SUSY and Higgs mass predictions

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DESY Hamburg

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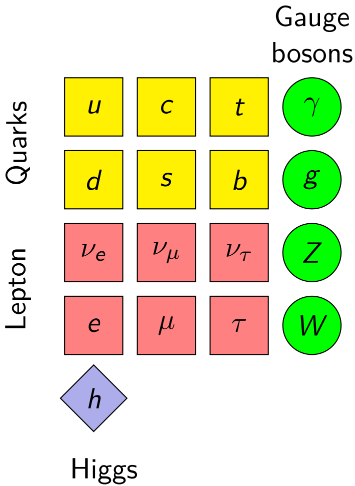
The Standard Modell of particle physics



Describes

- Quarks, Leptons, Higgs
- electromagnetic, strong, weak interactions

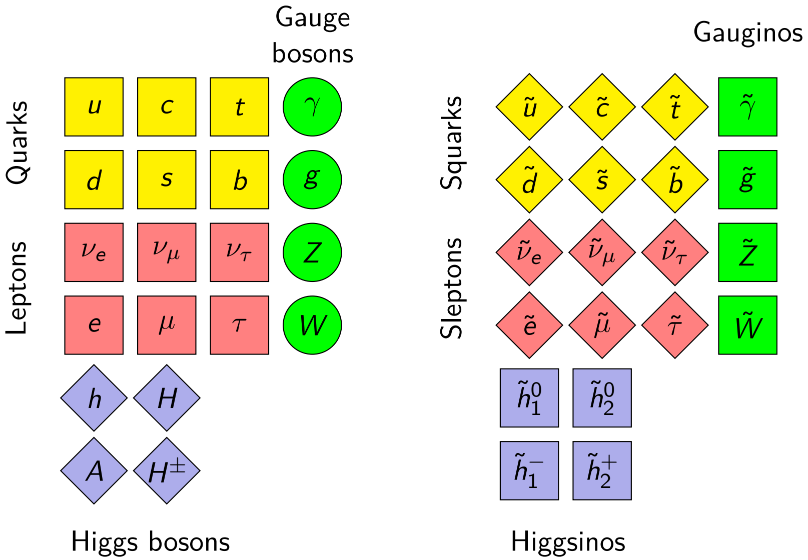
Problems:

- no gravitation
- no dark matter

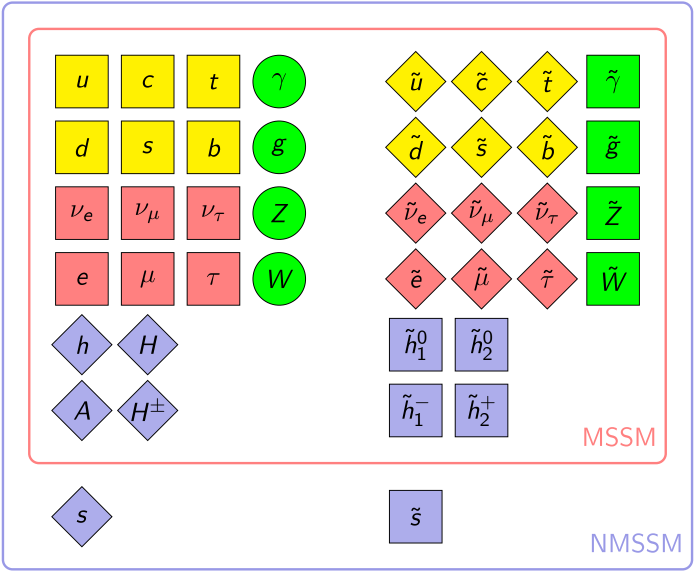
Weaknesses:

- no unification of gauge couplings
- hierarchy problem
- prediction of $(g-2)_\mu$

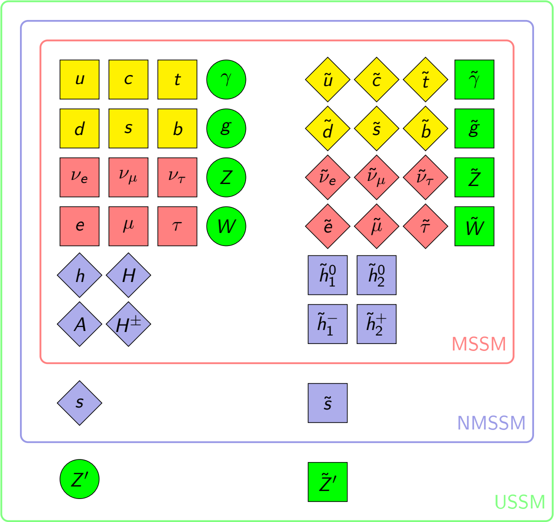
Minimal Supersymmetric Standard Modell (MSSM)



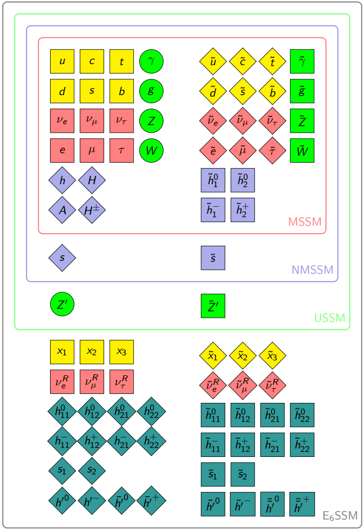
Next-to-MSSM (NMSSM)



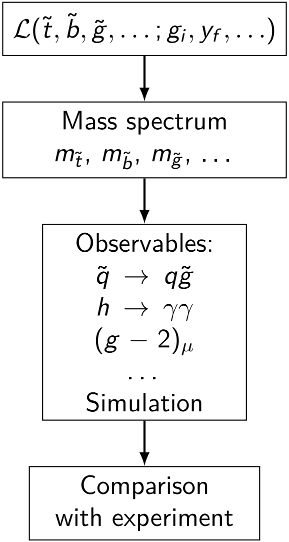
$U(1)'$-extended Supersymmetric Standard Modell (USSM)



Exceptional Supersymmetric Standard Modell (E_6SSM)



Comparison with experiment



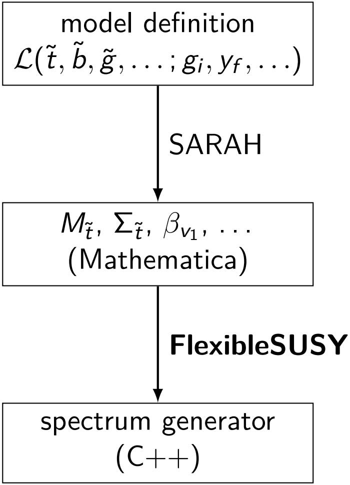
Publicly available SUSY spectrum generators

Model	spectrum generator
SM	SMH
THDM	2HDMC
MSSM	ISASUSY, FeynHiggs, SOFTSUSY, SPheno, SuSeFlav, SuSpect, SUSYHD
NMSSM	NMSPEC, SOFTSUSY
USSM	–
CE_6SSM	CE6SSMSpecGen
any SUSY-Modell	SARAH, **FlexibleSUSY**

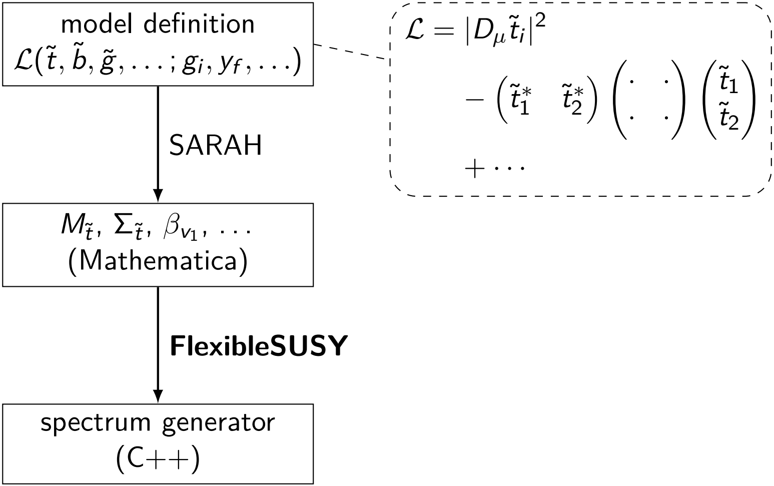
FlexibleSUSY: a SUSY spectrum generator generator

FlexibleSUSY

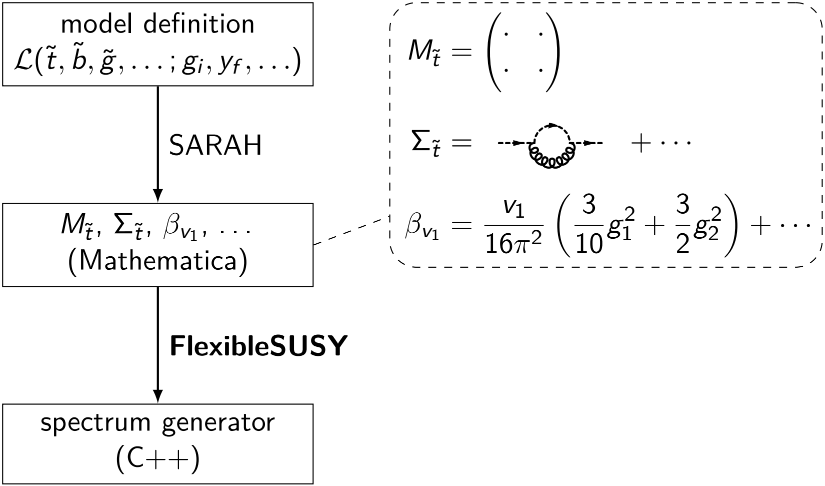
How a spectrum generator is generated



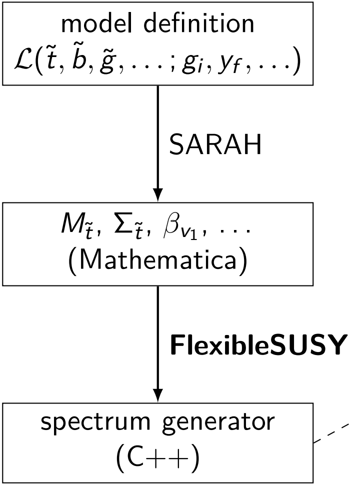
How a spectrum generator is generated



How a spectrum generator is generated



How a spectrum generator is generated




```
Matrix<2,2> get_mass_matrix_St() {
  Matrix<2,2> mass_matrix;

  mass_matrix(0,0) = ...;
  mass_matrix(0,1) = ...;
  mass_matrix(1,0) = ...;
  mass_matrix(1,1) = ...;

  return mass_matrix;
}

complex<double> self_energy_St() {
  complex<double> self_energy;

  self_energy += ...;
  self_energy += ...;
  self_energy += ...;

  return self_energy;
}

double beta_v1() {
  double beta_v1;

  beta_v1 = v1*(0.3*Sqr(g1)
     + 1.5*Sqrt(g2))/(16.*Sqr(Pi) + ...;

  return beta_v1;
}
```

Available models in FlexibleSUSY

Supersymmetric models:

MSSM, NMSSM, SMSSM, USSM, E_6SSM, TMSSM, MRSSM, NE_6SSM, $\mu\nu$SSM, ...

Non-supersymmetric models:

SM, SM + split, THDM, THDM + Higgsinos, THDM + split, SM + singlet, TSM, ...

https://flexiblesusy.hepforge.org

Thank you!

Backup

Available models with MSSM high-scale origin

Model	RGEs	h self-energy contributions	matching conditions to the MSSM
MSSM (“full model”)	3L	$1L + 2L\ O((\alpha_t+\alpha_b)\alpha_s)$ $+ 2L\ O((\alpha_t+\alpha_b)^2)$	–
THDM	2L	1L	$1L\ \lambda_i\ O((\alpha_t+\alpha_b+\alpha_\tau)\alpha_i)$ $+ 2L\ \lambda_i\ O(\alpha_t^2\alpha_s)$ [1508.00576]
THDM + $\tilde{h}_i$	2L	1L	$1L\ \lambda_i\ O((\alpha_t+\alpha_b+\alpha_\tau)\alpha_i)$ $+ 2L\ \lambda_i\ O(\alpha_t^2\alpha_s)$ [1508.00576]
THDM + split	2L	1L	$1L\ \lambda_i\ O((\alpha_t+\alpha_b+\alpha_\tau)\alpha_i)$ $+ 2L\ \lambda_i\ O(\alpha_t^2\alpha_s)$ [1508.00576]
SM + split	2L	$1L + 2L\ O(\alpha_t(\alpha_s+\alpha_t))$ $+ 3L$ gluino $O(\alpha_t\alpha_s^2)$	$1L\ \tilde{g}_{ij}\ O(\alpha_t+\alpha_i)$ $+ 1L\ \lambda\ O((\alpha_t+\alpha_i)^2)$ $+ 2L\ \lambda\ O(\alpha_s\alpha_t^2)$ [1407.4081]
SM (“EFT”)	3L	$1L + 2L\ O(\alpha_t(\alpha_s+\alpha_t))$	$1L\ \lambda\ O((\alpha_t+\alpha_i)^2+\alpha_b^2+\alpha_\tau^2)$ $+ 2L\ \lambda\ O((\alpha_s+\alpha_t)\alpha_t^2)$ [1407.4081, 1504.05200]
SM (“automatic EFT”)	3L	1L	$1L\ \lambda + O(p^2/M_S^2)$ terms

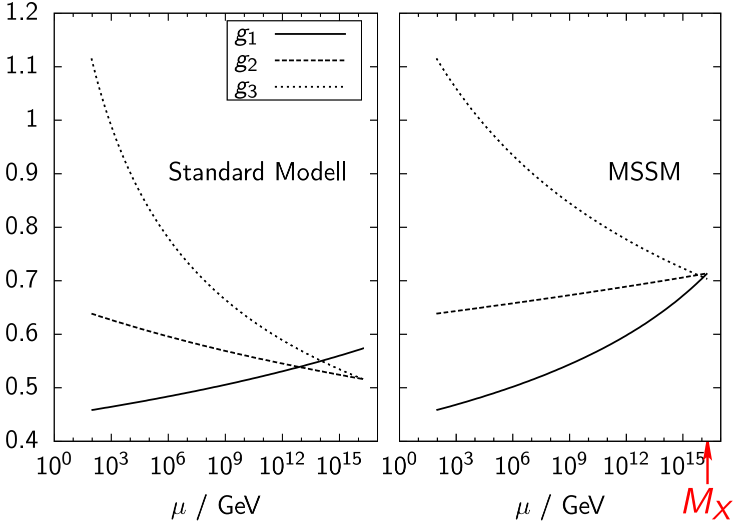
Minimal Supersymmetric Standard Modell (MSSM)

Field	$SU(3)_c \times SU(2)_L \times U(1)_Y$	$SU(5)$
$Q_i = (Q_{u_i} \quad Q_{d_i})$	$(\mathbf{3}, \mathbf{2}, \frac{1}{6})_i$	
$\bar{U}_i$	$(\bar{\mathbf{3}}, \mathbf{1}, -\frac{2}{3})_i$	$(\mathbf{10})_i$
$\bar{E}_i$	$(\mathbf{1}, \mathbf{1}, 1)_i$	
$\bar{D}_i$	$(\bar{\mathbf{3}}, \mathbf{1}, \frac{1}{3})_i$	$(\bar{\mathbf{5}})_i$
$L_i = (L_{\nu_i} \quad L_{e_i})$	$(\mathbf{1}, \mathbf{2}, -\frac{1}{2})_i$	
	$(\bar{\mathbf{3}}, \mathbf{1}, \frac{1}{3})$	$(\bar{\mathbf{5}})$
$H_1 = (H_1^0 \quad H_1^-)$	$(\mathbf{1}, \mathbf{2}, -\frac{1}{2})$	
	$(\mathbf{3}, \mathbf{1}, -\frac{1}{3})$	$(\mathbf{5})$
$H_2 = (H_2^+ \quad H_2^0)$	$(\mathbf{1}, \mathbf{2}, \frac{1}{2})$	
V_g^a	$(\mathbf{8}, \mathbf{1}, 0)$	$\ni (\mathbf{24})$
V_W^i	$(\mathbf{1}, \mathbf{3}, 0)$	$\ni (\mathbf{24})$
V_Y	$(\mathbf{1}, \mathbf{1}, 0)$	$\ni (\mathbf{24})$

Minimal Supersymmetric Standard Modell (MSSM)

$$\mathcal{W}_{\mathsf{MSSM}} = \mu(H_1 H_2) - y^e_{ij}(H_1 L_i)\bar{E}_j - y^d_{ij}(H_1 Q_i)\bar{D}_j - y^u_{ij}(Q_i H_2)\bar{U}_j$$

Advantage of the MSSM: Gauge Coupling Unification



Weakness of the MSSM: Fine-tuning problem

$$(m_h^{\text{pole}})^2 \approx m_Z^2 \cos^2 2\beta + \Delta m_h^2,$$

$$\begin{aligned} m_h^{\text{pole}} &\approx 125\,\text{GeV} \\ m_Z &\approx 91\,\text{GeV} \\ \Rightarrow \Delta m_h &\gtrsim 87\,\text{GeV} \end{aligned}$$

$\Rightarrow$ large splitting between m_t and $m_{\tilde{t}_i}$

$\Rightarrow$ large SUSY breaking terms

$\Rightarrow$ spoils SUSY's solution to hierarchy problem

Weakness of the MSSM: μ-Problem

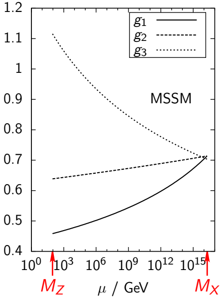
$$\mathcal{W}_{\text{MSSM}} = \mu(H_1 H_2) + \cdots$$

On the one hand:
μ has its origin at the GUT scale M_X

$$\Rightarrow \mu \sim M_X \sim 10^{16}\ \text{GeV}$$

On the other hand:
μ fixed by EWSB at M_Z

$$\Rightarrow \mu \sim M_Z \sim 10^{2}\ \text{GeV}$$



Solution: introduce new Higgs singlet S with VEV v_s

$\Rightarrow$ Next-to Minimal Supersymmetric Standard Modell (NMSSM)

Next-to-MSSM (NMSSM)

Field	$SU(3)_c \times SU(2)_L \times U(1)_Y$	$SU(5)$
$Q_i = (Q_{u_i} \;\; Q_{d_i})$	$(\mathbf{3}, \mathbf{2}, \frac{1}{6})_i$	$(\mathbf{10})_i$
$\bar{U}_i$	$(\bar{\mathbf{3}}, \mathbf{1}, -\frac{2}{3})_i$	
$\bar{E}_i$	$(\mathbf{1}, \mathbf{1}, 1)_i$	
$\bar{D}_i$	$(\bar{\mathbf{3}}, \mathbf{1}, \frac{1}{3})_i$	$(\bar{\mathbf{5}})_i$
$L_i = (L_{\nu_i} \;\; L_{e_i})$	$(\mathbf{1}, \mathbf{2}, -\frac{1}{2})_i$	
	$(\bar{\mathbf{3}}, \mathbf{1}, \frac{1}{3})$	$(\bar{\mathbf{5}})$
$H_1 = (H_1^0 \;\; H_1^-)$	$(\mathbf{1}, \mathbf{2}, -\frac{1}{2})$	
	$(\mathbf{3}, \mathbf{1}, -\frac{1}{3})$	$(\mathbf{5})$
$H_2 = (H_2^+ \;\; H_2^0)$	$(\mathbf{1}, \mathbf{2}, \frac{1}{2})$	
S	$(\mathbf{1}, \mathbf{1}, 0)$	$(\mathbf{1})$
V_g^a	$(\mathbf{8}, \mathbf{1}, 0)$	$\ni (\mathbf{24})$
V_W^i	$(\mathbf{1}, \mathbf{3}, 0)$	$\ni (\mathbf{24})$
V_Y	$(\mathbf{1}, \mathbf{1}, 0)$	$\ni (\mathbf{24})$

Next-to-MSSM (NMSSM)

$$\mathcal{W}_{\text{MSSM}+S} = \lambda S(H_1 H_2) + \frac{\kappa}{3} S^3 + \frac{\mu'}{2} S^2 + \xi_F S$$
$$+ \mu(H_1 H_2) - y^e_{ij}(H_1 L_i)\bar{E}_j - y^d_{ij}(H_1 Q_i)\bar{D}_j - y^u_{ij}(Q_i H_2)\bar{U}_j$$

Next-to-MSSM (NMSSM)

$$\mathcal{W}_{\text{MSSM}+S} = \lambda S(H_1 H_2) + \frac{\kappa}{3} S^3 + \frac{\mu'}{2} S^2 + \xi_F S \\ + \mu(H_1 H_2) - y^e_{ij}(H_1 L_i)\bar{E}_j - y^d_{ij}(H_1 Q_i)\bar{D}_j - y^u_{ij}(Q_i H_2)\bar{U}_j$$

Impose Z_3 symmetry to forbid dimensionful couplings and solve the μ-problem
$\Rightarrow$

$$\mathcal{W}_{\text{NMSSM}} = \lambda S(H_1 H_2) + \frac{\kappa}{3} S^3 \\ - y^e_{ij}(H_1 L_i)\bar{E}_j - y^d_{ij}(H_1 Q_i)\bar{D}_j - y^u_{ij}(Q_i H_2)\bar{U}_j$$

Advantage of the NMSSM: Reduced m_h Fine-tuning

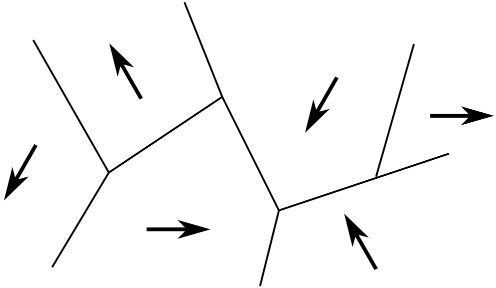
$$(m_h^{\text{pole}})^2 \approx \underbrace{\underbrace{m_Z^2 \cos^2 2\beta}_{\text{MSSM}} + \frac{\lambda^2 v^2}{2} \sin^2 2\beta}_{\text{NMSSM}} + \Delta m_h^2$$

$$\Rightarrow \Delta m_h \gtrsim 55\,\text{GeV}$$

MSSM: $\Delta m_h \gtrsim 87\,\text{GeV}$

Problem of the NMSSM: Domain Walls

Problem: $\mathcal{W}_{\text{NMSSM}}$ has a *discrete* Z_3 symmetry.
$\Rightarrow$ domain walls



Solution: new *continuous* gauge symmetry $U(1)'$

$\Rightarrow$ $U(1)'$-extended Supersymmetric Standard Modell (USSM)

$U(1)'$-extended Supersymmetric Standard Modell (USSM)

Field	$G_{SM} \times U(1)'$	$SU(5) \times U(1)'$
$Q_i = (Q_{u_i} \quad Q_{d_i})$	$(\mathbf{3}, \mathbf{2}, \frac{1}{6}, N_Q)_i$	$(\mathbf{10}, N_{10})_i$
$\bar{U}_i$	$(\bar{\mathbf{3}}, \mathbf{1}, -\frac{2}{3}, N_U)_i$	
$\bar{E}_i$	$(\mathbf{1}, \mathbf{1}, 1, N_E)_i$	
$\bar{D}_i$	$(\bar{\mathbf{3}}, \mathbf{1}, \frac{1}{3}, N_D)_i$	$(\bar{\mathbf{5}}, N_{\bar{5}})_i$
$L_i = (L_{\nu_i} \quad L_{e_i})$	$(\mathbf{1}, \mathbf{2}, -\frac{1}{2}, N_L)_i$	
	$(\bar{\mathbf{3}}, \mathbf{1}, \frac{1}{3}, N_X)$	$(\bar{\mathbf{5}}, N_{\bar{5}})$
$H_1 = (H_1^0 \quad H_1^-)$	$(\mathbf{1}, \mathbf{2}, -\frac{1}{2}, N_{H_1})$	
	$(\mathbf{3}, \mathbf{1}, -\frac{1}{3}, N_X)$	$(\mathbf{5}, N_5)$
$H_2 = (H_2^+ \quad H_2^0)$	$(\mathbf{1}, \mathbf{2}, \frac{1}{2}, N_{H_2})$	
S	$(\mathbf{1}, \mathbf{1}, 0, N_S)$	$(\mathbf{1}, N_1)$
V_g^a	$(\mathbf{8}, \mathbf{1}, 0, 0)$	$\ni (\mathbf{24}, 0)$
V_W^i	$(\mathbf{1}, \mathbf{3}, 0, 0)$	$\ni (\mathbf{24}, 0)$
V_Y	$(\mathbf{1}, \mathbf{1}, 0, 0)$	$\ni (\mathbf{24}, 0)$
V_N	$(\mathbf{1}, \mathbf{1}, 0, 0)$	$\ni (\mathbf{1}, 0)$

$U(1)'$-extended Supersymmetric Standard Modell (USSM)

If $N_S \neq 0$ and $N_S + N_{H_1} + N_{H_2} = 0$
$\Rightarrow$ all S^n terms forbidden

$$\mathcal{W}_{\text{USSM}} = \lambda S(H_1 H_2) - y^e_{ij}(H_1 L_i)\bar{E}_j - y^d_{ij}(H_1 Q_i)\bar{D}_j - y^u_{ij}(Q_i H_2)\bar{U}_j$$

Advantage of the USSM: Reduced m_h Fine-tuning

$$(m_h^{\text{pole}})^2 = (m_h^{\text{tree}})^2 + \Delta m_h^2$$

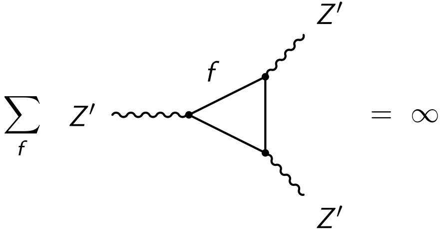
$$(m_h^{\text{tree}})^2 \approx \underbrace{\underbrace{\underbrace{m_Z^2 \cos^2 2\beta}_{\text{MSSM}} + \frac{\lambda^2 v^2}{2} \sin^2 2\beta}_{\text{NMSSM}} + \frac{m_Z^2}{4}\left(1 + \frac{1}{4}\cos 2\beta\right)^2}_{\text{USSM}}$$

$$\Rightarrow \Delta m_h \gtrsim 32\,\text{GeV}$$

MSSM: $\Delta m_h \gtrsim 87\,\text{GeV}$
NMSSM: $\Delta m_h \gtrsim 55\,\text{GeV}$

Problem of the USSM: Anomalies

Problem: $U(1)'$-charges are arbitrary
(as long as $\mathcal{W}_{\text{USSM}}$ is gauge invariant)
$\Rightarrow$ unsuitable choice can lead to gauge anomalies:



Solution: anomaly-free gauge group, e.g. $SO(10)$ or E_6

$\Rightarrow$ Exceptional Supersymmetric Standard Modell (E_6SSM)

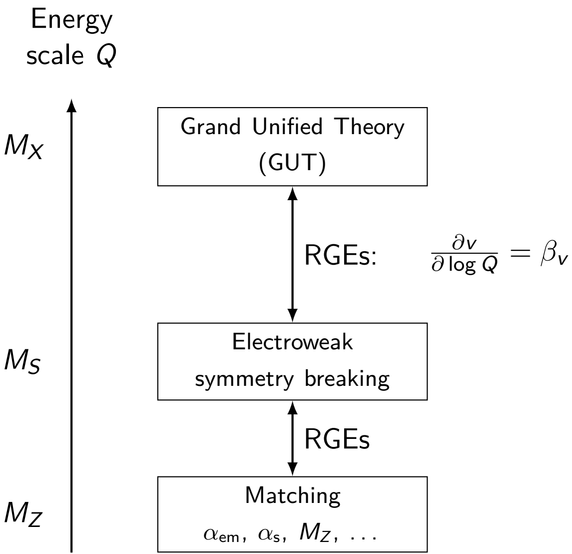
Exceptional Supersymmetric Standard Modell (E_6SSM)

Field	$G_{SM} \times U(1)_N$	$SU(5) \times U(1)_N$	E_6
$Q_i = (Q_{u_i} \quad Q_{d_i})$	$(\mathbf{3}, \mathbf{2}, \frac{1}{6}, 1)_i$	$(\mathbf{10}, 1)_i$	$(\mathbf{27})_i$
$\bar{U}_i$	$(\bar{\mathbf{3}}, \mathbf{1}, -\frac{2}{3}, 1)_i$	$(\mathbf{10}, 1)_i$	$(\mathbf{27})_i$
$\bar{E}_i$	$(\mathbf{1}, \mathbf{1}, 1, 1)_i$	$(\mathbf{10}, 1)_i$	$(\mathbf{27})_i$
$\bar{D}_i$	$(\bar{\mathbf{3}}, \mathbf{1}, \frac{1}{3}, 2)_i$	$(\bar{\mathbf{5}}, 2)_i$	$(\mathbf{27})_i$
$L_i = (L_{\nu_i} \quad L_{e_i})$	$(\mathbf{1}, \mathbf{2}, -\frac{1}{2}, 2)_i$	$(\bar{\mathbf{5}}, 2)_i$	$(\mathbf{27})_i$
$\bar{X}_i$	$(\bar{\mathbf{3}}, \mathbf{1}, \frac{1}{3}, -3)_i$	$(\bar{\mathbf{5}}, -3)_i$	$(\mathbf{27})_i$
$H_{1i} = (H_{1i}^0 \quad H_{1i}^-)$	$(\mathbf{1}, \mathbf{2}, -\frac{1}{2}, -3)_i$	$(\bar{\mathbf{5}}, -3)_i$	$(\mathbf{27})_i$
X_i	$(\mathbf{3}, \mathbf{1}, -\frac{1}{3}, -2)_i$	$(\mathbf{5}, -2)_i$	$(\mathbf{27})_i$
$H_{2i} = (H_{2i}^+ \quad H_{2i}^0)$	$(\mathbf{1}, \mathbf{2}, \frac{1}{2}, -2)_i$	$(\mathbf{5}, -2)_i$	$(\mathbf{27})_i$
S_i	$(\mathbf{1}, \mathbf{1}, 0, 5)_i$	$(\mathbf{1}, 5)_i$	$(\mathbf{27})_i$
$\bar{N}_i$	$(\mathbf{1}, \mathbf{1}, 0, 0)_i$	$(\mathbf{1}, 0)_i$	$(\mathbf{27})_i$
$H' = (H'^0 \quad H'^-)$	$(\mathbf{1}, \mathbf{2}, -\frac{1}{2}, 2)$	$\ni (\bar{\mathbf{5}}, 2)'$	$\ni (\mathbf{27})'$
$\bar{H}' = (\bar{H}'^+ \quad \bar{H}'^0)$	$(\mathbf{1}, \mathbf{2}, \frac{1}{2}, -2)$	$\ni (\mathbf{5}, -2)'$	$\ni (\overline{\mathbf{27}})'$
V_g^a	$(\mathbf{8}, \mathbf{1}, 0, 0)$	$\ni (\mathbf{24}, 0)$	$\ni (\mathbf{78})$
V_W^i	$(\mathbf{1}, \mathbf{3}, 0, 0)$	$\ni (\mathbf{24}, 0)$	$\ni (\mathbf{78})$
V_Y	$(\mathbf{1}, \mathbf{1}, 0, 0)$	$\ni (\mathbf{24}, 0)$	$\ni (\mathbf{78})$
V_N	$(\mathbf{1}, \mathbf{1}, 0, 0)$	$\ni (\mathbf{1}, 0)$	$\ni (\mathbf{78})$

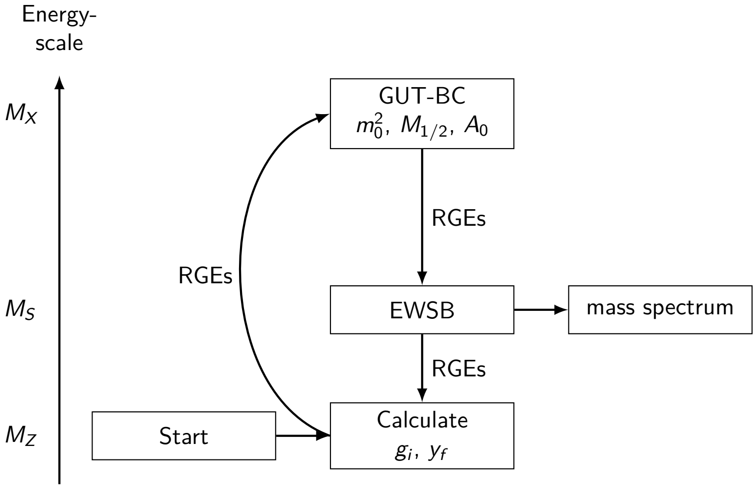
Exceptional Supersymmetric Standard Modell (E_6SSM)

$$\begin{aligned}\mathcal{W}_{\mathsf{E_6SSM}} = &\lambda_3 S_3 (H_{13} H_{23}) \\ &- y^e_{ij} (H_{13} L_i) \bar{E}_j - y^d_{ij} (H_{13} Q_i) \bar{D}_j - y^u_{ij} (Q_i H_{23}) \bar{U}_j \\ &+ \kappa_{ij} S_3 (X_i \bar{X}_j) + \lambda_{\alpha\beta} S_3 (H_{1\alpha} H_{2\beta}) + \mu' (H' \bar{H}')\end{aligned}$$

Physical problem statement

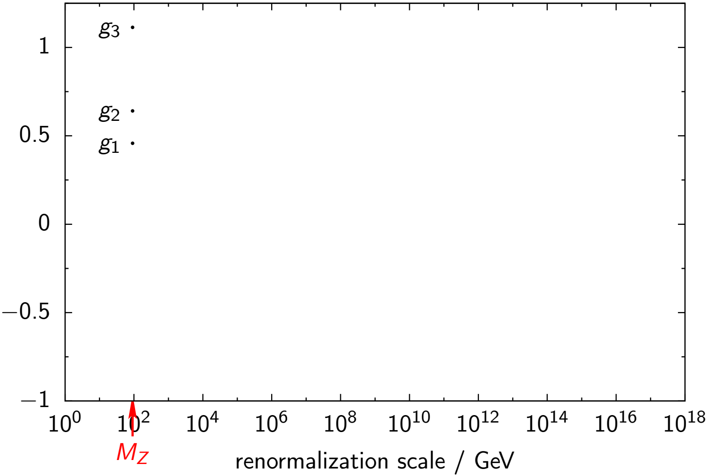


Algorithm to calculate the mass spectrum



Algorithm to calculate the mass spectrum

Iteration step 1: calculate gauge couplings $g_i^{\overline{\text{DR}}}(M_Z)$



Calculate gauge coupling $g_3^{\overline{\text{DR}}}(M_Z)$

Input: $\alpha_{\text{s,SM}}^{(5),\overline{\text{MS}}}(M_Z) = 0.1185$

$\rightarrow$

$$\alpha_{\text{s}}^{\overline{\text{DR}}}(M_Z) = \frac{\alpha_{\text{s,SM}}^{(5),\overline{\text{MS}}}(M_Z)}{1 - \Delta\alpha_{\text{s,SM}}(M_Z) - \Delta\alpha_{\text{s}}(M_Z)}$$

with

$$\Delta\alpha_{\text{s,SM}}(\mu) = \frac{\alpha_{\text{s}}}{2\pi}\left[-\frac{2}{3}\log\frac{m_t}{\mu}\right]$$

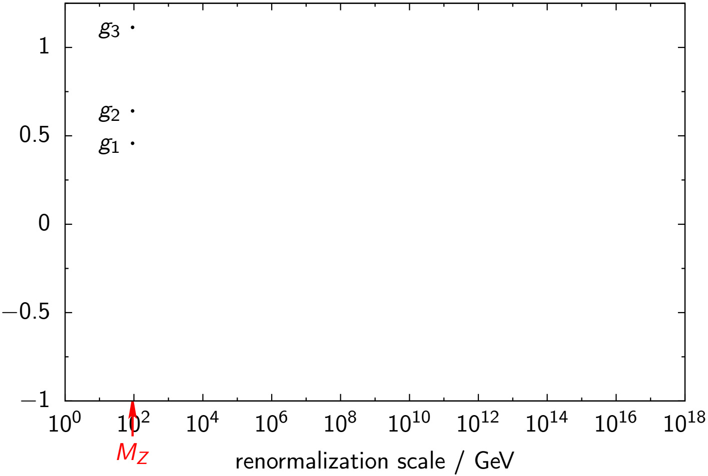
$$\Delta\alpha_{\text{s}}(\mu) = \frac{\alpha_{\text{s}}}{2\pi}\left[\frac{1}{2} - \sum_{\text{SUSY particle } f} T_f \log\frac{m_f}{\mu}\right]$$

$\Rightarrow$

$$g_3^{\overline{\text{DR}}}(M_Z) = \sqrt{4\pi\alpha_{\text{s}}^{\overline{\text{DR}}}(M_Z)}$$

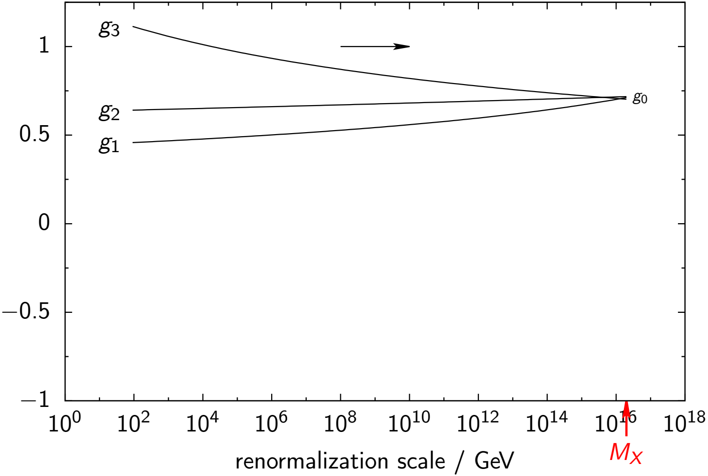
Algorithm to calculate the mass spectrum

Iteration step 1: calculate gauge couplings $g_i^{\overline{\text{DR}}}(M_Z)$



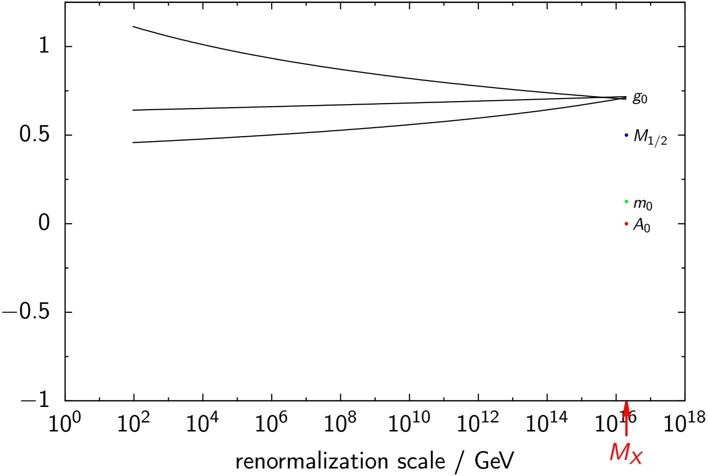
Algorithm to calculate the mass spectrum

Iteration step 1: RG running of gauge couplings to M_X



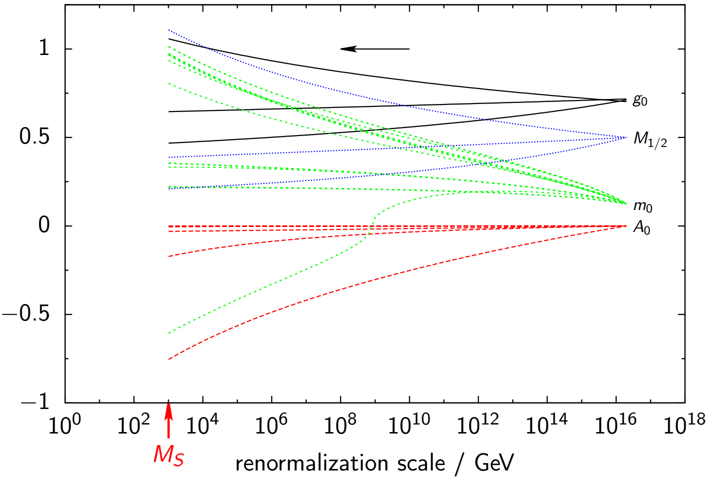
Algorithm to calculate the mass spectrum

Iteration step 1: impose boundary conditions at M_X



Algorithm to calculate the mass spectrum

Iteration step 1: RG running to M_S, impose EWSB conditions



Solve EWSB conditions

Solve EWSB conditions by fixing N model parameters $(p_1, \ldots, p_N)$:

$$0 = \frac{\partial V^{\text{tree}}}{\partial v_i} - t_i(m_f) \qquad\qquad (i = 1, \ldots, N)$$

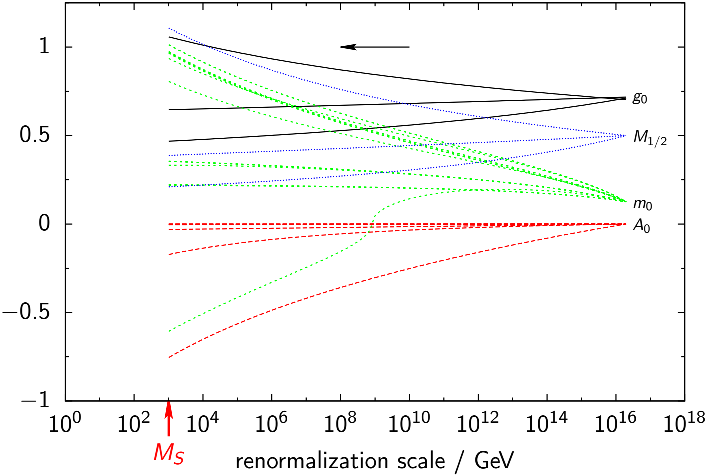
For example: CMSSM solve for $(\mu, B\mu)$

$$0 = m_{h_1}^2 v_1 + |\mu|^2 v_1 - B\mu v_2 + \frac{\bar{g}^2}{8}(v_1^2 - v_2^2) v_1 - t_1(m_f)$$
$$0 = m_{h_2}^2 v_2 + |\mu|^2 v_2 - B\mu v_1 - \frac{\bar{g}^2}{8}(v_1^2 - v_2^2) v_2 - t_2(m_f)$$

where $\bar{g}^2 = g_Y^2 + g_2^2$

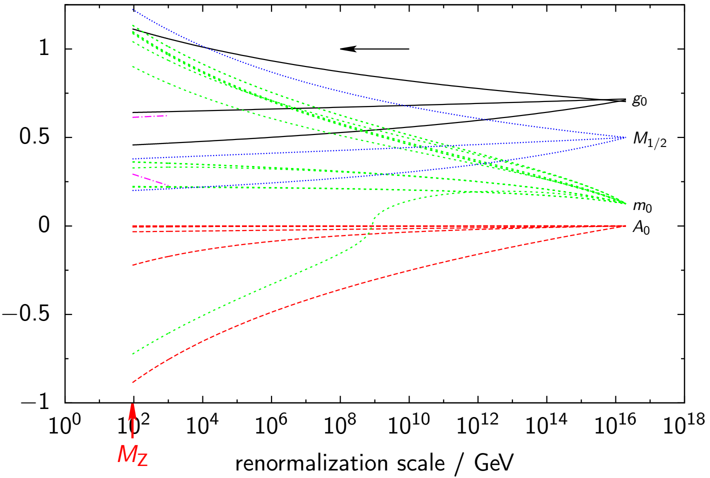
Algorithm to calculate the mass spectrum

Iteration step 1: RG running to M_S, impose EWSB on $(\mu, B\mu)$



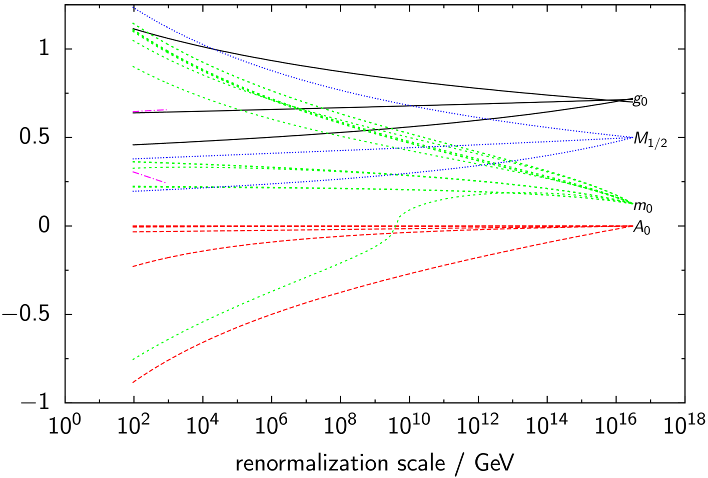
Algorithm to calculate the mass spectrum

Iteration step 1: RG running to M_Z



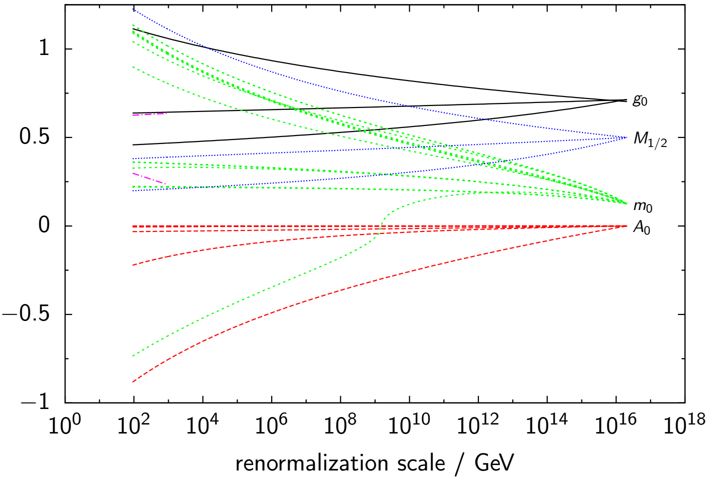
Algorithm to calculate the mass spectrum

Iteration step 2:



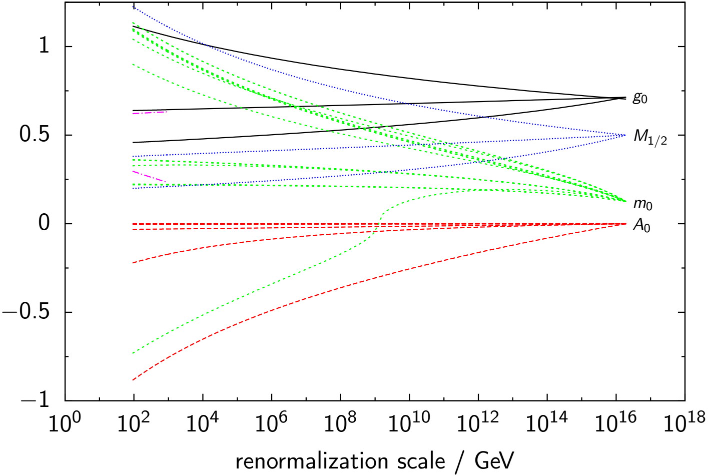
Algorithm to calculate the mass spectrum

Iteration step 3:

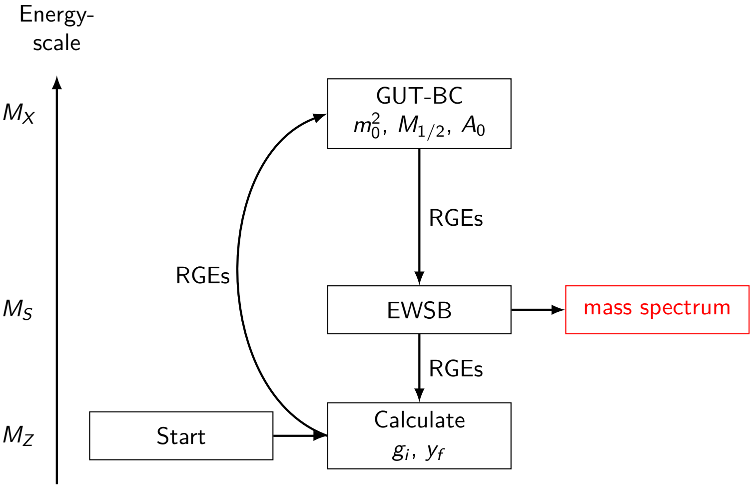


Algorithm to calculate the mass spectrum

Iteration step 8: convergence



Algorithm to calculate the mass spectrum



Calculate the pole mass spectrum

Solve for each particle f:

$$0 = \det\left[p^2\mathbf{1} - M_f + \hat{\Sigma}_f(p^2)\right]$$

For example f = Higgs:

$$M_h = \begin{pmatrix} (M_h)_{11} & (M_h)_{12} \\ (M_h)_{12} & (M_h)_{22} \end{pmatrix}$$

$$(M_h)_{11} = m_{h_1}^2 + |\mu|^2 + \frac{1}{8}(g_Y^2 + g_2^2)(3v_1^2 - v_2^2)$$

$$(M_h)_{12} = -\frac{1}{2}(B\mu + B\mu^*) - \frac{1}{4}v_2 v_1(g_Y^2 + g_2^2)$$

$$(M_h)_{22} = m_{h_2}^2 + |\mu|^2 + \frac{1}{8}(g_Y^2 + g_2^2)(3v_2^2 - v_1^2)$$

$$\hat{\Sigma}_h(p^2) = \Sigma_h(p^2) - \delta M_h^2 + (p^2\mathbf{1} - M_h^2)\delta Z_h,$$

$$\delta M_h^2 = \Sigma_h(p^2)\Big|_\Delta, \qquad \delta Z_h = -\,\Sigma_h'(p^2)\Big|_\Delta$$

Parameters scans in the CMSSM, NMSSM, USSM, E_6SSM

Models: CMSSM, NMSSM, USSM, E_6SSM

mSUGRA-inspired GUT scale BCs:

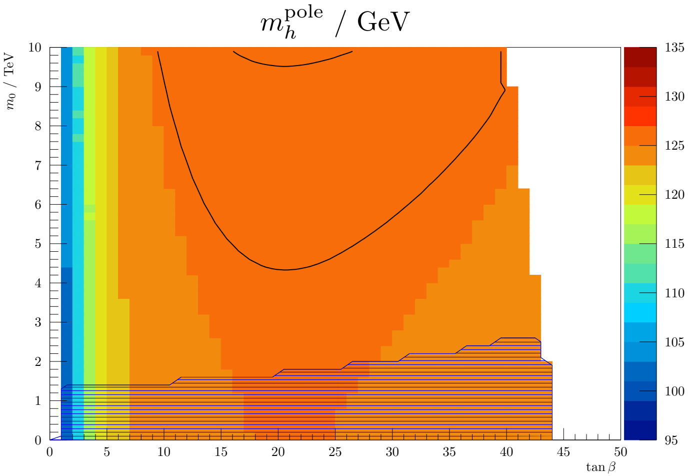
$$(m_f^2)_{ij}(M_X) = m_0^2 \delta_{ij}$$
$$A_{ij}^f(M_X) = A_0$$
$$M_i(M_X) = M_{1/2}$$

parameters fixed by EWSB conditions at M_S:

CMSSM:	$\mu, B\mu$
NMSSM:	κ, v_s, m_s^2
USSM:	$m_{h_1}^2, m_{h_2}^2, m_s^2$
E_6SSM:	$m_{h_1}^2, m_{h_2}^2, m_s^2$

2-dimensional scan over: m_0, $\tan\beta = v_2/v_1$

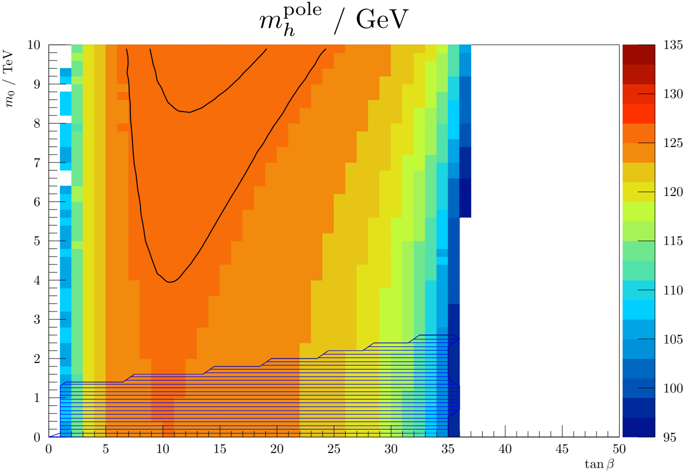
CMSSM parameter scan



$M_{1/2} = A_0 = 5\,\text{TeV}, \text{sign}\,\mu = +1$

Higgs mass contours at $m_h^{\text{pole}} = (125.7 \pm 0.4)\,\text{GeV}$

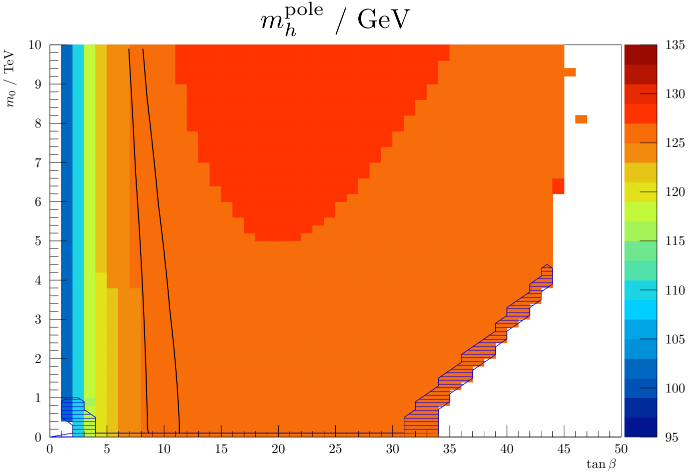
NMSSM parameter scan



$M_{1/2} = -A_0 = 5\,\text{TeV}, \lambda(M_X) = 0.1, \text{sign}\ v_s = +1$

Higgs mass contours at $m_h^{\text{pole}} = (125.7 \pm 0.4)\,\text{GeV}$

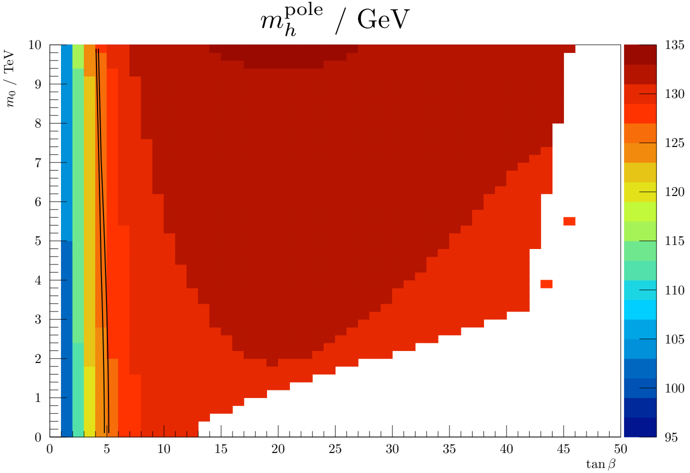
USSM parameter scan



$M_{1/2} = A_0 = 5\,\text{TeV}, \lambda(M_X) = 0.1, v_s = 10\,\text{TeV}$

Higgs mass contours at $m_h^{\text{pole}} = (125.7 \pm 0.4)\,\text{GeV}$

E_6SSM parameter scan



$M_{1/2} = A_0 = 5\,\text{TeV}, \lambda(M_X) = \kappa(M_X) = 0.1, v_s = 10\,\text{TeV}$

Higgs mass contours at $m_h^{\text{pole}} = (125.7 \pm 0.4)\,\text{GeV}$