Measuring the angle β at a Super B factory

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SuperB

5th Super B Workshop

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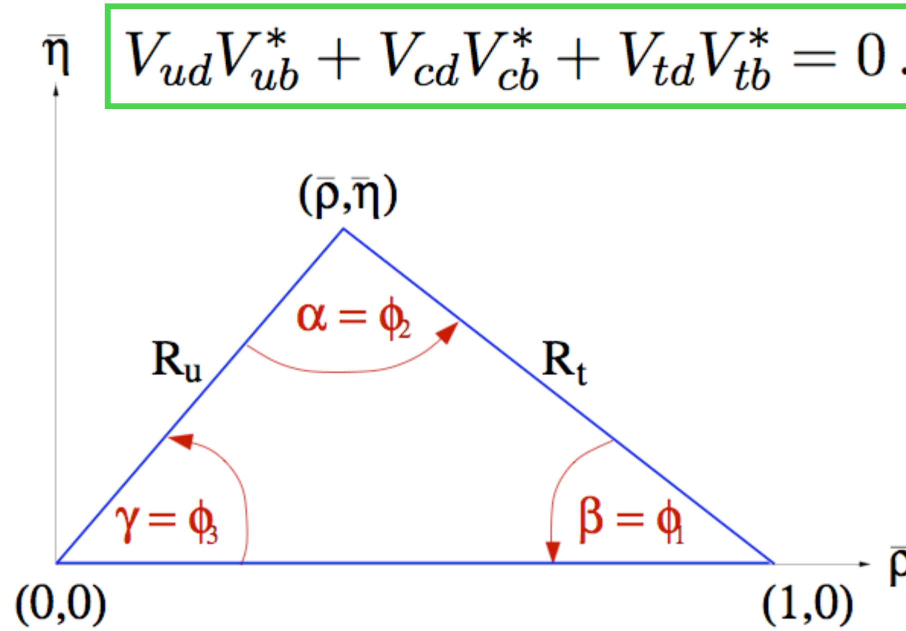
Overview

- Measurements of sin2β, cos2β, and limits on β from :
  - β from charmonium,
  - 'Complementary measurements' of β from 'open-charm' and other charmonium,
  - 'alternative measurements' of β from penguins.

and extrapolation to higher luminosities.

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



$$\beta \equiv \phi_1 = \arg\left[-\frac{V_{cd}V_{cb}^{*}}{V_{td}V_{tb}^{*}}\right]$$

Many ways to measure sin2b and cos2b

(More details in following slides ...)

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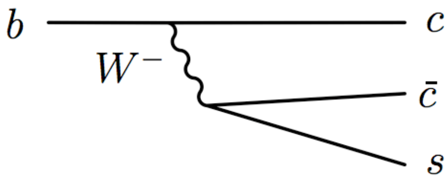
$b \rightarrow c\bar{c}s$

charmonium



$$J/\psi K_S, \psi(2S)K_S, \chi_{c1}K_S$$
$$\eta_c K_S, J/\psi K_L$$
$$J/\psi K^{*0}(K_S\pi^0)$$

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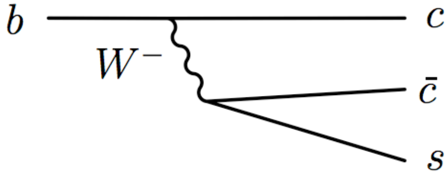

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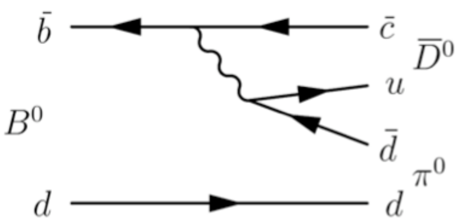
Color-suppressed $b \to c\bar{u}d$



$D^{(*)0}{}_{CP}h^0, D^{(*)}h^0,$

latter with $D \to K_S\pi^+\pi^-$

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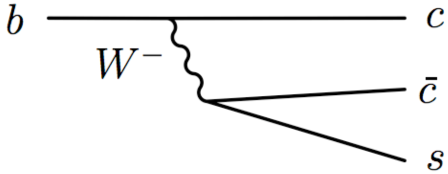

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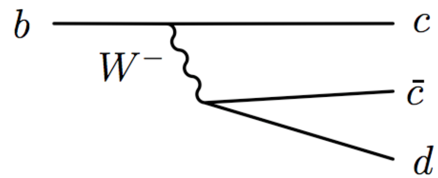
$b \to c\bar{c}d$ charm or charmonium



$D^{(*)+}D^{(*)-}, \ J/\psi\pi^0$

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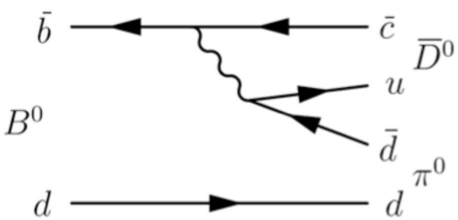

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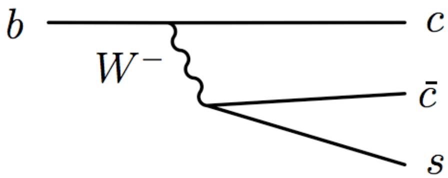

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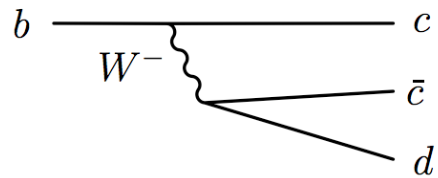
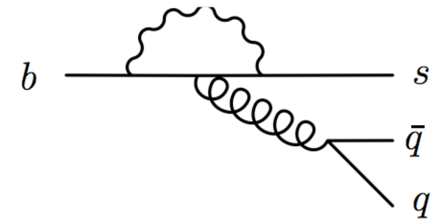


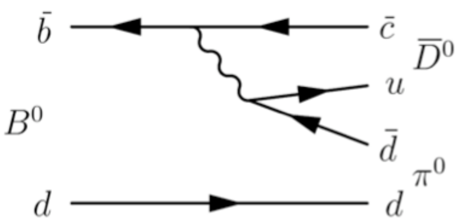
$D^{(*)+}D^{(*)-}, \; J/\psi\pi^0$

$b \to s\bar{s}s$ & $b \to s\bar{d}d$
penguin dominated



$\phi K_S, K^+K^-K^0,$
$K_S K_S K_S, \eta' K_S, K_S\pi^0,$
$\omega K_S, f_0 K_S$

Color-suppressed $b \to c\bar{u}d$



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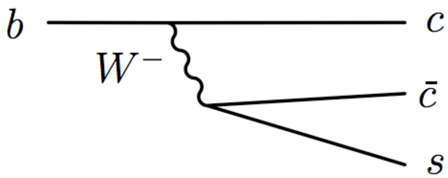

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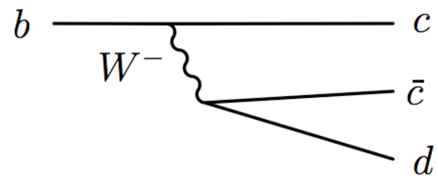

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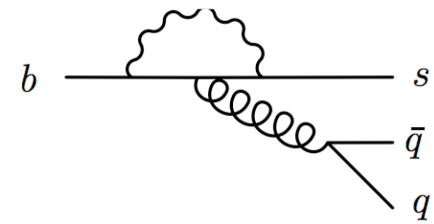
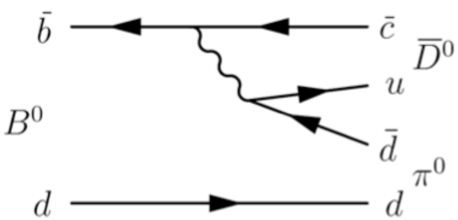


$\phi K_S, K^+K^-K^0,$
$K_SK_SK_S, \eta' K_S, K_S\pi^0,$
$\omega K_S, f_0K_S$

Color-suppressed $b \to c\bar{u}d$



$D^{(*)0}{}_{CP}h^0, D^{(*)}h^0,$

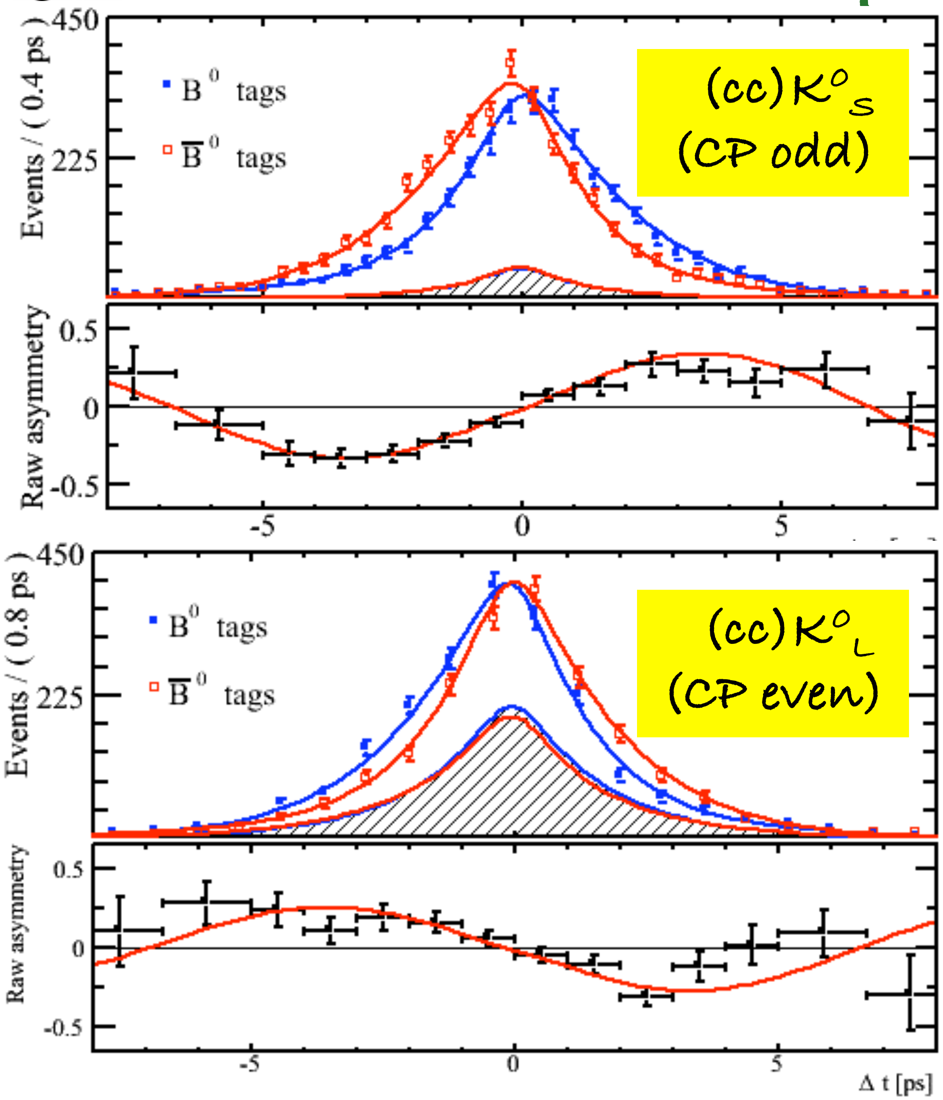
latter with $D \to K_S\pi^+\pi^-$

Increasing sensitivity to new physics

Increasing tree diagram contribution

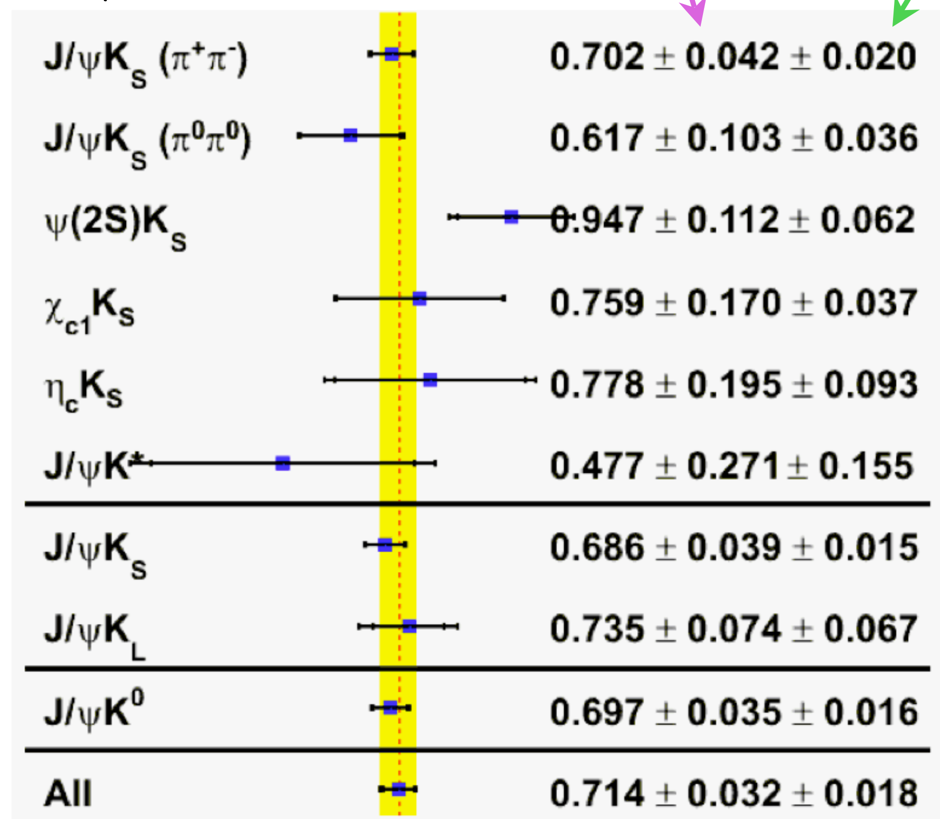
sin2β from b→ccs decays

Sin2b from b→ccs



- BaBar, 383 M BB pairs.
- hep-ex/0703021, submitted to PRL.

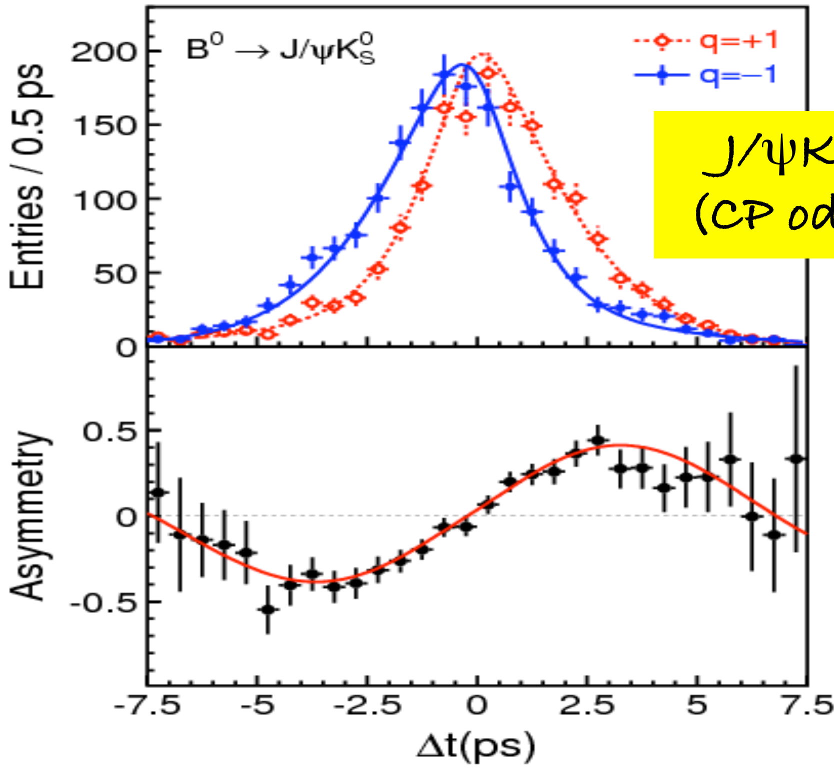
stat. syst.

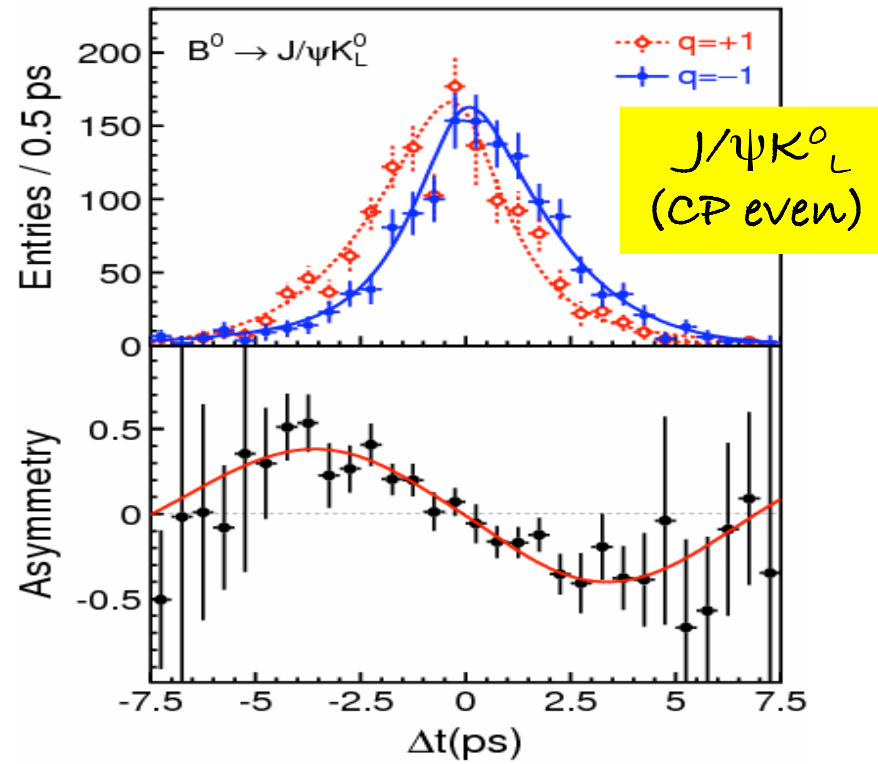


- Now with systematics for each golden mode separately, J/ψK^0_S and J/ψ K^0 modes.
- Also |λ| measurements - see backup slides.

Sin2β from b→ccs

- Belle, 535 M BB pairs. PRL 98 (2007) 031802)





- $J/\psi K^0_S$ only

$\sin 2\phi_1 = +0.643 \pm 0.038_{total}$

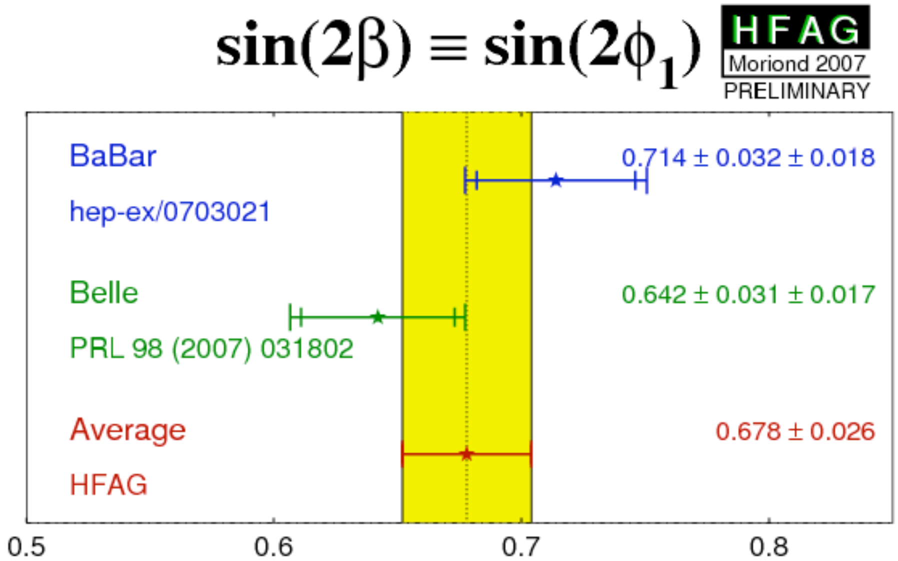
$A = -0.001 \pm 0.028_{total}$

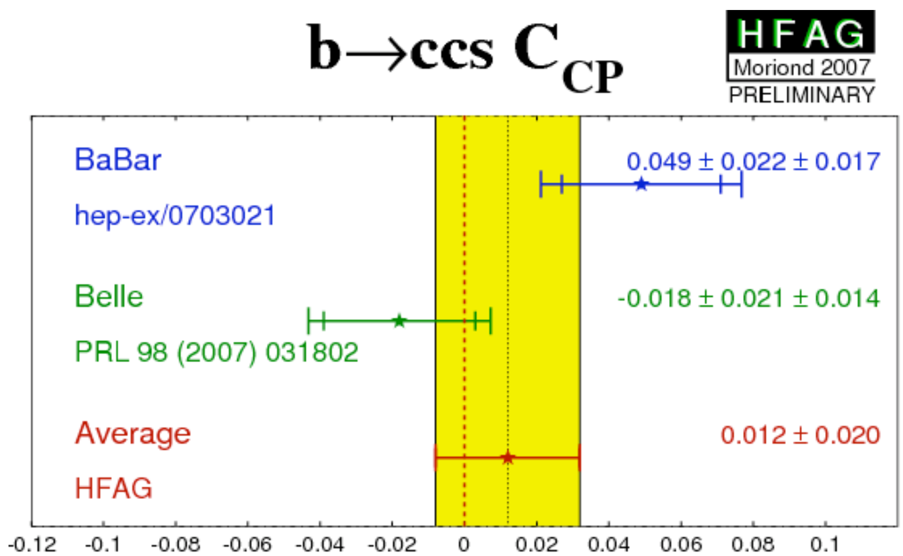
- $J/\psi K^0_L$ only

$\sin 2\phi_1 = +0.641 \pm 0.057_{total}$

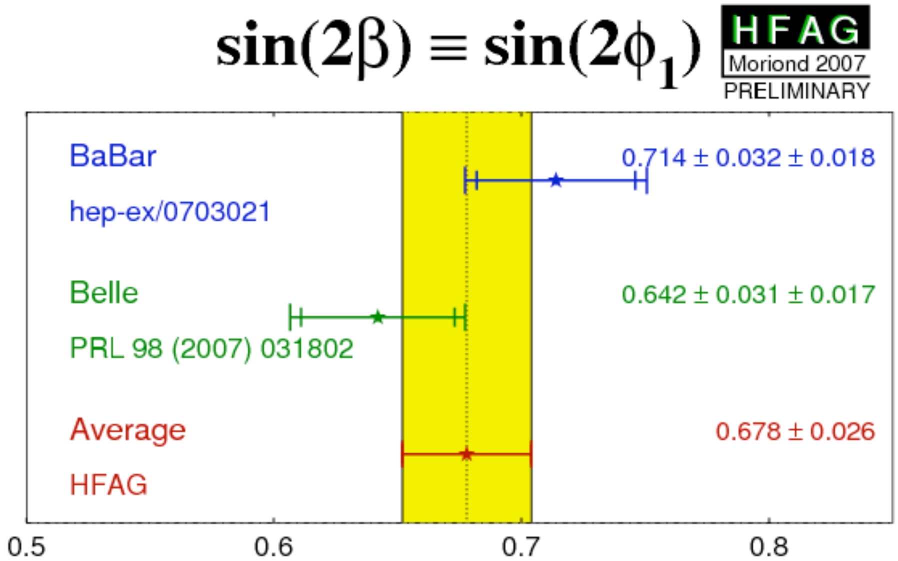
$A = -0.045 \pm 0.033_{total}$

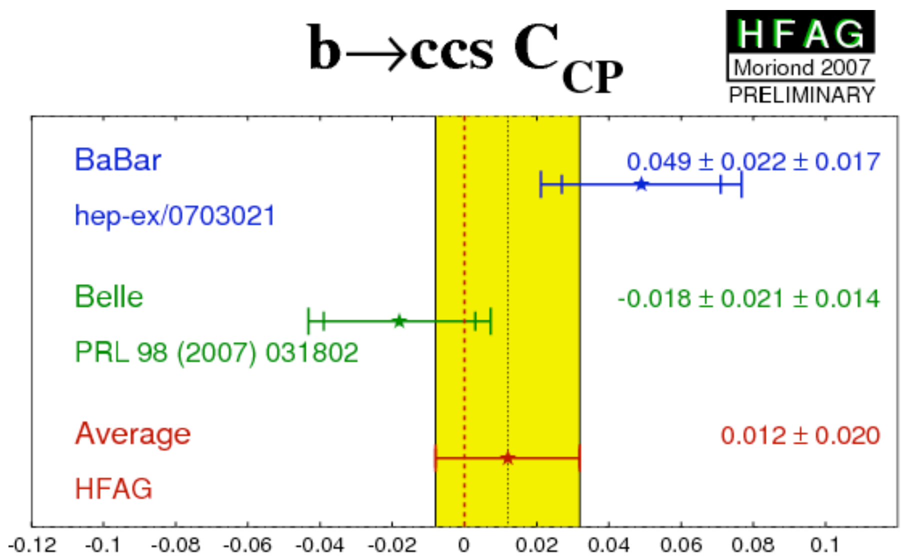
sin2β from b→ccs

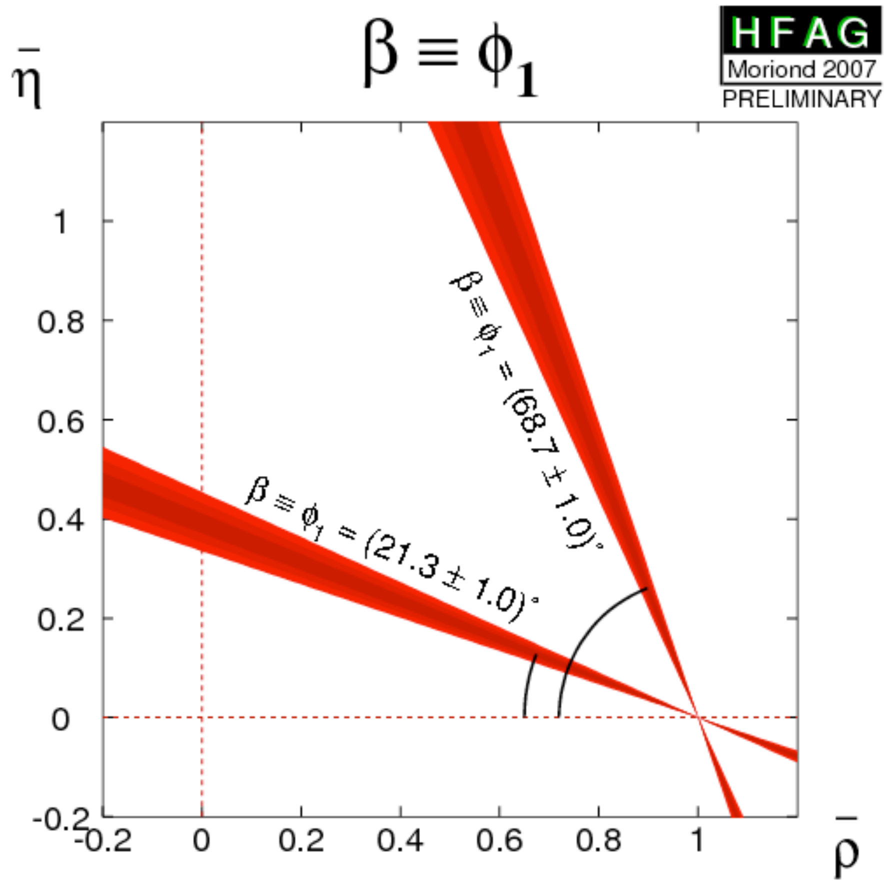




sin2β from b→ccs







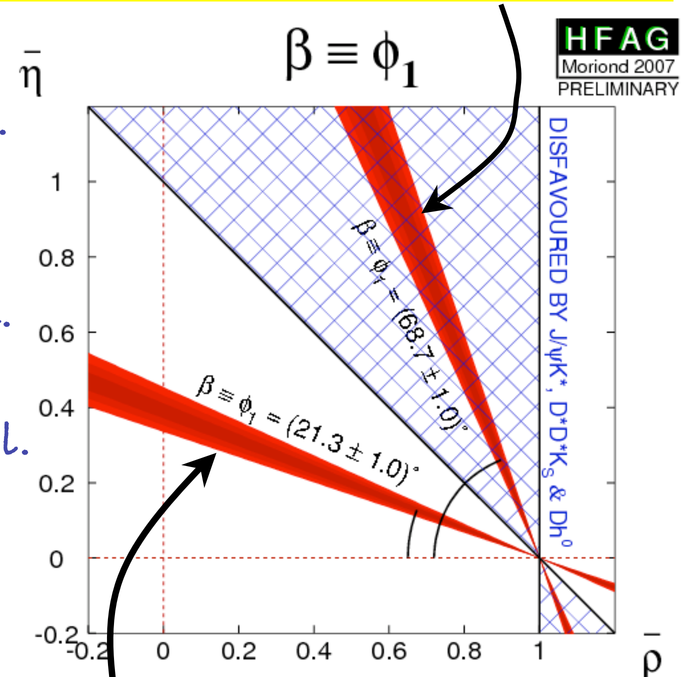
- 4 solutions for β from the b → ccs sin2β measurement

The 4-fold ambiguity in β - resolved ?

- Reduce 4-fold ambiguity to 2-fold ambiguity ($\beta \rightarrow \pi/2 - \beta$) by measuring (the sign of) cos2β. Negative cos2β ruled out by:

-ve solution, $\beta = \phi_1 = (68.7 \pm 1.0)^o$

- Time-dependent Dalitz analysis of
  - $B^0 \rightarrow D^{*+}D^{*-}K^0{}_S$
    - BaBar: PRD 74, 091101 (2006), 94% CL.
  - $B^0 \rightarrow D^0(K^0{}_S\pi^+\pi^-)h^0$
    - BaBar: hep-ex/060105, 87% CL.
    - Belle: PRL 97, 081801 (2006), 98.3% CL.
  - $B^0 \rightarrow K^+K^-K^0$
    - BaBar: 21° favoured over 69° at 4.6σ level.



- Time-dependent angular analysis of $B^0 \rightarrow J/\psi\, K^{*0}$
  - BaBar : PRD 71, 032005 (2005), 87% CL.
  - Belle : PRL 95, 091601 (2005).

+ve solution, $\beta = \phi_1 = (21.3 \pm 1.0)^o$
"Strongly favoured"

We already have a 1° measurement of β – so what next ?

- Achille's talk (yesterday), and the following talks on α and γ will talk about whether 1° measurements of these angles are possible.
  - We (β) are already there (expect <1° by the end of B-factory running)
  - Question: Why push further ?

We already have a 1° measurement of β
- why push further ?

- Answers.

We already have a 1° measurement of β – why push further ?

- Answers.
  - (a) We can – we already know how to do these measurements.
    - If nothing else its 'a <u>really dumb</u> (?) sanity check'.

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  - (b) The constraints from indirect measurements will also be very stringent.

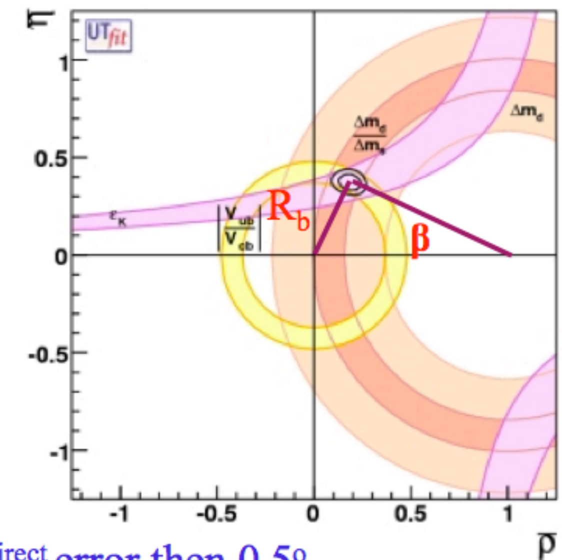
Direct measurement of Φ_d (=2β in the SM) is tested against indirect prediction which is fixed by R_b (the V_{ub}/V_{cb} side)

R_b now known to 7% from V_{ub} inclusive

→ translates into β^{indirect} of 1.6°

Compare with (Super-)LHCb ***stat*** error:

(Super-)LHCb	2 fb^{-1}	10 fb^{-1}	100 fb^{-1}
σ (stat)	0.66°	0.30°	0.09°



Looks OK… but precision on R_b will improve as lattice improves V_{ub} exclusive.
Must plan for R_b precision of ~2% → β^{indirect} error then 0.5°

Taken from Guy Wilkinson's talk at the January 2007 LHCb upgrade Workshop.

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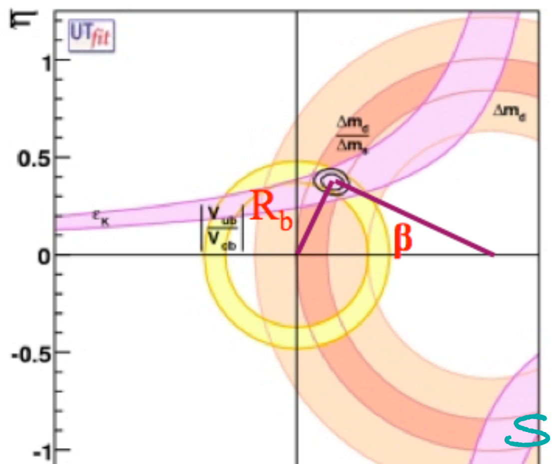

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SuperB CDR

Observable	B Factories (2 ab^{-1})	Super$B$ (75 ab^{-1})
$\|V_{cb}\|$ (exclusive)	4% (∗)	1.0% (∗)
$\|V_{cb}\|$ (inclusive)	1% (∗)	0.5% (∗)
$\|V_{ub}\|$ (exclusive)	8% (∗)	3.0% (∗)
$\|V_{ub}\|$ (inclusive)	8% (∗)	2.0% (∗)

We already have a 1° measurement of ϐ
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  - (c) Although systematics limited, improvements in detector-related systematics will benefit many other analyses.

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  - (d) It's a 'standard candle'
    - (1) Comparison with complementary measurements of β from $b \to ccd$ and $b \to cud$.
    - (2) Comparison with penguin $b \to sqq$ modes – a 'standard candle' assumes increased importance as precision on penguin β measurements increases.

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- Address (c) and (d) in later slides.
- There are others which I may have forgotten & opinion may vary as to the relative importance of the above answers.

b→ccs at higher luminosities

(Theory & controlling penguins)

systematics limited

- Expected precision for sin2b ($J/\psi K^0_S$) - CDR Table 2-1.

Observable	HFAG (~840 fb^{-1})	B Factories (2 ab^{-1})	Super$B$ (75 ab^{-1})
$\sin(2\beta)$ $(J/\psi\, K^0)$	0.026	0.018	0.005 (†)

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- Small Standard Model theoretical uncertainty...
  - $\Delta S_{J/\psi\, KS} \equiv S_{J/\psi\, KS}$ - sin2b ~O(10^{-3}). Li and Mishima. hep-ph/0610120.
  - $\Delta S_{J/\psi\, KS} \equiv S_{J/\psi\, KS}$ - sin2b ~O(10^{-4}). Boos et. al. Phys. Rev. D. 70 036006 (2006)
    - Not important for the (non-Super) & SuperB-factories.

SuperB

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    - Not important for the (non-Super) & SuperB-factories.

- Controlling our penguins with the "data-driven" method - using $J/\psi\pi^0$ to control the penguin contribution in $J/\psi K^0_S$. Ciuchini et. al. - PRL 95, 221804 (2005).
  - LHCb approach (Fleischer, Eur. Phys. J. C10 (1999) 299) is to try to measure CP asymmetries in $B^0_s \rightarrow J/\psi K^0_S$ and relate these to $B^0 \rightarrow J/\psi K^0_S$ through U-spin.
    - Precision of approach has not yet been evaluated.

Taken from Guy Wilkinson's talk at the January 2007 LHCb Upgrade Workshop.

SuperB

$b \to c\bar{c}s$ at higher luminosities

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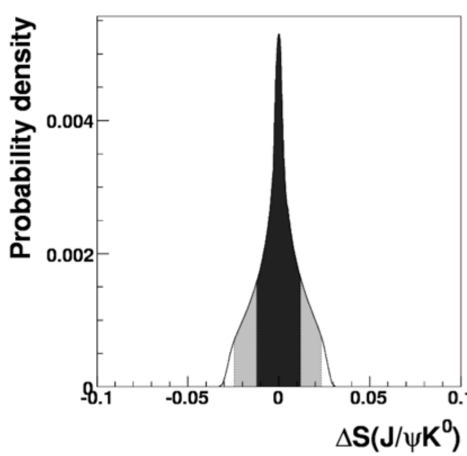
Marco Ciuchini.
4th CKM Workshop.
Nagoya, Dec. 2006.



- Using current B-Factory datasets.

$\Delta S(J/\psi K^0) = \sin2\beta_{eff} - \sin2\beta$

$= 0.000 \pm 0.012$

- Close to current systematic error.
  - Belle (535 M BB) : ± 0.018
  - BaBar (386 M BB) : ± 0.017

SuperB

b→ccs at higher luminosities

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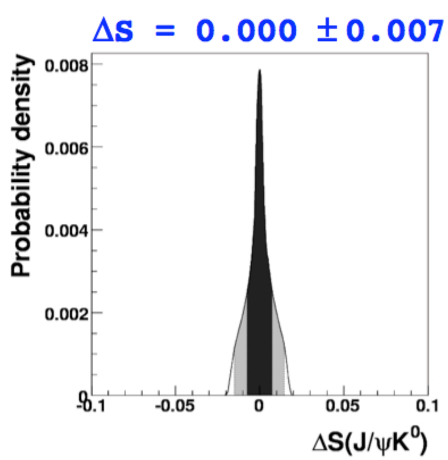


- At 2 ab^{-1} (shown).
- At 30 ab^{-1} : $\Delta S = 0.000 \pm 0.003$.
- At 75 ab^{-1} : $\Delta S = 0.000 \pm 0.00$????
  - ...but less than the ±0.005 "irreducible" systematic error.

b→ccs at higher luminosities
(Systematics - I)

Source	Irreducible	Error of $\sin 2\phi_1$
Wrong tag		0.007
Physics parameters		0.002
Vertexing	√	0.012
Background fraction		0.006
Background $\|\Delta t\|$ shape		0.001
Resolution function		0.005
Resolution parameterization	√	0.006
Tag-side interference	√	0.001
Possible fit bias		0.008
Total		0.019

Table 4.11: Systematic errors for $\sin 2\phi_1$ measured with the $J/\psi K_S$ mode at 140 fb^{-1}.

Tables taken from "Letter of Intent for KEK Super B Factory" (2004).

- KEK Super B LOI from 2004 shows irreducible systematic error contributions from:
  - Vertexing,
  - Resolution parameterisation,
  - Tag-side interference.
- Extrapolations to 50 ab^{-1} show that σ(statistical) ≈ σ(irreducible systematic)

		Statistical	Systematic		Total
			reducible	irreducible	
$\sin 2\phi_1$	(140 fb^{-1})	0.080	0.014		0.082
	(5 ab^{-1})	0.013	0.002	0.013	0.019
	(50 ab^{-1})	0.004	0.001		0.014
$\mathcal{S}_{J/\psi K_S^0}$	(140 fb^{-1})	0.080	0.014		0.082
	(5 ab^{-1})	0.013	0.002	0.014	0.019
	(50 ab^{-1})	0.004	0.001		0.015
$\mathcal{A}_{J/\psi K_S^0}$	(140 fb^{-1})	0.056	0.017		0.070
	(5 ab^{-1})	0.009	0.003	0.038	0.039
	(50 ab^{-1})	0.003	0.001		0.038

Table 4.13: Expected errors at 140 fb^{-1}, 5 ab^{-1} and 50 ab^{-1}.

Taken from the talk "$b \to c\bar{c}s$ decays at BaBar" given at 4th CKM Workshop. Nagoya, Dec. 2006. Numbers are from the preliminary BaBar sin2β result described in hep-ex/0607107.

Contributions to the systematic error on sin2β

(At 316 fb^{-1} : Total systematic error = ± 0.019, total statistical error = ± 0.034)

	316 fb^{-1}
Description of background events • CP content of peaking background • Background shape uncertainties	±0.007
Mistag differences between B_{CP} and BFlav samples	±0.009
Composition and content of $J/\psi K^0_L$ background	±0.007
Δt resolution and detector effects • Silicon detector and alignment uncertainty (± 0.0005) • Δt resolution model	±0.008
Beam spot position	±0.008
Fixed Δm, ΔΓ/Γ	±0.003
Tag-side interference/DCSD decays	±0.002
MC statistics/bias	±0.003

Does not scale with sqrt(N)

Katherine George . 4th International Workshop on the CKM Unitarity Triangle.
December 12th - 16th, 2006, Nagoya, Japan.

Taken from the talk "$b \to c\bar{c}s$ decays at BaBar" given at 4th CKM Workshop. Nagoya, Dec. 2006. Numbers are from the preliminary BaBar sin2β result described in hep-ex/0607107.

Contributions to the systematic error on sin2β

(At 316 fb^{-1} : Total systematic error = ± 0.019, total statistical error = ± 0.034)

	316 fb^{-1}	→ 2 ab^{-1}
Description of background events	±0.007	±0.003
– CP content of peaking background		
– Background shape uncertainties		
Mistag differences between B_{CP} and BFlav samples	±0.009	±0.004
Composition and content of $J/\psi K^0_L$ background	±0.007	±0.003
Δt resolution and detector effects	±0.008	±0.003
– Silicon detector and alignment uncertainty	(± 0.0005)	±0.0005
– Δt resolution model		
Beam spot position	±0.008	±0.008
Fixed Δm, ΔΓ/Γ	±0.003	±0.001
Tag-side interference/DCSD decays	±0.002	±0.002
MC statistics/bias	±0.003	±0.001
		±0.010

Does not scale with sqrt(N)

Katherine George . 4th International Workshop on the CKM Unitarity Triangle.
December 12th - 16th, 2006, Nagoya, Japan.

$b \to c\bar{c}s$ at higher luminosities

(Systematics - III)

- ±0.010 @ 2ab^{-1} of which I estimate ~±0.008 is currently "irreducible" with the current detectors.
  - Future improvements can come from:
    - An "improved" detector,
    - Use of higher statistics control samples at Super B,
    - Subsequent improvements in upcoming BaBar/Belle publications.

b→ccs at higher luminosities
(Systematics - III)

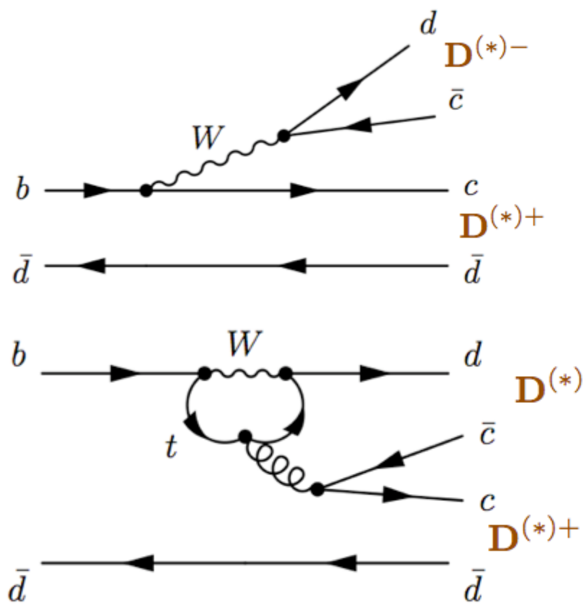
- ±0.010 @ 2ab^{-1} of which I estimate ~±0.008 is currently "irreducible" with the current detectors.
  - Future improvements can come from:
    - An "improved" detector,
    - Use of higher statistics control samples at Super B,
    - Subsequent improvements in upcoming BaBar/Belle publications.
- CDR - may be possible to reduce this error to ±0.005 (total).

Observable	B Factories (2 ab^{-1})	Super$B$ (75 ab^{-1})
$\sin(2\beta)$ $(J/\psi\, K^0)$	0.018	0.005 (†)
$\cos(2\beta)$ $(J/\psi\, K^{*0})$	0.30	0.05

Complimentary measurements of β

Complementary measurements of β

$B^0 \to J/\psi\pi^0$ and $B^0 \to D^{+(*)} D^{-(*)}$



- Same tree and penguin diagrams as $b \to c\bar{c}s$ ('s' replaced by a 'd')
- Penguin diagram has a different weak phase
  - could have a more significant contribution than in $b \to c\bar{c}s$ modes,
  - ∴ sizeable deviations from $b \to c\bar{c}s$ may suggest New Physics in the $b \to d$ penguin topology.
    - e.g.(*) $\tilde{b}$ and gluino masses in the range 100-300 GeV can produce measurable differences in value of sin2β obtained from $b \to c\bar{c}s$ and $b \to c\bar{c}d$ decays.

(*) Y. Grossman and M. P. Worah, Phys. Lett. B **395**, 241 (1997) [arXiv:hep-ph/9612269].

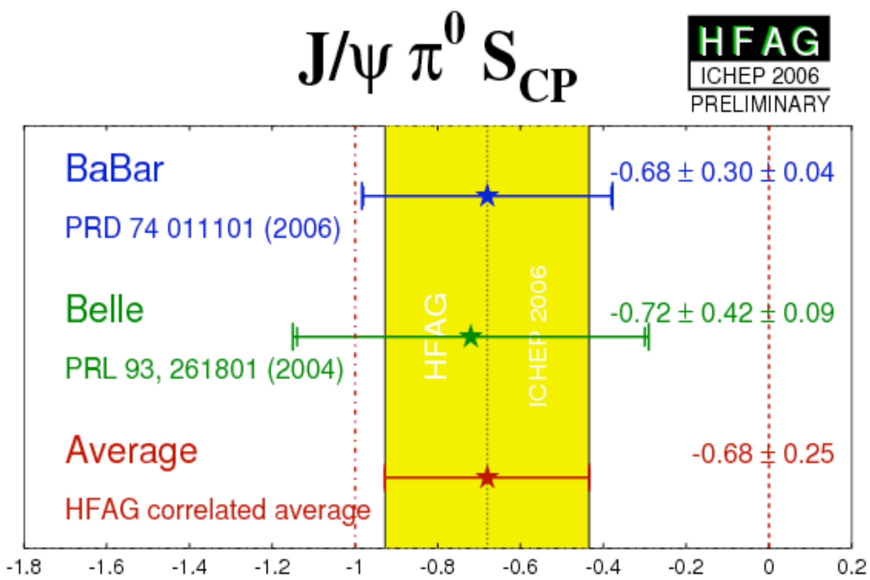
$B^0 \to D^{+(*)} D^{-(*)}$

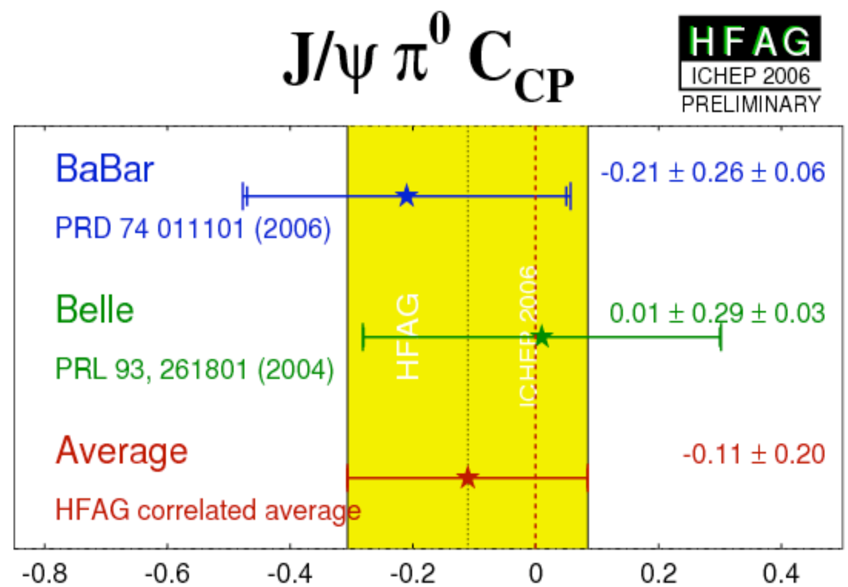
- D^+D^- is a CP-eigenstate,
- $D^{*+}D^{*-}$ is a CP-admixture ∴ angular analysis required.
- $D^{*+}D^-$ are not CP-eigenstates, but C=0 and S≈-sin2β in the SM.
- Penguin contribution expected to be small (~2-10%). Xing, PRD 61, 014010 (2000).

Time-dependent CP Asymmetries in b →ccd transitions
($B^0 \rightarrow J/\psi\pi^0$)

232 M BB pairs.

152 M BB pairs.



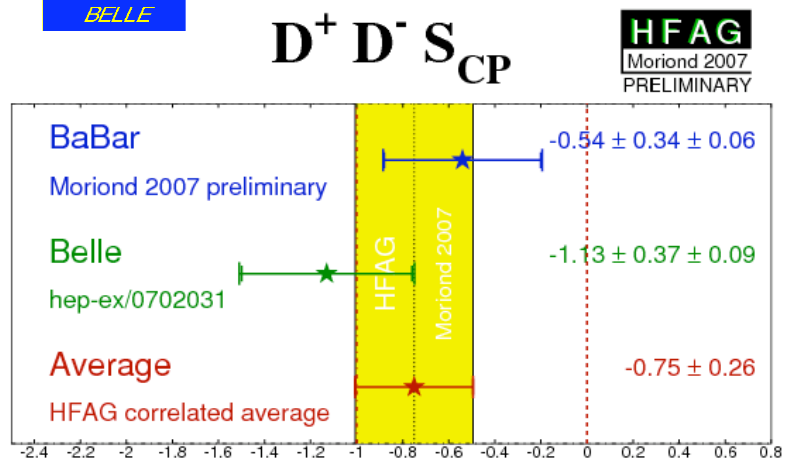


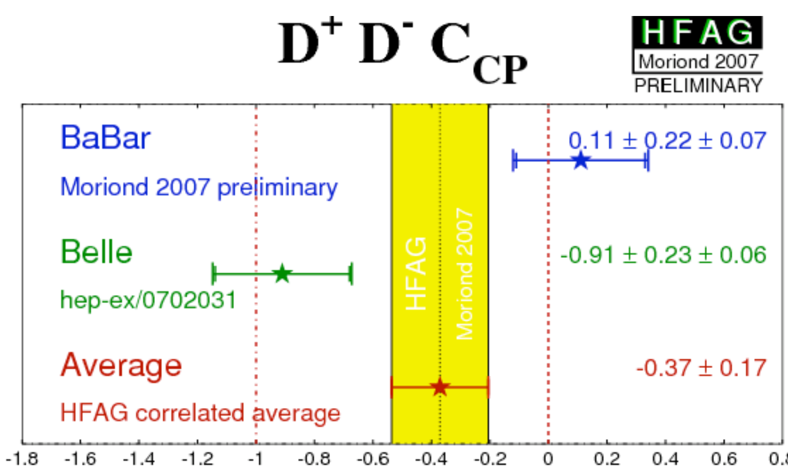
- Current measurements indicate that $S(J/\psi\pi^0)$ and $C(J/\psi\pi^0)$ are consistent with $S = -\sin 2\beta_{b\rightarrow ccs}$ and $C = 0$.

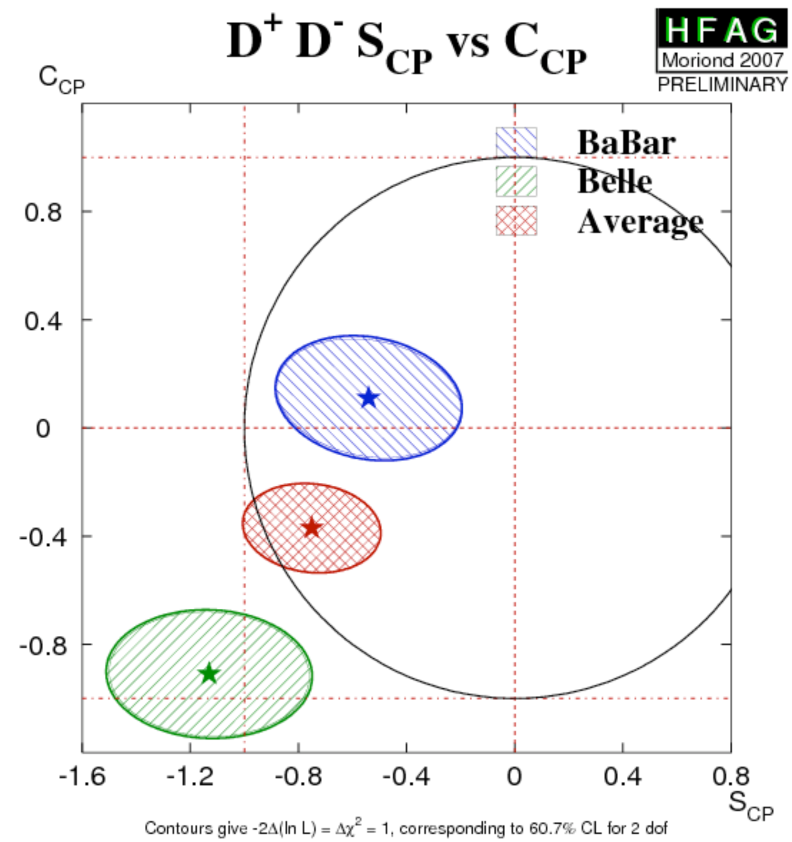
Time-dependent CP Asymmetries in b →ccd transitions ($B^0 \to D^+D^-$)

383 M BB pairs.

535 M BB pairs.







- Belle : Evidence for direct CPV at 3.2σ.
  - Not confirmed by BaBar.
- Belle result is outside of physical region, with the average very close to the boundary.
  - HFAG warning - interpret average with care.

Time-dependent CP Asymmetries in b →ccd transitions
(Evidence for CP Violation in $B^0 \to D^{*+}D^-$)

383 M BB pairs.

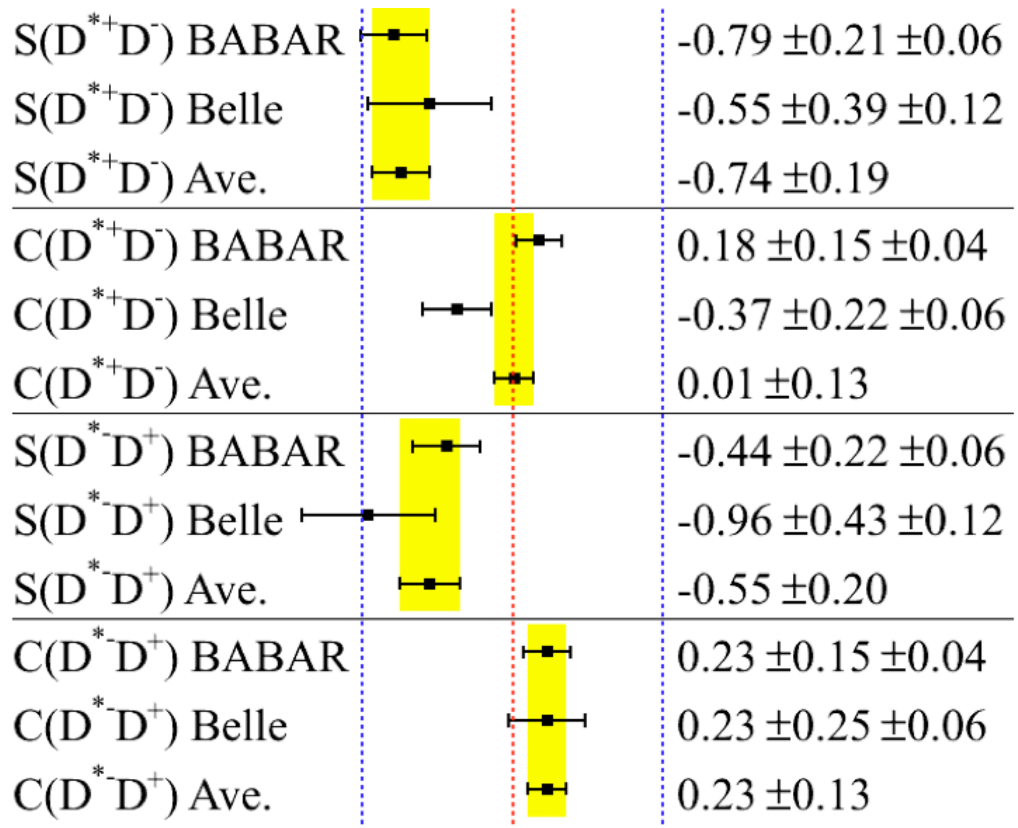
185 M BB pairs.

- Not a CP eigenstate.
- Analyse $D^{*+}D^-$ and $D^{*-}D^+$ modes separately.

$$\frac{A(D^{*+}D^-)}{A(D^{*-}D^+)} = Re^{i\delta}$$

$$S_\pm = \frac{2R\sin(2\beta \pm \delta)}{1+R^2}$$

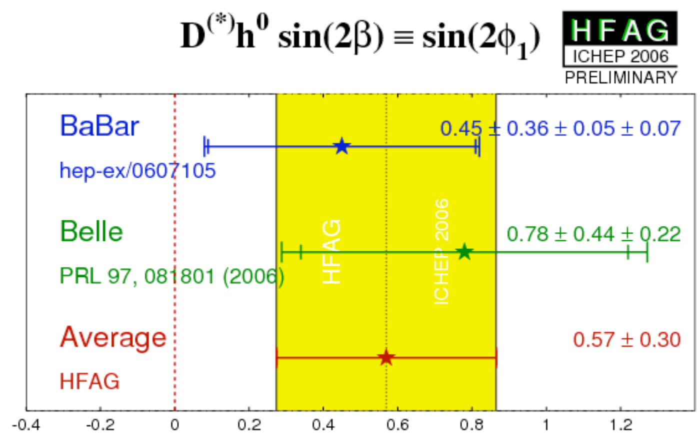
$$(S_+ - S_-)/2 = \frac{2R}{1+R^2}\cos\delta\sin 2\beta$$

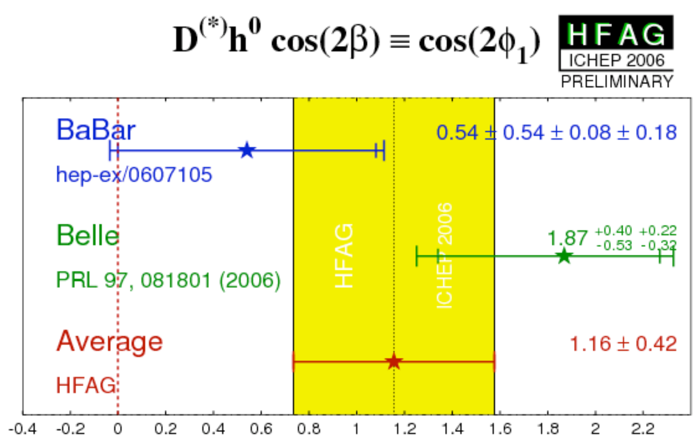


- If no CPV (and no penguin), $S_+ = S_-$ and $C_+ = C_-$
- $\cos\delta\sin 2\beta \neq 0$ at 4σ level.

Complementary measurements of β

$B^0 \to D^0 h^0$





With multi-body decays

- e.g. $D^0 \to K^0{}_S \pi^+ \pi^-$
- Time-dependent Dalitz analysis of the D decay allows a direct determination of β.
- Measure both cos2β and sin2β.
- Belle : cos2β > 0 @ 98.3% CL.
- BaBar : cos2β > 0 @ 87% CL.

Without multi-body decays

- BaBar : hep-ex/0703019
  - $\sin 2\beta_{eff} = +0.56 \pm 0.23 \pm 0.05$
  - $C = -0.23 \pm 0.16 \pm 0.04$

Time-dependent CP Asymmetries in $b \to c\bar{c}d$ transitions (Systematics)

Observable	B Factories (2 ab^{-1})	Super$B$ (75 ab^{-1})
$\sin(2\beta)$ $(J/\psi\, K^0)$	0.018	0.005 (†)
$\cos(2\beta)$ $(J/\psi\, K^{*0})$	0.30	0.05
$\sin(2\beta)$ (Dh^0)	0.10	0.02
$\cos(2\beta)$ (Dh^0)	0.20	0.04
$S(J/\psi\,\pi^0)$	0.10	0.02
$S(D^+D^-)$	0.20	0.03

- Selected 'complementary' measurements of β from $b \to c\bar{c}d$ transitions are not limited by systematics, statistics or theoretical errors.
- Complementary measurements of β ~few degrees are achievable.

$\sin 2\beta_{eff}$ from penguins

Sin2β in b→s penguin dominated modes

- b→s penguin dominated modes, e.g. $B^0 \to \varphi K^0_S$, $B^0 \to \eta' K^0_S$, $B^0 \to K^0K^0K^0$ (reconstructed as $B^0 \to K^0_S K^0_S K^0_S$), $B^0 \to \pi^0 K^0_S$, $B^0 \to \rho^0 K^0_S$, $B^0 \to \omega K^0_S$, $B^0 \to \pi^0\pi^0 K^0_S$ and $B^0 \to f^0 K^0_S$, are some of the most interesting places to look for New Physics effects.
  - "Of the penguin modes, only ϕK^0_S really possible at LHCb". Wilkinson, LHCb upgrade workshop, Jan 2007.

- Modes with the smallest theoretical uncertainties are $B^0 \to \varphi K^0_S$, $B^0 \to \eta' K^0_S$, and $B^0 \to K^0K^0K^0$.

- How large can ΔS_f be in the SM ?

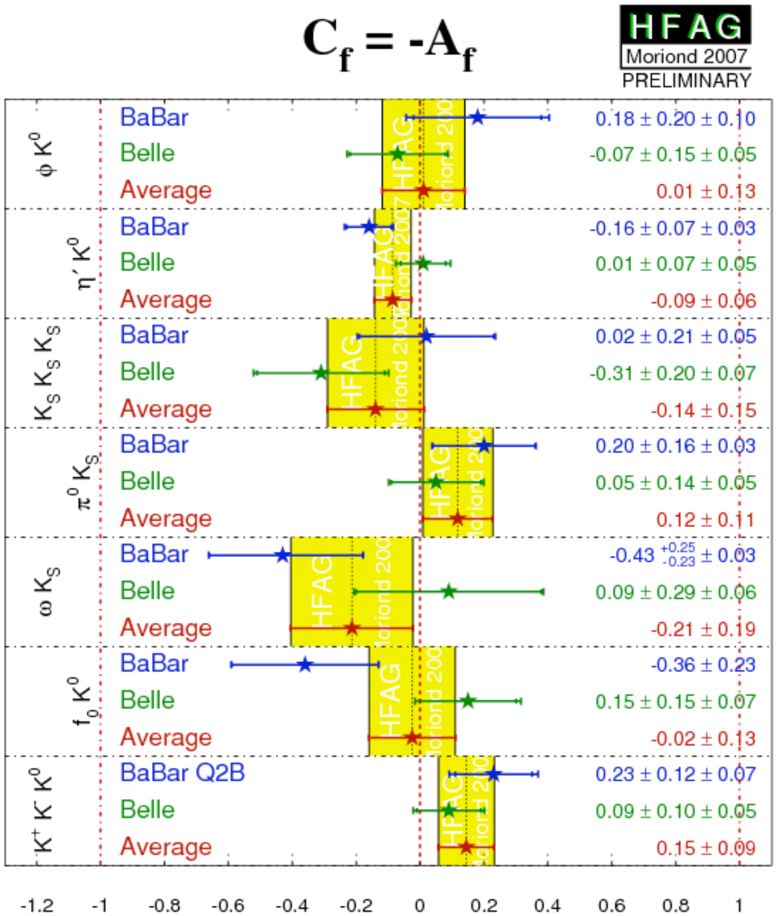
$$\Delta S_f \equiv -\eta_f S_f - S_{J/\psi K_S}$$

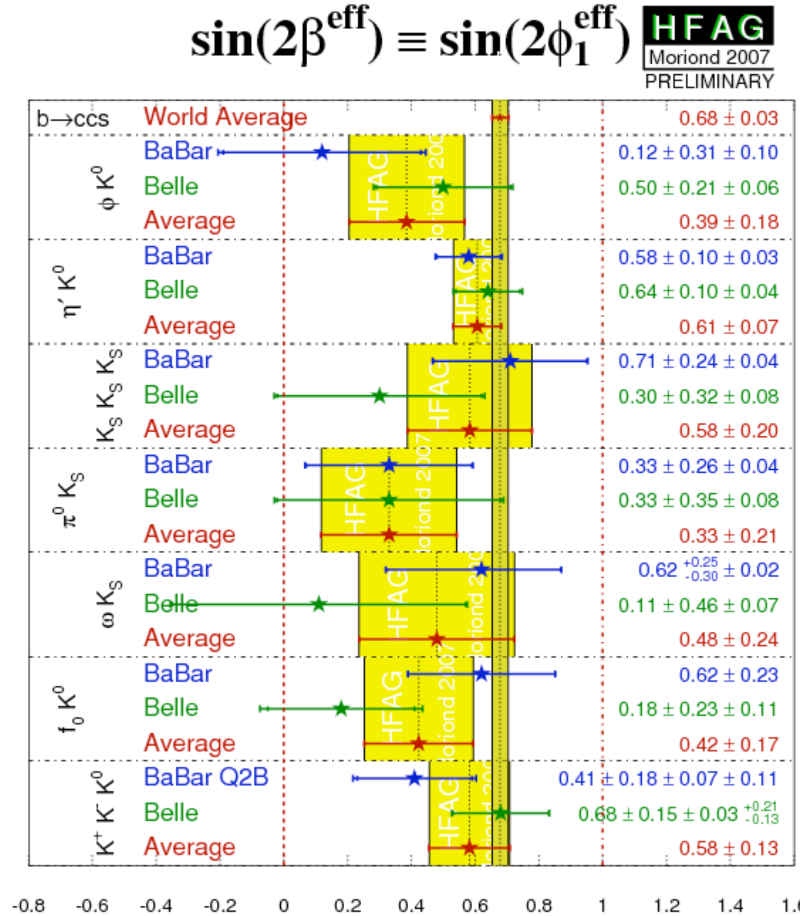
Tables taken from Chua, hep-ph/0605301. Proceedings of talk given at FPCP'06.

ΔS_f	QCDF	pQCD	SCET
ϕK_S	0.02 ± 0.01	$0.020^{+0.005}_{-0.008}$	
ωK_S	0.13 ± 0.08		
$\rho^0 K_S$	$-0.08^{+0.08}_{-0.12}$		
$\eta' K_S$	0.01 ± 0.01		-0.02 ± 0.01 -0.01 ± 0.01
ηK_S	$0.10^{+0.11}_{-0.07}$		-0.03 ± 0.17 $+0.07 \pm 0.14$
$\pi^0 K_S$	$0.07^{+0.05}_{-0.04}$	$0.06^{+0.02}_{-0.03}$	0.08 ± 0.03
$f_0 K_S$	0.02 ± 0.00		
$a_0 K_S$	0.02 ± 0.01		
$\bar{K}_0^{*0} \pi^0$	$0.00^{+0.03}_{-0.05}$ $0.02^{+0.00}_{-0.02}$		

sin2β in b→s penguin dominated modes

Hint of $\sin 2\beta_{charmless} < \sin 2\beta_{b\to ccs}$



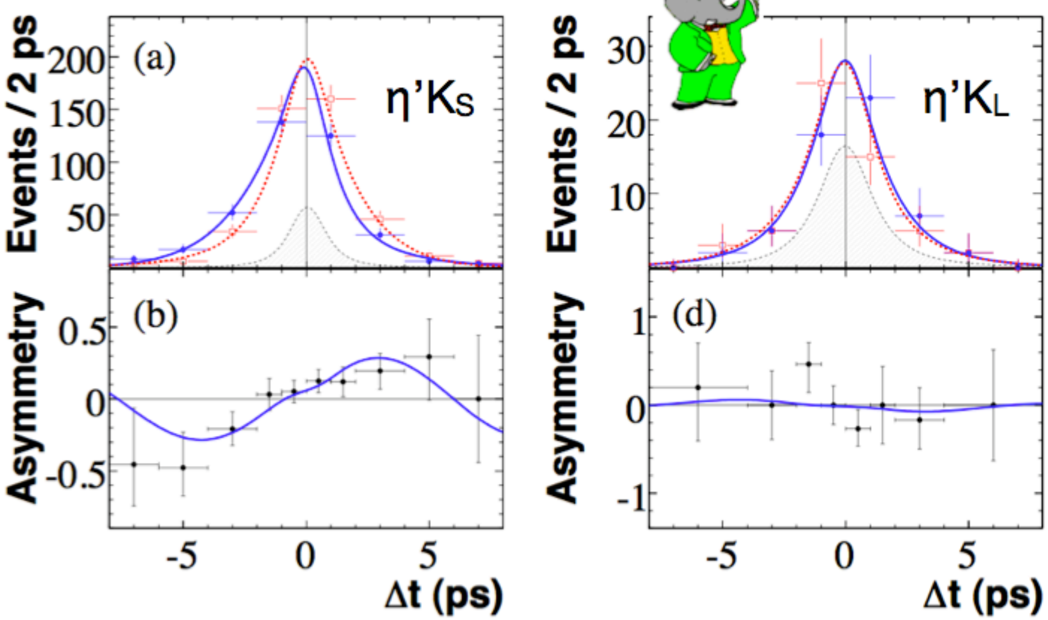


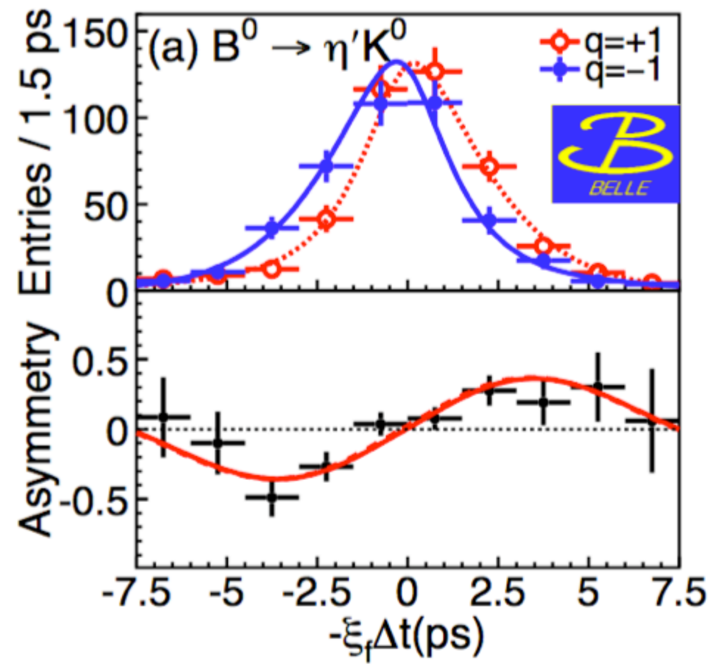
- N.B. these plots exclude ρK^0_S and $\pi^0\pi^0K^0_S$ which have large statistical errors with current datasets.

$B^0 \to \eta' K^0$

383 M BB pairs.

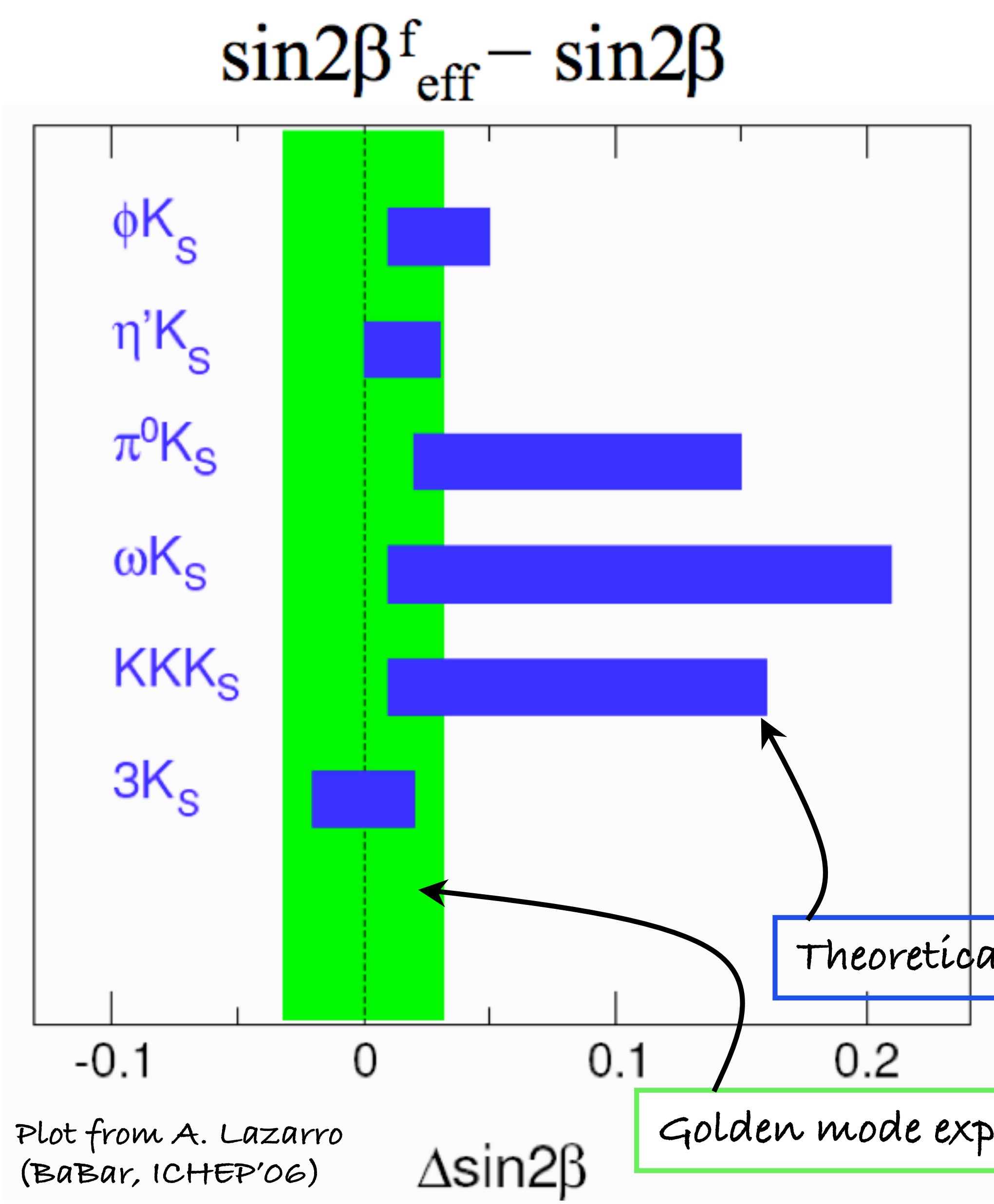
535 M BB pairs.





- $\sin 2\beta_{eff} = +0.58 \pm 0.10 \pm 0.03$ $\sin 2\beta_{eff} = +0.64 \pm 0.10 \pm 0.04$
- $C = -0.16 \pm 0.07 \pm 0.03$ $C = \pm 0.01 \pm 0.07 \pm 0.05$
- $> 5\sigma$ CP observation

sin2β in b→s penguin dominated modes



Plot from A. Lazarro (BaBar, ICHEP'06)

- Theoretically, ΔS_f is small and positive in most cases.
- Experimentally, ΔS_f are all negative.

Beneke, PLB 620, 143 (2005)
Mishima, Sanda, PRD 72, 114005 (2005)
Williamson, Zupan, PRD 74, 014003 (2006)
Cheng, Chua, Soni, PRD, 014006 (2005)

Theoretical correction and uncertainty

Golden mode experimental uncertainty (as of ICHEP'06)

sin2β in b→s penguin dominated modes

(Systematics)

Observable	B Factories (2 ab^{-1})	Super$B$ (75 ab^{-1})
$\sin(2\beta)$ $(J/\psi\, K^0)$	0.018	0.005 (†)
$\cos(2\beta)$ $(J/\psi\, K^{*0})$	0.30	0.05
$\sin(2\beta)$ (Dh^0)	0.10	0.02
$\cos(2\beta)$ (Dh^0)	0.20	0.04
$S(J/\psi\, \pi^0)$	0.10	0.02
$S(D^+D^-)$	0.20	0.03
$S(\phi K^0)$	0.13	0.02 (∗)
$S(\eta' K^0)$	0.05	0.01 (∗)
$S(K_S^0 K_S^0 K_S^0)$	0.15	0.02 (∗)
$S(K_S^0 \pi^0)$	0.15	0.02 (∗)
$S(\omega K_S^0)$	0.17	0.03 (∗)
$S(f_0 K_S^0)$	0.12	0.02 (∗)

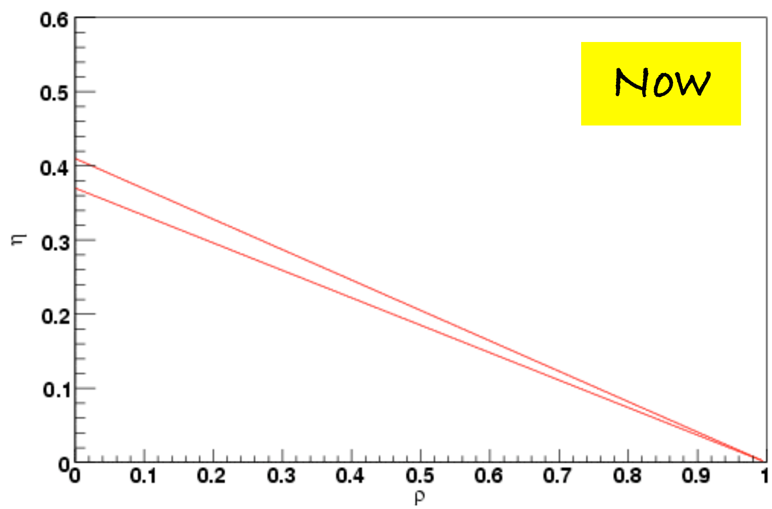
Theoretically limited at 75 ab^{-1}

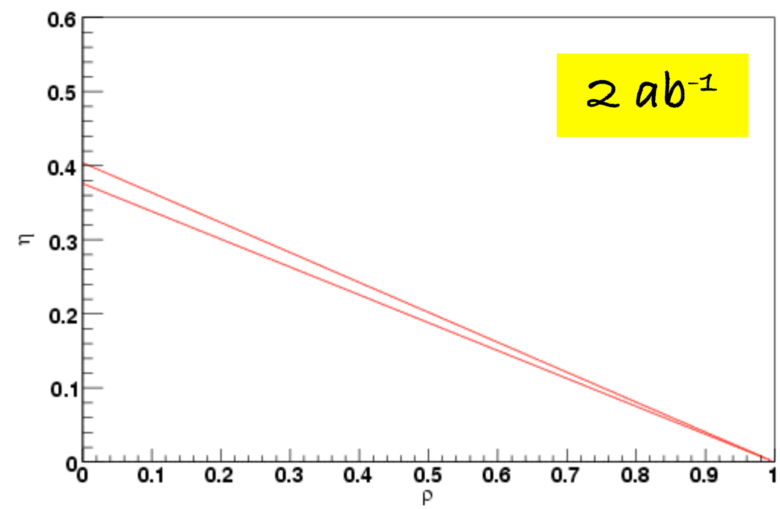
- $B^0 \to \eta' K^0_S$ becomes theoretically dominated earlier than other penguin modes. Proposed use of "data-driven" methods to control theoretical errors.
  - Grossman, Ligetti, Nir & Quinn (hep-ph/0303171),
  - Gronau, Rosner & Zupan (hep-ph/0403027 and hep-ph/0608085).

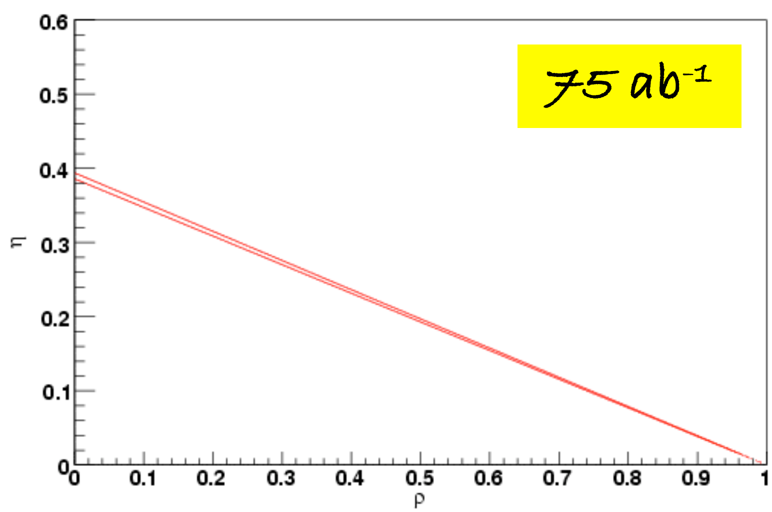
α and $\beta_{b \to ccs}$ in the ρ-η plane

β in the $\bar{\rho} - \bar{\eta}$ plane

(Plots from A. Bevan)



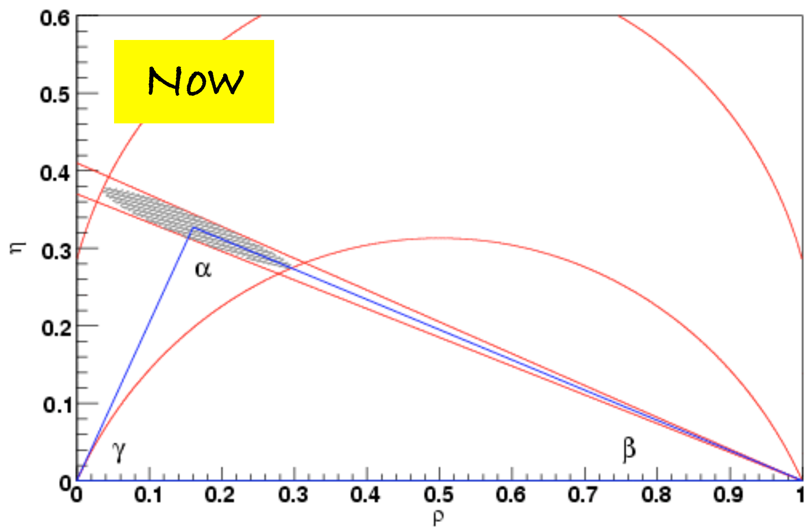


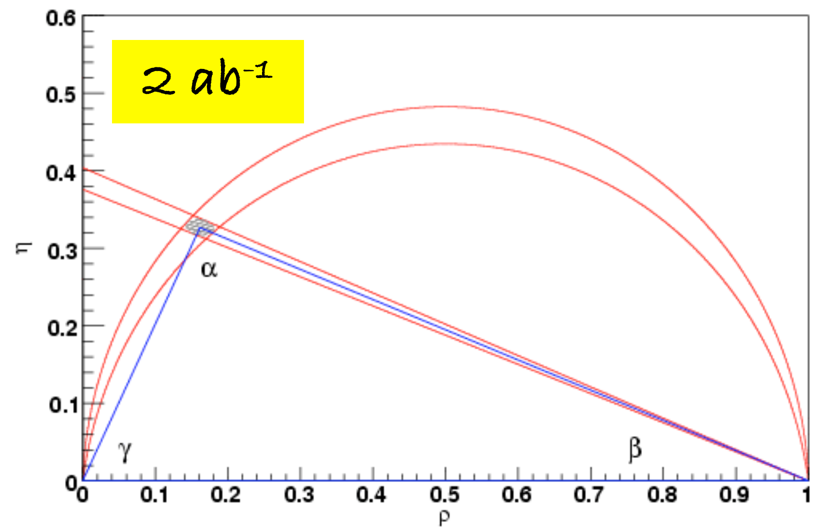


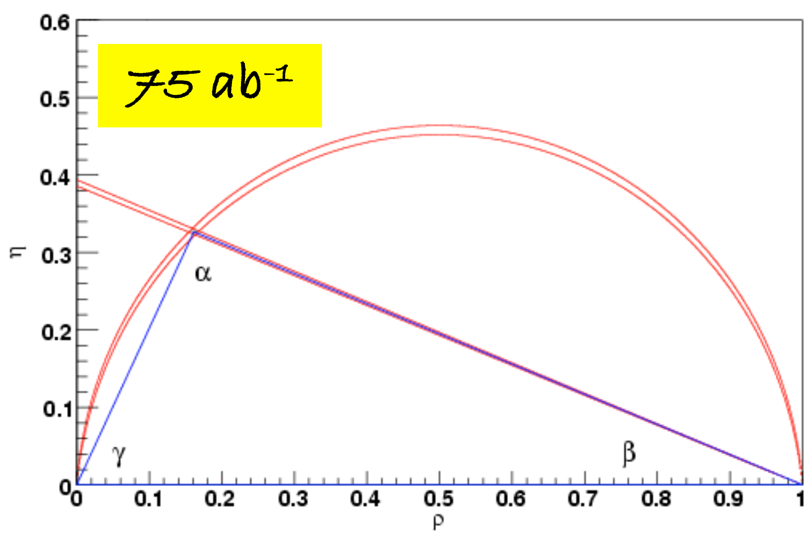
- Input:
  - $b \rightarrow c\bar{c}s$ β from HFAG (21.3^{o}).
- Assumption on error 'scaling':
  - β - taken from CDR Table 2-1.
    - $2ab^{-1}$ ($\pm 0.7^{o}$) and $75ab^{-1}$ ($\pm 0.2^{o}$)

using α and β to constrain the unitarity triangle

(Plots from A. Bevan)





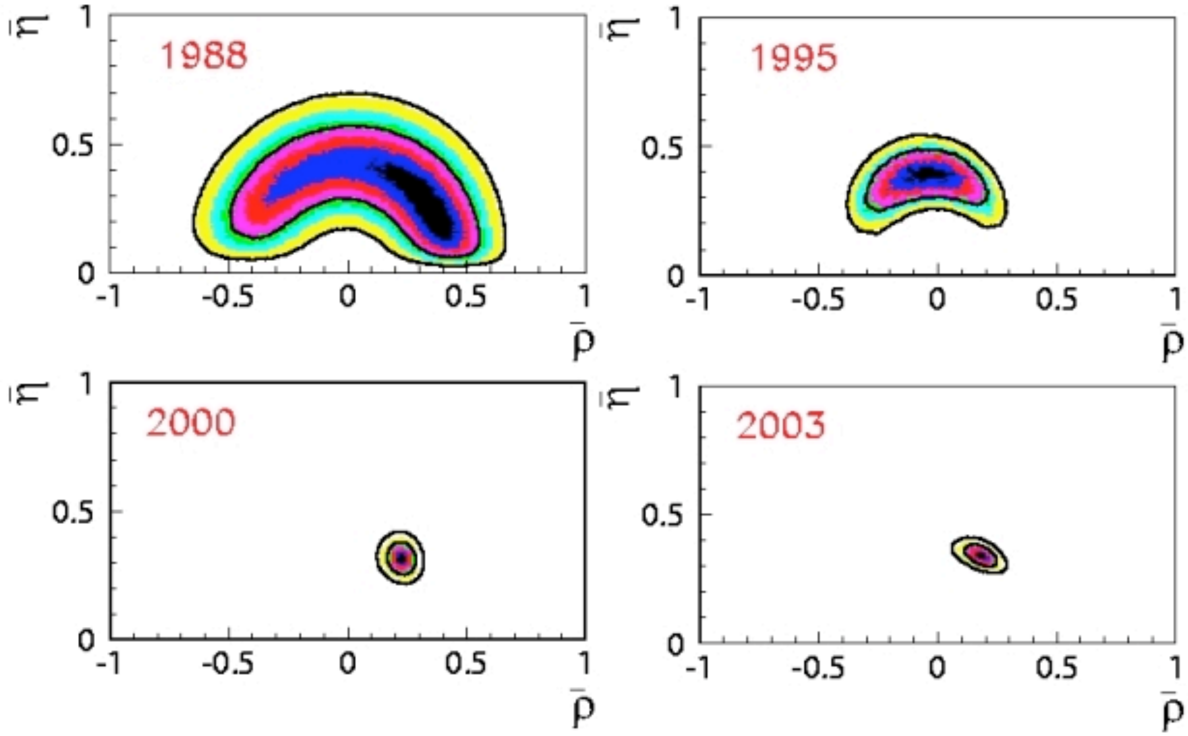


- Inputs:
  - α from BaBar $B^0 \to \rho^+\rho^-$ (95°).
  - $b \to ccs$ β from HFAG (21.3°).
  - No input from γ.
- Assumptions on error 'scaling':
  - α - see Adrian's talk
  - β - taken from CDR Table 2-1.

The 30 year evolution ?

(1988 - 2018)

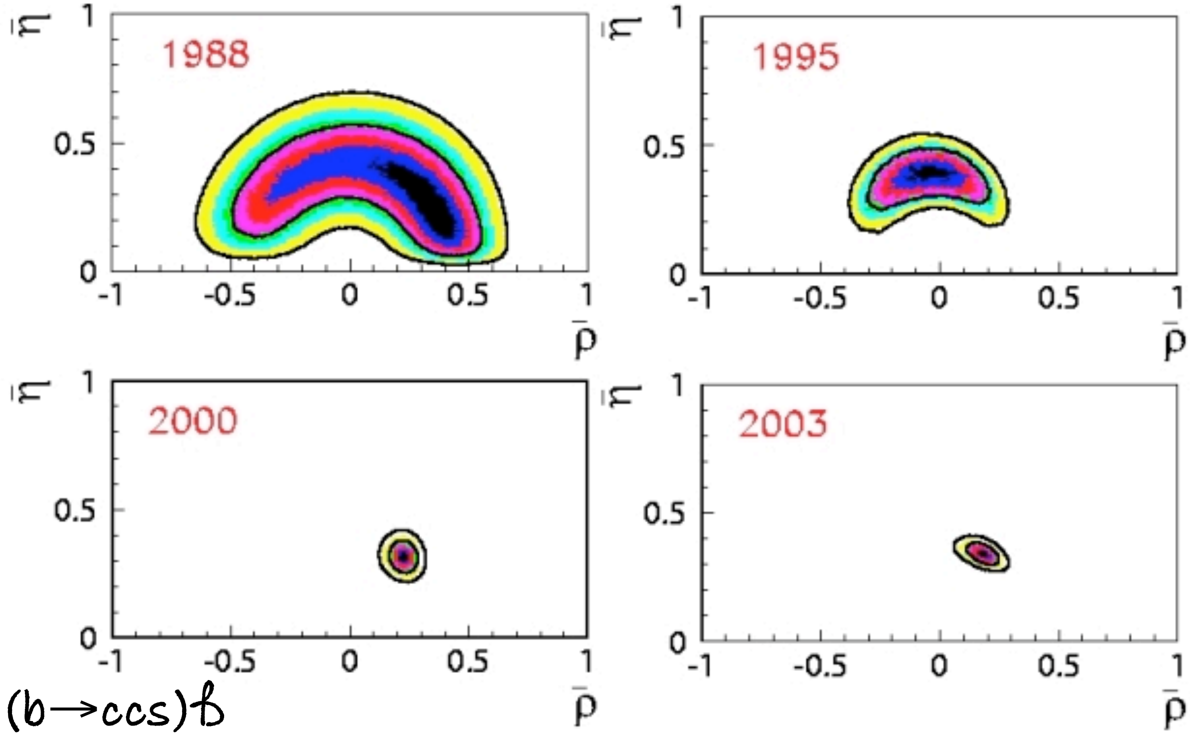
- 15 year evolution from UT Fit ...



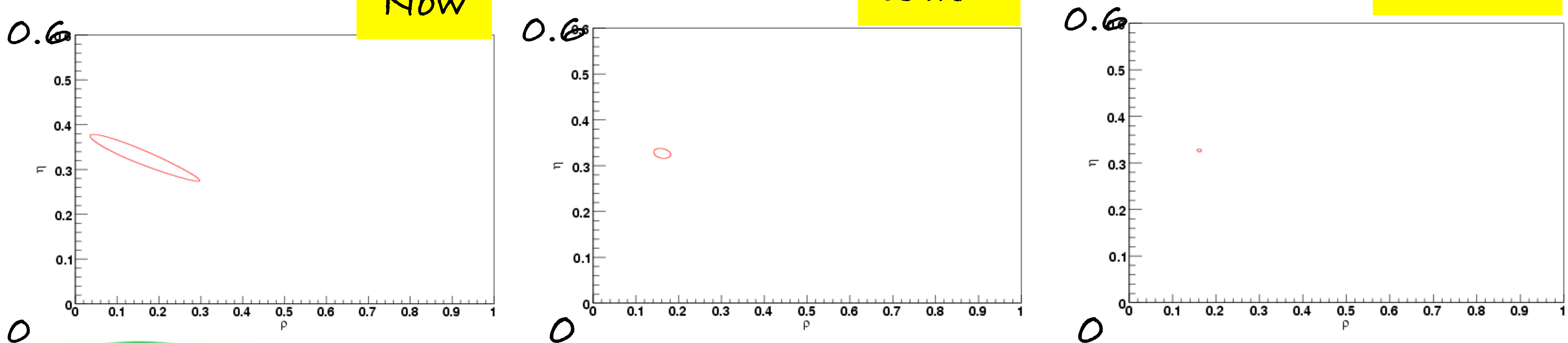
The 30 year evolution ?

(1988 - 2018)

- 15 year evolution from UT Fit ...



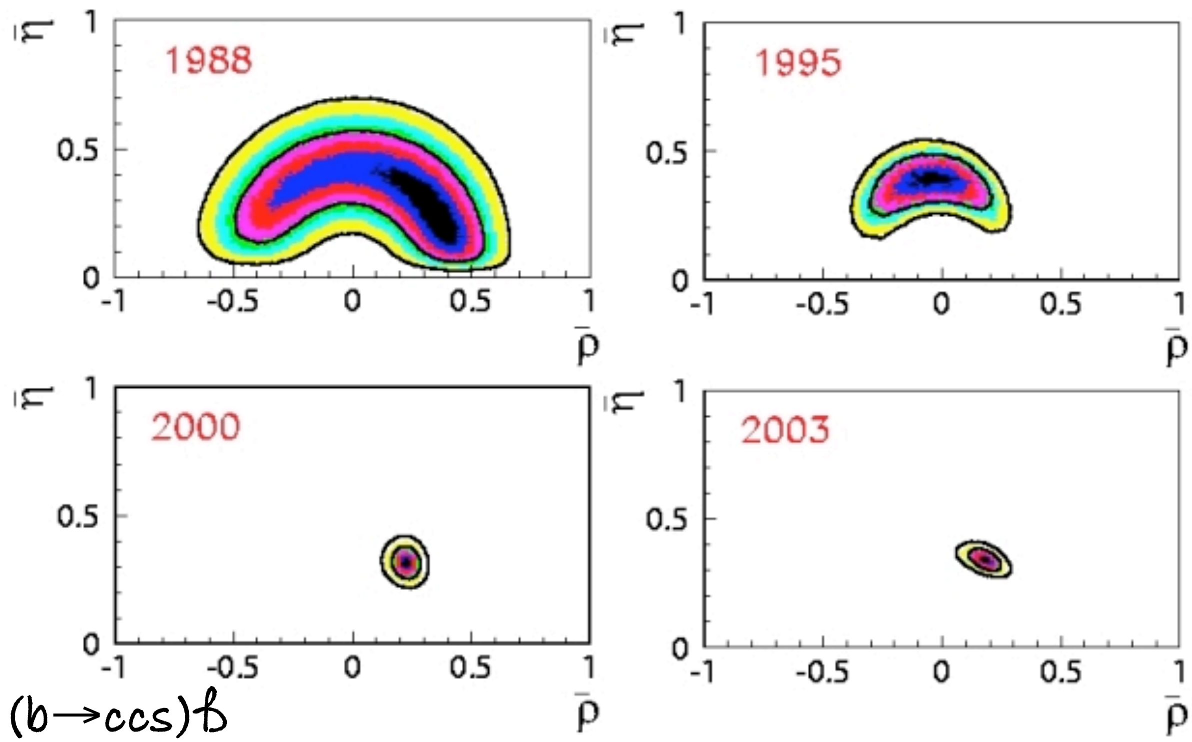
- Only assuming an α and $(b \to ccs)\beta$ evolution. Note the smaller axis ranges.



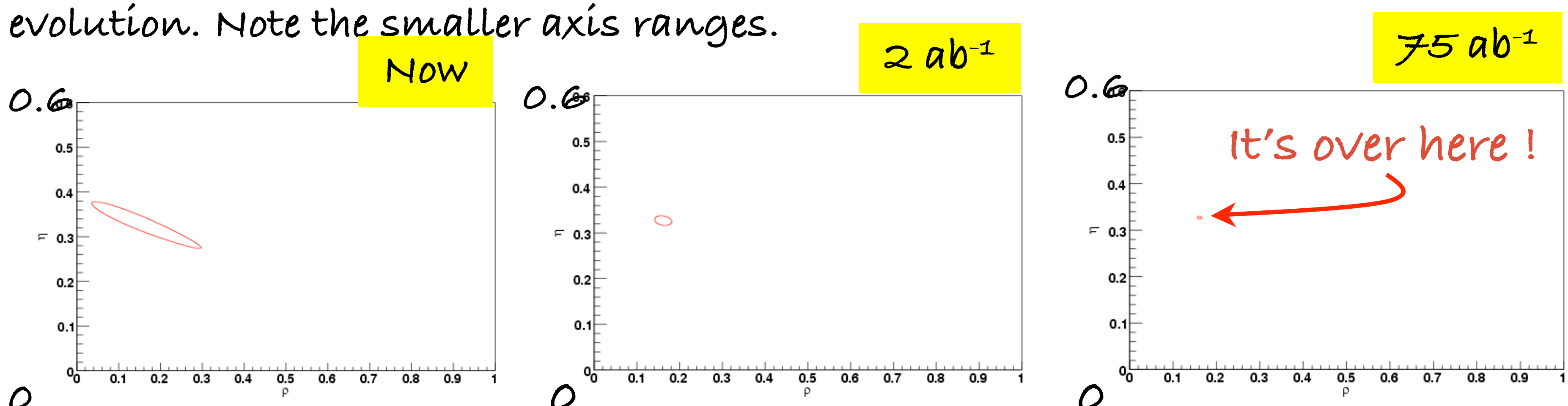
The 30 year evolution ?

(1988 - 2018)

- 15 year evolution from UT Fit ...



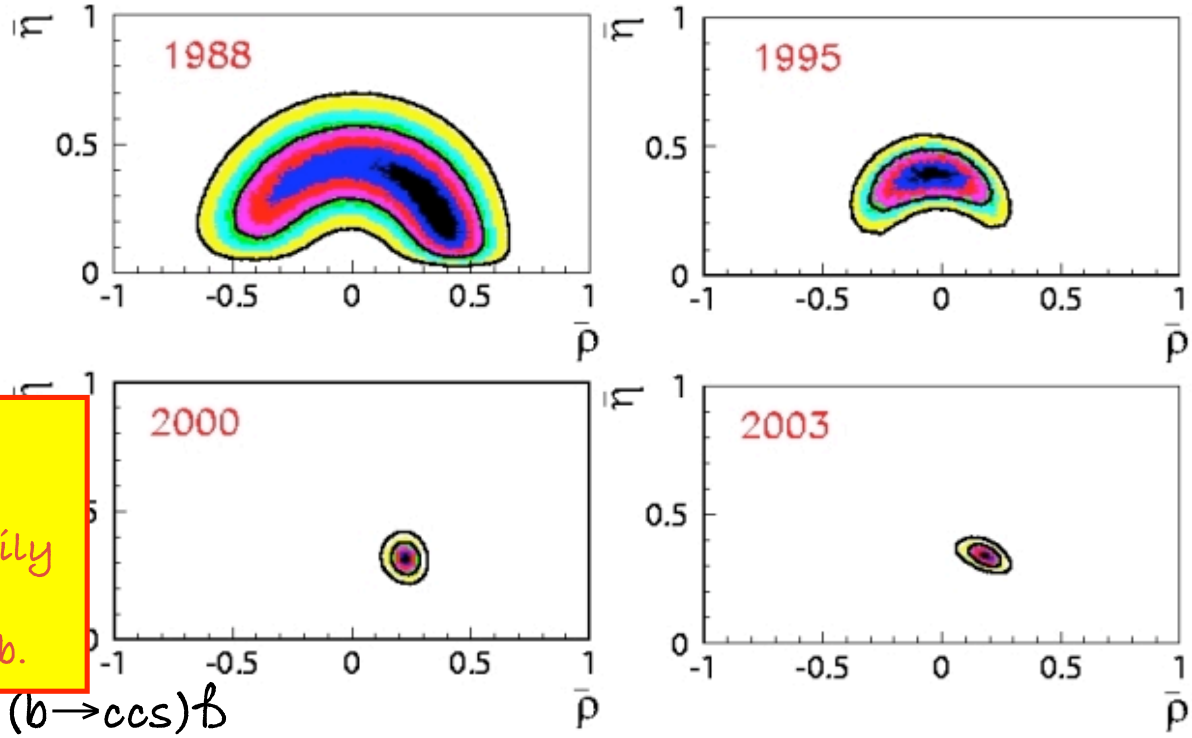
- Only assuming an α and (b→ccs) β evolution. Note the smaller axis ranges.



The 30 year evolution ?

(1988 - 2018)

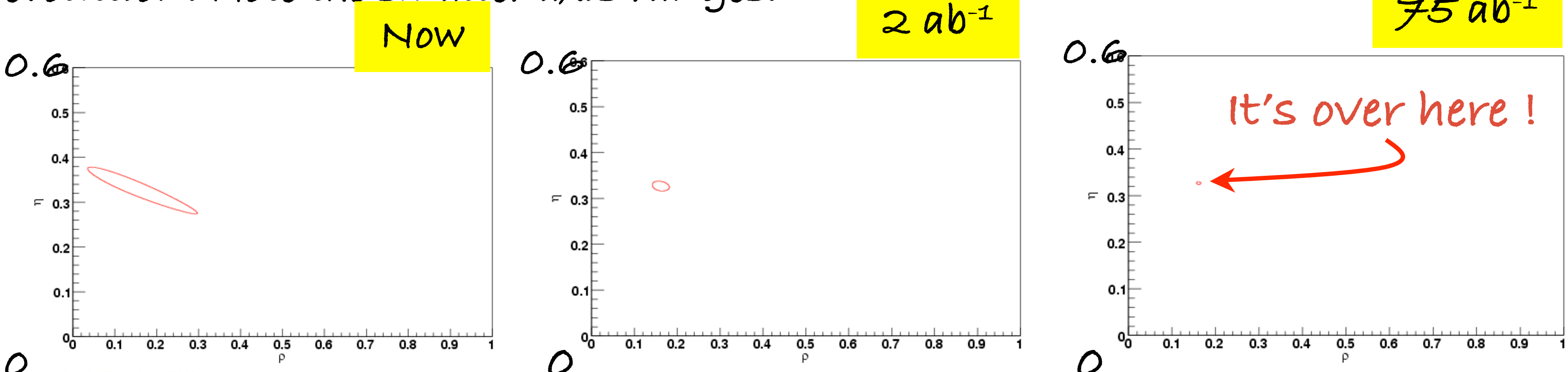
- 15 year evolution from UT Fit ...



WARNING !!

- Just for illustration!
- Past performance is not necessarily an indication of future returns !
- Excludes many things e.g. LHCb.

- Only assuming an α and (b→ccs)β evolution. Note the smaller axis ranges.



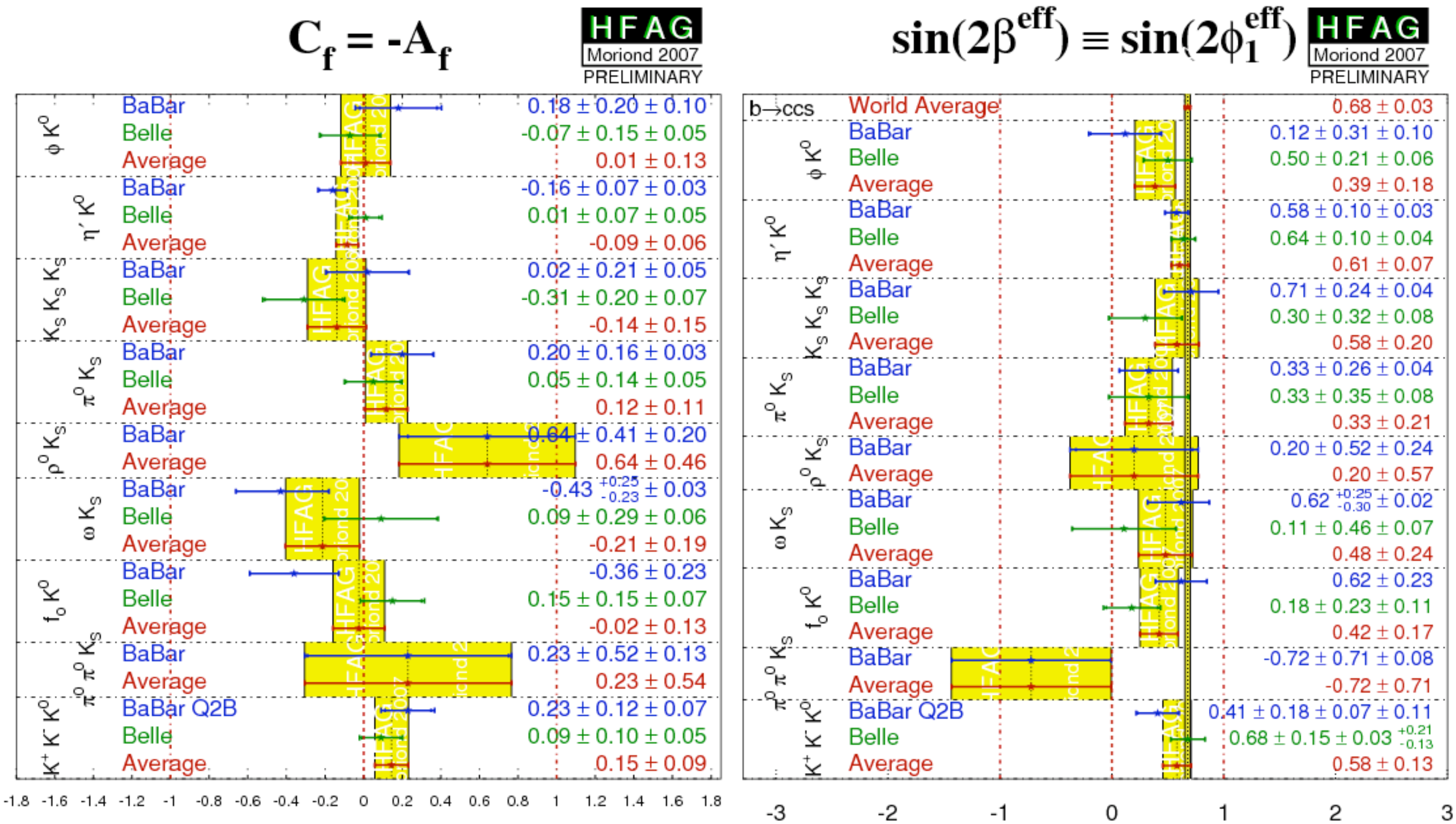
Summary

Summary

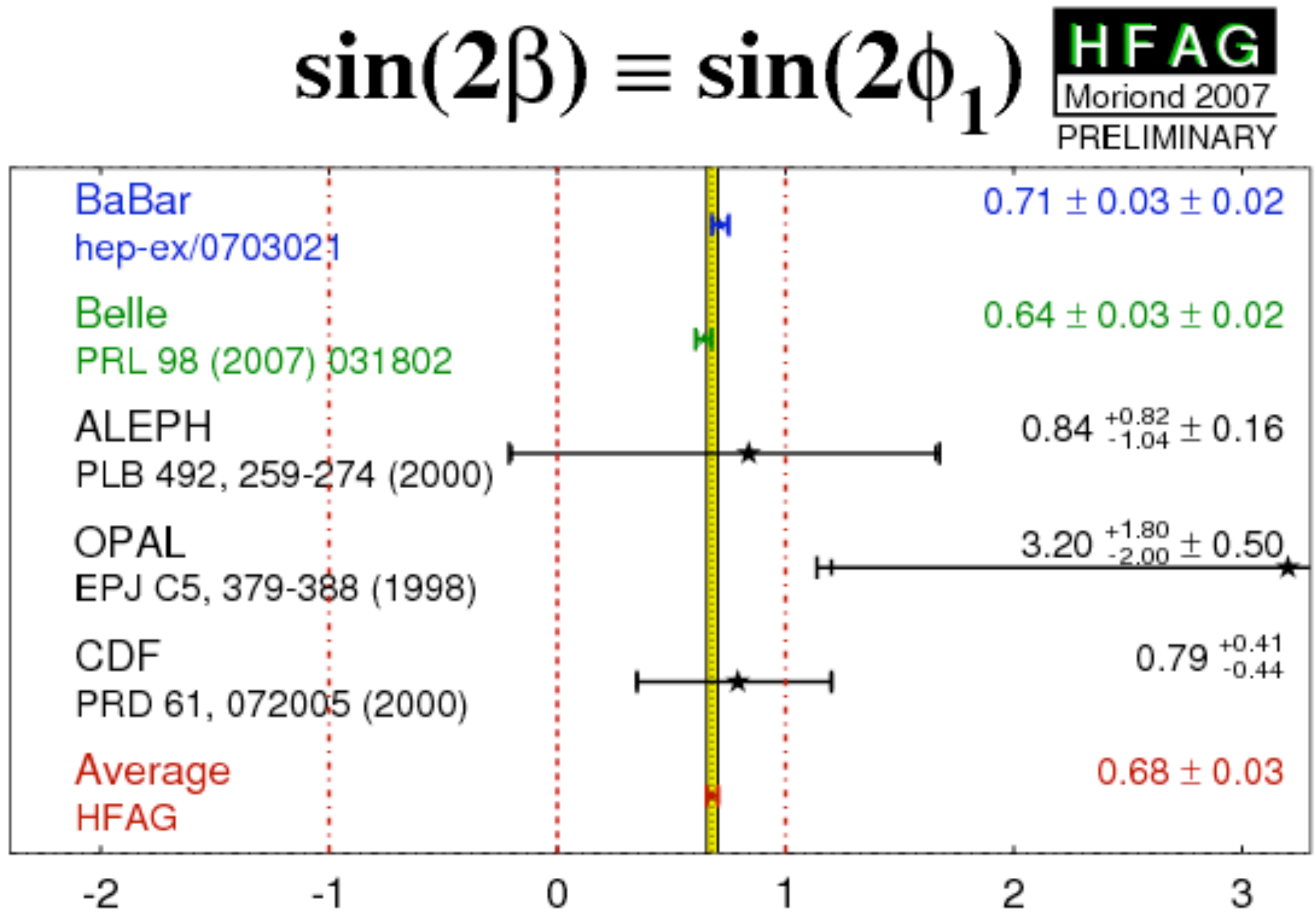
- Sub-1° measurements of β_{ccs}
  - Effort needed in reducing the "irreducible" systematics:
    - Vertexing, tag-side interference and beam-spot.
  - "Data-driven" method to control penguins will prove even more useful at a higher luminosity.
- Experiments in a hadronic environment are not competitive for:
  - the 'complementary' ($b \rightarrow ccd$) measurements of β, (not systematics, statistics or theoretically limited at Super B)
  - the 'alternative' ($b \rightarrow s$ penguin) measurements of β (theoretically limited at Super B).
- Not the *raison d'etre* for SuperB, but measuring β is a necessary part of the program.

Need more slides ?

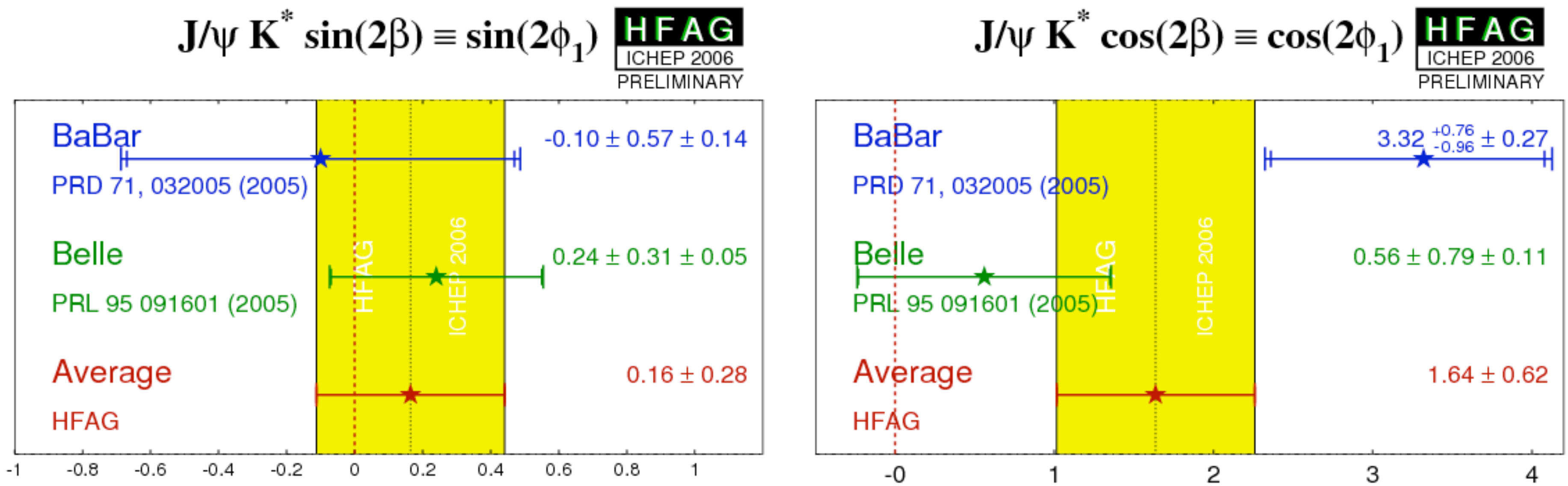
sin2β in b→s penguin dominated modes



Average of $\sin 2\beta \equiv \sin 2\phi_1$



Time-dependent transversity analysis of $B^0 \to J/\psi K^*$



BaBar : 88 M BB pairs.

Belle: 275 M BB pairs.