Possible Interplay of Collider and Flavour Physics

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Workshop on Flavour in the Era of the LHC
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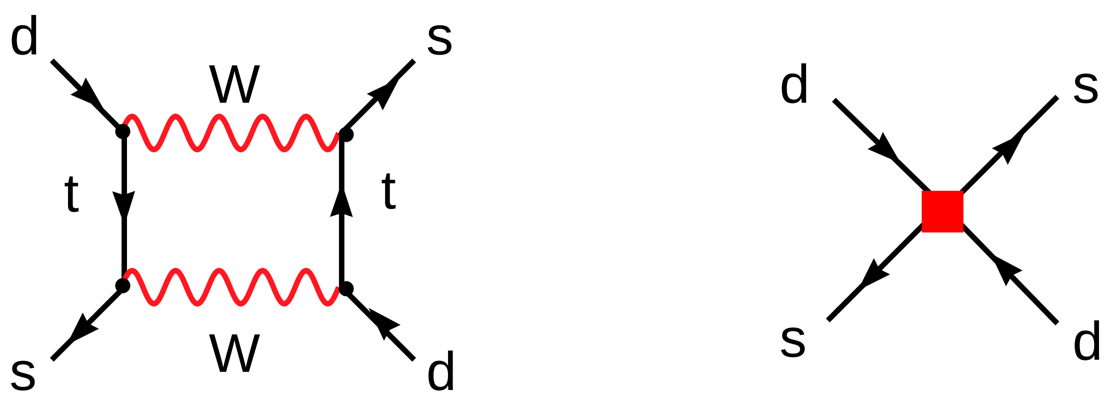
Flavour problem

$$\mathcal{L} = \mathcal{L}_{Gauge} + \mathcal{L}_{Higgs} + \sum_i \frac{c_i^{New}}{\Lambda} \mathcal{O}_i^{(5)} + \ldots$$

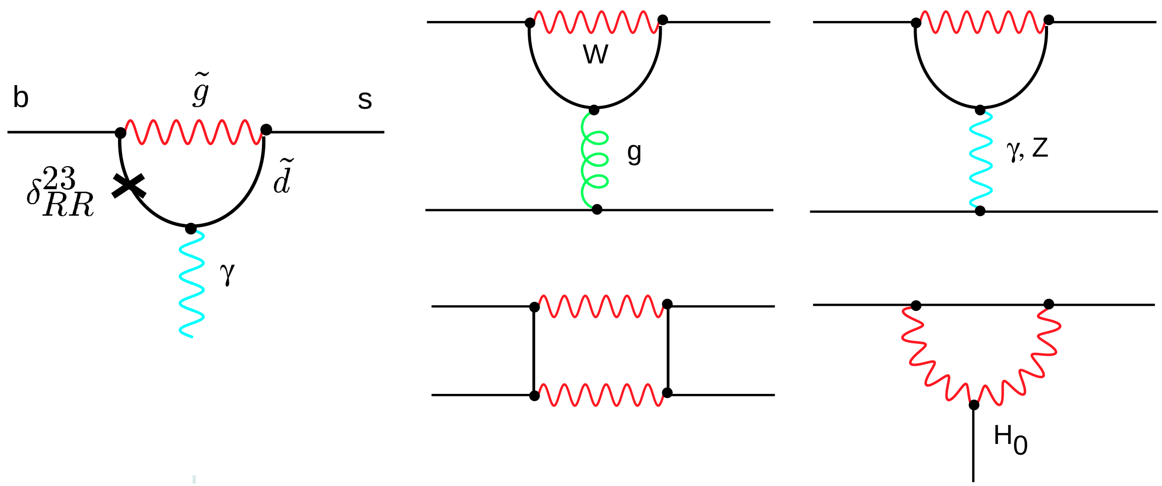
- SM as effective theory valid up to cut-off-scale Λ
- $K^0 - \bar{K}^0$-mixing $\mathcal{O}^6 = (\bar{s}\, d)^2$: $c^{SM}/M_W^2 \times (\bar{s}\, d)^2 + c^{New}/\Lambda^2 \times (\bar{s}\, d)^2 \Rightarrow \Lambda > 100\,\text{TeV}$



- Natural stabilisation of Higgs boson mass (i.e. supersymmetry) $\Rightarrow \Lambda \sim 1\,\text{TeV}$
  (but: little hierarchy problem)
- Expectation: flavour mixing restricted by additional symmetries

Rare decays and CP violating observables allow to analyse flavour symmetry breaking.

- Flavourblind elektroweak structure of $\mathcal{O}_i$:
  - connects various (theoretically clean !) observables:
  $A_{CP}(B_d \to \Phi K_S) \Leftrightarrow BR(B \to X_s \gamma)$



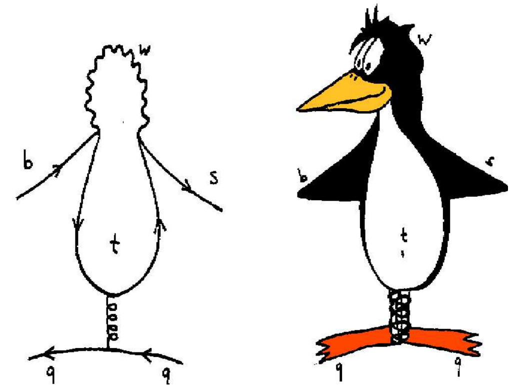
  - allows for model-independent analysis:

- Flavour part of $\mathcal{O}_i$:
  - new flavour structures, i.e. squark-mixing in SUSY or
  - minimal flavour violation flavour symmetry / CP broken by Yukawa couplings

  * $[b \to s] \leftrightarrow [b \to d] \leftrightarrow [s \to d]$ * RG-invariant definition (d'Ambrosio et al.)

There is no strict theoretical argument available that there must be new flavour structures at the electroweak scale.

Exploration of higher scales via FCNC



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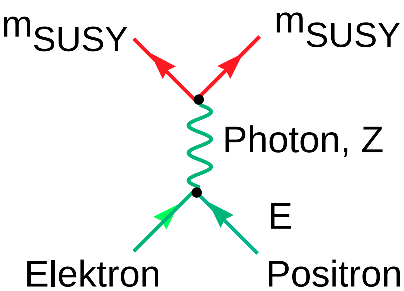
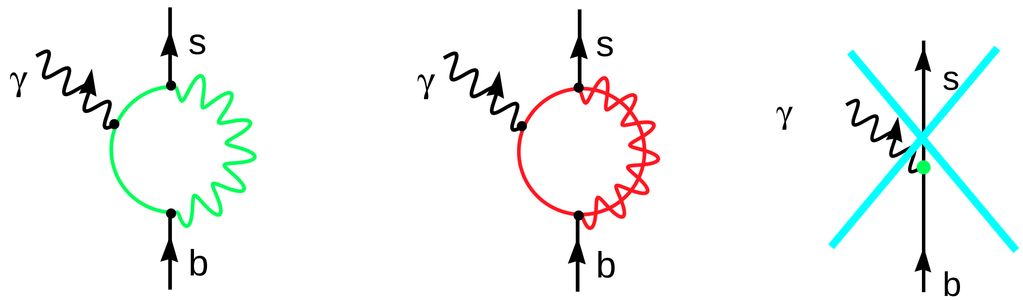
Direct:



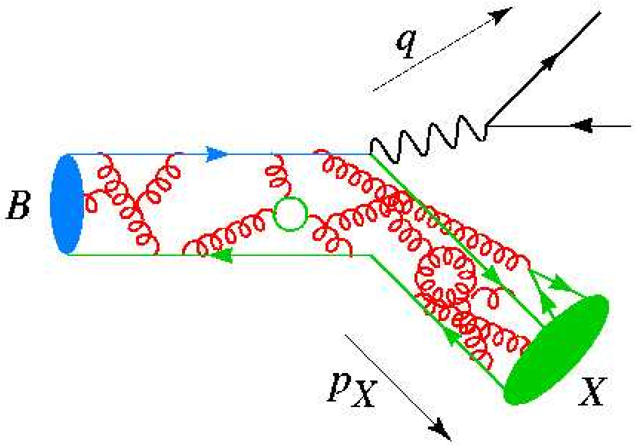
$2m_{SUSY}c^2 \leq E$

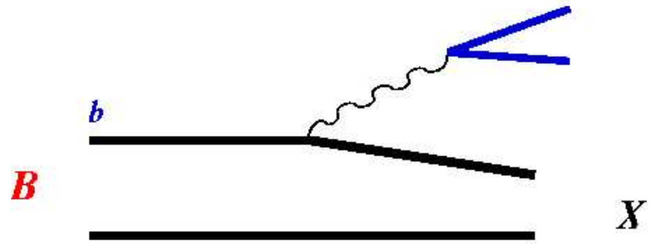
Indirect:



- High sensitivity for 'New Physics' ($\leftrightarrow$ elektroweak precision data, 10% $\leftrightarrow$ 0.1%)
- This indirect search via FCNC takes place today in complete darkness.
- But this indirect information will be most valuable if the nature of new physics identified in the direct search at the LHC.

Complementarity of flavour factories and LHC.





Separation of new physics effects and hadronic uncertainties!

Three strategies:

* focus on inclusive modes:

$$\Gamma(\bar{B} \to X_s\gamma) \stackrel{m_b\to\infty}{\longrightarrow} \Gamma(b \to X_s^{parton}\gamma)\,, \quad \Delta^{nonpert.} \sim \Lambda_{QCD}^2/m_b^2$$

No linear term Λ_{QCD}/m_b
(perturbatively calculable contribution dominant)

* focus on ratios of exclusive modes like asymmetries
(hadronic uncertainties partially cancel out, i.e. $A_{FB}(B \to K^*\ell^+\ell^-)$)

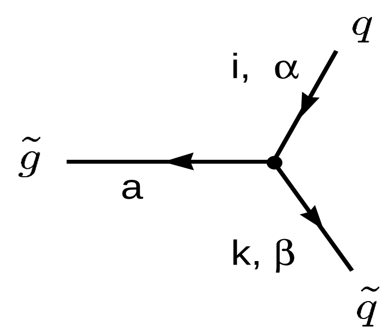
* focus on specific decays like $K \to \pi\nu\bar{\nu}$
(hadronic matrix elements known from experiment)

Complementarity of LHCb, SuperB and rare kaon experiments.

Correlations between B and collider physics via squark mixing within SUSY

- In the unconstrained MSSM (too many ?) new contributions to flavour violation
  - CKM induced contributions from H^+, χ^+ exchanges
  - flavour mixing in the sfermion mass matrix

- Gluino-quark-squark coupling: $-i g_s T^a_{\beta\alpha} (\Gamma^{ki}_{QL} P_L - \Gamma^{ki}_{QR} P_R)$



- Possible disalignment of quarks and squarks
  - quark mass matrices are diagonal !
  - squarks are rotated 'parallel' to their fermionic superpartners !
  - in general not mass eigenstates: $\tilde{q}_{L,R} = \Gamma^+_{QL,R} \tilde{q}_i$

Sfermion mass matrix in uMSSM in $\tilde{q}_{L,R}$ basis:

$$\mathcal{M}^2_{D/U} = (F/D)^{D/U}_{6\times 6} + \begin{pmatrix} m^2_{Q,LL} & m^2_{D/U,LR} \\ m^2_{D/U,RL} & m^2_{(D/U,RR} \end{pmatrix}$$

from F, D terms	from soft breaking
3×3 diagonal submatrices	m^2_i not diagonal

FCNC are induced by off-diagonal (off-generational) terms in $m^2_{LL}, m^2_{RR}, m^2_{LR}$

- Low energy constraints
  - K-physics: ϵ'/ϵ, K^0-$\bar{K}^0$ mixing, . . .
    significantly constrain $1-2$ and $1-3$ mixing
  - B-physics: $b \to s\gamma$, ΔM_{B_s}, . . .
    most important beyond SM contributions: H^+, $\tilde{\chi}_i^+$, $\tilde{g}$

- Correlations to Collider Physics
  - Squark decays:

$$\begin{aligned} \tilde{u}_i &\to u_j \tilde{\chi}_k^0 \,,\, d_j \tilde{\chi}_l^+ \\ \tilde{d}_i &\to d_j \tilde{\chi}_k^0 \,,\, u_j \tilde{\chi}_l^- \end{aligned}$$

    with $i = 1,..,6$, $j = 1,2,3$, $k = 1,..,4$ and $l = 1,2$.
  - These decays are governed by the same mixing matrices as the contributions to flavour violating low-energy observables and no GIM or Super-GIM is active.

Squarks can have large flavourviolating decay modes, compatible with present data from flavour physics.

Strategy

- take SPS1a as starting point:

  $M_0 = 100$ GeV, $M_{1/2} = 250$ GeV
  $A_0 = -100$ GeV, $\tan\beta = 10$, $\mu > 0$
  $\Rightarrow$
  $M_2 = 192$ GeV, $\mu = 351$ GeV
  $m_{H^+} = 403$ GeV $m_{\tilde{g}} = 594$ GeV, $m_{\tilde{t}_1} = 400$ GeV
  $m_{\tilde{t}_2} = 590$ GeV, $m_{\tilde{q}_R} \simeq 550$ GeV, $m_{\tilde{q}_L} \simeq 570$ GeV

  (SPheno 2.0)

- vary off-diagonal squark mass entries.

- accept points with $2 \leq 10^4$ BR$(b \to s\gamma) \leq 4.5$ and $\Delta M_{B_s} \geq 14$ ps^{-1}

- For simplicity: real parameters only

- QCD corrections for $b \to s\gamma$ as given in
  Borzumati et al., Phys. Rev. D62, 075005 (2000) and
  Besmer et al., Nucl.Phys.B609:359 (2001)

- ΔM_{B_s}, as given in
  Baek et al. , Phys. Rev. D64, 095001 (2001)

$\Rightarrow$ Typical results:

Branching ratios (in %) of u-type squarks

	$\tilde{\chi}_1^0 c$	$\tilde{\chi}_1^0 t$	$\tilde{\chi}_2^0 c$	$\tilde{\chi}_2^0 t$	$\tilde{\chi}_3^0 c$	$\tilde{\chi}_3^0 t$	$\tilde{\chi}_4^0 c$	$\tilde{\chi}_4^0 t$	$\tilde{\chi}_1^+ s$	$\tilde{\chi}_1^+ b$	$\tilde{\chi}_2^+ s$	$\tilde{\chi}_2^+ b$
$\tilde{u}_1$	4.7	18	5.2	9.6	6×10^{-3}	0	0.02	0	11.3	46.4	2×10^{-3}	4.7
$\tilde{u}_2$	19.6	1.1	0.4	17.5	2×10^{-2}	0	6×10^{-2}	0	0.5	57.5	3×10^{-3}	2.9
$\tilde{u}_3$	7.3	3.7	20	1.4	6×10^{-2}	0	0.6	0	40.3	3.1	1	18.5
$\tilde{u}_6$	5.7	0.4	11.1	5.3	4×10^{-2}	5.7	0.6	13.2	22.9	13.1	0.6	8.0

Branching ratios (in %) of d-type squarks

	$\tilde{\chi}_1^0 s$	$\tilde{\chi}_1^0 b$	$\tilde{\chi}_2^0 s$	$\tilde{\chi}_2^0 b$	$\tilde{\chi}_3^0 s$	$\tilde{\chi}_3^0 b$	$\tilde{\chi}_4^0 s$	$\tilde{\chi}_4^0 b$	$\tilde{\chi}_1^- c$	$\tilde{\chi}_1^- t$	$\tilde{\chi}_2^- c$	$\tilde{\chi}_2^- t$	$\tilde{u}_1 W^-$
$\tilde{d}_1$	1.2	5.7	8.4	30.6	2×10^{-2}	1.5	0.2	0.9	16.6	34.1	0.6	0	0
$\tilde{d}_2$	17.4	5.8	5.1	15.7	7×10^{-2}	7.4	0.3	09.2	9.7	19.7	0.7	0	8.8
$\tilde{d}_4$	14.7	21.7	11.3	2.2	5×10^{-2}	10.6	0.5	8.4	22.1	3.6	1.2	0	3.4
$\tilde{d}_6$	1.7	0.5	20.5	6.9	0.1	0.9	1.2	1.3	40.3	10.2	3.4	11.1	1.8

Gluino branching ratios larger than 1%.

Final state	BR [%]	Final state	BR [%]
$\tilde{u}_1 c$	12.9	$\tilde{d}_1 s$	7.2
$\tilde{u}_1 t$	5.7	$\tilde{d}_1 b$	19.8
$\tilde{u}_2 c$	0.4	$\tilde{d}_2 s$	6.1
$\tilde{u}_2 t$	7.6	$\tilde{d}_2 b$	4.7
$\tilde{u}_3 c$	0.6	$\tilde{d}_3 d$	10.0
$\tilde{u}_4 u$	5.5	$\tilde{d}_4 s$	3.5
$\tilde{u}_5 u$	3.0	$\tilde{d}_4 b$	4.9
		$\tilde{d}_5 d$	2.1

Conclusions on correlations via squark mixing

- $b \to s\gamma$ and ΔM_{B_s} (still ?) allow for large mixings between second and third gen. squarks, for example $\tilde{t}_i$, $\tilde{c}_i$ can have large flavour violating decay modes,
- makes life at LHC potentially more interesting and more difficult,
- information from ILC or flavour factories needed for the analysis of LHC data.

Future tasks:

- Most MC analyses at the LHC are done within MSUGRA only:
  mostly flavour diagonal, squark mass degeneracy

- Experimental issue of flavour tagging

- Necessary update to be done:
  $b \to s\ell^+\ell^-$, $A_{CP}(b \to s\gamma)$, $A_{FB}(b \to s\ell^+\ell^-)$,...

- Extension of the Les Houches Accord for flavour-nondiagonal quantities
  ($\to$ Peter Skands et al.)

- Need of program sets to connect collider with low-energy data
  (program sets existing on each side!)