CKM Fits : What the Data Say (Focused on B Physics)

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CKM Fits: What the Data Say

(focused on B-Physics)

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Outline

- CKM phase invariance and unitarity
- Statistical issues
- CKM metrology
  - Inputs
    - Tree decays: $|V_{ub}|,|V_{cb}|$
    - Loop decays: $\Delta m_d, \Delta m_s, \varepsilon_K$
    - UT angles: α, β, γ
  - The global CKM fit
- What about New Physics?
- Conclusion

- Charm is interesting in several special areas, but I will concentrate on b's

The Unitary Wolfenstein Parameterization

- The standard parameterization uses Euler angles and one CPV phase → unitary !

$$V = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{pmatrix}$$

Chau and Keung
PRL **53**, 1802 (1984)
[and PDG]

- Now, define $s_{12} \equiv \lambda$ $s_{23} \equiv A\lambda^2$ $s_{13}e^{-i\delta} \equiv A\lambda^3(\rho - i\eta)$

Buras *et al.*,
PRD **50**, 3433 (1994)

- And insert into *V* → *V* is still unitary ! With this one finds (to all orders in λ) :

$$\rho + i\eta = \frac{\sqrt{1-A^2\lambda^4}(\bar\rho + i\bar\eta)}{\sqrt{1-\lambda^2}\left[1-A^2\lambda^4(\bar\rho + i\bar\eta)\right]}$$

where: $$\bar\rho + i\bar\eta = -\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}$$

Charles *et al.*
EPJC **41**, 1 (2005)

$$\lambda^2 \equiv \frac{|V_{us}|^2}{|V_{ud}|^2 + |V_{us}|^2} \qquad A^2\lambda^4 \equiv \frac{|V_{cb}|^2}{|V_{ud}|^2 + |V_{us}|^2}$$

Physically meaningful quantities are phase-convention invariant

→ Four unknowns [unitary-exact and phase-convention invariant]: $A, \lambda, \bar\rho, \bar\eta$

The CKM Matrix: Four Unknowns

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)

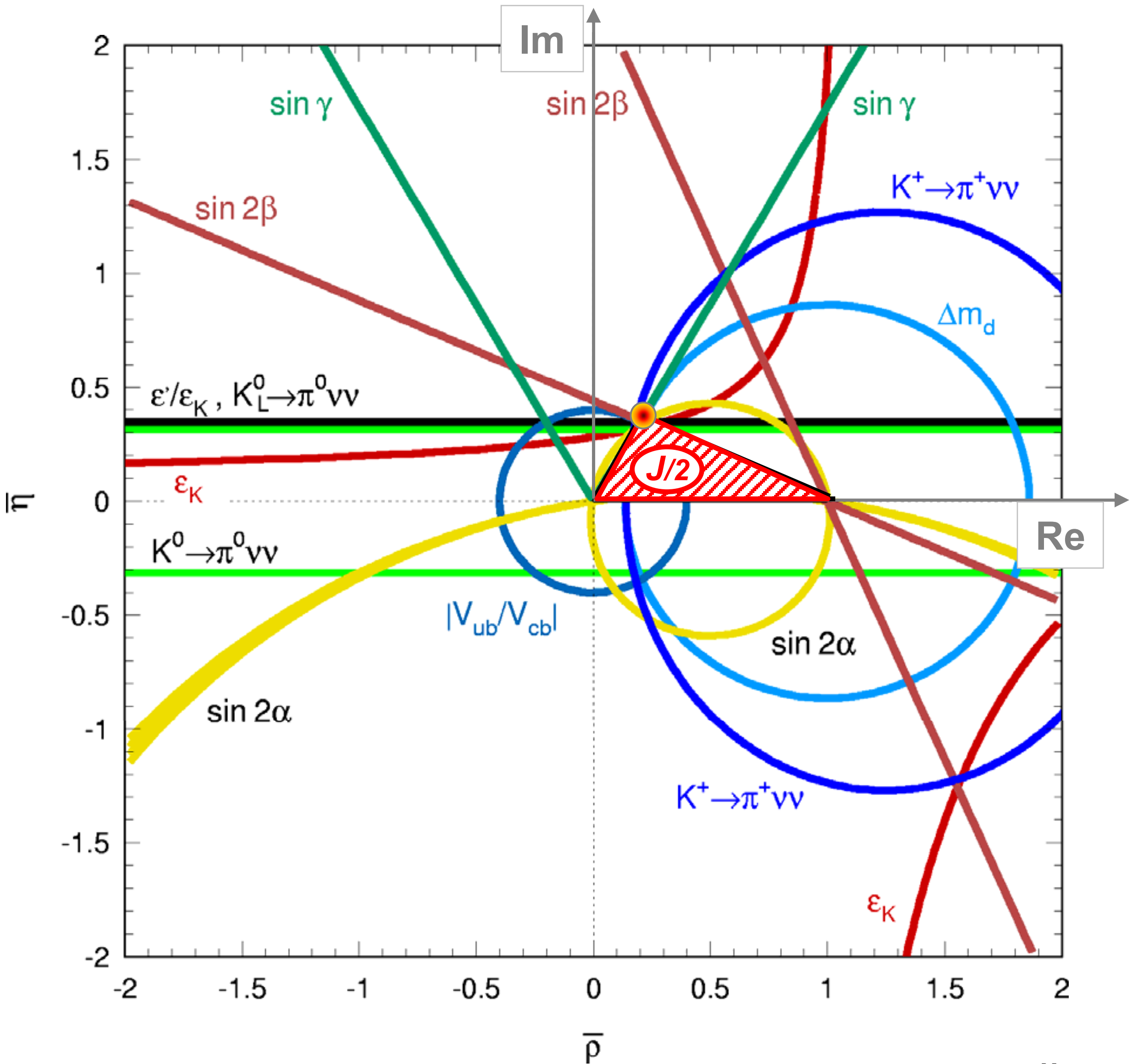
Predictive Nature of KM Mechanism

All measurements
must agree

<u>Pre B-Factory:</u>

Can the KM mechanism describe flavor dynamics of many constraints from vastly different scales?

This is what matters and not the measurement of the CKM phase's value *per se*



The (rescaled) Unitarity Triangle: The B_d System

Convenient method to illustrate (dis-)agreement of observables with CKM predictions

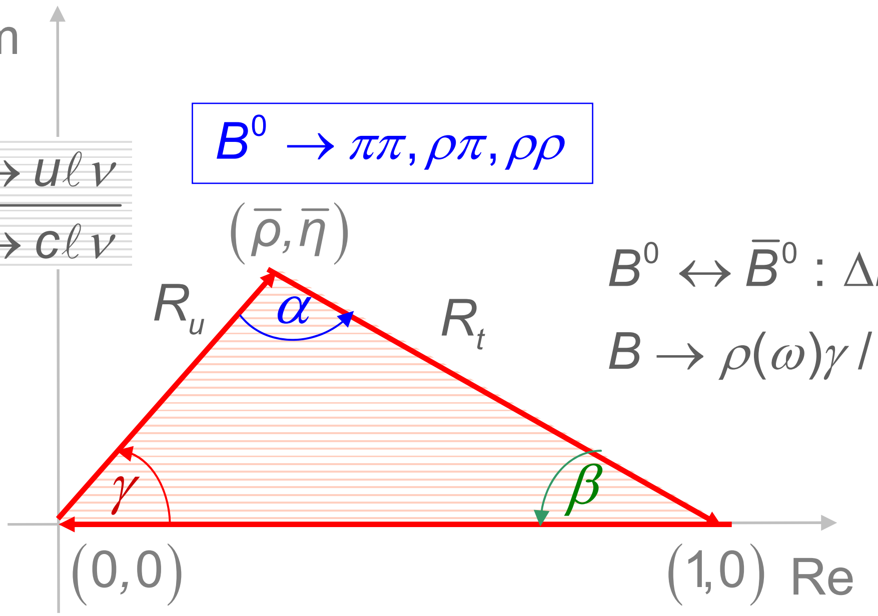
$$\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*} + 1 + \frac{V_{td}V_{tb}^*}{V_{cd}V_{cb}^*} = 0$$

phase invariant : $\overline{\rho} + i\overline{\eta}$

"There is no such thing as α/ϕ_2"
$[\alpha = \pi - (\beta+\gamma)]$

$$\frac{b \to u \ell \nu}{b \to c \ell \nu}$$

$B^0 \to \pi\pi, \rho\pi, \rho\rho$



$B^0 \leftrightarrow \overline{B}^0 : \Delta m_d$

$B \to \rho(\omega)\gamma \,/\, B \to K^{(*)}\gamma$

$B \to D^{(*)}K^{(*)}$

$B \to D_{K_S^0\pi^+\pi^-}K^{(*)}$

$B^0 \to DK_S^0$, ...

$B^0 \to D^*\pi(\rho)$

$b \to c\overline{c}s$

$B^0 \to J/\psi K_S^0$, ...

$B^0 \to \phi K_S^0$, ...

$b \to s\overline{s}s$

The Unitarity Triangle: The B_s System (hadron machines)

(sb) triangle ("B_s triangle"):

$$V_{us}V_{ub}^* + V_{cs}V_{cb}^* + V_{ts}V_{tb}^* = 0$$

$$O(\lambda^4) + O(\lambda^2) + O(\lambda^2) = 0$$

➔ squashed triangle

$$\chi = \beta_s = \arg\left[-\frac{V_{cs}V_{cb}^*}{V_{ts}V_{tb}^*}\right]$$

Attention: sign

(ut) triangle:

$$V_{td}V_{ud}^* + V_{ts}V_{us}^* + V_{tb}V_{ub}^* = 0$$

$$O(\lambda^3) + O(\lambda^3) + O(\lambda^3) = 0$$

➔ non-squashed triangle

$B_s^0 \leftrightarrow \bar{B}_s^0 : \Delta m_s / \Delta m_d$

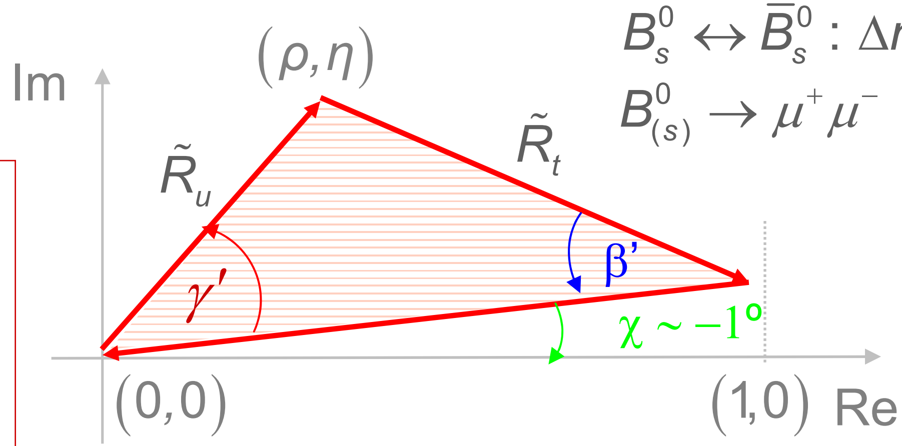
$B_{(s)}^0 \rightarrow \mu^+\mu^-$ (BR for $B_d^0 \sim 1\times10^{-10}$) (BR for $B_s^0 \sim 4\times10^{-9}$)

$B_s^0 \rightarrow D_s K$

$B_s^0 \rightarrow K^+K^-$

$B_s^0 \rightarrow J/\psi K_S^0$

$B_s^0 \rightarrow D_s^+ D_s^-$, ...



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

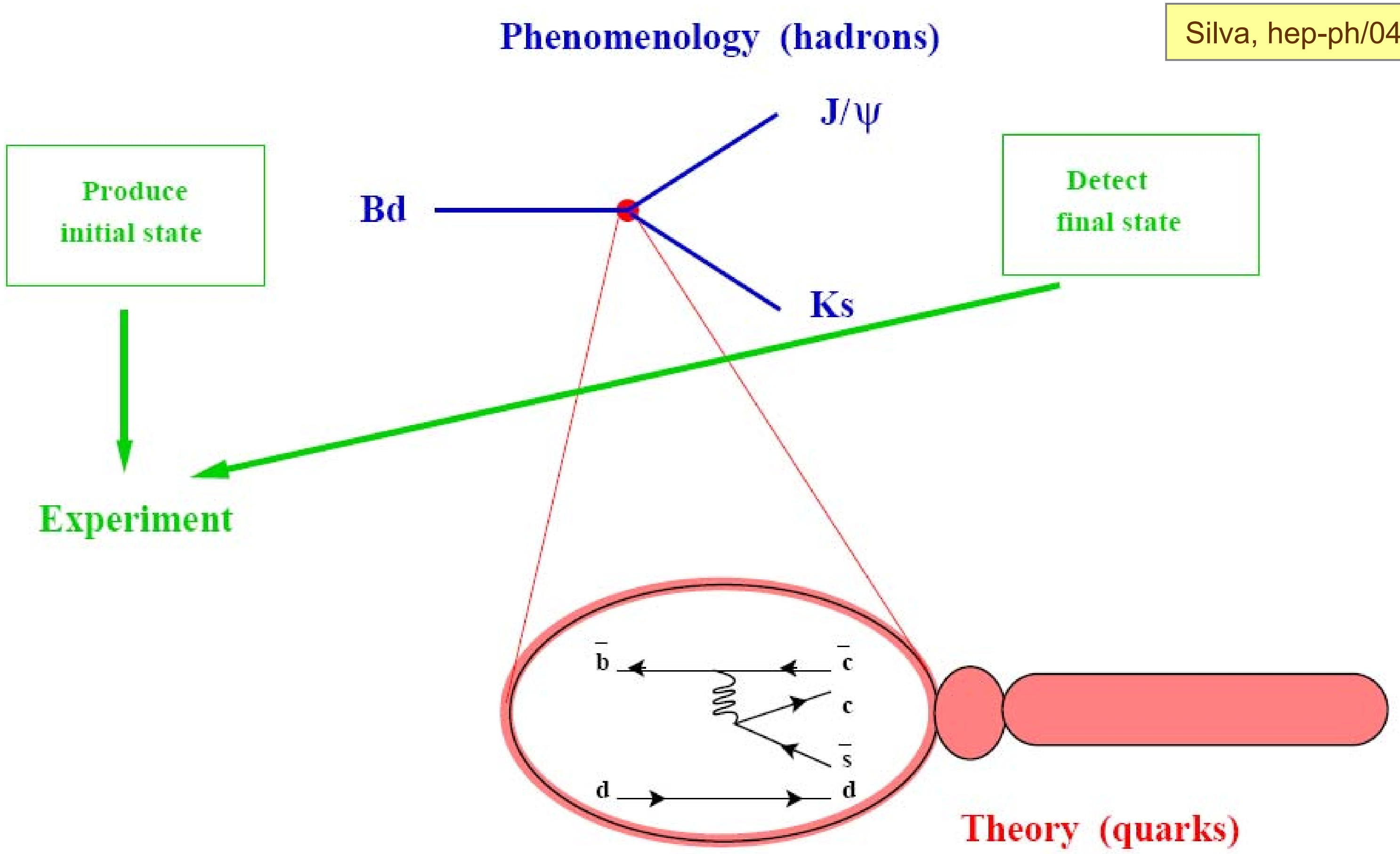
$B_s^0 \rightarrow J/\psi\phi$, ...

$B_s^0 \rightarrow \phi\phi$, ...

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

Generic B physics experiment

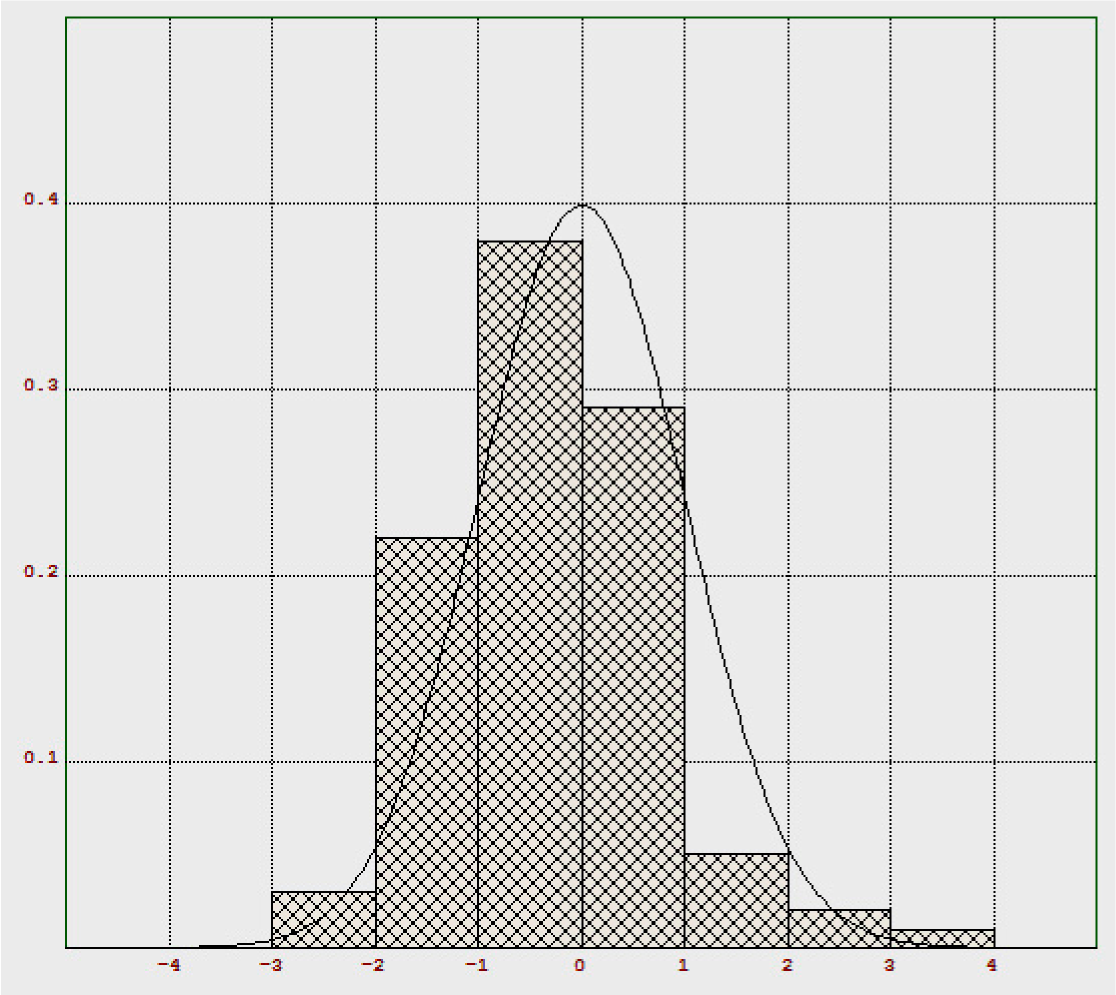
Silva, hep-ph/0410351



Probing short distance (quarks) but confined in hadrons (what we observe)

➔ QCD effects must be under control (various tools: HQET, SCET, QCDF, LQCD,…)
➔ "Theoretical uncertainties" have to be controlled **quantitatively** in order to test the Standard Model. There is however no systematic method to do that.

Digression: Statistics



Digression: Statistics

D.R. Cox, Principles of Statistical Inference, CUP (2006)
W.T. Eadie et al., Statistical Methods in Experimental Physics, NHP (1971)
www.phystat.org

Statistics tries answering a wide variety of questions ➔ two main different! frameworks:

Frequentist: probability **about the data** (randomness of measurements), given the model

P(data|model) [only repeatable events (Sampling Theory)]

Hypothesis testing: given a model, assess the **consistency** of the data with a particular parameter value ➔ 1-CL curve (by varying the parameter value)

Bayesian: probability **about the model** (degree of belief), given the data

P(model|data) ✪Likelihood(data,model) × **Prior(model)**

P(data|model) ≠ P(model|data):

model: Male or Female
data: pregnant or not pregnant

P (pregnant | female) ~ 3%

but

P (female | pregnant) >>>3%

Lyons – CDF Stat Committee

Although the graphical displays appear similar: the meaning of the "Confidence level" is not the same. It is especially important to understand the difference in a time where one seeks deviation of the SM.

Digression: Statistics (cont.)

Mayo – Error and the Growth of Experimental Knowledge, UCP(1996)

The Bayesian approach in physical science fails in the sense that nothing guarantees that *my* uncertainty assessment is any good for *you* - I'm just expressing an **opinion (degree of belief)**. To convince you that it's a good uncertainty assessment, I need to show that the **statistical model** I created makes good predictions in situations where we know what the **truth** is, and the process of **calibrating predictions** against reality is inherently frequentist."

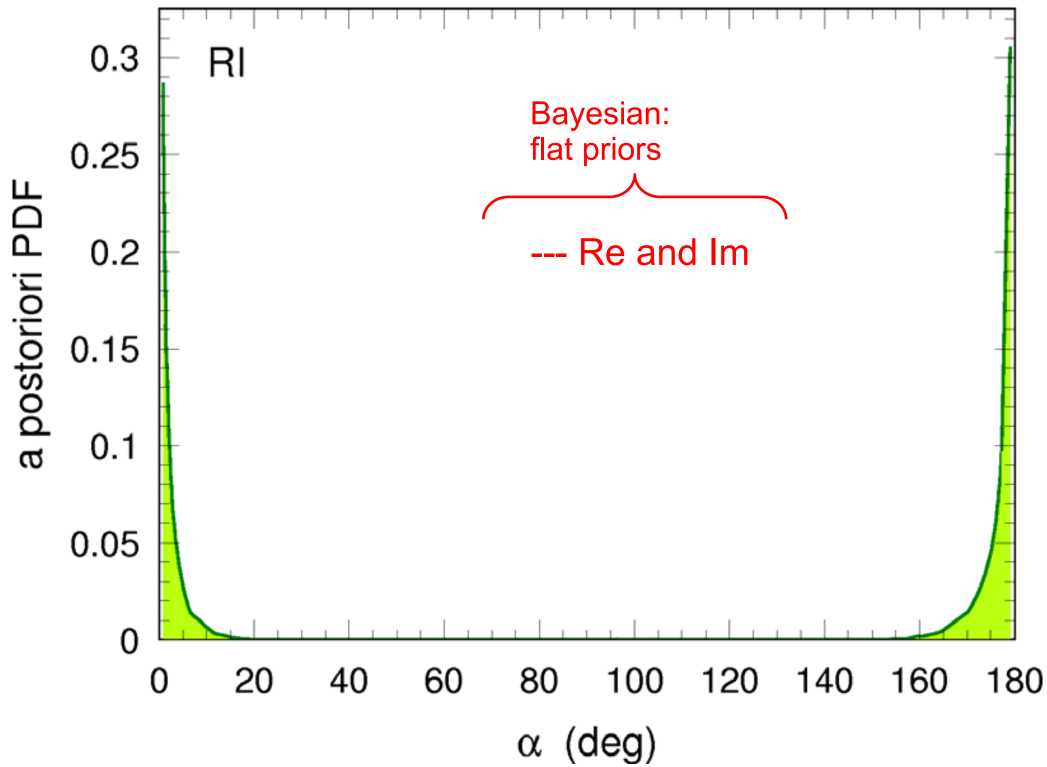
hep-ph/0607246: "Bayesian Statistics at Work: the Troublesome Extraction of the CKM Angle α" (J. Charles *et al.*)

How to read a Posterior PDF?

➔ updated belief (after seeing the data) of the plausible values of the parameter

↳ it's a bet on a proposition to which there is no scientific answer

$B \to \rho\rho$ (*w/o theoretical errors*):



My talk is about "**What the Data say**", thus I will stick to the frequentist approach 

Metrology: Inputs to the Global CKM Fit

I) Direct Measurement: magnitude

$|V_{ud}|$ and $|V_{us}|$ [not discussed here]

$|V_{ub}|$ and $|V_{cb}|$

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

CPV in K^0 mixing [not discussed here]

B_d and B_s mixing

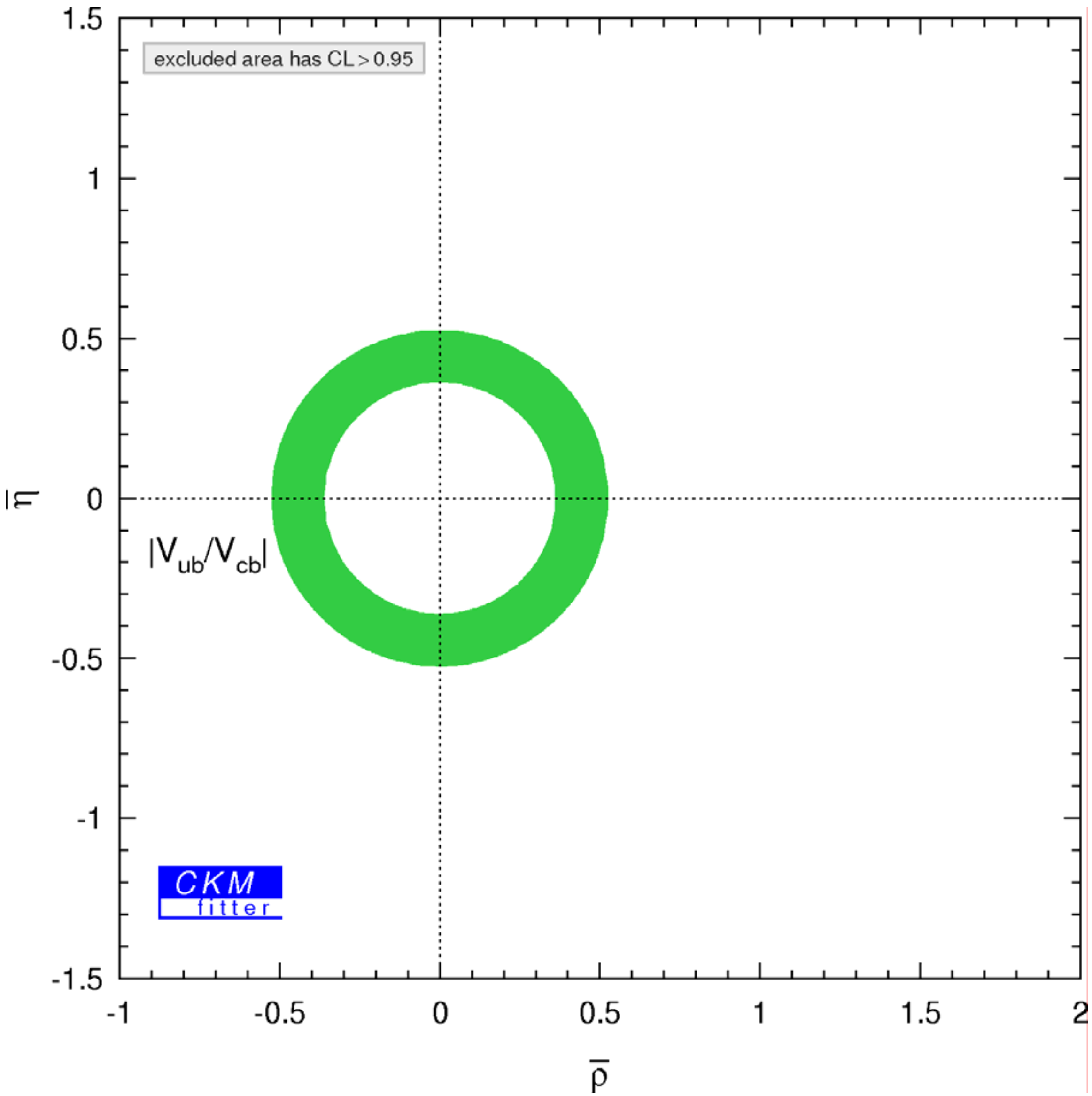
II) Angle Measurements:

sin 2β

α : ($B \to \pi\pi, \rho\rho, \rho\pi$)

γ : ADS, GLW, Dalitz (GGSZ)

$|V_{cb}|$ and $|V_{ub}|$



excluded area has CL > 0.95
|Vub/Vcb|
CKM fitter
1.5
1
0.5
0
-0.5
-1
-1.5
-1
-0.5
0
0.5
1
1.5
2
ρ̄
η̄

$|V_{cb}|$ (→ A) and $|V_{ub}|$

For $|V_{cb}|$ and $|V_{ub}|$ exist exclusive and inclusive semileptonic approaches (complementary)

	exclusive	inclusive
$b \to u$	$B \to \pi \ell\nu$	$B \to X_u \ell\nu$
$b \to c$	$B \to D^* \ell\nu$	$B \to X_c \ell\nu$
dominant uncertainties	Form factor	OPE ($\lvert V_{cb,ub}\rvert$) and shape function ($\lvert V_{ub}\rvert$)

OPE parameters measured from data (spectra and moments of $b \to s\gamma$ and $b \to c\ell\nu$ distributions)

- $|V_{ub}|$ ($\to \rho^2 + \eta^2$) is crucial for the SM prediction of $\sin(2\beta)$
- $|V_{cb}|$ ($\to A$) is important in the kaon system (ε_K, BR($K \to \pi\nu\nu$), …)

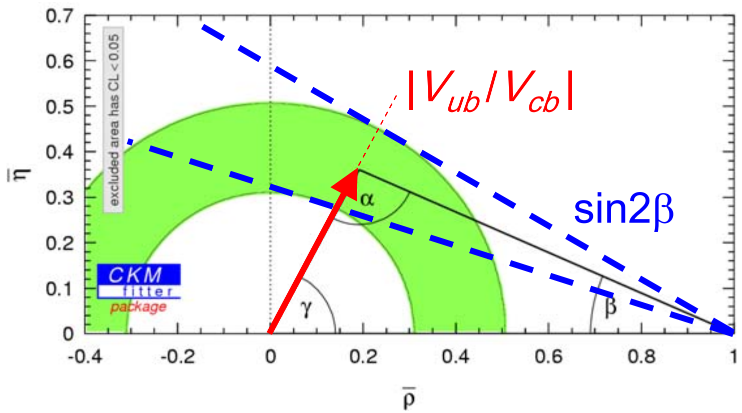
Complication for charmless decays:

$$\frac{\Gamma(b \to u l\nu)}{\Gamma(b \to c l\nu)} \approx \frac{|V_{ub}|^2}{|V_{cb}|^2} \approx \frac{1}{50}$$

→ need to apply kinematic cuts to suppress $b \to c\ell\nu$ background

→ measurements of partial branching fractions in restricted phase space regions

→ theoretical uncertainties more difficult to evaluate



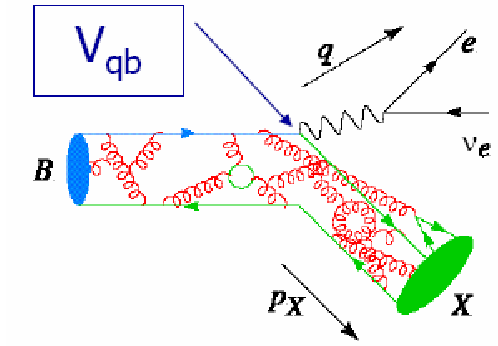
$|V_{cb}|$ and $|V_{ub}|$

$|V_{cb}|$: Precision measurement: 1.7% !

$|V_{cb}|_{incl.}[10^{-3}] = 41.70 \pm 0.70$ PDG06

$|V_{cb}|_{excl.}[10^{-3}] = 39.7 \pm 2.0$ ICHEP06

w/ FF=0.91±0.04

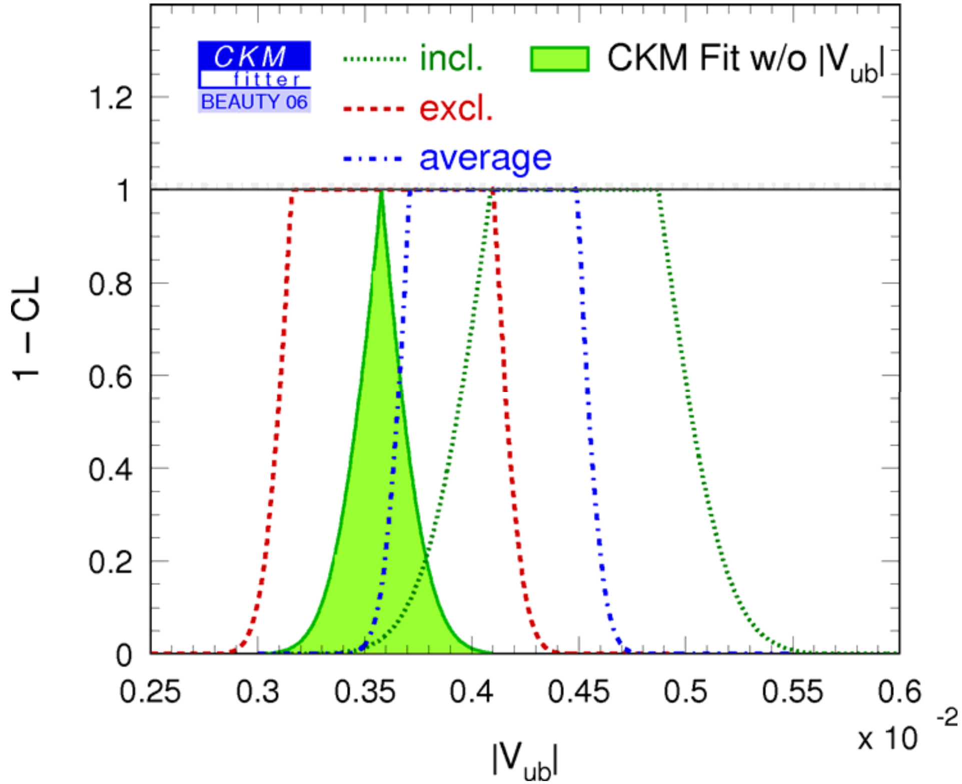


$|V_{ub}|$:

- SF params. from $b \to c l \nu$, OPE from BLNP
- BR precision ~8%, |Vub| excl. ~ 16%: theory dominated
- HFAG with our error budget

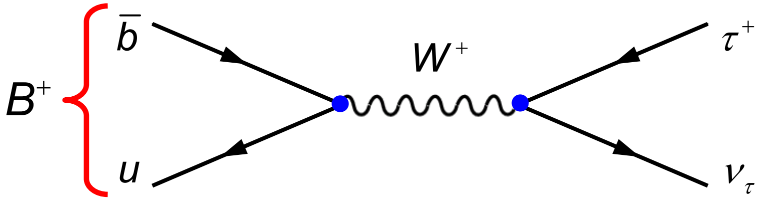
our average

$|V_{ub}|\,[10^{-3}] = 4.10 \pm 0.09_{exp} \pm 0.39_{theo}$



$B^+ \to \tau^+\nu_\tau$

- helicity-suppressed annihilation decay sensitive to $f_B \times |V_{ub}|$
- Powerful together with Δm_d : removes f_B (Lattice QCD) dependence
- Sensitive to charged Higgs replacing the W propagator



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

ICHEP06

BR[10^{-4}]=0.88 $^{+0.68}_{-0.67}$ (stat) ± 0.11(syst)

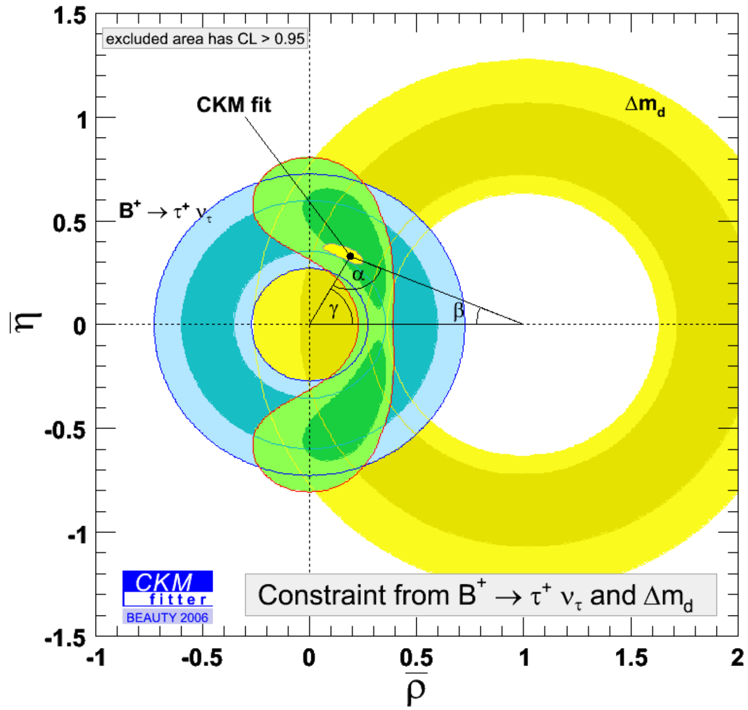
(320m)

BR[10^{-4}]=1.79 $^{+0.56}_{-0.49}$ (stat) $^{+0.39}_{-0.46}$ (syst)

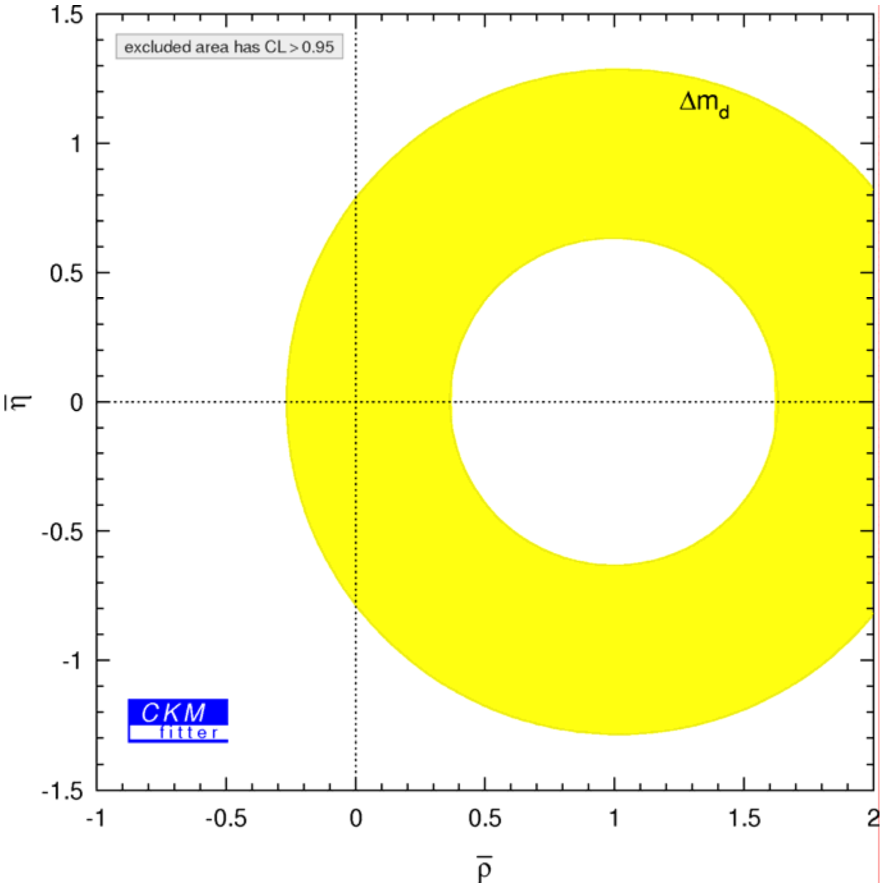
(447m)

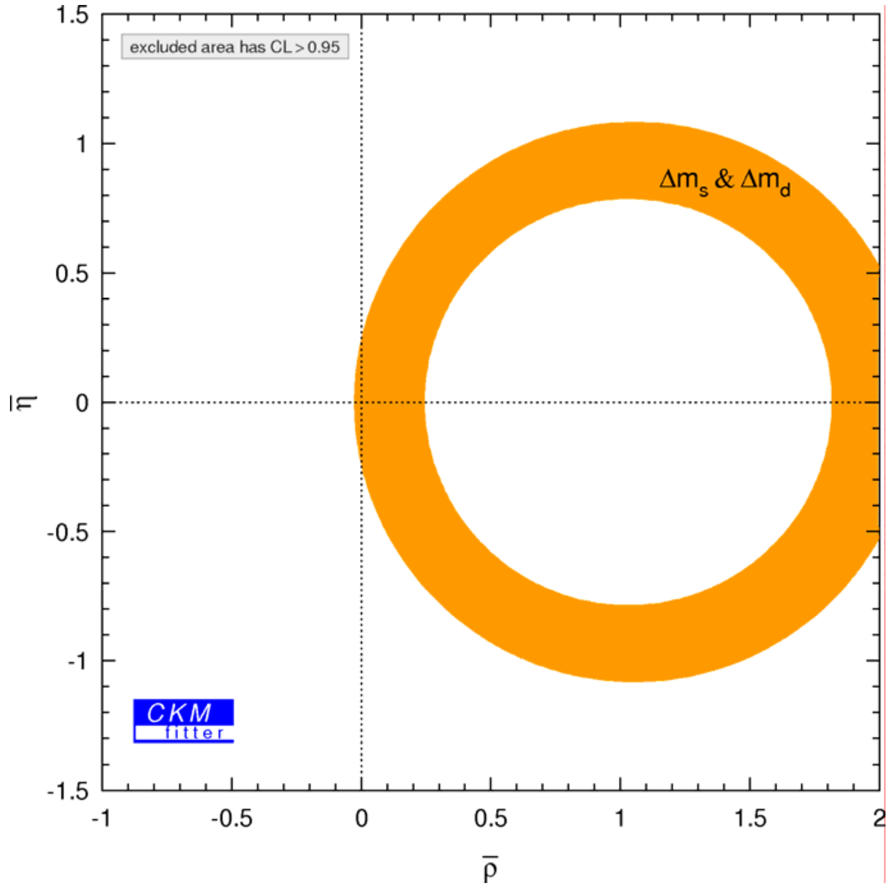
- Prediction from global CKM fit :

$$\mathrm{BF}(B^+ \to \tau^+\nu_\tau) = (0.87^{+0.13}_{-0.20}) \times 10^{-4}$$



Δm_d and Δm_s





Δm_d and Δm_s: constraints in the (ρ-η) plane

$$\Delta m_s = \frac{G_F^2}{6\pi^2} m_{B_s} m_W^2 \eta_B S_0(x_t) f_{B_s}^2 B_s \left|V_{ts} V_{tb}^*\right|^2$$

Very weak dependence on $\bar{\rho}$ and $\bar{\eta}$

The point is:

$$f_{B_s}^2 B_s = \frac{f_{B_s}^2 B_s}{f_{B_d}^2 B_d} f_{B_d}^2 B_d = \xi^2 f_{B_d}^2 B_d$$

ξ: SU(3)-breaking corrections

Measurement of Δm_s reduces the uncertainties on $f^2_{B_d} B_d$ since ξ is better known

from Lattice QCD $\sigma_{rel}\left(f^2_{B_{d/s}} B_{d/s}\right) = 36\%$ $\rightarrow$ $\sigma_{rel}\left(\xi^2 = f^2_{B_s} B_s / f^2_{B_d} B_d\right) = 10\%$

➔Leads to improvement of the constraint from Δm_d measurement on $|V_{td} V^*_{tb}|^2$

$$\Delta m_d = \frac{G_F^2}{6\pi^2} m_{B_d} m_W^2 \eta_B S_0(x_t) f_{B_d}^2 B_d \left|V_{td} V_{tb}^*\right|^2 \propto A^2 \lambda^6 \left[(1-\bar{\rho})^2 + \bar{\eta}^2\right]$$

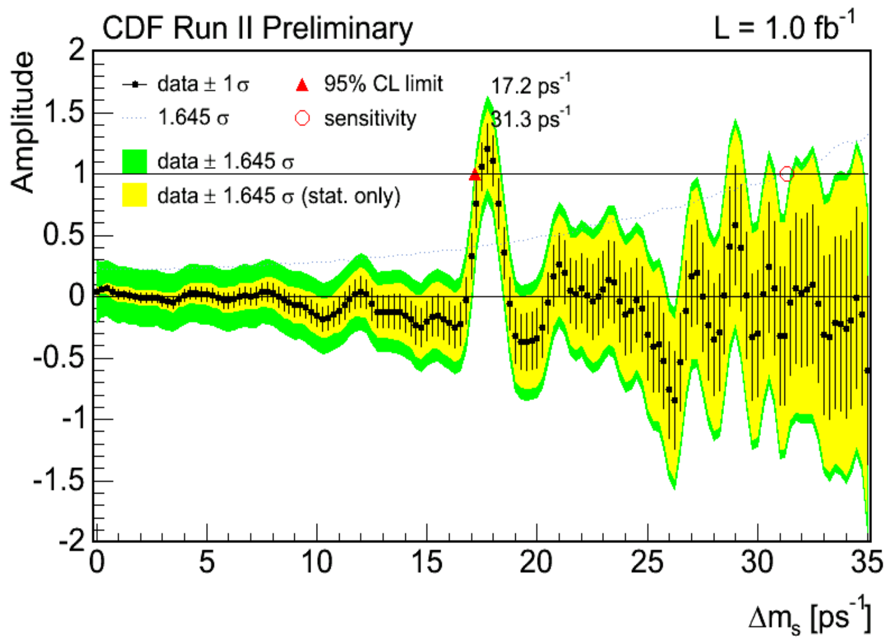
Δm_s

hep-ex/0603029

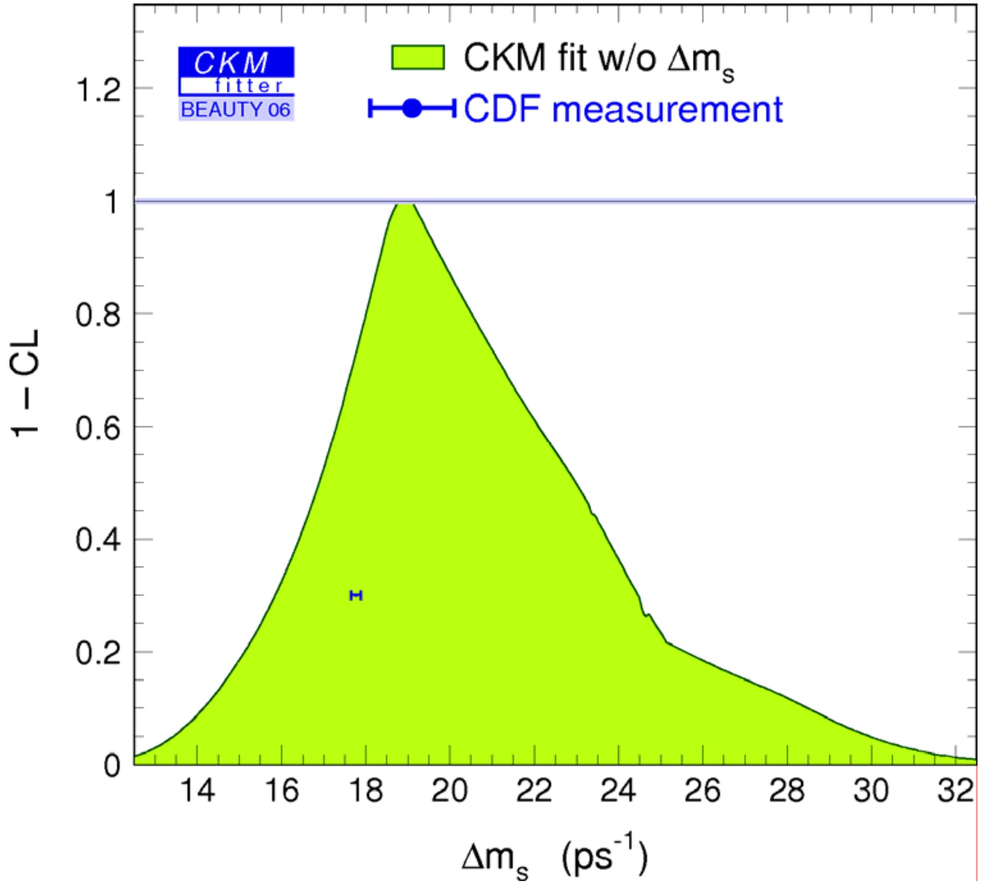
17 < Δm_s < 21 ps^{-1} @90 C.L.

hep-ex/0609040

Δm_s : 17.77±0.10(stat.) ± 0.07 (syst.) ps^{-1}



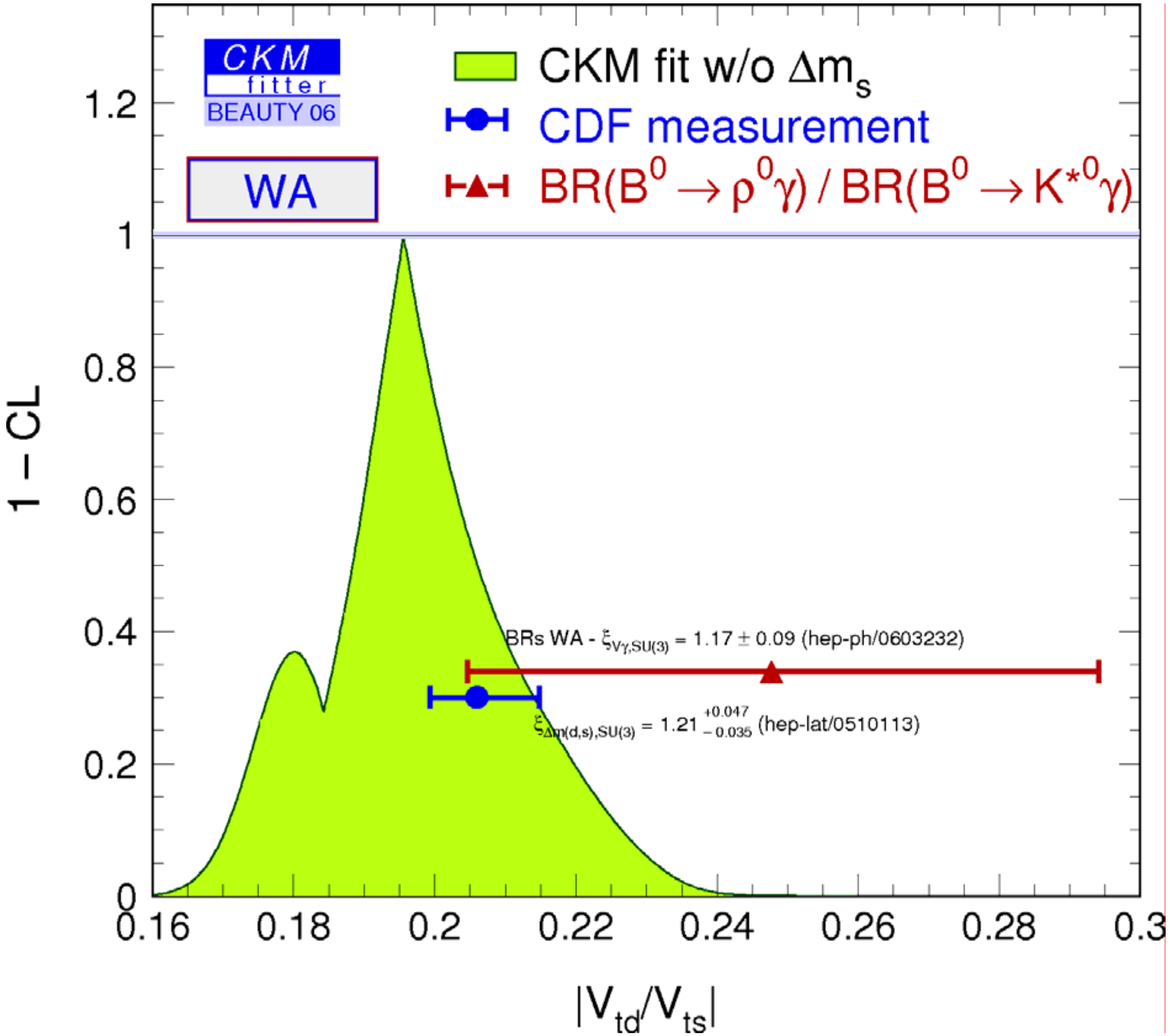
The signal has a significance of 5.4σ



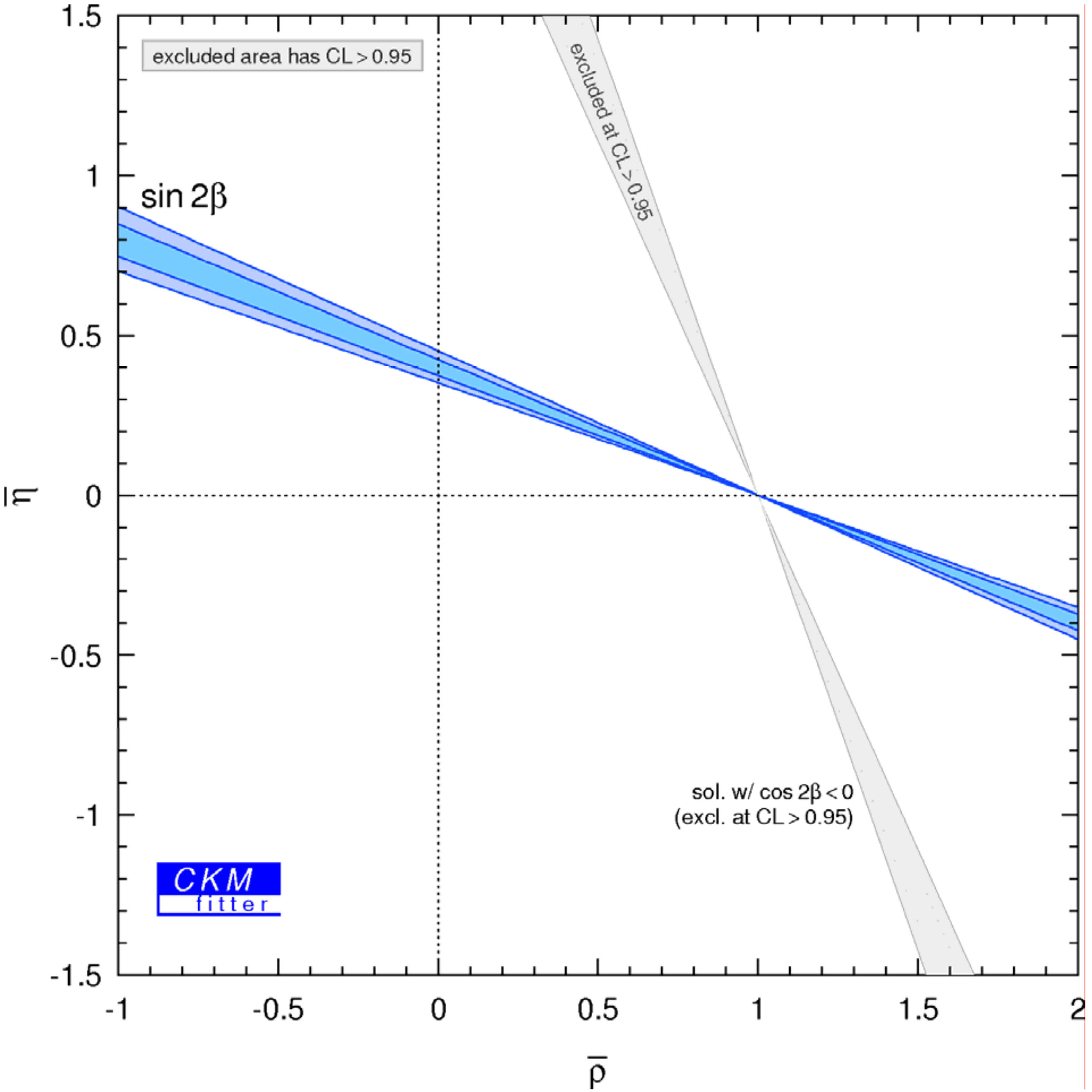
Constraint on $|V_{td}/V_{ts}|$

$$\frac{\Delta m_d}{\Delta m_s} = \frac{m_{Bd}}{m_{Bs}} \xi_{\Delta m}^{-2} \frac{|V_{td}|^2}{|V_{ts}|^2}$$

➔ First strong indication that B_s-$\overline{B}_s$ mixing is probably SM-like.



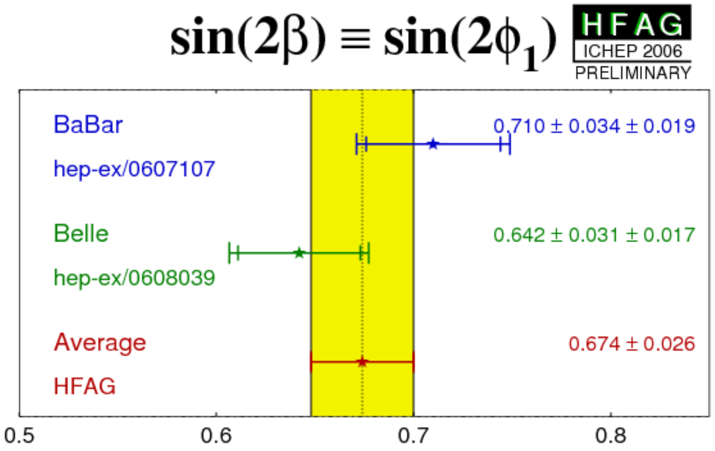
angle β



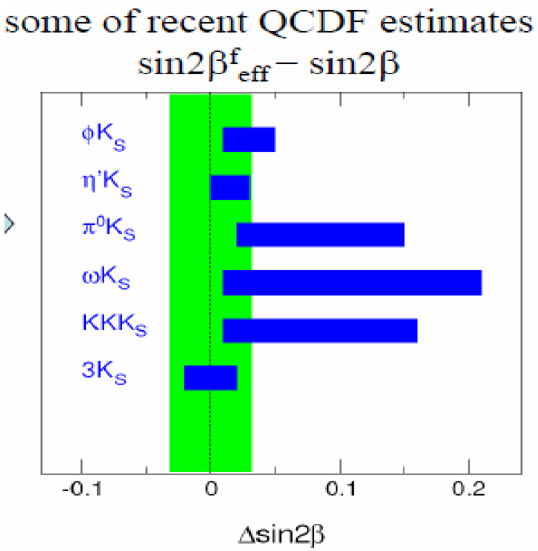
excluded area has CL > 0.95
sin 2β
excluded at CL > 0.95
sol. w/ cos 2β < 0
(excl. at CL > 0.95)
CKM
fitter
1.5
1
0.5
0
-0.5
-1
-1.5
-1
-0.5
0
0.5
1
1.5
2
$\bar{\eta}$
$\bar{\rho}$

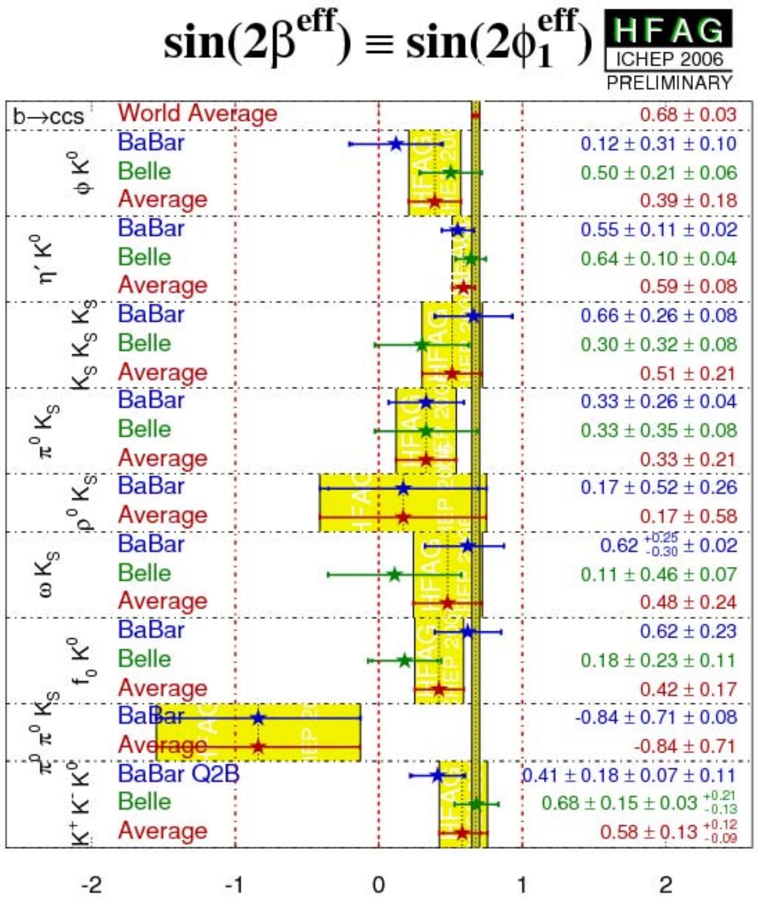
$\sin 2\beta$

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



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

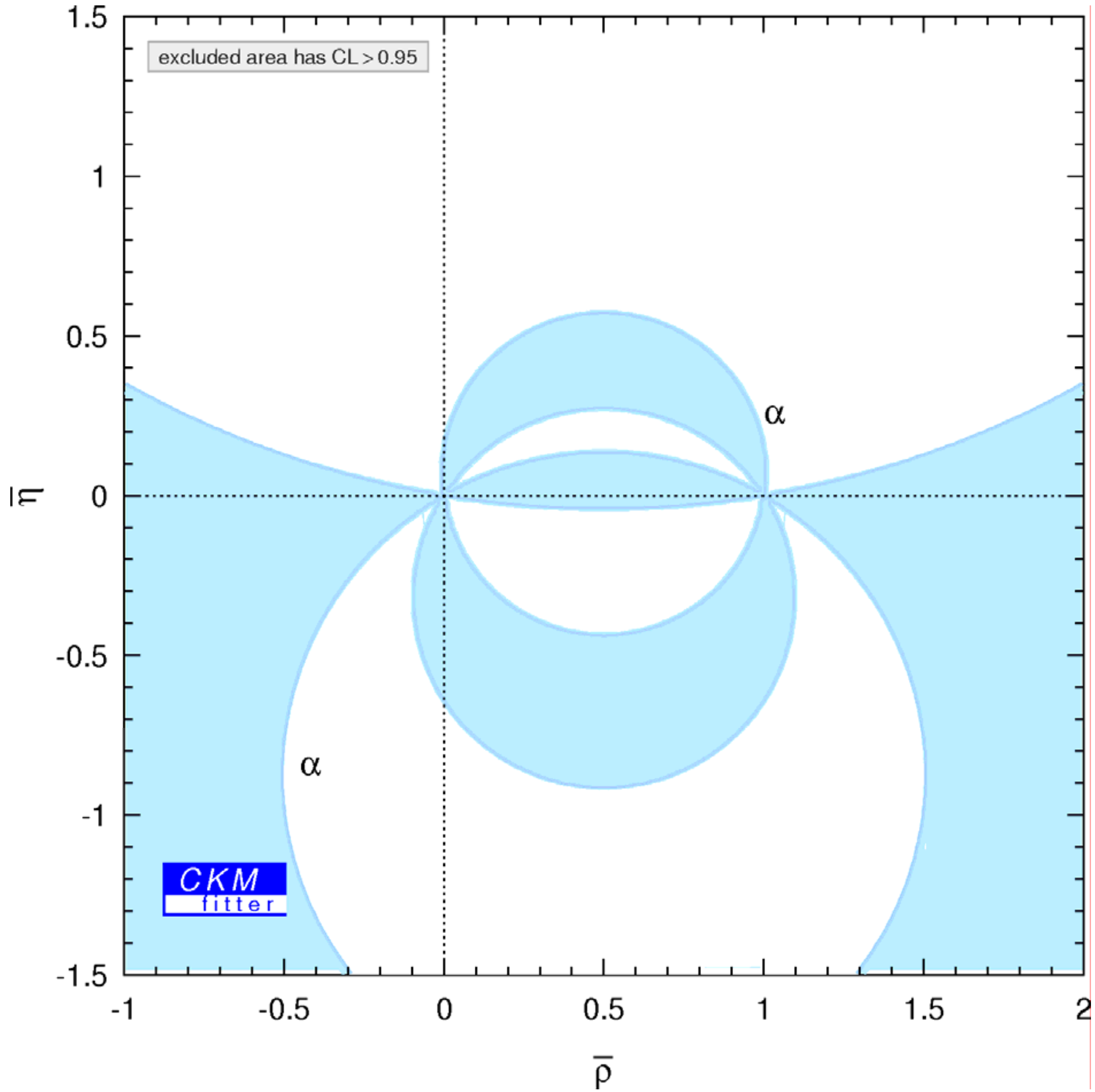




NP can contribute differently among the various s-penguin modes (Naïve average: 0.52±0.05).

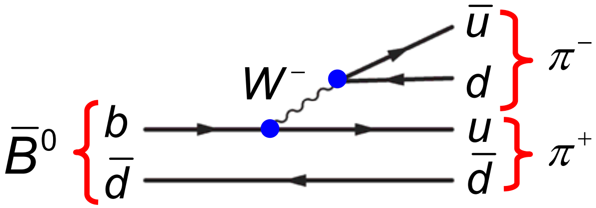
NB: a disagreement would falsify the SM. The interference NP/SM amplitudes introduces hadronic uncertainties
➔ Cannot determine the NP parameters cleanly

angle α



excluded area has CL > 0.95
1.5
1
0.5
0
-0.5
-1
-1.5
-1
-0.5
0
0.5
1
1.5
2
$\bar{\eta}$
$\bar{\rho}$
α
α
CKM
fitter

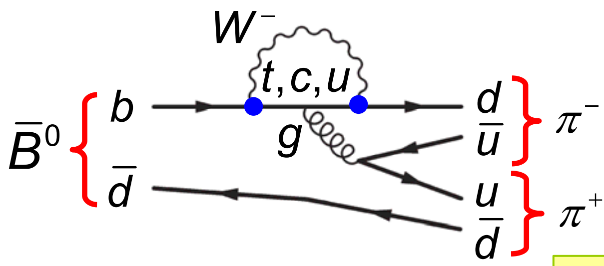
angle α



Tree : dominant

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

$\propto \lambda^{3}$



Penguin : competitive ?

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

$\propto \lambda^{3}$

- Time-dependent CP observable :

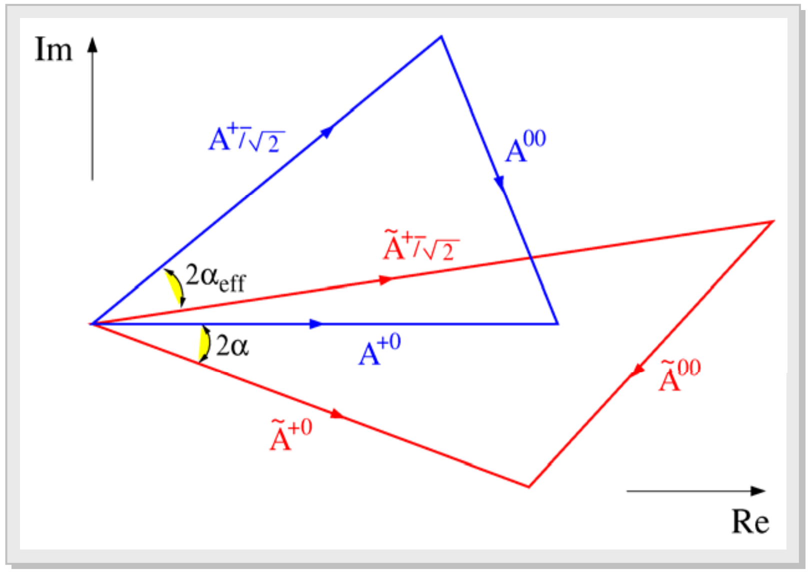
$$A_{h^+h^-}(t) = S_{h^+h^-}\sin(\Delta m_d t) - C_{h^+h^-}\cos(\Delta m_d t)$$

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

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])

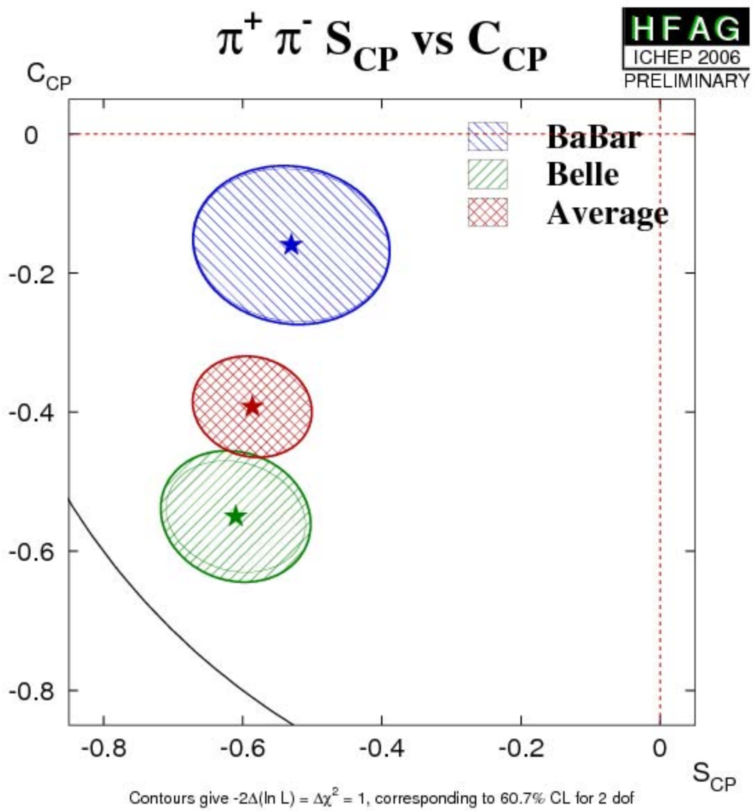


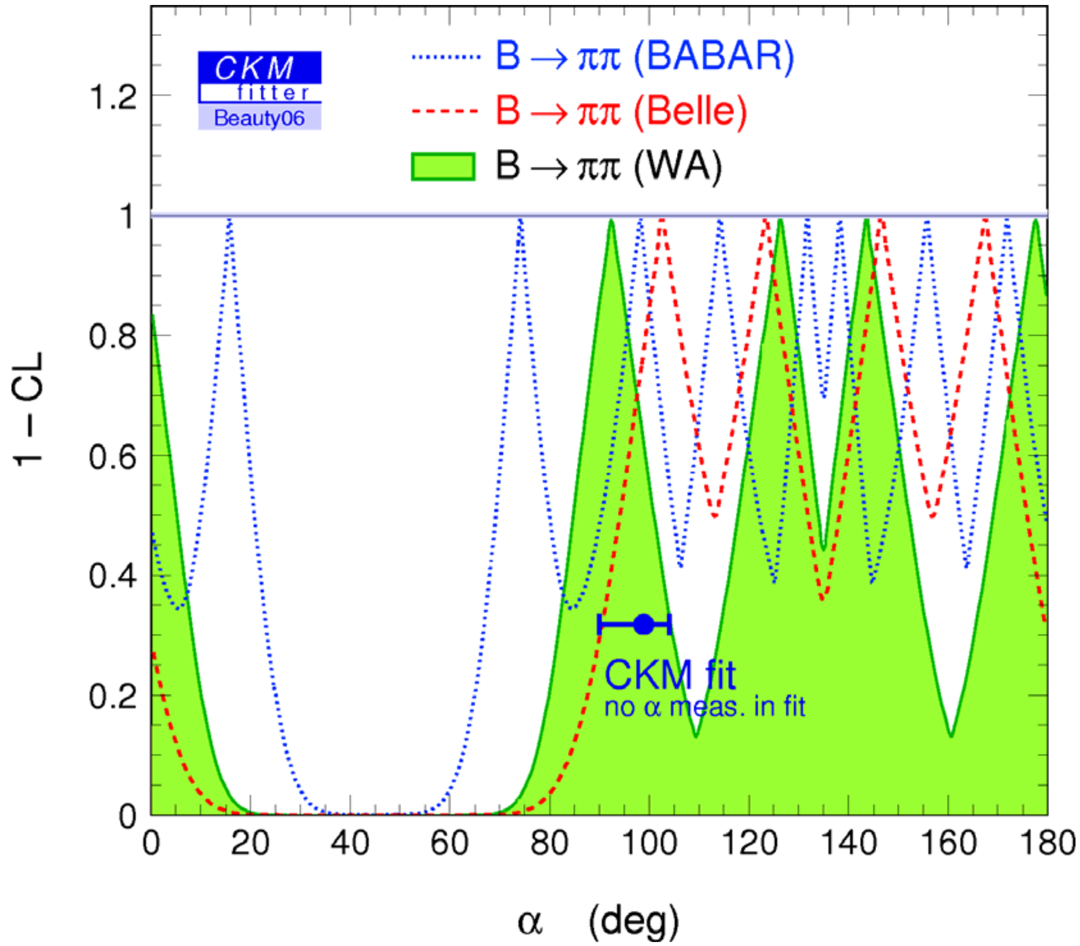
Isospin Analysis: B→ ππ

	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: $B \to \rho\rho$

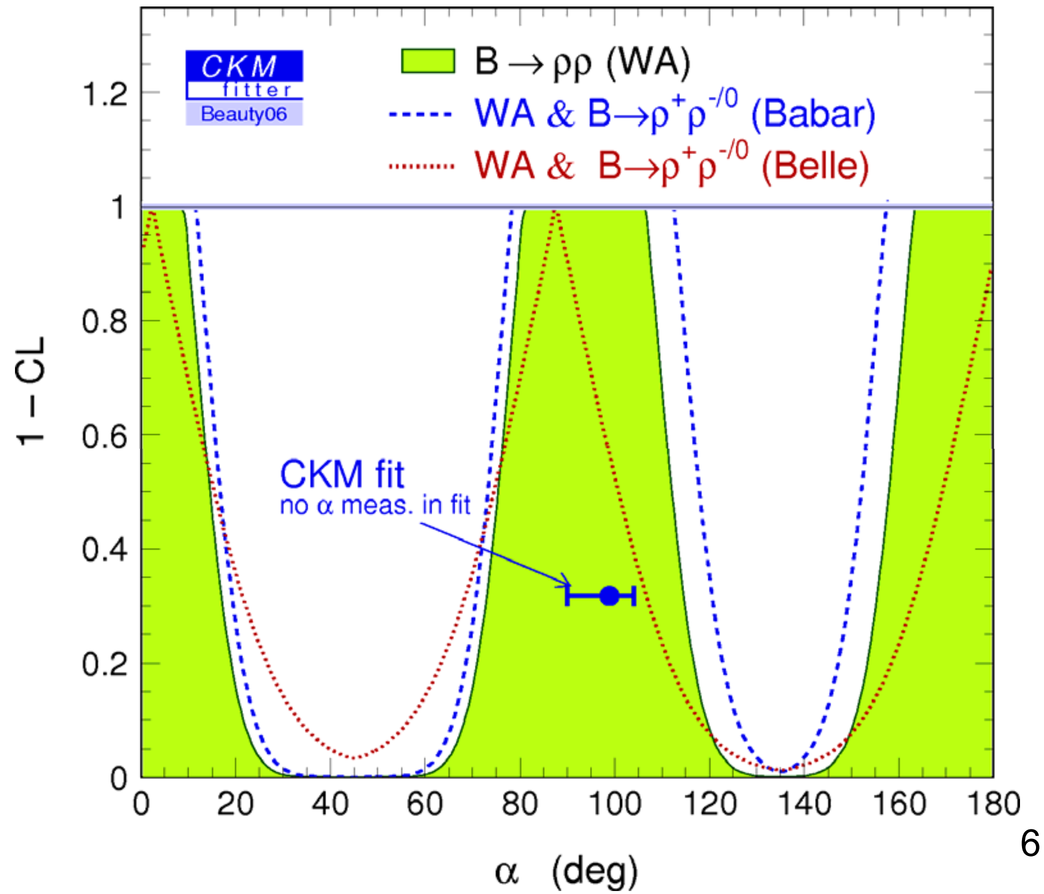
	BABAR (347m)	Belle (275m)	Average
$S_{\rho\rho}$	$-0.19 \pm 0.21\,^{+0.05}_{-0.07}$	$0.08 \pm 0.41 \pm 0.09$	-0.13 ± 0.19
$C_{\rho\rho}$	$-0.07 \pm 0.15 \pm 0.06$	$0.0 \pm 0.3 \pm 0.09$	-0.06 ± 0.14

	BABAR (347m)
f_L^{00}	$0.86\,^{+0.11}_{-0.13} \pm 0.06$
BR^{00}	$(1.2 \pm 0.4 \pm 0.3) \times 10^{-6}$

- Isospin analysis :

$\alpha = [\,94 \pm 21\,]^\circ$

BABAR & Belle



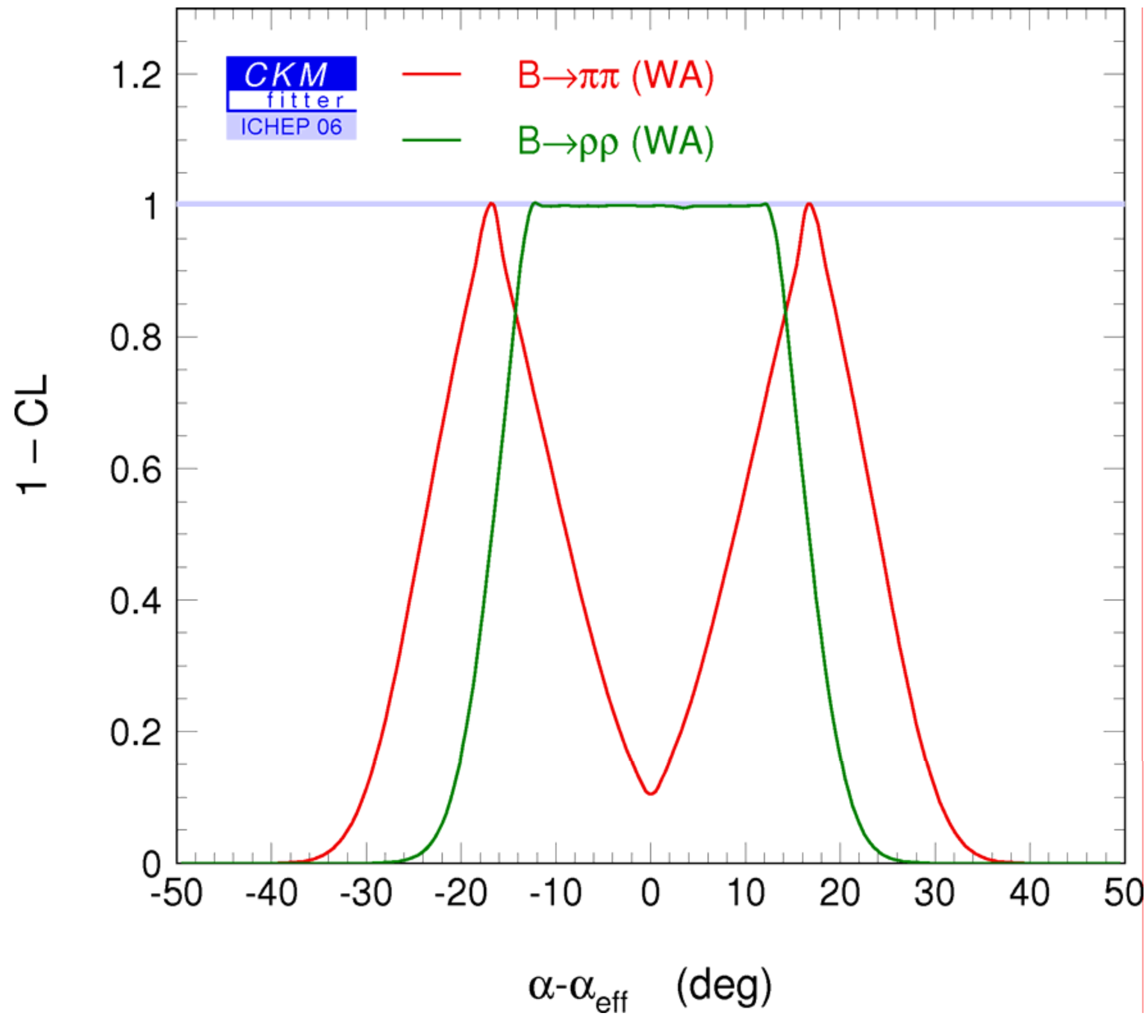
Isospin Analysis: angle α_{eff} [$B \rightarrow \pi\pi/\rho\rho$]

- Isospin analysis $B \rightarrow \pi\pi$:

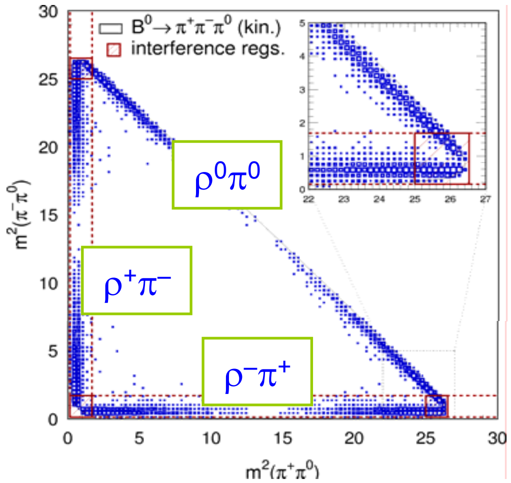
  $|\alpha-\alpha_{eff}| < 32.1^{o}$ (95% CL)

- Isospin analysis $B \rightarrow \rho\rho$:

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



The $B \to \rho\pi$ System



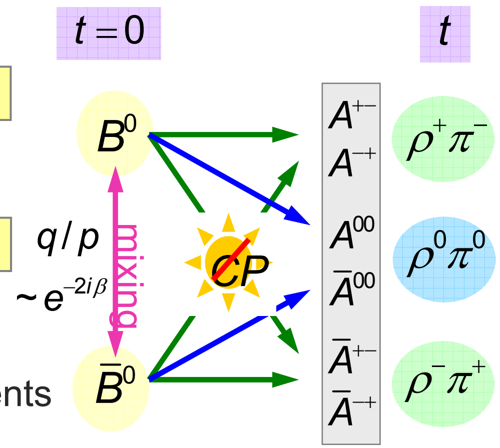
Dominant mode $\rho^+\pi^-$ is not a *CP* eigenstate

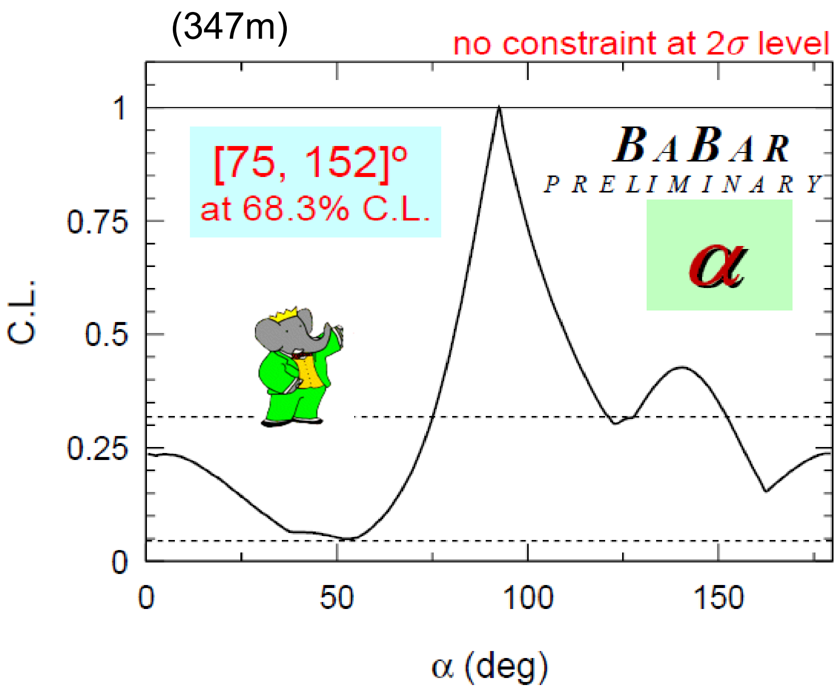
Aleksan *et al*, NP B361, 141 (1991)

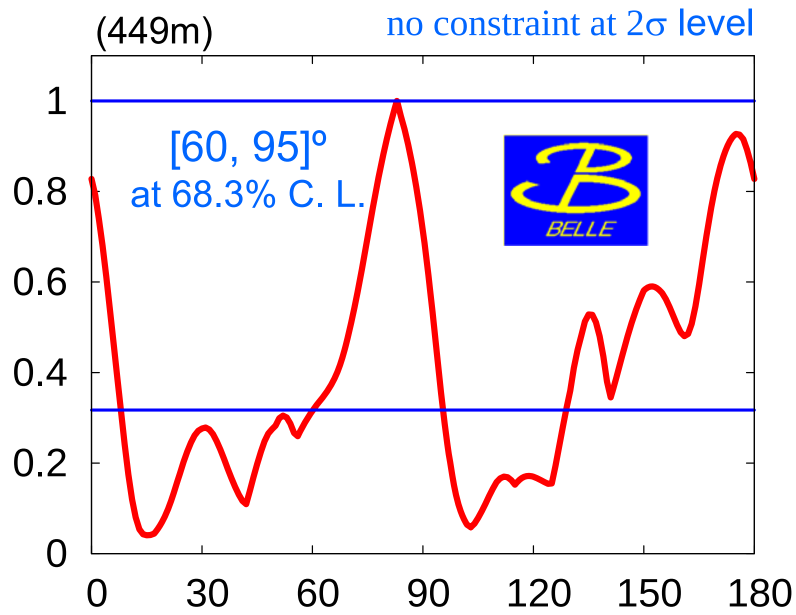
Amplitude interference in Dalitz plot

Snyder-Quinn, PRD 48, 2139 (1993)

- simultaneous fit of α and strong phases
- Measure 26 (27) bilinear Form Factor coefficients
- correlated χ^2 fit to determine physics quantities





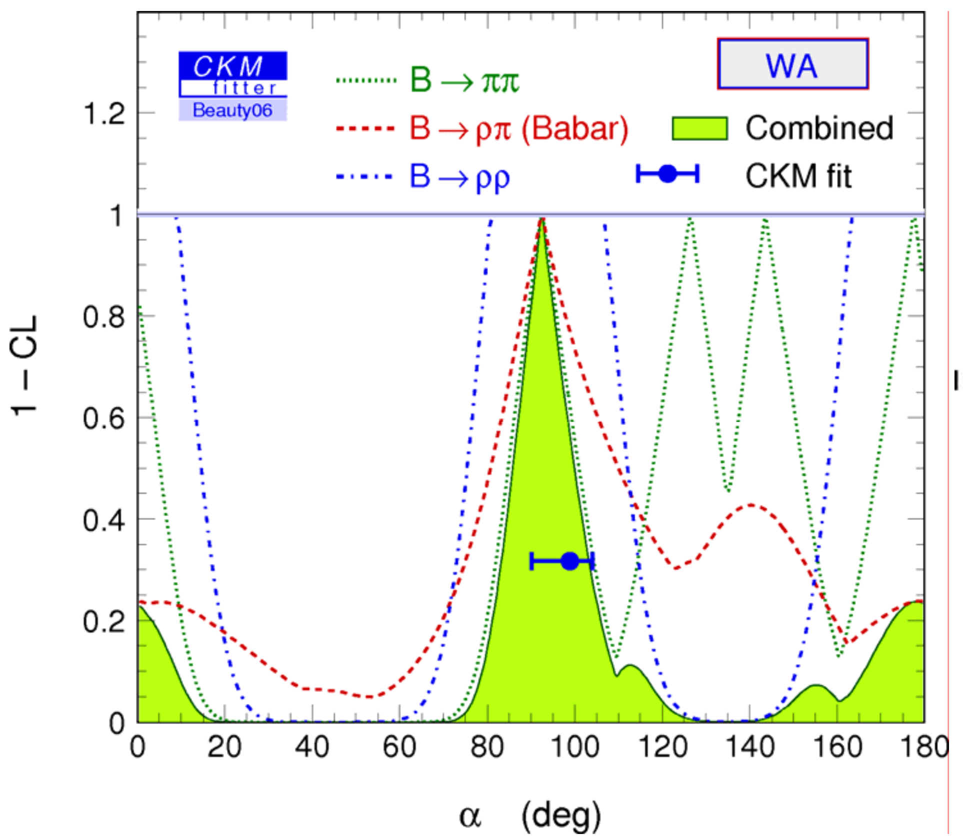


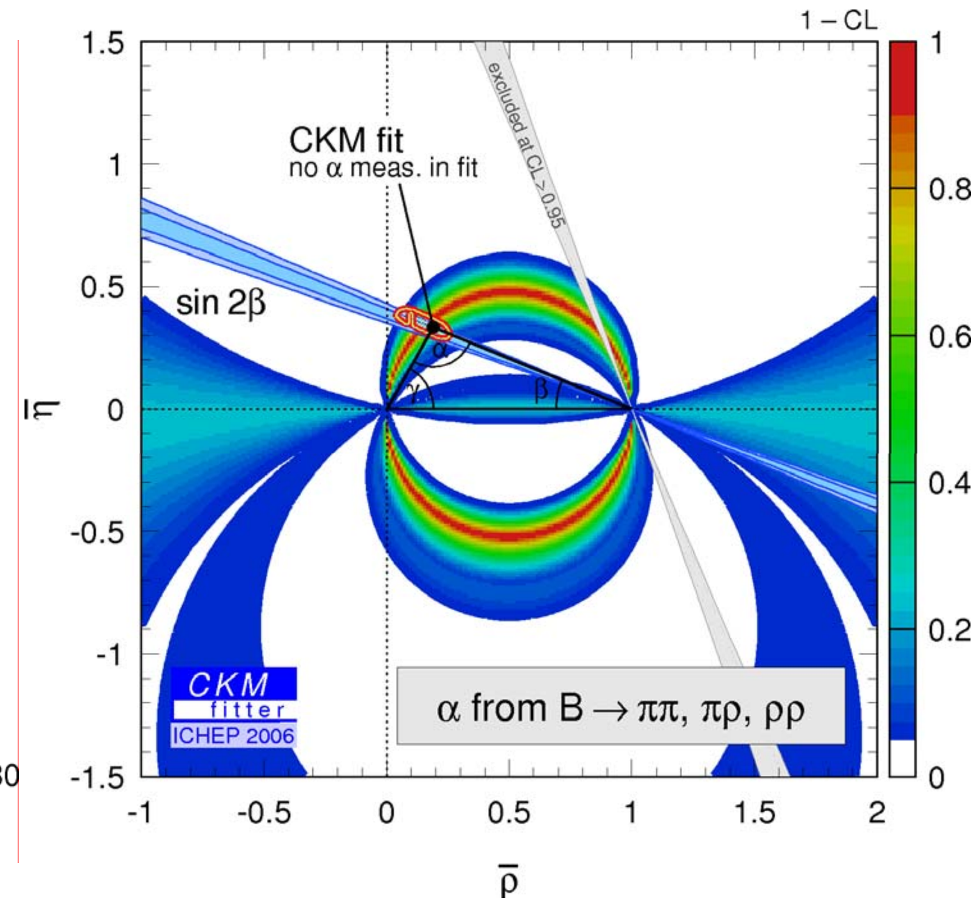
Dalitz analysis + isospin (pentagon) analysis

Lipkin *et al*., PRD 44, 1454 (1991)

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

$\alpha_{\text{B-Factories}} = [\ 93\ ^{+11}_{-9}\ ]^{\circ}$ $\Rightarrow$ $\alpha_{\text{Global Fit}} = [\ 100\ ^{+5}_{-7}\ ]^{\circ}$

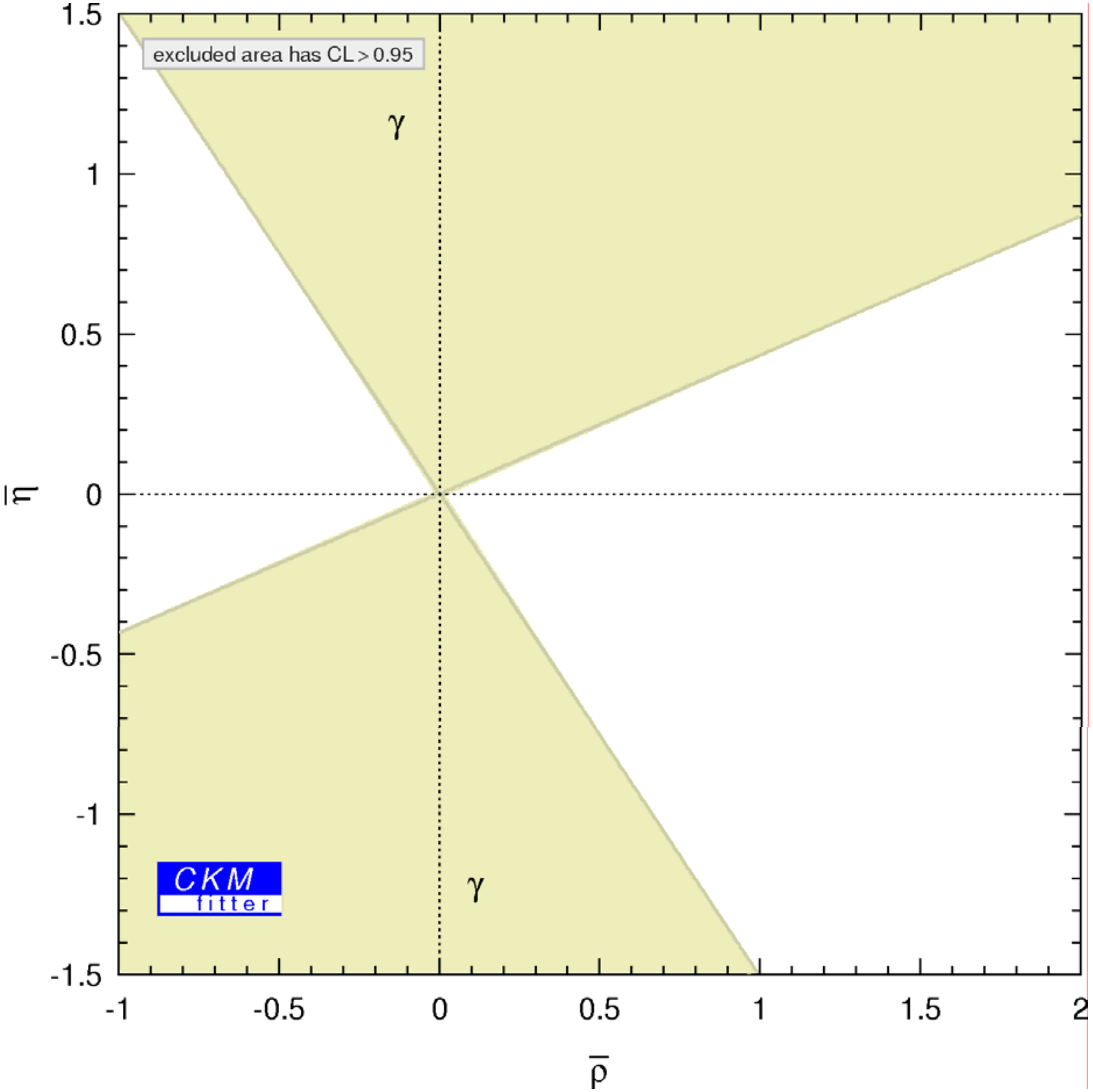




B→ρρ: at very large statistics, systematics and model-dependence will become an issue

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

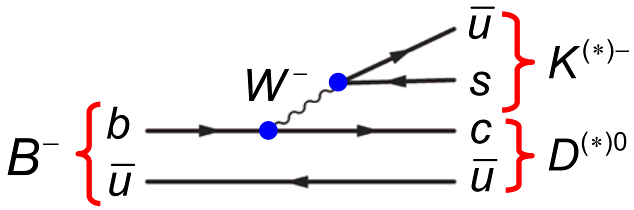
angle γ

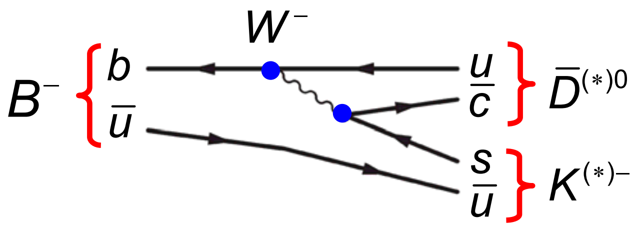


excluded area has CL > 0.95
γ
γ
CKM fitter
1.5
1
0.5
0
-0.5
-1
-1.5
-1
-0.5
0
0.5
1
1.5
2
$\bar{\eta}$
$\bar{\rho}$

angle γ [next UT input that is not theory limited]

$b \to c\bar{u}s, u\bar{c}s$





No Penguins ☺

Tree: dominant

$\propto V_{cb}V_{us}^*$
$\propto \lambda^3$

Tree: color-suppressed

$\propto V_{ub}V_{cs}^*$
$\propto \lambda^3\sqrt{\rho^2+\eta^2}$

relative CKM phase : γ

Several variants:

- GLW : D^0 decays into CP eigenstate
- ADS : D^0 decays to $K^-\pi^+$ (favored) and $K^+\pi^-$ (suppressed)
- GGSZ : D^0 decays to $K_S\pi^+\pi^-$ (interference in Dalitz plot)
  - All methods fit simultaneously: γ, r_B and δ *(different r_B and δ)*

Gronau-London, PL B253, 483 (1991); Gronau-Wyler, PL B265, 172 (1991)

Atwood-Dunietz-Soni, PRL 78, 3257 (1997)

Giri *et al*, PRD 68, 054018 (2003)

r_B, r_B^* } how small ?

σ_γ depends significantly on the value of r_B

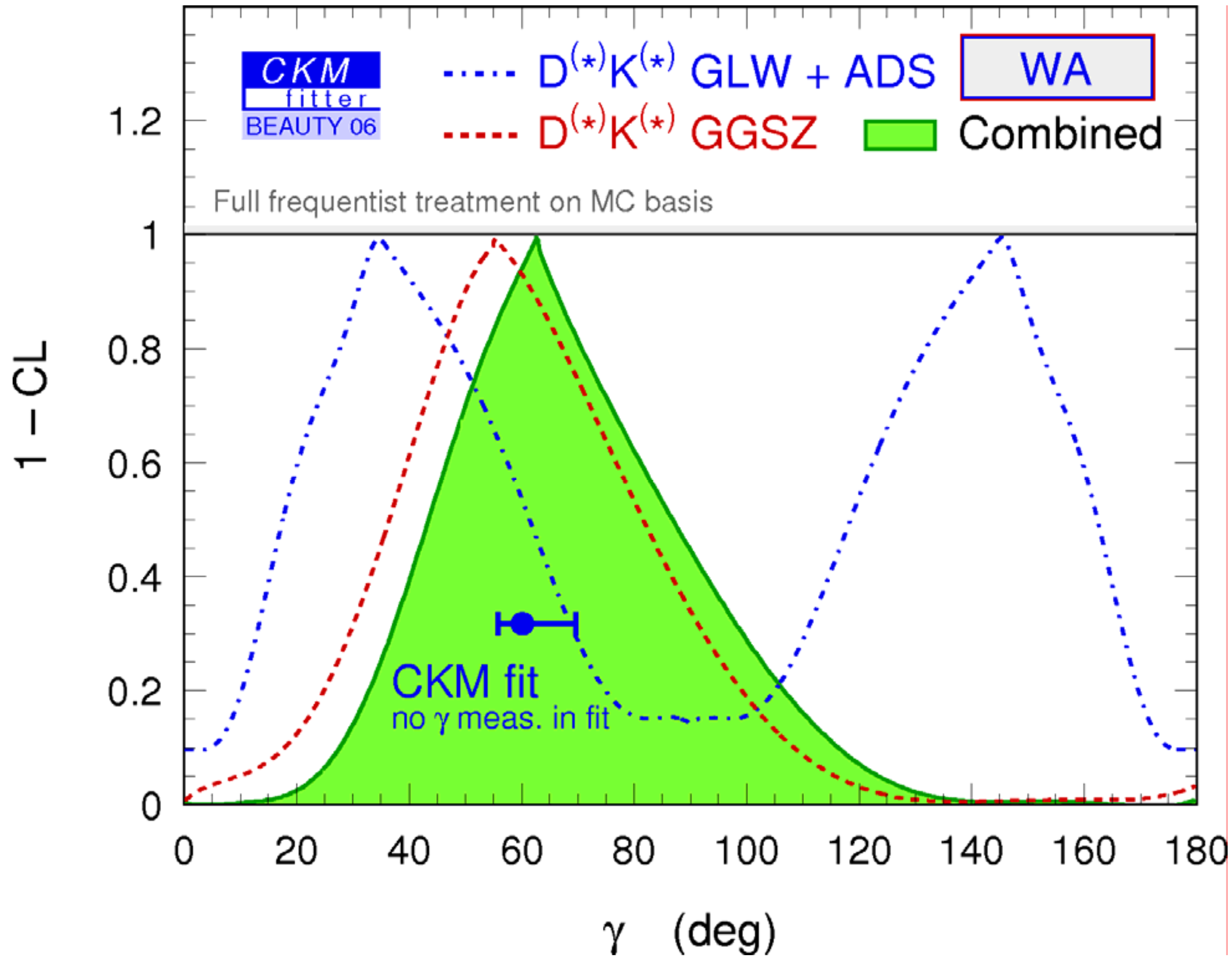
Constraint on γ

$\gamma_{\text{B-Factories}} = [\,60\ ^{+38}_{-24}\,]^{\circ}$ ➡ $\gamma_{\text{Global Fit}} = [\,59\ ^{+9}_{-4}\,]^{\circ}$

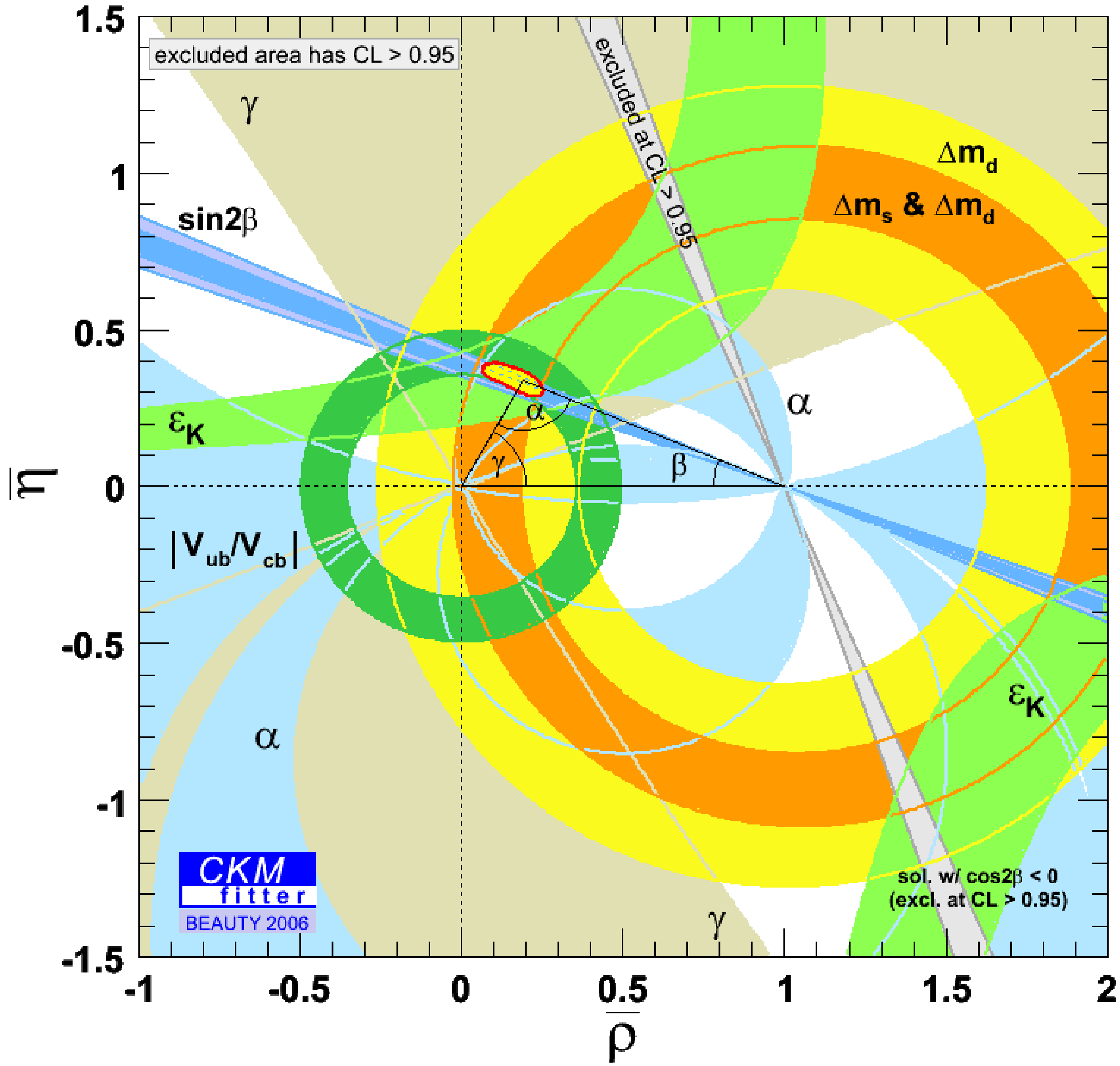
$r_B(DK) = 0.10^{+0.03}_{-0.04}$

$r_B(D^*K) = 0.10^{+0.04}_{-0.06}$

$r_B(DK^*) = 0.11^{+0.09}_{-0.11}$



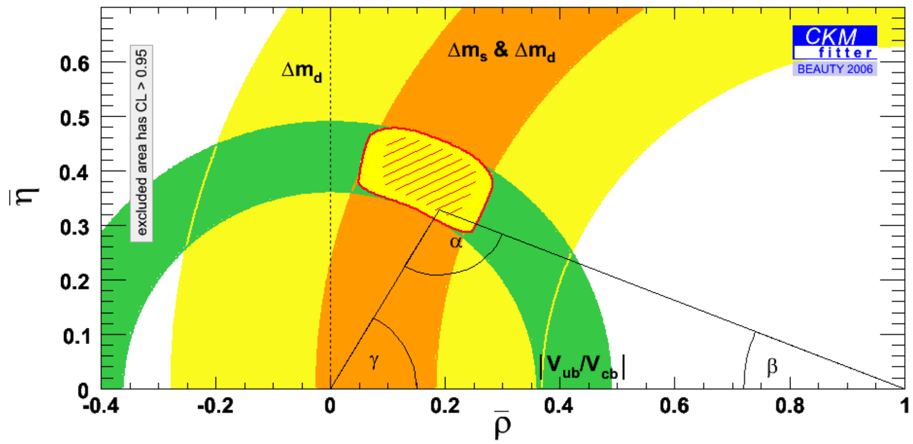
Putting it all together — the global CKM fit

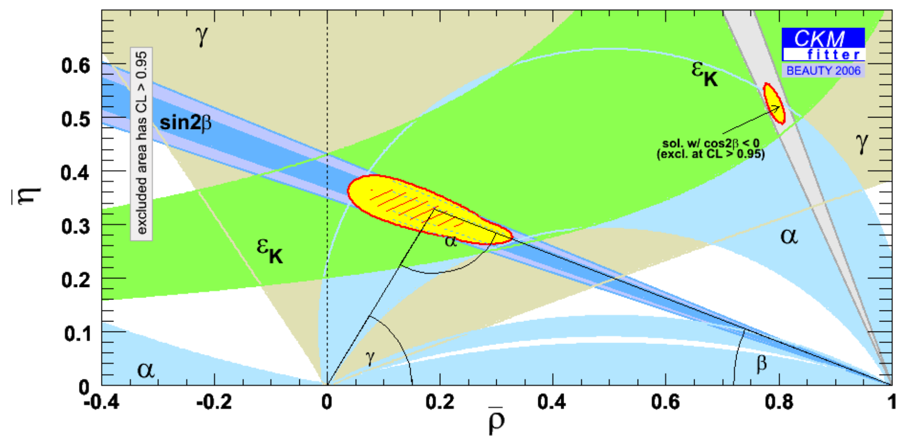


Inputs:

- $\left|\frac{V_{ub}}{V_{cb}}\right|$
- Δm_d
- Δm_s
- $B \to \tau\nu$
- $|\varepsilon_K|$
- $\sin 2\beta$
- α
- γ

The global CKM fit: Testing the CKM Paradigm

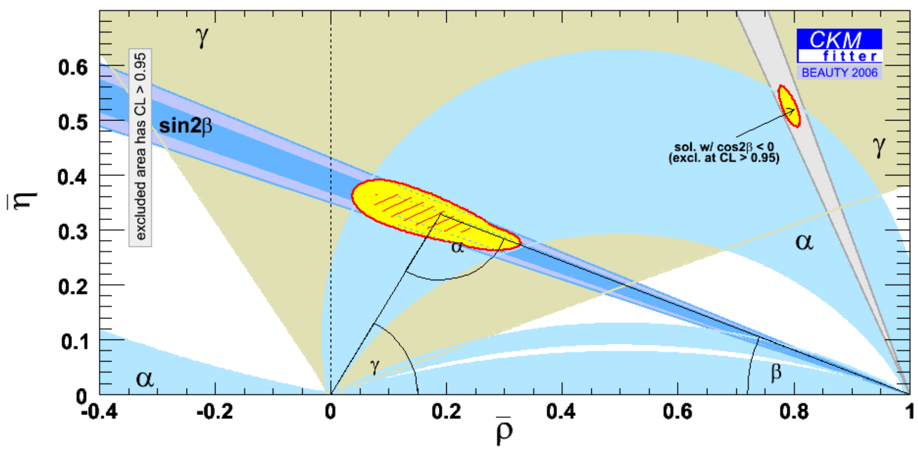


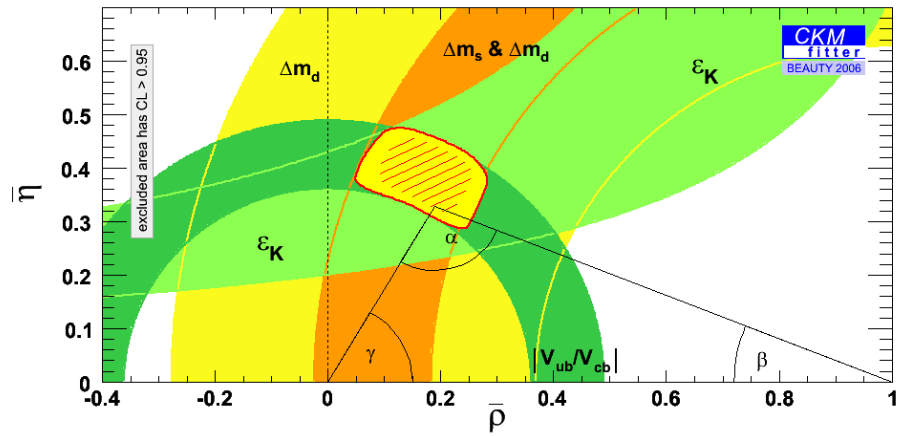


CP Conserving

CP Violating

CP-insensitive observables imply CP violation !

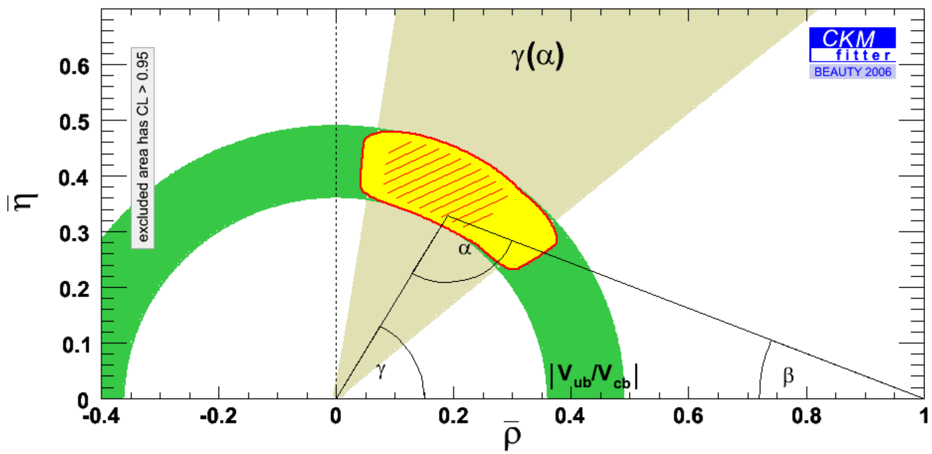


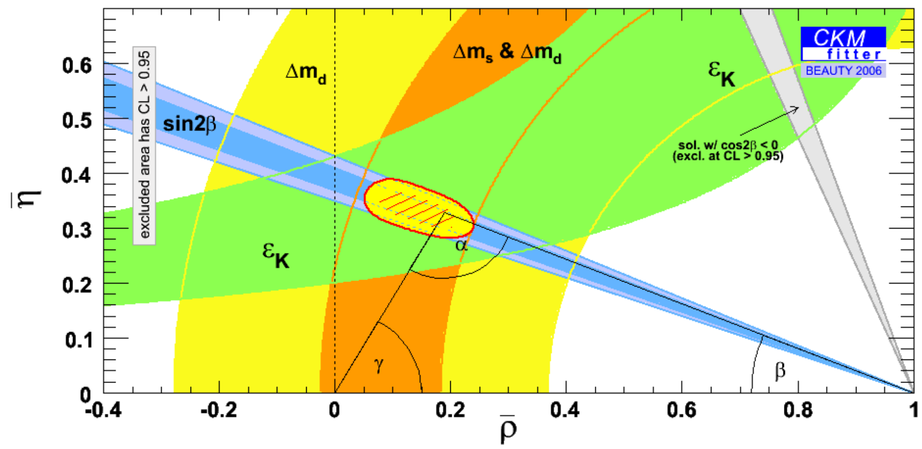


Angles (no theory)

No angles (with theory)

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





Tree (NP-Free) "Reference UT"

Loop

[No NP in ΔI=3/2 b→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 ΔF=1 rare decays are not yet measured
➔ Sensitive to NP

The global CKM fit: selected predictions

- Wolfenstein parameters:

$$A = 0.806^{+0.014}_{-0.014} \quad \lambda = 0.2272^{+0.0010}_{-0.0010} \quad \bar{\rho} = 0.195^{+0.022}_{-0.055} \quad \bar{\eta} = 0.326^{+0.027}_{-0.015}$$

- Jarlskog invariant:

$$J = (2.91^{+0.25}_{-0.14}) \times 10^{-5}$$

- UT Angles:

$$\alpha = (99.0^{+4.0}_{-9.4})^{\circ} \quad \beta = (22.03^{+0.72}_{-0.62})^{\circ} \quad \gamma = (59.0^{+9.2}_{-3.7})^{\circ} \qquad \Sigma_{meas.} = (175^{+40}_{-27})^{\circ}$$

- UT sides:

$$R_u = 0.380^{+0.011}_{-0.009} \quad R_t = 0.868^{+0.060}_{-0.025}$$

- B-B mixing:

$$\Delta m_s = (18.9^{+5.7}_{-2.8})\, ps^{-1}$$ (CKM Fit)

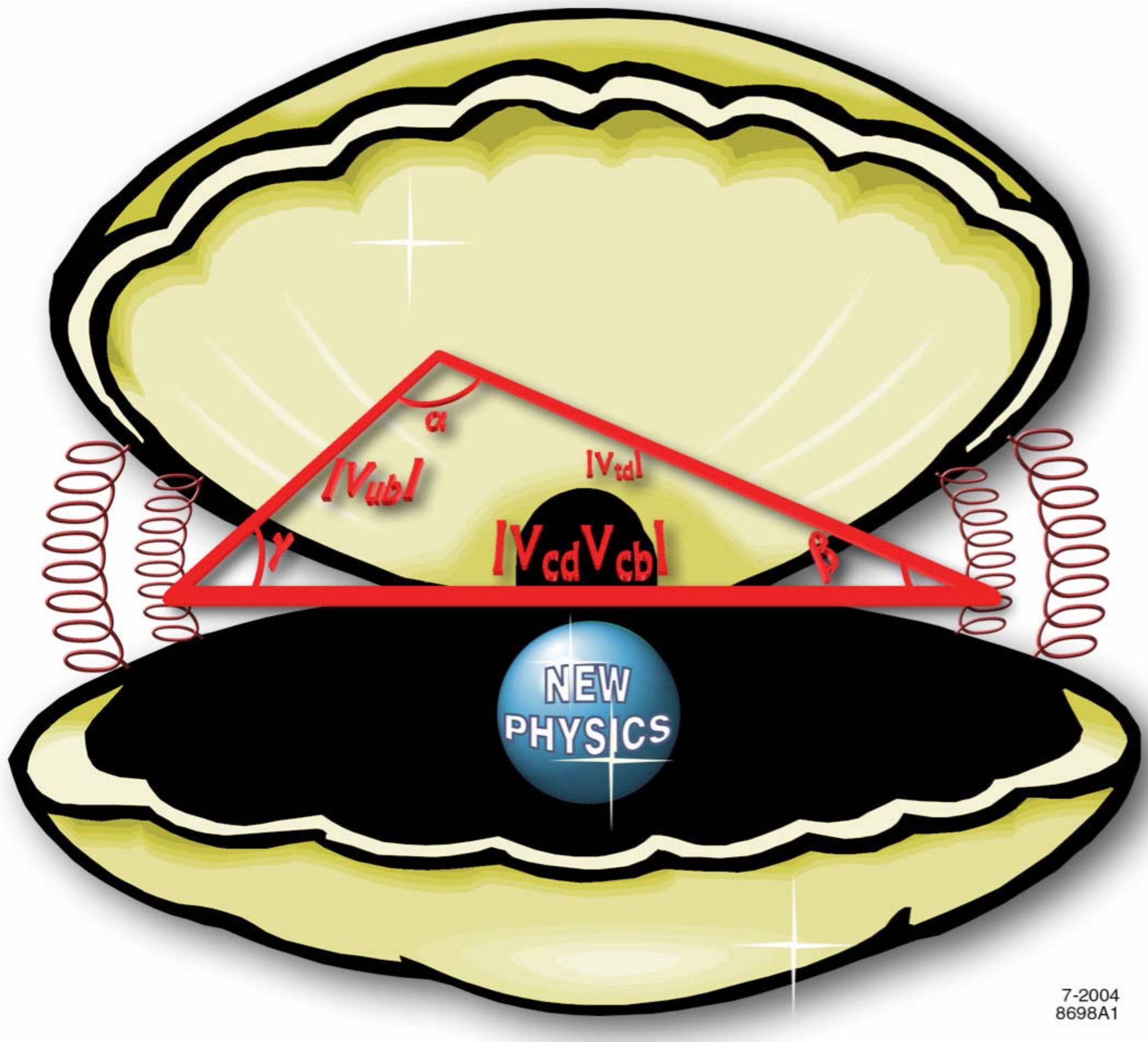
Δm_s : 17.77±0.1(stat.) ± 0.07 (syst.) ps^{-1} (direct,CDF)

- B→τν

$$\mathrm{BF}(B^+ \to \tau^+ \nu_\tau) = (0.87^{+0.13}_{-0.20}) \times 10^{-4}$$ (CKM Fit)

$$(1.45^{+0.46}_{-0.43}) \times 10^{-4}$$ (direct,WA)

New Physics?

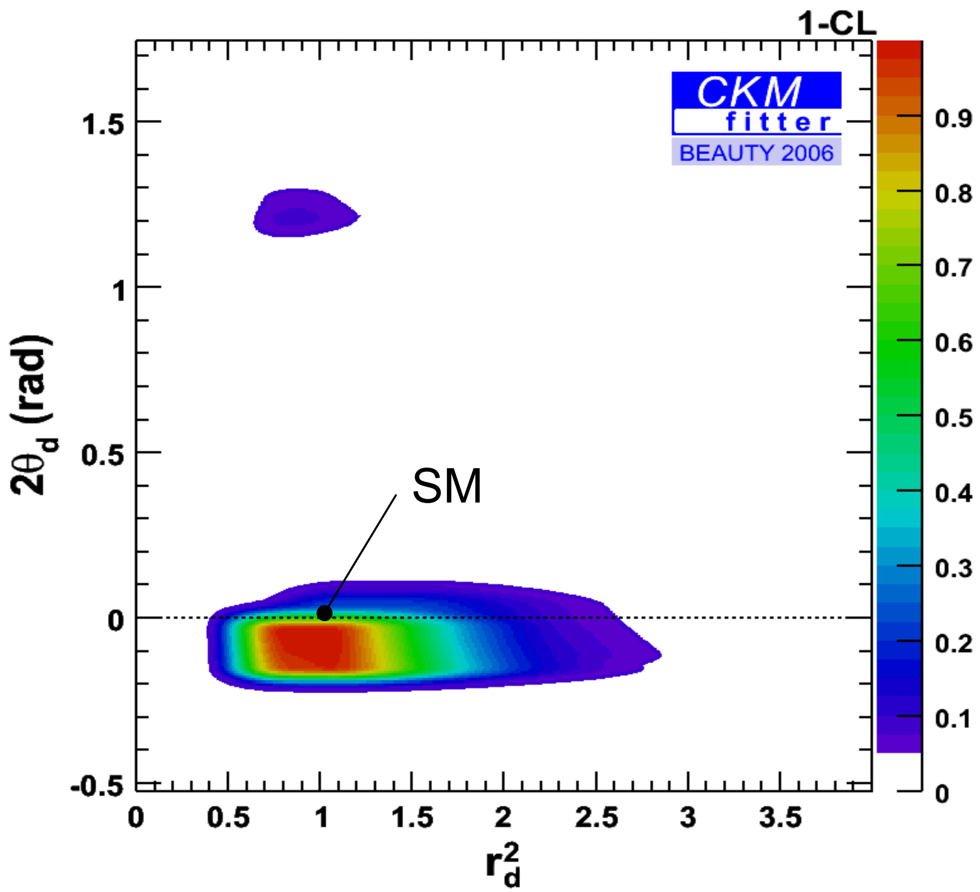


Courtesy A. Roodman

New Physics in B_d-$\overline{B}_d$ Mixing?

$$r_d^2 \exp(2 i \theta_d) = \frac{\langle B^0 | H_{eff}^{full} | \overline{B}^0 \rangle}{\langle B^0 | H_{eff}^{SM} | \overline{B}^0 \rangle}$$

No significant modification of the B-$\overline{B}$ mixing amplitude



NP Parameterization in B_s system

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

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

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

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

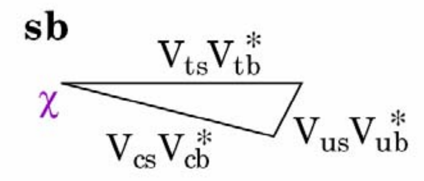
Width difference: $\Delta\Gamma_s^{CP} = (\Delta\Gamma_s)^{SM} \cos^2(2\chi - 2\theta_s)$

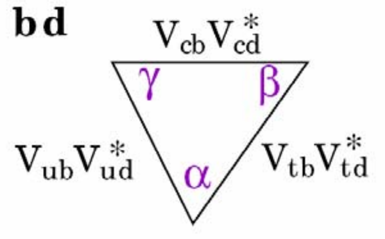
Semileptonic asymmetry:
$A^s_{SL} = -\mathrm{Re}(\Gamma_{12}/M_{12})^{SM} \sin(2\theta_s)/r_s^2$

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

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

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)

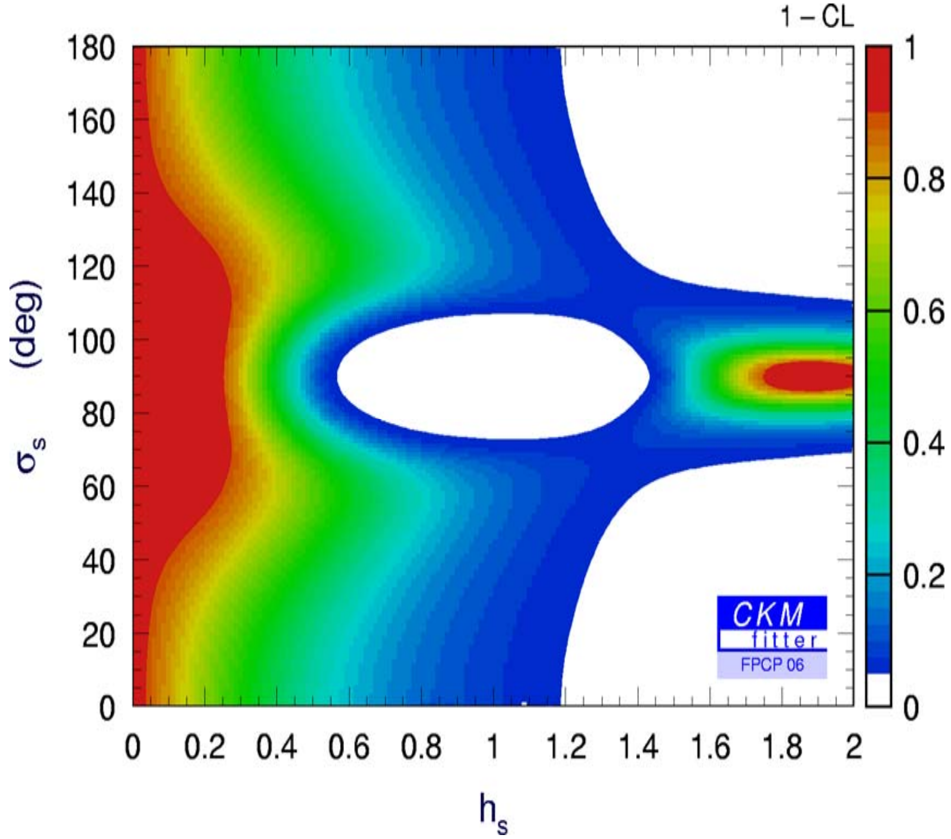




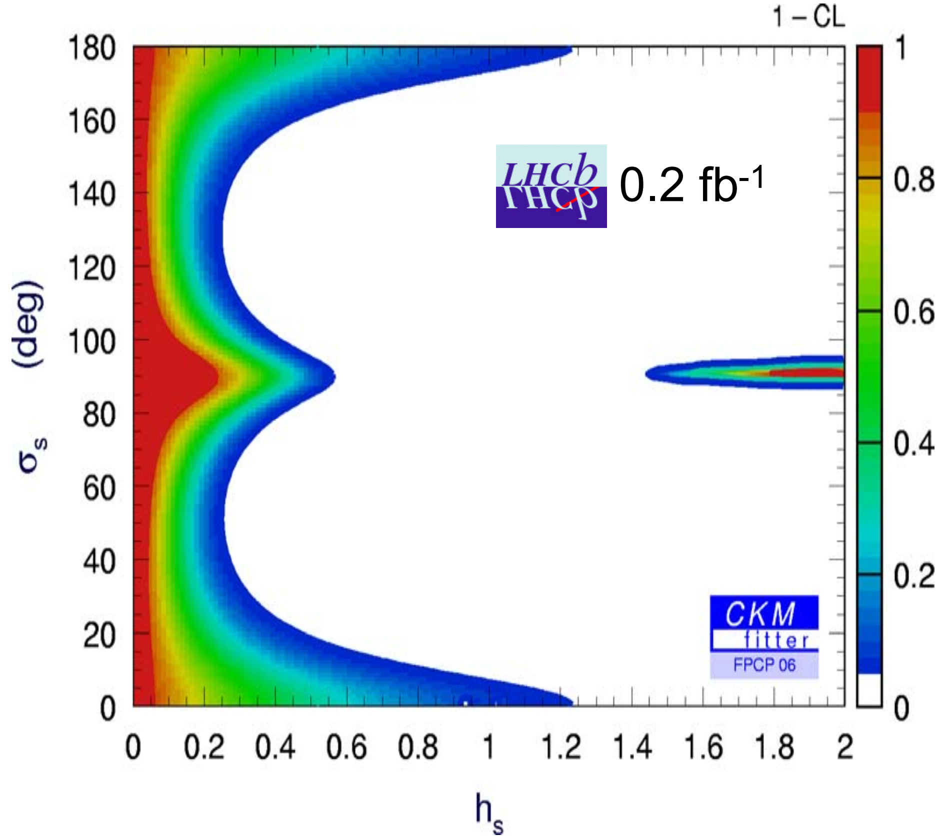
B_s mixing phase very small in SM: $\chi = -1.02 + 0.06$ (deg)
➔Bs mixing: very sensitive probe to NP

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)

B_s-mixing phase

ICHEP06 – Conf note 5144

(Preliminary)

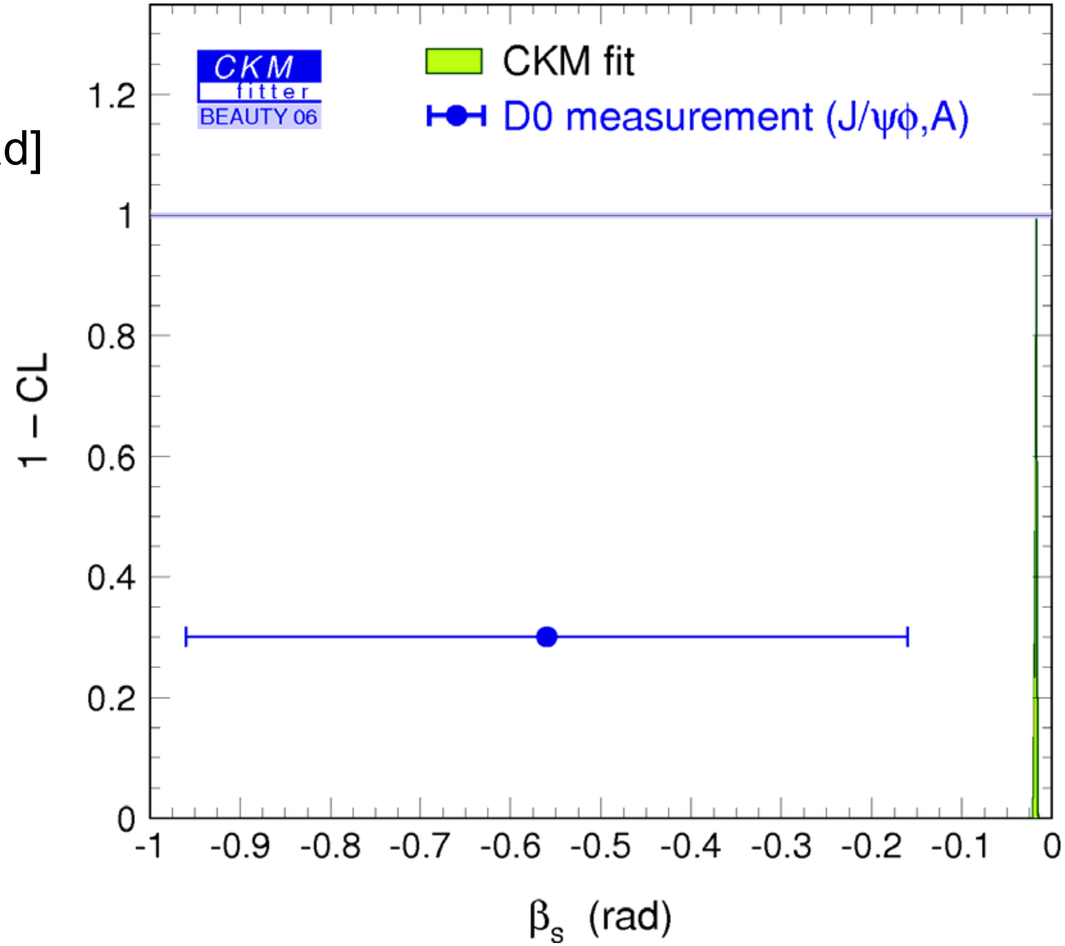
$$\beta_s = (-0.56^{+0.44}_{-0.41}) \text{ (stat+syst) [rad]}$$

Time-dependent angular distribution of untagged decays $B_s \to J/\psi\phi$ + charge asymmetry

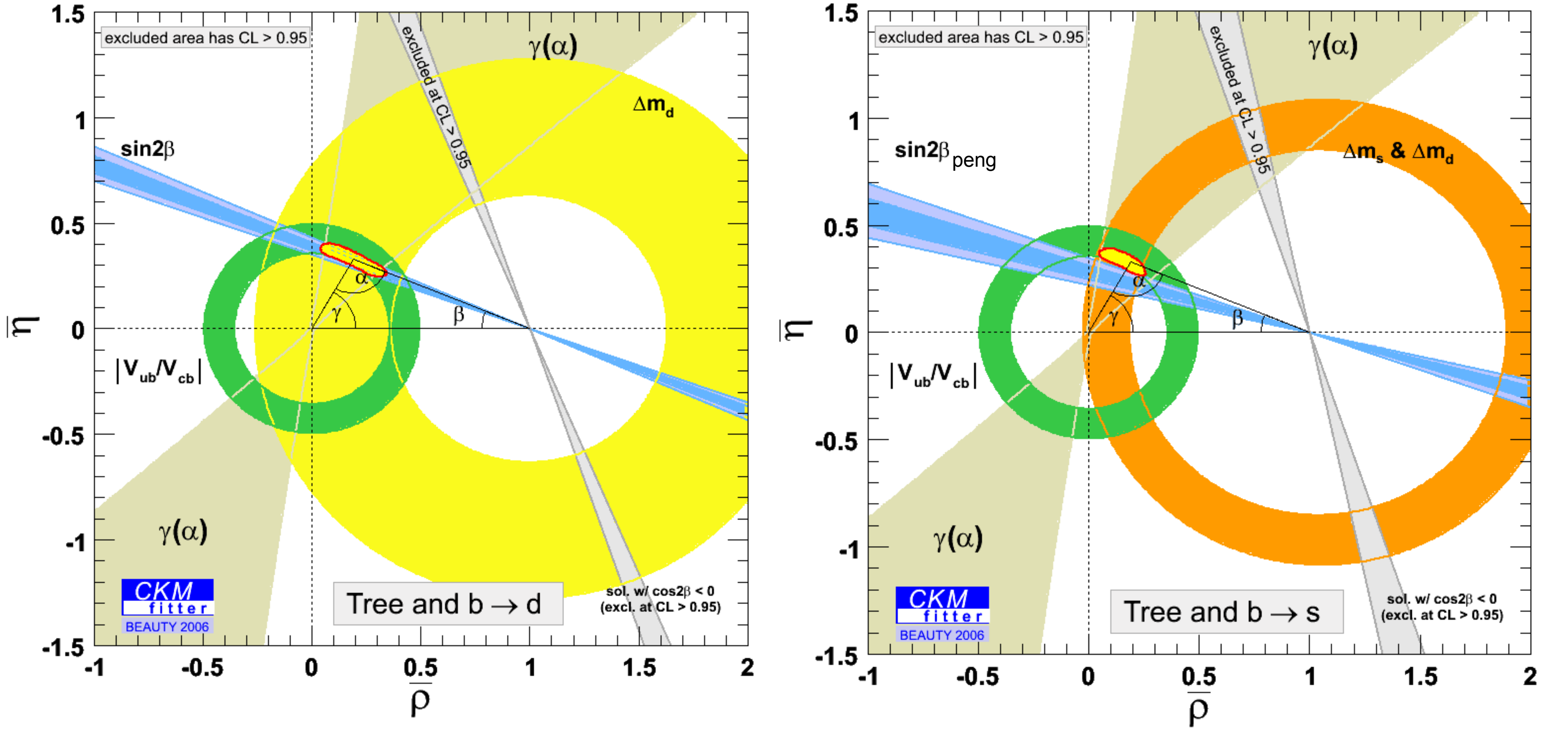
- Prediction from global CKM fit :

$$\beta_s = (-0.0175^{+0.0015}_{-0.0008}) \text{ [rad]}$$

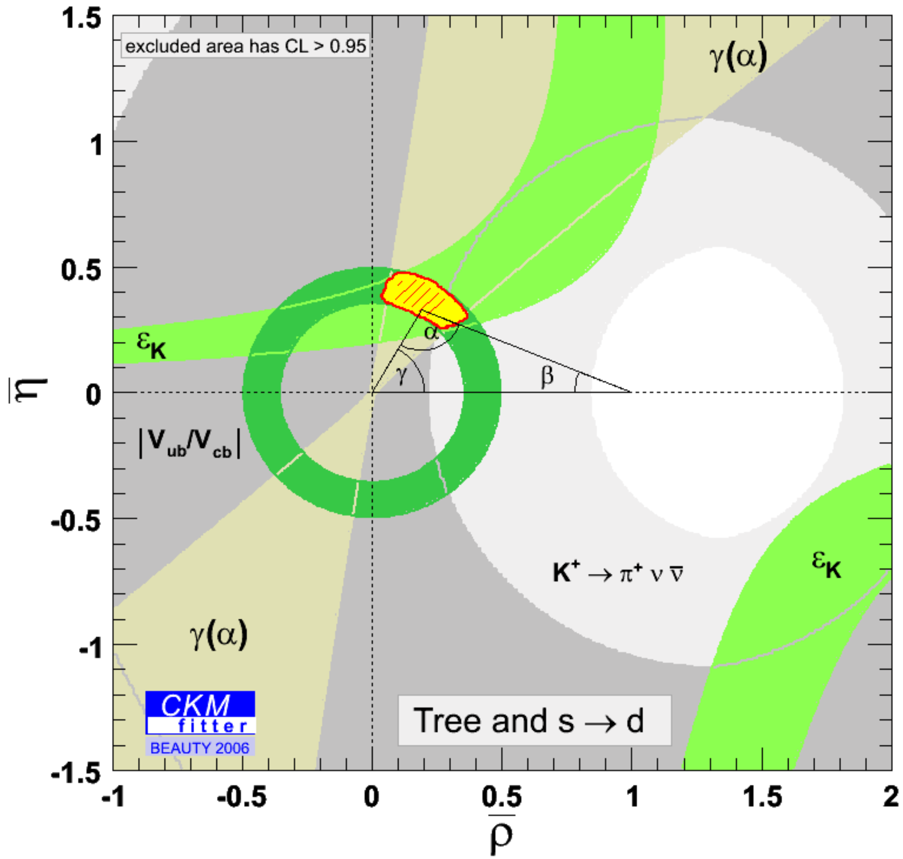
➔ Precision prediction
➔ Sensitive test to NP

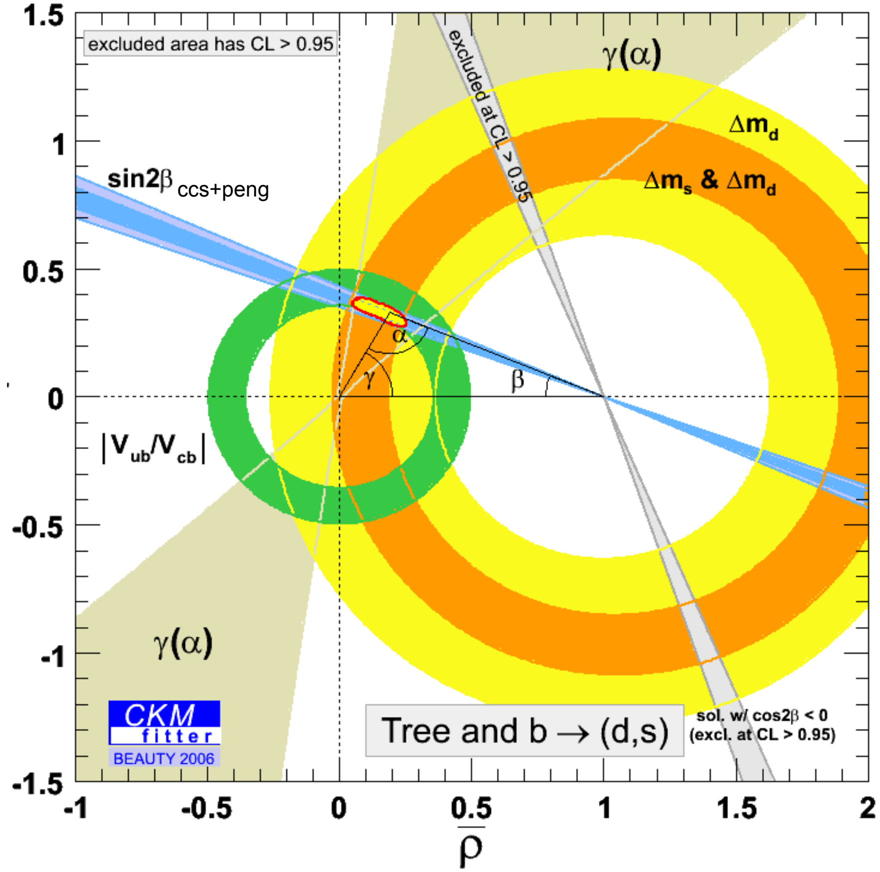


NP in b→s transitions?



NP related solely to the third generations?





Conclusion

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

•Improvement of Lattice QCD is very desirable [Charm/tau factory will help]

•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")

•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}, …]

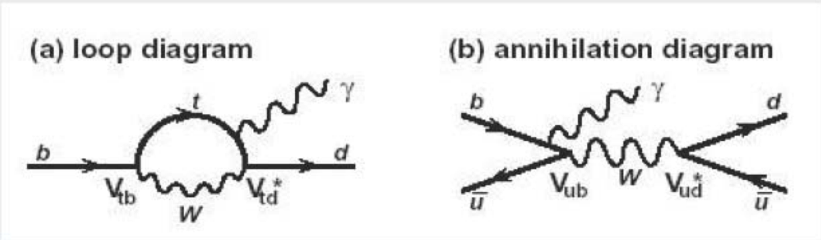
• Before claiming NP discovery, be sure that everything is "under control" (assumptions, theoretical uncertainties, etc.)
➔ null tests of the SM

• There are still plenty of measurements yet to be done

BACKUP SLIDES

Radiative Penguin Decays: BR(B→ργ)/BR(B→K*γ)

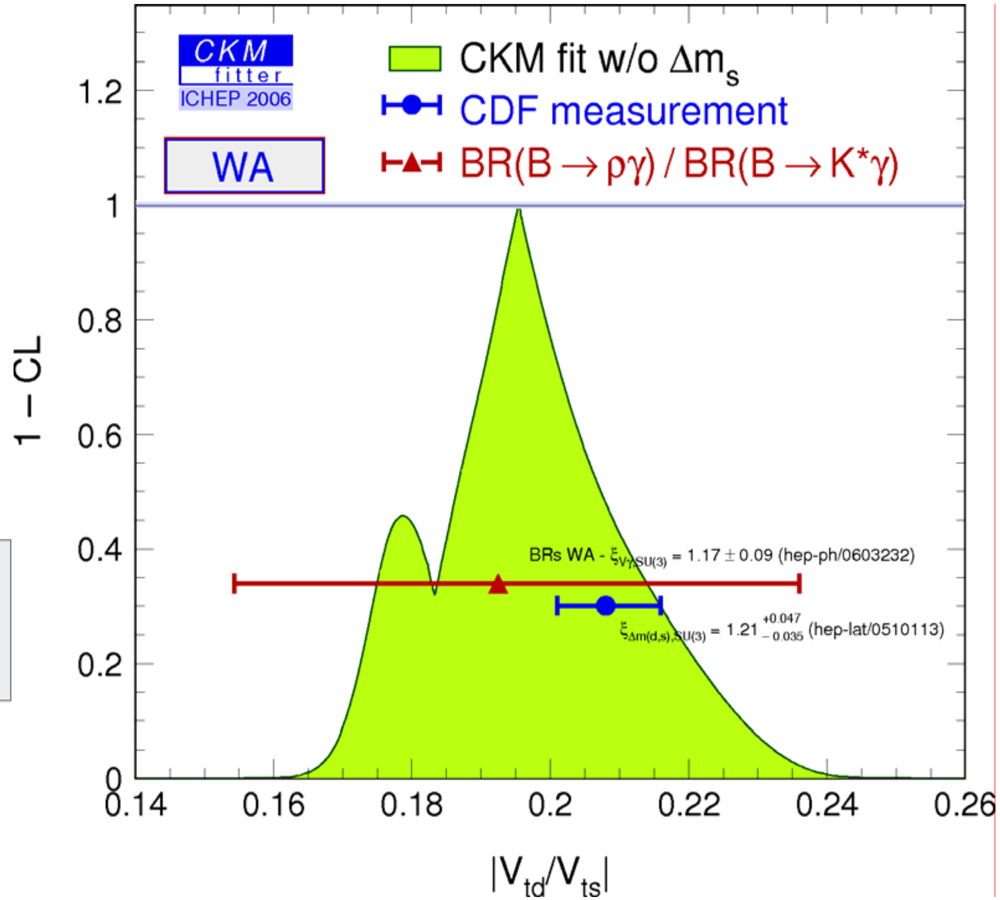
$B \to \rho\gamma$ ($\propto |V_{td}|^2$) & $B \to K^*\gamma$ ($\propto |V_{ts}|^2$) sensitive to New Physics

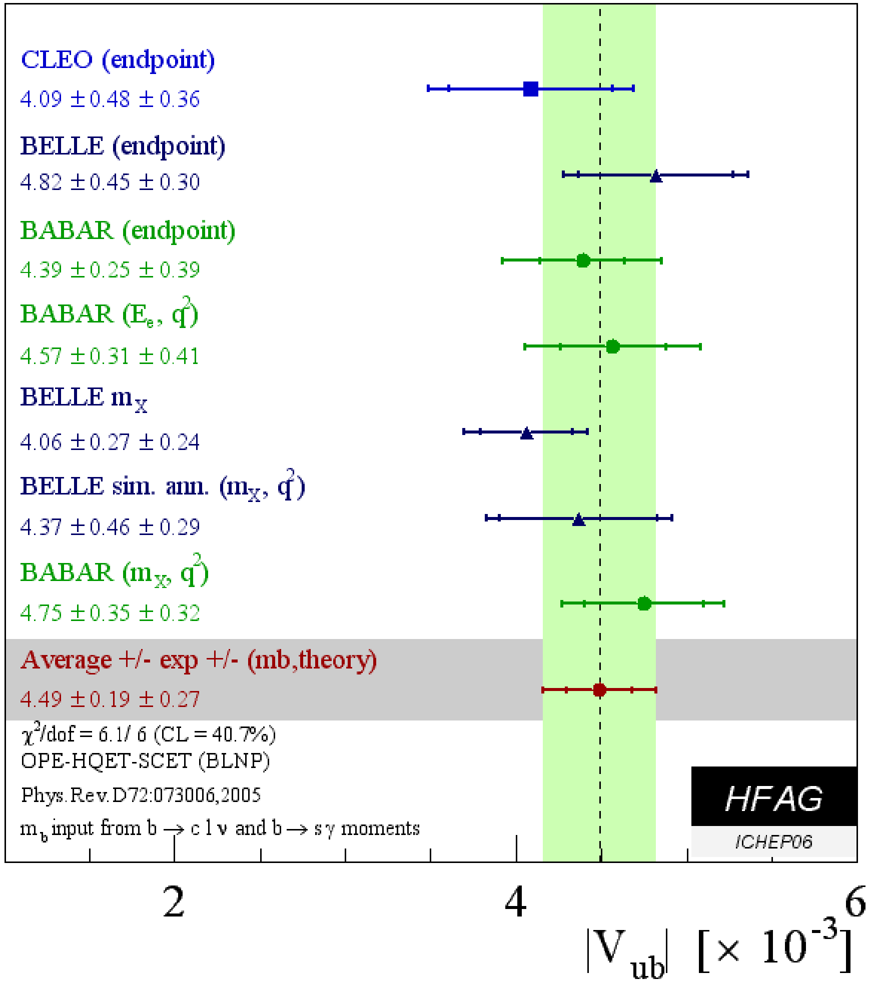


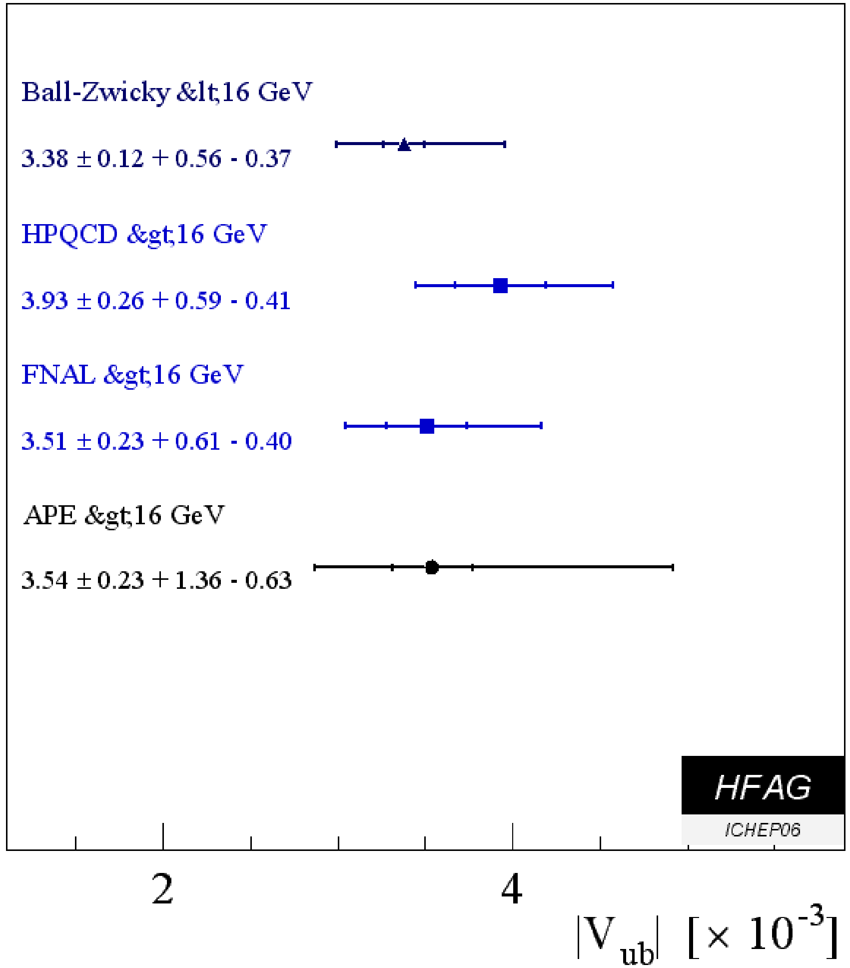
Additional amplitude contribution to charged modes => less reliable

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

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




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

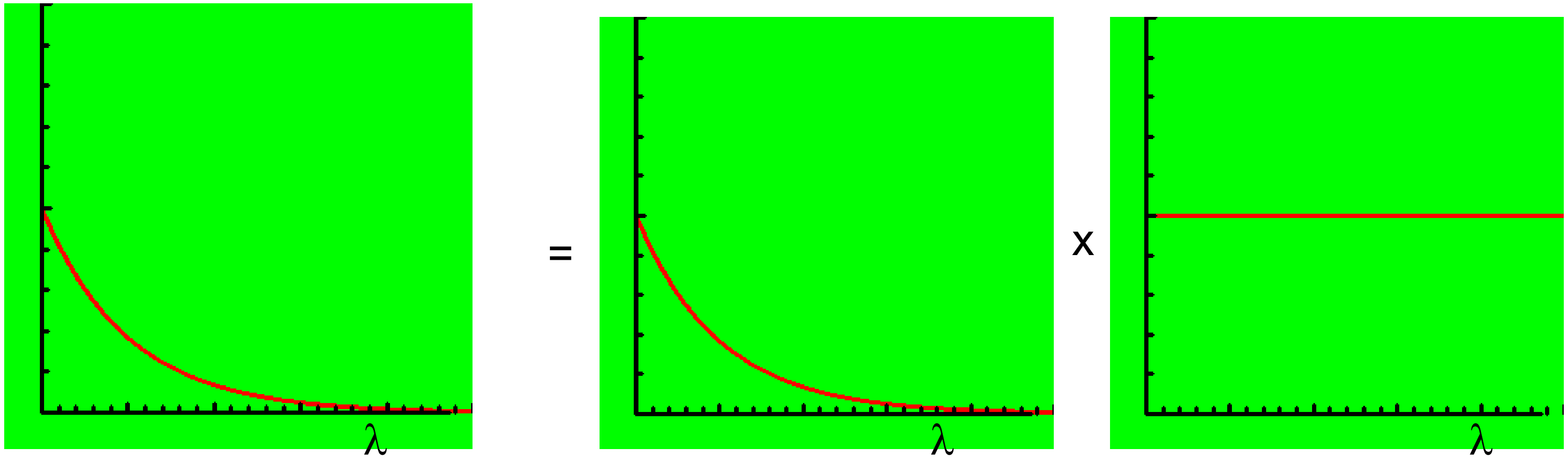
	$b \to s$	$b \to d$	$s \to d$
$\Delta F=2$ box	ΔM_{Bs} $A_{CP}(B_s \to \psi\phi)$	ΔM_{Bd} $A_{CP}(B_d \to \psi K)$	ΔM_K, ε_K
$\Delta F=1$ 4−quark box	$B_d \to \phi K$, $B_d \to K\pi$, ...	$B_d \to \pi\pi$, $B_d \to \rho\pi$, ...	ε'/ε, $K \to 3\pi$, ...
gluon penguin	$B_d \to X_s \gamma$, $B_d \to \phi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

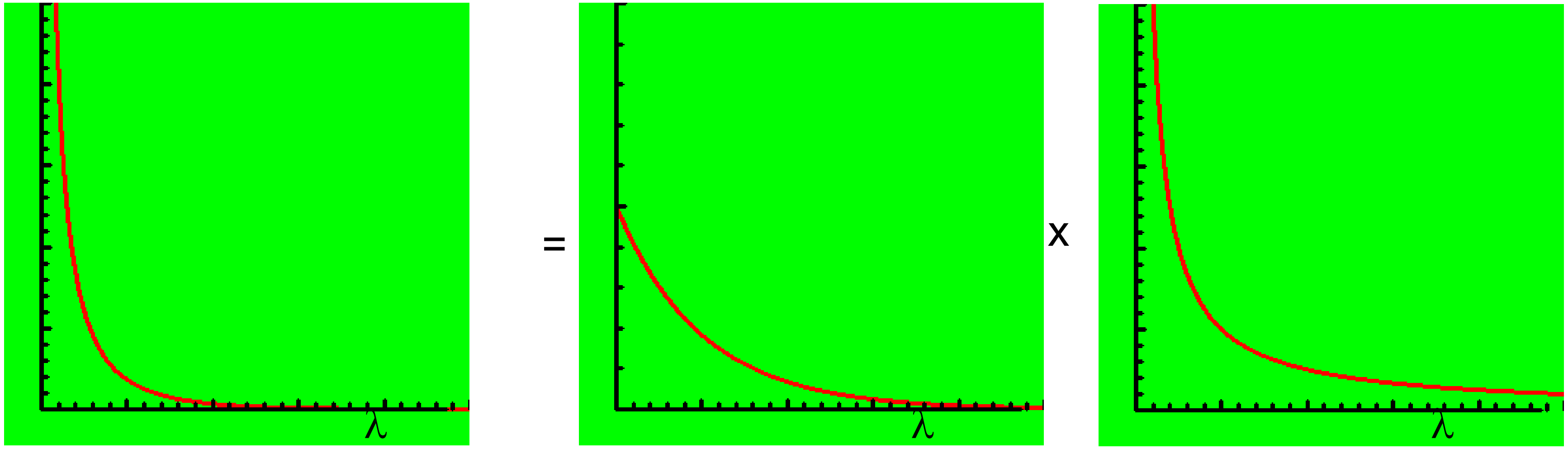
Prior: uniform

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

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!

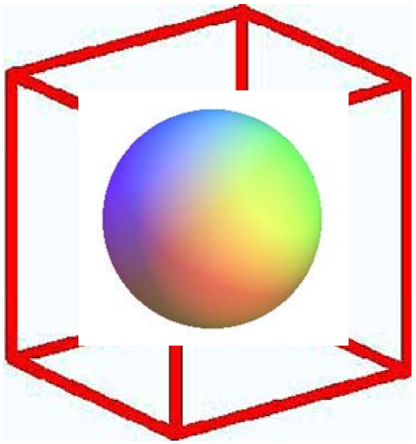
$$\int_0^3 P(\lambda)\, d\lambda >> 0.95$$

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.
- Beware snake-oil merchants in the physics community who will sell you Bayesian statistics (new – cool – easy – intuitive) and don't bother about robustness.

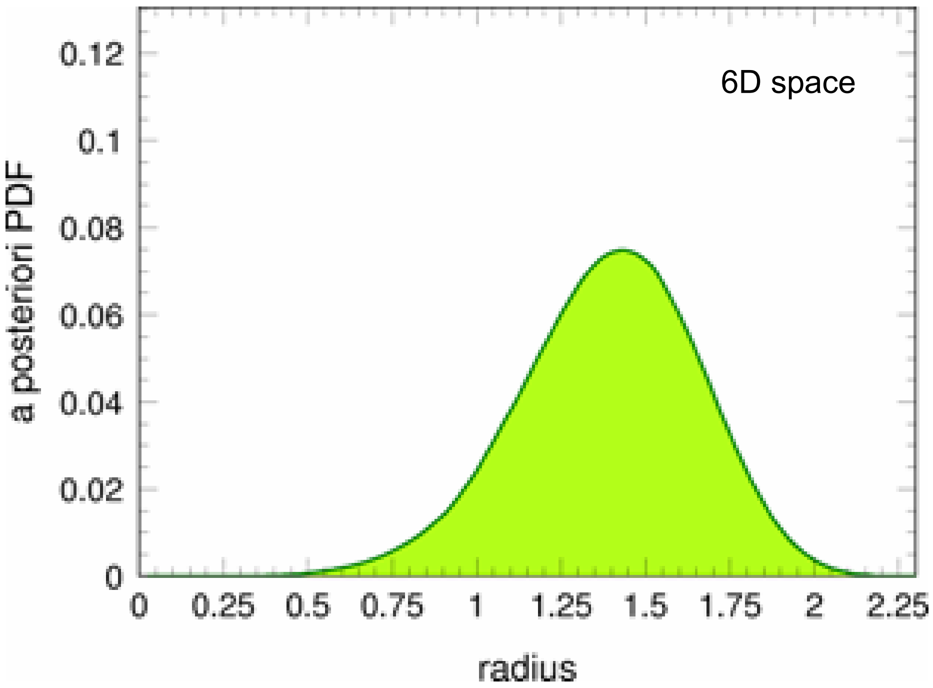
Digression: Statistics(cont.)

Hypersphere:



One knows nothing about the individual Cartesian coordinates x,y,z…

What do we known about the **radius** $r = \sqrt{(x^2+y^2+\ldots)}$ **?**



One has achieved the remarkable feat of learning something about the radius of the hypersphere, whereas one knew nothing about the Cartesian coordinates and without making any experiment.