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SUSY Measurements with ATLAS: Hadronic Signatures and Focus Point

Outline

- Reconstruction of gluino, right-handed squarks and 3rd generation squarks for some low-mass mSUGRA benchmark points
- First study of gluino decays in the focus-point region

Bulk and Focus Point regions

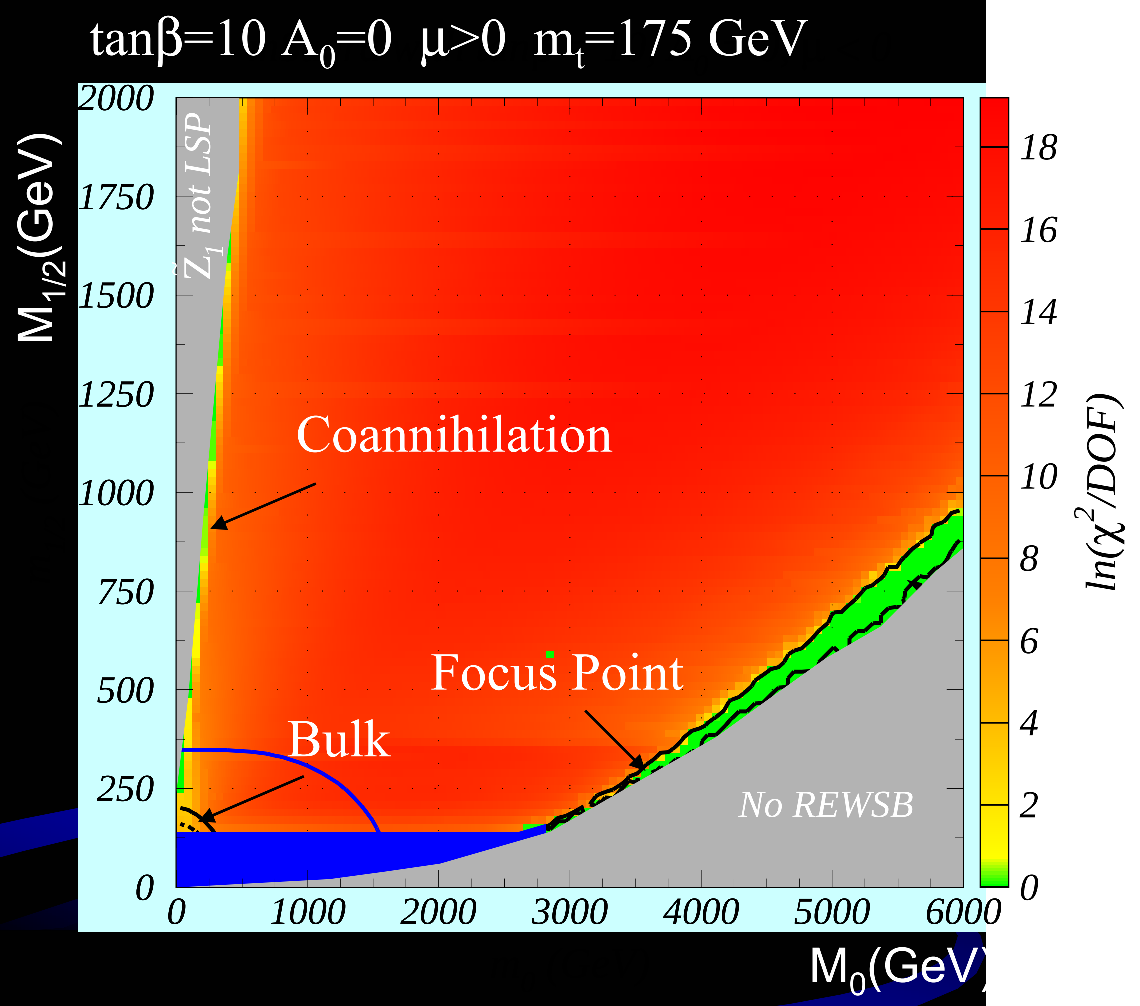
Green: Regions of mSUGRA parameter space that give an acceptably low density of relic neutralinos

1st part of the talk

Bulk low-mass: Several well-studied benchmark points

2nd part of the talk

Focus Point: Studies started more recently.



H. Baer and C. Balazs, arXiv:hep-ph/0303114

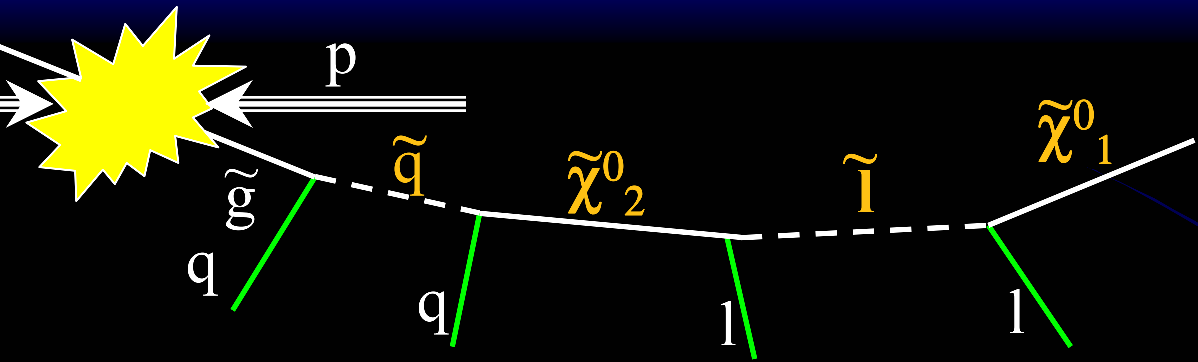
Possible SUSY timeline

- Phase 1- Discovery: See excess of events with large missing energy, make sure they are from New Physics

- Phase 2 - First SUSY masses: Reconstruction of leptonic decays, combine lepton with jets
  - G. Comune's talk

- Phase 3 - More SUSY masses: Combine with b-jets and reconstructed tops. Purely hadronic final states.
  - This talk

Phase 2: a typical decay chain



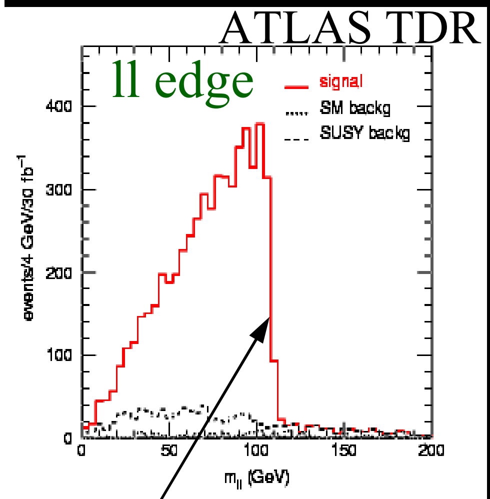
Other possibilities:

$\tilde\chi^0_2 \rightarrow \tilde\chi^0_1\, l^+l^-$

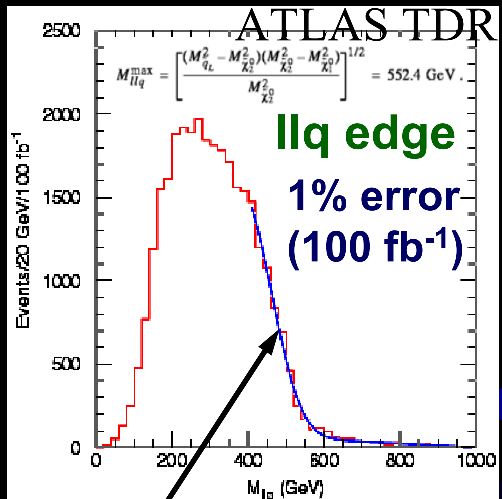
$\tilde\chi^0_2 \rightarrow \tilde\chi^0_1\, h \rightarrow \tilde\chi^0_1 bb$

The invariant mass of each combination has a minimum or a maximum which provides one constraint on the masses of $\tilde\chi^0_1$ $\tilde\chi^0_2$ $\tilde l$ $\tilde q$

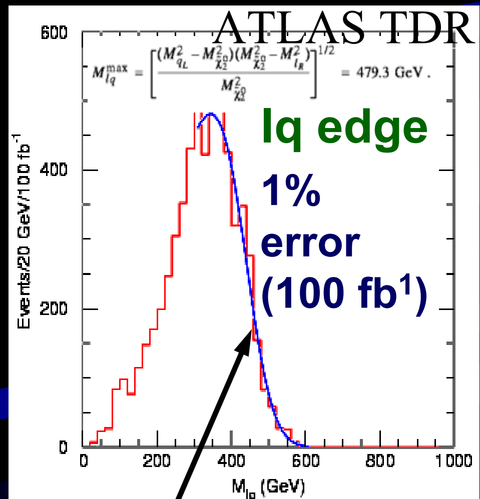
LHCC Point 5



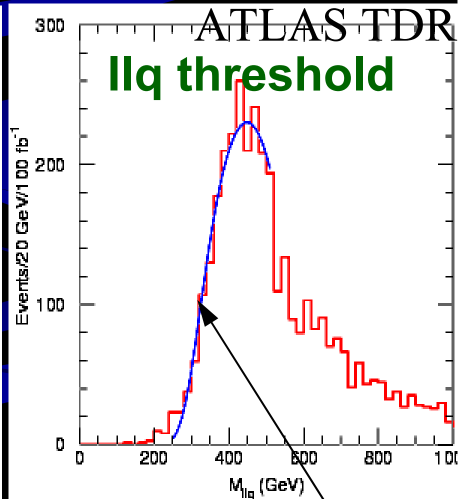
$$M_{ll}^{max} = M(\tilde\chi^0_2)\sqrt{1-\frac{M^2(\tilde l_R)}{M^2(\tilde\chi^0_2)}}\sqrt{1-\frac{M^2(\tilde\chi^0_1)}{M^2(\tilde l_R)}}$$



$$M_{llq}^{max} = \left[\frac{(M^2_{\tilde q_L}-M^2_{\tilde\chi^0_2})(M^2_{\tilde\chi^0_2}-M^2_{\tilde\chi^0_1})}{M^2_{\tilde\chi^0_2}}\right]^{1/2}$$



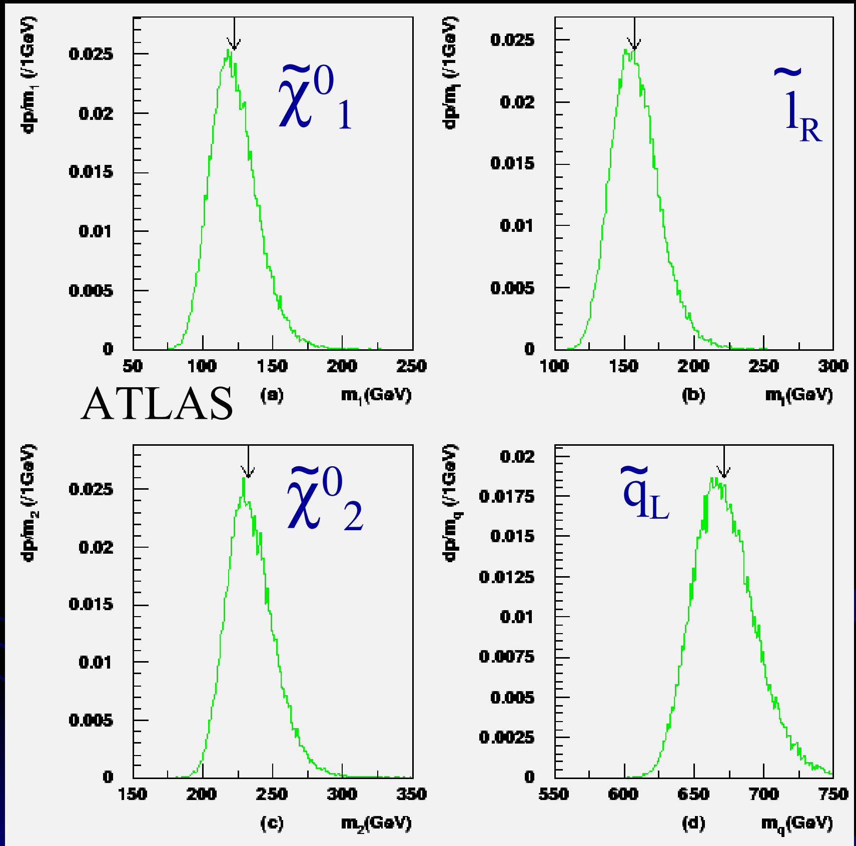
$$M_{lq}^{max} = \left[\frac{(M^2_{\tilde q_L}-M^2_{\tilde\chi^0_2})(M^2_{\tilde\chi^0_2}-M^2_{\tilde l_R})}{M^2_{\tilde\chi^0_2}}\right]^{1/2}$$



$$(m_{llq}^{min})^2 = \Big\{\big[\,2\tilde l(\tilde q-\tilde\xi)(\tilde\xi-\tilde\chi)+(\tilde q+\tilde\xi)(\tilde\xi-\tilde l)(\tilde l-\tilde\chi) - (\tilde q-\tilde\xi)\sqrt{(\tilde\xi+\tilde l)^2(\tilde l+\tilde\chi)^2-16\tilde\xi\tilde l^2\tilde\chi}\,\big]/(4\tilde l\tilde\xi)$$

Model-independent masses

- Combine measurements from edges from different jet/lepton combinations to obtain 'model-independent' mass measurements.



masses (GeV)	LHCC5	SPS1a
$m(\tilde{\chi}^0_1)$	122	96
$m(\tilde{l}_R)$	157	143
$m(\tilde{\chi}^0_2)$	233	177
$m(\tilde{q}_L)$	687-690	537-543

Sparticle	Expected precision (100 fb^{-1})
$\tilde{q}_L$	± 3%
$\tilde{\chi}^0_2$	± 6%
$\tilde{l}_R$	± 9%
$\tilde{\chi}^0_1$	± 12%

Going up the decay chain

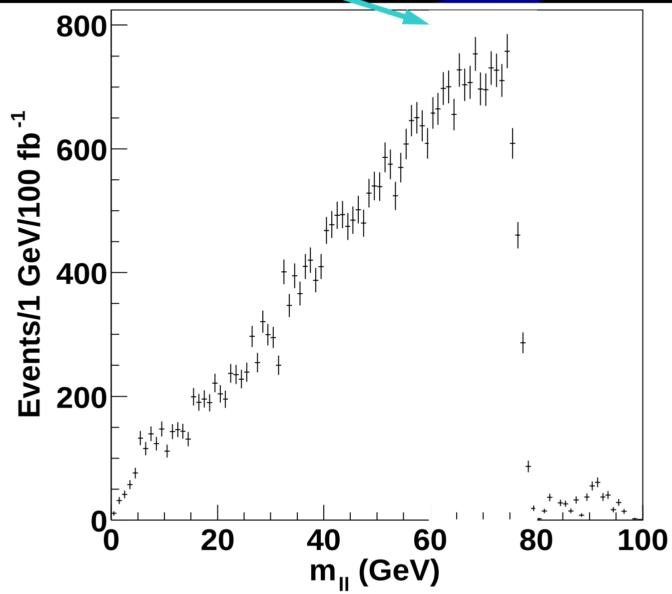
- Once the mass of the $\tilde{\chi}^0_1$ is known, it is possible to get the momentum of the $\tilde{\chi}^0_2$ using the approximate relation

$$p(\tilde{\chi}^0_2) = \left(1 - m(\tilde{\chi}^0_1)/m(ll) \right) p_{ll}$$

valid for lepton pairs with invariant mass near the edge.

- The $\tilde{\chi}^0_2$ can be combined with b-jets to reconstruct the gluino mass peak:

$$\tilde{g} \rightarrow b\tilde{b} \rightarrow bb\tilde{\chi}^0_2$$



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Example: SPS1a

B.K.Gjelsten et al., ATL-PHYS-2004-007

$M_0 = 100$ GeV
$M_{1/2} = 250$ GeV
$\tan\beta = 10$
$A = -100$ GeV
$\mu > 0$

$M(\tilde{g}) = 611$ GeV
$M(\tilde{b}_1) = 515$ GeV
$M(\tilde{b}_2) = 539$ GeV
$M(\tilde{\chi}^0_2) = 177$ GeV

Gluino and sbottom reconstruction

Good combinations.
m($\tilde{g}$) and m($\tilde{b}$) correlated
(Dominant error from
$\tilde{\chi}^0_2$ Momentum affects both)

Bad $\tilde{\chi}^0_2$ b combinations (b-jet is from gluino decay)

ATLAS - ATL-PHYS-2004-007

a reasonable statistics for the analysis. We plot in Fig 4 the flavour-subtracted distribution of $m(\tilde{\chi}^0_2 b)$ versus $m(\tilde{\chi}^0_2 bb)$, for both b jets, assuming the nominal values for $m(\tilde{\chi}^0_1)$ and $m(\tilde{\chi}^0_2)$. Two well-separated regions appear in the plot, of which one corresponds to the

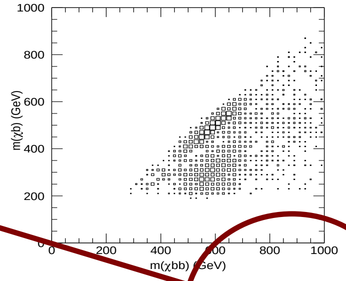

Figure 4: Distribution of $m(\tilde{\chi}^0_2 b)$ versus $m(\tilde{\chi}^0_2 bb)$ for events passing the selections.

correct $\tilde{\chi}^0_2 b$ pai[illegible] for the reconstruction of the $\tilde{b}$, and shows a strong correlation between the $\tilde{g}$ and the $\tilde{b}$ [illegible]ass. The second region corresponds to the situation in which $m(\tilde{\chi}^0_2 b)$ is calculated taki[illegible] the b-jet from the $\tilde{g} \to b\tilde{b}$ decay. We select the interesting region on the 2-dimensional p[illegible] by requiring $380 < m(\tilde{\chi}^0_2 b) < 600$ GeV and $m(\tilde{\chi}^0_2 bb) - m(\tilde{\chi}^0_2 b) > 150$ GeV. The main residual background consists where the cascade identified by OS-SF the lepton pair originates from a squark of the first four generations, and the leading b is part of a different cascade. We suppress this background by requiring that the invariant mass of the $\tilde{\chi}^0_2$ with the leading jet not tagged as b is outside of the interval 400 GeV to 600 GeV. The $m(\tilde{\chi}^0_2 bb)$ after these cuts is shown in Fig. 5. Superimposed in blue is the residual background. The width of the distribution is dominated by the $\tilde{\chi}^0_2$ momentum mismeasurement. The statistical uncertainty on the peak position is ~ 4 GeV for 100 fb^{-1} and ~ 2.5 GeV for 300 fb^{-1}, and the central value is ~ 10 GeV lower than the nominal $\tilde{g}$ mass. The displacement of the fit value from the nominal value is related to an underestimate of the energy of part of the b jets.

For this analysis we assume that both $\tilde{\chi}^0_1$ and $\tilde{\chi}^0_2$ would be measured with the technique described in the previous section. As already discussed above, this results in a strong correlation between the measured $\tilde{\chi}^0_1$ and $\tilde{\chi}^0_2$ masses which can be parametrized as:

$$m(\tilde{\chi}^0_2) = 82.85 + 0.977 \times m(\tilde{\chi}^0_1)$$

Therefore, to evaluate the dependence of the measured gluino mass on the assumed $\tilde{\chi}^0_1$ and $\tilde{\chi}^0_2$ masses, we varied only the $\tilde{\chi}^0_1$ mass between 76 and 116 GeV, and the $\tilde{\chi}^0_2$ mass

7

Gluino mass reconstruction

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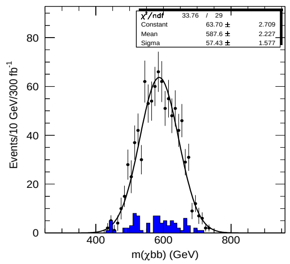

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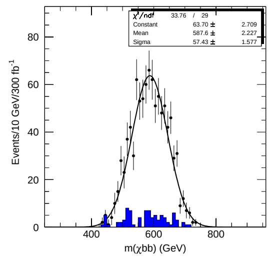

Figure 5: $m(\tilde{\chi}^0_2 bb)$ after all cuts. The residual SUSY background is shown in blue. Superimposed is a gaussian fit. The distribution is shown for an integrated statistics of 300 fb^{-1}

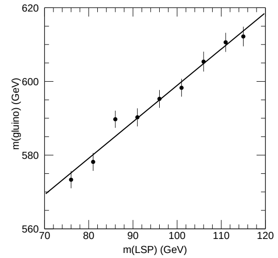

Figure 6: *Estimated $m(\tilde{g})$ as a function of the $m(\tilde{\chi}^0_1)$ assumed as input of the fit.*

8

Reconstructed gluino mass. Width dominated by $\tilde{\chi}^0_2$ momentum.

Gluino mass as a function of the assumed $\tilde{\chi}^0_1$ mass.

$m(\tilde{g})-0.99m(\tilde{\chi}^0_1) = (500.0 \pm 6.4)$ GeV with 300 fb^{-1}

Error is statistical plus 1% uncertainty on jet energy scale

Central value 10 GeV lower than nominal because b-jet energy underestimated

sbottom mass

$m(\tilde\chi^0_2\, bb)$ and $m(\tilde\chi^0_2\, b)$ strongly correlated : use the difference

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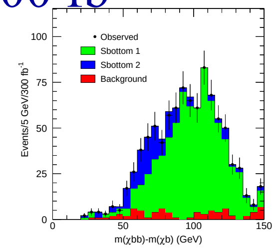
300 fb^{-1}



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300 fb^{-1}

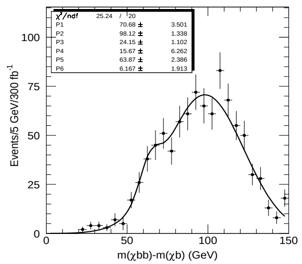

Figure 8: Distribution of $m(\tilde\chi^0_2 bb) - m(\tilde\chi^0_2 b)$ for an integrated luminosity of 300 fb^{-1}. Superimposed is the fit performed assuming the sum of two gaussian distributions.

10

With 300 fb^{-1} it should be possible to separate the $\tilde b_1$ and $\tilde b_2$ peaks

$m(\tilde g)-m(\tilde b_1) = (103.3 \pm 1.8)$ GeV $m(\tilde g)-m(\tilde b_2) = (70.6 \pm 2.6)$ GeV

With lower statistics only measure the average

Right-handed squark

$\tilde{q}_R$ does not couple to Wino
$\tilde{\chi}^0_1$ is nearly a Bino
$\tilde{\chi}^0_2$ is nearly a Wino

$\Rightarrow$ $\tilde{q}_R \rightarrow q\, \tilde{\chi}^0_1$

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Combine the transverse momentum of two leading jets with missing transverse momentum as follows:

$$M_{T2}^2 = \min_{\not{p}_1 + \not{p}_2 = \not{p}_T} \left[\max \left\{ m_T^2(p_T^{\ell_1}, \not{p}_1), m_T^2(p_T^{\ell_2}, \not{p}_2) \right\} \right]$$

Maximum of this variable is $m(\tilde{q}_R)-m(\tilde{\chi}^0_1)$

$m(\tilde{q}_R)-m(\tilde{\chi}^0_1) = (424.2 \pm 10.9)$ GeV

Note: can reconstruct $\tilde{l}_L \rightarrow l\, \tilde{\chi}^0_1$ with same technique

$m(\tilde{l}_L)-m(\tilde{\chi}^0_1) = (106.1 \pm 1.6)$ GeV

30 fb^{-1}

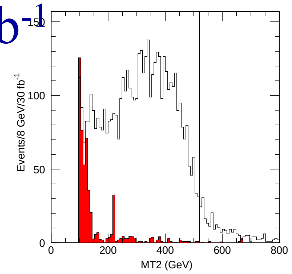


Figure 14: Distribution of M_{T2} for the events passing the cuts. In red is shown the Standard Model background. The integrated statistics in the plot is 30 fb^{-1}.

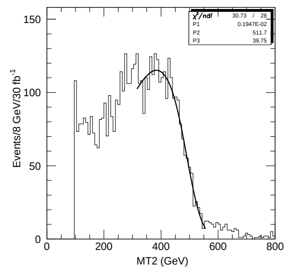


Figure 15: Distribution of M_{T2} for events passing the cuts. Superimposed is the fit described in the text.

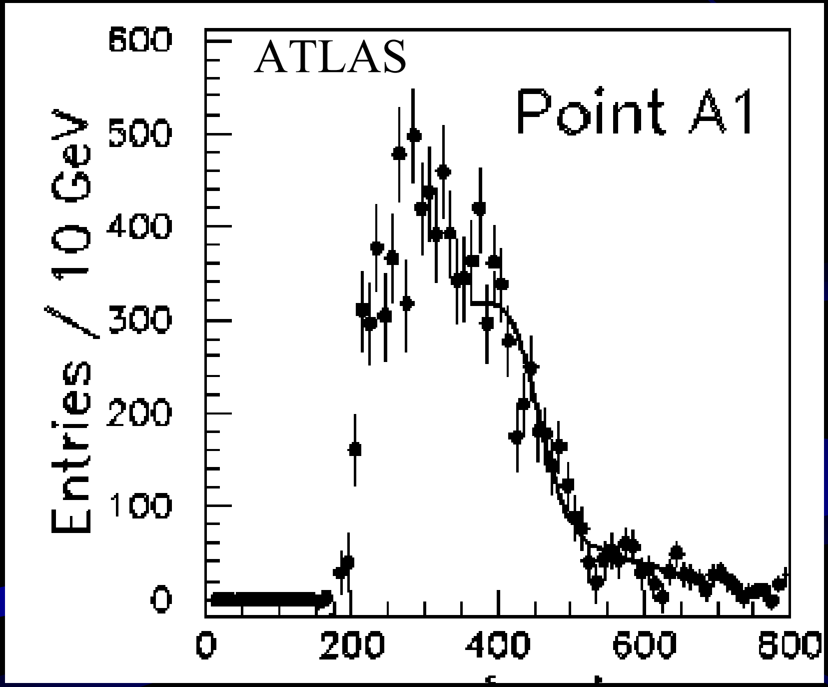
19

Purely hadronic final states

Aim is to reconstruct $\tilde{g} \rightarrow t\tilde{t}_1 \rightarrow tb\tilde{\chi}^{\pm}_1$ or $\tilde{g} \rightarrow b\tilde{b} \rightarrow bt\,\tilde{\chi}^{\pm}_1$

tb invariant mass has a maximum function of the masses of $\tilde{g}$, $\tilde{b}$(or $\tilde{t}$) and $\tilde{\chi}^{\pm}_1$
Two closely spaced edges from the two decays: can measure a weighed average.

Selections:
- total jet energy and missing energy
- 2 b-jets
- lepton veto
- 4 to 6 non-b jets



Reconstruction:
- m(jj) close to m(W)
- m(jjb) close to m(t)
- W-sidebands to estimate and subtract combinatorial background

See J. Hisano et al., Phys. Rev. D68, 035007 for details

Focus Point region

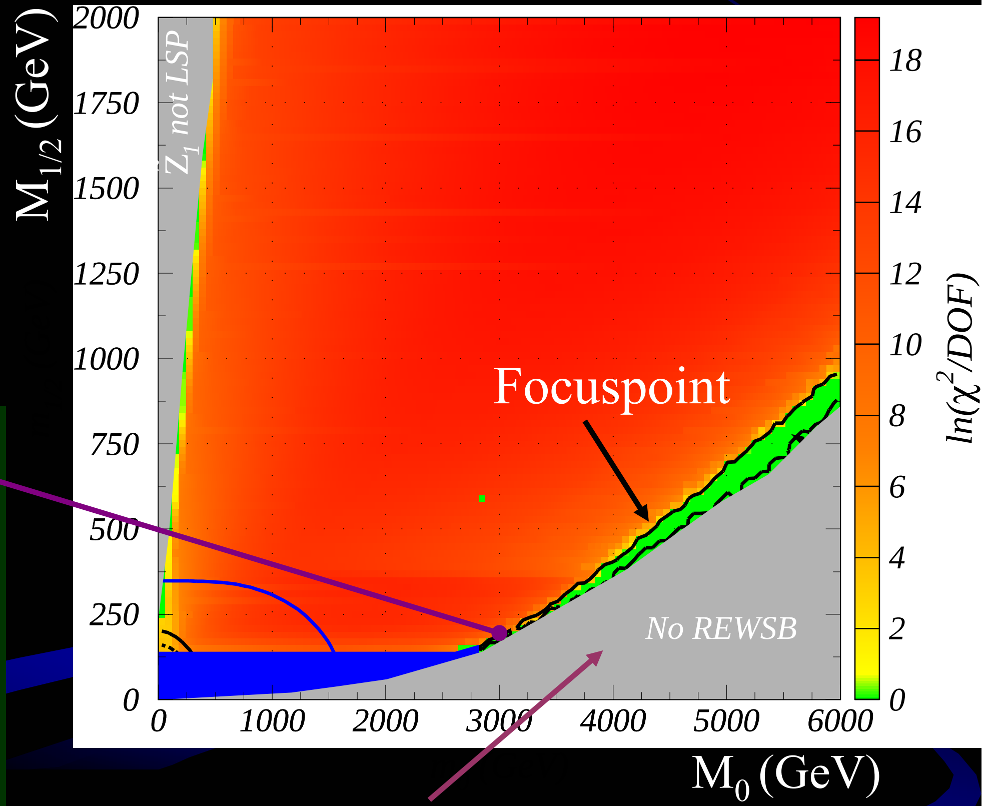
Large scalar mass: heavy squarks and sleptons.
Relatively low gaugino mass.
Low μ, large Higgsino/Bino mixing $\Rightarrow$ low density of relic neutralinos, compatible with WMAP limits.

The FP region has an high neutralino-nucleon cross section, so it will be probed by direct searches for dark matter.

Problems:

- Very sensitive to top mass
- Large discrepancies between SUSY mass calculators

Selected point for detailed study
$m_0 = 3000$ GeV
$M_{1/2} = 215$ GeV
Tan $\beta = 10$
$A_0 = 0$ - $\mu>0$
M(top) = 175 GeV



No EWSB solution

Mass spectrum

- Heavy squarks and leptons.
- Heavy Higgs (except h)
- Lighter gluino (640 GeV) decays into charginos and neutralinos

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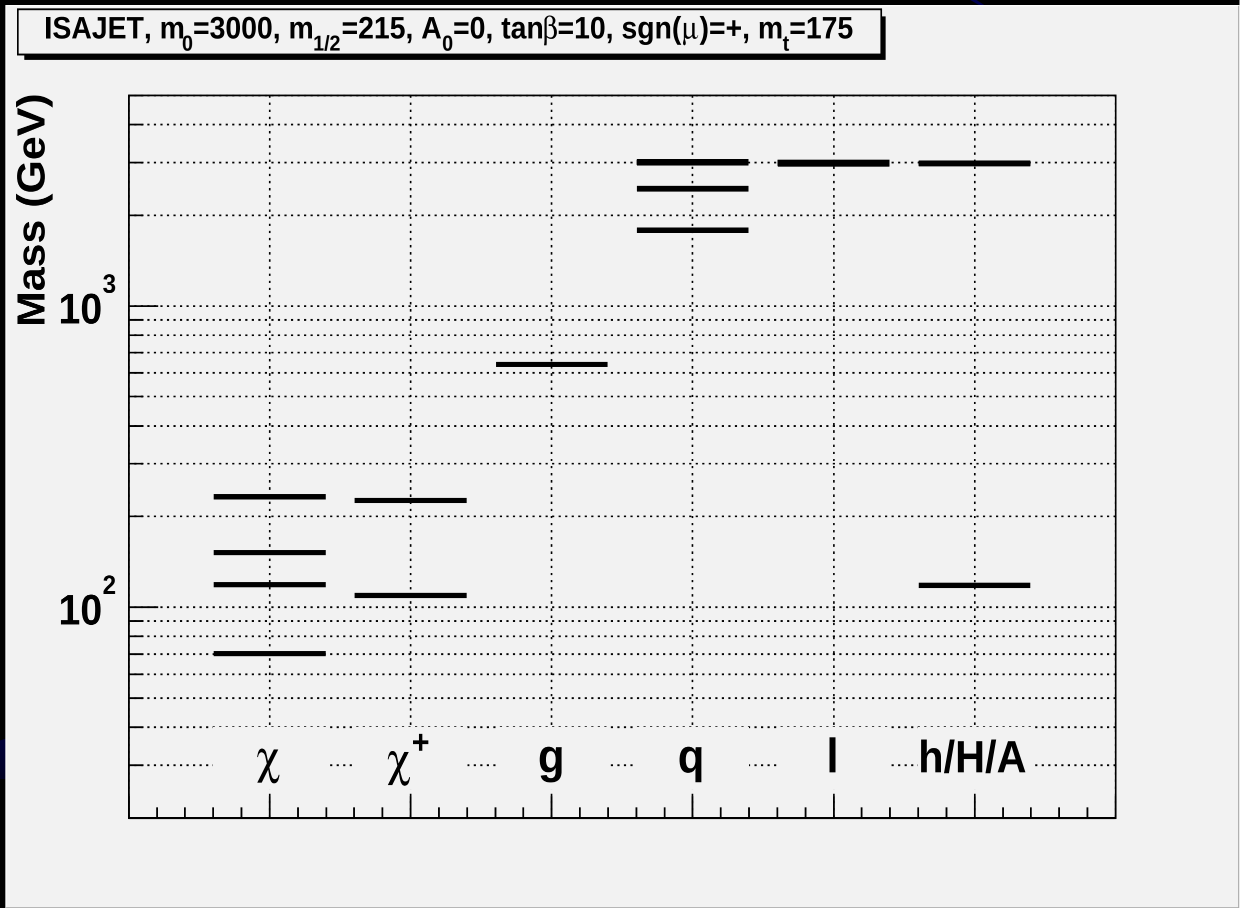
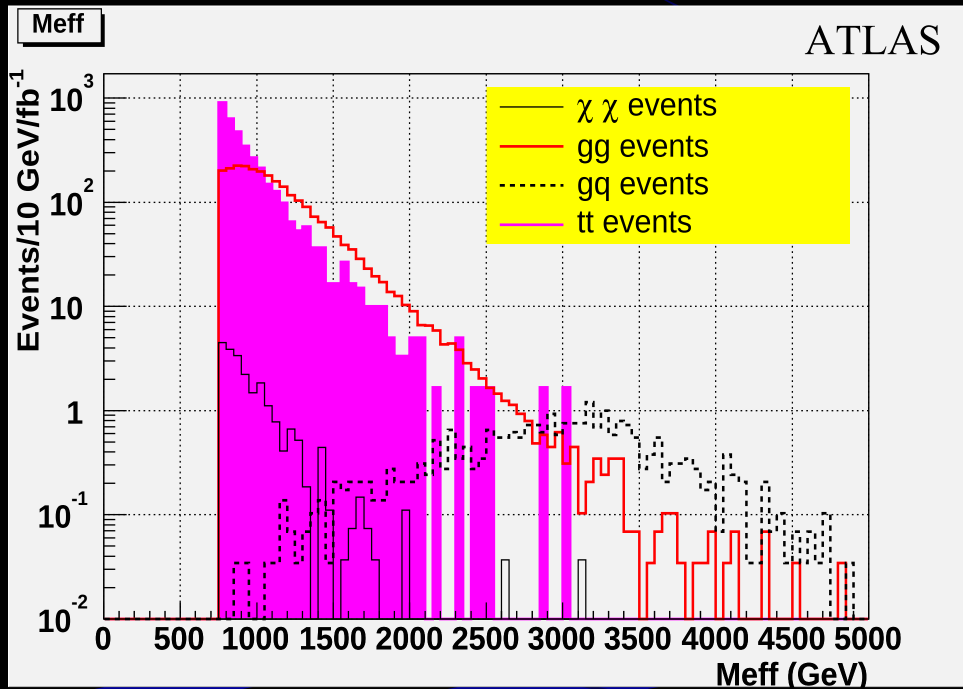


Production x-Section

$\tilde{\chi}\tilde{\chi}$	13.3 pb
$\tilde{g}\tilde{g}$	3.76 pb
$\tilde{q}\tilde{g}$	0.023 pb

- Neutralino/chargino production abundant but without jet/missing energy signature (mass similar or lower than top mass).
- Gluino pair production followed by decay into chargino/neutralino is dominant after cuts to reject SM
- squarks still visible with enough luminosity

M_{eff} = Jet energy + E_T^{miss}



The gluino decays to chargino or neutralino via three-body decays:

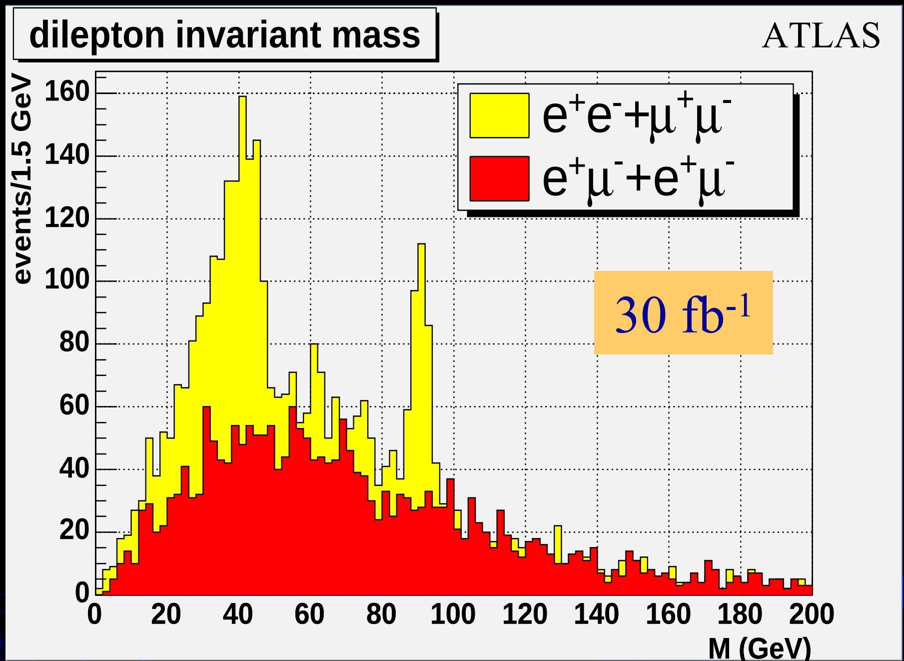
$$\tilde{g} \rightarrow \tilde{\chi}\, qq$$

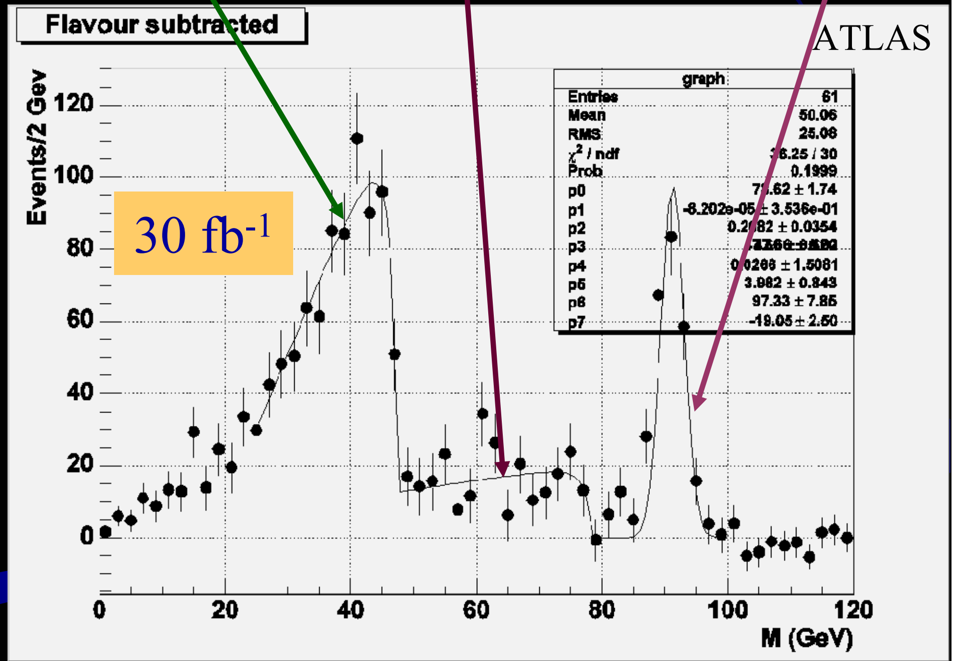
Dilepton analysis

Direct three-body decay $\tilde{\chi}^0_n \rightarrow \tilde{\chi}^0_1\, ll$

Edge gives $m(\tilde{\chi}^0_n)-m(\tilde{\chi}^0_1)$

$\tilde{\chi}^0_2 \rightarrow \tilde{\chi}^0_1\, ll$ $\tilde{\chi}^0_3 \rightarrow \tilde{\chi}^0_1\, ll$ $Z^0 \rightarrow ll$

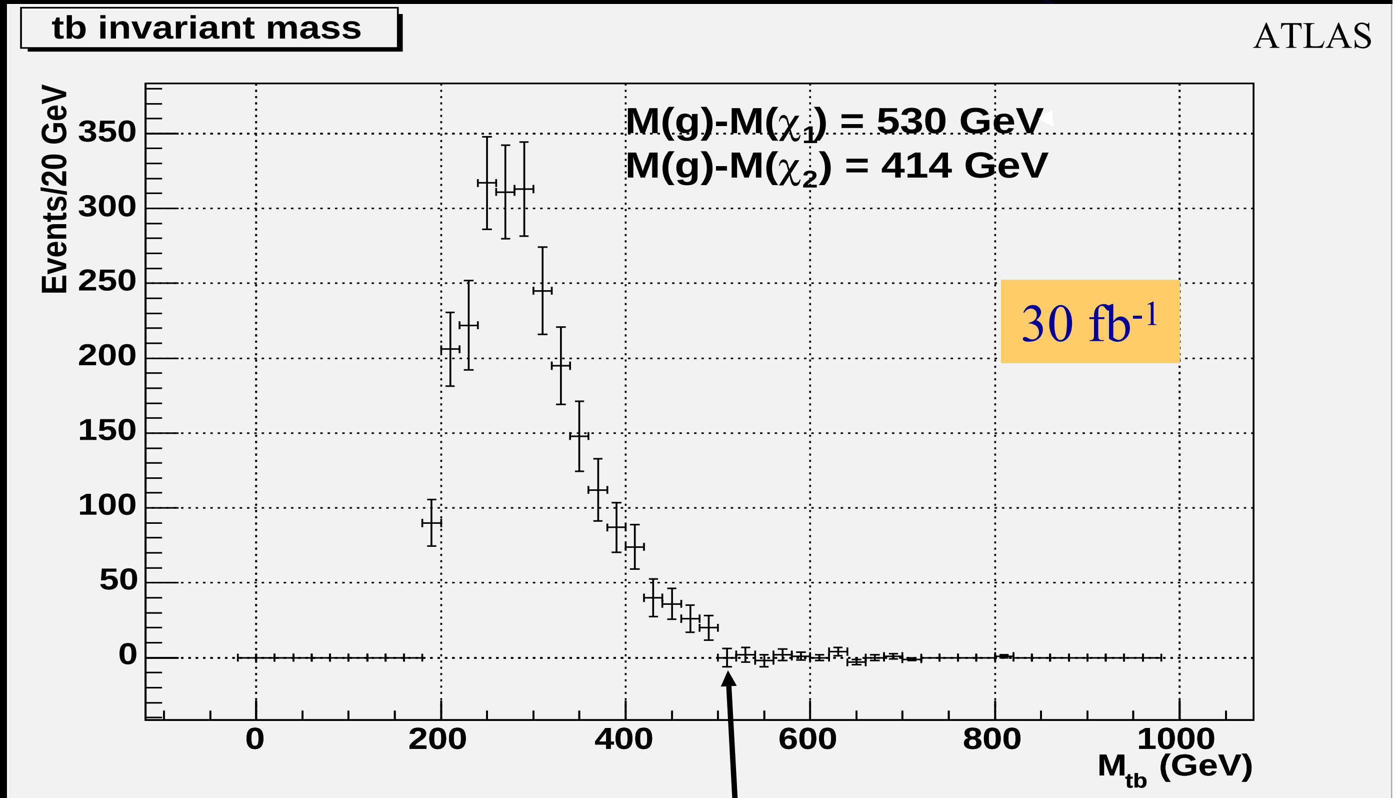




Combination with jets to reconstruct the gluino mass is under study.

Gluino to chargino decay

Direct three-body decay: $\tilde{g} \rightarrow \tilde{\chi}^{\pm}\, tb$



$m(\tilde{g})-m(\tilde{\chi}^{\pm}{}_1) = 530$ GeV

Conclusions

- After the mass of the LSP has been measured with kinematic edges, the mass peaks of heavier particles can be reconstructed.
- A detailed analysis has been performed for point SPS1a: a large number of SUSY masses can be measured with a precision of 5 to 12 GeV with a statistics of 300 fb^{-1}.
- The same reconstruction techniques can be used for other regions of parameter space.
- Most studies done with fast simulation (parameterized detector response) so far. Analysis with detailed detector simulation has been started.
- New regions of parameter space, guided by relic density constraints, are also an hot topic. A detailed characterization of the selected point in the focus point region is being made.