Unitary Triangle, LHC and B factories

Alex Bondar

Novosibirsk State University

Beyond The Standard Model of Particle Physics
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Cabibbo-Kobayashi-Maskawa (CKM) matrix "V"

– Fundamental in Standard Model (SM)

– Four parameters ($\theta_{12}, \theta_{13}, \theta_{23}, \phi \leftrightarrow A, \lambda, \rho, \eta$)

– Source of CP violation in SM

Testing the SM – V is unitary 3×3 matrix in SM

– Additional generations can make non-unitary

– Can test unitarity relations with measurements of magnitudes and/or phases

New physics can show up in loops, often at same order as SM graphs

– Look for differences among quantities that should be the same in SM, or for deviations from SM predictions

CKM matrix and Unitarity Triangle

Wolfenstein parameterization:

$$V_{\mathrm{CKM}} = \begin{pmatrix} 1-\frac{1}{2}\lambda^2-\frac{1}{8}\lambda^4 & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda+\frac{1}{2}A^2\lambda^5[1-2(\rho+i\eta)] & 1-\frac{1}{2}\lambda^2-\frac{1}{8}\lambda^4(1+4A^2) & A\lambda^2 \\ A\lambda^3[1-(1-\frac{1}{2}\lambda^2)(\rho+i\eta)] & -A\lambda^2+\frac{1}{2}A\lambda^4[1-2(\rho+i\eta)] & 1-\frac{1}{2}A^2\lambda^4 \end{pmatrix} \begin{matrix} u \\ c \\ t \end{matrix}$$

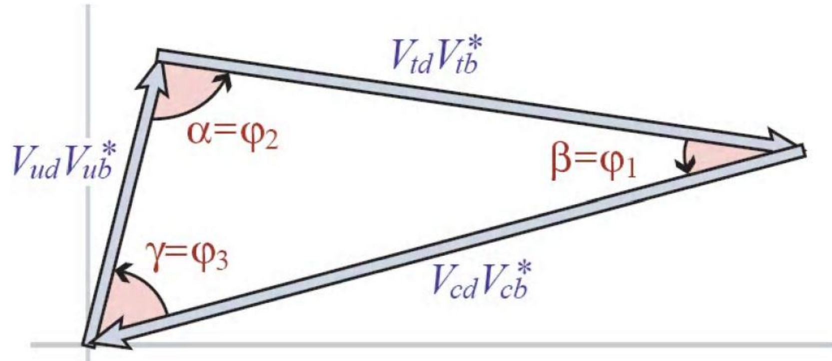
$$\begin{matrix} d & & s & & b \end{matrix}$$

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

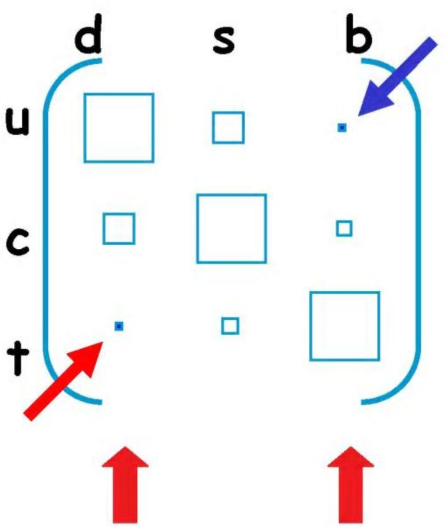
$$\alpha \equiv \varphi_2 \equiv \arg\left(-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right),$$

$$\beta \equiv \varphi_1 \equiv \arg\left(-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right),$$

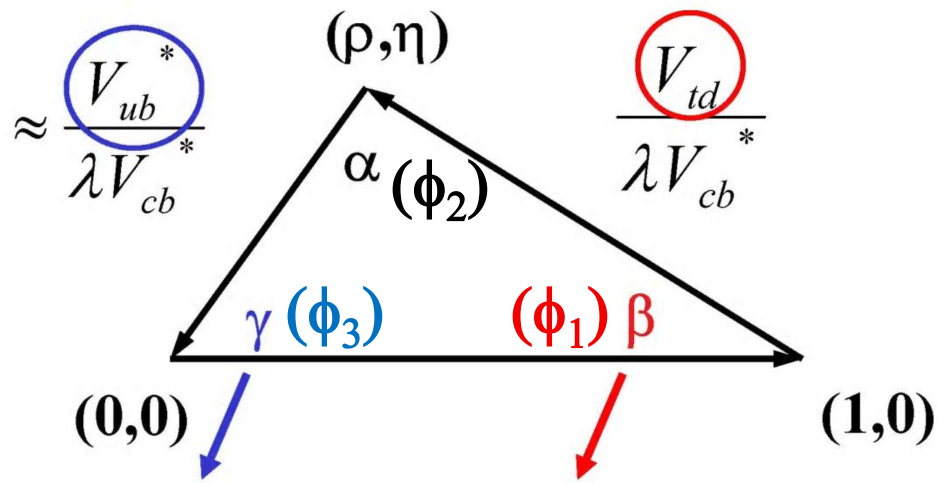
$$\gamma \equiv \varphi_3 \equiv \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right),$$



The "normalized" Unitarity Triangle



apply unitarity constraint to these two columns



$$\gamma \approx \arg V_{ub}^* \qquad \beta \approx -\arg V_{td} \qquad \alpha = \pi - \beta - \gamma$$

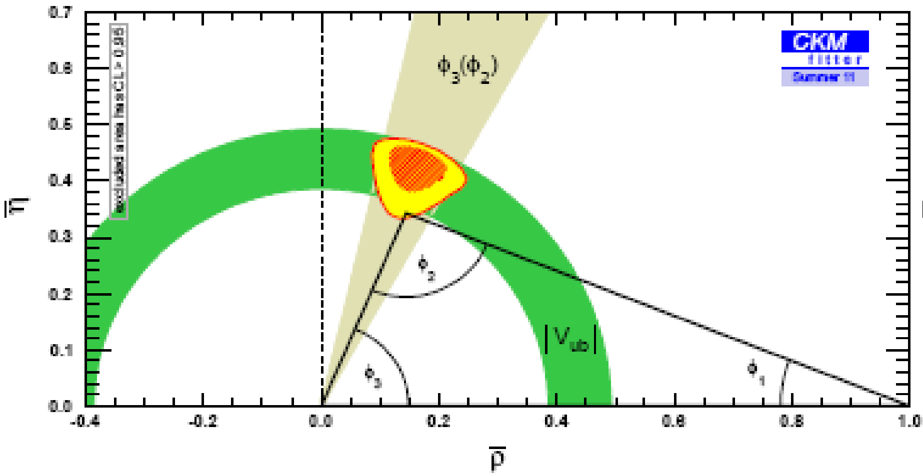
Orders of magnitude for Wolfenstein parameters:

$$\lambda \approx 0.22\,, \quad A \approx 0.8\,, \quad \sqrt{\rho^2 + \eta^2} \approx 0.4$$

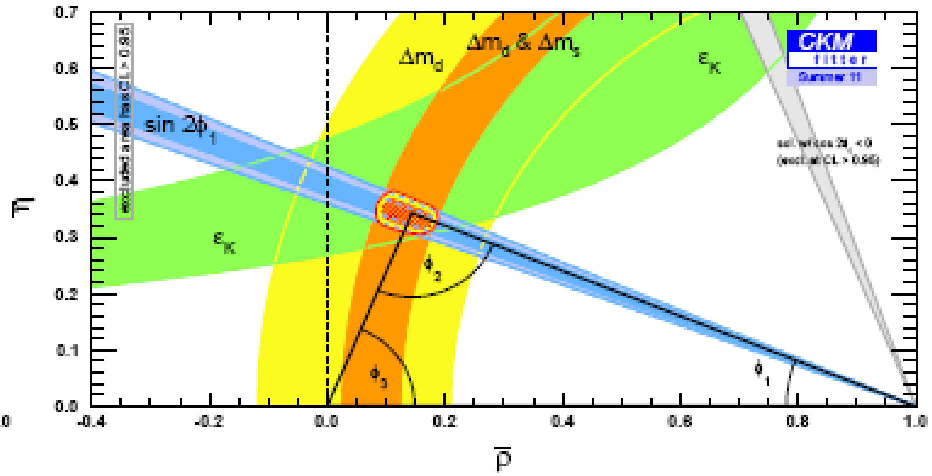
$$\frac{V_{ud} V_{ub}^*}{V_{cd} V_{cb}^*} + 1 + \frac{V_{td} V_{tb}^*}{V_{cd} V_{cb}^*} = 0$$

$$V_{cd} = \lambda\,, \quad V_{ud} \approx V_{tb} \approx 1$$

Tree vs Loop



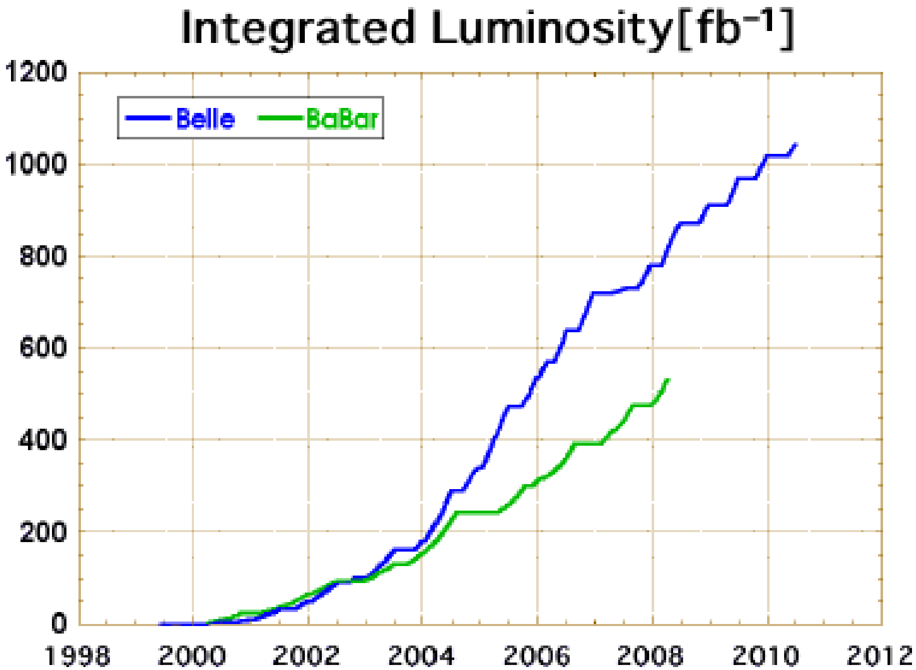
Tree measurements
(SM: phase and size of V_{ub})

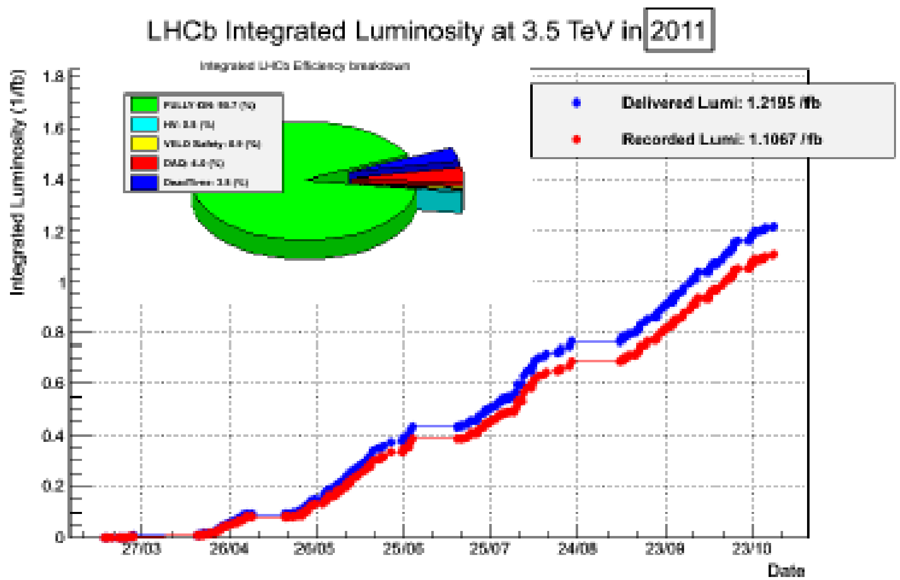


Loop measurements
(SM: phase and size of V_{td})

- Tree measurements free from NP contributions (ϕ_3 and $|V_{ub}|$), Loop measurements may be affected by NP (ϕ_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



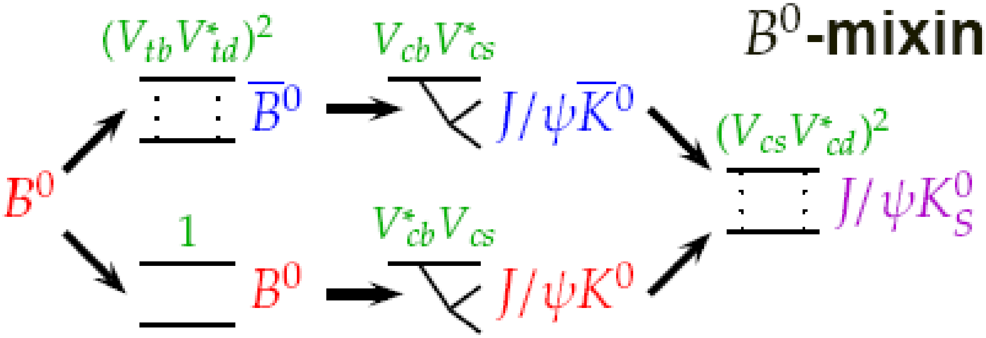


2011: 1.0 fb^{-1} @ $\sqrt{s}$ = 7 GeV
2012: Expect 1.5 fb^{-1} @ $\sqrt{s}$ = 8 GeV

- **Belle+BaBar total 1240 M** $B\overline{B}$ **+** (even more) **charm +** τ
  BaBar (1999–2008) > 500 fb^{-1}, Belle (1999–2010) > 1000 fb^{-1}
- **LHCb 1.0 fb^{-1}** (2011) **+ 0.6 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, . . .**

Angles and CPV

Time-dependent CPV measurements



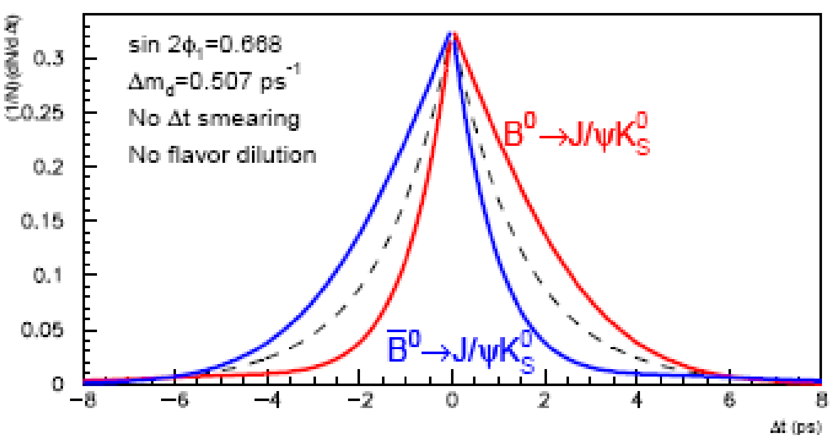
Beautiful experimental setup

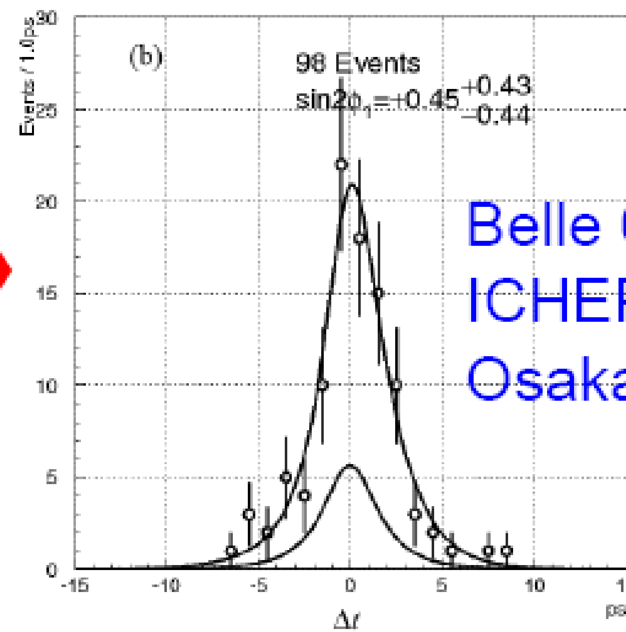
B^0**-mixing +** $b \to c\bar{c}s$ **+** K^0**-mixing**

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

$$\Gamma(\overline{B}^0) \propto e^{-t/\tau}\left(1 - \sin 2\phi_1 \sin \Delta m t\right)$$

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

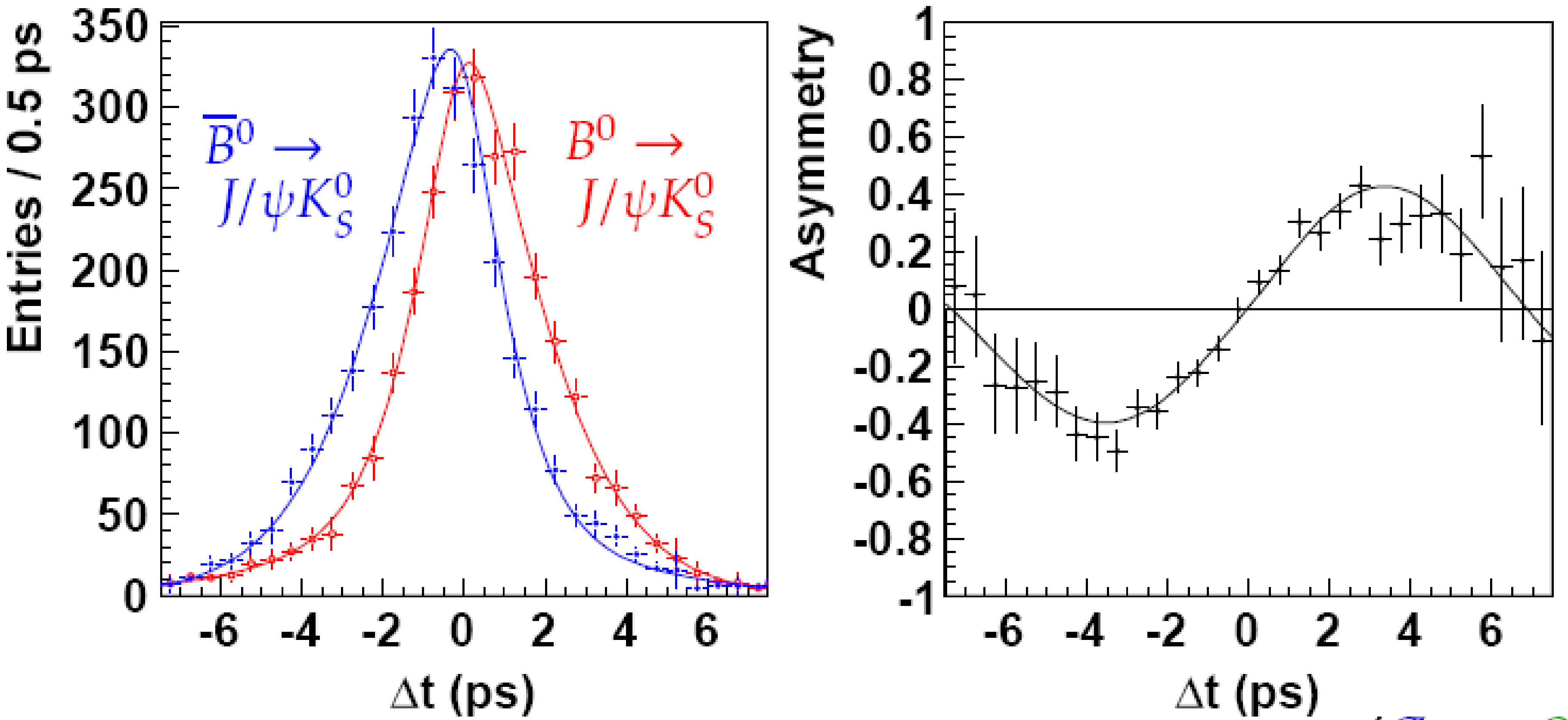




Belle 6 fb^{-1}
ICHEP 2000
Osaka

$\sin(2\phi_1)$ from $B \to J/\psi K_S$

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



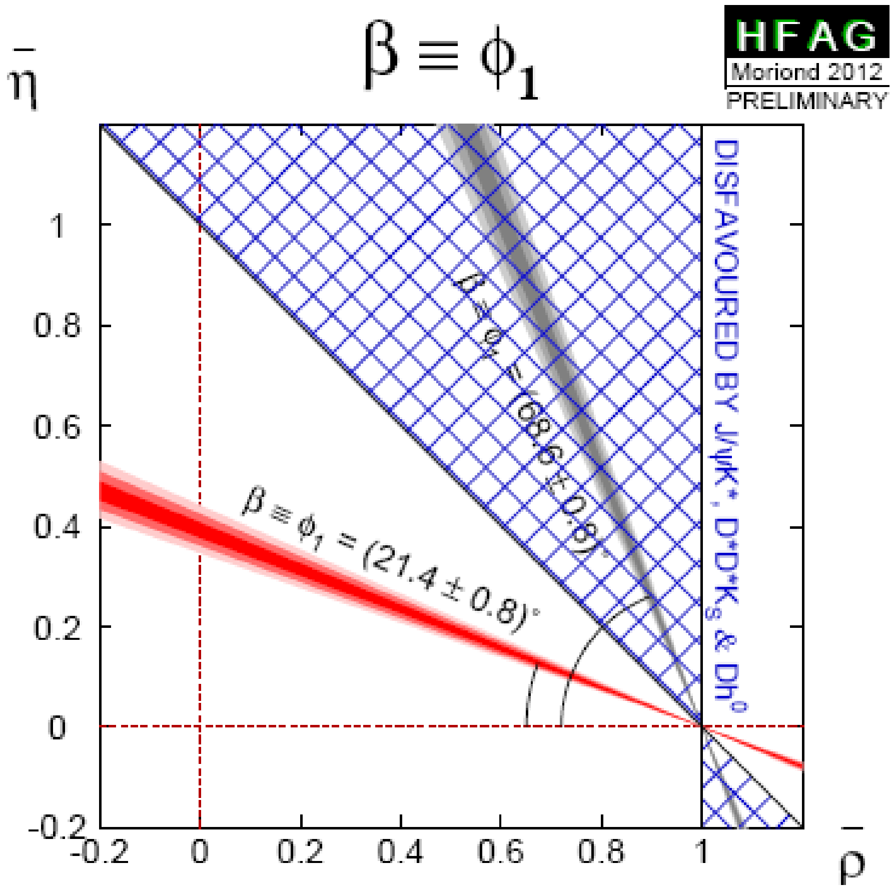
$(\mathcal{A}_f = -C_f)$

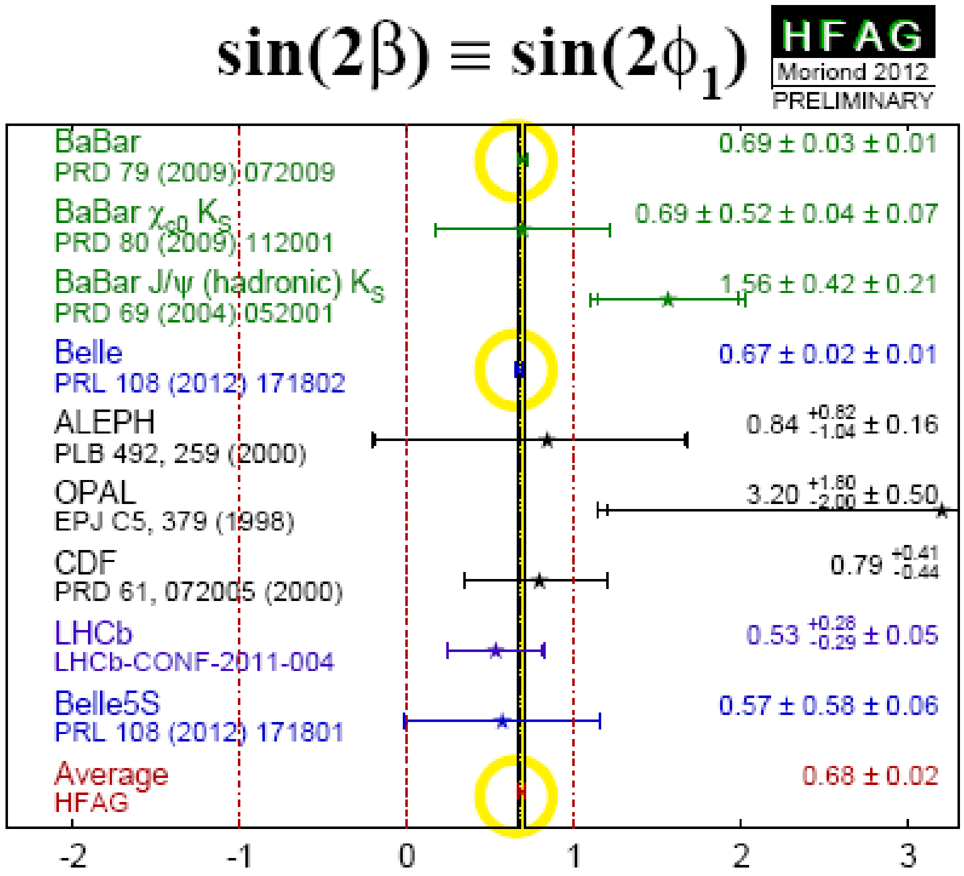
$$\mathcal{P}(\Delta t) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}} \times \left\{1 + q\left[\mathcal{S}_f \sin(\Delta m \Delta t) + \mathcal{A}_f \cos(\Delta m \Delta t)\right]\right\}$$

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

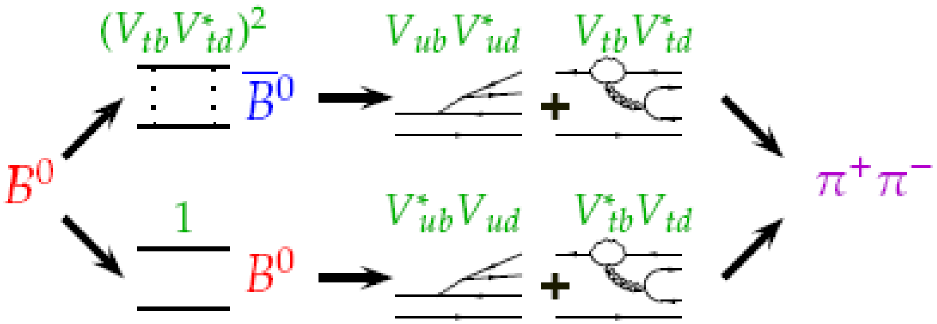
ϕ_1/β from $b \to c\bar{c}s$: status

- **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





ϕ_2/α and penguins



$$\Gamma(B^0) \propto e^{-t/\tau}\,(1+\mathcal{S}_{\pi\pi}\sin\Delta mt + \mathcal{A}_{\pi\pi}\cos\Delta mt)$$

$$\Gamma(\overline{B}^0) \propto e^{-t/\tau}\,(1-\mathcal{S}_{\pi\pi}\sin\Delta mt + \mathcal{A}_{\pi\pi}\cos\Delta mt)$$

$\mathcal{S}_{\pi\pi} = \sqrt{1-\mathcal{A}_{\pi\pi}^2}\sin 2\phi_2^{\rm eff}$, **where** $\phi_2^{\rm eff} = (\phi_2+\kappa)$ **is not** ϕ_2

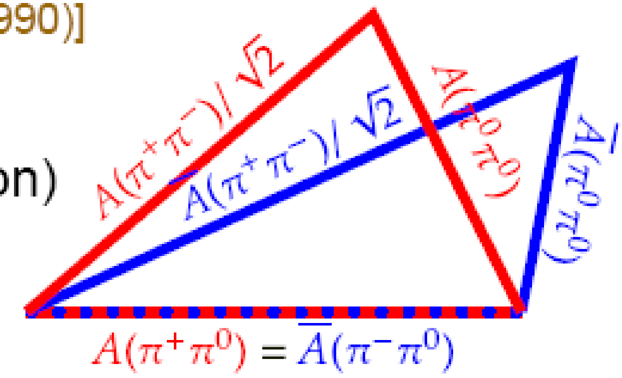
- **Isospin analysis** [Gronau-London PRL65,3381(1990)]

  Relations with $B^+ \to \pi^+\pi^0$ and $B^0 \to \pi^0\pi^0$

  (same for $B \to \rho\rho$ after resolving polarization)

  Isospin breaking effects are small ($\sim 2°$)

  [EW penguins, $m_u \neq m_d$, $\pi - \eta^{(\prime)}$ mixing]



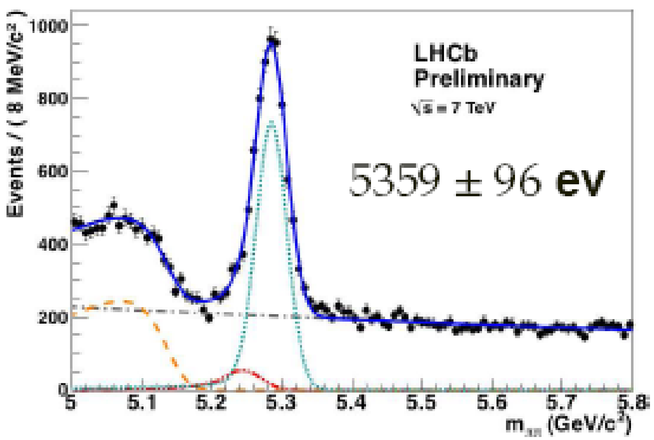
- **Time-dependent Dalitz analysis** [Snyder-Quinn PRD48,2139(1993)]

  $B^0 \to \pi^+\pi^-\pi^0$ contains $\rho^+\pi^-$, $\rho^-\pi^+$, $\rho^0\pi^0$ and their interferences

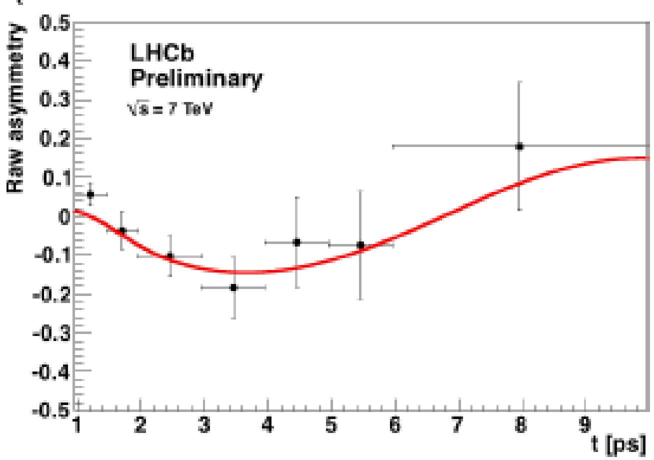
  ϕ_2/α directly determined, $\rho^\pm\pi^0$ and $\rho^0\pi^+$ for further improvement

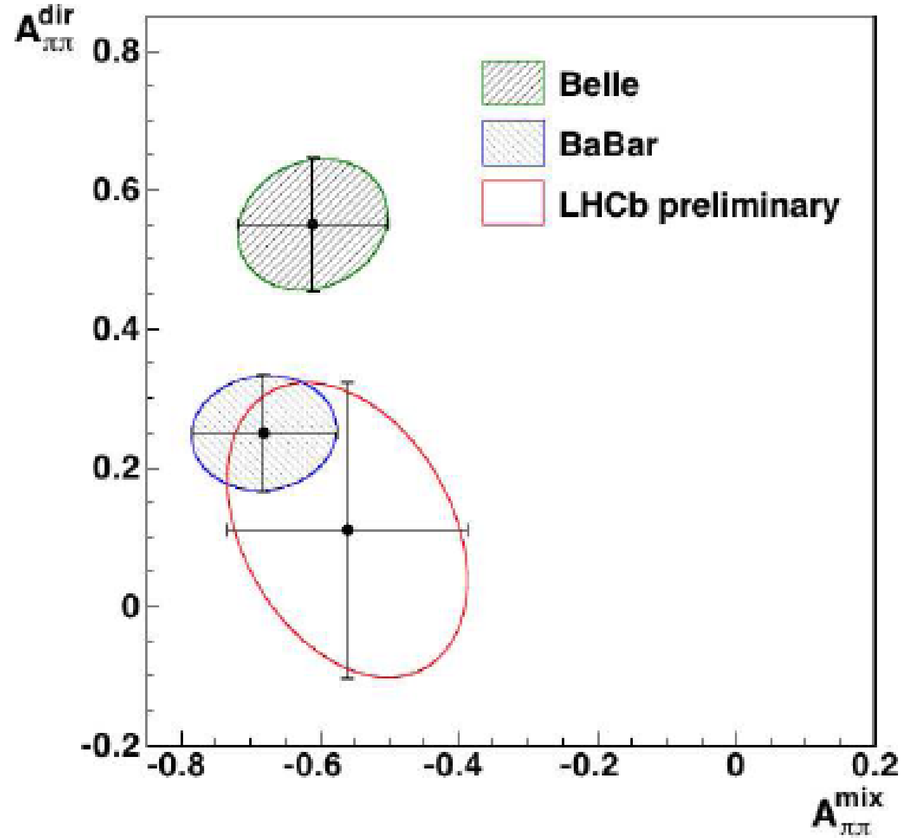
$B \rightarrow \pi^+\pi^-$ by LHCb

Huge signal sample



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



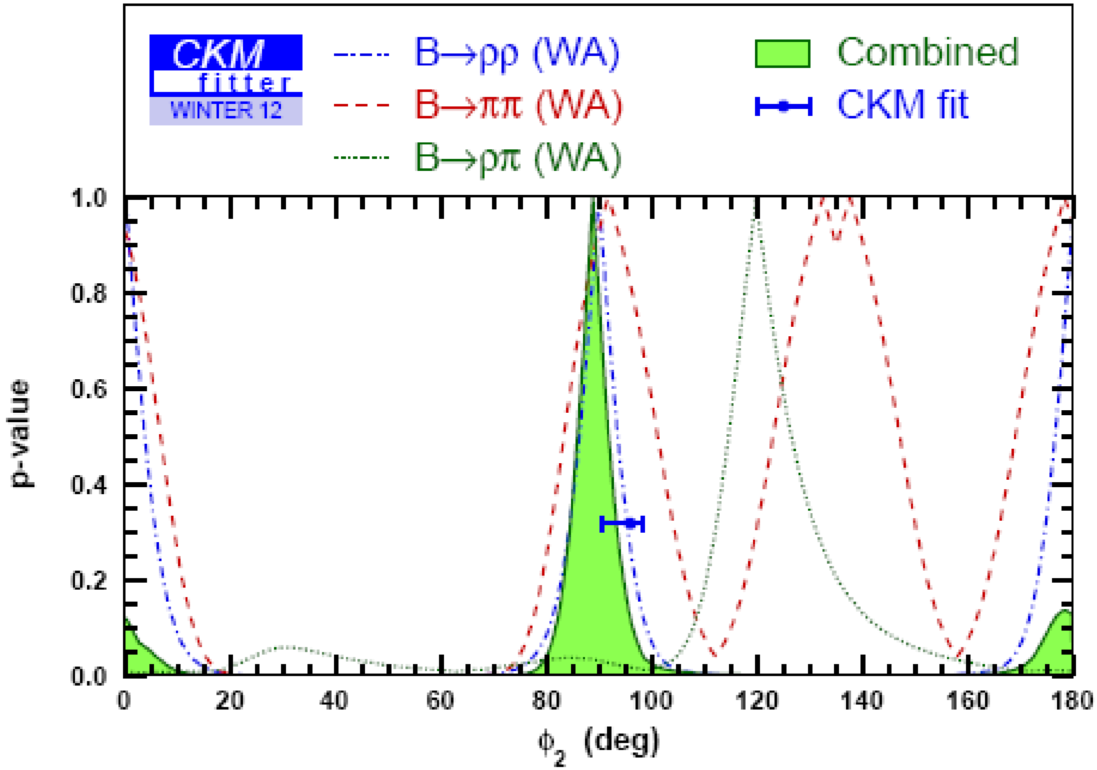


[LHCb 0.7 fb^{-1}, LHCb-CONF-2012-007]

$$\mathcal{S}_{\pi\pi} = A^{\text{mix}}_{\pi\pi} = 0.56 \pm 0.17 \pm 0.03$$
$$\mathcal{A}_{\pi\pi} = A^{\text{dir}}_{\pi\pi} = 0.11 \pm 0.21 \pm 0.03$$

First significant (3.2σ) mixing-induced CPV measurement at a hadron collider

ϕ_2/α from b → uud : status



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

[CKMfitter Moriond2012]

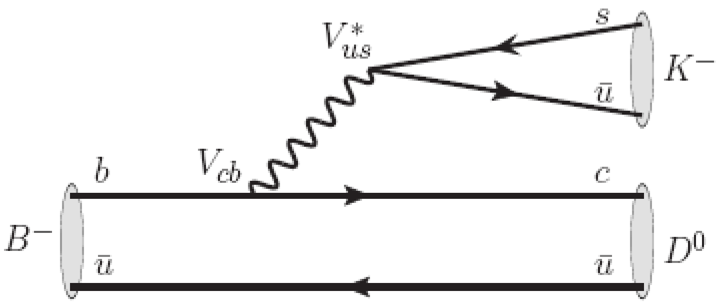
- **Multifold ambiguity solved by combination of $\pi\pi$, $\rho\pi$ and $\rho\rho$**
  ⇒ Consistent solution exists, $\rho\rho$ bound is most stringent

  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 ϕ_2/α related measurements are homework for Belle II/SuperB

Measurement of ϕ_3/γ in $B \to DK$ decays

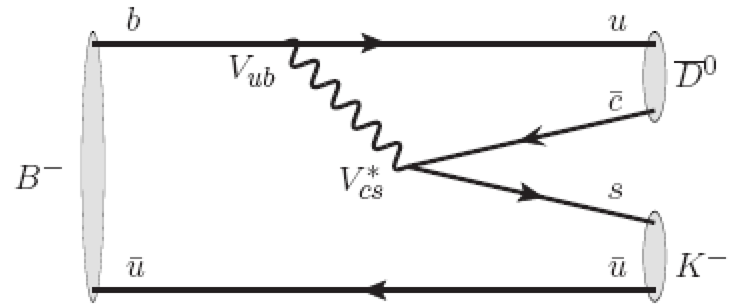
$B^- \to D^0 K^-$:



$$A \sim V_{cb} V^*_{us} \sim A\lambda^3$$

$+$

$B^- \to \overline{D}^0 K^-$:



$$A \sim V_{ub} V^*_{cs} \sim A\lambda^3(\rho - i\eta)$$

If D^0 and $\overline{D}^0$ decay into the same final state: $|\tilde{D}\rangle = |D^0\rangle + re^{i\theta}|\overline{D}^0\rangle$

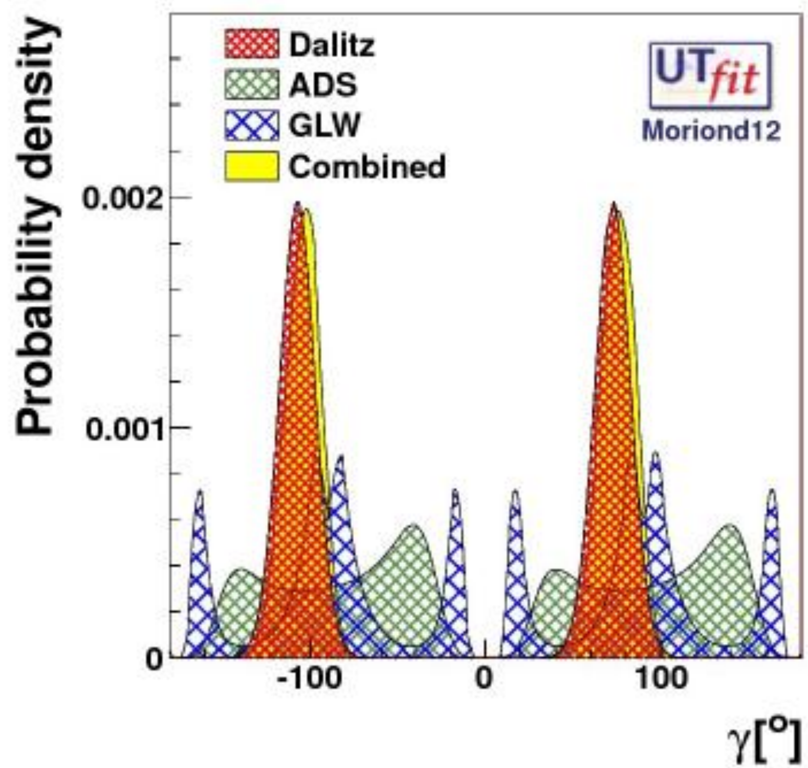
Relative phase in $B^+ \to DK^+$: $\theta = +\phi_3 + \delta_B$

$B^- \to DK^-$: $\theta = -\phi_3 + \delta_B$

Ratio of the two amplitudes:

$$r = \left| \frac{A(B^- \to \overline{D}^0 K^-)}{A(B^- \to D^0 K^-)} \right| = \left| \frac{V_{ub} V^*_{cs}}{V_{cb} V^*_{us}} \right| \times [\text{Color supp}] \sim 0.1$$

- Several choices of the D decays:
  - $D \to KK, \pi\pi, K_S\pi^0, K_S\phi, K_S\omega$, … (Gronau, London, and Wyler)
  - $D \to K\pi, K\pi\pi^0$, … (Atwood, Dunietz, and Soni)
  - $D \to K_S\pi\pi, K_SKK$, … (*Bondar*, Giri, Grossman, Soffer, and Zupan)

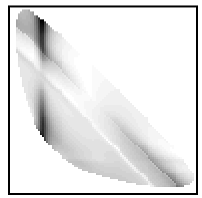
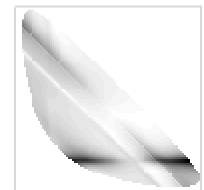


$\gamma = (75.5 \pm 10.5)^\circ$

Dalitz analysis of D decays from B→DK

Use $B^{\pm} \to DK^{\pm}$ modes with 3-body decay $D \to K_S^0 \pi^+ \pi^-$.
Dalitz plot density: $d\sigma_{\pm}(m_+^2, m_-^2) \sim |M_{\pm}|^2 dm_+^2 dm_-^2$

$$|M_{\pm}(m_+^2, m_-^2)|^2 = |f_D(m_+^2, m_-^2) + re^{i\delta_B \pm i\phi_3} f_D(m_-^2, m_+^2)|^2$$

$= \Big|$  $+ re^{i\delta_B \pm i\phi_3}$  $\Big|^2$

$\overline{D}^0 \to K_S^0 \pi^+ \pi^-$ amplitude f_D is extracted from continuum $(D^{*\pm} \to D\pi^{\pm})$, parametrized as a set of two-body amplitudes.

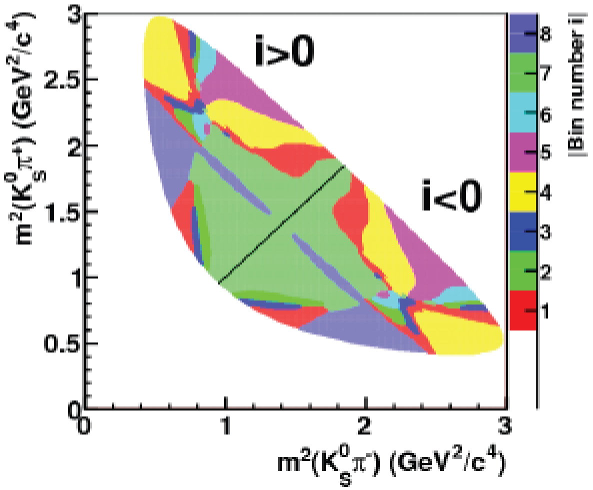
Only $|f_D|^2$ is observable $\Rightarrow$ Model dependence as a result.

Latest Belle result: $\phi_3 = [78^{+11}_{-12} \pm 4(\mathrm{syst}) \pm 9(\mathrm{model})]^\circ$ (605 fb^{-1})

$$r_B = 0.16 \pm 0.04 \pm 0.01(\mathrm{syst})^{+0.05}_{-0.01}(\mathrm{model})$$

Model error would dominate precise measurements at Super B factories.

Solution: use binned Dalitz plot and deal with numbers of events in bins



$$M_i^{\pm} = h\{K_i + r_B^2 K_{-i} + 2\sqrt{K_i K_{-i}}(x_{\pm} c_i + y_{\pm} s_i)\}$$

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

$M_i^{\pm}$: numbers of events in $D \to K^0_S \pi^+\pi^-$ bins from $B^{\pm} \to DK^{\pm}$

K_i: numbers of events in bins of flavor $\overline{D}^0 \to K^0_S \pi^+\pi^-$ from $D^* \to D\pi$.

c_i, s_i contain information about strong phase difference between symmetric Dalitz plot points $(m^2_{K^0_S\pi^+}, m^2_{K^0_S\pi^-})$ and $(m^2_{K^0_S\pi^-}, m^2_{K^0_S\pi^+})$:

$$c_i = \langle \cos \Delta\delta_D \rangle, \quad s_i = \langle \sin \Delta\delta_D \rangle$$

Obtaining c_i, s_i

Coefficients c_i, s_i can be obtained in $\psi(3770) \to D^0\overline{D}^0$ decays.
Use quantum correlations between D^0 and $\overline{D}^0$.

- If both D decay to $K_S^0\pi^+\pi^-$, the number of events in i-th bin of $D_1 \to K_S^0\pi^+\pi^-$ and j-th bin of $D_2 \to K_S^0\pi^+\pi^-$ is

$$M_{ij} = K_i K_{-j} + K_{-i} K_j - 2\sqrt{K_i K_{-i} K_j K_{-j}}(c_i c_j + s_i s_j).$$

  $\Rightarrow$ constrain c_i and s_i.

- If one D decays to a CP eigenstate, the number of events in i-th bin of another $D \to K_S^0\pi^+\pi^-$ is

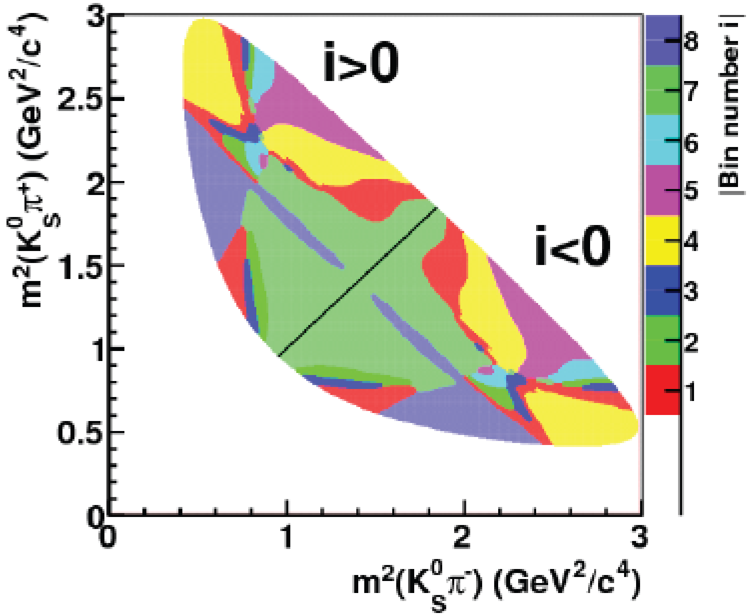
$$M_i = K_i + K_{-i} \pm 2\sqrt{K_i K_{-i}} c_i.$$

  $\Rightarrow$ constrain c_i.

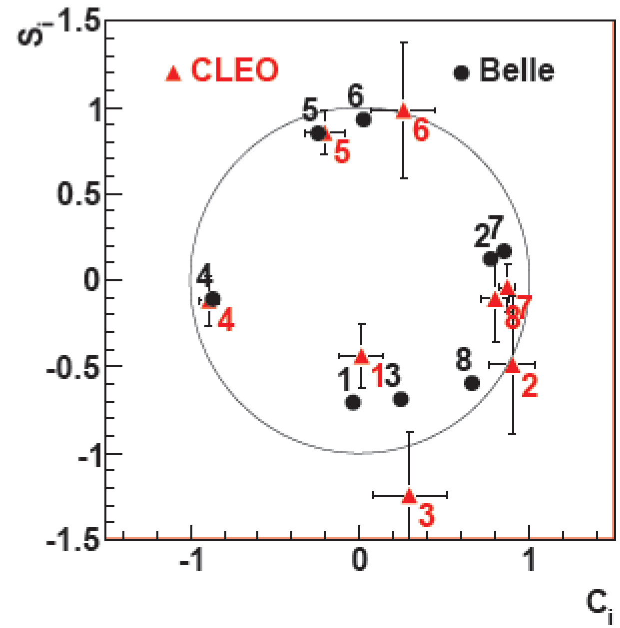
c_i, s_i measurement has been done by CLEO and can be done in future at BES-III.

CLEO measurement of c_i, s_i

Binned analysis reduces stat. precision.
Can improve this by choosing a binning inspired by $\overline{D}^0 \to K_S^0\pi^+\pi^-$ model.
[CLEO collaboration, PRD **82**, 112006 (2010)]



Optimized $\overline{D}^0 \to K_S^0\pi^+\pi^-$ binning using BaBar 2008 measurement.



Measured c_i, s_i values and predictions by Belle model

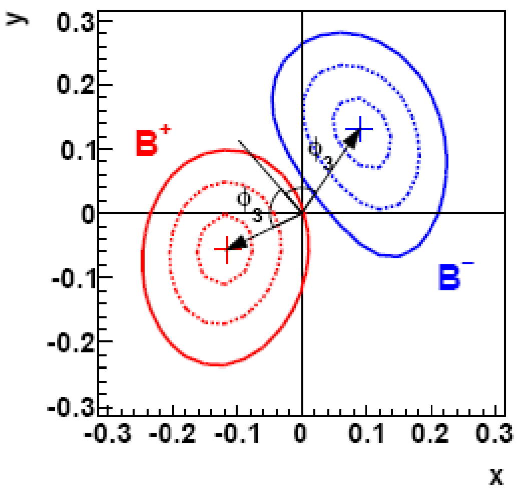
Optimal binning depends on model, but ϕ_3 does not.
Bad model $\Rightarrow$ worse precision, but no bias!

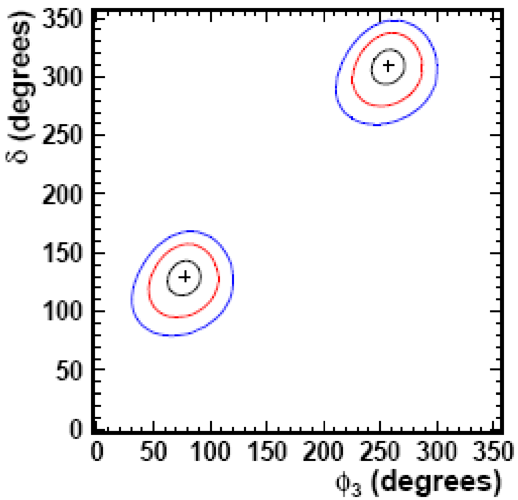
Results of ϕ_3/γ measurement

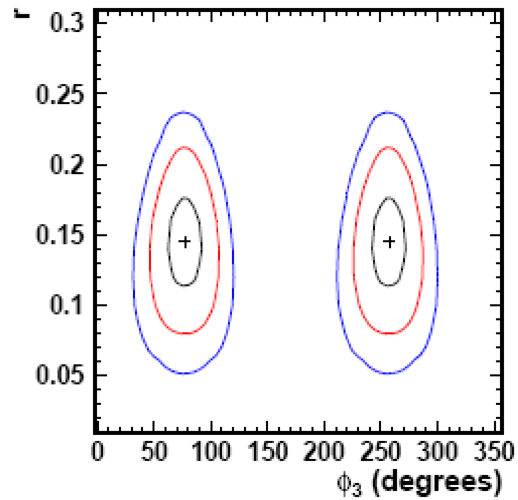
Accepted to Phys.Rev.D
[arXiv:1204.6561]

Simultaneous fit to signal selection variables in all bins

Free parameters: (x, y), normalization, background fractions in bins.







$$x_- = +0.095 \pm 0.045 \pm 0.014 \pm 0.017$$
$$y_- = +0.137^{+0.053}_{-0.057} \pm 0.019 \pm 0.029$$
$$\mathrm{corr}(x_-, y_-) = -0.315$$
$$x_+ = -0.110 \pm 0.043 \pm 0.014 \pm 0.016$$
$$y_+ = -0.050^{+0.052}_{-0.055} \pm 0.011 \pm 0.021$$
$$\mathrm{corr}(x_+, y_+) = +0.059$$

$$\phi_3 = (77.3^{+15.1}_{-14.9} \pm 4.2 \pm 4.3)^\circ$$
$$r_B = 0.145 \pm 0.030 \pm 0.011 \pm 0.011$$
$$\delta_B = (129.9 \pm 15.0 \pm 3.9 \pm 4.7)^\circ$$

1st error is statistical, 2nd — systematic, 3rd — c_i, s_i precision.

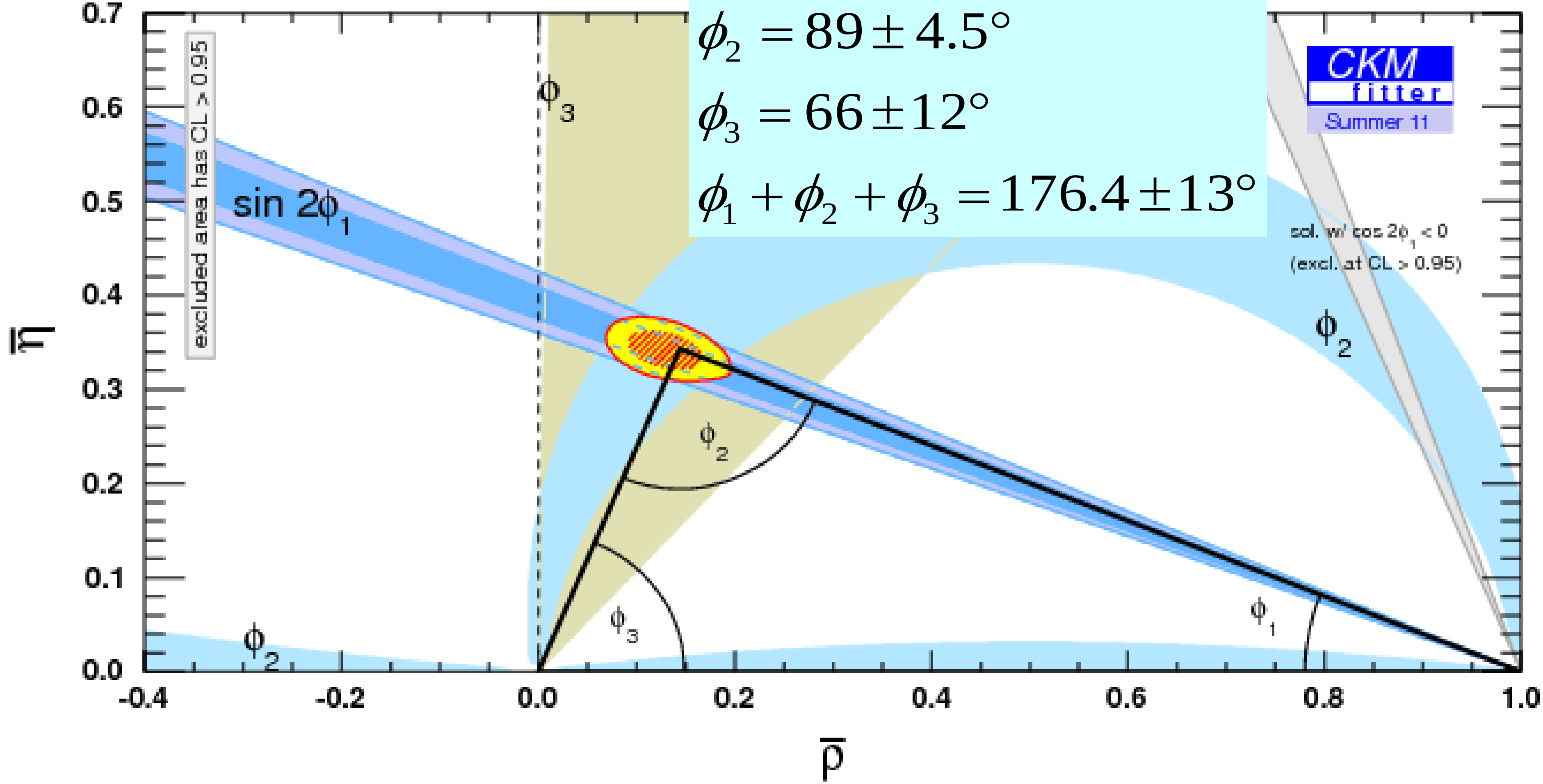
CPV Results

$\phi_1 = 21.4 \pm 0.8^\circ$

$\phi_2 = 89 \pm 4.5^\circ$

$\phi_3 = 66 \pm 12^\circ$

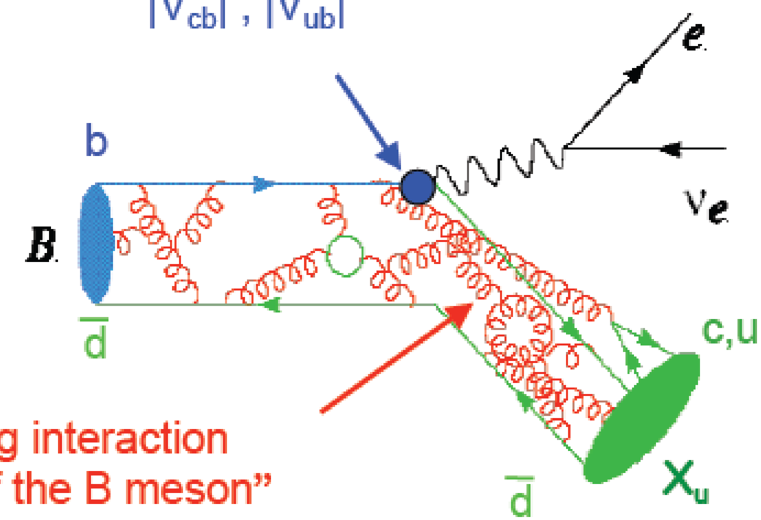
$\phi_1 + \phi_2 + \phi_3 = 176.4 \pm 13^\circ$



LHCb prospects for ϕ_3: half statistics of Belle's sample with 2011 data of $1fb^{-1}$, but less background

V_{ub}

2 Complementary approaches
using **different** theoretical tools,
and **different** experimental
signatures.
→Crucial independent
consistency check.



Inclusive: $$\Gamma(B \to X_c \ell \nu) = \frac{G_F^2 m_b^5}{192\pi^3}|V_{cb}|^2[[1 + A_{ew}]A_{nonpert}A_{pert}]$$

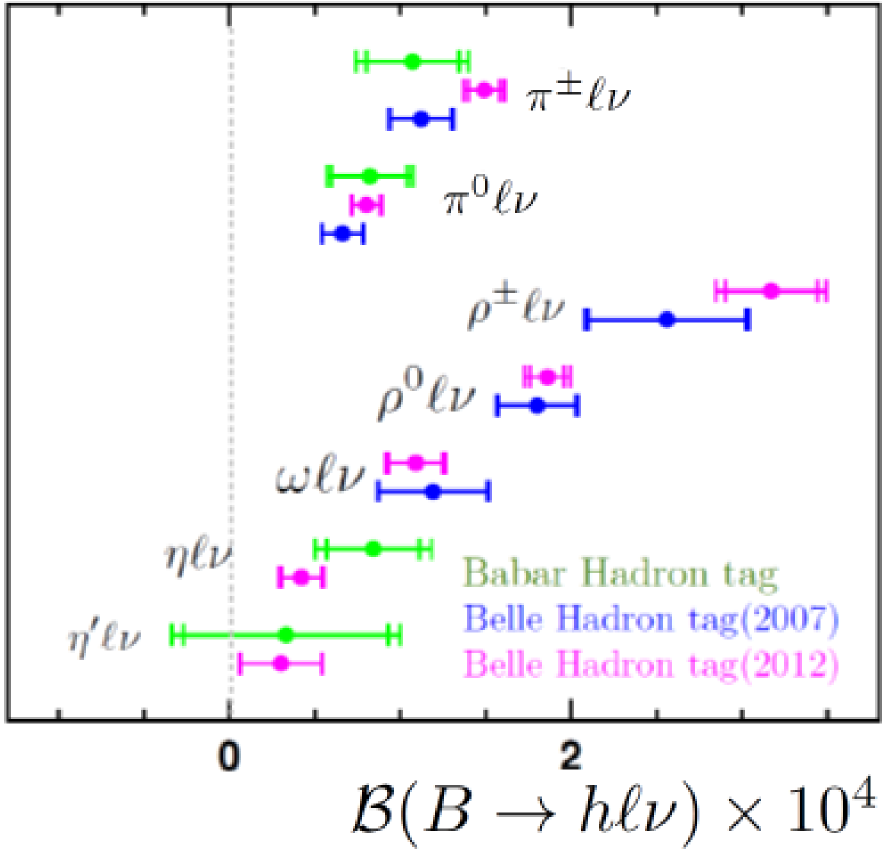
sum over all hadron final states
(heavy quark symmetry)

free quark decay

QCD corrections

Exclusive: $$\frac{d\Gamma(B \to \pi \ell \nu)}{dq^2} = \frac{G_F^2}{24\pi^2}|V_{ub}|^2 p_\pi^3 |f_+(q^2)|^2$$

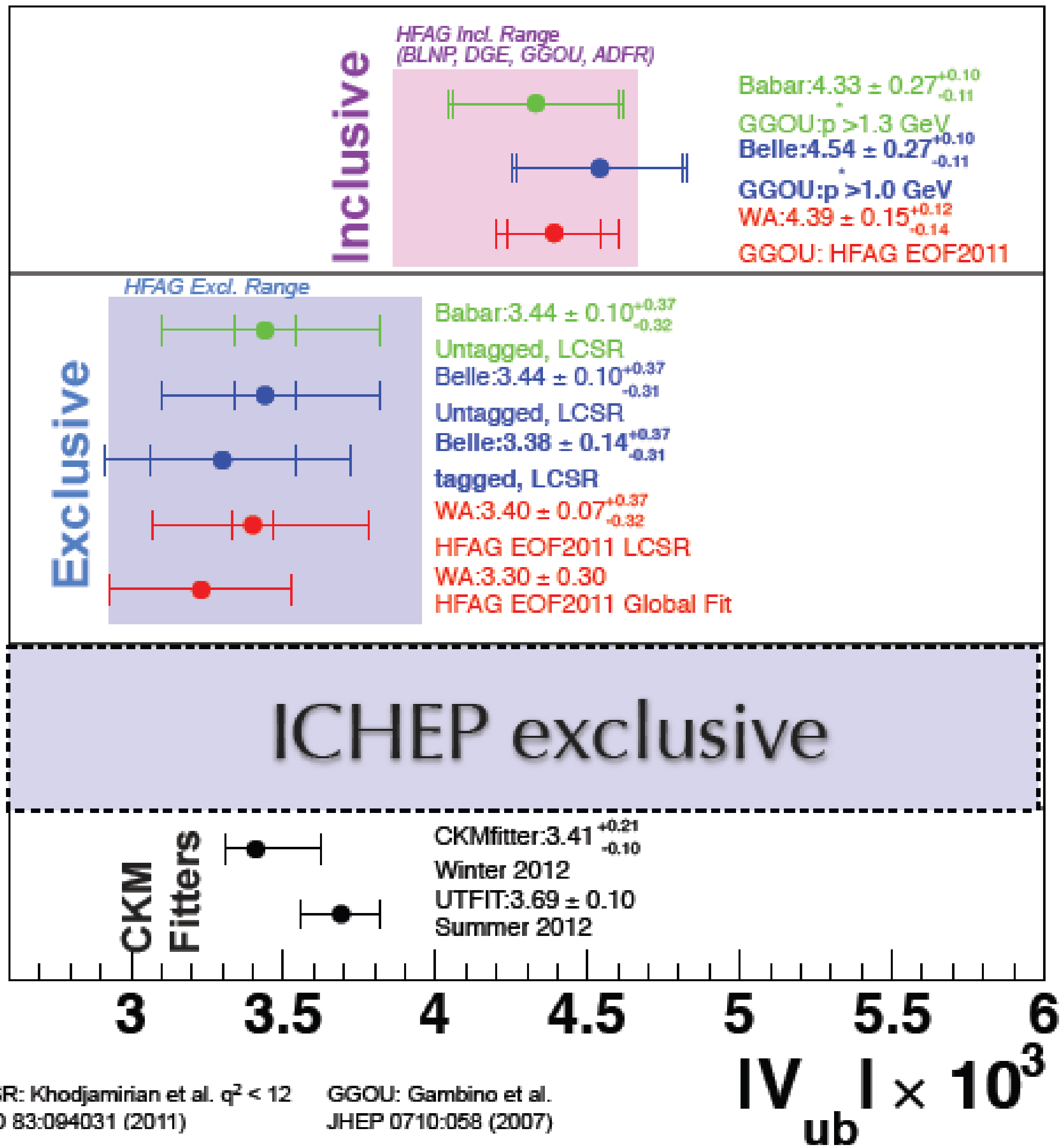
B → π form factor (lattice QCD)



$$\mathcal{B}(B^0 \to \pi^- \ell^+ \nu_l) = (1.49 \pm 0.09 \pm 0.07) \times 10^{-4}$$
$$\mathcal{B}(B^+ \to \pi^0 \ell^+ \nu_l) = (0.80 \pm 0.08 \pm 0.04) \times 10^{-4}$$
$$\mathcal{B}(B^0 \to \rho^- \ell^+ \nu_l) = (3.17 \pm 0.27 \pm 0.18) \times 10^{-4}$$
$$\mathcal{B}(B^+ \to \rho^0 \ell^+ \nu_l) = (1.86 \pm 0.10 \pm 0.09) \times 10^{-4}$$
$$\mathcal{B}(B^+ \to \omega \ell^+ \nu_l) = (1.09 \pm 0.16 \pm 0.08) \times 10^{-4}$$
$$\mathcal{B}(B^+ \to \eta \ell^+ \nu_l) = (0.42 \pm 0.12 \pm 0.05) \times 10^{-4}$$
$$\mathcal{B}(B^+ \to \eta' \ell^+ \nu_l) < 0.57 \times 10^{-4} \text{ @ } 90\% CL.$$

[Belle Preliminary Results]

→ **Significantly improved branching ratios compared to the past results.**



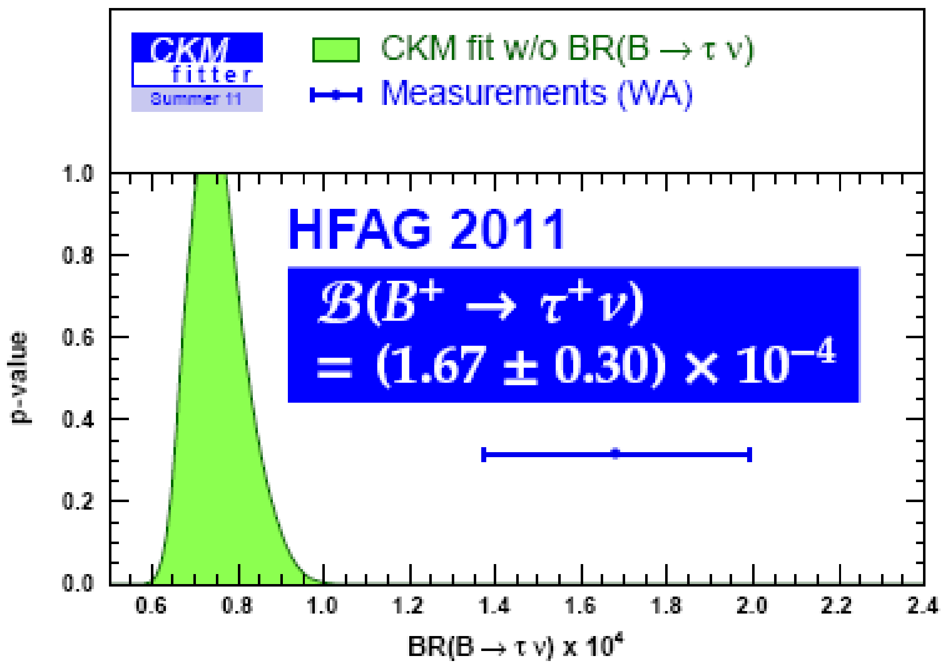
LCSR: Khodjamirian et al. $q^2 < 12$
PRD 83:094031 (2011)

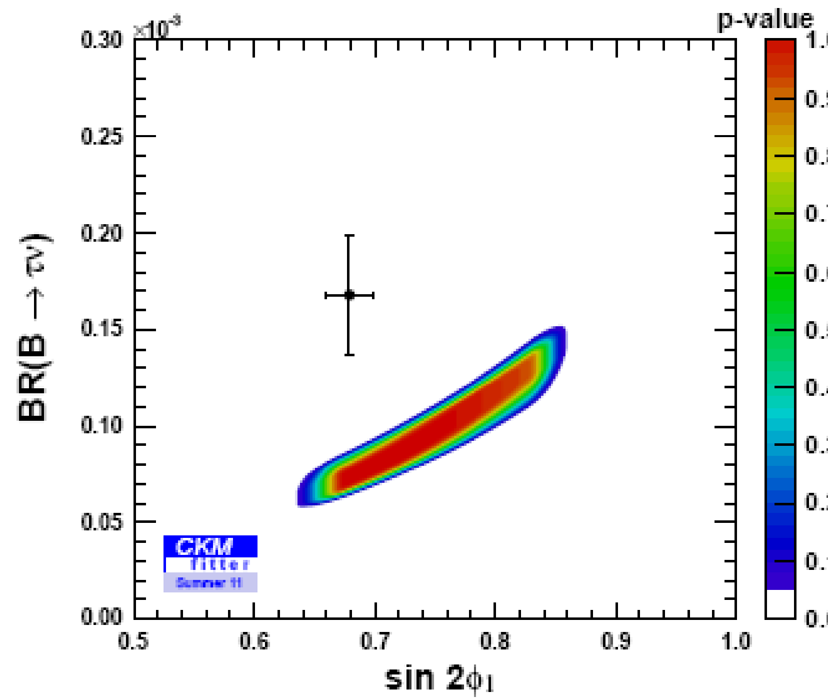
GGOU: Gambino et al.
JHEP 0710:058 (2007)

- ΔIncl.~6% (↓from 18% in 2004)
  ΔExcl.~10%
  Up to 2-3 σ difference between Excl.-Incl.

V_{ub} and $B \to \tau\nu$

- **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** Δm_d **and other CKM** (and no more direct constraint to $|V_{ub}|$)

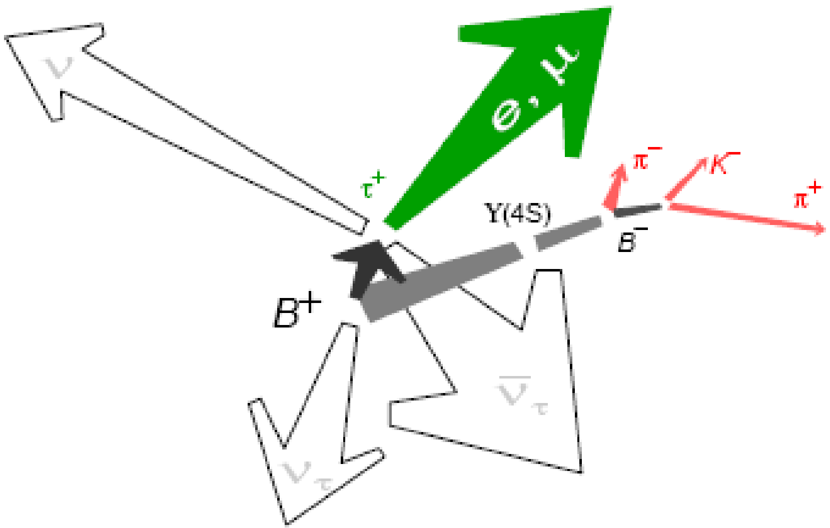




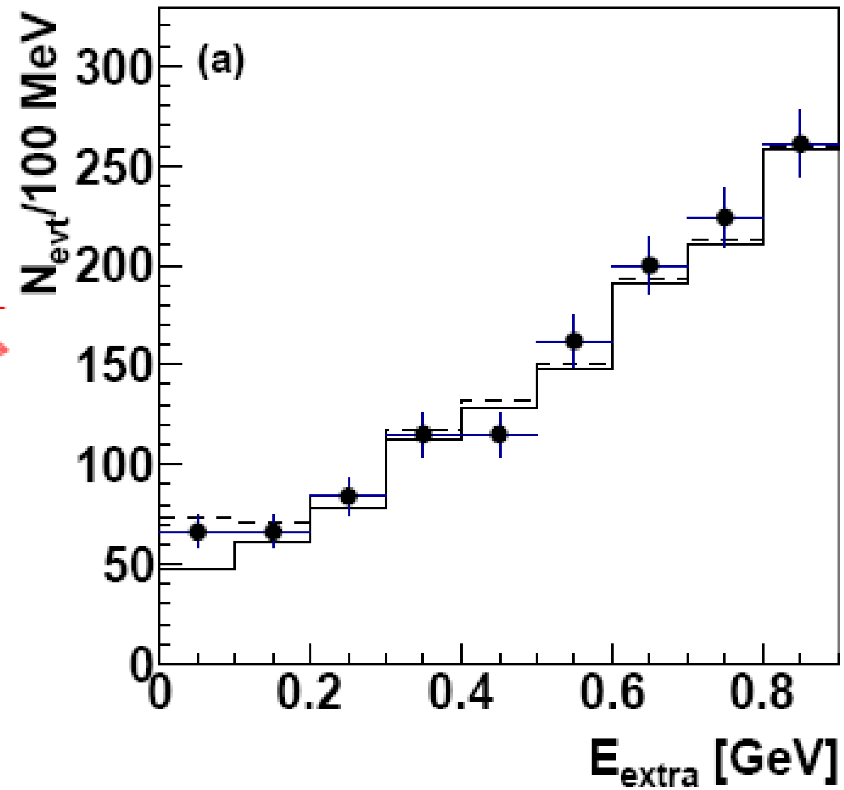
status before ICHEP: **2.8σ tension in direct vs indirect** $B^+ \to \tau^+\nu$

New Babar's results $B \to \tau\nu$

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



[ICHEP2012, arxiv:1207.0698]



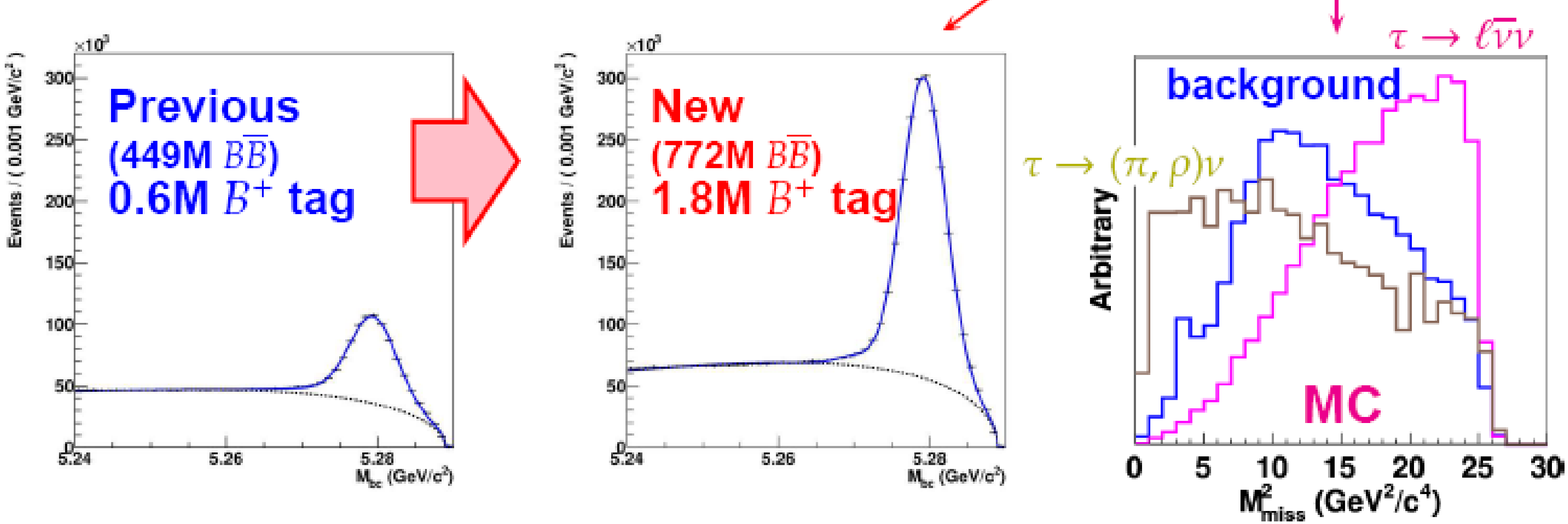
- 4 τ modes: $(e\bar{\nu}\nu,\ \mu\bar{\nu}\nu,\ \pi\nu,\ \rho\nu)$
- Signal peak at 0 in the remnant calorimeter energy

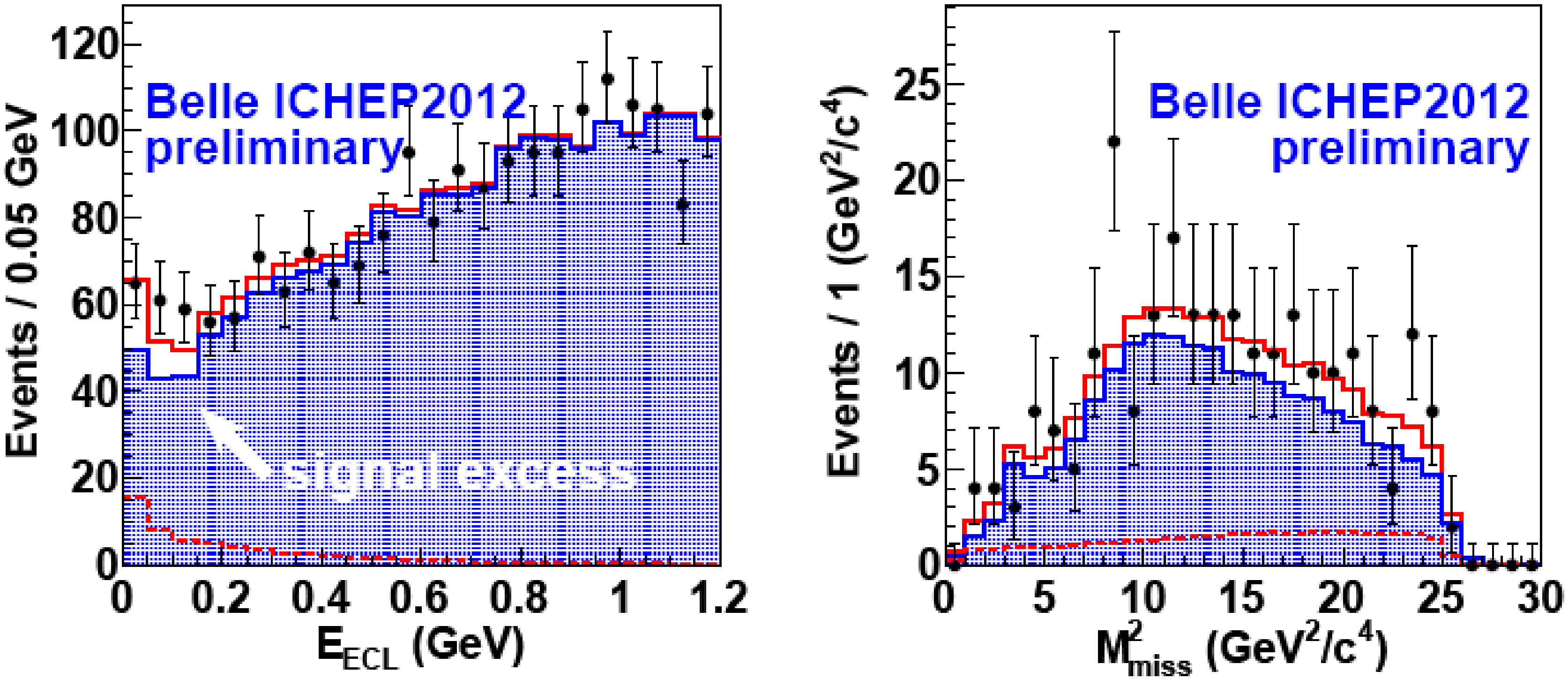
$$\mathcal{B}(B^+ \to \tau^+\nu) = (1.83\,^{+0.53}_{-0.49} \pm 0.24) \times 10^{-4} \quad (3.8\sigma)$$

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

New Belle's results $B \to \tau\nu$

- **72%** more data: 449M $\to$ 772M $B\overline{B}$
- Improved (slow) track efficiency by **reprocessing**
- New hadronic-tag algorithm — **Neurobayes** neural network
- Newly added K_L **veto** after understanding data/MC difference
- **3× tag, 3.7× efficiency, ~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}



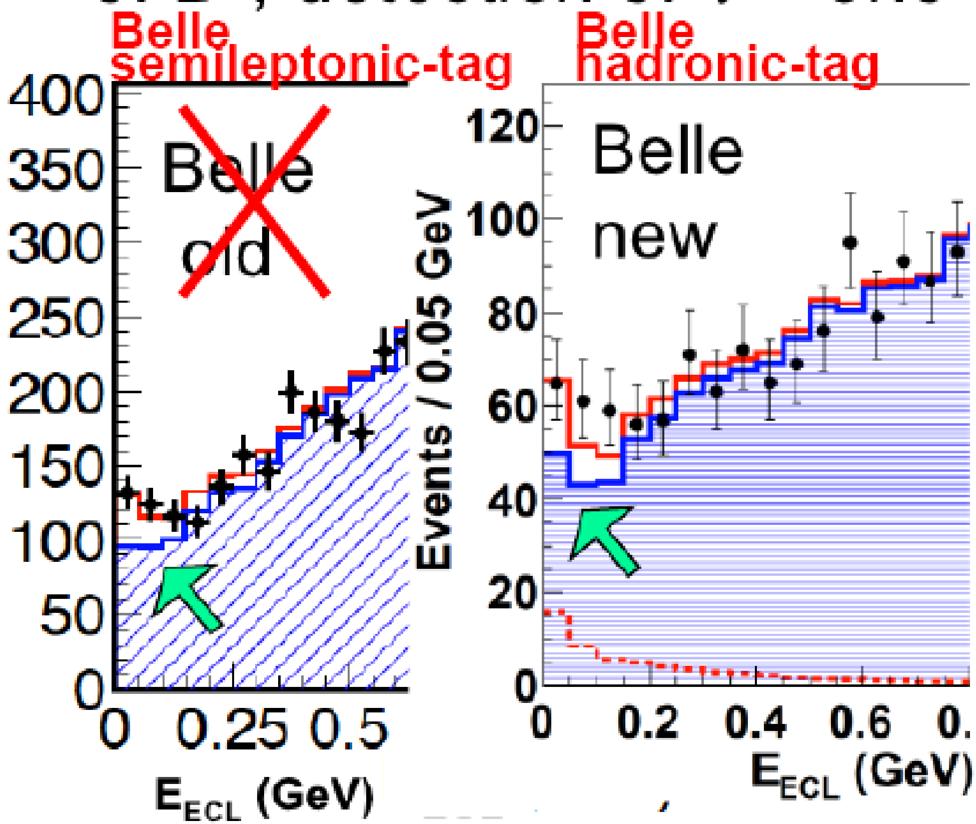


$\mathcal{B}(B^+ \to \tau^+ \nu) = (0.72\,^{+0.27}_{-0.25} \pm 0.11) \times 10^{-4}$ ($62\,^{+23}_{-22}$ **events, 3.0**σ)

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 τ ($e\nu\nu$, $\mu\nu\nu$, $\pi\nu$, $\rho\nu$) give consistent results
New K^0_L veto is not killing the true signal, and more checks were made. . .

Peaking Backgrounds

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



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

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

$B \to \tau\nu$ 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) (x 10^6)	(set A) 449	771	
		(set A) 449	(set B) 332
Efficiency (x 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($B^+ \to \tau^+\nu$) (x 10^{-4})	$1.79^{+0.56}_{-0.49}$	$1.08^{+0.37}_{-0.35}$	$0.24^{+0.39}_{-0.34}$
		$0.72^{+0.27}_{-0.25}$	

1.6σ

2.5σ

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

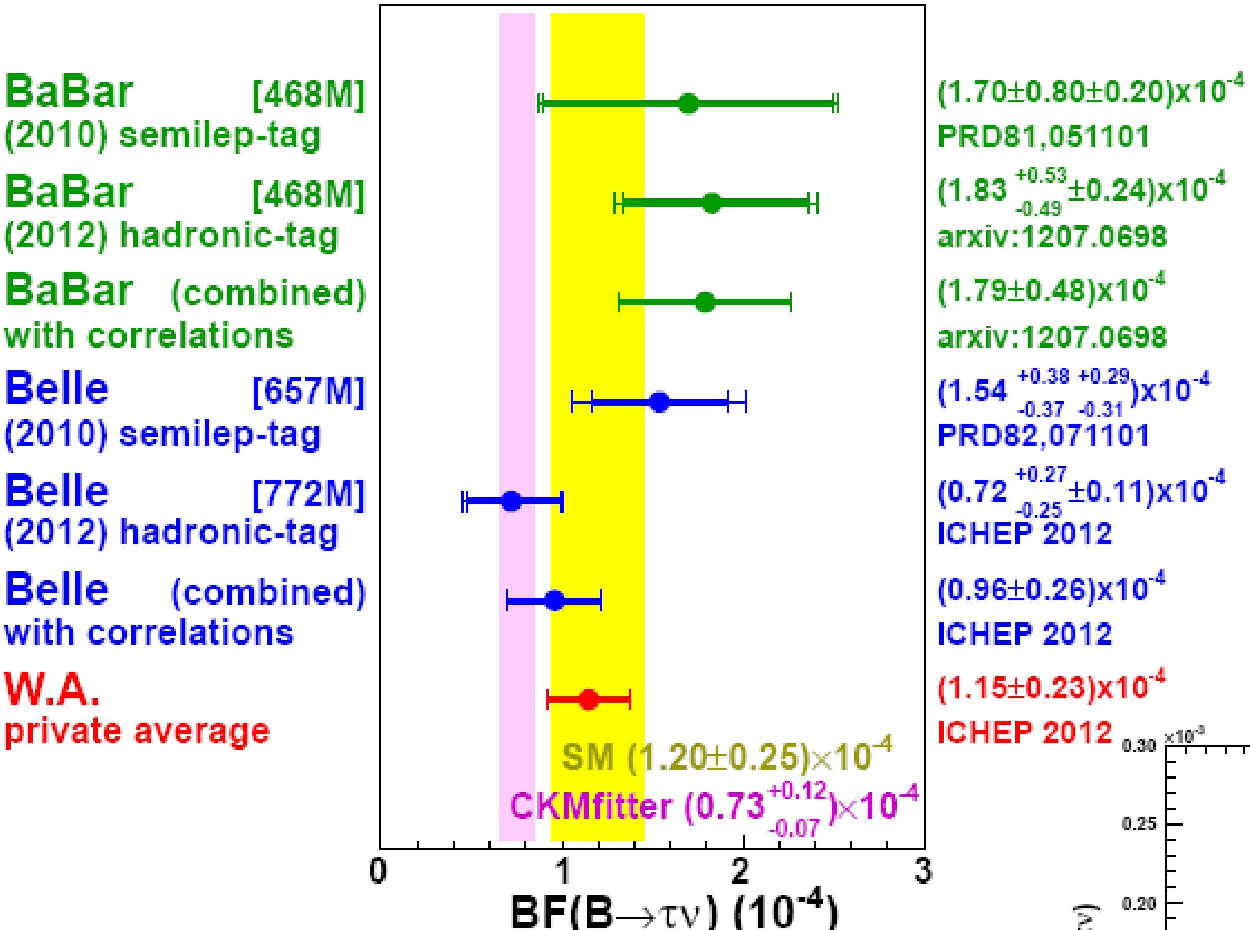
SET B: corresponds to the data-set not used in 2006

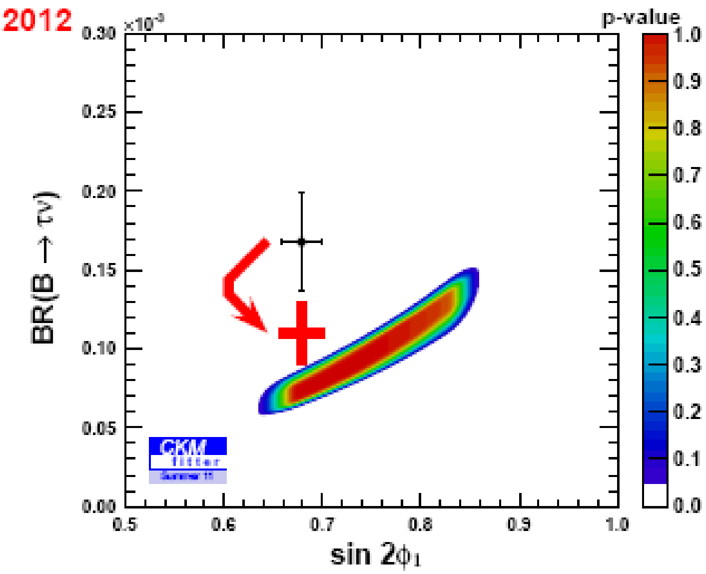
SET A': corresponds to the data-set used in 2006, but reproduced

All events used for the New Analysis

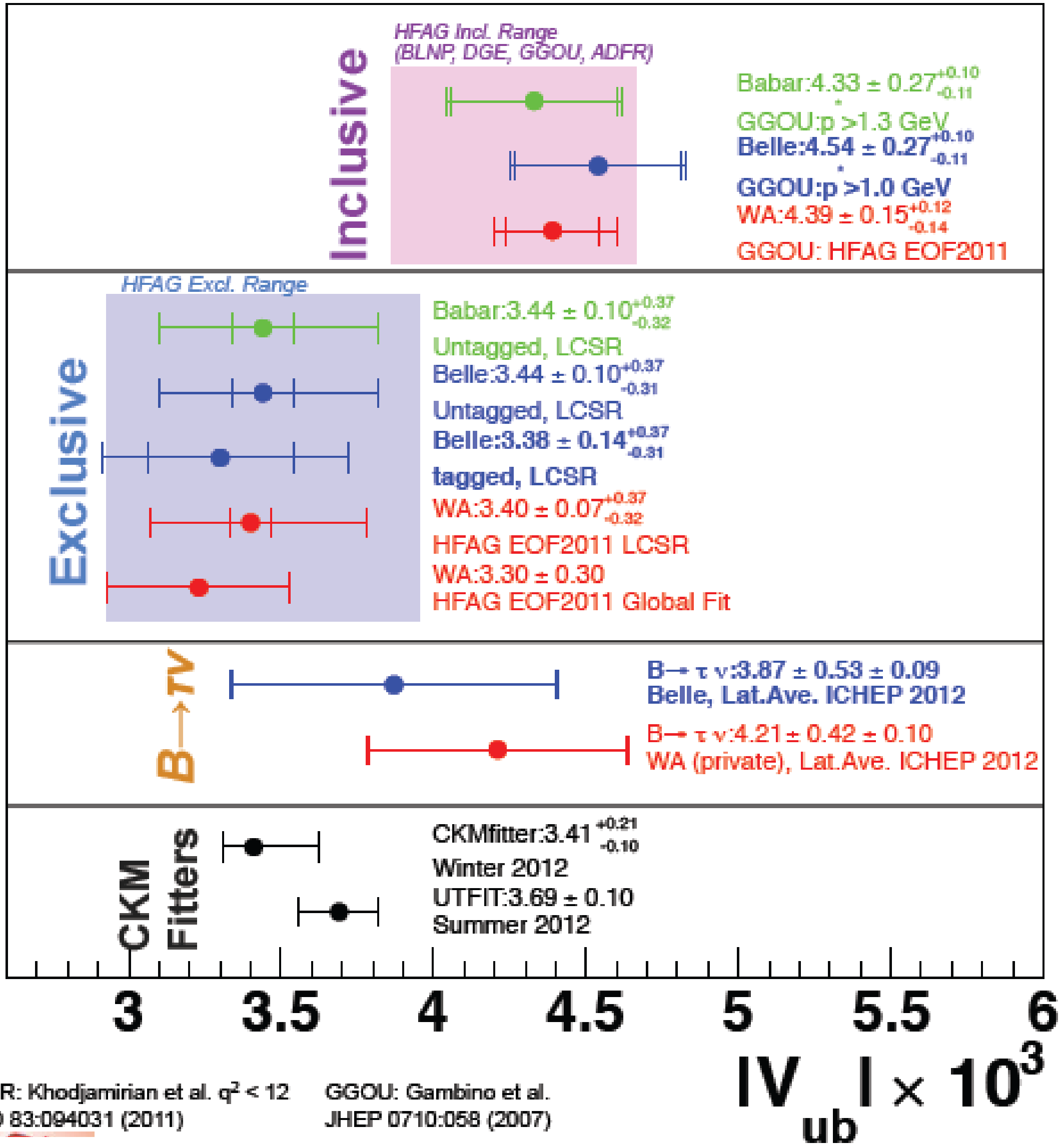
Old (set A) vs. New (set B) : 2.5σ difference
New results. set A' vs. set B : 1.6σ difference
Old (set A) vs. New (set A') : 1.2σ difference

*Old result (set A) vs. New (only for non-overlapping events in the set A)
BF(non-overlapping events) = (0.6 +- 0.4)x10^-4 → 1.9 σ difference





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



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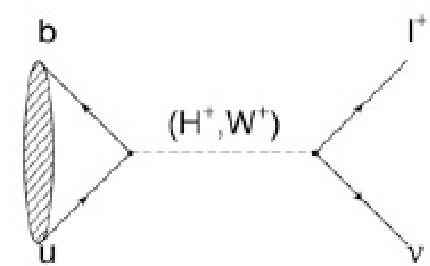
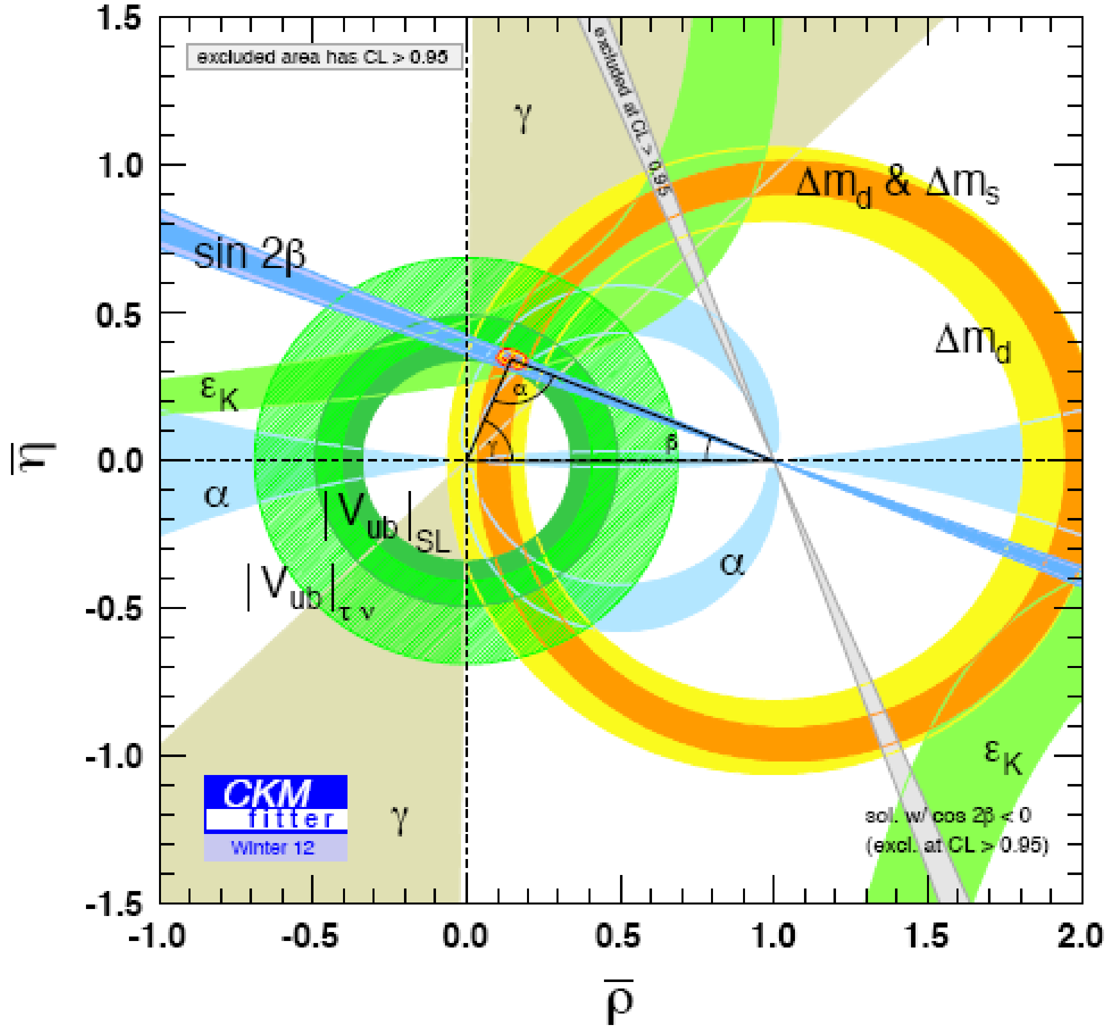
- ΔIncl.~6% (↓from 18% in 2004)
  ΔExcl.~10%
  Up to 2-3 σ difference between Excl.-Incl.

- **New** Belle results on **B→τν @ICHEP 2012** in agreement with both methods.

  ΔLeptonic.~10%!!





$|V_{ud}|, |V_{us}|$

$|V_{cb}|, |V_{ub}|_{SL}$

$B \to \tau\nu$

$\Delta m_d, \Delta m_s$

ϵ_K

$\sin 2\beta$

α

γ

$A = 0.812^{+0.015}_{-0.022}$

$\lambda = 0.2254^{+0.0006}_{-0.0010}$

$\bar{\rho} = 0.145^{+0.027}_{-0.027}$

$\bar{\eta} = 0.343^{+0.015}_{-0.015}$

(68% CL)

Summary

•Still good agreement with Standard Model (CKM) prediction based on a global fit of the Unitarity Triangle

•Need to verify with a better precision (LHCb and BelleII/SuperB in near future)

•CP violation in the B meson decays is well established at the B factories

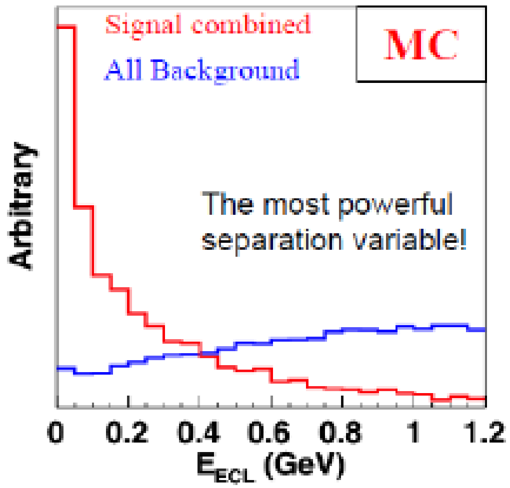
•Further search for Beyond Standard Model physics in CP violation. Two main motivations:

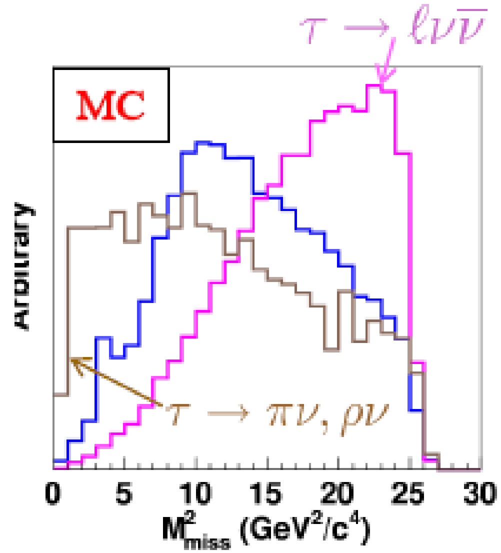
- The strength of CP violation in the SM is not sufficient to generate the observed Baryon Asymmetry in the Universe
- Almost all extensions of the SM have new sources of CP violation which can in principle be detected

Thank you for your attention!

$$B^+ \to \tau^+ \nu_\tau$$

- *The fitting variables*





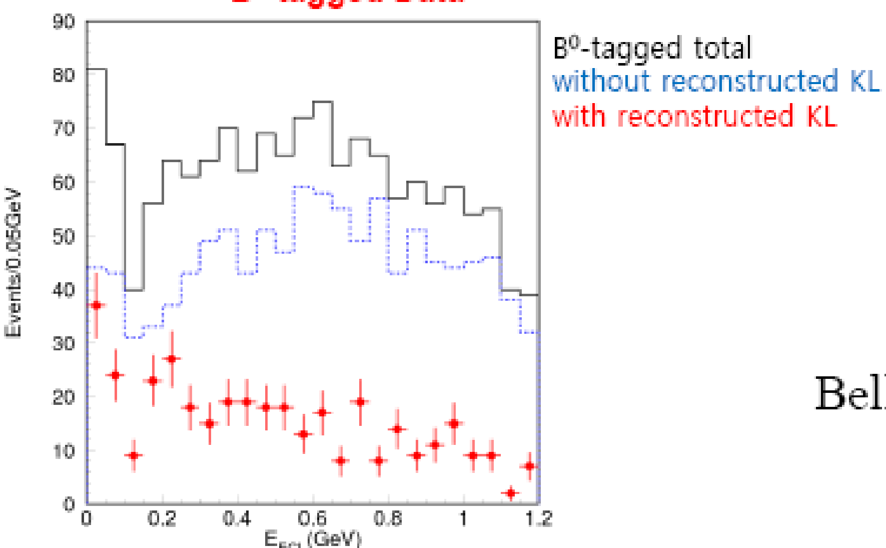
Using these variables for 2D histogram PDF fitting.

<u>Improves the signal significance by about 20%</u>

Use of 2-D fitting will reduce the sensitivity to peaking backgrounds in E_{ECL}.

<u>Peaking background **enhanced** sample</u>

B^0-tagged Data



Background rejection using the K_L is introduced

→ Effective to reduce the peaking background

<u>Improves the signal significance by about 5%</u>

Belle full data + improvement of analysis

Expected signal significance : 6.3σ for Br($B \to \tau\nu$)=1.65×10^{-4}

Validation of Analysis

Validated with Data

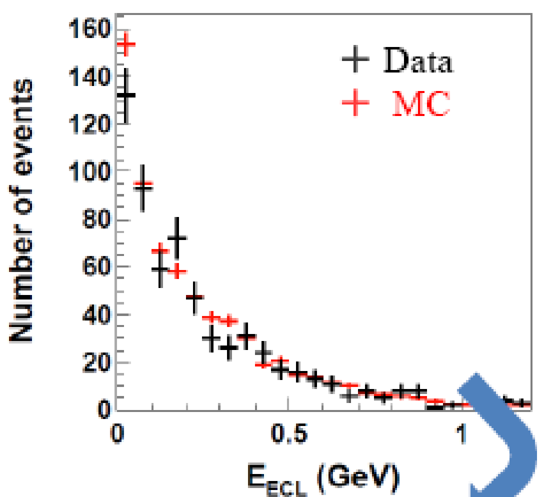
$B^+ \to \tau^+ \nu_\tau$

1. Sophisticated B tagging algorithm
2. Background rejection using K_L

} **Reconstruction efficiencies calibrated with Data**

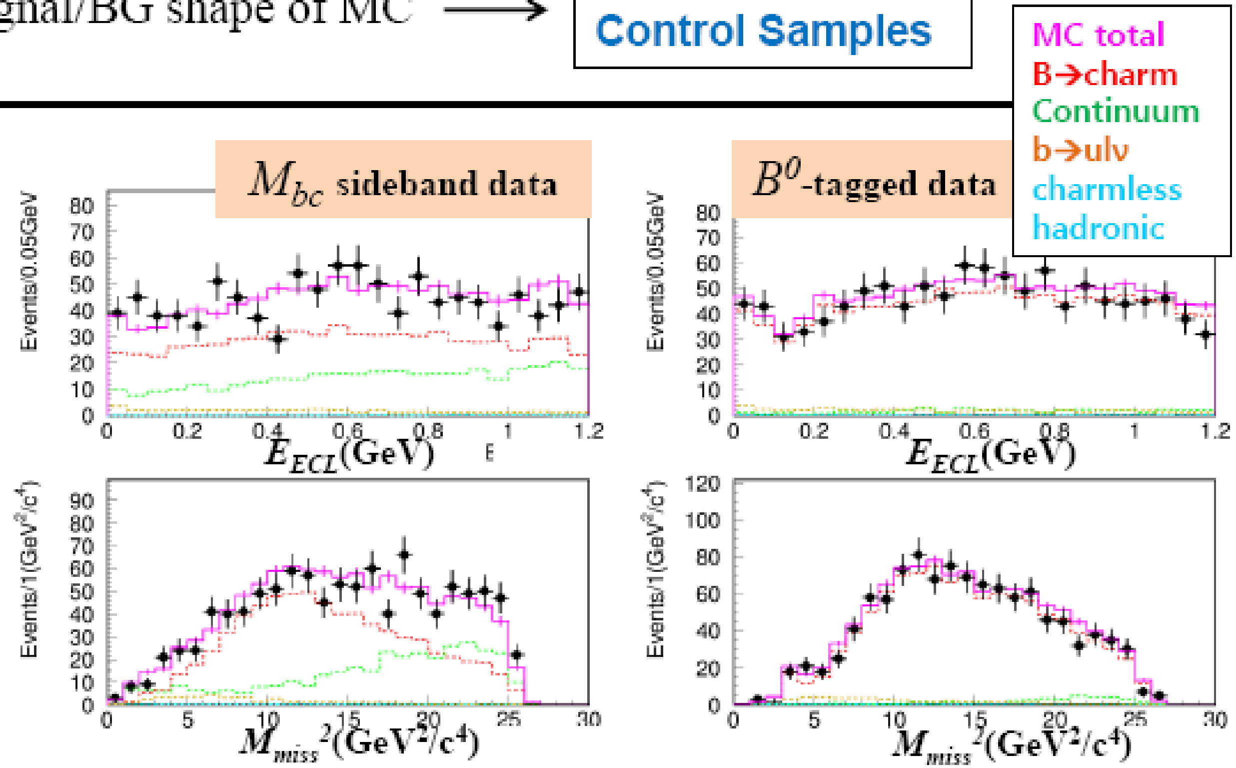
3. E_{ECL} and $M_{miss}{}^2$ signal/BG shape of MC ⟶ **Confirmed with Control Samples**

Reconstruct $B \to D^{(*)}\ell\nu$ as the signal



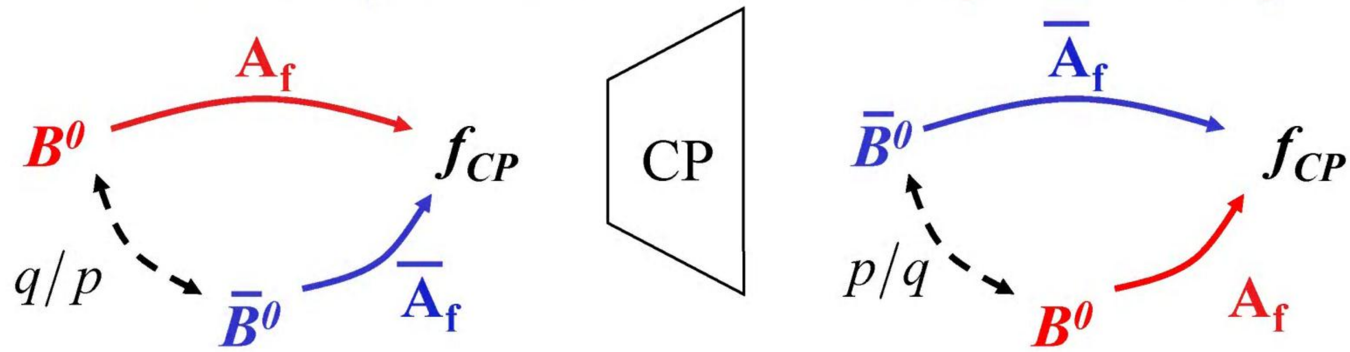
$\mathcal{B}(B^- \to D^{*0}\ell^-\bar{\nu}_\ell) = [5.60 \pm 0.22(stat) \pm 0.28(syst)]\%$

Consistent with the PDG world average: (5.68±0.19)%



Data-MC consistency is also confirmed with E_{ECL} sideband and wrong charge combination events.

Time-dependent CP asymmetry



Interference between mixing and decay to a CP eigenstate f_{CP}

$$\Rightarrow \quad \Gamma\left(B^0_{phys}(t) \to f_{CP}\right) \neq \Gamma\left(\bar{B}^0_{phys}(t) \to f_{CP}\right)$$

Flavor-tagged time-dependent decay rates are different!
they are governed by the "CP parameter":

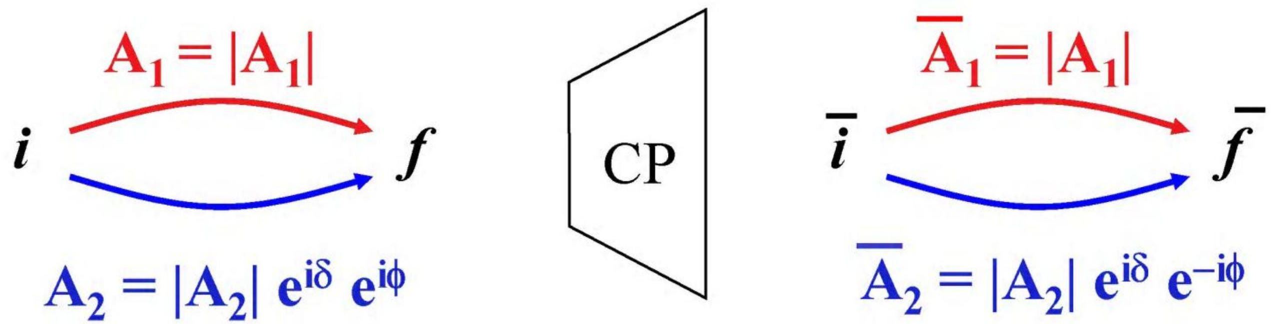
$$\lambda_{f_{CP}} = \eta_{f_{CP}} \frac{q}{p} \frac{\bar{A}_{f_{CP}}}{A_{f_{CP}}}$$

CP eigenvalue

$\approx e^{-i2\beta}$ from mixing

Amplitude ratio

Observables: "direct" CP asymmetry

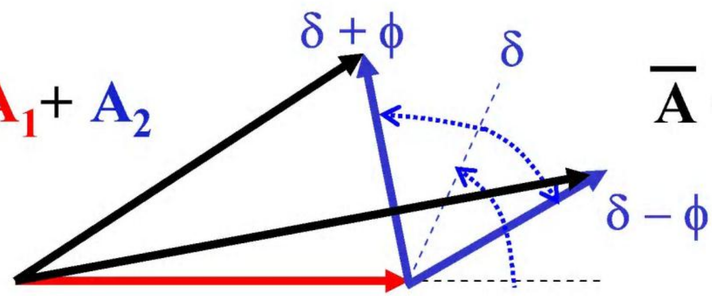


$\delta \to \delta$ (CP-conserving)

$\phi \to -\phi$ (CP-violating)

Time-integrated "direct" CP asymmetry requires two amplitudes and $\delta \neq 0$:

$A = A_1 + A_2$

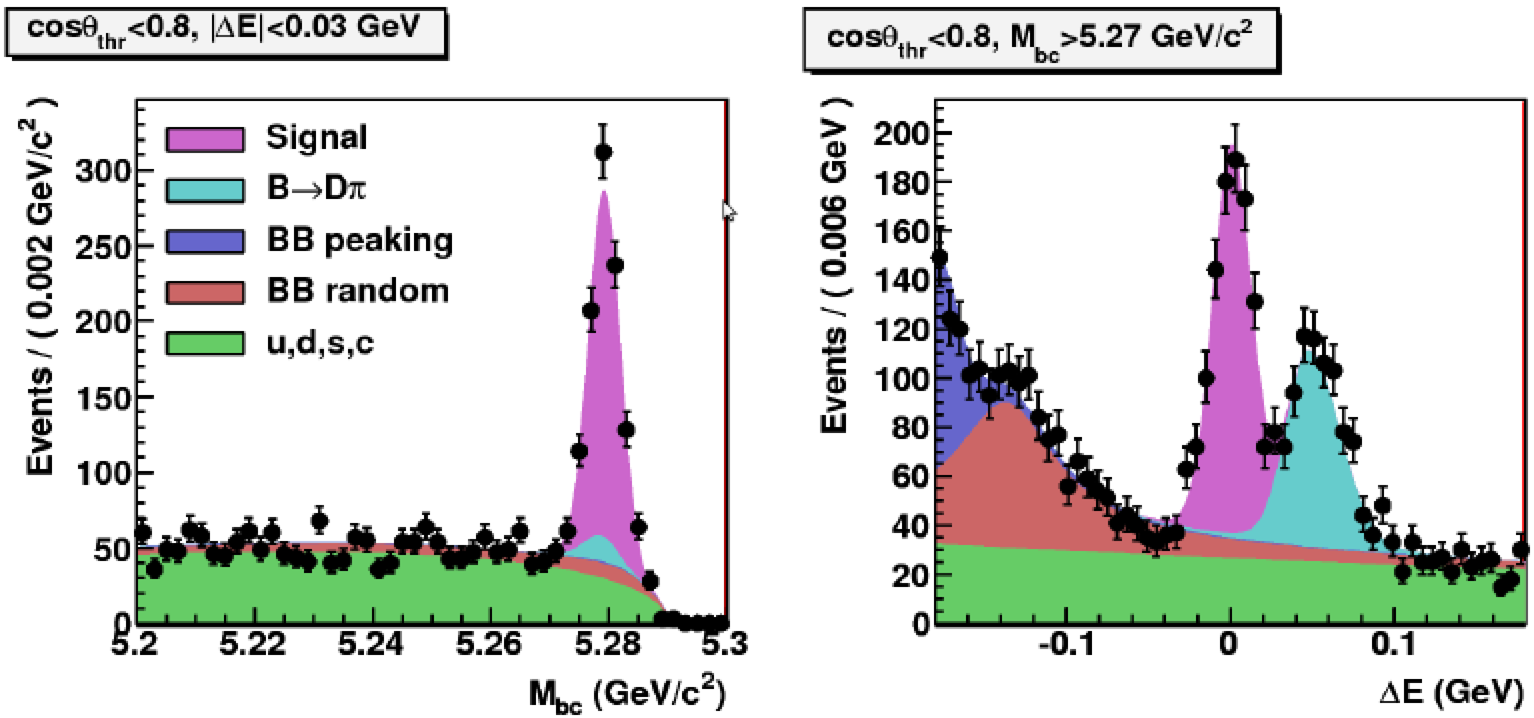


$\overline{A} = \overline{A}_1 + \overline{A}_2 \neq A$

B->DK, D-> $K_s\pi^+\pi^-$ signal selection

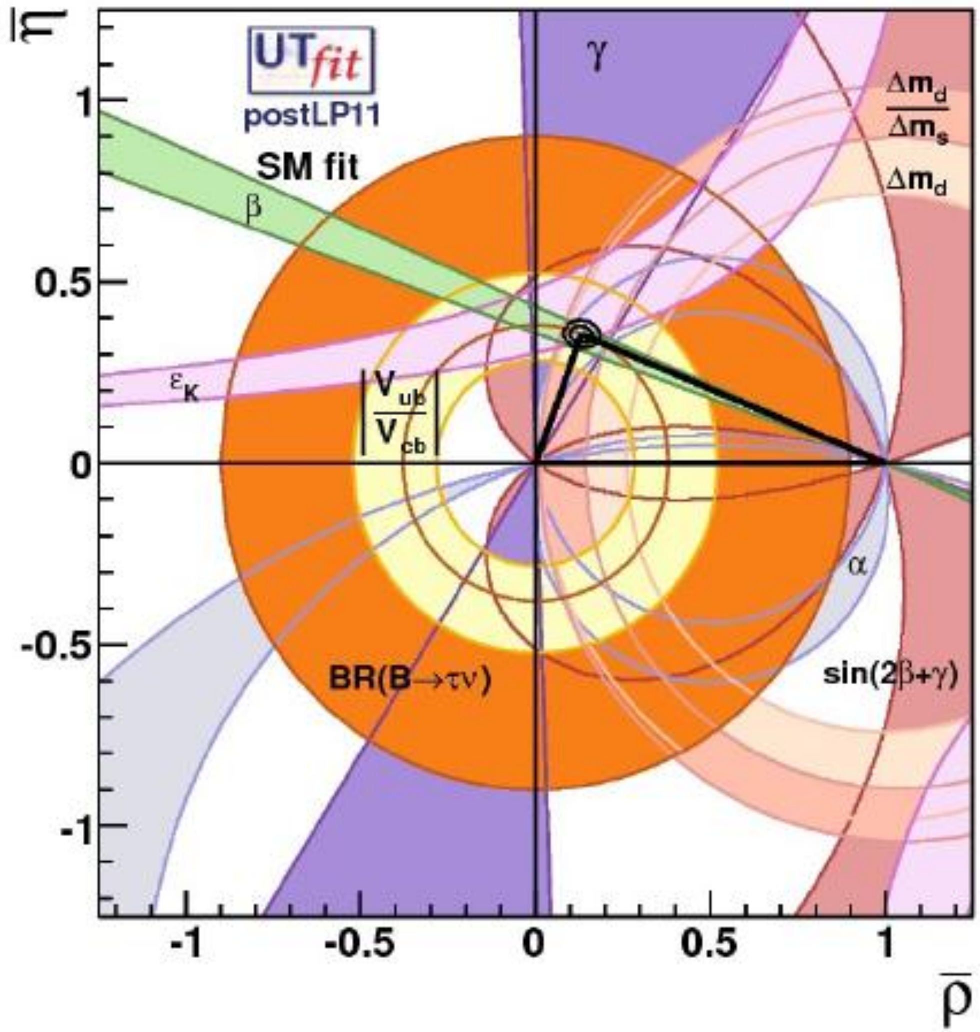
Use 711 fb^{-1} sample (772M $B\overline{B}$ pairs). Belle preliminary

Data reprocessed with new tracking $\Rightarrow$ improved efficiency (12% $\rightarrow$ 16%)



Signal selection variables: $M_{\rm bc}$, ΔE, event shape ($\cos\theta_{\rm thr}$, "virtual calorimeter" Fisher discriminant). 4D unbinned fit to get signal yield.

Signal yield: 1176 ± 43 events ($\sim 55\%$ more data than in prev. analysis)



levels @
95% Prob

$\bar{\rho}$ **= 0.131 ± 0.022**

$\bar{\eta}$ **= 0.354 ± 0.015**

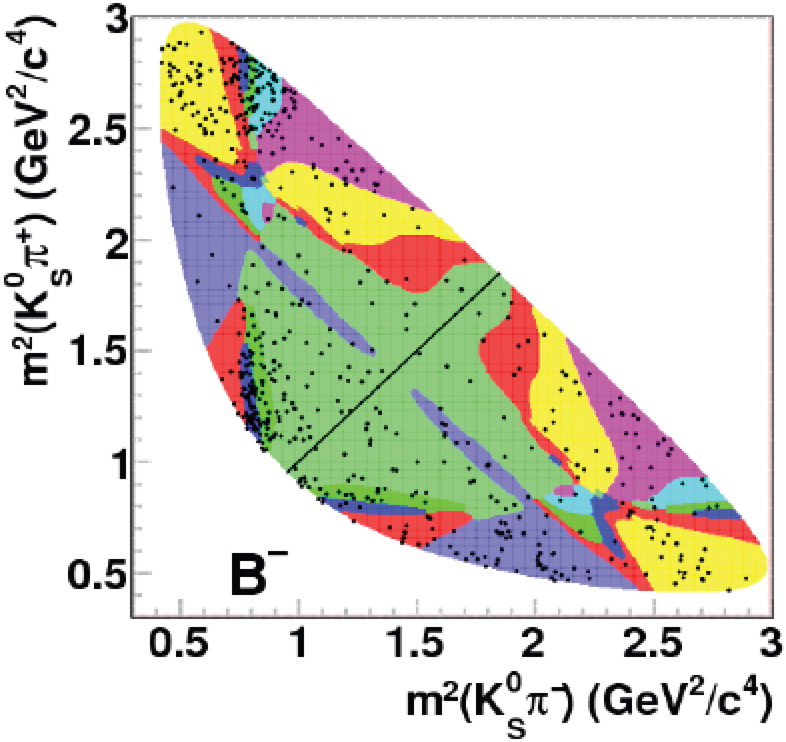
$\beta = (22 \pm 1)°$

$\gamma = (70 \pm 3)°$

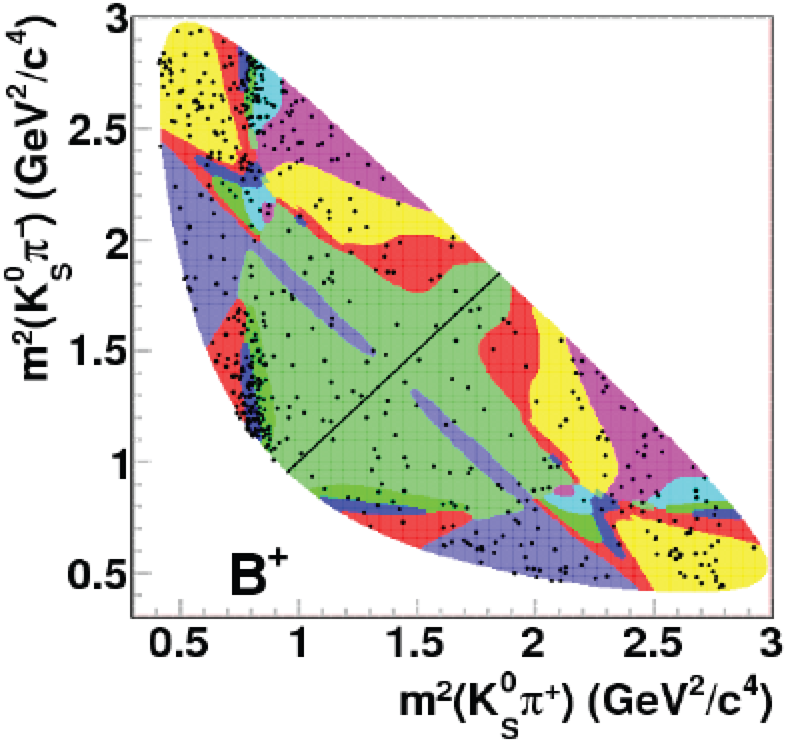
$\alpha = (88 \pm 3)°$

Dalitz plots

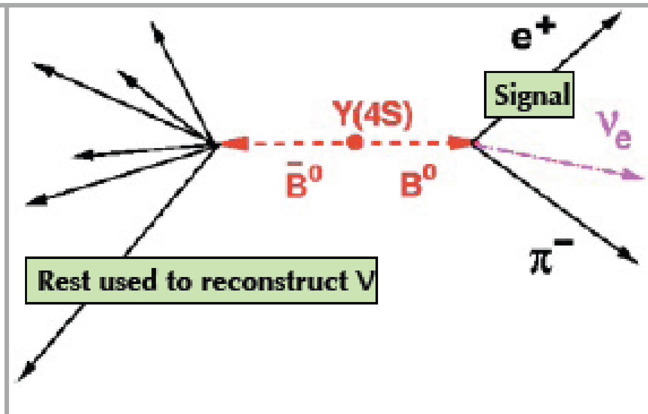
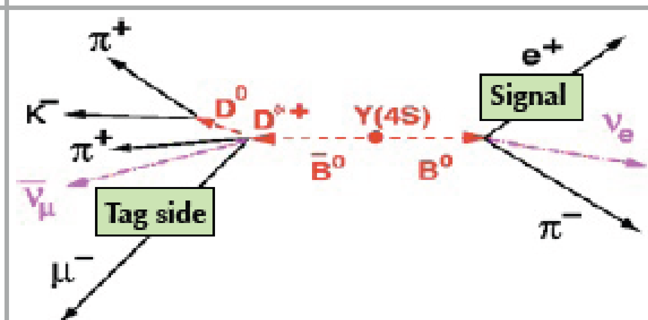
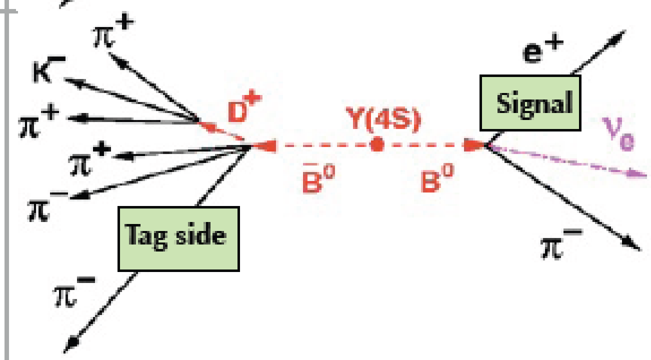
$B^- \to D^0 K^-$:

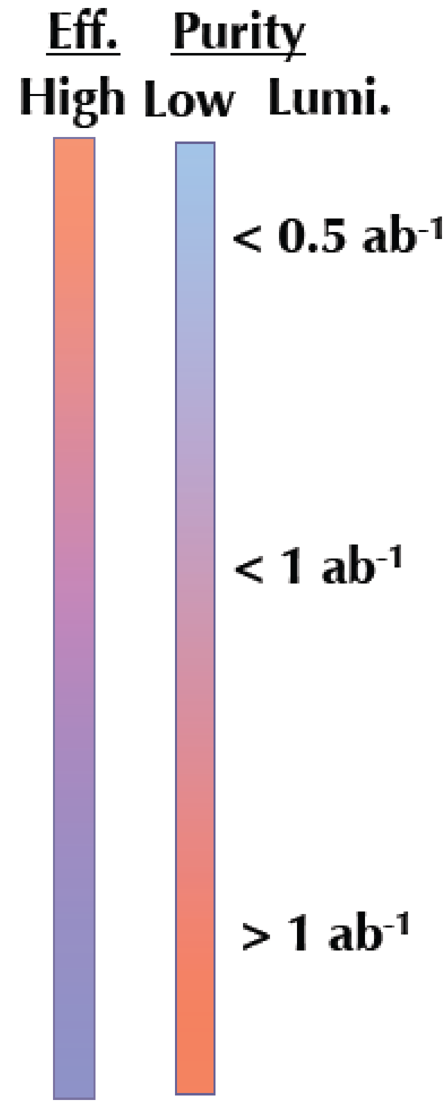


$B^+ \to D^0 K^+$:



Dalitz plots for signal-enriched region:
($M_{\rm bc} > 5.27$ GeV$/c^2$, $|\Delta E| < 30$ MeV, $\cos\theta_{\rm thr} < 0.8$).

Untagged Initial 4-momentum known missing 4-momentum = one ν Reconstruct B → X_q l ν using m_B (beam-constrained) and $\Delta E = E_B - E_{beam}$	
Semileptonic Tag One B reconstructed in $D^{(*)}$ l ν modes. **Two missing ν** in event.	
Full Reconstruction Tag One B reconstructed completely in a known b → c mode without ν.	



New Belle's V_{ub} results

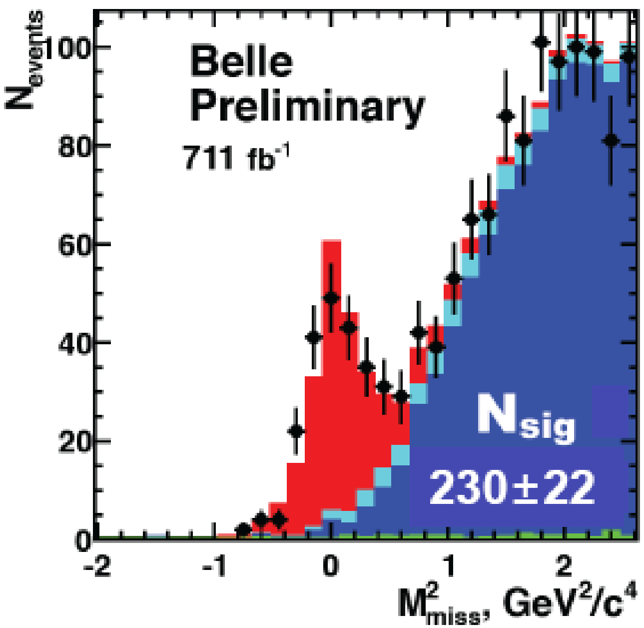
- Full $\Upsilon(4S)$ data used ($N(B\bar{B})$ = 772M / 711fb^{-1})
- Signal yield extracted from maximum-likelihood fit to M^2_{miss}

$$M^2_{miss} = (E_{CM} - E_{B_{tag}} - E_{B_{sig}})^2 - (P_{B_{tag}} - P_{B_{sig}})^2$$

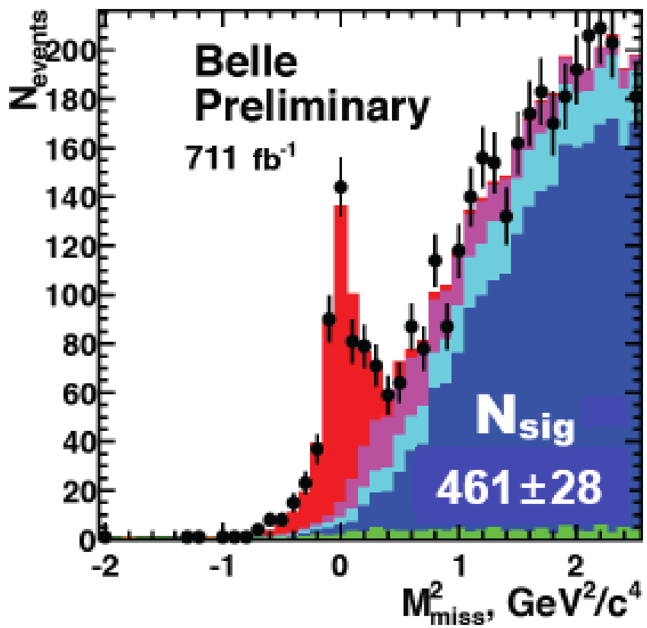
E and $P_{B_{tag}}$: Energy and momentum of the tagged-B
E and $P_{B_{sig}}$: Energy and momentum of signal side B particles

The cleanest measurement of these modes!

$B^+ \to \pi^0 \ell^+ \nu$



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



signal
B --> ρ l ν
other X_u l ν
B --> X_c l ν
continuum

stat. error only for N_{sig}

Major systematic uncertainty from hadronic tag efficiency ~ 5.0%