

Recent results on CP violation and CKM UT angles from Belle and BABAR

BEACH 2010
IX International Conference on Hyperons, Charm and Beauty Hadrons

Rula Magna
University of Perugia

The Conference offers an opportunity for both theorists and experimentalists from the high-energy physics community to discuss all aspects of hyperon and heavy flavor physics.

- Charm and B meson decays
- Symmetry Violations
- Physics beyond Standard Model
- Heavy quark production in hadron and lepton interactions
- Quarkonium spectroscopy and production
- Advances in theoretical calculations
- Hyperon physics
- Top quark physics
- New experimental facilities and projects

PERUGIA, Italy
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Contacts:
 INFN Sezione di Perugia
 c/o Piazza degli Ebrei, University of Perugia
 via A. Pascoli
 06122 Perugia (Italy)
 Phone: +39 075 5842748
 Fax: +39 075 5842796
 E-mail: beach2010@ppg1.infn.it
 Web: www.ppg.infn.it/beach2010/

Sponsor:
 Maria Pizzini, Maria Biondi

Technical Assistance:
 Felicia Mariani, Maria Pizzini



Gagan Mohanty
Tata Institute (TIFR), India

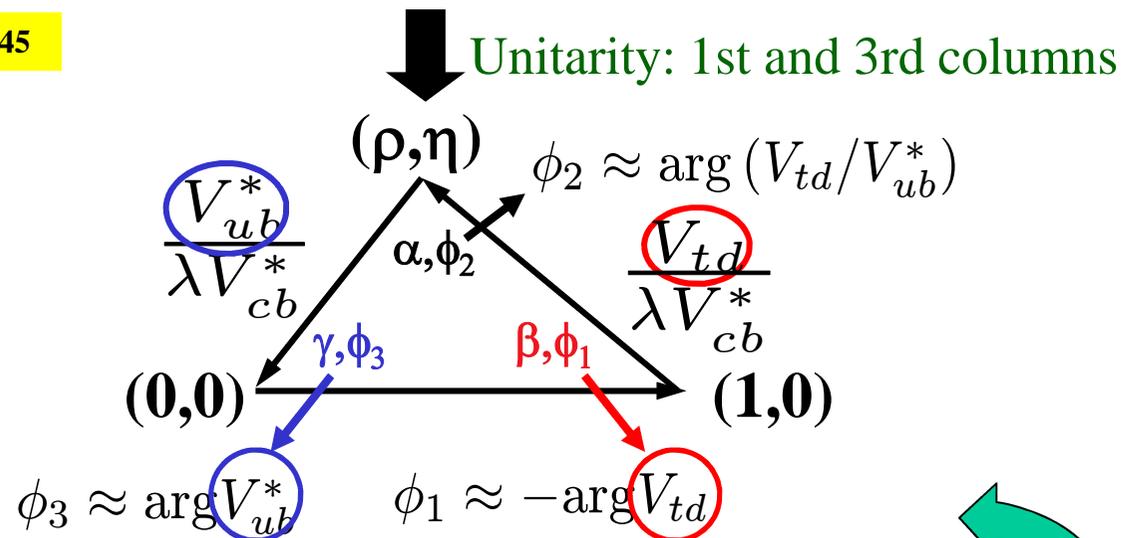
CP violation in the SM

- Single phase in the CKM matrix (**flavor** → **mass**) is the key piece

$$V = \begin{pmatrix} V_{ud} = 1 - \frac{1}{2}\lambda^2 & V_{us} = \lambda & V_{ub} = A\lambda^3(\rho - i\eta) \\ V_{cd} = -\lambda & V_{cs} = 1 - \frac{1}{2}\lambda^2 & V_{cb} = A\lambda^2 \\ V_{td} = A\lambda^3(1 - \rho - i\eta) & V_{ts} = -A\lambda^2 & V_{tb} = 1 \end{pmatrix} + \mathcal{O}(\lambda^4)$$

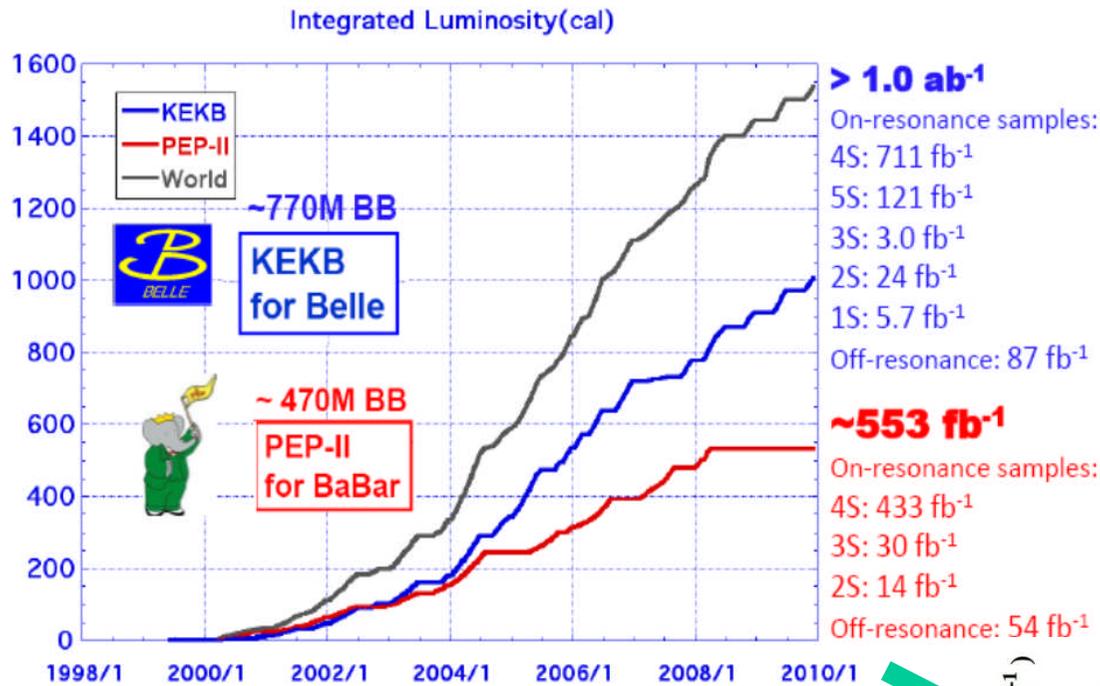
Wolfenstein, PRL 51 (1983) 1945

$\lambda \sim 0.22$	$A \sim 0.80$
$\rho \sim 0.16$	$\eta \sim 0.34$



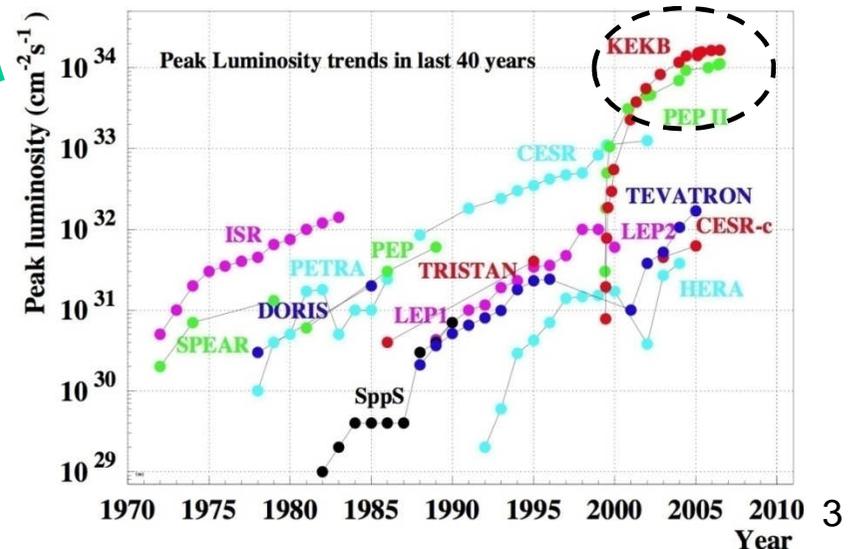
- Check consistency of the CKM framework:
 - measure three angles and two sides of the UT
 - search for potential new physics contributions

A tale of two experiments

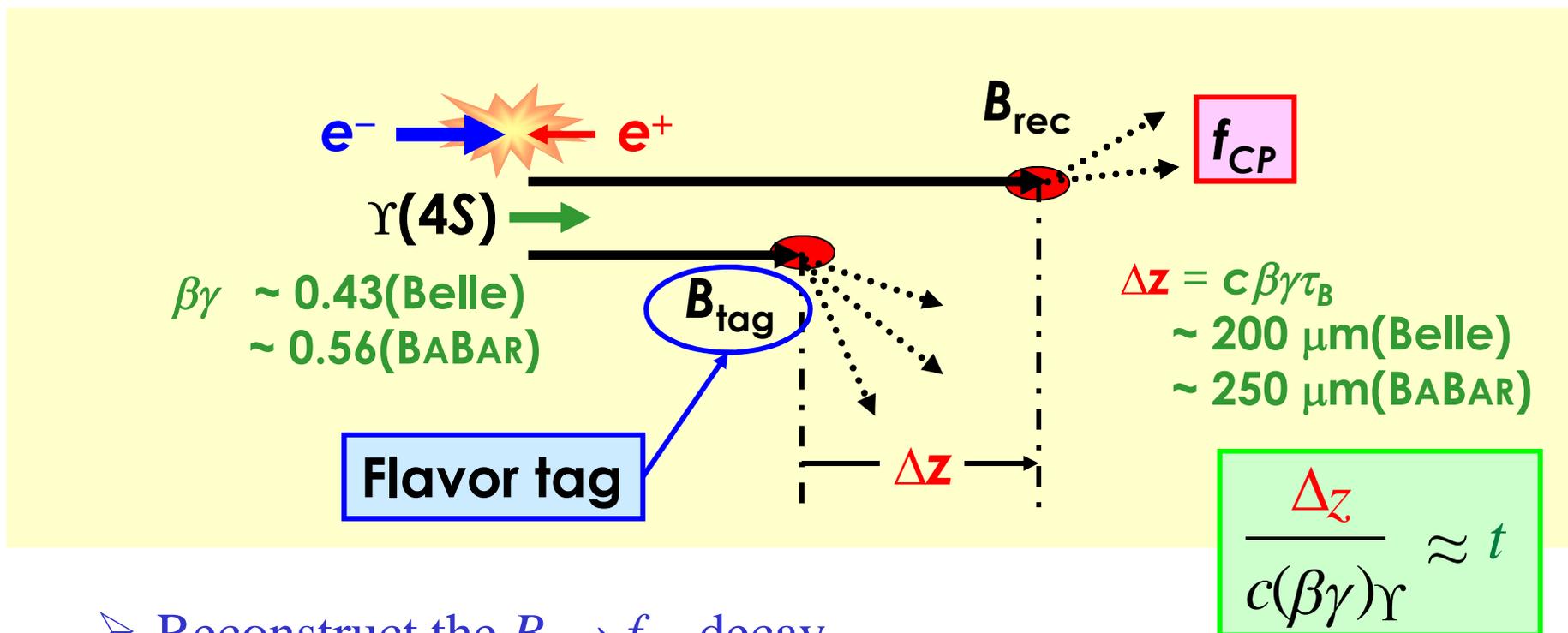


- Belle and BABAR have together collected over 10^9 $B\bar{B}$ pairs:
 - ✓ Test the SM mechanism for CP violation
 - ✓ Explore rare B decays; a window to new physics

- Right plot compares the peak luminosity performance of KEKB and PEP-II with rest



Principle of measurement



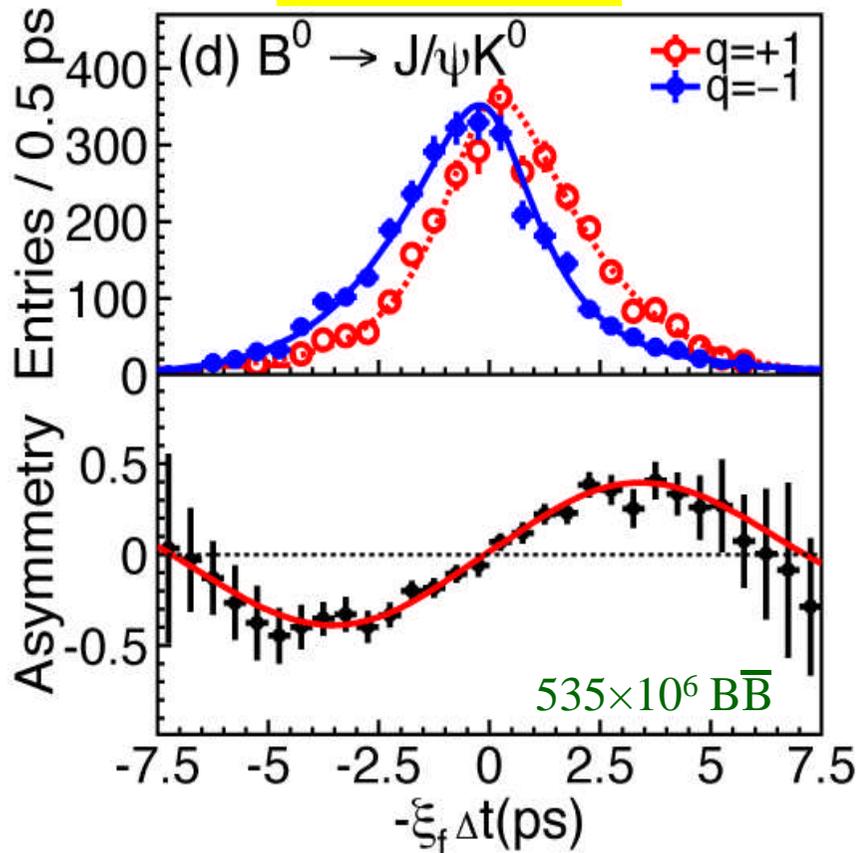
- Reconstruct the $B \rightarrow f_{CP}$ decay
- Measure proper time difference (t) and find the flavor of B_{tag}
- Evaluate
$$A_{CP}(t) = \frac{N[\bar{B}^0(t) \rightarrow f_{CP}] - N[B^0(t) \rightarrow f_{CP}]}{N[\bar{B}^0(t) \rightarrow f_{CP}] + N[B^0(t) \rightarrow f_{CP}]}$$

$$S_f \sin(\Delta mt) + A_f \cos(\Delta mt)$$

$\sin 2\phi_1$ with charmonium+ K^0 modes



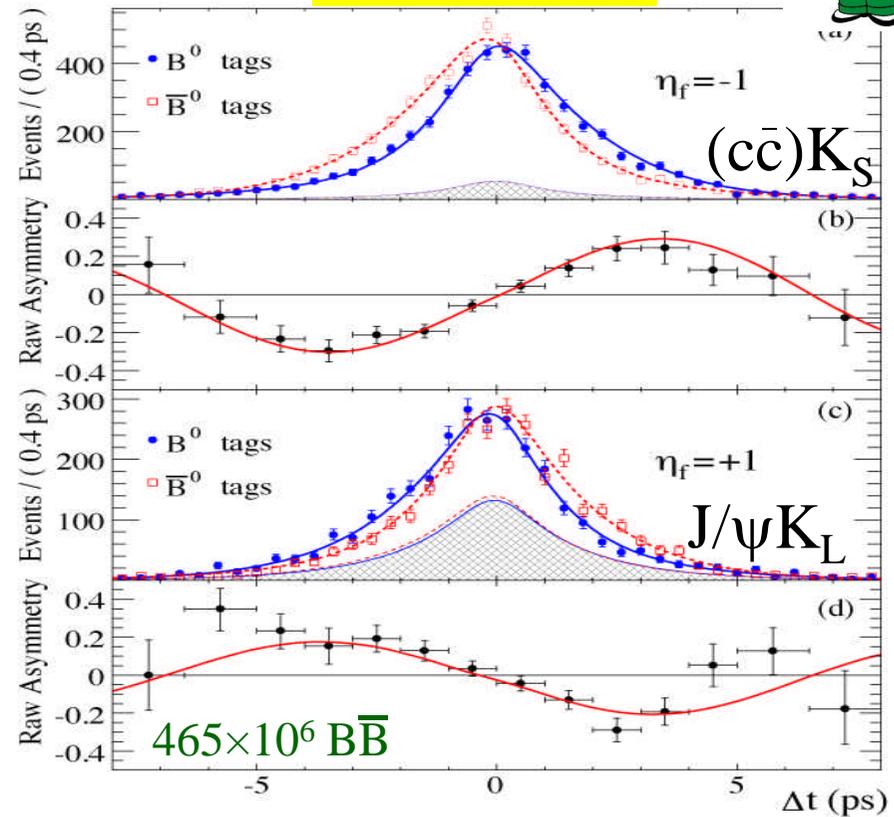
PRL 98 (2007) 031802



$$S_f = \sin(2\phi_1) = 0.642 \pm 0.031 \pm 0.017$$

$$A_f = 0.018 \pm 0.021 \pm 0.014$$

PRD 79 (2009) 072009



$$\sin(2\phi_1) = 0.687 \pm 0.028 \pm 0.012$$

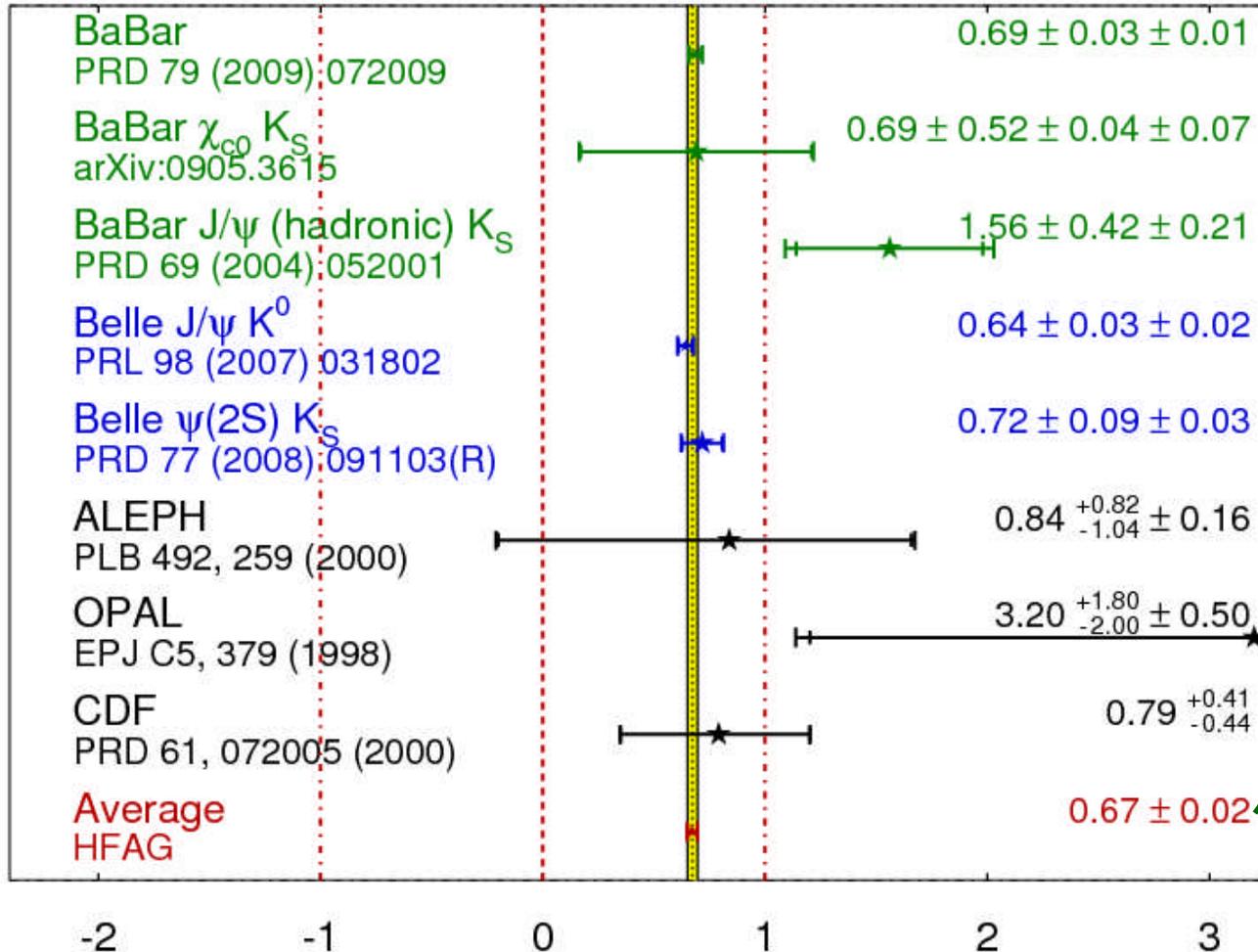
$$A_f = -0.024 \pm 0.020 \pm 0.016$$



Standard candle

$$\sin(2\beta) \equiv \sin(2\phi_1)$$

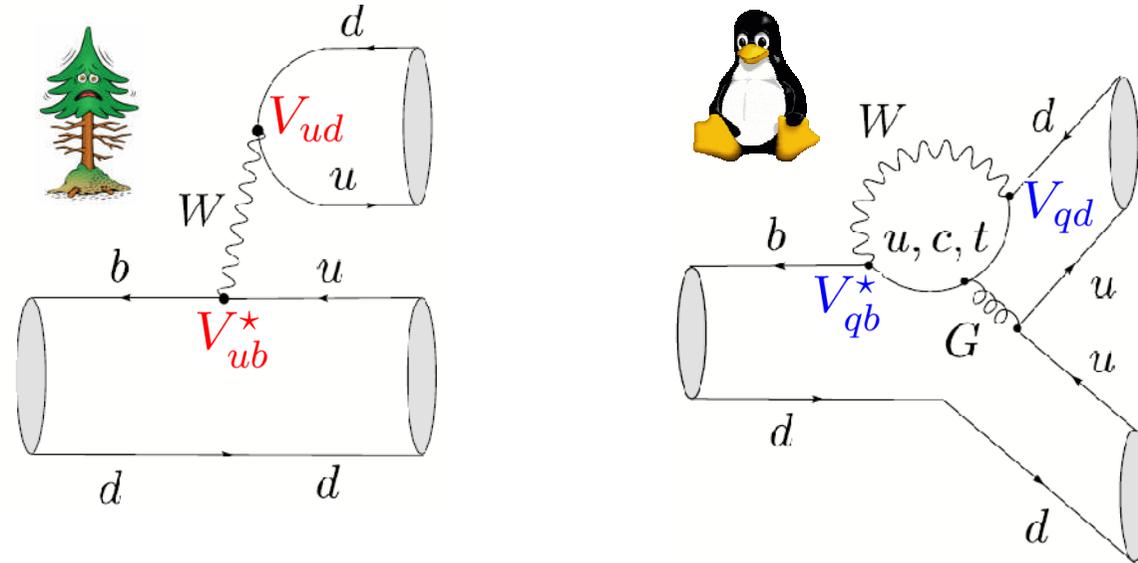
HFAG
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See the transition:
LEP → Tevatron →
B factories

Entered the precision
phase: 3% uncertainty

The second UT angle: ϕ_2



- Tree-level $b \rightarrow u\bar{u}d$ transitions are sensitive to ϕ_2
 - $B^0 \rightarrow \pi^+\pi^-, (\rho\pi)^0, \rho^+\rho^-$ and so on..
- Possible penguin amplitudes also contribute, leading to

$$A_f \neq 0 \quad \text{and} \quad S_f = \sqrt{1 - A_f^2} \sin(2\phi_2^{\text{eff}})$$

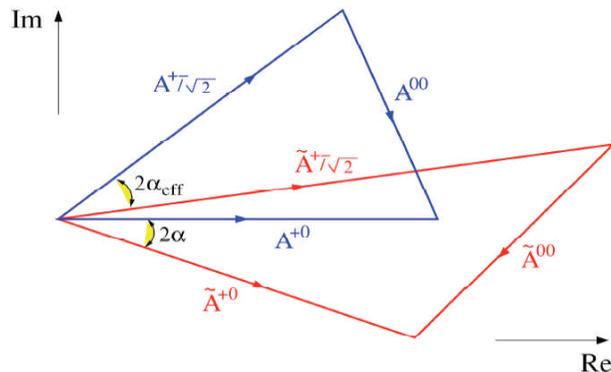
Error shrinks day-by-day

- Almost a precision measurement

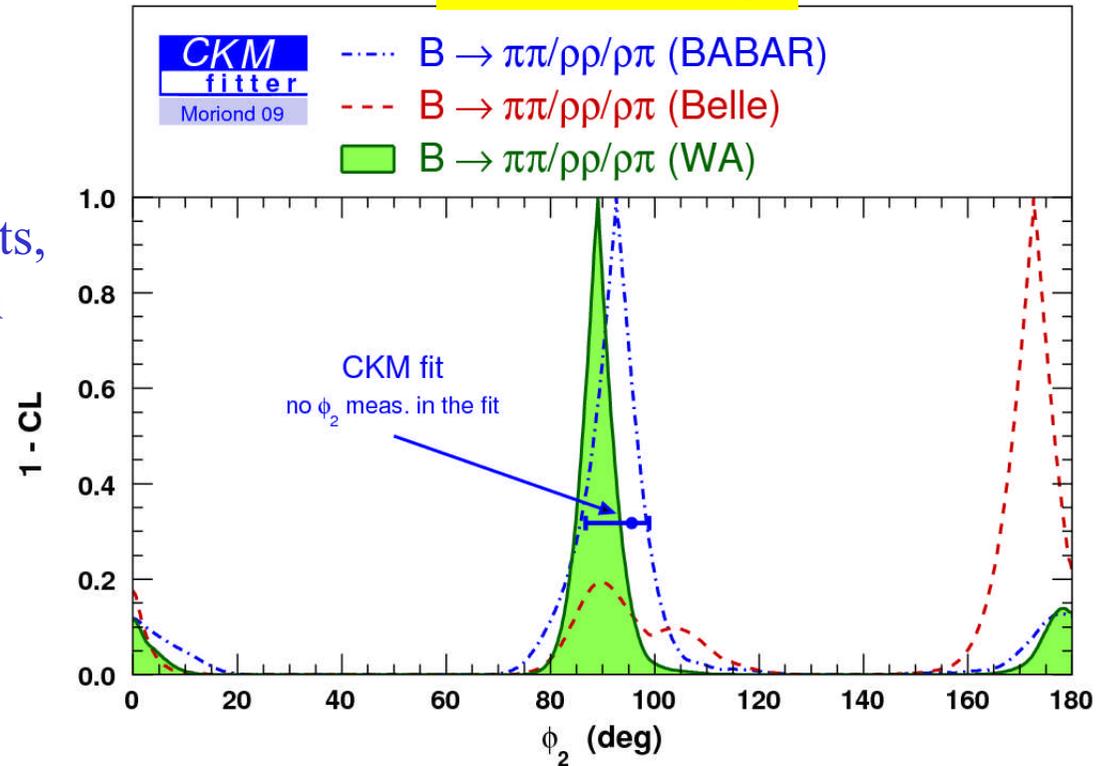
$$\phi_2 = (89.0^{+4.4}_{-4.2})^\circ$$

- Dominated by the $B \rightarrow \rho\rho$ results, that rely on the isospin relation

Gronau & London, PRL 65 (1990) 3381



Current world-average



- New measured BF of $B^+ \rightarrow \rho^+ \rho^0$ has stretched the base of the two isospin triangles, making them degenerate

PRL 102 (2009) 141802



- ❖ Belle's final results on $B \rightarrow \rho\rho$, especially $B^+ \rightarrow \rho^+ \rho^0$, are eagerly awaited for

What about ϕ_3 ?

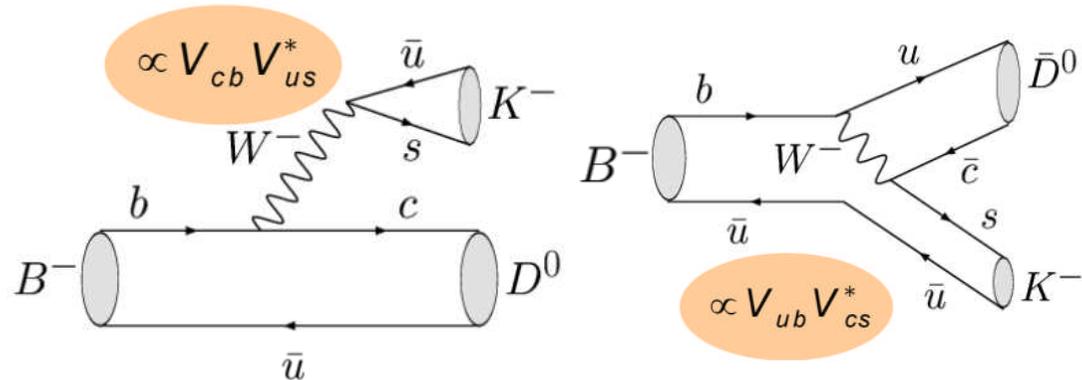
➤ Various methods proposed: Gronau-London-Wyler **PLB 253 (1991) 483** **PLB 265 (1991) 172**

Atwood-Dunietz-Soni **PRL 78 (1997) 3257** **PRD 63 (2001) 036005** Giri-Grossman-Soffer-Zupan **PRD 68 (2003) 054018**

➤ Basic strategy is to exploit the interference between two contributing amplitudes

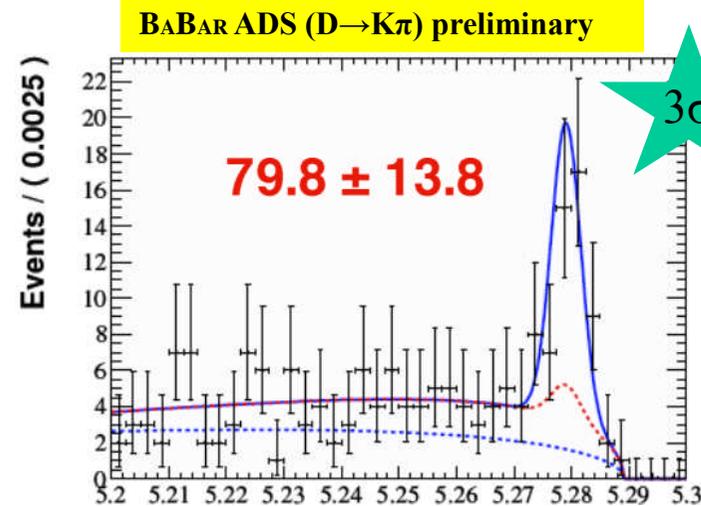
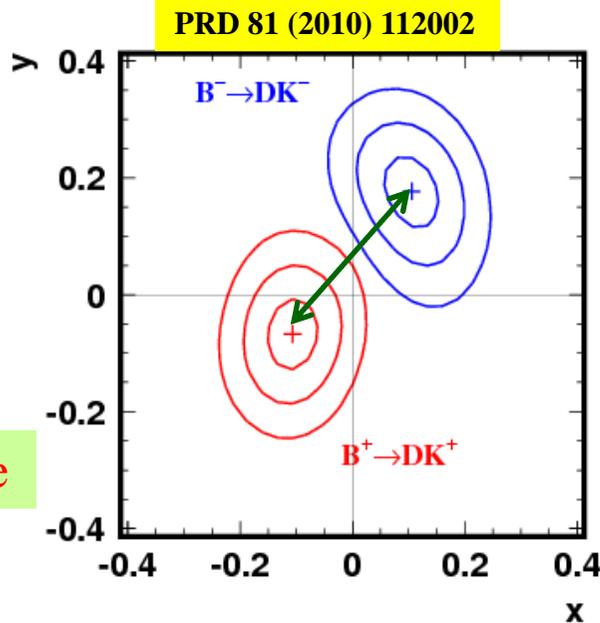
➤ Main bottle-neck: **small signal**

➤ Now, seems like beginning of an end?



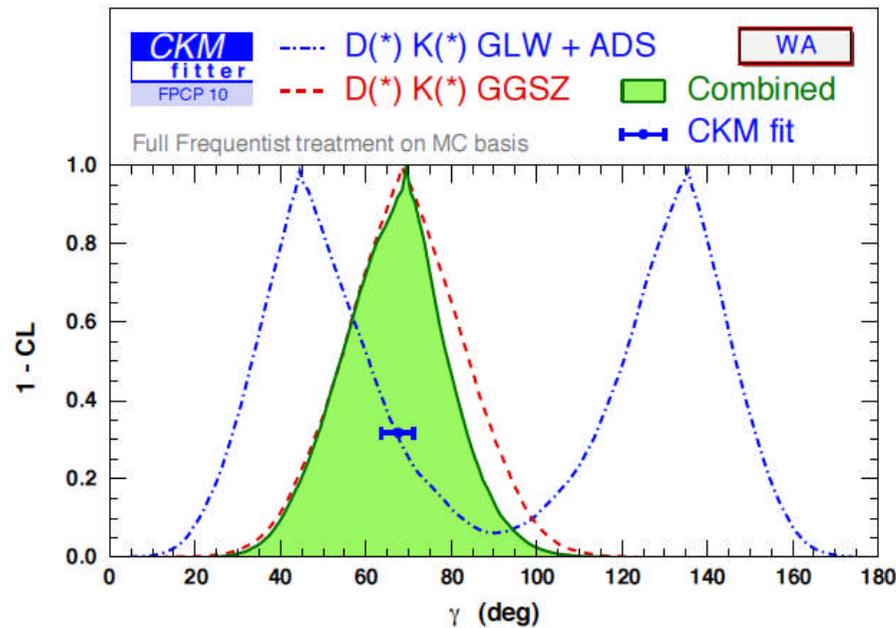
$\mathbf{x}_{\pm} = r_{\pm} \cos(\pm\phi_3 + \delta)$
 $\mathbf{y}_{\pm} = r_{\pm} \sin(\pm\phi_3 + \delta)$,
 r is the ratio of two amplitudes, δ is the strong phase diff. between them

3.5 σ evidence

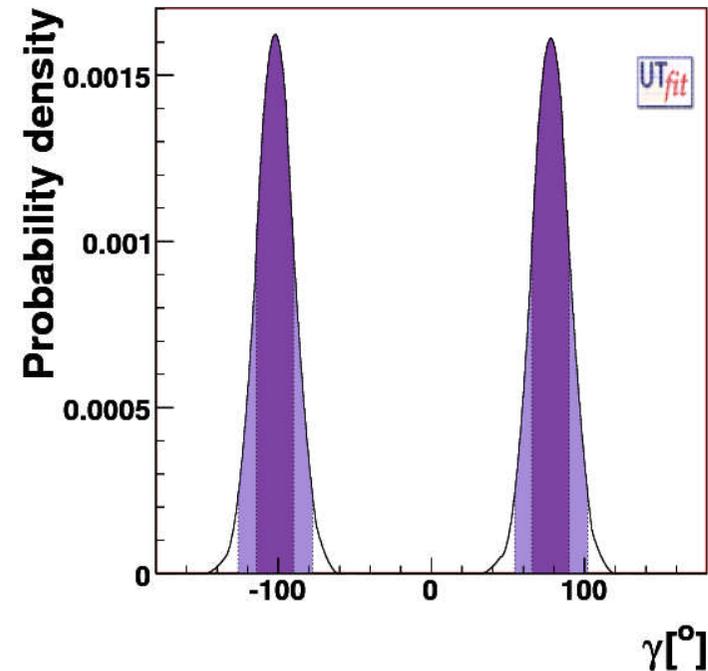


Putting everything together

Frequentist



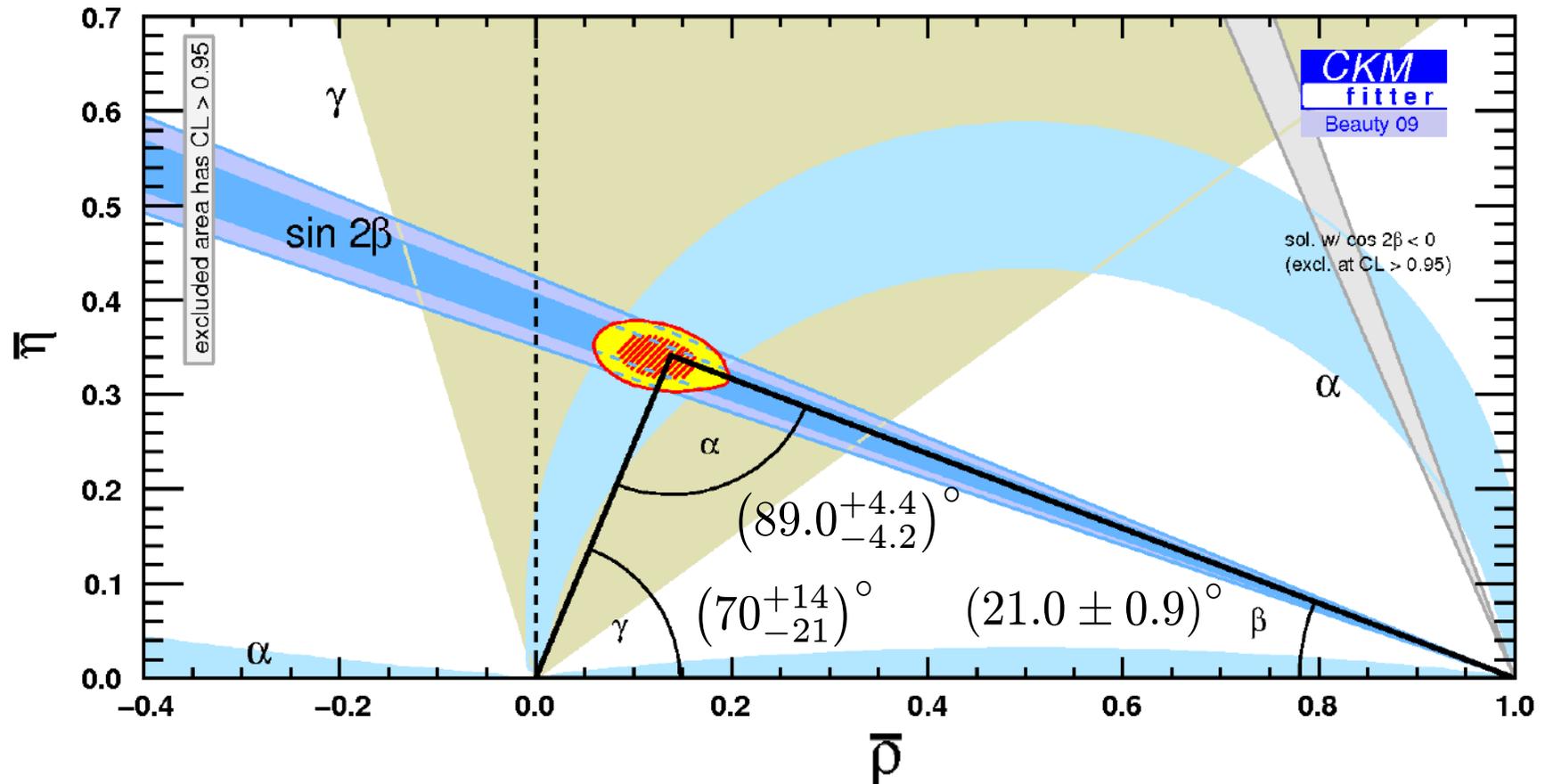
Bayesian



- Measurement: $\phi_3 = (70_{-21}^{+14})^\circ$ frequentist vs. $\phi_3 = (74 \pm 11)^\circ$ Bayesian
- Fit prediction: $\phi_3 = (67.7_{-4.1}^{+3.6})^\circ$ frequentist vs. $\phi_3 = (69.6 \pm 3.0)^\circ$ Bayesian

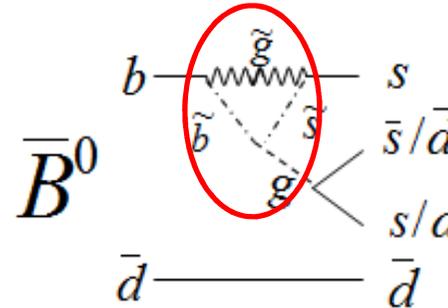
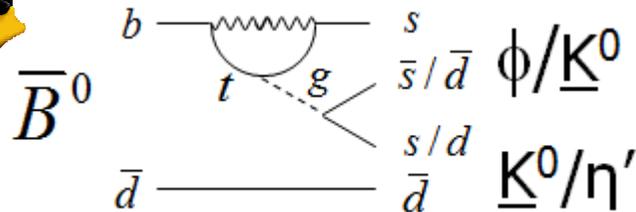
❖ Need a better precision of the measurement

Current world average



- As far as φ_3 is concerned, it is fair to say that we have made a head-start
- ❑ Final word will come from LHCb and (future) super flavor factories
- ✓ The latter would further improve the measurements of φ_1 and φ_2 too

Probing new physics in CP violation

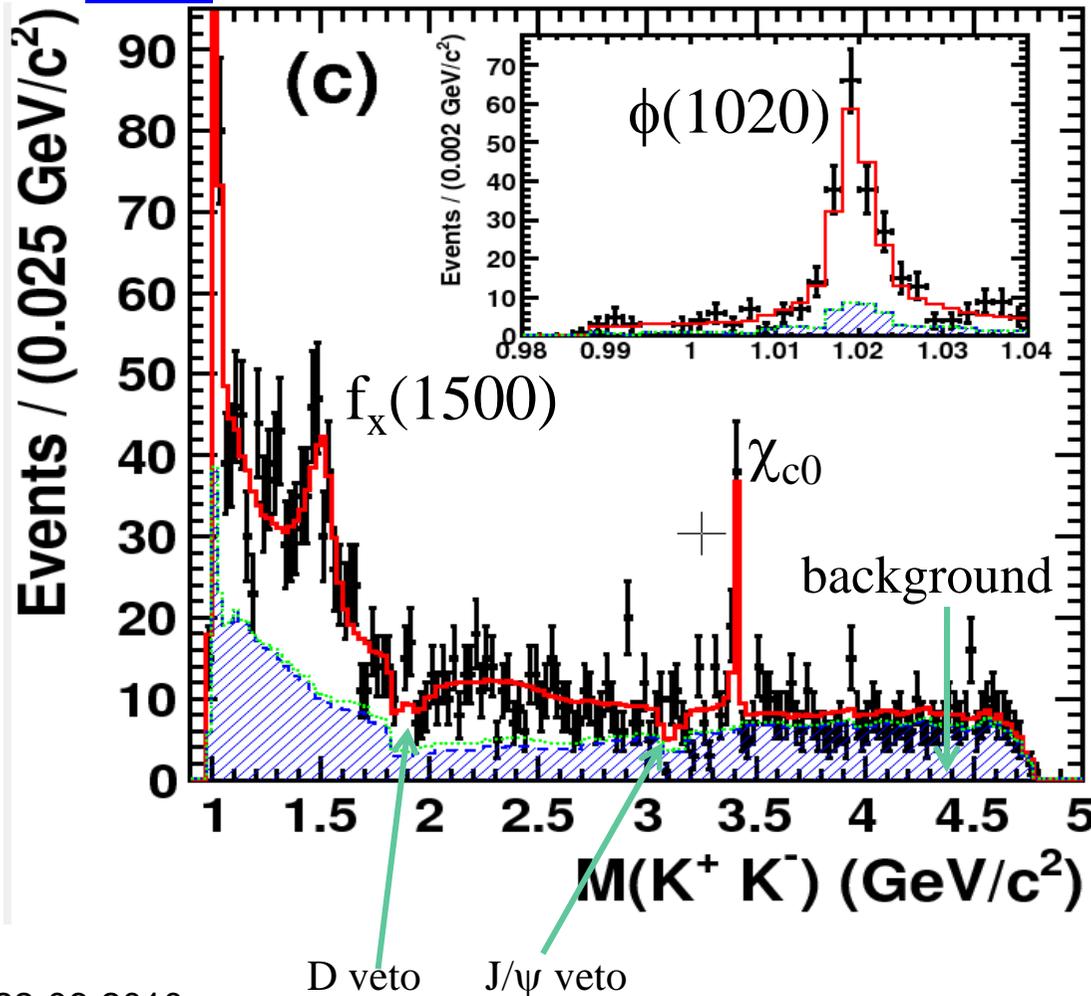


- Study of CP violation in decays dominated by the penguin diagram, e.g., $B^0 \rightarrow \phi K_S$, constitutes an ideal probe
 - ❑ Potential new physics effects, such as SUSY (right plot)
- Compare the measured CP parameters S_f and A_f with that obtained from the charmonium+ K^0 modes: **standard candle**

Dalitz-plot analysis of $B^0 \rightarrow K_S K^+ K^-$



Solution 1



- Perform time-dependent CP violation study of the $B^0 \rightarrow K_S K^+ K^-$ Dalitz plot
- Measure $(\phi_1)^{\text{eff}}$ without trigonometric ambiguity
- Need to handle the issue of multiple solutions
- We have used results of the $B^+ \rightarrow K^+ K^- K^+$ Dalitz plot to determine the best solution

Combined results in $B \rightarrow \phi K_S$ and $f_0(980)K_S$



$657 \times 10^6 B\bar{B}$

To be submitted to PRD

	Solution 1
$A_{CP}(f_0 K_S^0)$	$-0.30 \pm 0.29 \pm 0.11 \pm 0.09$
$\phi_1^{\text{eff}}(f_0 K_S^0)$	$(31.3 \pm 9.0 \pm 3.4 \pm 4.0)^\circ$
$A_{CP}(\phi K_S^0)$	$+0.04 \pm 0.20 \pm 0.10 \pm 0.02$
$\phi_1^{\text{eff}}(\phi K_S^0)$	$(32.2 \pm 9.0 \pm 2.6 \pm 1.4)^\circ$

third error: Dalitz-plot model uncertainty

arXiv:0808.0700 [hep-ex]

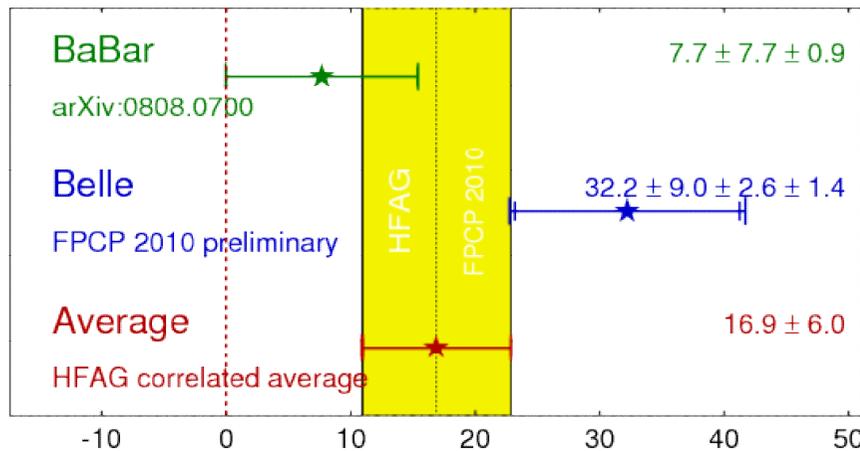
Name	Solution (1)
1 $A_{CP}(\phi K_S^0)$	$0.14 \pm 0.19 \pm 0.02$
2 $\beta_{\text{eff}}(\phi K_S^0)$	$(7.7 \pm 7.7 \pm 0.9)^\circ$
3 $A_{CP}(f_0 K_S^0)$	$0.01 \pm 0.26 \pm 0.07$
4 $\beta_{\text{eff}}(f_0 K_S^0)$	$(8.5 \pm 7.5 \pm 1.8)^\circ$



$465 \times 10^6 B\bar{B}$

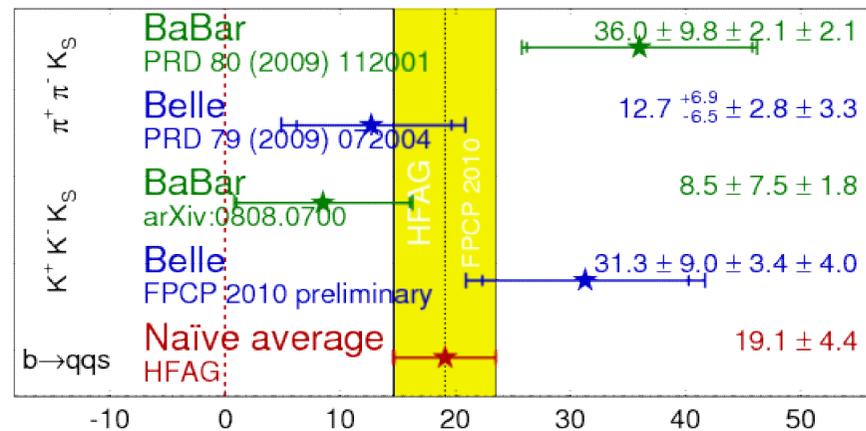
$K^+ K^- K_S \beta(\phi K_S)$

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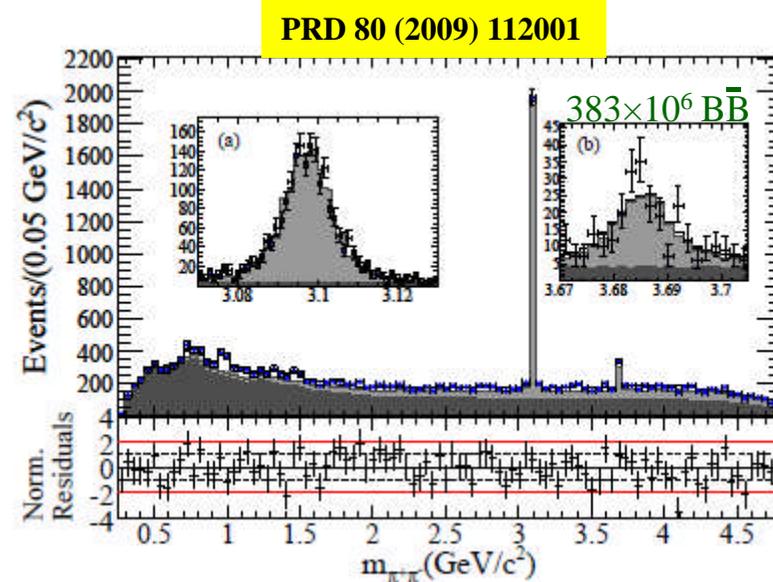
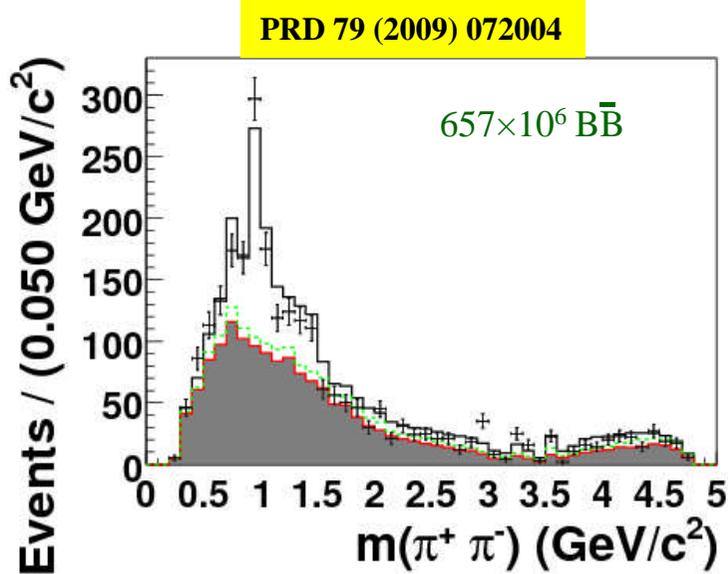
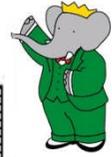
Merged $b \rightarrow qqs \beta(f_0 K_S)$

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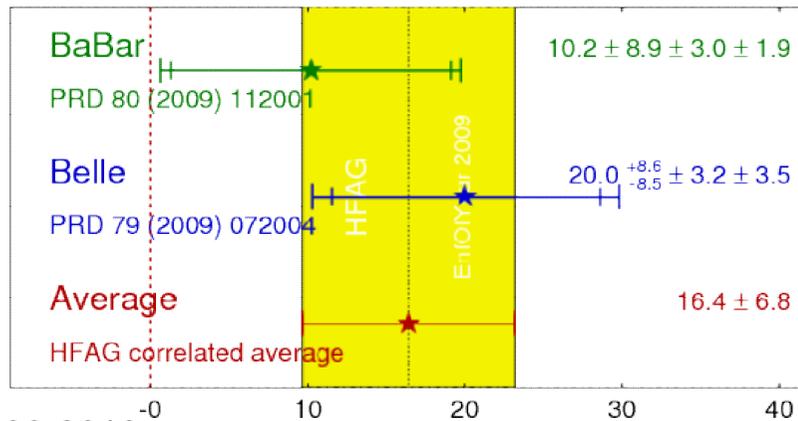


➤ Consistent with SM predictions at the current sensitivity

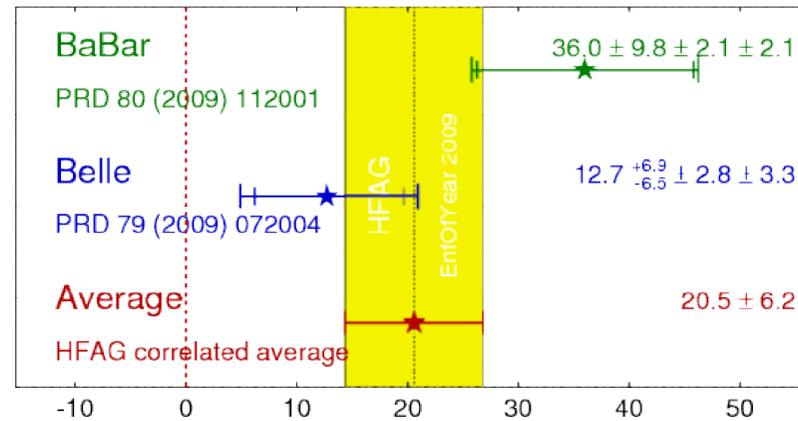
CPV results from $B^0 \rightarrow K_S \pi^+ \pi^-$



$\pi^+ \pi^- K_S \beta(\rho K_S)$ **HFAG**
 EntOfYear 2009
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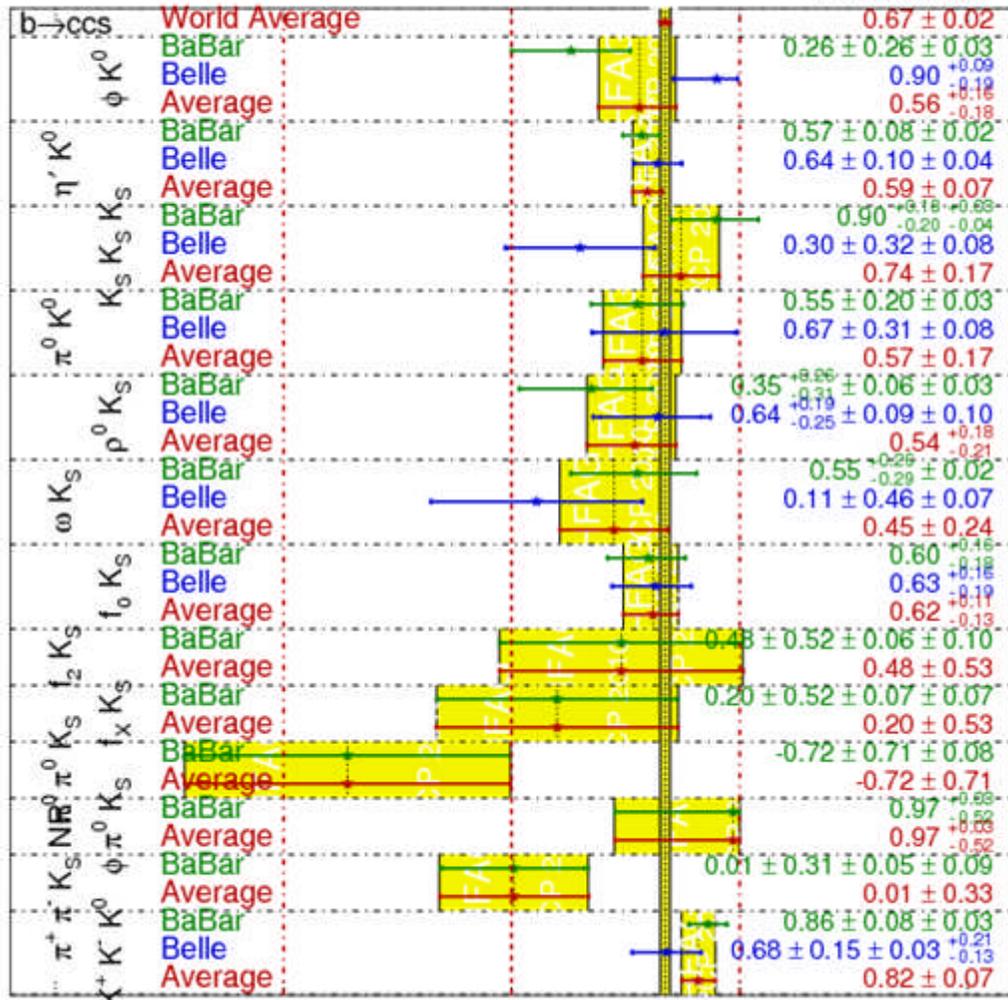
$\pi^+ \pi^- K_S \beta(f_0 K_S)$ **HFAG**
 EntOfYear 2009
 PRELIMINARY



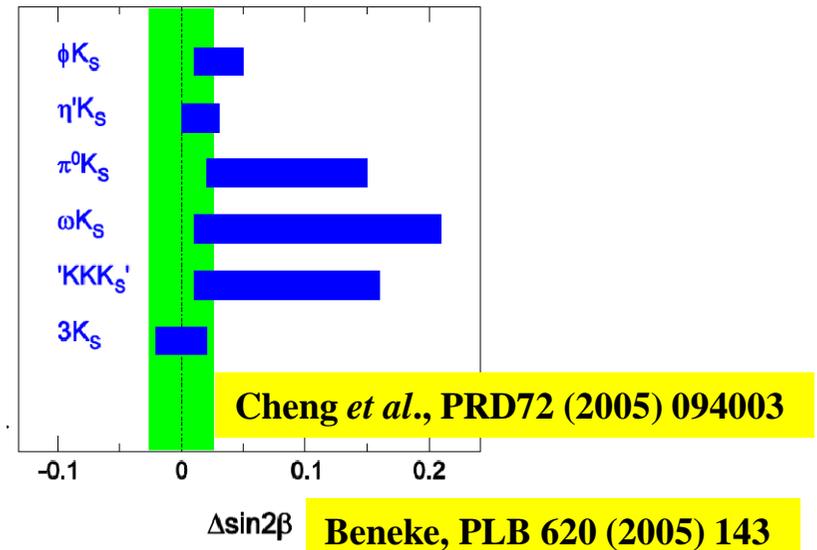
Compilation of effective $\sin 2\phi_1$

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

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- Precision is limited by the statistics
- To obtain sensitivities at 1% level, we need $O(50 \text{ ab}^{-1})$ of integrated luminosity
- One can then compare with theory uncertainty

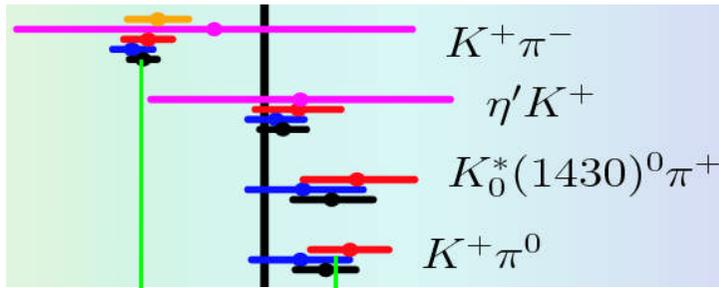


Williamson & Zupan, PRD 74 (2006) 014003



Nature 452 (2008) 332

Direct CP violation



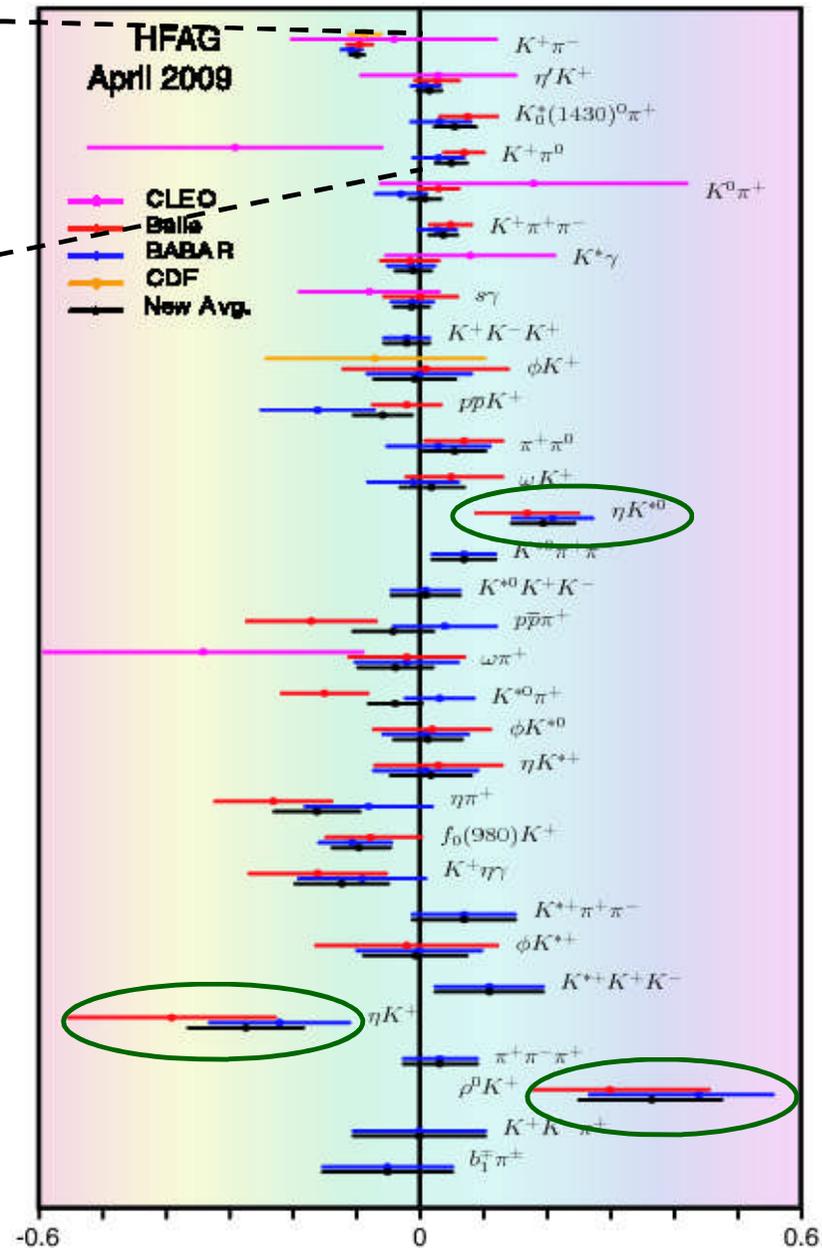
$$\Delta A_{K\pi} = A_{CP}(K^+\pi^0) - A_{CP}(K^+\pi^-) = +0.144 \pm 0.029$$

- Both decay channels occur via the same diagrams at tree level $\rightarrow \Delta A_{K\pi}$ should be zero
- Possible interpretation within the SM and with new physics
- ✓ Precise measurement of the $K^0\pi^0$ mode will be useful to check isospin relation

Gronau, PLB 627 (2005) 82

- Interesting $\sim 3\sigma$ evidences found:
 $B^0 \rightarrow \eta K^{*0}$, $B^+ \rightarrow \eta K^+$ and $\rho^0 K^+$ (circled)
 $B^0 \rightarrow \rho^+ \pi^-$ and $B^+ \rightarrow D^{(*)0} K^+$

22-06-2010



Closing Remarks

- Both the B factories – Belle and BABAR – have established the CKM paradigm as the only source of CPV in the SM
- CPV content is however too little (by $\sim 10^{10}$) to explain the prevailing matter-antimatter asymmetry in our universe
- We know that something is there that we do not know fully
- There are a number of intriguing hints
 - $\sin(2\phi_1)^{\text{eff}}$ in some penguin dominated decays
 - Direct CP asymmetry difference ($\Delta A_{K\pi}$)
 - ...
- Look forward to the final updates from Belle (more data and improved tracking software), while warming up to the next generation experiments  LHCb and super flavor factories