Flavour Physics in the LHC Era

- CP violation in the Standard Model
- Measurements today (mainly B-factories)
- How to probe New Physics with Flavour Physics
- What will we learn at LHCb/LHC
- Conclusions

Conveners

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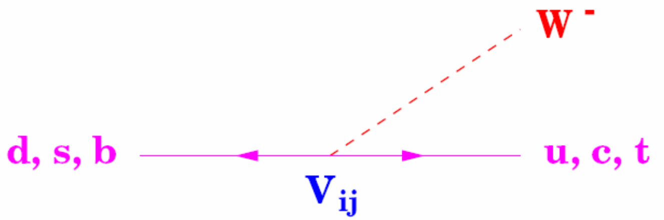
Flavour in the Era of the LHC

- Workshop Aims
  - outline and document a programme for flavour physics for the next decade
  - **addressing in particular the complementarity and synergy between the LHC and the flavour factories with respect to the discovery and exploration potential for new physics.**
- Workshop Format
  - 3 Working Groups (WG1, WG2 & WG3)
  - Opening meeting in Nov 2005 with plenary sessions and with the start of the WG activities
  - 2-3 meetings of the WG's to take place during the following year
  - Final plenary meeting at the end
  - Yellow Report

CP Violation in Standard Model

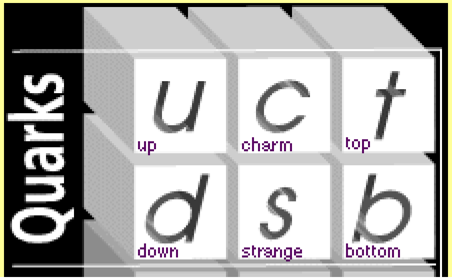
- 1973 Kobayashi & Maskawa introduced 3rd generation of quarks to explain CP violation in kaons – before discovery of b (and c) quark
- Couplings between different quark generations
- Weak and mass eigenstates of quarks not identical

Cabibbo-Kobayashi-Maskawa Mechanism



$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \mathrm{V_{CKM}} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

$$j^\mu = \begin{pmatrix} \bar{u} & \bar{c} & \bar{t} \end{pmatrix} \gamma^\mu (1-\gamma^5) \mathrm{V_{CKM}} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$



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

CKM Mechanism

- Properties of quark flavour changing CKM Matrix
  - Complex → $2n^2$ parameters for n generations
  - Unitary $V^\dagger V = 1$ → n^2 conditions, Phases → 2n-1 unobservable
  - # of independent parameters $2n^2 - n^2 - (2n-1) = (n-1)^2$
  - n = 3 generations → 3 Euler angles, 1 complex phase ⇒ $\not{CP}$

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + \partial V_{CKM}$$

$$\partial V_{CKM} = \begin{pmatrix} 0 & 0 & 0 \\ -iA^2\lambda^5\eta & 0 & 0 \\ A\lambda^5(\rho+i\eta)/2 & A\lambda^4(1/2-\rho-i\eta) & 0 \end{pmatrix}$$

Important in LHC era

- $\not{CP}$ in the Standard model ⇔ $\eta \neq 0$

CKM Unitarity Triangles

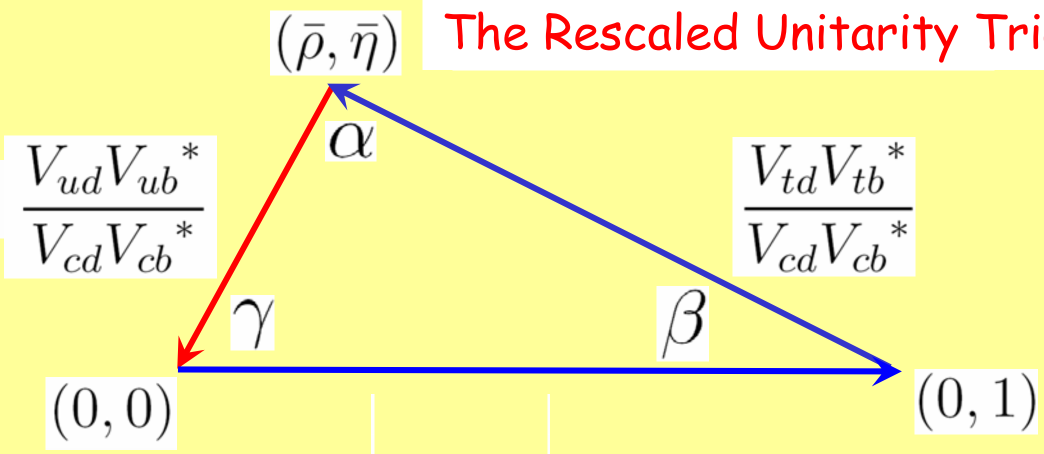
The CKM Matrix is complex and unitary

$$\begin{pmatrix} V_{ud}^* & V_{cd}^* & V_{td}^* \\ V_{us}^* & V_{cs}^* & V_{ts}^* \\ V_{ub}^* & V_{cb}^* & V_{tb}^* \end{pmatrix} \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

9 unitarity relations

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

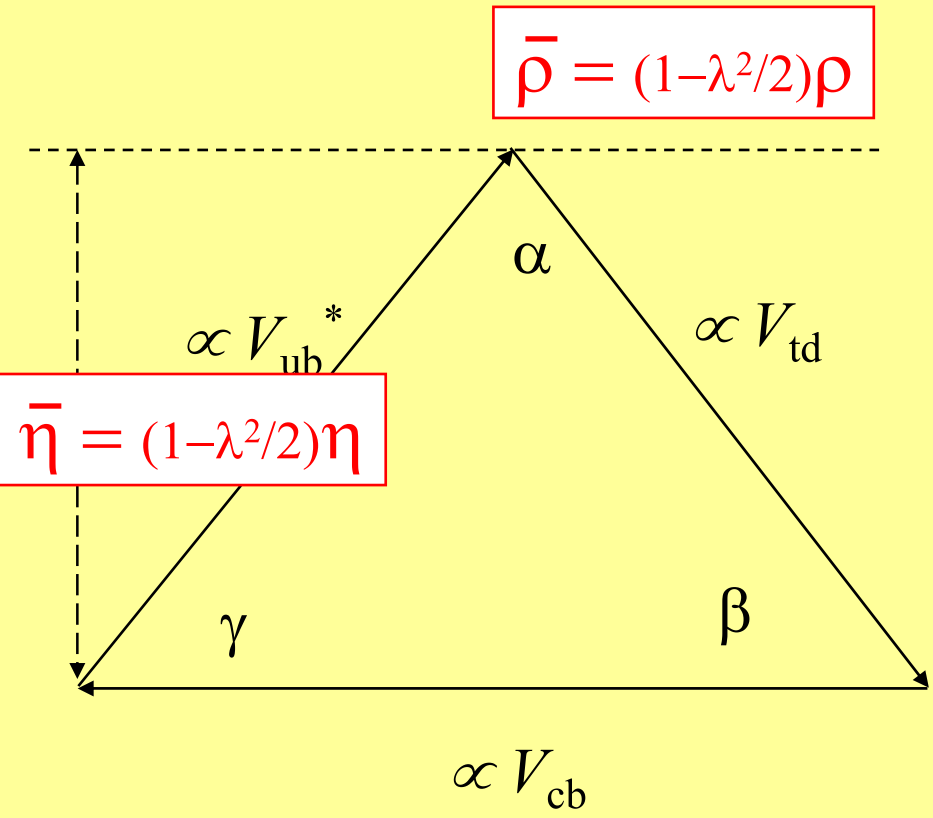
The Rescaled Unitarity Triangle (UT)

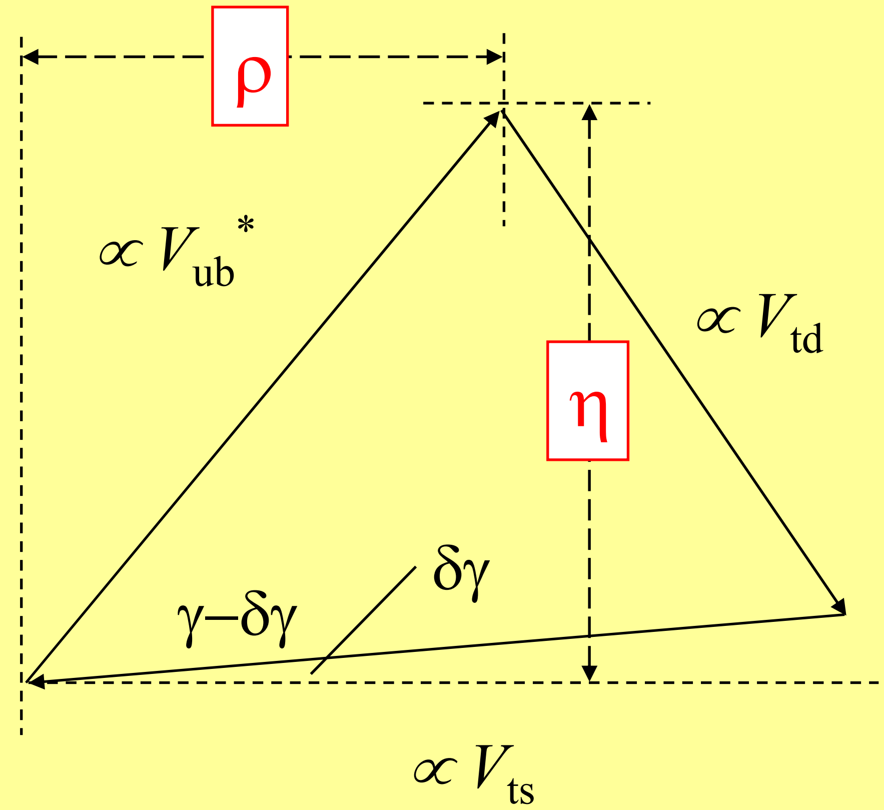


Experimentally measure lengths - CKM matrix elements – and angles - CPV asymmetries – Constrains apex of rescaled UT

CKM Unitarity Triangles

$$V_{td}V_{tb}^* + V_{cd}V_{cb}^* + V_{ud}V_{ub}^* = 0 \qquad V_{td}V_{ud}^* + V_{ts}V_{us}^* + V_{tb}V_{ub}^* = 0$$





$$\arg V_{cb} = 0,\ \arg V_{ub} = -\gamma,\ \arg V_{td} = -\beta,\ \arg V_{ts} = \pi + \delta\gamma$$

~~CP~~ in SM is small $\quad J_{CP} = \lambda^6 A^2 \eta = O\left(10^{-5}\right)$

$B \to X_u \ell \bar{\nu}$

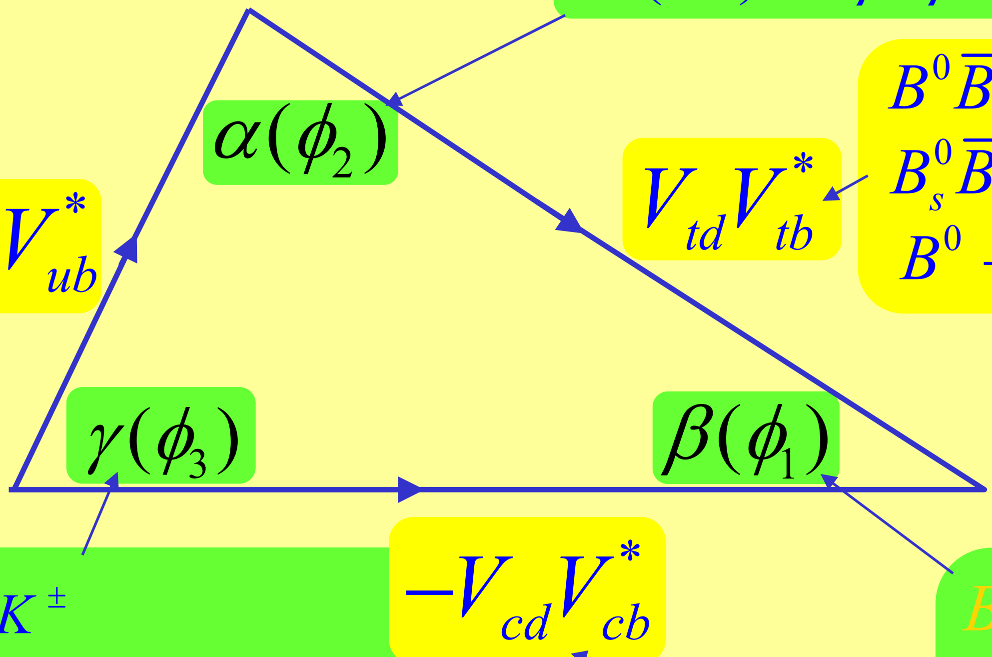
$B \to \pi \ell \bar{\nu}$

$B^0(\bar{B}^0) \to \rho^+\rho^-,\ \rho\pi,\ \pi^+\pi^-$

$B^0\bar{B}^0$ oscillation rate

$B_s^0\bar{B}_s^0$ oscillation rate

$B^0 \to \rho^0\gamma$



$B^\pm \to (\bar{D}^0/D^0)K^\pm$

$\to (\bar{D}^0/D^0)_{CP}K^\pm$ (GLW)

$\to K^+K^-\pi^\pm$ (ADS)

$\to (K_S^0\pi^+\pi^-)\ K^\pm$ (Dalitz plot)

$B \to X_c \ell \bar{\nu}$

$B \to D^* \ell \bar{\nu}$

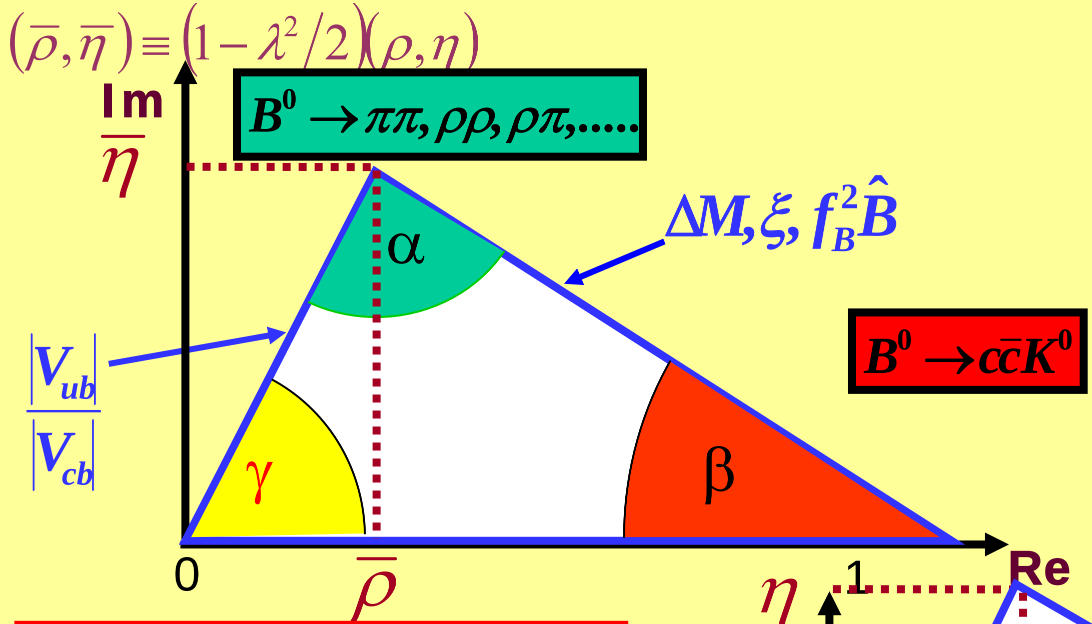
τ_B

$B^0(\bar{B}^0) \to (c\bar{c})K_S^0$

$B^0(\bar{B}^0) \to (s\bar{s})K_S^0$

$B^0(\bar{B}^0) \to (c\bar{c}d\bar{d})$

Unitarity Triangles



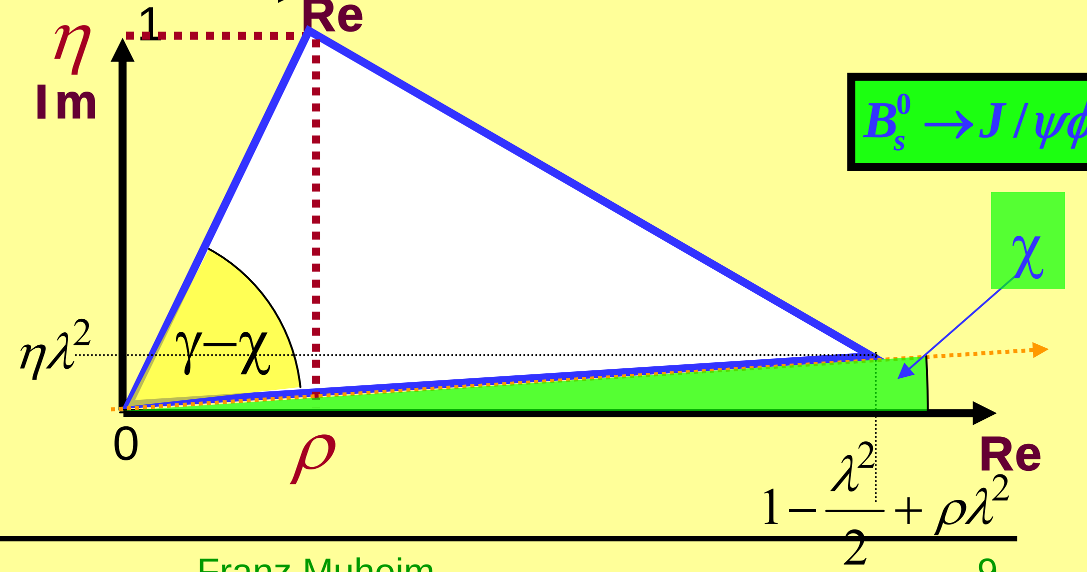
2β: B_d mixing phase
-2χ: B_s mixing phase
γ: weak decay phase

Wolfenstein: $V_{ub}=e^{-i\gamma}$

$B_d\to DK,DK^*$

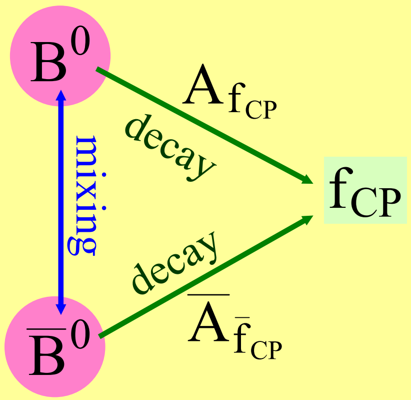
$B_s\to D_sK \quad (\gamma-2\chi)$

$B_d\to D^*\pi \quad (\gamma+2\beta)$



CP in Interference between Mixing and Decay

$$A_{f_{CP}}(t) = \frac{\Gamma\left(\bar{B}^0(t) \to f_{CP}\right) - \Gamma\left(B^0(t) \to f_{CP}\right)}{\Gamma\left(\bar{B}^0(t) \to f_{CP}\right) + \Gamma\left(B^0(t) \to f_{CP}\right)}$$



$$A_{f_{CP}}(t) = S \cdot \sin(\Delta m \cdot t) \text{ - } C \cdot \cos(\Delta m \cdot t)$$

$$S = \frac{2 \cdot \mathrm{Im}(\lambda)}{1 + |\lambda|^2} \qquad C = \frac{1 - |\lambda|^2}{1 + |\lambda|^2}$$

$$\lambda = \sqrt{\frac{M_{12}^* - \frac{i}{2}\Gamma_{12}^*}{M_{12} - \frac{i}{2}\Gamma_{12}}} \cdot \frac{\langle f_{CP} | H | \bar{B}^0 \rangle}{\langle f_{CP} | H | B^0 \rangle} = \frac{q}{p} \cdot \frac{\bar{A}_f}{A_f}$$

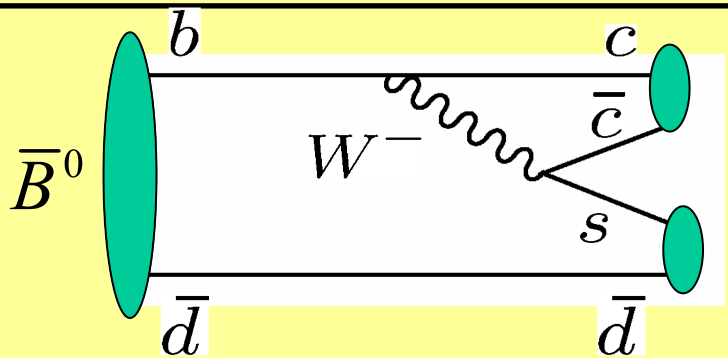
For a single decay amplitude: $|q/p|=1$

$$|\lambda| = 1 \quad \Rightarrow \quad S = \mathrm{Im}(\lambda), \;\; C = 0$$

$$A_{f_{CP}}(t) = \mathrm{Im}(\lambda) \cdot \sin(\Delta m \cdot t)$$

If there is New Physics it could be in the decay amplitude or the mixing amplitude

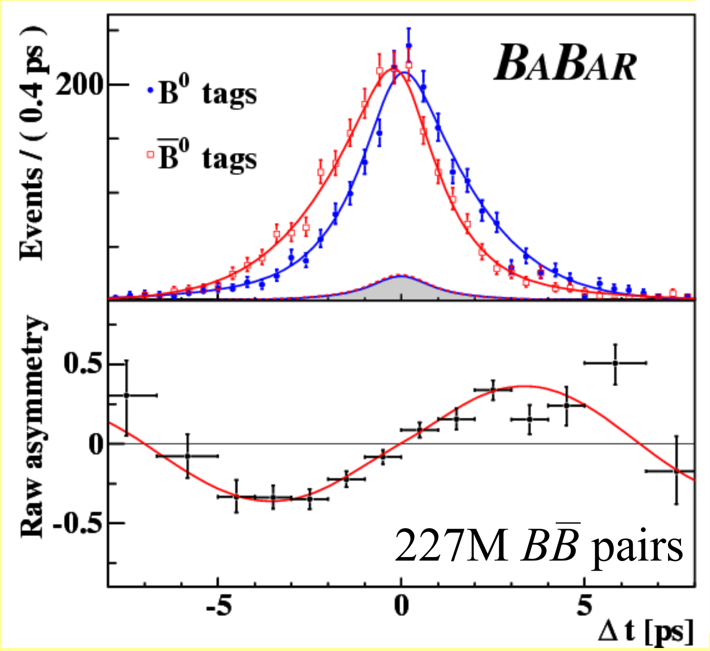
B_d Mixing Phase 2β

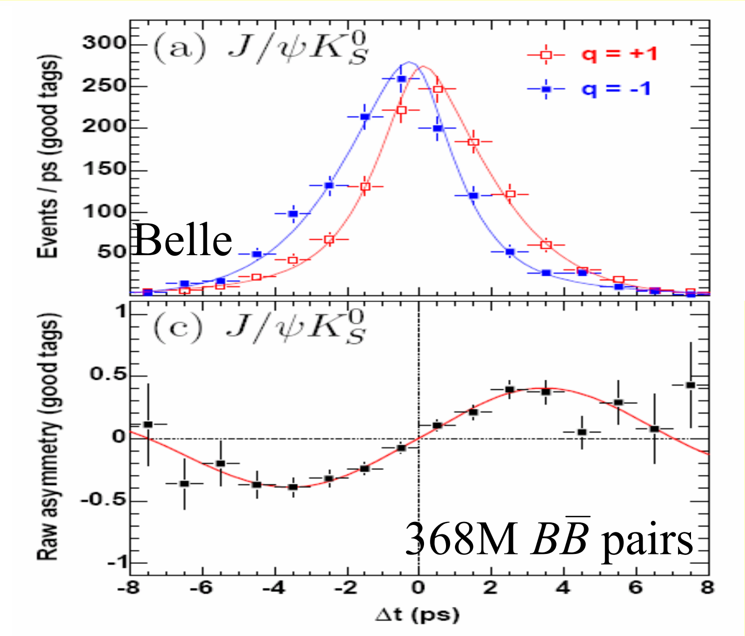


$J/y\ ,\ y\,(2S),\ c_{c1},\ h_c$

$\bar{K}^0 \to K_S^0, K_L^0$

$\bar{K}^{*0} \to K_S^0 \pi^0$



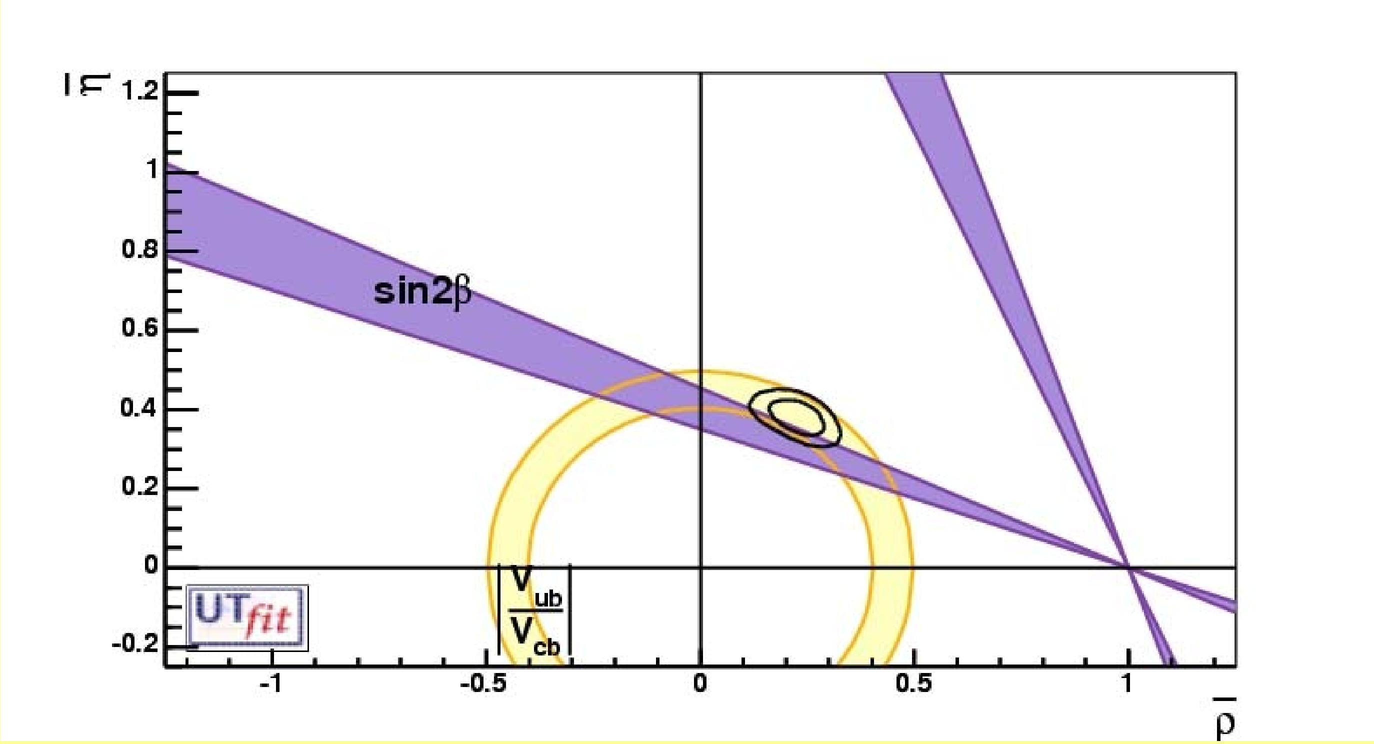


$\sin 2\beta = +0.722 \pm 0.040 \pm 0.023$

$\sin 2\phi_1 = +0.652 \pm 0.039 \pm 0.020$

SM test - sin2β vs Vub

Stocchi



sin2β=0.687±0.032
From direct measurement

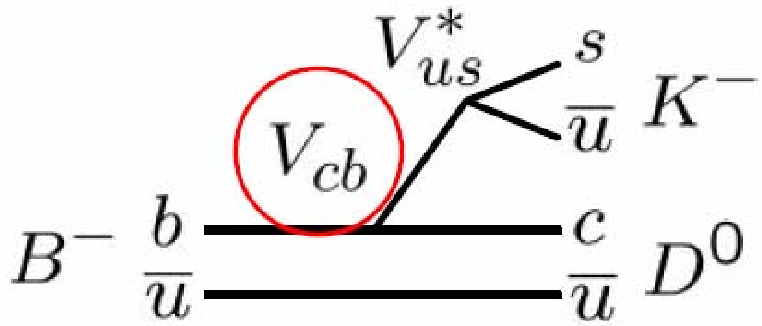
weak disagreement

sin2β =0.791±0.034
from indirect determination

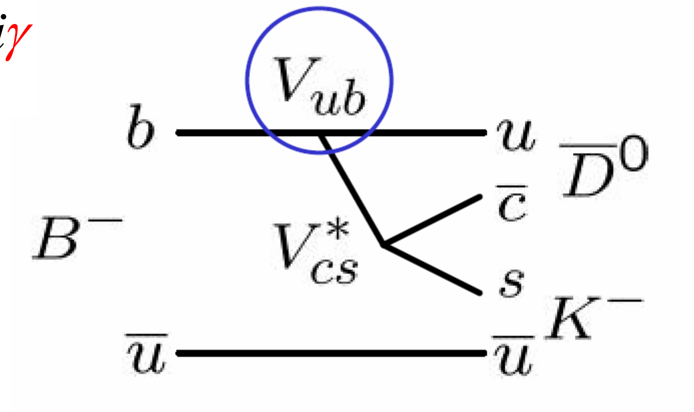
$$\left|V_{ub}\right|_{\mathrm{WAvg}} = (4.38 \pm 0.19_{\mathrm{expt}} \pm 0.27_{m_b,\ \mathrm{theory}}) \times 10^{-3}$$

γ from direct CP violation

Cavoto



$$e^{i\delta_B} e^{-i\gamma}$$



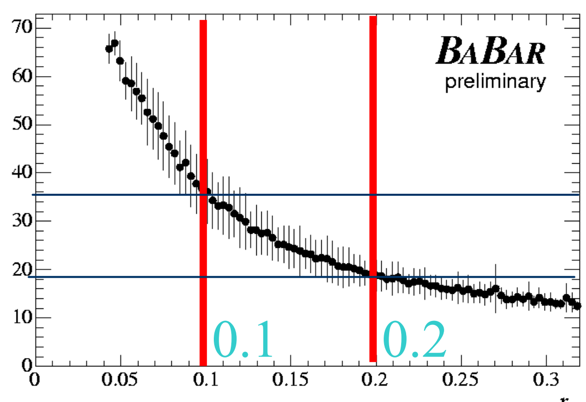
Interference when D final state common to both D^0 and $\bar{D}^0$

Relative size (r_B) of B decay amplitudes

$$r_B = \left| \frac{A(b \to u)}{A(b \to c)} \right|$$

$\sigma(\gamma)$

(degrees)

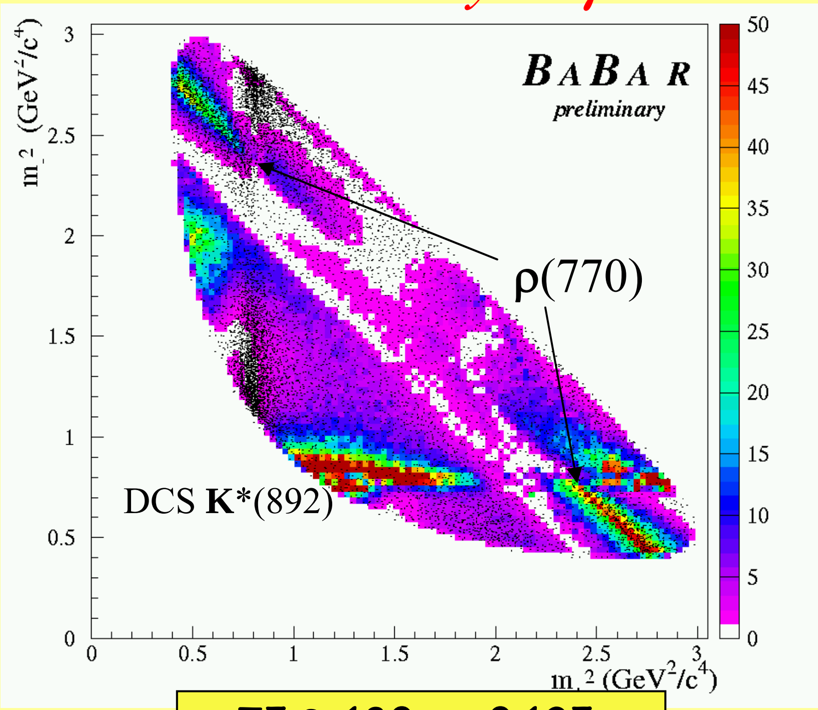


r_B

Larger r_B, larger interference, **better** γ experimental precision

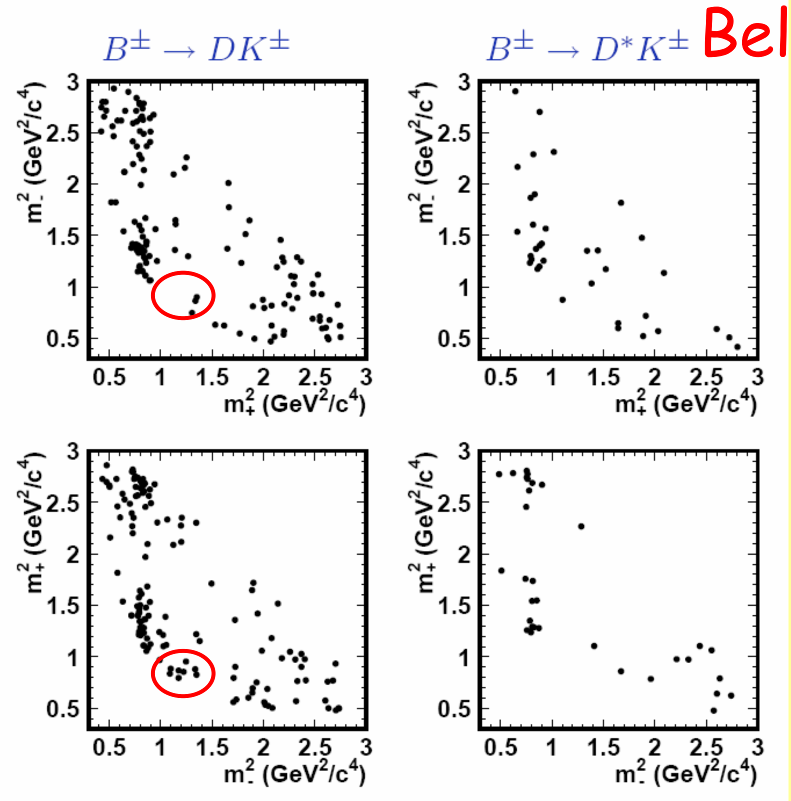
γ from B->DK Dalitz analysis

Sensitivity to γ



γ=75,δ=180,r_B=0.125

Belle

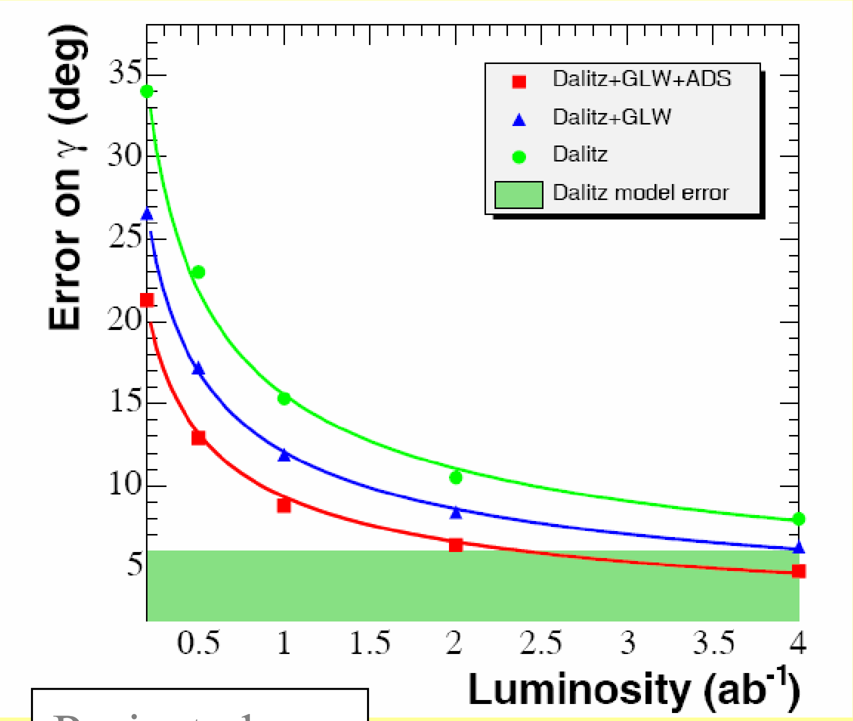


BaBar $\gamma = [67° \pm 28°$ *(stat.)* $\pm 13°$ *(syst. exp.)* $\pm 11°$ ***(Dalitz model*)*** $]$

Belle $\phi_3 = 68°\,^{+14°}_{-15°}\,(\text{stat}) \pm 13°(\text{syst}) \pm 11°(\text{model})$

Cavoto
Gershon

Projected γ Precision from B->DK



Projected sys error due to D^0 Dalitz plot

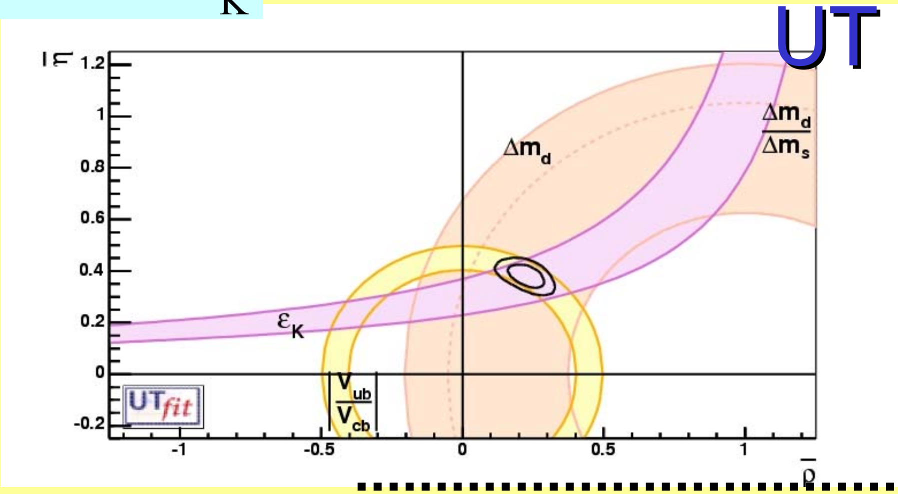
Candidate for LHCb's statistically most precise determination of γ

$\sigma(\gamma) \sim 5^\circ$ in one year ?

To be studied during this workshop …

UT Fit

Sides + ε_K

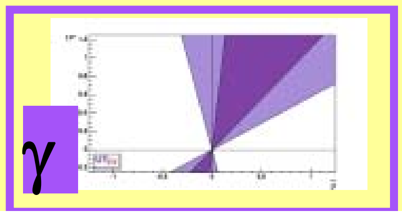


$\rho = 0.224 \pm 0.042$
[0.136, 0.306] @ 95% Prob.

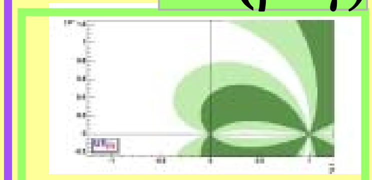
$\eta = 0.381 \pm 0.030$
[0.,320, 0.437] @ 95% Prob.

UT with angles only

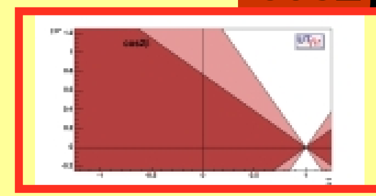
γ



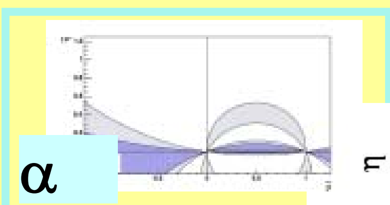
$\sin(\beta+\gamma)$

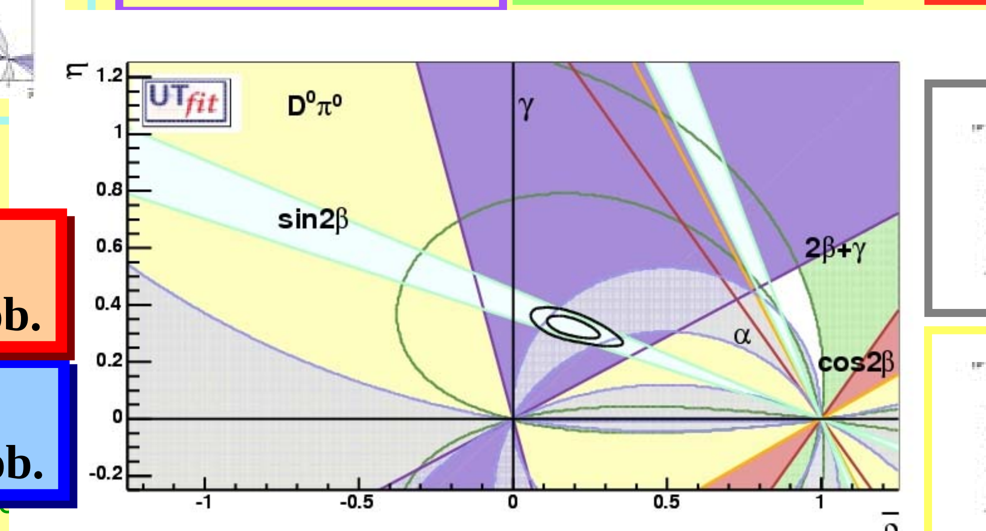


$\cos 2\beta$

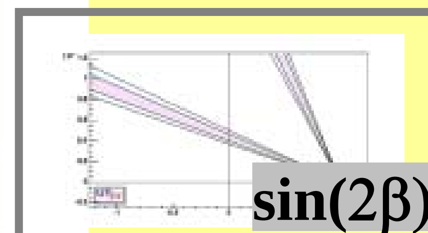


α

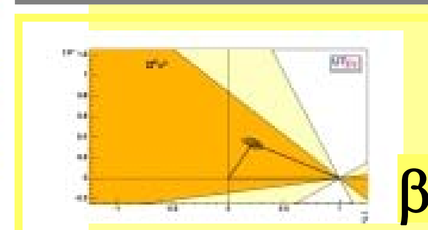




$\sin(2\beta)$



β



$\rho = 0.193 \pm 0.057$
[0.083, 0.321] @ 95% Prob.

$\eta = 0.321 \pm 0.027$
[0.266, 0.376] @ 95% Prob.

CKM mechanism dominates

Nir

$$S_{\psi K} = +0.69 \pm 0.03 \ \Leftrightarrow \ \sin 2\beta(\text{CKM fit}) = +0.74^{+0.07}_{-0.03}$$

The KM mechanism successfully passed its first precision test

$$\alpha(\pi\pi, \pi\rho, \rho\rho) = \left[101^{+16}_{-9}\right]^o \ \Leftrightarrow \ \alpha(\text{CKM fit}) = 96 \pm 16^o$$

The KM mechanism successfully passed its second precision test

$$\gamma(DK) = \left[63^{+15}_{-13}\right]^o \ \Leftrightarrow \ \gamma(\text{CKM fit}) = \left[57^{+7}_{-14}\right]^o$$

The KM mechanism successfully passed its third precision test

We are very likely beyond the era of « alternatives» to the CKM picture.
NP would appear as «corrections» to the CKM picture

Is there still room for new physics ?

NP in B_d-$\overline{B}_d$ mixing (I)

Robert

- Assumption ⇔ no NP in tree-mediated decay amplitudes:
  - |Vub|/|Vcb| and γ are the main inputs constraining the CKM
- Introduce NP in ΔB=2 transitions
  - accounted for model-independently through two additional parameters

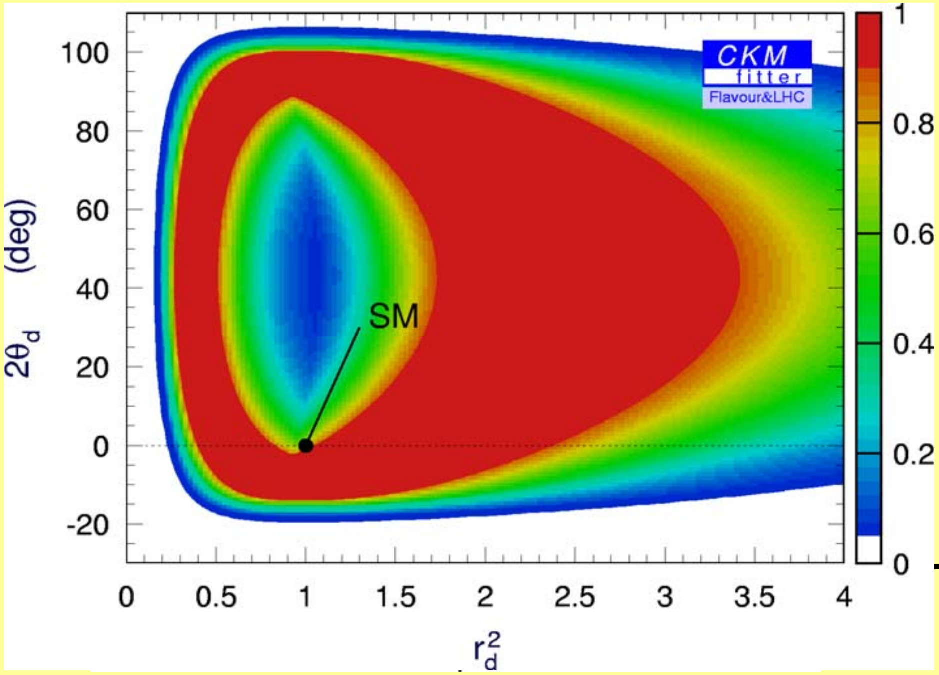
$$r_d^2 e^{i2\theta_d} = \frac{\langle B^0 | H_{eff}^{full} | \overline{B}^0 \rangle}{\langle B^0 | H_{eff}^{SM} | \overline{B}^0 \rangle}$$

$$\rightarrow |V_{ub}|, |V_{cb}|$$

$$\rightarrow r_d^2 \Delta m_d$$

$$\rightarrow \sin(2\beta + 2\theta_d)$$

$$\rightarrow \cos(2\beta + 2\theta_d)$$



- The SM value on $2\theta_d$=0 is at the border of the CL_{Max} region.
- Shows slight disagreement between V_{ub} and sin(2β).
- Any region with $2\theta_d > \pi/2$ and $r_d^2 > 3$ is discarded.

NP in B_d-$\bar{B}_d$ mixing (II)

⇔ Adding γ measurements.

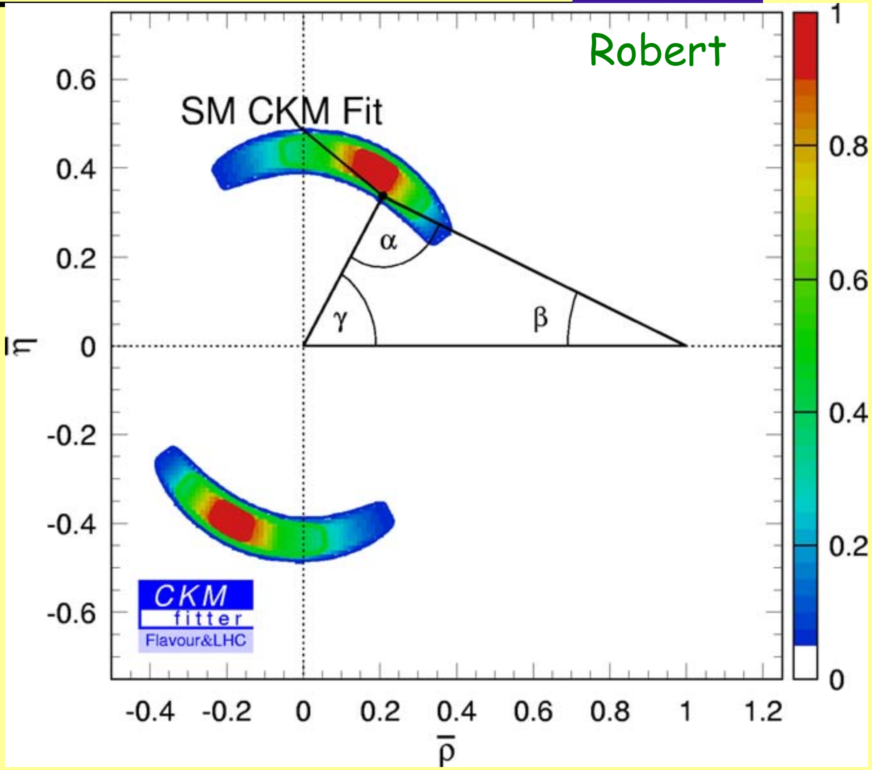
$\rightarrow |V_{ub}|/|V_{cb}|$

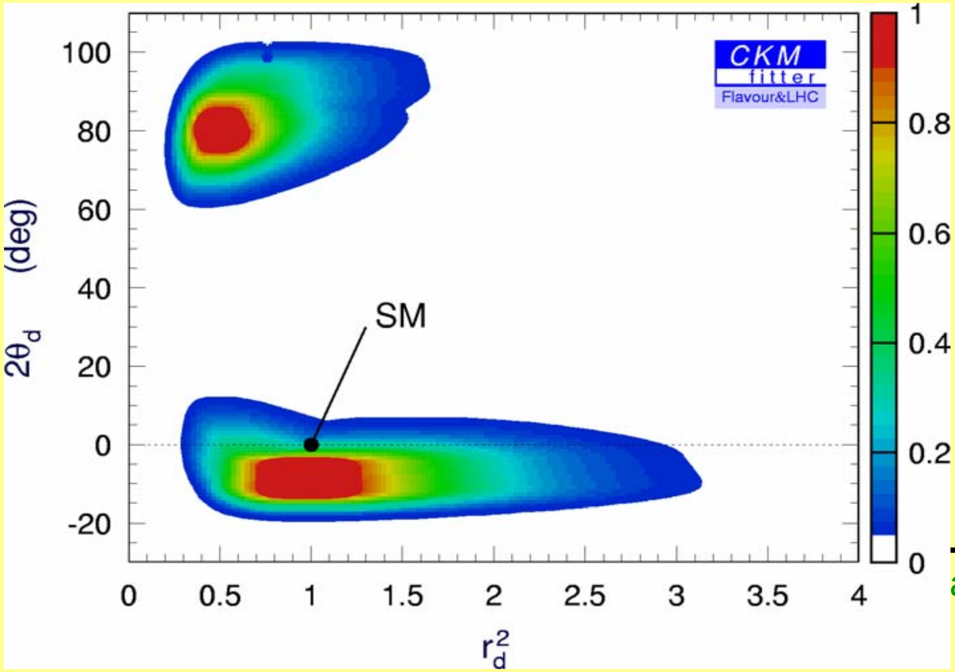
$\rightarrow r_d^2 \Delta m_d$

$\rightarrow \sin(2\beta + 2\theta_d)$

$\rightarrow \cos(2\beta + 2\theta_d)$

$\rightarrow \gamma \quad (ADS + GLW + GGSZ)$





- V_{ub} and γ constrain the CKM parameters.
- Two solutions for NP parameters emerge.

NP in B_d-$\overline{B}_d$ mixing (III)

⇔ Adding α measurements.

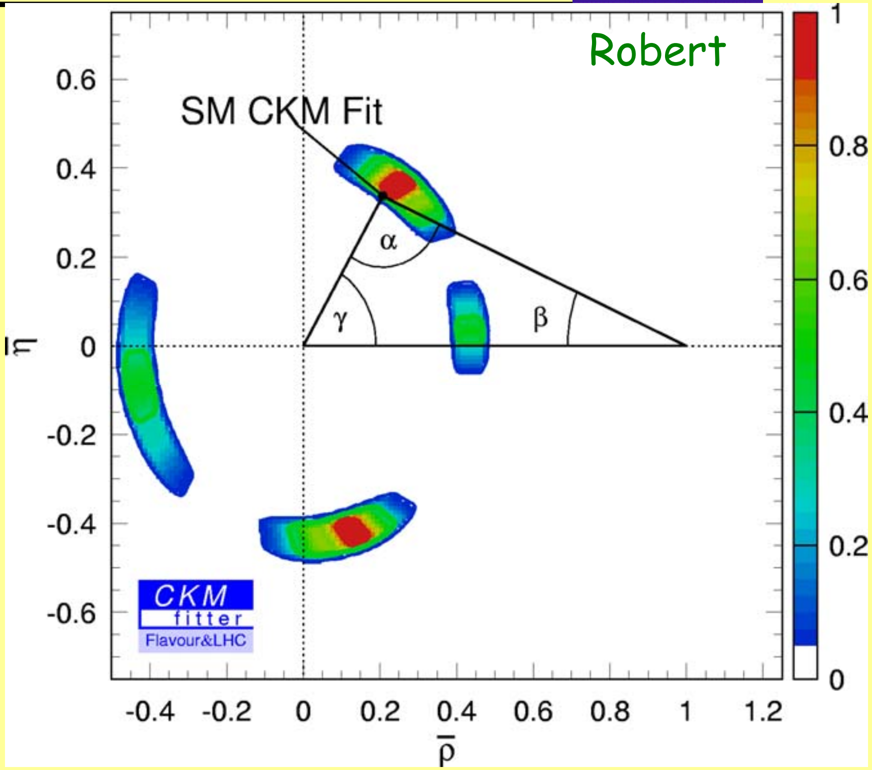
$\rightarrow |V_{ub}|/|V_{cb}|$

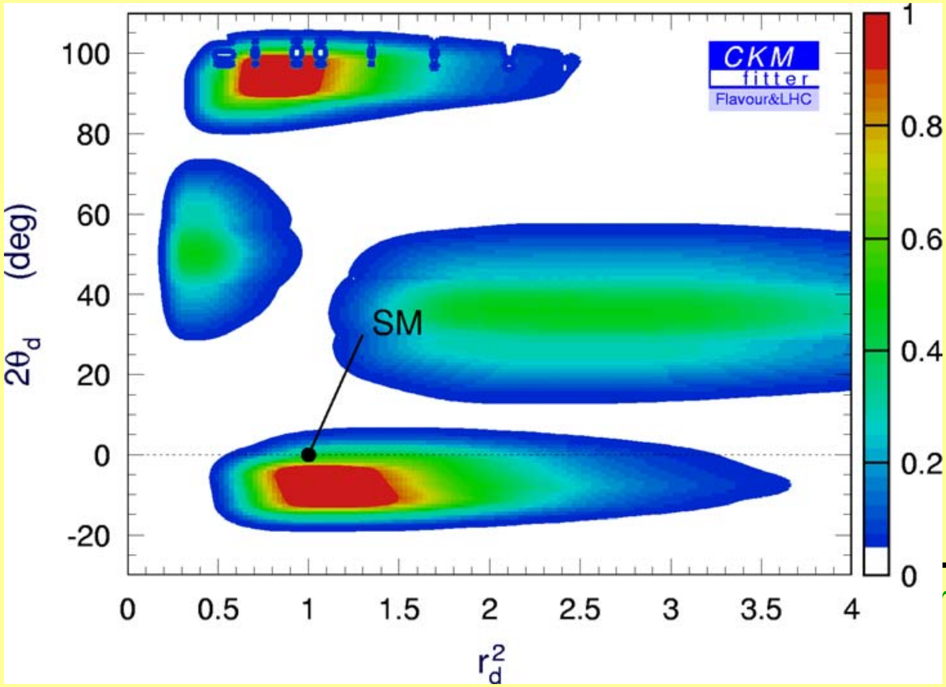
$\rightarrow r_d^2 \Delta m_d$

$\rightarrow \sin(2\beta + 2\theta_d)$

$\rightarrow \cos(2\beta + 2\theta_d)$

$\rightarrow \sin(2\beta + 2\theta_d + 2\gamma)$





The α constraint (w/o γ) displays also four solutions.

⇔ Reinforce the SM region but the preferred NP region is not the one defined by γ.

NP in B_d-$\overline{B}_d$ mixing (IV)

$\rightarrow |V_{ub}|/|V_{cb}|$

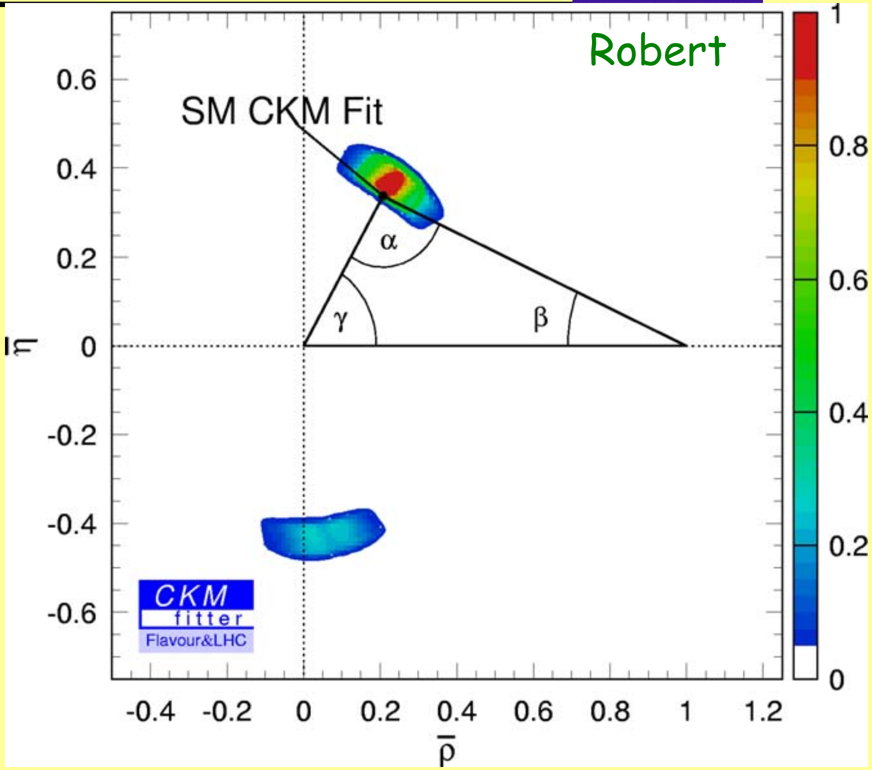
$\rightarrow r_d^2 \Delta m_d$

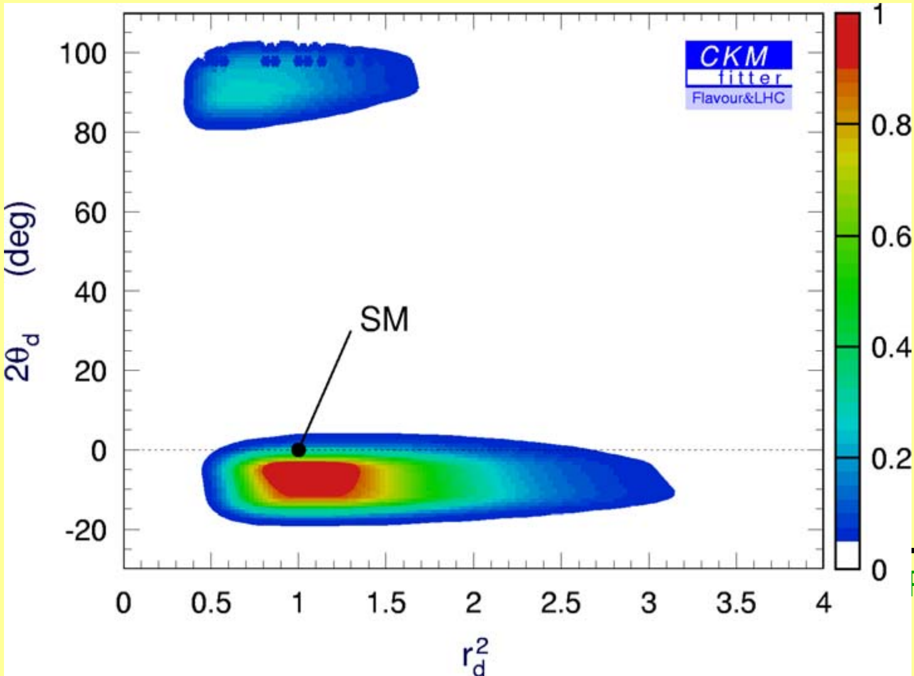
$\rightarrow \sin(2\beta + 2\theta_d)$

$\rightarrow \cos(2\beta + 2\theta_d)$

$\rightarrow \gamma \quad (ADS + GLW + GGSZ)$

$\rightarrow \sin(2\beta + 2\theta_d + 2\gamma)$





γ and α are of major importance in constraining the NP parameters.

NB: $\sin(2\beta+2\theta_d+\gamma)$ is not included. (almost no influence.)

NP in B_d-$\bar{B}_d$ mixing a_{SL} in the game

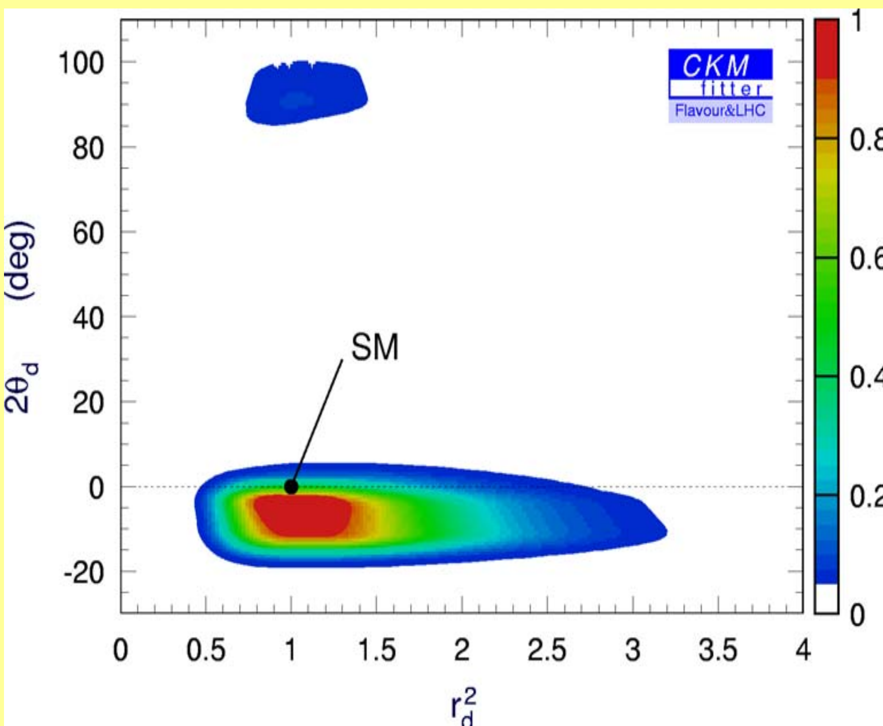
Robert

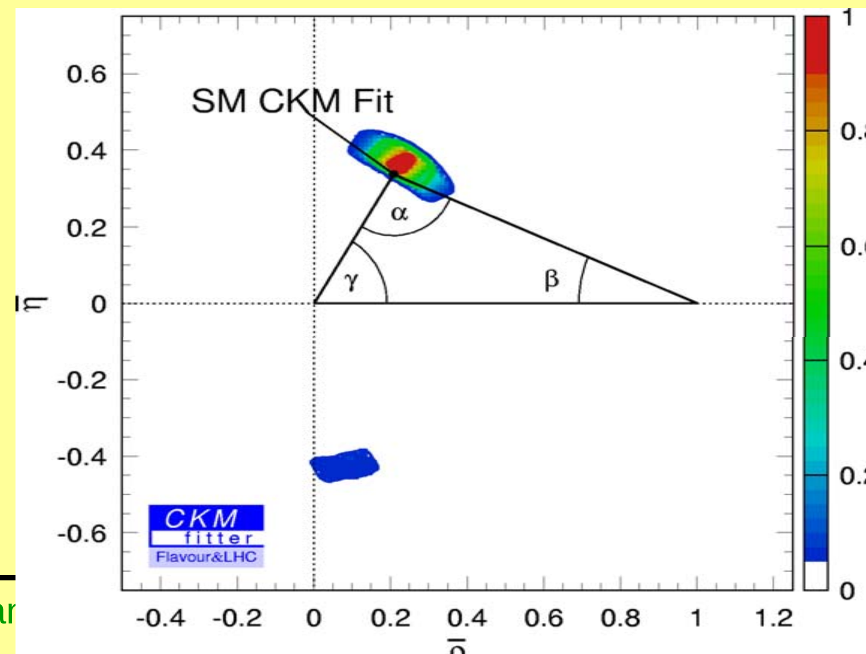
$$a_{SL} = -\mathrm{Re}\left(\frac{\Gamma_{12}}{M_{12}}\right)^{SM} \frac{\sin 2\theta_d}{r_d^2} + \mathrm{Im}\left(\frac{\Gamma_{12}}{M_{12}}\right)^{SM} \frac{\cos 2\theta_d}{r_d^2}$$

(Γ_{12}/M_{12} is considered here at Leading Order)

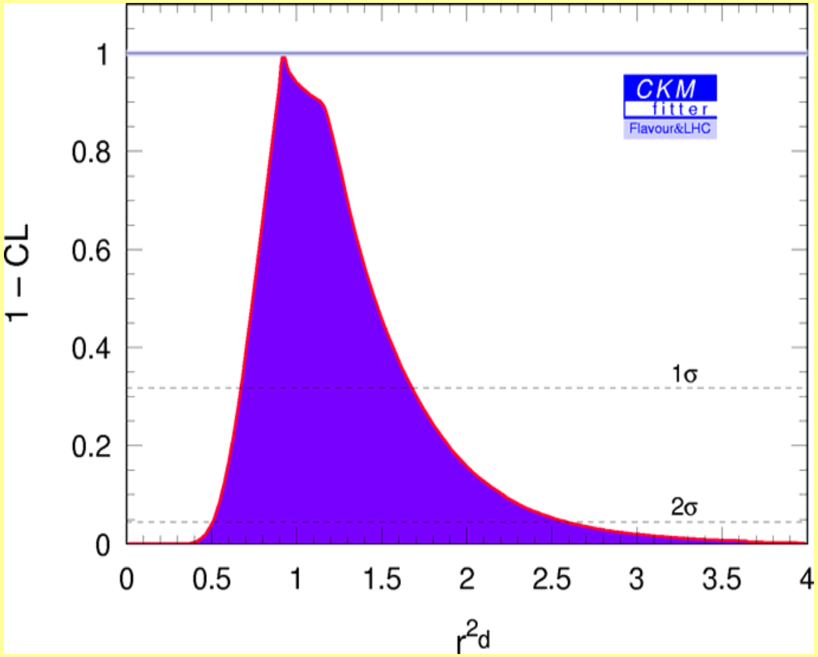
Though the experimental precision is far from the prediction, a_{SL} is a crucial input for constraining NP parameters. Only observable depending on both r_d^2 and $2\theta_d$.

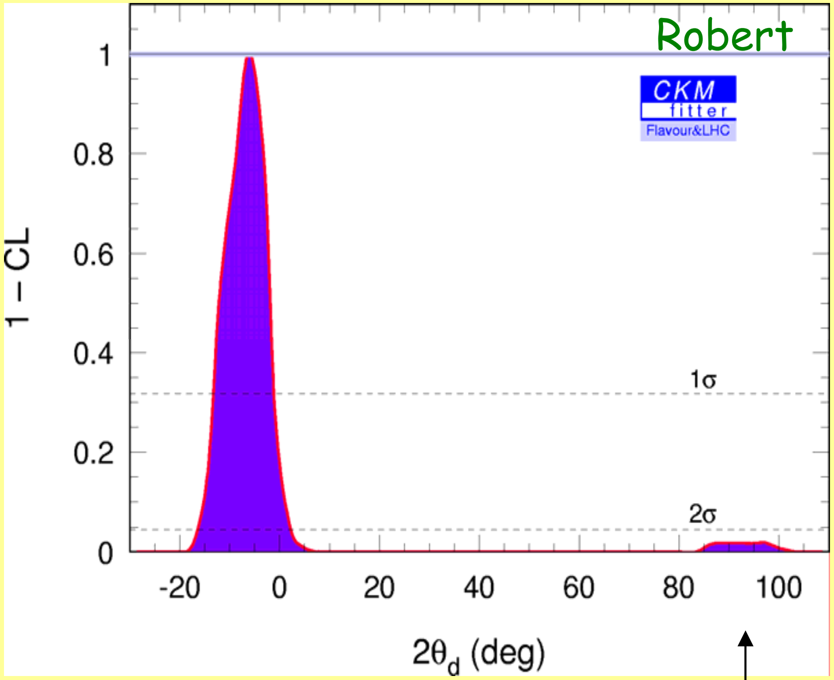
a_{SL}= -0.0026 ± 0.0067 (HFAG 2005)





NP parameters extraction





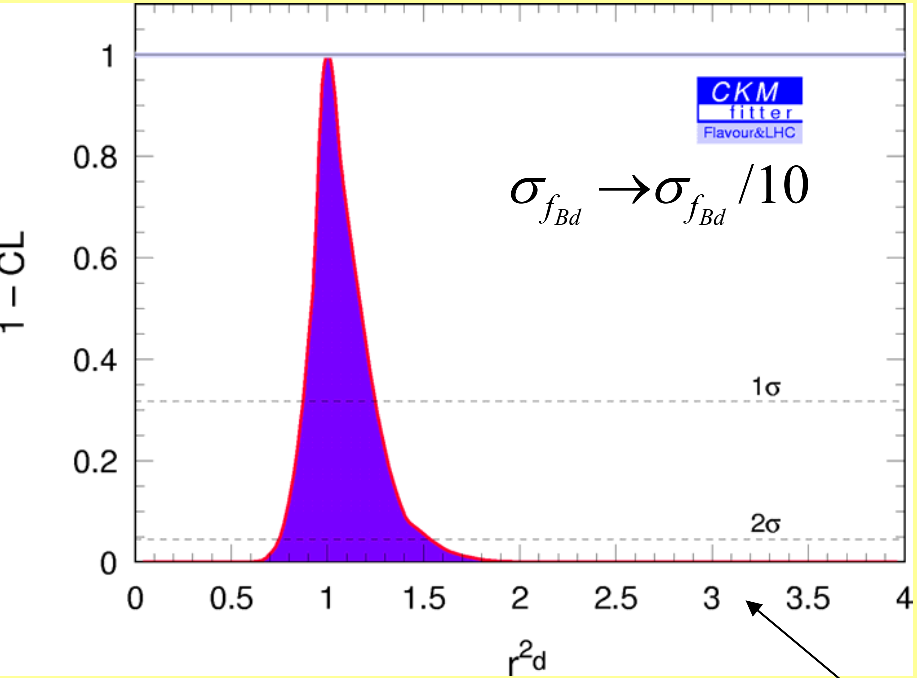
- $\rightarrow |V_{ub}|/|V_{cb}|$
- $\rightarrow r_d^2 \Delta m_d$
- $\rightarrow \sin(2\beta + 2\theta_d)$
- $\rightarrow \cos(2\beta + 2\theta_d)$
- $\rightarrow \gamma \quad (ADS + GLW + GGSZ)$
- $\rightarrow \alpha \quad \sin(2\beta + 2\theta_d + 2\gamma)$
- $\rightarrow a_{SL}$

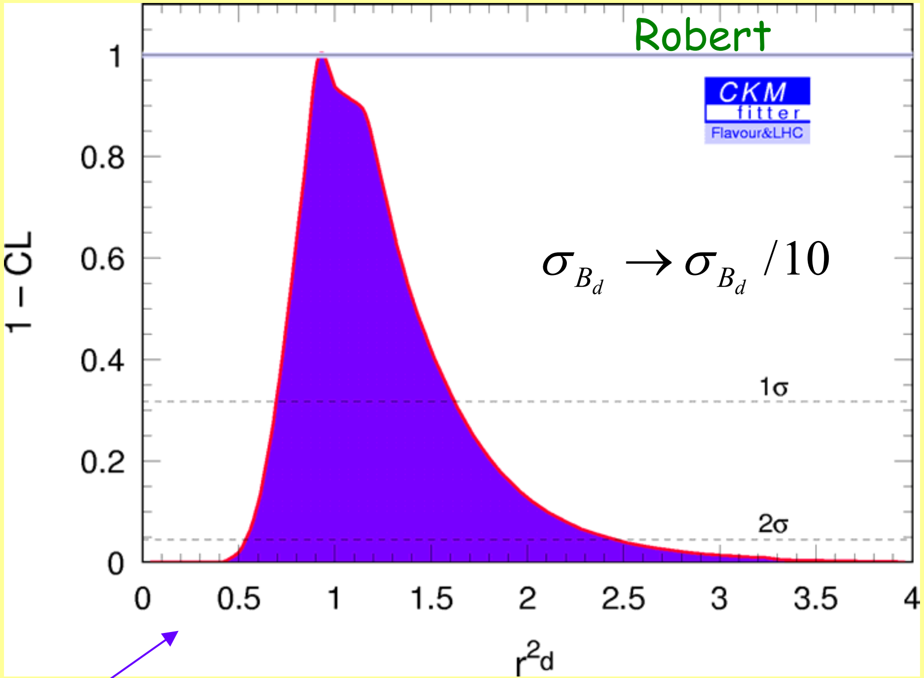
$$\begin{cases} r_d^2 = 0.92^{+0.73}_{-0.23} \\ 2\theta_d = -5.3^{+3.2}_{-8.8} \ \text{deg} \end{cases}$$

(Uncertainties are given at 1σ)

The NP solution at π/2 has 1-CL < 3%.

Influence of non-pert. hadronic parameters in Δm_d





$$\Delta m_d = \frac{G_F^2}{6\pi^2}\eta_B m_{B_d} f_{B_d}^2 B_d m_W^2 S(x_t)\left|V_{td}V_{tb}^*\right| r_d^2$$

- As far as the lattice uncertainties are considered, fB_d is the relevant parameter to improve.
- A factor 2 has important impact. A factor 10 is not decisive with the current experimental uncertainties of the observables.

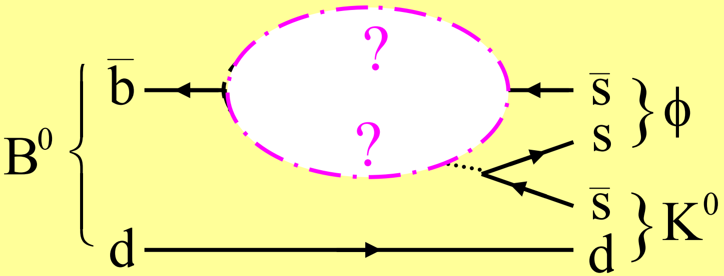
Motivation for continuing

- SM cannot be the ultimate theory
  - must be a low-energy effective theory of a more fundamental theory at a higher energy scale, expected to be in the TeV region (accessible at LHC !)
- How can New Physics (NP) be discovered and studied ?
  - NP models introduce new particles, dynamics and/or symmetries at the higher scale. These new particles could
    - be produced and discovered as real particles at energy frontier (LHC)
    - appear as virtual particles in loop processes, leading to observable deviations from the pure SM expectations in flavour physics and CP violation

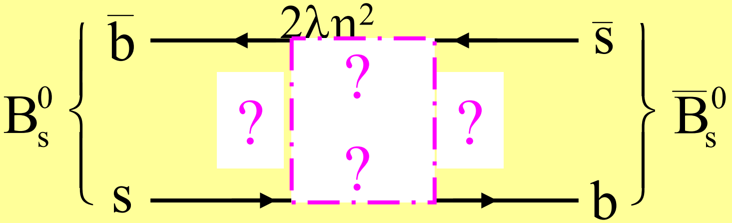
New Physics

$\Delta m_s \neq \Delta m_s^{SM} \propto |V_{ts}^2|$,

$\phi_s \neq \phi_s^{SM} = -\arg(V_{ts}^2) = -2\lambda\eta^2$



$B^0 \to \phi K^0$ decay: "Penguin" diagram



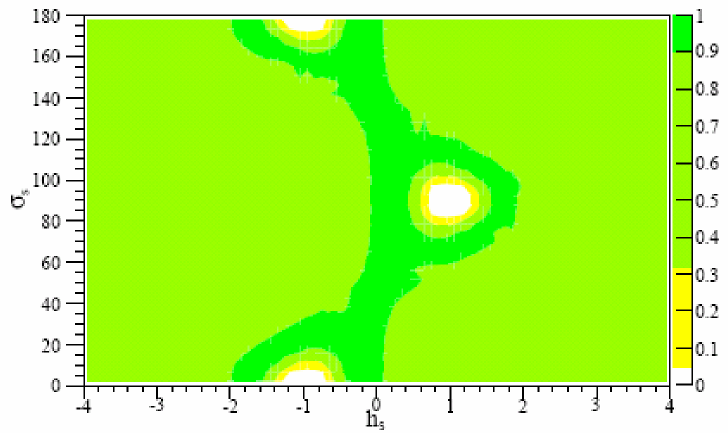
$\bar{B}_s$–B_s oscillations: "Box" diagram

New Physics in B_s Mixing

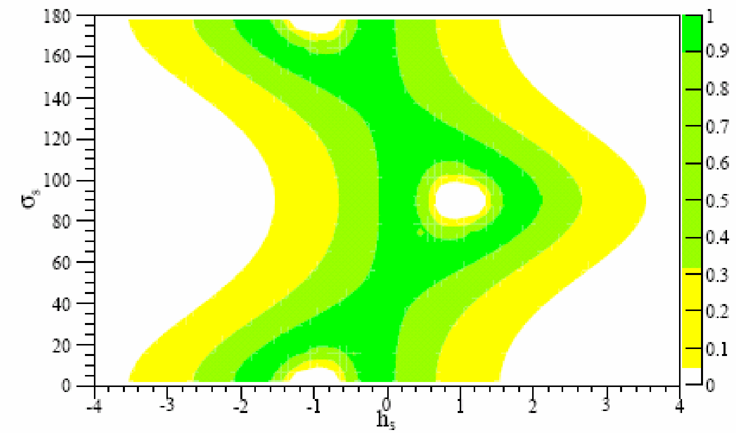
- Alternative NP parameterisation

$$
\begin{aligned}
\Delta m_d &= \left|1 + h_d e^{2i\sigma_d}\right| \Delta m_d^{\rm SM} \,, \\
S_{\psi K} &= \sin\left[2\beta + \arg\left(1 + h_d e^{2i\sigma_d}\right)\right] \,, \\
\Delta m_s &= \left|1 + h_s e^{2i\sigma_s}\right| \Delta m_s^{\rm SM} , \\
S_{\psi\phi} &= \sin\left[2\beta_s + \arg\left(1 + h_s e^{2i\sigma_s}\right)\right] \,, \\
A_{\rm SL} &= Im\left[\frac{\Gamma_{12}^d}{M_{12}^d\left(1 + h_d e^{2i\sigma_d}\right)}\right] \,,, \\
M_{12}^{\rm K} &\propto \left[\lambda_t^{*2}\eta_2 S_0\left(1 + h_K e^{2i\sigma_K}\right) + \ldots\right]
\end{aligned}
$$

Is there New Physics in $B_s^0 \overline{B}_s^0$ mixing?



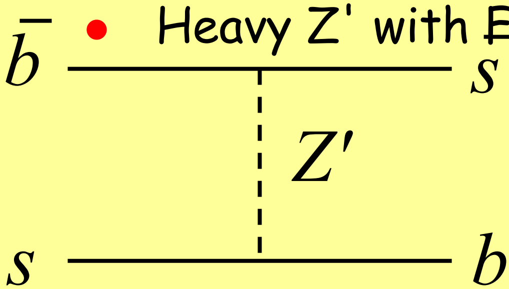
Current



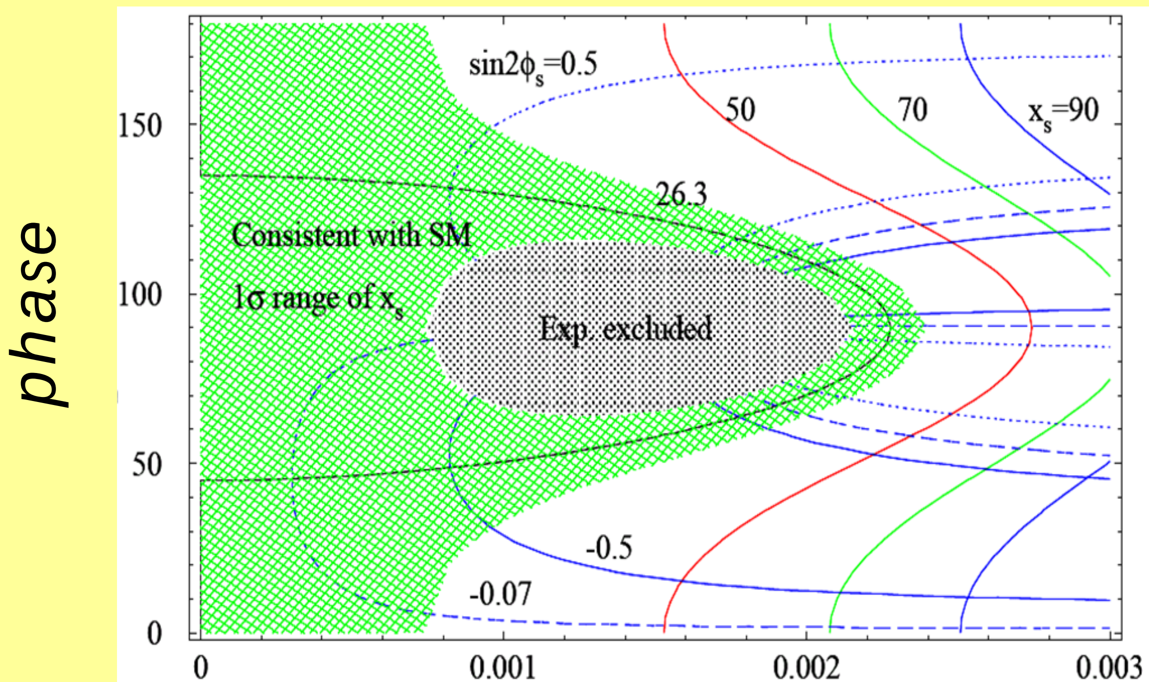
If $Dm_s = (18.3 \pm 0.3)\text{ps}^{-1}$

Agashe, Papucci, Perez, Pirjol

- Heavy Z' with FCNC.



Barger, Chiang, Jiang, Langacker Phys.Lett.B596:229-239,2004



$$magnitude \propto \left| \frac{m_Z}{m_{Z'}} B_{sb}^{LL} \right|$$

LHCb (BTEV) or why yet another B-Physics Experiment?

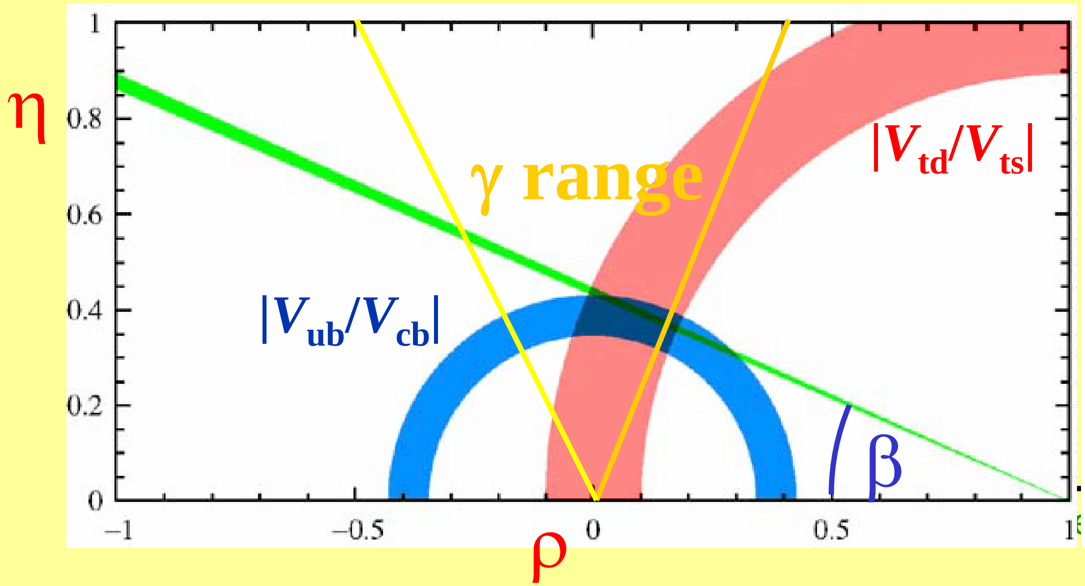
FM

2003

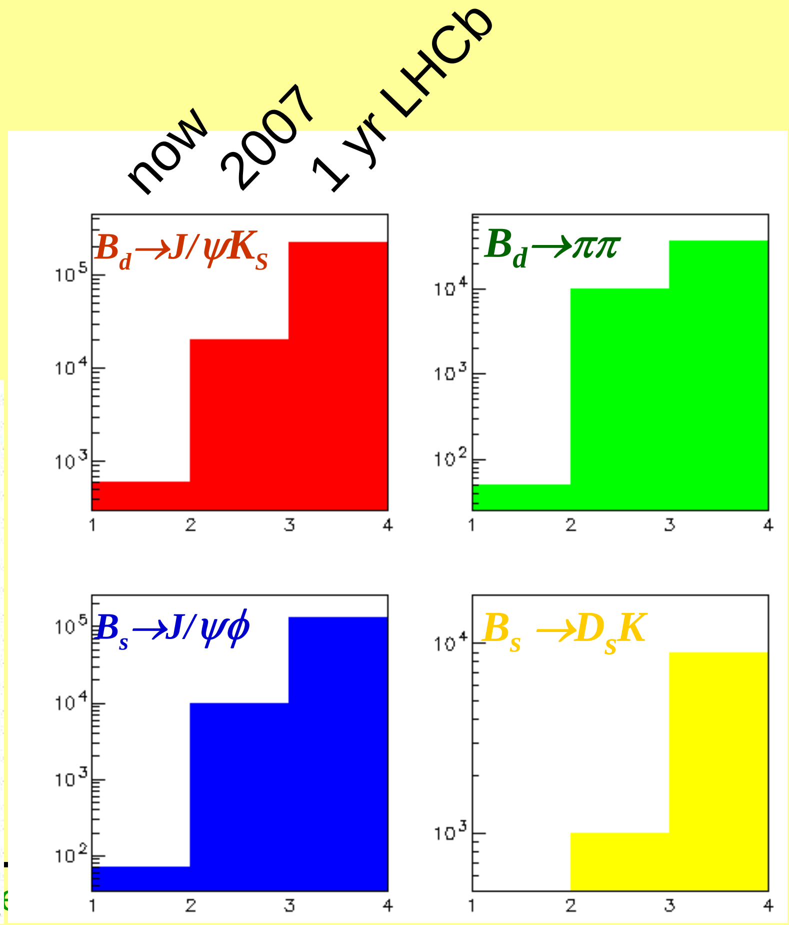
B-Factories and Tevatron are doing great physics!

Not enough!

2007 γ and $\delta\gamma$ poorly known



Statistics
# of reconstructed events



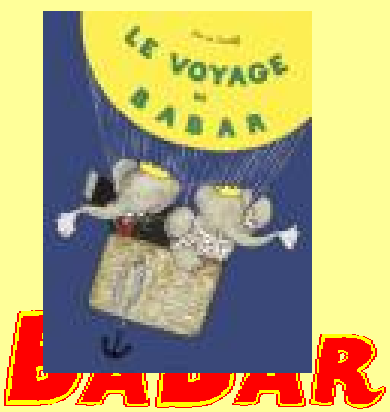
An Endangered Species Act for heavy quarks in the US?

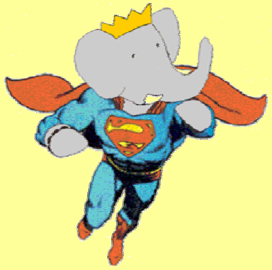
Hitlin

2003 2005 2005 2005

u c t | d s b

2006-2008



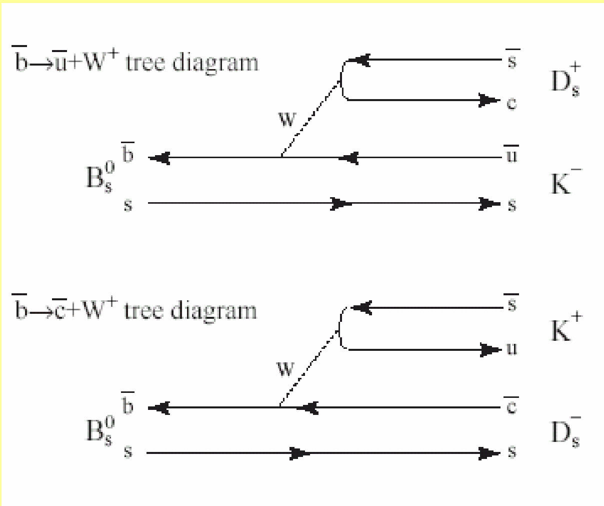


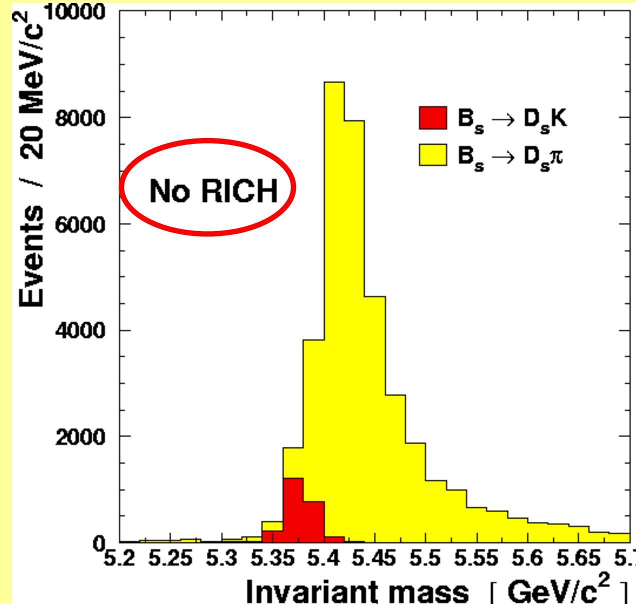
SUPER BABAR

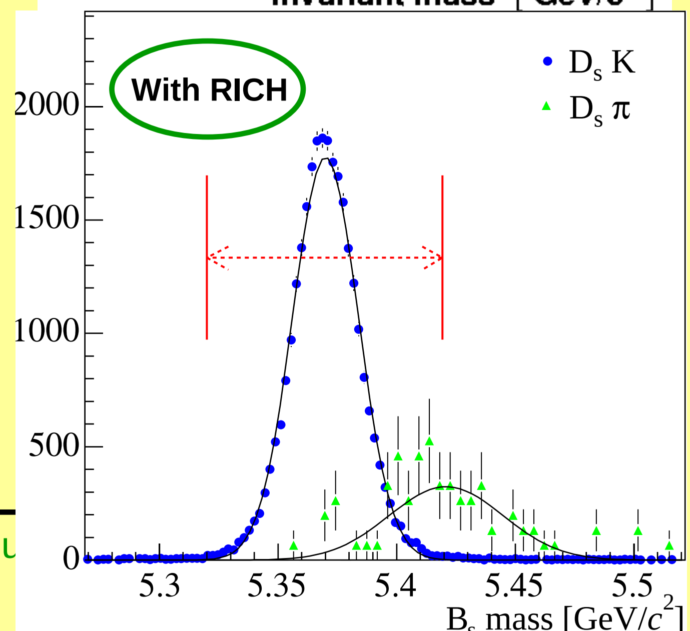
LHCb

- Precision measurements of CKM angle γ
- Bs mixing
- Rare Hadronic decays

γ from $B_s \to D_s^{\mp}K^{\pm}$



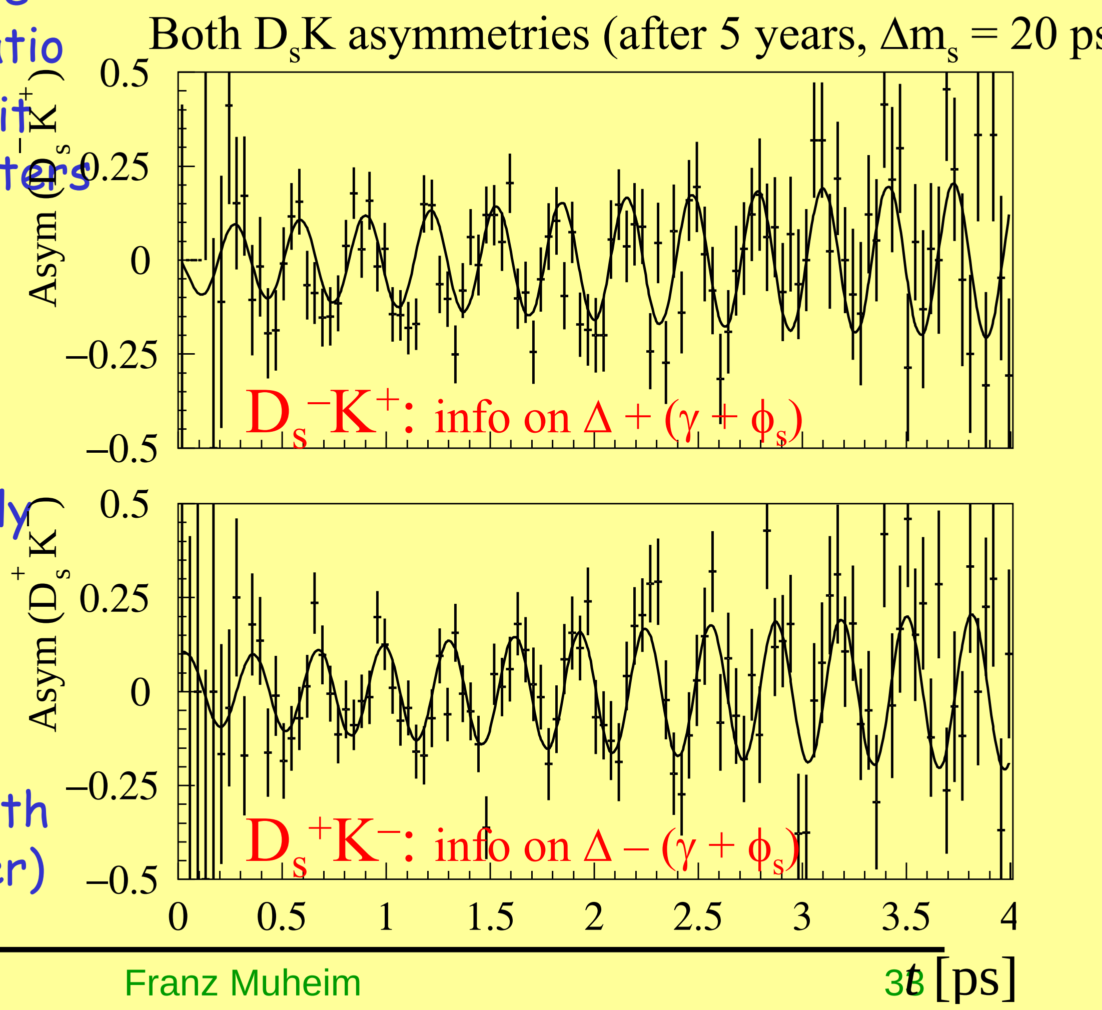




- Two tree decays (b→c and b→u) of $O(\lambda^3)$
  - Interference via B_s mixing
  - Weak phase of Vub = $e^{-i\gamma}$ for b→u diagram
  - theoretically clean
  - insensitive to New Physics
- Large Background ~20
  - from CKM allowed decay $B_s^0 \to D_S\pi$
  - need RICH, residual background ~10%
- Expect 5.4 k events in 1 year
  - S/Bbb > 1 at 90% CL

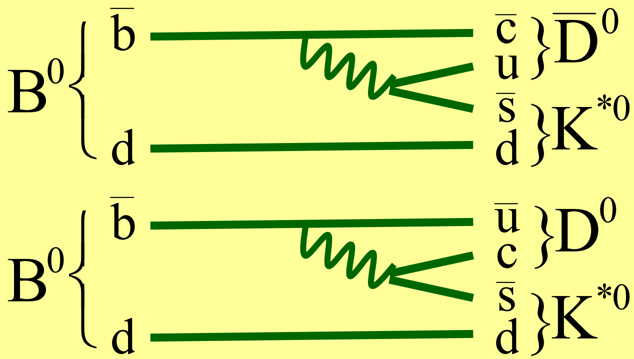
γ from $B_s \to D_sK$

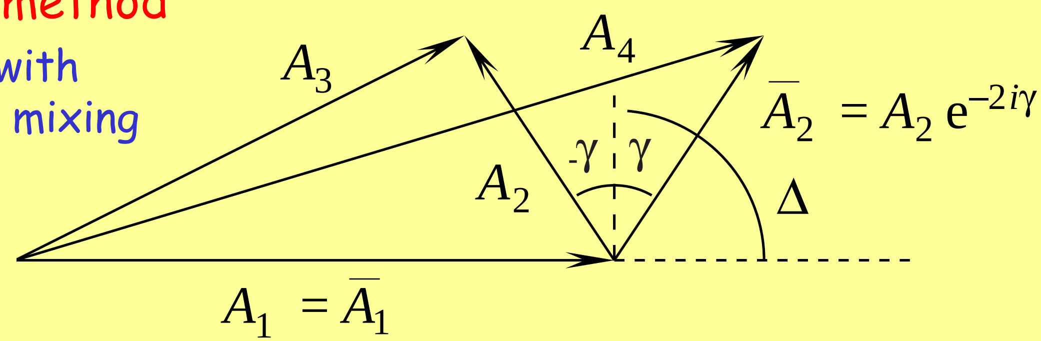
- Fit the 4 tagged time-dependent rates:
  - Extract $\phi_s + \gamma$, strong phase difference Δ, amplitude ratio
  - $B_s \to D_s\pi$ also used in the fit to constrain other parameters (mistag rate, Δm_s, $\Delta\Gamma_s$ …)
- $\sigma(\gamma)$ ~ 14° in one year (if Δm_s = 20 ps^{-1})
  - expected to be statistically limited
  - 8-fold ambiguity can be resolved ($\to$ 2-fold) if $\Delta\Gamma_s$ large enough, or using $B^0 \to D\pi$ together with U-spin symmetry (Fleischer)



γ from $B^0 \to D^0 K^{*0}$

- Dunietz variant of Gronau-Wyler method
  - Two colour-suppressed diagrams with $|A_2|/|A_1| \sim 0.4$ interfering via D^0 mixing





$A_1 = A(B^0 \to \overline{D}{}^0 K^{*0})$: $b \to c$ transition, phase 0

$A_2 = A(B^0 \to D^0 K^{*0})$: $b \to u$ transition, phase $\Delta + \gamma$

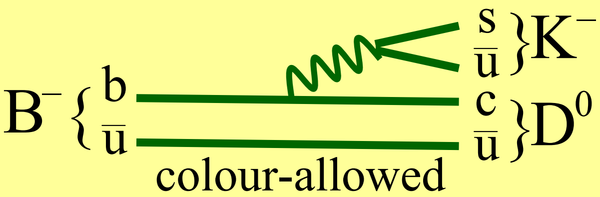
$A_3 = \sqrt{2}\, A(B^0 \to D_{CP} K^{*0}) = A_1 + A_2$, because $D_{CP} = (D^0 + \overline{D}{}^0)/\sqrt{2}$

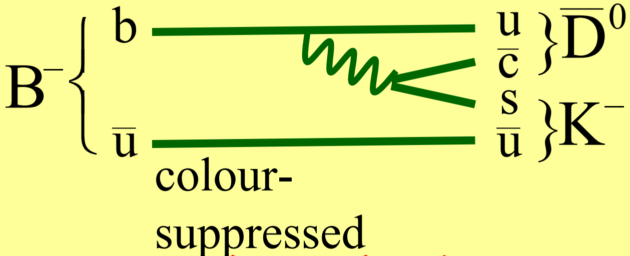
- Measure 6 decay rates (self-tagged + time-integrated):
  - LHCb expectations for 2 fb^{-1} ($\gamma = 65°$, $\Delta = 0$)

Mode (+ cc)	Yield	S/B_{bb} (90%CL)
$B^0 \to \overline{D}{}^0 (K^+\pi^-) K^{*0}$	3.4k	> 2
$B^0 \to D^0 (K^-\pi^+) K^{*0}$	0.5k	> 0.3
$B^0 \to D^0_{CP} (K^+K^-) K^{*0}$	0.6k	> 0.3

$\to \sigma(\gamma) \sim 8°$ in one year

γ from $B^\pm \to DK^\pm$





Weak phase difference = γ
Magnitude ratio = $r_B \sim 0.15$

- New ADS (Atwood, Dunietz, Soni) method:
  - Clean measurement of γ for LHCb
  - Measure the relative rates of $B^- \to DK^-$ and $B^+ \to DK^+$ decays with neutral D's observed in final states such as:
    - $K^-\pi^+$ and $K^+\pi^-$, $K^-\pi^+\pi^-\pi^+$ and $K^+\pi^-\pi^+\pi^-$, K^+K^-
  - These depend on:
    - Relative magnitude, weak and strong phase between $B^- \to D^0K^-$ and $B^- \to \bar{D}^0K^-$
    - Relative magnitudes and strong phases between $D^0 \to K^-\pi^+$ and DCS $D^0 \to K^-\pi^+$, and between $D^0 \to K^-\pi^+\pi^-\pi^+$ and $D^0 \to K^-\pi^+\pi^-\pi^+$
  - Can solve for all unknowns, including the weak phase γ
- Candidate for LHCb's statistically most precise determination of γ
  - $\sigma(\gamma) \sim 5^\circ$ in one year ? To be studied during this workshop …

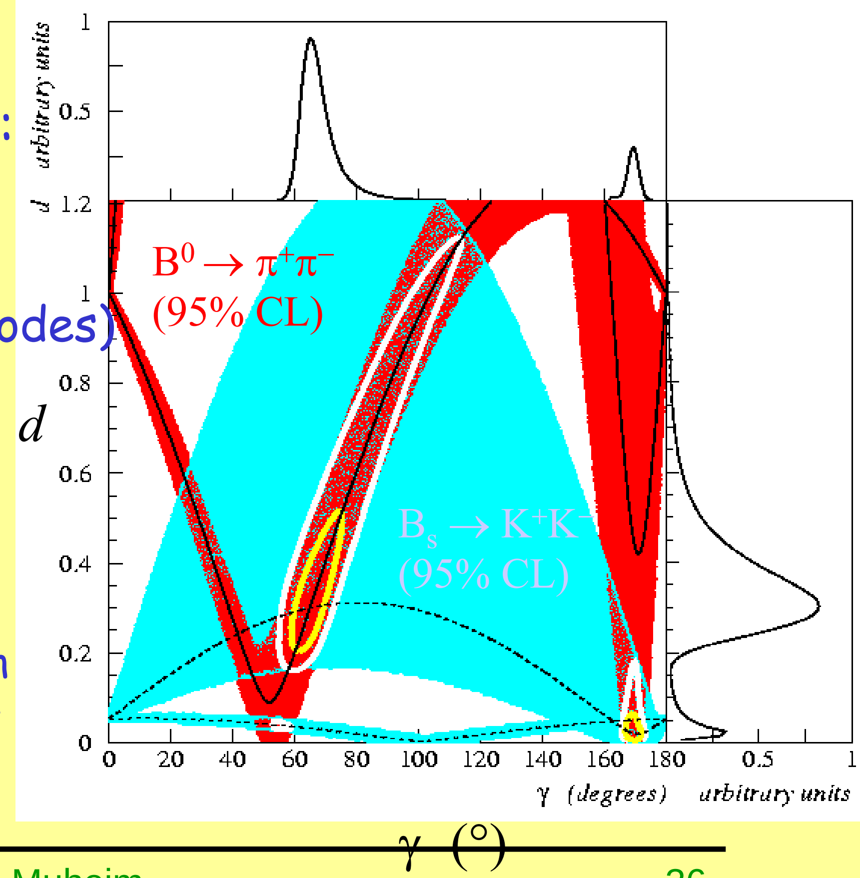
[also $B \to D^0K$, with $D^0 \to K_S\pi\pi$ Dalitz analysis]

γ from $B^0 \to \pi^+\pi^-$ and $B_s \to K^+K^-$

- For each mode, measure time-dependent CP asymmetry:

$$A_{CP}(t) = A_{dir}\cos(\Delta m t) + A_{mix}\sin(\Delta m t)$$

  - A_{dir} and A_{mix} depend on mixing phase, angle γ, and ratio of penguin to tree amplitudes = $d\,e^{i\theta}$
- Exploit U-spin symmetry (Fleischer):
  - Assume $d_{\pi\pi}=d_{KK}$ and $\theta_{\pi\pi}=\theta_{KK}$
  - 4 measurements and 3 unknowns (taking mixing phases from other modes) $\to$ can solve for γ
- LHCb expectations (one year):
  - 26k $B^0 \to \pi^+\pi^-$
  - 37k $B_s \to K^+K^-$ $\to \sigma(\gamma) \sim 5°$
    - Uncertainty from U-spin assumption
    - Sensitive to new physics in penguins

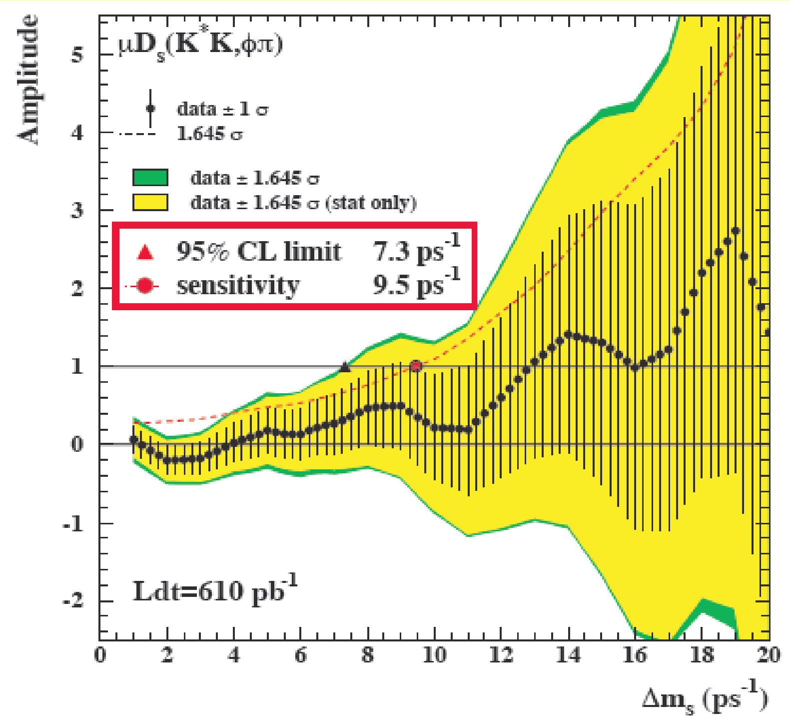


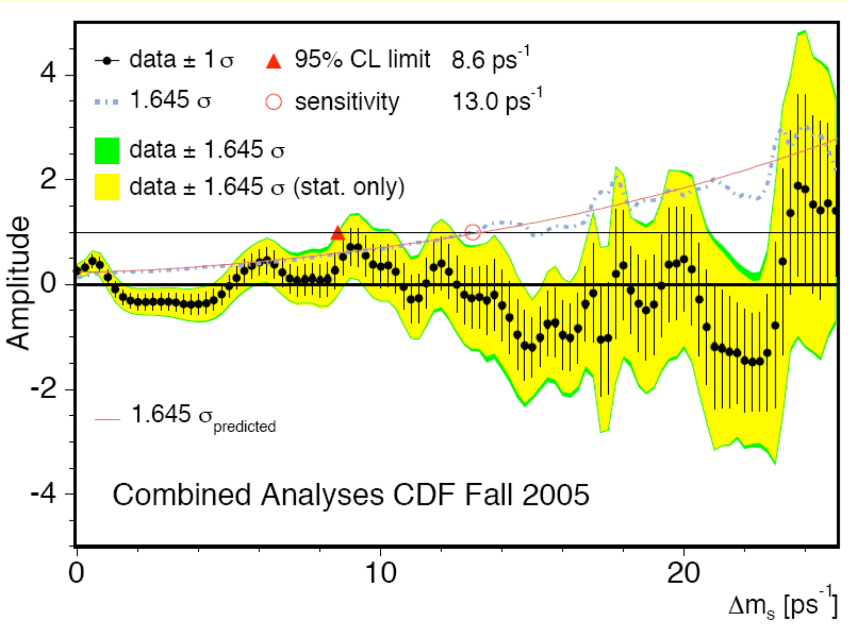
New Bs mixing results - Tevatron

D0

CDF

Ay Oldeman



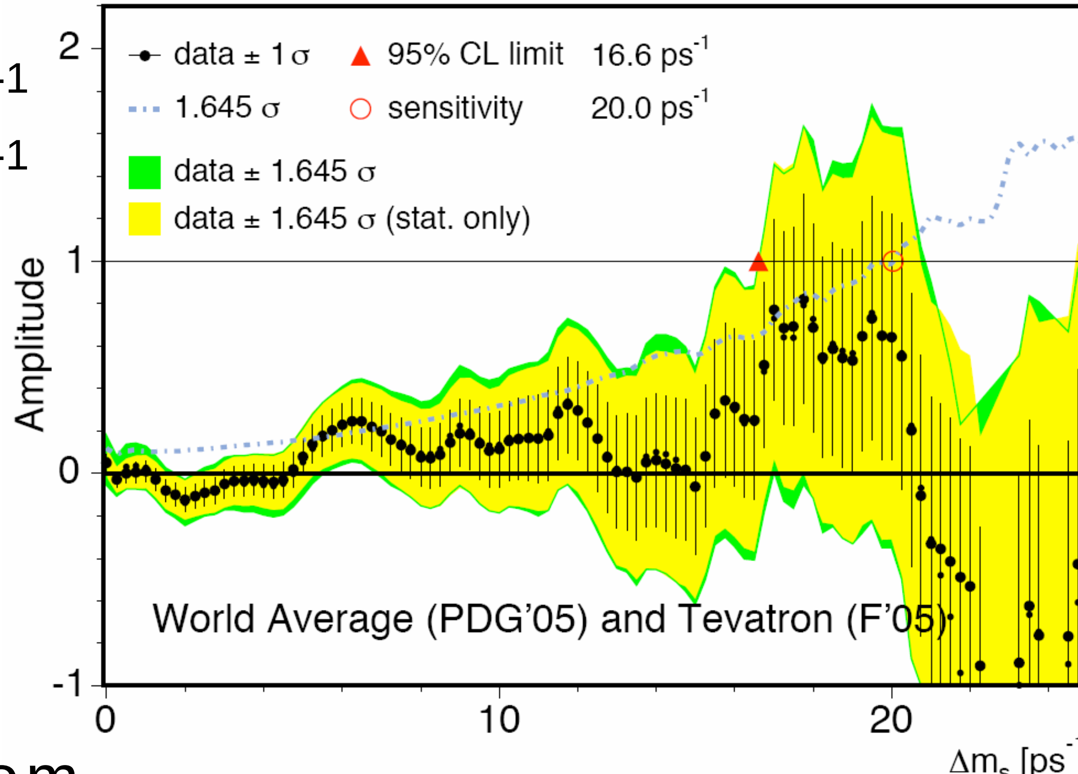


$\varepsilon D^2 = 1.55 \pm 0.09\%$

$\Delta m_s > 8.6 ps^{-1}$, sensitivity $13.0 ps^{-1}$

New world average

limit 14.5 → 16.6 ps^{-1}
sensitivity 18.3 → 20.0 ps^{-1}

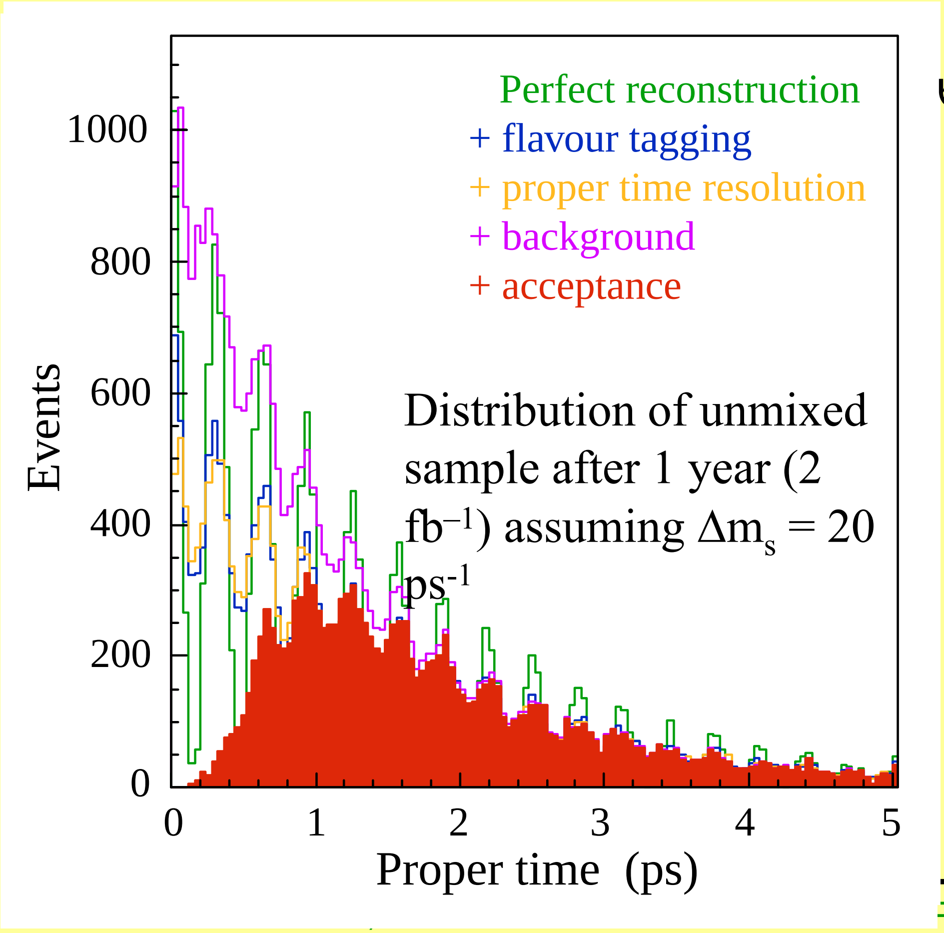


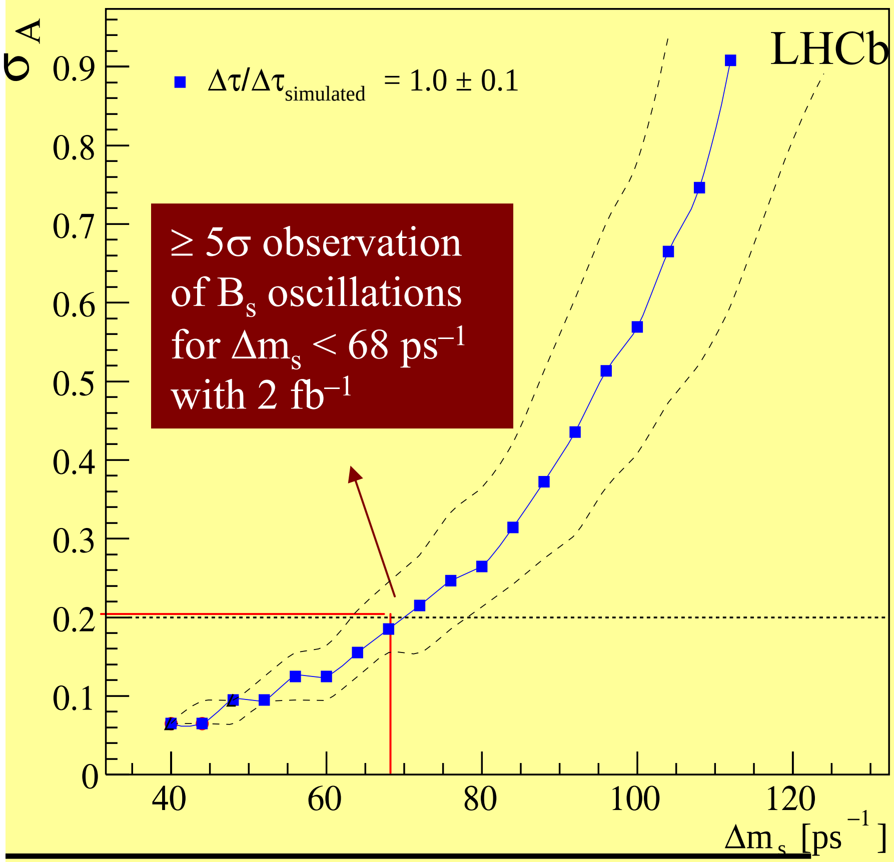
Further improvements from

- more data
- more decay channels (e.g. $B_s \rightarrow D_s^* \pi$)
- Same-side and opposite-side kaon tags

B_s oscillations

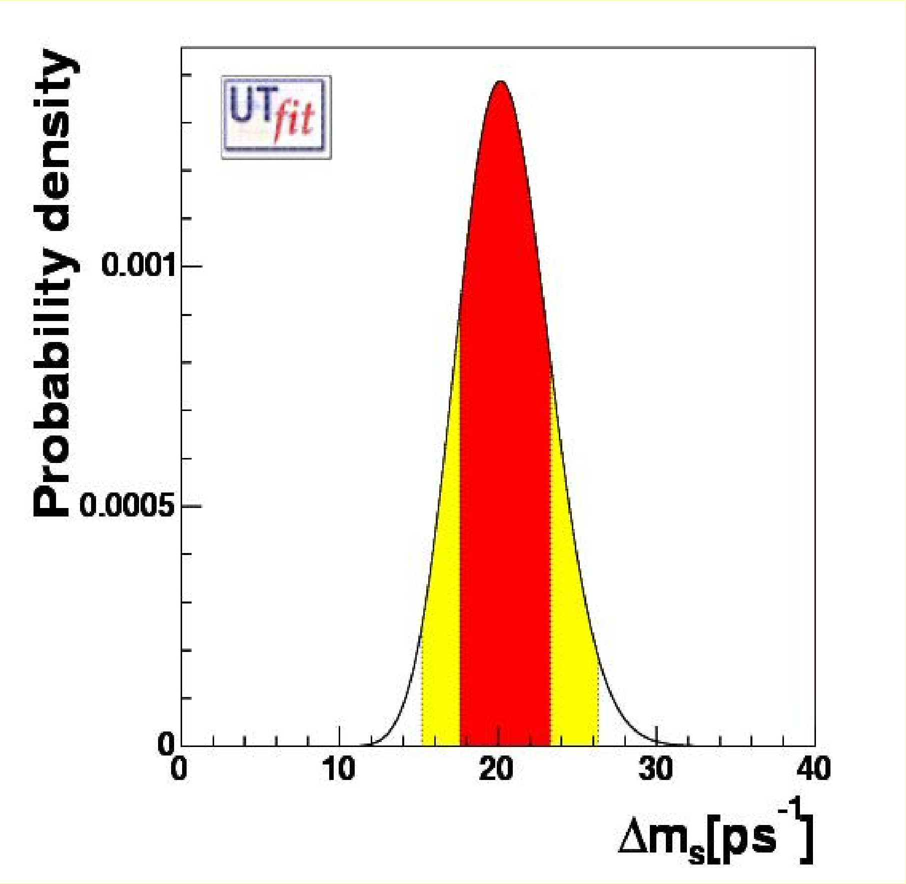
- Measurement of Δm_s is one of the first LHCb physics goals
  - Expect 80k $B_s \rightarrow D_s^- \pi^+$ events per year (2 fb^{-1}), average σ_t ~ 40 fs
  - S/B ~ 3 (derived from 10^7 fully simulated inclusive $b\bar{b}$ events)





B_s oscillations

- Current SM expectation of Δm_s (UTFit collab.):

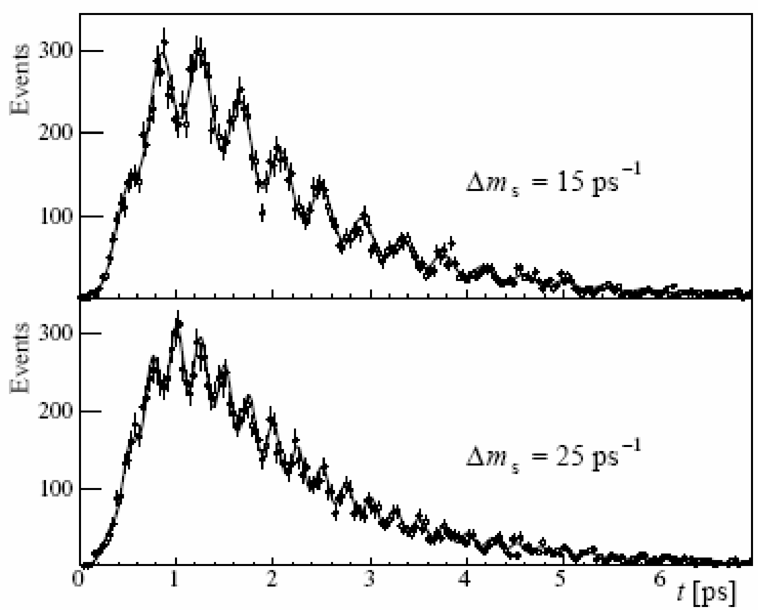


- LHC reach for 5σ observation:

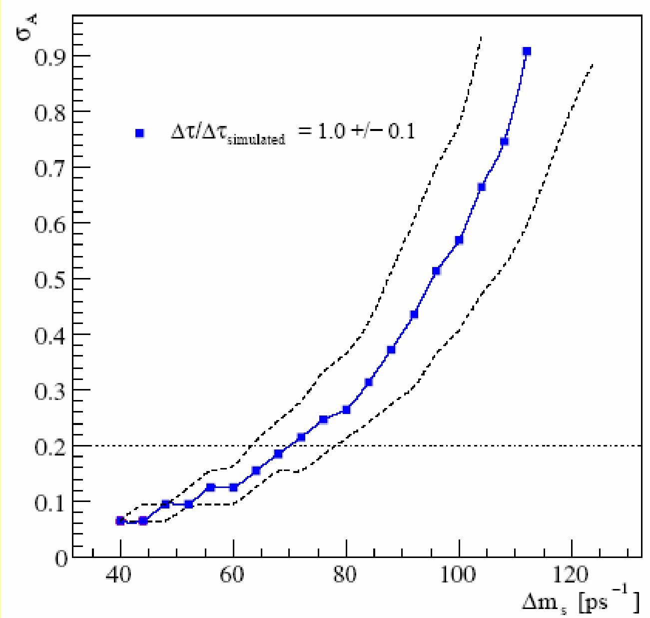
ATLAS/CMS	**30 fb^{-1}**	**3 years**
LHCb	**0.25 fb^{-1}**	**1/8 year**

LHCb Δm_s sensitivity

Fernandez



Decay rate for unmixed B_s^0



Statistical uncertainty on amplitude factor A (σ_A) versus ΔM_s

Sensitivity limit:
ΔM_s for which $5 \cdot \sigma_A = 1 = A$

In 1 year, $\geq 5\sigma$ observation of B_s^0 oscillations up to $\Delta M_s = 68$ ps^{-1}

$\longrightarrow$ could exclude full SM range

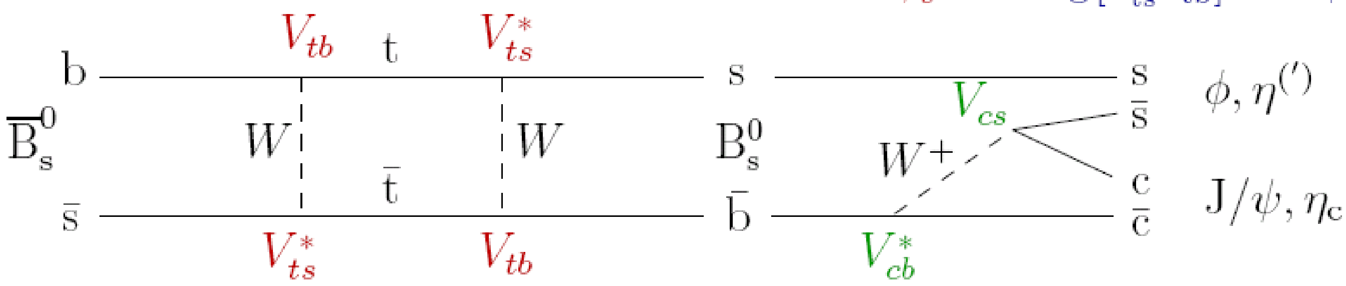
'Immediate' measure of ΔM_s if small: 1/8 year LHCb running! (0.25 fb^{-1}, $\Delta M_s = 40$ ps^{-1})

LHCb ϕ_s sensitivity

Mixing-induced CP violation: phase mismatch $\phi_s - 2\phi_D \approx \phi_s \neq 0, \pi$

"first mix, then decay"

- $\phi_s \stackrel{\text{SM}}{\equiv} 2\arg[V_{ts}^* V_{tb}] \approx -2\beta_s = \mathcal{O}(-0.04)$ rad



→ CP-asymmetry directly measures $\phi_s = \mathcal{O}(-0.04)$ rad (for given $\eta_{f_{CP}}$)

$$\mathcal{A}_{CP}(t) = \frac{-\eta_{f_{CP}} \sin(\phi_s) \sin(\Delta M_s t)}{\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) - \eta_{f_{CP}} \cos(\phi_s) \sinh\left(\frac{\Delta\Gamma_s t}{2}\right)}$$

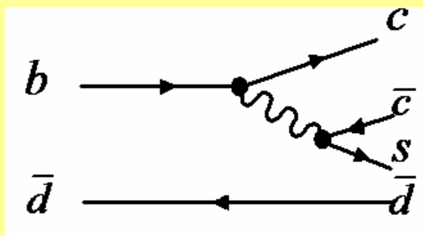
Channels	$\sigma(\phi_s)$ [rad]	Weight $(\sigma/\sigma_i)^2$ [%]
$B_s^0 \to J/\psi\ \eta(\gamma\ \gamma)$	0.112	6.4
$B_s^0 \to J/\psi\ \eta(\pi^+\ \pi^-\ \pi^0)$	0.148	3.6
$B_s^0 \to \eta_c\ \phi$	0.106	7.1
Combined three pure CP eigenstates channels	0.068	17.1
$B_s^0 \to J/\psi\ \phi$	0.031	82.9
Combined all four CP eigenstates channels	0.028	100.0

With 10 fb^{-1} (5 years): $\sigma(\phi_s) \sim 0.013$ rad $\longrightarrow$ $\sim 3\sigma$ for $\phi_s = -0.04$ rad (SM)

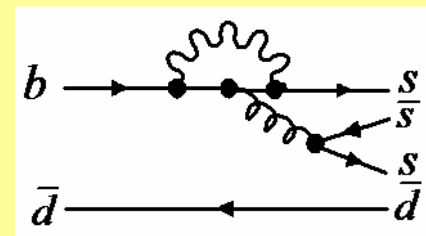
NP in b → s Transitions

- In the Standard Model we expect the same value for "sin2β" in □ b ® $c\bar{c}s$, b ® $c\bar{c}d$, b ® $s\bar{s}s$, b ® $d\bar{d}s$ modes, but different SUSY models can produce different asymmetries
- Since the penguin modes have branching fractions one or two orders of magnitude less than tree modes, need large luminosity (Super-B factory) or large cross section (LHCb)

B^0 ® $J/y\, K_S^0$

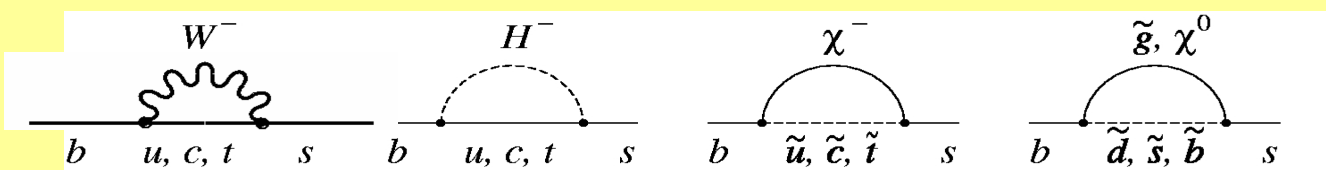


B^0 ® $f\, K_S^0$



$$l_{tree} = \frac{q}{p}\frac{\bar{A}}{A} = h\frac{V_{tb}^{*}V_{td}}{V_{tb}V_{td}^{*}}\frac{V_{cb}V_{cs}^{*}}{V_{cb}^{*}V_{cs}} = (-1)e^{-2ib}$$

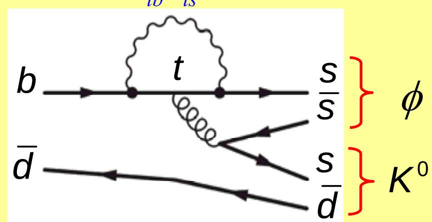
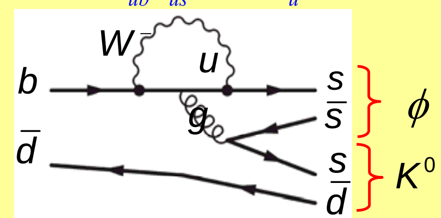
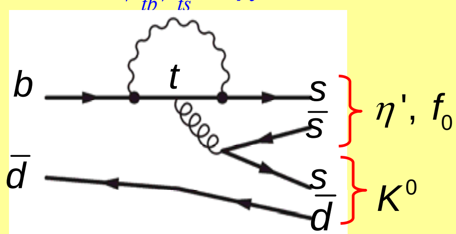
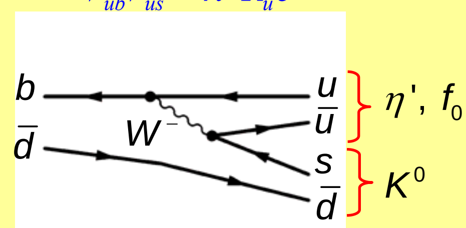
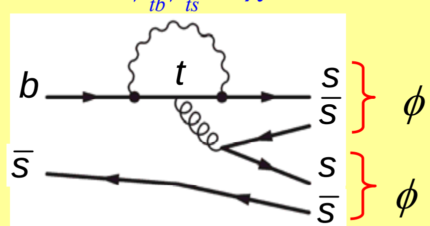
$$l_{penguin} = \frac{q}{p}\frac{\bar{A}}{A} = h\frac{V_{tb}^{*}V_{td}}{V_{tb}V_{td}^{*}}\frac{V_{tb}V_{ts}^{*}}{V_{tb}^{*}V_{ts}} = (-1)e^{-2ib}$$



$$\lambda = e^{i(2\beta+\phi^{\rm SUSY})}\frac{|\bar{A}|}{|A|} \quad \Rightarrow S_{\phi K} = \sin(2\beta + \phi^{\rm SUSY})$$

In general $S_{J/\psi K_S} \neq S_{\phi K_S}$; $C_{J/\psi K_S} \neq C_{\phi K_S}$

Penguin and Trees in b ® $s s\bar{s}, s d\bar{d}$

<table>
<tr><th>b ® $s s\bar{s}, s d\bar{d}$ mode</th><th>B ×10^{-6}</th><th></th><th></th></tr>
<tr><td>B^0 ® $f K_S^0$</td><td>4</td><td>$\propto V_{tb}V_{ts}^* \sim \lambda^2$
</td><td>$\propto V_{ub}V_{us}^* \sim \lambda^4 R_u e^{-i\gamma}$
</td></tr>
<tr><td>B^0 ® $h¢K_S^0$</td><td>29</td><td>$\propto V_{tb}V_{ts}^* \sim \lambda^2$
</td><td>$\propto V_{ub}V_{us}^* \sim \lambda^4 R_u e^{-i\gamma}$
</td></tr>
<tr><td>$B_s^0 \to \phi\phi$</td><td>5</td><td>$\propto V_{tb}V_{ts}^* \sim \lambda^2$
</td><td></td></tr>
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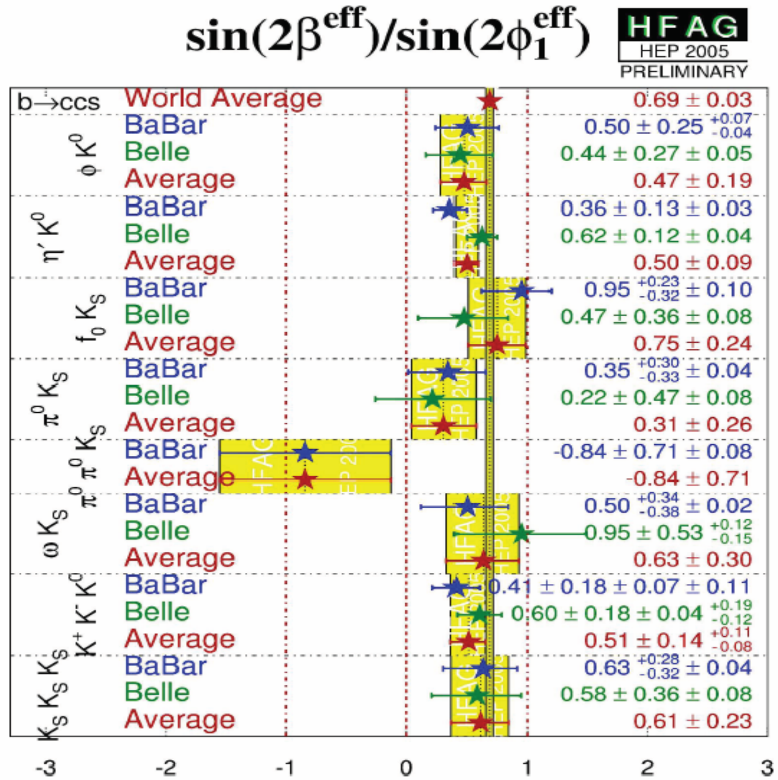
B^0 ® $J/y K_S^0$	440

Issues: triggering, charged/neutral vertexing, ...

sin2β from Hadronic Penguins

Current Experimental Status



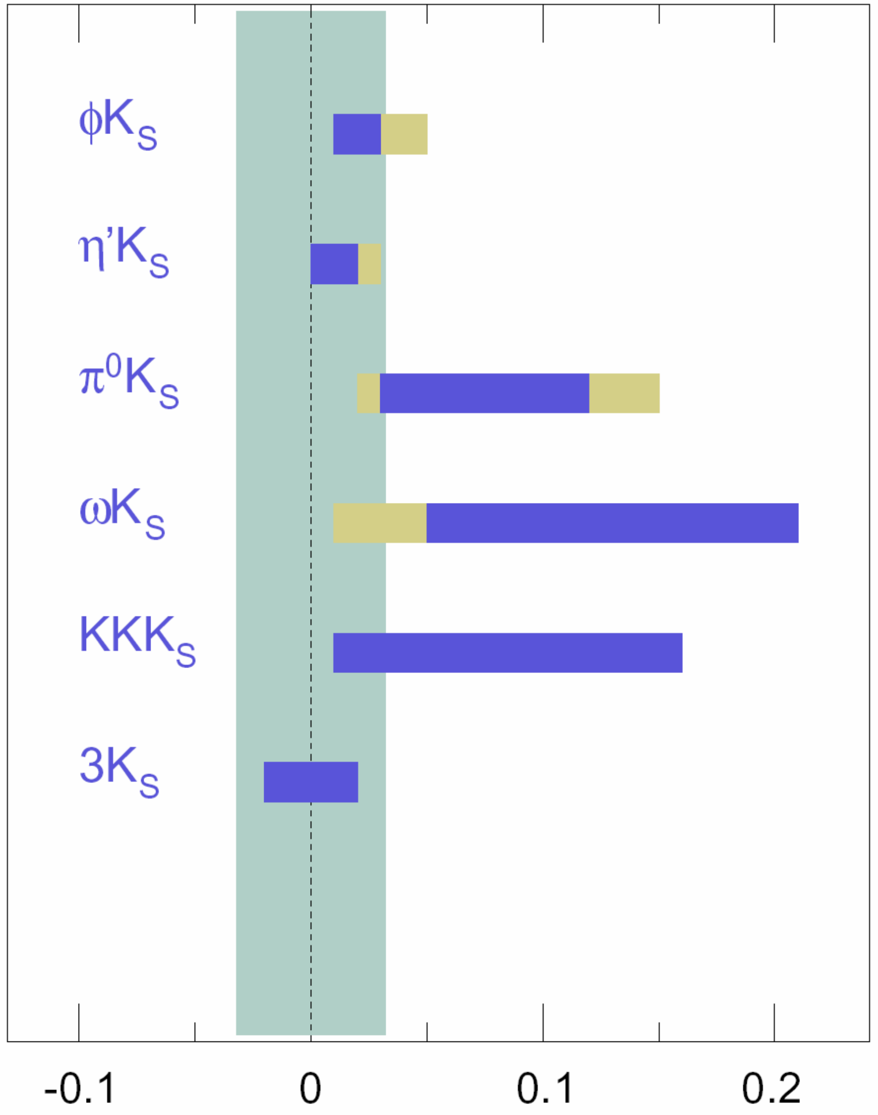
Good agreement between BaBar and Belle

Consistency among different channels

Maurizio Pierini
Flavor in the era of the LHC

11

How good are the SM predictions?



Two body:
Beneke, PLB 620 (2005) 143

blue = ±1 sigma
grey = full range

Calculations within framework of QCD factorization

Three body:
Cheng, Chua & Soni, hep-ph/0506268

$$\Delta = S_{penguin} - \sin 2\beta$$

squark mass matrix (d sector)

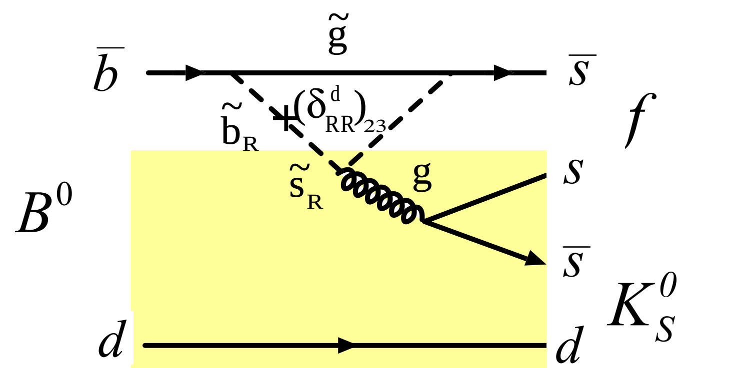
Flavour structure: Super$B$, LHCb

$$\begin{pmatrix} m^2_{\tilde d_L} & m_d(A_d - \mu\tan\beta) & (\Delta^d_{12})_{LL} & (\Delta^d_{12})_{LR} & (\Delta^d_{13})_{LL} & (\Delta^d_{13})_{LR} \\ & m^2_{\tilde d_R} & (\Delta^d_{12})_{RL} & (\Delta^d_{12})_{RR} & (\Delta^d_{13})_{RL} & (\Delta^d_{13})_{RR} \\ & & m^2_{\tilde s_L} & m_s(A_s - \mu\tan\beta) & (\Delta^d_{23})_{LL} & (\Delta^d_{23})_{LR} \\ & & & m^2_{\tilde s_R} & (\Delta^d_{23})_{RL} & (\Delta^d_{23})_{RR} \\ & & & & m^2_{\tilde b_L} & m_b(A_b - \mu\tan\beta) \\ & & & & & m^2_{\tilde b_R} \end{pmatrix}$$

Mass spectrum: LHC, LC

Assuming all Δ's small and squarks nearly degenerate, we can use mass insertion approximation (MIA):

$$(d^d_{ij})_{AB} = \frac{(D^d_{ij})_{AB}}{\tilde{m}^2}$$

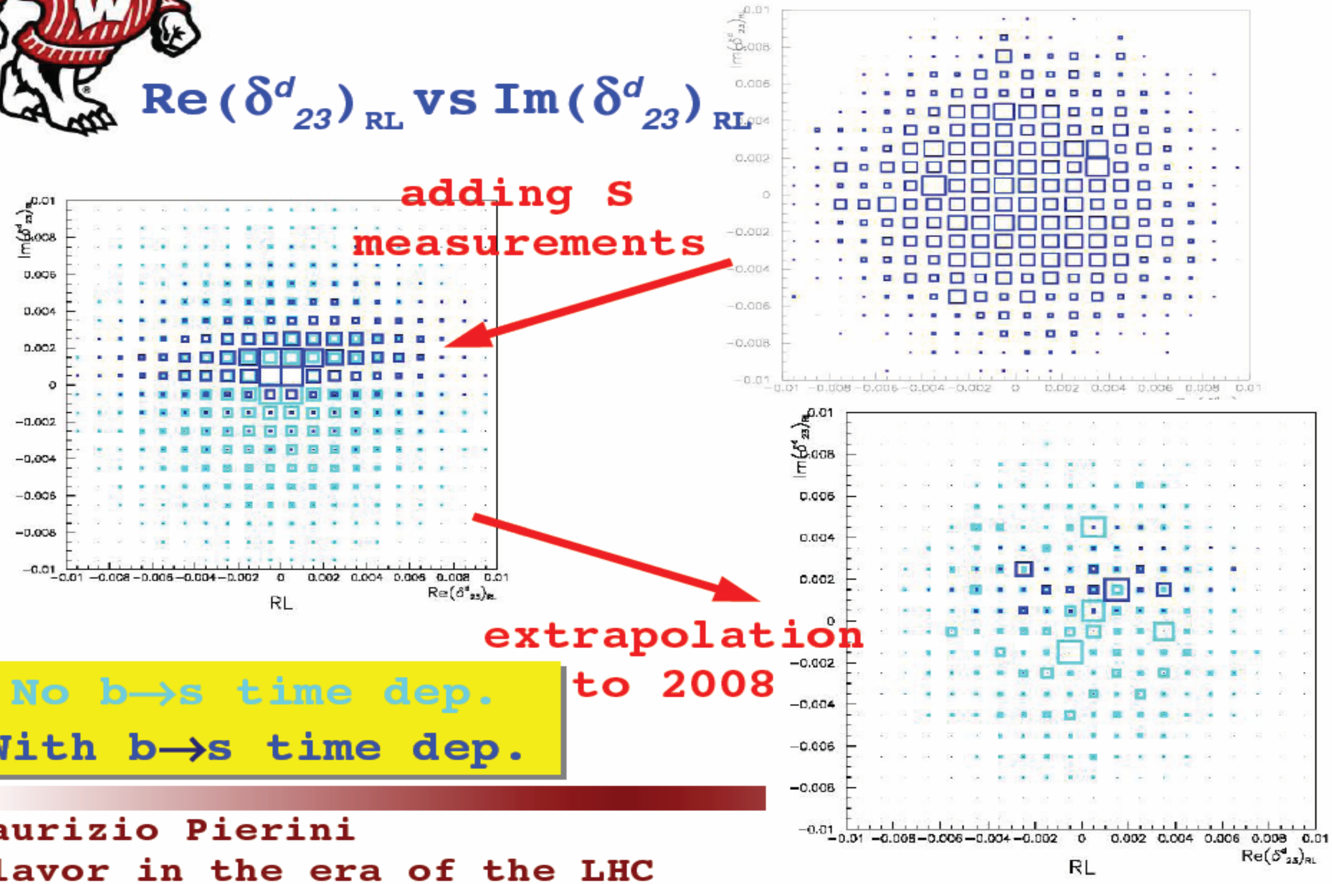


Flavour mixing parametrization
$b \to s\ (23)$, $\quad b \to d\ (13)$

Off diagonal terms can provide unique information on *CP* phases

Limits on SUSY mass insertion parameters

$Re(\delta^d_{23})_{RL}$ vs $Im(\delta^d_{23})_{RL}$



No b→s time dep.

With b→s time dep.

Maurizio Pierini

Flavor in the era of the LHC

LHCb $B_s \rightarrow \phi K_S$

Yuehong

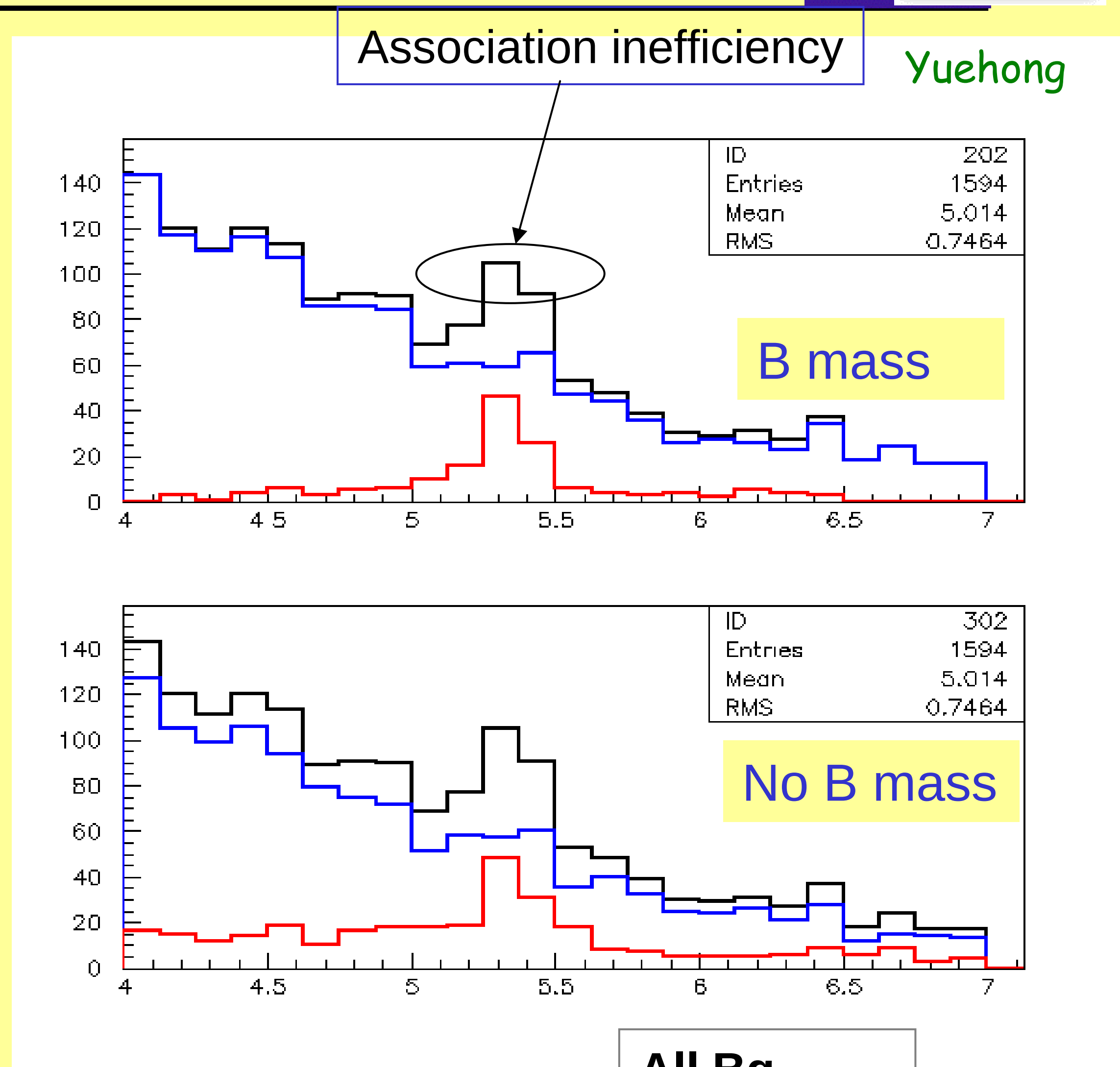
- Most recent study by Yuehong
- All together 1595 events out of 476K events generated in acceptance pass L0*L1 and final selection cuts without considering HLT and tagging
- Nominal annual untagged events

$$N_{selected} / year$$
$$= 2 \cdot N_{Bd} \times \prod Br \times total\ \ Efficiency$$
$$= \left[0.78 \times 10^{12}\right] \times \left[1.4 \times 10^{-6}\right] \times \left[0.3471 \times 1595 / 476000\right]$$
$$= 1270$$

  - Compared with ~800 events/year in lhcb-note 2004-001
- Further reduced by HLT inefficiency: factor of XX?

LHCb $B_s \to \phi\phi$

- Work by Yuehong
- Use signal sample
- Fit B
- [mass constrain B]
- Choose PV with smallest IP significance
- Direction fit
- Set direction fit $\chi 2$ cut to for 90% signal eff.
- Check bg rejection
- Only half bg. Left with mass constraint
- no bias for mass or life time is induced by the B mass constraint
- Alternative method: use direction fit to improve B mass
- Plan
  - Study $Bs \to \phi\phi$ reconstruction and sensitivity (Judith, Yuehong, FM)

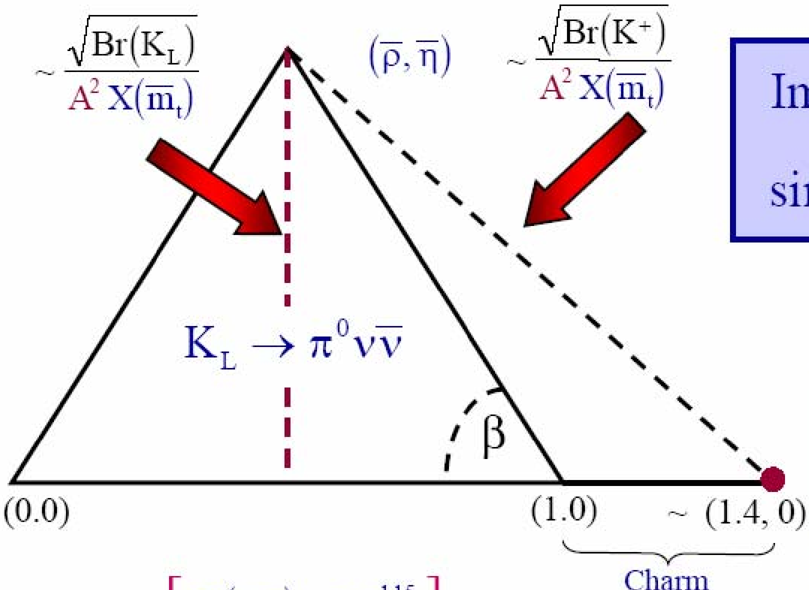


Rare Kaon Decays

Buras

UT from $K \to \pi\nu\bar{\nu}$

Buchalla
AJB



$[\ X(\overline{m}_t) \sim \overline{m}_t^{1.15}\ ]$

$(0.37 \pm 0.04) \Rightarrow P_c \sim \frac{P_c}{A^2 X(\overline{m}_t)}$

$$\mathrm{Im}\,\lambda_t = F_1(\overline{m}_t, Br(K_L))$$

$$\sin 2\beta = F_2(P_c, Br(K_L), Br(K^+))$$

$$\lambda_t = V_{ts}^* V_{td}$$

$\sin 2\beta$ $(K \to \pi\nu\bar{\nu})$ ⟺ $\sin 2\beta$ $(B \to J/\psi, K_s$ $\to \varphi K_s)$

K-Physics ⟺ B - Physics

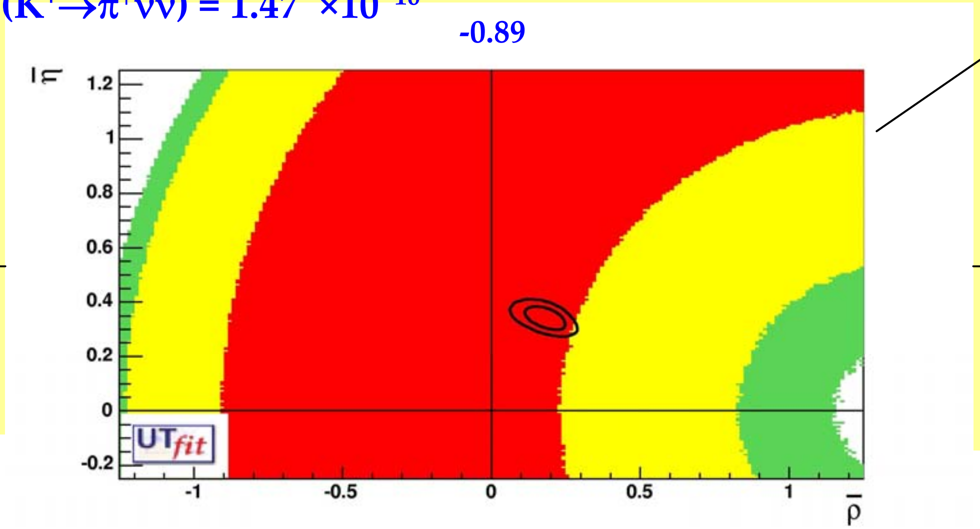
Test of SM and Beyond

$K^+ \rightarrow \pi^+\nu\nu$ at CERN/SPS

- Present (E787/949): **BR($K^+\rightarrow\pi^+\nu\nu$) = 1.47 $\times 10^{-10}$ $^{+1.30}_{-0.89}$**

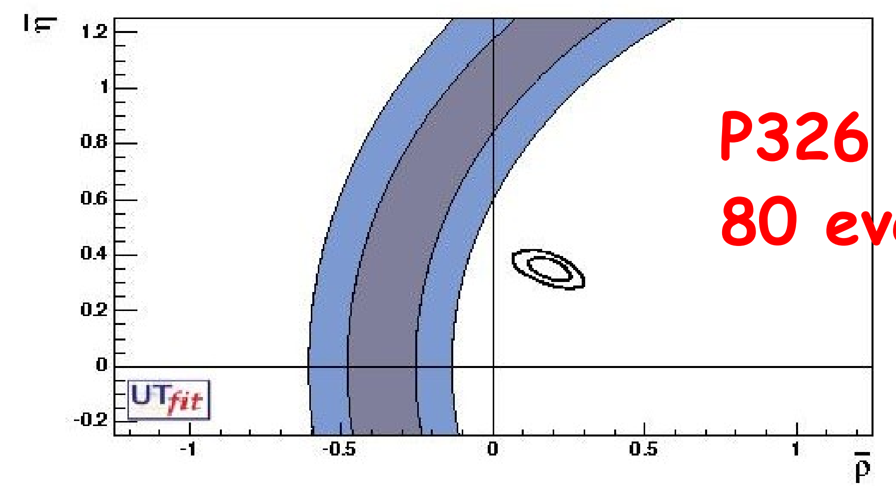
Ruggiero

Current constraint on ρ,η plane

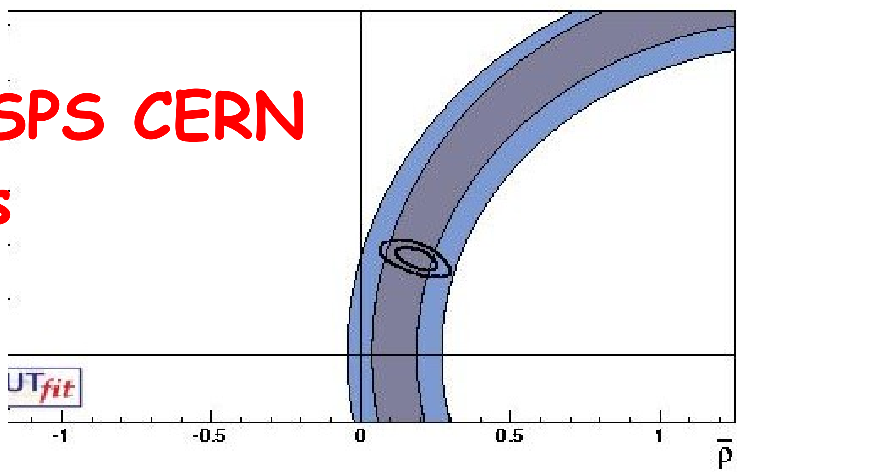


100 events
Mean: E787/949

100 events
Mean: SM

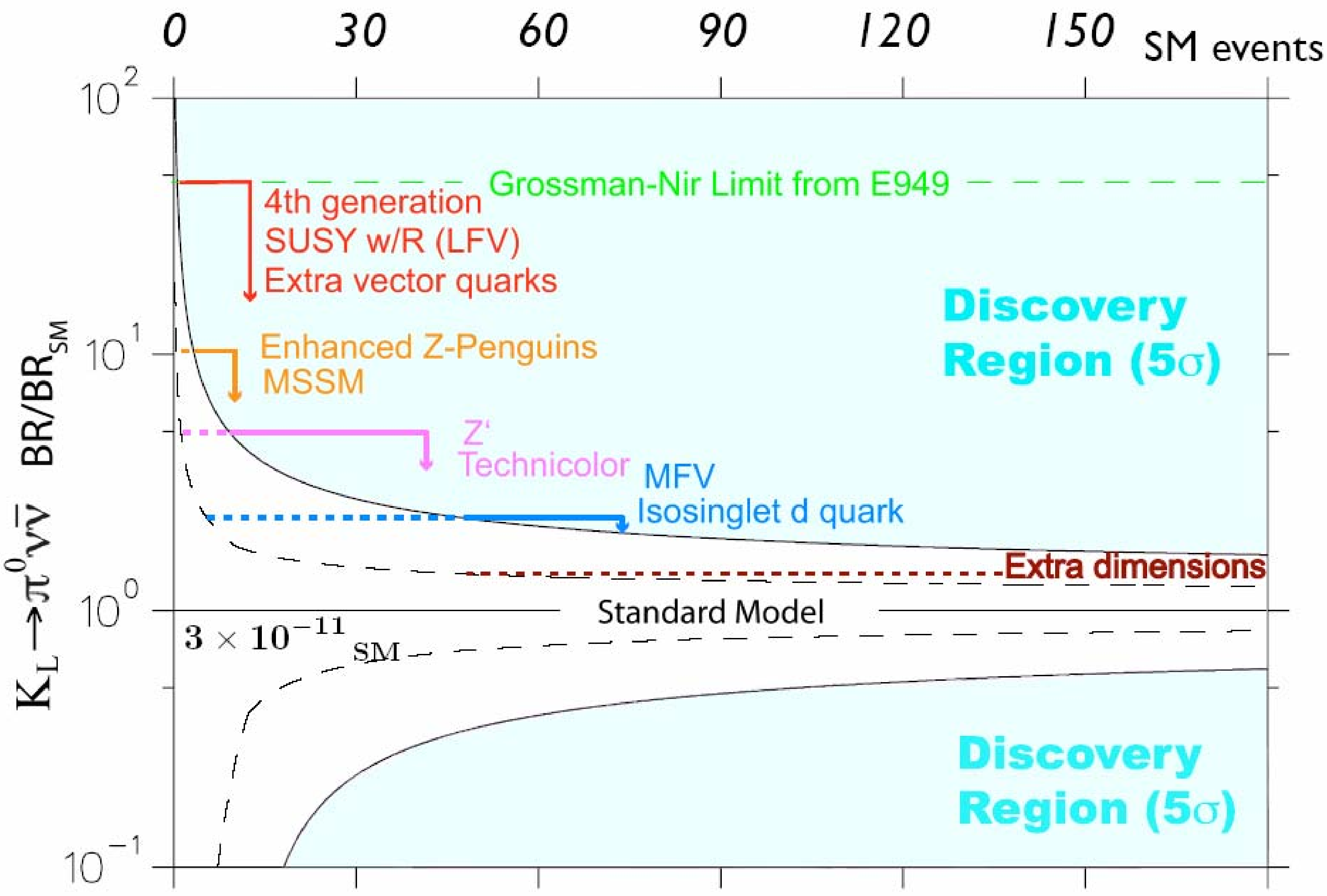


P326 at SPS CERN
80 events



$K^0_L \to \pi^0\nu\nu$ at JPARC

Komatsubara



based on Bryman-Buras-Isidori-Littenberg, hep-ph/0505171

b → d gamma

$B \to \rho(\omega)\gamma$ at BaBar

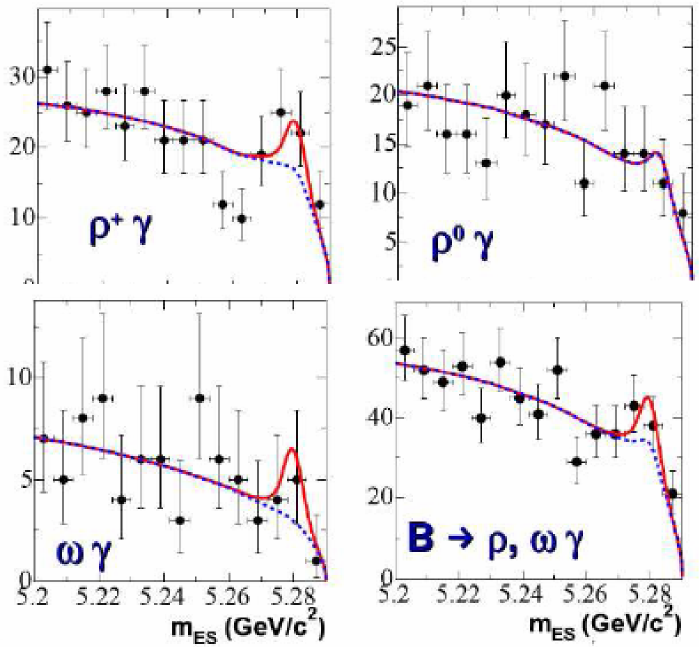
PRL 94, 011801 (2005)

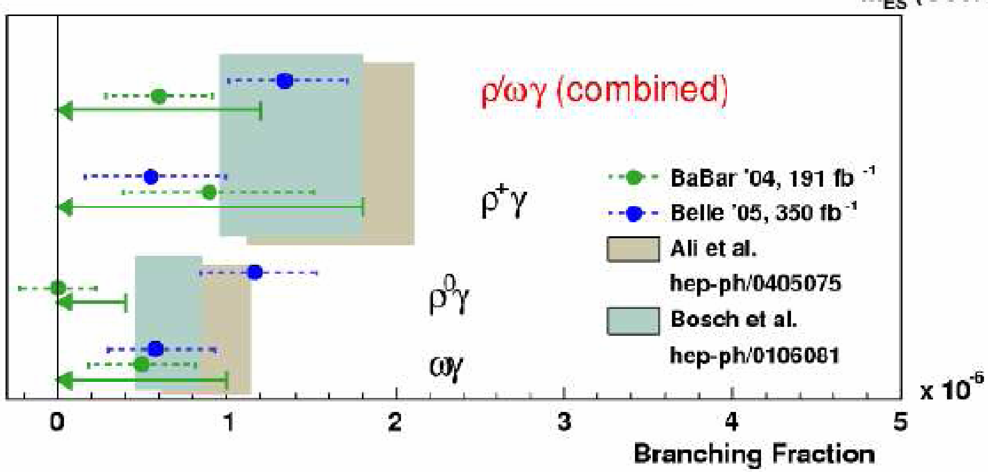
(210 million $B\bar{B}$ pairs)

BaBar sees 2σ excesses in $B^+ \to \rho^+\gamma$, $B^0 \to \omega\gamma$

Combined 90% C.L. upper limit:

$BF(B \to \rho(\omega)\gamma) < 1.2 \times 10^{-6}$





For $B^0 \to \rho^0\gamma$ Belle and BaBar differ by $\approx 3\sigma$!

B->K*l+l- F-B asymmetry

Belle, 2005

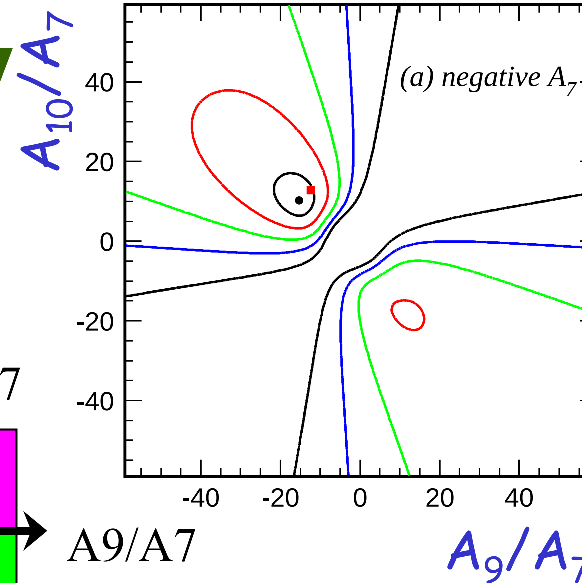
Iijima

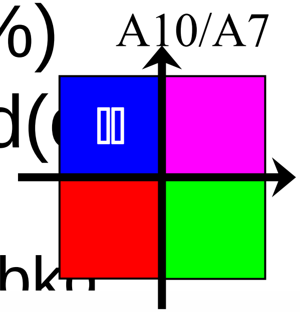
- 357fb^{-1} (386M BB)
- N(K*ll)=114+-14 (purity 44%)
- Unbinned M.L. fit to dΓ^2/dsd(
  - 8 event categories
    - Signal + 3 cross-feed + 4 bkg
  - Ali et al's form factor
  - Fix $|A_7|$ to SM
  - Float A_9/A_7 and A_{10}/A_7
- Results;

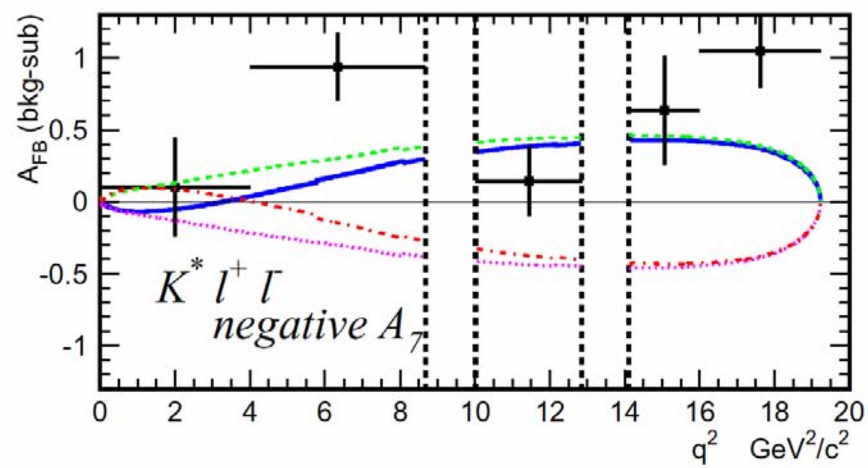
$$A_{FB}^{\text{bkg-sub}}(B \to K^*\ell\ell) = 0.56 \pm 0.13(\text{stat.})$$

$$A_9/A_7 = -15.3^{+3.4}_{-4.8} \pm 1.1,$$
$$A_{10}/A_7 = 10.3^{+5.2}_{-3.5} \pm 1.8,$$

$$A_9/A_7 = -16.3^{+3.7}_{-5.7} \pm 1.4,$$
$$A_{10}/A_7 = 11.1^{+6.0}_{-3.9} \pm 2.4,$$







Sign of A_9A_{10} is negative !

See Hep-ex/0508009 &
A.Ishikawa's talk at EPS05

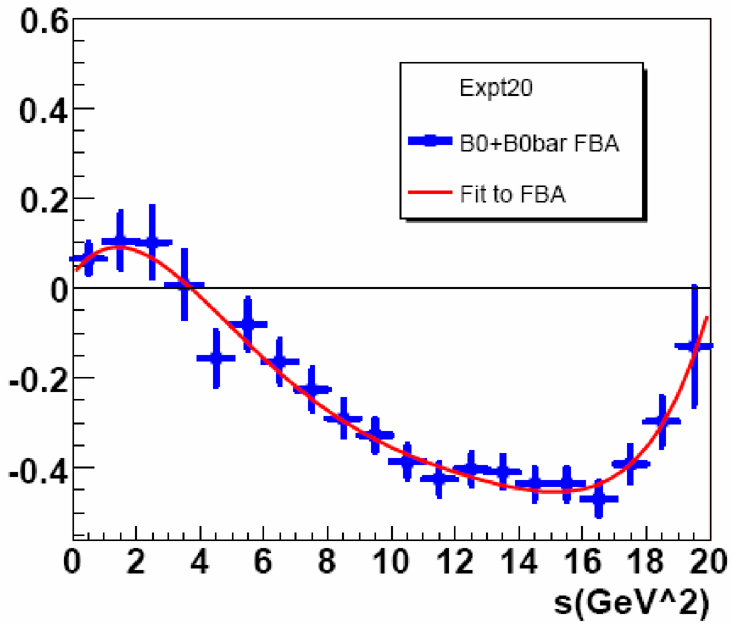
Koppenburg
Iijima
Playfer

AFB in B → K*ll

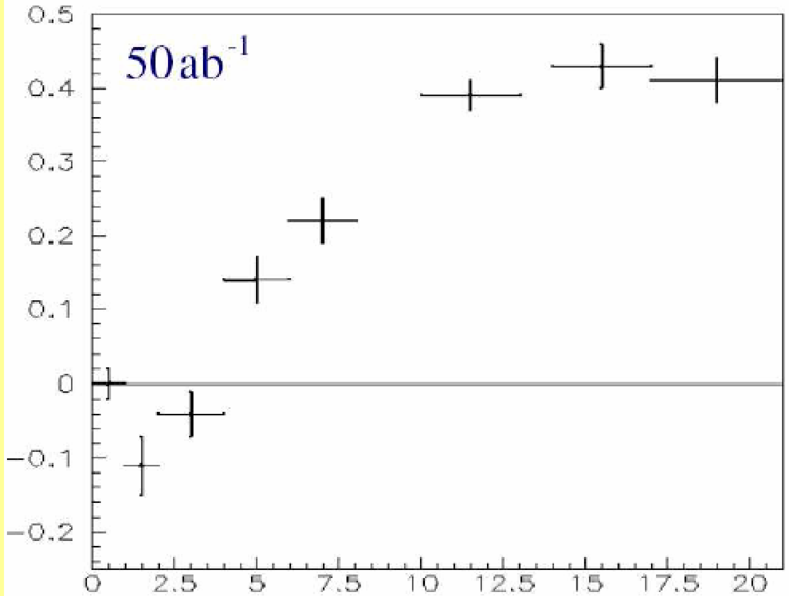
LHCb

- $2\ \text{fb}^{-1}$: $(4.0 \pm 1.2)\ \text{GeV}^2$
- $10\ \text{fb}^{-1}$: $(4.0 \pm 0.5)\ \text{GeV}^2$

$\Rightarrow$ 13% error on $C_7^{\text{Eff}}/C_9^{\text{Eff}}$



Super B-factory



$-A_{FB}$ vs q^2

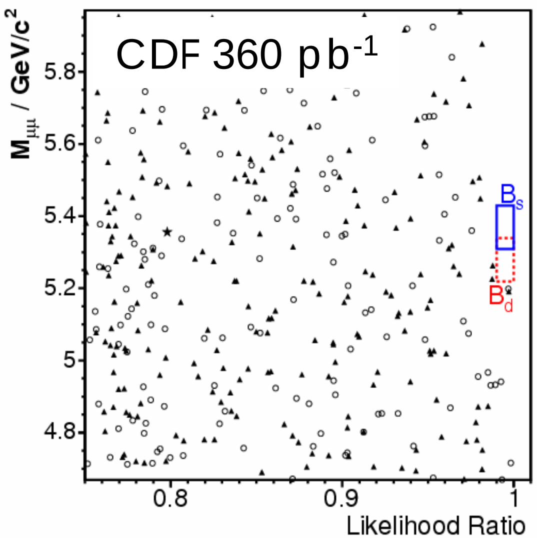
SuperB factory with $50/ab$

δC_{10} ~14%

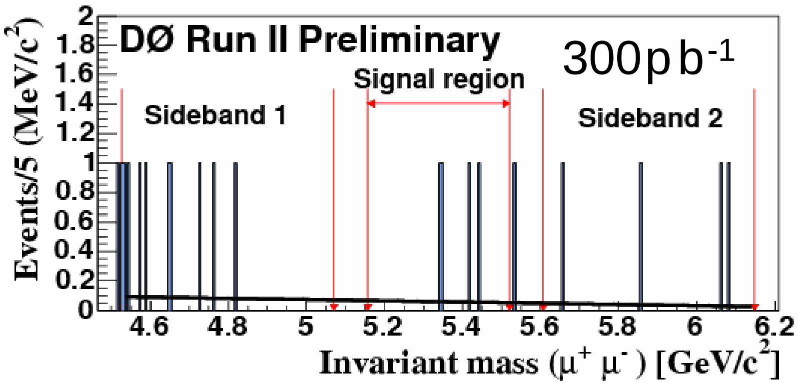
$\delta\, q_0^2/q_0^2$ ~11% ~5%

$B_s \to \mu^+\mu^-$ at Tevatron

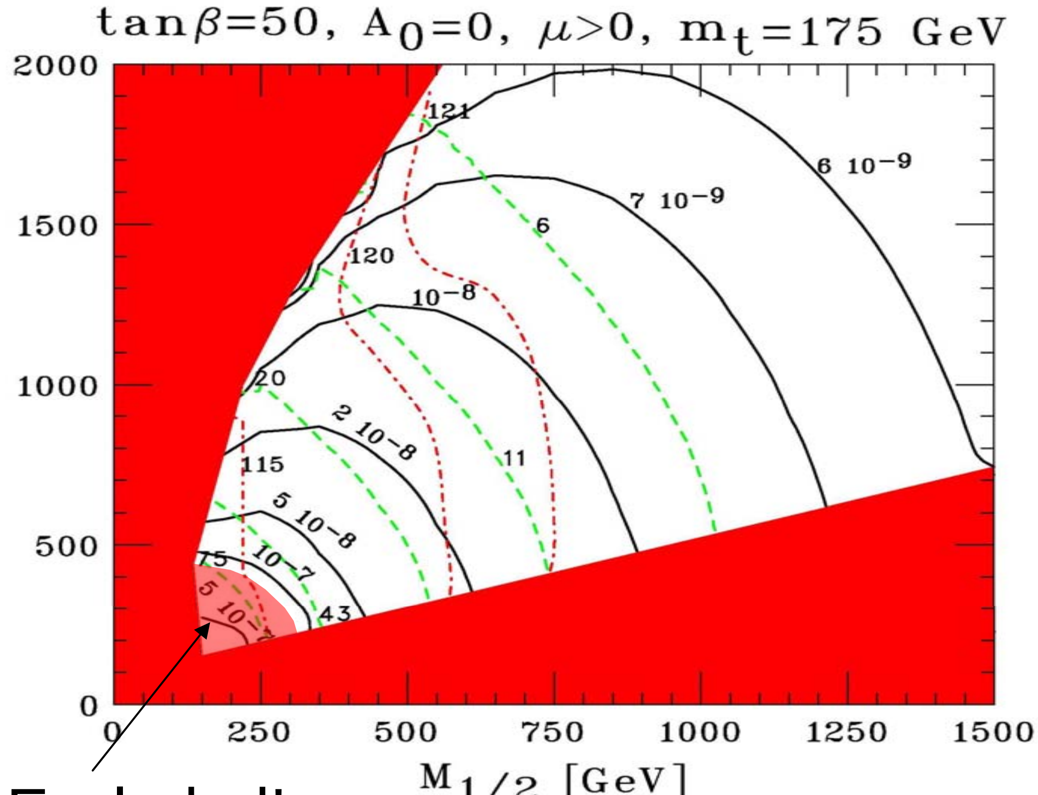
CDF & D0



$B_s \to \mu^+\mu^-$
$< 2.0\times10^{-7}$



$B_s \to \mu^+\mu^-$
$< 3.9\times10^{-7}$



Excluded!

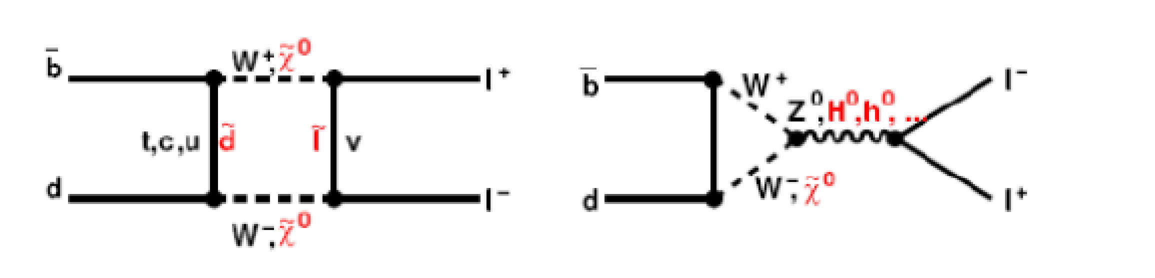
Combined limit:

- $B_s \to \mu^+\mu^- < 1.5\times10^{-7}$
  hep-ex/0508058

$B_s \to \mu^+\mu^-$ at LHC

- Very rare decay, sensitive to new physics:
  - BR ~ 3.5 × 10^{-9} in SM, can be strongly enhanced in SUSY
  - Current limit from Tevatron (CDF+D0): 1.5 × 10^{-7} at 95% CL

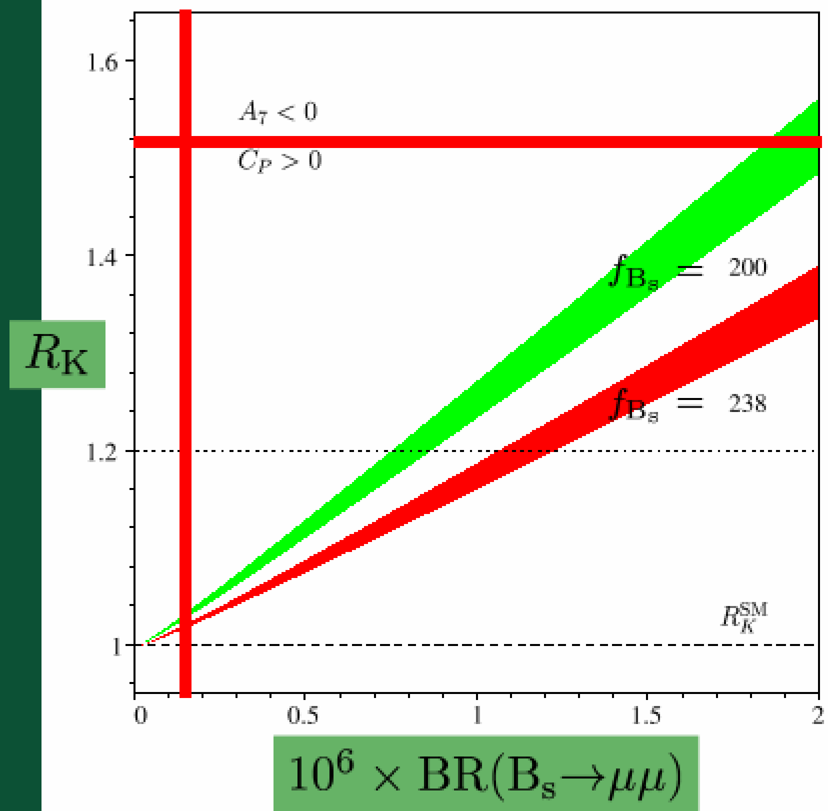
Schneider
Speer
Nikitine



		$B_s \to \mu^+ \mu^-$ signal (SM)	$b \to \mu$, $b \to \mu$ background	Inclusive bb background	Single event sensit. [10^{-10}]
LHCb	1 yr - 2 fb^{-1}	17	< 100	< 7500	
ATLAS	10 fb^{-1} 30 fb^{-1}	7 21	~ 20 ~ 60		2.7 0.9
CMS	10 fb^{-1} 100 fb^{-1}	7 26	< 1 < 6.4		

Relation to $B_s \to \mu\mu$

$R_K = \Gamma(B \to K\mu\mu) / \Gamma(B \to Kee)$



[Hiller & Krüger, hep-ph/0310219]

Experimental status:

R_X	BaBar ($208\ fb^{-1}$) [hep-ex/0507005]
R_K	$1.06 \pm 0.48 \pm 0.05$
R_{K^*}	$0.93 \pm 0.46 \pm 0.12$
	Belle ($250\ fb^{-1}$) [hep-ex/0410006]
R_K	$1.38\ ^{+0.39}_{-0.41}\ ^{+0.06}_{-0.07}$
R_{K^*}	$0.98\ ^{+0.30}_{-0.31} \pm 0.08$

$B_s \to \mu\mu$: The present CDF limit is $1.5 \cdot 10^{-7}$ at 90% CL [hep-ex/0508036]

Summary

Table from G. Isidori

th. error $\lesssim 10\%$
○ (grey) = exp. error $\lesssim 10\%$
○ = exp. error $\sim 30\%$

FLAVOUR COUPLING:

ELECTROWEAK STRUCTURE	$b \to s$ $(\sim\lambda^2)$	$b \to d$ $(\sim\lambda^3)$	$s \to d$ $(\sim\lambda^5)$
$\Delta F=2$ 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	$B_s \to \mu\mu$	$B_d \to \mu\mu$	$K_{L,S} \to \mu\mu$

Still a lot of room for B physics contributions from LHC !

Pattern of Deviation from SM

Table from M. Hazumi

Unitarity triangle | Rare decays

	B_d-unitarity	ε	$\Delta m(B_s)$	$B \to \phi K_S$	$B \to X_s\gamma$ indirect CP	$b \to s\gamma$ direct CP
mSUGRA	-	-	-	-	-	+
SU(5)SUSY GUT + nR (degenerate)	-	+	+	-	+	-
SU(5)SUSY GUT + nR (non-degenerate)	-	-	+	++	++	+
U(2) Flavor symmetry	+	+	+	++	++	++

++: Large, +: sizable, -: small

"DNA Identification" of New Physics from Flavor Structure

T.Goto, Y.Okada, Y.Shimizu,T.Shindou, M.Tanaka (2002, 2004) + SuperKEKB LoI

Conclusions

- CKM mechanism is very likely dominant source for ~~CP~~ in quark sector
  - B-factories (BaBar and BELLE) have succeeded beyond their own expectations
  - Complete alternatives ruled out, e.g. superweak
  - Size and phase of NP contributions in B_d mixing ($b \to d$) severely constrained
  - Large corrections in $b \to s$ transitions still possible, e.g. B_s mixing
- The hadronic flavour sector will contribute significantly to the overall LHC effort to find and study New Physics beyond the SM
  - New Physics will be probed at LHC in B meson loop decays
    - **Unique access to excellent $b \to s$ observables**
      B_s mixing magnitude and phase, exclusive $b \to s\mu\mu$, $B \to \mu\mu$
    - Large phase space can already be covered with the first 10^7 s of data
  - LHCb will improve precision on CKM angles
    - **Several γ measurements from tree decays**: $\sigma_{stat}(\gamma)$ ~2.5° in 5 years
    - May reveal inconsistencies with other/indirect measurements after several years
  - Looking forward to start of LHC machine commissioning and first collisions in 2007
    - LHCb aiming for complete detector in early 2007, ready to exploit nominal luminosity from day 1
    - Possible competition ATLAS/CMS specific areas
    - Any evidence of NP from B factories?