CKM Fits: What the Data Say

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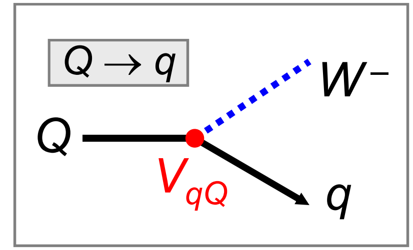
On behalf of the CKMfitter group
http://ckmfitter.in2p3.fr

The CKM Matrix: Four Unknowns

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



unitarity-exact and convention-independent version of the Wolfenstein parametrization

$$\lambda^2 \equiv \frac{|V_{us}|^2}{|V_{ud}|^2 + |V_{us}|^2} \qquad A^2\lambda^4 \equiv \frac{|V_{cb}|^2}{|V_{ud}|^2 + |V_{us}|^2} \qquad \bar\rho + i\bar\eta \equiv -\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}$$

Measurement of Wolfenstein parameters:

- λ from $|V_{ud}|$ (nuclear transitions) and $|V_{us}|$ (semileptonic K decays)
  → combined precision: 0.5%
- A from $|V_{cb}|$ (inclusive and exclusive semileptonic B decays)
  → combined precision: 2%
- $\bar\rho$, $\bar\eta$ from (mainly) CKM angle measurements:
  → combined precision: 20% (ρ), 7% (η)

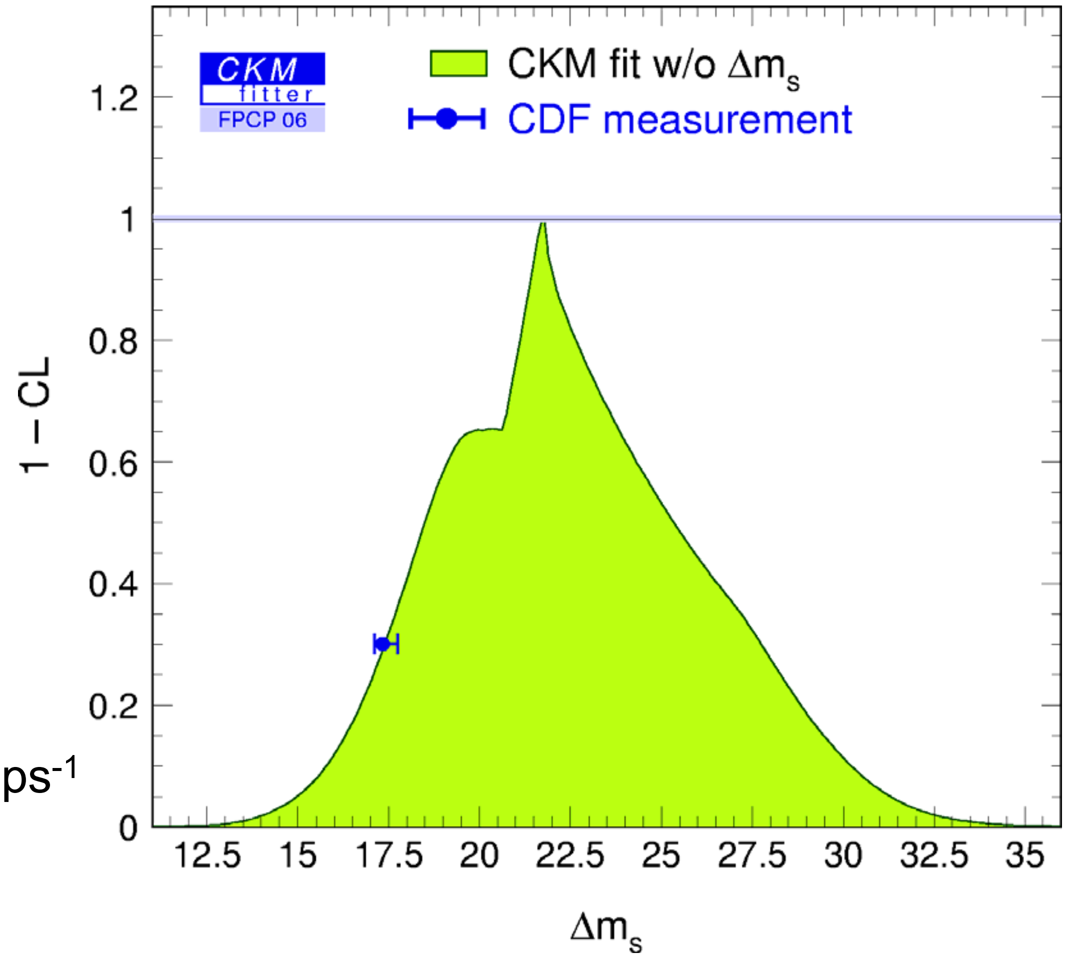
Inputs: Δm_s

hep-ex/0603029

$17 < \Delta m_s < 21\ ps^{-1}$ @90 C.L.

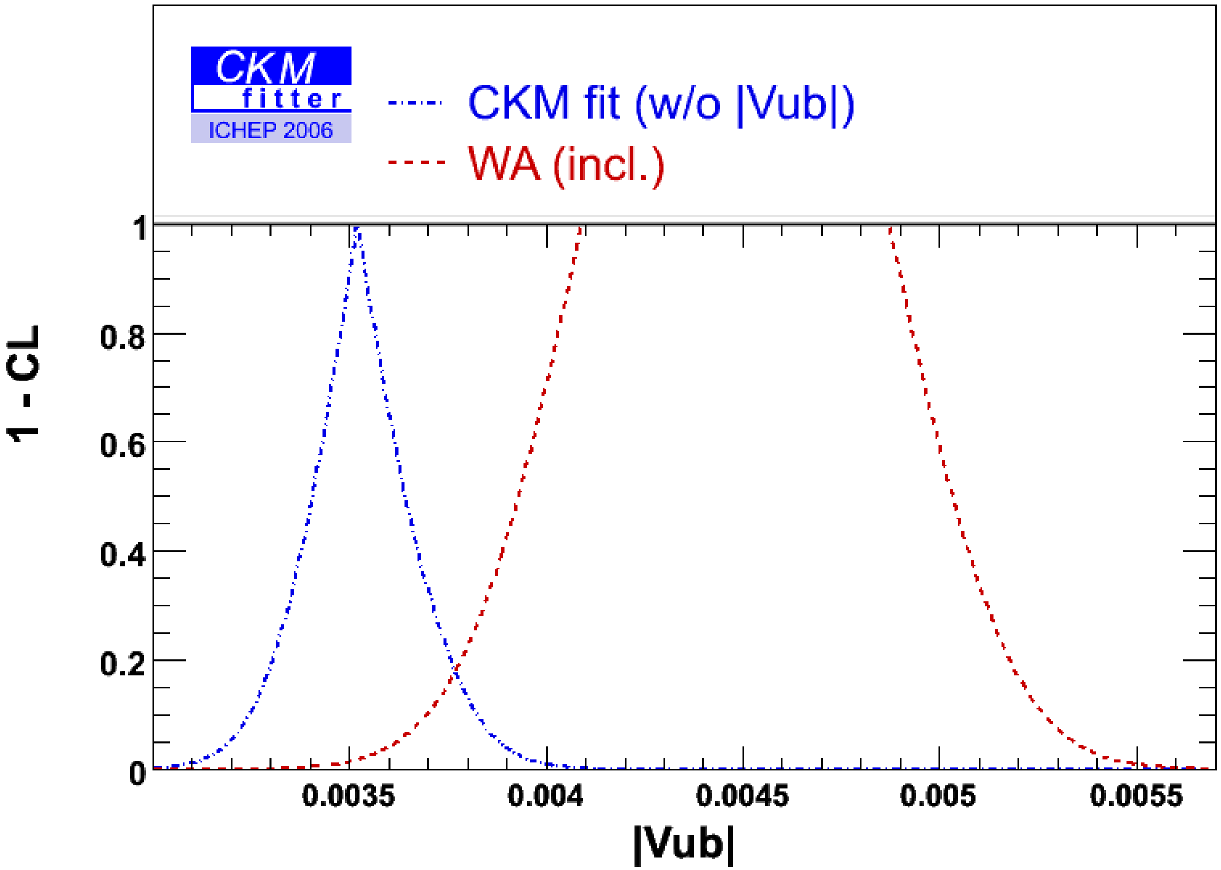
hep-ex/0606027

Δm_s : $17.31\ ^{+0.33}_{-0.18}$ (stat.) $\pm$ 0.07 (syst.) ps^{-1}



Inputs (major changes): $|V_{ub}|$ (incl.)

|Vub| (incl.) [10^{-3}] = 4.48 ± 0.24 ± 0.39 (our average)



Inputs (major changes): $\sin 2\beta$

- "The" *raison d'être* of the *B* factories:

$\sin 2\beta =$

0.710	0.034	0.019	[BABAR(348m)]
0.642	0.031	0.017	[Belle (532m)]
0.674	0.026 (0.023 stat-only)		

ICHEP '06

$C(J/\psi K^0) =$

0.070	0.028	0.018	[BABAR]
-0.018	0.021	0.014	[Belle]
0.012	0.022 (0.017 stat-only)		

- Conflict with $\sin 2\beta_{\mathrm{eff}}$ from *s*-penguin modes ? (New Physics (NP)?)

$\sin 2\beta(\eta' K^0) =$

0.55	0.11	0.02	[BABAR(347m)]
0.64	0.10	0.02	[Belle (532m)]
0.60	0.08		

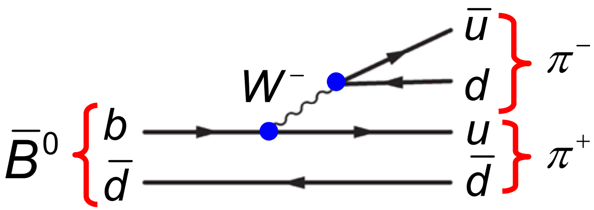
$\sin 2\beta(\phi K^0) =$

0.12	0.34		[BABAR(347m)]
0.44	0.27	0.05	[Belle (386m)]
0.31	0.21		

NP can contribute differently among the various s-penguin modes
Meaning of the average?

NB: a disagreement would falsify the SM. The interference NP/SM amplitudes introduces hadronic uncertainties
➔ Cannot determine the NP parameters cleanly

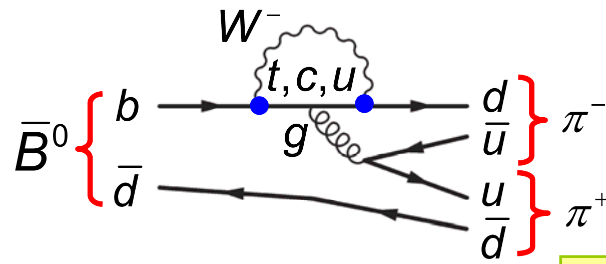
Inputs (major changes): angle α



Tree : dominant

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

$\propto \lambda^3$



Penguin : competitive ?

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

$\propto \lambda^3$

- Time-dependent CP observable :

realistic scenario

$$A_{h^+h^-}(t) = S_{h^+h^-}\sin(\Delta m_d t) - C_{h^+h^-}\cos(\Delta m_d t)$$

$$= \sqrt{1-C^2_{h^+h^-}}\,\sin(2\alpha_{\rm eff})\cdot\sin(\Delta m_d t) - C_{h^+h^-}\cos(\Delta m_d t)$$

Time-dependent *CP* analysis of $B^0 \to \pi^+\pi^-$ alone determines $\alpha_{\rm eff}$: but, we need α !

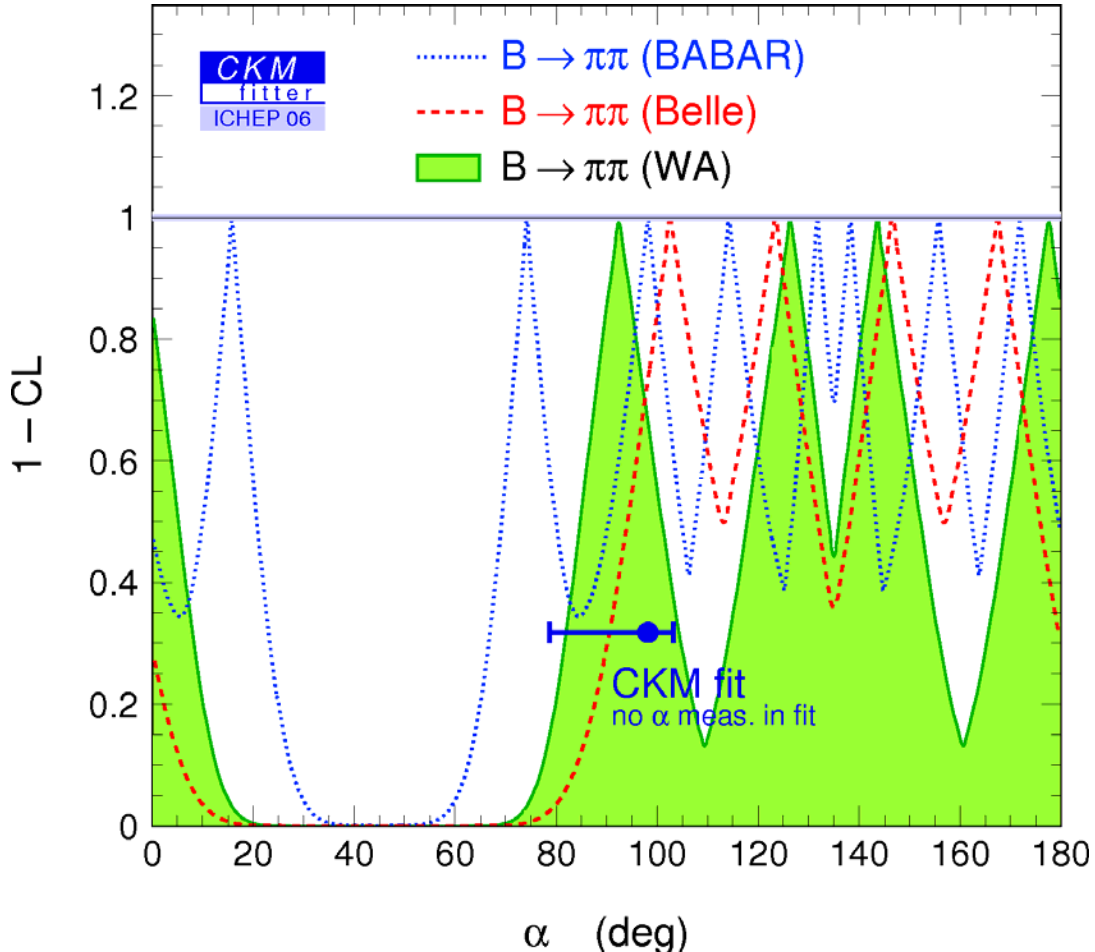
→ Isospin analysis (α can be resolved up to an 8-fold ambiguity within [0,π])

Isospin Analysis: B→ ππ

	BABAR (347m)	Belle (532m)	Average
$S_{\pi\pi}$	–0.53 ± 0.14 ± 0.02	–0.61 ± 0.10 ± 0.04	–0.58 ± 0.09
$C_{\pi\pi}$	–0.16 ± 0.11 ± 0.03	–0.55 ± 0.08 ± 0.05	–0.39 ± 0.07

"agreement": **2.6σ**

BABAR & Belle



Isospin Analysis: B→ ρρ

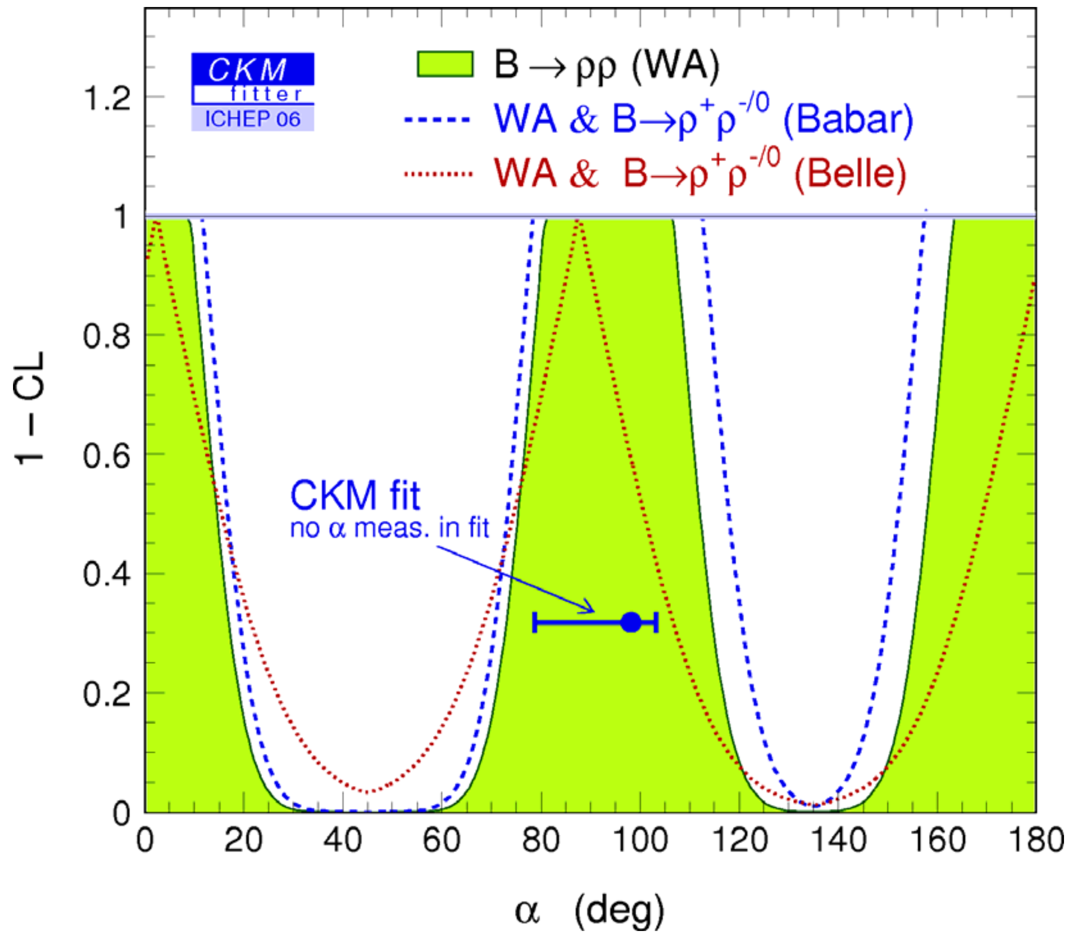
	BABAR (347m)	Belle (275m)	Average
$S_{\rho\rho}$	–0.19 0.21 $^{+0.05}_{-0.07}$	0.08 0.41 0.09	–0.13 0.19
$C_{\rho\rho}$	–0.07 0.15 0.06	0.0 0.3 0.09	–0.06 0.14

	BABAR (347m)
f_L^{00}	0.86 $^{+0.11}_{-0.13}$ 0.06
BR^{00}	(1.2 0.4 0.3)x10^{-6}

- Isospin analysis :

α = [94 21] °

BABAR & Belle



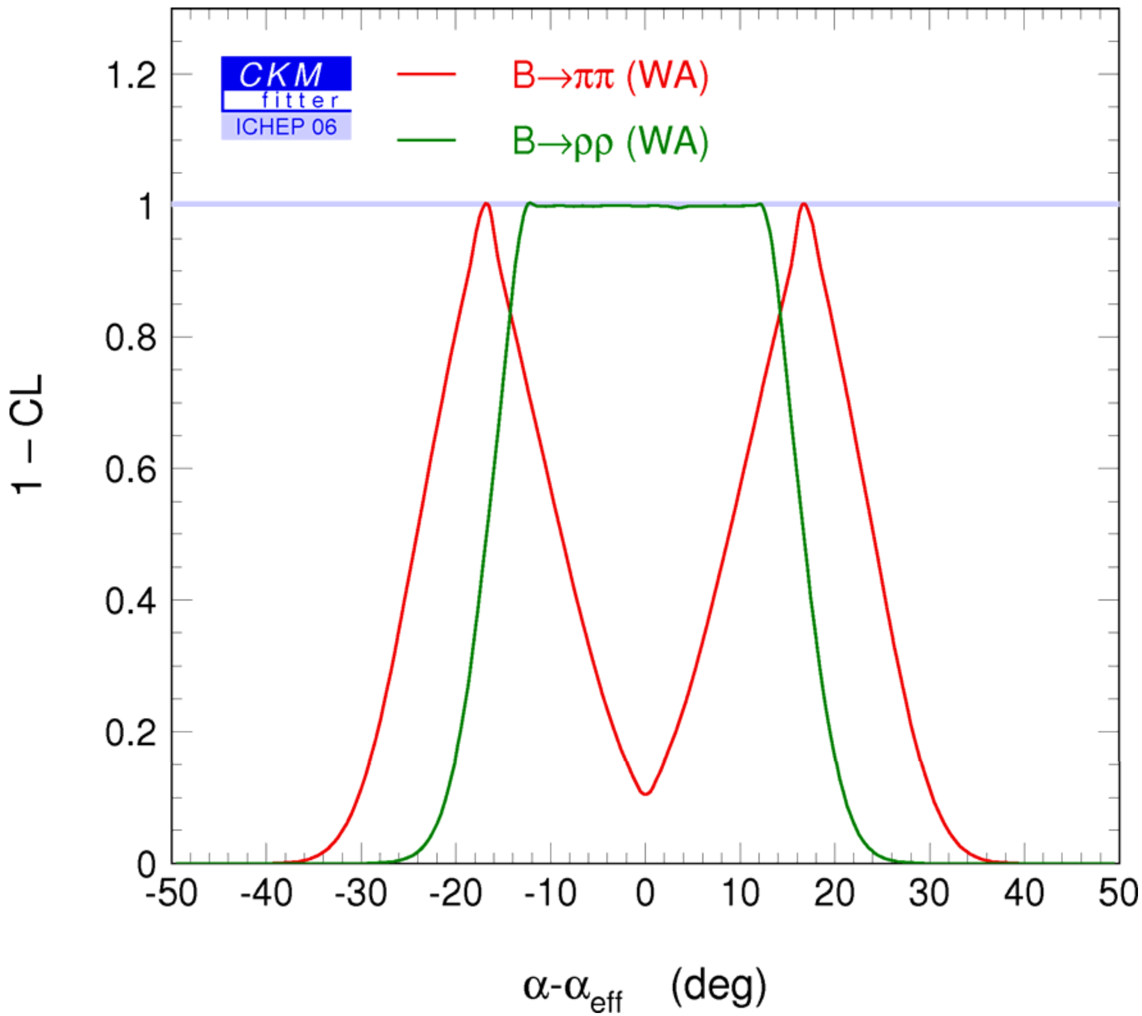
Isospin Analysis: angle α_{eff} [B→ ππ/ρρ]

- Isospin analysis B→ππ:

  $|\alpha-\alpha_{eff}| < 32.1^o$ (95% CL)

- Isospin analysis B→ρρ:

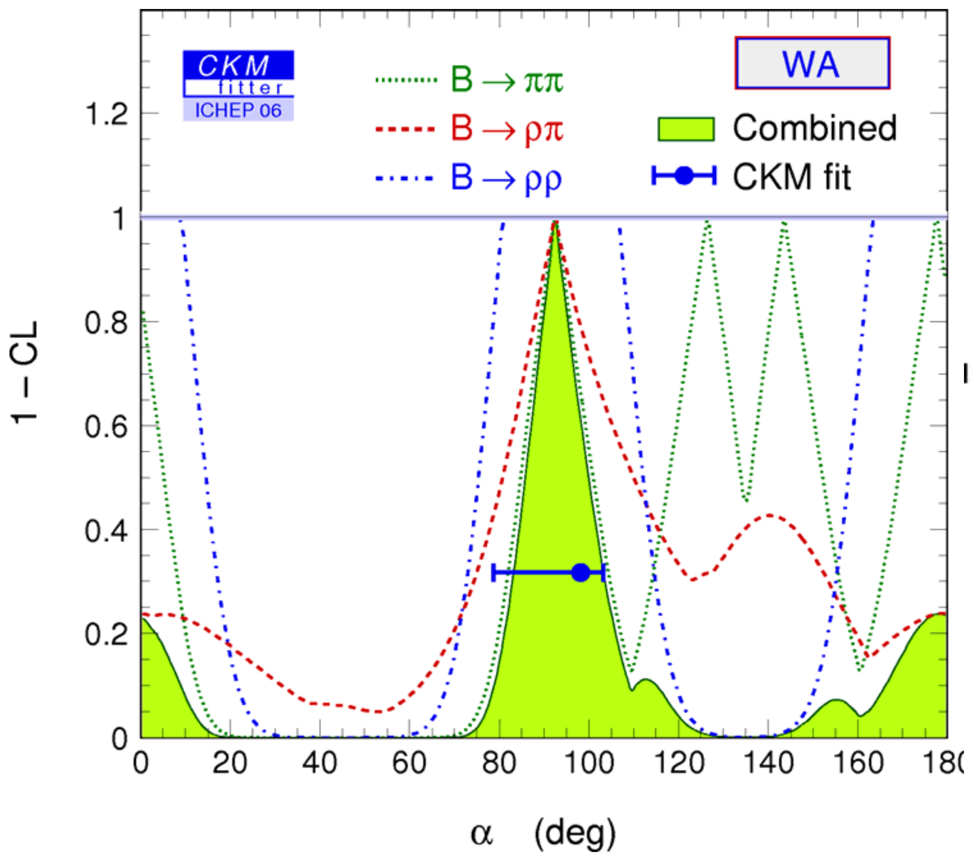
  $|\alpha-\alpha_{eff}| < 22.4^o$ (95% CL)

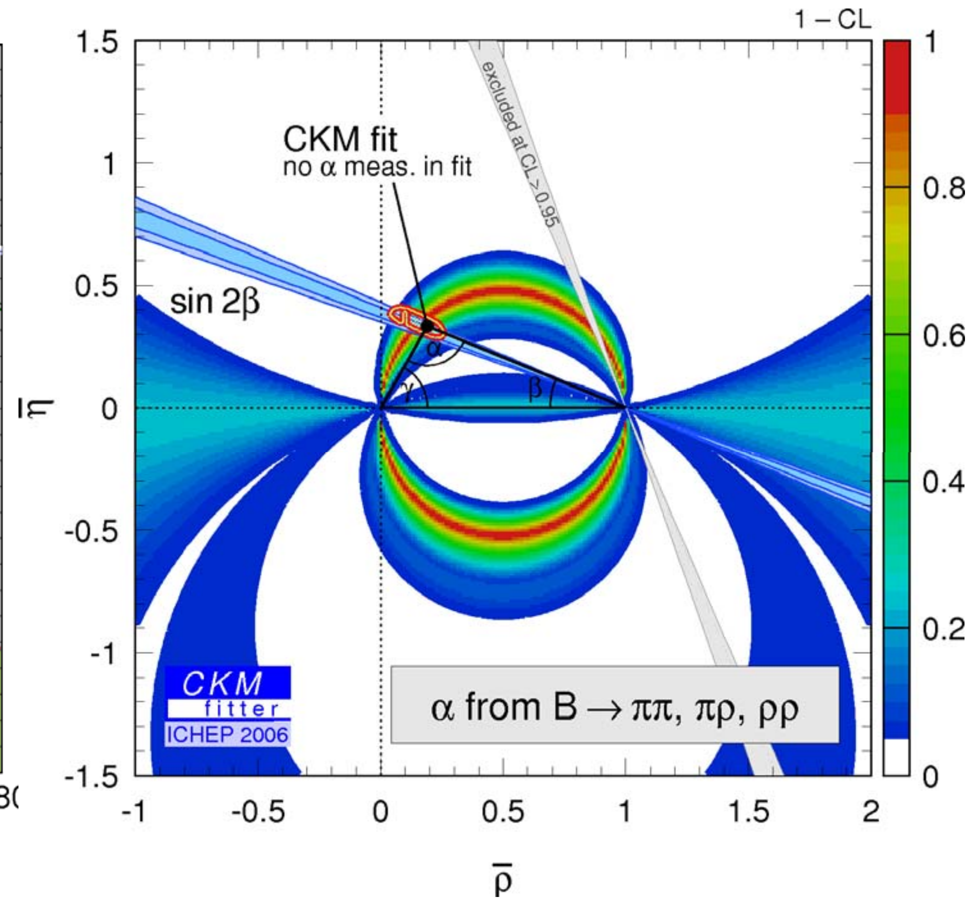


Isospin Analysis: angle α [$B\rightarrow\pi\pi/\rho\pi/\rho\rho$]

$\alpha_{\text{B-Factories}} = [\,93\,^{+11}_{-9}\,]^\circ$ → $\alpha_{\text{Global Fit}} = [\,98\,^{+5}_{-19}\,]^\circ$

(include new $\rho\pi$ Dalitz BABAR)

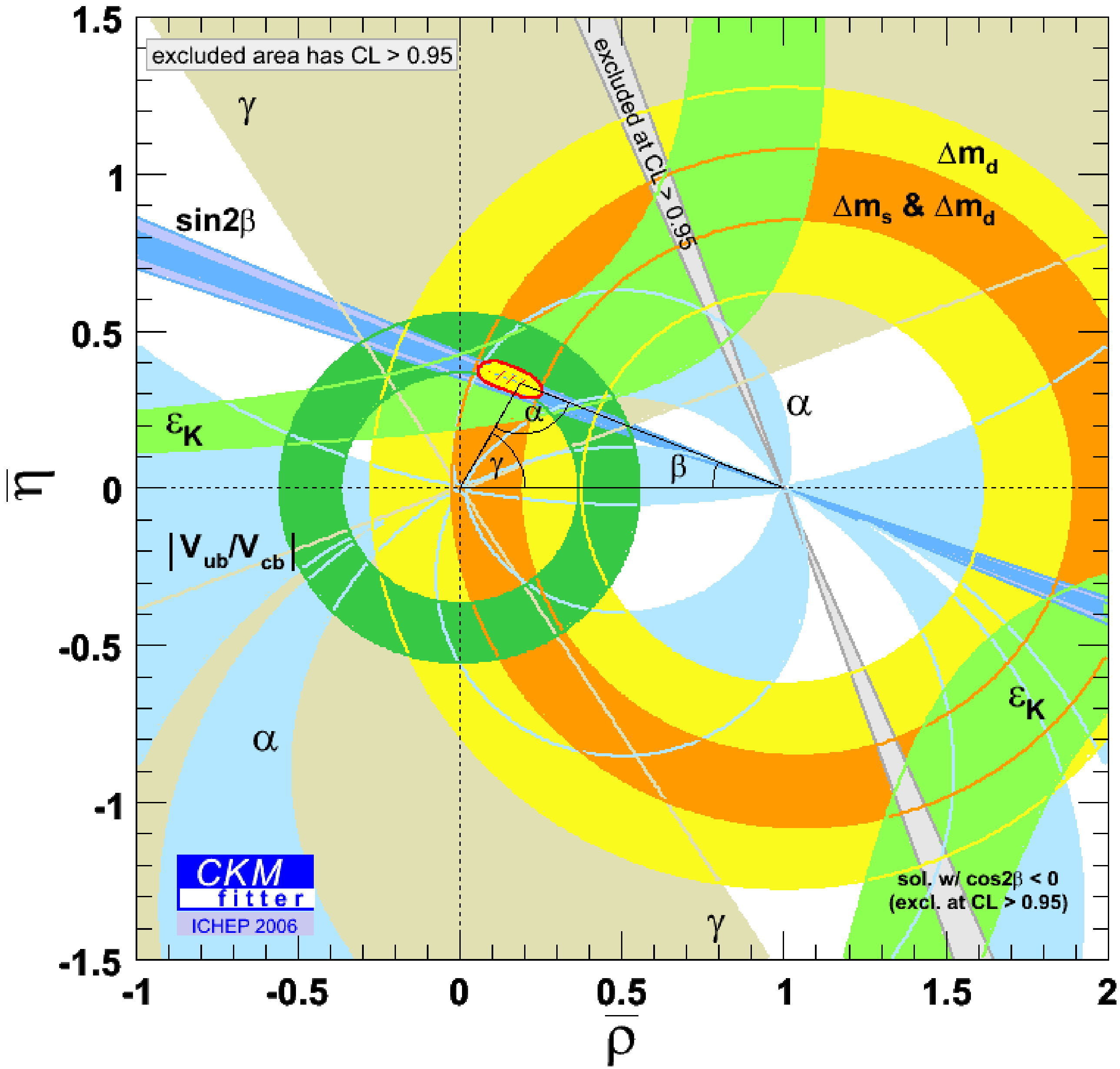




B→ρρ: at very large statistics, systematics and model-dependence will become an issue

B→ρπ Dalitz analysis: model-dependence is an issue !

Putting it all together



Inputs:

$\left|\frac{V_{ub}}{V_{cb}}\right|$

Δm_d

Δm_s

$B \to \tau\nu$

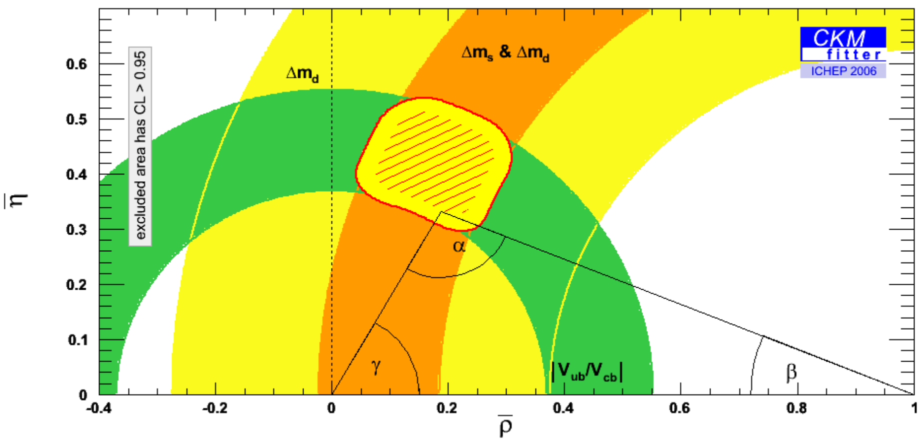
$|\varepsilon_K|$

$\sin 2\beta$

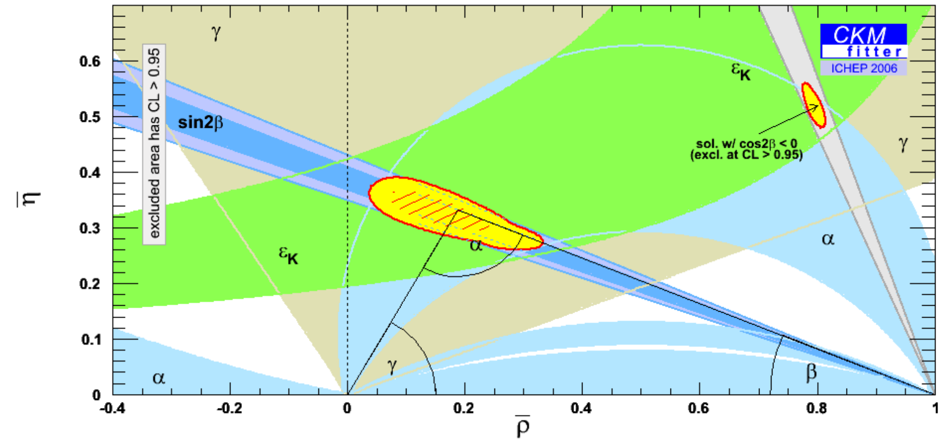
α

γ

The global CKM fit: Testing the CKM Paradigm

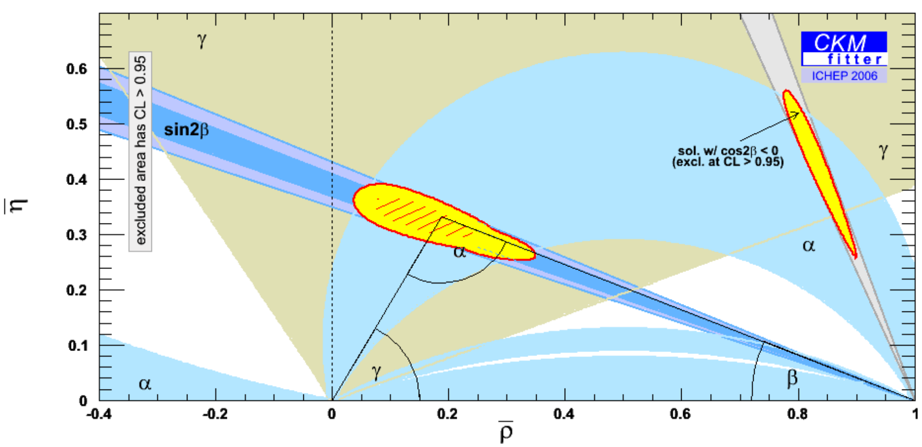


CP Conserving

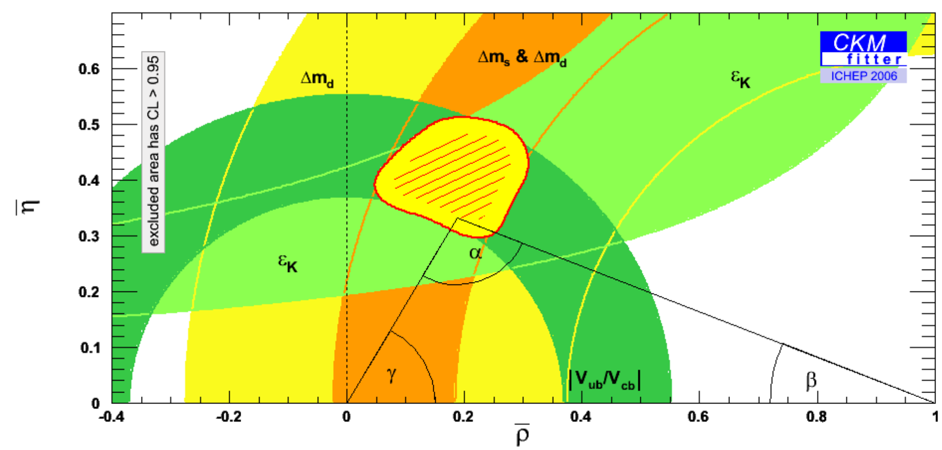


CP Violating

CP-insensitive observables imply CP violation !

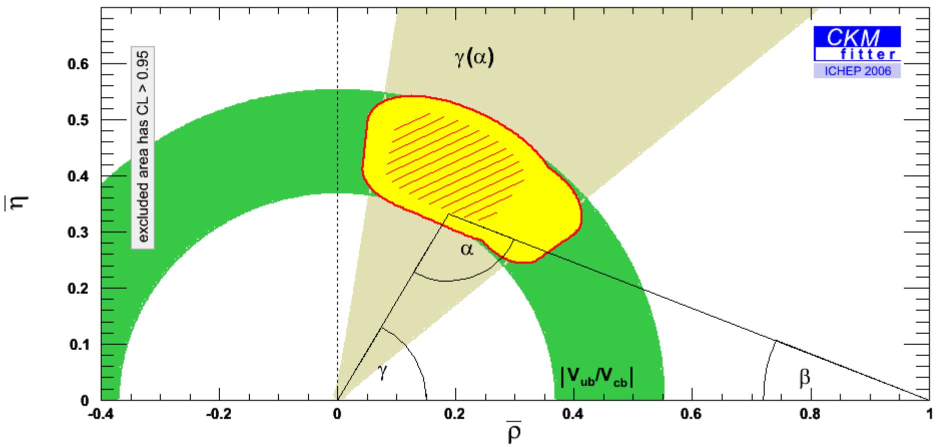


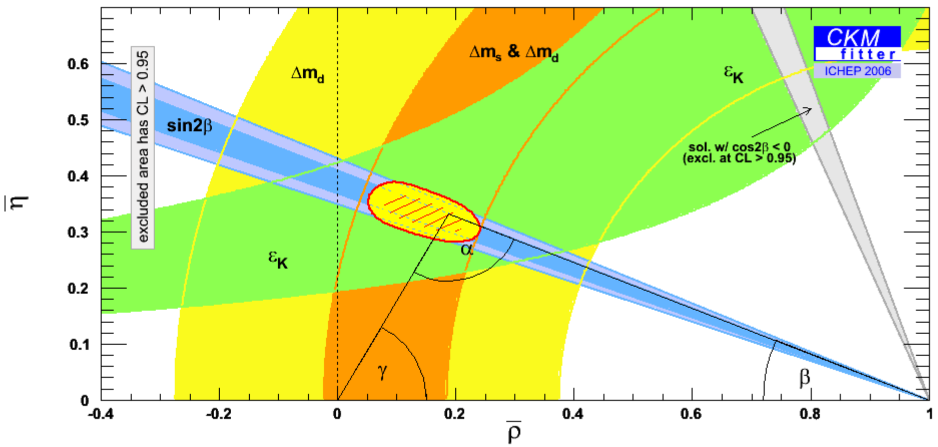
Angles (no theory)



No angles (with theory)

The global CKM fit: Testing the CKM Paradigm (cont.)





Tree (NP-Free)

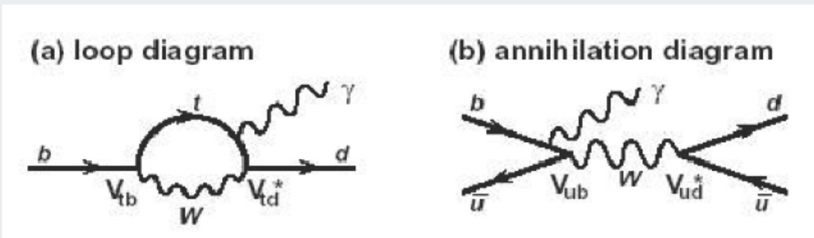
Loop

[No NP in $\Delta I=3/2$ $b\to d$ EW penguin amplitude
Use α with β (charmonium) to cancel NP amplitude]

CKM mechanism: dominant source of CP violation
The global fit is not the whole story: several $\Delta F=1$ rare decays are not yet measured
➔ Sensitive to NP

Radiative Penguin Decays: BR($B \to \rho\gamma$)/BR($B \to K^*\gamma$)

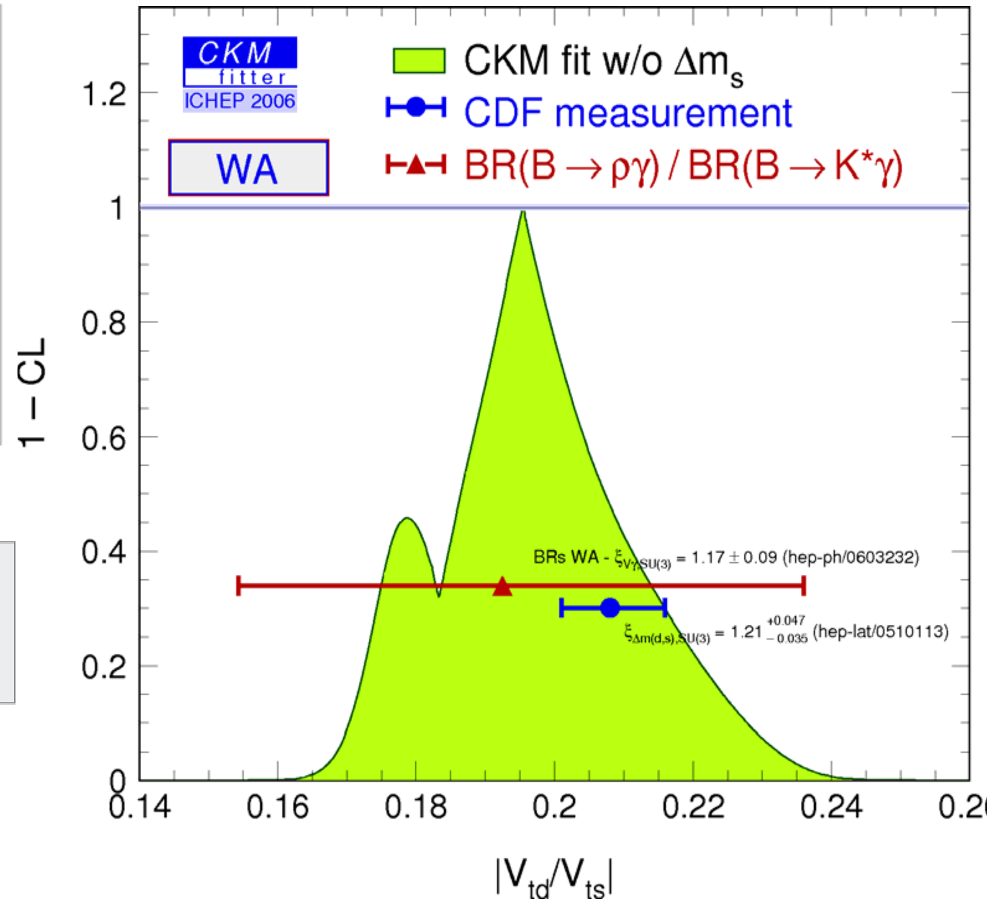
$B \to \rho\gamma$ ($\propto |V_{td}|^2$) & $B \to K^*\gamma$ ($\propto |V_{ts}|^2$) sensitive to New Physics



Additional amplitude contribution to charged modes => less reliable

$$\frac{BF(B^0 \to \rho^0\gamma)}{BF(B^0 \to K^{*0}\gamma)} = 1.023\,\frac{1}{2}\left|\frac{V_{td}}{V_{ts}}\right|^2 \xi^{-2}(1+\Delta)$$

	BABAR (347m)	Belle (386m)
$\rho^0\gamma$	$0.77^{+0.21}_{-0.19} \pm 0.07$	$1.25^{+0.37}_{-0.33}{}^{+0.07}_{-0.06}$
$\rho^+\gamma$	$1.06^{+0.35}_{-0.31} \pm 0.09$	$0.55^{+0.42}_{-0.36}{}^{+0.09}_{-0.08}$



NP Parameterization in B_s system

Grossman, PL **B380**, 99 (1996)
Dunietz, Fleischer, Nierste, PRD **63**, 114015 (2001)

$$\frac{\left\langle B_s^0 \middle| H_{eff}^{SM+NP} \middle| \overline{B}_s^0 \right\rangle}{\left\langle B_s^0 \middle| H_{eff}^{SM} \middle| \overline{B}_s^0 \right\rangle} = r_s^2 e^{i2\theta_s} = 1 + h_s e^{i2\sigma_s}$$

Hypothesis: NP in loop processes only (negligible for tree processes)

Mass difference: $\Delta m_s = (\Delta m_s)^{SM} r_s^2$

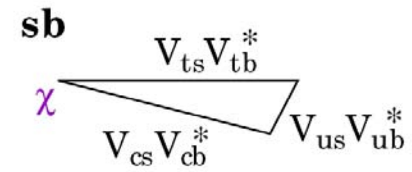
Width difference: $\Delta\Gamma_s^{CP} = (\Delta\Gamma_s)^{SM} \cos^2(2\chi - 2\theta_s)$

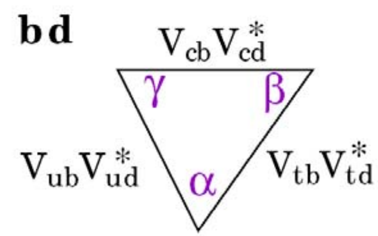
Semileptonic asymmetry:
$A^s_{SL} = -\mathrm{Re}(\Gamma_{12}/M_{12})^{SM} \sin(2\theta_s)/r_s^2$

$S\psi\phi = \sin(2\chi - 2\theta_s)$

NP wrt to SM:
- reduces $\Delta\Gamma_s$
- enhances Δm_s

$$\chi = \arg\left(-V_{ts}V_{tb}^{*} / V_{cs}V_{cb}^{*}\right)$$



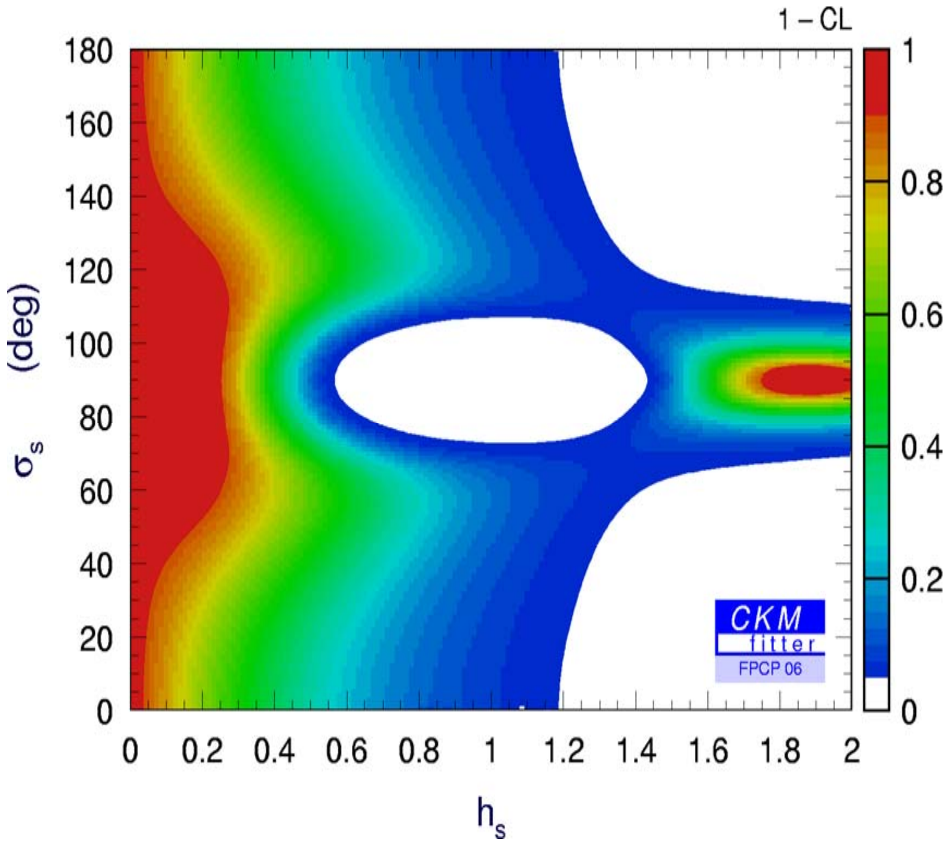


UT of B_d system: non-degenerated
➔ (h_d, σ_d) strongly correlated to the determination of (ρ, η)
UT of B_s system: highly degenerated
➔ (h_s, σ_s) almost independent of (ρ, η)

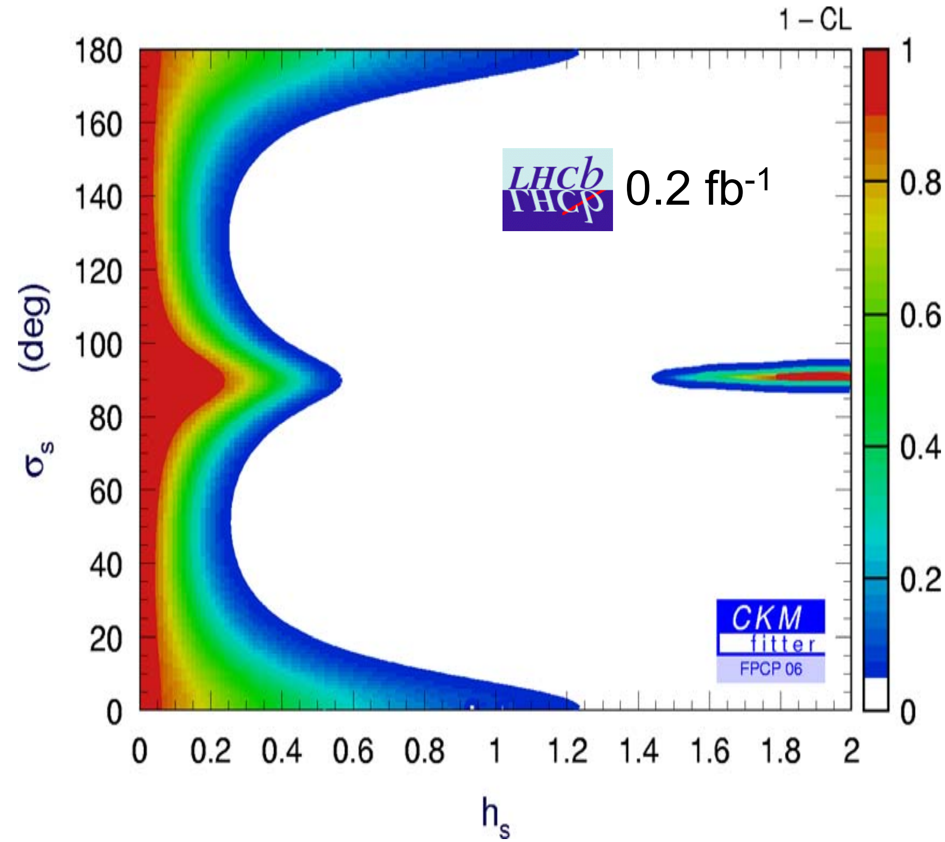
B_s mixing phase very small in SM: χ=1.05+0.06 (deg)
➔Bs mixing: very sensitive probe to NP

NP in B_s System

Δm_s, $\Delta\Gamma_s$ and A^s_{SL}



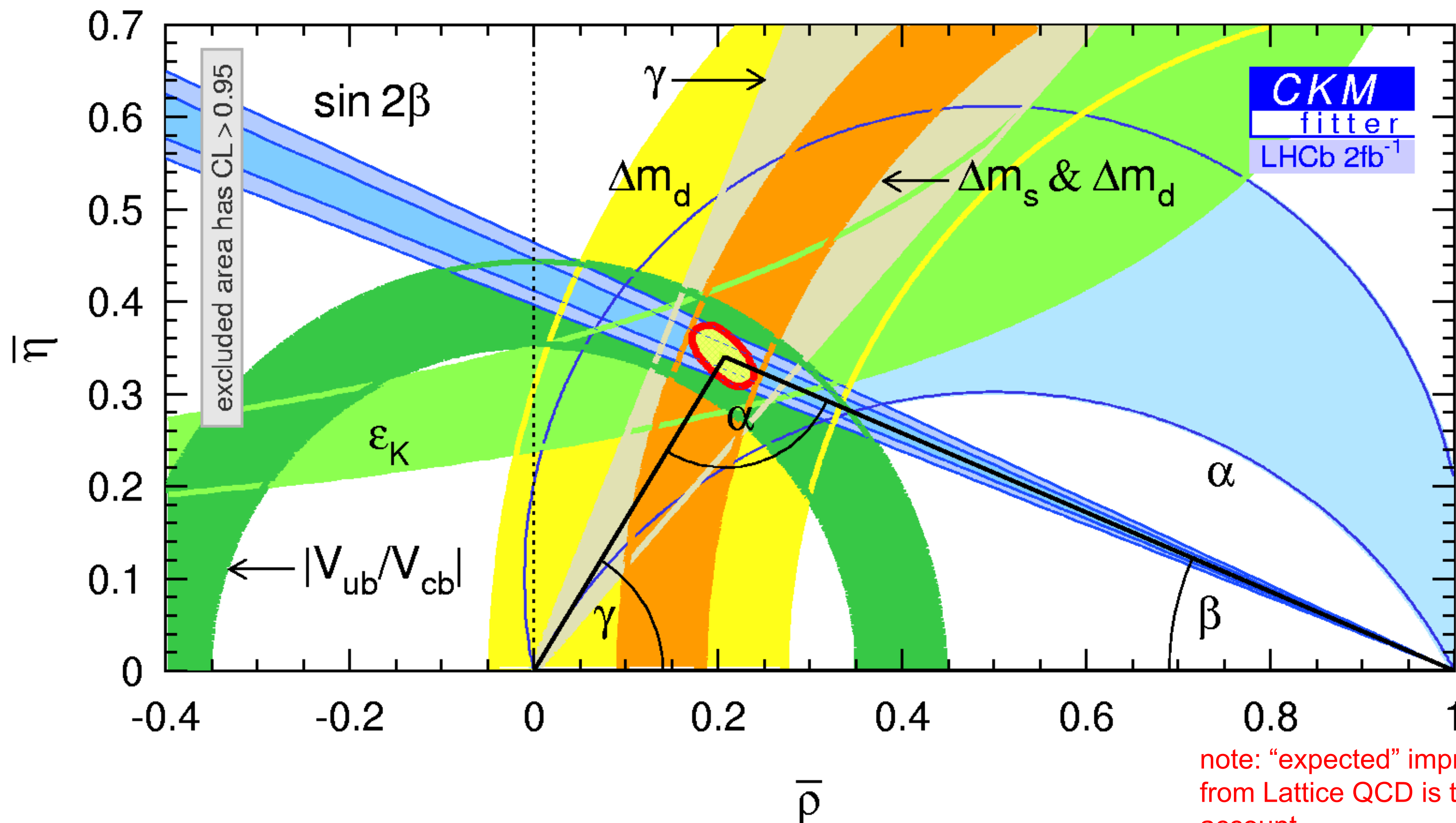
$\sigma(\Delta m_s)$= 0.035, $\sigma(\sin(2\chi)$=0.1



First constraint for NP in the B_s sector
Still plenty of room for NP
Large theoretical uncertainties: LQCD

h_s ~<= 3 (h_d ~<=0.3, h_K ~<= 0.6)

Prospective: LHCb 2fb^{-1} (2010 ?)?



note: "expected" improvement from Lattice QCD is taken into account.

assumptions: $\sigma(\Delta m_s)=0.01$ | $\sigma(\sin 2\beta)=0.02$ | $\sigma(\alpha) = 10^o$ | $\sigma(\gamma) = 5^o$

Conclusion

• CKM mechanism: success in describing flavor dynamics of many constraints from vastly different scales.

• With the increase of statistics, lots of assumptions will be needed to be reconsidered [e.g., extraction of α from $B \rightarrow 3\pi, 4\pi$, etc., P_{EW}, …]

• B_s: an independent chapter in Nature's book on fundamental dynamics

  • there is no reason why NP should have the same flavor structure as in the SM

  • B_s transitions can be harnessed as powerful probes for NP (χ: "NP model killer")

• Before claiming NP discovery, be sure that everything is "under control" (assumptions, theoretical uncertainties, etc.)

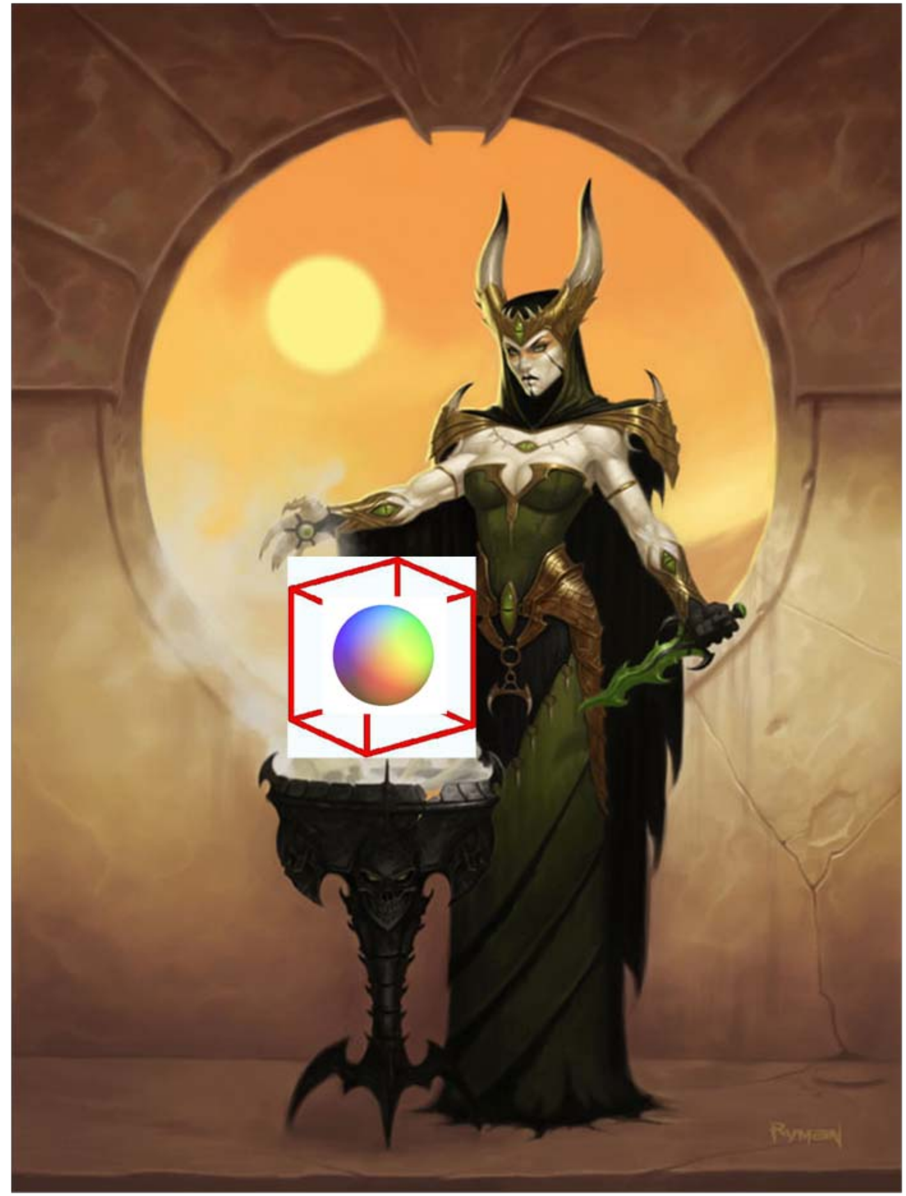
• There are still plenty of measurements yet to be done

Do Not Miss:

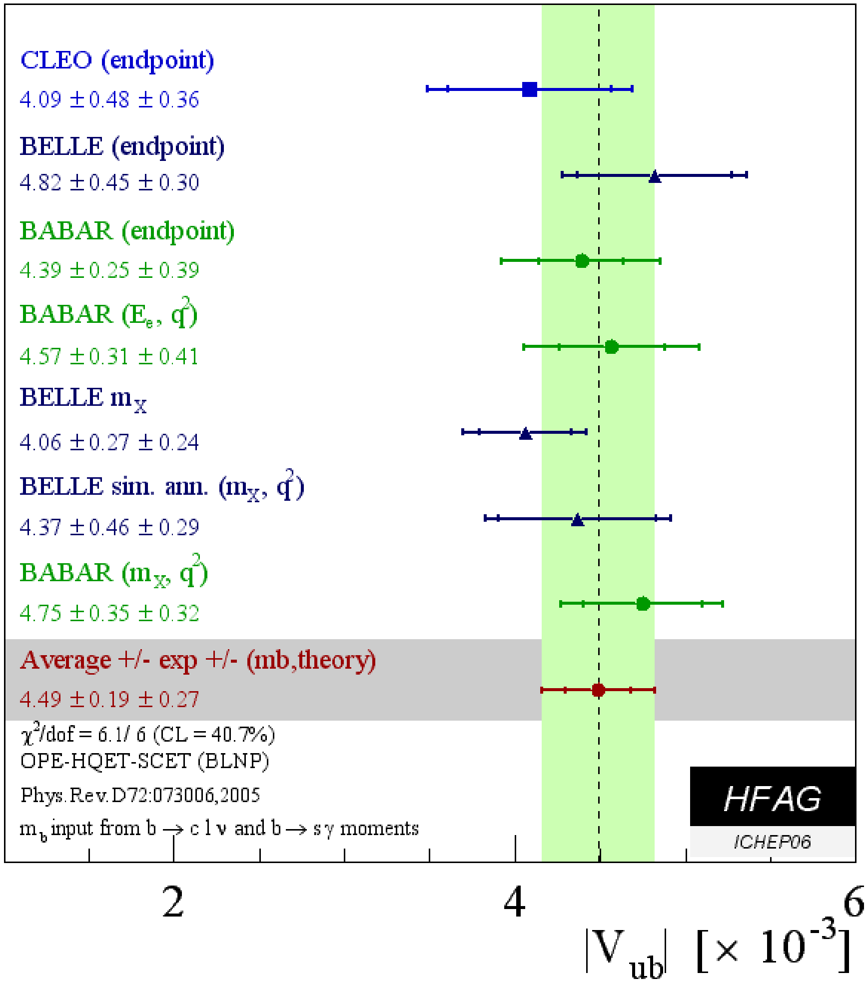
hep-ph/0607246

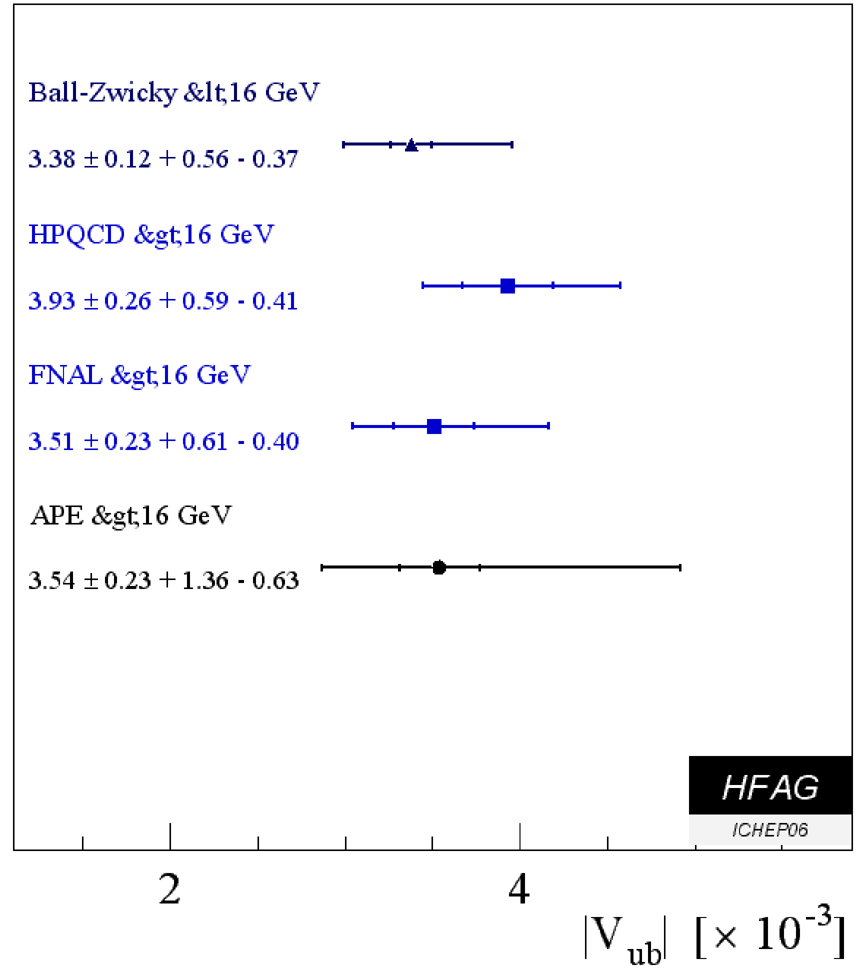
Bayesian Statistics at Work:
the Troublesome
Extraction of the CKM Angle α

(J. Charles, A. Höcker, H. Lacker
F.R. Le Diberder and S. T'Jampens)



BACKUP SLIDES


CLEO (endpoint)
4.09 ± 0.48 ± 0.36
BELLE (endpoint)
4.82 ± 0.45 ± 0.30
BABAR (endpoint)
4.39 ± 0.25 ± 0.39
BABAR (E_e, q^2)
4.57 ± 0.31 ± 0.41
BELLE m_X
4.06 ± 0.27 ± 0.24
BELLE sim. ann. (m_X, q^2)
4.37 ± 0.46 ± 0.29
BABAR (m_X, q^2)
4.75 ± 0.35 ± 0.32
Average +/- exp +/- (mb,theory)
4.49 ± 0.19 ± 0.27
χ^2/dof = 6.1/ 6 (CL = 40.7%)
OPE-HQET-SCET (BLNP)
Phys.Rev.D72:073006,2005
m_b input from $b \to c\,l\,\nu$ and $b \to s\,\gamma$ moments
HFAG
ICHEP06
2
4
6
$|V_{ub}|$ [$\times 10^{-3}$]


Ball-Zwicky <16 GeV
3.38 ± 0.12 + 0.56 - 0.37
HPQCD >16 GeV
3.93 ± 0.26 + 0.59 - 0.41
FNAL >16 GeV
3.51 ± 0.23 + 0.61 - 0.40
APE >16 GeV
3.54 ± 0.23 + 1.36 - 0.63
HFAG
ICHEP06
2
4
$|V_{ub}|$ [$\times 10^{-3}$]

FLAVOR STRUCTURE

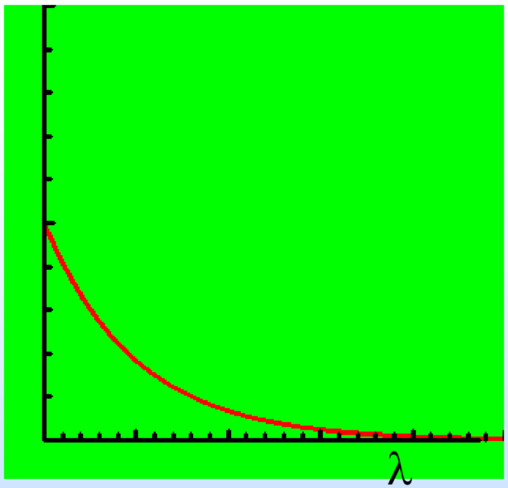
ELECTROWEAK STRUCUTRE	b → s	b → d	s → d
ΔF=2 box	ΔM_{Bs} $A_{CP}(B_s \to \psi\phi)$	ΔM_{Bd} $A_{CP}(B_d \to \psi K)$	ΔM_K, ε_K
ΔF=1 4−quark box	$B_d \to \phi K$, $B_d \to K\pi$, ...	$B_d \to \pi\pi$, $B_d \to \rho\pi$, ...	ε'/ε, $K \to 3\pi$, ...
gluon penguin	$B_d \to X_s\,\gamma$, $B_d \to \phi K$, $B_d \to K\pi$, ...	$B_d \to X_d\,\gamma$, $B_d \to \pi\pi$, ...	ε'/ε, $K_L \to \pi^0 \ell^+\ell^-$, ...
γ penguin	$B_d \to X_s\,\ell^+\ell^-$, $B_d \to X_s\,\gamma$ $B_d \to \phi K$, $B_d \to K\pi$, ...	$B_d \to X_d\,\ell^+\ell^-$, $B_d \to X_d\,\gamma$ $B_d \to \pi\pi$, ...	ε'/ε, $K_L \to \pi^0 \ell^+\ell^-$, ...
Z^0 penguin	$B_d \to X_s\,\ell^+\ell^-$, $B_s \to \mu\mu$ $B_d \to \phi K$, $B_d \to K\pi$, ...	$B_d \to X_d\,\ell^+\ell^-$, $B_d \to \mu\mu$ $B_d \to \pi\pi$, ...	ε'/ε, $K_L \to \pi^0 \ell^+\ell^-$, $K \to \pi\nu\nu$, $K \to \mu\mu$, ...
H^0 penguin	$B_s \to \mu\mu$	$B_d \to \mu\mu$	$K_{L,S} \to \mu\mu$

G. Isidori – Beauty '03

Bayes at work

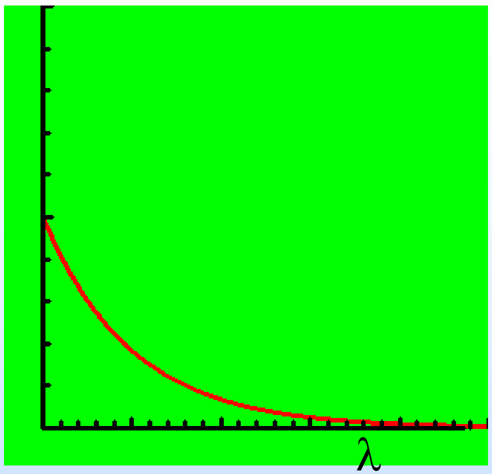
Zero events seen

$P(n; \lambda) = e^{-\lambda}\lambda^n/n!$



Posterior $P(\lambda)$

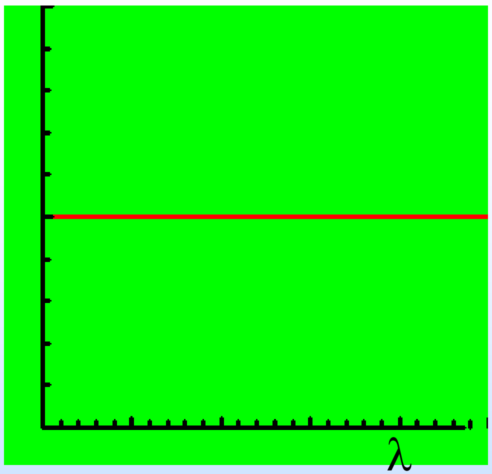
=



$P(0 \text{ events}|\lambda)$

(Likelihood)

x



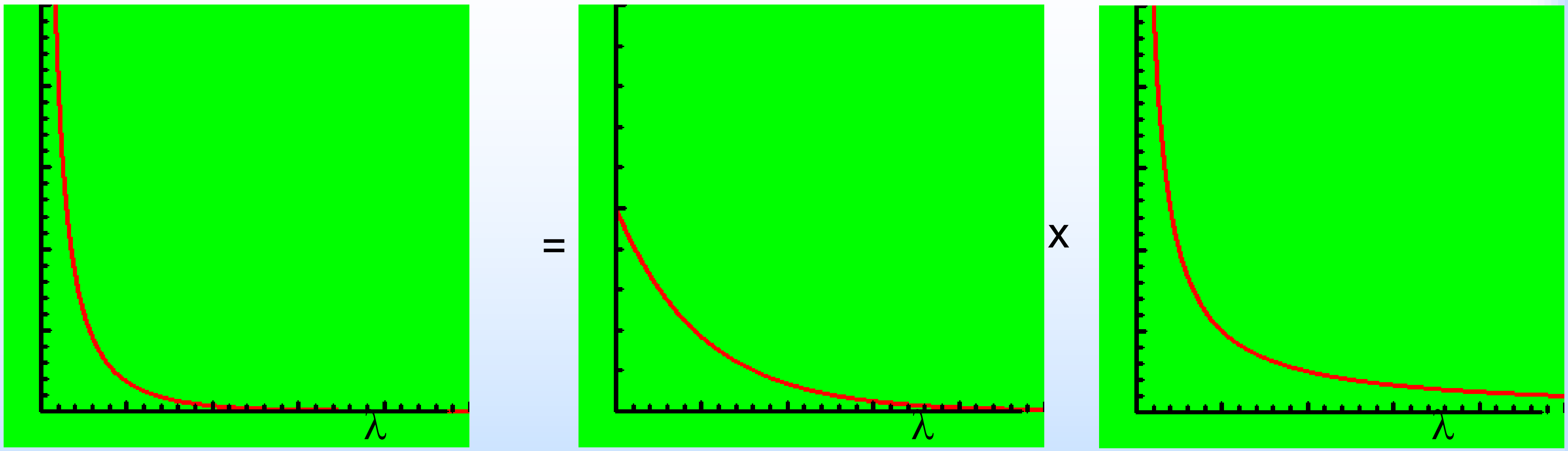
Prior: uniform

$\int_0^3 P(\lambda)\, d\lambda = 0.95$

Same as Frequentist limit -
Happy coincidence

Bayes at work again

Is that uniform prior really credible?



Posterior P(λ) P(0 events|λ) Prior: uniform in ln λ

Upper limit totally different!

$$\int_0^3 P(\lambda)\, d\lambda >> 0.95$$

Bayes: the bad news

- The prior affects the posterior. It is your choice. That makes the measurement subjective. This is BAD. (We're physicists, dammit!)
- A Uniform Prior does not get you out of this.