Flavor Theory

Flavor as a portal beyond the Standard Model

Matthias Neubert
Johannes Gutenberg University Mainz

International Europhysics Conference on High-Energy Physics
Grenoble, France, 21-27 July 2011

Introduction - Flavor as a portal beyond the SM

- Besides the **hierarchy problem** (mechanism of EWSB) and the **dark-matter puzzle**, the **origin of flavor** is one of the big, unsolved mysteries of fundamental physics
  - connected to deep questions such as the **matter-antimatter asymmetry** in the Universe, the **origin of fermion generations**, and the reason for the **striking hierarchies** observed in the spectrum of fermion masses and mixing angles
  - in SM, **flavor physics is connected to EWSB** via the Higgs Yukawa interactions
- Flavor physics is an issue for any extension of the SM ("flavor problem")

Introduction - Flavor as a portal beyond the SM

- For almost two decades, when SUSY was the most popular extension of the SM, flavor physics was largely ignored and considered irrelevant to high-energy discovery physics

- The reason was that SUSY has little to say about the origin of flavor -- and worse, that flavor is potentially problematic for many (generic) SUSY models
- Fortunately, in recent years the situation has changed significantly
- Flavor is now generally viewed as a **key ingredient** of any BSM theory, which may help to **discover New Physics** (even beyond the direct LHC reach) and **decipher its nature**

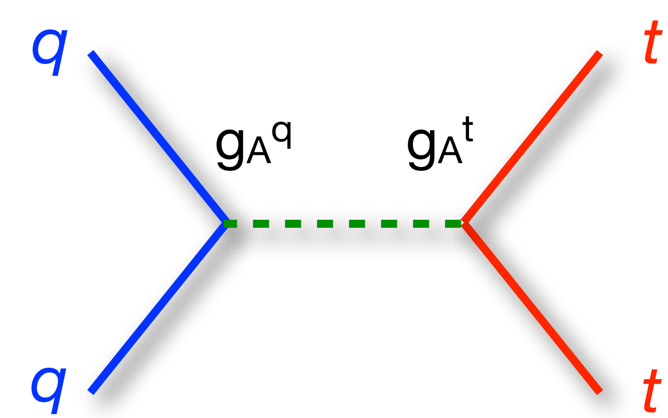
Introduction - Flavor as a portal beyond the SM

Intriguing example: Anomalous top-quark forward-backward asymmetry at the Tevatron

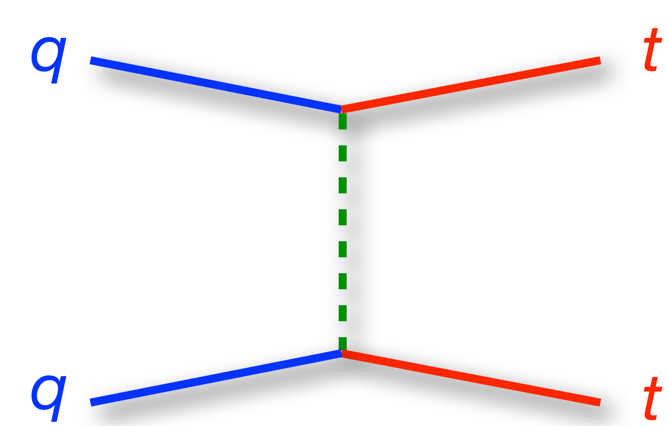
- New Physics contribution from s- or t-channel exchange of a new heavy particle, interfering with SM tree-level contribution

- In all but one model,*) the existence of new heavy particles with **non-trivial flavor structure** is required!

see e.g.:
Grinstein, Kagan, Trott, Zupan (2011);
Blum, Hochberg, Nir (2011);
Haisch, Westhoff (2011)
Westhoff @ EPS11



$\cos\theta$ term $\propto -g_A^q\, g_A^t$, and hence these couplings must have opposite sign ($g_A^q \neq g_A^t$)



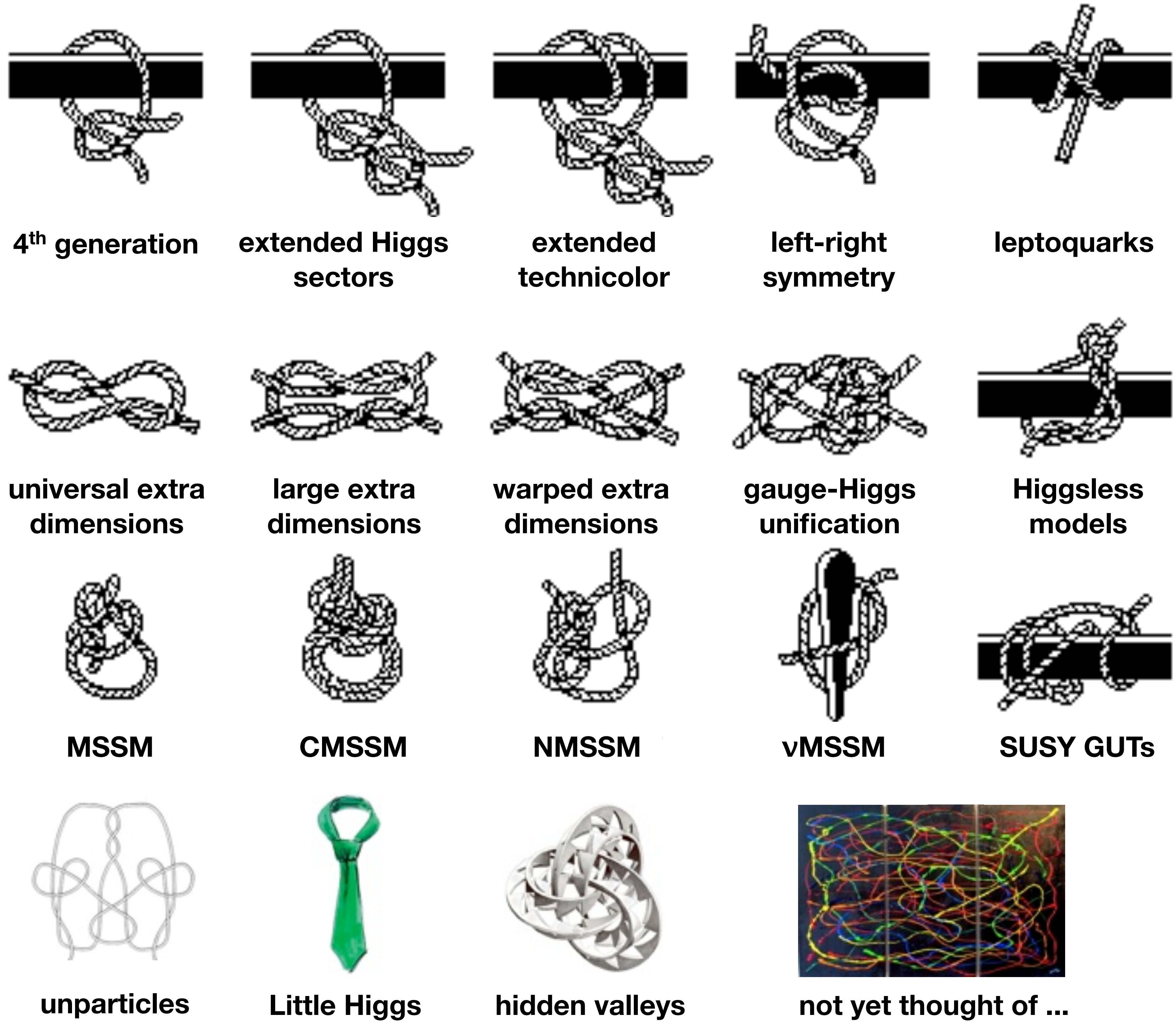
requires flavor off-diagonal couplings of top to light quarks

*) Tavarez, Schmalz (2011): light axigluon model

Standard Model and Beyond: The Gordian Knot

What is the “New Physics” and how to find it ?

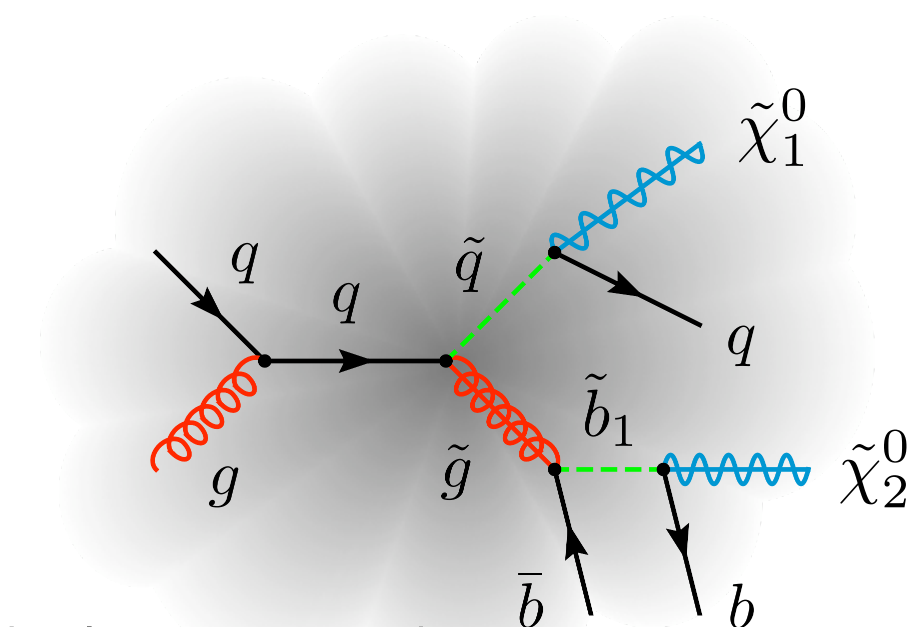
Standard Model and Beyond



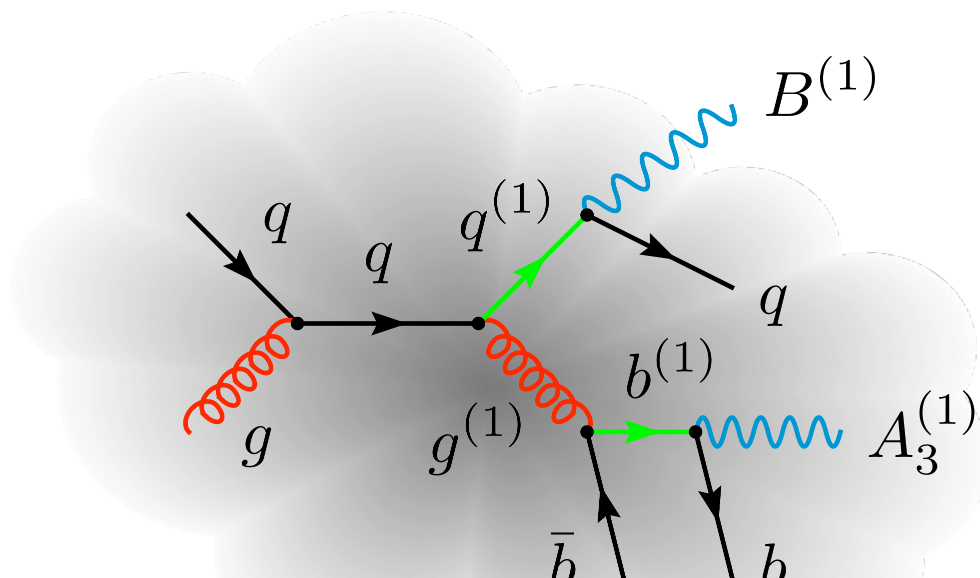
Complementary of direct and indirect searches

Weiler @ EPS11

- Production of **new particles** at high-energy colliders probes directly the structure of matter and its interactions
- But quite different scenarios of New Physics can lead to very similar signatures and hence to experimental signals that are difficult to disentangle
- Low-energy precision measurements study quantum corrections from **virtual particles**, offering indirect insights into the structure of matter and its interactions
- In the history of physics, this has often provided **first clues** about a new layer of reality (e.g. weak interactions, charm and top quarks, Higgs boson, ...), since it provides sensitivity to higher energy scales



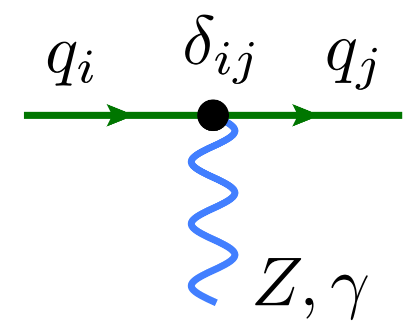
Minimal supersymmetric SM (MSSM)



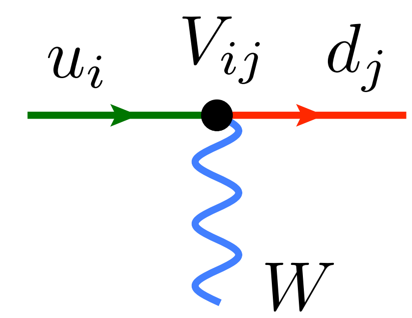
Universal Extra Dimensions (UED)

Legacy of the B factories (BaBar, Belle, CDF, D0)

- Spectacular confirmation of the CKM model as the **dominant source of flavor and CP violation**
- All flavor-violating interactions encoded in Yukawa couplings to Higgs boson
- Suppression of flavor-changing neutral currents (FCNCs) and CP violation in quark sector due to **unitarity** of CKM matrix, **small mixing angles**, and **GIM mechanism** *)



δ: unit matrix



V: CKM matrix

$$\boldsymbol{V} \approx \begin{array}{c} \\ \\ \end{array} \begin{array}{cc} \begin{array}{ccc} d & s & b \end{array} & \\ \begin{pmatrix} 1 & \lambda & \lambda^3 \\ -\lambda & 1 & \lambda^2 \\ -\lambda^3 & -\lambda^2 & 1 \end{pmatrix} & \begin{array}{c} u \\ c \\ t \end{array} \end{array}$$

λ ≈ 0.22: Cabibbo angle

N. Cabibbo M. Kobayashi T. Maskawa

2008 Nobel Prize to Kobayashi, Maskawa

*) EPS HEPP Prize 2011 to Glashow, Iliopoulos, Maiani

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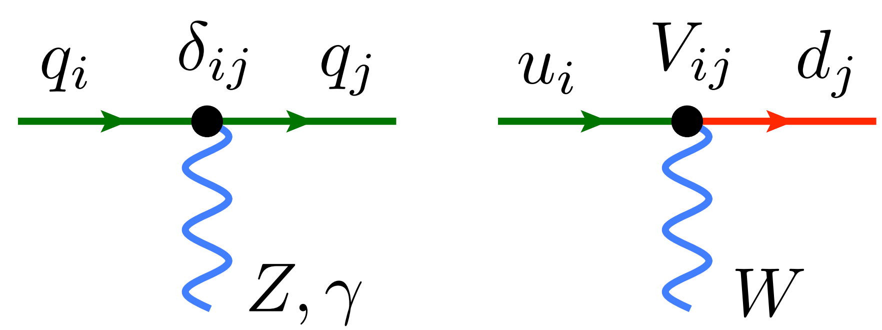
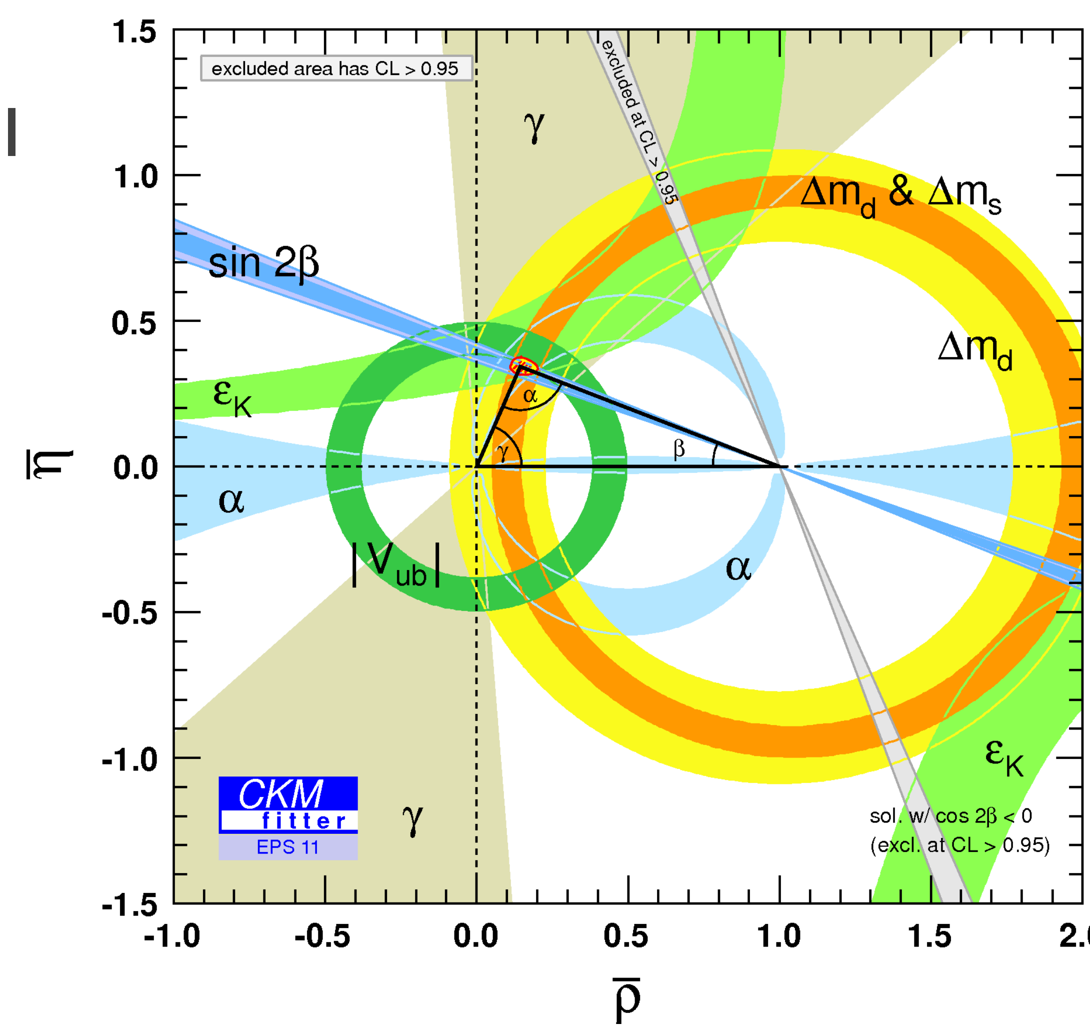


δ: unit matrix   *V*: CKM matrix

N. Cabibbo   M. Kobayashi   T. Maskawa

2008 Nobel Prize to Kobayashi, Maskawa



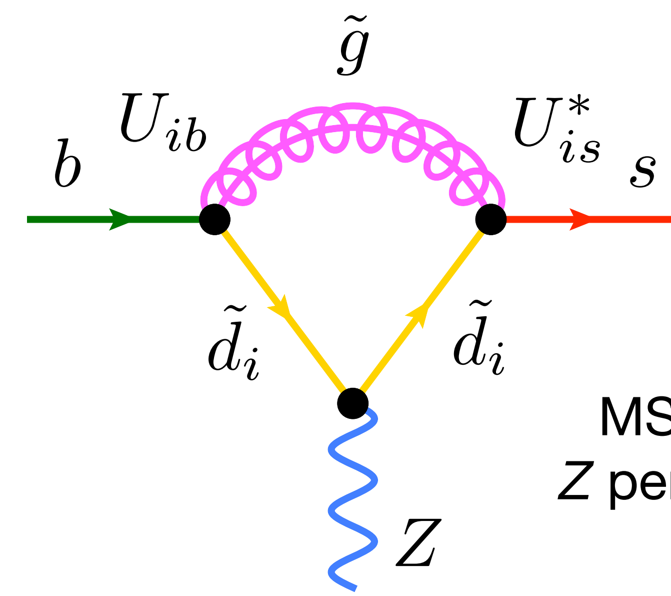
Niess @ EPS11; see also: Bona @ EPS11

*) EPS HEPP Prize 2011 to Glashow, Iliopolous, Maiani

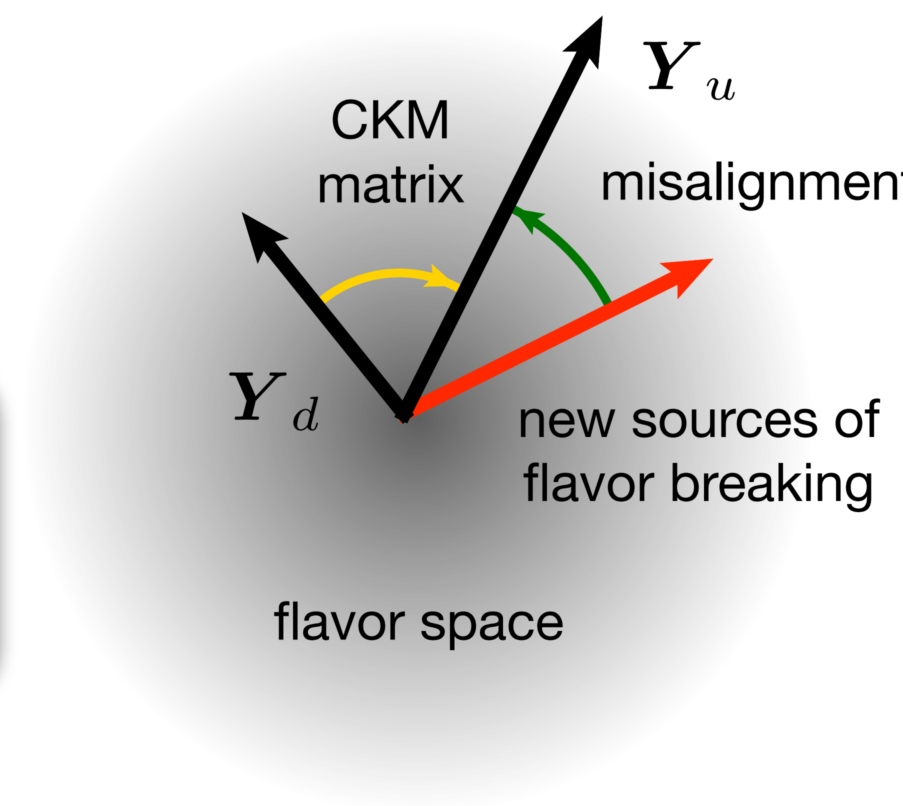
Flavor Structure in the SM and Beyond

In extensions of the SM, additional flavor and CP violation can arise from exchange of new scalar (H^+, $\tilde{q}$, ...), fermionic ($\tilde{g}$, t', ...), or gauge (Z',W', ...) degrees of freedom

- new flavor-violating terms in general not aligned with SM Yukawa couplings $\boldsymbol{Y}_u$, $\boldsymbol{Y}_d$
- can lead to excessive FCNCs, unless:
  - new particles are very heavy: $\tilde{m}_i >> 1$ TeV
  - their masses are degenerate: $\Delta\tilde{m}_{ij} << \tilde{m}_i$
  - or mixing angles are very small: $U_{ij} << 1$

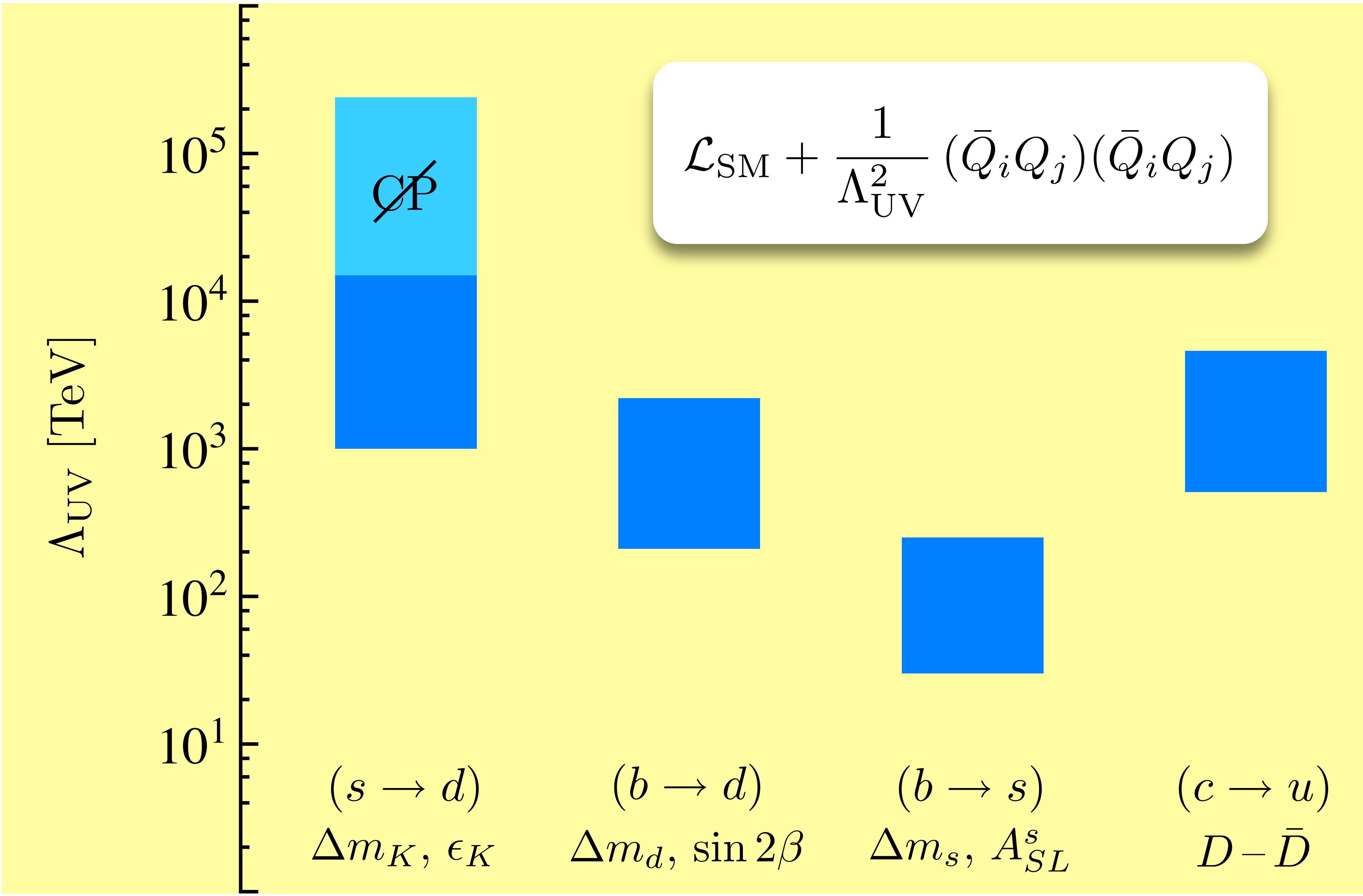


MSSM
Z penguin



The absence of dominant New Physics signals in FCNCs implies strong constraints on the flavor structure of TeV-scale physics!

Flavor Structure in the SM and Beyond



Generic bounds without a flavor symmetry

Introduction - Flavor as a portal beyond the SM

A more refined look indeed hints at some tensions with the SM in several areas of flavor physics:

B_d-meson system

- Tensions in UT fit
- V_{ub} crisis
- $\sin 2\beta$ tree vs. penguin

B_s-meson system

- CPV in B_s-meson mixing
- Anomalous like-sign dimuon production
- Rare decay $B_s \to \mu^+\mu^-$

At present, some of the most tantalizing hints (not more) of BSM physics -- besides $(g-2)_\mu$ and the top-quark forward-backward asymmetry at the Tevatron -- come from the flavor sector!

We live in exciting times, since many of these hints will very soon be cross-checked and perhaps corroborated at LHC!

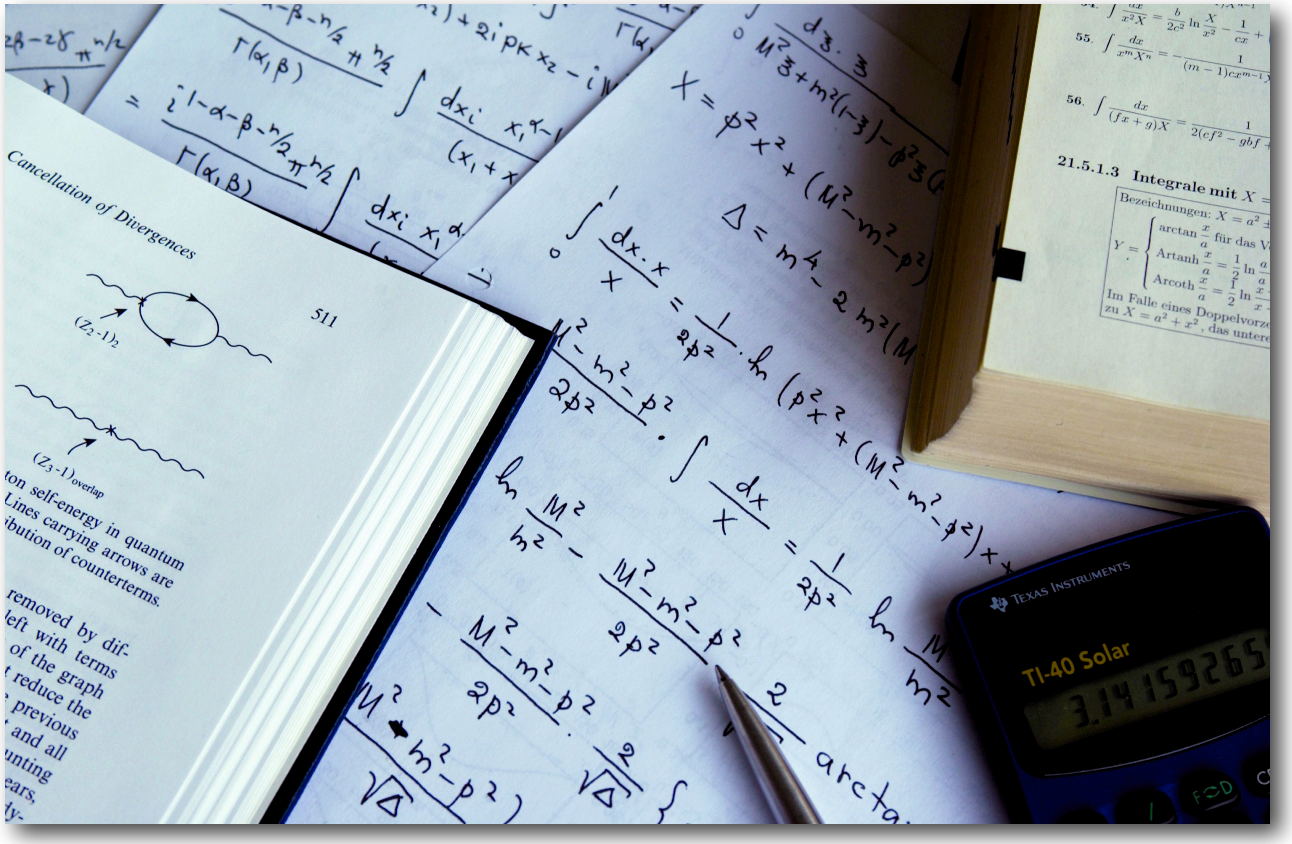
Outline

- Recent developments in flavor theory
- Hints for New Physics in B-meson mixing
- Hints for New Physics in B-meson decays
- Outlook

Unfortunately no time for:

- Production of heavy flavors
- Spectroscopy and exotic states
- Detailed discussion of hadronic B-meson decays
- Detailed discussion of improved CKM measurements
- Charm decays and D-meson mixing ...

Recent developments in flavor theory



Recent developments in flavor theory

- Intense theory effort of hard-core QFT calculations for flavor observables (~1990-2010) based on **heavy-quark expansions**, **effective field theories** and **lattice QCD** has been a triumph of particle phenomenology

  Blossier @ EPS11; Tantalo @ EPW11

- Many important conceptual developments (HQET, NRQCD, QCDF, SCET, LCSR, ...)

  Khodjamirian @ EPS11; Melikhov @ EPS11

- In several cases, **irreducible theoretical uncertainties** have been reached

- Compared to a few years ago, there have been relatively few new theoretical calculations with a direct impact on phenomenology
  - discuss three examples

Inclusive semileptonic B-decay spectra

✷ extraction of $|V_{cb}|$, $|V_{ub}|$, m_b, m_c, heavy-quark parameters

- Two-loop QCD corrections ($\sim\alpha_s^2$) to differential $B\to X_q l\nu$ (for q=c,u) have been calculated

  Melnikov (2008); Pak, Czarnecki (2008); Biswas, Melnikov (2009); Bonciani, Ferroglia (2008); Asatrian, Greub, Pecjak (2008); Beneke, Huber, Li (2008); Bell (2008)

- Their effects on moments have been computed Gambino (2011)

- Higher-order power corrections $\sim 1/m_b^{4,5}$ have been estimated Mannel, Turczyk, Uraltsev (2010)

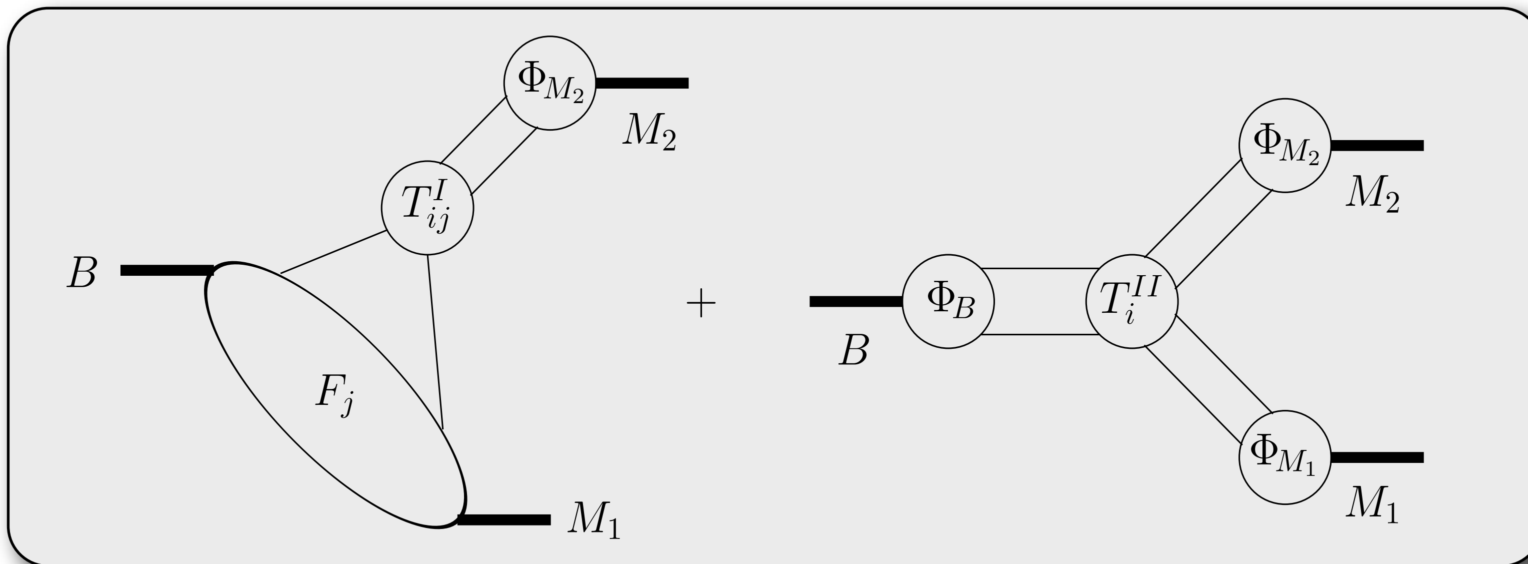
- One-loop QCD corrections to the leading power-suppressed corrections have still only been calculated for the kinetic operator ($\sim\alpha_s\cdot\mu_\pi^2/m_b^2$) Becher, Boos, Lunghi (2007)

- Resummation of Sudakov logarithms in the shape-function region has been completed at NNLO ($\sim N^3LL$)

  Greub, MN, Pecjak (2009)

QCD factorization for hadronic B decays

Calculation of BBNS kernels $T_{ij}^{I,II}$ at NNLO:



- One-loop corrections to hard spectator scattering (tree and penguin topologies) Beneke, Jäger (2005); Kivel (2006); Pilipp (2007); Beneke, Jäger (2006); Jain, Rothstein, Stewart (2007)
- Imaginary parts of two-loop vertex corrections Bell (2007)
- Two-loop vertex corrections to topological tree amplitudes Beneke, Huber, Li (2009); Bell 2009
- 2-loop penguin topologies in progress Bell, Beneke, Huber, Li

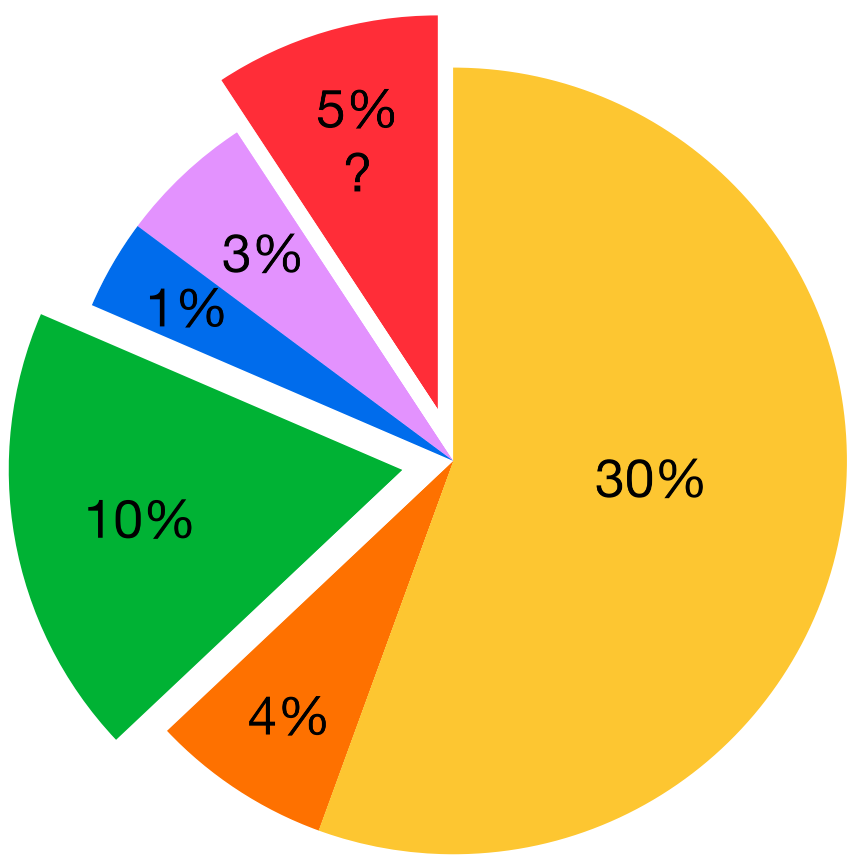
Non-local power corrections in B→X$_s$γ decay

$$\mathcal{B}(B \to X_s\gamma)_{\rm SM}^{E_\gamma > 1.6\ \rm GeV} = \mathcal{B}(B \to X_c e\bar{\nu})_{\rm exp} \left[\frac{\Gamma(b \to s\gamma)}{\Gamma(b \to ce\bar{\nu})} \right]_{\rm LO}$$

$$\times \left\{ 1 + \mathcal{O}(\alpha_s) + \mathcal{O}(\alpha) + \mathcal{O}(\alpha_s^2) + \mathcal{O}\left(\frac{\Lambda_{\rm QCD}^2}{m_b^2}\right) + \mathcal{O}\left(\frac{\Lambda_{\rm QCD}^2}{m_c^2}\right) + \mathcal{O}\left(\frac{\Lambda_{\rm QCD}}{m_b}\right) \right\}$$

Misiak et al. (2006)

Benzke, Lee, MN, Paz (2010)



NLO QCD

NLO EW

NNLO QCD

LO QCD + local $1/m_b^2$

LO QCD + local $1/m_c^2$

non-local (!) $1/m_b$

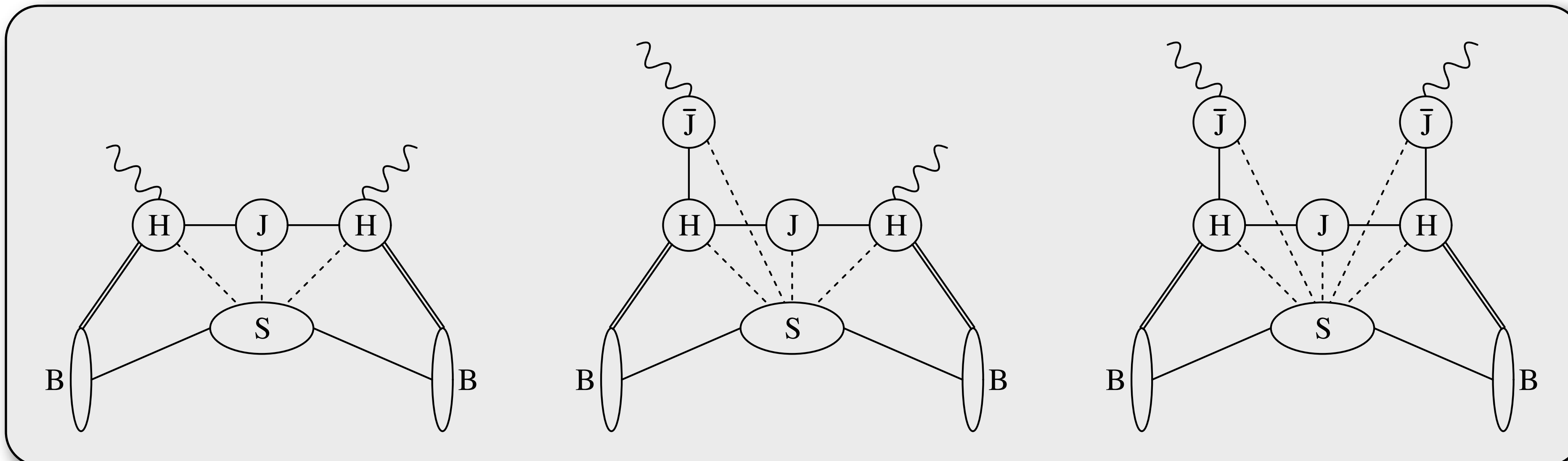
perturbative

non-perturbative

relative size of corrections compared to leading-order (LO) branching ratio

Non-local power corrections in B→$X_s\gamma$ decay

Systematic analysis of non-local Λ_{QCD}/m_b corrections based on **novel factorization theorem** derived using soft-collinear effective theory:



Benzke, Lee, MN, Paz (2010)

- Estimate **irreducible theoretical uncertainty** in the calculation of the B→$X_s\gamma$ branching ratio of about ±5% (relative error)
- Show that non-local power corrections give the formally **leading contribution** to the direct CP asymmetry in the Standard Model:

$$\mathcal{A}_{X_s\gamma}^{\rm SM} \approx \left(1.11 \times \frac{\tilde{\Lambda}_{17}^u - \tilde{\Lambda}_{17}^c}{300\,\mathrm{MeV}} + 0.69\right)\%$$

Recent developments in flavor theory

- *Important:* Some of the theoretical tools originally developed for flavor physics have found important applications in other fields, e.g.:
  - Renormalon calculus for estimating power corrections for non-Euclidean observables (1990s)
  - SCET applications to collider physics: an effective field theory approach to **factorization**, **Sudakov resummation**, and **jet physics**
  - SCET applications to heavy-ion physics

Flavor phenomenology in extensions of the SM

- Much recent activity on a variety of models, including:
  - SUSY models (MSSM, CMSSM, BMSSM, ...)
  - (SUSY-) GUTs

    e.g.: Buras, Nagai, Paradisi (2010); Girrbach et al. (2011)
    Girrbach @ EPS11

    Crivellin @ EPS11; Straub @ EPS11; Jones=Perez @ EPS11
  - models with extra dimensions (UED, RS, ...)
  - models with extended Higgs sectors

    e.g.: Buras, Carlucci, Gori, Isidori (2010); Blankenburg, Isidori (2011)
  - models with a 4th generation

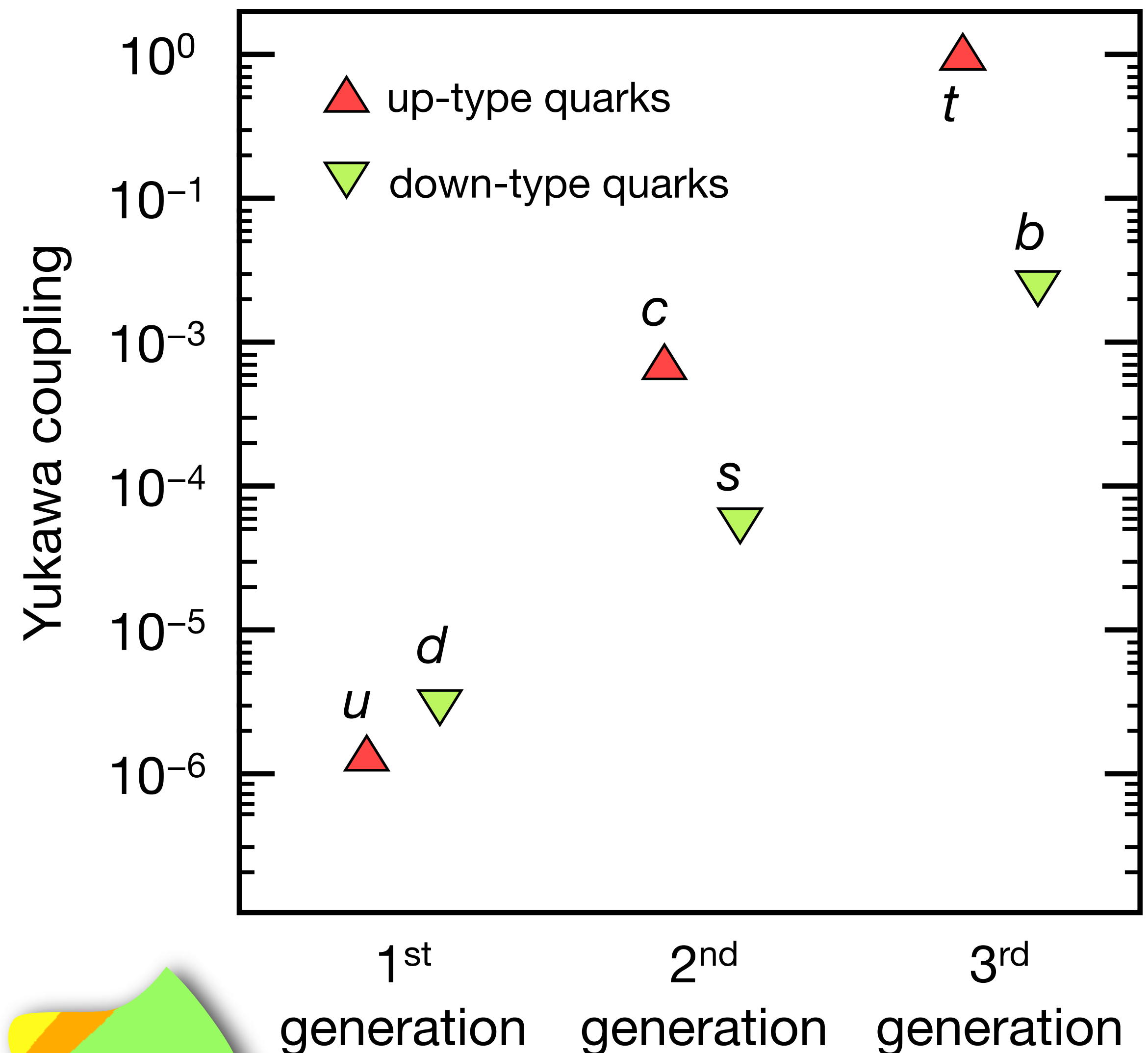
    e.g.: Buras et al. (2010); Rohrwild et al. (2009, 2010, 2011)
    Soni @ EPS11; Xu @ EPS11
  - models with new gauge bosons W', Z'
- Models featuring a **warped extra dimension (Randall-Sundrum)** offer a simultaneous, **geometrical solution to the hierarchy and flavor problems**
  - very different from SUSY

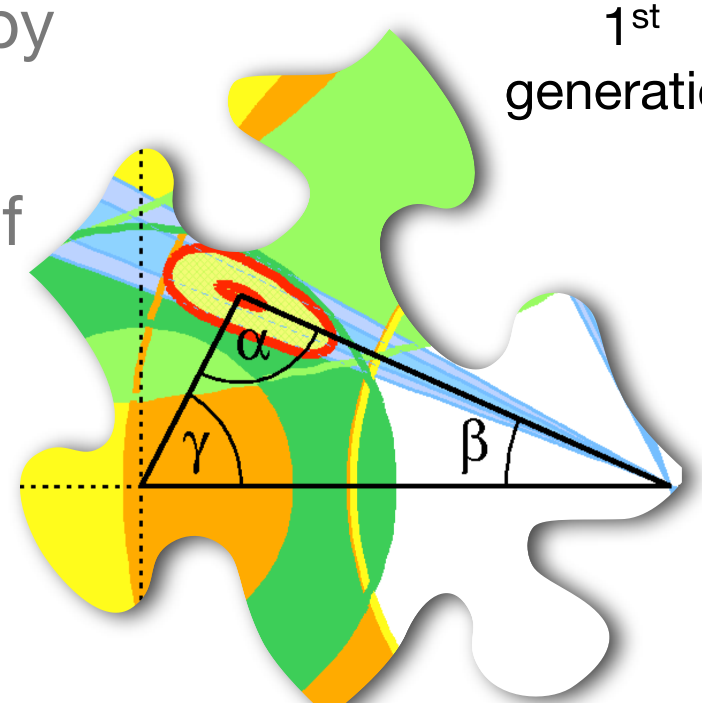
    Csaki, Falkowski, Weiler (2008);
    Casagrande, Goertz, Haisch, MN, Pfoh (2008);
    Blanke, Buras, Duling, Gori, Weiler (2008);
    Blanke, Buras, Duling, Gemmler, Gori (2008);
    Bauer, Casagrande, Haisch, MN (2009)

What is the dynamics of flavor?

While SM **describes** flavor physics very accurately, it does not **explain** its mysteries:

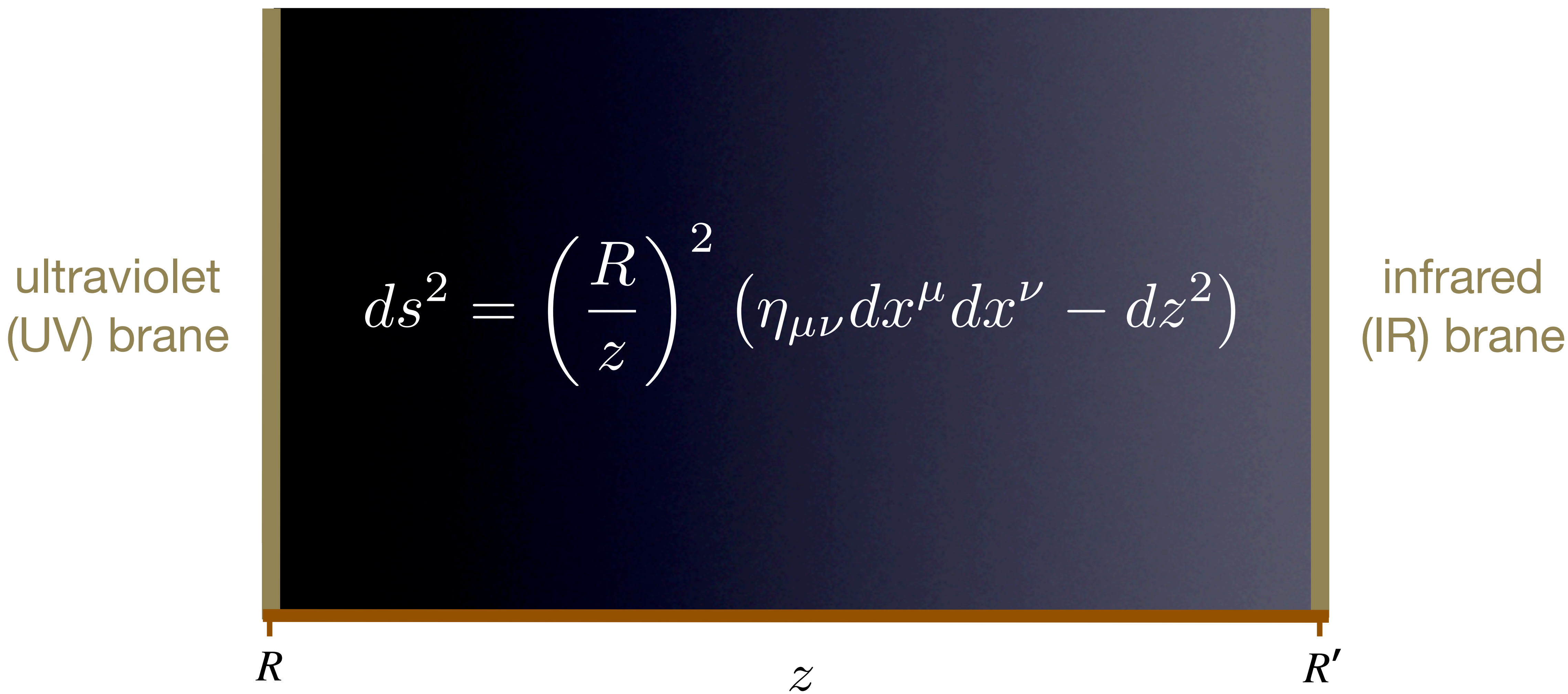
- Why are there three generations in nature?
- Why does the spectrum of fermion masses cover so many orders of magnitude?
- Why is the mixing between different generations governed by small mixing angles?
- Why is the CP-violating phase of the CKM matrix unsuppressed?





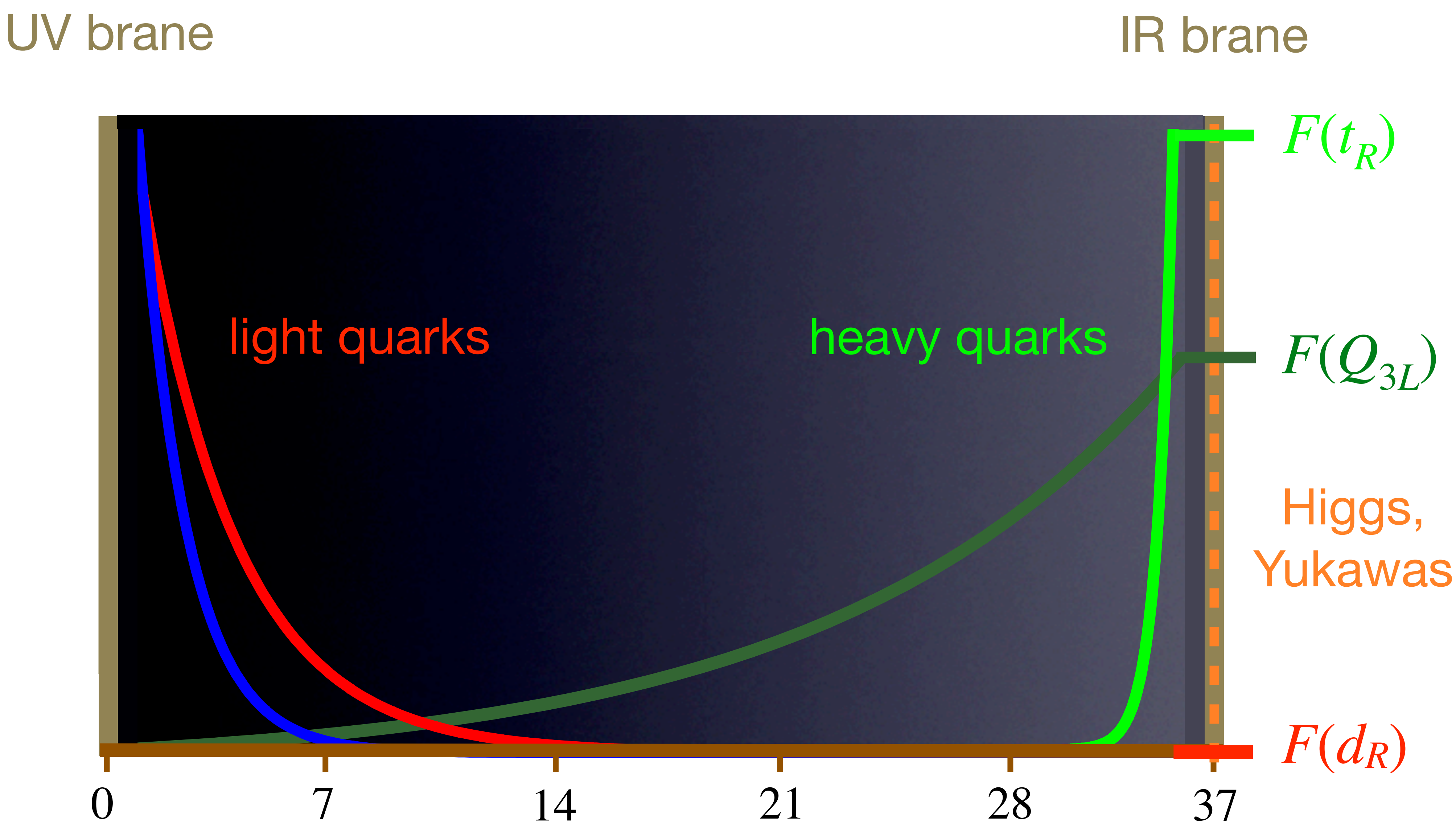
Flavor structure in RS models

Randall, Sundrum (1999)



- Solution to gauge hierarchy problem via gravitational redshift
- AdS/CFT calculable strong electroweak-symmetry breaking: holographic technicolor, composite Higgs
- Unification possible due to logarithmic running of couplings

Flavor structure in RS models



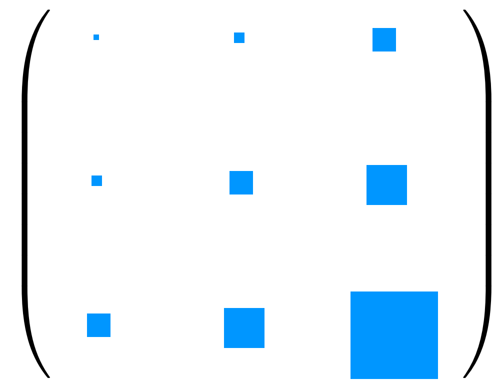
Localization of fermions in extra dimension depends exponentially on **O(1) parameters** related to the five-dimensional **bulk masses.** Overlaps $F(Q_L)$, $F(q_R)$ with IR-localized Higgs sector and Yukawa couplings are **exponentially small** for light quarks, while O(1) for top quark

Grossman, Neubert (1999); Ghergetta, Pomarol (2000)

Hierarchies of quark masses and CKM angles

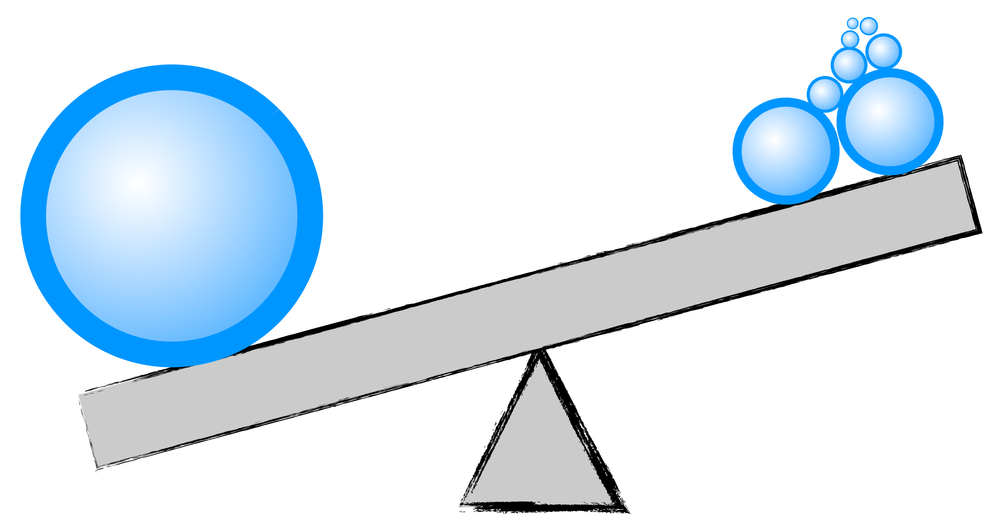
SM mass matrices can be written as: Huber (2003)

$$\boldsymbol{m}_q^{\mathrm{SM}} = \frac{v}{\sqrt{2}} \,\mathrm{diag}\left[F(Q_i)\right] \boldsymbol{Y}_q \,\mathrm{diag}\left[F(q_i)\right] =$$



where $\boldsymbol{Y}_q$ with $q = u,d$ are structureless, complex Yukawa matrices with O(1) entries, and $F(Q_i) << F(Q_j)$, $F(q_i) << F(q_j)$ for $i < j$

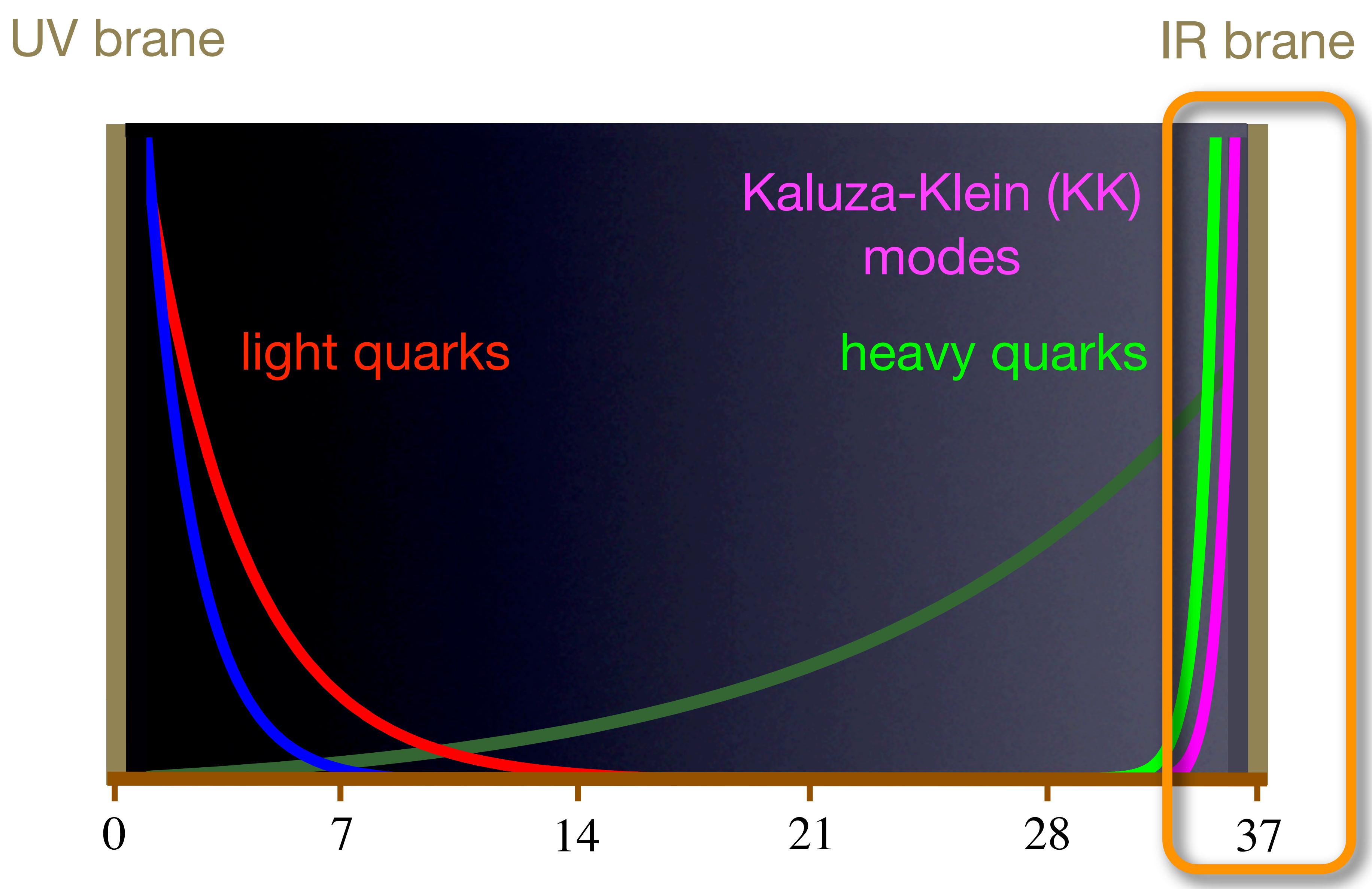
- In analogy to seesaw mechanism, matrices of this form give rise to hierarchical mass eigenvalues and mixing matrices
- Hierarchies can be adjusted by O(1) variations of bulk mass parameters
- Yet the CKM phase is predicted to be O(1)



Warped-space Froggatt-Nielsen mechanism!

Casagrande et al. (2008); Blanke et al. (2008)

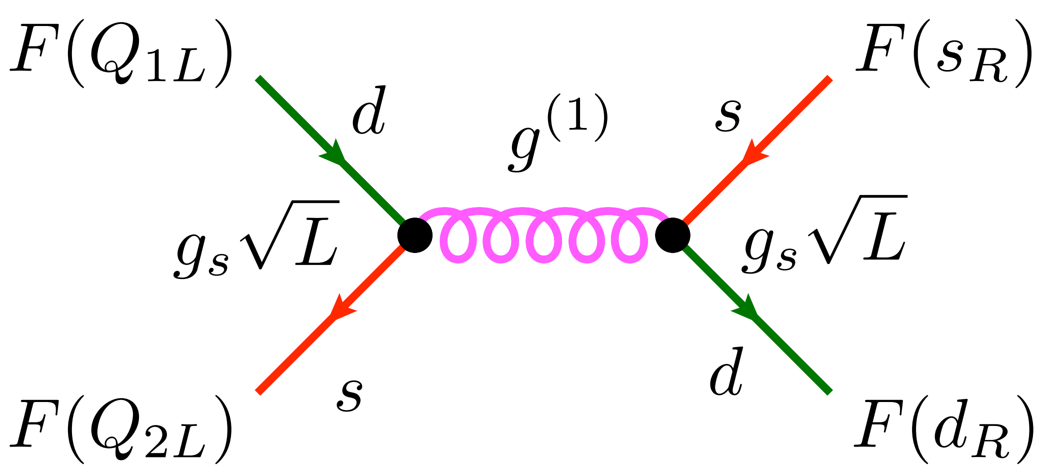
Flavor structure in RS models



Kaluza-Klein (KK) excitations of SM particles live close to the IR brane

Davoudiasl, Hewett, Rizzo (1999); Pomarol (1999)

RS-GIM protection of FCNCs

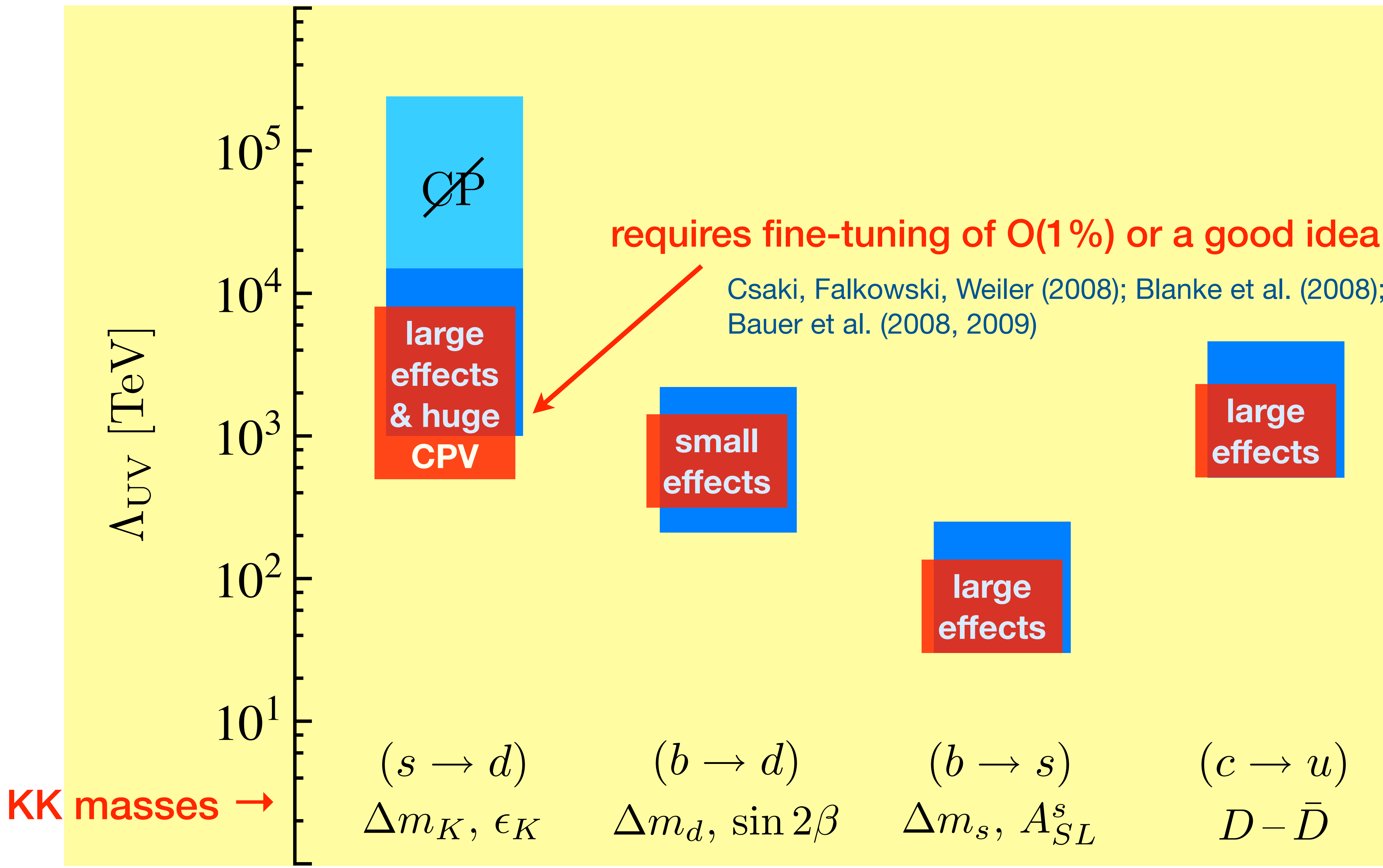


$$\sim \frac{g_s^2}{M_{\rm KK}^2}\, L\; F(Q_{1L})F(d_R)\; F(Q_{2L})F(s_R)$$

- Quark FCNCs are induced at tree-level through virtual exchange of KK gauge bosons (including KK gluons!) Huber (2003); Burdman (2003); Agashe et al. (2004); Casagrande et al. (2008)
- Resulting FCNC couplings depend on same exponentially small overlaps $F(Q_L)$, $F(q_R)$ that generate fermion masses
- FCNCs involving quarks other than top are strongly suppressed (true for all induced FCNC couplings) Agashe et al. (2004)

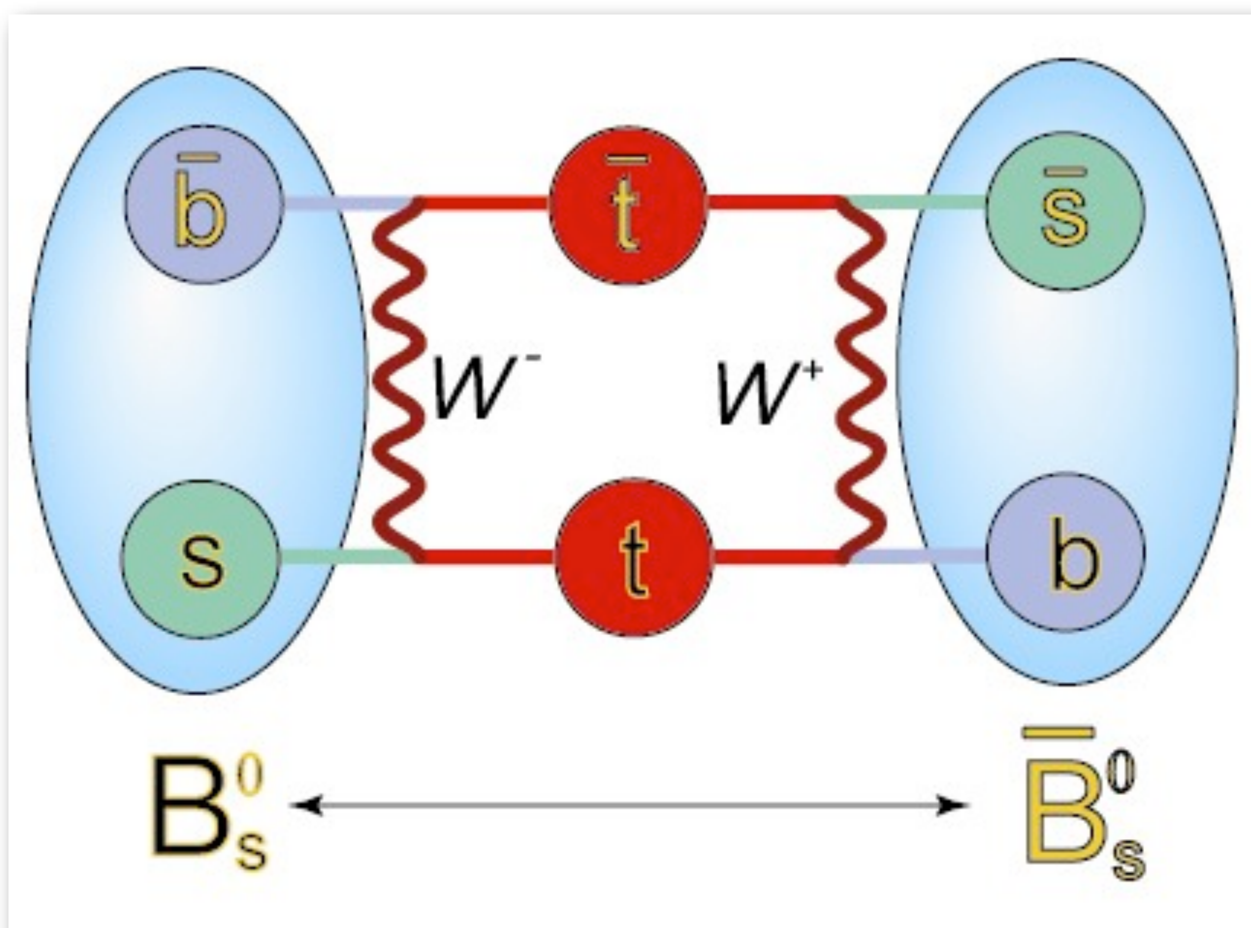
This mechanism suffices to suppress all but one of the dangerous FCNC couplings!

RS-GIM Protection of FCNCs



RS-GIM protection with KK masses of order few TeV

Hints for New Physics in B-meson mixing



Basic formulae

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

Three observables:

$$\phi_q = \arg(-M_{12}^q/\Gamma_{12}^q)$$ CPV phase

$$\Delta M_q = M_H^q - M_L^q = 2\,|M_{12}^q|$$ oscillation frequency (short-distance)

$$\Delta\Gamma_q = \Gamma_L^q - \Gamma_H^q = 2\,|\Gamma_{12}^q|\cos\phi_q$$ width difference (common final states)

Flavor-specific (e.g. semileptonic) asymmetries, assuming no CPV in the decay amplitudes:

$$a_{\mathrm{fs}}^q = a_{\mathrm{SL}}^q = \mathrm{Im}\,\frac{\Gamma_{12}^q}{M_{12}^q} = \frac{|\Gamma_{12}^q|}{|M_{12}^q|}\sin\phi_q = \frac{\Delta\Gamma_q}{\Delta M_q}\tan\phi_q$$

Parametrization of New Physics effects (assuming NP only in M_{12}^q):

$$\frac{M_{12}^q}{M_{12}^{\mathrm{SM},q}} = \Delta_q = |\Delta_q|\,e^{\mathrm{i}\phi_q^\Delta} = 1 + h_q\,e^{\mathrm{i}2\sigma_q}$$

CP-violating observables

Mixing-induced, time-dependent CP asymmetries in decays to CP eigenstates:

$$S_{\psi K} = \sin(2\beta + \phi_d^{\Delta}) \qquad\qquad S_{\psi\phi} = \sin(2\beta_s - \phi_s^{\Delta})$$

Semileptonic asymmetry measured at B factories: $a_{\rm SL}^d$

Flavor-specific asymmetry in tree-level $B_s^0 \to \mu^+ D_s^- X$ decays (D0): $a_{\rm fs}^s = a_{\rm SL}^s$

Like-sign dimuon charge asymmetry (D0):

$$A_{\rm sl}^b = \frac{N_b^{++} - N_b^{--}}{N_b^{++} + N_b^{--}} = C_d\, a_{\rm SL}^d + (1 - C_d)\, a_{\rm SL}^s\,; \qquad C_d = 0.594 \pm 0.022$$

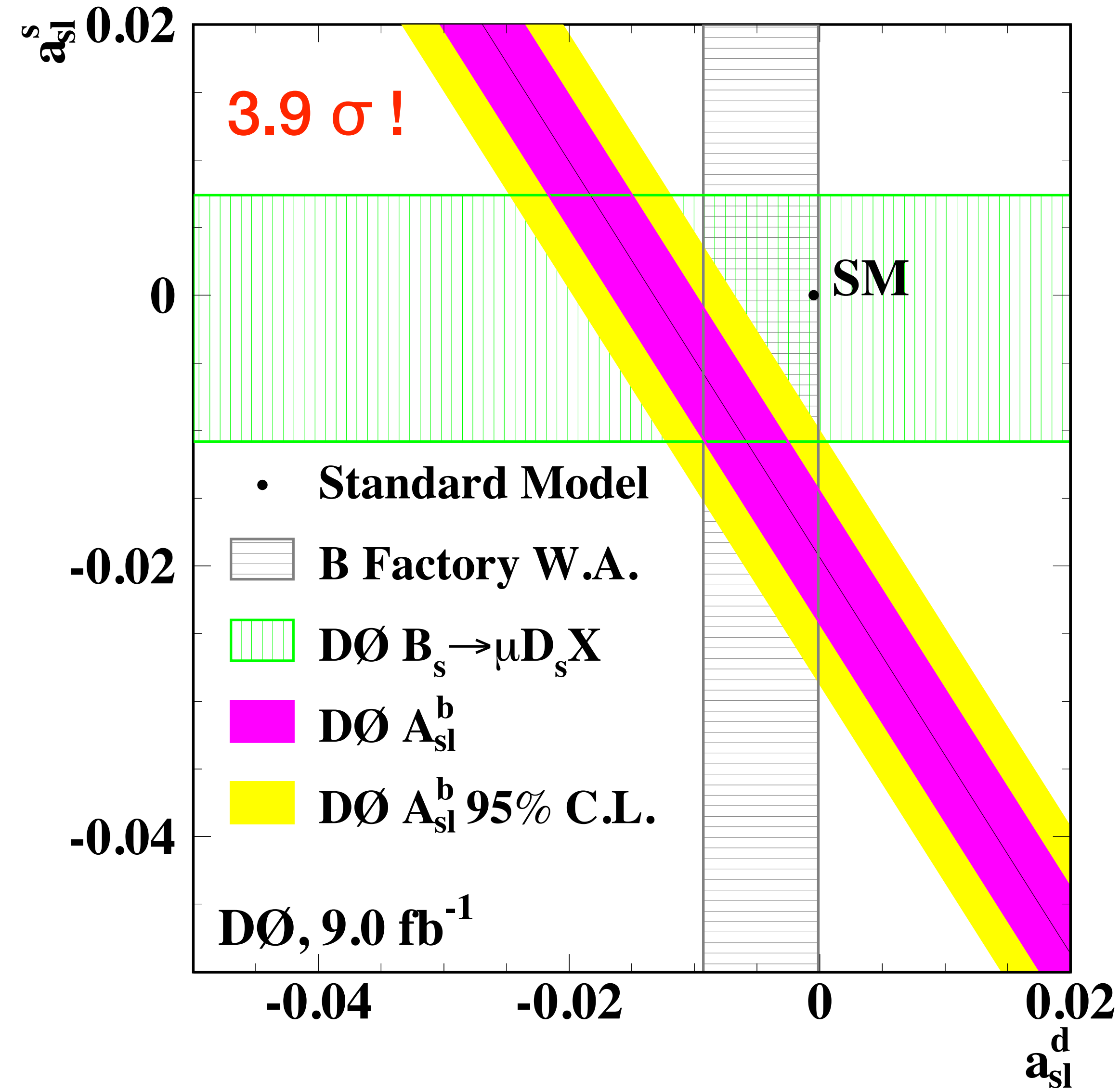
determined from data

✳ No need to use the theoretical prediction for $\Delta\Gamma_s$!

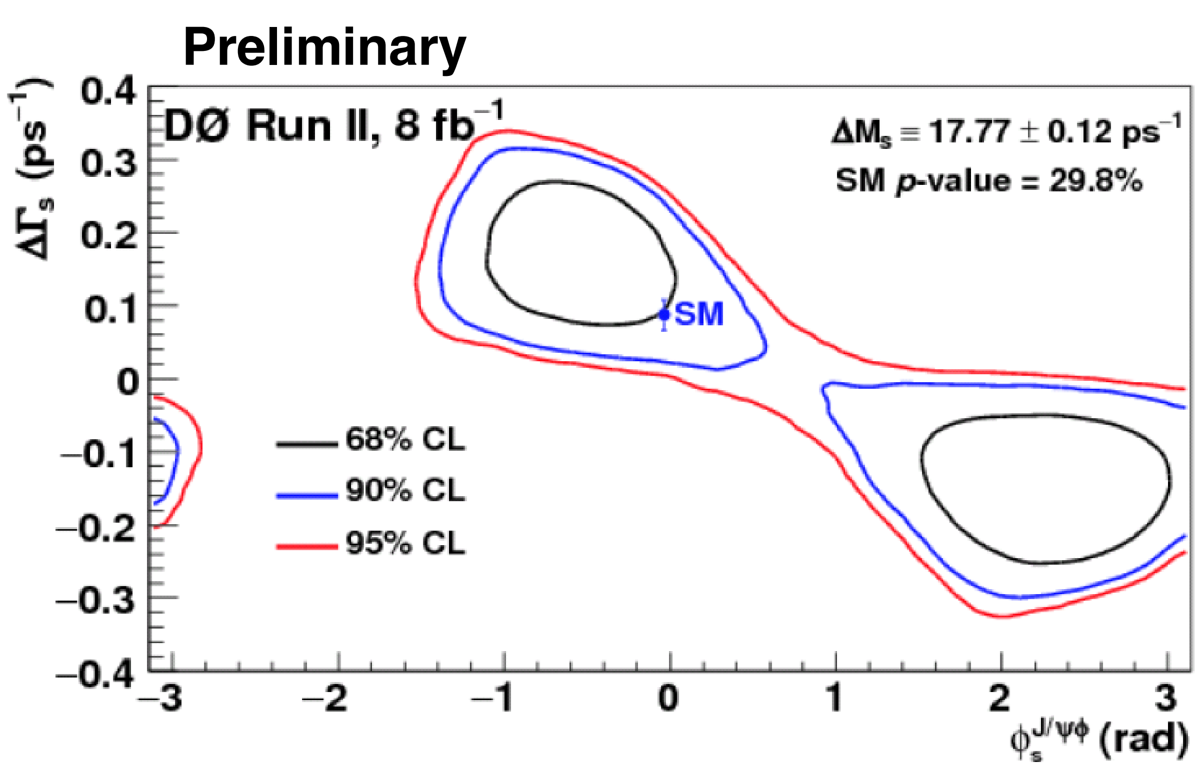
Tevatron data

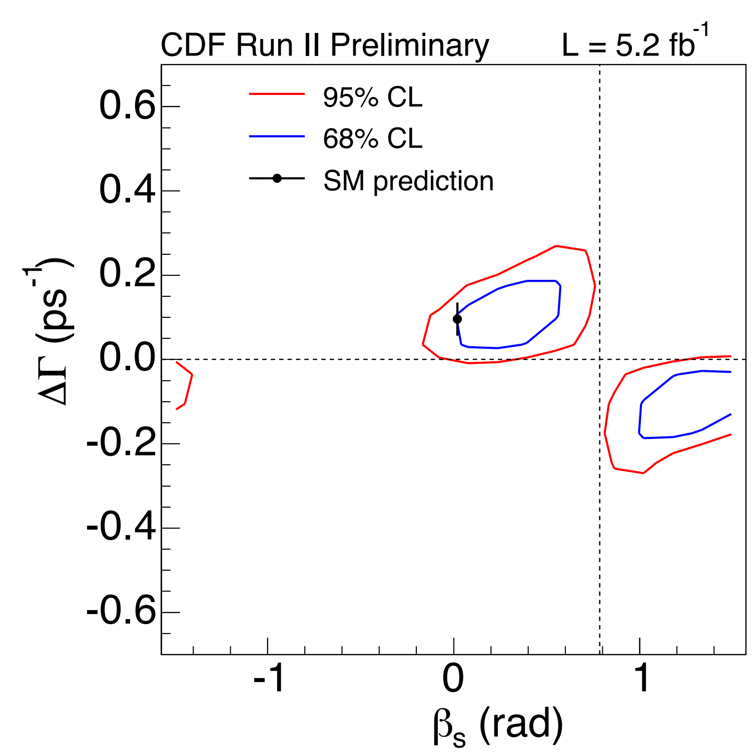
Like-sign dimuon charge asymmetry (D0):

- not an easy measurement
- if taken at face value, a rather compelling hint of New Physics!



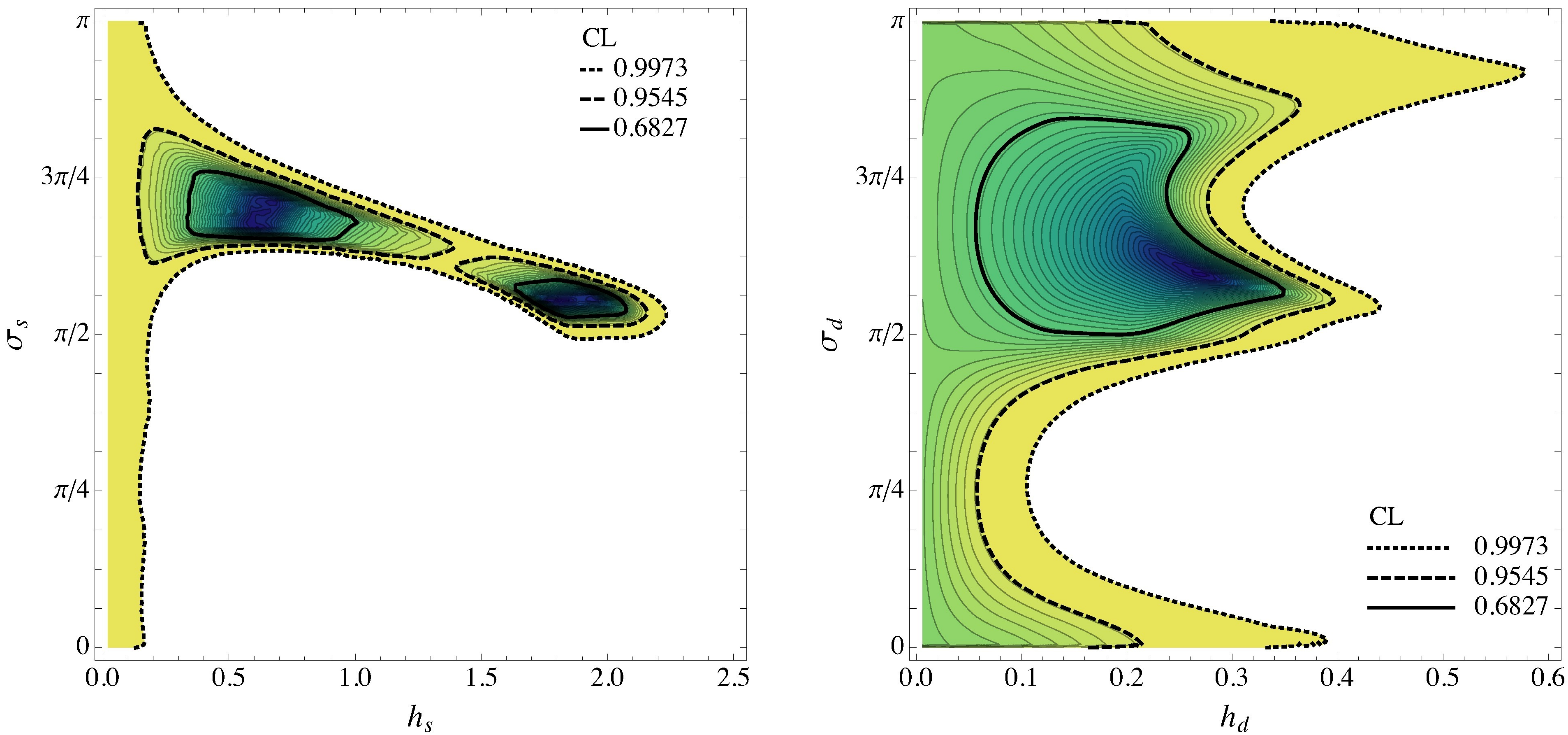
Mixing-induced CP asymmetry (B_s):





Theoretical analyses (prior to D0 update)

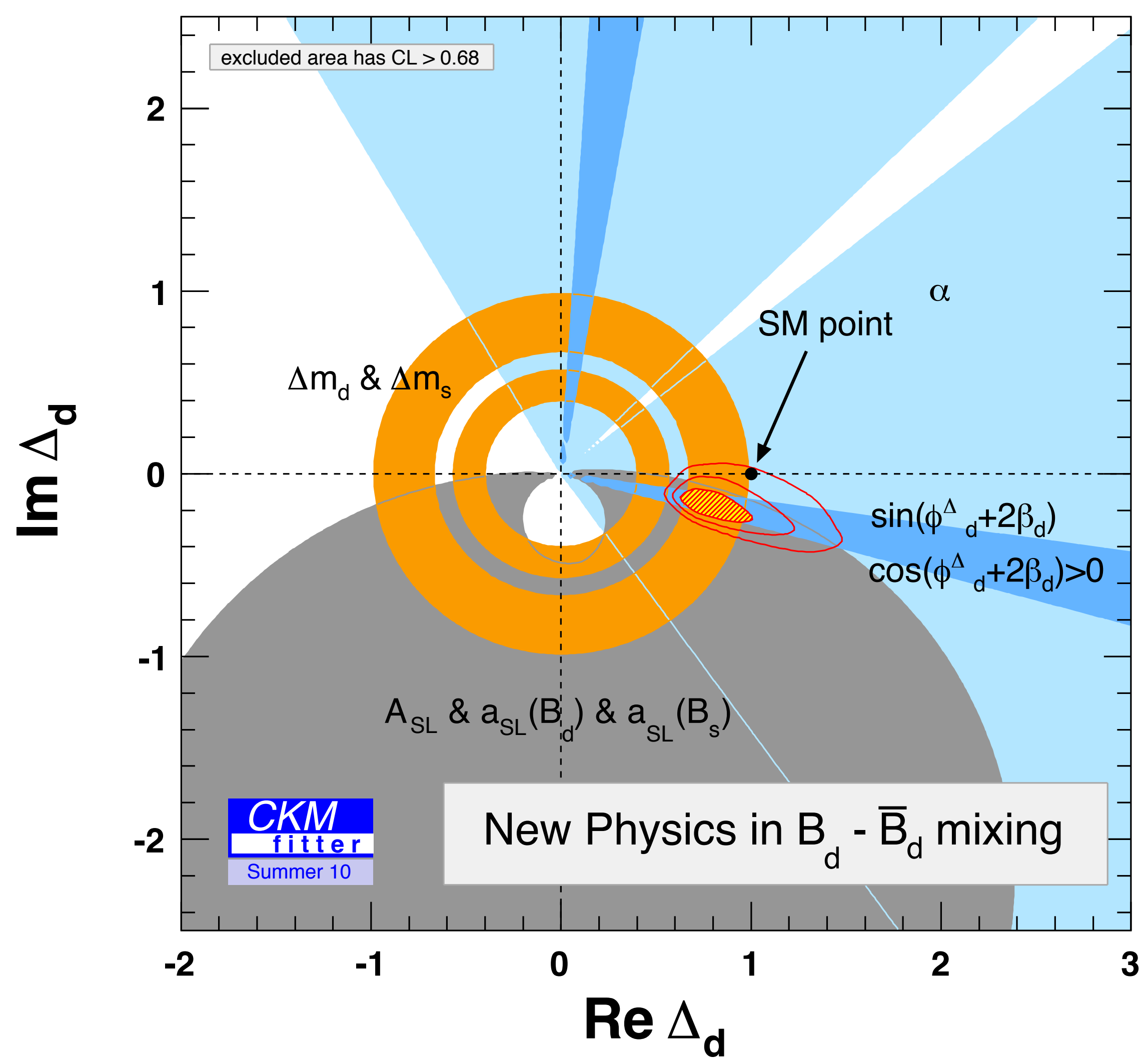
Constraints on New Physics parameters (h_d,σ_d) and (h_s,σ_s): Ligeti, Papucci, Perez, Zupan (2010)

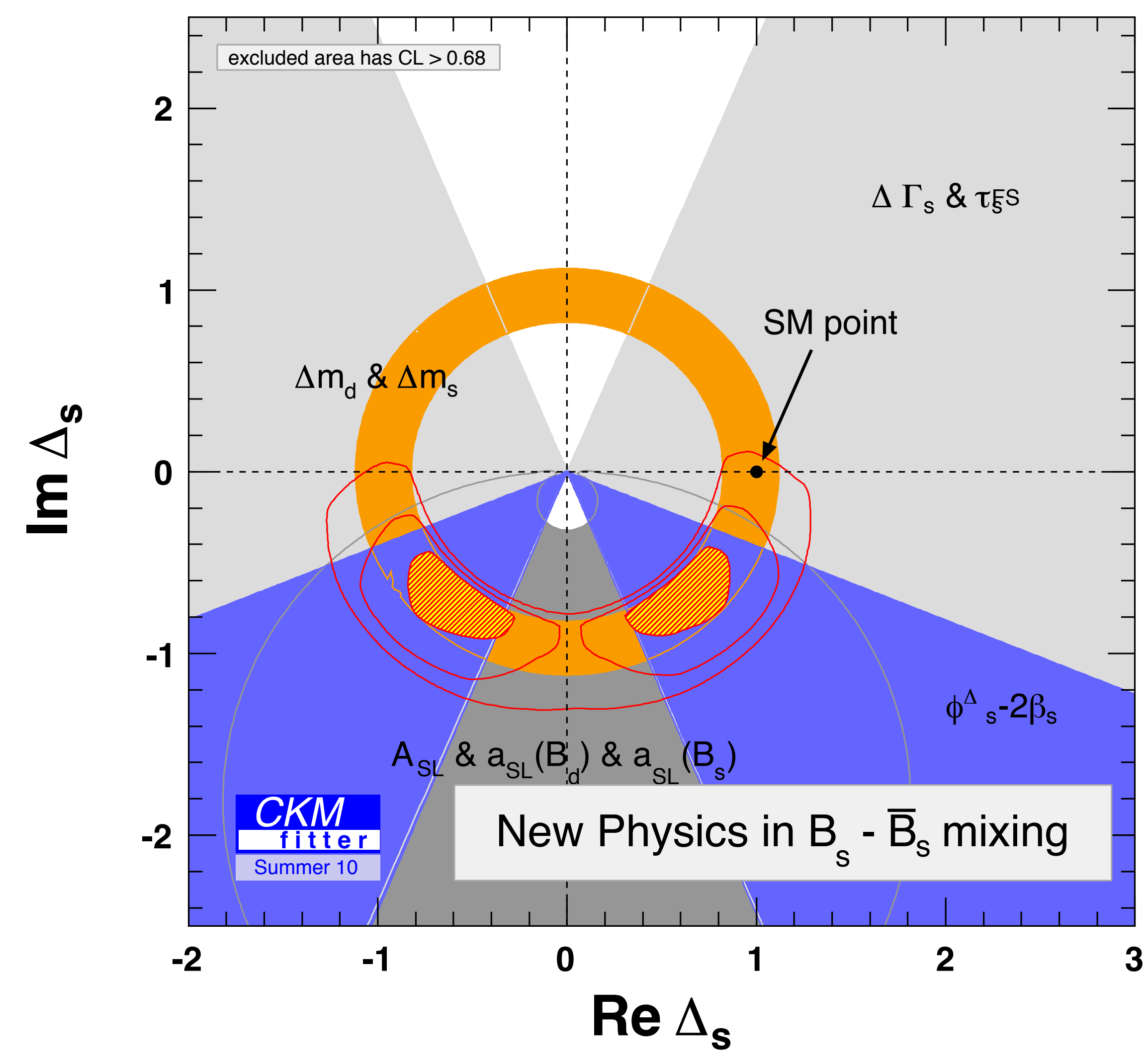


- SM (h_d=h_s=0) disfavored at **<3σ** in B_s mixing and **<2σ** in B_d mixing
- case h_d=h_s and σ_d=σ_s (e.g., minimal flavor violation models) **strongly disfavored**

Theoretical analyses (prior to D0 update)

Constraints on New Physics parameters Δ_d and Δ_s: Lenz, Nierste + CKMfitter (2010)



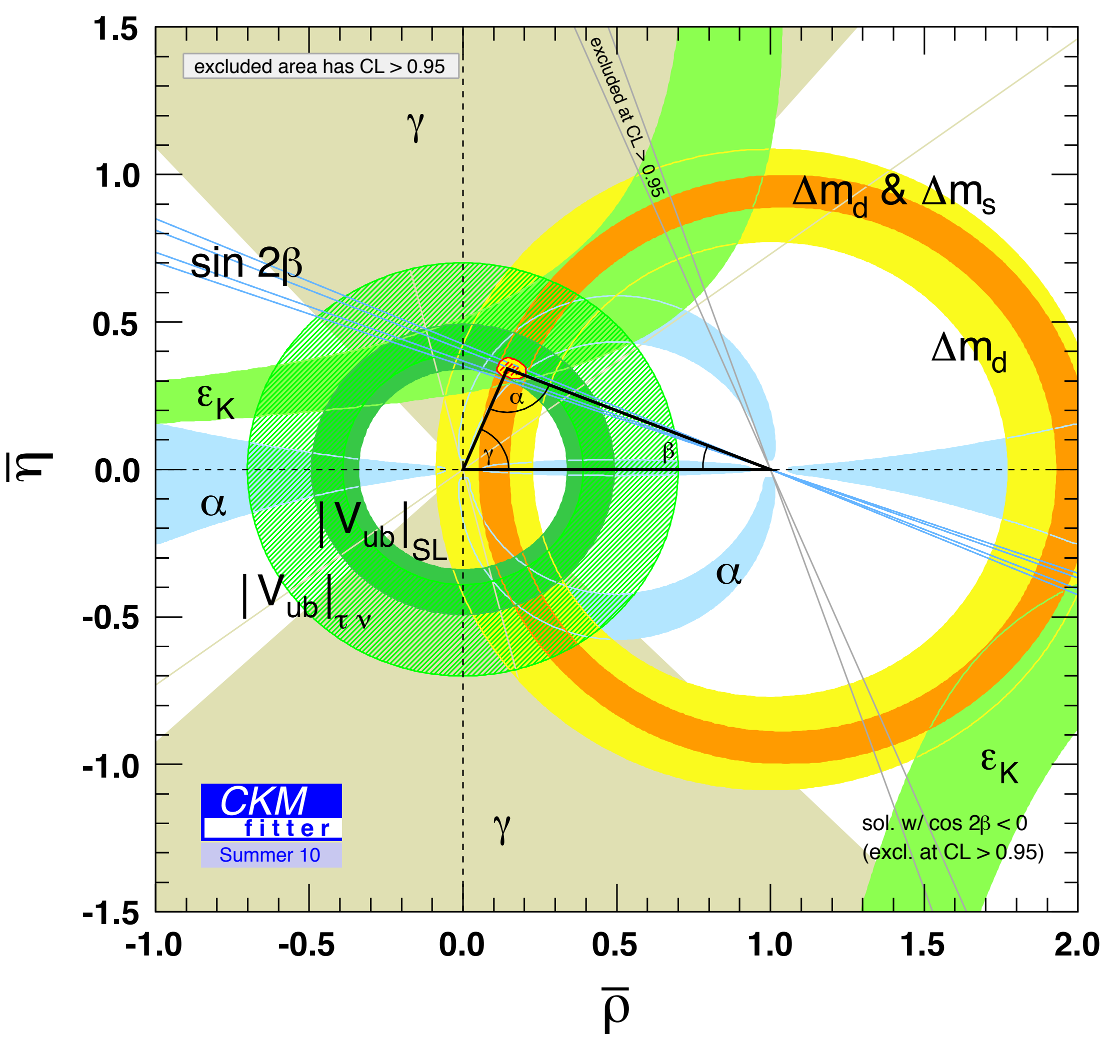


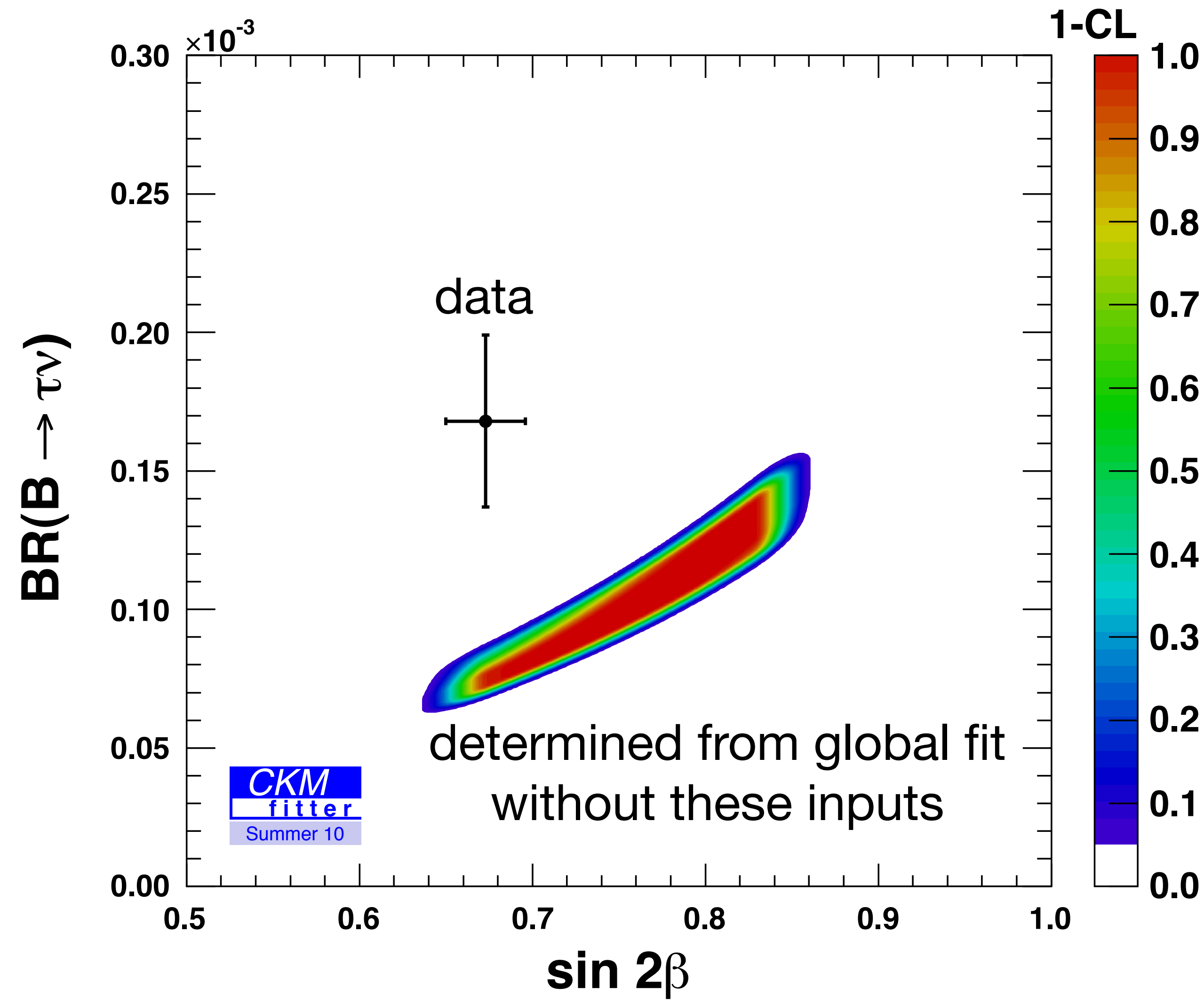
- SM (Δ_d=Δ_s=1) disfavored at **3.6σ** (≈4.2σ after D0 update)
- no indication of New Physics in K-$\overline{\text{K}}$ mixing
- minimal flavor violation (Δ_d=Δ_s real) disfavored at **3.7σ** (generalized MVF is still ok)

Theoretical analyses without CPV in B_s mixing

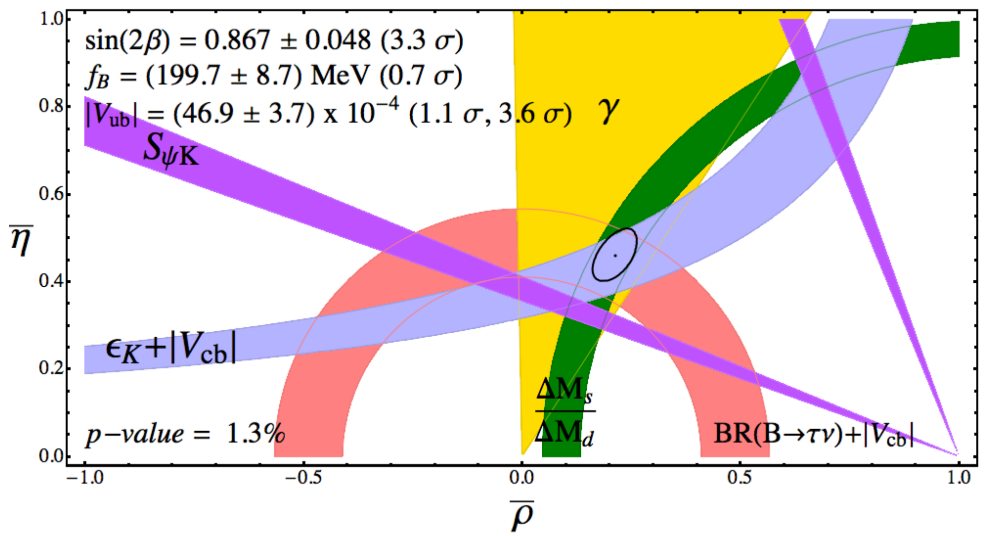
Much of this is driven by the **anomalous like-sign dimuon asymmetry** seen at D0, but there is also **tension** in the standard **unitarity-triangle fit** if the Tevatron results on CP violating in B_s mixing are left out:

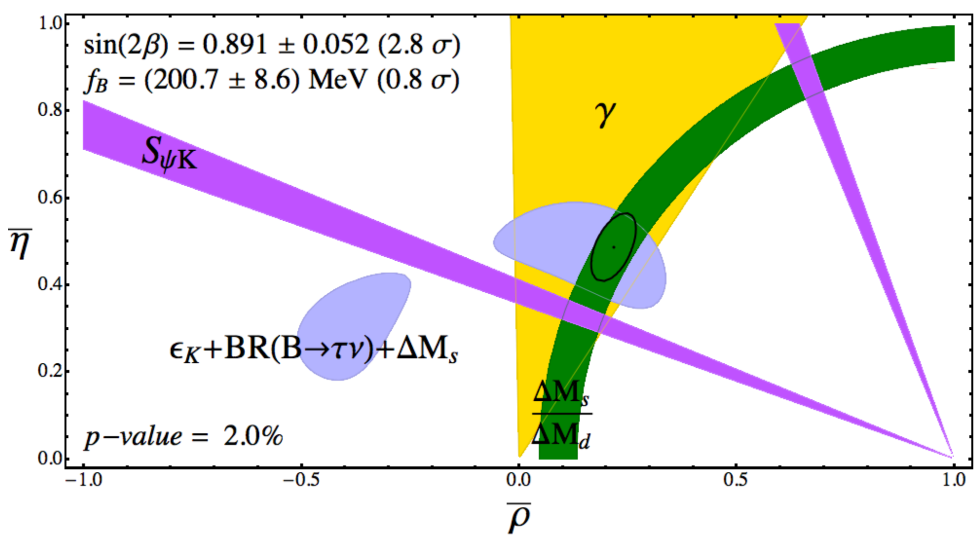
Lenz, Nierste + CKMfitter (2010)

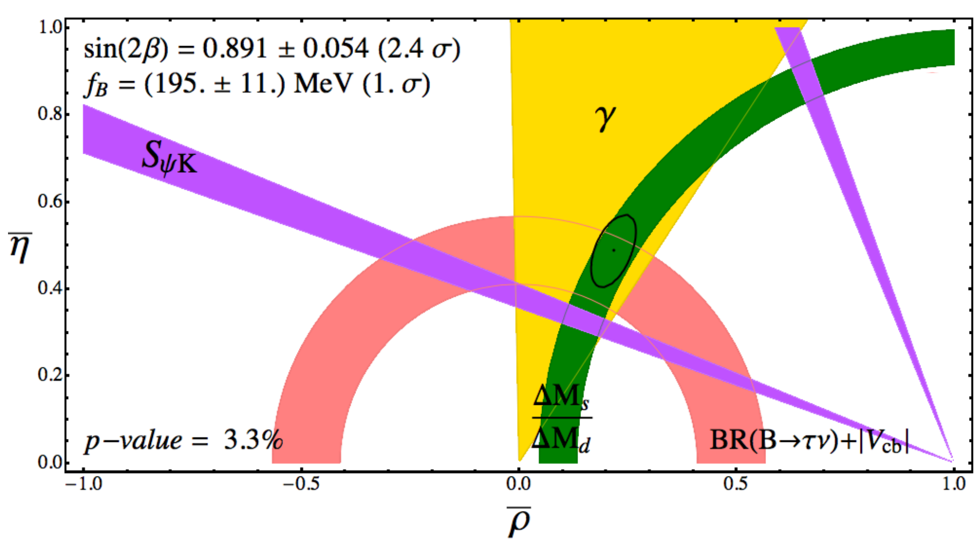




Theoretical analyses without CPV in B_s mixing







Unitarity-triangle fit with different inputs:

- input: V_{cb}, ε_K, γ, $\Delta M_{d,s}$, B→τν
- output: sin2β, f_B, $|V_{ub}|$

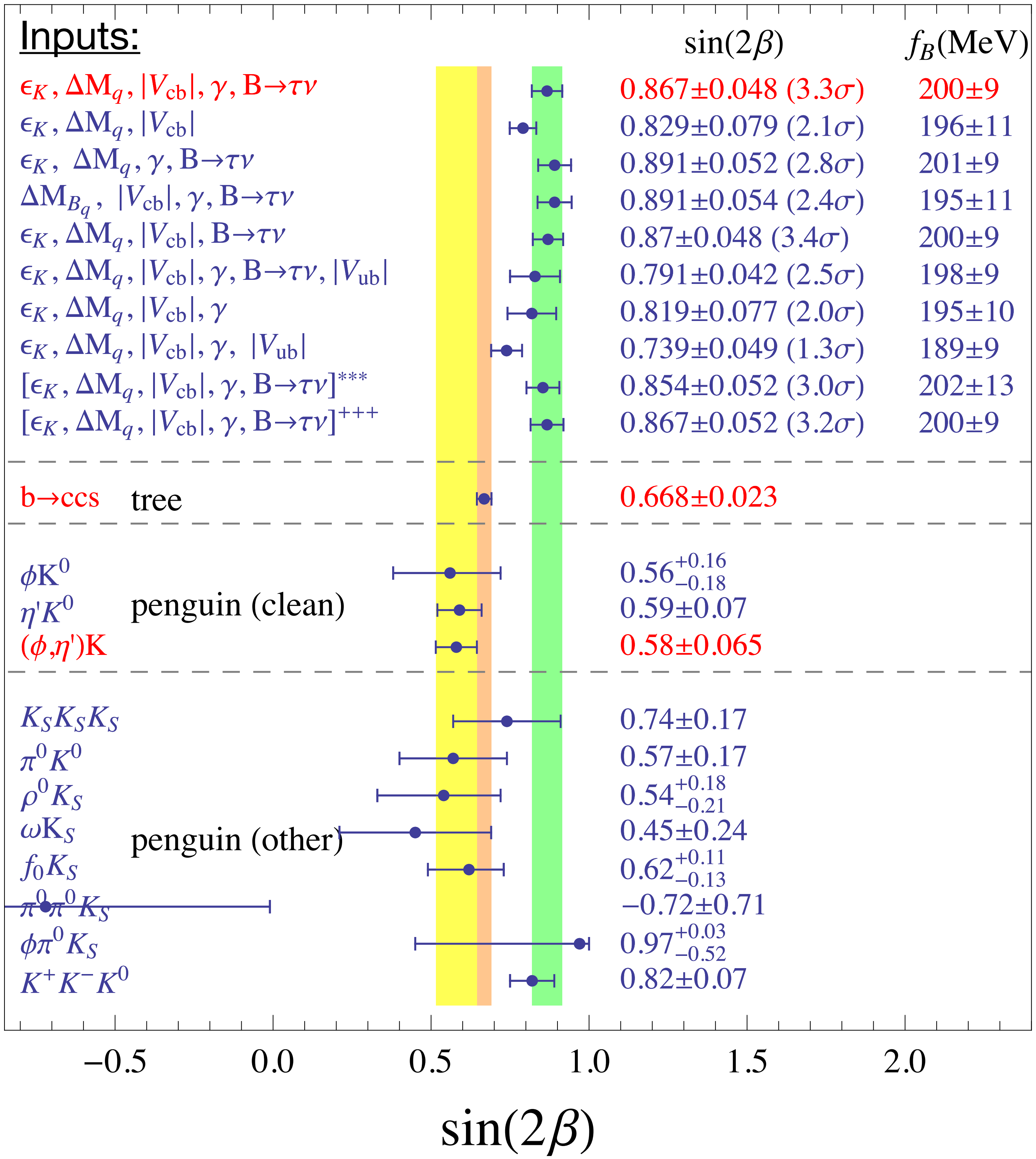
➡ obtain excellent fit, hinting at New Physics in B_d mixing

- input: same as above, but without use of semileptonic decays (V_{cb})

- input: same as above, but without use of K-$\overline{K}$ mixing

Lunghi, Soni (2010)

Theoretical analyses without CPV in B_s mixing



*** lattice errors increased by 50%

+++ adding hadronic uncertainty $\delta\Delta S_{\psi K}$=0.021

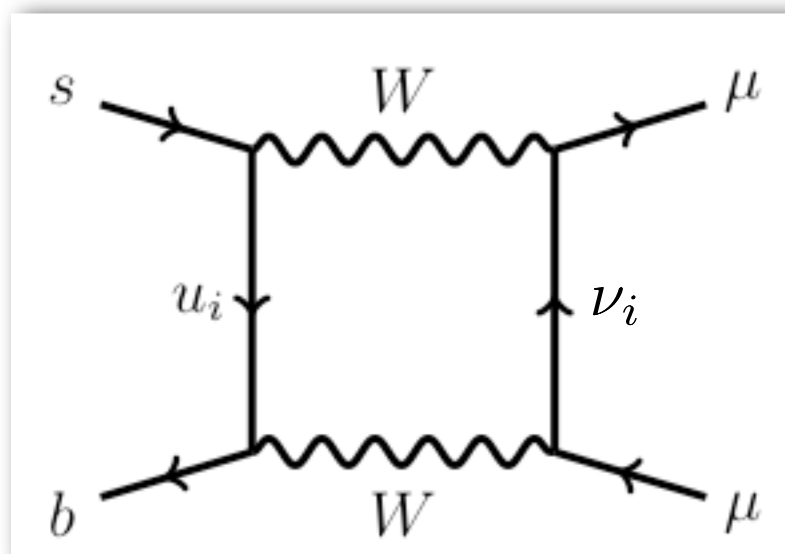
➡ consistent determination of sin2β **much larger** than direct measurement !

➡ direct measurement from mixing-induced CP violation in tree-level decays

➡ direct measurement from mixing-induced CP violation in penguin modes (interpreted as a hint for New Physics in penguin-induced FCNC processes)

Lunghi, Soni (2010)

Hints for New Physics in B-meson decays



Three intriguing observations

- Several measurements of rare $B_{u,d}$ and B_s decays suggest the existence of New Physics contributions in the decay amplitudes, not related to B-meson mixing:
    - discrepancies in the determinations of V_{ub} from inclusive semileptonic decays $B \to X_u l\nu$, exclusive semileptonic decays $B \to \pi l\nu$, and leptonic decay $B \to \tau\nu$ ("V_{ub} crisis")
    - large difference of (14.4±2.9)% in the direct CP asymmetries measured in $B^0 \to K^+\pi^-$ vs. $B^+ \to K^+\pi^0$ decays, which is in conflict with the prediction of (2.2±2.4)% from QCD factorization ("$B \to K\pi$ puzzle")
    - enhanced $B_s \to \mu^+\mu^-$ branching ratio observed by CDF (but not by LHCb and CMS ☹)

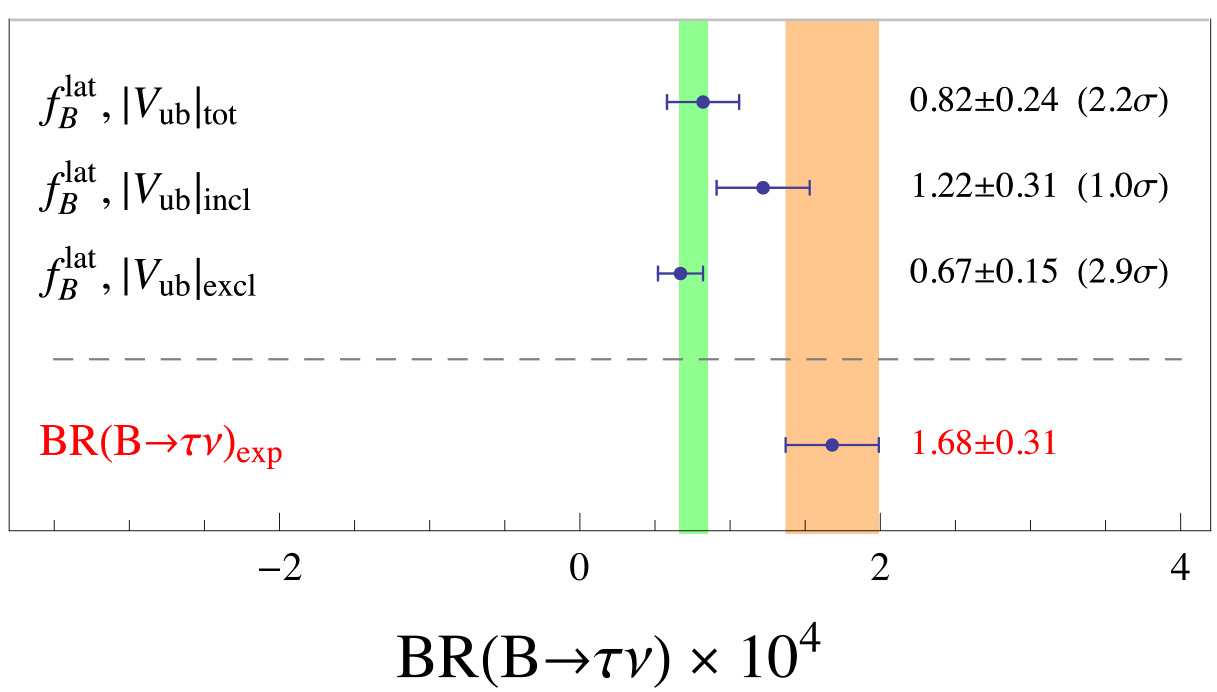
The “V_{ub} crisis”

For many years, there has been a persistent discrepancy between determinations of $|V_{ub}|$ from **inclusive and exclusive semileptonic decays** of B mesons ($B \to X_u l \nu$ vs. $B \to \pi l \nu$). HFAG quotes:

$$|V_{ub}|_{\rm incl} = (4.32 \pm 0.16 \pm 0.22) \cdot 10^{-3}$$

$$|V_{ub}|_{\rm excl} = (3.51 \pm 0.10 \pm 0.46) \cdot 10^{-3}$$

Measurement of the purely leptonic decay $B \to \tau\nu$ sharpen the discrepancy further:



(not most up-to-date values!)

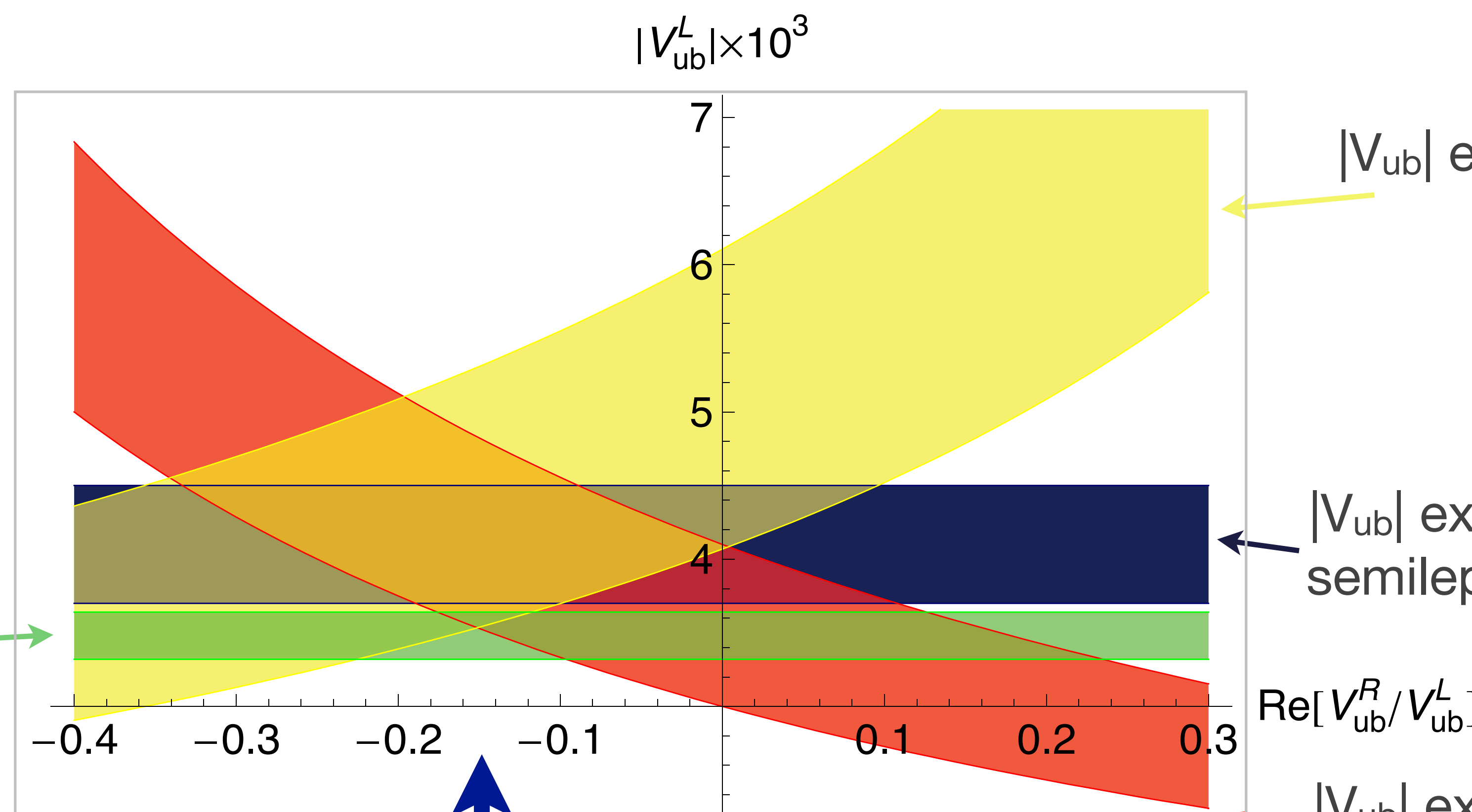
Lunghi, Soni (2010)

The "V_{ub} crisis"

A very elegant solution is offered by the addition of a **right-handed weak current** with coupling V_{ub}^R, which enters as $|V_{ub}^L+V_{ub}^R|^2$ in $B\rightarrow\pi l\nu$, $|V_{ub}^L-V_{ub}^R|^2$ in $B\rightarrow\tau\nu$, and $|V_{ub}^L|^2+|V_{ub}^R|^2$ in $B\rightarrow X_u l\nu$:

➡ a small admixture of approx. -15% of right-handed current (i.e. from gluino-squark loops in MSSM) brings all three measurements in agreement with each other!

Crivellin (2009);
see also: Buras, Gemmler (2011)



$|V_{ub}|$ extracted from leptonic $B\rightarrow\tau\nu$ decay

$|V_{ub}|$ extracted from inclusive semileptonic $B\rightarrow X_u l\nu$ decays

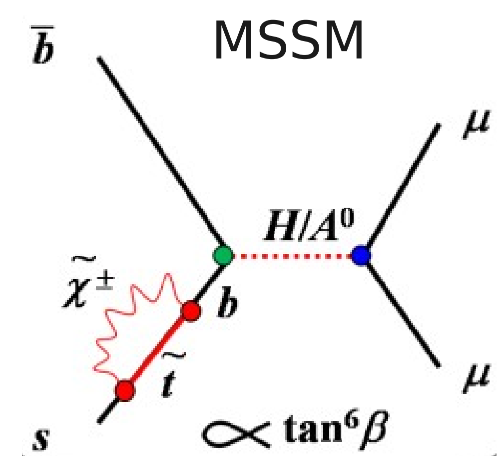
$|V_{ub}|$ extracted from UT fit

$|V_{ub}|$ extracted from exclusive semileptonic $B\rightarrow\pi l\nu$ decay

-15% admixture of a right-handed current

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

- interesting rare decays, which can be much enhanced in models with a warped extra dimension or SUSY models with large tanβ



Excess in B_s mode reported by CDF:

$\mathcal{B}(B_s \to \mu^+\mu^-) = (1.8^{+1.1}_{-0.9}) \cdot 10^{-8}$	SM: $(3.2 \pm 0.2) \cdot 10^{-9}$
$\mathcal{B}(B_d \to \mu^+\mu^-) < 6.0 \cdot 10^{-9}$	SM: $(1.0 \pm 0.1) \cdot 10^{-10}$

Unfortunately no excess seen at LHCb (CMS):

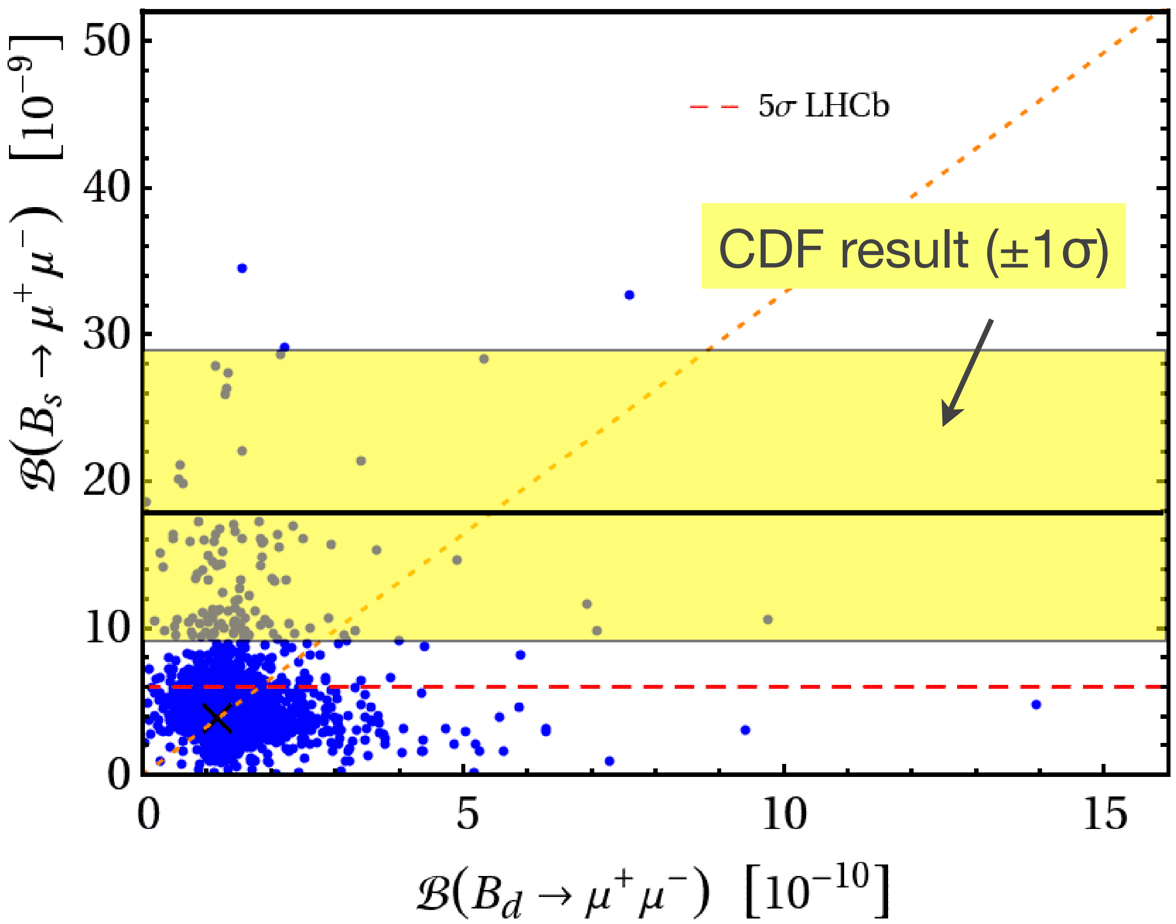
$$\mathcal{B}(B_s \to \mu^+\mu^-) < 1.5\ (1.9) \cdot 10^{-8}$$
$$\mathcal{B}(B_d \to \mu^+\mu^-) < 5.2\ (4.6) \cdot 10^{-9}$$

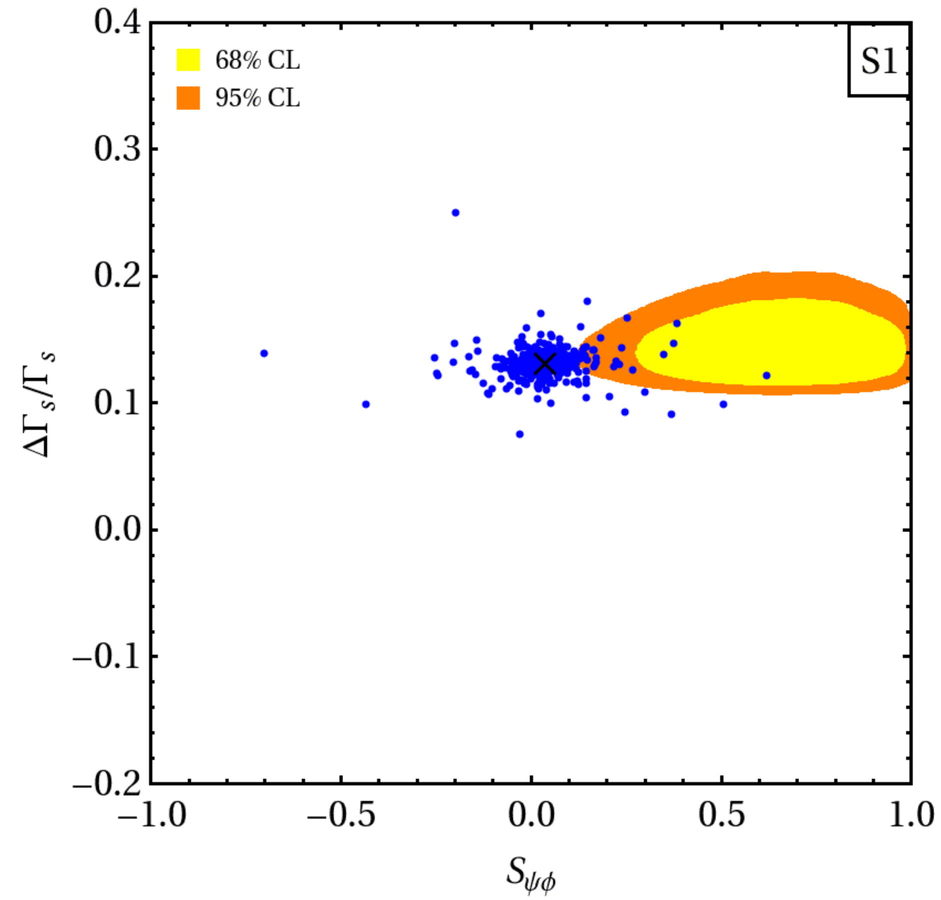
(at 95% CL)

These bounds to not rule out the CDF result, but without refined LHC measurements the situation is inconclusive!

Theoretical predictions: Randall-Sundrum model

Both rare modes $B_{d,s} \to \mu^+\mu^-$ can be significantly enhanced over their SM values:





Bauer, Casagrande, Haisch, MN (2009);
see also: Blanke et al. (2008)

Theoretical predictions: Randall-Sundrum model

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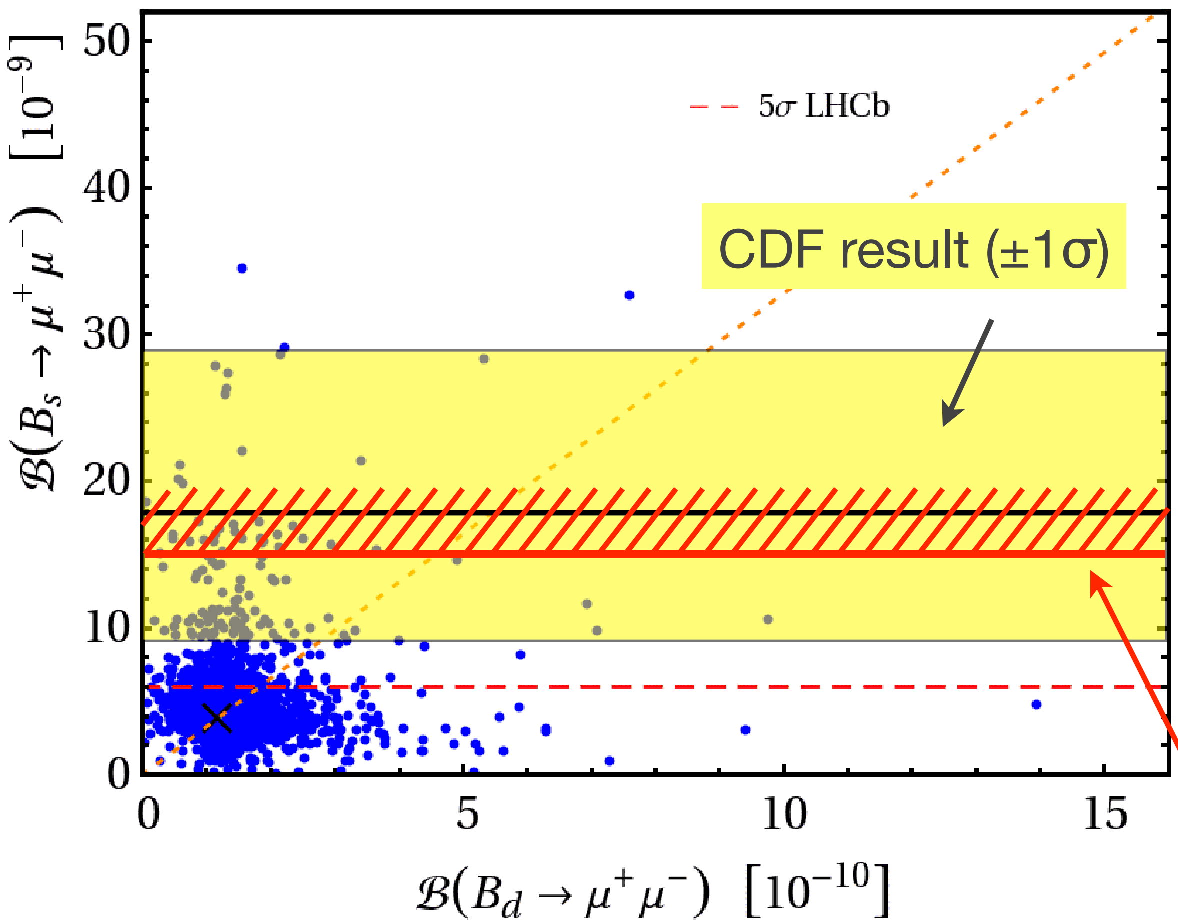
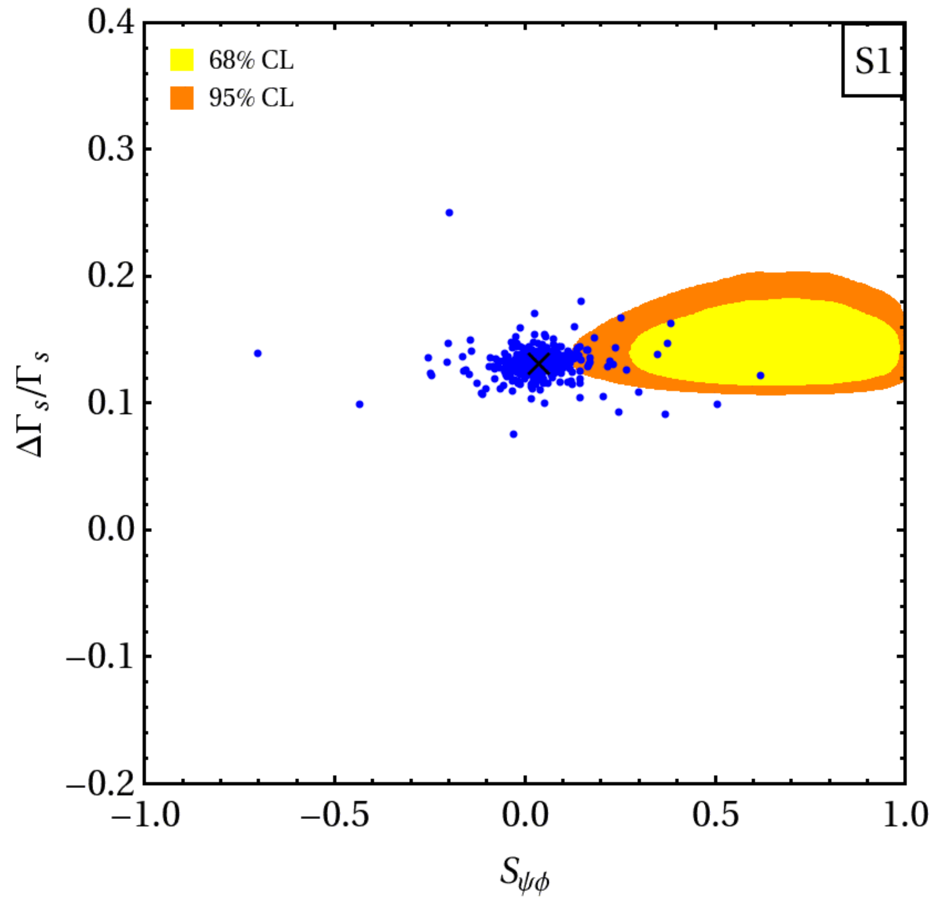




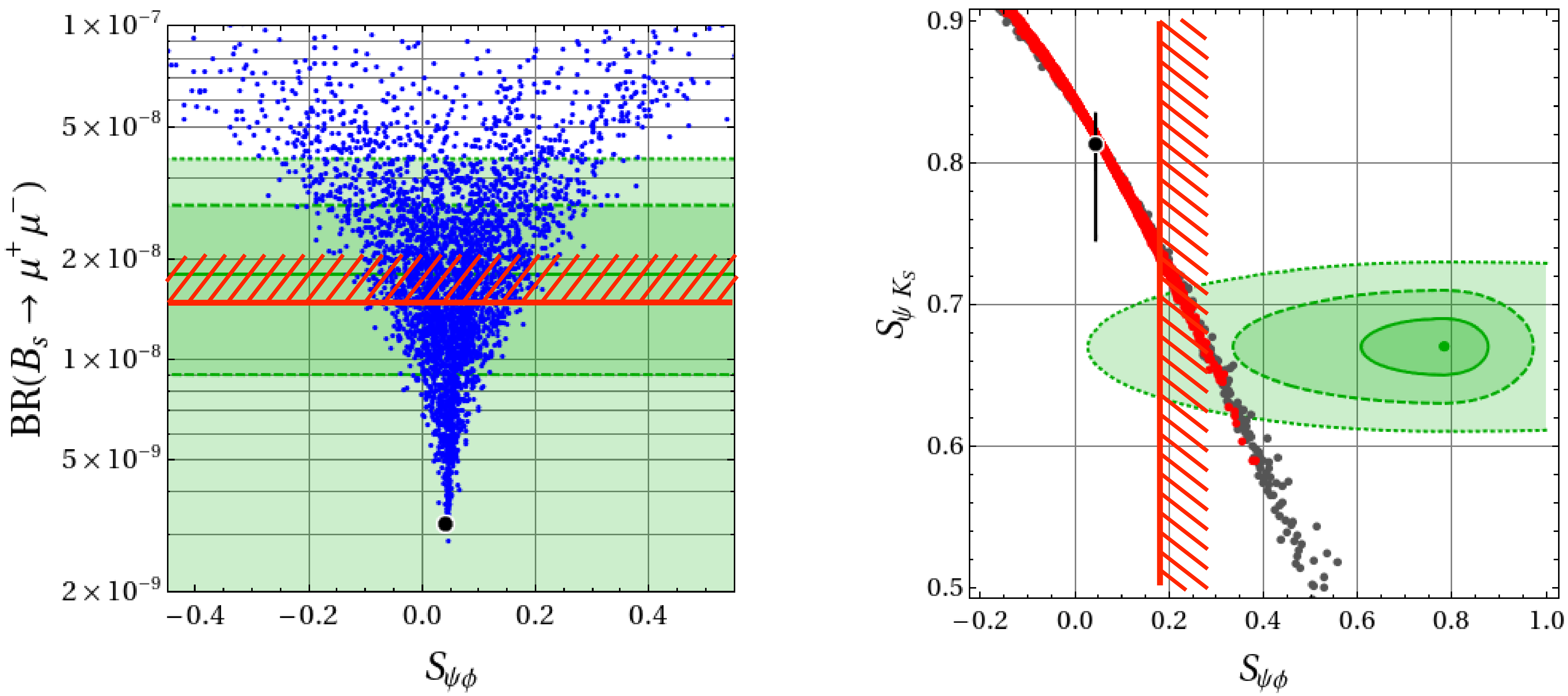
Bauer, Casagrande, Haisch, MN (2009);
see also: Blanke et al. (2008)

LHCb upper bound (95% CL)

- New results on $B_s \to \mu^+\mu^-$ begin cutting into the interesting parameter space
- Expected effects in B_s mixing are unlikely to reproduce the central values of the data

Theoretical predictions: BMSSM

A generalized SUSY model with additional CP phases in the Higgs sector from higher-dimensional operators can give rise to interesting effects in the B_s system:

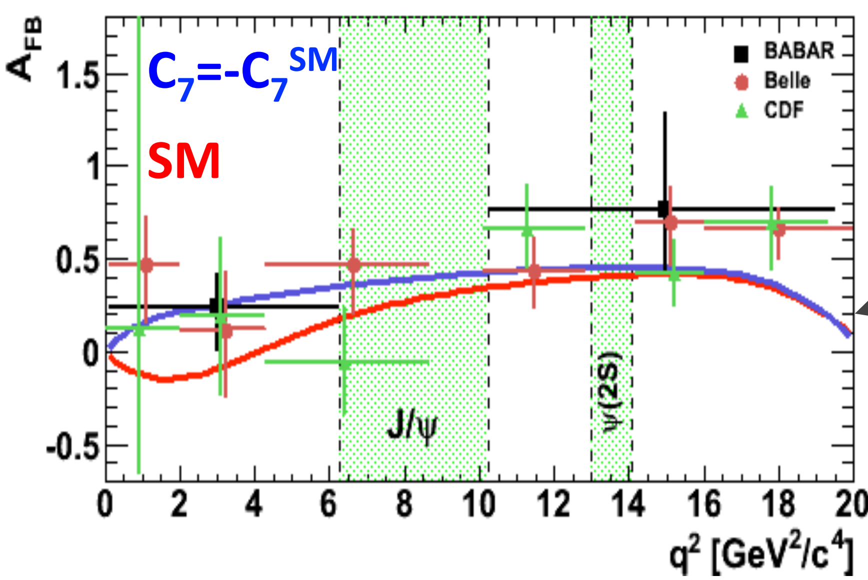


Altmannshofer, Carena, Gori, de la Puente (2011)

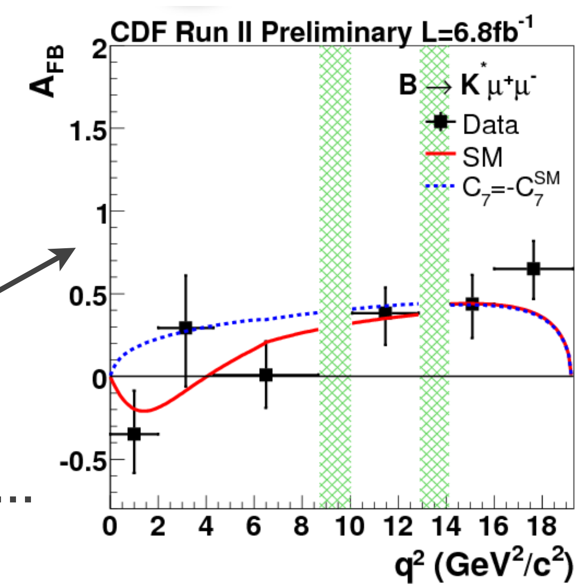
- New upper bound on $B_s \to \mu^+\mu^-$ implies an interesting upper limit on the magnitude of the New Physics contributions to CP violation in B_d and B_s mixing

Forward-backward asymmetry in B→K*μ⁺μ⁻

A lesson how quickly tentative hints can disappear with improved measurements (in a closely related rare decay mode):

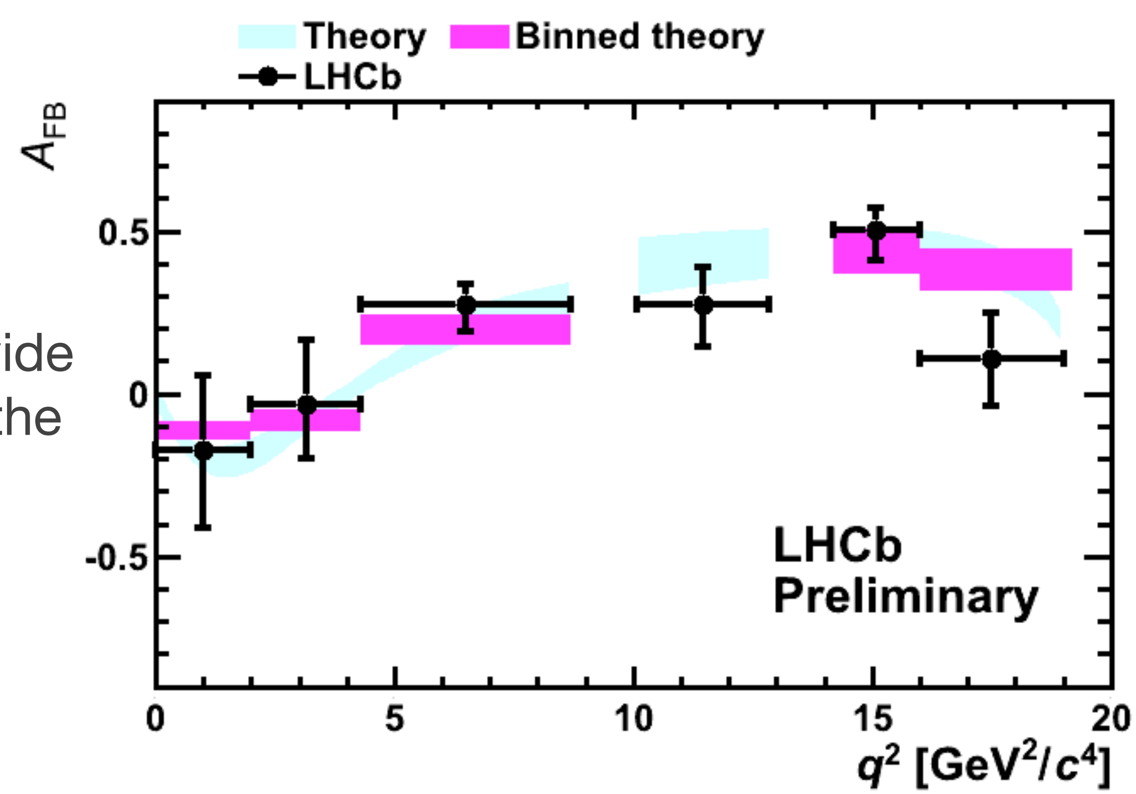


B-factory data prior to EPS11 hinted at a positive asymmetry for all q^2



CDF update for EPS11 is already closer to the SM ...

... and new LHCb data provide a textbook confirmation of the SM prediction!



see also:
Bobeth @ EPS11;
Descotes-Genon @ EPS11

Outlook

Flavor as a portal beyond the Standard Model

The first collisions at the LHC mark the beginning of a fantastic era for particle physics, which holds promise of ground-breaking discoveries

ATLAS and CMS discoveries alone are unlikely to provide a complete understanding of the observed phenomena

Flavor physics (more generally, low-energy precision physics) will play a key role in unravelling what lies beyond the Standard Model, providing access to energy scales and couplings unaccessible at the energy frontier

Existing hints about New Physics flavor signature suggest that only the synergy of LHC and high-precision experiments will give us the key to solving the puzzles of the Terascale