Flavor Physics

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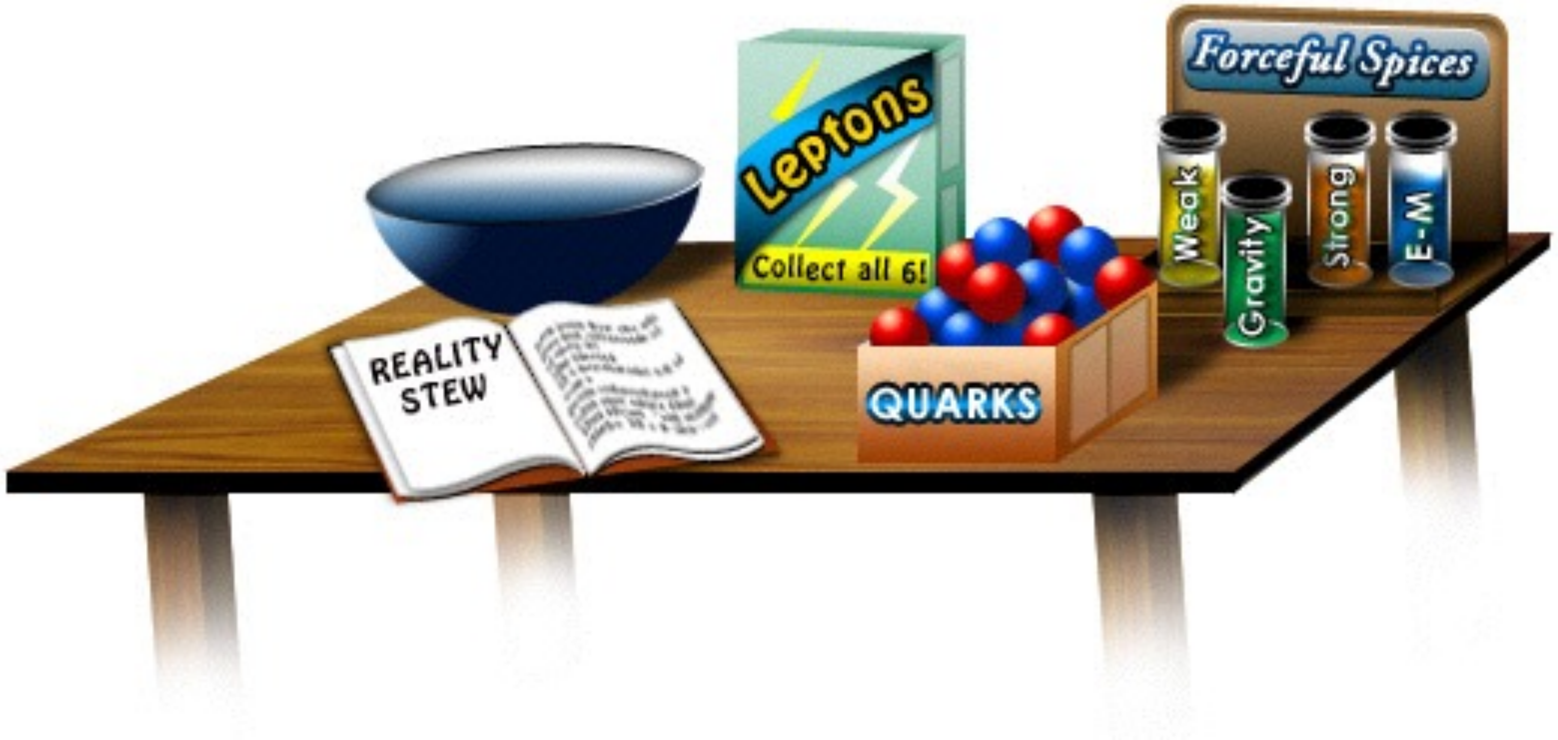
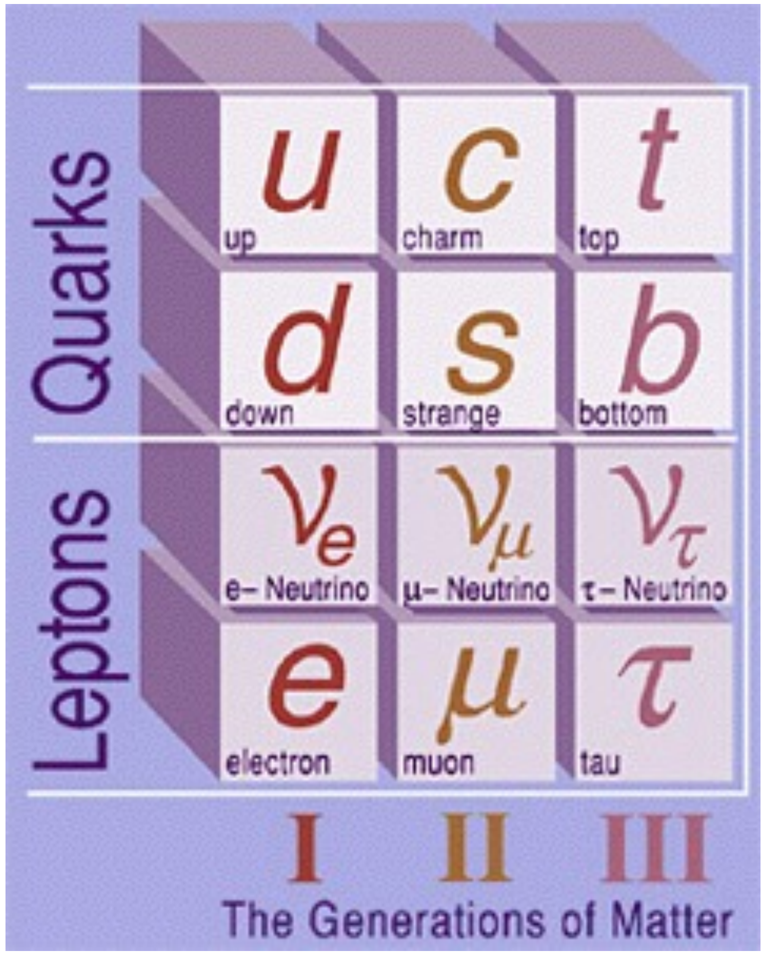
Rencontre de Physique des Particules 2016
[previously in 2009]



Flavor Physics



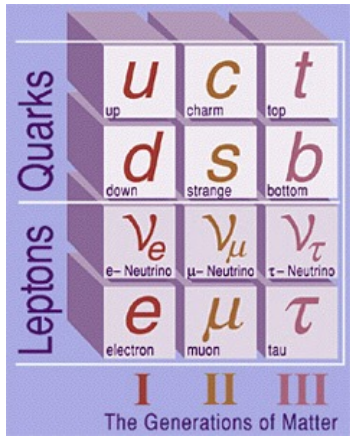
In the Standard Model

- ✘ Gauge sector entirely fixed by symmetry

$$i\bar{\psi}\not{D}\psi \qquad D_\mu = \partial_\mu - ig_s t_a A^a_\mu - ig\mathbf{T}\cdot\mathbf{W}_\mu - ig'\frac{Y}{2}B_\mu$$

- ✘ Flavor sector loose (a bunch of parameters)

13 of 21 are fermion masses and q.mixing parameters



We know

fermions come in 3 generations

$$\begin{pmatrix} \nu_e & u \\ e & d' \end{pmatrix} \qquad \begin{pmatrix} \nu_\mu & c \\ \mu & s' \end{pmatrix} \qquad \begin{pmatrix} \nu_\tau & t \\ \tau & b' \end{pmatrix}$$

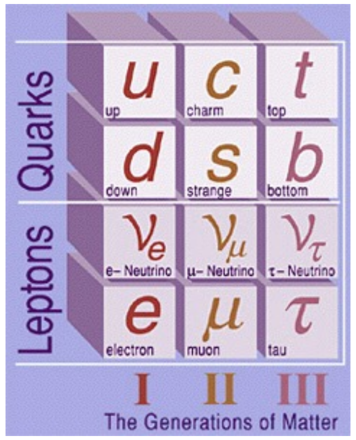
$$\left\{ \begin{pmatrix} \nu_e \\ e \end{pmatrix}_L, \quad (\nu_e)_R, \quad e^-_R \right\}, \quad \left\{ \begin{pmatrix} u \\ d' \end{pmatrix}_L, \quad u_R, \quad d_R \right\}$$

- ✘ All generations interact equally with gauge bosons
- ✘ Neutral currents:

$$eQ_f \bar{f} \gamma_\mu f \mathcal{A}^\mu, \qquad \frac{e}{2 s_W c_W} \bar{f} \gamma_\mu (v_f - a_f \gamma_5) f \; Z^\mu$$

- ✘ Charged currents:

$$\frac{g}{2\sqrt{2}} \bar{\nu}_\ell \gamma_\mu (1 - \gamma_5) \ell \; W^{\dagger\mu}, \qquad \frac{g}{2\sqrt{2}} \bar{u} \gamma_\mu (1 - \gamma_5) d \; W^{\dagger\mu}$$



We know

- ✘ P and C broken by weak int. but CP is a symmetry (1 gen)
- ✘ Going from the gauge to mass basis

$$\mathcal{L}_{Y}^{\mathrm{SM}} = -Y_d^{ij}\overline{Q}_L^i \phi D_R^j - Y_u^{ij}\overline{Q}_L^i \widetilde{\phi} U_R^j + \mathrm{h.c.}$$

$$\mathcal{L}_{Y}^{\mathrm{SM}} = -\left(1+\frac{h}{v}\right)\left[m_d \bar{d} d + m_u \bar{u} u + m_e \bar{e} e\right]$$

- ✘ With 3 gen trickier - cannot simultaneously diagonalize *u* and *d* — mixing: CKM matrix
- ✘ V_{CKM} unitary ⇒ 3 real parameters + 1 phase (CPV!)

$$\lambda \qquad A \qquad \rho \qquad \eta$$

CKM-ology

$$\lambda \qquad A \qquad \rho \qquad \eta$$

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

$$\lambda = \sin\theta_C \approx 0.224 \qquad A \simeq 0.82 \qquad \sqrt{\rho^2+\eta^2} \approx 0.45$$

- ✘ Fix CKM entries through tree level processes; over constrain by loop-induced ones
- ✘ V_{CKM} unitary ⇒ 3 real parameters + 1 phase (CPV!)

Example : Kaon physics

Tree level decays

hadronic uncertainty!

$K \to \pi \ell \nu$ $\longleftrightarrow$ $\langle \pi | \bar{s} \gamma_\mu u | K \rangle \to f_{0,+}(q^2)$

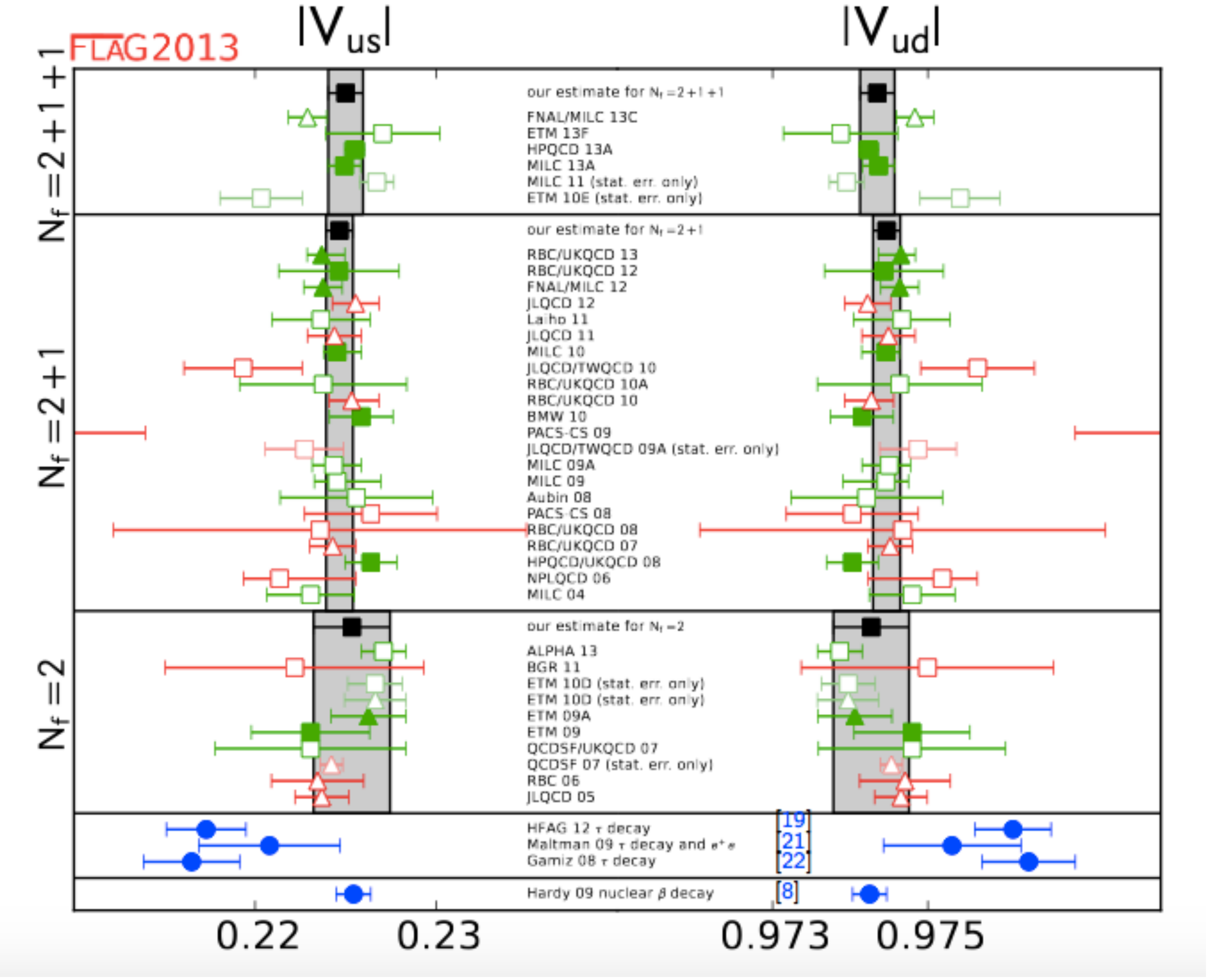
$K \to \mu \nu$ $\longleftrightarrow$ $\langle 0 | \bar{s} \gamma_\mu u | K \rangle \to f_K$

f_K / f_π

Nonperturbative QCD - symmetries help (eg. Ademollo-Gatto) but ultimately needs LQCD

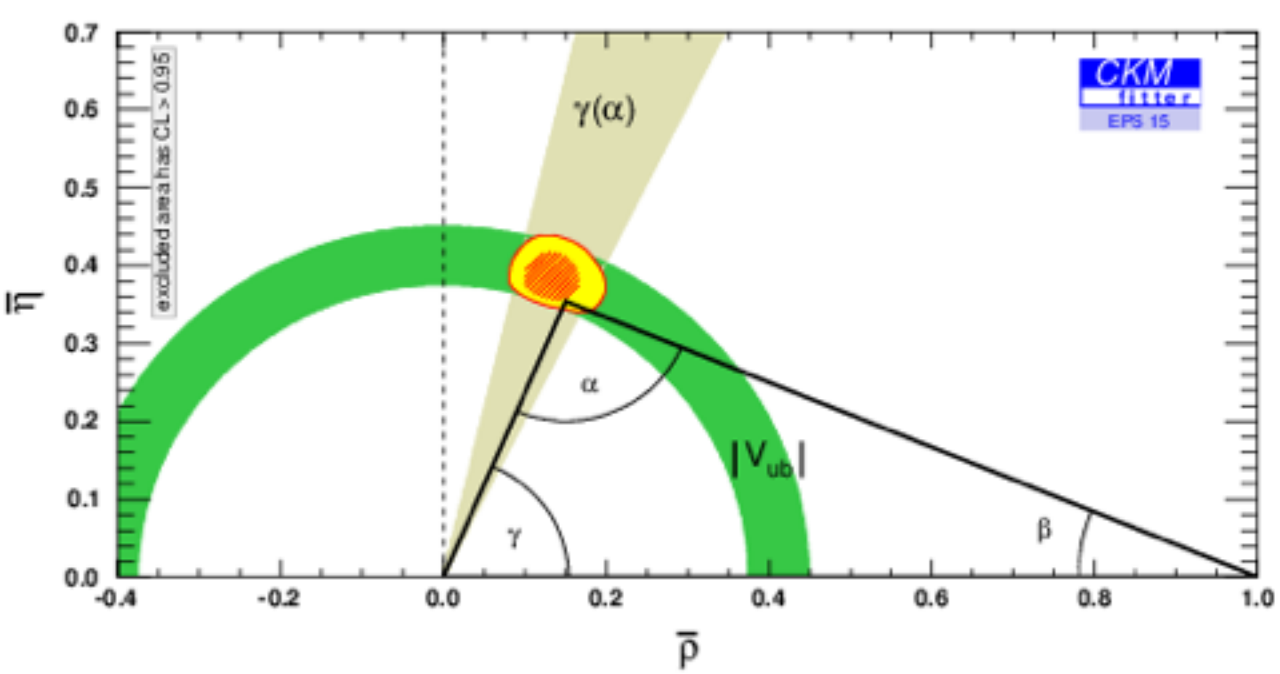
Huge coordinated effort! (cf. FLAG review - new to appear soon!)

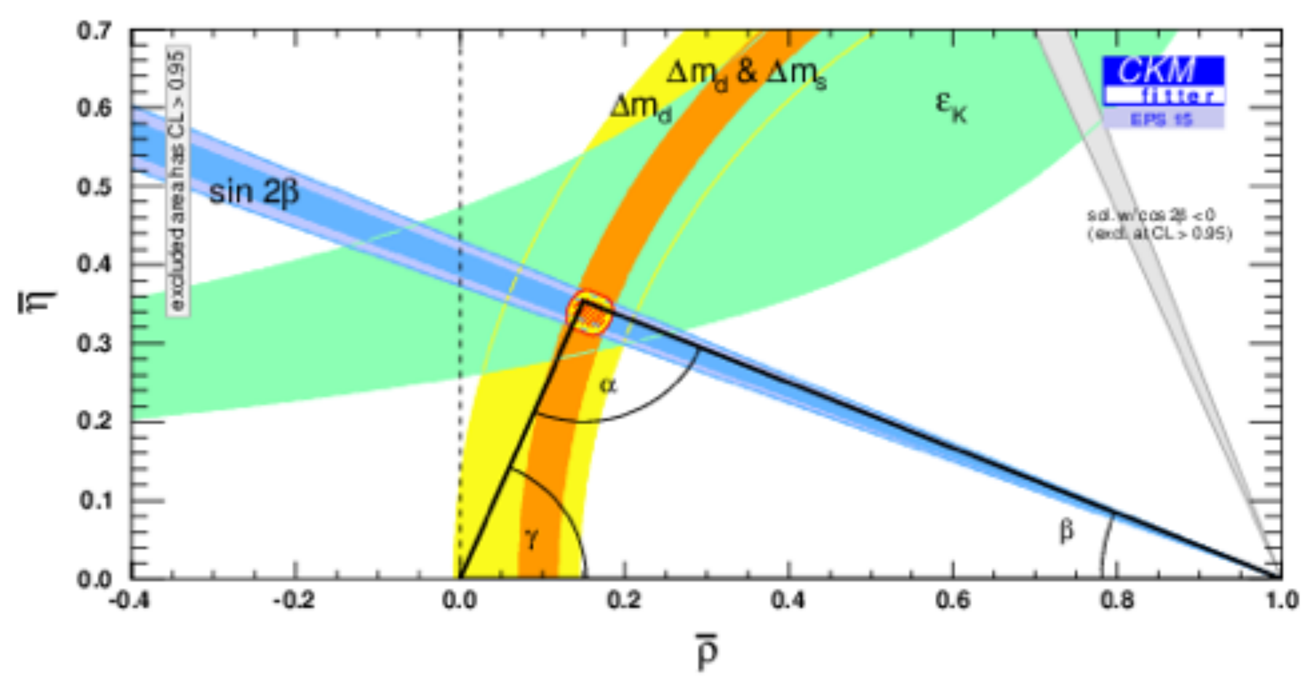
LQCD


FLAG2013
|V_us|
|V_ud|
N_f =2+1+1
N_f =2+1
N_f =2
our estimate for N_f =2+1+1
FNAL/MILC 13C
ETM 13F
HPQCD 13A
MILC 13A
MILC 11 (stat. err. only)
ETM 10E (stat. err. only)
our estimate for N_f =2+1
RBC/UKQCD 13
RBC/UKQCD 12
FNAL/MILC 12
JLQCD 12
Laiho 11
JLQCD 11
MILC 10
JLQCD/TWQCD 10
RBC/UKQCD 10A
RBC/UKQCD 10
BMW 10
PACS-CS 09
JLQCD/TWQCD 09A (stat. err. only)
MILC 09A
MILC 09
Aubin 08
PACS-CS 08
RBC/UKQCD 08
RBC/UKQCD 07
HPQCD/UKQCD 08
NPLQCD 06
MILC 04
our estimate for N_f =2
ALPHA 13
BGR 11
ETM 10D (stat. err. only)
ETM 10D (stat. err. only)
ETM 09A
ETM 09
QCDSF/UKQCD 07
QCDSF 07 (stat. err. only)
RBC 06
JLQCD 05
HFAG 12 τ decay
Maltman 09 τ decay and e⁺e⁻
Gamiz 08 τ decay
Hardy 09 nuclear β decay
[19]
[21]
[22]
[8]
0.22
0.23
0.973
0.975

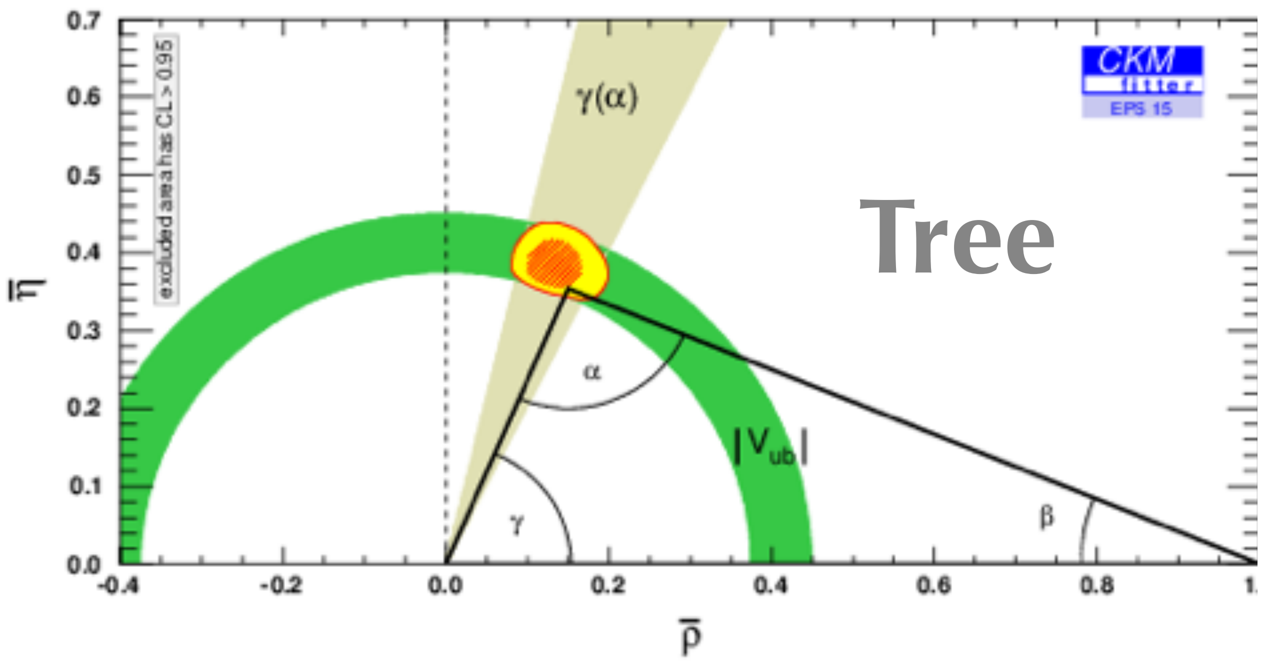
Experiments

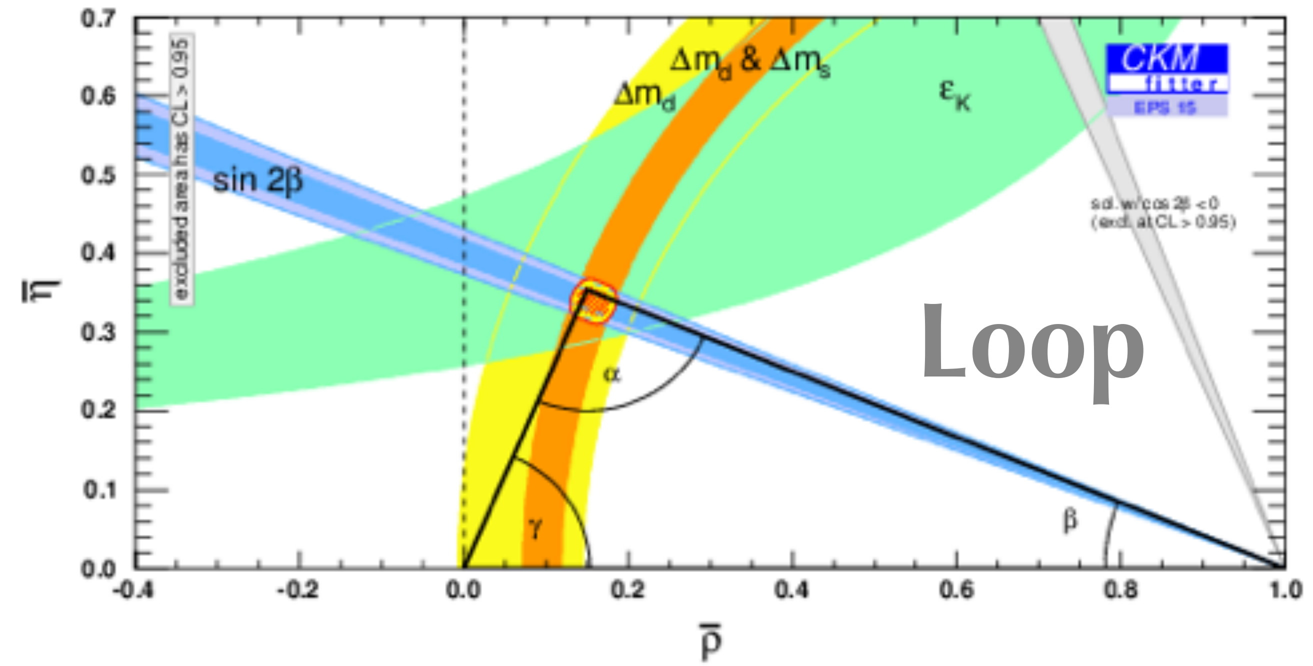
- K-factories u,d,s [NA62]
- Tau-charm τ,c [BES III]
- B-factories b,c,τ [Belle2 !]
- LHC t,b,c
- LC t,…
- νF





CKM





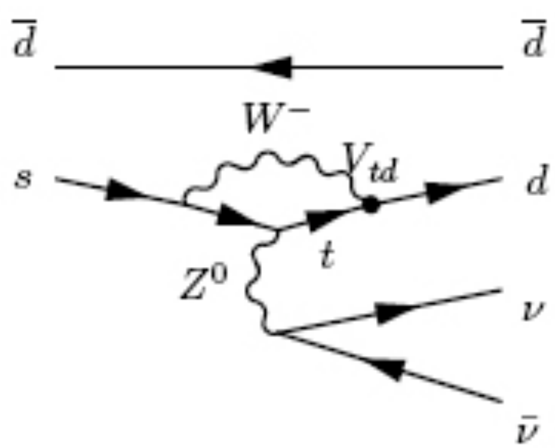
Impressively — TL UT and LP UT agree to less than 10% [Emi says experiment will do do better! Benoit says lattices will too!]

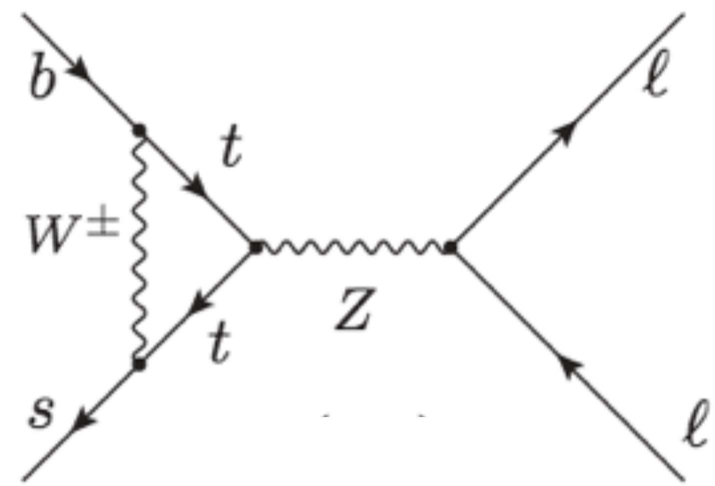
Only tensions in Vub and Vcb (inclusive Vs. exclusive) but all in all, CKM is very unitary!

2008, Nobel Prize

Strategy:

fix V_{ij} by tree level processes, then look for NP in FCNC





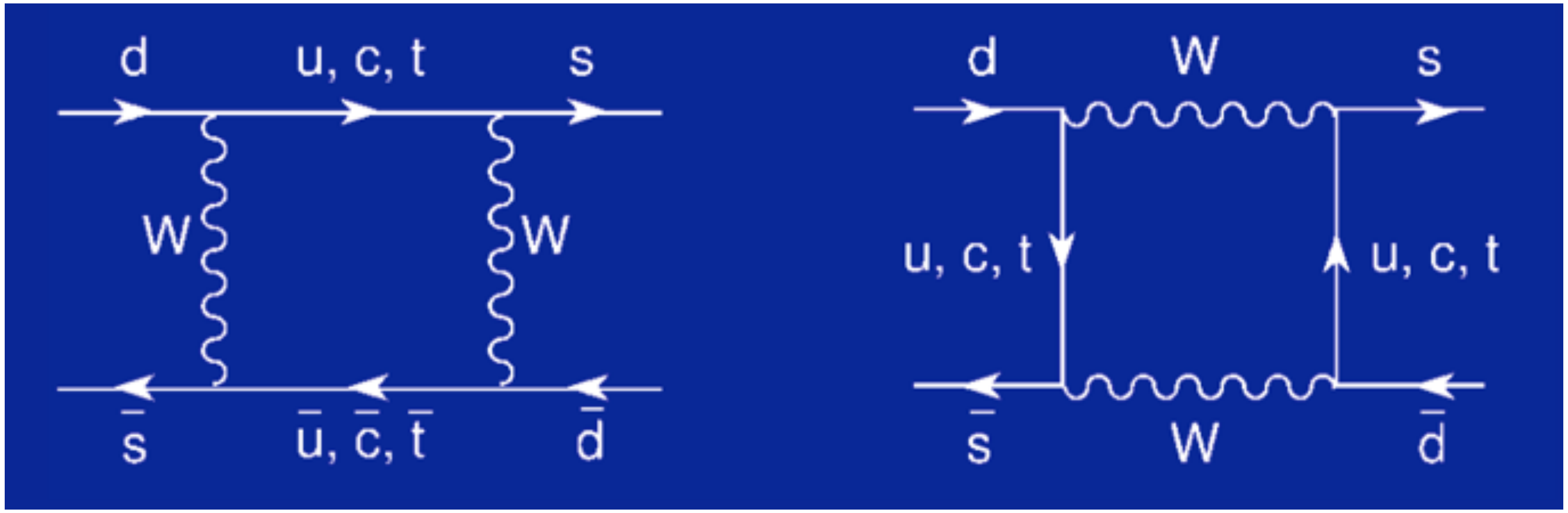
$\mathcal{B}(B_s \to \mu^+\mu^-)_{\text{theo.}} = 3.34\,\left(^{+13}_{-25}\right) \times 10^{-9}$ $\mathcal{B}(B_s \to \mu^+\mu^-)_{\text{LHCb+CMS}} = 2.9(7) \times 10^{-9}$

C_{ij}	1	$V_{ti}V_{tj}^*$
$B_s \to \mu^+\mu^-$	> 10 TeV	> 2.5 TeV
$K \to \pi\nu\bar{\nu}$	> 100 TeV	> 1.8 TeV

$$O = \frac{1}{\Lambda^2} C_{ij} \bar{Q}_i \gamma^\mu Q_j H^\dagger D_\mu H$$

Strategy:

fix V_{ij} by tree level processes, then look for NP in FCNC



$$O = \frac{1}{\Lambda^2} C'_{ij} \bar{Q}_i \gamma^\mu Q_j \bar{Q}_i \gamma_\mu Q_j$$

C'_{ij}	1	$\lvert V_{ti} V^*_{tj} \rvert^2$
$K^0 - \overline{K}^0$	$> \ 2 \times 10^4$ TeV	> 8 TeV
$B^0 - \overline{B}^0$	$> \ 0.5 \times 10^4$ TeV	> 5 TeV
$B^0_s - \overline{B}^0_s$	$> \ 0.1 \times 10^4$ TeV	> 5 TeV

Flavor puzzle

C_{ij}	1	$V_{ti}V_{tj}^*$
$B_s \to \mu^+\mu^-$	> 10 TeV	> 2.5 TeV
$K \to \pi\nu\bar{\nu}$	> 100 TeV	> 1.8 TeV

C'_{ij}	1	$\lvert V_{ti}V_{tj}^*\rvert^2$
$K^0 - \overline{K}^0$	$> \ 2 \times 10^4$ TeV	> 8 TeV
$B^0 - \overline{B}^0$	$> \ 0.5 \times 10^4$ TeV	> 5 TeV
$B_s^0 - \overline{B}_s^0$	$> 0.1 \times 10^4$ TeV	> 5 TeV

- For natural C~O(1), NP scale is huge
- Need lots of fine tuning to reduce NP scale to O(1TeV) as needed to mend the hierarchy problem
- Way out: NP is (almost) aligned with the SM
- MFV

MFV

To protect quark flavor mixing BSM, assume flavor symmetry is the one present in the limit of vanishing Yukawa's, U(3)^3, and that two quark Yukawa, *Yu* and *Yd*, are the only symmetry breaking and CP violating terms

$$\mathcal{L}_Y^{\rm SM} = -Y_d^{ij}\overline{Q}_L^i \phi D_R^j - Y_u^{ij}\overline{Q}_L^i \widetilde{\phi} U_R^j + \text{h.c.}$$

Promote *Yu* and *Yd* to non-dynamical fields. Higher dim operators made of SM fields and *Yud*.
Eigenvalues of *Yud* small except for top, off-diagonal elements suppressed $\Longrightarrow \left[Y_u (Y_u)^\dagger\right]^n_{i\neq j} \approx y_t^{2n} V_{ti}^* V_{tj}$

D'Ambrosio et al. NPB645(2002)155
Marcello, Smith, NPB 817(2009)1
...
Isidori, Straub EPJC72(2012)2103
Smith HDR-2015

Questions and progress

- ✘ Why is there flavor? Why families? Why 3?
- ✘ Why such a strong hierarchy?
- ✘ Why quark mixing is small (and lepton mixing is large)?
- ✘ Why is there quark alignment?
- ✘ How to solve strong CP-problem? [Peccei-Quinn elegant solution, but where are axions?]
- ✘ Need CPV in quark and lepton sector for BAU
- ✘ Does the scalar sector play a non-trivial role in the questions of flavor?
- ✘ Branco, Grimus and Lavoura figured out a symmetry which imposed on SM+2HDM provides a structure of Yukawas such that there is no FCNC at tree-level and their strength controlled by CKM (!)

b⟶s anomalies

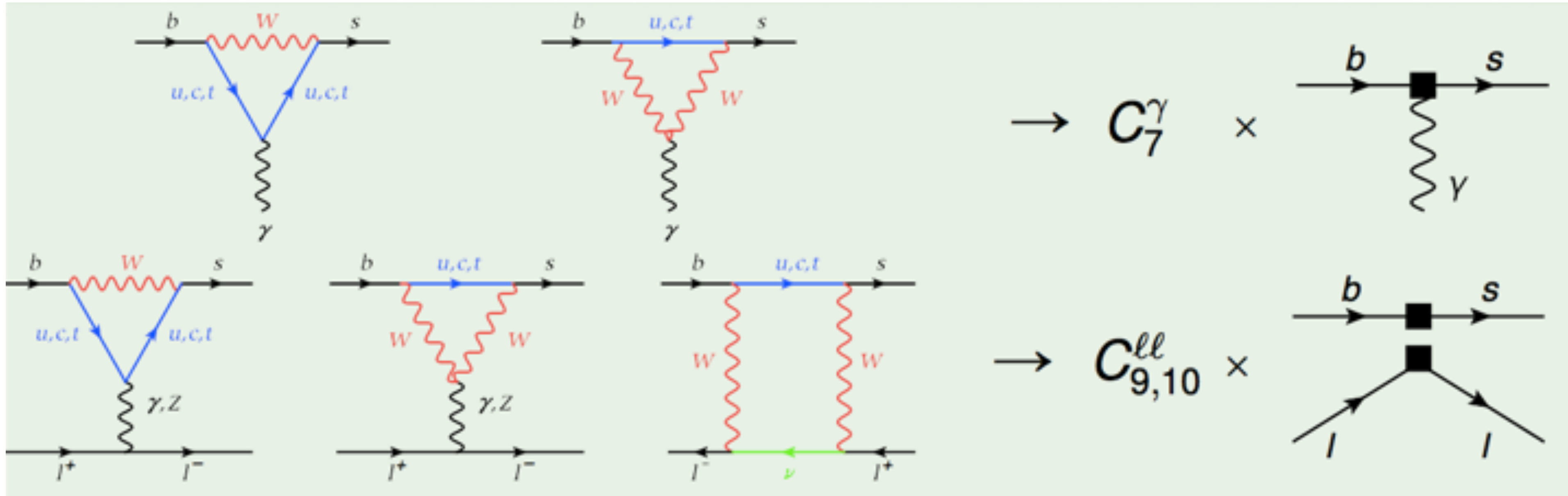
2.6σ away from SM in R_K

$$R_K = \frac{\mathcal{B}(B \to K\mu^+\mu^-)_{q^2\in[1,6]\ \mathrm{GeV}^2}}{\mathcal{B}(B \to Ke^+e^-)_{q^2\in[1,6]\ \mathrm{GeV}^2}} = 0.745\ \left({}^{+90}_{-74}\right)\ (36)_{\mathrm{LHCb}} \neq 1 + \mathcal{O}(m_\mu^2/m_b^2)$$

Can we claim to have seen LFUV?

LHCb will soon improve this number and also measure R_{K^*}

Basics



$$\mathcal{H}_{\text{eff}} = -\frac{4\,G_F}{\sqrt{2}} V_{tb} V_{ts}^* \left[C_1 \mathcal{O}_1 + C_2 \mathcal{O}_2 + \sum_{i=3}^{6} C_i \mathcal{O}_i + \sum_{i=7,8,9,10,P,S} (C_i \mathcal{O}_i + C_i' \mathcal{O}_i') \right]$$

$$\mathcal{O}_7 = \frac{e}{g^2} m_b (\bar{s} \sigma_{\mu\nu} P_R b) F^{\mu\nu}, \qquad \mathcal{O}_7' = \frac{e}{g^2} m_b (\bar{s} \sigma_{\mu\nu} P_L b) F^{\mu\nu},$$

$$\mathcal{O}_8 = \frac{1}{g} m_b (\bar{s} \sigma_{\mu\nu} T^a P_R b) G^{\mu\nu\, a}, \qquad \mathcal{O}_8' = \frac{1}{g} m_b (\bar{s} \sigma_{\mu\nu} T^a P_L b) G^{\mu\nu\, a},$$

$$\mathcal{O}_9 = \frac{e^2}{g^2} (\bar{s} \gamma_\mu P_L b)(\bar{\mu} \gamma^\mu \mu), \qquad \mathcal{O}_9' = \frac{e^2}{g^2} (\bar{s} \gamma_\mu P_R b)(\bar{\mu} \gamma^\mu \mu),$$

$$\mathcal{O}_{10} = \frac{e^2}{g^2} (\bar{s} \gamma_\mu P_L b)(\bar{\mu} \gamma^\mu \gamma_5 \mu), \qquad \mathcal{O}_{10}' = \frac{e^2}{g^2} (\bar{s} \gamma_\mu P_R b)(\bar{\mu} \gamma^\mu \gamma_5 \mu),$$

$$C_7^{\text{eff}} = \frac{4\pi}{\alpha_s} C_7 - \frac{1}{3} C_3 - \frac{4}{9} C_4 - \frac{20}{3} C_5 - \frac{80}{9} C_6$$

$$C_8^{\text{eff}} = \frac{4\pi}{\alpha_s} C_8 + C_3 - \frac{1}{6} C_4 + 20 C_5 - \frac{10}{3} C_6$$

$$C_9^{\text{eff}} = \frac{4\pi}{\alpha_s} C_9 + Y(q^2)$$

!!!

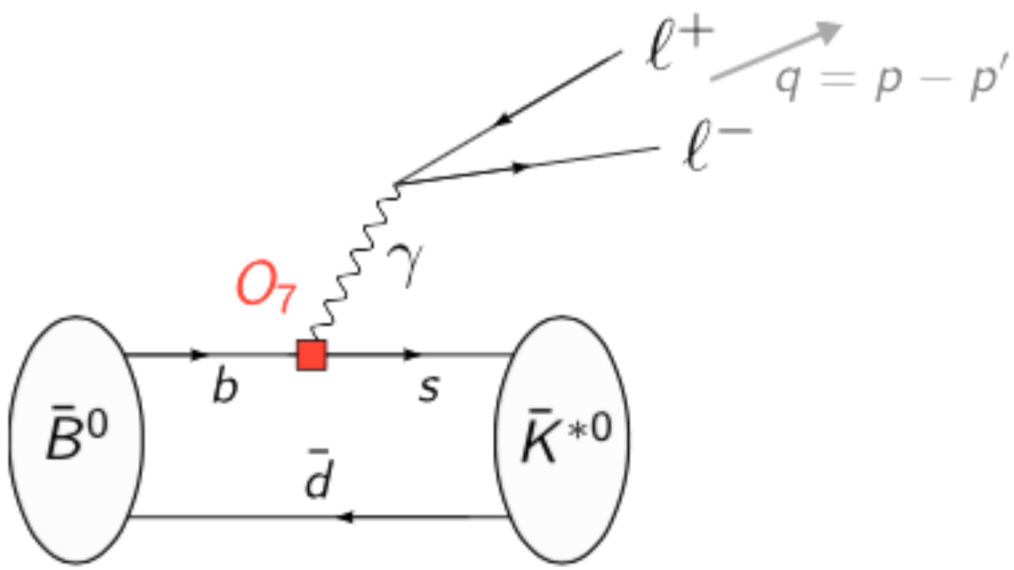
$$Y(q^2) = \frac{4}{3} C_3 + \frac{64}{9} C_5 + \frac{64}{27} C_6 - \frac{1}{2} h(q^2, 0) \left(C_3 + \frac{4}{3} C_4 + 16 C_5 + \frac{64}{3} C_6 \right)$$
$$+ h(q^2, m_c) \left(\frac{4}{3} C_1 + C_2 + 6 C_3 + 60 C_5 \right) - \frac{1}{2} h(q^2, m_b) \left(7 C_3 + \frac{4}{3} C_4 + 76 C_5 + \frac{64}{3} C_6 \right)$$

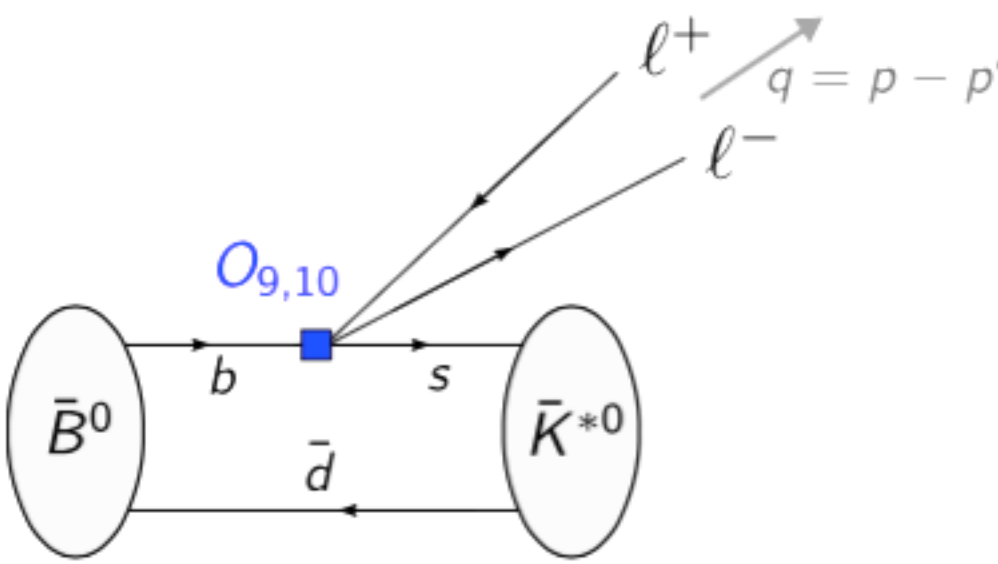
Very slowly varying functions of q^2

$$\mathcal{M} = \frac{G_F\,\alpha}{\sqrt{2}\pi} V_{tb} V_{ts}^* \Big[(\mathcal{A}_\mu + \mathcal{T}_\mu) \bar{u}_\ell \gamma^\mu v_\ell + \mathcal{B}_\mu \bar{u}_\ell \gamma^\mu \gamma_5 v_\ell \Big],$$

$$\mathcal{A}_\mu = -\frac{2m_b}{q^2} q^\nu C_7 \langle K^* | \bar{s}\, i\sigma_{\mu\nu} \tfrac{1+\gamma_5}{2} b\, | B \rangle + C_9 \langle K^* | \bar{s} \gamma_\mu \tfrac{1-\gamma_5}{2} b\, | B \rangle$$

$$\mathcal{B}_\mu = C_{10} \langle K^* | \bar{s} \gamma_\mu \tfrac{1-\gamma_5}{2} b\, | B \rangle$$

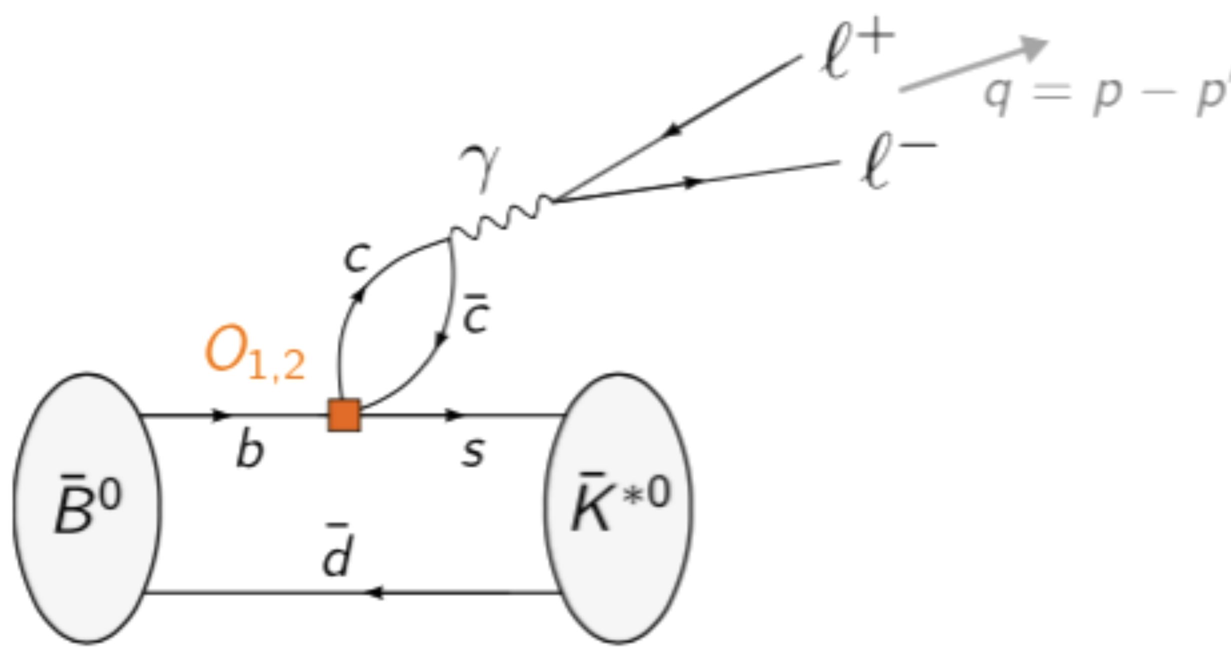




Can be and are computed on the lattice

$$\mathcal{M} = \frac{G_F\,\alpha}{\sqrt{2}\pi} V_{tb} V_{ts}^* \Big[(\mathcal{A}_\mu + \mathcal{T}_\mu) \bar{u}_\ell \gamma^\mu v_\ell + \mathcal{B}_\mu \bar{u}_\ell \gamma^\mu \gamma_5 v_\ell \Big],$$

$$\mathcal{T}_\mu = \frac{-16 i \pi^2}{q^2} \sum_{i=1\ldots6;8} C_i \int \mathrm{d}^4x\ e^{iq\cdot x} \langle K^* |\, \mathrm{T}\ O_i(0)\, j_\mu(x)\, | B \rangle$$



Cannot be computed on the lattice

- work either at very low or very high q^2

$b \longrightarrow s$ anomalies

2.6σ away from SM in R_K

$$R_K = \frac{\mathcal{B}(B \to K\mu^+\mu^-)_{q^2\in[1,6]\ \mathrm{GeV}^2}}{\mathcal{B}(B \to Ke^+e^-)_{q^2\in[1,6]\ \mathrm{GeV}^2}} = 0.745\,\left({}^{+90}_{-74}\right)\,(36)_{\mathrm{LHCb}} \neq 1 + \mathcal{O}(m_\mu^2/m_b^2)$$

- Better still: hadronic uncertainties cancel
- Need another experiment (Belle2!)
- Scalar operators can't explain. Vector ones could: NP in $C^{\mu\mu}_9$ but not C^{ee}_9. Similarly with C_9', C_{10} and C_{10}'
- Leptoquark models explicitly accommodate this feature
- Models with Z' [gauging a U(1) flavor subgroup, or merely introducing vector-like couplings to muons]

b⟶s anomalies

2.6σ away from SM in R_K

Leptoquark models

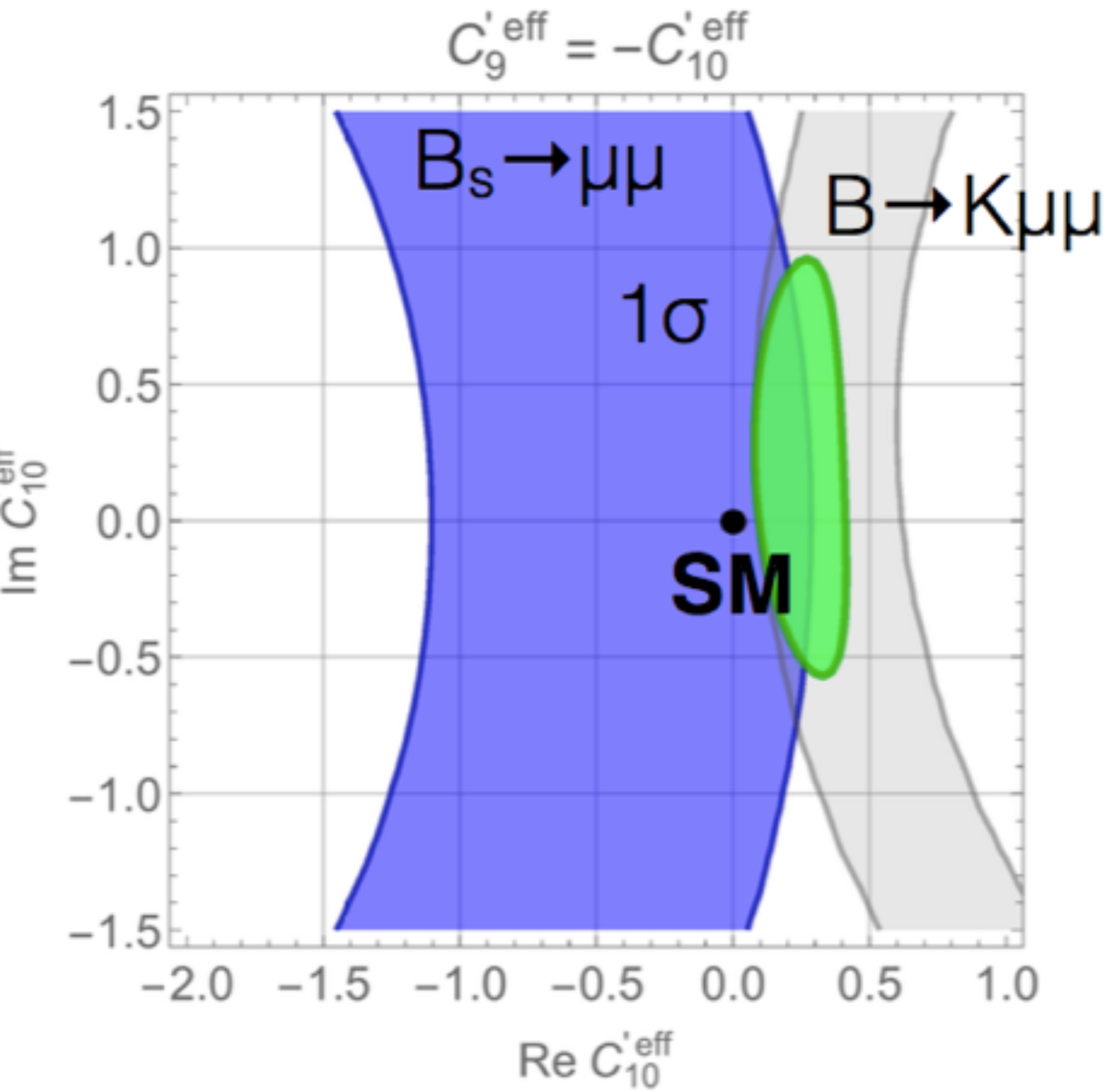
Representations of scalar LQs under $SU(3) \otimes SU(2) \otimes U(1)^*$

$(3,2)_{7/6}$	Increases B→Kμμ	$\bar{Q} e_R$		
$(3,2)_{1/6}$	Decreases B→Kμμ	$\bar{L} d_R$		$\Delta(3,2)_{1/6}$
$(\bar{3},3)_{1/3}$	Proton destabilizing	$\overline{Q^C} i\tau_2 \vec{\tau} L$	$\overline{Q^C} i\tau_2 \vec{\tau} Q$	
$(\bar{3},1)_{4/3}$	Proton destabilizing	$\overline{d_R^C} \ell_R$	$\overline{u_R^C} u_R$	

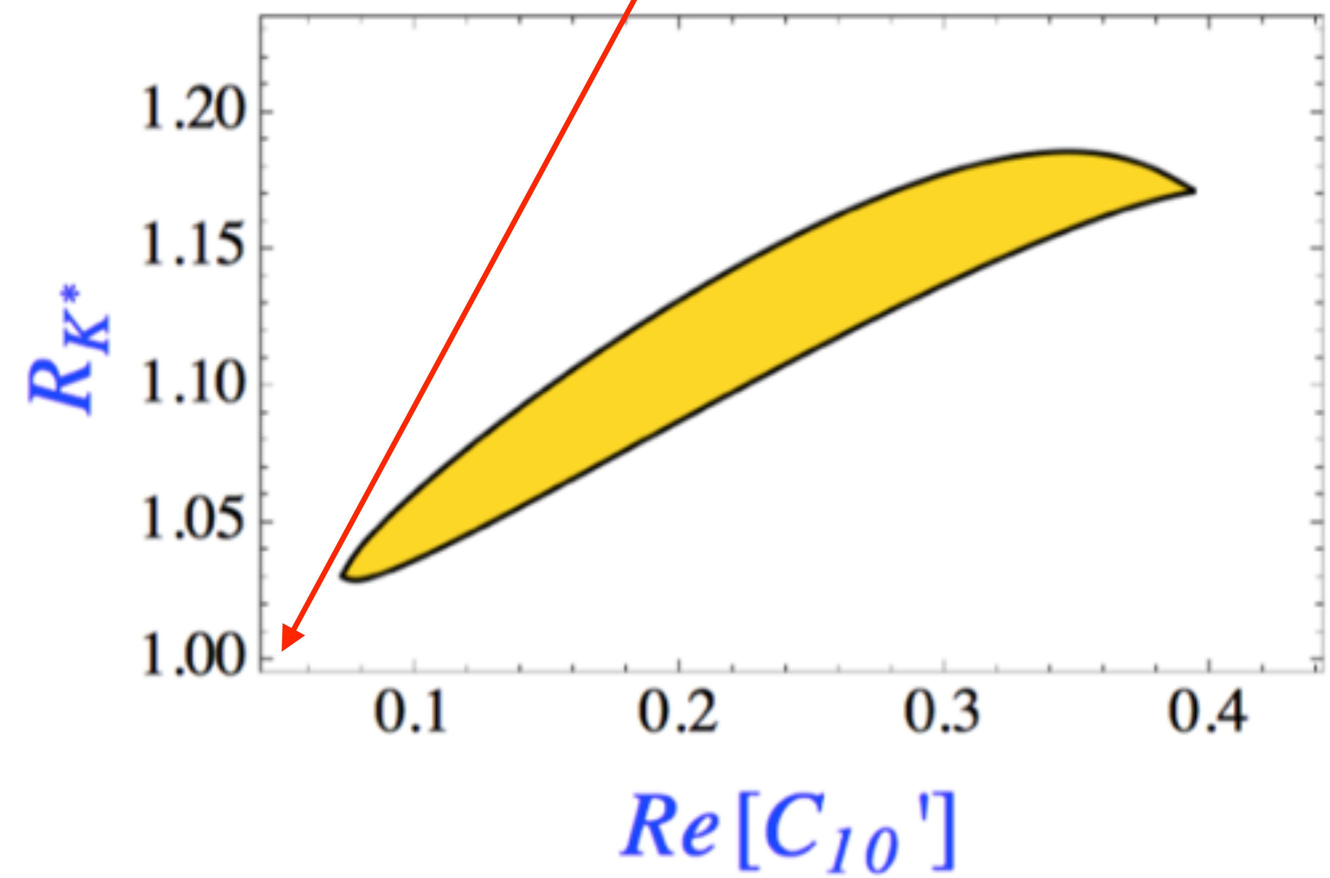
$$C'_{10} = -C'_9 = \frac{-\pi}{2\sqrt{2} G_F V_{tb} V_{ts}^* \alpha} \frac{Y_{\mu b} Y_{\mu s}^*}{m_\Delta^2}$$

b⟶s anomalies

2.6σ away from SM in R_K



Larger than 1! Opposite to what happens in the scenario with C_9=-C_{10}

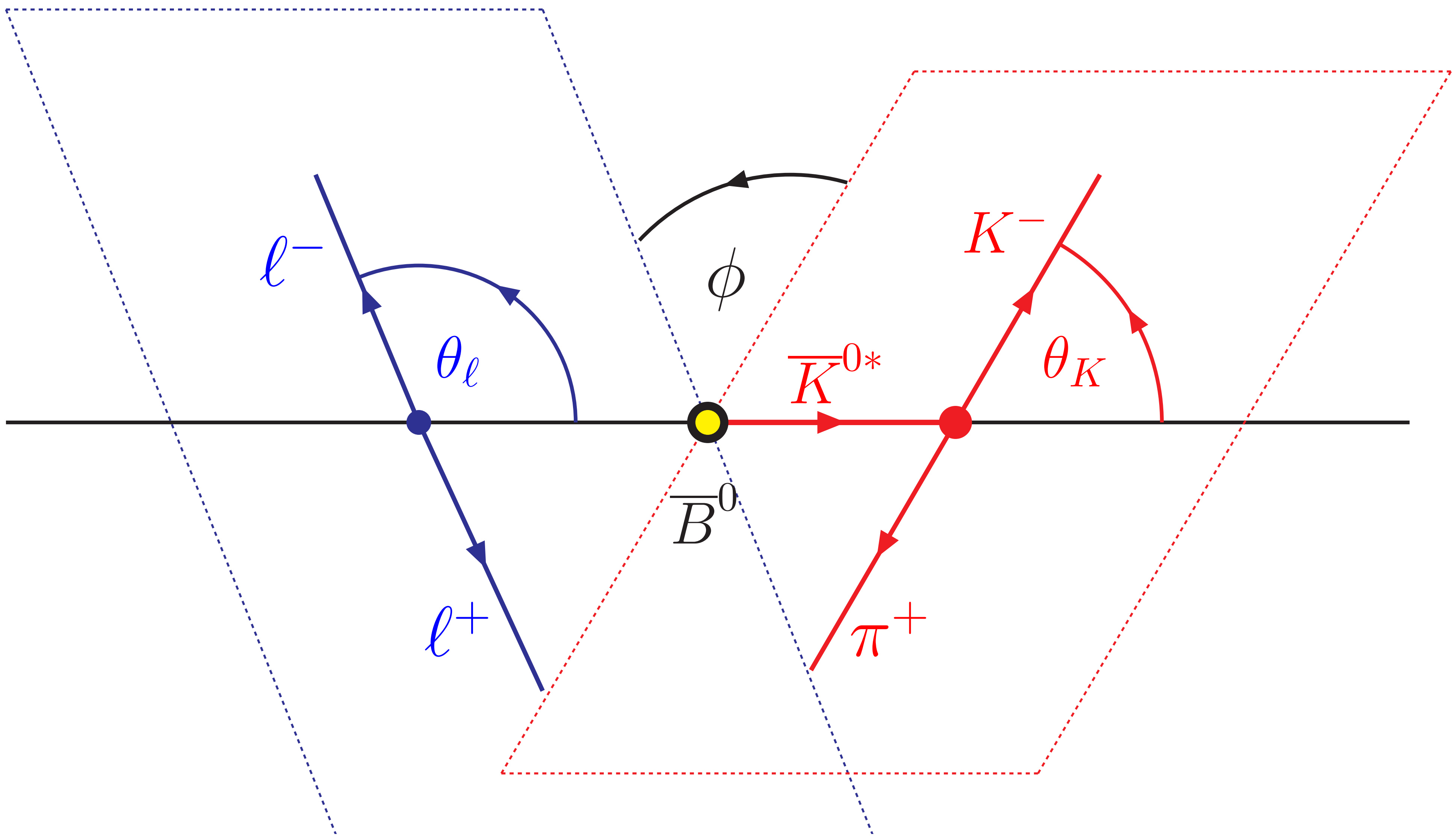


$$R_K(C'_{10}) = 1.001(1) - 0.46\ \mathrm{Re}[C'_{10}] - 0.094(3)\ \mathrm{Im}[C_{10}{}'] + 0.057(1)|C'_{10}|^2$$

Remaining form factor uncertainties

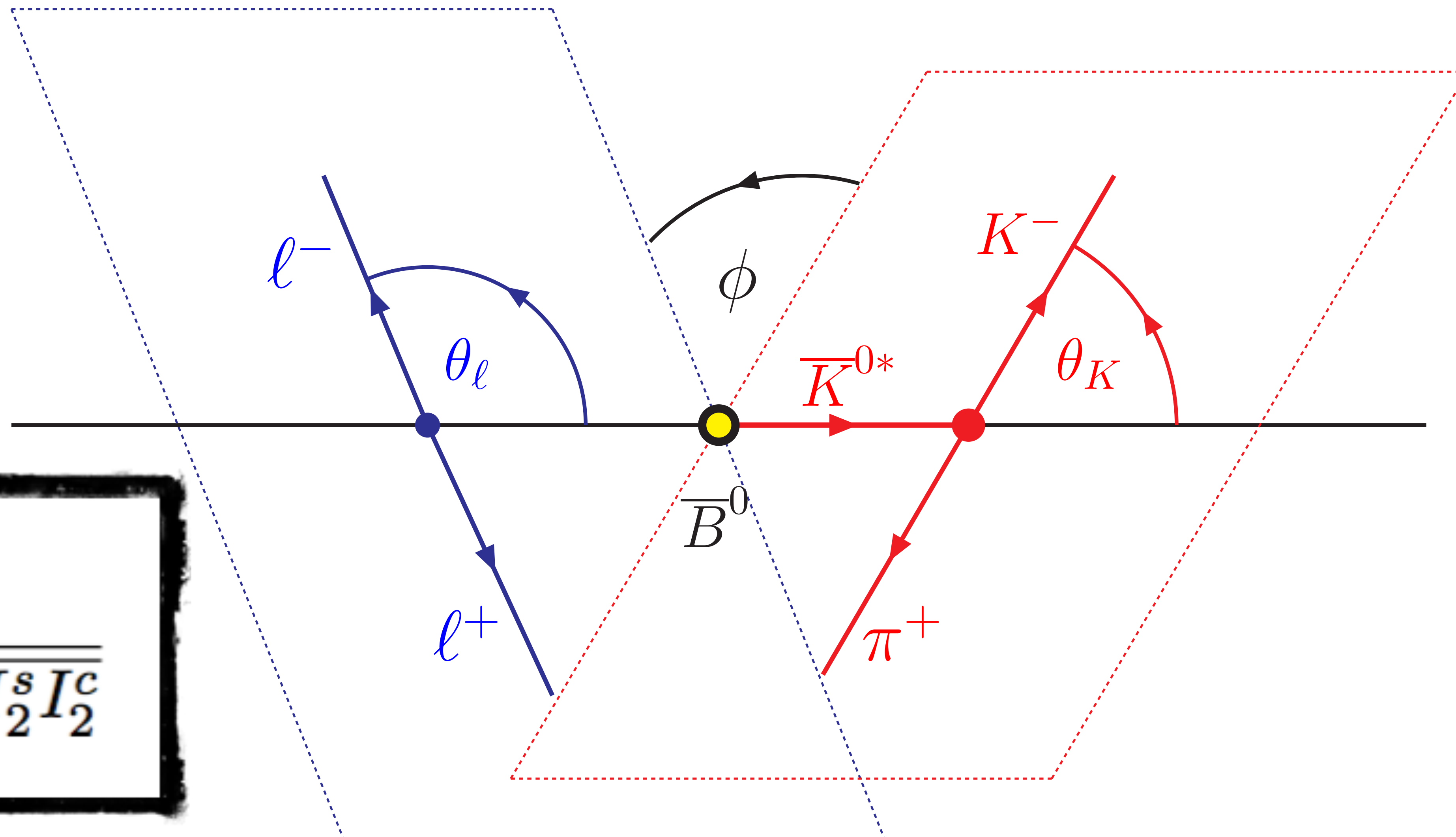
Better sensitivity to NP:

$B \to K^* \ell^+ \ell^-$



$$\frac{d^4\Gamma(\bar{B}^0 \to \bar{K}^{*0}\ell^+\ell^-)}{dq^2\ d\cos\theta_\ell\ d\cos\theta_K\ d\phi} = \frac{9}{32\pi} I(q^2, \theta_\ell, \theta_K, \phi)$$

Full decay distribution



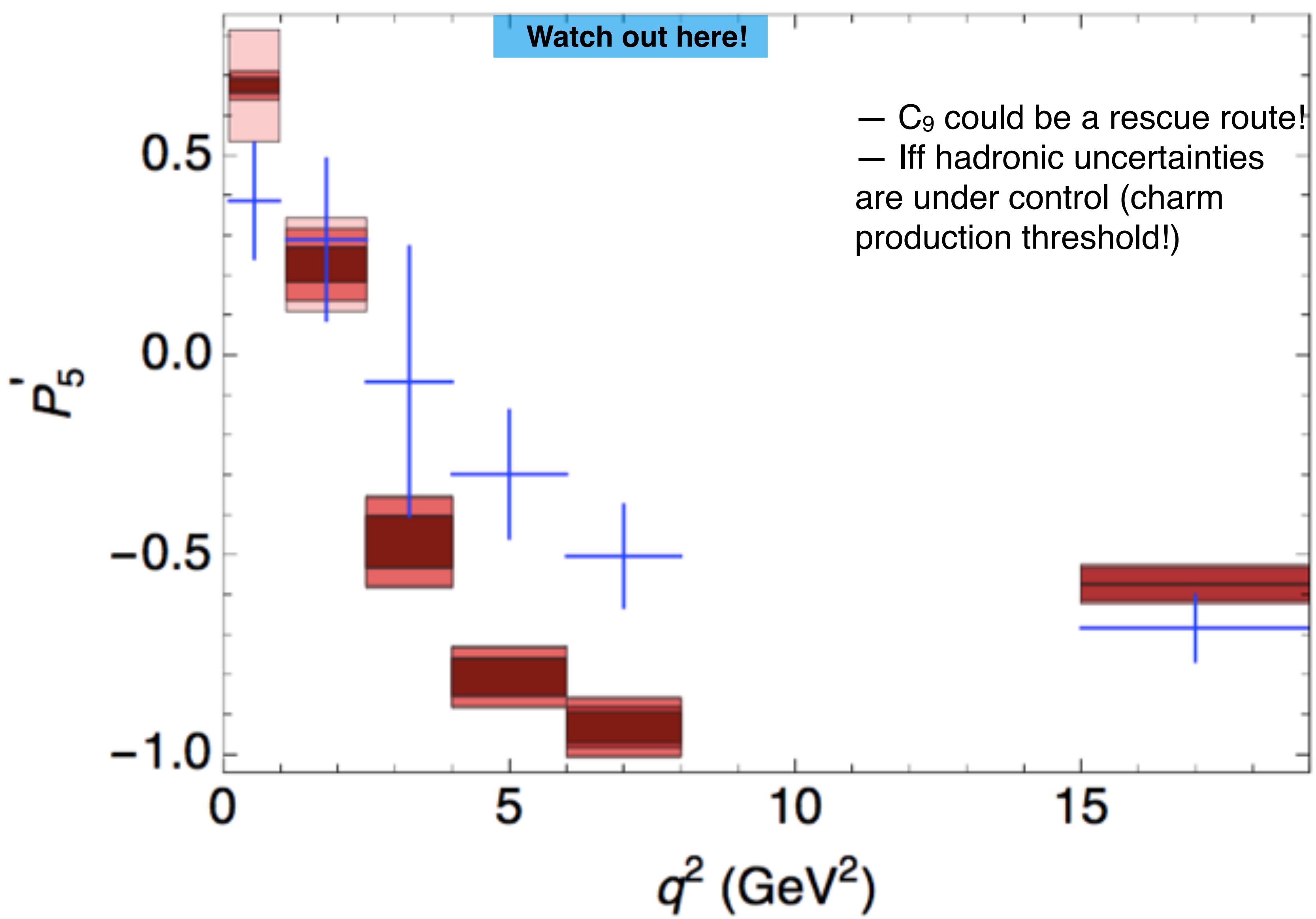
$$\boxed{P_5' = \frac{I_5}{\sqrt{-4 I_2^s I_2^c}}}$$

✓

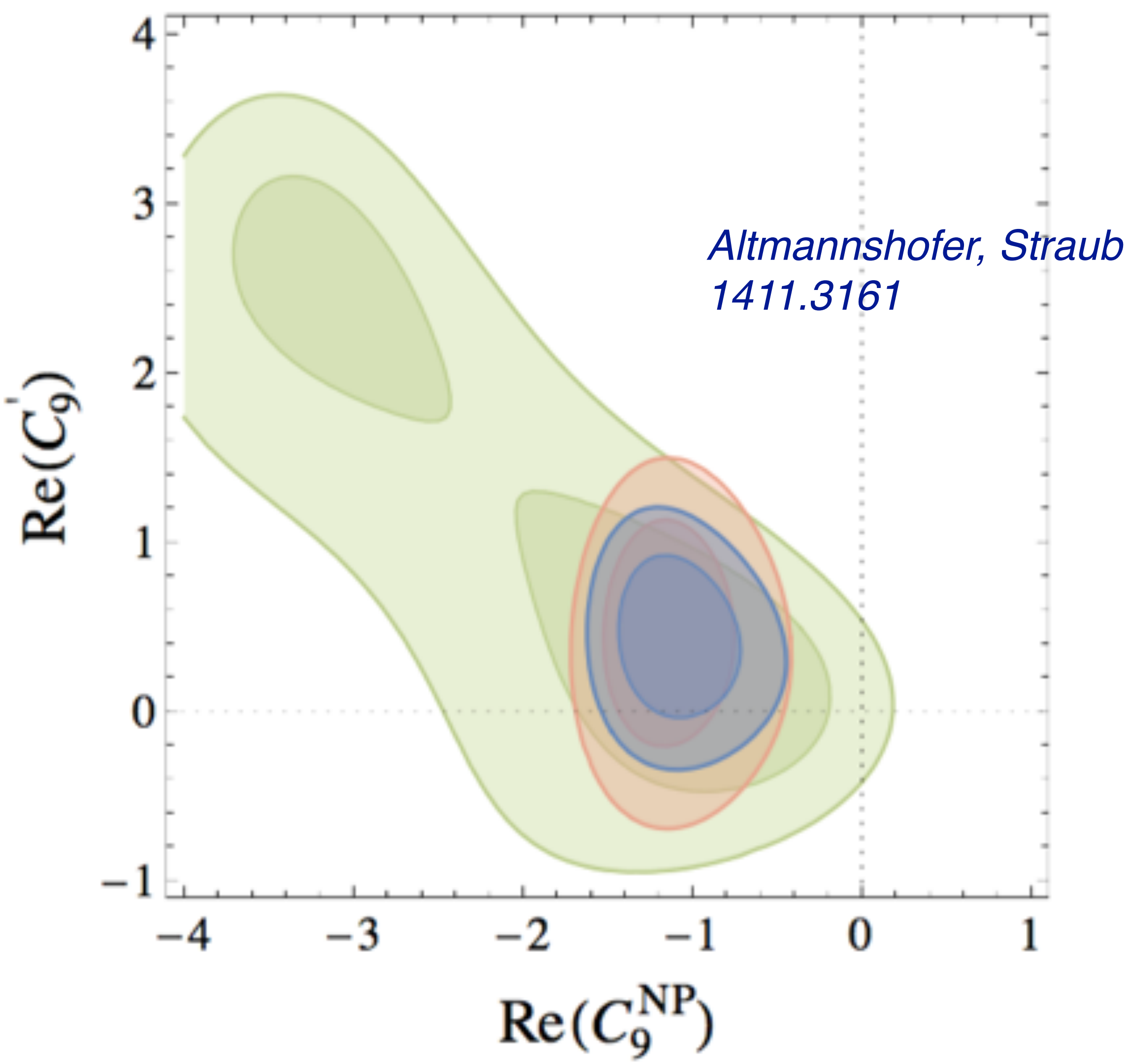
$$\begin{aligned} I(q^2,\theta_\ell,\theta_K,\phi) \;=\;& I_1^s(q^2)\sin^2\theta_K + I_1^c(q^2)\cos^2\theta_K + \left[\underline{I_2^s(q^2)}\sin^2\theta_K + \underline{I_2^c(q^2)}\cos^2\theta_K\right]\cos 2\theta_\ell \\ &+ I_3(q^2)\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + I_4(q^2)\sin 2\theta_K\sin 2\theta_\ell\cos\phi \\ &+ \underline{I_5(q^2)}\sin 2\theta_K\sin\theta_\ell\cos\phi \\ &+ \left[I_6^s(q^2)\sin^2\theta_K + I_6^c(q^2)\cos^2\theta_K\right]\cos\theta_\ell + I_7(q^2)\sin 2\theta_K\sin\theta_\ell\sin\phi \\ &+ I_8(q^2)\sin 2\theta_K\sin 2\theta_\ell\sin\phi + I_9(q^2)\sin^2\theta_K\sin^2\theta_\ell\sin 2\phi \end{aligned}$$

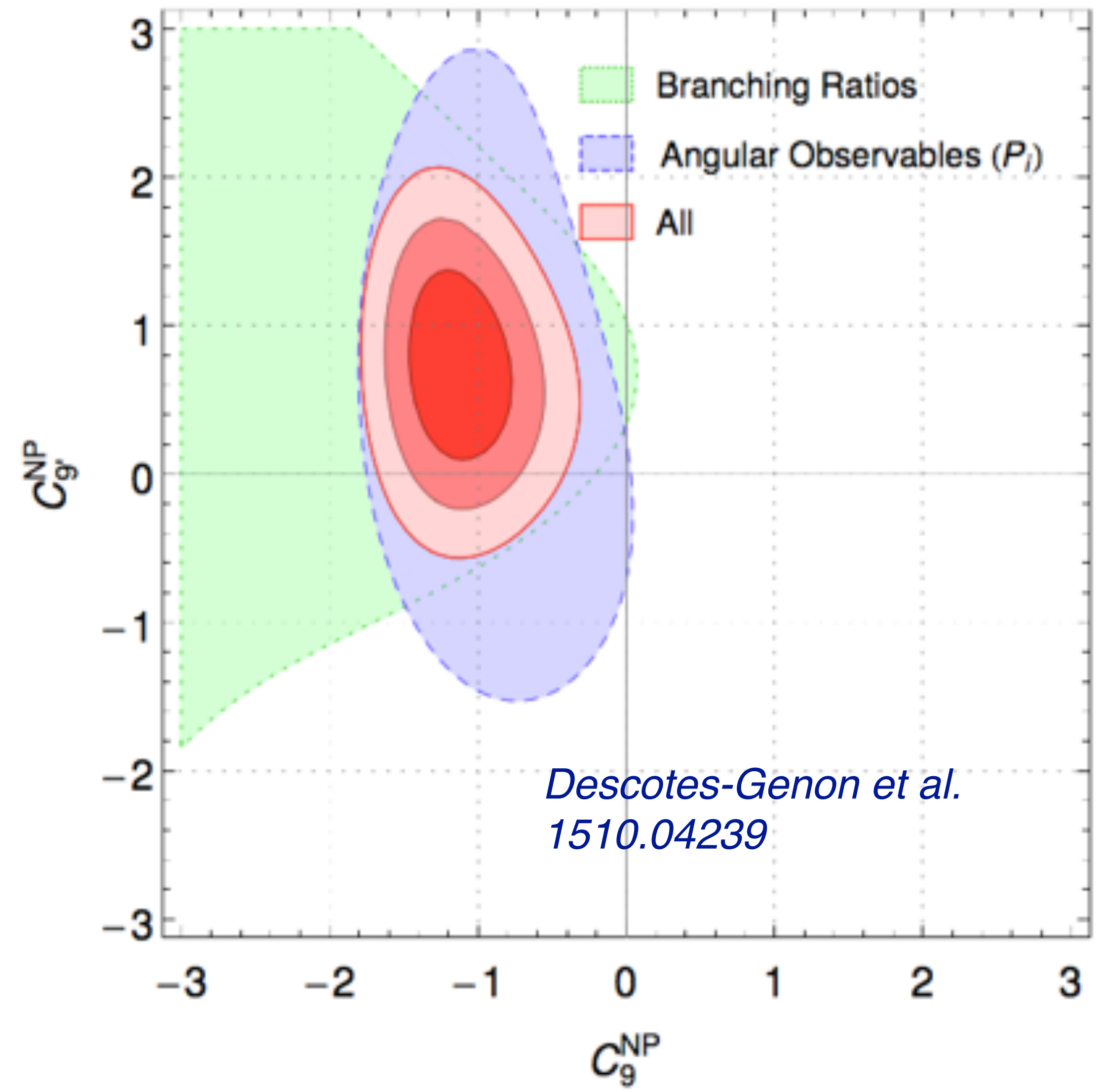
b⟶s anomalies

2-3σ deviation from SM [esp. P_5']



b⟶s anomalies



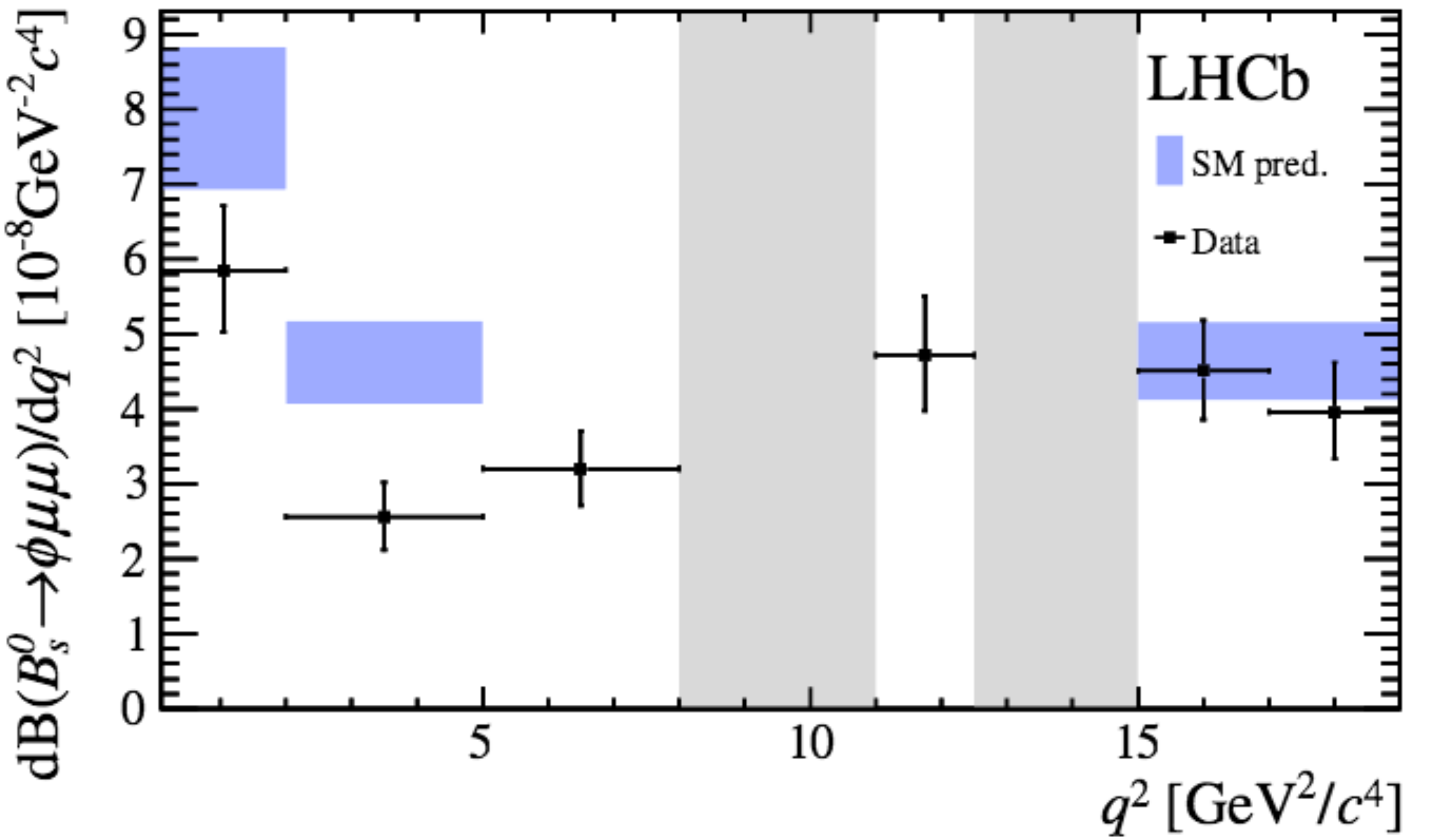


- Theory errors still subject to controversies.
- Some quantities are more sensitive to hadronic uncertainties than others (maybe sticking to the clean observables only?)
- Ciuchini et al [1512.07157] claim that the whole discrepancy can be absorbed into (unknown) power corrections due to charm loops.

b⟶s anomalies

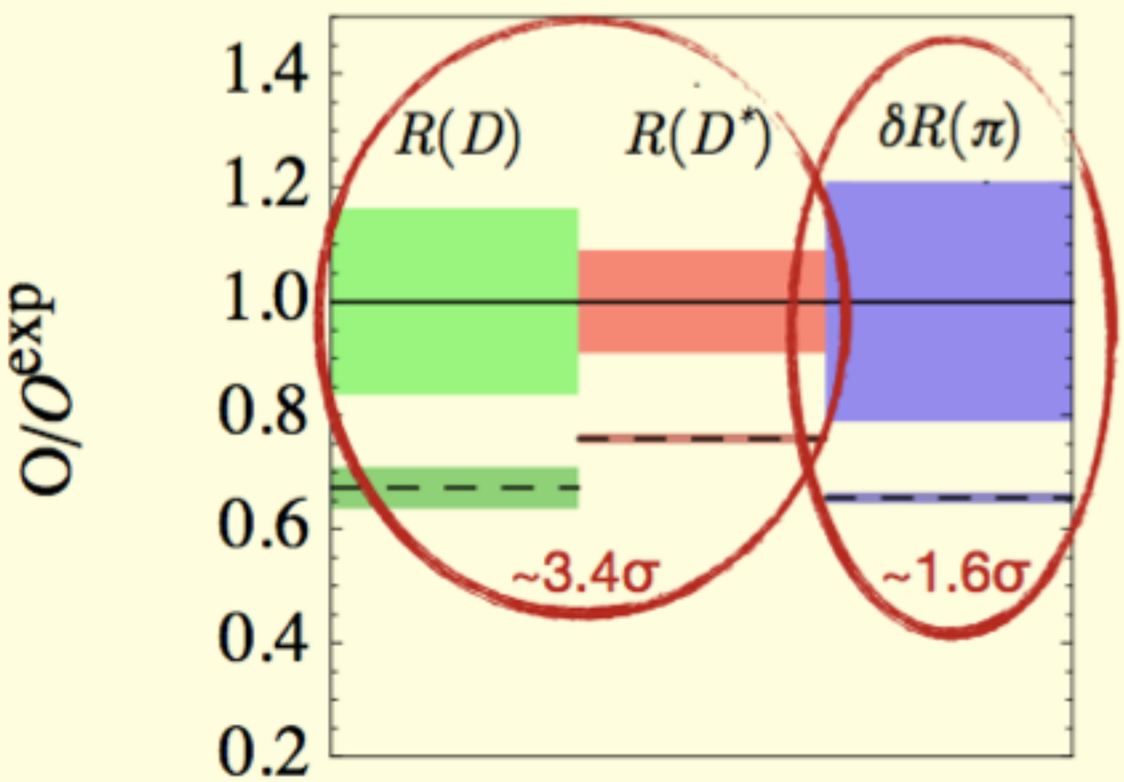
3.1σ in $B\to\phi\mu\mu$ bellow SM at low q^2

1506.08777



Theory error - subject to controversies… If OK, then NP in C_9 could fill the gap between experiment and SM.

R_D R_{D^*}



$$\delta R(\pi) \equiv \frac{\tau(B^0)}{\tau(B^-)} \frac{\mathcal{B}(B^- \to \tau^- \bar{\nu})}{\Delta\mathcal{B}(\bar{B}^0 \to \pi^+ \ell^- \bar{\nu})}$$

$$R(D) \equiv \frac{\mathcal{B}(B \to D\tau\nu)}{\mathcal{B}(B \to D\ell\nu)} \qquad R(D^*) \equiv \frac{\mathcal{B}(B \to D^*\tau\nu)}{\mathcal{B}(B \to D^*\ell\nu)}$$

BaBar, 1205.5442, 1303.0571
Babar, 1207.0698
Belle, 1208.4678

LHCb [1506.08614]

$$\mathcal{R}(D^*) = 0.336 \pm 0.027\,(\text{stat}) \pm 0.030\,(\text{syst})$$

$$\mathcal{R}(D^*)^{\text{theo.}} = 0.252(3)$$

Fajfer et al [1203.2654]

- Theory error, one form factor completely unknown but HQET helps (error that entails?) LQCD may help!

Model builders stuck

- Cannot accommodate $b \to s$ anomalies, R_{D^*}, R_D and the CMS hint, $B(h \to \tau\mu) = 0.83(38)\%$
- Either some information is not yet reliable, or the model turns be baroque

- Attempt 1: U(1) gauge group Q(e)=0, Q(μ)=1,Q(τ)=-1 $\Longrightarrow$ Z′ with vector like quarks (charged under L_τ-L_μ) [1403.1269]; second doublet [in 2HDM] breaks L_τ-L_μ, inducing the LFV [1501.00993]

- Attempt 2: 3HDM with gauged B-L charges [1503.03477]

- Attempt 3: Weakly break $U(2)^5$ plus vector LQ - nonrenormalizable [1503.03477]

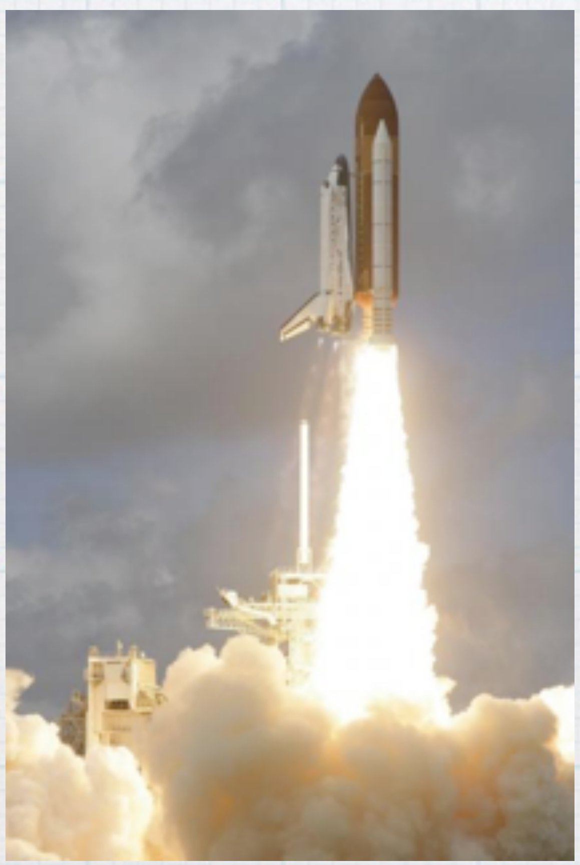
- Attempt 4: Single scalar LQ with (3,1,-1/3) and mass around 1 TeV:
- passes R_{D^*}, R_D and R_K [1511.01900]

Flavor Physics in the LHC era

2009

LHC @ high p_T

Unique effort toward the high energy frontier



to determine the energy scale of New Physics

Flavor Physics

Collective effort

EDMs

CPV in B_s systems

Universality tests in B & K

g-2

LFV in μ and τ decays

Rare B decays

Rare K decays

Improved CKM fits

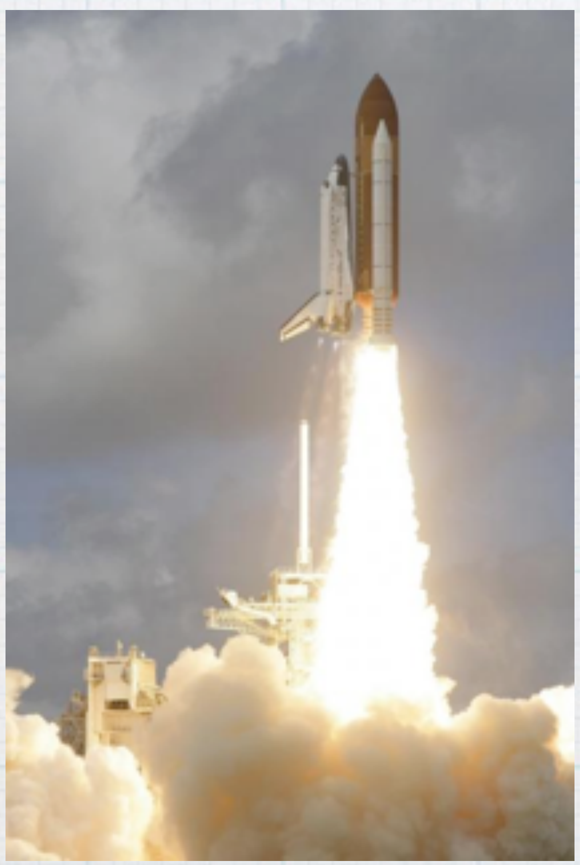
to determine the flavor structure of New Physics

Two complementary ways to study NP

2009

LHC @ high p_T

Unique effort toward the high energy frontier



to determine the energy scale of New Physics

Flavor Physics

Super-flavor machines

Super-Belle (YES) & Super-B (???)

EDMs

CPV in B_s systems

Universality tests in B & K

g-2

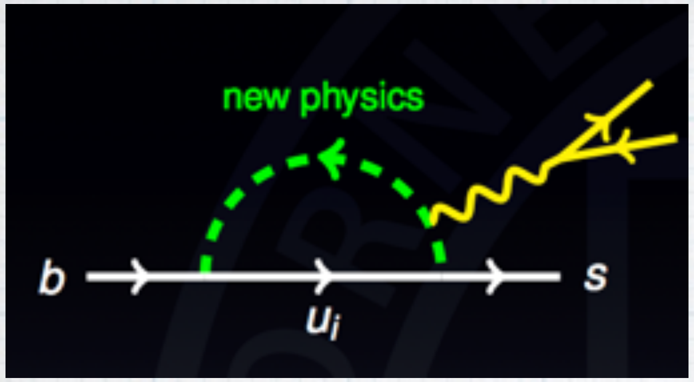
LFV in μ and τ decays

Rare B decays

Rare K decays

Improved CKM fits

to determine the flavor structure of New Physics



Where to look?

2009

- Check on the scalar form factor in Kl3 [RH current in Higgsless theories or binding the charged Higgs (for large tanβ) → Similar possible with $B \to D\tau\nu$, D-decays - rich ground for zero-tests]
- $b \to s\, l\, l$ [Many asymmetries (esp FB), sensitive to either SUSY or XD; Exclusive $B \to K^{(*)}ll$, $D \to K/\pi ll$ - rich ground for zero-tests]
- $K \to \pi\nu\nu$ [very clean-up to the isospin & higher order ew corrections; $B \to K\nu\nu$ interesting]
- $B_s \to \mu\mu$ [in MSSM its amplit. enhanced by $\tan^3\beta$; $B_s \to \mu\mu / B_d \to \mu\mu$?]
- γ from $B \to DK$ [isospin relations among $b \to c\bar{u}s$ $b \to u\bar{c}s$,]
- $B_{s,d} \to KK, K\pi, \pi\pi$ [explore LHCb, Tevatron - discrepancies?!]
- $\tau \to \mu\gamma$, $\mu \to e\gamma$ [helps CPV in ν-sector]
- $B_c \to$ all [and many other consistency checks]

2009

QCD tests/constraints

- Spectroscopy [scalars, tetraquark, hybrid...]
- Non-leptonic decays [FSI from the data?! Lattice cannot help! Theory?]
- Range of validity of effective theories [ChPT, NRQCD, HQET; can SCET be made useful?]
- QCD factorization
- Duality [quark hadron duality works well until?]
- Flavor singlet sector [terra incognita! η' - unknown physics]
- Always check on the lattice results!
- Soft photons are trouble [eg. $B \to \tau \nu \gamma$ OK, but $B \to \mu \nu \gamma$ is not]

2009

MESSAGES

- New Physics - Hierarchy Vs Flavor problem
  [towards solution(s)]
- QCD is NOT solved yet! [Lattice QCD is the only tool for the ab-initio calculations → indispensable *(merci à l'IN2P3)*, but there are far more things you cannot do with Lattices than those that you can; NEED an analytic understanding of non-perturbative QCD]
- LHC is blunt-machine [NP signal will hopefully be discovered but to understand what NP, need cleaner experiment ➠ Super-Belle, Super-B ; watch out for Super-B workshops]
- Check on the reported discrepancies [but believe anything under 3σ ; many new modes will be explored, current results improved]
- FLAVOR PHYSICISTS IN FRANCE [many retire(d), pure phenomenology persons in Sec.02 - rarity (IN2P3 has got a few)]

2016

MESSAGES

- All from 2009 and some more.
- A few cracks are here: USE THE EXPERIMENTAL DATA TO DO PHYSICS!
- Model building: more observables - towards understanding flavor and CPV
- LFV can be tackled in SL modes
- Higgs flavour era around the corner?