SUSY with ATLAS: leptonic signatures, coannihilation region

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Physics at LHC

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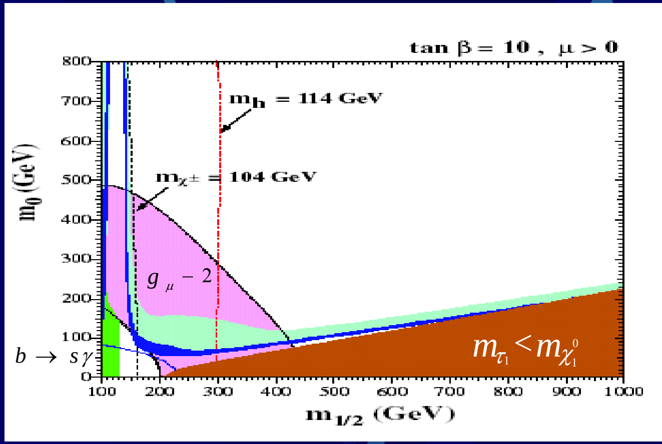
SUSY

- Candidate theory for the physics beyond SM
  - A symmetry in nature connects fermions and bosons
    - Particle zoology is “doubled” by the super partners
  - super partners are heavy (they eluded detection so far after all)
  - One can build a constrained version of SUSY depending from a small number of parameters
    - mSUGRA, AMSB, GMSB….
- SUSY is a hot candidate for cold dark matter
  - RPC theories incorporate neutral massive stable particle naturally
    - Direct connection to relic cold dark matter density ($\Omega\ h^2$)

mSUGRA

- mSUGRA is a RPC SUSY model and lives in a 5 parameters space: $m_{1/2}$, m_0, A_0, $\tan(\beta)$, sign(μ)

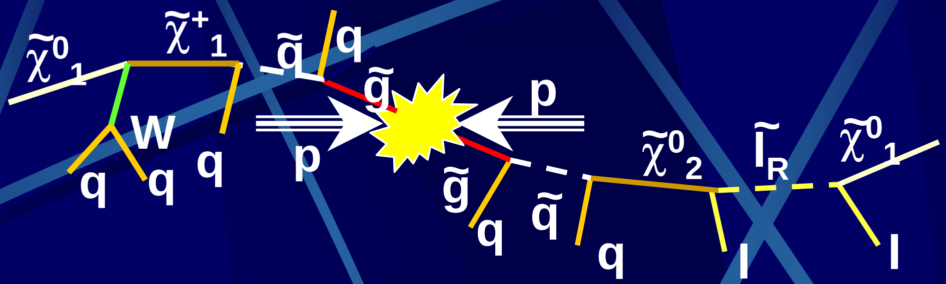


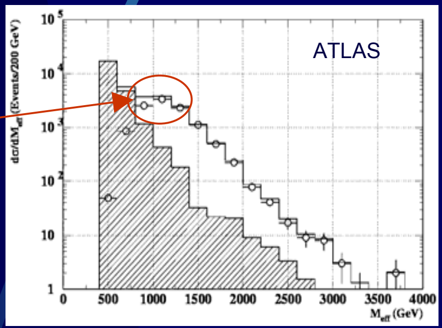
(new Wilkinson Microwave Anisotropy Probe (**WMAP**) constraints change the allowed regions hep-ph/0303043)

-Regions of this space are theoretically and/or experimentally excluded. Several different points have been studied and characterized in the past.

masses, BR and total SUSY CS depend on the 5 parameters => choosing a mSUGRA point means choosing a different particle phenomenology => different analysis techniques are needed

Analysis techniques





- Initial SUSY mass scale should be easy to find
- How to measure the SUSY mass spectrum?
- Two classes of techniques are generally used to analyze SUSY events and reconstruct particle masses
  - Leptons/jets combinations edges
  - Jet/heavy flavor tagging and sidebands (see talk from T. Lari)
- Hard isolated leptons xEt and large jet activity
- Undetected particles => Kinematical endpoints
  - already used in the past in W->v+l decay
  - Invariant mass distributions of different particles combinations have a maximum and the distributions show edge-like behavior

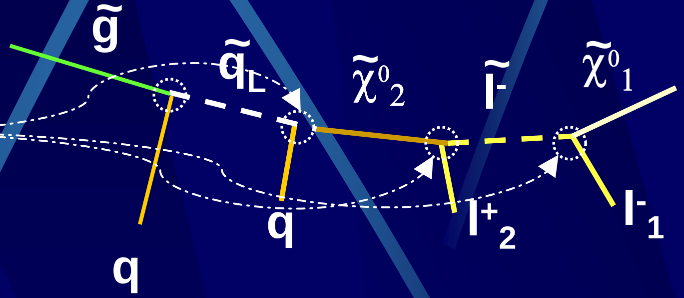
Endpoint technique

- In every double two body decay

$$p_1 \rightarrow p_2 + P^{\pm} \rightarrow p_3 + P^{\pm}P^{\mp}$$

- In the limit of $m_P \sim 0$ the following relation holds

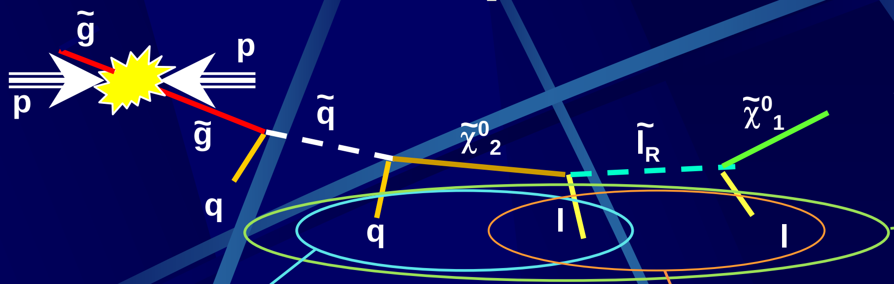
$$m_{P^{\pm}P^{\mp}}^{max} = m_{p_1}\sqrt{1-\frac{m_{p_2}^2}{m_{p_1}^2}}\cdot\sqrt{1-\frac{m_{p_3}^2}{m_{p_2}^2}}$$



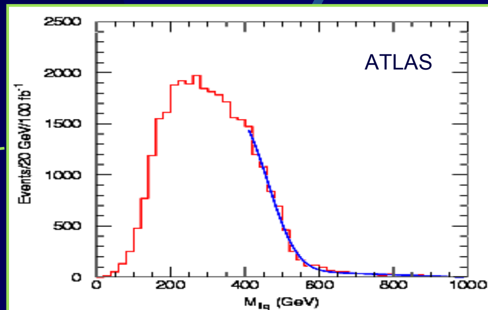
- Other more complex relations can be established between sparticle masses and invariant mass combinations of decay products
- In a typical long SUSY decay chain several of this relations can be established

=> from kinematical edges to particle masses

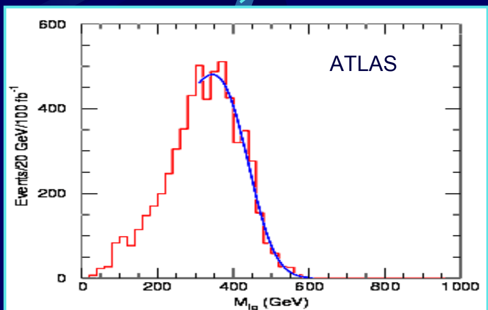
Leptonic endpoints



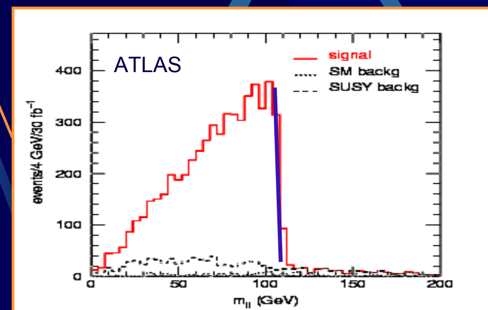
l=e,μ



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



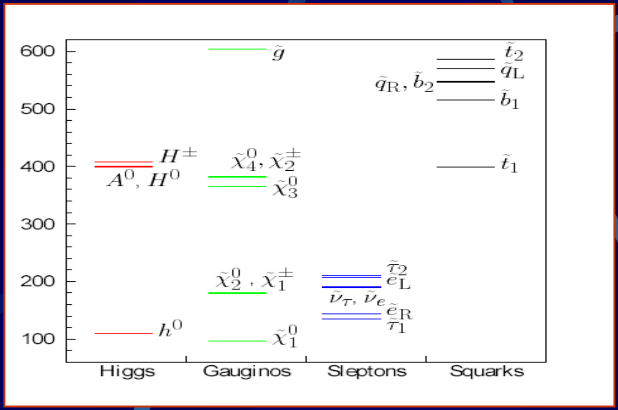
$$M_{lq}^{max} = \left[\frac{(M^2_{\tilde q_L} - M^2_{\tilde\chi^0_2})(M^2_{\tilde\chi^0_2} - M^2_{\tilde l_R})}{M^2_{\tilde\chi^0_2}}\right]^{1/2}$$



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

- SM BGD is reduced cutting on large xEt and hard jets
- SM and SUSY self BG is removed using Opposite Sign/Same Flavor-Opposite Sign/Opposite Flavor (OS/SF-OS/OF) technique

An example: sps1 point



SPS1a mass spectrum

- $m_{1/2}$=250 GeV;
- m_0=100GeV;
- A_0=100 GeV;
- tan(β)=10;
- sign(μ)=+.

- With the edge technique it is possible to establish sparticles masses/errors analyzing the decay:

$$\tilde{q}_L \longrightarrow q\tilde{\chi}^0_2 \longrightarrow q l_2^{\pm} \tilde{l}_R^{\mp} \longrightarrow q l_2^{\pm} l_1^{\mp} \tilde{\chi}^0_1$$

- Masses of heavier gauginos were reconstructed using the edge technique to the decay chains:

$$\begin{array}{llll} \tilde{q}_L \rightarrow & \tilde{\chi}^0_4 & q & \\ & \hookrightarrow & \tilde{\ell}^{\pm}_L & \ell^{\mp} \\ & & \hookrightarrow \tilde{\chi}^0_1 & \ell^{\pm} \\ & & \hookrightarrow \tilde{\chi}^0_2 & \ell^{\pm} \end{array}$$

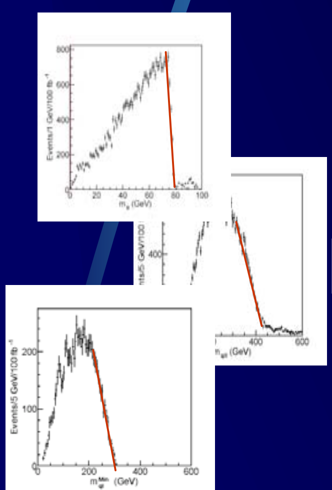
$$\begin{array}{llll} \tilde{q}_L \rightarrow & \tilde{\chi}^0_4 & q & \\ & \hookrightarrow & \tilde{\ell}^{\pm}_R & \ell^{\mp} \\ & & \hookrightarrow \tilde{\chi}^0_1 & \ell^{\pm} \end{array}$$

sps1a (cont.d)

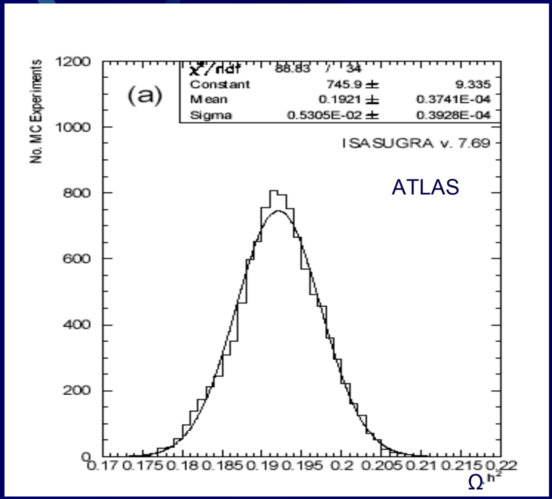
- This point has thus been recently fully characterized
- (more on) Relic density value has been constrained
  - Sparticles masses relations and errors on them can be used to generate different MonteCarlo LHC experiments

=> constraint Ωh^2 to few %

(this is doable in mSUGRA, for MSSM needs more constraints)



Variable	Value (GeV)	
$m_{\ell\ell}^{max}$	77.07	0.08
$m_{\ell\ell q}^{max}$	428.5	4.5
$m_{\ell q}^{low}$	300.3	3.1
$m_{\ell q}^{high}$	378.0	3.9
$m_{\ell\ell q}^{min}$	201.9	2.6
$m_{\ell\ell b}^{min}$	183.1	4.1
$m(\ell_L) - m(\tilde{\chi}_1^0)$	106.1	1.6
$m_{\ell\ell}^{max}(\tilde{\chi}_4^0)$	280.9	2.3
$m_{\tau\tau}^{max}$	80.6	5.1
$m(\tilde{g}) - 0.99 \times m(\tilde{\chi}_1^0)$	500.0	6.4
$m(\tilde{q}_R) - m(\tilde{\chi}_1^0)$	424.2	10.9
$m(\tilde{g}) - m(\tilde{b}_1)$	103.3	1.8
$m(\tilde{g}) - m(\tilde{b}_2)$	70.6	2.6



B.K. Gjelsten, E. Lytken, D.J. Miller, P. Osland, G. Polesello (ATL-PHYS-2004-007)
G. Polesello, D. Tovey (ATL-PHYS-2004-008)

Coannihilation region

Relic density is sensitive to Coannihilation processes of LSP with heavier sparticles. Relative importance of this effect with respect of coannihilation of LSP with itself is controlled by

$$\sigma_{\chi\not\chi}/\sigma_{\chi\chi}, \sigma_{\not\chi\not\chi}/\sigma_{\chi\chi}$$

This effect is generally important when

$$(m_{\not\chi} - m_{\chi}) \sim T_f \sim m_{\chi}/20$$

T_f (freeze out Temperature = 2.73 K)

$\sigma_{\chi\not\chi}$ CS for LSP/sparticle coannihilation $(\tilde{\tau}\tilde{\chi} \to Z\tau)$

$\sigma_{\not\chi\not\chi}$ sparticle/sparticle $(\tilde{\tau}\tilde{\ell} \to \ell\tau)$

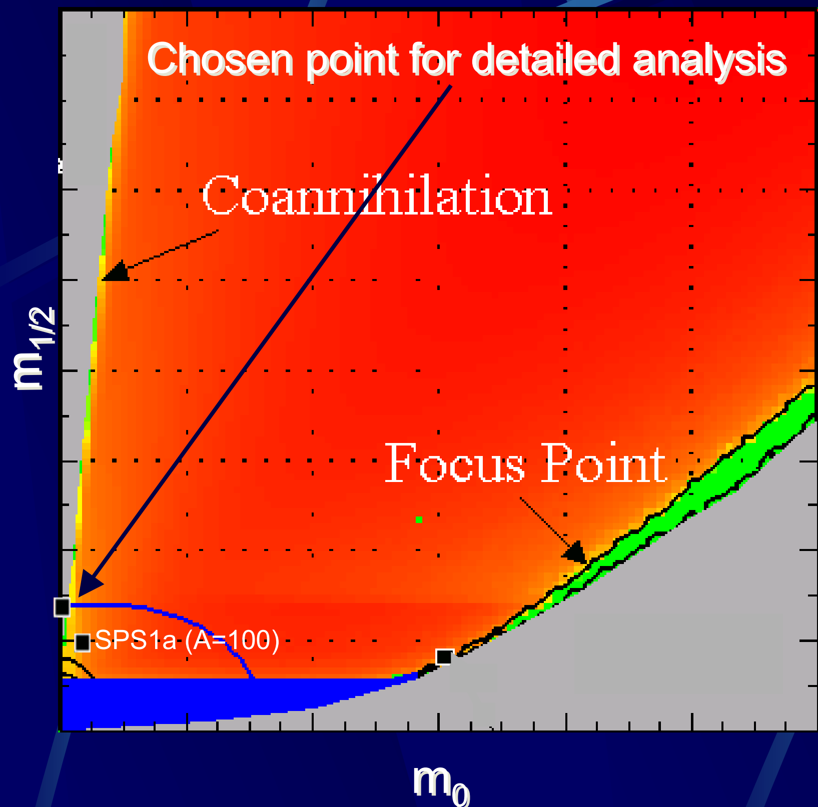
$\sigma_{\chi\chi}$ and LSP/LSP annihilation

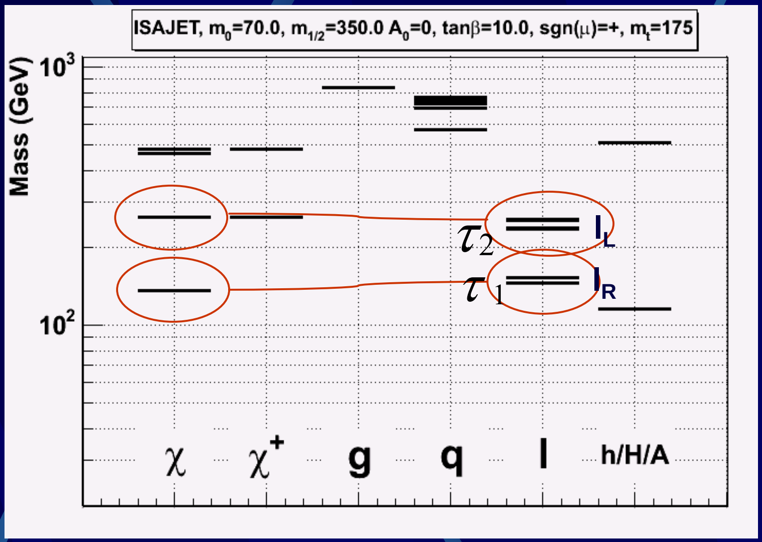
Coannihilation is particularly enhanced when LSP is mainly Bino

The coanni. of LSP happens with slightly heavier ℓ_R $(\ell = \tau, e, \mu)$

J. Ellis et al. (hep-ph/9905481)

Coannihilation point





Coannihilation point mass spectrum

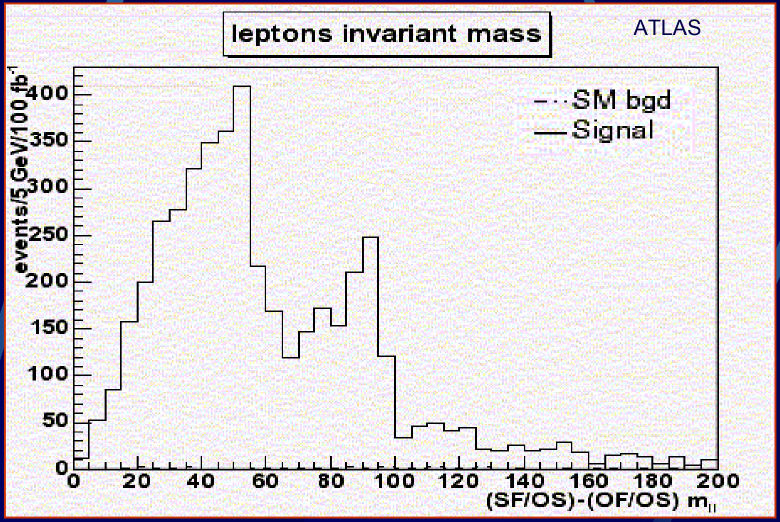
- $m_{1/2}$=350.0 GeV;
- m_0=70.0 GeV;
- A_0=0 GeV;
- tan(β) = 10.0;
- μ > 0
- Total CS = 7.8 pb

The defining feature is that sleptons masses are close to LSP mass => slow leptons

Lepton signature

$$\tilde{q}_L \xrightarrow[32\%]{} \tilde{\chi}_2^0 + q$$
$$\tilde{\chi}_2^0 \xrightarrow[6\%,\,3\%]{} \ell^{\pm}_{L,R} + \ell^{\mp}$$
$$\ell^{\pm}_{L,R} \xrightarrow[100\%]{} \ell^{\pm} + \tilde{\chi}_1^0 \qquad (\ell = e, \mu)$$

100 fb^{-1}



$$m^{max}_{\ell^+\ell^-} \approx 57\,GeV, 101\,GeV$$

(two edges are expected)

$$m_{\ell_R} - m_{\chi_1^0} \approx 17\,GeV$$

(Only right sleptons contribute to coannihilation)

$$m_{\chi_2^0} - m_{\ell_L} \approx 8\,GeV$$

(there is always at least a soft lepton in the event)

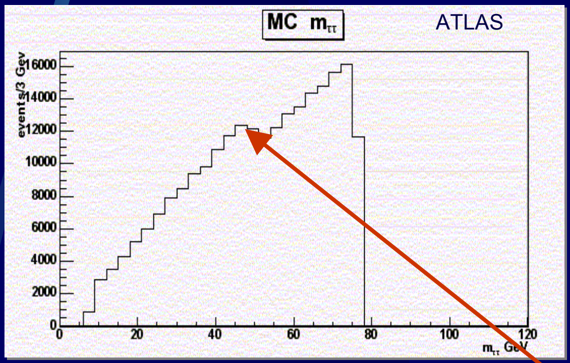
- **xE_T > 200 GeV**
- **2 SF/OS leptons Pt_1>20 GeV, Pt_2>10 GeV**
- **≥1 jets with Pt>150 GeV**
- **OS/OF subtraction**

(ATLFAST & HERWIG+ISAWIG)

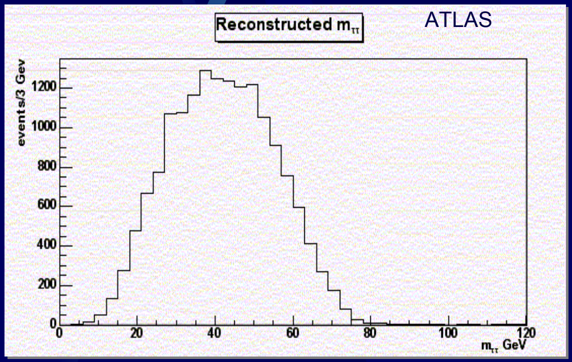
Tau signature

- Taus are different from other leptons because of the hadronic decay (neutrino escapes undetected)
- SUSY is a chiral theory and spin/polarization plays an important role
  - because of polarization in some of the tau decay modes ($\tau \rightarrow \nu + \pi$) the neutrino carries large fraction of the initial tau momentum ($\tilde{\tau}_1 \sim \tilde{\tau}_R$)
- $\tilde{q}_L \xrightarrow[32\%]{} \tilde{\chi}_2^0 + q; \quad \tilde{\chi}_2^0 \xrightarrow[19\%,\,2\%]{} \tilde{\tau}_{1,2}^{\pm} + \tau^{\mp}; \; \tilde{\tau}_{1,2}^{\pm} \xrightarrow[100\%,\,95\%]{} \tau^{\pm}$
- $m_{\tilde{\tau}_1} - m_{\tilde{\chi}_1^0} \approx 10\,GeV; m_{\tilde{\chi}_2^0} - m_{\tilde{\tau}_2} \approx 6\,GeV$ (very soft taus are expected)

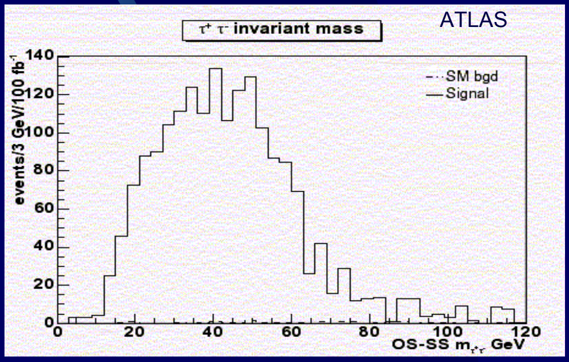
$100fb^{-1}$ **(ATLFAST & HERWIG+ISAWIG)**



Minv from MC undecayed taus



Minv from MC decayed taus



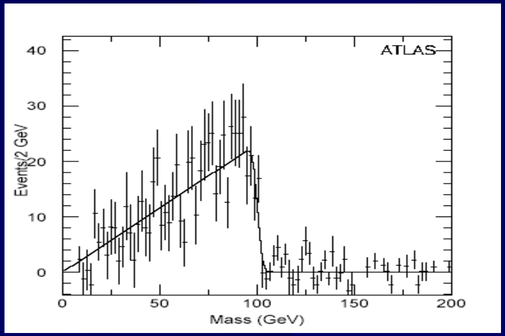
Minv from reconstructed taus

($\tilde{\tau}_2$ decay edge unlikely to be seen)

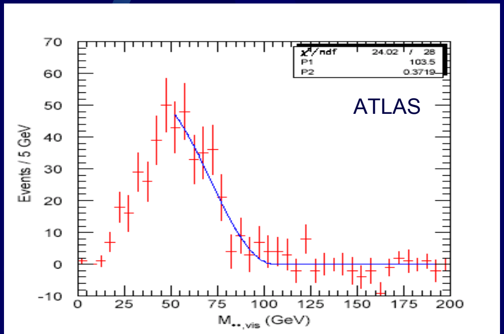
$m_{\tau\tau}^{max} \approx 79\,GeV$

Plans for the coannihilation region analysis

- Fully characterize this point with the fast simulation
- SUSY group is currently active producing a large sample of fully simulated events (GEANT4) for the coannihilation point.
- Plans are to repeat the exercise done last year in the bulk region improving tau reconstruction, given its central role in the physics of coannihilation region



Reconstructed lepton edge



Reconstructed tau edge

(examples of leptons/tau edges done with full simulation for modified point 5)

(ATL-PHYS-2004-011)

Conclusions

- The leptons/jets edge technique has proven to be a very powerful tool in our hands to establish SUSY particles mass spectrum and establish errors on those masses.
- Recently this technique has been exploited to measure heavier charginos masses/edges and to constraint relic dark matter density