Recent progress in heavy flavor physics
-- Flavor Anomalies

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$\sim 3.5\sigma$ $(g-2)_\mu$ anomaly

$\sim 3.5\sigma$ non-standard like-sign dimuon charge asymmetry

$\sim 3.5\sigma$ enhanced $B \to D^{(*)}\tau\nu$ rates $R_{D^{(*)}}$

$\sim 3.5\sigma$ suppressed branching ratio of $B_s \to \phi\mu^+\mu^-$

$\sim 3\sigma$ tension between inclusive and exclusive determination of $|V_{ub}|$

$\sim 3\sigma$ tension between inclusive and exclusive determination of $|V_{cb}|$

$2-3\sigma$ anomaly in $B \to K^*\mu^+\mu^-$ angular distributions P_5'

$2-3\sigma$ SM prediction for ϵ'/ϵ below experimental result

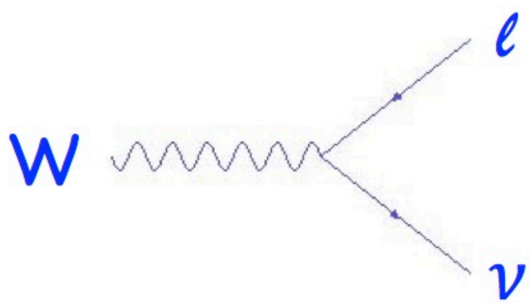
$\sim 2.5\sigma$ lepton flavor non-universality in $B \to K\mu^+\mu^-$ vs. $B \to Ke^+e^-$ R_K

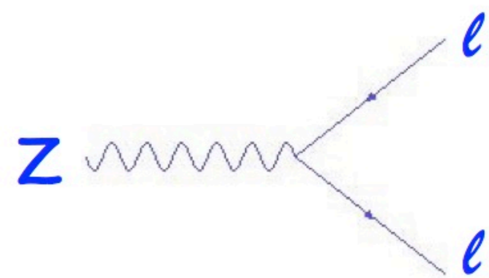
$\sim 2.5\sigma$ non-zero $h \to \tau\mu$

Lepton universality

Lepton couplings to gauge bosons in the standard model are all the same

Very well tested, PDG averages:





$$\frac{B(W^+ \to \mu^+\nu)}{B(W^+ \to e^+\nu)} = 0.991 \pm 0.018$$

$$\frac{B(W^+ \to \tau^+\nu)}{B(W^+ \to e^+\nu)} = 1.043 \pm 0.024$$

$$\frac{B(W^+ \to \tau^+\nu)}{B(W^+ \to \mu^+\nu)} = 1.070 \pm 0.026$$

$$\frac{B(Z \to \mu^+\mu^-)}{B(Z \to e^+e^-)} = 1.0009 \pm 0.0028$$

$$\frac{B(Z \to \tau^+\tau^-)}{B(Z \to e^+e^-)} = 1.0019 \pm 0.0032$$

.9977 (SM)

Current new physics signal in B physics

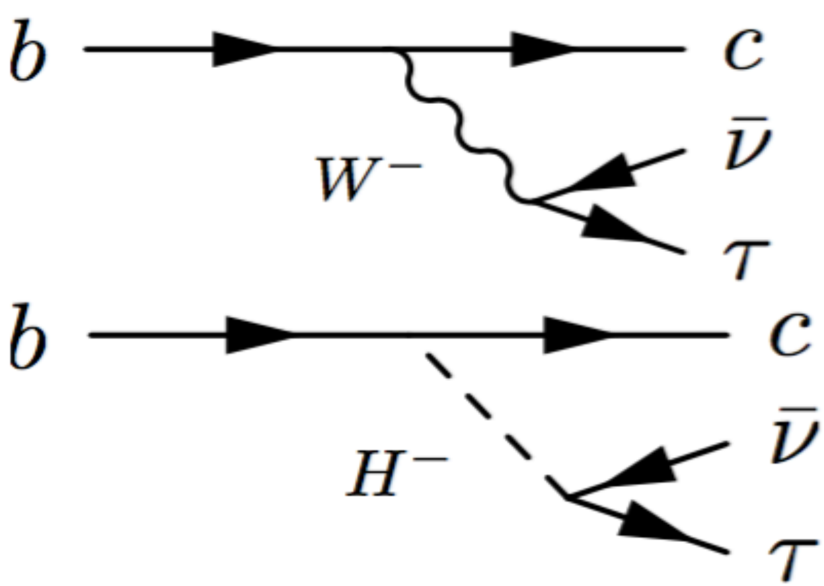
$\bar{B} \to D^{(*)}\tau\bar{\nu}$ Br ~ 0.7+1.3 % in the SM

Not rare, but two or more missing neutrinos

Data available since 2007 (Belle, BABAR, LHCb)

Theoretical motivation

W.S. Hou and B. Grzadkowski (1992)



SM: gauge coupling

lepton universality

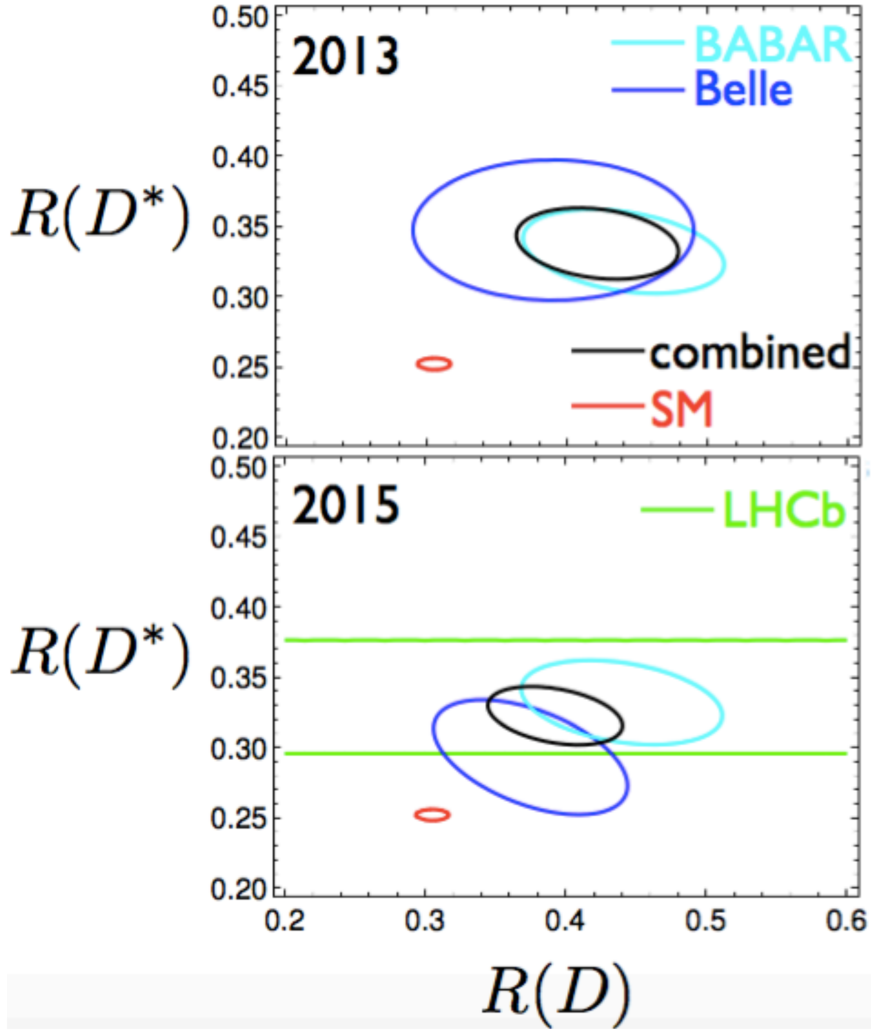
Type-II 2HDM (SUSY)

Yukawa coupling

$\propto m_b m_\tau \tan^2\beta$

$$R(X) = \frac{\Gamma(B \to X\tau\bar{\nu})}{\Gamma(B \to X(e/\mu)\bar{\nu})}$$

Experiments



$$R(D) = 0.421 \pm 0.058$$
$$R(D^*) = 0.337 \pm 0.025$$

~3.5σ

Y. Sakaki, MT, A. Tayduganov, R. Watanabe

$$R(D) = 0.391 \pm 0.041 \pm 0.028$$
$$R(D^*) = 0.322 \pm 0.018 \pm 0.012$$

~3.9σ HFAG

Standard model predictions

Theoretical uncertainty: form factors

data from $\bar{B} \to D^{(*)} \ell \bar{\nu}$ $(\ell = e, \mu)$

+ HQET or pQCD

+ lattice QCD

$R(D) = 0.296 \pm 0.016$ (Fajfer, Kamenik, Nisandzic)

0.302 ± 0.015 (Sakaki, MT, Tayduganov, Watanabe)

0.299 ± 0.011 (Bailey et al.)

$0.337^{+0.038}_{-0.037}$ (Fan, Xiao, Wang, Li)

$0.391 \pm 0.041 \pm 0.028$ (Exp. HFAG)

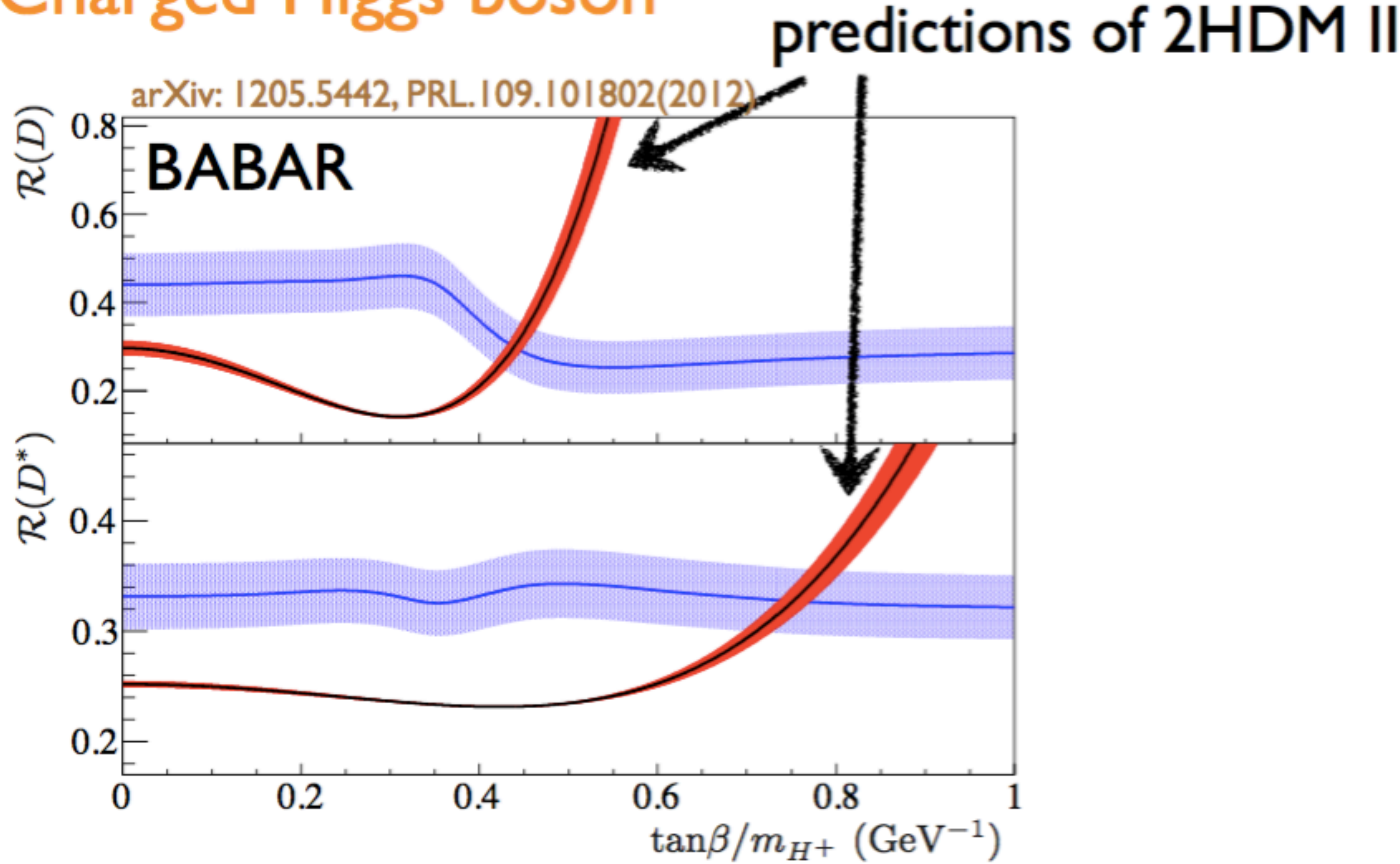
$R(D^*) = 0.252 \pm 0.003$ (Fajfer, Kamenik, Nisandzic)

0.252 ± 0.004 (Sakaki, MT, Tayduganov, Watanabe)

$0.269^{+0.021}_{-0.020}$ (Fan, Xiao, Wang, Li)

$0.322 \pm 0.018 \pm 0.012$ (Exp. HFAG)

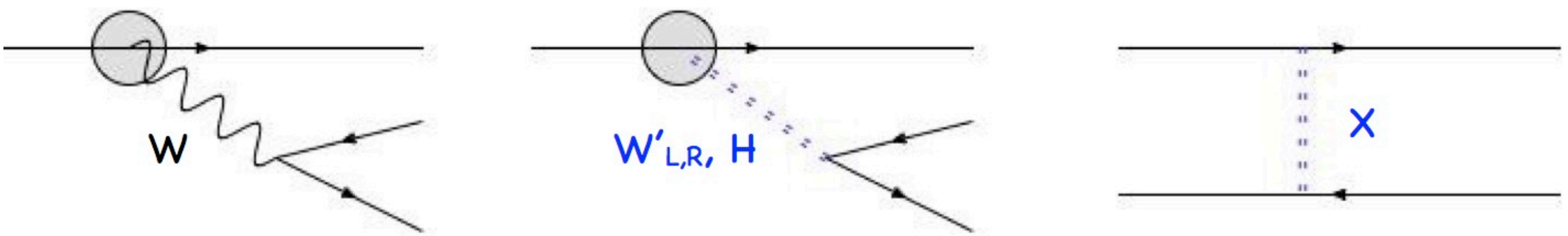
Charged Higgs boson



Charged Higgs *excluded* at 99.8% CL

first surprise in $b \to c\, \tau\, \nu$

- apparently the τ has a stronger coupling
- at tree level, several possible other couplings



- new W gauge boson with non-universal couplings (our model W_R)
- leptoquark - need very specific flavour structure
- charged Higgs, seems a natural explanation but the simple models do not work

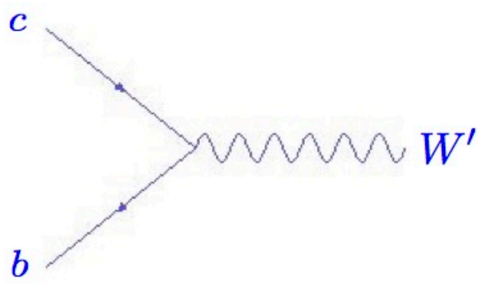
Nothing seen in other meson decay

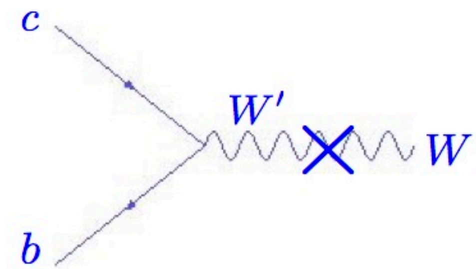
	Exp. (PDB)	SM
$\frac{B(K^+ \to \pi^0 \mu^+ \nu)}{B(K^+ \to \pi^0 e^+ \nu)}$	0.6608±0.0029	0.6631±0.0042 (Cirigliano et al)
$\frac{B(K^+ \to e^+ \nu)}{B(K^+ \to \mu^+ \nu)}$	2.488±0.009(10^{-5})	2.477±0.001 (10^{-5}) (Cirigliano et al)
$\frac{B(\pi^+ \to e^+ \nu(\gamma))}{B(\pi^+ \to \mu^+ \nu(\gamma))}$	1.2327±0.0023(10^{-4})	1.2352±0.0005(10^{-4}) (Marciano, Sirlin)

- no simple models
- need to arrange the flavour structure to single out this family: b, τ

W′ and semileptonic B decay to tau

quark sector





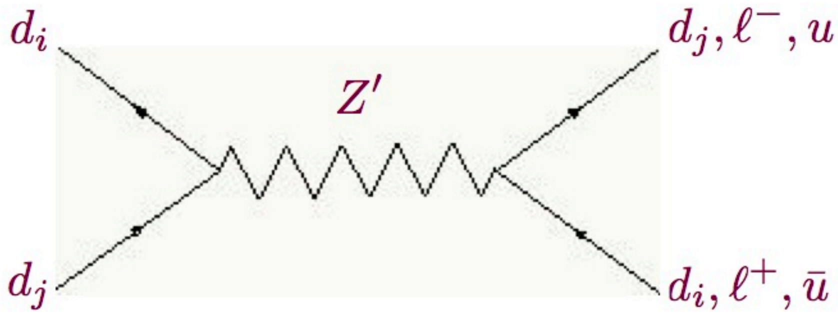
$$\mathcal{L}_W = -\frac{g_L}{\sqrt{2}}\bar{U}_L\gamma^\mu V_{KM} D_L(\cos\xi_W W_\mu^+ - \sin\xi_W W_\mu^{'+}) -\frac{g_R}{\sqrt{2}}\bar{U}_R\gamma^\mu V_R D_R(\sin\xi_W W_\mu^+ + \cos\xi_W W_\mu^{'+}) + \text{h. c.},$$

- two (sets) of parameters come into play
- mixing between W and W′
- right handed analog of CKM matrix

previously worked out constraints

*HFAG-2012

*From $b \to s\gamma$ = $(3.55 \pm 0.25) \times 10^{-4}$ $\quad -0.0013 \leq \frac{g_R}{g_L}\xi_W \leq 0.0027$



strongest constraints from meson mixing

FCNC constraints can be summarised by $\quad V^d_{Rbi} \sim \delta_{bi}$

with $V_L^{u,d} = V_R^{u,d},\ V_L^{u\dagger} V_L^d = V_{CKM}$ this allows us to predict

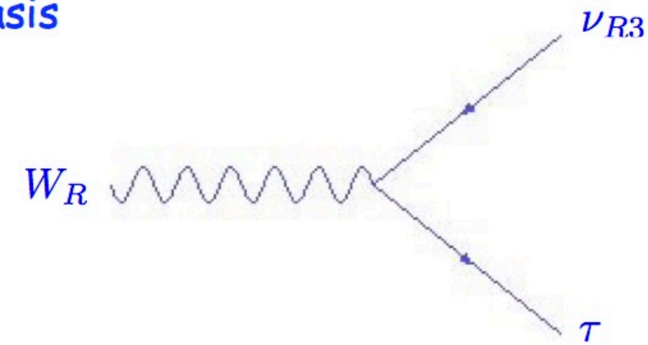
$$V_R = (V_{Rij}) = (V^{u*}_{Rti} V^d_{Rbj}) \qquad V_R \sim \begin{pmatrix} 0 & 0 & A\lambda^3 \\ 0 & 0 & A\lambda^2 \\ 0 & \lambda^4 & 1 \end{pmatrix}$$

$$V^u_{Rtc} \sim V_{cb}, V^u_{Rtu} \sim V_{ub}$$

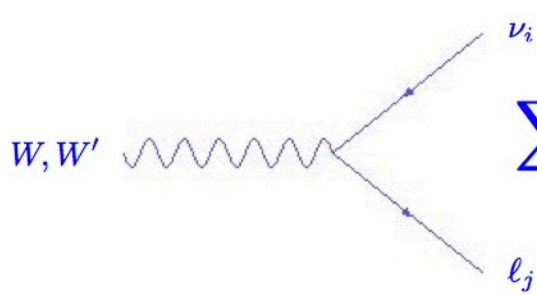
W´and semileptonic B decay to tau

weak eigenstate basis

lepton sector



- need the new right-handed neutrino to be light
- it is possible to have a scalar sector that gives an acceptable neutrino mass spectrum and mixing



no interference if neutrino mass << charged lepton mass

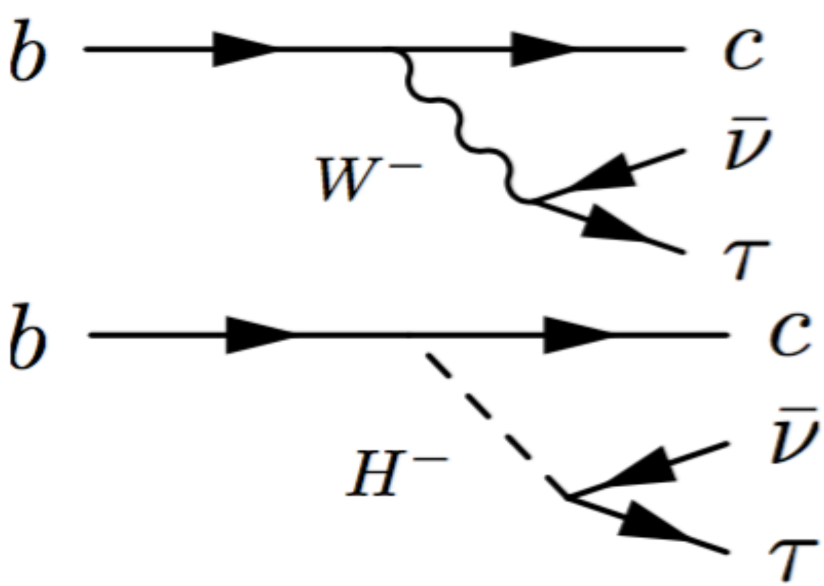
$$\sum_i |M_{\rm lepton}|^2 \propto \begin{cases} 1 & \text{for } \ell_L \\ |V^{\ell}_{R3j}|^2 & \text{for } \ell_R. \end{cases}$$

~ 1 for j = τ

rotates RH charged lepton to mass eigenstate

Very recent measurement of LHCb

$$R(J/\psi) = \frac{Br(B_c \to J/\psi\tau\nu)}{Br(B_c \to J/\psi\mu\nu)} = 0.71 \pm 0.17 \pm 0.18.$$



It is 2σ away from the SM predictions

$B \to \tau\ \nu$

CKMfitter

$$\mathcal{B}(B^+ \to \tau^+\nu) = \begin{cases} \text{with meas.} & 0.851^{+0.035}_{-0.038} \times 10^{-4} \\ \text{without} & 0.821^{+0.034}_{-0.028} \times 10^{-4} \end{cases}$$

Heavy Flavor Averaging Group - October 2016

Compilation of B^+ and B^0 Leptonic Branching Fractions ($\times 10^{-6}$) - UL at 90% CL

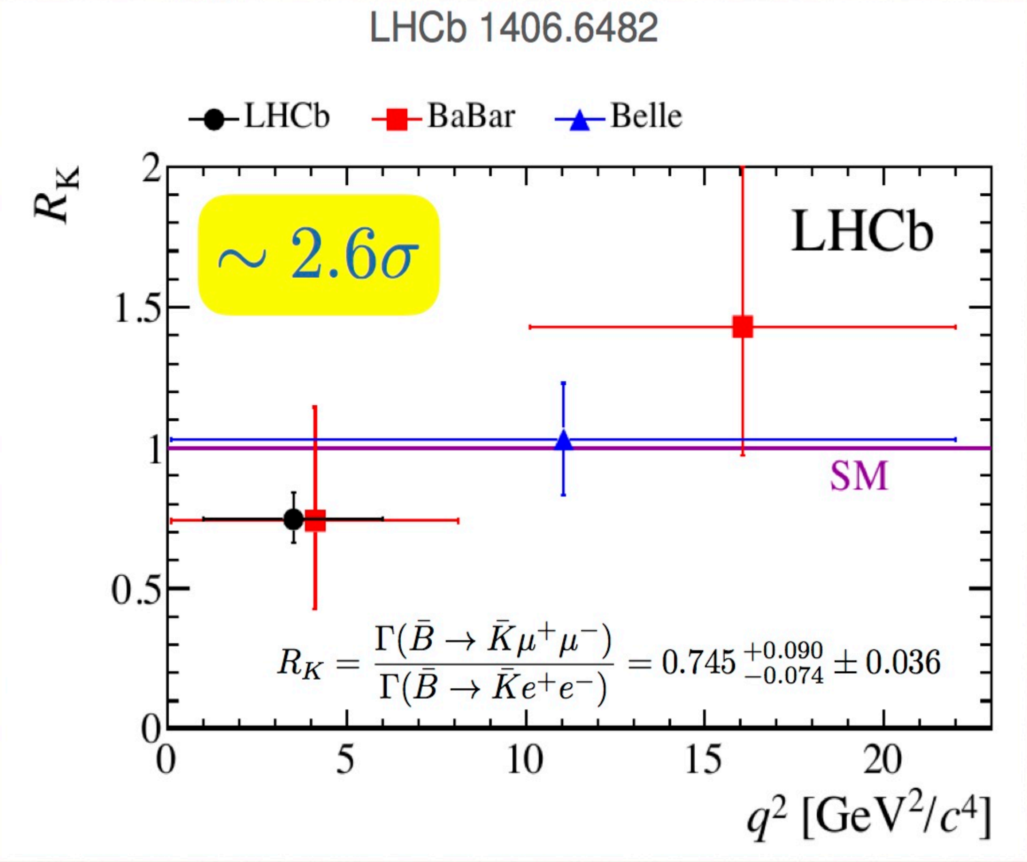
In PDG2014 New since PDG2014 (preliminary) New since PDG2014 (published)

Mode	PDG2014 Avg.	BABAR	Belle
$e^+\nu$	< 0.98	< 1.9	< 0.98 †
$\mu^+\nu$	< 1.0	< 1.0	< 1.7 †
$\tau^+\nu$	114 ± 27	179 ± 48 ‡	$91 \pm 19 \pm 11$ ‡

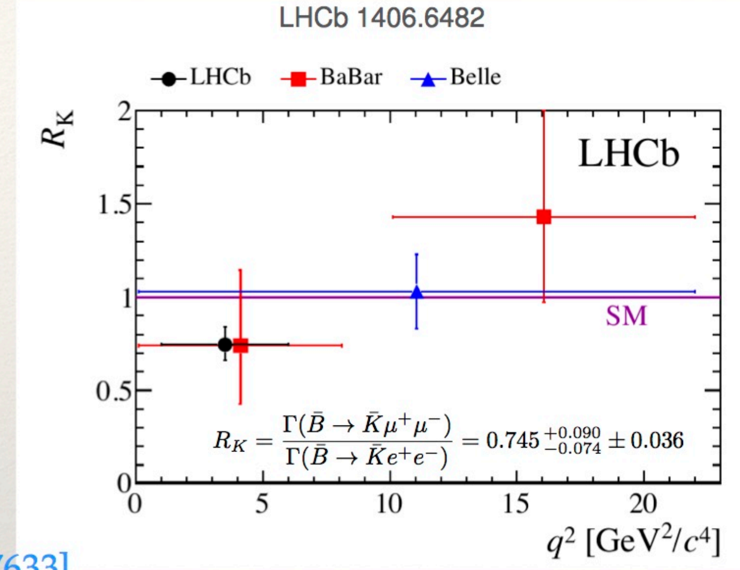
$$\frac{\Gamma(B^- \to \tau^-\nu)}{\Gamma(B^- \to \tau^-\nu_\tau)_{SM}} = F^u_{W'} - 2\ F^u_{\text{Mix}} \quad \sim 1.3 \quad \text{with} \frac{V_{Rub}}{V_{ub}} \sim \frac{V_{Rcb}}{V_{cb}}$$

Non-universal B→ K μμ / ee rates

- LHCb observation of a violation of lepton universality in the rare decays B→Kμμ vs. B→Kee — if confirmed — would be the most spectacular LHC discovery after the Higgs boson:

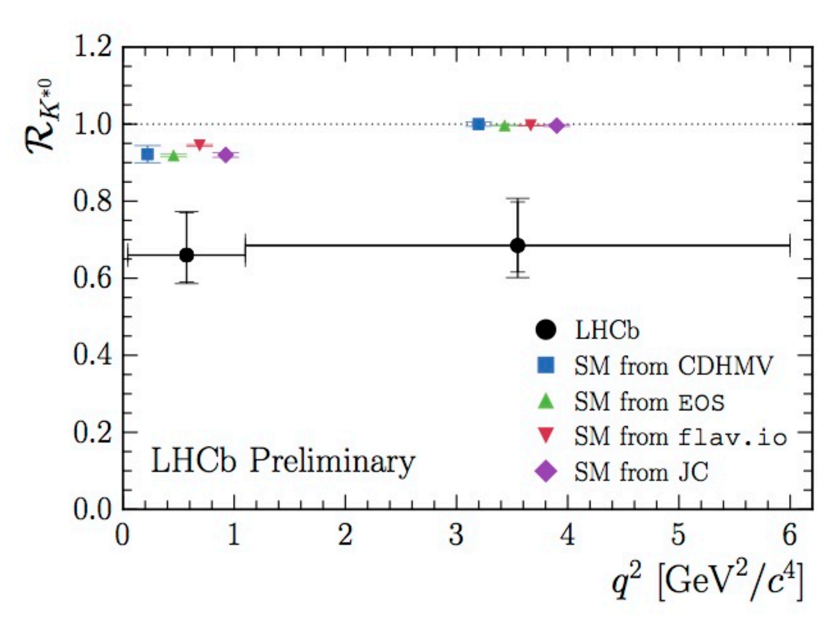


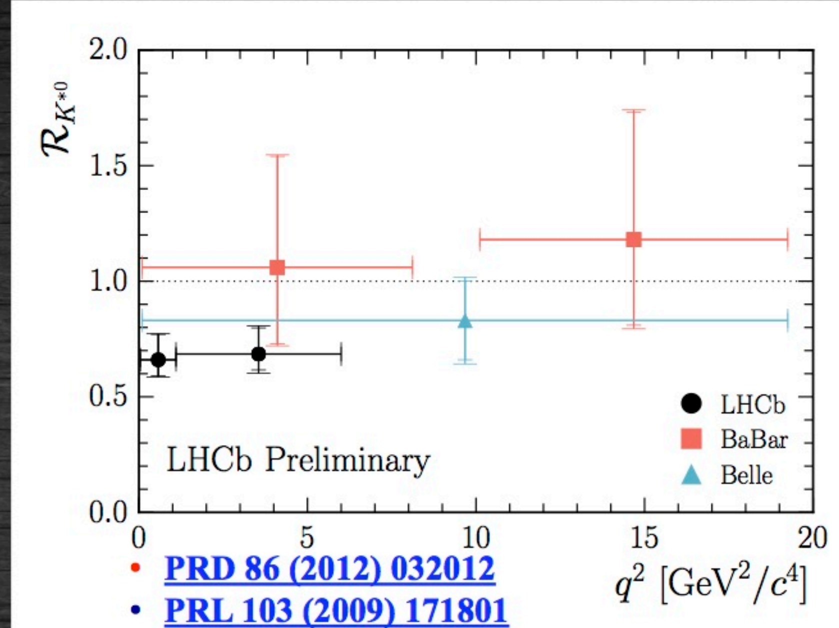
Non-universal B→ K μμ / ee rates



- In SM this ratio equals 1 to high accuracy
- Leading deviations arise from QED corrections, giving rise to large logarithms involving the ratio $m_B / m_{\mu,e}$
- The effects have been estimated and were found to be of O(1%) [Bordone, Isidori, Pattori: 1605.07633]
- SM prediction **very clean**!
- Eagerly awaiting an update from LHCb (electron reconstruction efficiency is rather different from that for muons)…
- Teaser on R_{K^*} People wait for that until two years later

Results – II

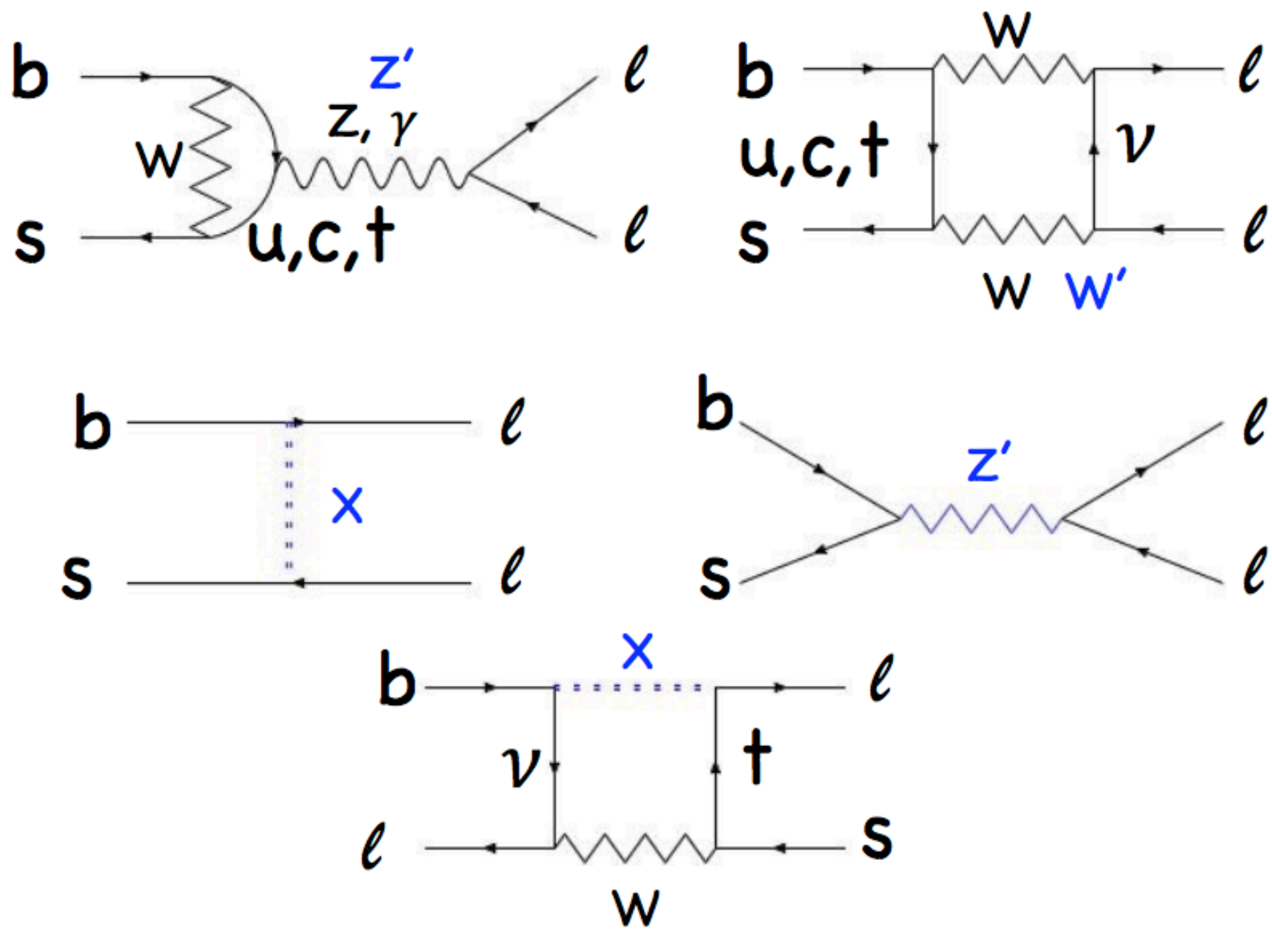




- The compatibility of the result in the **low-q^2** with respect to the SM prediction(s) is of **2.2-2.4** standard deviations
- The compatibility of the result in the **central-q^2** with respect to the SM prediction(s) is of **2.4-2.5** standard deviations

Second surprise in b→ s *l*+*l*-

apparently the μ has a weaker coupling than the electron at tree and loop level, many possible other NP couplings



Violation of lepton flavor universality

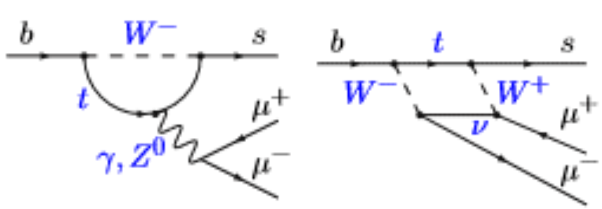
$$R(K) = \frac{BF(B \to K\mu^+\mu^-)}{BF(B \to Ke^+e^-)} \qquad R(K^*) = \frac{BF(B \to K^*\mu^+\mu^-)}{BF(B \to K^*e^+e^-)}$$

theoretically very clean!

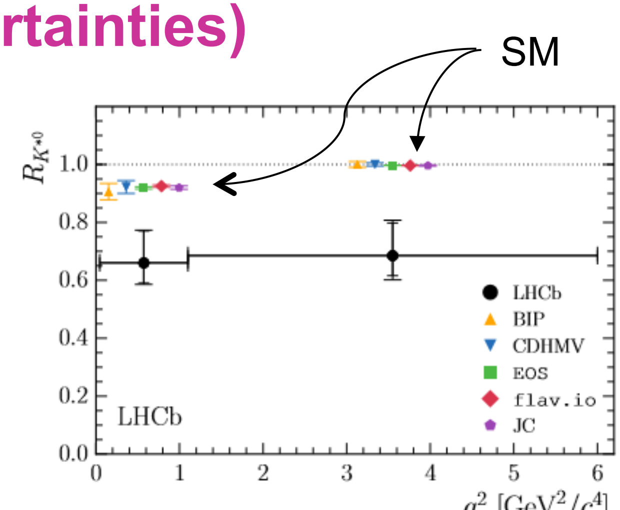
Observable	Expt (LHCb)	SM	σ
R(K), q^2=[1, 6] GeV^2	$0.745^{+0.090}_{-0.074}\pm0.036$	1.00±0.01	2.6
R(K^{*0}), q^2=[0.045, 1.1]	$0.66^{+0.11}_{-0.07}\pm0.03$	~ 0.920	2.1-2.3
R(K^{*0}), q^2=[1.1, 6]	$0.69^{+0.11}_{-0.07}\pm0.05$	~ 0.996	2.4-2.5

arXiv:1705.05802

For q^2 < 6 GeV^2, SM predictions for $b \to s\mu^+\mu^-$ consistently overshoot the data (also for $B_s \to \phi\mu^+\mu^-$, $\Lambda_b \to \Lambda\mu^+\mu^-$; both involve unknown hadronic uncertainties)



Loop, GIM, CKM suppressed



A lot of theoretical discussions

Capdevila et al [1704.05340]

Altmannshofer, Steangl, Straub [1704.05435]

D'Amico et al [1704.05438]

Hiller, Nisandzic [1704.05444]

Geng et al [1704.05446]

Ciuchini et al [1704.05447]

Celis et al [1704.05672]

Becirevic, Sumensari [1704.05835]

Cai et al [1704.05849]

Kamenik, Soreq, Zupan [1704.06005]

Sala, Straub [1704.06188]

Di Chiara et al [1704.06200]

Ghosh [1704.06240]

Alok, D. Kumar, J. Kumar, Sharma [1704.07347]

Alok et al [1704.07397]

Wang, Zhao [1704.08168]

Bonilla, Modak, Srivastava, Valle [1705.00915]

Bishara, Haisch, Monni [1705.03465]

Megias, Panico, Pujolas Quiros [1705.04822]

Tang, Wu [1705.05643]

Hurth, Mahmoudi, Santos, Neshatpour [1705.06274]

Poh, Raby [1705.07007]

Datta, Kumar, Liao, Marfatia [1705.08423]

Das, Hati, Kumar, Mahajan [1705.09188]

Bardhan, Byakti, Ghosh [1705.09305]

Matsuzaki, Nishiwaki, Watanabe [1706.01463]

Luzio, Nardecchia [1706.01868]

Chiang, He, Tandean, Yuan [1706.02696]

Chauhan, Kindr, Narang [1706.04598]

King [1706.06100]

Chivukula, Isaacson, Mohan et al [1706.06575]

Khalil [1706.07337]

He, Valencia [1706.07570]

Doršner, Fajfer, Faroughy, Košnik [1706.07779]

Buttazzo, Greljo, Isidori, Marzocca [1706.07808]

Choudhury, Kundu, Mandal, Sinha [1706.08437]

Cline, Camalich [1706.08510]

Crivellin, Mueller, Signer, Ulrich [1706.08511]

Guo, Han, Li, Liao, Ma [1707.00522]

Chen, Nomura [1707.03249]

Baek [1707.04573]

Bian, Choi, Kang, Lee [1707.04811]

$$H_{eff} \propto \frac{\alpha}{4\pi} V_{tb} V_{ts}^{*} (C_9 O_9 + C_{10} O_{10} + C'_9 O'_9 + C'_{10} O'_{10})$$

$$O_9 = (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \ell) \qquad O'_9 = (\bar{s}\gamma_\mu P_R b)(\bar{\ell}\gamma^\mu \ell)$$

$$O_{10} = (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \gamma_5 \ell) \qquad O'_{10} = (\bar{s}\gamma_\mu P_R b)(\bar{\ell}\gamma^\mu \gamma_5 \ell)$$

SM$\Rightarrow$ $C_9^{SM} \approx -C_{10}^{SM} \approx 4.2$, $C'^{SM}_9 = C'^{SM}_{10} = 0$

- **Best fit to R(K) & R(K*) in one individual WC $\Rightarrow$ NP in** C_9^μ, C_9^e, C_{10}^μ, C_{10}^e. **NP in primed operators do not play a role**

Altmannshofer et al.; Hiller et al. & many others

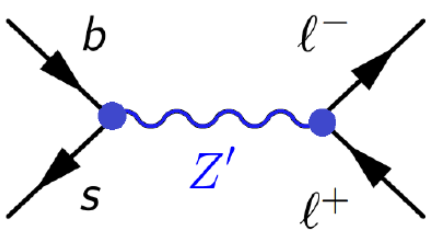
$C_{9,\mu}^{NP} \approx -C_{10,\mu}^{NP} \approx -1.3$, $C_{9,e}^{NP} \approx -C_{10,e}^{NP} \approx -1.3$

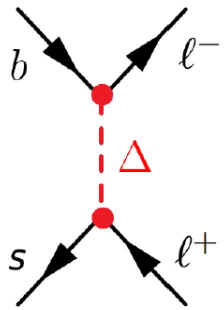
- **Global fit to angular observables of B→ K*$\mu^+ \mu^-$ and BF of** $B_s \to \phi\mu^+\mu^-$ $\Rightarrow$ **NP in** C_9^μ **favored, in** C_9^e **not favored.**

NP models capable of generating $C_{9,10}^{NP}$:

- Tree level:
  - Z', $SU(2)_L$ singlet or triplet
  - leptoquark, spin 0 or 1
  - SUSY with R-parity violating interactions

- Loop level:
  - Z' penguin
  - new heavy scalars/vectors





Flavour anomalies and New Physics

If confirmed by future analyses, what does this point to?

$R_{D^{(*)}} \quad \Leftrightarrow \quad \tau \neq e, \mu$

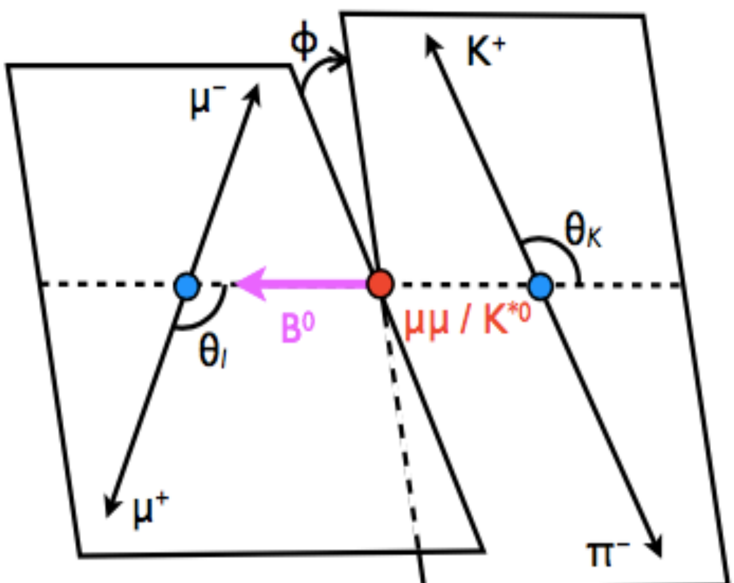
$R_K \quad \Leftrightarrow \quad \mu \neq e$

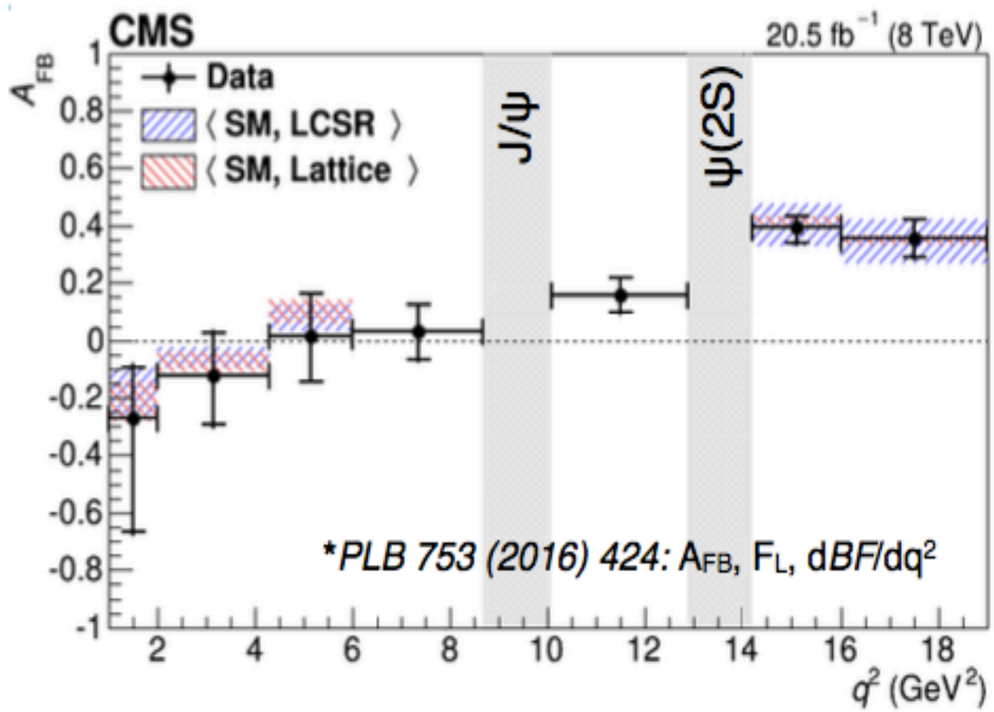
SM gauge interactions do not distinguish between different leptons, and Higgs exchange is irrelevant; hence need new particles beyond the SM with new types of interactions

- $U(1)_{\tau-\mu}$ → new Z' boson coupling with opposite sign to μ/τ
- New particles with Yukawa-like interactions, leptoquarks (better: lepto-quark-bosons)

Angular analysis of B→ K^* μμ decays

Rare B→K^*μμ decays offer a rich laboratory for new-physics searches via differential angular distributions as a functions of lepton invariant mass:





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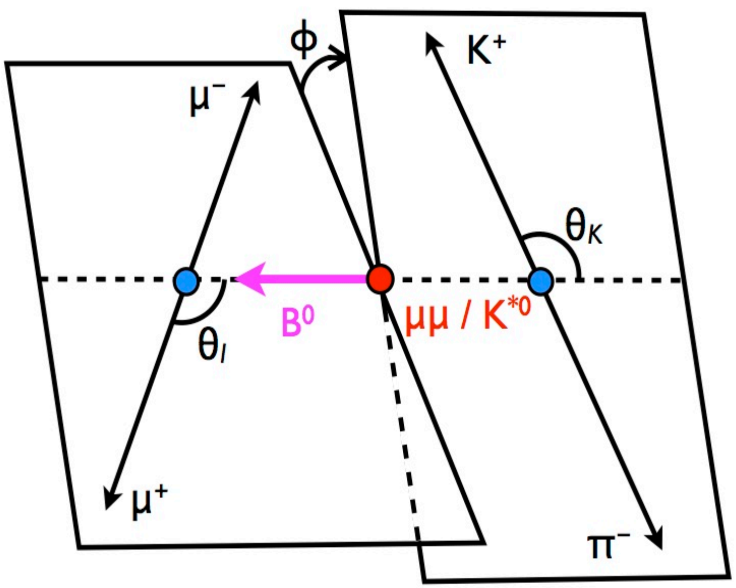


$$\frac{1}{d\Gamma/dq^2}\frac{d^4\Gamma}{dq^2\, d\cos\theta_l\, d\cos\theta_K\, d\phi} = \frac{9}{8\pi}\left\{\frac{2}{3}\left[(F_S + A_S\cos\theta_K)(1-\cos^2\theta_l) + A_S^5\sqrt{1-\cos^2\theta_K}\sqrt{1-\cos^2\theta_l}\cos\phi\right] + (1-F_S)\left[2F_L\cos^2\theta_K(1-\cos^2\theta_l) + \frac{1}{2}(1-F_L)(1-\cos^2\theta_K)(1+\cos^2\theta_l) + \frac{1}{2}P_1(1-F_L)(1-\cos^2\theta_K)(1-\cos^2\theta_l)\cos 2\phi + 2P_5'\cos\theta_K\sqrt{F_L(1-F_L)}\sqrt{1-\cos^2\theta_K}\sqrt{1-\cos^2\theta_l}\cos\phi\right]\right\}$$

S-wave and S&P-wave interference

P-wave

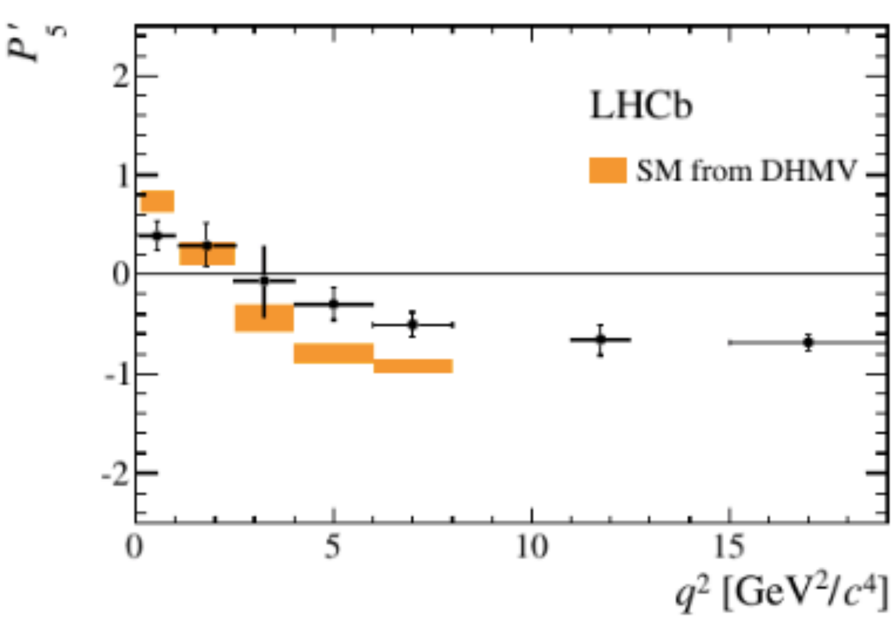
Angular analysis of B→ K* μμ decays

It is useful to construct observables which are less sensitive for hadronic uncertainties related to form factors

[Descotes-Genon, Matias, Ramon, Virto: 1207.2753]

One particular such observable — called P_5' — shows a large discrepancy with the SM prediction in a particular q^2 range:

LHCb 1512.04442



2.8σ deviation in q^2 bin between [4, 6] GeV^2
(3.0σ in bin [6, 8] GeV^2)

Global fits

- from J. Matias, Moriond EW 2017:

Global analysis of $b \to s\mu\mu$ anomalies

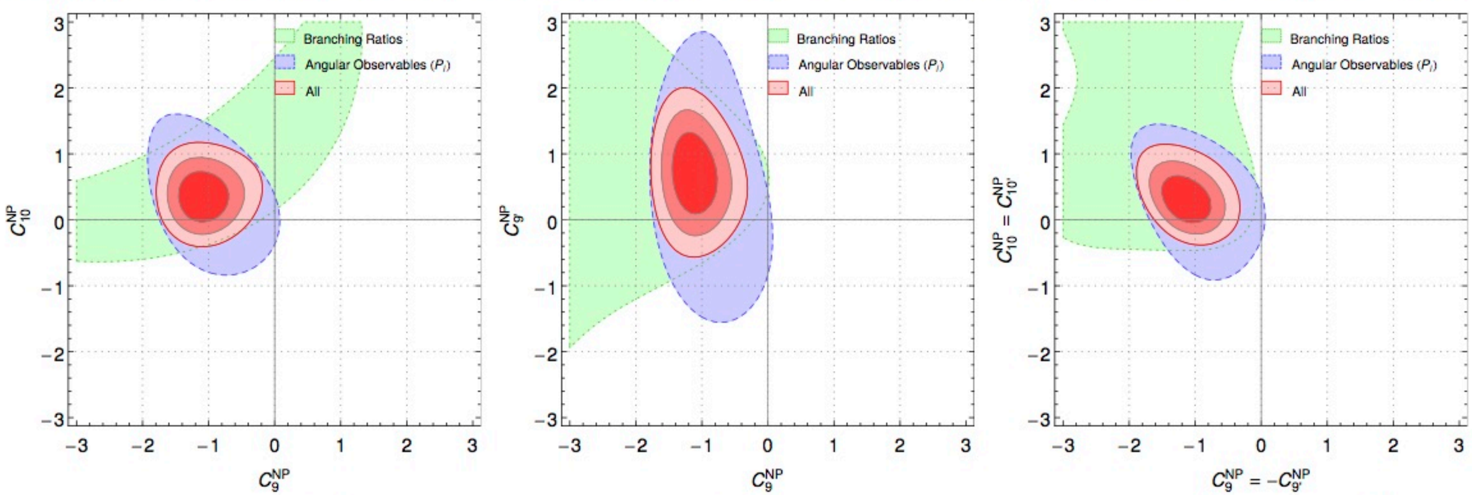
[Descotes, Hofer, JM, Virto]

96 observables in total (LHCb for exclusive, no CP-violating obs)

- $B \to K^*\mu\mu$ ($P_{1,2}$, $P'_{4,5,6,8}$, F_L in 5 large-recoil bins + 1 low-recoil bin)+available electronic observables.
- $B_s \to \phi\mu\mu$ (P_1, $P'_{4,6}$, F_L in 3 large-recoil bins + 1 low-recoil bin)
- $B^+ \to K^+\mu\mu$, $B^0 \to K^0\ell\ell$ (BR) ($\ell = e, \mu$)
- $B \to X_s\gamma$, $B \to X_s\mu\mu$, $B_s \to \mu\mu$ (BR), $B \to K^*\gamma$ (A_I and $S_{K^*\gamma}$)

Beyond 1D several favoured scenarios

Allowing for more than one Wilson coefficient to vary different scenarios with pull-SM beyond 4σ pop-up:



(C_9, C_{10}) (C_9, C'_9) $(C_9 = -C'_9$ & $C_{10} = C'_{10})$

- BR and angular observables both favour $C_9^{\rm NP} \simeq -1$ in all 'good scenarios'.

best 2 parameter fit

- looks like fits prefer left-handed structure
- –previous model not favoured in this case?
- –tree-level FCNC are right-handed
- –one loop corrections of electroweak strength are left -handed also, could give the right size
- –full model is very complicated and would need a multi (>2) C_i fit
- another non-universal Z' that is left handed

$B \to K\pi$ puzzle

- $K^+\pi^-$ and $K^+\pi^0$ differ by subleading amplitudes P_{ew} and C.

  Their CP asymmetries are expected to be similar.

$$A(B_d^0 \to K^+\pi^-) = -P'\left(1 + \frac{T'}{P'}e^{i\phi_3}\right),$$

$$\sqrt{2}A(B^+ \to K^+\pi^0) = -P'\left[1 + \frac{P'_{ew}}{P'} + \left(\frac{T'}{P'} + \frac{C'}{P'}\right)e^{i\phi_3}\right]$$

- The experimental data differ by **5σ! A puzzle!**

$A_{CP}(K^+pi^-) = (-9.7 \pm 1.2)\%$

$A_{CP}(K^+pi^0) = (4.7 \pm 2.6)\%$

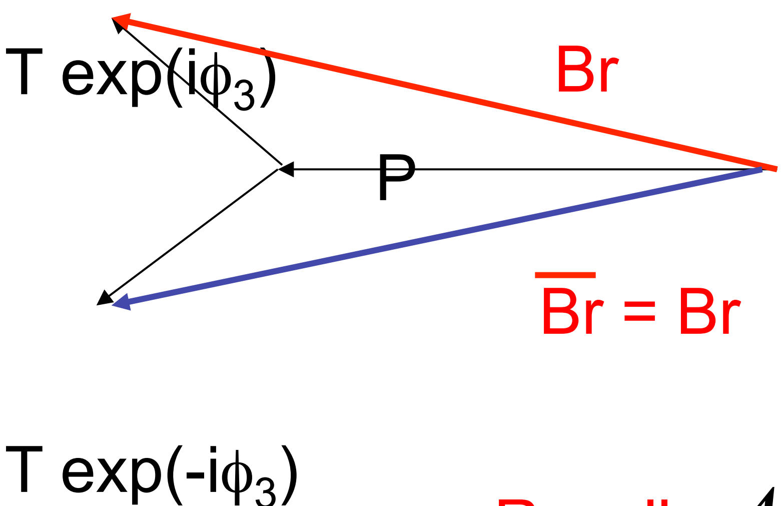
$$\frac{T'}{P'} \sim \lambda\,, \quad \frac{P'_{ew}}{P'} \sim \lambda\,, \quad \frac{C'}{P'} \sim \lambda^2$$

↑

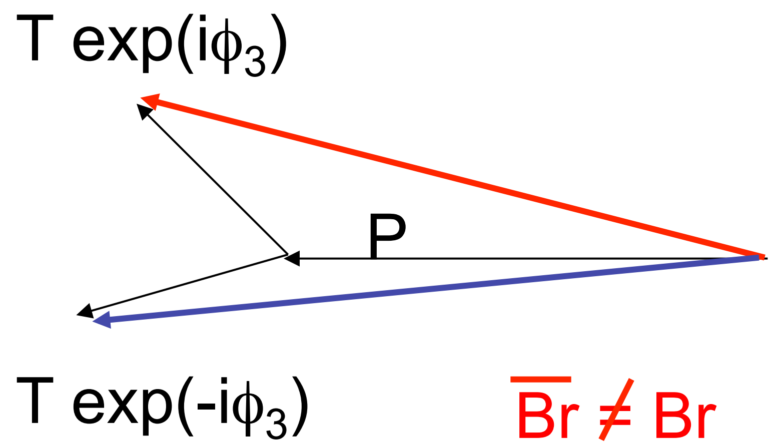
$(C_2/C_4)(V_{us}V_{ub}/V_{ts}V_{tb})$» $(1/\lambda^2)(\lambda^5/\lambda^2)$» λ

Direct CP violation

If $\delta_T=0$



If $\delta_T\neq 0$



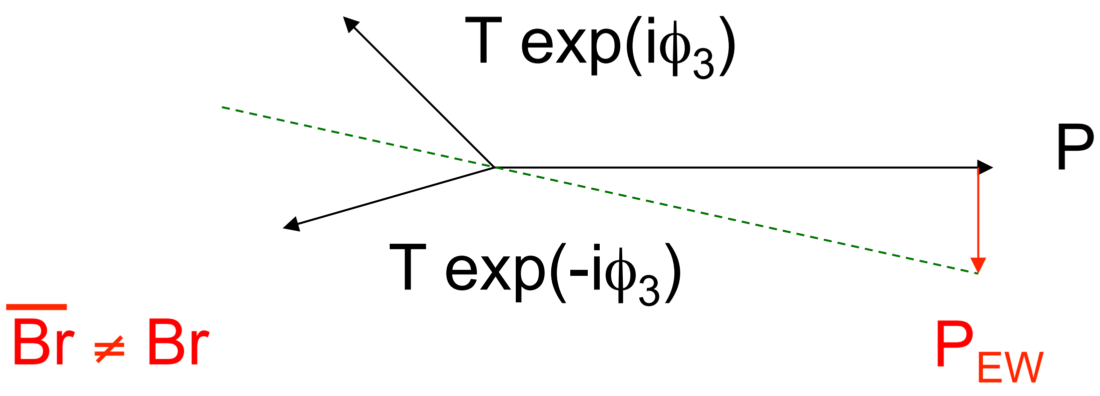
$\overline{Br} \neq Br$

Direct ~~CP~~

Recall $A_{CP} \propto \sin\delta \sin\phi$

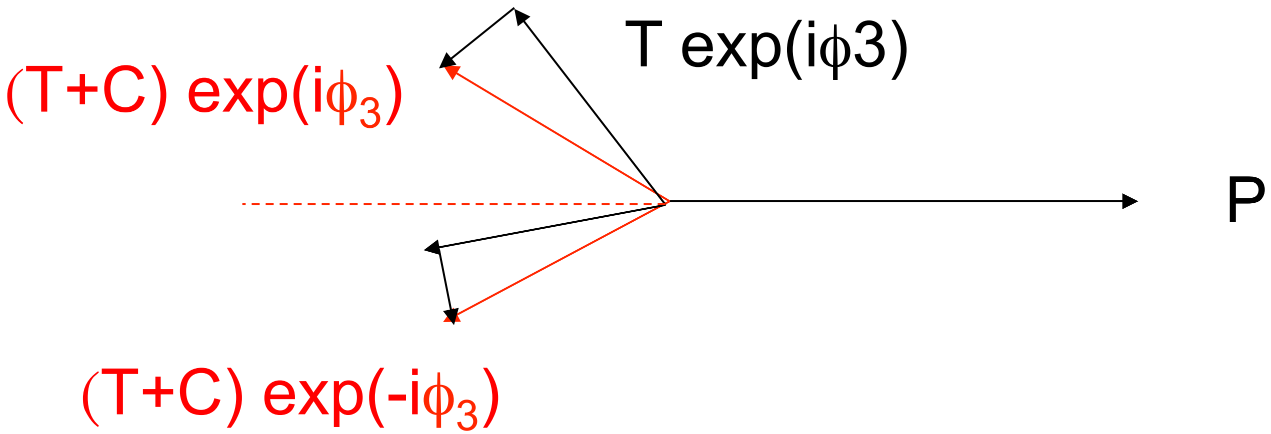
Explanation 1

- **Large $K^+\pi^-$ CP implies large δ_T**
- **Large P_{EW} to cancel its effect (Buras, Yoshikawa et al.) in $K^+\pi^0$ new physics?**



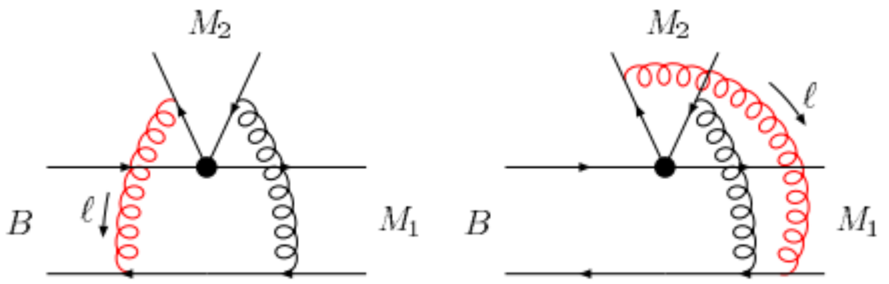
Explanation 2

- **Or large C (with large strong phase) to cancel its effect (Charng and Li; He and McKellar) in $K^+\pi^0$) mechanism missed in SM calculation?**



Color suppressed tree diagram (a_2) is too small, without big strong phase in perturbative QCD calculations

- However, NLO diagrams related to nonfactorizable amplitudes contributing to Glauber divergence



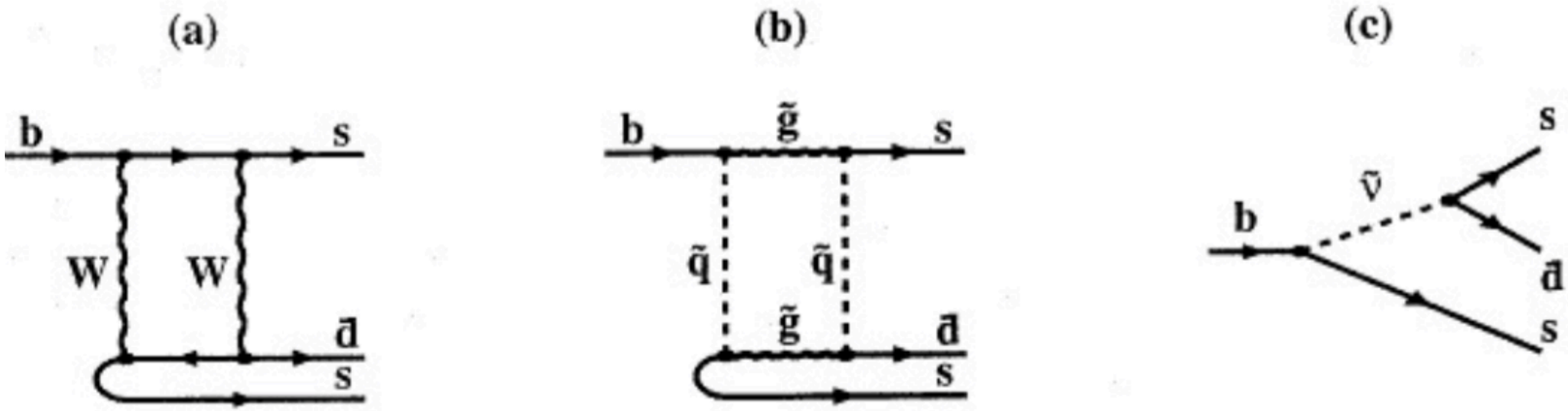
H.-n. Li and S. Mishima, PRD 83, 034023 (2011).

- Collinear region $(l^+, l^-, l_T) \sim (Q, m^2/Q, m)$
- Soft region ~ (m,m,m)
- Glauber region $\sim (m^2/Q, m^2/Q, m)$

- **Resummation of the large logarithms give a jet function, which has a large strong phase**

Search for new physics in hadronic B decays - 1 example

K. Huitu, C.D. Lü, P. Singer D.X. Zhang, **Phys. Rev. Lett. 81, 4313 (1998), hep-ph/9809566.**



$b \to ss\bar{d}$ transition (a) SM, (b) MSSM, (c) MSSM with R-parity violating coupling

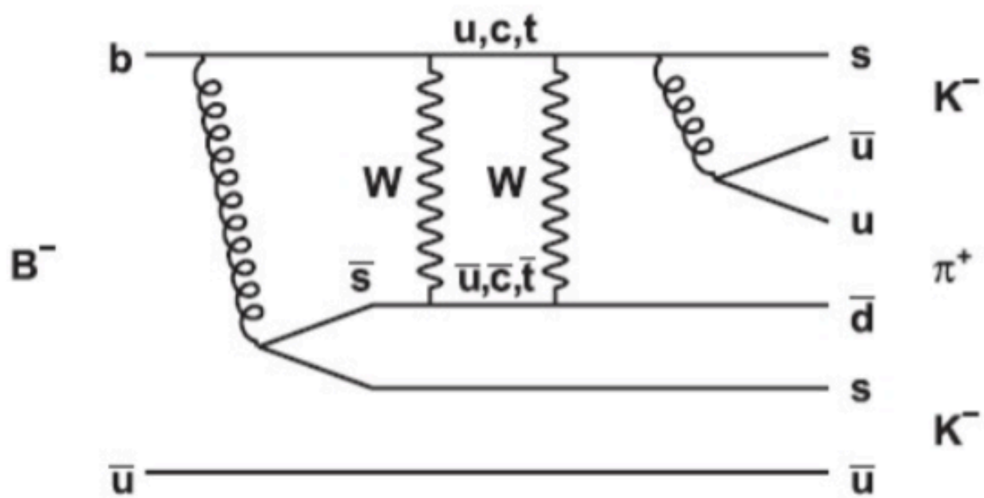
SM BRs: ~ 10 $^{-14}$,

Some New physics can reach 10 $^{-6}$

Experimental search starting from OPAL @ LEP, phys. Lett. B 476 (2000) 233, later searched also by Belle/Babar

BABAR collaboration, Phys. Rev. D 78 (2008) 091102 [arXiv:0808.0900]

A search for the decay $B^- \to K^- K^- \pi^+$, Using a sample of $(467 \pm 5) \times 10^6$ $B\overline{B}$ pairs collected with the BABAR detector.



Result : No evidence for these decays was found and a upper limit was set as

$$\mathcal{B}(B^- \to K^- K^- \pi^+) < 1.6 \times 10^{-7}$$

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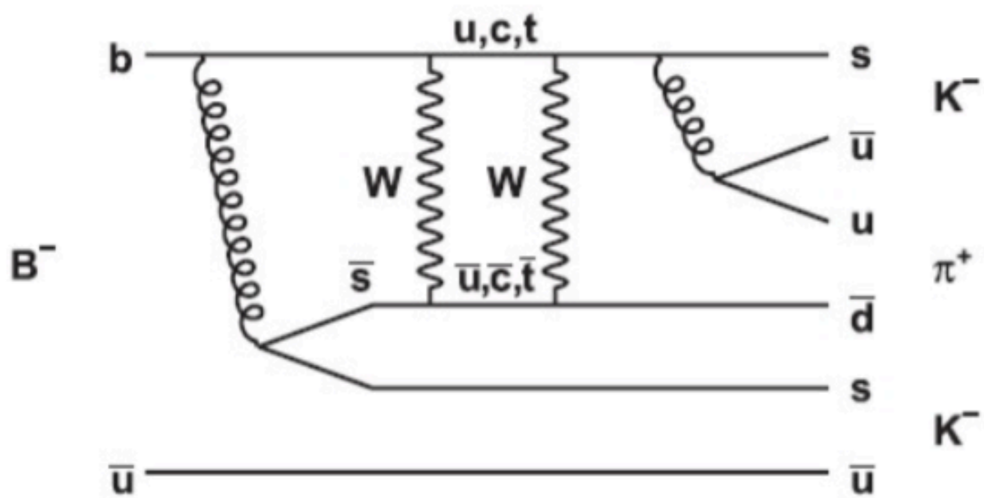


Similar channel $B^- \to \pi^- \pi^- K^+$

Result : No evidence for these decays was found and a upper limit was set as

$$\mathcal{B}(B^- \to K^- K^- \pi^+) < 1.6 \times 10^{-7}$$

Recent LHCb result:

Physics Letters B 765 (2017) 307–316

$$\mathcal{B}(B^+ \to K^+K^+\pi^-) < 1.1 \times 10^{-8}$$

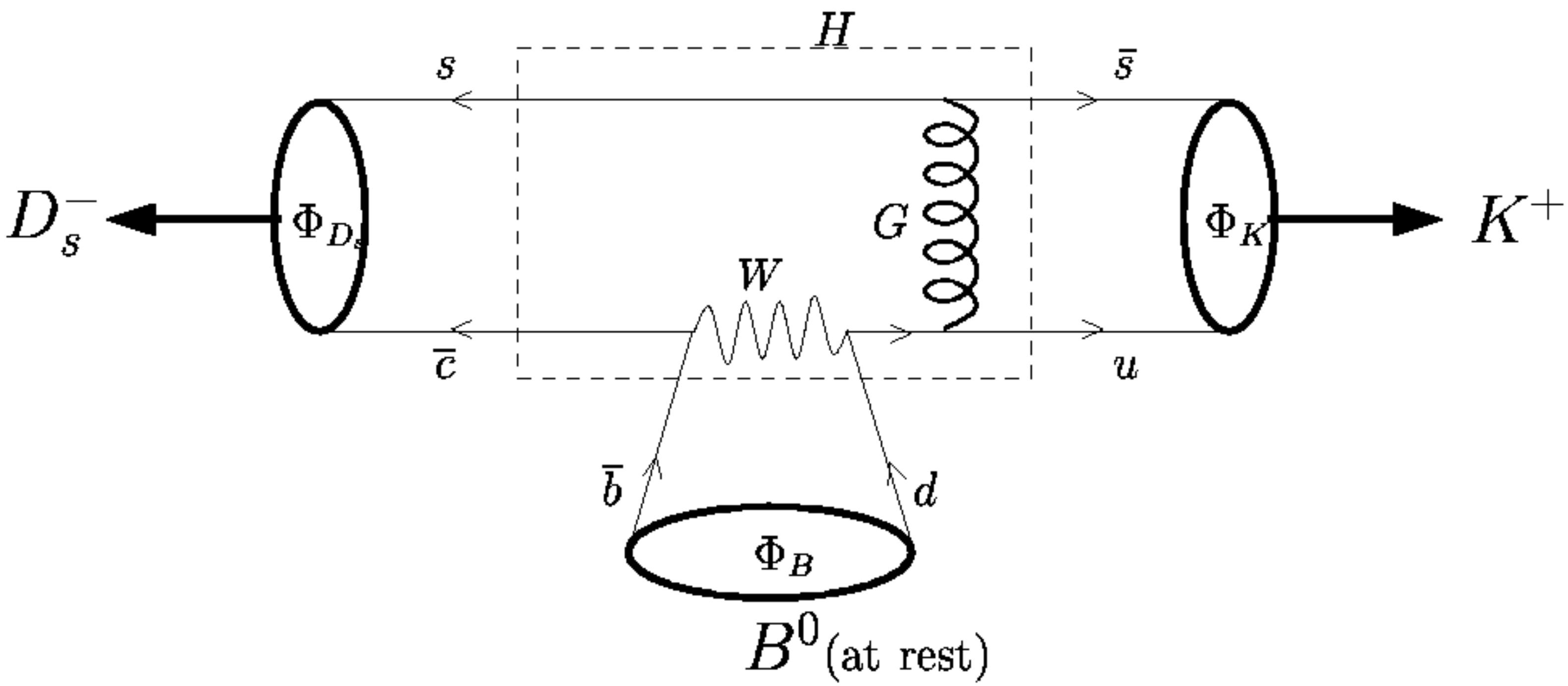
$$\mathcal{B}(B^+ \to \pi^+\pi^+K^-) < 4.6 \times 10^{-8}.$$

Recent theoretical results in Randall-Sundrum model:

Chinese Physics C41 (2017) 053106

Br(b→ss d-bar) can reach to 10^{-10}

Pure annihilation type decay:
PQCD Picture of $B^0 \to D_S^- K^+$



Six quark interaction inside the dashed line

W exchange process

Theoretical Results:

$$Br(B^0 \to D_S^- K^+) = (4.6^{+0.8}_{-0.6}) \times 10^{-5}$$

$$Br(B^0 \to D_S^{*-} K^+) = (2.7 \pm 0.6) \times 10^{-5}$$

Reported by Ukai in BCP4 (2001) before Exps:

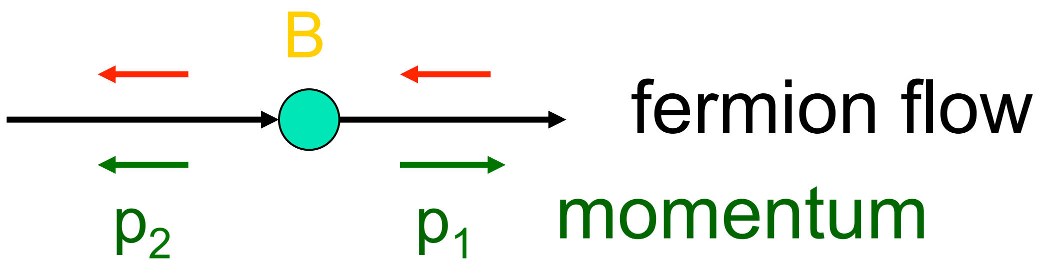
Lü, Ukai, hep-ph/0210206

$$Br(B^0 \to D_S^- K^+) = (4.6^{+1.2}_{-0.6} \pm 1.3) \times 10^{-5}, Belle$$

$$Br(B^0 \to D_S^- K^+) = (3.2 \pm 1.0 \pm 1.0) \times 10^{-5}, BaBar$$

Helicity suppressed: pseudo-scalar decays to two massless quarks

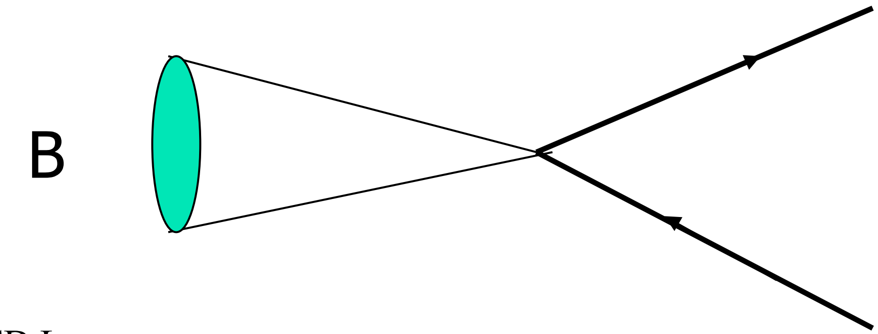
spin (this configuration is not allowed)



Like $B \to e\ \nu_e$

pseudo-scalar B requires spins in opposite directions, namely, helicity conservation

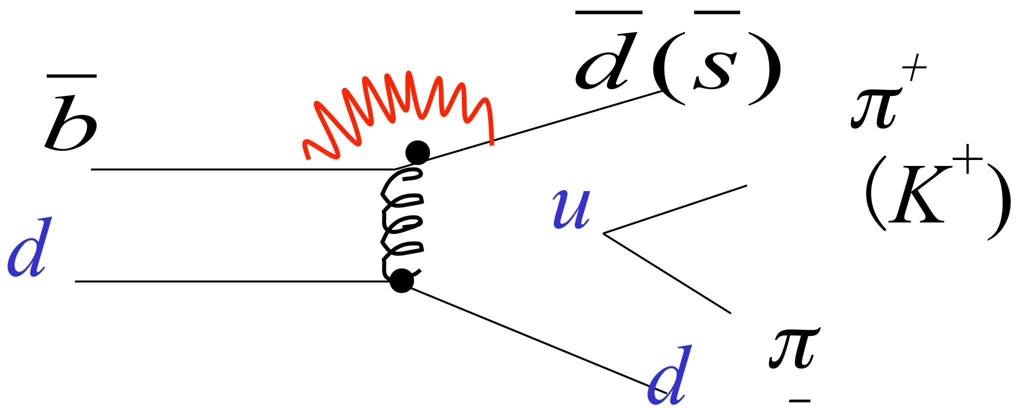
Annihilation suppression $\sim 1/m_B \sim 10\%$



For (V-A)(V-A), left-handed current

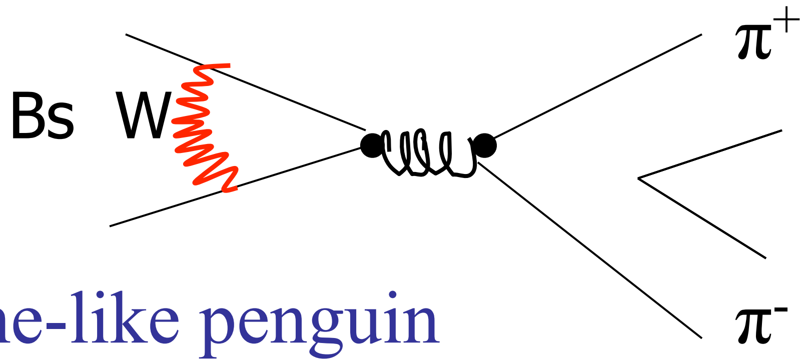
No suppression for O$_6$

- **Space-like penguin**
- **Become (s-p)(s+p) operator after Fiertz transformation   Chirally enhanced**
- **No suppression, contribution "big" (20-30%)**



Pure annihilation type decay $B_s \to \pi^+\pi^-$

- **Very rare decay predicted in PRD76, 074018 (2008)**
- **BR=$(5.7 \pm 1.7)\times10^{-7}$**
- **No one expected to be measured**

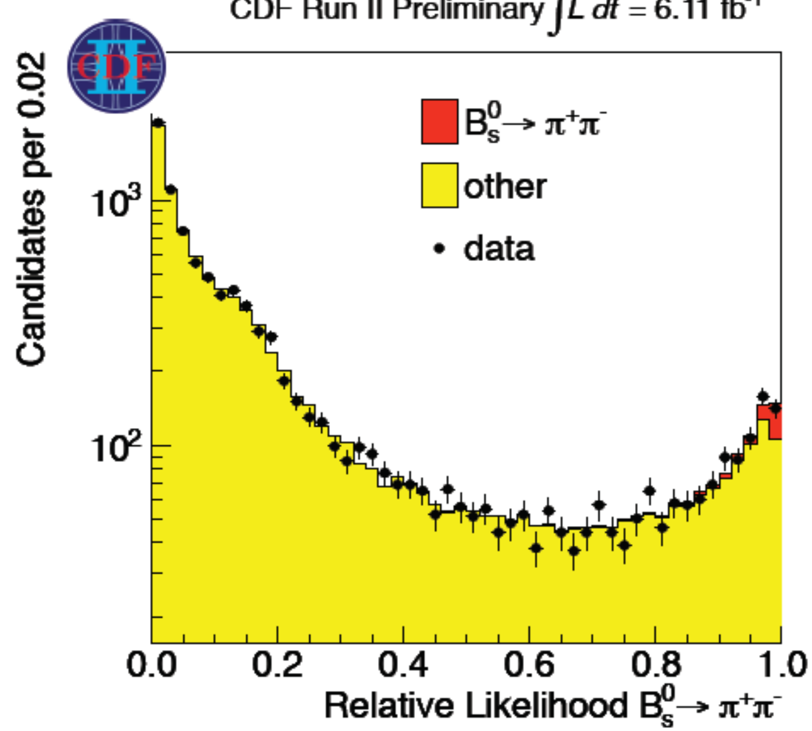


Time-like penguin

CDF Results

F.Ruffini, 1107.5760ex

First evidence: $B^0{}_s \to \pi^+\pi^-$



$$\frac{f_s}{f_d} \times \frac{\mathcal{B}(B_s^0 \to \pi^+\pi^-)}{\mathcal{B}(B^0 \to K^+\pi^-)} = 0.008 \pm 0.002\ (stat.)\ \pm 0.001\ (syst.).$$

$$\mathcal{B}(B_s^0 \to \pi^+\pi^-) = (0.57 \pm 0.15\ (stat.) \pm 0.10\ (syst.)) \times 10^{-6}.$$

Agreement with pQCD: $0.57^{+0.18}_{-0.16}$ PRD 76, 074018(2008), and 0.42± 0.06 from Y Li et al., PRD 70, 034009 (2004)

F. Ruffini 19

Summary

- Some flavor anomalies have been discussed
- The tension between SM and experiments at the level of **3σ level**
- Theoretical study of non-leptonic D/B meson decays making great improvement with helping from rich experimental data
- **Flavor sector has only been tested at the 10% level and can be done much better**
- **We are still waiting for a clear New physics signal in the heavy flavor sector**

Thanks !