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Light Neutralino in the MSSM

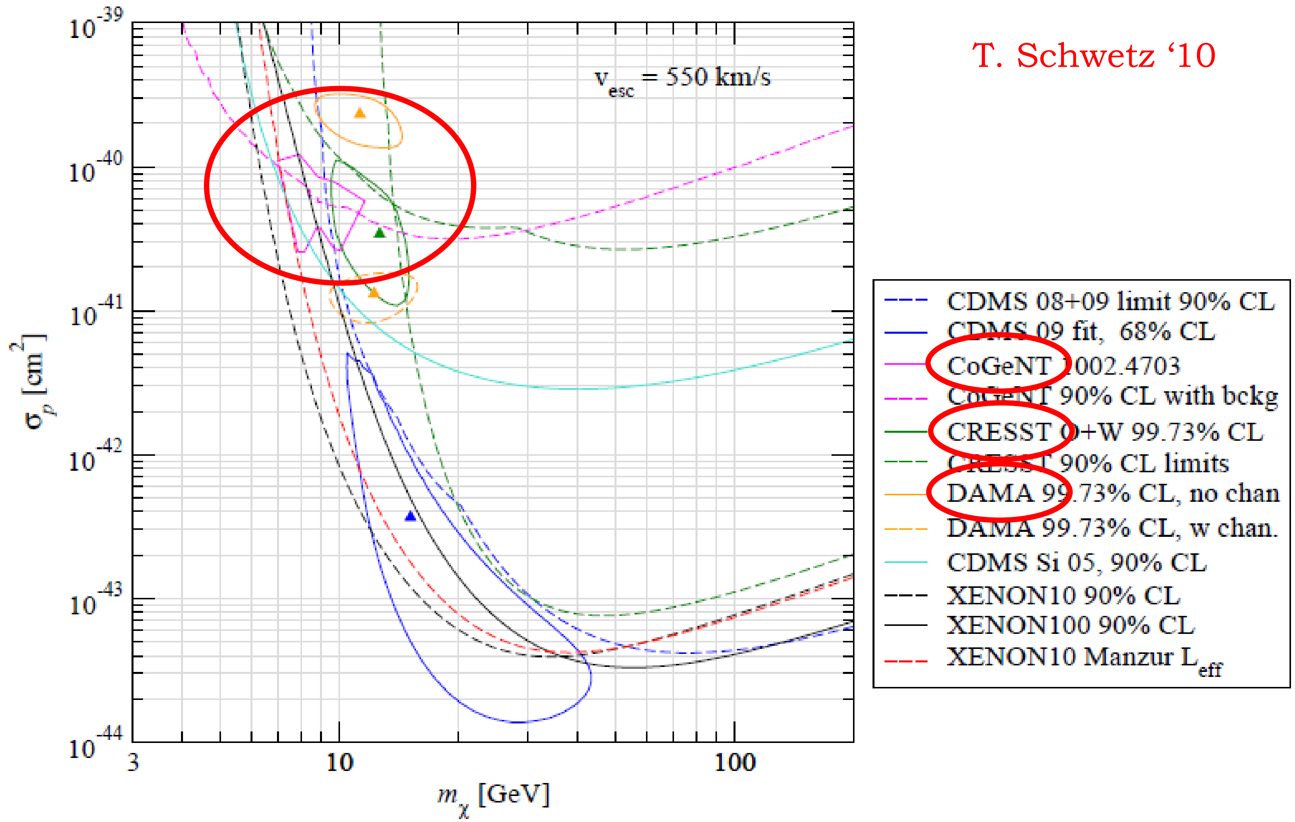
Lorenzo Calibbi

Max-Planck-Institut für Physik, Munich

MAX-PLANCK-GESELLSCHAFT

based on: L.C., T. Ota, Y. Takanishi, arXiv:1104.1134 [hep-ph]

Motivations



T. Schwetz '10

$$\Rightarrow \quad m_\chi \sim 7 \div 10 \text{ GeV}\,, \quad \sigma^{SI}_{\chi N} \sim 10^{-41} \div 10^{-40} \text{ cm}^2$$

e.g. Hooper et al. '10

Is it possible with MSSM Neutralino DM?

Kuflik et al. '10, Feldman et al. '10, Vasquez et al. '10, Fornengo et al. '10

Light Neutralino Dark Matter

MSSM neutralinos: $\left(\tilde{B}, \tilde{W}_3, \tilde{H}_d^0, \tilde{H}_u^0\right)$

$$\mathbf{M}_{\tilde{N}} = \begin{pmatrix} M_1 & 0 & -c_\beta\, s_W\, m_Z & s_\beta\, s_W\, m_Z \\ 0 & M_2 & c_\beta\, c_W\, m_Z & -s_\beta\, c_W\, m_Z \\ -c_\beta\, s_W\, m_Z & c_\beta\, c_W\, m_Z & 0 & -\mu \\ s_\beta\, s_W\, m_Z & -s_\beta\, c_W\, m_Z & -\mu & 0 \end{pmatrix}$$

MSSM charginos:

$$\mathcal{M}_\pm = \begin{pmatrix} M_2 & \sqrt{2} M_W \sin\beta \\ \sqrt{2} M_W \cos\beta & \mu \end{pmatrix}$$

Lightest eigenstate:

$$\tilde{\chi}_1^0 = a_1 \tilde{B} + a_2 \tilde{W}_3 + a_3 \tilde{H}_d^0 + a_4 \tilde{H}_u^0$$

LEP chargino searches:

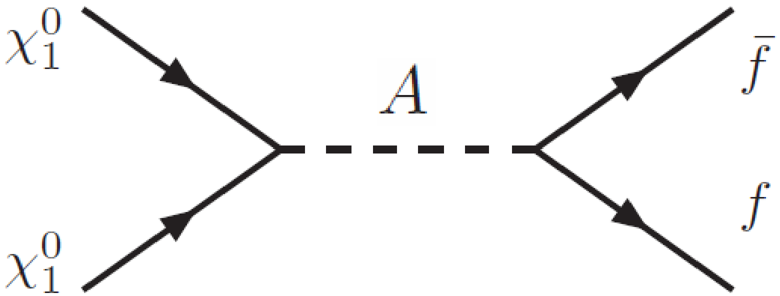
⇩

$$M_2,\ \mu \gtrsim 90\ \text{GeV}$$

$$M_1 \ll M_2,\ \mu \iff \tilde{\chi}_1^0 \approx \tilde{B}$$

Efficient annihilation required

(sfermion exchange not enough due to LEP mass limits e.g. Dreiner et al. '09)

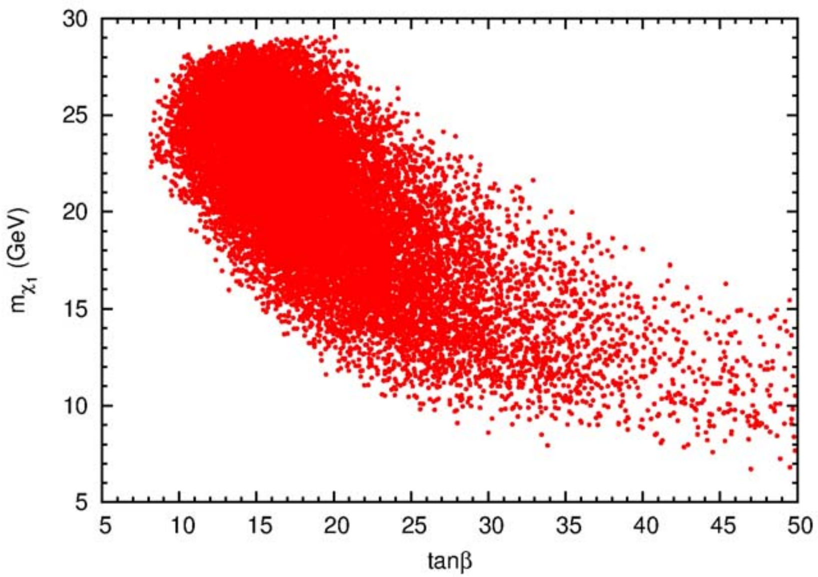


$$\propto \frac{m^2_{\tilde{\chi}^0_1}}{m^2_A} \frac{m_f}{v} (a_1 a_{3,4}) \tan\beta$$

Drees Nojiri '92

Small $m_{\tilde{\chi}^0_1} \Longleftrightarrow$ large $\tan\beta$, small m_A (and μ)

Bottino et al. '02, '04, '08, '10



Light Higgs sector, large(-ish) $\tan\beta$

$\Longrightarrow$ phenomenologically challenging

see e.g.: Buras et al. '02,
Isidori Paradisi '06,
Barenboim et al. '07,
Eriksson et al. '08,
Altmannshofer et al. '09,
Altmannshofer Straub '10,
...

Mild dependence on SUSY parameters

$$B^+ \to \tau^+ \nu_\tau$$

$$B^+ \to D^0 \tau^+ \nu_\tau$$

$$K^+ \to \mu^+ \nu_\mu$$

$$D_s^+ \to \tau^+ \nu_\tau$$

Strong dependence on SUSY parameters

$$b \to s\gamma$$

$$B_s \to \mu^+ \mu^-$$

Mild dependence on SUSY parameters

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Strong dependence on SUSY parameters

$$b \to s\gamma$$
$$B_s \to \mu^+ \mu^-$$

$$R_{B\tau\nu} \equiv \frac{\mathrm{BR}(B \to \tau\nu)}{\mathrm{BR}(B \to \tau\nu)_{\mathrm{SM}}} \simeq \left[1 - \frac{m_B^2}{m_{H^\pm}^2} \frac{\tan^2\beta}{1+\epsilon\tan\beta}\right]^2$$

Hou '93, Akeroyd Recksiegel '03, Isidori Paradisi '06

$$R_{\ell 23} \equiv \left| \frac{V_{us}(K \to \ell\nu)}{V_{us}(K \to \pi\ell\nu)} \times \frac{V_{ud}(\beta\ \text{decay})}{V_{ud}(\pi \to \ell\nu)} \right| \simeq \left| 1 - \frac{m_K^2}{m_{H^\pm}^2} \left[1 - \frac{m_d}{m_s}\right] \frac{\tan^2\beta}{1+\epsilon\tan\beta} \right|$$

Antonelli et al. '08, '10

$$R_{D\ell\nu} \equiv \frac{\mathrm{BR}(B \to D\tau\nu)}{\mathrm{BR}(B \to De\nu)}$$

Kamenik Mescia '08

$$\mathrm{BR}(D_s \to \tau\nu)$$

Akeroyd Mahmoudi '09

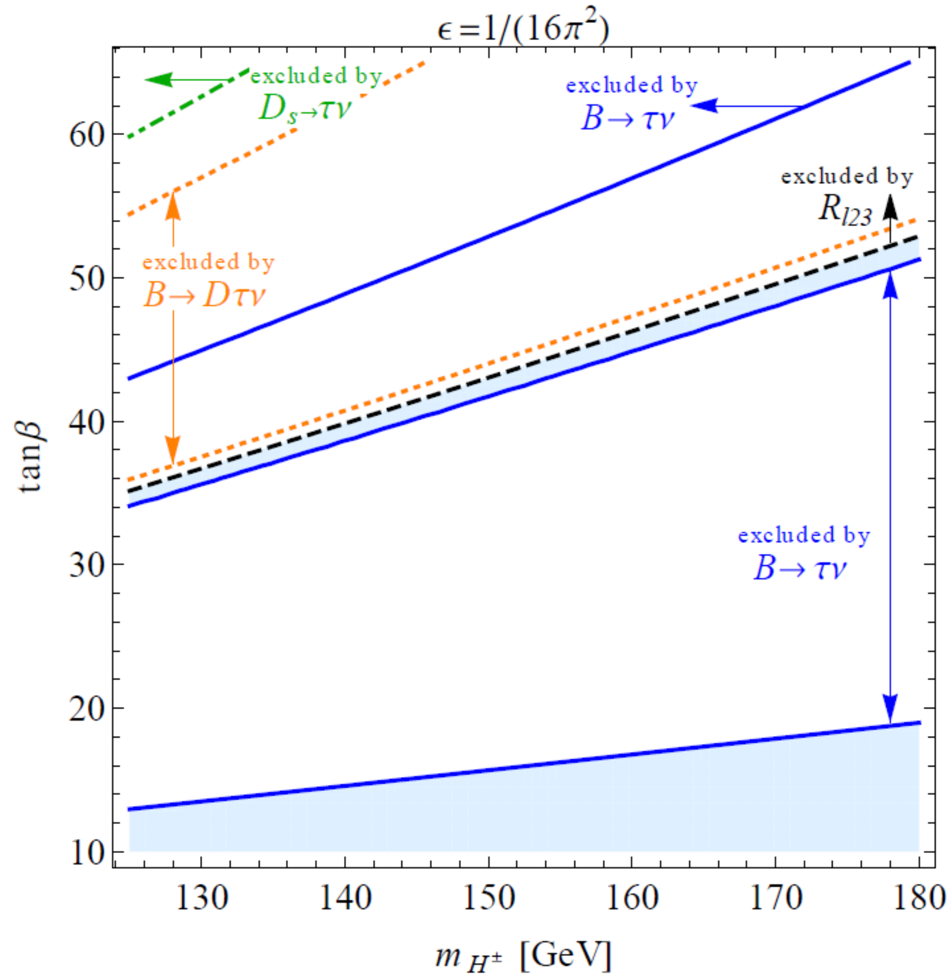
Experimental ranges:

$$0.52 < R_{B\tau\nu} < 2.61$$

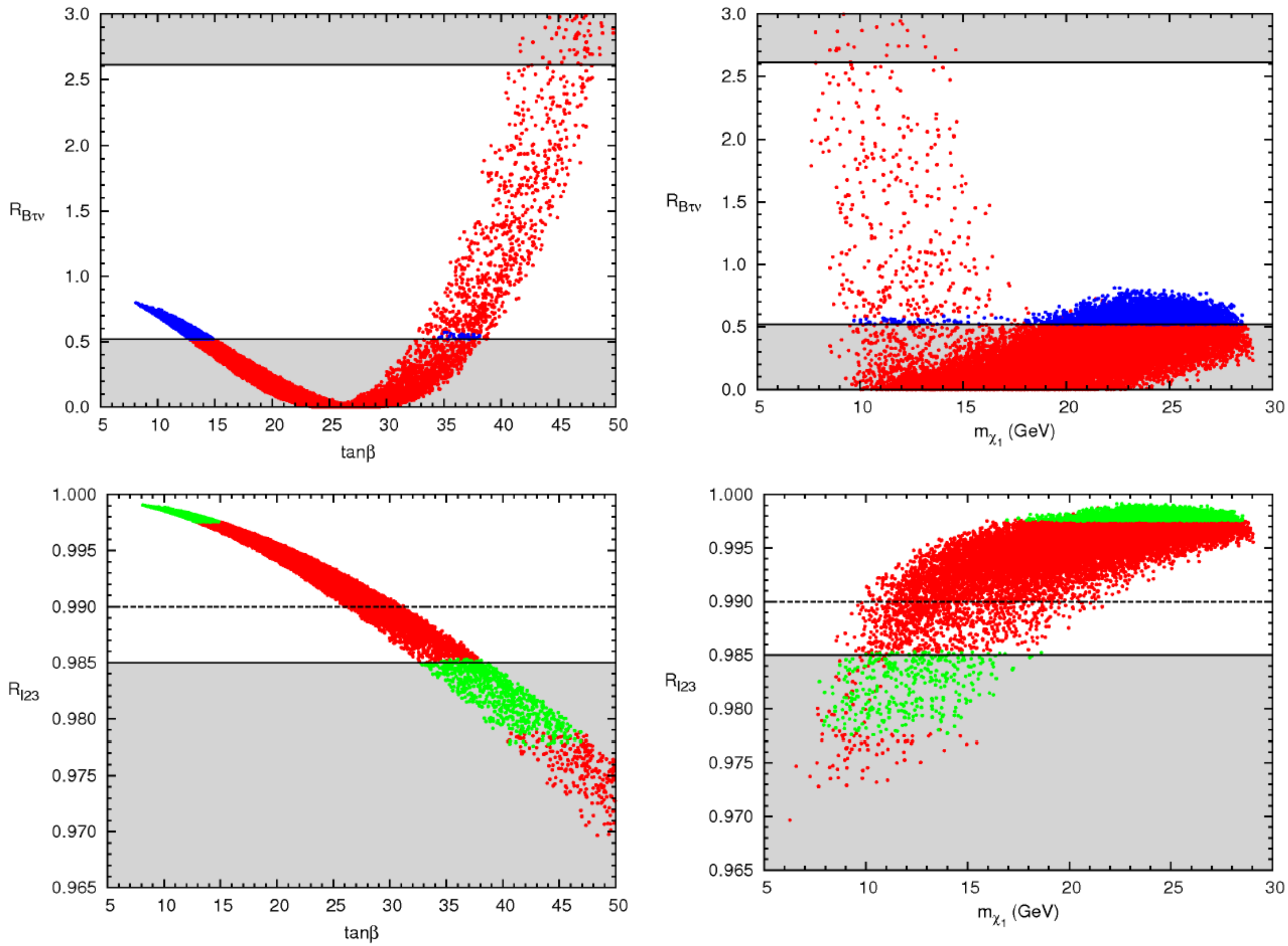
$$0.985 < R_{\ell 23}(K \to \mu\nu) < 1.013$$

$$0.151 < R_{D\ell\nu} < 0.681$$

$$4.7 \times 10^{-2} < \mathrm{BR}(D_s \to \tau\nu) < 6.1 \times 10^{-2}$$



Low-energy constraints



Numerical analysis

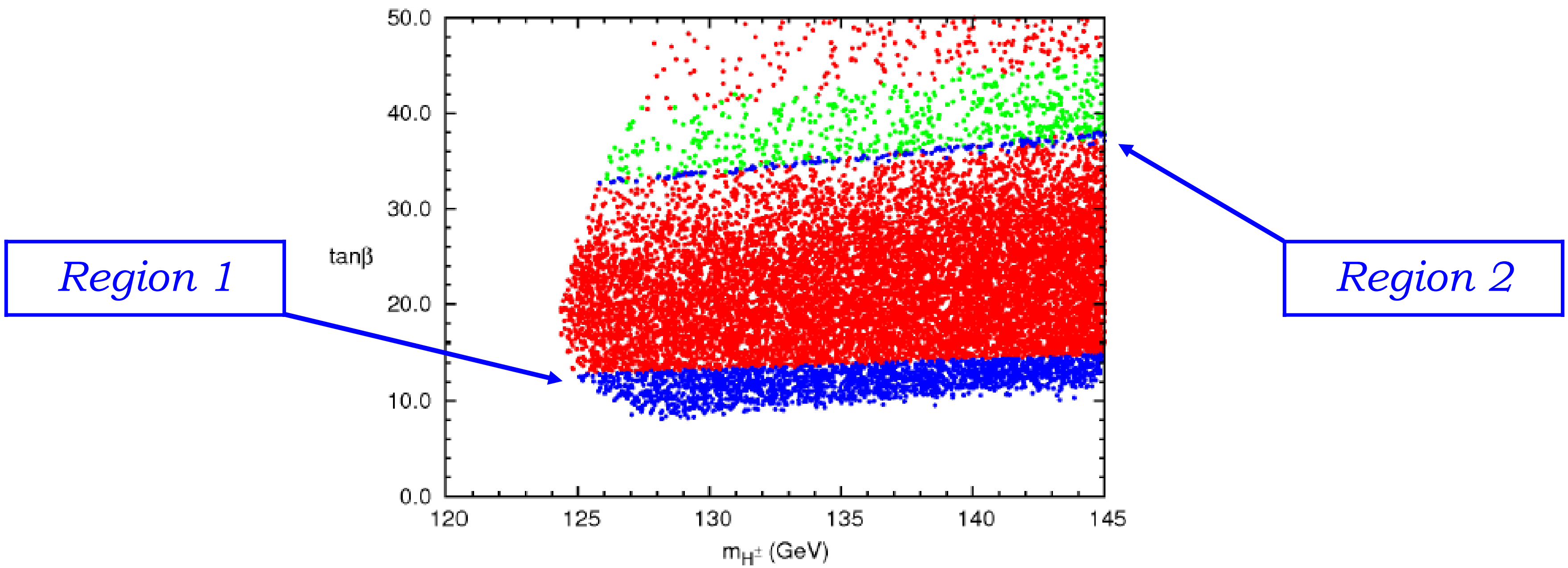
Djouadi et al. '02
Belanger et al. '06
Mahmoudi '08

MSSM parameters to scan: (SuSpect, micrOMEGAs, SuperIso)

Low-E values $\tan\beta, \quad M_1, \quad M_2, \quad M_3, \quad a_0, \quad \mu, \quad m_A, \quad m_{\tilde{q}}, \quad m_{\tilde{\ell}}, \quad (A_{u,d} = a_0\, Y_{u,d} m_{\tilde{q}})$

Ranges:

$$M_1 \in [7, 30]\ \text{GeV}, \quad M_2 \in [100, 600]\ \text{GeV}, \quad M_3 \in [400, 1200]\ \text{GeV},$$
$$m_A \in [90, 120]\ \text{GeV}, \quad \mu \in [100, 200]\ \text{GeV}, \quad a_0 \in [-2, 2],$$
$$m_{\tilde{q}} \in [400, 1200]\ \text{GeV}, \quad m_{\tilde{\ell}} \in [100, 1200]\ \text{GeV}, \quad \tan\beta \in [5, 50].$$



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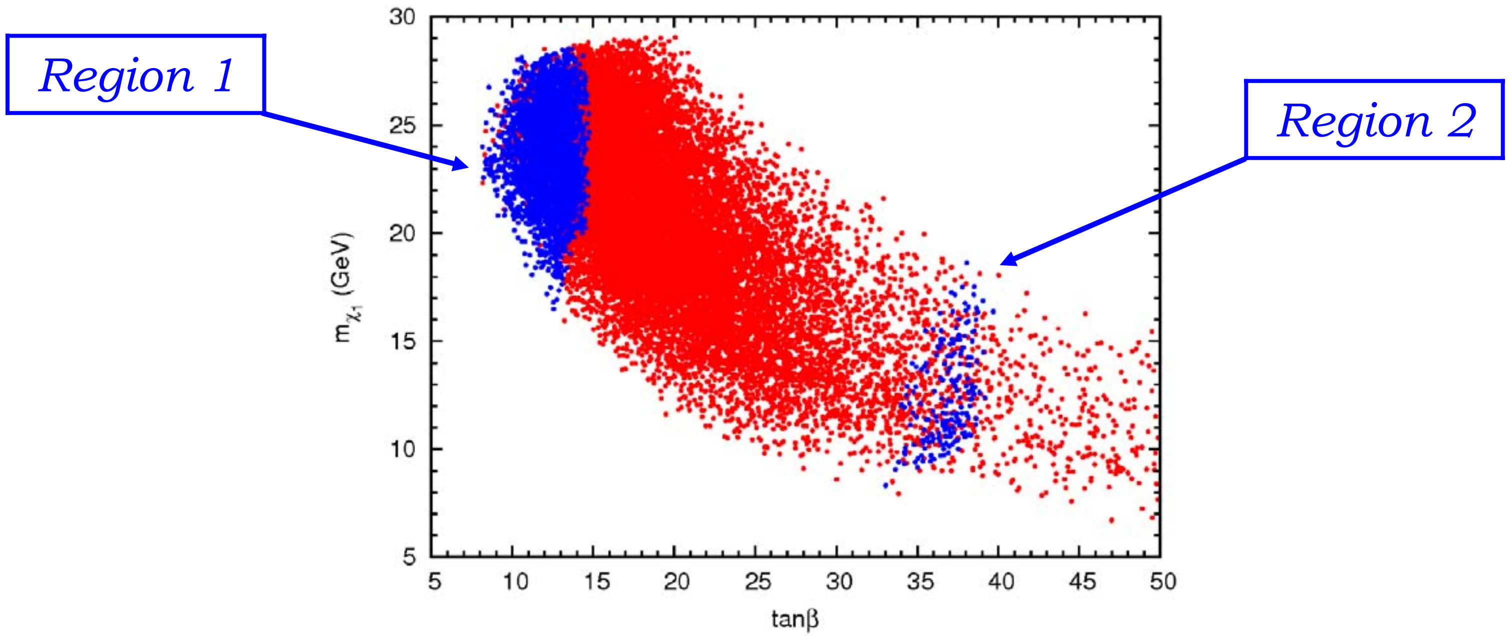

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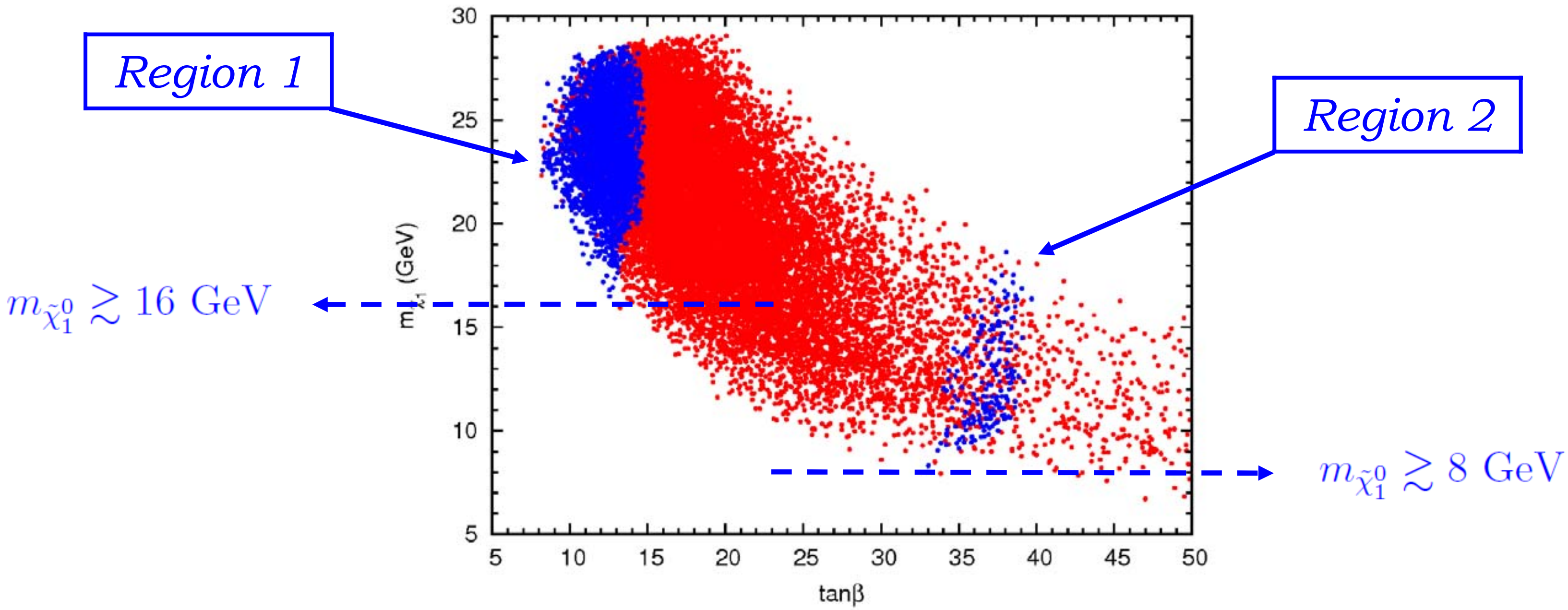
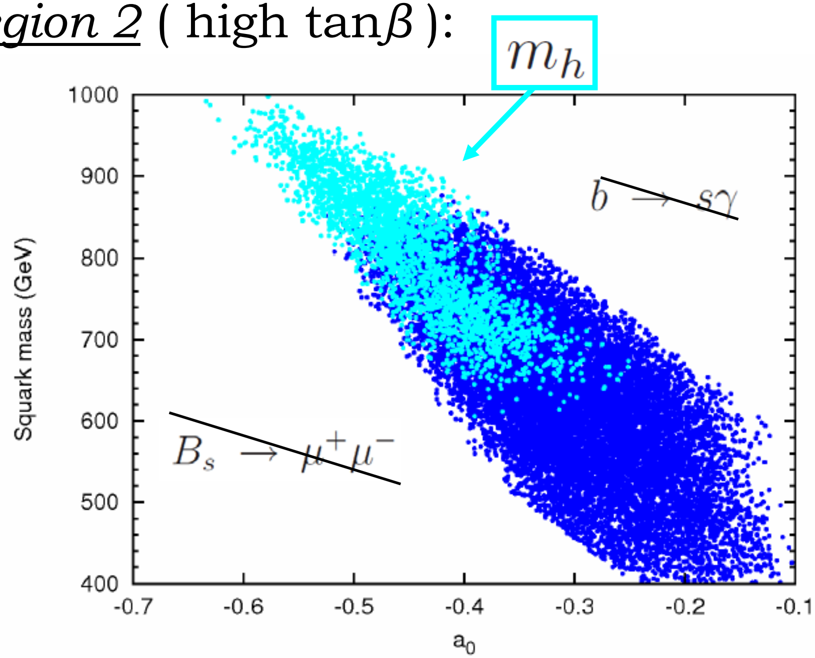
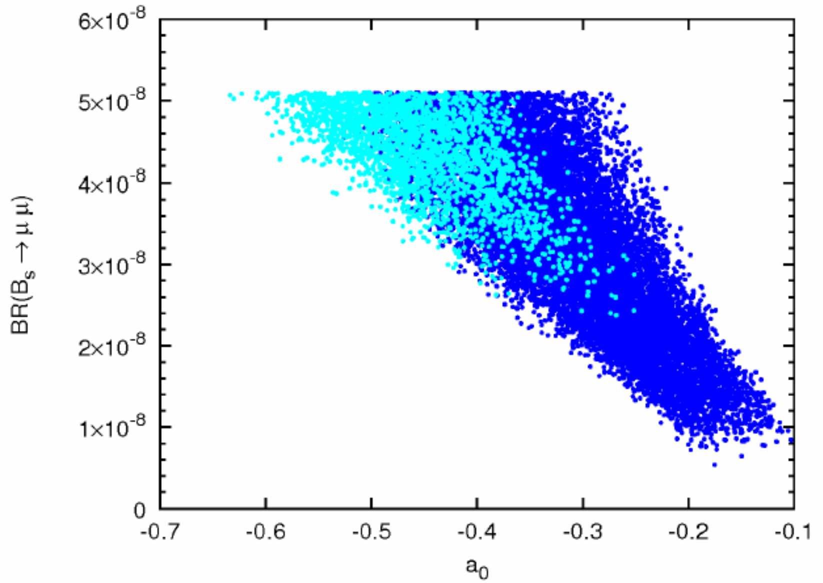


Region 1 (low tanβ):

- $b \to s\gamma$ $\Longrightarrow$ $m_{\tilde{q}} \lesssim 800$ GeV and $a_0 \lesssim -0.4$
- LEP bound on m_h $\Longrightarrow$ $m_{\tilde{q}} \gtrsim 500$ GeV and $a_0 \lesssim -0.8$
- $\mathrm{BR}(B_s \to \mu\mu)$ max. twice SM prediction

Region 2 (high tanβ):



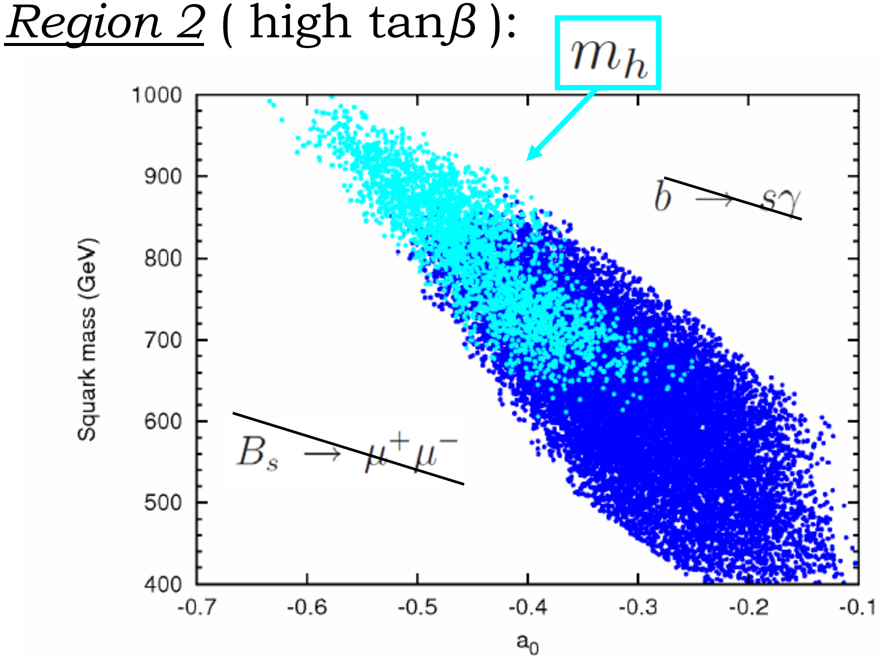


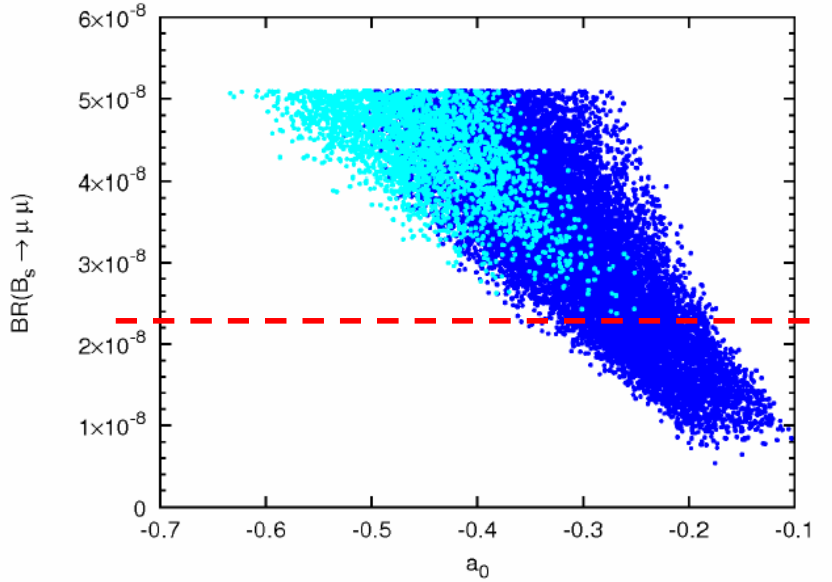
Phenomenological consequences

Region 1 (low $\tan\beta$):

- $b \to s\gamma$ ⇒ $m_{\tilde{q}} \lesssim 800$ GeV and $a_0 \lesssim -0.4$
- LEP bound on m_h ⇒ $m_{\tilde{q}} \gtrsim 500$ GeV and $a_0 \lesssim -0.8$
- $\mathrm{BR}(B_s \to \mu\mu)$ max. twice SM prediction

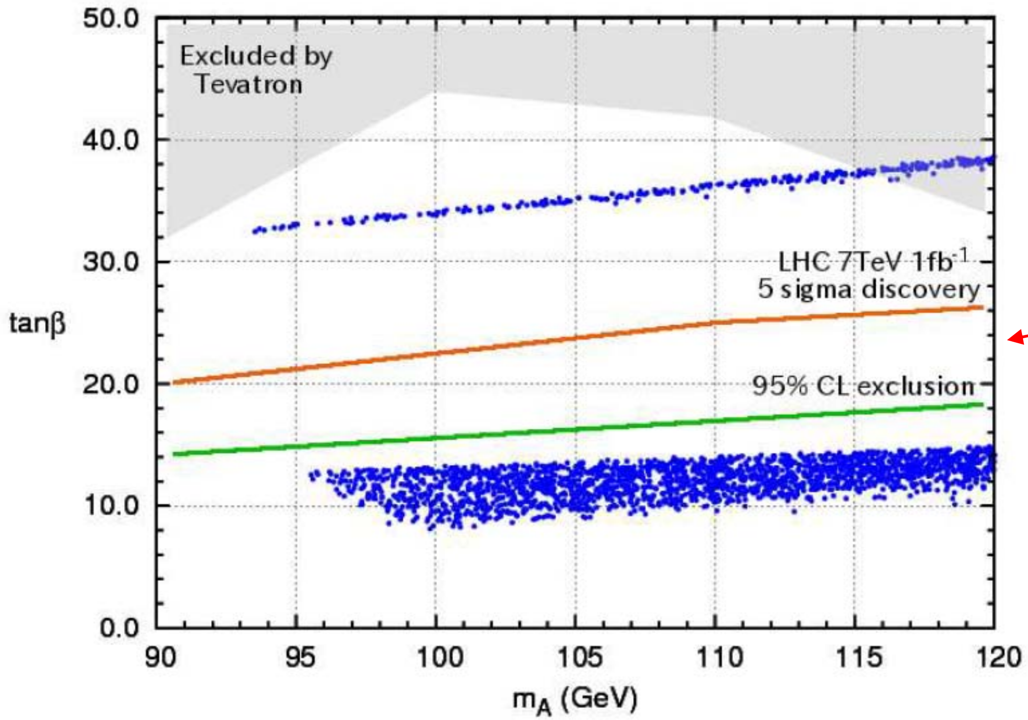
Region 2 (high $\tan\beta$):





⇒ $\mathrm{BR}(B_s \to \mu\mu) \gtrsim 2 \times 10^{-8}$ Tested within 2011 by LHCb!

Higgs searches (e.g. $pp \to X\,\Phi \to \tau\tau$ at LHC):



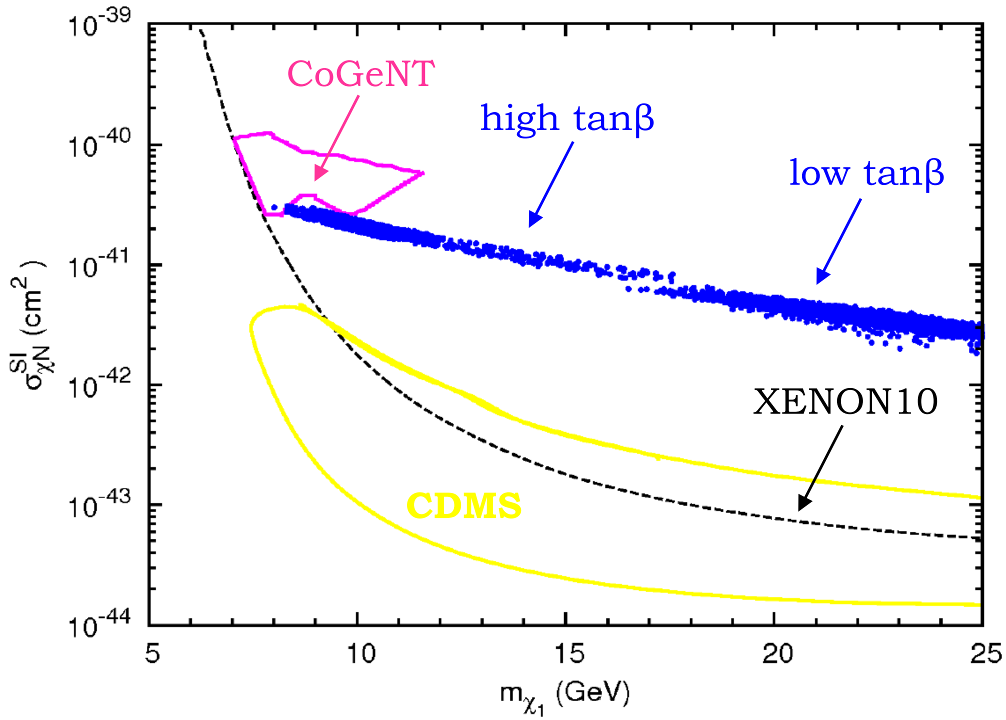
CMS note 2010-008

Region 2 tested within 2011 by LHC Higgs searches!

Updates: first CMS searches, Region 1 already excluded? CMS arXiv:1104.1619

(see however J. Baglio arXiv: 1105.1085 and Djouadi's talk)

Direct searches



Uncertainties: hadronic matrix elements e.g. Fornengo et al. '10

local DM density and velocity e.g. Belanger et al. '10

Updates: CoGeNT reported annual modulation

XENON100 released new exclusion see however Arina et al. '11

Conclusions

• WMAP bound combined with constraints from low-energy observables selects two regions of the parameter space:

Low tanβ region with:

$$m_{\tilde{\chi}_1^0} \gtrsim 16 \text{ GeV}$$

$$\sigma^{\rm SI}_{\chi N} \sim 10^{-42} \div 10^{-41} \text{ cm}^2$$

High tanβ strip with:

$$m_{\tilde{\chi}_1^0} \gtrsim 8 \text{ GeV}$$

$$\sigma^{\rm SI}_{\chi N} \gtrsim \mathcal{O}(10^{-41}) \text{ cm}^2$$

• High tanβ strip will be tested in the upcoming months by means of LHC Higgs bosons and $B_s \to \mu\mu$ searches.

• High tanβ strip can account for CoGeNT, CRESST, DAMA signals. Direct searches are the most promising way of testing the low tanβ region (which indeed seems to be already strongly disfavoured by XENON100).

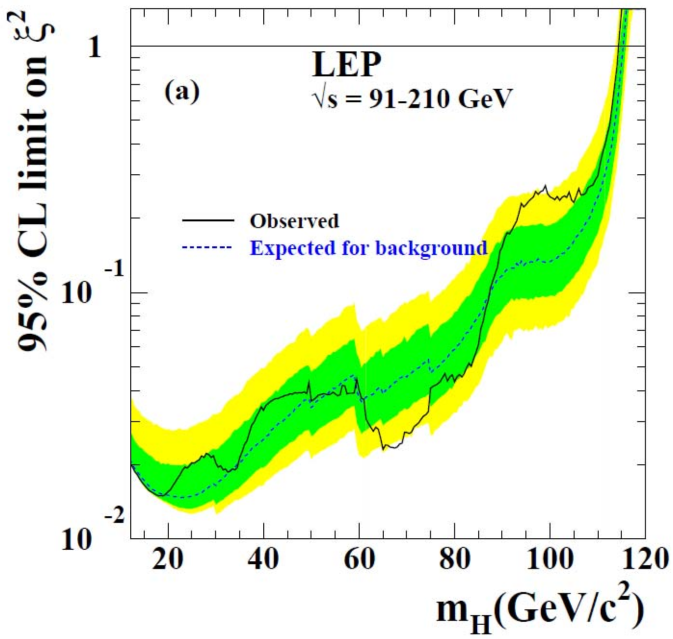
Obrigado!

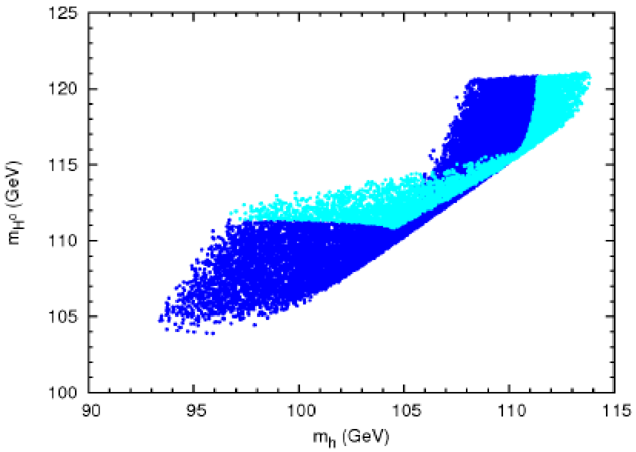
Additional slides

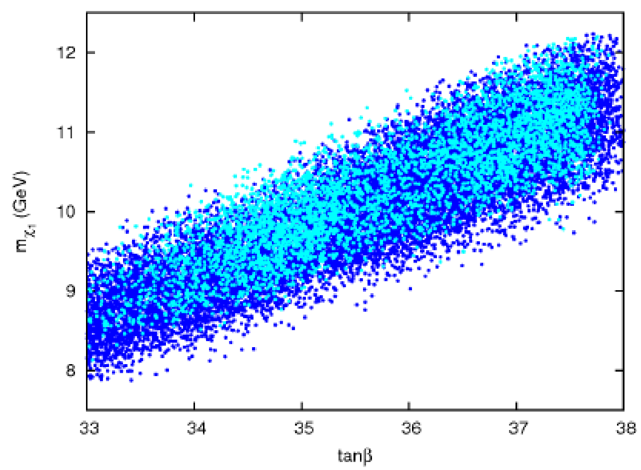
Constraints

	Observable	Allowed range
WMAP	$\Omega_{\rm DM} h^2$	$[0.101,\ 0.123]$
LEP	m_h	> 92.8 GeV
	m_A	> 93.4 GeV
	$M_{\tilde{\chi}_1^+}$	> 94 GeV
	$\Gamma(Z \to \tilde{\chi}_1^0 \tilde{\chi}_1^0)$	< 3 MeV
	$\sigma(e^+e^- \to \tilde{\chi}_1^0 \tilde{\chi}_{2,3}^0)$	< 0.1 pb
Group (i)	$R_{B\tau\nu}$	$[0.52,\ 2.61]$
	$R_{\ell 23}$	$[0.985,\ 1.013]$
	$R_{D\ell\nu}$	$[0.151,\ 0.681]$
	${\rm BR}(D_s \to \tau\nu)$	$[0.047,\ 0.061]$
Group (ii)	${\rm BR}(b \to s\gamma)$	$[2.89,\ 4.21] \times 10^{-4}$
	${\rm BR}(B_s \to \mu^+\mu^-)$	$< 5.1 \times 10^{-8}$

LEP Higgs mass constraints







Low-energy observables within *Region 2*