ON THE RENORMALISATION OF THE NMSSM

Guillaume CHALONS

LPT Orsay

based on G. Bélanger, V. Bizouard, F. Boudjema, GC, PRD93 (2016) 11, 115031
G. Bélanger, V. Bizouard, F. Boudjema, GC, *to appear*

NMSSM Workshop, Orsay, November '16

STATING THE CHALLENGE

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  - which observable to take as input, in the absence of any exp. meas.(apart from Higgs and SM) ??
  - Choice of input almost infinite
  - Mixing: states tangled up
  - Breaking up degeneracies, signs...(even phases? But here only $\mathbb{R}$ param)

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- At NLO things get even more complicated
  - Additional mixing due to field renorm.
  - Scale/Scheme dependence of the parameters (related to choice of input at LO)
  - Rad. cor. under control ?

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Currently, no obvious choice of input to guide us, make educated guesses (*e.g* start with masses) and test. Benefit from experience gained with the MSSM (from LO and NLO studies). Stay agnostic and test several possibilities to gain insights.

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COUNTING PARAMETERS

$$W_{NMSSM}^{\mathbb{Z}_3} = W_{MSSM}|_{\mu=0} + \lambda \hat{S}\hat{H}_u \cdot \hat{H}_d + \frac{\kappa}{3}\hat{S}^3$$

$$-\mathcal{L}_{\text{soft}} = m_{H_u}^2 |H_u|^2 + m_{H_d}^2 |H_d|^2 + m_S^2 |S|^2 + (\lambda A_\lambda H_u \cdot H_d S + \frac{1}{3}\kappa A_\kappa S^3 + h.c)$$

with

$$H_d = \begin{pmatrix} v_d + (h_d^0 + ia_d^0)/\sqrt{2} \\ H_d^- \end{pmatrix}, \quad H_u = \begin{pmatrix} H_u^+ \\ v_u + (h_u^0 + ia_u^0)/\sqrt{2} \end{pmatrix}, \quad S = s + (h_s^0 + ia_s^0)/\sqrt{2}$$

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NMSSM HIGGS POTENTIAL WITH $\mathbb{Z}_3$ SYMMETRY, $\mathbb{R}$ PARAM

$$\begin{aligned} V_{Higgs} =& |\lambda(H_u^+ H_d^- - H_u^0 H_d^0) + \kappa S^2|^2 + (m_{H_u}^2 + |\lambda S|^2)\left(|H_u^0|^2 + |H_u^+|^2\right) \\ &+ (m_{H_d}^2 + |\lambda S|^2)\left(|H_d^0|^2 + |H_d^+|^2\right) + \frac{g^2 + g'^2}{8}\left(|H_u^0|^2 + |H_u^+|^2 - |H_d^0|^2 - |H_d^-|^2\right)^2 \\ &+ \frac{g^2}{2}|H_u^+ H_d^{0*} + H_u^0 H_d^{-*}|^2 + m_S^2|S|^2 + (\lambda A_\lambda (H_u^+ H_d^- - H_u^0 H_d^0)S + \frac{1}{3}\kappa A_\kappa S^3 + h.c). \end{aligned}$$

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&+ (m_{H_d}^2 + |\lambda S|^2)\left(|H_d^0|^2 + |H_d^+|^2\right) + \frac{M_Z^2}{4v^2}\left(|H_u^0|^2 + |H_u^+|^2 - |H_d^0|^2 - |H_d^-|^2\right)^2 \\
&+ \frac{M_W^2}{v^2}|H_u^+ H_d^{0*} + H_u^0 H_d^{-*}|^2 + m_S^2|S|^2 + (\lambda A_\lambda (H_u^+ H_d^- - H_u^0 H_d^0)S + \frac{1}{3}\kappa A_\kappa S^3 + h.c).
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and $\tan\beta = v_u/v_d$ and s

$$diag(m_{h_1^0}^2, m_{h_2^0}^2, m_{h_3^0}^2) = S_h M_S^2 S_h^t, \quad diag(m_{A_1^0}^2, m_{A_2^0}^2, 0) = P_a M_P^2 P_a^t, \quad m_H^\pm$$

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NEUTRALINO SECTOR

$$Y = \underbrace{\begin{pmatrix} M_1 & 0 & -M_Z s_W c_\beta & M_Z s_W s_\beta & 0 \\ \cdot & M_2 & M_Z c_W c_\beta & -M_Z c_W s_\beta & 0 \\ \cdot & \cdot & 0 & -\mu_{\text{eff}} & -\lambda v s_\beta \\ \cdot & \cdot & \cdot & 0 & -\lambda v c_\beta \\ \cdot & \cdot & \cdot & \cdot & 2\kappa s \end{pmatrix}}_{\xrightarrow{N}(\tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_3^0, \tilde{\chi}_4^0, \tilde{\chi}_5^0)}$$

CHARGINO SECTOR

$$X = \underbrace{\begin{pmatrix} M_2 & \sqrt{2} M_W s_\beta \\ \sqrt{2} M_W c_\beta & \mu_{\text{eff}} \end{pmatrix}}_{\xrightarrow{U,V}(\tilde{\chi}_1^\pm, \tilde{\chi}_2^\pm)}$$

$$\boxed{\mu_{\text{eff}} \equiv \mu = \lambda s}$$

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INPUT PARAMETERS

All in all we have

$$\underbrace{g, g'}_{\text{SM}}, \underbrace{v_u, v_d, s, \lambda, \kappa}_{\text{Higgs \& } \tilde{\chi}}, A_\lambda, A_\kappa, m^2_{H_u}, m^2_{H_d}, m^2_S, M_1, M_2$$

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we trade some for physical parameters

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- Min. cond. $\Longrightarrow \boxed{t_{h^0_i} \equiv 0}$, $i = u, d, s$
- Remains 8 parameters/variables to be determined (and their resp. counterterms once going to renormalisation).
- Equivalently, we need to find 8 exp inputs/definitions which are linked unambigously to the original 8 parameters ($C^8_{13} = 1287$ choices if masses)
- Ex: Even at LO knowing 8 masses is not enough, because of mixing knowledge of nature (singlet/doublet, bino/wino etc...) desirable!

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SECTORS

- Fermion $\longrightarrow$ as in the SM
- Gauge $\longrightarrow$ as in the SM
- Sfermion $\longrightarrow$ as in the MSSM

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$$\boxed{\mathcal{L}^0 = \mathcal{L}(\lambda_i, M_{ij}, \phi_i) + \delta\mathcal{L}(\lambda_i, M_{ij}, \phi_i, \delta\lambda_i, \delta M_{ij}, \delta Z_{ij})}$$

SHIFTS

- $\Phi_i^0 \longrightarrow (\delta_{ij} + \frac{1}{2}\delta Z_{ij})\Phi_j$
- $\lambda_i^0 \longrightarrow \lambda_i + \delta\lambda_i,\ v_i^0 \longrightarrow v_i + \delta v_i$
- $M_{ij}^{0\,2} \longrightarrow M_{ij}^2 + \delta M_{ij}^2$
- $T_i^0 \longrightarrow T_i + \delta T_i$

ON-SHELL SCHEME

- $\widetilde{\mathcal{R}e}\hat{\Sigma}_{ii}(M_i^2) = 0 \longrightarrow \delta M^2$
- $\widetilde{\mathcal{R}e}\hat{\Sigma}'_{ii}(M_i^2) = 0 \longrightarrow \delta Z_{ii}$
- $\widetilde{\mathcal{R}e}\hat{\Sigma}_{ij}(M_i^2) = 0 \longrightarrow \delta Z_{ij}$
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- $\widetilde{\mathcal{R}e}\hat{T}_i = 0 \longrightarrow \delta T_i$

- In our framework, no shift on mixing matrices S_h, P_a, N, U, V, implicitely contained in $\delta M_{ij}/\delta Z_{ij}$, same with the gauge-fixing (not shown here)

- Choose a minimum set of 8 conditions to renormalise the parameters

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INVERTING THE PROBLEM

- In its most generality we get a 8×8 matrix system to invert

$$\underbrace{\begin{pmatrix} \delta\text{input}_1 - \delta R_1 \\ \delta\text{input}_2 - \delta R_2 \\ \delta\text{input}_3 - \delta R_3 \\ \delta\text{input}_4 - \delta R_4 \\ \delta\text{input}_5 - \delta R_5 \\ \delta\text{input}_6 - \delta R_6 \\ \delta\text{input}_7 - \delta R_7 \\ \delta\text{input}_8 - \delta R_8 \end{pmatrix}}_{\delta\vec{m}} = \underbrace{\begin{pmatrix} W_{11} & W_{12} & W_{13} & W_{14} & W_{15} & W_{16} & W_{17} & W_{18} \\ W_{21} & W_{22} & W_{23} & W_{24} & W_{25} & W_{26} & W_{27} & W_{28} \\ W_{31} & W_{32} & W_{33} & W_{34} & W_{35} & W_{36} & W_{37} & W_{38} \\ W_{41} & W_{42} & W_{43} & W_{44} & W_{45} & W_{46} & W_{47} & W_{48} \\ W_{51} & W_{52} & W_{53} & W_{54} & W_{55} & W_{56} & W_{57} & W_{58} \\ W_{61} & W_{62} & W_{63} & W_{64} & W_{65} & W_{66} & W_{67} & W_{68} \\ W_{71} & W_{72} & W_{73} & W_{74} & W_{75} & W_{76} & W_{77} & W_{78} \\ W_{81} & W_{82} & W_{83} & W_{84} & W_{85} & W_{86} & W_{87} & W_{88} \end{pmatrix}}_{\mathcal{W}_8} \underbrace{\begin{pmatrix} \delta t_\beta \\ \delta A_\lambda \\ \delta A_\kappa \\ \delta\lambda \\ \delta\kappa \\ \delta M_1 \\ \delta M_2 \\ \delta\mu \end{pmatrix}}_{\delta\vec{\mathcal{M}}}$$

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☞ Solution :

$$\boxed{\delta\vec{\mathcal{M}} = \frac{(\text{com}\mathcal{W}_8)^T}{\det\mathcal{W}_8}\delta\vec{m}} \quad \text{iff} \quad \boxed{\det W \neq 0}$$

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☞ Even better: choose inputs$_i$ such that $\mathcal{W}_8$ is block diagonal
$\mathcal{W}_8 = \mathcal{W}_n \oplus \mathcal{W}_m \oplus \cdots$, $n + m + \cdots = 8$

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- Simplest choice with 8 masses as inputs $\Longrightarrow$ only 2-pt functions to consider (easy to handle, process independent, masses gauge-invariant by def.).

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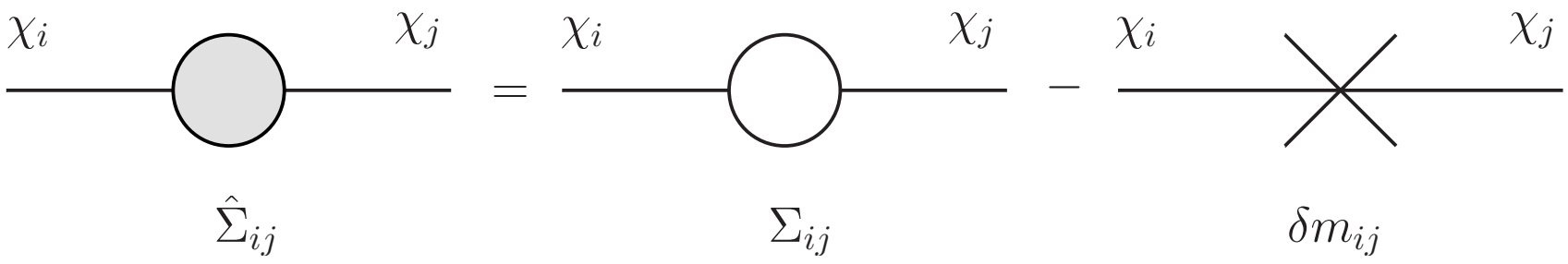
ON-SHELL RENORMALISATION OF THE -INO SECTOR

G. Bélanger, V. Bizouard, F. Boudjema, **GC**, PRD93 (2016) 11, 115031

COUNTER-TERMS

- $\chi_i \longrightarrow (\delta_{ij} + \frac{1}{2}\delta Z_{ij})\chi_j$
- $Y_{ij} \longrightarrow Y_{ij} + \delta Y_{ij}$ (the same for the matrix X)



ON-SHELL RENORMALISATION SCHEME

- $i = j$: Residue at the pole is 1 $\longrightarrow \delta Z_{\tilde{\chi}_i \tilde{\chi}_i}$
- $i \neq j$: No transition $i \leftrightarrow j$ when external leg on-shell : $\longrightarrow \delta Z_{\tilde{\chi}_i \tilde{\chi}_j}$
- $m^2_{\tilde{\chi}_i}$ is the pole of the propagator: $\longrightarrow \delta m^2_{\tilde{\chi}_i}$.
- 6 $\delta m^2_{\tilde{\chi}_i} \Longleftrightarrow \mathcal{W}_6$ with $\delta M_1, \delta M_2, \delta\mu, \delta\kappa, \delta\lambda$ and δt_β as variables ($\delta\mu = \delta(\lambda s)$).

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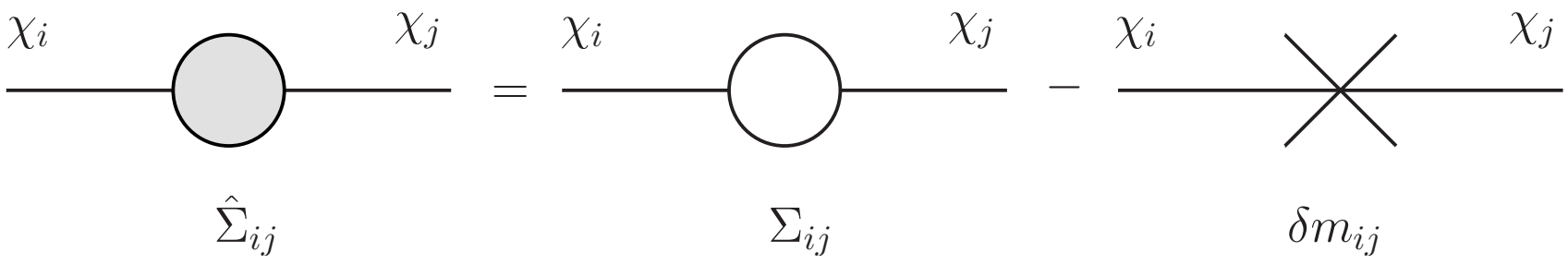

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- $m^2_{\tilde{\chi}_i}$ is the pole of the propagator: $\longrightarrow \delta m^2_{\tilde{\chi}_i}$.
- 6 $\delta m^2_{\tilde{\chi}_i} \Longleftrightarrow \mathcal{W}_6$ with $\delta M_1, \delta M_2, \delta\mu, \delta\kappa, \delta\lambda$ and δt_β as variables ($\delta\mu = \delta(\lambda s)$).
- Remaining masses get a finite correction at one-loop:
  $m^{2\,1L}_{\tilde{\chi}_j} = m^{2\,TL}_{\tilde{\chi}_j} + \delta m^2_{\tilde{\chi}_j} + \widetilde{\mathcal{R}e}\Sigma_{\tilde{\chi}_j \tilde{\chi}_j}(m^2_{\tilde{\chi}_j})$

Orsay

IMPORTANCE OF WELL-CHOSEN INPUTS

CHARGINO SECTOR AT 1L

$$\mathrm{diag}(\delta m_{\tilde{\chi}_i^\pm}) = U^* \delta X V^\dagger,\ \delta X = \begin{pmatrix} \delta M_2 & \sqrt{2}\delta(M_W s_\beta) \\ \sqrt{2}\delta(M_W c_\beta) & \delta\mu \end{pmatrix} \xrightarrow{\mathcal{W}_2^{\chi^\pm}} \delta M_2 \ \&\ \delta\mu$$

NEUTRALINO SECTOR AT 1L

$$\mathrm{diag}(\delta m_{\tilde{\chi}_i^0}) = N^* \delta Y N^\dagger,\ \delta Y = \begin{pmatrix} \delta M_1 & 0 & -\delta(M_Z s_W c_\beta) & \delta(M_Z s_W s_\beta) & 0 \\ \cdot & \delta M_2 & \delta(M_Z c_W c_\beta) & -\delta(M_Z c_W s_\beta) & 0 \\ \cdot & \cdot & 0 & -\delta\mu & -\delta(\lambda v s_\beta) \\ \cdot & \cdot & \cdot & 0 & -\delta(\lambda v c_\beta) \\ \cdot & \cdot & \cdot & \cdot & 2\delta(\kappa s) \end{pmatrix}$$

$$\boxed{\delta m_{\tilde{\chi}_i^0} = C_1 \delta M_1 + C_2 \delta M_2 + C_\mu \delta\mu + C_\kappa \delta\kappa + C_\lambda \delta\lambda + C_{t_\beta} \delta t_\beta + \delta R_i}$$

- Pick 4 $m_{\tilde{\chi}_i^0} \xrightarrow{\mathcal{W}_4^{\chi^0}} \delta M_1, \delta\lambda/\delta s, \delta\kappa, \delta t_\beta$, if $C_i \simeq \epsilon \ll 1 \rightarrow \delta M_i \sim 1/\epsilon \times \delta m_{\tilde{\chi}_i^0} \gg 1$
- Better pick $\widetilde{B}^0, \widetilde{H}^0_{1,2}, \widetilde{S}^0 \Longrightarrow$ prior knowledge of content ? Accessible experimentally ?

LPT Orsay

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-

$$\begin{pmatrix} \delta m_{\tilde{\chi}_1^\pm} \\ \delta m_{\tilde{\chi}_2^\pm} \\ \delta m_{\tilde{\chi}^0_{\text{“singlino”}}} \\ \delta m_{\tilde{\chi}^0_{\text{“bino”}}} \\ \delta m_{\tilde{\chi}^0_{\text{“higgsino”}}} \\ \delta m_{\tilde{\chi}^0_{\text{“higgsino”}}} \end{pmatrix} = \mathcal{W}_6 \begin{pmatrix} \delta\mu \\ \delta M_2 \\ \delta\kappa \\ \delta M_1 \\ \delta\lambda \\ \delta t_\beta \end{pmatrix} + \delta\mathcal{R}_6 \quad ,$$

LPT Orsay

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- Better pick $\widetilde{B}^0, \widetilde{H}^0_{1,2}, \widetilde{S}^0 \Longrightarrow$ prior knowledge of content ? Accessible experimentally ?
- λ, t_β intertwined, & in off diag., if λ small, t_β extraction difficult
- Unless significant mixing C_λ & C_{t_β} generically small $\rightarrow$ bad extraction of $\delta\lambda, \delta t_\beta, \delta\kappa$
- If $\delta t_\beta^{\overline{\mathrm{DR}}} \Rightarrow \mathcal{W}_5 = \mathcal{W}_3^{\chi^0} \oplus \mathcal{W}_2^{\chi^\pm} \Rightarrow$ Mixed $\overline{\mathrm{DR}}$-OS scheme

LPT Orsay

RENORMALISATION OF THE HIGGS SECTOR

G. Bélanger, V. Bizouard, F. Boudjema, **GC**, *to appear*

☞ λ and t_β difficult to extract from the gaugino sector $\longrightarrow$ resort to Higgs sector

$$m^2_{H^\pm} = \frac{2\mu(A_\lambda + \kappa s)}{s_{2\beta}} + M_W^2 - \lambda v^2$$

LPT Orsay

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CP-ODD MASS MATRIX

$$M^2_P = \begin{pmatrix} M^2_A & \lambda v(A_\lambda + \kappa s) \\ \cdot & \lambda v^2(A_\lambda + 4\kappa s)\frac{s_{2\beta}}{2s} - 3\kappa A_\kappa s \end{pmatrix} \rightarrow \text{pick } m_{A^0_{1,2}} \Rightarrow \delta A_\lambda \ \& \ \delta A_\kappa$$

LPT Orsay

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CP-EVEN MASS MATRIX

$$M^2_S = \begin{pmatrix} M^2_Z c^2_\beta + M^2_A s^2_\beta & (2\lambda^2 v^2 - M^2_Z - M^2_A)\, s_\beta c_\beta & \lambda v(2\mu c_\beta - (A_\lambda + 2\kappa s)s_\beta) \\ \cdot & M^2_Z s^2_\beta + M^2_A c^2_\beta & \lambda v(2\mu s_\beta - (A_\lambda + 2\kappa s)c_\beta) \\ \cdot & \cdot & \lambda v^2 A_\lambda \frac{c_\beta s_\beta}{s} + \kappa s(A_\kappa + 4\kappa s) \end{pmatrix}$$

Orsay

SUMMARY OF THE VARIOUS SCHEMES

MIXED $\overline{\mathrm{DR}}$-OS SCHEMES

☞ $\mathcal{W}_8 = \mathcal{W}_{1,t_\beta} \oplus \overbrace{\mathcal{W}_2^{\chi^\pm}}^{M_2,\mu} \oplus \overbrace{\mathcal{W}_3^{\chi^0}}^{M_1,\lambda,\kappa} \oplus \overbrace{\mathcal{W}_2^{A^0}}^{A_\lambda,A_\kappa} \rightarrow t_{ijk}$ (suited when only gaugino decays)

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LPT Orsay

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ON-SHELL SCHEMES

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Orsay

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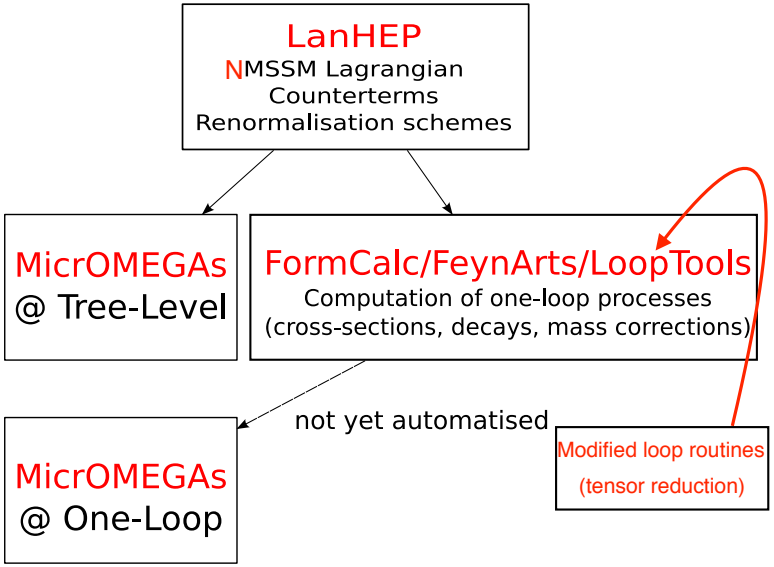
- ...

Or simply go all $\overline{\mathrm{DR}}$

LPT Orsay

AUTOMATIC TOOL FOR ONE-LOOP CALCULATIONS: SLOOPS



SLOOPS

An automatic code for calculation of loops diagrams for $\mathcal{SM}$ and $\mathcal{BSM}$ processes with application to colliders, astrophysics and cosmology.

- Automatic derivation of the CT Feynman rules and computation of the CT's
- Models renormalized: SM, MSSM, NMSSM, Wino DM, **xSM** (w/ & w/o v_s),
- Modularity between different renormalisation schemes.
- Non-linear gauge fixing.
- Checks: results UV,IR finite and gauge independent.

http://code.sloops.free.fr/

LPT Orsay

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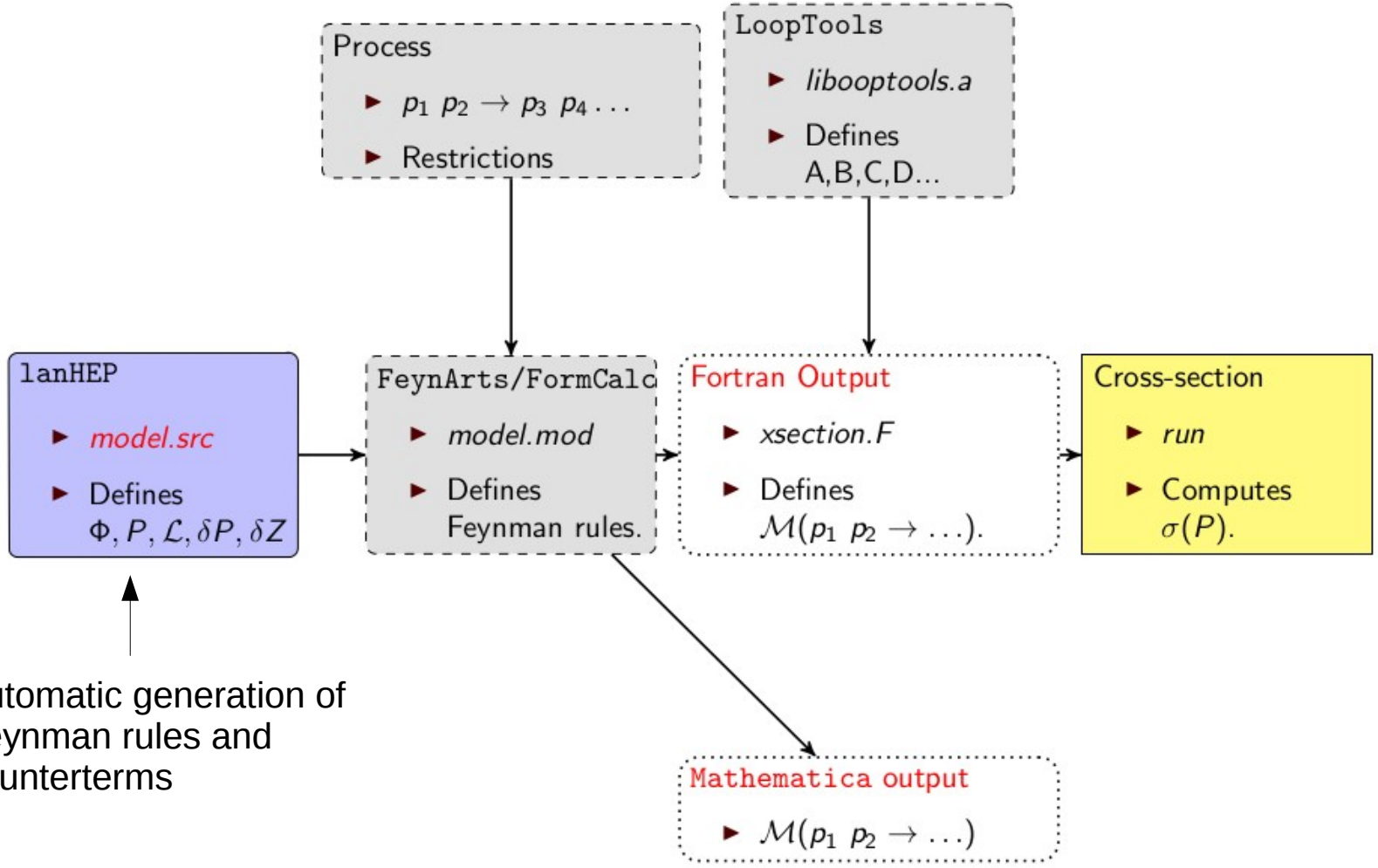

Automatic generation of Feynman rules and counterterms

LPT Orsay

APPLICATION TO GAUGINO CORRECTED MASSES

G. Bélanger, V. Bizouard, F. Boudjema, **GC**, PRD93 (2016) 11, 115031

	M_1	M_2	μ	λ	κ	t_β
Value (GeV)	1000	150	250	0.1	0.1	10

$m_{\tilde{\chi}_1^0} \simeq m_{\widetilde{W}^0} < m_{\tilde{\chi}_2^0} \simeq m_{\widetilde{H}^0} < m_{\tilde{\chi}_3^0} \simeq m_{\widetilde{H}^0} < m_{\tilde{\chi}_4^0} \simeq m_{\widetilde{S}^0} < m_{\tilde{\chi}_5^0} \simeq m_{\widetilde{B}^0}$ and $m_{\widetilde{W}^\pm} < m_{\widetilde{H}^\pm}$

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Scheme	Masses	Point 1
OS_{1234}	$m^{tree}_{\tilde{\chi}_5}$	1002.17
	$m^{1-loop}_{\tilde{\chi}_5}$	**-27%**
OS_{2345}	$m^{tree}_{\tilde{\chi}_1}$	125.67
	$m^{1-loop}_{\tilde{\chi}_1}$	-1‰
t_{123}	$m^{tree}_{\tilde{\chi}_4}$	500.78
	$m^{1-loop}_{\tilde{\chi}_4}$	**-203%**
	$m^{tree}_{\tilde{\chi}_5}$	1002.17
	$m^{1-loop}_{\tilde{\chi}_5}$	**42%**
t_{345}	$m^{tree}_{\tilde{\chi}_1}$	125.67
	$m^{1-loop}_{\tilde{\chi}_1}$	-0.5‰
	$m^{tree}_{\tilde{\chi}_2}$	257.30
	$m^{1-loop}_{\tilde{\chi}_2}$	2‰
$\overline{\mathrm{DR}}$	$m^{1-loop}_{\tilde{\chi}_1}$	8%
	$m^{1-loop}_{\tilde{\chi}_2}$	3%
	$m^{1-loop}_{\tilde{\chi}_3}$	3%
	$m^{1-loop}_{\tilde{\chi}_4}$	-0.1‰
	$m^{1-loop}_{\tilde{\chi}_5}$	-7‰

LPT Orsay

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LPT Orsay

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- If all "natures" are not covered $\Rightarrow$ rad. cor out of control
- Require "insider" knowledge to control them

LPT Orsay

APPLICATION TO GAUGINO CORRECTED MASSES

G. Bélanger, V. Bizouard, F. Boudjema, **GC**, PRD93 (2016) 11, 115031

	M_1	M_2	μ	λ	κ	t_β
Value (GeV)	1000	150	250	0.1	0.1	10

$m_{\tilde{\chi}_1^0} \simeq m_{\widetilde{W}^0} < m_{\tilde{\chi}_2^0} \simeq m_{\widetilde{H}^0} < m_{\tilde{\chi}_3^0} \simeq m_{\widetilde{H}^0} < m_{\tilde{\chi}_4^0} \simeq m_{\widetilde{S}^0} < m_{\tilde{\chi}_5^0} \simeq m_{\widetilde{B}^0}$ and $m_{\widetilde{W}^\pm} < m_{\widetilde{H}^\pm}$

Scheme	Masses	Point 1
OS_{1234}	$m^{tree}_{\tilde{\chi}_5}$	1002.17
	$m^{1-loop}_{\tilde{\chi}_5}$	**-27%**
OS_{2345}	$m^{tree}_{\tilde{\chi}_1}$	125.67
	$m^{1-loop}_{\tilde{\chi}_1}$	-1‰
t_{123}	$m^{tree}_{\tilde{\chi}_4}$	500.78
	$m^{1-loop}_{\tilde{\chi}_4}$	**-203%**
	$m^{tree}_{\tilde{\chi}_5}$	1002.17
	$m^{1-loop}_{\tilde{\chi}_5}$	**42%**
t_{345}	$m^{tree}_{\tilde{\chi}_1}$	125.67
	$m^{1-loop}_{\tilde{\chi}_1}$	-0.5‰
	$m^{tree}_{\tilde{\chi}_2}$	257.30
	$m^{1-loop}_{\tilde{\chi}_2}$	2‰
$\overline{\mathrm{DR}}$	$m^{1-loop}_{\tilde{\chi}_1}$	8%
	$m^{1-loop}_{\tilde{\chi}_2}$	3%
	$m^{1-loop}_{\tilde{\chi}_3}$	3%
	$m^{1-loop}_{\tilde{\chi}_4}$	-0.1‰
	$m^{1-loop}_{\tilde{\chi}_5}$	-7‰

- If all "natures" are not covered $\Rightarrow$ rad. cor out of control
- Require "insider" knowledge to control them
- Knowing the full spectrum is not enough $\Rightarrow$ info about "nature" needed to guide choice of scheme ($\rightarrow$ decays, cross sections)

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- If all "natures" are not covered $\Rightarrow$ rad. cor out of control
- Require "insider" knowledge to control them
- Knowing the full spectrum is not enough $\Rightarrow$ info about "nature" needed to guide choice of scheme ($\rightarrow$ decays, cross sections)
- Masses are not very sensitive to λ & t_β which, however, are crucial for decays

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	tree (MeV)	t_{345}	OS_{2345}	$OS_{245h_2A_1A_2}$	$\overline{\mathrm{DR}}$
$\tilde{\chi}_4^0 \to W^\pm \tilde{\chi}_1^\pm$	10.4	(2%)	(75%)	(-8%)	(-8%)
$\tilde{\chi}_4^0 \to W^\pm \tilde{\chi}_2^\pm$	22.9	(15%)	(84%)	(1%)	(7%)
$\tilde{\chi}_4^0 \to Z \tilde{\chi}_1^0$	6.26	(3%)	(76%)	(-7%)	(-9%)
$\tilde{\chi}_4^0 \to Z \tilde{\chi}_2^0$	26.2	(14%)	(82%)	(-0.7%)	(7%)
$\tilde{\chi}_4^0 \to Z \tilde{\chi}_3^0$	3.12	(17%)	(93%)	(10%)	(1%)

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- ☞ $\widetilde{S}^0$ decays only possible through mixing $\Longrightarrow$ very sensitive to λ
- ☞ All other decays (not shown here) are under control (weak dep. in t_β and λ)

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- ☞ $OS_{245h_2A_1A_2}$ $\longrightarrow$ good reconstruction from Higgs sector (in diag. entries)

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- $\widetilde{S}^0$ decays only possible through mixing $\Longrightarrow$ very sensitive to λ
- All other decays (not shown here) are under control (weak dep. in t_β and λ)
- $OS_{245h_2A_1A_2} \to$ good reconstruction from Higgs sector (in diag. entries)
- Corrections in $OS_{245h_2A_1A_2} \simeq \overline{\mathrm{DR}}$

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Point A($Q_{\rm susy} = 1117.25$GeV, $m_t = 173$GeV, $m_{h_1^0} = 125.45$GeV(1-loop OS))

M_1	700	λ	0.1	A_κ	0	$m_{\tilde{Q}_3}$	1740	$m_{\tilde{D},\tilde{U}_{1,2}}$	1000
M_2	1000	κ	0.1	A_t	4000	$m_{\tilde{U}_3}$	800	$m_{\tilde{L}_3}$	1000
M_3	1000	μ	120	A_b	1000	$m_{\tilde{D}_3}$	1000	$m_{\tilde{l}_3}$	1000
t_β	10	A_λ	150	A_l	1000	$m_{\tilde{Q}_{1,2}}$	1000	$m_{\tilde{L},\tilde{l}_{1,2}}$	1000

$\lambda A_\lambda = 15$GeV, $A_t/A_\lambda \sim 27$

Point B($Q_{\rm susy} = 753.55$GeV, $m_t = 146.94$GeV, $m_{h_1^0} = 124.44$GeV(1-loop OS))

M_1	120	λ	0.67	A_κ	0	$m_{\tilde{Q}_3}$	750	$m_{\tilde{D},\tilde{U}_{1,2}}$	1500
M_2	300	κ	0.2	A_t	1000	$m_{\tilde{U}_3}$	750	$m_{\tilde{L}_3}$	1500
M_3	1500	μ	200	A_b	1000	$m_{\tilde{D}_3}$	1500	$m_{\tilde{l}_3}$	1500
t_β	1.92	A_λ	405	A_l	1000	$m_{\tilde{Q}_{1,2}}$	1500	$m_{\tilde{L},\tilde{l}_{1,2}}$	1500

$\lambda A_\lambda = 271$GeV, $A_t/A_\lambda \sim 2.5$

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APPLICATION TO HIGGS DECAYS

		Point A	Point B
h_1^0	h_d^0	1.1%	22.5%
	h_u^0	**98.6%**	**67.4%**
	h_s^0	0.3%	10.1%
h_2^0	h_d^0	0.1%	0.%
	h_u^0	0.3%	12.5%
	h_s^0	**99.6%**	**87.5%**
h_3^0	h_d^0	**98.8%**	**77.5%**
	h_u^0	1.1%	19.7%
	h_s^0	0.1%	2.8%
A_1^0	a_d^0	0%	1.8%
	a_u^0	0%	0.5%
	a_s^0	**100%**	**97.7%**
A_2^0	a_d^0	**99.0%**	**76.9%**
	a_u^0	1.0%	20.8%
	a_s^0	0.0%	2.3%

Point A: h_u, h_s, h_d, a_s, a_d

Point B: h_u, h_s, h_d, a_s, a_d

		Point A	Point B
$\tilde{\chi}_1^0$	$\tilde{B}^0$	-	**56.6%**
	$\tilde{W}^0$	-	32.3%
	$\tilde{h}^0$	**98.4%**	10.3%
	$\tilde{S}^0$	0.77%	0.8%
$\tilde{\chi}_2^0$	$\tilde{B}^0$	-	4.0%
	$\tilde{W}^0$	-	2.6%
	$\tilde{h}^0$	**99.5%**	19.3%
	$\tilde{S}^0$	-	**74.0%**
$\tilde{\chi}_3^0$	$\tilde{B}^0$	-	10.1%
	$\tilde{W}^0$	-	-
	$\tilde{h}^0$	0.9%	**78.9%**
	$\tilde{S}^0$	**99.1%**	11.0%
$\tilde{\chi}_4^0$	$\tilde{B}^0$	**99.6%**	18.1%
	$\tilde{W}^0$	-	12.3%
	$\tilde{h}^0$	-	**55.8%**
	$\tilde{S}^0$	-	13.7%
$\tilde{\chi}_5^0$	$\tilde{B}^0$	-	11.2%
	$\tilde{W}^0$	**99.3%**	**52.8%**
	$\tilde{h}^0$	0.69%	35.7%
	$\tilde{S}^0$	-	0.4%

Point A: $\tilde{h}$, $\tilde{h}$, $\tilde{s}$, $\tilde{b}$, $\tilde{w}$

Point B: $\tilde{b}$, $\tilde{s}$, $\tilde{h}$, $\tilde{h}$, $\tilde{w}$

Beware. B much more mixing, A quite pure

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POINT A: HIGGS DECAYS WITH SINGLET/SINGLINOS

- singlets: $h_2^0, A_1^0, \tilde{\chi}_3^0$, $m_{h_2^0} = 240$ GeV, $m_{h_3^0, A_2^0, H^\pm} \sim 570$ GeV, $Q_{\rm SUSY} = \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}} = 1117$ GeV

Decays	$t_{134A_1A_2}(Q_{\rm SUSY})$	$OS_{34h_2A_1A_2H^+}$	$\overline{\rm DR}(m_{parent})$	$\overline{\rm DR}(Q_{\rm SUSY})$

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$h_2^0 \to A_1^0 A_1^0$	(128%)	(-12%)	(0.4%)	(-0.4%)

☞ At LO (with $(A_\kappa = 0)$, $g_{h_2^0 A_1^0 A_1^0}$ stems from $\kappa^2 S^4$

$\to g_{h_2^0 A_1^0 A_1^0} \propto \kappa^2 s \propto (\kappa s)^2/s \propto \boxed{\lambda/\mu(\kappa s)^2 \sim \lambda/m_{\widetilde{H}^\pm} \times m^2_{\widetilde{S}^0}}$.

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☞ $m_{\widetilde{S}^0}$ constrains $(\kappa s)^2$ and $m_{\widetilde{H}^\pm}$ constrains μ well. Finite shift on λ is key. We have

$$\boxed{\delta\lambda/\lambda|^{\rm t_{134}}_{\rm fin.} = 62.26\% \text{ and } \delta\lambda/\lambda|^{\rm OS}_{\rm fin.} = -7.88\%}$$

and loop correction is $\delta\Gamma/\Gamma \sim 2\delta\lambda/\lambda$ due to finite part of CT.

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and loop correction is $\delta\Gamma/\Gamma \sim 2\delta\lambda/\lambda$ due to finite part of CT.

☞ Small $\overline{\rm DR}$ corrections $\to$ pure virtual corrections negligible and κ, s do not run much (confirmed if one inspects the resp. $\beta_{\kappa,s}$ functions).

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Decays	$t_{134A_1A_2}(Q_{\rm SUSY})$	$OS_{34h_2A_1A_2H^+}$	$\overline{\rm DR}(m_{parent})$	$\overline{\rm DR}(Q_{\rm SUSY})$
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$h_3^0 \to \tilde{\chi}_1^0 \tilde{\chi}_3^0$	(122%)	(-3%)	(2%)	(0.3%)
$h_3^0 \to \tilde{\chi}_2^0 \tilde{\chi}_3^0$	(126%)	(-35%)	(3%)	(1.1%)
$A_2^0 \to \tilde{\chi}_1^0 \tilde{\chi}_3^0$	(130%)	(-31%)	(8%)	(6.2%)
$A_2^0 \to \tilde{\chi}_2^0 \tilde{\chi}_3^0$	(122%)	(-5%)	(-0.4%)	(-1.9%)
$H^+ \to \tilde{\chi}_1^+ \tilde{\chi}_3^0$	(125%)	(-18%)	(3%)	(1.1%)

☞ Same usual suspects, corrections in t_{134} accounted for by $\delta\lambda|_{\rm fin.}$. In $OS_{34h_2A_1A_2H^+}$ renormalisation of δt_β kicks in.

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$h_3^0 \to h_1^0 h_2^0$	(116%)	(79%)	(52%)	(-1.7%)

☞ For t_{134} & $OS_{34h_2A_1A_2H^+}$: same reasons as before

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POINT A: HIGGS DECAYS WITH SINGLET/SINGLINOS

- singlets: $h_2^0, A_1^0, \tilde{\chi}_3^0$, $m_{h_2^0} = 240$ GeV, $m_{h_3^0, A_2^0, H^\pm} \sim 570$ GeV, $Q_{\rm SUSY} = \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}} = 1117$ GeV

Decays	$t_{134A_1A_2}(Q_{\rm SUSY})$	$OS_{34h_2A_1A_2H^+}$	$\overline{\rm DR}(m_{parent})$	$\overline{\rm DR}(Q_{\rm SUSY})$
$h_2^0 \to A_1^0 A_1^0$	(128%)	(-12%)	(0.4%)	(-0.4%)
$h_3^0 \to \tilde{\chi}_1^0 \tilde{\chi}_3^0$	(122%)	(-3%)	(2%)	(0.3%)
$h_3^0 \to \tilde{\chi}_2^0 \tilde{\chi}_3^0$	(126%)	(-35%)	(3%)	(1.1%)
$A_2^0 \to \tilde{\chi}_1^0 \tilde{\chi}_3^0$	(130%)	(-31%)	(8%)	(6.2%)
$A_2^0 \to \tilde{\chi}_2^0 \tilde{\chi}_3^0$	(122%)	(-5%)	(-0.4%)	(-1.9%)
$H^+ \to \tilde{\chi}_1^+ \tilde{\chi}_3^0$	(125%)	(-18%)	(3%)	(1.1%)
$h_3^0 \to h_1^0 h_2^0$	(116%)	(79%)	(52%)	(-1.7%)

☞ For t_{134} & $OS_{34h_2A_1A_2H^+}$: same reasons as before

☞ Large corrections $\overline{\rm DR}$? Pt A has small mixing: $g_{h_1h_2h_3} \simeq g_{h_u h_s h_d} \sim \lambda \boxed{A_\lambda} + 2\kappa\mu$.

$$16\pi^2 \frac{1}{A_\lambda} \frac{dA_\lambda}{A_\lambda} \sim 3h_t^2 \frac{A_t}{A_\lambda} \quad \text{recall} \quad \boxed{A_t/A_\lambda \sim 27!!}$$

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- Large corrections $\overline{\rm DR}$? Pt A has small mixing: $g_{h_1h_2h_3} \simeq g_{h_u h_s h_d} \sim \lambda \boxed{A_\lambda} + 2\kappa\mu$.

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- Correction in $\overline{\rm DR}$ driven by running of A_λ
- An MSSM-like point with large A_t to reproduce correct $m_H^{\rm SM}$ entitled to large EW rad. cor., even in $\overline{\rm DR}$, for decays driven by A_λ. For Pt A can be absorbed by setting $\bar{\mu} = Q_{\rm SUSY}$. $Q_{\rm SUSY}$ always the right choice ?

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POINT B: HIGGS DECAYS WITH SINGLET/SINGLINOS

- Mixing important $\lambda = 0.67$, no pure state, in principle better extraction of counterterms

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Decays	SloopS $t_{123}(Q_{\rm SUSY})$	SloopS $OS_{12h_2A_1A_2H^+}$	$\overline{\rm DR}(m_{parent})$	$\overline{\rm DR}(Q_{\rm SUSY})$
$h_3^0 \to \tilde{\chi}_1^0\tilde{\chi}_2^0$	10.8%	(14%)	(5%)	(3%)
$h_3^0 \to A_1^0 Z$	(8.4%)	(3%)	(-3%)	(-8 %)
$h_3^0 \to h_2^0 h_1^0$	(-131.4%)	(-25%)	(-106%)	(-50%)
$h_3^0 \to h_2^0 h_2^0$	(41.8 %)	(6%)	(13%)	(-28%)
$A_2^0 \to \tilde{\chi}_1^+\tilde{\chi}_1^-$	(8.2 %)	(7%)	(2%)	(1%)
$A_2^0 \to \tilde{\chi}_1^0\tilde{\chi}_1^0$	(18.1%)	(32%)	(2%)	(2%)
$A_2^0 \to Zh_2^0$	(-10.27 %)	(12%)	(-16%)	(-9%)
$A_2^0 \to A_1^0 h_1^0$	(-40.9 %)	(-0.3%)	(-32%)	(-17%)
$H^+ \to \tilde{\chi}_1^+\tilde{\chi}_2^0$	(8.4%)	(6%)	(10%)	(8%)
$H^+ \to W^+ h_2^0$	(-11%)	(11%)	(-18%)	(-10%)
$H^+ \to W^+ A_1^0$	(7.9%)	(2%)	(-3%)	(-9%)
$H^+ \to \tilde{\chi}_1^+\tilde{\chi}_1^0$	(12.5 %)	(21%)	(9%)	(9%)

- Due to large mixing, dependence on parameters much more involved.
- Still renormalisation of λ, t_β and running of A_λ (although smaller due to smaller A_t/A_λ) lead the corrections
- OS scheme gives reasonable corrections
- For $\overline{\rm DR}$ even $\bar{\mu} = Q_{\rm SUSY}$ does not absorb all the corrections most probably because A_λ is not the only driver of the decay

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SUMMARY

- Full renormalisation (all sectors) of the NMSSM at one-loop completed.
- Implemented into an automatic tool SLOOPS
- Various schemes investigated $\longrightarrow$ large scheme dependence for some observables, depending on the scenario
- Currently impossible to choose what is the best scheme for reconstructing parameters. As long as only predictions are concerned, $\overline{\mathrm{DR}}$ scheme sufficient but large pure EW corrections are possible in some scenarios (in particular when singlets are involved in MSSM-like points). Not always clear how to tame them by choosing appropriate $\bar{\mu}$
- ON-SHELL schemes based solely on masses are algebraically sufficient to renormalise the model, BUT this is probably too optimistic given the current status of BSM searches at the LHC
- Must go **beyond only masses** as inputs. If some are discovered, in any case the way they are produced and decay will give crucial information (composition of the mixed states), and this even in the case where the whole spectrum is measured

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