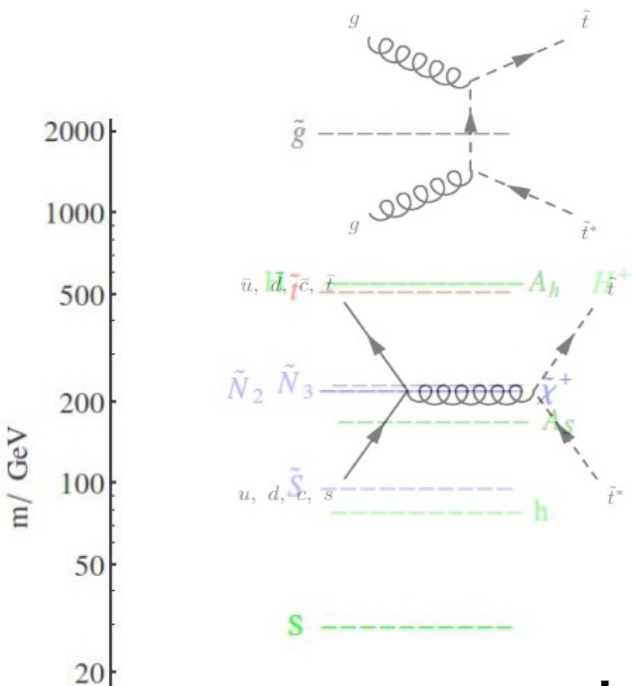
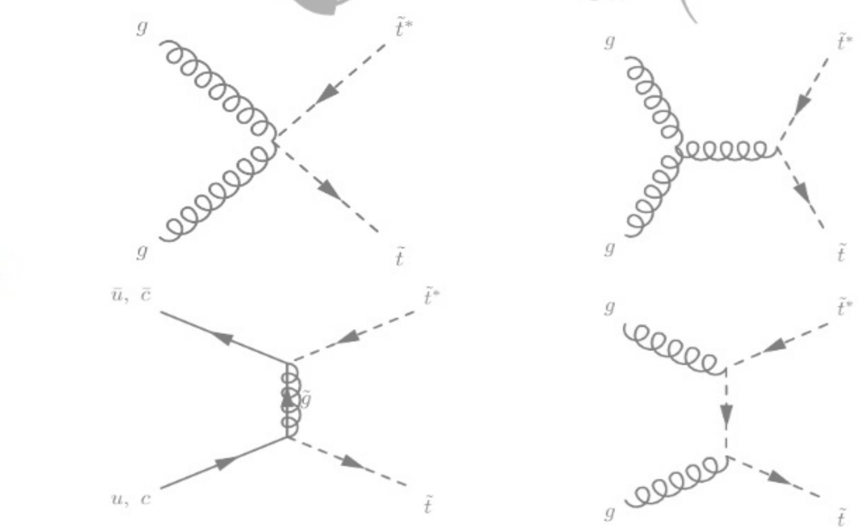
The Next to Minimal Supersymmetric Standard Model in the Alignment Limit

$$-i\mathcal{M}^2 = \text{(loop of } f\text{)} = i\frac{\lambda_f^2}{8\pi^2}\left(\Lambda^2 - 3m_f^2\log\left(\frac{\Lambda^2}{m_f^2}\right) + \ldots\right)$$





James Scoville
University of Oxford

16 July 2014

What is the NMSSM?

MSSM

NMSSM

What is the NMSSM?

MSSM

$$\begin{pmatrix}\hat{H}_d & \hat{H}_u\end{pmatrix}$$

NMSSM

$$\begin{pmatrix}\hat{H}_d & \hat{H}_u & \hat{S}\end{pmatrix}$$

What is the NMSSM?

MSSM

$$\left(\hat{H}_d \quad \hat{H}_u\right)$$

$$\begin{pmatrix} h \\ H \end{pmatrix}, \begin{pmatrix} G^0 \\ A \end{pmatrix}, \begin{pmatrix} G^+ \\ H^+ \end{pmatrix}, \begin{pmatrix} \chi_1^0 \\ \chi_2^0 \end{pmatrix}, \chi_1^+$$

NMSSM

$$\left(\hat{H}_d \quad \hat{H}_u \quad \hat{S}\right)$$

$$\begin{pmatrix} h \\ H \\ S \end{pmatrix}, \begin{pmatrix} G^0 \\ A \\ A_S \end{pmatrix}, \begin{pmatrix} G^+ \\ H^+ \end{pmatrix}, \begin{pmatrix} \chi_1^0 \\ \chi_2^0 \\ \chi_3^0 \end{pmatrix}, \chi_1^+$$

What is the NMSSM?

MSSM

$$\left(\hat{H}_d \quad \hat{H}_u\right)$$

$$\begin{pmatrix} h \\ H \end{pmatrix}, \begin{pmatrix} G^0 \\ A \end{pmatrix}, \begin{pmatrix} G^+ \\ H^+ \end{pmatrix}, \begin{pmatrix} \chi_1^0 \\ \chi_2^0 \end{pmatrix}, \ \chi_1^+$$

$$W \supset \mu \hat{H}_u \cdot \hat{H}_d$$

NMSSM

$$\left(\hat{H}_d \quad \hat{H}_u \quad \hat{S}\right)$$

$$\begin{pmatrix} h \\ H \\ S \end{pmatrix}, \begin{pmatrix} G^0 \\ A \\ A_S \end{pmatrix}, \begin{pmatrix} G^+ \\ H^+ \end{pmatrix}, \begin{pmatrix} \chi_1^0 \\ \chi_2^0 \\ \chi_3^0 \end{pmatrix}, \ \chi_1^+$$

$$W \supset \lambda \hat{S} \hat{H}_u \cdot \hat{H}_d + \frac{\kappa}{3} \hat{S}^3$$

What is the NMSSM?

MSSM

$$\left(\hat{H}_d \quad \hat{H}_u\right)$$

$$\begin{pmatrix} h \\ H \end{pmatrix}, \begin{pmatrix} G^0 \\ A \end{pmatrix}, \begin{pmatrix} G^+ \\ H^+ \end{pmatrix}, \begin{pmatrix} \chi_1^0 \\ \chi_2^0 \end{pmatrix}, \chi_1^+$$

$$W \supset \mu \hat{H}_u \cdot \hat{H}_d$$

$$V_{H^4} = \frac{g_1^2 + g_2^2}{8}\left(|H_u|^2 - |H_d|^2\right)^2 + \frac{1}{2} g_2^2 \left|H_u^\dagger H_d\right|^2$$

NMSSM

$$\left(\hat{H}_d \quad \hat{H}_u \quad \hat{S}\right)$$

$$\begin{pmatrix} h \\ H \\ S \end{pmatrix}, \begin{pmatrix} G^0 \\ A \\ A_S \end{pmatrix}, \begin{pmatrix} G^+ \\ H^+ \end{pmatrix}, \begin{pmatrix} \chi_1^0 \\ \chi_2^0 \\ \chi_3^0 \end{pmatrix}, \chi_1^+$$

$$W \supset \lambda \hat{S} \hat{H}_u \cdot \hat{H}_d + \frac{\kappa}{3} \hat{S}^3$$

$$+ |\lambda H_u \cdot H_d|^2 + \ldots$$

Higgs couplings in (N)MSSM

$$\begin{pmatrix} \hat{h} \\ \hat{H} \\ \hat{S} \end{pmatrix} = \begin{pmatrix} \cos(\beta) & \sin(\beta) & 0 \\ -\sin(\beta) & \cos(\beta) & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \Re(H_d) \\ \Re(H_u) \\ \Re(S) \end{pmatrix}$$

$$\mathscr{L} = \frac{M_Z^2}{\sqrt{2}v} Z^\mu Z_\mu \hat{h} + \ldots$$

Higgs couplings in (N)MSSM

$$\begin{pmatrix} \hat{h} \\ \hat{H} \\ \hat{S} \end{pmatrix} = \begin{pmatrix} \cos(\beta) & \sin(\beta) & 0 \\ -\sin(\beta) & \cos(\beta) & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \Re(H_d) \\ \Re(H_u) \\ \Re(S) \end{pmatrix}$$

$$\mathscr{L} = \frac{M_Z^2}{\sqrt{2}v} Z^\mu Z_\mu \hat{h} + \frac{M_Z}{\sqrt{2}v} Z_\mu [\hat{H}\partial^\mu \hat{A} - \hat{A}\partial^\mu \hat{H}] + \dots$$

What is the alignment limit?

$$\mathscr{L} \supset -\frac{1}{2}\begin{pmatrix}\hat{h} & \hat{H} & \hat{S}\end{pmatrix} M_H^2 \begin{pmatrix}\hat{h} \\ \hat{H} \\ \hat{S}\end{pmatrix}$$

$$\begin{pmatrix} M_Z^2 + (v^2\lambda^2 - M_Z^2)\sin^2(2\beta) + \Delta_{rad}^2 & \frac{1}{2}\left(v^2\lambda^2 - M_Z^2\right)\sin(4\beta) + \frac{\Delta_{rad}^2}{\tan(\beta)} & v\lambda\left(2\lambda v_S - (A_\lambda + 2\kappa v_S)\sin(2\beta)\right) \\ & M_{\hat{A}}^2 - \left(v^2\lambda^2 - M_Z^2\right)\sin^2(2\beta) + \frac{\Delta_{rad}^2}{\tan^2(\beta)} & -v\lambda\left(A_\lambda + 2\kappa v_S\right)\cos(2\beta) \\ & & \frac{1}{3}M_{\hat{A}_S}^2 + \kappa v_S \Delta A_\kappa \end{pmatrix}$$

What is the alignment limit?

$$\mathscr{L} \supset -\frac{1}{2} \begin{pmatrix} \hat{h} & \hat{H} & \hat{S} \end{pmatrix} M_H^2 \begin{pmatrix} \hat{h} \\ \hat{H} \\ \hat{S} \end{pmatrix}$$

$$M_H^2 = \begin{pmatrix} M_{hh} & M_{hH} & M_{hS} \\ & M_{HH} & M_{HS} \\ & & M_{SS} \end{pmatrix}$$

What is the alignment limit?

$$\mathscr{L} \supset -\frac{1}{2} \begin{pmatrix} \hat{h} & \hat{H} & \hat{S} \end{pmatrix} M_H^2 \begin{pmatrix} \hat{h} \\ \hat{H} \\ \hat{S} \end{pmatrix}$$

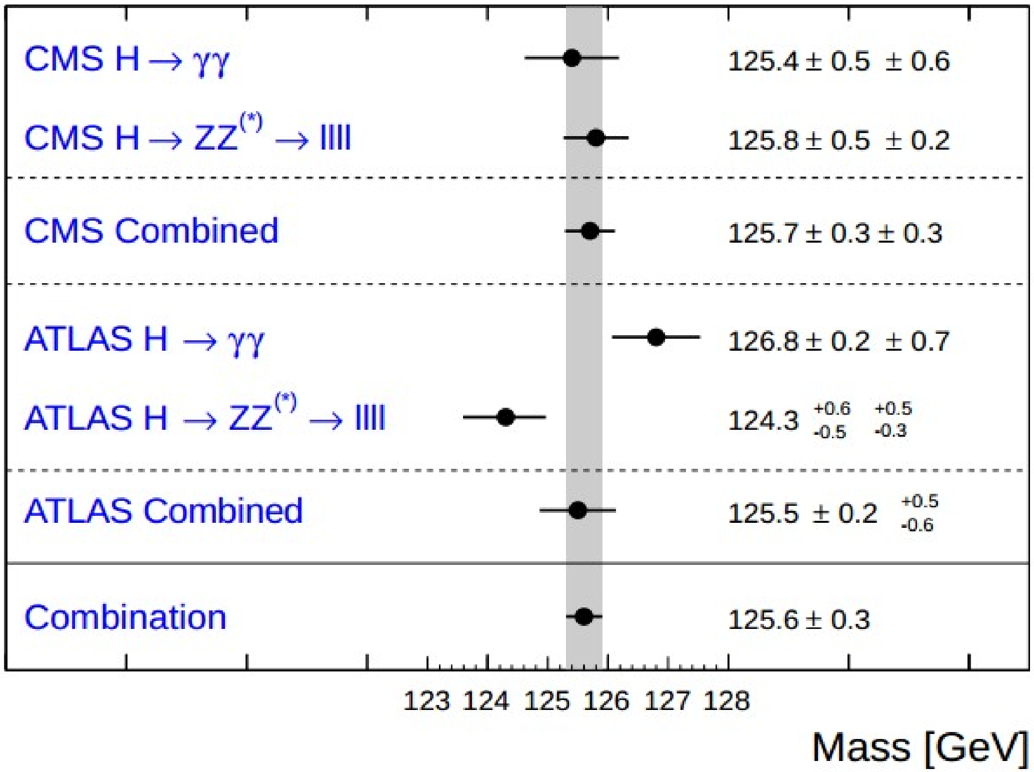
$$M_H^2 = \begin{pmatrix} M_{hh} & M_{hH} & M_{hS} \\ & M_{HH} & M_{HS} \\ & & M_{SS} \end{pmatrix}$$

What is the alignment limit?

$$\mathscr{L} \supset -\frac{1}{2} \begin{pmatrix} \hat{h} & \hat{H} & \hat{S} \end{pmatrix} M_H^2 \begin{pmatrix} \hat{h} \\ \hat{H} \\ \hat{S} \end{pmatrix}$$

$$M_H^2 = \begin{pmatrix} M_{hh} & \boxed{M_{hH} \quad M_{hS}} \\ & M_{HH} & M_{HS} \\ & & M_{SS} \end{pmatrix}$$

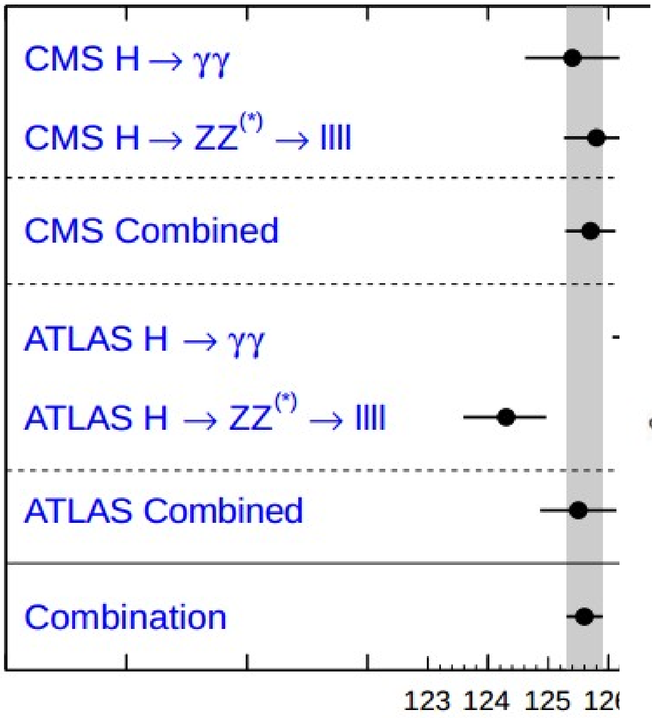
Why the alignment limit is interesting...

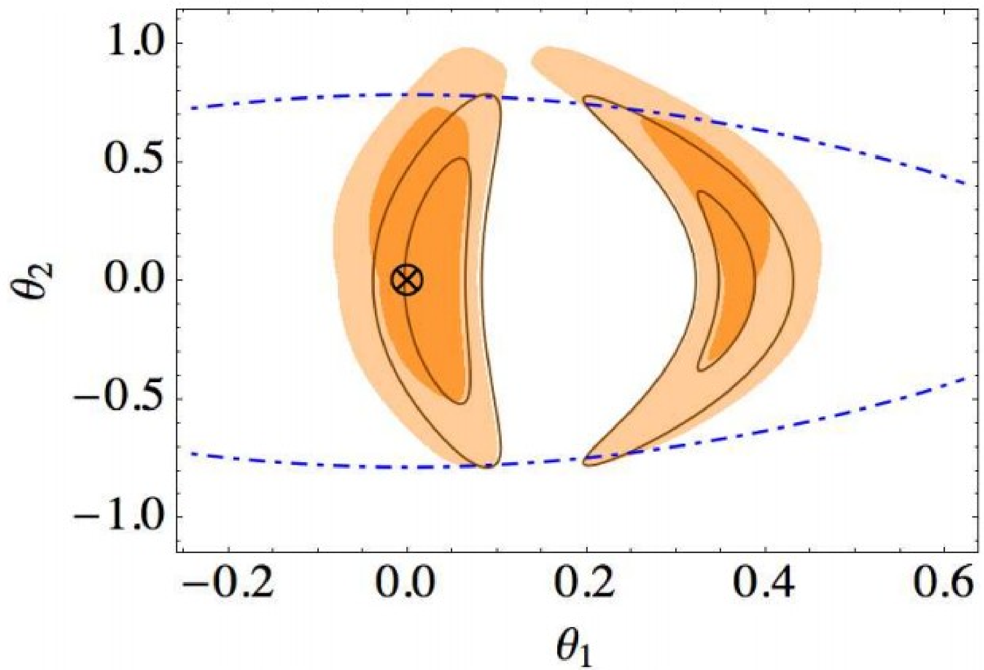


[J. Beringer et al. (Particle Data Group), PR D86, 010001 (2012) 2013 update]

Why the alignment limit is interesting…

…but not the only interesting region

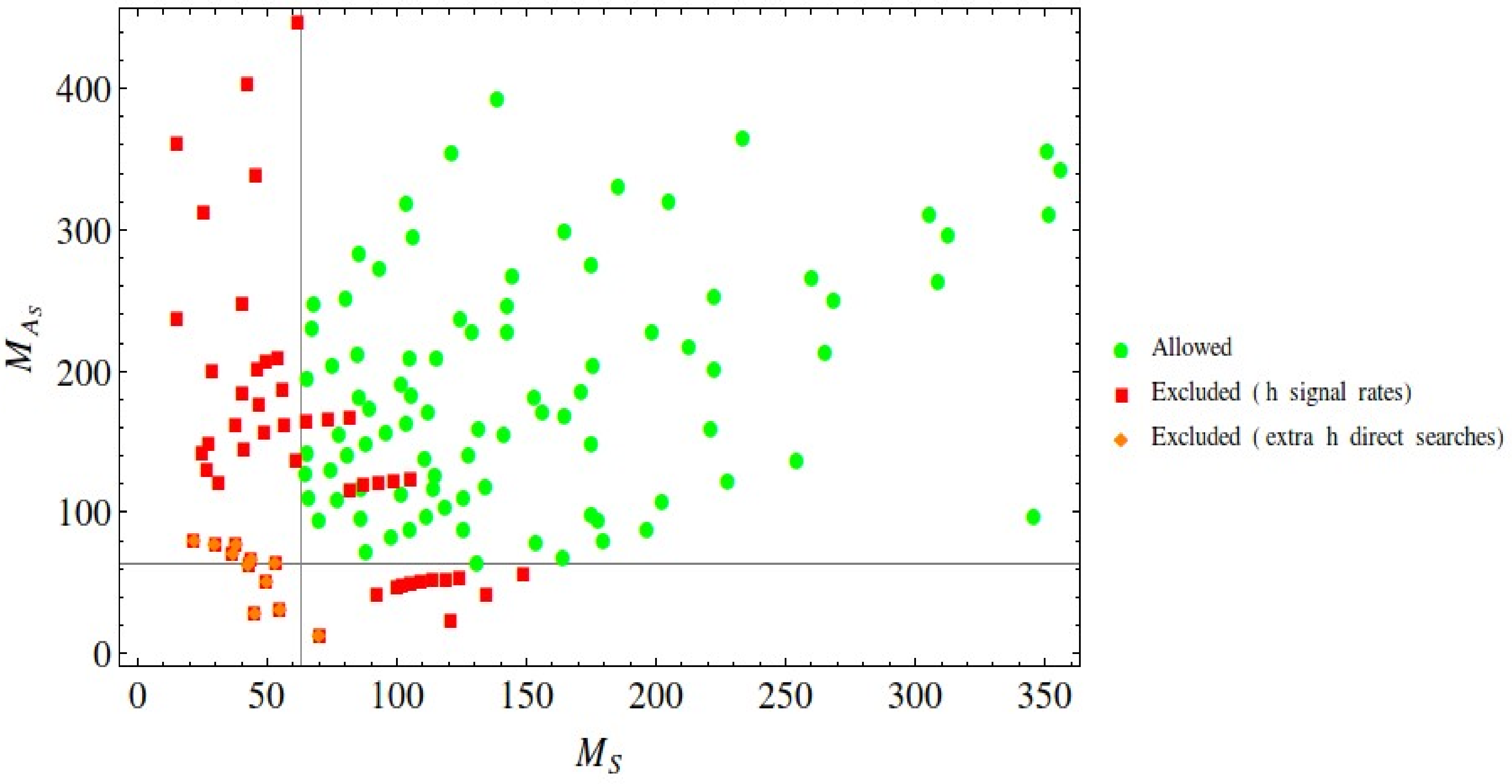




[K. Jeong et al. arXiv:1407.0955]

[J. Beringer et al. (Particle Data Group), PR D86, 010001 (2012) 2013 update]

What are the limits on the extra scalars?



What are the limits on the Charginos/Neutralinos?