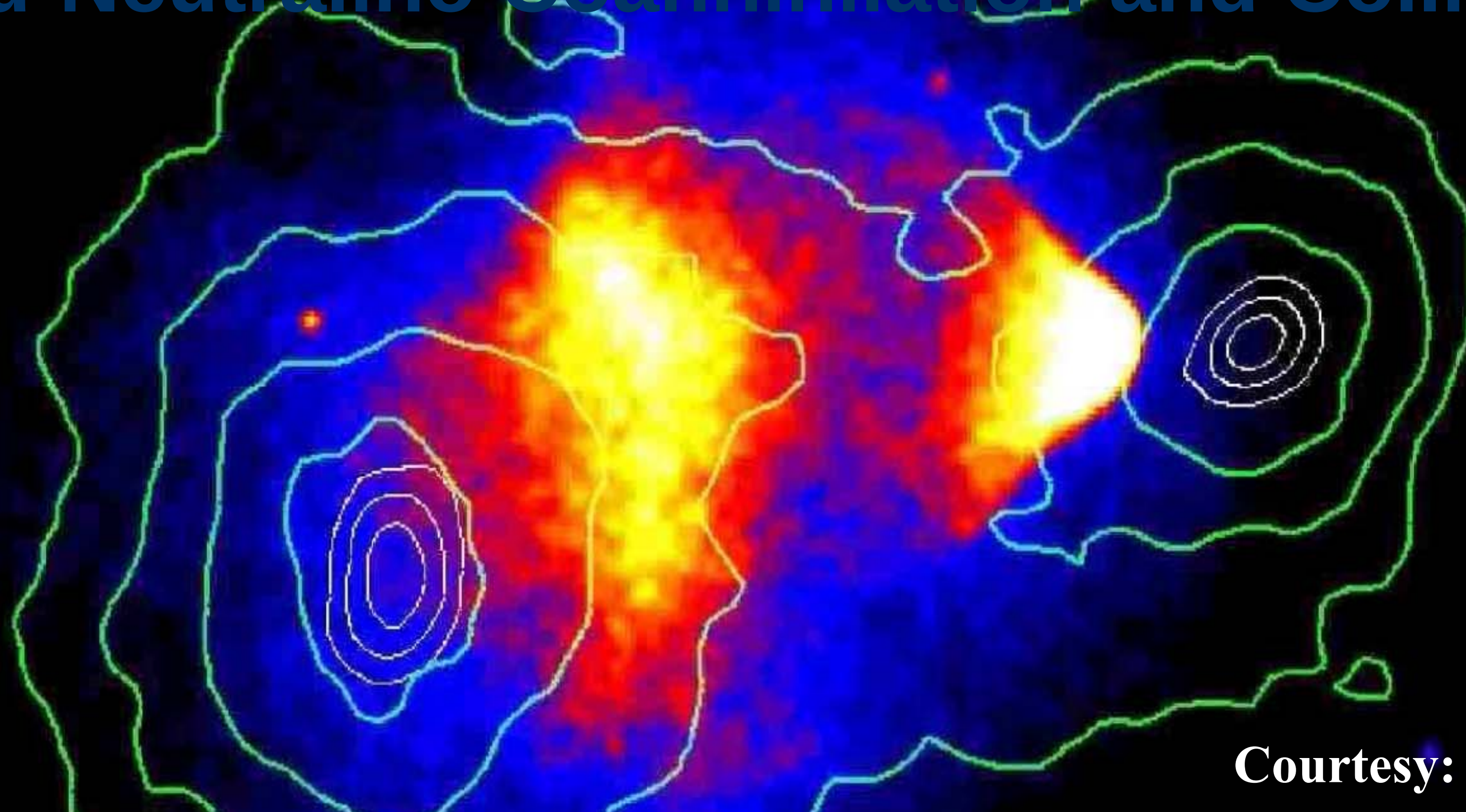
Stau-Neutralino Coannihilation and Collider



Courtesy: NASA

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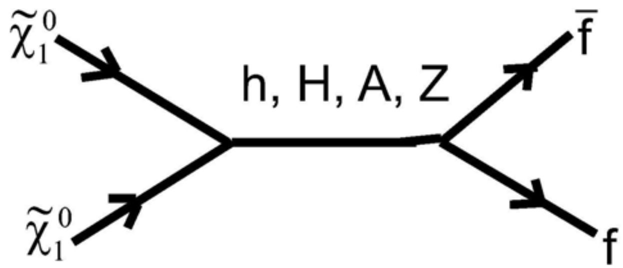
OUTLINE

- **Cosmology, SUSY, WIMP**
- **Stau neutralino coannihilation in minimal supergravity (mSUGRA) model**
- **Prospects of detection at the LHC and determination of masses**
- **Determination of $\Omega_{\tilde{\chi}_1^0} h^2$**
- **Conclusion**

Phys. Lett. B618, 182 (2005); B639, 46 (2006); hep-ph/0608193

CDM = Neutralino ; NLSP = stau

$$\left(\Omega_{\rm CDM}\right)^{-1} \propto \Bigg[$$



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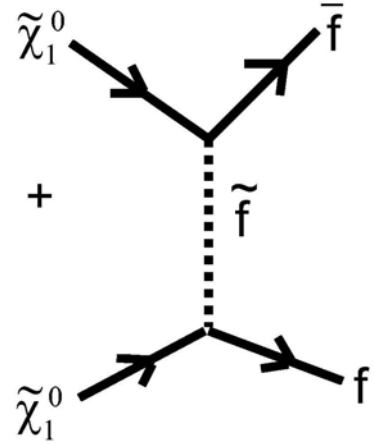
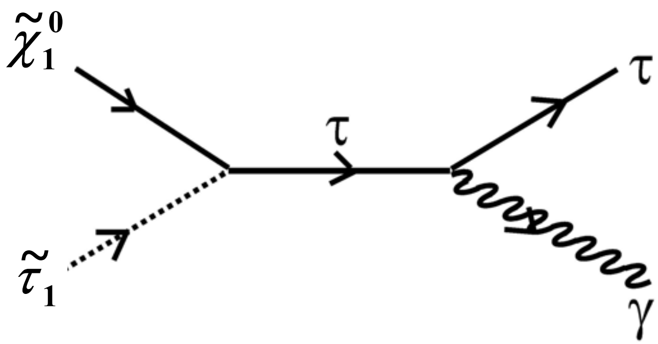


$$\Bigg]^2$$

$$+ \Bigg[$$



$$\Bigg]^2$$

$$e^{-\Delta M / 20}$$

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

Griest, Seckel '91

Can the mSUGRA naturally provide small ΔM?

Minimal Supergravity (mSUGRA)

4 parameters + 1 sign

$m_{1/2}$	Common gaugino mass at M_G
m_0	Common scalar mass at M_G
A_0	Trilinear coupling at M_G
$\tan\beta$	$\langle H_u \rangle / \langle H_d \rangle$ at the electroweak scale
sign(μ)	Sign of Higgs mixing parameter ($W^{(2)} = \mu H_u H_d$)

Experimental Constraints

i. $M_{\mathrm{Higgs}} > 114$ GeV $\quad M_{\mathrm{chargino}} > 104$ GeV

ii. $2.2 \times 10^{-4} < Br\,(b \to s\,\gamma) < 4.5 \times 10^{-4}$

iii. $0.094 < \Omega_{\tilde{\chi}_1^0} h^2 < 0.129$

iv. $(g-2)_\mu$

Stau Neutralino Coannihilation and GUT Scale

In mSUGRA model the lightest stau seems to be naturally close to the lightest neutralino mass especially for large tanβ

For example, the lightest selectron mass is related to the lightest neutralino mass in terms of GUT scale parameters:

$$m^2_{\tilde{E}^c} = m_0^2 + 0.15 m_{1/2}^2 + (37\ \text{GeV})^2 \qquad m^2_{\tilde{\chi}_1^0} = 0.16 m_{1/2}^2$$

Thus for $m_0 = 0$, $m^2_{\tilde{E}^2}$ becomes degenerate with $m^2_{\tilde{\chi}_1^0}$ at $m_{1/2} = 370$ GeV, i.e. the coannihilation region begins at

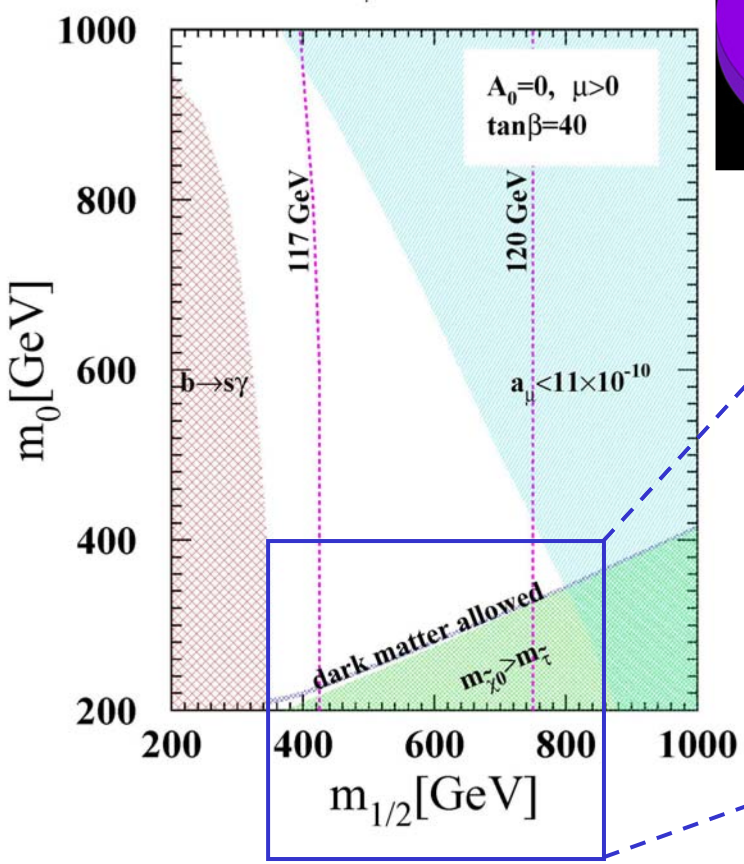
$m_{1/2} = (370\text{-}400)$ GeV

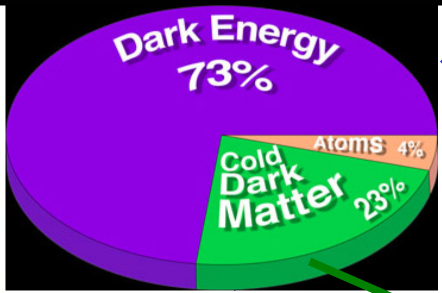
For larger $m_{1/2}$ the degeneracy is maintained by increasing m_0 and we get a corridor in the m_0 - $m_{1/2}$ plane.

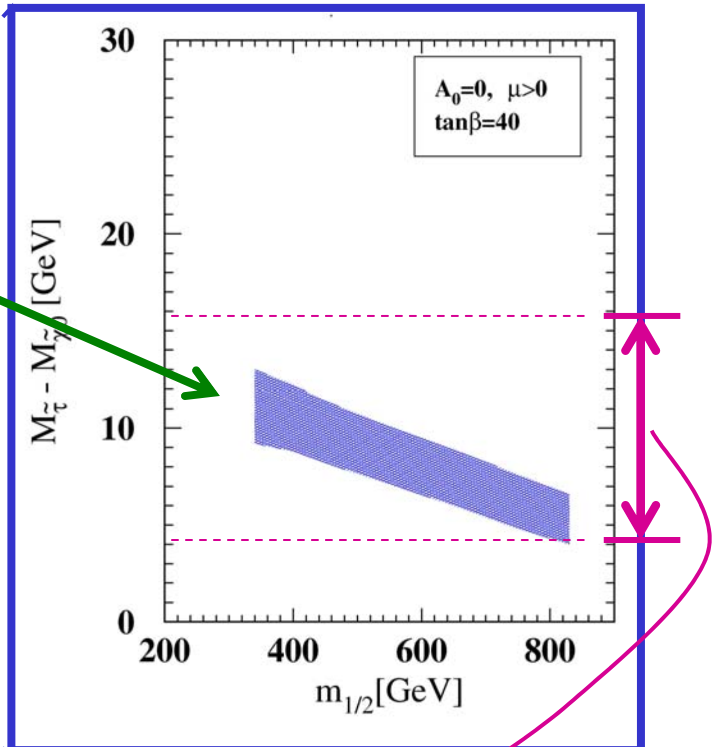
The coannihilation channel occurs in most SUGRA models with non-universal soft breaking,

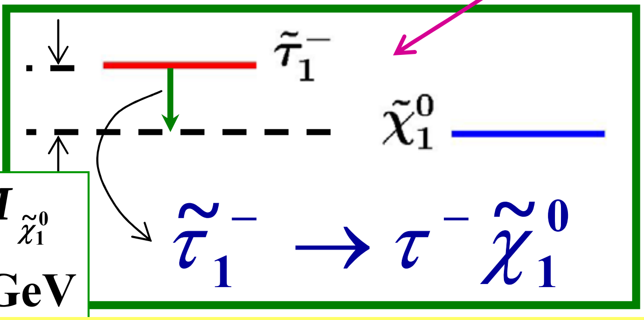
Cosmologically Allowed Region

$\tan\beta = 40,\ \mu > 0,\ A_0 = 0$







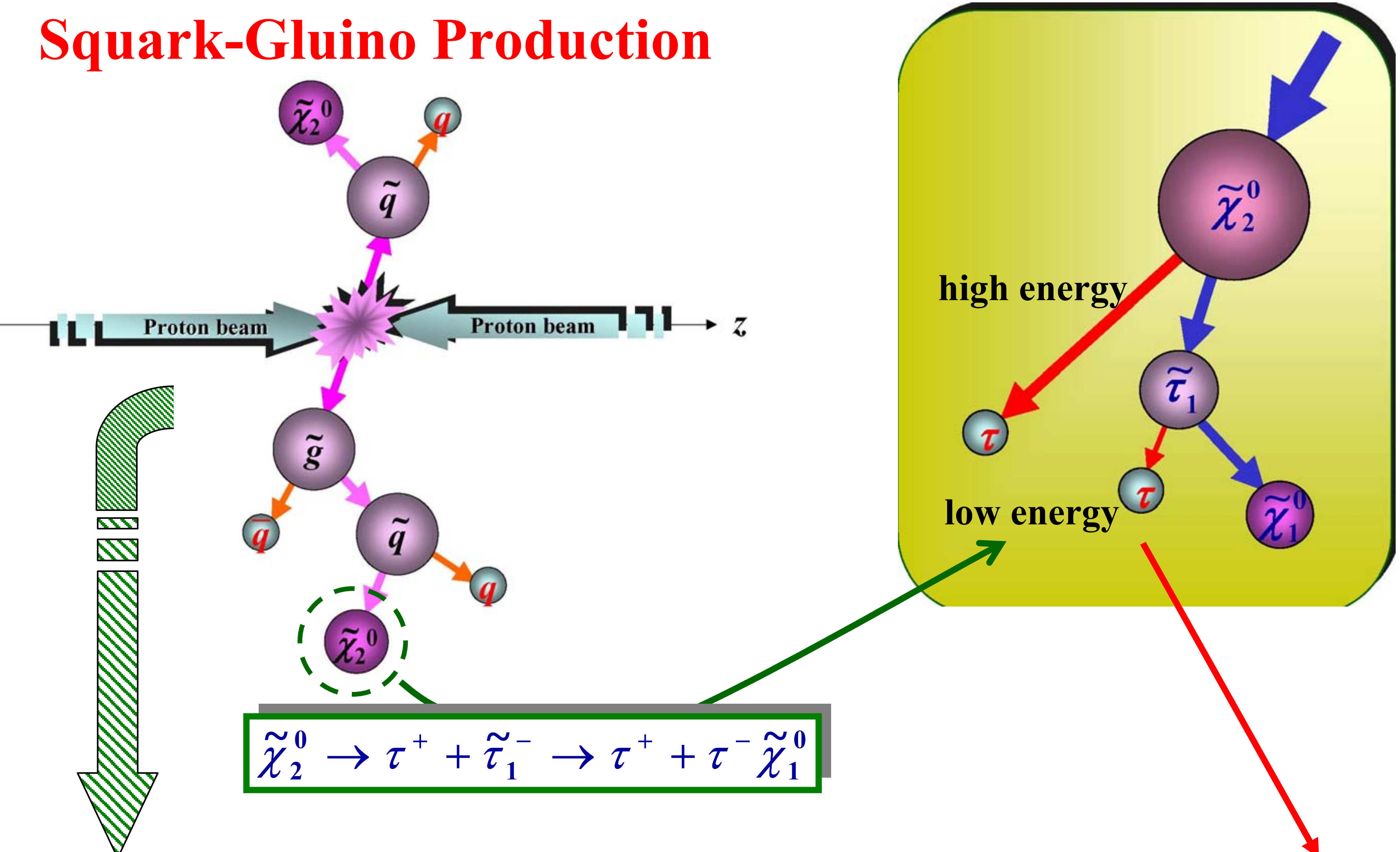


$$\Delta M \equiv M_{\tilde\tau_1} - M_{\tilde\chi_1^0}$$
$$= 5 \sim 15\ \text{GeV}$$

Can we measure ΔM at colliders?

SUSY Signature at the LHC

Squark-Gluino Production



$$\tilde{\chi}_2^0 \rightarrow \tau^+ + \tilde{\tau}_1^- \rightarrow \tau^+ + \tau^- \tilde{\chi}_1^0$$

Triggering the jets and missing E_T → E_T^{miss} + jets + τ's

$M_{\tau\tau}^{vis}$ in ISAJET

Version 7.69 ($m_{1/2}$ = 347.88, m_0 = 201.06) → M_{gluino} = 831

Chose di-τ pairs from neutralino decays with

(a) |η| < 2.5

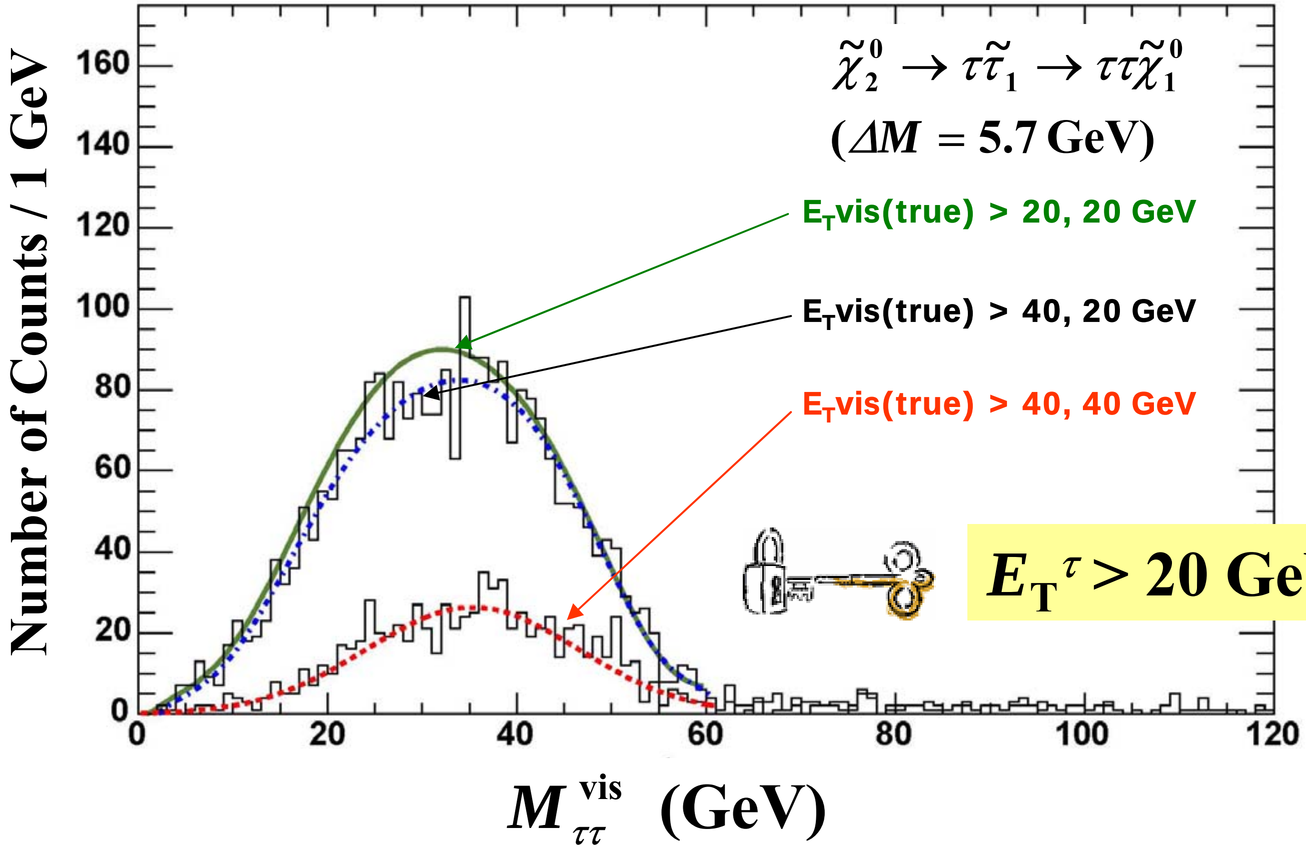
(b) τ = hadronically-decaying tau

$\tilde{\chi}_2^0 = 264.116$

$\tilde{\chi}_1^0 = 137.441$

$\tilde{\tau}_1 = 143.141$

$endpont = 62.01$



E_T^{τ} > 20 GeV is essential!

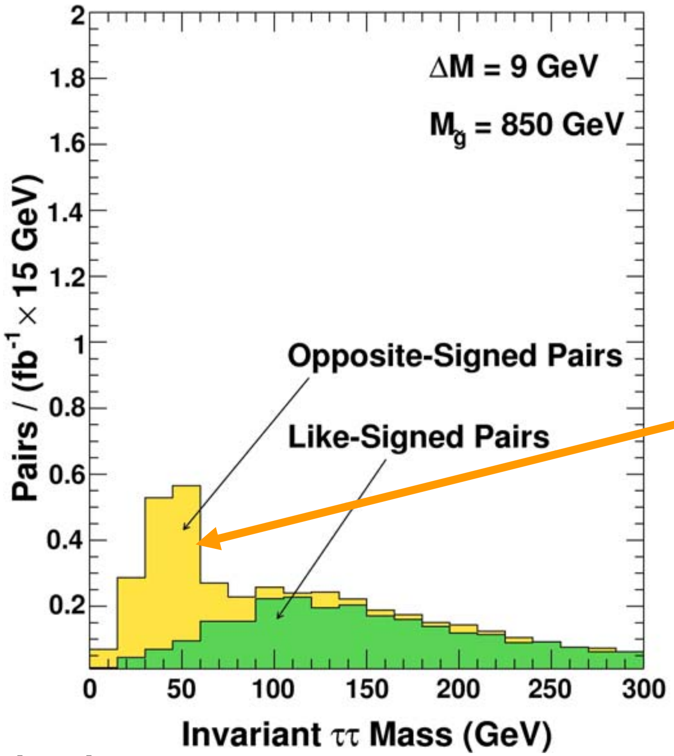
E_T^{miss} + 1j + 3τ Analysis : $M_{\tau\tau}$

Much smaller SM background, but a lower acceptance

[1] ISAJET + PGS sample of E_T^{miss}, 1 jet and at least 3 taus with E_T^{vis} > 40, 40, 20 GeV and ε_τ = 50%, fake ($f_{j\rightarrow\tau}$) = 1%. Final cuts :

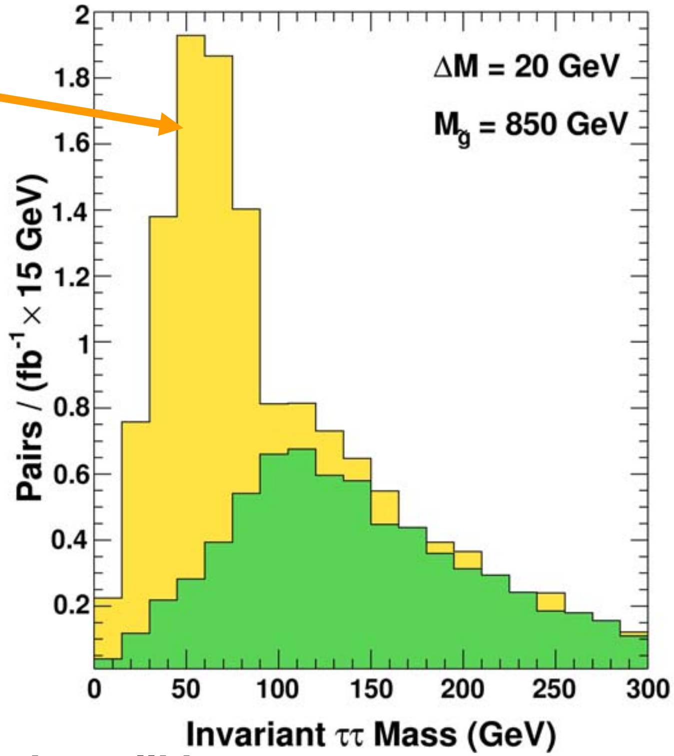
E_T^{jet1} > 100 GeV, E_T^{miss} > 100 GeV, E_T^{jet1} + E_T^{miss} > 400 GeV

[2] Select OS low di-tau mass pairs, subtract off LS pairs



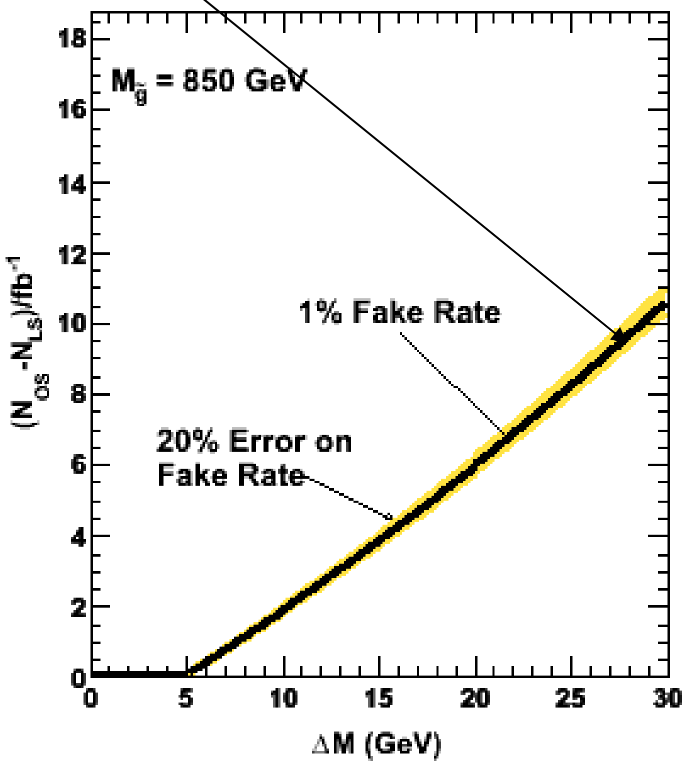
Large ΔM:
- **Many events**
- **Large mass**

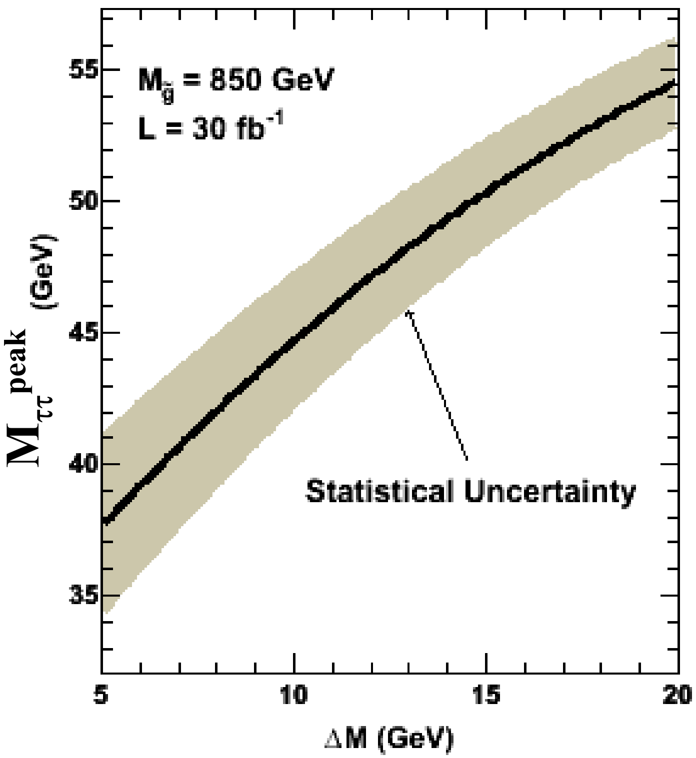
Small ΔM:
- **Few events**
- **Small mass**



E_T^{miss} + 1j + 3τ Analysis

Small dependence on the uncertainty of $f_{j\rightarrow\tau}$

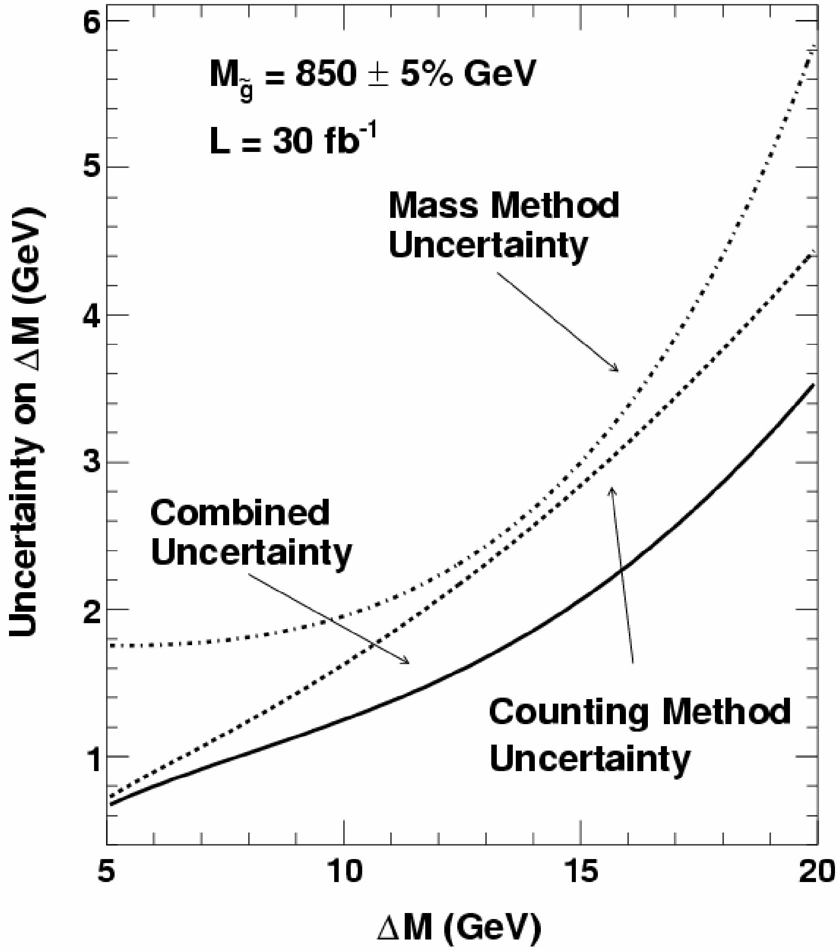




Note: $f_{j\rightarrow\tau}$ = 0% → 1.6 counts/fb^{-1} for ΔM=10 GeV

3τ Analysis: Combined Results

- Use N_{OS-LS} and $M_{\tau\tau}$ to <u>independently</u> measure ΔM
- Both produce high quality measurements
- We assume a gluino mass
- Dominant uncertainty
  - 5% uncertainty on M_{gluino}



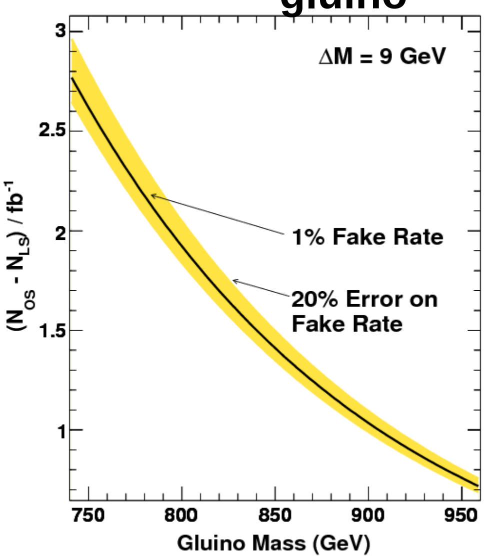
- Combined results:

$$\Delta M = 10 \pm 1.3 \text{ GeV } (30 \text{ fb}^{-1})$$

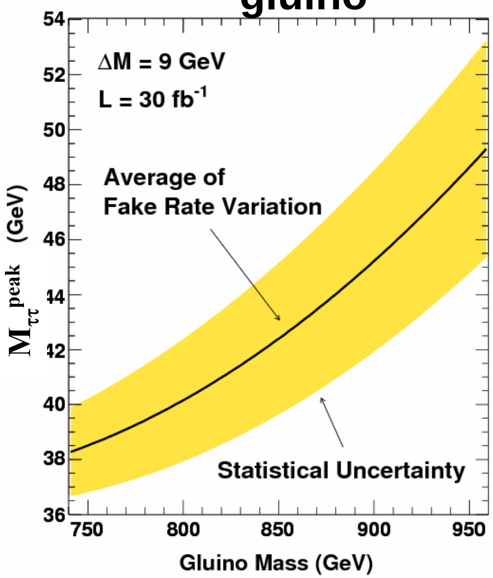
3τ Analysis (cont'd)

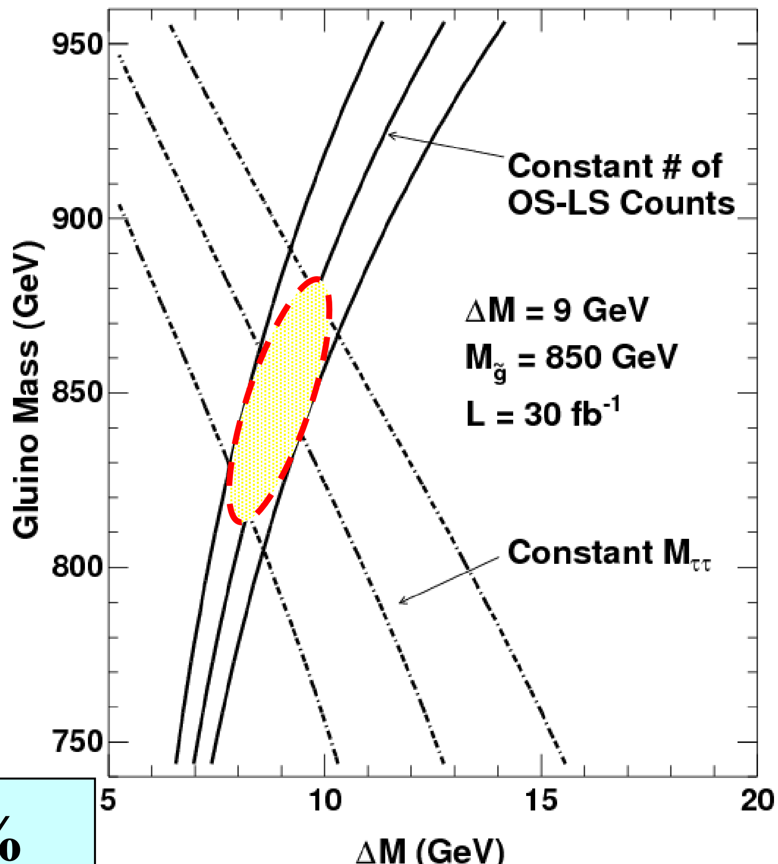
➢ Next: combine $N_{OS\text{-}LS}$ and $M_{\tau\tau}$ values to measure ΔM and M_{gluino} <u>simultaneously</u>

Counts drop with M_{gluino}



Mass rises with M_{gluino}

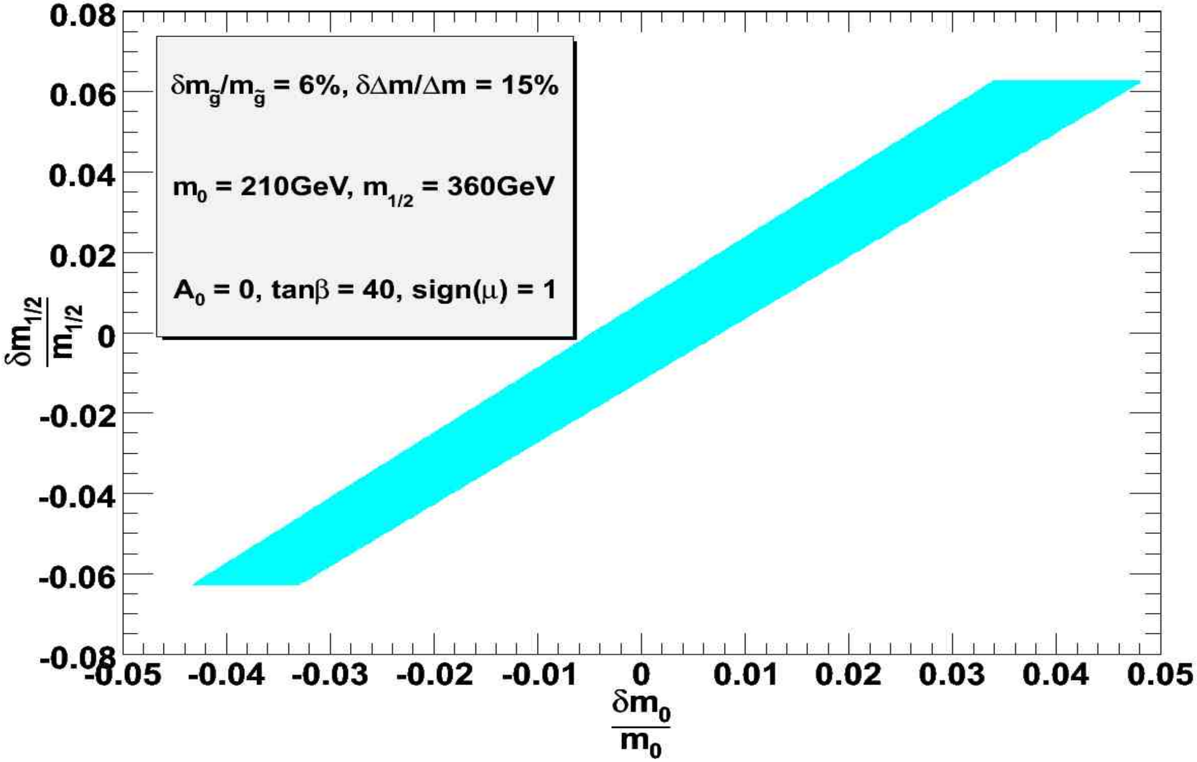




$\delta\Delta M/\Delta M$ ~15% and $\delta M_{gluino}/M_{gluino}$ ~6%

Determination of m_0 and $m_{1/2}$

ΔM and M_{gluino} → m_0 and $m_{1/2}$
(for fixed A_0 and $\tan\beta$)

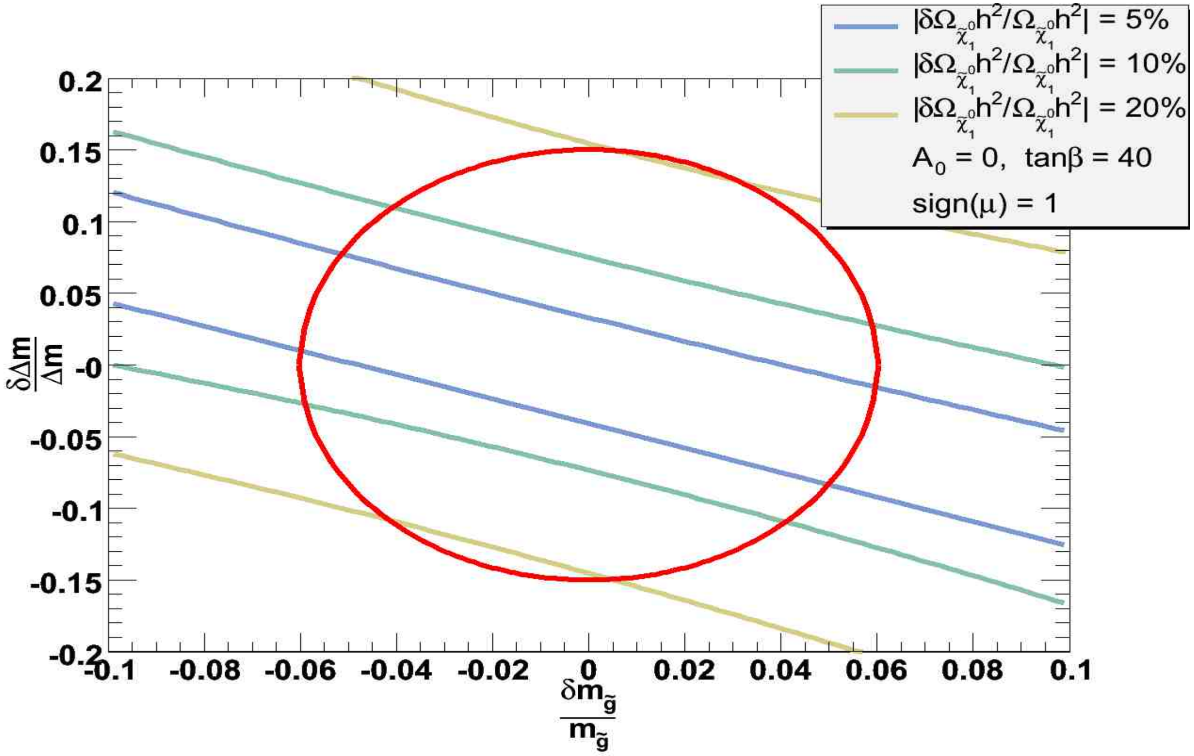


We determine $\delta m_0/m_0 \sim 5\%$ and $\delta m_{1/2}/m_{1/2} \sim 6\ \%$ with $L=30\ fb^{-1}$ (for $A_0=0$, $\tan\beta=40$)

Determination of $\Omega_{\tilde{\chi}_1^0} h^2$

ΔM and M_{gluino} → $\Omega_{\tilde{\chi}_1^0} h^2$

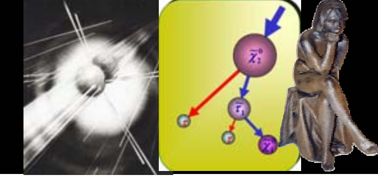
(for fixed A_0 and $\tan\beta$)



$\delta\Omega h^2/\Omega h^2 \sim 20\%$ with L=30 fb^{-1}

(for A_0=0, $\tan\beta$=40)

Conclusion

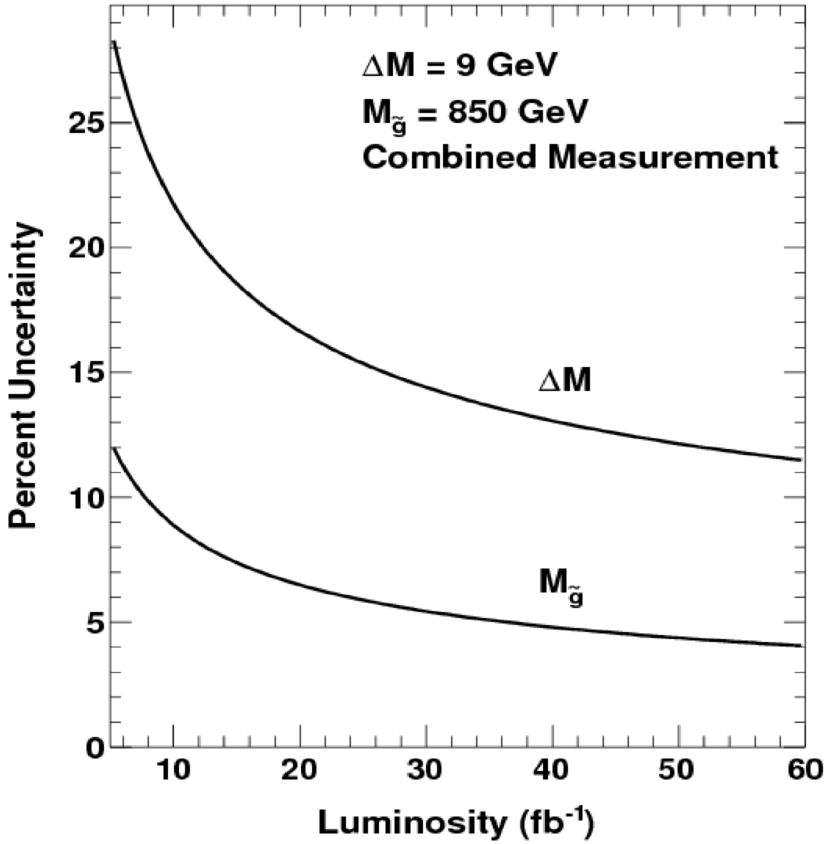


- **Signals in the stau-neutralino coannihilation region are studied using mSUGRA model as a bench mark scenario ($\Delta M \sim 10$ GeV)**
- **LHC: Two analyses with visible $E_T^{\tau} > 20$ GeV:**
  - **2τ analysis: Discovery with 10 fb^{-1}**
    - **$\delta\Delta M/\Delta M \sim 18\%$ using M_{peak} with 5% gluino mass error**
  - **3τ analysis: Combine $N_{\text{OS-LS}}$ and M_{peak} measurements**
    - **$\delta\Delta M/\Delta M \sim 15\%$ and $\delta M_{\text{gluino}}/M_{\text{gluino}} \sim 6\%$ with no gluino mass assumption**

    (It may be hard to measure the gluino mass otherwise due to the low energy taus in the signal.)
  - **The analyses can be done for the other models that don't suppress χ_2^0 production.**
- ✓ **Comparison: $\delta\Delta M/\Delta M \sim 10\%$ (500 fb^{-1}) at the ILC if we implement a very forward calorimeter to reduce two-γ background.**
- **$\delta m_0/m_0 \sim 4\%$, $\delta\Omega h^2/\Omega h^2 \sim 20\%$ for $A_0=0$, $\tan\beta=40$ with L=30 fb^{-1}**

Backups

3τ Analysis: Accuracy in ΔM & M_{gluino}



→ **22% - 15% (10 - 30 fb^{-1})**

→ **9% - 6% (10 - 30 fb^{-1})**