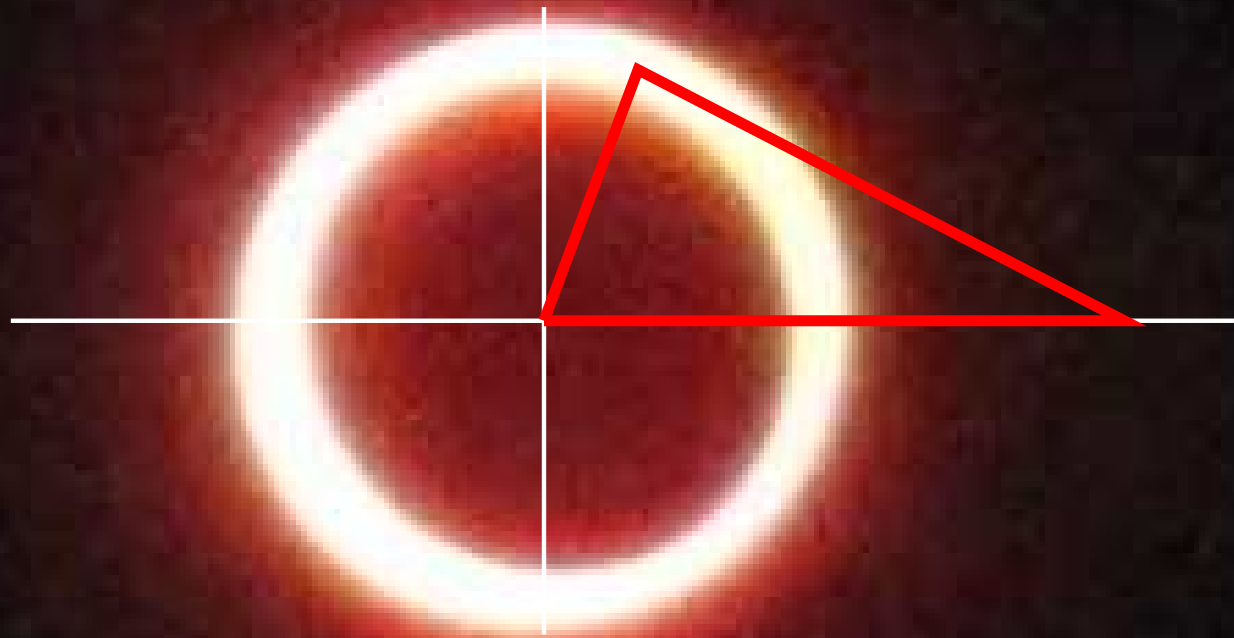


# CP Violation and CKM Measurements

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*36<sup>th</sup> International Conference on High Energy Physics  
4–11 July, 2012, Melbourne*



*Annular Solar Eclipse in Tsukuba at 07:35am, 21 May 2012*

# Outline

- Introduction
- CKM measurements in loop processes
- CKM measurements in tree processes
- CP violation in charm and tau
- Summary

## Disclaimers —

1. *New Physics in Flavor already discussed by S.Stone yesterday*
2. *Semileptonic B decays already discussed by P.Urquijo 30 minutes ago*
3. *Only selected topics — any missing results are due to my choice or fault (skipped: CPV in B decays less related to CKM,  $A_{sl}$ ,  $B_s$  mixing and CPV)*
4. *Notations — only  $(\phi_1, \phi_2, \phi_3)$  in many places, equivalent to  $(\beta, \alpha, \gamma)$  and  $S = A^{\text{mix}}$ ,  $A = A^{\text{mix}} = -C$  are used for CPV parameters*

# CKM

**Gauge interaction with Kobayashi-Maskawa mechanism:**

The diagram shows a quark line labeled  $(u, c, t)$  entering from the left. It interacts with a  $W^-$  boson (represented by a wavy line) which then decays into a quark line labeled  $(d, s, b)$ .

$$-\frac{g}{\sqrt{2}} (\bar{u}_L, \bar{c}_L, \bar{t}_L) \gamma^\mu W_\mu^+ \mathbf{V}_{\text{CKM}} \begin{pmatrix} d_L \\ s_L \\ b_L \end{pmatrix} + \text{h.c.}$$

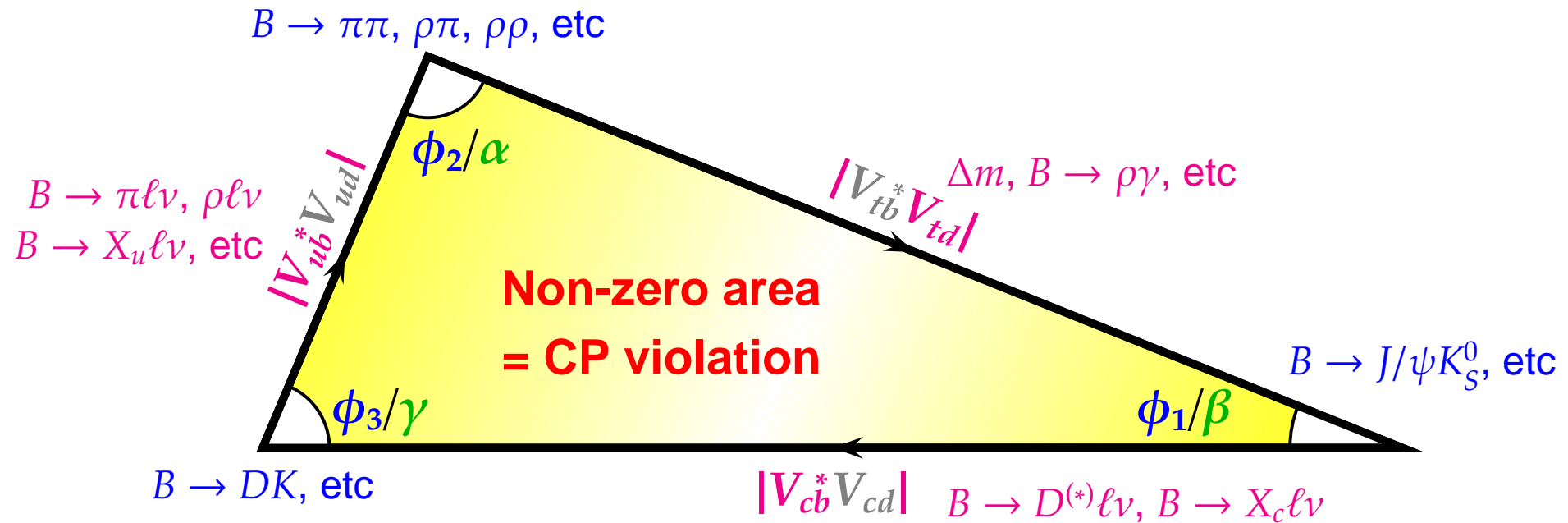
**Misalignment between mass and weak eigenstates generates mixing beyond generations:  $(d, s, b) \neq (d', s', b') = \mathbf{V}_{\text{CKM}}(d, s, b)$**

$$\mathbf{V}_{\text{CKM}} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \approx \begin{pmatrix} 1 - \frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1 - \frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1 - \rho - i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

**Irreducible complex phase is the source of CP violation in SM**

# $b$ - $d$ Unitarity Triangle (off-diagonal elements)

Unitarity relation in complex plane  $V_{ub}^* V_{ud} + V_{cb}^* V_{cd} + V_{tb}^* V_{td} = 0$   
 provides a rich set of CPV observables



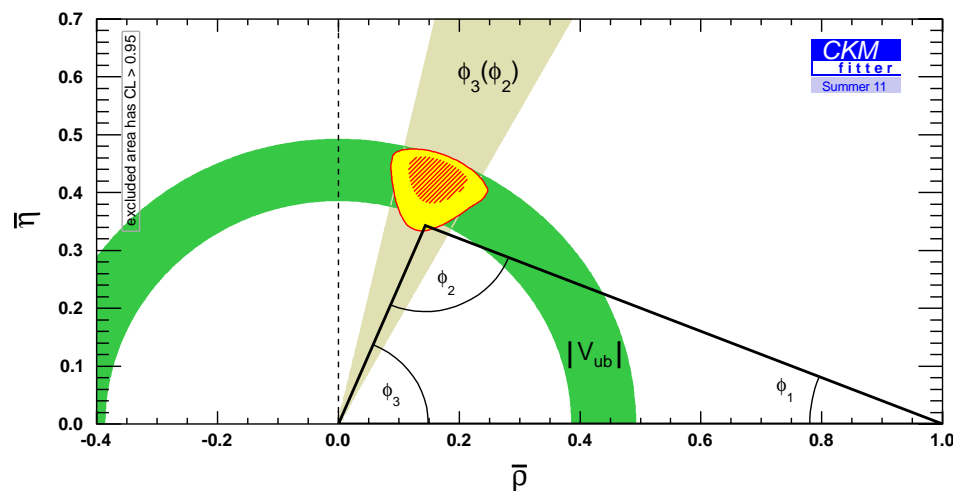
$$\phi_1/\beta = -\arg\left(\frac{V_{cb}^* V_{cd}}{V_{tb}^* V_{td}}\right), \quad \phi_2/\alpha = -\arg\left(\frac{V_{tb}^* V_{td}}{V_{ub}^* V_{ud}}\right), \quad \phi_3/\gamma = -\arg\left(\frac{V_{ub}^* V_{ud}}{V_{cb}^* V_{cd}}\right)$$

$\Leftrightarrow$  **Less (hardly) visible  $s$ - $b$  ( $d$ - $s$ ) triangles**

$$V_{us}^* V_{ub} + V_{cs}^* V_{cb} + V_{ts}^* V_{tb} = 0 \quad - \quad (\lambda^4 : \lambda^2 : \lambda^2) \Rightarrow \beta_s \sim 1^\circ$$

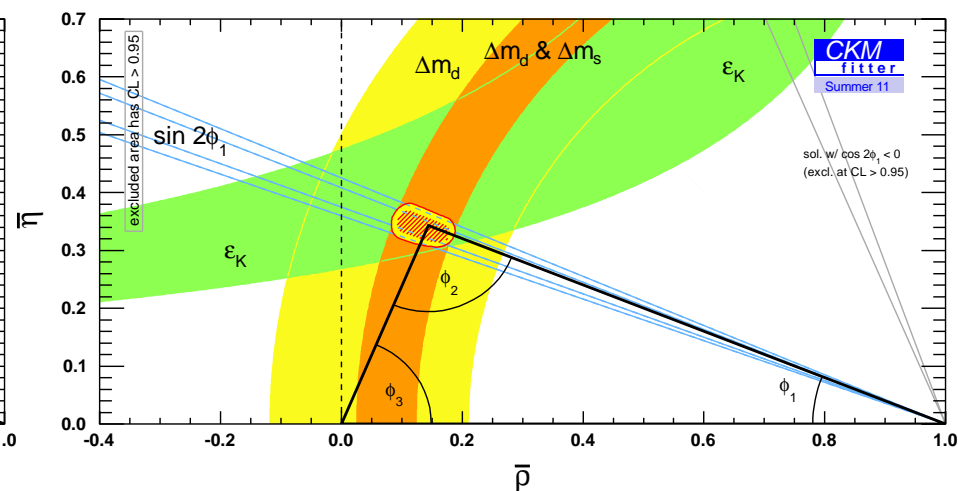
$$V_{ud}^* V_{us} + V_{cd}^* V_{cs} + V_{td}^* V_{ts} = 0 \quad - \quad (\lambda^1 : \lambda^1 : \lambda^5)$$

# Tree vs Loop



## Tree measurements

(SM: phase and size of  $V_{ub}$ )

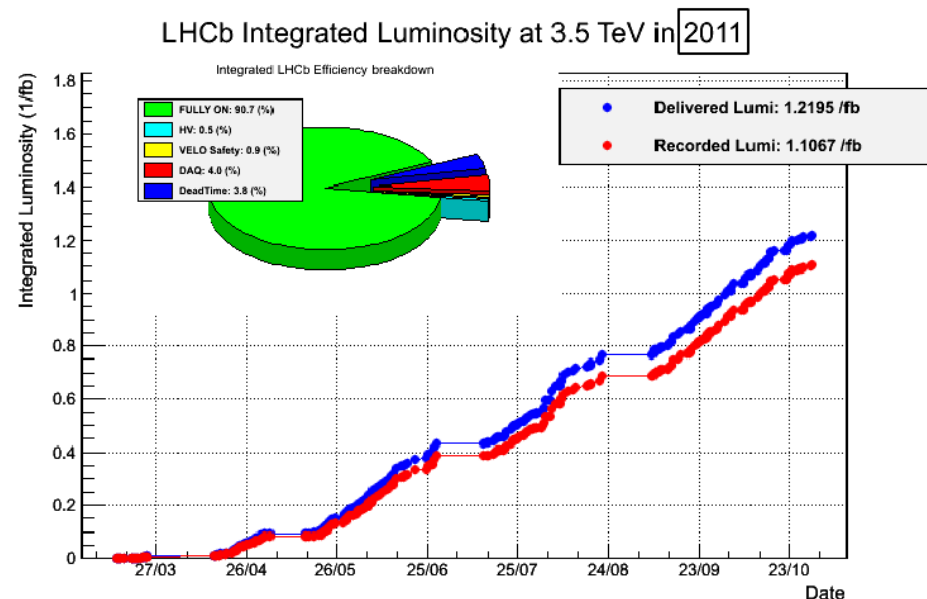
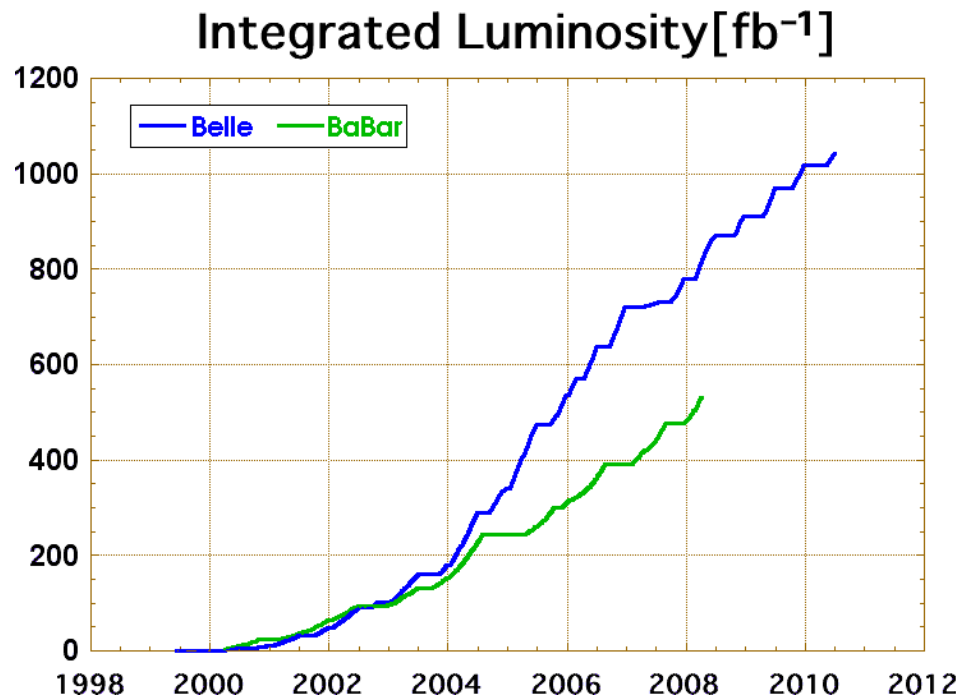


## Loop measurements

(SM: phase and size of  $V_{td}$ )

- Tree measurements free from NP contributions ( $\phi_3$  and  $|V_{ub}|$ ),  
Loop measurements may be affected by NP ( $\phi_1$  and  $|V_{td}|$ )
- Experimental precision:  $\phi_1 \gg \phi_2 \gg \phi_3, |V_{cb}| \gg |V_{td}|, |V_{ub}|$   
Theoretical cleanness:  $\phi_3 > \phi_1 > \phi_2 \gg |V_{cb}| \gg |V_{ub}|, |V_{td}|$

# Heavy Flavor Dataset

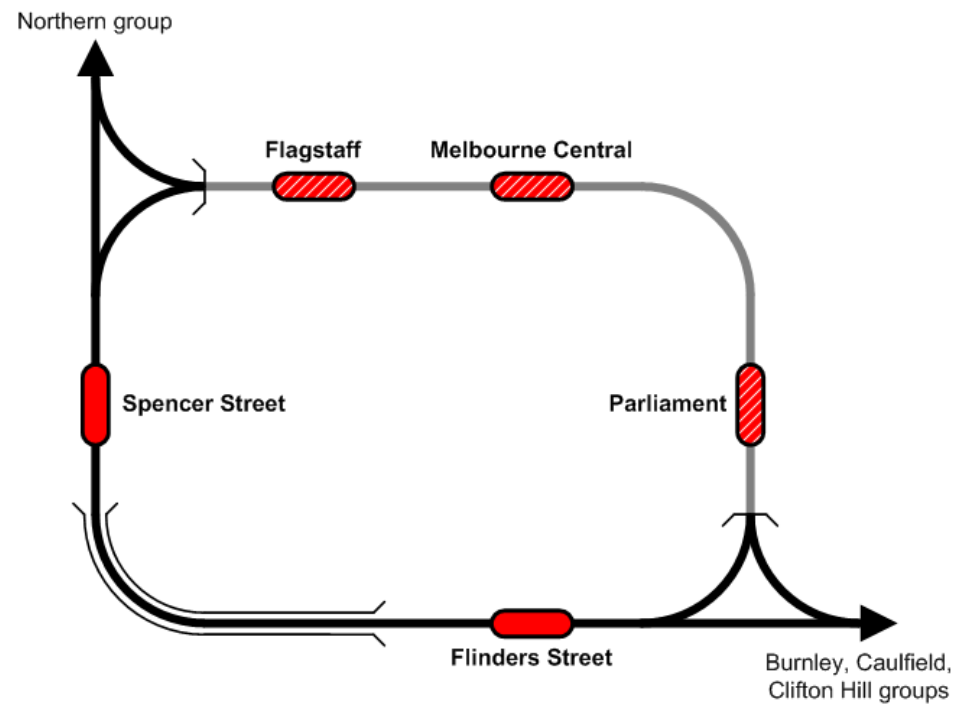


**2011:**  $1.0 \text{ fb}^{-1}$  @  $\sqrt{s} = 7 \text{ GeV}$

**2012:** Expect  $1.5 \text{ fb}^{-1}$  @  $\sqrt{s} = 8 \text{ GeV}$

- **Belle+BaBar total 1240 M  $B\bar{B}$  + (even more) charm +  $\tau$**   
BaBar (1999–2008)  $> 500 \text{ fb}^{-1}$ , Belle (1999–2010)  $> 1000 \text{ fb}^{-1}$
- **LHCb  $1.0 \text{ fb}^{-1}$  (2011) +  $0.6 \text{ fb}^{-1}$  (2012 June) + more to come**  
already surpassing Belle/BaBar in all charged track final state modes
- **Other players:** CLEO(-c), BESIII, CDF, D0, ATLAS, CMS, ...,  
**and averaging / fitting groups:** HFAG, CKMfitter, UTfit, ...  
(COLOR codes above are used to indicate the players)

# Loop Measurements

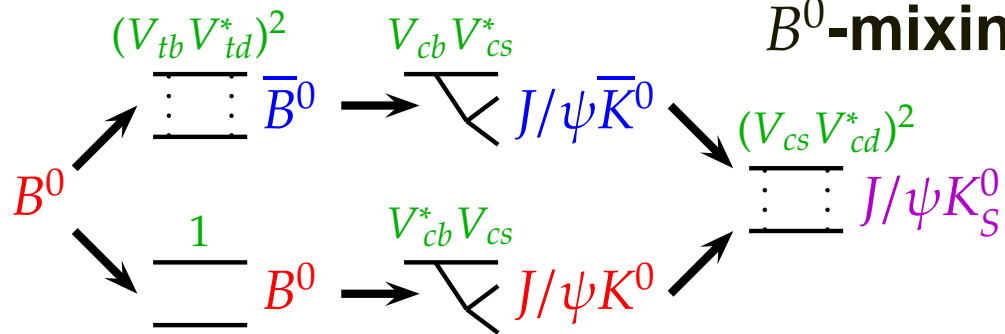


*City Loop of Melbourne*

# Time-dependent CP asymmetry

Beautiful experimental setup

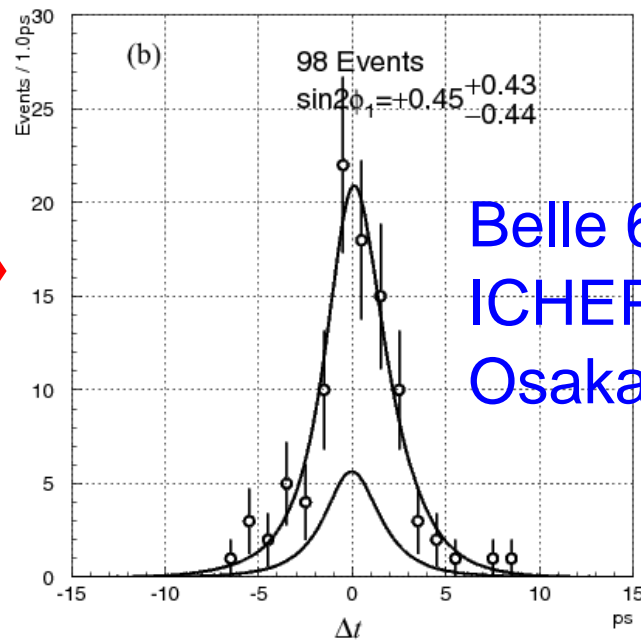
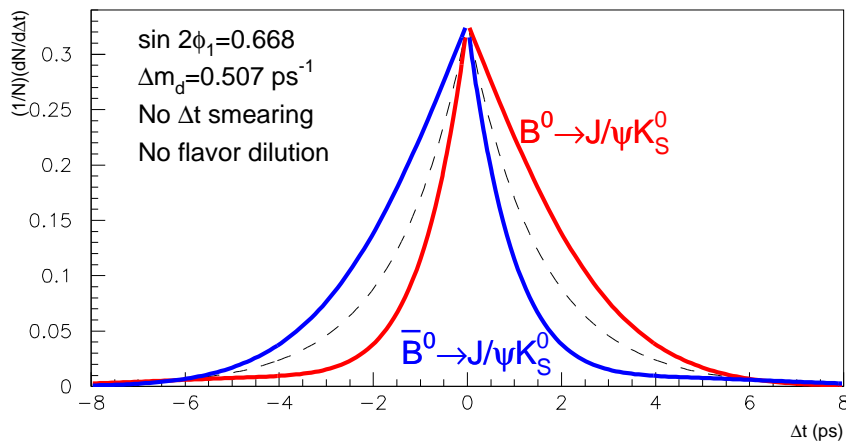
$B^0$ -mixing +  $b \rightarrow c\bar{c}s$  +  $K^0$ -mixing



$$\Gamma(B^0) \propto e^{-t/\tau} (1 + \sin 2\phi_1 \sin \Delta mt)$$

$$\Gamma(\bar{B}^0) \propto e^{-t/\tau} (1 - \sin 2\phi_1 \sin \Delta mt)$$

Decay time measurement (1.5ps)  
and lot of data  $O(30 \text{ fb}^{-1})$  needed

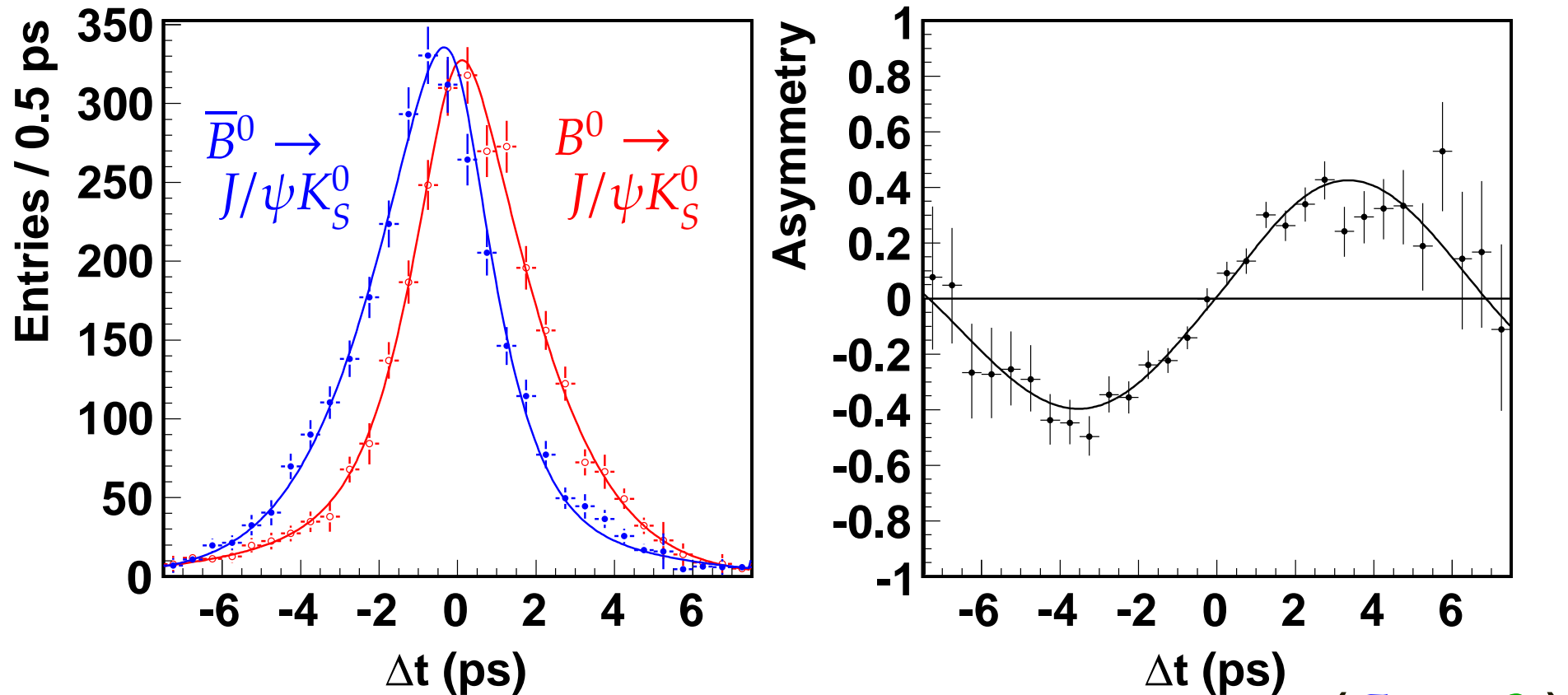


Belle  $6 \text{ fb}^{-1}$   
ICHEP 2000  
Osaka

Starting point of B-factory era

# $\phi_1 / \beta$ from $B \rightarrow J/\psi K_S^0$ — State of Art

Belle 772 M  $B\bar{B}$  PRL 108, 171802 (2012)



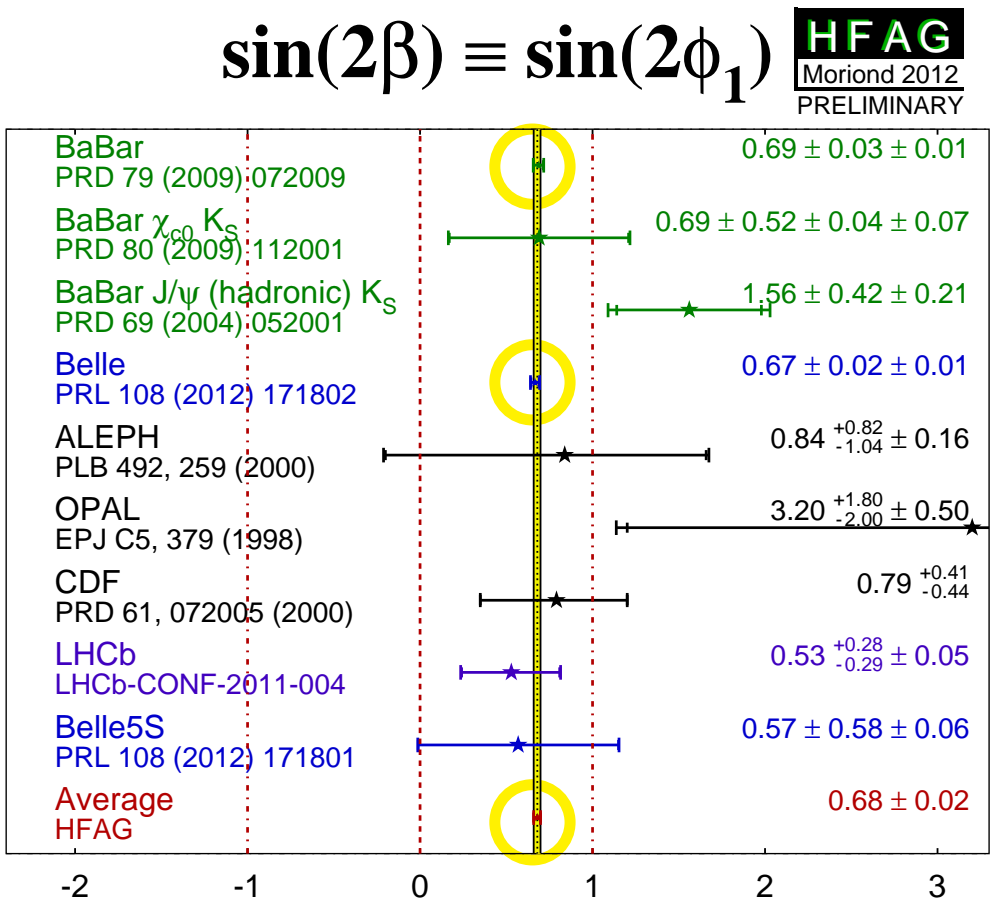
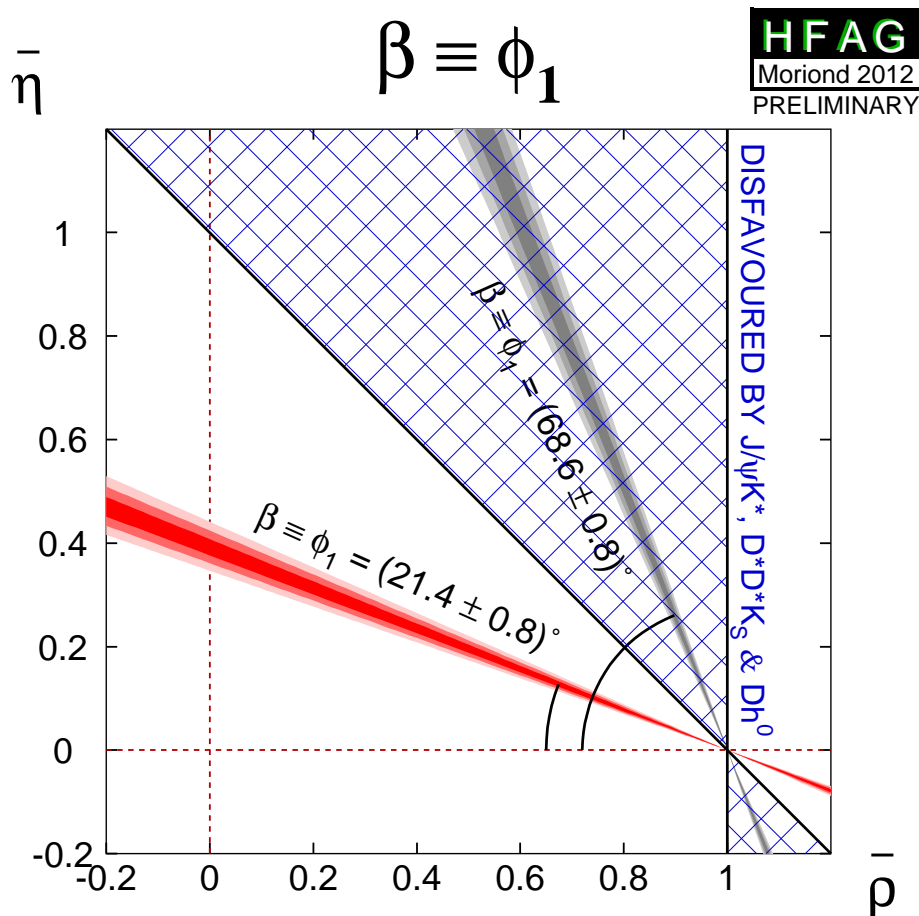
$$\mathcal{P}(\Delta t) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}} \times \left\{ 1 + q \left[ \mathcal{S}_f \sin(\Delta m \Delta t) + \mathcal{A}_f \cos(\Delta m \Delta t) \right] \right\}$$

$(\mathcal{A}_f = -C_f)$

- Belle's final data sample (772 M  $B\bar{B}$ ) (BaBar's look very similar)
- Golden mode ( $B \rightarrow J/\psi K_S^0$ ) (only good flavor-tag sample shown)

# $\phi_1 / \beta$ from $b \rightarrow c\bar{c}s$ — status

- **More modes added:**  $\psi(2S)K_S^0$ ,  $\chi_{c1}K_S^0$ ,  $J/\psi K_L^0$ , ...
- $\sin 2\phi_1 = 0.68 \pm 0.02$ ,  $\phi_1 = (21.4 \pm 0.8)^\circ$  (2-fold ambiguity resolved)
- $A_f = -0.005 \pm 0.017$  (consistent with 0 at <2%)
- **Still statistics limited!**  $\Rightarrow$  homework for Belle II/SuperB



# Other $\phi_1 / \beta$ modes (1): $B^0 \rightarrow D^{(*)+}D^{(*)-}$

$B$ -mixing +  $b \rightarrow c\bar{c}d$  — sensitive to  $\phi_1/\beta$

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

CP-eigenstate

$\mathcal{S} = \sin 2\phi_1$ ,  $\mathcal{A} = 0$   
if negligible penguin

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

mix of CP-odd/even

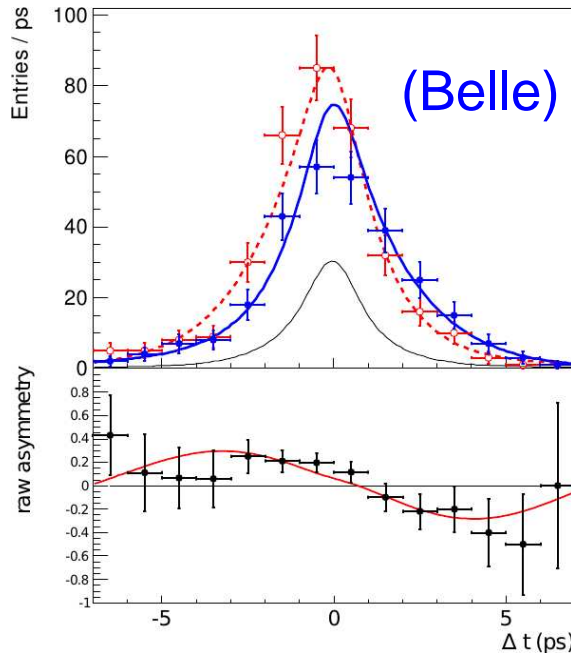
$\mathcal{S}$ ,  $\mathcal{A}$  for each of  
longitudinal / transverse

$$B^0 \rightarrow D^\pm D^{*\mp}$$

Not a CP-eigenstate

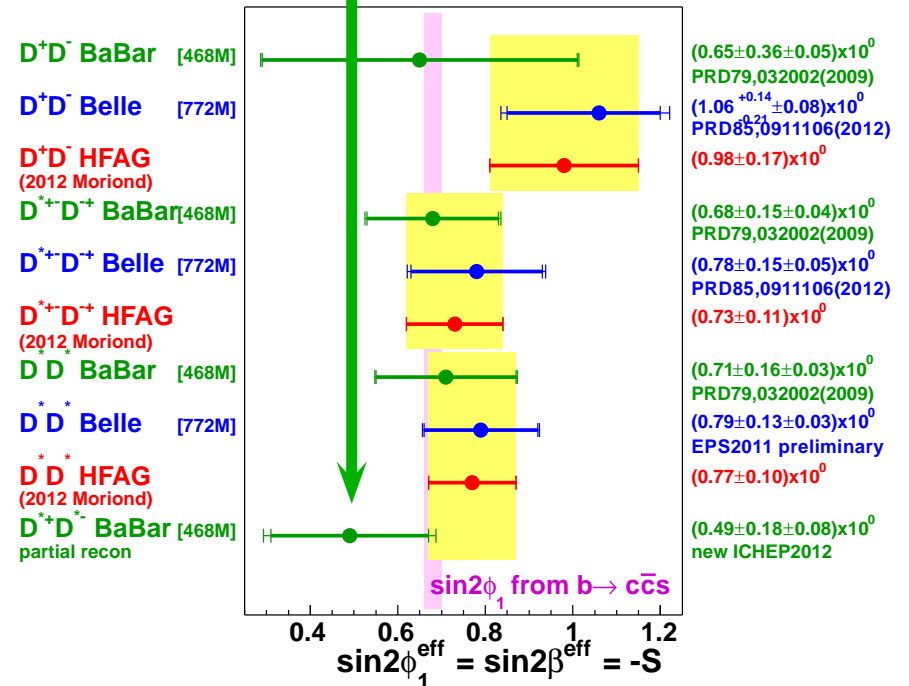
2 amplitudes  $\times$  2 modes  
 $\Rightarrow C, \mathcal{S}, \mathcal{A}, \Delta\mathcal{S}, \Delta\mathcal{A}$

## $D^{*+}D^{*-}$ full reconstruction



## New partial reconstruction (BaBar)

(one of  $D^*$  of  $D^*D^*$  is tagged only by slow  $\pi$ )



$5.4\sigma$  CPV,  $P_{\text{odd}} = 14 \pm 2 \pm 1\%$

# Other $\phi_1 / \beta$ modes (2): charmless $B$ decays

- $b \rightarrow sq\bar{q}$  transition  $\rightarrow$  numerous charmless final states
- $\sin 2\phi_1$  in SM, penguin loop may be altered by NP  
And there used to be a large discrepancy from other  $\phi_1/\beta$
- Latest addition by BaBar:

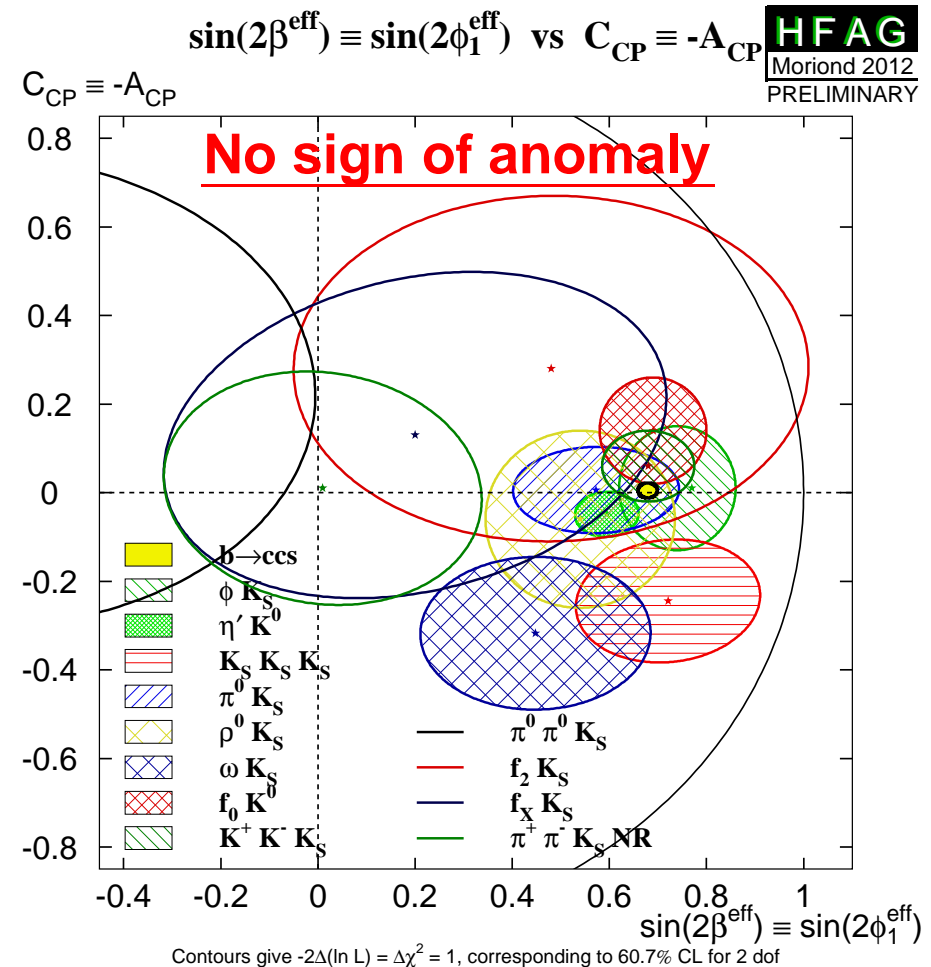
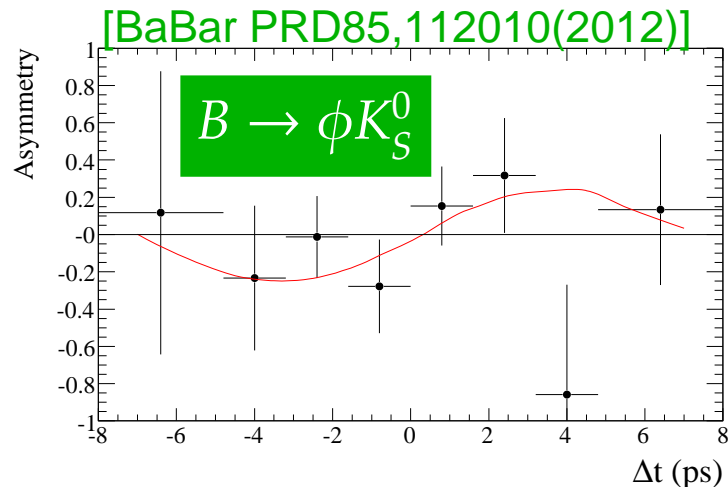
$$B \rightarrow \phi K_S^0 \text{ (468M } B\bar{B}\text{)}$$

$$\phi_1^{\text{eff}} / \beta^{\text{eff}} = (21 \pm 6 \pm 2)^\circ$$

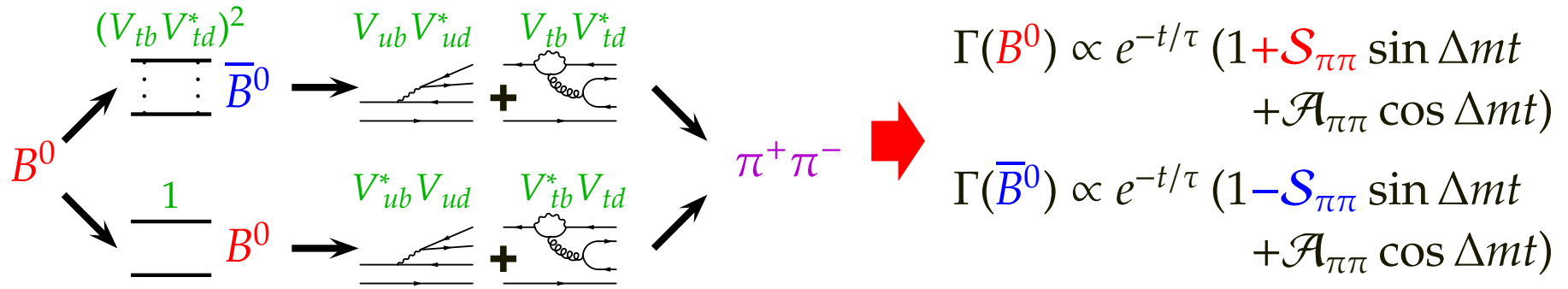
$$B \rightarrow K^+ K^- K_S^0 \text{ (not } \phi/f_0\text{)}$$

$$\phi_1^{\text{eff}} / \beta^{\text{eff}} = (20.3 \pm 4.3 \pm 1.2)^\circ$$

Fully compatible with  $\phi_1/\beta$



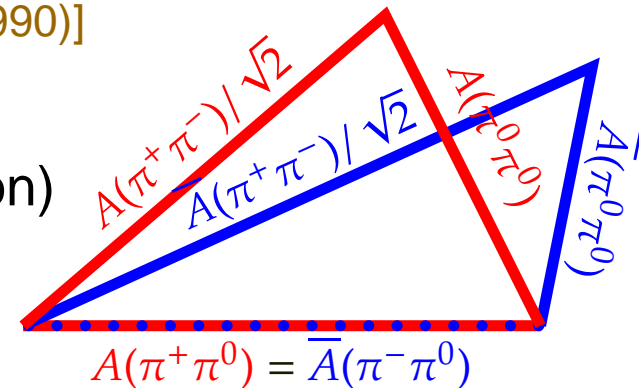
# $\phi_2 / \alpha$ and Penguin Pollution



$$\mathcal{S}_{\pi\pi} = \sqrt{1 - \mathcal{A}_{\pi\pi}^2} \sin 2\phi_2^{\text{eff}}, \text{ where } \phi_2^{\text{eff}} = (\phi_2 + \kappa) \text{ is not } \phi_2$$

## ● Isospin analysis [Gronau-London PRL65,3381(1990)]

- Relations with  $B^+ \rightarrow \pi^+ \pi^0$  and  $B^0 \rightarrow \pi^0 \pi^0$  (same for  $B \rightarrow \rho\rho$  after resolving polarization)
- Isospin breaking effects are small ( $\sim 2^\circ$ ) [EW penguins,  $m_u \neq m_d$ ,  $\pi - \eta^{(\prime)}$  mixing]

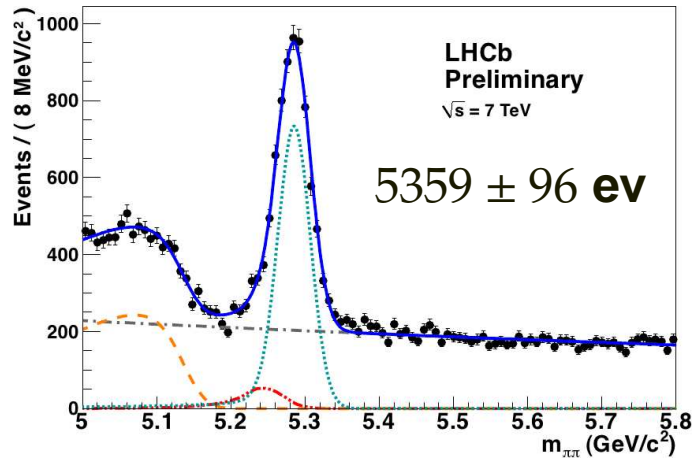


## ● Time-dependent Dalitz analysis [Snyder-Quinn PRD48,2139(1993)]

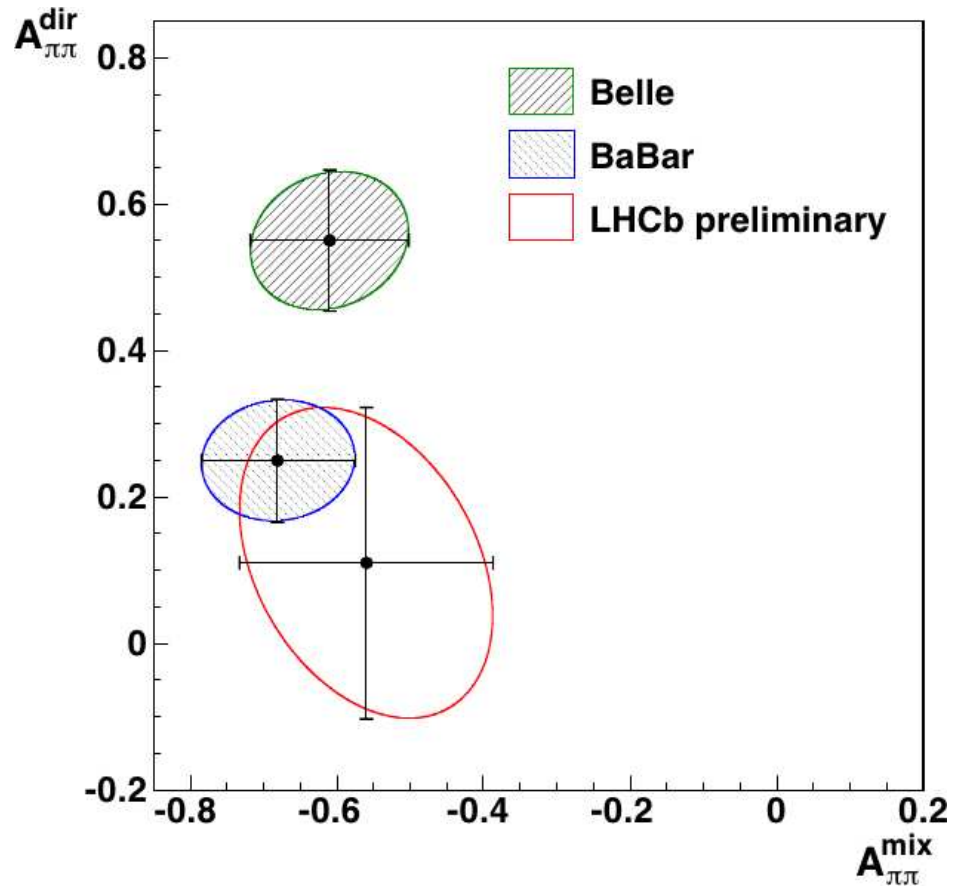
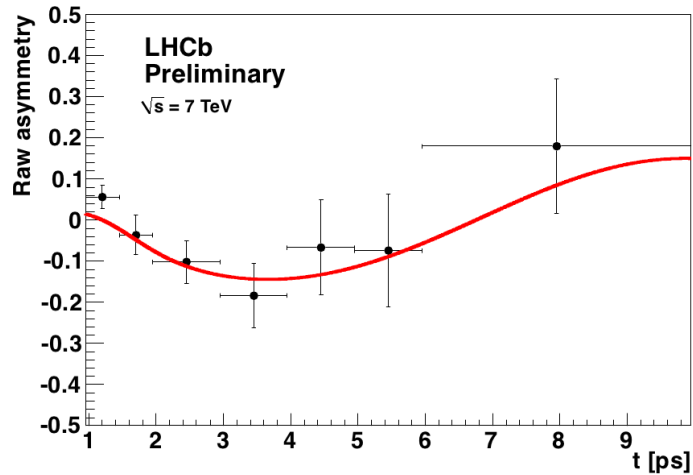
- $B^0 \rightarrow \pi^+ \pi^- \pi^0$  contains  $\rho^+ \pi^-$ ,  $\rho^- \pi^+$ ,  $\rho^0 \pi^0$  and their interferences
- $\phi_2 / \alpha$  directly determined,  $\rho^\pm \pi^0$  and  $\rho^0 \pi^+$  for further improvement

# $B \rightarrow \pi^+ \pi^-$ by LHCb

## Huge signal sample



Tagging  $\epsilon^{\text{eff}} = (2.3 \pm 0.1\%)$   
 ( $\Leftrightarrow \epsilon^{\text{eff}} \sim 30\%$  at Belle/BaBar)



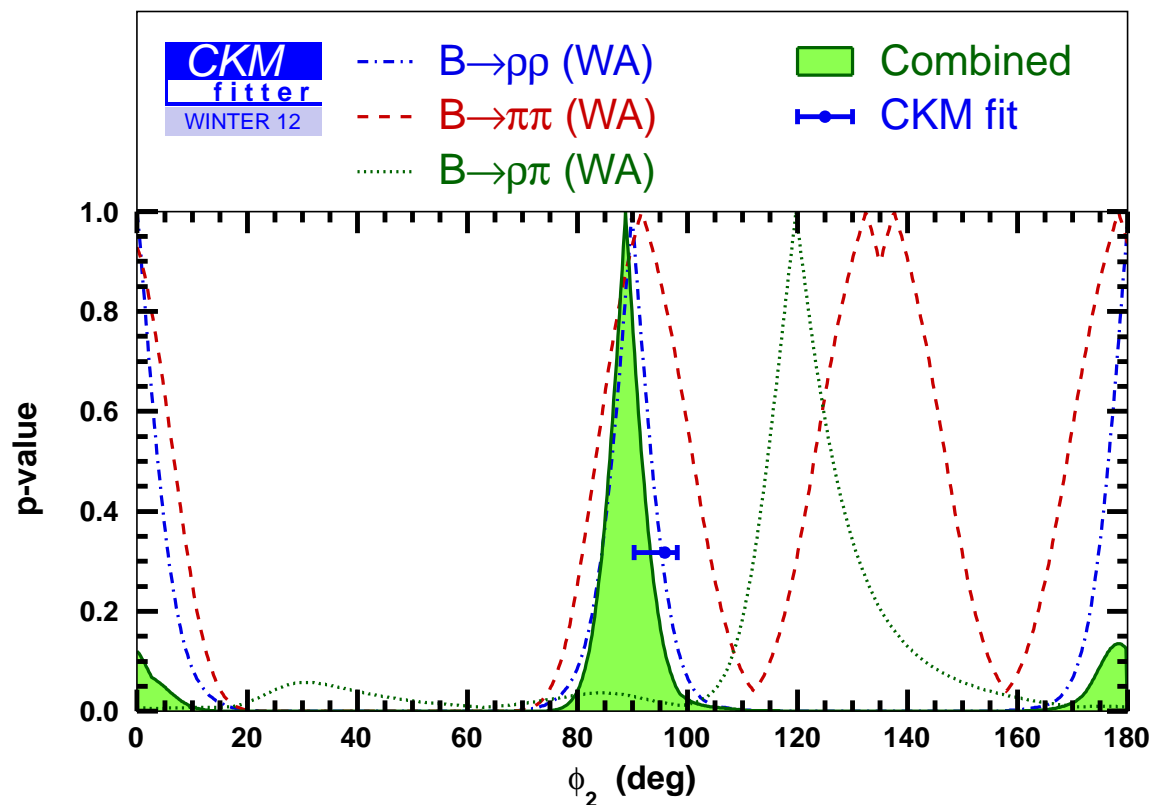
[LHCb  $0.7 \text{ fb}^{-1}$ , LHCb-CONF-2012-007]

$$S_{\pi\pi} = A_{\pi\pi}^{\text{mix}} = 0.56 \pm 0.17 \pm 0.03$$

$$\mathcal{A}_{\pi\pi} = A_{\pi\pi}^{\text{dir}} = 0.11 \pm 0.21 \pm 0.03$$

First significant ( $3.2\sigma$ ) mixing-induced CPV measurement at a hadron collider

# $\phi_2 / \alpha$ from $b \rightarrow u\bar{d}d$ : status



$$\phi_2 / \alpha = (88.7^{+4.6}_{-4.2})^\circ$$

[CKMfitter Moriond2012]

- **Multifold ambiguity solved by combination of  $\pi\pi$ ,  $\rho\pi$  and  $\rho\rho$**   
 **$\Rightarrow$  Consistent solution exists,  $\rho\rho$  bound is most stringent**
- Many Belle's / some BaBar's results yet to be updated to the full statistics, LHCb will further improve  $\mathcal{S}_{\pi\pi}$  and  $\mathcal{A}_{\pi\pi}$
- Further  $\phi_2/\alpha$  related measurements are homework for Belle II/SuperB

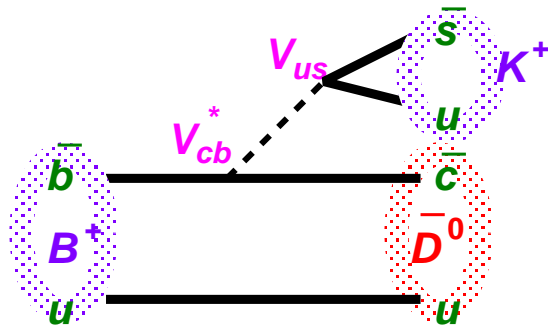
# Tree Measurements



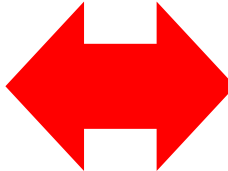
*Tokyo Sky Tree — tallest tower in the world, opened May 22, 2012*

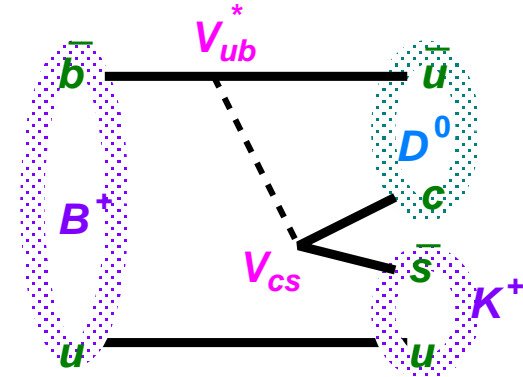
# $\phi_3 / \gamma$ from $B \rightarrow DK$

$$A(B^- \rightarrow D^0 K^-) \propto \lambda^3$$



$$A(B^- \rightarrow \bar{D}^0 K^-) \propto \lambda^3(\rho + i\eta)$$

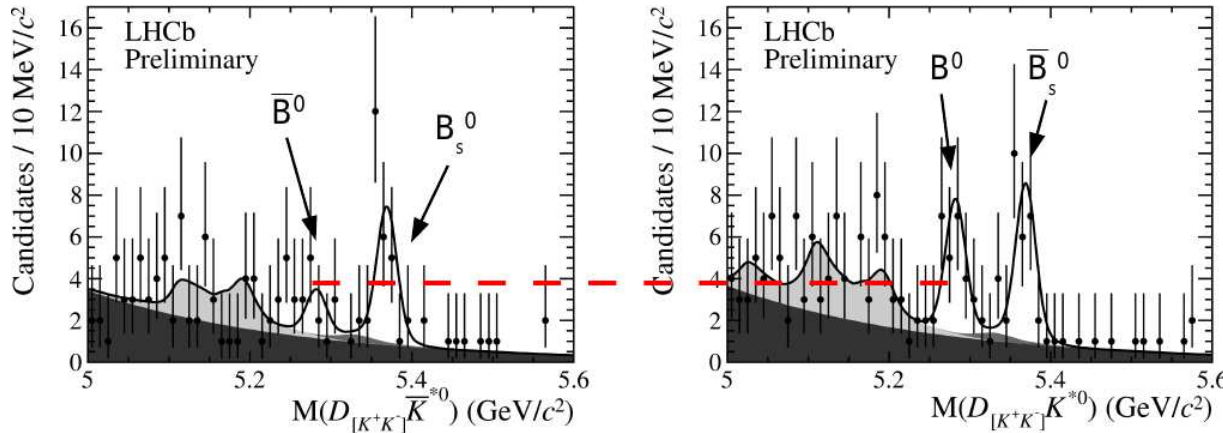
  
**Tree only**  
 $D^0$  and  $\bar{D}^0$  mix



- **GLW** —  $B^- \rightarrow D_{cp} K^-$  &  $B^+ \rightarrow D_{cp} K^+$  ( $D_{cp} \rightarrow K^+ K^-, \pi^+ \pi^-, K_S^0 \pi^0, \dots$ )
- **ADS** —  $B^- \rightarrow D_{dcs}^0 K^-$  &  $B^+ \rightarrow \bar{D}_{dcs}^0 K^+$  ( $D_{dcs}^0 \rightarrow K^+ \pi^-, K^+ \pi^- \pi^0, \dots$ )
  - 3 unknowns ( $\phi_3/\gamma$ ,  $r_B$  and  $\delta_B$ ), need more than one mode to resolve
  - 2 observables ( $A_{cp}$  and  $R_{cp}$ ) for each mode
- **GGSZ** —  $B \rightarrow DK$ ,  $D \rightarrow K_S^0 \pi^+ \pi^-$ , **strong phase from Dalitz plot**
  - Need  $D$  decay model (sum of resonances),  
or phase measured at  $\psi(3770)$  (CLEO-c or future BESIII)
  - Most sensitive to  $\phi_3$

# $B \rightarrow DK^{(*)}$ by LHCb

**GLW** ( $B^0 \rightarrow D_{cp}K^{*0}$ ,  $D_{cp} \rightarrow K^+K^-$ , new)



**GLW**  $B^0 \rightarrow DK^{*0}$

[LHCb-CONF-2012-024]

$$A_{cp} = -0.47^{+0.24}_{-0.25} \pm 0.02$$

$$R_{cp} = 1.42^{+0.41}_{-0.35} \pm 0.07$$

**GLW**  $B \rightarrow DK$

[LHCb PLB712,203(2012)]

$$A_{cp} = 0.14 \pm 0.03 \pm 0.01$$

$$R_{cp} = 1.01 \pm 0.04 \pm 0.01$$

(not shown)

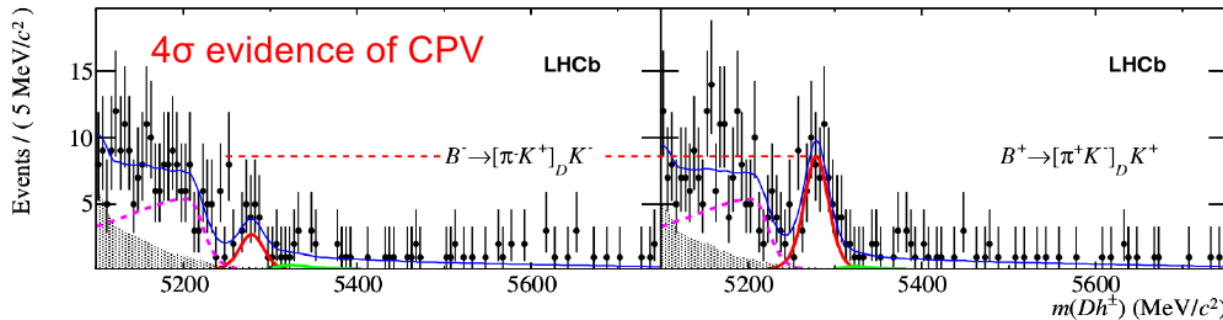
**ADS**  $B \rightarrow DK$

[LHCb PLB712,203(2012)]

$$A_{cp} = -0.52 \pm 0.15 \pm 0.02$$

$$R_{cp} = 0.015 \pm 0.002 \pm 0.000$$

**ADS** ( $B^- \rightarrow D^0K^-$ ,  $D^0 \rightarrow K^+\pi^-$  DCSD)



● LHCb: world's most precise measurements for these

● Belle/BaBar: dominating in other modes with  $K_S^0$  or  $\pi^0$

# $\phi_3 / \gamma$ status

$D^0(\bar{D}^0) \rightarrow K_S^0 \pi^+ \pi^-$  Dalitz plots

**GGSZ**

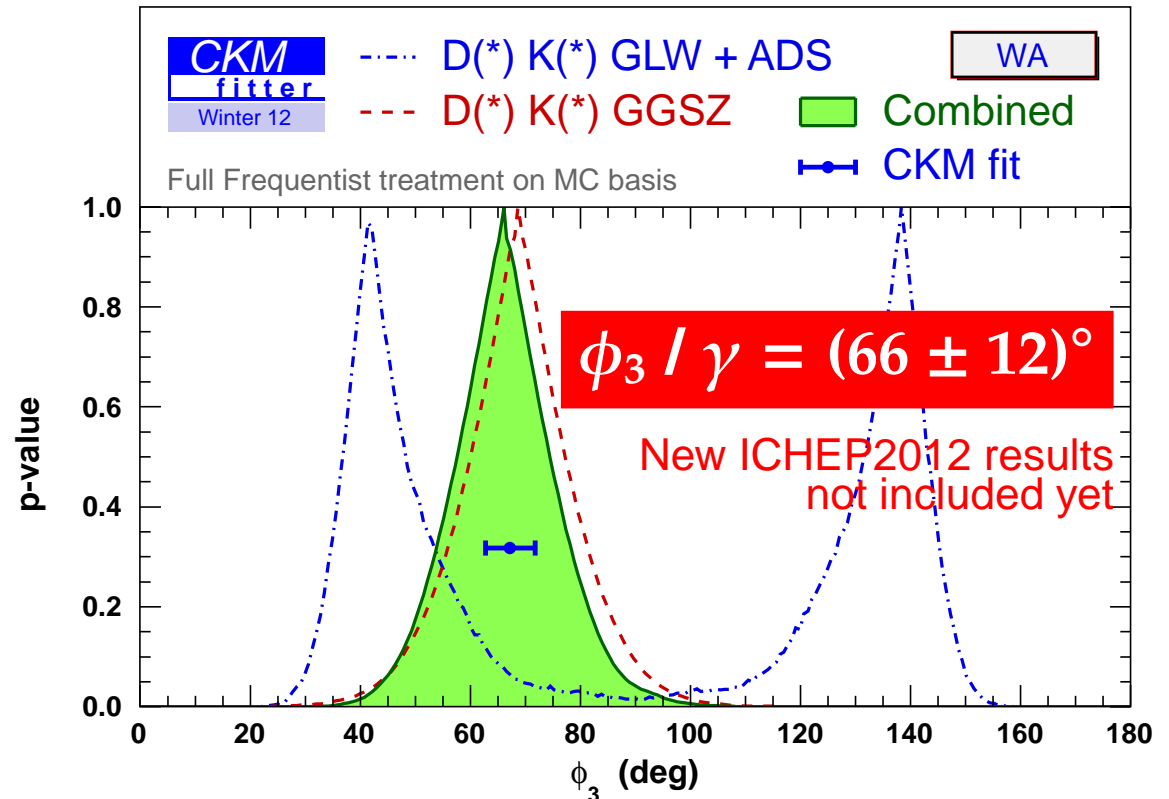
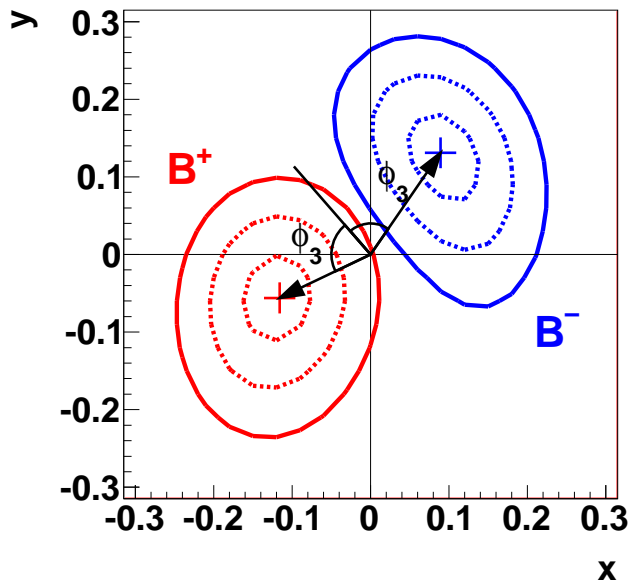
$$P^+ = |A + r_B e^{i(\delta_B + \phi_3)} \bar{A}|^2 = \left| \text{[Dalitz Plot]} + r_B e^{i(\delta_B + \phi_3)} \text{[Dalitz Plot]} \right|^2$$

$$= |P| + r_B^2 |\bar{P}| + 2 \sqrt{P\bar{P}} (x_+ \cos \delta_D + y_+ \sin \delta_D)$$

where  $x_{\pm} = r_B \cos(\delta_B \pm \phi_3)$ ,  $y_{\pm} = r_B \sin(\delta_B \pm \phi_3)$



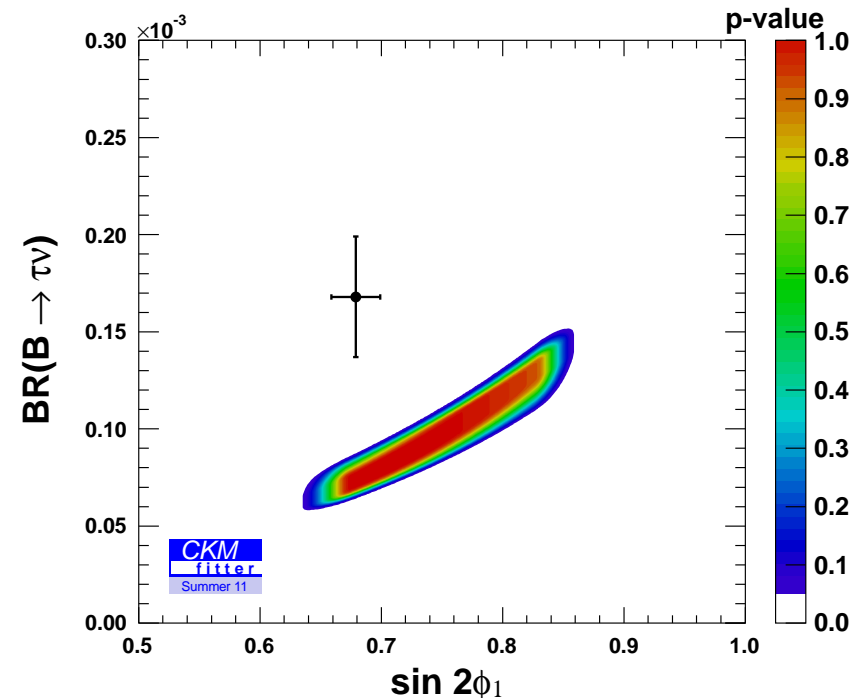
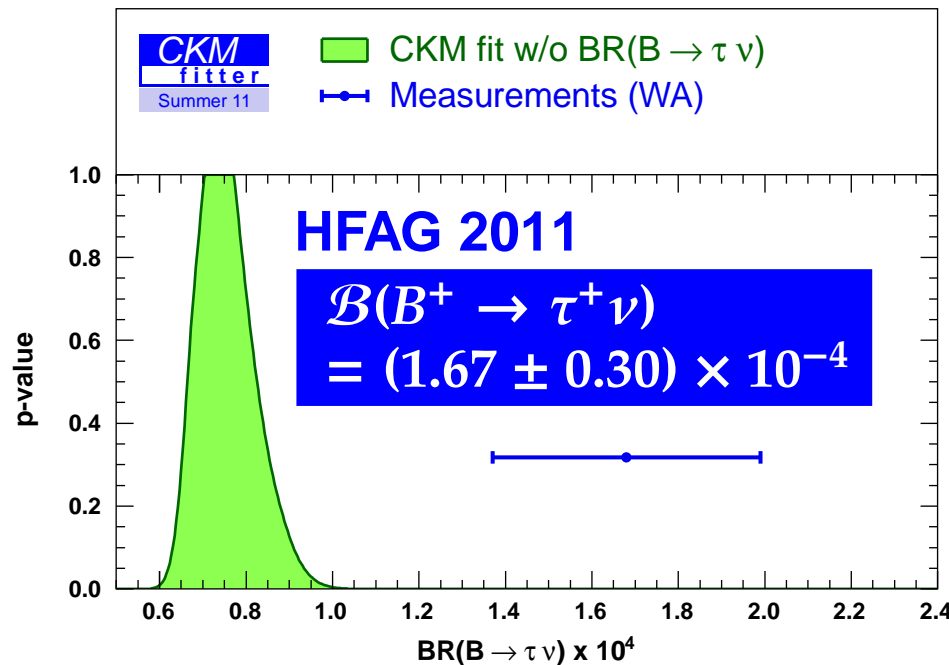
[Belle 657M  $B\bar{B}$  to appear in PRD]



**LHCb prospects:** half statistics of Belle's sample with 2011 data of  $1 \text{ fb}^{-1}$

# $V_{ub}$ and $B \rightarrow \tau \nu$

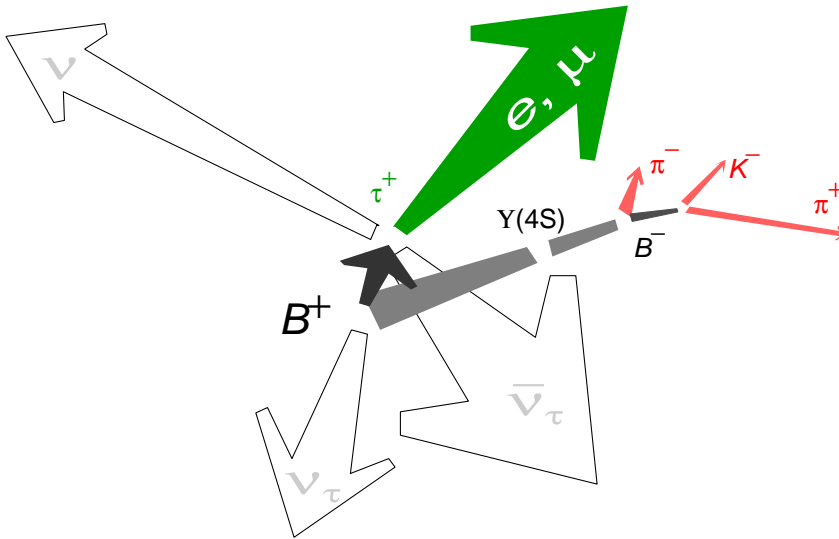
- Purely leptonic decay, proportional to  $f_B^2 |V_{ub}|^2$  (in SM) or sensitive to charged Higgs (in type-II 2HDM)
- However,  $f_B$  is not precisely known (only from Lattice)
- Instead, more reliable constraint from  $\Delta m_d$  and other CKM (and no more direct constraint to  $|V_{ub}|$ )



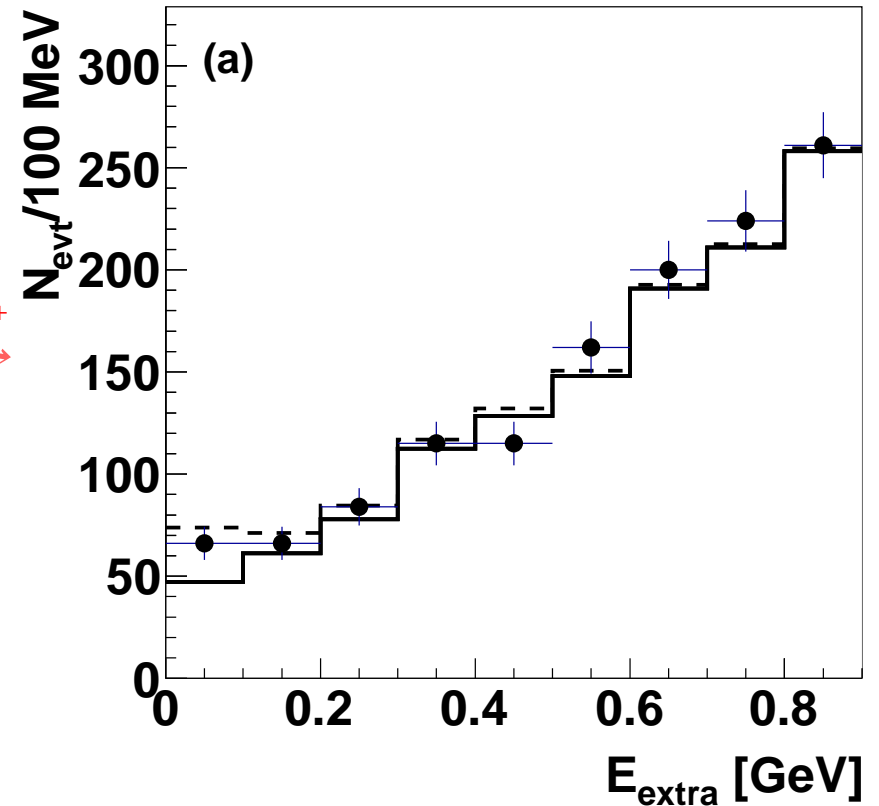
status before ICHEP: **2.8 $\sigma$  tension** in direct vs indirect  $B^+ \rightarrow \tau^+ \nu$

# BaBar $B^+ \rightarrow \tau^+ \nu$ Hadronic-tag (New)

- Finalized the previous preliminary result using hadronic-tag (468M  $B\bar{B}$ )



[ICHEP2012, arxiv:1207.0698]



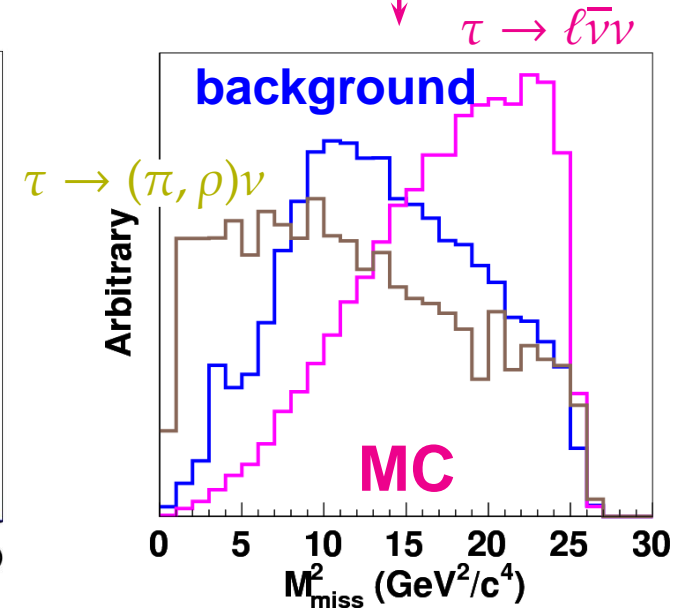
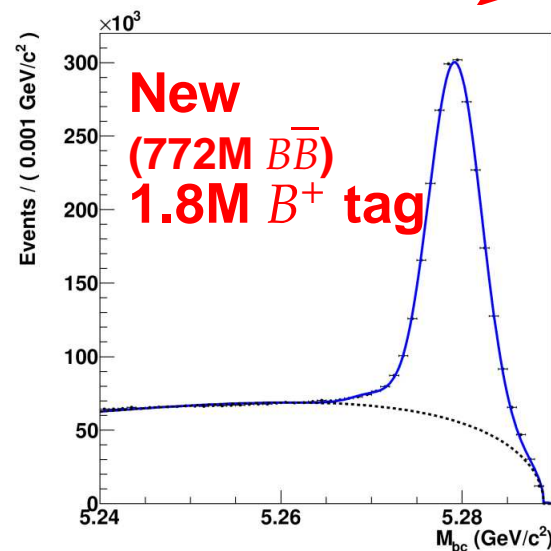
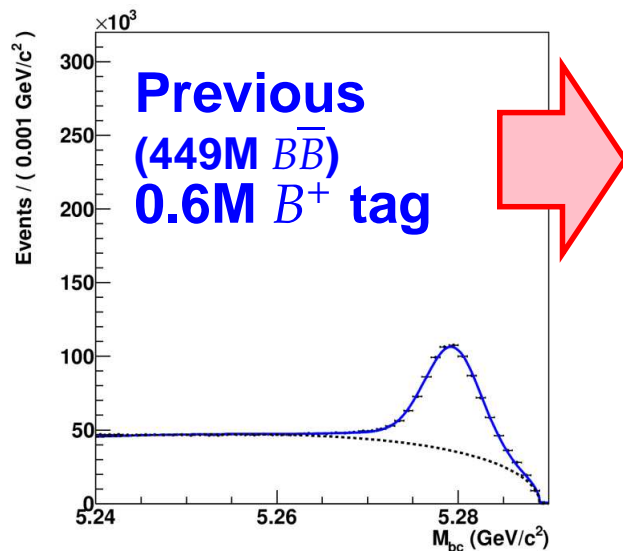
- 4  $\tau$  modes: ( $e\bar{\nu}\nu$ ,  $\mu\bar{\nu}\nu$ ,  $\pi\nu$ ,  $\rho\nu$ )
- Signal peak at 0 in the remnant calorimeter energy

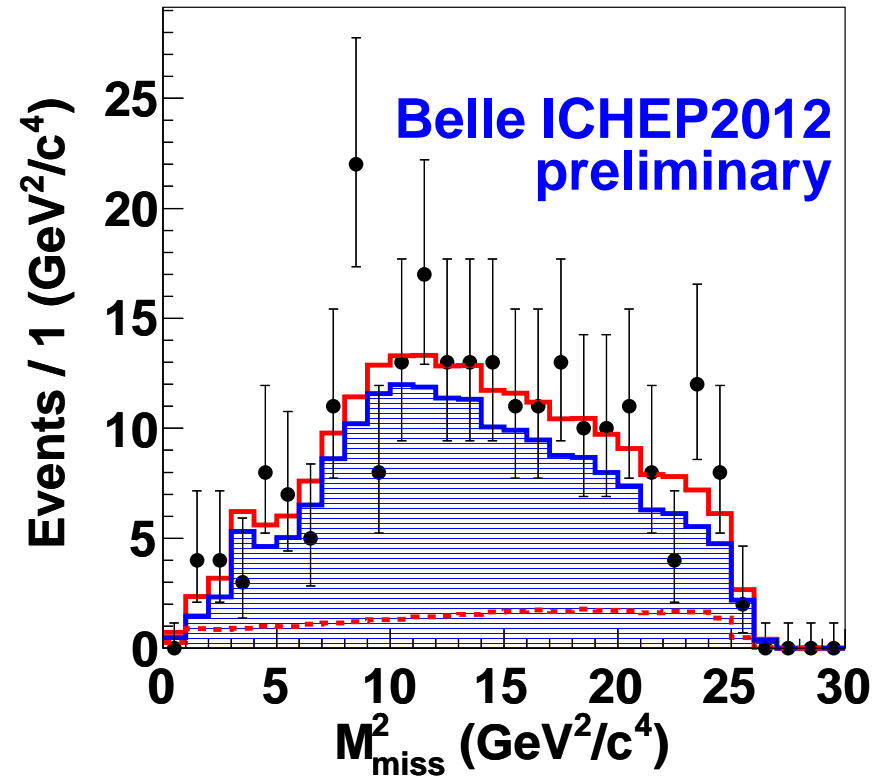
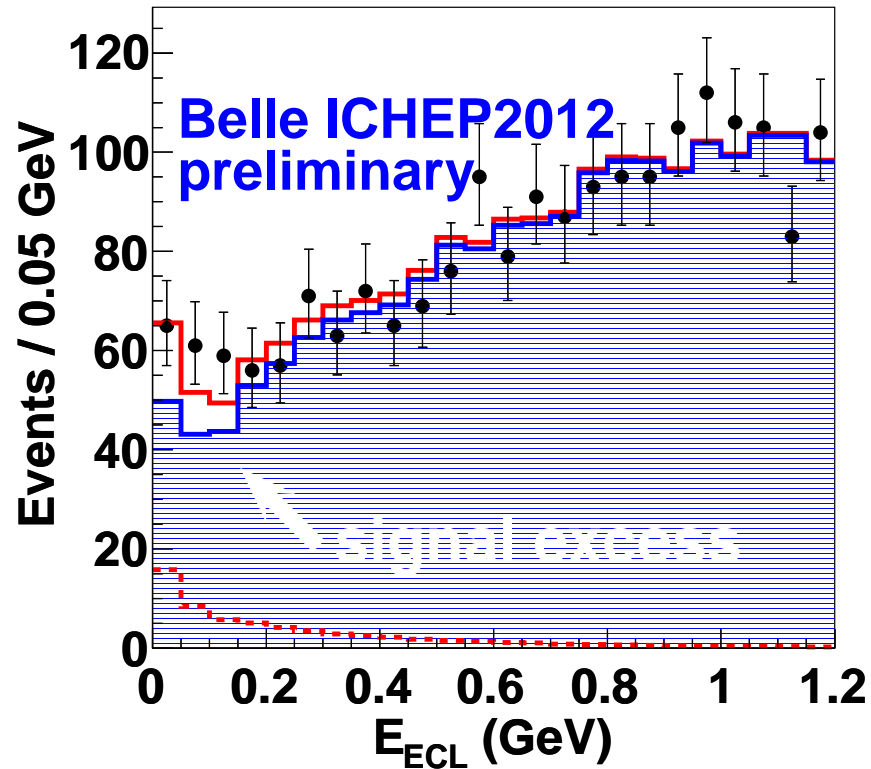
$$\mathcal{B}(B^+ \rightarrow \tau^+ \nu) = (1.83^{+0.53}_{-0.49} \pm 0.24) \times 10^{-4} \quad (3.8\sigma)$$

(BaBar average with semileptonic-tag:  $\mathcal{B}(B^+ \rightarrow \tau^+ \nu) = (1.79 \pm 0.48) \times 10^{-4}$ )

# Belle's $B^+ \rightarrow \tau^+ \nu$ Hadronic-tag (New)

- 72% more data: 449M  $\rightarrow$  772M  $B\bar{B}$
- Improved (slow) track efficiency by reprocessing
- New hadronic-tag algorithm — Neurobayes neural network
- Newly added  $K_L$  veto after understanding data/MC difference
- 3 $\times$  tag, 3.7 $\times$  efficiency,  $\sim$ half statistical error
- Better understanding of peaking background
- Newly including missing-mass in the fit
- Signal peak at 0 in the remnant calorimeter energy  $E_{ECL}$





$$\mathcal{B}(B^+ \rightarrow \tau^+ \nu) = (0.72^{+0.27}_{-0.25} \pm 0.11) \times 10^{-4} \quad (62^{+23}_{-22} \text{ events, } 3.0\sigma)$$

First 57% of data (same as previous sample) gives  $\mathcal{B} = (1.08^{+0.37}_{-0.35}) \times 10^{-4}$ ,  
consistent with previous result  $< 1.9\sigma$  even if fully overlapped

Additional 43% data gives low branching fraction  $\mathcal{B} = (0.24^{+0.34}_{-0.39}) \times 10^{-4}$

Sub-decays of  $\tau$  ( $e\nu\nu$ ,  $\mu\nu\nu$ ,  $\pi\nu$ ,  $\rho\nu$ ) give consistent results

New  $K_L^0$  veto is not killing the true signal, and more checks were made...

**BaBar** [468M]  
 (2010) semilep-tag

**BaBar** [468M]  
 (2012) hadronic-tag

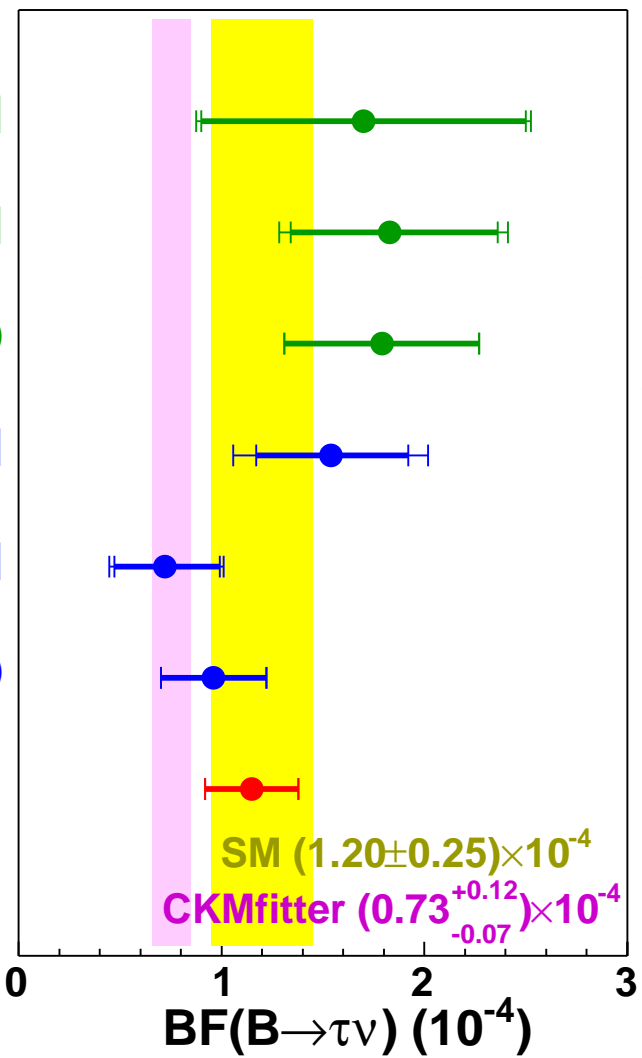
**BaBar** (combined)  
 with correlations

**Belle** [657M]  
 (2010) semilep-tag

**Belle** [772M]  
 (2012) hadronic-tag

**Belle** (combined)  
 with correlations

**W.A.**  
 private average (MN)



$(1.70 \pm 0.80 \pm 0.20) \times 10^{-4}$   
 PRD81,051101

$(1.83^{+0.53}_{-0.49} \pm 0.24) \times 10^{-4}$   
 arxiv:1207.0698

$(1.79 \pm 0.48) \times 10^{-4}$   
 arxiv:1207.0698

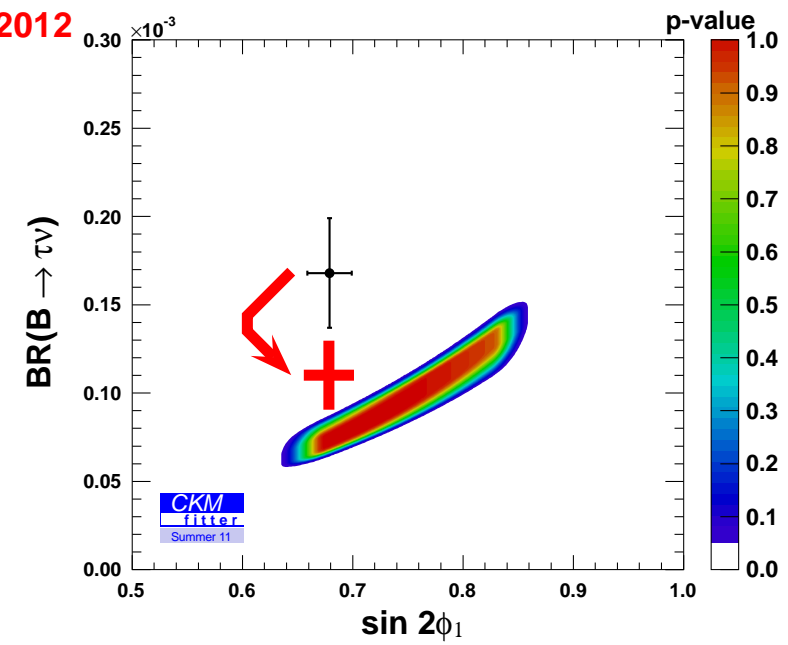
$(1.54^{+0.38}_{-0.37} \pm 0.29 \pm 0.31) \times 10^{-4}$   
 PRD82,071101

$(0.72^{+0.27}_{-0.25} \pm 0.11) \times 10^{-4}$   
 ICHEP 2012

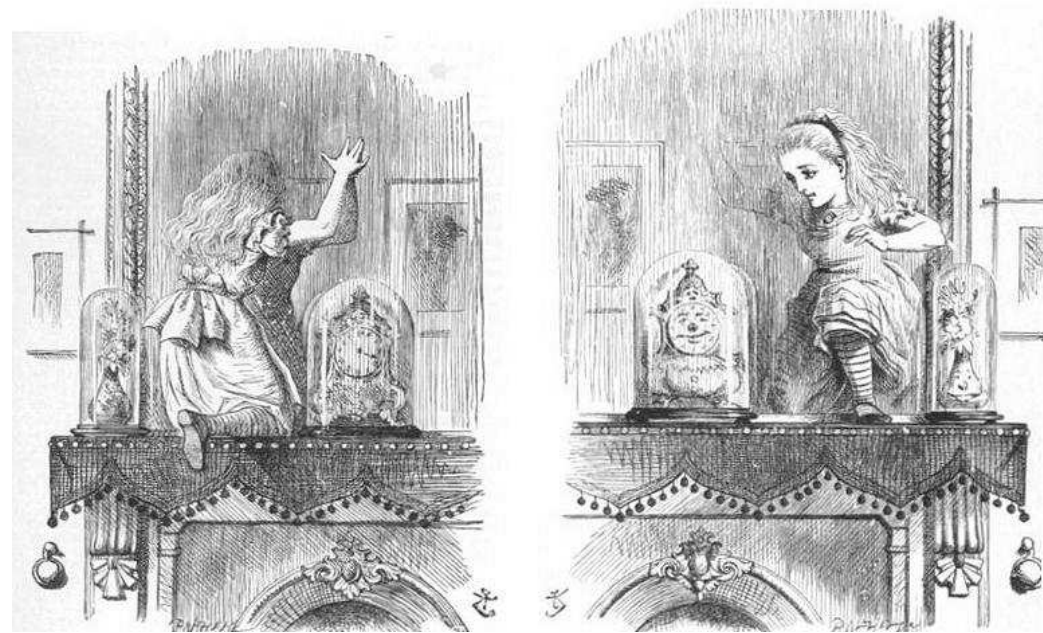
$(0.96 \pm 0.26) \times 10^{-4}$   
 ICHEP 2012

$(1.15 \pm 0.23) \times 10^{-4}$   
 ICHEP 2012

**Tension between  $B^+ \rightarrow \tau^+ \nu$  world average and CKM fit becomes much smaller**



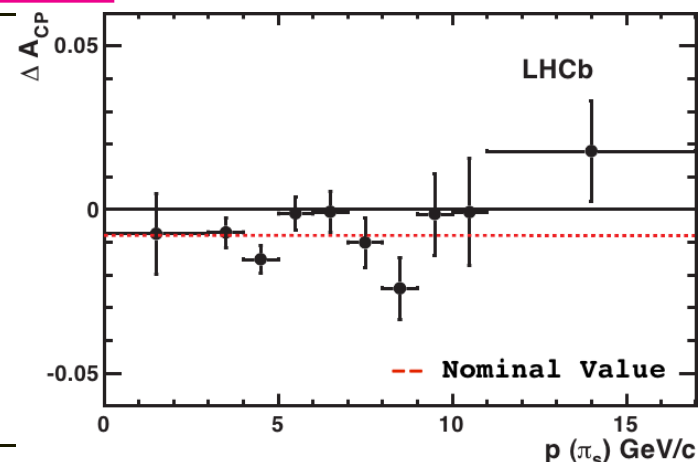
# CPV in charm & $\tau$



# Direct CPV in $D^0 \rightarrow K^+K^-$ and $\pi^+\pi^-$

$$\Delta A_{cp} = A_{cp}(D^0 \rightarrow K^+K^-) - A_{cp}(D^0 \rightarrow \pi^+\pi^-) \quad [\%]$$

<b>LHCb</b>	$-0.82 \pm 0.21 \pm 0.11$	PRL2012
<b>CDF</b>	$-0.62 \pm 0.21 \pm 0.10$	charm2012
<b>BaBar</b>	(see below)	PRD2011
<b>Belle</b>	$-0.87 \pm 0.41 \pm 0.06$	ICHEP2012
<b>WA</b>	$-0.678 \pm 0.147 (>4\sigma)$	HFAG2012



**CDF** ( $p\bar{p}$ ):  $A_{\text{raw}}(f) = A_{cp}(f) + A_D(\pi_s)$  [slow pion detection]

**LHCb** ( $pp$ ):  $A_{\text{raw}}(f) = A_{cp}(f) + A_D(\pi_s) + A_P(D^{*+})$  [production]

**Belle** ( $e^+e^-$ ):  $A_{\text{raw}}(f) = A_{cp}(f) + A_D(\pi_s) + A_{\text{FB}}(D)$  [forward-backward]

( $B \rightarrow D$  has to be removed to avoid CPV in  $B$  decays in many analysis)

## Individual $A_{CP}$ are not significant

	$A_{cp}(D^0 \rightarrow K^+K^-) \quad [\%]$	$A_{cp}(D^0 \rightarrow \pi^+\pi^-) \quad [\%]$
<b>CDF</b>	$-0.24 \pm 0.22 \pm 0.09$	$+0.22 \pm 0.24 \pm 0.11$
<b>BaBar</b>	$0.00 \pm 0.34 \pm 0.13$	$-0.24 \pm 0.52 \pm 0.22$
<b>Belle</b>	$-0.32 \pm 0.21 \pm 0.09$	$+0.55 \pm 0.36 \pm 0.09$

**Need to search  
for  $A_{CP}$  in  
other modes**

# $D^0$ mixing and $(x, y)$

$D^0$  mixing WA at  $10\sigma$ , but no single measurement with  $>5\sigma$

$$x = \frac{m_1 - m_2}{\bar{\Gamma}}, \quad y = \frac{\Gamma_1 - \Gamma_2}{\bar{\Gamma}}, \quad y_{CP} = y \cos \phi + \frac{A_M}{2} x \sin \phi, \quad A_\Gamma = -x \sin \phi + \frac{A_M}{2} x \cos \phi$$

●  $y_{CP}$  from  $\tau(D^0 \rightarrow K^+K^-)/\tau(D^0 \rightarrow K^- \pi^+)$  ( $y_{CP} = y$  if no CPV)

● New Belle result ( $976 \text{ fb}^{-1}$ ):

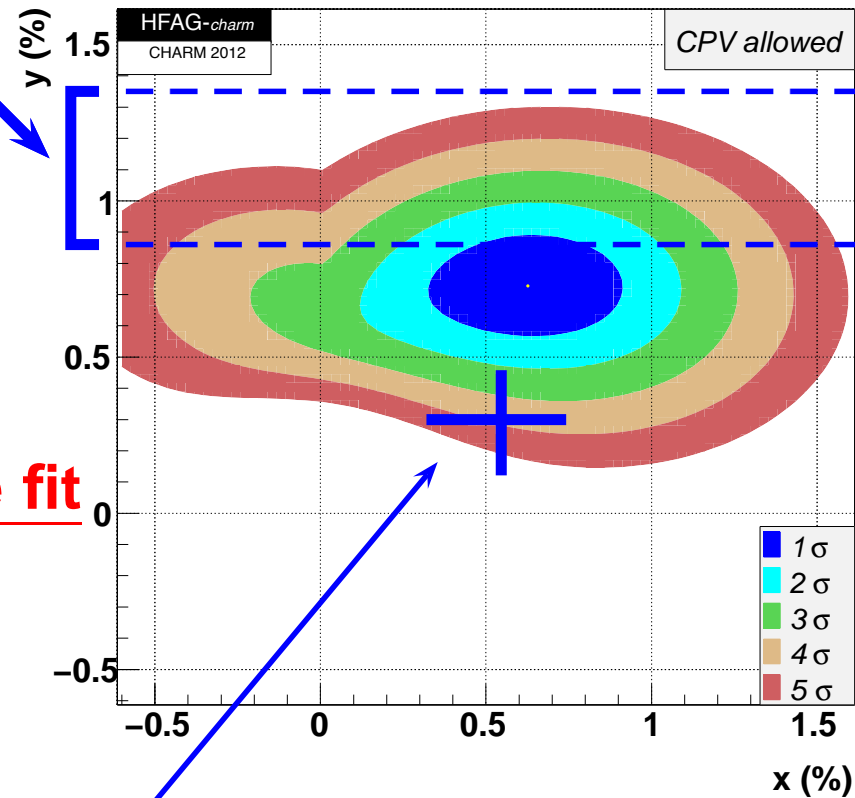
$$y_{CP} = (1.11 \pm 0.22 \pm 0.11)\% \quad (4.5\sigma)$$

$$A_\Gamma = (-0.03 \pm 0.20 \pm 0.08)\%$$

● New BaBar result ( $468 \text{ fb}^{-1}$ ):

$$y_{CP} = (0.72 \pm 0.18 \pm 0.12)\% \quad (3.3\sigma)$$

$$A_\Gamma = (+0.09 \pm 0.26 \pm 0.06)\%$$



**No asymmetry observed in lifetime fit**

●  $(x, y)$  from  $D^0 \rightarrow K_S^0 \pi^+ \pi^-$   
time-dependent Dalitz

● New Belle result ( $920 \text{ fb}^{-1}$ ):

$$x = (0.56 \pm 0.19 \begin{smallmatrix} +0.03 & +0.06 \\ -0.09 & -0.09 \end{smallmatrix})\%, \quad y = (0.30 \pm 0.15 \begin{smallmatrix} +0.04 & +0.03 \\ -0.08 & -0.06 \end{smallmatrix})\%$$

# Direct CPV in $D^+ \rightarrow K_S^0 \pi^+$

$$A_{cp}(D^+ \rightarrow K_S^0 \pi^+) = A_{cp}(D_{\text{intrinsic}}) + A_{cp}(K_S^0)$$

- CPV due to  $K_S^0$  mixing is dominant:  $(-0.332 \pm 0.006)\%$
- correction due to finite decay acceptance (e.g., 4% for Belle) and  $K^0/\bar{K}^0$  cross-section difference with detector material

**Belle**  $(-0.363 \pm 0.094 \pm 0.067)\%$

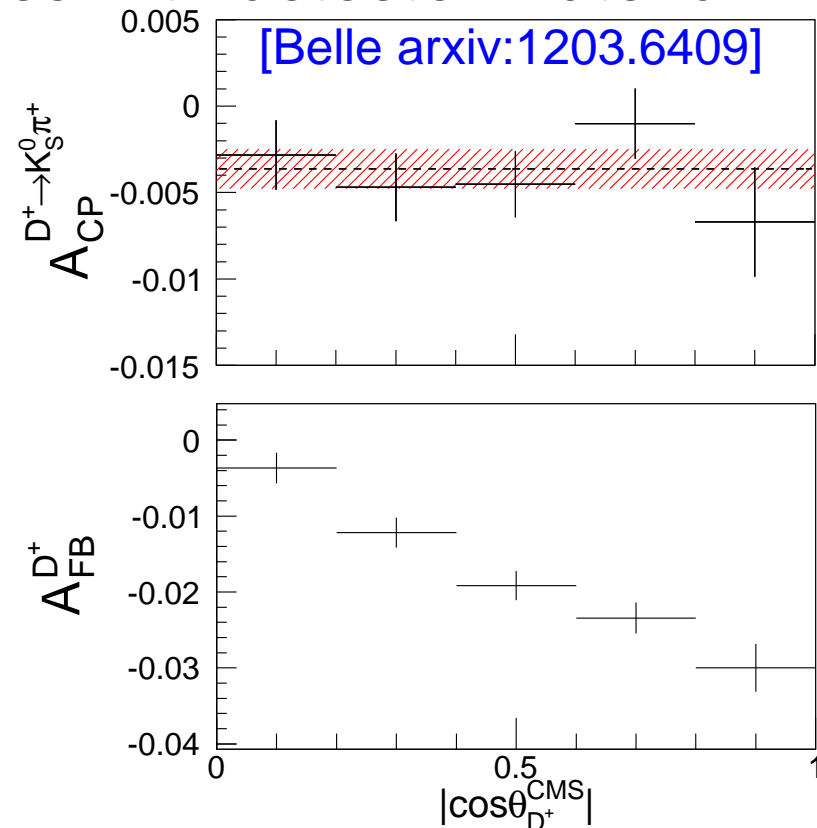
**BaBar**  $(-0.44 \pm 0.13 \pm 0.10)\%$

**CLEO**  $(-1.3 \pm 0.7 \pm 0.3)\%$

**FOCUS**  $(-1.6 \pm 1.5 \pm 0.9)\%$

**WA**  $(-0.41 \pm 0.09)\%$

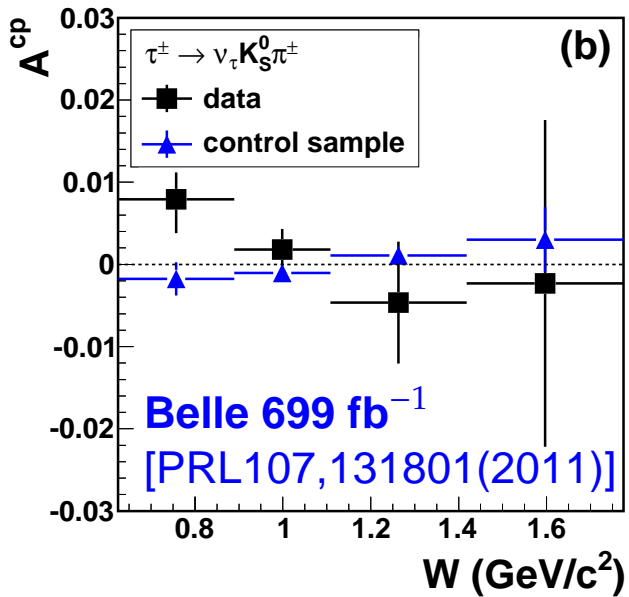
**>4 $\sigma$  non-zero CPV, but fully consistent with  $K_S^0$  asymmetry, and intrinsic charm asymmetry is consistent with zero**



# Direct CPV in $\tau \rightarrow K_S^0 \pi^+ (n\pi^0) \nu_\tau$

$$A_{cp}(\tau^- \rightarrow K_S^0 \pi^- \nu_\tau) = A_{cp}(\tau_{\text{intrinsic}}) - A_{cp}(K_S^0) \quad (\text{note opposite sign})$$

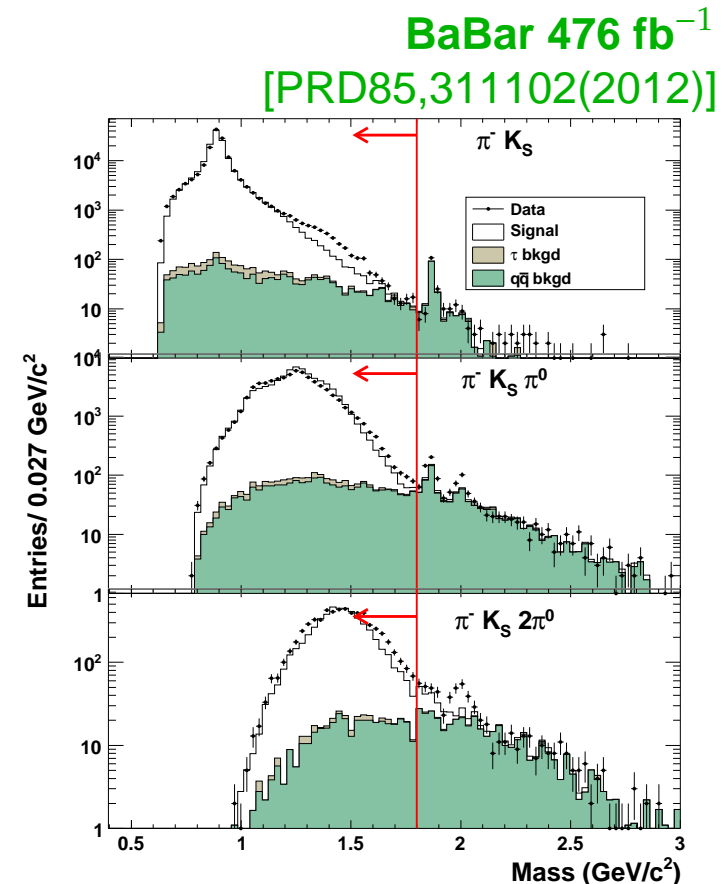
Probing CPV in quark sector through  $\tau$ -lepton decays?



● Belle measures  $W$  dependence for  $\tau^- \rightarrow \pi^- K_S^0 \nu_\tau$ , and found  $A_{CP}(\tau_{\text{intrinsic}})$  is consistent with zero

● BaBar adds 0,1,2  $\pi^0$  and integrates:  
 $A_{cp} = (-0.36 \pm 0.23 \pm 0.11)\%$  (2.8 $\sigma$ )  
 [SM expectation (+0.36  $\pm$  0.01)%]

*CPV opposite of expectation from  $K_S^0$  asymmetry?*



BaBar 476 fb<sup>-1</sup>  
 [PRD85,311102(2012)]

# Summary

*Fireworks at Docklands, Melbourne, 7pm, 6 July 2012*

# CKM / CPV status TODAY

## ● CKM unitarity triangle

- $\phi_1 = (21.4 \pm 0.8)^\circ$  — done 😊
- $\phi_2 = (88.7^{+4.6}_{-4.2})^\circ$ , still more to come from Belle and BaBar (and LHCb)
- $\phi_3 = (66 \pm 12)^\circ$ , LHCb opening new door on  $B \rightarrow DK$
- $V_{ub}$  and  $V_{cb}$  — new results still flowing in

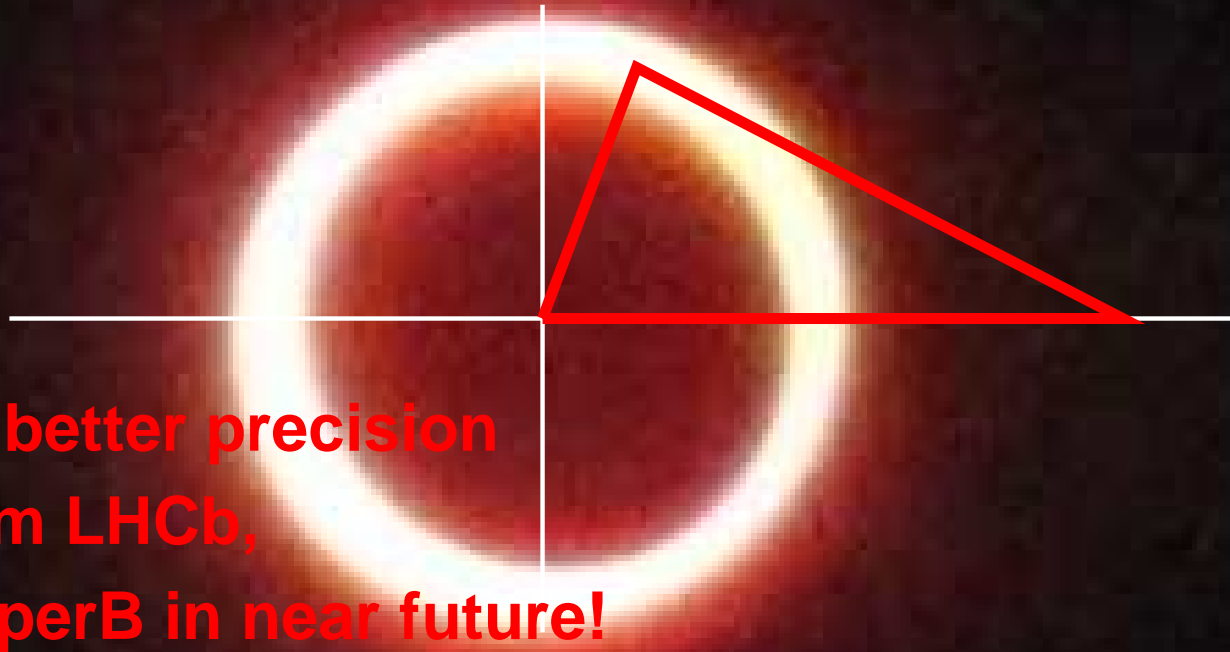
## ● $B^+ \rightarrow \tau^+ \nu$ and CKM — one of the most interesting tensions

- Tension decreased with new Belle result (!)

## ● More CP violation

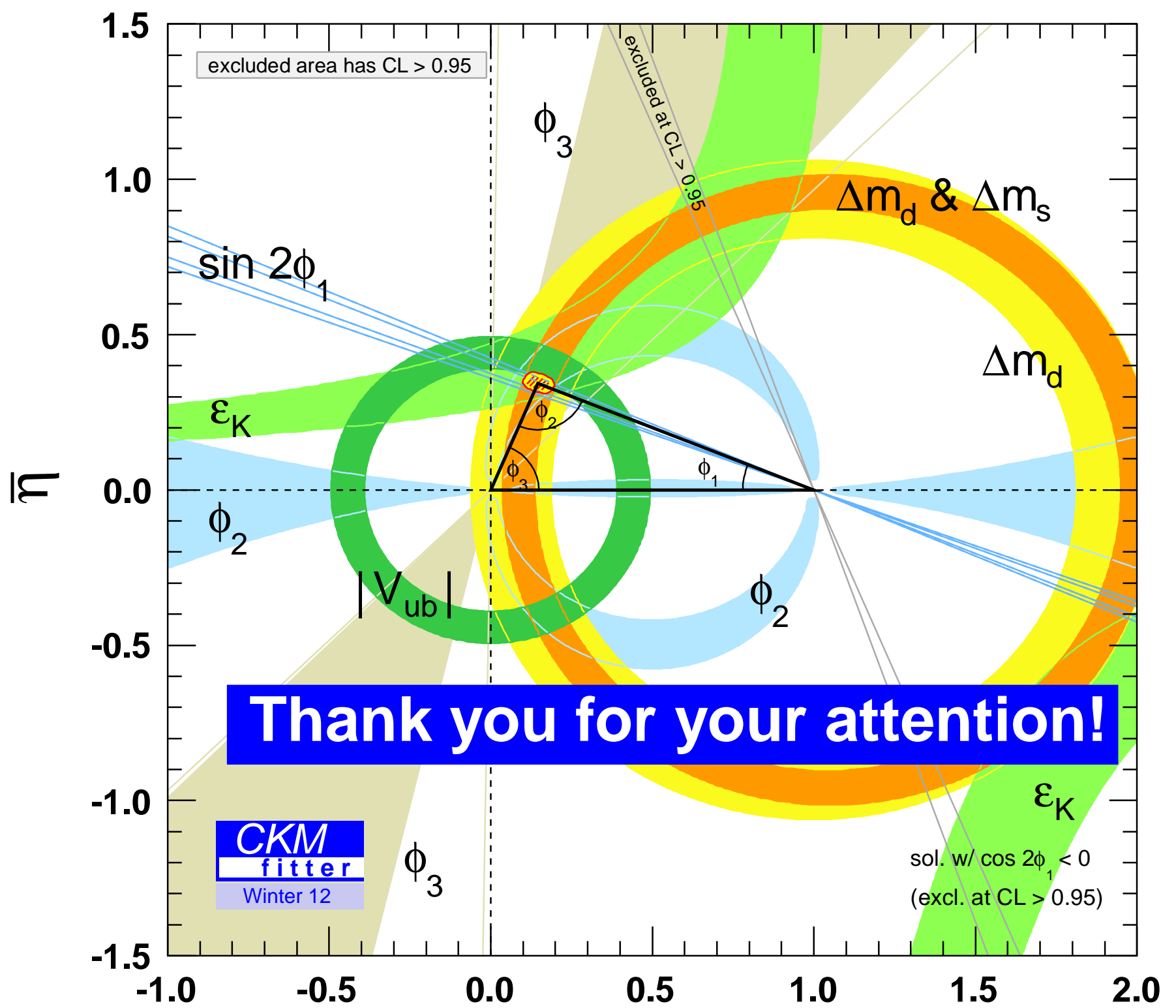
- CPV in  $B$  decays is not so rare any more (many new results skipped!)
- CPV searches in  $D$  and  $\tau$  are reaching the sensitivity to produce some interesting results (e.g.  $\Delta A_{cp}$ )

**Are we seeing the unitarity triangle closing at  $\sim 10\%$  accuracy, or is it just a coincidence?**



**Need to verify with a better precision with data coming from LHCb, and from Belle II / SuperB in near future!**

*Annular Solar Eclipse in Tsukuba at 07:35am, 21 May 2012*

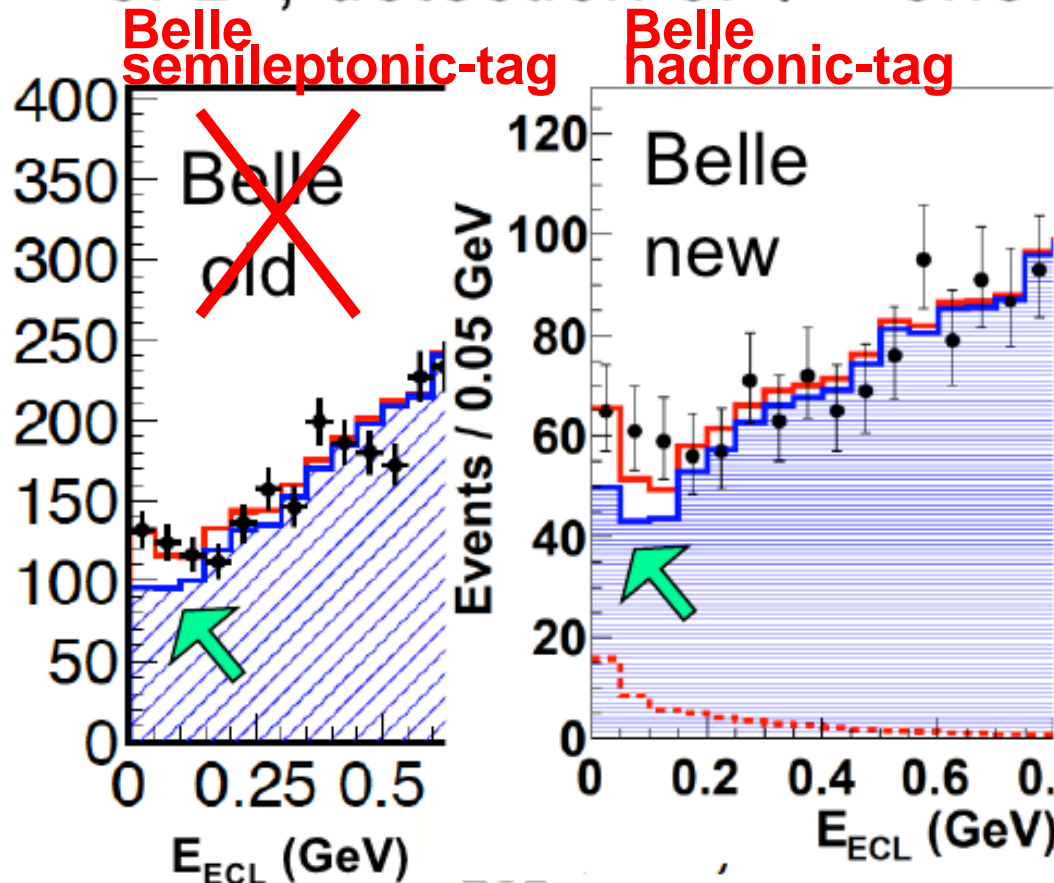


# Backup

## Correction &amp; comments

# Peaking Backgrounds

- Since  $e^+e^- \rightarrow B^+B^-$ , analysis uses reconstruction of  $B^+$ , detection of  $\tau \rightarrow$  one track & small extra E



Peaking background may look more significant in the hadronic-tag?

- Background level of semileptonic-tag is higher
- New hadronic-tag includes missing mass in the fit, some of the peaking background are included in the projection instead of cut out

# $B \rightarrow \tau\nu$ comparison with 2006 result

	PRL 97 (2006)	ICHEP 2012	
Analysis	hadronic tag 1D fit to $E_{ECL}$	hadronic tag(new) 2D fit to $(E_{ECL}, M_{miss}^2)$	
N(BB) ( $\times 10^6$ )	(set A) 449	(set A) 449	(set B) 332
Efficiency ( $\times 10^{-4}$ )	3.0	11.2	
N(signal yield)	$24.1^{+7.6}_{-6.6}$	$54.1^{+18.8}_{-17.4}$	$8.6^{+14.0}_{-12.4}$
$Br(B^+ \rightarrow \tau^+\nu)$ ( $\times 10^{-4}$ )	$1.79^{+0.56}_{-0.49}$	$1.08^{+0.37}_{-0.35}$	$0.24^{+0.39}_{-0.34}$
		$0.72^{+0.27}_{-0.25}$	

## conservative comparison

1. Only with statistical error.
2. Assuming all the signal candidates in the old analysis become signal candidates in the new analysis.

SET A: the data-set used in 2006

SET B: corresponds to the data-set not used in 2006

SET A': corresponds to the data-set used in 2006, but reproduced

All events used for the New Analysis

Old (set A) vs. New (set B) :  $2.5\sigma$  difference  
 New results. set A' vs. set B :  $1.6\sigma$  difference  
 Old (set A) vs. New (set A') :  $1.2\sigma$  difference

\*Old result (set A) vs. New (only for non-overlapping events in the set A)  
 $BF(\text{non-overlapping events}) = (0.6 \pm 0.4) \times 10^{-4} \rightarrow 1.9\sigma$  difference

# $V_{cb}$ and $V_{ub}$ summary

## $|V_{cb}|$ Exclusive ( $D^*lv$ )

- Exp. error 1.4%
- LQCD norm. 1.9%

$$|V_{cb}| = (39.04 \pm 0.55 \pm 0.73) \cdot 10^{-3}$$

## $|V_{cb}|$ Inclusive

- Exp. error 1.1%
- Theory error 1.4%

$$|V_{cb}| = (41.88 \pm 0.44 \pm 0.59) \cdot 10^{-3}$$

## $|V_{ub}|$ Exclusive ( $\pi lv$ )

- Exp. error 5.5%
- LQCD norm. 7.5%

$$|V_{ub}| = (3.23 \pm 0.18 \pm 0.24) \cdot 10^{-3}$$

## $|V_{ub}|$ Inclusive

- Exp. error 3.6%
- Theory error 3.9%

$$|V_{ub}| = (4.41 \pm 0.15 \pm 0.17) \cdot 10^{-3}$$

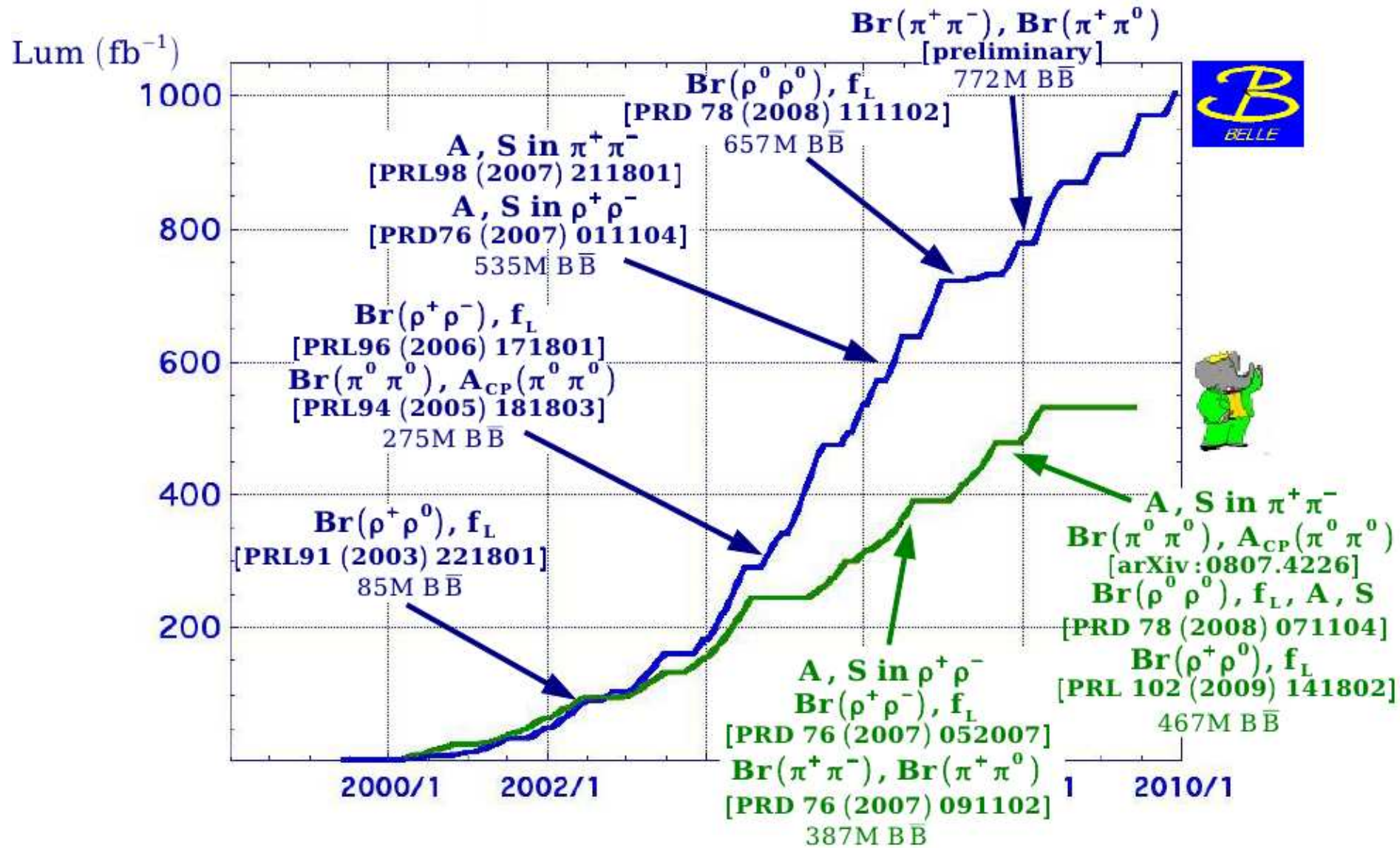
2.4  $\sigma$

2.7  $\sigma$

P. Urquijo

**Tension between inclusive and exclusive results, partly as a consequence of the great efforts to reduce the errors**

# $\phi_2 / \alpha$ history



# Unitarity Relations (diagonal elements)

[See e.g. T.Gershon LP2011 / arXiv:1112.1984 for details]

●  $|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = (0.97425(22))^2 + (0.2253(9))^2 + (0.0036)^2$   
 $= \underline{0.99995 \pm 0.00061}$

●  $|V_{ud}|$  from compilation of 20  $0^+ \rightarrow 0^+$  nuclei transitions

●  $|V_{us}|$  from  $K_{\ell 3}$ ,  $|V_{us}/V_{ud}|$  from  $K_{\ell 2}/\pi_{\ell 2}$  ( $|V_{us}|$  from  $\tau$  not in agreement)

●  $|V_{ub}|$  is almost negligible

●  $|V_{cd}|^2 + |V_{cs}|^2 + |V_{cb}|^2 = (0.230(11))^2 + (0.963(11)(24))^2 + (0.041)^2$   
 $= \underline{0.982 \pm 0.056}$

●  $|V_{cd}|$  from fixed-target charm production  $\nu d \rightarrow cX$

●  $|V_{cs}|$  from CLEO-c  $D \rightarrow K\ell\nu$  (dominant error from LQCD)

●  $|V_{cb}|$  is almost negligible

●  $|V_{td}|^2 + |V_{ts}|^2 + |V_{tb}|^2 = 1 ?$

●  $|V_{tb}|$  from CDF ( $0.95 \pm 0.05$ ), D0 ( $0.95 \pm 0.02$ ), CMS ( $0.99 \pm 0.02$ )

●  $|V_{td}/V_{ts}|$  known from  $B$  &  $B_s$  mixing  $\Delta m_s/\Delta m_d$