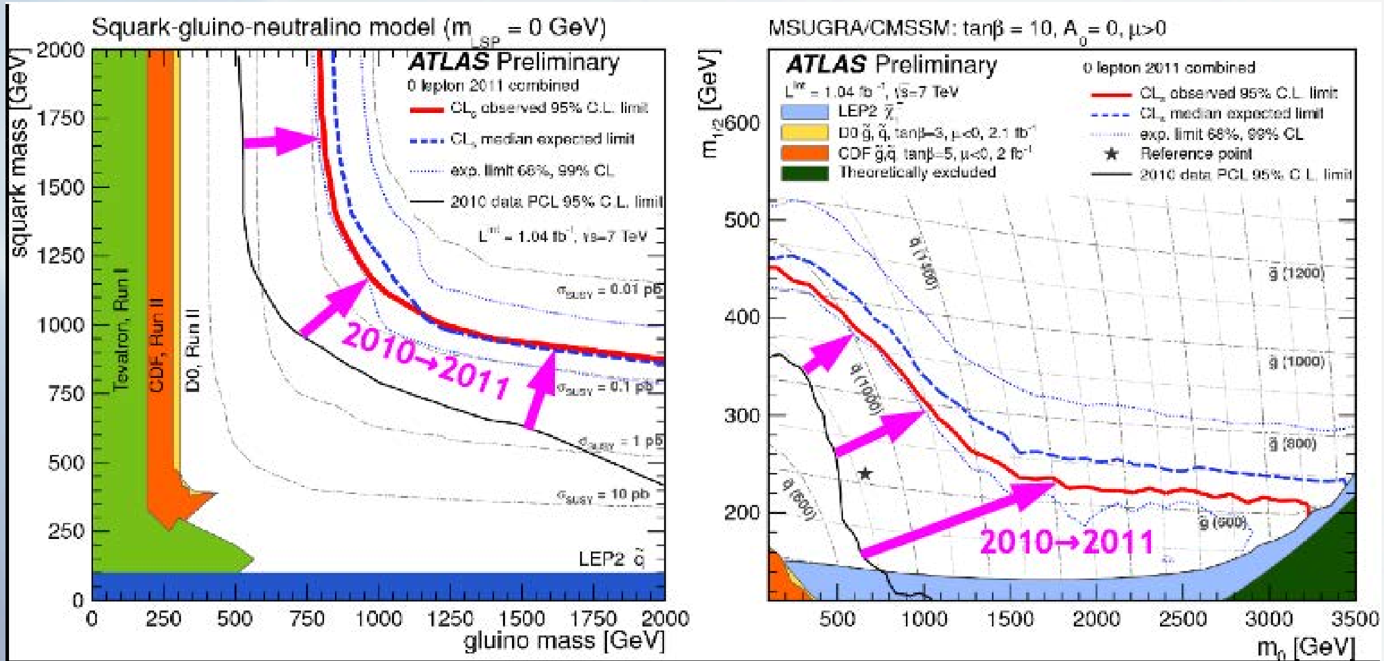
First SUSY results @ LHC

SUSY in 0-lepton channel

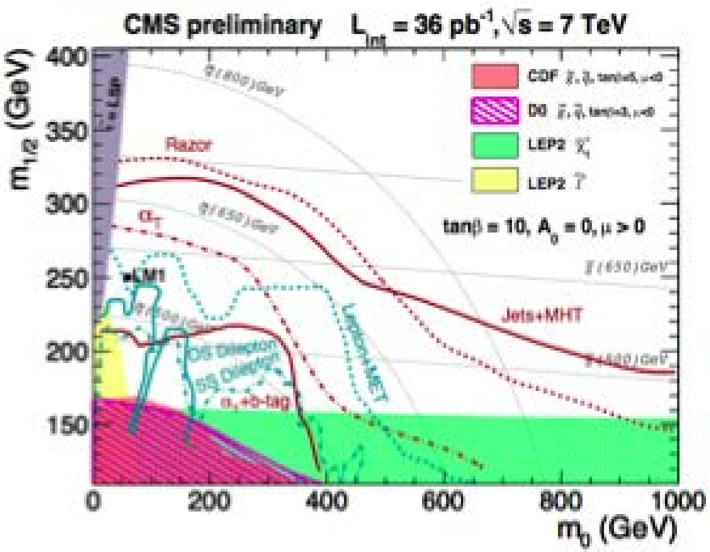


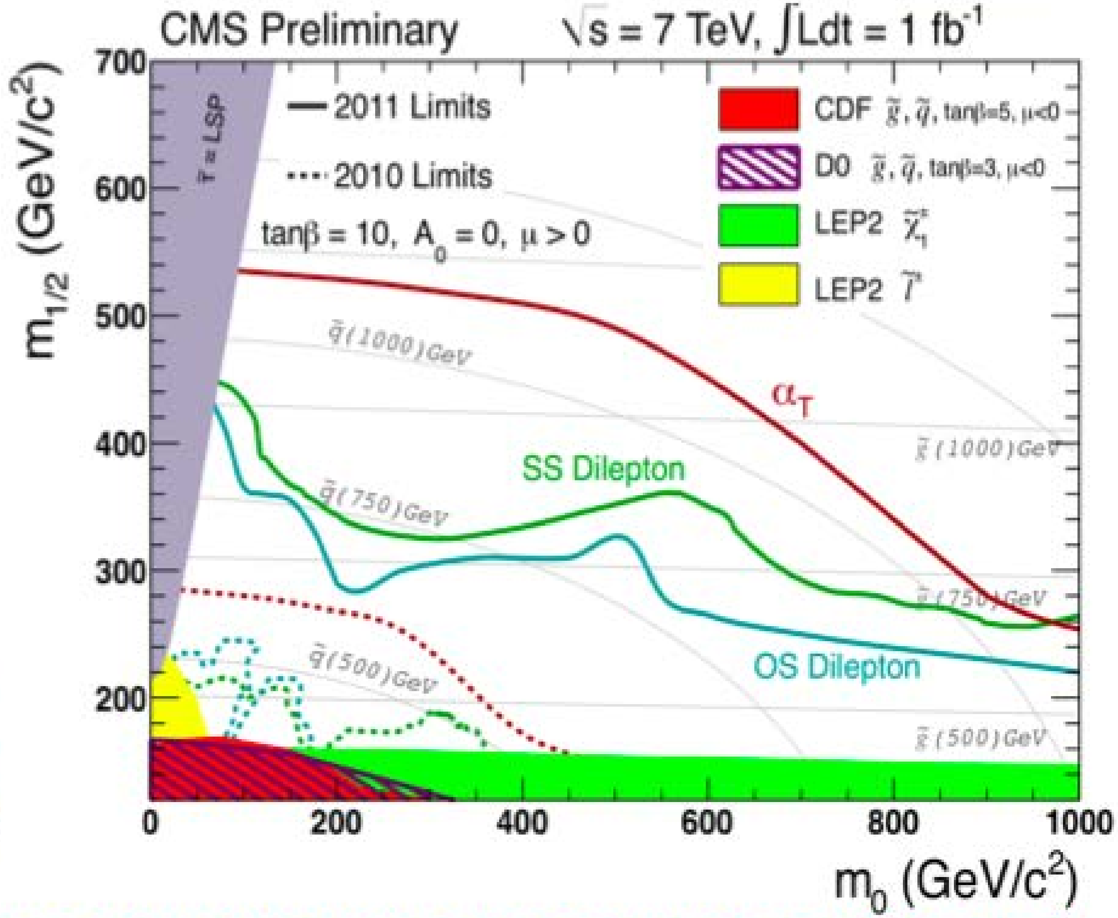
Simplified model with two q generations, m(χ 0)~0*1*mg>800 GeV mq>850 GeV
Equal mass case: mg=mq>1.075 TeV

MSUGRA/CMSSM: tanβ=10, A0=0, μ>0 Equal mass case: mq=mg > 980 GeV

Progress on SUSY Searches

Results of the first three SUSY analyses completed on 2011 data (α_T , Same Sign and Opposite Sign dileptons).





Within the constrained SSM models we are crossing the border of excluding gluinos and squarks up to 1TeV and beyond. The air is getting thin for constrained SUSY. More conclusive results after summer.

Search for supersymmetry in events involving third generation squarks and sleptons with ATLAS

LHC Seminar
February 14, 2012

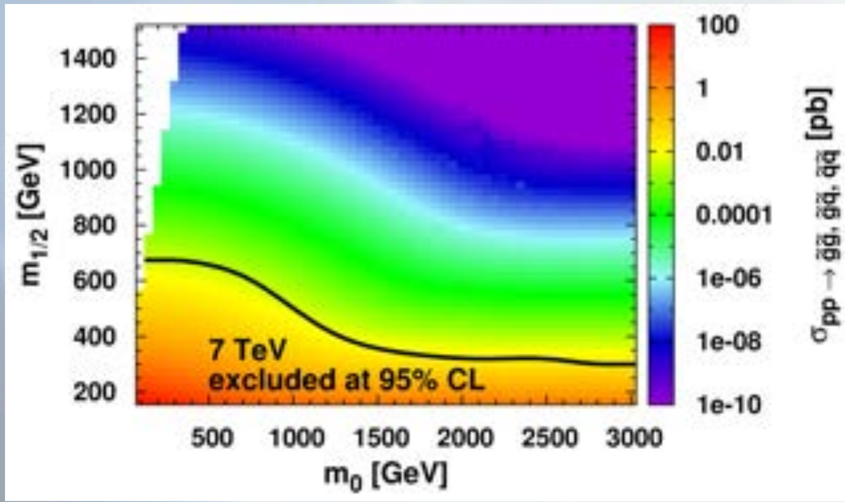
Ximo Poveda (University of Wisconsin-Madison)
on behalf of the ATLAS Collaboration

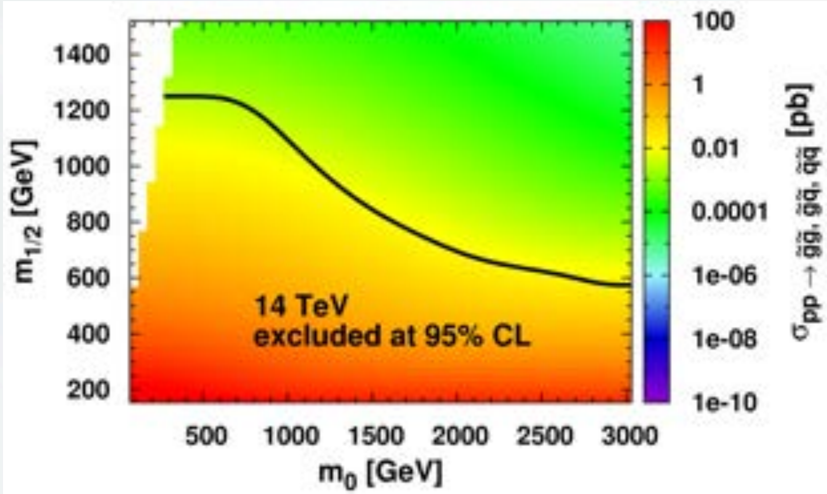
Summary

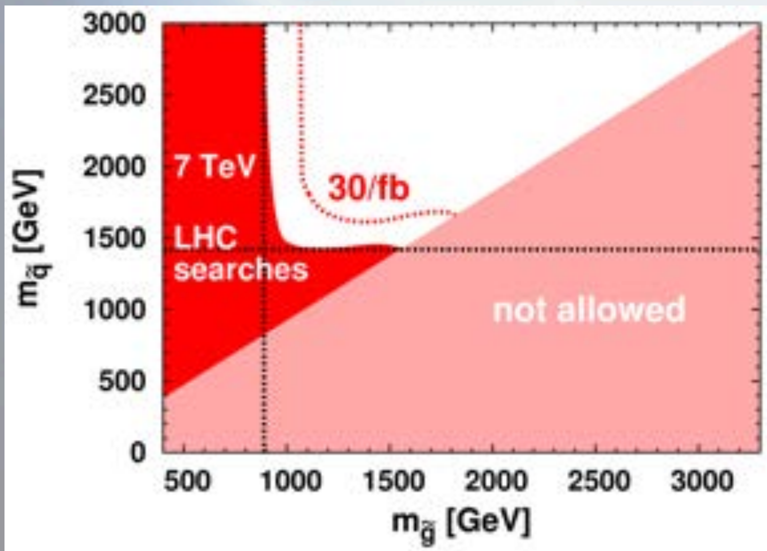
- Variety of searches for SUSY events with third generation squarks and sleptons
- Exploring signatures with heavy quarks or tau leptons using 2 fb^{-1} of data:
  - 1 or 2 τ leptons: gluino or squark mediated $\tilde{\tau}_1$ production
  - 2 b-jets + lepton veto: direct $\tilde{b}_1\tilde{b}_1^*$ production
  - 0 lepton + b-jets: gluino mediated $\tilde{b}_1$ production
  - 1 lepton + b-jets: direct $\tilde{t}_1\tilde{t}_1^*$ and gluino mediated $\tilde{t}_1$ production
  - 2 SS leptons: gluino mediated $\tilde{t}_1$ production
- No significant excess observed over SM expectations → Limits on the masses of the sparticles in a various SUSY scenarios

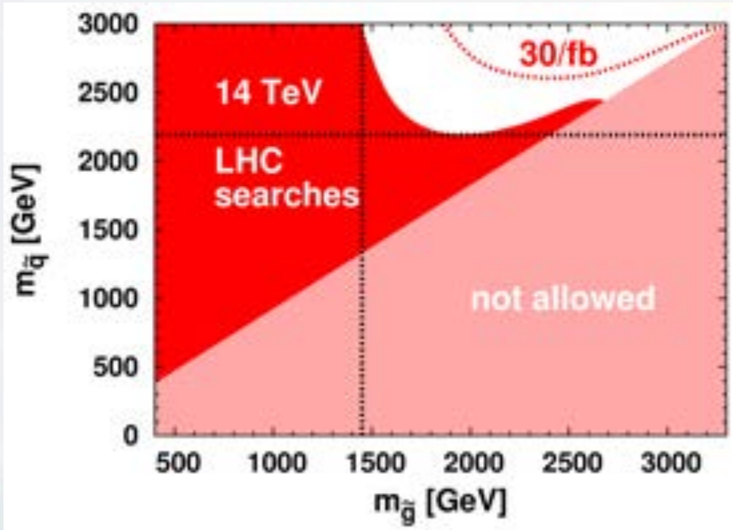
$\tilde{b}_1\tilde{b}_1^*$ (MSSM)	$\tilde{b}_1 \to b\tilde{\chi}_1^0$	$m_{\tilde{b}_1} = 390$ GeV ($m_{\tilde{\chi}_1^0} = 0$)	2 b-jets
$\tilde{b}_1\tilde{b}_1^*$ (MSSM)	$\tilde{b}_1 \to b\tilde{\chi}_1^0$	$m_{\tilde{b}_1} = 350$ GeV ($m_{\tilde{\chi}_1^0} = 120$ GeV)	2 b-jets
$\tilde{g}\tilde{g}$, $\tilde{b}_1\tilde{b}_1^*$ (MSSM)	$\tilde{g} \to \tilde{b}_1 b$, $\tilde{b}_1 \to b\tilde{\chi}_1^0$	$m_{\tilde{g}} = 920$ GeV ($m_{\tilde{b}_1} < 800$ GeV)	0ℓ + b-jets
$\tilde{g}\tilde{g}$ (simpl. model)	$\tilde{g} \to \bar{b}\tilde{\chi}_1^0$	$m_{\tilde{g}} = 900$ GeV ($m_{\tilde{\chi}_1^0} < 300$ GeV)	0ℓ + b-jets
$\tilde{g}\tilde{g}$, $\tilde{t}_1\tilde{t}_1^*$ (MSSM)	$\tilde{g} \to \tilde{t}_1 t$, $\tilde{t}_1 \to t\tilde{\chi}_1^0$	$m_{\tilde{g}} = 620$ GeV ($m_{\tilde{t}_1} < 440$ GeV)	1ℓ + b-jets
$\tilde{g}\tilde{g}$, $\tilde{t}_1\tilde{t}_1^*$ (MSSM)	$\tilde{g} \to \tilde{t}_1 t$, $\tilde{t}_1 \to t\tilde{\chi}_1^0$	$m_{\tilde{g}} = 650$ GeV ($m_{\tilde{t}_1} < 450$ GeV)	2ℓSS
$\tilde{g}\tilde{g}$ (simpl. model)	$\tilde{g} \to t\bar{t}\tilde{\chi}_1^0$	$m_{\tilde{g}} = 700$ GeV ($m_{\tilde{\chi}_1^0} < 100$ GeV)	1ℓ + b-jets
$\tilde{g}\tilde{g}$ (simpl. model)	$\tilde{g} \to t\bar{t}\tilde{\chi}_1^0$	$m_{\tilde{g}} = 650$ GeV ($m_{\tilde{\chi}_1^0} < 215$ GeV)	2ℓSS
$\tilde{g}\tilde{g}$ (simpl. model)	$\tilde{g} \to tb + \tilde{\chi}_1^0$	$m_{\tilde{g}} = 710$ GeV ($m_{\tilde{\chi}_1^0} < 100$ GeV)	1ℓ + b-jets

LHC Reach at 7 and 14 TeV









Energy is more important than luminosity

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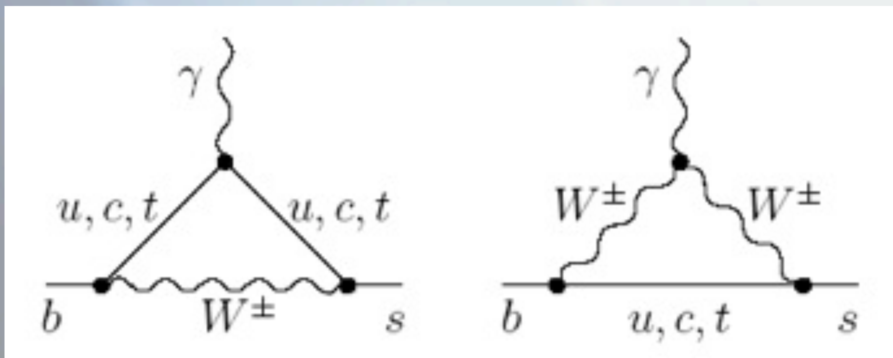
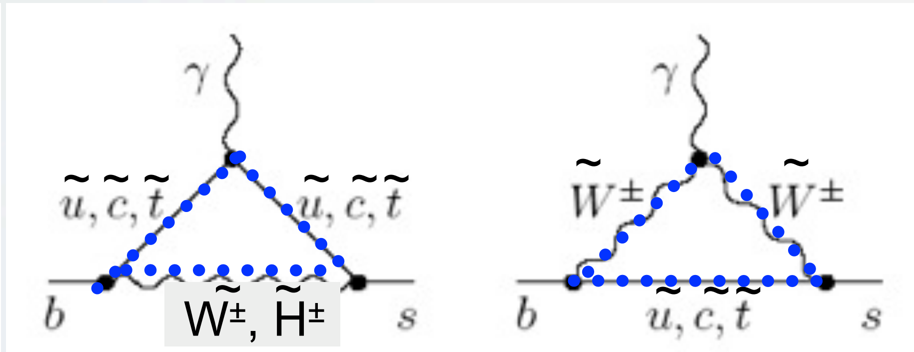
B->sγ decay rate

Standard Model

MSSM

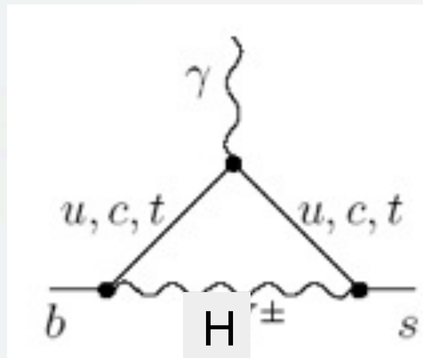




SM: $\mathcal{B}(B \to X_s\gamma) = (3.28 \pm 0.33) \times 10^{-4}$.

MSSM

$$\mathcal{BR}(b \to s\gamma)|_{\chi^{\pm}} \propto \mu A_t \tan\beta f(m_{\tilde{t}_1}, m_{\tilde{t}_2}, m_{\chi^{\pm}}) \frac{m_b}{v(1+\Delta m_b)}$$



Experiment $\mathbf{B(B \to X_s\gamma) = (3.43 \pm 0.36) \times 10^{-4}}$

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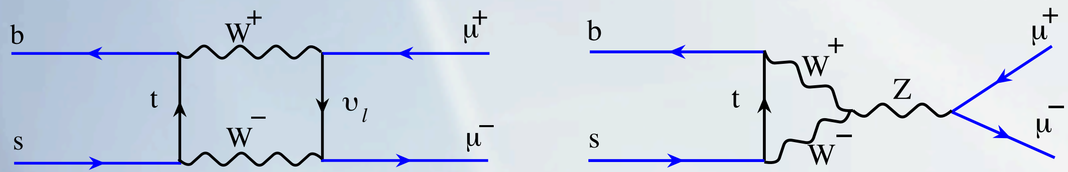
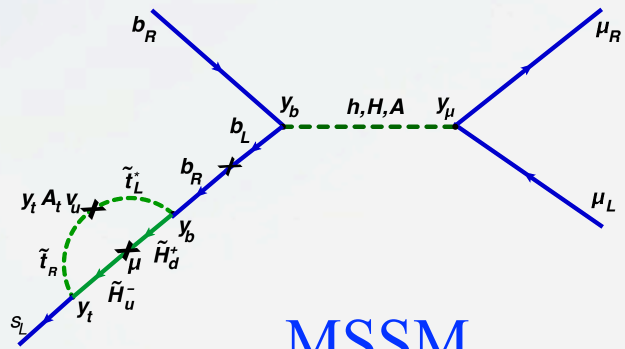
Rare Decays: $Br[B_s \to \mu^+\mu^-]$



SM



MSSM

SM: Br=3.5⋅10^{-9}

Ex: <4.5⋅ 10^{-8}

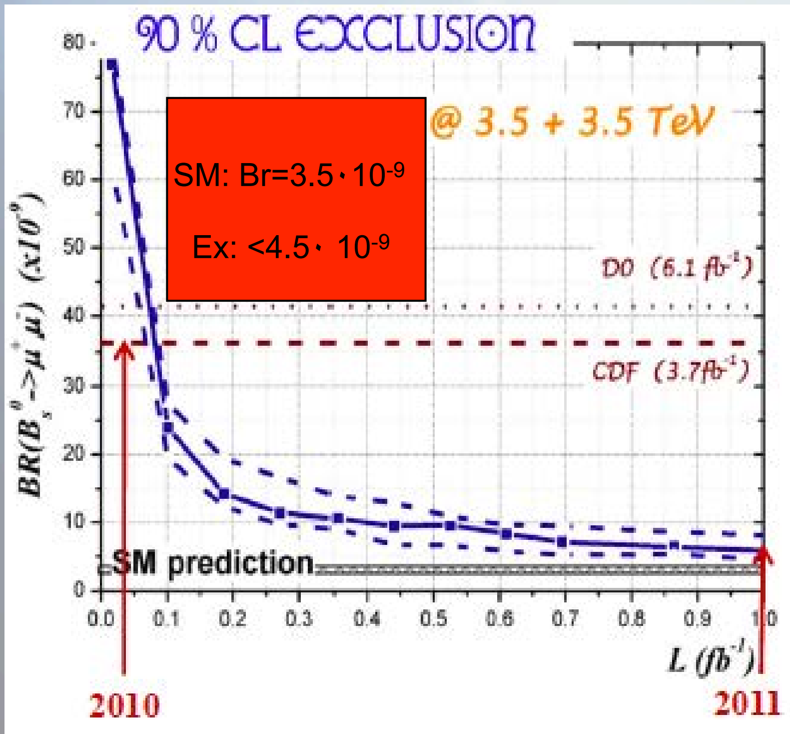
$$Br[B_s \to \mu\mu] = \frac{2\tau_B m_B^5}{64\pi} f_{B_s}^2 \sqrt{1-\frac{4m_l^2}{m_B^2}} \left[\left(1-\frac{4m_l^2}{m_B^2}\right)\left|\frac{(C_S-C_S')}{(m_b+m_s)}\right|^2 + \left|\frac{(C_P-C_P')}{(m_b+m_s)} + 2\frac{m_\mu}{m_{B_s}^2}(C_A-C_A')\right|^2\right]$$

$$C_S \simeq \frac{G_F\alpha}{\sqrt{2}\pi} V_{tb}V_{ts}^* \left(\frac{\tan^3\beta}{\sin^2\theta_W}\right)\left(\frac{m_b m_\mu m_t \mu}{M_W^2 M_A^2}\right)\frac{\sin 2\theta_{\tilde{t}}}{2}\left(\frac{m_{\tilde{t}_1}^2 \log\left[\frac{m_{\tilde{t}_1}^2}{\mu^2}\right]}{\mu^2-m_{\tilde{t}_1}^2} - \frac{m_{\tilde{t}_2}^2 \log\left[\frac{m_{\tilde{t}_2}^2}{\mu^2}\right]}{\mu^2-m_{\tilde{t}_2}^2}\right)$$

Enhancement

Suppression

Rare Decays: $Br[B_s \to \mu^+\mu^-]$ Constraint

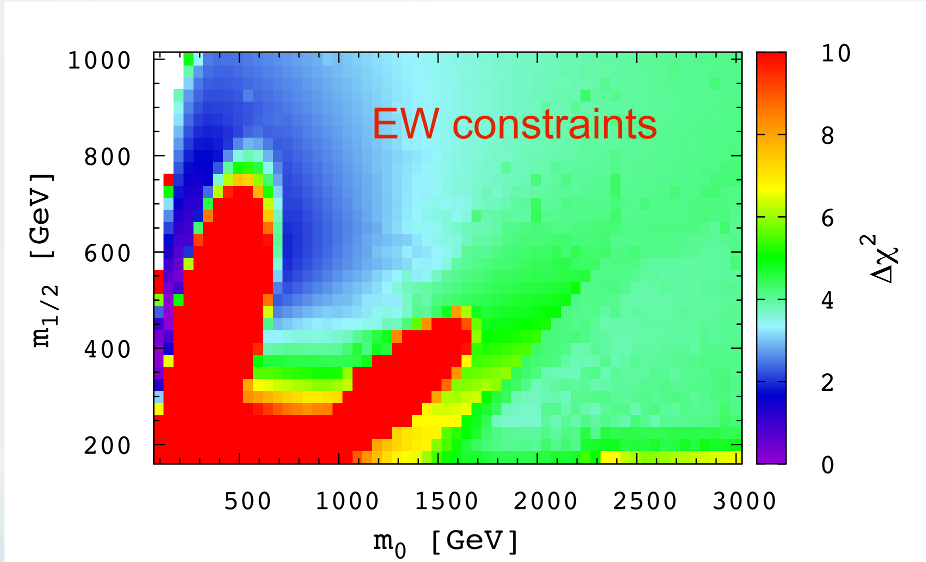


95% C.L. Excluded regions for

$$Br[B_s \to \mu^+\mu^-] < 4.5 \cdot 10^{-9}$$

$$Br[B_s \to X_s\gamma] = (3.55 \pm 0.24) \cdot 10^{-4}$$

$$Br[B_u \to \tau\nu] = (1.68 \pm 0.31) \cdot 10^{-4}$$



Negative interference is possible

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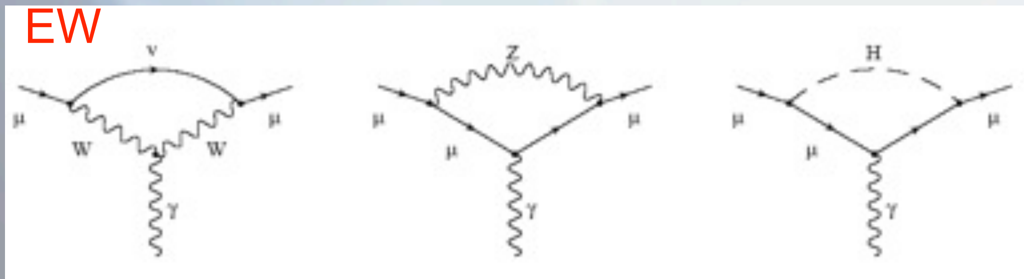
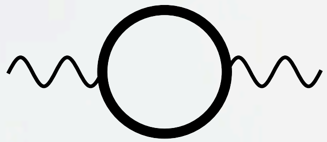
Anomalous magnetic moment

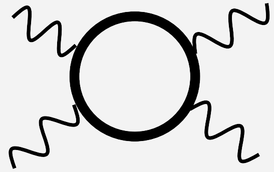
$$a_\mu^{exp} = 11\,659\,202\,(14)(6)\cdot 10^{-10}$$
$$a_\mu^{SM} = 11\,659\,159.6\,(6.7)\cdot 10^{-10}$$

$$a_\mu^{exp} - a_\mu^{SM} = (\,27\pm10\,)\cdot 10^{-10}$$

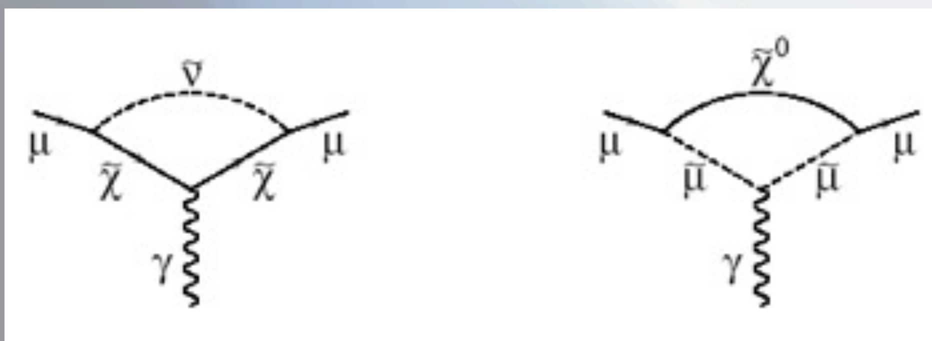
$$a_\mu^{QED} = 11\,658\,470.56\,(0.29)\cdot 10^{-10}$$
$$a_\mu^{weak} = 15.1\,(0.4)\cdot 10^{-10}$$
$$a_\mu^{hadr} = 673.9\,(6.7)\cdot 10^{-10}$$




vacuum pol


light-light scat

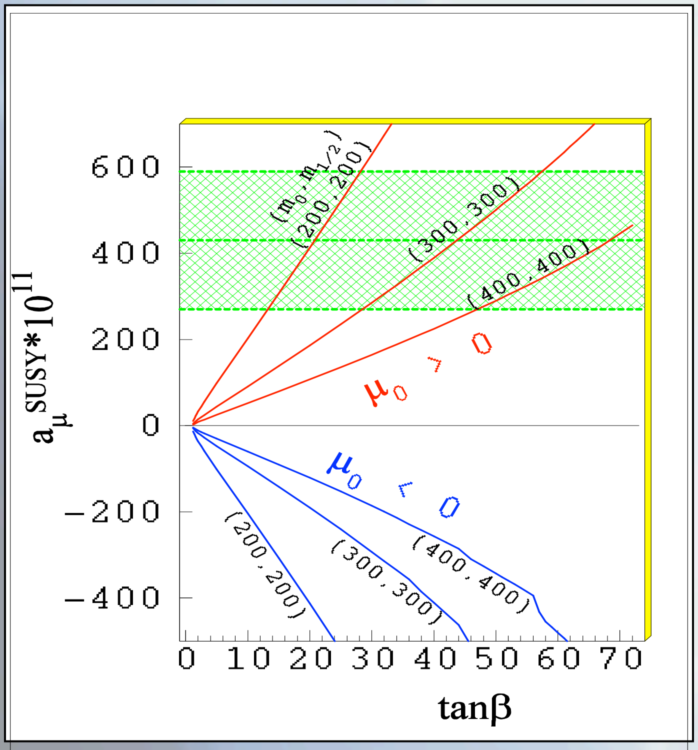
$$|a_\mu^{SUSY}| \simeq \frac{\alpha(M_Z)}{8\pi\, Sin^2\theta_W}\frac{m_\mu^2}{M_{SUSY}^2} tan\beta\left(1-\frac{4\alpha}{\pi}log\frac{M_{SUSY}}{m_\mu}\right) \simeq 140\cdot 10^{-11}\left(\frac{100\text{ GeV}}{M_{SUSY}}\right)^2 tan\beta$$

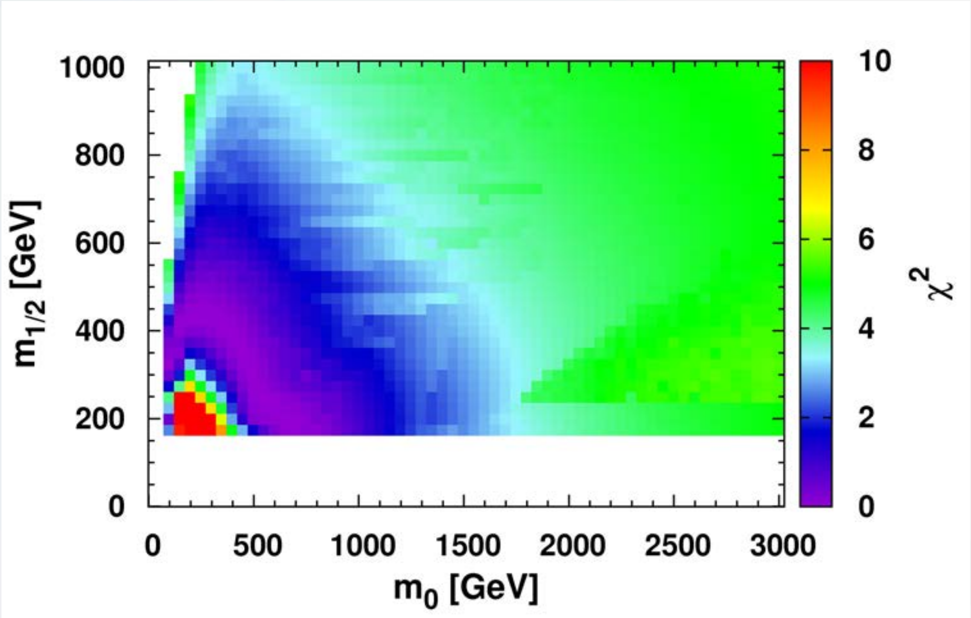


Suppression

Enhancement

g-2 Constraint on Parameter space





The only requirement that limits the SUSY masses from above

Fixes the sign of μ

Almost excluded by rare decay

$$Br[B_s \to \mu^+\mu^-]$$

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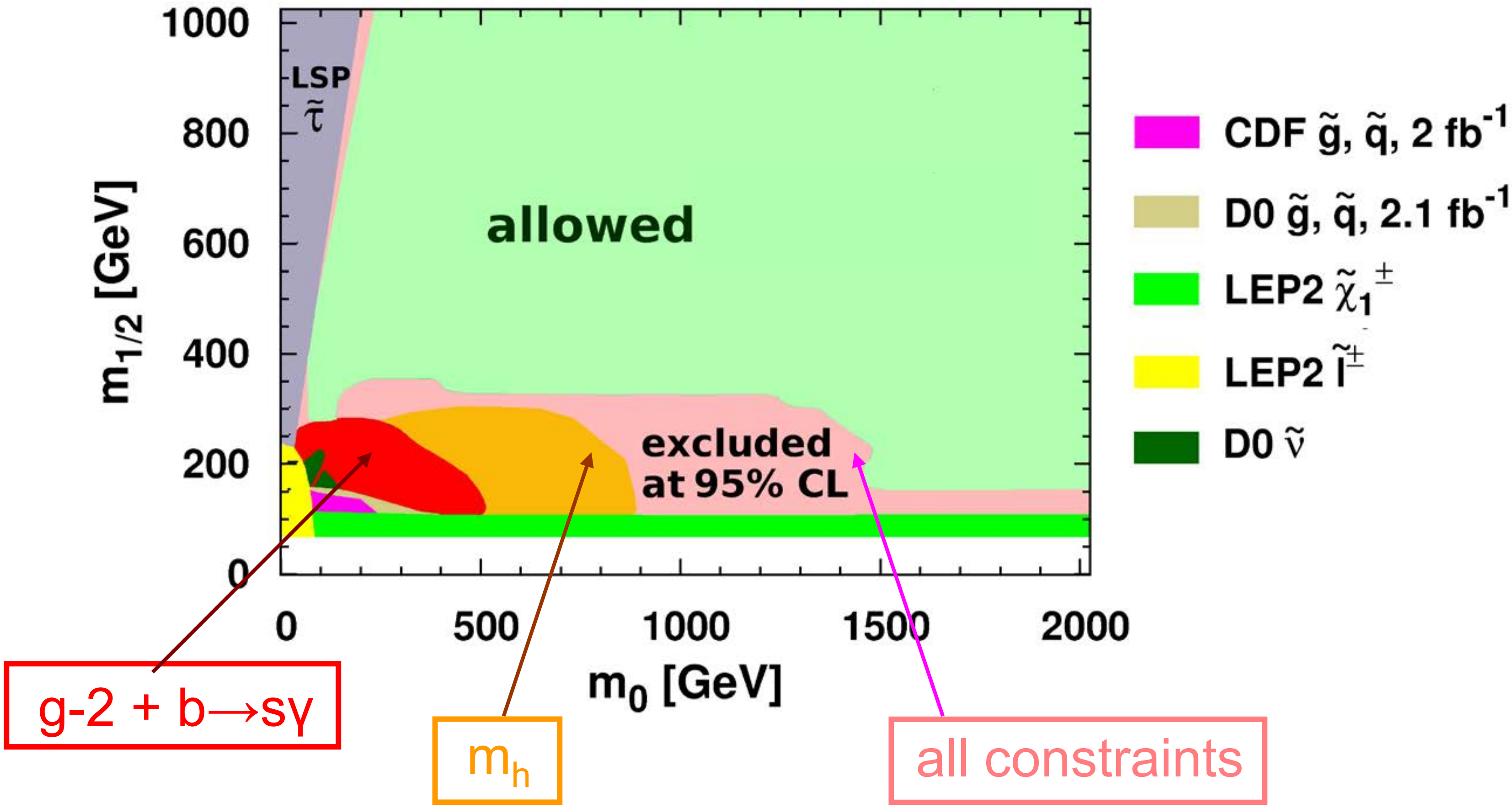
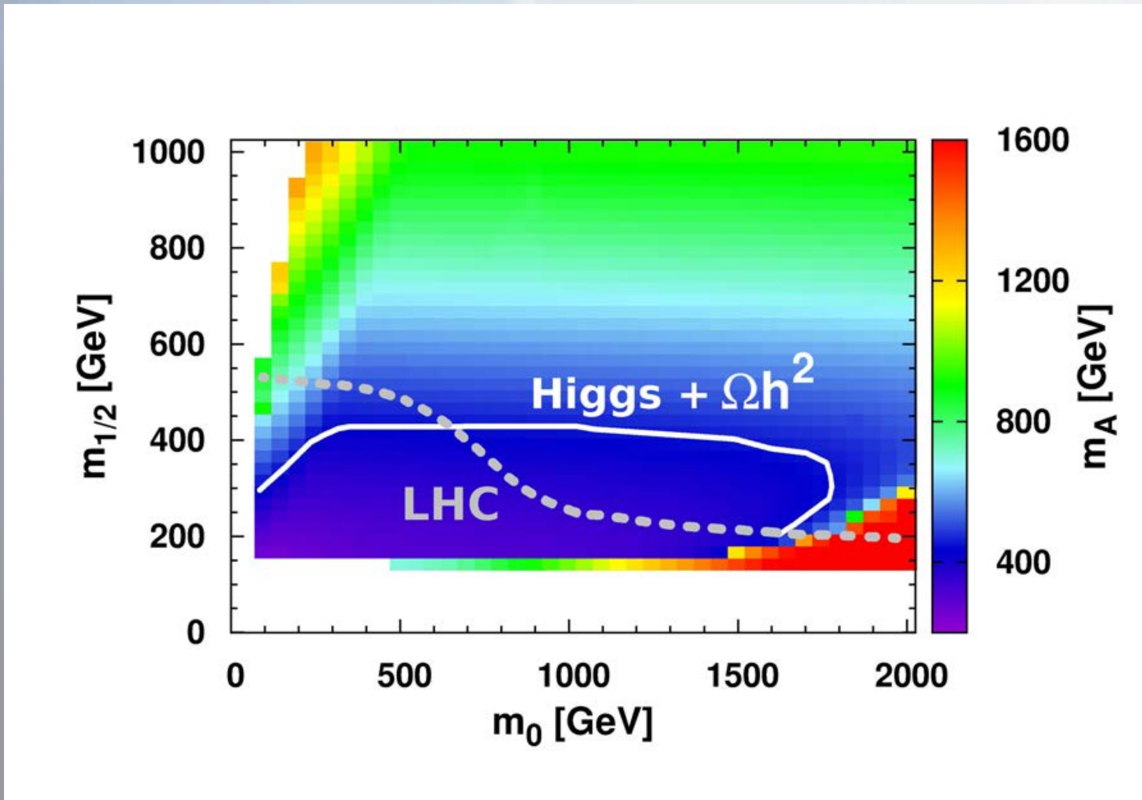
Pre-LHC Constraints

- Allowed parameter space (95% CL contour) in the m_0-$m_{1/2}$ plane including all constraints



SUSY Limits including the LHC without Direct DM Search



This includes:

- the Higgs searches,
- the rare decays,
- the relic abundancy
- and collider limits

The values of A_0 and $\tan\beta$ are ajusted

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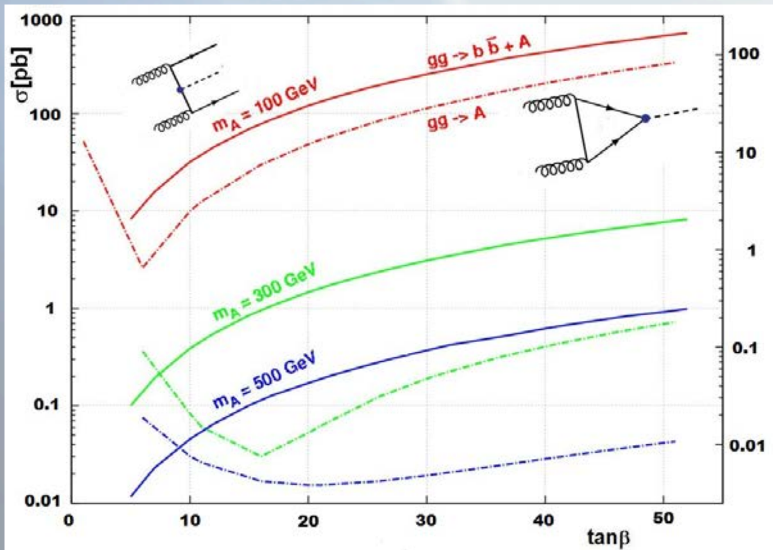
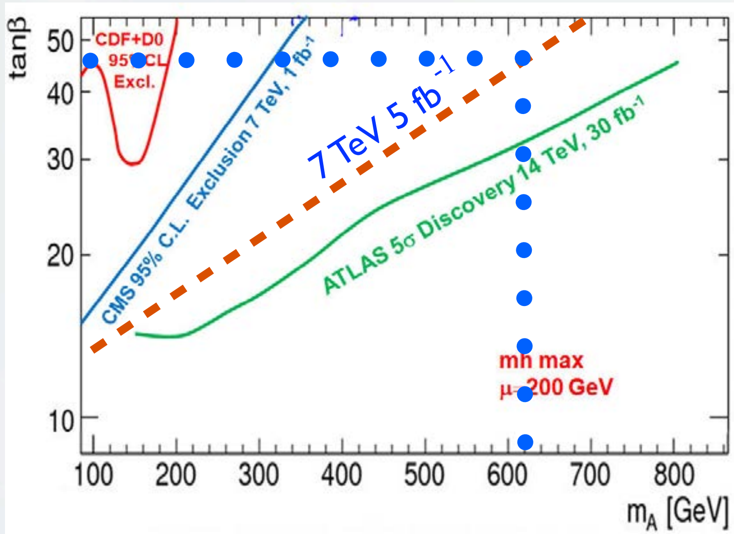
Heavy Higgs Production at the LHC





$$\sigma_{Higgs} = \frac{1}{32}\int_0^1 dx_1 dx_2\; g[x_1]\; g[x_2]\; |\mathcal{M}_{Higgs}|^2 \frac{2\pi}{m^2_{Higgs}} \delta(E^2 x_1 x_2 - m^2_{Higgs})$$

$$\mathcal{M}_h = \frac{\alpha_s}{4\pi}\frac{m_h^2}{2\sqrt{2}v}\left(\frac{\cos\alpha}{\sin\beta}F^h_{1/2}[\frac{4m_t^2}{m_h^2}] - \frac{\sin\alpha}{\cos\beta}F^h_{1/2}[\frac{4m_b^2}{m_h^2}]\right),$$

$$\mathcal{M}_H = \frac{\alpha_s}{4\pi}\frac{m_H^2}{2\sqrt{2}v}\left(\frac{\sin\alpha}{\sin\beta}F^H_{1/2}[\frac{4m_t^2}{m_H^2}] + \frac{\cos\alpha}{\cos\beta}F^H_{1/2}[\frac{4m_b^2}{m_H^2}]\right),$$

$$\mathcal{M}_A = \frac{\alpha_s}{4\pi}\frac{m_A^2}{2\sqrt{2}v}\left(\frac{\cos\beta}{\sin\beta}F^A_{1/2}[\frac{4m_t^2}{m_A^2}] + \frac{\sin\beta}{\cos\beta}F^A_{1/2}[\frac{4m_b^2}{m_A^2}]\right)$$

Dark Matter Detection

Direct detection

DAMA, Zeplin,
CDMS, Edelweiss

No convincing evidence so far
Hope for new results soon

Indirect detection

- EGRET -> GLAST(FERMI)
Diffuse Gamma Rays
- HEAT, AMS01 -> PAMELA
Positrons in Cosmic Rays
- BESS -> AMS02
Antiprotons in Cosmic Rays

Search for DM annihilation!

Why WIMP?

Boltzman Equation

Hubble constant

$$\frac{dn_\chi}{dt} + 3Hn_\chi = -<\sigma v>(n_\chi^2 - n_{\chi,eq}^2), \qquad H = \dot{R}/R$$

Relic Abundance

$$\Omega_\chi h^2 = \frac{m_\chi n_\chi}{\rho_c} \approx \frac{3\cdot 10^{-27} cm^3 \sec^{-1}}{<\sigma v>}$$

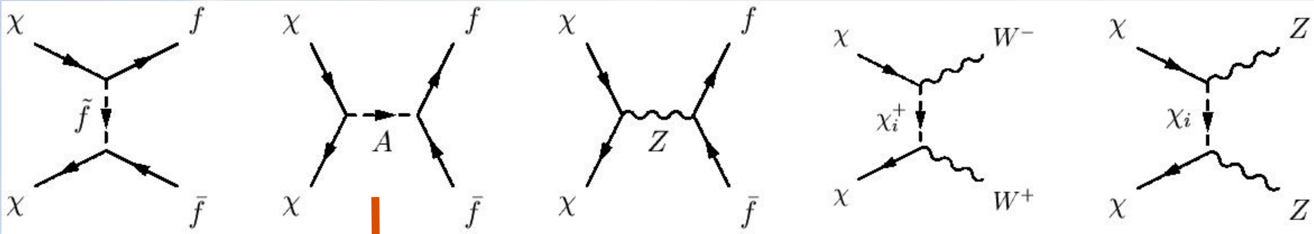
$$\Omega_\chi h^2 \sim 0.113 \pm 0.009,$$

$$v \sim 300\ km/\sec$$

$$\sigma \sim 10^{-34} cm^2 = 100\, pb$$

Typical EW x-section

Relic Abundace of the Dark Matter



$$\propto \frac{m_\chi \cdot m_f}{m_{\tilde{f}}^2} \qquad \propto \frac{\tan\beta \cdot m_f}{m_W} N_1 N_{3(4)} \qquad \propto \frac{m_f \cdot m_\chi}{m_Z^2} N^2_{3(4)} \qquad \propto \frac{1}{1+(m_{\chi_i^+}/m_\chi)^2-(m_W/m_\chi)^2}$$

$$\tan\beta \cdot m_d \leftrightarrow \frac{m_{f_u}}{\tan\beta} \qquad (m_{\chi_i^+}, m_W) \leftrightarrow (m_{\chi_i}, m_Z)$$

$$\tilde{\chi}^0 = N_1 \tilde{\gamma} + N_2 \tilde{z} + N_3 \tilde{H}_1^0 + N_4 \tilde{H}_2^0$$

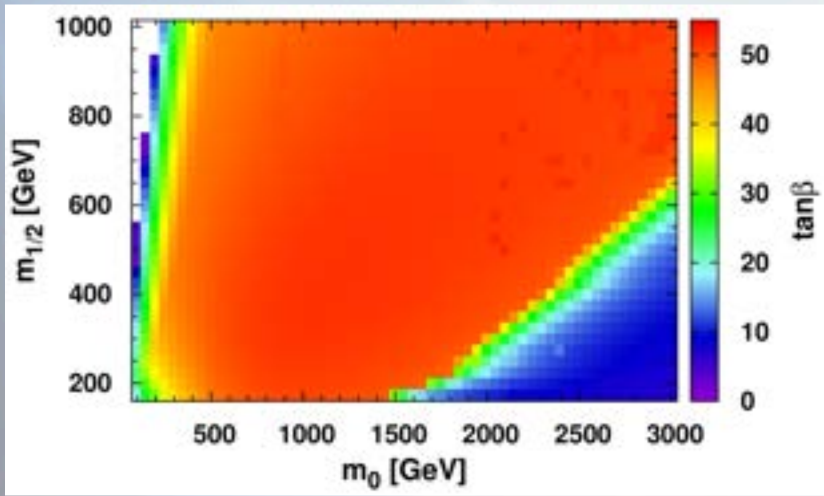
The Dark Matter Annihilation

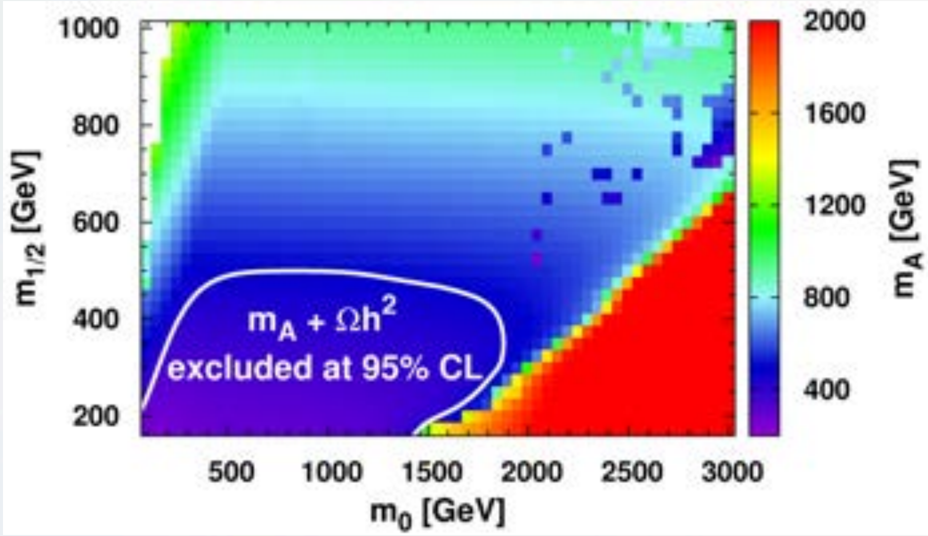
$$<\sigma v>= 2 \cdot 10^{-26} cm^3/s$$

Resonance in s-channel

$$<\sigma v>\sim \frac{M_\chi^4 m_b^2 \tan^2\beta}{\sin^4 2\theta_W \, M_Z^2} \frac{(N_{31}\sin\beta - N_{41}\cos\beta)^2 (N_{21}\cos\theta_W - N_{11}\sin\theta_W)^2}{(4M_\chi^2 - M_A^2)^2 + M_A^2\Gamma_A^2}$$

Relic Abundace of the DM Constraint





The value of $\tan\beta$

$\tan\beta \approx 50$ almost everywhere except for the coannihilation regions

The value of m_A

m_A may be as low as 500 GeV except for the coannihilation regions

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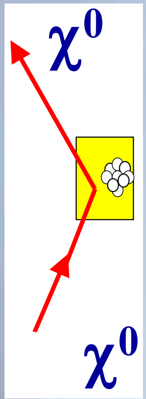
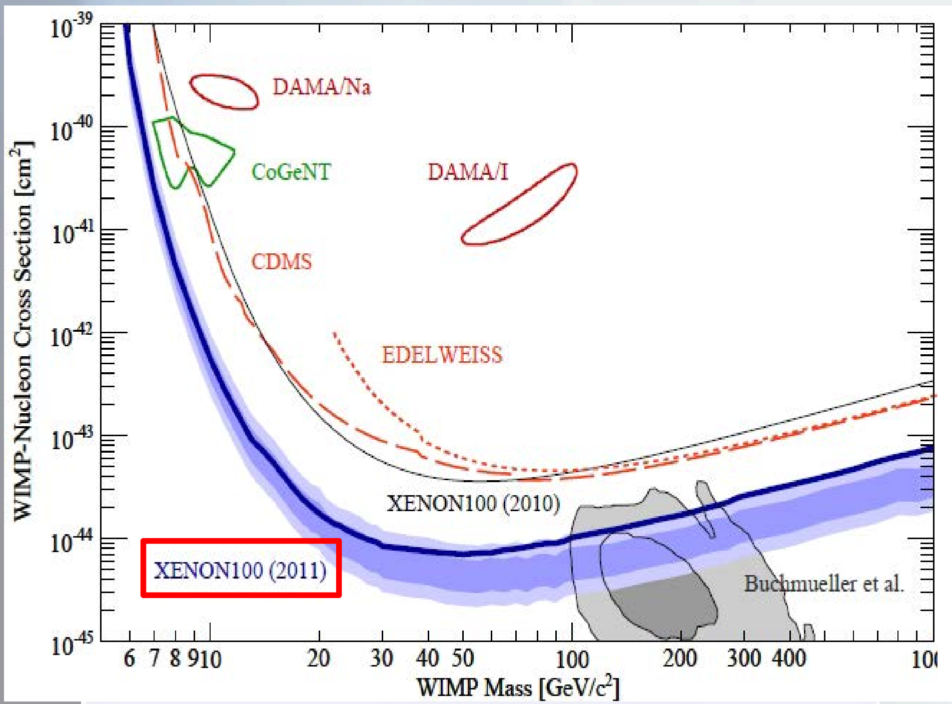
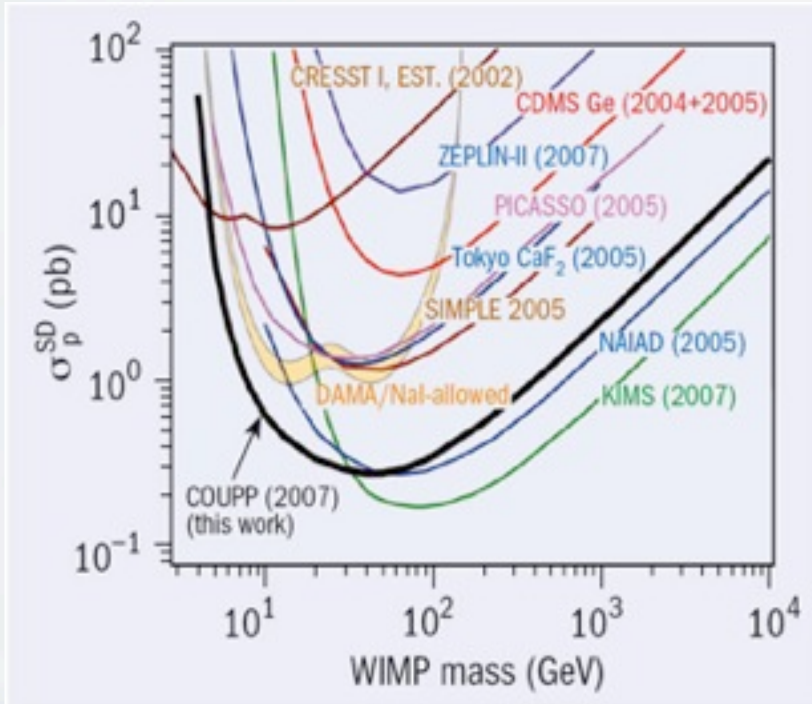


Recent Results on Direct Detection

Spin Independent



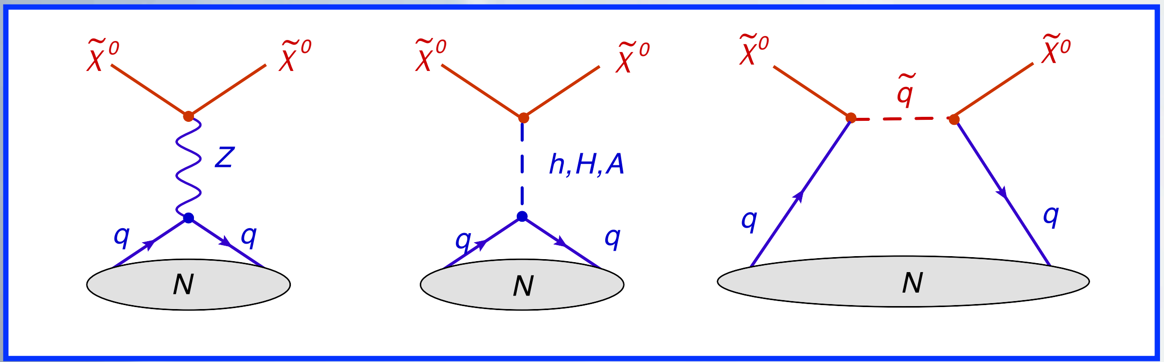
Spin Dependent

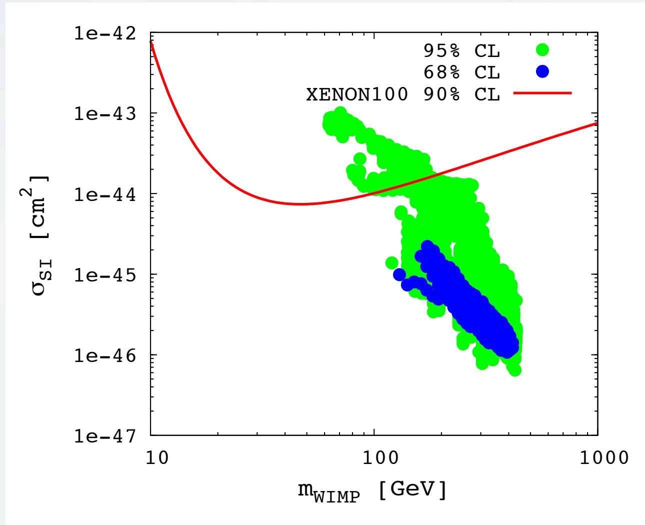


The Chicagoland Observatory for Underground Particle Physics (COUPP)

Cryogenic Dark Matter Search (CDMS)

Direct DM Searches





$$\sigma = \frac{4}{\pi}\frac{m_{\rm DM}^2 m_N^2}{(m_{\rm DM}+m_N)^2}\left(Zf_p + (A-Z)f_n\right)^2$$

$$f_{p,n} = \sum_{q=u,d,s} G_q f_{Tq}^{(p,n)}\frac{m_{p,n}}{m_q} + \frac{2}{27} f_{TG}^{(p,n)} \sum_{q=c,b,t} G_q \frac{m_{p,n}}{m_q} \qquad m_p f_{Tq}^{(p)} \equiv \langle p|m_q\bar{q}q|p\rangle$$

$$\begin{aligned}
G_q(A) &= 0,\\
G_u(h) &= \frac{-e^2 m_u}{2\sin^2 2\theta_W M_Z}(N_{21}\cos\theta_W - N_{11}\sin\theta_W)\frac{\cos\alpha}{\sin\beta}\frac{(N_{41}\cos\alpha + N_{31}\sin\alpha)}{M_h^2},\\
G_d(h) &= \frac{e^2 m_d}{2\sin^2 2\theta_W M_Z}(N_{21}\cos\theta_W - N_{11}\sin\theta_W)\frac{\sin\alpha}{\cos\beta}\frac{(N_{41}\cos\alpha + N_{31}\sin\alpha)}{M_h^2},\\
G_u(H) &= \frac{-e^2 m_u}{2\sin^2 2\theta_W M_Z}(N_{21}\cos\theta_W - N_{11}\sin\theta_W)\frac{\sin\alpha}{\sin\beta}\frac{(N_{41}\sin\alpha - N_{31}\cos\alpha)}{M_H^2}.\\
G_d(H) &= \frac{-e^2 m_d}{2\sin^2 2\theta_W M_Z}(N_{21}\cos\theta_W - N_{11}\sin\theta_W)\frac{\cos\alpha}{\cos\beta}\frac{(N_{41}\sin\alpha - N_{31}\cos\alpha)}{M_H^2}
\end{aligned}$$

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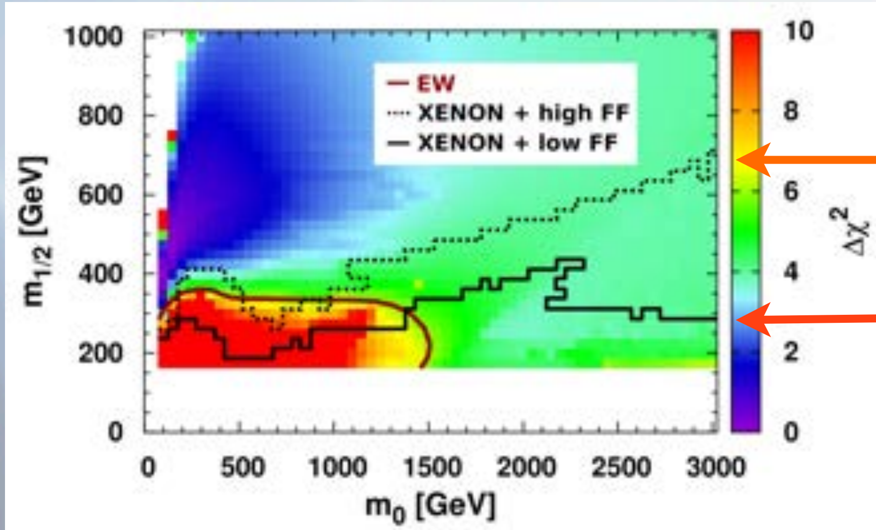
SUSY Limits from Direct DM Search

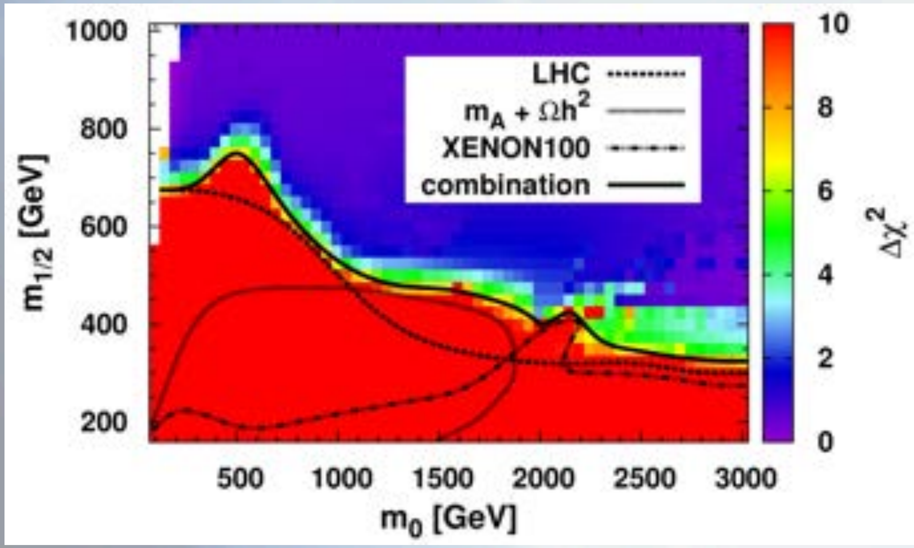


Low Energy Form Factors

Lattice Form Factors

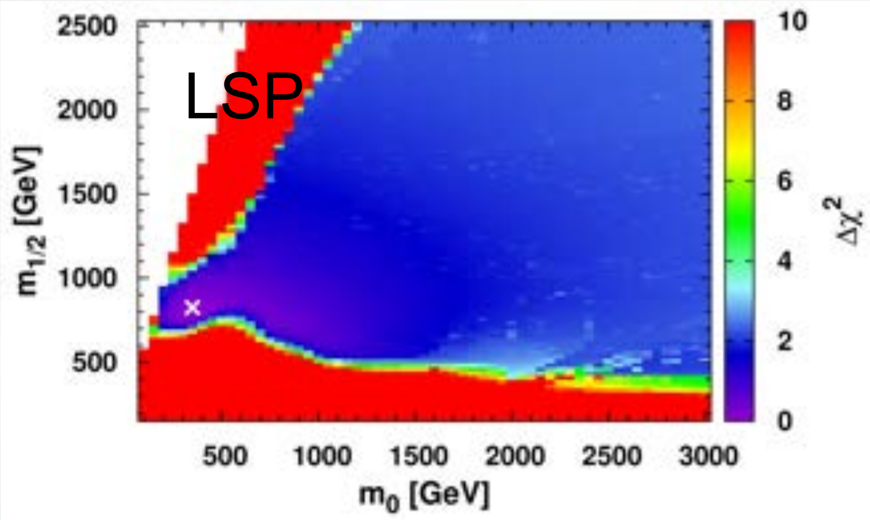
- LHC constraints are rather insensitive to large values of m_0
- They can be supplemented by direct DM searches

SUSY Limits from Combined Fit to all Data with 5/fb



The values of $\tan\beta$ and A_0 are adjusted

Larger scale for $m_{1/2}$



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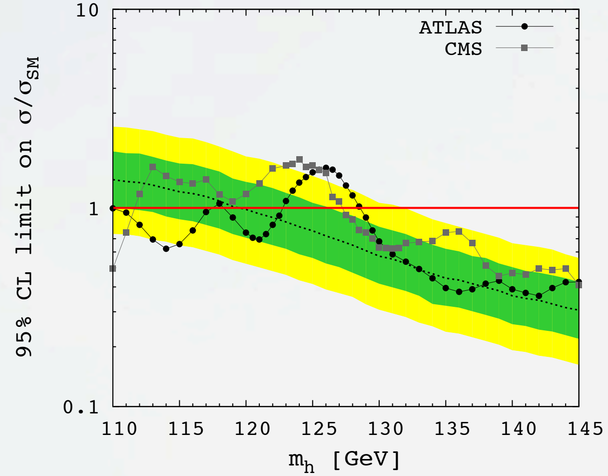
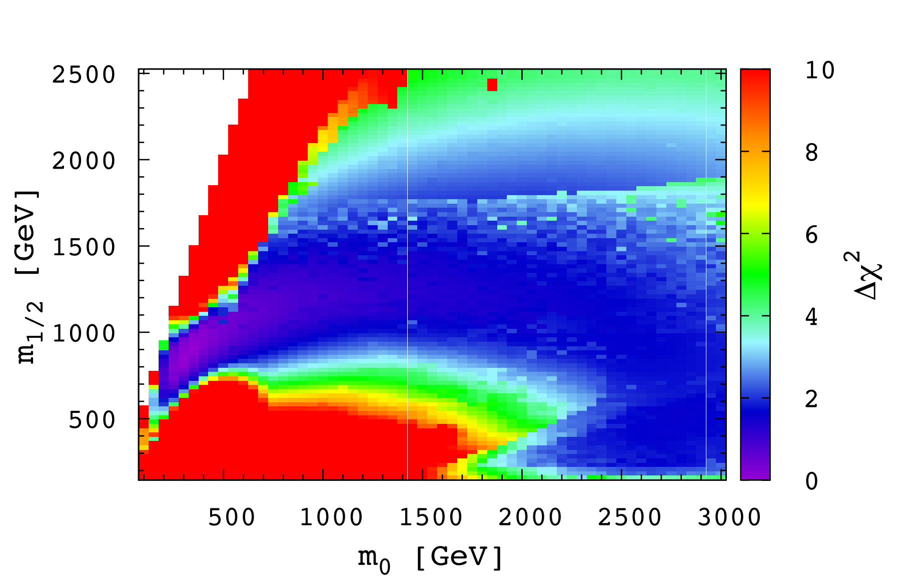
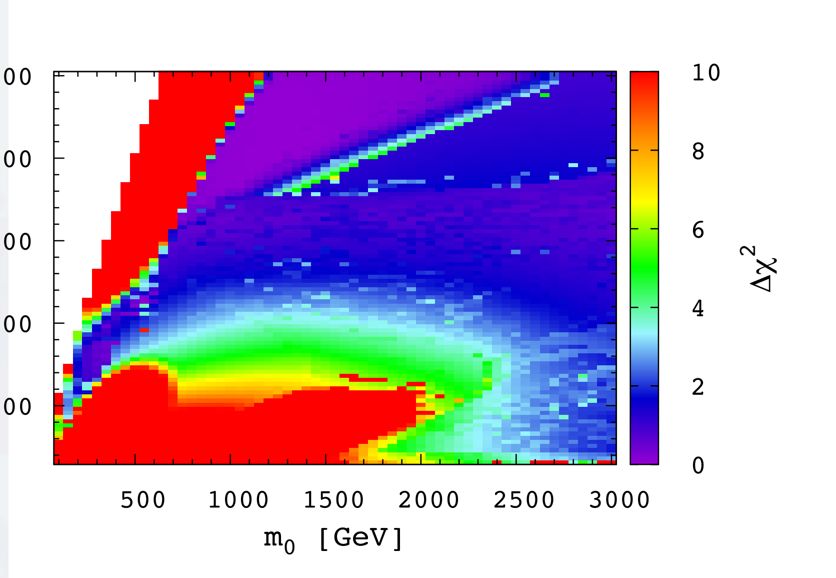
Constraints from the lightest Higgs of 125 GeV







$M_{Higgs} = 119 \pm 1.8\ GeV$

$M_{Higgs} = 125 \pm 3.6\ GeV$

Conclusions

• LHC is on the way of covering the parameter space of the MSSM

• Modern combined limit on $m_{1/2}$ is about 500 GeV for $m_0 < 1000\ GeV$

• This implies the lower limit on the WIMP mass of 210 GeV and gluino of 1190 GeV

• For larger values of m_0 the values of $m_{1/2}$ drop below 350 GeV which gives LSP mass of 130 GeV and gluino mass of 970 GeV

• Today's lower limit on squark masses (except $\tilde{t}$) is 1400 GeV and gluino mass is 900 GeV

Let 2012 be the year of Higgs discovery and SUSY evidence!

SUSY: Pros and Cons

Pro :

- Provides natural framework for unification with gravity
- Leads to gauge coupling unification (GUT)
- Solves the hierarchy problem
- Provides the mechanizm for spontaneous EWSB
- Is a solid quantum field theory
- Provides natural candidate for the WIMP cold DM
- Predicts new particles and thus generates new job positions

Contra :

Does not shed new light on the problem of

- Quark and lepton mass spectrum
- Quark and lepton mixing angles
- the origin of CP violation
- Number of flavours
- Baryon assymetry of the Universe

Doubles the number of particles

We love SUSY!