Flavour-blind MSSM at large tan β

FCNC beyond the decoupling limit

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- interesting case for Yukawa unification: $y_b \approx y_t \approx 1$,

$$\text{then} \quad \tan\beta = \frac{v_u}{v_d} \sim \mathcal{O}\left(\frac{m_t}{m_b}\right) \sim \mathcal{O}(50)$$

tan β-enhancement

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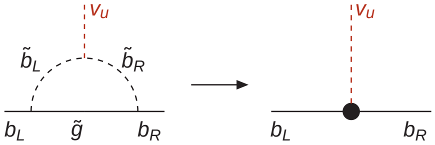
- How should we account for such $\mathcal{O}(1)$ corrections?

Accounting for tan β-enhanced corrections

1. Effective Lagrangian in the decoupling limit

[Babu,Kolda; Buras,Chankowski,Rosiek,Slawianowska; Dedes,Pilaftsis]

- assume $M_{\text{SUSY}} \gg M_{\text{EW}}$ and integrate out SUSY fields, keep only Higgs and SM fields, e.g.



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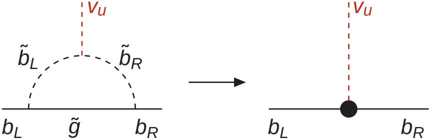
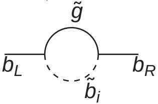


2. Calculation in the full MSSM beyond decoupling (our work)
   - $\tan\beta$-enhanced mass corrections from finite self-energies:



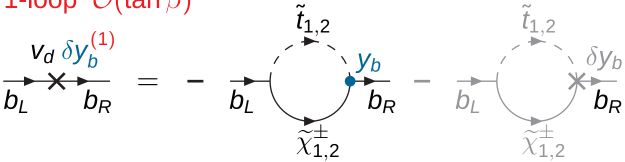
$$\propto \tan\beta \qquad \longrightarrow y_b \propto m_b^{\text{bare}} = \frac{m_b}{1+\Delta_b}$$

   - resummation to all orders $(loop \cdot \tan\beta)^n$
     [Carena,Garcia,Nierste,Wagner]

Going beyond decoupling: resummation

- Renormalize tan β-enhanced corrections on-shell
  Example: Chargino self-energy

1-loop $\mathcal{O}(\tan\beta)$



$$v_d\,\delta y_b^{(1)} = -v_d\, y_b\, \Delta_b^{\tilde{\chi}^\pm} \quad \text{with} \quad \Delta_b^{\tilde{\chi}^\pm} \sim \mathcal{O}(loop \cdot \tan\beta)$$

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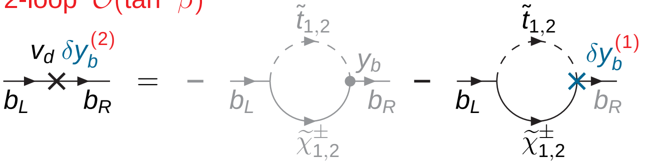
2-loop $\mathcal{O}(\tan^2\beta)$



$$v_d\,\delta y_b^{(2)} = -v_d\,\delta y_b^{(1)}\,\Delta_b^{\tilde{\chi}^{\pm}}$$

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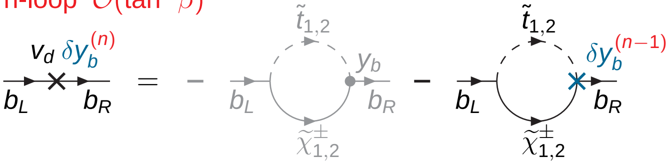
n-loop $\mathcal{O}(\tan^n \beta)$



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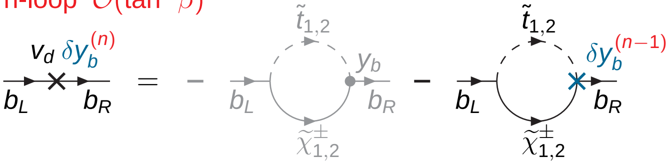

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- by recursion: $\delta y_b^{(n)} = y_b^{\text{ren}} (-\Delta_b^{\tilde{\chi}^\pm})^{n+1}$

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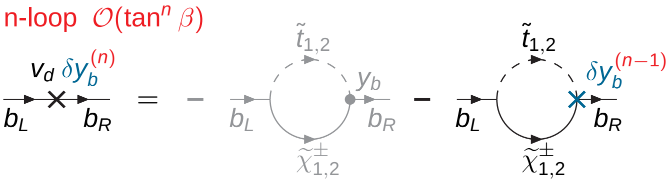

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- by recursion: $\delta y_b^{(n)} = y_b^{\text{ren}} (-\Delta_b^{\tilde{\chi}^{\pm}})^{n+1}$
- resummation:

$$y_b^{\text{bare}} = y_b^{\text{ren}} + \sum_{n=0}^{\infty} \delta y_b^{(n)} = \frac{y_b^{\text{ren}}}{1 + \Delta_b^{\tilde{\chi}^{\pm}}} = \frac{m_b}{v_d (1 + \Delta_b^{\tilde{\chi}^{\pm}})}$$

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- $M_{\text{SUSY}} \sim M_{\text{EW}}$ is natural
- validity of the assumption $M_{\text{SUSY}} \gg M_{\text{EW}}$ unclear, test accuracy
- study $\tan\beta$-enhanced effects in couplings of SUSY particles
  (inaccessible in eff. Lagrangian approach since SUSY particles are integrated out)

Three Questions

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c) new effects in FCNC processes?

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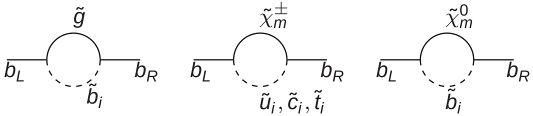
  $\rightarrow$ some freedom to choose...



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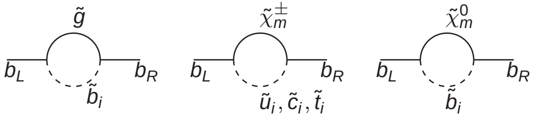

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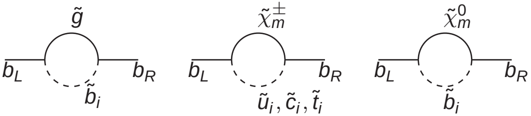

- to clarify things, write $\Delta_b = \Delta_b^{\tilde{g}} + \Delta_b^{\tilde{\chi}^{\pm}} + \Delta_b^{\tilde{\chi}^0}$
- from Feynman diagrams:
  - gluino contribution depends on $\theta_{\tilde{b}}, \varphi_{\tilde{b}}, m_{\tilde{b}_1}, m_{\tilde{b}_2}$
  - chargino contribution depends on m_b from Yukawa coupling
  - neutralino contribution depends on m_b and $\theta_{\tilde{b}}, \varphi_{\tilde{b}}, m_{\tilde{b}_1}, m_{\tilde{b}_2}$

Results: a) Scheme dependence in mass renormalization

Renormalization depends on choice of input parameters:

i) expressing Δ_b by μ, $\tan\beta$, $m_{\tilde{b}_1}$, $m_{\tilde{b}_2}$: (simplest formula)

$$y_b = \frac{m_b}{v_d(1 + \Delta_b^{\tilde{g}} + \Delta_b^{\tilde{\chi}^\pm} + \Delta_b^{\tilde{\chi}^0})} = \frac{m_b}{v_d(1 + \epsilon_b \tan\beta)}$$

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iii) expressing Δ_b by μ, $\tan\beta, m_{\tilde{b}_L}, m_{\tilde{b}_R}$: (popular for numerics)
$\rightarrow$ direct resummation impossible, only iterative use of formula i) works

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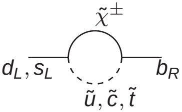

$$= m_b \frac{\epsilon_{FC} \tan\beta}{1 + \epsilon_b \tan\beta} V_{tb}^{*} V_{ti}$$

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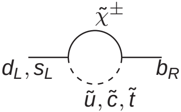

$$= m_b \frac{\epsilon_{FC} \tan\beta}{1 + \epsilon_b \tan\beta} V_{tb}^* V_{ti} \qquad \text{(i=d,s)}$$

- solution: absorb self-energies in matrix-valued field renormalization

$$\begin{pmatrix} d_L \\ s_L \\ b_L \end{pmatrix}^{\text{bare}} = \left(1 + \frac{\delta Z^L}{2}\right) \begin{pmatrix} d_L \\ s_L \\ b_L \end{pmatrix}$$

and likewise for right-handed fields

[similar approach by Buras,Chankowski,Rosiek,Slawianowska]

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- $(\epsilon_{\rm FC}\tan\beta)^n$ effects can be *resummed to all orders*. Yields

$$\frac{\delta Z^L_{bi}}{2} = -\frac{\epsilon_{\rm FC}\tan\beta}{1+(\epsilon_b-\epsilon_{\rm FC})\tan\beta} V^*_{tb}V_{ti}$$

$$\frac{\delta Z^R_{bi}}{2} = -\frac{m_i}{m_b}\left[\frac{\epsilon_{\rm FC}\tan\beta}{1+(\epsilon_b-\epsilon_{\rm FC})\tan\beta} + \frac{(1+\epsilon_b\tan\beta)\,\epsilon^*_{\rm FC}\tan\beta}{(1+\epsilon^*_i\tan\beta)(1+(\epsilon_b-\epsilon_{\rm FC})\tan\beta)}\right] V^*_{tb}V_{ti}$$

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- this results in corrections to the CKM matrix

[Denner,Sack; Gambino,Grassi,Madricardo]

$$V^{\rm bare} = \begin{pmatrix} V_{ud} & V_{us} & K^*V_{ub} \\ V_{cd} & V_{cs} & K^*V_{cb} \\ KV_{td} & KV_{ts} & V_{tb} \end{pmatrix} \quad , \quad K = \frac{1+\epsilon_b\tan\beta}{1+(\epsilon_b-\epsilon_{\rm FC})\tan\beta}$$

(numerically different from eff. Lagrangian approaches)

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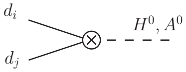

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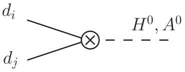

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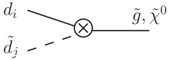

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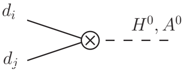

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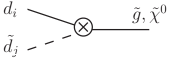

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- No, because: $\delta Z^L_{bi} \propto V^*_{tb} V_{ti}\, \epsilon_{\text{FC}} \tan\beta$
  $\rightarrow$ CKM structure of MFV preserved
  $\rightarrow$ estimate: $\epsilon_{\text{FC}} \tan\beta \rightarrow -\frac{y_t^2}{32\pi^2} \tan\beta$ for equal SUSY masses

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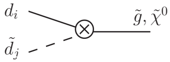

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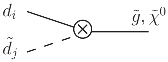

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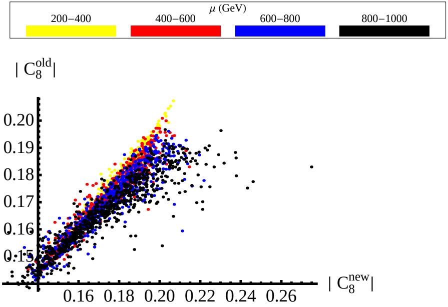

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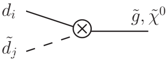

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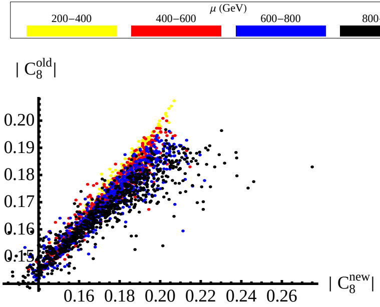

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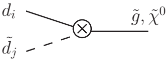

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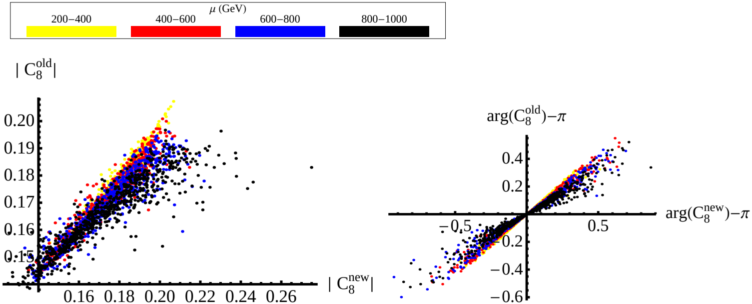
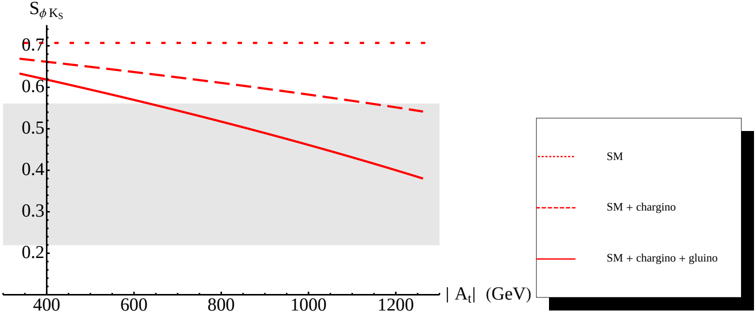


Results: c) New effects in FCNC processes

- estimate of mixing-induced CP asymmetry in $B^0 \to \phi K_S$ in leading-order QCD factorization, including tan β-enhanced C_8: [Buchalla,Hiller,Nir,Raz;...]



Here parameter point with rather large $\mu = 800$ GeV used, compatible with experimental $\mathcal{B}(\bar{B} \to X_s\gamma)$

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- the resummed effects can be incorporated into counterterm Feynman rules

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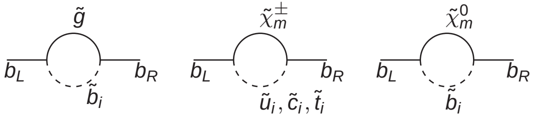
Backup slides

Backup: Scheme dependence in m_b-resummation

- observation: sbottom-mixing can (but need not) be expressed by m_b and SUSY-breaking parameters
  $\longrightarrow$ some freedom to choose input parameters...



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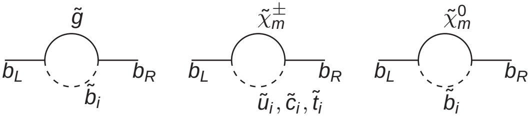

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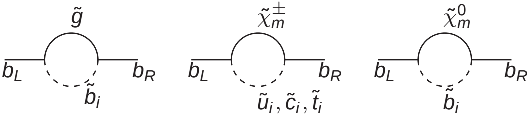


- to clarify things, write $\Delta_b = \Delta_b^{\tilde{g}} + \Delta_b^{\tilde{\chi}^\pm} + \Delta_b^{\tilde{\chi}^0}$
- from Feynman diagrams:
  - gluino contribution depends on $\theta_{\tilde{b}}, \varphi_{\tilde{b}}, m_{\tilde{b}_1}, m_{\tilde{b}_2}$
  - chargino contribution depends on m_b from Yukawa coupling
  - neutralino contribution depends on m_b and $\theta_{\tilde{b}}, \varphi_{\tilde{b}}, m_{\tilde{b}_1}, m_{\tilde{b}_2}$

Backup: parameter points

Scan ranges for C_7 and C_8: $\tan\beta = 40 - 60$, any value for φ_{A_t},

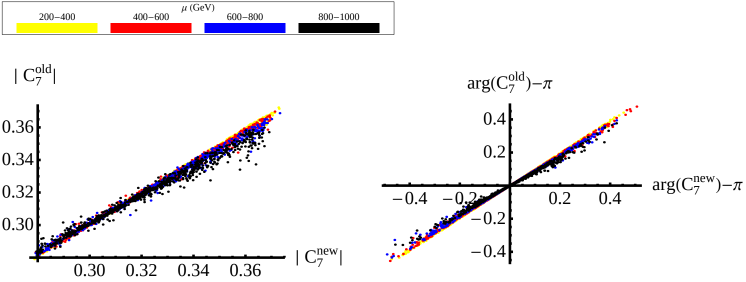
	min (GeV)	max (GeV)
$\tilde{m}_{Q_L}, \tilde{m}_{u_R}, \tilde{m}_{d_R}$	250	1000
$\lvert A_t \rvert$	100	1000
μ, M_1, M_2	200	1000
M_3	300	1000
m_{A^0}	200	1000

Parameter point used for $S_{\phi K_S}$:

$\tilde{m}_{Q_L}, \tilde{m}_{u_R}, \tilde{m}_{d_R}$	600 GeV	$\tan\beta$	50
μ	800 GeV	m_{A^0}	350 GeV
M_1	300 GeV	M_2	400 GeV
M_3	500 GeV	φ_{A_t}	$3\pi/2$

Backup: C_7 and other operators

- effect of gluino-squark contribution in $C_7(m_b)$ accidentally small (suppressed by a numerical factor from loop function)



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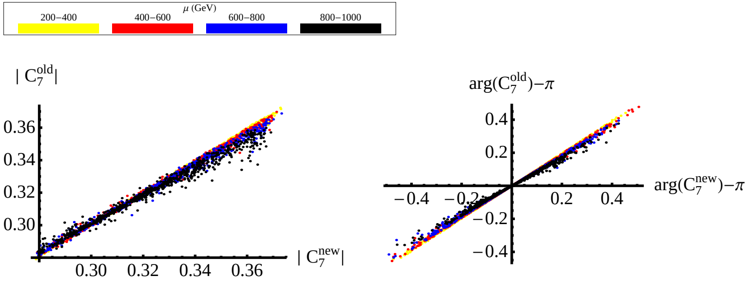

- effective four-quark operators in $\mathcal{H}^{\Delta B=1}$ and $\mathcal{H}^{\Delta B=2}$: gluino-squark loops suppressed by GIM-like cancellation between $\tilde{b}$- and $\tilde{s}$-loops $\to$ negligible compared to chargino-squark loops

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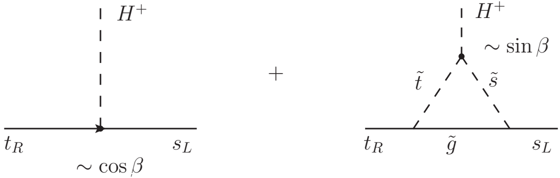

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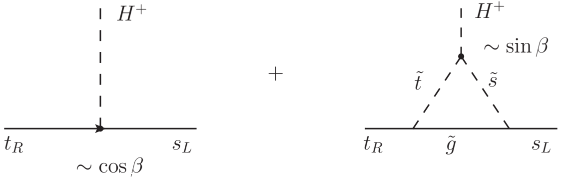

- this effect is local only in the decoupling limit, but cannot be cast into a Feynman rule in the full calculation

Backup: relation to effective CKM matrix from BCRS

- Buras, Chankowski, Rosiek, Slawianowska find for the effective CKM matrix:

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- They find that the result agrees numerically with the formula from eff. Lagrangian if ϵ-factors are replaced by full self-energies
- We prove this analytically via the resummation (iteration not needed!)