Signals of Supercritical String Theory at the LHC

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Outline

Supersymmetric Access to Cosmology at the LHC

- **Dark Matter Connection**
  - **Stau-Neutralino Co-annihilation → σ_{CDM}**
- **Dark Energy Connection**
  - **Supercritical String Cosmology (SSC) → $\sigma_{CDM(SSC)}$**

Key Signals at the LHC

- **Co-annihilation region vs. SSC**
- **Mass?**

Summary

Thinking of Cosmological Connection

Astrophysics

$$\underbrace{\Omega_{\tilde{\chi}_1^0} h^2}_{0.23} \sim \int_0^{x_f} \frac{1}{\langle \sigma_{\text{ann}} v \rangle} dx$$

$$\underbrace{\langle \sigma_{\text{ann}} v \rangle}_{0.9\,\text{pb}} = \frac{\pi \alpha^2}{8 M^2}$$

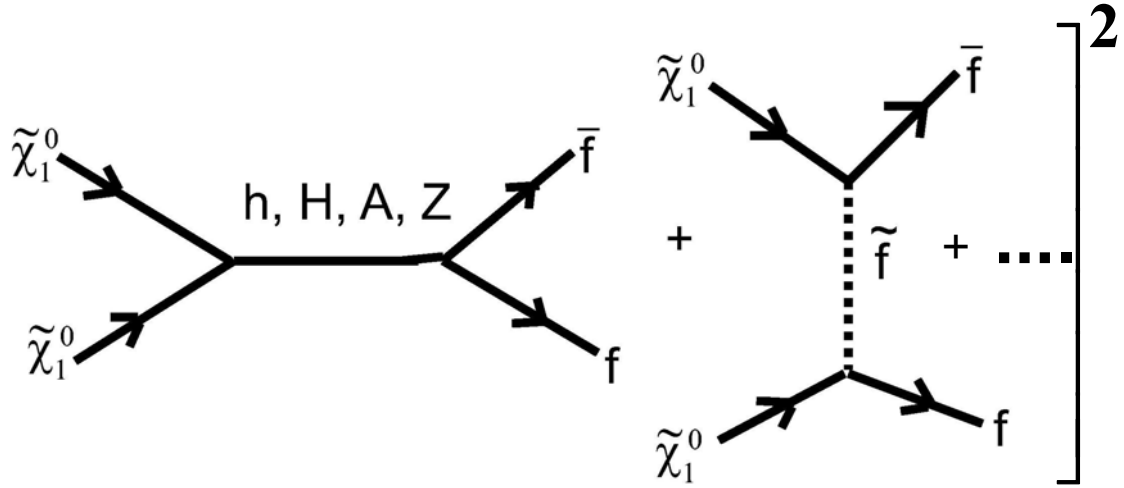
CDM = Neutralino ($\tilde{\chi}_1^0$)

SUSY

SUSY is an interesting class of models to provide a massive neutral particle (*M* ~ 100 GeV) and weakly interacting (WIMP).

Anatomy of σ_{CDM}

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



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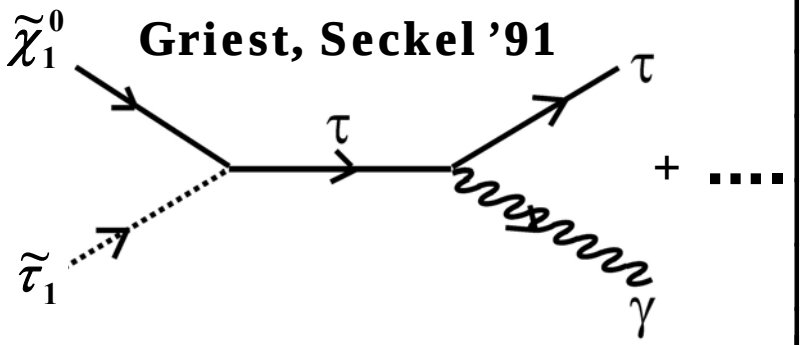
Co-annihilation Process

Griest, Seckel '91

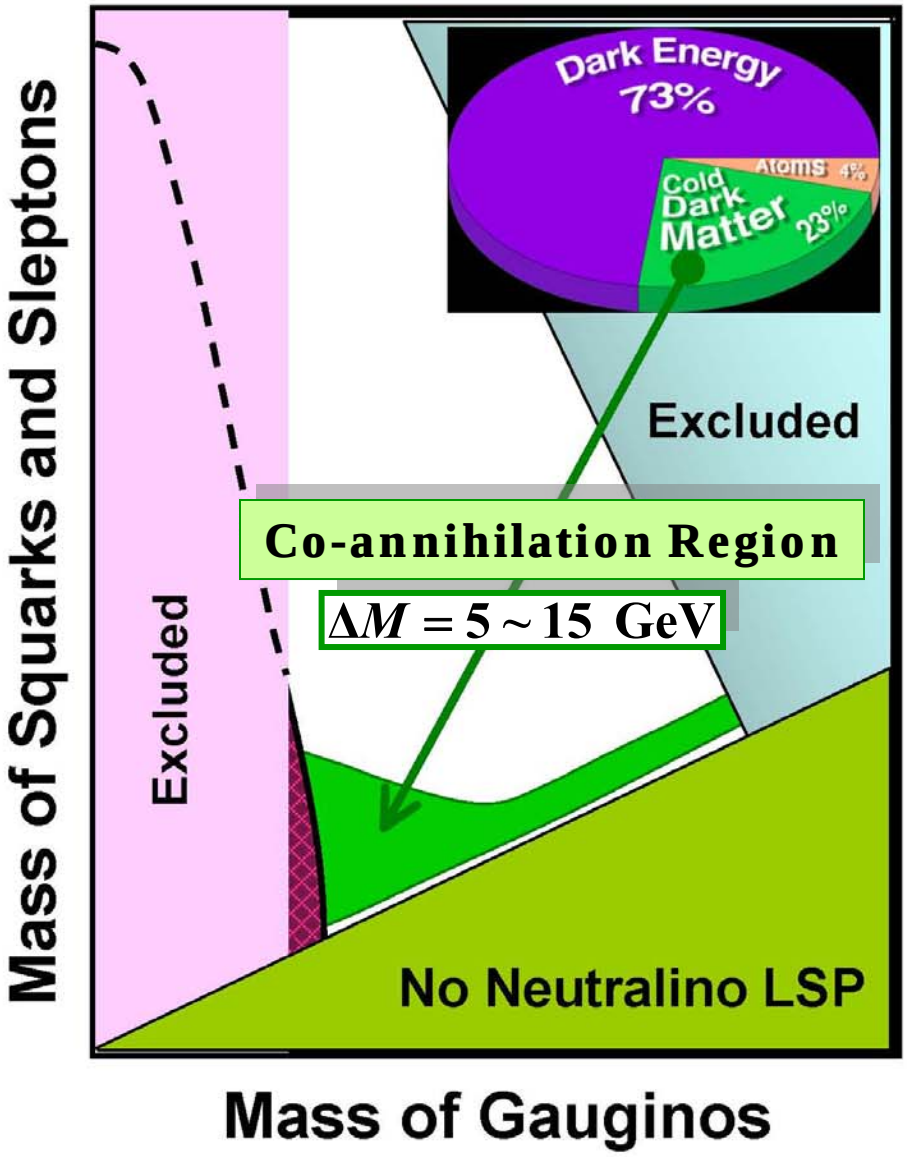


$$e^{-\Delta M / 20}$$

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

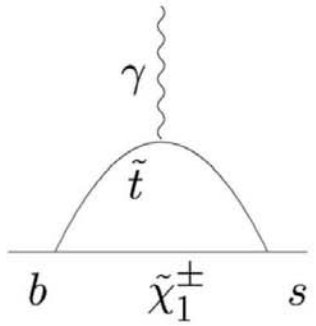
Use mSUGRA as a benchmark model

Dark Matter Allowed Region

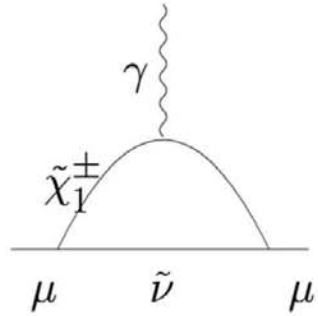


Higgs Mass (M_h)

Branching Ratio $b \to s\gamma$



Magnetic Moment of Muon

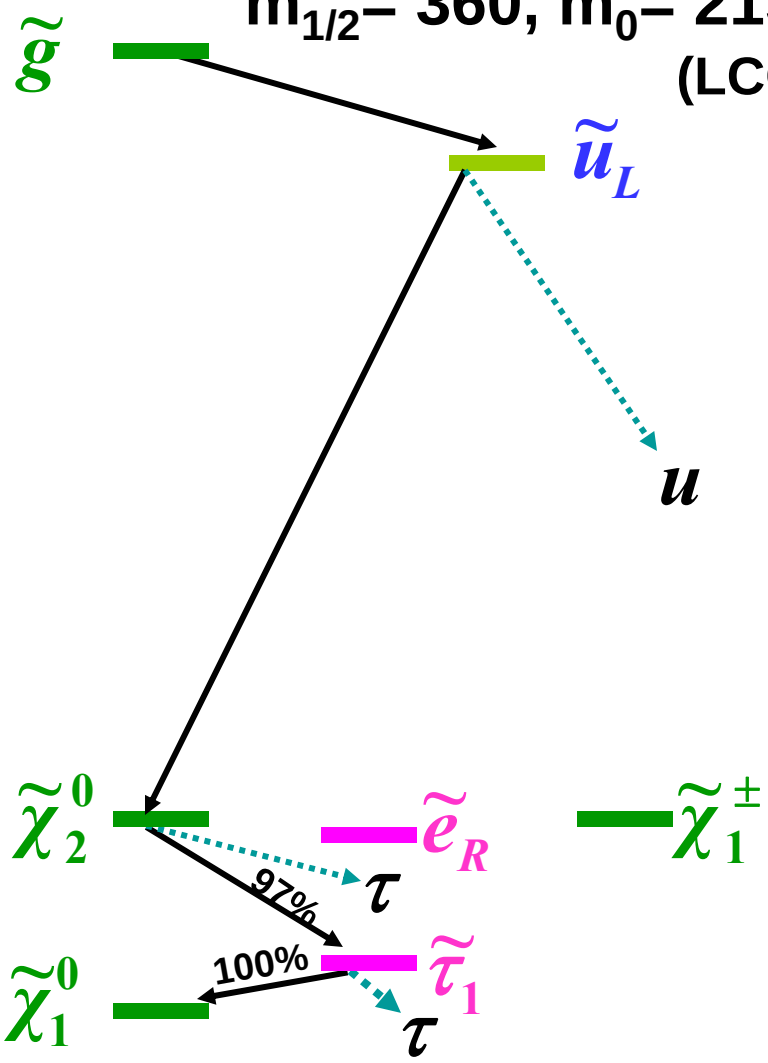


WMAP Favored region

mSUGRA Case Study at $\tan\beta = 40$

$m_{1/2}$= 360, m_0= 215, $\tan\beta$ = 40, m_{top}= 175

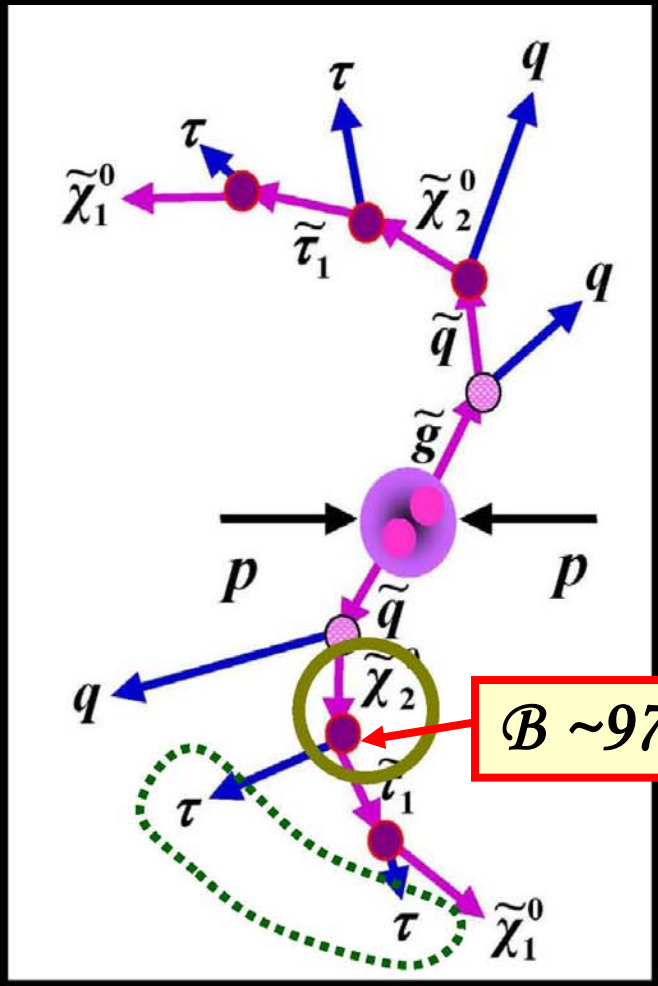
(LCC3 Point)



m_0	215
$\tilde{g}$	831
$\tilde{u}_L$	765
$\tilde{u}_R$	741
$\tilde{t}_2$	744
$\tilde{t}_1$	579
$\tilde{\tau}_2$	333
$\tilde{e}_L$	326
$\tilde{\chi}_2^0$	266
$\tilde{e}_R$	256
$\tilde{\tau}_1$	154.8
$\tilde{\chi}_1^0$	144.2
$\Delta M(\equiv M_{\tilde{\tau}_1} - M_{\tilde{\chi}_1^0})$	10.6
$M_{\tau\tau}^{\max}$	78.7

Signal in Co-annihilation Region

Phys. Lett. B 639 (2006) 46

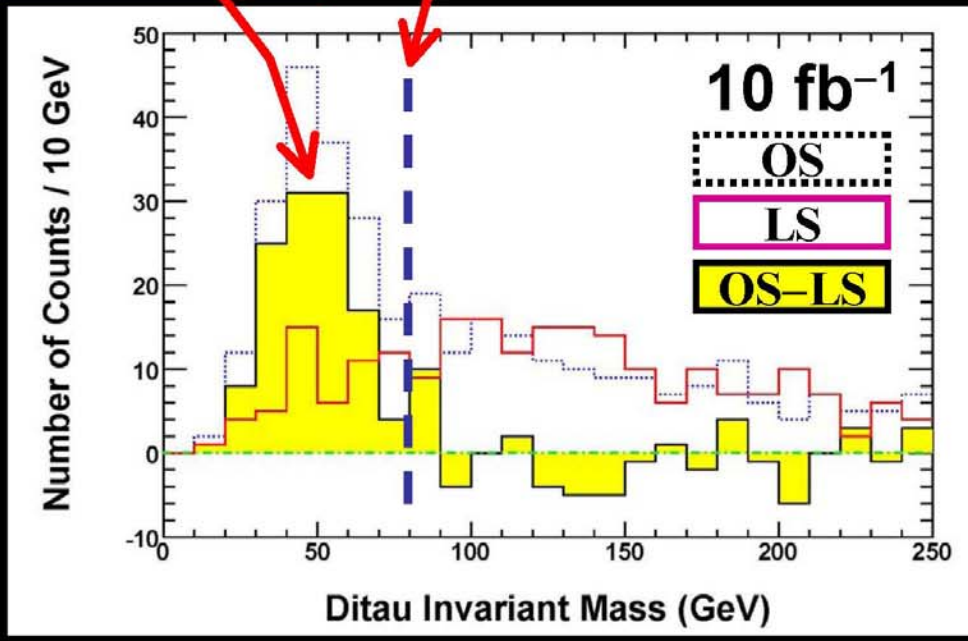


$\mathcal{B}$ ~97%

$$M_{\tau\tau}^{\max} = M_{\tilde{\chi}_2^0}\sqrt{1-\frac{M_{\tilde{\tau}_1}^2}{M_{\tilde{\chi}_2^0}^2}}\sqrt{1-\frac{M_{\tilde{\chi}_1^0}^2}{M_{\tilde{\tau}_1}^2}}$$

$M^{\max}$(true) = 78.7 GeV

M^{peak} = 47.1 GeV

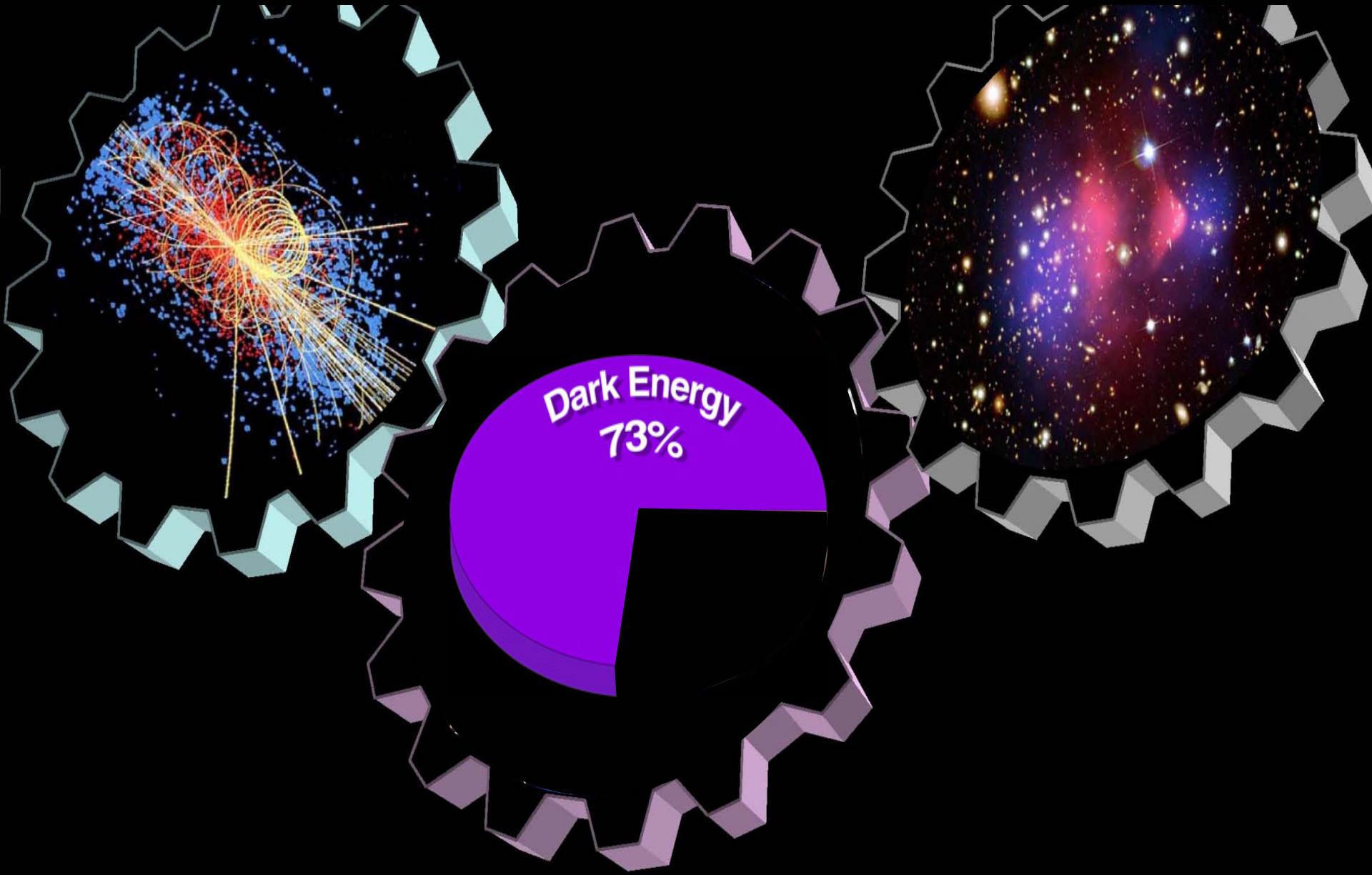


OS–LS counts with $M_{\tau\tau}$ < 100 GeV:

$p_T{}^{\tau} > 20$ GeV is essential!

SUSY : 125 counts

However, there is a another story …



w

Is $w = -1$ for all times?

Quintessence – Scalar field dark energy

w varies in time.

LMD Scenario

"Smoothly evolving Supercritical-String Dark Energy relaxes Supersymmetric-Dark-Matter Constraints"

A.B. Lahanas, N.E. Mavromatos, D.V. Nanopoulos

hep-ph/0612152

Supercritical-String-Cosmology (SSC)

$$\frac{dn}{dt} = -3\,H\,n - \langle \sigma\, \mathrm{v} \rangle (n^2 - n_{eq}^2)$$

Critical term

Non-critical term

$$\frac{dn}{dt} = -3\,H\,n - \langle \sigma\, \mathrm{v} \rangle (n^2 - n_{eq}^2) + \dot{\phi}\; n + \frac{g}{m_\chi}$$

Translating to Particle Physics

$$\underbrace{\Omega_{\tilde{\chi}_1^0} h^2}_{0.23} \sim \int_0^{x_f} \frac{1}{\langle \sigma_{\text{ann}} v \rangle} dx$$

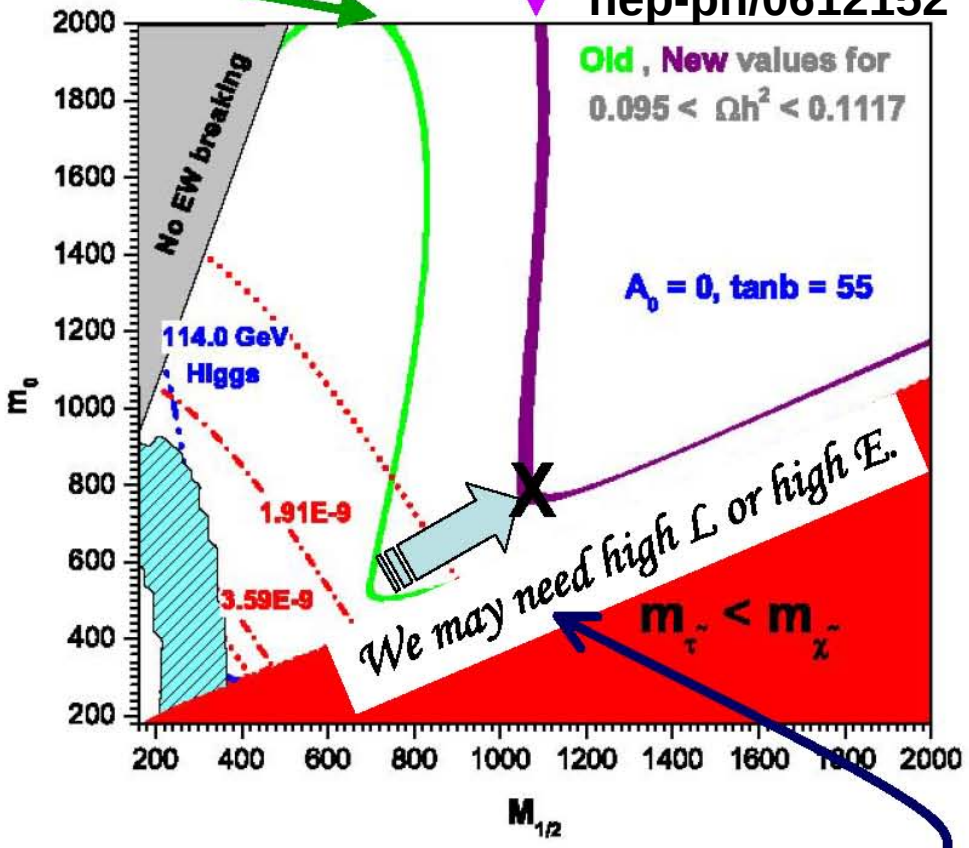
$$\underbrace{\Omega_{\tilde{\chi}_1^0} h^2}_{0.23} \sim \int_0^{x_f} \frac{1}{\langle \sigma_{\text{ann}} v \rangle f(x)} dx$$

hep-ph/0612152

SSC off-equilibrium and time-dependent-dilaton effects
→ A smoothly evolving dark energy for the last 10 billion years

f(*x*) = The supersymmetric dark matter density (neutralinos) dilute by a factor O(10)

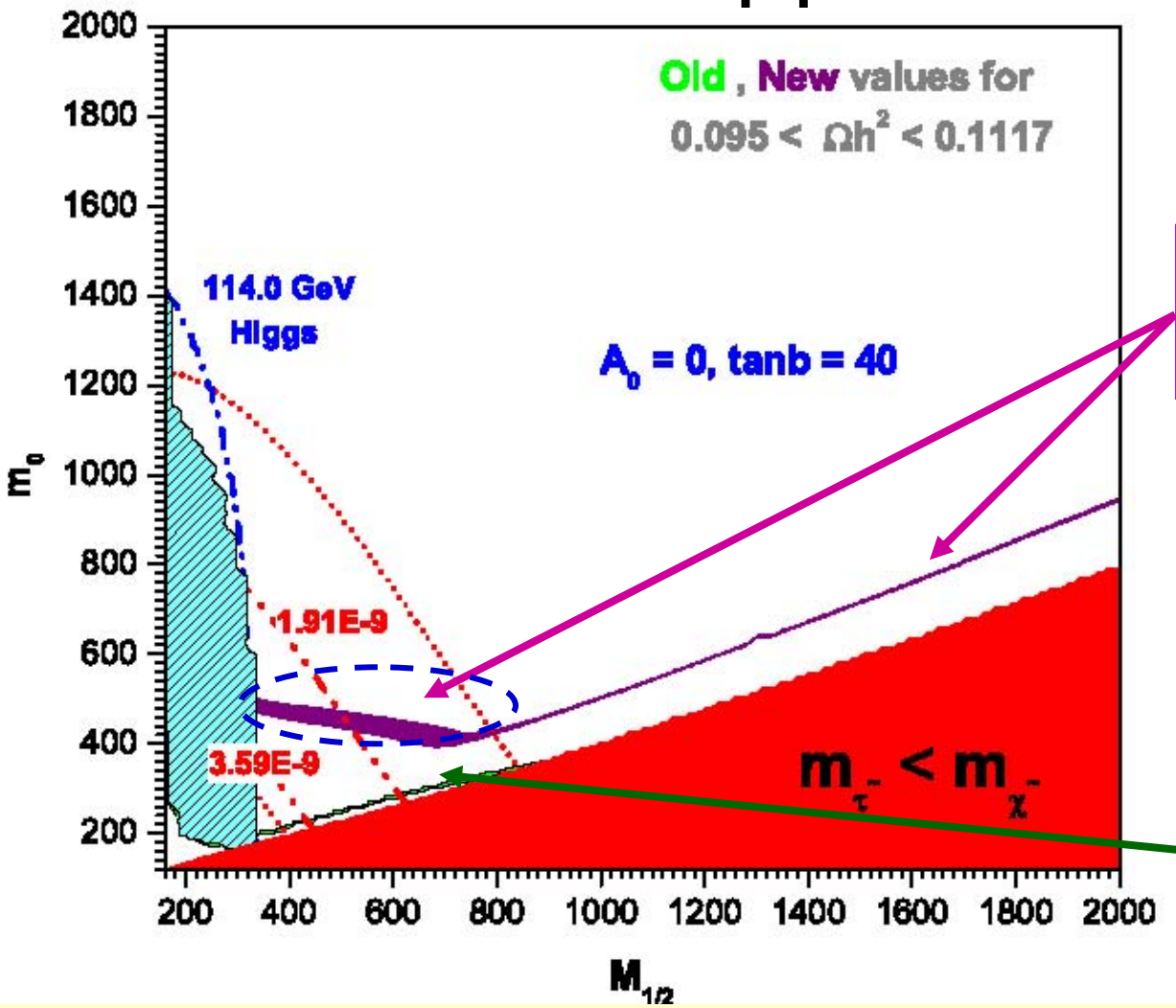
We need to anticipate searches and discoveries to discriminate between conventional cosmology and SSC.



Tends to push heavier SUSY mass region. This means …

SSC Case Study at $\tan\beta = 40$

hep-ph/0612152



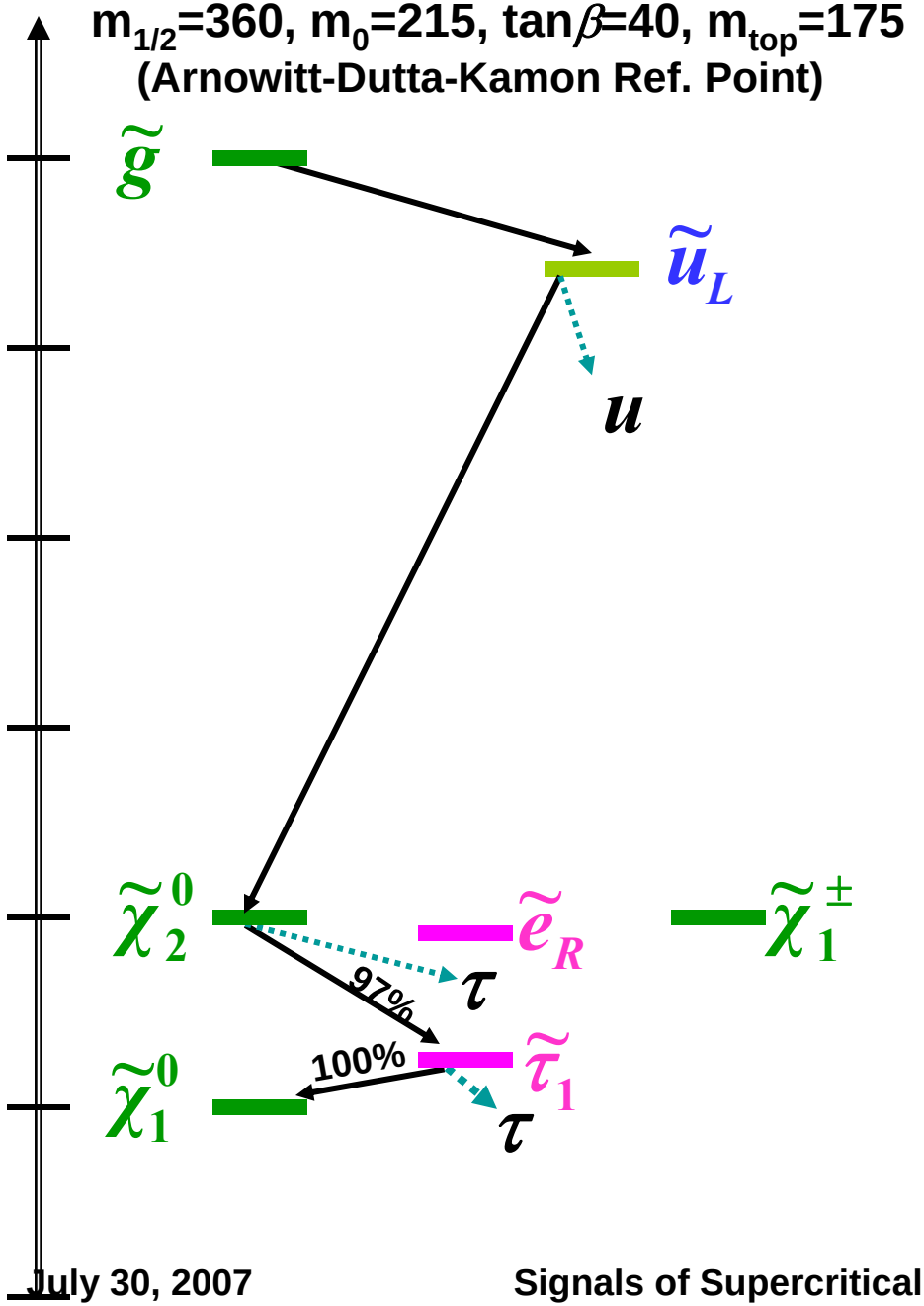
$$\underbrace{\Omega_{\tilde{\chi}_1^0} h^2}_{0.23} \sim \int_0^{x_f} \frac{1}{\langle \sigma_{\text{ann}} v \rangle f(x)} dx$$

$$\underbrace{\Omega_{\tilde{\chi}_1^0} h^2}_{0.23} \sim \int_0^{x_f} \frac{1}{\langle \sigma_{\text{ann}} v \rangle} dx$$

Let's look into signals in the region

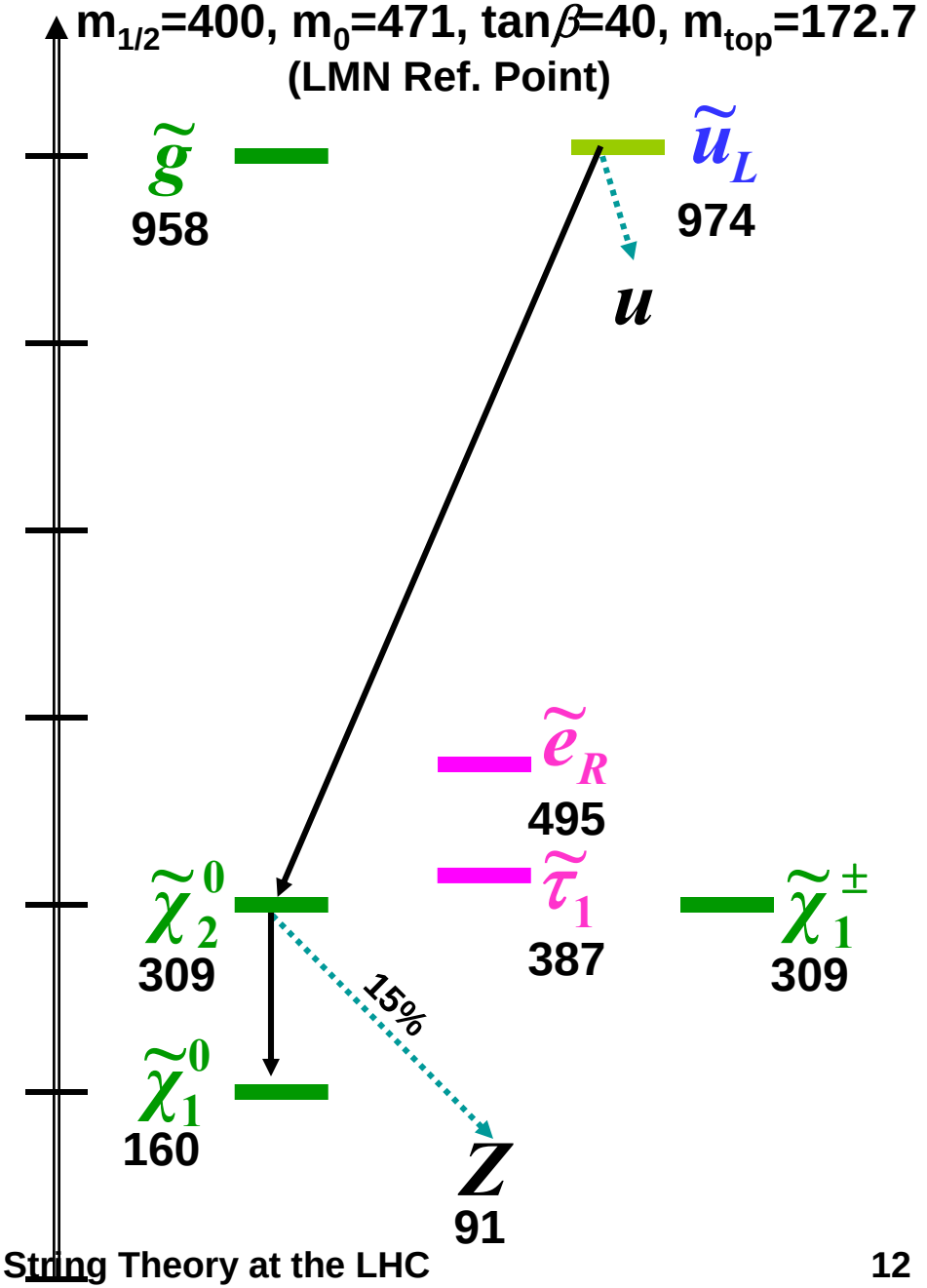
Co-annihilation region

$m_{1/2}$=360, m_0=215, tanβ=40, m_{top}=175
(Arnowitt-Dutta-Kamon Ref. Point)

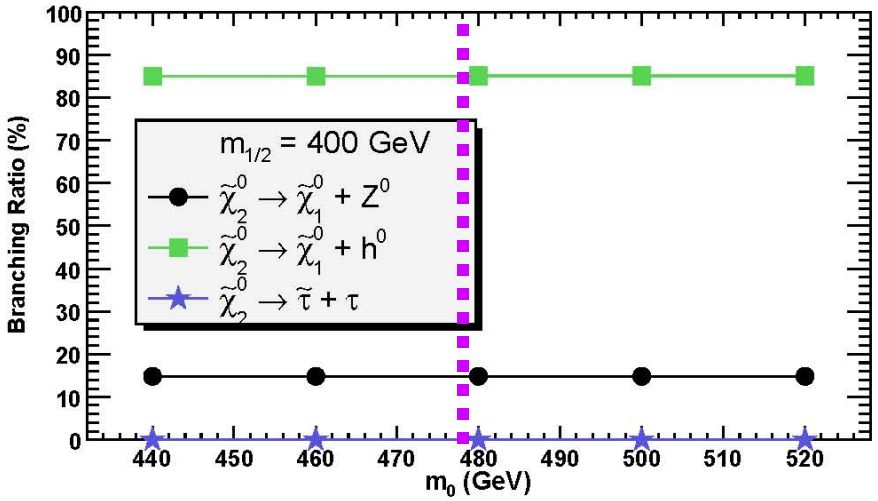


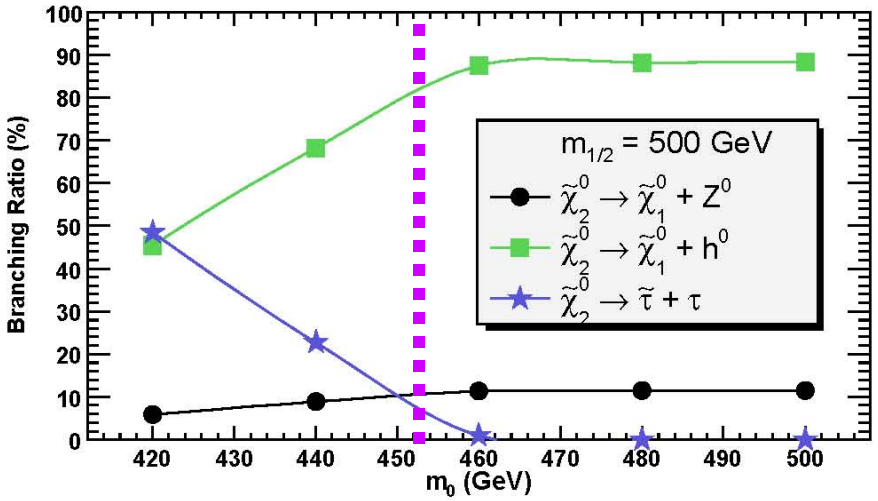
Supercritical String

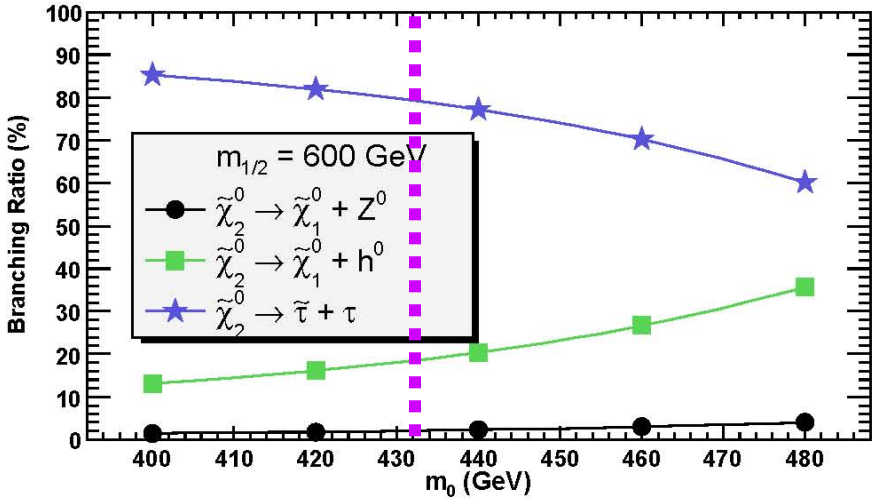
$m_{1/2}$=400, m_0=471, tanβ=40, m_{top}=172.7
(LMN Ref. Point)

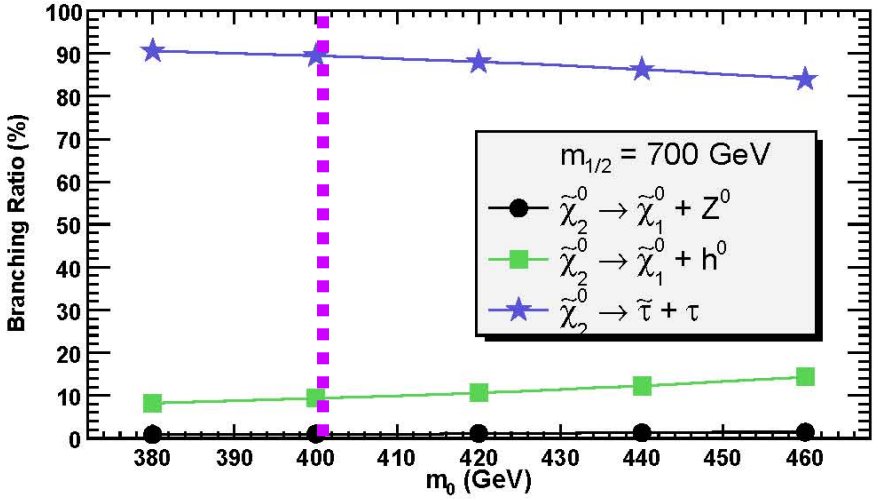


χ_2^0 Decay Branching Ratios





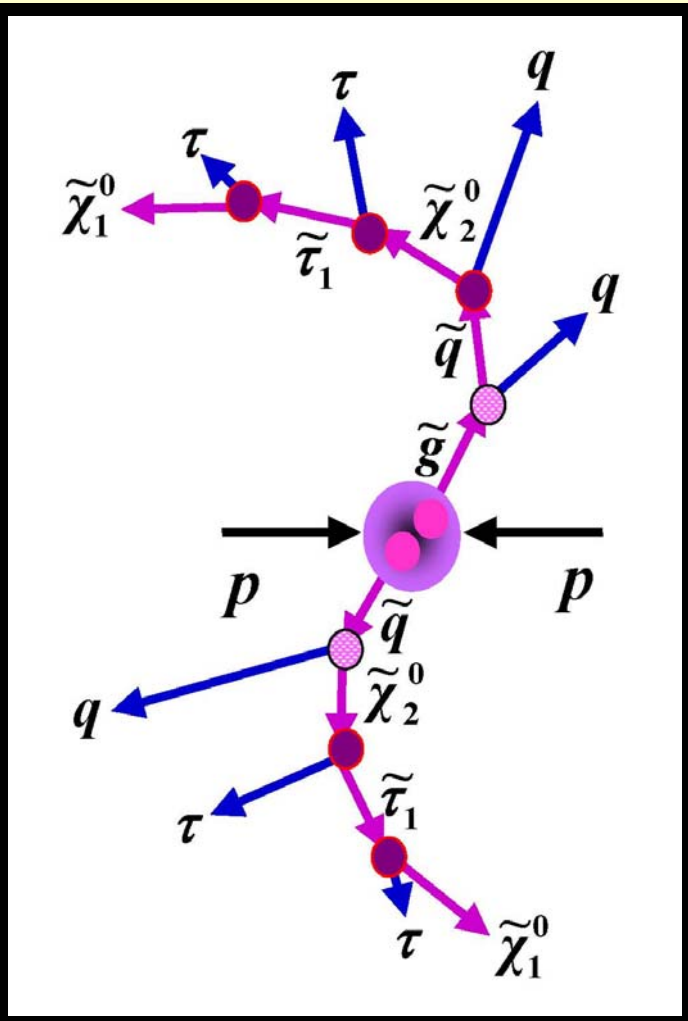




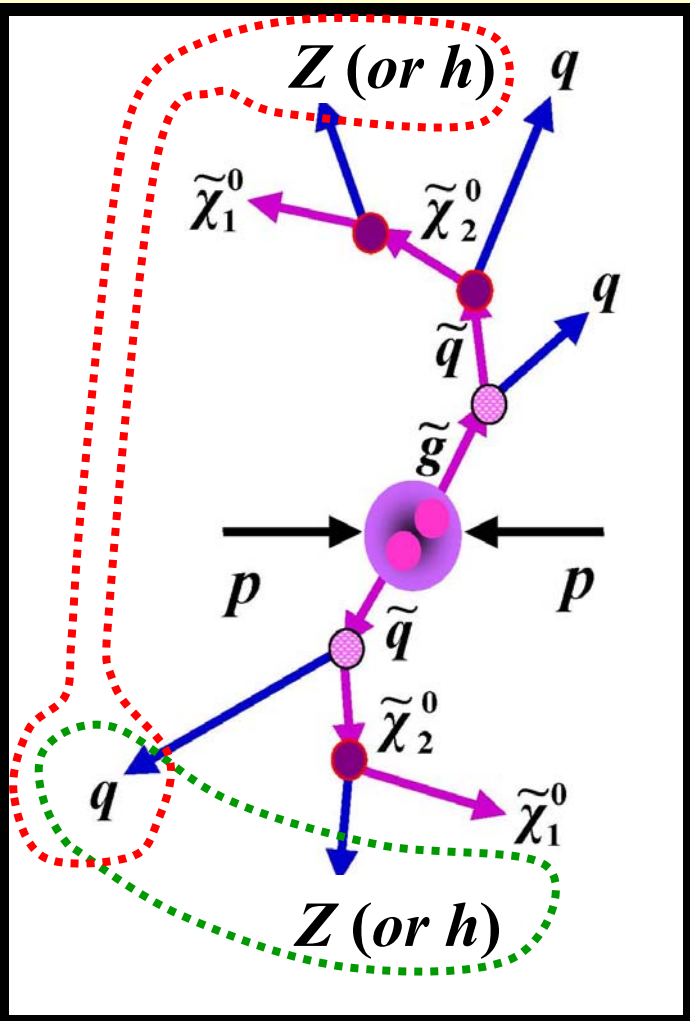
Identify and classify χ_2^0 decays

Key Reactions at the LHC

Co-annihilation region



Supercritical String

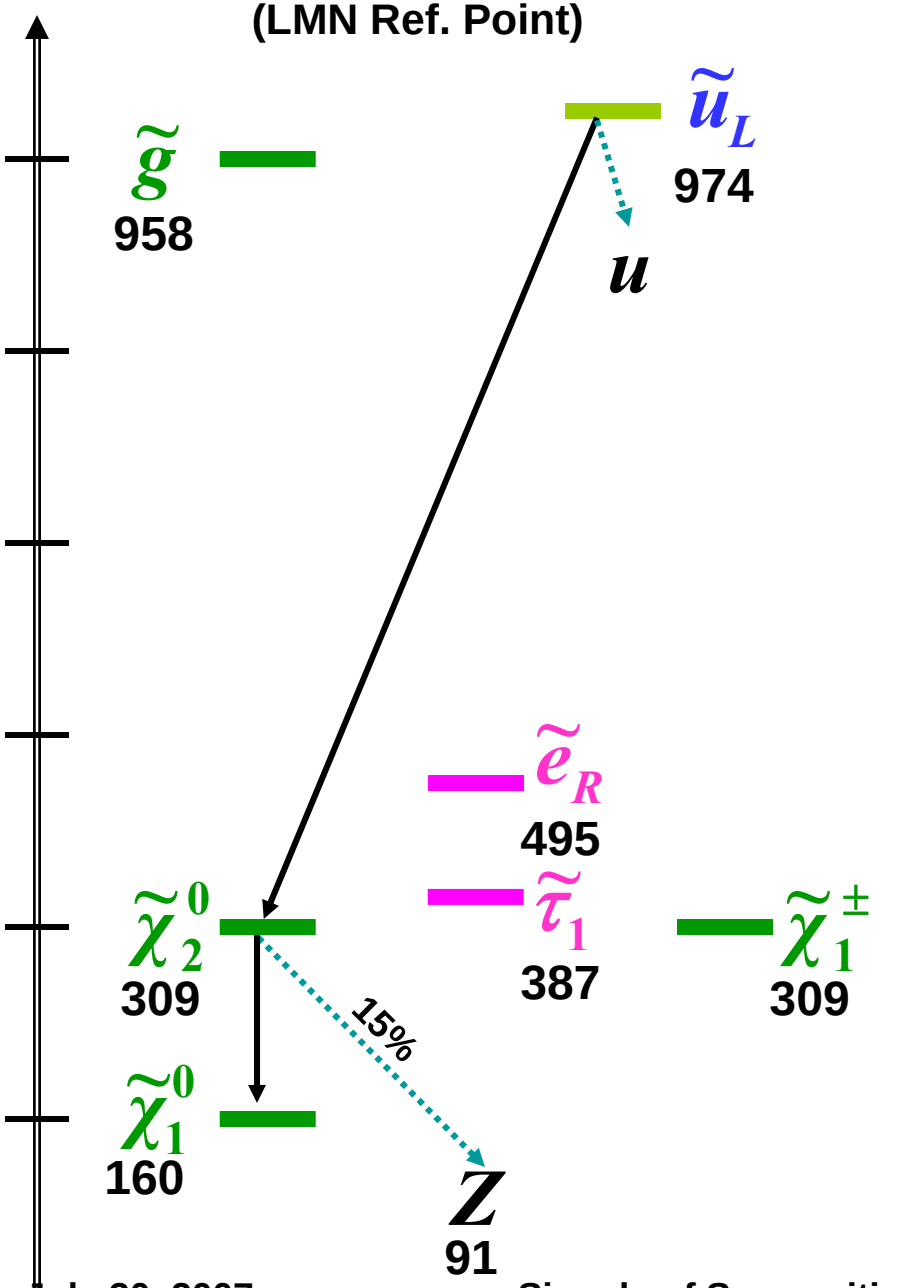


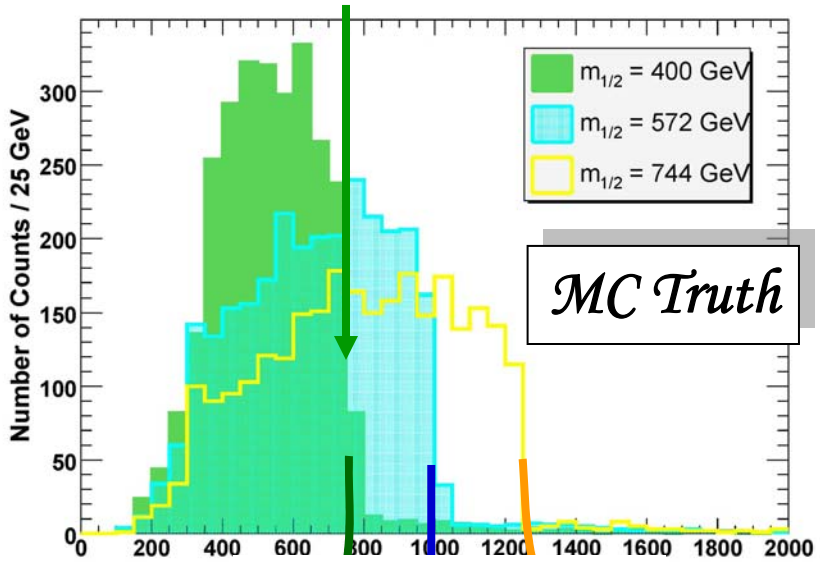
Check $M(\ell\ell j)$ and $M(bbj)$

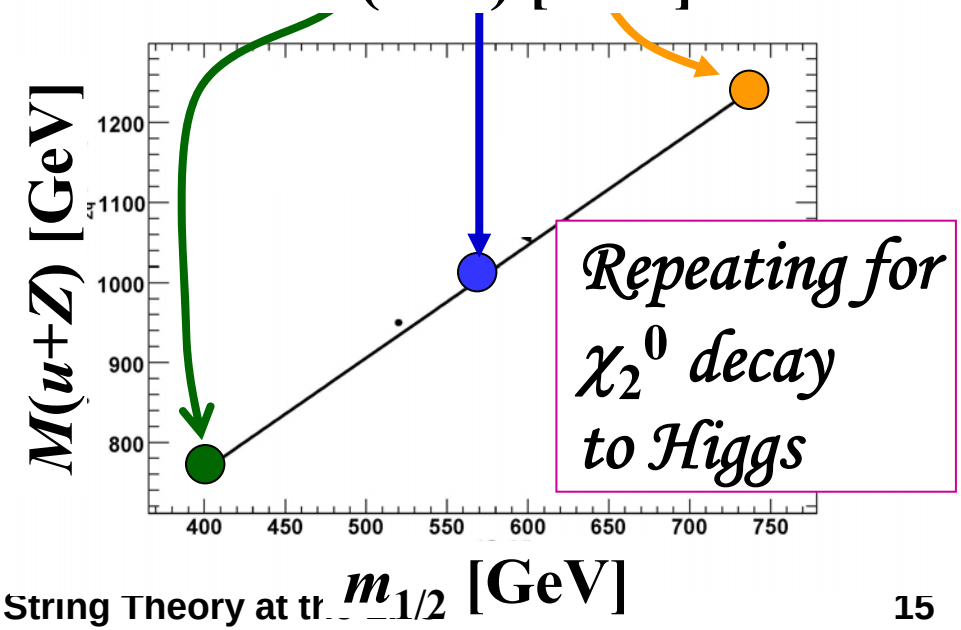
$m_{1/2}$=400, m_0=471, tanβ=40, m_{top}=172.7
(LMN Ref. Point)

$$\tilde{u}_L \rightarrow u\tilde{\chi}_2^0 \rightarrow u Z \tilde{\chi}_1^0$$

End Point of $M(u+Z) \approx M(\tilde{u}_L) - M(\tilde{\chi}_1^0)$







$E_T^{miss} + 2j + 2\tau$ Analysis Path

Cuts to reduce the SM backgrounds (*W*+jets, …)

$E_T^{miss} > 200$ GeV, N(jet) ≥ 2 with $E_T > 100$ GeV

$E_T^{miss} + E_T^{j1} + E_T^{j2} > 600$ GeV; N(lepton) ≥ 2 with $P_T > 20$ GeV

CATEGORIZE opposite sign (OS) dileptons

OS *ee*, $\mu\mu$

Low mass ($\mathcal{M}_2$) *histogram*

High mass ($\mathcal{M}_1$) *histogram*

OS $e\mu$

Low mass ($\mathcal{M}_2$) *histogram*

High mass ($\mathcal{M}_1$) *histogram*

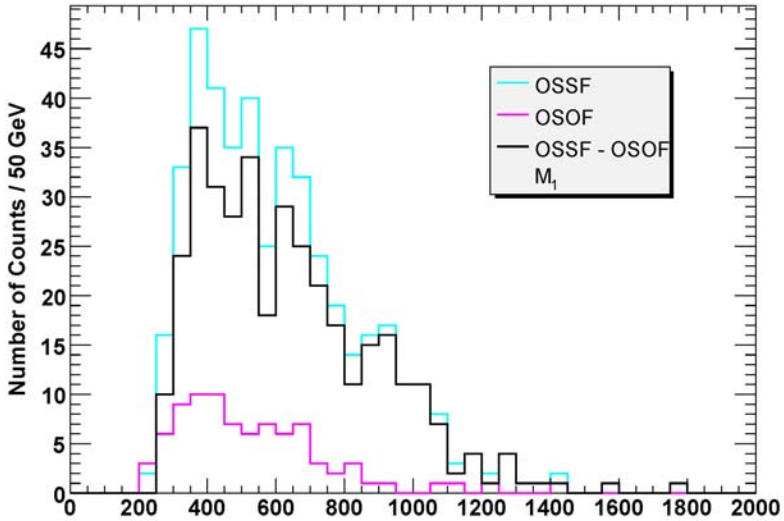
Low OSSF → **Low OSSF–OSOF** ← **Low OSOF**

High OSSF → **High OSSF–OSOF** ← **High OSOF**

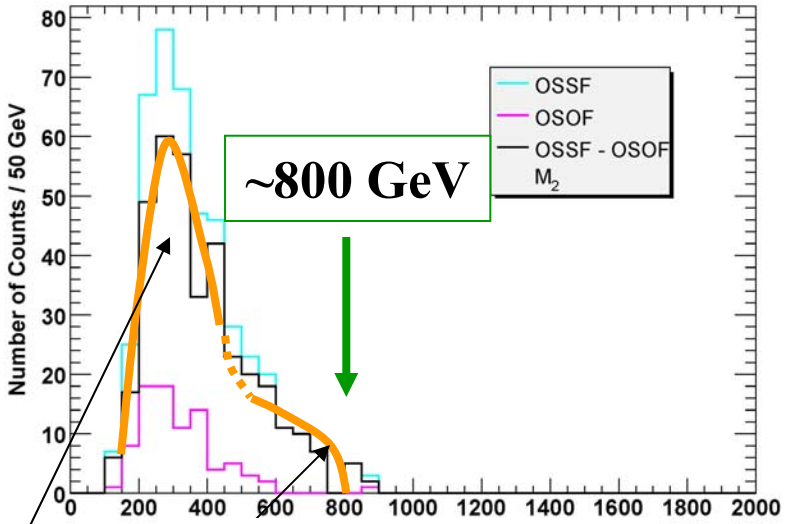
Anatomy : Mass Distributions

$m_{1/2}$=400, m_0=471, tanβ=40

78 fb^{-1}



$\mathcal{M}_1(\ell\ell j)$ [GeV]



$\mathcal{M}_2(\ell\ell j)$ [GeV]

$$e.g.,\ \tilde{g} \underbrace{\rightarrow}_{34\%} t\tilde{t}_1 \underbrace{\rightarrow}_{12\%} tt\,\tilde{\chi}_2^0 \underbrace{\rightarrow}_{17\%} tt\,Z\tilde{\chi}_1^0$$

$$\tilde{u}_L \rightarrow u\tilde{\chi}_2^0 \rightarrow u\,Z\,\tilde{\chi}_1^0$$

Mass determination & higgs channel … Work in progress

Summary

Cosmology ... Dark Matter and Dark Energy

Supercritical-String-Cosmology (SSC)

Scalar Field Dark Energy

... Smoothly evolving DE for 10 B years

Translating to Particle Physics :

$$\sigma_{CDM(SSC)} \sim \sigma_{CDM} / 10$$

Implication at the LHC

SUSY masses will be heavier than those in co-annihilation region

Simultaneous searches for χ_2^0 decays to h and Z

Measurement of Ω_{CDM} ... Work in progress

Backups