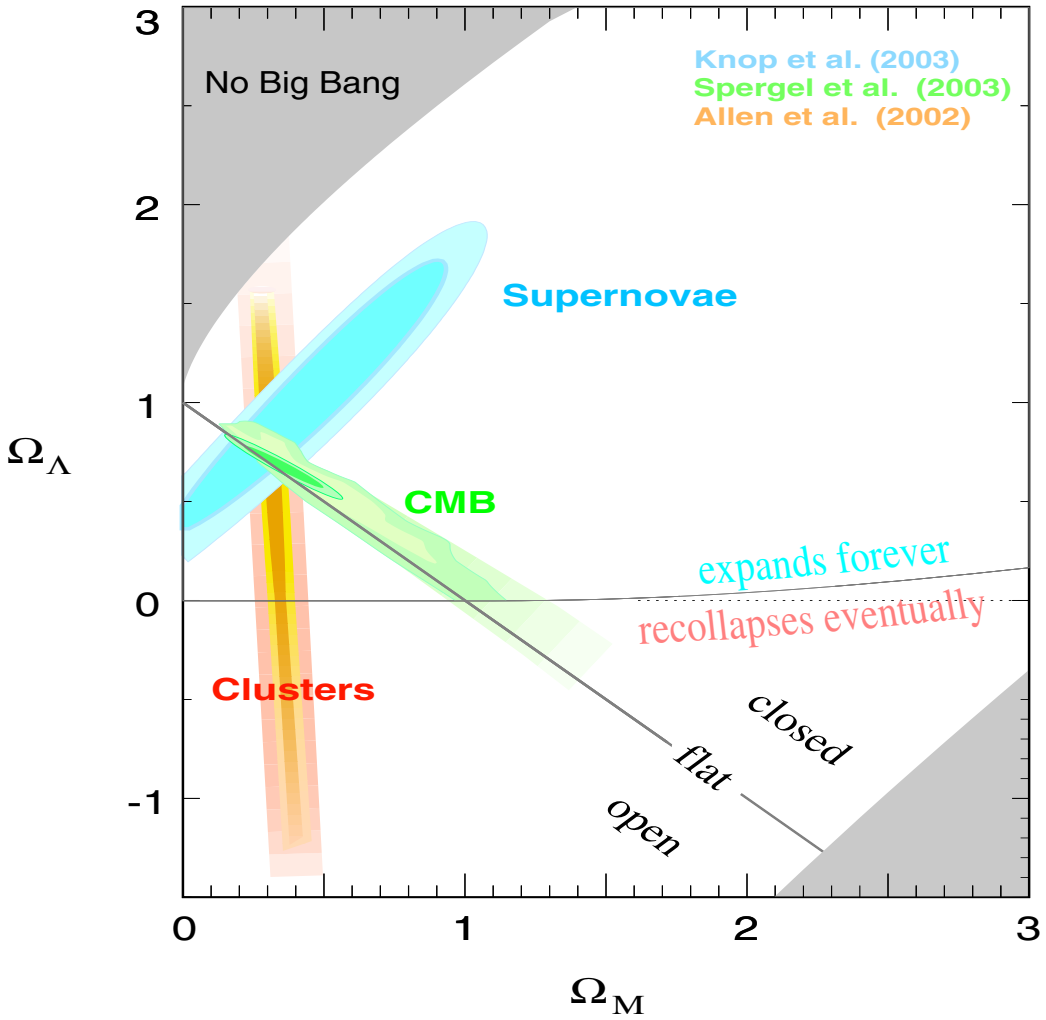
Investigating SUSY Dark Matter at the ILC

Werner Porod

IFIC-CSIC

- Cosmological data and dark matter candidates
- Neutralino LSP
- Gravitino LSP
- Theoretical uncertainties
- Conclusions

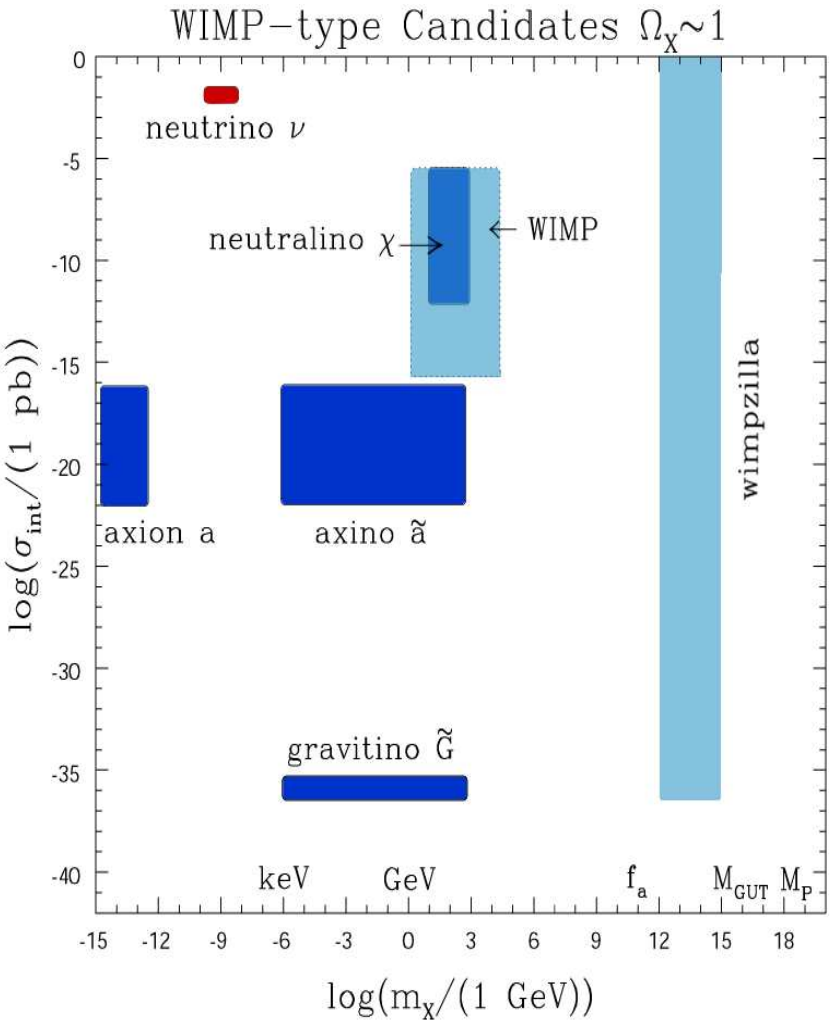
Cosmological Data



$$\Omega_B = (4 \pm 0.4)\%$$
$$\Omega_{DM} = (23 \pm 4)\%$$
$$\Omega_\Lambda = (73 \pm 4)\%$$

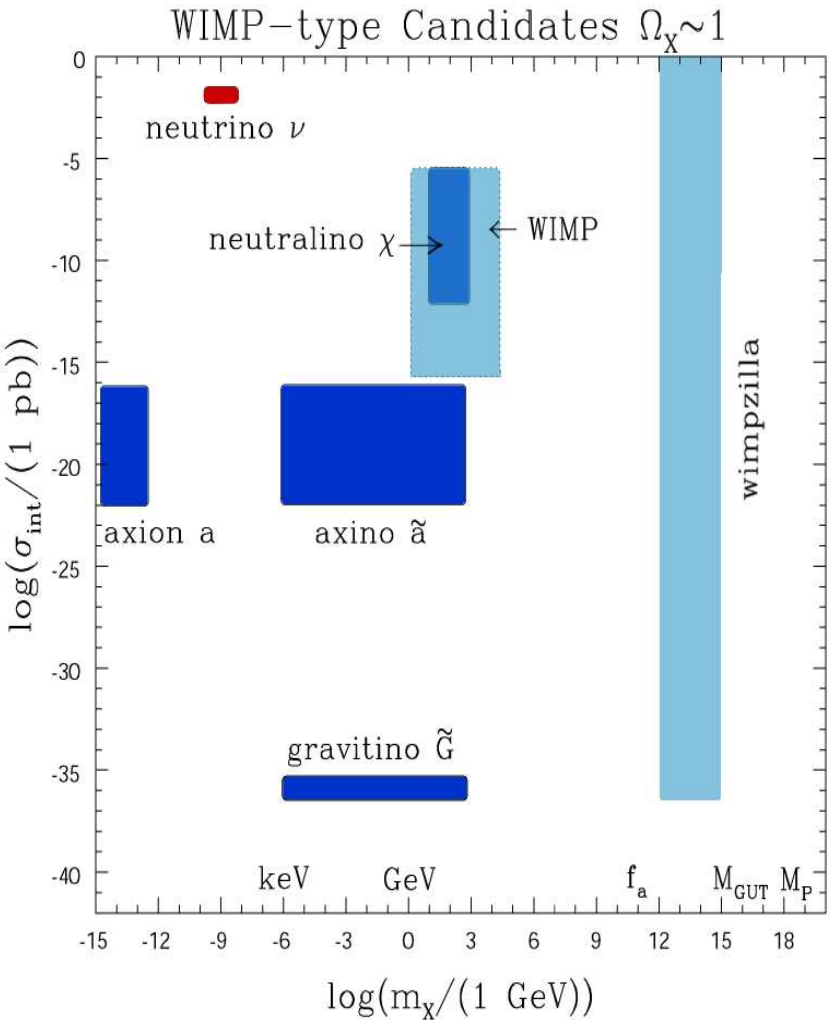
R.A. Knopp et al., astro-ph/0309368

Dark Matter Candidates



L. Roszkowski, astro-ph/0404052

Dark Matter Candidates



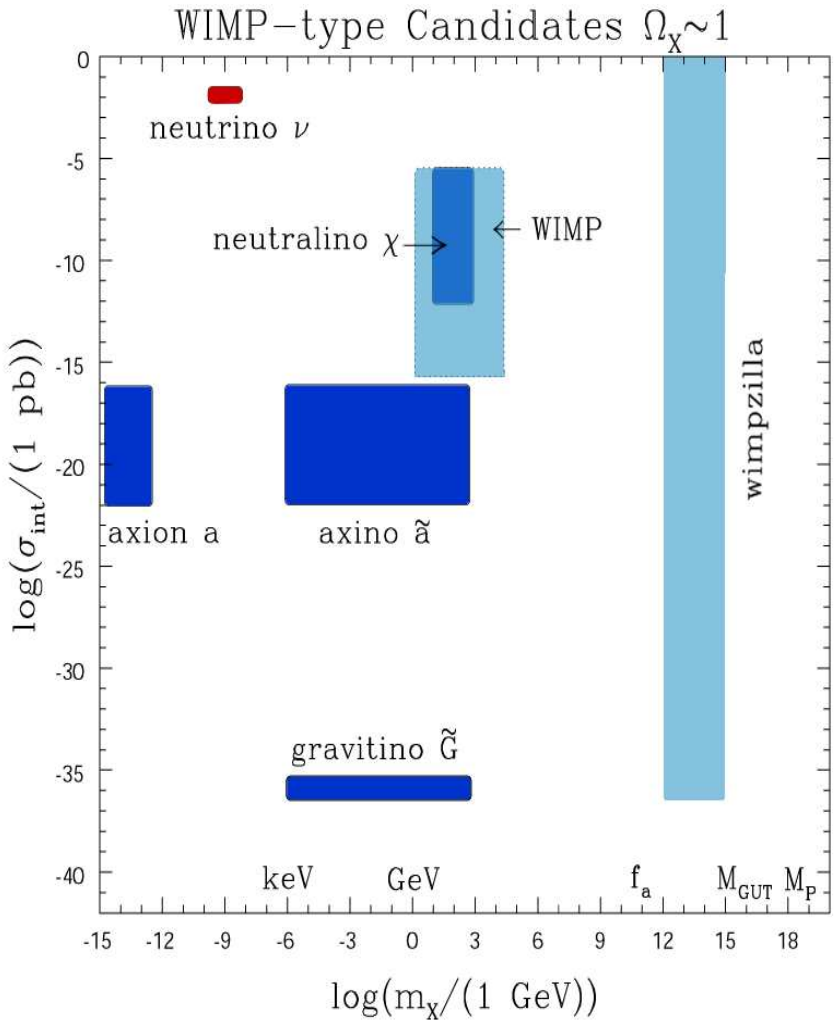
$$\tilde{\chi}_i^0 = N_{ij}(\tilde{\gamma}, \tilde{Z}, \tilde{h}_d^0, \tilde{h}_u^0)_j$$

main parameters:

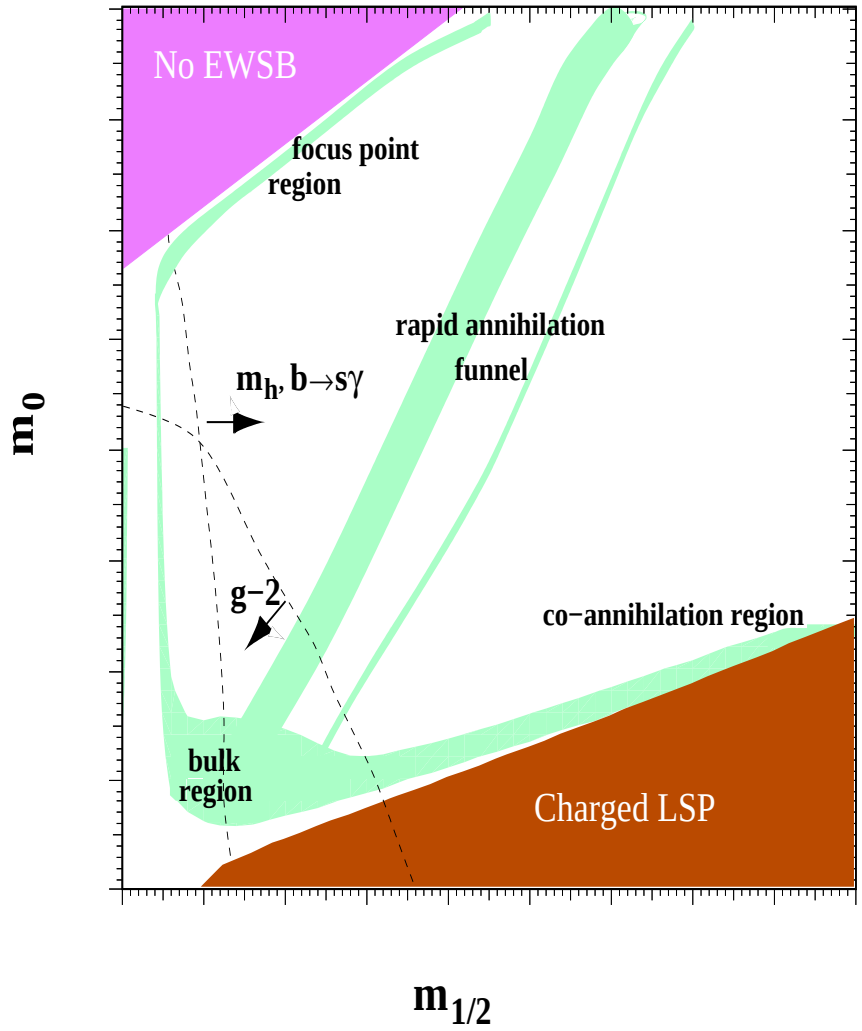
$M_1,\ M_2,\ \mu,\ \tan\beta$

L. Roszkowski, astro-ph/0404052

Dark Matter Candidates

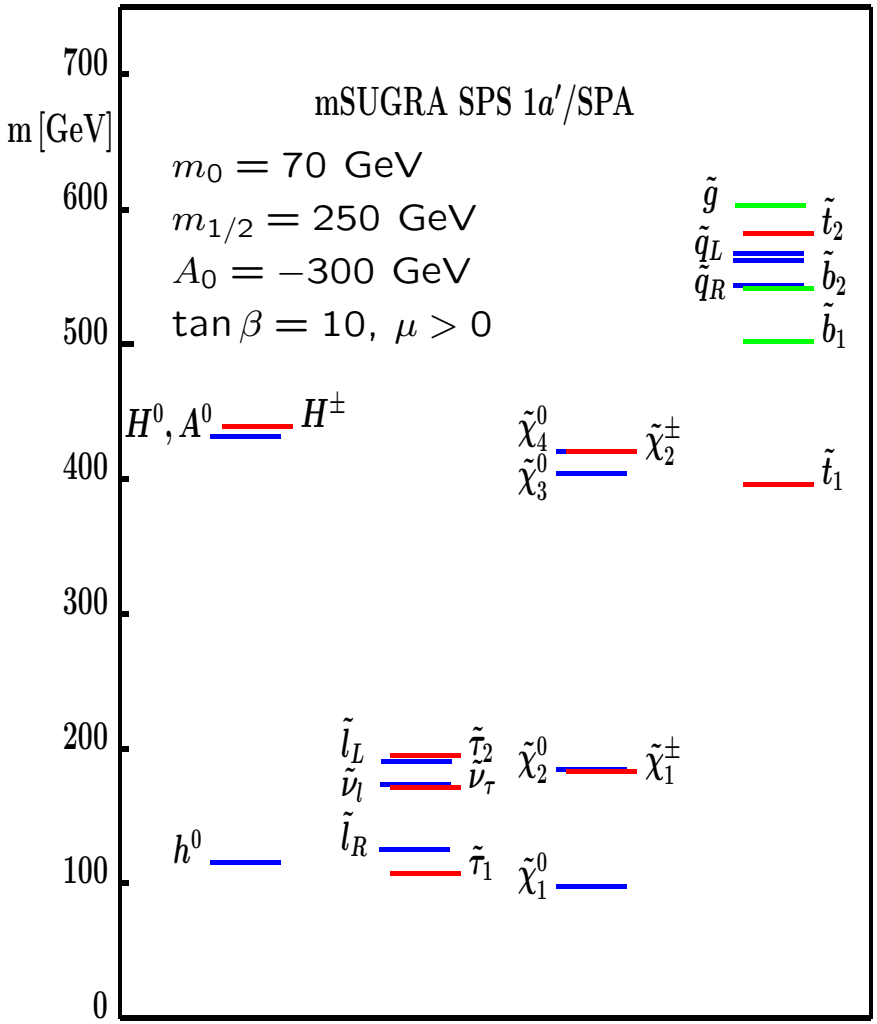


L. Roszkowski, astro-ph/0404052

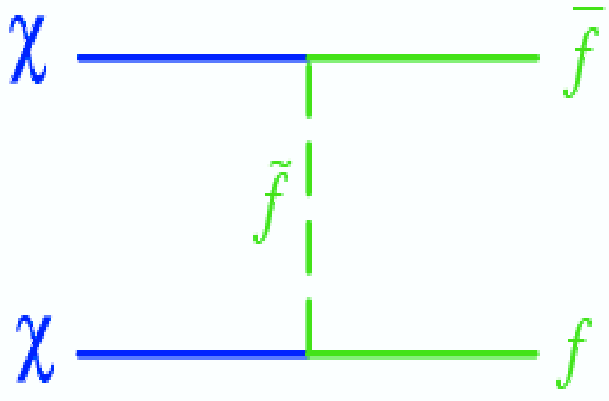


J. Feng, hep-ph/0509309

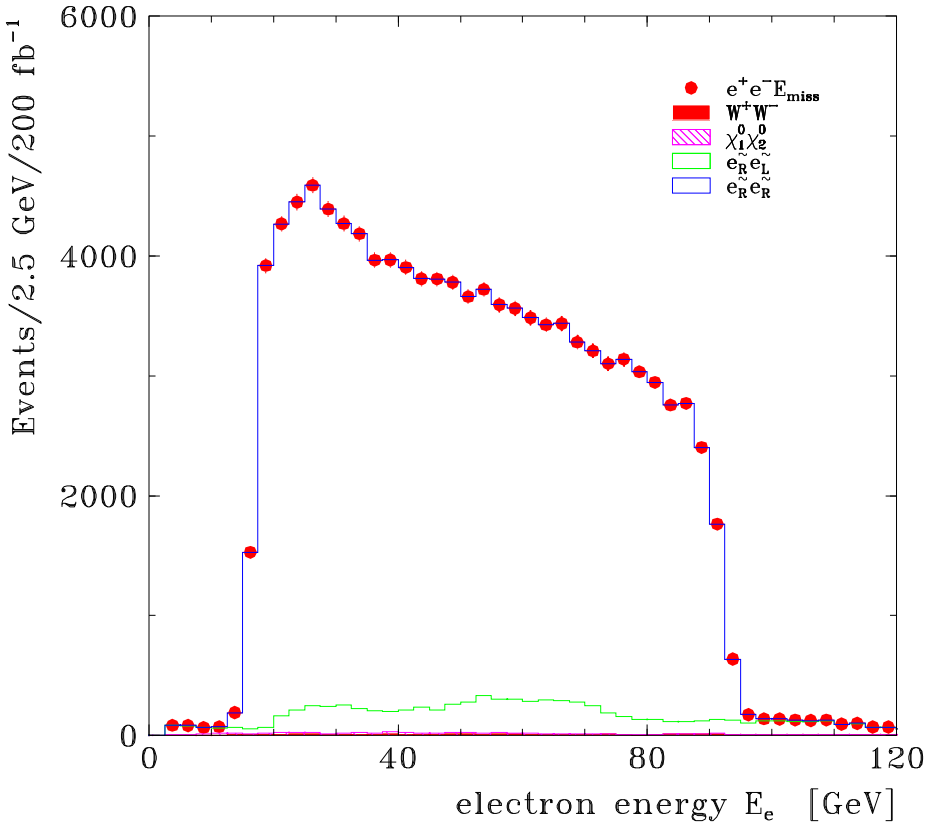
Bulk region



http://spa.desy.de/spa

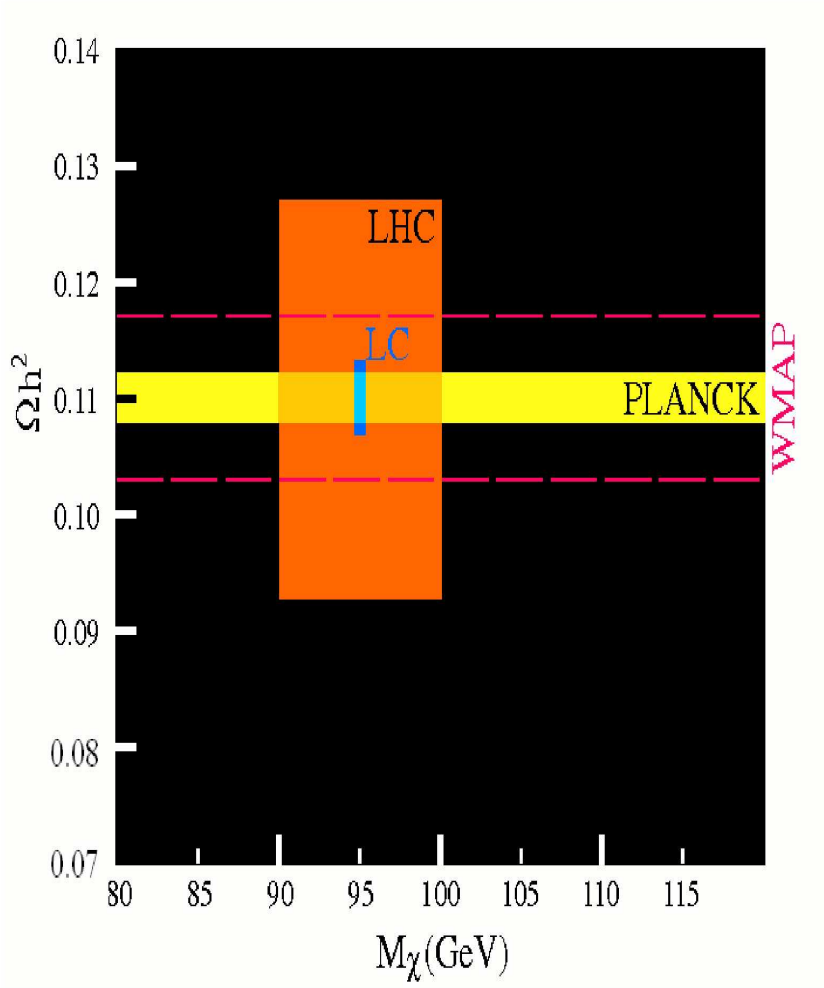


dominated by $\tilde{l}_R$



$\Rightarrow m_{\tilde{\chi}_1^0} = 0.08$ GeV, $m_{\tilde{e}_R} = 0.09$ GeV

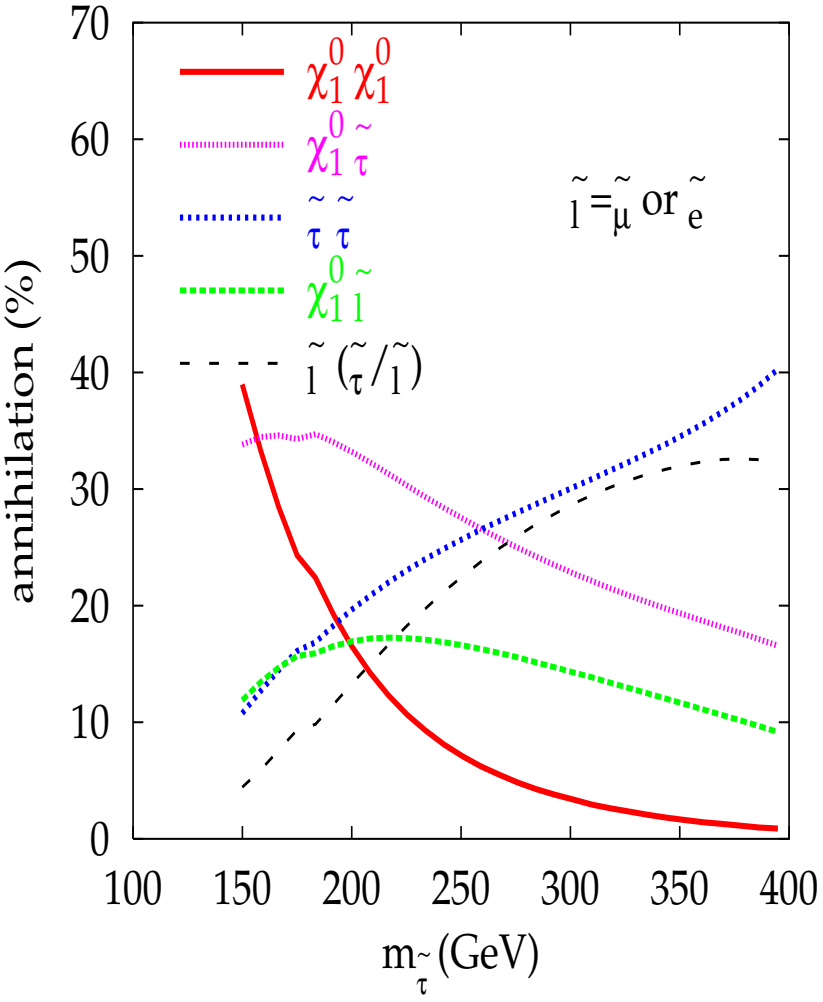
U. Martyn, hep-ph/0408226

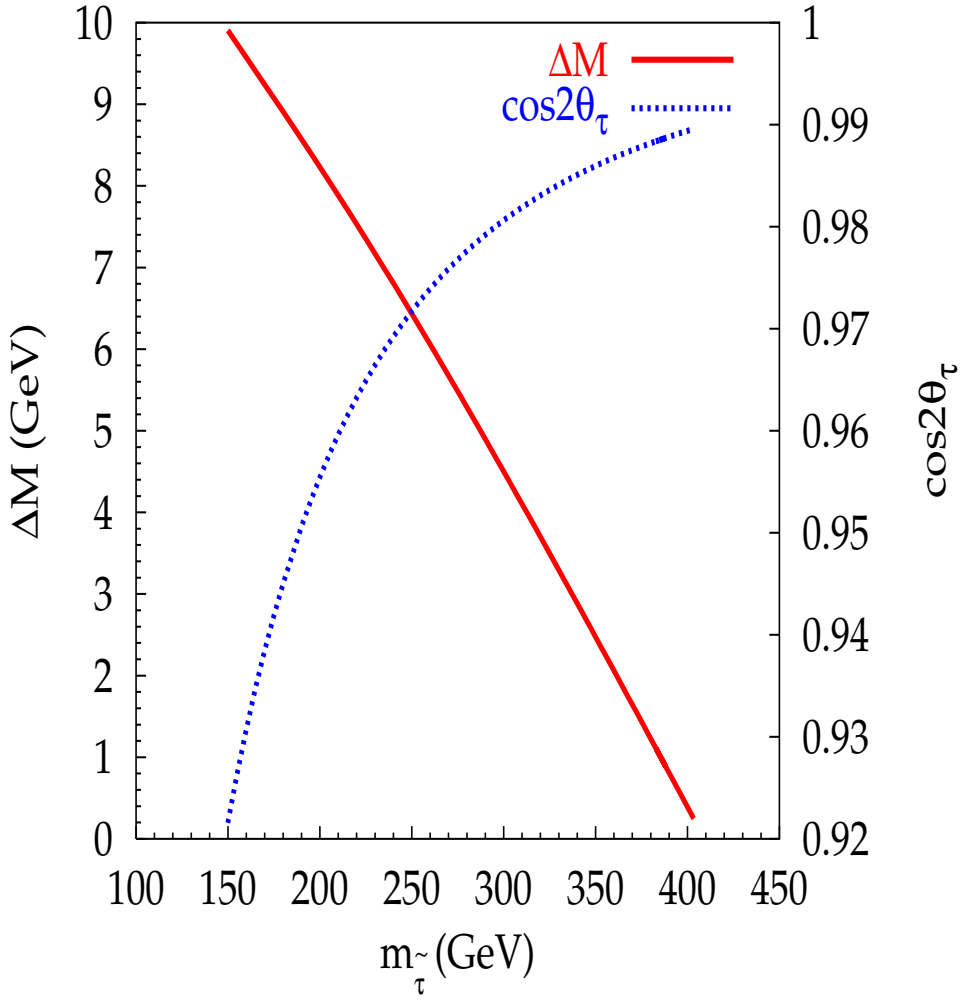


M. Berggren, F. Richard, Z. Zhang

hep-ph/0510088

Stau Coannihilation





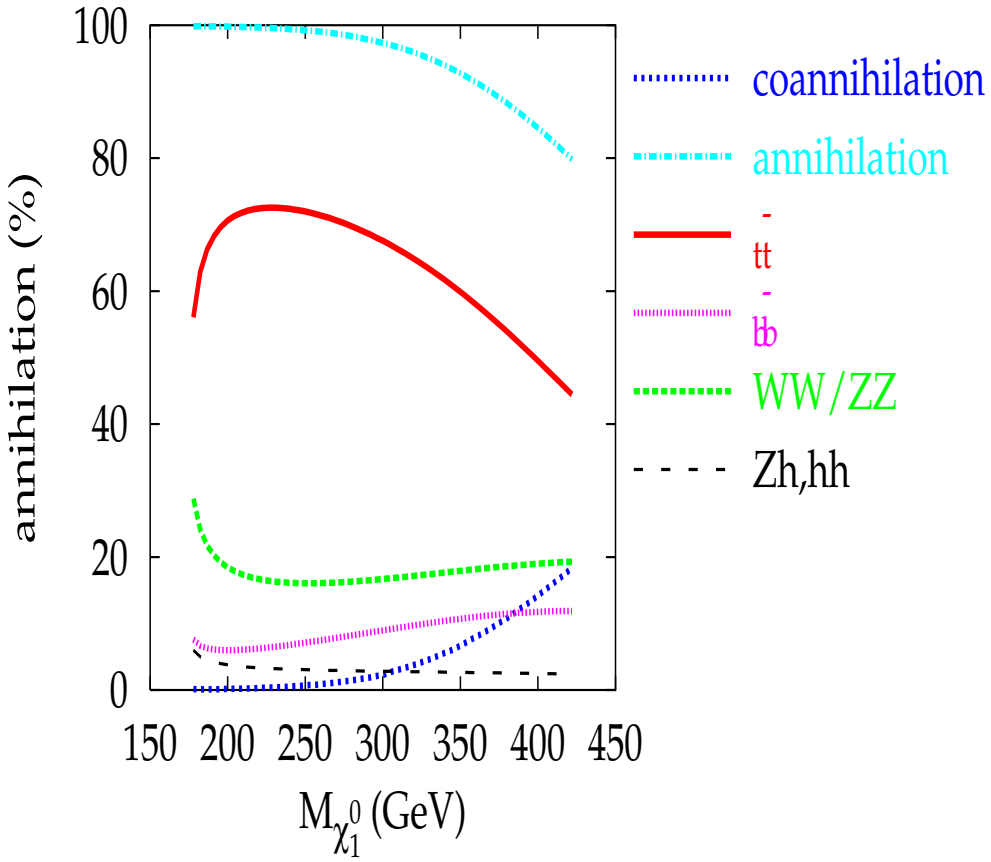
B.C. Allanach, G. Bélanger, F. Boudjema, A. Pukhov hep-ph/0410091

Model	A′	C′	D′	G′
$M1/2$	600	400	525	375
$m0$	107	80	101	113
$\tan\beta$	5	10	10	20
$\mu(m_Z)$	773	519	-663	485
m_χ	242	158	212	148
m_{e_R}	251	174	224	185
m_{τ_1}	249	167	217	157
Δm	7	9	5	9
$\Omega_{\rm DM}h^2$	0.09	0.12	0.09	0.12
Optimal $\sqrt{s}$ GeV	505	337	442	316
Error on Δm GeV	0.487	0.165	0.541	0.132
Error on $\Omega_{DM}h^2$ in %	3.4	1.8	6.9	1.6

P. Bambade, M. Berggren, F. Richard, Z. Zhang, hep-ph/00406010

Focus point

characterized: $m_0 \simeq O(1-10)$ TeV $\Rightarrow |\mu| \sim O(M_{1,2})$



B.C. Allanach et al., hep-ph/0410091

$m_{\tilde{e},\tilde{\nu}}$ from A_{FB} of $\tilde{\chi}_i^0$, $\tilde{\chi}_j^\pm$

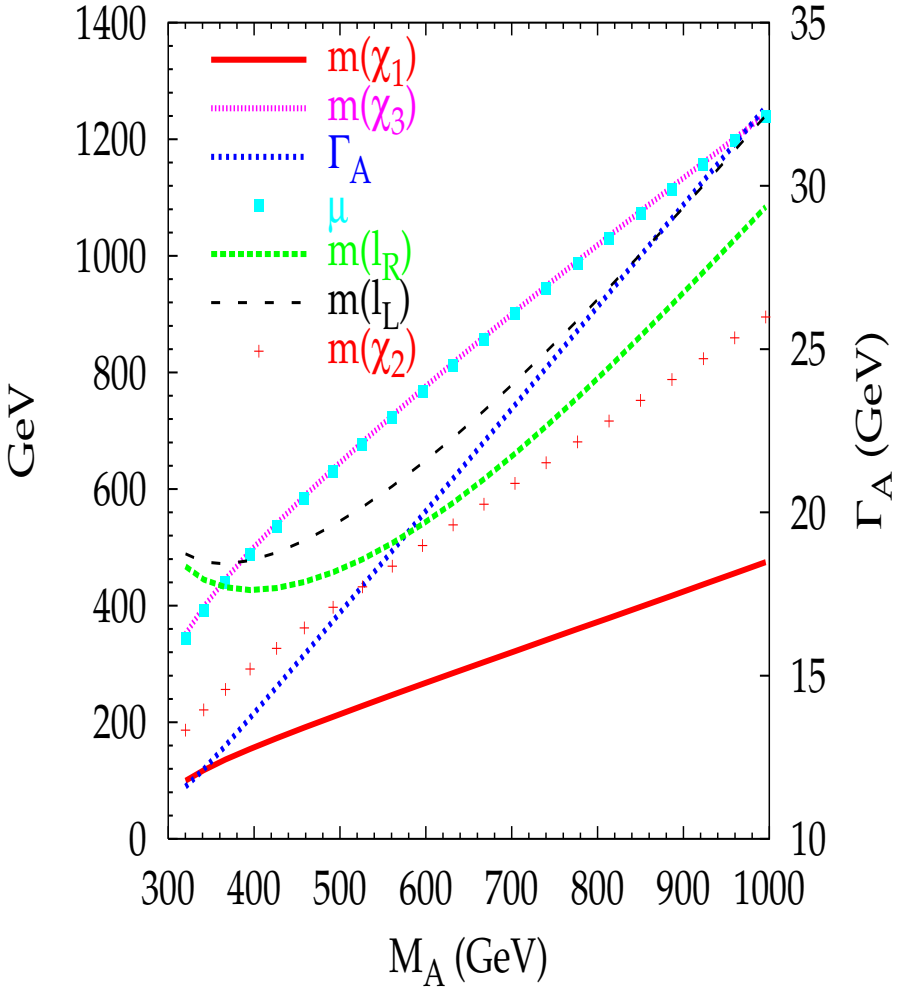
(exploiting full spin information)

G. Moortgat-Pick

talk at Snowmass'05

Higgs Funnel

requires large $\tan\beta \gtrsim 40$, important: $2m_{\tilde{\chi}_1^0} \simeq m_{A^0}$



B.C. Allanach, G. Bélanger, F. Boudjema, A. Pukhov hep-ph/0410091

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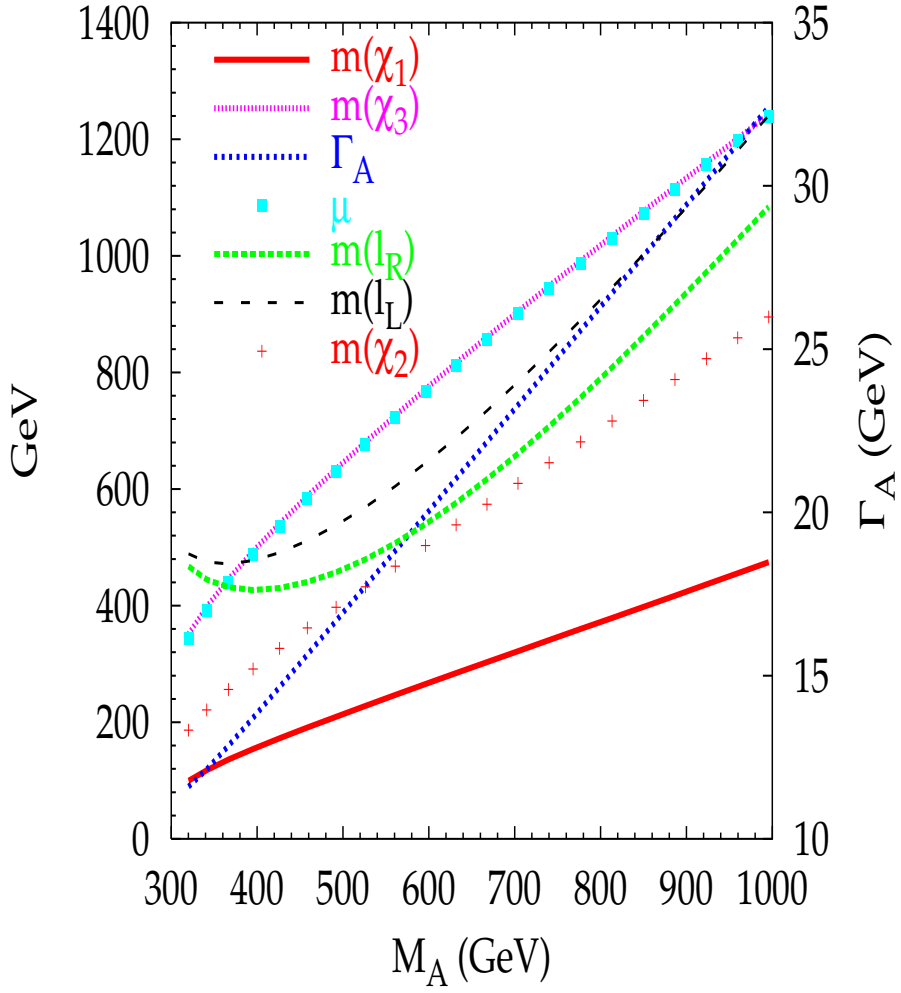
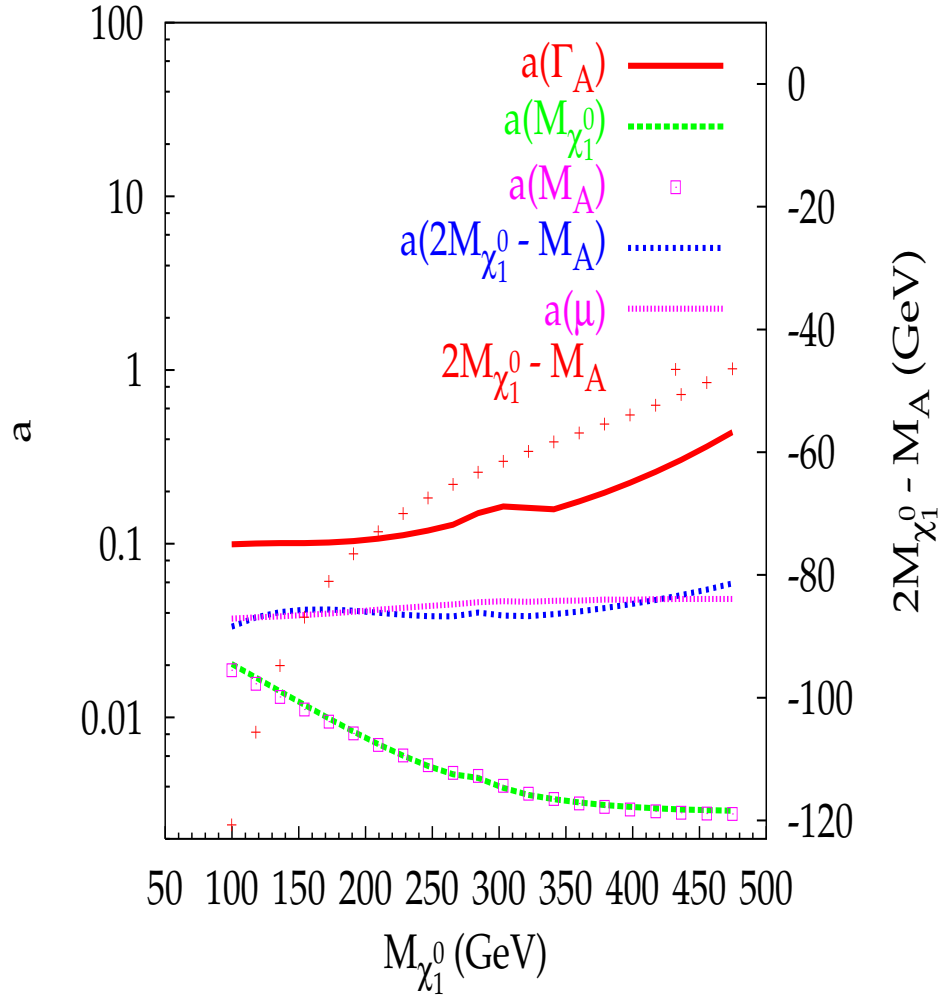




B.C. Allanach, G. Bélanger, F. Boudjema, A. Pukhov hep-ph/0410091

Incomplete list of interesting scenarios

- M. Drees, hep-ph/0502075: LEP anomalies due to light h^0, A^0, gives additional funnel for $m_{\tilde{\chi}_1^0}$; details of h^0 scenario can be found in A. Djouadi, M. Drees and J. L. Kneur, hep-ph/0504090

- W. de Boer hep-ph/0508108: EGRET excess of diffuse galactic γ rays, focus point like, large $\tan\beta$

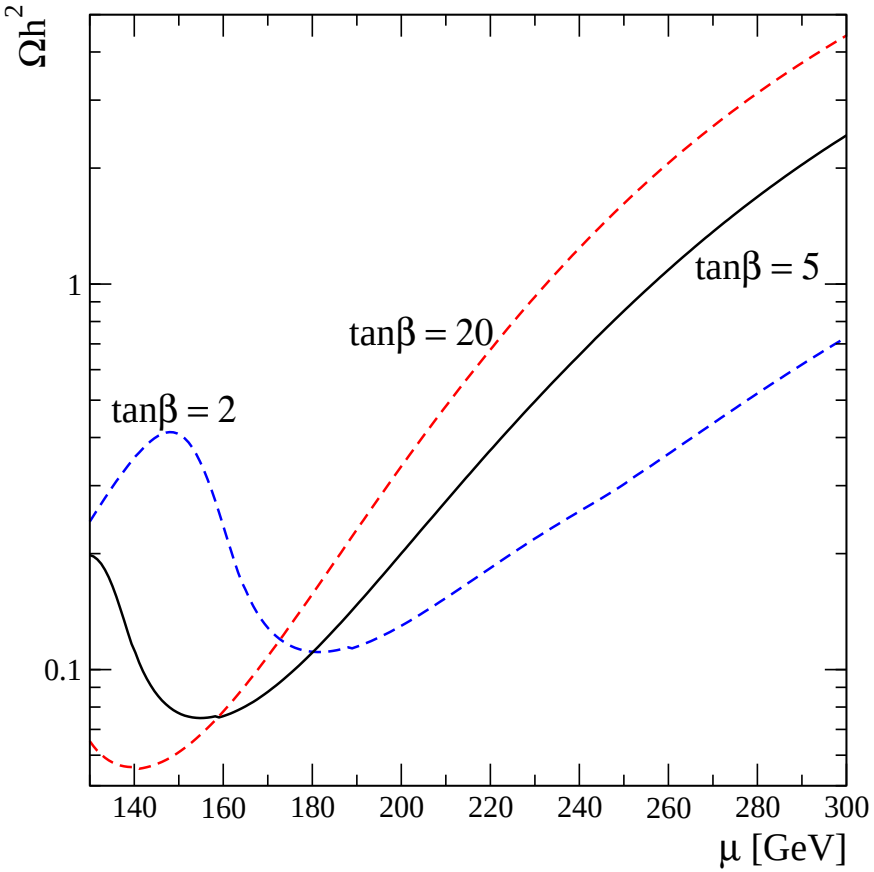
- C. Boehm, A. Djouadi and M. Drees, hep-ph/9911496: light stop co-annihilation; M. Carena et al., hep-ph/0508152: remaining scalars very heavy if at the same time electroweak baryogenesis

- H. Baer et al., hep-ph/0511034, sign(M_1) = - sign(M_2), requires bino-wino coannihilation $\rightarrow$ only 3-body decays of $\tilde{\chi}_2^0$, enhanced $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0\gamma$

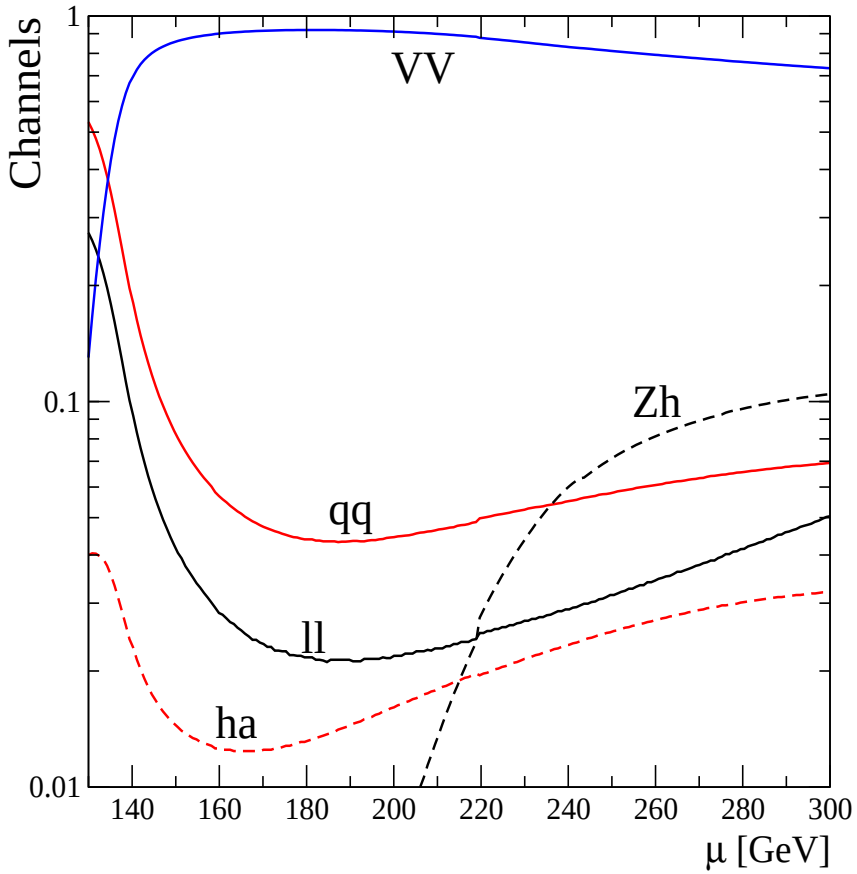
- . . .

NMSSM

MSSM + singlet; add $\lambda \hat{S} \hat{H}_u \hat{H}_d + \frac{1}{3}\kappa \hat{S}^3$



G. Bélanger et al., hep-ph/0505142



$\tan\beta = 5$

Gravitino Dark Matter

$m_{3/2} \simeq O(100)$ GeV[†] $\Rightarrow$ very longlived NLSP

$\Omega_{3/2}h^2 = \frac{m_{3/2}}{m_{NLSP}}\Omega_{NLSP}h^2$

Neutralinos: $\tilde{\chi}^0 \to \tilde{G}\gamma,\ \tilde{G}Z,\ \tilde{G}h^0$: disfavoured by BBN

Sleptons: $\tilde{l}_R \to \tilde{G}l$

3-body decays $\tilde{l} \to \tilde{G}lZ,\ \tilde{G}\nu W$ also constrained by BBN

[†] J. Ellis, K. Olive, Y. Santoso, V. Spanos '03; W. Buchmüller, K. Hamaguchi, M. Ratz, T. Yanagida '04; J.L. Feng, S. Su, F. Takayama '04; J.L. Feng, B.T. Smith '04; ...

GMSB

light gravitino LSP, $\tilde{\chi}_1^0$ of $\tilde{l}_R$ NLSP

Standard thermal history of the universe:

$$\Omega_{3/2}h^2 \simeq 0.11 \left(\frac{m_{3/2}}{100\,\text{eV}}\right)\left(\frac{100}{g_*}\right) \qquad (g_* \simeq 90 - 140)$$

Current data: $\Omega_M h^2 \simeq 0.134 \pm 0.006$, $\Omega_B h^2 \simeq 0.023 \pm 0.001$

$\Rightarrow m_{3/2} \simeq 100$ eV if DM candidate, warm dark matter
constraints from Lyman-α forest: $m_{WDM} \gtrsim 550$ eV
(M. Viel et al., arXiv:astro-ph/0501562)

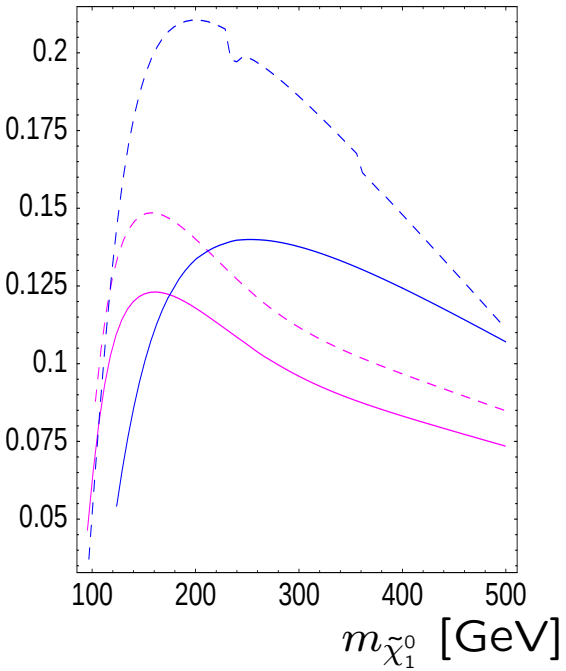
$\Rightarrow$ assume additional entropy production, e.g. non-standard decays of messenger particles
(E. Baltz, H. Murayama, astro-ph/0108172; M. Fujii and T. Yanagida hep-ph/0208191)

Broken R-parity

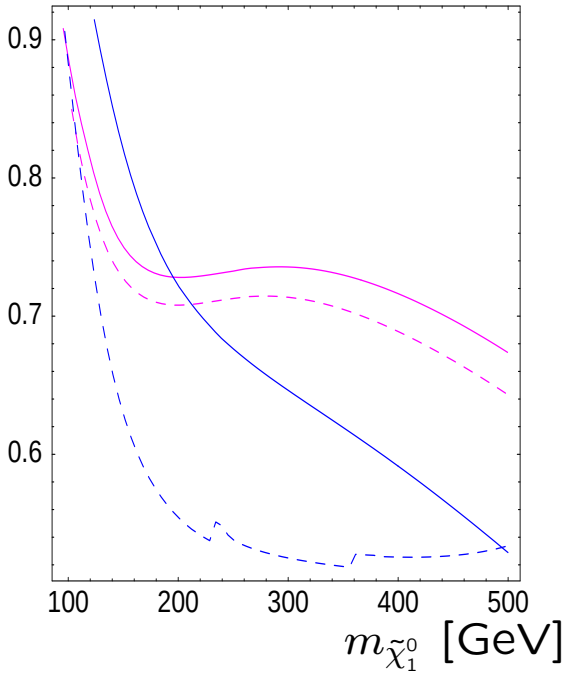
— $\tan\beta = 10,\ \mu > 0$, - - $\tan\beta = 10,\ \mu < 0$ $\quad m_{3/2} = 100$ eV, $n_5 = 1$

— $\tan\beta = 35,\ \mu > 0$, - - $\tan\beta = 35,\ \mu < 0$

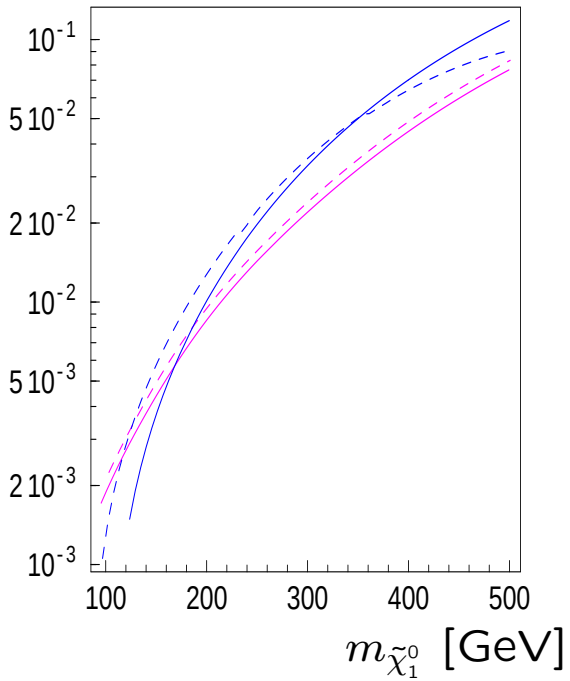
BR($\sum_i W l_i$)



BR($\sum_{ij} \nu_i \tau l_j$)



BR($\tilde{G}\gamma$)



M. Hirsch, W. Porod, D. Restrepo, hep-ph/0503059

Theoretical Uncertainties

- Numerical solution of the Boltzmann equations: up to 1%

- spectrum calculation, e.g. $m_0 = 70$ GeV, $m_{1/2} = 350$ GeV, $A_0 = 0$, $\tan\beta = 10$, $\mu > 0$

	ISAJET 7.71	SOFTSUSY 1.9	SPHENO 2.2.2	SUSPECT 2.3
$\tilde{\chi}_1^0$	136.7	140.0	139.5	140.0
$\tilde{\tau}_1$	147.7	145.7	147.1	149.7
$\tilde{e}_R$	155.7	153.8	155.4	157.6
h^0	115.8	113.1	113.4	113.3
$m_{\tilde{\tau}_1} - m_{\tilde{\chi}_1^0}$	11.0	5.7	7.6	9.7
Ω	0.136	0.069	0.092	0.120

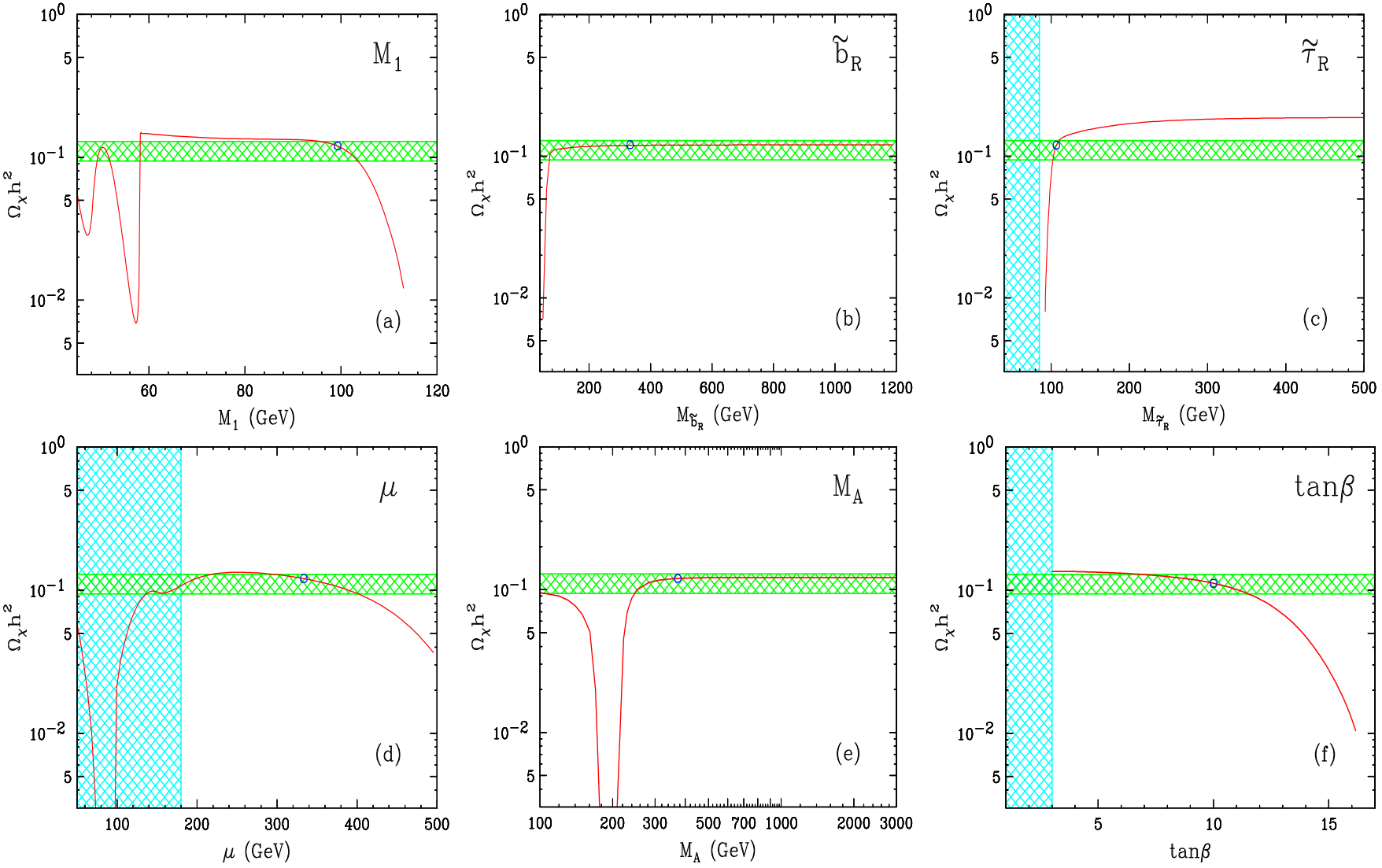
G. Bélanger, S. Kraml, A. Pukhov, hep-ph/0502079

- missing higher order corrections
  Supersymmetry Parameter Analysis (SPA) project:
  http://spa.desy.de/spa

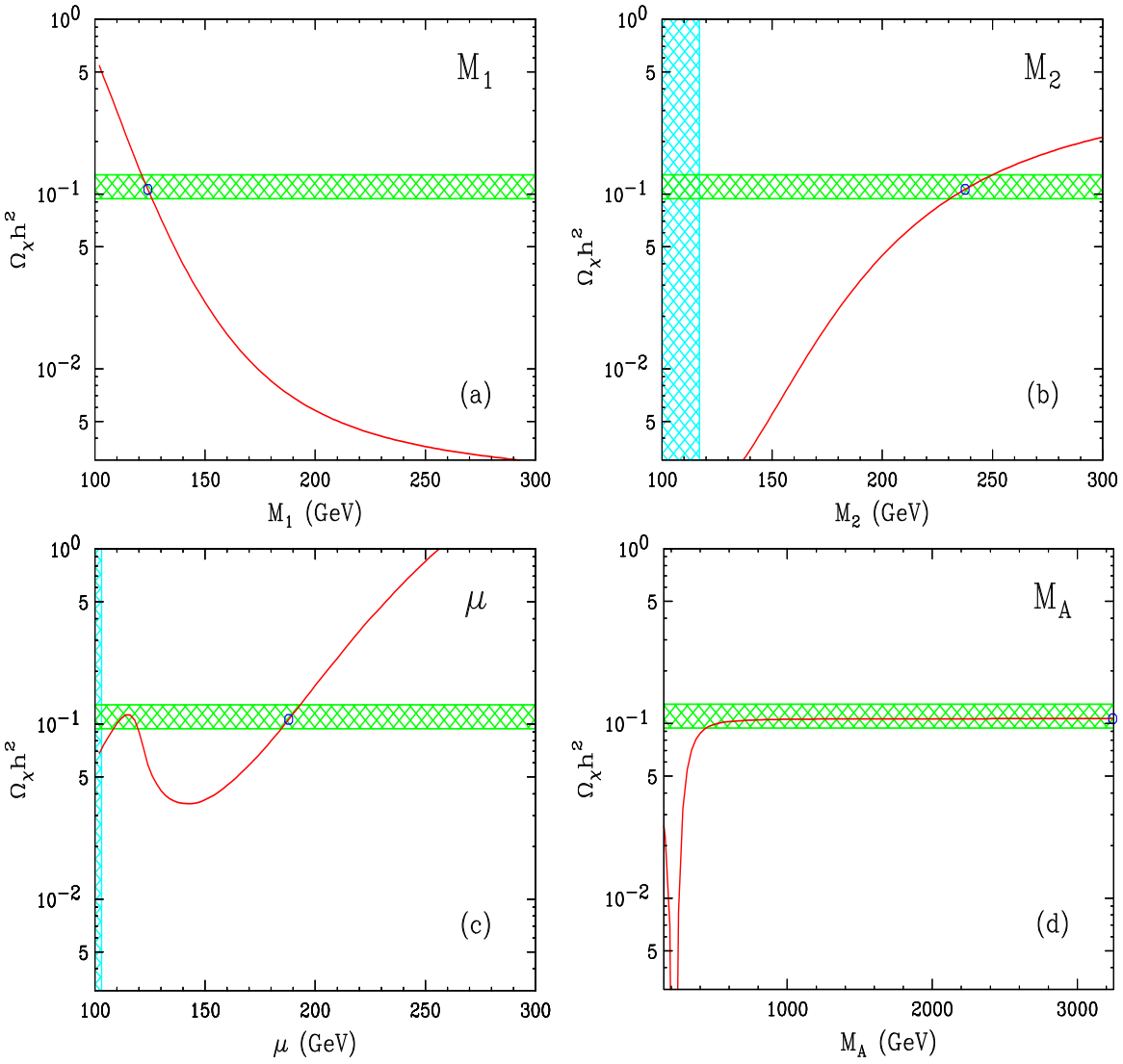
Conclusions

- At an ILC SUSY particles will be measured very precisly
- $\Rightarrow$ allows for cross-checks of cosmological ideas

Parameter Dependencies



A. Birkendal, K. Matchev, hep-ph/0507214



A. Birkendal, K. Matchev, hep-ph/0507214