hep-ph/0705??? (hopefully)

[M.Ibe and RK]

Stau NLSP at LHC

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A little bit of theoretical motivation

MSSM: Supersymmetric Standard Model ⊕ 100+ soft ~~SUSY~~ mass parameters

well-defined ???

This is analogous to the Standard Model ⊖ Higgs boson

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

???

We need the Standard SUSY model which defines a sensible simplification of the 100+ parameters.

mSUGRA? minimal Gauge mediation?

No. These assuptions are not supported by theory.

In the SM

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

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

$$\longrightarrow \quad M_W = \frac{1}{\sqrt{2}} g v \qquad M_H = \sqrt{\lambda_H} v$$

In SUSY, it's similar.

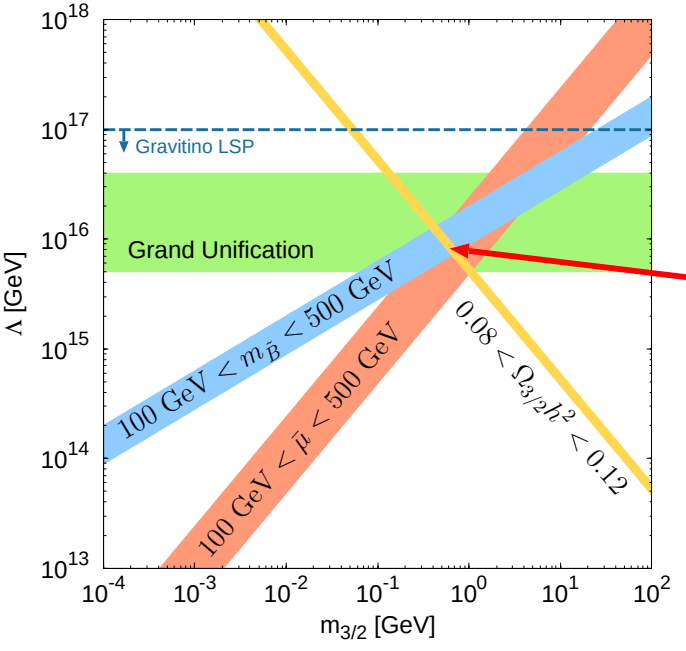
$$V(S) = |F_S|^2 - \frac{|F_S|^2 |S|^2}{\Lambda^2} + \cdots$$

Two parameters:
- Λ : self interaction of S
- F_S : scale of the supersymmetry breaking

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

gaugino masses:
- $m_{1/2} \sim \dfrac{F_S}{M_{\rm Pl}}$ (gravity mediated SUSY breaking)
- $m_{1/2} = \dfrac{\alpha}{4\pi} \dfrac{F_S}{\langle S \rangle}$ (gauge mediated SUSY breaking)

Two parameters: $m_{3/2}$, Λ



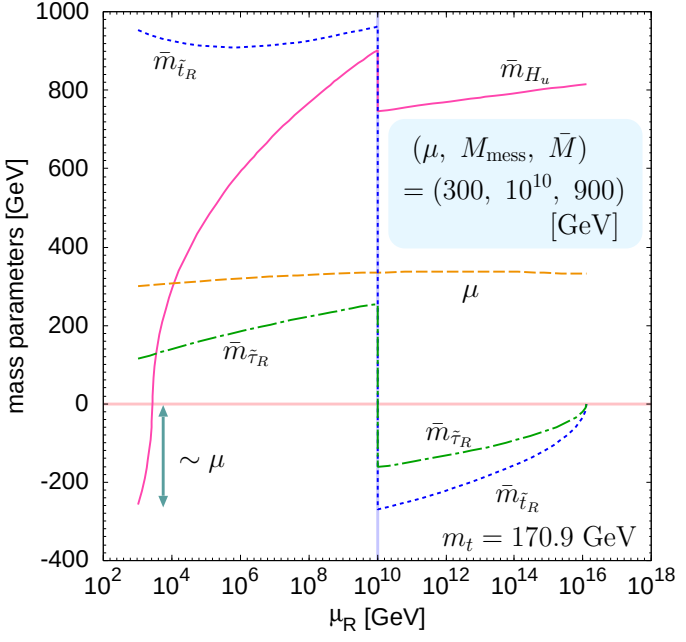
Assumption:
Higgs and S have interactions with similar strength with the S-self interaction.

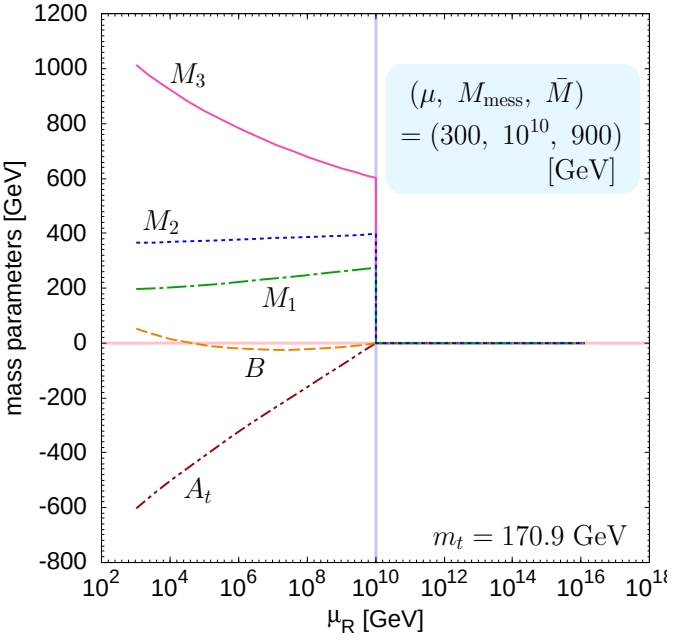
This is a perfect spot:

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

Oh, great. We've gotta study this.

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



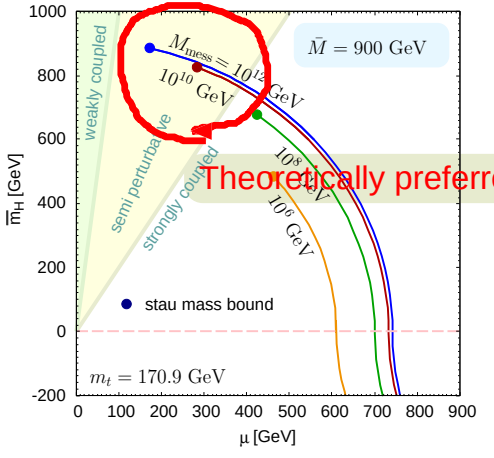


We have three parameters: $[\mu, M_{\rm mess}, \bar{M}]$ defines the Lagrangian

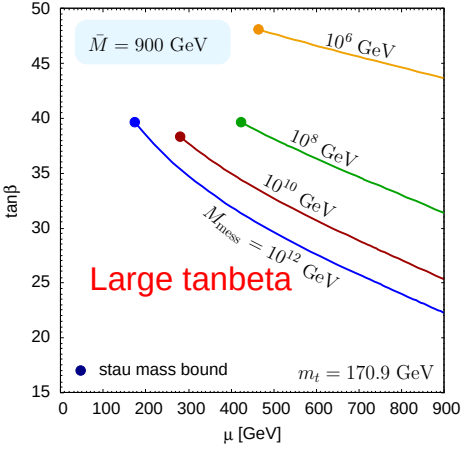
$$\left(\bar{M} = M_3/g_3^2 \equiv \frac{F_S}{\langle S \rangle}\right)$$

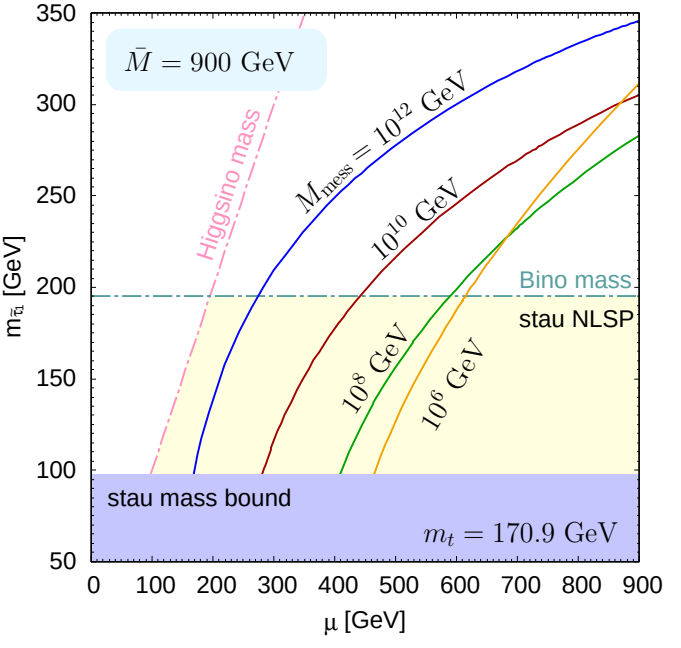
Very simple

Electroweak Symmetry breaking



Theoretically preferred





light Higgsino + light stau

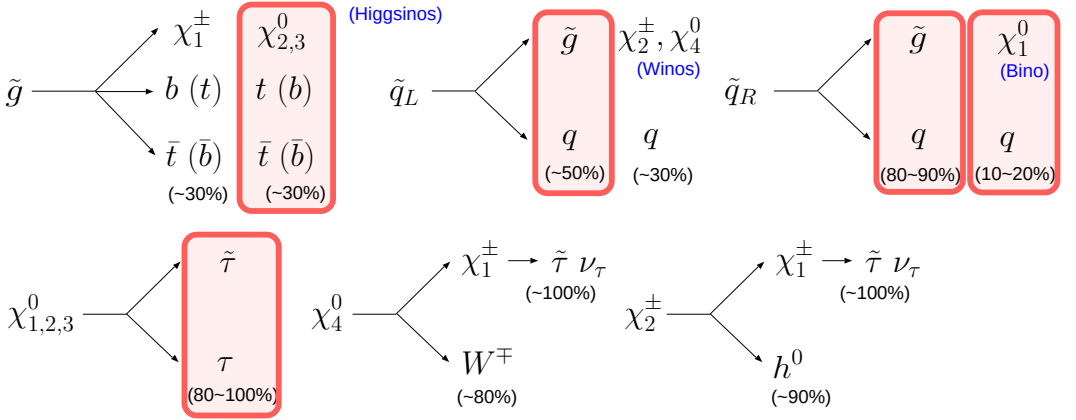
Stau NLSP is plausible

Benchmark point: $[\mu, M_{\rm mess}, \bar{M}] = [300, 10^{10}, 900][\rm GeV]$

light Higgsino

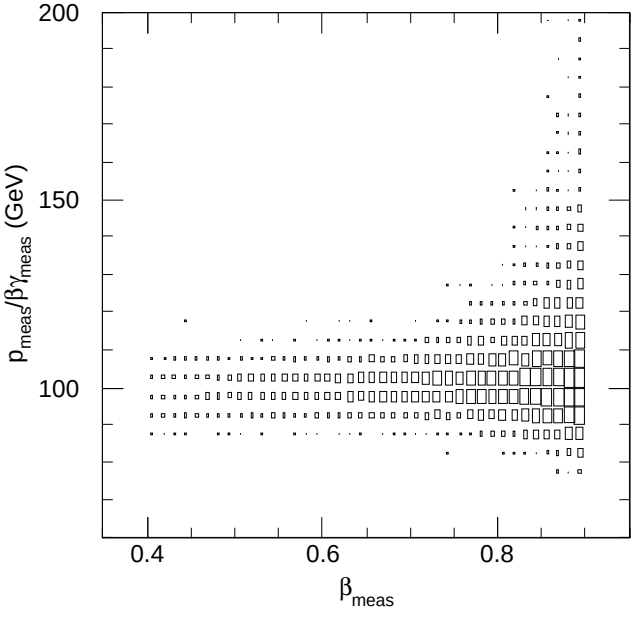
→ Stau NLSP (116GeV)

lifetime: 3000 seconds almost stable, leave charged tracks



zoo of 3rd generation particles + 2 slow charged tracks

Gorgeous! but analysis is difficult... no clear lepton signals



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

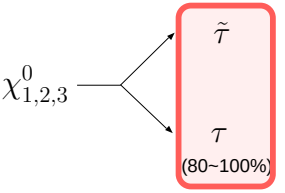
measure momentum and velocity.

resolution of the velocity is roughly

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

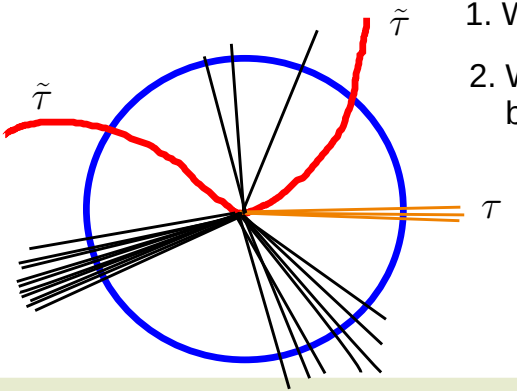
stau mass can be measured with an accuracy of 100MeV!!

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.

Event selection

* Trigger (fast stau can be used as a trigger because it looks like a muon.)

* Two stau candidates

one of them should be $\beta\gamma < 2.2$ this takes care most of the SM background

$$\beta' - 0.05 < \beta_{\rm meas} < \beta' + 0.05 \qquad \left(\beta' = \sqrt{\frac{p^2_{\rm meas}}{p^2_{\rm meas} + m^2_{\tilde{\tau}}}}\right)$$

consistency with measured stau mass
(this is not very powerful if stau is light)

$$\left.\begin{array}{l} p_T > 20\ {\rm GeV} \\ \beta\gamma > 0.4 \end{array}\right\}$$ to ensure the stau to reach to the muon system

* $M_{\rm eff} > 800\ {\rm GeV}$

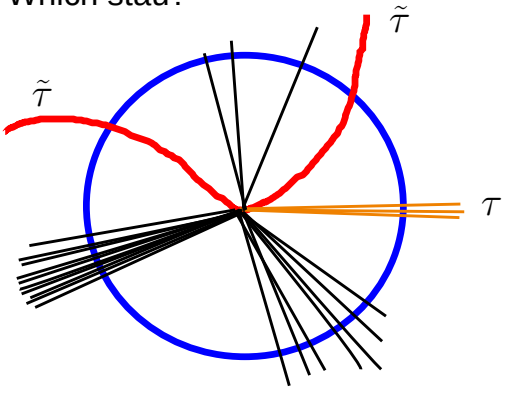
* one tau-tagged jet we assumed $\epsilon_\tau = 50\%, \quad R = 100$

$p_T > 40\ {\rm GeV}$

42,900/30fb^-1 ⟶ 2,014/30fb^-1

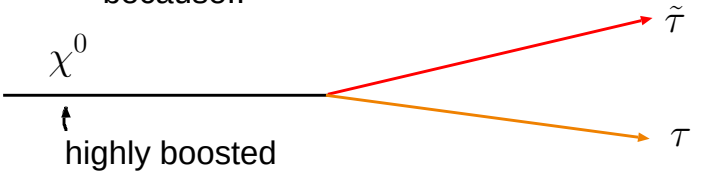
(1,529 with true tau and stau)

Which stau?

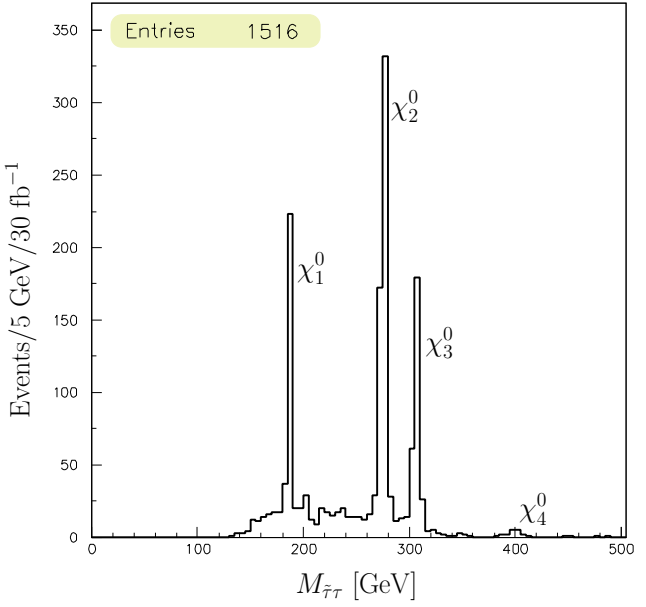


We selected a stau with smaller $M_{\tilde{\tau}\tau}$

because..



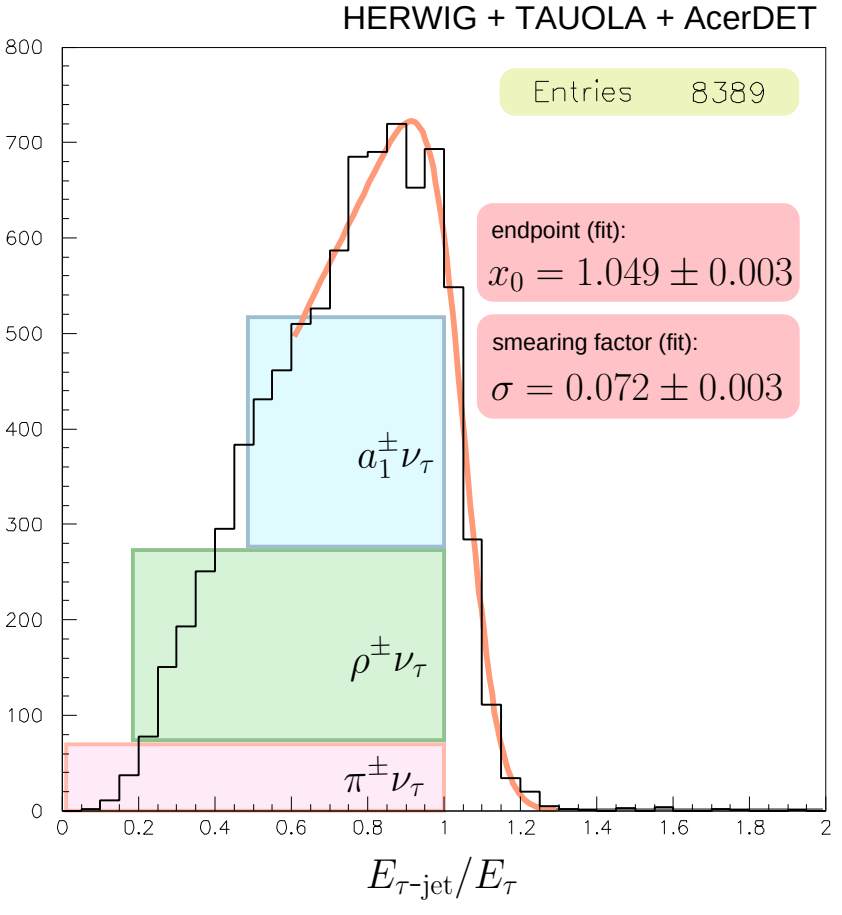
$$E_\tau,\ E_{\tilde{\tau}} \gg m_{\chi^0}$$



=> wrong combination tends to give a larger value of $M_{\tilde{\tau}\tau}$

We can select the correct combination with a probability of 70% by this strategy.

tau energy?



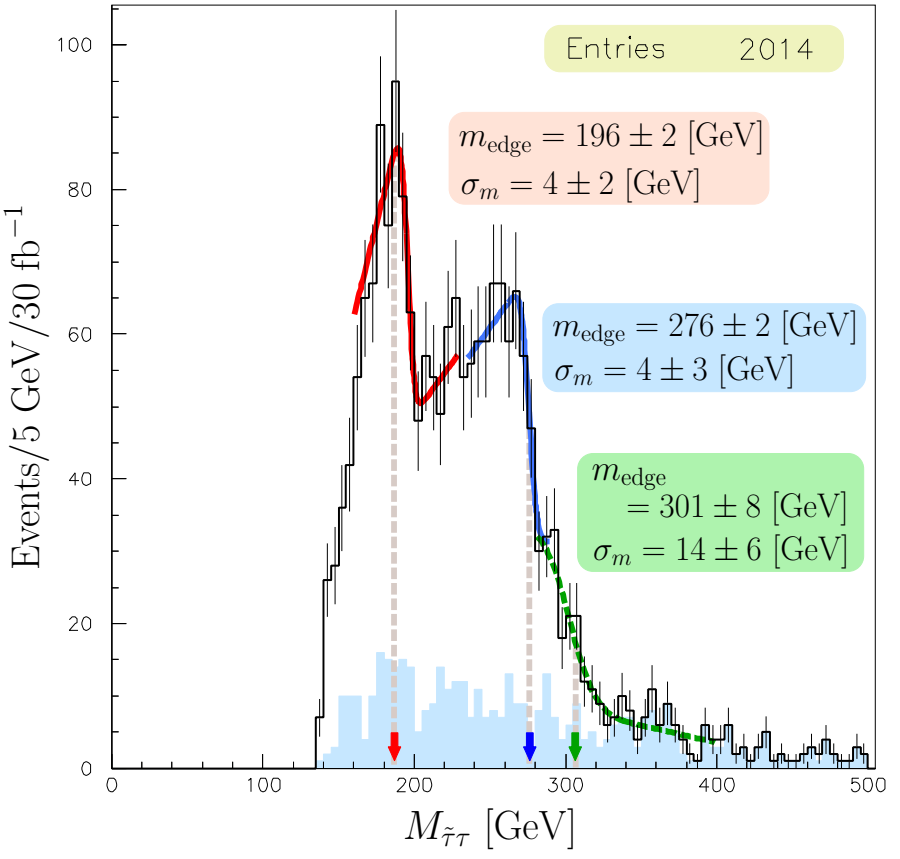
there is a sharp edge
at E(jet)/E(tau)=1

The shape is understandable
from 2-body kinematics

thresholds at meson
masses are smeared
by the finite widths of mesons

We can expect sharp edges
at neutralino masses
in the M(stau-tau) distribution.

Invariant mass

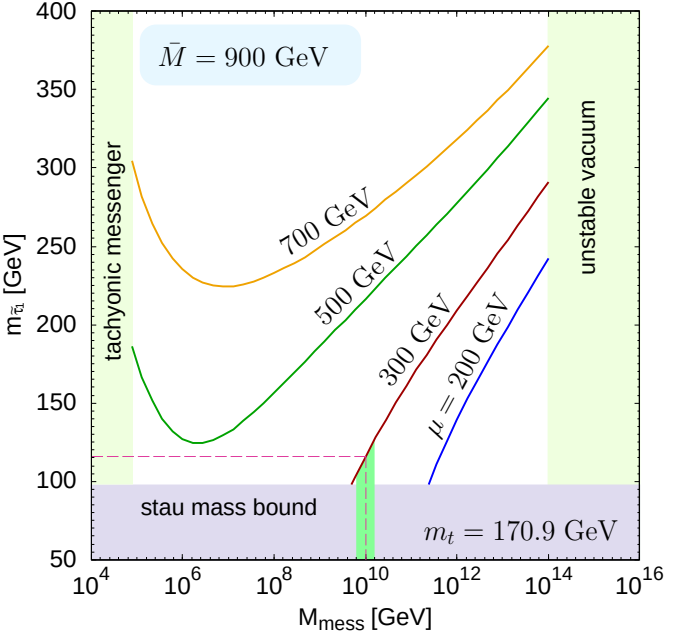


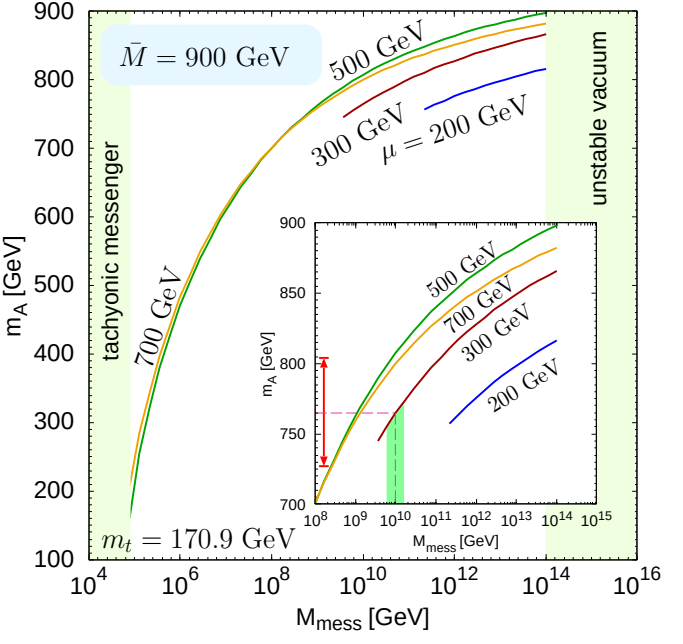
We can clearly see the edge structures.

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.





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

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.