Experimental status of the CKM matrix

A personal (and biased!) selection of topics

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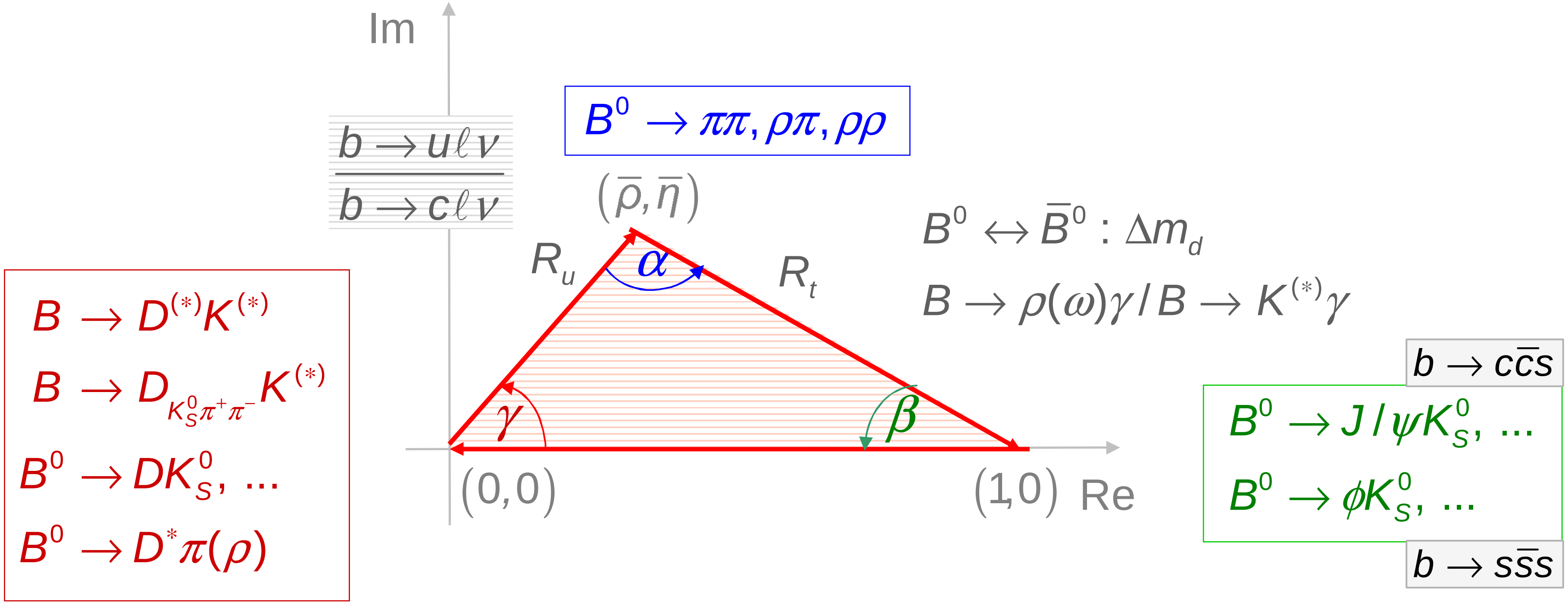
This talk

- Many subjects to choose from !
  - we had excellent discussions on V_{ub} and B_S .. skip
  - concentrate on tests of CKM angles as of today
  - A few words on the physics potential of K physics
  - Quasi-backup : places where the global CKM fit hints at ~2σ effects

The case for the B factories



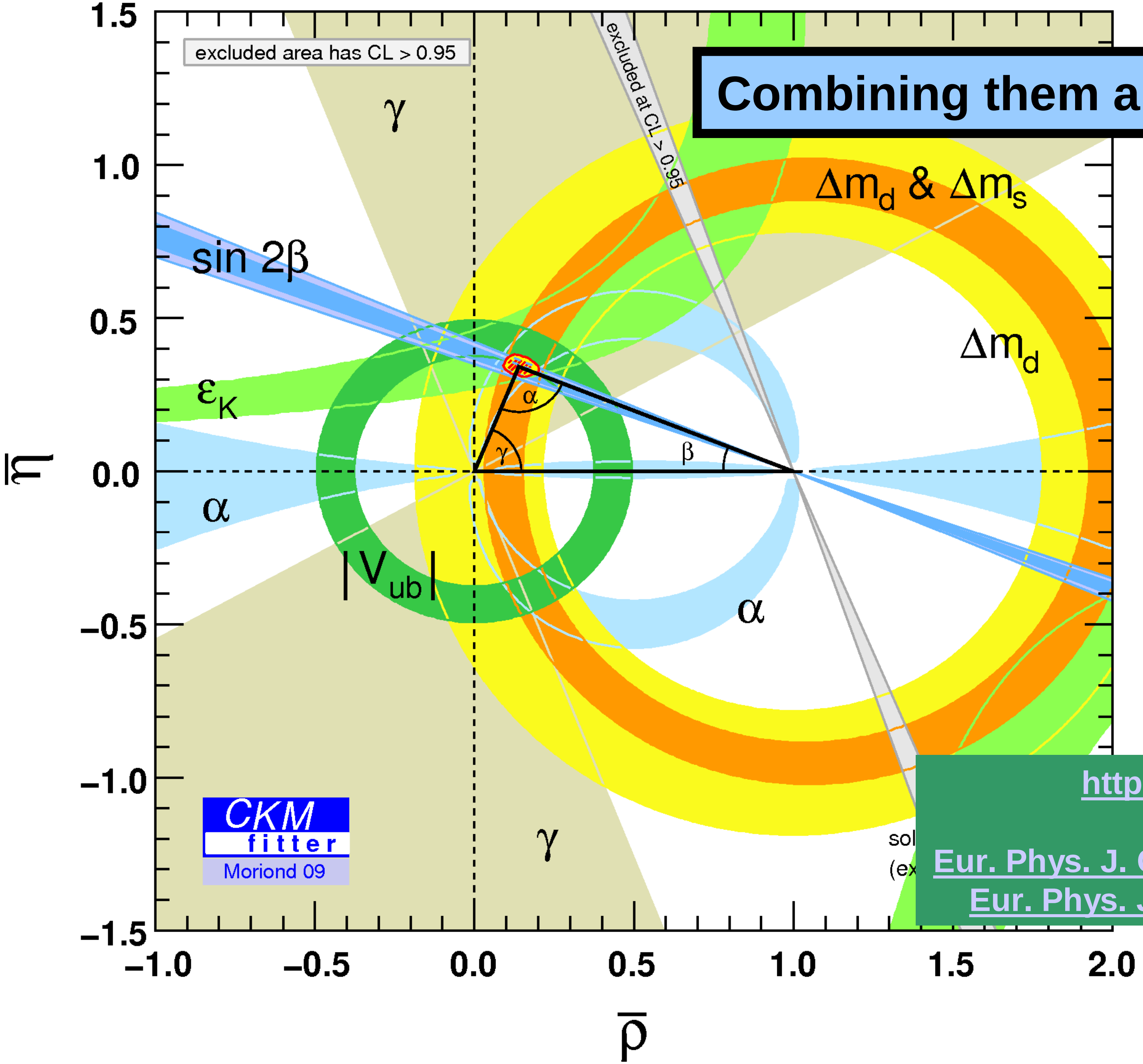
Several CKM-related observables can be accessed by studying B decays

- **overconstrain UT sides and angles**

The CKM mechanism predicts specific correlation patterns :

- **Any deviation from CKM would be a sign of non-SM physics !**
- **The structure of these deviations could teach us about New Physics**

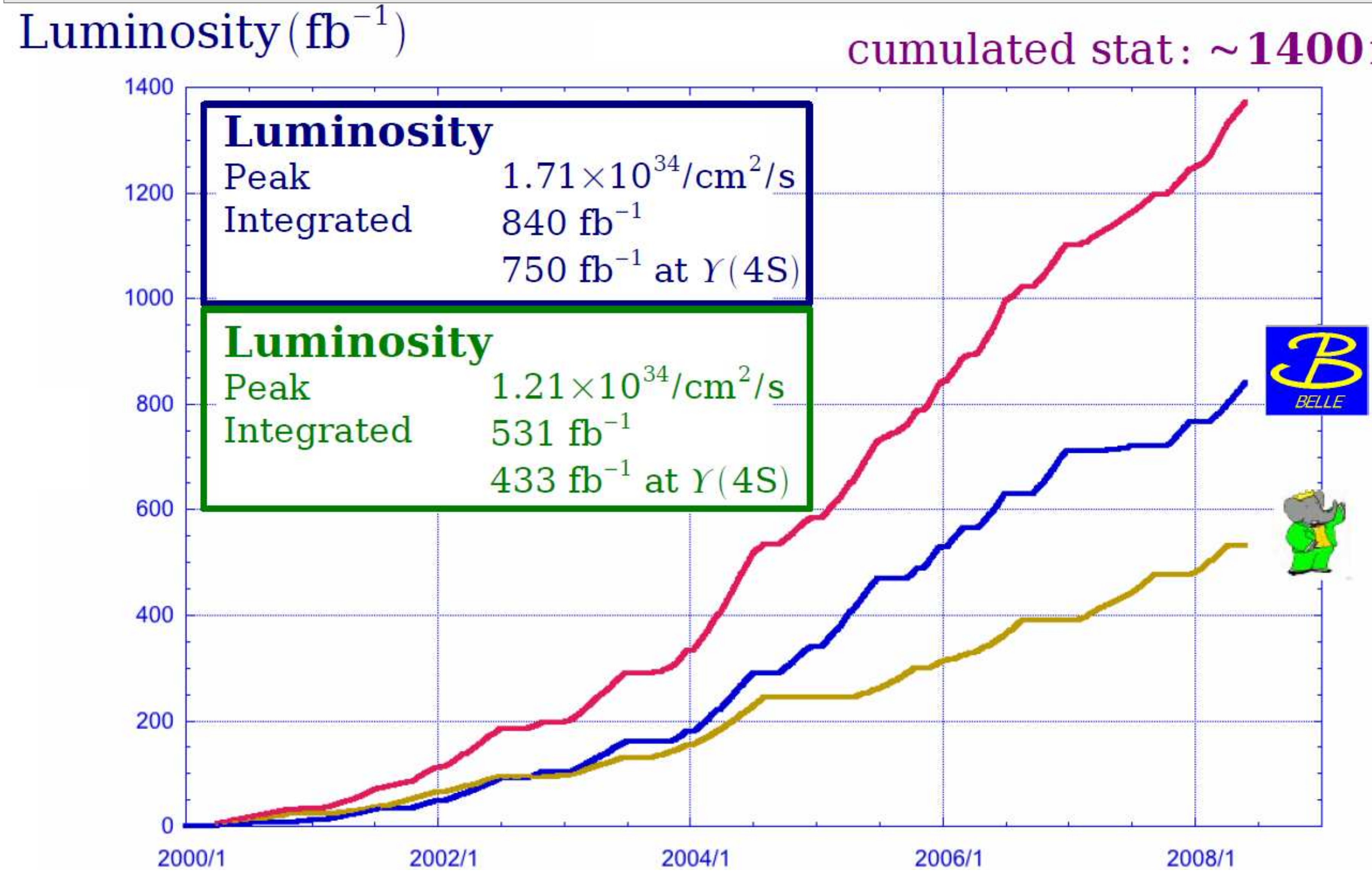
Combining them all together…



http://ckmfitter.in2p3.fr

Eur. Phys. J. C21, 225-259 (2001)
Eur. Phys. J. C41, 1-131 (2005)

cumulated stat: ~**1400 fb^{-1}**



BaBar: $\sim 465\times10^6 B\bar{B}$ pairs = final sample

Belle: $\sim 657\times10^6 B\bar{B}$ pairs = max. current sample (final sample will probably be $\sim 800\times10^6 B\bar{B}$ pairs)

Experimental Technique : time-dependent CP asymmetries

- *CP* Violation due to the interference of decays with and without mixing

$$\text{Prob}(\overline{B}^0(t) \to f_{CP}) \neq \text{Prob}(B^0(t) \to f_{CP})$$

- Direct *CP* Violation due to interference of decay amplitudes with different weak and strong phases

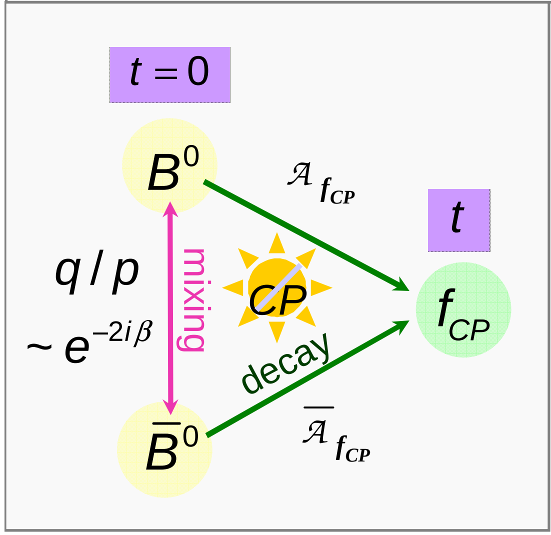
$$\text{Prob}(\overline{B} \to \overline{f}) \neq \text{Prob}(B \to f)$$

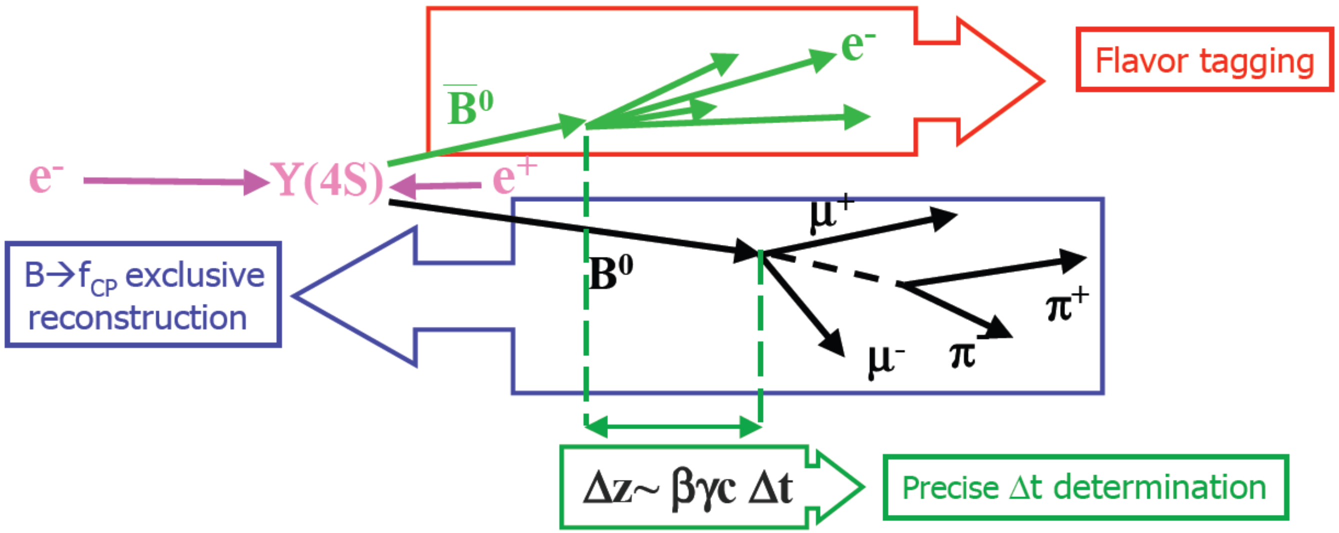
- Time-dependent CP asymmetries :

$$\frac{\Gamma(\overline{B}^0(t) \to f_{CP}) - \Gamma(B^0(t) \to f_{CP})}{\Gamma(\overline{B}^0(t) \to f_{CP}) + \Gamma(B^0(t) \to f_{CP})} = S_{f_{CP}} \sin(\Delta m_d t) - C_{f_{CP}} \cos(\Delta m_d t)$$

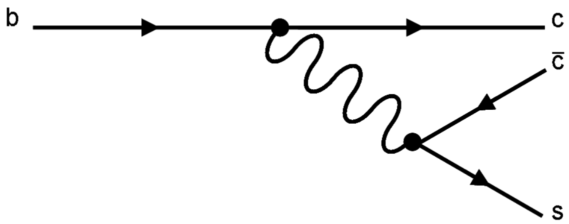
for $b \to c\bar{c}s$ **modes ("golden")**
i.e. $(B^0 \to J/\psi K^0_s)$

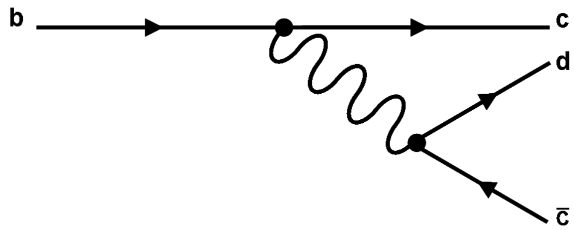
$$S_{f_{CP}} = \sin 2\beta \qquad C_{f_{CP}} = 0$$

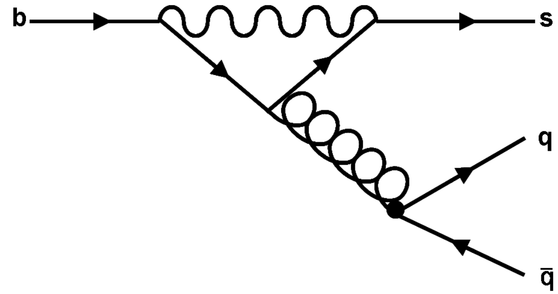




The path to β : reference decay modes







b→cc̄s

(charmonium)
Tree dominance
"golden modes"

b→cc̄d

(charmonium, open charm)
Tree dominance
Loops may contribute

b→qq̄s

(charmless)
Penguin dominance :
sensitive to non-SM loops
Beware of "tree pollution"

$S = \sin 2\beta, C = 0$

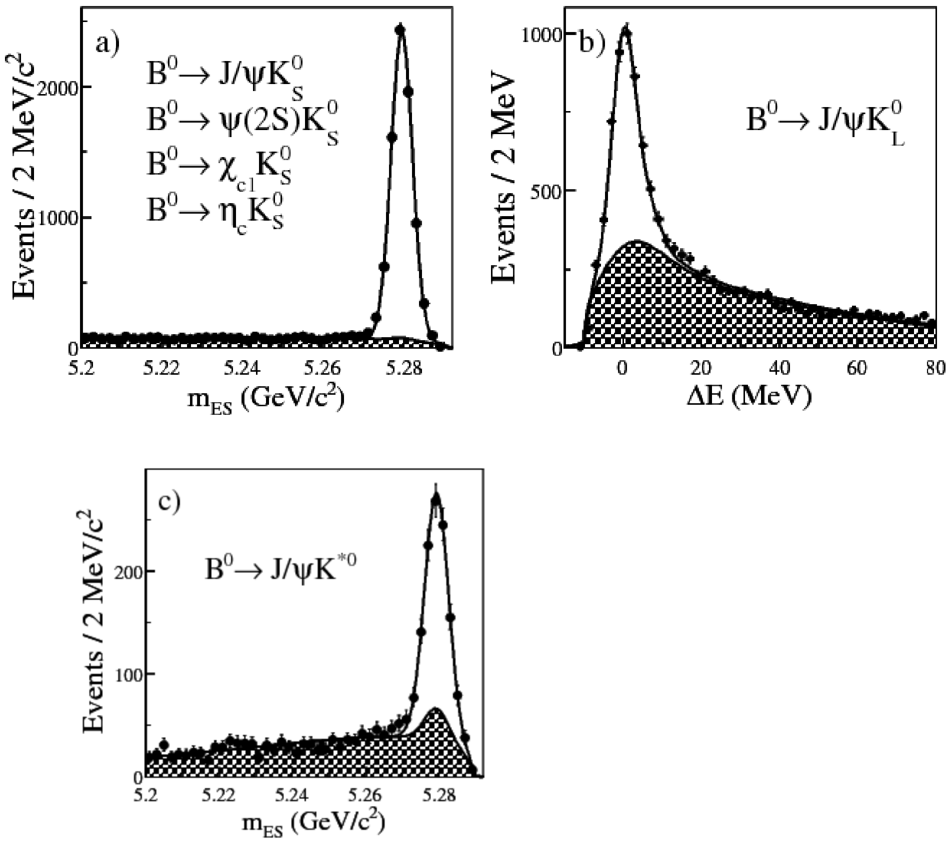
$S \sim \sin 2\beta, C \sim 0$

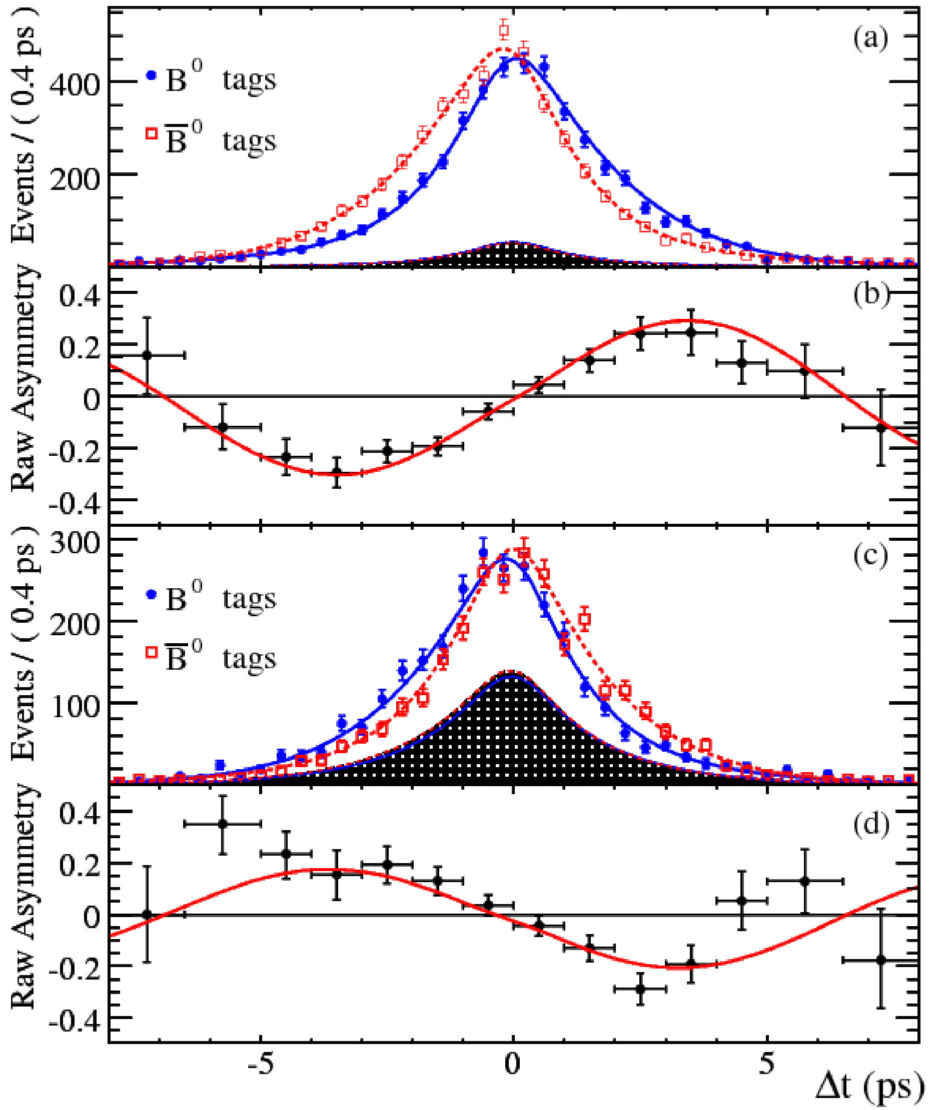
$$J/\psi K^0_S \quad , \quad \psi(2S) K^0_S$$
$$\chi_{c1} K^0_S \quad , \quad \eta_c K^0_S$$
$$J/\psi K^0_L \quad , \quad J/\psi K^{*0}$$

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

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

The path to β *with* $b\to c\bar{c}s$

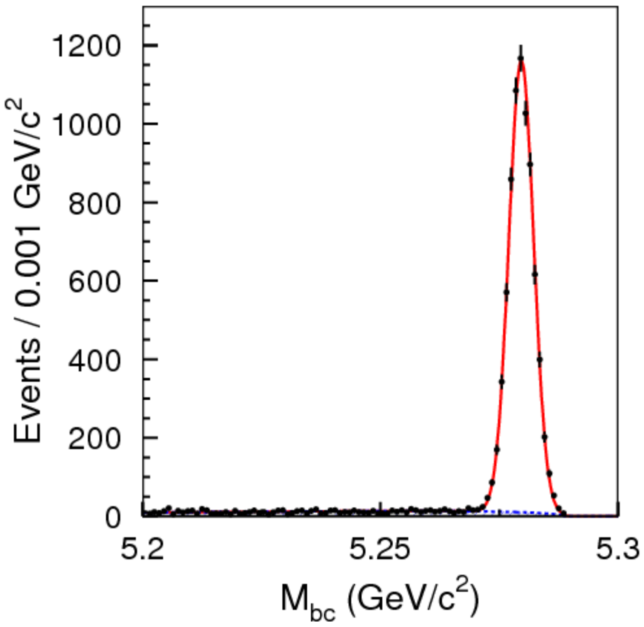


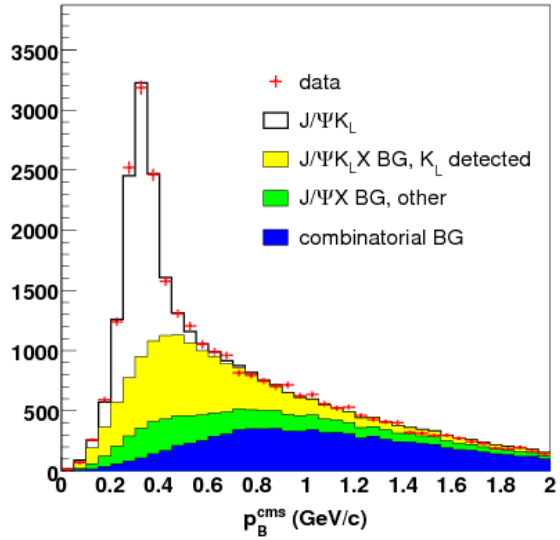


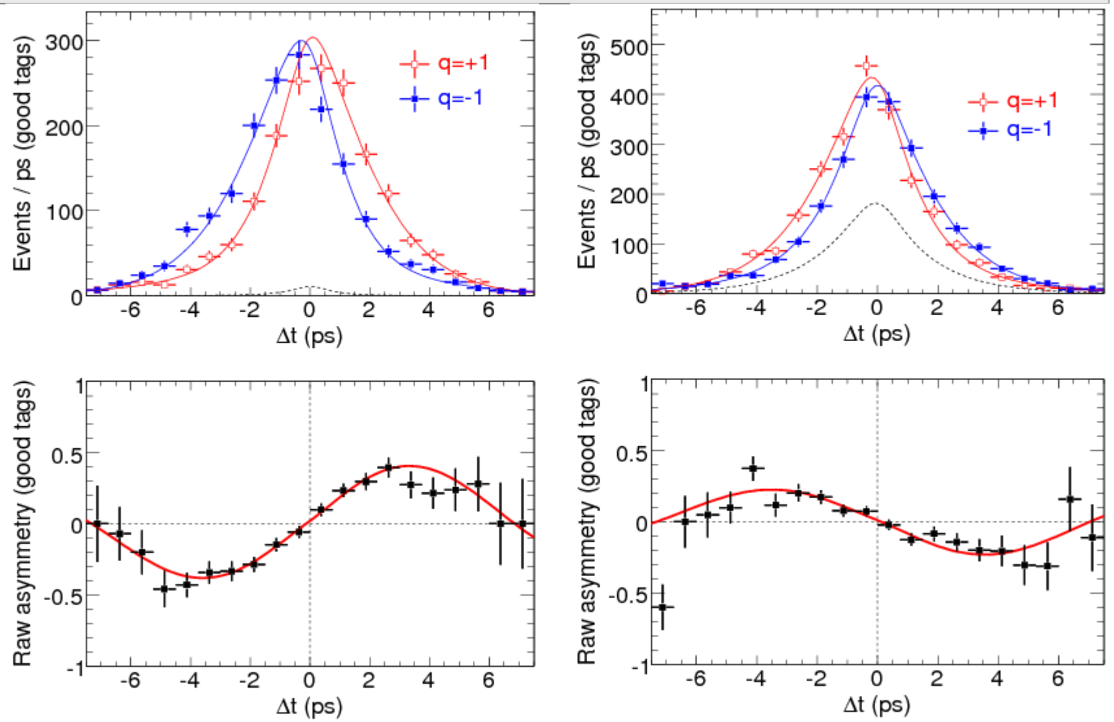
BABAR arXiv : 0902.1708 $465\times10^6 B\bar{B}$

$$c\bar{c}K^{(*)0} \quad : \quad \sin 2\beta = 0.687 \pm 0.028 \pm 0.012$$

The path to β *with* b→c$\bar{c}$s







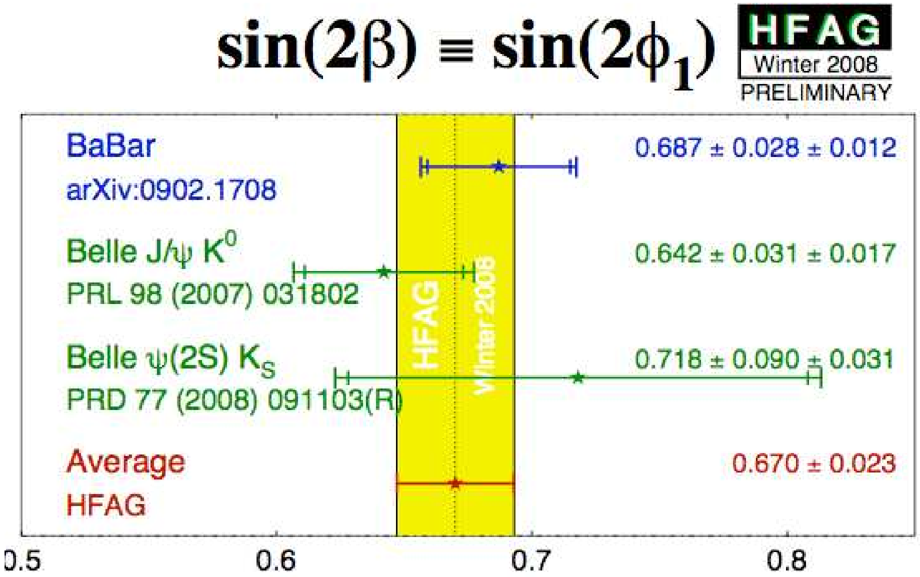
$BELLE$ PRL 98 (2007) 031802 $535 \times 10^6 B\bar{B}$

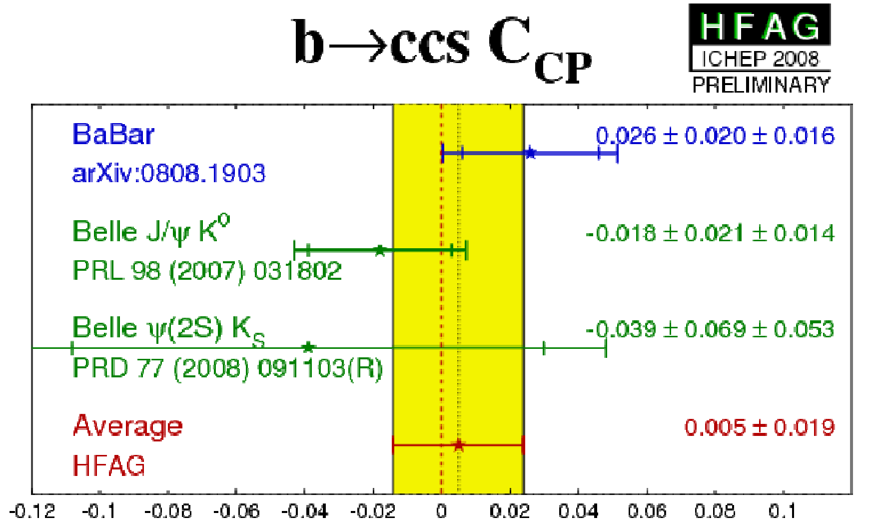
PRD 77 (2008) 091103 $657 \times 10^6 B\bar{B}$

$$J/\psi K^0 \quad : \quad \sin 2\beta = 0.642 \pm 0.031 \pm 0.017$$

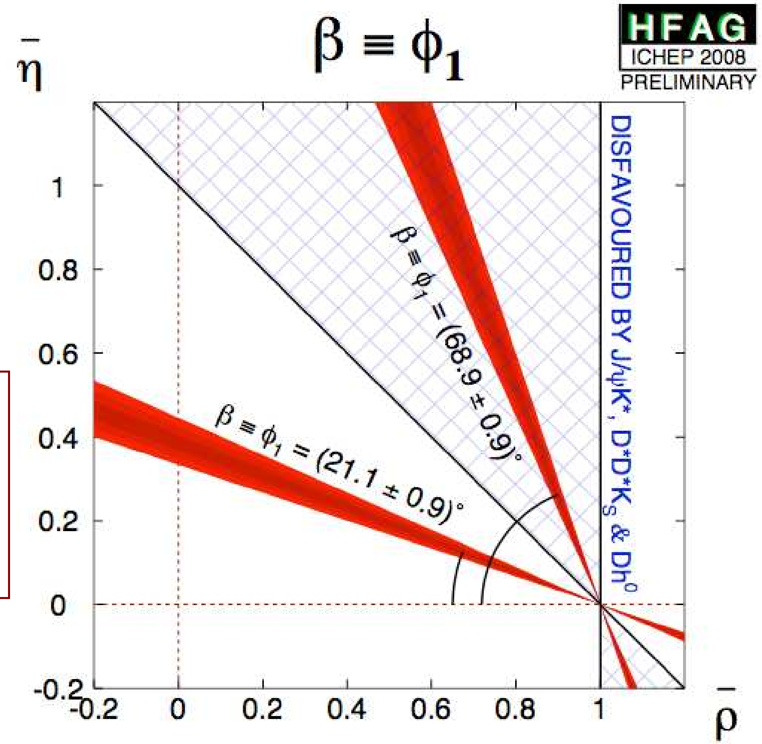
$$\psi(2S) K_S \quad : \quad \sin 2\beta = 0.72 \pm 0.09 \pm 0.03$$

The path to β *with* $b \to c\bar{c}s$





$$\beta(b \to c\bar{c}s) = (21.1 \pm 0.9)^\circ$$

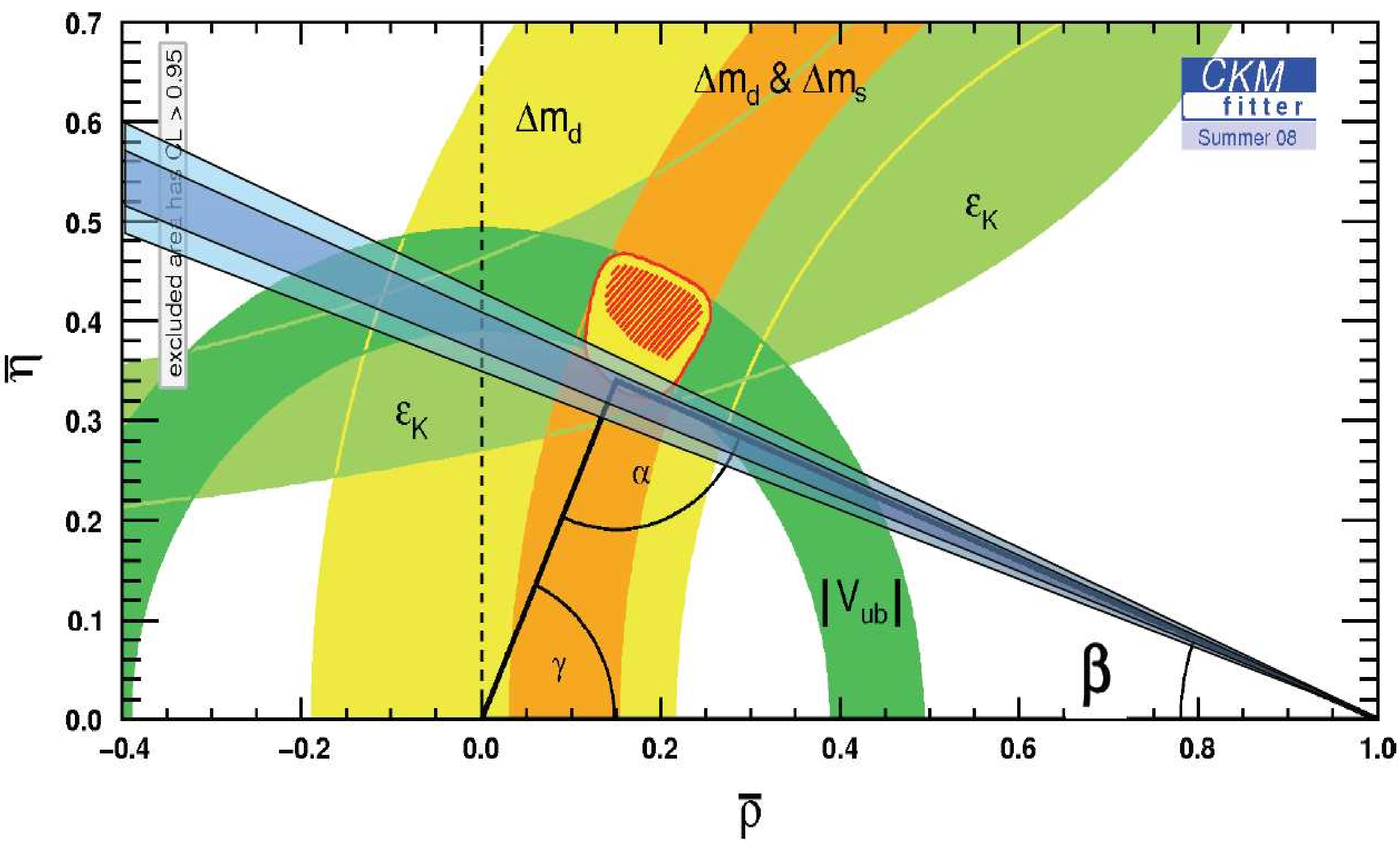


Trigonometric degeneracy in sin(2β) **lifted via**

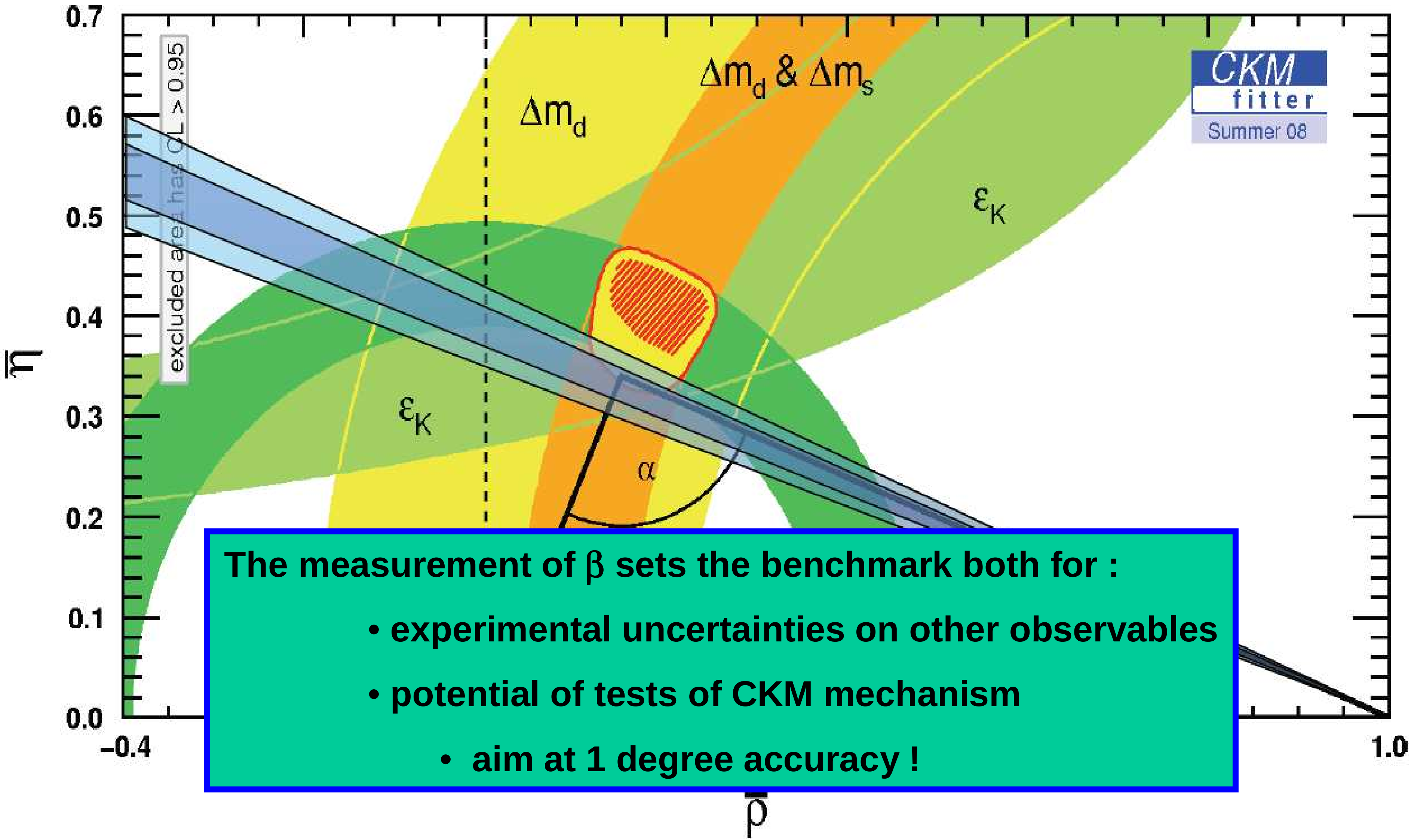
$B \to J/\psi K^*$, $B \to D^*D^*K_S$, $B \to D^{(*)}_{(CP)}h^0$

each having (different levels of) sensitivity to cos(2β)

β : first successful test of CKM



β : first successful test of CKM



The measurement of β sets the benchmark both for :

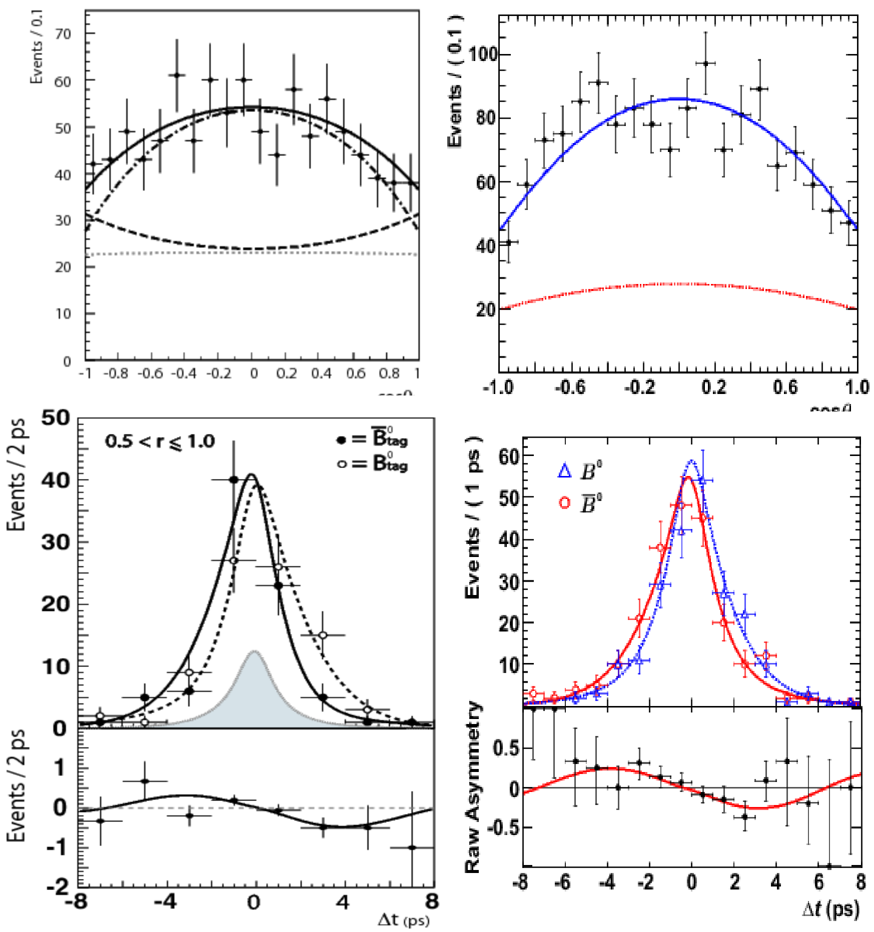
- **experimental uncertainties on other observables**
- **potential of tests of CKM mechanism**
  - **aim at 1 degree accuracy !**

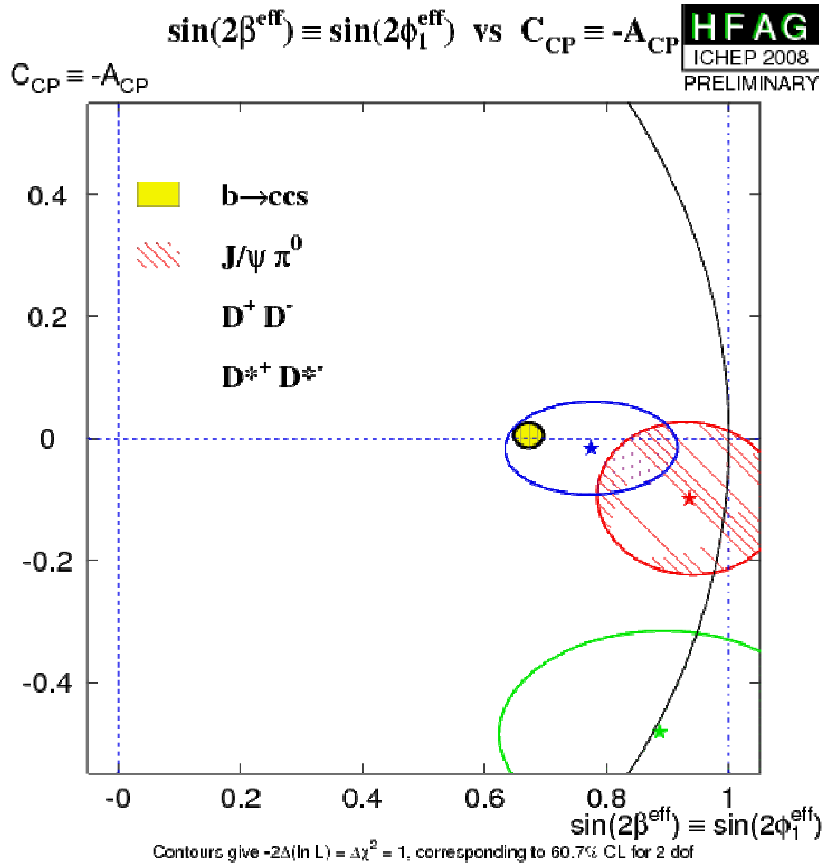
Time-dependent CP asymmetries in $b \to c\bar{c}d$ *modes*

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

V-V decay :

admixture of CP-odd and CP-even





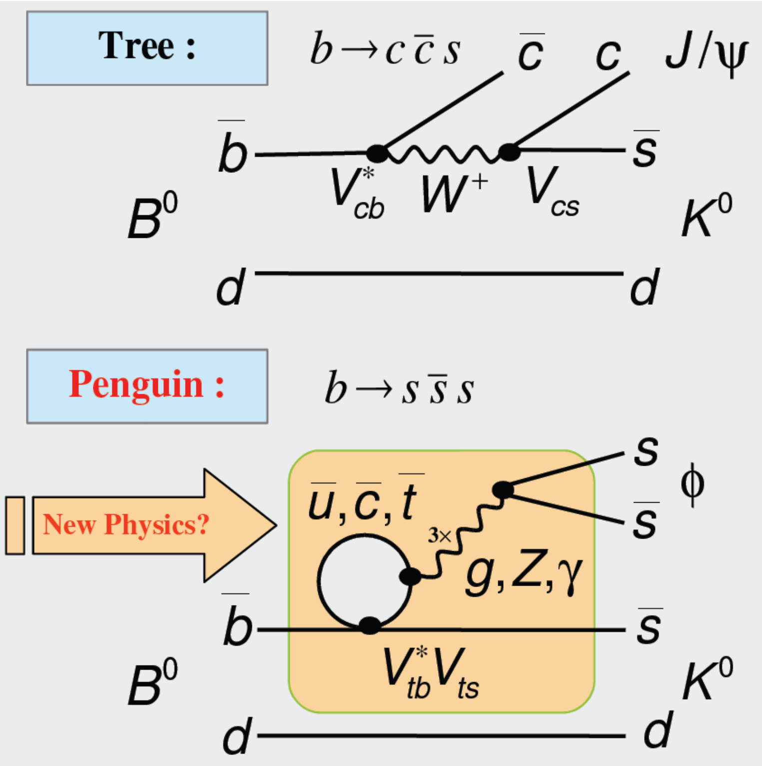
Summary of S,C in $b \to c\bar{c}d$ **modes :**

good agreement with $b \to c\bar{c}s$ **for D*D* ,** $J/\psi\pi^0$

D^+D^- **at physical boundary…**

All limited by statistics

b→s *penguins : loop-dominance*



- b→c$\bar{c}$s :
  - **tree-dominated decays**
  - **penguins carry same weak phase**
- b→q$\bar{q}$s :
  - **pure "internal" or "flavour-singlet" penguins**
  - **dominant phase, same CKM factors as** b→c$\bar{c}$s
  - **high mass scales involved in loops**
  - **non-SM contributions could contribute**
  - **a window to New Physics !**
  - **often, more than one phase involved ("tree pollution")**

Standard Model	New Physics
$S_{q\bar{q}s} = S_{c\bar{c}s} + \Delta S_{SM} = \sin 2\beta$	$S_{c\bar{c}s} + \Delta S_{SM} \neq S_{q\bar{q}s}$
$C_{c\bar{c}s} \sim C_{q\bar{q}s} \sim 0$	$C_{c\bar{c}s} \neq C_{q\bar{q}s}$

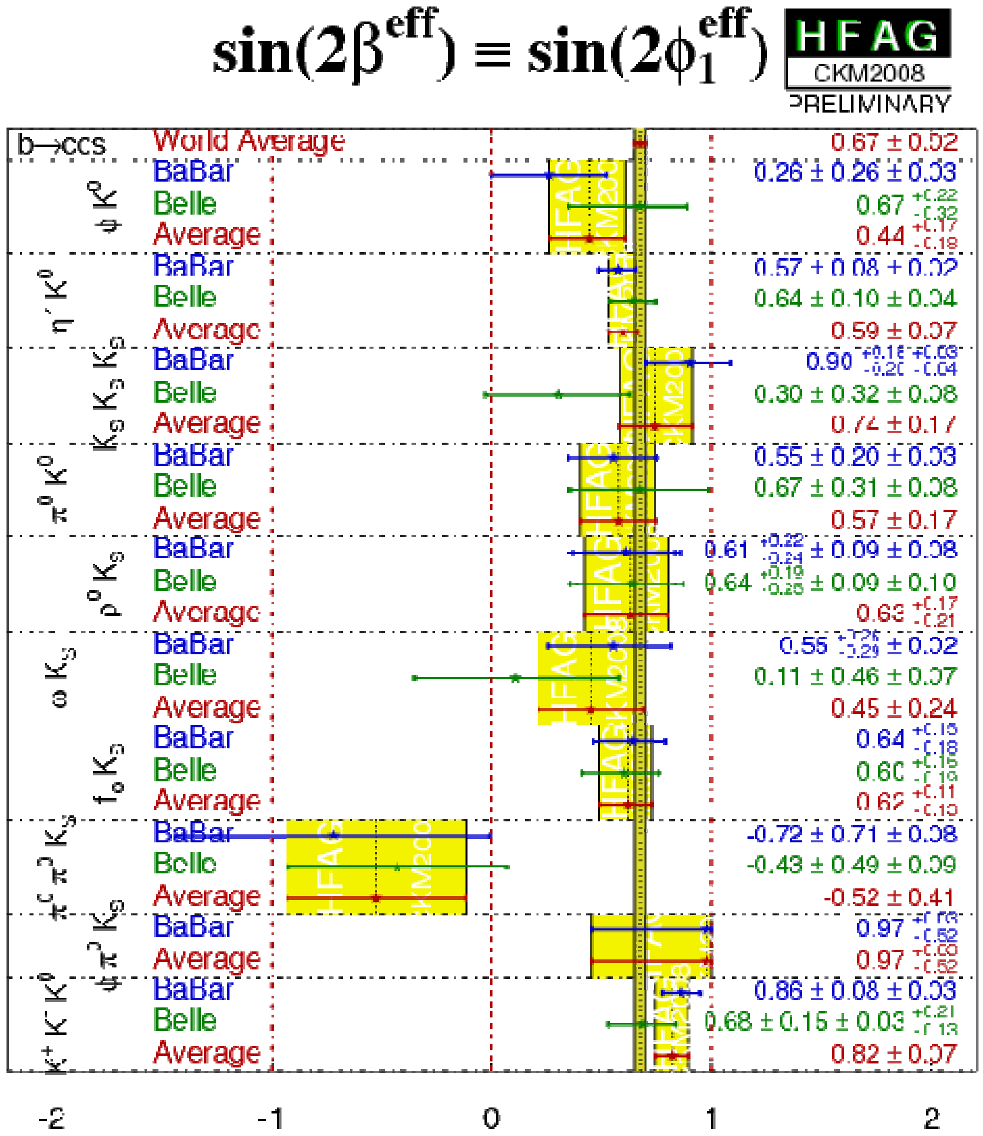
Input from theory : **evaluate ΔS_{SM} for each mode**
identify clean modes (with small ΔS_{SM} expected)

S *from* b→s *penguins vs.* sin2β

HFAG compilation

Measurements available for 10 modes

Many of the results in the compilation are new or recently updated (ICHEP2008, CKM'08).



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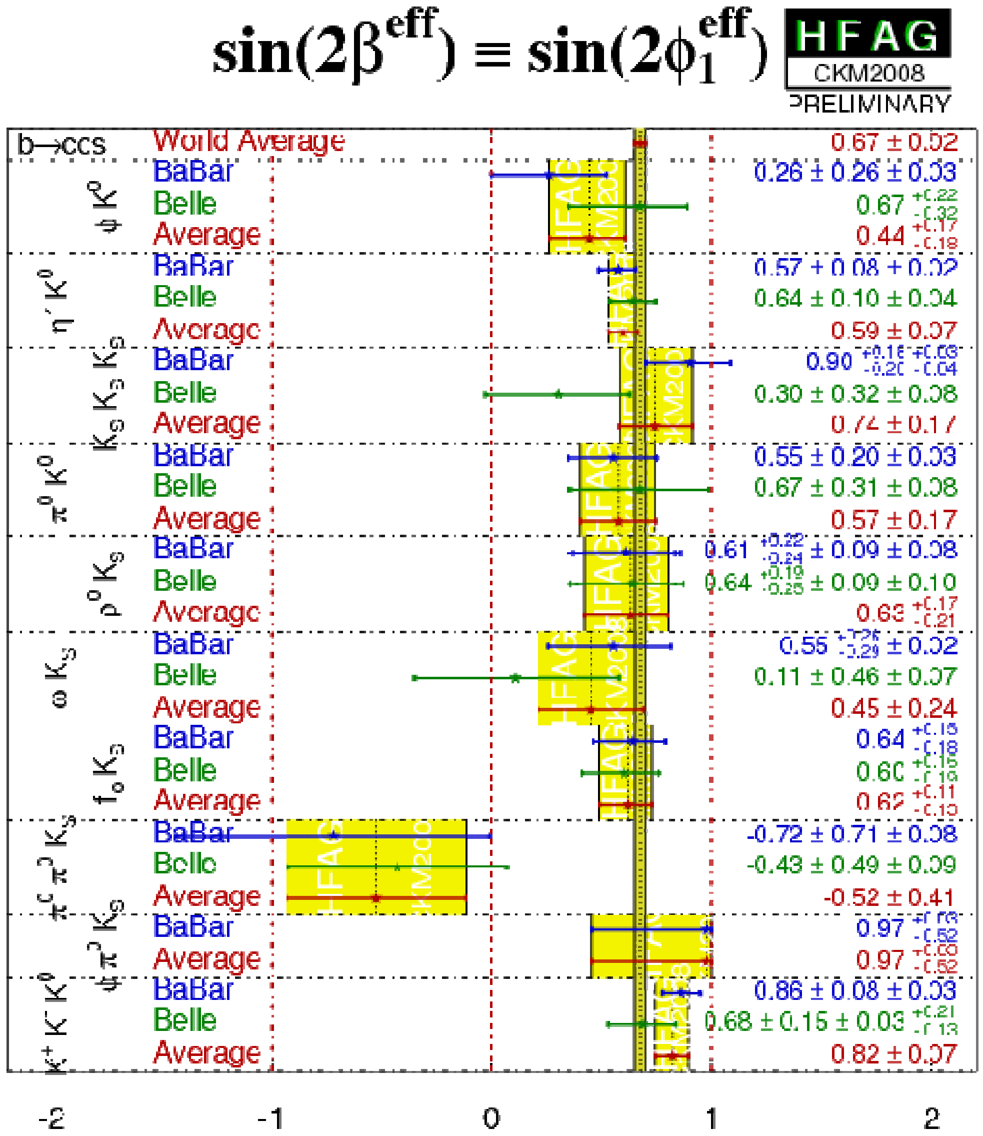
Big effort from B factories to clarify hints of trends/deviations in previous compilations



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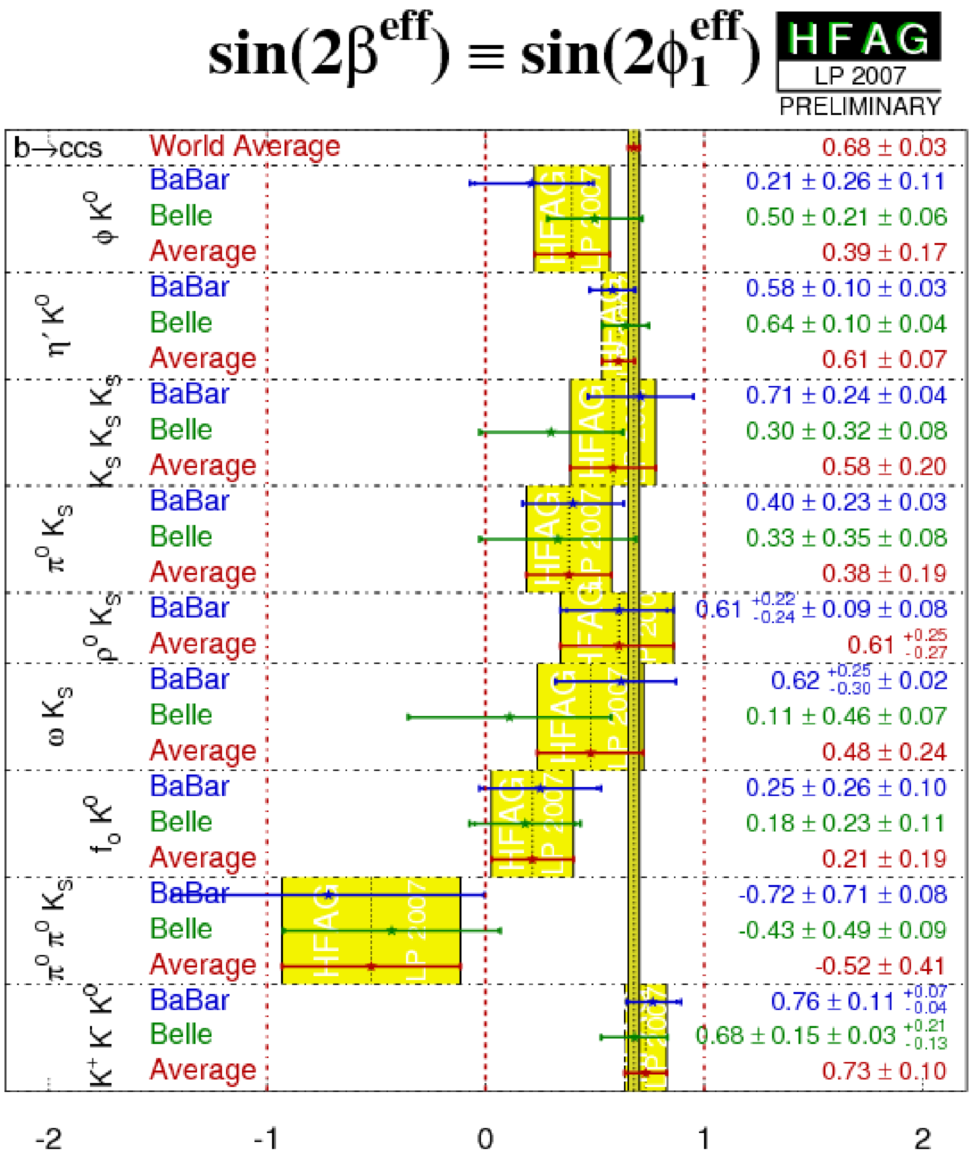
(e.g. in 2007)



S *from* b→s *penguins vs.* sin2β

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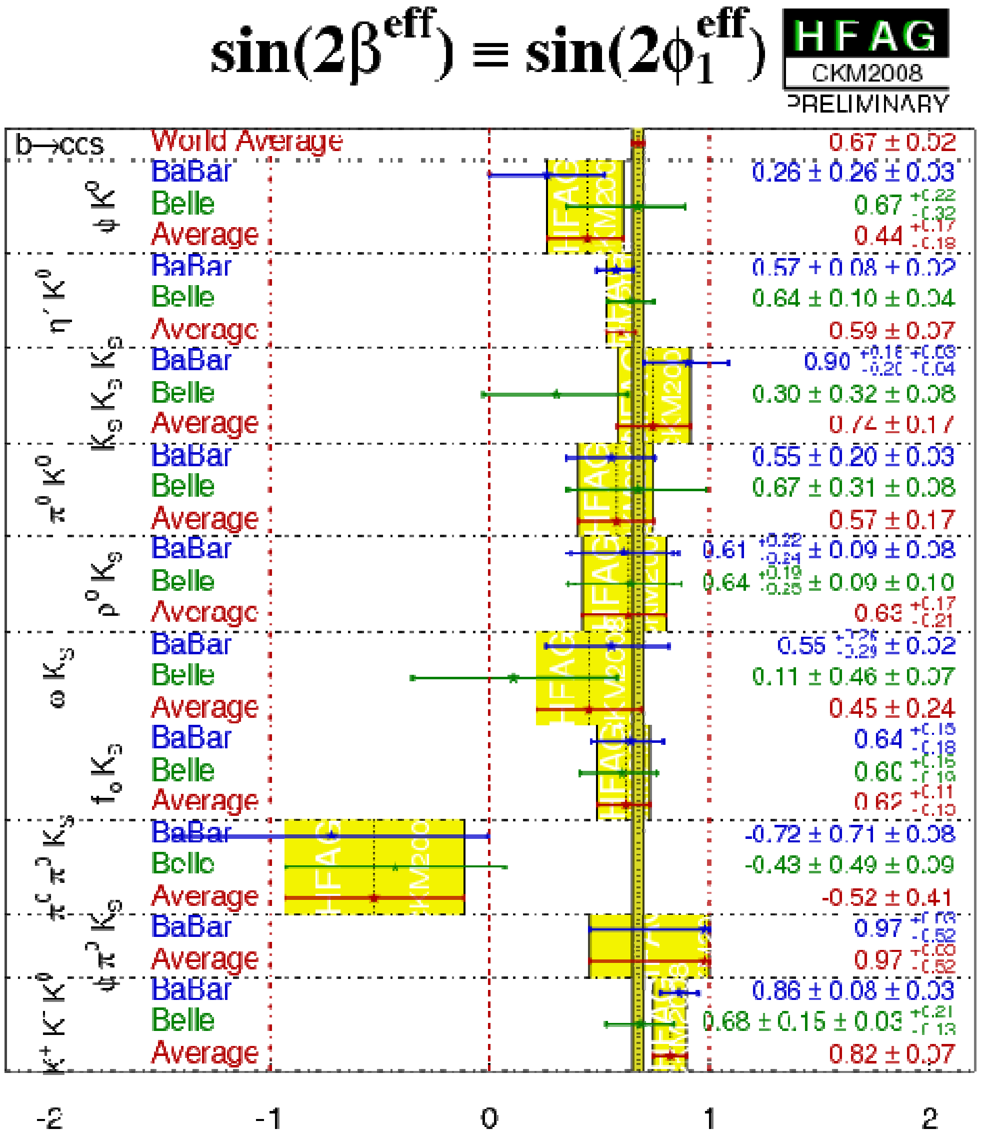
Beware of naïve averaging !
(each mode has its own ΔS…)

Still…
… for most of the modes,

the theoretical SM prediction is ΔS > 0

current central values are ΔS < 0



S *from* b→s *penguins vs.* sin2β

HFAG compilation

Browder,Gershon,Pirjol,AS,Zupan,arXiv:0802.3201(RMP)

TABLE VIII Expectations for ΔS_f in three cleanest modes.

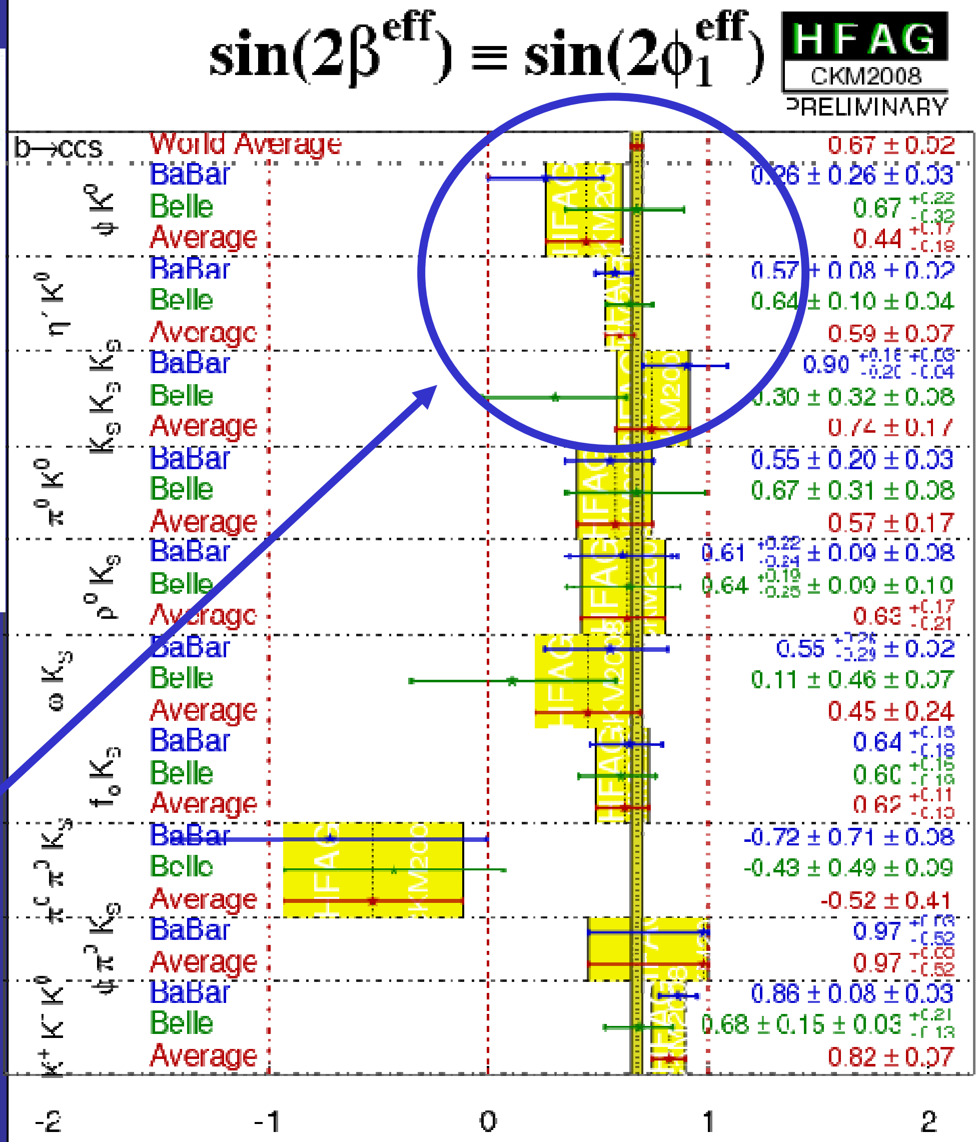
Model	ϕK^0	$\eta' K^0$	$K_S K_S K^0$
QCDF+FSI[a]	$0.03^{+0.01}_{-0.04}$	$0.00^{+0.00}_{-0.04}$	$0.02^{+0.00}_{-0.04}$
QCDF[b]	0.02 ± 0.01	0.01 ± 0.01	
QCDF[c]	0.02 ± 0.01	0.01 ± 0.02	
SCET[d]		-0.019 ± 0.009 -0.010 ± 0.010	
pQCD[e]	0.02 ± 0.01		

[a] Cheng *et al.* (2005a,b) [b] Beneke (2005)
[c] Buchalla *et al.* (2005) [d] Williamson and Zupan (2006)
[e] Li and Mishima (2006)

Beware of naïve averaging !
(each mode has its own ΔS…)

Inspect the cleanest modes:

$B^0 \to \eta' K^0_S$ **(first $q\bar{q}s$ mode with >5σ CPV)**
$B^0 \to \phi K^0_S$
$B^0 \to K^0_S K^0_S K^0_S$



S *from* b→s *penguins vs.* sin2β

HFAG compilation

Measurements available for 10 modes

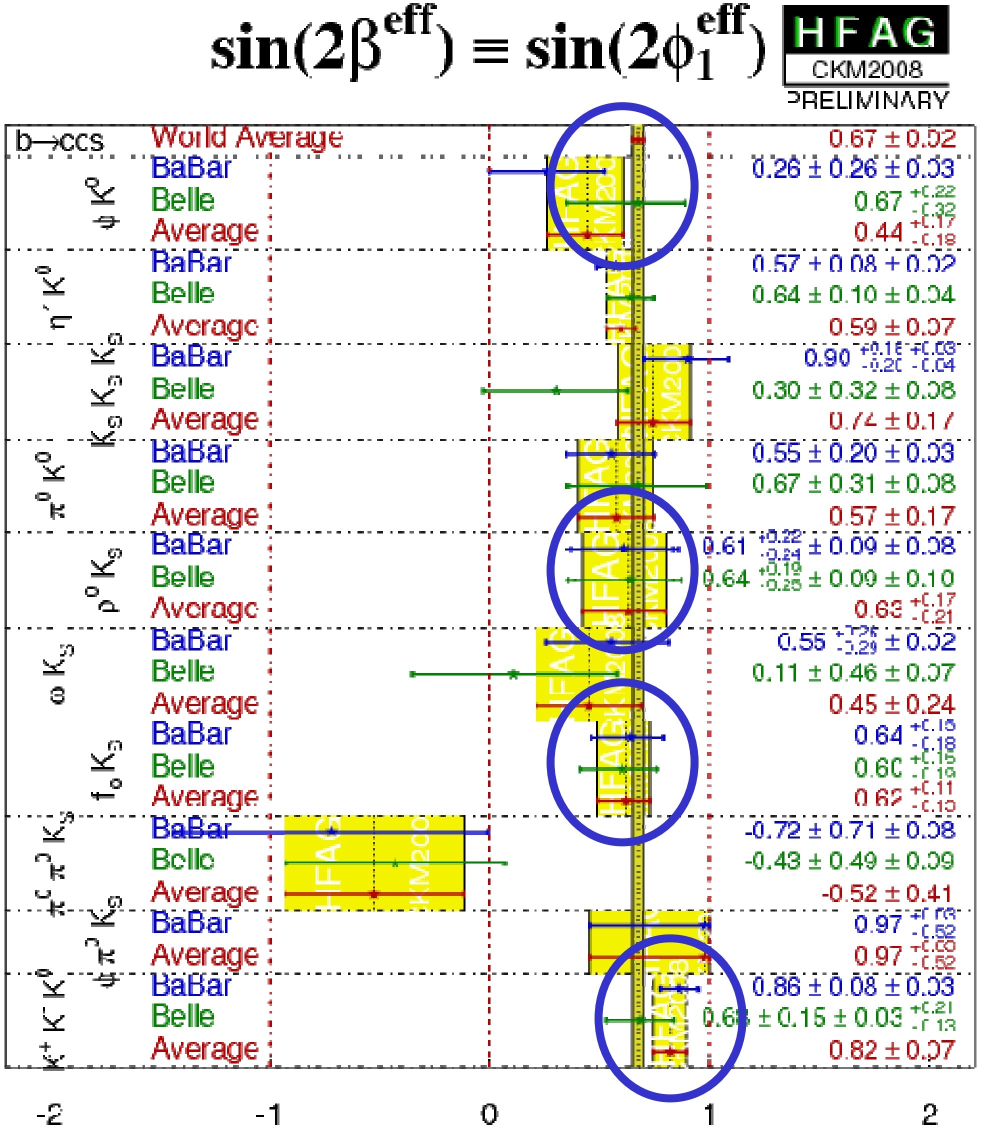
Many of the results in the compilation are new or recently updated (ICHEP2008, CKM'08).

Big effort from B factories to clarify hints of trends/deviations in previous compilations

Beware of naïve averaging !
(each mode has its own ΔS…)

Exploit the potential of amplitude analyses on modes contributing to three-body decays :

Available : $B^0 \to \pi^+\pi^- K^0_S$, $B^0 \to K^+K^-K^0_S$



b→sq$\bar{q}$ *penguins : the time-dependent Dalitz Plot analyses*

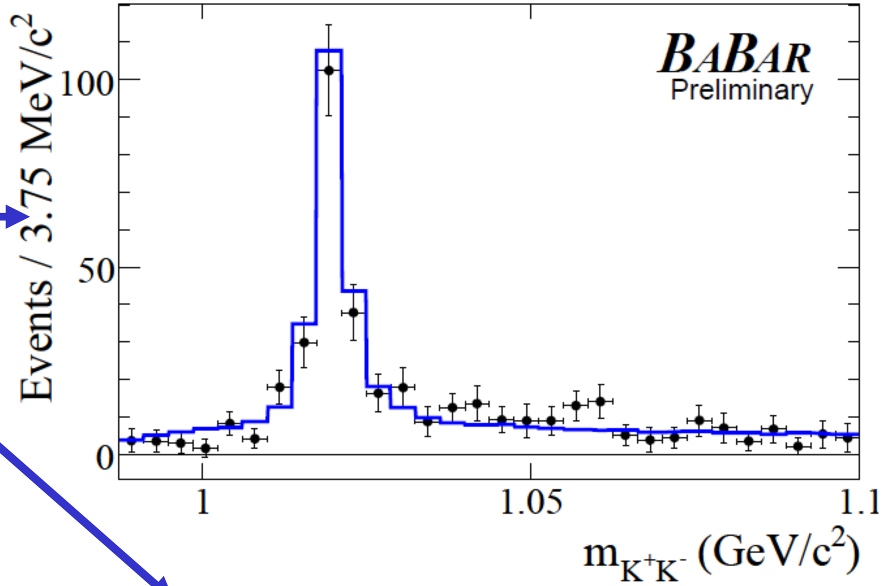
- **Time-dependent amplitude analyses of** $B^0 \to K^0_S \pi^+ \pi^-$ **and** $B^0 \to K^0_S K^+ K^-$
  - **Technically challenging :**
    - **3-D signal decay amplitude (DP + time)**
    - **huge phase space (B much heavier than light resonances)**
    - **several intermediate modes contribute**
  - **Direct acces to Weak phase** β_{eff} **!**
    - **counting-rate analyses access only to** $S=\sin 2\beta_{eff}$
    - **trigonometry ambiguities resolved by interference**
  - **Intermediate modes related to** β_{eff} **include**
    - ϕK_S and $f_0 K_S$ **in** $B^0 \to K^0_S K^+ K^-$
    - $f_0 K_S$ and $\rho^0 K_S$ **in** $B^0 \to K^0_S \pi^+ \pi^-$

b→sq$\bar{q}$ *penguins : TD-amplitude analysis of $B^0 \to K^+K^-K^0_S$*

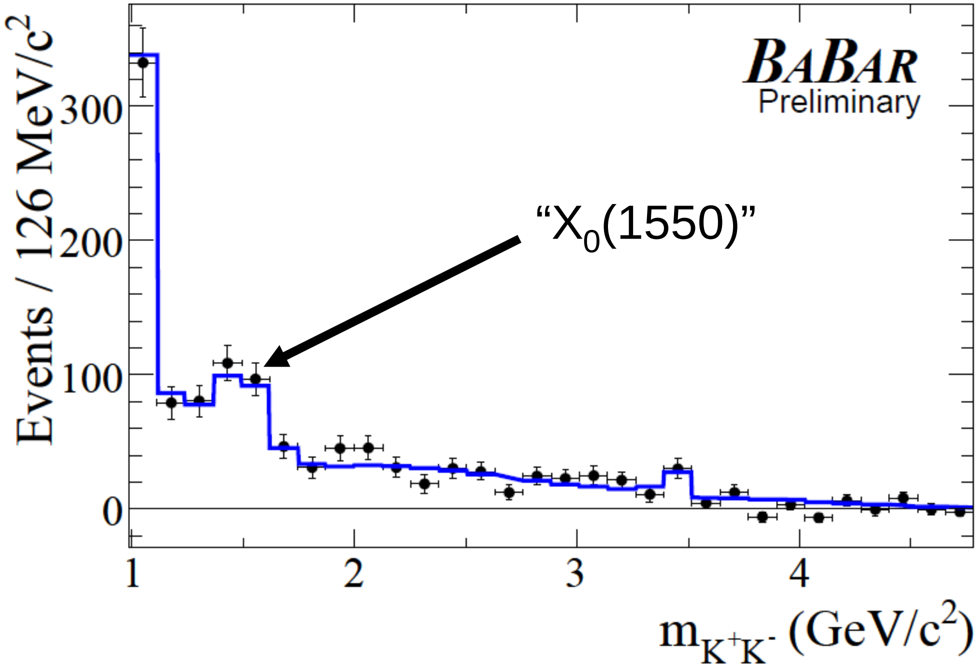
$B^0 \to K^0_S K^+ K^-$: BABAR, Phys. Rev. Lett. 99, 161802 (2007) N(BB) = 383 M
update arXiv:0808.0700 N(BB) = 465 M

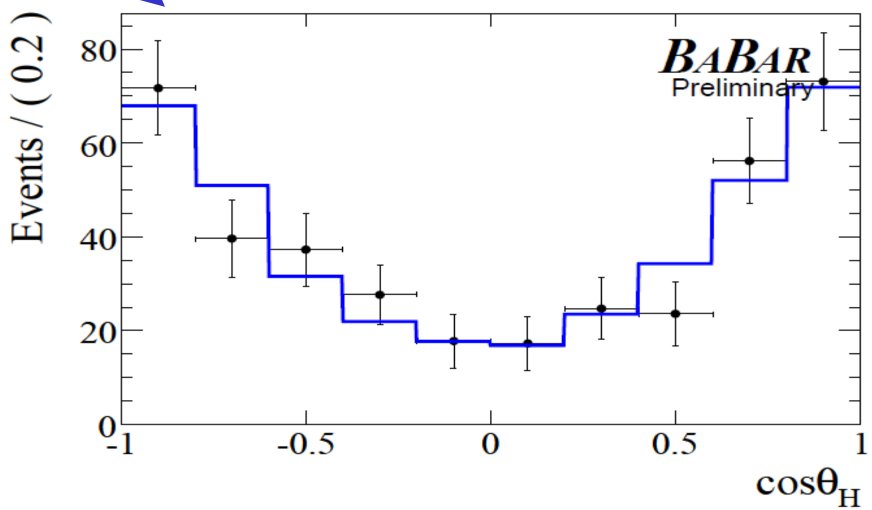
Background-subtracted distributions

Zoom in the low-mass region (ϕ,f_0 –dominated)



High-mass spectrum

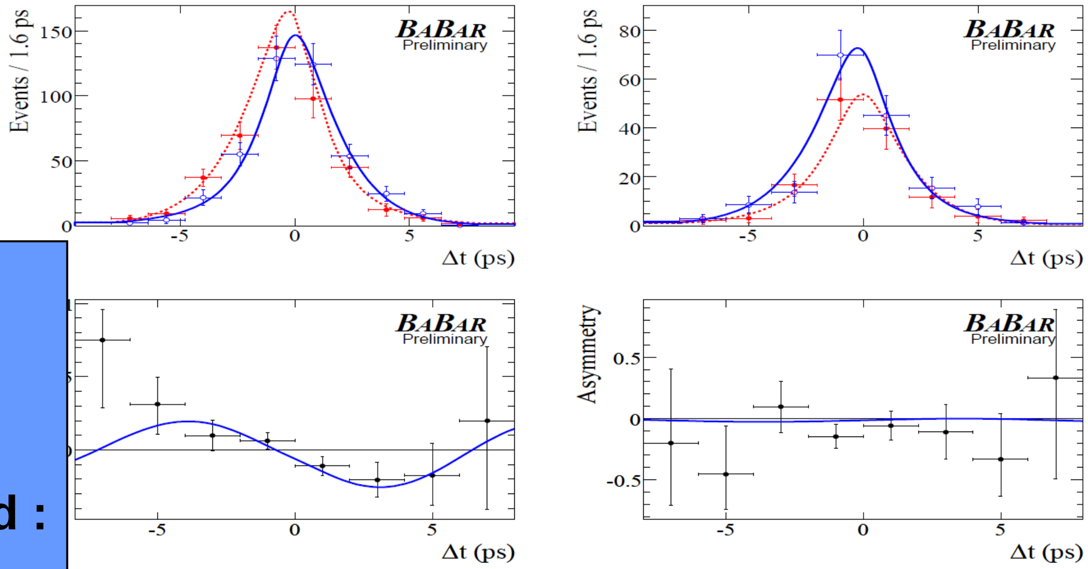




b→sq̄q *penguins : TD-amplitude analysis of* $B^0 \to K^+K^-K^0_S$

$B^0 \to K^0_S K^+ K^-$: BABAR, Phys. Rev. Lett. 99, 161802 (2007) N(BB) = 383 M
update arXiv:0808.0700 N(BB) = 465 M

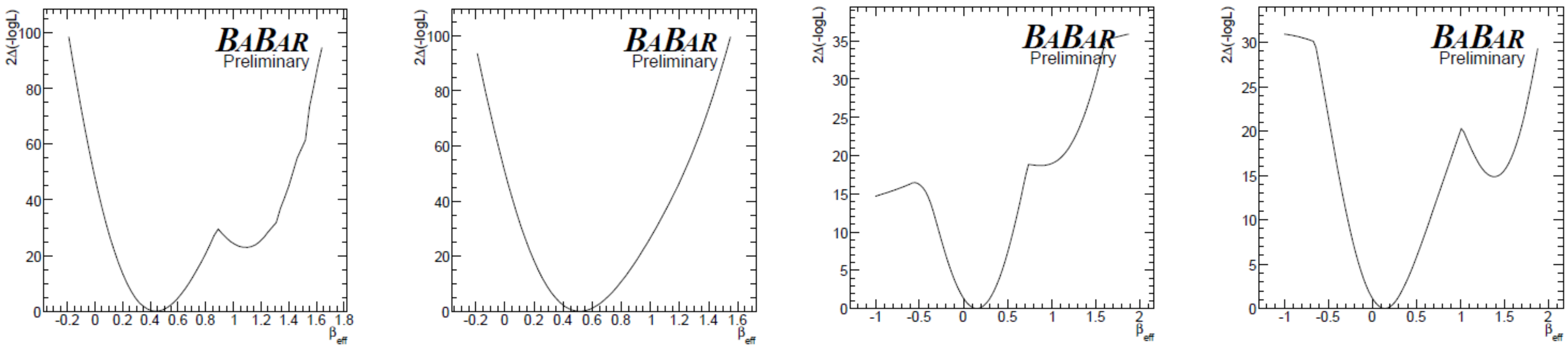
Background-subtracted time distrs.
(at high- and low- mass)



Likelihood vs. β_{eff} :

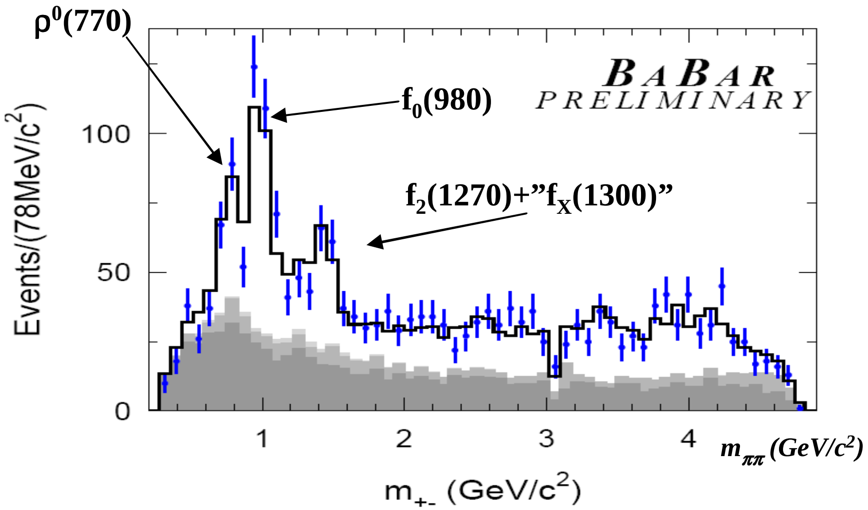
CP violation at 6.7σ !

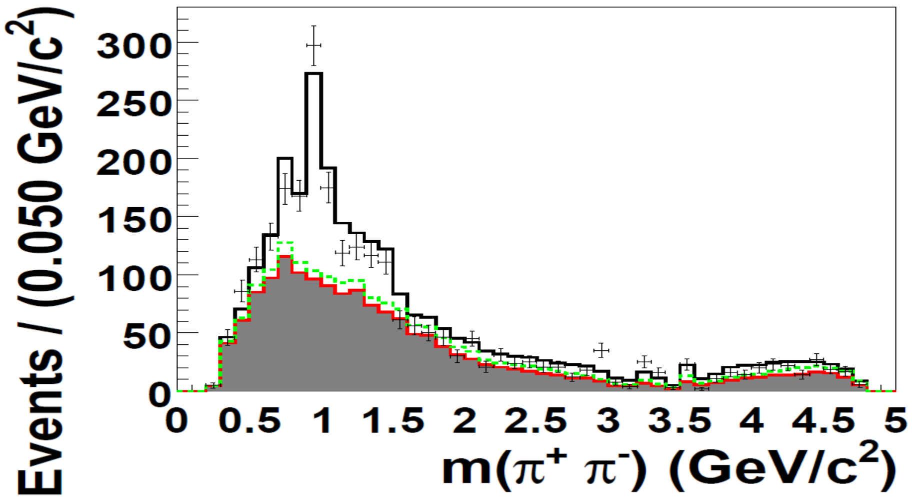
Trigonometric ambiguities resolved :
(i.e. $\pi/2-\beta_{eff}$ excluded at 4.8σ)



Entire DP | High-mass region | $f_0(980)$Ks | $\phi(1020)$Ks

$b \to s\bar{q}q$ *penguins : TD-amplitude analysis of* $B^0 \to \pi^+\pi K^0_S$

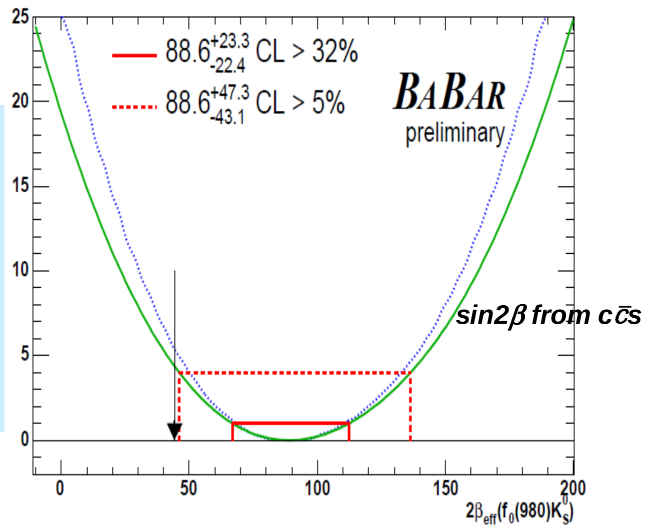


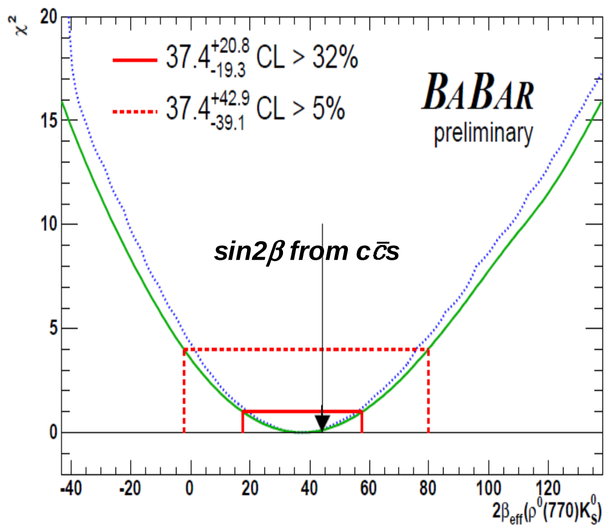


$B^0 \to K^0_S\pi^+\pi^-$: BABAR, arXiv:0708.2097 N(BB) = 383 M

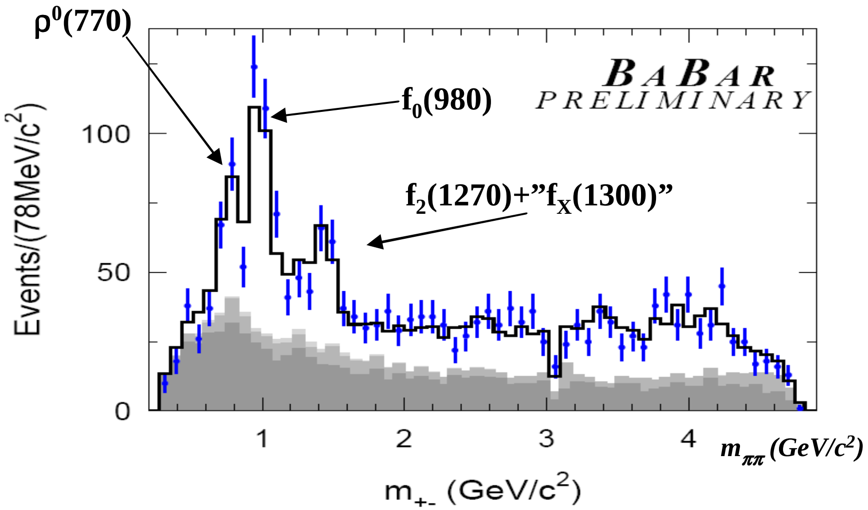
BaBar :
f_0K_s : $2\beta_{eff} = 0$ *excl. at* 4.3σ
f_0K_s : $2\beta_{eff} = 180$ *excl. at* 3.9σ

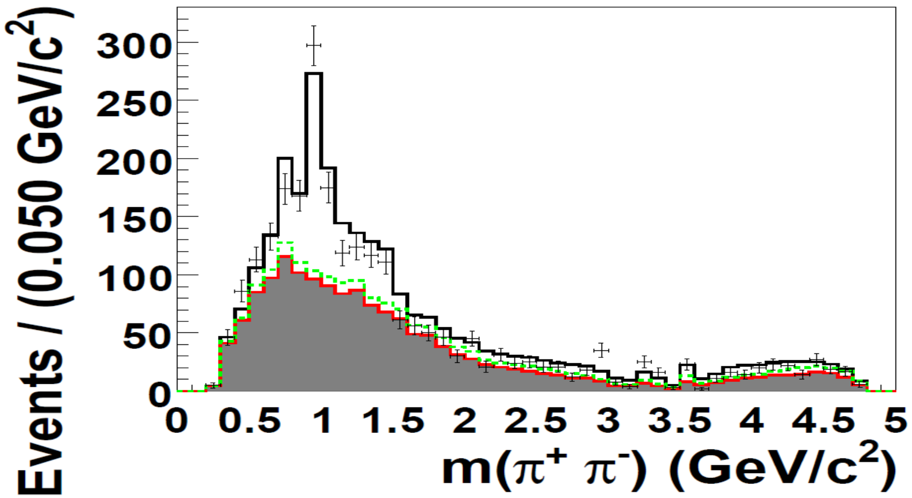
ρ_0K_S : mirror solution disfavoured at 3.8σ



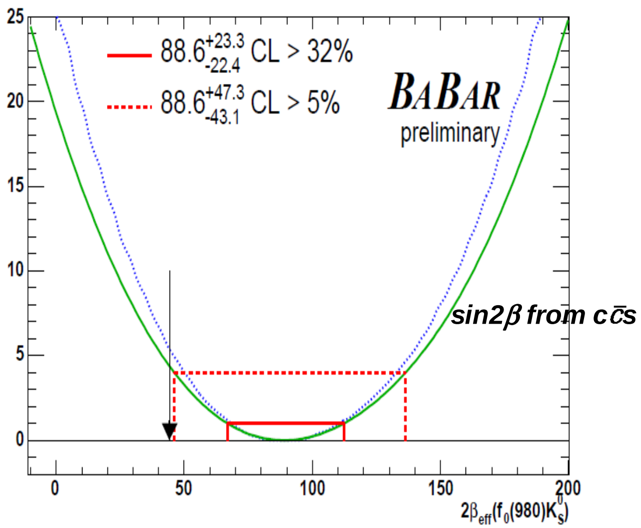


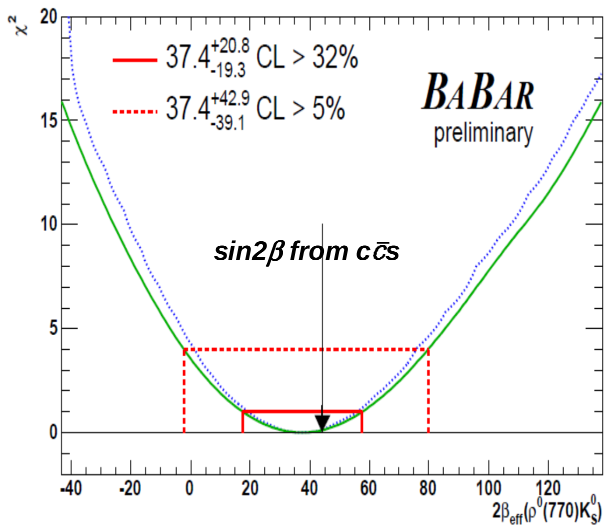
$b\to s\bar{q}q$ *penguins : TD-amplitude analysis of* $B^0\to\pi^+\pi^- K^0_S$





$B^0\to K^0_S\pi^+\pi^-$: BABAR, update in final notice





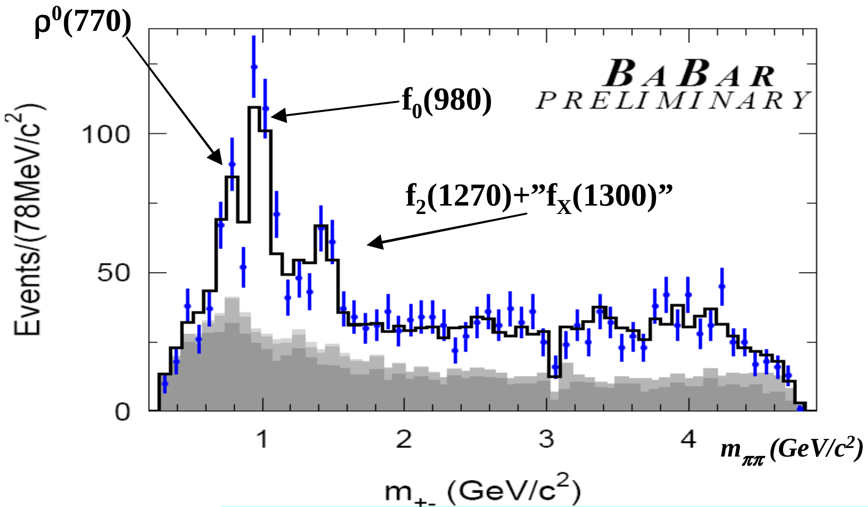
BaBar :

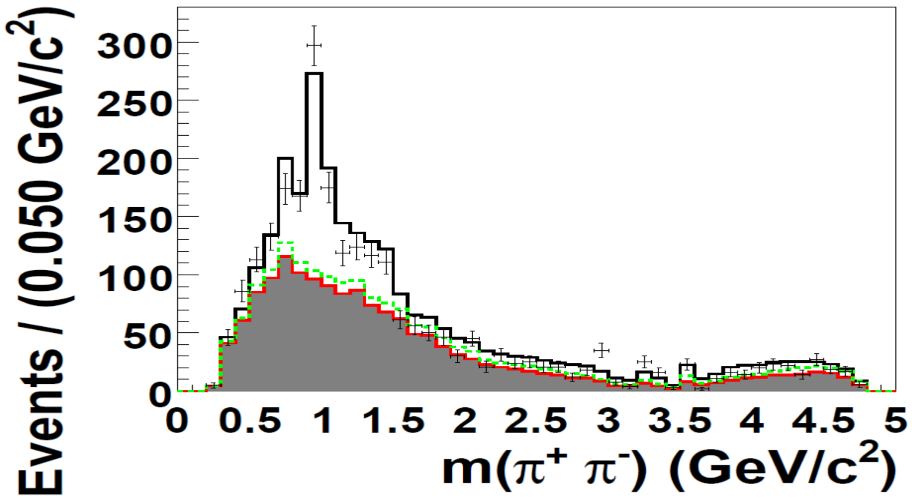
f_0K_s : $2\beta_{eff} = 0$ *excl. at* 4.3σ

f_0K_s : $2\beta_{eff} = 180$ *excl. at* 3.9σ

ρ_0K_S : mirror solution disfavoured at 3.8σ

b→sq̄q *penguins : TD-amplitude analysis of* $B^0 \to \pi^+ \pi K^0_S$



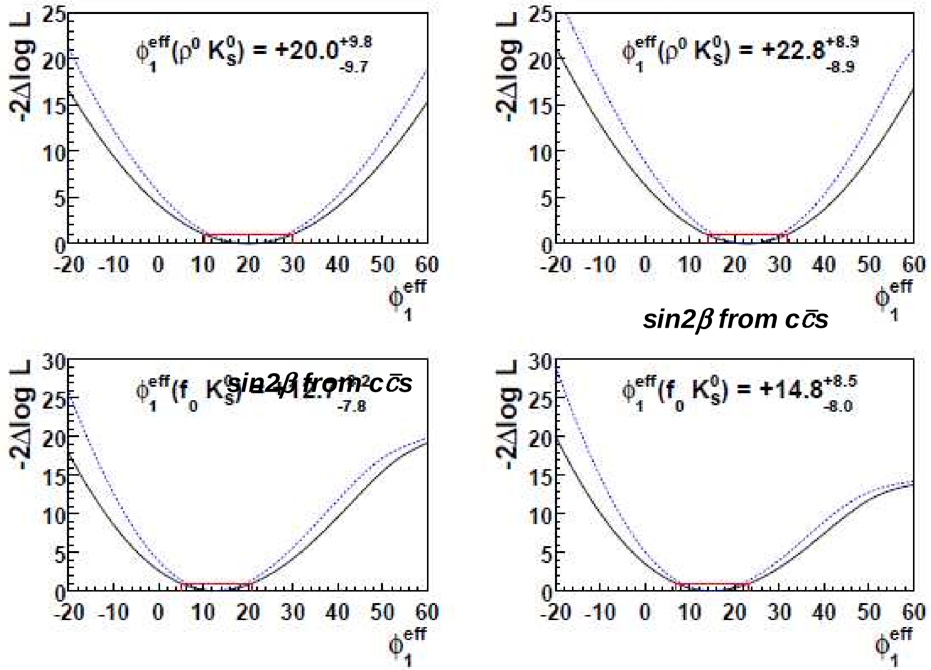


$B^0 \to K^0_S \pi^+ \pi^-$: Belle, arXiv:0811.3665 N(BB) = 657 M

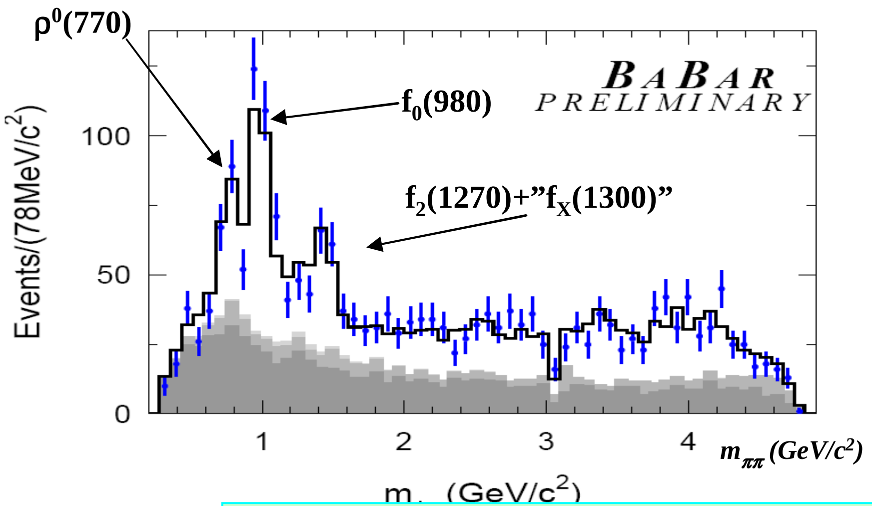
Belle :

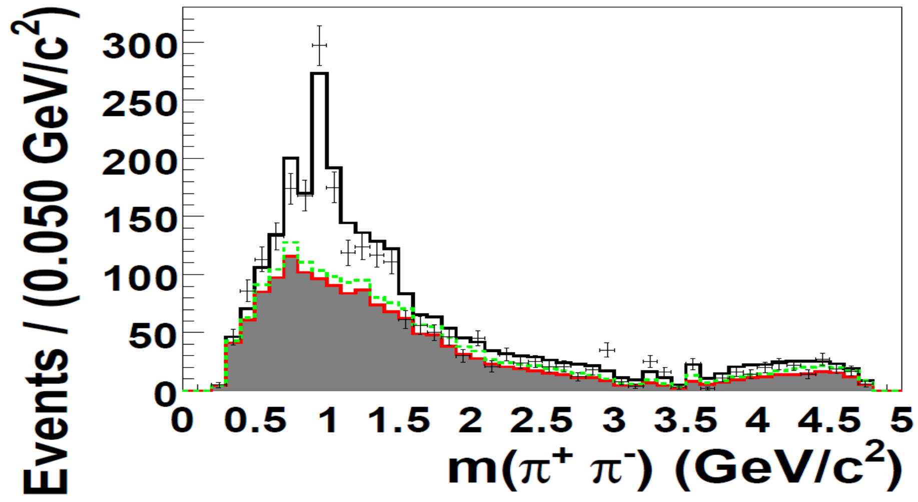
Two solutions

No evidence for CP violation for either f_0K_s nor $\rho_0 K_s$



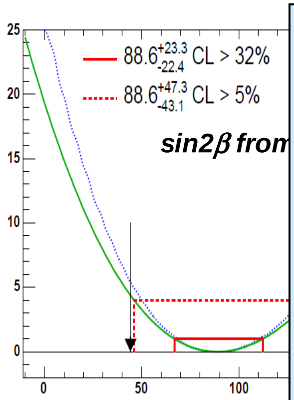
b→sq$\bar{q}$ *penguins : the time-dependent Dalitz analyses*

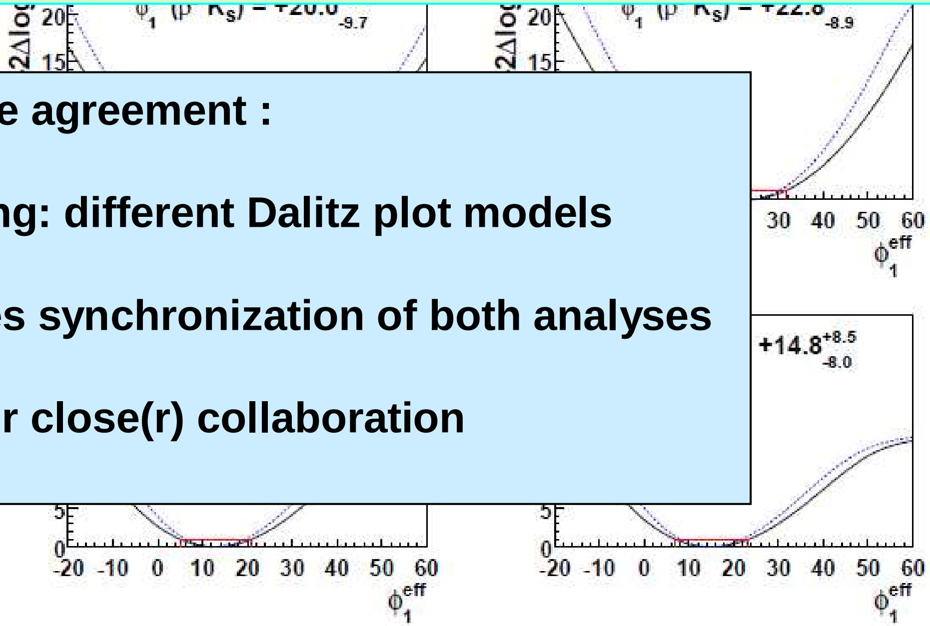




$B^0 \to K^0_S \pi^+\pi^-$: Belle, arXiv:0811.3665 N(BB) = 657 M

$B^0 \to K^0_S \pi^+\pi^-$: BaBar, arXiv:0708.2097 N(BB) = 383 M





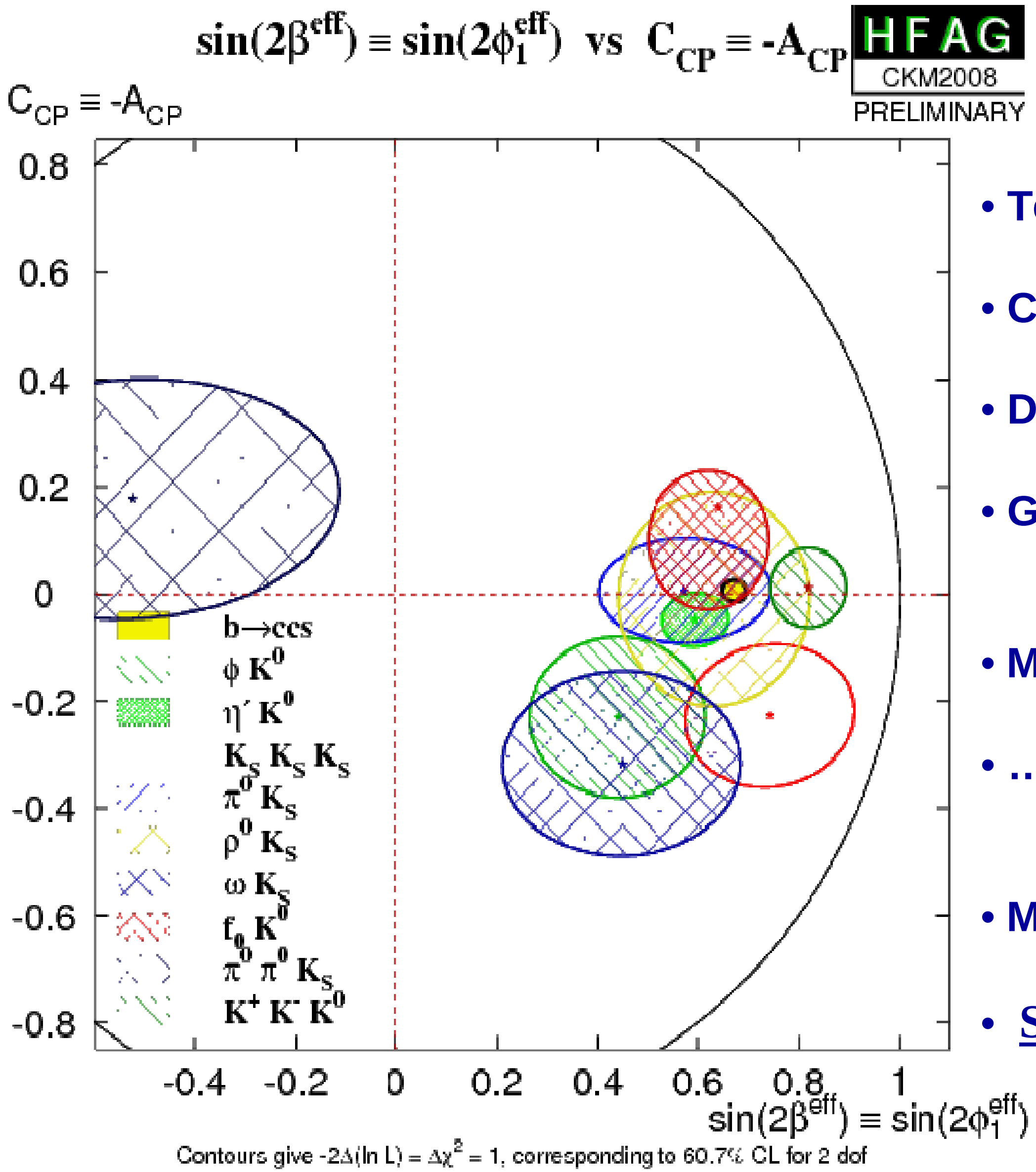
Quantification of BaBar/Belle agreement :

Not straightforward averaging: different Dalitz plot models

Correct combination requires synchronization of both analyses

…interesting opportunity for close(r) collaboration

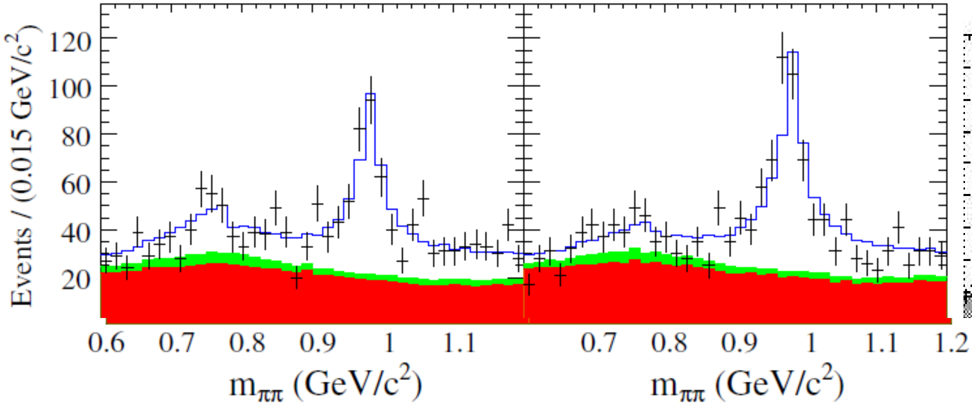
b→sq$\bar{q}$ *penguins : summary*

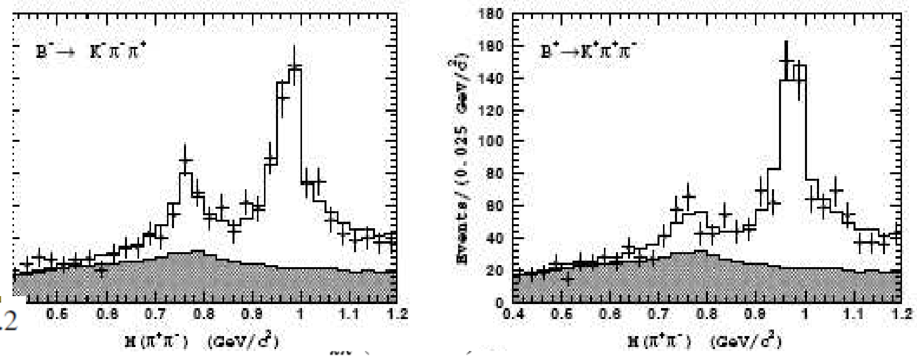


- **Ten modes in the** b→q$\bar{q}$s **family studied**
- **CP violation established in several modes**
- **Direct CP asymetries Compatible with zero**
- **Global agreement with golden** b→c$\bar{c}$s
- **Most values of *S* below** b→c$\bar{c}$s **value …**
- **… while theoretical calculations suggest *opposite* trend …**
- **Measurements limited by statistics**
- <u>Sound case for higher-statistics projects</u>

More physics from $B \to K\pi\pi$ Dalitz-plot analyses

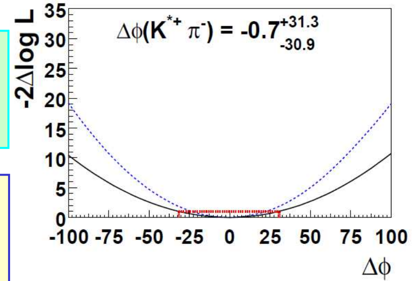
$B^+ \to K^+ \pi^- \pi^+$: BaBar, PRD 78 (2008) 012004 N(BB) = 465 M
Belle, ICHEP-CONF N(BB) = 657 M (tbc)



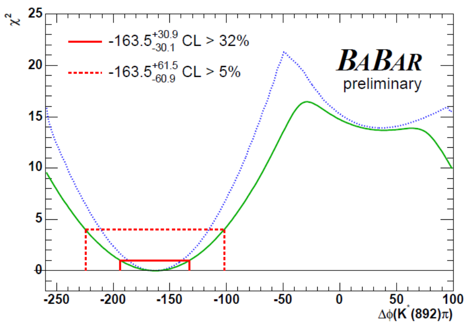


First evidence for Direct CPV in a charged decay

$$HFAG \quad A_{CP}(\rho^0 K^+) = (42^{+8}_{-10})\%$$



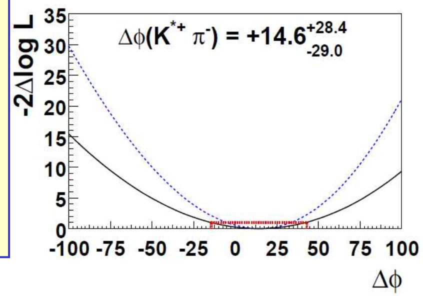
$B^0 \to K^+ \pi^- \pi^0$: BaBar, PRD 78 (2008) 052005 N(BB) = 232 M
update arXiv:0807.4567 N(bb) = 465 M



CPS, Phys. Lett. B 645, 201 (2007)
GPSZ, Phys. Rev. D 75, 014002 (2007):

Phases in $B^0 \to K^*(892)^+ \pi^-$ **and** $B^0 \to K^*(892)^0 \pi^0$ **can provide a constraint to the CKM matrix**

(stat. limited, requires BaBar/Belle synchronisation)



α from time-dependent CP asymmetries in b→uūd decays

Time-dependent CP Asymmetries in $B^0/\overline{B}^0 \to \pi^+\pi^-$ decays

(similar for $\rho^+\rho^-$)

$$a_{CP}(\Delta t) \equiv \frac{\Gamma(\overline{B}^0(t)\to\pi^+\pi^-)-\Gamma(B^0(t)\to\pi^+\pi^-)}{\Gamma(\overline{B}^0(t)\to\pi^+\pi^-)+\Gamma(B^0(t)\to\pi^+\pi^-)}$$

$$= S^{+-}\sin(\Delta m_d \Delta t) - C^{+-}\cos(\Delta m_d \Delta t)\ ,$$

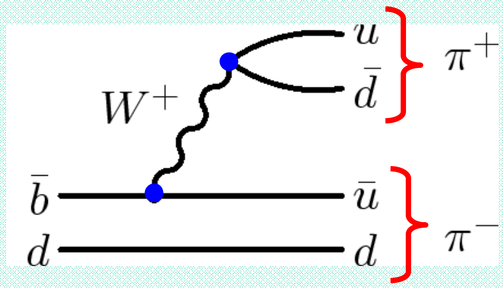
$$S^{+-} = \frac{2\mathrm{Im}\left(e^{-2i\beta}\frac{\overline{A^{+-}}}{A^{+-}}\right)}{1+|\frac{\overline{A^{+-}}}{A^{+-}}|^2} \quad \text{et} \quad C^{+-} = \frac{|A^{+-}|^2-|\overline{A^{+-}}|^2}{|A^{+-}|^2+|\overline{A^{+-}}|^2}$$

$$A^{+-} = V_{ub}V_{ud}^{*}\,T + V_{tb}V_{td}^{*}\,P$$

Tree :

$\propto V_{ub}V_{ud}^{*}$

$\propto \lambda^3$



With a single weak phase (i.e. negligible penguins) :

$\mathbf{C = 0}$

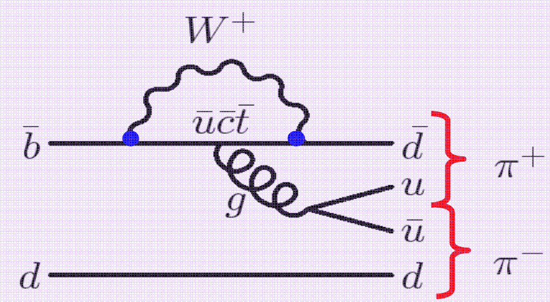
$\mathbf{S = \sin(-2(\beta+\gamma)) = \sin 2\alpha}$

direct access to α

Penguin :

$\propto V_{tb}V_{td}^{*}$

$\propto \lambda^3$



$\mathbf{C \neq 0}$

Penguin pollution :

$\mathbf{S = \sqrt{1-C^2}\,\sin(2\alpha_{eff}) \neq \sin 2\alpha}$

Additional information required : use isospin SU(2) symmetry

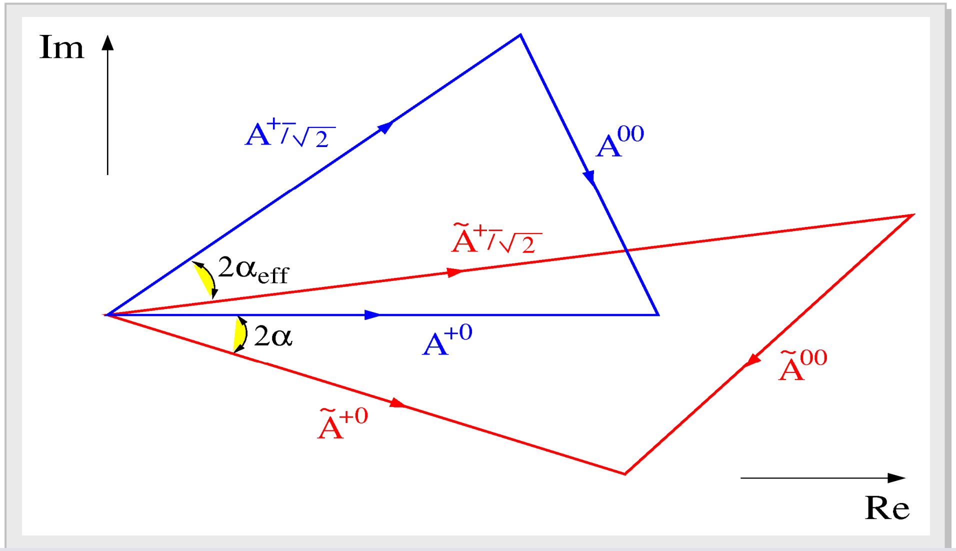
α *from isospin analysis of* $B\to\pi\pi$

Triangular relation on amplitudes :

$$A(B^0 \to \pi^+\pi^-) - \sqrt{2}A(B^+ \to \pi^+\pi^0) + \sqrt{2}A(B^0 \to \pi^0\pi^0) = 0$$

(plus a similar relation for the CP-conjugated amplitudes)

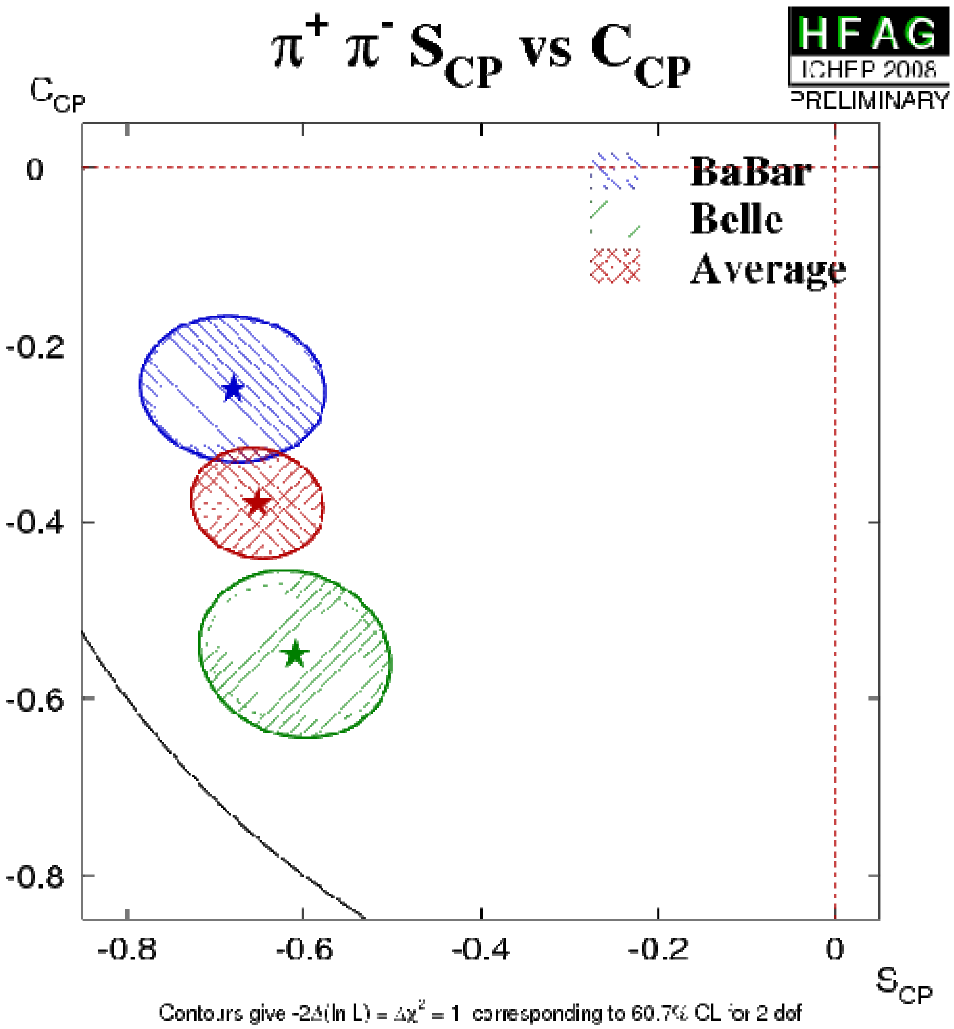
- neglect EW penguins
  - shifts α by ~ 2^o
  - A+0 pure tree : no DCPV
  - testable against data
- neglect isospin-breaking effects



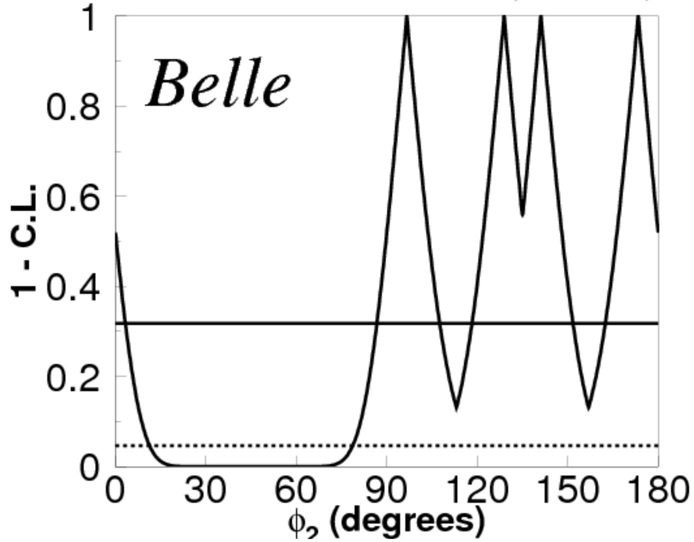
α can be resolved up to an 8-fold ambiguity within $[0,\pi]$

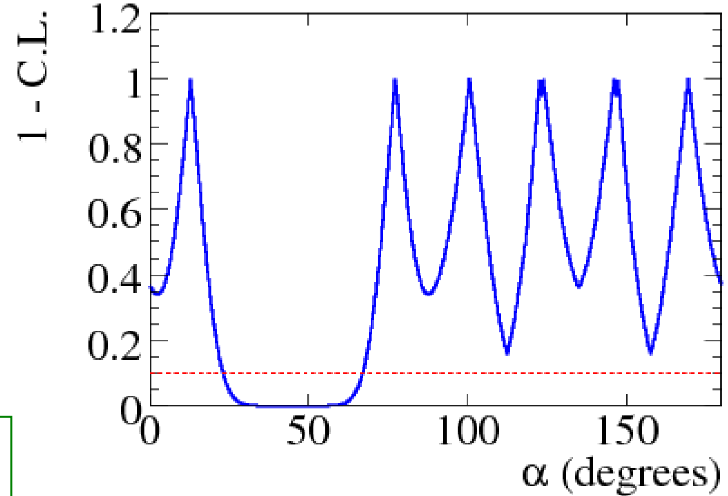
Unknowns	Observables	Constraints	Account
α, T^{+-}, P^{+-}, T^{+0}, P^{+0}, T^{00}, P^{00}	B^{+-}, $S_{\pi\pi}$, $C_{\pi\pi}$ B^{+0}, A_{CP} B^{00}, (S_{00}), C_{00}	2 isospin triangles and one common side	13 unknowns – 7 observables – 5 constraints – 1 global phase = 0 ☺

α *from isospin analysis of* B→ππ



535×10^6 $B\bar{B}$ pairs
PRL98, 221801(2007)



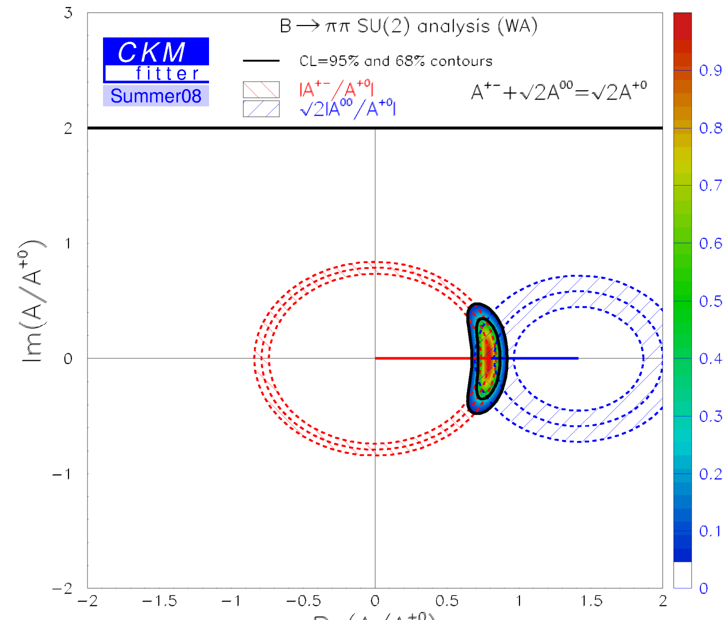


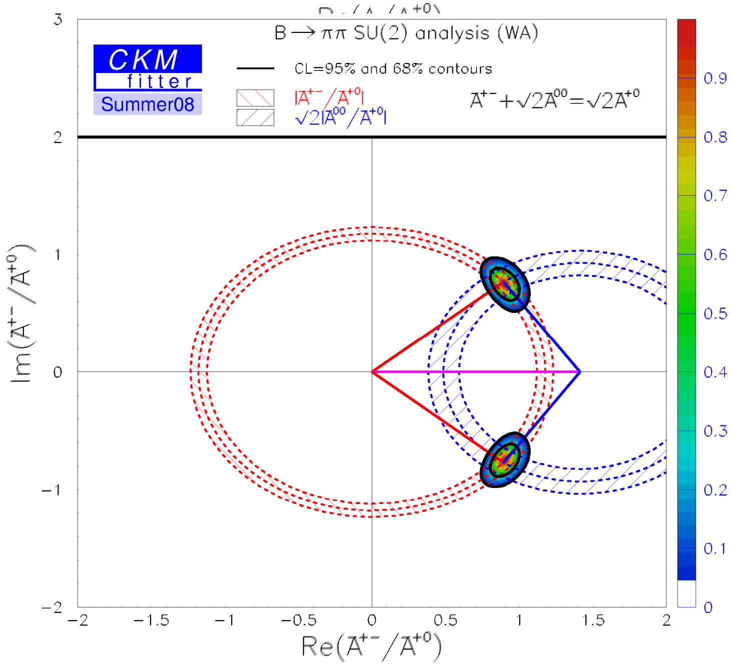
467×10^6 $B\bar{B}$ pairs
ArXiv:0807.4226

S,C(ππ) :

BaBar/Belle now within 1.9σ

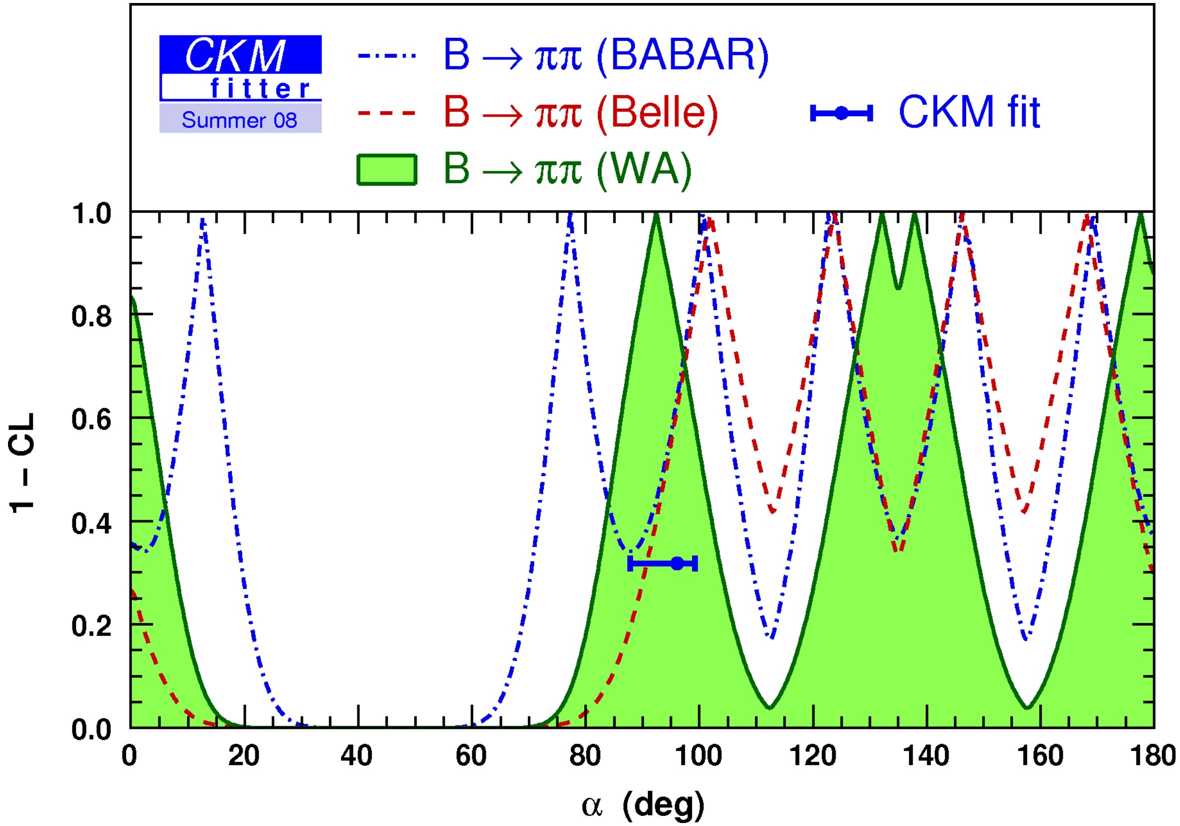
Isospin analysis of B→ππ





One of the 2 triangles does not close :

four-fold solution on $\alpha(\pi\pi)$



α *from isospin analysis of* B→ρρ

- **Much like B→$\pi\pi$**

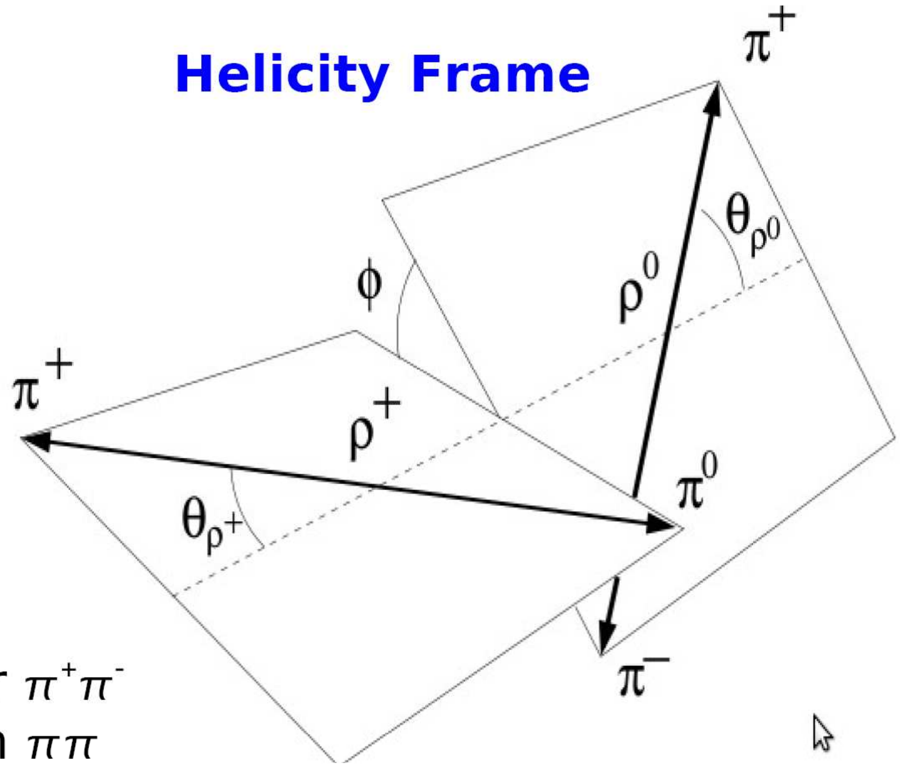
- **Disadvantages:**

- Wide ρ resonances
- V-V decay: different polarization states (L=0,1,2)
  ⇒ Longitudinal: CP-even
  ⇒ Transverse: Mixed CP states

- **Advantages:**

- BF($\rho^+\rho^-$) ~ 5 times larger than for $\pi^+\pi^-$
- Penguin pollution smaller than in $\pi\pi$
- ρ 99% longitudinally polarized
- Possible to measure S($\rho^0\rho^0$)
  ⇒ raise degeneracy in ambiguities

Helicity Frame



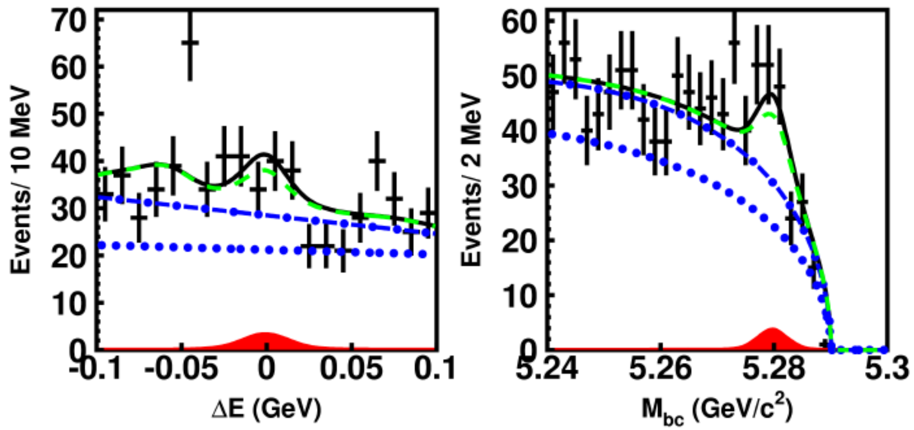
$$\frac{d^2\Gamma}{\Gamma d\cos\theta_1 d\cos\theta_2} = \frac{9}{4}\left[f_L \cos^2\theta_1 \cos^2\theta_2 + \frac{1}{4}(1-f_L)\sin^2\theta_1 \sin^2\theta_2\right],$$

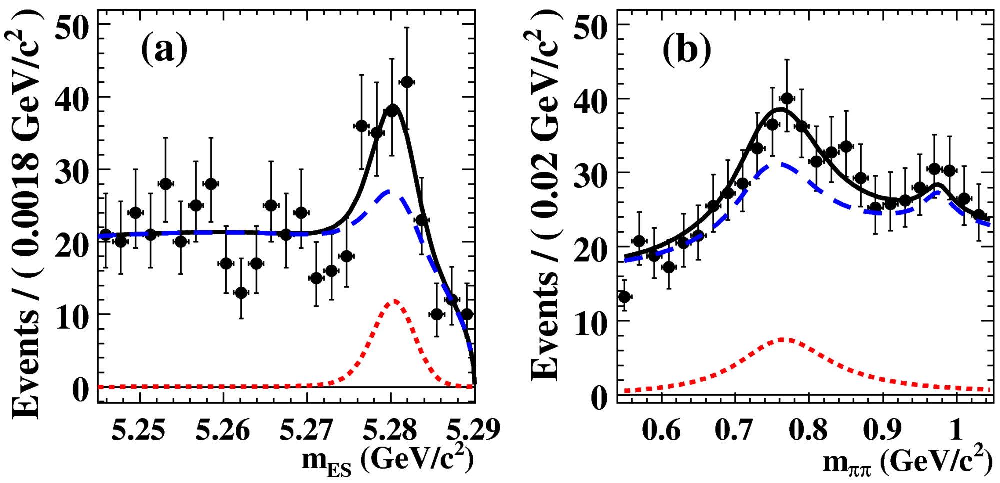
$B^0 \to \rho^0\rho^0$ ***is small !***

BELLE $657 \times 10^6\ B\bar{B}$ **pairs** **[PRD78, 111102(R)]**

$$N_S(\rho^0\rho^0) = 24.5^{+23.6+10.1}_{-22.1-16.2}\quad(\Sigma = 1.0\ \sigma)$$

$$Br(B^0 \to \rho^0\rho^0) < 1.0 \times 10^{-6}\ @\ 90\%\,C.L.$$
$$= (0.4 \pm 0.4^{+0.2}_{-0.3}) \times 10^{-6}$$





BaBar

$$N_S(\rho^0\rho^0) = 99^{+35}_{-34} \pm 15$$
$$(\Sigma = 3.1\ \sigma)$$

465M BB PRD78:071104 (2008)

⇒ Measurement of C_L^{00} and S_L^{00}

$$C_L(\rho^0\rho^0) = 0.2 \pm 0.8 \pm 0.3$$
$$S_L(\rho^0\rho^0) = 0.3 \pm 0.7 \pm 0.2$$

$$Br(B^0 \to \rho^0\rho^0) = (0.92 \pm 0.32 \pm 0.14) \times 10^{-6}$$

SU(2) triangle even more squashed

Improved measurement of $B^+ \rightarrow \rho^+\rho^0$

- Improved event selection (better efficiency)
- Better Background suppression
- Better BB background model
- Model variables correlations with mult-Dim PDFs

1122±63 signal Events | **465M BB hep-ex/0921.3522 (2009)**

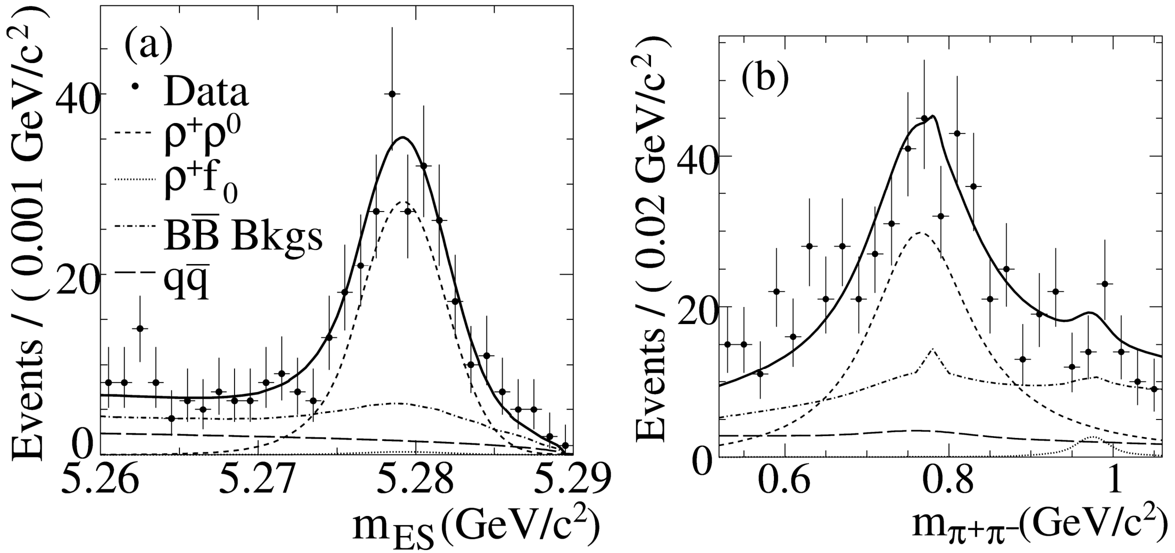
$BF(\rho^+\rho^0) = (23.7 \pm 1.4 \pm 1.4)\times 10^{-6}$

$f_L(\rho^+\rho^0) = 0.950 \pm 0.015 \pm 0.006$

$A_{CP}(\rho^+\rho^0) = -0.054 \pm 0.055 \pm 0.010$

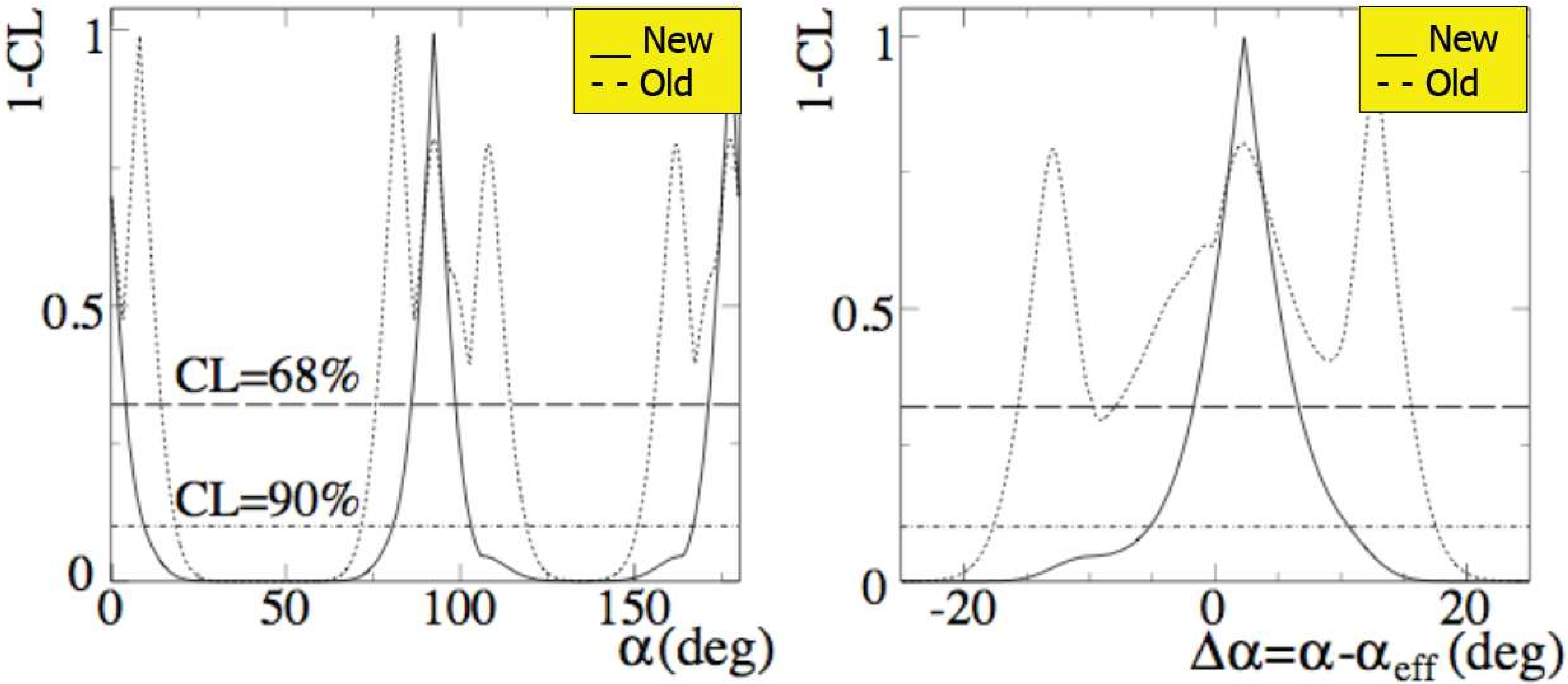
→ **Higher central value w.r.t. BaBar previous Analysis**

PRL97:261801 (2006)



SU(2) triangle even more squashed

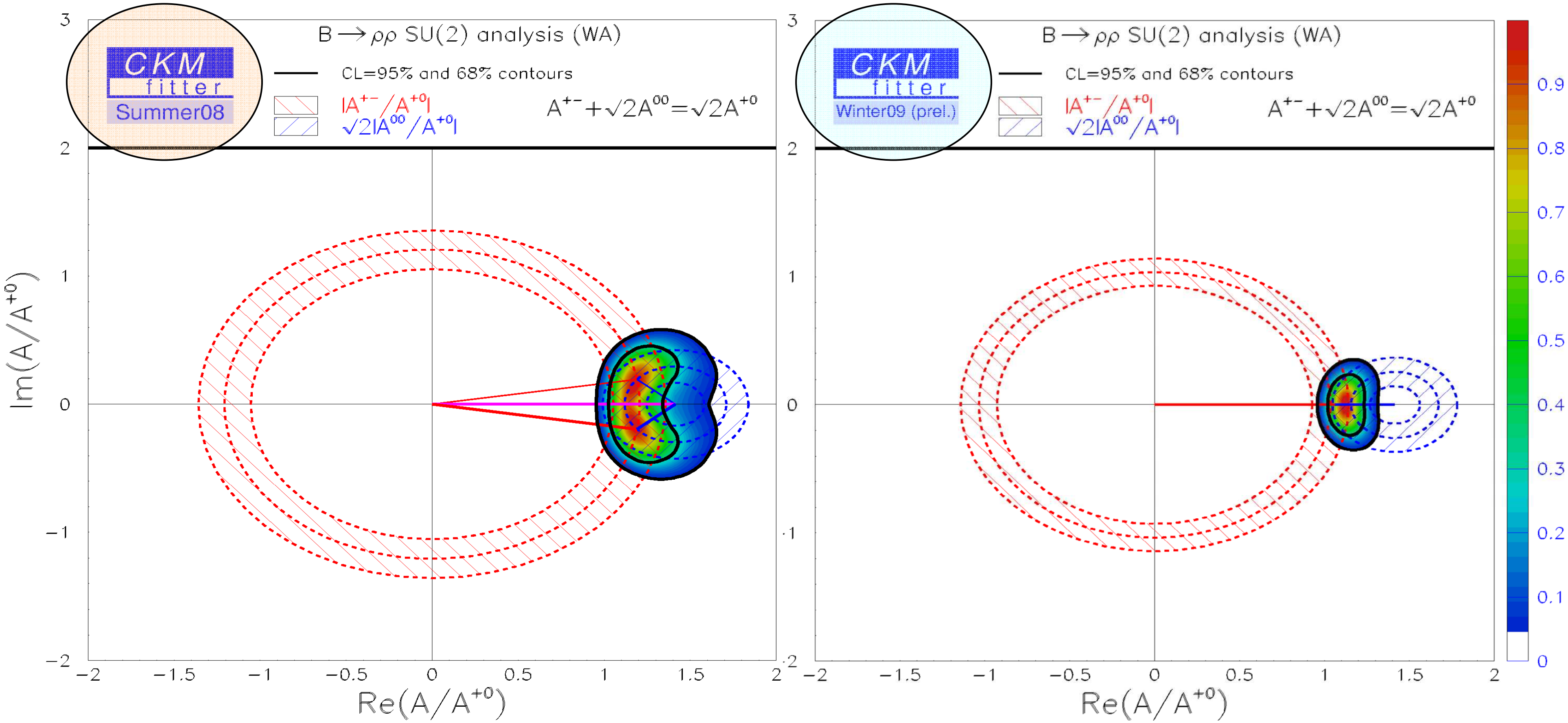
BaBar : Isospin analysis of B→ρρ



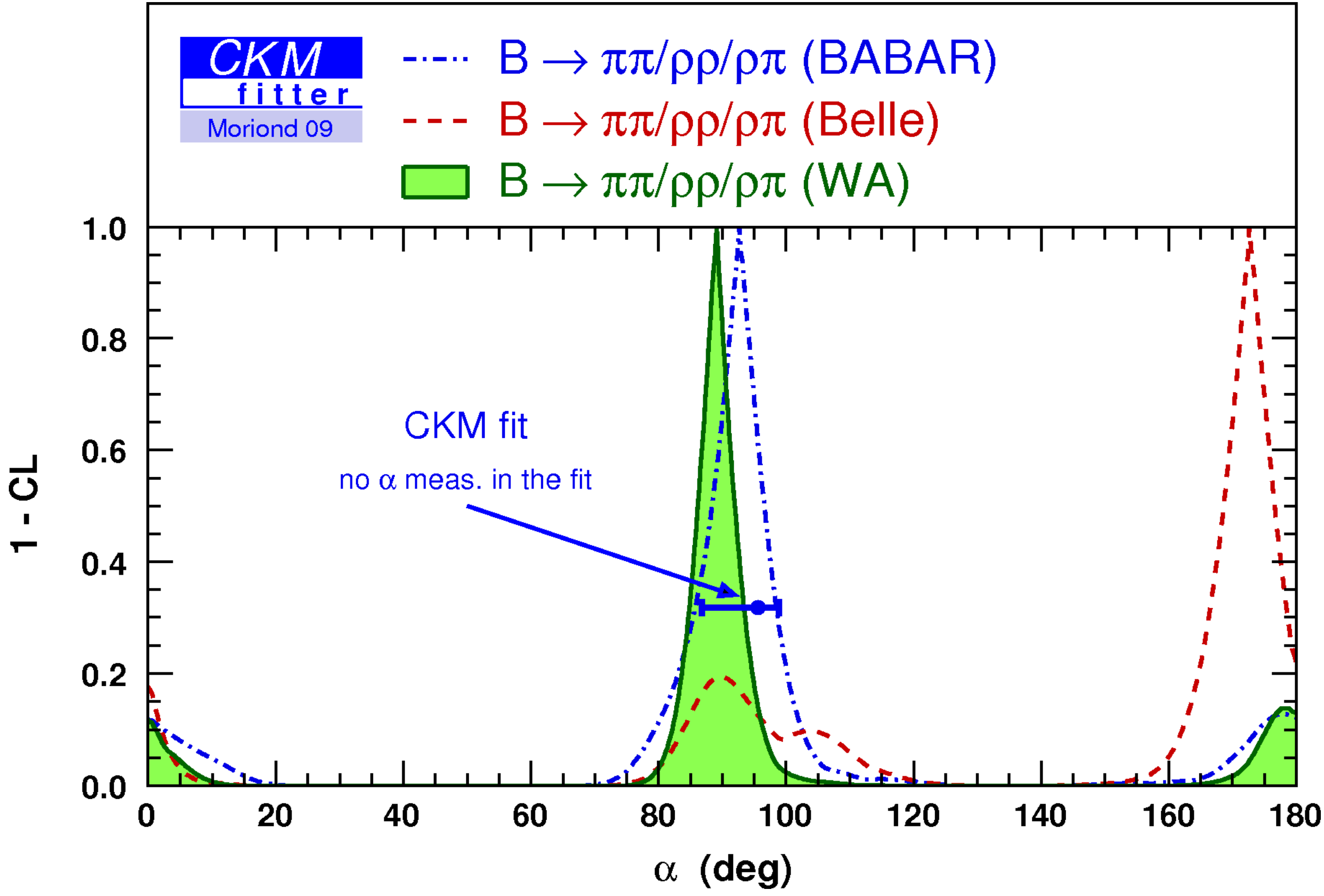
$$-1.8^{o} < \Delta\alpha < 6.7^{o}$$

Isospin analysis of B→ρρ

Both B and B isospin triangles do not close (consistent within errors)
mirror solutions are degenerated in a single peak



α as of Moriond 2009 : a precision measurement!



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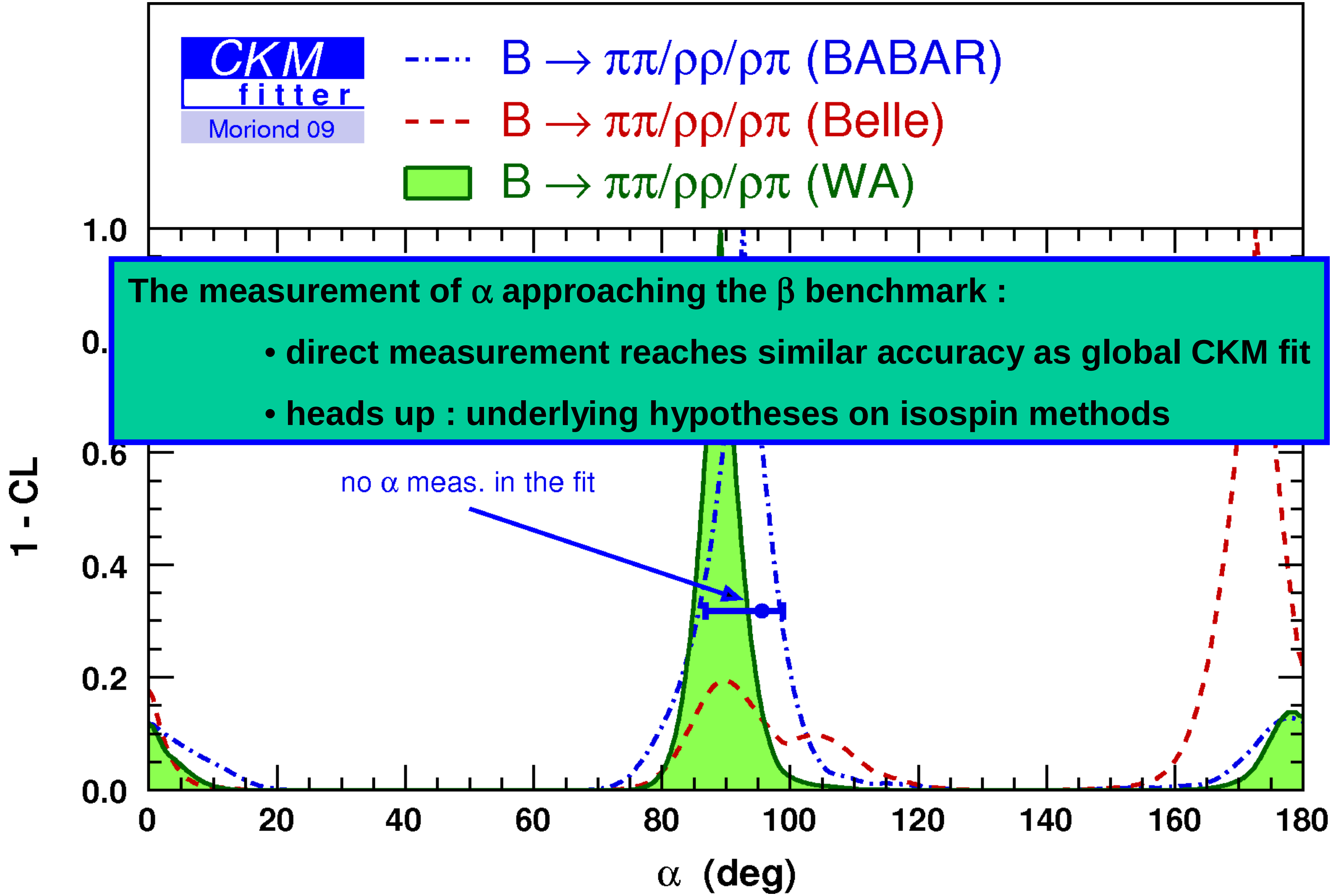


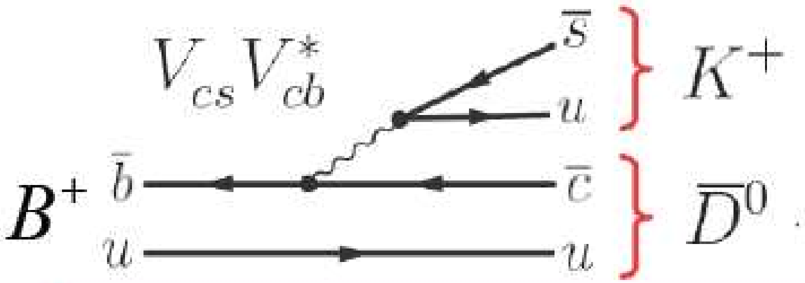
The measurement of α approaching the β benchmark :

- **direct measurement reaches similar accuracy as global CKM fit**
- **heads up : underlying hypotheses on isospin methods**

The most difficult angle ...

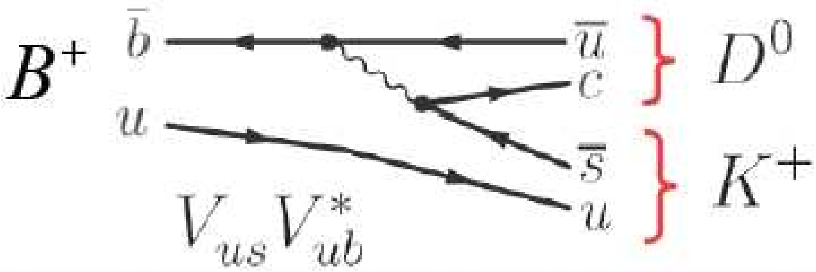
Use interference between $B^+ \to D^0K^+$ and $B^+ \to \overline{D}^0K^+$ with both D^0 and $\overline{D}^0$ decaying to the same final state f

Cabibbo allowed



$$A(B^+ \to \overline{D}^0 K^+) \propto V_{cb}^* V_{us} \propto \lambda^3$$

Cabibbo and color suppressed



$$A(B^+ \to D^0 K^+) \propto V_{ub}^* V_{cs} \propto \lambda^3 r_B e^{i\delta_B} e^{i\gamma}$$

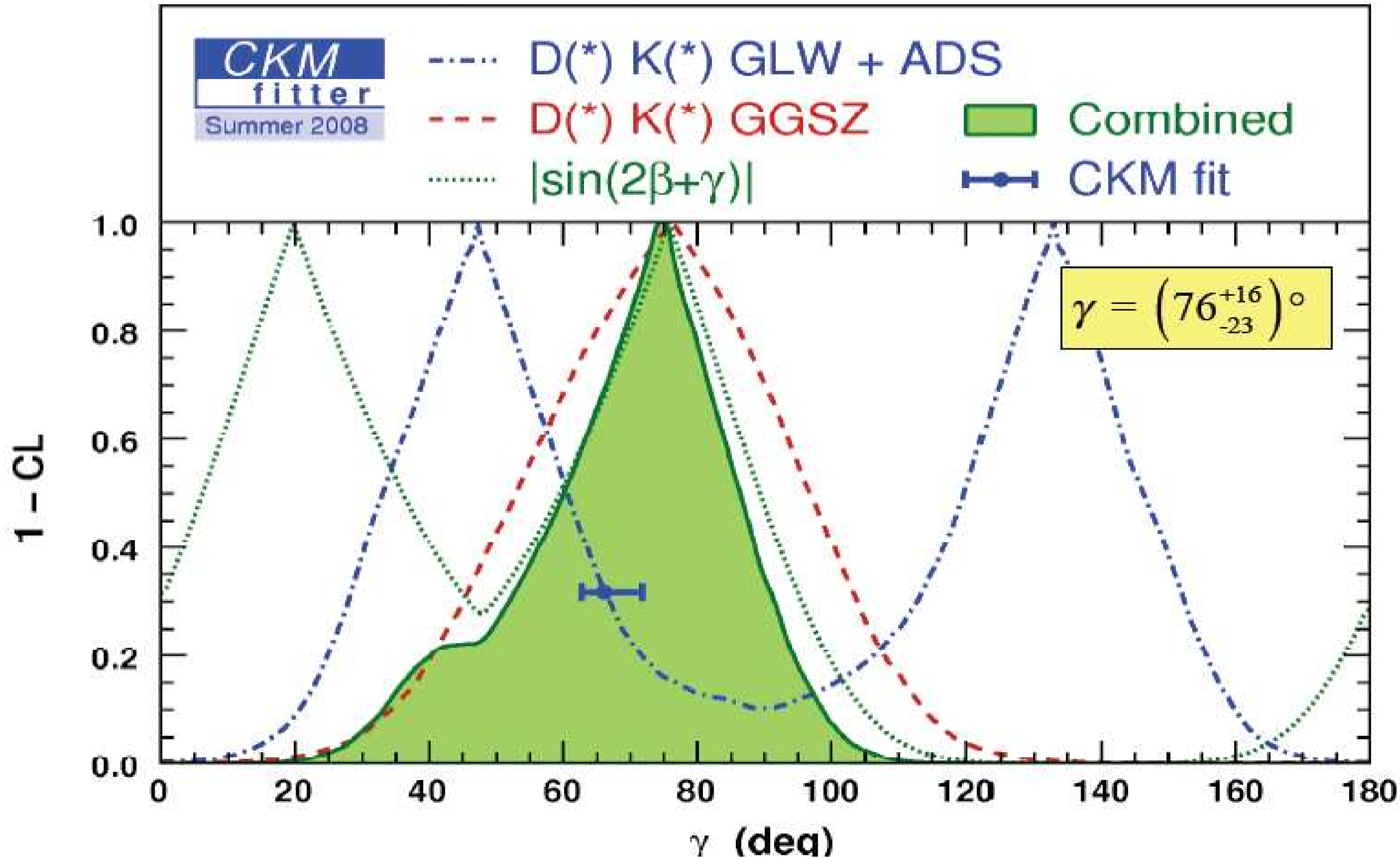
NB: only tree diagrams: 100% Standard Model

The most difficult angle …

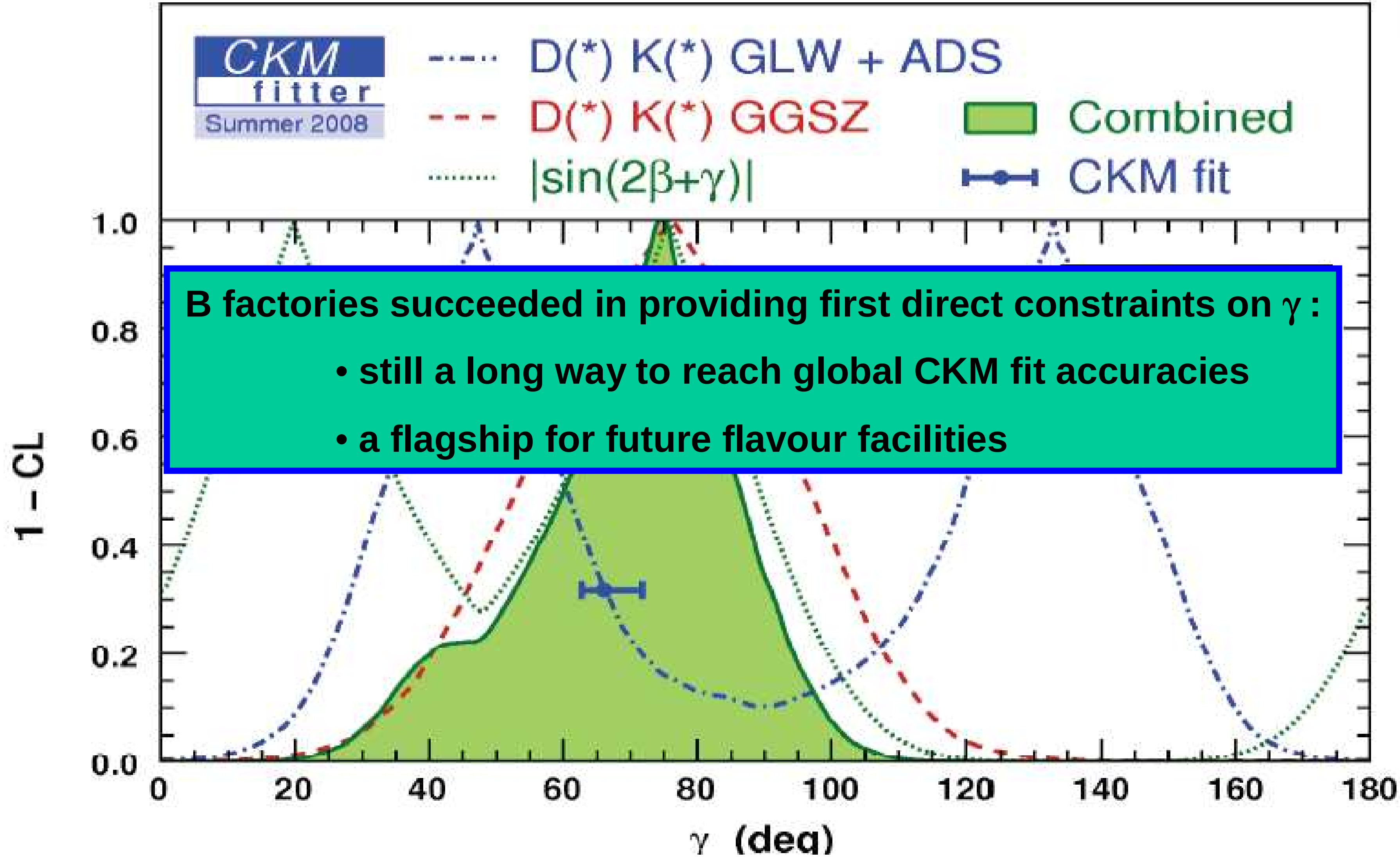
- GWL (Gronau, Wyler, London)
  - D → CP eigenstate
    - Theoretically clean
    - Small interference: needs more data
- ADS (Atwood, Dunietz, Soni)
  - $A(\bar{D} \to f)$ is doubly Cabibbo suppressed
    - Larger interference
    - Small BF: needs more data
- Dalitz method (Giri, Grossman, Soffer, Zupan)
  - Exploits interference pattern in Dalitz plot in $D \to K_S \pi^+ \pi^-$
    - Combines many modes → statistical advantage
    - Small systematics due to Dalitz model

Currently most sensitive

Summary of γ measurements



Summary of γ measurements



B factories succeeded in providing first direct constraints on γ :

- **still a long way to reach global CKM fit accuracies**
- **a flagship for future flavour facilities**

The most difficult angle … some thoughts

Paths towards a non B→charm measurement of γ?

Recurring issue, often discussed in litterature

Several charmless systems (i.e. $K\pi$, $K\pi\pi$) are in principle sensitive to γ

direct CP violation shows γ should be at play !

Most proposed extraction techniques require either :

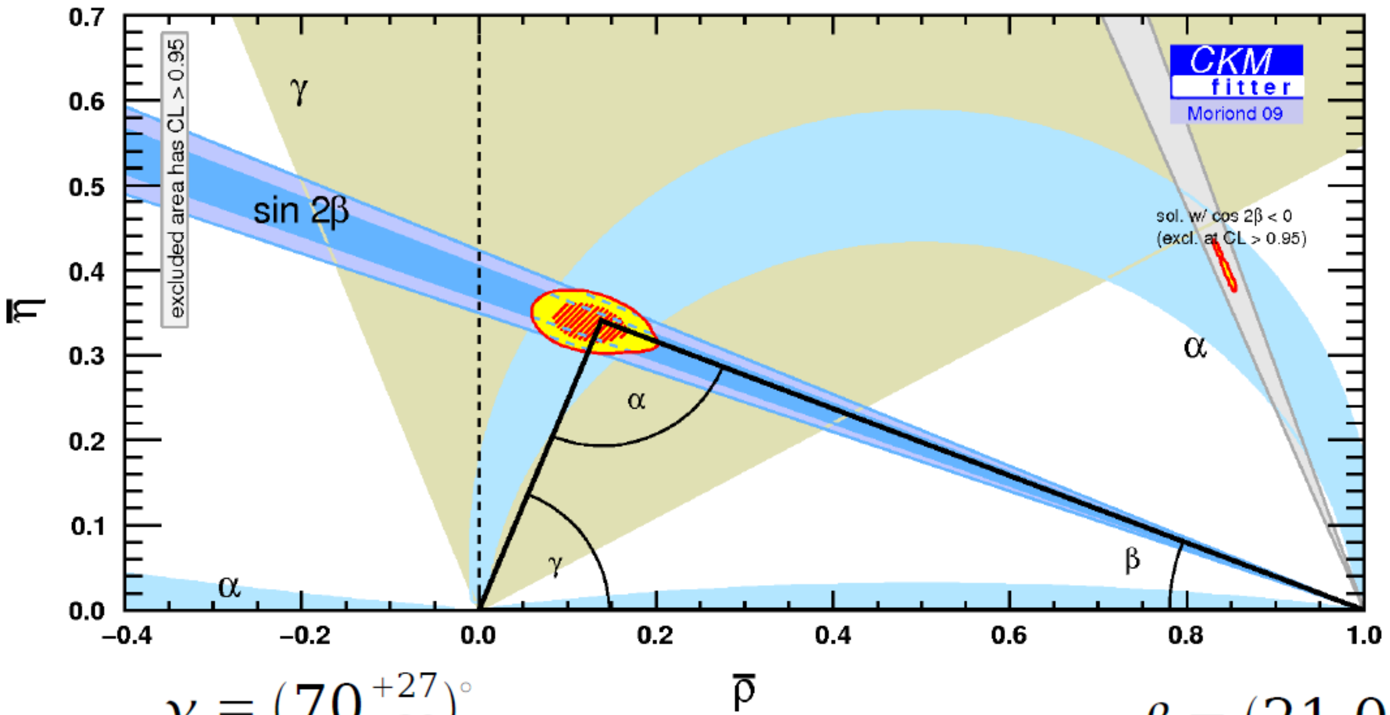
(difficult to control) external hypotheses, i.e. on hadronic parameters

(difficult to access) observables, i.e. TD-CP of $K^0\pi^0$ or Dalitz phases

Ideas welcome!

Summary for the Angles

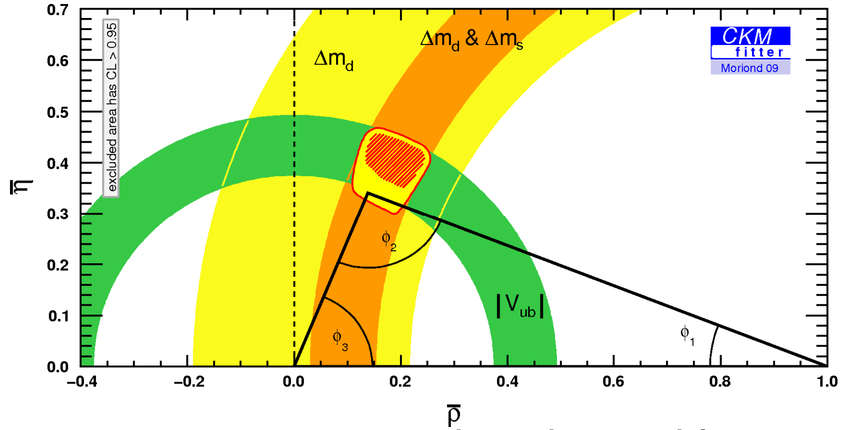
$$\alpha = (89.0^{+4.4}_{-4.2})^\circ$$
$$\text{(WA, CKMfitter, Winter09)}$$



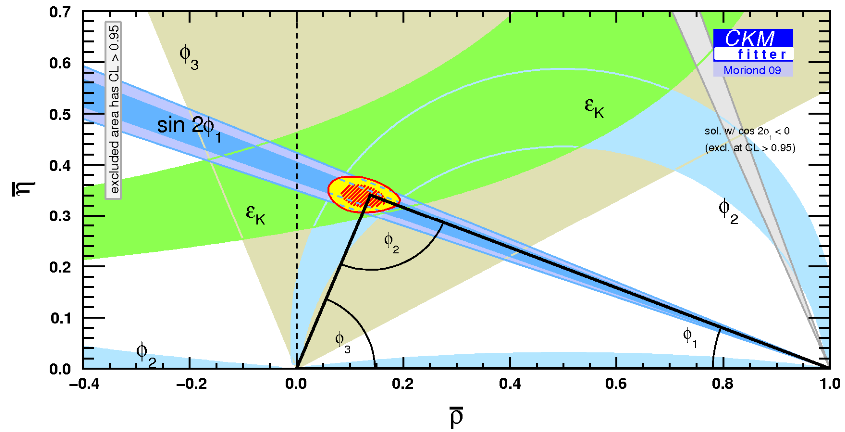
$$\gamma = (70^{+27}_{-29})^\circ$$
$$\text{(WA, CKMfitter, CKM08)}$$

$$\beta = (21.0 \pm 0.9)^\circ$$
$$\text{(WA, HFAG, Winter09)}$$

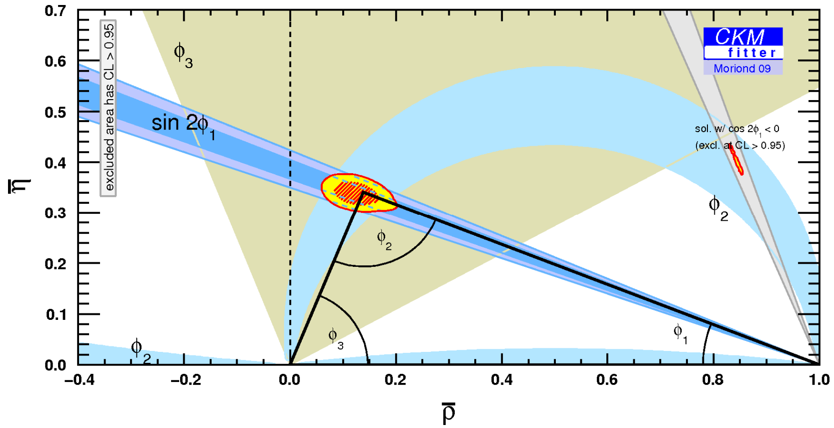
Summary on CKM via angles



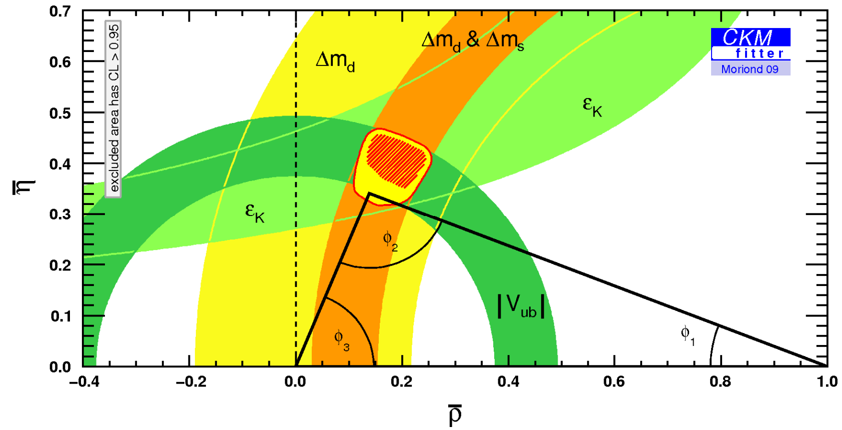
CP-Conserving observables imply CP violation.



CP-Violating observables stresses the same feature



Angles (small theoretical uncertainties)

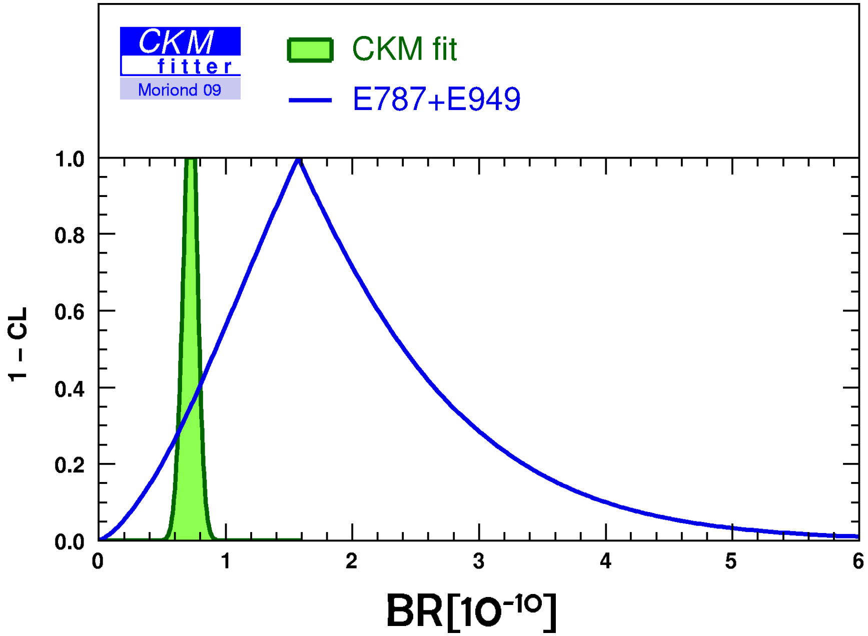


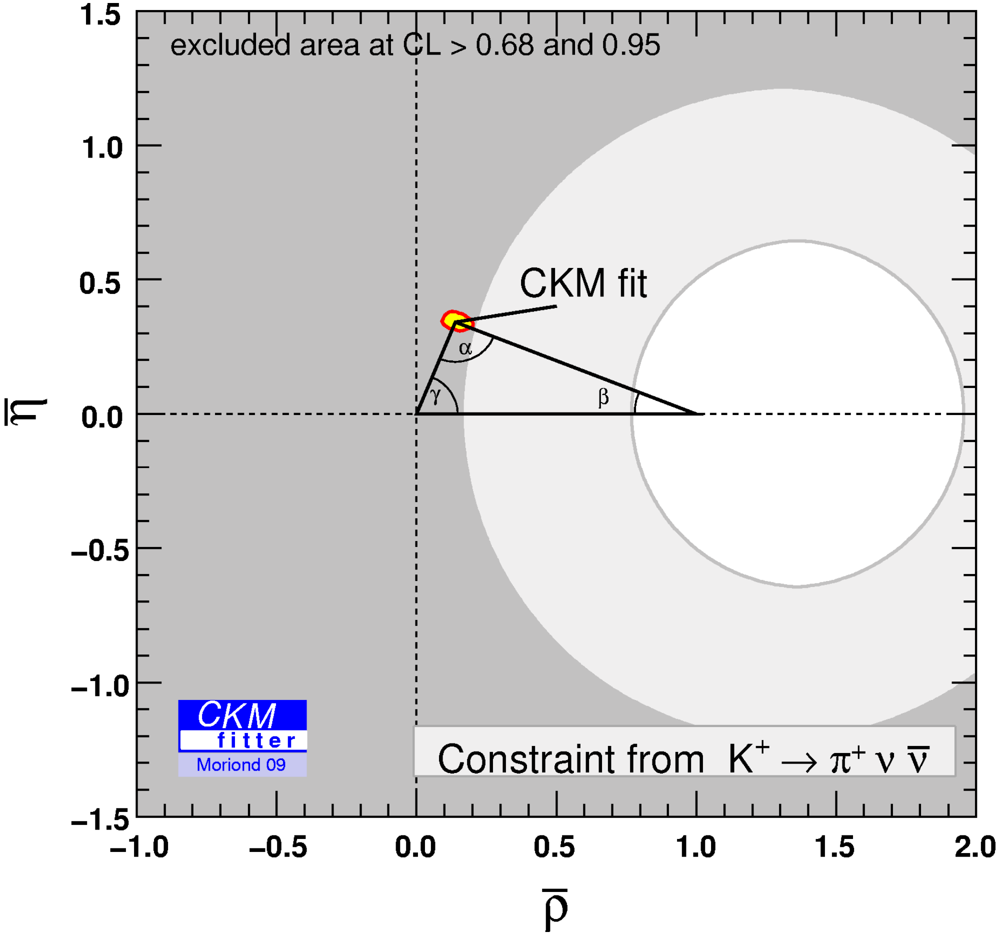
No angles (theoretical uncertainties dominate)

A word on the ultra-rare kaon decay $K^+ \to \pi^+ \nu \bar{\nu}$

- Recent E949 update (arXiv:0903.0030 with 5 events (& incl. E787)): **BR $[10^{-10}]$=** $1.73^{+1.15}_{-1.05}$
- BR parameterization as Brod & Gorbahn '08 (PRD 78, 034006)
  NLO QED-QCD & EW corr. to the charm quark contribution
  $\alpha_s(m_Z)$=0.1176(20) & $m_c(m_c)$=1.286(13)(40)

CKM fit: BR$[10^{-10}]$= $0.80^{+0.08}_{-0.10}$





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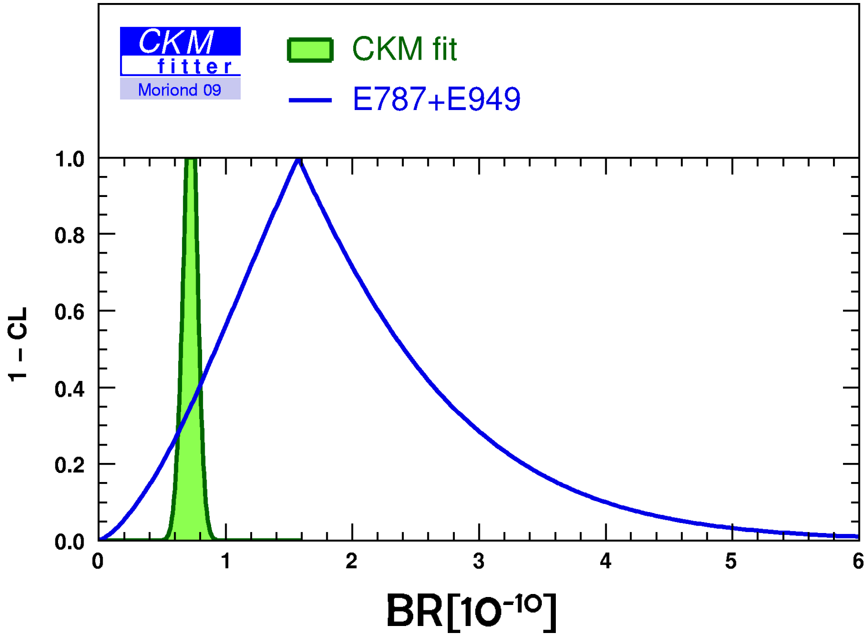

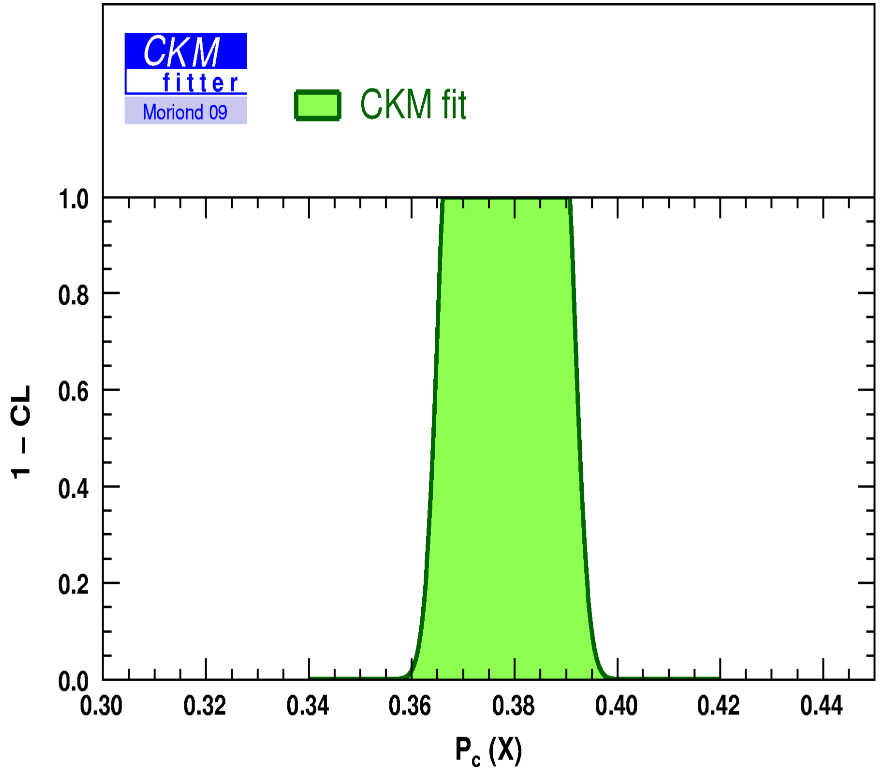

Charm term Pc(X) controlled at ~few %

A word on CKM from kaons

- Recent E949 update (arXiv:0903.0030 with 5 events (& incl. E787)): **BR $[10^{-10}]=1.73^{+1.15}_{-1.05}$**

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  $\alpha_s(m_Z)=0.1176(20)$ & $m_c(m_c)=1.286(13)(40)$

CKM fit: BR$[10^{-10}]=$ $0.80^{+0.08}_{-0.10}$

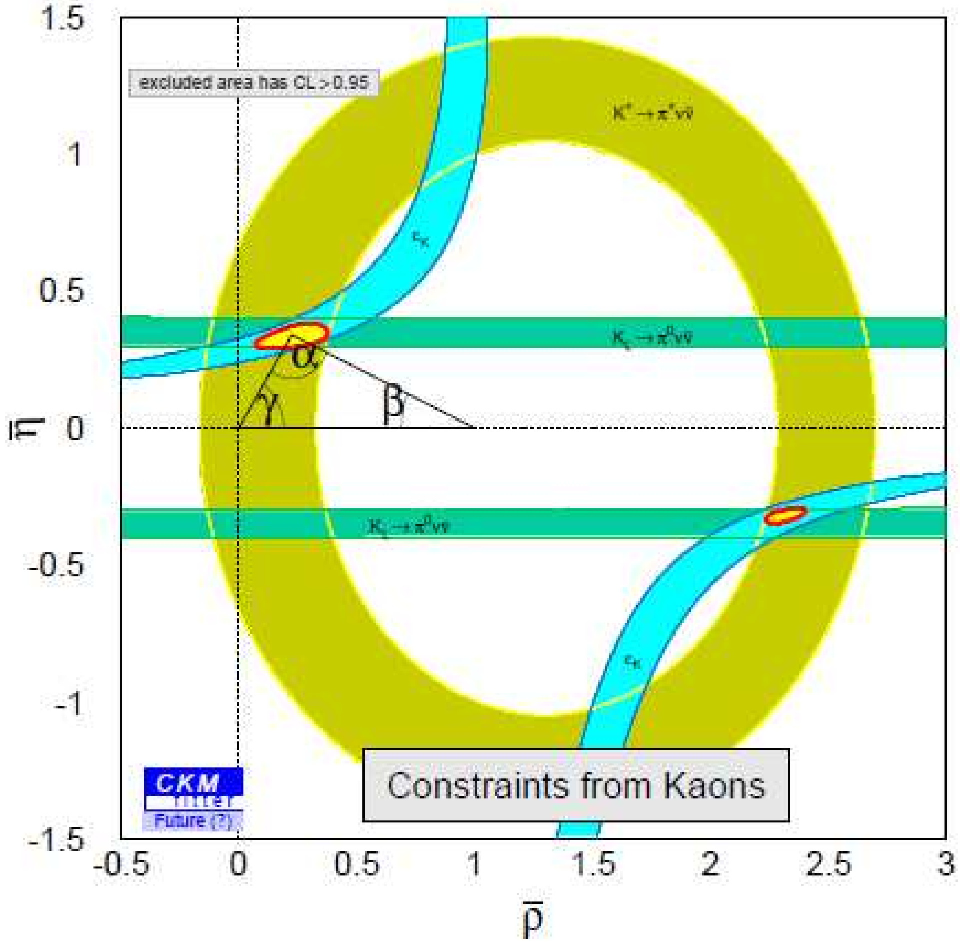
Prospective study : assume

- **$K^+ \to \pi^+ \nu\nu$ measured by NA62 (~10%)**
- **$K_L \to \pi^0 \nu\nu$ measured by J-PARC (~15%)**
- **mild improvement on theory error for ε_K**

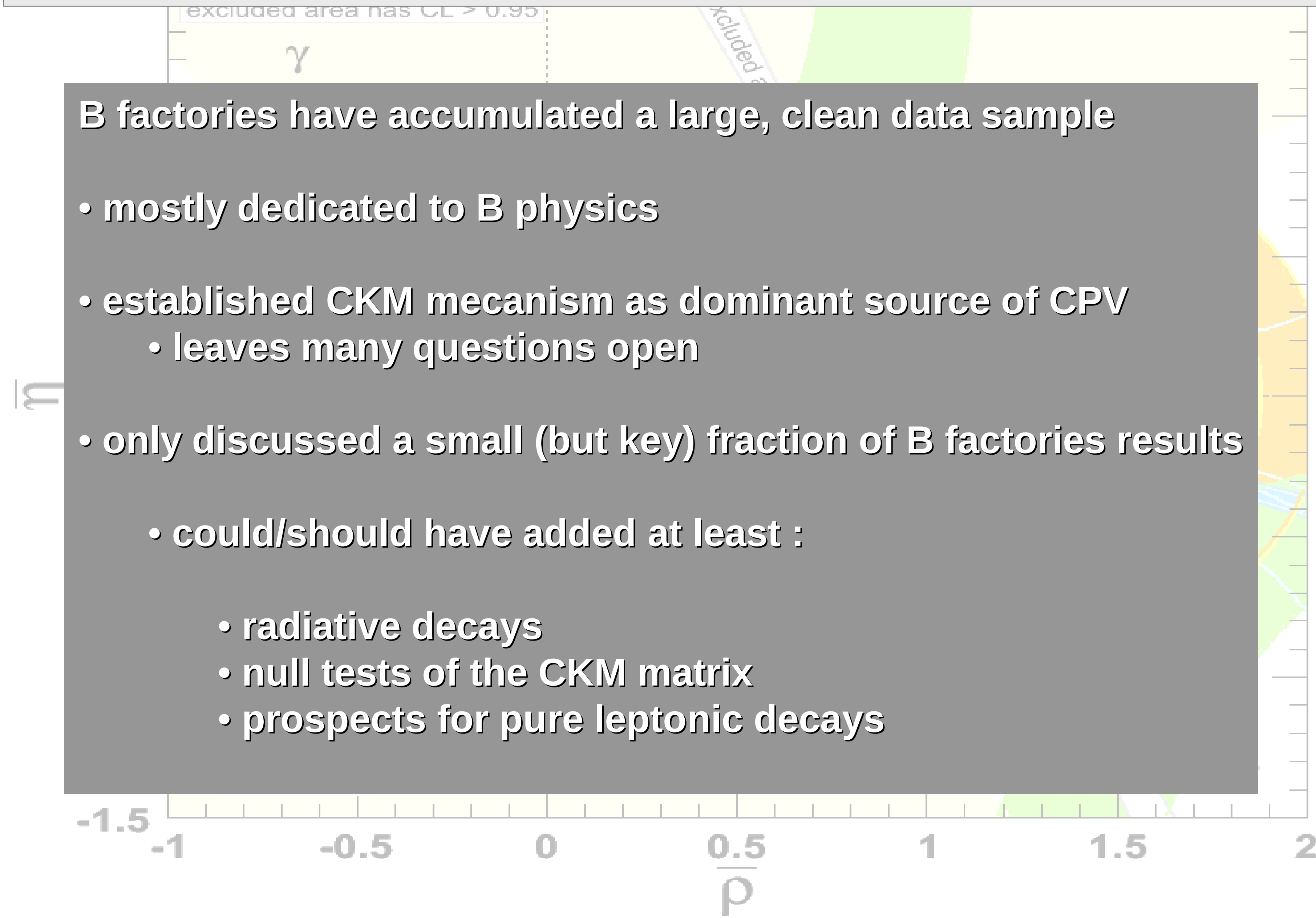
A strongly constrained CKM matrix

Only using Kaon inputs

Caveat: plot uses a pre-NNLO treatment of Pc(X)…



Summary



B factories have accumulated a large, clean data sample

- **mostly dedicated to B physics**

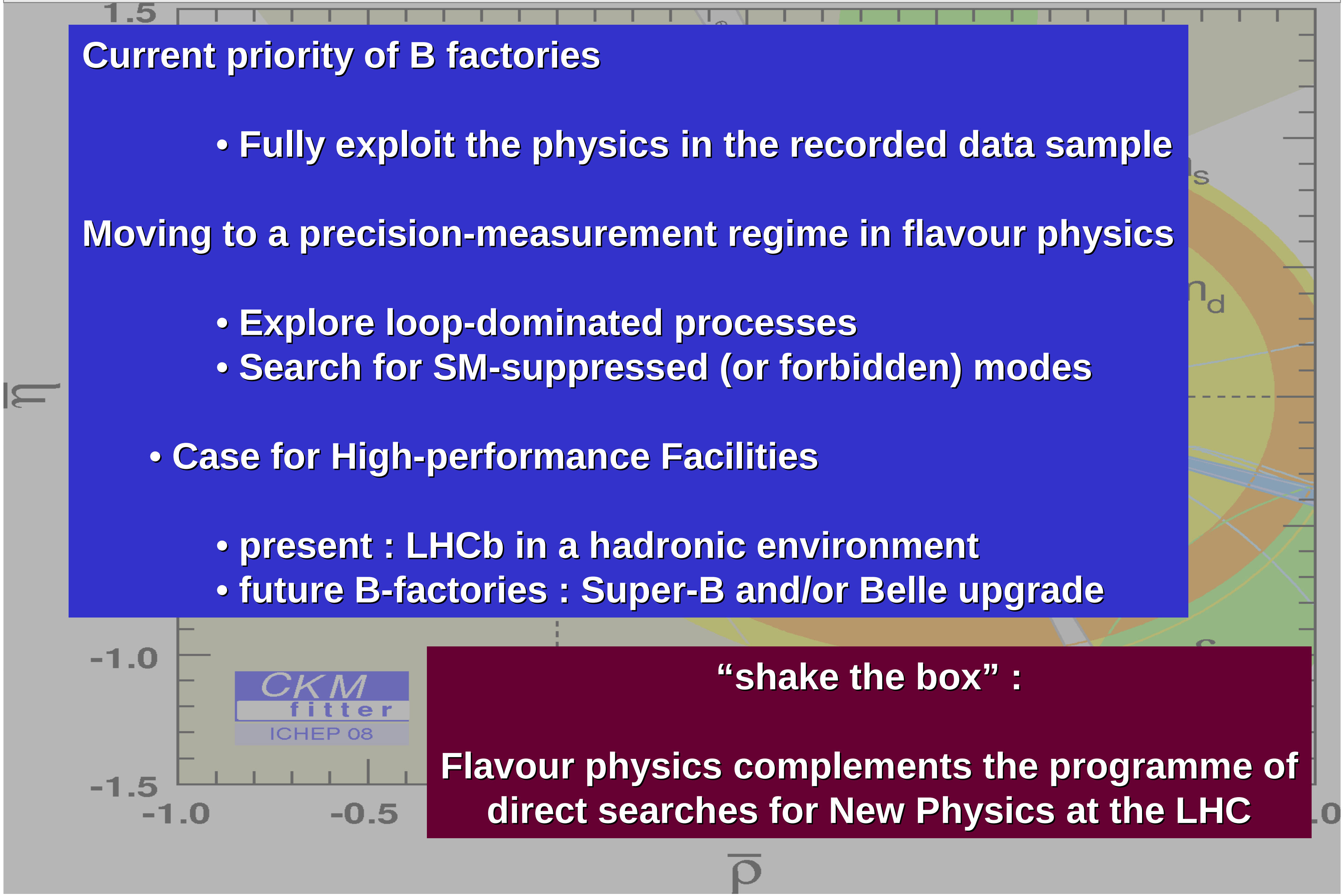
- **established CKM mecanism as dominant source of CPV**
  - **leaves many questions open**

- **only discussed a small (but key) fraction of B factories results**

  - **could/should have added at least :**

    - **radiative decays**
    - **null tests of the CKM matrix**
    - **prospects for pure leptonic decays**

Conclusions



Current priority of B factories

- Fully exploit the physics in the recorded data sample

Moving to a precision-measurement regime in flavour physics

- Explore loop-dominated processes
- Search for SM-suppressed (or forbidden) modes

- Case for High-performance Facilities

- present : LHCb in a hadronic environment
- future B-factories : Super-B and/or Belle upgrade

“shake the box” :

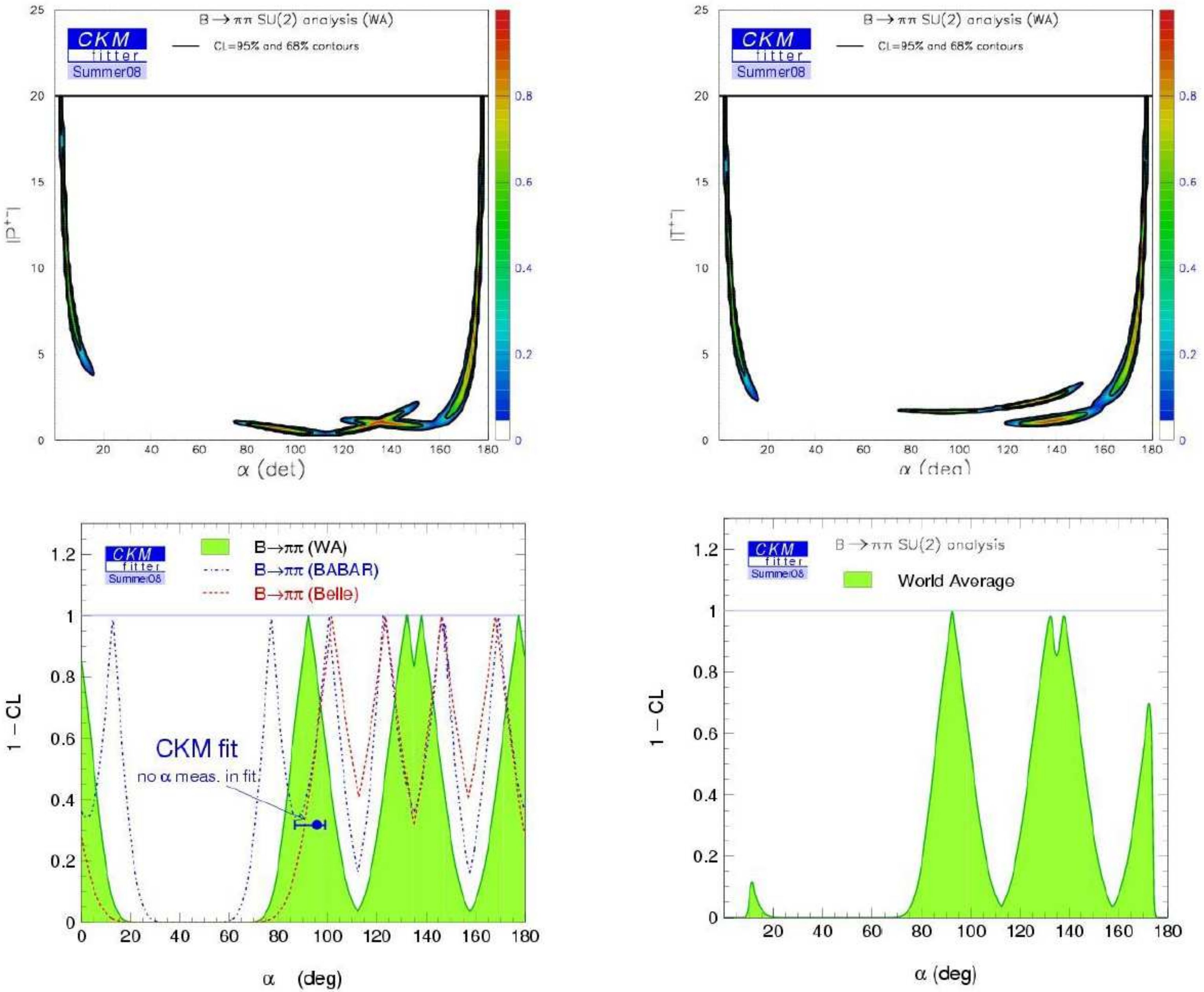
Flavour physics complements the programme of direct searches for New Physics at the LHC

Backup material

Mostly borrowed from my CKMfitter colleagues

More details on V. Tisserand's presentation at Moriond09

P and T

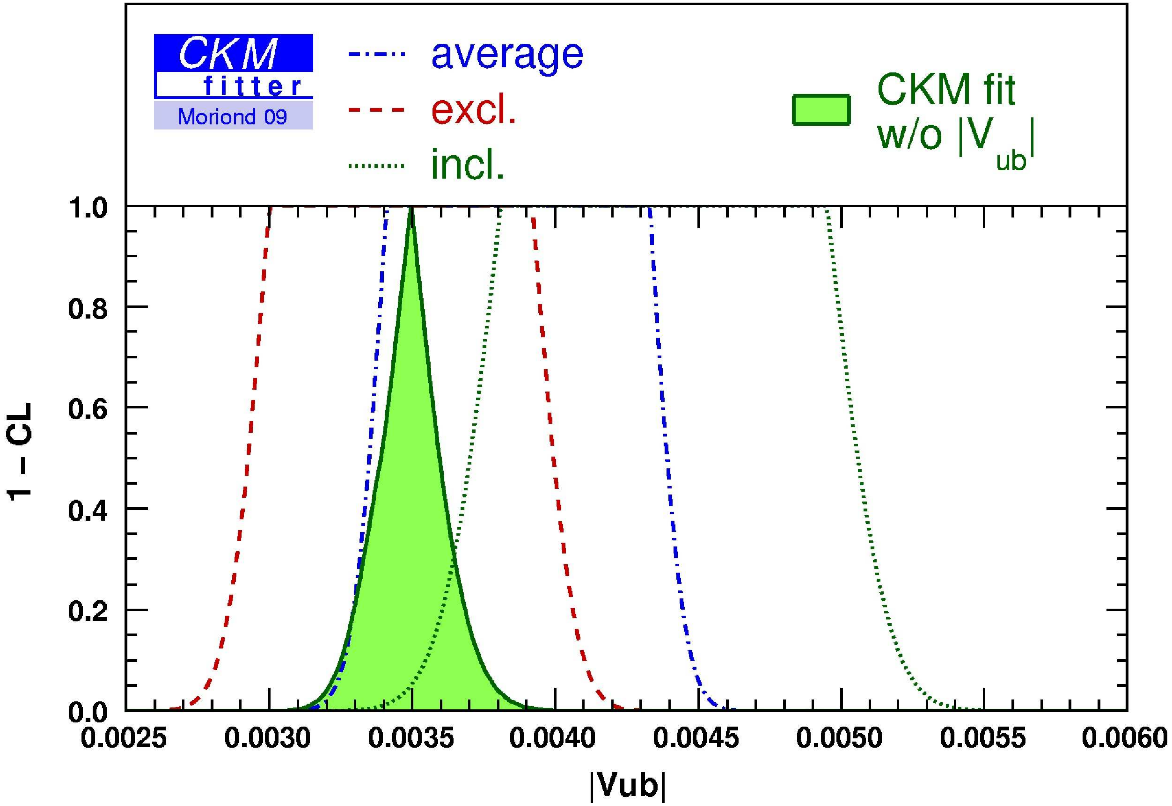


B → ππ SU(2) analysis (WA)
CKM fitter Summer08
CL=95% and 68% contours
|P+-|
α (deg)
|T+-|
B→ππ (WA)
B→ππ (BABAR)
B→ππ (Belle)
CKM fit
no α meas. in fit
1 − CL
World Average
α (deg)

2) CKM Matrix: The SM Fit inside 95%CL. frémissements?

2.4.1 $|V_{ub}|$ vs $\sin 2\beta$?

It is actually more a $|V_{ub}|$ vs $|V_{ub}|$ tension. We are living with a significant difference between exclusive and inclusive measurements: a longstanding issue. The $\sin 2\beta$ measurement prefers the exclusive value.

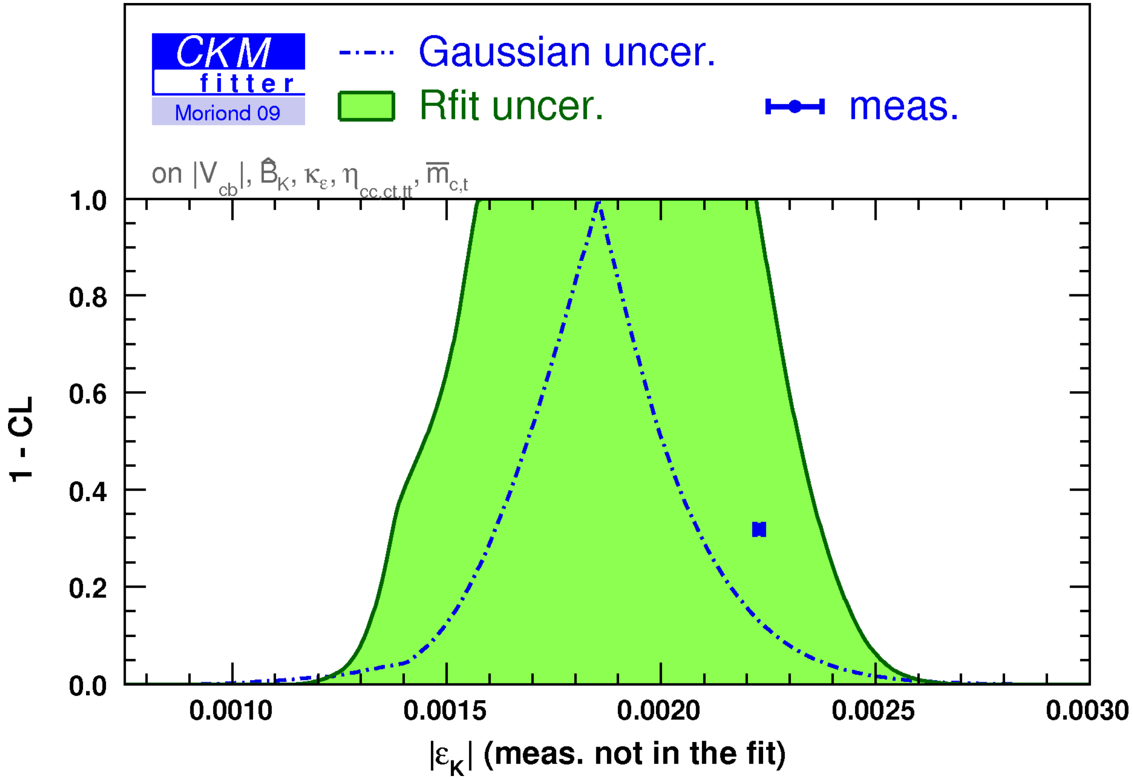


2.4.2 $|\varepsilon_K|$ vs sin2β?

Buras & Guadagnoli recently advocated necessity of an additional parameter in the SM lowering the prediction. The resulting tension $|\varepsilon_K|$ vs sin2β might have very appealing explanations (Soni & Lunghi).

✓We included the additional parameter and got the result in green.
✓Slight change as expected w.r.t to the standard fit.

✓The tension arises if all the uncertainties on QCD parameters are gaussien. Are they ?



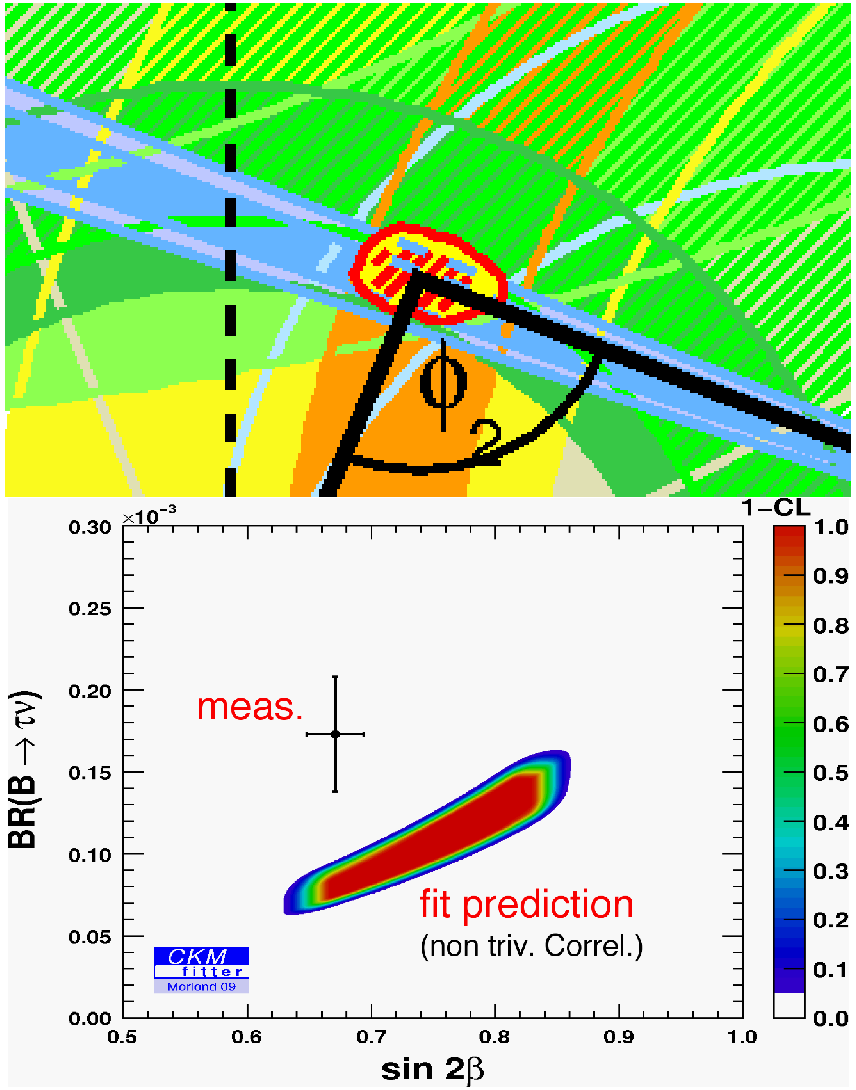
2.4.3 BR($B^+ \to \tau^+ \nu$) vs sin 2β?

Actually a large effect:

Tension between sin(2β) (I) & BR($B^+ \to \tau^+ \nu$) (II) (through |Vub|):

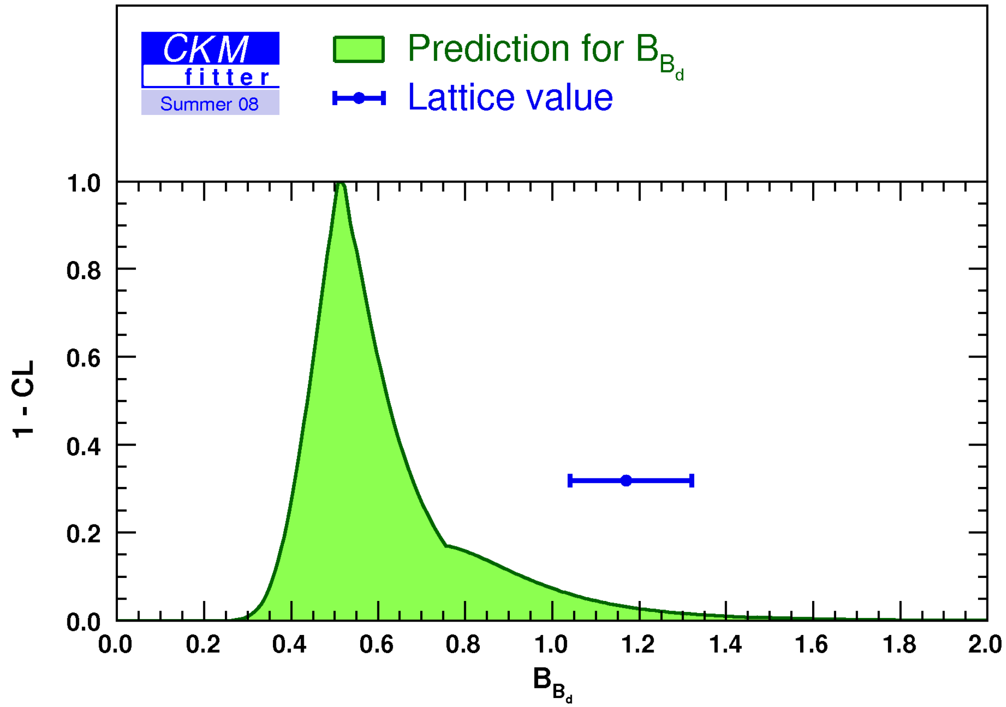
Removing I/II in the CKM global fit,

the $\chi 2_{min}$ drops by 2.3/2.4 σ.



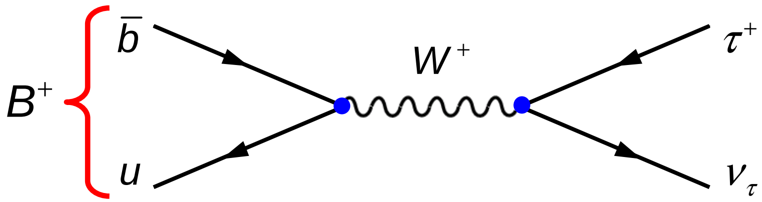
2.4.3 **BR($B^+ \to \tau^+ \nu$)** vs sin 2β?

Looking in the detail, it is a non trivial correlation; we could think of |Vub|, $|\varepsilon_K|$, f_{Bd}…Actually, analysing simultaneouly Δm_d and **BR($B^+ \to \tau^+ \nu$)** gives a theory free determination of the B_{Bd} factor and the tension is brought there.



$B^+ \to \tau^+\nu$ experim.

- helicity-suppressed annihilation decay sensitive to $f_B \times |V_{ub}|$
- Sensitive to tree-level charged Higgs replacing the W propagator.



$$BR(B^+ \to \tau^+\nu) = \frac{G_F^2 m_B \tau_B}{8\pi} m_\tau^2 \left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 f_B^2 \, |V_{ub}|^2$$

BR[10^{-4}]=1.80 ± 0.63
- 1.80±1.00 (had)
- 1.80±0.81 (semi-lept)

BR[10^{-4}]=1.70 ± 0.42
- 1.79±0.71 (had)
- 1.65±0.52 (semi-lept)

Measurement are consistent & WA:

BF[10^{-4}]= 1.73 ± 0.35

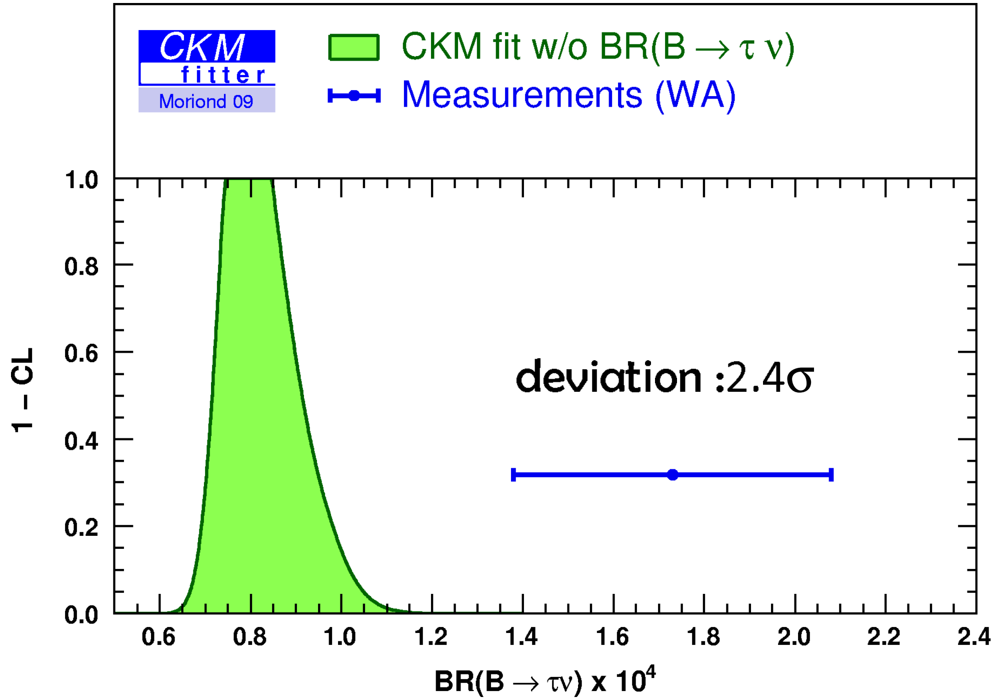
Measurement from global CKMfit:

BF[10^{-4}]= $0.796^{+0.154}_{-0.093}$

Inputs:

$|V_{ub}|$
Δm_d
Δm_s
$|\varepsilon_K|$
$\sin 2\beta$
α
γ

f_{Bd} from our own LQCD average:
f_{Bs}/f_{Bd}= 1.196(8)(23) & f_{Bs}= 228(3)(17)



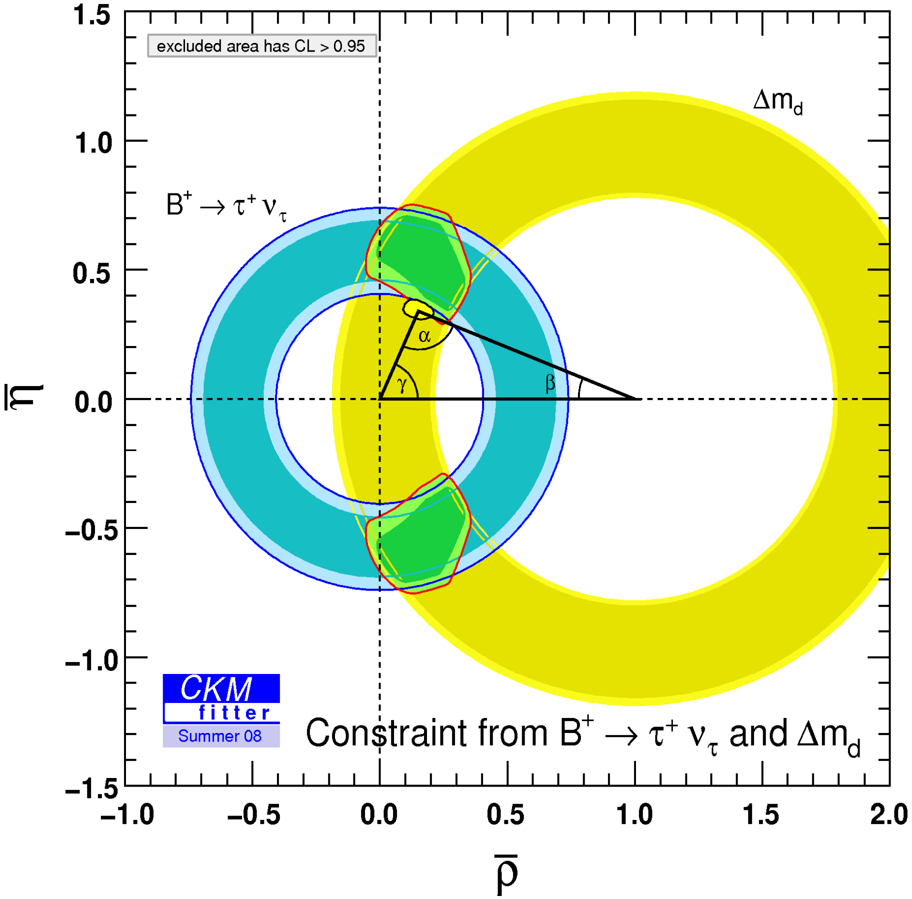
new CLEO-c '09 $D^+_s \to \tau^+\nu$ (~fine)...

$B^+ \to \tau^+ \nu$ theory.

Powerful together with Δm_d : removes f_B (Lattice QCD) dependence

(left with B_d errors anyway). If error of f_{Bd} small : 2 circles that intersect at ~90°

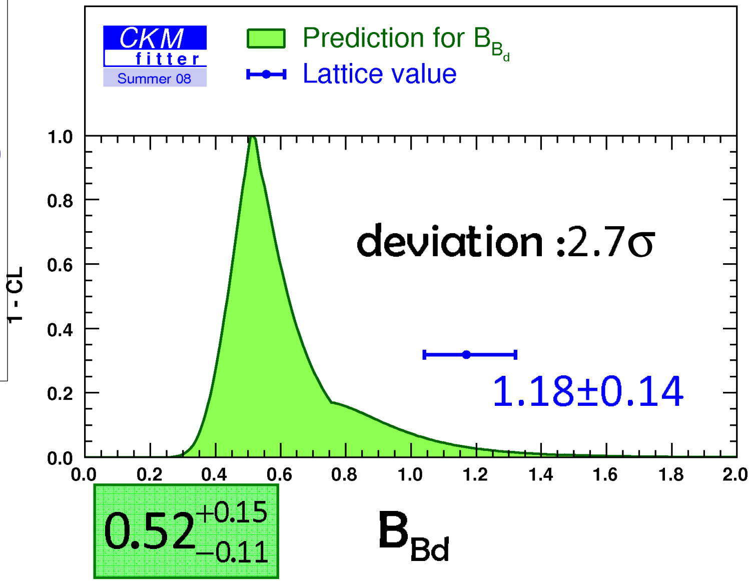
$$\frac{BR(B^+ \to \tau^+ \upsilon)}{\Delta m_d} = \frac{3\pi}{4} \frac{m_\tau^2 \tau_{B^+}}{m_W^2 S(x_t)} \left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 \frac{\sin^2(\beta)}{\sin^2(\gamma)} \frac{1}{|V_{ud}|^2 B_{B_d}}$$



Inputs:

Δm_d
$B \to \tau\nu$
$\gamma(=\pi-\beta-\alpha)$
$\sin 2\beta$
$|V_{ud}|$

Theory free prediction for B_{Bd}



$0.52^{+0.15}_{-0.11}$

The tension is not driven by V_{ub} (SL) nor f_{Bd} (nor ε_K)