New constraints on flavour violating supersymmetry

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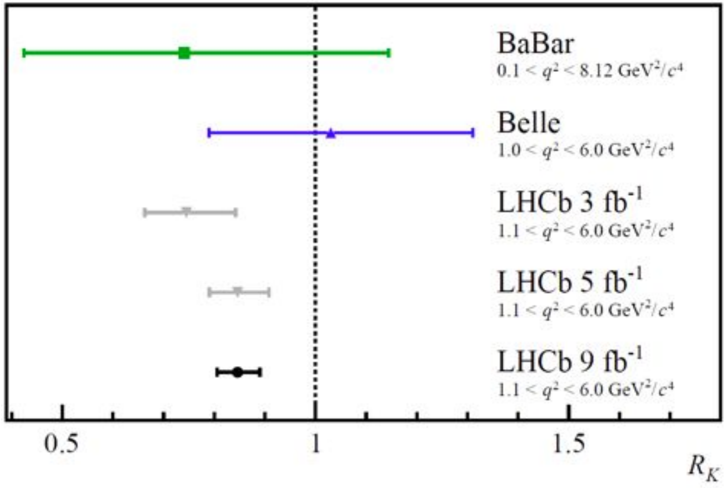
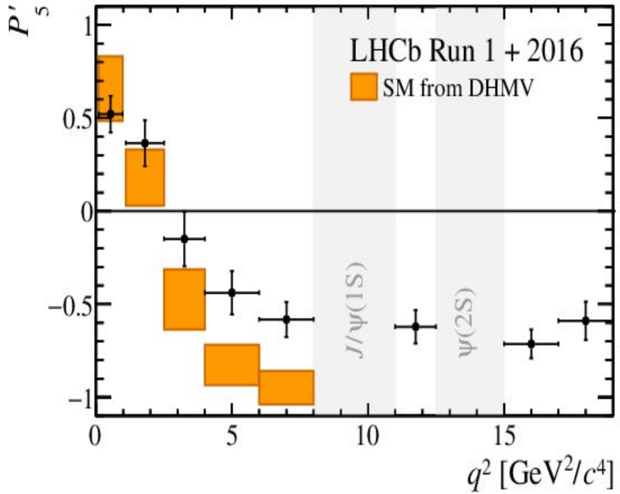
Context

Flavour anomalies and LHCb





They are not alone !

A coherent set of observables present similar tensions: $R_{K'}$ $BR(B^0 \to K^{*0}\mu^+\mu^-)$, etc.

R_K latest update (March 2021).
3.1σ tension with the SM
[2103.11769]

Tension in P'_5 : 2.5σ for q^2 bins :
[4,6[for 2.9σ for [6,8[, [2003.04831]

All observables in the b -> s ll sector admit a coherent NP fit ([2104.10058], [2012.12207], etc) .

$$\mathcal{H}_{\text{eff}} = -\frac{4G_F}{\sqrt{2}} K^*_{ts} K_{tb} \left[\sum_{i=1}^{8} C_i(\mu) O_i + \frac{\alpha}{4\pi} \sum_{i=9}^{10} \tilde{C}_i(\mu) O_i \right] \quad O_9 = (\bar{s}_L \gamma_\mu b_L) \bar{l} \gamma^\mu l$$

Flavour anomalies in the SUSY context

- Strong and persisting flavour anomalies.
- The flavour structure of the SM is still unexplained.
- Exploration of non-universal flavour models is pertinent.

- No SUSY signal so far at 13 TeV.
- Explored models are simple and heavily constrained, constraints often model dependent
- SUSY contributes to C9 at +1-loop level -> difficult to significantly reduce its value.

Theoretical set-up

pMSSM

- More general than constrained models (e.g. CMSSM).
- Still reasonably small to allow for doable computations.
- Main assumptions :
  - No new source of CP-violation
  - No FCNC
  - Universality of generations 1&2
  - Minimal Flavour Violation (MFV)
- 19 free parameters :

$\tan\beta, \mu, M_A$ — higgs sector

$M_1 M_2 M_3$ — gaugino sector

$m_{\tilde{q}}, m_{\tilde{u}_R}, m_{\tilde{d}_R}, m_{\tilde{l}}, m_{\tilde{e}_R}$ — 1/2 generation masses

$m_{\tilde{Q}}, m_{\tilde{t}_R}, m_{\tilde{b}_R}, m_{\tilde{L}}, m_{\tilde{\tau}_R}$ — 3rd generation masses

A_t, A_b, A_τ — Trilinear couplings

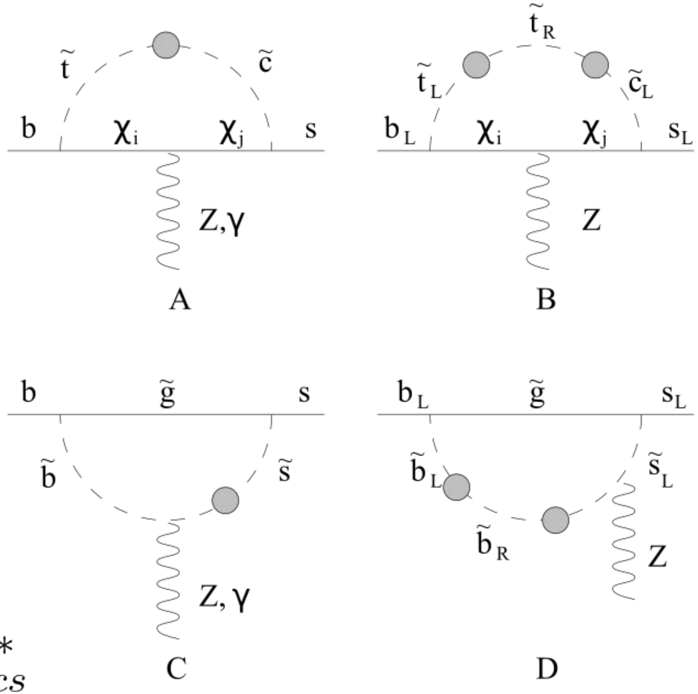
Non Minimal Flavour Violation and the MIA

- Mass Insertion Approximation in the b->sll context [9906286]
- Flavour Expansion Theorem [1504.00960]

- Obtain Feynman rules in flavour basis, expand mass matrices around off-diagonal elements.

$$(m^{\tilde{f}})^2_{AB} = \begin{pmatrix} ((m^{\tilde{f}})^2_{AB})_{11} & (\Delta_{AB})_{12} & (\Delta_{AB})_{13} \\ (\Delta_{AB})_{21} & ((m^{\tilde{f}})^2_{AB})_{22} & (\Delta_{AB})_{23} \\ (\Delta_{AB})_{31} & (\Delta_{AB})_{32} & ((m^{\tilde{f}})^2_{AB})_{33} \end{pmatrix}$$

$$(\delta^f_{ij})_{AB} = \frac{(m^{\tilde{f}}_{ij})^2_{AB}}{M^2_{sq}} \qquad (C_9)^Z_{\tilde{H}\tilde{W}} \propto (\delta^u_{23})_{LR} \frac{\lambda_t}{g_2} \frac{K^*_{cs}}{K^*_{ts}}$$



MIA diagrams contributing to b->sll. [9906286].

Exploring the parameter space

- NMFV assuming only squark flavour mixing yields up to O(70) free parameters !
  - Grid Sampling efficiency : ~ 0.005%
  - ML methods ineffective for unknown distributions
  - Hamiltonian MC could prove efficient but not guaranteed

Needs simplifications for now.

- The **Mass Insertion Approximation** allows to add some flavour mixings and expand around the squark mass matrices.
- Additional parameters up to 10. (no slepton or gen 1-2 mix) with the pMSSM parameters , dim(space) ~ 30.
  - Theoretical constraints on/and parameter distribution known.
  - ML methods efficient for fast inference of parameters and observables.

Set up

- Parameters are varied over very wide ranges, and sampled from uniform distribution
- RGE and spectrum performed using public code SOFTSUSY
- Wilson coefficients and observables are calculated using `Superiso` (dev version)
- Only theoretically valid pMSSM points in specific ranges of Wilson coefficients are kept.

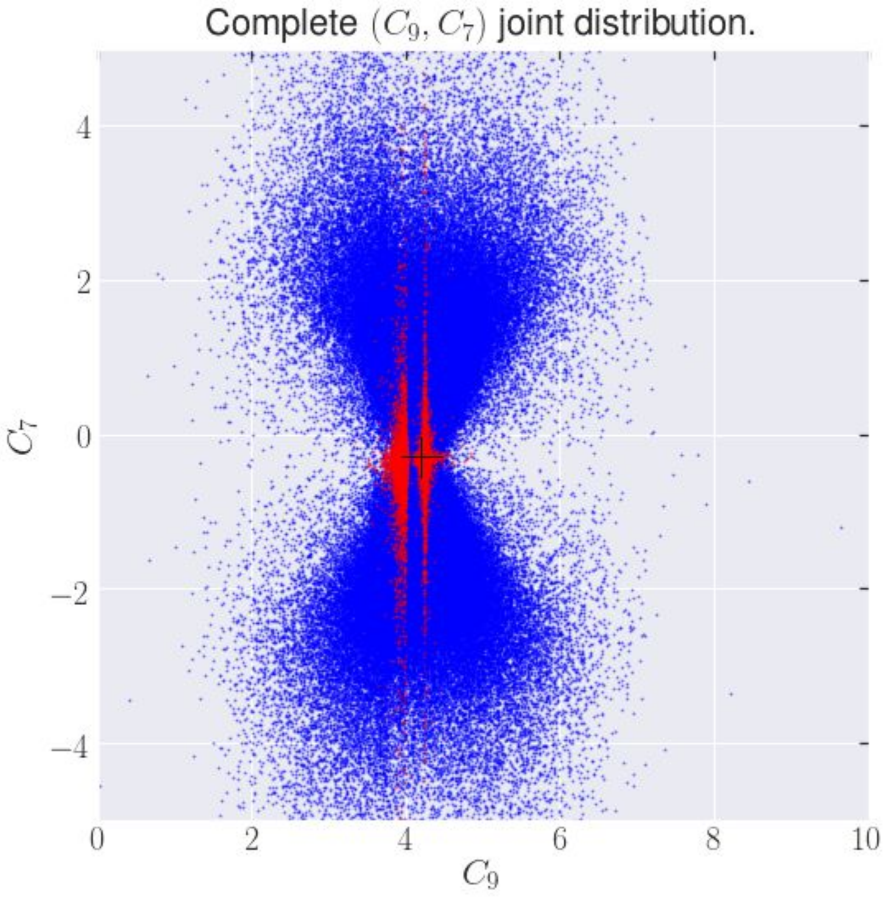
Parameter ranges

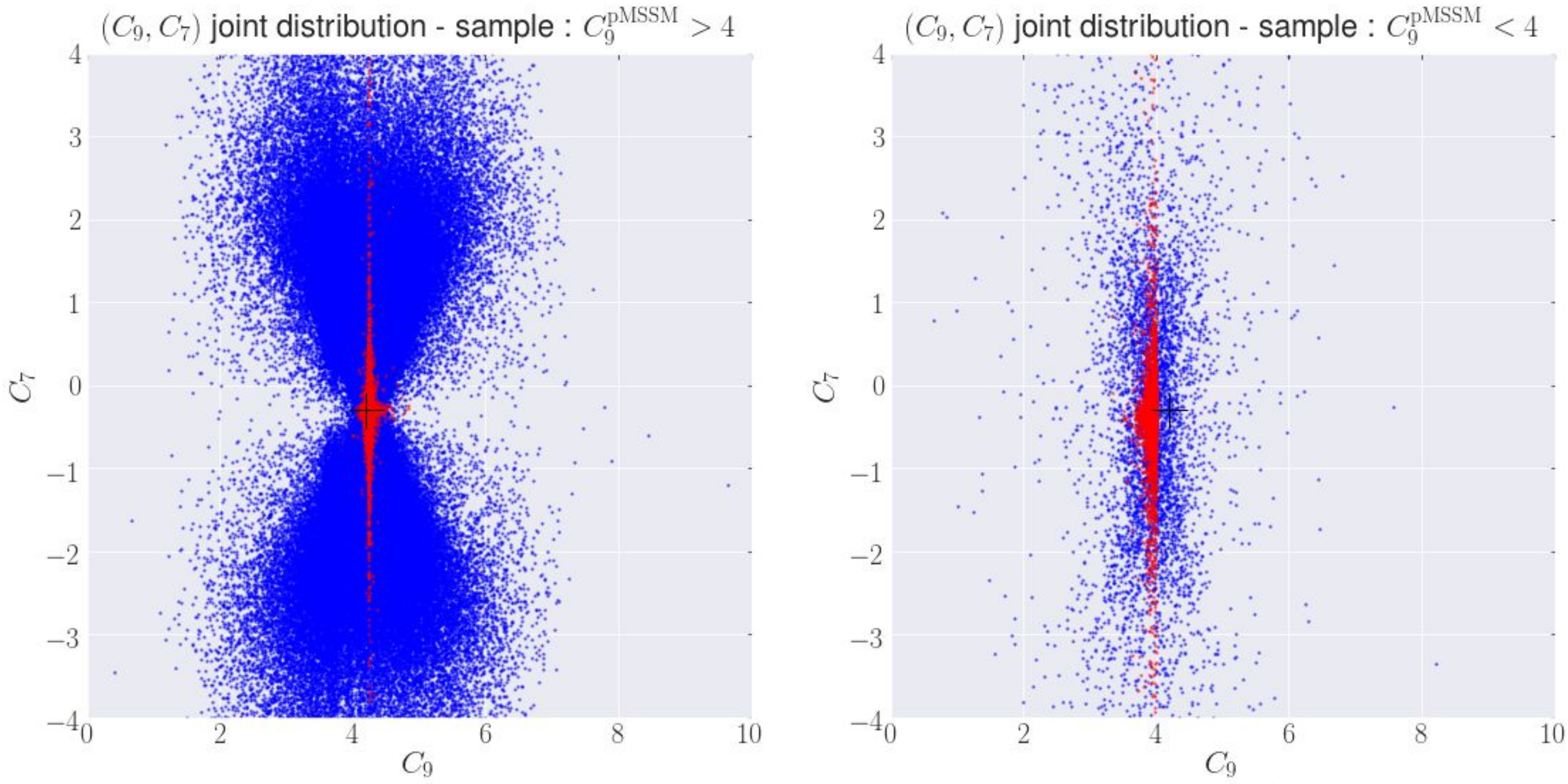
pMSSM parameter	Range
M_1	$[50, 5000]$
M_2	$[50, 5000]$
M_3	$[50, 5000]$
M_A	$[50, 5000]$
$\tan\beta$	$[2, 60]$
μ	$[-10000, 10000]$
A_t	$[-10000, 10000]$
A_b	$[-10000, 10000]$
A_τ	$[-10000, 10000]$
$M_{\tilde{e}_L} = M_{\tilde{\mu}_L}$	$[50, 5000]$
$M_{\tilde{e}_R} = M_{\tilde{\mu}_R}$	$[50, 5000]$
$M_{\tilde{\tau}_L}$	$[50, 5000]$
$M_{\tilde{\tau}_R}$	$[50, 5000]$
$M_{\tilde{q}_{1L}} = M_{\tilde{q}_{2L}}$	$[50, 5000]$
$M_{\tilde{q}_{3L}}$	$[50, 3000]$
$M_{\tilde{u}_R} = M_{\tilde{c}_R}$	$[50, 5000]$
$M_{\tilde{d}_R} = M_{\tilde{s}_R}$	$[50, 5000]$
$M_{\tilde{t}_R}$	$[50, 5000]$
$M_{\tilde{b}_R}$	$[50, 5000]$
$(\delta^{\tilde{u}}_{23})_{LR}$	$[-1, 1]$
$(\delta^{\tilde{u}}_{23})_{LL}$	$[-1, 1]$
$(\delta^{\tilde{u}}_{33})_{LR}$	$[-1, 1]$
$(\delta^{\tilde{d}}_{23})_{LL}$	$[-1, 1]$
$(\delta^{\tilde{d}}_{23})_{RR}$	$[-1, 1]$
$(\delta^{\tilde{d}}_{23})_{RL}$	$[-1, 1]$
$(\delta^{\tilde{d}}_{23})_{LR}$	$[-1, 1]$
$(\delta^{\tilde{d}}_{33})_{RL}$	$[-1, 1]$
$(\delta^{\tilde{d}}_{33})_{LR}$	$[-1, 1]$

Results

Spreading the distribution

- 1.7 x 10^5 / 1.6x 10^7 valid points.
- Scan constraints :
  - Tachyon
  - Charged LSP
  - Excluded LEP masses
  - Right set : C_9 in [4,4.5]
  - Left set : C_9 < 4
- Corresponding NMFV points obtained by recalculating the Wilson coeffs. on the same pMSSM points.
- Impressive spreading of the pMSSM distribution.
- Most of these points (~ 10^5) are excluded, but behaviour is remarkable.

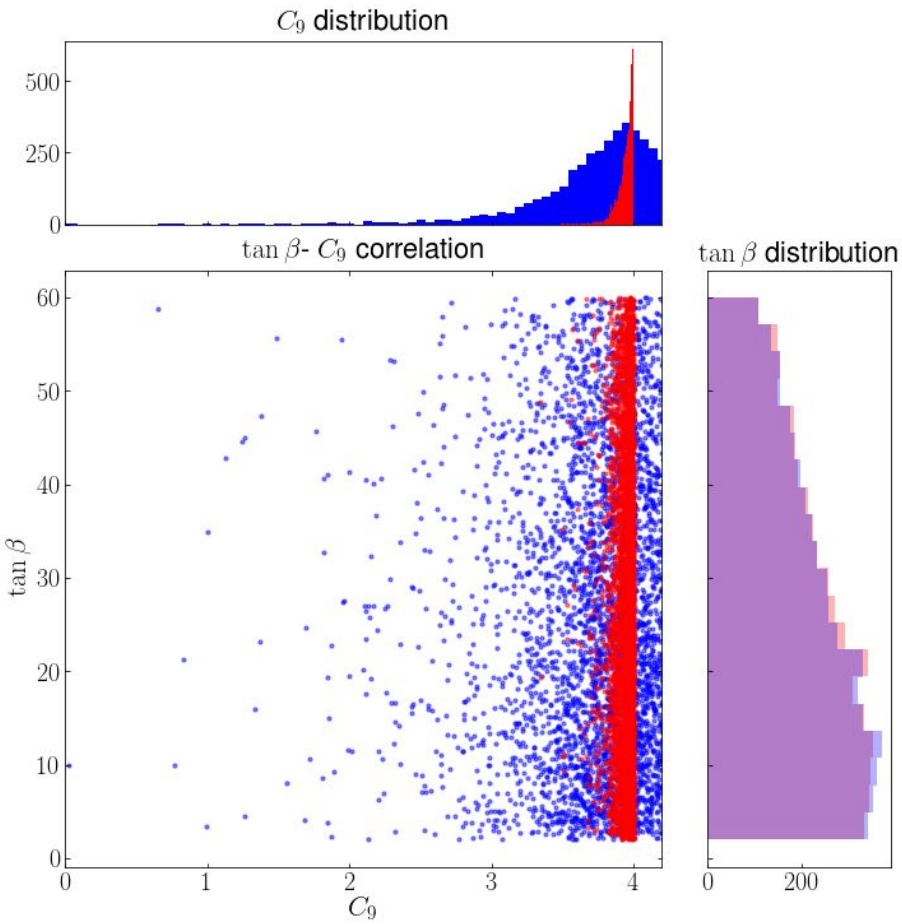


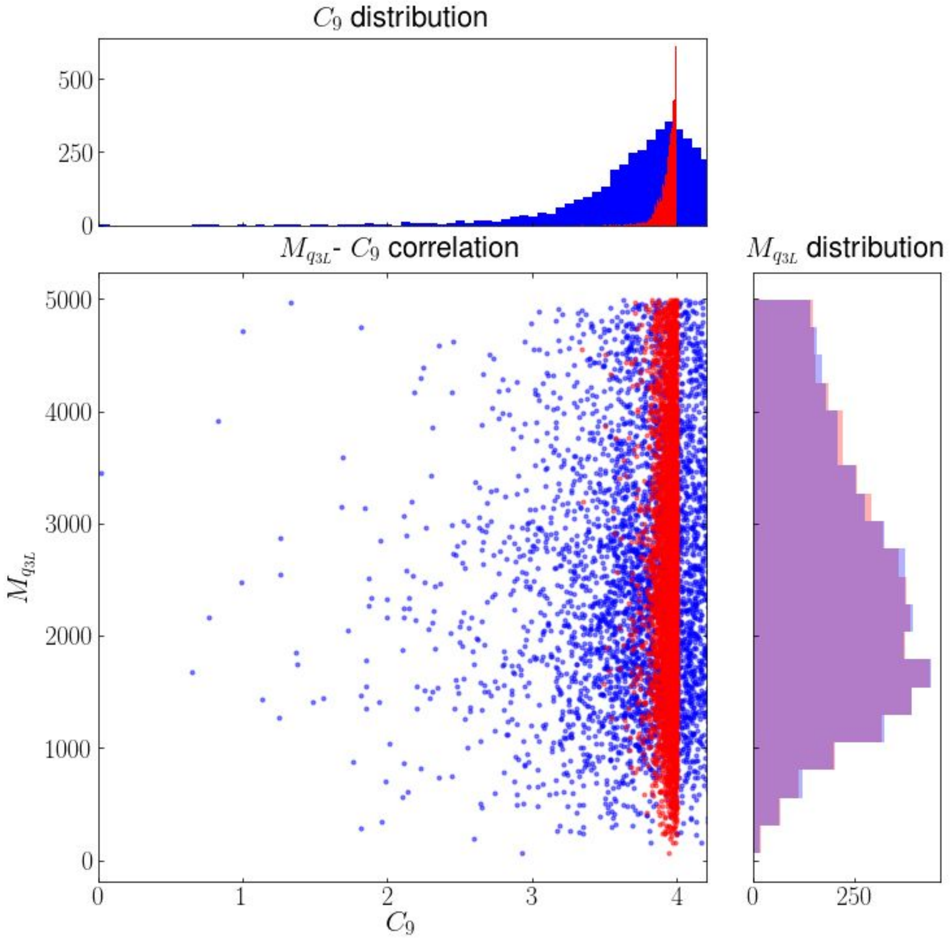


Sample size : 1.6 x 10^5 points

Sample size : 5 x 10^3 points

Correlated distributions, $C9^{PMSSM} < 4$



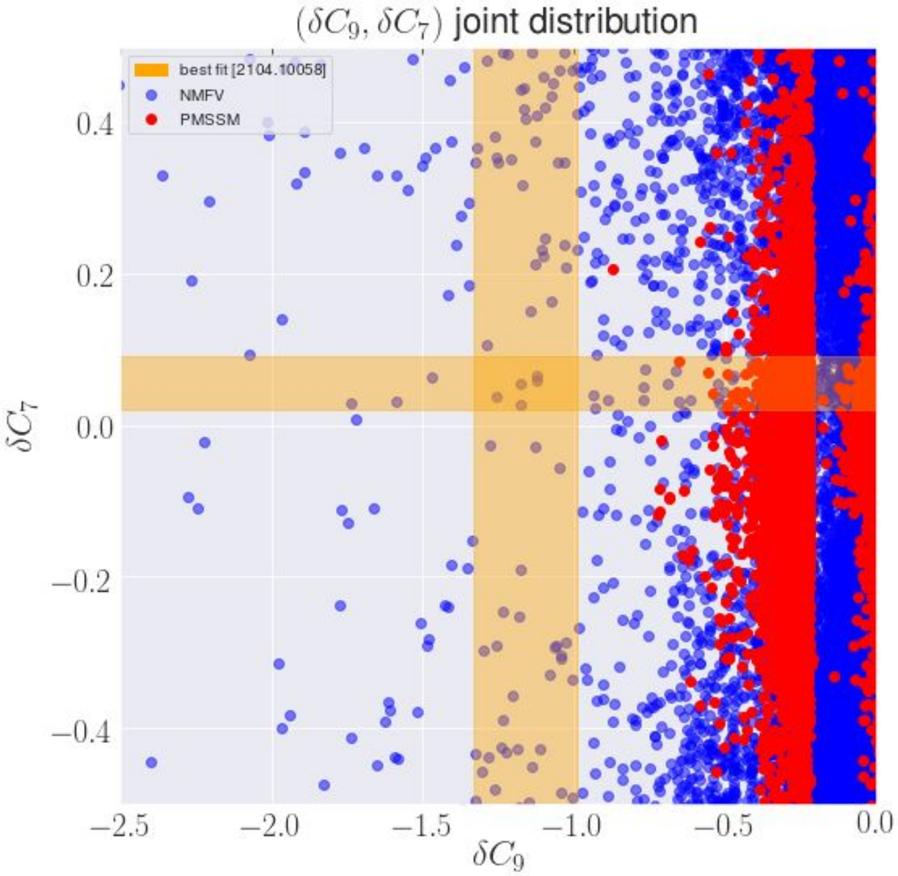


Best fit for two Wilson coefficients

- Best fit in the (δC9,δC7) plane , using the 20 operator global fit from [2104.10058].

- Some points are compatible with this fit.

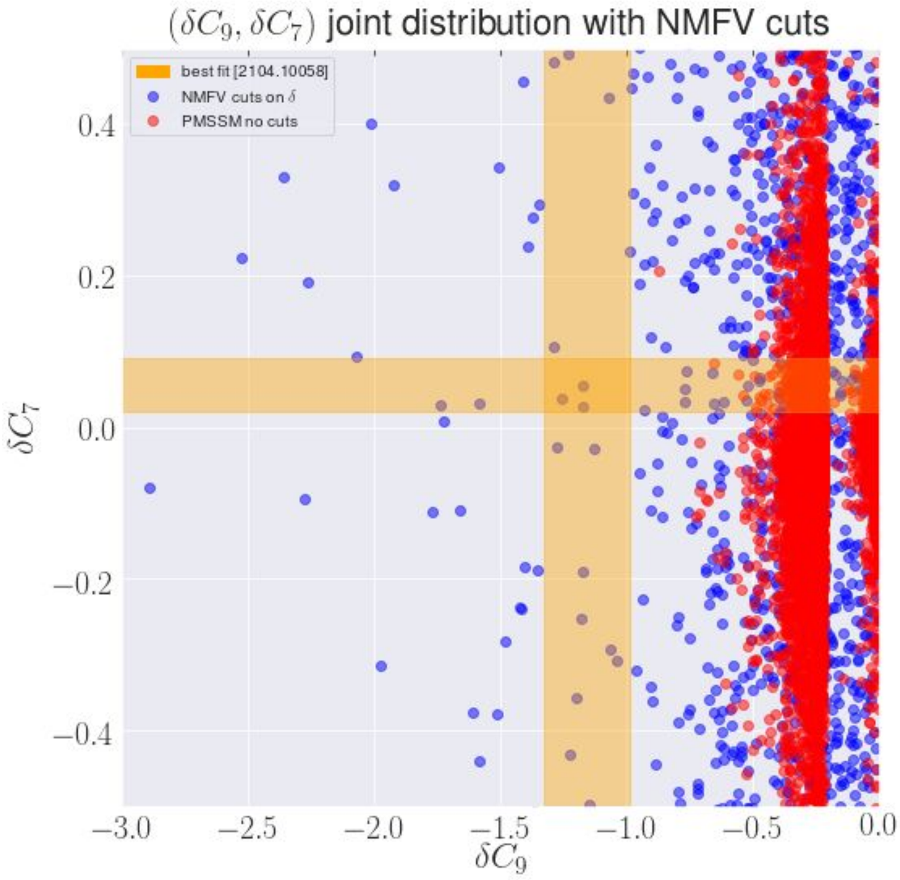
- Constraints :
  - RGE passing points (non tachyonic)
  - No charged LSP
  - LEP mass limits



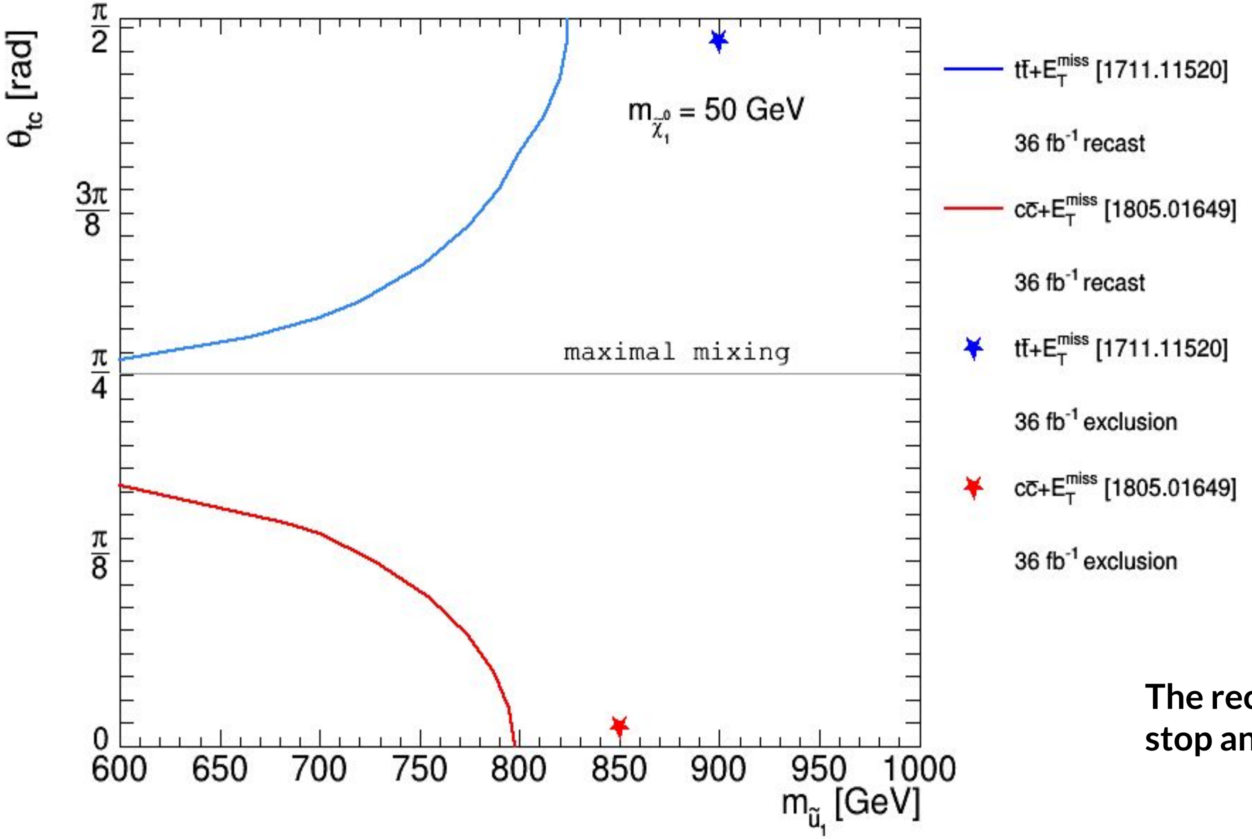
Best-fit and other constraints

- Best fit in the (δC9,δC7) plane , using the 20 operator global fit from [2104.10058].

- Constraints :
  - RGE passing points (non tachyonic)
  - No charged LSP
  - LEP mass limits
  - NMFV constraints[1509.05414]



Squark mixing and LHC limits



Recast of ATLAS searches by Chakraborty et al. [1808.07488]

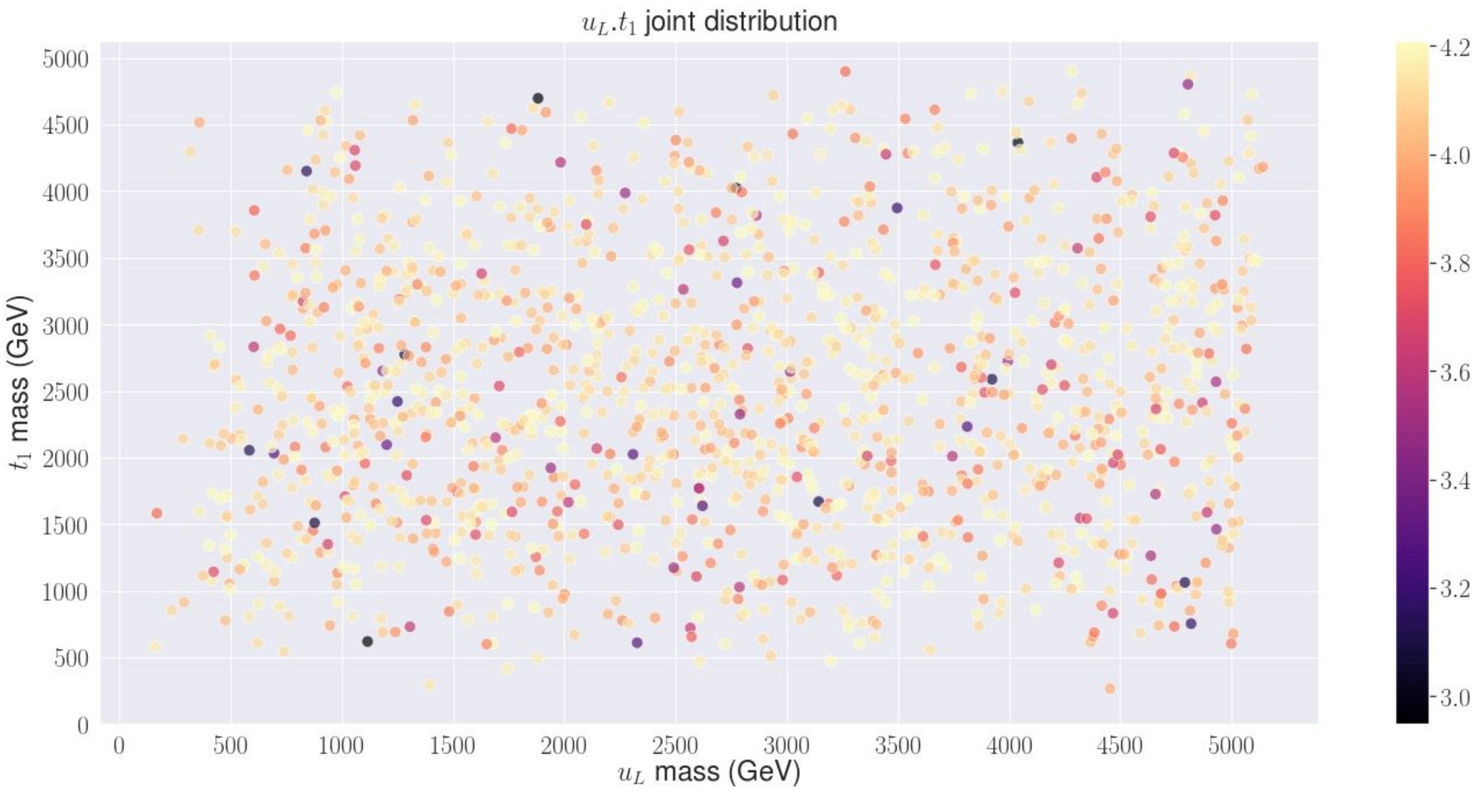
Simplified model of squark flavour violation :

$$\begin{pmatrix} \tilde{u}_1 \\ \tilde{u}_2 \end{pmatrix} = \begin{pmatrix} \cos\theta_{tc} & \sin\theta_{tc} \\ -\sin\theta_{tc} & \cos\theta_{tc} \end{pmatrix} \begin{pmatrix} \tilde{c}_R \\ \tilde{t}_R \end{pmatrix}$$

$$m_{\chi_1^0} = 50 \text{ GeV}$$

The recast severly reduces the ATLAS limits on stop and scharm massses [50-250 GeV}.

Squark mass distribution



Color scale : C9

Conclusion

- The NMFV approach using the MIA/FET gives promising results in the Wilson coefficient sector.

- Some presented model points correspond to Wilson coefficient fits, but need further investigation to check direct search limits.

- Finding model points in these highly dimensional parameter spaces is challenging. First results encouraging.