Dark Matter and the LHC

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Dark Matter

Existence of Dark Matter in the universe by now well established

Studies of clusters of galaxies suggest $\Omega_{DM} \simeq 0.2$ to 0.3 where $\Omega_X = \rho_X/\rho_{crit}$

From anisotropies in Cosmic Microwave Background (WMAP): $\Omega_{DM} = 0.23 \pm 0.04$

From nucleosynthesis, only 4% of total matter density baryonic

From analyses of structure formation in the universe: most DM must be "cold", non-relativistic at onset of galaxy formation.

DM candidates must be stable on cosmological time scales, interact very weakly with EM radiation, and give the right relic density. Main particle candidates:

- Axions
- Weakly Interacting Massive Particles (WIMP)

  Mass: 10 GeV – few TeV, and cross section of $\sim$ weak strength

R-parity conserving SUSY provides candidate WIMP: Lightest SUSY Particle (LSP)

Concentrate on LHC contribution to understanding of SUSY LSP Dark Matter

Experimental approaches to Dark Matter

Information form large variety of experiments. Expect stringent tests in the next decade

- WIMP searches
  1. Direct WIMP searches: look for elastic scattering of WIMP on nuclei
  2. Indirect WIMP searches: look for annihilation products of WIMPS in galactic halo
- Cosmological measurements
- Production of WIMPS in accelerator experiments

Concentrate here on LHC experiments, and focus on SUSY neutralino Dark Matter

Explore what kind of information the LHC can produce on Dark Matter candidates

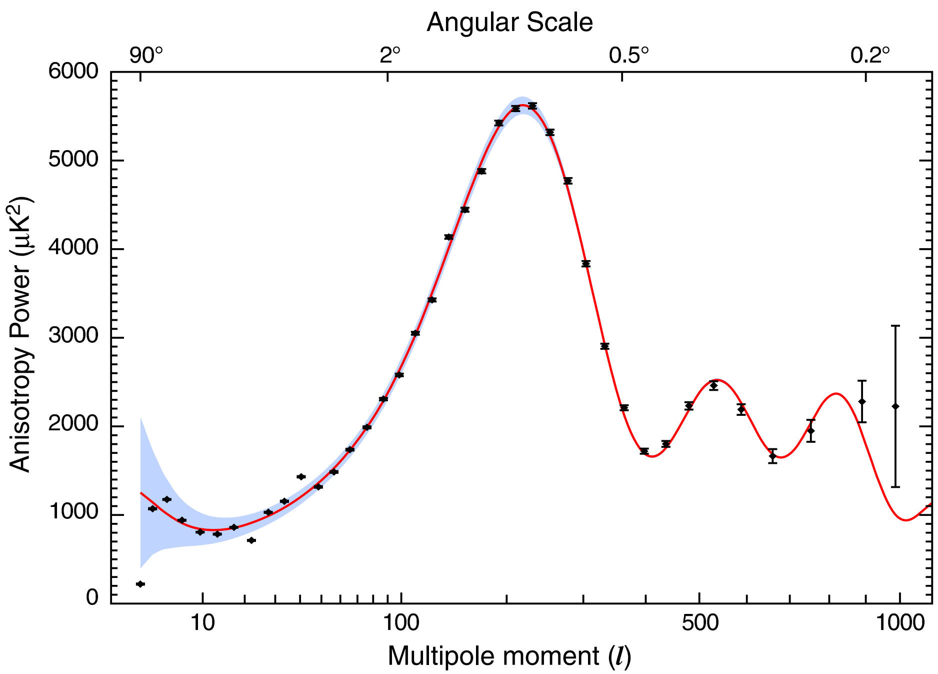
Study how to combine LHC information with direct searches and cosmology measurements

Cosmological measurements of DM relic density

Anisotropies in Cosmic Microwave Background carry information about the conditions at the time of decoupling

- Accurate measurement of the spectrum of CMB fluctuations from WMAP
- Galaxy power spectrum measured by the 2-degree Field (2dF) Galaxy Redshift Survey

Measurements can be fitted to a standard cosmological model (ΛCDM) defined in terms of few fundamental parameters (RPP 2006). Relevant ones for this talk:



WMAP3 alone

Hubble parameter $h = 0.73^{+0.03}_{-0.04}$

Total matter density $\Omega_M h^2 = 0.127^{+0.007}_{-0.009}$

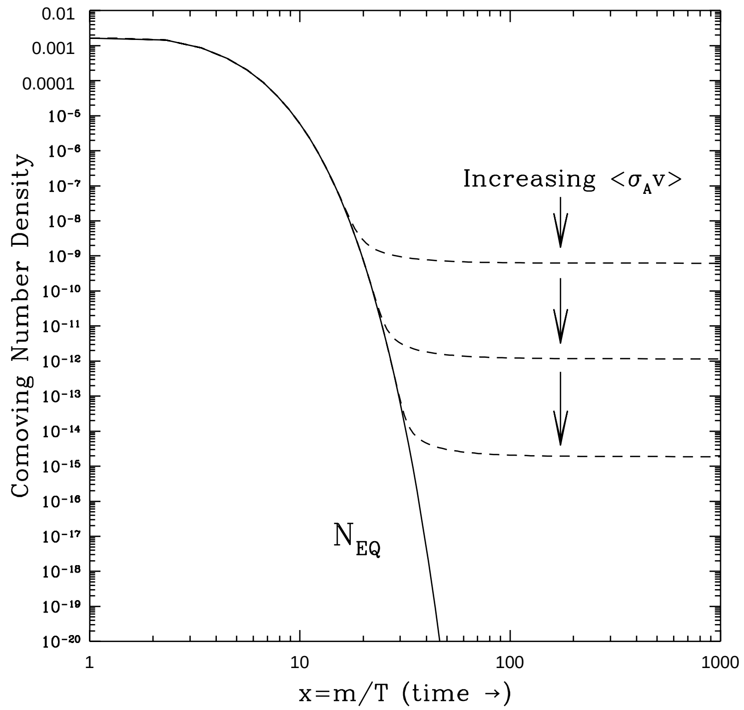
Baryon density $\Omega_b h^2 = 0.0223^{+0.0007}_{-0.0009}$

Relic Density and LSP annihilation Cross-Section

At first, when $T \gg m_\chi$ all particles in thermal equilibrium

Universe cools down and expands:

- When $T < m_\chi$ is reached only annihilation: density becomes exponentially suppressed
- As expansion goes on, particles can not find each other: freeze out and leave a relic density



Master equation is:

$$\frac{dn}{dt} = -3Hn - < \sigma_A v > (n^2 - n_{eq}^2) \quad (1)$$

The relic density is:

$$\Omega_{\tilde{\chi}_1^0} = m_{\tilde{\chi}_1^0} n_{\tilde{\chi}_1^0} / \rho_{cri}, \quad \rho_{cri} = h^2 \times 1.91 \times 10^{-29} \mathrm{gcm}^{-3} \quad (2)$$

From solving Boltzmann equation:

$$\Omega_{\tilde{\chi}_1^0} \propto 1/ < \sigma_A v > \quad (3)$$

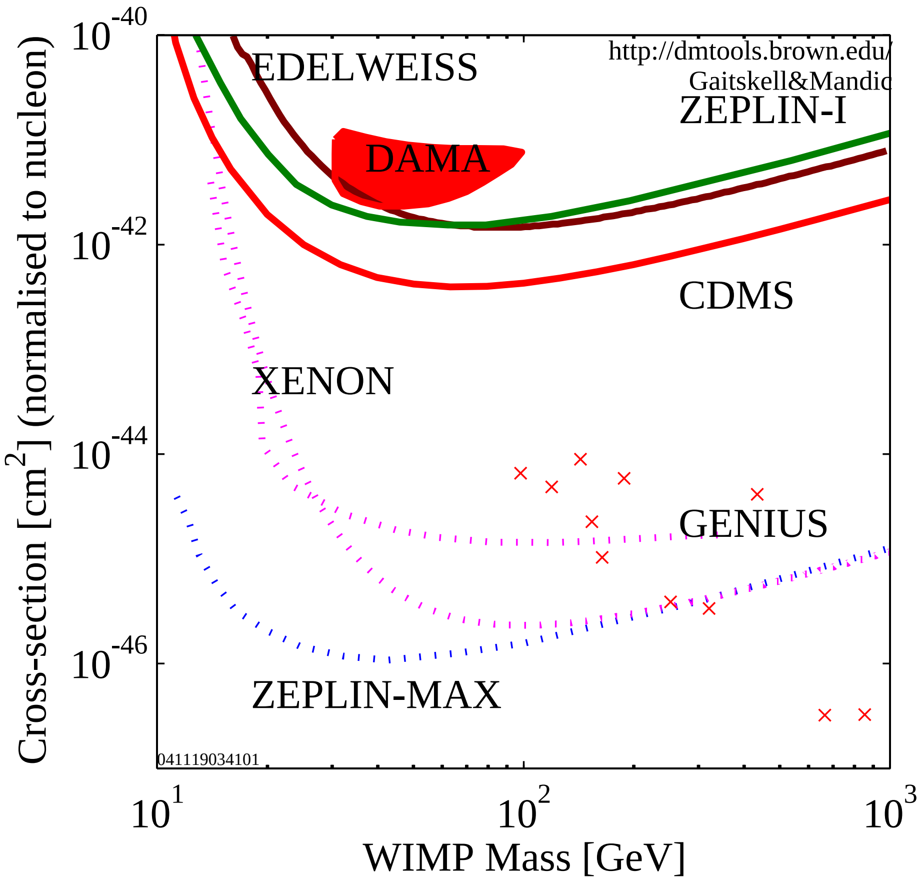
From LHC measurements can evaluate LSP annihilation X-section and thence predict relic density and verify agreement with cosmological measurements

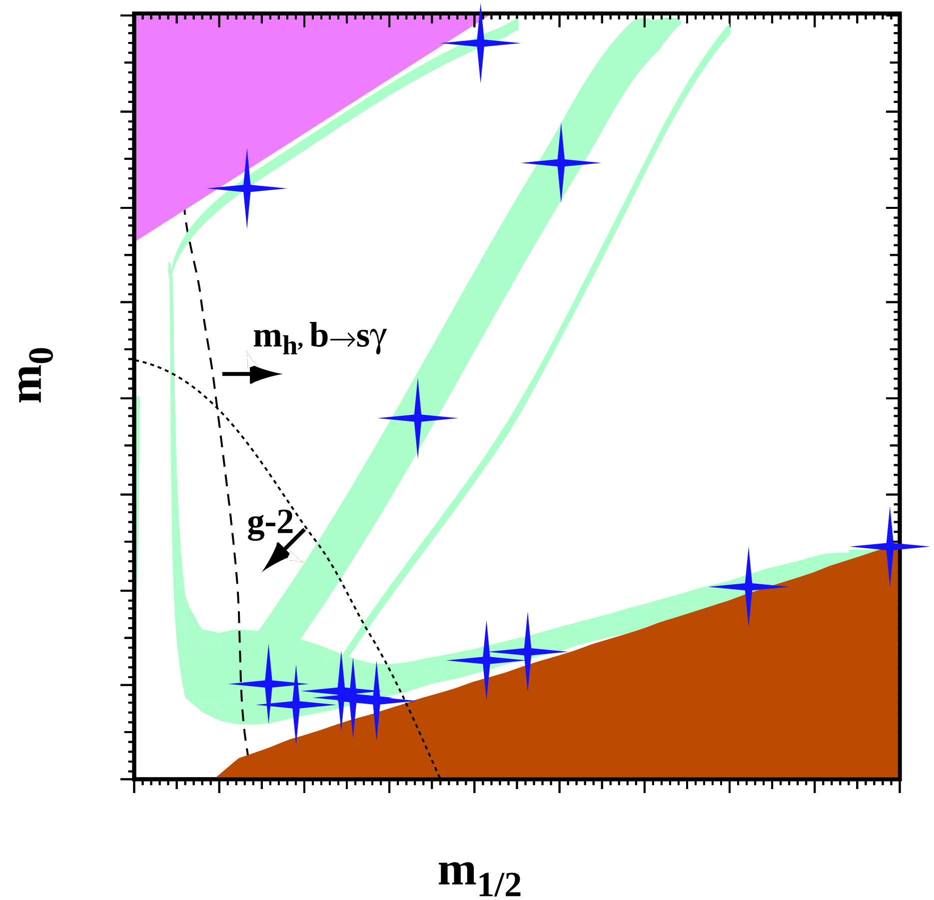
Direct DM Searches

Within next 10 year next generation of tonne scale direct detection experiments should have acquired several years of data

Will give sensitivity to scalar WIMP-nucleon cross section $\sim 10^{-10}$ pb

Region of interest for LHC SUSY studies covered



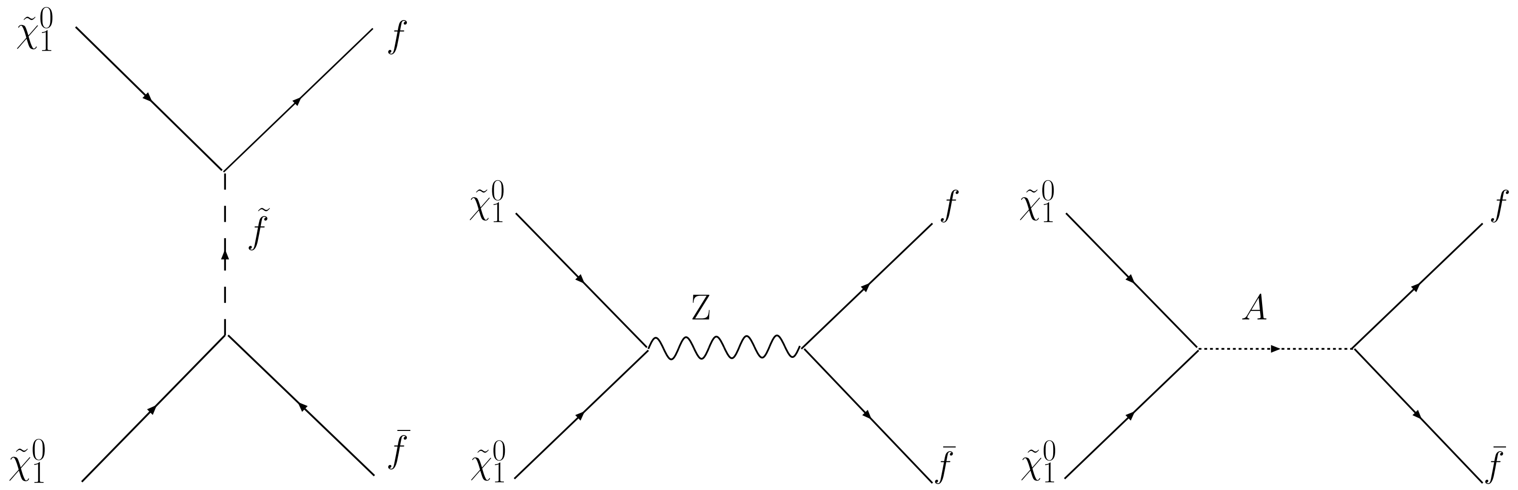


Neutralino relic density prediction from SUSY parameter measurement

Want to calculate σ_A, cross section for neutrino annihilation $\tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow X$.

Many different processes. Main contributions:

$\tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow ff$

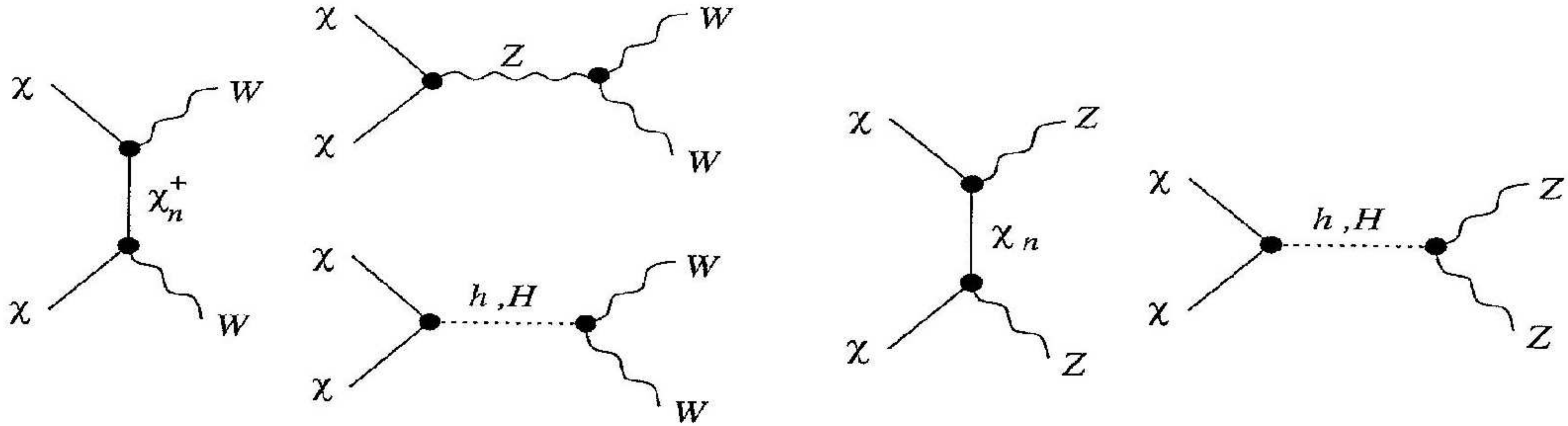


If one sfermion light and $\tilde{\chi}_1^0$ is mostly gaugino t-channel exchange dominates annihilation cross-section

If ones sfermion almost degenerate with $\tilde{\chi}_1^0$, also significant contribution for co-annihilation

$\tilde{\chi}_1^0\tilde{f} \rightarrow A(Z)f$

$\tilde{\chi}_1^0 \tilde{\chi}_1^0 \rightarrow WW(ZZ)$



Z s-channel exchange: dominant for $\tilde{\chi}_1^0$ with large higgsino component

Calculation of σ_A and convolution with velocity distribution of relic neutralinos to calculate available in public programs:

- DarkSUSY
- micrOMEGAs
- ISASUGRA

As input to calculation programs all the masses and couplings of sparticles contributing to neutralino annihilation needed

Question is whether the measurements which LHC can perform for a given MSSM point allow to fully perform this calculation

Answer possible only by going to a specific model point and performing full analysis of available constraints

Studies restricted to model points for which detailed experimental study available in leiterature

Use guidance from well-constrained model (mSUGRA) to identify phenomenologies compatible with WMAP Dark matter density

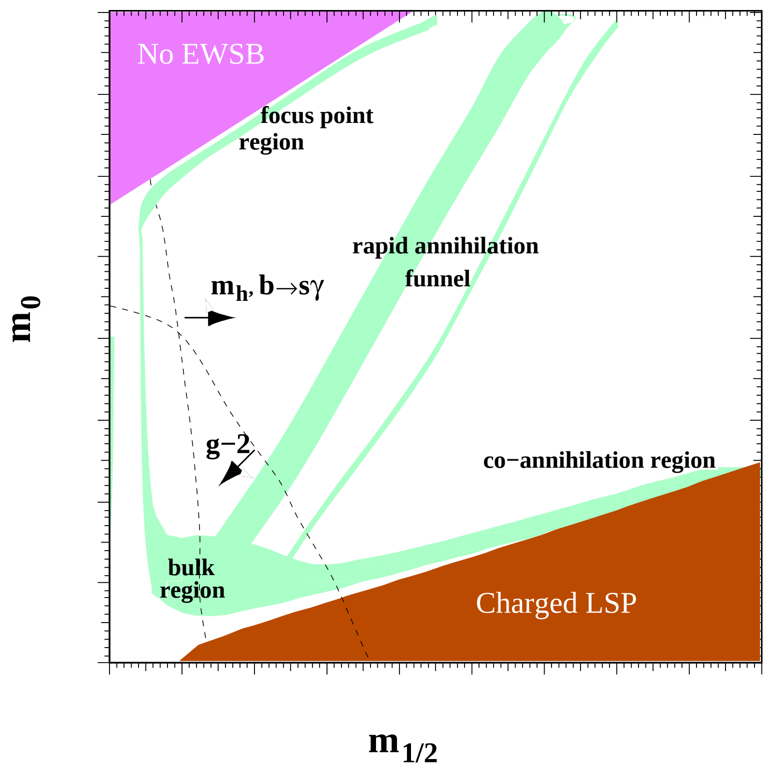
Nota Bene: mSUGRA is only used as convenient framework for selecting model points. Studies on these points are performed in MSSM.

Guidance fom mSUGRA

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.):



- Bulk region: annihilation dominated by slepton exchange, easy LHC signatures fom $\tilde{\chi}_2^0 \to \tilde{\ell}\ell$
- 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!
- 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
- Focus Point: high m_0, large higgsino content ⇒ enhanced annihilation through coupling to W/Z Sfermions outside LHC reach, study gluino decays.

SUSY Dark Matter Strategy

SUSY studies at the LHC will proceed in 4 steps:

- SUSY discovery phase (inclusive searches). Success assumed.
- Inclusive studies (comparison of significance in inclusive channels etc.)

  Relevance to DM: verify if discovered signal provides a possible DM candidate
- Exclusive studies (calculation of model-independent SUSY masses using kinematics)

  Relevance to DM: Model-independent calculation of LSP mass, compare with direct searches
- Interpretation of results in terms of SUSY breaking
  - Fit measured quantities to constrained model (e.g. mSUGRA)

    Relevance to DM: model-dependent calculation of relic density, $\sigma(\chi p)$, etc.
  - Perform additional more complex measurements, such as BR's and rare decays, and reconstruct MSSM parameters

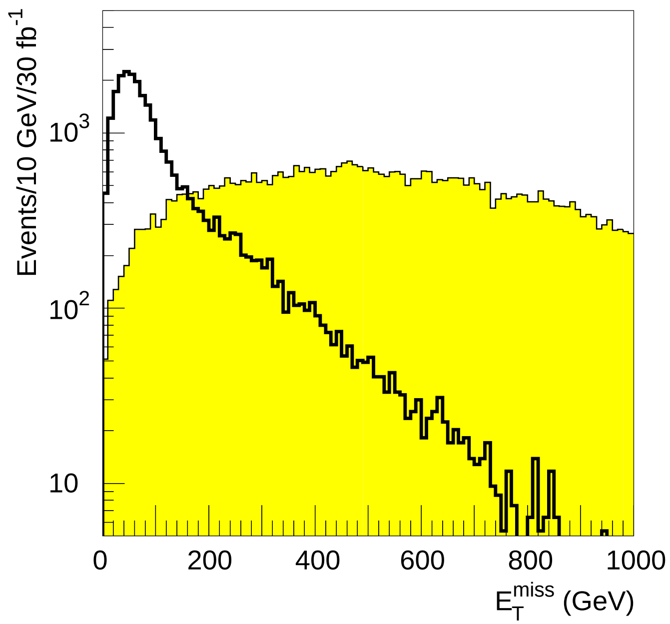
    Relevance to DM: model-independent calculation of relic density $\sigma(\chi p)$, etc.

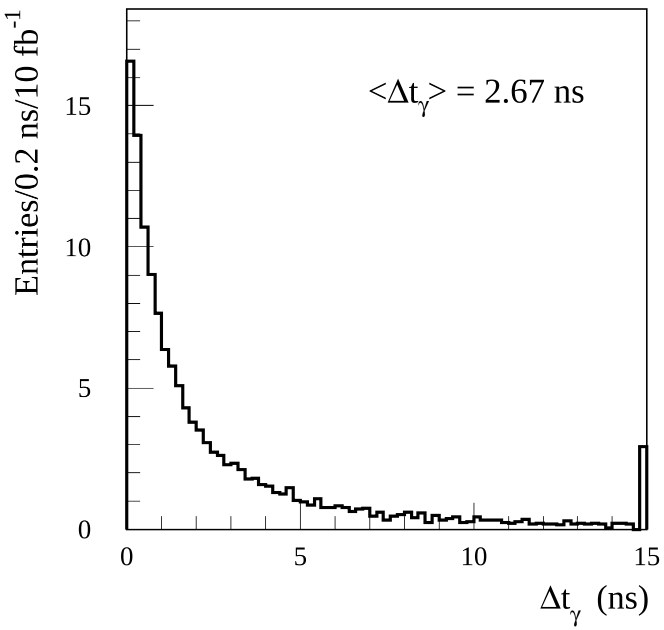
Inclusive Studies

Following any discovery of SUSY next task will be to test broad features of potential Dark Matter candidate

Question 1: Is R-parity conserved?

- If YES possible DM candidate
- Loophole: LHC experiments sensitive only to lifetimes $\lesssim 1$ ms ($\ll t_U \sim 13.7$ Gyr) $\Rightarrow$ need confirmation from direct DM detection





Question 2: Is the LSP the lightest neutralino?

- Natural in many MSSM models
- If YES then test for consistency with astrophysics
- If NO, then what is it?
- e.g. Light gravitino DM from GMSB models (not considered here)

Measurement of model parameters

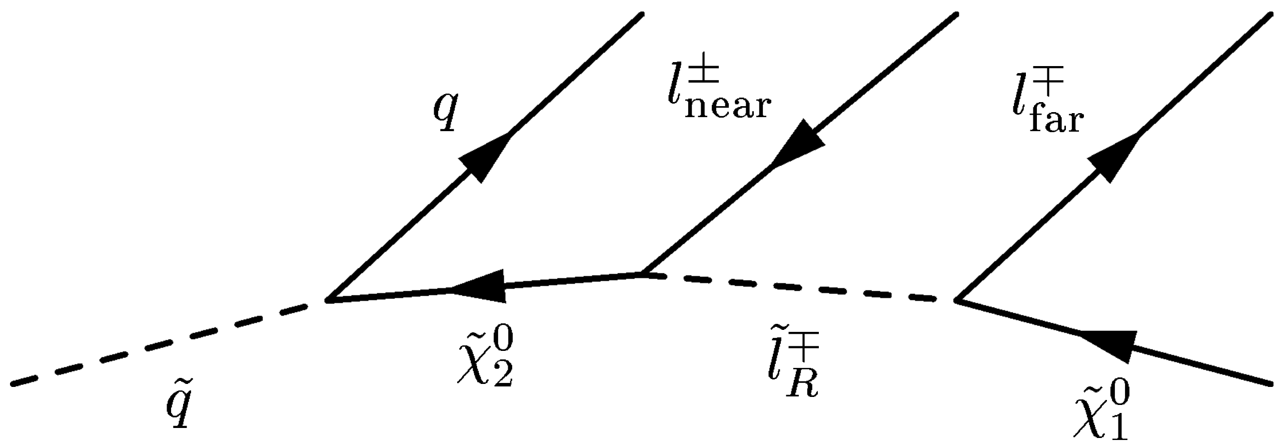
Identify exclusive decay chains including leptons or b-jets

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.

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



Edges and thresholds in invariant mass distributions among visible products functions of sparticle masses (see e.g. Allanach et al.)

Example: study of Snowmass SPS1a Point

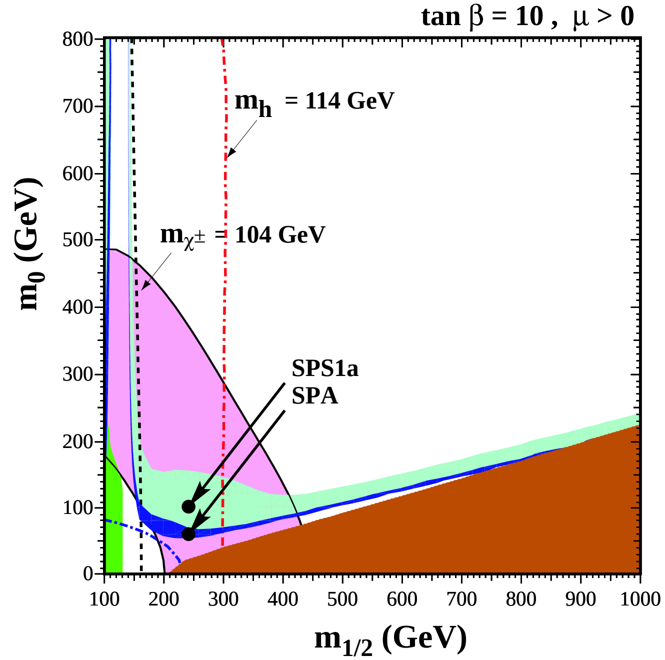
Snowmass Point 1

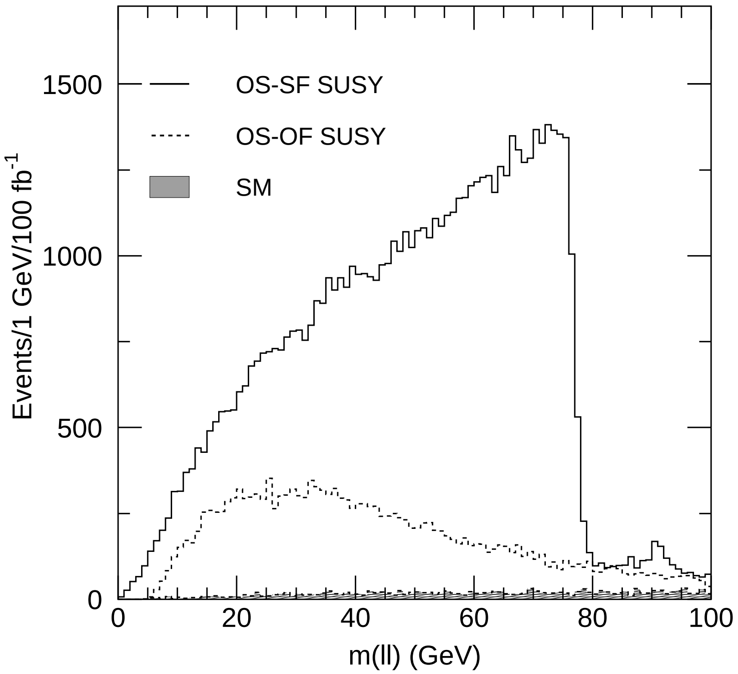
$m_0 = 100$ GeV, $m_{1/2} = 250$ GeV $A = -100$ GeV, $\tan\beta = 10$, $\mu > 0$

Total cross-section: $\sim$50 pb, BR($\tilde{\chi}_2^0 \to \tilde{\ell}_R \ell$)=12.6%

SPA: similar point, compatible with WMAP:

$m_0 = 70$ GeV, $m_{1/2} = 250$ GeV $A = -300$ GeV, $\tan\beta = 10$, $\mu > 0$





Lepton-lepton edge

Select events with high jet multiplicity and $\not{E}_T$

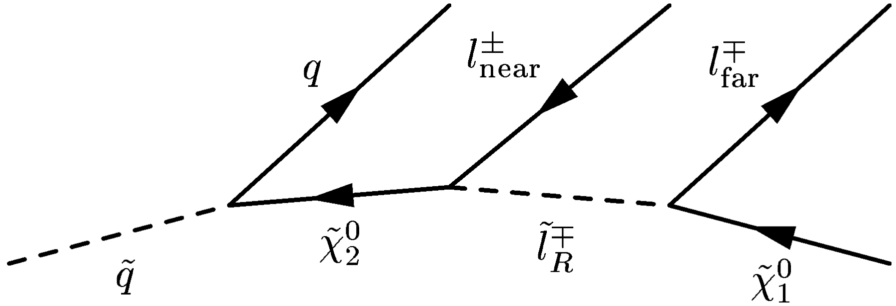
Require two opposite-sign same-flavour e, μ (OSSF)

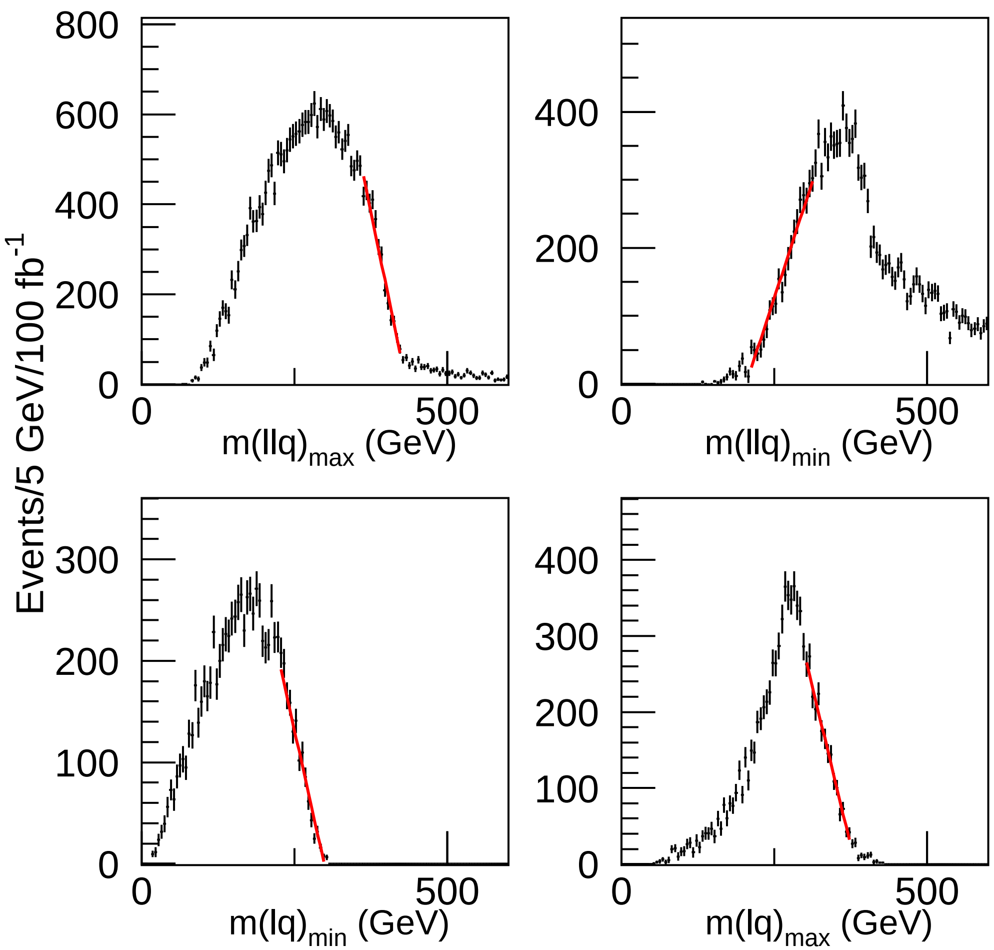
SUSY background: uncorrelated $\tilde{\chi}_1^\pm$ decays

Subtract SUSY and SM background via flavour correlation: $e^+e^- + \mu^+\mu^- - e^\pm\mu^\mp$

Fit to sharp edge + Gaussian smearing

Lepton-lepton-jet edges





Distributions fall ~linearly to end point.

Shapes modified by resolutions and backgrounds, recently progress in using full shape

Statistical uncertainty from linear fit at the %

Enough constraints to solve for masses of four involved sparticles

Strong correlation among calculated sparticle masses, as edges measure mass differences

Obtain measurement of $m(\tilde{\chi}^0_1)$ to a few GeV, and of $m(\tilde{\chi}^0_2) - m(\tilde{\chi}^0_1)$ and $m(\tilde{\ell}_R) - m(\tilde{\chi}^0_1)$ to a few hudred MeV.

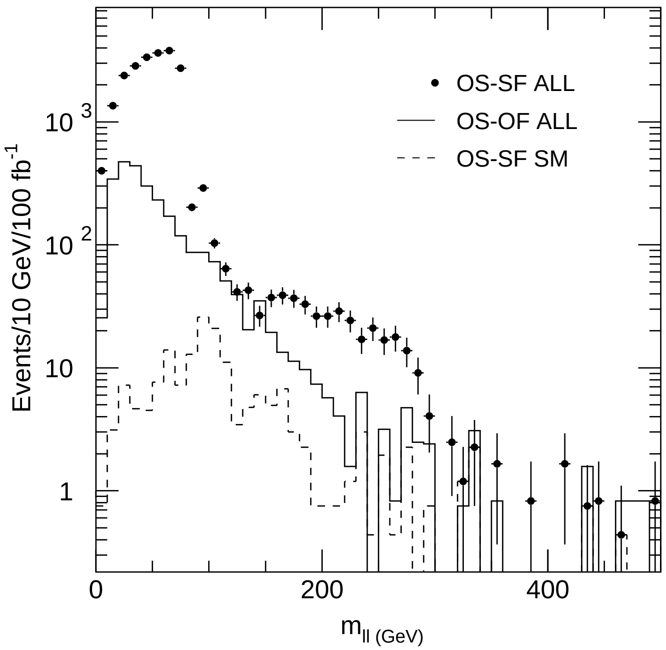
Measurement of $\tilde\chi^0_4$ mass

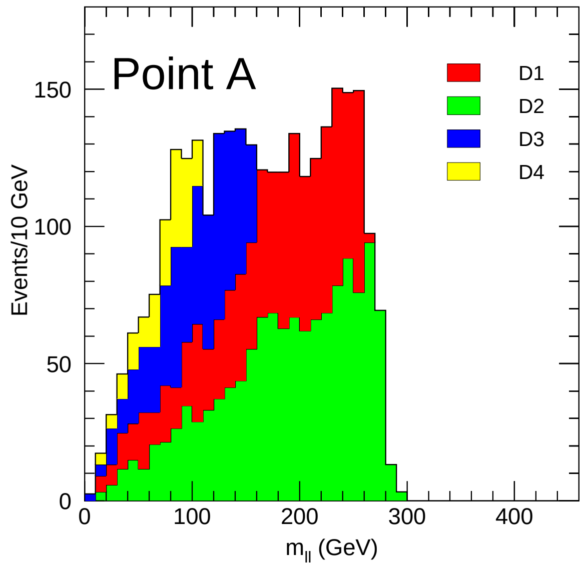
OS-SF dilepton invariant mass for:

$$\tilde q_L \to \tilde\chi^0_4 \; q, \quad \tilde\chi^0_4 \to \tilde\ell^\pm_R \; \ell^\mp, \quad \tilde\ell^\pm_R \to \tilde\chi^0_1 \; \ell^\pm \qquad [D1]$$

$$\tilde q_L \to \tilde\chi^0_4 \; q, \quad \tilde\chi^0_4 \to \tilde\ell^\pm_L \; \ell^\mp, \quad \tilde\ell^\pm_L \to \tilde\chi^0_1 \; \ell^\pm \qquad [D2]$$

$$\tilde\ell^\pm_L \to \tilde\chi^0_2 \; \ell^\pm \qquad [D3]$$





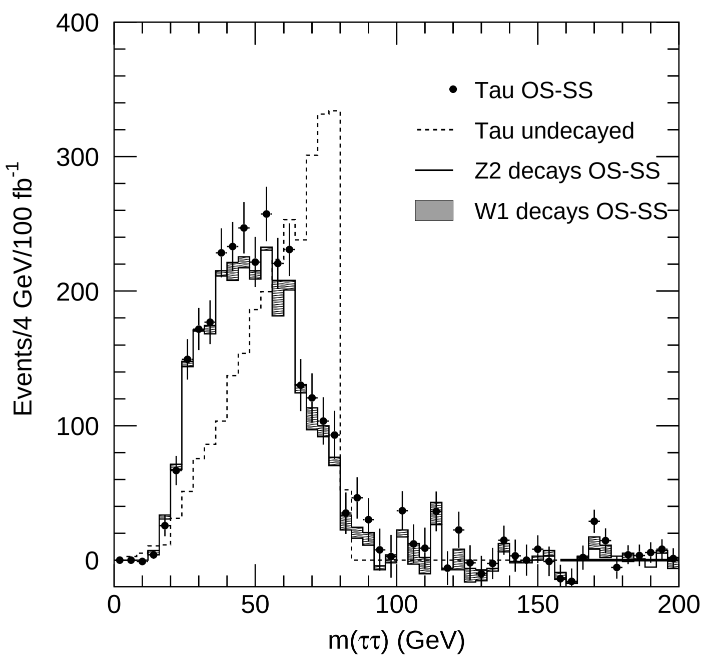
Measurement of edge position function of $m(\tilde\chi^0_4)$, $m(\tilde\ell_L)$, $m(\tilde\chi^0_1)$

If $m(\tilde\ell_L)$ measured in direct production, measure $m(\tilde\chi^0_4)$ with $\sim$4 GeV precision for 100 fb^{-1}

Measurement of $\tilde{\chi}_2^0 \to \tilde{\tau}_1 \tau$

Exploit excellent ATLAS tagging capability for τ jets

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



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

: Two measurements sensitive to $\tilde{\tau}$ mixing possible:

- Position of $\tau\tau$ end point: sensitive to $\tilde{\tau}_1$ mass

Detailed study on achievable precision in progress.

Assume here variation between 0.5 and 5 GeV

- Number of events in edge can be used to measure:

$BR(\tilde{\chi}_2^0 \to \tilde{\ell}_R \ell)/BR(\tilde{\chi}_2^0 \to \tilde{\tau}_1 \tau)$

No detailed experimental study available: assume 10% systematic uncertainty

These are the basic inputs to the relic density calculation.

Additional mass measurements of $\tilde{q}_L$, $\tilde{b}_1$, $\tilde{b}_2$ $t\tilde{o}p_1$ mainly check that squark exchange not relevant

Shown only measurements most relevant for DM, a few other measurements possible, building on knowledge ofmasses of $\tilde{q}_L$, $\tilde{\ell}_R$, $\tilde{\chi}_2^0$, $\tilde{\chi}_1^0$ masses.

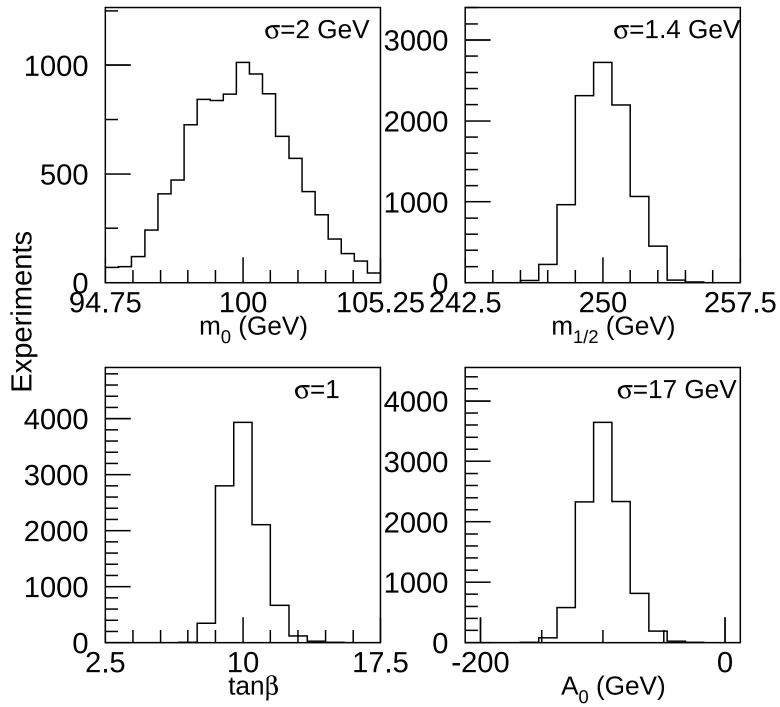
Wrap up: available measurements for SPS1a (300 fb^{-1}):

		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

Using the measurements: model-dependent approach

Postulate SUSY breaking model, and verify if any set of the model parameters fits measured quantities.

⇒ Measure precision with which mSUGRA models can be fixed



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

Additional errors would come from detailed implementation of RGEs (Allanach, Kraml, Porod)

Exercise relies on interpretation of kinematic signatures as SUSY decay chains

Spin information needed to confirm SUSY interpretation (discussion in working group)

Academic exercise: nobody tell us it is indeed mSUGRA, however interesting to verify our model discrimination power

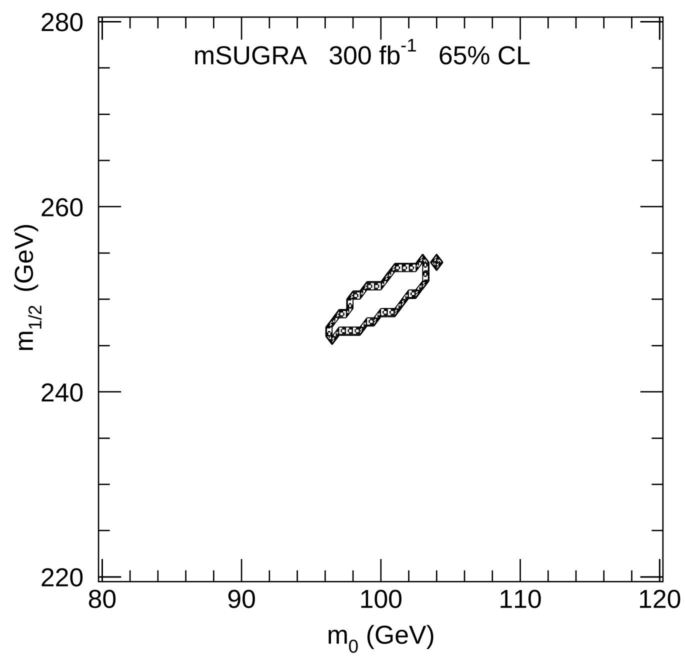
Model Dependent (mSUGRA) Relic density prediction

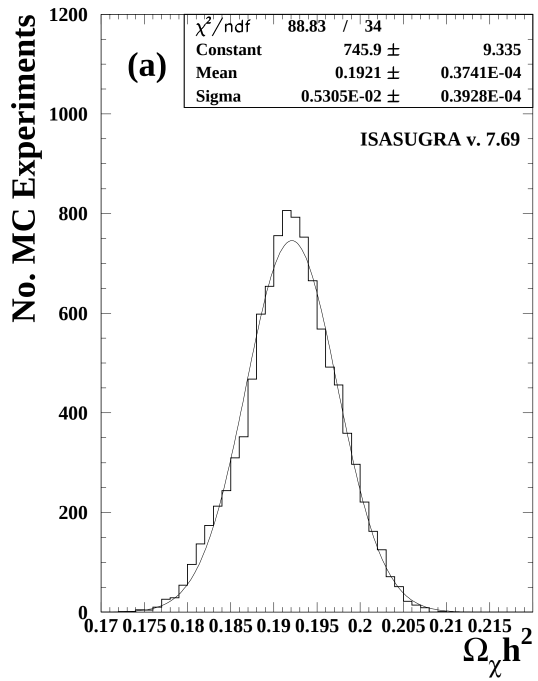
Find point in $(m_0,\, m_{1/2},\, \tan\beta,\, A_0)$ space with best fit to measured quantities

Calculate confidence region in parameter space with n MonteCarlo experiments

From RGE equations calculate all of the weak scale parameters and thence the $\tilde{\chi}_1^0$ annihilation cross-section

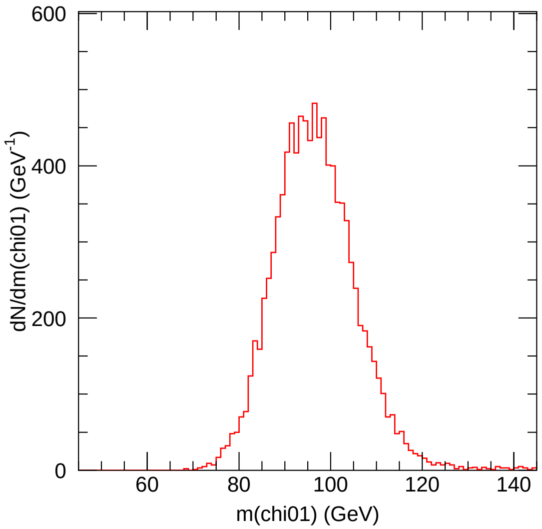
$\Rightarrow$ Translate into confidence interval for Dark matter density (G.P., D.Tovey)





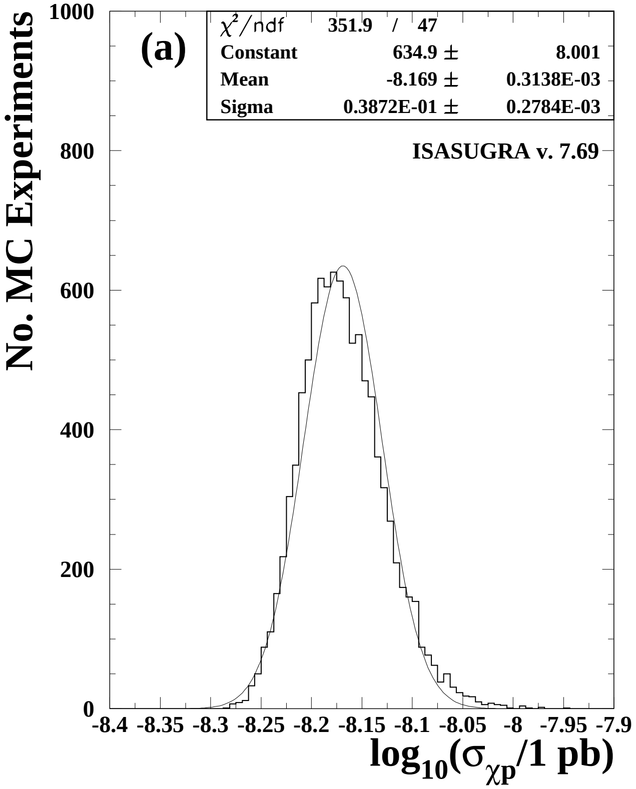
Result: $\Omega_{\tilde{\chi}_1^0} h^2 = 0.192 \pm 0.005$

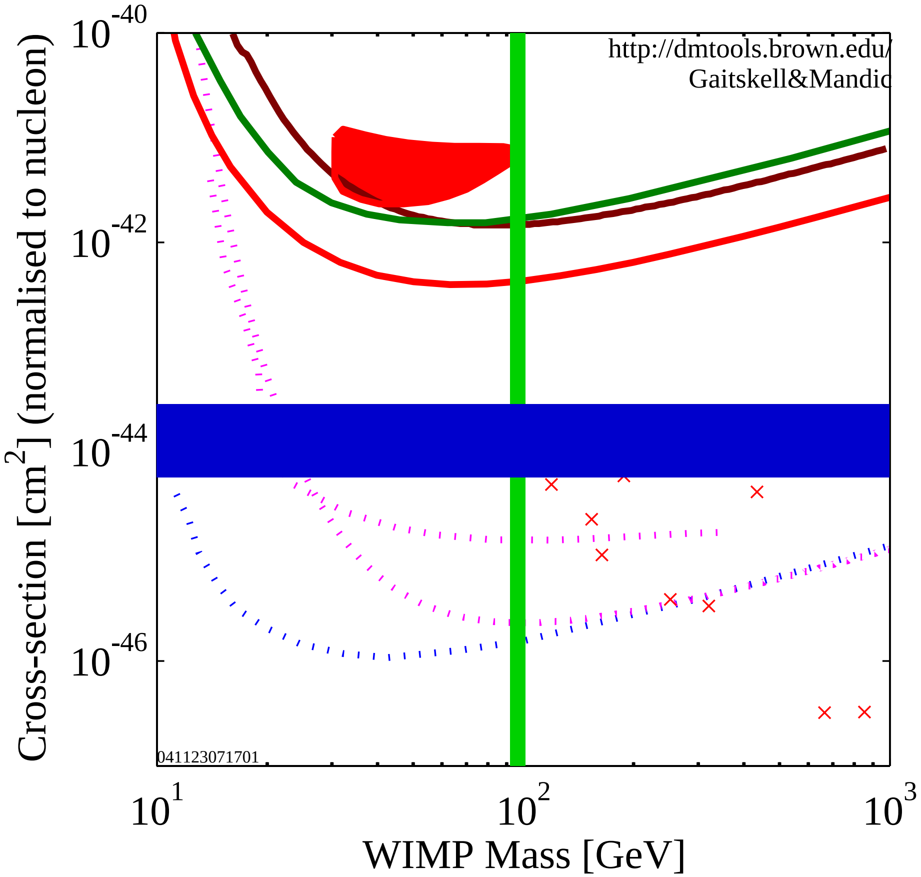
Connection to direct DM detection experiments



$$m_{\tilde{\chi}_1^0} = 96.05 \pm 4.7 \text{ GeV (300 fb}^{-}1)$$

$$log_{10}(\sigma_{\chi p}/1\text{pb}) = -8.17 \pm 0.39$$





From LHC measurements to relic density in MSSM

Two detailed studies addressing LHC in literature:

- Nojiri, G.P., Tovey: JHEP 0603:063,2006 (hep-ph/0512204)

  Only SPA point, based on detailed studies for SPS1a point performed in ATLAS

  Use micrOMEGAs program, only relic density

  Exclusively focused on LHC

  "Direct method":

  - Build MonteCarlo experiments defined by a set of "measurements" generated by picking a value from a gaussian distribution, according to central values and errors from detailed studies
  - For each experiment extract constraints on the MSSM model
  - Based on constraints calculate relic density for each experiment. Distribution over experiments of obtained DM properties interpreted as experimental spread

  Takes automatically into account all experimental correlations

  Requires careful "a posteriori" consideration of unconstrained parameters

- Baltz, Battaglia, Peskin, Wizansky: hep-ph/0602187

  Studies 4 model points: SPS1a, based on LHC and ILC studies, a focus point, a coannihilation, and a Higgs funnel model, based on ILC studies.

  Use DarkSUSY program, many different measurements studied

  Compares and combines LHC, ILC-500, ILC-1000

  "MSSM scan":

  Perform scan over the full 24 parameters of MSSM

  Calculate the probability distribution for the relevant observables as induced by the probability distributions of the 24 x parameters defining the model, as given in Bayesian statistics as a function of the measured quantities.

  Scan on 24-parameter space using a Markov chain technique

  Correctly takes into account the dependence on all 24 parameters of the model

  If insufficient constraints distribution may depend on assumed initial distribution and details of Markov chain algorithm

Steps for direct approach

- Identify annihilation processes likely to give a significant contribution

  Main ingredient: neutralino composition, if it is a Bino, Wino, Higgsino or a mix

  Reconstruct the neutralino matrix from available constraints

  If not enough constraints fix unconstrained parameters

- For relevant processes calculate couplings and masses of involved sparticles.

  In particular, if the annihilation $\tilde{\chi}_1^0\tilde{\chi}_1^0 \to \tilde{\tau}_1\tilde{\tau}_1$ and co-annihilation $\tau_1\tilde{\chi}_1^0 \to \tau Z(A)$ important, complete calculation of the mixing in the stau sector

- Check that there are no resonance which would enhance a specific channel

  Example $m(H/A) = 2m(\tilde{\chi}_1^0)$

- Calculate LSP relic density

- Vary parameters which were kept fixed because of weak constraints, and evaluate dependence of the result on them

Step 1: solving neutralino matrix

Use measured masses for $\tilde{\chi}^0_1$, $\tilde{\chi}^0_2$ and $\tilde{\chi}^0_4$

Input fixed value for $\tan\beta$, and get numerically the values of M_1, M_2, μ.

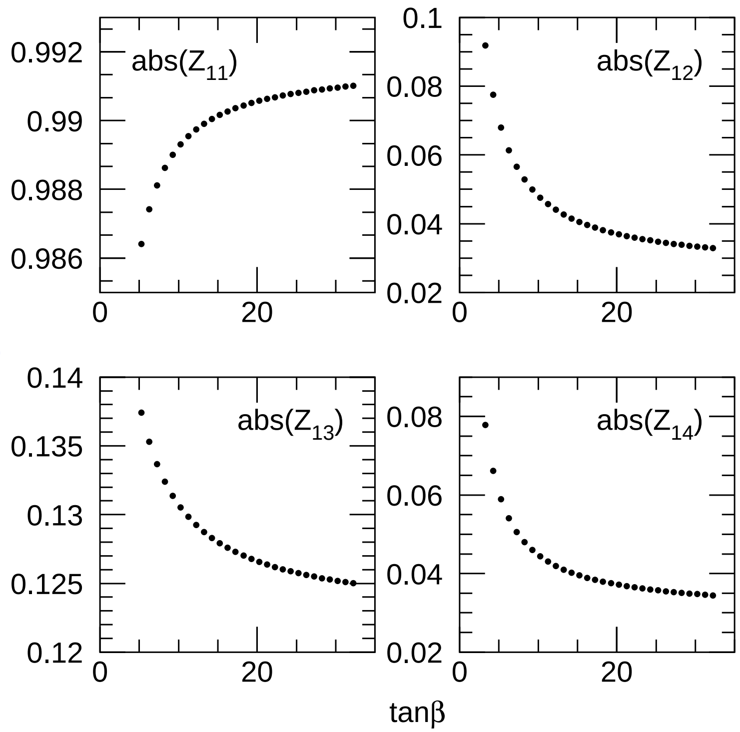
Annihilation X-section determined by components of the lightest neutralino:

$$\tilde{\chi}^0_1 = Z_{11}\tilde{B} + Z_{12}\tilde{W}^3 + Z_{13}\tilde{H}^0_1 + Z_{14}\tilde{H}^0_2$$

Experimental spread is 0.03% for bino component and 1-2% for other components

Study the dependence of the values of the neutralino components from the assumed value of $\tan\beta$

Little dependence for the bino component, larger variation for subdominant component



Step 2: stau sector

$\tilde{\tau}_1$ and $\tilde{\tau}_2$ produced from the mixing of $\tilde{\tau}_L$ and $\tilde{\tau}_R$ through a mixing angle θ_τ

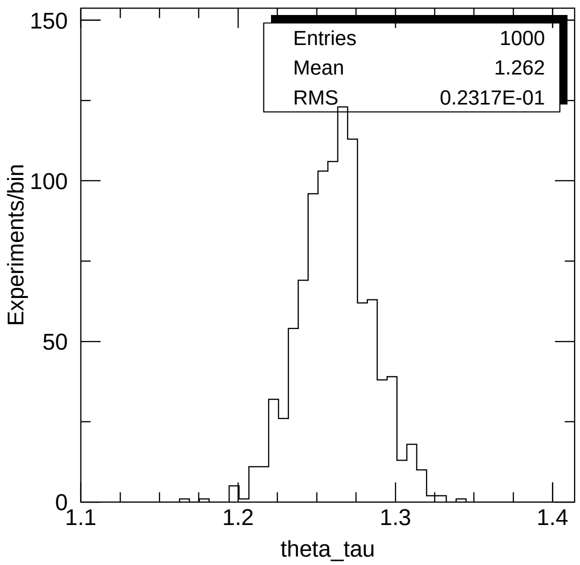
Assume no mixing in the sleptons sector for the first two generations

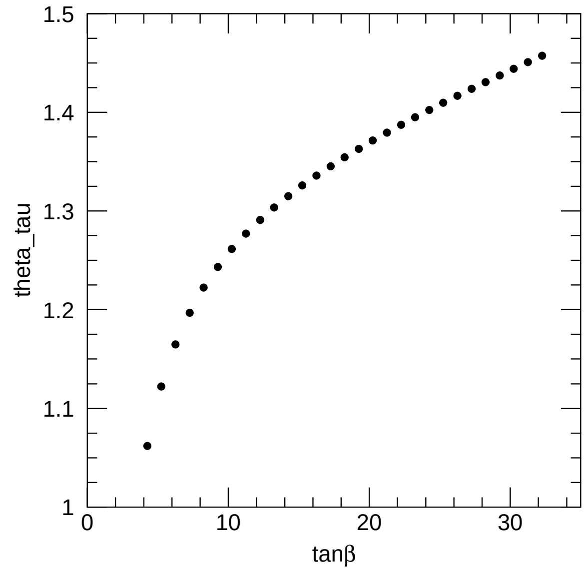
From the knowledge of the neutralino mixing matrix, $m(\tilde{\tau}_1)$, and $BR(\tilde{\chi}_2^0 \to \tilde{\ell}_R \ell)/BR(\tilde{\chi}_2^0 \to \tilde{\tau}_1 \tau)$ can extract the value of θ_τ

Show distribution of calculated θ_τ for the MonteCarlo experiments

Uncertainty from experimental error is $\sim 2\%$

Large uncertainty (25-30%) from $\tan\beta$ spread





$\tilde{\tau}$ sector not fully solved, need one more parameter, $m(\tilde{\tau}_2)$ or $m(\tilde{\tau}_R)$

$m(\tilde{\tau}_2) > m(\tilde{\chi}_2^0)$, otherwise it would be seen in $\tilde{\chi}_2^0$ decay

For $\tan\beta = 10$, if require $|A_\tau| < 5$ TeV, $m(\tilde{\tau}_2) < 250$ GeV

Constraints from higgs sector

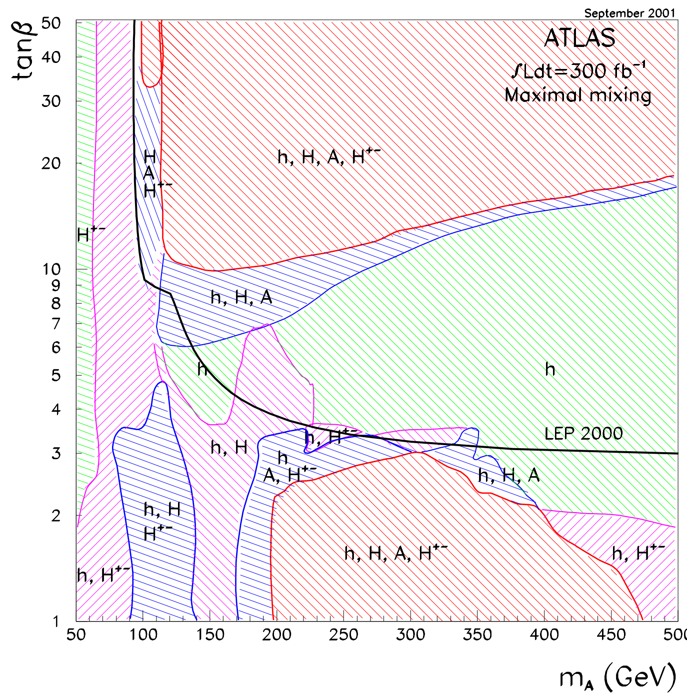
h can be discovered over the whole parameter space

For high $\tan\beta$ little info on $\tan\beta$ from $m(h)$

Can assume approx $\tan\beta > 5$, $m(A) > 200$ GeV.

Need detailed study of stop sector for better limits

Heavy higgses can not be discovered at the LHC in their SM decay modes for the selected model: m(A)∼425 GeV, $\tan\beta = 10 \Rightarrow$ try with SUSY sector



- Detection of $A/H \to$bb in chargino/neutralino decays

Kinematically closed: can probably put a limit $m(A/H) < m(\tilde{\chi}^0_4) - m(\tilde{\chi}^0_1) \sim 300$ GeV from non-observation of $H/A \to bb$ peak in cascade decays. Detailed analysis needed

- Detection of $A/H \to \tilde{\chi}^0_2\tilde{\chi}^0_2 \to 4\ell\ell$

Very small rate: ~ 40 events/experiment for 300 fb^{-1}. Need detailed background study to verify observability.

Calculation of relic matter density

Use the soft parameters as extracted from the mass and BR measurements.

The stop can be observed in this point in the gluino decay, and $m(\tilde{t}_1) > m(\tilde{\chi}_1^{\pm}) \rightarrow$ no impact of light stop on relic density prediction

$\tan\beta$, $m(A)$, $m(\tilde{\tau}_2)$ affect the relic density measurement and are badly constrained

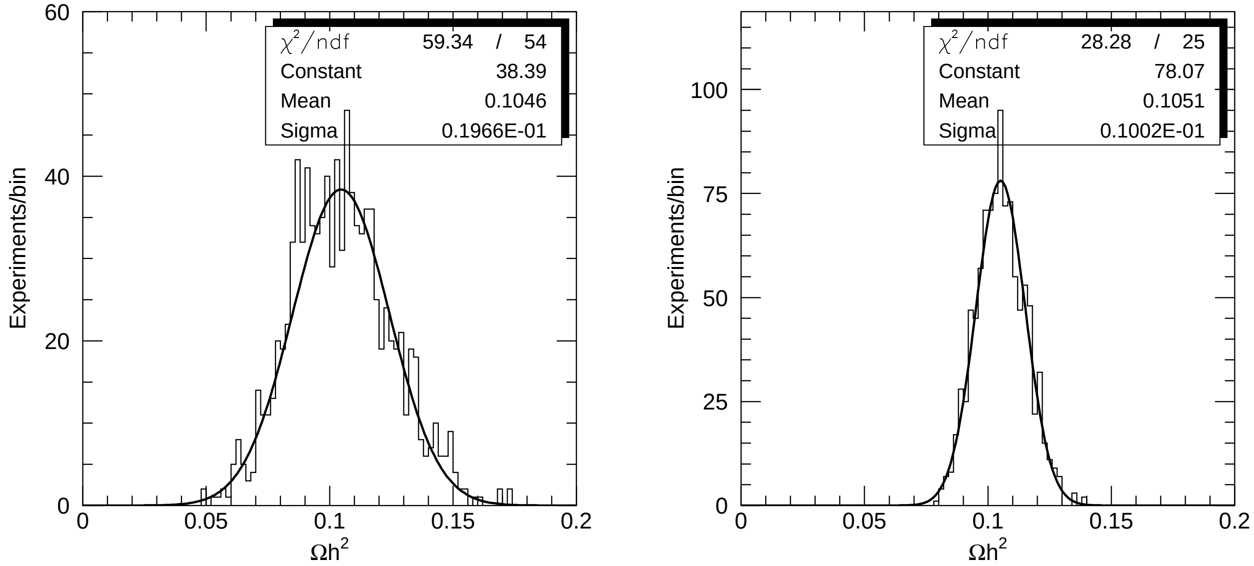
Fix them at nominal value, calculate relic density for each MonteCarlo experiment with Micromegas 1.36

Uncertainty dominated by error on on $\tau\tau$ edge position

Show distribution of calculated $\Omega_\chi h^2$ for:

$\Delta(m_{\tau\tau}) = 5$ GeV (left)

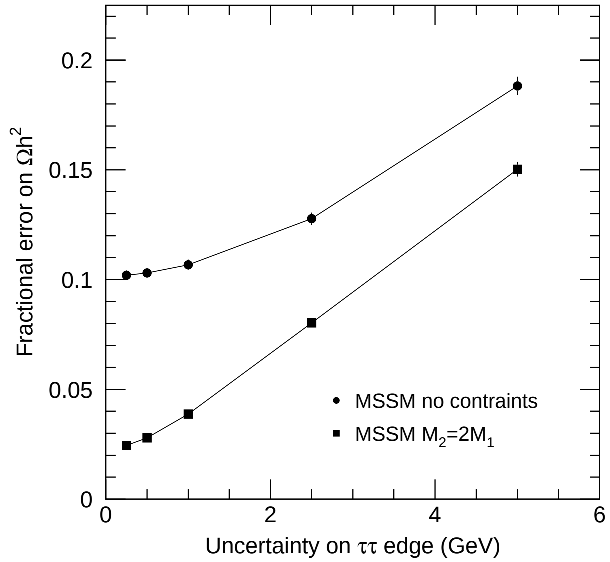
$\Delta(m_{\tau\tau}) = 0.5$ GeV (right)

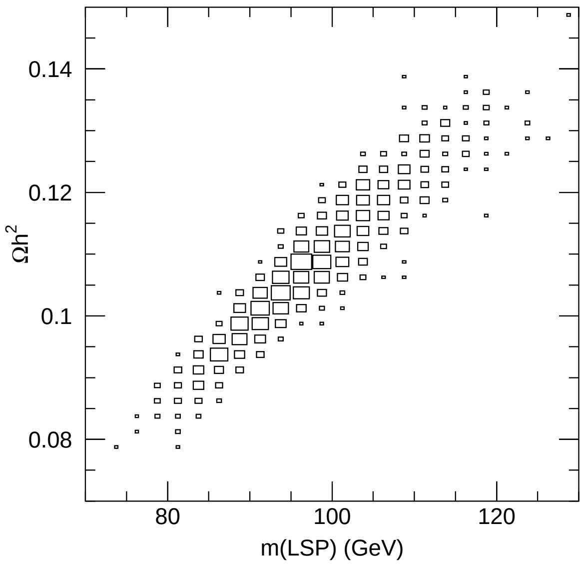


If the error on $m_{\tau\tau}$, better than 1 GeV measurement error of 10% on $\Omega_\chi h^2$

Limits on achievable precision

If MSSM with no constraints assumed, still $\sim 10\%$ error on $\Omega_\chi h^2$, even if infinite precision on $m(\tau\tau)$



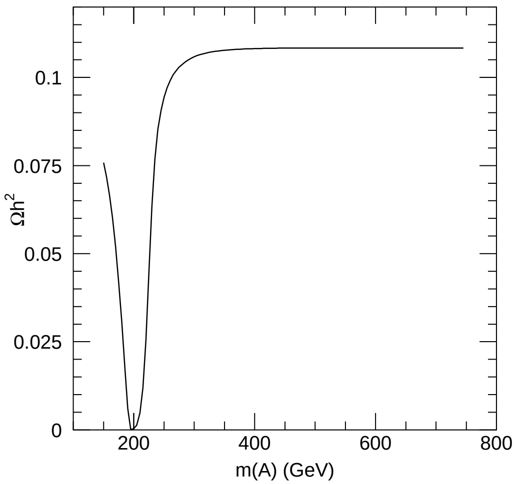


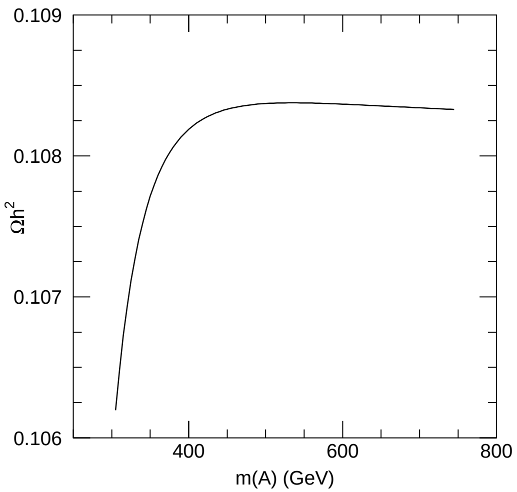
Next most important error source from uncertainty on $\tilde{\chi}_1^0$ mass

Now consider contribution from badly known $\tan\beta$, $m(A)$, $m(\tilde{\tau}_2)$

Uncertainty from badly constrained parameters

Method: vary concerned parameter in relevant range, and recalculate all other soft SUSY breaking parameters such that measurable masses and BR are kept at measured value



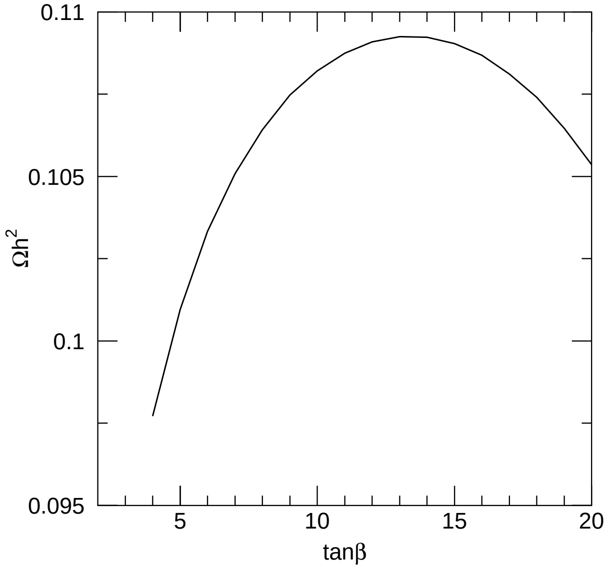


$m(A)$ dependency. Three scenarios:

- No handle on $m(A/H)$ Resonant annihilation of neutralino possible: can only give upper limit on $\Omega_\chi h^2$
- Lower limit of approximately 300 GeV on the H/A mass from non-observation in SUSY cascade decays.
  Spread on $\Omega_\chi h^2$ of ∼1%
- H/A is discovered in its $\tilde{\chi}_2^0\tilde{\chi}_2^0$ decay mode.
  No contribution from $m(A)$ to the spread on $\Omega_\chi h^2$

It might be necessary to go to upgraded LHC to be able to detect H/A in SUSY decay modes

Uncertainties (continued)



$\tan\beta$ dependency

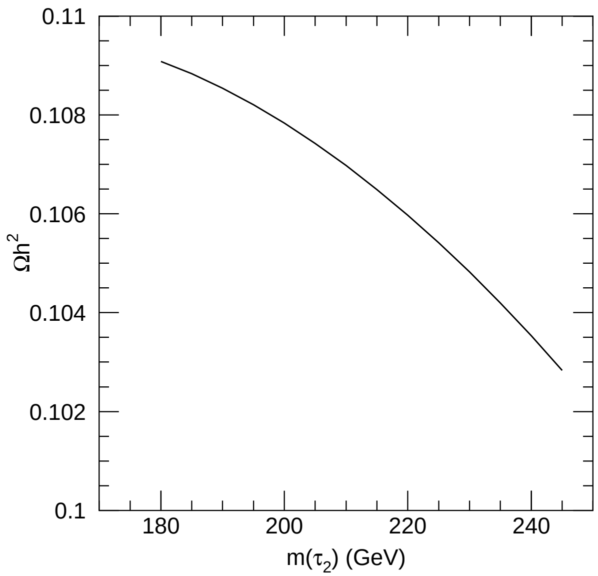
All dependency coming from $\tilde{\chi}_1^0\tilde{\chi}_1^0 \to \tau\tau$

Caused by dependency of θ_τ on $\tan\beta$

The relic density estimate varies by $\sim 11\%$, depending on the lower limit one can assume on $\tan\beta$ from the higgs sector.

$m(\tilde{\tau}_2)$ dependency

The variation with $m(\tilde{\tau}_2)$ is $\sim 7\%$, for the assumed range of $\tilde{\tau}_2$ mass, i.e. $m(\tilde{\tau}_2) > m(\tilde{\chi}_2^0)$ and $A_\tau < 5$ TeV



Conclusions on SPA point from direct method

Neutralino annihilation is dominated by slepton exchange.

Can demonstrate that higgsino component is small

Enough measurements to predict the neutralino relic density from slepton/stau exchange

Dominant factors: precision on $\tau\tau$ edge position, ignorance of $m(\tilde{\tau}_2)$

Detection of heavy higgs boson necessary to exclude the possibility of resonant annihilation into them, and to help constraining $\tan\beta$

If one assumes $m(H/A) < 300$ GeV can be excluded and 1 GeV systematic uncertainty on $m(\tau\tau)$ can predict $\Omega_\chi h^2$ at the 10% level.

Caveats:

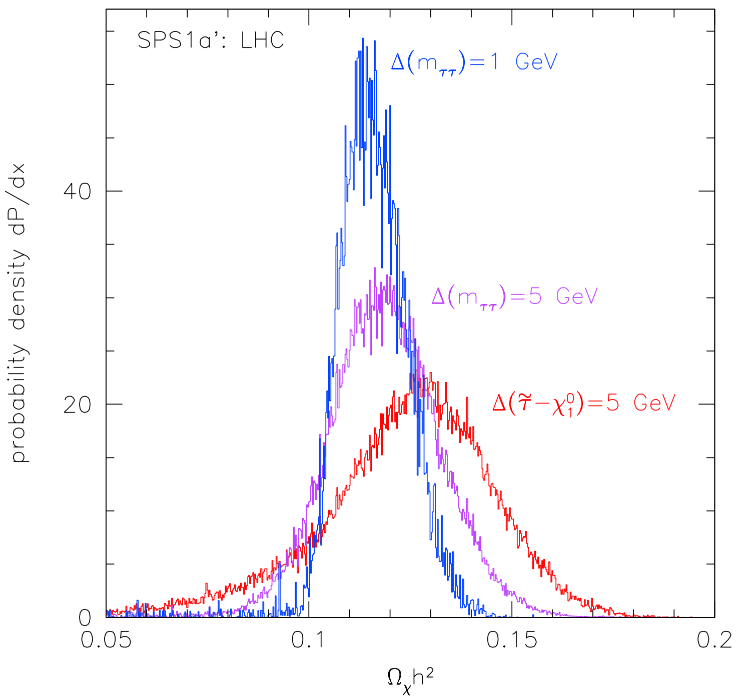
- Conclusion only valid if annihilation via slepton exchange dominates
- SUSY signals observed at the LHC can be confirmed as Dark Matter only with input (observations) from direct Dark Matter searches

Comparison with MSSM parameter scan

Used LHC constraints equivalent to ones of direct study.

Heavy higgs constraints: $m(A) > 200$ GeV or $\tan\beta < 7.0(m(A)/200)$

Original work done for SPS1a, repeated for SPA for comparison



Conclusions equivalent to direct study:

- Small uncertainty from unknown values of $\tan\beta$ and of $m(\tilde{\tau}_2)$
- Dominant uncertainty from $m(\tau\tau)$ measurement
- Similar numerical results:

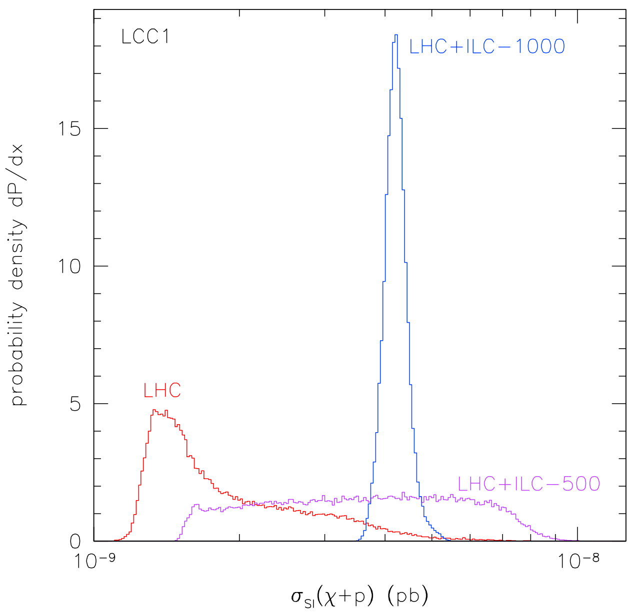
$\Delta(m_{\tau\tau}) = 5$ GeV $\rightarrow \Delta\Omega_\chi h^2 \sim 15\%$

$\Delta(m_{\tau\tau}) = 1$ GeV $\rightarrow \Delta\Omega_\chi h^2 \sim 12\%$

Nice consistency check of two approaches

Direct detection cross section from MSSM scan

Evaluate spin-averaged neutralino-proton cross-section $\sigma_{\chi p}$ at threshold



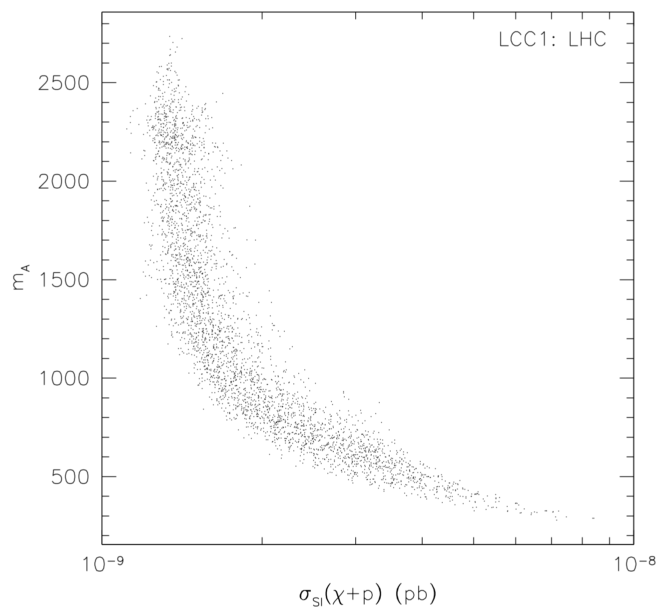
Basically no constraint from LHC measurements

Spurious shape in probability distribution due to scanning technique and initial assumption on distribution of scan variables.

Cross-section dominated by t-channel exchange of heavy Higgs H^0

For high $m(A)$, σ dominated by light higgs h

Constraint if $H/A \to \tilde{\chi}_2^0 \tilde{\chi}_2^0$ detectable (SuperLHC)



Focus point: significant higgsino component in $\tilde{\chi}_1^0$

Recent ATLAS study: De Sanctis, Lari, Montesano, Troncon

$m_0 = 3550$ GeV, $m_{1/2} = 300$ GeV, $A = 0$ GeV, $\mu > 0$, $\tan\beta = 10$, $m(top) = 175$ GeV

$m(\tilde{g}) \sim 850$ GeV, $m(\tilde{\chi}_1^0) = 103.4$ GeV, $m(\tilde{\chi}_1^0) = 160.37$ GeV, $m(\tilde{\chi}_1^0) = 179.76$ GeV (ISA771)

Produce both $\tilde{\chi}_2^0$ and $\tilde{\chi}_3^0$ in $\tilde{g} \to qq\tilde{\chi}_i^0$ decays

Study OS-SF spectra for three-body decays

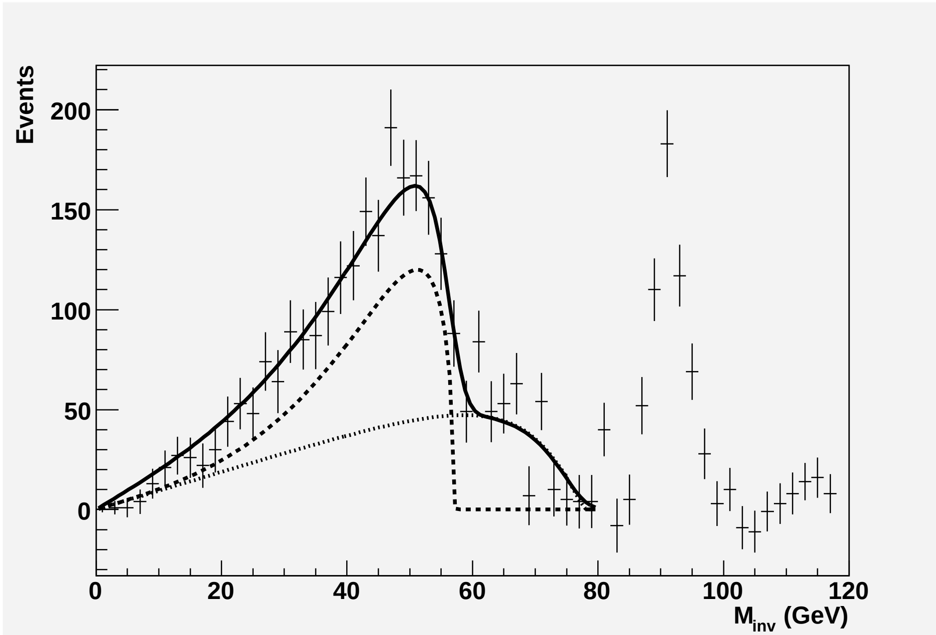
$\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 \ell^+ \ell^-$

$\tilde{\chi}_3^0 \to \tilde{\chi}_1^0 \ell^+ \ell^-$

From fit of three-body shape:

$\Delta(m(\tilde{\chi}_2^0) - m(\tilde{\chi}_1^0)) = 0.4$ GeV

$\Delta(m(\tilde{\chi}_3^0) - m(\tilde{\chi}_1^0)) = 1.4$ GeV



Not enough constraints to solve the neutralino mass matrix, even fixing $\tan\beta$

Constraint from direct production cross-section $pp \to \tilde{\chi}_2^0 \tilde{\chi}_1^\pm \to 3\ell$ ($\sigma \times BR =\sim 40$ fb)? (in progress)

Focus point results from MSSM scan

Similar focus point:

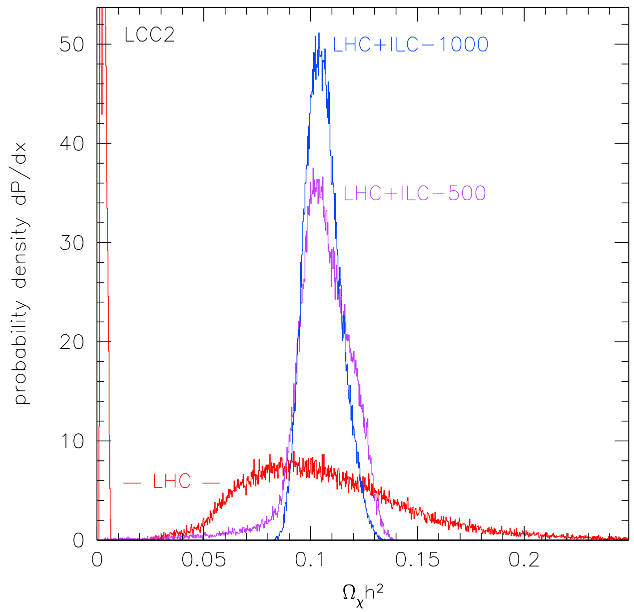
$m_0 = 3280$ GeV, $m_{1/2} = 300$ GeV $A = 0$ GeV,

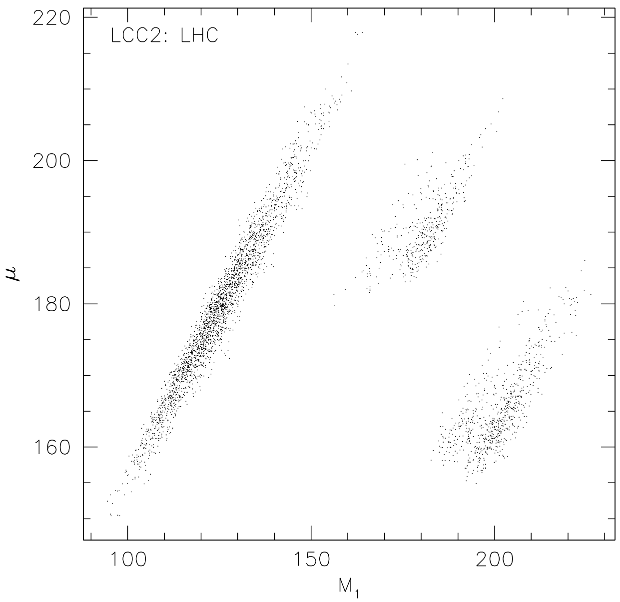
$\mu > 0$, $\tan\beta = 10$

Assume (extrap. from ILC analyses):

- $\Delta(m(\tilde{\chi}_2^0) - m(\tilde{\chi}_1^0)) = 1$ GeV
- $\Delta(m(\tilde{\chi}_3^0) - m(\tilde{\chi}_1^0)) = 1$ GeV
- $\Delta(m(\tilde{\chi}_1^0) = 10$ GeV

$m(\tilde{\chi}_1^0)$ constraint is wild guess: no explicit analysis





For LHC data three different solution islands in (M_1, μ) plane, corresponding to bino-, wino-, and higgsino-like neutralino.

Wrong solutions responsible for peak at zero in relic density estimate

Not enough constraints from LHC

Conclusions

The LHC will be able to measure through kinematic analysis several parameters of the SUSY models

In the case annihilation involving light sleptons is the dominant process enough information should be available to predict LSP relic density

Main weakness is in region of intermediate $\tan\beta$ with heavy Higgs bosons of mass$\gtrsim$300 GeV, where $\tan\beta$ and heavy Higgs masses undetermined

In regions where all scalars have high mass, and gaugino has significant higgsino component, only few constraints available, not enough to constrain DM. More studies needed

Combination of results of Collider and DM experiments necessary to achieve global understanding of DM issue