QCD@Work 2012

International Workshop on QCD - Theory and Experiment

Lecce - June 18-21, 2012

Flavour Violation Patterns in the Light of Recent LHCb Data

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Technische Universität München

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Outline

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- New measures and old tensions in flavour data

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  - Two-Higgs-Doublet Model with MFV and Flavour-Blind Phases

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- Beyond Minimal Flavour Violation
  - Gauged Flavour Symmetries

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- Minimal Flavour Violation at large
  - Two-Higgs-Doublet Model with MFV and Flavour-Blind Phases
- Beyond Minimal Flavour Violation
  - Gauged Flavour Symmetries
- Conclusions and Outlook

$S_{\psi\varphi}$ and $B_{d,s} \to \mu^+\mu^-$: Vanishing Hopes

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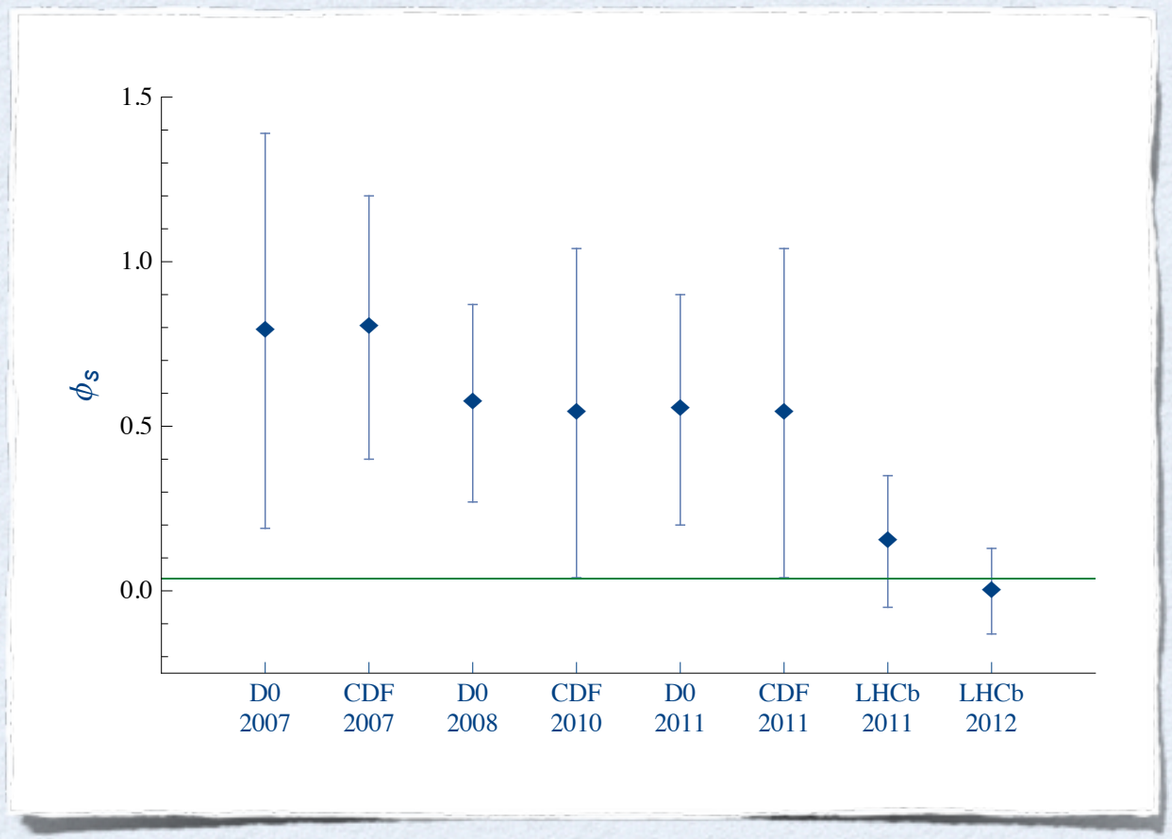
$S_{\psi\phi}$: mixing-induced CP asymmetry in the B_s system



LHCb Collab., PRL **108** (2012)
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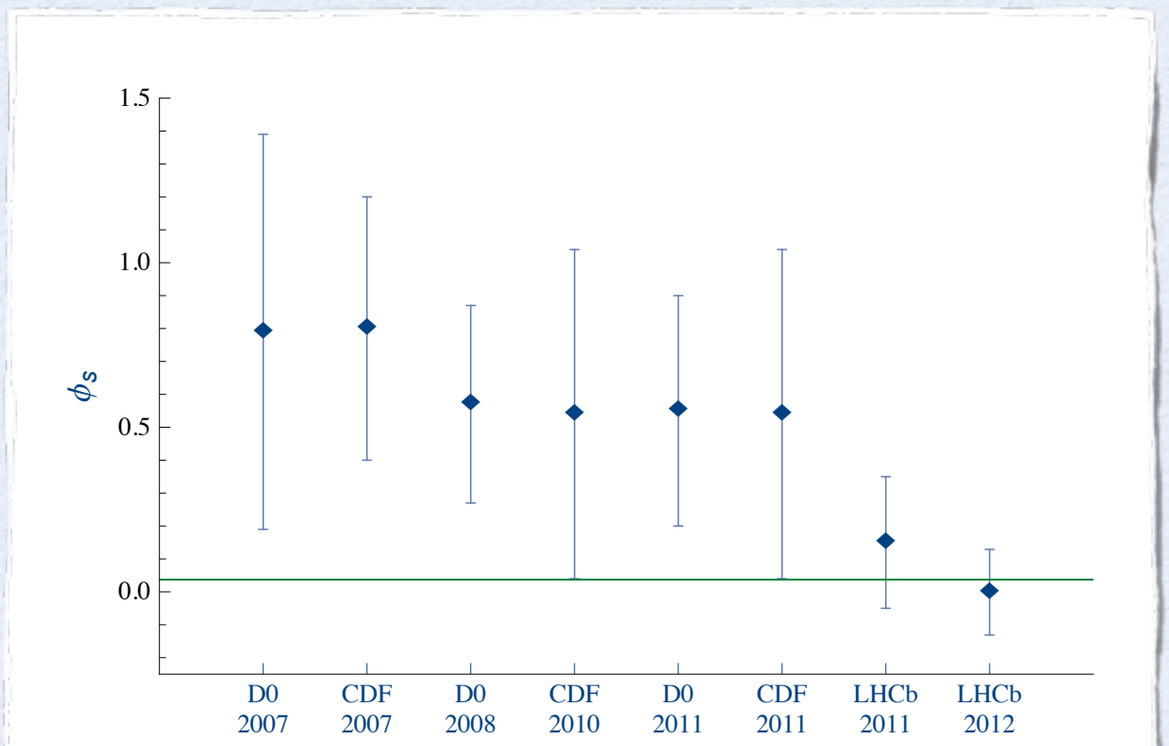

LHCb Collab., PRL **108** (2012)
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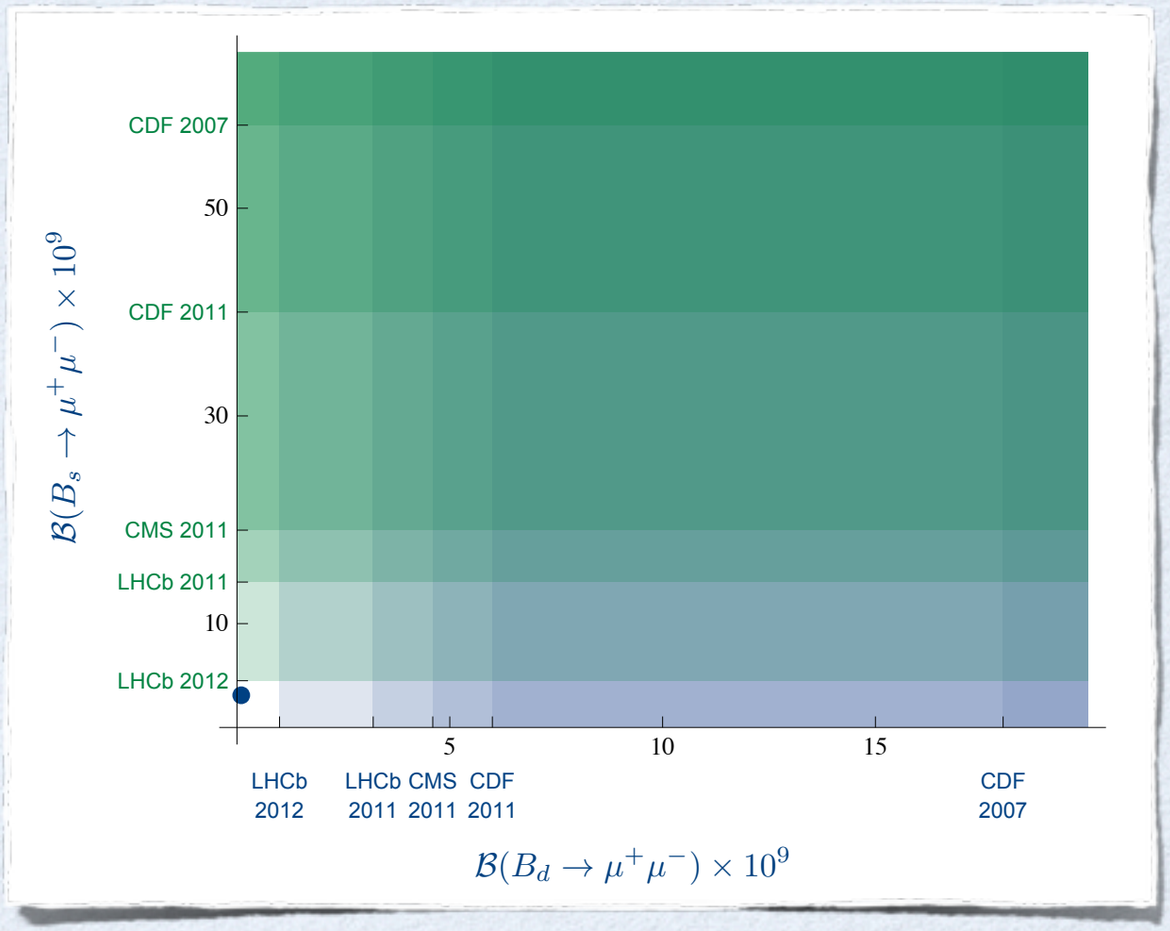
$B_{d,s} \to \mu^+\mu^-$: very sensible to contributions of new heavy particles



LHCb Collab., Phys. Lett. B **708** (2012)
LHCb Collab., 1203.4493

Tensions in the Unitarity Triangle: ε_K – $S_{\psi Ks}$ vs. V_{ub}

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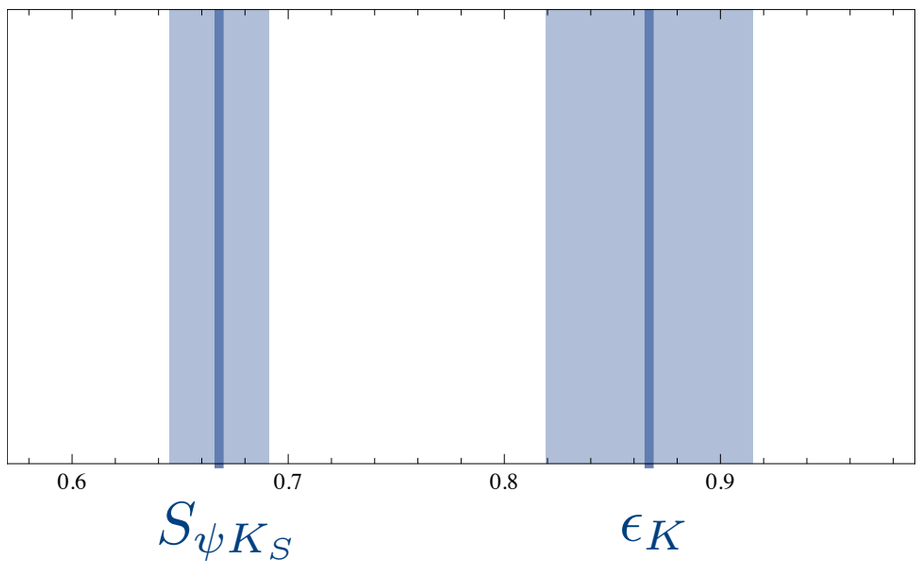
sin2β from...



3.2σ discrepancy

Buras and Guadagnoli, Phys. Rev. D **78** (2008)
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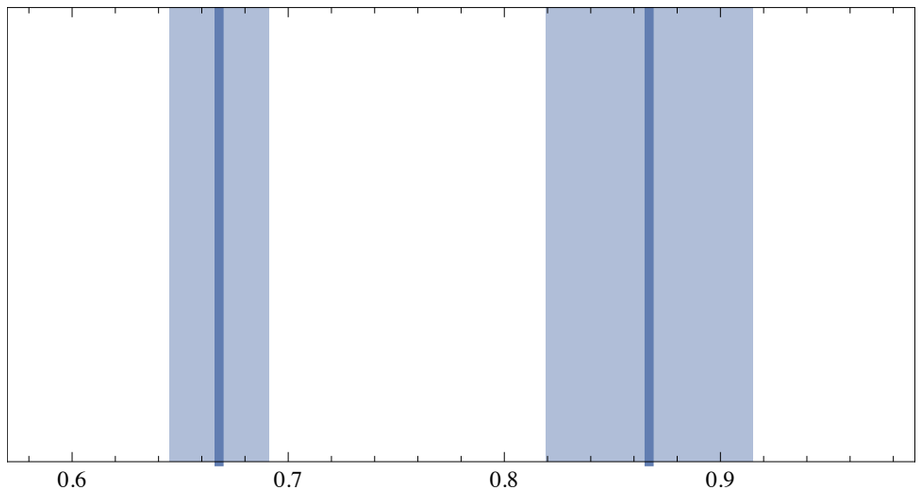

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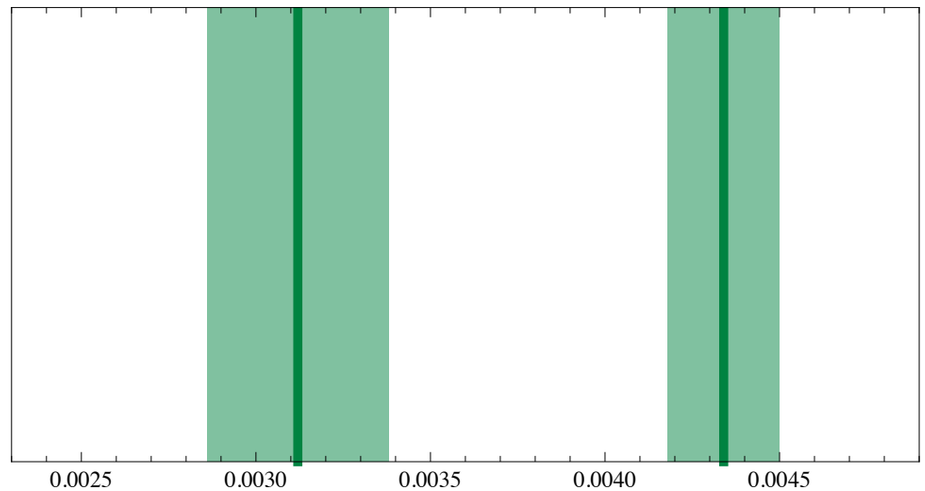
Determination of $|V_{ub}|$ ...



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HFAG, 1010.1589

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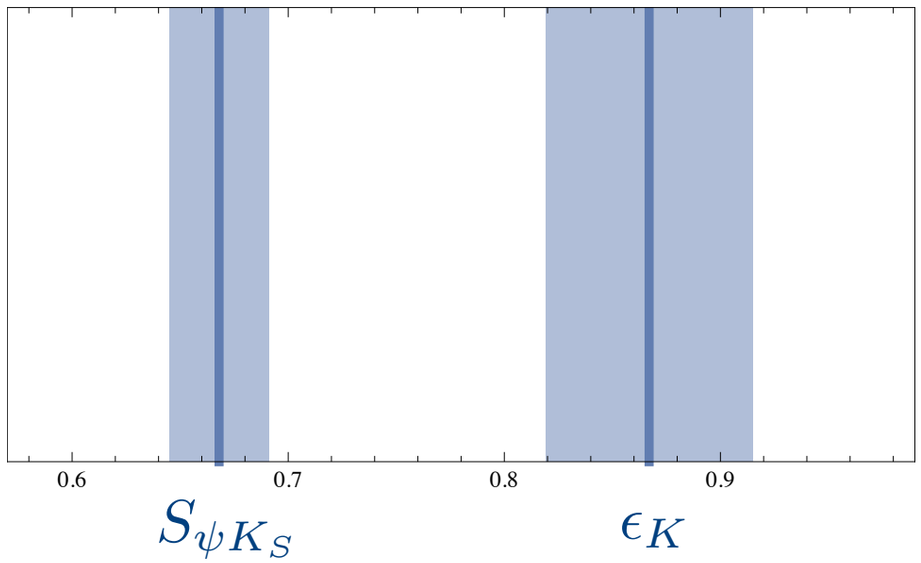

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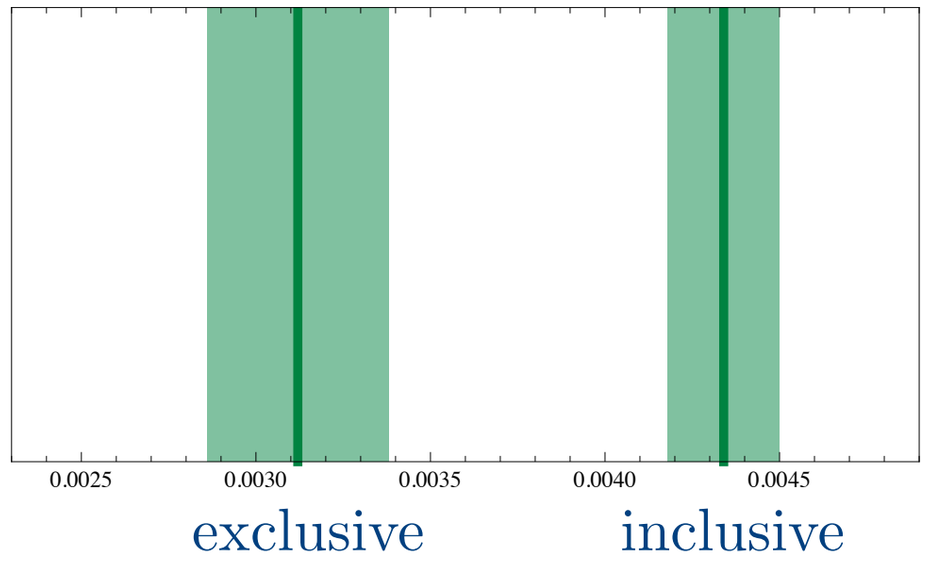

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Scenario 1

exclusive V_{ub}
ε_K below the data
$S_{\psi Ks}$ in agreement with data

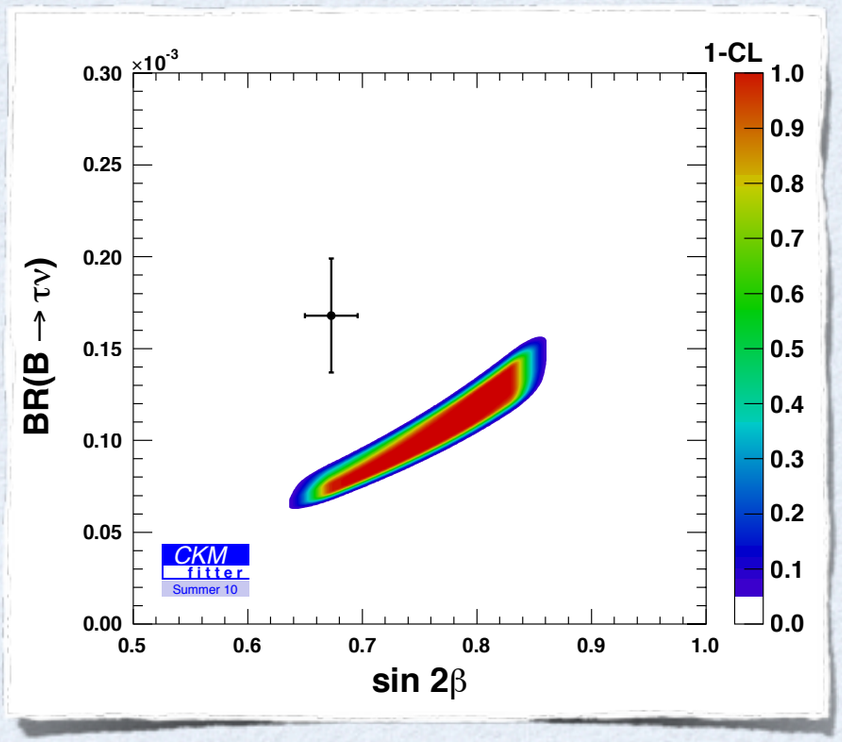
Scenario 2

inclusive V_{ub}
ε_K in agreement with data
$S_{\psi Ks}$ above the data

More Tensions

More Tensions

2.9σ discrepancy
between BR(B → τ ν) and
its prediction from fits



Lenz, Nierste and CKMfitter, 1203.0238

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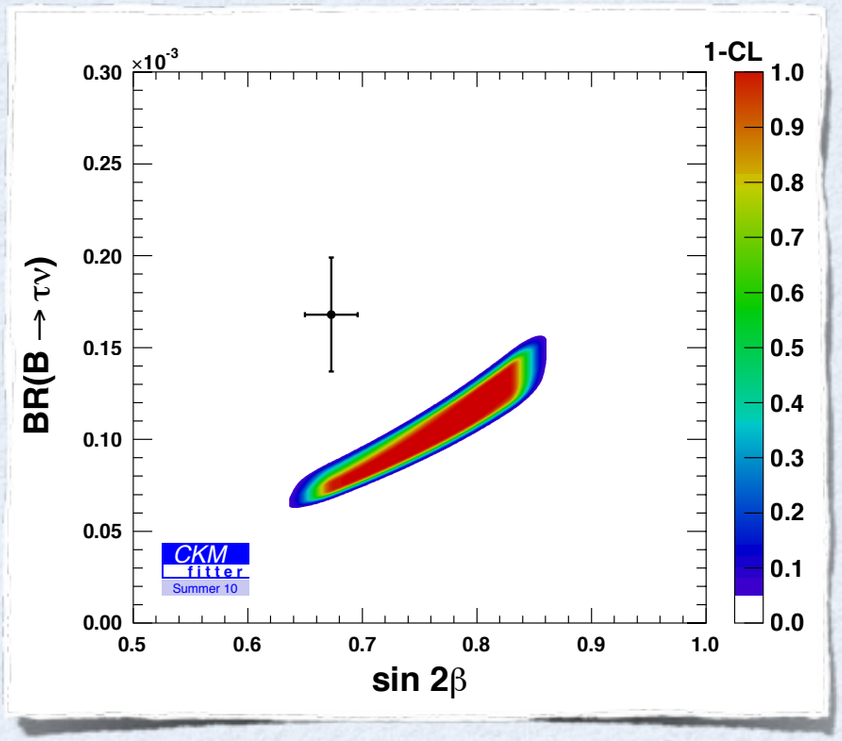

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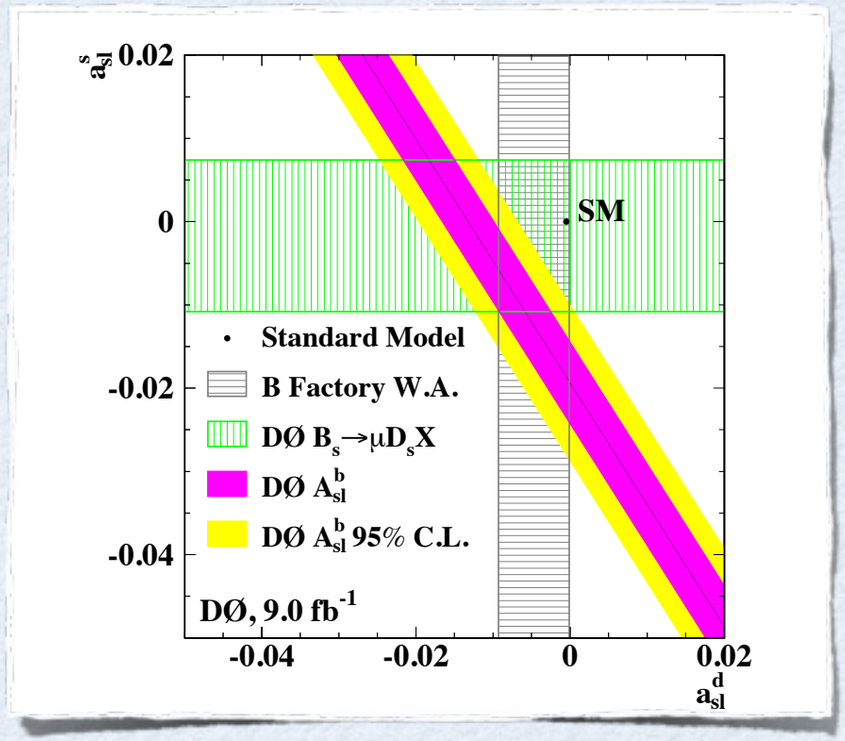
3.9σ deviation

of the semileptonic CP asymmetry in $B_{d,s}$ decays from its SM prediction



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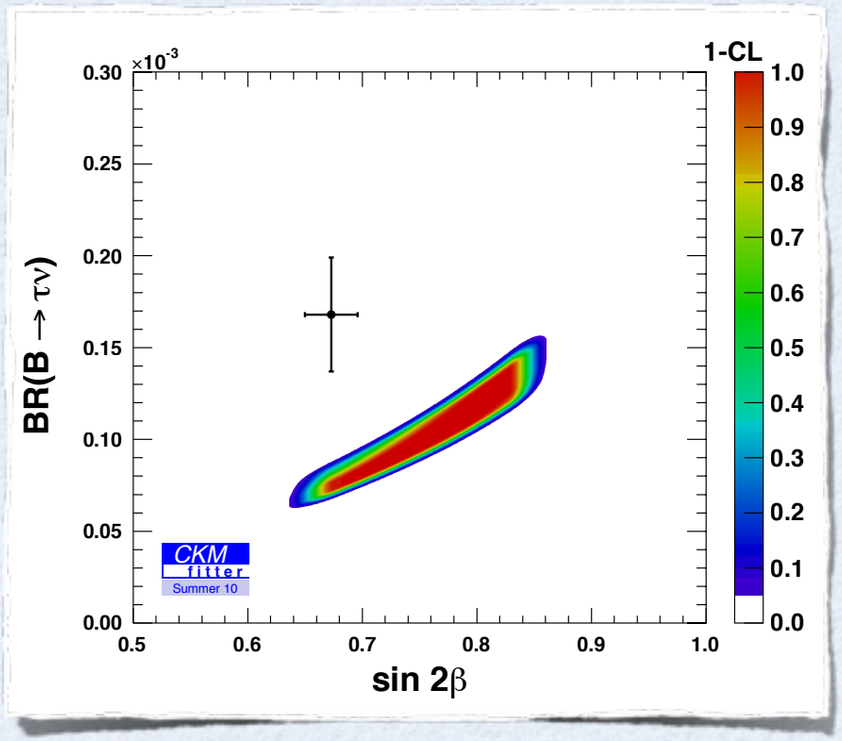

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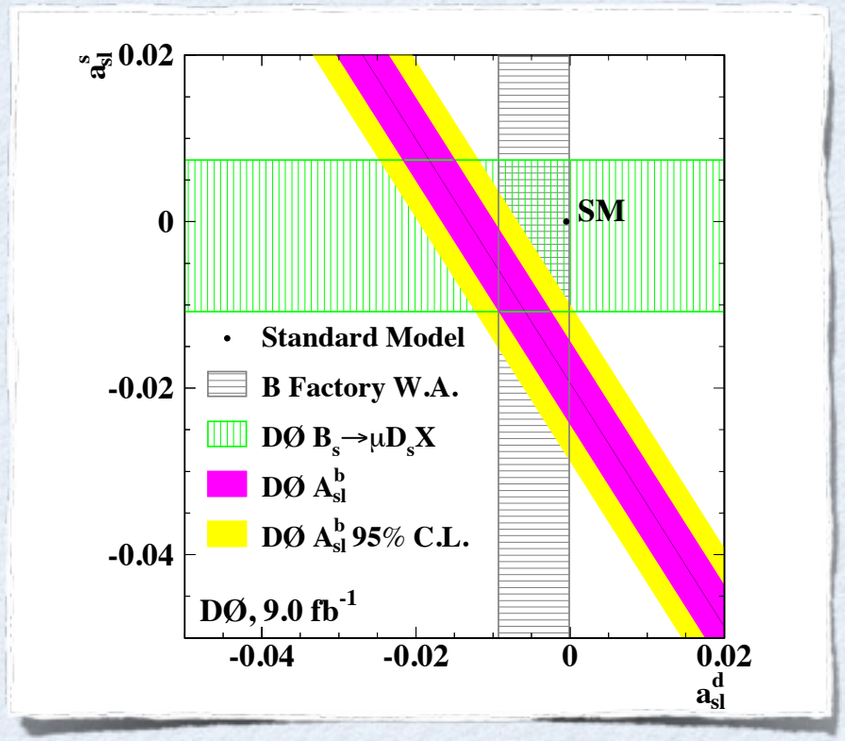

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... and few more 1-2 σ anomalies in $B \to X_s \gamma$, $B \to X_s l^+ l^-$, $B \to K^* l^+ l^-$ ...

Buras and Girrbach, 1204.5064

Definition and Implications

Constrained Minimal Flavour Violation

Definition and Implications

All flavour changing transitions are governed by the CKM matrix with the CKM phase being the only source of CP violation.

The only relevant operators in the effective Hamiltonian below the weak scale are those that are also relevant in the SM.

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- $S_{\psi K_S}$ and $S_{\psi\varphi}$ are as in the SM.

- For fixed CKM parameters determined in tree-level decays, $|\varepsilon_K|$, ΔM_s and ΔM_d can only be enhanced relative to SM predictions, and this happens in a correlated manner.

- There are correlations between various observables:

$$\frac{\mathcal{B}(B_s\to\mu^+\mu^-)}{\mathcal{B}(B_d\to\mu^+\mu^-)}=\frac{\tau(B_d)}{\tau(B_s)}\frac{m_{B_d}}{m_{B_s}}\frac{F_{B_d}^2}{F_{B_s}^2}\left|\frac{V_{td}}{V_{ts}}\right|^2 r(\mu^+\mu^-)=\frac{\hat{B}_d}{\hat{B}_s}\frac{\tau(B_d)}{\tau(B_s)}\frac{\Delta M_s}{\Delta M_d}\frac{r(\Delta M)}{r(\mu^+\mu^-)}$$

$$\frac{\Delta M_d}{\Delta M_s}=\frac{m_{B_d}}{M_{B_s}}\frac{\hat{B}_d}{\hat{B}_s}\frac{F_{B_d}^2}{F_{B_s}^2}\left|\frac{V_{td}}{V_{ts}}\right|^2 r(\Delta M)$$

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Facing the New Data

Constrained Minimal Flavour Violation

Facing the New Data

- $S_{\psi K_S}$ cannot be modified ⟶ Scenario 1 for V_{ub}
- ε_K can be enhanced ⟶ solution of the $S_{\psi K_S}$ - ε_K tension.
- enhancement of ε_K ⟶ correlated enhancement of ΔM_s and ΔM_d

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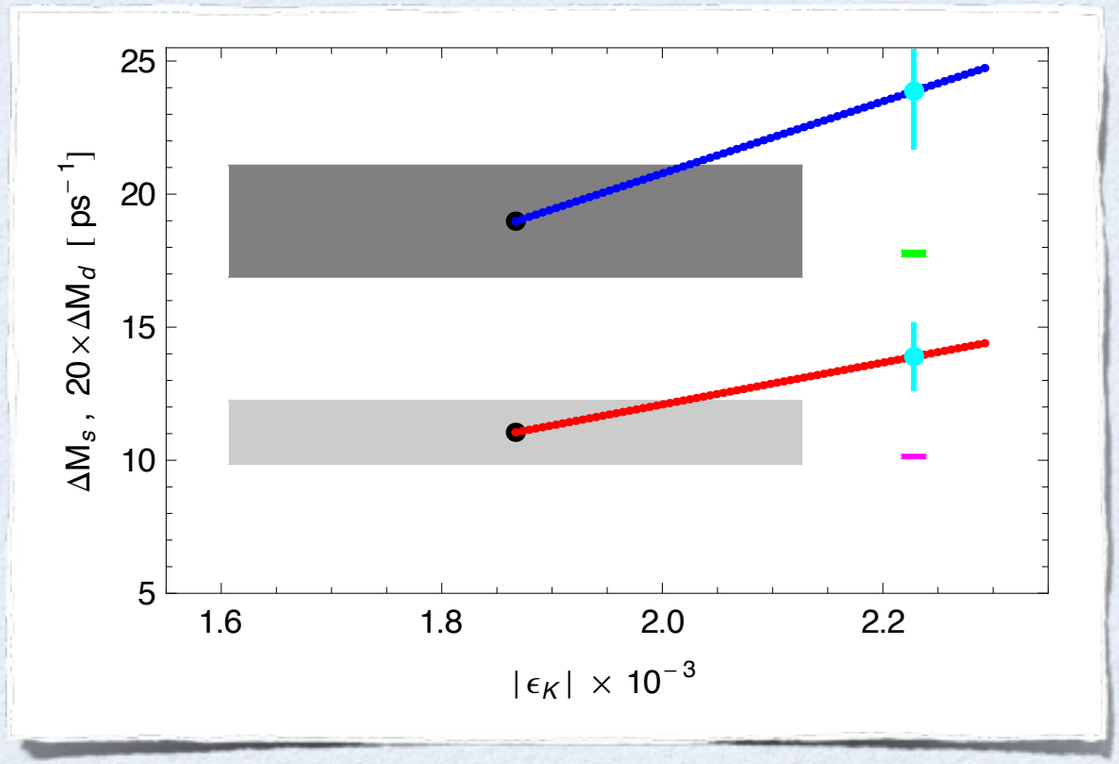

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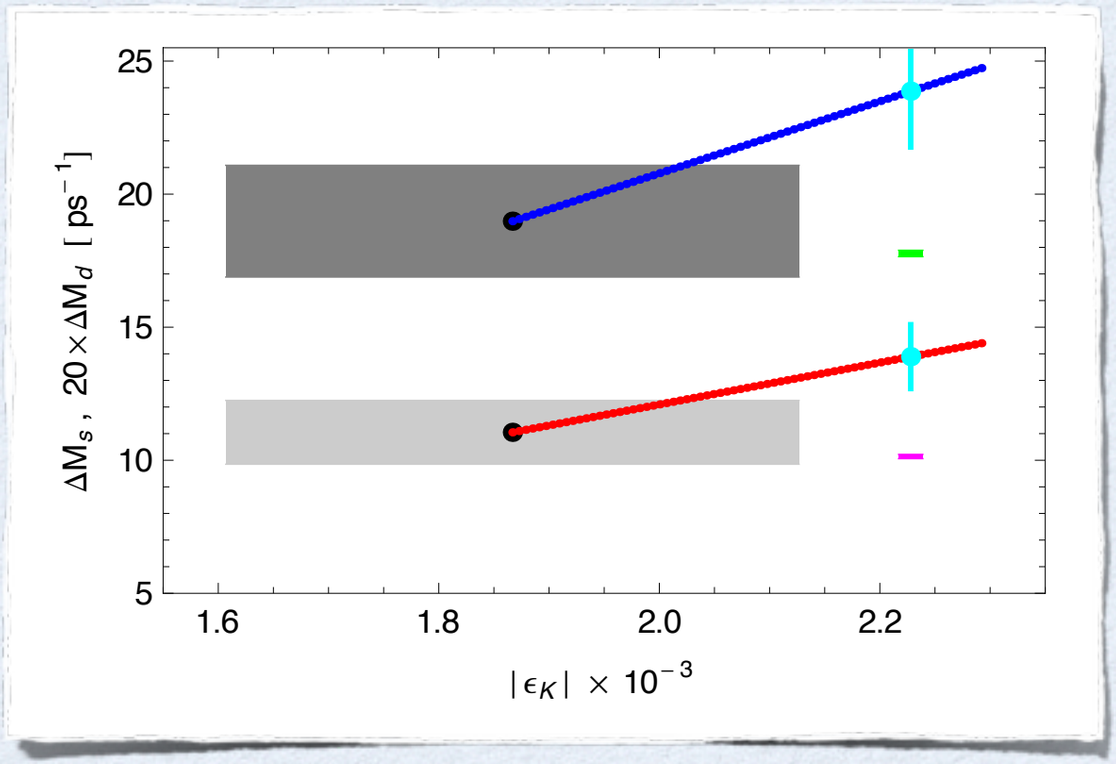
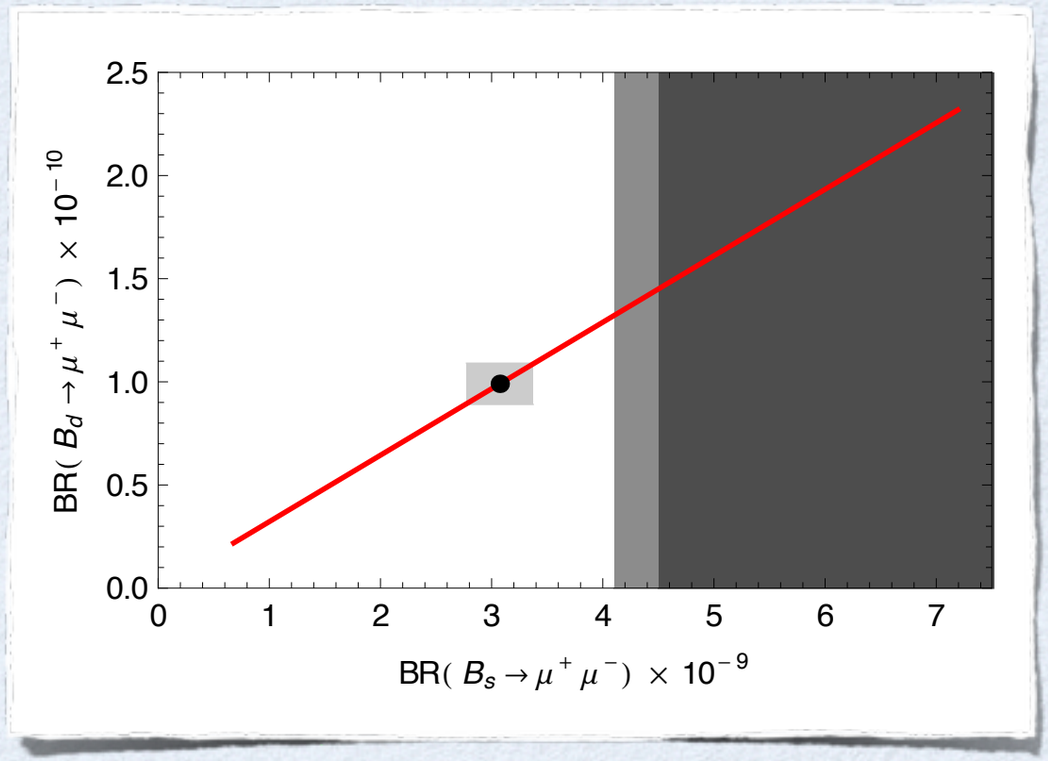


Correlations: an indipendent test of CMFV



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Definition and Application to 2HDM

DEFINITION AND APPLICATION TO 2HDM

Successful symmetry + symmetry-breaking pattern of the SM:

large global flavour symmetry in the gauge sector

$$\mathcal{G}_q = (SU(3) \otimes U(1))^3$$

broken only by the Yukawa couplings

$$\mathcal{L}_Y = -\bar{Q}_L Y_d D_R H - \bar{Q}_L Y_u U_R H^c$$

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Flavour symmetry is formally recovered by promoting the Yukawa couplings to spurions

$$Y_u \sim (3, \bar{3}, 1)_{SU(3)^3} \qquad Y_d \sim (3, 1, \bar{3})_{SU(3)^3}$$

Minimal Flavour Violation hypotesis

A theory satisfies the MFV criterion if it is formally invariant under $\mathcal{G}_q$.

D'Ambrosio *et al.*, Nucl. Phys. B **645** (2002)

MFV AT LARGE: 2HDM$_{\overline{\text{MFV}}}$

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Application to 2HDM:

$$\mathcal{L}^{\text{FCNC}}_{\text{MFV}} = \frac{1}{\sin\beta} \bar{d}^i_L \left[\left(a_0 V^\dagger {\lambda_u}^2 V + a_1 V^\dagger {\lambda_u}^2 V \Delta + a_0 \Delta V^\dagger {\lambda_u}^2 V \right) \lambda_d \right]_{ij} d^j_R \, \frac{S_2 + i S_3}{\sqrt{2}} + \text{h.c.}$$

double CKM suppression + down-type Yukawa suppression

In general a_i can be complex → Flavour Blind Phases

D'Ambrosio *et al.*, Nucl. Phys. B **645** (2002)

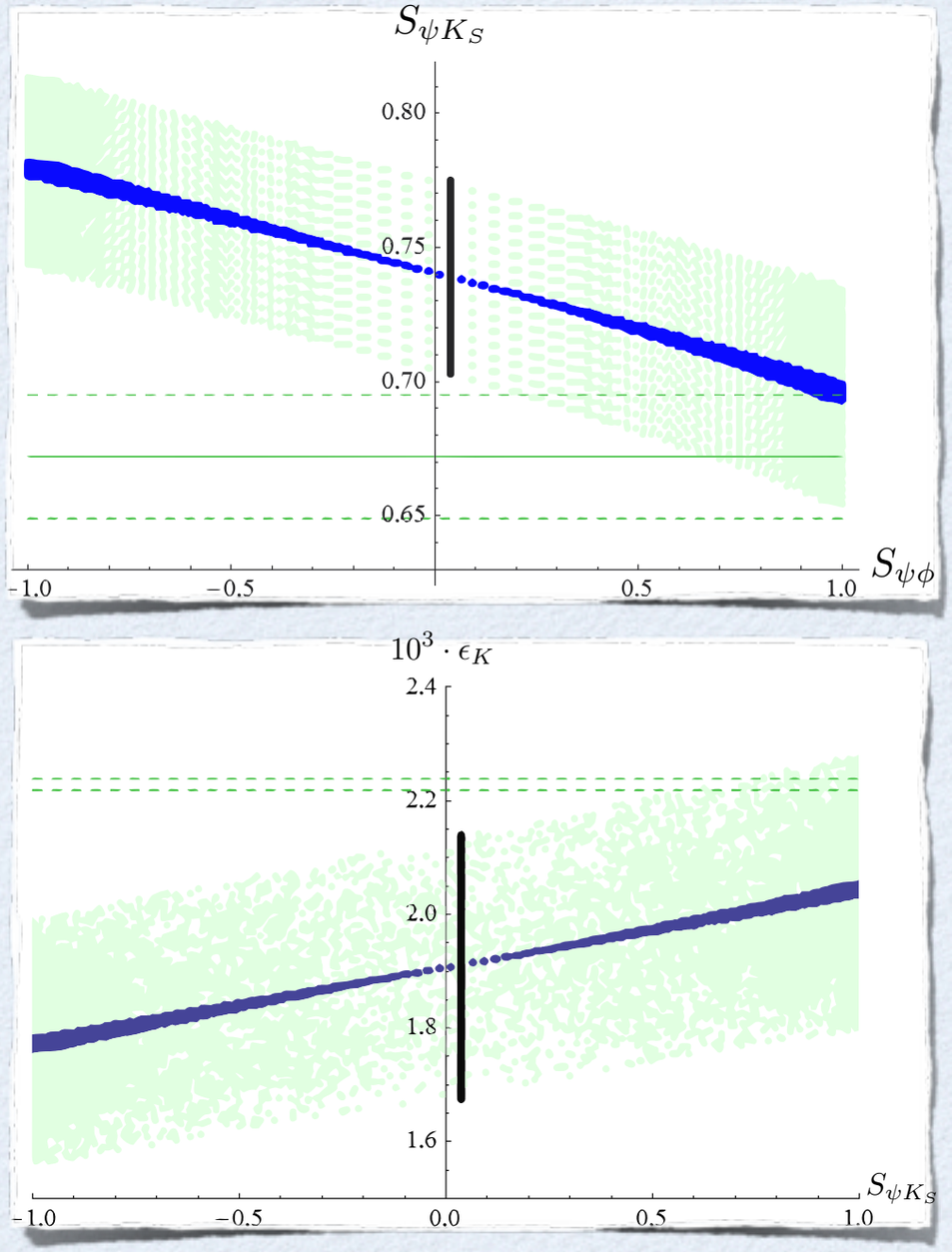
Buras, MVC, Gori and Isidori, JHEP 1010

PHENOMENOLOGICAL ANALYSIS

MFV at Large: 2HDM$_{\overline{\text{MFV}}}$

Phenomenological Analysis

Room for a large $S_{\psi\varphi}$ that automatically solves the $S_{\psi K_S}$ - ε_K tension!



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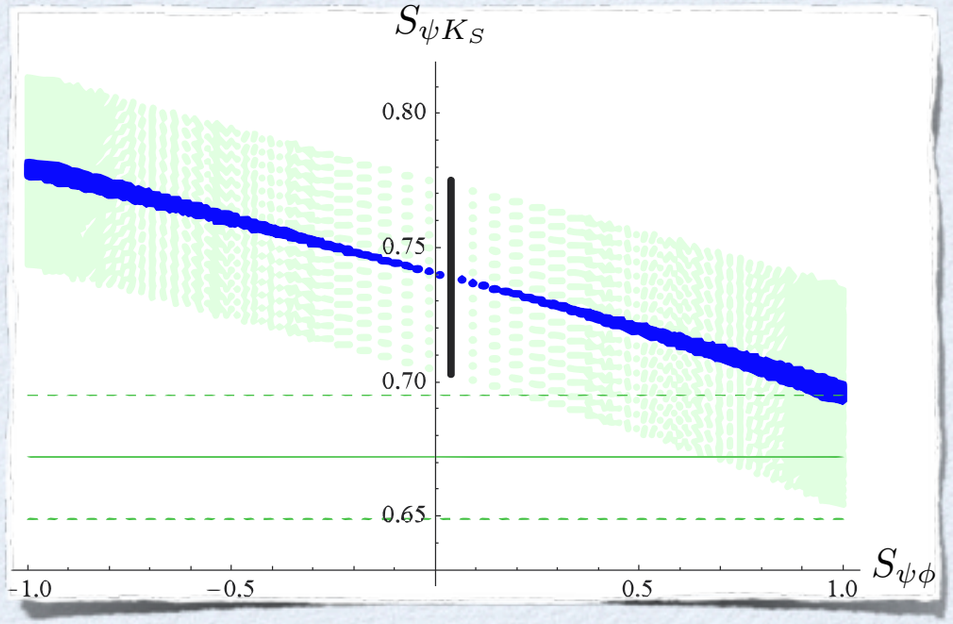

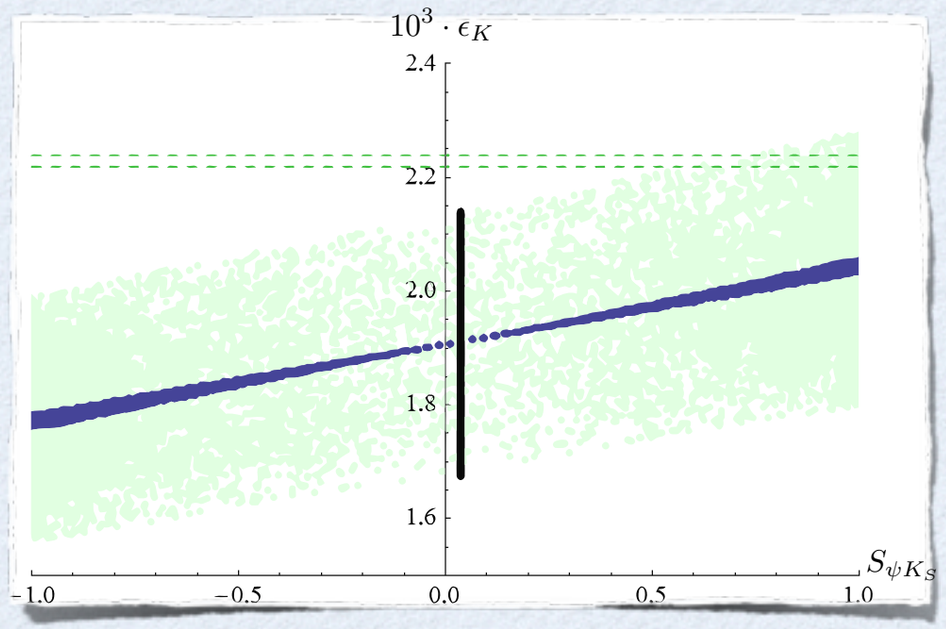

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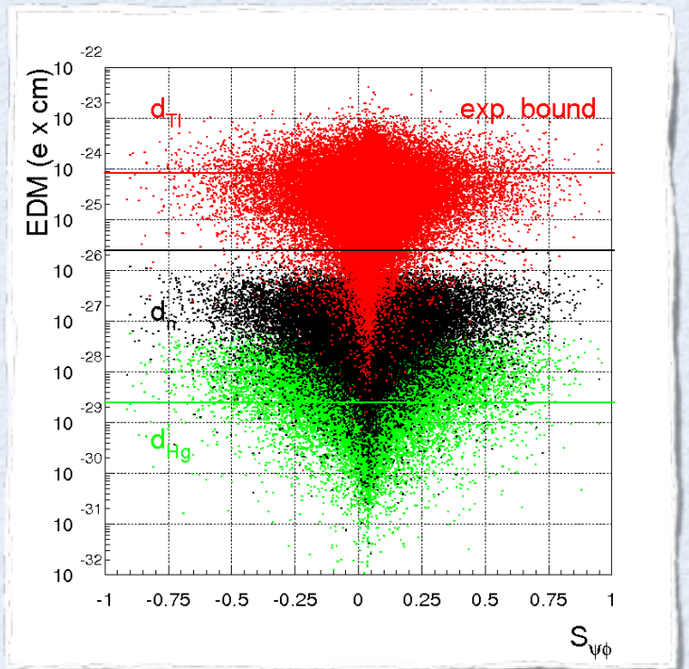
A large $S_{\psi\varphi}$ does not spoil the EDMs



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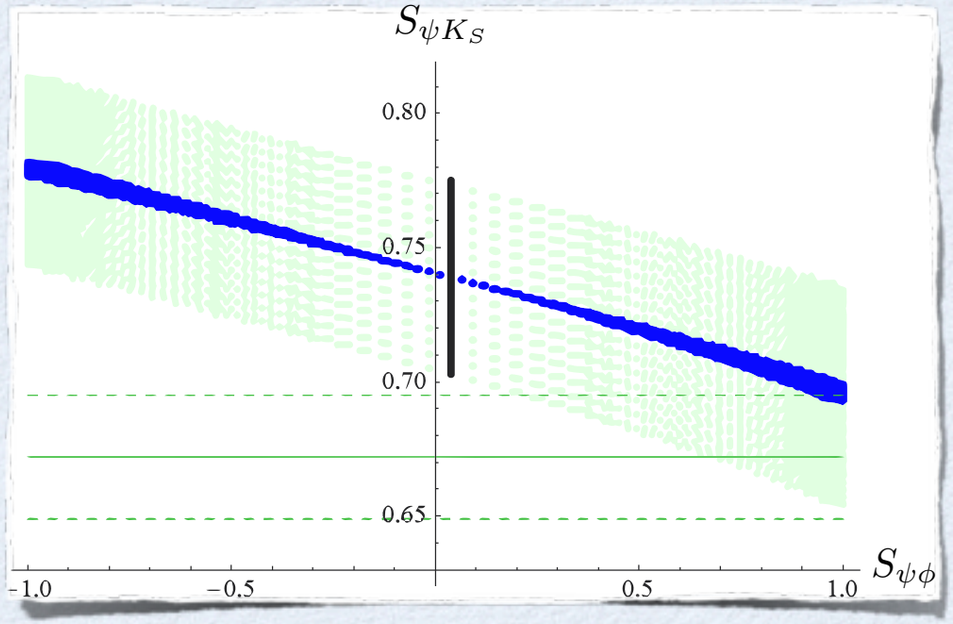

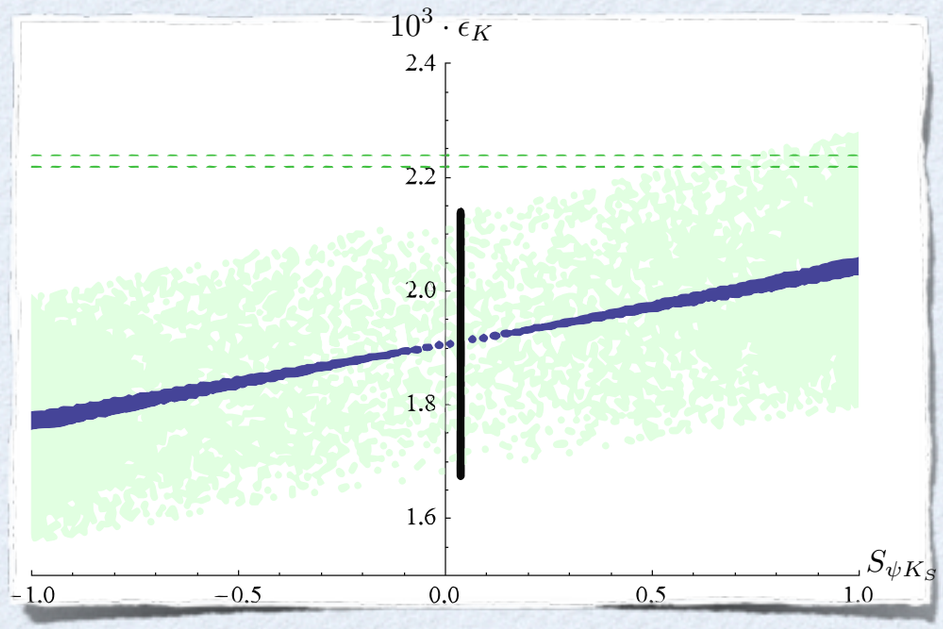

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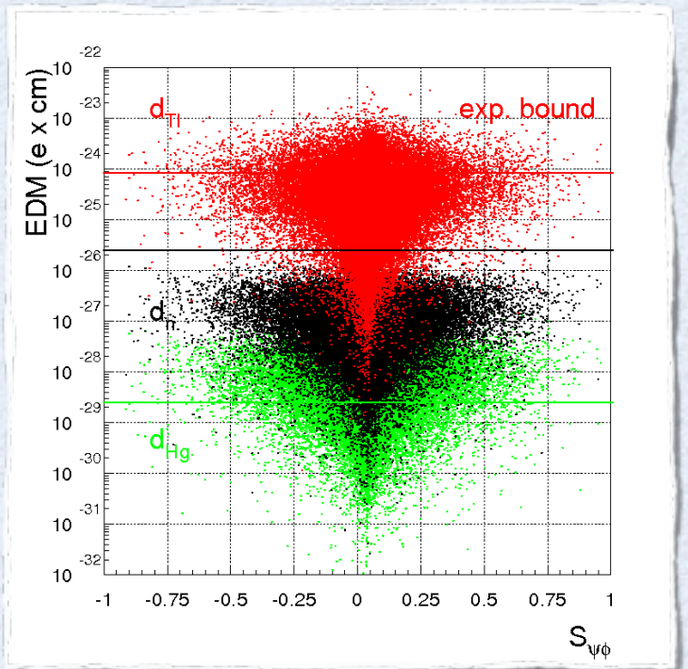
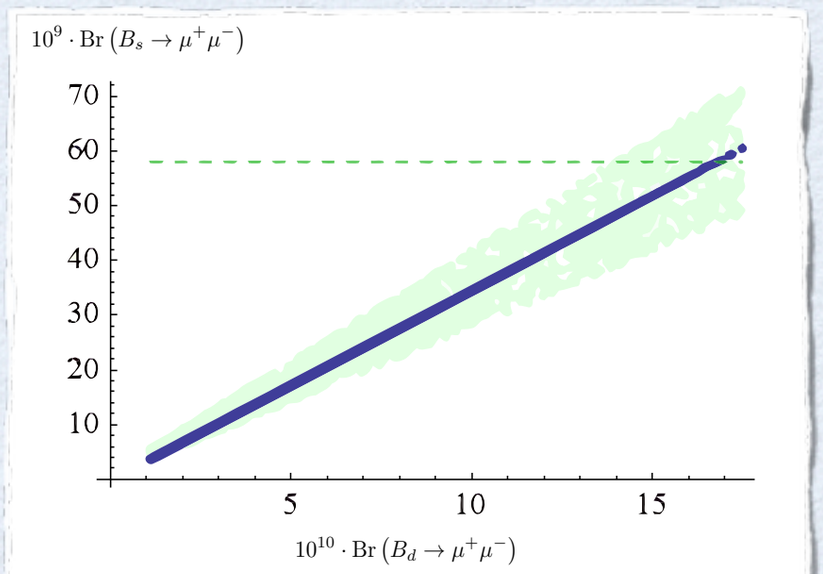


$B_{d,s} \to \mu^+\mu^-$ correlation



MFV at Large: 2HDM$_{\overline{\text{MFV}}}$

Updates after LHCb

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Negligible contributions to ε_K

↓

Scenario 2 for V_{ub}

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softening of the BR($B \to \tau\, \nu$) tension

Buras and Girrbach, 1204.5064

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Negligible contributions to ε_K

↓

Scenario 2 for V_{ub}

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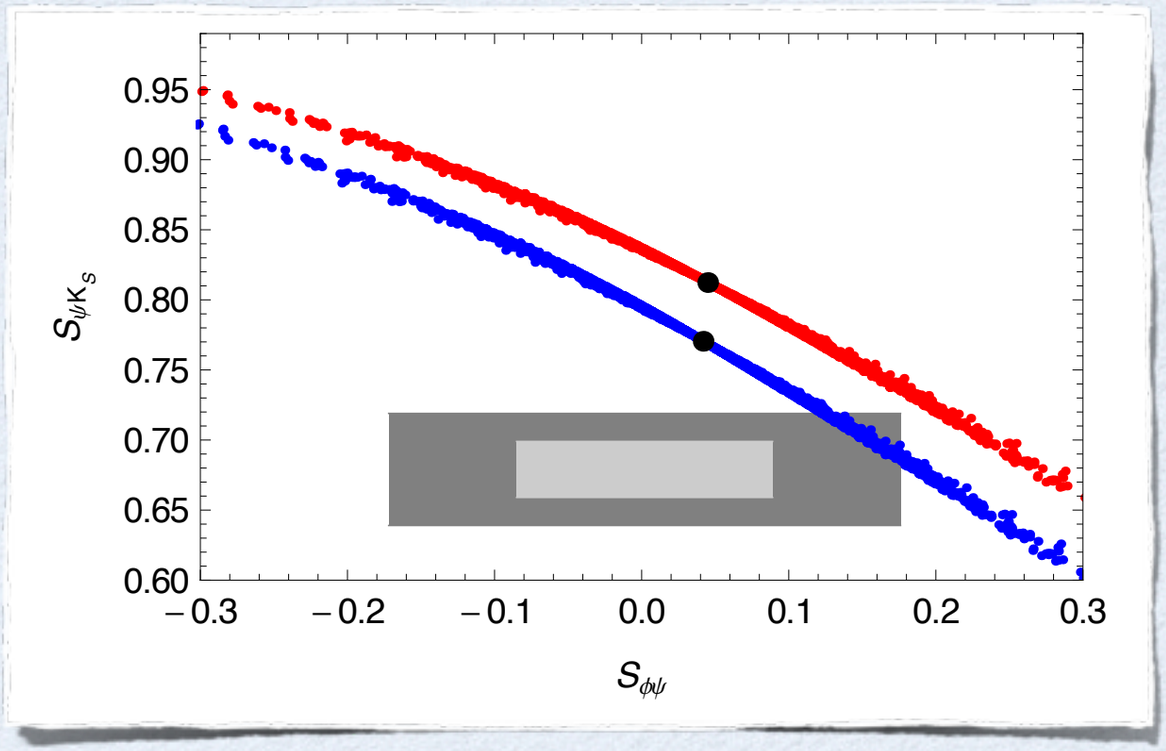
softening of the BR($B \to \tau\, \nu$) tension

No large $S_{\psi\varphi}$

↓

the $S_{\psi K_S}$ - ε_K tension cannot be improved better than to 2σ



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THE MODEL

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Structure

The flavour group $\mathcal{G}_q$ is a gauge symmetry of Nature.

Y_u and Y_d are physical scalar fields, whose vevs break $\mathcal{G}_q$.

There are 4 new quarks that make the theory non anomalous.

Grinstein, Redi, Villadoro - JHEP 1011

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There are 4 new quarks that make the theory non anomalous.

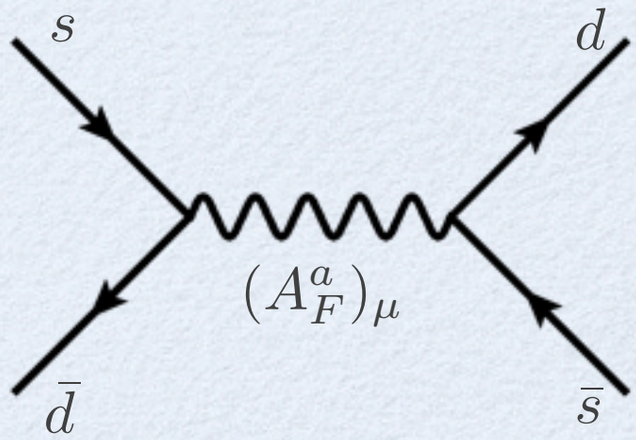
The flavour gauge bosons mediate FCNCs, but the new quarks generate a mechanism of inverted hierarchy that suppresses them effectively.

SM fermion mass terms:

$$\frac{\langle H \rangle}{\langle Y_D \rangle} \bar{Q}_L D_R \quad \rightarrow \quad \langle Y_F \rangle \propto \frac{1}{\text{SM Yukawas}}$$

Boson mass terms:

$$\langle H \rangle^2 \langle Y_D \rangle^2 (A_D)_\mu (A_D)^\mu \quad \rightarrow \quad m_{A_F} \propto \frac{1}{\text{SM Yukawas}}$$



Suppressed by (down SM Yukawa)^4

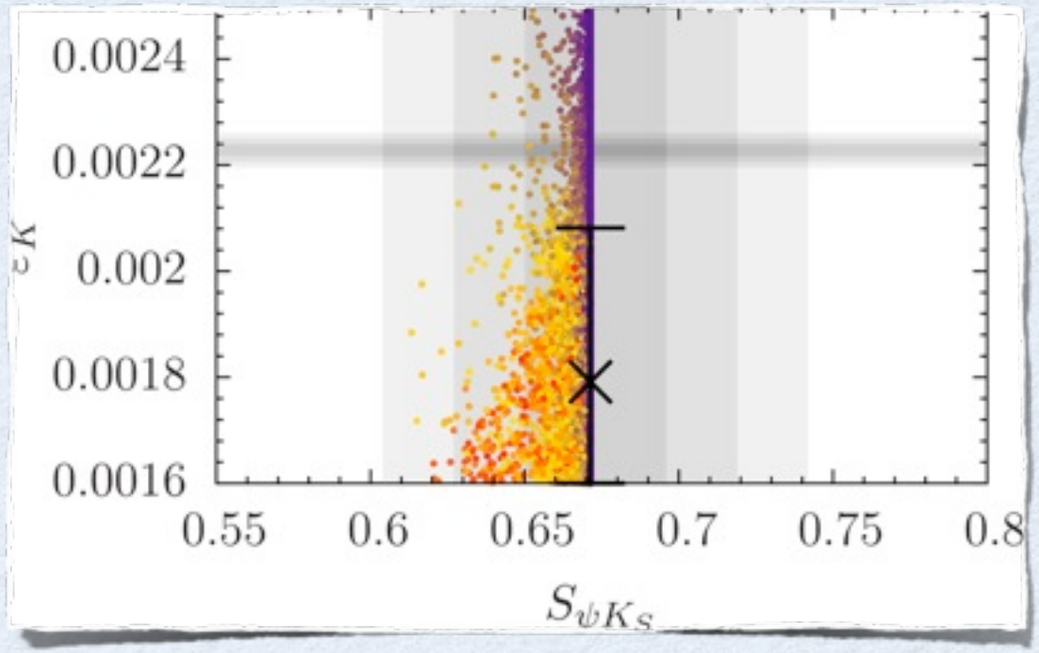
Grinstein, Redi, Villadoro - JHEP 1011

PHENOMENOLOGICAL ANALYSIS - I

Beyond MFV: Gauged Flavour Symmetries

Phenomenological Analysis - I

The $S_{\psi K_S}$ - ε_K tension can be solved...



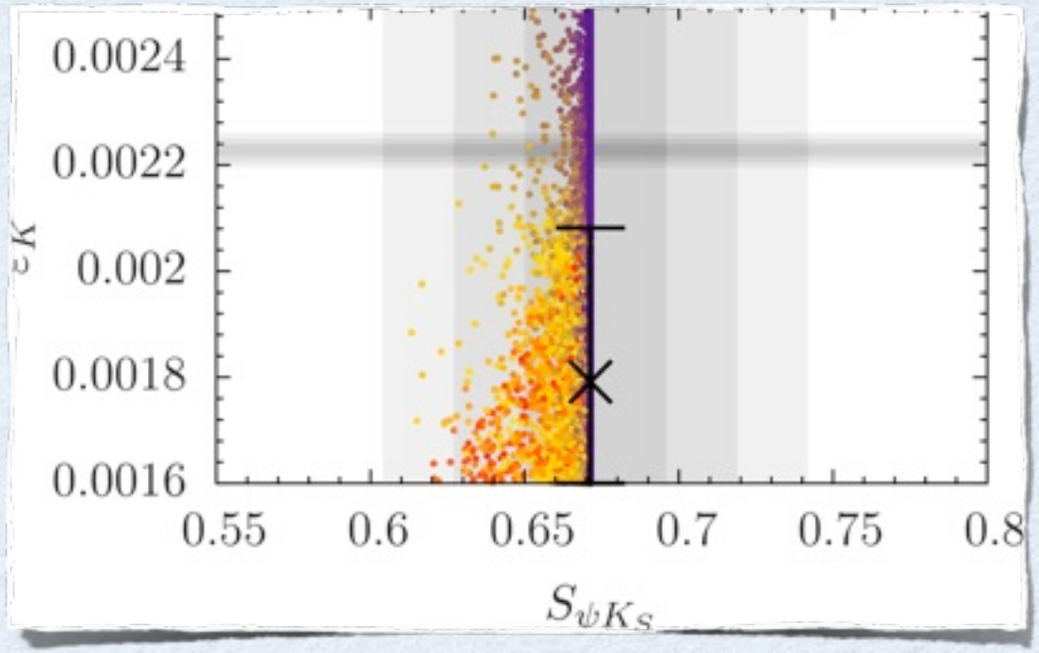
Buras, MVC, Merlo and Stamou - JHEP 1203

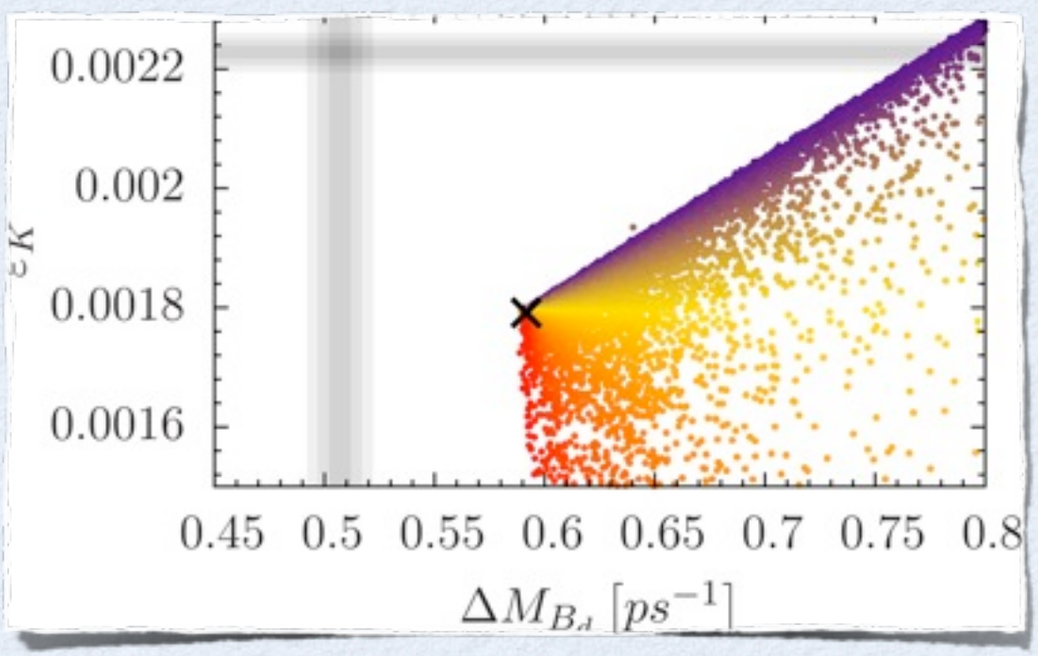
Beyond MFV: Gauged Flavour Symmetries

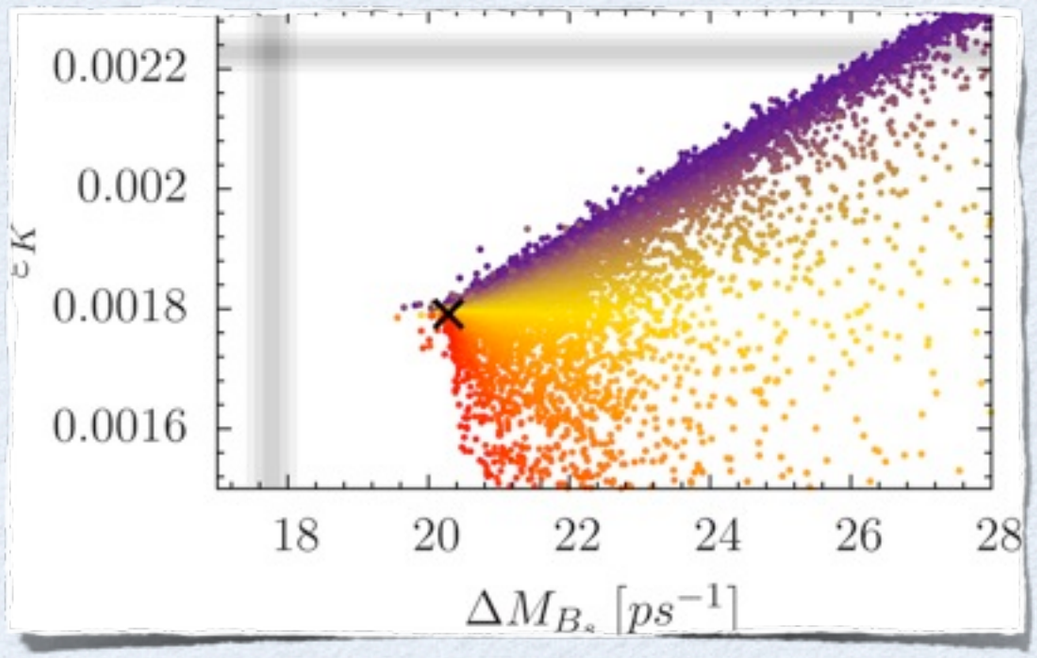
Phenomenological Analysis - I

The $S_{\psi K_S}$ - ε_K tension can be solved...

... but this automatically worsens the agreement of ΔM_s and ΔM_d .







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PHENOMENOLOGICAL ANALYSIS - II

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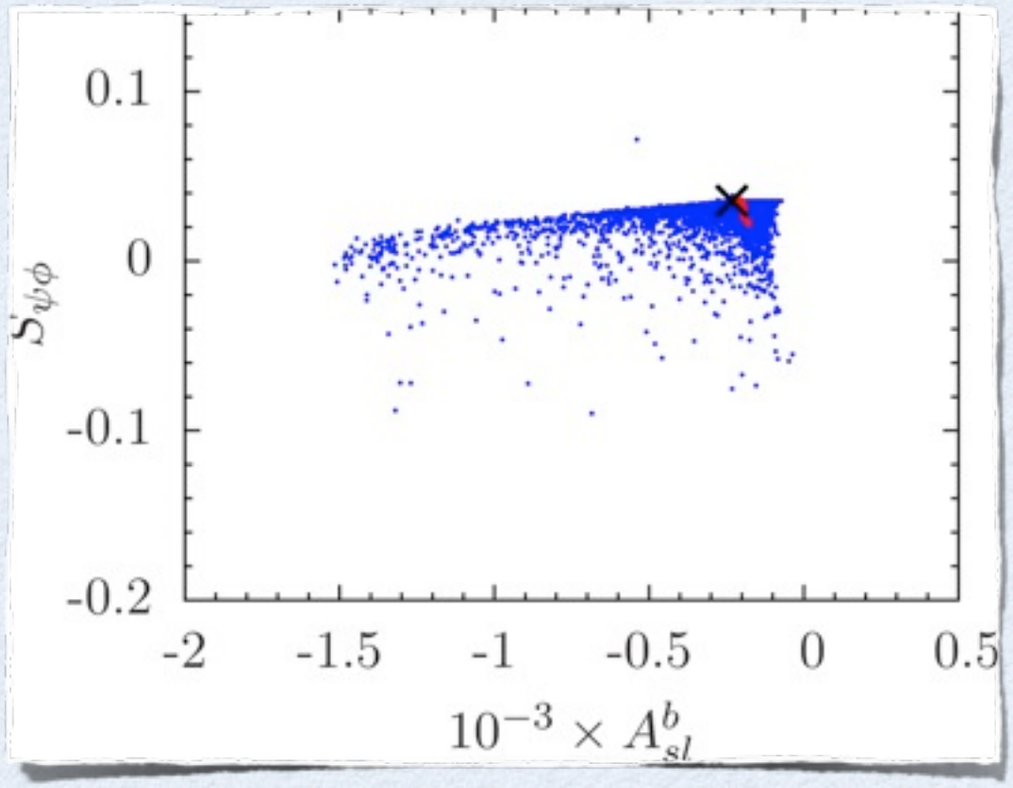

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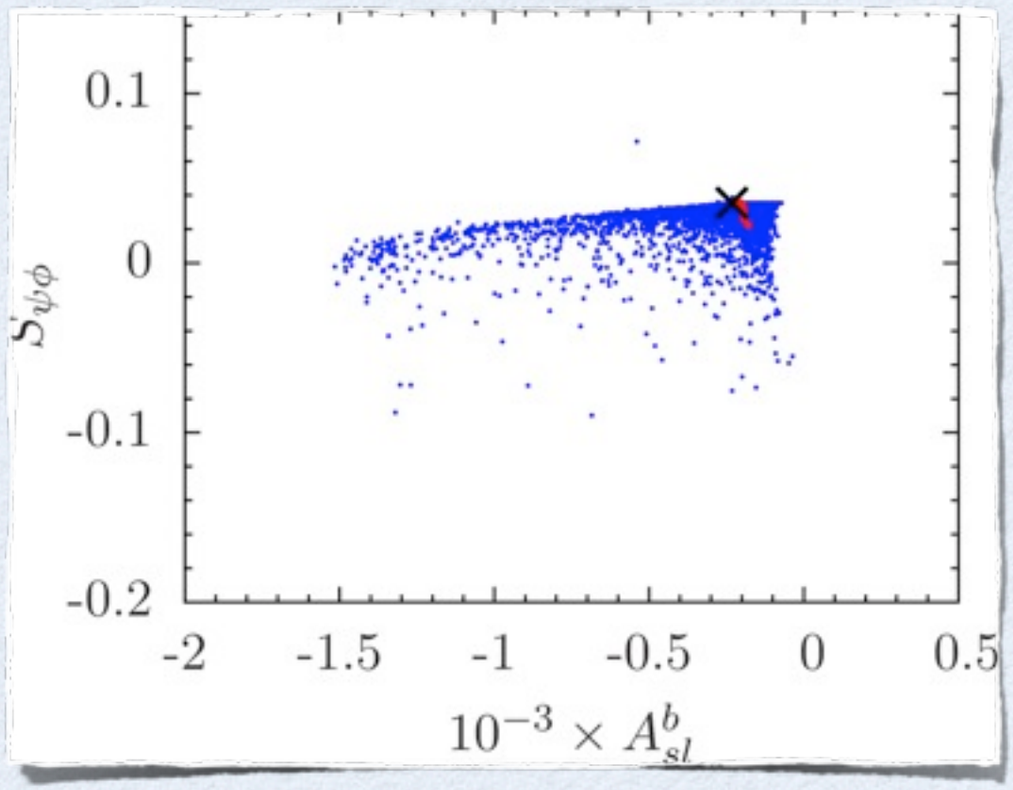

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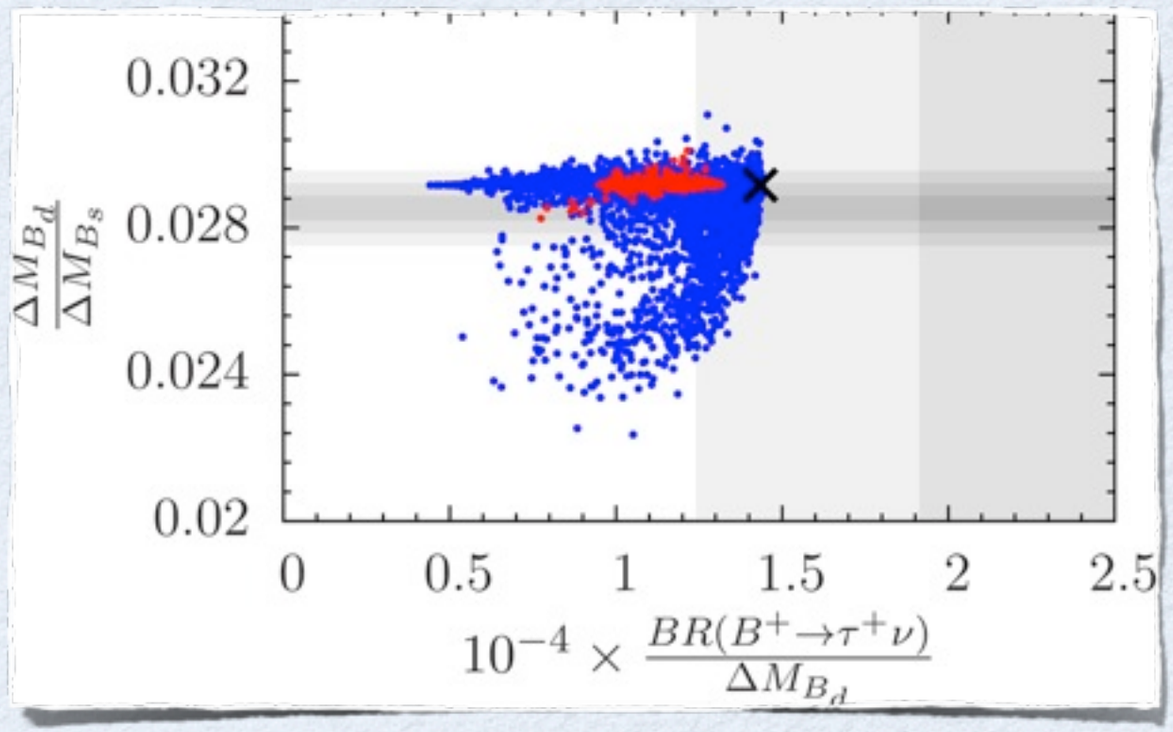

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- More that 20 different BSM scenarios have been studied in Munich during the last decade; this work has produced a database of deviations from SM and correlations for each of them. Hence, we have already the tools to test the models, and we are starting to receive the data to make more conclusive statements on them.

Thanks!