The fundamental law(s) of nature is hypothesized to be symmetric between bosons and fermions.

Fermion ($S = \frac{1}{2}$) $\leftrightarrow$ Boson ($S = 0$ or $1$)

Have they been observed? $\Rightarrow$ Not yet.
Feynman Diagrams for SUSY Decays

SUSY partner of $W$ boson: chargino

\[ W^+ \rightarrow \nu_\tau \quad \tau^+ \]

SUSY partner of $W$ boson: neutralino

Lightest neutralinos are always in the final state! This neutralino is the dark matter candidate!!

SUSY partner of $\tau$ lepton: stau

\[ \tilde{\tau} \rightarrow \tilde{\chi}_1^0 \]

SUSY partner of $Z$ boson: neutralino

\[ Z^0 \rightarrow \tau^- \quad \tau^+ \]

\[ \tilde{\tau} \rightarrow \tilde{\chi}_1^0 \]
Sign of SUSY Unification

$M_{\text{SUSY}} \sim 500-3000 \text{ GeV}/c^2$ and two (and only two) Higgs doublets

What else?
Cosmic Connection

CDM = The matter which is present without any electromagnetic interaction.

CDM = Neutralino ($\tilde{\chi}_1^0$)

To explain the amount of the CDM, there must be another SUSY particle whose mass must be closer to the neutralino. (see the next slide.)

Is it possible to observe these features in other experiments (e.g., Dark matter detection, Collider experiments)?
Minimal Supergravity (mSUGRA)

- SUSY model with two Higgs fields \((H_u\) and \(H_d\)) in the framework of unification:

1) All SUSY masses are unified at the grand unified scale.

\[ m_{1/2} \quad \text{for gaugino masses} \]
\[ m_0 \quad \text{for squarks and sleptons} \]

2) Two more parameters:

- tan\(\beta\)
- \(A_0\)
Power of $\tan\beta$

I always want you to be slimmer than your cousin SELECTRON.

This $\tan\beta$ also controls the SUSY masses, especially, the 3rd generation SUSY particles, such as $\tilde{t}$, $\tilde{b}$ and $\tilde{\tau}$. 
Neutralino = CDM

\[ \left( \Omega_{\text{CDM}} \right)^{-1} \propto \begin{bmatrix} \tilde{\chi}_1^0 & h, H, A, Z & \tilde{f} \\ \tilde{\chi}_1^0 & f & \tilde{f} \\ \end{bmatrix}^2 \]

\[ + \begin{bmatrix} \tilde{\chi}_1^0 & \tau & \tau \\ \tilde{\tau}_1 & \tau & \gamma \\ \end{bmatrix} \]

\[ e^{-\Delta M / 20} \]

\[ \Delta M \equiv M_{\tilde{\tau}_1} - M_{\tilde{\chi}_1^0} \]

\[ \square \text{mSUGRA naturally provides a lighter stau.} \]
Cosmologically Allowed Region

- **Higgs Mass** \( (M_h) \)
- **Branching Ratio** \( b \rightarrow s\gamma \)
- **Magnetic Moment of Muon**
- **CDM allowed region**

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**Mass of Squarks and Sleptons**

**Mass of Gauginos**

**Excluded**
What are the signals from the narrow co-annihilation corridor?
Mass Relations at Large $\tan\beta$

What are the signals at colliders?

Small $\Delta M$

$\Delta M \equiv M_{\tilde{\tau}_1} - M_{\tilde{\chi}_1^0} = 5 \sim 15$ GeV

CDM candidate
TAMU is joining CMS at the LHC.

- C.M. Energy = 14 TeV
  - New Energy Frontier
- 2 large detectors:
  - CMS and ATLAS
- Performance:
  - Bound to find or exclude Higgs
  - Discover or almost exclude SUSY
**ILC vs. LHC**

**ILC**
- **Stau-pair production** \( \tau^+ \tau^- \tilde{\chi}^0_1 \tilde{\chi}^0_1 \)
- **Neutralino-pair production** \( \tau^+ \tau^- \tilde{\chi}^0_1 \tilde{\chi}^0_1 \)

- \( \Delta M \equiv M_{\tilde{\tau}} - M_{\tilde{\chi}^0_1} = 5 \sim 15 \text{ GeV} \)
- \( E(\tau) \) is small because \( \Delta M \) is small.

**LHC**
- **Squark-gluino production** cross section is very large.

- **Key decay:** \( \tilde{\chi}^0_2 \rightarrow \tau^+ + \tilde{\tau}^0 \rightarrow \tau^+ + \tau^+ \tilde{\chi}^0_1 \)
- **Signal:** \( \geq 3 \tau \) (two high and one low energy) + jets (q’s, g’s) + missing energy (\( \tilde{\chi}^0_1 \))
- **Backgrounds:** SM \( t\bar{t} \) and other SUSY processes
CDF highest $H_T$ Event

$E_{T1} = 172$ GeV
$E_{T2} = 153$ GeV
$E_{T3} = 80$ GeV
$E_T = 223$ GeV
$E_{T4} = 65$ GeV

$H_T = E_{T1} + E_{T2} + E_{T3} = 404$ GeV

The event might look like this:

- $E_T = 223$ GeV
- $E_{T1} = 172$ GeV
- $E_{T2} = 153$ GeV
- $E_{T3} = 80$ GeV
- $E_{T4} = 65$ GeV

$H_T = E_{T1} + E_{T2} + E_{T3} = 404$ GeV

**Diagram:**
- Seed track
- Not associated with tau candidate
- Signal
- Isolation

November 3, 2005 Probing Supersymmetric Connection with Dark Matter