

# Experimental situation of the $\sin 2\beta$ measurement in hadronic penguin modes

Alfio Lazzaro

Università degli Studi and INFN, Milano

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# Overview

- Time Dependent CP violation asymmetry and CKM angle  $\beta$  measurements
- New Physics effects in  $b \rightarrow s$  penguin amplitudes
- Measurements from the beginning of B-Factories to the latest updates (**historical prospect**)
  - Measurement results from **HFAG webpage**. Refer to them for specific references
- Conclusion



# Time-Dependent CP-Asymmetry

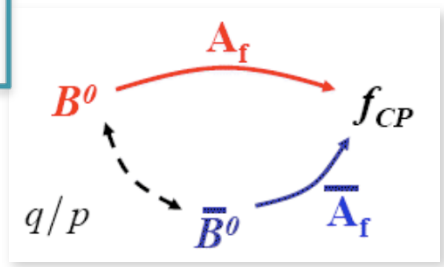
- Time-dependent (TD) decay rate asymmetry for coherent  $B$  mesons to final state  $f$

$$\begin{aligned}
 A_f(\Delta t) &= \frac{\Gamma(\bar{B}^0 \rightarrow f_{CP}) - \Gamma(B^0 \rightarrow f_{CP})}{\Gamma(\bar{B}^0 \rightarrow f_{CP}) + \Gamma(B^0 \rightarrow f_{CP})} \\
 &= C_f \cos(\Delta m_d \Delta t) - S_f \sin(\Delta m_d \Delta t)
 \end{aligned}$$

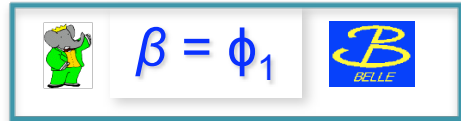
↑ ↑  
**Physics observables**

- $C_f$  related to **direct CP**
- $S_f$  related to **CP asymmetry in interference between mixing and decay**


 $C_f = -A_f$ 


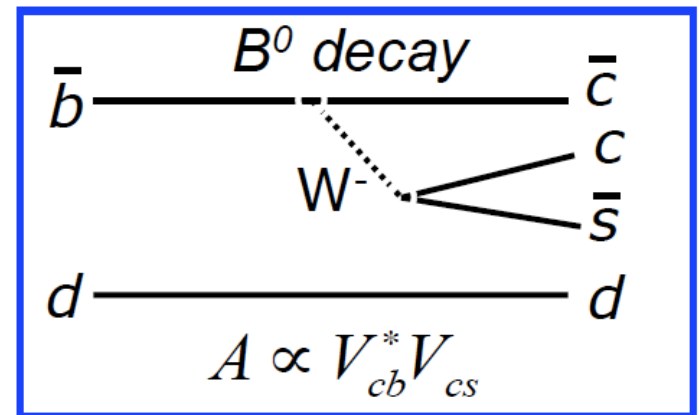


# $\beta$ measurements



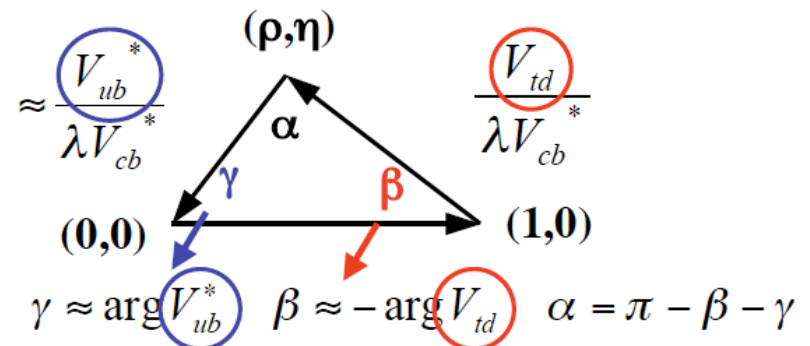
- In case of tree dominated  $b \rightarrow c\bar{c}s$  decays, such as  $B^0 \rightarrow J/\psi K_S^0$

$$\begin{aligned} C_f &= 0 \\ S_f &= \sin 2\beta \end{aligned}$$

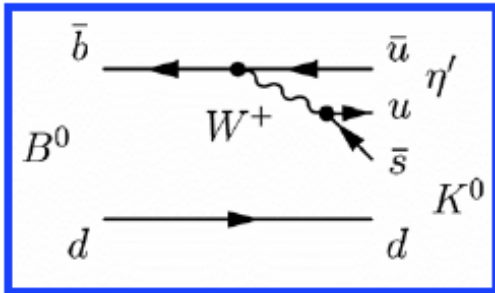
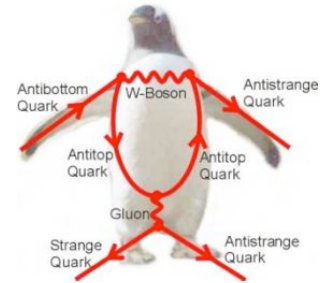


- $\beta$  is CKM phase related to CP Violation in the Standard model (SM)

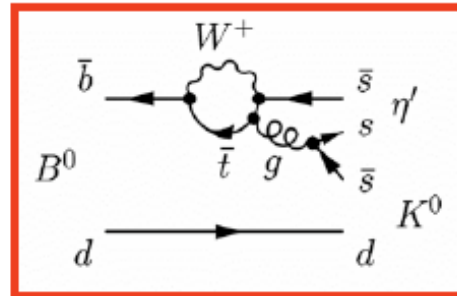
$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$



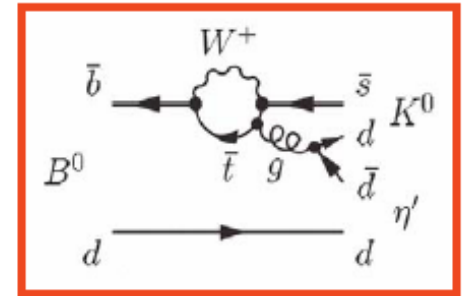
# TD in $b \rightarrow s$ penguin modes



Tree diagram  
suppressed



Loop (“penguin”)  
diagram dominant

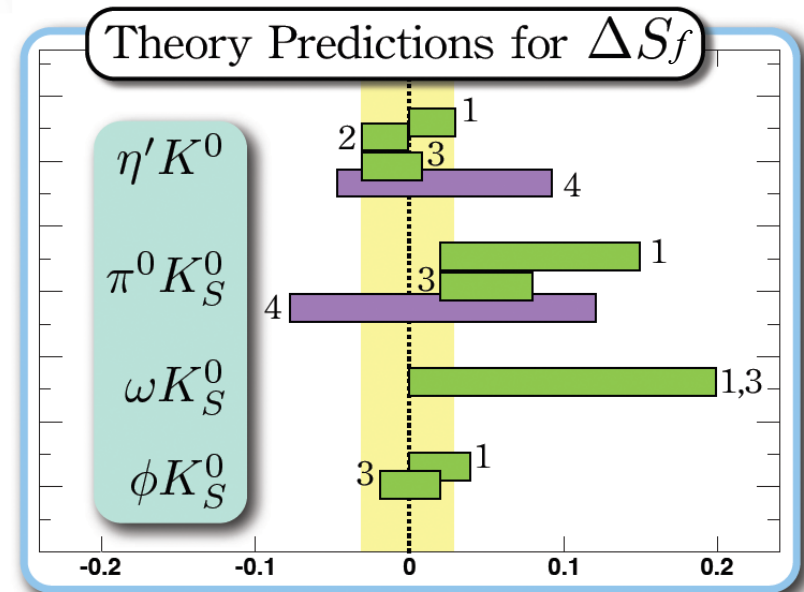


- Alternative measurement of  $\sin 2\beta$
- Contributions from suppressed diagrams with different weak phase produce deviation  $\Delta S_f = S_f - \sin 2\beta$ 
  - $\sin 2\beta$  well constrained from charmonium decays
  - Theoretical constraints on  $\Delta S_f$



# Standard Model Effects

- In SM  $\Delta S_f$  expected small and **mode dependent**
- Some predictions give unsigned intervals
- Deviation from SM expectation if large  $\Delta S_f$  is found
  - Deviation in single modes

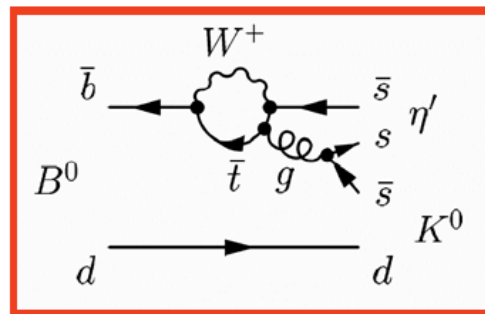


- <sup>1</sup>QCDF Beneke, PLB620, 143 (2005)  
<sup>2</sup>SCET/QCDF Williamson, Zupan, PRD74, 014003 (2006)  
<sup>3</sup>QCDF Cheng, Chua, Soni, PRD72, 014006 (2005)  
<sup>4</sup>SU(3) Gronau, Rosner, Zupan, PRD74, 093003 (2006)

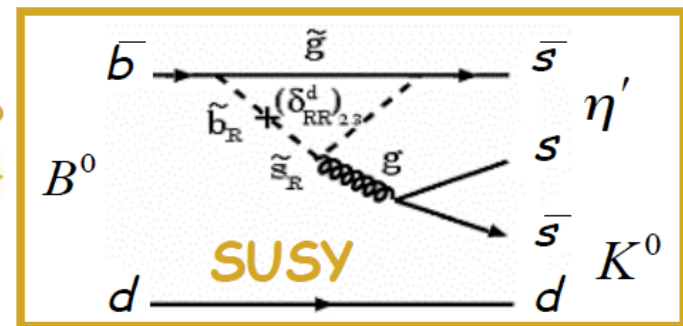
From J. Hirschauer talk @ ICHEP08

# New Physics Effects

- Penguins modes are sensitive to New Physics (NP) contribution: new heavy particles in the loop could give large value of  $\Delta S$ , not explained by the SM (Buchalla et al., JHEP 0509,074(2005))



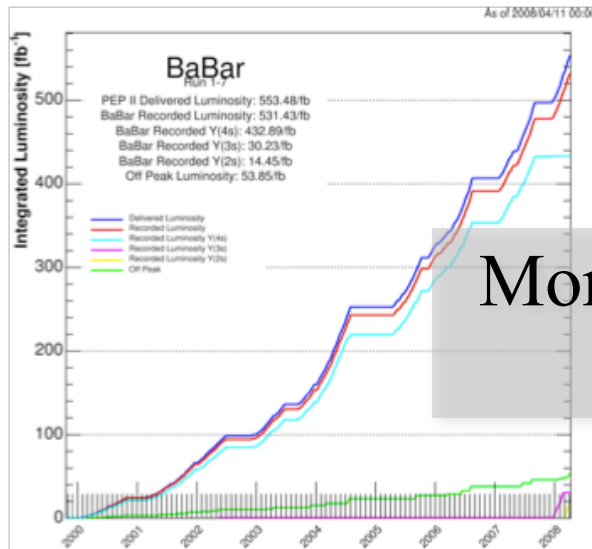
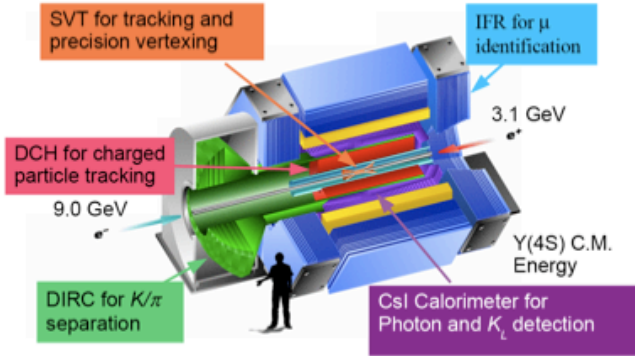
Loop (penguin) diagram dominated



Possible contribution from New Physics (NP): new heavy particles in the loop

- Clear NP effect is large deviation is found in **single modes**

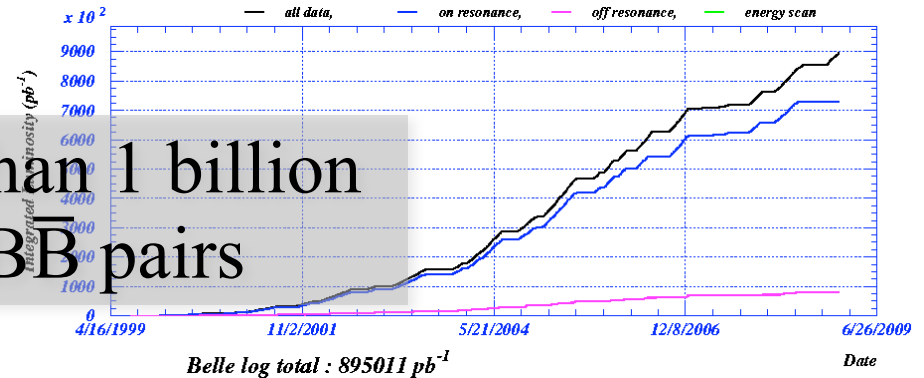
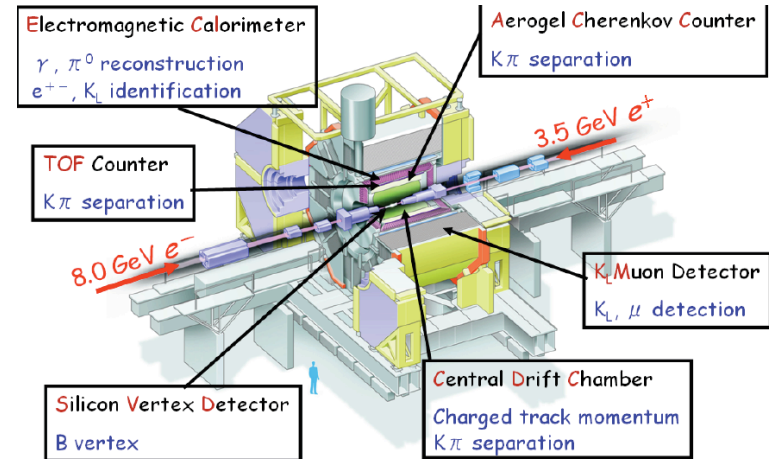
# BaBar-PEP II @ SLAC



More than 1 billion  
of  $B\bar{B}$  pairs

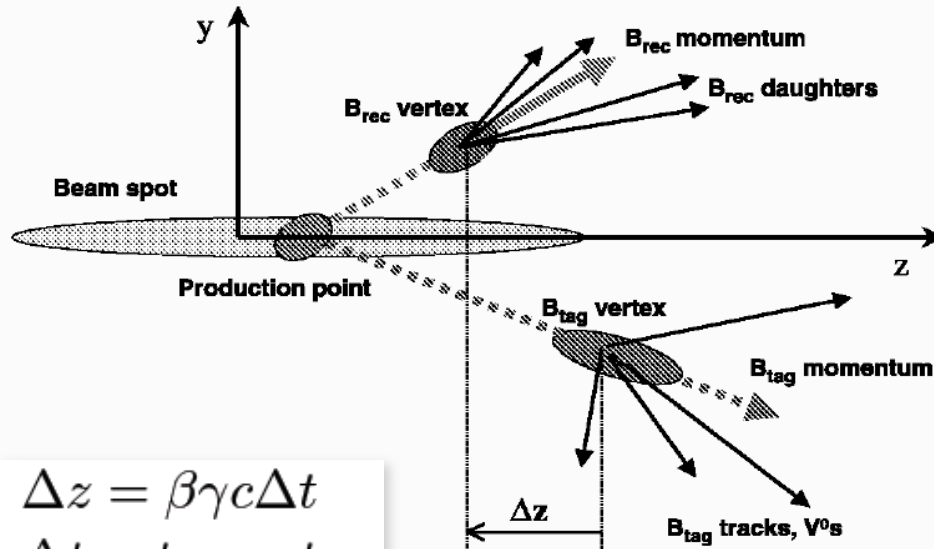


# Belle-KEKB @ KEK





# B $\bar{B}$ Time Evolution



Fully reconstructed  $B$ : signal

Partial reconstructed  $B$ :  
identify his flavor using a  
tagging algorithm

$$\Delta z = \beta\gamma c\Delta t$$

$$\Delta t = t_{CP} - t_{tag}$$

Decay rate  $f_+$  for  $B_{CP} \rightarrow f$  when  $B_{tag}$  is a  $B^0$  ( $\bar{B}^0$ ):

$$f_{\pm}(\Delta t) = \frac{e^{-|\Delta t|/\tau}}{4\tau} [1 \pm (-\eta_f S_f \sin(\Delta m_d \Delta t) - C_f \cos(\Delta m_d \Delta t))] \quad (\eta_f \text{ is } CP \text{ eigenvalue})$$

(to be modify for experimental  $\Delta t$  resolution and tagging performance)

# Analysis Method

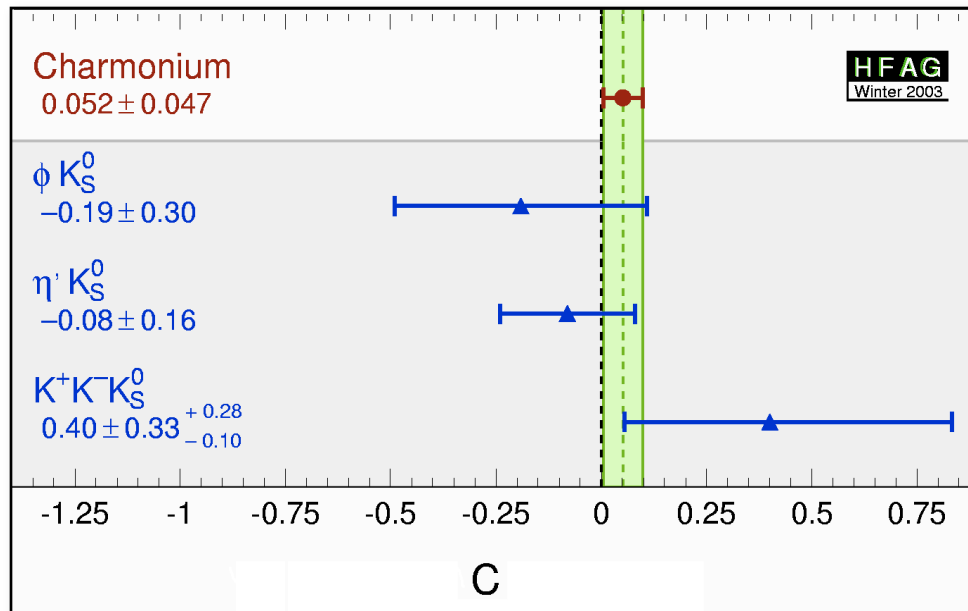
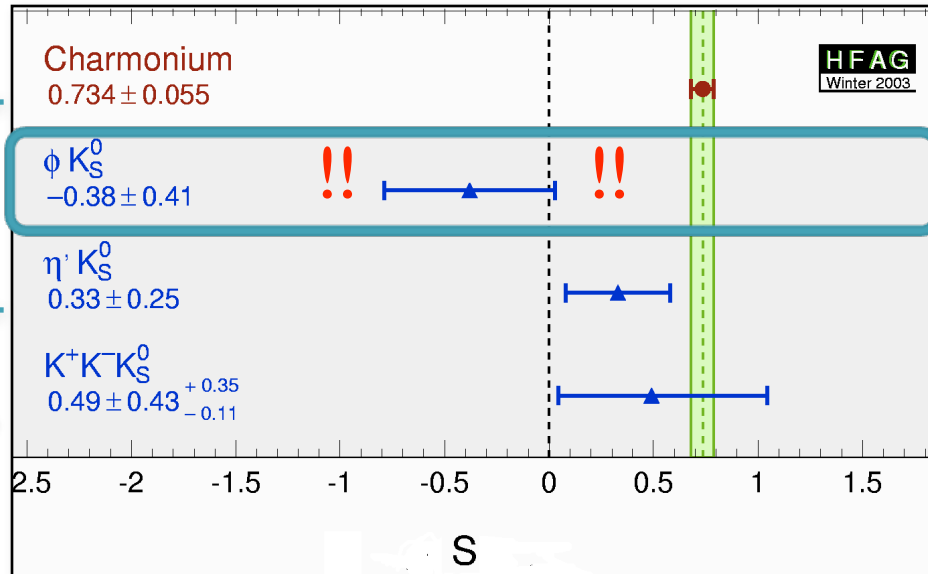
- Maximum likelihood fits to extract the signal parameters
- Based on Quasi-two-body (Q2B) or Dalitz plot analyses (for 3 body decays  $KKK^0$  and  $\pi\pi K^0$ )
  - parameters  $S_f$  and  $C_f$  from a ML fit on  $\Delta t$  variable
  - Dalitz plot analysis allows to extract directly the several TD parameters for the Q2B resonances and to resolve the trigonometric ambiguity in the measurement of  $\beta$
- Reconstructed several sub-decays for each mode in order to increase the statistics (e.g.  $K^0$  in  $K_S^0$  and  $K_L^0$ ,  $K_S^0$  in neutral and charged pions)

# Winter 2003: 3 modes studied

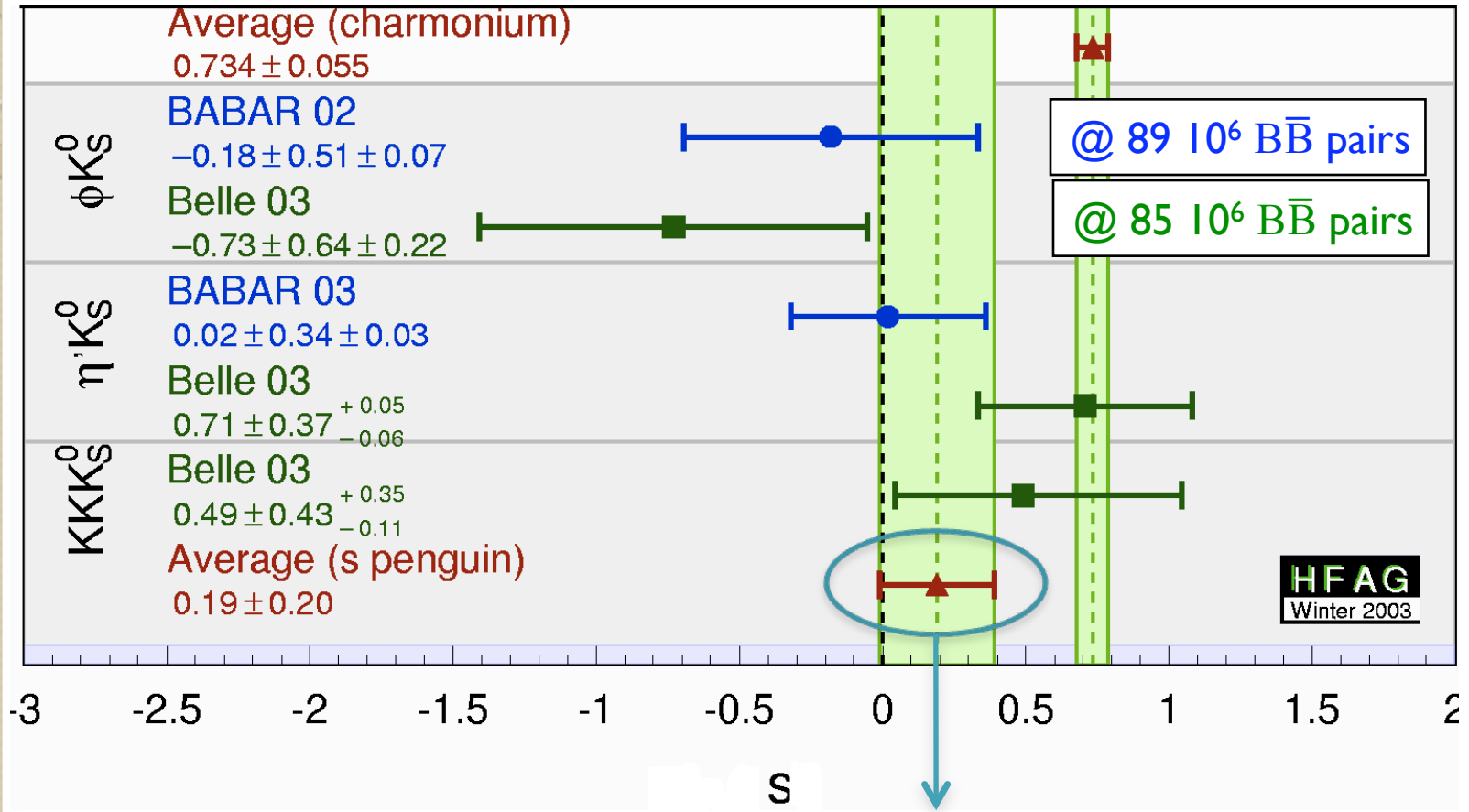
Q2B analysis

Excluding  $\phi$  mass region.  
Main contribution so  
systematic due to CP  
content of the final state

No Direct CP

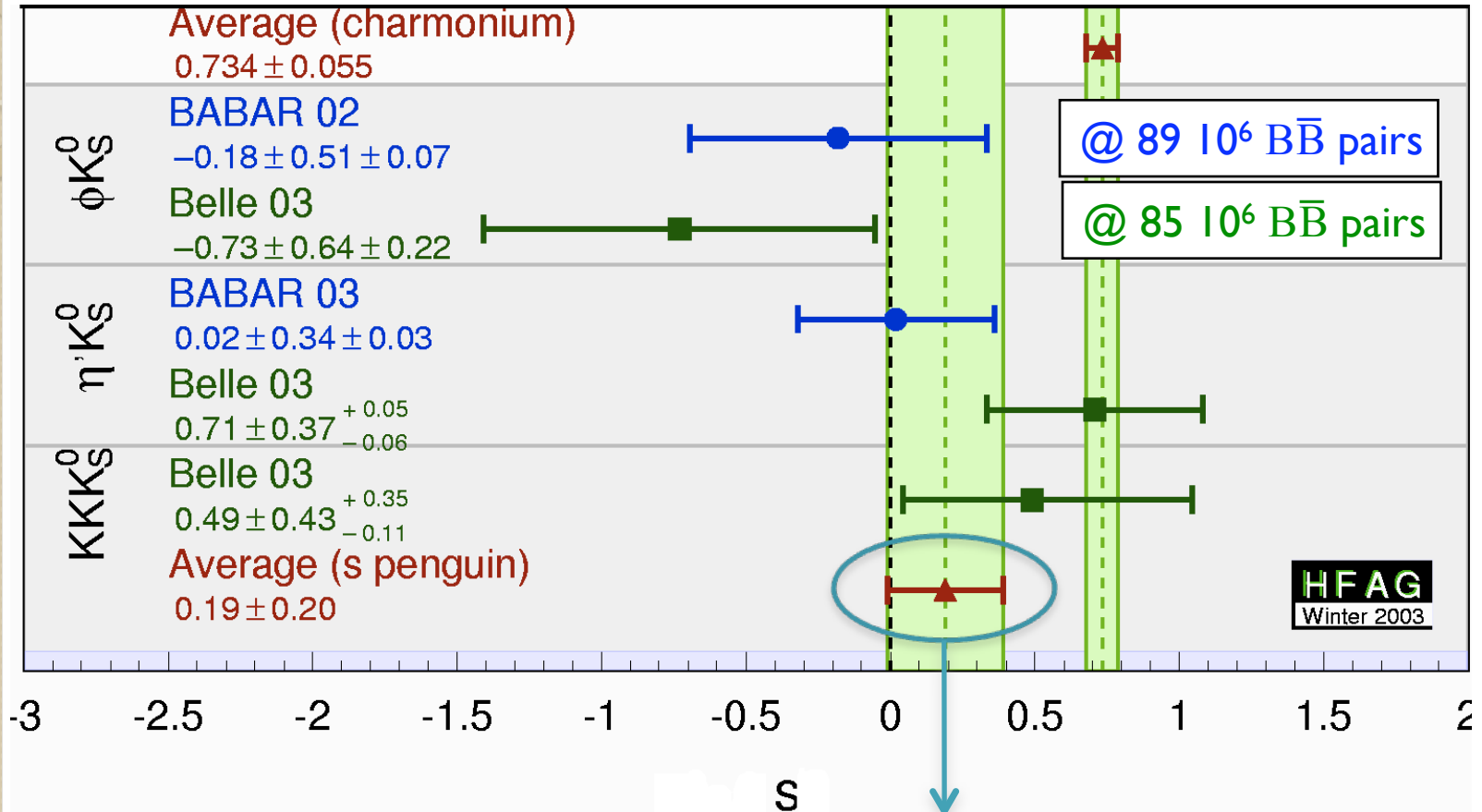


# 2003: details



Average does not consider theoretical uncertainties and correlated systematic errors!!!

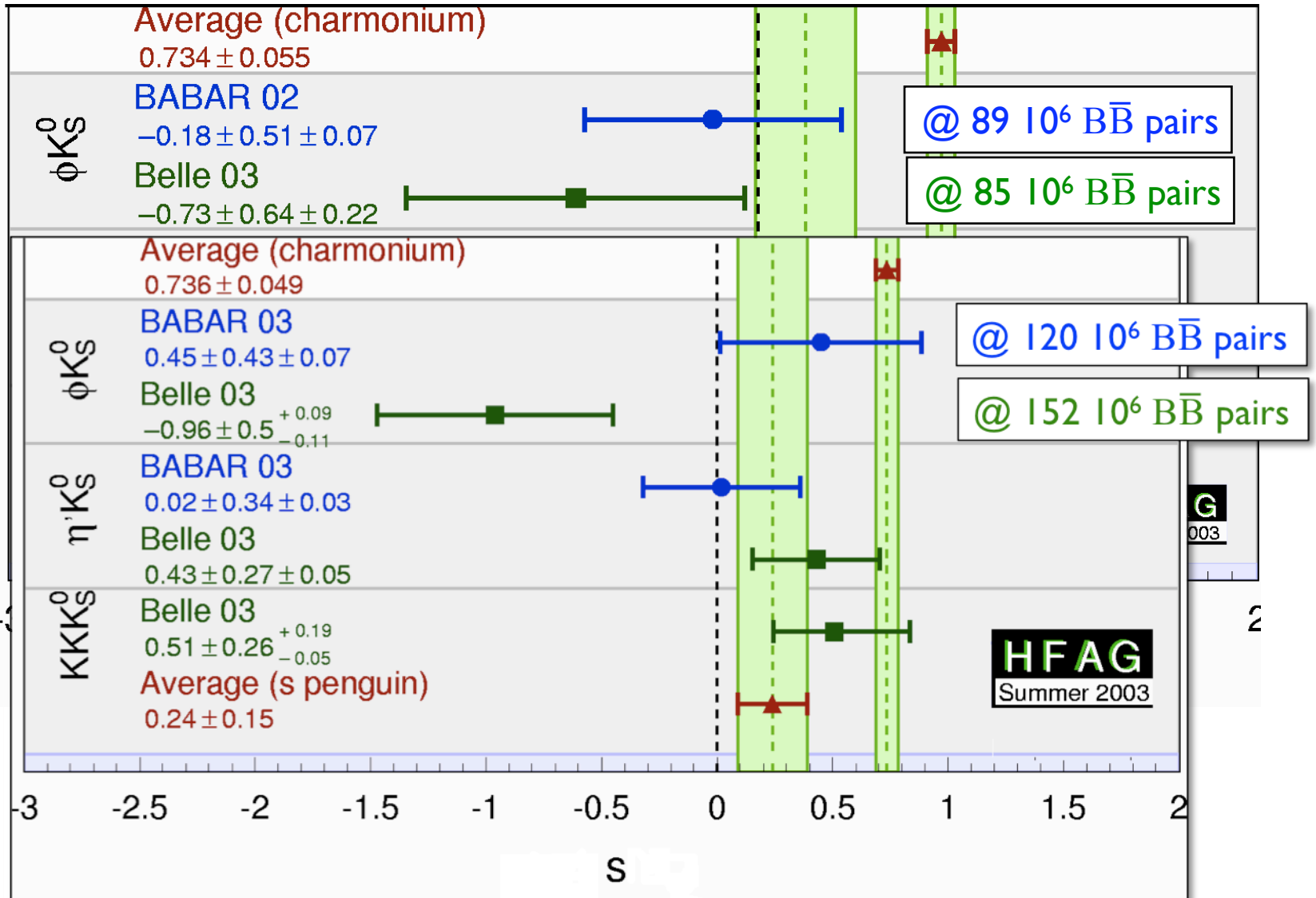
# 2003: details



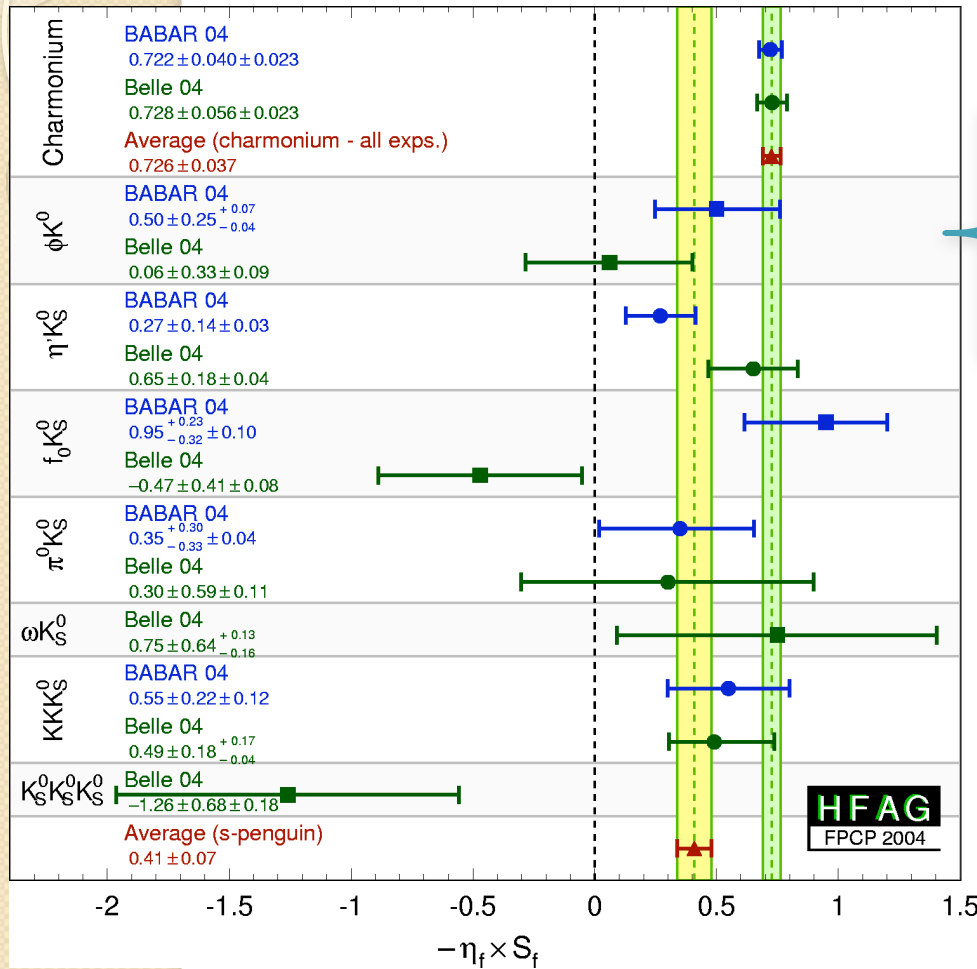
Average does not consider theoretical uncertainties and correlated systematic errors!!!



# 2003: details



# New modes in Summer 2004



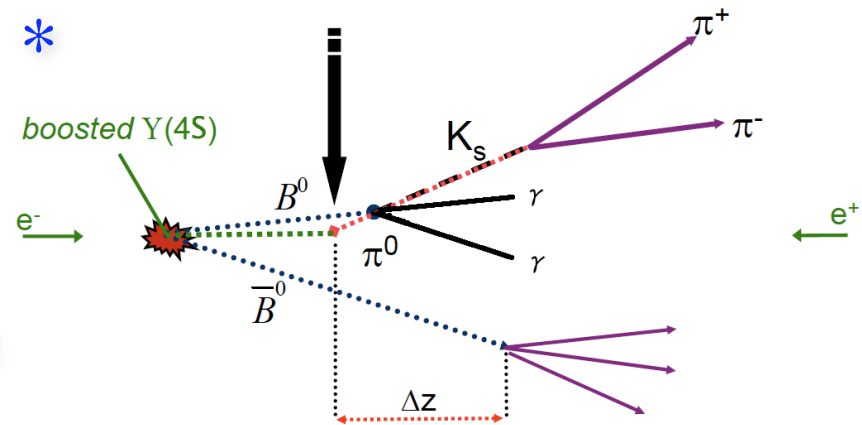
Q2B analyses (S wave contribution considered in the systematics)  
 Added  $K_L^0$  mode (opposite CP eigenvalue of  $K_S^0$ )

Quasi 2-body analyses with  $f_0(980) \rightarrow \pi^+ \pi^-$

\*

Q2B analysis, excluding  $\phi$  mass region

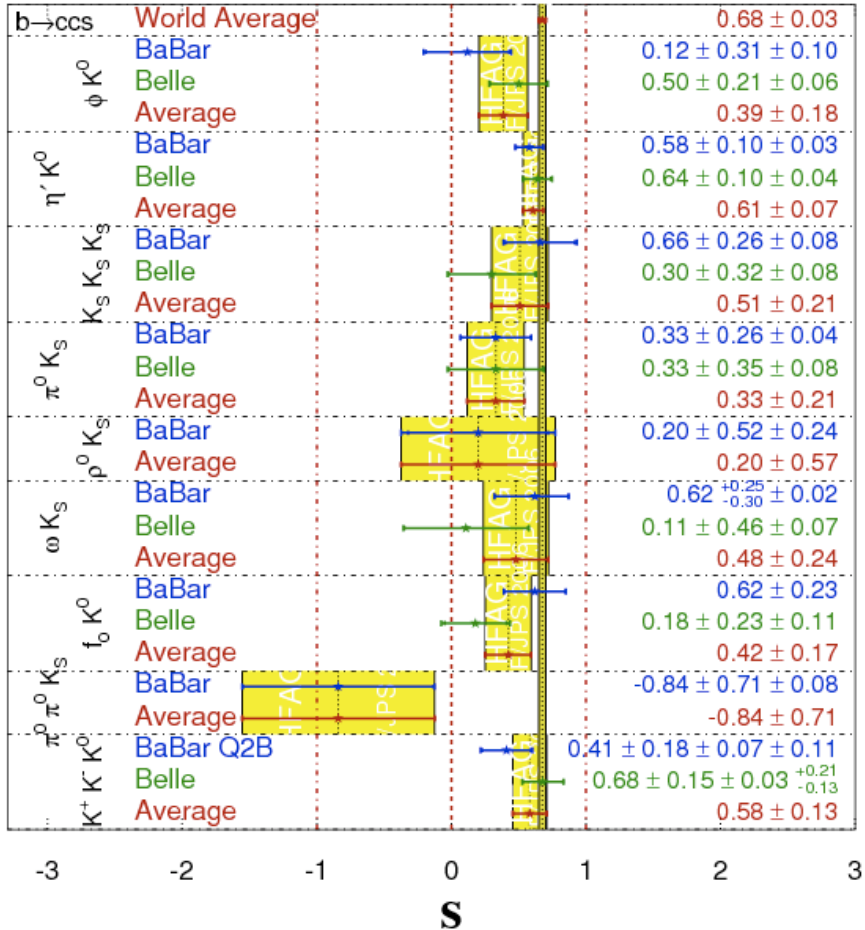
\*



\*  $B^0 \rightarrow \pi^0 K_S^0$ : B vertex decay reconstructed for  $K_S^0$  and boost trajectories (2003)

# 2006: CP violation observation

**HFAG**  
DPF/JPS 2006  
PRELIMINARY



BaBar: TD Dalitz plot analysis of  $K^+ K^- K^0$   
 Belle: Q2B analysis  
**← CP Violation observation!!!**

Q2B analysis

BaBar & Belle: Q2B analysis for  $f_0 \rightarrow \pi^+ \pi^-$   
 BaBar:  $f_0 \rightarrow K^+ K^-$  Dalitz plot &  
 $f_0 \rightarrow \pi^+ \pi^-$  Q2B

Q2B analysis, excluding  $\phi$  mass region

# $\eta' K^0$ mode (last update)

- Large BF ( $65 \times 10^{-6}$ ) yields small errors on  $S_f$  and  $C_f$ .

7 decay channels:

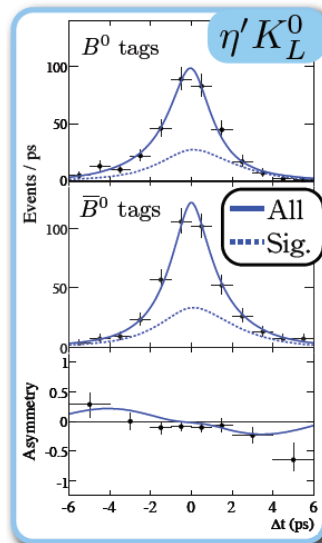
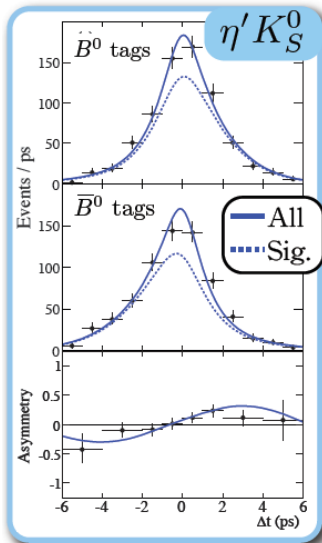
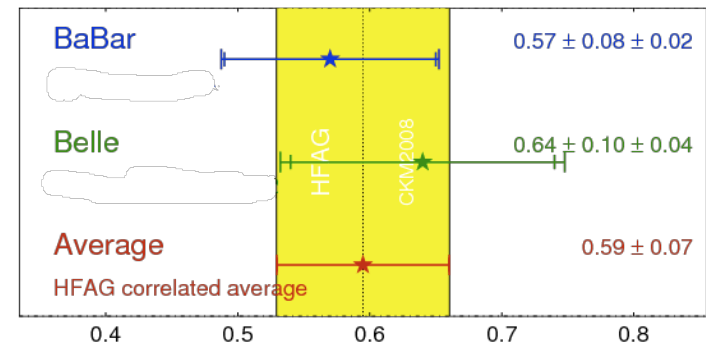
$$\eta'(\rho\gamma, \eta_{\gamma\gamma}\pi^+\pi^-, \eta_{3\pi}\pi^+\pi^-) K_S(\pi^+\pi^-)$$

$$\eta'(\rho\gamma, \eta_{\gamma\gamma}\pi^+\pi^-) K_S(\pi^0\pi^0)$$

$$\eta'(\eta_{\gamma\gamma}\pi^+\pi^-, \eta_{3\pi}\pi^+\pi^-) K_L$$

$\eta' K^0 S_{CP}$

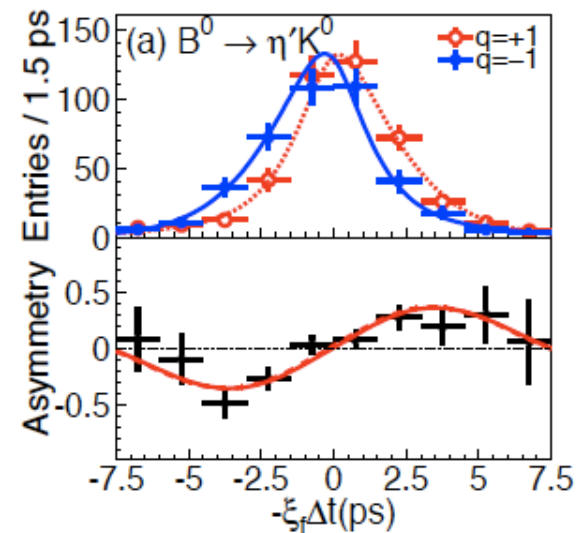
**HFAG**  
CKM2008  
PRELIMINARY



2500 signal events

14/4/09

Alfio Lazzaro

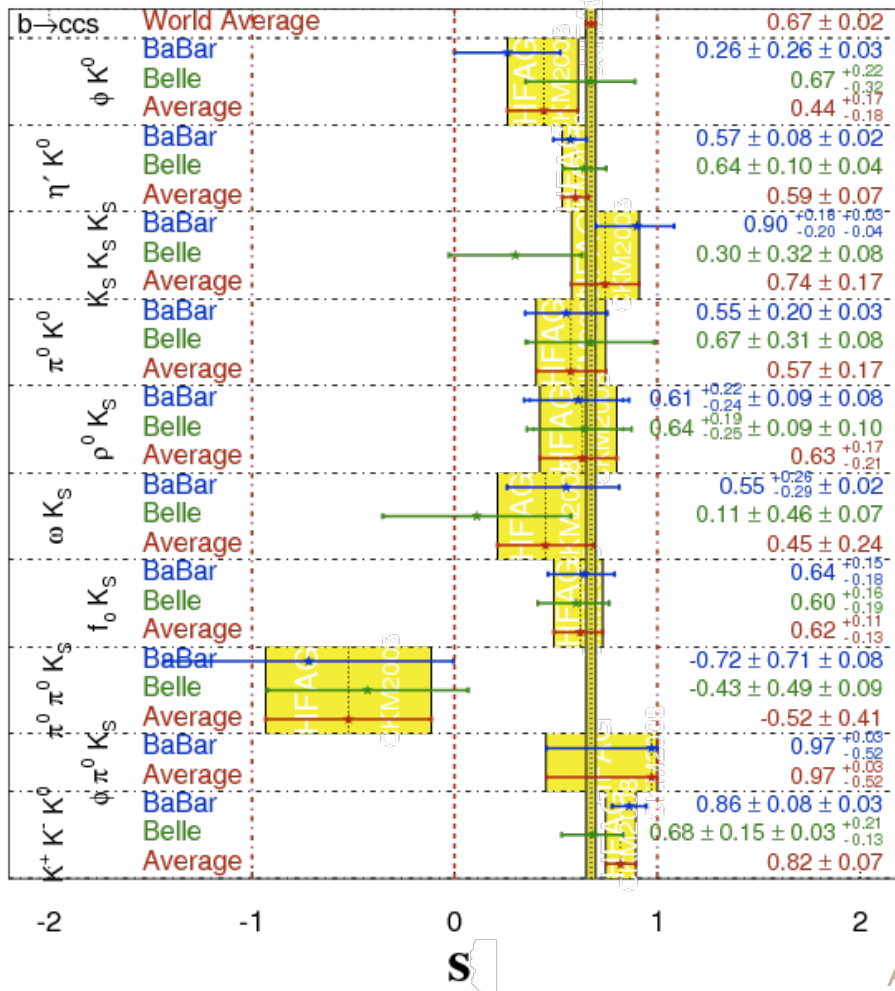


1900 signal events



# Last Updates (2008): S

**HFAg**  
CKM2008  
PRELIMINARY



Good agreement between the two experiments

TD Dalitz plot analysis of  $K^+K^-K^0$

← Same error as 2003 charmonium measurement

TD Dalitz plot analysis of  $\pi^+\pi^-K^0_S$

TD Dalitz plot analysis of  $K^+K^-K^0$  &  $\pi^+\pi^-K^0_S$

← Large Error

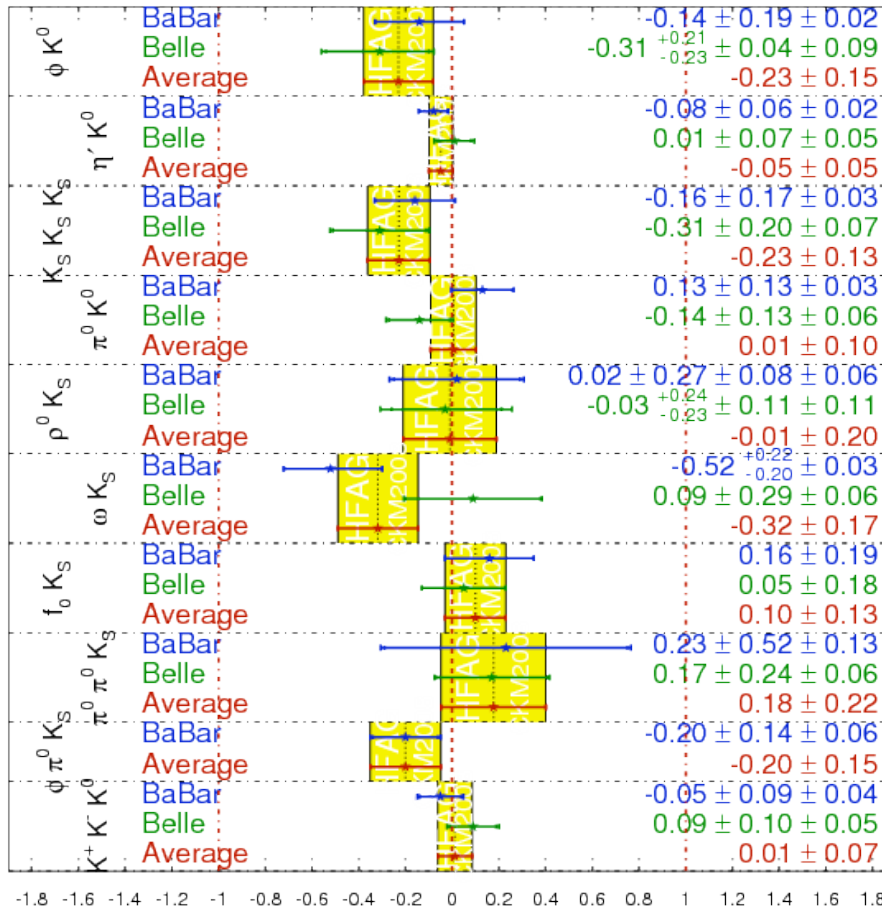
← Last mode added to the penguin “family” (angular analysis)



# Last Updates (2008): C

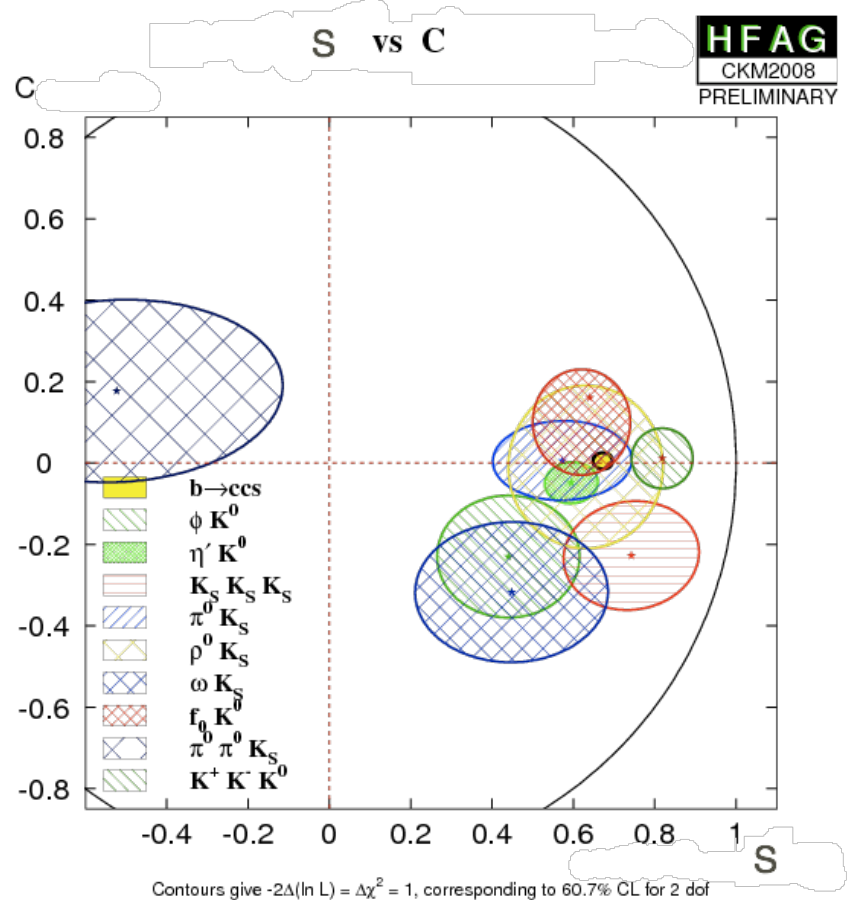
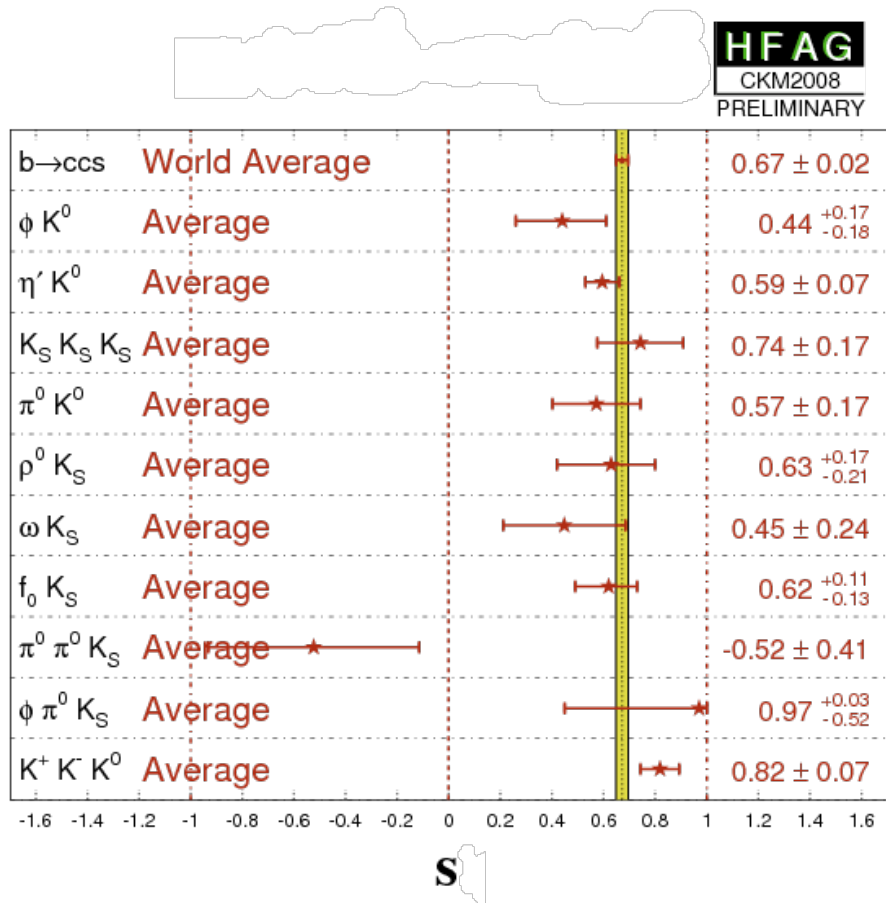
$$C_f = -A_f$$

**HFAG**  
CKM2008  
PRELIMINARY



Agreement between the two experiments

# Last Updates (2008): Averages



Good agreement with SM expectation

# Conclusion

- Impressive achievements in time-dependent analysis for penguin modes
  - Many modes studied
  - Complex analyses, with several improvements over the years
  - Measurements still statistically limited
- Results in agreement with SM expectations
- We experienced several fluctuations in the past years
  - Lesson 1: more and more data needed
- More updates from Babar, using final dataset, and Belle expected in the future, but not enough (I think) to find something new
  - Lesson 2: more and more data needed