Renormalisation of the NMSSM in SloopS

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Outline

- NMSSM
- SloopS
- Renormalisation
- Some numerical results
- Status/prospects

NMSSM

- MSSM + a new Higgs gauge singlet chiral superfield
- Solves the μ-problem : $M_Z^2 \simeq -2\mu^2 + 2\frac{m_{H_d}^2 - \tan^2\beta m_{H_u}^2}{\tan^2\beta - 1}$

...by generating this parameter dynamically

$$\mu \hat{H}_u.\hat{H}_d \longrightarrow \lambda \hat{S}\hat{H}_u.\hat{H}_d$$

- Higgs potential :

$$V_{Higgs} = |\lambda(H_u^+H_d^- - H_u^0H_d^0 + \kappa S^2)|^2 + (m_{H_u}^2 + |\lambda s|^2)\left(|H_u^0|^2 + |H_u^+|^2\right)$$
$$(m_{H_d}^2 + |\lambda s|^2)\left(|H_d^0|^2 + |H_d^+|^2\right) + \frac{g_1^2 + g_2^2}{8}\left(|H_u^0|^2 + |H_u^+|^2 - |H_d^0|^2 - |H_d^-|^2\right)^2$$
$$+ \frac{g_2^2}{2}|H_u^+H_d^{0*} + H_u^0H_d^{-*}|^2 + m_S^2|S|^2 + (\lambda A_\lambda(H_u^+H_d^- - H_u^0H_d^0)S + \frac{1}{3}\kappa A_\kappa S^3)$$

NMSSM

- Extended Higgs sector :
  - 3 CP-even Higgs bosons h_1, h_2, h_3
  - 2 Pseudoscalars A_1, A_2
  - 2 charged Higgs bosons $H^{\pm}$
- h_1 or h_2 could be the one observed at LHC

  → if h_1 is gauge singlet, it avoids all constraints and can be very light
- Easier to get a 125 GeV Higgs boson than in MSSM

$$m_h^2 = m_{h,MSSM}^2 + \lambda^2 v^2 \sin^2(2\beta)$$

NMSSM

- Need of precise computations of physical observables
  - Decays and cross-sections at colliders
  - Dark Matter annihilation for relic density
- One-loop radiative corrections (EW+QCD)
  - MSSM : full renormalisation of EW sector

    N.Baro, F.Boudjema : arXiv:0807.4668, 0906.1665
    N.Baro, F.Boudjema, G.Chalons, S.Hao : 0910.3293

  - NMSSM : in progress (this talk)

Renormalisation of the NMSSM

Charginos — Higgs

- M_1, M_2, μ, $\tan(\beta)$, λ, κ, A_λ, A_κ, m_{Hd}, m_{Hu}, m_{Hs}

Neutralinos

$$\tan(\beta) = \frac{v_u}{v_d}$$

- $\tan(\beta)$ links together all sectors : OS-scheme complicated !
- Easier : take a DR condition for $\tan(\beta)$ to decouple sectors :
  - μ, M_2 from the 2 charginos
  - M_1, λ, κ from 3 neutralinos (singlino, bino, higgsino)
  - A_λ, A_κ, from 2 pseudoscalars (or two Higgs bosons)
  - m_{Hd}, m_{Hu}, m_{Hs} from minimization equations of Higgs potential

Renormalisation of fermions

- For a fermion : $\tilde{\chi}_i = \begin{pmatrix} \chi_i^L \\ \chi_i^{R*} \end{pmatrix}$

Shift : $\chi_{i_0}^{R,L} = \left(\delta_{ij} + \frac{1}{2}\delta Z_{ij}^{R,L} \right) \chi_j^{R,L}$

- Decomposition of the self-energy :

$$\Sigma_{ij}(q) = P_L \Sigma_{ij}^{LS}(q^2) + P_R \Sigma_{ij}^{RS}(q^2) + \not{q} P_L \Sigma_{ij}^{LV}(q^2) + \not{q} P_R \Sigma_{ij}^{RV}(q^2)$$

Then :

$$\left\{ \begin{aligned} \hat{\Sigma}_{ij}^{LS} &= \Sigma_{ij}^{LS} - (\delta m_{ij} + \frac{1}{2} m_{\tilde{\chi}_j} \delta Z_{ji}^R + \frac{1}{2} m_{\tilde{\chi}_i} \delta Z_{ij}^L) \\ \hat{\Sigma}_{ij}^{RS} &= \Sigma_{ij}^{RS} - (\delta m_{ji}^* + \frac{1}{2} m_{\tilde{\chi}_i} \delta Z_{ij}^{R*} + \frac{1}{2} m_{\tilde{\chi}_j} \delta Z_{ji}^{L*}) \\ \hat{\Sigma}_{ij}^{LV} &= \Sigma_{ij}^{LV} + \frac{1}{2}(\delta Z_{ij}^L + \delta Z_{ji}^{L*}) \\ \hat{\Sigma}_{ij}^{RV} &= \Sigma_{ij}^{RV} + \frac{1}{2}(\delta Z_{ij}^{R*} + \delta Z_{ji}^{R*}) \end{aligned} \right.$$

There are relations between these components

Renormalisation of fermions

- Renormalized self-energy :

$$\hat{\Sigma}_{ij}(q) = \Sigma_{ij}(q) - P_L \delta m_{ij} - P_R \delta m^*_{ji} + \frac{1}{2}(\not{q} - m_{\tilde{\chi}_i}) \left[\delta Z^L_{ij} P_L + \delta Z^{R*}_{ij}\right] + \frac{1}{2}\left[\delta Z^{L*}_{ji} P_R + \delta Z^R_{ji} P_L\right](\not{q} - m_{\tilde{\chi}_j})$$

- OS Renormalisation conditions :
  - If particle i chosen as input : $Re\hat{\Sigma}_{ii}(m^2_{\chi_i}) = 0 \longrightarrow \delta m_{\chi_i}$
  - Residue 1 at pole mass : $Re\hat{\Sigma}'_{ii}(m^2_{\chi_i}) = 0 \longrightarrow \delta Z^L_{ii}, \delta Z^R_{ii}$
  - No mixing of fields when on-shell

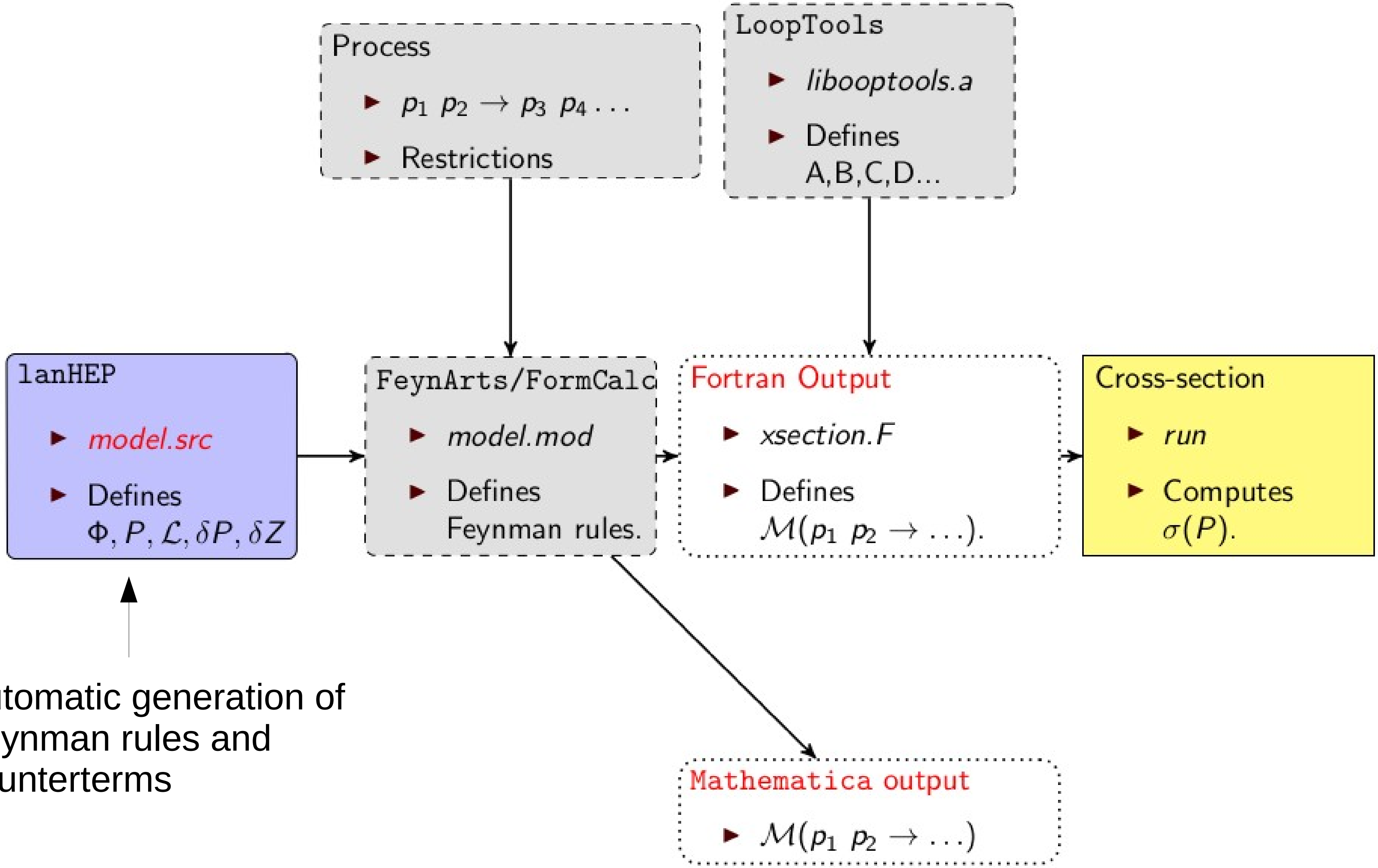
$$Re\hat{\Sigma}_{ij}(m^2_{\chi_i}) = 0 \longrightarrow \delta Z^L_{ij}, \delta Z^R_{ij}$$

- We can derive the same kind of equations for scalar and vector sectors

SloopS

- A code for the calculation of cross section at one loop in SUSY (Boudjema, Baro, Semenov, Chalons)
- Renormalisation of MSSM in EW sector performed in the OS-scheme
- Full renormalisation of NMSSM (this talk)

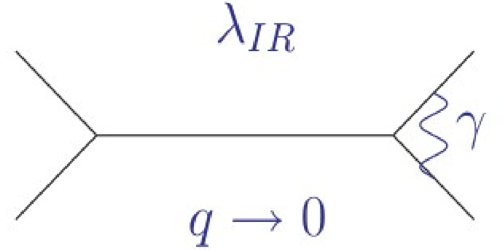
SloopS



Automatic generation of Feynman rules and counterterms

Convergence tests in SloopS

- UV convergence (parameter CUV in SloopS) :
  - Corrected mass of particles (except input masses)
  - Decay widths and cross-sections
- IR convergence for all processes with charged particles in external legs



→ Must add the emission of a soft photon to compensate this divergence

Renormalisation in SloopS

- Comparison of 3 schemes :
  - a complete OS scheme : scheme 1
  - 2 schemes with the 2 charginos for M_2, μ ; 3 neutralinos (out of 5) for M_1,λ, κ ; 2 pseudoscalars for A_λ, A_κ as inputs and DR condition for tan(β)

$$Y = \begin{pmatrix} M_1 & 0 & -M_Z s_W c_\beta & M_Z s_W s_\beta & 0 \\ 0 & M_2 & M_Z c_W c_\beta & -M_Z c_W s_\beta & 0 \\ -M_Z s_W c_\beta & M_Z c_W c_\beta & 0 & -\mu & -\lambda v_u \\ M_Z s_W s_\beta & -M_Z c_W s_\beta & -\mu & 0 & -\lambda v_d \\ 0 & 0 & -\lambda v_u & -\lambda v_d & 2\kappa s \end{pmatrix}$$

We have to choose the dominantly bino, singlino and higgsino neutralinos as inputs !

Scheme 1, 2 : χ_3,χ_4,χ_5 in inputs

Scheme 3 : χ_1,χ_2,χ_3 in inputs

Some numerical results

- Point 1 : $\lambda = \kappa = 0.1, \mu = 250\text{GeV}, M_2 = 150\text{GeV}, M_1 = 100\text{GeV}$
- Corrected neutralino masses :

Neutralino	1 (wino)	2 (higgsino)	3 (higgsino)	4 (singlino)	5 (bino)
Tree level Mass (GeV)	115.1041	253.8877	285.8382	500,5707	1002,3747
Scheme 1	115.319341	262.0348773	X	X	X
Scheme 1+CUV	115.319341	262.034874	X	X	X
Scheme 2	115.109467	260.119646	X	X	X
Scheme 2+CUV	115.109467	260.119647	X	X	X
Scheme 3	X	X	X	263937.572	-74415.3742
Scheme 3+CUV	X	X	X	263937.57	-74415.374

Scheme 1, 2 : χ_3,χ_4,χ_5 in inputs

Scheme 3 : χ_1,χ_2,χ_3 in inputs

CUV=1D7

Some numerical results

- Point 2 : $\lambda = 0.4, \kappa = 0.05, \mu = 300\text{GeV}, M_2 = 600\text{GeV}, M_1 = 230\text{GeV}$
- Corrected neutralino masses :

Neutralino	1 (singlino)	2 (bino)	3 (higgsino)	4 (higgsino)	5 (wino)
Tree level Mass (GeV)	79,7315	212.7909	306.8552	312.1424	617.7648
Scheme 1	228.09357	195.036774	X	X	X
Scheme 1+CUV	-3730629.78	273613.275	X	X	X
Scheme 2	1002.88195	138.255926	X	X	X
Scheme 2+CUV	1002.87923	138.256135	X	X	X
Scheme 3	X	X	X	310.0896337	617.661892
Scheme 3+CUV	X	X	X	310.089638	617.661892

Scheme 1, 2 : χ_3,χ_4,χ_5 in inputs

Scheme 3 : χ_1,χ_2,χ_3 in inputs

CUV=1D7

Some numerical results

- Point 1 : $\lambda = \kappa = 0.1, \mu = 250\text{GeV}, M_2 = 150\text{GeV}, M_1 = 100\text{GeV}$
- Example of decay width :

Decay	$\chi_2 \rightarrow \chi_1 Z$	$\chi_3 \rightarrow \chi_1 Z$
Tree level	0.274557833794966	0.209621631302729E-01
Scheme 1	-0.823466302716225E-01	0.697615942811072E-02
Scheme 1+CUV	-0.823466373063868E-01	0.697616067790450E-02
Scheme 2	-0.600777732707610E-01	-0.159642882159480E-02
Scheme 2+CUV	-0.600777762227011E-01	-0.159642913743119E-02
Scheme 3	0.127343390004787	0.553976357663007
Scheme 3+CUV	0.127343387000663	0.553976353747825

Not a good scheme for this point

Scheme 1, 2 : χ_3,χ_4,χ_5 in inputs

Scheme 3 : χ_1,χ_2,χ_3 in inputs

CUV=1D7

Some numerical results

- Point 2 : $\lambda = 0.4, \kappa = 0.05, \mu = 300\text{GeV}, M_2 = 600\text{GeV}, M_1 = 230\text{GeV}$
- Example of decay width :

Decay	$\chi_2 \rightarrow \chi_1 Z$	χ[illegible] $\rightarrow \chi_1 Z$
Tree level	0.757393429965566E-02	0.146744603331006
Scheme 1	-0.641105618017964E-02	-0.871356114976032E-01
Scheme 1+CUV	344.942932560662	1796.63789321358
Scheme 2	-0.780467901919033E-01	-0.460262038982495
Scheme 2+CUV	-0.780465531089403E-01	-0.460260607145755
Scheme 3	0.228595111777075E-02	-0.328493548245809E-02
Scheme 3+CUV	0.228595185537751E-02	-0.328491107952903E-02

Numerical instability (Scheme 1, Scheme 1+CUV)

Not a good scheme for this point (Scheme 2, Scheme 2+CUV)

Scheme 1, 2 : χ_3,χ_4,χ_5 in inputs

Scheme 3 : χ_1,χ_2,χ_3 in inputs

CUV=1D7

Status

- Different OS-schemes possible : have to choose the best one for a given point.
- Chargino/neutralinos sectors : finite corrected masses, decay widths and cross-sections.
- Higgs sector :
  - Finite corrected masses for charged and pseudoscalar Higgs bosons. For CP-even : only with the gauge+Higgs contributions to the self-energy.
  - Decay widths : UV finite if neutralinos/charginos in final state. Problem with decays in (s)fermions

Prospects

- Still some issues with finiteness and numerical results in particular in the Higgs sector to address
- Computation of radiative corrections to some physical observables :
  - Precise calculation of Dark Matter relic density. For example in the annihilation of 2 singlinos.
  - Interplay of NMSSM scenarios with dark matter and collider observables)