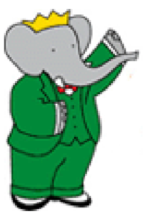
CP & T VIOLATION AT BABAR AND BELLE



Concetta Cartaro

SLAC

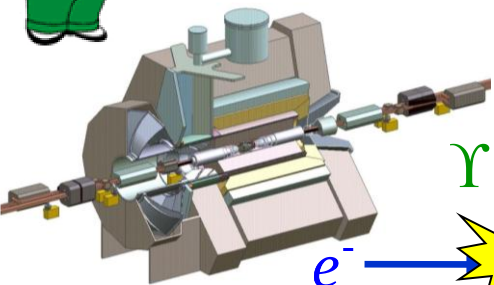
On Behalf of BaBar Collaboration

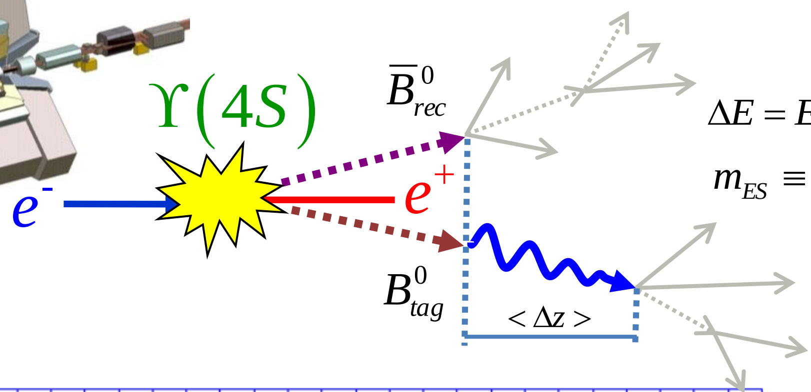
Beauty 2013

14th International Conference on B-Physics at Hadron Machines

Bologna, April 8th, 2013

B Factories Datasets

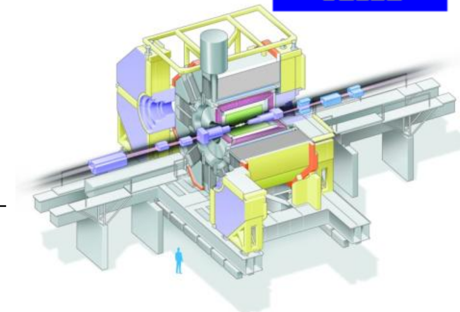


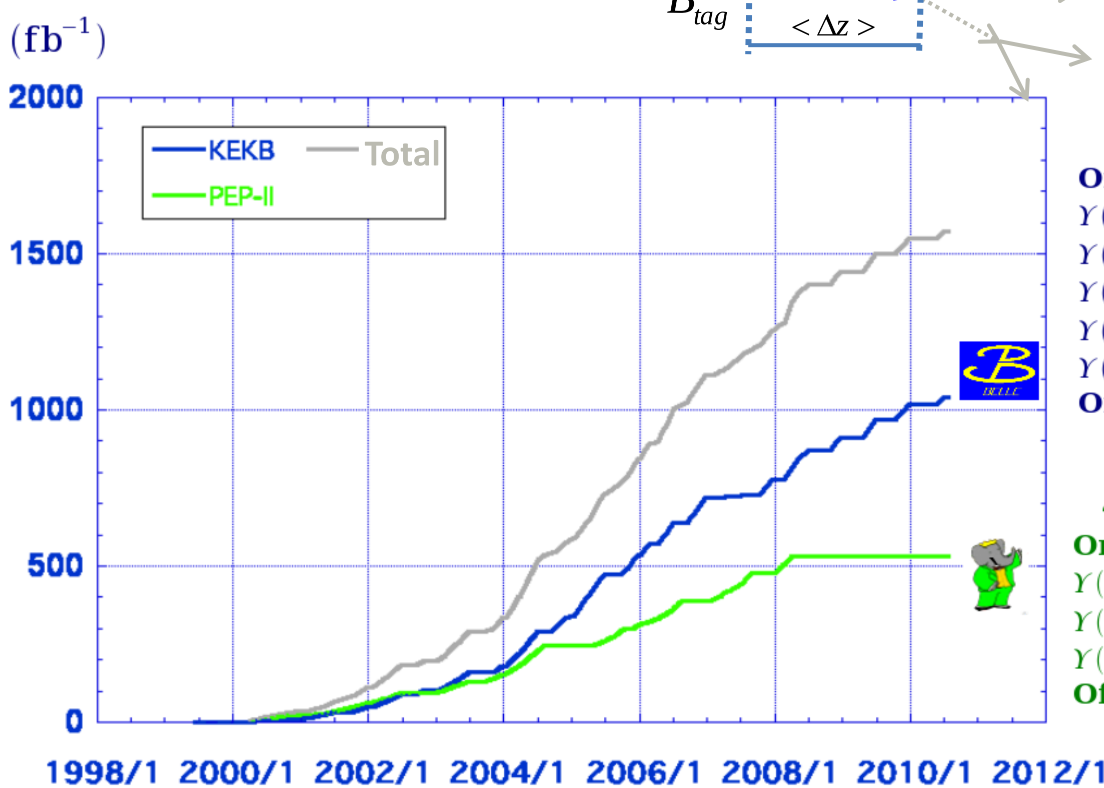


$$\Delta E = E^*_B - E^*_{beam}$$

$$m_{ES} \equiv m_{bc} = \sqrt{E^{*\,2}_{beam} - |\vec{p}^{\,*}_B|^2}$$

where $E^*_B \to E^*_{\text{beam}}$
$\vec{p}^{\,*}_B \approx 300\ \text{MeV}/c$





http://jaguar.itep.ru/external/send_file.php?type=pdf&oid=22660

$> 1\ \text{ab}^{-1}$

On resonance:
$\Upsilon(5S)$: 121 fb^{-1}
$\Upsilon(4S)$: 711 fb^{-1}
$\Upsilon(3S)$: 3 fb^{-1}
$\Upsilon(2S)$: 24 fb^{-1}
$\Upsilon(1S)$: 6 fb^{-1}
Off reson./scan:
$\sim 100\ \text{fb}^{-1}$

e^+ at 3.5 GeV
e^- at 8.0 GeV
$\beta\gamma$=0.425
Δz=200μm

$\sim 550\ \text{fb}^{-1}$

On resonance:
$\Upsilon(4S)$: 433 fb^{-1}
$\Upsilon(3S)$: 30 fb^{-1}
$\Upsilon(2S)$: 14 fb^{-1}
Off resonance:
$\sim 54\ \text{fb}^{-1}$

e^+ at 3.1 GeV
e^- at 9.0 GeV
$\beta\gamma$=0.56
Δz=250μm

$\Upsilon(1S)$ decays accessed via
$\Upsilon(2S,3S) \to \Upsilon(1S)\ \pi^+\pi^-$

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OVERVIEW

- T & CPT Violation
- CP Violation
  - Beta
    - $B \to D^*D^*$
  - Alpha
    - $B \to \rho\pi$
    - $B \to \pi\pi$, $B \to \rho\rho$
  - Gamma combination
    - $B \to DK$
  - CPV in mixing
- Summary

All results shown are based on full statistics unless stated otherwise:
470×10^6 $B\bar{B}$
772×10^6 $B\bar{B}$

T Violation: the Problem

- Identify a T-conjugate pair of processes that can be experimentally distinguished and measured to exploit the time asymmetry

$$A_T = \frac{P(|i\rangle \to |f\rangle) - P(|f\rangle \to |i\rangle)}{P(|i\rangle \to |f\rangle) + P(|f\rangle \to |i\rangle)}$$

- Measure time-dependent asymmetries making use of the quantum EPR entanglement from $\Upsilon(4S)$
  - $\Upsilon(4S)$ is a $J^{PC} = 1^{--}$ state and the $B\bar{B}$ system is produced in a P-wave
  - When the first B decays at t_1 the other B state is definite and will evolve in time until it decays at t_2

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

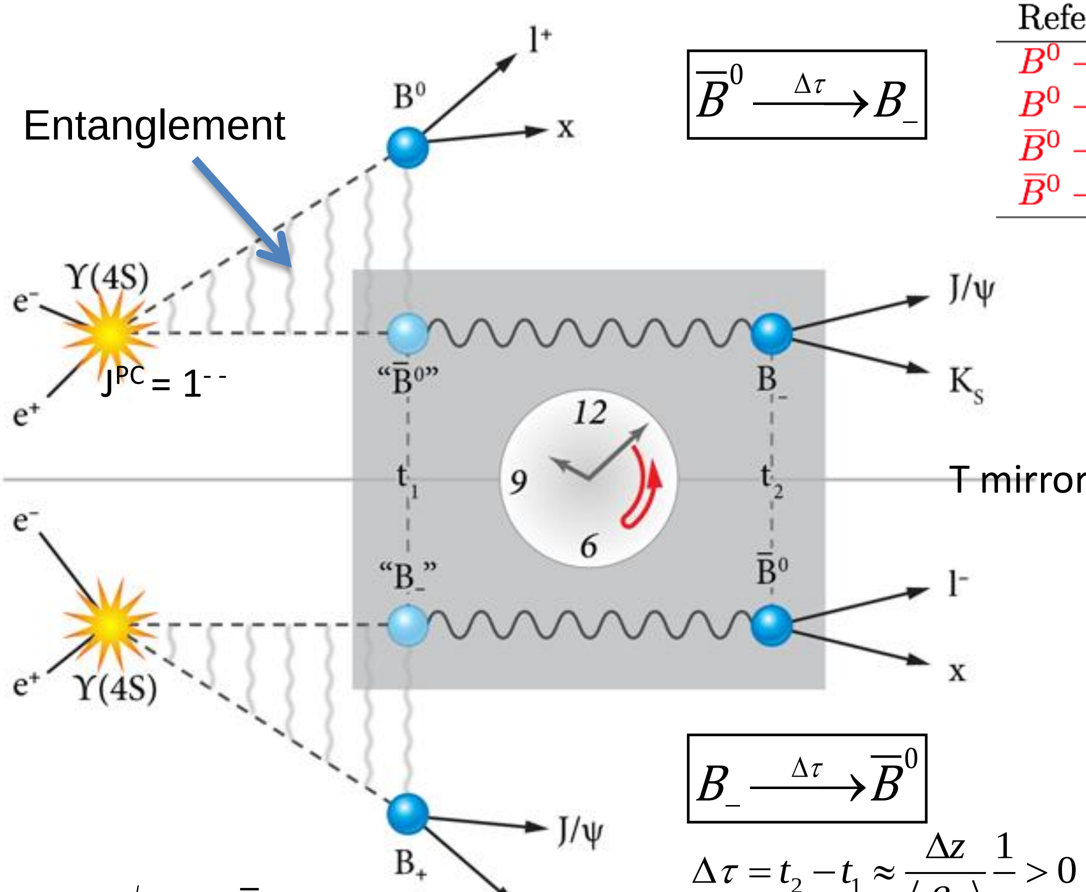
  - Conversely B_+ and B_- states are an orthogonal combination of the flavor eigenstates

Bernabeu & Bañuls, PLB464, 117 (1999)

Quinn, J. Phys. Conf. Ser. 171, 012001 (2009)

Wolfenstein, Int. Jour. Mod. Phys. E8, 501 (1999)

T VIOLATION: THE IDEA



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

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

$$\Delta\tau = t_2 - t_1 \approx \frac{\Delta z}{\langle\beta\gamma\rangle}\frac{1}{c} > 0$$

βγ ~ 0.56 @BABAR

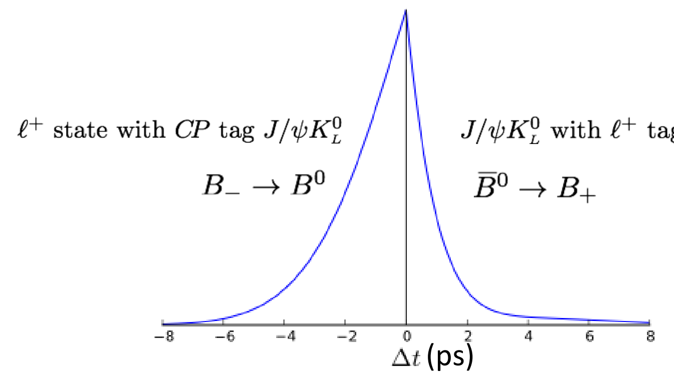
$B_+ \approx 1/\sqrt{2}[B^0 + \overline{B}^0]$
$B_- \approx 1/\sqrt{2}[B^0 - \overline{B}^0]$

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

Signed decay time difference

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

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



<u>Flavor tag</u>: Semileptonic decays project a B-flavor state: *$l^+ \to B^0$ ($\overline{B}^0$ flavor tag) and $l^- \to \overline{B}^0$ (B^0 flavor tag)*
<u>CP tag</u>: Decays to $J/\psi\ K_{L,S}$ project a CP eigenstate: *$J/\psi K_L \to B_+$ (B_- CP tag) and $J/\psi K_S \to B_-$ (B_+ CP tag)*

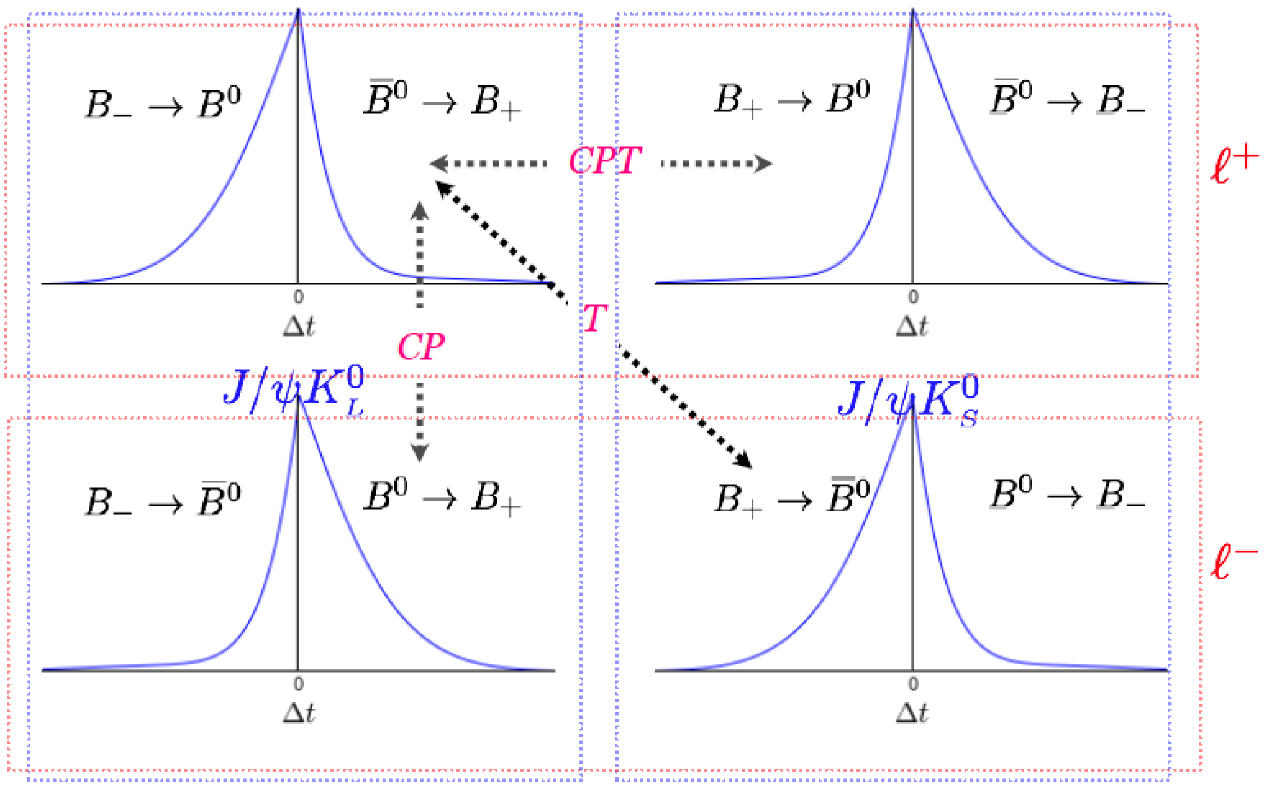
Phys. Rev. Lett. **109**, 211801 (2012)

T VIOLATION: THE MEASUREMENT

$$g^{\pm}_{\alpha,\beta}(\Delta\tau) \propto e^{-\Gamma\Delta\tau}\left[1 + C^{\pm}_{\alpha,\beta}\cos(\Delta m\Delta\tau) + S^{\pm}_{\alpha,\beta}\sin(\Delta m\Delta\tau)\right] \qquad \alpha \in \left\{B^0, \bar{B}^0\right\} \qquad \beta \in \left\{K^0_S, K^0_L\right\}$$

$$A_T \cong \frac{\Delta C^{\pm}_T}{2}\cos(\Delta m\Delta t) + \frac{\Delta S^{\pm}_T}{2}\sin(\Delta m\Delta t) \qquad C^{\pm}_{\alpha,\beta} = \frac{1-|\lambda|^2}{1+|\lambda|^2} \qquad S^{\pm}_{\alpha,\beta} = \frac{2\,\mathrm{Im}\lambda}{1+|\lambda|^2}$$

Where + refers to the flavor tag, and – refers to the CP tag



- In total
  - 4 independent T comparisons
  - 4 independent CP comparisons
  - 4 independent CPT comparisons
- T implies
  - Opposite Δt
  - Different reco states
    - $J/\psi\ K_S$ vs $J/\psi\ K_L$
  - Opposite flavor states

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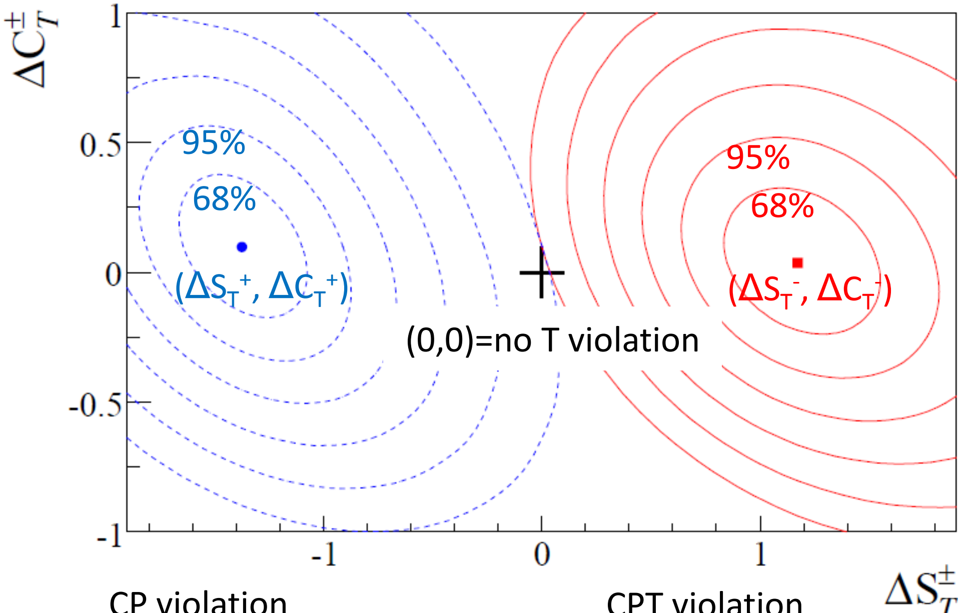
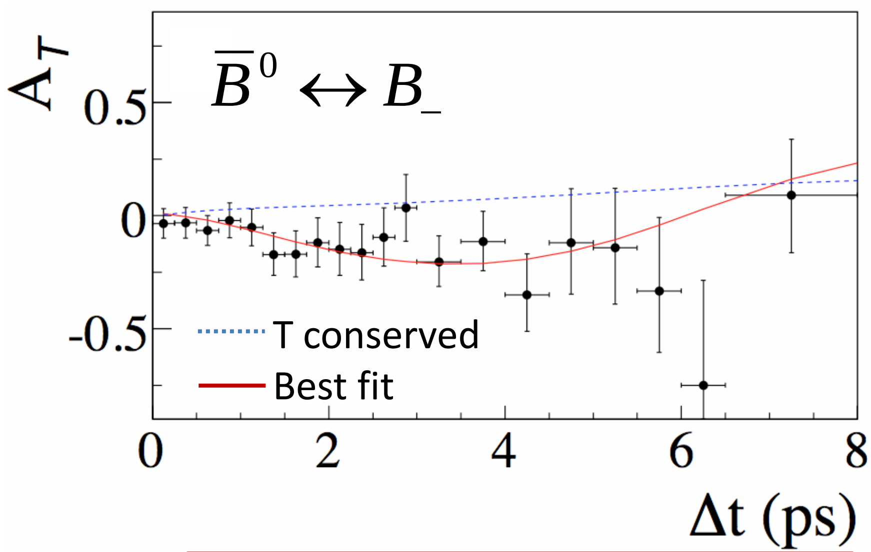
Phys. Rev. Lett. **109**, 211801 (2012)

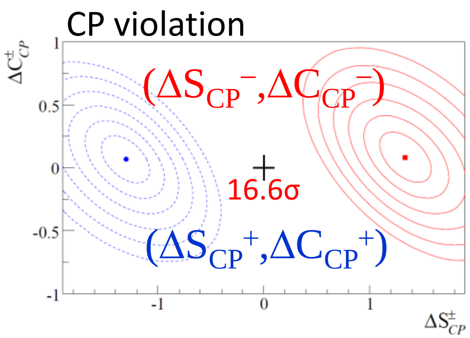
T VIOLATION: THE RESULTS

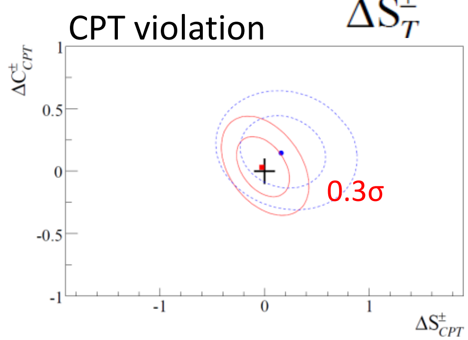
- Simultaneous ML fit to all flavor- and CP-eigenstates samples for Δt>0 and Δt<0 events.
- Obtain 8 sets of S, C parameters, define from these the T-violating parameters ΔS, ΔC.

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









T-violation observed at >14σ
Measurement independent from any assumption on CP or CPT

Observed T violation as due to compensate CP violation

PRD **85**, 071105(R) (2012)
535×10^6 M $B\bar{B}$

TIME DEPENDENT CPT VIOLATION

- General PDF to describe a neutral B meson decay

$$\mathcal{P}(\Delta t) = \frac{1}{2\tau_{B_d}} e^{-|\Delta t|/\tau_{B_d}} \left[\frac{|\eta_+|^2 + |\eta_-|^2}{2} \cosh\left(\frac{\Delta\Gamma_d}{2}\Delta t\right) - \mathcal{R}e(\eta_+^* \eta_-) \sinh\left(\frac{\Delta\Gamma_d}{2}\Delta t\right) + \frac{|\eta_+|^2 - |\eta_-|^2}{2} \cos(\Delta m \Delta t) + \mathcal{I}m(\eta_+^* \eta_-) \sin(\Delta m \Delta t) \right],$$

z is the CPT violating complex parameter

$$\eta_+ = A_1 \bar{A}_2 - \bar{A}_1 A_2$$
$$\eta_- = \sqrt{1-z^2}\left(\frac{p}{q} A_1 A_2 - \frac{q}{p} \bar{A}_1 \bar{A}_2\right) + z\left(A_1 \bar{A}_2 + \bar{A}_1 A_2\right)$$

  - Assuming no CPT violation (*z*=0), $\Delta\Gamma_d \cong 0$, $|q/p| \cong 1$:
    - S is related to mixing induced CP violation and A to direct CP violation

$$\mathcal{P}(\Delta t) = \frac{1}{4\tau_{B_d}} e^{-|\Delta t|/\tau_{B_d}} \{1 \pm [\mathcal{S} \sin(\Delta m \Delta t) + \mathcal{A} \cos(\Delta m \Delta t)]\}$$

Fit parameters
include eight physics parameters, with three of them being

$\mathcal{R}e(z)$

$\mathcal{I}m(z)$

$\Delta\Gamma_d$

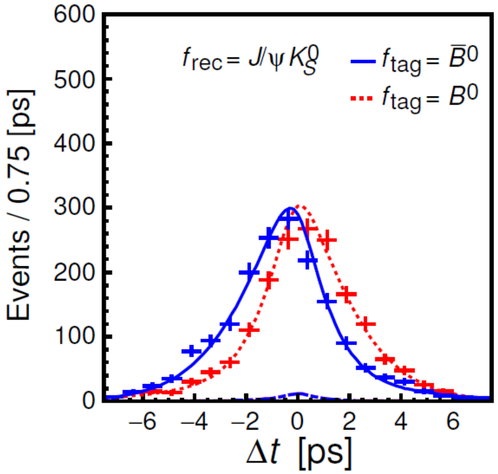
Decay modes:

B decay mode	$N_{\rm ev}$	Purity (%)	Sensitivity
$J/\psi K_S$	7713	97.0	Mainly $\mathcal{R}e(z)$ and $\Delta\Gamma_d$
$J/\psi K_L$	10966	59.2	
$D^-\pi^+$	39366	83.2	Mainly $\mathcal{I}m(z)$ and flavor tagging quality
$D^{*-}\pi^+$	46292	81.5	
$D^{*-}\rho^+$	45913	66.3	
$D^{*-}\ell^+\nu_\ell$	383818	75.2	
$J/\psi K^+$	32150	97.3	Resolution parameters
$\bar{D}^0\pi^+$	216605	63.9	

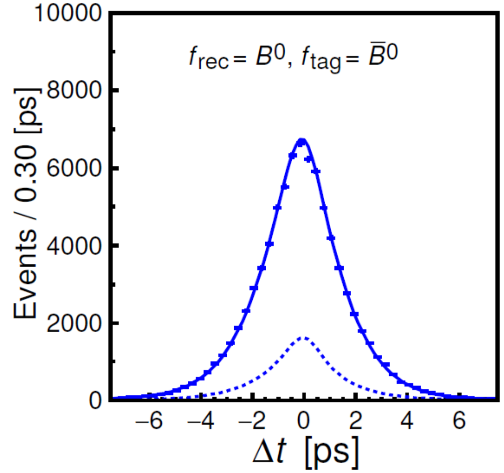
PRD **85**, 071105(R) (2012)

CPT VIOLATION RESULTS

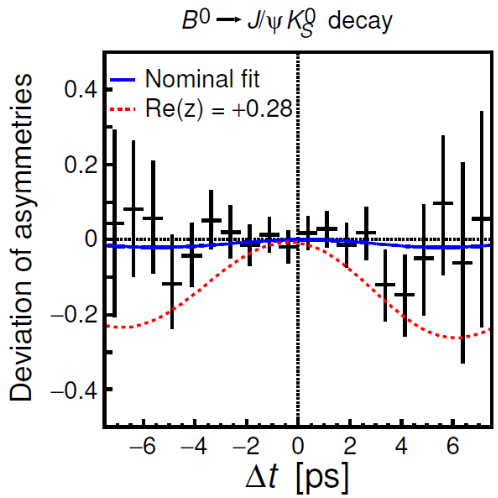
$B^0 \rightarrow J/\psi K_S$

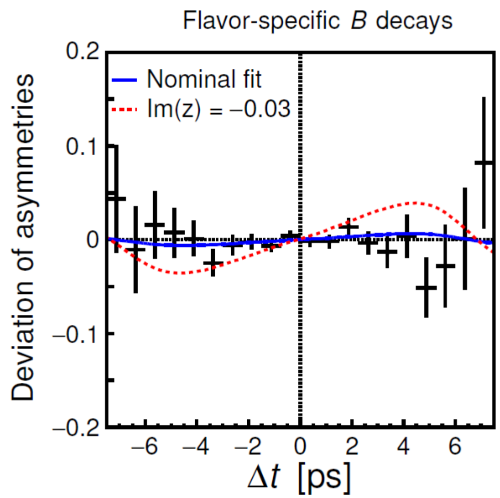


$B^0 \rightarrow$ flavor specific



$$
\begin{aligned}
Re(z) &= (1.9 \pm 3.7 \pm 3.3) \cdot 10^{-2} \\
Im(z) &= (-5.7 \pm 3.3 \pm 3.3) \cdot 10^{-3} \\
\Delta\Gamma_d/\Gamma_d &= (-1.7 \pm 1.8 \pm 1.1) \cdot 10^{-2}
\end{aligned}
$$

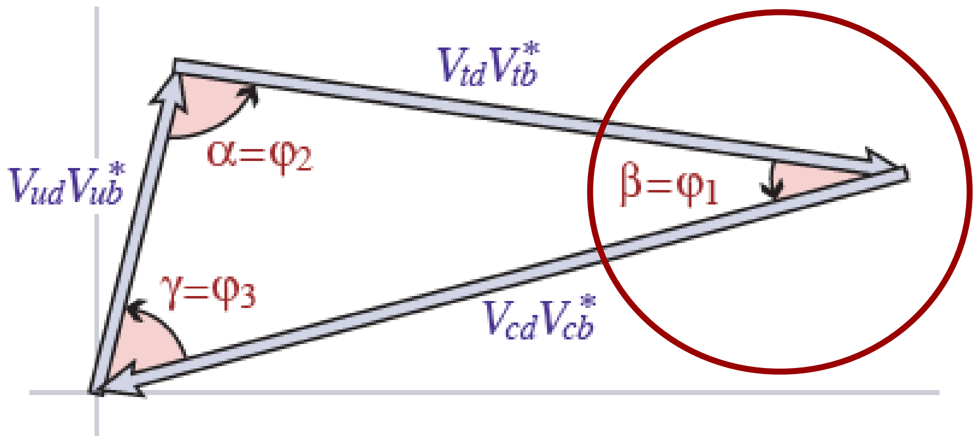




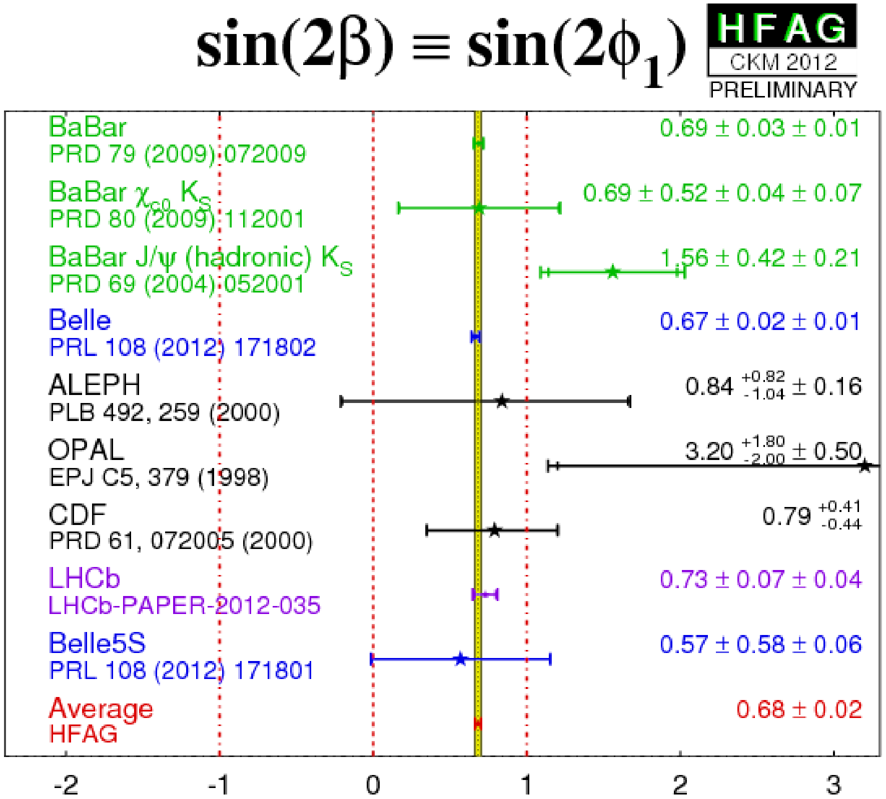
$$
\begin{aligned}
\tau_{B^0} &= 1.531 \pm 0.004 \text{ ps} \\
\tau_{B^+} &= 1.640 \pm 0.006 \text{ ps} \\
\Delta m_d &= 0.506 \pm 0.003 \text{ ps}^{-1} \\
\lambda_{CP} - 1 &= (1.1 \pm 0.38) \cdot 10^{-3} \\
\arg(\eta_{CP}\lambda_{CP}) &= -0.700 \pm 0.042
\end{aligned}
$$

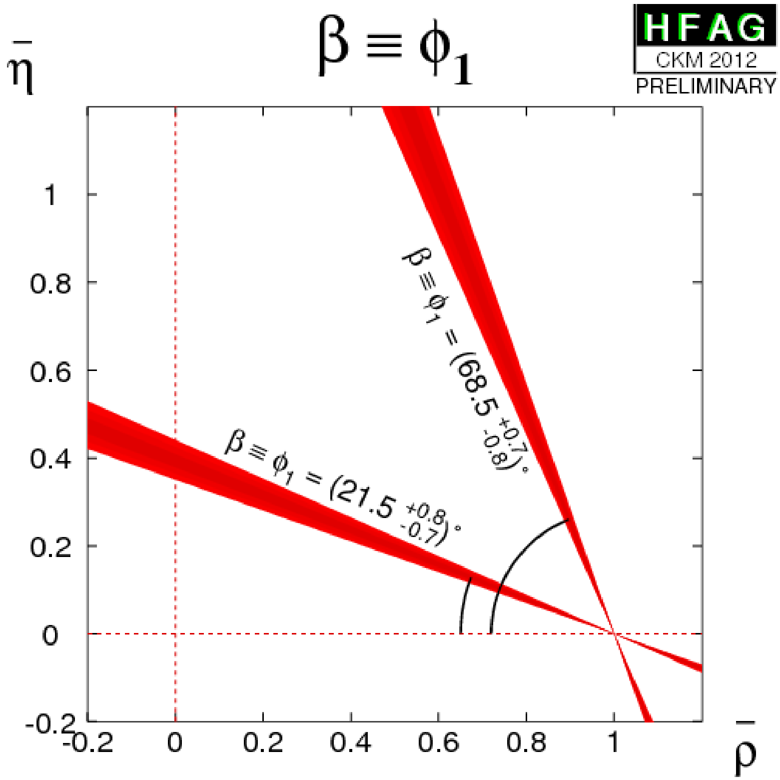
$$
\lambda_{CP} = \frac{q}{p} \frac{A_{\bar{B}^0 \rightarrow f_{CP}}}{A_{\bar{B}^0 \rightarrow f_{CP}}}
$$

UNITARY TRIANGLE

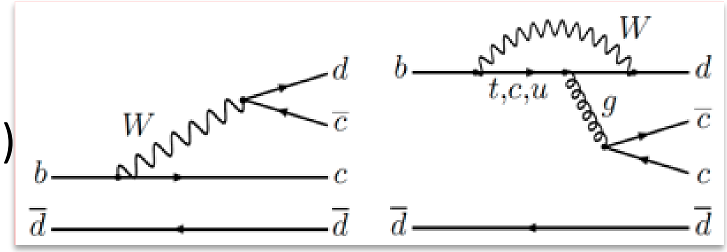


SIN2β IN CHARMONIUM

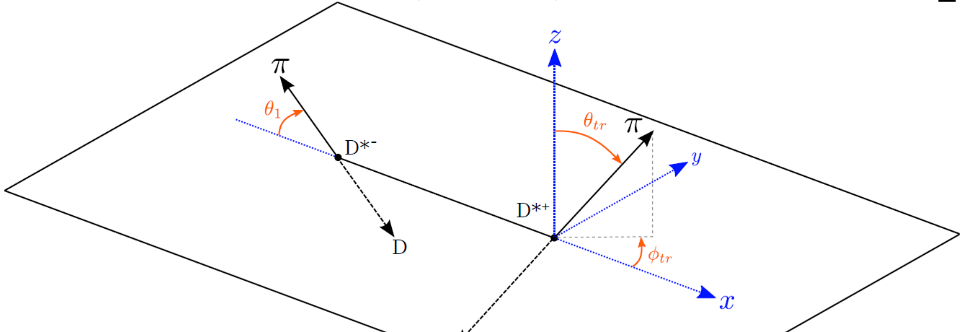




$B^0 \rightarrow D^{+*}D^{-*}$



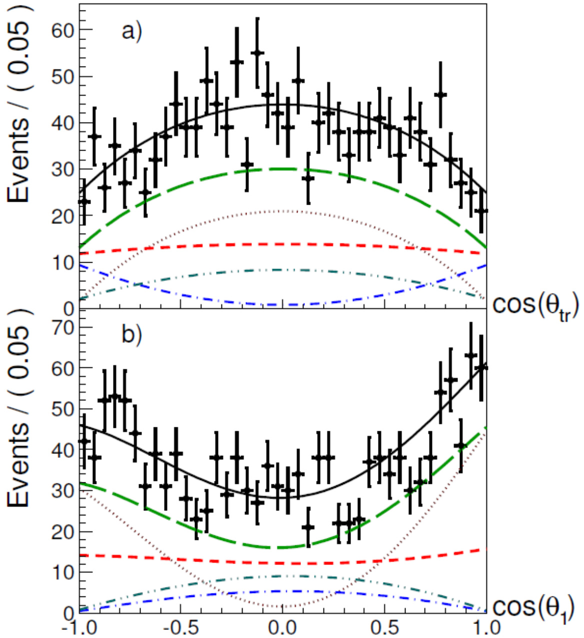
- Measurement of sin(2β) in b→ccd
  - Time Dependent asymmetry sensitive to $S_\eta \sim \eta \sin(2\beta)$
    - If penguin contribution can be neglected
    - In the SM, penguin contributions lead to corrections of ~few % to the determination of sin2β from the TD CPV asymmetry
  - Large deviation in S_η w.r.t. b→ccs transitions could indicate physics beyond the SM
- VV final state: mixture of CP=+1 and CP=-1 depending on final state polarization
  - Angular analysis with fully reconstructed events needed to separate CP eigenstates
  - BaBar and Belle full reconstruction analyses measured the CP even component, CPV parameters S_+ and C_+, and the fraction $R_\perp$ of CP-odd amplitude, $R_\perp$=0.158±0.028±0.006



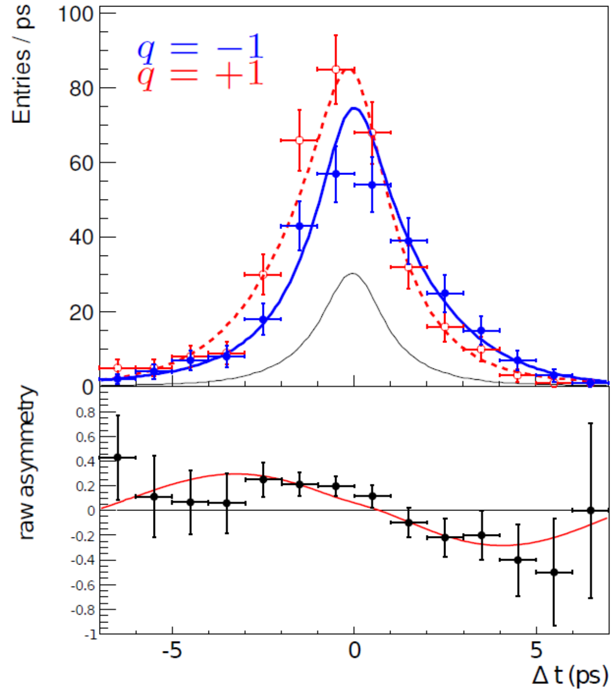
$$\frac{1}{\Gamma}\frac{d^4\Gamma}{d\cos\theta_1 d\cos\theta_{tr} d\phi_{tr} dt}$$

Z. Z. Xing, Phys. Lett. **B443**, 365 (1998).
Z. Z. Xing, Phys. Rev. **D61**, 014010 (1999).
M. Gronau, J. L. Rosner and D. Pirjol, Phys. Rev. D **78**, 033011 (2008).
Y. Grossman and M. P. Worah, Phys. Lett. **B395**, 241 (1997).
R. Zwicky, Phys. Rev. D **77**, 036004 (2008).

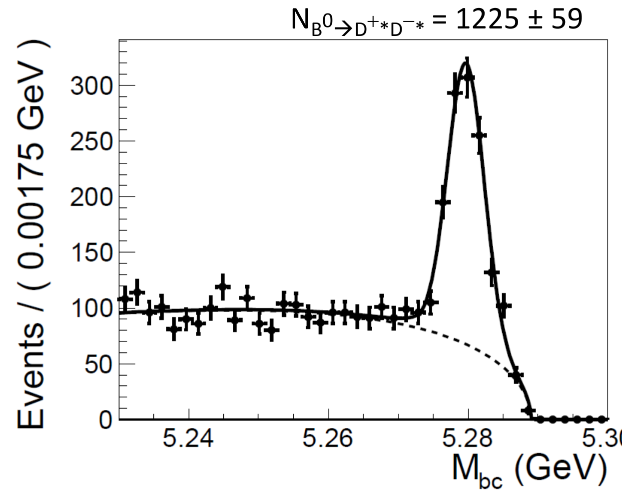
$B^0 \rightarrow D^{+*}D^{-*}$



Purple: CP-even, Blue: CP-odd



First observation of mixing induced CP violation in $B^0 \rightarrow D^{+*}D^{-*}$ decays (5.4 σ)



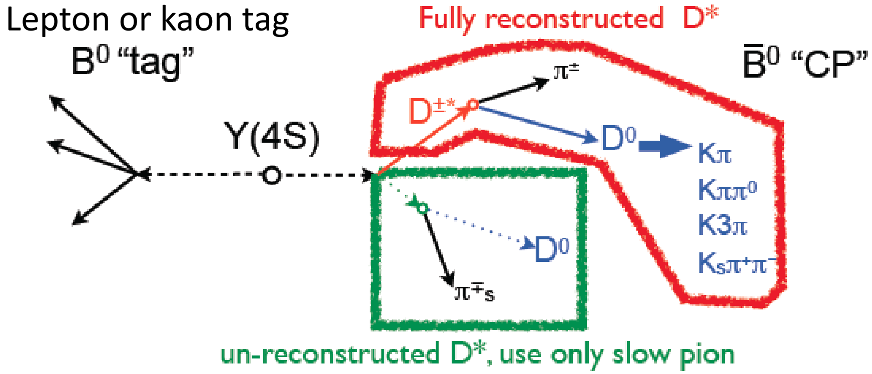
$R_{\perp}$ = 0.138 ± 0.024 (stat) ± 0.006 (syst)

S_{CP} = −0.79 ± 0.13 (stat) ± 0.03 (syst)

A_{CP} = +0.15 ± 0.08 (stat) ± 0.04 (syst)

PRD **86**, 112006 (2012)

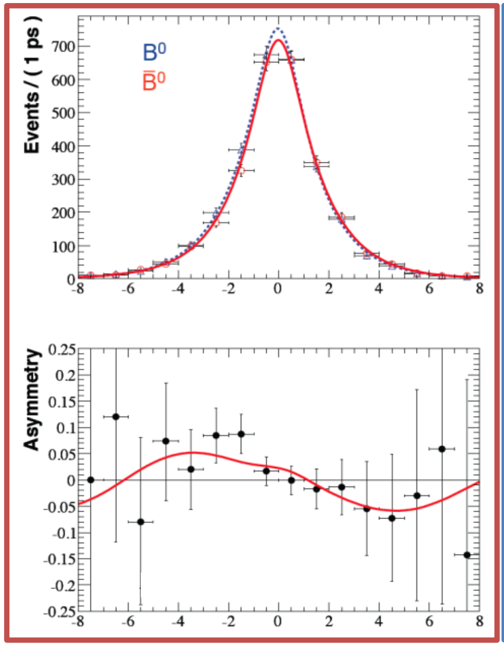
$B^0 \rightarrow D^{+*}D^{-*}$



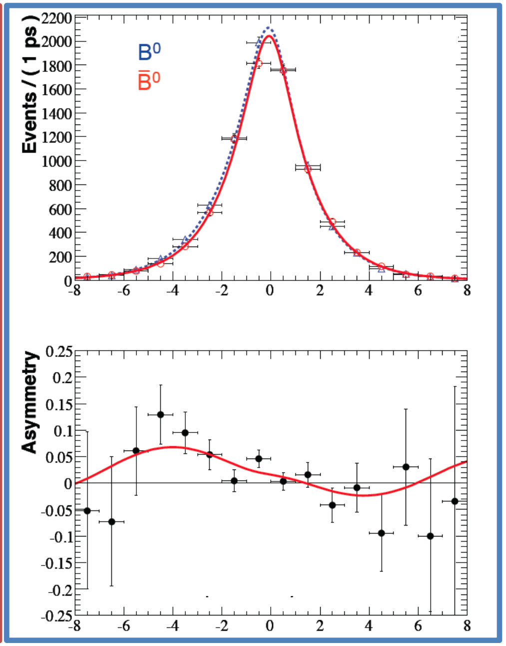
In a partial reconstruction analysis, we measure average S and C parameters which are related to C+ and S+ by the relations $C=C_+$ and $S=S_+(1-2R_\perp)$

Pros: gain in statistics (with an almost independent sample)
Cons: Higher background, larger systematic uncertainty

Lepton tag



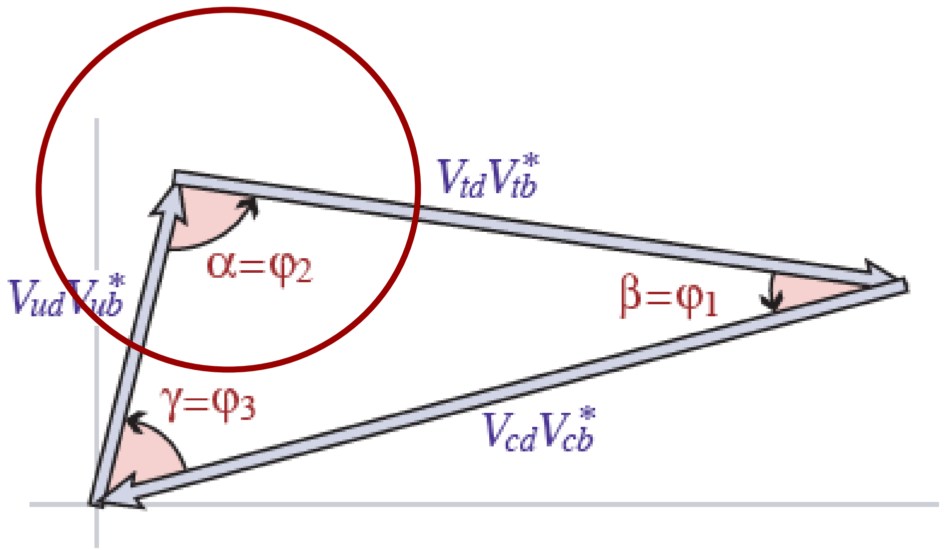
Kaon tag



- Assuming negligible penguin contributions then
  - $S_+ = -S_-$; $C = C_+$
  - $S = S_+ (1 - 2R_\perp)$,
- Using[1] $R_\perp = 0.158 \pm 0.029$
  - $C_+ = +0.15 \pm 0.09 \pm 0.04$
  - $S_+ = -0.49 \pm 0.18 \pm 0.07 \pm 0.04$

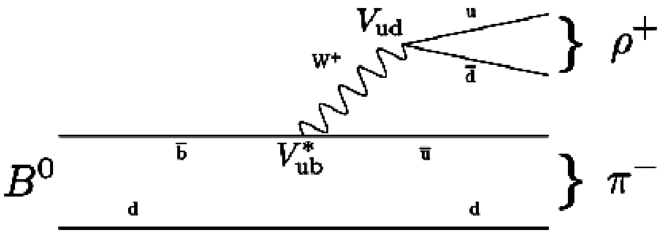
stat. syst. $R_\perp$

[1]B. Aubert et al. (BABAR collaboration), Phys. Rev. D79, 032002 (2009)

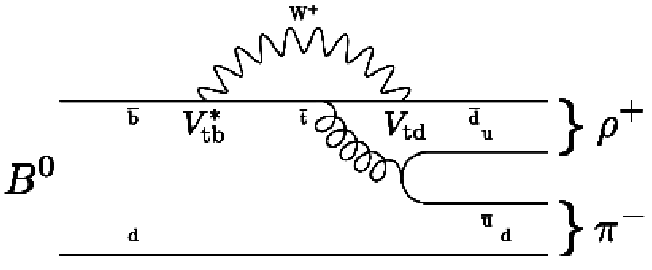

$V_{td}V_{tb}^*$
$\alpha=\varphi_2$
$V_{ud}V_{ub}^*$
$\beta=\varphi_1$
$\gamma=\varphi_3$
$V_{cd}V_{cb}^*$

$B^0 \to (\pi^+\pi^-)_{\rho^0}\pi^0$

- Interference between mixing and decay would allow to compute sin2α a-la sin2β
- Tree and penguin diagram have comparable size. Their interference:
  - introduces a strong phase difficult to compute
  - may induce a sizable amount of direct CP violation
- Time dependent analysis across the ρπ Dalitz plot permits – in principle – an unambiguous measurement of α



Tree Diagram



Penguin Diagram

Snider- Quinn Phys.Rev. D 48,2139 (1993)

$B^0 \to \pi^+\pi^-\pi^0$

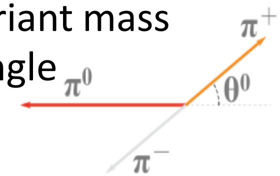
- Squared Dalitz plot to enhance interference regions

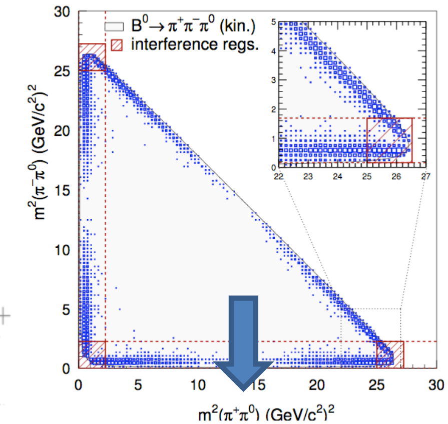
$$m' \equiv \frac{1}{\pi}\arccos\left(2\frac{m_0 - m_0^{min}}{m_0^{max} - m_0^{min}} - 1\right)$$

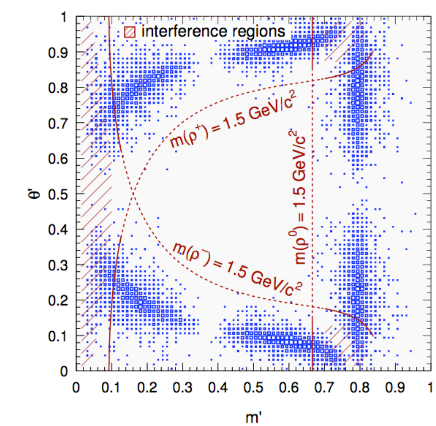
$$\theta' \equiv \frac{1}{\pi}\theta_0$$

$m_0 = \pi^+\pi^-$ invariant mass

θ_0 = helicity angle







- Observe direct CP violation from the asymmetries

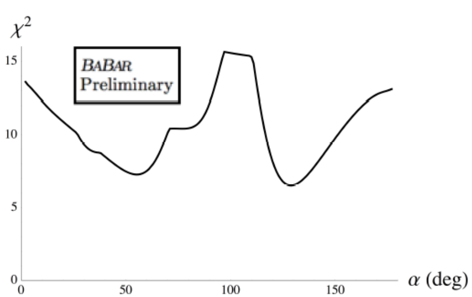
Preliminary

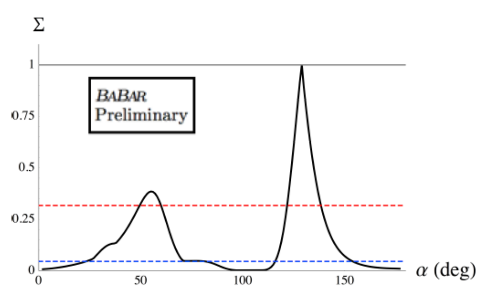
$$\mathcal{A}_{\rho\pi}^{+-} \equiv \frac{\Gamma(\overline{B}^0 \to \rho^-\pi^+) - \Gamma(B^0 \to \rho^+\pi^-)}{\Gamma(\overline{B}^0 \to \rho^-\pi^+) + \Gamma(B^0 \to \rho^+\pi^-)} = 0.09^{+0.05}_{-0.06} \pm 0.04$$

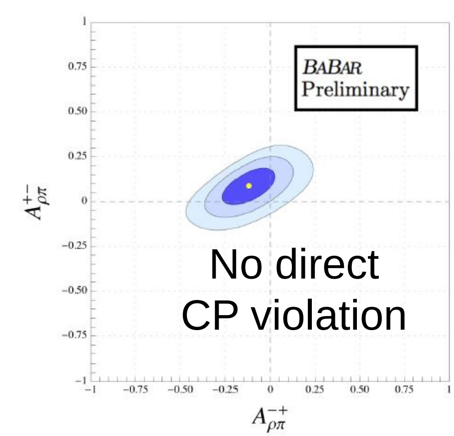
$$\mathcal{A}_{\rho\pi}^{-+} \equiv \frac{\Gamma(\overline{B}^0 \to \rho^+\pi^-) - \Gamma(B^0 \to \rho^-\pi^+)}{\Gamma(\overline{B}^0 \to \rho^+\pi^-) + \Gamma(B^0 \to \rho^-\pi^+)} = -0.12 \pm 0.08^{+0.04}_{-0.05}$$

- α scan
  - Parameter scan confirms bias seen in earlier analysis.
    - It cannot be interpreted in terms of Gaussian statistics due to small S/N

Preliminary



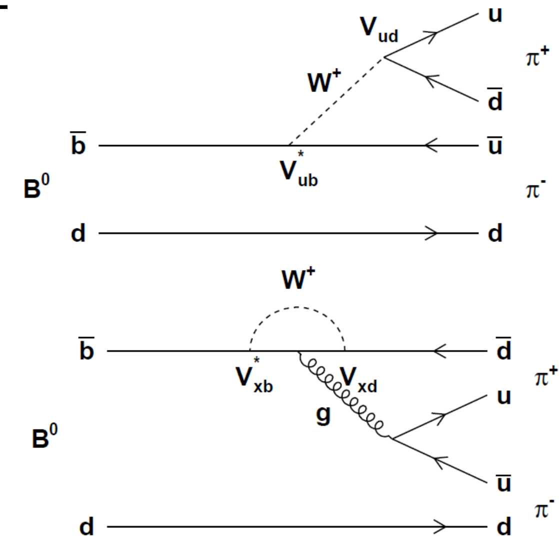


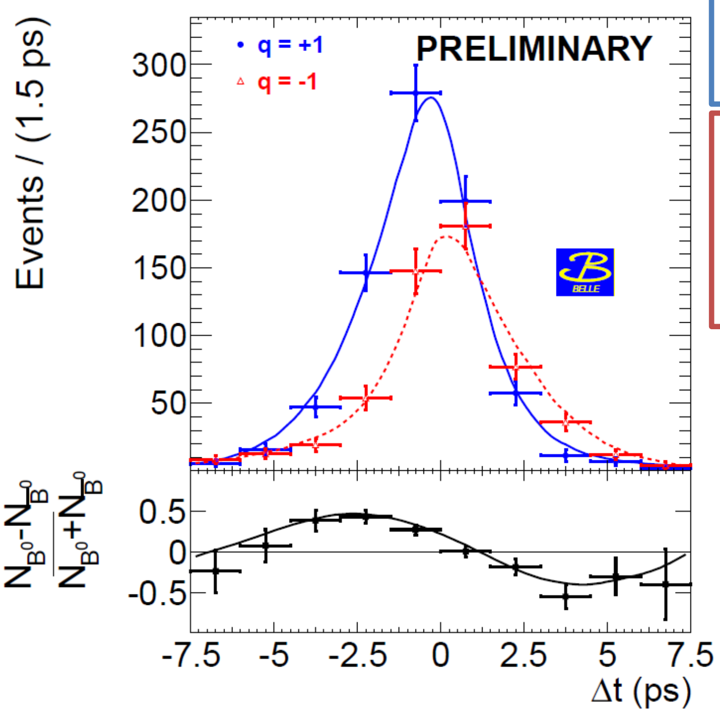


Preliminary: arxiv:1302.0551

ϕ_2 FROM $B^0 \to \pi^+\pi^-$

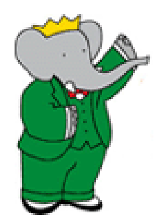
- S→SS decay, simultaneous fit including $B^0 \to \pi^+\pi^-, K^\pm\pi^\mp, K^+K^-$
- Simultaneous fit of branching ratios and CP asymmetries





Measured observable
$\phi_2^{eff} = \phi_2 + \Delta\phi_2$

$S_{CP}(\pi^+\pi^-) = -0.636 \pm 0.082 \pm 0.027$
$A_{CP}(\pi^+\pi^-) = +0.328 \pm 0.061 \pm 0.027$
$23.8^\circ < \phi_2 < 66.8^\circ$ ruled out at 1σ

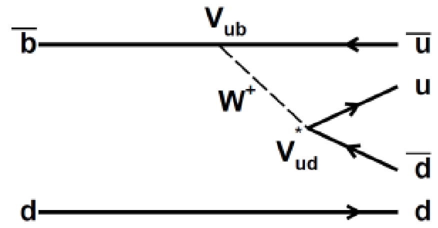


PRD **87**,052009,2013

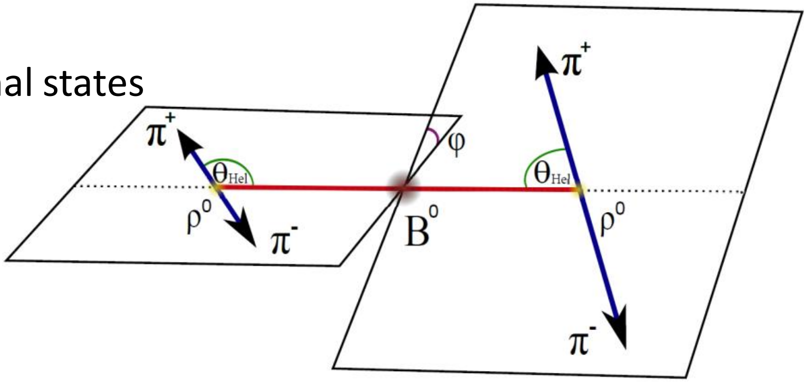
$$
\begin{aligned}
S_{\pi^+\pi^-} &= -0.68 \pm 0.10 \pm 0.03, \\
C_{\pi^+\pi^-} &= -0.25 \pm 0.08 \pm 0.02, \\
A_{K^-\pi^+} &= -0.107 \pm 0.016^{+0.006}_{-0.004}, \\
C_{\pi^0\pi^0} &= -0.43 \pm 0.26 \pm 0.05
\end{aligned}
$$

$\alpha \in [71^\circ, 109^\circ]$ 68% CL
$\alpha \notin [23^\circ, 67^\circ]$ 90% CL

ϕ_2 FROM $B^0 \to \rho^0 \rho^0$



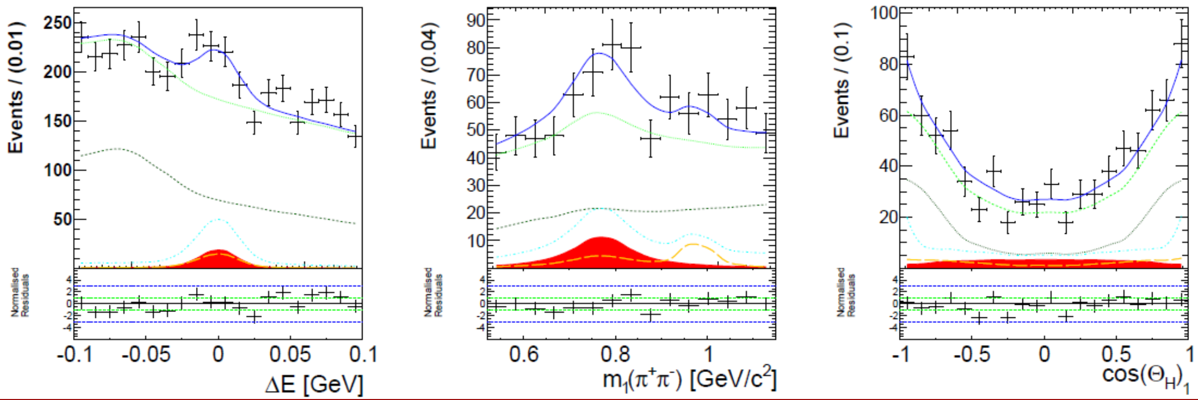
- Tree-dominated, color -suppressed, S → VV decay
- four charged pion final state, S/N ratio ~0.1%
- superposition of CP+ and CP- states, separation through helicity analysis
  - f_L: fraction of longitudinal polarization(LP) for CP+ final states
- extract $\Delta\phi_2$ with isospin analysis



$$f_L = 0.21^{+0.18}_{-0.22} \pm 0.11$$

$$\mathcal{B}(B^0 \to \rho^0\rho^0) < 1.5 \ \ (1.02 \pm 0.30 \pm 0.22)$$

$$\mathcal{B}(B^0 \to f_0\rho^0) \times (f_0 \to \pi^+\pi^-) = (0.86 \pm 0.27 \pm 0.15)$$ ⟶ First 3σ evidence



$B^0 \to \rho^0\rho^0$, $B^0 \to f_0\rho^0$, 4π final states, $B\bar{B}$ bkg, total non-peaking bkg, total

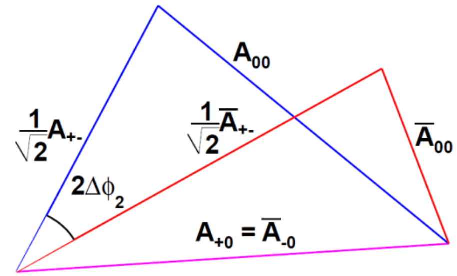
EXTRACTION OF ϕ_2

- Extraction of ϕ_2 with isospin analysis
  - Bose statistics (tree: I=0,2; penguin: I=0 only) allows to formulate relations of the decay amplitudes A: $\overline{A}^{+-} = A(\overline{B} \to \rho^+ \rho^-)$

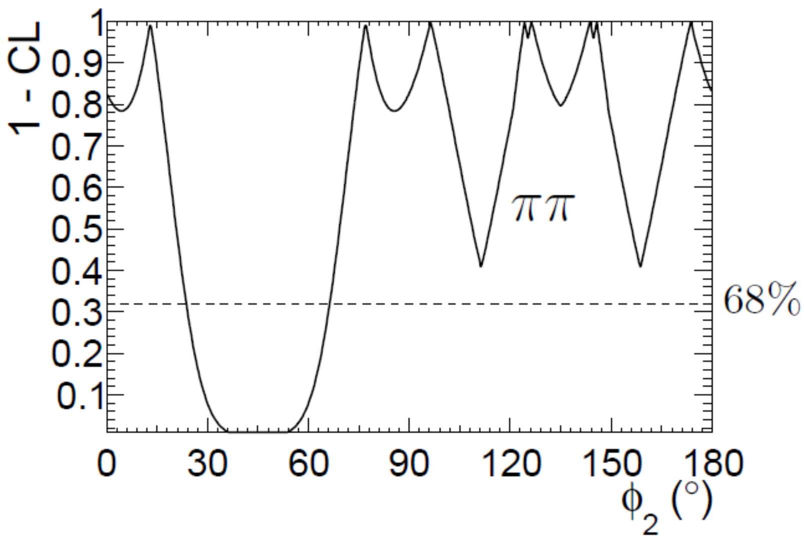
$$\frac{1}{\sqrt{2}} A^{+-} + A^{00} = A^{+0}$$

$$\frac{1}{\sqrt{2}} \overline{A}^{+-} + \overline{A}^{00} = A^{-0}$$

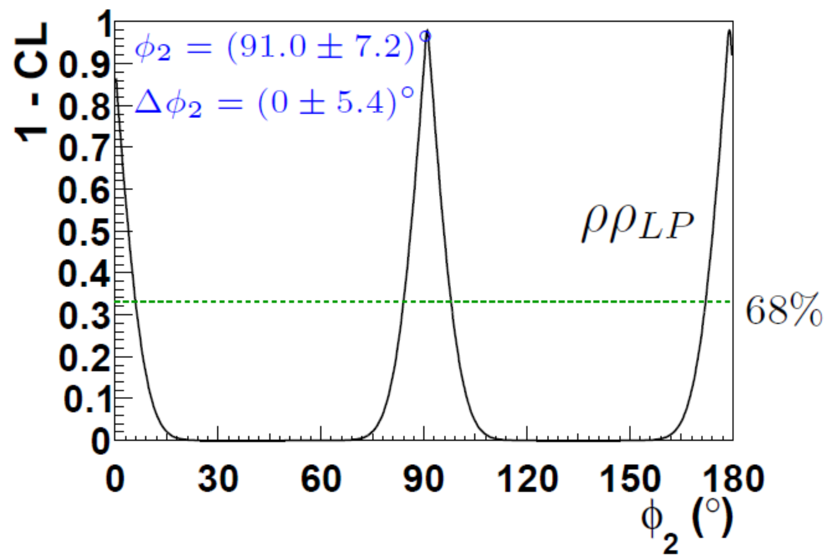
$$A^{+0} = \overline{A}^{-0} \text{ (no penguin)}$$



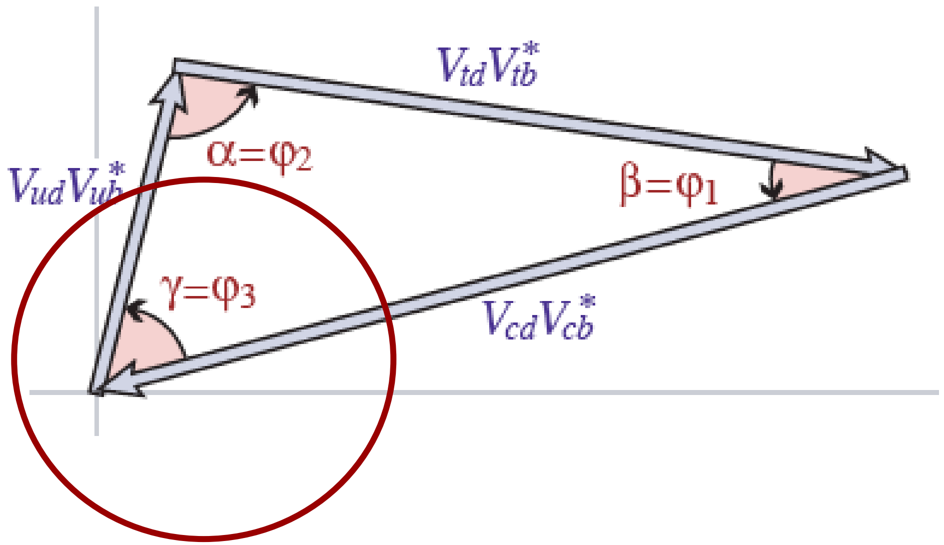
M. Gronau and D. London, PRL 65 3381 (1990)



23.8° < ϕ_2 < 66.8° Excluded at 1σ
| ϕ_2|> 44.25° Excluded

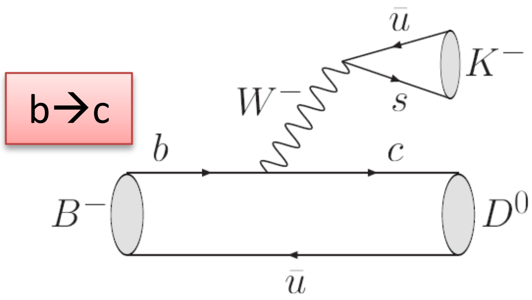


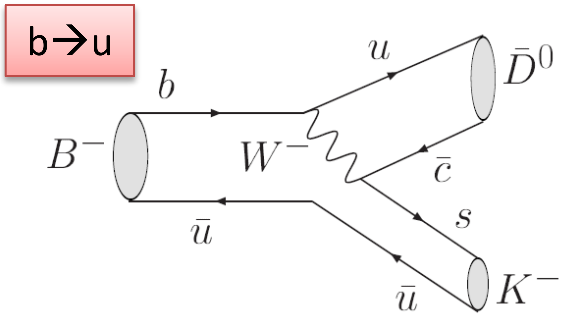
Using the LP fraction of
$(B^0 \to \rho^0 \rho^0)|_{LP} = (0.21 \pm 0.36) \times 10^{-6}$



$V_{td}V_{tb}^*$
$\alpha=\varphi_2$
$V_{ud}V_{ub}^*$
$\beta=\varphi_1$
$\gamma=\varphi_3$
$V_{cd}V_{cb}^*$

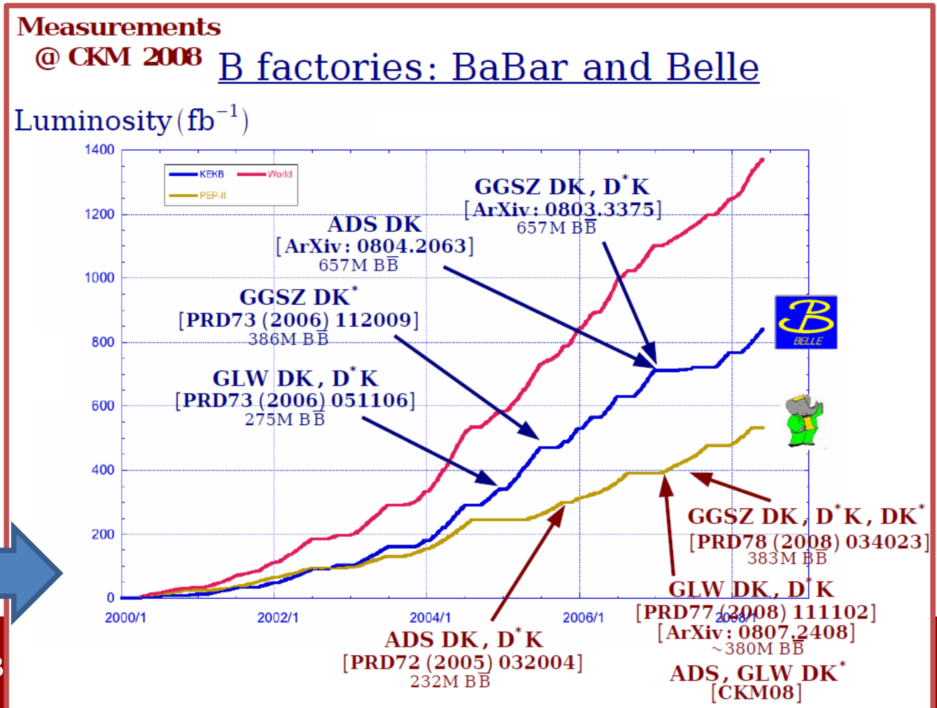
$B \to D^{(*)}K^{(*)}$

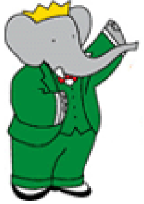




- Only tree level contributions
  - Low theoretical uncertainties
  - b→cūs favorite transitions compared to CKM and color suppressed b→ucs̄
    - D^0 from $B^- \to D^0K^-$ decays in a mode open to $B^- \to \bar{D}^0K^-$
  - The interference between favored and suppressed depends on
    - Relative weak phase γ
      - Same for all modes
    - Ratio $r_B = |A(b \to u)| / |(A(b \to c)|$
    - Strong (CP conserving) phase δ_B
- Great wealth of publications

K.Trabelsi @ CKM2012

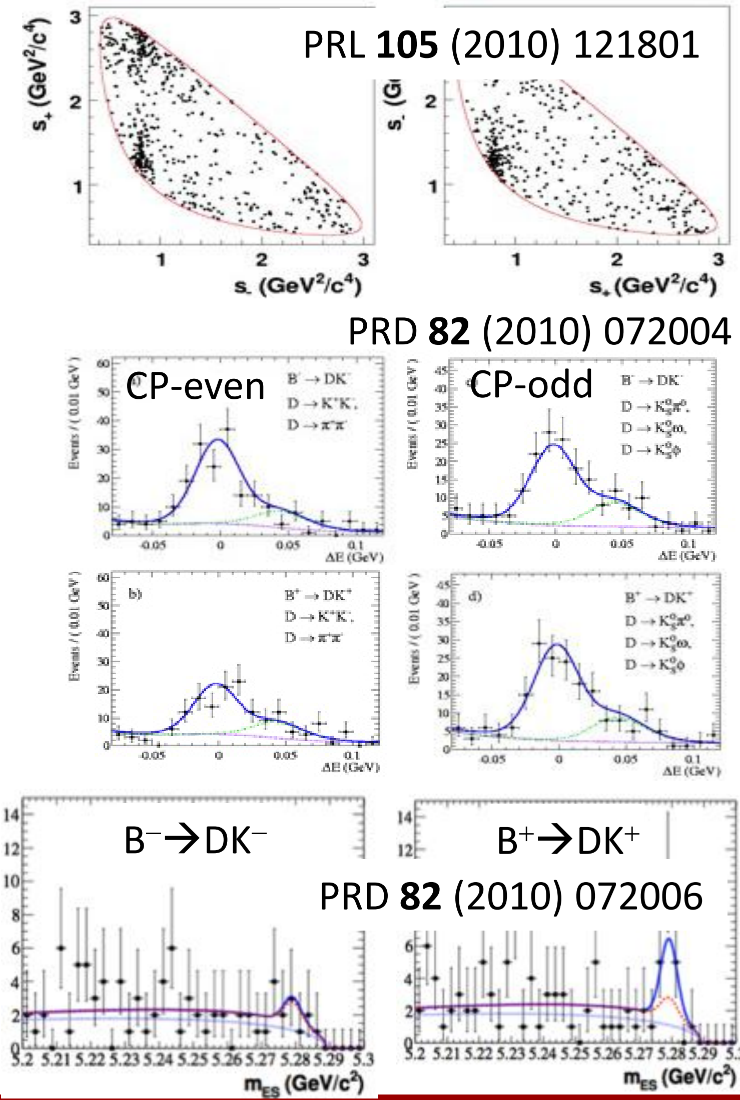




$B \to D^{(*)}K^{(*)}$ Analysis Methods

- Giri-Grossman-Soffer-Zupan (GGSZ) Method
  - A. Giri, Yu. Grossman, A. Soffer, J. Zupan, PRD 68, 054018(2003)
  - Three-body decays
- Gronau-London-Wyler (GLW) Method
  - M. Gronau, D. London, D. Wyler, PLB253,483 (1991); PLB 265, 172 (1991)
  - CP eigenstates
- Atwood-Dunietz-Soni (ADS) Method
  - D. Atwood, I. Dunietz, A. Soni, PRL 78, 3357 (1997)
  - Doubly -Cabbibo suppressed decays

$D \to K_S^0\pi^+\pi^-,\quad K_S^0K^+K^-$



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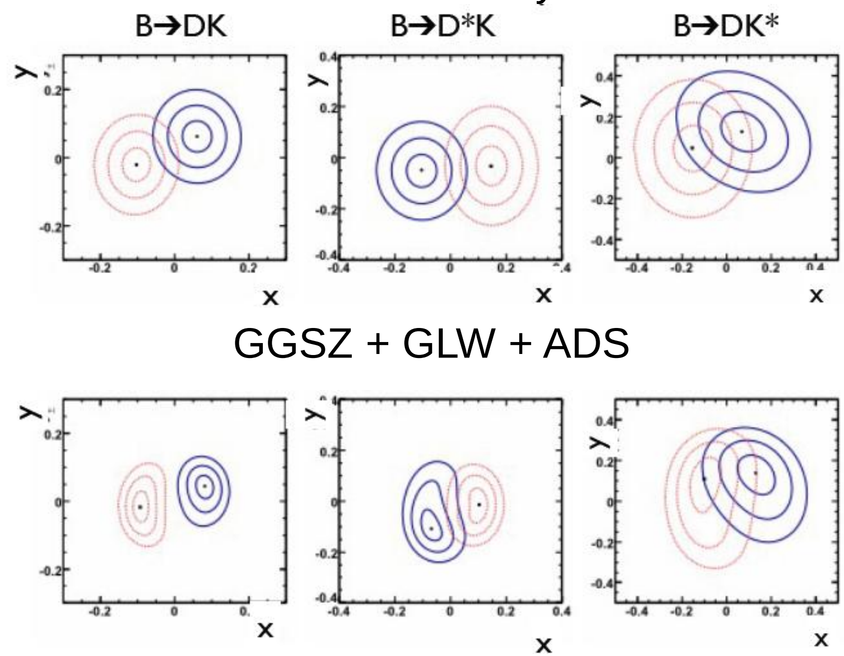
Phys. Rev. D **87**, 052015 (2013)

COMBINATION

- Parameterize the experimental likelihood convoluted with systematic errors.
- Express the GLW and ADS parameters through Cartesian coordinates.
- Build global likelihood as a product of partial PDFs inserting also the external constrains to charm sector.
- Maximize the Likelihood and extract the best values of coordinates and D hadronic decays parameters.
  - 18 fit parameters
  - 39 input observables
- Make projections of Cartesian coordinates.
- Compute gamma.

$$x_{\pm} = \mathrm{Re}(r_B e^{i(\delta \pm \gamma)}) = r_B \cos(\delta \pm \gamma)$$
$$y_{\pm} = \mathrm{Im}(r_B e^{i(\delta \pm \gamma)}) = r_B \sin(\delta \pm \gamma)$$
$$z_{\pm} = x_{\pm} + i \cdot y_{\pm}$$

GGSZ only



Results in Cartesian coordinates (systematic errors include also the model errors from the GGSZ analysis)

	Real part (%)	Imaginary part (%)
z_-	$8.1 \pm 2.3 \pm 0.7$	$4.4 \pm 3.4 \pm 0.5$
z_+	$-9.3 \pm 2.2 \pm 0.3$	$-1.7 \pm 4.6 \pm 0.4$
z^*_-	$-7.0 \pm 3.6 \pm 1.1$	$-10.6 \pm 5.4 \pm 2.0$
z^*_+	$10.3 \pm 2.9 \pm 0.8$	$-1.4 \pm 8.3 \pm 2.5$
z_{s-}	$13.3 \pm 8.1 \pm 2.6$	$13.9 \pm 8.8 \pm 3.6$
z_{s+}	$-9.8 \pm 6.9 \pm 1.2$	$11.0 \pm 11.0 \pm 6.1$

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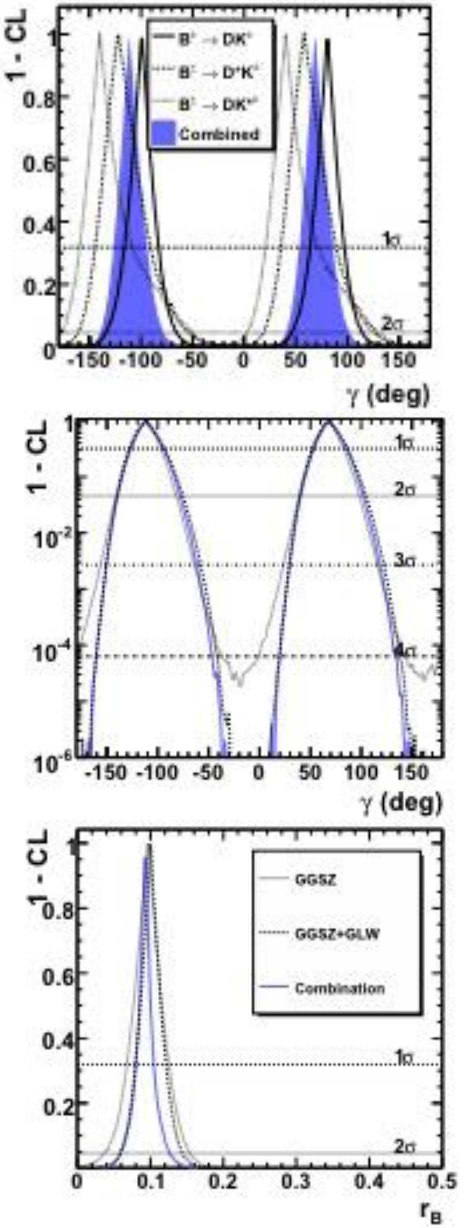
EXTRACTION OF γ

- Transform the combined Cartesian coordinates into polar coordinates γ and $\{r_B, \delta_B\}$ for each decay type.
- Use the frequentist (Neyman) approach.
- The scan relies on the pseudo-experiments
- The significance of the CP violation is 5.9σ (to be compared to 3.5σ) for the GGSZ method.
- The uncertainty on γ increases since the preferred value of r_B lower for the combination.

$$\gamma = (69^{+17}_{-16})^{o}$$

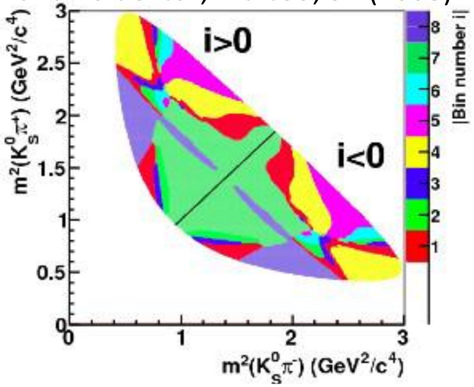
Parameter	68.3% C.L. Combination	68.3% C.L. GGSZ	95.5% C.L. Combination	95.5% C.L. GGSZ
γ (°)	69^{+17}_{-16}	68^{+15}_{-14}	[41, 102]	[39, 98]
r_B (%)	$9.2^{+1.3}_{-1.2}$	9.6 ± 2.9	[6.0, 12.6]	[3.7, 15.5]
r^*_B (%)	$10.6^{+1.9}_{-3.6}$	$13.3^{+4.2}_{-3.9}$	[3.0, 14.7]	[4.9, 21.5]
κr_s (%)	$14.3^{+4.8}_{-4.9}$	$14.9^{+6.6}_{-6.2}$	[3.3, 25.1]	< 28.0
δ_B (°)	105^{+16}_{-17}	119^{+19}_{-20}	[72, 139]	[75, 157]
δ^*_B (°)	-66^{+21}_{-31}	-82 ± 21	[−132, −26]	[−124, −38]
δ_s (°)	101 ± 43	111 ± 32	[32, 166]	[42, 178]



PRD **85**, 112014 (2012)
Preliminary: arXiv:1205.0422

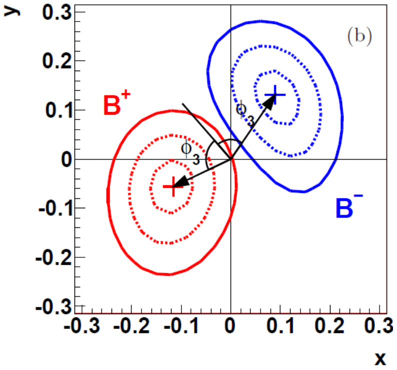
ϕ_3 FROM $B \rightarrow DK^{(*)}$

Bondar and Poluektov, EPJ C55, 51 (2008)



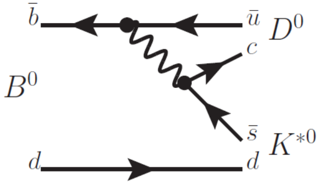
- A model independent approach:
  Binned Dalitz method: avoid the modeling error by "optimal " binning of the Dalitz plot
  - Choice of bins guided by model , but extraction of γ is not biased by this choice
  - Minimize $\chi 2$ in fit to all bins for each mode

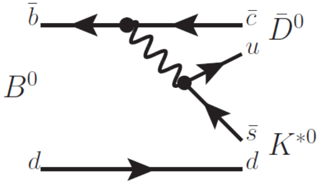
$$\phi_3 = (77.3^{+15.1}_{-14.9} \pm 4.1 \pm 4.3)^\circ$$
$$r_B = 0.145 \pm 0.030 \pm 0.010 \pm 0.011$$
$$\delta_B = (129.9 \pm 15.0 \pm 3.8 \pm 4.7)^\circ,$$



- $B \rightarrow DK^{(*0)}$, $D \rightarrow K^- \pi^+$ decays are also studied
  - CP-violating angle ϕ_3 affects its decay rate via the interference between b→u and b→c transitions.

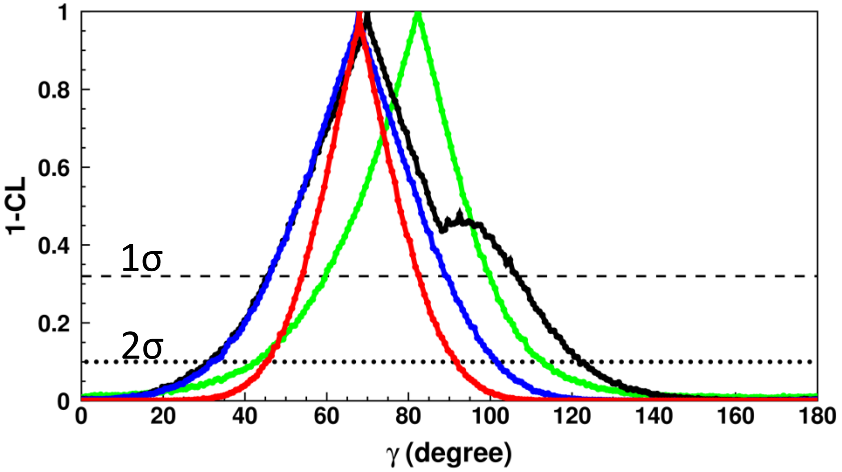
$$\mathcal{R}_{DK^{*0}} \equiv \frac{\Gamma(B^0 \to [K^-\pi^+]_D K^+\pi^-)}{\Gamma(B^0 \to [K^+\pi^-]_D K^+\pi^-)}$$
$$= (4.1^{+5.6+2.8}_{-5.0-1.8}) \times 10^{-2}$$

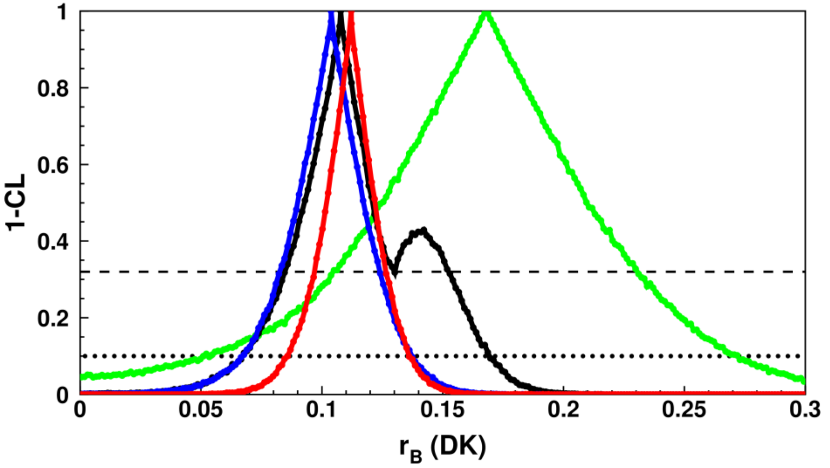




$$\mathcal{R}_{DK^{*0}} < 0.16 \text{ at the 95\% confidence level}$$

ϕ_3 FROM $B \to D^{(*0)} K$





- GGSZ:
  - $\gamma = [82\,_{-23}^{+18}]^\circ$
- GGSZ+ADS:
  - $\gamma = [70\,_{-24}^{+37}]^\circ$
- GGSZ+ADS+δ_D
  - $\gamma = [68 \pm 22]^\circ$
- **GGSZ+GLW+ADS+δ_D**
  - $\gamma = [68\,_{-14}^{+15}]^\circ$

$r_B = 0.168^{+0.063}_{-0.064}$

$r_B = 0.108^{+0.045}_{-0.023}$

$r_B = 0.104^{+0.020}_{-0.021}$

$\mathbf{r_B = 0.112^{+0.014}_{-0.015}}$

K.Trabelsi @ CKM2012

CPV IN B^0 MIXING

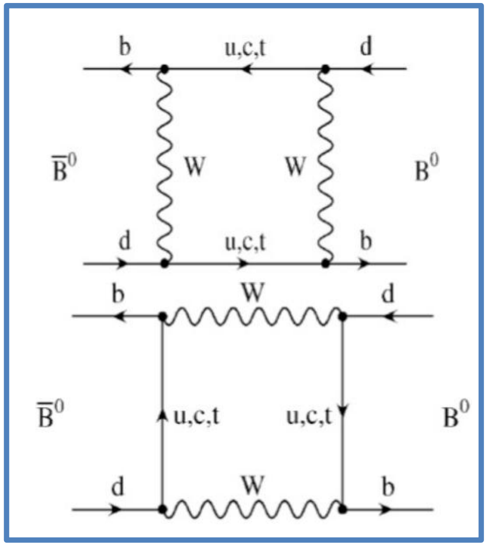
BaBar Preliminary

- CPV in mixing if $P(\overline{B}_d \rightarrow B_d) \neq P(B_d \rightarrow \overline{B}_d)$
- Small effect in the SM: $O(10^{-4})$
- Time independent CP Asymmetry measurement
  - Usually measured through B semileptonic decays

$$A_{CP} = \frac{N(B^0_, B^0) - N(\overline{B}^0_, \overline{B}^0)}{N(B^0_, B^0) + N(\overline{B}^0_, \overline{B}^0)} = \frac{1-|q/p|^4}{1+|q/p|^4} \approx 2(1-|q/p|)$$

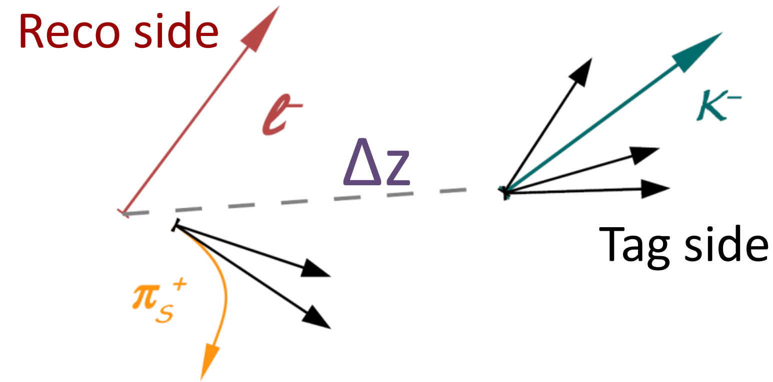
- New approach
  - 1^{st} B^0 from partial reconstruction: $B^0 \rightarrow D^{*-}\ell^+\nu_\ell$
  - 2^{nd} B^0 tagged using charged kaons

$$A_{CP} = \frac{N(l^+K^+) - N(l^-K^-)}{N(l^+K^+) + N(l^-K^-)}$$

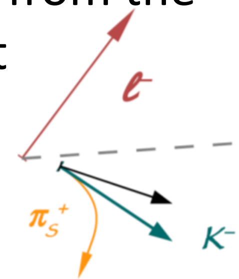


New Particles in the boxes could modify SM expectations

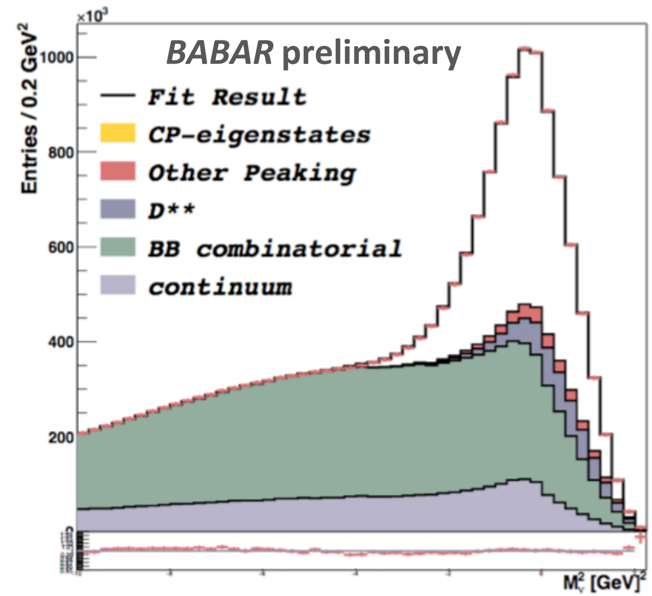
$B \to D^* \ell \nu$ Partial Reconstruction



- Partial Reconstruction using only the lepton and the soft π from $D^{*-} \to D^0 \pi^-$
- Kaon-Tagging: equal charge kaons from the reco side mimicking a mixed event distinguished using
  - $\Delta z = z_\ell - z_K$ (in the Lab)
  - $\cos(\theta_{\ell K})$ (in $\Upsilon(4S)$ rest frame)



- Assume B^0 at rest in $\Upsilon(4S)$ frame
- Compute missing mass from four momenta difference
  - $M^2_\nu = (E_{beam} - E_{D^*} - E_\ell)^2 - (P_{D^*} + P_\ell)^2 = (P_B - P_{D^*} - P_\ell)^2$
- A_{CP} extraction
  - 4D binned fit to $\cos(\theta_{\ell K})$, Δz, M^2_ν and p_K simultaneously on 8 samples ($e^\pm K^\pm$, $\mu^\pm K^\pm$)



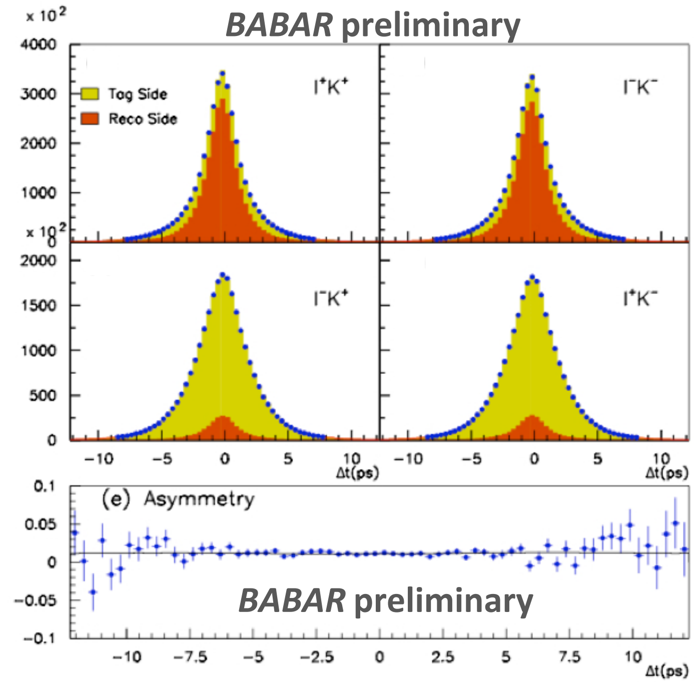
$B \to D^* \ell \nu$ Results

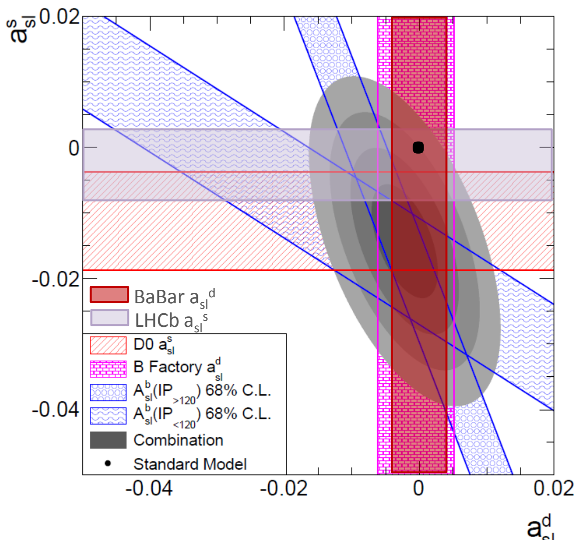
- Asymmetry:

$$\mathcal{A}_{CP} = (0.06 \pm 0.17^{+0.36}_{-0.32})\%$$

$$1 - |q/p| = (0.29 \pm 0.84^{+1.78}_{-1.61}) \times 10^{-3}$$

- Consistent with HFAG average
- Consistent with SM expectations
- Single most precise measurement





D0:PRL 110, 011801 (2013) + LHCb ICHEP2012 + BaBar (this measure)

✓HFAG average from ϒ(4S) measurement in agreement with SM

✓Hadronic colliders measure combination of Bs and Bd CP

✓D0 result on charge asymmetry of like-sign dimuons 3.9 σ away from SM

SUMMARY

BaBar Preliminary $B \rightarrow \rho^0 \pi^0$

$B^0 \rightarrow \pi^+\pi^-$

Belle Preliminary arxiv:1302.0551

BaBar PRD **87**,052009,2013

$B^0 \rightarrow \rho^0 \rho^0$

Belle Preliminary arxiv:1212.4015

Canonical sin2β from ccs

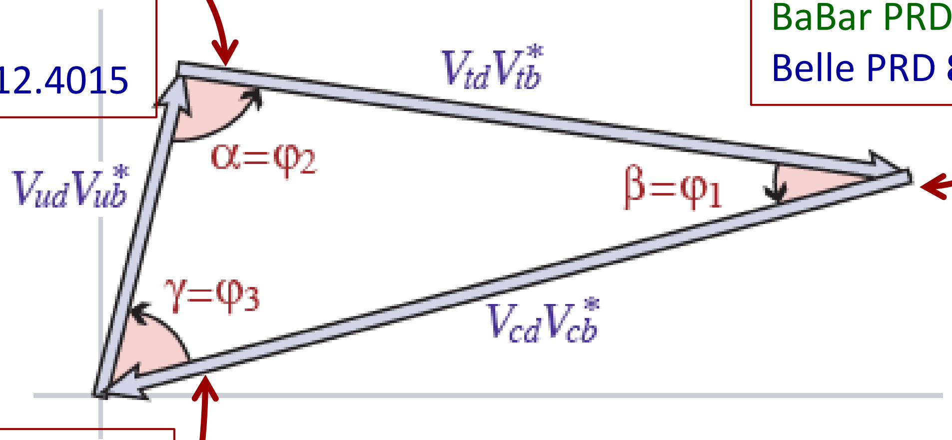
BaBar PRD 79(2009)072009

Belle PRL 108 (2012) 171802

B→D*D*

BaBar PRD **86**, 112006 (2012)

Belle PRD **86**, 071103(R) (2012)



Combination

BaBar PRD **87**, 052015 (2013)

Belle PRD **85**, 112014 (2012)

Belle Preliminary: arXiv:1205.0422

PLUS:

T Violation

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

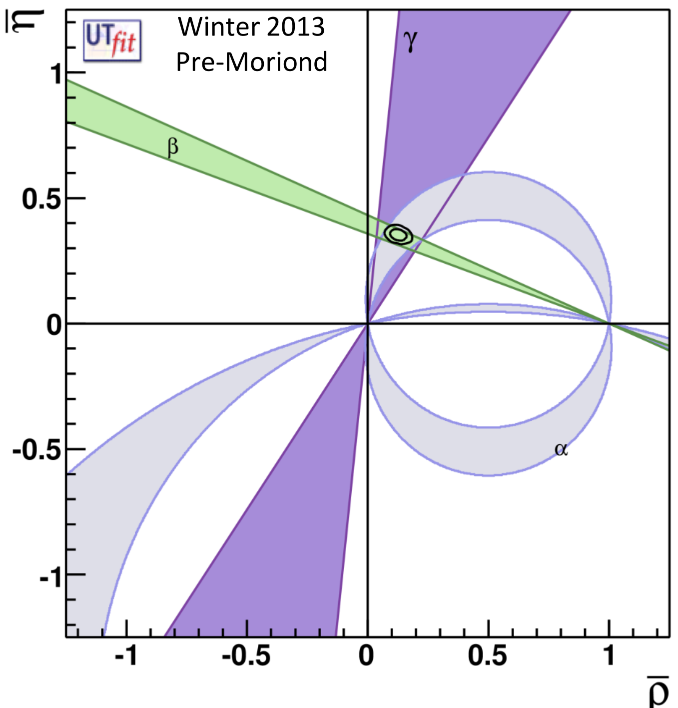
CPT Violation

Belle PRD **85**, 071105(R) (2012)

CPV in B mixing

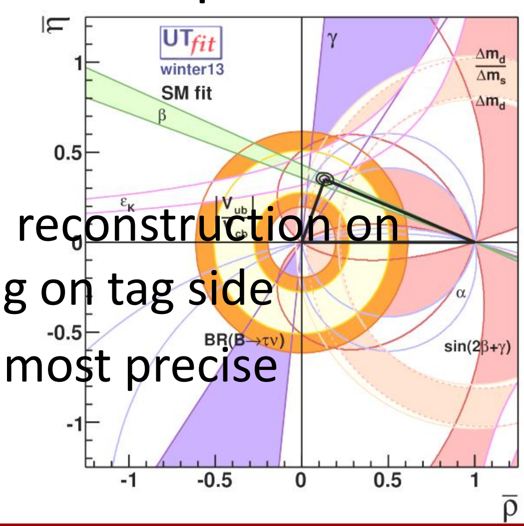
BaBar Preliminary

CONCLUSION



Winter 2013,Pre-Moriond: new BaBar γ combination not included

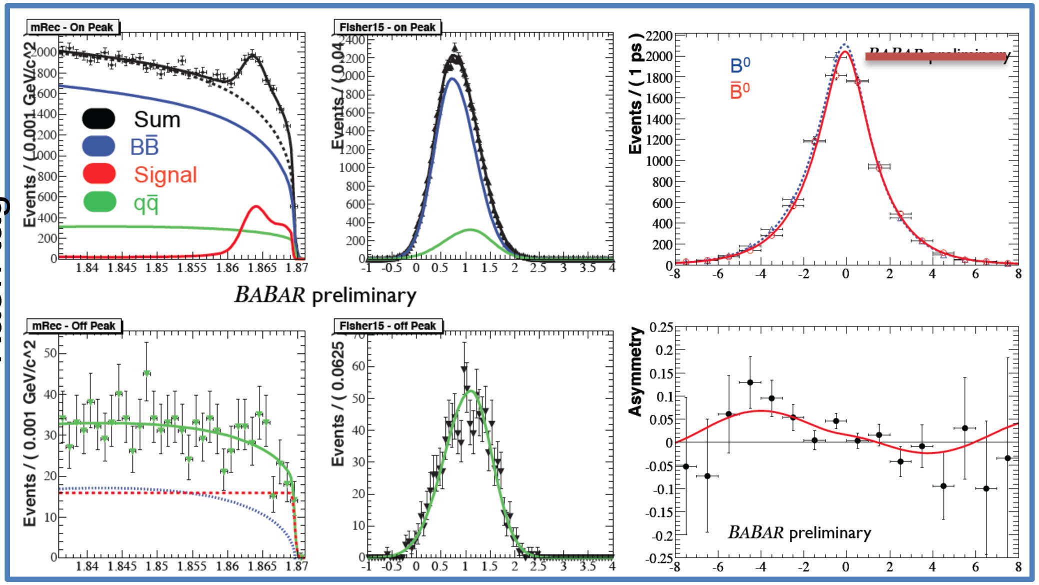
- 1st unambiguous T-Violation result at >14σ
- Sin2β and CPV well established by the B-factories, looking for effects beyond SM in b→ccd.
- Improving constraints on α.
- Value of γ from multiple measurements in perfect agreement with the SM prediction (~69°)
- CPV in B^0 mixing
  - New approach: D* partial reconstruction on reco side and kaon tagging on tag side
  - No asymmetry but single most precise measurement



$B \rightarrow D^*D^*$ Details (1)

Kinematic Fit | Time Dependent Fit

Kaon tag



$$C = +0.12 \pm 0.11$$
$$S = -0.42 \pm 0.16$$

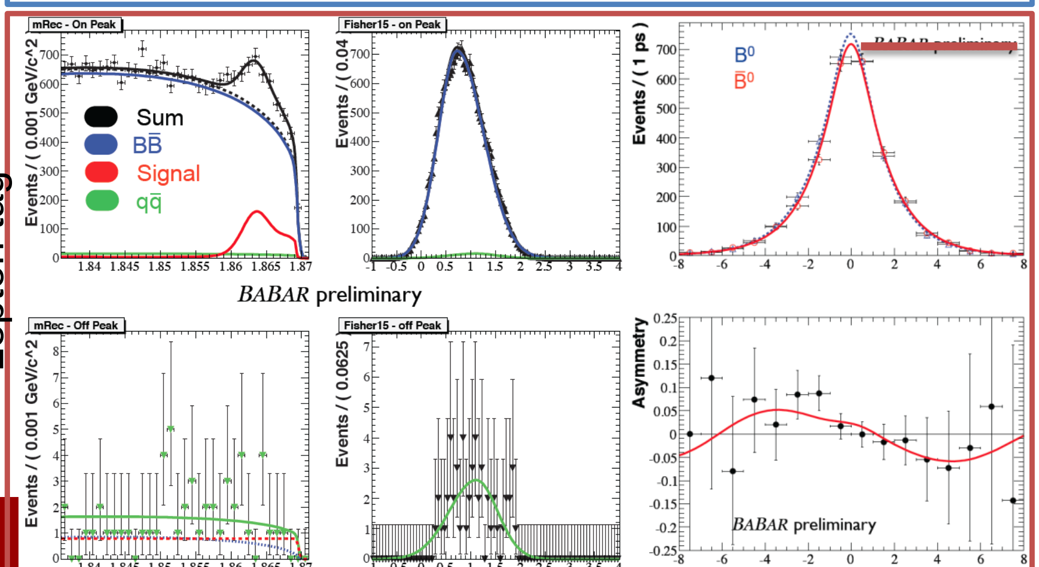
Inclusive of K+lepton tags

- Inclusive combination
  - $C = +0.15 \pm 0.09 \pm 0.04$
  - $S = -0.34 \pm 0.12 \pm 0.05$
- Assuming negligible penguin contributions:
  - $S_+ = -S_-$; $C = C_+$
  - $S = S_+ (1 - 2R_\perp)$,
- Using $R_\perp = 0.158 \pm 0.02$
  - $C_+ = +0.15 \pm 0.09 \pm 0.04$
  - $S_+ = -0.49 \pm 0.18 \pm 0.07 \pm 0.04$

stat. syst. $R_\perp$

Babar measurement of $R_\perp$

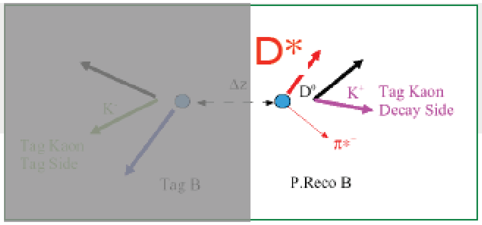
Lepton tag



$$C = +0.20 \pm 0.15$$
$$S = -0.21 \pm 0.20$$

$B \rightarrow D^*D^*$ Details (2)

Tagging



- Mis-tag due to unreconstructed D^0 tracks
  - This introduces an additional dilution D=(1-α), where α is the fraction of tags coming from the missing D^0
  - This fraction can be obtained from data with some input from signal MC
  - Can be reduced with a cut on the cosine of the opening angle between the tagging track and the missing D^0 direction θ_{tag}

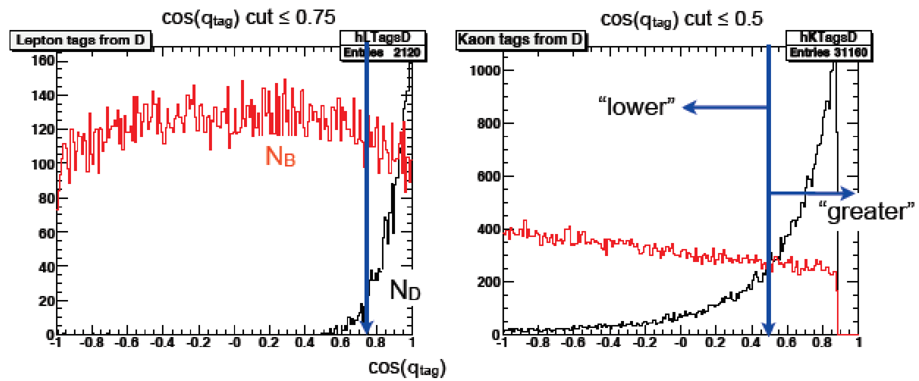


Figure 2.1: Signal Monte Carlo distributions of $\cos(\vartheta_{\rm tag})$ for tracks from the missed D^0 (black) and from the other B^0 (red); lepton tags on the left, kaon tags on the right.

GIRI-GROSSMAN-SOFFER-ZUPAN (GGSZ) METHOD

A. Giri, Yu. Grossman, A. Soffer, J. Zupan, PRD 68, 054018(2003)

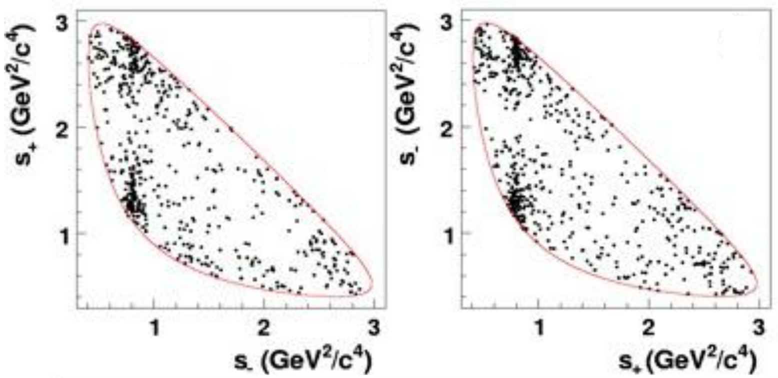
- Cartesian observables

$$x_{\pm} = \mathrm{Re}(r_B e^{i(\delta \pm \gamma)}) = r_B \cos(\delta \pm \gamma)$$

$$y_{\pm} = \mathrm{Im}(r_B e^{i(\delta \pm \gamma)}) = r_B \sin(\delta \pm \gamma)$$

$$z_{\pm} = x_{\pm} + i \cdot y_{\pm}$$

$$D \rightarrow K_S^0 \pi^+ \pi^-, \quad K_S^0 K^+ K^-$$



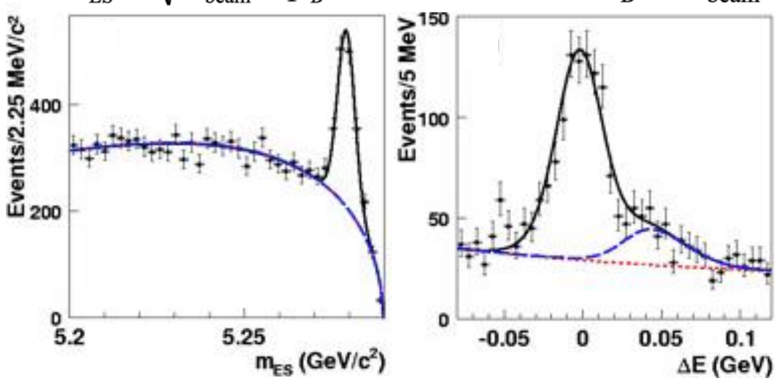
	Real part (%)	Imaginary part (%)
z_-	$6.0 \pm 3.9 \pm 0.7 \pm 0.6$	$6.2 \pm 4.5 \pm 0.4 \pm 0.6$
z_+	$-10.3 \pm 3.7 \pm 0.6 \pm 0.7$	$-2.1 \pm 4.8 \pm 0.4 \pm 0.9$
z^*_-	$-10.4 \pm 5.1 \pm 1.9 \pm 0.2$	$-5.2 \pm 6.3 \pm 0.9 \pm 0.7$
z^*_+	$14.7 \pm 5.3 \pm 1.7 \pm 0.3$	$-3.2 \pm 7.7 \pm 0.8 \pm 0.6$
z_{s-}	$7.5 \pm 9.6 \pm 2.9 \pm 0.7$	$12.7 \pm 9.5 \pm 2.7 \pm 0.6$
z_{s+}	$-15.1 \pm 8.3 \pm 2.9 \pm 0.6$	$4.5 \pm 10.6 \pm 3.6 \pm 0.8$

Errors are statistical, systematic and model

Signal is separated from background using mES, Fisher (on event shape variables), ΔE, (s−, s+) (invariant masses squared of $K_s\pi$+ and $K_s\pi$-)

$$D \rightarrow K_S^0 \pi^+ \pi^-$$

$$m_{ES} = \sqrt{E_{\mathrm{beam}}^2 - p_B^2} \qquad \Delta E = E_B - E_{\mathrm{beam}}$$



The reconstruction efficiency is 22%
Fit for yields and CP violating parameters

PRL **105** (2010) 121801

GRONAU-LONDON-WYLER (GLW) METHOD

M. Gronau, D. London, D. Wyler, PLB253,483 (1991); PLB 265, 172 (1991)

Observables

$$A_{CP\pm} = \frac{\Gamma(B^- \to D^0_{CP\pm}K^-) - \Gamma(B^+ \to D^0_{CP\pm}K^+)}{\Gamma(B^- \to D^0_{CP\pm}K^-) + \Gamma(B^+ \to D^0_{CP\pm}K^+)}$$

$$R_{CP\pm} = 2\frac{\Gamma(B^- \to D^0_{CP\pm}K^-) + \Gamma(B^+ \to D^0_{CP\pm}K^+)}{\Gamma(B^- \to D^0 K^-) + \Gamma(B^+ \to \bar{D}^0 K^+)}$$

In polar coordinates

$$R_{CP\pm} = 1 + r_B^2 \pm 2r_B \cos\gamma \cos\delta_B$$

$$A_{CP\pm} = \frac{\pm 2r_B \cos\gamma \cos\delta_B}{R_{CP\pm}}$$

Or using $r_B^2 = [(x_-^2) + (y_-^2) + (x_+^2) + (y_+^2)]$

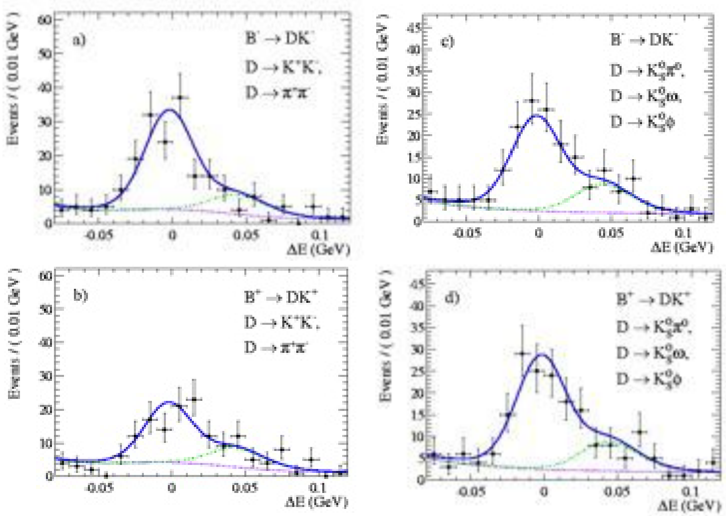
$$R_{CP\pm} = 1 + r_B^2 \pm (x_- + x_+)$$

$$A_{CP\pm} = \pm(x_- - x_+)/\left[1 + r_B^2 \pm (x_- + x_+)\right]$$

- Many analyses available: B→DK, D*K,DK*
- D^0→$K_s\varphi$ decay removed from the final results in order to avoid correlation with GGSZ method. For B→DK: the measurement w/o $K_s\varphi$ is available, for other B decays we inflate the errors by 10% (as it is observed in the B→DK).

$$CP+ : D^0_{CP+} \to K^+K^-, \pi^+\pi^-$$
$$CP- : D^0_{CP-} \to K^0_s\pi^0, K^0_s\omega, K^0_s\phi$$
$$\mathrm{CA} : D^0 \to K^-\pi^+$$

CP-even CP-odd



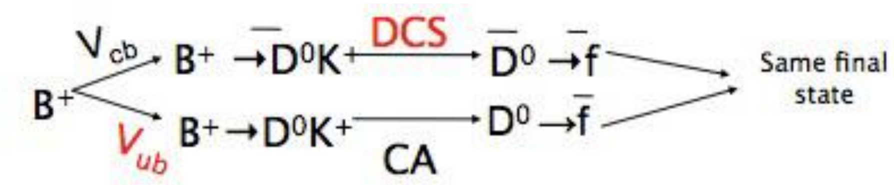
Simultaneous fit to the subsamples corresponding to different D decays. Direct CPV at 3.6σ in B→D_{CP+}K decays

PRD **82** (2010) 072004

ATWOOD-DUNIETZ-SONI (ADS) METHOD

D. Atwood, I. Dunietz, A. Soni, PRL 78, 3357 (1997)

- Interference between Doubly-Cabibbo-Suppressed modes and Cabibbo Allowed



- $B^+ \to DK^+$, $D \to K^+\pi^-$ Same Sign
- $B^+ \to DK^+$, $D \to K^-\pi^+$ Opposite Sign
- Different set of variables not statically correlated

$$R^+ = \frac{\Gamma([K^-\pi^-]K^+)}{\Gamma([K^+\pi^-]K^+)} = \left[\frac{\text{opposite sign events yield}}{\text{same sign events yield}}\right]_{B^+}$$

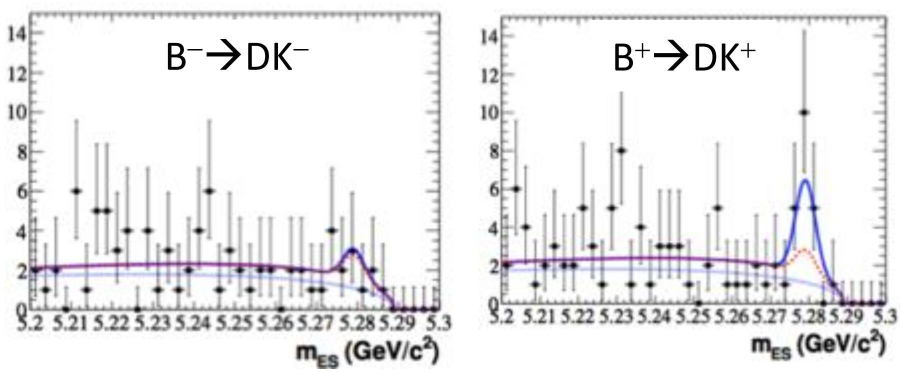
$$R^- = \frac{\Gamma([K^+\pi^-]K^-)}{\Gamma([K^-\pi^+]K^-)} = \left[\frac{\text{opposite sign events yield}}{\text{same sign events yield}}\right]_{B^-}$$

Correlation to cartesian coordinates

$$R_\pm = r_{B\pm}^2 + r_{D^0}^2 + 2r_{D^0}(x_\pm \cos\delta_{D^0} - y_\pm \sin\delta_{D^0})$$

where

$$r_{B\pm}^2 = [(x_\pm^2) + (y_\pm^2)]$$



Fitting directly R_{ADS} and R+, R- to reconstruct asymmetry.
PRD **82** (2010) 072006

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