_s^0 K_s^0$ Amplitude Analysis

- Significance estimated from change in log-likelihood when the magnitude of each resonance's amplitude is set to 0
- The fit fractions (FF) indicate a high degree of destructive interference

$$FF_j \equiv \frac{\int\int \left(|\mathcal{A}_j|^2 + |\overline{\mathcal{A}}_j|^2\right) ds_{12} ds_{23}}{\int\int \left(|\mathcal{A}|^2 + |\overline{\mathcal{A}}|^2\right) ds_{12} ds_{23}}$$

- Inclusive branching fraction consistent with PDG

Mode	$\mathcal{B}$ [$\times 10^{-6}$]
Inclusive $B^0 \to K_S^0 K_S^0 K_S^0$	$6.19 \pm 0.48 \pm 0.15 \pm 0.12$
$f_0(980) K_S^0$, $f_0(980) \to K_S^0 K_S^0$	$2.7\,^{+1.3}_{-1.2} \pm 0.4 \pm 1.2$
$f_0(1710) K_S^0$, $f_0(1710) \to K_S^0 K_S^0$	$0.50\,^{+0.46}_{-0.24} \pm 0.04 \pm 0.10$
$f_2(2010) K_S^0$, $f_2(2010) \to K_S^0 K_S^0$	$0.54\,^{+0.21}_{-0.20} \pm 0.03 \pm 0.52$
NR, $K_S^0 K_S^0 K_S^0$	$13.3\,^{+2.2}_{-2.3} \pm 0.6 \pm 2.1$
$\chi_{c0} K_S^0$, $\chi_{c0} \to K_S^0 K_S^0$	$0.46\,^{+0.25}_{-0.17} \pm 0.02 \pm 0.21$

Mode	Parameter	
$f_0(980) K_S^0$	FF	$0.44\,^{+0.20}_{-0.19}$
	Phase [rad]	0.09 ± 0.16
	Significance [σ]	3.0
$f_0(1710) K_S^0$	FF	$0.07\,^{+0.07}_{-0.03}$
	Phase [rad]	1.11 ± 0.23
	Significance [σ]	3.3
$f_2(2010) K_S^0$	FF	$0.09\,^{+0.03}_{-0.03}$
	Phase [rad]	2.50 ± 0.20
	Significance [σ]	3.3
NR	FF	$2.16\,^{+0.36}_{-0.37}$
	Phase [rad]	0.0
	Significance [σ]	8.0
$\chi_{c0} K_S^0$	FF	$0.07\,^{+0.04}_{-0.02}$
	Phase [rad]	0.63 ± 0.47 -
	Significance [σ]	3.9
	Total FF	$2.84\,^{+0.71}_{-0.66}$

Fit Results For Amplitude Analysis

- $B^0 \to K^+K^-K^+$ Results:

Decay mode	$\mathcal{B}(B^+ \to K^+K^-K^+) \times FF_j$ (10^{-6})	A_{CP} (%)	$\Delta\phi_j$ (deg)
$\phi(1020)K^+$	$4.48 \pm 0.22^{+0.33}_{-0.24}$	$12.8 \pm 4.4 \pm 1.3$	$23 \pm 13^{+4}_{-5}$
$f_0(980)K^+$	$9.4 \pm 1.6 \pm 2.8$	$-8 \pm 8 \pm 4$	$9 \pm 7 \pm 6$
$f_0(1500)K^+$	$0.74 \pm 0.18 \pm 0.52$		
$f_2'(1525)K^+$	$0.69 \pm 0.16 \pm 0.13$	$14 \pm 10 \pm 4$	$-2 \pm 6 \pm 3$
$f_0(1710)K^+$	$1.12 \pm 0.25 \pm 0.50$		
$\chi_{c0}K^+$	$1.12 \pm 0.15 \pm 0.06$		$-4 \pm 13 \pm 2$
NR	$22.8 \pm 2.7 \pm 7.6$	$6.0 \pm 4.4 \pm 1.9$	0 (fixed)
NR (S-wave)	$52^{+23}_{-14} \pm 27$		
NR (P-wave)	$24^{+22}_{-12} \pm 27$		

$B^+ \to K^0_s K^0_s K^+$ Results:

Decay mode	$\mathcal{B}(B^+ \to K^0_S K^0_S K^+) \times FF_j$ (10^{-6})
$f_0(980)K^+$	$14.7 \pm 2.8 \pm 1.8$
$f_0(1500)K^+$	$0.42 \pm 0.22 \pm 0.58$
$f_2'(1525)K^+$	$0.61 \pm 0.21^{+0.12}_{-0.09}$
$f_0(1710)K^+$	$0.48^{+0.40}_{-0.24} \pm 0.11$
$\chi_{c0}K^+$	$0.53 \pm 0.10 \pm 0.04$
NR (S-wave)	$19.8 \pm 3.7 \pm 2.5$

- $B^0 \to K^+K^-K^0_s$ Results:

Decay mode	$\mathcal{B}(B^0 \to K^+K^-K^0) \times FF_j$ (10^{-6})
$\phi(1020)K^0$	$3.48 \pm 0.28^{+0.21}_{-0.14}$
$f_0(980)K^0$	$7.0^{+2.6}_{-1.8} \pm 2.4$
$f_0(1500)K^0$	$0.57^{+0.25}_{-0.19} \pm 0.12$
$f_2'(1525)K^0$	$0.13^{+0.12}_{-0.08} \pm 0.16$
$f_0(1710)K^0$	$4.4 \pm 0.7 \pm 0.5$
$\chi_{c0}K^0$	$0.90 \pm 0.18 \pm 0.06$
NR	$33 \pm 5 \pm 9$
NR (S-wave)	$30 \pm 5 \pm 8$
NR (P-wave)	$3.1 \pm 0.7 \pm 0.4$