arXiv:0705.3686 [hep-ph]

[M.Ibe and RK]

Sweet Spot Supersymmetry

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Structure of the MSSM

well-defined

MSSM: Supersymmetric Standard Model

⊕ 100+ soft ~~SUSY~~ mass parameters

???

This is analogous to the Standard Model ⊖ Higgs boson

SU(3)xSU(2)xU(1) gauge theory ⊕ quark + lepton masses, W+Z boson masses

???

Let's construct the Standard MSSM!!!

Standard Model

SU(2)xU(1) symmetric sector

gauge interaction ⟷

Higgs sector

$$V(H) = \frac{\lambda_H}{4}(|H|^2 - v^2)^2$$

$$M_W = \frac{1}{\sqrt{2}} g v$$

- λ_H : self interaction of the Higgs boson
- v : scale of the electroweak symmetry breaking

$$M_H = \sqrt{\lambda_H} v$$

Standard MSSM

Supersymmetric sector ⟷

~~SUSY~~ sector

$$V(S) = |F_S|^2 - \left[\frac{(S^\dagger S)^2}{\Lambda^2}\right]_D + \cdots$$

Interaction terms

$$\left(\frac{1}{g^2} + \frac{S}{M_{\rm Pl}} + \cdots\right) W^\alpha W_\alpha \quad \text{(gravity)}$$

$$\left(\frac{1}{g^2} + \frac{1}{(4\pi)^2} \log S\right) W^\alpha W_\alpha \quad \text{(gauge)}$$

$$\frac{1}{g^2} W^\alpha W_\alpha \quad \text{(anomaly)}$$

- $1/\Lambda^2$: self interaction of S
- F_S : scale of the supersymmetry breaking

$$m_S = \frac{F_S}{\Lambda} \qquad \langle S \rangle = \frac{\sqrt{3}\Lambda^2}{6 M_{\rm Pl}}$$

$$m_{3/2} = \frac{F_S}{\sqrt{3} M_{\rm Pl}}$$

Sweet Spot Supersymmetry

$$K = S^\dagger S - \frac{(S^\dagger S)^2}{\Lambda^2}$$

$$+ \left(\frac{c_\mu S^\dagger H_u H_d}{\Lambda} + \text{h.c.}\right) - \frac{c_H S^\dagger S (H_u^\dagger H_u + H_d^\dagger H_d)}{\Lambda^2}$$

$$+ \left(1 - \frac{4g^4}{(4\pi)^4} C_2(R) (\log |S|)^2 \right) \Phi^\dagger \Phi \ ,$$

$$W = W_{\text{Yukawa}}(\Phi) + m^2 S + w_0 \ ,$$

$$f = \frac{1}{2}\left(\frac{1}{g^2} - \frac{2}{(4\pi)^2} \log S\right) W^\alpha W_\alpha \ .$$

SUSY breaking sector

coupling to Higgs sector
(direct communication
a la gravity mediation)

(gauge mediation)

coupling to matter

coupling to gauge fields

Now we have closed Lagrangian. Hybrid of gravity and gauge mediation.

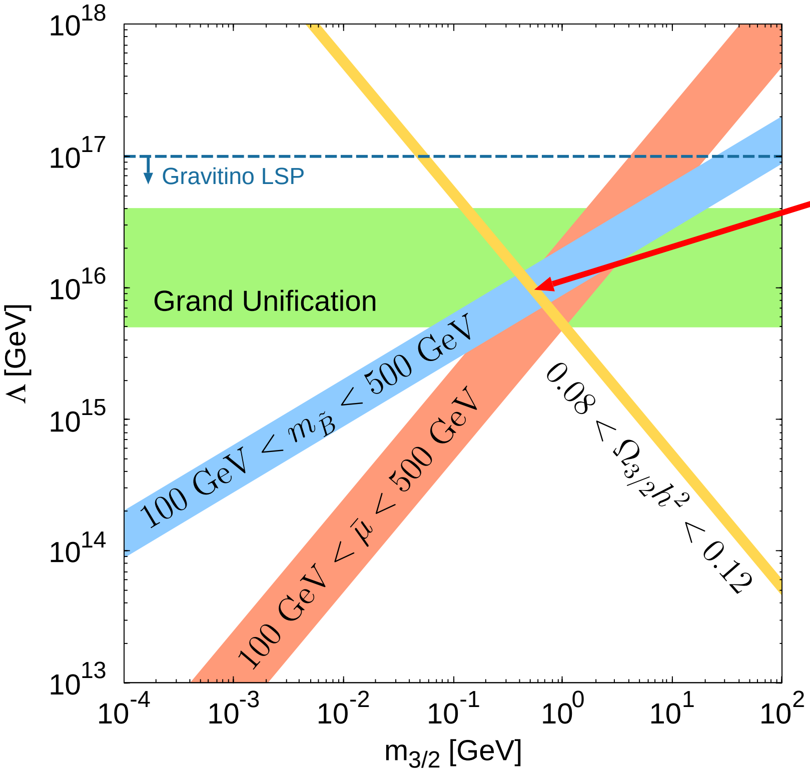
We can calculate all the spectrum and interaction terms.

Singularity at S=0 represents messenger fields in gauge mediation.

$$\langle S \rangle = \frac{\sqrt{3}\Lambda^2}{6 M_{\text{Pl}}}$$

The minimum is not at the singularity. ==> self consistent

Sweet Spot Supersymmetry



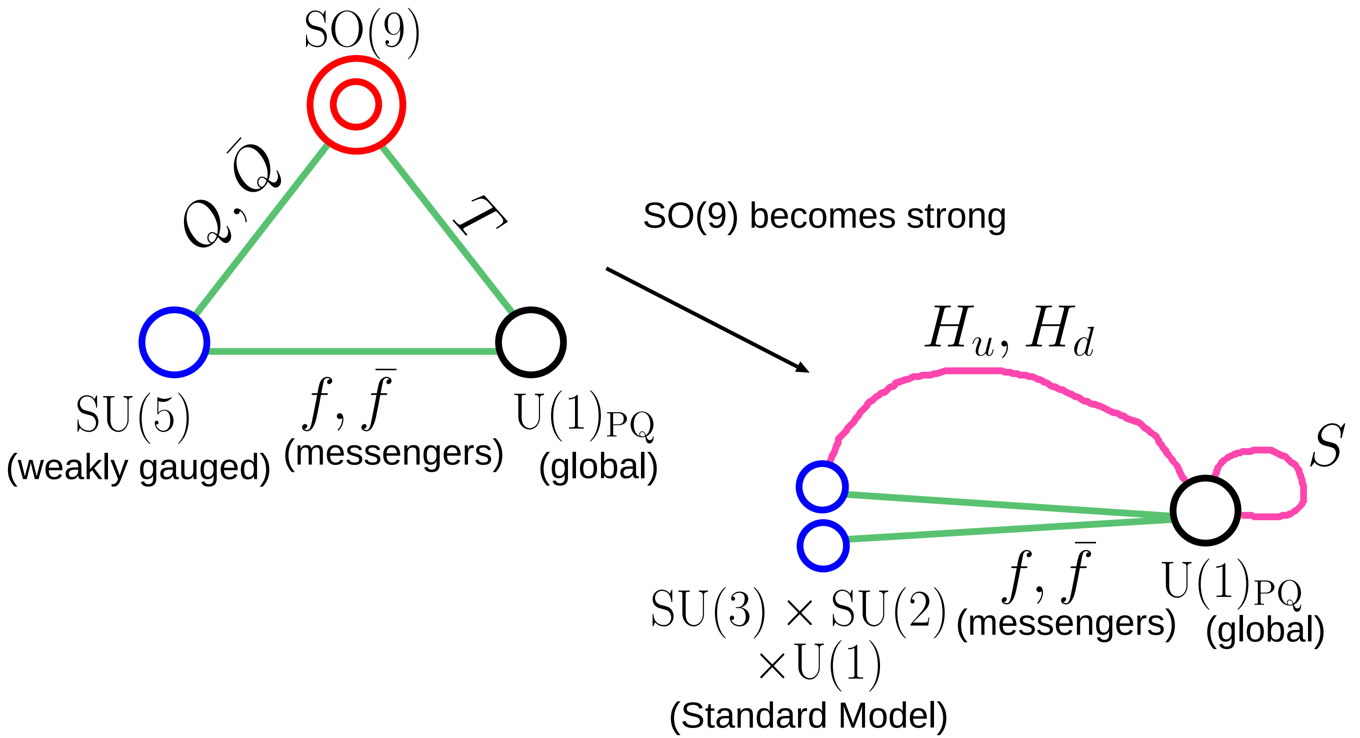
This is a perfect spot:

- grand unification
- gravitino dark matter
- no FCNC/CP problem
- no proton decay problem
- no mu-problem
- no moduli/gravitino problem...

Not only that
there is an incredibly simple
GUT model to UV complete
this theory without neither
DT splitting problem nor
proton decay problem.

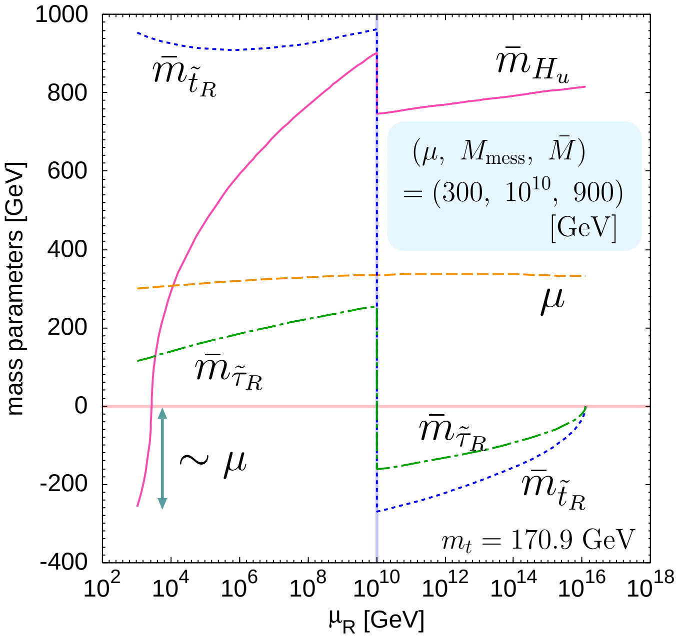
Oh, great. We've gotta study this.

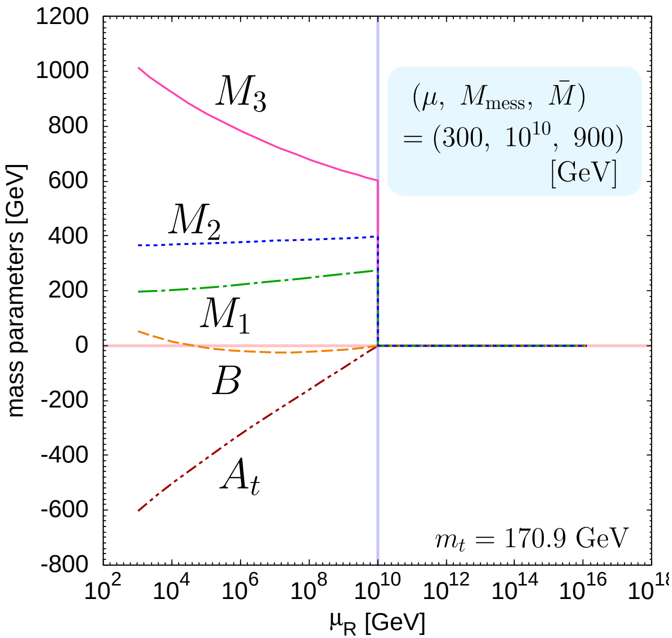
A UV model [RK '06]



Unification of
Higgs+SUSY breaking+GUT breaking dynamics

Soft SUSY breaking terms (Hybrid of gauge and gravity mediation)



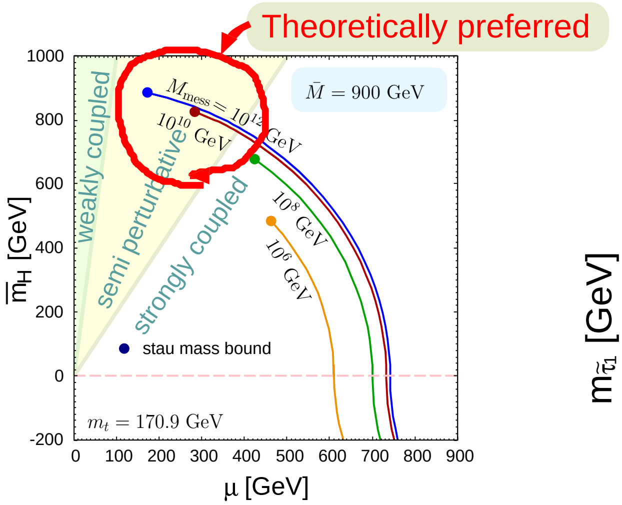


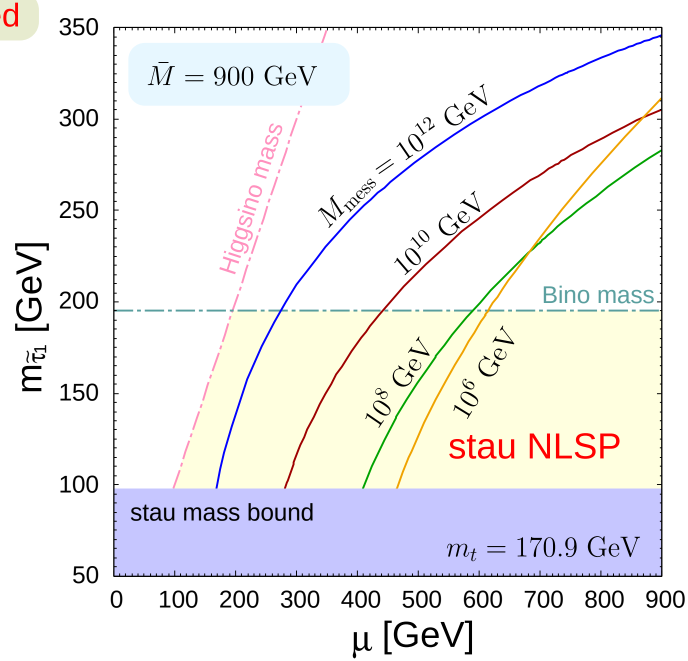
We have three parameters: $[\mu, M_{\rm mess}, \bar{M}]$ defines the Lagrangian

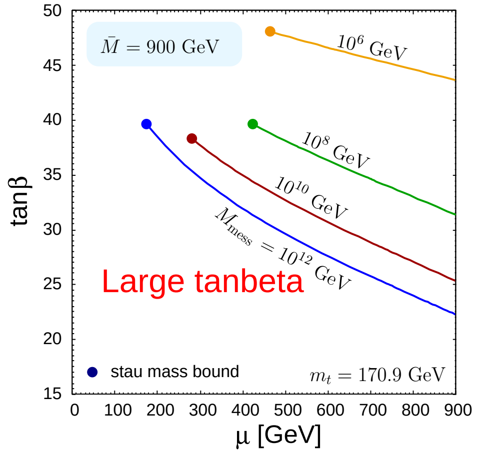
$$\left(\bar{M} = M_3/g_3^2 \equiv \frac{F_S}{\langle S \rangle}\right)$$

Very simple

Electroweak Symmetry breaking







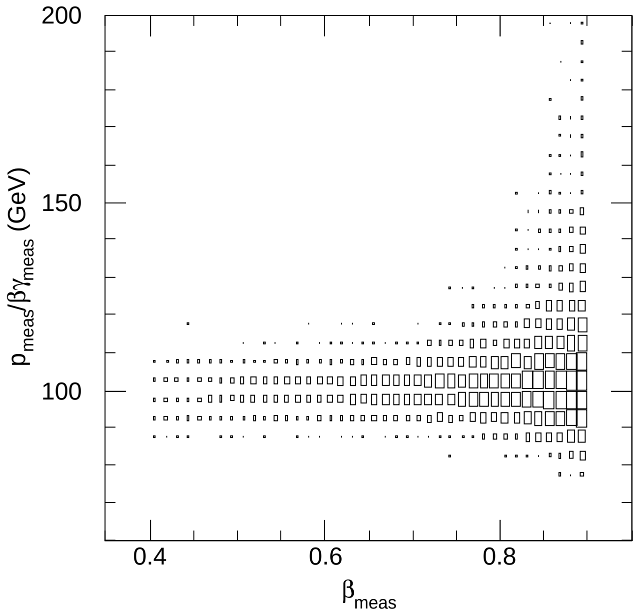
light Higgsino + light stau

Stau NLSP is plausible

Stau mass measurement at LHC

[Ambrosanio, Mele, Petrarca, Polesello, Rimoldi '00]

stau is almost stable (lifetime=O(1000s))



$$m_{\tilde{\tau}} = \frac{p_{\tilde{\tau}}}{\beta\gamma}$$

measure momentum and velocity.

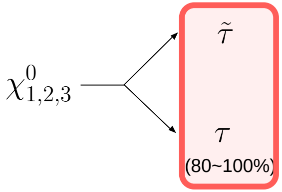
resolution of the velocity is roughly

$$\frac{\sigma(\beta)}{\beta} = 3\% \times \beta$$

stau mass can be measured with an accuracy of 100MeV!!

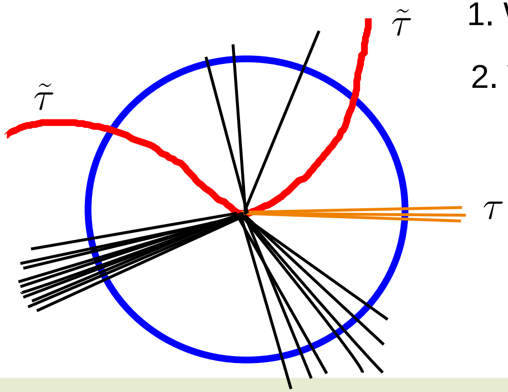
Neutralino mass measurement

[Hinchliffe and Paige '98]
[Ellis, Raklev, Oye '06]



$$m_{\chi^0} = M_{\tilde{\tau}\tau}$$

But...



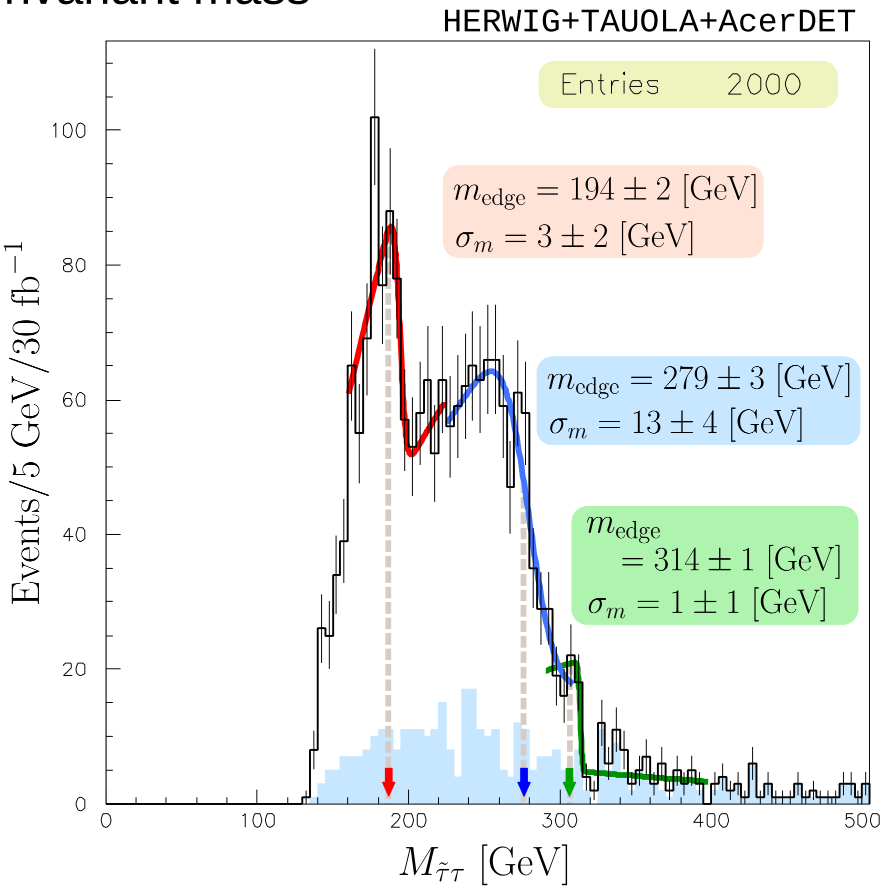
1. Which is the correct combination?
2. We don't know tau 4-momentum because of the missing ET by a neutrino.

Hinchiliffe and Paige (Gauge med.): select 1 stau events and endpoint analysis

Ellis et al (mSUGRA): -- use leptonic mode and use information of charge
-- decomposition of missing ET to tau direction
-- loose beta cut to enhance the statistics

Both are not directly applicable, but we basically follow Hinchiliffe and Paige.

Invariant mass



We select stau which gives a smaller value of the invariant mass.
(efficiency = 70%)

We can clearly see the edge structures.

main background is wrong combination and tau mis-identification.

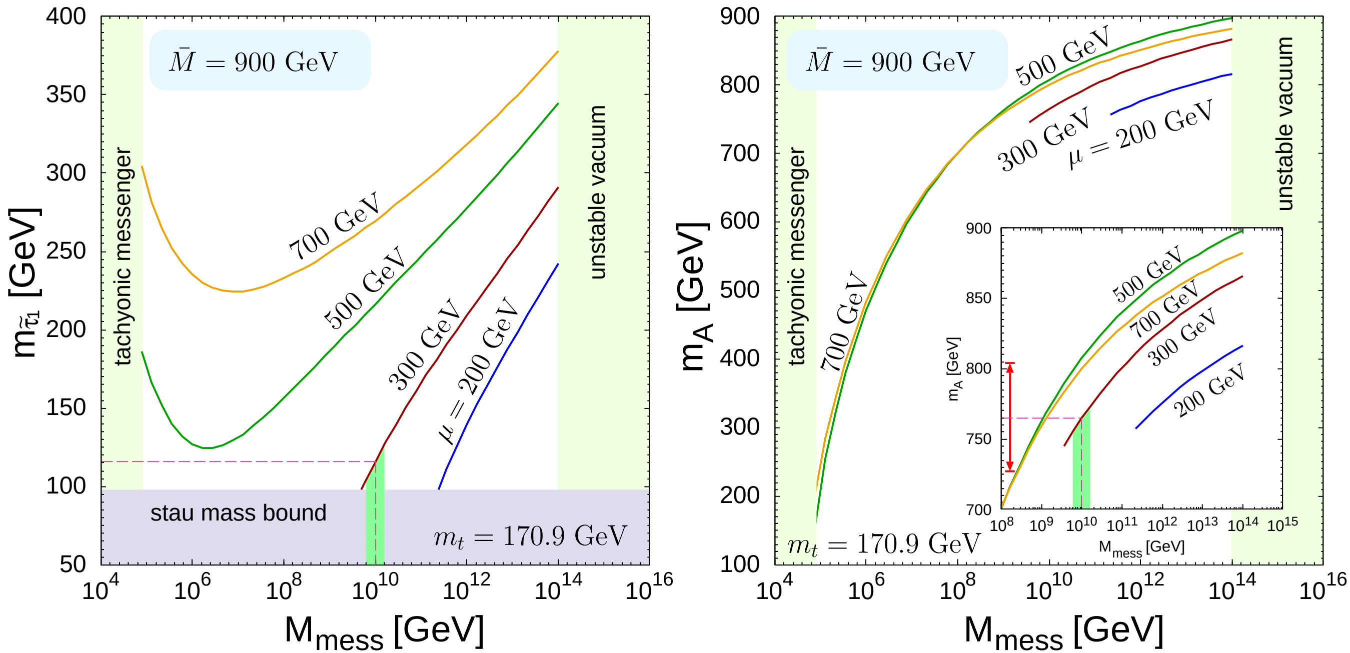
We can measure

$$m_{\chi_1^0},\ m_{\chi_2^0}$$

with an accuracy of O(5%)

From $m_{\tilde{\tau}},\ m_{\chi_1^0},\ m_{\chi_2^0}$ all the parameters can be fixed.

Parameter fixing



$$\Delta\mu \sim 20 \text{ GeV},\ \Delta\bar{M} \sim 50 \text{ GeV},\ \Delta\log_{10} M_{\text{mess}} \sim 0.2$$

for $[\mu, M_{\text{mess}}, \bar{M}] = [300, 10^{10}, 900]$ GeV

all the specrum is now calculable. For example,

$$m_A = 765 \pm 40 \text{ GeV}$$

We can perform a non-trivial test of the model.

Summary

* There is a sweet spot in SUSY model space.

* stau NLSP has a good theoretical support.

* very different from neutralino LSP scenarios.

* many things needs to be understood for more precise measurement of neutralino masses, such as calibration of tau-jet momentum and physics of mis-identification.