Johns Hopkins 36th Workshop

Latest News on the Fermi scale from LHC and Dark Matter searches

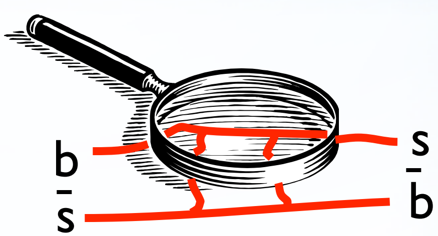
Conference

Status of indirect searches for NP in Flavour Physics at LHC.

Frederic Teubert

CERN, PH Department

on behalf of the LHCb Collaboration, including results from ATLAS and CMS



Indirect Searches for NP

If the **energy** of the particle collisions is high enough, we can discover NP detecting the production of "real" new particles.

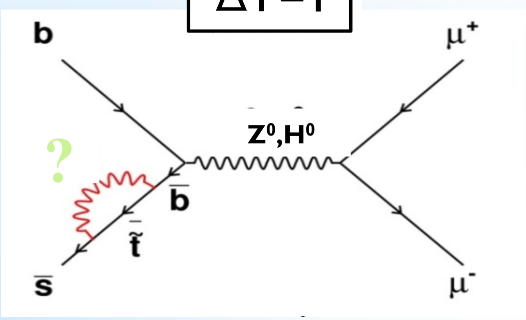
If the **precision** of the measurements is high enough, we can discover NP due to the effect of "virtual" new particles in loops.

Contrary to what happens in "non-broken" gauge theories like QED or QCD, the effect of **heavy ($M>q^2$) new particles does not decouple** in weak and Yukawa interactions.

Therefore, precision measurements of FCNC can reveal NP that may be **well above the TeV scale**, or can provide key information on the **couplings and phases** of these new particles if they are visible at the TeV scale.

Direct and indirect searches ***are both needed and equally important, complementing each other.***

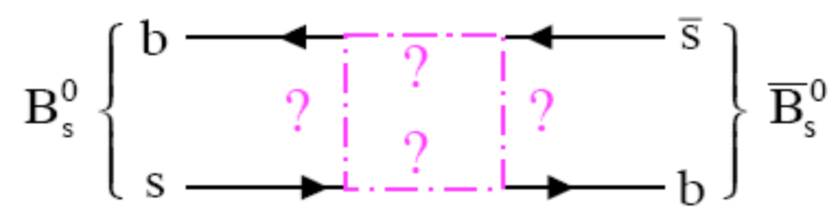
Δ F=1



$B_s \rightarrow \mu^+\mu^-$ Higgs "Penguin"

Δ F=2

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



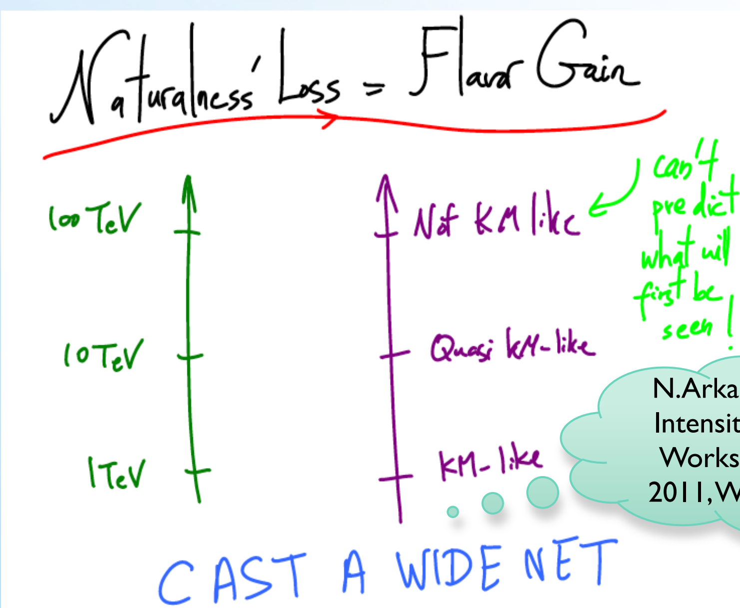
B_s–$\bar{B}_s$ oscillations: "Box" diagram

Status of Searches for NP

So far, no significant signs for NP from direct searches at LHC while a Higgs-like boson has been found with a mass of ~125 GeV/c^2.

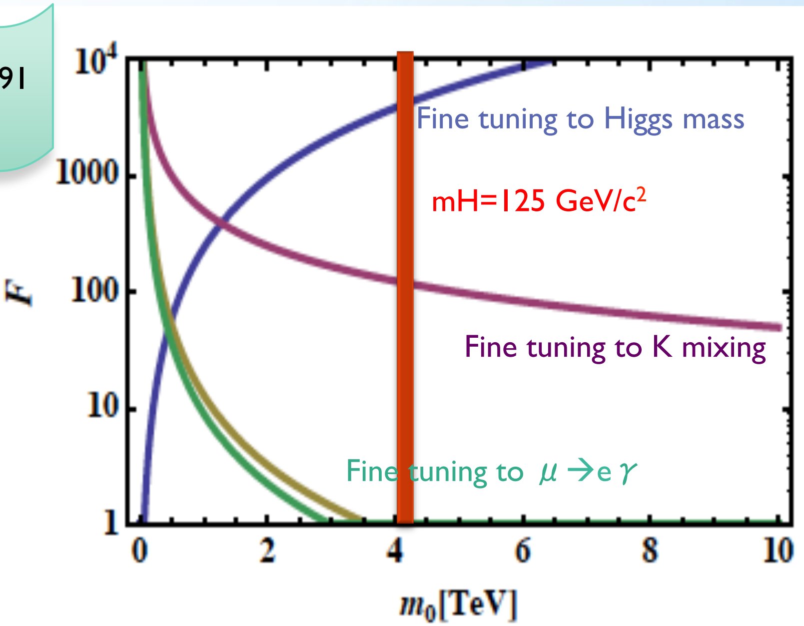
Before LHC, expectations were that *"naturally"* the masses of the new particles would have to be light in order to reduce the *"fine tuning"* of the EW energy scale. However, the absence of NP effects observed in flavour physics implies some level of *"fine tuning"* in the flavour sector → **NP FLAVOUR PROBLEM** → Minimal Flavour Violation (MFV).

As we push the energy scale of NP higher (within MSSM the measured value of the Higgs mass pushes the scale up), the NP FLAVOUR PROBLEM is reduced, hypothesis like MFV look less likely → **chances to see NP in flavour physics have, in fact, increased!**



arXiv:1205.7091

N.Arkani-Hamed, Intensity Frontier Workshop (Nov 2011, Washington)



FCNC in the SM

$U_i = \{u, c, t\}$:

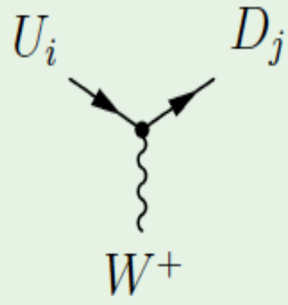
$Q_U = +2/3$

$D_j = \{d, s, b\}$:

$Q_D = -1/3$

$$\mathcal{L}_{CC} = \frac{g_2}{\sqrt{2}} (\bar{u}, \bar{c}, \bar{t}) \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \gamma^\mu P_L \begin{pmatrix} d \\ s \\ b \end{pmatrix} W^+_\mu$$

~ Cabibbo-Kobayashi-Maskawa (CKM) matrix



In the SM quarks are allowed to change flavour as a consequence of the Yukawa mechanism which is parameterized in a complex CKM couplings matrix. Using Wolfenstein parameterization:

A=0.81±0.02
λ = 0.225±0.001

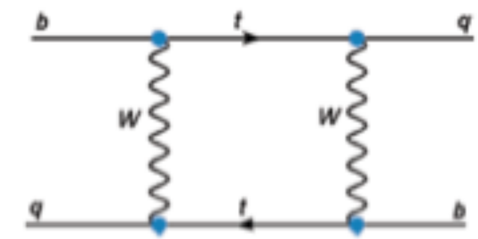
$$V = \begin{pmatrix} 1-\lambda^2/2-\lambda^4/8 & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda & 1-\lambda^2/2-\lambda^4/8(1+4A^2) & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2+A\lambda^4/2(1-2(\rho+i\eta)) & 1-A^2\lambda^4/2 \end{pmatrix} + O(\lambda^5)$$

Imposing unitarity to the CKM matrix results in six equations that can be seen as the sum of three complex numbers closing a triangle in the plane. Two of these triangles are relevant for the study of CP-violation in B-physics and define the angles:

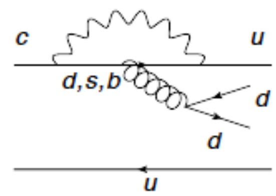
$$\alpha = \arg\left(\frac{-V_{td}V^*_{tb}}{V_{ud}V^*_{ub}}\right), \quad \beta = \arg\left(\frac{-V_{cd}V^*_{cb}}{V_{td}V^*_{tb}}\right) \text{ and } \gamma = \arg\left(\frac{-V_{ud}V^*_{ub}}{V_{cd}V^*_{cb}}\right)$$

$$\beta_s = \arg\left(\frac{-V_{cb}V^*_{cs}}{V_{tb}V^*_{ts}}\right)$$

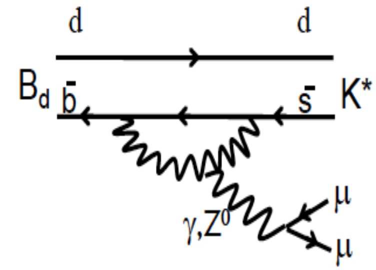
FCNC in the SM



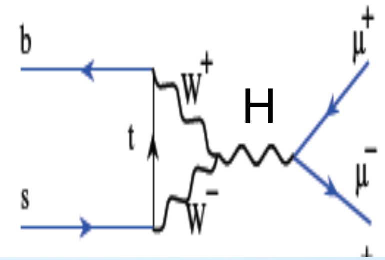
ΔF=2 box



QCD Penguin



EW Penguin



Higgs Penguin

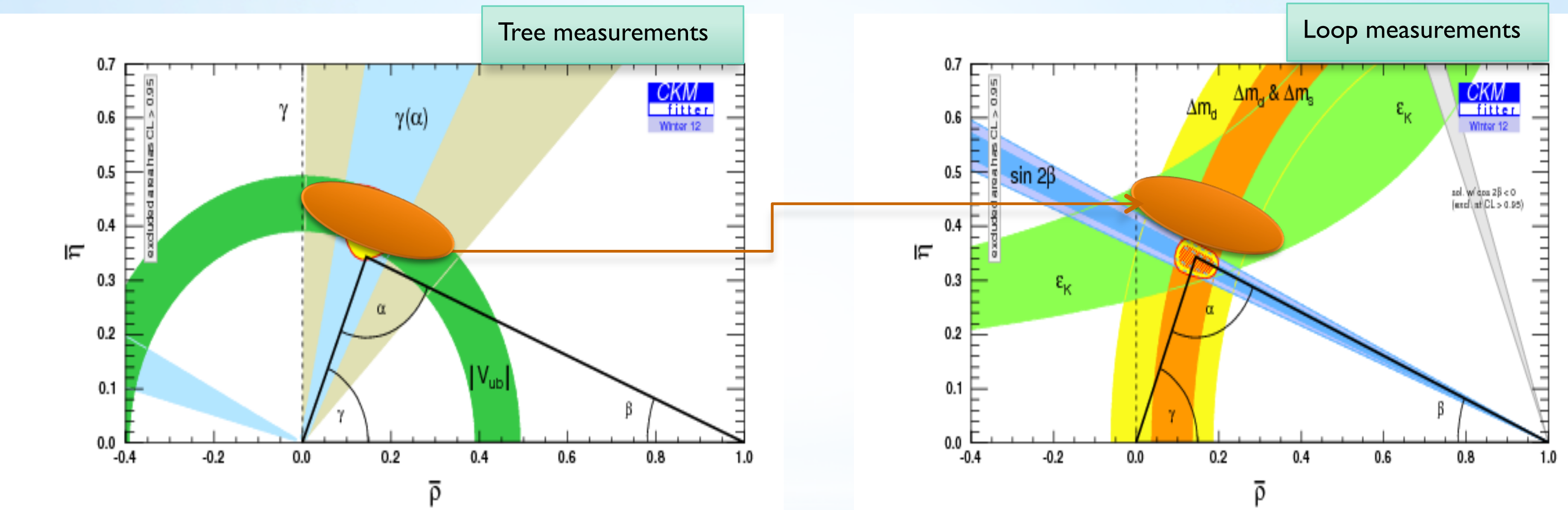
*Map of Flavour transitions and type of loop processes: → **Map of this talk!***

	b→s ($\lvert V_{tb}V_{ts}\rvert \propto \lambda^2$)	**b→d ($\lvert V_{tb}V_{td}\rvert \propto \lambda^3$)**	**s→d ($\lvert V_{ts}V_{td}\rvert \propto \lambda^5$)**	**c→u ($\lvert V_{cb}V_{ub}\rvert \propto \lambda^5$)**
ΔF=2 box	ΔM_{Bs}, **$A_{CP}(B_s \to J/\Psi\, \Phi)$**	ΔM_B, $A_{CP}(B \to J/\Psi K)$	ΔM_K, ε_K	x,y, q/p, Φ
QCD Penguin	**A_{CP}(B→hhh)**, $B \to X_s \gamma$	**A_{CP}(B→hhh)**, $B \to X \gamma$	$K \to \pi^0 ll$, ε'/ε	**Δa_{CP}(D→hh)**
EW Penguin	**$B \to K^{(*)} ll$**, $B \to X_s \gamma$	**$B \to \pi ll$**, $B \to X \gamma$	$K \to \pi^0 ll$, $K^\pm \to \pi^\pm \nu \nu$	$D \to X_u ll$
Higgs Penguin	**$B_s \to \mu \mu$**	**$B \to \mu \mu$**	**$K \to \mu \mu$**	**$D \to \mu \mu$**

Tree vs loop measurements

$\mathbf{V_{ij}}$ are not predicted by the SM. Both real and imaginary components need to be measured!

If we assume NP enters only at loop level, it is interesting to compare the determination of the CKM parameters (ρ, η) from processes dominated by tree diagrams **($\mathbf{V_{ub}}$ and γ)** with the ones from loop diagrams **(ΔM_d & ΔM_s, β and ε_K)**.



Need to improve the precision of the measurements at tree level to (dis-)prove the existence of NP phases.

Tree Level Measurements: V_{ub},V_{cb},arg(V_{ub})

V_{ub} phase: (SM value of ρ η)

q=u: with D and anti-D in same final state

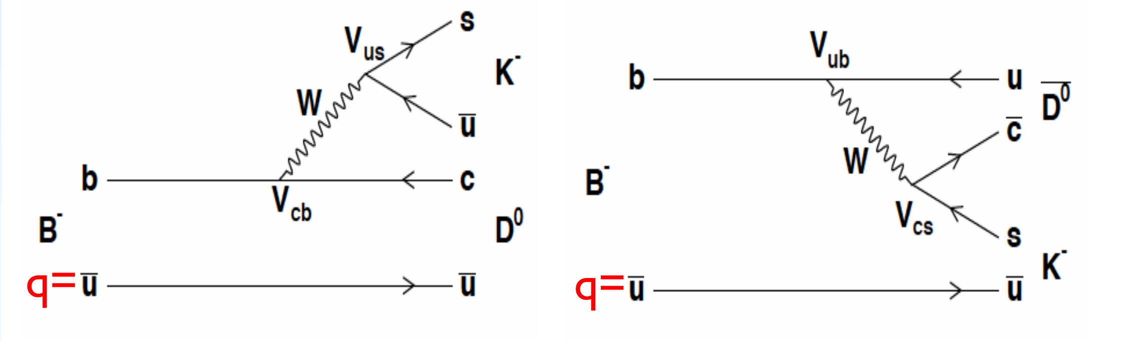
$B^{\pm}\rightarrow DX_s$ X_s={$K^{\pm}$, $K^{\pm}\pi\pi$, $K^{*\pm}$,…}

q=d: with D and anti-D in same final state

$B\rightarrow DK^*$

q=s: Time dependent CP analysis.

$B_s\rightarrow D_sK$



In the case q=u,d the experimental analysis is relatively simple, selecting and counting events to measure the ratios between B and anti-B decays. However the extraction of γ requires the knowledge of the ratio of amplitudes ($r_{B(D)}$) and the difference between the strong and weak phase in B and D decays ($\delta_{B(D)}$)→**charm factories input (CLEO/BESIII).**

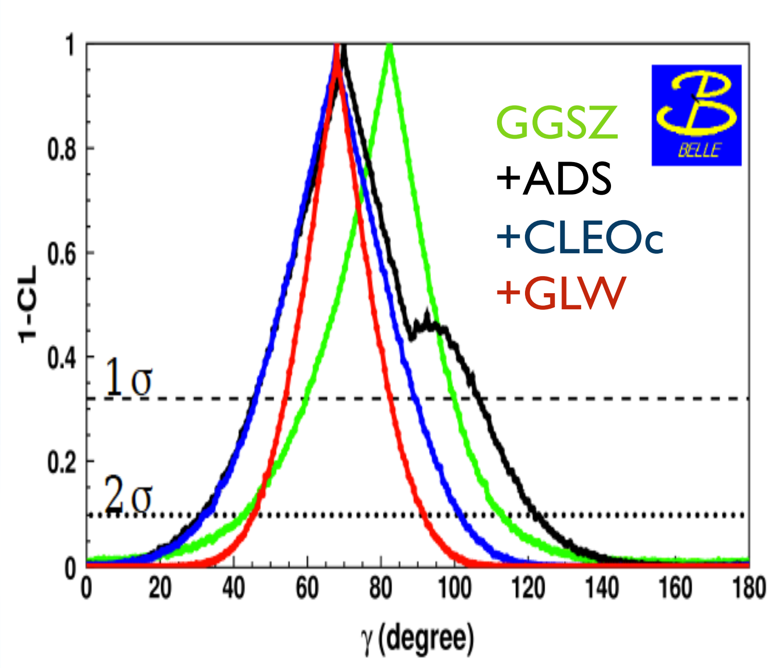
In the case q=s, a time dependent CP analysis is needed, and to extract γ we need to know β_s.

The most precise determination of γ from B-factories is from the Dalitz analysis (*GGSZ* method) of the decays $B^{\pm}\rightarrow D(K_s\pi\pi)$ $K^{\pm}$. Combining with the decays $B\rightarrow D_{CP}X_s$ (*GLW* method) and the decays $B\rightarrow D(K^+\pi^-(\pi^0))X_s$ (*ADS* method):

Results shown at CKM2012

BABAR: $\gamma = 69^{+17}_{-16}{}^\circ$ (r_b(DK)=0.092±0.013)

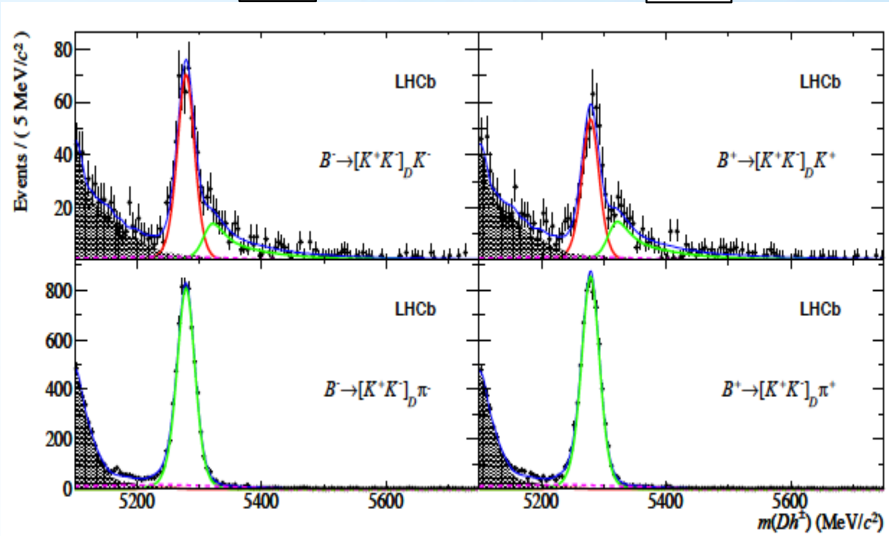
Belle : $\gamma = 68^{+15}_{-14}{}^\circ$ (r_b(DK)=0.112±0.015)



CKMFITTER combination: $\gamma = 66 \pm 12^\circ$

V_{ub} phase: LHCb using $B^{\pm} \rightarrow D[hh]h^{\pm}$ (*GLW* PLB253, 483 (1991))

B- arXiv:1203.3662 B+



Exploit interference of D0/D0-bar decaying in the same CP eigenstate.

$$R_{CP+} = 1 + r_B{}^2 + 2\kappa r_B \cos\delta_B \cos\gamma$$

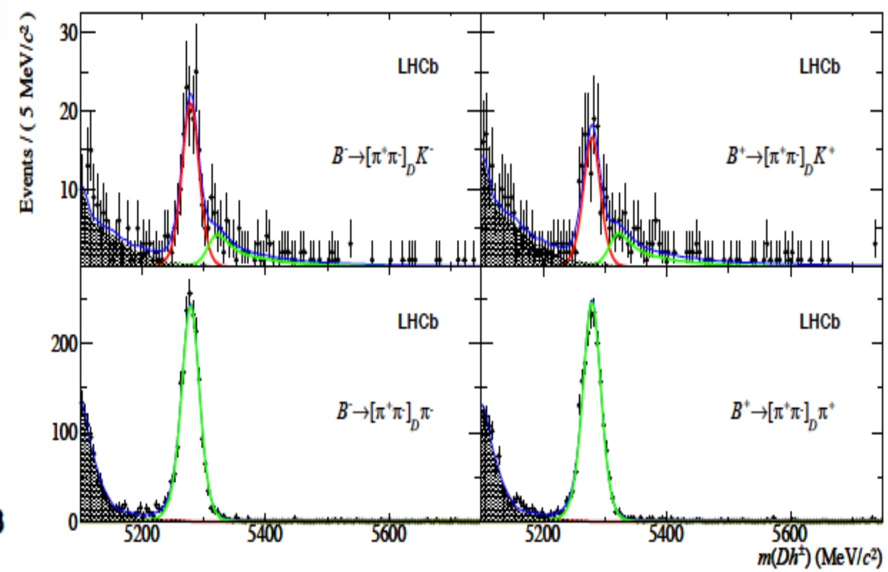
$$A_{CP+} = \frac{2\kappa r_B \sin\delta_B \sin\gamma}{R_{CP+}}$$

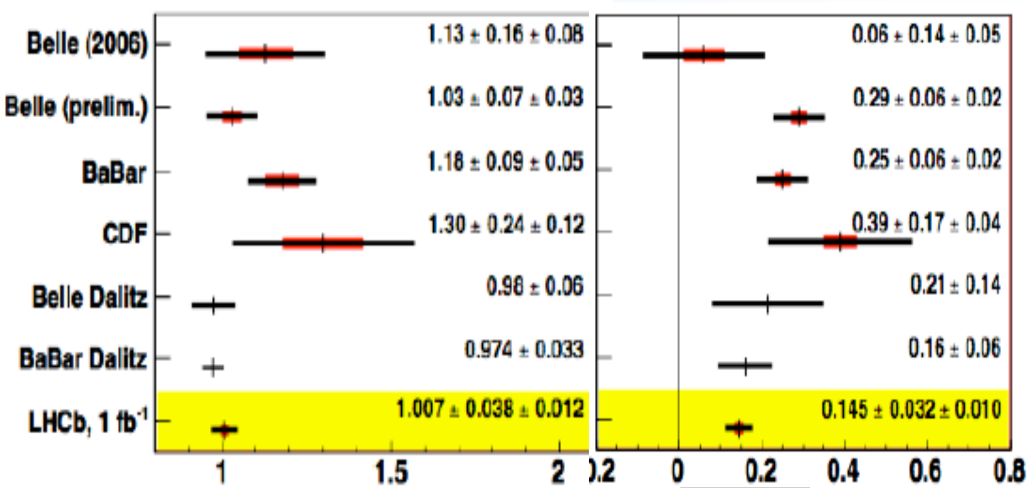
→average partial rate

→ CP asymmetry

With r_B (ratio of decay amplitudes), δ_B (strong phase difference) and κ (coherence factor [0-1]).

Clear asymmetry observed in B→DK (4.5 σ) while none observed in B→Dπ.





R_{CP+} A_{CP+}

V_{ub} phase: LHCb using $B^\pm \to D[K\pi, K3\pi]h^\pm$ (*ADS* PRL78, 3357 (1997))

Exploit interference of D0/D0-bar decaying in the same final state.

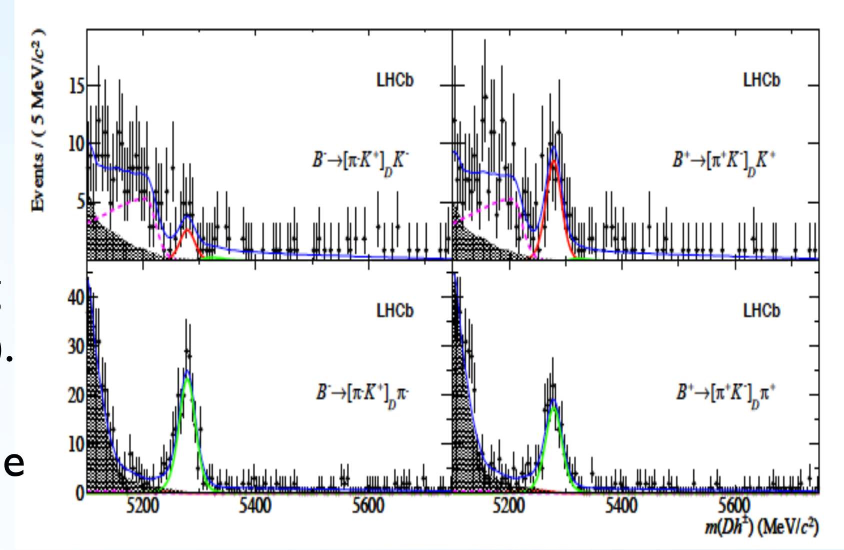
$$\mathcal{R}_s^{ADS} = {r_B}^2 + {r_D}^2 + 2\kappa r_B r_D \cos(\delta_B + \delta_D) \cos\gamma$$

$$\mathcal{A}_s^{ADS} = 2\kappa r_B r \sin(\delta_B + \delta_D) \sin\gamma / \mathcal{R}_s^{ADS}$$

With r_D (ratio of D decay amplitudes) and δ_D (strong phase difference in D amplitudes, measured at CLEOc).

Clear asymmetry observed in $B \to DK$ (4.0σ) and some evidence in $B \to D\pi$ (2.4σ). First observation of the suppressed *ADS* decays $B \to DK/D\pi$ with $D \to K3\pi$.

B^- arXiv:1203.3662 B^+



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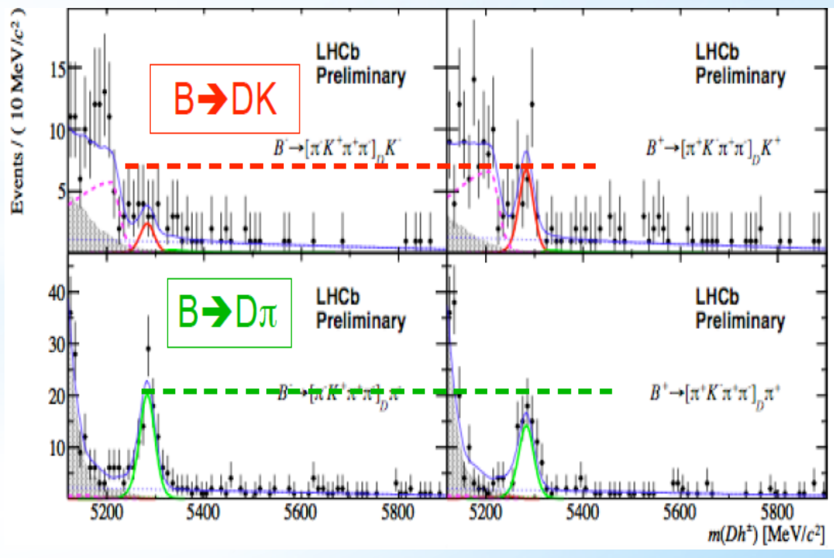
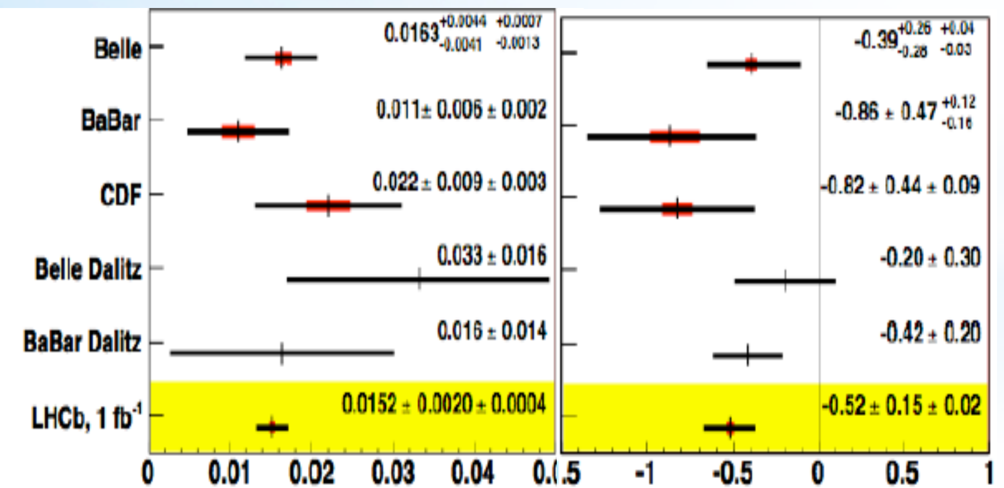


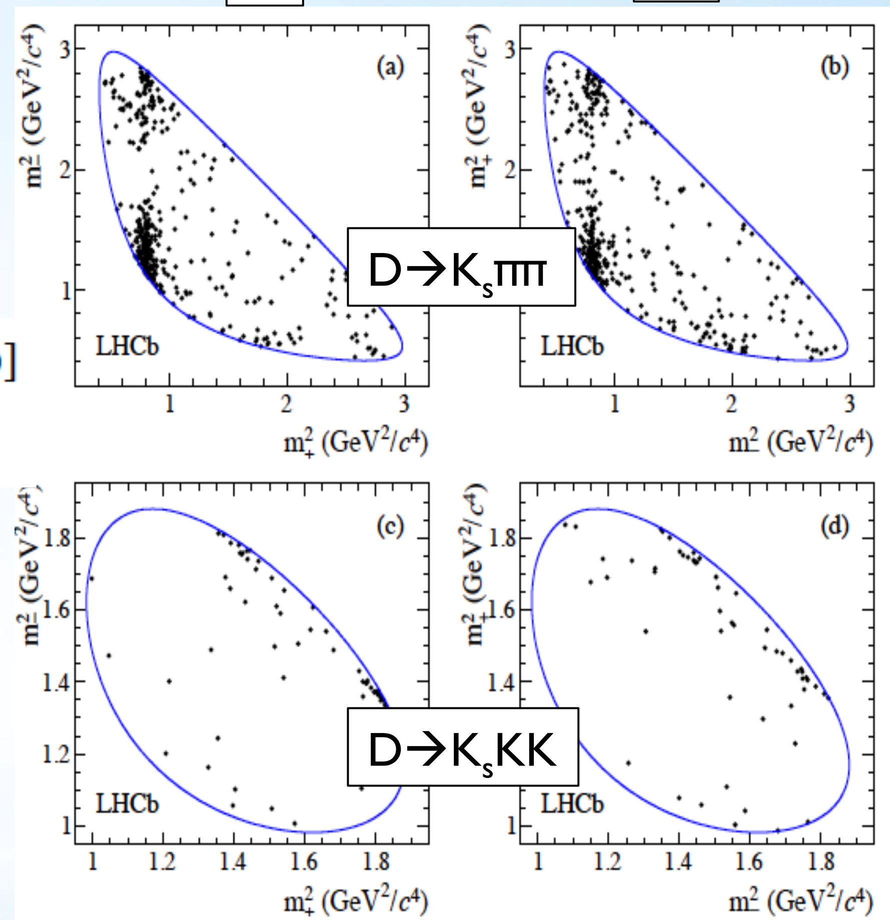


R_{ADS} A_{ADS}

V_{ub} phase: LHCb using $B^{\pm}\to D[K_s hh]h^{\pm}$ (*GGSZ* PRD68, 054018 (2003))

The difference between the strong phase between D0 and anti-D0 varies over the Dalitz bin. Rather than using a model, take bin by bin the measured values at CLEO → clean definition of systematic.

B⁻ arXiv:1209.5869 B⁺

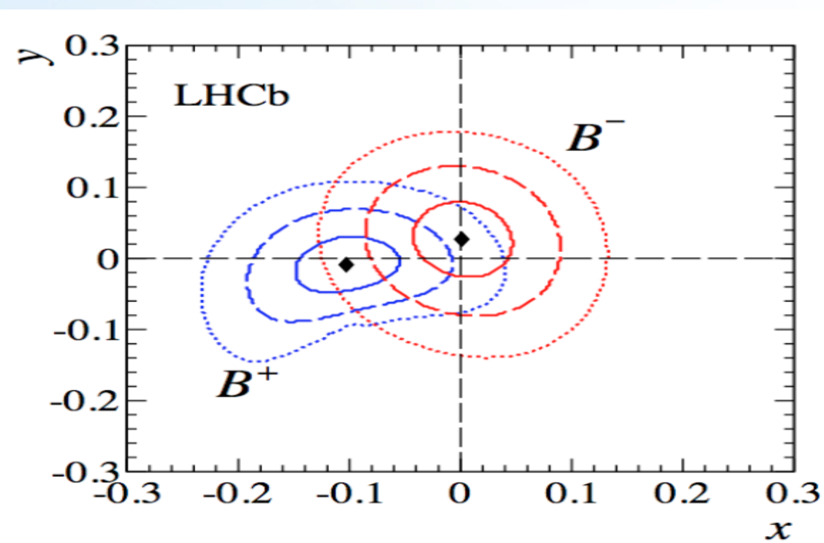


In each bin count the number of candidates:

$$N^{+}_{+i} = n_{B^+}[K_{-i} + (x_+^2 + y_+^2)K_{+i} + 2\sqrt{K_{+i}K_{-i}}(x_+c_{+i} - y_+s_{+i})]$$

$$x_{\pm} = r_B\cos(\delta_B \pm \gamma), y_{\pm} = r_B\sin(\delta_B \pm \gamma)$$

where for each bin (i), K_i is the flavour tagged yield, c_i and s_i are CLEO inputs. Essentially a counting experiment in each bin of the Dalitz plot



(stat)±(syst)±(CLEO)

$$x_- = (0.0 \pm 4.3 \pm 1.5 \pm 0.6) \times 10^{-2}, \quad y_- = (2.7 \pm 5.2 \pm 0.8 \pm 2.3) \times 10^{-2},$$

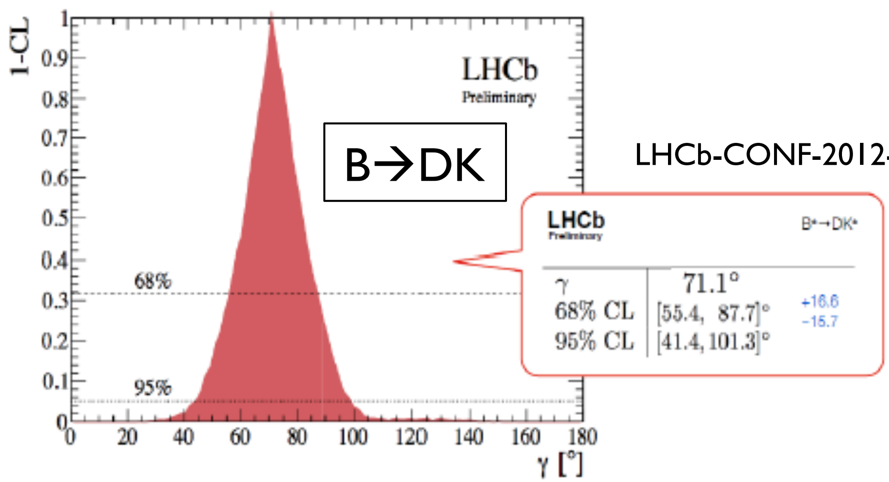
$$x_+ = (-10.3 \pm 4.5 \pm 1.8 \pm 1.4) \times 10^{-2}, \quad y_+ = (-0.9 \pm 3.7 \pm 0.8 \pm 3.0) \times 10^{-2},$$

Similar precision as B-factories.

V_{ub} phase:LHCb combination

Analysis	N_{obs}	Parameters
$B^+ \to Dh^+$, $D \to hh$, GLW/ADS	14	γ, r_B, δ_B, r_B^π, δ_B^π, $R_{K/\pi}$, $r_{K\pi}$, $\delta_{K\pi}$, ΔA_{CP}
$B^+ \to DK^+$, $D \to K_S^0 h^+ h^-$, GGSZ	4	γ, r_B, δ_B
$B^+ \to Dh^+$, $D \to K\pi\pi\pi$, ADS	7	γ, r_B, δ_B, r_B^π, δ_B^π, $R_{K/\pi}$, $r_{K3\pi}$, $\delta_{K3\pi}$, $\kappa_{K3\pi}$
Cleo $D^0 \to K\pi$, $D^0 \to K\pi\pi\pi$	9	x_D, y_D, $\delta_{K\pi}$, $\delta_{K3\pi}$, $\kappa_{K3\pi}$, $r_{K\pi}$, $r_{K3\pi}$, $\mathcal{B}(K\pi)$, $\mathcal{B}(K\pi\pi\pi)$
ΔA_{CP}	1	ΔA_{CP}

Available analysis combined to extract value of γ. However notice the large multi-parameter fit!



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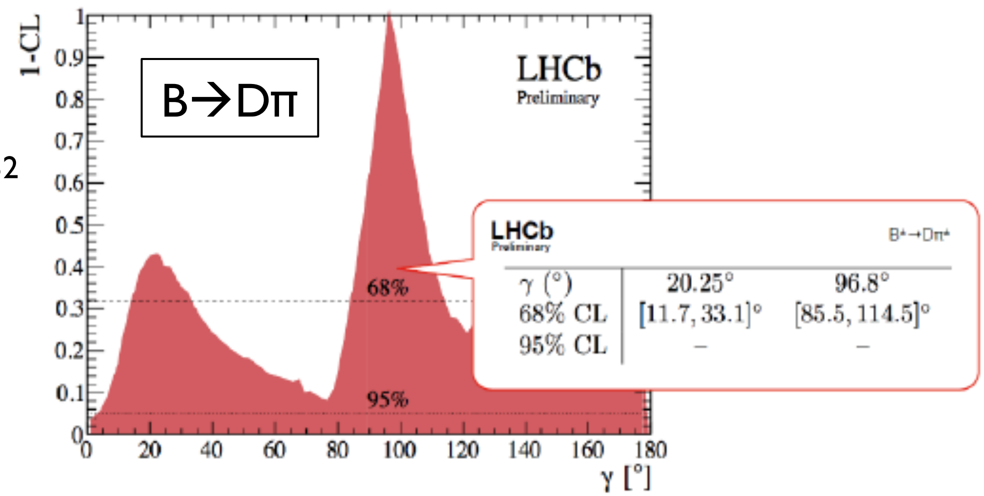


Second solution appears when including B→Dπ, which is within one sigma of the B→DK.

BABAR: $\gamma = 69\ ^{+17}_{-16}{}^\circ$ (r_b(DK)=0.092±0.013)
Belle : $\gamma = 68\ ^{+15}_{-14}{}^\circ$ (r_b(DK)=0.112±0.015)
LHCb : $\gamma = 71\ ^{+17}_{-16}{}^\circ$ (r_b(DK)=0.095±0.009)
preliminary

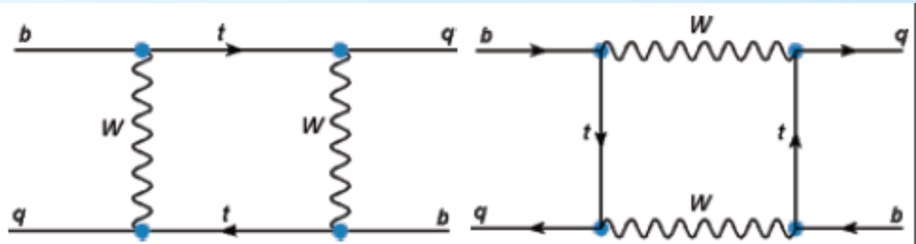
Naïve average: $\gamma = 70\pm10°$

ΔF=2 Box Measurements

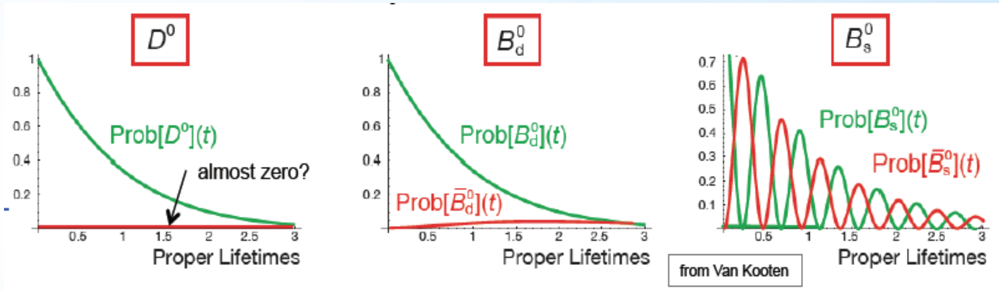
ΔF=2 box in b→q transitions theory

dispersive absorptive

$$i\frac{d}{dt}\begin{pmatrix}|B_q(t)\rangle\\ |\bar{B}_q(t)\rangle\end{pmatrix} = \left(\hat{M}^q - \frac{i}{2}\hat{\Gamma}^q\right)\begin{pmatrix}|B_q(t)\rangle\\ |\bar{B}_q(t)\rangle\end{pmatrix}$$



In principle one expects NP to affect the dispersive part, i.e. new heavy particles ($M>q^2$) contributing virtually to the box diagram. The absorptive part is dominated by the production of real light particles ($M<q^2$).



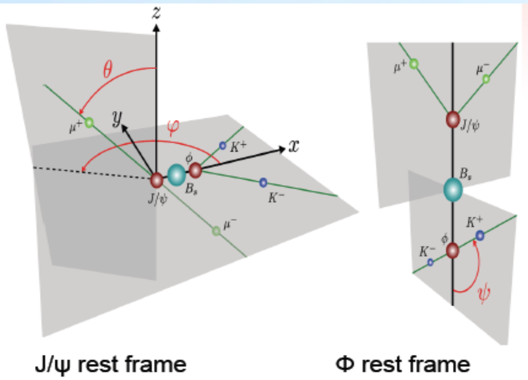
The oscillation frequency is given by
$\Delta M_q \sim 2|M^q_{12}|$.

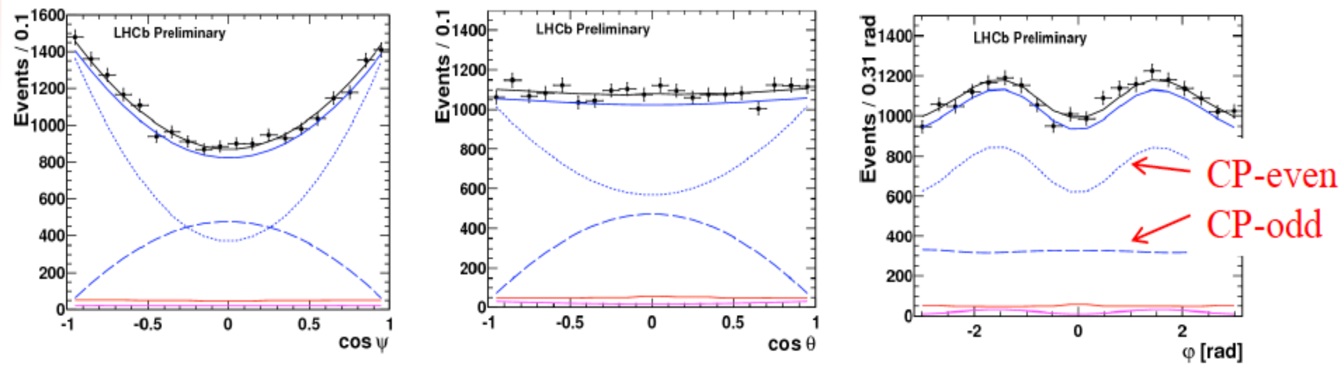
The width difference by
$\Delta\Gamma_q \sim 2|\Gamma^q_{12}|\cos(\varphi_q)$ with $\varphi_q = \arg(-M^q_{12}/\Gamma^q_{12})$.

Within the SM φ_q is very small (0.1 for B_d and 0.004 for B_s). Hence expect very small CP violation in the oscillation, or equivalently very small values for
$a^q_{fs} = |\Gamma^q_{12}/M^q_{12}|\sin(\varphi_q)$.

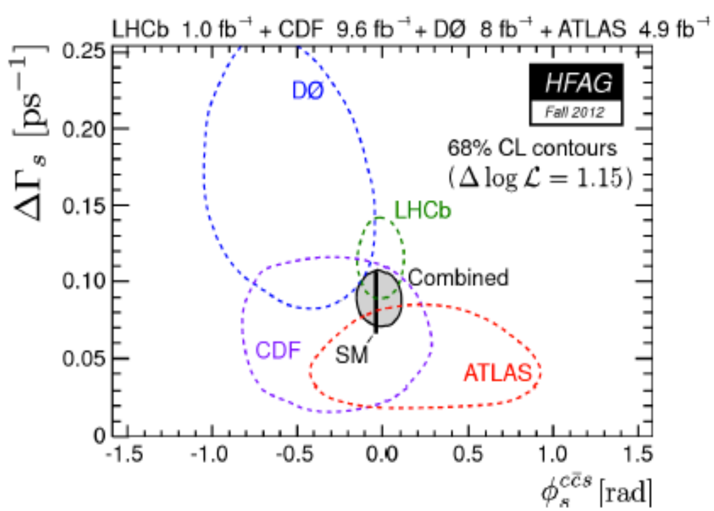
Δ F=2 box in b→s transitions

Large CP phases from NP contributing to the dispersive part (M^s_{12}) have already been excluded by the precise LHCb time-dependent angular analysis of the decay $B_s \to J/\Psi\ \Phi$.





Also ATLAS has produced a first measurement of β_s=0.22±0.42 and $\Delta\Gamma_s$ =0.053±0.022 (arXiv:1208.0572) from an untagged sample (due to larger $\Delta\Gamma_s$ sensitivity through cos(β_s)).
And CMS has produced also a first measurement of $\Delta\Gamma_s$ = 0.048±0.024 (CMS-PAS-BPH-11-006).



LHCb results: LHCb-CONF-2012-002

β_s= -0.002±0.087 (SM:-0.04)

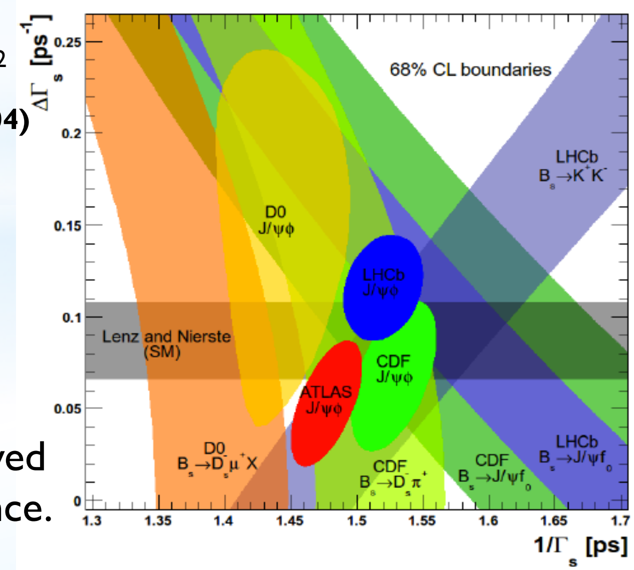
$\Delta\Gamma_s$=0.092±0.011/ps

Combined results:

β_s= $-0.013^{+0.083}_{-0.090}$

$\Delta\Gamma_s$=$0.089^{+0.011}_{-0.013}$/ps

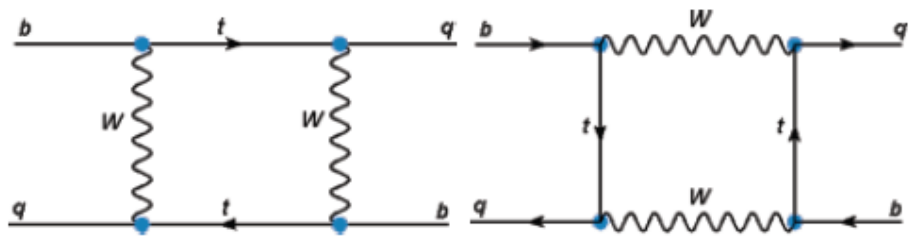
Sign ambiguity in $\Delta\Gamma_s$ removed by LHCb using m_{KK} dependence.



$\Delta F=2$ box in $b \to q$ transitions: NP in dispersive part

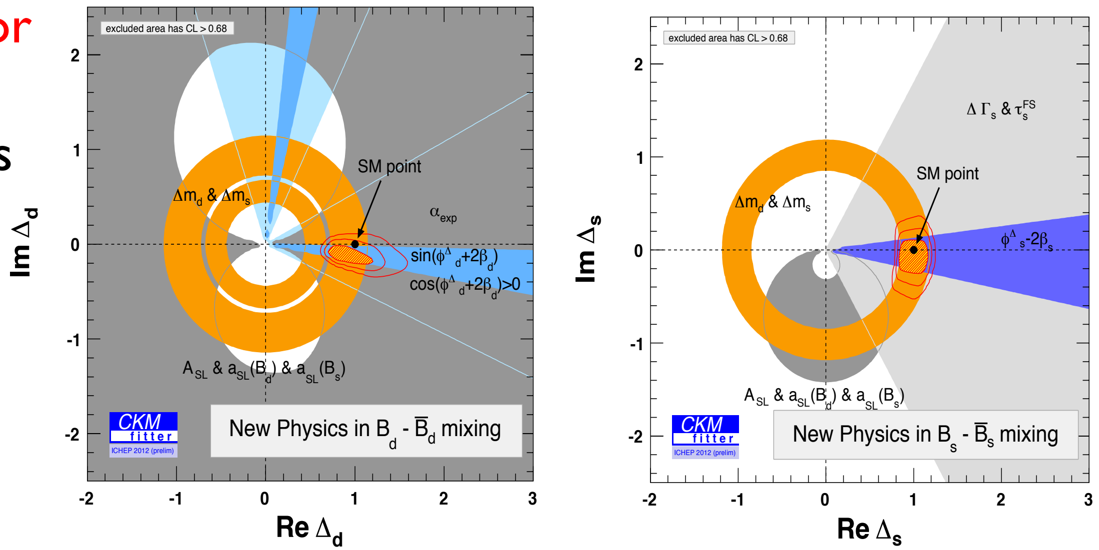
$$\langle B_q^0 | M_{12}^{SM+NP} | \overline{B}_q^0 \rangle \equiv \Delta_q^{NP} . \langle B_q^0 | M_{12}^{SM} | \overline{B}_q^0 \rangle$$

$$\Delta_q^{NP} = Re(\Delta_q) + i\, Im(\Delta_q) = |\Delta_q| e^{i\phi^{\Delta_q}}$$



Courtesy S. Descotes-Genon on behalf of CKMfitter coll.

No significant evidence of NP in B_d or B_s mixing (B_d plot updated with new $B \to \tau\ \nu$ results). B_s results much less sensitive to uncertainties in SM predictions == tree measurements.



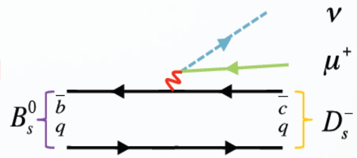
New CP phases in dispersive contribution to box diagrams constrained to be <12% (<20%) for B_d(B_s).

Need "percent" precision to disentangle new CP phases in B_d and B_s mixing

ΔF=2 box in b→q transitions (flavour specific asymmetries)

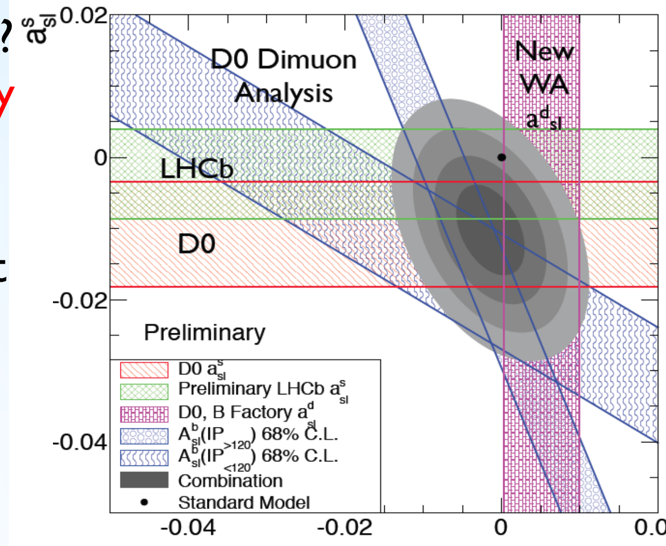
$B_q^0 \to D_q^- \mu^+ \nu_\mu$: Allowed

$\overline{B}_q^0 \to D_q^- \mu^+ \nu_\mu$: Not allowed directly



$$a_{SL}^q = \frac{\Gamma(\overline{B}(t)\to f) - \Gamma(B(t)\to \overline{f})}{\Gamma(\overline{B}(t)\to f) + \Gamma(B(t)\to \overline{f})} = \frac{N_b^{++} - N_b^{--}}{N_b^{++} + N_b^{--}}$$

Could it be that we have large NP effects in the absorptive part?
D0 measurement of the flavour specific semileptonic asymmetry uses also the much larger sample of single muons (with much reduced sensitivity to a_{SL} but similar background than dimuon) to reduce drastically systematic uncertainties. The measurement is a linear combination of $a_{SL}(B_d)$ and $a_{SL}(B_s)$.



arXiv:1106.6308

D0 Dimuon: $a_{SL}(B_d)$ = (-0.12±0.52)%, $a_{SL}(B_s)$ = (-1.81±1.06)%

arXiv:1208.5813 arXiv:1207.1769

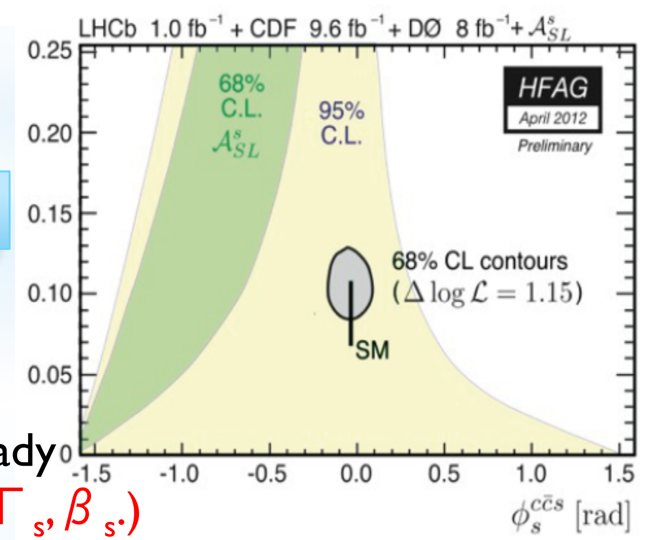
D0 exclusive: $a_{SL}(B_d)$ = (0.68±0.47)%, $a_{SL}(B_s)$ = (-1.08±0.74)%

LHCb-2012-022

LHCb exclusive ($B_s \to D_s[\Phi\pi]\mu\nu X$): preliminary **$a_{SL}(B_s)$ = (-0.24±0.63)%**

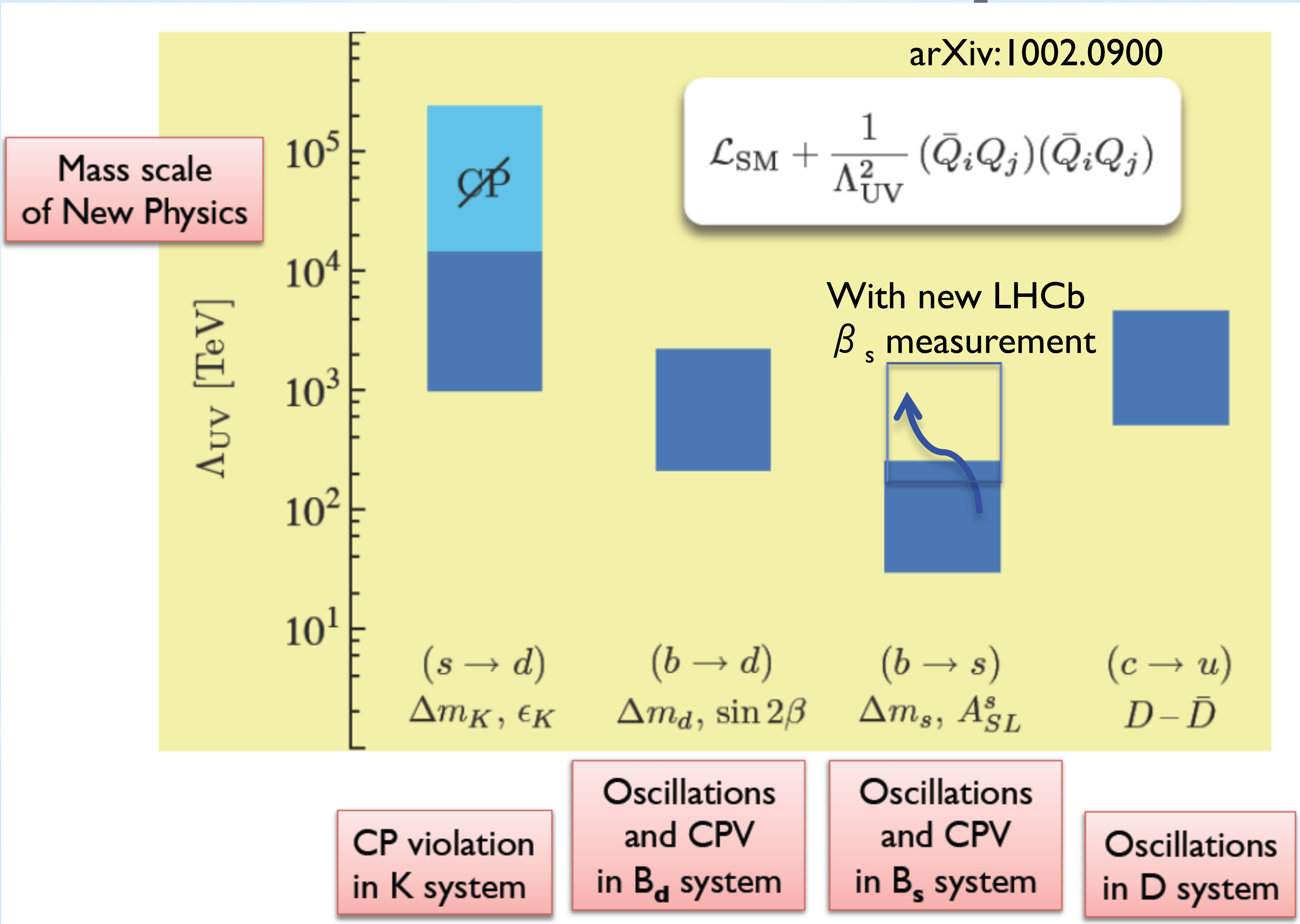
World average: $a_{SL}(B_d)$ = (-0.15±0.29)%, $a_{SL}(B_s)$ = (-1.02±0.42)%

$a_{SL}(B_s)$ is 2.5 σ from SM.



LHCb needs to add more channels and more data and a precise measurement of $A_{SL}(B_d)$ to be able to conclude, but there is already a clear tension between D0 $a_{SL}(B_s)$ and the measurement of ($\Delta\Gamma_s$, β_s.)

Δ F=2 box implications

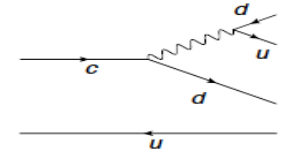


$\Delta F=1$ QCD Penguins

ΔF=1 in c→u QCD penguins: Direct CP violation in Charm decays

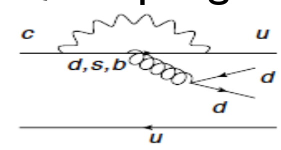
$$A_{CP}(D^0 \to h^+h^-) = \frac{\Gamma(D^0 \to h^+h^-) - \Gamma(\overline{D}^0 \to h^+h^-)}{\Gamma(D^0 \to h^+h^-) + \Gamma(\overline{D}^0 \to h^+h^-)}.$$

Tree



$(|V_{cd}V_{ud}| \propto \lambda)$
$(|V_{cs}V_{us}| \propto \lambda)$

QCD penguin



$(|V_{cb}V_{ub}| \propto \lambda^5)$

No evidence yet of CP violation in charm mixing, but could we have large (unexpected) direct CP violation in Charm (penguin) decays?

A priori, consensus was CP violation O(1%) would be "clear" sign for NP.

$\Delta A_{CP}=A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-)$ cancels detector and production asymmetries to first order. The SM and most NP models predicts opposite sign for KK and ππ, hence no sensitivity lost by taking the subtraction.

Within the SM, use of U-spin and QCD factorization leads to ΔA_{CP}~4 P/T ~0.04%. There is no problem to enhance this in NP models, the question is really if subleading SM contributions are well under control. For instance, the U-spin approximation is challenged by the measurement B(D→ππ)~2.8 B(D→KK).

A posteriori, there is no consensus if CP violation O(1%) is a "clear" sign for NP.

$\Delta F=1$ in c→u QCD penguins: Direct CP violation in Charm decays

$D^{*\pm} \to D^0 \pi^\pm \to [h^+h^-] \pi^\pm$ charge of the pion determines the flavour of D^0. Most of the systematics cancel in the subtraction, and are controlled by swapping the LHCb magnetic field. LHCb first evidence for direct CP violation in charm decays with 0.6/fb:

ΔA_{CP}=(-0.82±0.24)% LHCb (PRL 108, 111602 (2012))

TABLE II. Summary of absolute systematic uncertainties for ΔA_{CP}.

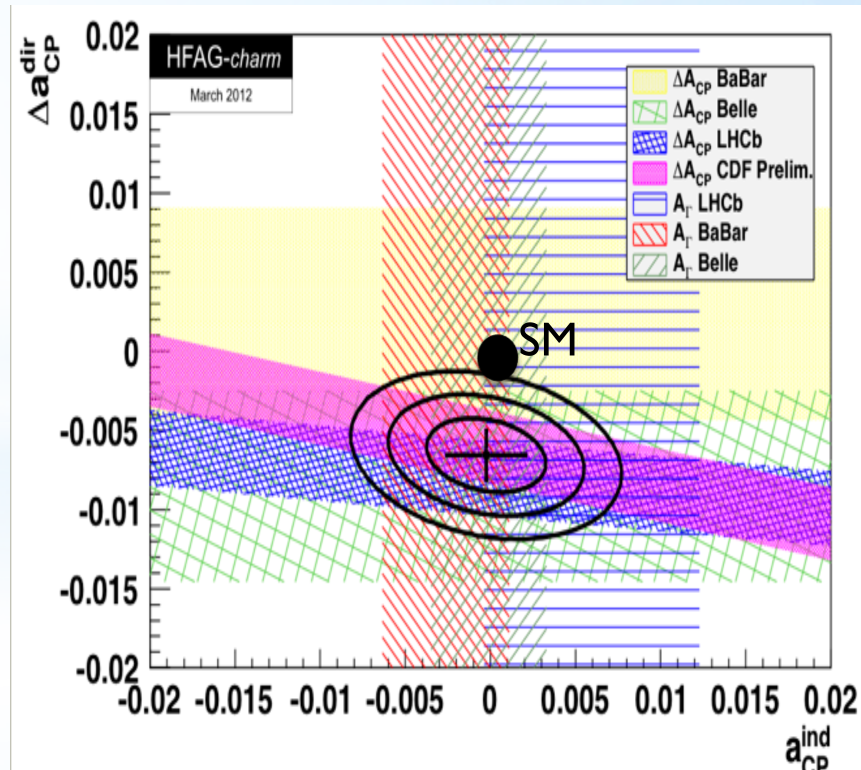
Source	Uncertainty
Fiducial requirement	0.01%
Peaking background asymmetry	0.04%
Fit procedure	0.08%
Multiple candidates	0.06%
Kinematic binning	0.02%
Total	0.11%

confirmed later by:

ΔA_{CP}=(-0.62±0.23)% CDF (PRL 109, 111801 (2012))

ΔA_{CP}=(-0.87±0.41)% BELLE (Preliminary ICHEP 2012)

$$\Delta A_{CP} \equiv A_{CP}(K^-K^+) - A_{CP}(\pi^-\pi^+) = [a_{CP}^{\rm dir}(K^-K^+) - a_{CP}^{\rm dir}(\pi^-\pi^+)] + \frac{\Delta\langle t\rangle}{\tau} a_{CP}^{\rm ind}.$$



Direct CPV evidence (>4σ)

a_{CP}^{ind} =(-0.02±0.23)%

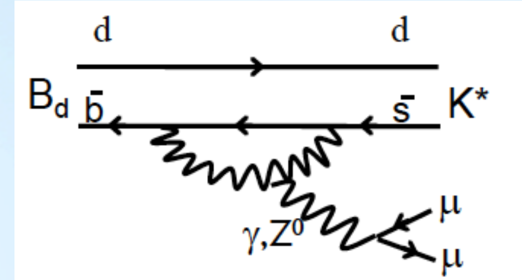
Δa_{CP}^{dir}=(-0.66±0.15)%

Is it SM or not? More work for theorists and for experiments to find CPV in related channels!

ΔF=1 EW Penguins

ΔF=1 EW penguins in b→s transitions: B→K*$\mu\mu$ angular analysis

$b \to s \; (|V_{tb}V_{ts}| \propto \lambda^2)$

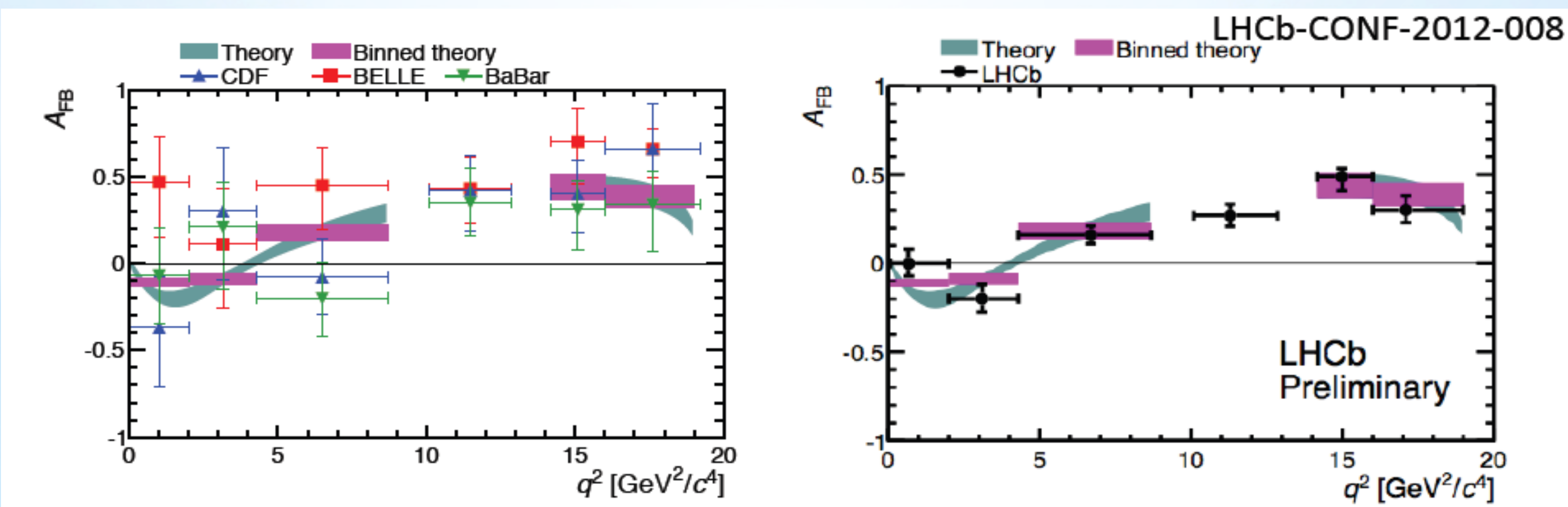


B→K*$\mu\mu$ is the golden mode to test new vector(-axial) couplings in b→s transitions. K*→Kπ is self tagged, hence angular analysis ideal to test helicity structure.

Results from **B-factories and CDF** very much limited by the statistical uncertainty. **LHCb** already has in 2011 the largest sample (~900 candidates). A_{FB} vs q^2 found to be in good agreement with SM predictions, and allowed the first determination of the zero-crossing point:

LHCb Preliminary: $q^2(A_{FB}=0)=4.9^{+1.1}_{-1.3}\ \mathrm{GeV}^2/c^4$

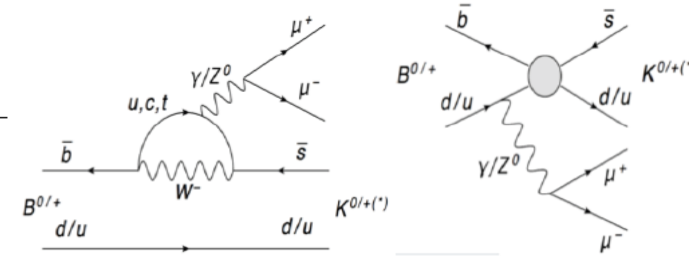
Many more theoretical clean observables are available with larger statistics.



Strong constraints in generic models of NP. Interest to improve the precision.

Δ F=1 EW penguins in b→s transitions: B→K(*)$\mu\ \mu$ Isospin analysis

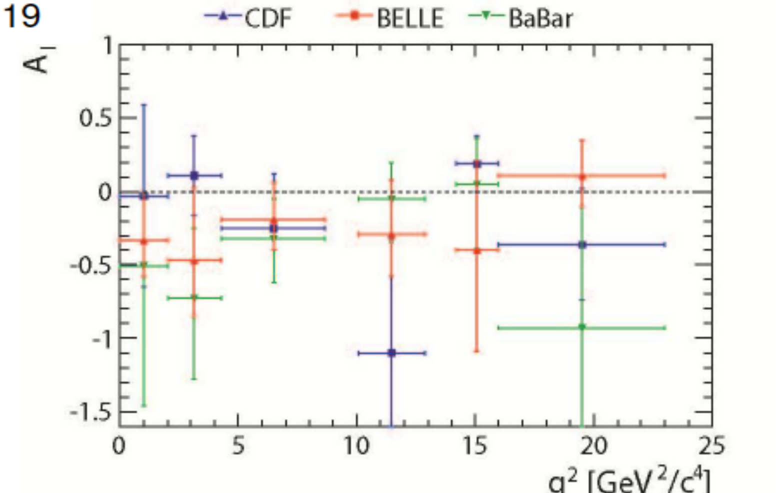
# of evts	BaBar 2012 471 M $B\bar{B}$	Belle 2009 605 fb^{-1}	CDF 2011 6.8 fb^{-1}	LHCb 2011 1 fb^{-1}
$B^0 \to K^{*0}\ell\bar{\ell}$	$137 \pm 44^{\dagger}$	$247 \pm 54^{\dagger}$	164 ± 15	900 ± 34
$B^+ \to K^{*+}\ell\bar{\ell}$			20 ± 6	76 ± 16
$B^+ \to K^+\ell\bar{\ell}$	$153 \pm 41^{\dagger}$	$162 \pm 38^{\dagger}$	234 ± 19	1250 ± 42
$B^0 \to K^0_S\ell\bar{\ell}$			28 ± 9	60 ± 19



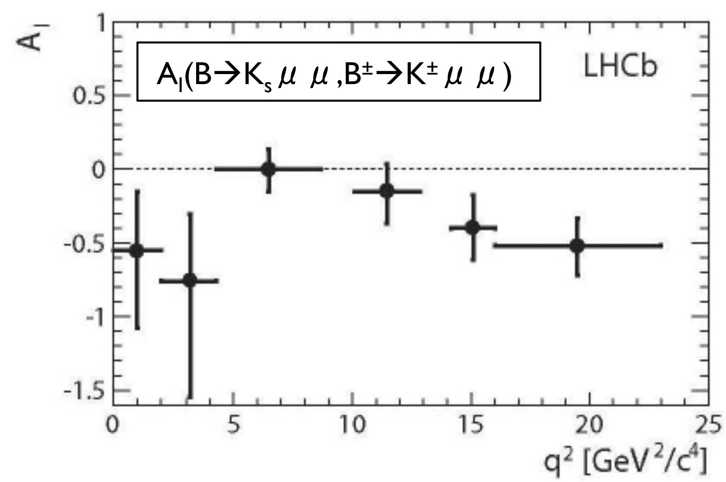
$$A_I = \frac{\mathcal{B}(B^0 \to K^{(*)0}\mu^+\mu^-) - \frac{\tau_0}{\tau_+}\mathcal{B}(B^\pm \to K^{(*)\pm}\mu^+\mu^-)}{\mathcal{B}(B^0 \to K^{(*)0}\mu^+\mu^-) + \frac{\tau_0}{\tau_+}\mathcal{B}(B^\pm \to K^{(*)\pm}\mu^+\mu^-)}$$

Within the SM the decays **B→K$\mu\ \mu$** and **B$^+$→K$^+$$\mu\ \mu$** are expected to have very similar BR, (O(%) differences at low q^2).

While this is indeed what is observed for **B→K*$\mu\ \mu$** and **B$^+$→K^{*+}$\mu\ \mu$**, **recent LHCb results** seem to confirm previous less precise measurements of the isospin asymmetry in B→K$\mu\ \mu$ decays to be significantly negative (>4σ).



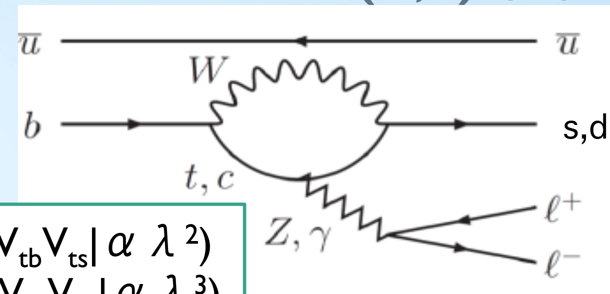
arXiv:1205.3422



[arXiv:1205.3422]

<u>No clear interpretation so far.</u>

ΔF=1 EW penguins in b→s,d transitions: $B^\pm \to (K,\pi)^\pm \mu\mu$



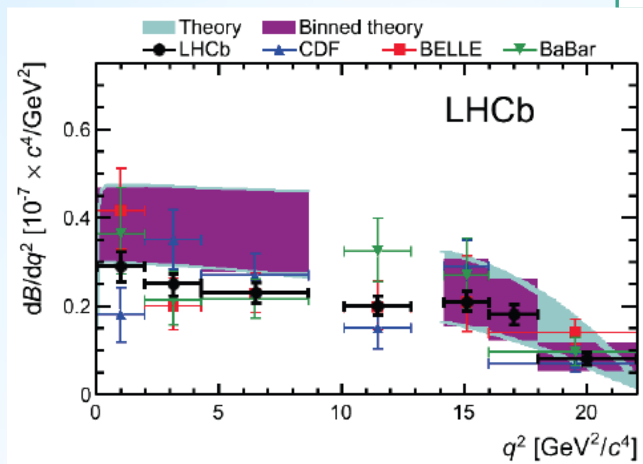
b→s ($|V_{tb}V_{ts}| \alpha \lambda^2$)
b→d ($|V_{tb}V_{td}| \alpha \lambda^3$)

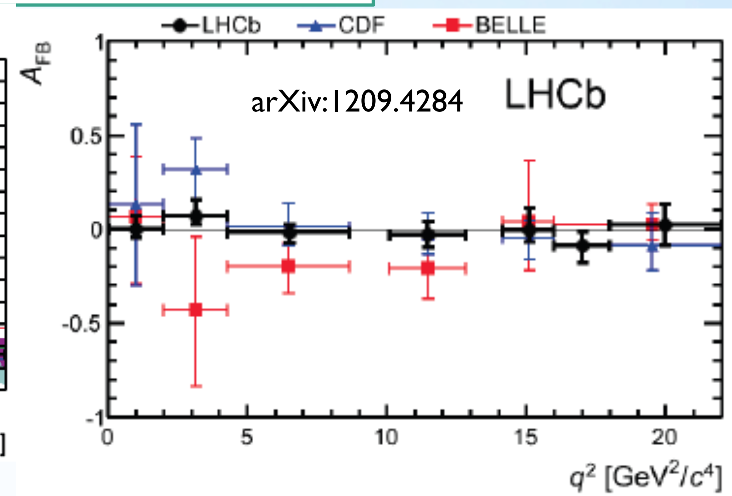
The decay $B^\pm \to K^\pm \mu\mu$ is complementary to $B \to K^* \mu\mu$, as the spin of $K^\pm$ implies much larger sensitivity to new scalar and tensor contributions. Angular analysis only depends on one angle, and A_{FB} is expected to be very close to zero in the SM.

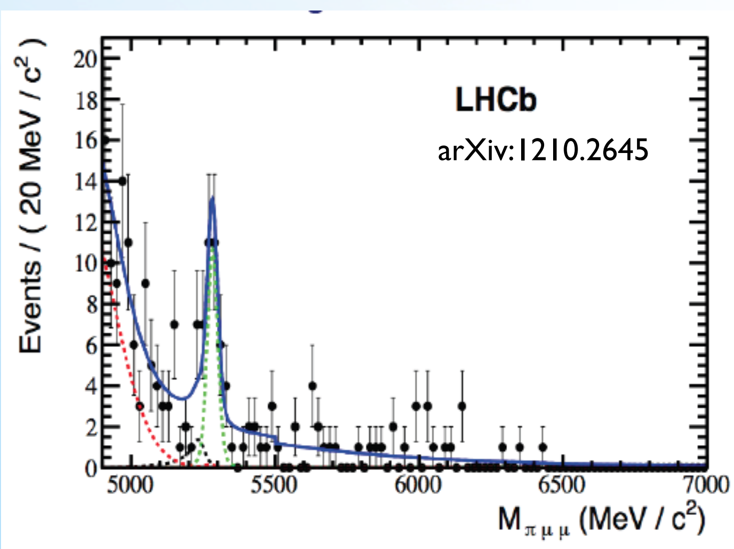
LHCb measures

$BR(B^\pm \to K^\pm \mu\mu) = (4.36 \pm 0.15 \pm 0.18) \times 10^{-7}$

compared with previous W.A. $(4.8 \pm 0.4) \times 10^{-7}$







The decay $B^\pm \to \pi^\pm \mu\mu$ is suppressed by $|V_{td}|/|V_{ts}|$. LHCb has a first observation (5.2σ) of this decay with 1/fb data.

$BR(B^\pm \to \pi^\pm \mu\mu) = (2.3 \pm 0.6 \pm 0.1) \times 10^{-8}$

in agreement with SM expectations. **The rarest B decay ever observed,** as we wait for $B_s \to \mu\mu$

Δ F=1 EW penguins in b→s transitions: Implications

$$\mathcal{H}_{\rm eff} = -\frac{4\,G_F}{\sqrt{2}} V_{tb}V_{ts}^* \frac{e^2}{16\pi^2}\sum_i (C_i O_i + C_i' O_i') + {\rm h.c.}$$

$$O_7 = \frac{m_b}{e}(\bar{s}\sigma_{\mu\nu}P_R b)F^{\mu\nu}\,, \qquad O_8 = \frac{g m_b}{e^2}(\bar{s}\sigma_{\mu\nu}T^a P_R b)G^{\mu\nu\,a}\,,$$

$$O_9 = (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \ell)\,, \qquad O_{10} = (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu\gamma_5 \ell)\,,$$

$$O_S = m_b(\bar{s}P_R b)(\bar{\ell}\ell)\,, \qquad O_P = m_b(\bar{s}P_R b)(\bar{\ell}\gamma_5\ell)\,,$$

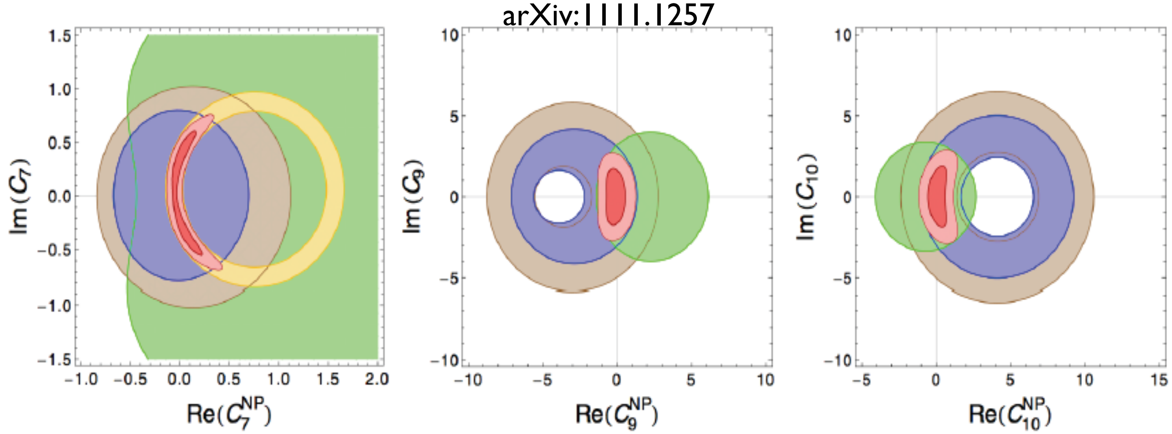
The vector(-axial) operators (O_9,O_{10}) are very much constrained by B→K* μ μ .

Radiative decays are good at constraining O_7 and O_8.

$B_{(s)}$→ μ μ (not shown here) is very effective to constrain O_S and O_P.

Complementarity of observables allow full scan of NP models.

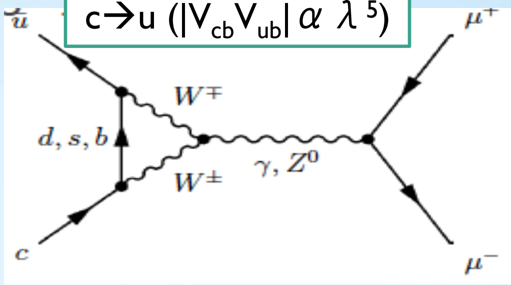
arXiv:1111.1257



Agreement with SM implies (as in Δ F=2 processes) strong limits: Either the scale of NP is in the range >15 TeV for couplings O(1) or if the couplings are loop suppressed the scale of NP is constrained to be typically >0.3 TeV in a model independent approach. Within a given model, like SUSY scenarios, correlations between observables may push the scale of NP further away.

$\Delta F=1$ Higgs Penguins

ΔF=1 Higgs penguins in c→u transitions: Charm decays



The pure leptonic decays of **D,K and B** mesons are a particular interesting case of EW penguin. The **helicity suppression** of the vector(-axial) terms, makes these decays particularly sensitive to new (pseudo-)scalar interactions →**Higgs penguins!**

Short distance contribution to D→$\mu\mu$ decays is O(10^{-18}) within the SM. Long distance contributions could be indeed much larger, but they are limited to be below 6×10^{-11} from the existing limits on D→$\gamma\gamma$. **Charm decays complement K and B mesons decays.**

Experimental control of the peaking background is crucial (D→ππ). Best existing limit before this spring/summer was from **Belle, <1.4×10^{-7}@90%C.L.**

LHCb-CONF-2012-005

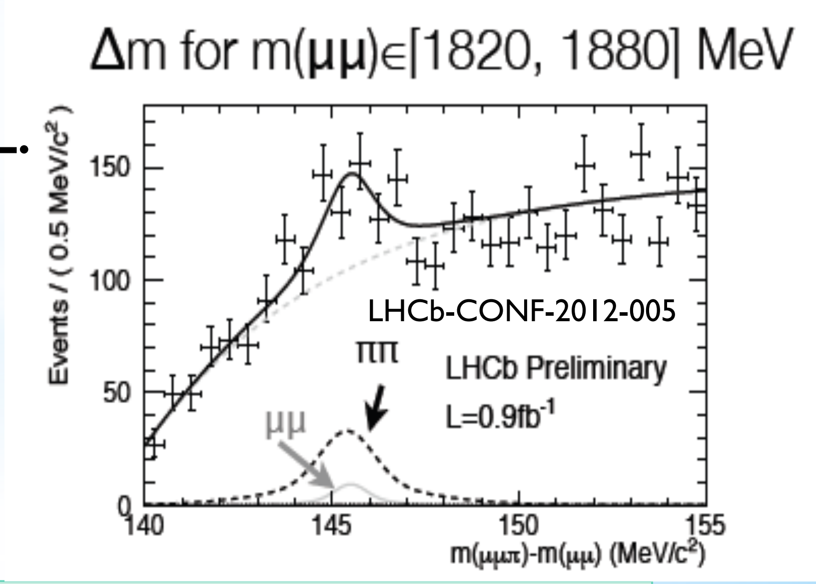
LHCb results this spring using D*→Dπ:
<1.3(1.1)$\times10^{-8}$@95(90)%C.L.

CMS results this summer: <5.4×10^{-7}@90%C.L.

CMS-PAS-BPH-11-017

BABAR results this summer show a slight excess of candidates (8 observed, 3.9±0.6 bkg) which was interpreted as a **two-sided 90% C.L. limit, [0.6,8.1]$\times10^{-7}$, tension with LHCb results.**

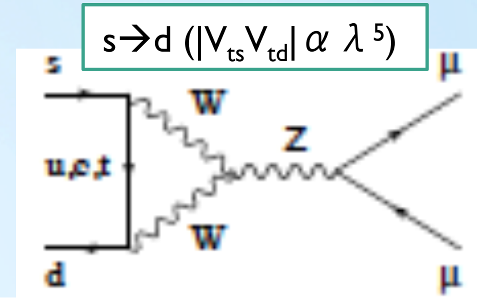
arXiv:1206.5419



LHCb will study the theoretical clean region between 10^{-8} and 10^{-11}

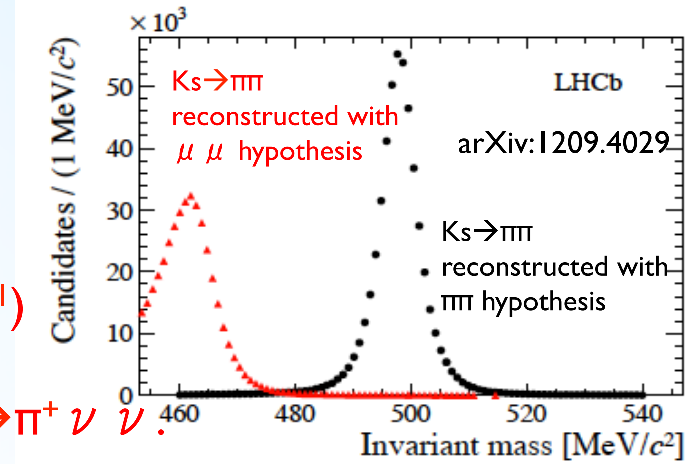
ΔF=1 Higgs penguins in s→d transitions: Kaon decays

BR($K_L \to \mu\mu$)=(6.84±0.11)x10^{-9} (BNL E871, PRL84 (2000)) measured to be in agreement with SM, but completely dominated by absorptive (long distance) contributions. In the case of $K_s \to \mu\mu$ the absorptive part is calculated to be 5x10^{-12}.



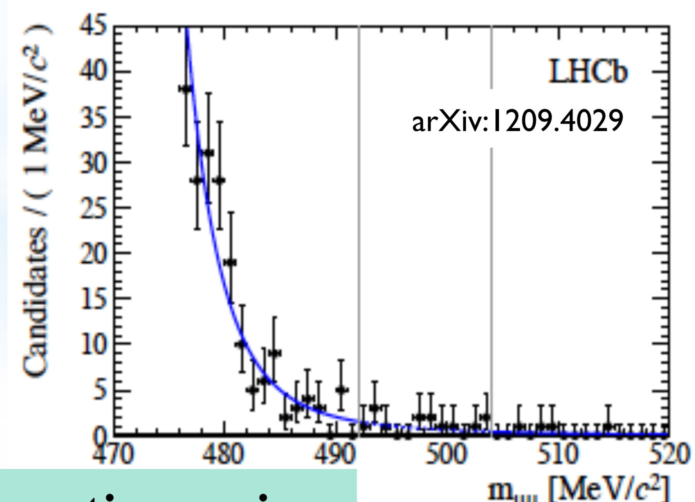
The best existing limits on $K_s \to ll$ at 90% C.L. are:

BR($K_s \to \mu\mu$)<3.2x10^{-7} (PLB44 (1973))
BR($K_s \to ee$) <9x10^{-9} (KLOE, PLB672 (2009))



In particular a measurement of BR($K_s \to \mu\mu$) of O(10^{-10}-10^{-11}) would be a clear indication of NP in the dispersive part, and would increase the interest of a precise measurement of $K^+ \to \pi^+ \nu\nu$.

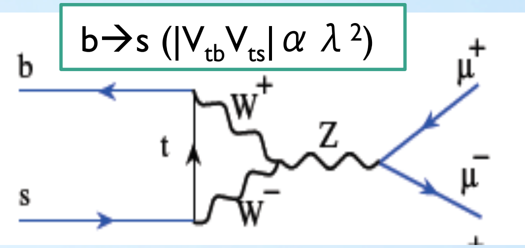
LHC produces 10^{13} K_s in the LHCb acceptance. Trigger was not optimized for this search in 2011 (it is now for the 2012 data taking period). Excellent LHCb invariant mass resolution critical to reduce peaking bkg.



Mass distribution compatible with bkg hypothesis:
BR($K_s \to \mu\mu$)<11(9)x10^{-9} at 95(90)% C.L.
x30 improvement!

Excellent prospects to reach the interesting region

ΔF=1 Higgs penguins in b→d,s transitions: B decays



The pure leptonic decay of the B mesons is well predicted theoretically, and experimentally is exceptionally clean (in particular for B_s, peaking background is very small). Within the SM,

$BR_{SM}(B_s \to \mu\mu) = (3.2\pm0.3)\times10^{-9}$ (arXiv:1208.0934, when comparing with time integrated measurement this value needs to be corrected by ~1.1)

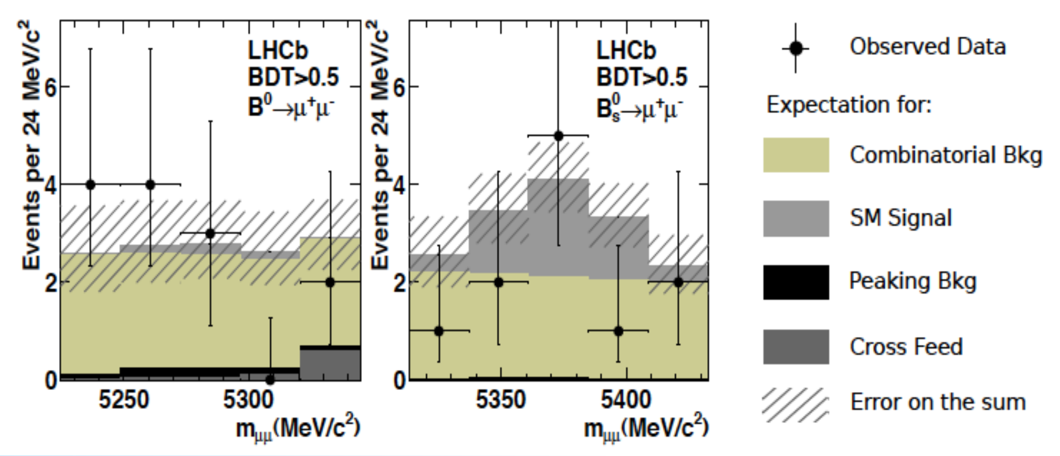
$BR_{SM}(B \to \mu\mu) = (1.0\pm0.1)\times10^{-10}$

Superb test for new (pseudo-)scalar contributions. Within the MSSM this BR is proportional to $\tan^6\beta / M_A^4$

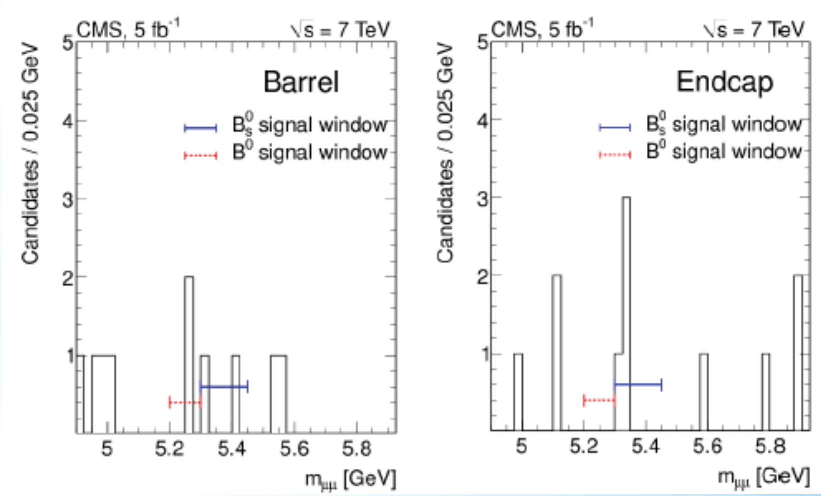
Main difficulty of the analysis is large ratio B/S. **ATLAS, CMS** and **LHCb** estimate the background expected from the sidebands. **LHCb** is also using the signal shape from control channels, rather than just a counting experiment. All experiments normalize to a known B decay ($B^+ \to J/\Psi K^+$).

In the B_s mass window the background is completely dominated by combinations of real muons (main handle is the invariant mass resolution).

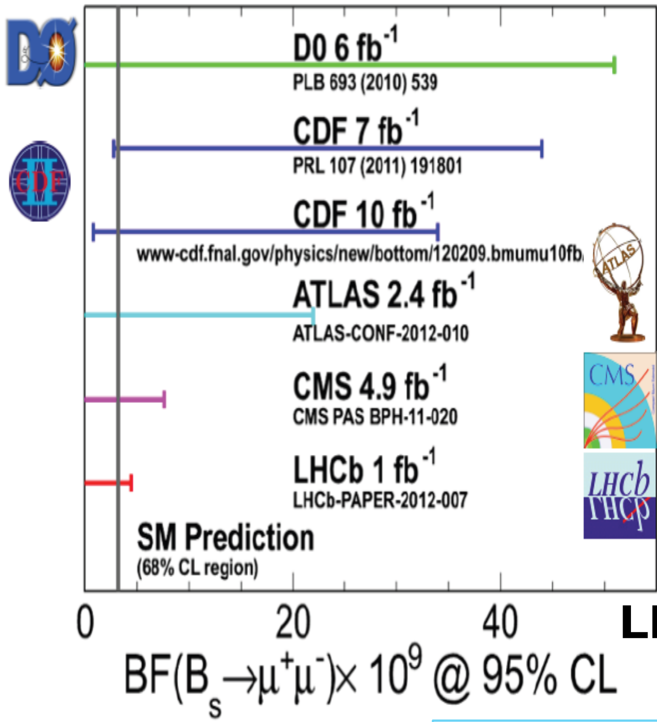
arXiv:1203.4493



arXiv:1203.3976



ΔF=1 Higgs penguins in b→d,s transitions: B decays



Limits for B^0_s at 95% C.L.

- D0
  - BR($B^0_s \to \mu^+\mu^-$) < 51×10^{-9}
- CDF
  - BR($B^0_s \to \mu^+\mu^-$) < 31×10^{-9}
- ATLAS
  - BR($B^0_s \to \mu^+\mu^-$) < 22×10^{-9}
- CMS
  - BR($B^0_s \to \mu^+\mu^-$) < 7.7×10^{-9}
- LHCb
  - BR($B^0_s \to \mu^+\mu^-$) < 4.5×10^{-9}

Limits for B^0 at 95% C.L.

- CDF
  - BR($B^0 \to \mu^+\mu^-$) < 4.6×10^{-9}
- CMS
  - BR($B^0 \to \mu^+\mu^-$) < 1.8×10^{-9}
- LHCb
  - BR($B^0 \to \mu^+\mu^-$) < 1.0×10^{-9}

LHCb and CMS are the experiments **with highest sensitivity:** *rule of thumb:* ***1/fb(LHCb)~7/fb(CMS)*** **as in 2011 analysis.**

Preliminary upper limits (95% CL) LHCb-CONF-2012-017

LHC combination: **BR($B_s \to \mu\mu$)< $4.2\text{x}10^{-9}$** *(most probable value ~$1.5\text{x}10^{-9}$)*

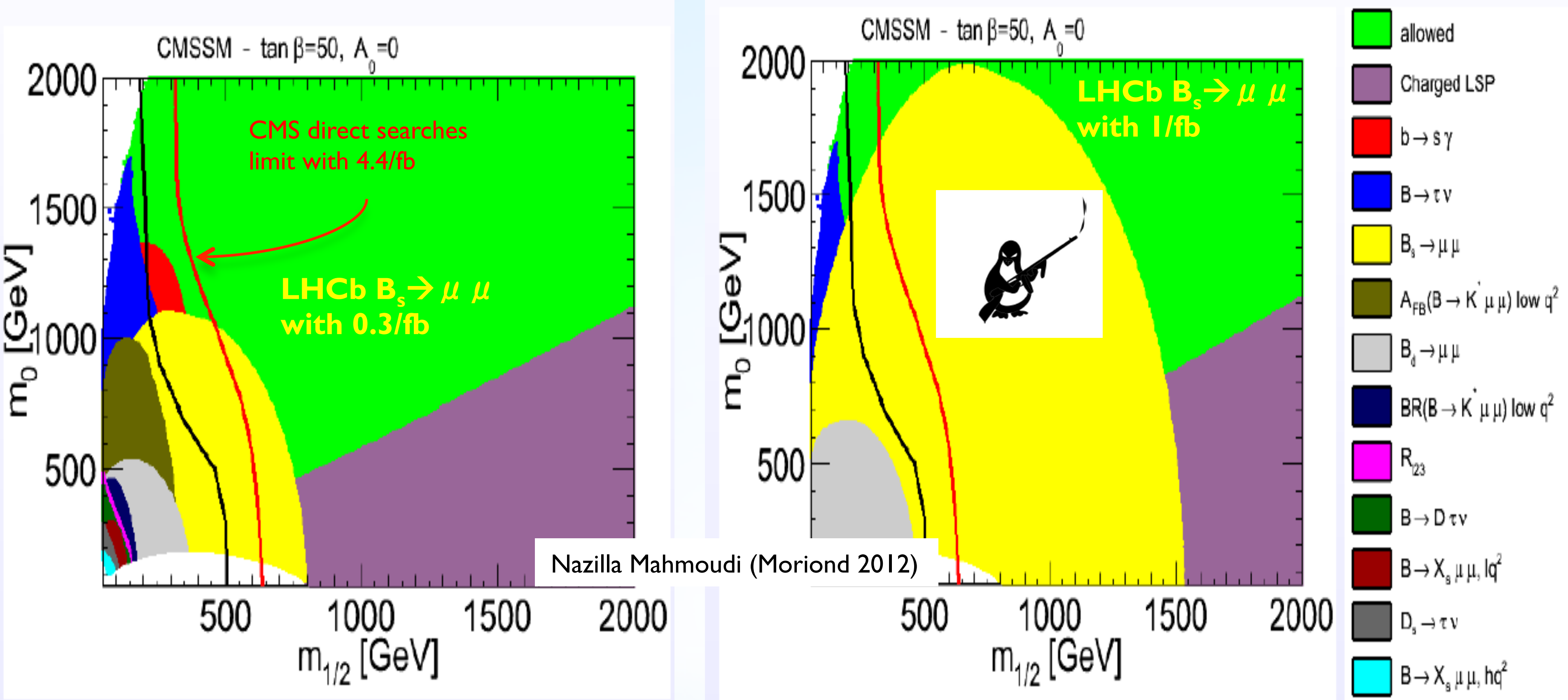
BR($B \to \mu\mu$)< $8.1\text{x}10^{-10}$

The probability that the observed number of B_s candidates is in agreement with **background only is 5%** (i.e. **~2σ evidence**).

Good chances that with 2012 data the combination of CMS and LHCb (or even a single exp.) provides enough evidence (>3σ)

Next measure ratio BR($B \to \mu\mu$)/BR($B_s \to \mu\mu$)

Δ F=1 Higgs penguins in b→s,d transitions: Implications

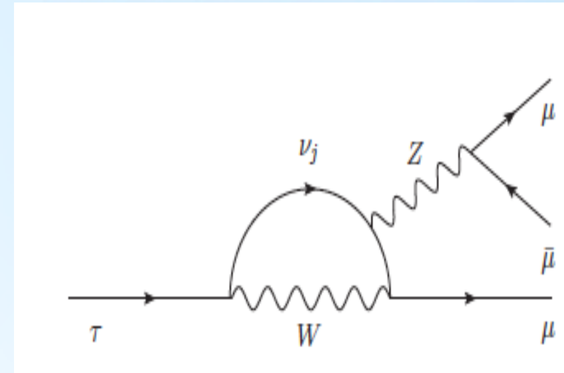


Latest limits on $B_s \to \mu\ \mu$ strongly constraint the parameter space for CMSSM, complementing direct searches from ATLAS/CMS.

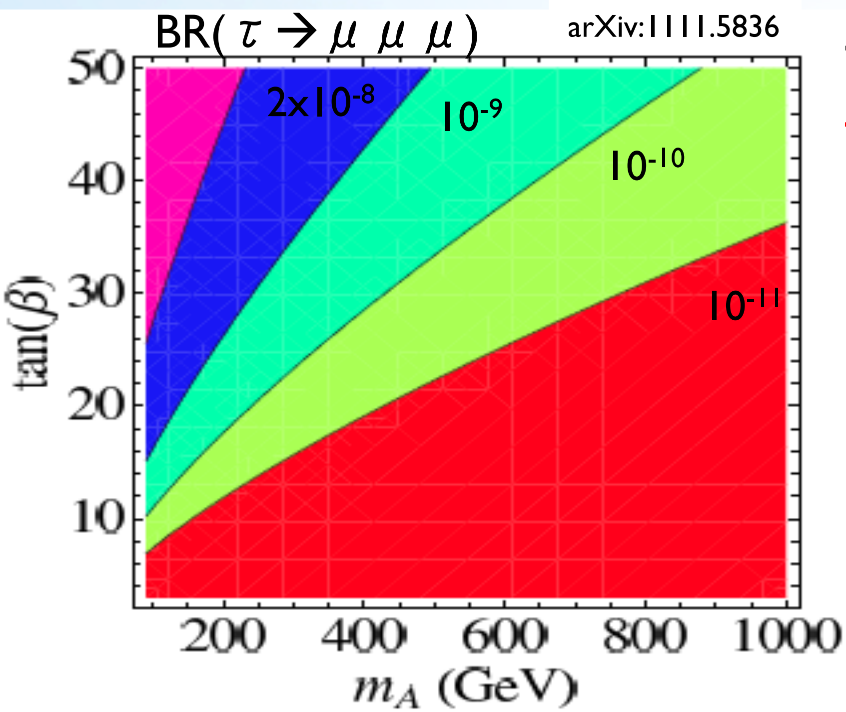
Charged Lepton Flavour Violation

Tau Flavour Violation Decays: $\tau \rightarrow \mu\ \mu\ \mu$

The discovery of neutrino oscillations implies CLFV at some level. Many extensions of the SM to explain neutrino masses, introduce large CLFV effects (depends on the nature of neutrinos, Dirac vs Majorana).



The ratio between $\tau \rightarrow \mu\ \gamma$ and $\tau \rightarrow \mu\ \mu\ \mu$ is a very powerful test of NP models. The decay in 3 μ is interesting in models with no dipole dominance (e.g. scalar currents). Typically MSSM predictions in the range [10^{-10}-10^{-9}].



Taus are **copiously produced** both at flavour-factories and at LHC (mainly from charm decays, $D_s \rightarrow \tau\ \nu$, ~8x$10^{10}$ taus produced within the LHCb acceptance).

Best limits at 90% C.L., so far, from B-factories:

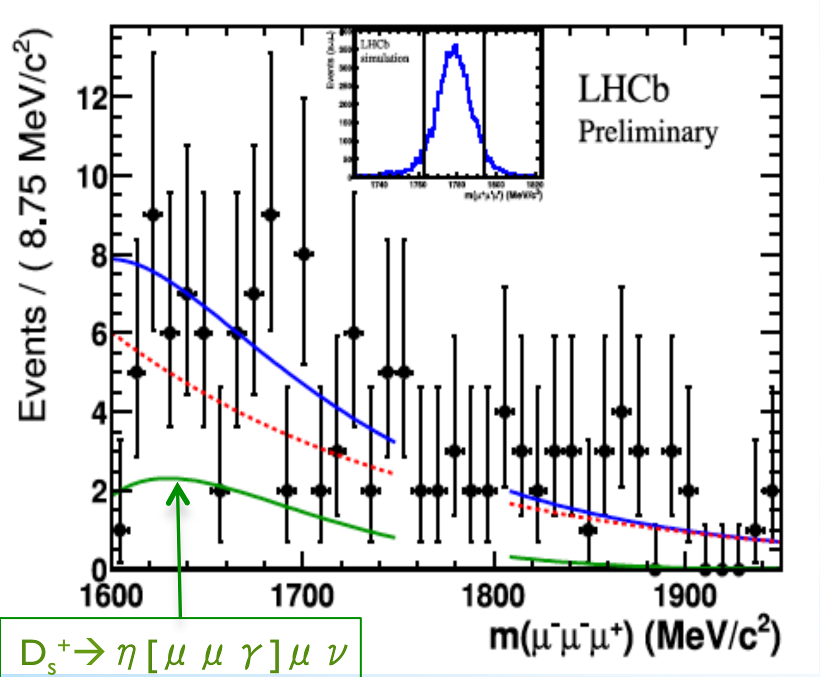
	BR($\tau \rightarrow \mu\ \gamma$)		BR($\tau \rightarrow \mu\ \mu\ \mu$)
BELLE:	4.5x10^{-8}	arXiv:1001.3221	2.1x10^{-8}
BABAR:	4.4x10^{-8}	arXiv:1002.4550	3.3x10^{-8}

Tau Flavour Violation Decays: $\tau \rightarrow \mu\ \mu\ \mu$

LHCb has performed for the first time at hadron colliders a search for $\tau \rightarrow \mu\ \mu\ \mu$ in 1/fb at $\sqrt{s}$=7 TeV.

Number of candidates is normalized to the number of $D_s \rightarrow \phi[\mu\ \mu]\pi$, the measured bb and cc cross-section at LHCb, and the fractions of B→ τ and D→ τ from LEP/B-factories.

LHCb-CONF-2012-015



$D_s^+ \rightarrow \eta[\mu\ \mu\ \gamma]\mu\ \nu$

Search in bins of invariant mass, PID and topological discriminant. Distribution compatible with background hypothesis:

BR($\tau \rightarrow \mu\ \mu\ \mu$)<7.8(6.3)x10^{-8} at 95(90)% CL.

Preliminary result subject to improvements in the rejection of the main background in the sensitive bins ($D_s^+ \rightarrow \eta[\mu\ \mu\ \gamma]\mu\ \nu$).

The **LHCb-upgrade** with 50/fb at $\sqrt{s}$~14 TeV should reach **BR($\tau \rightarrow \mu\ \mu\ \mu$)<[10^{-10}-10^{-9}] at 90% CL.**

Conclusions

Conclusions

Interest in precision flavour measurements is stronger than ever. In some sense it would have been very "unnatural" to find NP at LHC7 from direct searches with the SM CKM structure.

There are few interesting anomalies, most notably the observation of a large direct CP violation in charm decays, but in general the agreement with the SM is excellent → **large NP contributions, O(SM), ruled out in many cases.**

There is a priory as many good reasons to find NP by measuring precisely the Higgs couplings as by precision measurements in the flavour sector!

The search has just started with 1/fb at LHC7. **LHCb upgrade** plans to collect ~50/fb with a factor ~2 increase in bb cross-section. **ATLAS/CMS** plan to collect ~300/fb by 2022.

We don't know yet what is the scale of NP→ cast a wide net!

Backup

(Parenthesis)Advantages/Disadvantages of Existing Facilities

Common “past” knowledge:

lepton colliders → precision measurements vs **hadron colliders** → discovery machines

After the achievements at the TeVatron in precision EW measurements (W mass) and B-physics results (ΔM_s) and in particular the astonishing initial performance of LHCb, I think the above mantra **is over simplistic and not true**.

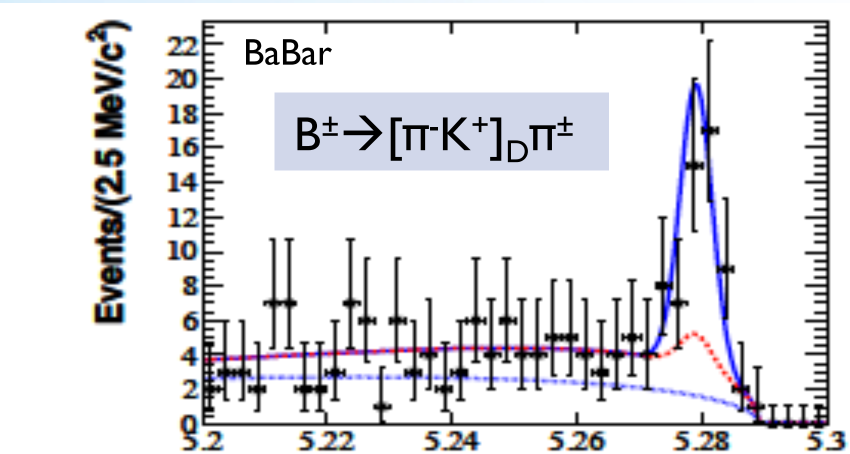
Lepton colliders have the advantage of a known CoM energy, and high luminosities

(10^{34}-10^{36}) $cm^{-2}s$. However, at the $\Upsilon(4S)$ only $_{B(d,u)}$ mesons are produced.

Hadron colliders have a very large cross-section ($\sigma_{bb}(LHC7) \sim 3\times10^5 \sigma_{bb}(\Upsilon(4S))$), very performing detectors and trigger system. Effective tagging efficiency is typically x10 better at lepton colliders.

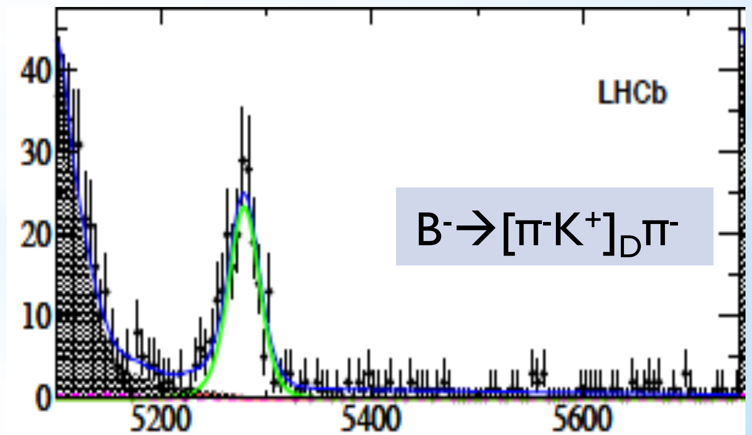
Rule of thumb: ***1/fb at 7TeV at LHCb is equivalent to (1-5)/ab at the B-factories before tagging.***

arXiv:1006.4241



Energy-substituted mass (GeV/c^2)

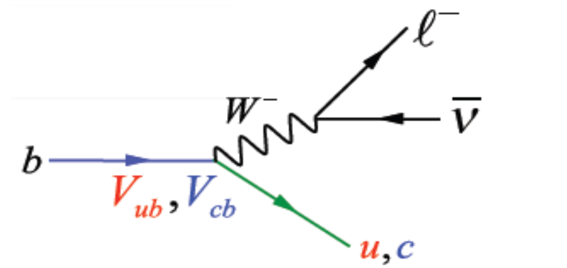
arXiv:1203.3662



Invariant mass (MeV/c^2)

b→u,c: Charged Currents (NP at tree level?)

$$\Gamma_x \equiv \Gamma(b \to x \ell \nu) \propto |V_{xb}|^2$$



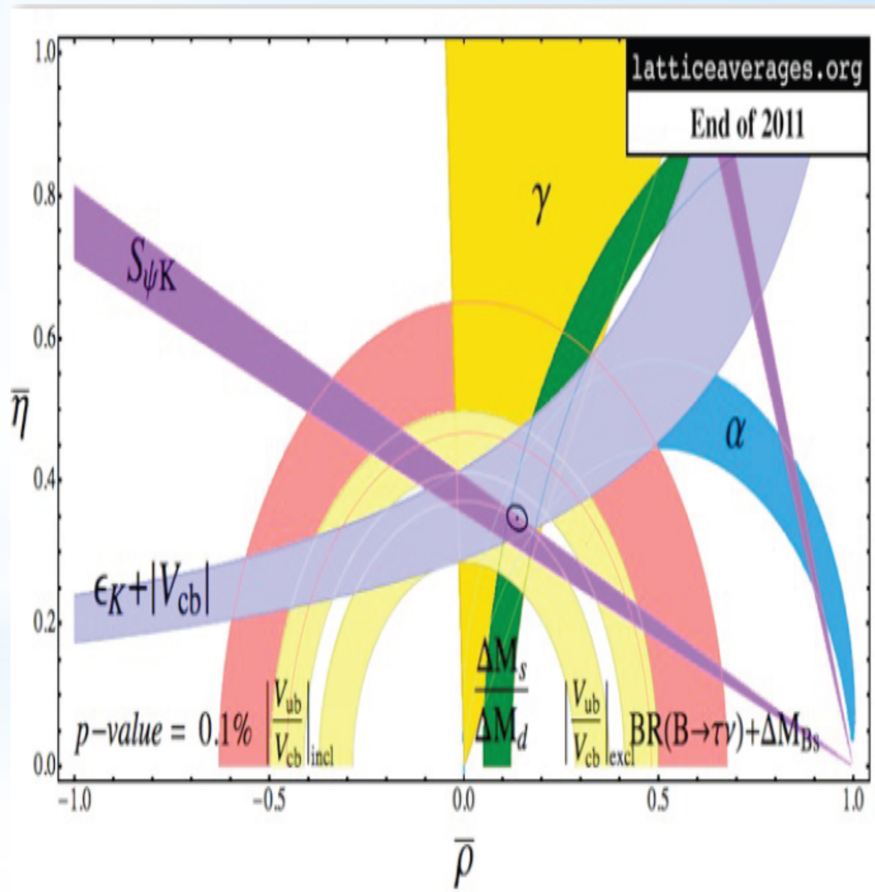
Measured values of V_{ub} at B-factories using inclusive or exclusive methods show a discrepancy at the 2-3 σ level:

V_{ub}(incl.)~1.3V_{ub}(excl.).

Both methods suffer from **large theoretical and experimental uncertainties.** Next generation B-factories will produce hadronic tagged, high statistics, high purity samples. LHCb is expected to provide competitive results in exclusive modes.

<u>Progress with lattice calculations but still a big challenge for theory!</u>

For some time the measured BR(B→ τ ν) has been about **3 σ higher than the CKM fitted** value, in better agreement with the **inclusive V_{ub}** result.



b→u,c: Charged Currents (NP at tree level?)

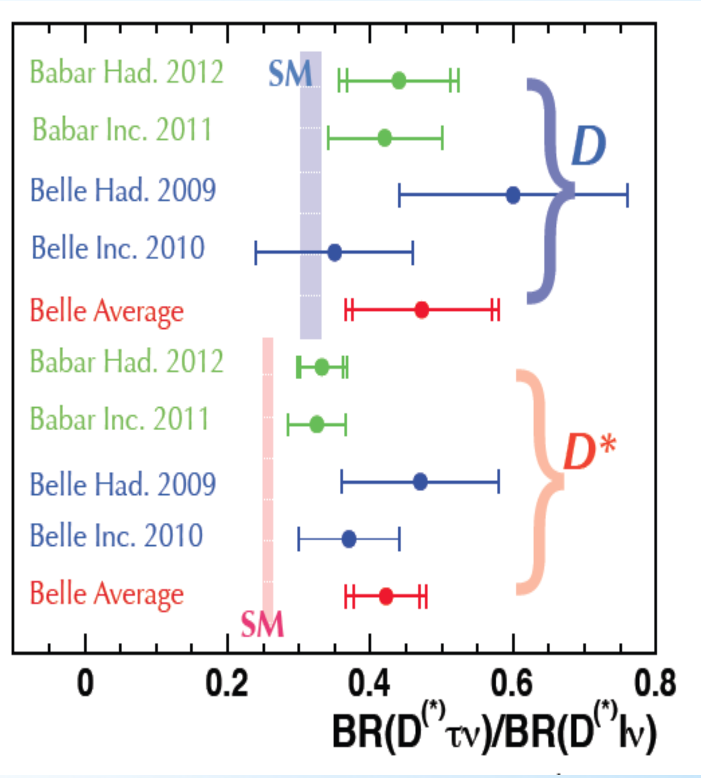
This summer **Belle** presented a more precise hadron tag analysis, in better agreement with the fitted CKM value: **$BR(B\to\tau\nu))_{exp}$= (0.72±0.28)x10^{-4} vs CKM fit:(0.83±0.09)x10^{-4}**

arXiv:1208.4678

BABAR also presented this summer a more precise measurement of BR(B→D(*) $\tau\nu$)/BR(B→D(*)l ν) which combined are **3.4 σ higher than SM**. arXiv:1205.5442

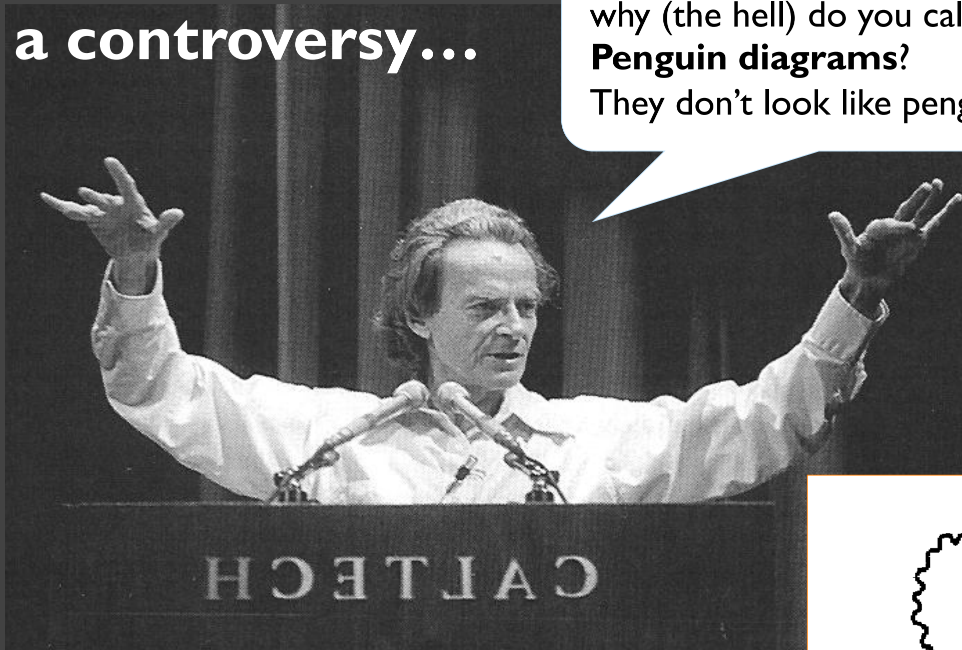
Not obvious NP explanation.

Belle should be able to reduce the uncertainties on B→D(*) $\tau\nu$ soon at similar level than BABAR using a similar technique.



Although these may be interesting results, there is no significant evidence yet that should force us to reconsider the hypothesis that NP enters mainly through loops, and tree measurements are a very good approximation to the SM predictions

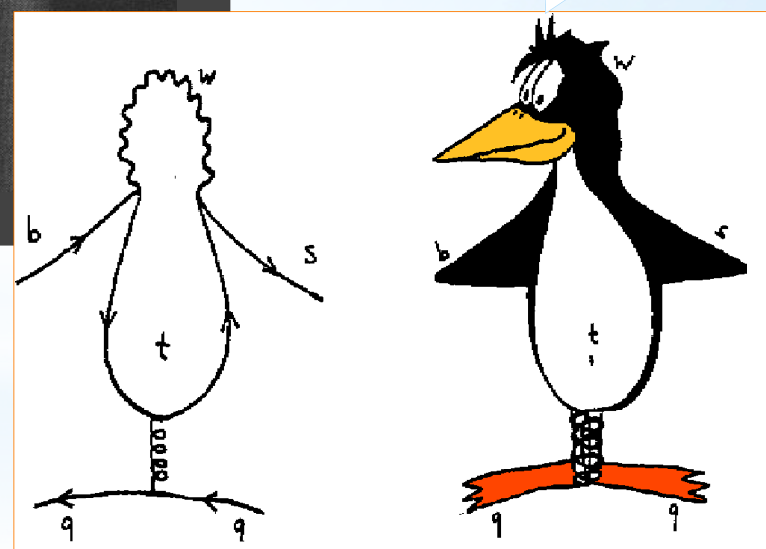
Why Penguins?



mirror image of Richard Feynman

why (the hell) do you call these
Penguin diagrams?
They don't look like penguins!

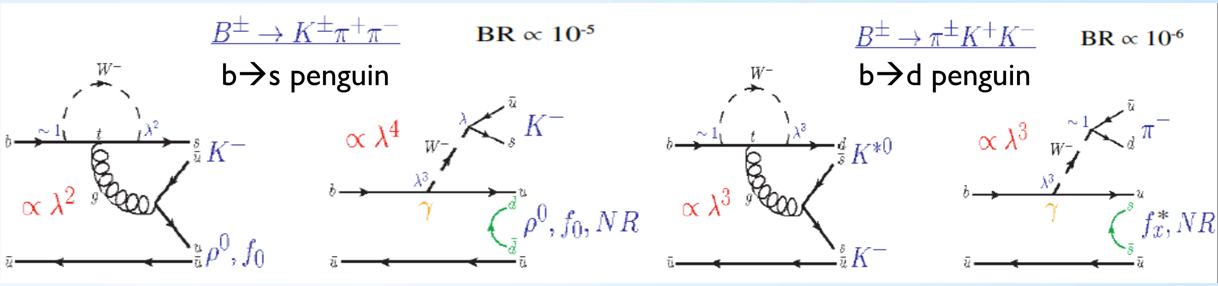
I've never seen a
Feynman diagram
that looks like **you** ☺



Taken from A. Hoecker Summer Student lectures at CERN (2006)

ΔF=1 b→s,d QCD penguins: Direct CP violation in B→3h

In principle, 3-body charmless B decays is also a way to access γ, trough the interference between tree and penguin decays → not a tree level measurement.



LHCb has **preliminary** measurements of large integrated along Dalitz plot CP asymmetries:

b→s QCD penguin (LHCb-CONF-2012-18)

$A_{CP}(B^\pm \to K^\pm\pi\pi) = 0.034 \pm 0.009 \pm 0.008$

$A_{CP}(B^\pm \to K^\pm KK) = -0.046 \pm 0.009 \pm 0.009$

b→d QCD penguin (LHCb-CONF-2012-28)

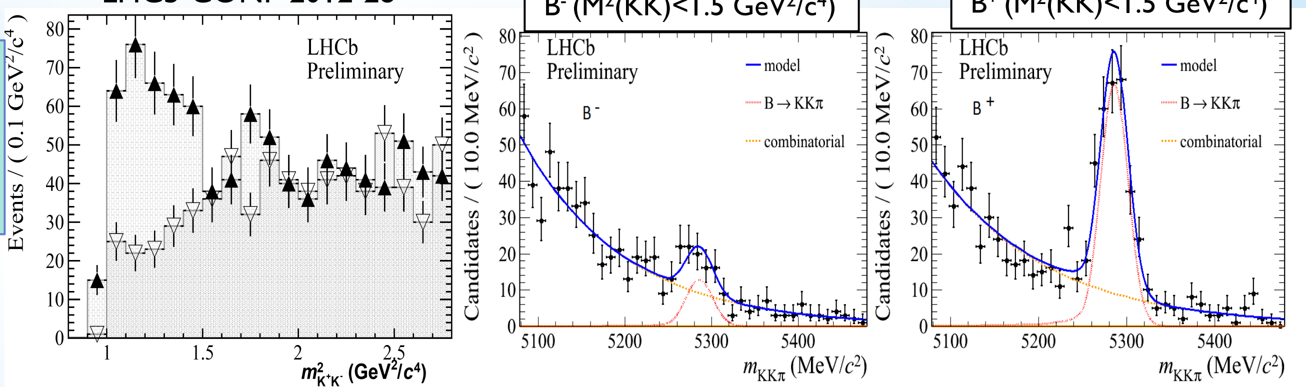
$A_{CP}(B^\pm \to \pi^\pm KK) = -0.153 \pm 0.046 \pm 0.020$

$A_{CP}(B^\pm \to \pi^\pm\pi\pi) = 0.120 \pm 0.020 \pm 0.020$

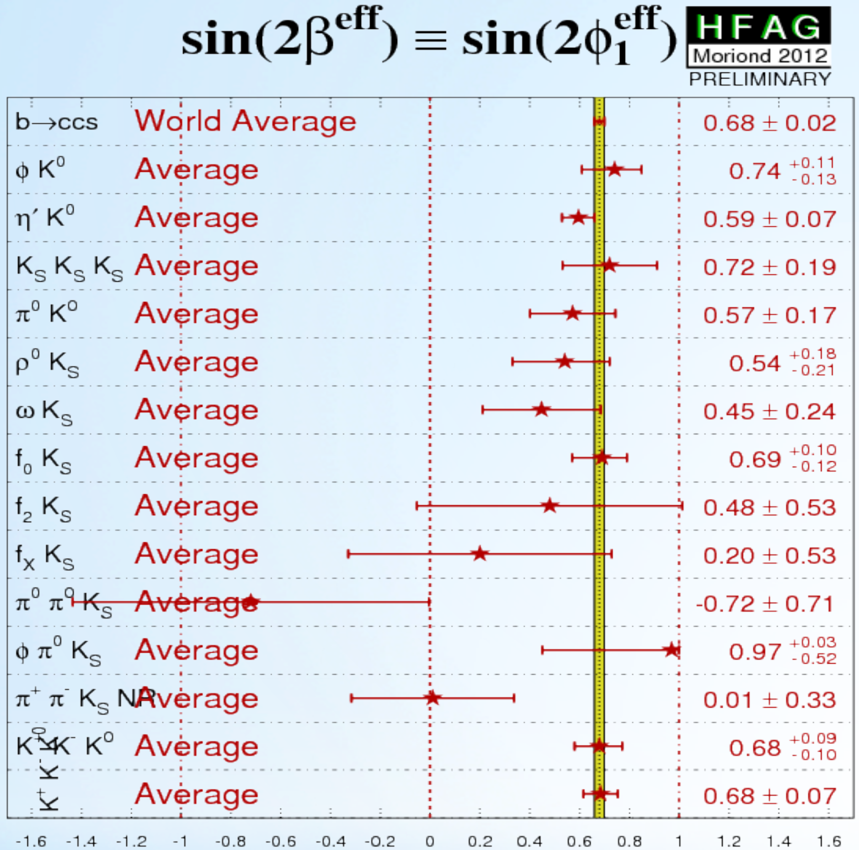
Interestingly, the larger CP violation effects appear in special kinematic regions not dominated by narrow resonances. For example, for the decay $B^\pm \to \pi^\pm KK$ a large excess of B^+ over B^- decays is observed for $M^2(KK) < 1.5\ GeV^2/c^4$, as previously indicated by BABAR.

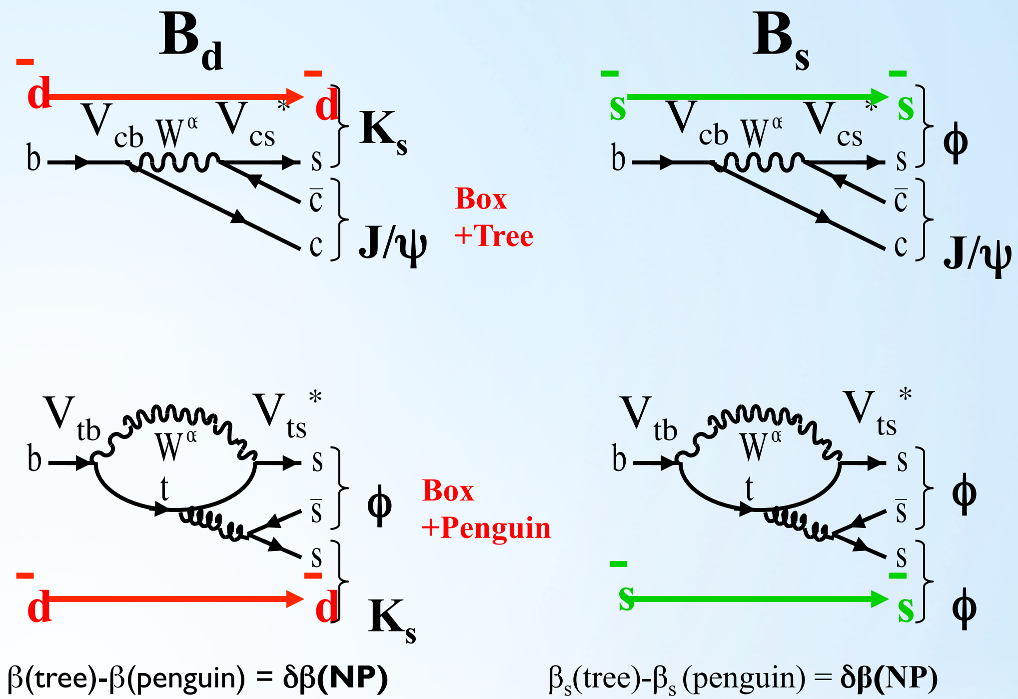
Some kind of hadron dynamics is working to generate such large A_{CP}.

LHCb-CONF-2012-28



$\Delta F=1\ b\rightarrow s$ QCD penguins





No significant discrepancy between b→ccs and s-penguin measurements. However, there may be a tendency and effects O(δβ~-10%) are not excluded.

The effect of the same s-penguins can be measured precisely at LHCb both in the B_d and B_s system. Future super-B factories may improve further on B_d decays.

An O(%) measurement can reveal NP effects in s-penguins

Summary of experimental results

Observable class of observables)	SM prediction	Ultimate th. error	Present result	Future (S)LHCb	Future SuperB	Future Other
$\lvert V_{us}\rvert$ $[K \to \pi\ell\nu]$	input	$0.1\%_{(\mathrm{Latt})}$	0.2252 ± 0.0009	-	-	
$\lvert V_{cb}\rvert$ $[\times 10^{-3}]$ $[B \to X_c\ell\nu]$	input	1%	40.9 ± 1.1	-	$1\%_{\mathrm{excl}}$, $0.5\%_{\mathrm{incl}}$	
$\lvert V_{ub}\rvert$ $[\times 10^{-3}][B \to \pi\ell\nu]$	input	$5\%_{(\mathrm{Latt})}$	4.15 ± 0.49	-	$3\%_{\mathrm{excl}}$, $2\%_{\mathrm{incl}}$	
γ $[B \to DK]$	input	$< 1^\circ$	$(70^{+27}_{-30})^\circ$	0.9°	1.5°	
$S_{B_d \to \psi K}$	2β	$\lesssim 0.01$	0.671 ± 0.023	0.0035	0.0025	
$S_{B_s \to \psi\phi, \psi f_0(980)}$	$2\beta_s$	$\lesssim 0.01$	-0.002 ± 0.087	0.008	-	
$S_{[B_s \to \phi\phi]}$	$2\beta_s^{eff}$	$\lesssim 0.05$	-	0.03	-	
$S_{[B_s \to K^{*0}\bar{K}^{*0}]}$	$2\beta_s^{eff}$	$\lesssim 0.05$	-	0.02	-	
$S_{[B_d \to \phi K^0]}$	$2\beta^{eff}$	$\lesssim 0.05$	-	0.03	0.02	
$S_{[B_d \to K^0_S \pi^0 \gamma]}$	0	$\lesssim 0.05$	-0.15 ± 0.20	-	0.02	
$S_{[B_s \to \phi\gamma]}$	0	$\lesssim 0.05$	-	0.02	-	
$A^d_{\mathrm{SL}}[\times 10^{-3}]$	-0.5	0.1	-5.8 ± 3.4	0.2	4	
$A^s_{\mathrm{SL}}[\times 10^{-3}]$	2.0×10^{-2}	$< 10^{-2}$	-2.4 ± 6.3	0.2	-	
$\mathcal{B}(B \to \tau\nu)[\times 10^{-4}]$	1	$5\%_{\mathrm{Latt}}$	(1.14 ± 0.23)	-	4%	
$\mathcal{B}(B \to \mu\nu)[\times 10^{-7}]$	4	$5\%_{\mathrm{Latt}}$	< 13	-	5%	
$\mathcal{B}(B \to D\tau\nu)[\times 10^{-2}]$	1.02 ± 0.17	$5\%_{\mathrm{Latt}}$	1.02 ± 0.17	[under study]	2%	
$\mathcal{B}(B \to D^*\tau\nu)[\times 10^{-2}]$	1.76 ± 0.18	$5\%_{\mathrm{Latt}}$	1.76 ± 0.17	[under study]	2%	
$\mathcal{B}(B_s \to \mu^+\mu^-)[\times 10^{-9}]$	3.5	$5\%_{\mathrm{Latt}}$	< 4.2	0.15	-	
$R(B_{s,d} \to \mu^+\mu^-)$	0.29	$\sim 5\%$	-	$\sim 35\%$	-	
$q_0(A^{FB}_{B \to K^*\mu^+\mu^-})[\mathrm{GeV}^2]$	4.26 ± 0.34			2%	-	
$A_{\mathrm{T}}^{(2)}(B \to K^*\mu^+\mu^-)$	$< 10^{-3}$			0.04	-	
$A_{\mathrm{CP}}(B \to K^*\mu^+\mu^-)$	$< 10^{-3}$			0.5%	1%	
$B \to K\nu\bar{\nu}[\times 10^{-6}]$	4	$10\%_{\mathrm{Latt}}$	< 16	-	0.7	
$\lvert q/p\rvert_{D-\mathrm{mixing}}$	1	$< 10^{-3}$	0.91 ± 0.17	$O(1\%)$	2.7%	
ϕ_D	$\lesssim 0.1\%$		—	$O(1^\circ)$	1.4°	
$a^{\mathrm{dir}}_{\mathrm{CP}}(\pi\pi)(\%)$	$\lesssim 0.3$		0.20 ± 0.22	0.015	[under study]	
$a^{\mathrm{dir}}_{\mathrm{CP}}(KK)(\%)$	$\lesssim 0.3$		-0.23 ± 0.17	0.010	[under study]	
$a^{\mathrm{dir}}_{\mathrm{CP}}(\pi\pi\gamma, KK\gamma)$	$\lesssim 0.3\%$			[under study]	[under study]	
$\mathcal{B}(\tau \to \mu\gamma)[\times 10^{-9}]$	0		< 44	-	2.4	
$\mathcal{B}(\tau \to 3\mu)[\times 10^{-10}]$	0		< 210(90% CL)	1-80	2	
$\mathcal{B}(\mu \to e\gamma)[\times 10^{-12}]$	0		< 2.4(90% CL)			~ 0.1 MEG ~ 0.01 PSI-future ~ 0.01 Project X
$\mathcal{B}(\mu N \to eN)(Tl)$	0		$< 4.3 \times 10^{-12}$			10^{-18} PRISM
$\mathcal{B}(\mu N \to eN)(Al)$	0		-			10^{-16} COMET, Mu2e
$\mathcal{B}(K^+ \to \pi^+\nu\bar{\nu})[\times 10^{-11}]$	8.5	8%	$17.3^{+11.5}_{-10.5}$			$\sim 10\%$ NA62 $\sim 5\%$ ORKA $\sim 2\%$ Project X
$\mathcal{B}(K_L \to \pi^0\nu\bar{\nu})[\times 10^{-11}]$	2.4	10%	< 2600			$\sim 100\%$ KOTO $\sim 5\%$ Project X
$\mathcal{B}(K_L \to \pi^0 e^+e^-)_{SD}$	1.4×10^{-11}	30%	$< 28 \times 10^{-11}$			$\sim 10\%$ Project X

Table 5: Status and future prospects of selected $B_{s,d}$, D, K, and LFV observables. The SuperB column refers to a generic super B factory, collecting $50\mathrm{ab}^{-1}$ at the $\Upsilon(4S)$.

Yields at LHCb and B-factories

Decay	LHCb		Belle		Ratio
$B_u \to J/\psi K$	10049	34 pb^{-1}	41315	711 fb^{-1}	5.1
$B_u \to D^0{}_{CP}\pi$	1270	34 pb^{-1}	2163	250 fb^{-1}	4.3
$B_d \to K\pi$	838	35 pb^{-1}	4000	480 fb^{-1}	2.9
$B_u \to K\ell\ell$	35	35 pb^{-1}	161	605 fb^{-1}	2.6
$B_d \to K^*\ell\ell$	144	165 pb^{-1}	230	605 fb^{-1}	2.3
$B_d \to J/\psi K_S^0$	1100	33 pb^{-1}	12681	711 fb^{-1}	1.9
$B_d \to K^*\gamma$	485	88 pb^{-1}	450	78 fb^{-1}	1.0
$B_s \to J/\psi\phi$	1414	95 pb^{-1}	45	24 fb^{-1}	7.9
$B_s \to J/\psi f_0$	111	33 pb^{-1}	63	121 fb^{-1}	6.5
$B_s \to \phi\gamma$	60	88 pb^{-1}	18	24 fb^{-1}	0.9
$D^+ \to \phi\pi$	$90k$	35 pb^{-1}	$237k$	955 fb^{-1}	10