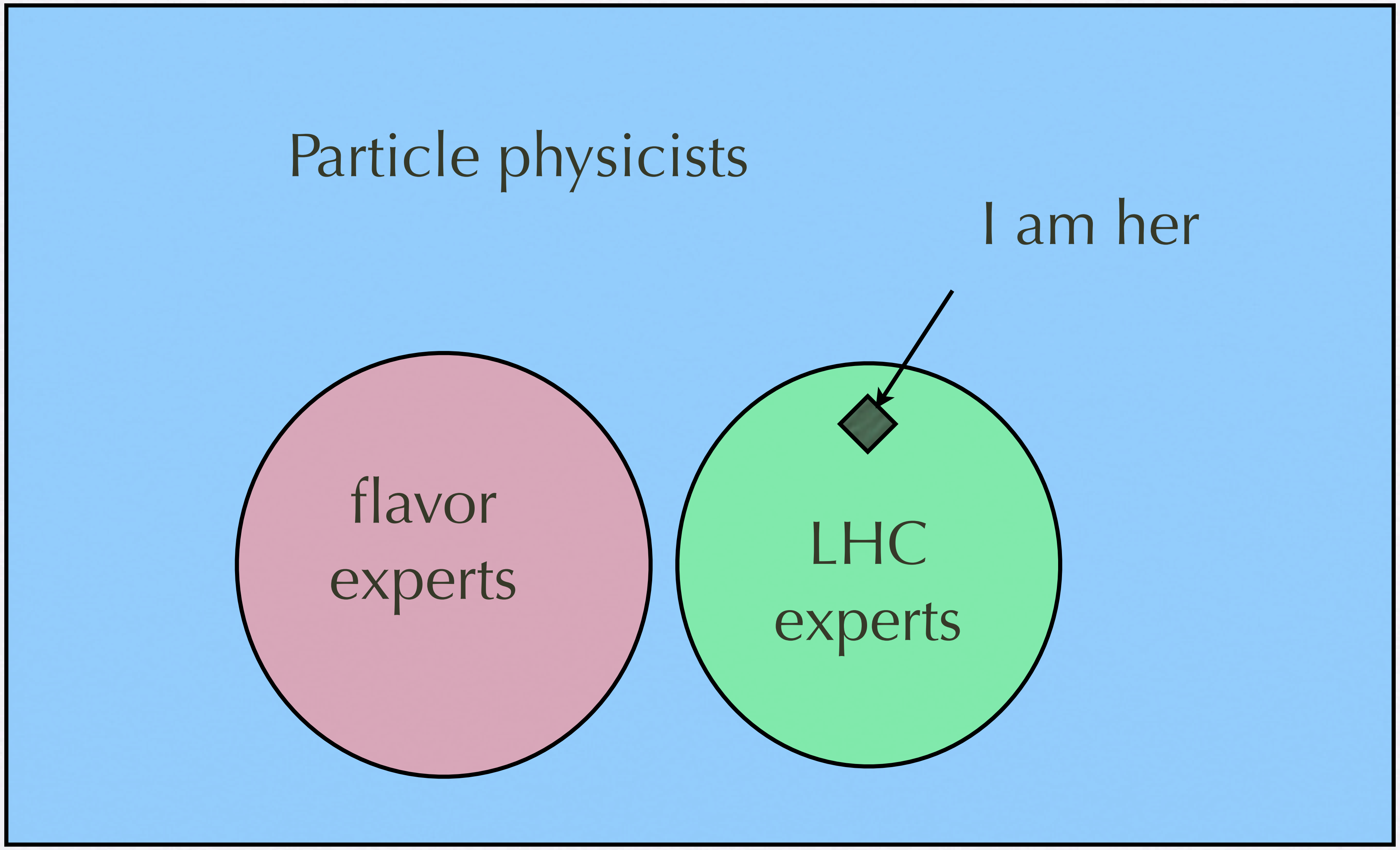
SUSY at LHC connection to flavor physics

for “flavor physics in the era of LHC”

Mihoko M. Nojiri

YITP, Kyoto University
Moving to KEK
from Jan, 2006

Starting from excuses....



Whatever I talk about “flavor physics” can be wrong.
(It might be more useful if you ask numbers you want from LHC directly to me)
Also forgive me about improper references.

Why LHC is related to "flavor physics"

- It sets scale of the new physics
- It measures important parameters. For the case of supersymmetry, it is
  - B physics : charged higgs, sbottom and stop at LHC
  - LFV: determination and slepton masses, direct searches
  - μ, $\tan\beta$

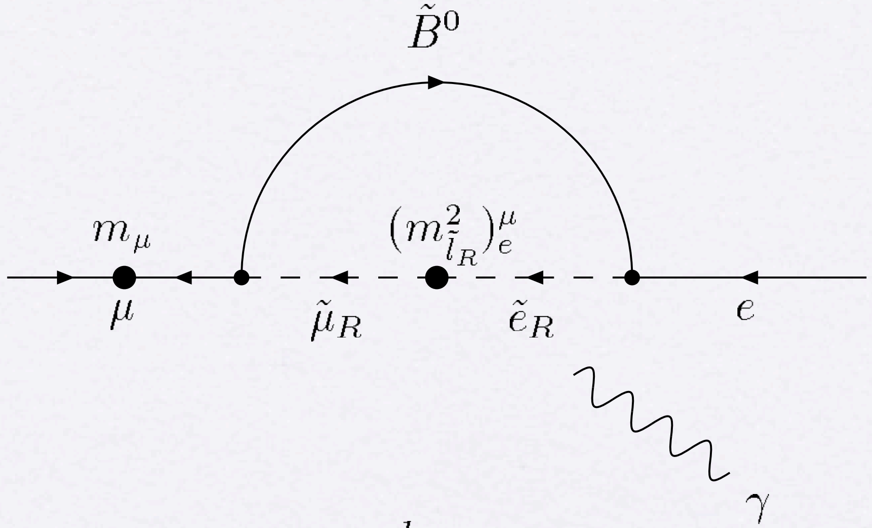
Note : We know nothing about that now

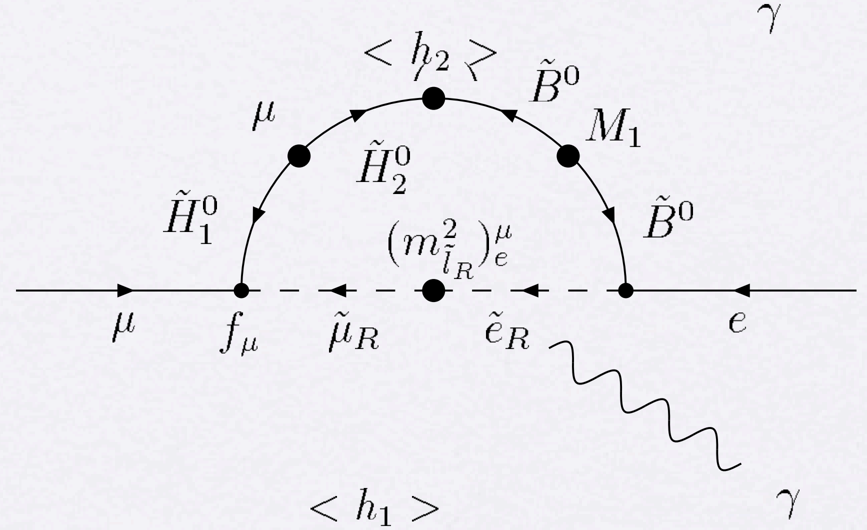
What do we want to know for LFV?

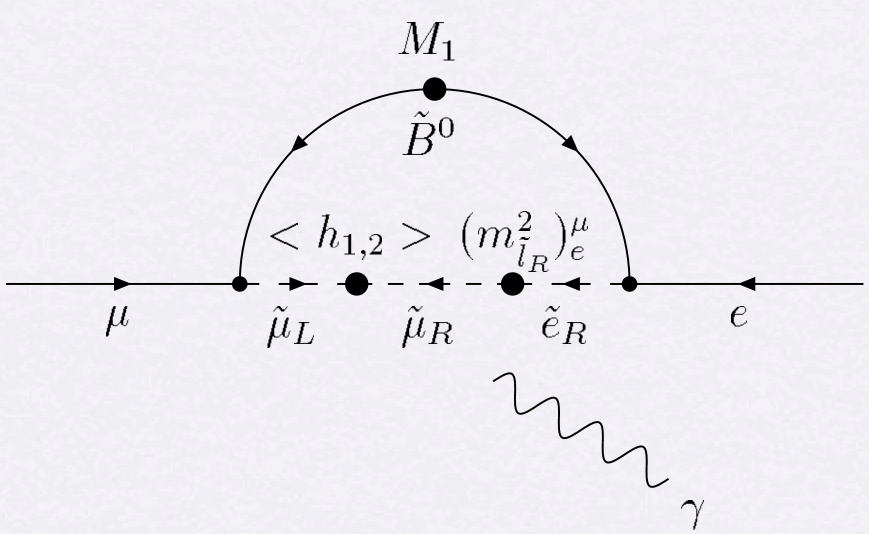
- What we need (for SU(5) GUT)
  - tanβ: Yukawa coupling
  - $m_{R\,(12)}$
  - M_1,μ : neutralino mass matrix

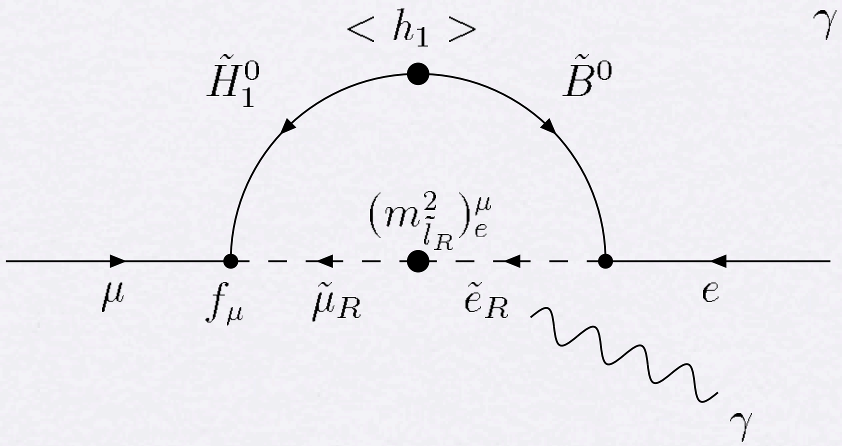
M_2 and m_L for SU(5)+ν_R(see-saw)

Distinguish Left and Right sleptons is important



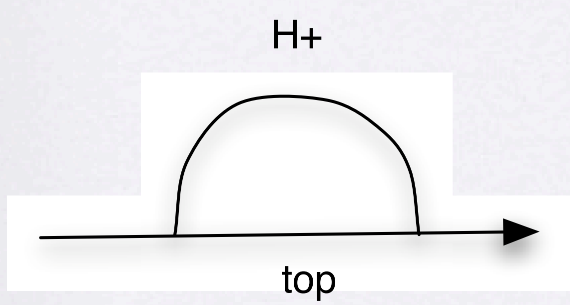


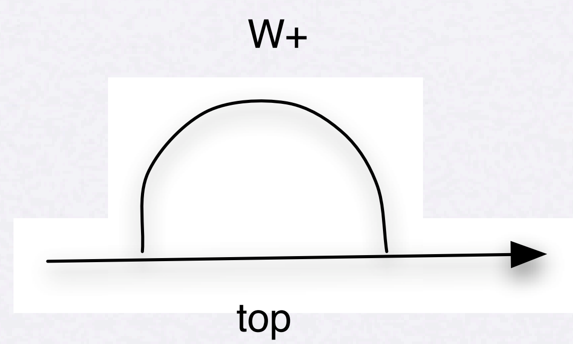


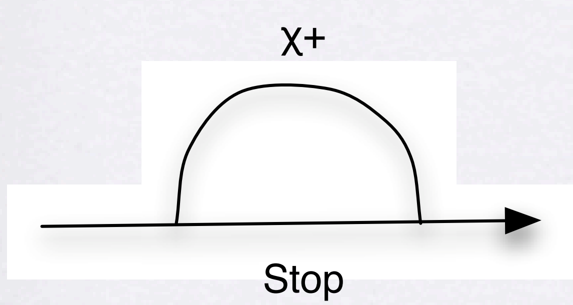


what do we want to know for B physics

- many competing diagrams
- Cancellations.
- Ex:$b \to s\gamma$: What is charged Higgs mass, stop mass and mixing angle?







if chargino diagram does not exist mH^+~300GeV is excluded

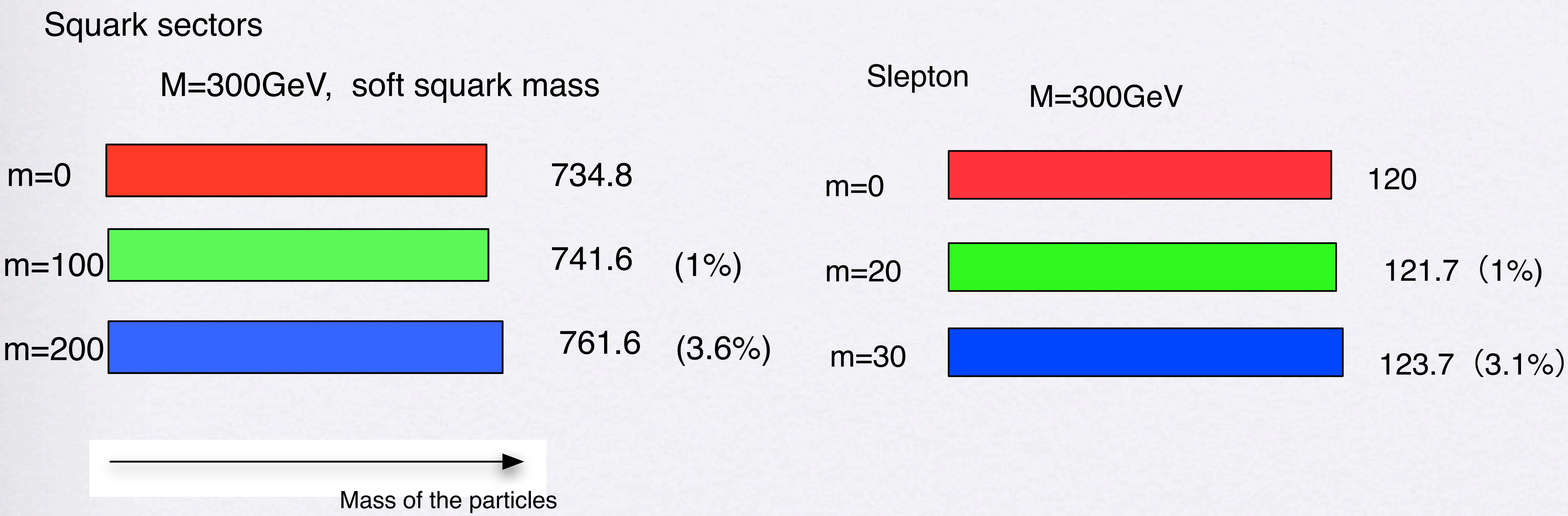
How to put LHC constraint in the flavor analysis

- Most Flavor studies is performed in the form of scatter plot to show the deviation from SM.
- LHC will come. You may want to put minimum and model independent constraint to your analysis. What are they?
- Most of LHC analysis have been done in a few points in MSUGRA. How generic are they? You confused..

Access to the Flavor structure

We have seen in Franks talk that we might have high sensitivity in squark and slepton masses.
(1% for squarks, and O(1GeV) for slepton mass differences)

What does this means?



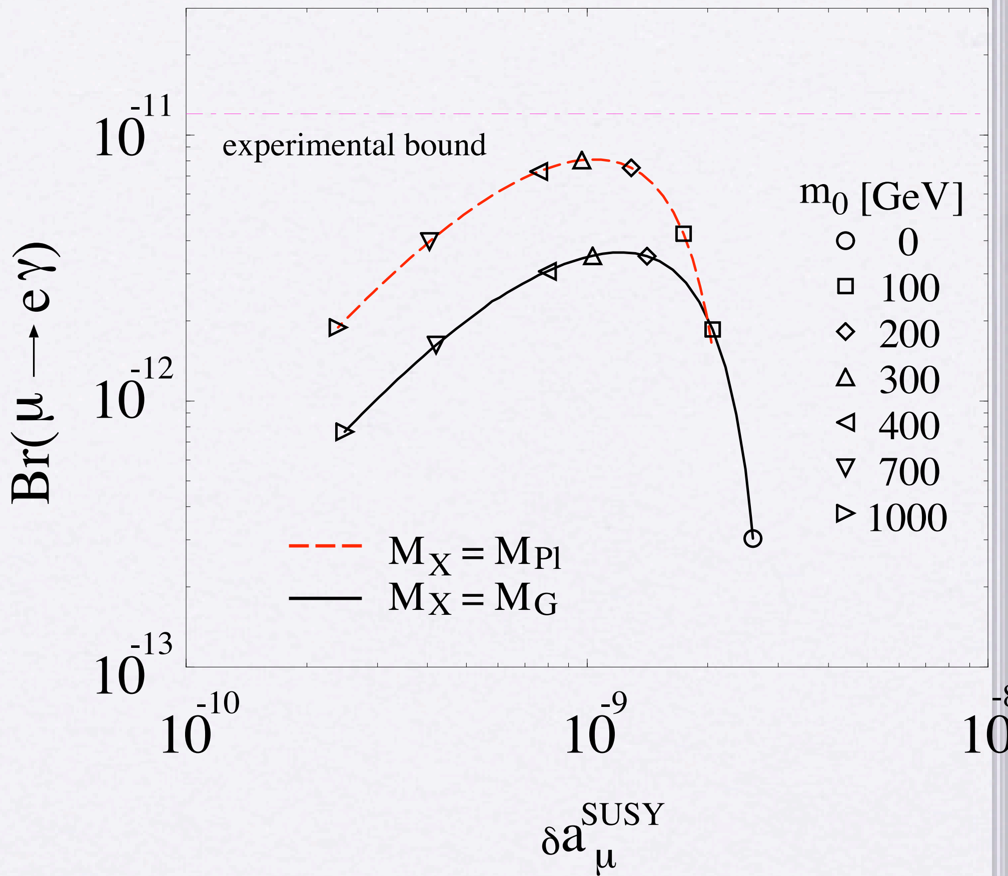
gaugino mass dominates the squark masses
and it is universal. All fancy flavor effects are reduced.

$$\left[\frac{10\ \text{TeV}}{m_{\tilde{q},\tilde{g}}}\right]^2 \left[\frac{\Delta m^2_{\tilde{q}_{12}}/m^2_{\tilde{q}}}{0.1}\right]^2 \lesssim 1\ .$$

K bound is not too difficult to satisfy if m<M at GUT scale

Flavor and LHC

- The effect of non-diagonal scalar mass m(ij) at GUT scale (but of the order of diagonal scalar mass) will be suppressed at lower scale. $\delta m^2/m^2 < 0.01$ is possible for $m \ll M$
- LFV is large for m~M or m>M regions.
- LHC measurements are good when $m \ll M$. No clean result for the other MSUGRA points.

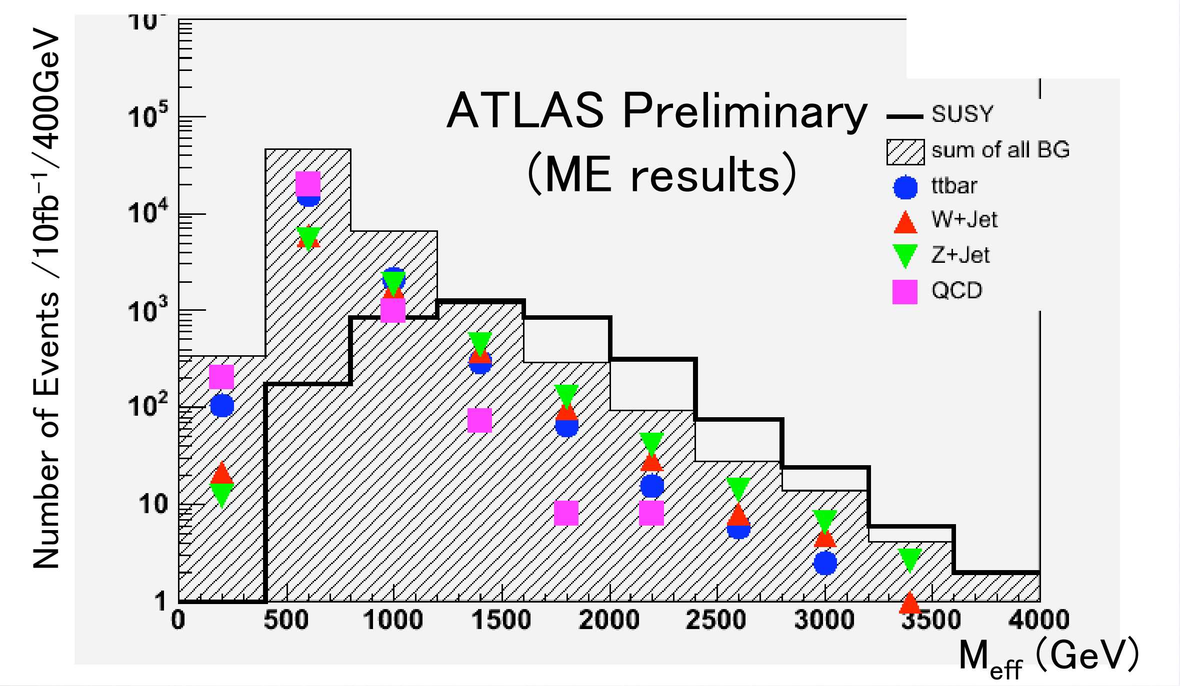


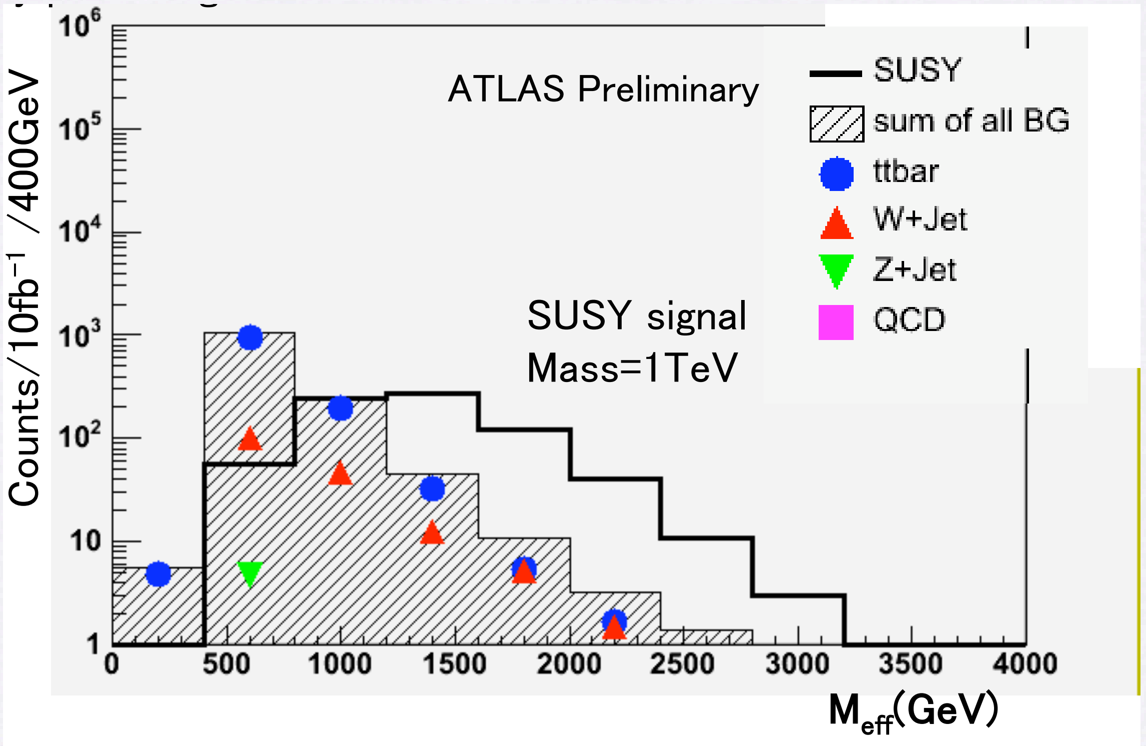
Hisano and Tobe(2001)
M_2=250 GeV, tanβ=10
SUSY sea-saw model
V_{13}=0.05, $Y_t=Y_{\nu\tau}$

SUSY scale determination for m≫M

- Peak position of M_{eff} reflects 2xM_{SUSY}, but we have more SM background than originally thought.
- M_{eff} (One lepton), same strategy but model dependent?
- 3 body decay of gluino. less efficient?
- We only measure gluino masses. squark decays immediately to gluino and hard to reconstruct.

Asai et al

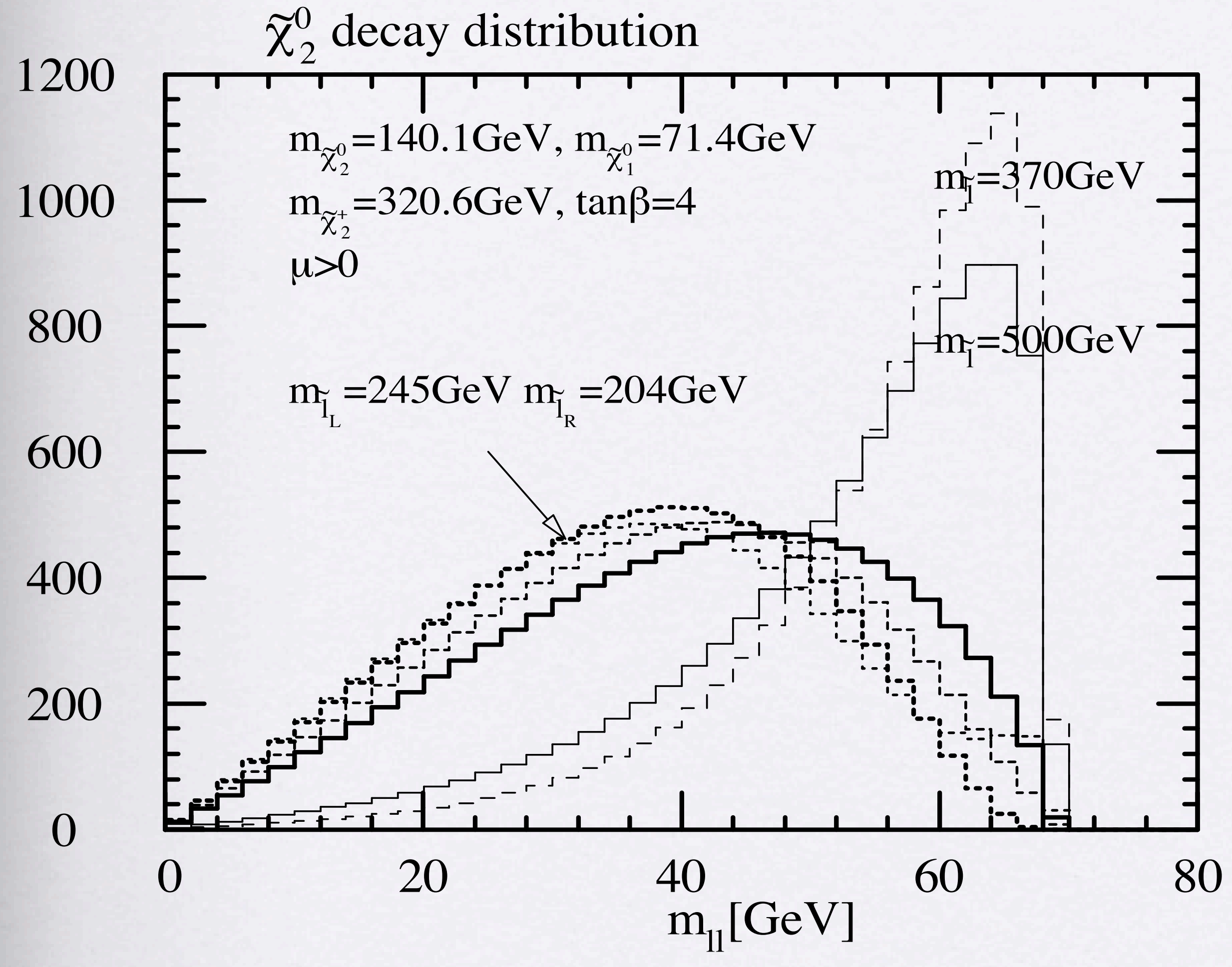




Slepton masses and $\tilde{\chi}_2^0$ decay distribution

- m≫ M: all 2 body decays into slepton is closed

- virtual process $\tilde{\chi}_2^0 \to ll\tilde{\chi}_1^0$?
  The decay distribution depends on left hand slepton masses in MSUGRA



when $\tilde{l}_R$ is open, virtual $\tilde{l}_L$ contribution appear beyond the two body end points.

$$\Gamma(\tilde{\chi}_2^0 \to ll\tilde{\chi}_1^0)/\Gamma(\tilde{\chi}_2^0 \to l\tilde{l}_R \to ll\tilde{\chi}_1^0)$$

Γ(3 body)/Γ(two bodies) =0.05 for SPS1a.

Life with cosmological constraints

A) Bulk region: Bino like.
Slepton exchange sets Ω

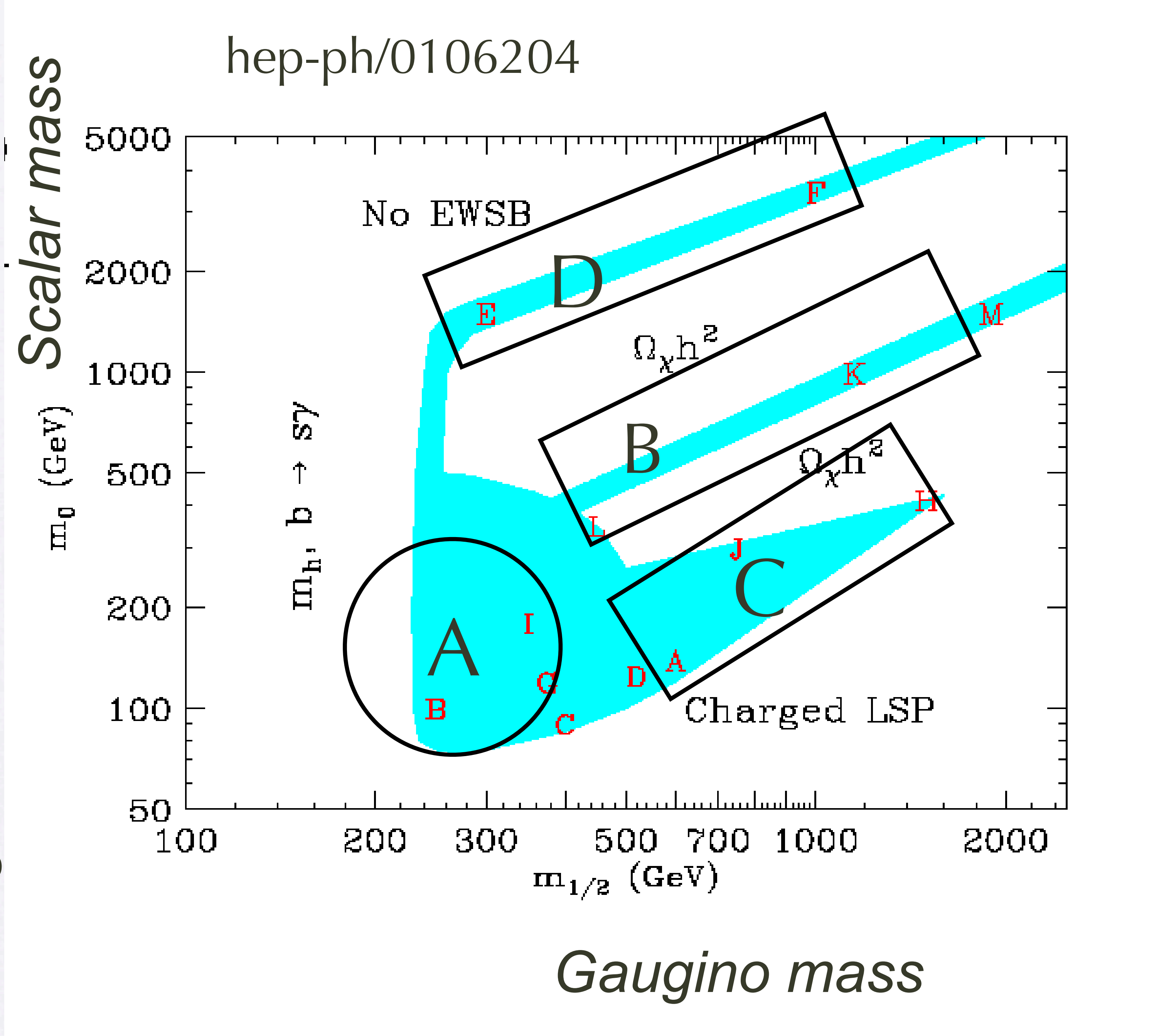
$$\Omega h^2 \propto m_{\tilde{l}}^4 / m_{\tilde{\chi}}^2$$

too large mass density

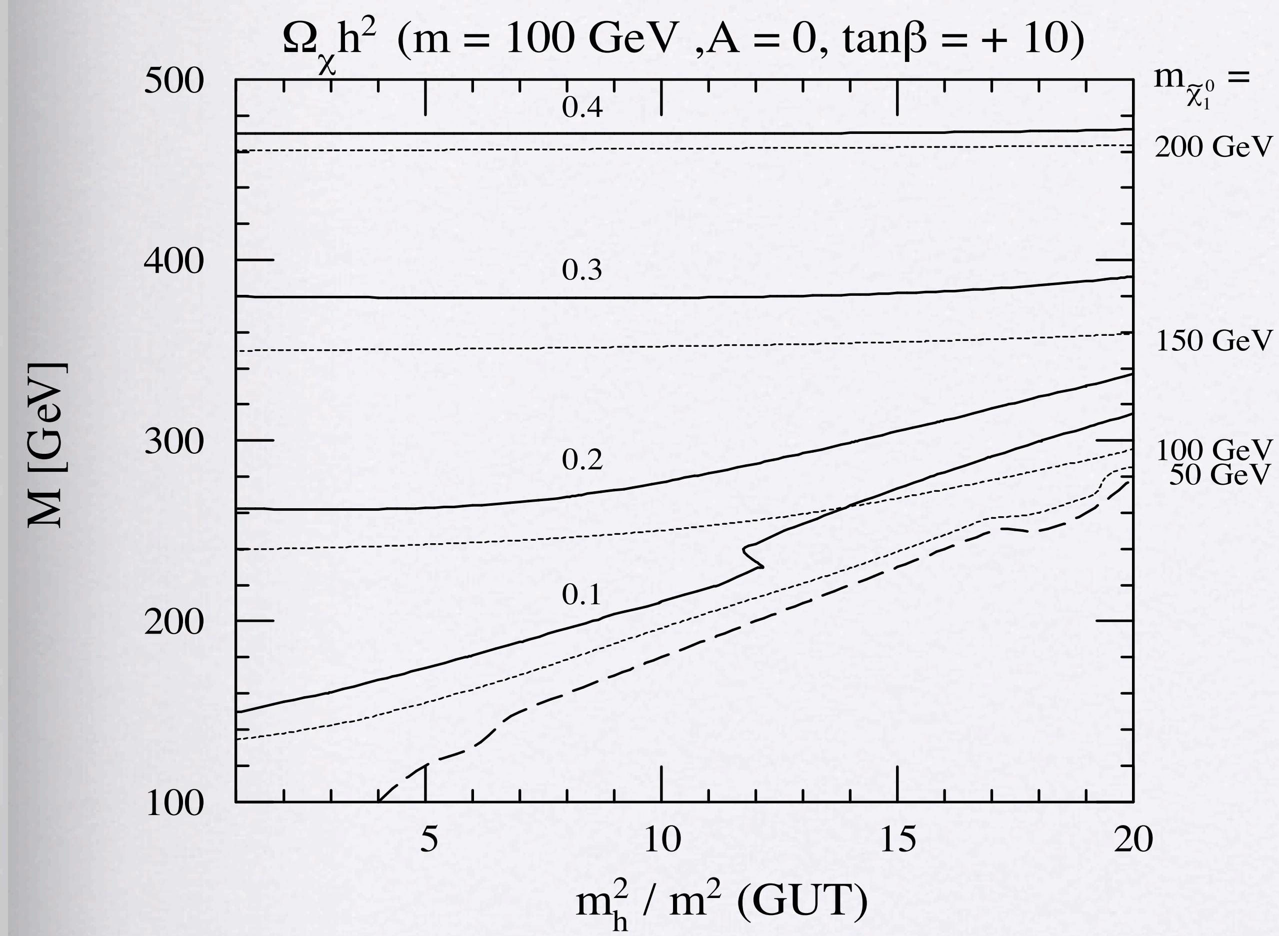
B) Higgs pole effect near
$m_H = 2 m_\chi$

C) $\tilde{\tau}\tilde{\chi}$ co-annihilation

D) focus point region
significant higgsino-gaugino mixing



MSUGRA might be too much



- μ parameter is determined so that v_H is correct.
- So if m_H at GUT scale is much higher than m_{16}, MSUGRA prediction for μ can be evaded. More LSP pair annihilation into W, h
- m_H (1,2) can be tuned independently so that higgs pole effect is enhanced.

simultaneously affects LFV through

1)LR mixing of sfermions

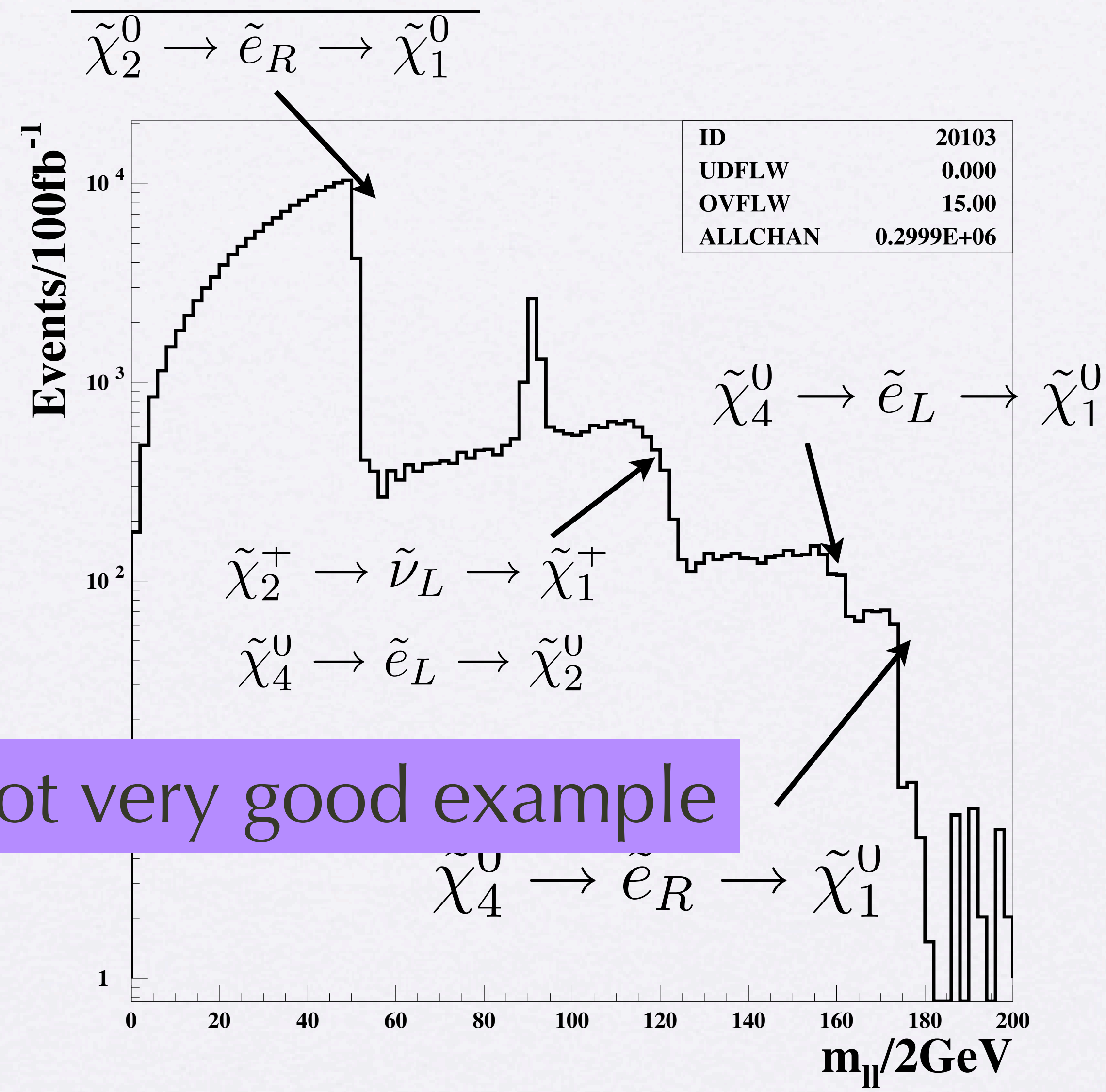
2) Higgsino mass insertions

Some recent benchmarks hep-ph 058198 for CMS (light mH

life with cosmological constraint

What happens if μ is smaller

- More gaugino component in $\tilde{\chi}_4^0$ if $M_2 \sim \mu$
- mass difference between 1st and 2nd ino smaller
- heavier ino becomes gaugino if $M_2(M_1) > \mu$, longer cascade decay as squark dominantly decay into gaugino (heavier ino)
- several ino signature



Drees et al
PRD63,035008(2001)

m=90GeV M=250GeV
μ =200GeV tanβ=10

Example of tanβ determination

scalar-muon LR mixing

if $\tilde{\chi}_2^0 \sim \widetilde{W}$ then decay width $\Gamma(\tilde{\chi}_2^0 \to \tilde{l}_R l)$ is so suppressed.

Small left component of scalar muon affects decay branching ratios strongly.

$$\tilde{\mu}_1 \sim \tilde{\mu}_R + \epsilon_L \tilde{\mu}_L \qquad \epsilon_L \sim m_\mu(\mu \tan\beta + A_\mu)/(m_L^2 - m_R^2)$$

$$\begin{aligned} \Gamma(l) &\propto L^2 + R^2 \\ L &= g \cos\theta_l N_{\widetilde{W}2} \\ R &= g_Y \sin\theta_l N_{\widetilde{B}2} \end{aligned}$$

tanβ	Br(e)	Br(μ) /Br(e)	S (300fb-1)
10	6.3%	1.04	5.6
20	1.2%	1.17	7.8

Goto et al (2004) PRD70:075016

Importance of relative branching ratio

$$\Gamma(\tau) : \Gamma(\mu) : \Gamma(e) \sim$$
$$(g \cos\theta_\tau N_{\widetilde{W}})^2 : (g \cos\theta_\mu N_{\widetilde{W}})^2 + (g_Y N_{\widetilde{B}})^2 : (g_Y N_{\widetilde{B}})^2$$

ignore bino component

Both of them contribute

ignore selectron mixing

relative branching ratio is important. Note systematics are very different

- μ : clean, outer muon system
- e: inner tracking $+E_{cal}$
- τ : decay into hadron, jet isolation , ν_τ missing, efficiency~50%

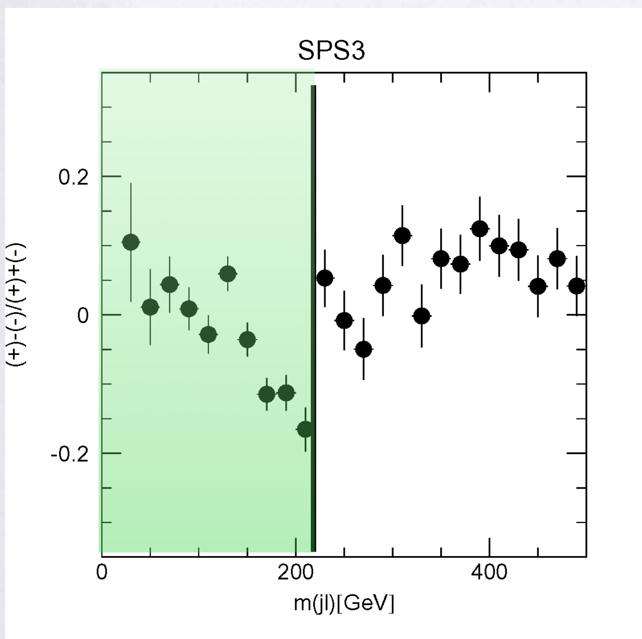
For 3 body decay and $\mu > M_2 > M_1$, left hand slepton dominates....

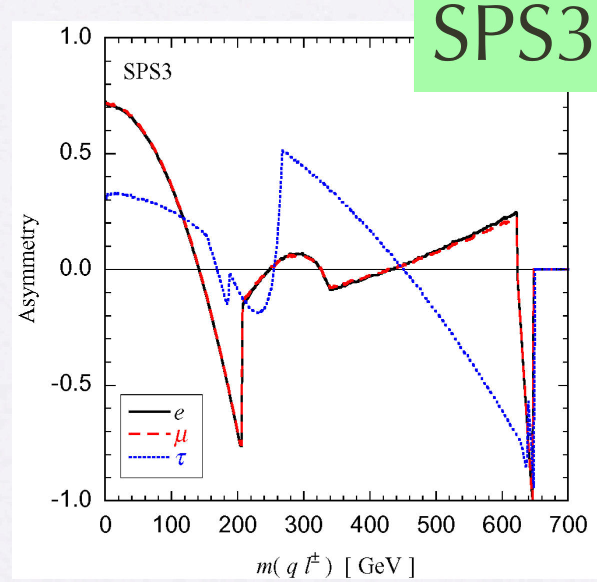
Left or right??

- at LHC(pp collider) σ (squark)≫ σ(anti-squark)
- MSUGRA case $\tilde{q} \rightarrow \tilde{\chi}_2^0 q \rightarrow \tilde{l} l q \rightarrow \tilde{\chi}_1^0 q l l$
- wino-like ino produced from left-hand squarks
- wino is polarized(in average). it decays into lepton /anti-lepton equally (Majorana). lepton/anti-lepton correlation to wino(jet) direction is opposite. charge asymmtry.
- NOTE, slepton further decay into lepton. look into the distribution near the jl edge(it may not be end point)

Left or right, simulations

- m(jl) distribution tell us combination of the chirality of squark and slepton in the cascade decays.

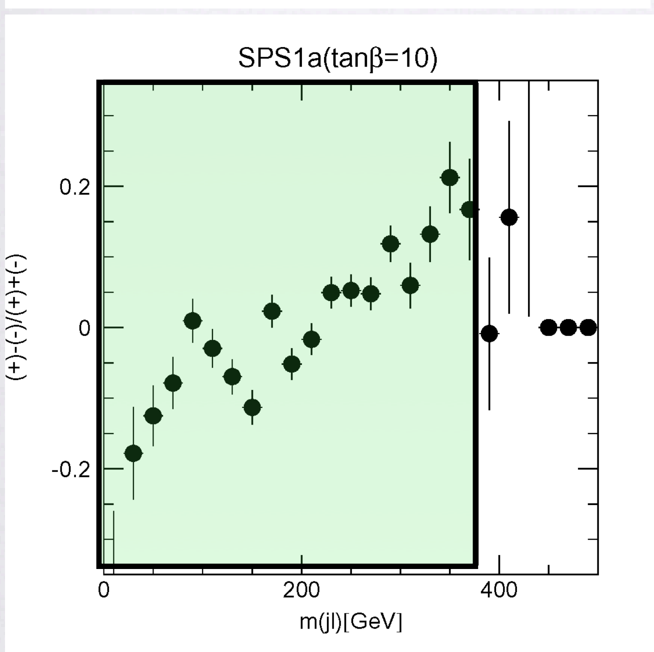


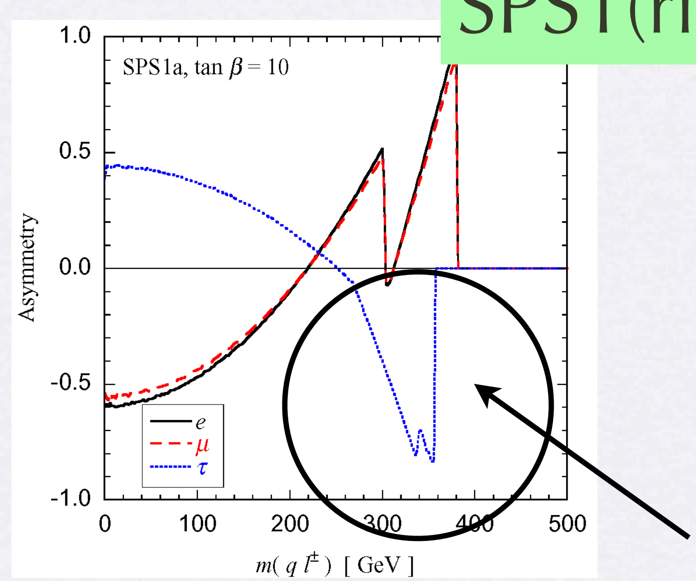


SPS3 (left)

$$\tilde{q}_L \to \tilde{\chi}_2^0 q \to \tilde{l}_L l q$$

$$m(ql) = 230 \text{ GeV}$$





SPS1(right)

$$\tilde{q}_L \to \tilde{\chi}_2^0 q \to \tilde{l}_R l q$$

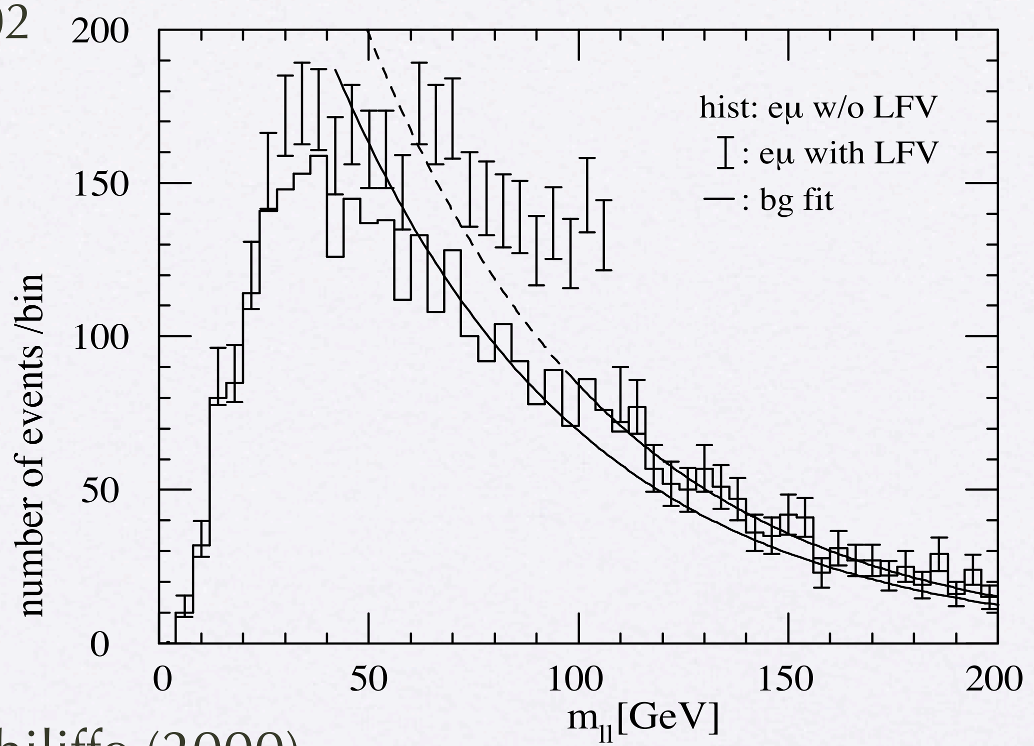
$$m(ql) = 380 \text{ GeV}$$

Kawagoe, Goto, Nojiri (2004)

stau$_1$ behave like left

Flavor violation in slepton decays

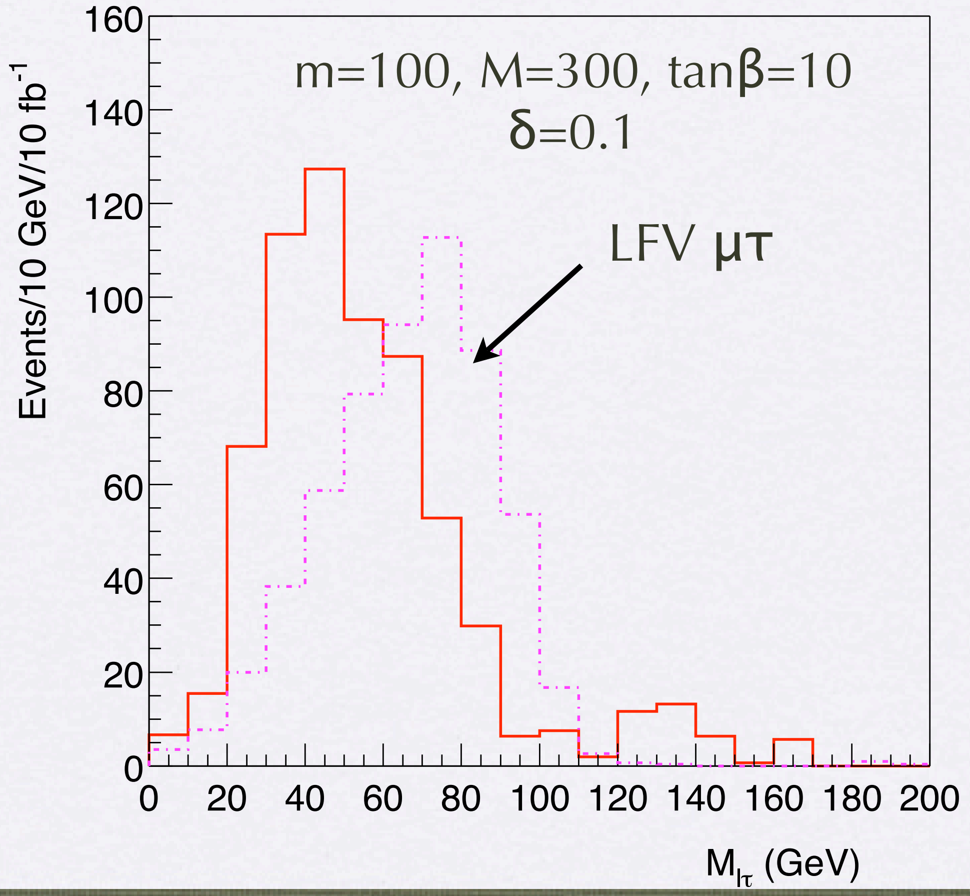
PRD65:116002
Hisano et al



- LFV in 2 body decay

- signal:
  edge in eμ distribution
  shoulder in eτ, $\tau\mu$ distribution

Hinchiliffe (2000)

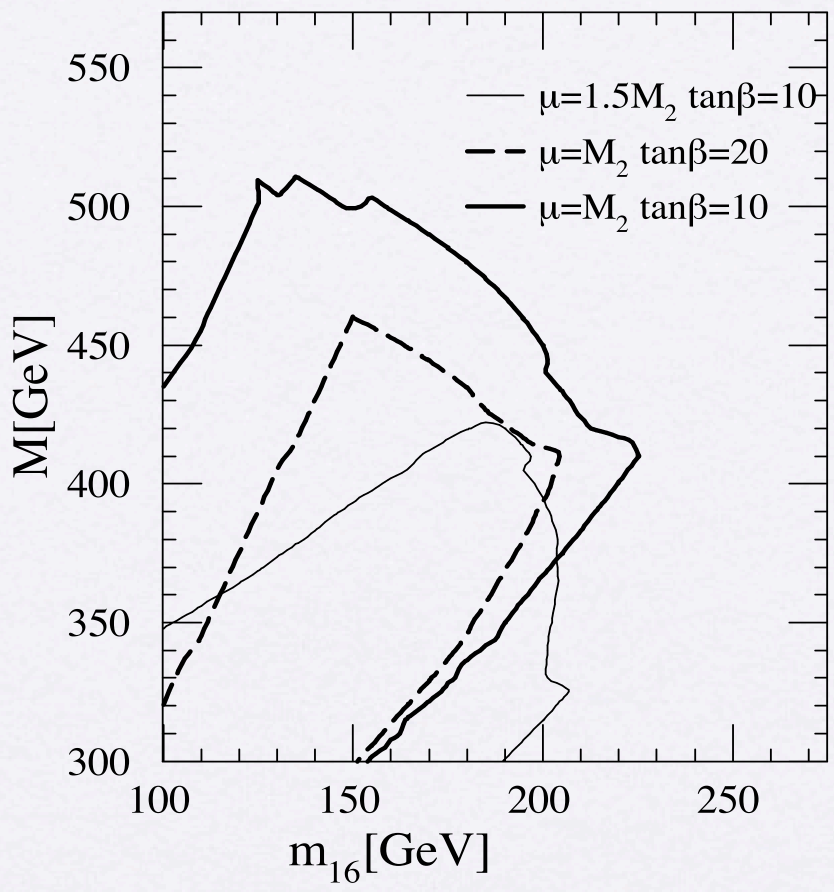


- Loop process:
  GIM like suppression and
  cancellation among diagrams.

$$BR(\tau \to \mu\gamma) \approx 1.1 \times 10^{-6} \left(\frac{\delta}{1.4}\right)^2 \left(\frac{100\,\mathrm{GeV}}{M_{\tilde{\ell}}}\right)^4$$

$$\delta \equiv M^2_{\mu\tau}/M^2_L$$

L= 100fb^{-1}, Δm=1.2GeV, sin2θ=0.5



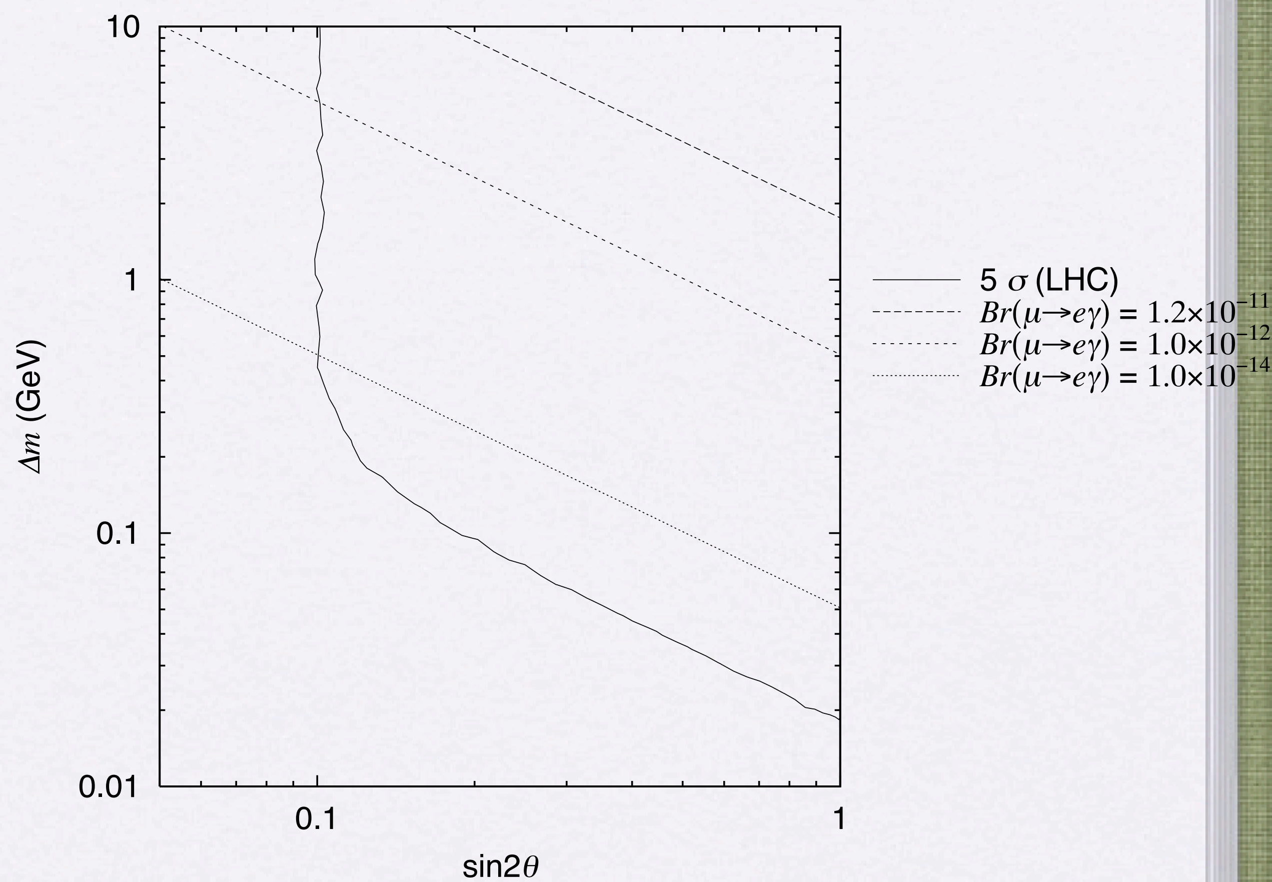
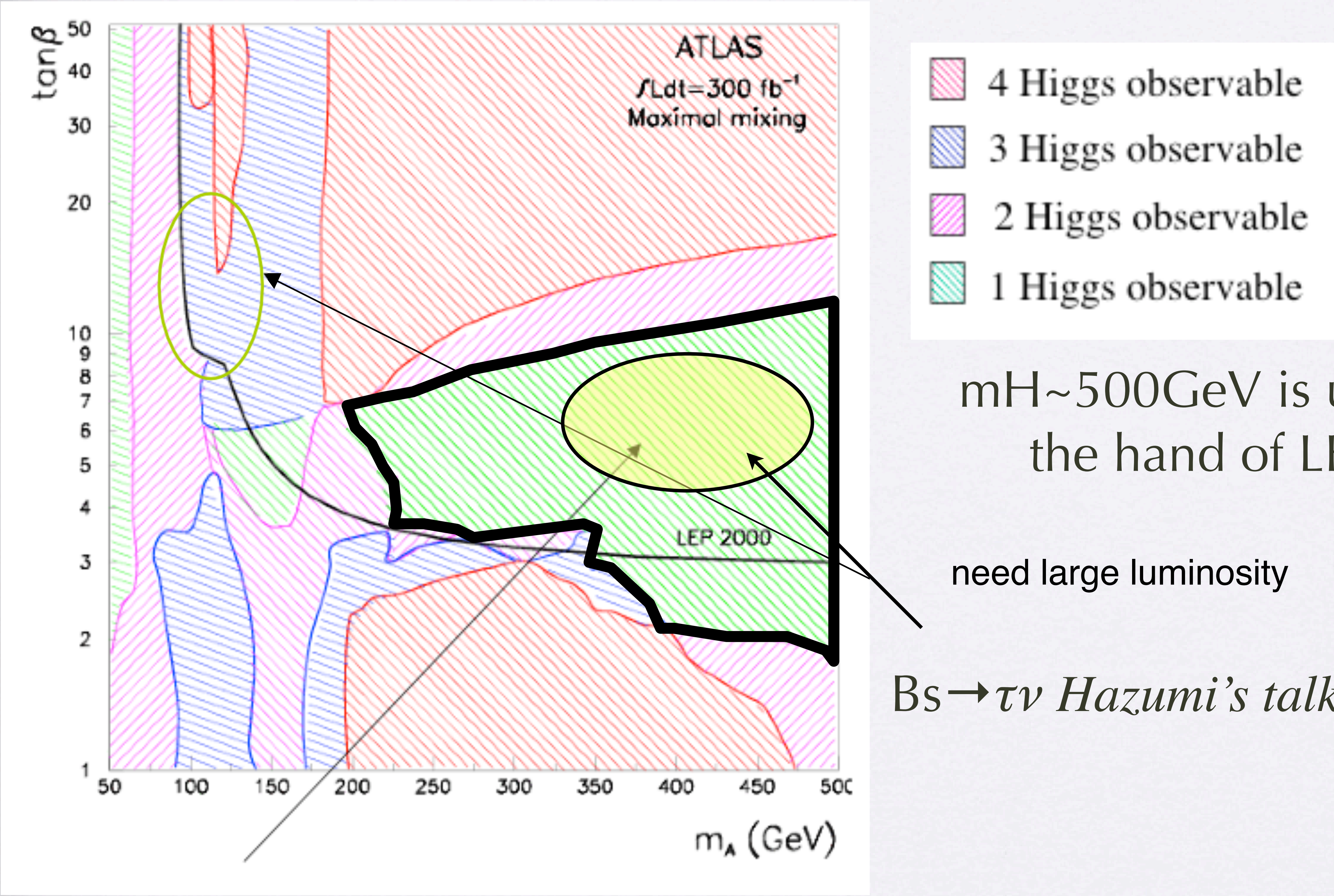


Figure 7: $\sqrt{\Delta\chi^2} = 5$ contours for the LFV discovery. The thick solid line is for $\mu = 1.5M_2$ and $\tan\beta = 10$ in the cMSSM, the thick dashed line for $\mu = M_2$ and $\tan\beta = 20$, and the solid line for $\mu = M_2$ and $\tan\beta = 10$. We fix the $\tilde{e}_R$-$\tilde{\mu}_R$ mixing angle θ as $\sin 2\theta = 0.5$ and the slepton mass difference $\Delta m = 1.2$ GeV at the GUT scale.

μ=M$_2$

LHC and MSSM Higgs

in connection with B physics



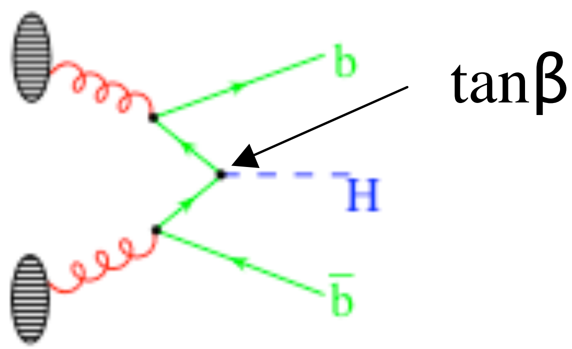
mH~500GeV is under the hand of LHC

need large luminosity

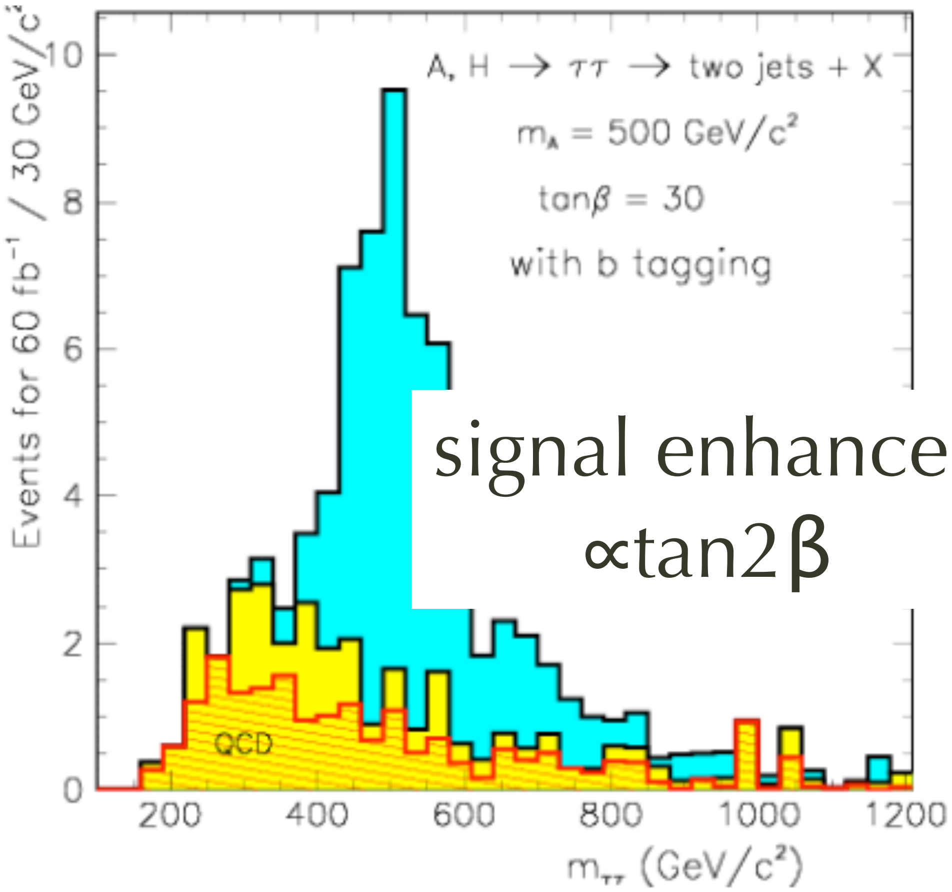
Bs→*τν Hazumi's talk*

Only one higgs doublet

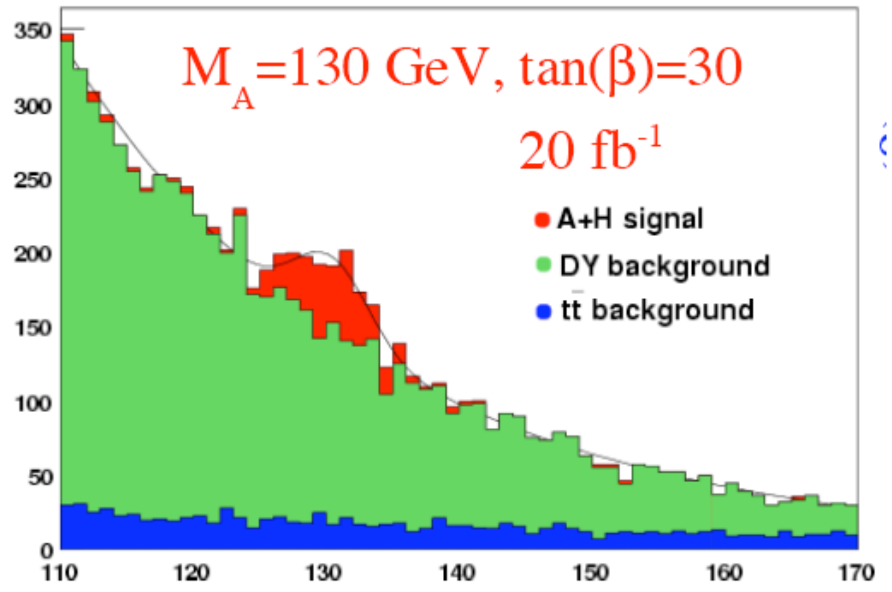
H/A production



gg→bbH/A→ τ τ 、μ μ 、(bb)



signal enhances
$\propto \tan 2\beta$

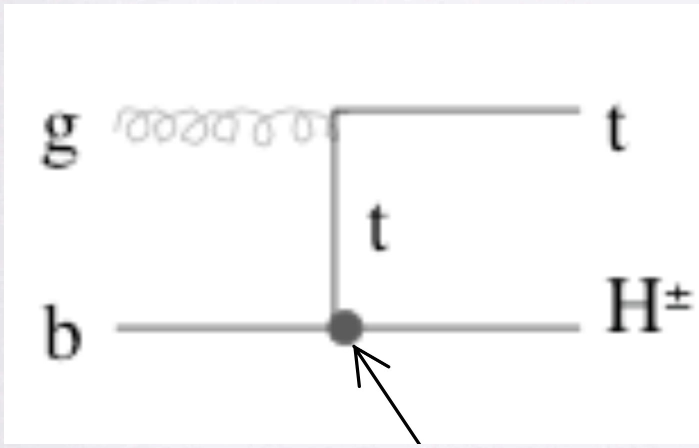


← decay into μμ may be seen as well

$m_A \sim m_H \sim m_{H+}$

Here we are assuming all SUSY particles are heavy.
Any loopholes or more information?

charged higgs searches at LHC



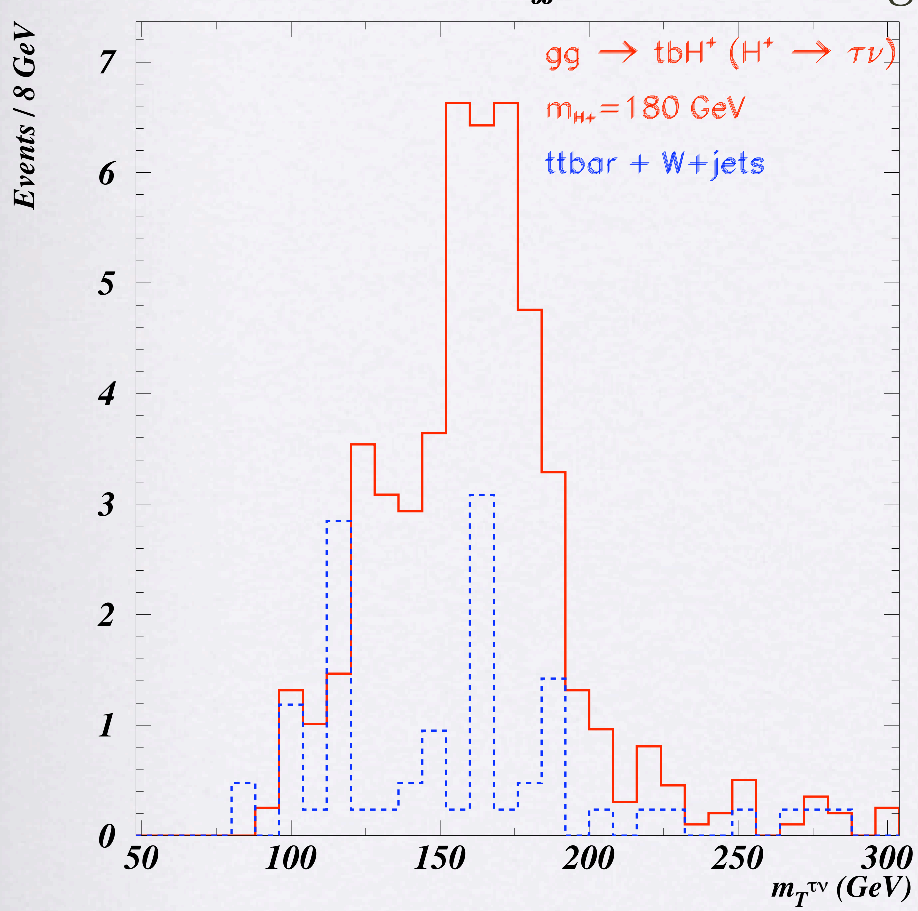
mass can be reconstructed
(with transverse missing momentum)

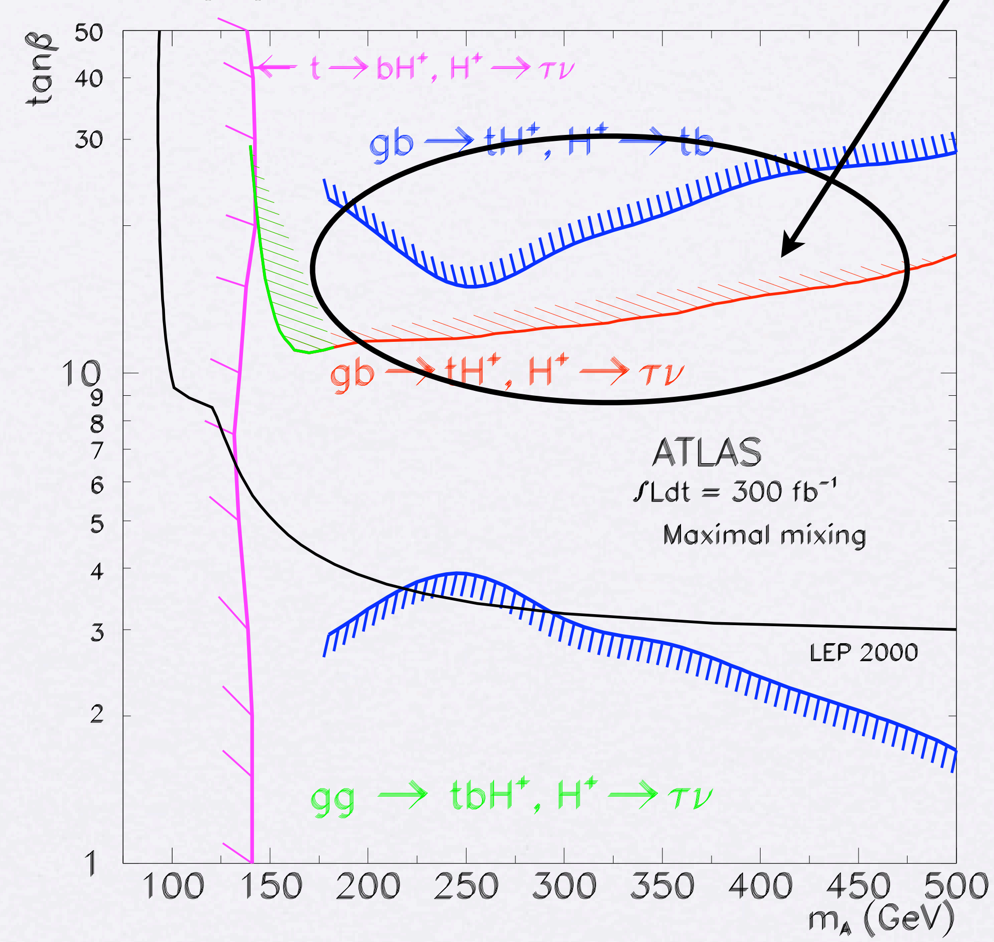
$$L = \frac{g}{\sqrt{2}m_W} H^+ (\bar{t}\,(m_t \cot\beta P_L + m_d \tan\beta P_R)d + m_\tau \tan\beta \bar{\nu}\tau_R) + hc$$

Assamagan et al hep-ph/0402057

Br?

$H^+tb \to \tau\nu jjbb$





connection to B physics

- Example $b \to s\,\gamma$, large cancellation among diagrams
- You will have an access of the charged higgs mass, branching ratio.
- What can you say about chargino loop contribution? Stop mass and mixings (2-3)

✓ What is the info on stop from LHC??

3rd generation squark mass matrix

- MSSM parameters $m_{L_3}, m_{\tilde{t}_R}, m_{\tilde{b}_R}, A_b, A_t$

$$\begin{pmatrix} m^2_{\tilde{b}_L} & -m_b(A_b + \mu \tan\beta) \\ -m_b(A_b + \mu \tan\beta) & m^2_{\tilde{b}_R} \end{pmatrix}$$

$$m_{\tilde{t}_1}, m_{\tilde{t}_2}, \theta_t, m_{\tilde{b}_1}, m_{\tilde{b}_2}, \theta_b$$

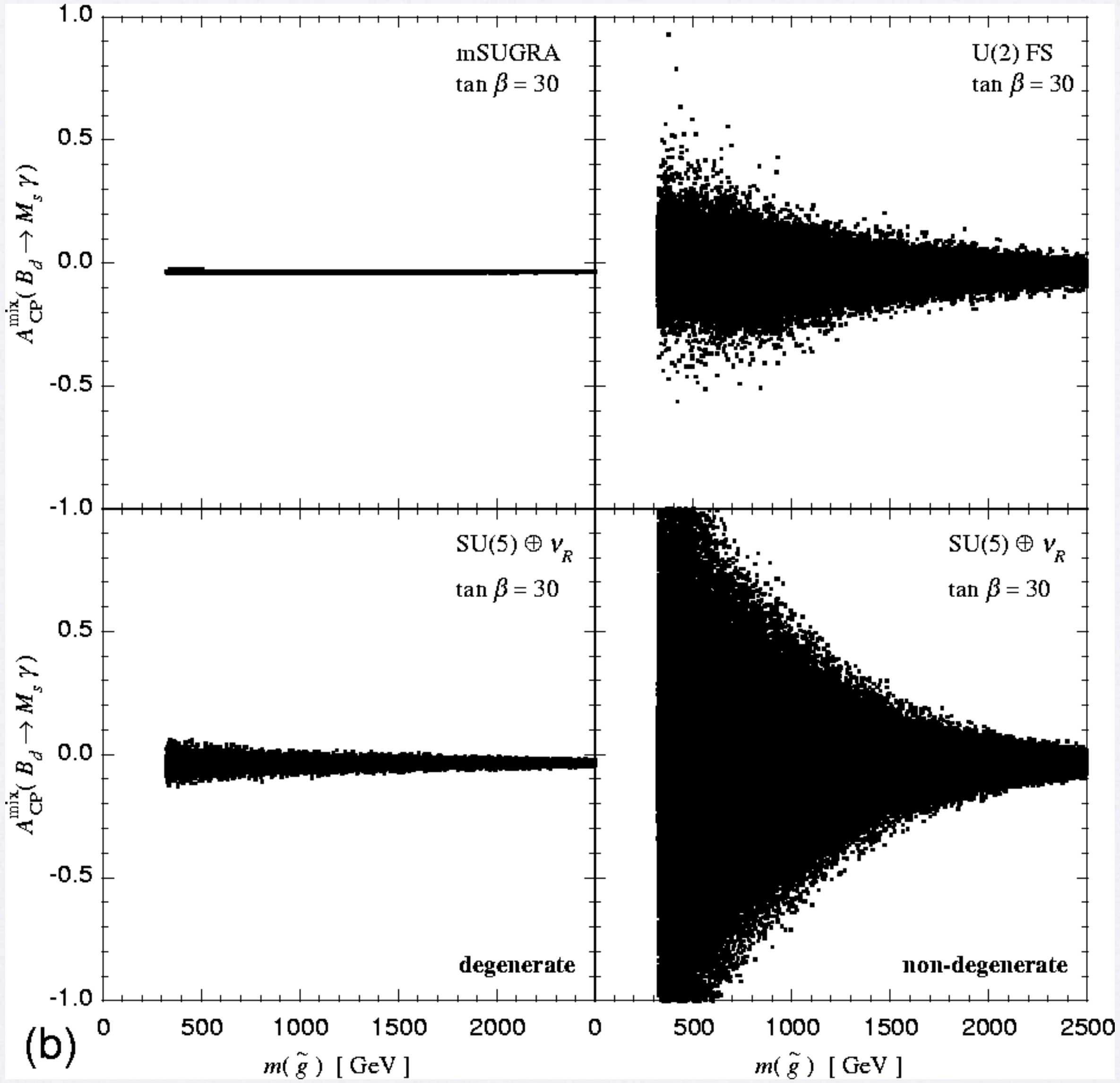
$$\begin{pmatrix} m^2_{\tilde{t}_L} & -m_t(A_t + \mu \cot\beta) \\ -m_t(A_t + \mu \tan\beta) & m^2_{\tilde{t}_R} \end{pmatrix}$$

In MSUGRA: The 1st and 2nd squark mass are heavier than 3rd due to RGE running and mixings.
SUSY events contain many b jets. b tagging efficiency is 60%

Production : direct production from gluon(small)
decay from gluino (dominant if open)

non-MSUGRA boundary condition in 3rd generation in B physics

- You may find surprise in B flavor violation process— this may comes from....
  - GUT scale neutrino mass assuming Y_t-$Y_{\nu\tau}$
  - Non universal boundary condition
- stop and sbottom mass may also depends on such thing

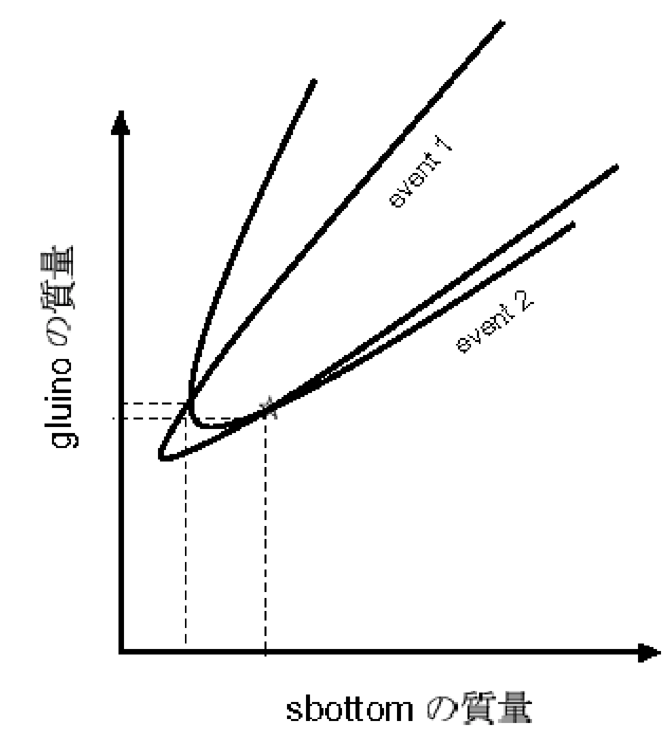


Goto et al PRD70:035012(2004)

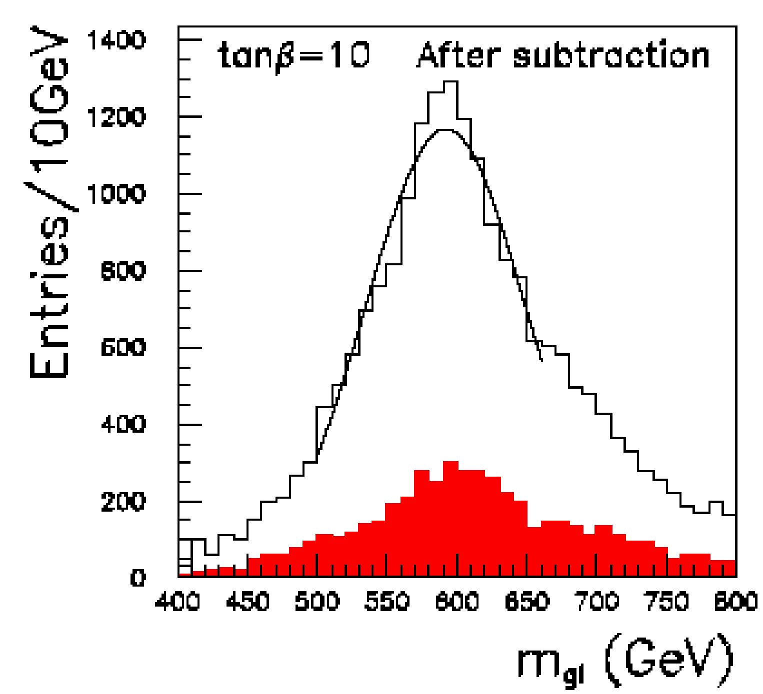
Exact treatment
for gluino and sbottom reconstruction

Longest cascade decays that can be "solved" event by event even though LSP is missing

$$
\begin{aligned}
m^2_{\tilde{\chi}} &= p^2_{\chi} \\
m^2_{\tilde{l}} &= (p_{\chi} + p_{l_1})^2 \\
m^2_{\tilde{\chi}_2} &= (p_{\chi} + p_{l_1} + p_{l_2})^2 \\
m^2_{\tilde{b}_1} &= (p_{\chi} + p_{l_1} + p_{l_2} + p_{j_1})^2 \\
m^2_{\tilde{g}} &= (p_{\chi} + p_{l_1} + p_{l_2} + p_{j_1} + p_{j_2})^2
\end{aligned}
$$



Kawagoe et al, PRD71:035008, 2005



- Assume we know lighter masses
- 3 mass constraints for p(LSP) -> one degree of freedom in 2dim gluino and squark mass space
- 2 events-> mass fixed
- After mass fix, the missing momentum is solved

sbottom mass reconstruction

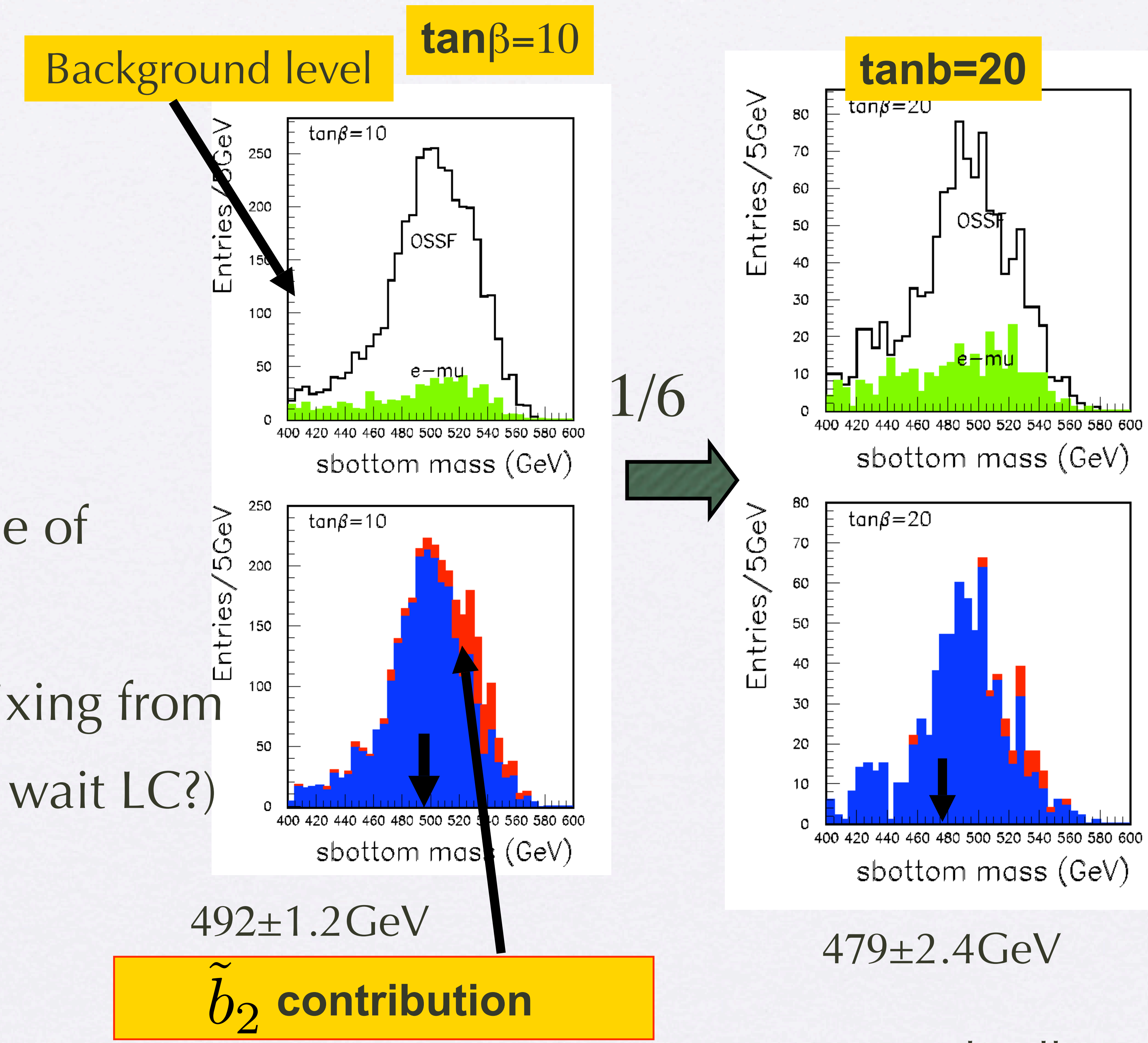
(two b jets and two lepton channel)

LHC may address

a) tanβ dependence of sbottom mass

b) size of the LR mixing from Br into $\tilde{\chi}_2^0$ (need to wait LC?)

c) existence of $\tilde{b}_2$?



Kawagoe, MMN, Polesello 04

Flavor violation in sbottom decays at LHC?

- ϵ_b=60%, not impressive
- take high p_T jet which comes from LFV sbottom decay+ b jet from gluino→b sb_1 might work(using "mass relation" as cut).
- for O(1000) bbll decay, 360 must be tagged. for full flavor violation it is only 90 events.

	No flavor violation ϵ_b=0.6	full violation ϵ_b=1	full violation ϵ_b=0.6
bbll	0.6x0.6=0.36	0.25	0.09
jbll	0.6x0.4=0.24	0.25	0.21
bjll	0.6x0.4=0.24	0.25	0.21
jjll	0.4x0.4=0.16	0.25	0.49

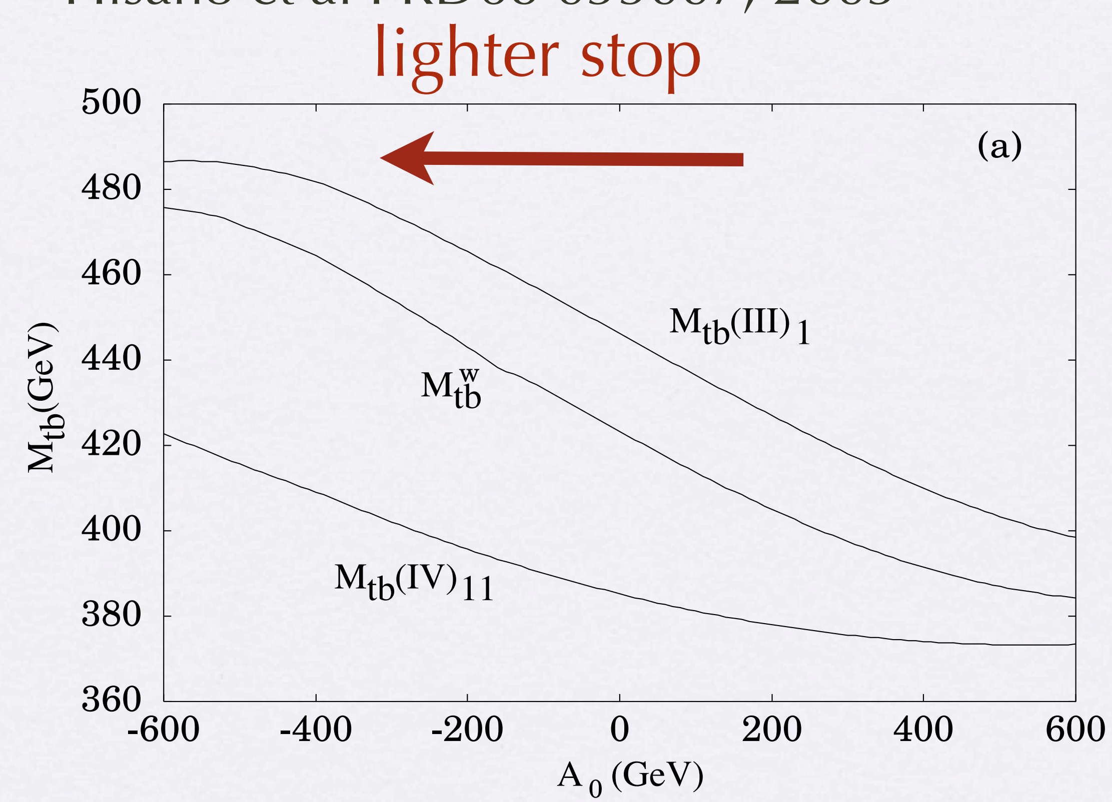
scalar top at LHC

$$\tilde{g} \to \tilde{t}t \to bt\tilde{\chi}^{\pm} \Rightarrow \quad Br(\tilde{t}) \quad M_{tb}(\tilde{t})$$
$$\tilde{g} \to \tilde{b}b \to bt\tilde{\chi}^{\pm} \Rightarrow \quad Br(\tilde{b}) \quad M_{tb}(\tilde{b})$$

- two subsequent cascade decays give tb end point. It is not dominated by single process.
- hadronic top decay can be reconstructed .
- The tb end point give you information of stop mass.

$$M_{tb}^{w} = \frac{Br(\tilde{t})M_{tb}(\tilde{t}) + Br(\tilde{b})M_{tb}(\tilde{b})}{Br(\tilde{t}) + Br(\tilde{b})}$$

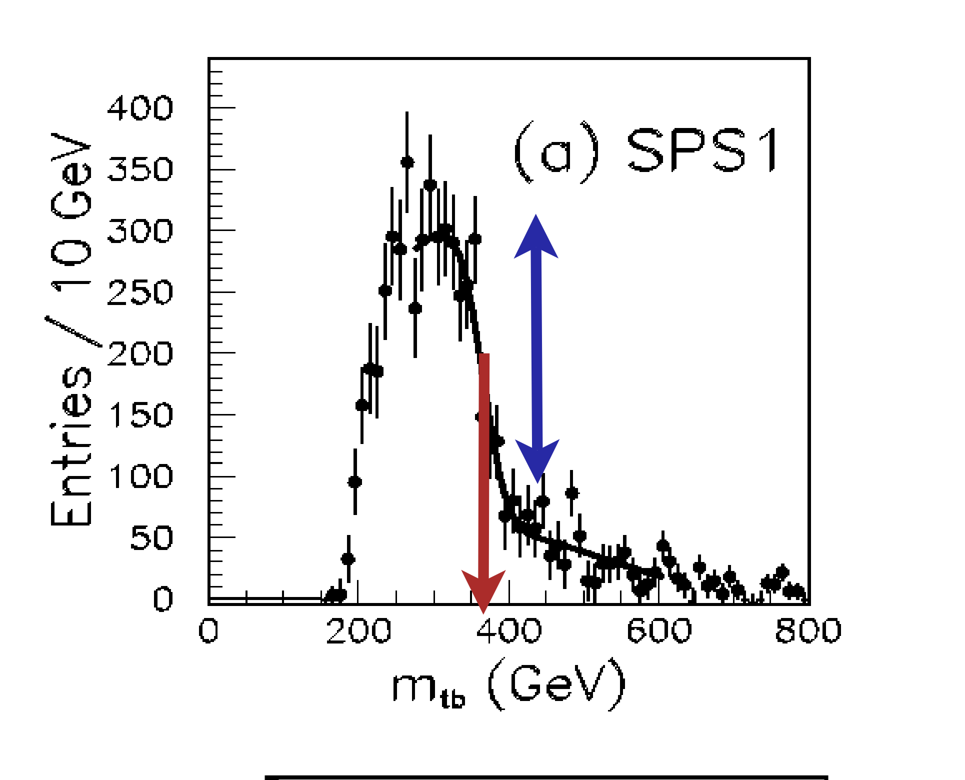
Hisano et al PRD68 035007, 2003



Difference between two body and three body

Biggest branching ratio

$$\tilde{g} \rightarrow (t\tilde{t} \text{ or } b\tilde{b}) \rightarrow tb\tilde{\chi}_1^{\pm}$$



SPS1a: edge with ΔM_{tb} ~4GeV for 100fb^{-1}

height h and edge M_{tb} may be used

to understand stop sector

SPS2 :(focus points M=300GeV)

No edge as expected

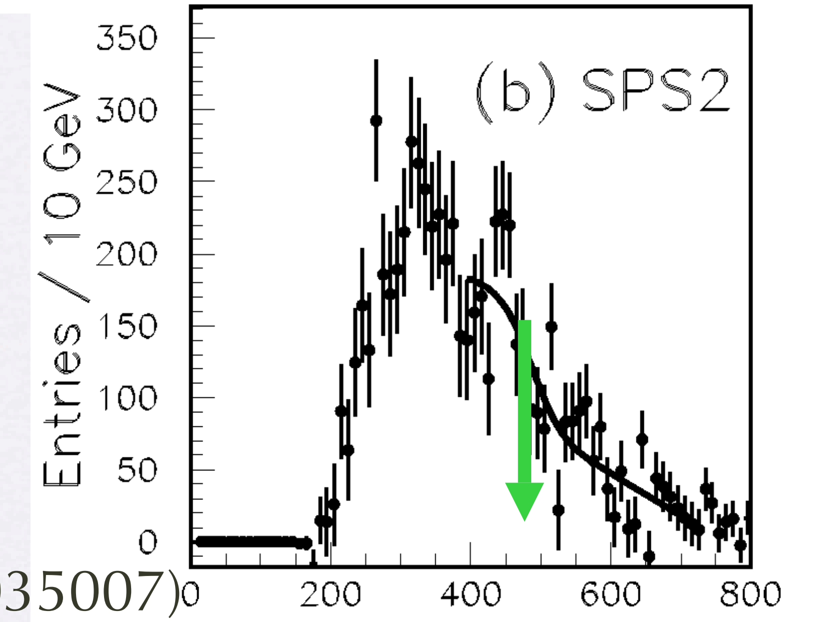
Lower bound of stop and sbottom mass?

Limited statistics but distribution may reflect

$$m_{\tilde{g}} - m_{\tilde{\chi}_2^+} \sim 480\text{GeV}$$

$$m_{\tilde{g}} - m_{\tilde{\chi}_1^+} \sim 560\text{GeV}$$

(Hisano et al PRD68.035007)

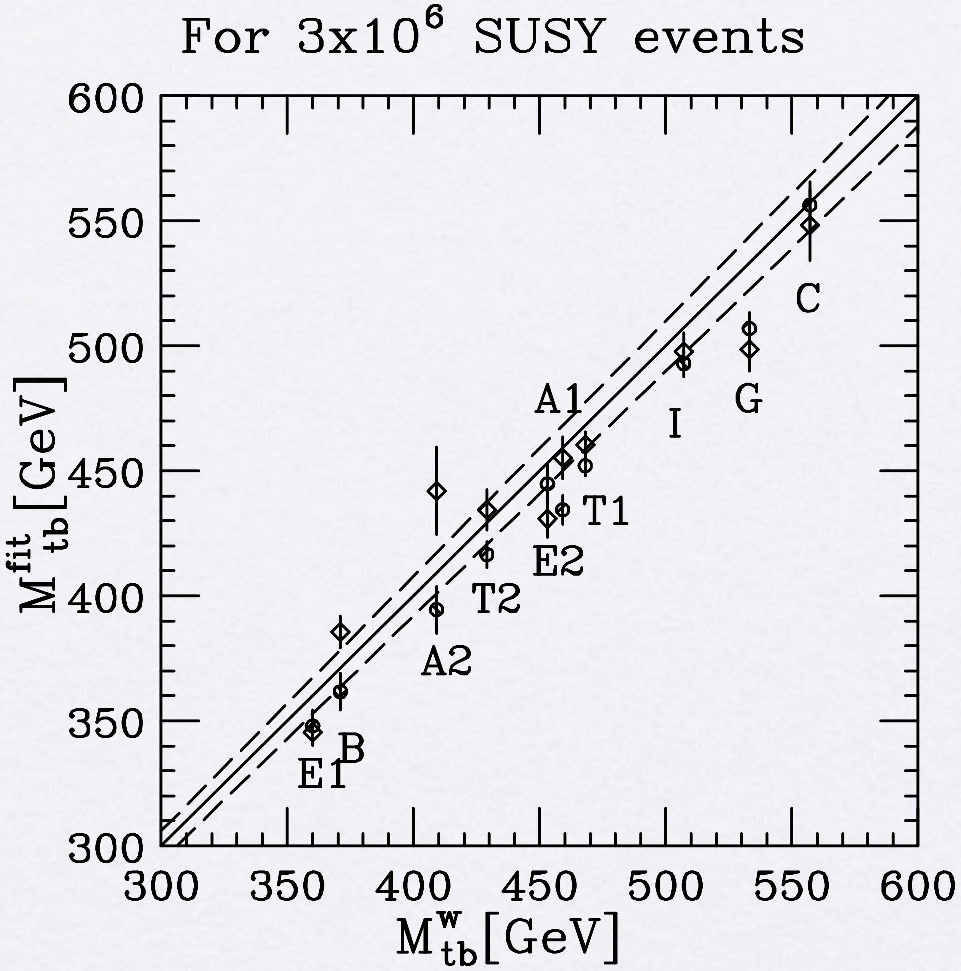


1000 fb^{-1} but cut must be optimized

Endpoint reconstruction

What will we see if we put this constrain to B rare decays?

- weighted end point is reconstructed correctly by the fit over wide region of parameter space.



- A1 A2: a msugra point but A changed maximally (m=100GeV, M=300GeV tanβ=10

- T1 T2 stop mass moved by changed stop_R mass

- B, C, I, G from paper hep-ph/0106203

- E1 E2, gluino decays only to stop and top.

From Planck scale to weak scale

Planck scale soft mass — Light at source

Interactions from GUT scale to weak scale — gas in between (line spectrum)

Soft term at weak scale knows everything between GUT to weak

Try together!