Effective Operators in the MSSM

Guillaume Drieu La Rochelle, LAPTH

MSSM Part I : a promising candidate

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- The SUSY solution

  MSSM
  - Supersymmetric
    - Free of quadratic divergences
    - Unification of the coupling constants
  - Minimal → Most natural extension

MSSM Part II : The desillusion

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  - An elusive Higgs

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Radiative Corrections, but ...

$$\boxed{M_h \; > 114.4 \text{ GeV}}$$

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- Far from complete
  - Mechanism for the susy breaking
  - The mu problem
  - The little hierarchy problem

Effective Field Theory

- Why? ⇒ Include high energy physics contribution without the explicit knowing of that high energy theory.

- How? ⇒ Global theory at low energy $\sim$ Low energy lagrangian + Effective Operators

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EFT How-To

1. Choose a scale high/low energy.
2. Choose a field theory for low energy physics (renormalizable).
3. Add some effective operators.

   (M,v,f) scales of effective theory
4. Infer the value of c_k :
   - from measurements
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$$f^4 \frac{c_k}{M^{d_k}} \mathcal{O}_k \left(\frac{\phi}{v} \right)$$

Compatible with **symmetries** of the low-energy theory

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  - Done in many Beyond the MSSM models

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Gauge
Susy ...

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- Which corrections to expect
- Each effective operator acts on several observables → **Correlations**

Choosing our Effective Operators

- Constraints
  - $f^4 \frac{c_k}{M^{d_k}} \mathcal{O}_k \left(\frac{\phi}{v} \right)$ $\boxed{c_k \, M^{d'_k} \, \mathcal{O}_k(\phi)}$ $M \sim 10 \text{ Tev}$

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Kähler Potential	Superpotential
Standard	Standard
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Effectif	$\frac{\mathbf{a}_1}{M^2}\,(H_1^\dagger e^{2gV_1} H_1)^2 + \frac{\mathbf{a}_2}{M^2}\,(H_2^\dagger e^{2gV_2} H_2)^2$ ...	Effectif	$\frac{\zeta_1}{M}\,(H_1.H_2)^2$ + ...
	Dimension 6		Dimension 5

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Base of Effective Operators

Dimension 5

$$\frac{\zeta_1}{M}(H_1.H_2)^2$$

Dimension 6

$$\frac{\mathbf{a}_i}{M^2}\,(H_i^\dagger e^{2gV_i}H_i)^2$$

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Strong action on masses

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Action on standard couplings

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Higgs/Neutralinos masses

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High versus Low

t_β

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  - Focus on the Higgs sector

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Spurion

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Superpotential term

Scalar higgs mixing

Theoretical Expectations

- Scalar Higgs potential
  - D and F terms

$$\boxed{\mathbf{H}_1 = H_1 + \sqrt{2}\theta\tilde{H}_1 + \theta^2 F_{H_1}}$$

- Scalar Higgs – Gauge bosons interactions
  - $\boxed{\mathcal{L} = (DH_1)^\dagger DH_1}$
- Standard fermions masses and couplings
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Theoretical Expectations

	Standard MSSM	Effective Operators
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$\dots$

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An automatic code :

- LanHEP
- Mathematica

Expected Consequences

- Theory $\longleftrightarrow$ Data
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The two effects add up at order 1

$$\boxed{m_h = m_{h\,0} + \delta_{\text{1-loop}} m_h + \delta_{\text{eff}} m_h}$$

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Predictions
Dark matter searches
Collider experiments

Constraints Coming from standard measurements

- Coupling between Z and standard fermions

$$\boxed{g_{Z\overline{f}f\ \mathrm{L/R}} = (1+\kappa_{\mathrm{L/R}})\ g_{Z\overline{f}f\ \mathrm{L/R}}(\mathrm{SM})}$$

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$$\kappa_{right} = (a_{10} - t_\beta^2 a_{30} + t_\beta^4 a_{20}) \frac{2(4c_W^2 - 1)}{e^2(1+2c_W^1)(1+t_\beta^2)^2} \frac{M_W^2}{M^2}$$

- Forward Backward asymmetries

Observable	Order0	a_{10}	a_{20}	a_{30}	Exp. Value
$A_{FB}(\mu)$	0.0181	0.000033	0.00052	-0.00013	0.0169 ± 0.0013
$A_{FB}(b)$	0.1053	0.0001	0.0017	-0.0004	0.0995 ± 0.0017
$A_{FB}(c)$	0.0753	0.00008	0.0012	-0.0003	0.0713 ± 0.0036

Constraints Coming from standard measurements

- Coupling between Z and standard fermions

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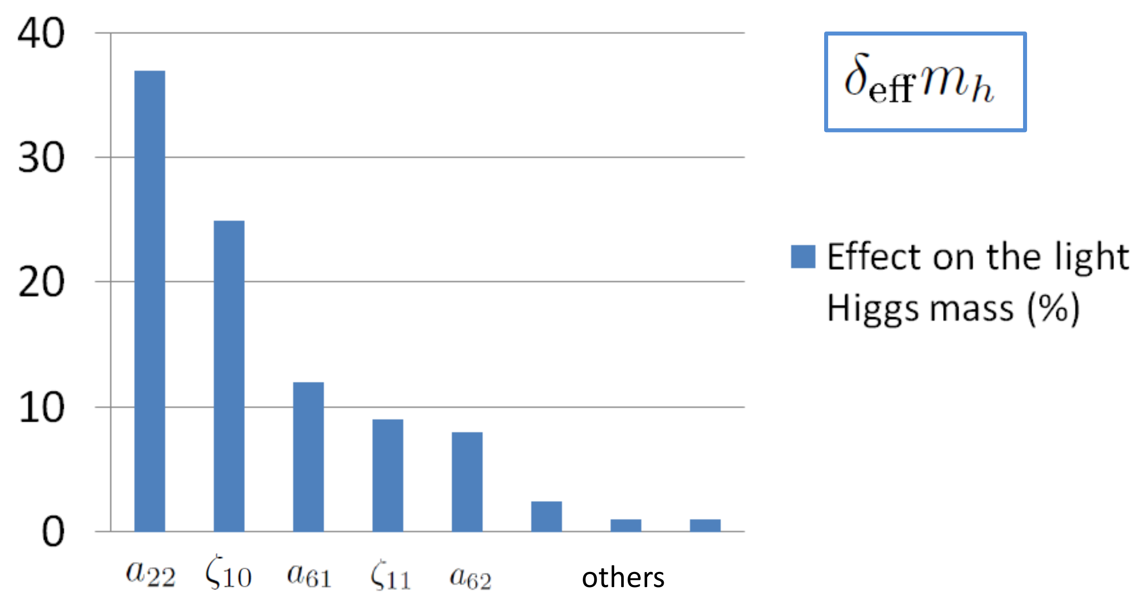
- Constraints quite loose $a_{i0} \sim 1$

Higgs/Neutralinos Masses

- Operators appearing :

	Main Operators	Effects
Neutralino mass	$a_{61},\ \zeta_{10}$	A few GeV
Light Higgs mass	$\zeta_{10},\ \zeta_{11},\ a_{22},\ a_{61},\ a_{62}$	10-20 GeV

$\boxed{\delta_{\text{eff}} m_h}$



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Correction to the light Higgs mass (from Antoniadis et al.)

$$\begin{aligned}
\delta' m_h^2 = {} & -2\,v^2\left[\alpha_{22}\,m_0^2 + (\alpha_{30}+\alpha_{40})\mu_0^2 + 2\alpha_{61}\,m_0\,\mu_0 - \alpha_{20}\,m_Z^2\right] - \frac{(2\,\zeta_{10}\,\mu_0)^2\ v^4}{m_A^2 - m_Z^2} \\
& + \frac{v^2}{\tan\beta}\left[\frac{1}{(m_A^2 - m_Z^2)}\Big(4\,m_A^2\,\big(\,(2\alpha_{21}+\alpha_{31}+\alpha_{41}+2\alpha_{81})\,m_0\,\mu_0 + (2\alpha_{50}+\alpha_{60})\,\mu_0^2 + \alpha_{62}\,m_0^2\big)\right. \\
& - \left.(2\alpha_{60} - 3\alpha_{70})\,m_A^2\,m_Z^2 - (2\alpha_{60}+\alpha_{70})\,m_Z^4\Big) + \frac{8\,(m_A^2 + m_Z^2)\ (\mu_0\,m_0\,\zeta_{10}\,\zeta_{11})\,v^2}{(m_A^2 - m_Z^2)^2}\right] \\
& + \mathcal{O}(1/\tan^2\beta)
\end{aligned}$$

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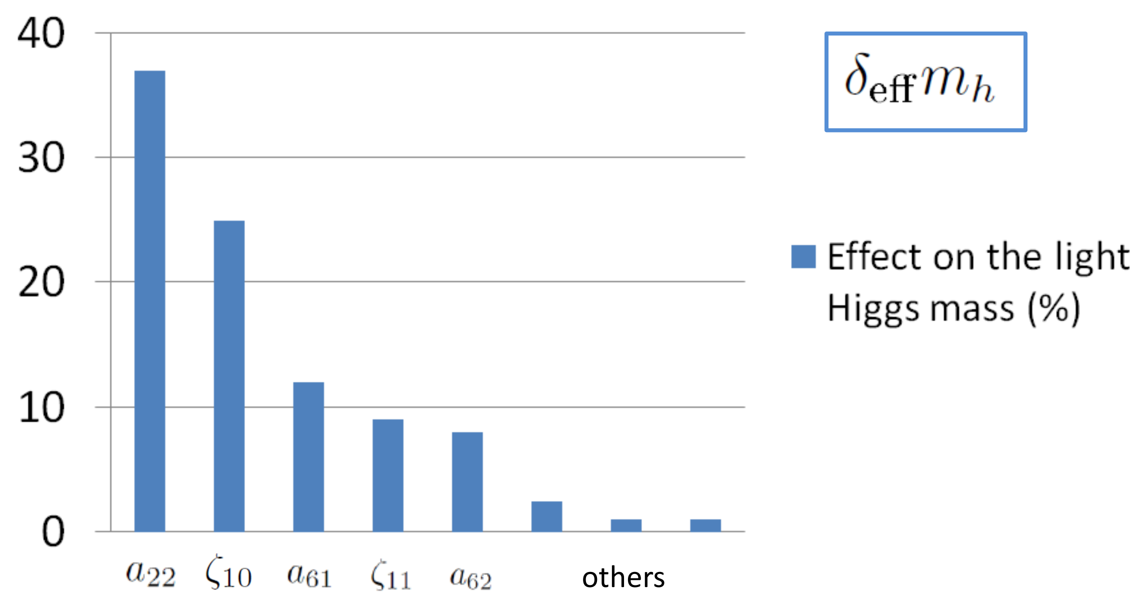

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  Most sensitive are : $\zeta_{10} \quad a_{61}$

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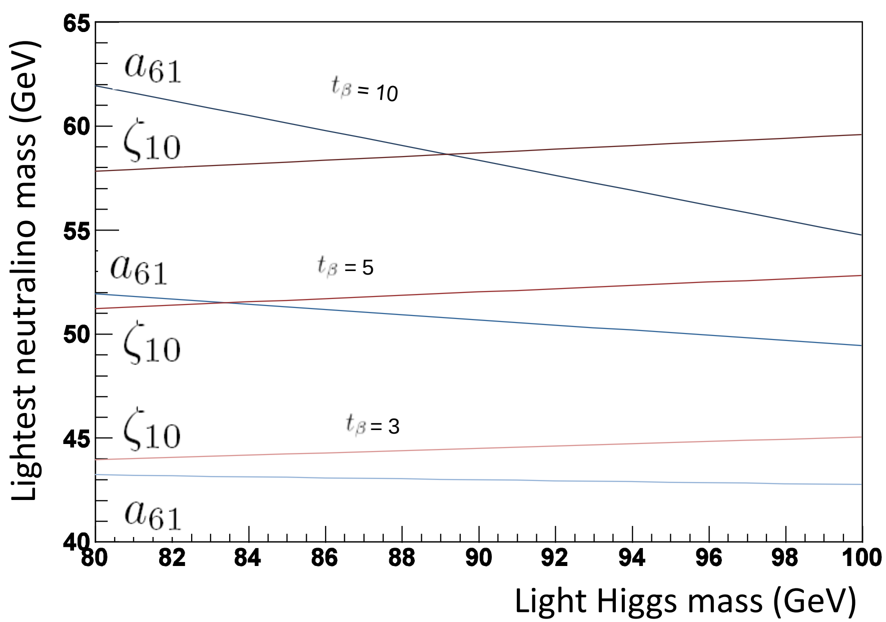
Higgs and neutralinos correlation for ζ_{10} a_{61}



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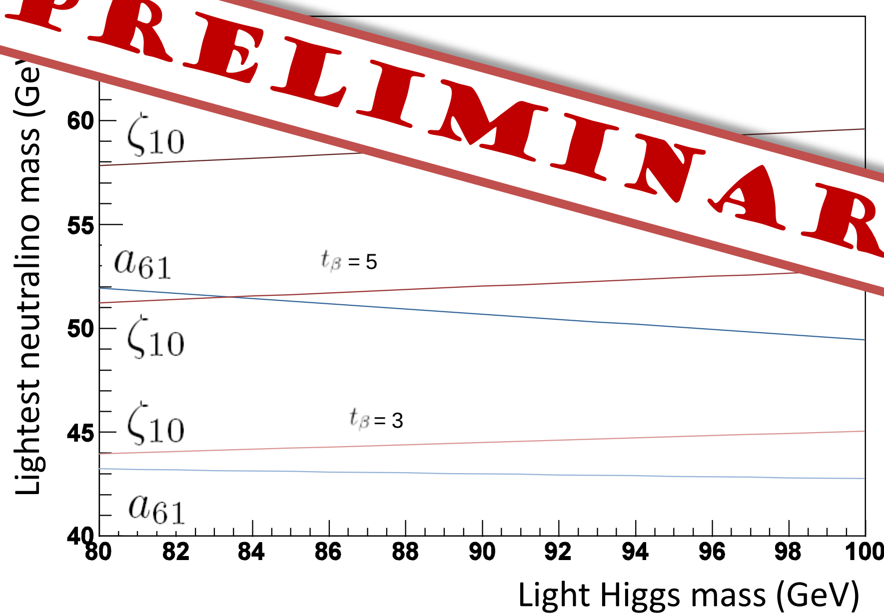

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- Can we include one in the other?
  - Use effective couplings to account for loops
  - Check whether a loop induces the same correlations than an effective operator

$\Longrightarrow$ Fasten one-loop calculations

Outlook

- Higgs phenomenology
- Effects on Dark Matter and colliders experiments
- Join effective operators with one loop calculations
- Infer what kind of physics leads to what kind of operators