The Abdus Salam International Centre for Theoretical Physics

1970-11

Signaling the Arrival of the LHC Era

8 - 13 December 2008

Beyond the Standard Model at the LHC - II

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SUSY searches at the LHC

II - Exclusive measurements

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Inclusive analysis: critical reassessment

I have shown how LHC experiment will try to discover RP conserving SUSY

A certain number of generic assumptions:

- Detection through discovery of squark and gluino production
- Squark and gluino decay to jets + some kind of $SU(2) \times U(1)$ gaugino/higgsino
- Mass difference between squark/gluino and gauginos with dominant BR such as to yield high p_T jets. More or less guaranteed in case of gluino accessible and gaugino mass unification
- Gauginos will decay into "something" and finally into an invisible LSP

Searches are therefore: 2 to 4 jets, depending on relation between gluino and squark masses + $\not{E}_T$ + "something"

Examples of "something": nothing, 1,2,3 leptons (e, μ) τ (hadronic), b-jets, Z , h

Generic variables: P_T/η of ingredients + estimator of mass of system. Canonically: $M_{\text{eff}} = \Sigma_i |p_{T(i)}| + E_T^{\text{miss}}$

How generic?

Typically reach shown on mSUGRA plane (to fix the rate "something"), but shown to cover other $\tilde{\chi}_1^0$ LSP scenarios

Will also e.g. cover most cases in GMSB (gravitino LSP)

- NLSP is $\tilde{\chi}_1^0$. If long lived: phenomenology as for mSUGRA

  If short lived: add photons to the "something"

  If medium lived (decay inside the detector):

  Discovery OK. Special algorithm for photons to perform measurements

- NLSP is $\tilde{\ell}/\tilde{\tau}_1$. If short lived: additional leptons in the "something".

  If long-lived need detector-specific studies

Address with 'ad hoc' searches cases where squarks/gluino outside LHC reach:

- searches for direct production of light stops
- direct gaugino/higgsino search in 3-lepton channel
- long lived heavy particles (staus or R-hadrons) $\Rightarrow$ very active field of exploration

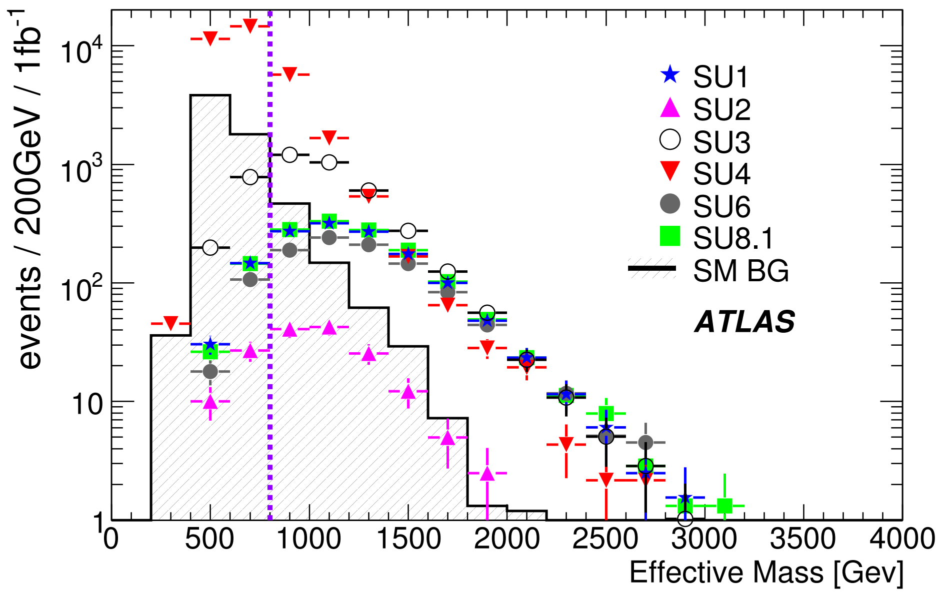
First measurement: SUSY mass scale from inclusive analysis

Look at multijet + $\not{E}_T$ signature.

Main discriminant variable together with $\not{E}_T$:

$$M_{\text{eff}} = \sum_i |p_{T(i)}| + E_T^{\text{miss}}$$

with $p_{T(i)}$ transverse momentum of jet i

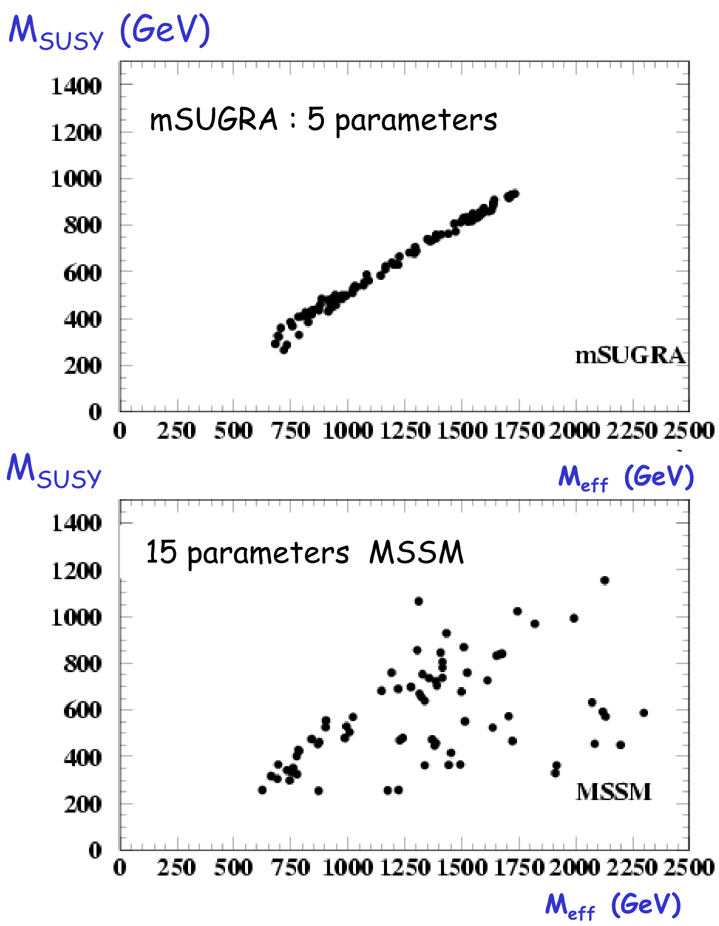


M_{eff} distribution for ATLAS SUSY benchmark points

Peak in M_{eff} distribution approximately tracks the mass scale of squarks/gluinos.

Define the SUSY mass scale as:

$$M_{\rm susy}^{\rm eff} = \left(M_{\rm susy} - \frac{M_\chi^2}{M_{\rm susy}} \right), \text{ with } M_{\rm SUSY} \equiv \frac{\Sigma_i\, M_i \sigma_i}{\Sigma_i\, \sigma_i}$$



Estimate $M_{\rm eff}$ peak by a gaussian fit to background-subtracted signal distributions

Test the correlation of $M_{\rm eff}$ with $M_{\rm susy}^{\rm eff}$ on random sets: mSUGRA and MSSM

Excellent correlation in mSUGRA, less good for MSSM

$\sim 10\%$ precision on SUSY mass scale for one year at high luminosity

Old work, to update with new backgrounds

What might we know after inclusive analyses?

Assume we have a MSSM-like SUSY model with $m_{\tilde{q}} \sim m_{\tilde{g}} \sim 600$ GeV

Observe excesses in $\not{E}_T + jets$ inclusive, and in some of the $\not{E}_T + jets +$ "something" channels. Null results in specialised searches

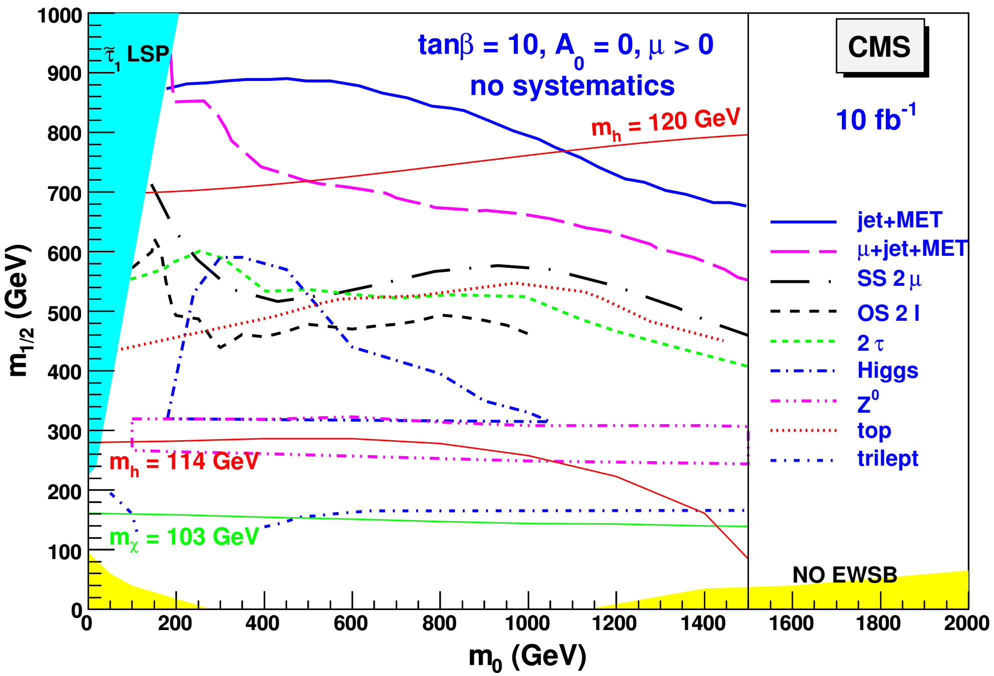
- Undetectable particles in the final state: $\not{E}_T$. Stable or ling-lived?
- Primary particles with mass∼600 GeV (M_{eff} study)
- Assigning spin hypotheses to produced sparticles can get an idea of couplings (exp. difficulty: need some assumption on gaugino spectrum to evaluate selection efficiency)
- Many more things depending on the excesses observed for the different "something". Examples:
  - Excess of of same-sign lepton pairs: some of the primary particles are Majorana
  - See same number of leptons and muons: lepton flavour $\sim$ conserved in first two generations
  - ....

How can we use it?

Too little information to zoom into a model

Probably with guess the composition of the produced primary particles

One can exclude detailed implementations of model



Ex. in mSUGRA for each point one has different inclusive signatures, and one can compare observed and predicted relative rates

Already quite a few theoretical attempts in this direction, e.g. LHC Olympics

However, more detailed info can be extracted from the data

What kind of info for establishing SUSY?

Long lists of requests. 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

Available observables:

- Sparticle masses,
- BR's of cascade decays
- Production cross-sections,
- Angular decay distributions

Measurements of observables depends on detail of model and requires development of ad-hoc techniques. Over last ten years strategy based on detailed MC study of reasonable candidate models

Did we focus too much on a too restricted class of models?

What path from the observables to the model?

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:

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

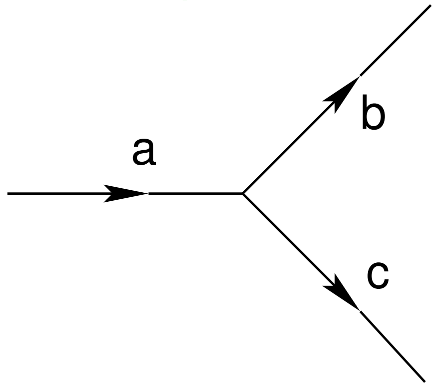
Most of work done on sparticle mass measurement

Briefly introduce the most basic mass measurement technique

The easiest mass constraint: cascade of two two-body decays

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

$\Rightarrow$ no mass peaks, but invariant mass distributions can give constraints



Consider 2-body decay $a \to b + c$

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

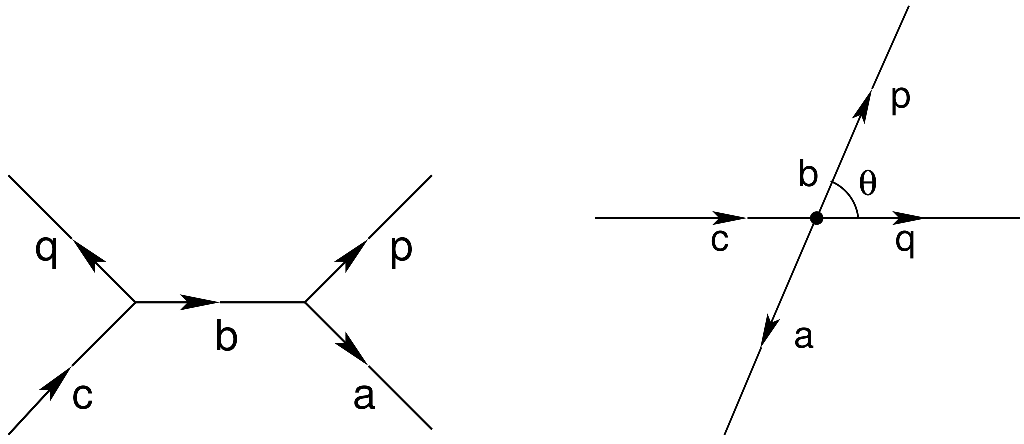
In rest frame of a:

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

Solve for $|\vec{p}|$: $\quad |\vec{p}|^2 = [m_b^2, m_a^2, m_c^2]$ where $[x, y, z] \equiv \frac{x^2+y^2+z^2-2(xy+xz+yz)}{4y}$

Decay momenta determined in terms of masses of involved particles

Now consider a sequence of two-body decays:



With c: original particle, a: invisible particle at the end of the chain ($\tilde{\chi}_1^0$); p and q the two visible particles of which we want to calculate the invariant mass m_{pq}

In rest frame of b: $m_{pq}^2 = m_p^2 + m_q^2 + 2(E_p E_q - |\vec{p_p}||\vec{p_q}|\cos\theta)$

Take the maximum ($\cos\theta = -1$) and p and q massless (quarks or leptons)

$$(m_{p,q}^{max})^2 = 4|\vec{p}||\vec{q}| = 4\sqrt{[0, m_b^2, m_a^2]}\sqrt{[0, m_b^2, m_c^2]}$$

Substitute formula for $[x, y, z]$:

$$(m_{pq}^{max})^2 = \frac{(m_c^2 - m_b^2)(m_b^2 - m_a^2)}{m_a^2}$$

Invariant mass distribution

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

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

Where $\cos\theta$ is the angle between visible p and q in b rest frame.

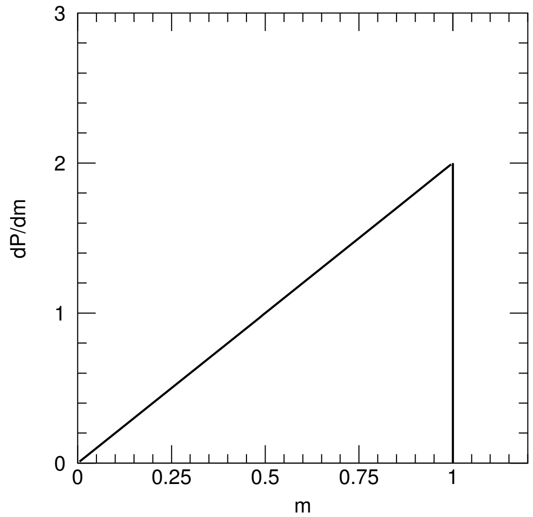
If p, q are massless: $m_{pq}^2 = 2|\vec{p_p}||\vec{p_q}|(1 - \cos\theta) \quad \text{and} \quad (m_{pq}^{max})^2 = 4|\vec{p_p}||\vec{p_q}|$

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:

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



Show the simplest example of ATLAS full simulation analyses where this distribution observable

Lepton-lepton edge

ATLAS Point SU3: $m_0 = 100$ GeV, $m_{1/2} = 300$ GeV

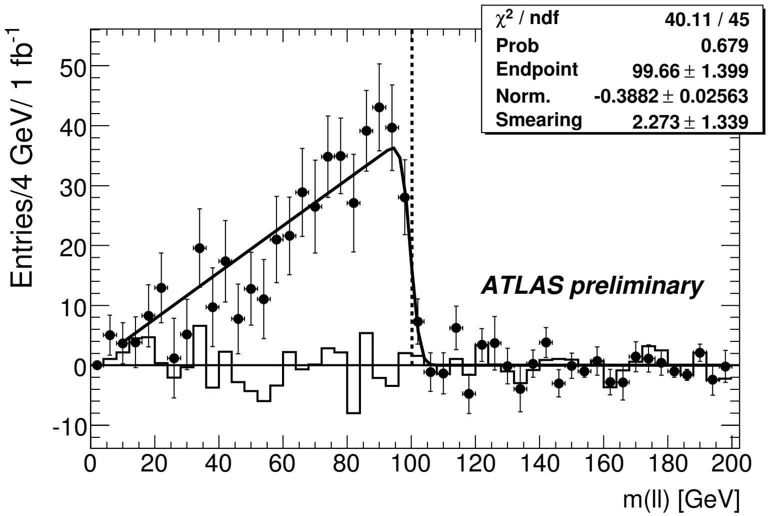
$A = -300$ GeV, $\tan\beta = 6$, $\mu > 0$

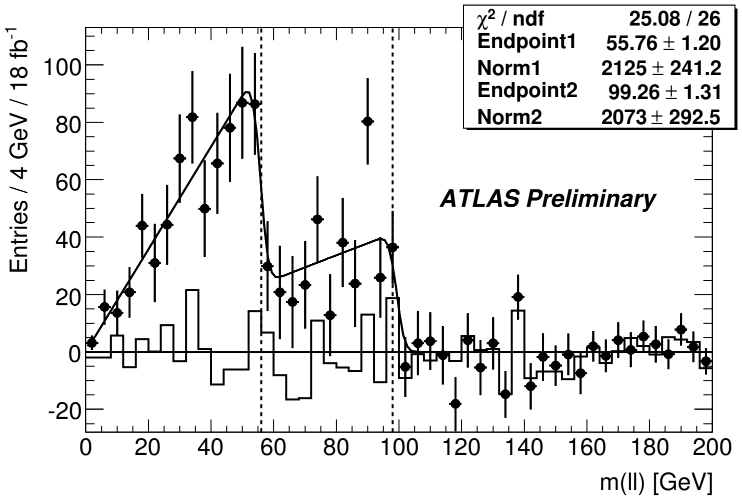
Canonical decay $\tilde{\chi}_2^0 \to \ell^{\pm}\tilde{\ell}_R^{\mp} \to \ell^{\pm}\ell^{\mp}\tilde{\chi}_1^0$

Plot the flavour-subtracted invariant mass for 1 fb^{-1}

$m(\tilde{\chi}_2^0) = 218.6$ GeV $m(\tilde{e}_R) = 155.5$ GeV $m(\tilde{\chi}_1^0) = 117.9$ GeV

$m(\ell\ell)_{max} = 100.2$ GeV, fit: $99.7 \pm 1.4 \pm 0.3$ GeV





More difficult situation: ATLAS Point SU1

$m_0 = 70$ GeV, $m_{1/2} = 350$ GeV $A = 0$ GeV, $\tan\beta = 10$, $\mu > 0$

Both ℓ_R and ℓ_L lighter than $\tilde{\chi}_2^0$. Two flavour-correlated edges from $\tilde{\chi}_2^0 \to \ell^{\pm}\tilde{\ell}_{R(L)}^{\mp} \to \ell^{\pm}\ell^{\mp}\tilde{\chi}_1^0$

In distribution for 18 fb^{-1} two edges for the two slepton helicities

Model independent mass determination

Shown realistic examples in which kinematic edges observed

Conforting to see that full simulation studies at low statistics tell us that these features may be observed beyond ATLFAST (no real life, though....). One step further is needed: extract from event kinematics absolute values for some of the masses.

Three families of techniques (and variations) proposed:

- Edge method (Many contributions: e.g. Paige, Hinchliffe, Lester, Miller, Osland)
- Mass relation method (Kawagoe, GP, Nojiri, Chen et al.)
- M_{T2} kink method (Lester, Barr, Cho et al.) method very recent and interesting: do not need long chains.

I will today only show the best studied one, the edge method

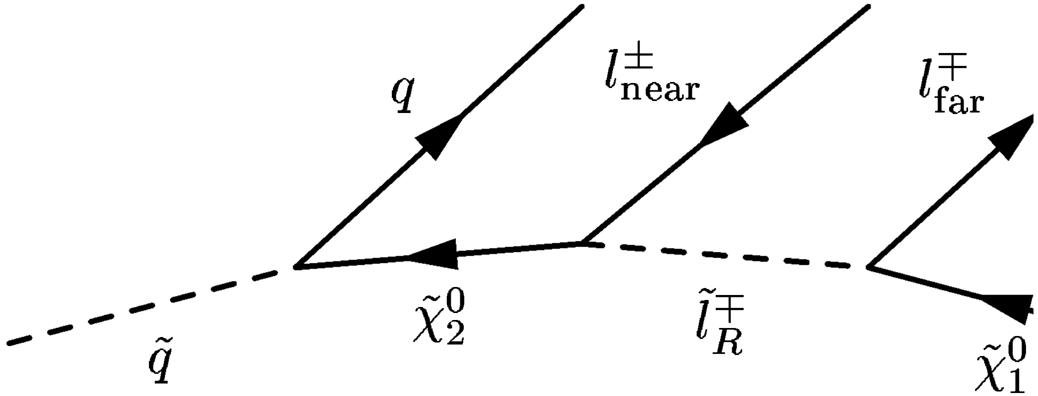
The edge method

With two decays only single mass combination $\Rightarrow$ only one edge constraint

Consider longer chain. Key result (Paige, Hinchliffe):

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.

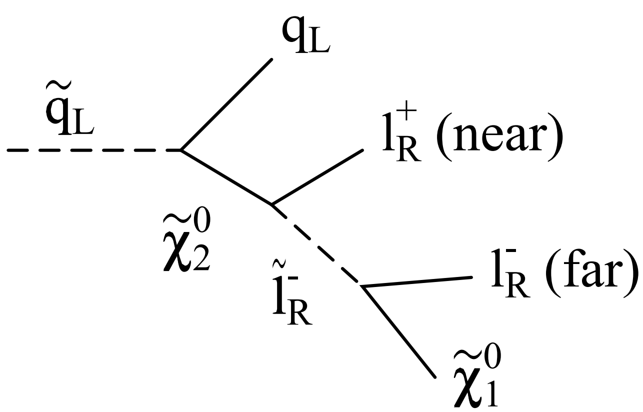
Example: full reconstruction of squark decays in models with light $\tilde{\ell}_R$ ($m_{\tilde{\ell}_R} < m_{\tilde{\chi}_2^0}$):



Three visible particles: 4 invariant mass combinations: (12), (13), (23), (123)

For first three minimum value is zero: only M_{max} constraint. For fourth both M_{max} and M_{min} constraint: total 5 constraints

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



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

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

l^+l^-q thresh

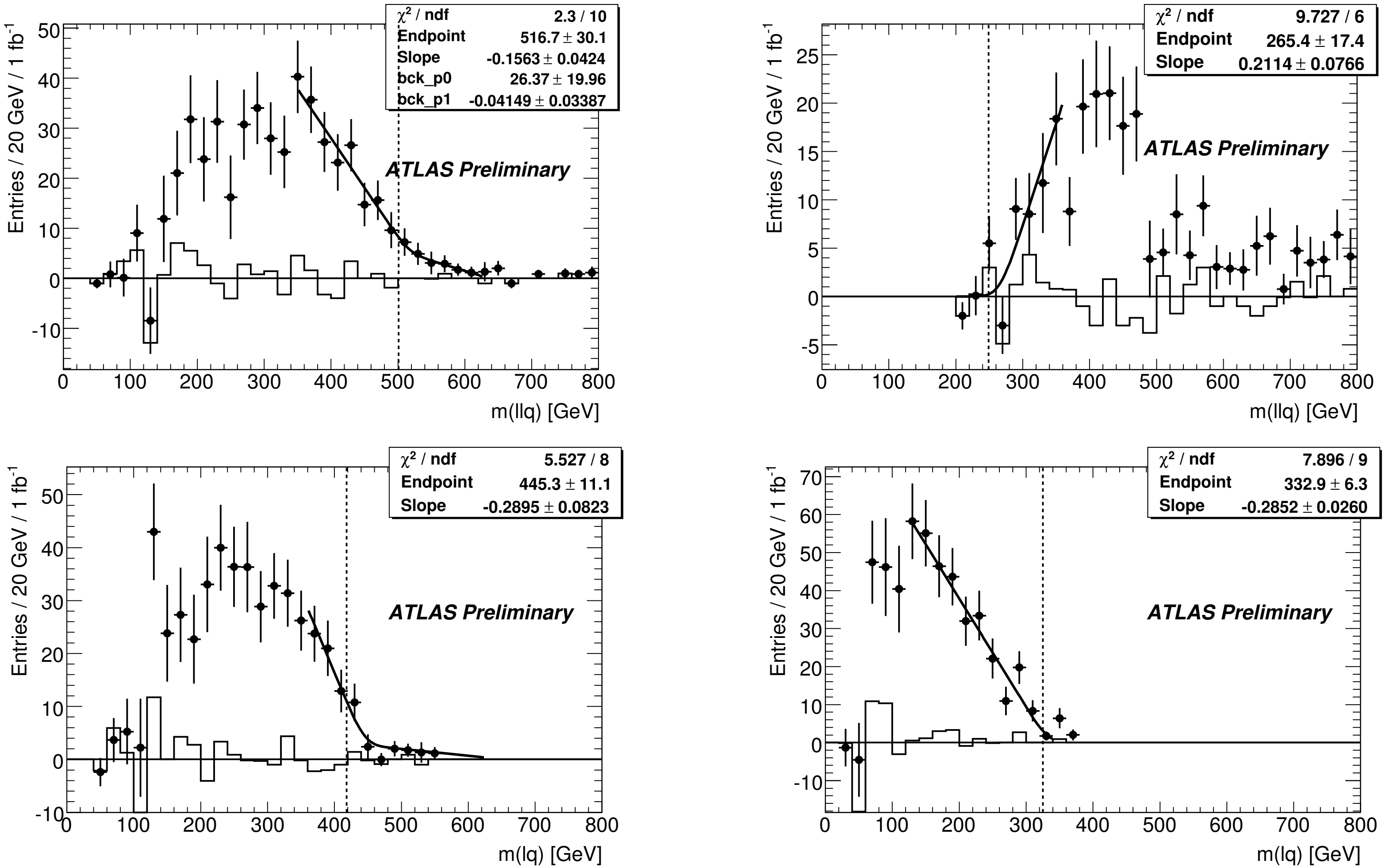
$$(m_{llq}^{\min})^2 = \begin{cases} [\ 2\tilde{l}(\tilde{q}-\tilde{\xi})(\tilde{\xi}-\tilde{\chi}) \\ +(\tilde{q}+\tilde{\xi})(\tilde{\xi}-\tilde{l})(\tilde{l}-\tilde{\chi}) \\ \quad -(\tilde{q}-\tilde{\xi})\sqrt{(\tilde{\xi}+\tilde{l})^2(\tilde{l}+\tilde{\chi})^2-16\tilde{\xi}\tilde{l}^2\tilde{\chi}}\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

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

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

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

Lepton-jet edges for ATLAS SU3 point



Fit to straight line for signal and straight line for background with gaussian smearing

Large systematics for this assumption expecially for $m_{\ell\ell q}$

Fit results for SU3 (1 fb^{1})

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

Results still preliminary

First error statistical, second systematic with fit, third from jet scale

Excellent consistency with 'true' values

Can invert algebraical relations defining edges to extract sparticle masses through a minuit fit

First error from MIGRAD, second one from energy scale

Reasonable mass measurement achieved, even with the low statistics considered

Much better measurement for mass differences, as the edges are essentialy sensitive to the differences

Observable	SU3 m_{meas} (GeV)	SU3 m_{MC} (GeV)
$m_{\tilde{\chi}_1^0}$	$88 \pm 60 \mp 2$	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)	SU3 Δm_{MC} (GeV)
$m_{\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0}$	$100.6 \pm 1.9 \mp 0.0$	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

Interpretation of results

The measurements do not depend a priori on a special choice of the model

For instance, we can state that in the data appear the decays:

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

$$
\begin{array}{l}
a \longrightarrow b \quad q \\
\quad\quad \hookrightarrow e \quad \tau^{\mp} \\
\quad\quad\quad\quad \hookrightarrow d \quad \tau^{\pm}
\end{array}
$$

Where we know the masses of a, b, c, d, e, and we might conjecture that a, b, d appearing in both decays are the same having the same masses

So we have a mass hierarchy, some of the decays related these particles and, perhaps, the relative rates

Having decay chains help restricting the possibilities, if one imposes some conservations, e.g. charges or quantum numbers

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

Among the models proposed to solve the hierarchy problem, various options providing a full spectrum of new particles, with cascade decays:

- Universal extra-dimensions: first KK excitation of each of the SM fields
- Little Higgs with T parity

Special feature of SUSY: if one identifies the heavy partners through their quantum numbers, the spins of all of them are wrong by $1/2$

Measurement of sparticle spins from decay products is very active field of phenomenological investigations

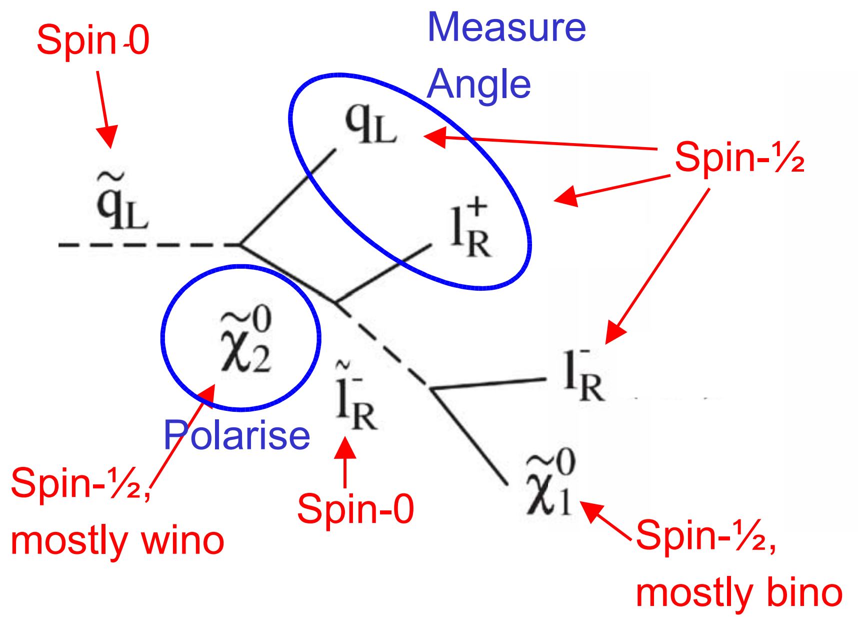
Spin measurement in squark decay (A. Barr)

Consider 'golden' squark decay chain in SPA point

Three visible particles in final state: 1 jet, two leptons

Spin analyser is the angle between the quark and the lepton from $\tilde{\chi}_2^0$ decay

No dynamic information from angle between two leptons, as $\tilde{\ell}_R$ is spin zero



Reminder: can cast invariant mass of two adjacent particles, e.g. ℓq in chain as dimensionless variable measuring θ:

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

We have seen that for intermediate particle with spin zero:

$$\frac{dP}{d\cos\theta} = \frac{1}{2} \quad \Rightarrow \frac{dP}{d\hat{m}} = 2\hat{m}$$

Spin 1/2: two cases:

- Lepton same helicity as quark:

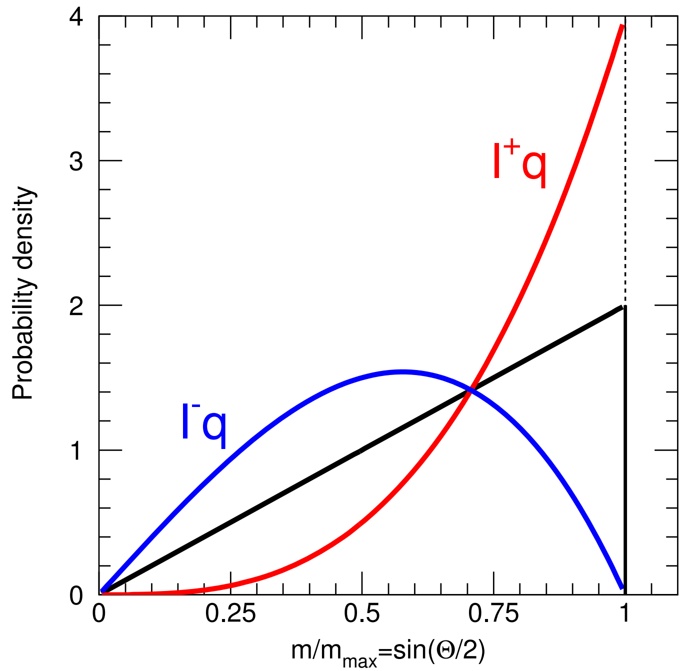
  l^+q, $l^-\bar{q}$ for $\tilde{q}_L$, $\tilde{\ell}_L$

  $$\frac{dP}{d\cos\theta} = \frac{1}{2}(1-\cos\theta) \quad \Rightarrow \frac{dP}{d\hat{m}} = 4\hat{m}^3$$

- Lepton opposite helicity to quark:

  l^-q, $l^+\bar{q}$ for $\tilde{q}_L$, $\tilde{\ell}_R$

  $$\frac{dP}{d\cos\theta} = \frac{1}{2}(1+\cos\theta) \quad \Rightarrow \frac{dP}{d\hat{m}} = 4\hat{m}(1-\hat{m}^2)$$



Difference in shape of m_{ℓ^+q} and m_{ℓ^-q}: indication for $\tilde{\chi}_2^0$ spin $1/2$

Experimental measurement

$\ell^{near} q$ shows nice charge asymmetry:

$\Rightarrow$ Excellent probe of $\tilde{\chi}_2^0$ spin

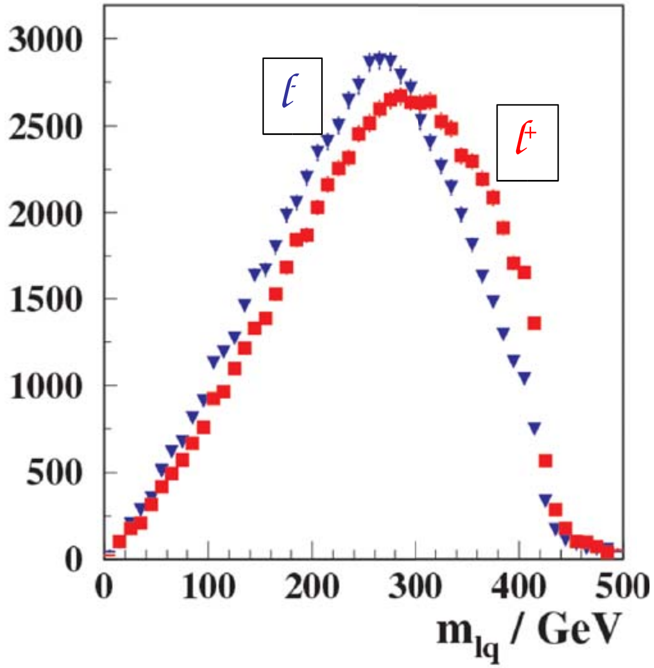
Experimental problems in measurement:

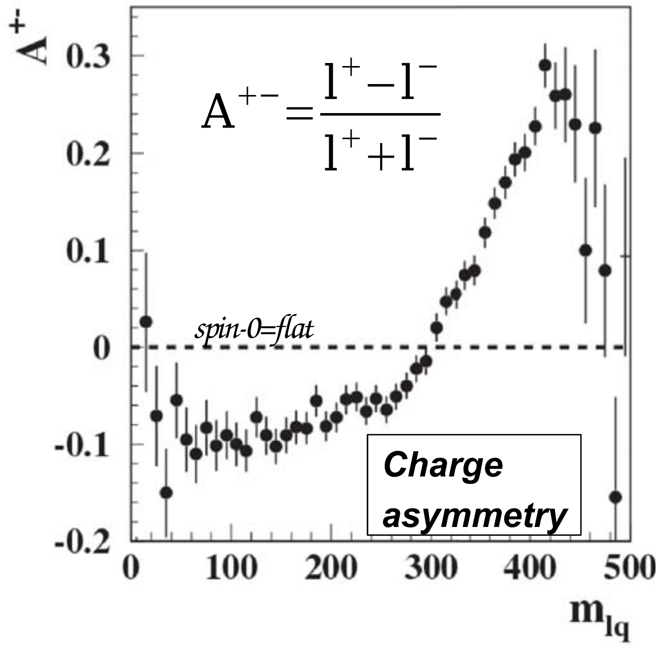
- $\ell^+ q = \ell^- \bar{q}$ and can't tell quark jet from anti-quark jet
  - q ($\bar{q}$) in decay chain come from squark (antisquark)
  - pp Collider $\rightarrow$ PDF favour production of squarks over anti-squarks, excess of quarks in decay chain
- Two leptons in the event, a priori indistinguishable
  - We are only interested in the first (near) lepton (from neutralino decay)
  - Second (far) lepton comes from the decay of a spin-0 particle, $\tilde{\ell}$: expect almost no distortion of asymmetry from invariant mass of jet with far lepton

Parton level asymmetry

We now build at parton level on simulated events the lepton-jet invariant mass, and take the bin-by-bin asymmetry of ℓ^+ and ℓ^- distributions

Experimentally measurable: both q and $\bar{q}$ in plot, both near and far lepton

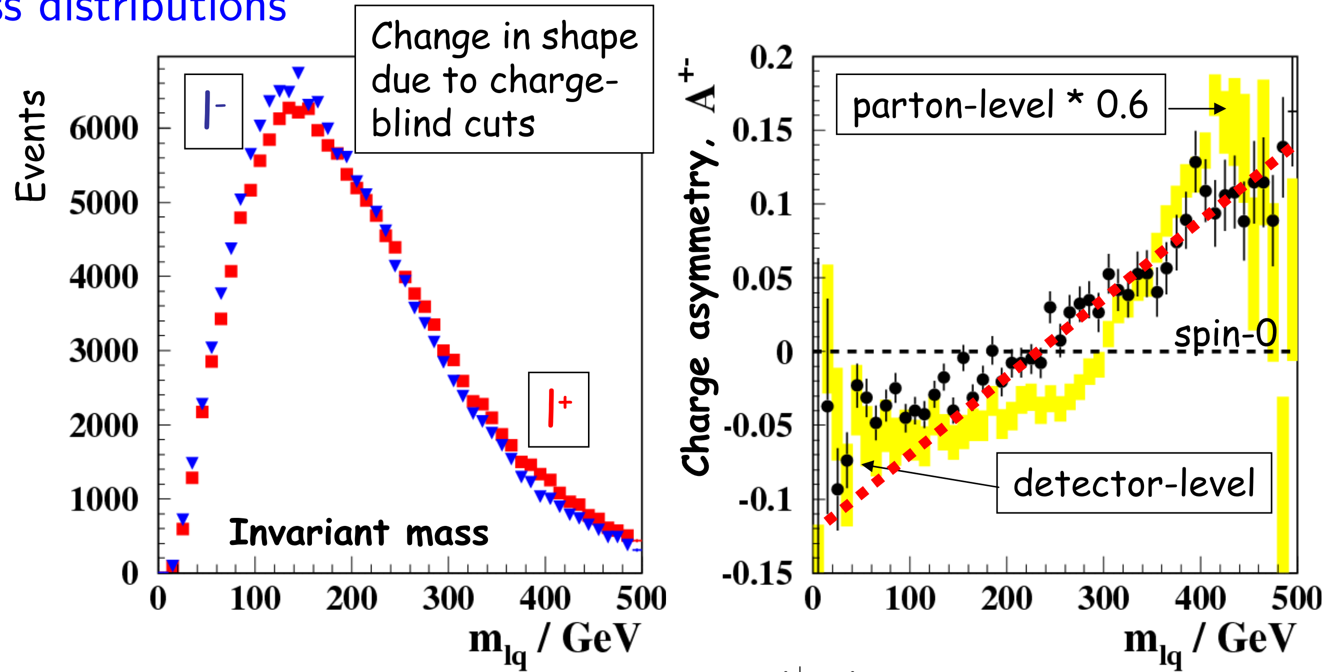




Shape shows clear deviation from what expected for spin-zero $\tilde{\chi}_2^0$

Observable asymmetry

From a sample of events in parametrised simulation build $\ell^+ j$ and $\ell^- j$ invariant mass distributions



Build bin-by bin charge asymmetry: $A = \frac{\ell^+ - \ell^-}{\ell^+ + \ell -}$

Strong dilution through detector smearing and background effects

Effect still observable, need approximately 150 fb^{-1}

Discrimination against spin-1 $\tilde{\chi}_2^0$ also possible if spectrum not too degenerate

Comparison with spin 1

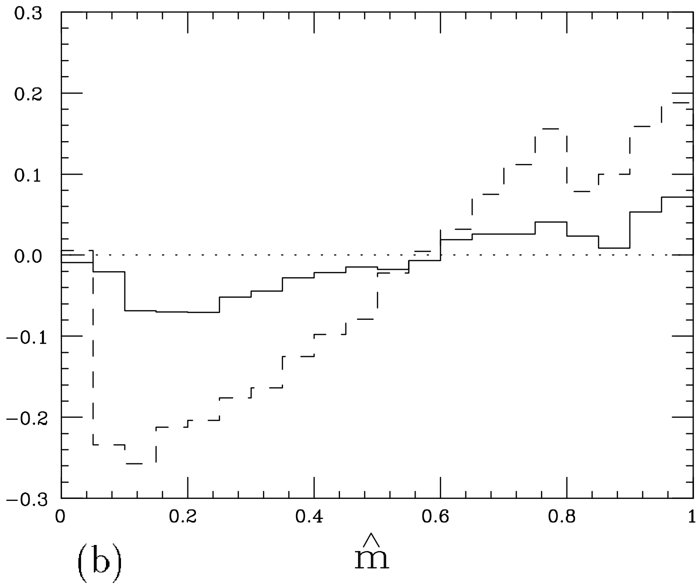
For the SPS1a SUSY model, it can be shown that $\tilde{\chi}_2^0$ is not a scalar

In competing models (UED) spin of partner of Z is 1, as in Standard Model

Not studied in previous analysis because model not available in MC generator

Comparison with spin one performed by theorists (Smillie, Webber) with very rough detector simulation

Same spectrum of sparticle masses as for SPS1a point with two spin assignments: SM-like (solid lines), SUSY (dashed lines)



Two spin assignments:

SM-like (solid lines), SUSY (dashed lines)

Excellent discrimination also against spin one case

Conclusions

No statistical problem for the quick discovery of SUSY at the LHC if $m(SUSY) \sim 1 - 2$ TeV

Clear but difficult signatures, long work on understanding detector performance and estimate Standard Model backgrounds. Main focus of ATLAS and CMS work

Can typically confirm signal through multiple signatures

Once convincing signal claimed, try to pin down what kind of SM extension generated deviation

A few benchmark models studied, and some general techniques developed for mass and spin measurements of SUSY particles

Lots of work to learn how to make use of all the experimental information

If indeed we do observe a signal, many years of excitement ahead of us

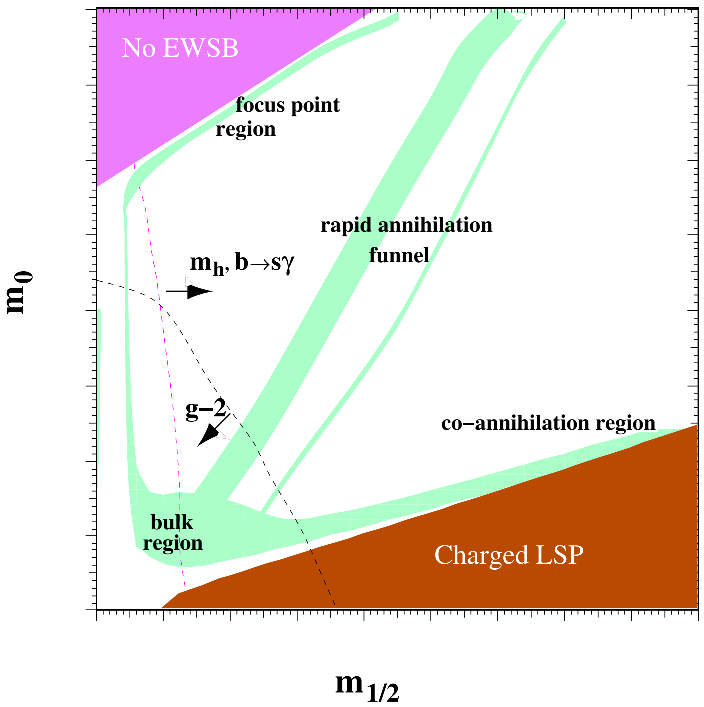
Backup

ATLAS Benchmarks

Large annihilation sross-section required by WMAP data

Boost annihilation via quasi-degeneracy of a sparticle with $\tilde{\chi}_1^0$, or large higgsino content of $\tilde{\chi}_1^0$

Regions in mSUGRA $(m_{1/2}, m_0)$ plane with acceptable $\tilde{\chi}_1^0$ relic density (e.g. Ellis et al.):



- SU3: Bulk region. Annihilation dominated by slepton exchange, easy LHC signatures fom $\tilde{\chi}_2^0 \to \tilde{\ell}\ell$
- SU1: Coannihilation region. Small $m(\tilde{\chi}_1^0) - m(\tilde{\tau})$ (1-10 Gev). Dominant processes $\tilde{\chi}_1^0\tilde{\chi}_1^0 \to \tau\tau$, $\tilde{\chi}_1^0\tilde{\tau} \to \tau\gamma$ Similar to bulk, but softer leptons!
- SU6: Funnel region. $m(\tilde{\chi}_1^0) \simeq m(H/A)/2$ at high $\tan\beta$ Annihilation through resonant heavy Higgs exchange. Heavy higgs at the LHC observable up to ∼800 GeV
- SU2: Focus Point high m_0, large higgsino content, annihilation through coupling to W/Z Sfermions outside LHC reach, study gluino decays.
- SU4: Light point. Not inspired by cosmology. Mass scale ~ 400 GeV, at limit of Tevatron reach

Parameters and cross-sections of benchmark Points

SU1: $m_0 = 70\,\text{GeV},\ m_{1/2} = 350\,\text{GeV},\ A_0 = 0,\ \tan\beta = 10,\ \mu > 0.$

SU2: $m_0 = 3550\,\text{GeV},\ m_{1/2} = 300\,\text{GeV},\ A_0 = 0,\ \tan\beta = 10,\ \mu > 0.$

SU3: $m_0 = 100\,\text{GeV},\ m_{1/2} = 300\,\text{GeV},\ A_0 = -300\,\text{GeV},\ \tan\beta = 6,\ \mu > 0.$

SU4: $m_0 = 200\,\text{GeV},\ m_{1/2} = 160\,\text{GeV},\ A_0 = -400\,\text{GeV},\ \tan\beta = 10,\ \mu > 0.$

SU6: $m_0 = 320\,\text{GeV},\ m_{1/2} = 375\,\text{GeV},\ A_0 = 0,\ \tan\beta = 50,\ \mu > 0.$

Signal	σ^{LO} (pb)	σ^{NLO} (pb)	N
SU1	8.15	10.86	200 K
SU2	5.17	7.18	50 K
SU3	20.85	27.68	500 K
SU4	294.46	402.19	200 K
SU6	4.47	6.07	30 K

Particle	SU1	SU2	SU3	SU4	SU6
$\tilde{u}_L$	760.42	3563.24	631.51	412.25	866.84
$\tilde{b}_1$	697.90	2924.80	575.23	358.49	716.83
$\tilde{t}_1$	572.96	2131.11	424.12	206.04	641.61
$\tilde{u}_R$	735.41	3574.18	611.81	404.92	842.16
$\tilde{b}_2$	722.87	3500.55	610.73	399.18	779.42
$\tilde{t}_2$	749.46	2935.36	650.50	445.00	797.99
$\tilde{e}_L$	255.13	3547.50	230.45	231.94	411.89
$\tilde{\nu}_e$	238.31	3546.32	216.96	217.92	401.89
$\tilde{\tau}_1$	146.50	3519.62	149.99	200.50	181.31
$\tilde{\nu}_\tau$	237.56	3532.27	216.29	215.53	358.26
$\tilde{e}_R$	154.06	3547.46	155.45	212.88	351.10
$\tilde{\tau}_2$	256.98	3533.69	232.17	236.04	392.58
$\tilde{g}$	832.33	856.59	717.46	413.37	894.70
$\tilde{\chi}_1^0$	136.98	103.35	117.91	59.84	149.57
$\tilde{\chi}_2^0$	263.64	160.37	218.60	113.48	287.97
$\tilde{\chi}_3^0$	466.44	179.76	463.99	308.94	477.23
$\tilde{\chi}_4^0$	483.30	294.90	480.59	327.76	492.23
$\tilde{\chi}_1^+$	262.06	149.42	218.33	113.22	288.29
$\tilde{\chi}_2^+$	483.62	286.81	480.16	326.59	492.42