ASPEN DARK MATTER WORKSHOP

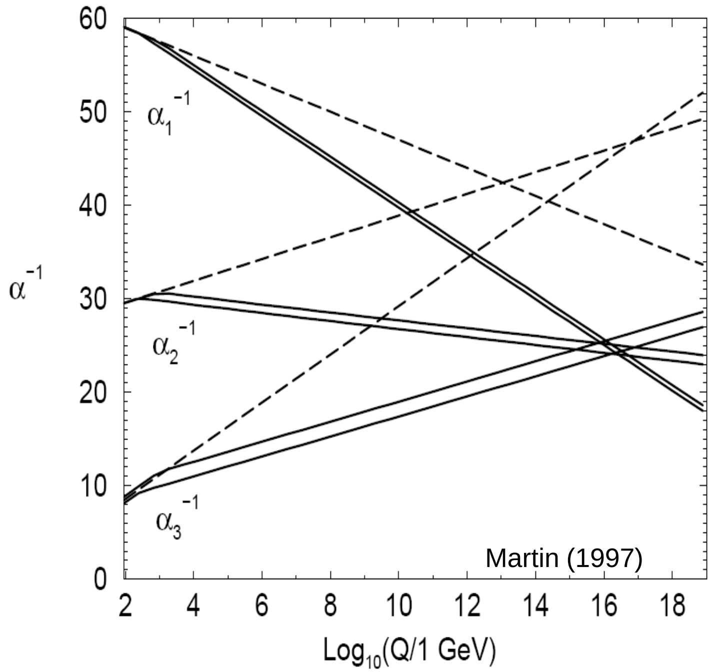
LHC / MODEL BUILDING DISCUSSION

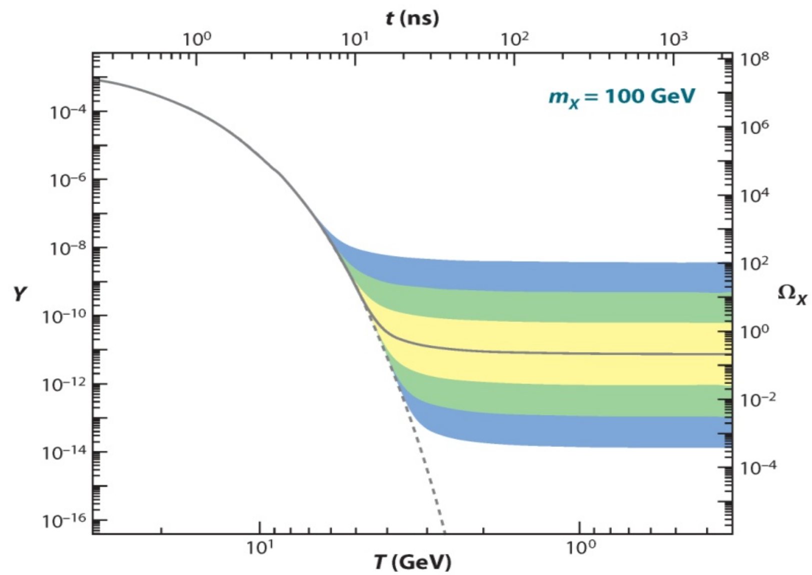
SUSY DARK MATTER CANDIDATES

- Jonathan Feng: SUSY Now
- Leszek Roszkowski: CMSSM/MSSM/NMSSM Dark Matter after LHC 8 TeV and XENON 100
- Genevieve Belanger: LHC Constraints on Light Neutralinos
- Yael Shadmi: Dark Matter from SUSY Hidden Sectors

SUSY NOW

- LHC has not yet discovered BSM physics, so what's the status of weak-scale SUSY now? Recall its main motivations.
- Gauge Coupling Unification
- Dark Matter





$$\Omega_\chi \propto \frac{1}{\langle \sigma v \rangle} \propto \tilde{m}^2$$

$$\begin{aligned} m_{\tilde{B}-\tilde{H}} &< 1.0 \text{ TeV} \\ m_{\tilde{W}} &< 2.7 - 3.0 \text{ TeV} \end{aligned}$$

Insensitive to superpartner masses

Thermal neutralino DM is still viable

- Naturalness

Highly subjective, but a standard procedure is to express the *Z* mass in terms of the fundamental SUSY parameters of a given model and require that there not be large cancelations

$$\mathcal{N}_i \equiv \left| \frac{\partial \ln m_Z^2}{\partial \ln a_i^2} \right| = \left| \frac{a_i^2}{m_Z^2} \frac{\partial m_Z^2}{\partial a_i^2} \right|$$

$$m_Z^2 = 2\frac{m_{H_d}^2 - m_{H_u}^2 \tan^2\beta}{\tan^2\beta - 1} - 2\mu^2$$

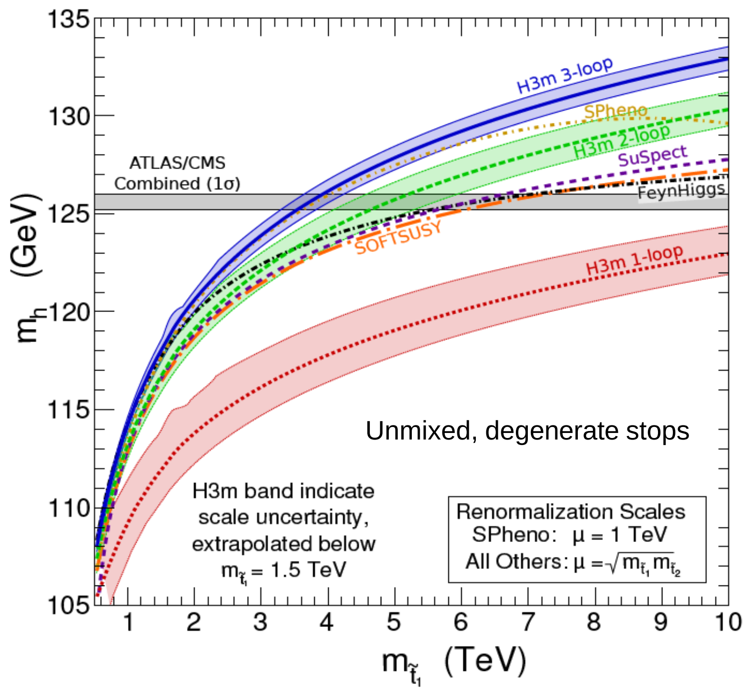
$$\begin{aligned}
M_1(m_{\text{weak}}) &= 0.41 M_1 \\
M_2(m_{\text{weak}}) &= 0.82 M_2 \\
M_3(m_{\text{weak}}) &= 2.91 M_3 \\
-2\mu^2(m_{\text{weak}}) &= -2.18\mu^2 \\
-2m_{H_u}^2(m_{\text{weak}}) &= 3.84 M_3^2 + 0.32 M_3 M_2 + 0.047 M_1 M_3 - 0.42 M_2^2 \\
&\quad +0.011 M_2 M_1 - 0.012 M_1^2 - 0.65 M_3 A_t - 0.15 M_2 A_t \\
&\quad -0.025 M_1 A_t + 0.22 A_t^2 + 0.0040 M_3 A_b \\
&\quad -1.27 m_{H_u}^2 - 0.053 m_{H_d}^2 \\
&\quad +0.73 m_{Q_3}^2 + 0.57 m_{U_3}^2 + 0.049 m_{D_3}^2 - 0.052 m_{L_3}^2 + 0.053 m_{E_3}^2 \\
&\quad +0.051 m_{Q_2}^2 - 0.110 m_{U_2}^2 + 0.051 m_{D_2}^2 - 0.052 m_{L_2}^2 + 0.053 m_{E_2}^2 \\
&\quad +0.051 m_{Q_1}^2 - 0.110 m_{U_1}^2 + 0.051 m_{D_1}^2 - 0.052 m_{L_1}^2 + 0.053 m_{E_1}^2
\end{aligned}$$

$$\begin{aligned}
m_{\tilde{H}} &\lesssim 640\ \text{GeV}\,(\mathcal{N}_{\max}/100)^{1/2} \\
m_{\tilde{B}} &\lesssim 3.4\ \text{TeV}\,(\mathcal{N}_{\max}/100)^{1/2} \\
m_{\tilde{W}} &\lesssim 1.2\ \text{TeV}\,(\mathcal{N}_{\max}/100)^{1/2} \\
m_{\tilde{g}} &\lesssim 1.4\ \text{TeV}\,(\mathcal{N}_{\max}/100)^{1/2} \\
m_{\tilde{t}_L,\tilde{b}_L} &\lesssim 1.0\ \text{TeV}\,(\mathcal{N}_{\max}/100)^{1/2} \\
m_{\tilde{t}_R} &\lesssim 1.1\ \text{TeV}\,(\mathcal{N}_{\max}/100)^{1/2} \\
m_{\tilde{b}_R} &\lesssim 4.1\ \text{TeV}\,(\mathcal{N}_{\max}/100)^{1/2} \\
m_{\tilde{\tau}_L,\tilde{\nu}_\tau} &\lesssim 4.0\ \text{TeV}\,(\mathcal{N}_{\max}/100)^{1/2} \\
m_{\tilde{\tau}_R} &\lesssim 4.0\ \text{TeV}\,(\mathcal{N}_{\max}/100)^{1/2} \\
m_{\tilde{c}_L,\tilde{s}_L,\tilde{u}_L,\tilde{d}_L} &\lesssim 4.0\ \text{TeV}\,(\mathcal{N}_{\max}/100)^{1/2} \\
m_{\tilde{c}_R,\tilde{u}_R} &\lesssim 2.7\ \text{TeV}\,(\mathcal{N}_{\max}/100)^{1/2} \\
m_{\tilde{s}_R,\tilde{d}_R} &\lesssim 4.0\ \text{TeV}\,(\mathcal{N}_{\max}/100)^{1/2} \\
m_{\tilde{\mu}_L,\tilde{\nu}_\mu,\tilde{e}_L,\tilde{\nu}_e} &\lesssim 4.0\ \text{TeV}\,(\mathcal{N}_{\max}/100)^{1/2} \\
m_{\tilde{\mu}_R,\tilde{e}_R} &\lesssim 4.0\ \text{TeV}\,(\mathcal{N}_{\max}/100)^{1/2}
\end{aligned}$$

EXPERIMENTAL CONSTRAINTS

- Collider constraints (see below)
- Flavor constraints are famously stringent, but are elegantly satisfied in some frameworks (e.g. gauge-mediated SUSY breaking).

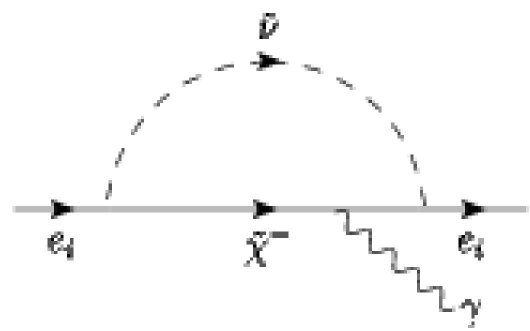
- Higgs boson mass



Feng, Kant, Profumo, Sanford (2013)

Requires heavy or highly mixed stops

- EDMs



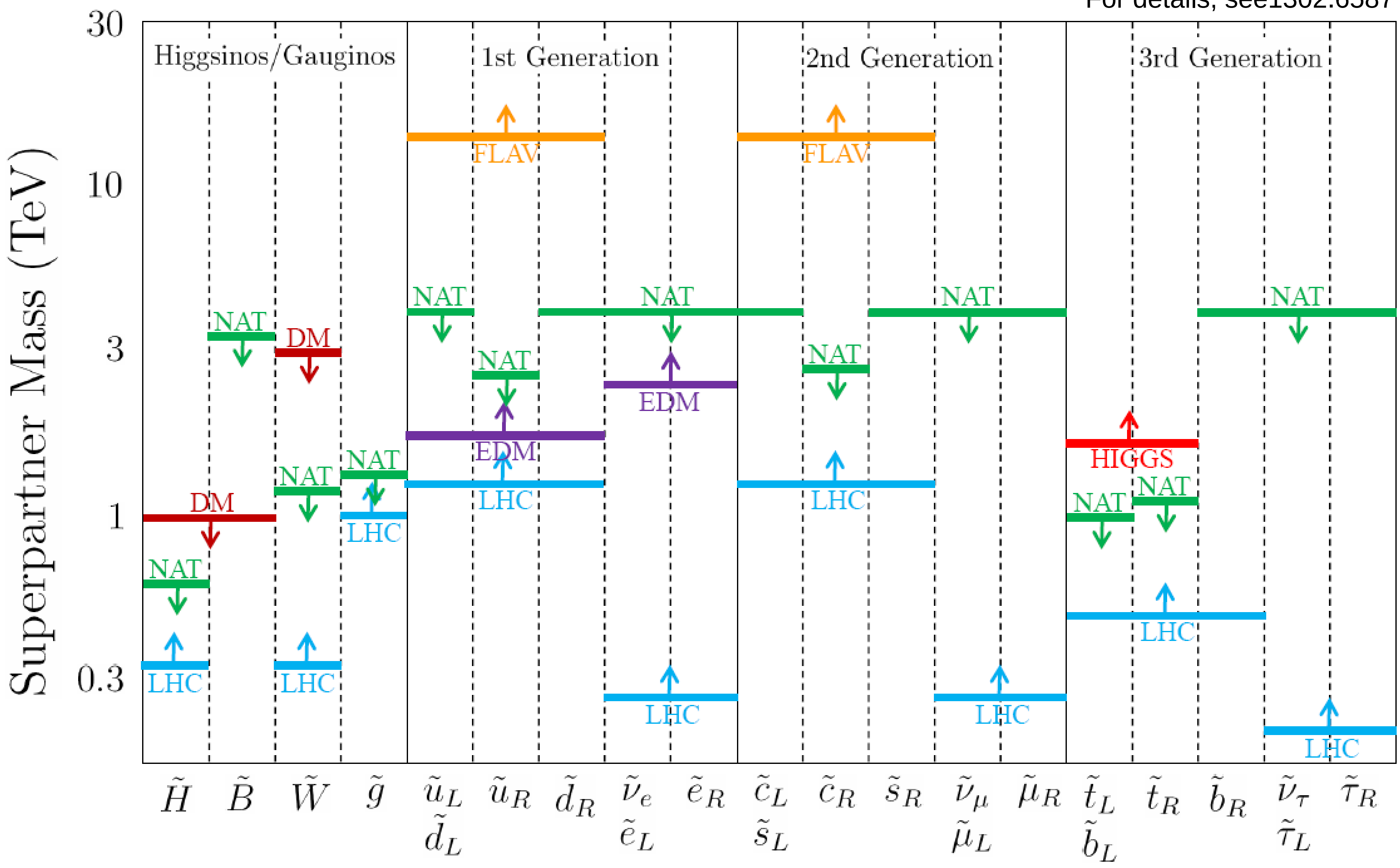
$$\left(\frac{2.5\ \text{TeV}}{m_{\tilde{l}}}\right)^2 \frac{|\mu M_2|}{m_{\tilde{l}}^2} \frac{\tan\beta}{10} \frac{\sin\theta_{\text{CP}}}{0.1} \lesssim \frac{d_e}{1.05 \times 10^{-27}\ e\,\text{cm}}$$

$$\left(\frac{1.7\ \text{TeV}}{m_{\tilde{q}}}\right)^2 \frac{|\mu M_2|}{m_{\tilde{q}}^2} \frac{\tan\beta}{10} \frac{\sin\theta_{\text{CP}}}{0.1} \lesssim \frac{d_n}{2.9 \times 10^{-26}\ e\,\text{cm}}$$

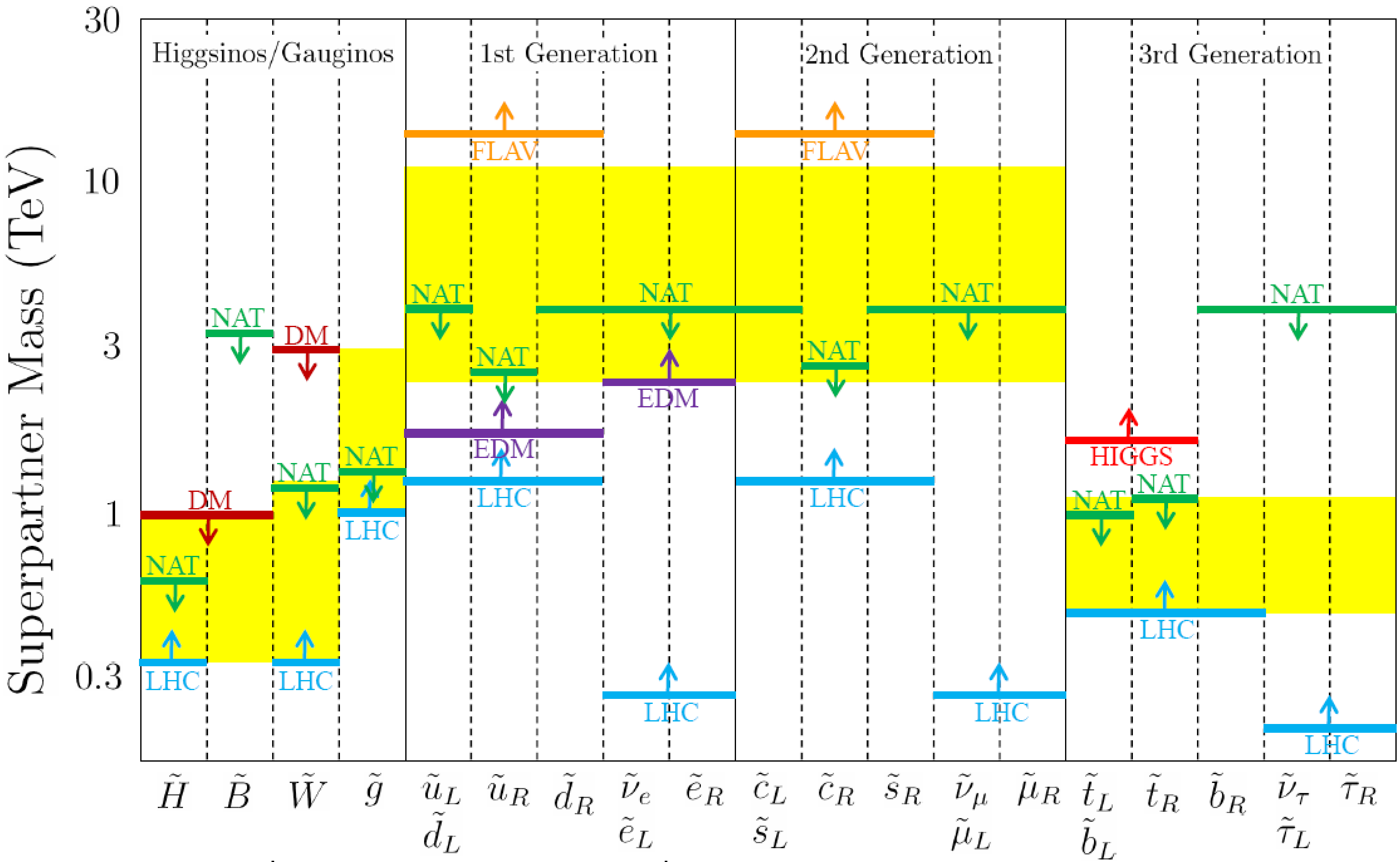
- Requires multi-TeV 1$^{\text{st}}$ generation squarks and sleptons if phases ~ 1

SUMMARY OF CONSTRAINTS

For details, see1302.6587

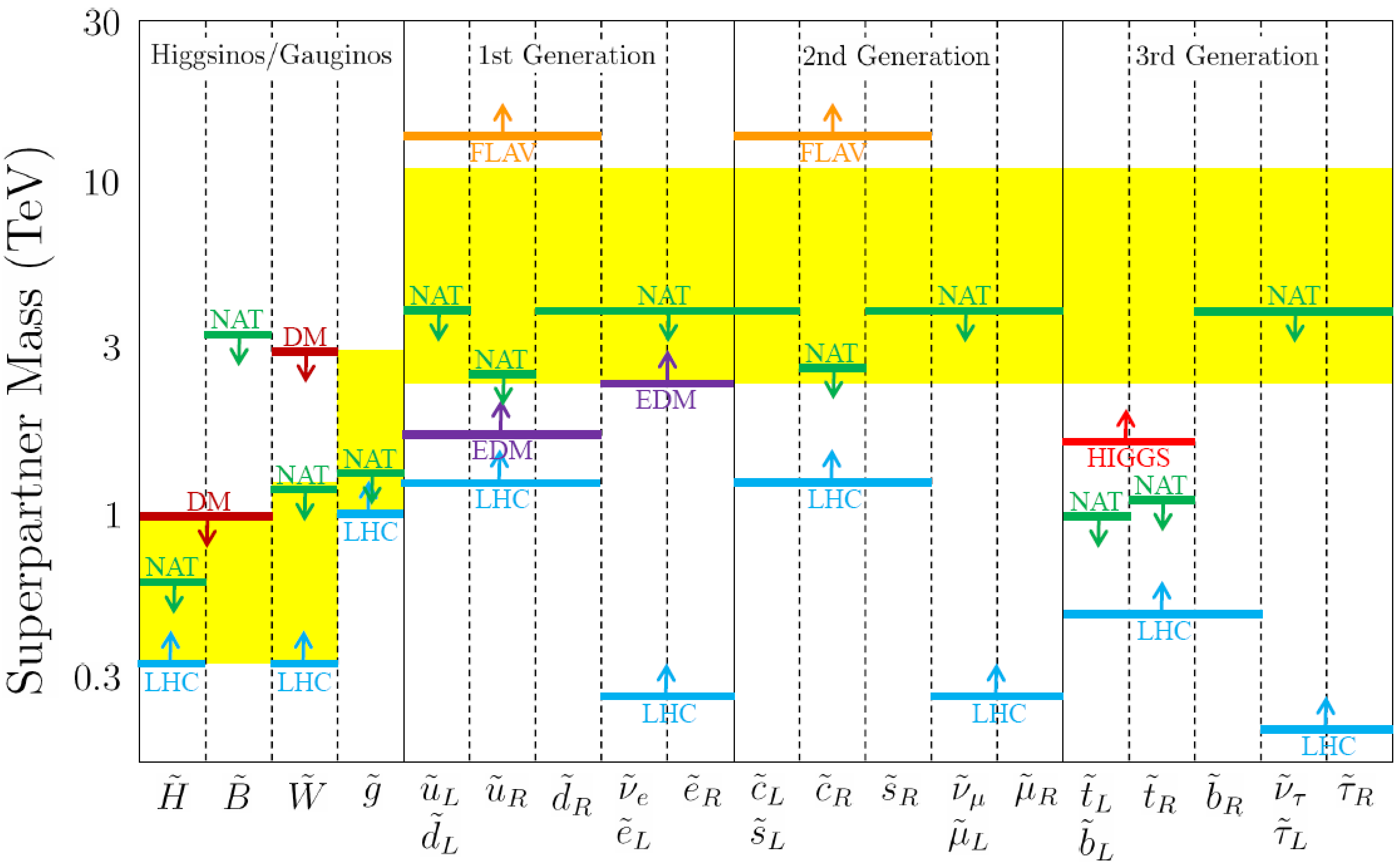


MODELS: MORE MINIMAL SUSY



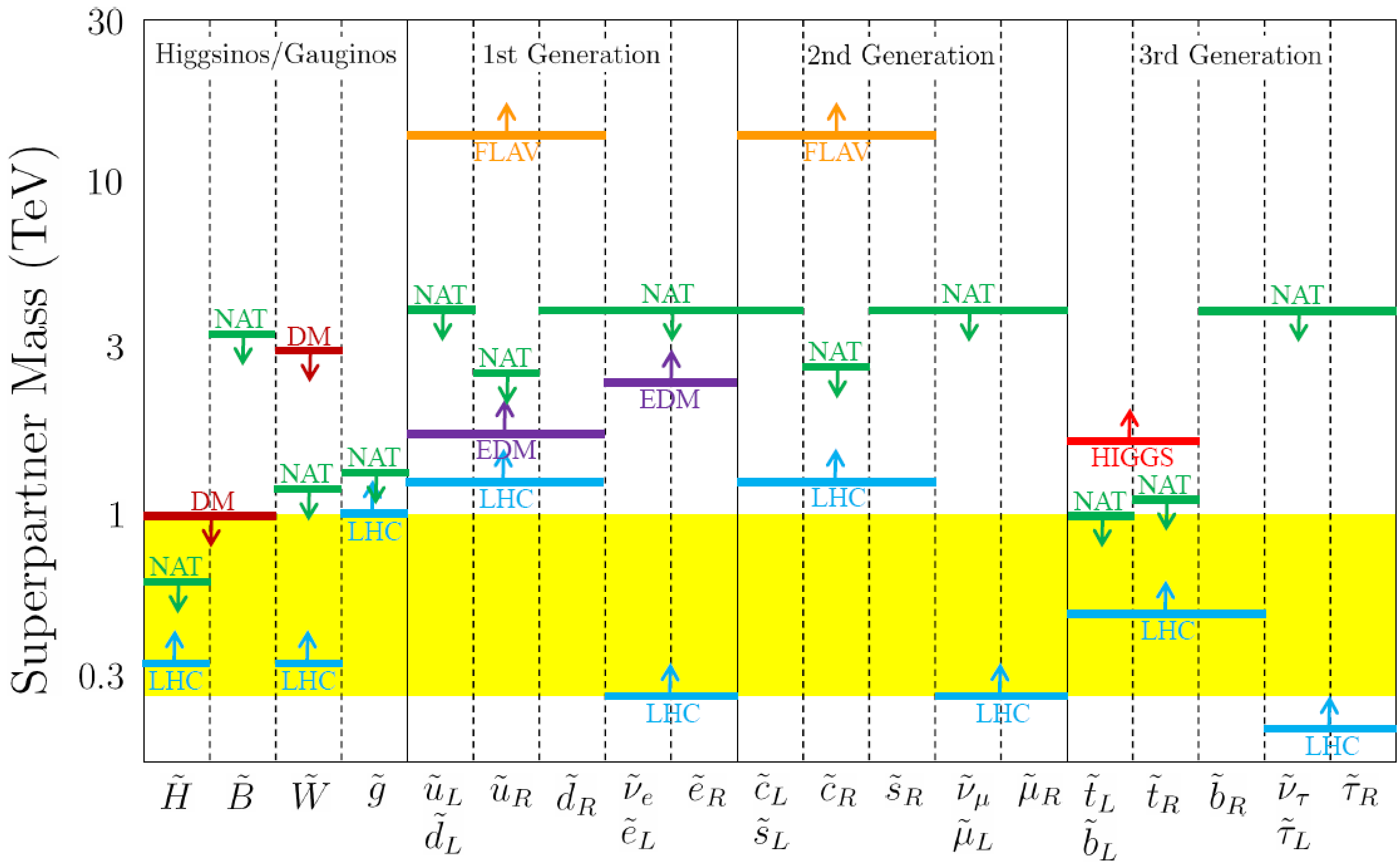
- Heavy 1st/2nd generation, light 3rd generation. Requires maximal stop mixing or new fields (e.g., NMSSM) to raise Higgs mass. See also Effective SUSY, U(1)-mediated SUSY, Superheavy SUSY, Natural SUSY, …

MODELS: FOCUS POINT SUSY



- All scalars heavy, sfermions light. Requires parameter correlations to be natural or give up on naturalness. See also PeV SUSY, Split SUSY, Spread SUSY, String-Motivated SUSY, Mini-Split SUSY, …

MODELS: COMPRESSED SUSY



- Reduce missing E_T, so all superpartners can be light. Requires maximal stop mixing or new fields (e.g., NMSSM) to raise Higgs mass, and small phases to satisfy EDM constraints. See also RPV SUSY, Stealth SUSY, …