

Title: Beyond the Standard Model “ Theory: BSM at high energy 2

Date: Jul 10, 2015 02:30 PM

URL: <http://pirsa.org/15070034>

Abstract:

$$W = M_{ij} \Phi_i \Phi_j + \lambda_{ijk} \Phi_i \Phi_j \Phi_k$$

built from
- chiral fields
- gauge inv.

$$\rightarrow V = M_{ij} \psi_i \psi_j + \lambda_{ijk} \phi_i \psi_j \psi_k + \sum_i \left| \frac{\partial W}{\partial \Phi_i} \right|_{\Phi_j \rightarrow \phi_j}^2$$

H $\Sigma_{1/2}$
Q, U, D, L, E

$W \supset H Q U^c$

$H^+ Q D^c$

$$W = M_{ij} \Phi_i \Phi_j + \lambda_{ijk} \Phi_i \Phi_j \Phi_k$$

- chiral fields
- gauge inv

$$\rightarrow V = M_{ij} \psi_i \psi_j + \lambda_{ijk} \phi_i \psi_j \psi_k + \sum_i \left| \frac{\partial W}{\partial \Phi_i} \right|_{\Phi_i \rightarrow \phi_i}^2$$

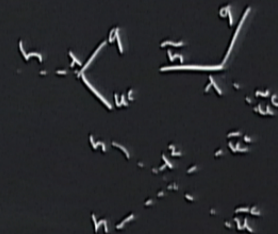
H_u $2_{+1/2}$
 Q, U, D, L, E

H_d $2_{-1/2}$

$$W \supset \lambda_u H_u Q U^c$$

$$H_u^+ Q D^c$$

$$+ \lambda_d H_d Q D^c + \lambda_e H_d L E^c$$

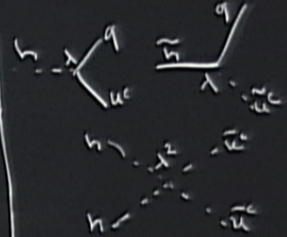


$$\rightarrow V = M_{ij} \psi_i \psi_j + \lambda_{ijk} \phi_i \psi_j \psi_k + \sum_{\Phi \rightarrow \phi_i} \left| \frac{\partial W}{\partial \Phi} \right|^2$$

H_u $2_{1/2}$
 Q, U, D, L, E

H_d $2_{-1/2}$

$$\boxed{W \supset \lambda_u H_u Q U^c + H_u^+ Q D^c + \lambda_d H_d Q D^c + \lambda_e H_d L E^c + \mu H_u H_d}$$



$H = \begin{pmatrix} h^+ \\ h^0 \end{pmatrix}$
 $h^+ \rightarrow$ eaten by W
 $h^0 \rightarrow$ eaten by Z

H^\pm
 $H^0 A^0$

$$\mu H_u H_d + \lambda' Q L D^c + \lambda'' U D D^c$$

$$h = \begin{pmatrix} h^+ \rightarrow \text{eaten by } W \\ \boxed{h^0} \rightarrow \text{eaten by } Z \end{pmatrix}$$

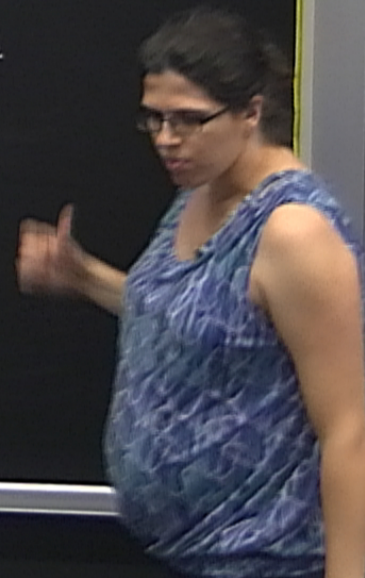
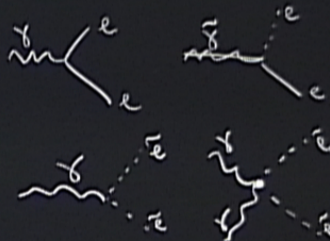
 H^\pm
 H^0
 A^0

$$\mu H_u H_d$$

$$+ \mu' H_u L + \lambda L L E^c + \lambda' Q L D^c + \lambda'' U D D^c$$

(R-parity)

- Gauge interactions
- Higgs potential (quartic!)



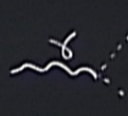
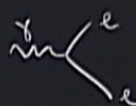
$$h = \begin{pmatrix} h^+ \rightarrow \text{eaten by } W \\ \boxed{h^0} \rightarrow \text{eaten by } Z \end{pmatrix}$$

 H^\pm
 $H^0 \quad A^0$

$$\mu H_u H_d$$

$$+ \underbrace{\mu H_u L + \lambda L L E^c + \lambda' Q L D^c + \lambda'' U D D^c}_{\text{R-parity}}$$

- Gauge interactions
- Higgs potential (quartic!)



$$D^\mu = g \sum \phi_i^\dagger T^a \phi_i$$

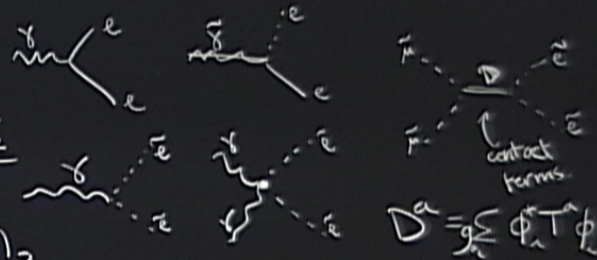
$$SV = \sum_i |D^\mu \phi_i|^2$$

$$h = \begin{pmatrix} h^+ \rightarrow \text{eaten by } W \\ \boxed{h^0} \rightarrow \text{eaten by } Z \end{pmatrix} \quad \begin{matrix} H^\pm \\ H^0 \end{matrix} \quad \begin{matrix} A^0 \\ \mu H_u H_d \\ + \mu' H_u L + \lambda L L E^c + \lambda' Q L D^c + \lambda'' U D D^c \end{matrix}$$

(R-parity)

- Gauge interactions
- Higgs potential (quartic!)

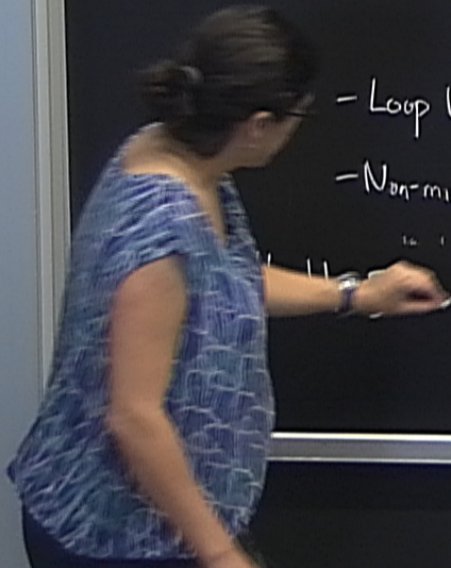
- Tree level $(|h_{u1}|^2 - |h_{d1}|^2)^2 \cdot \frac{g_1^2 + g_2^2}{8}$
 at tree level $m_h < m_{H^\pm}$



$$D^a = g_a \sum \phi_i^\dagger T^a \phi_i$$

$$SV = \sum_i |D_i|^2$$

- Loop level from SUSY
- Non-minimal new tree level sources.



CAUTION

$$h = \begin{pmatrix} h^+ \rightarrow \text{eaten by } W \\ \boxed{h^0} \rightarrow \text{eaten by } Z \end{pmatrix}$$

 H^\pm
 $H^0 A^0$

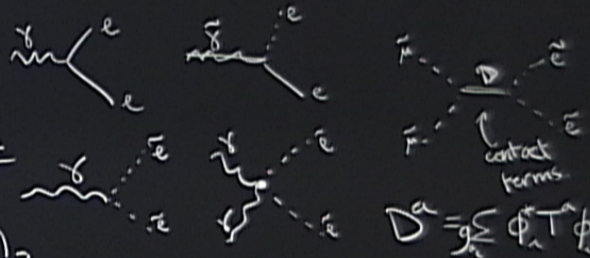
$$\mu H_u H_d$$

$$+ \mu' H_u L + \lambda L L E^c + \lambda' Q L D^c + \lambda'' U D D^c$$

(R-parity)

- Gauge interactions
- Higgs potential (quartic!)

- Tree level $(|h_u|^2 - |h_d|^2)^2 \cdot \frac{g_1^2 + g_2^2}{8}$
 at tree level $m_h < m_A$



$$D^a = \sum_i \phi_i^\dagger T^a \phi_i$$

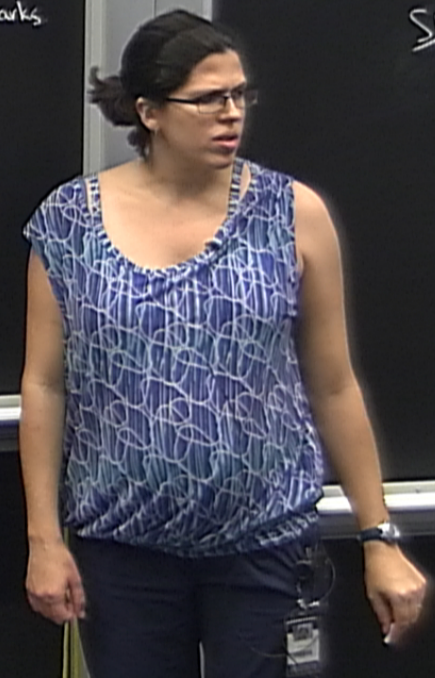
$$SV = \sum_i |D^a|^2$$

- Loop level from SUSY
- Non-minimal new tree level sources.

$$\int \mathcal{D}W = \lambda H_u H_d S \quad V > |h_u h_d|^2 \quad (\text{NMSSM})$$

$m^2 |\phi|^2$ eg $m^2 h_u^2 + m^2 |\tilde{q}|^2$
 $(\delta+1)$ of $SUSY_q$
 constrained by
 flavor meas
 - Nic = (ic D) flavor
 structure
or - Heavy squarks

$V = V_{SUSY}$
SUSY



CAUTION

$$\int d^2\theta d^2\bar{\theta} \frac{X^\dagger X}{M^2} \Phi^\dagger \Phi$$

$\langle X \rangle \sim F_X \theta^2$

$$\int d^2\theta X \Phi_1 \Phi_2$$

\int

$$m^2 |\phi|^2$$

$$B \phi_1 \phi_2$$

eg $m^2 h_u h_d^2 + m^2 |q|^2$
 $(3+1)$ of $SU(3)_q$
 constrained by
 flavor meas
 - N.c = (c.d) flavor
 structure
 or - Heavy squarks
 50-500 TeV

$$B_u h_u h_d$$

$$V = V_{SUSY} +$$

SUSY

CAUTION

CAUTION

$$\int d^2\theta d^2\bar{\theta} \frac{X^\dagger X}{M^2} \Phi^\dagger \bar{\Phi}$$

$\langle X \rangle \sim F, \theta^2$

$$m^2 \phi^2$$

eg $m^2 h_u h_d + m^2 |\tilde{q}|^2$
 $(\delta+1)$ of $SU(3)_q$
 constrained by flavor meas
 - N.c. = (i.e.) flavor structure

$$\int d^2\theta X \Phi_1 \Phi_2$$

$$B \phi_1 \phi_2$$

$$B h_u h_d$$

$$\int d^2\theta \frac{X}{M} \Phi_1 \Phi_2 \Phi_3$$

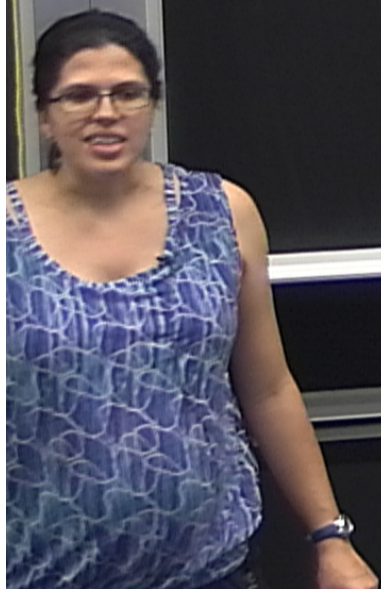
$$A \phi_1 \phi_2 \phi_3$$

$$A h_u \tilde{u} \tilde{q}$$

or - Heavy squarks
 50-500 TeV

$$V = V_{SUSY} +$$

SUSY



$$\int d^2\theta d^2\bar{\theta} \frac{X^\dagger X}{M^2} \Phi^\dagger \bar{\Phi}$$

$(X) \supset F, \theta^2$

$$m^2 \phi^2$$

eg $m^2 h_u h_d + m^2 |\tilde{q}|^2$

$(\mathfrak{g}+1)$ of $SU(3)_q$
 constrained by
 flavor meas
 - Nic = (ic 1) flavor
 structure

$$\int d^2\theta X \Phi_1 \Phi_2$$

$$B_2 \phi_1 \phi_2$$

$$B_n h_u h_d$$

$$\int d^2\theta \frac{X}{M} \Phi_1 \Phi_2 \Phi_3$$

$$A_2 \phi_1 \phi_2 \phi_3$$

$$A h \tilde{u}^c \tilde{q}$$

or - Heavy squarks
 50-500 TeV

$$V = V_{SUSY} +$$

SUSY

CAUTION

CAUTION

$$\int d^2\theta \frac{X^\dagger X}{M^2} \Phi^\dagger \bar{\Phi}$$

$\langle X \rangle \sim F_X \theta^2$

$$m^2 \phi^2$$

eg $m^2 h_u^2 + m^2 |\tilde{q}|^2$

$(\mathfrak{g}+1)$ of $SU(3)_q$
 constrained by
 flavor meas
 - N.c = (i.e.) flavor
 structure

$$\int d^2\theta X \Phi \Phi_2$$

$$\frac{B}{2} \phi_1 \phi_2$$

$$B_u h_u h_d$$

$$\int d^2\theta \frac{X}{M} \Phi_1 \Phi_2 \Phi_3$$

$$A \phi_1 \phi_2 \phi_3$$

$$A h \tilde{u}^c \tilde{q}$$

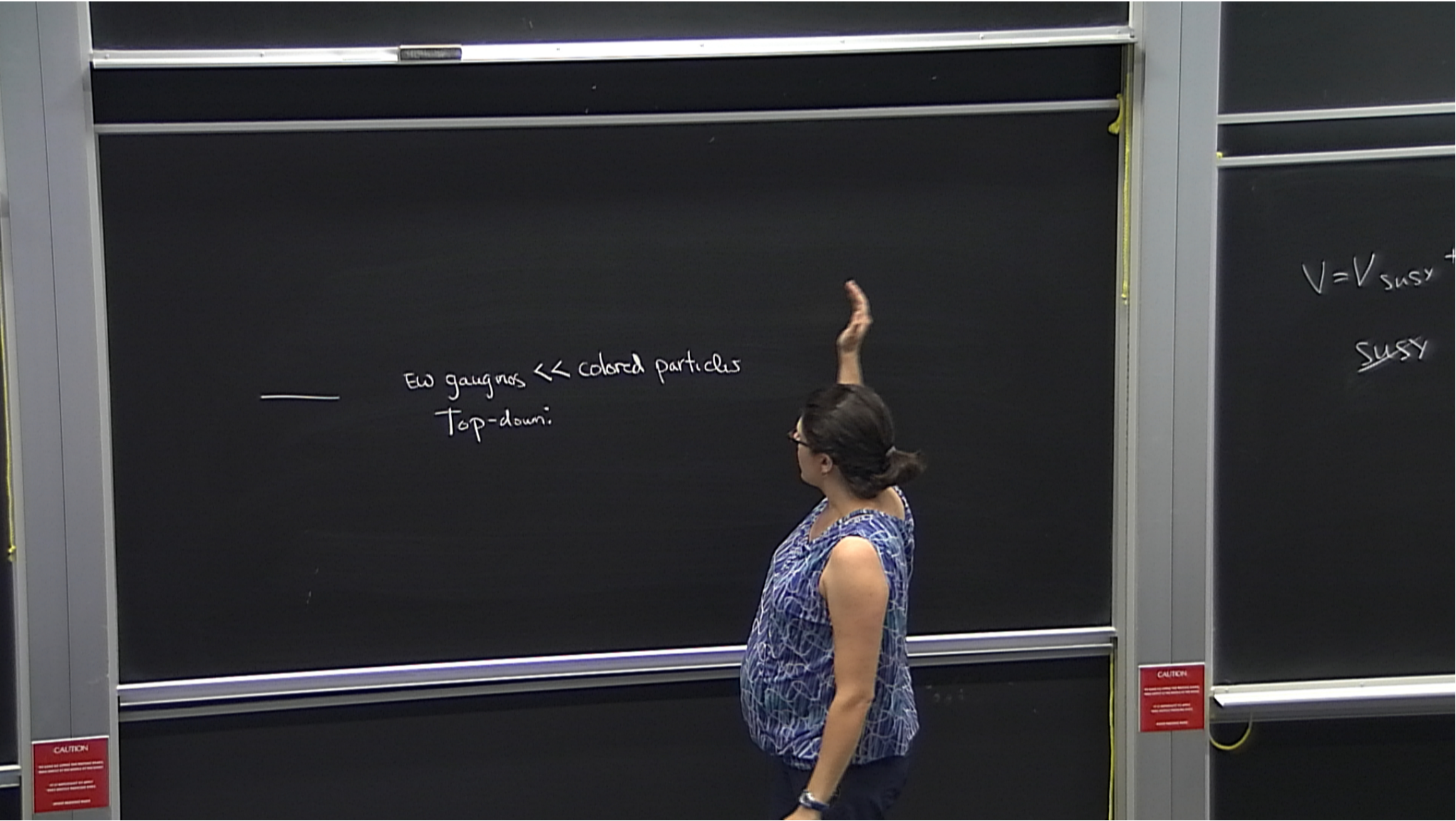
or - Heavy squarks
 50-500 TeV

$$V = V_{SUSY} +$$

SUSY

CAUTION

CAUTION



EW gauginos \ll colored particles

Top-down: Long RG evolution \rightarrow splitting

Bottom up: Neutral lightest superpartner

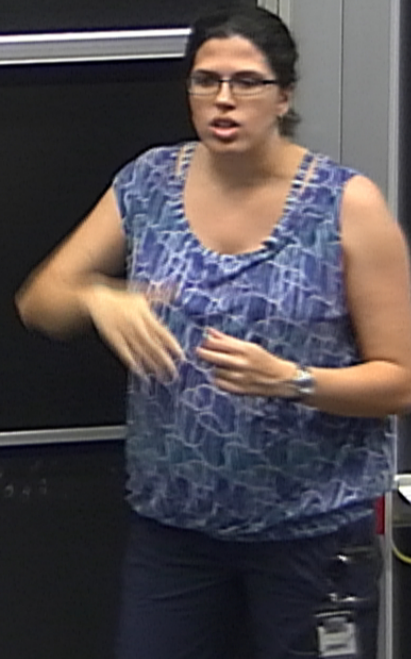
- Stable
- DM candidate
- Clean collider signals for decays

Top partners \ll Light-gen squarks "Natural SUSY"

Bottom-up
- With low med. scale, anchorate fine-tuning

$$V = V_{\text{SUSY}}$$

SUSY



CAUTION
No open flames or smoking in this area.
No eating or drinking in this area.
No use of mobile phones in this area.
No use of mobile phones in this area.

$$h = \begin{pmatrix} h^+ \rightarrow \text{eaten by } W \\ \boxed{h^0} \rightarrow \text{eaten by } Z \\ h^- \end{pmatrix}$$

$$H^\pm \quad H^0 \quad A^0$$

$$\mu H_u H_d$$

$$+ \mu' H_u L + \lambda L L E^c + \lambda' Q L D^c + \lambda'' U D D^c$$

(R-parity)

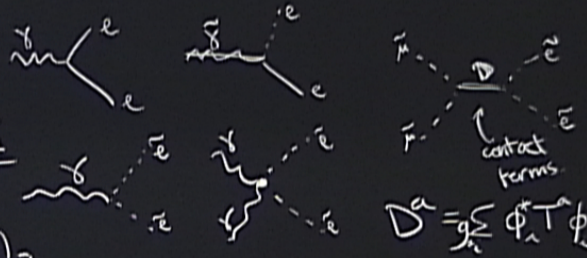
• Gauge interactions

• Higgs potential (quartic!)

- Tree level $(|h_u|^2 - |h_d|^2)^2 \cdot \frac{g_1^2 + g_2^2}{8}$
 at tree level $m_h < m_z$

- Loop level from SUSY

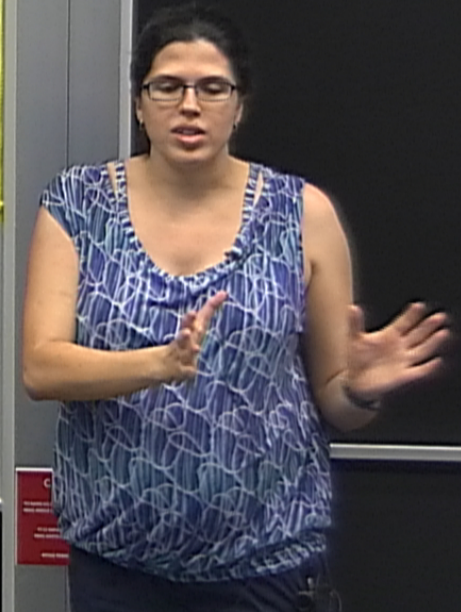
- Non-minimal new tree level sources.

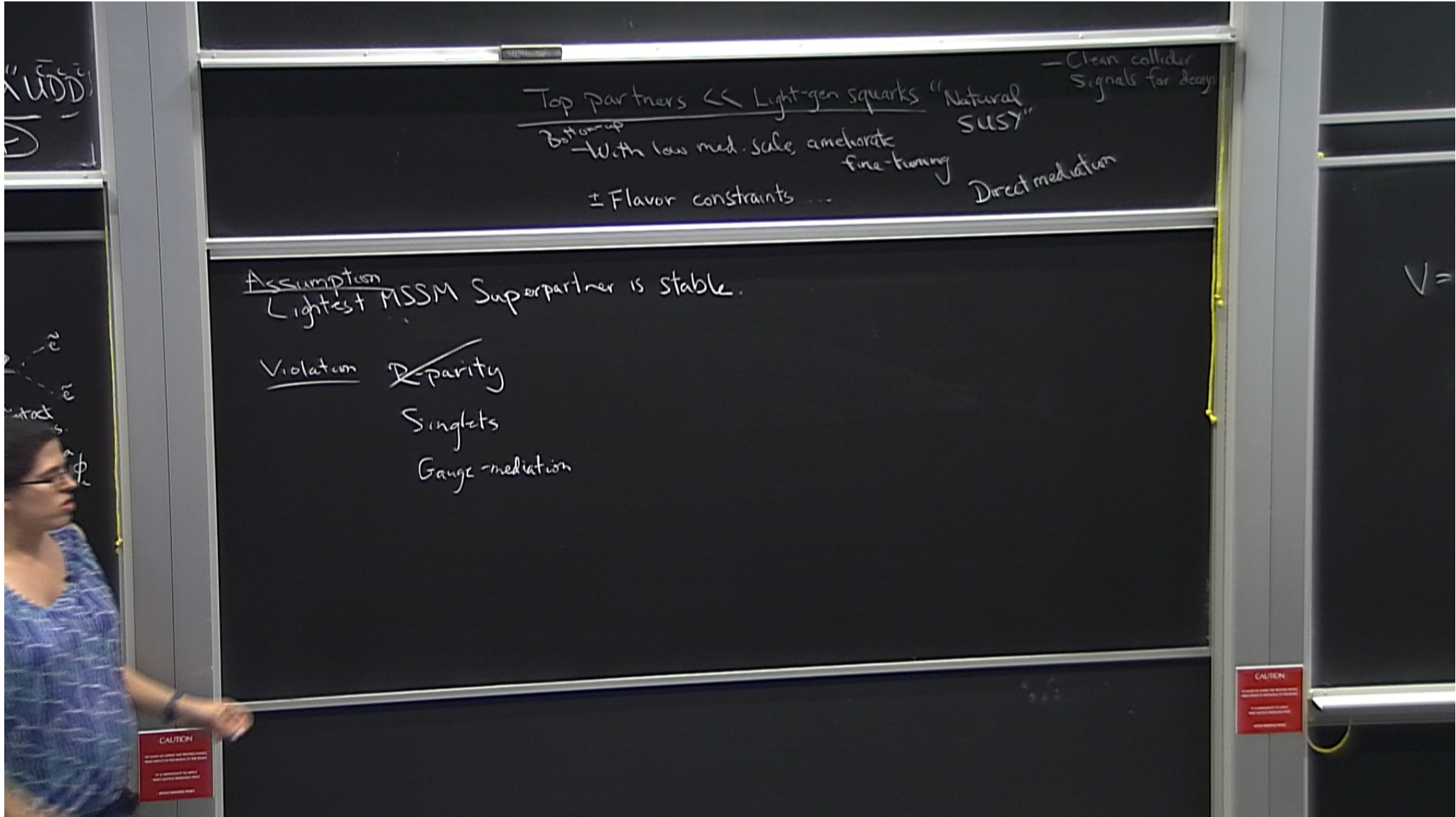


$$\mathcal{D}^a = g_a^i \phi_i^\dagger T^a \phi$$

$$\Delta V = \sum_i |D_i|^2$$

$$\mathcal{L}_5 = \lambda H_u H_d S \quad V > |h_u h_d|^2 \quad (\text{NMSSM})$$





Top partners \Leftarrow Light-gen squarks "Natural SUSY"
Bottom-up
- With low med. scale, ameliorate fine-tuning
 \pm Flavor constraints ...

- Clean collider signals for decay

Direct mediation

Assumption
Lightest MSSM Superpartner is stable.

Violations
~~R-parity~~
Singlets
Gauge-mediation

CAUTION
DO NOT TOUCH THE BOARD SURFACE
OR THE MARKERS OR ERASERS
OR THE ERASER BOARD

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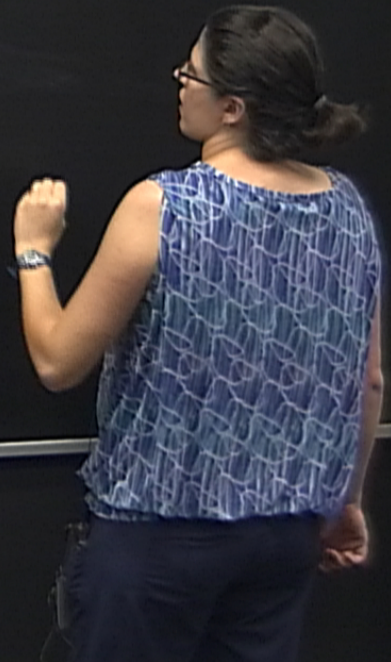
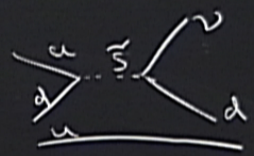
$\bar{u}d$
 $\bar{c}d$
 $\bar{s}d$

\bar{e}
 $\bar{\nu}_e$
 contact terms
 $\phi^\dagger T^a \phi$
 D^2

Top partners \ll Light-gen squarks "Natural SUSY"
 Bottom-up
 - With low med. scale, ameliorate fine-tuning
 \pm Flavor constraints ...
 - Clean collider signals for decay
 Direct mediation

Assumption
 Lightest MSSM Superpartner is stable.

Violation ~~R~~-parity
 Singlets
 Gauge-mediation



CAUTION
 ALL STUDENTS MUST WEAR SAFETY GLASSES AT ALL TIMES IN THIS LABORATORY.
 IT IS ESSENTIAL TO WEAR SAFETY GLASSES AT ALL TIMES.
 PLEASE WEAR YOUR SAFETY GLASSES.

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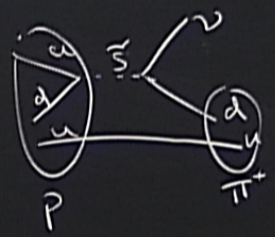
χ^2 UDD

\tilde{e}
 \tilde{e}
 contact terms
 $\phi^* T \phi$
 D^2

Top partners \ll Light-gen squarks "Natural SUSY"
 Bottom-up
 - With low med. scale, ameliorate fine-tuning
 \pm Flavor constraints ...
 Direct mediation
 - Clean collider signals for decay

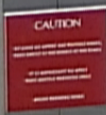
Assumption
 Lightest MSSM Superpartner is stable.

Violation ~~R~~-parity
 Singlets
 Gauge-mediation



$$T \sim \frac{m_p^5}{M_{SUSY}^4} \sim \text{couplings}$$

$V =$



Top partners \ll Light-gen squarks "Natural SUSY"

Bottom-up
 - With low med. scale, ameliorate fine-tuning

- Clean collider signals for decay

\pm Flavor constraints ...

Direct mediation

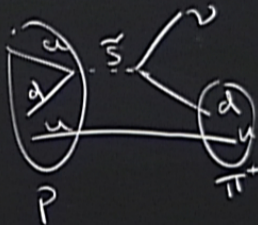
Assumption
 Lightest MSSM Superpartner is stable.

Violation

~~R-parity~~

Singlets

Gauge-mediation



$$T \sim \frac{m_p^5}{M_{\text{susy}}^4} \sim \text{couplings}$$

$$R = (-1)^{J+L+3B}$$

