Determination of Non-Universal SuperGravity (SUGRA) Models at the Large Hadron Collider

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Outline

Motivation and Model

Dark Matter, Supersymmetry, and nuSUGRA

LHC Measurement Techniques and nuSUGRA Observables

OS-LS, Previous Jet Subtract, Jet + 2τ, Jet + W, $M_{\rm eff}$

Conclusions

Motivation: Dark Matter

WMAP: Dark Matter is 23% of our universe!!

Supersymmetry (SUSY)

Between fermion (spin $1/2$) and boson (spin 0 or 1) particles:

SM fermion	SUSY boson	SM boson	SUSY fermion
$u,d,s...$	$\tilde{u},\tilde{d},\tilde{s}...$	g, W, Z, γ, h	$\tilde{g}$, $\tilde{\chi}^0_{1-4}$, $\tilde{\chi}^{\pm}_{1-2}$

Supersymmetry has a natural Dark Matter candidate: $\tilde{\chi}^0_1$!!

- Stable - does not decay.
- Neutral - does not interact with light.
- Weakly Interacting - right interaction for the amount of Dark Matter we see in the universe today!

mSUGRA vs. nuSUGRA

Unified Masses at the Grand Unified Scale: mSUGRA

m_0 $m_{1/2}$ A_0 $\tan(\beta)$ $\text{sign}(\mu)$

mSUGRA vs. nuSUGRA

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Unified Masses at the Grand Unified Scale: ~~mSUGRA~~ nuSUGRA

m_0 $m_{1/2}$ A_0 $\tan(\beta)$ ~~$\mathrm{sign}(\mu)$~~ $\mu(m_H)$

$\Rightarrow$

Base Point

Parameters at the GUT scale:

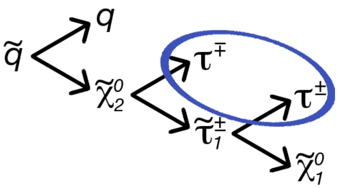
- $m_0 = 360$ GeV, $m_{1/2} = 500$ GeV, $A_0 = 0$ GeV, $\tan\beta = 40$
- Non-universal Higgs: $m_H = 732$ GeV (instead of 360 GeV)

		nuSUGRA	mSUGRA
$\tilde{\chi}_1^\pm \to$	$W^\pm \tilde{\chi}_1^0$	42%	2.4%
	$\nu\tilde{\tau}_1$	58%	98%
$\tilde{\chi}_2^0 \to$	$\tau\tilde{\tau}_1$	92%	99%

SUSY masses (in GeV):

$\tilde{g}$	$\tilde{u}_L$ $\tilde{u}_R$	$\tilde{t}_2$ $\tilde{t}_1$	$\tilde{b}_2$ $\tilde{b}_1$	$\tilde{e}_L$ $\tilde{e}_R$	$\tilde{\tau}_2$ $\tilde{\tau}_1$	$\tilde{\chi}_4^0$ $\tilde{\chi}_3^0$ $\tilde{\chi}_2^0$ $\tilde{\chi}_1^0$	$\tilde{\chi}_2^\pm$ $\tilde{\chi}_1^\pm$
1161	1114 1076	992 780	989 946	494 407	446 255	432 317 293 199	428 292

Subtraction Techniques

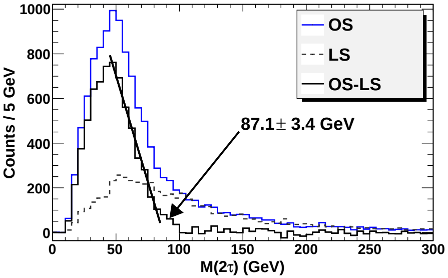


These Opposite Sign (OS) taus have related momentum.

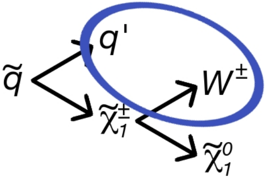
If I collect all OS taus, I will get related pairs plus random pairs.

However, if I collect all Like Sign (LS) taus, I will get only random pairs.

With enough statistics, if I perform the OS - LS subtraction, the random pairs will cancel, and I will be left with only the related pairs.



Subtraction Techniques

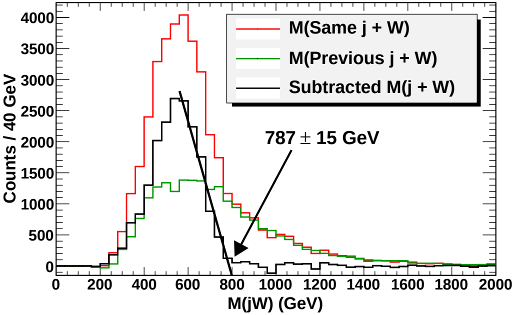


The *W* momentum is related to the momentum of this Same Event Jet.

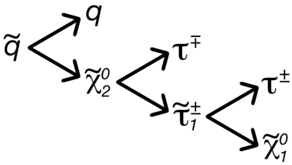
If I collect all W + Jet pairs, I will get related pairs plus random pairs.

However, if I use Jets from Previous Events, I will get only random pairs.

With enough statistics, if I normalize, then perform the Same Jet - Previous Jet subtraction, the random pairs will cancel, and I will be left with only the related pairs.

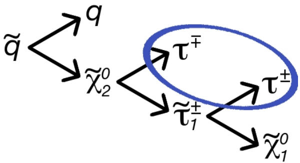


The Jet + 2τ Decay Chain



This decay chain provides three independent measurements:

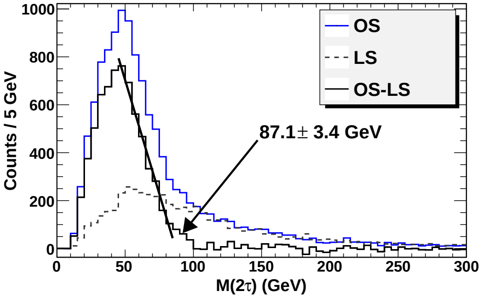
The Jet + 2τ Decay Chain



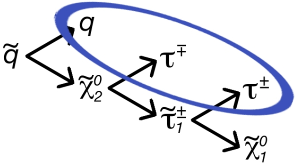
This decay chain provides three independent measurements.

1. The two τ invariant mass:

$$m(2\tau) = f_{2\tau}(m_0, m_{1/2}, A_0, \mu(m_H), \tan\beta)$$



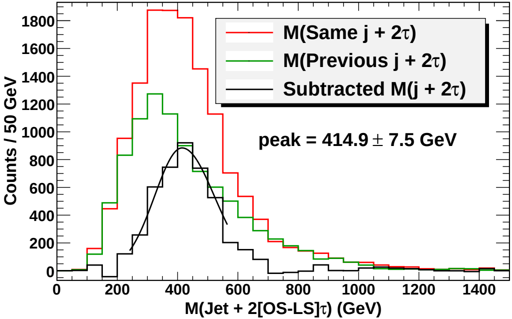
The Jet + 2τ Decay Chain



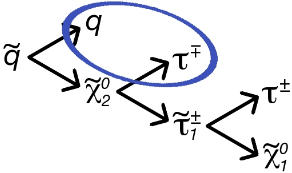
This decay chain provides three independent measurements.

2. The jet plus two τ invariant mass:

$$m(j+2\tau) = f_{j+2\tau}(m_0, m_{1/2}, \mu(m_H), \tan\beta)$$



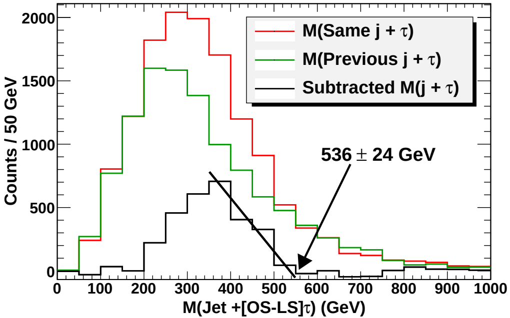
The Jet + 2τ Decay Chain



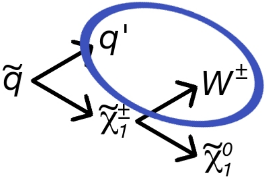
This decay chain provides three independent measurements.

3. The jet plus τ invariant mass:

$$m(j+\tau) = f_{j+\tau}(m_0, m_{1/2}, A_0, \mu(m_H), \tan\beta)$$



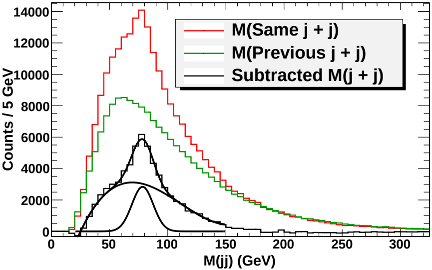
The Jet + *W* Decay Chain

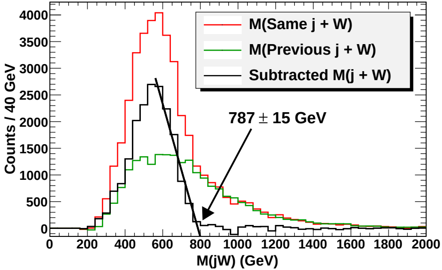


This decay chain provides one more independent measurement.

4. The jet plus *W* invariant mass:

$$m(j+W) = f_{j+W}(m_0, m_{1/2}, \mu(m_H), \tan\beta)$$



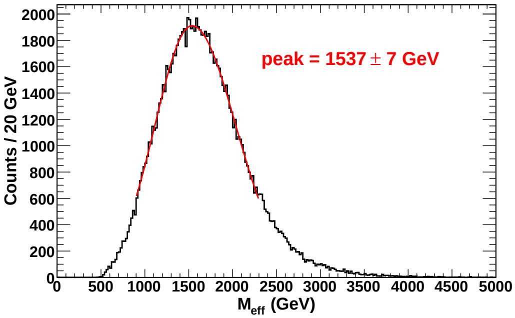


The Effective Mass M_{eff}

The last observable takes advantage of the fact that all nuSUGRA events have high energy jets from $\tilde{q}$ decays to quarks, and large missing energy from the $\tilde{\chi}_1^0$ leaving the detector.

5. The effective mass:

$$M_{\text{eff}} = f_{\text{eff}}(m_0, m_{1/2})$$



Conclusions

Preliminary, Estimated Uncertainties in Model Parameters and Dark Matter Relic Density:

$$m_0 = 359 \pm 10 \text{ GeV}, \; m_{1/2} = 502.5 \pm 2.9 \text{GeV}, \; m_H = 725 \pm 25 \text{GeV}$$
$$\Omega h^2 = 0.123 \pm 0.087 \Rightarrow 71\% \text{ uncertainty} >> \text{WMAP}$$

Also, these preliminary, estimated uncertainties are for a luminosity of 1500fb^{-1}!! Yikes... nuSUGRA is hard! We will need lots of data if Nature chooses this reality.

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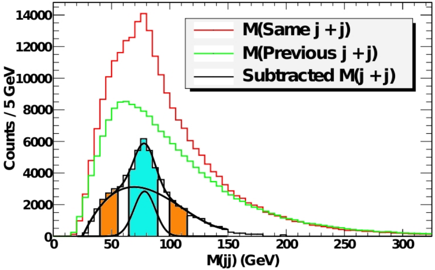
Backup Slide: Sideband Subtraction



These *W*-window Histogram Bins have *W*'s and some background.

These Sideband Histogram Bins contain mostly background.

If I fit the background shape and *W* peak, I can use the background shape to normalize the Sideband signal to the shape of the curve in the *W*-window. Then a Sideband Subtraction leaves a clean *W* signal.

Backup Slide: Solving for Model Parameters

Model Parameters may be solved for by using the model to find the functional forms for each of the observables listed above.

For example, here's $M_{\rm eff}$ as a function of $m_{1/2}$. Luckily, for this region of parameter space, $M_{\rm eff}$ does not depend so much on m_0. So simply inverting this function for $m_{1/2}$ as a function of $M_{\rm eff}$ determines $m_{1/2}$.