SUSY Dark Matter and Colliders

by

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BCA, Lester, hep-ph/0507283; BCA, Belanger, Boudjema, Pukhov, JHEP 0412 (2004) 020, hep-ph/0410091

Talk outline

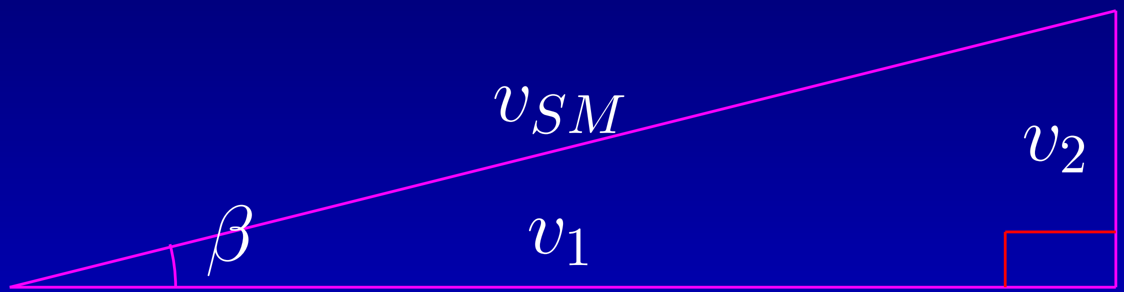
- SUSY dark matter
- Constraints on SUSY models
- Collider measurements

Electroweak Breaking

Both Higgs get vacuum expectation values:

$$\begin{pmatrix} H_1^0 \\ H_1^- \end{pmatrix} \rightarrow \begin{pmatrix} v_1 \\ 0 \end{pmatrix} \qquad \begin{pmatrix} H_2^+ \\ H_2^0 \end{pmatrix} \rightarrow \begin{pmatrix} 0 \\ v_2 \end{pmatrix}$$

and to get M_W correct, match with $v_{SM} = 246$ GeV:



$$\tan\beta = \frac{v_2}{v_1}$$

$$\mathcal{L} = h_t \bar{t}_L H_2^0 t_R + h_b \bar{b}_L H_1^0 b_R + h_\tau \bar{\tau}_L H_1^0 \tau_R$$

$$\Rightarrow \frac{m_t}{\sin\beta} = \frac{h_t v_{SM}}{\sqrt{2}}, \qquad \frac{m_{b,\tau}}{\cos\beta} = \frac{h_{b,\tau} v_{SM}}{\sqrt{2}}.$$

The Supersymmetric Standard Model

Standard Model particle
quark, spin 1/2
lepton, spin 1/2
higgs, spin 0
gluon, spin 1
Weak bosons, spin 1
graviton, spin 2

The Supersymmetric Standard Model

For every particle present in The Standard Model, we have a heavier supersymmetric copy with the same quantum numbers and couplings to forces but spin differing by 1/2 $\bar{h}$.

Standard Model particle	Supersymmetric copy(s)
quark, spin 1/2	2squarks, spin 0
lepton, spin 1/2	2sleptons, spin 0
$2\times$ higgs, spin 0	higgsinos, spin 1/2
gluon, spin 1	gluinos, spin 1/2
Weak bosons, spin 1	gauginos, spin 1/2
graviton, spin 2	gravitino, spin 3/2

Broken Symmetry

3 components of the Higgs particles are eaten by $W^{\pm}$, Z^0, leaving us with 5 physical states:

$$h^0, H^0\text{(CP+)}, \qquad A^0\text{(CP-)}, \qquad H^{\pm}$$

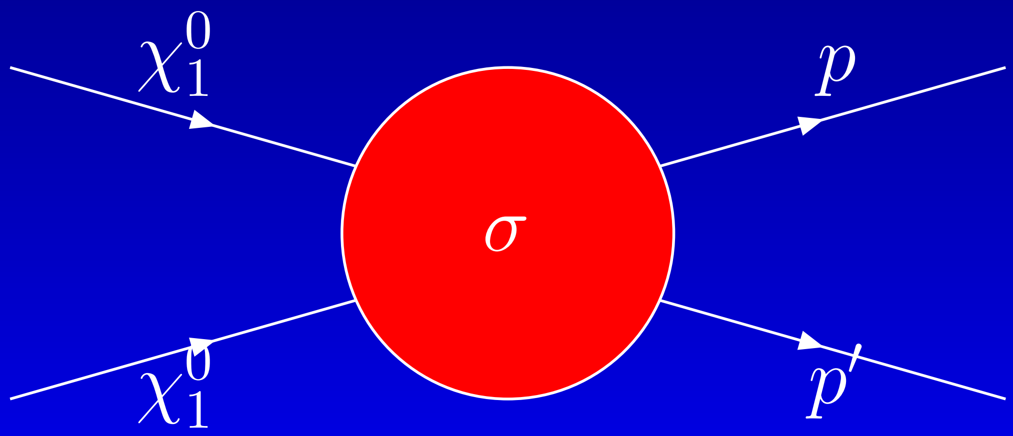
SUSY breaking and electroweak breaking imply particles with identical quantum numbers mix:

$$\begin{aligned}
(\tilde{u}_L, \tilde{u}_R) &\longrightarrow \tilde{u}_{1,2} \\
(\tilde{d}_L, \tilde{d}_R) &\longrightarrow \tilde{d}_{1,2} \\
(\tilde{e}_L, \tilde{e}_R) &\longrightarrow \tilde{e}_{1,2} \\
(\tilde{B}, \tilde{W}_3, \tilde{H}_1^0, \tilde{H}_2^0) &\longrightarrow \chi^0_{1,2,3,4} \\
(\tilde{W}^{\pm}, \tilde{H}^{\pm}) &\longrightarrow \chi^{\pm}_{1,2}
\end{aligned}$$

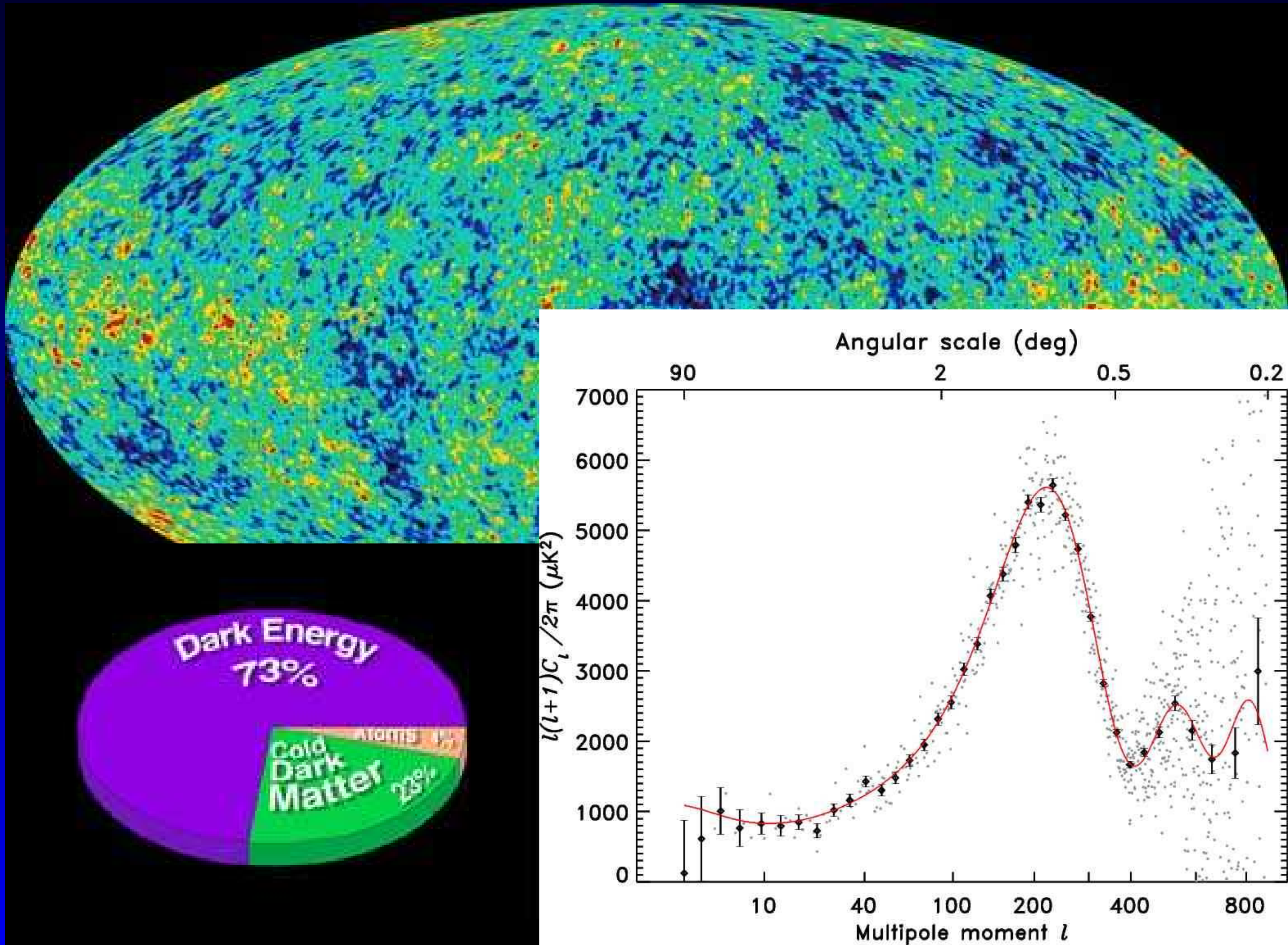
SUSY Dark Matter

- Galactic rotation curves
- Gravitational lensing effects
- WMAP + large scale structure

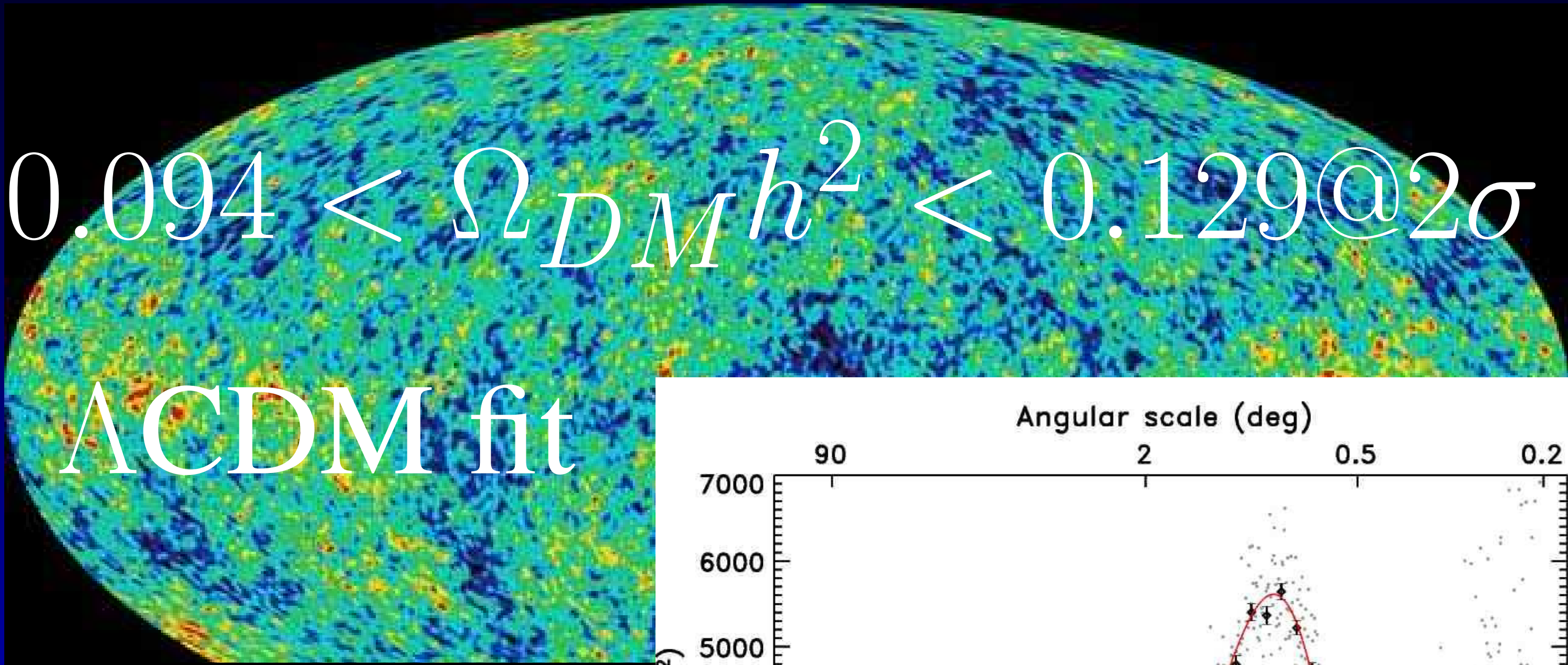
Imposing R_P, the neutralino is a good candidate. Must take into account annihilation in the early universe into ordinary matter:



WMAP Results

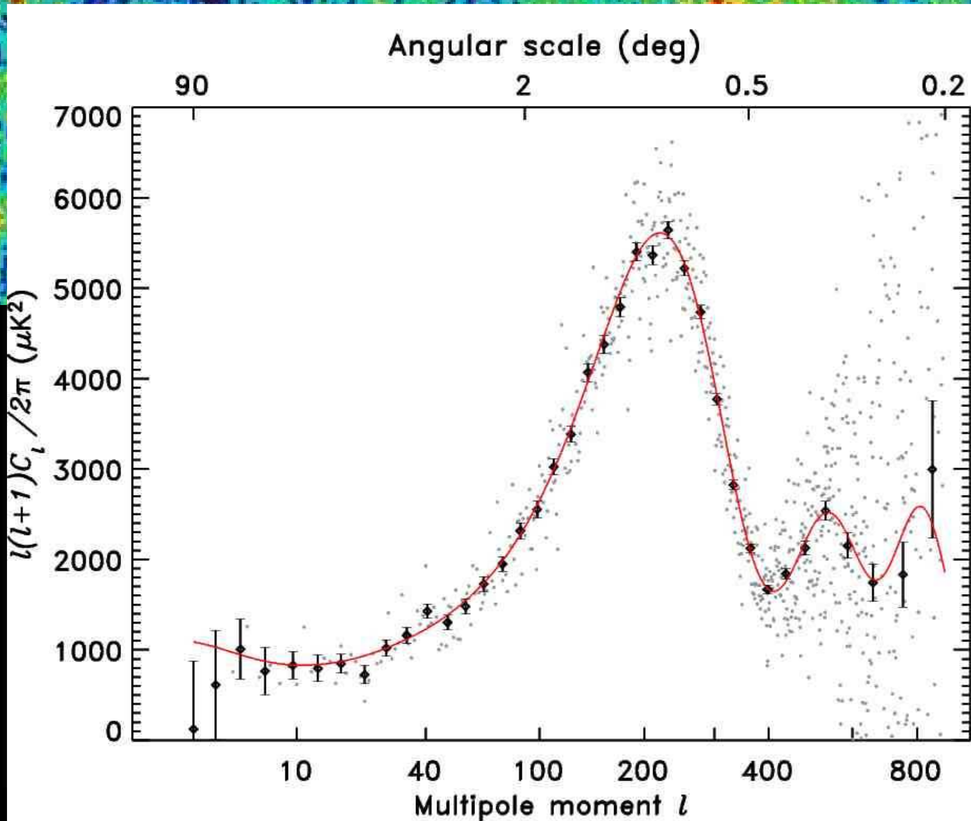


WMAP Results



$$0.094 < \Omega_{DM} h^2 < 0.129 @ 2\sigma$$

ΛCDM fit



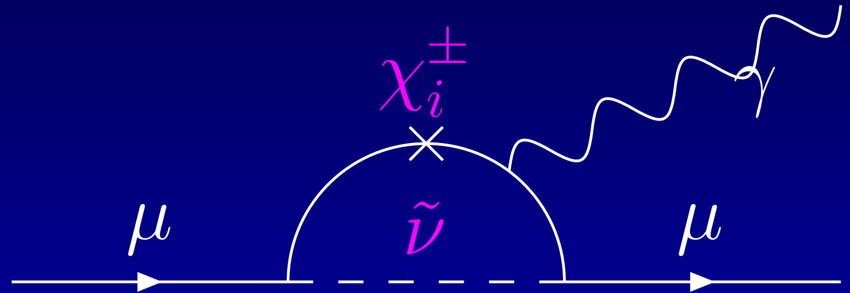
SUSY Prediction of Ωh^2

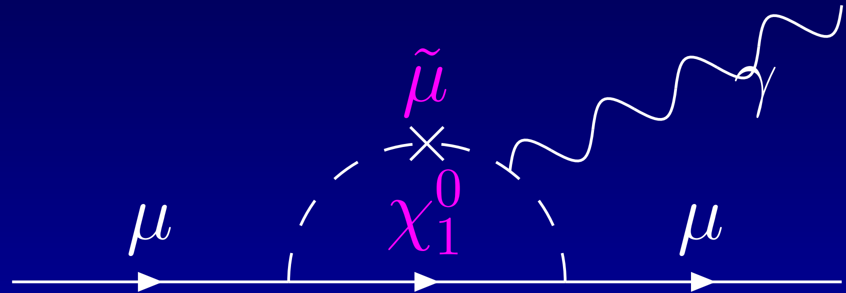
- Assume relic in thermal equilibrium with $n_{eq} \propto (MT)^{3/2} exp(-M/T)$.
- Freeze-out with $T_f \sim M_f/25$ once interaction rate $<$ expansion rate (t_{eq} critical)
- We use `microMEGAs` : $\Omega h^2 \propto 1/ < \sigma v >$ to solve coupled Boltzmann equations
- Generate SUSY spectrum with `SOFTSUSY` linked with SLHA

Belanger *et al*, CPC 149 (2002) 103
BCA, CPC 143 (2002) 305
BCA et al, JHEP0407 (2004) 036

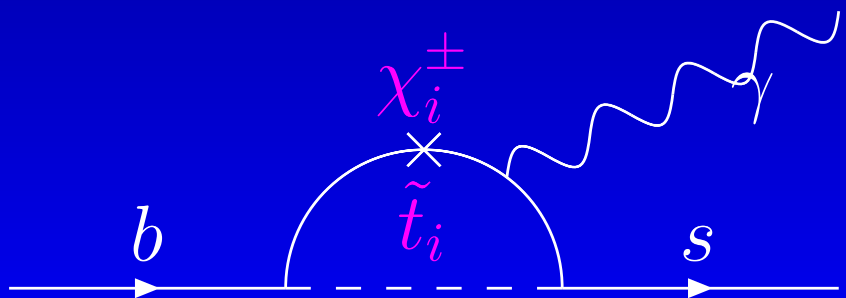
Additional observables

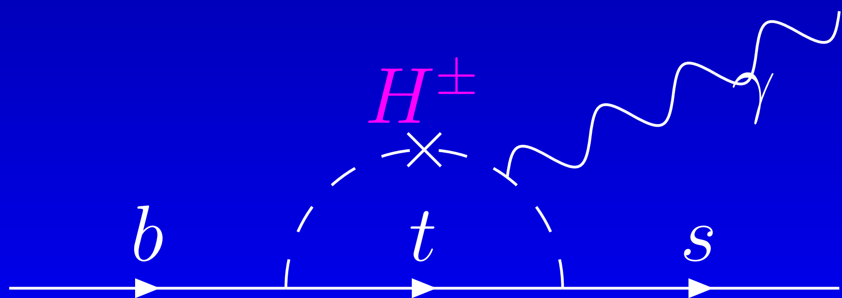
$$\delta \frac{(g-2)_\mu}{2} \sim 13 \times 10^{-10} \left(\frac{100 \text{ GeV}}{M_{SUSY}} \right)^2 \tan\beta$$





$$BR[b \to s\gamma] \propto \tan\beta (M_W/M_{SUSY})^2$$





Universality

Reduces number of SUSY breaking parameters from 100 to 3:

- $\tan\beta \equiv v_2/v_1$
- m_0, the common scalar mass (flavour).
- $M_{1/2}$, the common gaugino mass (GUT/string).
- A_0, the common trilinear coupling (flavour).

These conditions should be imposed at $M_X \sim O(10^{16-18})$ GeV and receive radiative corrections

$$\propto \; 1/(16\pi^2)\ln(M_X/M_Z).$$

Also, Higgs potential parameter sgn(μ)=± 1.

mSUGRA Regions

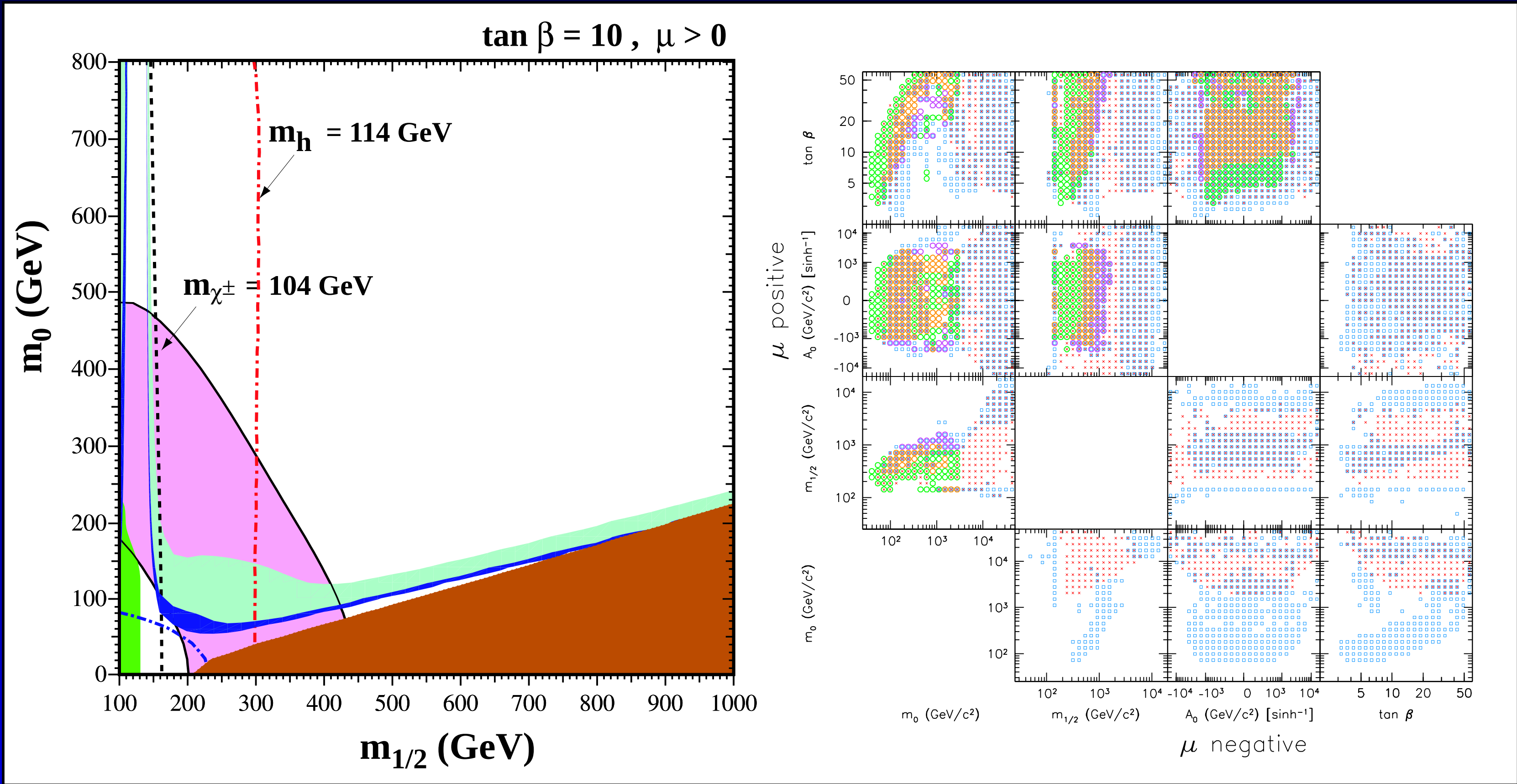
After WMAP+LEP2, bulk region diminished. Need specific mechanism to reduce overabundance:

- $\tilde{\tau}$ coannihilation: small m_0, $m_{\tilde{\tau}_1} \approx m_{\chi_1^0}$. Boltzmann factor $\exp(-\Delta M/T_f)$ controls ratio of species. $\tilde{\tau}_1 \chi_1^0 \to \tau\gamma$, $\tilde{\tau}_1 \tilde{\tau}_1 \to \tau\bar{\tau}$.
- Higgs Funnel: $\chi_1^0 \chi_1^0 \to A \to b\bar{b}/\tau\bar{\tau}$ at large $\tan\beta$. Also via h at large m_0 small $M_{1/2}$.
- Focus region: Higgsino LSP at large m_0: $\chi_1^0 \chi_1^0 \to WW/ZZ/Zh/t\bar{t}$.
- $\tilde{t}$ coannihilation: high $-A_0$, $m_{\tilde{t}_1} \approx m_{\chi_1^0}$. $\tilde{t}_1 \chi_1^0 \to gt$, $\tilde{t}\tilde{t} \to tt$

Datta, Djouadi, Drees, hep-ph/0504090

Constraints on SUSY Models

mSUGRA well-studied in literature: eg Ellis, Olive *et al* PLB565 (2003) 176; Roszkowski *et al* JHEP 0108 (2001) 024; Baltz, Gondolo, JHEP 0410 (2004) 052;…



Shortcomings

- Really, would like to combine likelihoods from different measurements
- Typically only 2d scans, but in general we have $\alpha_s(M_Z)$, m_t, m_b, m_0, $M_{1/2}$, A_0, $\tan\beta$ to vary
- Effective 3d type scan done which parameterises a 2d surface of correct Ωh^2
- Baltz *et al* managed to perform a 4d scan, but lost the likelihood interpretation. They used the impressive *Markov Chain Monte Carlo technique*.

Done in 2d in Ellis *et al*, hep-ph/0310356
Ellis *et al*, hep-ph/0411218

Markov-Chain Monte Carlo

Markov chain consists of list of parameter points $x^{(}t)$ and associated likelihoods $\mathcal{L}^{(t)}$

1. Pick a point at random for $x^{(1)}$
2. Pick a point around $x^{(t)}$ (say with a Gaussian width) as the potential new point.
3. If $\mathcal{L}^{(t+1)} > \mathcal{L}^{(t)}$, the new point is appended onto the chain. Otherwise, the proposed point is accepted with probability $\mathcal{L}^{(t+1)}/\mathcal{L}^{(t)}$. If *not* accepted, a copy of $x^{(t)}$ is added on to the chain.

Final density of x points $\propto \mathcal{L}$. Required number of points goes *linearly* with number of dimensions.

Implementation

Input parameters are: m_0, A_0, $M_{1/2}$, $\tan\beta$

- $m_t = 172.7 \pm 2.9$ GeV
- $m_b(m_b)^{\overline{MS}} = 4.2 \pm 0.2$ GeV,
- $\alpha_s(M_Z)^{\overline{MS}} = 0.1187 \pm 0.002$.

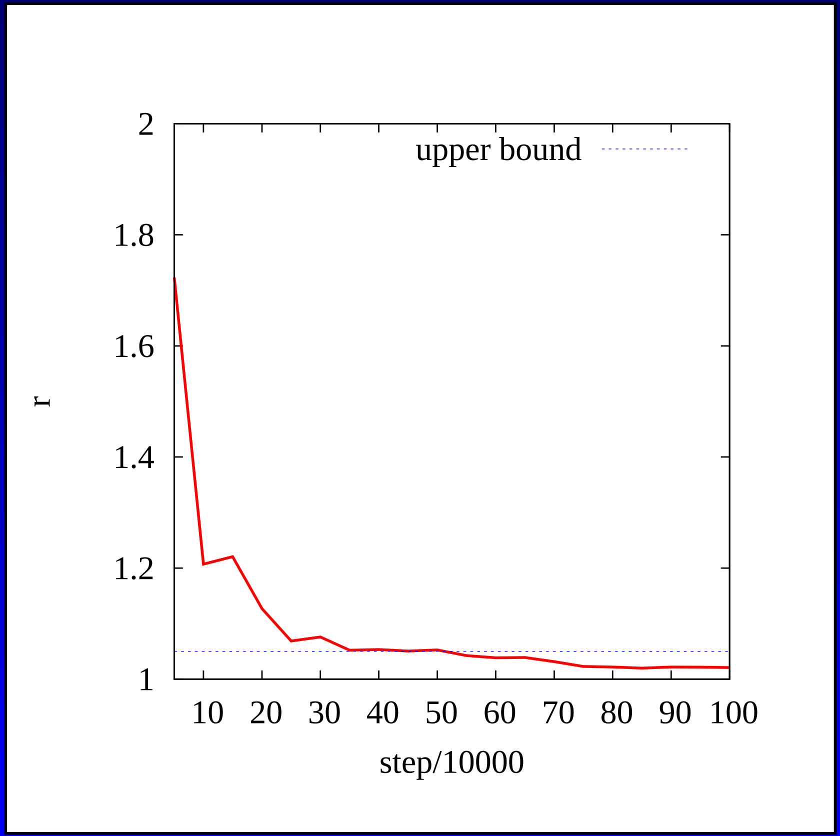
For the likelihood, we also use

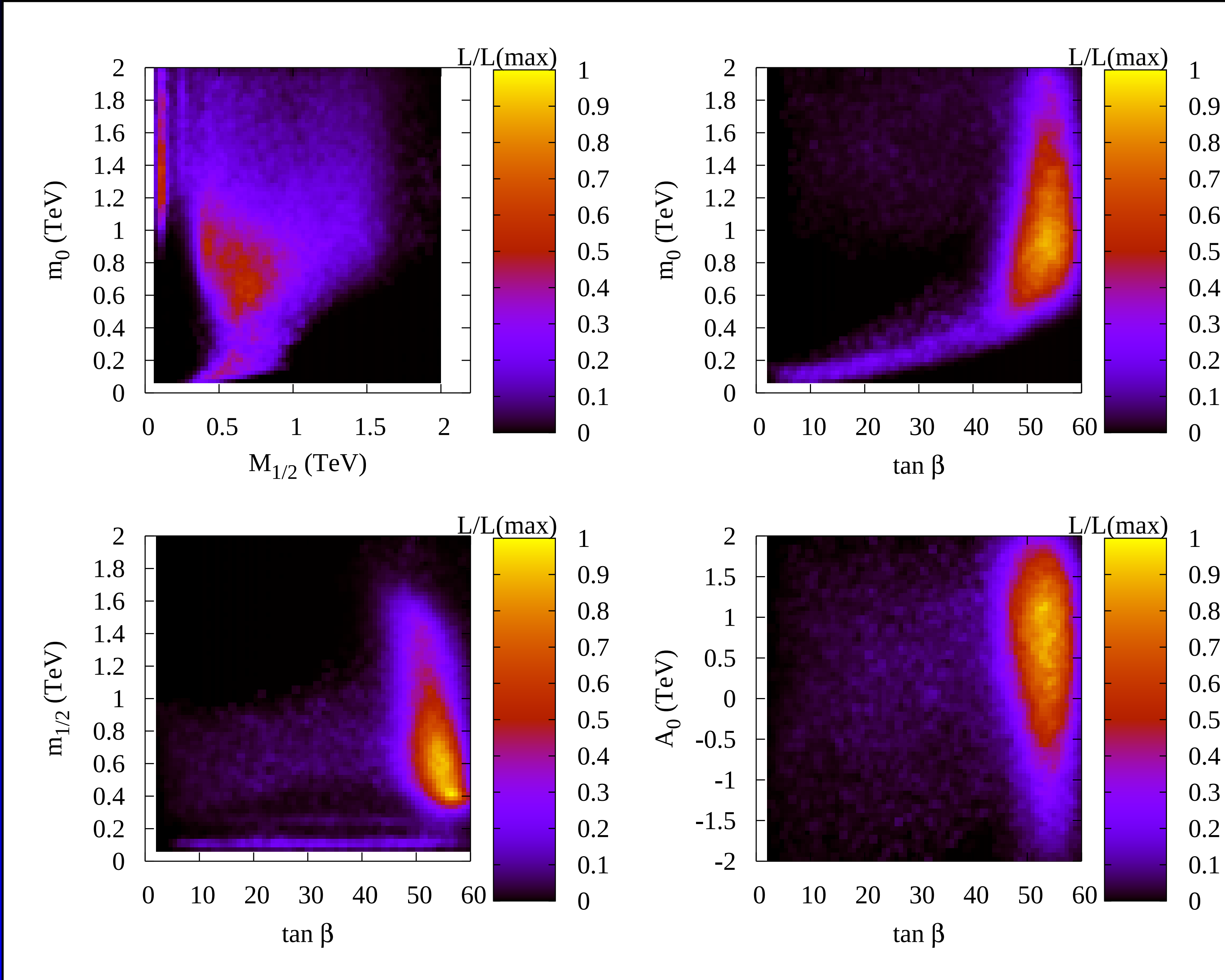
- $\Omega_{DM} h^2 = 0.1125^{+0.0081}_{-0.0091}$
- $\delta(g-2)_\mu/2 = (19 \pm 8.4) \times 10^{-10}$
- $BR[b \to s\gamma] = (3.52 \pm 0.42) \times 10^{-5}$

$$\ln \mathcal{L} = -\frac{1}{2} \sum_i \frac{(p_i - m_i)^2}{2\sigma_i^2} + c$$

Convergence

We run 9×1 000 000 points. By comparing the 9 independent chains with random starting points, we can provide a statistical measure of convergence: an upper bound r on the excepted variance decrease for infinite statistics.




L/L(max)
m_0 (TeV)
M_1/2 (TeV)
tan β
m_1/2 (TeV)
A_0 (TeV)

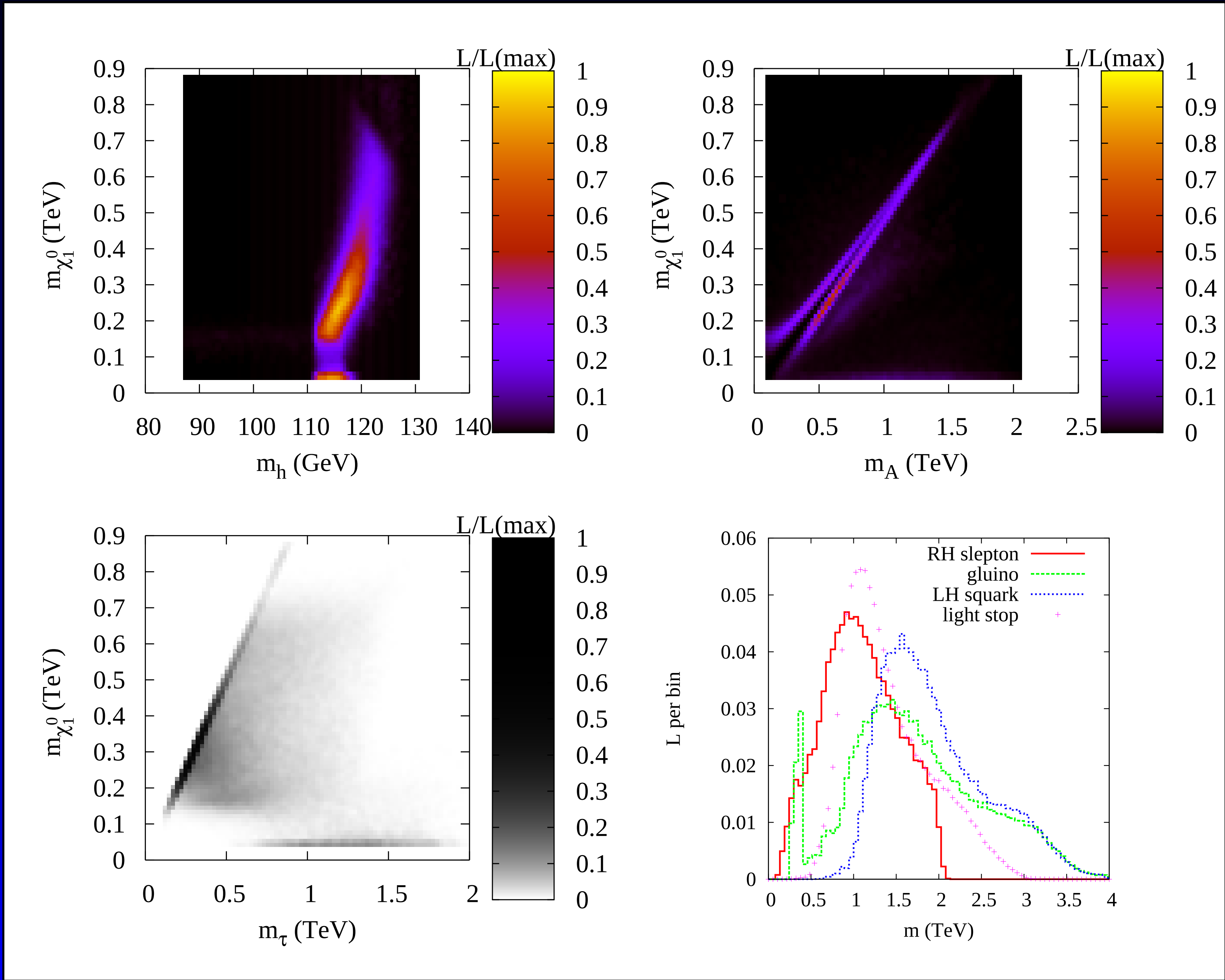
Annihilation Mechanism

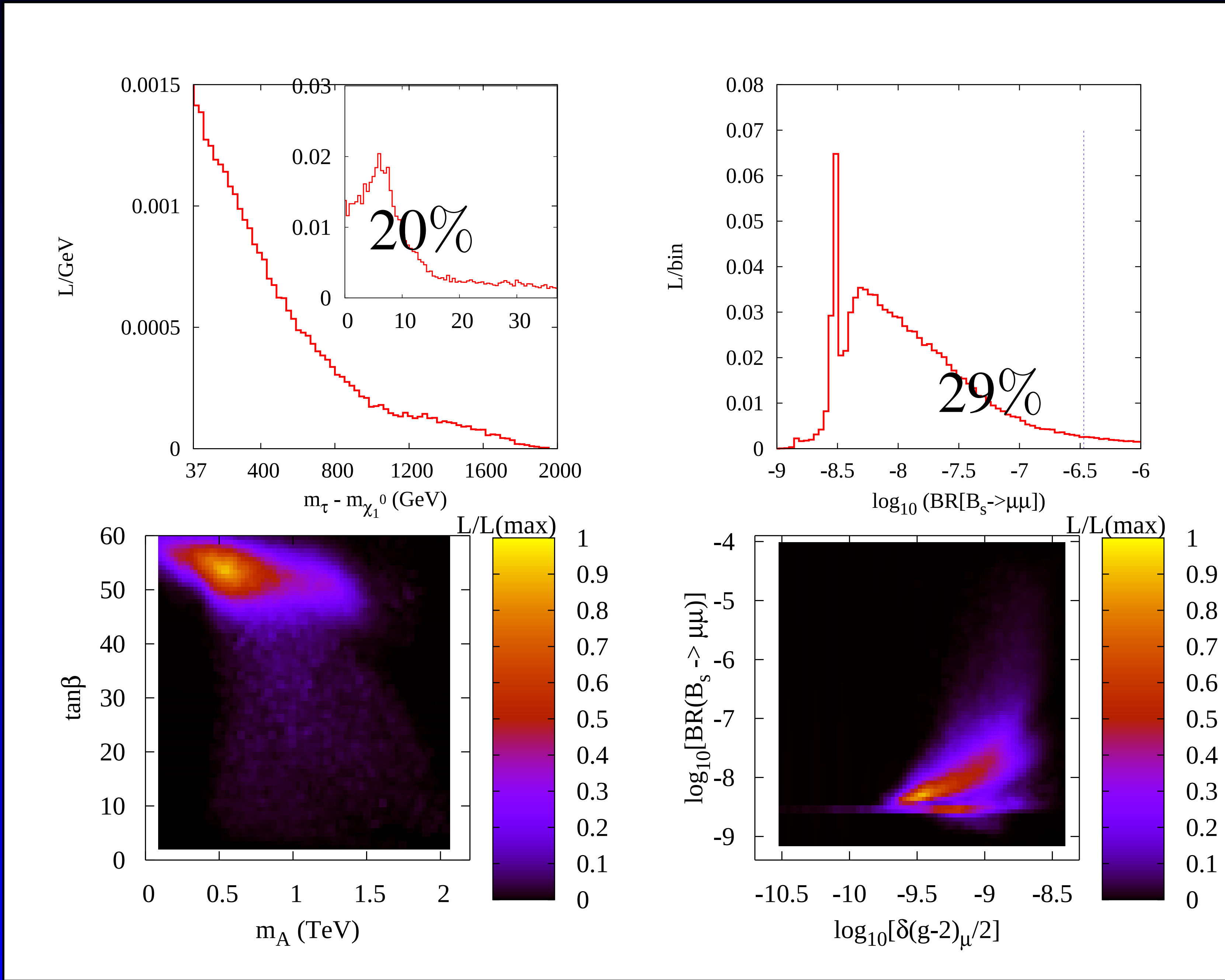
Define stau co-annihilation when $m_{\tilde{\tau}}$ is within 10% of $m_{\chi_1^0}$ and Higgs pole when $m_{h,A}$ is within 10% of $2m_{\chi_1^0}$.

Region	likelihood
h^0 pole	0.02±0.01
A^0 pole	0.41±0.03
$\tilde{\tau}$ co-an	0.27±0.04
$\tilde{t}$ co-an	$(2.1 \pm 4.8) \times 10^{-4}$

Table 0: Likelihood of being in a certain region of mSUGRA parameter space.

Likelihood of chain $\tilde{q}_L \to \chi_2^0 \to \tilde{l}_R \to \chi_1^0$ is 24±4%


L/L(max)
m_χ1^0 (TeV)
m_h (GeV)
m_A (TeV)
m_τ (TeV)
L per bin
m (TeV)
RH slepton
gluino
LH squark
light stop

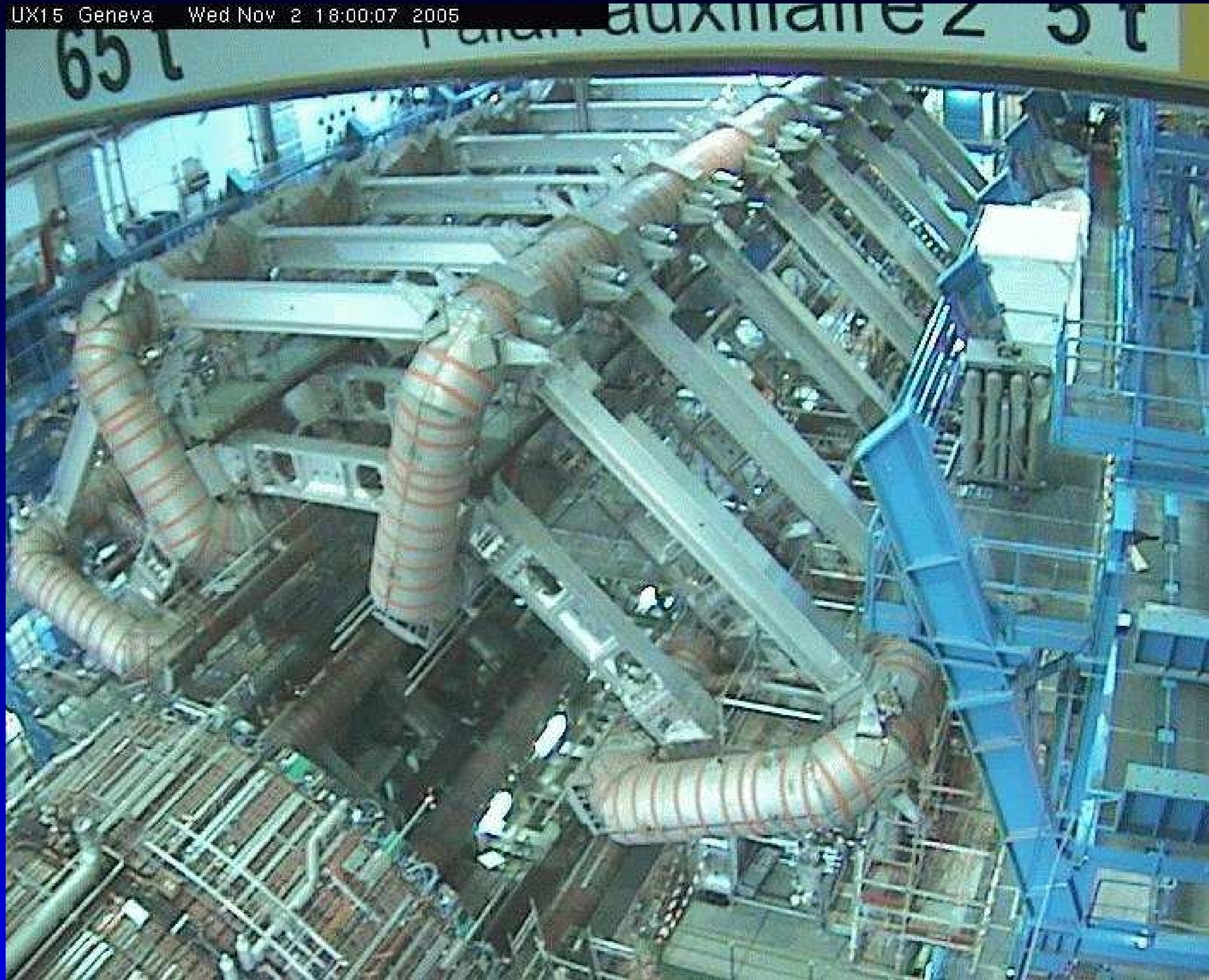


L/GeV
$m_{\tau} - m_{\chi_1^0}$ (GeV)
20%
L/bin
$\log_{10}$ (BR[B_s->μμ])
29%
L/L(max)
tanβ
m_A (TeV)
L/L(max)
$\log_{10}$[BR(B_s -> μμ)]
$\log_{10}[\delta(g-2)_\mu/2]$

Caveats

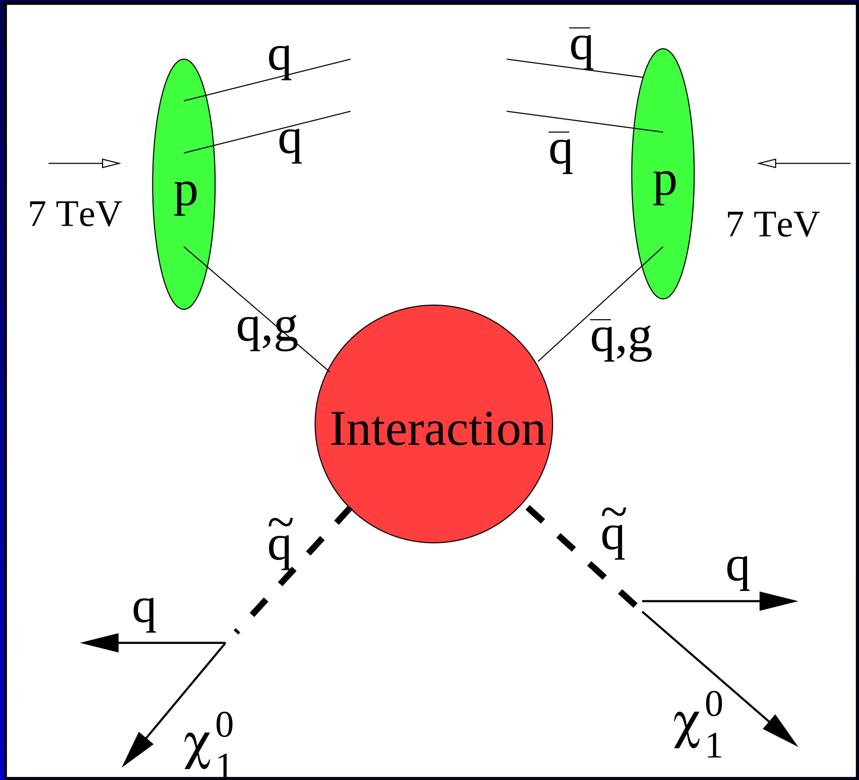
- Implicitly assumed that LSP constitutes *all* of dark matter
- Assumed radiation domination in post-inflation era. No clear evidence between freeze-out+BBN that this is the case (t_{eq} changes).
- Examples of non-standard cosmology that would change the prediction:
  - Extra degrees of freedom
  - Low reheating temperature
  - Extra dimensional models
  - Anisotropic cosmologies
  - Non-thermal production of neutralinos (late decays?)

LHC (ATLAS)



Collider SUSY Dark Matter Production

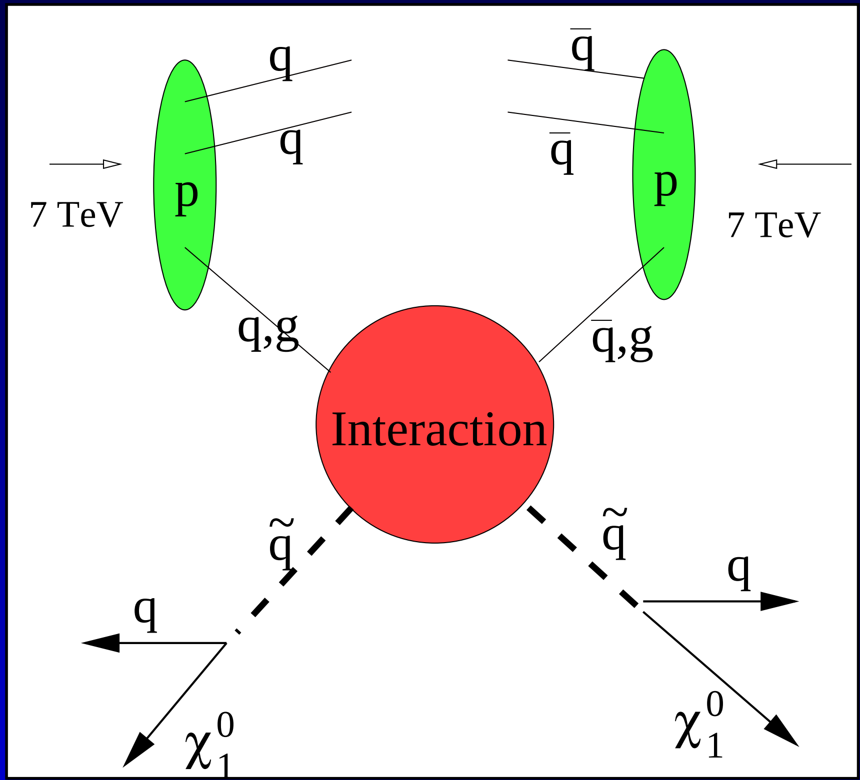
Strong sparticle production and decay to dark matter particles.



Q: Can we measure enough to predict σ?

Collider SUSY Dark Matter Production

Strong sparticle production and decay to dark matter particles.



Any dark matter candidate that couples to hadrons can be produced at the LHC

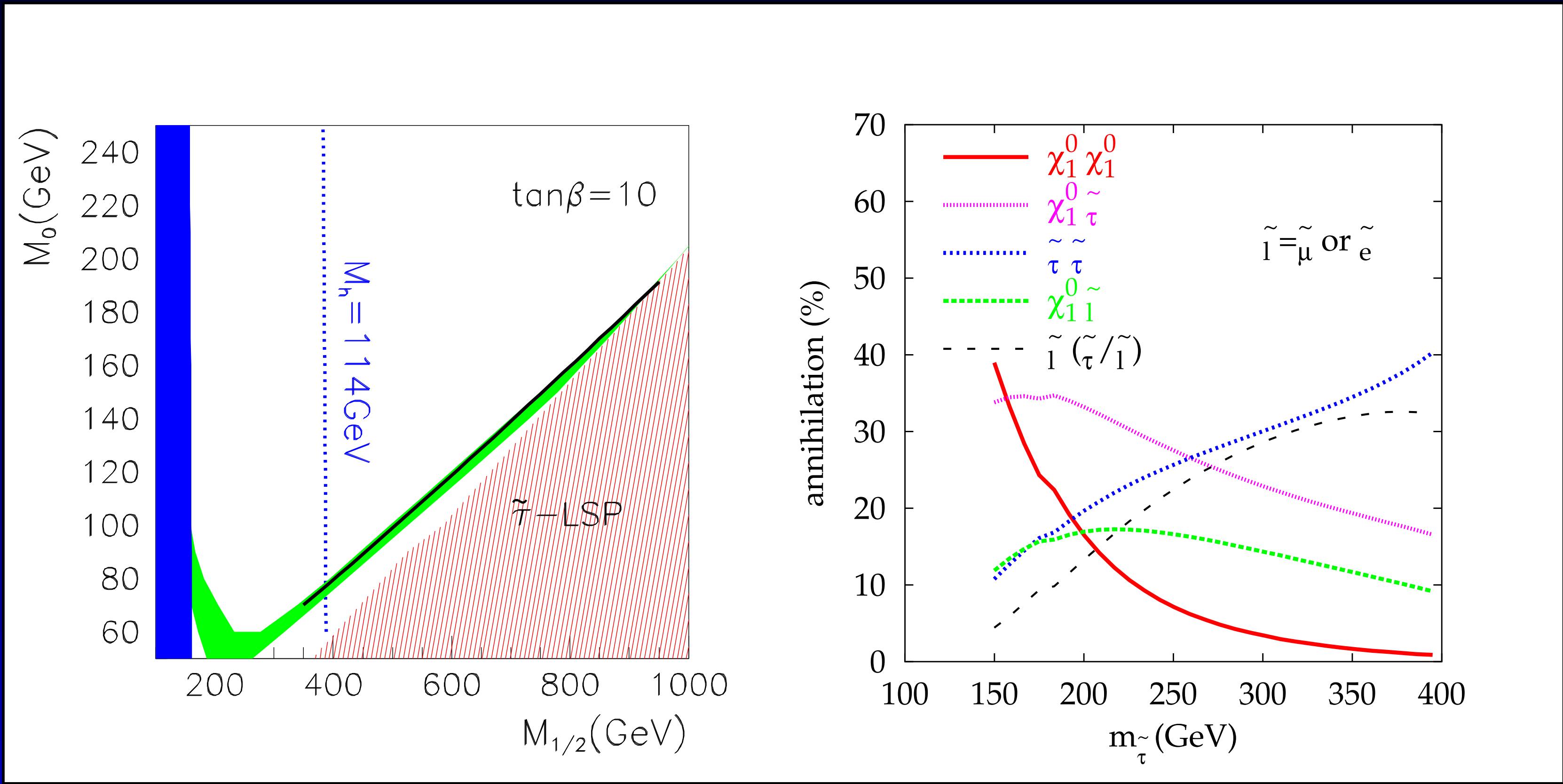
LHC vs LC in SUSY Measurement

- LHC (start date 2007) produces strongly interacting particles up to a few TeV. Precision measurements of mass *differences* possible if the decay chains exist: possibly per mille for leptons, several percent for jets.
- ILC has several energy options: 500-1000 GeV, CLIC up to 3 TeV. Linear colliders produce less strong particles but much easier to make precision measurements of masses/couplings.

$\mathcal{Q}$: What energy for LC?
$\mathcal{Q}$: What do we get from LHC ?

LHC/ILC Working Group Report: `hep-ph/0410364`

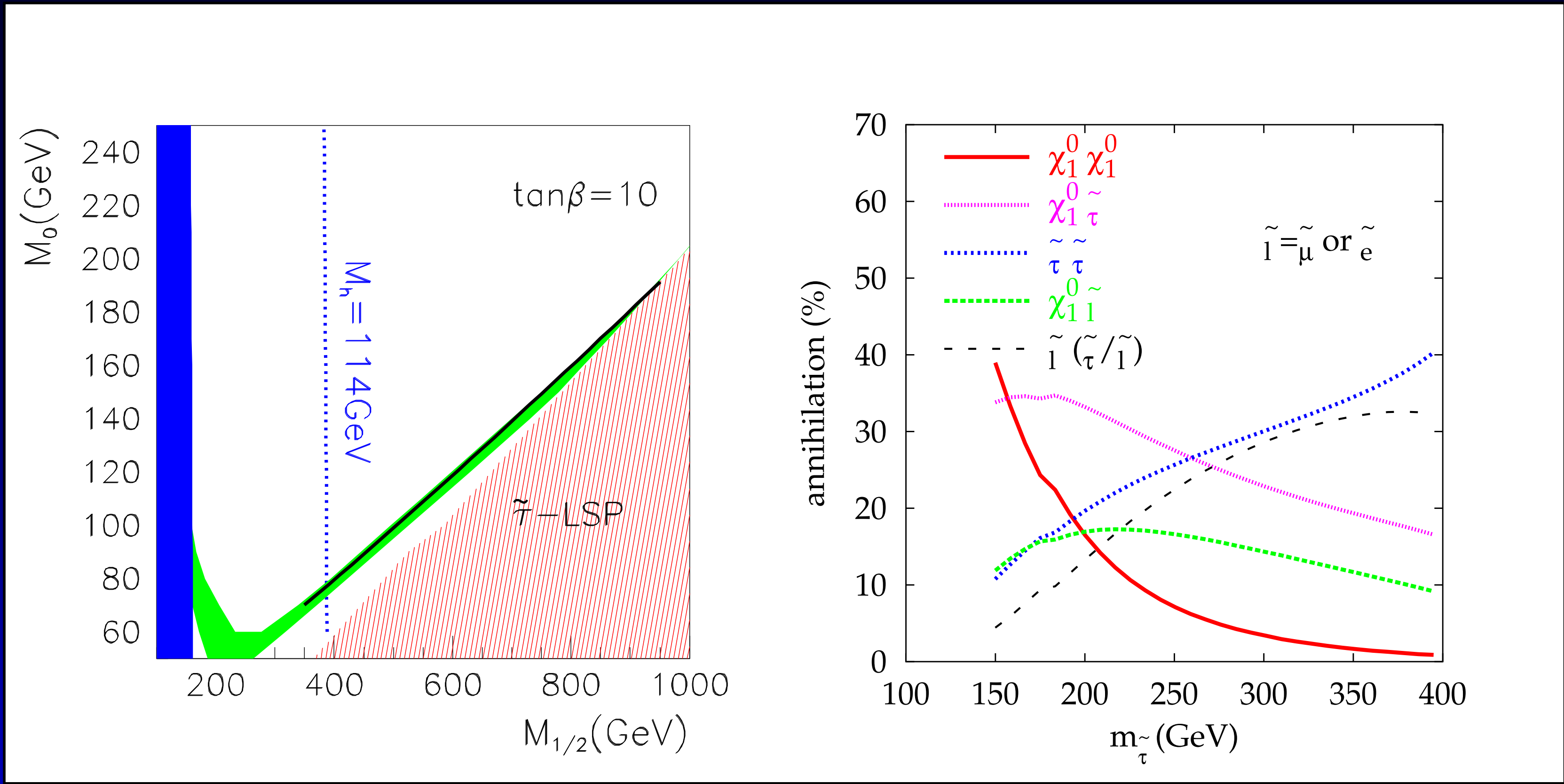
Coannihilation Slope



$$m^2_{\tilde{l}_R} \approx m_0^2 + 0.15 M^2_{1/2}, \qquad M_{\chi_1^0} \approx 0.4 M_{1/2}$$

Low enough $M_{1/2} \Rightarrow$ quasi-deegenerate $\tilde{\tau}$, $M_{\chi_1^0}$

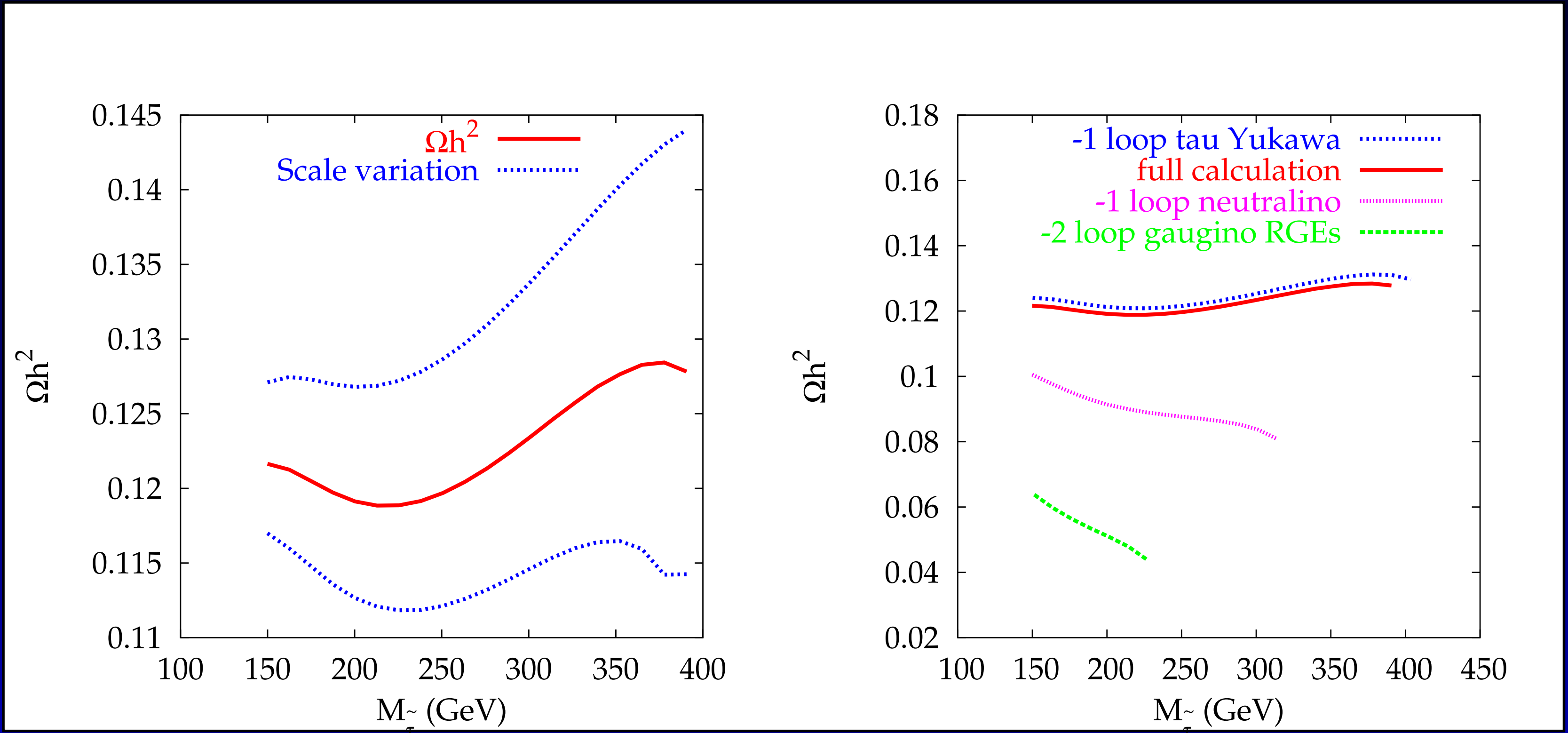
Coannihilation Slope



$$m^2_{\tilde{l}_R} \approx m_0^2 + 0.15 M^2_{1/2}, \qquad M_{\chi_1^0} \approx 0.4 M_{1/2}$$

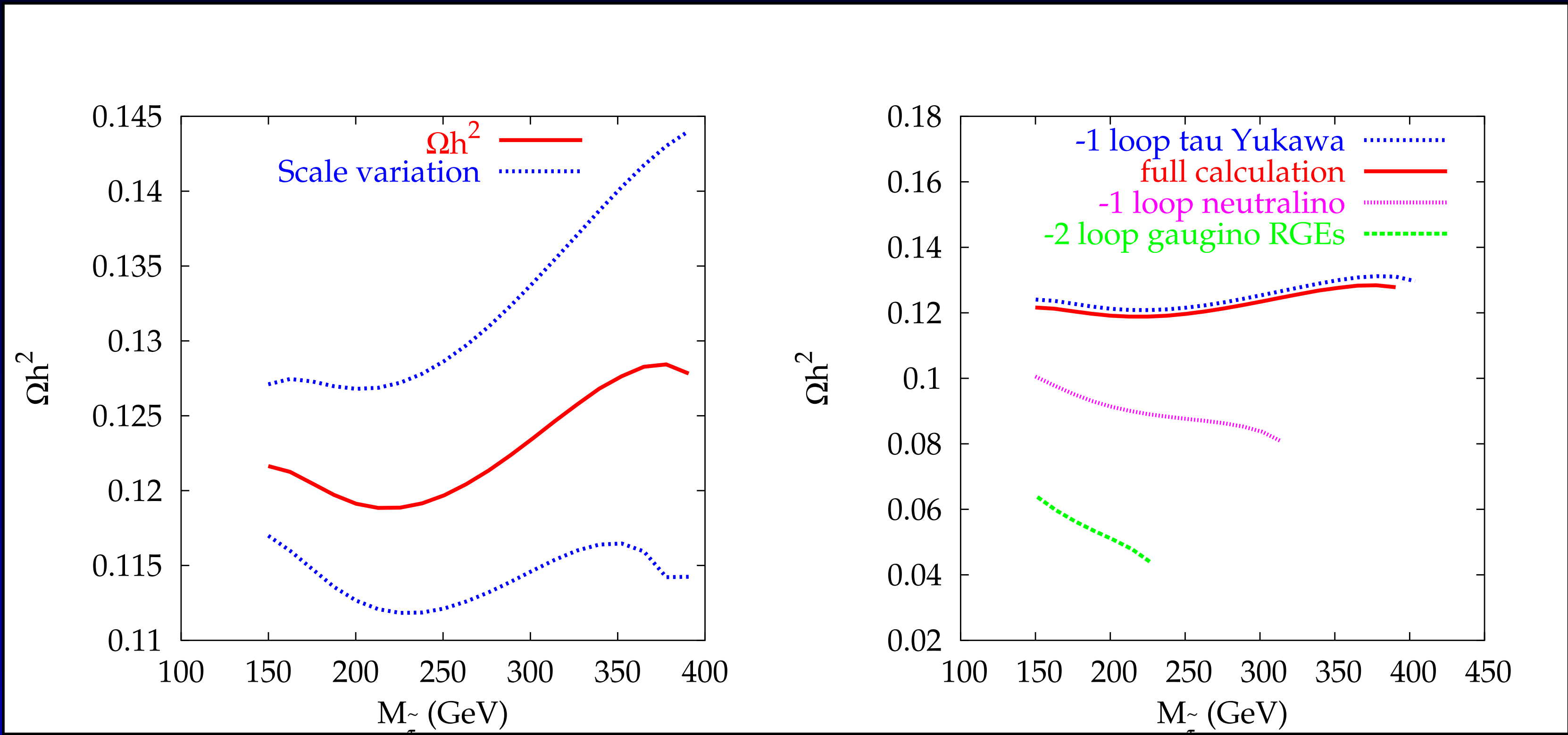
If we do not assume mSUGRA, we will also have to measure selectron and smuon properties.

Coannihilation Theory Uncertainties



Expect higher orders to be 100 times smaller than these differences: 3-loop terms could possibly be important!

Coannihilation Theory Uncertainties



Effect of 2-loop RGE terms suggest a possible effect from 3 loops. Jack and Jones find that it's not significant for the neutralino.

Iterative Procedure

What change in a parameter produces a 10% change in Ωh^2?

Take a parameter point with $\omega_{-1} \equiv \Omega h^2$. Change *one parameter at a time* by fraction a_0. Result is ω_0, then iterate

$$a_{i+1} = a_i \omega_{-1} \frac{10\%}{w_i - \omega_{-1}}.$$

Small accuracy $a \equiv a_\infty$ means the parameter has to be known very accurately in order to predict Ωh^2 to 10%.

For parameters that are zero, we take the absolute value as a rather than the fractional value.

Uncertainties

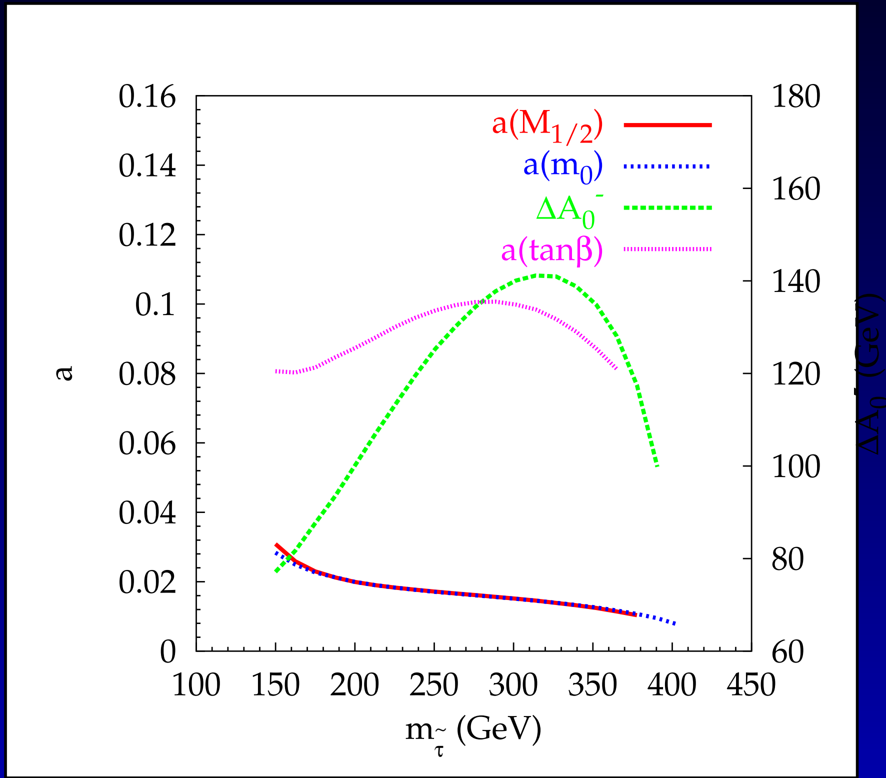
We use two approaches to determine what variation of parameters produce a 10% variation in Ωh^2:

- PmSUGRA - variation of weak scale parameters (*not* on mSUGRA trajectory): $m_{\chi_1^0}, M_A, m_b$ etc.
- mSUGRA - simple variation of mSUGRA parameters and experimental inputs: $m_0, M_{1/2}, \alpha_s(M_Z), m_t$ etc.

mSUGRA theory uncertainties estimated by varying scale at which radiative corrections added to sparticle masses:

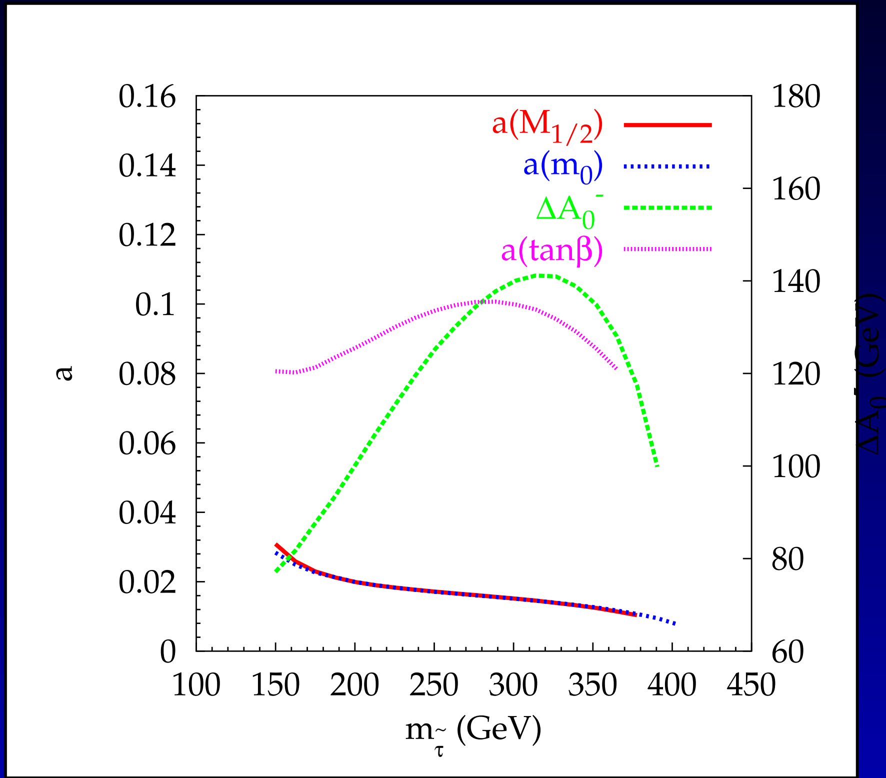
$$0.5 < x \equiv \frac{M_{SUSY}}{\sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}}} < 2, \qquad M_{SUSY} > M_Z$$

mSUGRA Coannihilation Uncertainties



$a(m_0) \approx a(M_{1/2})$ comes from the sensitivity to $\exp[-(m_{\tilde\tau} - M_{\chi_1^0})]$

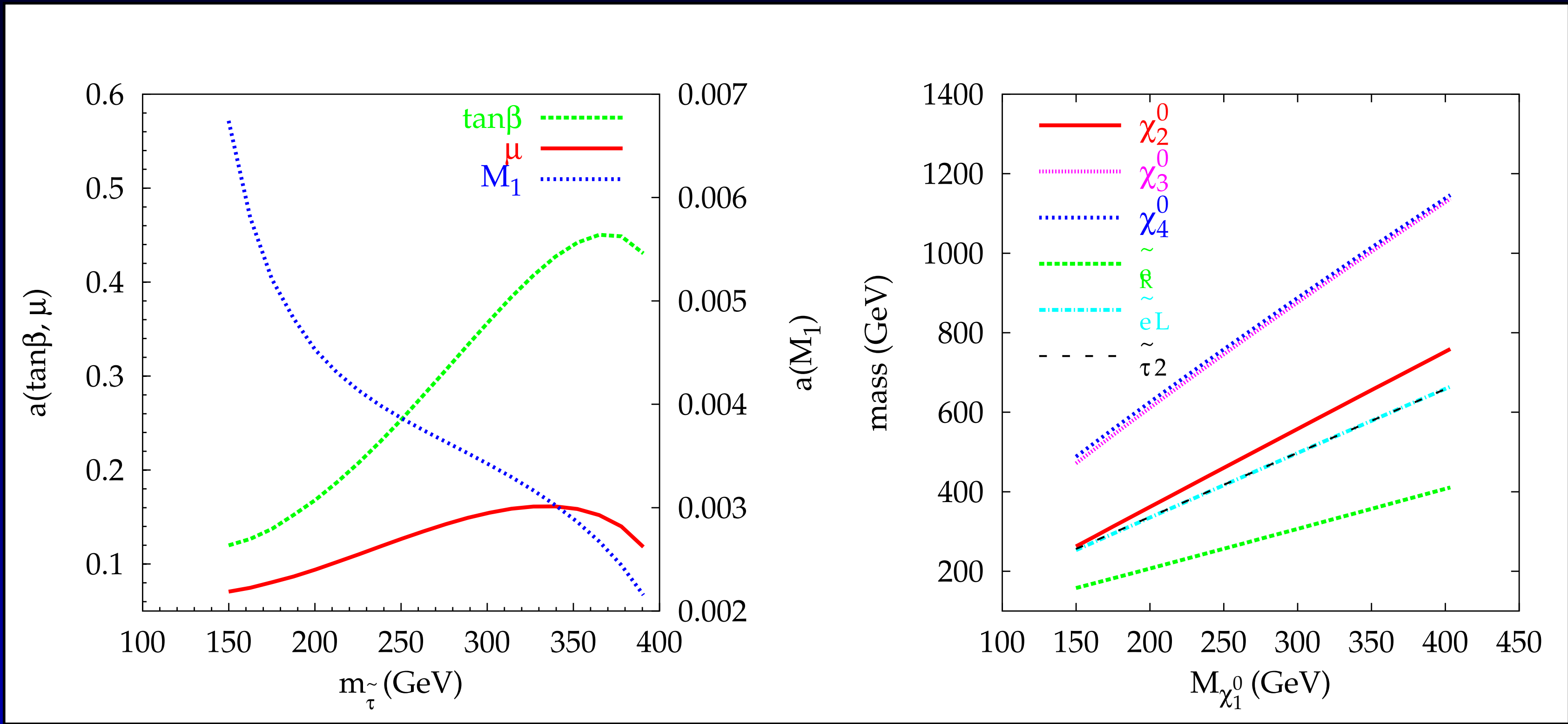
mSUGRA Coannihilation Uncertainties



Unknown whether accuracies can be reached - but it looks difficult : $\Delta\Omega h^2 \sim .03$ in diminished bulk region.

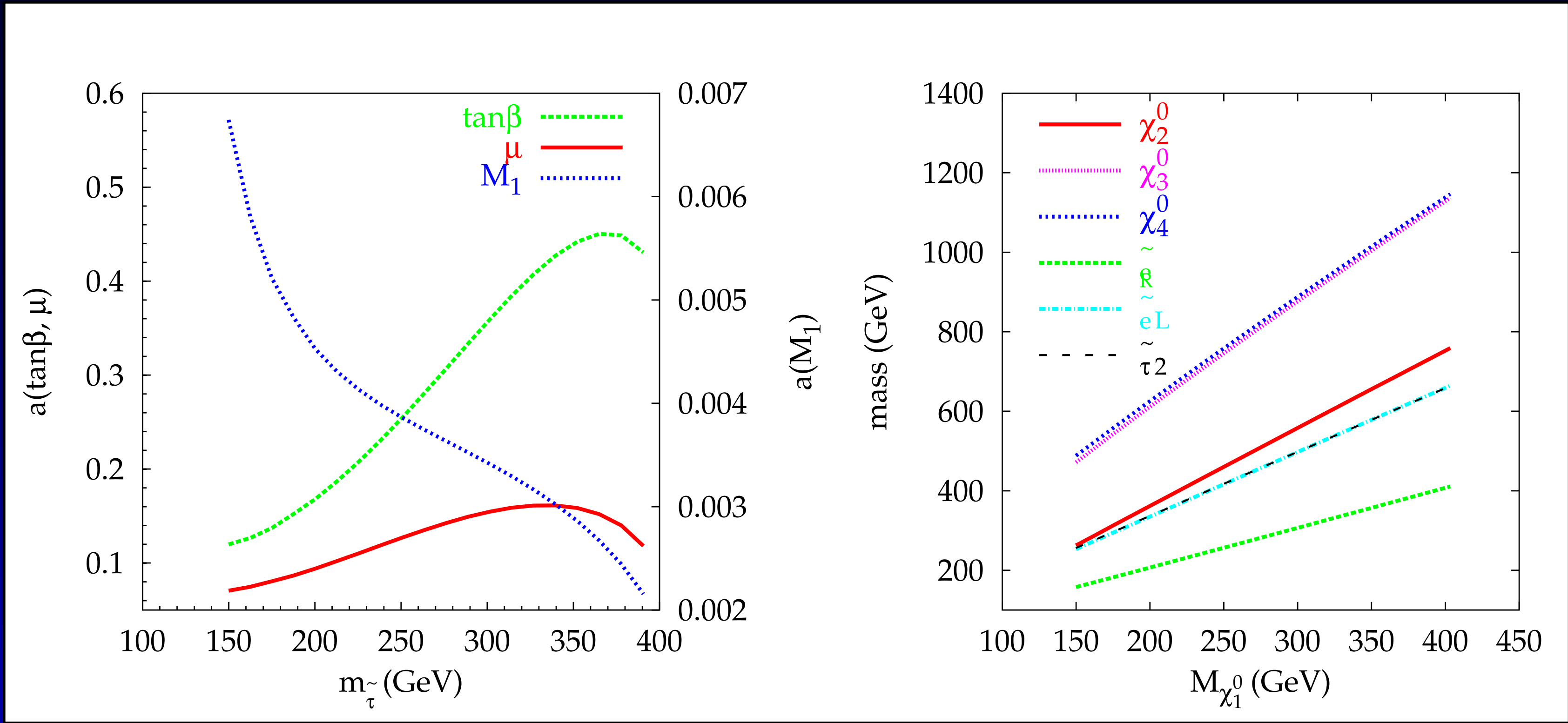
Polesello, Tovey, JHEP05 (2004) 071

PmSUGRA Coannihilation



RHS: Spectrum useful for optimal energy of linear collider. $\tilde{e}_R, \tilde{\mu}_R$ also possible. Cascade $\tilde{q}_L \rightarrow \chi_2^0 \rightarrow \tilde{e}_R \rightarrow \chi_1^0$ available.

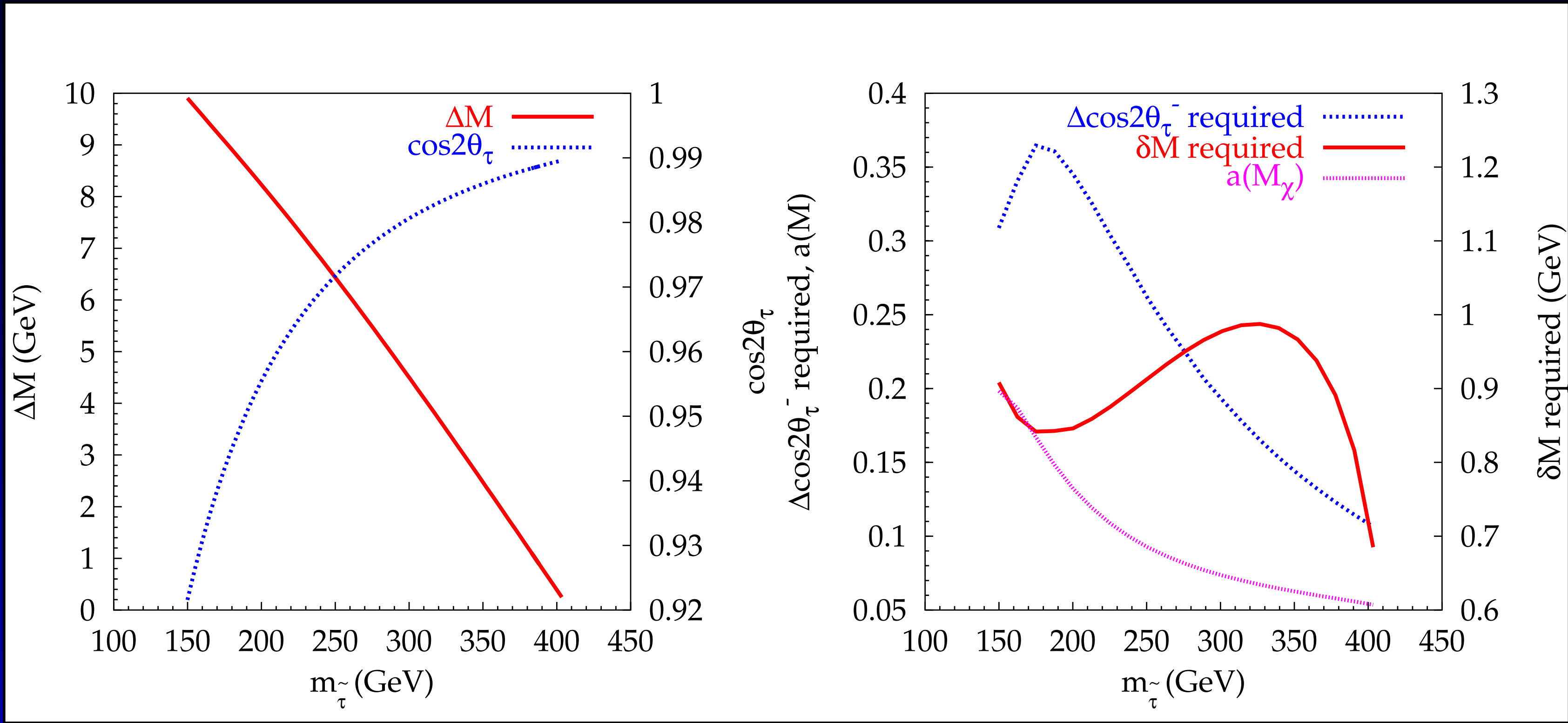
PmSUGRA Coannihilation



LHS: Dependences in left-hand plot all come from the effect on LSP mass.

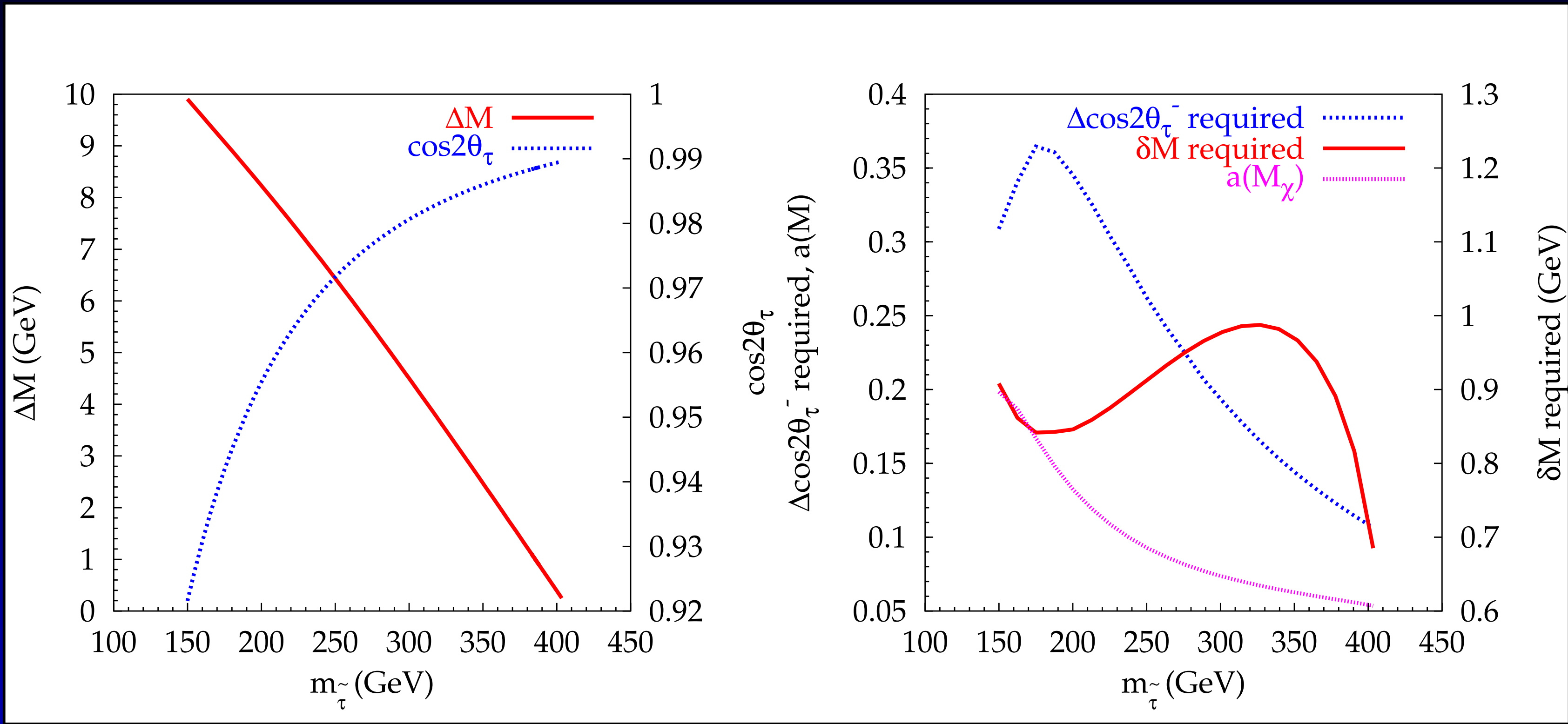
Need to know $M_{\chi_1^0}$ very accurately.

PmSUGRA Dependencies



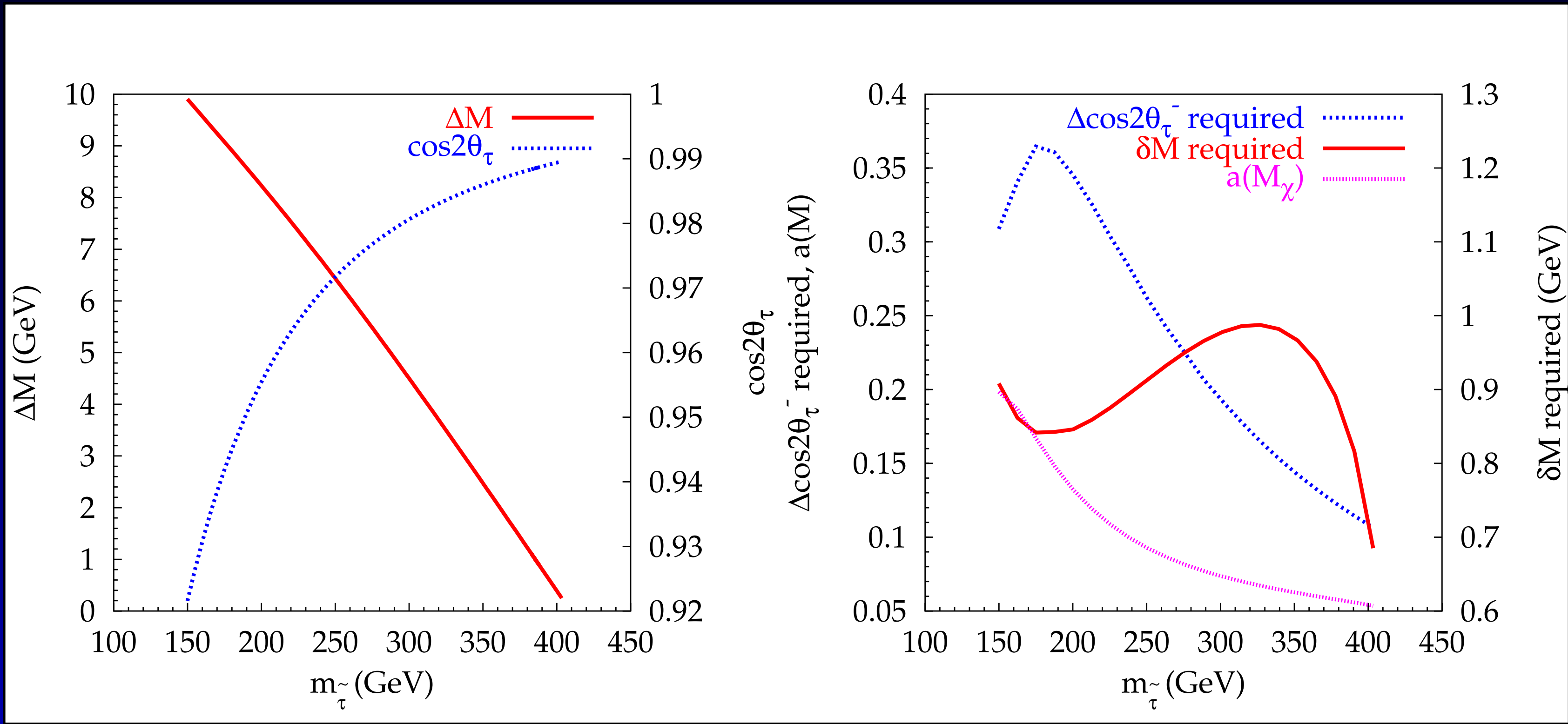
LHS: plots of quantities along mSUGRA slope. Below $\Delta M = 1.78$ GeV, no two-body stau decay. LC studies indicate $\Delta M > 5$ GeV is OK.

PmSUGRA Dependencies



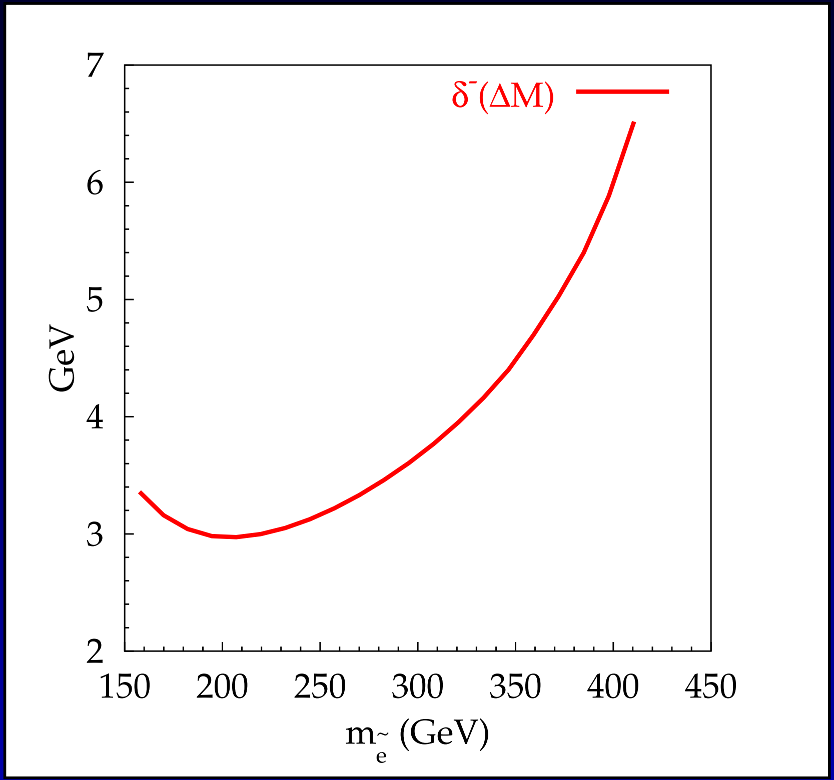
$\tilde{\tau}_1 \chi_1^0 \rightarrow \tau\gamma \propto 3\cos 2\theta_\tau + 5$ from coupling of neutralino to $\tilde{\tau}_{L/R}$.

PmSUGRA Dependencies



$a(M_\chi)$ found by keeping ΔM constant, δM by just varying stau mass. $m_{\tilde{e}}, m_{\tilde{\mu}}$ *needed to about* 1.5%

Slepton Dependence



Accuracy required on $m_{\tilde{l}} - m_{\chi_1^0}$ for WMAP precision. LC studies say this is acheivable, but need more work for $\cos\theta_\tau$ (=0.987±0.06 at lower end of slope).

Summary

- Markov chains bring out the multi-dimensionality of the space: is a lot less constrained than in 2d
- Still, current data is constraining
- LHC could produce copious amounts of SUSY dark matter
- Want to measure σ in order to predict Ωh^2 and test cosmological assumptions
- 10% accuracy will require ILC+LHC data
- Can control many uncertainties by measuring additional quantities: Γ_A, $m_{\tilde{\tau}} - M_{\chi_1^0}$, $\ldots$
- Non mSUGRA case could well be easier.
- Have *not* discussed direct detection yet

Supplementary Material

Likelihood

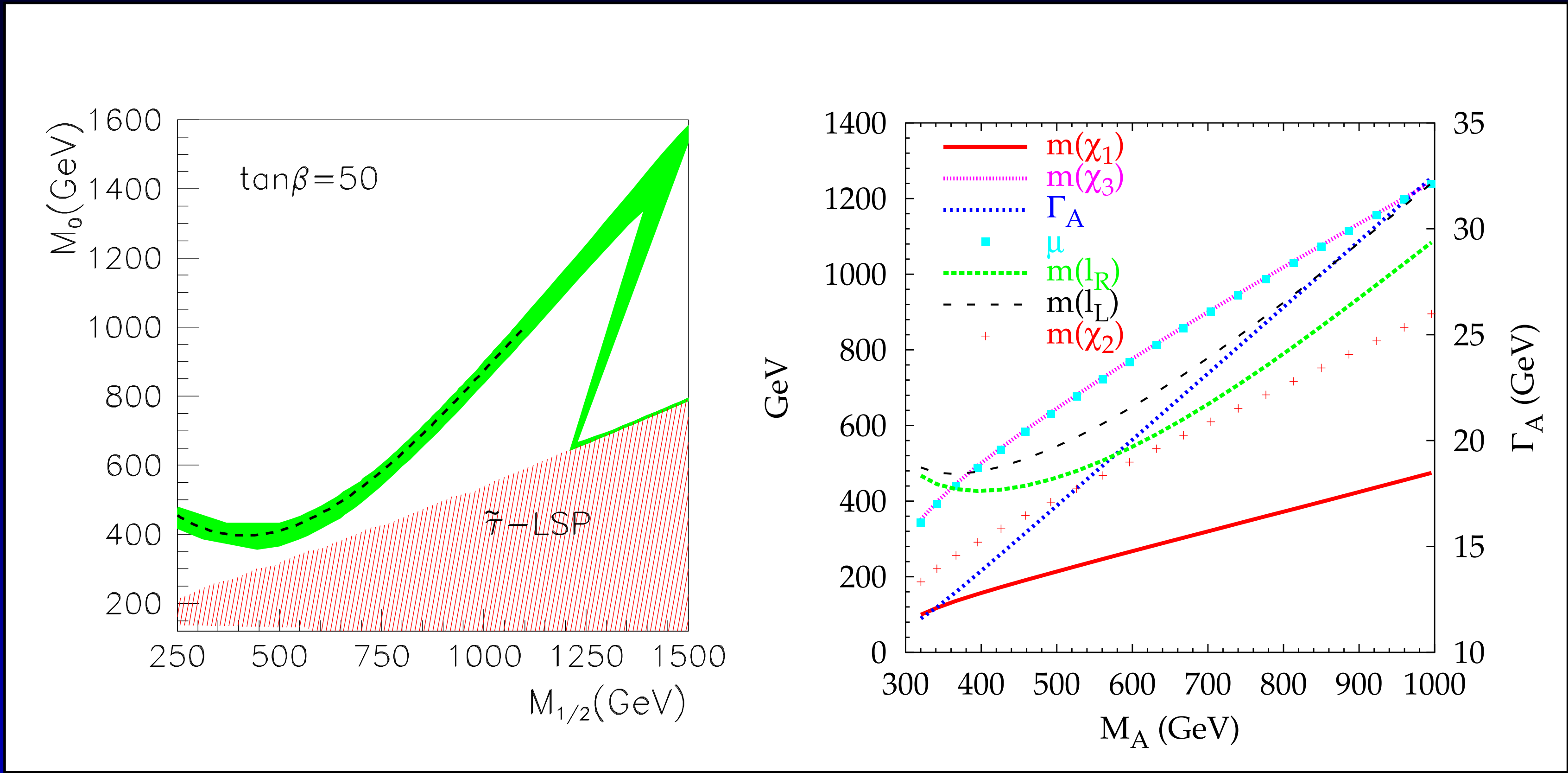
$\mathcal{L} \equiv p(d|m)$ is pdf of reproducing data d assuming mSUGRA model m (which depends on parameters).

$$p(m|d) = p(d|m)\frac{p(m)}{p(d)}$$

$$\frac{p(m_1|d)}{p(m_2|d)} = \frac{p(d|m_1)p(m_1)}{p(d|m_2)p(m_2)}$$

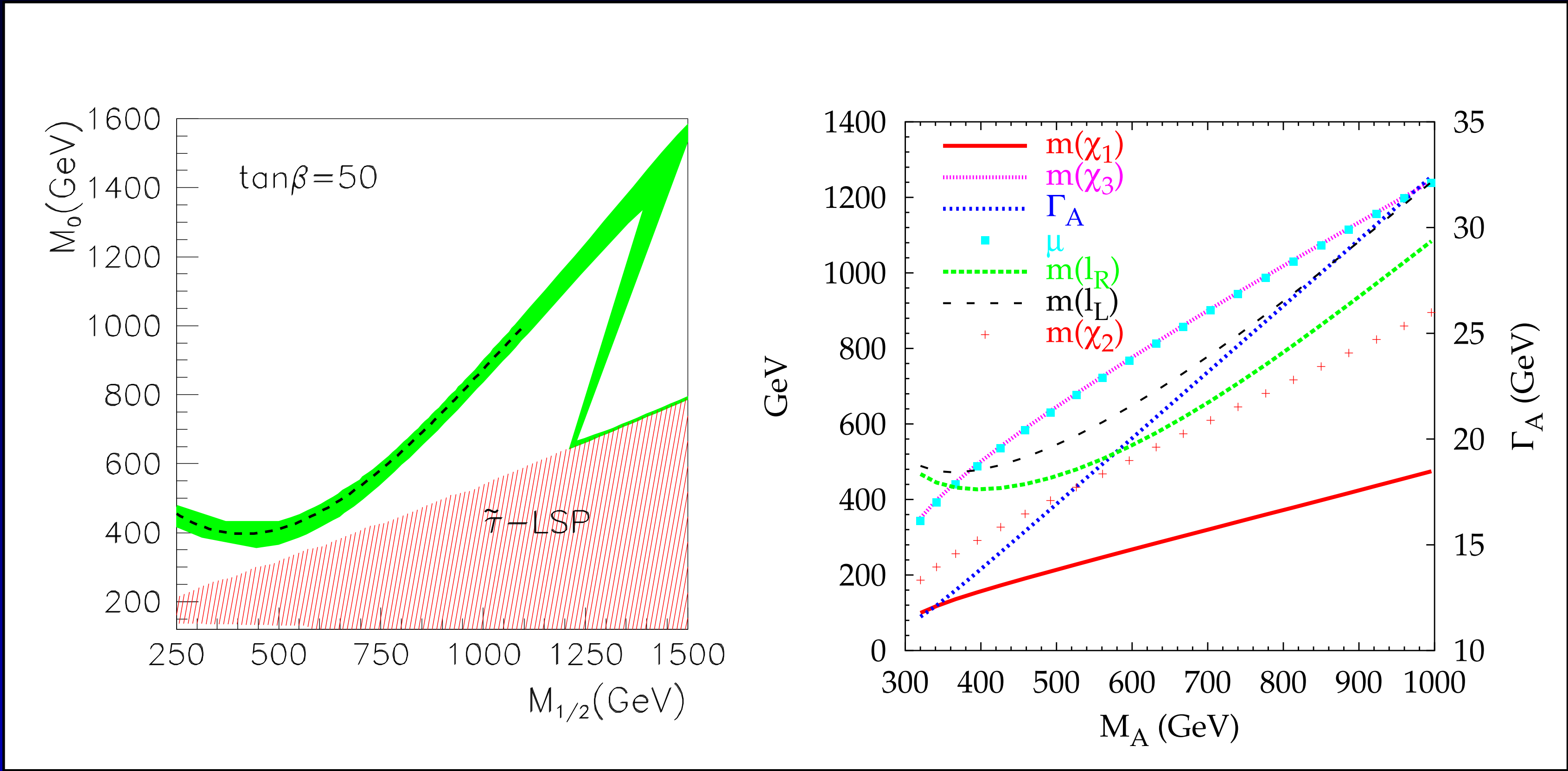
Thus, you can interpret the likelihood distribution as relative probabilities if your ratio of priors is 1. Otherwise, convolute it with YOUR priors!

Funnel Slope



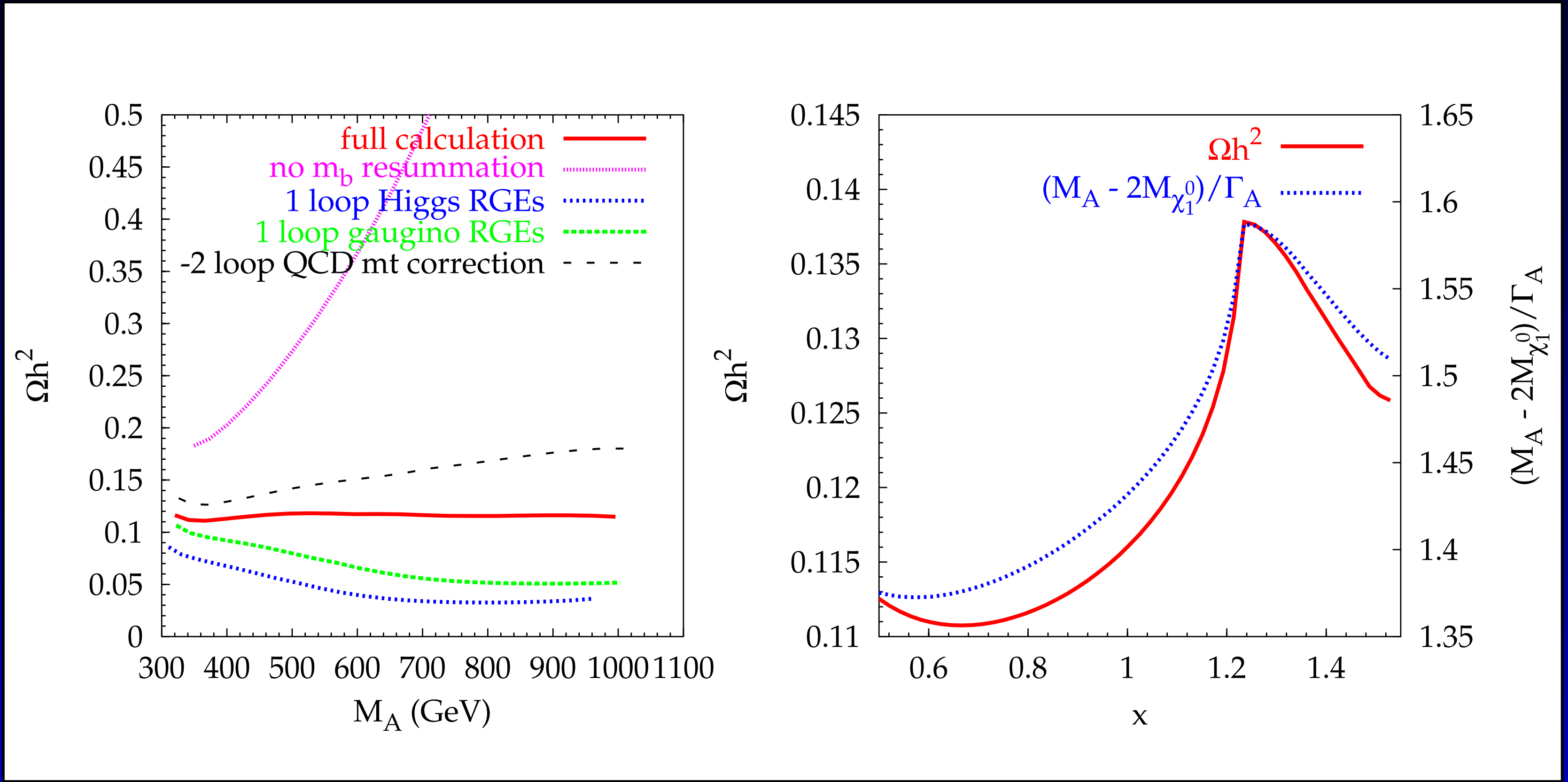
$$< \sigma v >^{-1} \sim \frac{4 m_{\chi_1^0} \Gamma_A}{g^2_{m_{\chi_1^0} \tilde{\chi}_1^0 A}} \left(4 \left(\frac{M_A - 2 m_{\chi_1^0}}{\Gamma_A} \right)^2 + 1 \right).$$

Funnel Slope



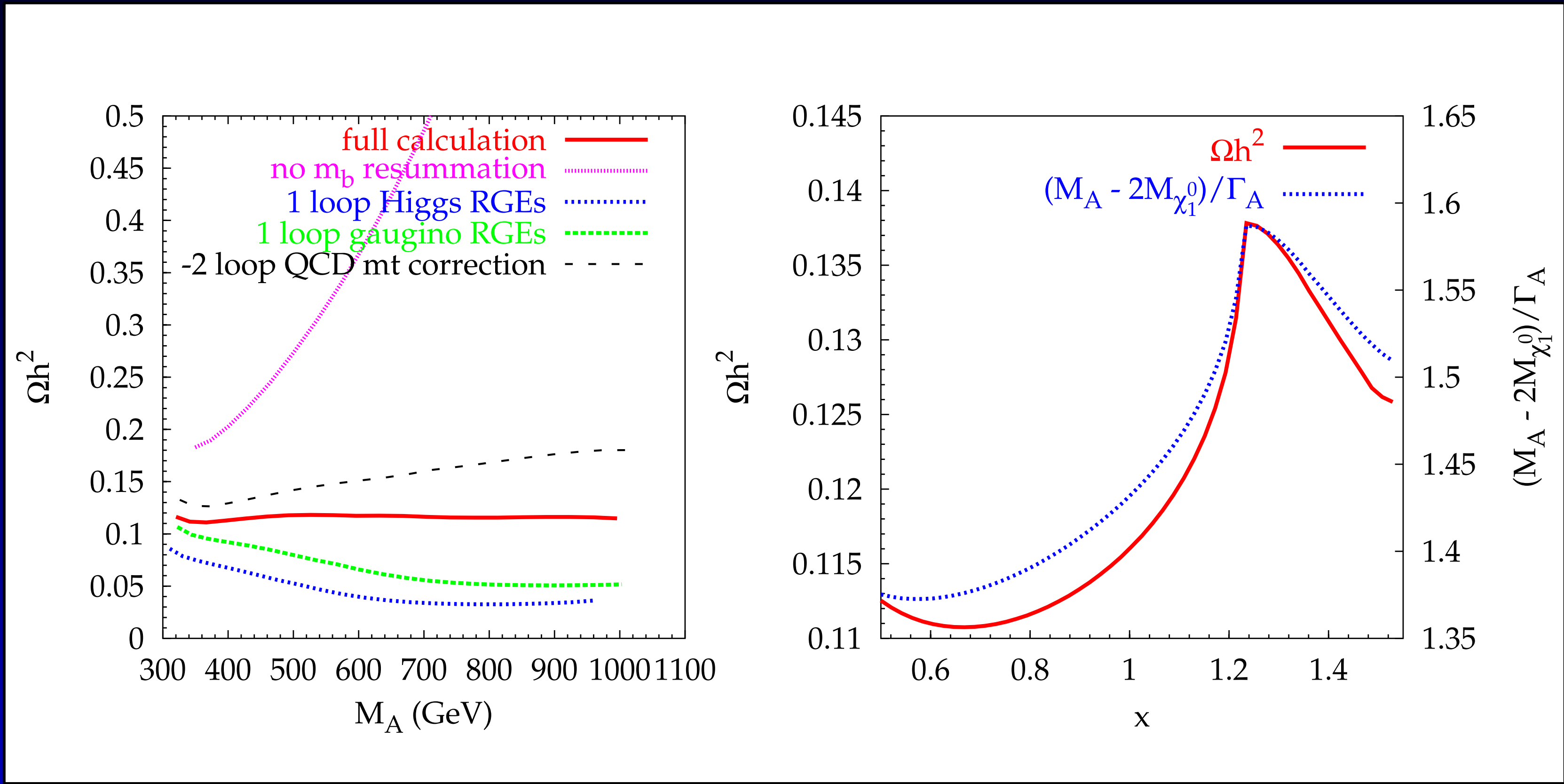
Notice that spectrum is quite *heavy*: need a high energy ILC! Γ_A will be important.

Funnel Theory Uncertainties



LHS: Γ_A affected by large $m_b^{SM}/(1+\Delta_{SUSY})$ corrections since $A \to b\bar{b} \propto Ab\bar{b}$ coupling $\propto m_b \tan\beta$, and $\tan\beta = 50$.

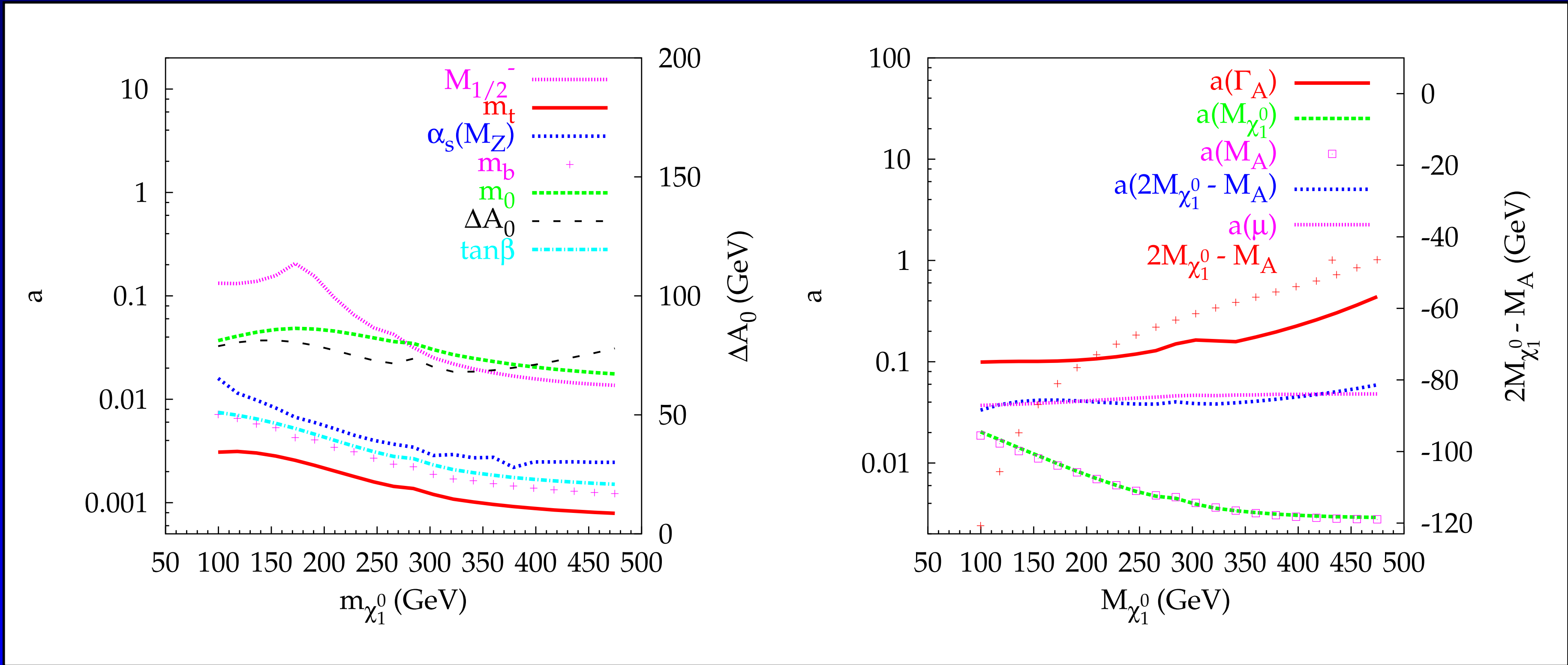
Funnel Theory Uncertainties



RHS: $x > 1.5$ yielded $M_A^2 < 0$ ie no EWSB. Strong correlation of theory error with its effect on $(M_A - 2M_{\chi_1^0})/\Gamma_A$ - could measure it!

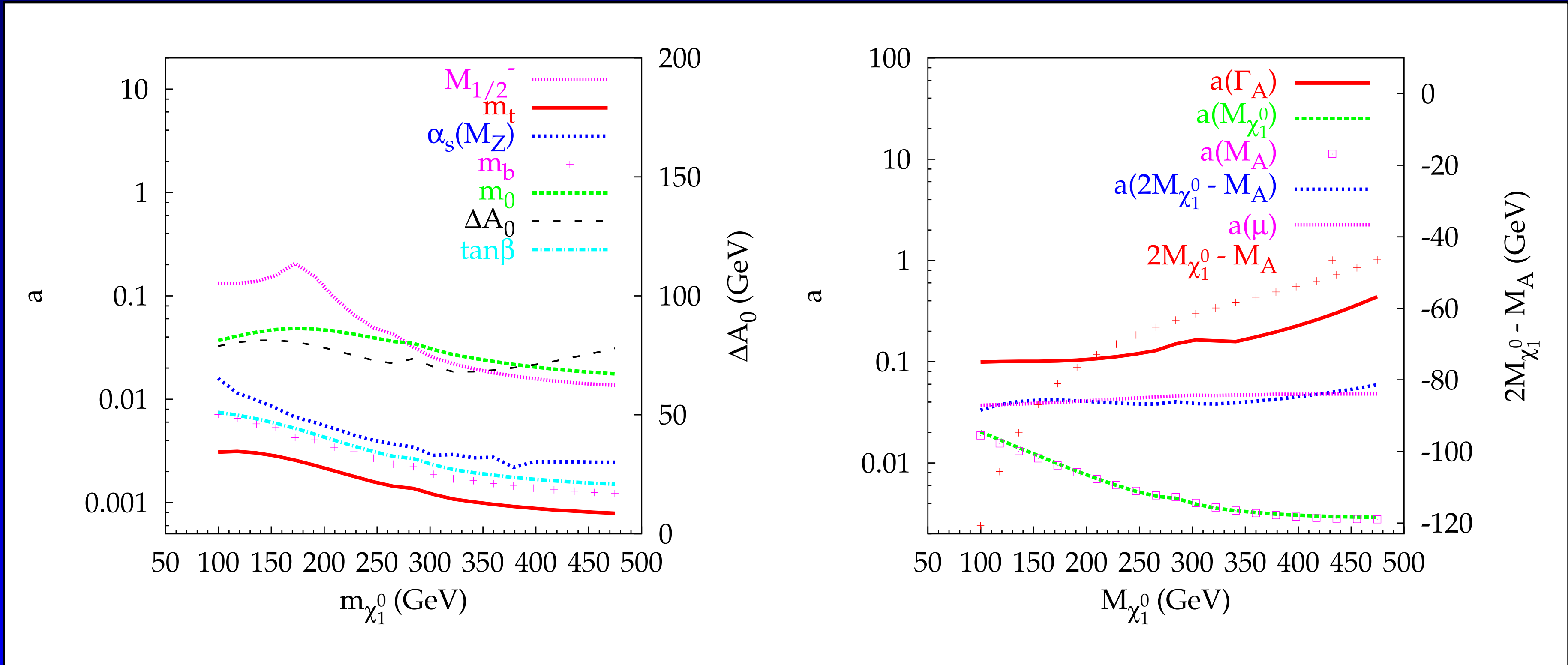
Funnel Accuracies

LHS: mSUGRA. $a(m_b)$ *worrying*. $\alpha_s(M_Z)$ dependence comes about through its effect on $m_b(m_b)$. m_0, $M_{1/2}$ might be feasible at LHC, m_t possible at ILC. $\tan\beta$ looks impossible.



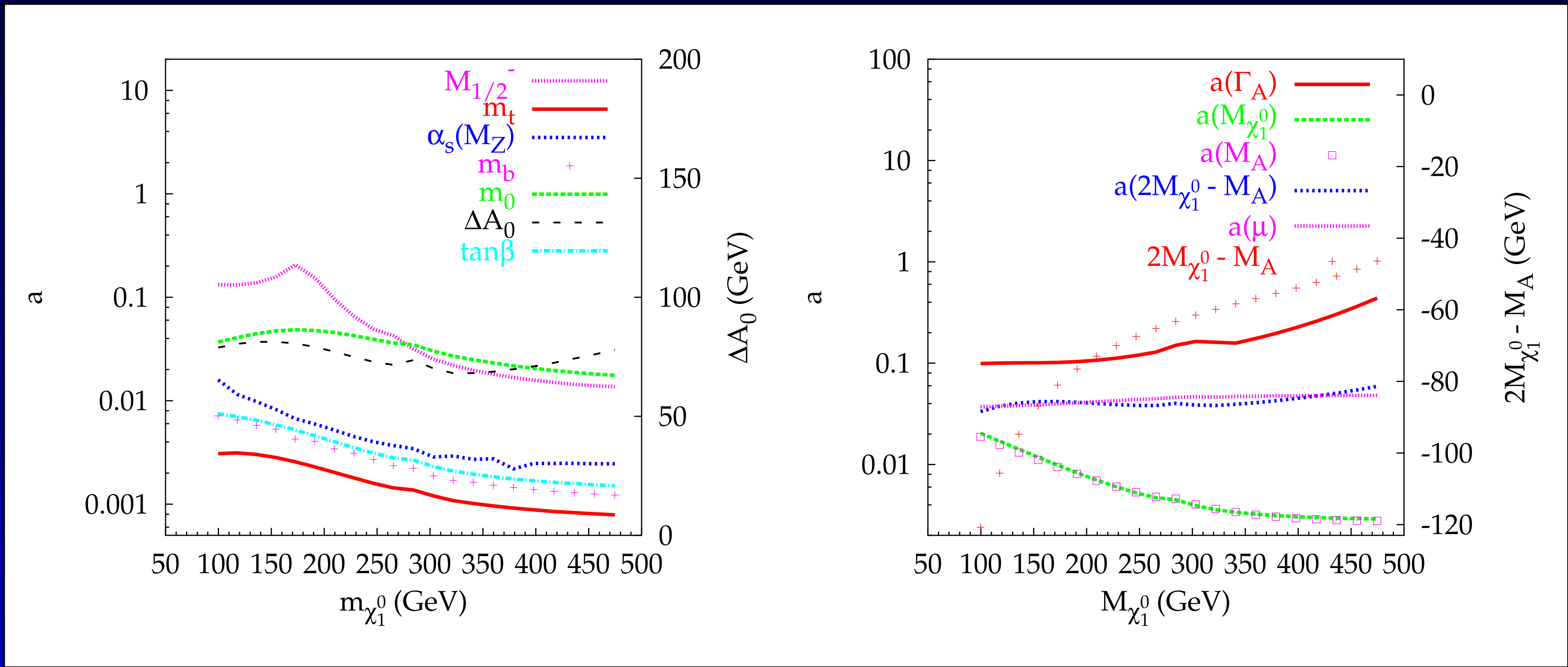
Funnel Accuracies

SM inputs and $\tan\beta$ uncertainties can be controlled by measuring M_A, Γ_A. $A\chi_1^0\chi_1^0$ coupling $\sim 1/\mu$. $\Gamma_A \propto M_A \tan^2\beta(m_b^2 + m_\tau^2)$ ($\gamma\gamma$ option of LC, $A \to \mu\mu$ at LHC).

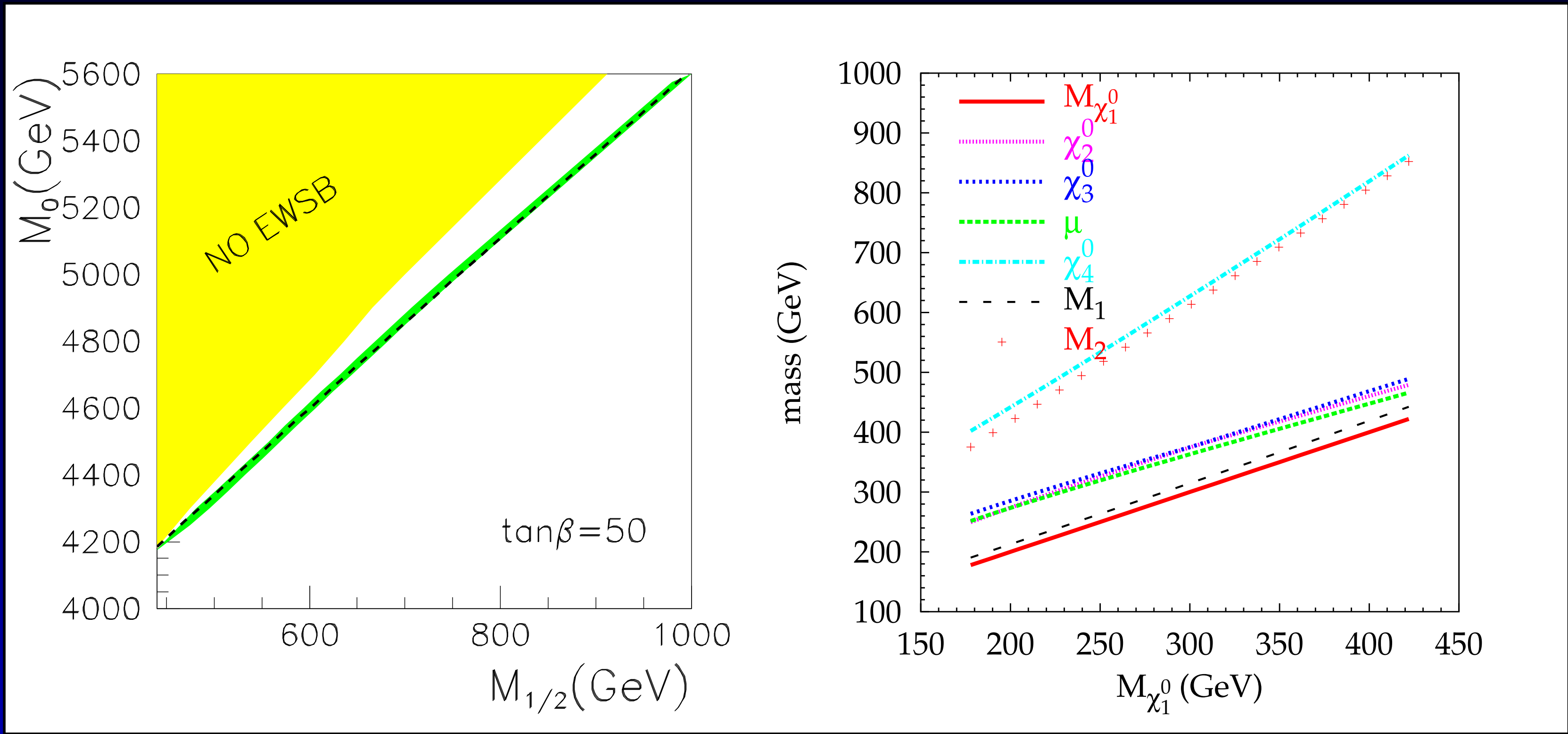


Funnel Accuracies

Mass of χ_1^0 is important, but not mixing (see $a(\mu)$).

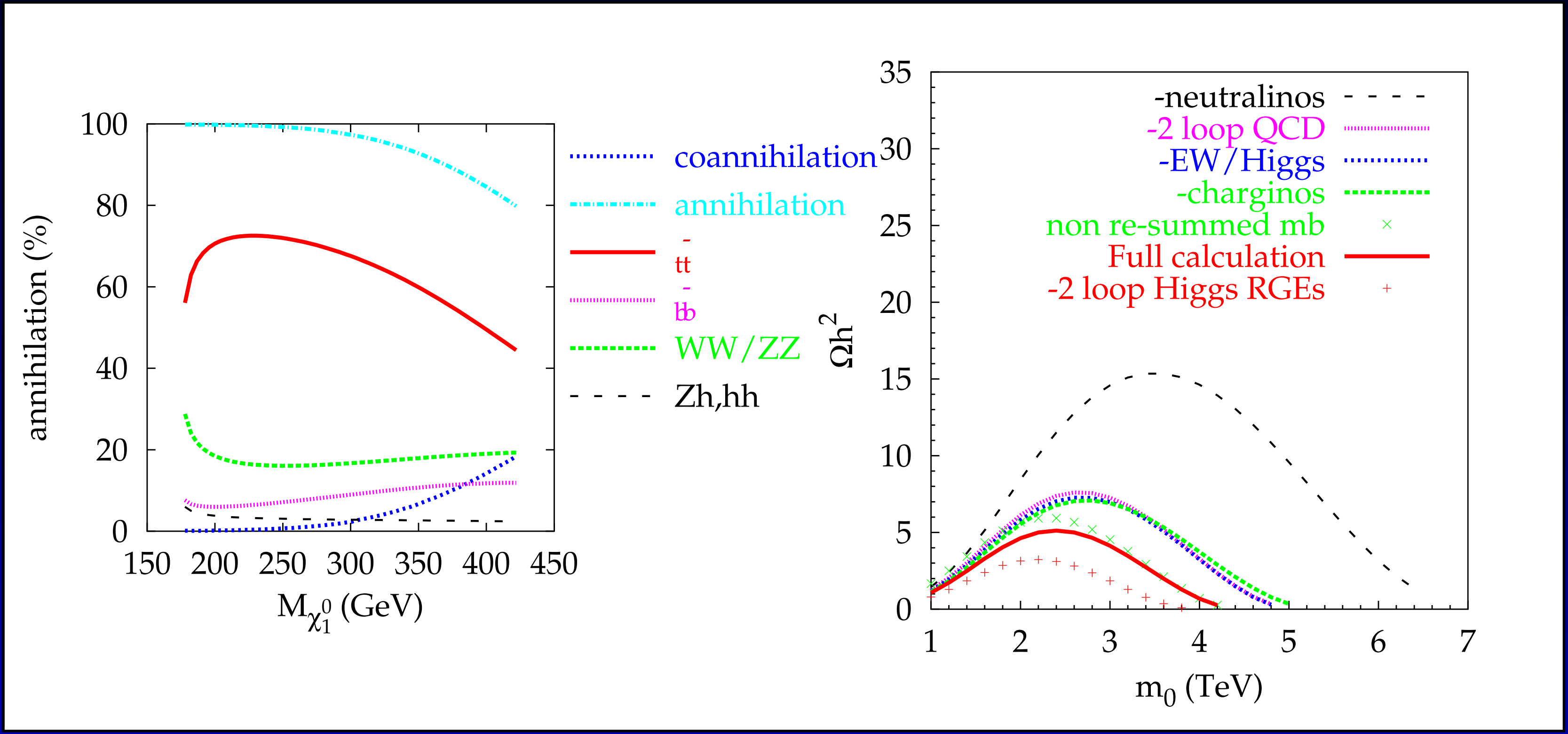


Focus Point Slope



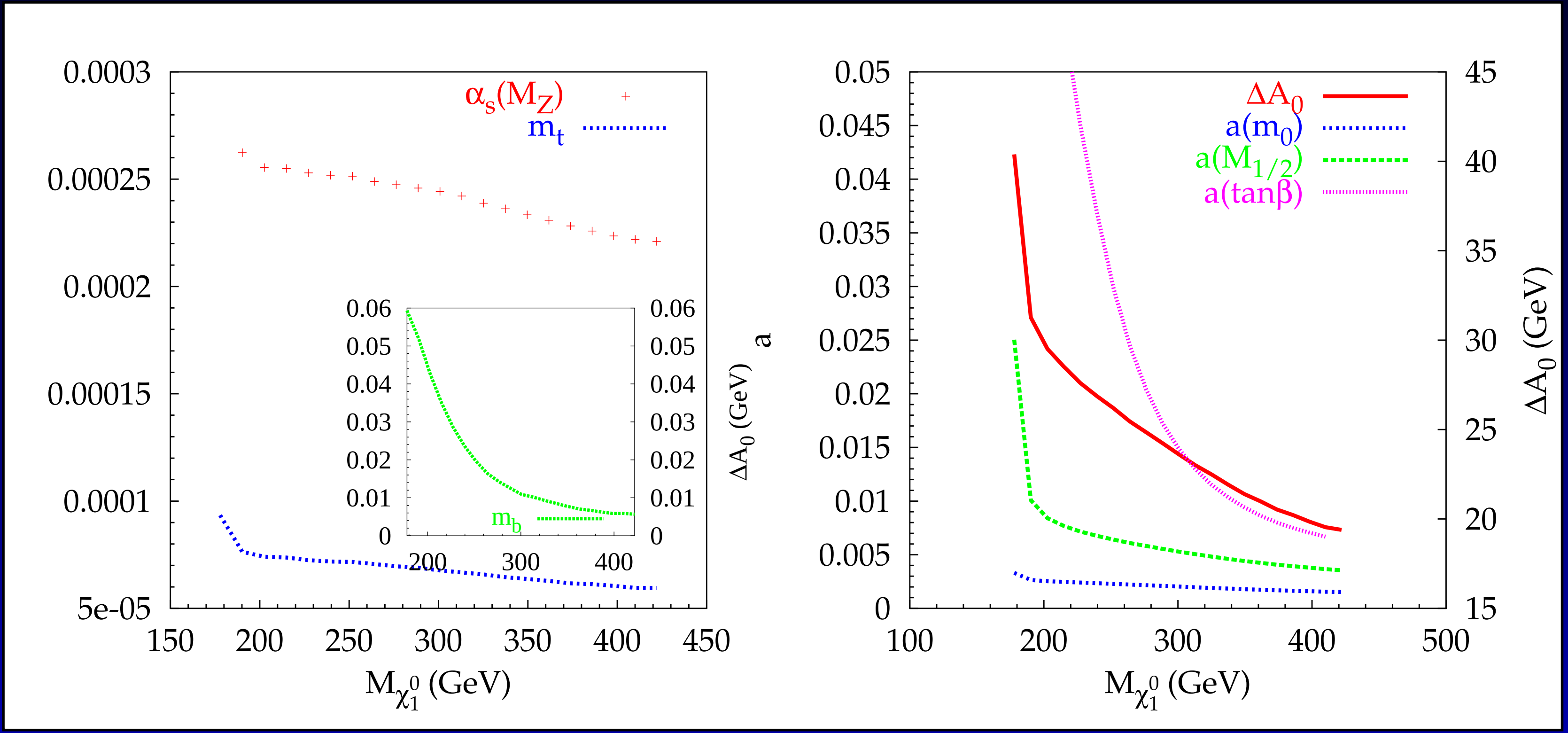
Heavy sfermions and A^0. $M_1 < \mu < M_2$, ie significant *Higgsino* component $\sim 25\%$.

Focus Channels and Theory



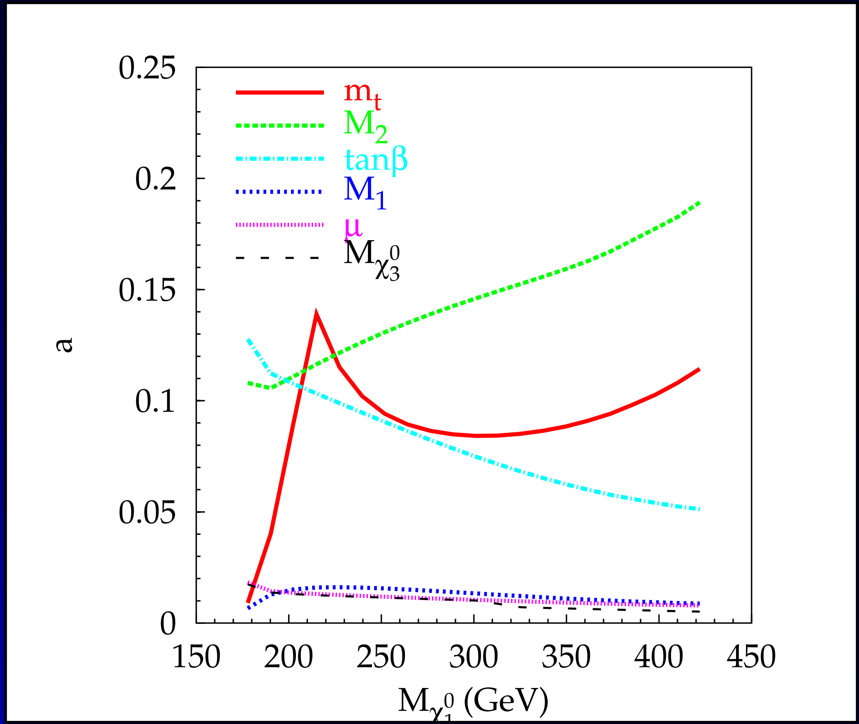
$t\bar{t}$ annihilation predominantly through Z. Coannihilation $\equiv \chi_1^0\chi_i^0$ or $\chi_1^0\chi_1^\pm$. Several competing channels.

Focus mSUGRA Accuracies



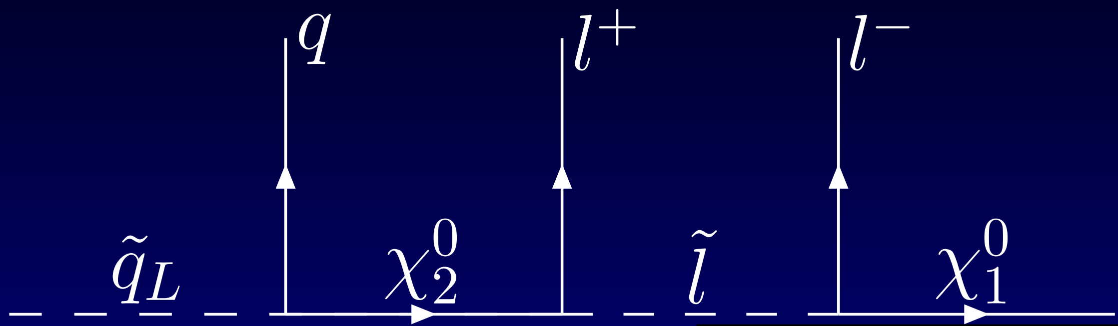
$\delta m_t = 30$ MeV might be possible at future ILC but $a(m_0) < 0.5\%$ looks completely unfeasible.

Focus PmSUGRA Accuracies



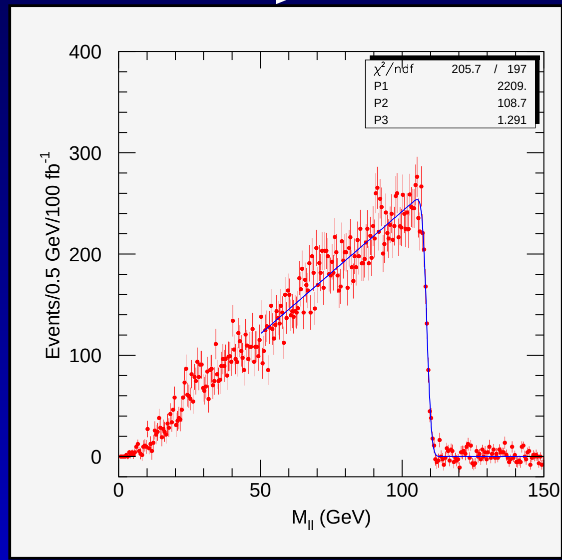
Easier outside of mSUGRA, eg μ no longer sensitive to m_t ($\propto$ coupling to neutral goldstone).

LHC SUSY Measurements



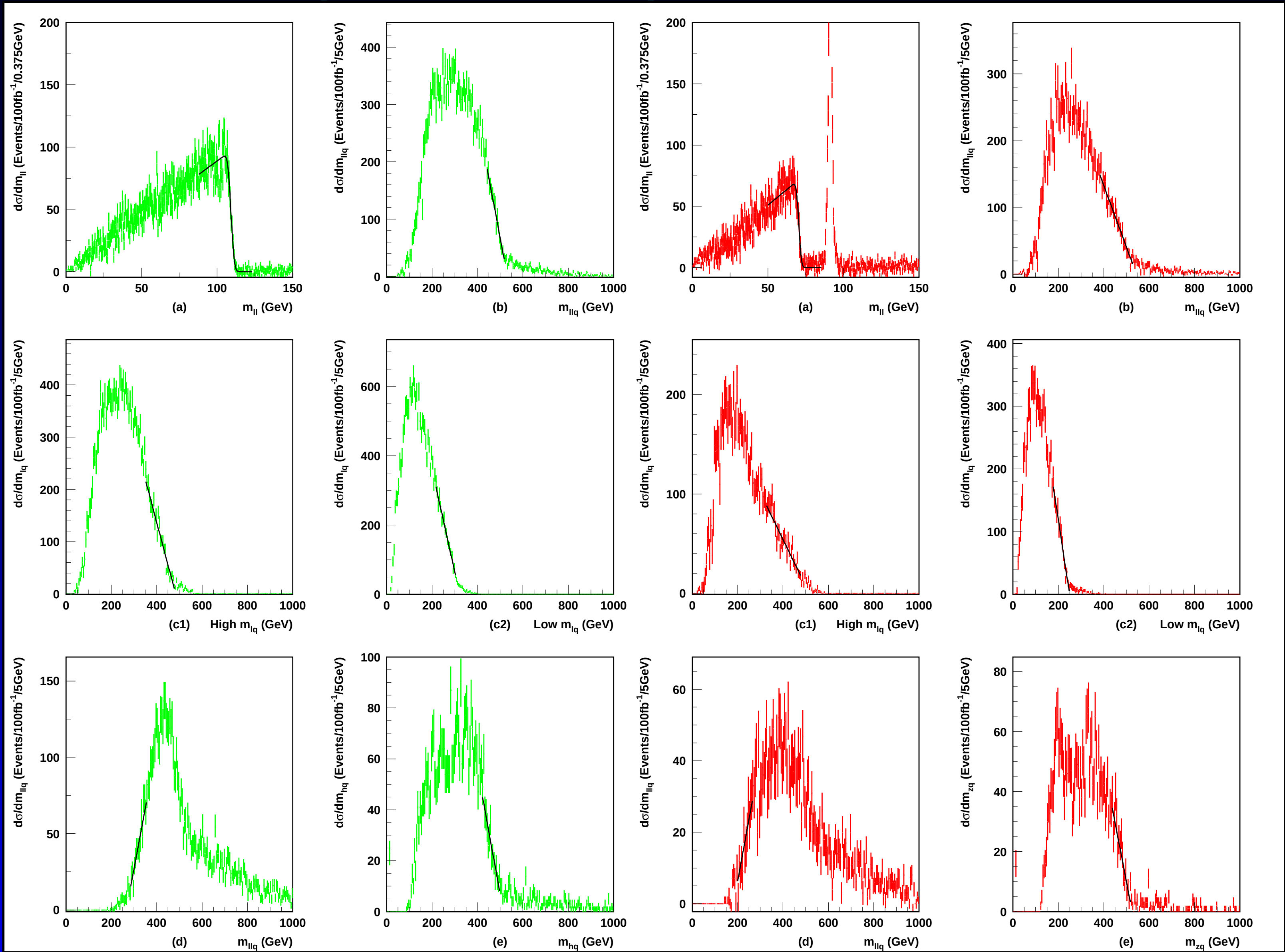
$m_{ll}^2 = (p_{l_1} + p_{l_2})^2$ edge position measures

$$\sqrt{\frac{(m^2_{\chi^0_2} - m^2_{\tilde{l}})(m^2_{\tilde{l}} - m^2_{\chi^0_1})}{m^2_{\tilde{l}}}}$$



BCA, C Lester, A Parker, B Webber, JHEP 09 (2000) 004

Edge Fitting at S5 and O1



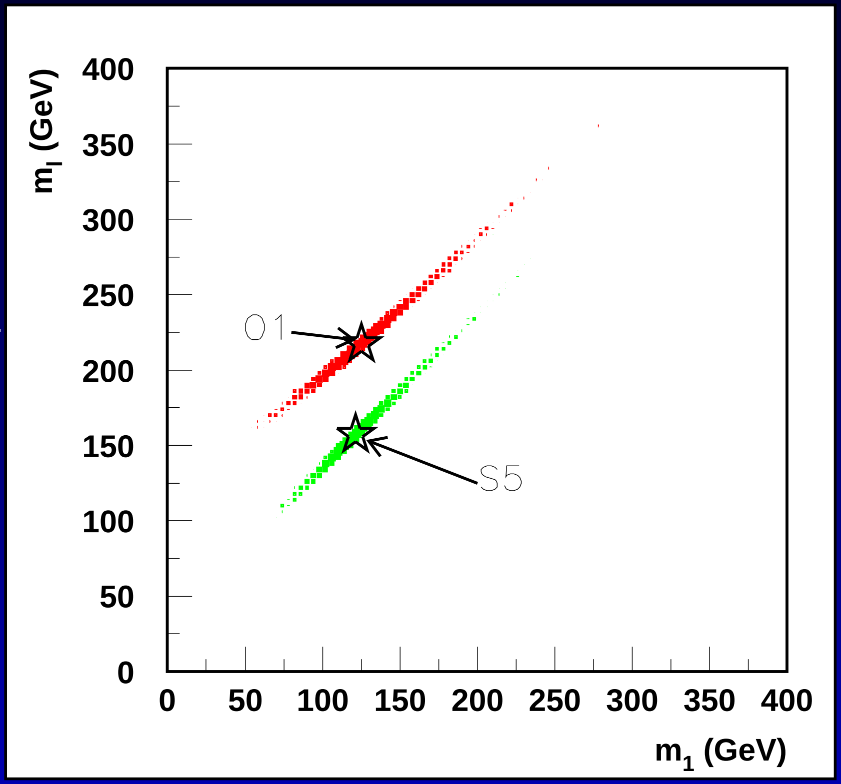
Edge Positions

endpoint	S5 fit	O1 fit
m_{ll}	109.10±0.13	70.47±0.15
m_{llq} edge	532.1±3.2	544.1±4.0
lq high	483.5±1.8	515.8±7.0
lq low	321.5±2.3	249.8±1.5
llq thresh	266.0±6.4	182.2±13.5

Best case lepton mass measurements can be as accurate as 1 per mille, but jets are a few percent

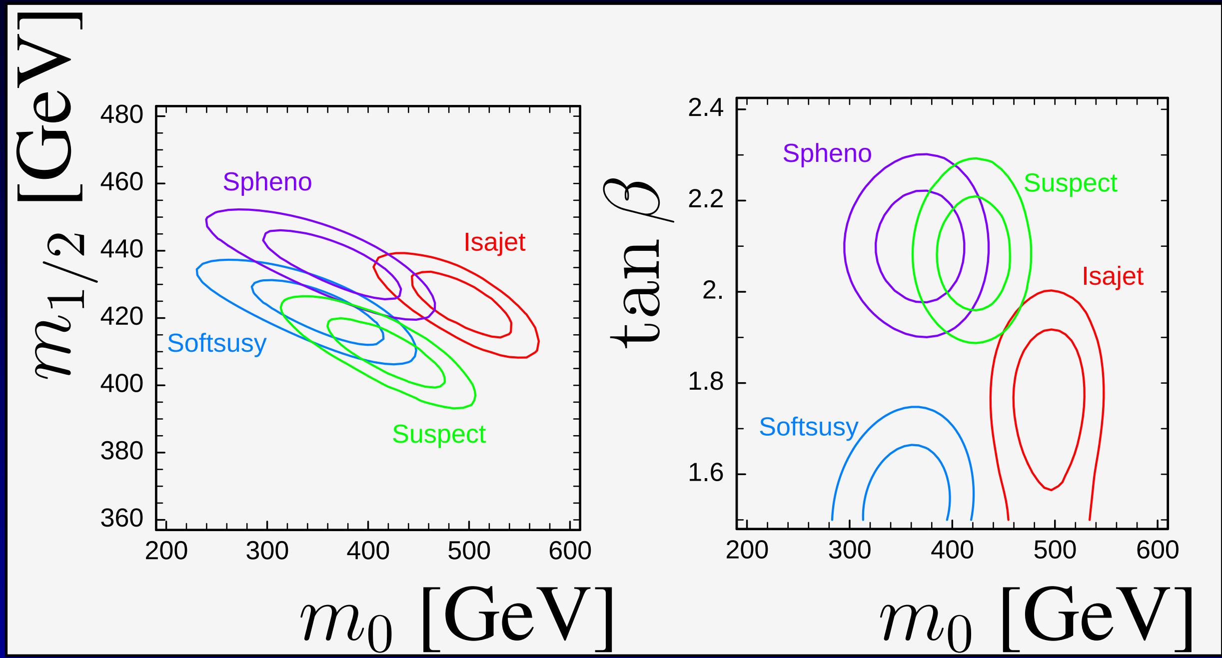
Edge to Mass Measurements

	width S5	width O1
χ_1^0	17	22
$\tilde{l}_R$	17	20
χ_2^0	17	20
$\tilde{q}$	22	20



Mass differences well constrained, but overall mass scale not so well constrained by LHC

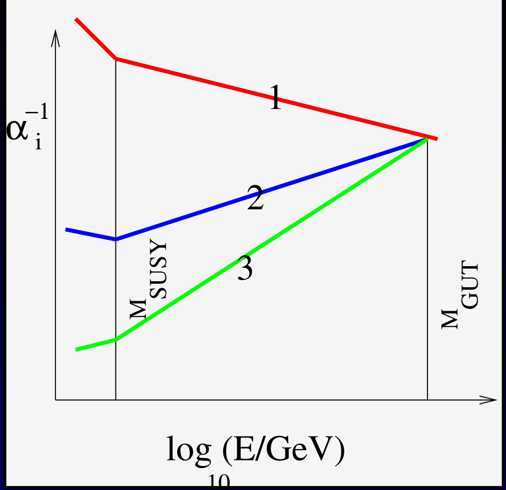
Fitting to SUSY Breaking Model



- Experimenters pick a SUSY breaking point
- They derive observables and errors after detector simulation
- We fit this "data" with our codes

BCA, S Kraml, W Porod, JHEP 0303 (2003) 016

SOFTSUSY



Get $g_i(M_Z)$, $h_{t,b,\tau}(M_Z)$.

↓

Run to M_S.

↓

REWSB, iterative solution of μ

↓

M_X. Soft SUSY breaking BC.

↓

Run to M_S. Calculate sparticle pole masses.

↓

Run to M_Z

BCA, Comp. Phys. Comm. 143 (2002) 305.

Other Observables

Often more complicated, eg m_{llq} edge:

$$\max\left[\frac{(m^2_{\tilde q}-m^2_{\chi^0_2})(m^2_{\chi^0_2}-m^2_{\chi^0_1})}{m^2_{\chi^0_2}}, \frac{(m^2_{\tilde q}-m^2_{\tilde l})(m^2_{\tilde l}-m^2_{\chi^0_1})}{m^2_{\tilde l}}, \right.$$

$$\left.\frac{(m_{\tilde q}m_{\tilde l}-m_{\chi^0_2}m_{\chi^0_1})(m^2_{\chi^0_2}-m^2_{\tilde l})}{m_{\chi^0_2}m_{\tilde l}}\right]$$

Also m_{lq}^{high}, m_{lq}^{low}, llq *threshold* , $M^2_{T_2}(m) =$

$$\min_{\not p_1+\not p_2=\not p_T}\left[\max\left\{m_T^2(p_T^{l_1},\not p_1, m), m_T^2(p_T^{l_2},\not p_2, m)\right\}\right],$$

$\max[M_{T_2}(m_{\chi^0_1})] = m_{\tilde l}]$ for dislepton production.

Statistics Study

- Choose two model-points: S5 ($m_0 = 100, m_{1/2} = 300, A_0 = 300, \tan\beta = 2.1, \mu > 0$) and O1 ($m_{\tilde{l}} = 177, m_{1/2} = 306, A_{\tilde{q}} = 137, m_{\tilde{q}} = 0, A_{\tilde{l}} = 306, \tan\beta = 10, \mu > 0$)
- Find cuts to measure "signal" endpoints
- Estimate expected accuracy of ATLAS measurement: 100 fb^{-1}
- Perform χ^2 fits of sparticle masses to expected positions of edges expected from an ensemble of experiments
- Interpret results as statistics of measurement on sparticle masses

Important points: there is no one

Cuts Example

We use ATLFAST2.16, HERWIG6.0, ISAWIG and ISAJET7.42. Assume 100 fb^{-1} of LHC data.

- $|\eta_j| \leq 5$, $p_T^j \geq 15$ GeV
- $p_T^e \geq 5$, $p_T^\mu \geq 6$, $|\eta_l| \leq 2.5$
- l isolation: 10 GeV in $\Delta R = 0.2$, $\Delta R(lj) \geq 0.4$.

eg for m_{ll}:

- 2 OSSF leptons, $p_T^{l_1} \geq p_T^{l_2} \geq 10$ GeV.
- $n_{jets} \geq 2$, $p_T^{j_1} \geq p_T^{j_2} \geq 150$ GeV, $\not{p}_T > 300$ GeV

OSSF-OSDF subtracts well the Standard Model background.

Uncertainties in Relic Density

Bulk region: $\tilde{B}\tilde{B} \rightarrow Z, h \rightarrow l\bar{l}$. Coannihilation: $\tilde{\tau}\chi_1^0 \rightarrow \tau + X$

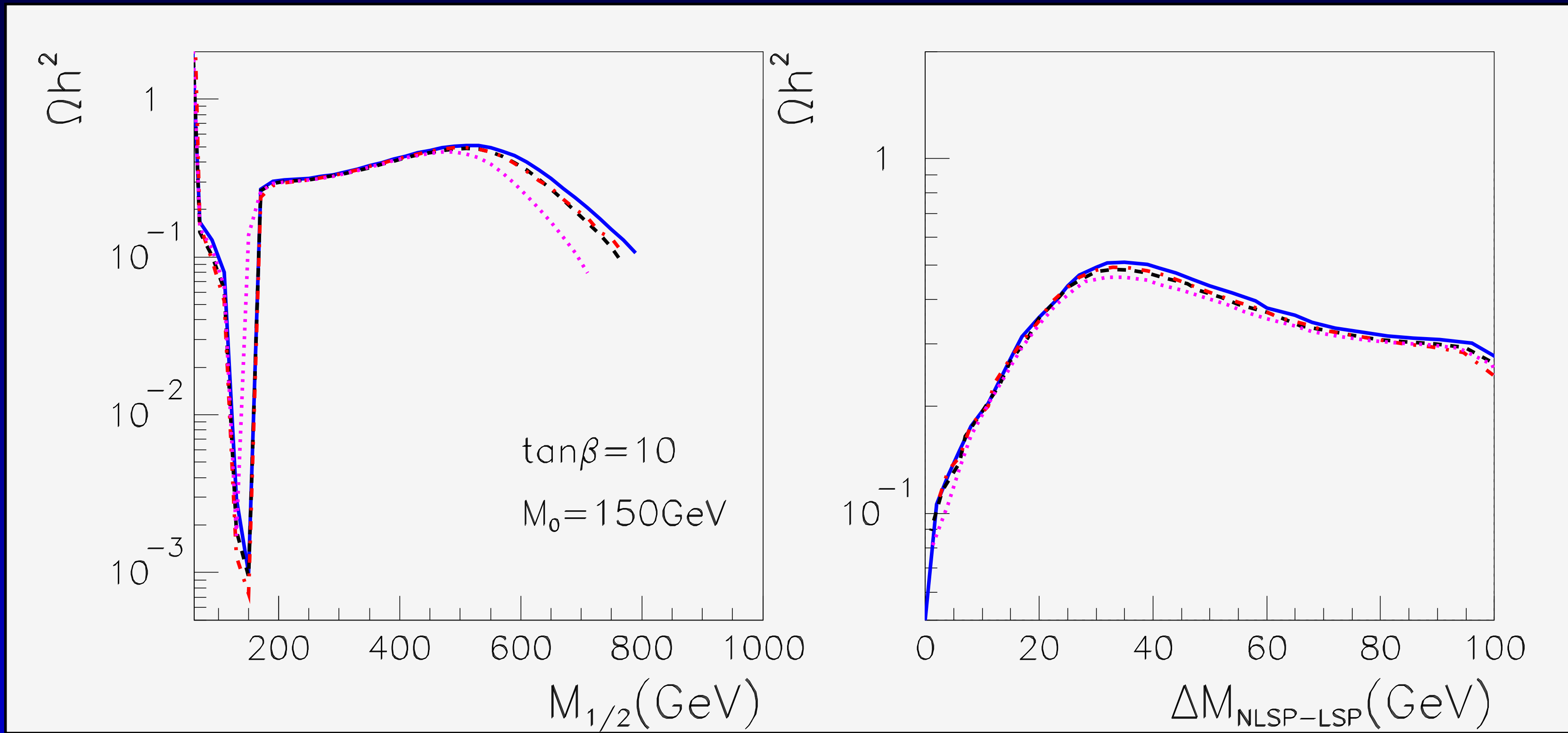


Figure 0: Bulk/coannihilation region. Full: `SoftSusy`, dotted: `SPheno`.

Focus Point

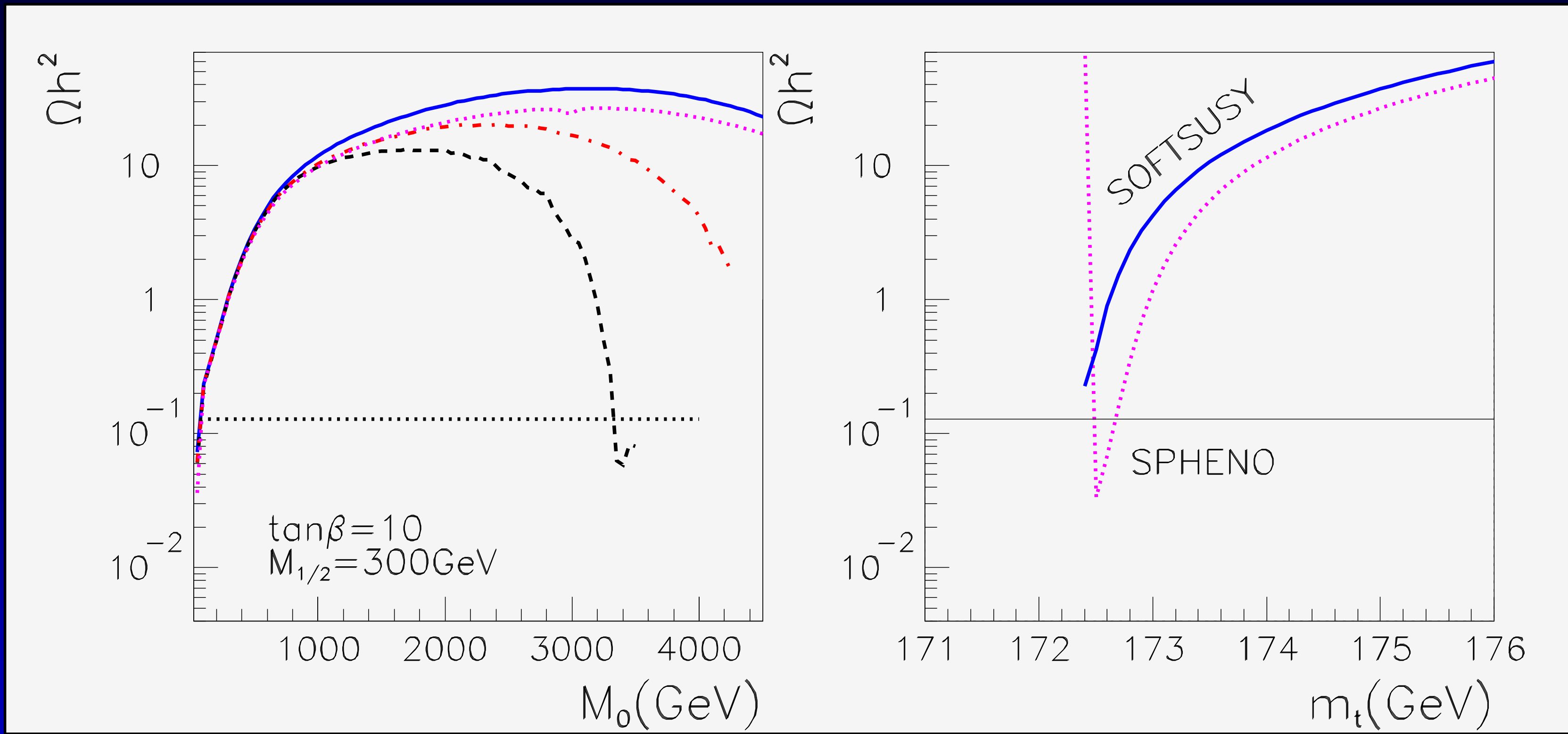


Figure 0: Focus point region. Full: `SoftSusy`, dotted: `SPheno`, dashed: `SuSpect`. Higgsino LSP annihilates into ZZ/WW

High $\tan\beta$

BCA, Belanger, Boudjema, Pukhov, Porod, hep-ph/0402161. Baer *et al*

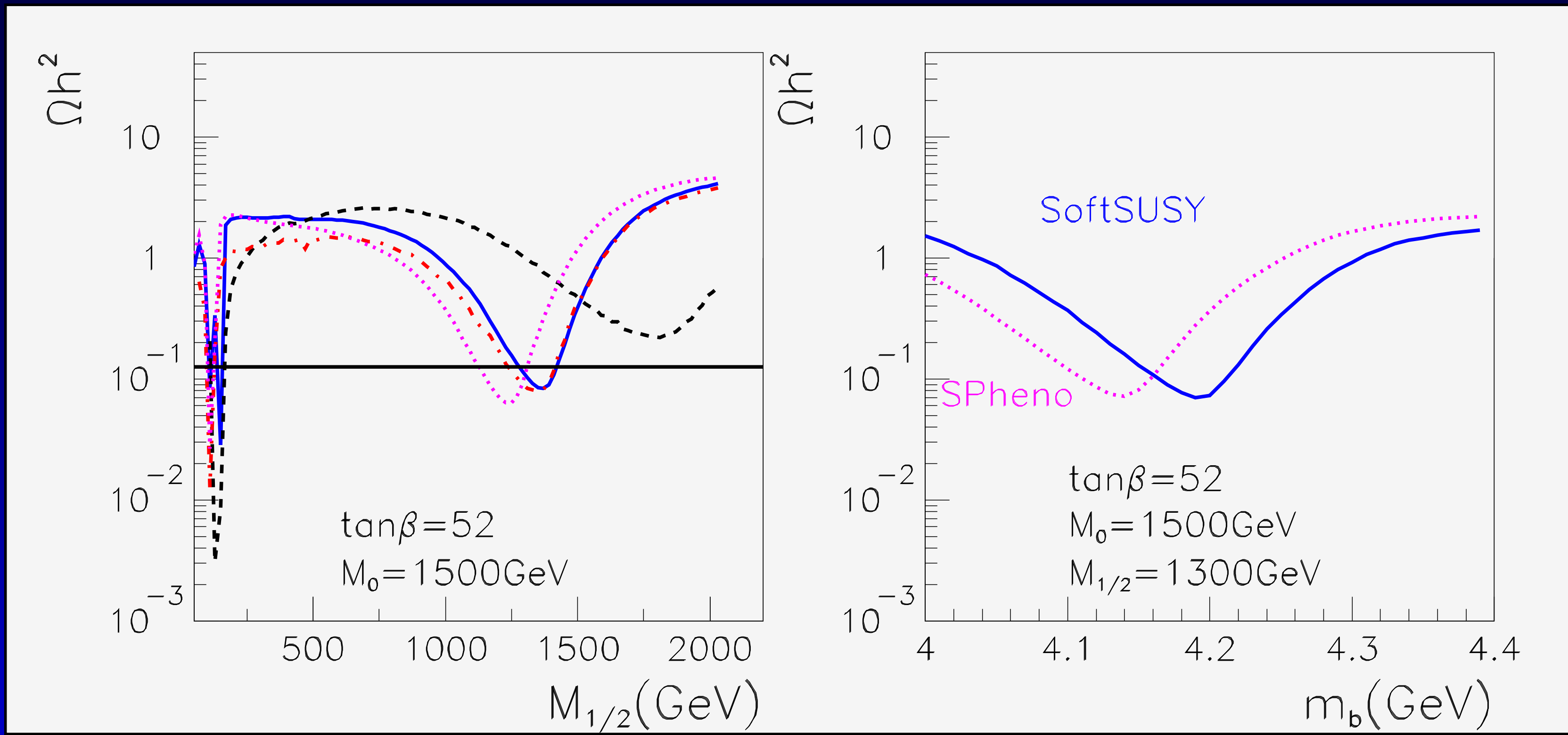


Figure 0: High $\tan\beta$ region. Full: `SoftSusy`, dotted: `SPheno`, dashed: `SuSpect`. Get annihilation into A.