SUSY effects in $\Delta F = 2$ transitions

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Outline

- **Introduction:** impact of FCNC processes on generic SUSY corrections
  $\Rightarrow$ New-Physics ‘flavour problem’
- **Approach 1:** use exp. info to constrain the general MSSM
  (general = with completely *free* soft terms)
- **Approach 2:** implement a natural “near-flavour-conservation” mechanism
  within the MSSM $\Rightarrow$ MFV-MSSM

SUSY: what we learn from FCNCs

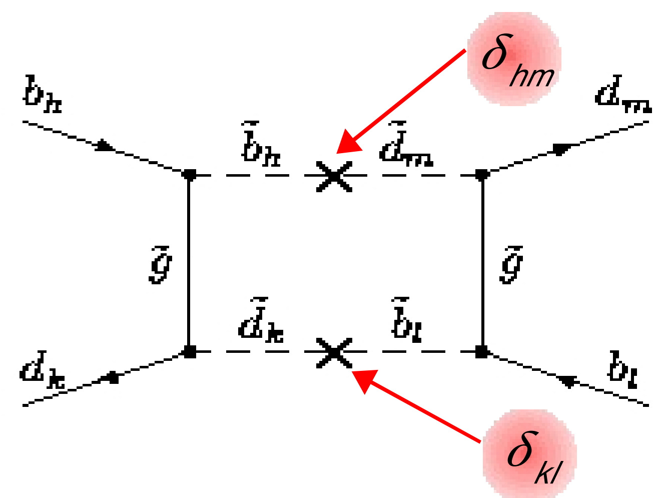
- FCNC effects **are small**
  (in principle ideal room for flavour-changing New Physics)
- ... but at the **quantitative** level
  no sensible discrepancy to date w.r.t. SM predictions

quark-FCNC processes
(within or outside the $\Delta F = 2$ case)
quantitatively confirm
the SM pattern of FCNC

Naïve assessment of SUSY effects

Example: $\Delta F = 2$ case

$$\text{SUSY corrections} \sim \left(\frac{\delta}{M_{\text{SUSY}}}\right)^2 \times f\,(\text{SUSY mass ratios})$$



Since mixing measurements check (within errors) with the SM, one has roughly:

$$|\,\text{SUSY corrections}\,| \leq \sqrt{\sigma_{\text{exp}}^2 + \sigma_{\text{th}}^2}$$

bounds on δ
(or rather, on δ / M_{SUSY})

$\boldsymbol{\sigma_{\text{th}} > 10\ \%}$ ***(!)***
Sensitivity to O(%) deviations from SM demands
steady improvement on the non-pert. error

Analysing FCNCs in SUSY

The SUSY (and NP in general) flavour problem

a) assuming $M_{\text{SUSY}} \sim O(\mathit{300}\ \text{GeV})$ [if we want it to stabilize the ~~EW~~ scale]

$\Longrightarrow\quad |\delta| < 10^{-2} \div 10^{-3}$

in absence of a symmetry principle (e.g. GIM-like mechanism) such small numbers are ugly

b) assuming $|\delta| \sim O(\mathit{1})$

$\Longrightarrow\quad M_{\text{SUSY}} \gg O(\text{TeV})$

back to "Separation-of-Scales" Problems

Theoretical approaches to SUSY flavour effects

❶ **Constrain the 'general' MSSM**
(with completely free soft terms)

Take the δ bounds "as they come" (from measured FCNCs) and study allowed effects on still-to-measure quantities (*e.g.* $A_{CP}\,[B_s \to \psi\phi]$, ...)

❷ **Maybe FCNC effects in SUSY are small, because already those in the SM are.**

Naturalness of "near-flavour-conservation" in SUSY: **MFV-MSSM**

Hall & Randall

D'Ambrosio *et al.*

❶

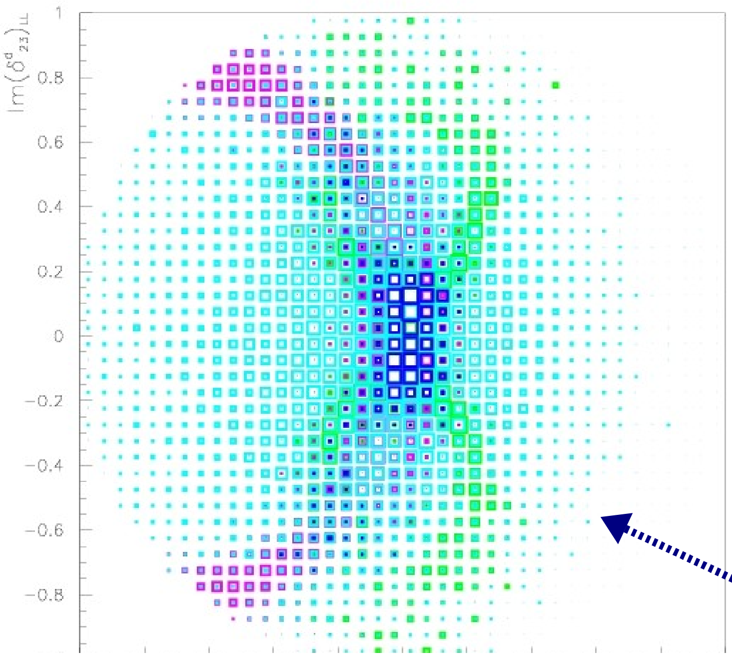
Constrain the general MSSM

Example: constraints from $b \to s$ FCNCs

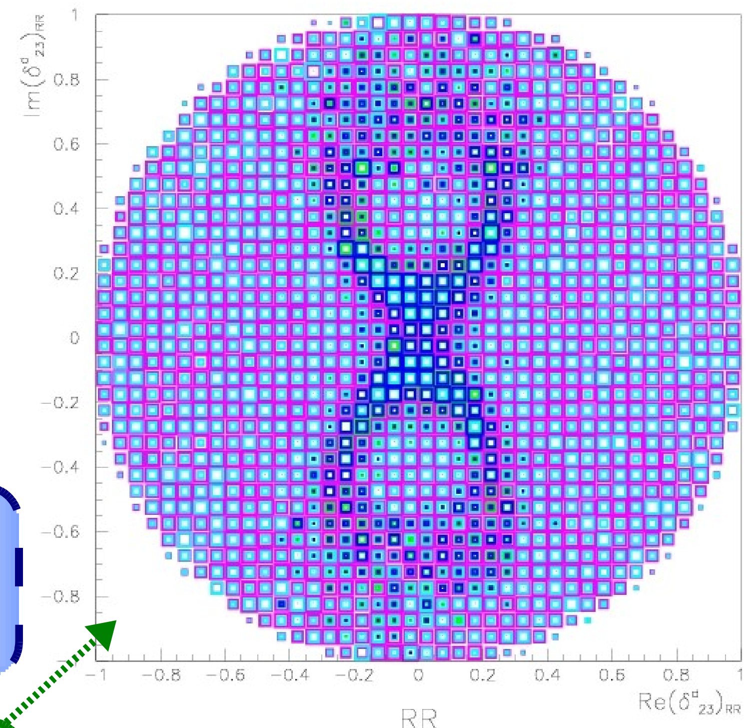
y-axis: $Im[(\delta^{23})_{XY}]$
x-axis: $Re[(\delta^{23})_{XY}]$

Constraints

- green square = Δm_s
- magenta square = $b \to s\ \gamma$
- cyan square = $b \to s\ l^+ l^-$
- blue square = all



LL only, tan β=3
⇩
[-0.15,+0.15] + *i* [-0.25,0.25]



RR only, tan β=3
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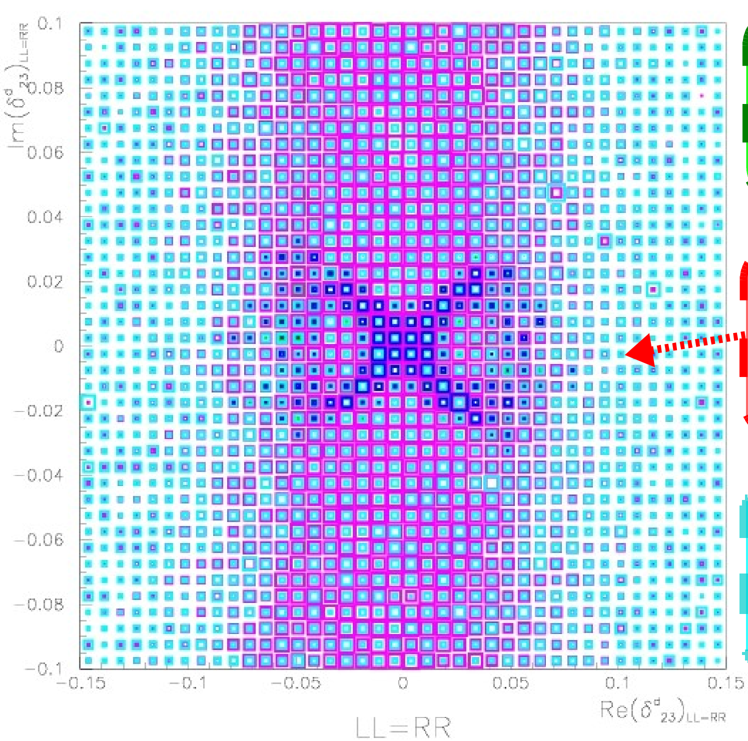
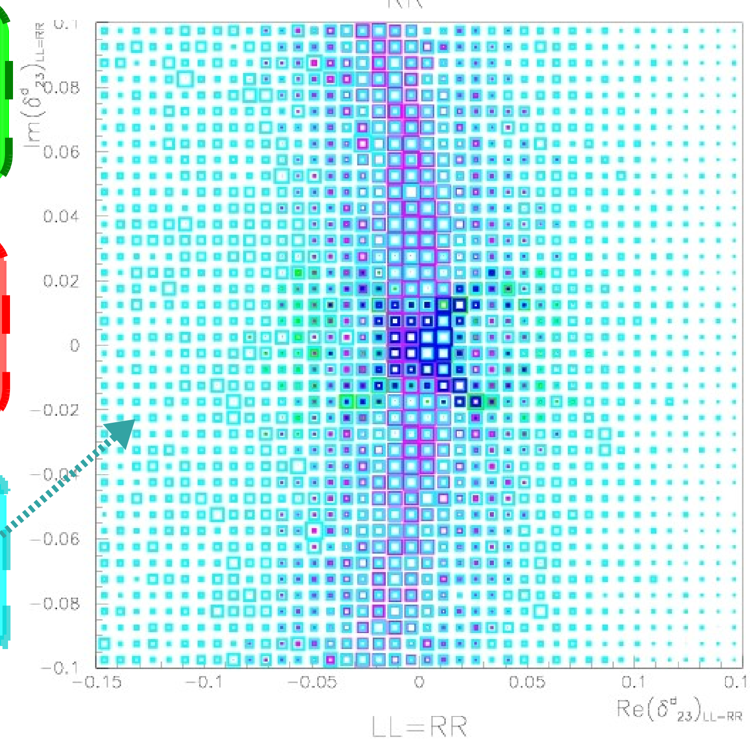
[-0.4,+0.4] + *i* [-0.9,0.9]



LL=RR, tan β=3
⇩
[-0.05,+0.05] + *i* [-0.03,0.03]

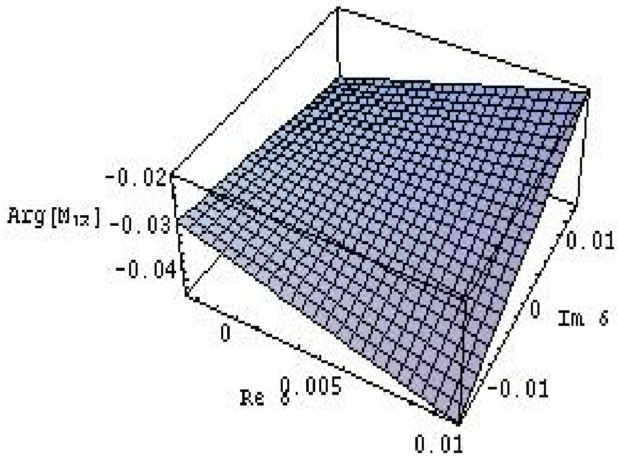


LL=RR, tan β=10
⇩
[-0.03,+0.03] + *i* [-0.02,0.02]

Implication on the B_s – mixing phase

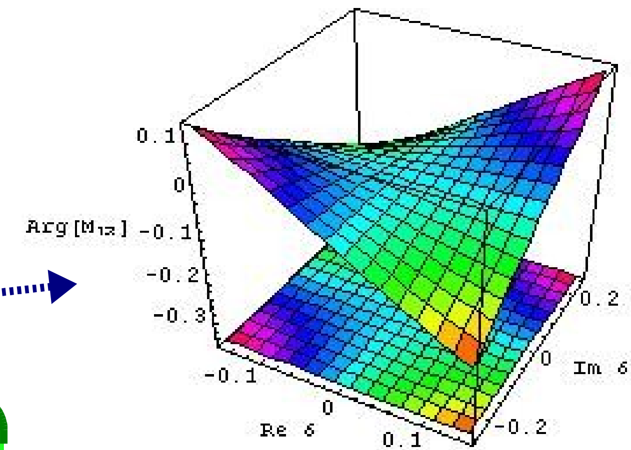
✔ In the SM one has $Arg\, M_{12}^{SM} \equiv Arg\{\langle \bar{B}_s | H_{eff,SM}^{\Delta B,S=2} | B_s \rangle\} = 2\lambda^2\eta \simeq 0.04$

☞ What is the allowed range for $Arg\, M_{12}^{MSSM}$ with the previous limits on the δ's ?

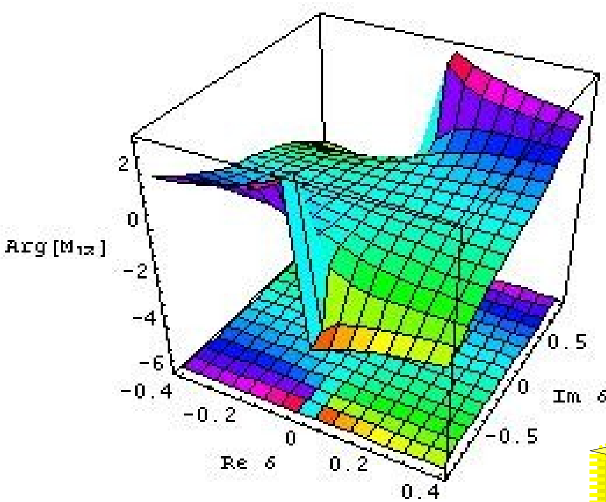


LR only, tan β=3
no sizable deviations
from the SM

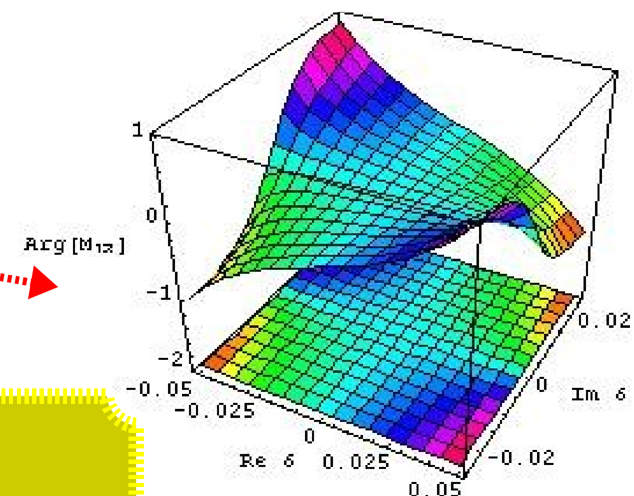
LL only, tan β=3
~ 10 × SM value are allowed



RR only, tan β=3
~ 100 × SM value are easy to get
(but RR is still mildly constrained...)



LL=RR, tan β=3
~ 100 × SM value are again easy
(yet LL=RR is severely constrained!)



The CP asymmetry in $B_s \to \psi\phi$
will provide a truly fantastic probe!

❷

Minimal Flavour Violation in the MSSM

Minimal Flavour Violation (MFV)

MFV:
In the SM, FCNC are small, because of the GIM mechanism.
Can extensions of the SM incorporate a *similar* mechanism
of near-flavour-(and CP)-conservation?

Controversial issue on how to define MFV

❶ **'pragmatic' definition, Buras *et al., '00*:**
in terms of allowed effective operators + explicit occurrence of the CKM

❷ **EFT definition, D'Ambrosio *et al., '02*:** in terms of the SM Yukawa couplings

Def. ❶ does not produce a consistent low-energy limit for the MSSM, even at low tan β

Altmannshofer, Buras, D.G., '07

- In fact, in extensions of the SM one has (by def.) **new**, a priori unrelated sources of flavour (and CP) violation.
- MFV can then only be defined as a 'symmetry requirement' for such **new** sources
- The set of allowed operators and FV structures is an **outcome** of such requirement

MFV 'principle'

☞ the SM Yukawa couplings are the *only* structures responsible for low-energy flavour and CP violation

⇒ every new source of flavour violation must be expressed as function of the SM Yukawa couplings

Example: soft mass term for 'left-handed' squarks

$$L_{\rm soft} = -\left(m_Q^{IJ}\right)^2 \left((\tilde{u}_L^I)^* \tilde{u}_L^J + (\tilde{d}_L^I)^* \tilde{d}_L^J \right) + \ldots$$

a priori new source of flavour violation

FC effects are <u>*naturally small*</u>: intuitively $\delta = O(1) \times f(\mathrm{CKM})$

MFV expansion

$$[m_Q^2]^T = \overline{m}^2 \left(a_1 \mathbf{1} + b_1 K^+ Y_u^2 K + b_2 Y_d^2 + O(Y_u^2 Y_d^2) \right)$$

squark mass scale **and** **expansion coefficients** **free parameters after the MFV expansion**

Strategy

☞ After expansions, mass scales are only a few. Then:

① Fix them to scenarios

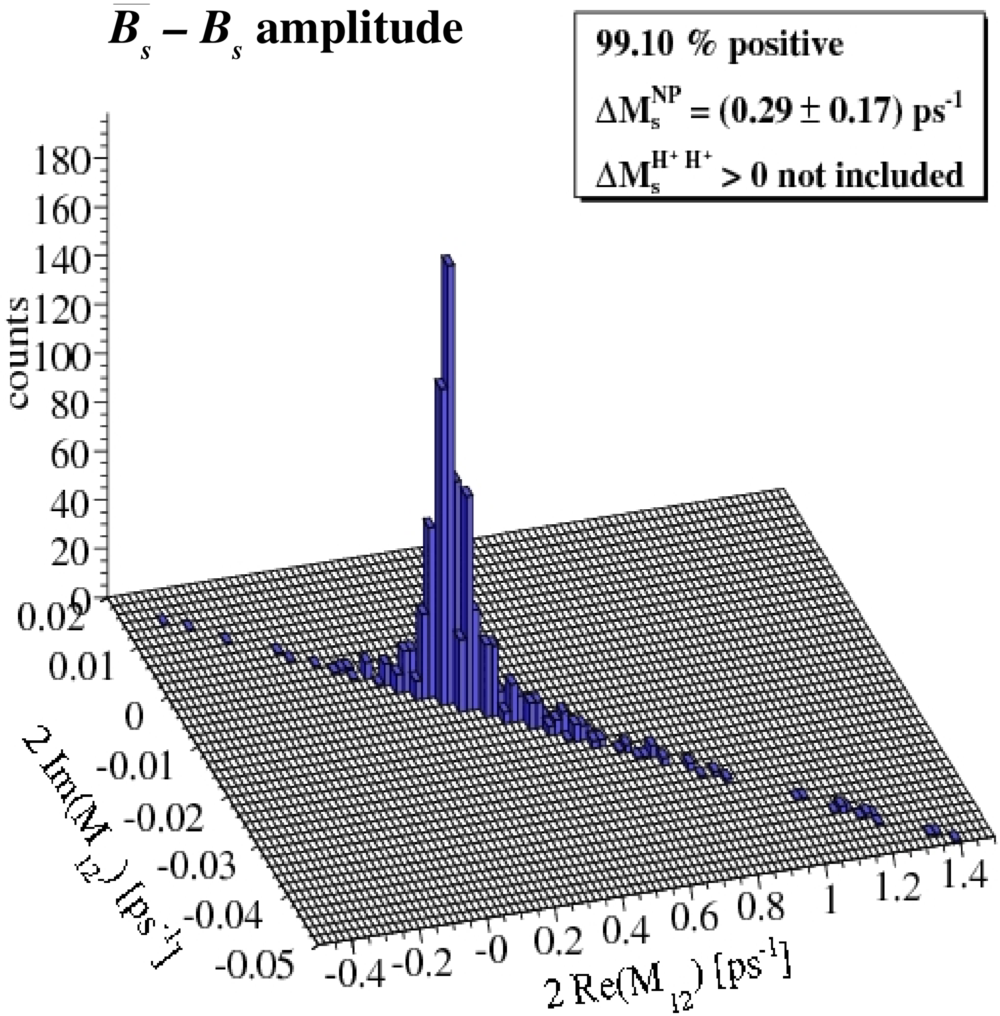
② Extract just the expansion coefficients (12 indep. parameters)

⇒ Dramatic increase in the predictivity and testability of the model

Δ*F*=2 example
for mass scales chosen as

$\overline{m}$ = *200* GeV		(squark scale)
M_g = *500* GeV		(gluino mass)
$M_{1,2}$ = *(100, 500)* GeV		(U(1)×SU(2) gaugino masses)
μ = *1000* GeV		(μ-parameter)

$\overline{B}_s - B_s$ amplitude



Comments

- Distributions of values, due to the extraction of the expansion parameters, are quite *narrow*
- Corrections are *naturally small*
- Corrections are *dominantly positive*. Signature of the MFV-MSSM at low tan β

Due to MFV,
the mixing phase is
aligned with the SM value

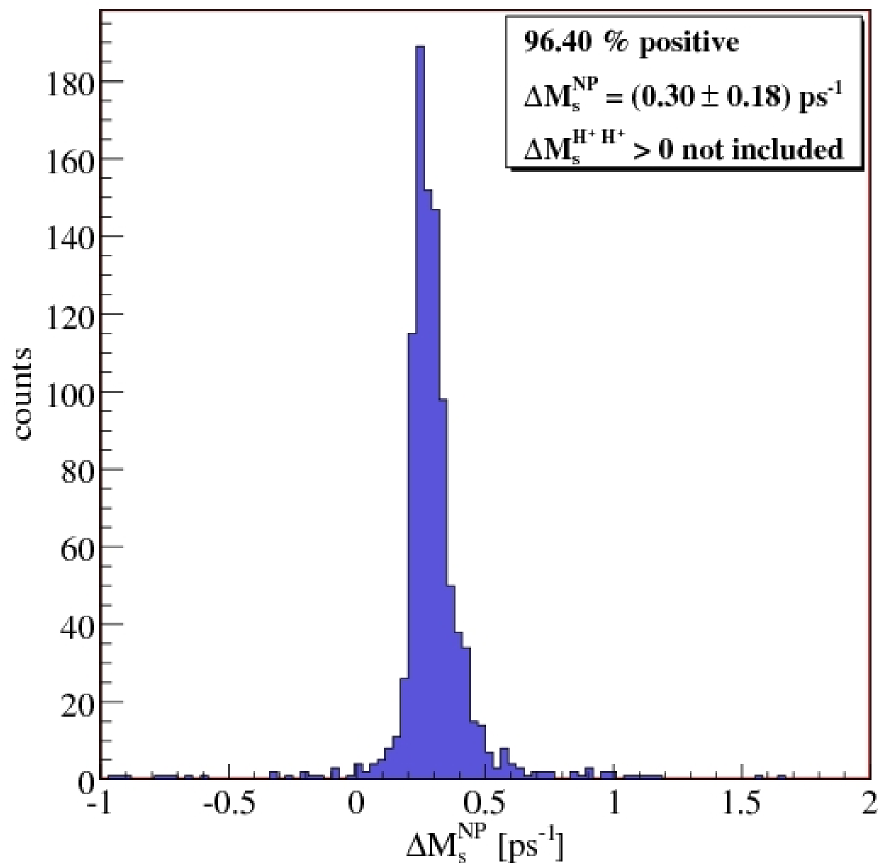
Analysis of the separate contributions

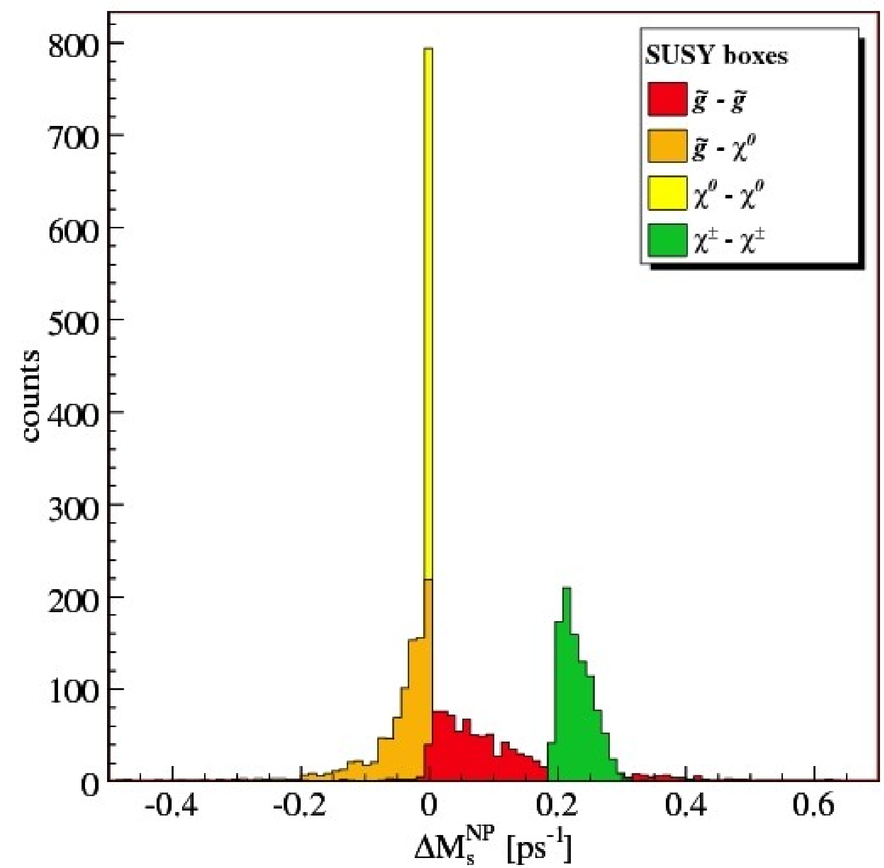
Note

When μ is large, LR entries in the squark mass matrices become relevant, even for low tan β.

They manifest dominantly in gluino contributions, which become competitive with chargino's.

Example with (GeV):
$m = 300$
$M_g = 300$
$M_{1,2} = (100,500)$
$\mu = 1000$



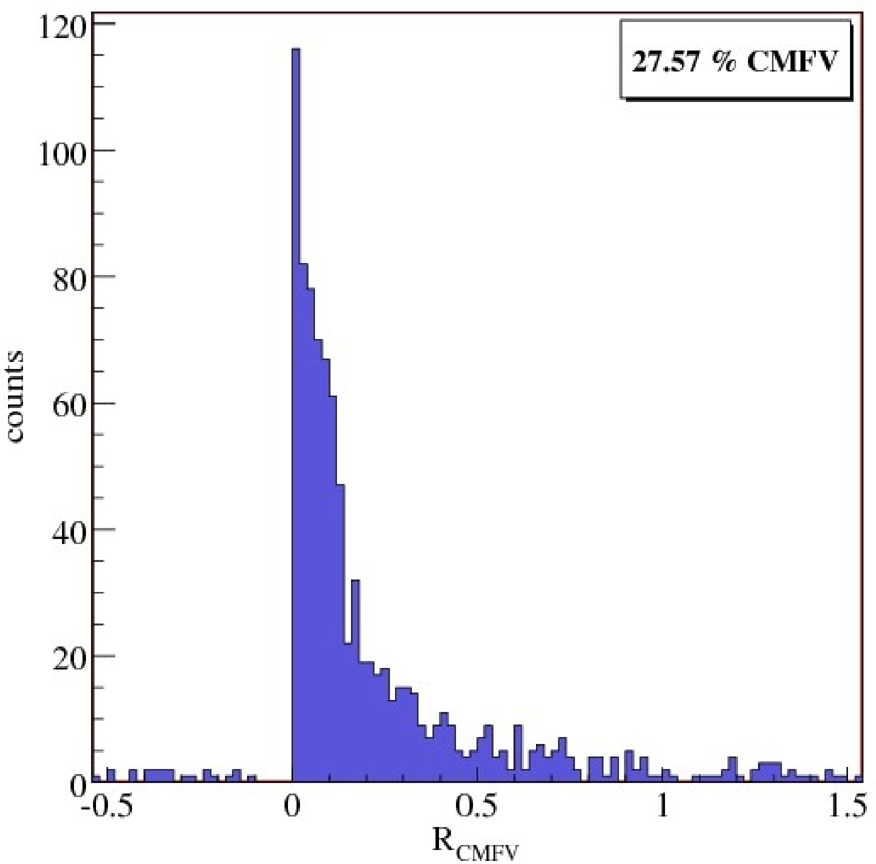


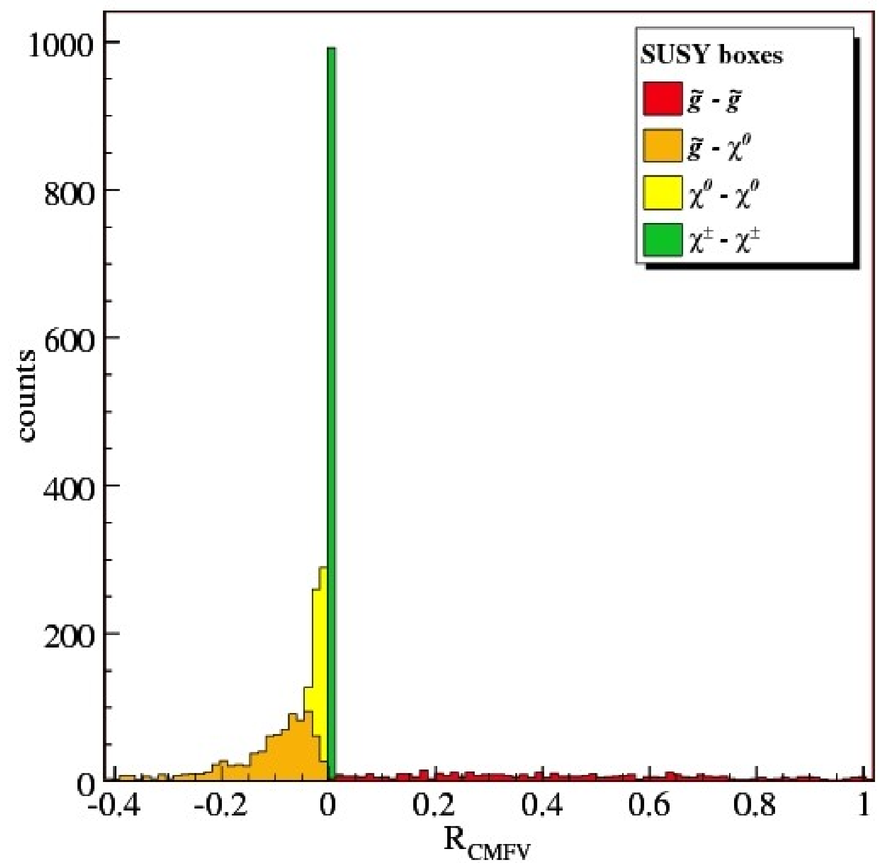
Test of 'constrained' MFV (CMFV) within the MSSM

The case of Q_1 -dominated MFV (so-called CMFV) can be tested by looking at the ratio

$$R_{CMFV} \equiv \frac{\text{contrib. to operators other than } Q_1}{\text{contrib. to } Q_1}$$

One can 'define' CMFV to hold when, *e.g.*
$|R_{CMFV}| < 0.05$





Conclusions

- ☑ In the general MSSM, SUSY effects are typically constrained to be **small** (exceptions: ($B_s \to \psi \phi$), ...) after imposing existing exp. input

- ☑ In the MFV-MSSM, SUSY effects are **naturally small**, due to a 'built-in' GIM-like mechanism.

In either case, to resolve such effects,
one needs a better control, O(few %),
of the effective operator matrix elements