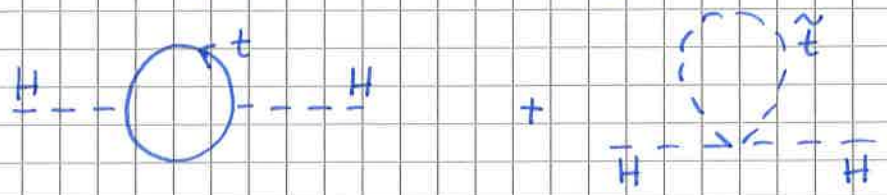
BSM physics at LHCb

LHCb UK student meeting
April 14, 2014
M. Blanke

1. Why BSM physics ? at LHCb ?

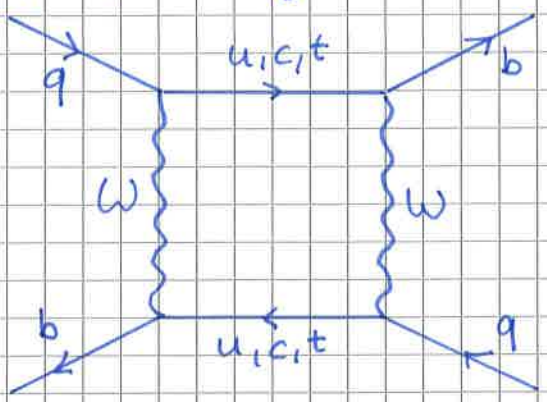
Why BSM physics ?
- hierarchy problem, stability of electroweak scale



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 !

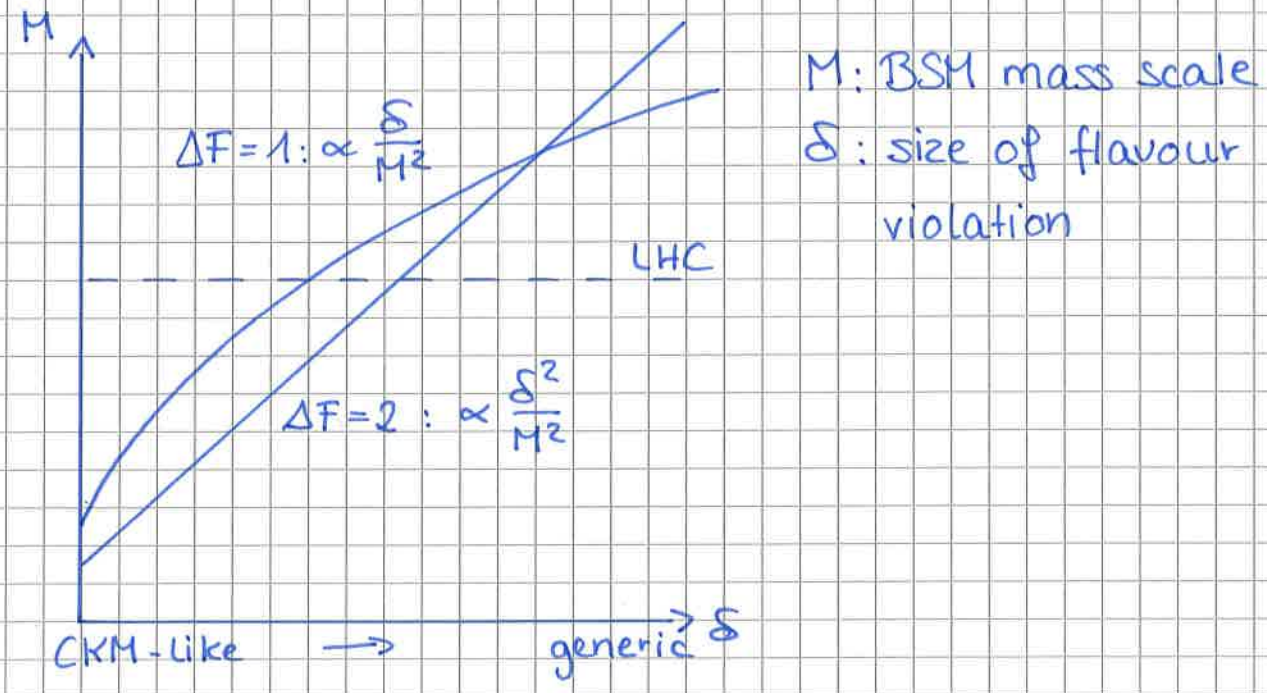
Flavour changing neutral current (FCNC) transitions in the SM are strongly suppressed
e.g. $B_q - \bar{B}_q$ mixing



- 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 ~~mas~~ matrix and smallness of most quark masses (except m_t) → GIM mechanism
- mediated only by left-handed interactions (W couplings)

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

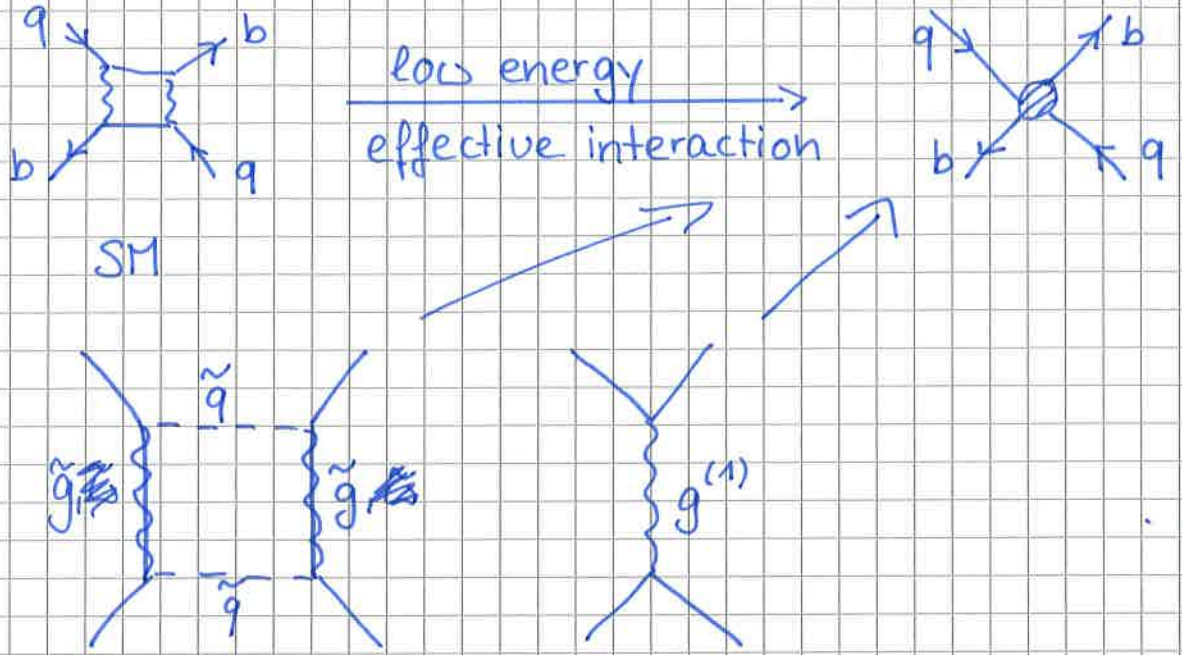
more sensitive than direct searches ?



M: BSM mass scale
δ: size of flavour violation

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

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



SUSY
squarks + gauginos

extra dimensions
Kaluza-Klein modes

describe effective interaction by effective Hamiltonian

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

$V_{tb}^* V_{tq}$: CKM elements

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

C_i: 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:

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

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

↑ non-perturbative physics
lattice QCD
main th. uncertainty

mass eigenstates

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

Physical observables

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

- width difference $\Delta\Gamma_q = \Gamma_H^q - \Gamma_L^q = 2|\Gamma_{12}^q|\cos\phi_q$
  (less sensitive to BSM physics)

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

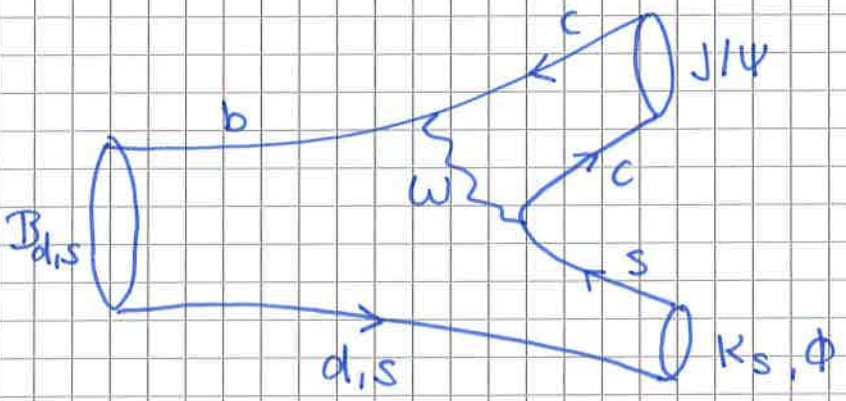
Status of ΔM_q

- 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 (γ, $|V_{ub}|$ ...)

Measuring CP violation: ϕ_d and ϕ_s

golden modes $B_d \to J/\psi K_S$ and $B_s \to J/\psi \phi$



↳ time dependent CP asymmetry, e.g.

$$A_{CP}^{J/\psi K_S}(t) = \frac{\Gamma(B_d(t) \to J/\psi K_S) - \Gamma(\bar{B}_d(t) \to J/\psi K_S)}{\Gamma(B_d(t) \to J/\psi K_S) + \Gamma(\bar{B}_d(t) \to J/\psi K_S)}$$

$$= C_{\psi K_S} \cos \Delta M_d t + S_{\psi K_S} \sin \Delta M_d t$$

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

hadronic uncertainties mostly cancel in A_{CP}

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

2β: CKM phase; ϕ_d^{BSM}: BSM phase

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

...

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

Status:

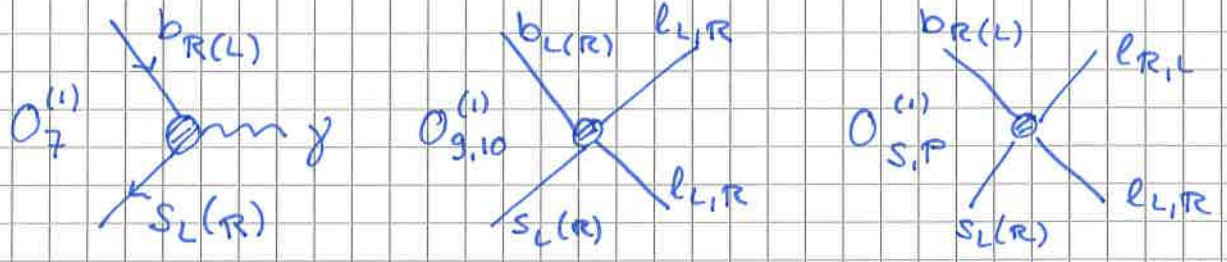
- data shows good agreement with SM prediction
- still quite some room for BSM physics, in particular in ϕ_s
  ↳ we're eagerly waiting for an update with the full 2012 data set!

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

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

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

at the level of the ~~4~~ low energy effective theory
(heavy particles integrated out)



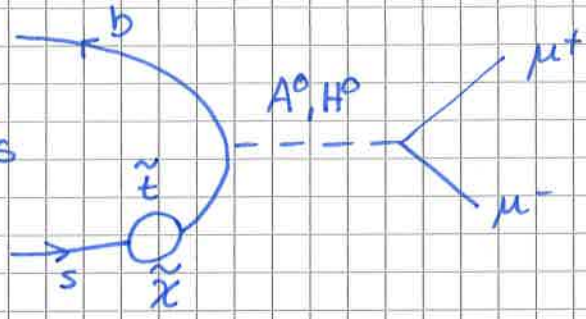
Sensitivity of different decays

	$O_7^{(\prime)}$	$O_9^{(\prime)}$	$O_{10}^{(\prime)}$	$O_{S,P}^{(\prime)}$
$B \to X_s\gamma, K^*\gamma$	×			
$B \to X_s \ell\ell$	×	×	×	
$B \to K^{(*)} \ell\ell$	×	×	×	
$B_s \to \mu\mu$			×	×

↳ 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



$$C_S \simeq -C_P \propto \frac{\mu A_t}{m_{\tilde{t}}^2} \frac{m_{B_s} m_\mu}{m_A^2} t_\beta^3$$

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 $B \to K^* \mu\mu$?

discrepancy in angular observable P_5'
↳ can be shown: BSM needed $C_9^{NP} \simeq -C_9' \simeq -1$

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 possibe
  improvements: th. prediction for matrix elements
  CKM elements (γ, V_{ub})
  data - $S_{\psi K_S}$, ϕ_s