A taste of $SU(5)$ at the LHC: A Bayesian analysis

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Based on: arXiv:1403.3397 and arXiv:1501.05307

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Model:

SUSY/GUT theories aimed at unifying the three gauge couplings of the SM. Simplest candidate $\longrightarrow$ $SU(5)$.

$$W = \lambda_1^{ij} \mathcal{H}_1 10_i \bar{5}_j + \lambda_2^{ij} \mathcal{H}_2 10_i 10_j$$

with: $\{Q_i, U_i, E_i\} \in \mathbf{10_i}$, $\{L_i, D_i\} \in \mathbf{\bar{5}_i}$.

- We assume that the source of SUSY breaking is SU(5) singlet
- Remember that $\lambda_2^{ij} \mathcal{H}_2 \mathbf{10_i 10_j} \in W$ is $\mathbf{10_i 10_j}$ symmetric, only the symmetric part of λ_2^{ij} survives.

This leads to:

$$\begin{aligned} y_u &= y_u^t \\ a_u &= a_u^t \\ m_Q^2 &= m_U^2 \end{aligned}$$

Theoretical uncertainty:

Let us focus on $a_u = a_u^t$.

1. Stays confined within the up-squark sector.
2. The gluino dominates the running $\longrightarrow$ flavorblind.

Conclusion: $a_u \sim a_u^t$ at the TeV scale.

$$\mathcal{A}_{23} = \left. \frac{|(a_u)_{23} - (a_u)_{32}|}{\mathrm{Tr}\{\mathcal{M}_{\tilde{u}}^2\}^{1/2}} \right|_{Q=1\,\mathrm{TeV}} \sim 1\%$$

Should leave a footprint in the SUSY spectrum.
Question: Can we detect the presence of a quasi-symmetric a_u in a SUSY spectrum?

Bayesian Framework:

Small piece of information: $m_{\tilde{u}_i}$, mixing angles.. $\longrightarrow$ Bayesian analysis.
Model inference $\longrightarrow$ H_1: $SU(5)$ false. H_0: $SU(5)$ True.
$H_0 = H_1(\mathcal{A}_{23} = 0)$
Bayes factor:

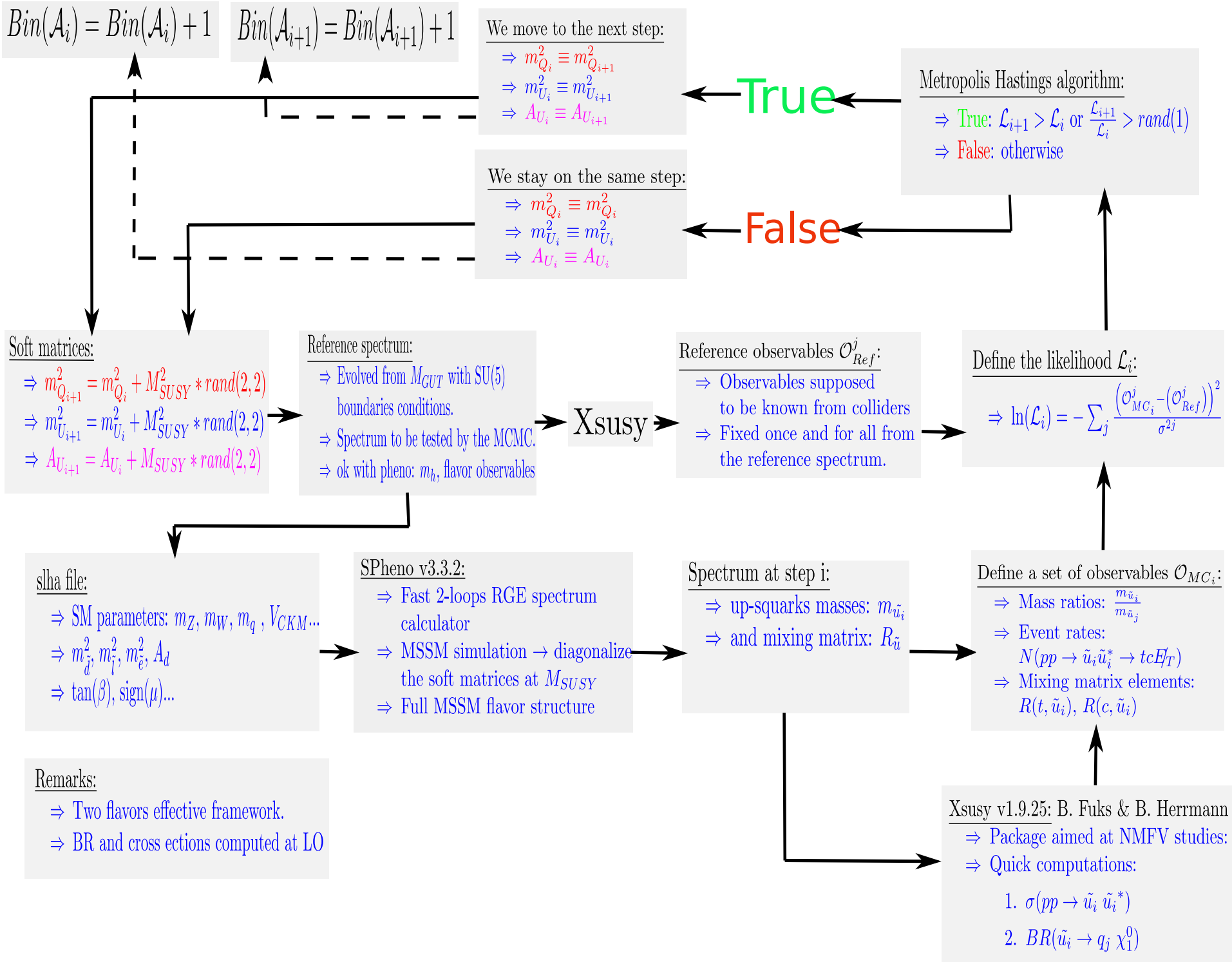
$$B_{01} = \frac{p(d|H_0)}{p(d|H_1)}\,.$$

SDDR:

$$S = \left.\frac{p(\mathcal{A}|d,H_1)}{\int d\mathcal{A}\, p(\mathcal{A}|d,H_1)}\frac{1}{p(\mathcal{A}|H_1)}\right|_{\mathcal{A}=0}\,.$$

Jeffrey's scale:

	Weak	Moderate	Strong
SDDR	$\gtrsim 3$	$\gtrsim 12$	$\gtrsim 150$


$Bin(\mathcal{A}_i) = Bin(\mathcal{A}_i) + 1$
$Bin(\mathcal{A}_{i+1}) = Bin(\mathcal{A}_{i+1}) + 1$
We move to the next step:
$\Rightarrow m^2_{Q_i} \equiv m^2_{Q_{i+1}}$
$\Rightarrow m^2_{U_i} \equiv m^2_{U_{i+1}}$
$\Rightarrow A_{U_i} \equiv A_{U_{i+1}}$
True
Metropolis Hastings algorithm:
$\Rightarrow$ True: $\mathcal{L}_{i+1} > \mathcal{L}_i$ or $\frac{\mathcal{L}_{i+1}}{\mathcal{L}_i} > rand(1)$
$\Rightarrow$ False: otherwise
We stay on the same step:
$\Rightarrow m^2_{Q_i} \equiv m^2_{Q_i}$
$\Rightarrow m^2_{U_i} \equiv m^2_{U_i}$
$\Rightarrow A_{U_i} \equiv A_{U_i}$
False
Soft matrices:
$\Rightarrow m^2_{Q_{i+1}} = m^2_{Q_i} + M^2_{SUSY} * rand(2,2)$
$\Rightarrow m^2_{U_{i+1}} = m^2_{U_i} + M^2_{SUSY} * rand(2,2)$
$\Rightarrow A_{U_{i+1}} = A_{U_i} + M_{SUSY} * rand(2,2)$
Reference spectrum:
$\Rightarrow$ Evolved from M_{GUT} with SU(5) boundaries conditions.
$\Rightarrow$ Spectrum to be tested by the MCMC.
$\Rightarrow$ ok with pheno: m_h, flavor observables
Xsusy
Reference observables $\mathcal{O}^j_{Ref}$:
$\Rightarrow$ Observables supposed to be known from colliders
$\Rightarrow$ Fixed once and for all from the reference spectrum.
Define the likelihood $\mathcal{L}_i$:
$\Rightarrow \ln(\mathcal{L}_i) = -\sum_j \frac{\left(\mathcal{O}^j_{MC_i} - (\mathcal{O}^j_{Ref})\right)^2}{\sigma^{2j}}$
slha file:
$\Rightarrow$ SM parameters: m_Z, m_W, m_q, V_{CKM}...
$\Rightarrow m^2_{\tilde{d}}, m^2_{\tilde{l}}, m^2_{\tilde{e}}, A_d$
$\Rightarrow \tan(\beta)$, sign(μ)...
SPheno v3.3.2:
$\Rightarrow$ Fast 2-loops RGE spectrum calculator
$\Rightarrow$ MSSM simulation $\rightarrow$ diagonalize the soft matrices at M_{SUSY}
$\Rightarrow$ Full MSSM flavor structure
Spectrum at step i:
$\Rightarrow$ up-squarks masses: $m_{\tilde{u}_i}$
$\Rightarrow$ and mixing matrix: $R_{\tilde{u}}$
Define a set of observables $\mathcal{O}_{MC_i}$:
$\Rightarrow$ Mass ratios: $\frac{m_{\tilde{u}_i}}{m_{\tilde{u}_j}}$
$\Rightarrow$ Event rates: $N(pp \rightarrow \tilde{u}_i \tilde{u}_i^* \rightarrow tc\not{E}_T)$
$\Rightarrow$ Mixing matrix elements: $R(t, \tilde{u}_i)$, $R(c, \tilde{u}_i)$
Remarks:
$\Rightarrow$ Two flavors effective framework.
$\Rightarrow$ BR and cross ections computed at LO
Xsusy v1.9.25: B. Fuks & B. Herrmann
$\Rightarrow$ Package aimed at NMFV studies:
$\Rightarrow$ Quick computations:
1. $\sigma(pp \rightarrow \tilde{u}_i\ \tilde{u}_i^*)$
2. $BR(\tilde{u}_i \rightarrow q_j\ \chi_1^0)$

Example:

Can we constrain the posterior pdf enough using top-polarimetry?

$BR(\tilde{c}_{L/R} \to h\, \tilde{t}_{R/L}) \propto |\delta_{23}^{L/R}|^2 \propto \left(a_U^2\right)_{23}$

- $N_{ht_- c}$: $p\, p \to \tilde{u}_i\, \tilde{u}_i^* \to h\, c\, t_L$
- $N_{ht_+ c}$: $p\, p \to \tilde{u}_i\, \tilde{u}_i^* \to h\, c\, t_R$

$$i = 1, 2, 3, 4$$

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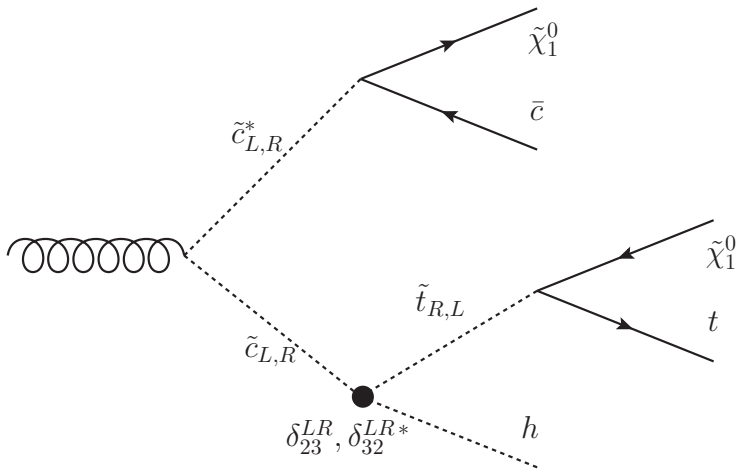
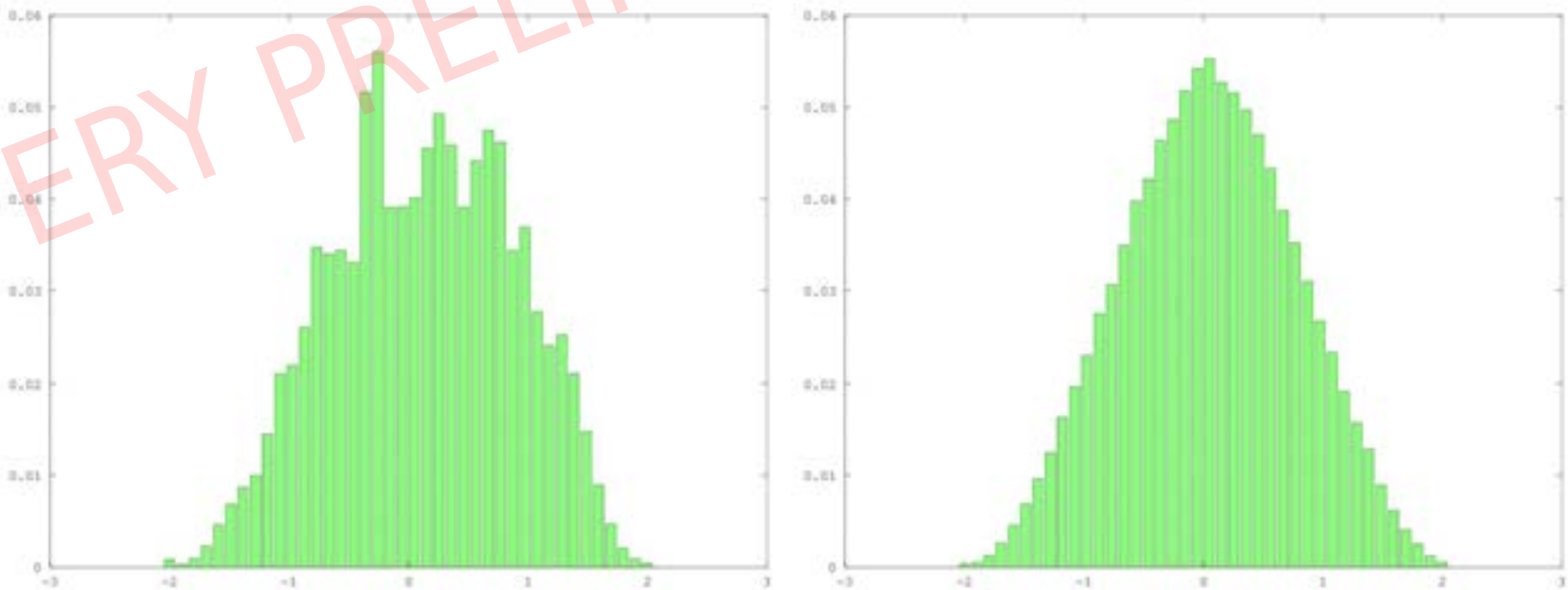


Results:

Left: posterior $p(\mathcal{A}_{23}|d, H_1)$ Right: prior $p(\mathcal{A}_{23}|H_1)$



$$S = 0.726$$

Conclusions:

- SUSY-$SU(5)$ implies $a_u = a_u^t$.
- Stable during the runnning down to M_{SUSY}.
- Bayesian statistical tests are possible to constrain a_u.
- Algorithm still to be tested.
- S. Fichet's talk: A taste of $SU(5)$ at the LHC : Terascale meeting Saclay 31/03.
- More on SU(5) tests:
  - arXiv:1403.3397
  - arXiv:1501.05307