GEFÖRDERT VOM

Bundesministerium für Bildung und Forschung

Exclusive SUSY measurements and determination of Lagrangian parameters from LHC data

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Establishing SUSY

Excess of events ≠ discovery of SUSY

Need to study properties of new physics (SUSY? Of which type?, ...)

Requires as many measurements as possible:

- Masses
- Couplings
- Spins

Subsequently compare with expectations from different models and extract corresponding model parameters

Here I will focus on measurements which are feasible with first data (mostly using 1 fb^{-1}) in some favourable mSUGRA scenarios

SUSY mass measurements at the LHC

No mass peaks due to two escaping LSPs per event, if R-parity is conserved

Main source of information about masses: χ_2^0 decays

$$\tilde{\chi}_2^0 \to \tilde{l}^\pm l^\mp \to \tilde{\chi}_1^0 l^+ l^-$$

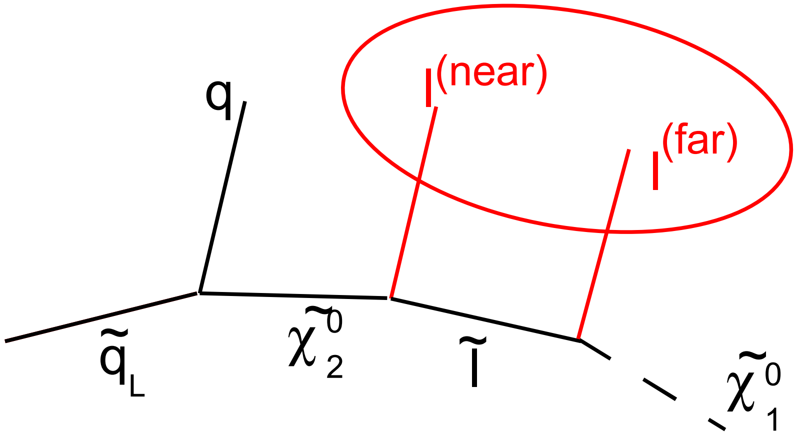
$$\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 Z^{(*)}$$

$$\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 h \to \tilde{\chi}_1^0 b \bar{b}$$

Such decay chains allow to extract masses in a model independent way under certain circumstances

On the following slides some important mass extraction techniques will be illustrated

Di-lepton mass spectrum



Position of endpoint of m_{ll} mass spectrum depends on masses of sparticles involved in decay chain:

$$m_{\ell\ell}^{\mathrm{edge}} = m_{\tilde{\chi}_2^0}\sqrt{1-\left(\frac{m_{\tilde{\ell}}}{m_{\tilde{\chi}_2^0}}\right)^2}\sqrt{1-\left(\frac{m_{\tilde{\chi}_1^0}}{m_{\tilde{\ell}}}\right)^2}$$

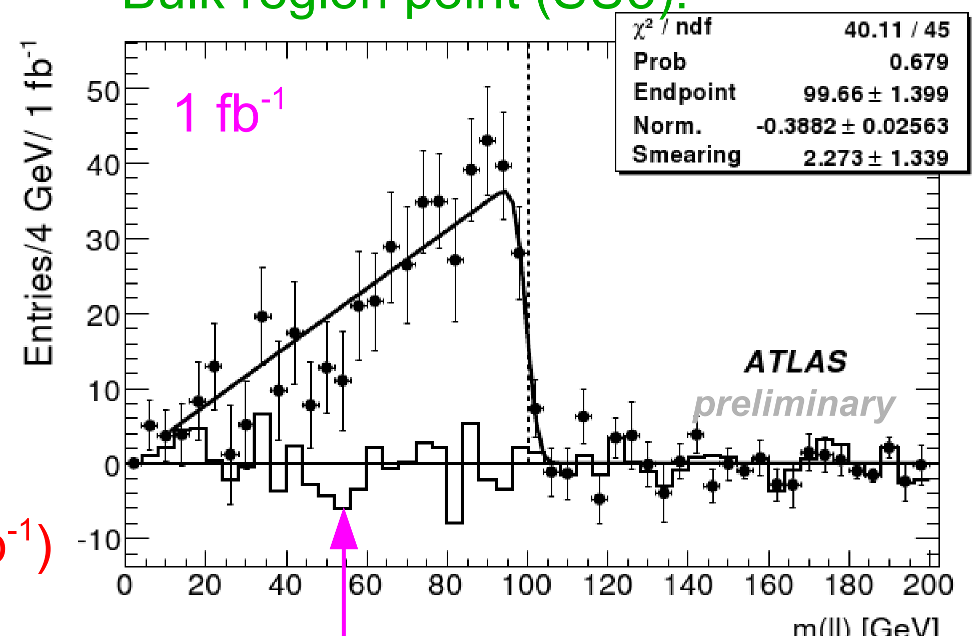
Use flavour-subtracted mass distribution to suppress combinatorial SUSY and SM background:

$$N(e^+e^-)/\beta + \beta N(\mu^+\mu^-) - N(e^\pm\mu^\mp)$$

efficiency correction

m_{ll}^{edge} = (99.7 ± 1.4 ± 0.3) GeV (1 fb^{-1})
(nominal: 100.2 GeV)

Bulk region point (SU3):



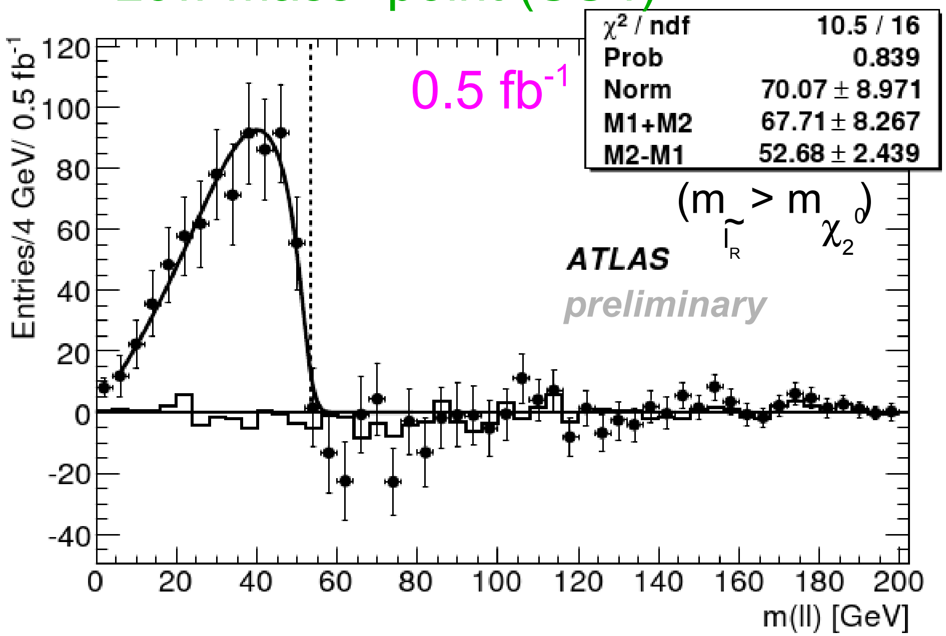
SM background

Di-lepton mass distributions: more examples

Apart from simple triangular shape in case of two-body decays, also more more complex cases can happen:

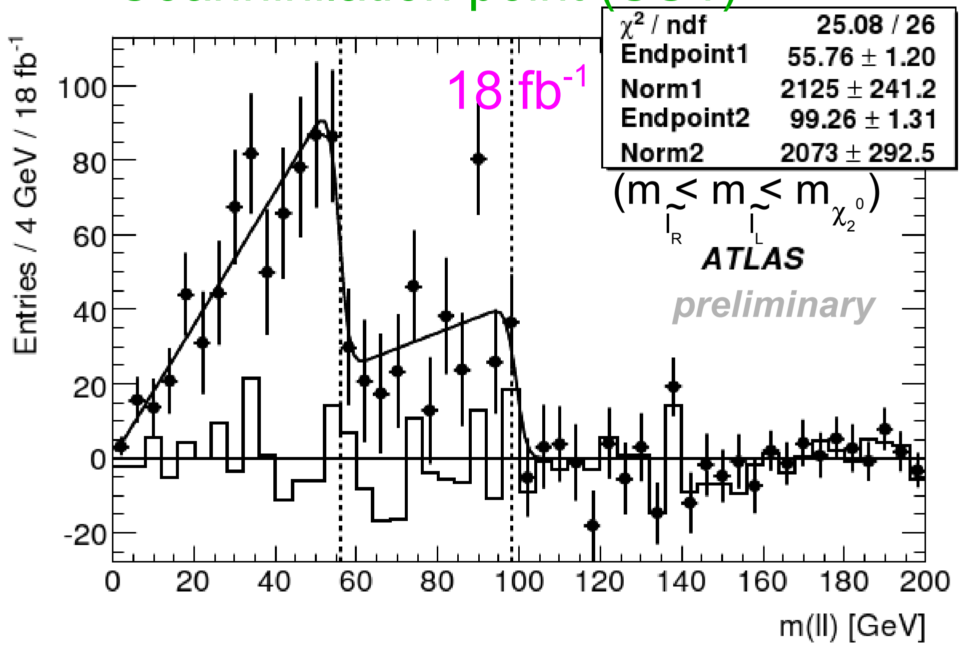
3-body decay of χ_2^0

"Low mass" point (SU4)



Two 2-body decays of χ_2^0

Coannihilation point (SU1)



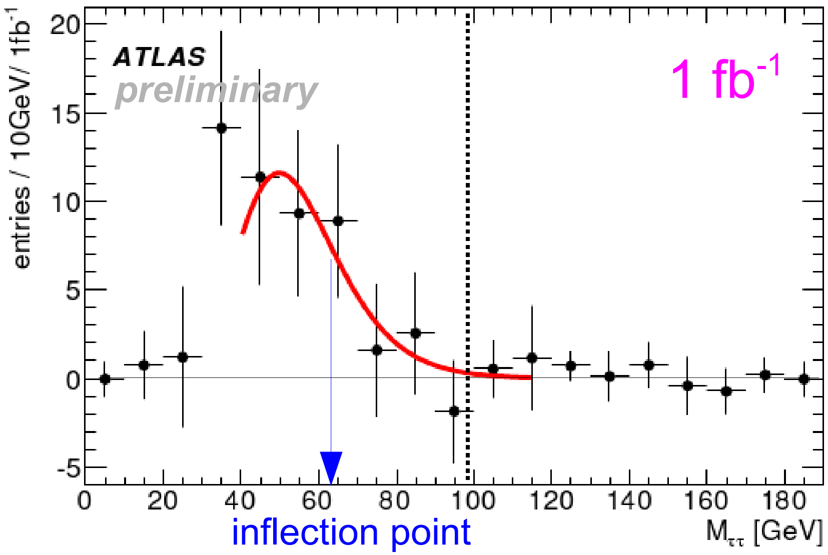
Shape depends on slepton mass

Two superimposed triangles

Endpoint position: $m_{\ell\ell}^{\text{edge}} = m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0}$

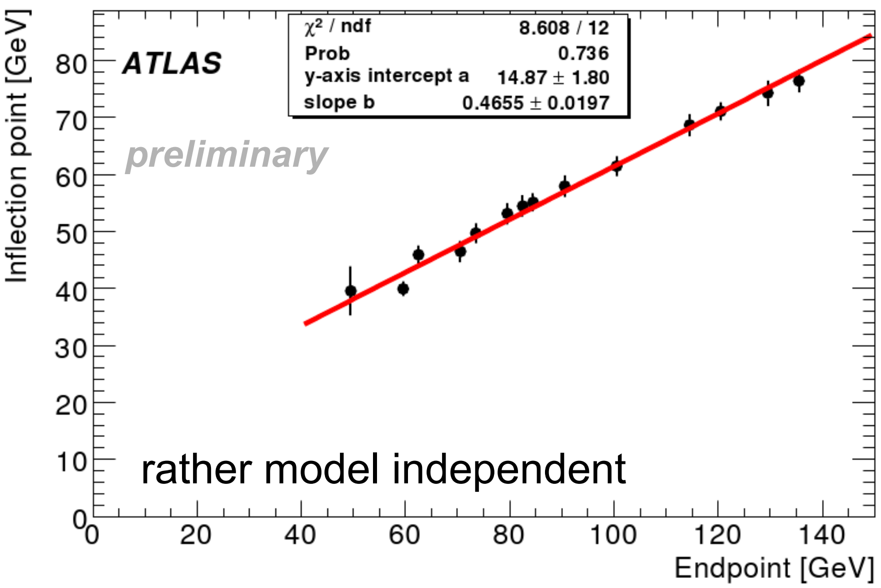
Di-tau mass spectrum

Bulk region point (SU3)



Measuring endpoint of di-tau mass ($\rightarrow \tilde{\tau}_1$ mass) is more difficult
$\rightarrow$ escaping neutrinos from tau decay

MC calibration



Strategy:

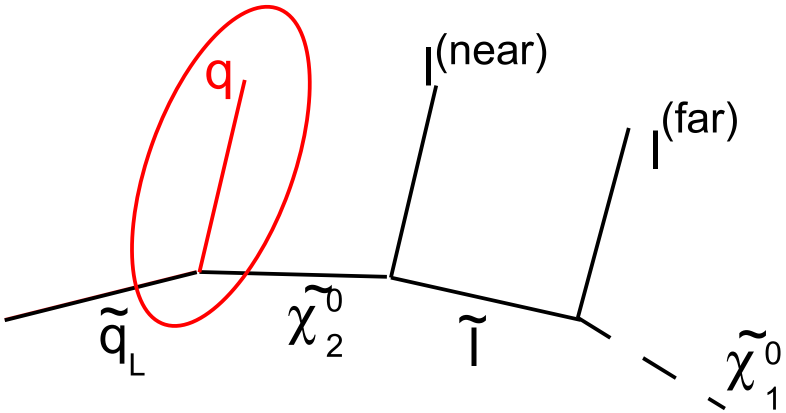
- Fit trailing edge of spectrum with suitable function
- Use inflection point as endpoint sensitive observable
- Perform MC calibration: inflection point $\rightarrow$ endpoint

$M_{\tau\tau}^{edge} = (102 \pm 17^{stat} \pm 5.5^{sys} \pm 7^{pol})$ GeV for 1 fb^{-1} (nominal: 98 GeV)

Leptons + jets edges

In order to derive masses, more constraints are needed

$\rightarrow$ walk up decay chain and add jet from $\tilde{q}_L$ decay

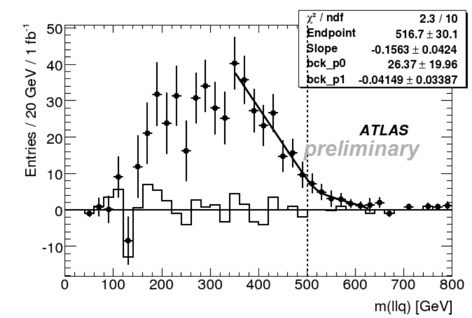


Different measurable combinations possible:

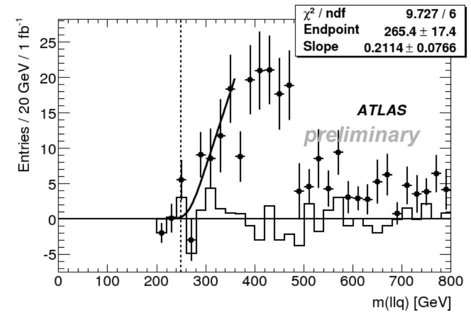
Endpoint	SU3 truth	SU3 measured (1 fb^{-1})
$m_{\ell\ell q}^{\max}$	501	$517 \pm 30 \pm 10 \pm 13$
$m_{\ell\ell q}^{\min}$	249	$265 \pm 17 \pm 15 \pm 7$
$m_{lq(\text{low})}^{\max}$	325	$333 \pm 6 \pm 6 \pm 8$
$m_{lq(\text{high})}^{\max}$	418	$445 \pm 11 \pm 11 \pm 11$

Sufficient constraints to solve for masses ($\rightarrow$ later)

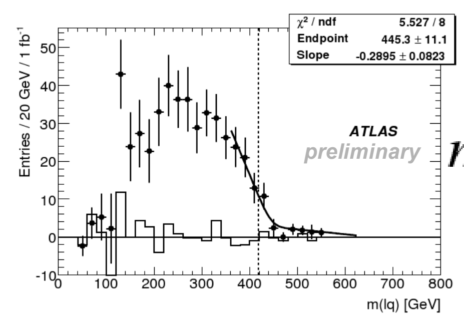
Bulk region point (SU3)



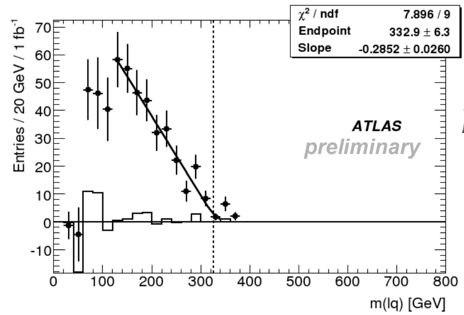
$m_{\ell\ell q}^{\max}$



$m_{\ell\ell q}^{\min}$



$m_{lq(\text{high})}^{\max}$



$m_{lq(\text{low})}^{\max}$

$\tilde{q}_R$ mass reconstruction

$\tilde{q}_R$ mass can be measured exploiting decay chain $\tilde{q}_R \rightarrow \tilde{\chi}_1^0 q$

Mass can be extracted using a generalisation of transverse mass: M_{T2} or “stransverse” mass

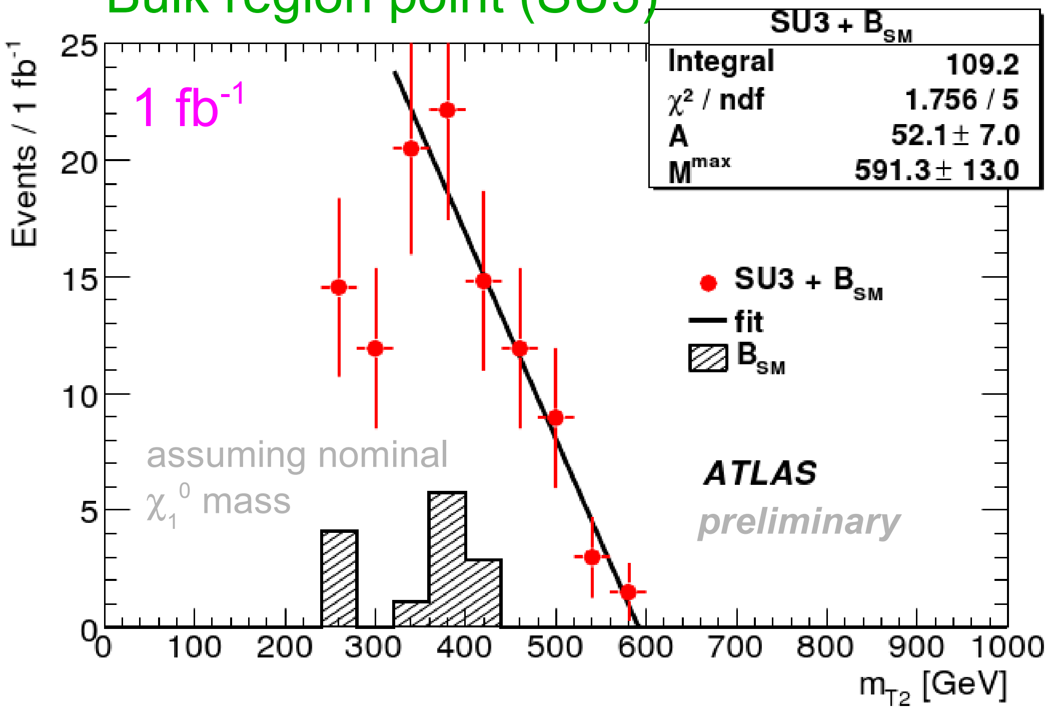
$$m_{\tilde{q}}^2 \geq M_{T2}^2 \equiv \min_{\not{p}_1 + \not{p}_2 = \not{p}_T} \left[\max \{ m_T^2(\mathbf{p}_{Tq}, \not{p}_1), m_T^2(\mathbf{p}_{Tq}, \not{p}_2) \} \right]$$

M_{T2} depends on $\tilde{q}_R$ *and* χ_1^0 mass
→ yields $\tilde{q}_R$ mass as function of χ_1^0 mass hypothesis

$(591 \pm 13 \text{ stat } ^{+13}_{-6} \text{ sys})$ GeV at nominal χ_1^0 mass for 1 fb^{-1}

(nominal: 637 GeV)

Bulk region point (SU3)



Higgs in SUSY decays

If $\tilde{\chi}^0_2 \rightarrow \tilde{\chi}^0_1 h$ is open, it might have significant BR

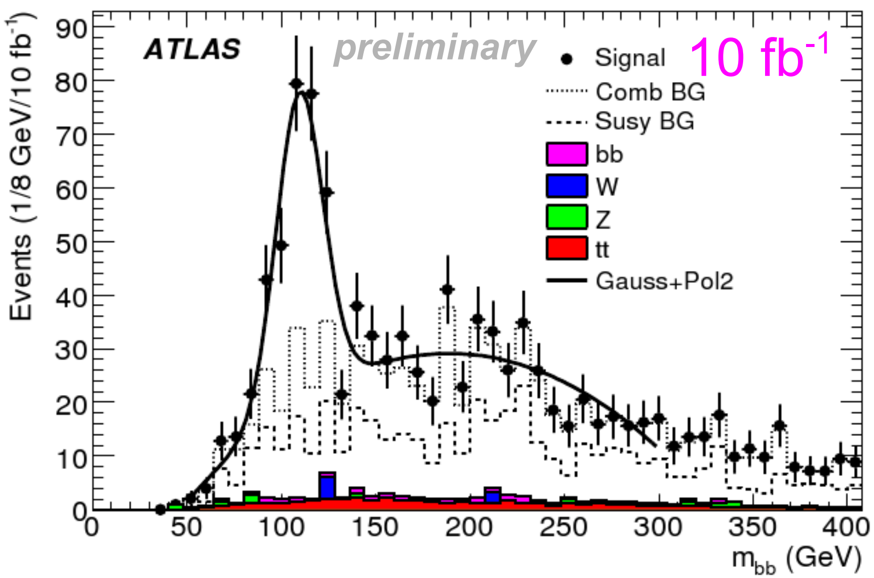
Large missing E_T signature of SUSY allows to exploit $h \rightarrow b\bar{b}$ channel

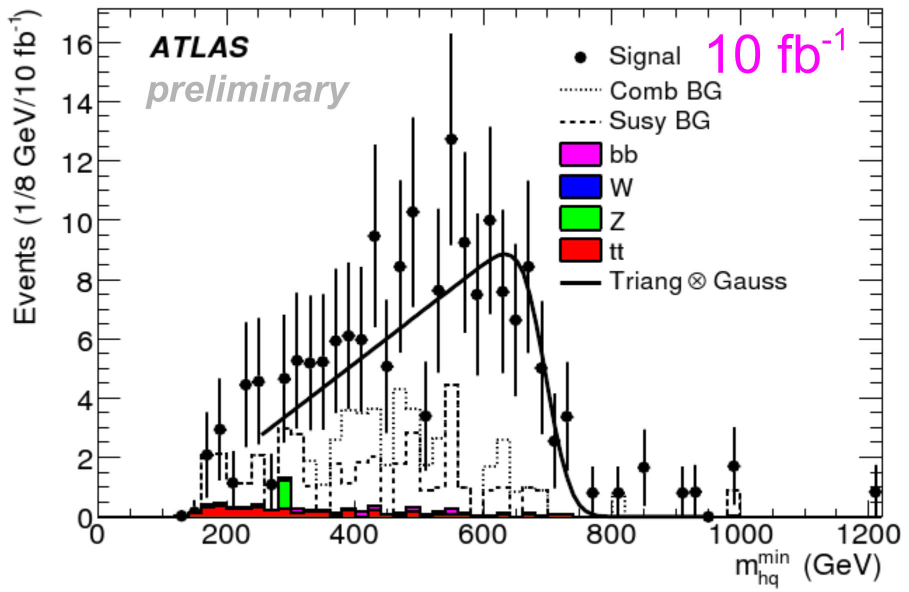
Consider decay chain $\tilde{q}_L \rightarrow \tilde{\chi}^0_2 q \rightarrow \tilde{\chi}^0_1 h\, q$

Higgs mass is obtained from peak in m_{bb}

Endpoint of m_{hq} provides information on SUSY particles involved in decay chain

m_{hq}^{edge} = (695 ± 15 stat ± 3 syst ± 35 JES) GeV for 10 fb^{-1} (nominal: 732 GeV)





Mass determination

Formulae for position of endpoints can be (numerically) solved for involved SUSY masses.

meas. endpoint — theor. endpoint expression

Performed by χ^2 minimisation:

$$\chi^2 = \sum_{k=1}^{n} \frac{(m_k^{\max} - t_k^{max}(m_{\tilde{\chi}_1^0}, m_{\tilde{\chi}_2^0}, m_{\tilde{\ell}_R}, m_{\tilde{q}_L}))^2}{\sigma_k^2}$$

From bulk region studies (SU3):

Observable	SU3 m_{meas} [GeV/c^2]	SU3 m_{MC} [GeV/c^2]
$m_{\tilde{\chi}_1^0}$	$88 \pm 60 \mp 2$	118
$m_{\tilde{\chi}_2^0}$	$189 \pm 60 \mp 2$	219
$m_{\tilde{q}}$	$614 \pm 91 \pm 11$	634
$m_{\tilde{\ell}}$	$122 \pm 61 \mp 2$	155
Observable	SU3 Δm_{meas} [GeV/c^2]	SU3 Δm_{MC} [GeV/c^2]
$m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0}$	$100.6 \pm 1.9 \mp 0.0$	100.7
$m_{\tilde{q}} - m_{\tilde{\chi}_1^0}$	$526 \pm 34 \pm 13$	516.0
$m_{\tilde{\ell}} - m_{\tilde{\chi}_1^0}$	$34.2 \pm 3.8 \mp 0.1$	37.6

preliminary

mSUGRA parameter fits

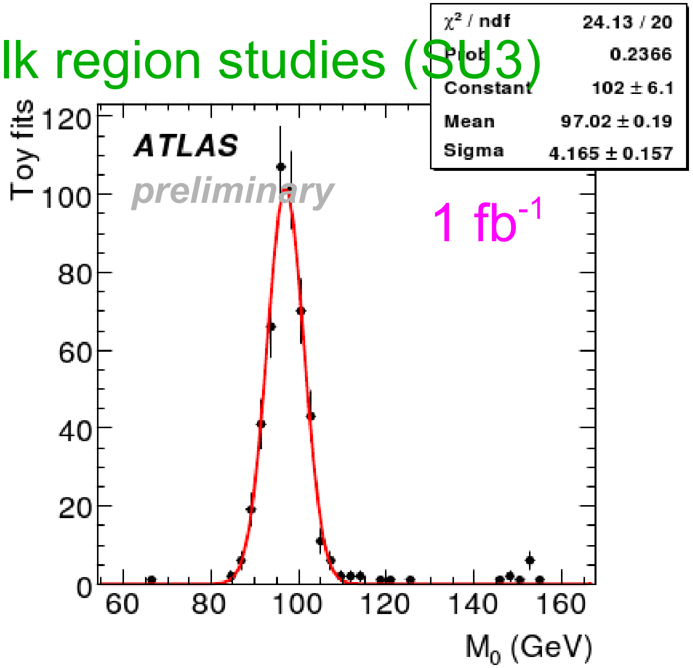
Final goal is to determine underlying SUSY model and its parameters from measurements

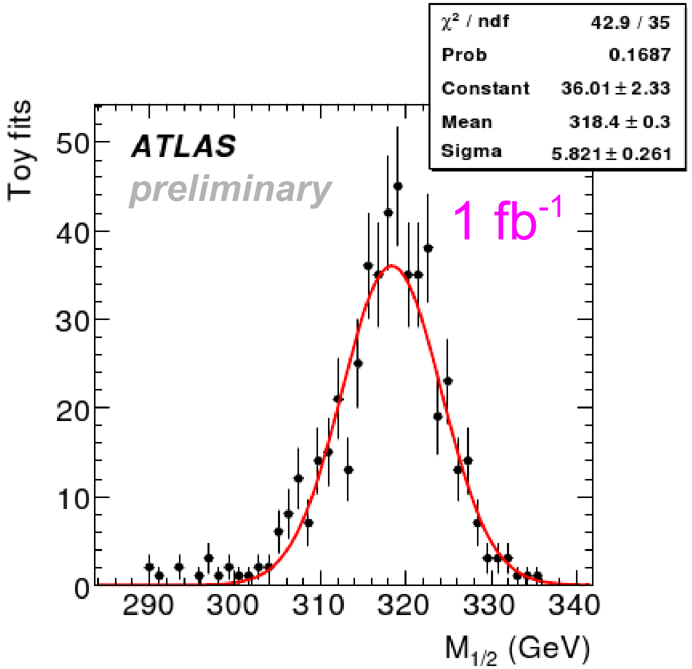
In the beginning only models with few parameters (e. g. mSUGRA) can be fitted

Fit performed using simulated annealing as implemented in Fittino

Parameter uncertainties obtained from spread of the results of many individual fits to toy experiments with input "measurements" smeared around truly measured values

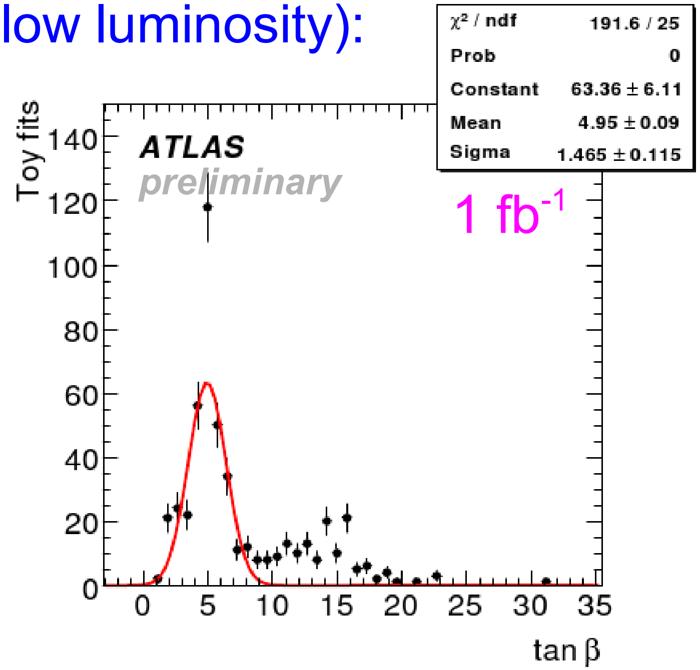
From bulk region studies (SU3)

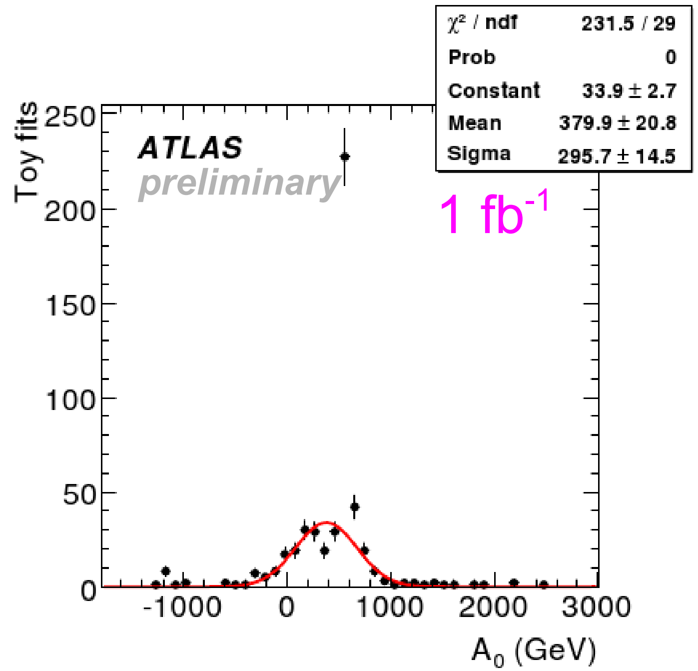




mSUGRA parameter fits

tan β and A_0 are more problematic (no information from Higgs sector at low luminosity):





Parameter	SU3 value	fitted value (mean)	exp. unc. (RMS)
		$\text{sign}(\mu) = +1$	
$\tan\beta$	6	7.4	4.6
M_0	100 GeV	98.5 GeV	$\pm$9.3 GeV
$M_{1/2}$	300 GeV	317.7 GeV	$\pm$6.9 GeV
A_0	$-$300 GeV	445 GeV	$\pm$408 GeV

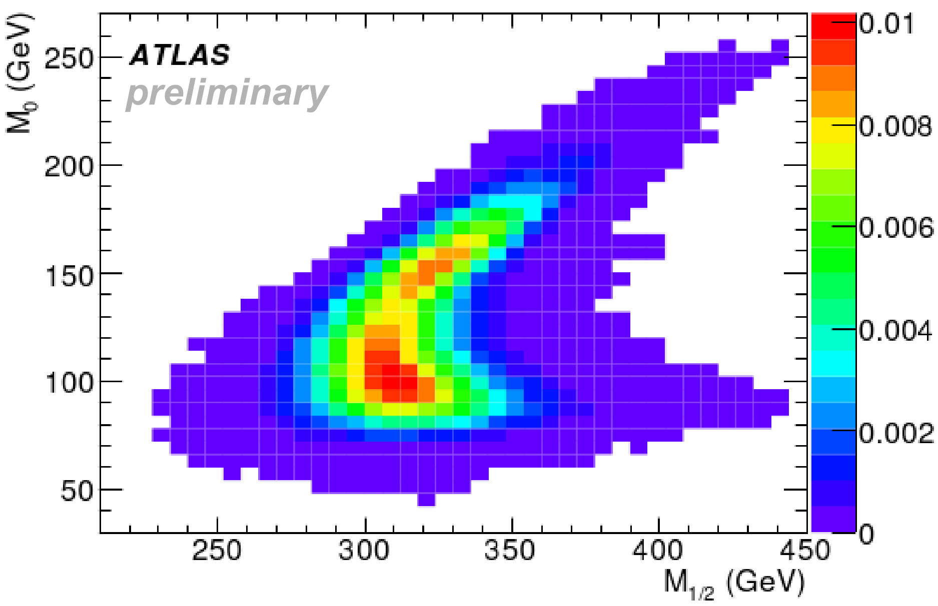
preliminary

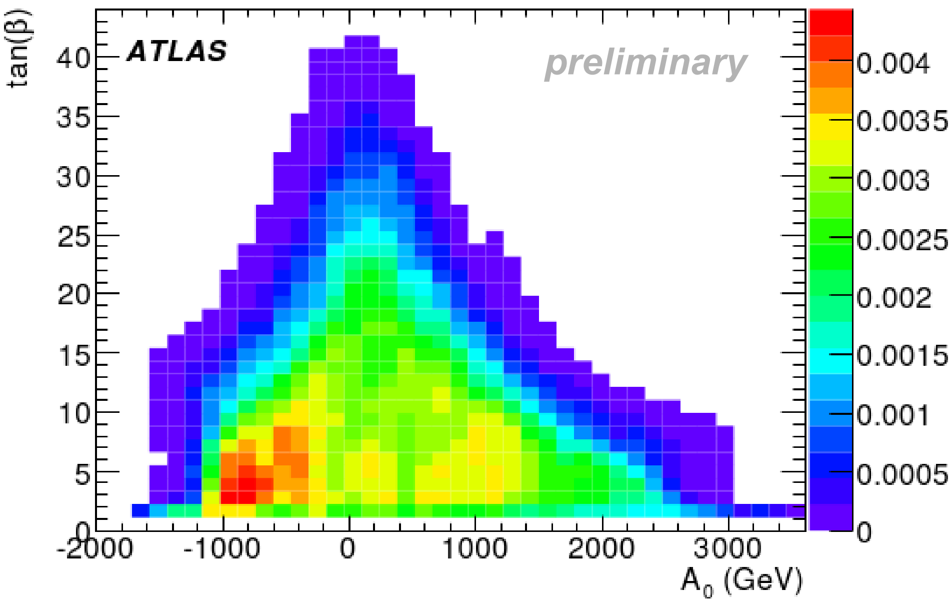
Summary

- Establishing SUSY means more than “just” seeing an excess of events
- In case of sub-TeV sparticle masses, first LHC data will already allow to perform rough SUSY spectroscopy
- First checks of high scale unification models are also feasible
- Higher precision and more difficult measurements will follow as luminosity increases
- A bit more patience is needed. First beams are only weeks ahead :-)

BACKUP MATERIAL

Markov Chain Monte Carlo





Fit with sign(μ) = -1 vs. fit with sign(μ) = +1

Parameter	SU3 value	fitted value	exp. unc.
		$\mathrm{sign}(\mu) = +1$	
$\tan\beta$	6	7.4	4.6
M_0	100 GeV	98.5 GeV	$\pm$9.3 GeV
$M_{1/2}$	300 GeV	317.7 GeV	$\pm$6.9 GeV
A_0	$-$300 GeV	445 GeV	$\pm$408 GeV
		$\mathrm{sign}(\mu) = -1$	
$\tan\beta$		13.9	$\pm$2.8
M_0		104 GeV	$\pm$18 GeV
$M_{1/2}$		309.6 GeV	$\pm$5.9 GeV
A_0		489 GeV	$\pm$189 GeV

ndof = 11

$\chi^2 = 12.6 \pm 0.2$

$\chi^2 = 15.4 \pm 0.3$

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