Reconstructing Sparticle Masses using Hadronic Decays

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[Based on Butterworth, Ellis, ARR, hep-ph/0702150]

Main Points

- Motivation: all hadronic SUSY decay chains
- Jet algorithms: the k_T-algorithm
- Summary of Monte Carlo simulation
- Conclusions

SUSY at the LHC

- Dominant SUSY cross section expected from squarks & gluinos
- These are likely to decay into gauginos
- Decays of squarks / gluinos give colour-charged decay products → high p_T jets
- Further leptonic gaugino decays much studied:

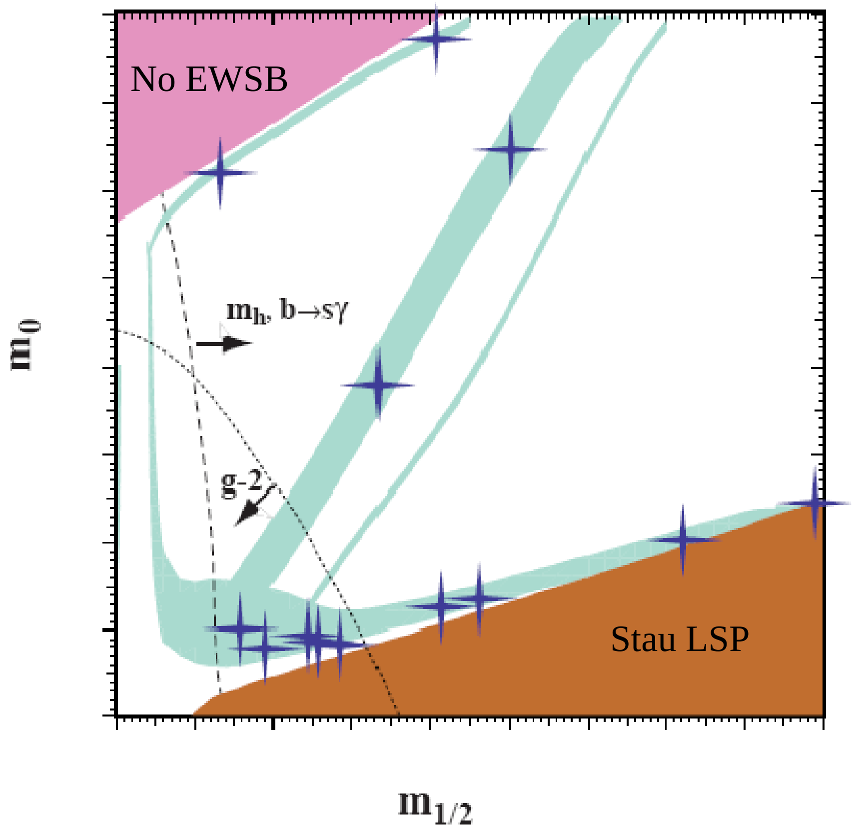
$$\tilde{q}_L \longrightarrow q\tilde{\chi}_2^0 \longrightarrow q\tilde{\ell}^{\pm}\ell^{\mp} \longrightarrow q\ell^{\mp}\ell^{\pm}\tilde{\chi}_1^0$$

SUSY at the LHC

- Dominant SUSY cross section expected from squarks & gluinos
- These are likely to decay into gauginos
- Decays of squarks / gluinos give colour-charged decay products → high p_T jets
- But what about decays into bosons?

$$\tilde{\chi}_1^{\pm} \to W\tilde{\chi}_1^0 \quad \tilde{\chi}_2^0 \to Z\tilde{\chi}_1^0 \quad \tilde{\chi}_2^0 \to h\tilde{\chi}_1^0$$

CMSSM



[Battaglia et al., hep-ph/0106204]

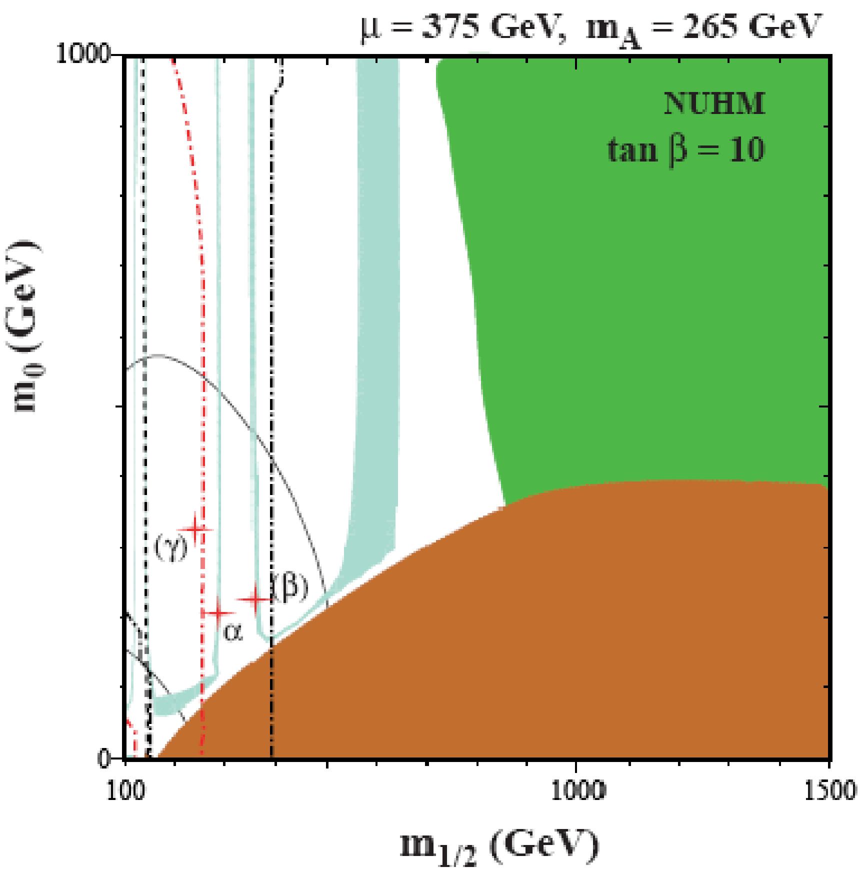
CMSSM for generic

$$A_0 \quad \tan(\beta) \quad \mathrm{sgn}\,\mu$$

Parameter space heavily constrained by WMAP results on Dark Matter

Some, but limited production of bosons

NUHM



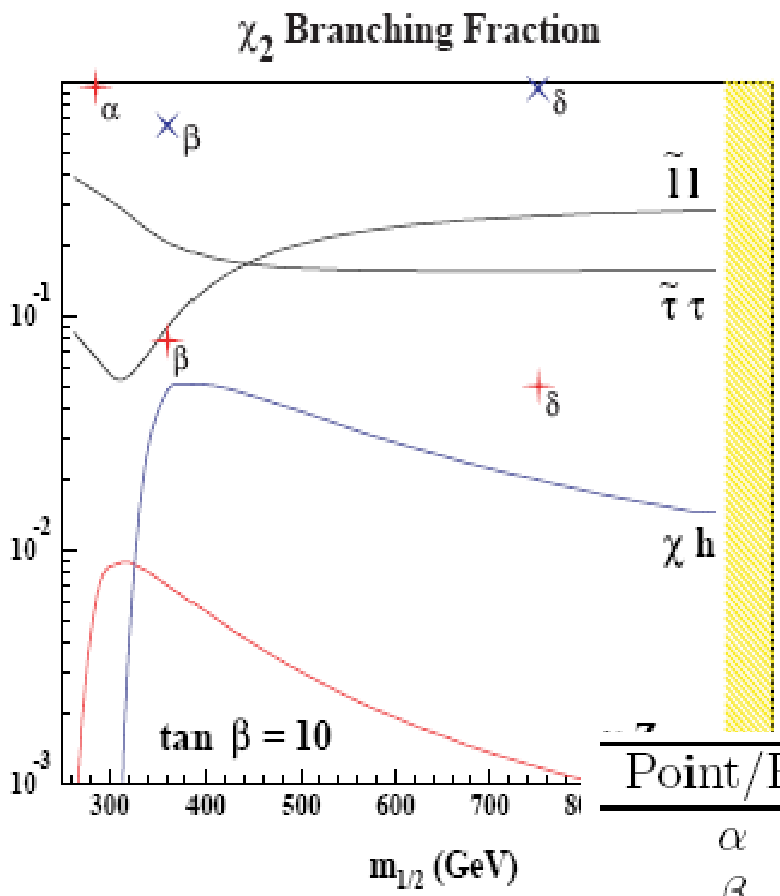
[De Roeck et al., hep-ph/0508198]

NUHM models relax unification of Higgs masses at the GUT scale

Other parameter values consistent with DM

Different decay channels "typical" for NUHM

Benchmarks



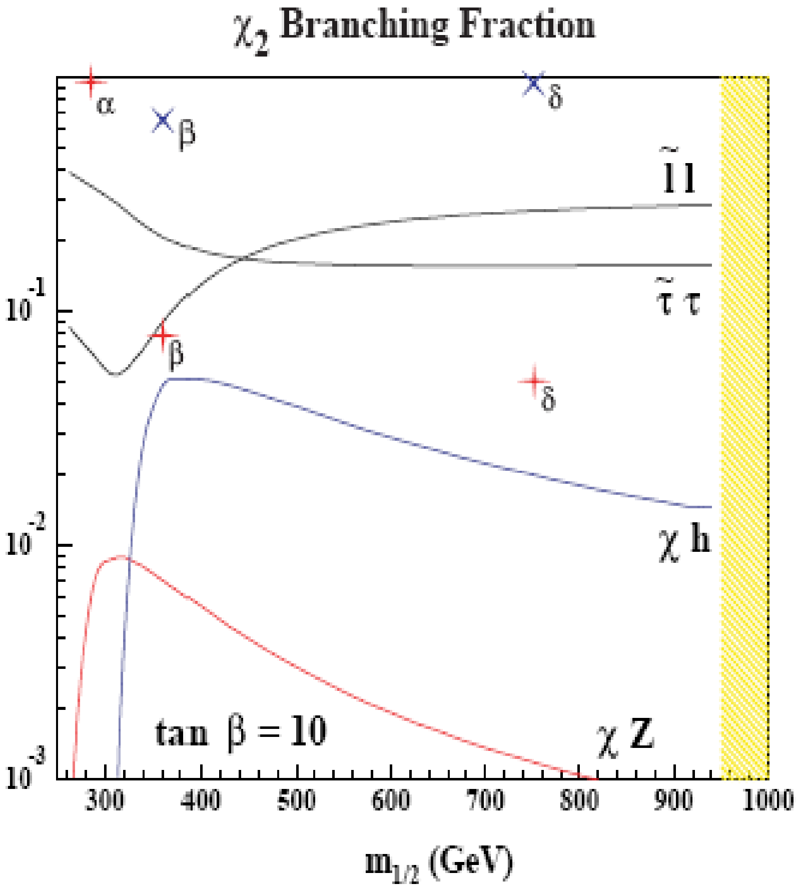
NUHM/GDM benchmark points: α, β, γ, δ

[De Roeck et al., hep-ph/0508198]

Relaxing the CMSSM can give large gaugino BR to massive bosons:

Point/BR	$\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 Z$	$\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 h$	$\tilde{\chi}_1^\pm \to \tilde{\chi}_1^0 W^\pm$
α	98.6	0.0	99.6
β	7.5	64.5	79.0
γ	0.0	0.0	99.9
δ	5.4	92.0	97.5

Benchmarks



NUHM/GDM benchmark points: α, β, γ, δ

[De Roeck et al., hep-ph/0508198]

Relaxing the CMSSM can give large gaugino BR to massive bosons

Hadronic W/Z/h-decays difficult to reconstruct due to large jet activity

Jet Algorithm

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- Important to extract as much information as possible from jets (not only for SUSY...)
- We use the k_T jet algorithm. This gives us:
  - By construction: a jet mass
  - Scale y where a jet separates into two sub-jets

The k_T-algorithm

1. For every pair of particles (k,l) calculate

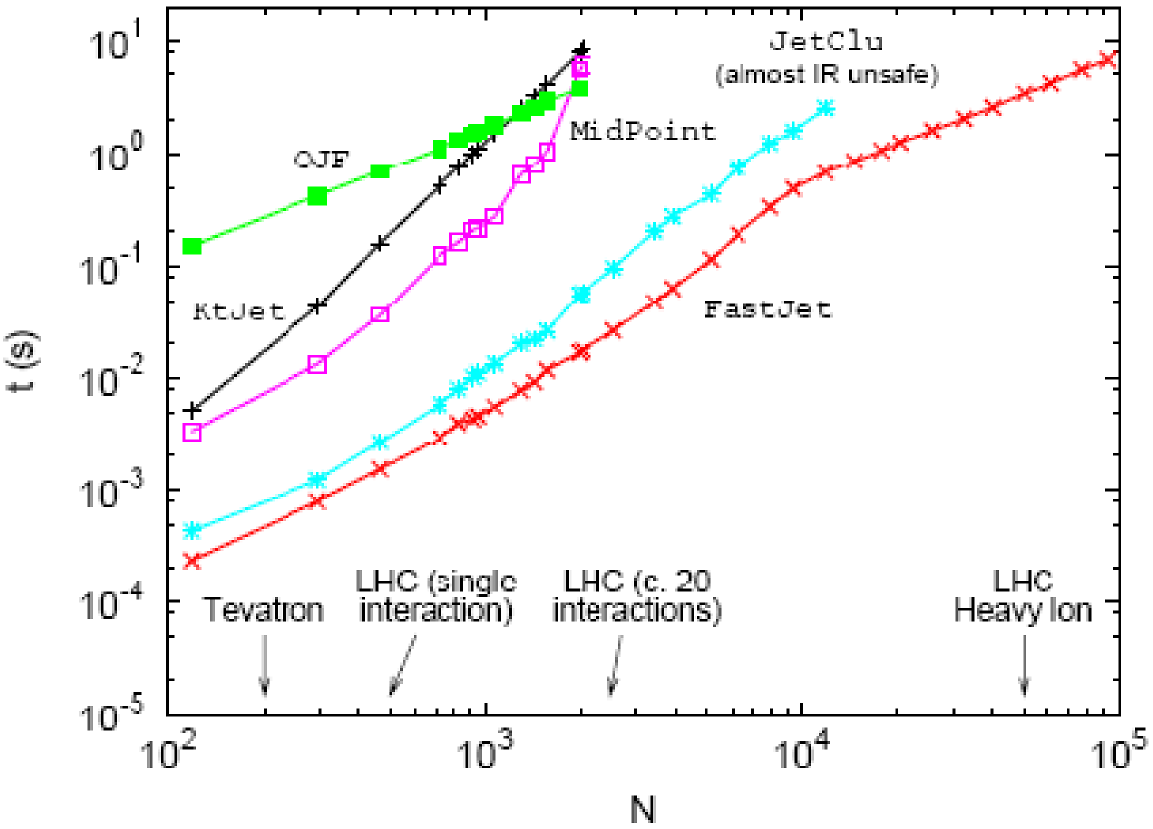
$$
\begin{aligned}
d_{kB} &= p_{Tk}^2 \\
d_{lB} &= p_{Tl}^2 \\
d_{kl} &= \min\,(p_{Tk}^2, p_{Tl}^2) R_{kl}^2 / R^2
\end{aligned}
$$

2. If d_{kB} or d_{lB} is smaller, the particle is labeled as a jet and removed
3. If d_{kl} is smaller, particles k and l are merged
4. Continue until all particles have been removed

Jet Algorithm

- Search for W/Z/h in jet pairs with correct mass give too large combinatorics
- We look for the collimated jets from the decay of a boosted heavy boson
- For jets from such a boson with mass M the expectation for $y p_T^2$ is $O(M^2)$
- For QCD jets initiated by single quark or gluon we expect $y \ll 1$

What About Speed?

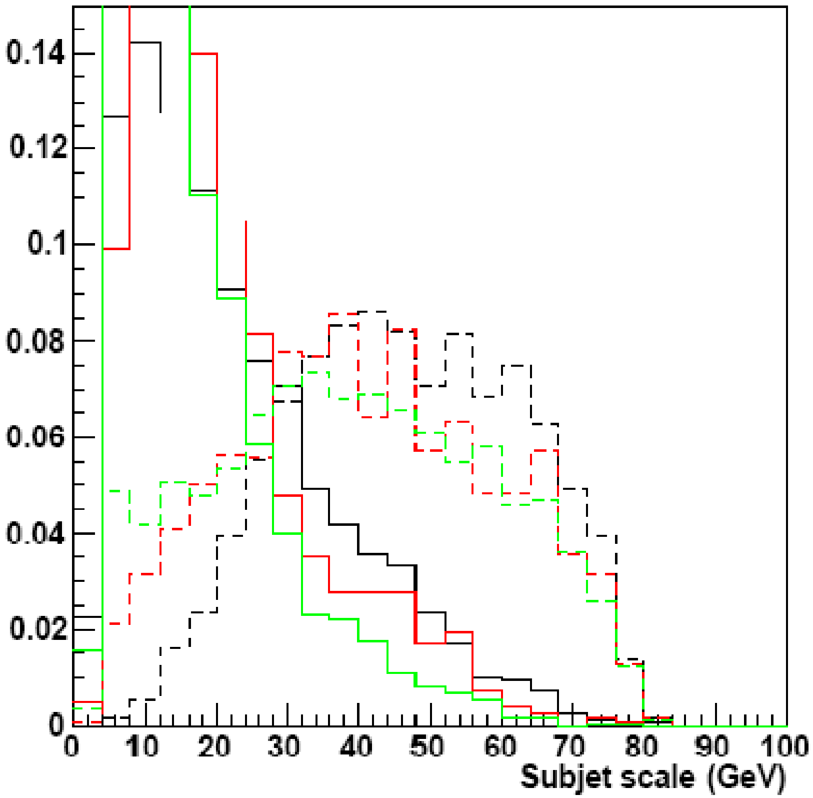


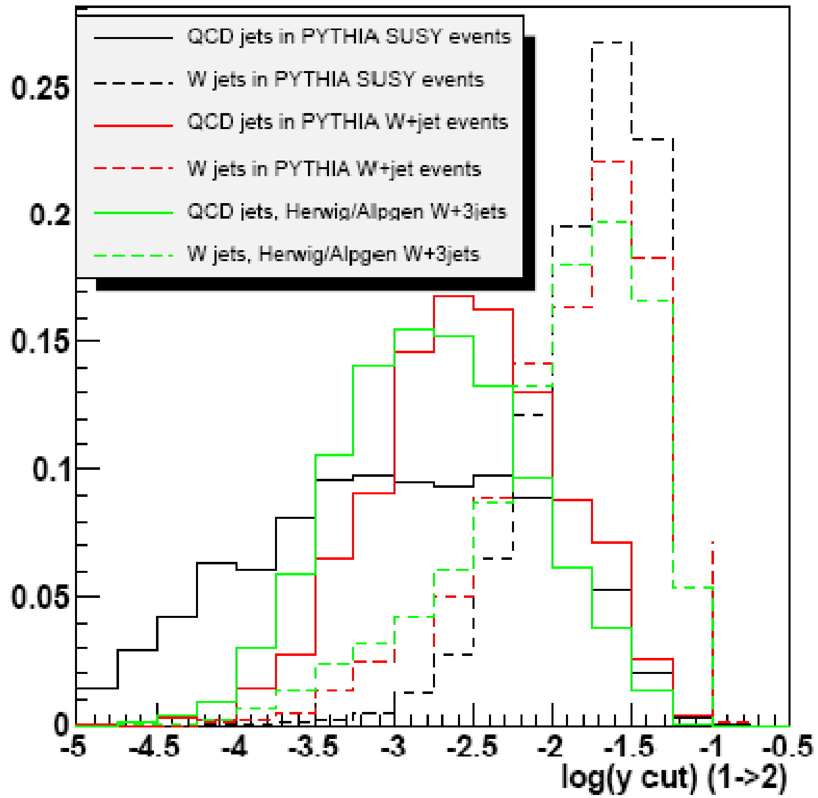
Traditional k_T computing time scales as N^3

FastJet shown to scale as $N \times \ln N$

[Cacciari, Salam, hep-ph/0512210]

Results of k_T-algorithm



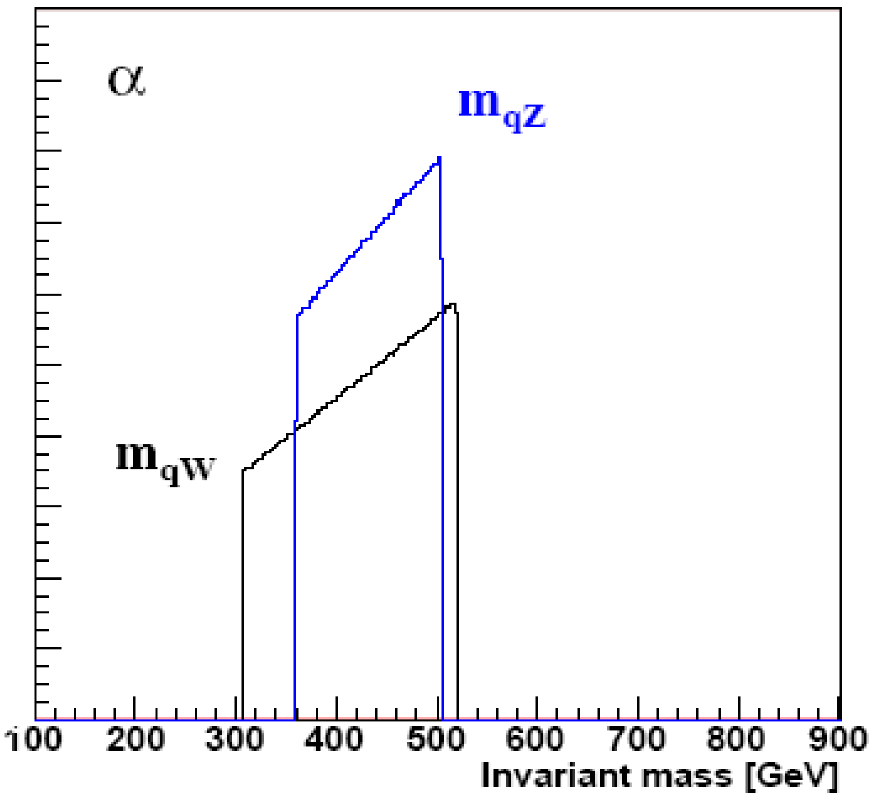


[Butterworth, Ellis, ARR, hep-ph/0702150]

Simulation

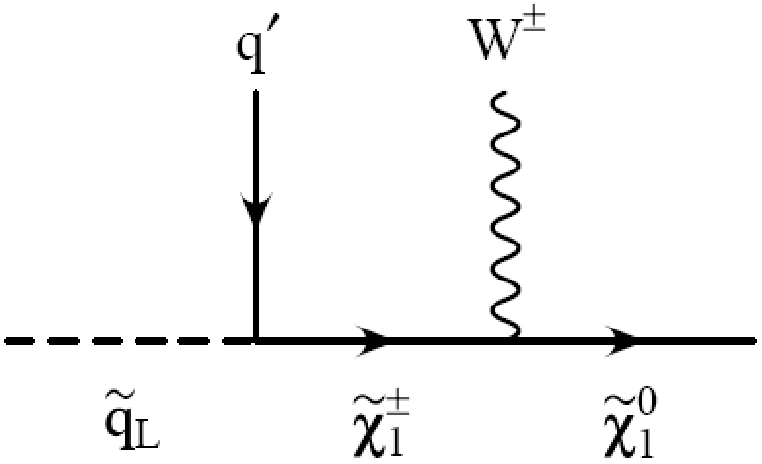
- Monte Carlo study using
  - PYTHIA 6.408 & CTEQ 5L (signal)
  - ALPGEN/HERWIG 6.510/JIMMY (background)
- No detector simulation!
- But quite a lot of background:
  - Wj, Zj, Wjj, Zjj, Wjjj, Zjjj, WW, WZ, ZZ, WWj, WZj, ZZj, WWjj, WZjj, ZZjj + ttbar
  - Statistics of 100-300 fb^{-1} for the most important backgrounds

Results – an Example

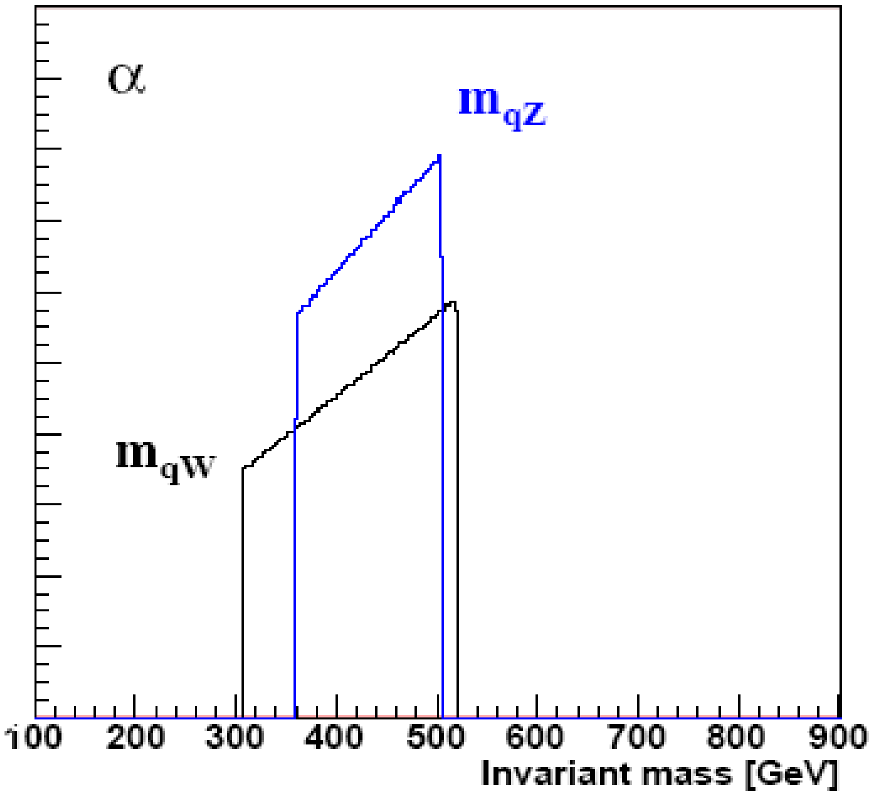


Looking for the decay

$$\tilde{q}_L \to q' \tilde{\chi}_1^{\pm} \to q' W \tilde{\chi}_1^0$$



Results – an Example



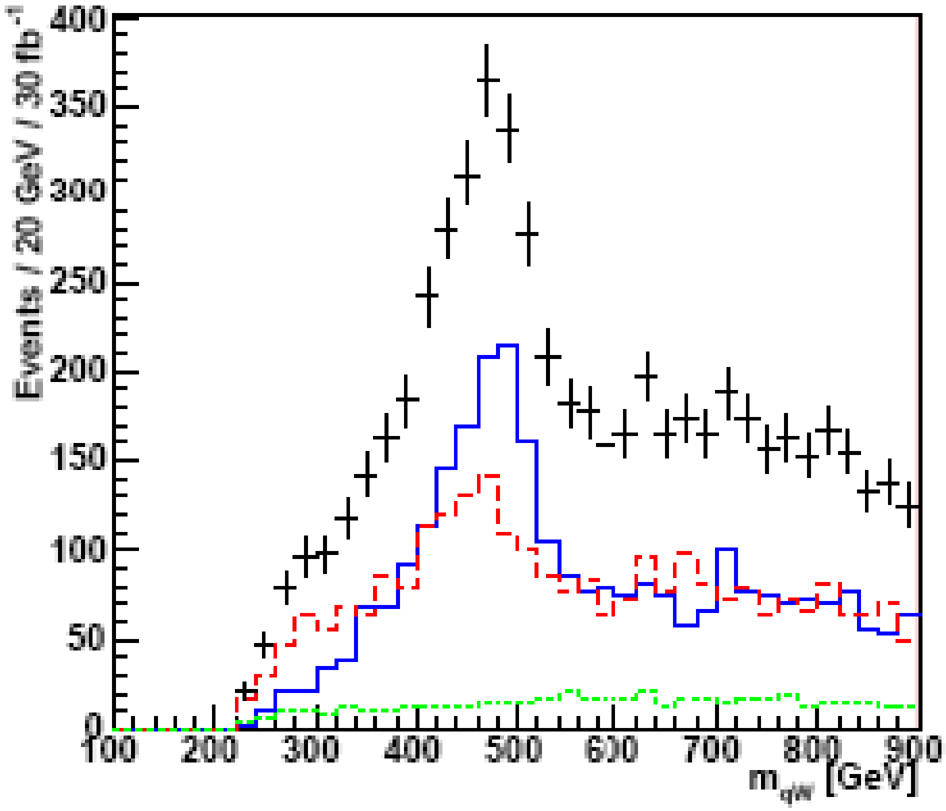
Looking for the decay

$$\tilde{q}_L \rightarrow q'\tilde{\chi}_1^{\pm} \rightarrow q'W\tilde{\chi}_1^0$$

SM background cuts:

- Missing E_T > 300 GeV
- Three jets with p_T > 200, 200, 150 GeV
- No leptons with p_T > 10 GeV

Results – an Example



Looking for the decay

$$\tilde{q}_L \to q'\tilde{\chi}_1^{\pm} \to q'W\tilde{\chi}_1^0$$

Identify W jets:

- Using a jet mass cut

$$75 < m_W < 105$$

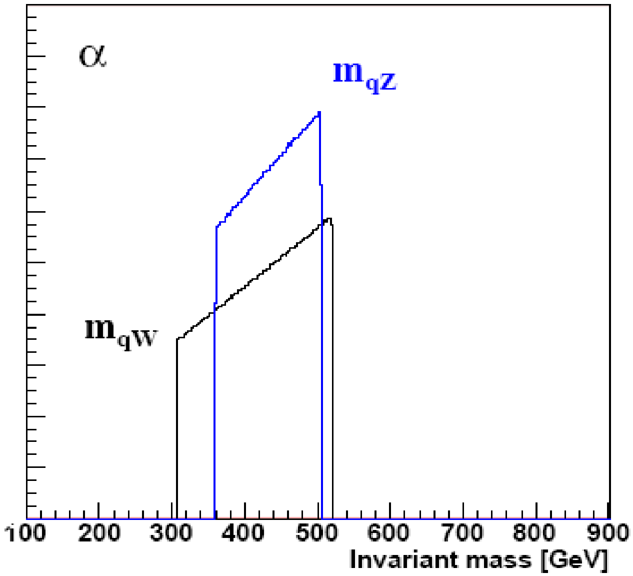
- Using a jet scale cut

$$1.5 < \log\left(p_T\sqrt{y}\right) < 1.9$$

Mass Constraints

Endpoints of distributions are given by:

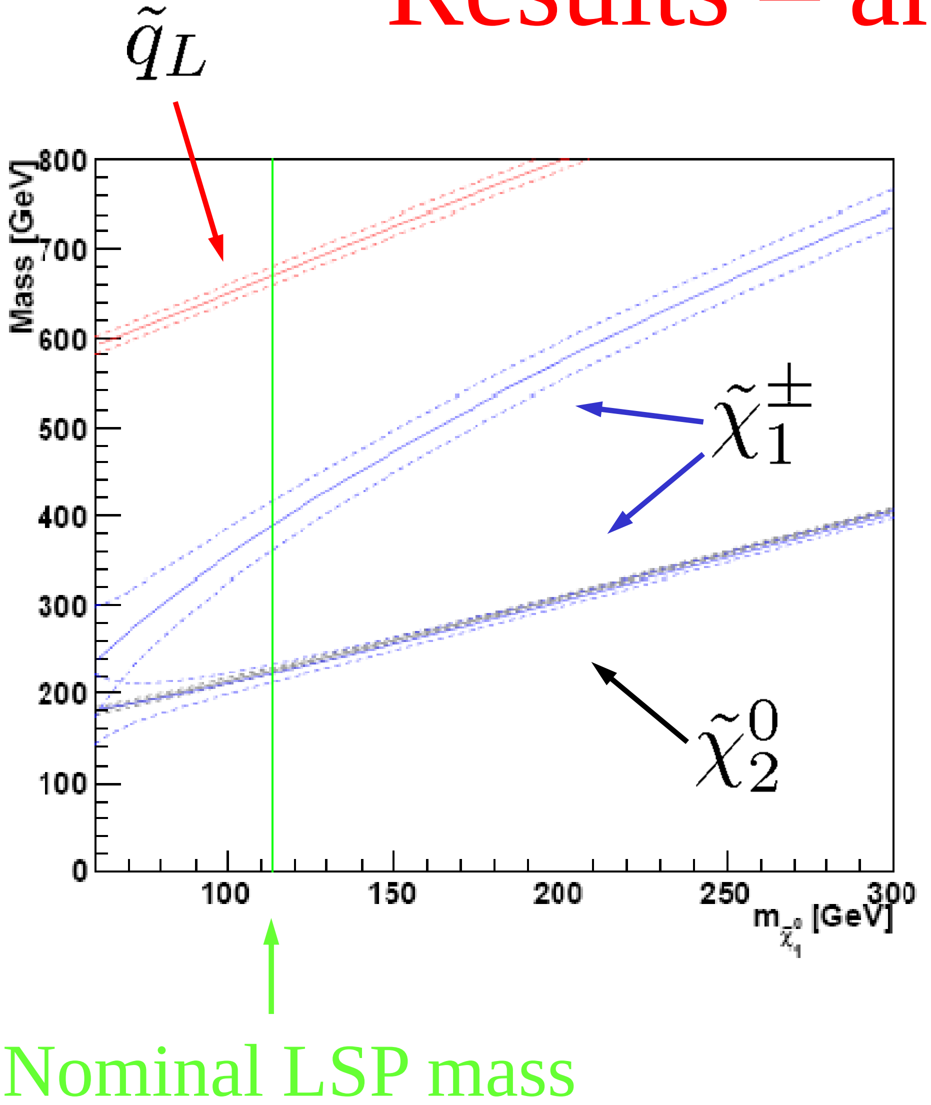
$$(m_{qW}^{\max/\min})^2 = m_W^2 + \frac{m_{\tilde{q}_L}^2 - m_{\tilde{\chi}_1^\pm}^2}{m_{\tilde{\chi}_1^\pm}}(E_W \pm |\vec{p}_W|)$$



where

$$|\vec{p}_W|^2 = \frac{(m_{\tilde{\chi}_1^\pm}^2 - m_{\tilde{\chi}_1^0}^2 - m_W^2)^2 - 4m_W^2 m_{\tilde{\chi}_1^0}^2}{4m_{\tilde{\chi}_1^\pm}^2}$$

Results – an Example



Looking for

$$\tilde{q}_L \to q'\tilde{\chi}_1^{\pm} \to q'W\tilde{\chi}_1^0$$

and using

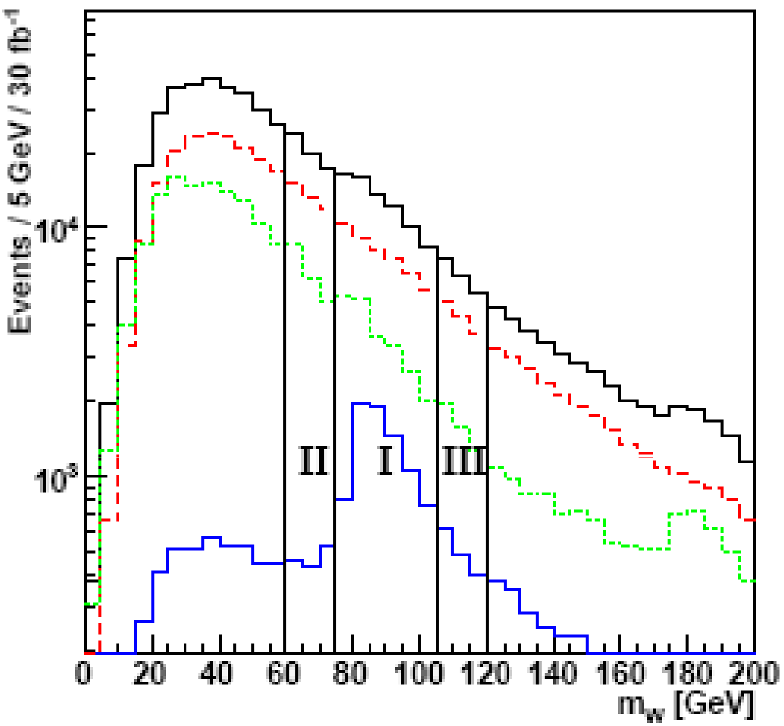
$$\tilde{q}_L \to q\tilde{\chi}_2^0 \to qZ\tilde{\chi}_1^0$$

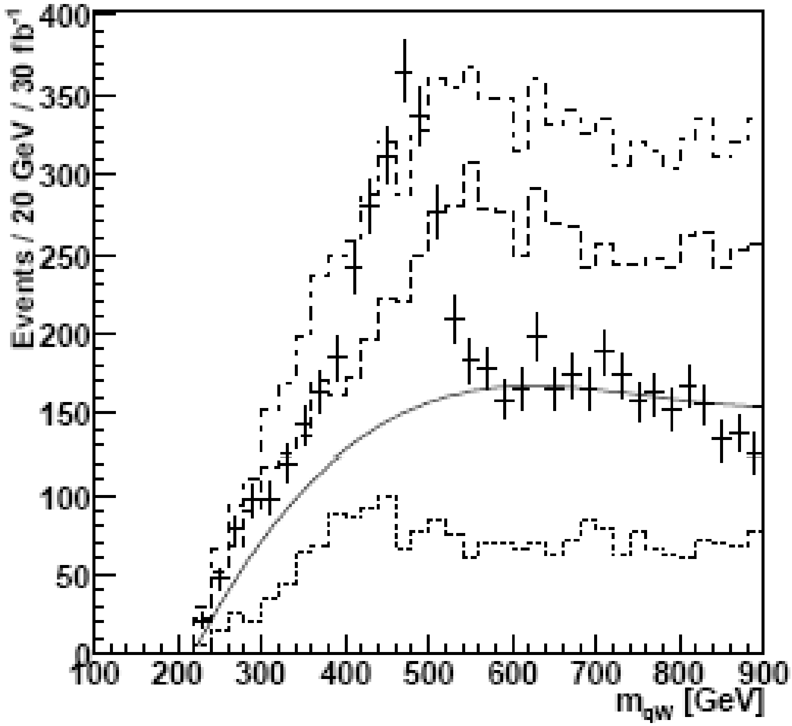
we get strong constraints between masses

Conclusions

- Cuts on jet properties – mass and separation scale – effective to isolate jets from the hadronic decays of heavy bosons
- The resulting invariant mass distributions put strong constraints on SUSY spectrum
- Important to understand systematics from UE & ISR + detector effects
- Many uses beyond in BSM and even BSUSY...

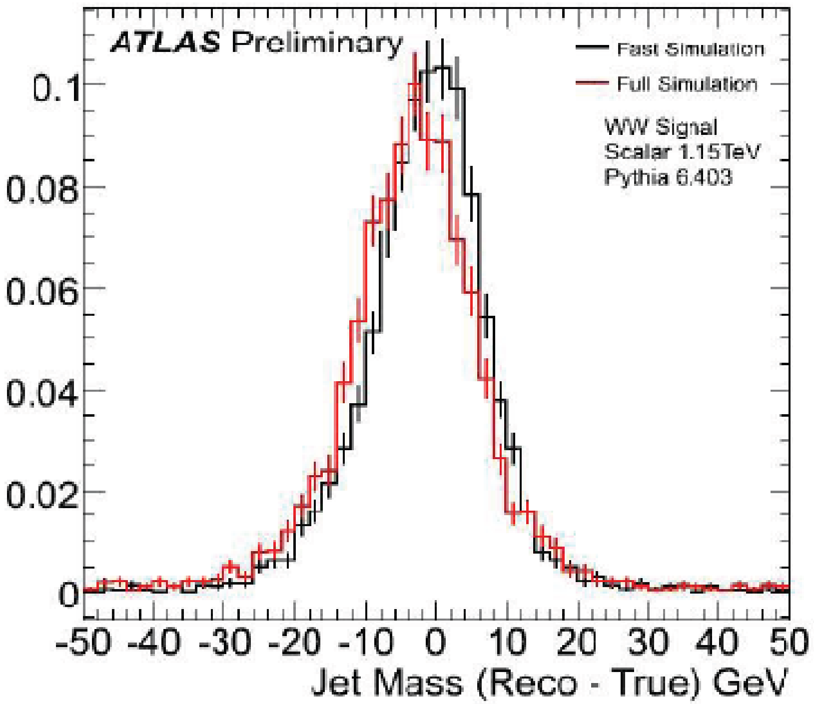
Sideband Subtraction

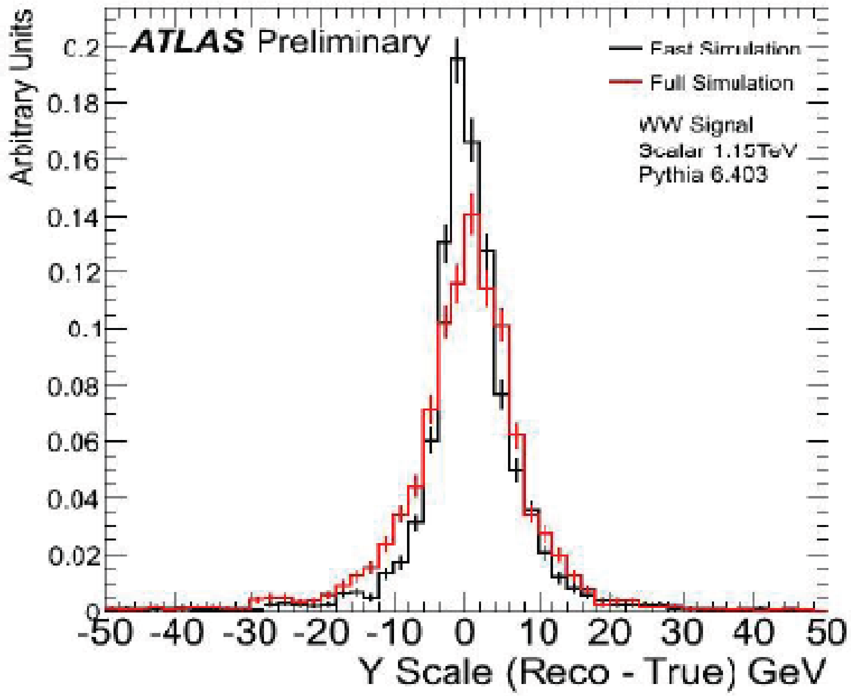




Detector Effects

Results from WW$\rightarrow$ WW scattering:





[Butterworth, Davison, ATLAS Jet/ETMiss Group]

mSUGRA?

The MSSM has four types of SUSY-breaking parameters:

$$m_0 \quad m_{1/2} \quad A_0 \quad B_0$$

mSUGRA $\Rightarrow A_0 = B_0 + m_0$ [Nilles, 1984]

CMSSM	mSUGRA
EWSB fixes B_0	EWSB fixes $\tan(\beta)$
$m_0 \quad m_{1/2}$	$m_0 \quad m_{1/2}$
$A_0 \quad \tan(\beta) \quad \text{sgn}\,\mu$	$A_0 \quad \text{sgn}\,\mu$