SUSY measurements with ATLAS detector

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Introduction

Why supersymmetric models?

- They solve the hierarchy problem
- They explain the amount of observed cosmological dark matter
- They are expected to appear at the TeV scale

. . . But they have a wide spectrum of new, unobserved particles

Outline

To claim the discovery of supersymmetries:

1. Observe beyond-SM events
2. Measure the masses of the new observed particles
3. Fit measurements with constrained models (mSUGRA, GMSB,. . .)

MSSM signature

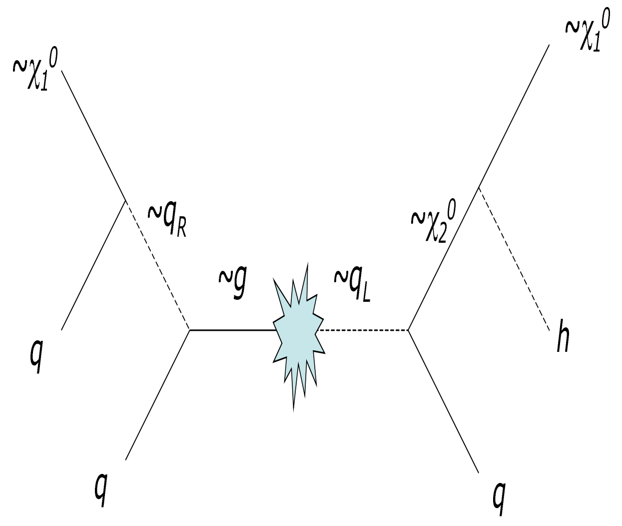
$$R = (-1)^{3(B-L)+2s}$$

SM particles and Higgs $R = 1$

Super-partners $R = -1$

In R-parity conserving models:

- B and L violating terms are removed
- Sparticles are produced in pairs
- Tipically $\tilde{g}$'s and $\tilde{q}$'s
- Each sparticle decays through one or more steps in LSP, giving high p_T jets
- LSP is stable and in most cases weakly interacting
  $\Rightarrow E_T^{miss}$ signature



How to prove that SM is violated

- Build discriminating variable

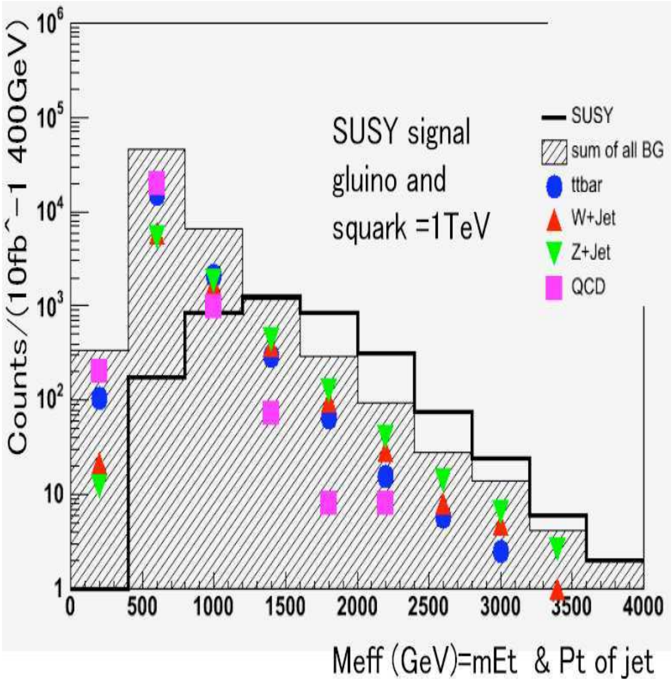
$$M_{eff} = \sum_{jet=1}^{4} |\vec{p}_T| + E_T^{miss}$$

- Knowledge of background sources
  - Irreducibles

$$\begin{array}{lcl} Z + Nj & \rightarrow & \nu\nu + Nj \\ W + Nj & \rightarrow & l\nu + Nj \\ t\bar{t} & \rightarrow & b\bar{b} + jj + l\nu \end{array}$$

  - Reducibles

QCD events with fake E_T^{miss}



S. Asai *et al.*

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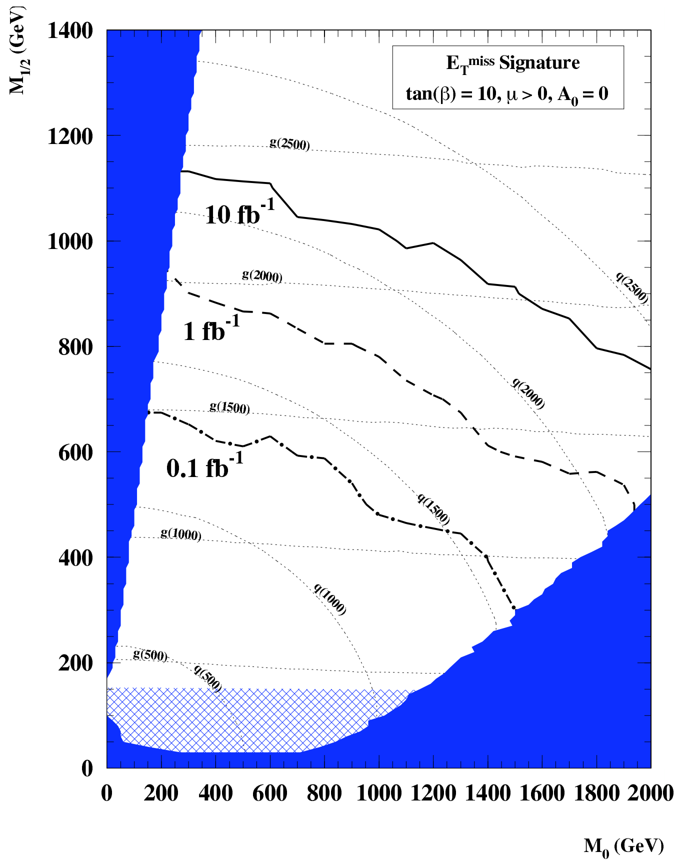


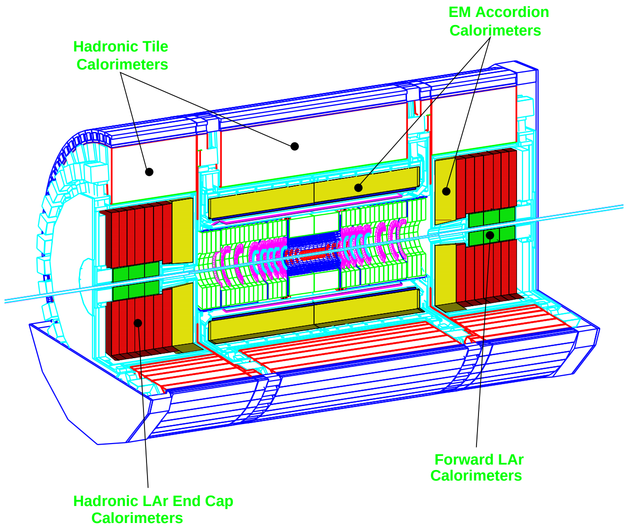
D. Tovey, SN-ATLAS-2002-020

E_T^{miss}: detector performances

To keep under control QCD background it is mandatory a good understanding of E_T^{miss}

- Full coverage $|\eta| < 5$

EM	Pb/LAr	$\|\eta\| < 3.2$
HAD	Fe/Scintillator	$\|\eta\| < 1.7$
HAD	Cu/LAr	$1.7 < \|\eta\| < 3.2$
FWD	Cu/LAr	$3 < \|\eta\| < 5$



- $\vec{E}_T^{miss} = -\sum_{\text{visible}} \vec{E}_T$

$\Rightarrow$ E_T^{miss} resolution is dominated by calorimeter:

$$\sigma(E_T^{miss}) \propto \sqrt{\sum_{\text{calo}} E_T}$$

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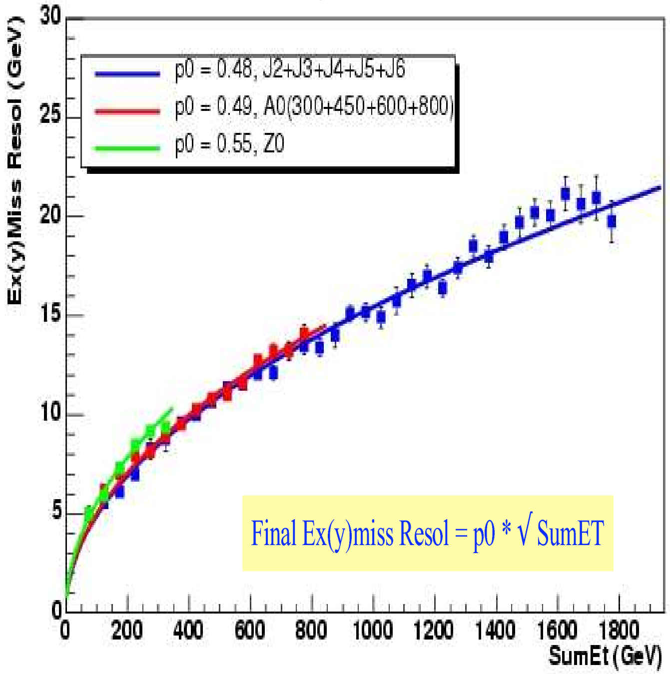


E_T^{miss}: in situ calibration

- $\tau\tau$ invariant mass reconstruction in

$$Z \to \tau_1\tau_2 \to l\ \nu_1\ j\ \nu_2$$
$$\nu_1 = \nu_\tau + \nu_l$$
$$\nu_2 = \nu_\tau$$

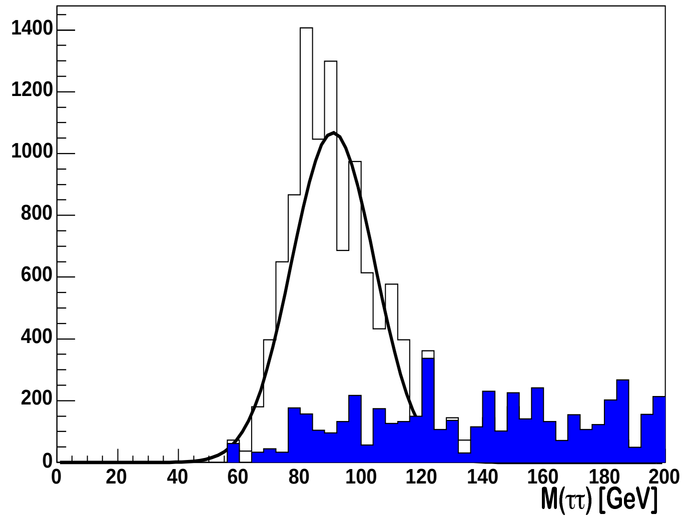
- Neutrino energies are obtained by solving the system

$$E_T^{miss}{}_{x,y} = (E(\nu_1)\hat{\nu}_1)_{x,y} + (E(\nu_2)\hat{\nu}_2)_{x,y}$$

- That can be solved provided that
  - Neutrino directions are known (collinear approximation: $\hat{\nu}_{1,2} = \hat{l}, \hat{j}$)
  - $\det = |\sin\Delta\varphi_{lj}| \neq 0$

$\Rightarrow$ Four-momenta of $\nu_{1,2}$ can be reconstructed

$\Rightarrow$ Four-momenta of $\tau_{1,2}$ can be reconstructed



- Expected 9000 events for 10 fb^{-1} in mass bin
- With about 20-30% of background
  - $W + j \to l\nu + j$
  - $t\bar{t}$ (semi-leptonic)
  - $b\bar{b}$ (semi-leptonic, not yet studied)

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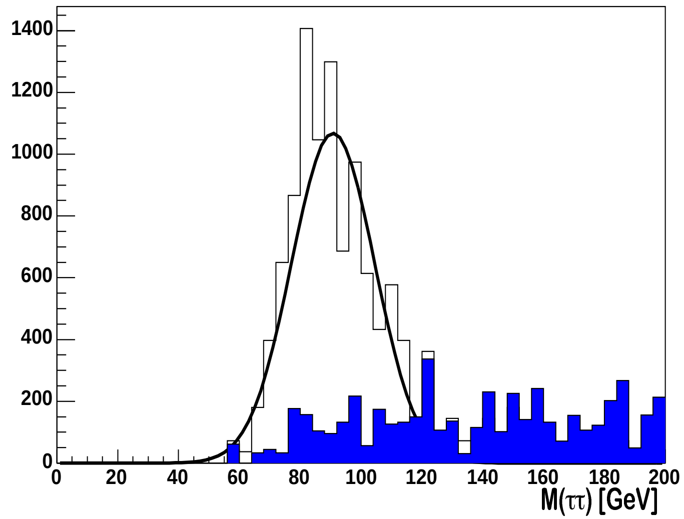
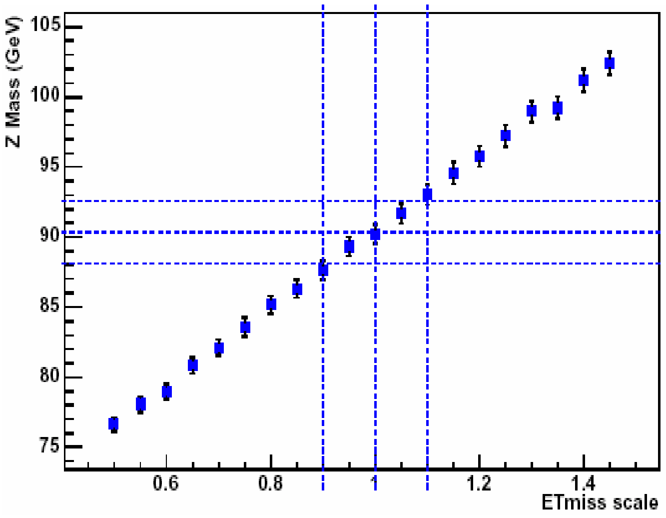
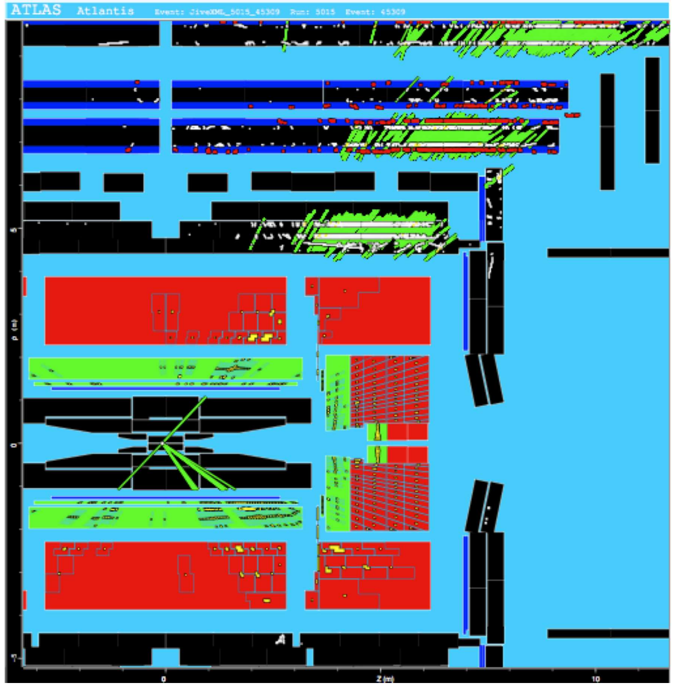




Fake E_T^{miss}

Detector *mistakes* can add tails to the gaussian resolution on E_T^{miss}

- Electronic and pile-up noise:
  - Accurate mapping of *hot calorimeter cells* will be needed
  - The study of *minimum-bias* events and the tuning of their simulation will be the goal with first data
- Fake muons (e.g. from cosmics)
- Mismeasured jets:
  - Jets in cracks
  - Punchthroughs



F. Paige, ATLAS Susy WG, 05/2006

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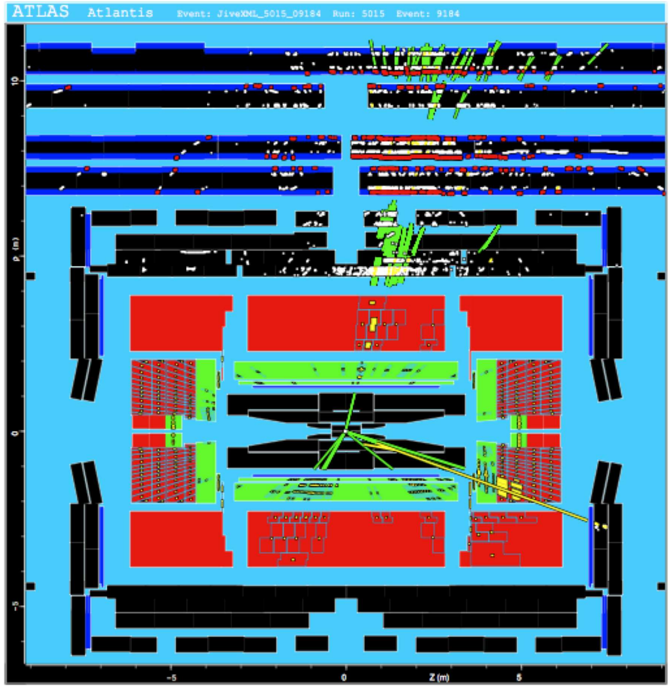


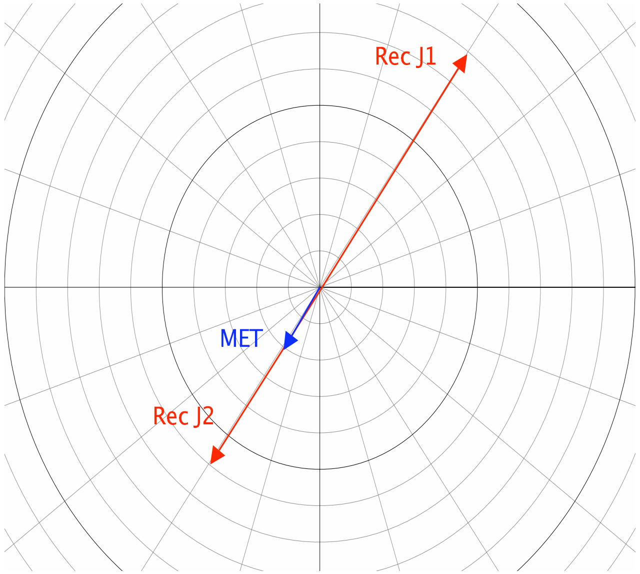
F. Paige, ATLAS Susy WG, 05/2006

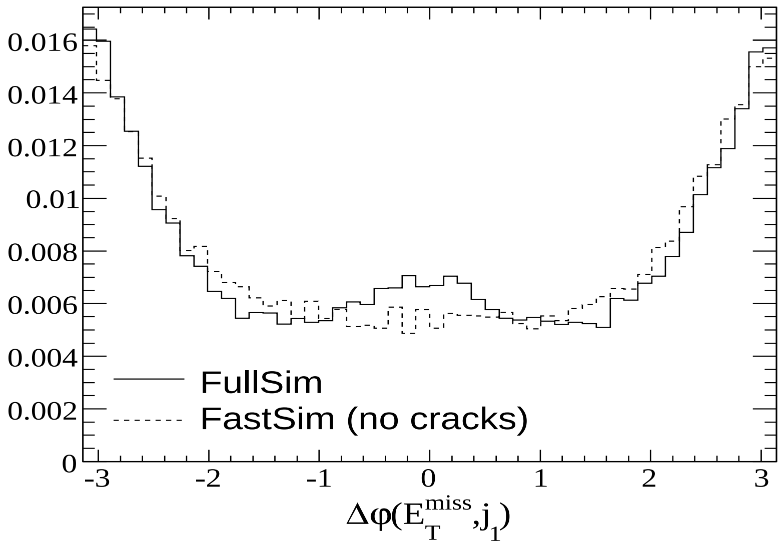
Fake E_T^{miss} rejection

Mismeasured jets example

- In a di-jet event: the hardest jet is usually opposite to $\vec{E}_T^{miss}$ in xy plane
- Events with one jet in a crack have $\varphi_{\vec{j}} \sim \varphi_{\vec{E}_T^{miss}}$

$\Rightarrow$ Isolation of $\vec{E}_T^{miss}$ contribute to suppress reducible backgrounds





Mass measurements of SUSY particles

- Two LSP escaping the detector

$\Rightarrow$ No resonances reconstruction

- Mass informations can be taken only from invariant mass endpoints

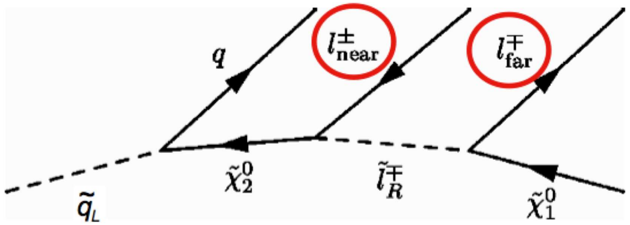
- Search for signatures with leptons or *b*-jets:
  - $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 ll$
  - $\tilde{\chi}_2^0 \rightarrow \tilde{l}l \rightarrow \tilde{\chi}_1^0 ll$
  - $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 Z \rightarrow \tilde{\chi}_1^0 ll$
  - $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 h \rightarrow \tilde{\chi}_1^0 bb$

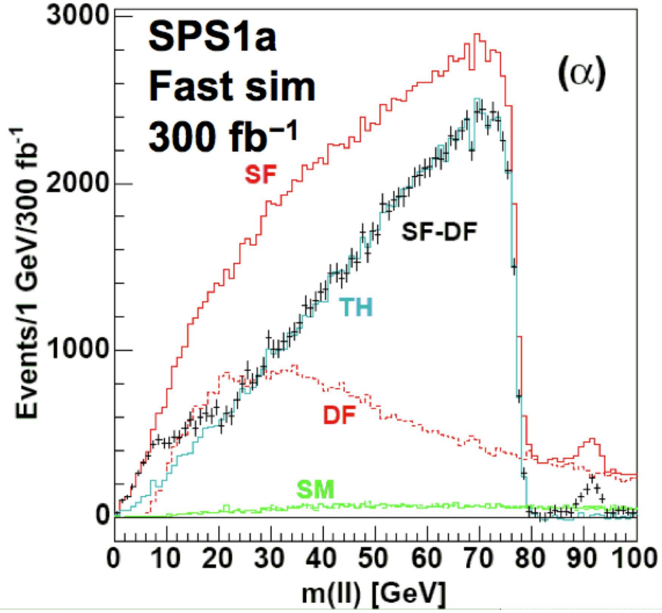
- Here examples for Point *SPS1a*:

$$(\; m_0 = 100 \text{ GeV}, \; m_{1/2} = 250 \text{ GeV}, \; A = -100 \text{ GeV}, \; \tan\beta = 10, \; \mu > 0 \;)$$

Dilepton signatures

- Three-body decay:
  - Slope at the endpoint
  - $m_{ll}^{edge} = m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0}$
- Two-body decay:
  - Sharp edge
  - $m_{ll}^{edge} = \frac{(m_{\tilde{\chi}_2^0}^2 - m_{\tilde{l}_R}^2)(m_{\tilde{l}_R}^2 - m_{\tilde{\chi}_1^0}^2)}{m_{\tilde{l}_R}^2}$
- Use Same Flavour (SF) leptons
- Elimination of events with uncorrelated leptons: by subtraction of Different Flavour (DF) leptons event

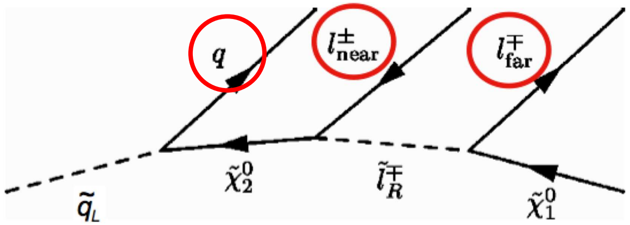




B. K. Gjelsten *et al.*,
ATL-PHYS-2004-007

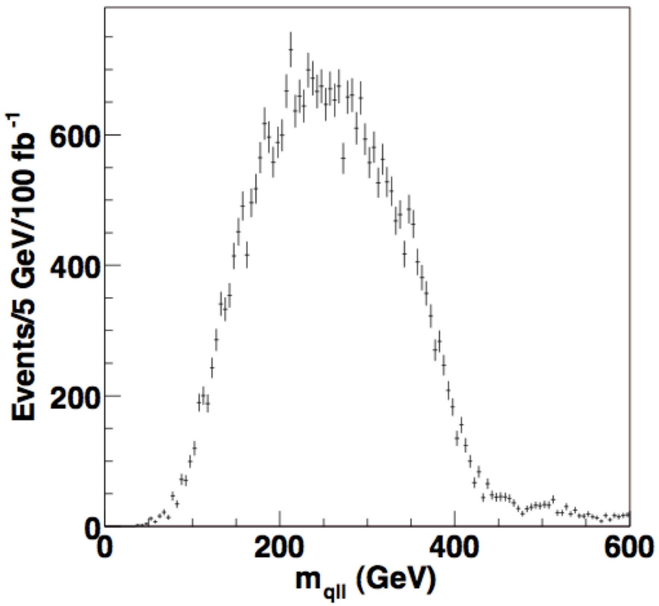
More complex signatures

- Adding one jet, we can reconstruct other kinematical edges
- From 4 endpoints, we can solve 4 unknown masses
- Strong correlations between masses



For 100 fb^{-1} of integrated luminosity

Edge	Nominal Value	Fit Value	Syst. Error Energy Scale	Statistical Error
$m(ll)^{\rm edge}$	77.077	77.024	0.08	0.05
$m(qll)^{\rm edge}$	431.1	431.3	4.3	2.4
$m(ql)^{\rm edge}_{\rm min}$	302.1	300.8	3.0	1.5
$m(ql)^{\rm edge}_{\rm max}$	380.3	379.4	3.8	1.8
$m(qll)^{\rm thres}$	203.0	204.6	2.0	2.8
$m(bll)^{\rm thres}$	183.1	181.1	1.8	6.3



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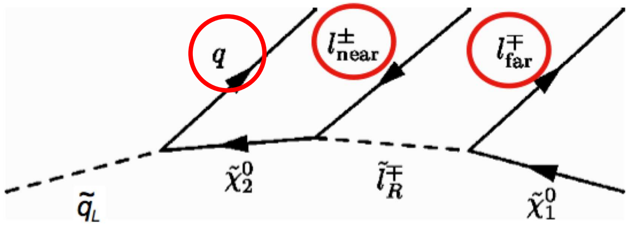
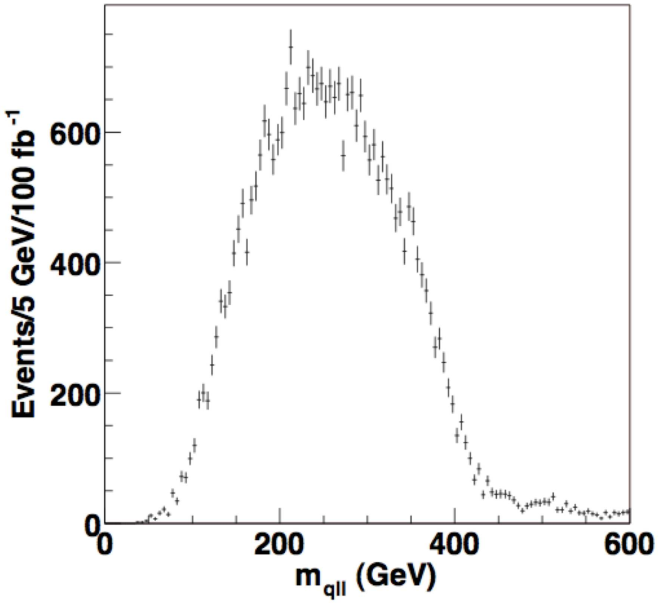


For 300 fb^{-1} of integrated luminosity

	LHC	LHC+LC (0.2%)	LHC+LC (1.0%)
$\Delta m_{\tilde{\chi}^0_1}$	4.8	0.19	1.0
$\Delta m_{\tilde{l}_R}$	4.8	0.34	1.0
$\Delta m_{\tilde{\chi}^0_2}$	4.7	0.24	1.0
$\Delta m_{\tilde{q}_L}$	8.7	4.9	5.1
$\Delta m_{\tilde{b}_1}$	13.2	10.5	10.6



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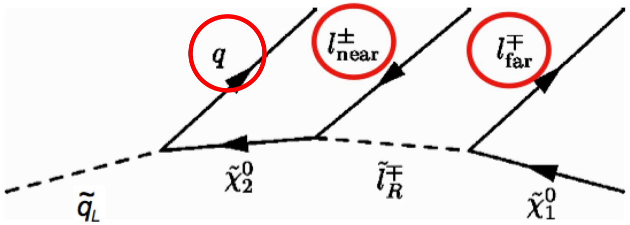

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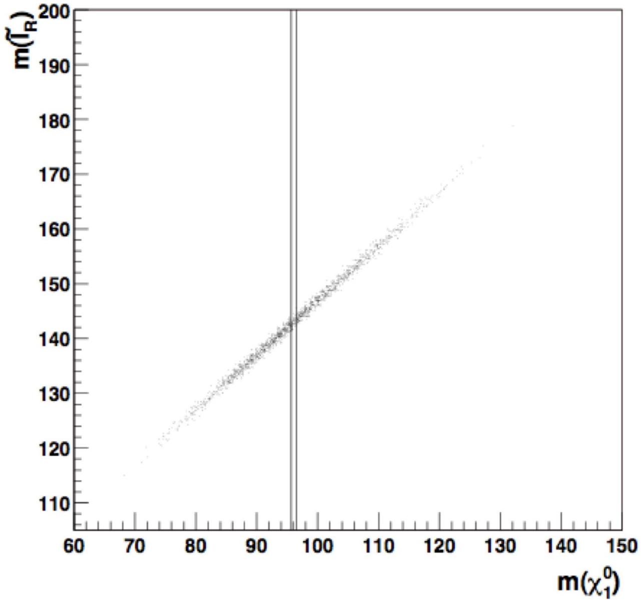
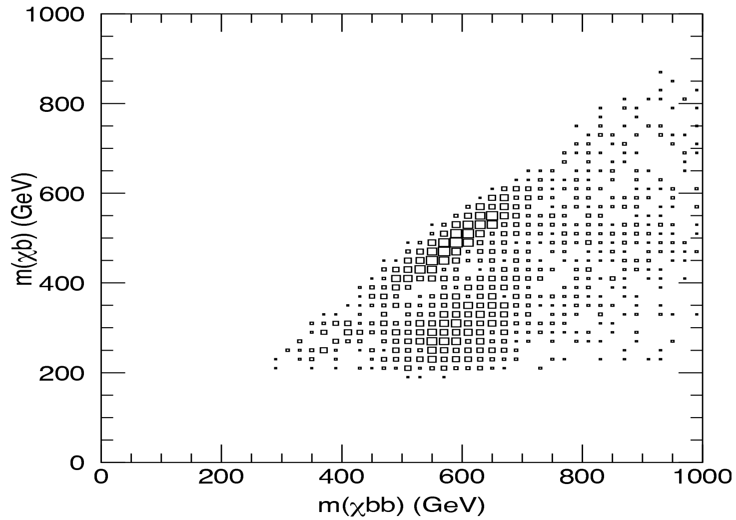


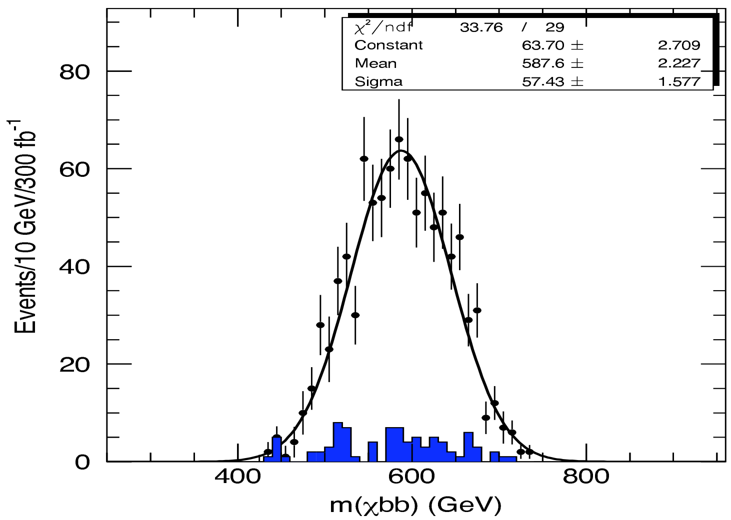
Gluino mass reconstruction

- Going on with the chain reconstruction…
- Better with $\tilde{b}$ instead of $\tilde{q}_L$ to suppress combinatorial background (bad jets association to ll mass)

$$\tilde{g} \to \tilde{b}b \to \tilde{\chi}_2^0 bb \; (\to \tilde{l}_R lbb) \to \tilde{\chi}_1^0 llbb$$

- In 3-body decay case, at the endpoint: $\vec{p}(\tilde{\chi}_2^0) = \left(1 - \frac{m(\tilde{\chi}_1^0)}{m(ll)}\right)\vec{p}(ll)$
- In 2-body decay case, approximately true if $m_{\tilde{\chi}_1^0} \ll m(\tilde{l}_R) \ll m(\tilde{\chi}_2^0)$
- Statistical uncertainty about 4 GeV for 100 fb^{-1}



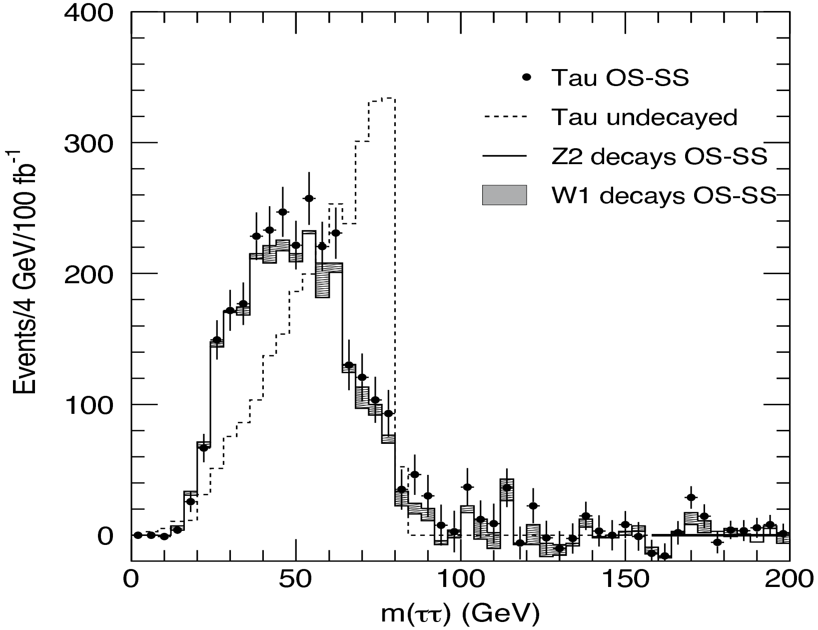


$\tau\tau$ signatures

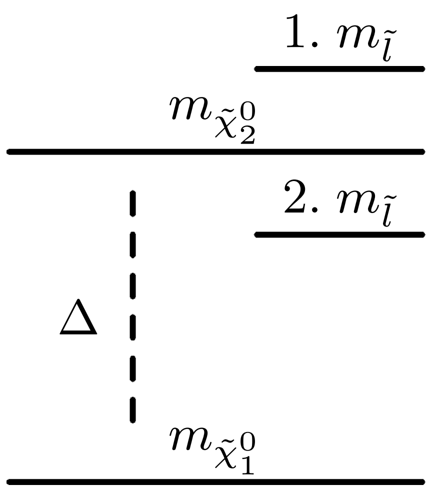
- For large values of $\tan\beta$ there is a non-negligible mixing between the two $\tilde{\tau}$'s

$\Rightarrow$ Significant splitting between $m_{\tilde{\tau}_1}$ and $m_{\tilde{\tau}_2}$, enhancing $BR(\tilde{\chi}_2^0 \rightarrow \tilde{\tau}_1 \tau)$ with respect to the other flavours

- Statistical uncertainty about 5 GeV (for 100 fb^{-1})
- Challenge to control systematics to 5 GeV



Higgs searches



Dominant $\tilde{\chi}_2^0$ decay mode depends on scenario

	1. $m_{\tilde{\chi}_2^0} < m_{\tilde{l}}$	2. $m_{\tilde{l}} < m_{\tilde{\chi}_2^0}$
$\Delta > m_h$	$\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 h$	$\tilde{\chi}_2^0 \to \tilde{l}l / \tilde{\chi}_1^0 h$
$m_Z < \Delta < m_h$	$\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 Z$	$\tilde{\chi}_2^0 \to \tilde{l}l$
$\Delta < m_Z$	$\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 ll$	$\tilde{\chi}_2^0 \to \tilde{l}l$

- If open $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 h$ has generally a substantial branching ratio
- A resonance may be reconstructed
- May provide a Higgs discovery mode
- $BR(h \to bb)$ enhanced by large $\tan\beta$ effects
- If visible ll channel is still the most powerful for mass measurements

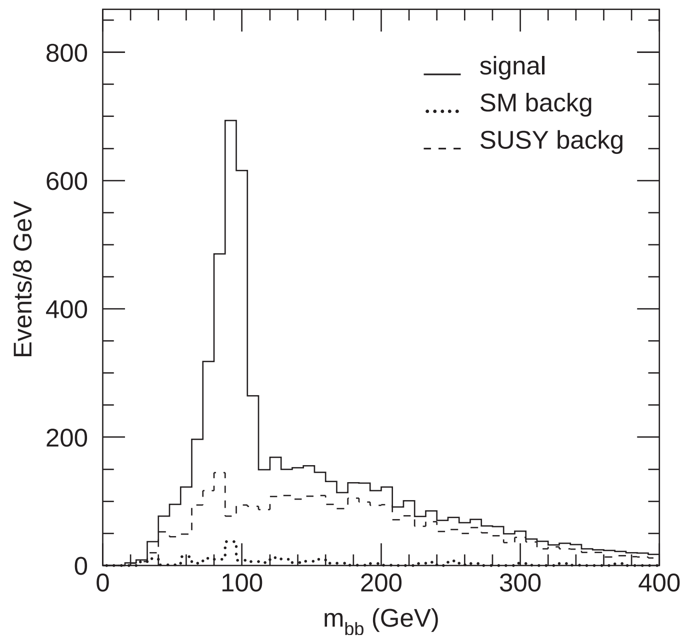
Higgs searches

- Case $m_{\tilde{l}} < m_{\tilde{\chi}_2^0}$ with $\Delta > m_h$
- About 20% of SUSY events contains one h
- Selection cuts:
  - $E_T^{miss} > 300$ GeV
  - 2 *b*-jets with $p_T > 50$ GeV
  - Veto on 3rd jet with $p_T > 50$ GeV
  - 2 *non-b*-jets with $p_T > 100$ GeV
  - Veto on leptons with $p_T > 10$ GeV
- Fast simulation study with:
  - b-tagging efficiency: 60%
  - c-rejection: 10
  - jet-rejection: 100
- Error on m_h of order 1% (jet energy scale uncertainty)

$L = 30$ fb^{-1}

Signal $\approx$ 2000

Backgroud $\approx$ 600



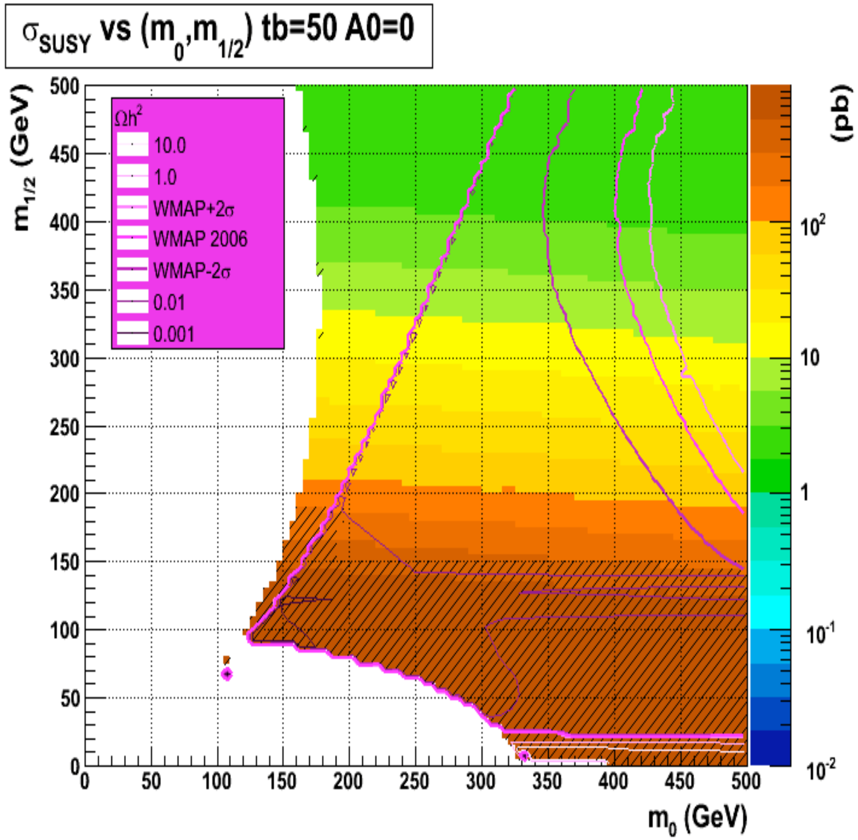
LHC Point 5:

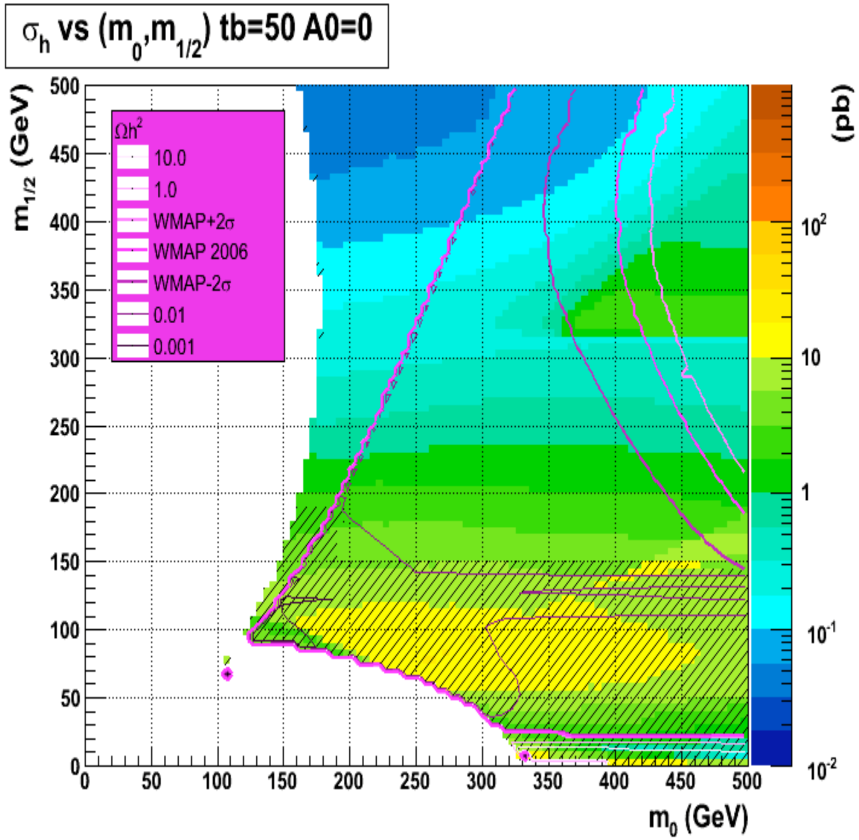
($m_0 = 100$ GeV, $m_{1/2} = 300$ GeV, $A = 300$ GeV, $\tan\beta = 2.1$, $\mu > 0$)

Higgs searches

- Scan of parameters
- At $\tan\beta = 50$, light Higgs production in the WMAP bulk region:

$$1/100 \lesssim \sigma_h/\sigma_{SUSY} \lesssim 1/10$$





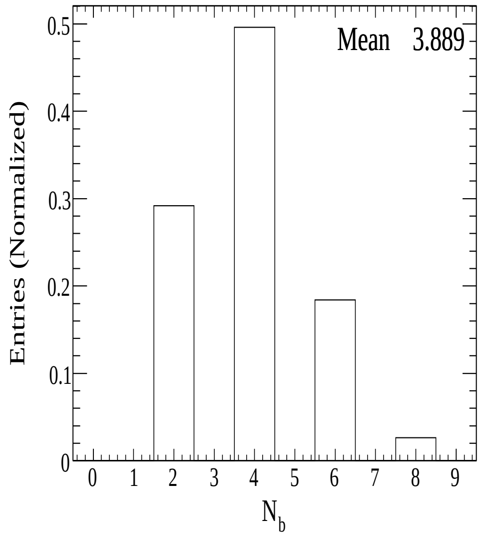
Higgs searches

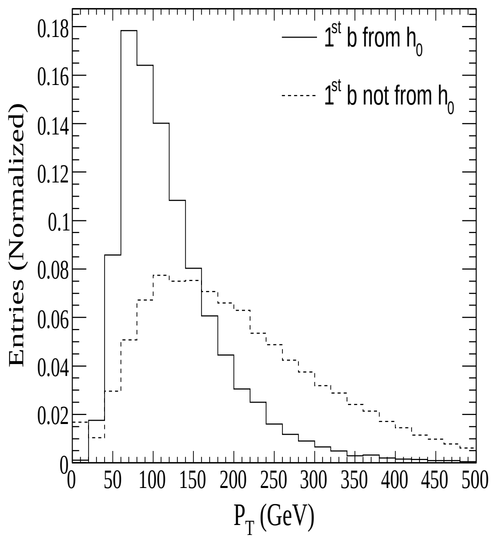
At large $\tan\beta$, the combinatorial background makes the measure challenging. For example,

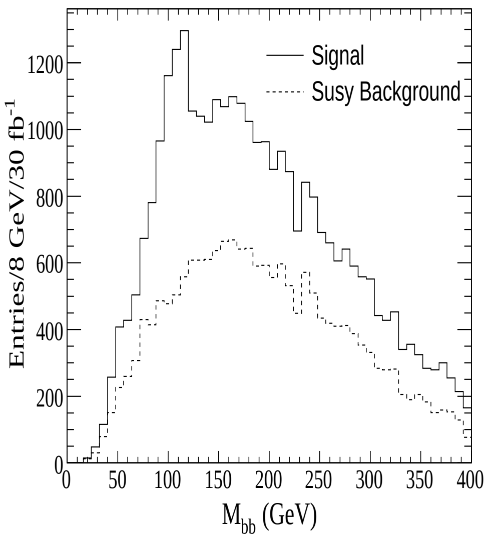
$$(\; m_0 = 390 \text{ GeV}, \; m_{1/2} = 325 \text{ GeV}, \; A = -100 \text{ GeV}, \; \tan\beta = 50, \; \mu > 0 \;)$$

$$\tilde{g} \rightarrow \tilde{b}_1 b_2 \rightarrow \tilde{\chi}_2^0 b_1 b_2 \rightarrow \tilde{\chi}_1^0 h b_1 b_2 \rightarrow \tilde{\chi}_1^0 b_1^h b_2^h b_1 b_2$$

Since $m(\tilde{b}_1) - m(\tilde{\chi}_2^0) \gg m(h) \Rightarrow P_T(b_1) \gg P_T(b_1^h)$



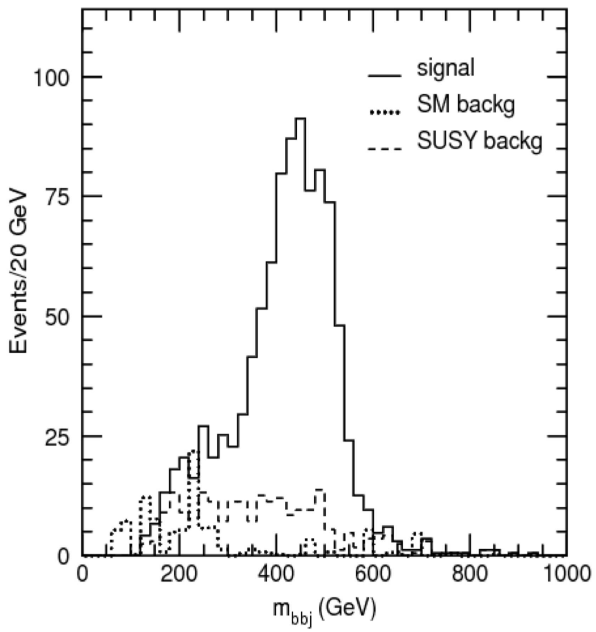


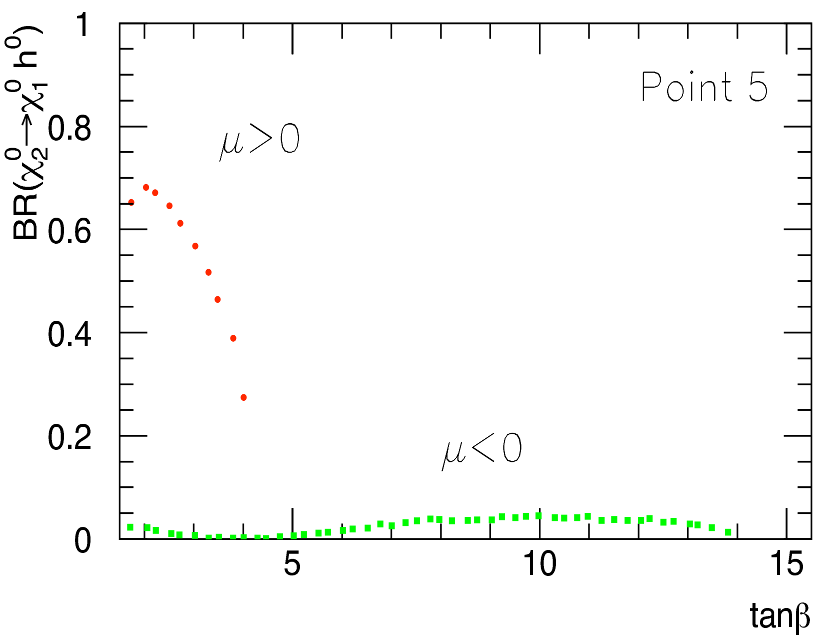


Higgs searches

Further analysis of SUSY particle masses

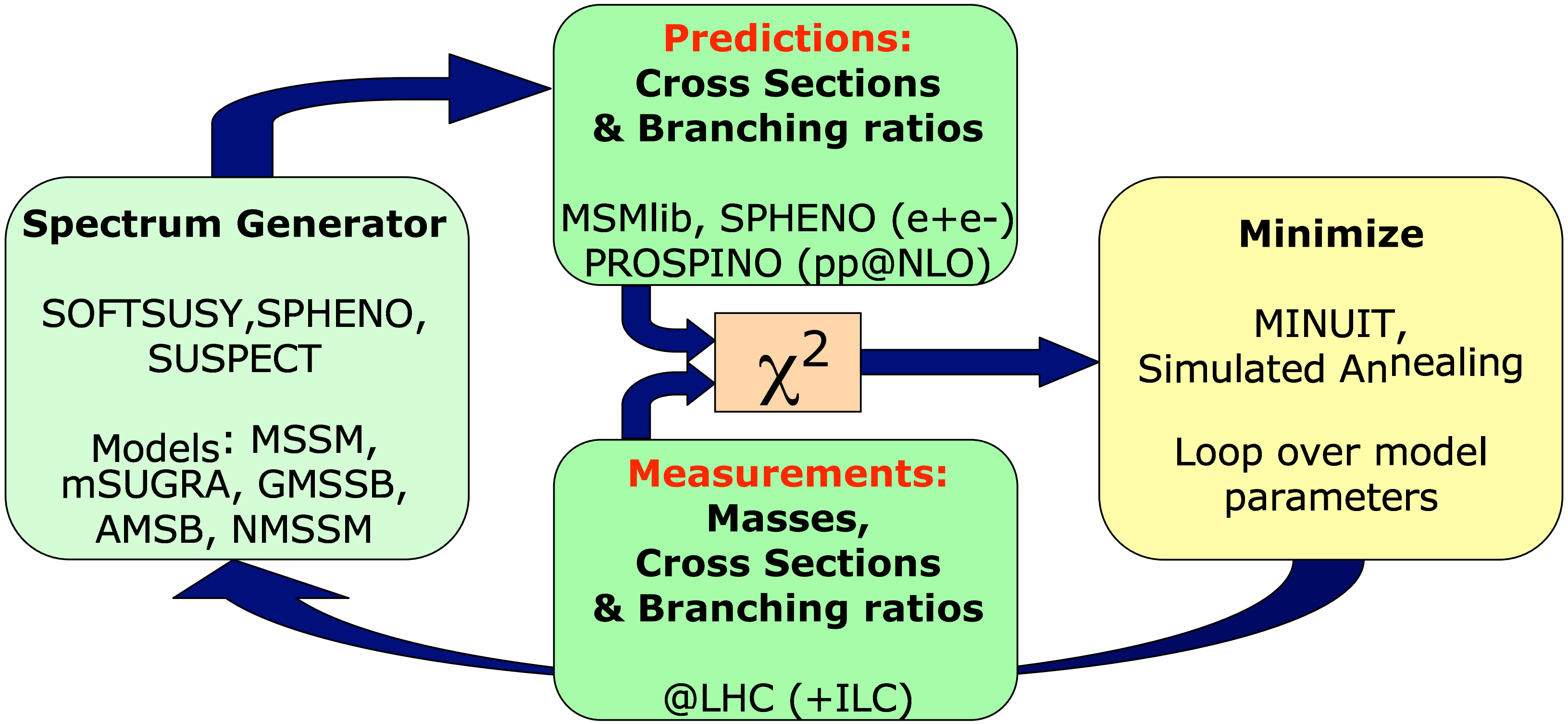
- Reconstruction of m_{bbj} invariant mass
- Extraction of $\tan\beta$ and sgn(μ) parameters with:
  - $m(h)$
  - Observed rate of $h \to b\bar{b}$ events
  - Observed rate of $Z \to l^+l^-$ events





Fitting mSUGRA parameters

SFITTER: R. Lafaye, T. Plehn, D. Zerwas, hep-ph/0512028



Fitting mSUGRA parameters

- Minimal SUGRA example: *SPS1a*
- Better to exploit edges than masses, due to the non trivial correlations
- Sign of μ fixed: $\text{sgn}(\mu) = +1$
- χ^2 to discriminate between $\text{sgn}(\mu) = \pm 1$

	SPS1a	ΔLHC masses	ΔLHC edges
m_0	100	**3.9**	**1.2**
$m_{1/2}$	250	**1.7**	**1.0**
tanβ	10	**1.1**	**0.9**
A0	-100	**33**	**20**

- Loosening the unification criteria
- Non unified scalar masses
- Higgs sector undermined (only h observed)

	SPS1a	LHC	ΔLHC
$m_0^{sleptons}$	100	**100**	**4.6**
$m_0^{squarks}$	100	**100**	**50**
m_H^2	10000	**9932**	**42000**
$m_{1/2}$	250	**250**	**3.5**
tanβ	10	**9.82**	**4.3**
A0	-100	**-100**	**181**

Conclusions

- New physics is expected at the TeV scale
- Supersymmetry is still one of the most attractive models
- May be discovered with few fb^{-1}
- Mass spectrum can be determined from mass edges measurements
- Higgs can be observed (and discovered) in SUSY cascades as a resonance in the bb invariant mass plot
- Provided that we control backgrounds and detector effects