Part 4: SUSY parameter measurements

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Establishing SUSY experimentally

Assume an excess seen in inclusive analyses: how does one verify wheteher it is actually SUSY? Need to demonstrate that:

- Every particle has a superpartner
- Their spin differ by $1/2$
- Their gauge quantum numbers are the same
- Their couplings are identical
- Mass relations predicted by SUSY hold

This can only be performed through precise measurements of masses, BR, cross-sections, angular distributions

Possibly full task will require high luminosity LC

Try to develop a strategy for performing as many as possible of these measurements at the LHC

Measurement of model parameters

The problem is the presence of a very complex spectroscopy due to long decay chains, with crowded final states

Many concurrent signatures obscuring each other

General strategy:

- Choose signatures identifying well defined decay chains
- Extract constraints on masses, couplings, spin from decay kinematics/rates
- Try to match emerging pattern to tentative template models, SUSY or anything else
- Having adjusted template models to measurements, try to find additional signatures to discriminate different options

In order to develop this program we need to base ourselves on guidance from theory: interesting signatures defined by prejudices on models one considers good candidates for BSM physics

Practical approach on Monte Carlo:

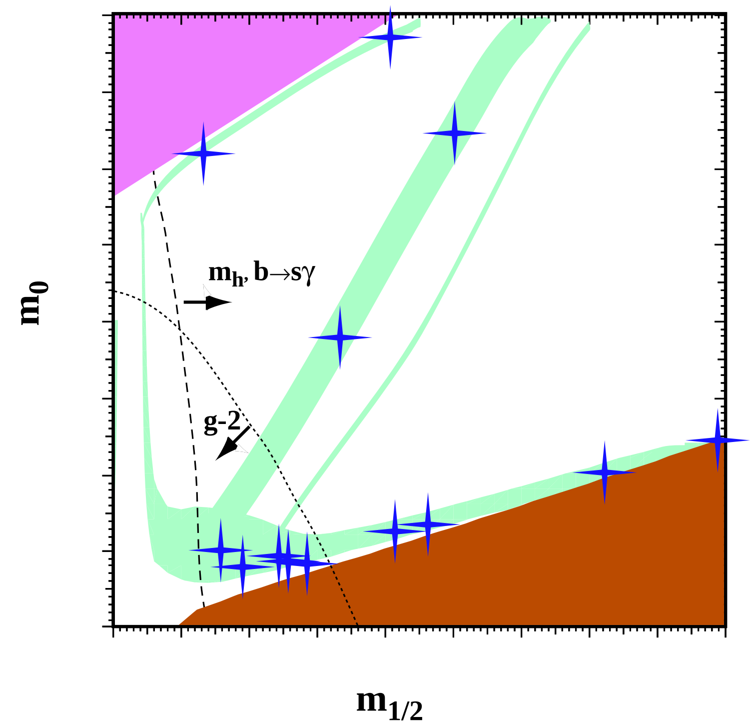
- Start from predictive models: masses and decay patterns defined in terms of few parameters. Example: mSUGRA
- For each model choose points in parameter space covering the main phenomenological scenarios (benchmark point)
- For each benchmark study in detail available signatures

Many groups defining banchmarks

Benchmarks evolve with contraints from astroparticles/low energy studies

Detailed analysis performed in ATLAS TDR on 11 model points (mSUGRA, GMSB. AMSB).

New points defined for final studies both in ATLAS and CMS



Show in detail application of this program to a SUGRA model point

Typical starting point: $\tilde{\chi}_2^0$ decays

QCD Background: need decay chains involving leptons (e,μ), b's, τ's

Consider signatures from $\tilde{\chi}_2^0$ decays:

- $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 Z^*$ (6% BR to $(e,\mu)\tilde{\chi}_1^0$ non–resonant)
- $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 Z$ (6% BR to $(e,\mu)\tilde{\chi}_1^0$ resonant)
- $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 h \to \tilde{\chi}_1^0 \bar{b}b$
- $\tilde{\chi}_2^0 \to \tilde{\ell}^{\pm(*)}\ell^{\mp} \to \tilde{\chi}_1^0 \ell^+\ell^-$ (ℓ mostly $\tilde{\tau}_1$ at high $\tan\beta$)

One or more of these decays present in all mSUGRA Points considered

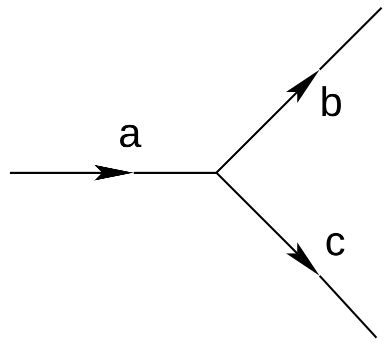
Abundantly produced: BR($\tilde{q}_L \to q\tilde{\chi}_2^0$) typically 30% in mSUGRA

R-parity conservation $\Rightarrow$ two undetected LSP's per event

$\Rightarrow$ no mass peaks, constraints from edges and endpoints in kinematic distributions

Key result: If a chain of at least three two-body decays can be isolated, can measure masses and momenta of involved particles in model-independent way.

Two-body kinematics



4-momentum conservation

$$m_a^2 = (E_b + E_c)^2 - (\vec{p_b} + \vec{p_c})^2 \qquad E_{b(c)}^2 = m_{b(c)}^2 + |\vec{p_b}|^2$$

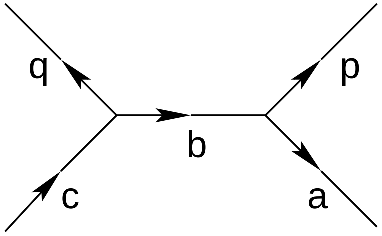
In rest frame of a: $\vec{p_b} + \vec{p_c} = 0 \Rightarrow |\vec{p_b}| = |\vec{p_c}| = |\vec{p}|$

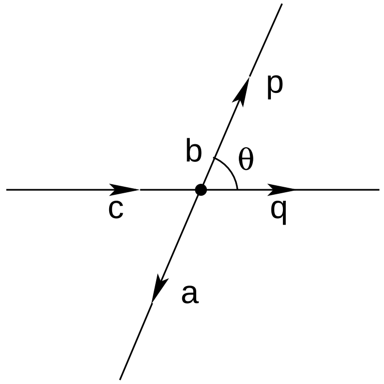
$$m_a^2 = (E_b + E_c)^2 \qquad m_a^2 = m_b^2 + m_c^2 + 2\,|\vec{p}|^2 + 2\,\sqrt{m_b^2 + |\vec{p}|^2}\,\sqrt{m_c^2 + |\vec{p}|^2}$$

Solve for $|\vec{p}|$: $|\vec{p}|^2 = [m_b^2, m_a^2, m_c^2]$ where

$$[x, y, z] \equiv \frac{x^2 + y^2 + z^2 - 2(xy + xz + yz)}{4y} \tag{1}$$

Cascade of successive two-body decays





Go to rest system of intermediate particle b:

$$|\vec{p}_p|^2 = |\vec{p}_a|^2 = [m_p^2, m_b^2, m_a^2] \qquad |\vec{p}_q|^2 = |\vec{p}_c|^2 = [m_q^2, m_b^2, m_c^2] \tag{2}$$

We are interested in the invariant mass of the two visible particles: m_{pq}^2:

$$m_{pq}^2 = (E_p + E_q)^2 - (\vec{p_q} + \vec{p_q})^2 = m_p^2 + m_q^2 + 2(E_p + E_q - |\vec{p_p}||\vec{p_q}|cos\theta)$$

m_{pq} has maximum or minimum value when p or q are back-to-back or collinear in rest frame of b:

$$(m_{pq}^{max})^2 = m_p^2 + m_q^2 + 2(E_p + E_q + |\vec{p_p}||\vec{p_q}|) \tag{3}$$

Let us specialize to the decay:

$$\tilde{q}_L \longrightarrow \tilde{\chi}^0_2 \quad q$$
$$\hookrightarrow \tilde{\ell}^{\pm}_R \quad \ell^{\mp}$$
$$\hookrightarrow \tilde{\chi}^0_1 \quad \ell^{\pm}$$

By substituting into Equation 3 $p, q \longrightarrow \ell^+\ell^-$, $c \longrightarrow \tilde{\chi}^0_2$, $b \longrightarrow \tilde{\ell}_R$, $a \longrightarrow \tilde{\chi}^0_1$, and by treating the leptons as massless, we obtain:

$$(m_{\ell\ell}^{max})^2 = 4|\vec{p}||\vec{q}| = 4\sqrt{[0, m^2_{\tilde{\ell}_R}, m^2_{\tilde{\chi}^0_1}]}\sqrt{[0, m^2_{\tilde{\ell}_R}, m^2_{\tilde{\chi}^0_2}]}$$

By substituting the formula for $[x, y, z]$ we obtain the desired result:

$$(m_{\ell\ell}^{max})^2 = \frac{(m^2_{\tilde{\chi}^0_2} - m^2_{\tilde{\ell}_R})(m^2_{\tilde{\ell}_R} - m^2_{\tilde{\chi}^0_1})}{m^2_{\tilde{\ell}_R}}$$

Invariant mass distribution

If the spin of the intermediate particle b is zero, the decay distribution is:

$$\frac{dP}{d\cos\theta} = \frac{1}{2}$$

Where $\cos\theta$ is the angle between the two visible particles in the rest frame of b

If the two visible particles p, q are massless:

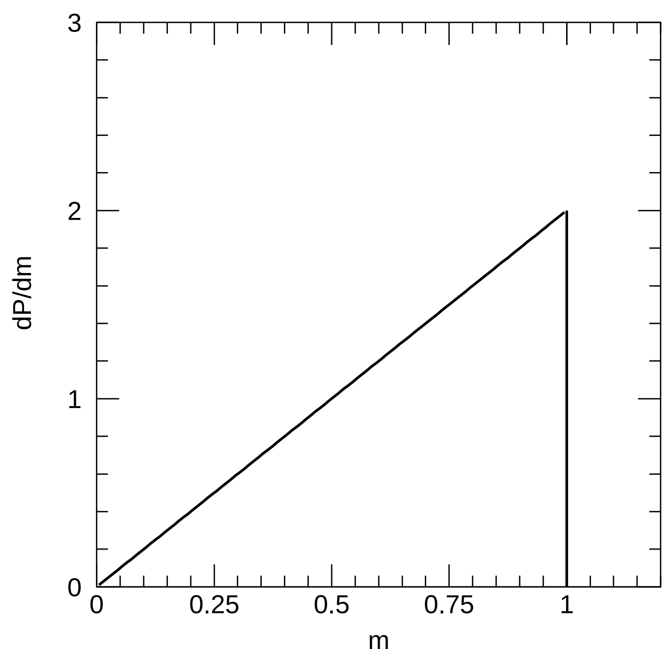
$$m_{pq}^2 = 2|\vec{p_p}||\vec{p_q}|(1-\cos\theta) \quad \text{and} \quad (m_{pq}^{max})^2 = 4|\vec{p_p}||\vec{p_q}|$$

We can thus define the dimensionless variable:

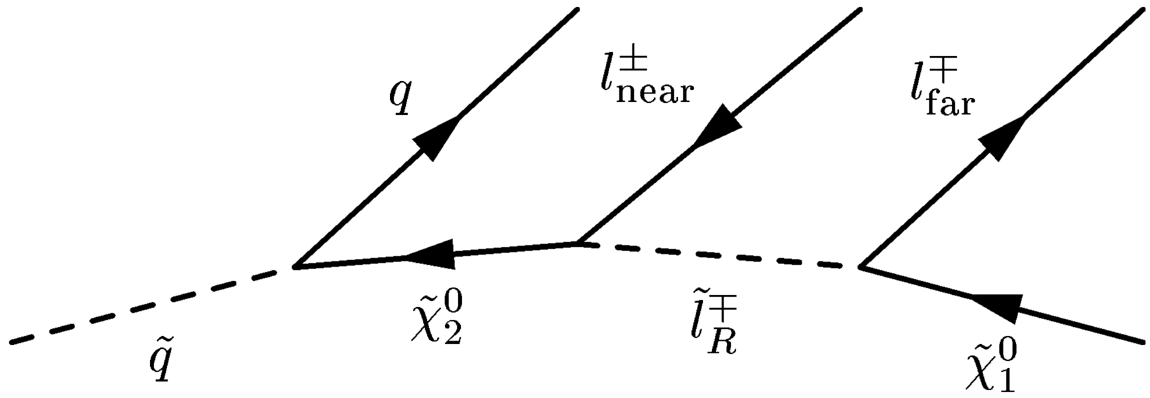
$$\hat{m}^2 = \frac{m_{pq}^2}{(m_{pq}^{max})^2} = \frac{1}{2}(1-\cos\theta) = \sin^2\frac{\theta}{2}$$

By a changement of variable:

$$\frac{dP}{d\hat{m}} = 2\hat{m}$$



Complete results for $\tilde{q}_L \to \tilde{\ell}\ell$ decay chain: (Allanach et al. hep-ph/0007009)



l^+l^- edge $\quad (m_{ll}^{\text{max}})^2 = (\tilde{\xi} - \tilde{l})(\tilde{l} - \tilde{\chi})/\tilde{l}$

l^+l^-q edge $\quad (m_{llq}^{\text{max}})^2 = (\tilde{q} - \tilde{\xi})(\tilde{\xi} - \tilde{\chi})/\tilde{\xi}$

l^+l^-q thresh $\quad (m_{llq}^{\text{min}})^2 = \begin{cases} [\ \ 2\tilde{l}(\tilde{q} - \tilde{\xi})(\tilde{\xi} - \tilde{\chi}) \\ +(\tilde{q} + \tilde{\xi})(\tilde{\xi} - \tilde{l})(\tilde{l} - \tilde{\chi}) \\ \quad -(\tilde{q} - \tilde{\xi})\sqrt{(\tilde{\xi} + \tilde{l})^2(\tilde{l} + \tilde{\chi})^2 - 16\tilde{\xi}\tilde{l}^2\tilde{\chi}}\ \ ] \\ /(4\tilde{l}\tilde{\xi}) \end{cases}$

$l^{\pm}_{\text{near}}q$ edge $\quad (m_{l_{\text{near}}q}^{\text{max}})^2 = (\tilde{q} - \tilde{\xi})(\tilde{\xi} - \tilde{l})/\tilde{\xi}$

$l^{\pm}_{\text{far}}q$ edge $\quad (m_{l_{\text{far}}q}^{\text{max}})^2 = (\tilde{q} - \tilde{\xi})(\tilde{l} - \tilde{\chi})/\tilde{l}$

With $\quad \tilde{\chi} = m^2_{\tilde{\chi}^0_1}, \qquad \tilde{l} = m^2_{\tilde{l}_R}, \qquad \tilde{\xi} = m^2_{\tilde{\chi}^0_2}, \qquad \tilde{q} = m^2_{\tilde{q}}$

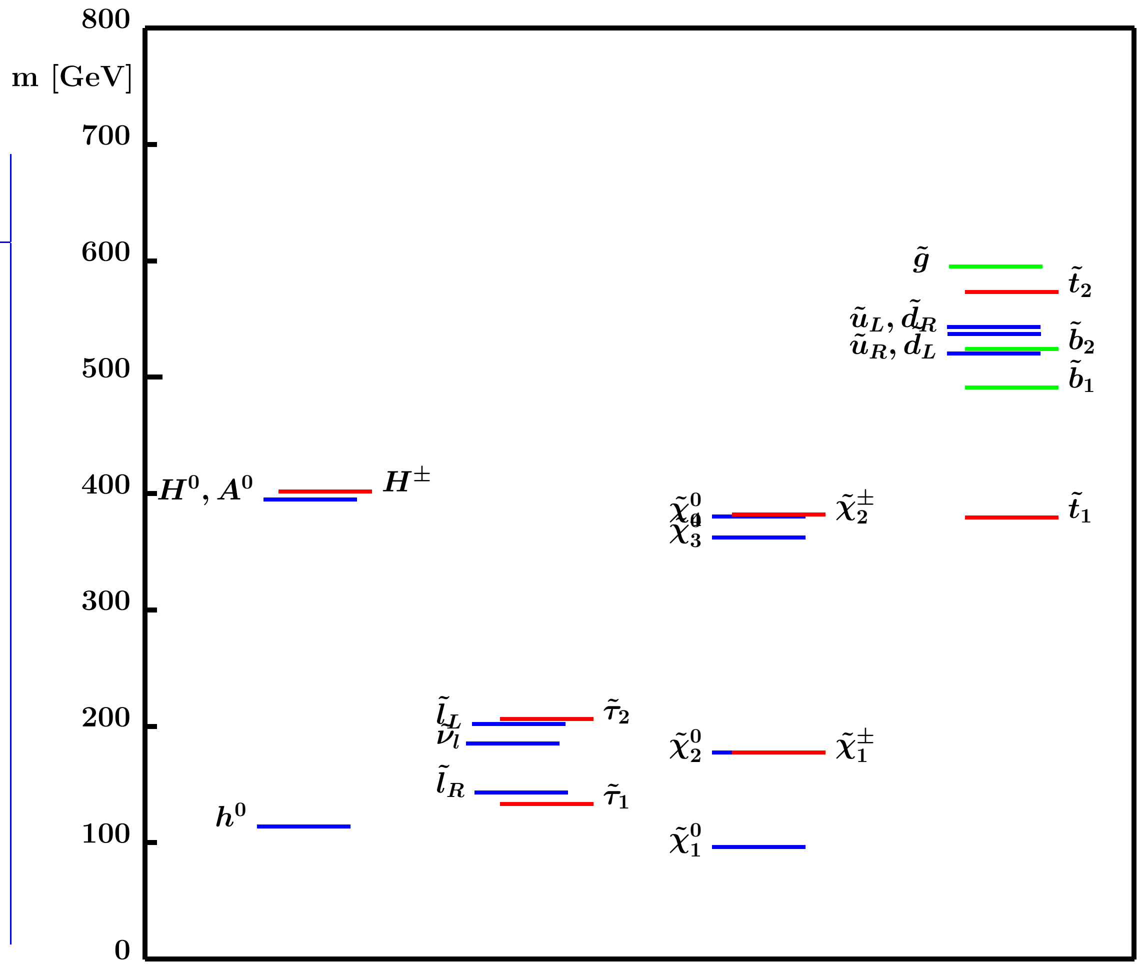
Example: Point SPS1a

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

Chosen as a point friendly to a 1 TeV linear Collider, with appropriate Dark Matter density predicted

Mass spectrum

Particle	Mass (GeV)	Particle	Mass (GeV)
$\tilde{g}$	595.5	$\tilde{u}_R$	520.5
$\tilde{u}_L$	537.3	$\tilde{d}_L$	543.0
$\tilde{b}_1$	491.9	$\tilde{t}_1$	379.1
$\tilde{e}_L$	202.1	$\tilde{e}_R$	143.0
$\tilde{\tau}_1$	133.4	$\tilde{\tau}_2$	206.0
$\tilde{\chi}_1^0$	96.5	$\tilde{\chi}_1^\pm$	176.4
$\tilde{\chi}_2^0$	176.8	$\tilde{\chi}_4^0$	377.8
h	114.0	A	394.4



Point SPS1a

Total cross-section: $\sim$50 pb

Identify long decay chain with clean signature from study of Branching Ratios:

BR($\tilde{g} \to \tilde{q}_L q$) $\sim$25% BR($\tilde{g} \to \tilde{q}_R q$) $\sim$40% BR($\tilde{g} \to \tilde{b}_1 b$) $\sim$17%

BR($\tilde{q}_L \to \tilde{\chi}_2^0 q$) $\sim$30% BR($\tilde{q}_L \to \tilde{\chi}^\pm q'$) $\sim$60%

BR($\tilde{\chi}_2^0 \to \tilde{\ell}_R \ell$)=12.6% BR($\tilde{\chi}_2^0 \to \tilde{\tau}_1 \tau$)=87% BR($\tilde{\chi}_1^\pm \to \tilde{\tau}_1 \nu_\tau$)$\sim 100\%$

Analysis strategy

- Measure $m_{\tilde{\chi}_1^0}$, $m_{\tilde{\ell}_R}$, $m_{\tilde{\chi}_2^0}$, $m_{\tilde{q}_L}$ from the $\tilde{q}_L \to \tilde{\ell}\ell$ decay chain
- Go up the decay chain one step: address $\tilde{g} \to \tilde{b}b$
- Identify shorter or rarer decay chains: $\tilde{\chi}_2^0 \to \tilde{\tau}_1 \tau$, $\tilde{\chi}_4^0 \to \tilde{\ell}\ell$, $\tilde{\ell} \to \ell\tilde{\chi}_1^0$, $\tilde{q}_R \to q\tilde{\chi}_1^0$

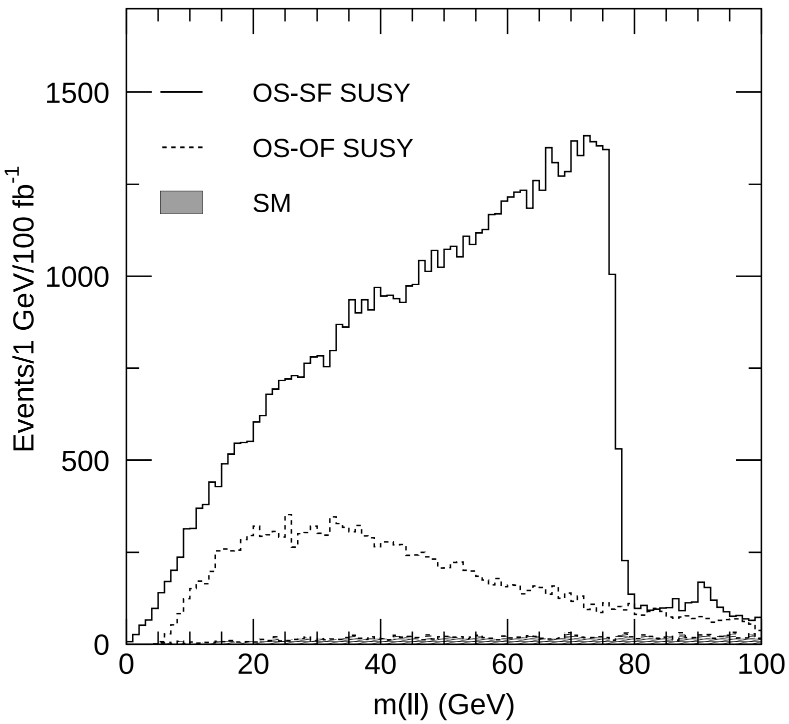
  and extract masses using measured $m_{\tilde{\chi}_1^0}$, $m_{\tilde{\chi}_2^0}$

Isolate SUSY signal by requiring:

- At least four jets: $p_{T,1} > 150$ GeV, $p_{T,2} > 100$ GeV, $p_{T,3} > 50$ GeV.
- $M_{\text{eff}} \equiv E_{T,\text{miss}} + p_{T,1} + p_{T,2} + p_{T,3} + p_{T,4} > 600$ GeV, $E_{T,\text{miss}} > \max(100 \text{ GeV}, 0.2 M_{\text{eff}})$
- Exactly two opposite-sign same-flavour e, μ (OSSF) with $p_T(l) > 20$ GeV and $p_T(l) > 10$ GeV

W and Z suppressed by jet requirements, and $\bar{t}t$ by hard kinematics

Build lepton-lepton invariant mass for selected events



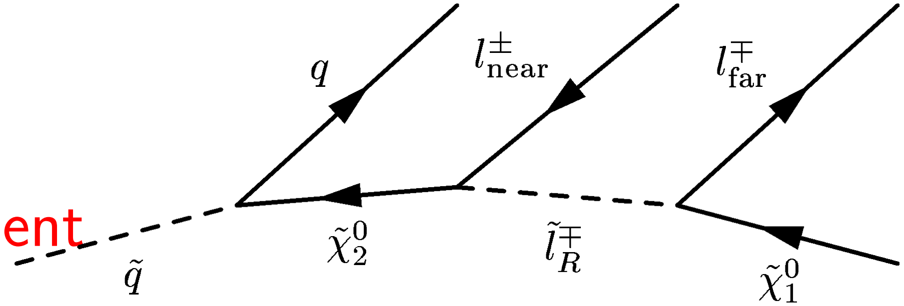
SM background almost negligible

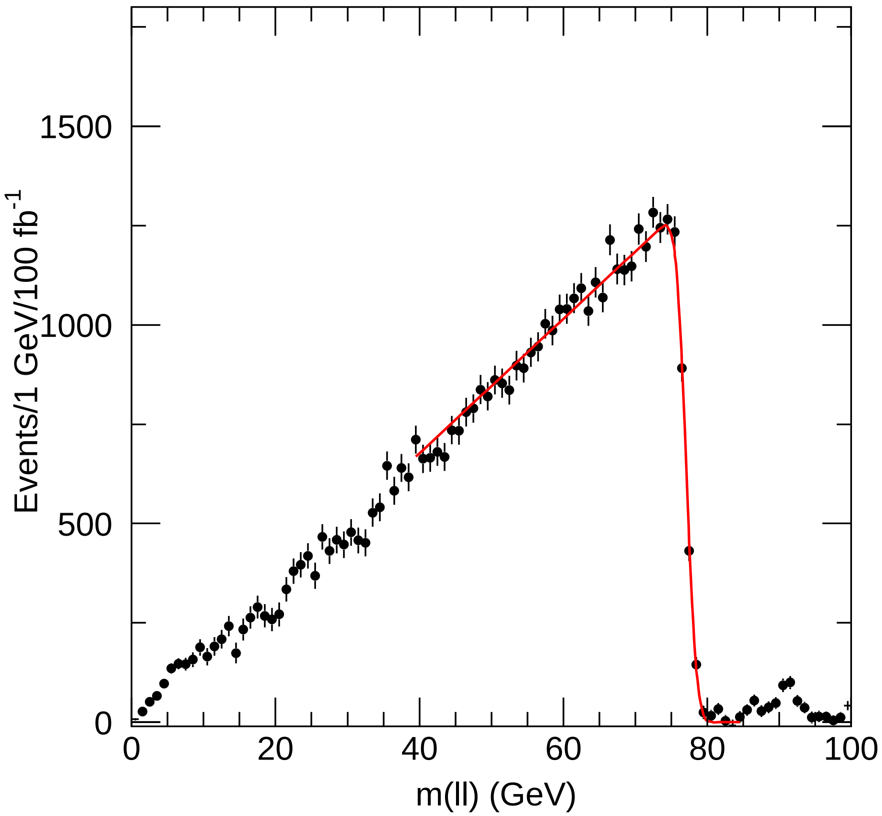
SUSY background mostly uncorrelated $\tilde{\chi}_1^{\pm}$ decays

Subtract SUSY and SM background using flavour correlation:

$e^+e^- + \mu^+\mu^- - e^{\pm}\mu^{\mp}$

Lepton-lepton edge measurement





$m_{\ell^+\ell^-}$ after flavour subtraction

Fit to sharp edge shape smeared by gaussian resolution

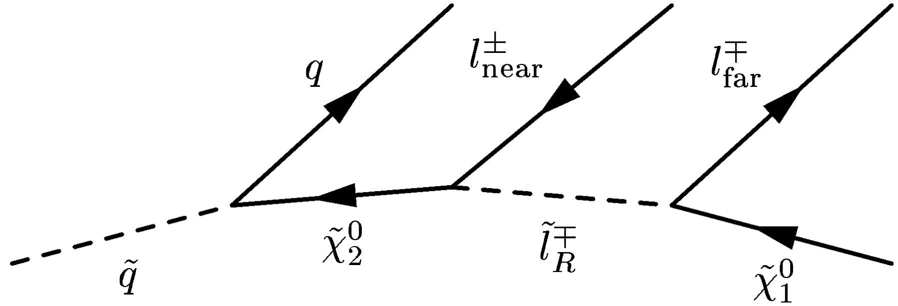
For 100 fb^{-1} statistical error on the fit comparable to 0.1$\%$ uncertainty on lepton energy scale

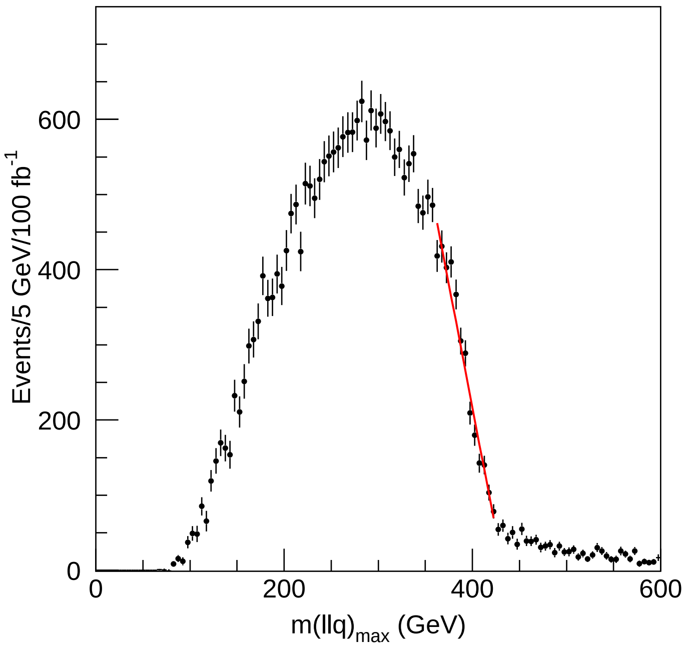
Very high precision measurement, comparable to W mass,

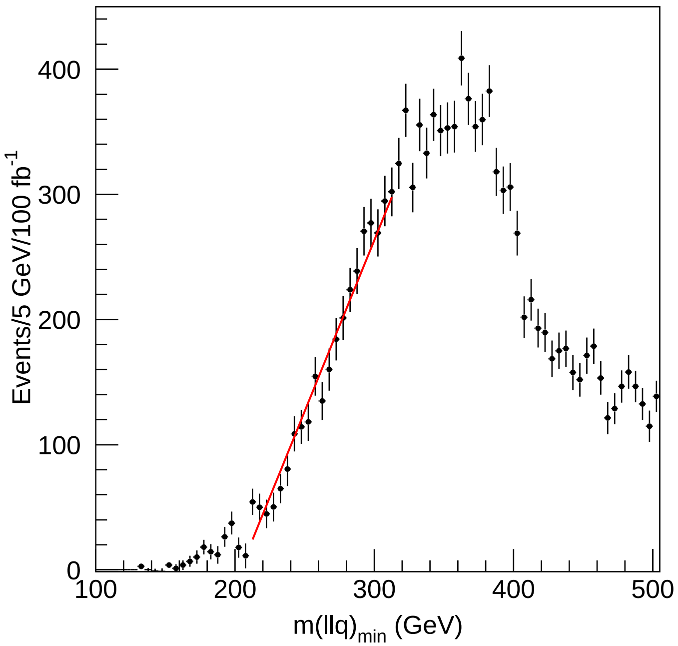
Need to understand systematic effects to fully exploit potential. Fit result (300 fb^{-1}):

$$m^{max}_{l^+l^-} = m_{\tilde{\chi}^0_2}\sqrt{1-\frac{m^2_{\tilde{\ell}_R}}{m^2_{\tilde{\chi}^0_2}}}\sqrt{1-\frac{m^2_{\tilde{\chi}^0_1}}{m^2_{\tilde{\ell}_R}}} = 77.077 \pm 0.03 \text{ (stat)} \pm 0.08 \text{ (E scale) GeV}$$

Lepton-lepton-jet edges







Consider two leading jets: plot min$(m_{\ell\ell j_1}, m_{\ell\ell j_2})$ (left), max$(m_{\ell\ell j_1}, m_{\ell\ell j_2})$ (right)

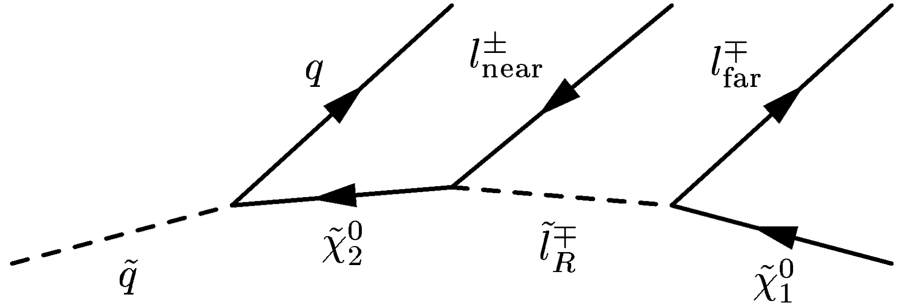
Distributions fall linearly to end (threshold) point.

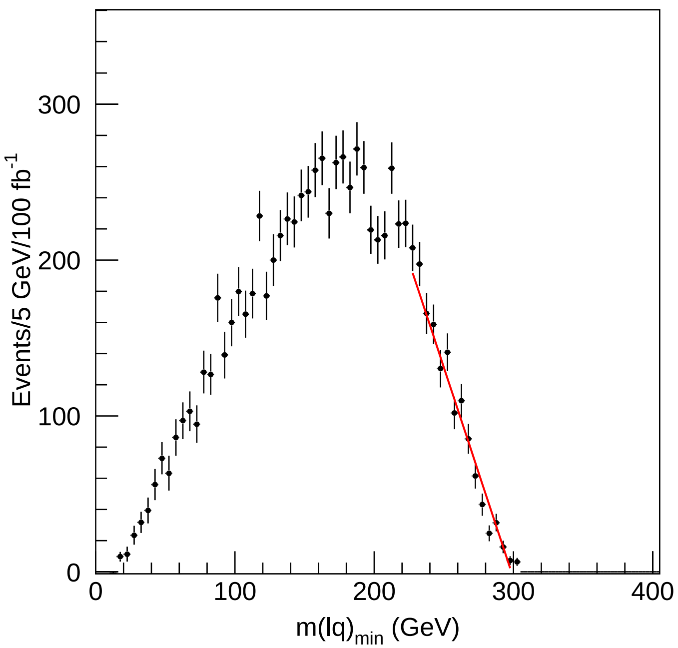
Shapes modified by resolutions and backgrounds, need detailed study

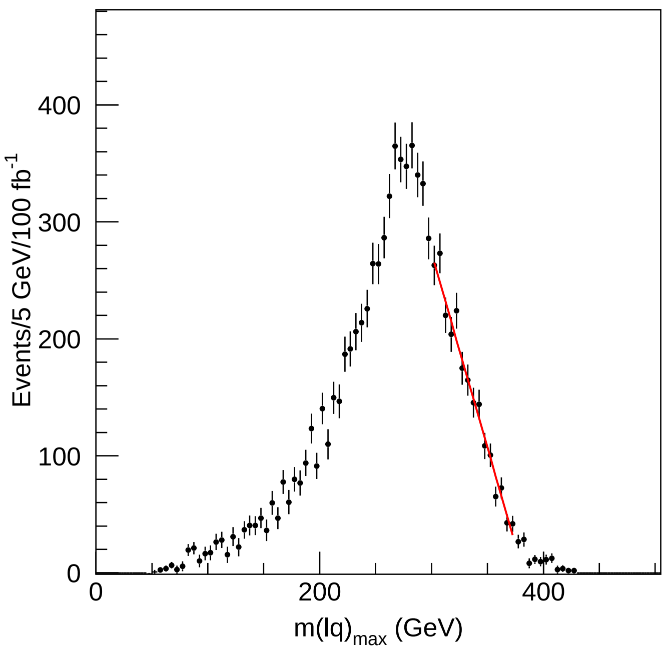
Evaluate statistical uncertainty with simple linear fit. Fit results (300 fb^{-1}):

$\Delta(m_{llq}^{max}) = \pm 1.4$ (stat)± 4.3 (scale) GeV, $\Delta(m_{llq}^{min}) = \pm 1.6$ (stat)± 2.0 (scale) GeV

Lepton-jet edges







Require $m_{\ell\ell}$ below edge, $m_{\ell\ell j} < 600$ GeV, choose jet giving minimum $m_{\ell\ell j}$

Define: $m_{lq(\text{high})} = \max\left(m_{l^+q}, m_{l^-q}\right)$ $\qquad m_{lq(\text{low})} = \min\left(m_{l^+q}, m_{l^-q}\right)$

Fit results (300 fb^{-1}):

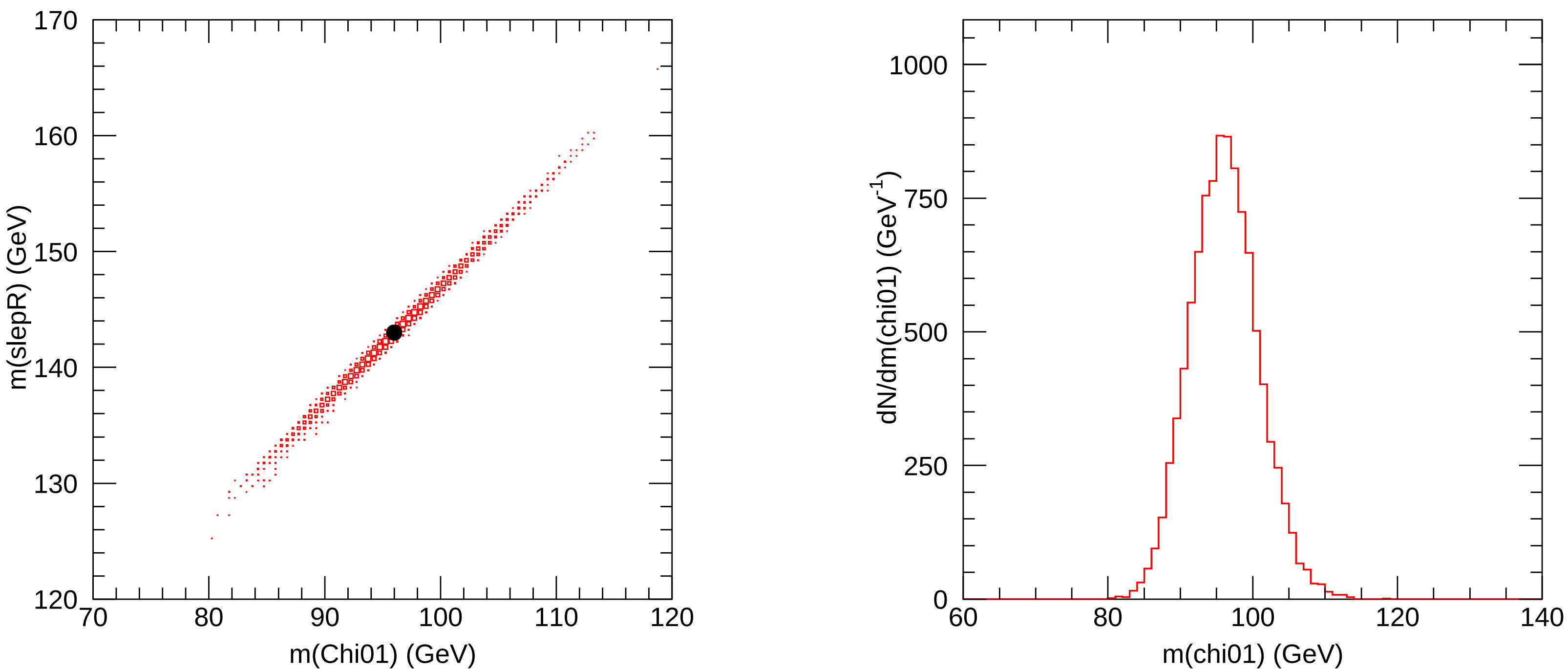
$\Delta(m_{lq(\text{high})}) == \pm 1.0$ (stat)± 3.8 (scale) GeV, $\Delta(m_{lq(\text{low})}) \pm 0.9$ (stat)± 3.0 (scale) GeV

Enough constraints: can solve for sparticle masses

Sparticle mass calculation

Generate sets of edge measurements normal distributed according to statistical errors estimated for 100 fb^{-1}. For each set solve numerically equations for sparticle masses.

Strong correlation among masses, as kinematic constraints measure mass differences



Probability distributions for reconstructed masses $\sim$ gaussian

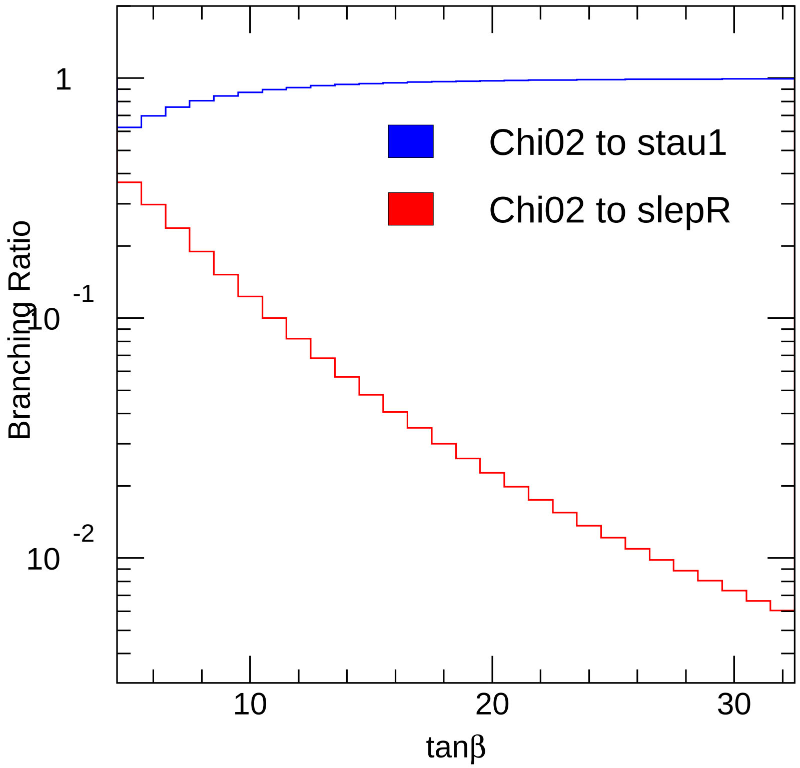
$\tilde{\chi}_1^0$, $\tilde{\chi}_2^0$, $\tilde{\ell}_R$ masses reconstructed with ~ 5 GeV , $\tilde{q}_L$ mass with ~ 9 GeV (300 fb^{-1})

Statistical and E-scale errors only, systematics should also be considered

High $tan\beta$ case:

Mixing in τ sector increases with increasing $\tan\beta$. Consequences:

- Decrease of $\tilde{\tau}_1$ mass with respect to ℓ_R
- In mSUGRA enhanced coupling to Wino $\tilde{\chi}_2^0$



$\tilde{\chi}_2^0 \to \tilde{\tau}_1\tau \to \tau\tau\tilde{\chi}_1^0$ dominates over

$\tilde{\chi}_2^0 \to \tilde{\ell}_R\ell \to \ell\ell\tilde{\chi}_1^0$

For significant region in $(m_0 - m_{1/2})$ plane lepton-lepton signal still detectable at high $\tan\beta$.

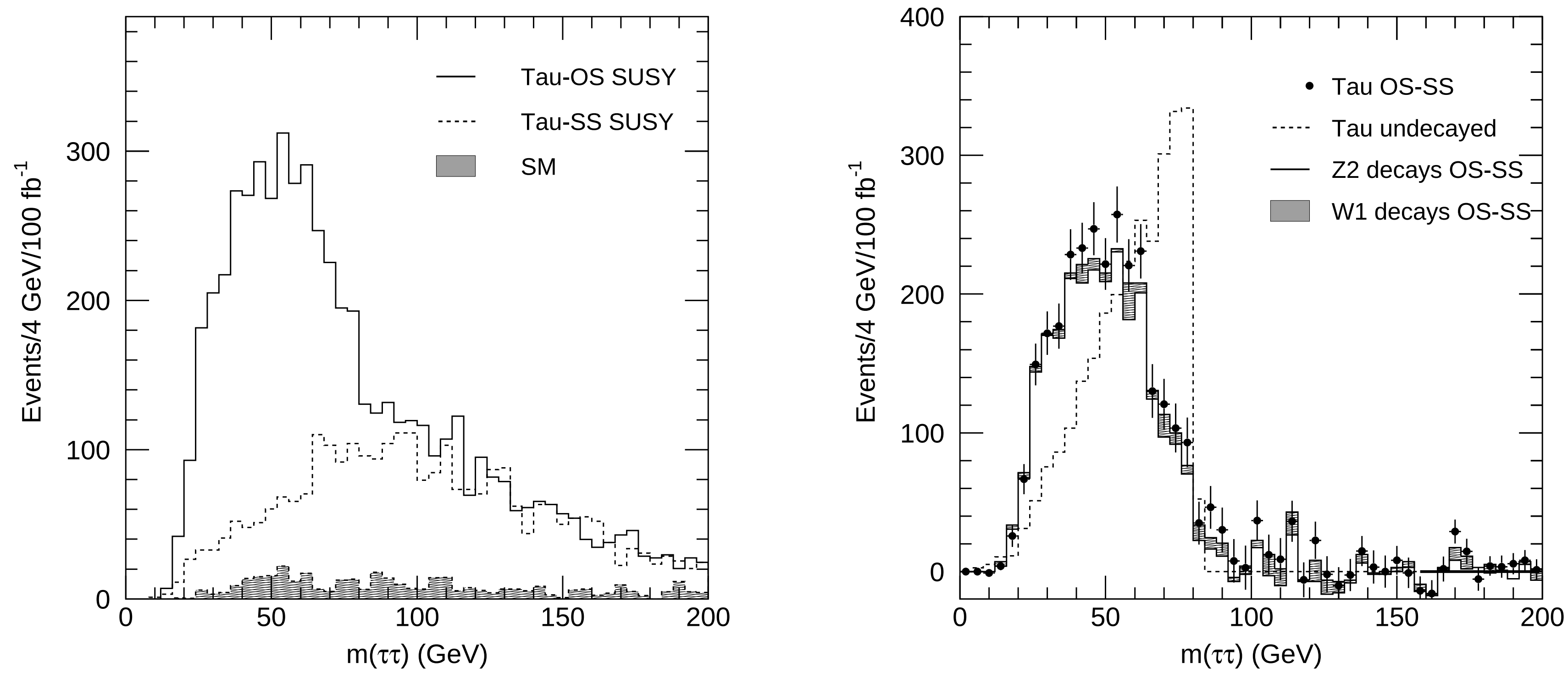
Observation of both decays gives handle on $\tan\beta$

Point SPS1A ($m_0 = 100$ GeV, $m_{1/2} = 250$ GeV, $\tan\beta = 10$, $A = -100$ GeV, $\mu > 0$)

Suppress Standard Model background with cuts on $\not{E}_T$, M_{eff}, jet multiplicity

Select decays $\tilde{\chi}_2^0 \to \tilde{\tau}_1 \tau$ requiring two jets tagged as hadronic τ decays.

Calculate invariant mass of $\tau^+\tau^-$ candidates



Subtract misidentified QCD jets using same-sign pairs

No sharp edge, but clear structure, a few GeV uncertainty on edge position

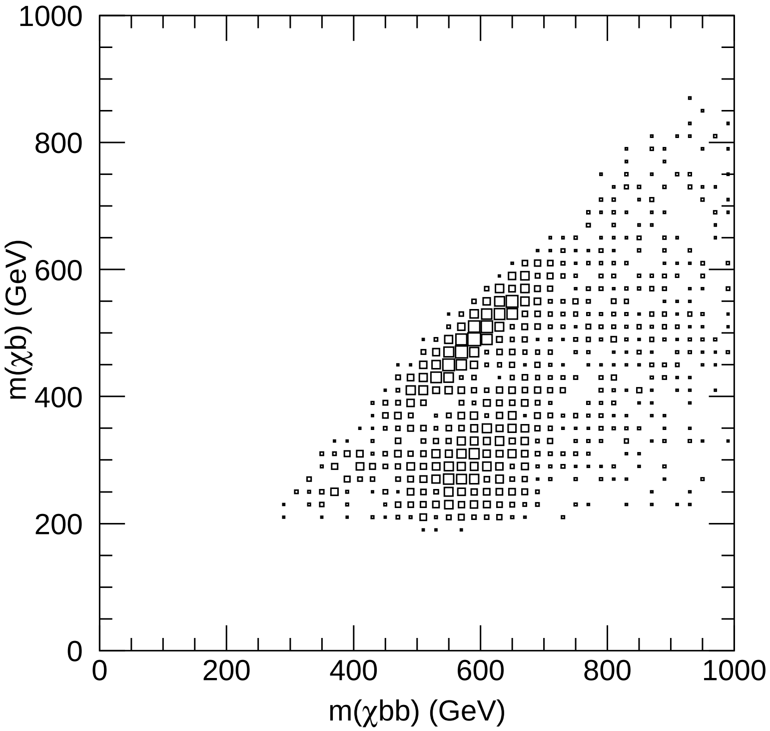
Gluino-sbottom mass reconstruction

From reconstruction of $\tilde{q}_L$ decay chain know $m(\tilde{\chi}_1^0)$, $m(\tilde{\chi}_2^0)$.

Building on this information go up the decay chain: study $\tilde{g} \to \tilde{b}_1 b$

Select events with OS-SF lepton pair. For $m_{\ell^+\ell^-}$ near edge, $\tilde{\chi}_1^0$ essentially at rest $\Rightarrow$

$$\vec{p}(\tilde{\chi}_2^0) \simeq (1 - \frac{m(\tilde{\chi}_1^0)}{m(\ell\ell)})\vec{p}_{\ell\ell} \quad \text{with} \quad \vec{p}_{\ell\ell} = \vec{p}_{\ell 1} + \vec{p}_{\ell 2}$$



Select events with $65 < m_{\ell\ell} < 78$ GeV

Reconstruct approximate $\tilde{\chi}_2^0$ momentum

Require two jets tagged as b

Reject events compatible with $\tilde{q}_L \tilde{\chi}_2^0$ decay ($\tilde{q} \neq \tilde{b}$)

Plot $m(\tilde{\chi}_2^0 b)$ versus $m(\tilde{\chi}_2^0 bb)$ (flavour subtracted)

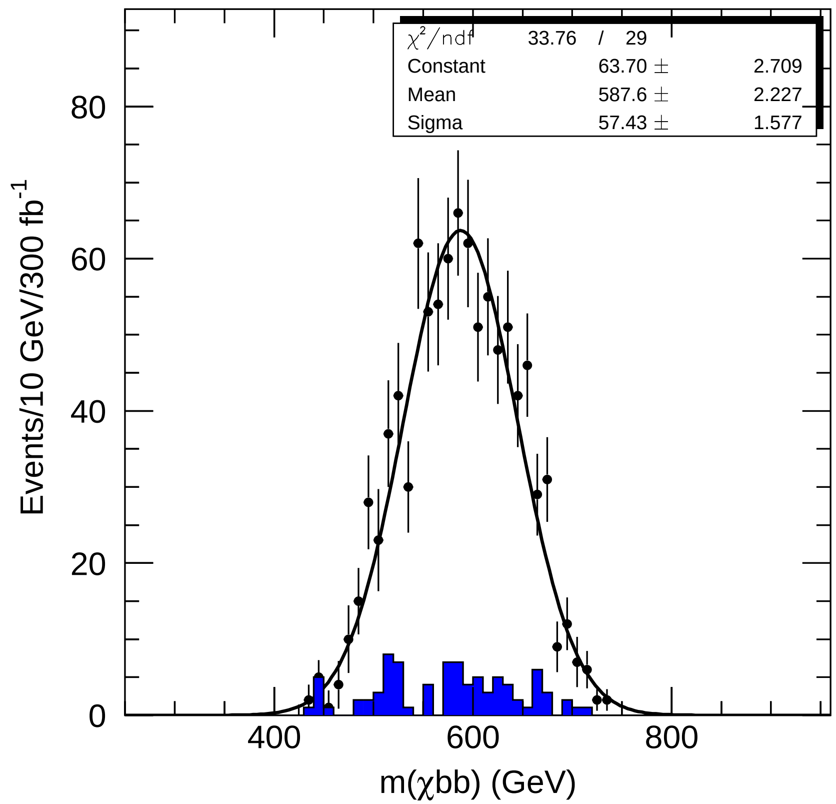
(two entries per event) $\Rightarrow$ observe structure

Select peak region in scatter plot by choosing $\tilde{\chi}^2_0$ coupling such that

$m(\tilde{\chi}^0_2 bb)$-$m(\tilde{\chi}^0_2 b) < 150$ GeV

$m(\tilde{\chi}^0_2 b)$ reconstructs $\tilde{g} \rightarrow \tilde{\chi}^0_2 b$ decay

Typically hardest jet selected because $m(\tilde{b}) - m(\tilde{\chi}^0_2) > m(\tilde{g}) - m(\tilde{b})$



Gluino mass measurement

Require selected $m(\tilde{\chi}^0_2 b)$ in peak region: $380 < m(\tilde{\chi}^0_2 b) < 600$ GeV

Plot $m(\tilde{\chi}^0_2 bb)$ distribution

Residual background small $\Rightarrow$ perform gaussian fit

Peak width determined by approximate $p(\tilde{\chi}^0_2)$

Statistical uncertainty on peak position: $\pm 4(2.2)$ Gev for 100 (300) fb^{-1}

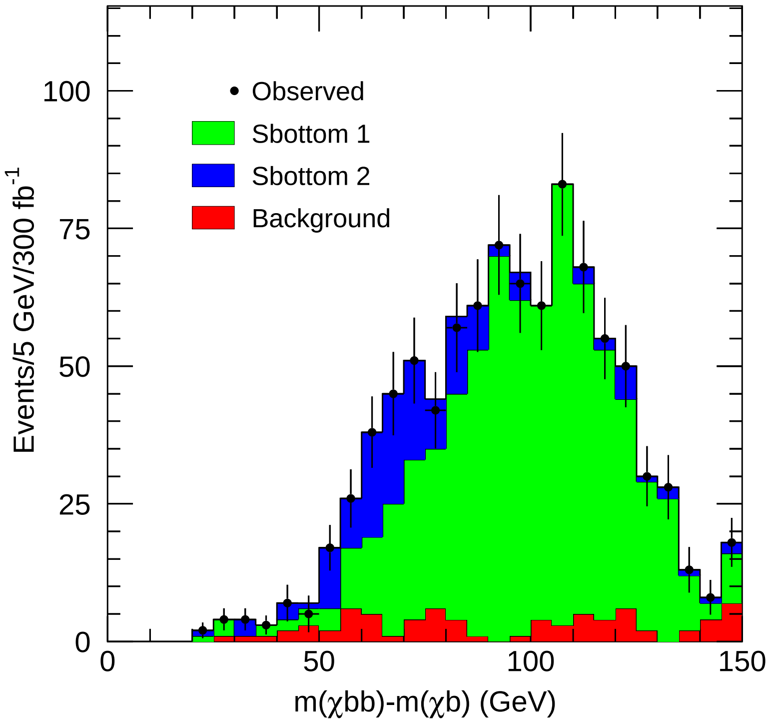
Dominated by 1% error on hadronic energy scale

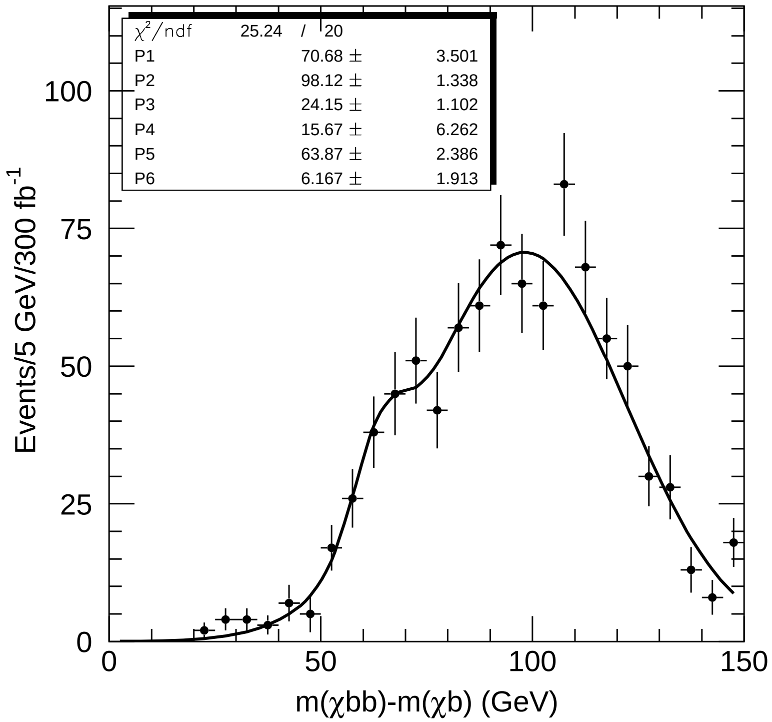
Sbottom mass measurement

Selected events are a mixture of $\tilde{g} \to \tilde{b}_1 b$ and $\tilde{g} \to \tilde{b}_2 b$

As shown in scatter plot, $m(\tilde{\chi}_2^0 b)$ strongly correlated with $m(\tilde{\chi}_2^0 bb)$

Can factor out the spread due to $p(\tilde{\chi}_2^0)$ by plotting $m(\tilde{\chi}_2^0 bb)$-$m(\tilde{\chi}_2^0 b)$





With 100 fb^{-1} two contributions probably indistinguishable, quote weighted mean

With 300 fb^{-1}, if excellent control of b-jet measurement is achieved, two peaks can be distinguished, and relative rate measured

Heavy gauginos in squark decays

Gaugino mixing matrix crucial ingredient in SUSY parameter study

$$\mathcal{M} = \begin{pmatrix} M_1 & 0 & -m_Z c_\beta s_W & m_Z s_\beta s_W \\ 0 & M_2 & m_Z c_\beta c_W & -m_Z s_\beta c_W \\ -m_Z c_\beta s_W & m_Z c_\beta c_W & 0 & -\mu \\ m_Z s_\beta s_W & -m_Z s_\beta c_W & -\mu & 0 \end{pmatrix} \quad (4)$$

In mSUGRA $|\mu| > M_2$, $\Rightarrow \tilde\chi_1^0 \sim \tilde B$, $\tilde\chi_2^0 \sim \tilde W^3$, $\tilde\chi_1^\pm \sim \tilde W^\pm$

Lighter gauginos give handle only on M_1 and M_2

For 100 fb^{-1}, $m(\tilde q, \tilde g) \sim 1$ TeV, we will collect a few 10^4 SUSY events

Rare squarks decays into heavier gauginos might be statistically accessible

In mSUGRA $\tilde\chi_3^0$ almost exclusively higgsino, BR($\tilde q_L \to \tilde\chi_3^0$) typically at the 0.1% level

$\tilde\chi_4^0$ and $\tilde\chi_2^+$ have typically some gaugino admixture:

BR ($\tilde q_L \to \tilde\chi_4^0, \tilde\chi_2^+$) a few % over significant parameter space

Need a clear signature allowing good separation from dominant light gauginos

BR($\tilde{\chi}_4^0, \tilde{\chi}_2^+ \to \ell^+\ell^- + X$) through sleptons $=$ a few $\%$

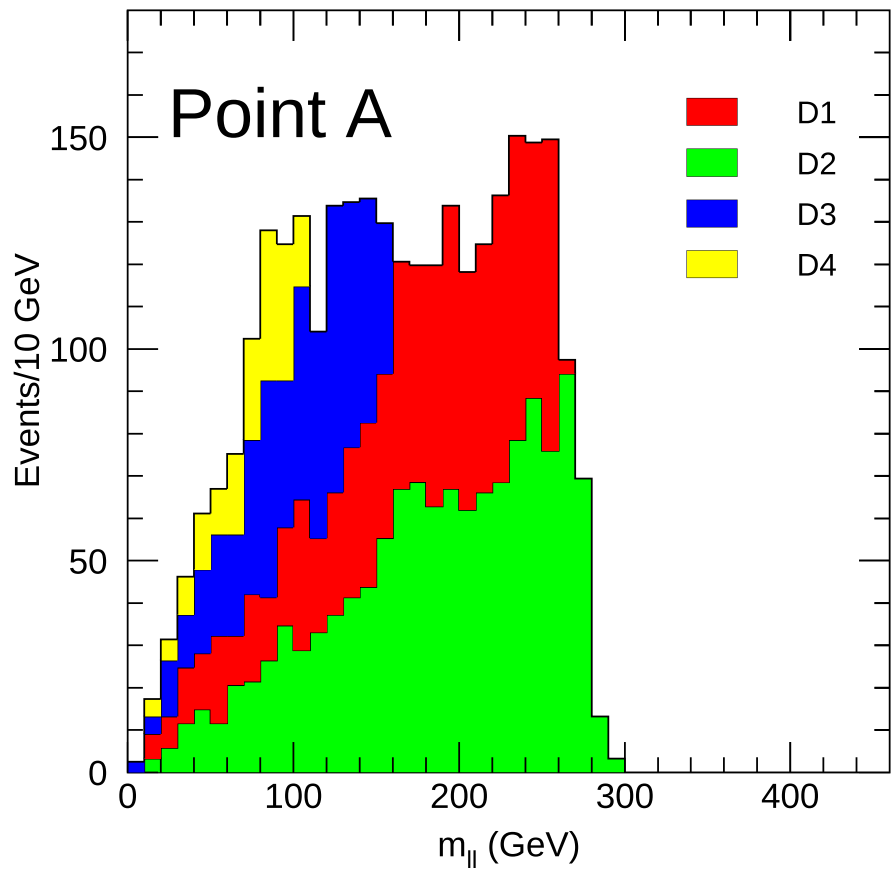
Opposite Sign, Same Flavour (OS-SF) leptons $\Rightarrow$ background subtraction.

Take example of SPS1A (m)

$$\tilde{q}_L \to \tilde{\chi}_4^0 \; q$$
$$\quad \hookrightarrow \tilde{\ell}_R^{\pm} \; \ell^{\mp}$$
$$\quad\quad \hookrightarrow \tilde{\chi}_1^0 \; \ell^{\pm} \qquad [D1]$$

$$\tilde{q}_L \to \tilde{\chi}_4^0 \; q$$
$$\quad \hookrightarrow \tilde{\ell}_L^{\pm} \; \ell^{\mp}$$
$$\quad\quad \hookrightarrow \tilde{\chi}_1^0 \; \ell^{\pm} \qquad [D2]$$
$$\quad\quad \hookrightarrow \tilde{\chi}_2^0 \; \ell^{\pm} \qquad [D3]$$

$$\tilde{q}_L \to \tilde{\chi}_2^{\pm} \; q'$$
$$\quad \hookrightarrow \tilde{\nu}_\ell \; \ell^{\pm}$$
$$\quad\quad \hookrightarrow \tilde{\chi}_1^{\pm} \; \ell^{\mp} \qquad [D4]$$



Edge in $\ell\ell$ invariant mass

Analysis requirements

- Exactly two SS-OF leptons ($P_T(1) > 20$ GeV, $P_T(2) > 10$ GeV)
- ≥ 3 jets, $P_t(j1) > 150$, $P_t(j2) > 100$, $P_t(j3) > 50$ GeV; $M_{eff} > 600$ GeV; $\not{E}_T > 100$ GeV
- $m_{\ell^+\ell^-} > 100$ GeV $\Rightarrow$ above $\tilde{\chi}_2^0$ edge
- $M_{T2} > 80$ GeV

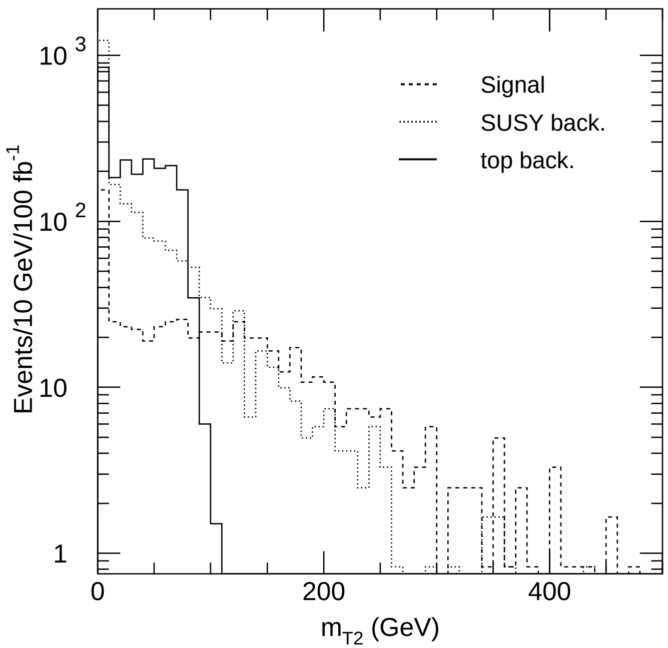
$$M_{T2}^2 \equiv \min_{\not{\mathbf{p}}_1+\not{\mathbf{p}}_2=\not{\mathbf{p}}_T} \left[\max\left\{m_T^2(\mathbf{p}_T^{l_1}, \not{\mathbf{p}}_1), m_T^2(\mathbf{p}_T^{l_2}, \not{\mathbf{p}}_2)\right\}\right]$$

where

$$m_T^2(\mathbf{p}_T^l, \mathbf{q}_T) \equiv 2(E_T^l Q_T - \mathbf{p}_T^l \cdot \mathbf{q}_T)$$

$E_T^l = |\mathbf{p}_T^l|$ and $Q_T = |\mathbf{q}_T|$

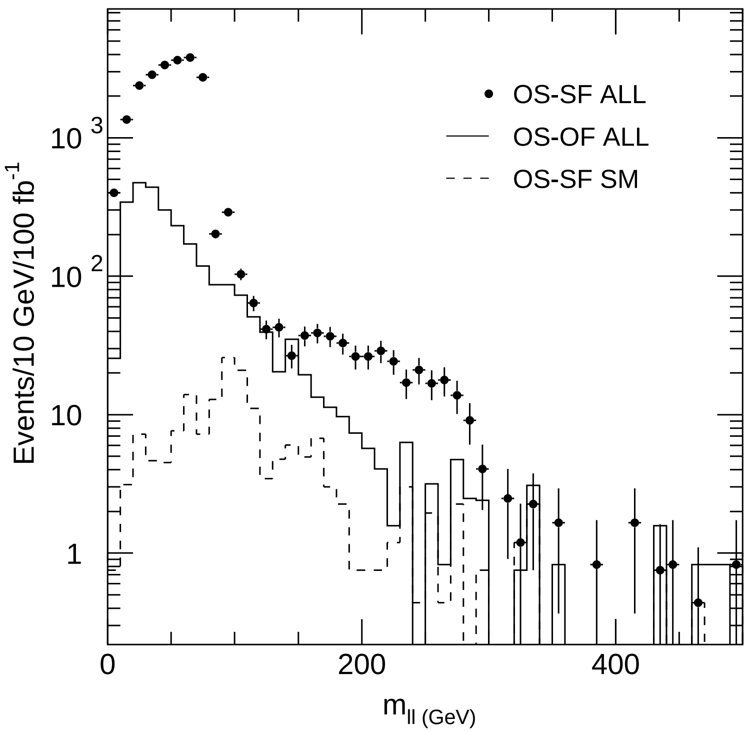
Cambridge M_{T2} variable with $m_\chi = 0$

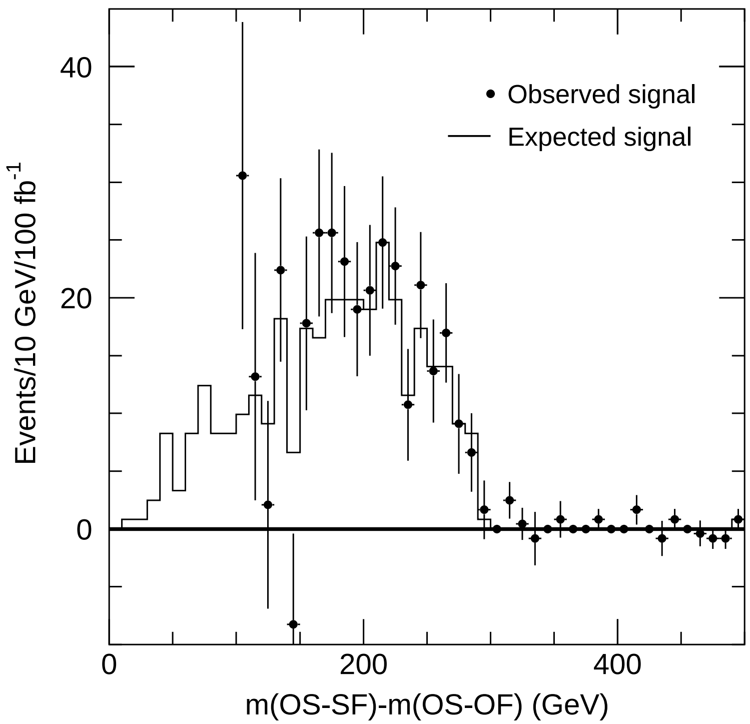


Strongly reduces $\bar{t}t$ and SUSY background from uncorrelated decays

After cuts events left for 100 fb^{-1}: $\sim$40 $\bar{t}t$ and $\sim$30 $W, Z+$ jets.

Look for an excess in $m(\ell^+\ell^-)$ distributions:





Analysis results after all cuts (100 fb^{-1}):

Point	N_{ev} Signal	Signif.	SUSY bck.	SM bck.	Interval (GeV)
A	259.1 $\pm$ 21.1	12.3	92.3	27.1	150–290

Precision on end-point measurement: 2.3 GeV (300 fb^{-1})

Difficult to assess which decay gives end point

Additional measurements build on measured $\tilde{q}_L$, $\tilde{\ell}_R$, $\tilde{\chi}_2^0$, $\tilde{\chi}_1^0$ masses:

- Measure slepton left direct production
- Use shorter decay chains to measure additional masses: $\tilde{q}_R \to \tilde{\chi}_1^0 q$, $\tilde{q}_L \to \tilde{\chi}_4^0 q$, ...

Available measurements for SPS1a (300 fb^{-1}):

		Errors		
Variable	Value (GeV)	Stat. (GeV)	Scale (GeV)	Total
$m_{\ell\ell}^{max}$	77.07	0.03	0.08	0.08
$m_{\ell\ell q}^{max}$	428.5	1.4	4.3	4.5
$m_{\ell q}^{low}$	300.3	0.9	3.0	3.1
$m_{\ell q}^{high}$	378.0	1.0	3.8	3.9
$m_{\ell\ell q}^{min}$	201.9	1.6	2.0	2.6
$m_{\ell\ell b}^{min}$	183.1	3.6	1.8	4.1
$m(\ell_L) - m(\tilde{\chi}_1^0)$	106.1	1.6	0.1	1.6
$m_{\ell\ell}^{max}(\tilde{\chi}_4^0)$	280.9	2.3	0.3	2.3
$m_{\tau\tau}^{max}$	80.6	5.0	0.8	5.1
$m(\tilde{g}) - 0.99 \times m(\tilde{\chi}_1^0)$	500.0	2.3	6.0	6.4
$m(\tilde{q}_R) - m(\tilde{\chi}_1^0)$	424.2	10.0	4.2	10.9
$m(\tilde{g}) - m(\tilde{b}_1)$	103.3	1.5	1.0	1.8
$m(\tilde{g}) - m(\tilde{b}_2)$	70.6	2.5	0.7	2.6

Interpretation of results

We have now a set of measurement of kinematic paramters

Results do not depend a priori on a special choice of the model

For instance, we can state that in the data appears the decay:

$$
\begin{array}{llll}
a \longrightarrow b & q & & \\
\quad\;\; \hookrightarrow & c & \ell^{\mp} & \\
& \quad \hookrightarrow & d & \ell^{\pm}
\end{array}
$$

Where something can be said about a, b, c, d. e.g.:

- d does not interact in the detector
- c should have lepton quantum number
- a should have baryon quantum number

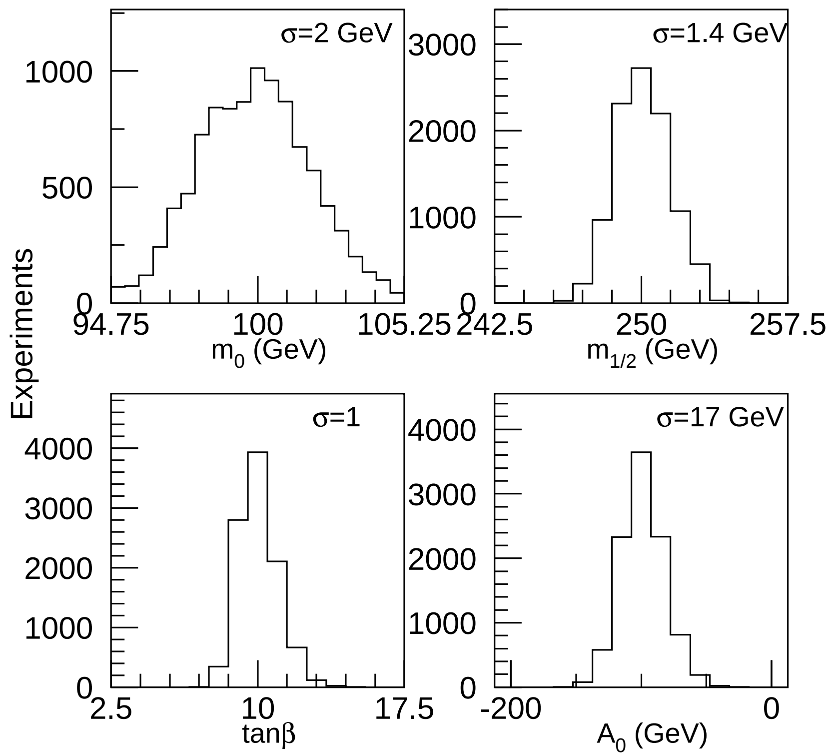
And we know the masses of a, b, c, d

Model dependence enters when we try to give a name to the particles, and match them to a template decay chain

Constraints on SUSY model from measurements

Measured mass relations can be used to constrain models

Simplest approach: postulate SUSY breaking model, and verify if any set of the model parameters fits measured quantities. Exercise performed for SPS1a postulating mSUGRA



- m_0 dominated by sleptons ($\Delta m_0 \sim 2\%$)
- $m_{1/2}$ " by light gauginos ($\Delta m_{1/2} \sim 0.6\%$)
- Need $\tilde{b}_1$ and $\tilde{b}_2$ for $\tan\beta$, otherwise long tails
- Trilinear couplings A_0 related to μ, fixed by $\tilde{\chi}^0_4$
- Wrong μ sign ruled out by bad fit

Measurements at the LHC can constrain SUSY models

Exercise relies on correct interpretation of kinematic signatures as SUSY decay chains

Spin information needed to confirm SUSY interpretation (in progress)