Developing Model Independent sparticle mass measurements at ATLAS

Cambridge SUSY Working Group

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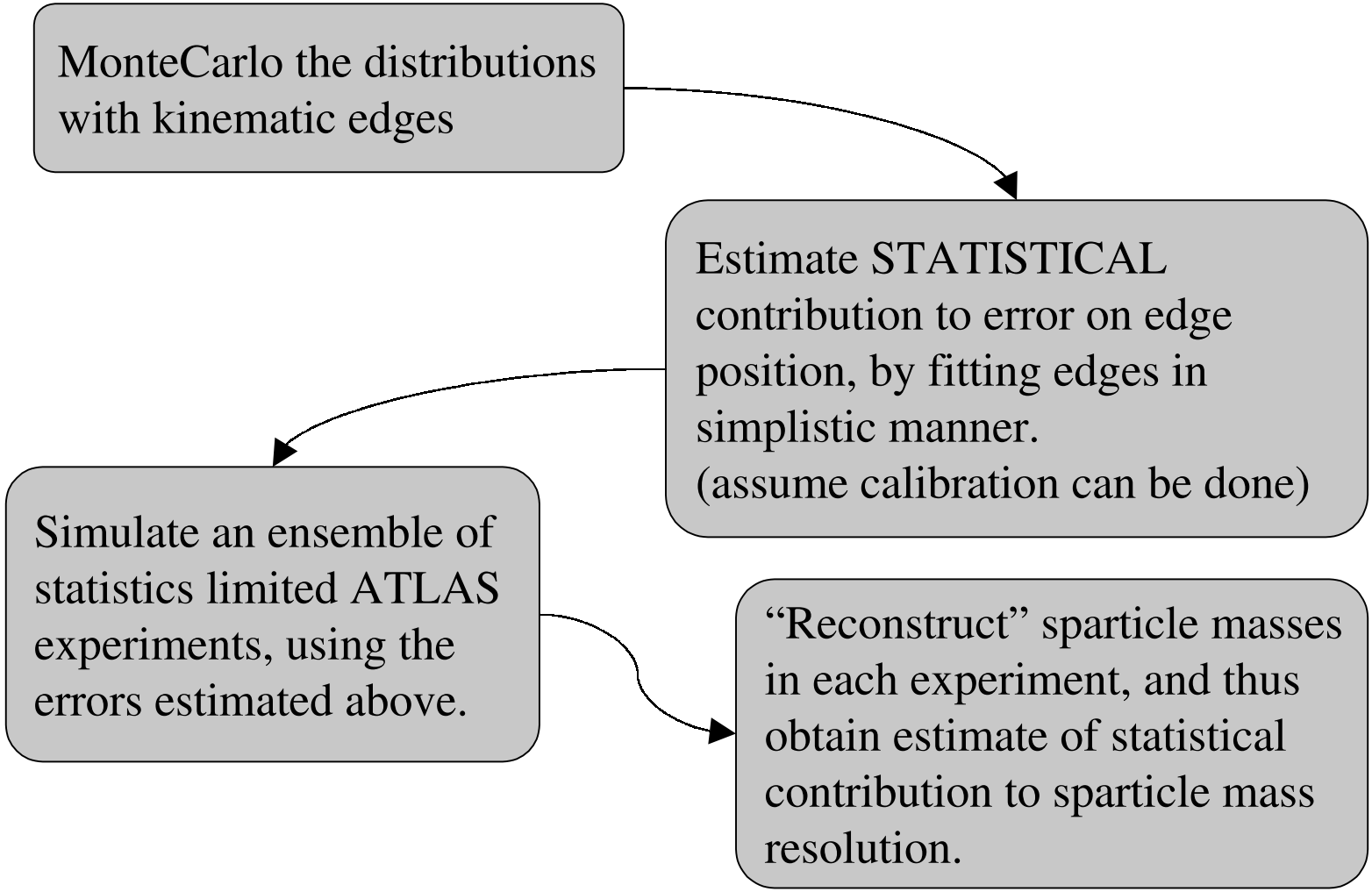
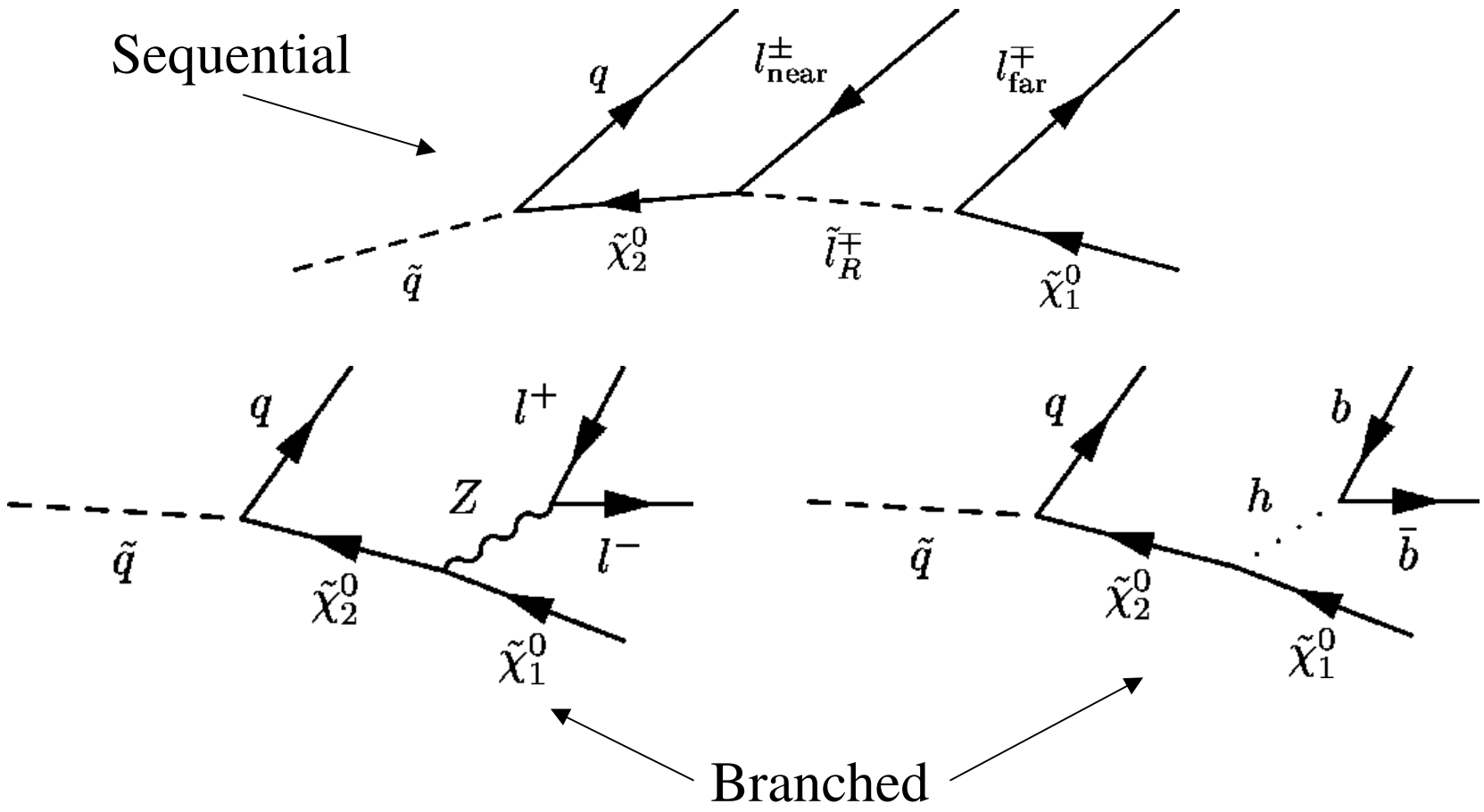
See also:

- authors paper: **hep-ph/0007009**, and
- principal reference: ATL-PHYS-2000-010
(Bachacou, Hinchliffe & Paige)

Overall technique



Decay chains used



Developments

- Removal of theoretical dependencies on mass relationships
- Addition of two new measurements: ΔM, {Low/High lq-edge}
- Simultaneous testing against second model with same set of cuts
- Reduce subjectivity in estimation of edge fitting resolutions

Edge positions

Related edge	Kinematic endpoint
l^+l^- edge	$(m_{ll}^{\max})^2 = (\tilde{\xi} - \tilde{l})(\tilde{l} - \tilde{\chi})/\tilde{l}$
l^+l^-q edge	$(m_{llq}^{\max})^2 = \begin{cases} \max\left[\frac{(\tilde{q}-\tilde{\xi})(\tilde{\xi}-\tilde{\chi})}{\tilde{\xi}}, \frac{(\tilde{q}-\tilde{l})(\tilde{l}-\tilde{\chi})}{\tilde{l}}, \frac{(\tilde{q}\tilde{l}-\tilde{\xi}\tilde{\chi})(\tilde{\xi}-\tilde{l})}{\tilde{\xi}\tilde{l}}\right] \\ \text{except for the special case in which } \tilde{l}^2 < \tilde{q}\tilde{\chi} < \tilde{\xi}^2 \text{ and} \\ \tilde{\xi}^2\tilde{\chi} < \tilde{q}\tilde{l}^2 \text{ where one must use } (m_{\tilde{q}} - m_{\tilde{\chi}_1^0})^2. \end{cases}$
Xq edge	$(m_{Xq}^{\max})^2 = X + (\tilde{q} - \tilde{\xi})\left[\tilde{\xi} + X - \tilde{\chi} + \sqrt{(\tilde{\xi} - X - \tilde{\chi})^2 - 4X\tilde{\chi}}\right]/(2\tilde{\xi})$
l^+l^-q threshold	$(m_{llq}^{\min})^2 = \begin{cases} [\ 2\tilde{l}(\tilde{q} - \tilde{\xi})(\tilde{\xi} - \tilde{\chi}) + (\tilde{q} + \tilde{\xi})(\tilde{\xi} - \tilde{l})(\tilde{l} - \tilde{\chi}) \\ \quad -(\tilde{q} - \tilde{\xi})\sqrt{(\tilde{\xi} + \tilde{l})^2(\tilde{l} + \tilde{\chi})^2 - 16\tilde{\xi}\tilde{l}^2\tilde{\chi}}\ ]/(4\tilde{l}\tilde{\xi}) \end{cases}$
$l^{\pm}_{\text{near}}q$ edge	$(m_{l_{\text{near}}q}^{\max})^2 = (\tilde{q} - \tilde{\xi})(\tilde{\xi} - \tilde{l})/\tilde{\xi}$
$l^{\pm}_{\text{far}}q$ edge	$(m_{l_{\text{far}}q}^{\max})^2 = (\tilde{q} - \tilde{\xi})(\tilde{l} - \tilde{\chi})/\tilde{l}$
$l^{\pm}q$ high-edge	$(m_{lq(\text{high})}^{\max})^2 = \max\left[(m_{l_{\text{near}}q}^{\max})^2, (m_{l_{\text{far}}q}^{\max})^2\right]$
$l^{\pm}q$ low-edge	$(m_{lq(\text{low})}^{\max})^2 = \min\left[(m_{l_{\text{near}}q}^{\max})^2, (\tilde{q} - \tilde{\xi})(\tilde{l} - \tilde{\chi})/(2\tilde{l} - \tilde{\chi})\right]$
M_{T2} edge	$\Delta M = m_{\tilde{l}} - m_{\tilde{\chi}_1^0}$

Table 4: The absolute kinematic endpoints of invariant mass quantities formed from decay chains of the types mentioned in the text for known particle masses. The following shorthand notation has been used: $\tilde{\chi} = m^2_{\tilde{\chi}_1^0}, \tilde{l} = m^2_{\tilde{l}_R}, \tilde{\xi} = m^2_{\tilde{\chi}_2^0}, \tilde{q} = m^2_{\tilde{q}}$ and X is m_h^2 or m_Z^2 depending on which particle participates in the "branched" decay.

The Models

S5: "LHC SUGRA Point 5" ... well known ...

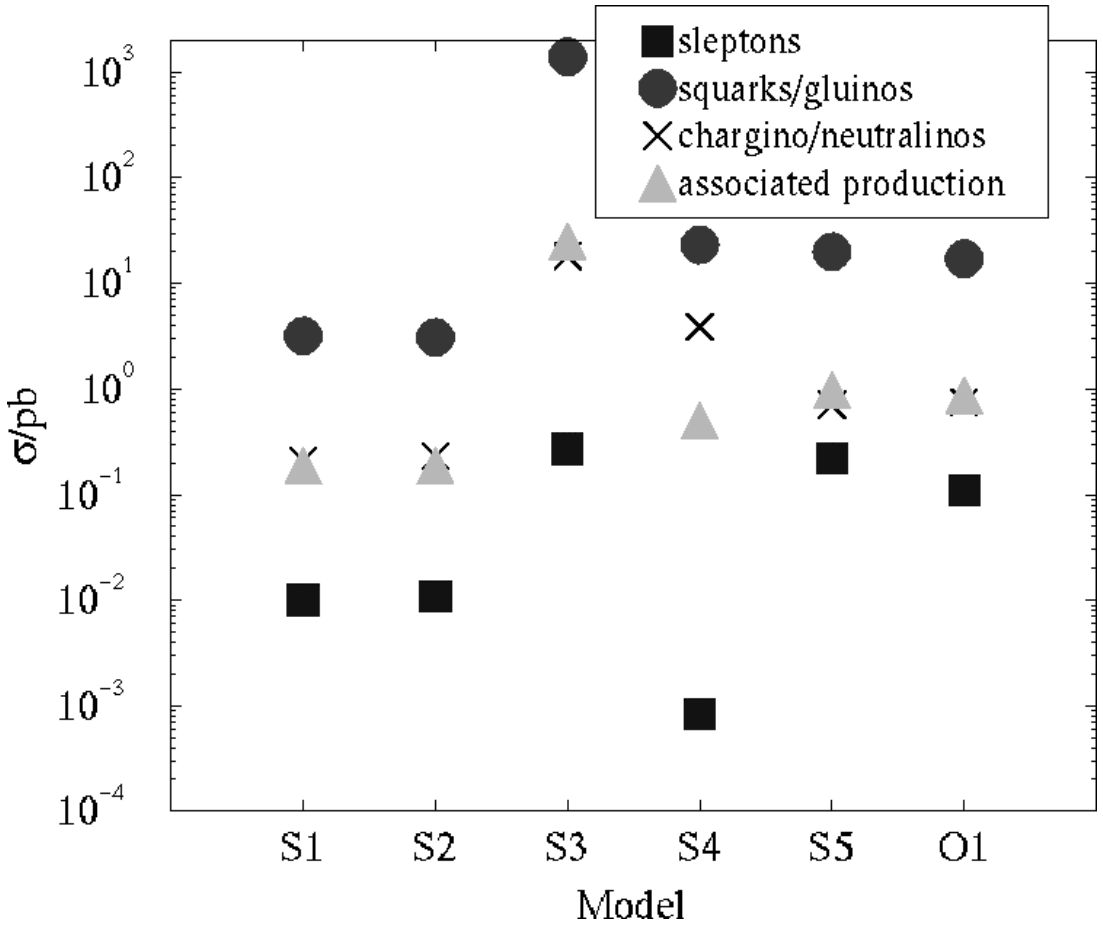
O1: "Optimised string model". Attempts to remove dangerous CCB/UFB problems. A three parameter, weak coupling model. It is non-universal, but in a family independent way. **Modular weights**:

$$n_{Q_L} = n_{d_R^c} = n_{u_R^c} = -2 \qquad n_{L_L} = n_{e_R^c} = n_{H_{1,2}} = -1$$

M_g	m_{u_L}	$m_{u_R^c}$	m_{d_L}	$m_{d_R^c}$	m_{b_1}	m_{b_2}	m_{t_1}	m_{t_2}	m_{ν_e}	m_{e_L}	$m_{e_R^c}$	m_{ν_τ}
747	660	632	664	630	608	636	494	670	273	284	217	271
733	**654**	**631**	**657**	**628**	**600**	**629**	**460**	**671**	**230**	**239**	**157**	**230**
m_{τ_1}	m_{τ_2}	$m_{\chi_1^0}$	$m_{\chi_2^0}$	$m_{\chi_3^0}$	$m_{\chi_4^0}$	$m_{\chi_1^+}$	$m_{\chi_2^+}$	m_{h^0}	m_{H^0}	m_{A^0}	m_{H^+}	
209	285	−125	−234	371	−398	−233	−398	114	450	449	456	
157	**239**	**−122**	**−233**	**499**	**−523**	**−232**	**−520**	**94**	**612**	**607**	**612**	

Table 3: Comparison of sparticle and Higgs spectrum of O1 and **S5** (in bold type). These spectra were calculated using `ISASUGRA` and all masses are quoted in GeV. Sign conventions are as in `ISAJET`. The masses of the second family of sparticles are approximately equal to those of the first.

Cross sections

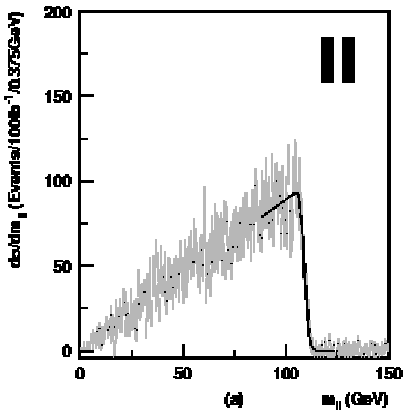


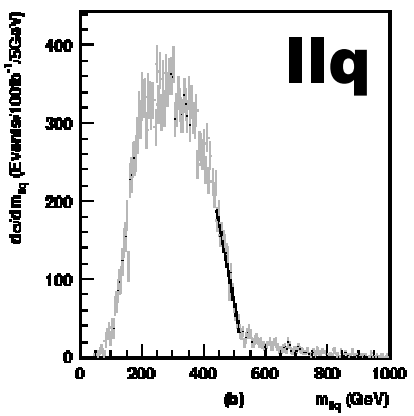
Typical cuts

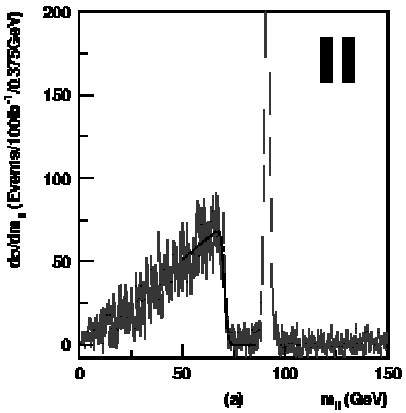
- Exactly 2 OSSF leptons > 10 GeV
- 2 jets > 150 GeV (A)
- 4 jets > 100,50,50,50 GeV (B)
- missing P_T > max(100 GeV, 0.2 M_{eff}) (A)
- missing P_T > 300 GeV (B)
- $m_{ll}^{max}/\sqrt{2}<m_{ll}<m_{ll}^{max}$ (llq-threshold only)
- "OSSF-OSDF" flavour subtraction
- $m_{ll} < m_{ll}^{max} + 1$ GeV (both lq-edges)

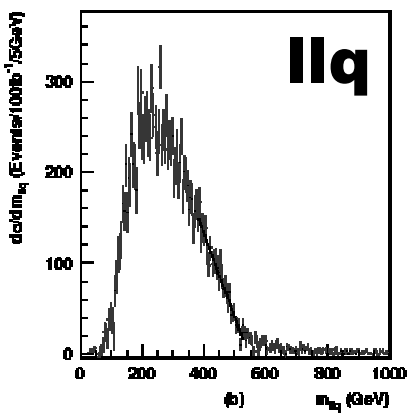
(A={ll-edge, llq-threshold}, B={others})

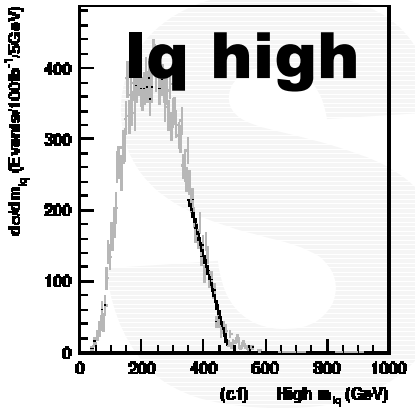
Fitted distributions

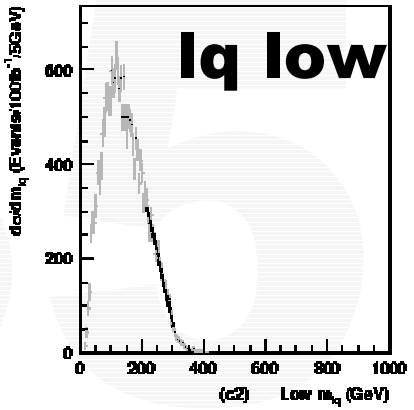


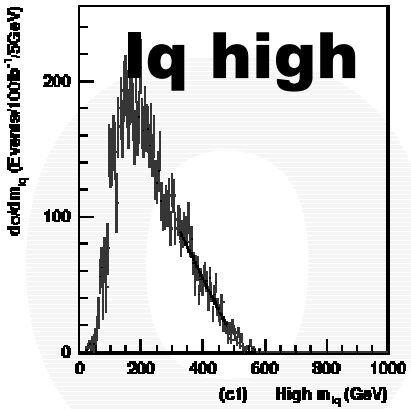


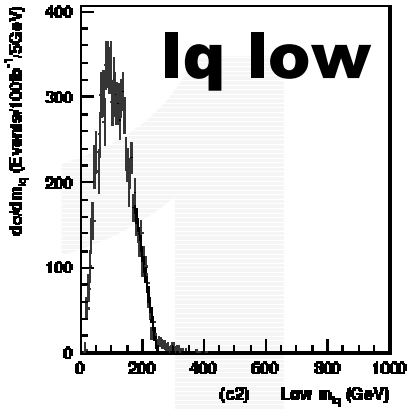


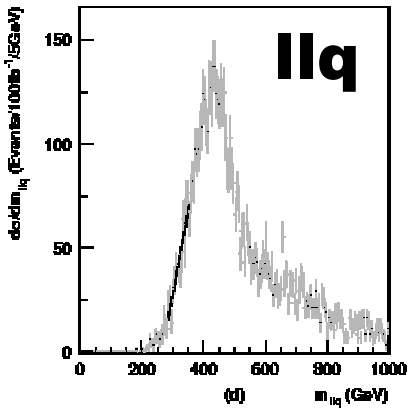


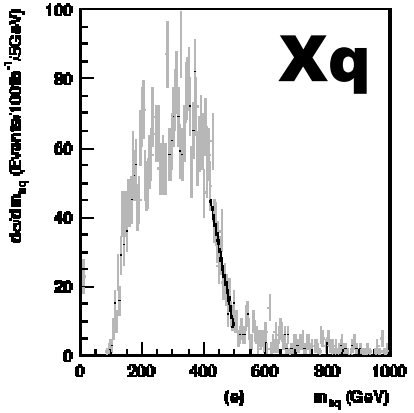


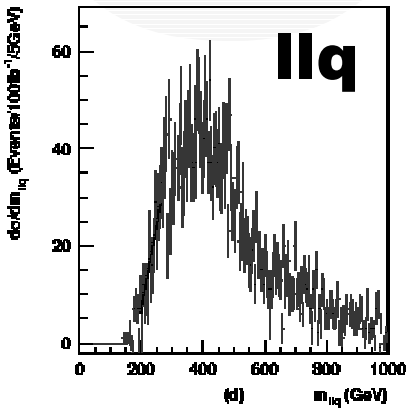


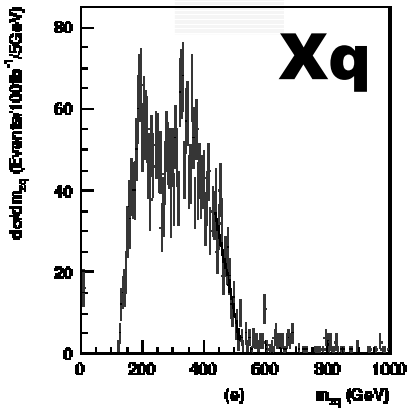










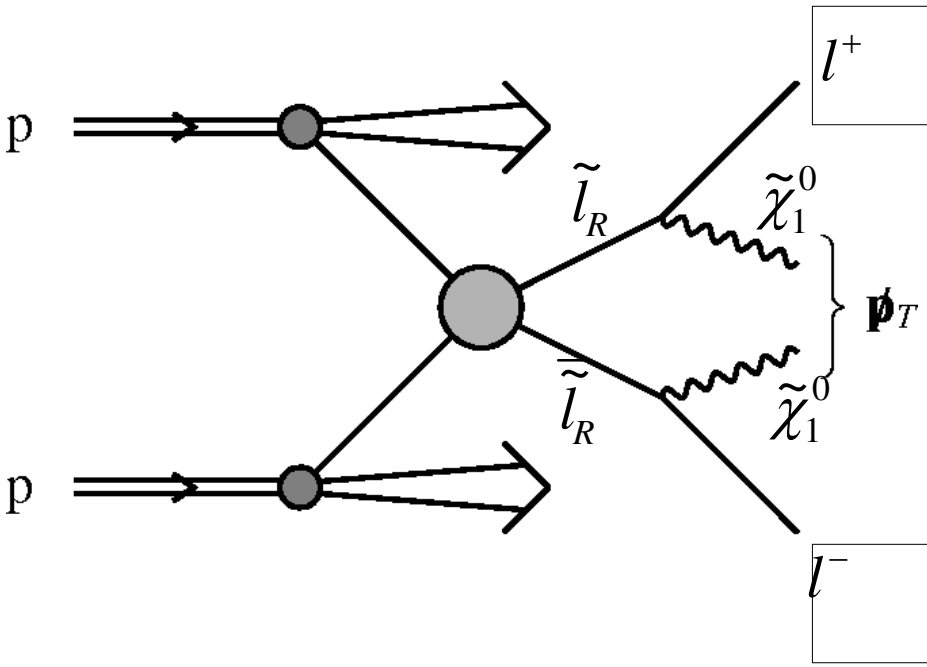


Fit results

Endpoint	S5		O1		Table 4 values	
	Fit	Fit error	Fit	Fit error	S5	O1
l^+l^- edge	109.10	0.13	70.47	0.15	109.12	70.50
l^+l^-q edge	532.1	3.2	544.1	4.0	536.7	530.5
$l^{\pm}q$ high-edge	483.5	1.8	515.8	7.0	464.2	513.6
$l^{\pm}q$ low-edge	321.5	2.3	249.8	1.5	337.0	231.3
l^+l^-q threshold	266.0	6.4	182.2	13.5	264.9	168.1
Xq edge	514.1	6.6	525.5	4.8	509.2	503.4
ΔM (M_{T2} edge)	——	——	——	10%	35.7	92.5

- Fitted edge positions (GeV)
- "Fit error" is statistical contribution only
- No jet energy calibration performed

$\Delta M = M_{T2}(X) - X$



Given:

- the lepton momenta
- the missing transverse momentum
- an estimate "X" of the neutralino mass

Deduce:

- lower bound $M_{T2}(X)$ on slepton mass
- slepton-neutralino mass difference ΔM

Dislepton event cuts

Hard cuts:

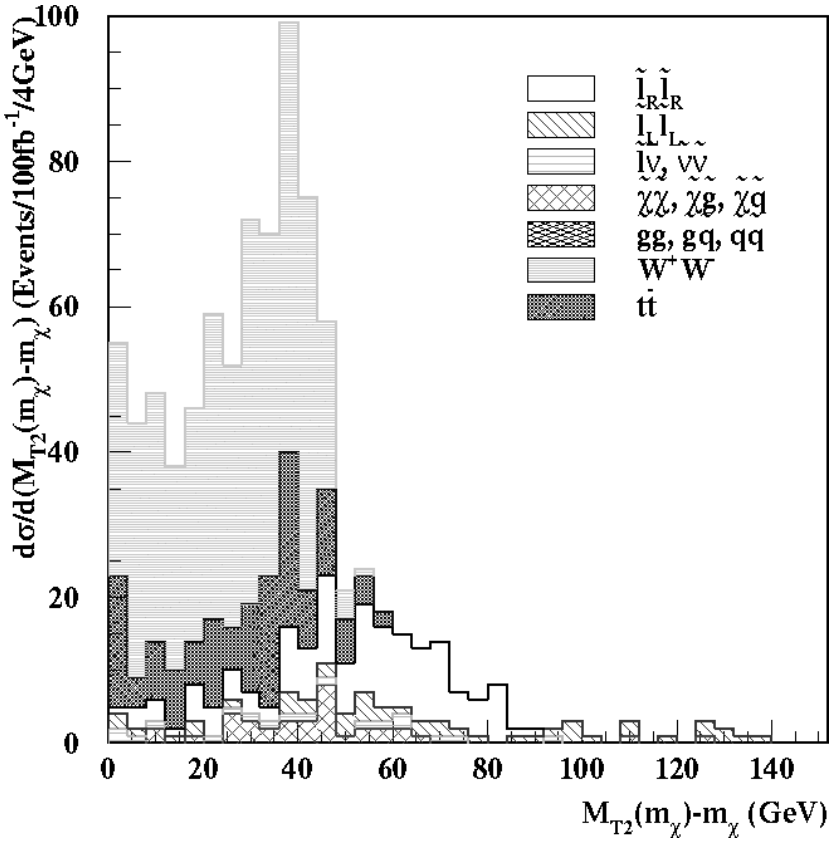
- Exactly 2 OSSF leptons > 50, 30 GeV
- $\delta_T = |p_T^{l1}, p_T^{l2} + p_T^{missing}| < 20$ GeV
- No jets above 40 GeV (50 GeV) - expect to lose 10% (1%) of signal to minimum bias events in same bunch crossing.
- m_{ll} not within 5 GeV of m_Z.
- $m_{ll}, p_T^{missing} > 80$ GeV

Soft cuts:

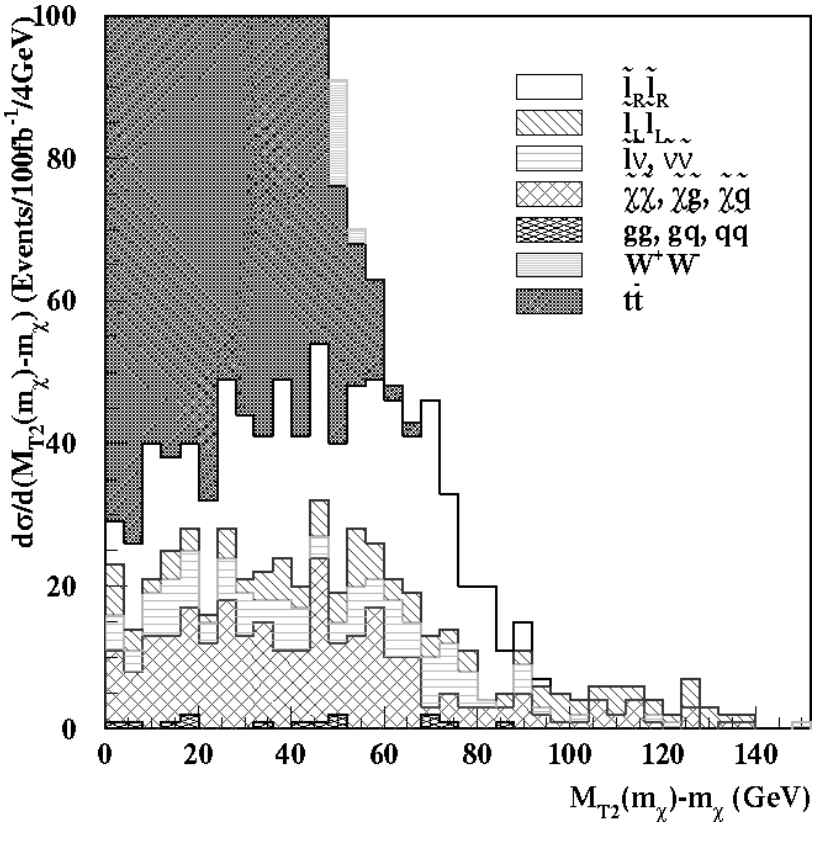
- $p_T^{missing}$ requirement lowered to 50 GeV
- $\delta_T < 90$ GeV
- No m_{ll} cuts at all.

ΔM - 50 GeV Jet Cut

(ÄM = 92 GeV)

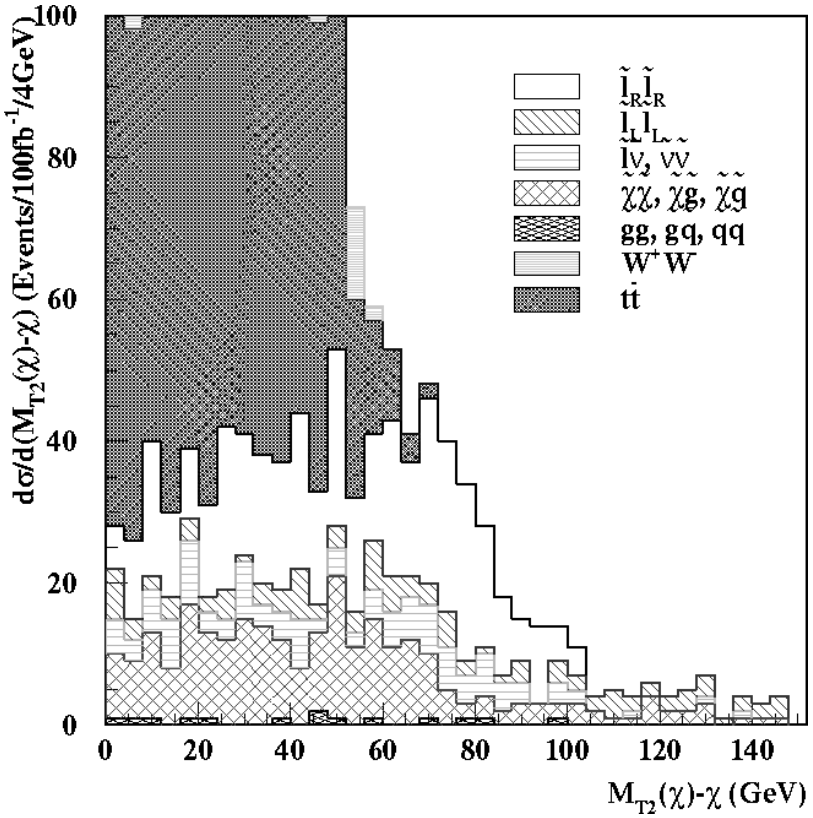


Hard cuts

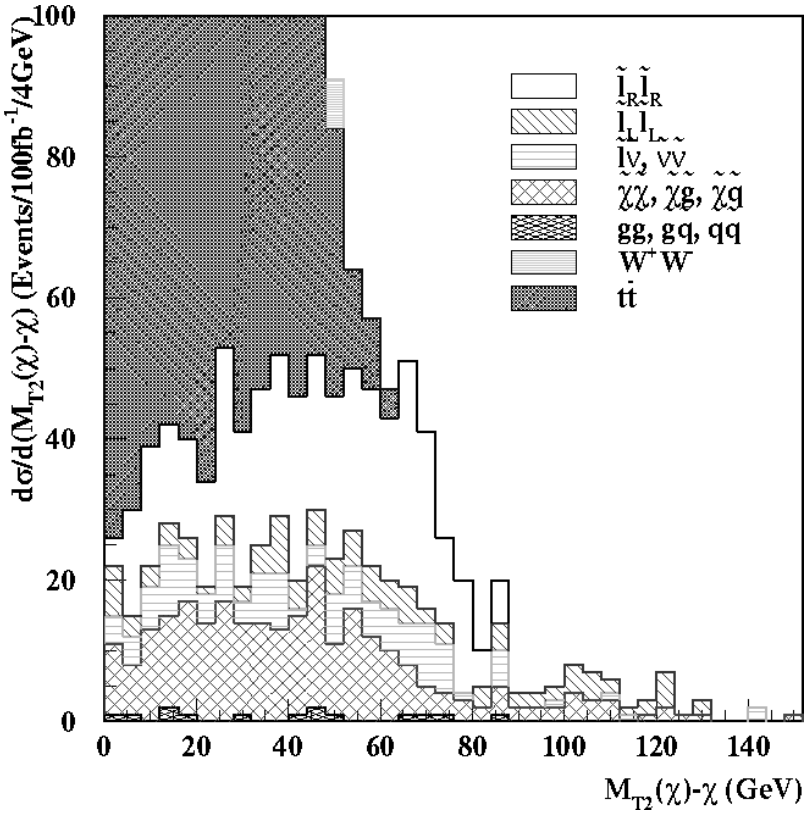


Soft cuts

ΔM - Dependence on Chi



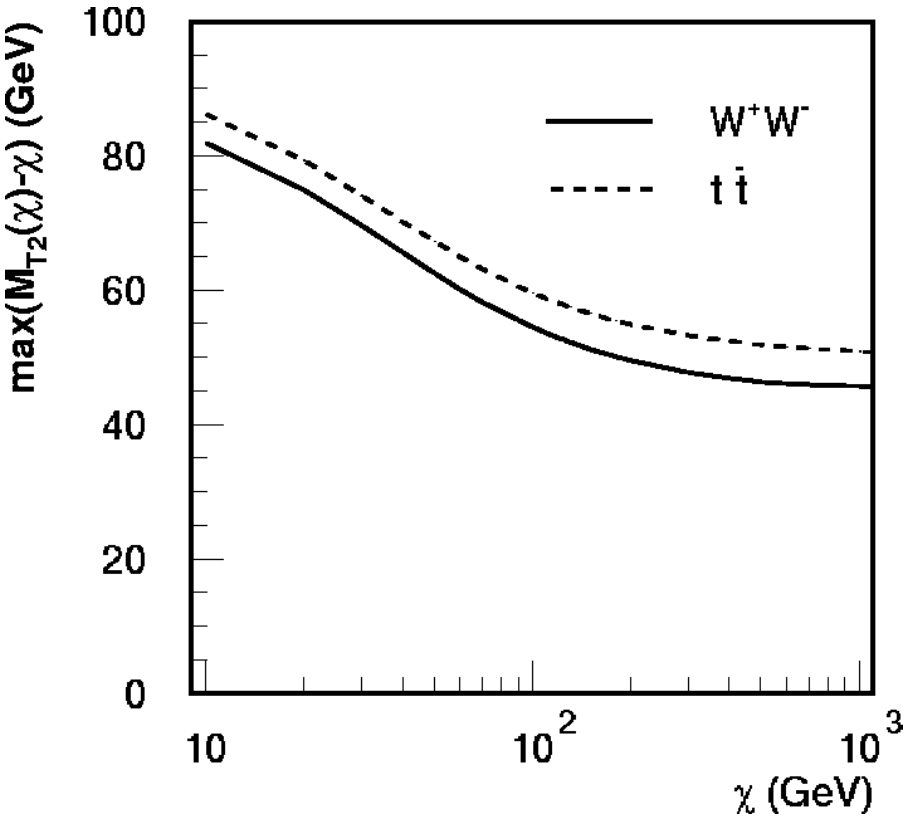
$\chi = 70$ GeV



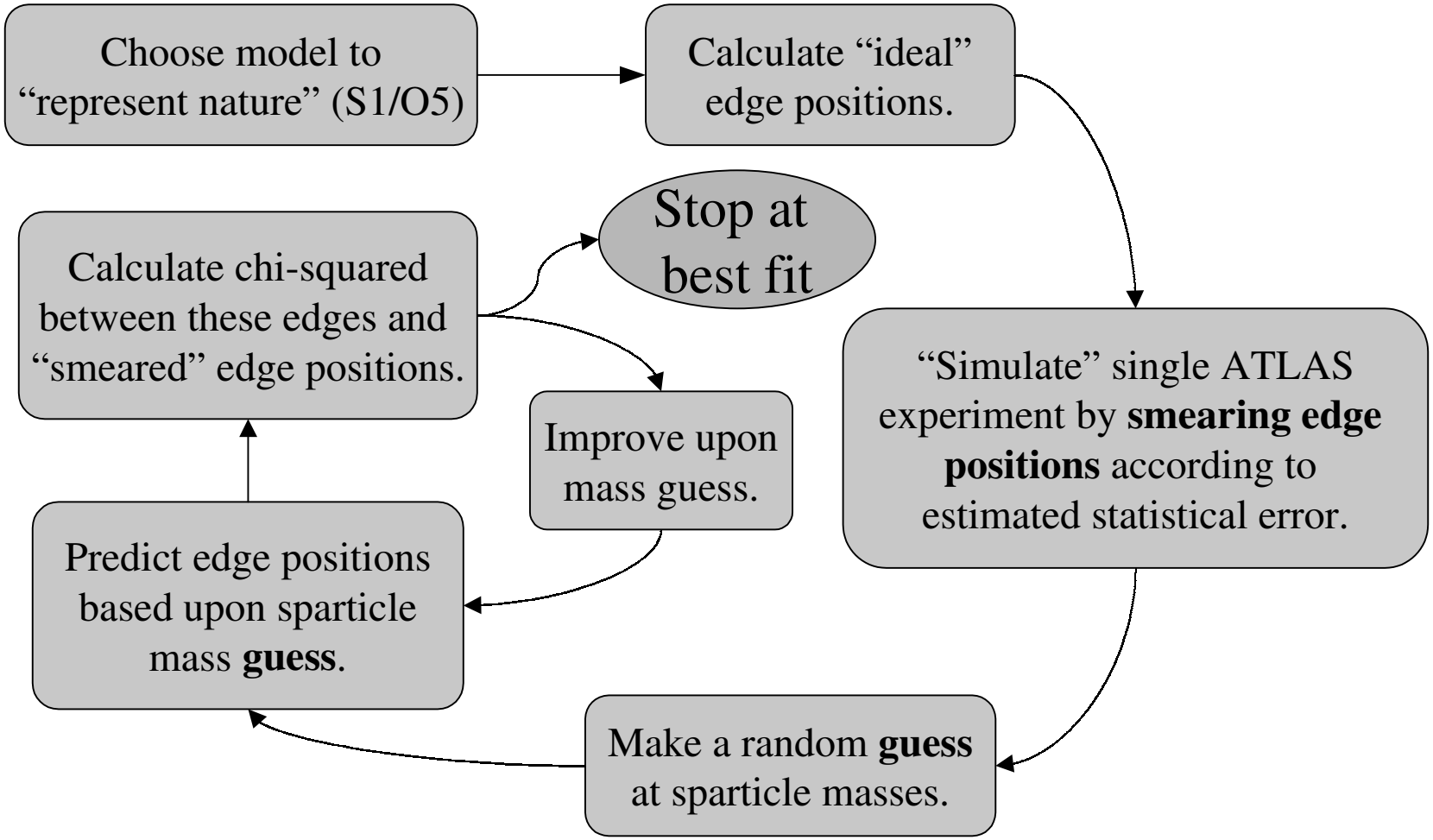
$\chi = 170$ GeV

ΔM - Backgrounds from SM

- Slepton ΔM edge is visible when slepton-neutralino mass difference is greater than about 60 GeV.

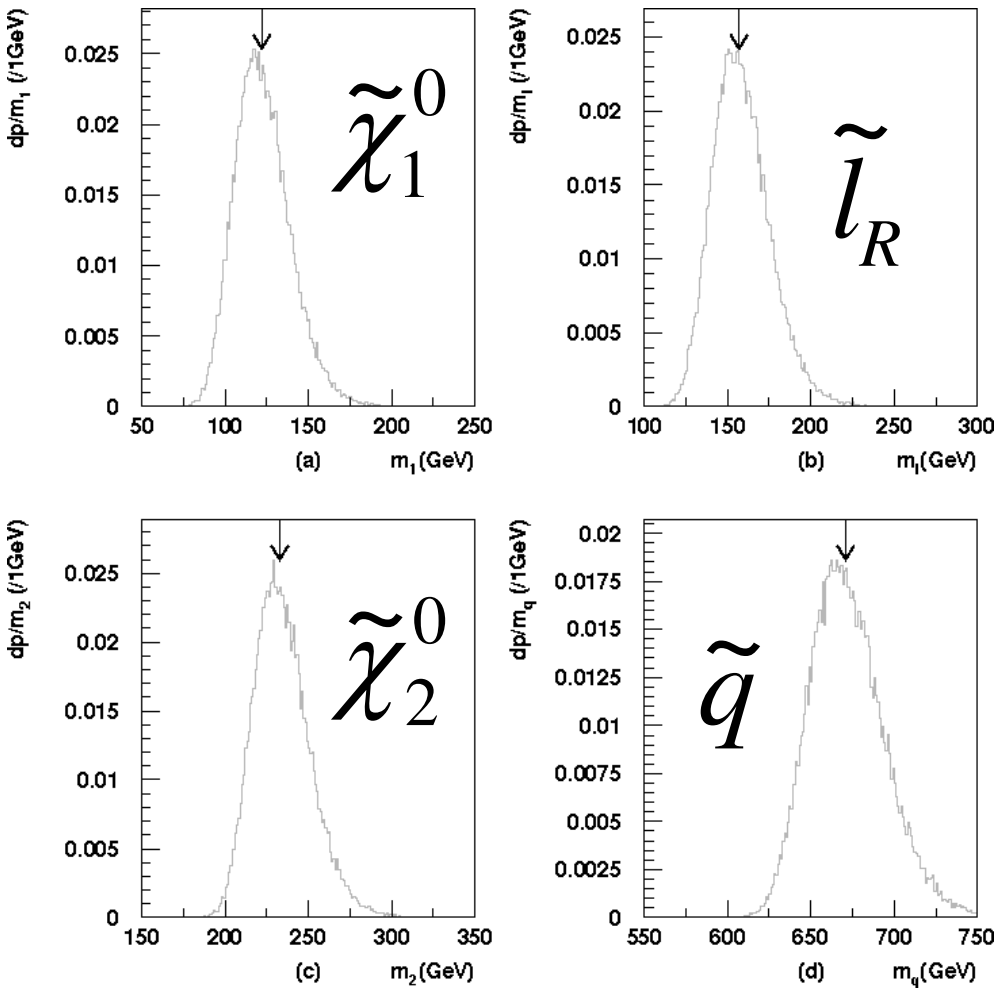


Reconstructing smasses



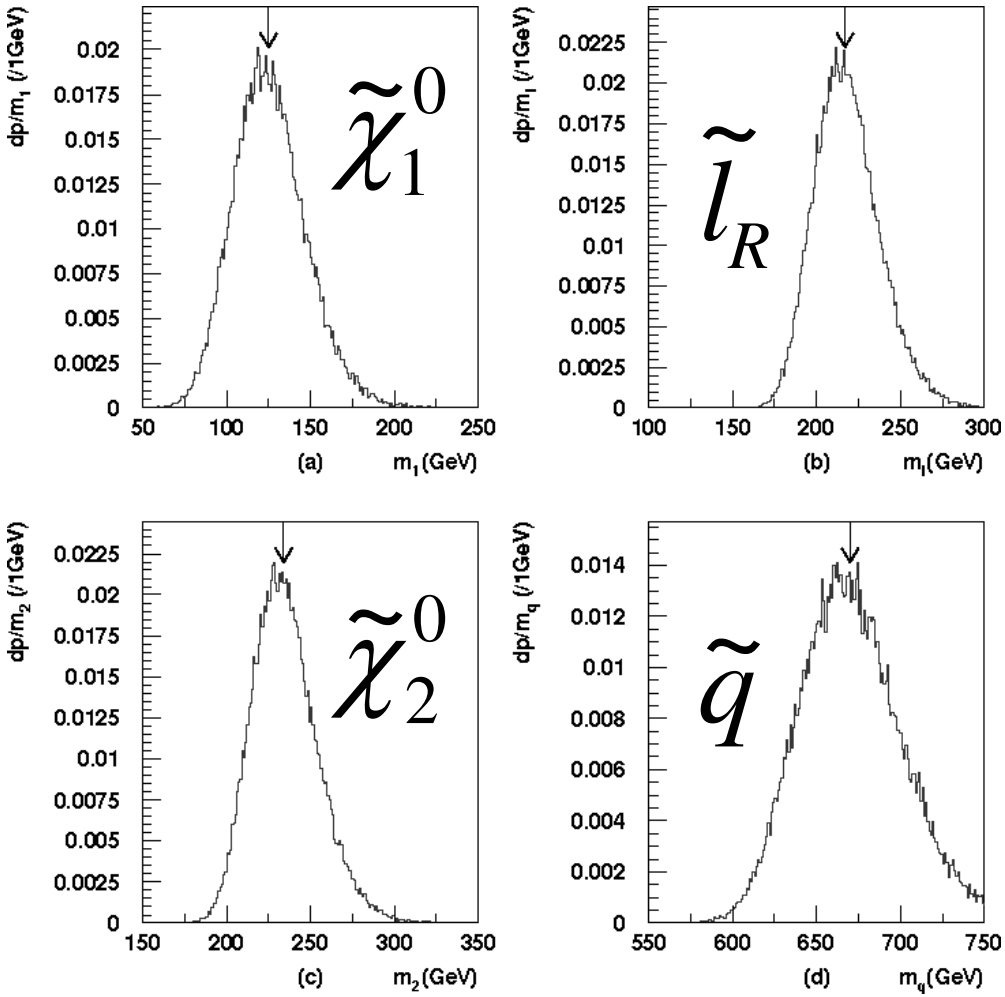
Fitted masses (S5)

- Fitted masses for an ensemble of ATLAS experiments
- Arrows indicate masses from model
- 17 GeV resolution on non-squarks
- 22 GeV resolution for squark scale



Fitted masses (O1)

- Fitted masses for an ensemble of ATLAS experiments
- Arrows indicate masses from model
- 20 GeV resolution on non-squarks
- 29 GeV resolution for squark scale

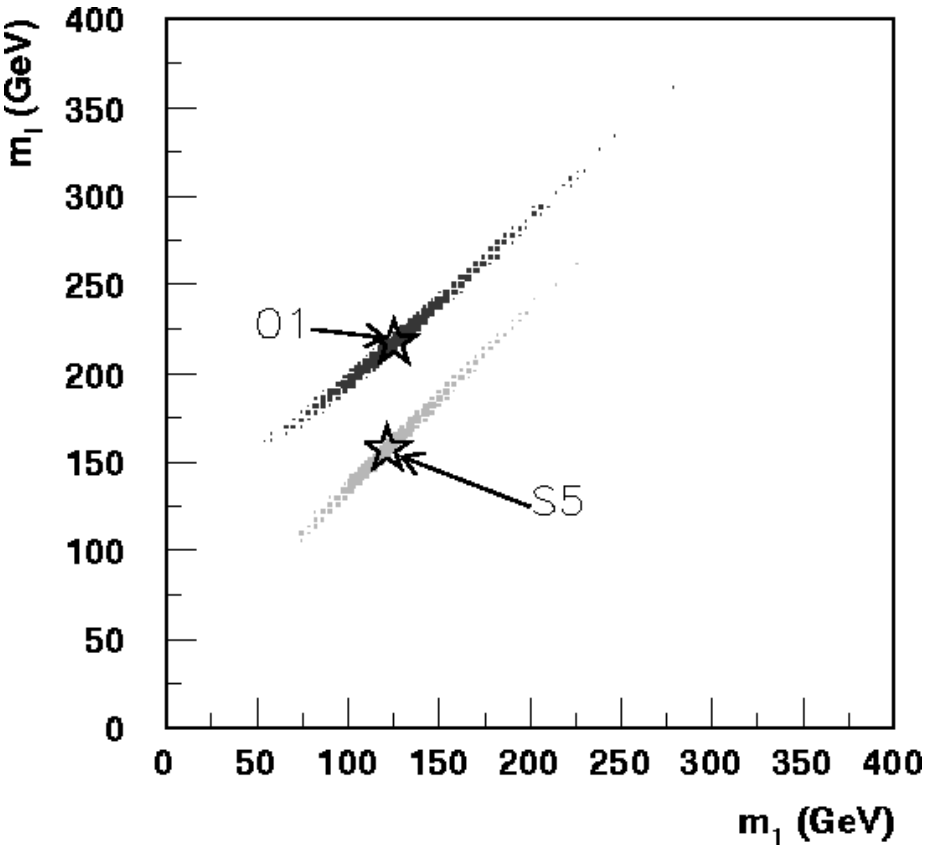


Reconstruction Widths

- 14-18 % for neutralino1
- 9-11 % for slepton
- 7-8 % for neutralino2
- 3-5 % for squark scale

	Fractional RMS $\sqrt{\overline{\varepsilon_p^2}}$		Fractional mean $\overline{\varepsilon_p}/10^{-3}$		Reconstruction width $\sqrt{\overline{(m_p - \overline{m_p})^2}}$	
p	S5	O1	S5	O1	S5	O1
$\tilde{\chi}_1^0$	0.140	0.175	11.4	8.0	17 GeV	22 GeV
$\tilde{l}_R$	0.112	0.091	8.8	5.7	17 GeV	20 GeV
$\tilde{\chi}_2^0$	0.074	0.084	6.0	5.3	17 GeV	20 GeV
$\tilde{q}$	0.034	0.047	2.7	2.4	22 GeV	29 GeV

Separation



- Left:
  - Reconstructed neutralino and slepton masses for an ensemble of ATLAS experiments
  - Good separation
  - Correlation evident