

BSM physics at LHCb

LHCb UK student meeting

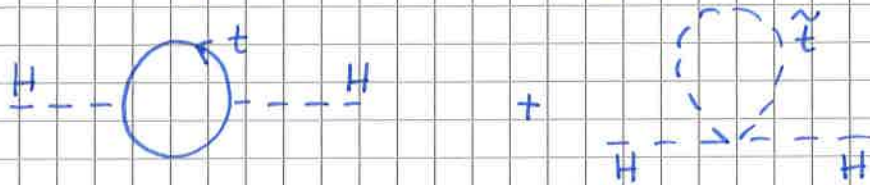
April 14, 2014

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1. Why BSM physics at LHCb?

Why BSM physics?

- hierarchy problem, stability of electroweak scale



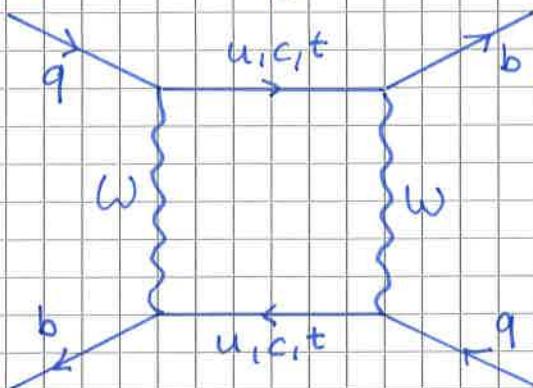
cancellation of quadratic divergence requires new particles around the TeV scale

- BUT so far nothing found in direct searches
are we looking in the wrong channels?
or is the new physics just a bit too heavy?

↳ we need complementary searches!

Flavour changing neutral current (FCNC) transitions in the SM are strongly suppressed

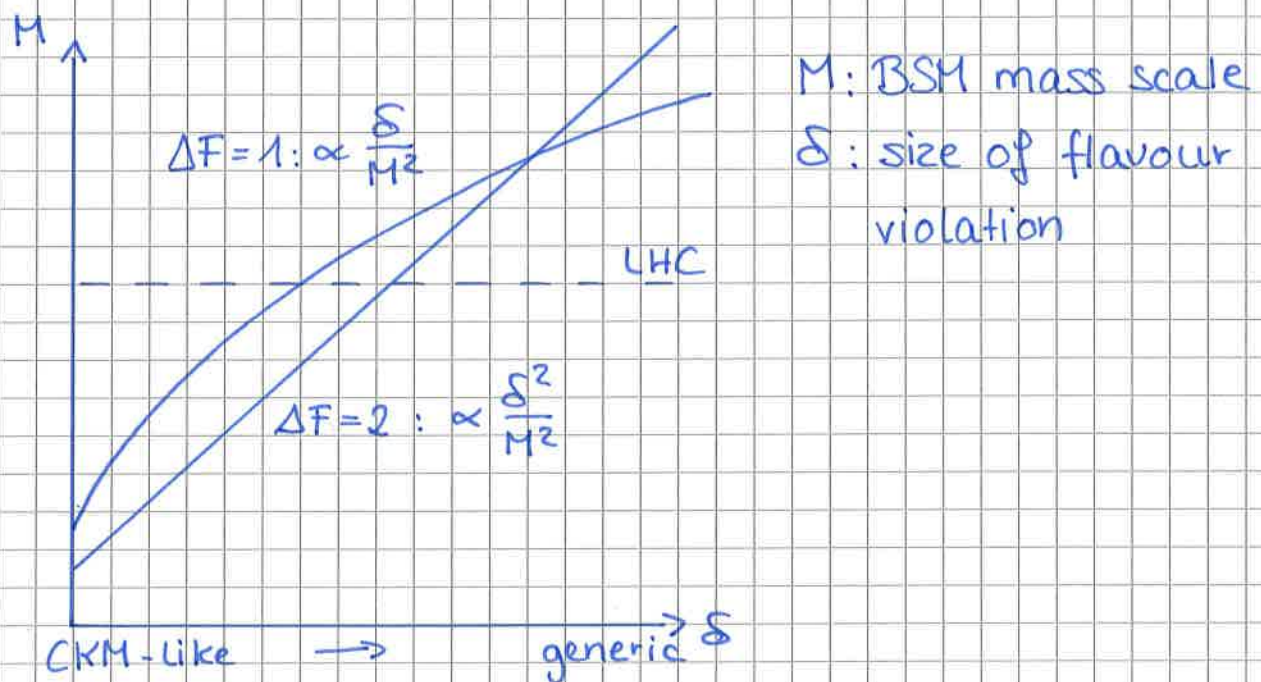
e.g. $B_q - \bar{B}_q$ mixing



- arise only at the Loop level
- proportional to off-diagonal elements of CKM matrix
 $V_{td}^* V_{tb} \sim 10^{-2}$ $V_{ts}^* V_{tb} \sim 4 \cdot 10^{-2}$
- unitarity of CKM ~~matrix~~ and smallness of most quark masses (except m_t) \rightarrow GIM mechanism
- mediated only by left-handed interactions (W couplings)

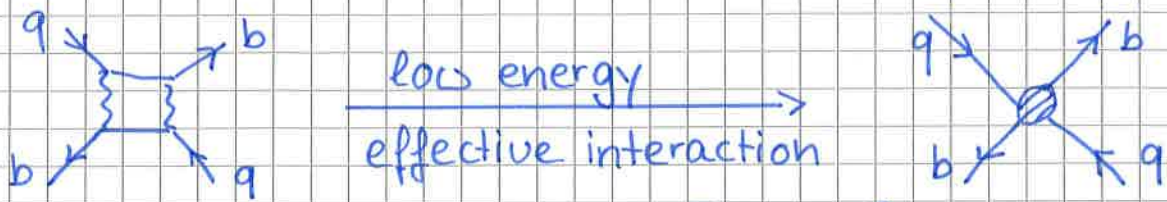
Any of these conditions could be violated by BSM physics!
 \Rightarrow FCNCs are very sensitive to new particles and interactions

more sensitive than direct searches?

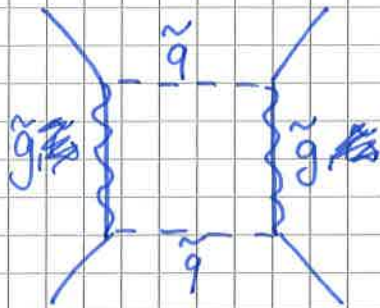


flavour observables - in particular meson-antimeson mixing - can probe much larger mass scales!

2. $B_{d,s} - \bar{B}_{d,s}$ mixing ($q = d, s$)

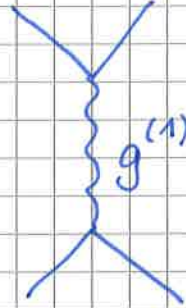


SM



SUSY

squarks + gauginos



extra dimensions

Kaluza-Klein modes

describe effective interaction by effective Hamiltonian

$$\mathcal{H}_{\text{eff}} \sim (V_{tb}^* V_{tq})^2 \sum_i C_i O_i$$

CKM elements

effective 4 fermion operators $(\bar{b}q)(\bar{b}q)$ with different Dirac structures

Wilson coefficients:
coupling strength in the eff. theory;

determined by short-distance physics

↳ sensitive to BSM contributions

eff. Hamiltonian determines time evolution

$$i \frac{d}{dt} \begin{pmatrix} |B_q(t)\rangle \\ |\bar{B}_q(t)\rangle \end{pmatrix} = \begin{pmatrix} M_q - \frac{i}{2} \Gamma_q & M_{12}^q - \frac{i}{2} \Gamma_{12}^q \\ M_{12}^{q*} - \frac{i}{2} \Gamma_{12}^{q*} & M_q - \frac{i}{2} \Gamma_q \end{pmatrix} \begin{pmatrix} |B_q(t)\rangle \\ |\bar{B}_q(t)\rangle \end{pmatrix}$$

sensitive to new physics:

$$M_{12}^q = \frac{1}{2m_B} \langle \bar{B}_q | \mathcal{H}_{\text{eff}} | B_q \rangle^*$$

$$\hookrightarrow M_{12}^q \sim (V_{tb} V_{tq}^*)^2 \sum_i C_i \langle O_i \rangle$$

↑ non-perturbative physics

mass eigenstates

$$|B_q^{L,H}\rangle = p |B_q\rangle \pm q |\bar{B}_q\rangle$$

Lattice QCD

main th. uncertainty

Physical observables

$$\rightarrow \text{mass difference } \Delta M_q = M_H^q - M_L^q = 2 |M_{12}^q|$$

$$- \text{width difference } \Delta \Gamma_q = \Gamma_H^q - \Gamma_L^q = 2 |\Gamma_{12}^q| \cos \phi_q$$

(less sensitive to BSM physics)

$$\rightarrow \text{mixing phase - CP violation: } \phi_q = \arg(-M_{12}^q / \Gamma_{12}^q)$$

status of ΔM_q

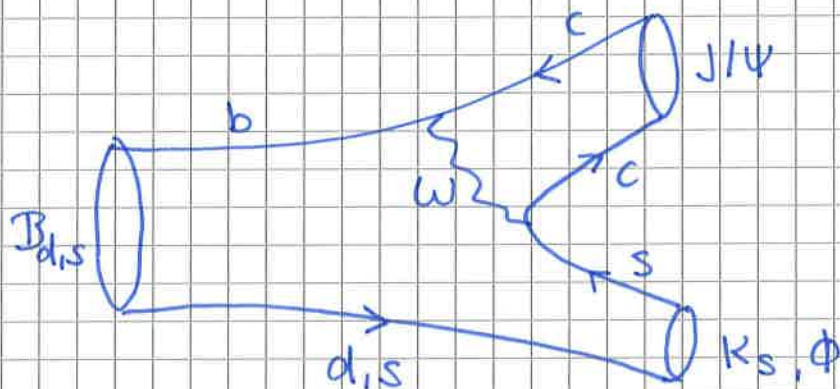
- precisely measured
- good agreement with SM
- dominated by large theory uncertainties
 - ↳ 20-30% BSM contribution still allowed

future progress needed

- more precise lattice calculations of relevant matrix elements
- also better determination of CKM parameters from tree level decays ($\gamma, |V_{ub}| \dots$)

Measuring CP violation: ϕ_d and ϕ_s

golden modes $B_d \rightarrow J/\psi K_s$ and $\bar{B}_s \rightarrow J/\psi \phi$



↳ time dependent CP asymmetry, e.g.

$$A_{CP}^{J/\psi K_s}(\pm) = \frac{\Gamma(B_d(\pm) \rightarrow J/\psi K_s) - \Gamma(\bar{B}_d(\pm) \rightarrow J/\psi K_s)}{\Gamma(B_d(\pm) \rightarrow J/\psi K_s) + \Gamma(\bar{B}_d(\pm) \rightarrow J/\psi K_s)}$$
$$= C_{\psi K_s} \cos \Delta M_d t + S_{\psi K_s} \sin \Delta M_d t$$

$S_{\psi K_s}$: interference between CP violation in mixing and decay

hadronic uncertainties mostly cancel in \mathcal{U}_{CP}

$$S_{\psi K_S} = \sin(\phi_d^{c\bar{c}s}) = \sin(2\beta + \phi_d^{BSM})$$

↑ CKM phase ↑ BSM phase

similarly for $B_s \rightarrow J/\psi \phi$

...

$$S_{\psi\phi} = \sin(2|\beta_s| - \phi_s^{BSM})$$

Status:

- data shows good agreement with SM prediction
- still quite some room for BSM physics, in particular in ϕ_s

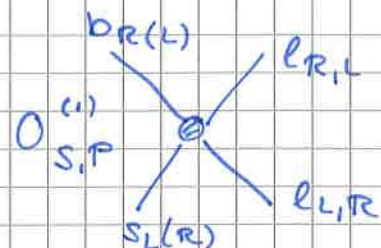
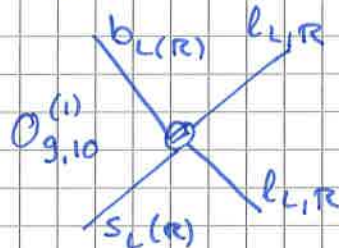
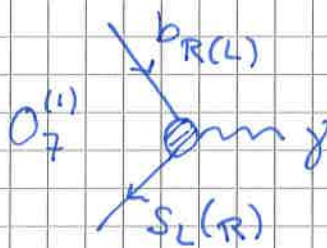
↳ We're eagerly waiting for an update with the full 2012 data set!

3. New physics in rare $b \rightarrow s$ decays

lots of $b \rightarrow s$ transitions that are sensitive to BSM physics

- hadronic: $B \rightarrow \Phi K, B \rightarrow \eta' K, B \rightarrow K\pi, B \rightarrow KK, \dots$
- radiative: $B \rightarrow X_s \gamma, B \rightarrow K^* \gamma, B_s \rightarrow \Phi \gamma, \dots$
- semi-leptonic: $B \rightarrow X_s \ell \ell, B \rightarrow K \ell \ell, B \rightarrow K^* \ell \ell, \dots$
- leptonic: $B_s \rightarrow \mu \mu$
 $B \rightarrow K \nu \bar{\nu}, B \rightarrow K^* \nu \bar{\nu}$

at the level of the Λ low energy effective theory
(heavy particles integrated out)



sensitivity of different decays

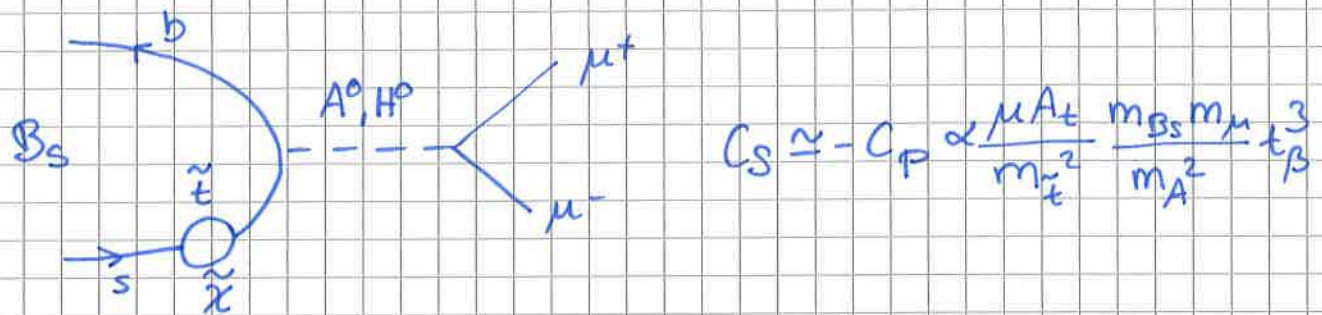
	$O_7^{(1)}$	$O_9^{(1)}$	$O_{10}^{(1)}$	$O_{S,P}^{(1)}$
$B \rightarrow X_s \gamma, K^* \gamma$	x			
$B \rightarrow X_s \ell \ell$	x	x	x	
$B \rightarrow K^{(*)} \ell \ell$	x	x	x	
$B_s \rightarrow \mu \mu$			x	x

↳ complementarity!

different BSM models contribute to different eff. operators
ambiguities can be resolved by global analysis

example: SUSY contribution to $O_{S,P}$

↳ generated by heavy Higgs exchange



huge enhancement possible for large $\tan \beta$!

→ data rule out large $\tan \beta$ if Higgs spectrum (H^0, A^0) is light

however, many models (e.g. composite Higgs, extra dim.) do not generate (pseudo)scalar operators

↳ data just start to probe these models
more precision needed

example: new physics in $B \rightarrow K^* \mu \mu$?

discrepancy in angular observable P'_S

↳ can be shown: BSM needed $C_g^{NP} \approx -C_g^I \approx -1$

which model? - SUSY: no, small effect

- comp. Higgs: — " —

- Z' boson: possible, but not very

well-motivated scenario

or: statistical fluctuation? → please ~~update~~ update result

with full dataset!

QCD corrections larger than expected?

Summary

- FCNC transitions strongly suppressed in the SM
 - ↳ very sensitive to BSM physics
 - complementary to direct searches at high p_T
- meson - antimeson mixing in good agreement with SM
 - ~30% BSM contribution still possible
 - improvements: th. prediction for matrix elements
CKM elements (γ, V_{ub})
data - $\phi_{\psi K_S}, \underline{\phi_S}$