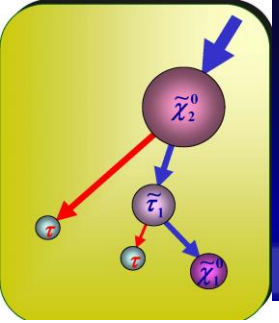
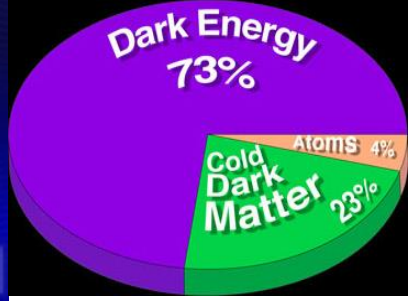


34th International Conference on High Energy Physics



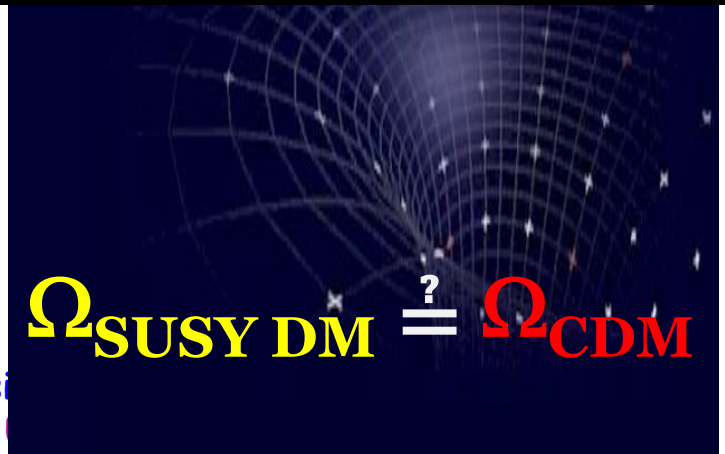
Measuring the Dark Matter Relic Density at the LHC

Richard Arnowitt, Bhaskar Dutta, Alfredo Gurrola,
Teruki Kamon, Abram Krislock & David Toback
Department of Physics, Texas A&M University

Hypothetical Timeline

- History to date:
  - Precision constraints on both the Dark Matter density and the Standard Model
  - Phenomenologist's use these results to constrain SUSY models → Tell the experimentalists at LHC where to look
- 2008-10: Establish that we live in a Supersymmetric world at the LHC
- 2011: Precision measurements of the particle masses and SUSY parameters → compare Dark Matter relic density predictions to those from WMAP

Combining Particle Physics with Cosmology

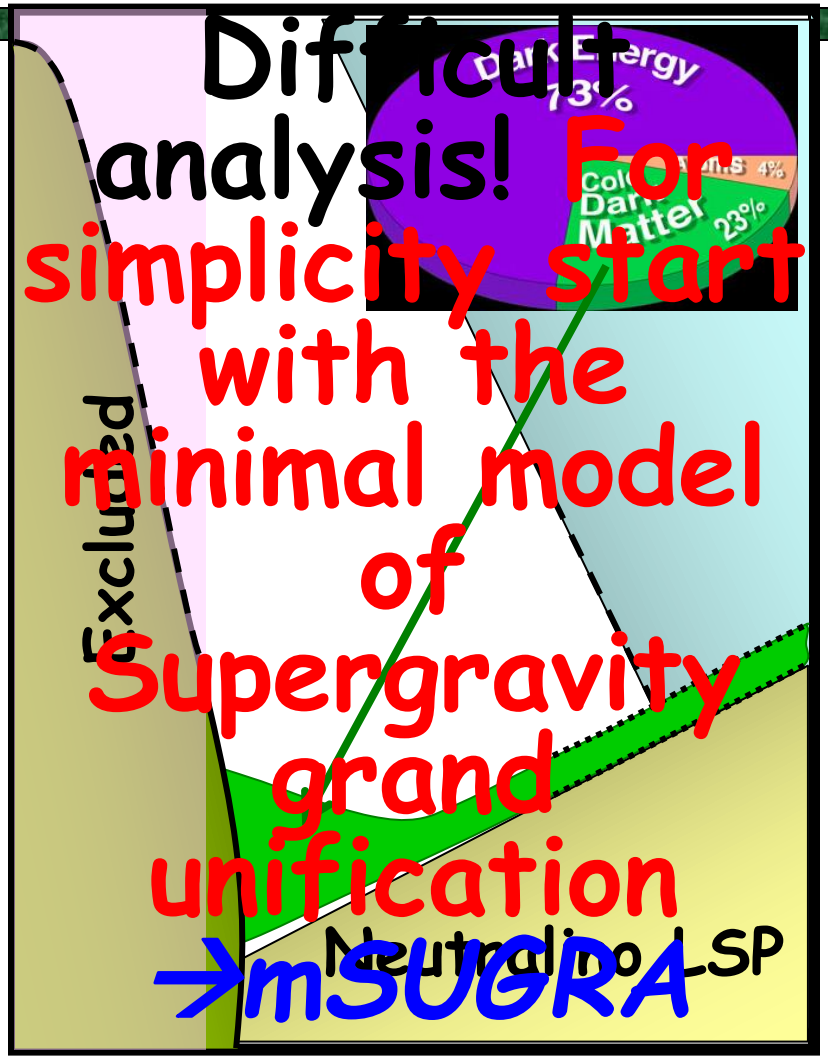


Outline of the Talk or *What if it were true?*

- Why current constraints and hints point to the co-annihilation region in Supersymmetry
- Lighting the way: Three important datasets
- Discovery and Measurement Techniques
  - First evidence for SUSY
  - A smoking gun for the co-annihilation region
  - Sparticle mass measurements and Universality checks
  - SUSY parameter measurements
  - Neutralino Relic Density prediction to be compared to $\Omega_{CDM}h^2$
- Conclusions

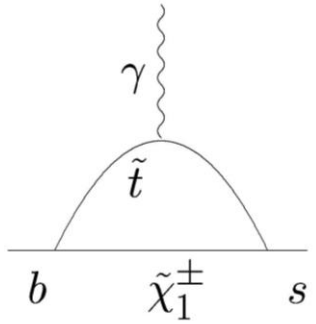
For more details see:
- Arnowitt, Dutta, Gurrola, Kamon, Krislock & D.T., PRL100 (2008) 231802
- Arnowitt *et al.*, PLB 649 (2007) 73
- Arnowitt *et al.*, PLB 639 (2006) 46

Experimental Constraints on mSUGRA

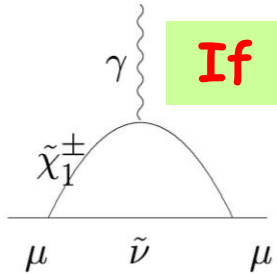


Higgs Mass (M_h)

Branching Ratio $b \to s\gamma$



Magnetic Moment of Muon



If confirmed…

WMAP Dark Matter Favored region

Towards Discovering the Dark Matter Favored Region

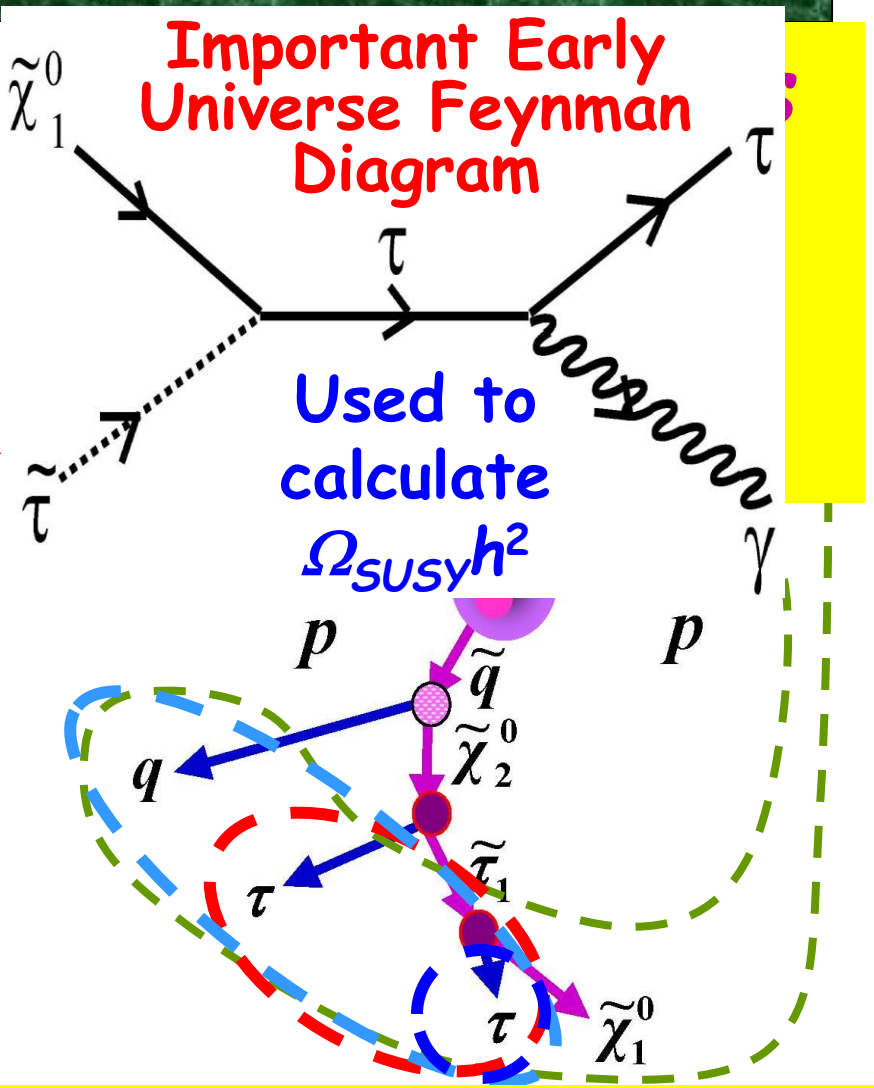
What's so special about this region?

Large amounts of a second sparticle in the early universe annihilate away the LSP to produce the Dark Matter relic density observed today

- "co-annihilation" region
- Griest, Seckel:`92

Our Analysis: Use important features of this model and the LHC to:

1. First evidence we live in a SUSY World
2. Show we are in SUSY and the Co-Annihilation region
3. Measure SUSY Masses and check Universality
4. Measure mSUGRA parameters
5. Determine $\Omega_{SUSY}h^2$



$M_{\tilde{\tau}} - M_{\tilde{\chi}_1^0} = \Delta M = \sim 10$ GeV

What do we want to know?

Measure the SUSY masses/parameters

Pick a baseline configuration

$M_0 = 210$ GeV

$M_{1/2} = 350$ GeV

$\tan\beta = 40$

$A_0 = 0$

$Sgn(\mu) > 0$

$M_{\tilde{g}} = 830$ GeV

$M_{\tilde{q}_L} = 748$ GeV

$M_{\tilde{\chi}_2^0} = 260$ GeV

$M_{\tilde{\tau}} = 151.3$ GeV

$M_{\tilde{\chi}_1^0} = 140.7$ GeV

$\Delta M = 10.6$ GeV

$\Omega_{\tilde{\chi}_1^0} h^2 = 0.1$

Use ISAJET-PGS-DarkSUSY

mSUGRA

Universality Relations:

$M_{\tilde{g}} / M_{\tilde{\chi}_2^0} = 3.19$

$M_{\tilde{g}} / M_{\tilde{\chi}_1^0} = 5.91$

Want to measure the values and test these relations

Three data sets: Discovery and Measurement

Sample 1: Met+Jets

- First direct evidence we live in a Supersymmetric World
- Important for Squark/Gluinos → m_0 and $m_{1/2}$

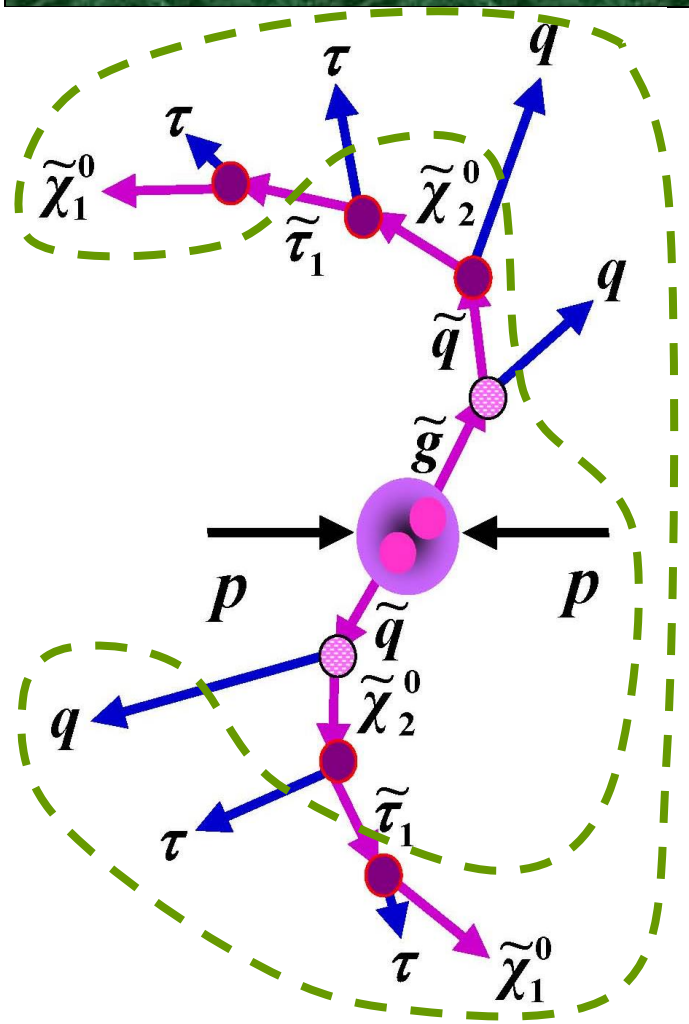
Sample 2: 2τ+jets+Met

- The co-annihilation diagrams played an important role in the early universe
- Study Squark decay chain →squark and gauginos masses → Check Universality

Sample 3: *b*+jets+met

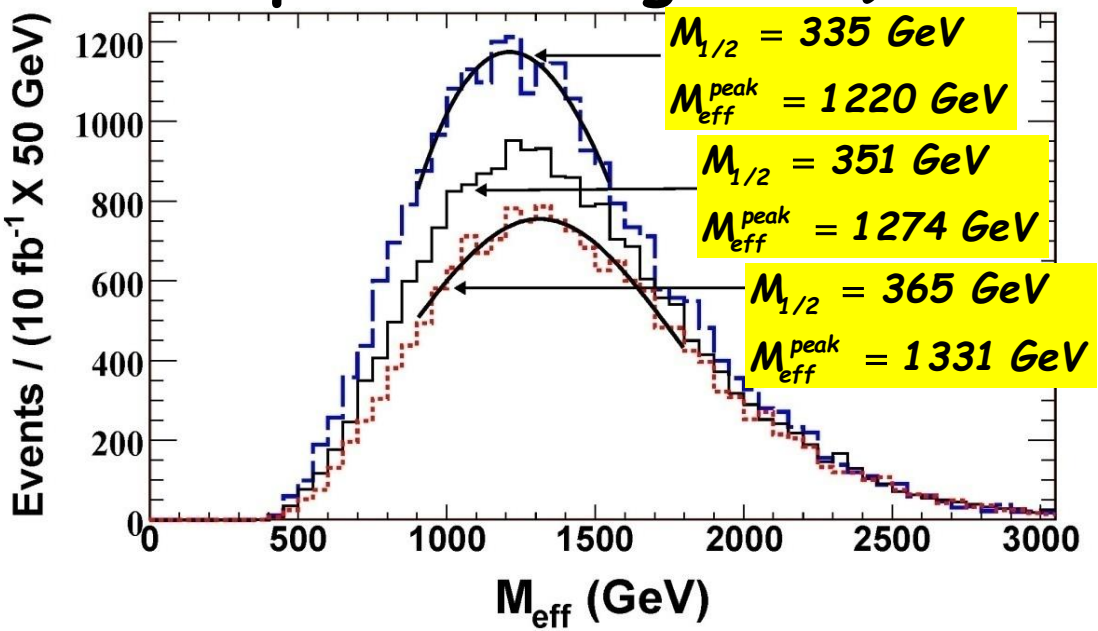
- We have enough information to measure the SUSY masses, parameters and Ωh^2
- Stops and sbottoms → Help untangle third generation mixing → A_0 and tanβ

Sample 1: Met+jets



Hinchliffe and Paige, Phys. Rev. D 55 (1997) 5520, but require no b-tags!

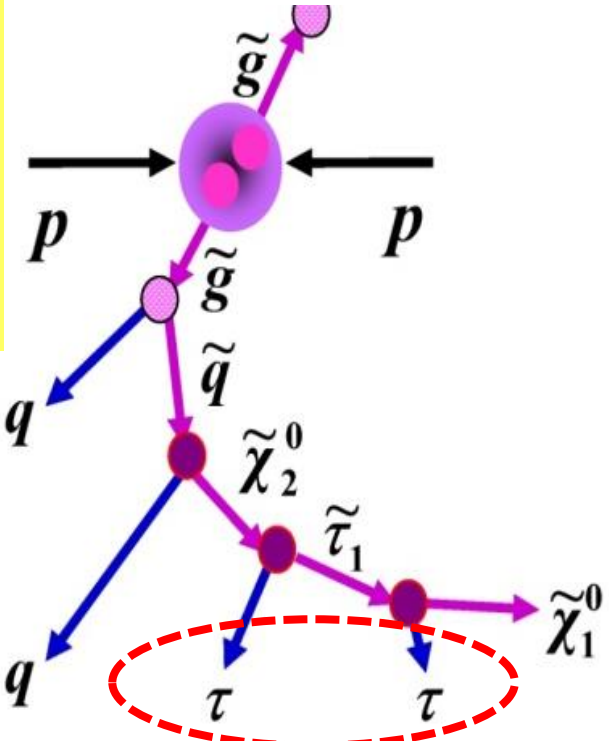
- An excess in this channel would be the first direct evidence for SUSY, within 50 pb^{-1}
- Measure M_{eff} of the jets+Met
  → Peak measurement would provide the SUSY scale at ~15% (M_0 and $M_{1/2}$, mass of the squarks and gluinos)



Sample 2: 2τ+2jets+Met

If low tanβ then
dilepton + jets + mets
data sets ⇒ $\tilde{\chi}_2^0$ decays should show an excess in ee/μμ/ττ

If high tanβ then
BR($\tilde{\chi}_2^0 \rightarrow \tau\tilde{\tau} \rightarrow \tau\tau\tilde{\chi}_1^0$) ~ 100%
⇒ Only see an excess in ττ

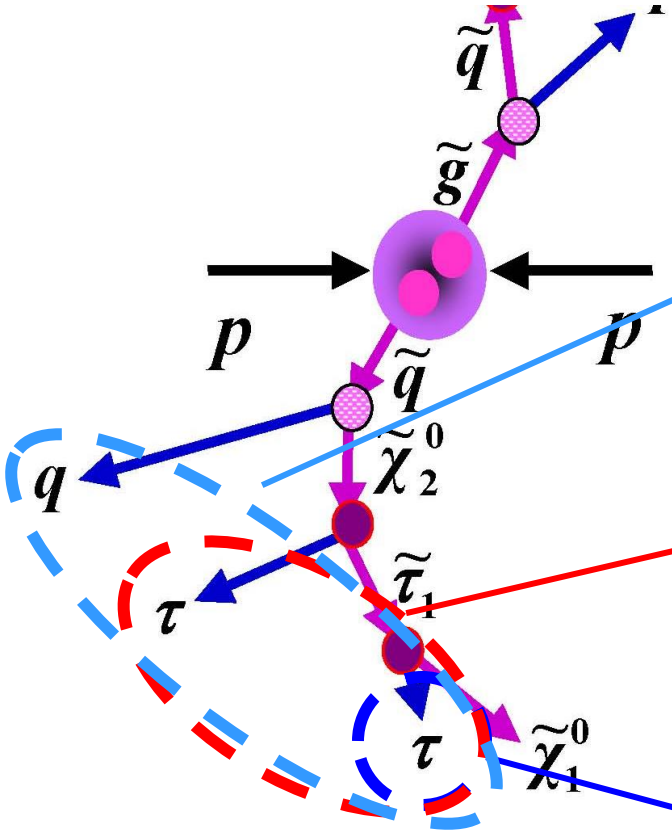


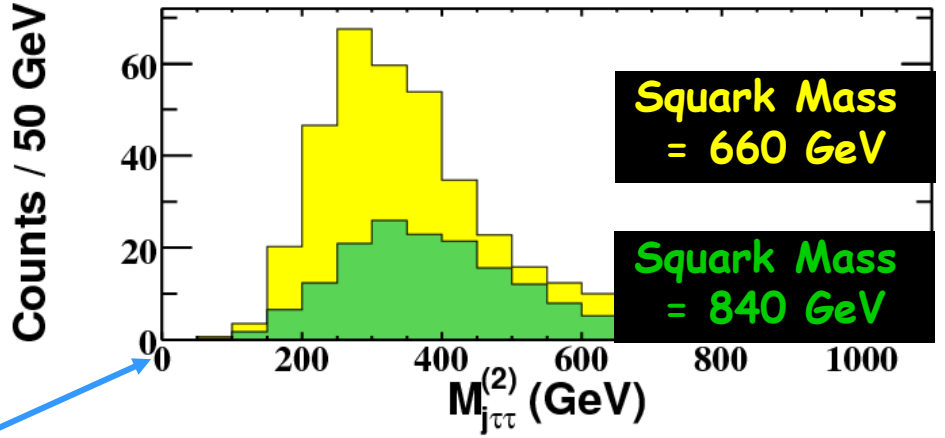
Nojiri, Polesselo, Tovey, JHEP 0603 (2006) 063

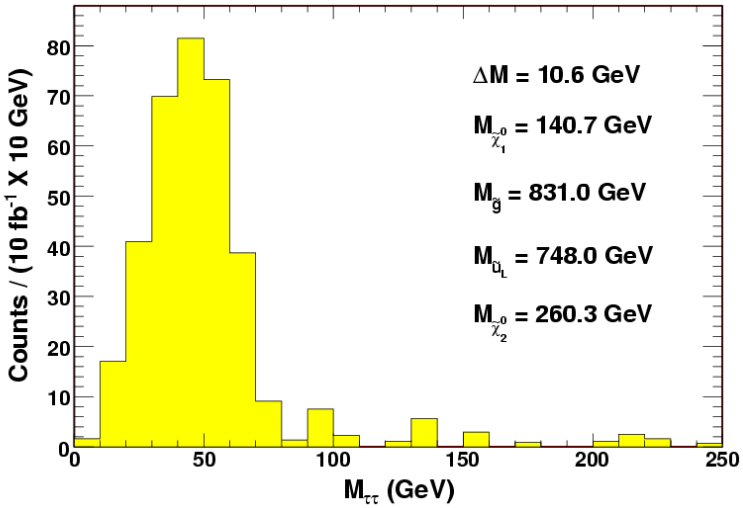
➔ Smoking gun we're in co-annihilation region

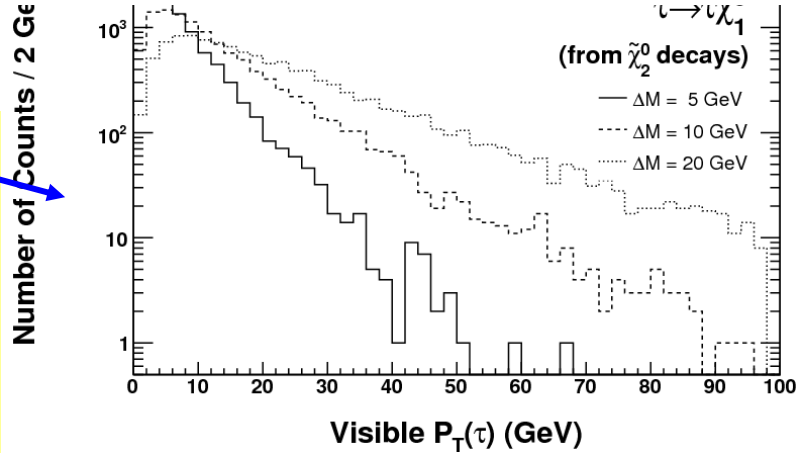
~~ee, μμ~~ and ττ decays

Lots of handles in th
provide good









Small ΔM can be detected in first few years of LHC ~100 Events

Allows us to show ΔM is small

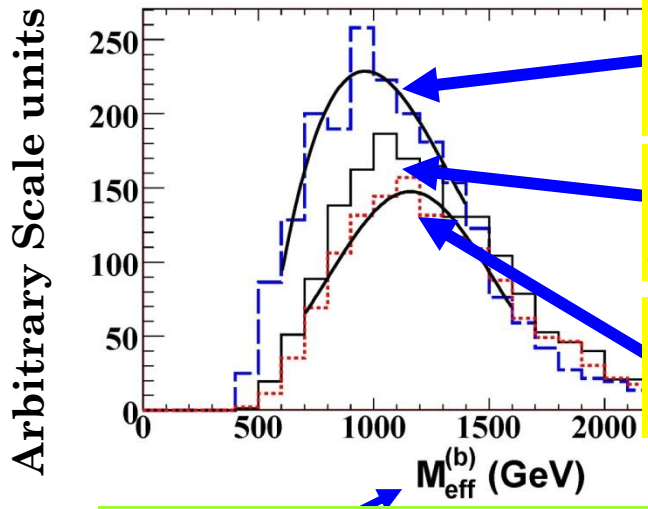
5 Good observables in all

Sample 3: *b*+jets+Met

In this scenario the stops and sbottoms are significantly lighter than the gluinos and other squarks

Create a new variable to measure the stop/sbottom mass scale. Use M_{eff}, but require the first jet to be a *b*

Require the original Meff to NOT have a *b*



$\tan\beta = 48$ $M_{eff}^{(b)peak} = 933$ GeV

$\tan\beta = 40$ $M_{eff}^{(b)peak} = 1026$ GeV

$\tan\beta = 32$ $M_{eff}^{(b)peak} = 1122$ GeV

$M_{eff}^{(b)peak}$ (& $M_{\tau\tau}^{peak}$)

...sensitive to $\tilde{t}/\tilde{b}$ masses

...sensitive to A_0 and $\tan\beta$

Since we don't allow b's in

M_{eff}^{peak} & $M_{j\tau\tau}^{peak}$

⇒ insensitive to A_0 and $\tan\beta$

Transform our Observables into Measurements

Slope

$M_{\tau\tau}^{peak}$

$M_{j\tau 1}^{(2)peak}$

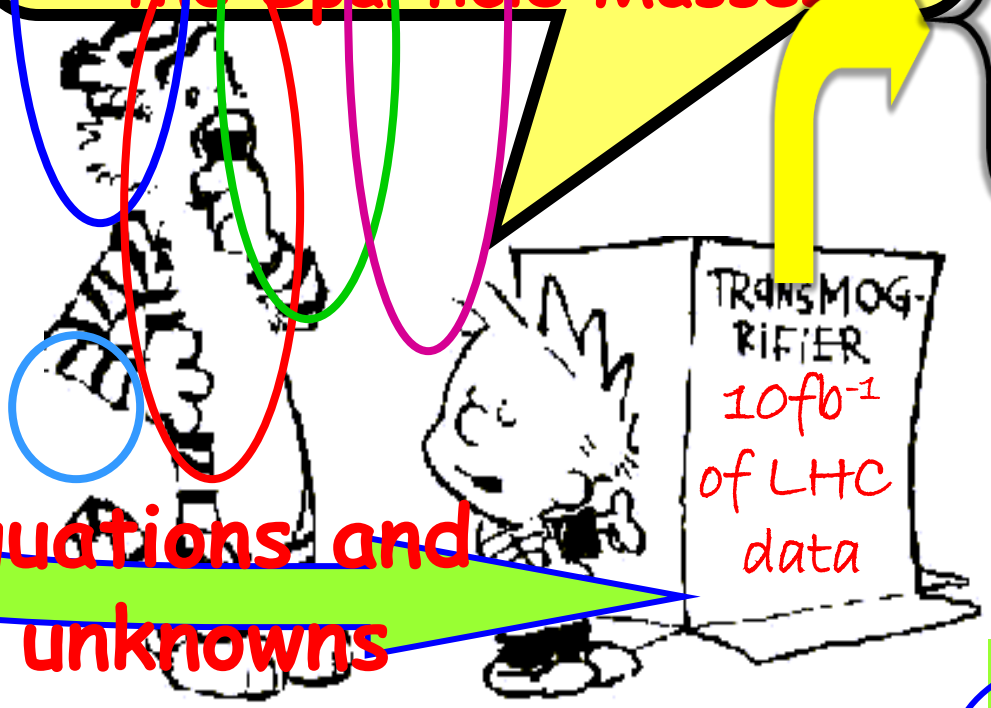
$M_{j\tau 2}^{(2)peak}$

$M_{j\tau\tau}^{(2)peak}$

M_{eff}^{peak}

Six Equations and Five unknowns

You see Hobbs, with lots of observables I can Transmogrify the measured quantities into the Sparticle Masses



$M_{\tilde{q}_L} = 748 \pm 25$

$M_{\tilde{g}} = 831 \pm 21$

$M_{\tilde{\chi}_2^0} = 260 \pm 15$

$M_{\tilde{\chi}_1^0} = 141 \pm 19$

$\Delta M = 10.6 \pm 2.0$

We can test gaugino universality to ~15%

$M_{\tilde{g}}/M_{\tilde{\chi}_2^0} = 3.1 \pm 0.2$

$M_{\tilde{g}}/M_{\tilde{\chi}_1^0} = 5.9 \pm 0.8$

Measure the mSUGRA Parameters and Ωh^2

and plugging this into DarkSUSY I can get $\Omega_{SUSY} h^2$

$M_{j\tau\tau}^{peak}$

$M_{\tau\tau}^{peak}$

M_{eff}^{peak}

$M_{eff}^{(b)peak}$

$m_0 = 210 \pm 5$

$m_{1/2} = 350 \pm 4$

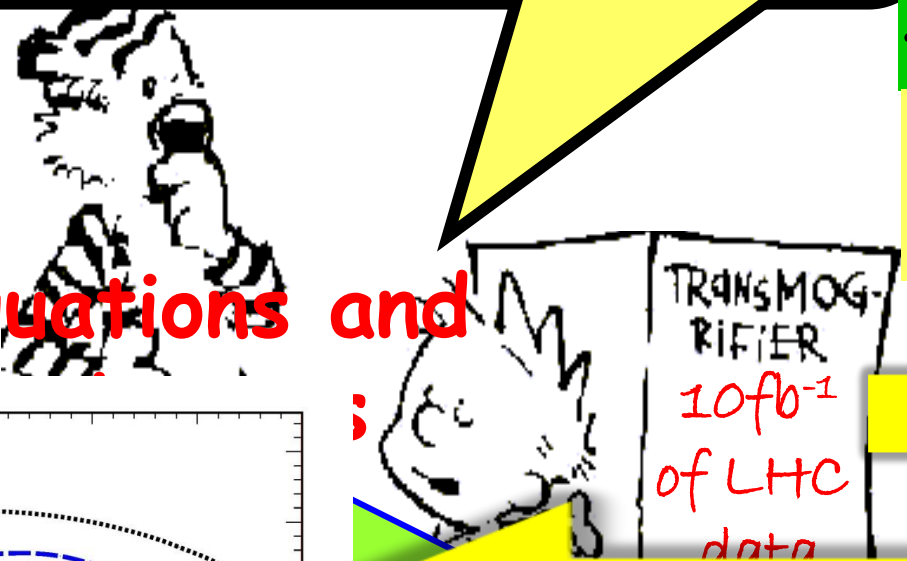
$A_0 = 0 \pm 16$

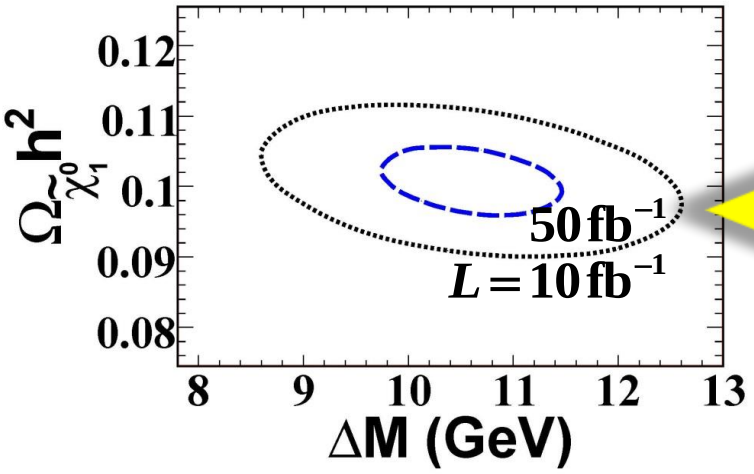
$\tan\beta = 40 \pm 1$

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

$f(m_0, m_{1/2} \tan\beta, A_0)$

Equations and



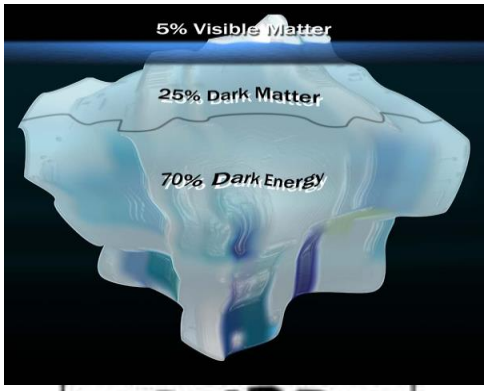


$\delta\Omega_{\tilde{\chi}_1^0} h^2 / \Omega_{\tilde{\chi}_1^0} h^2$ = 6.2% (30 fb^{-1})

= 4.1% (70 fb^{-1})

Conclusions

- If the co-annihilation region is realized in nature it provides a natural Smoking Gun that can be well measured with ~10 fb^{-1} of LHC data
- With the right datasets/observables we get
  - Sparticle mass measurements
  - Tests of Universality
  - Estimates of the SUSY parameters
  - Comparisons to precision WMAP data
  - These methods are applicable beyond minimal models and could help make measurements that would give us confidence we have discovered SUSY
- The future is bright for Particle Physics and Cosmology! But, we have a lot on our plate as the LHC data starts to come in!



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