Positron Fraction from Dark Matter Annihilation in the CMSSM

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Outline

CMSSM Constraints

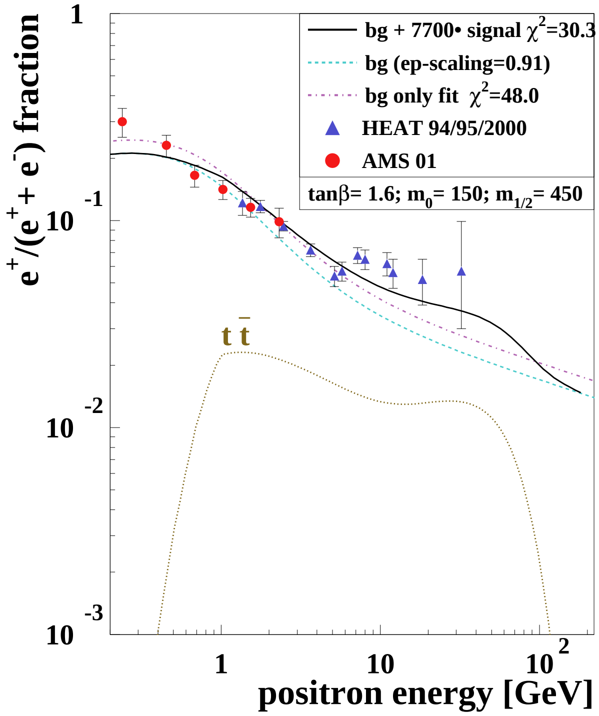
Positron fraction in the CMSSM Parameter Space

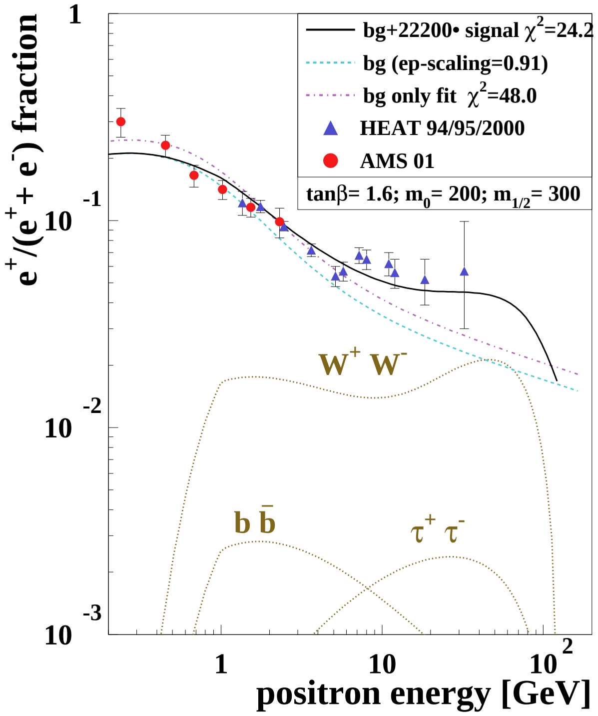
Comparison with HEAT data

Summary

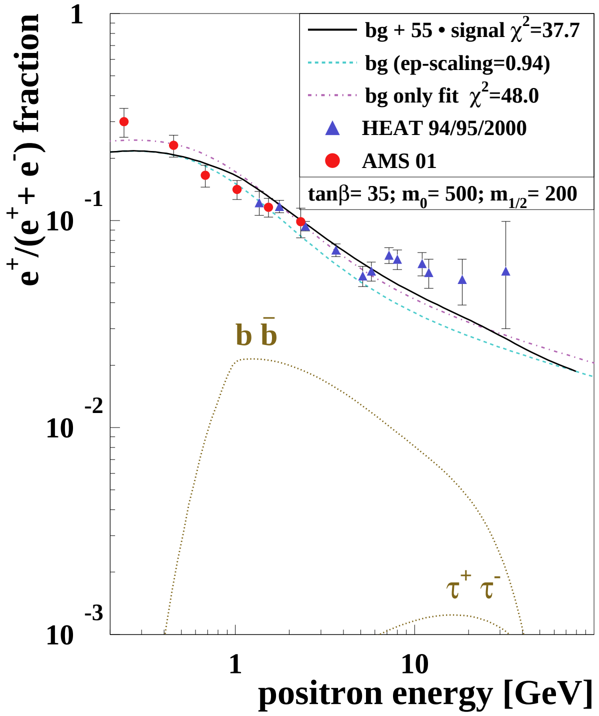
Typical Fits to HEAT Data

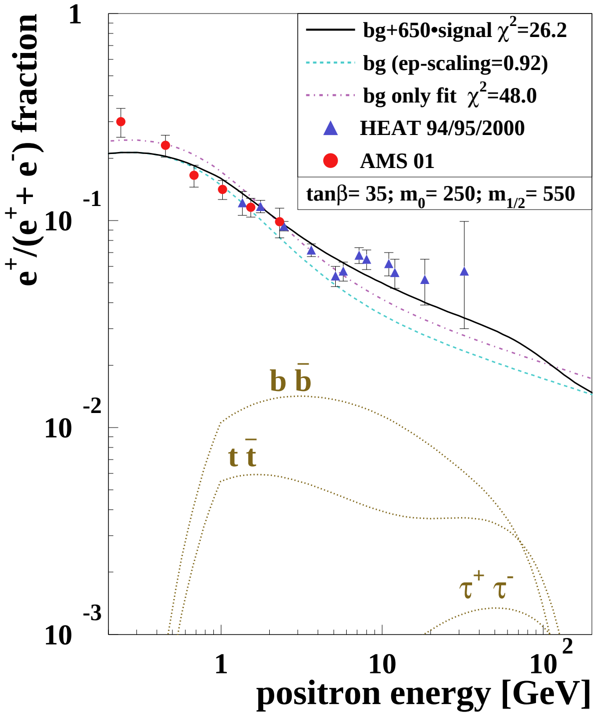
$\tan\beta = 1.6\ m_\chi^0 = 190$ $\tan\beta = 1.6\ m_\chi^0 = 120$





$\tan\beta = 35\ m_\chi^0 = 60$ $\tan\beta = 35\ m_\chi^0 = 230$





CMSSM Fitprocedure

Choose the 10 GUT supergravity inspired parameters:

$\mathbf{m_0},\ \mathbf{m_{1/2}},\alpha_{\mathbf{GUT}},\ \mathbf{M_{GUT}}$

$\mu,\ \mathbf{tan}\beta,\ \mathbf{A(0)},\ \mathbf{Y_t(0)},\ \mathbf{Y_b(0)},\mathbf{Y}_\tau\mathbf{(0)}$

Minimize the Higgs potential in order to determine $\mathrm{M_Z}$

Calculate masses and couplings at low energies by integrating about 30 coupled RGE's and decoupling sparticles at thresholds

calculate $Br(b \rightarrow s\gamma)$, a_μ^{SUSY}

Determine the best parameters by minimizing:

$$\chi^{\mathbf{2}} = \sum_i \frac{(\alpha_i(M_Z)-\alpha_i(MSSM))^2}{\sigma_i^2} \qquad \boxed{\rightarrow \mathbf{M_{GUT}},\ \alpha_{\mathbf{GUT}}}$$

$$+\frac{(\mathbf{m_t}-\mathbf{173})^{\mathbf{2}}}{\sigma_{\mathbf{t}}^{\mathbf{2}}} \qquad \rightarrow \mathbf{Y_t}$$

$$+\frac{(\mathbf{m_b}-\mathbf{4.9})^{\mathbf{2}}}{\sigma_{\mathbf{b}}^{\mathbf{2}}} \qquad \rightarrow \mathbf{Y_b}$$

$$+\frac{(\mathbf{m}_\tau-\mathbf{1.7771})^{\mathbf{2}}}{\sigma_\tau^{\mathbf{2}}} \qquad \rightarrow \mathbf{Y}_\tau$$

$$+\frac{(M_Z-91.18)^2}{\sigma_Z^2} \qquad \boxed{\rightarrow \mu^{\mathbf{2}}}$$

$$+\frac{(Br(b\rightarrow s\gamma)-2.96*10^{-4})^2}{\sigma_{bsg}^2}$$

$$+\frac{(a_\mu^{SUSY}-425*10^{-11})^2}{\sigma_{a_\mu}^2}$$

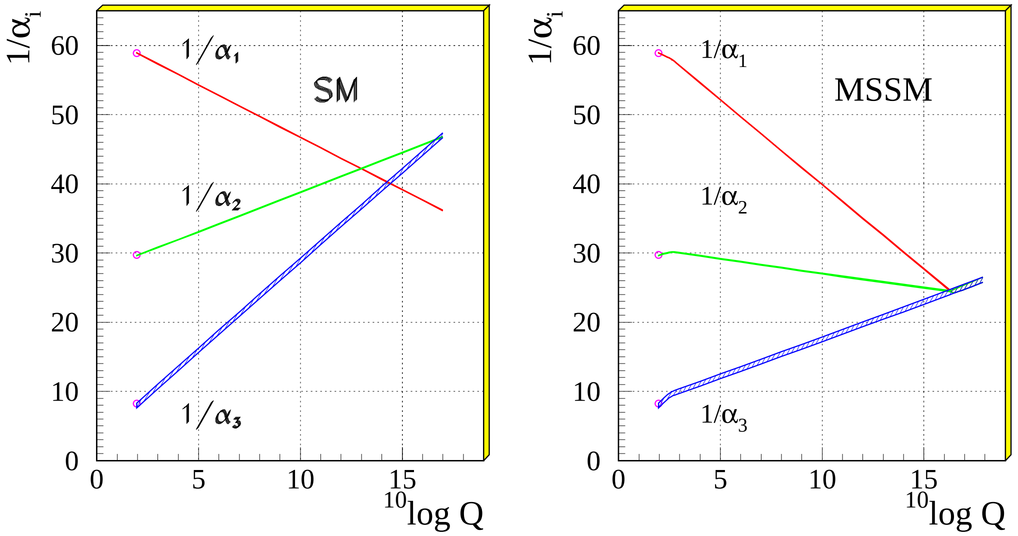
$$+\frac{(\tilde{M}-\tilde{M}_{lim})^2}{\sigma_{\tilde{M}}^2}\ for\ \tilde{M}<\tilde{M}_{lim}$$

$$+\chi^2(global\ EW\ precision\ data\ calc.\ in\ MSSM)$$

m_0 and $m_{1/2}$ strongly correlated.

Repeat fits for all pairs of $m_0,\ m_{1/2}$

Unification of the Coupling Constants in the SM and the minimal MSSM

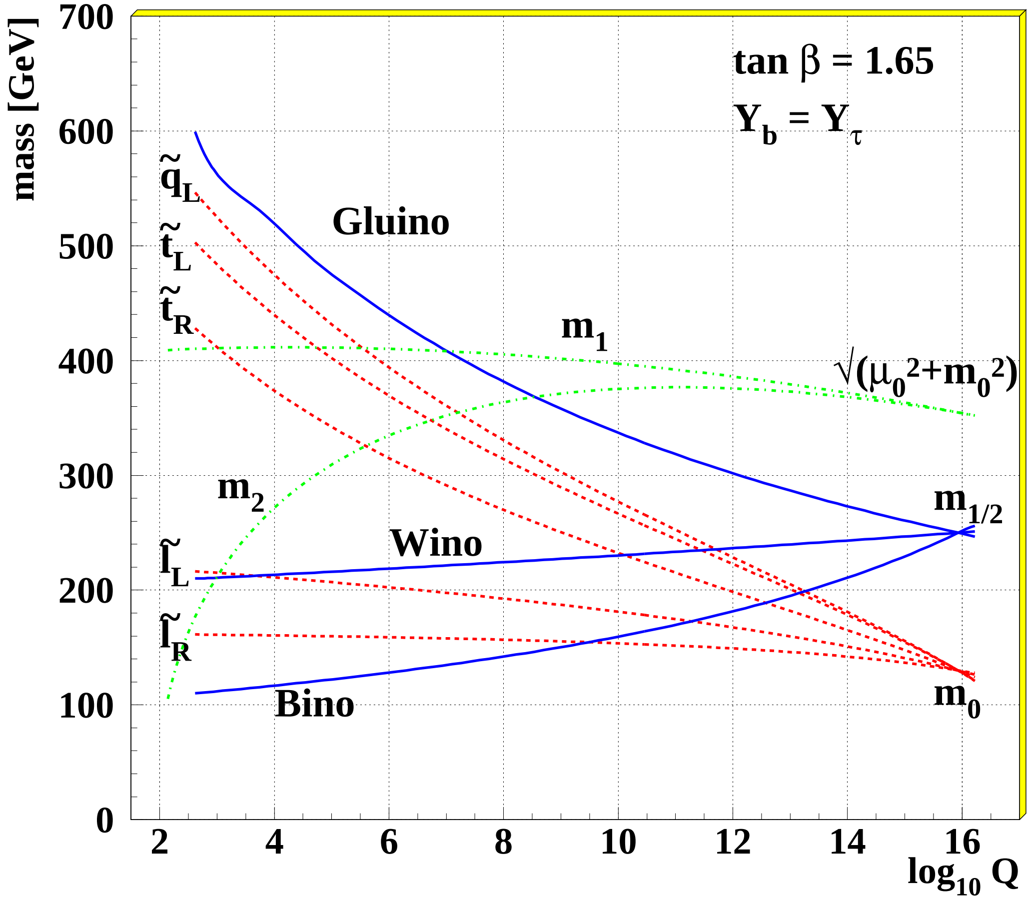


U. Amaldi, W. de Boer, H. Fürstenau, PL B260(1991) 447

$\alpha_1, \alpha_2, \alpha_3$ **coupling constants of electromagnetic –, weak–, and stong interactions**

$1/\alpha_i \propto \log Q^2$ **due to radiative corrections (LO)**

From RGE equations:

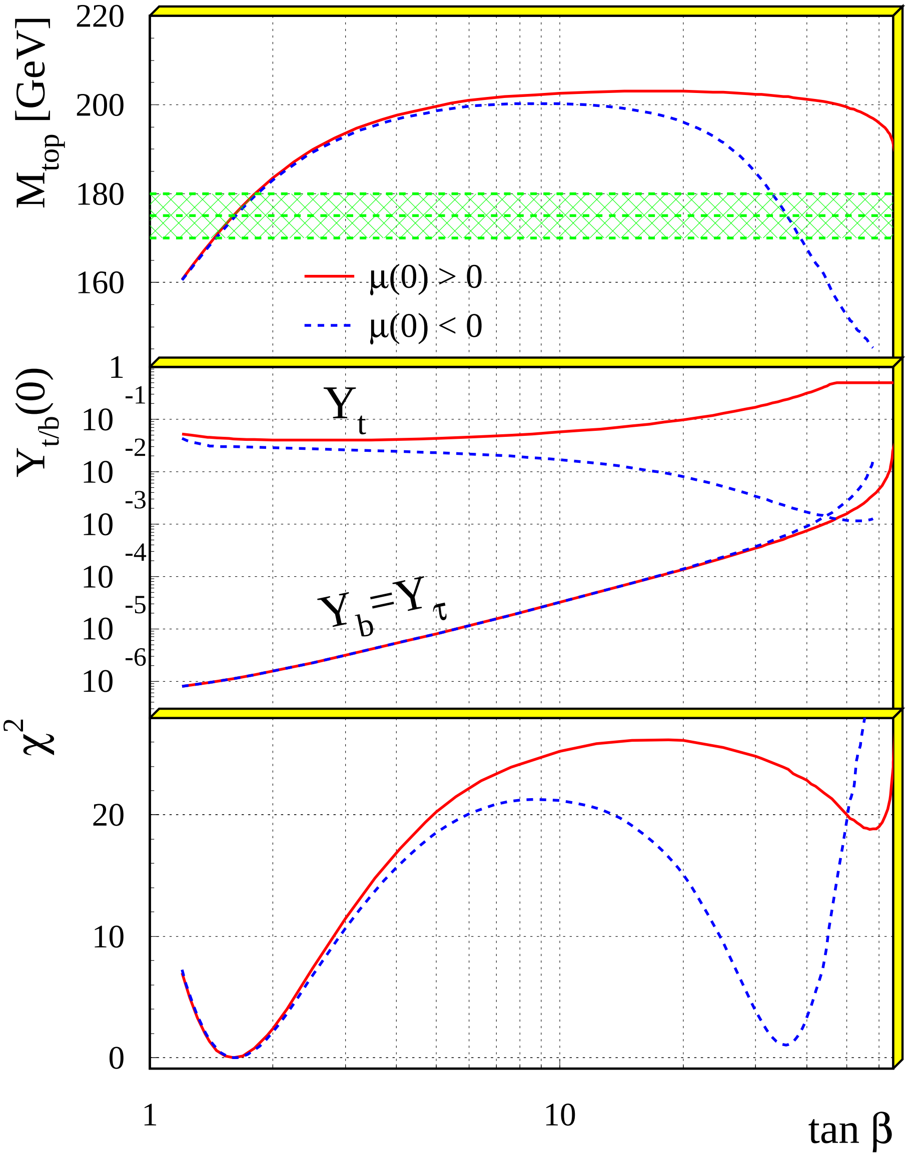


Yukawa Unification

$$\mathbf{M_t^2 = (4\pi v)^2\, Y_t\, \frac{\tan^2\beta}{1+\tan^2\beta}}$$
$$\mathbf{M_b^2 = (4\pi v)^2\, Y_b\, \frac{1}{1+\tan^2\beta}}$$
$$\mathbf{M_\tau^2 = (4\pi v)^2\, Y_\tau\, \frac{1}{1+\tan^2\beta}}$$

$$\mathbf{Y_b = Y_\tau \rightarrow}$$

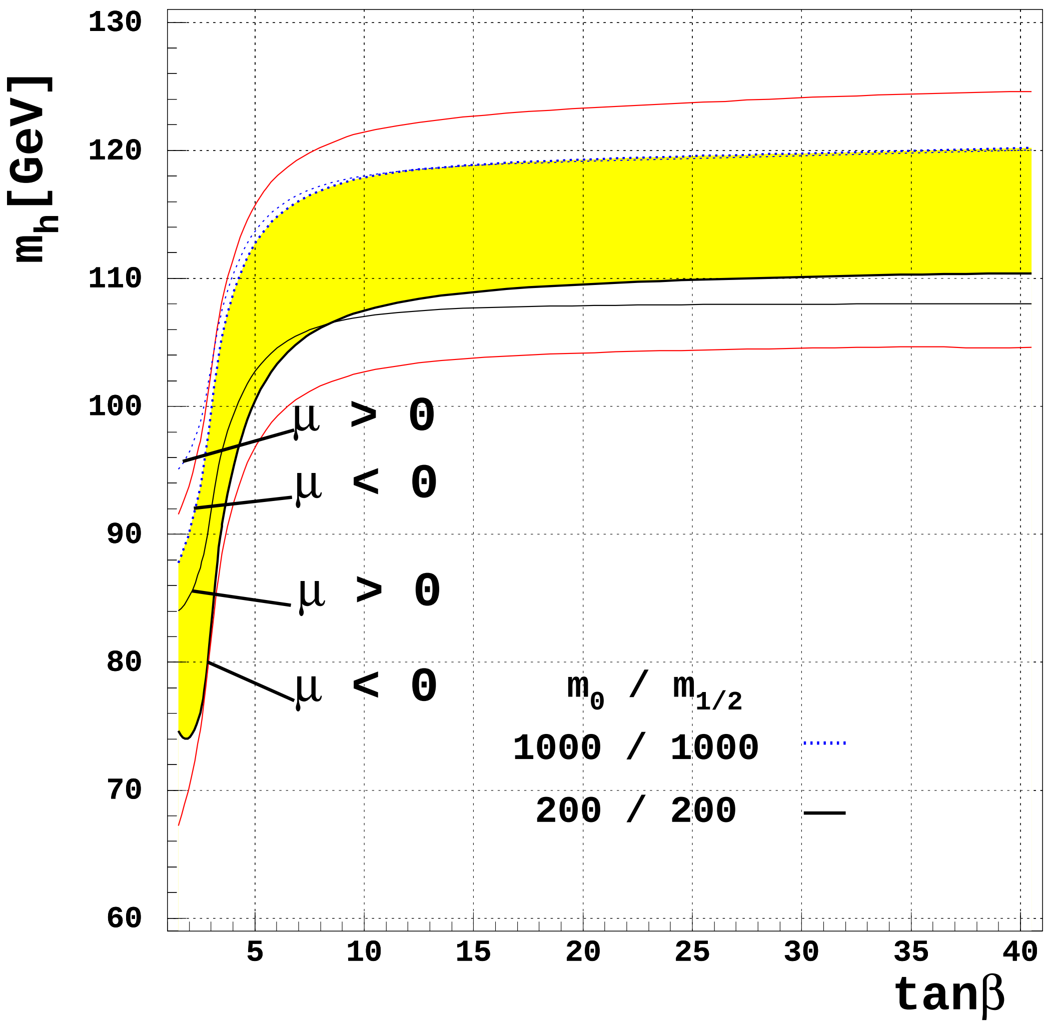
Relation between $\mathrm{M_t}$ and $\tan\beta$



Preferred: $\tan\beta = \mathbf{1.65 \pm 0.3}$ or $\mathbf{30} < \tan\beta < \mathbf{40}$

Low $\tan\beta$ scenario excluded by Higgs limit!

Higgs mass vs $\tan\beta$



$\tan\beta \leq 4.3$ **excluded by Higgs limit of 114 GeV!**

Yellow band in Figure:

$\mathbf{m_t = 175\ GeV: 110 < m_h < 120\ GeV}$

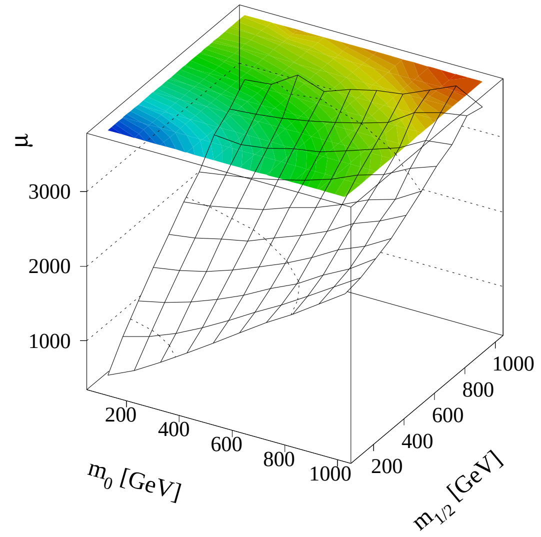
For $\mathbf{m_t = 175 \pm 5\ GeV: 105 < m_h < 125}$ **GeV**

or $\mathbf{m_h = 115 \pm 3\ (stopmasses)\ \pm 2\ (theory)\ \pm 5\ top\ mass\ GeV.}$

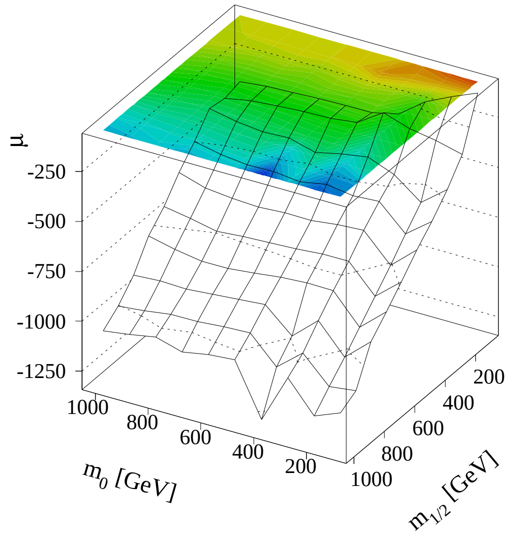
$(\sigma_{stop} = interval/\sqrt{12})$

Pseudoscalar Higgs heavy by EWSB

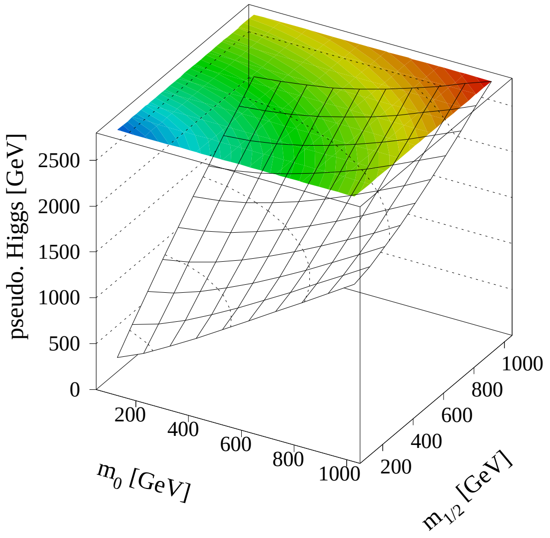
low tanβ



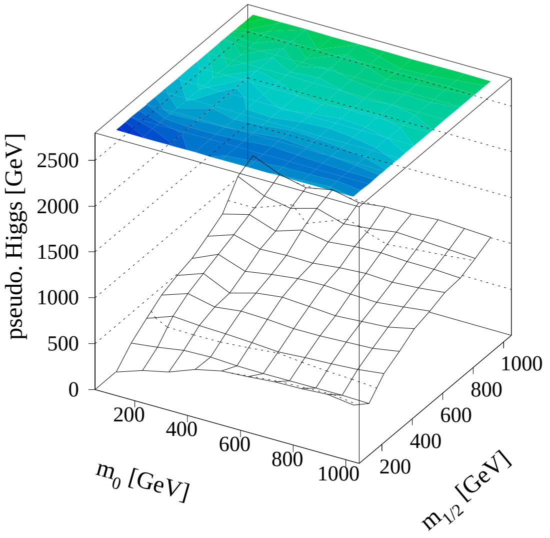
high tanβ



low tanβ



high tanβ



EWSB → large μ_0 → large m_A

Gaugino Fraction

From RGE (large $\tan\beta$)

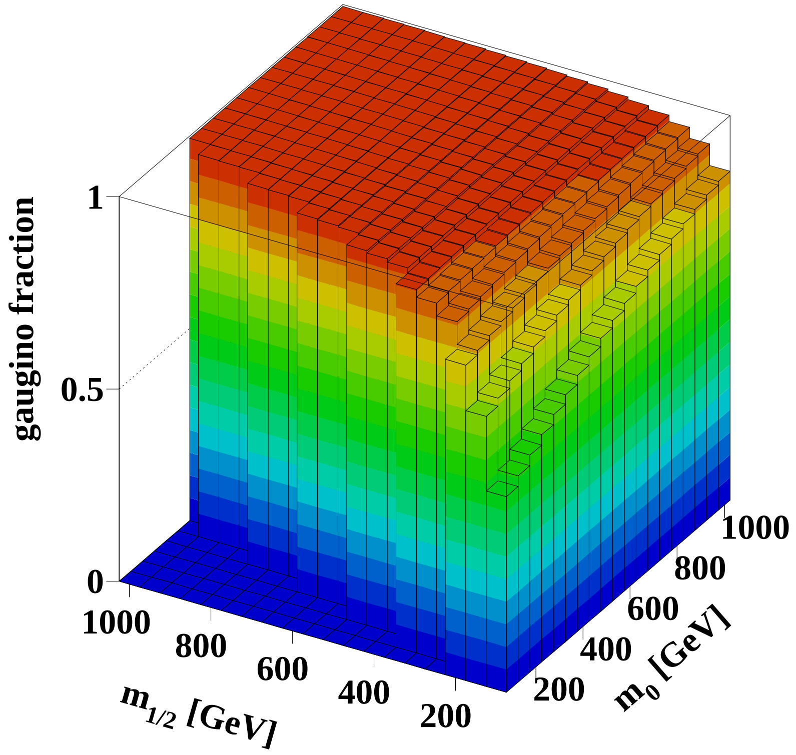
$$\begin{aligned} M_1(M_Z) &\approx 0.4 m_{1/2} \\ M_2(M_Z) &\approx 0.8 m_{1/2} \\ \mu(M_Z) &\approx m_{1/2} \end{aligned}$$

Neutralino: $\tilde{\chi}_i^0 = N_{i,1}\tilde{B} + N_{i,2}\tilde{W}^3 + N_{i,3}\tilde{H}_1^0 + N_{i,4}\tilde{H}_2^0$

Neutralino Mass Mixing Matrix:

$$\begin{pmatrix} M_1 & 0 & -M_Z\cos\beta\sin\theta_W & M_Z\sin\beta\sin\theta_W \\ 0 & M_2 & M_Z\cos\beta\cos\theta_W & -M_Z\sin\beta\cos\theta_W \\ -M_Z\cos\beta\sin\theta_W & M_Z\cos\beta\cos\theta_W & 0 & -\mu \\ M_Z\sin\beta\sin\theta_W & -M_Z\sin\beta\cos\theta_W & -\mu & 0 \end{pmatrix}$$

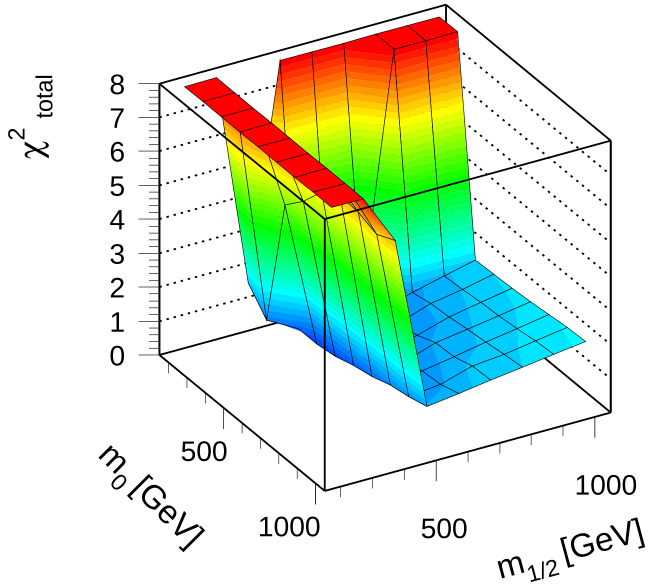
Gaugino Fraction: $Z_g^i = |N_{i1}|^2 + N_{i2}|^2$

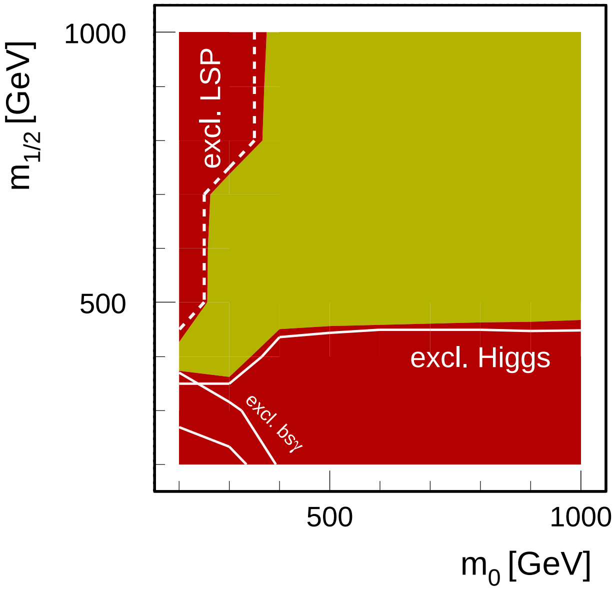


gaugino fraction

Large Z_g^i → SMALL coupling to Higgs and gauge bosons!

Allowed Parameter Regions for $\tan\beta = 35$





Constraints:

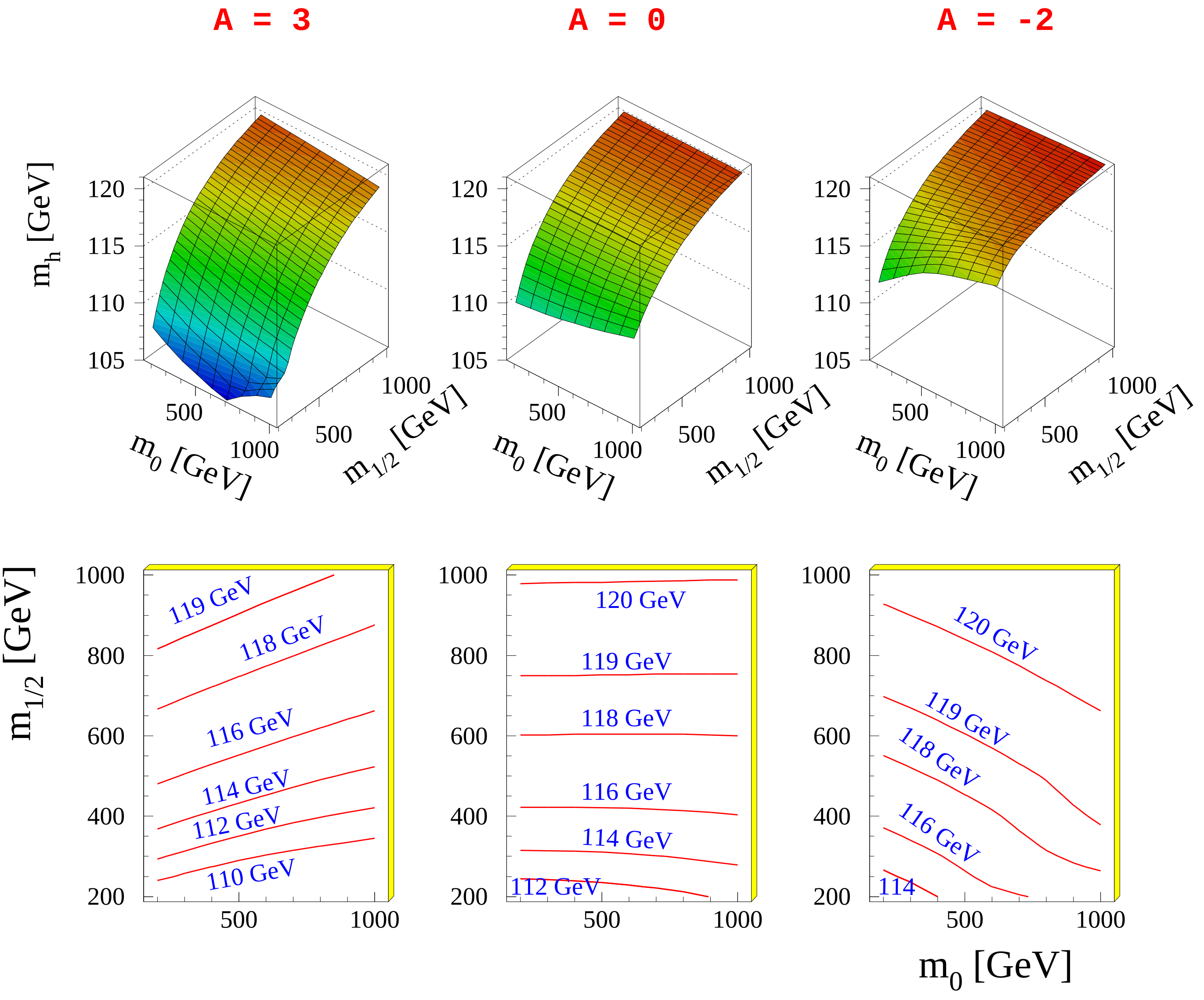
Gauge Unification and EWSB

Yukawa Unification (implies only $\tan\beta = 35$)

A_0 free (Fit prefers $A_0 > 0$)

Low $\tan\beta$ solution ($\tan\beta < 4.3$) excluded by LEP
Higgs limit $(m_h > 114\,GeV)$

Higgs Contours (high $\tan\beta$ scenario)



A = 3

A = 0

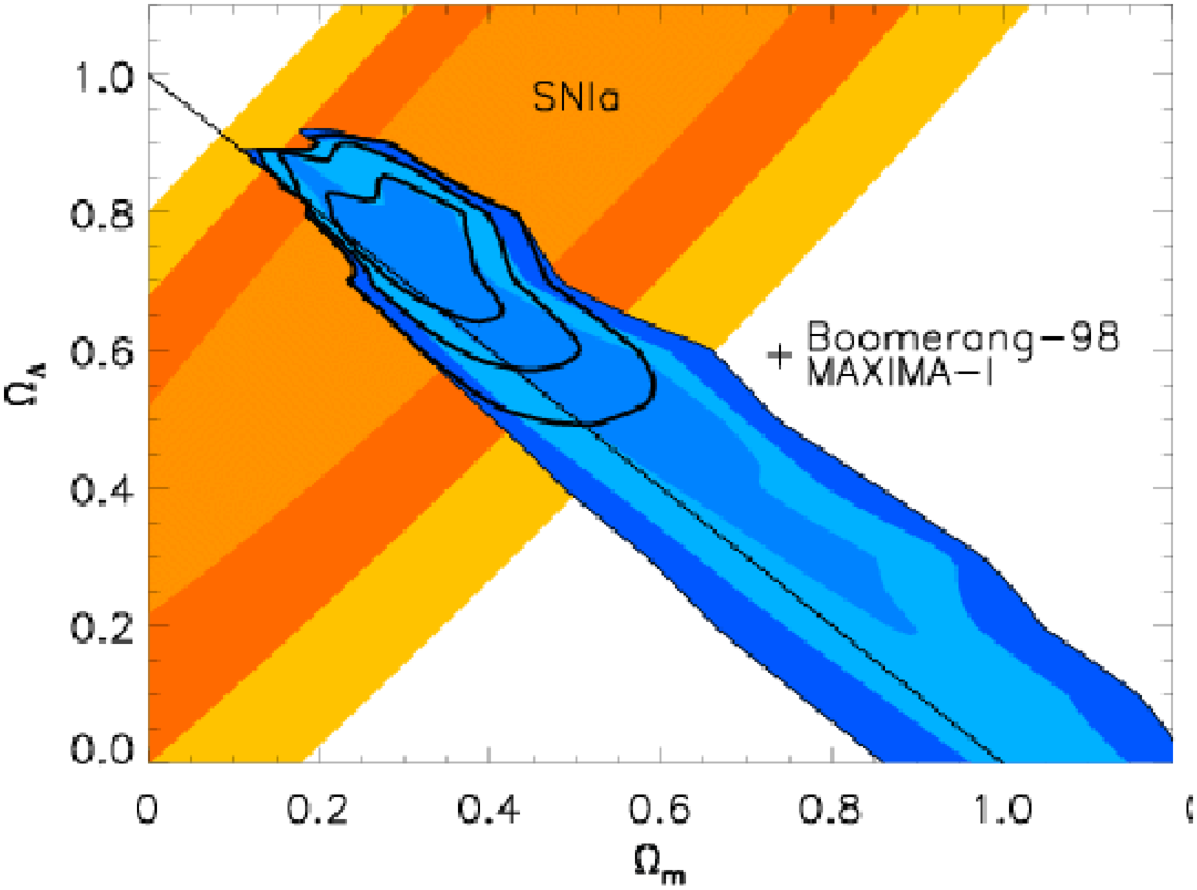
A = -2

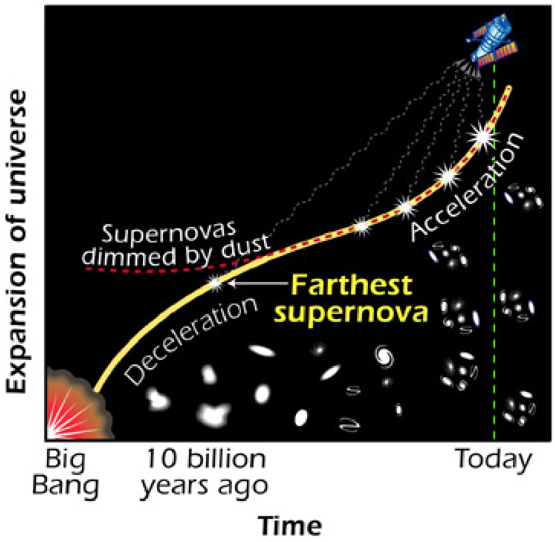
For $\mathbf{A_t = -2m_0}$ → hardly limit from $m_H > 114$ GeV

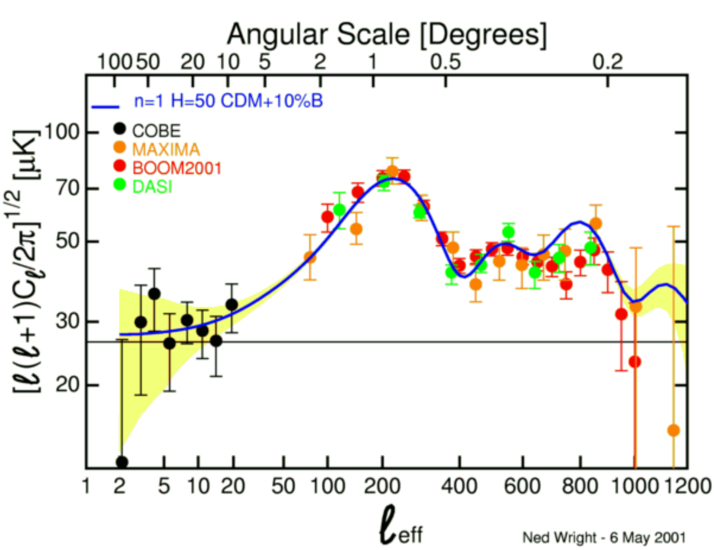
However, $b \to X_s\gamma$ prefers $A_t = 3m_0$

Then lower limits on SUSY from Higgs constraint

Evidence for Dark Matter



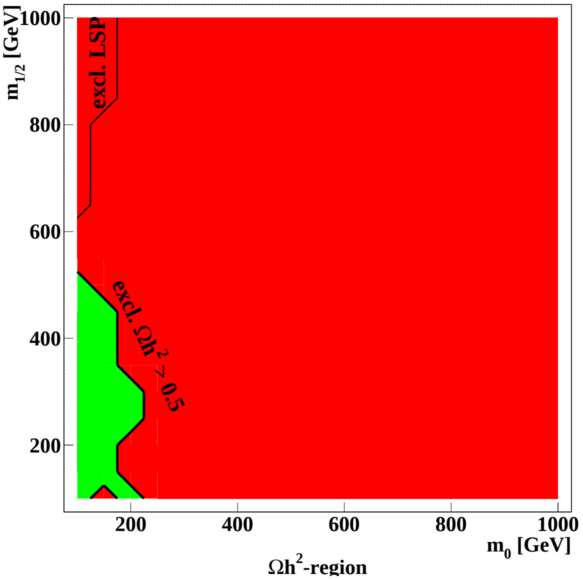


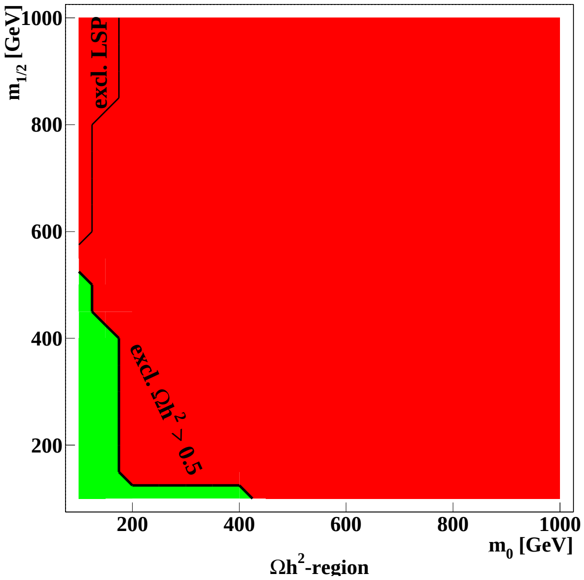


Reacceleration of universe, as measured by redshift from Supernova Ia, depends on DIFFERENCE of Ω_Λ and Ω_{Matter}, while position of first acoustic peak in the CMB is sensitive to the flatness of the universe, i.e. SUM of Ω_Λ and Ω_{Matter}.

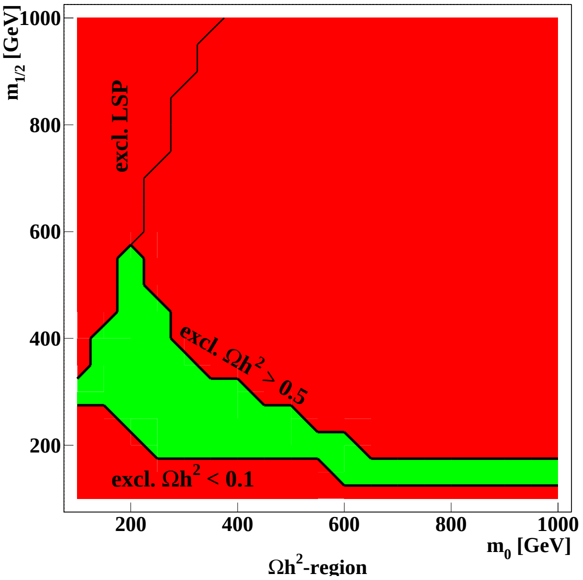
Dark Matter $\Omega h^2 = 0.3 \pm 0.2$

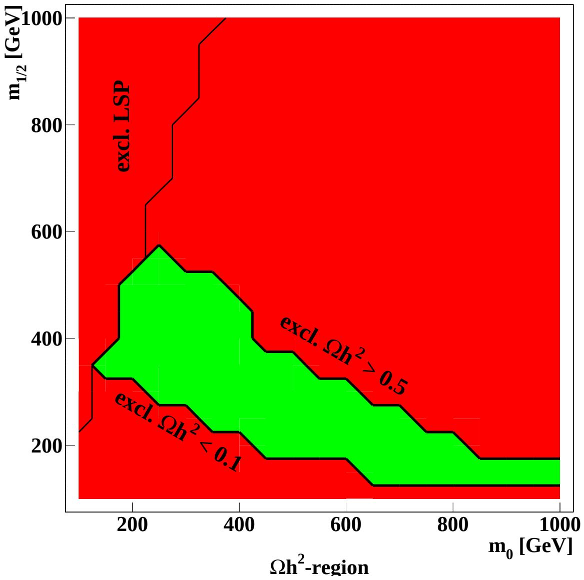
$\tan\beta = 1.6$ $\tan\beta = 5$





$\tan\beta = 20$ $\tan\beta = 35$

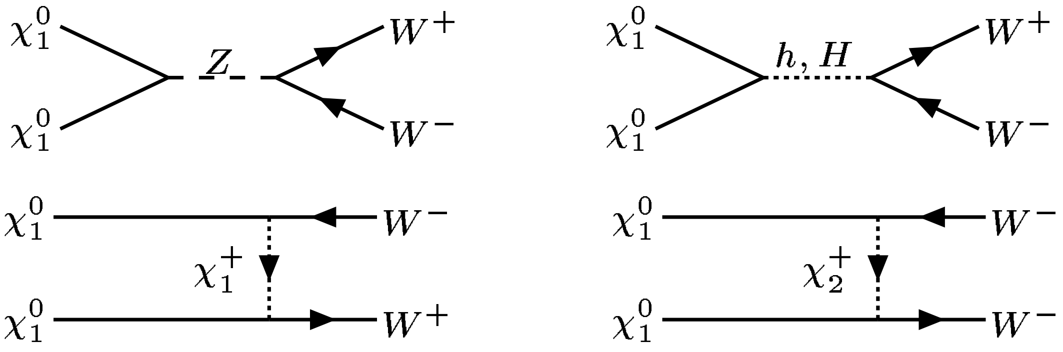




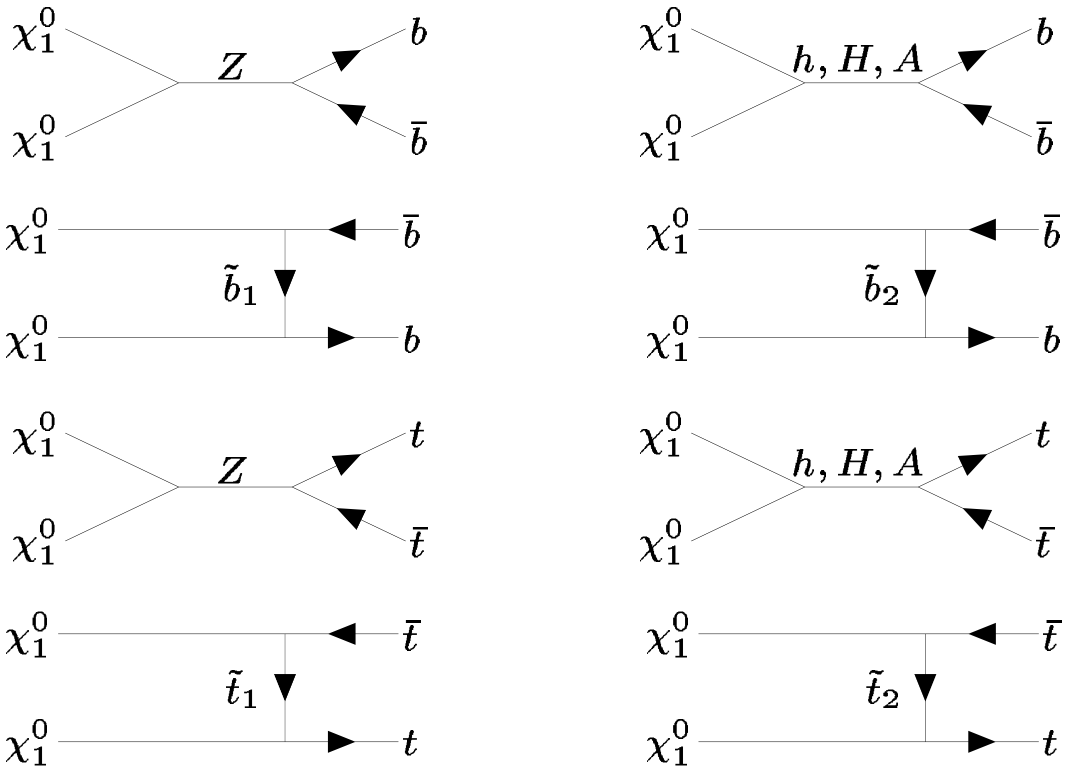
Green regions preferred by Boomerang and SN Ia

Diagrams for Neutralino Annihilation

Gauge Bosons



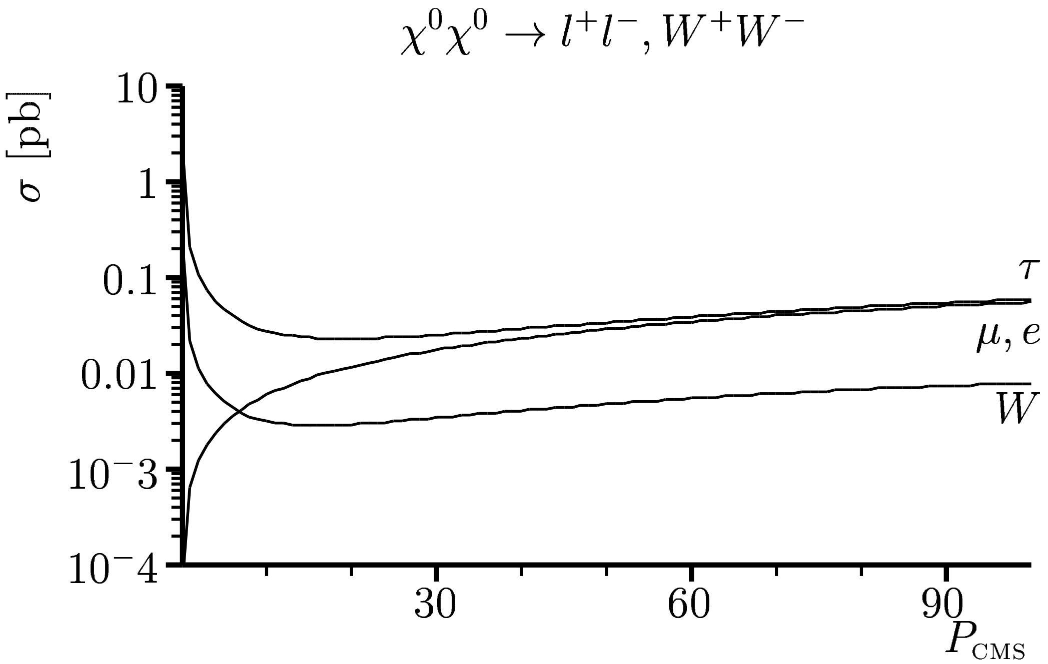
Sfermions



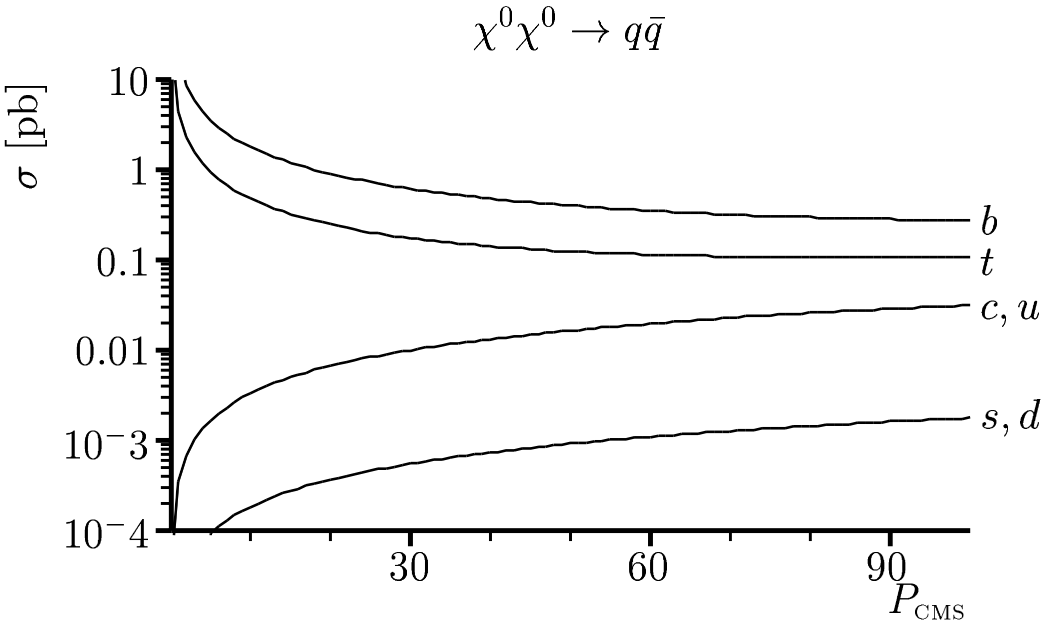
Only heavy final states relevant
(helicity conservation combined with neutralinos are Majorana particles → p-wave $\rightarrow \propto$ fermion mass !)
All x-sections strong function of $\tan\beta$
Interferences (Z-,t-channel) NEGATIVE
Interferences (Higgs-,t-channel) POSITIVE

t-channel Helicity suppression

$\sigma v \propto m_f^2$ at low neutralino momenta



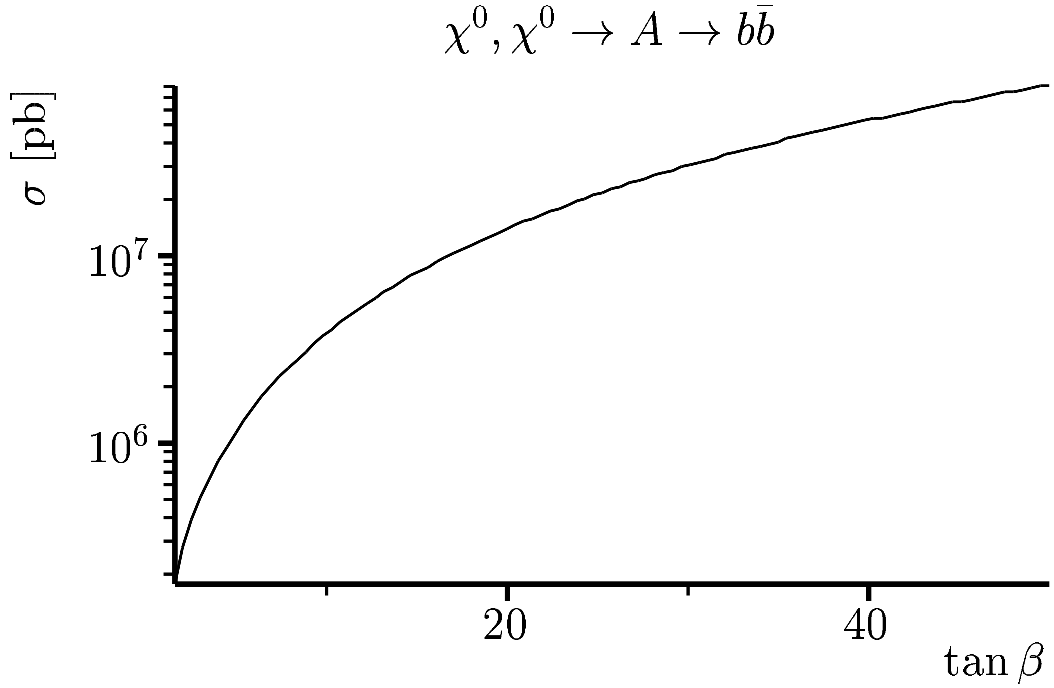
Same for quarks



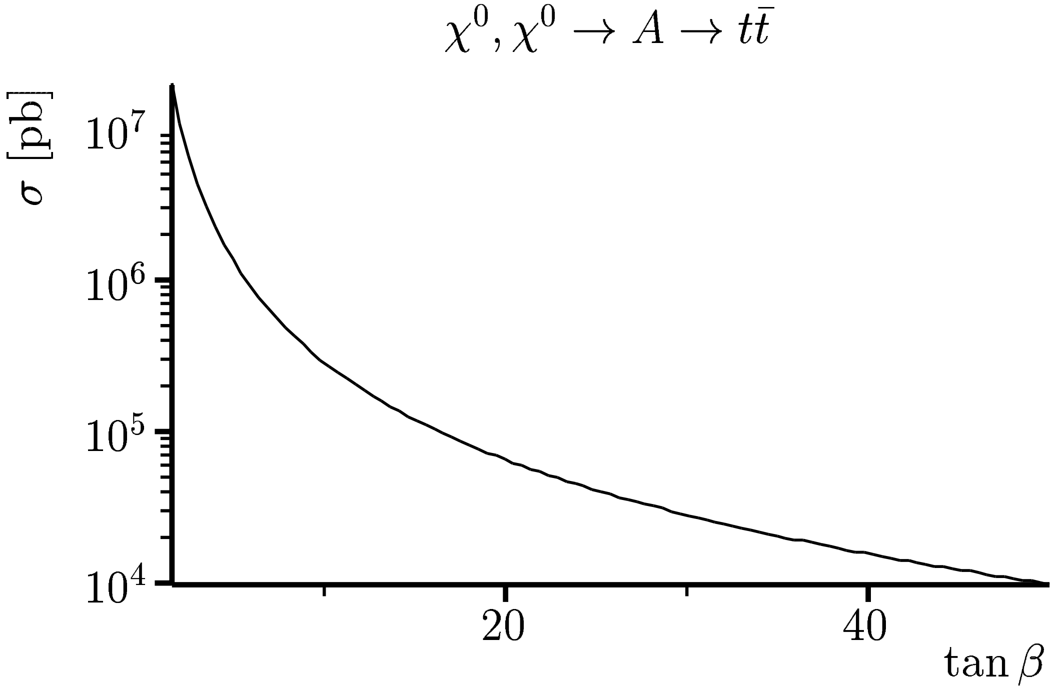
$m_0 = m_{1/2} = 500 \; tb = 35 \; \mu = 470 \; A_t = -1135 \; A_b = -1160$

Higgs exchange vs $\tan\beta$

$\chi_0\chi_0 \to A \to b\bar{b}$ **decays**

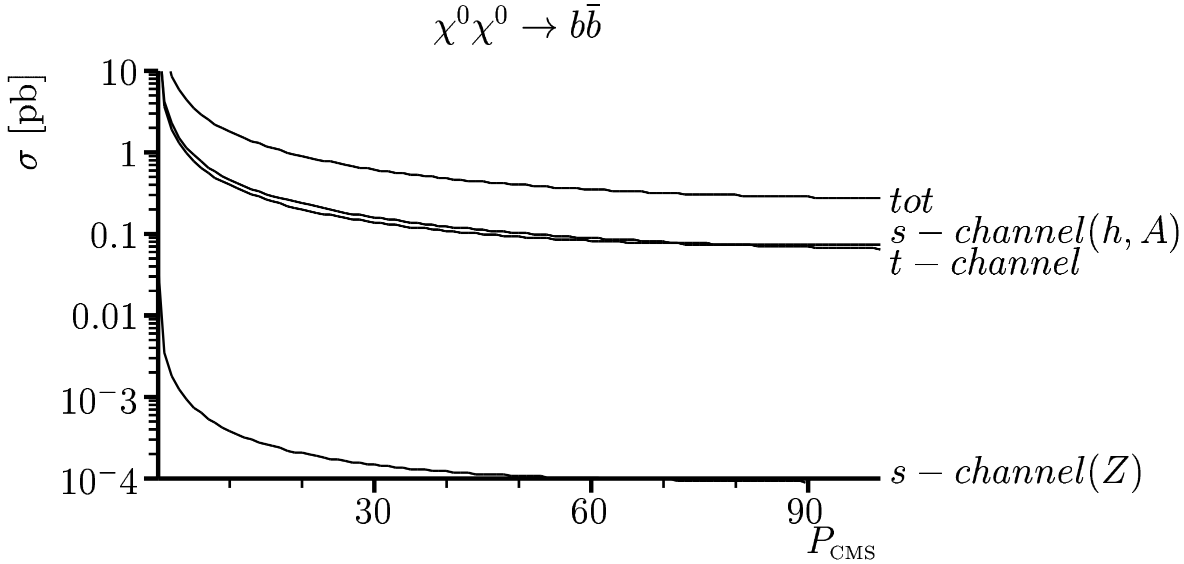


$\chi_0\chi_0 \to A \to t\bar{t}$ **decays**

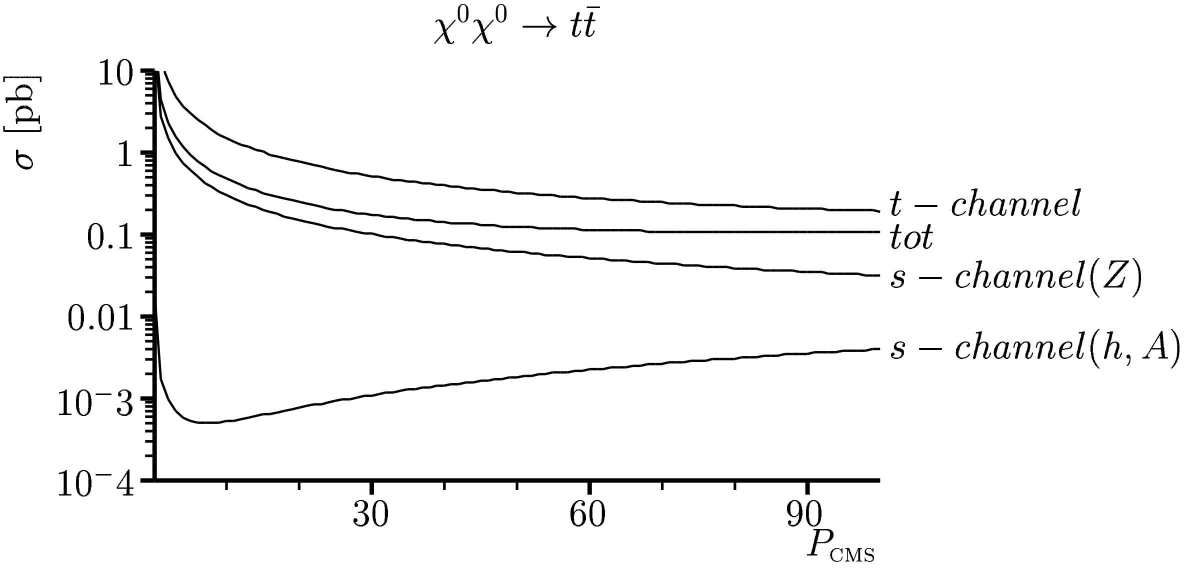


s,t-channel Interferences

Higgs large, Z small for $b\bar{b}$ final state



Higgs small, Z large for $t\bar{t}$ final state

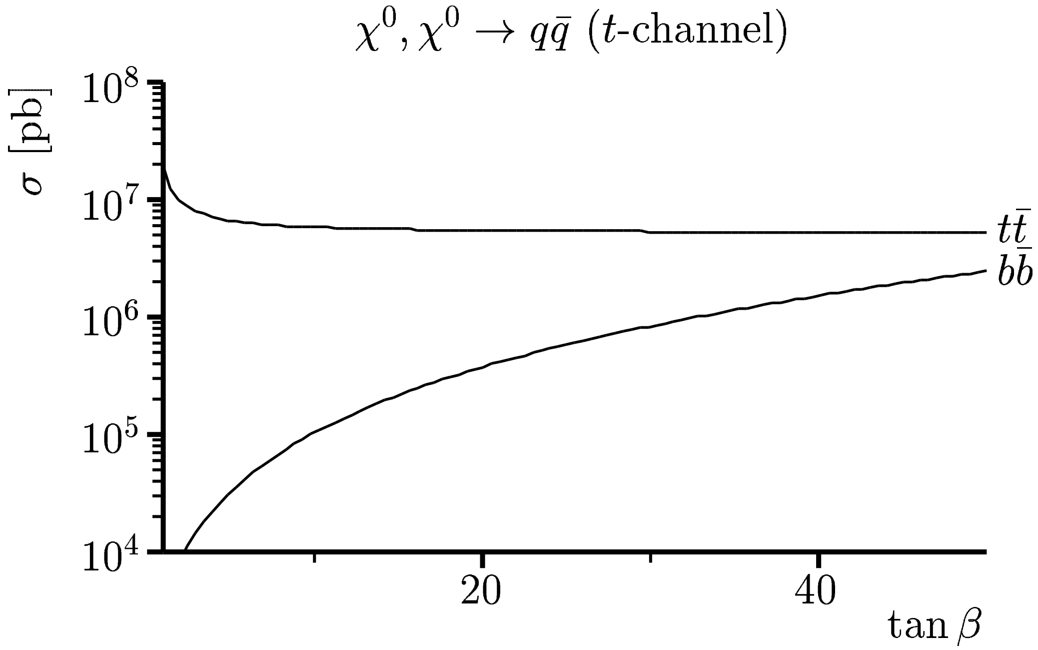


(t-ch, Higgs) Interf. POS , (t-ch, Z) Interf. NEG

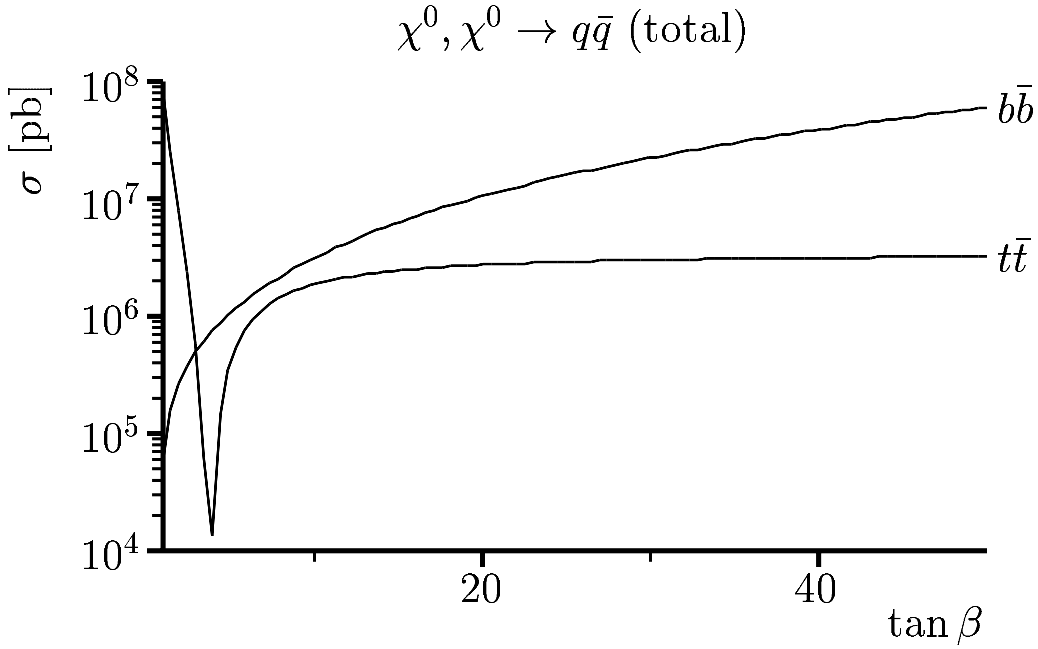
$m_0 = m_{1/2} = 500\ tb = 35\ \mu = 470\ A_t = -1135\ A_b = -1160$

x-section vs $\tan\beta$

$\chi_0\chi_0 \to t\bar{t}(b\bar{b})$ **(**$t - channel$**)**



$\chi_0\chi_0 \to t\bar{t}(b\bar{b})$ **(**σ_{tot}**)**



For $\tan\beta > 5$**:** $\chi_0\chi_0 \to b\bar{b}$ **DOMINANT!**

Comparison X-sections in CalcHEP and darkSUSY

$\langle\sigma v\rangle\left[\frac{\textbf{cm}^3}{\textbf{s}}\right]$

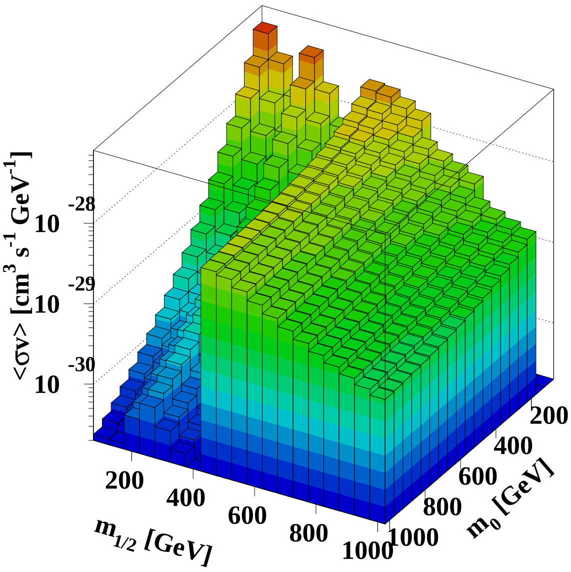
$\tan\beta = 35, m_A = 870$ **GeV**, $A_t = -1180, A_b = -1610$ **GeV**

$m_0 = 500$ **GeV**, $m_{1/2} = 500$ **GeV**

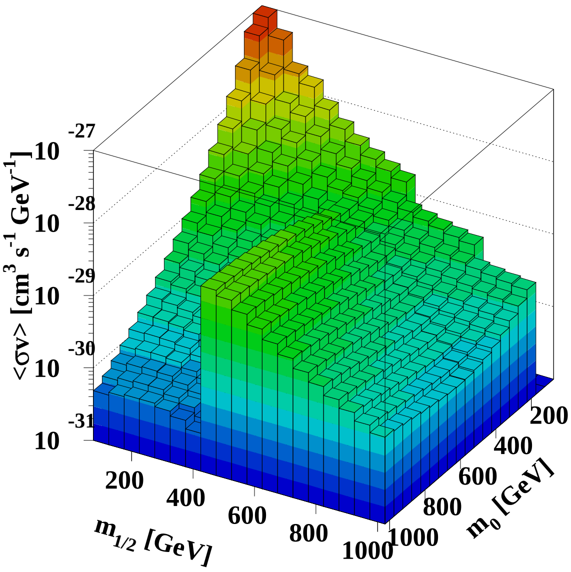
	CalcHEP	**darkSUSY**
$b\bar{b}$	$8.1 \cdot 10^{-28}$	$8.2 \cdot 10^{-28}$
$t\bar{t}$	$0.8 \cdot 10^{-28}$	$1.6 \cdot 10^{-28}$
$\tau^+\tau^-$	$3.8 \cdot 10^{-29}$	$4.8 \cdot 10^{-29}$
W^+W^-	$2.1 \cdot 10^{-30}$	$2.1 \cdot 10^{-30}$

Neutralino Annihilation X-sections

$\tan\beta = 1.6$ $\tan\beta = 5$

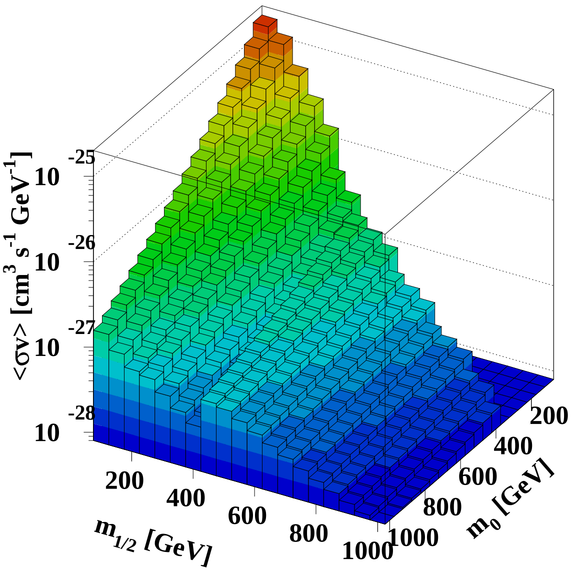


sigma v_{TOT}

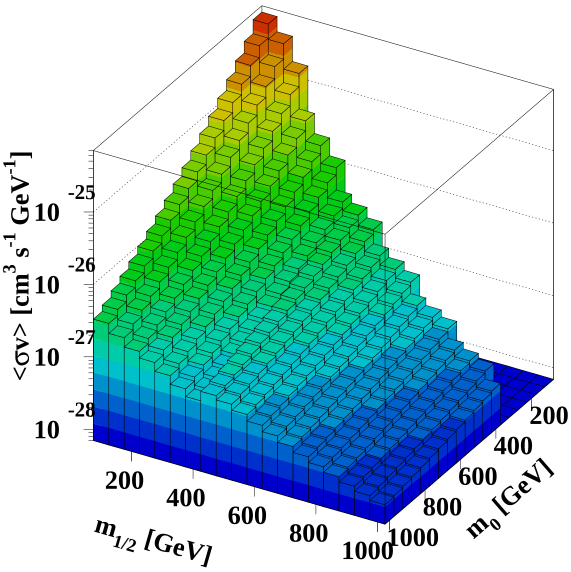


sigma v_{TOT}

$\tan\beta = 20$ $\tan\beta = 35$



sigma v_{TOT}



sigma v_{TOT}

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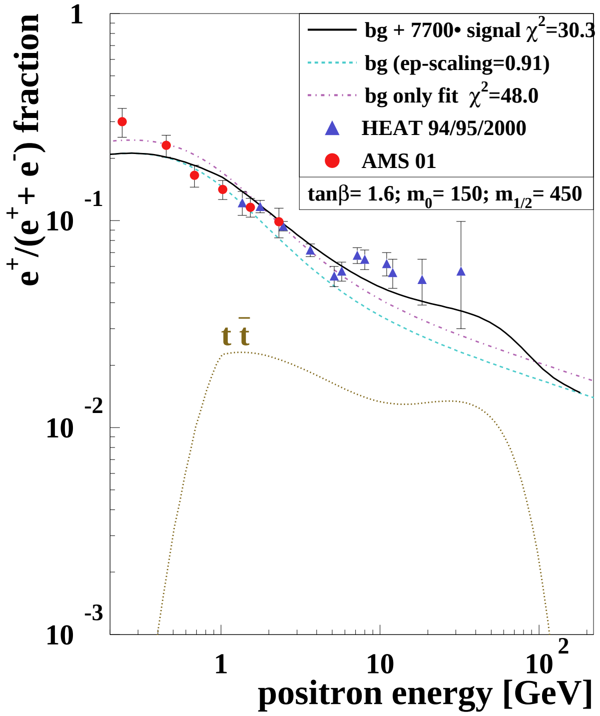
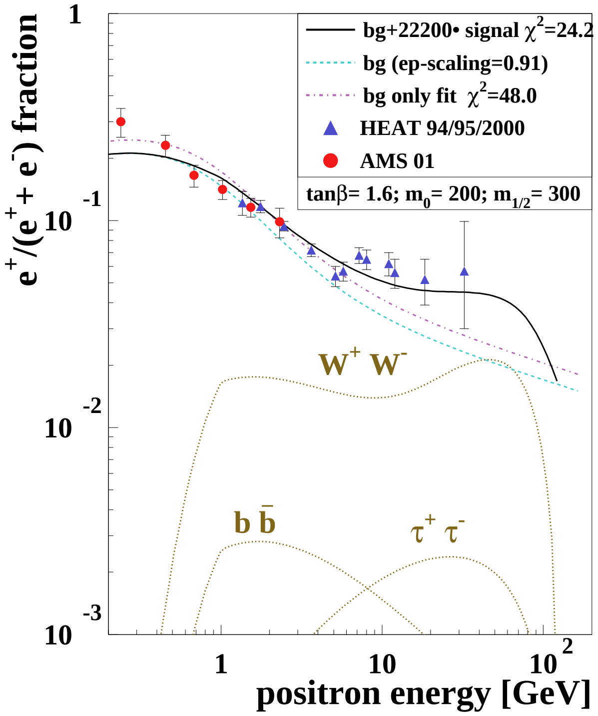
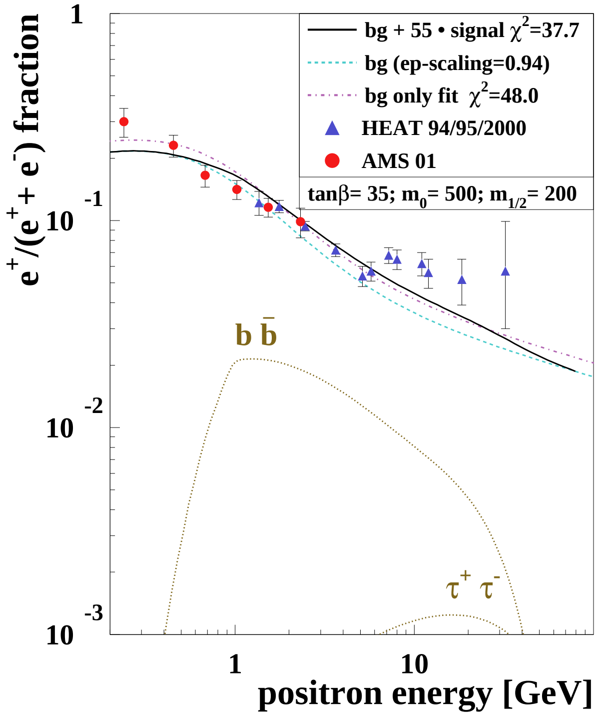
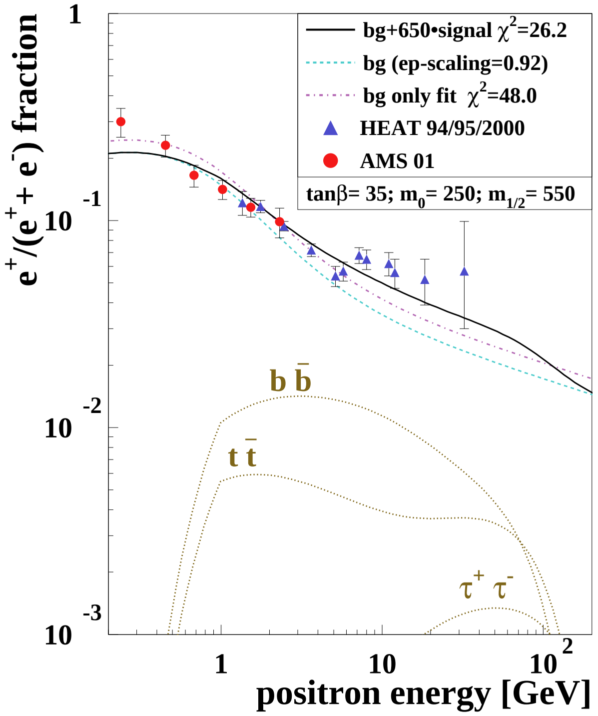




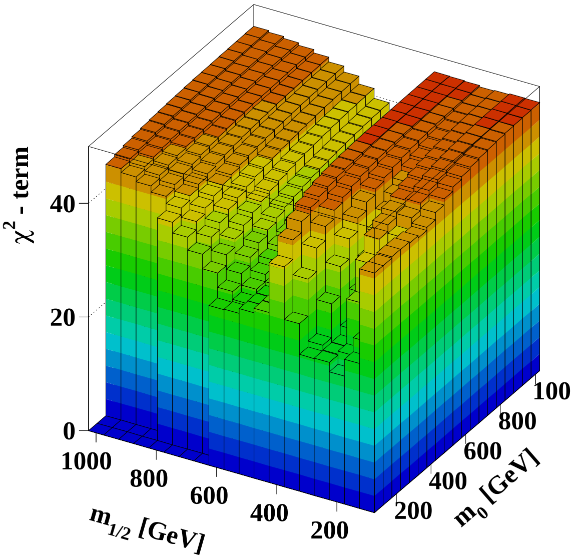
$\tan\beta = 35\ m_\chi^0 = 60$ $\tan\beta = 35\ m_\chi^0 = 230$



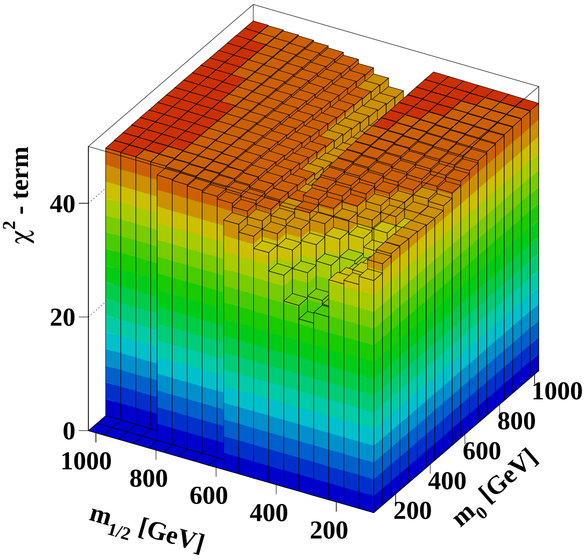


χ^2 contr. for HEAT Data

$\tan\beta = 1.6$ $\tan\beta = 5$

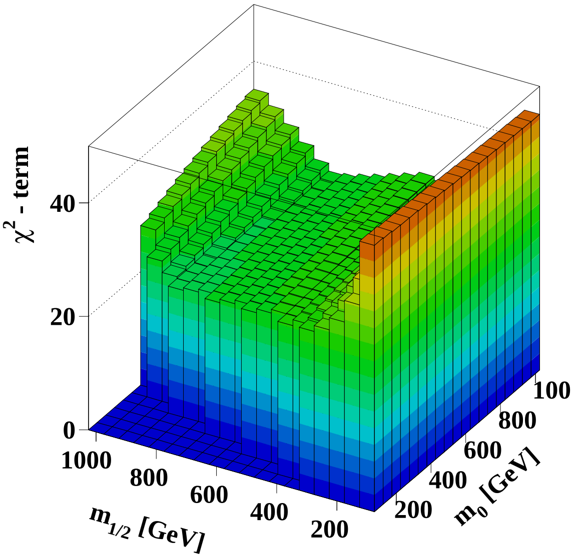


χ^2 - term

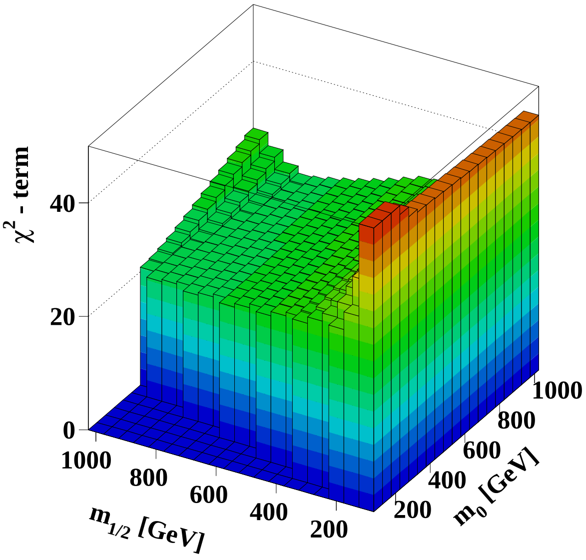


χ^2 - term

$\tan\beta = 20$ $\tan\beta = 35$



χ^2 - term

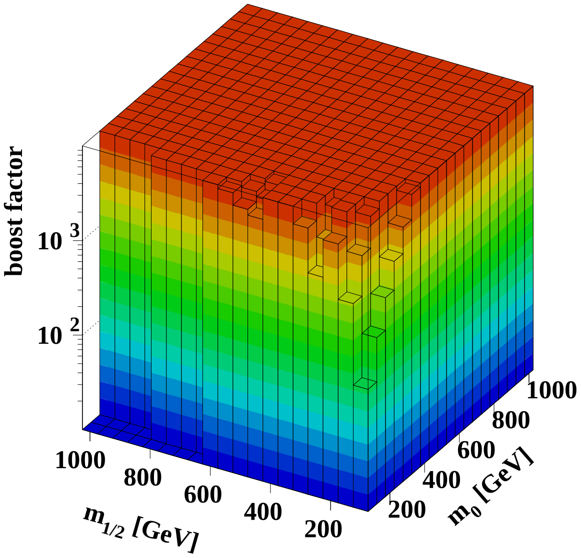


χ^2 - term

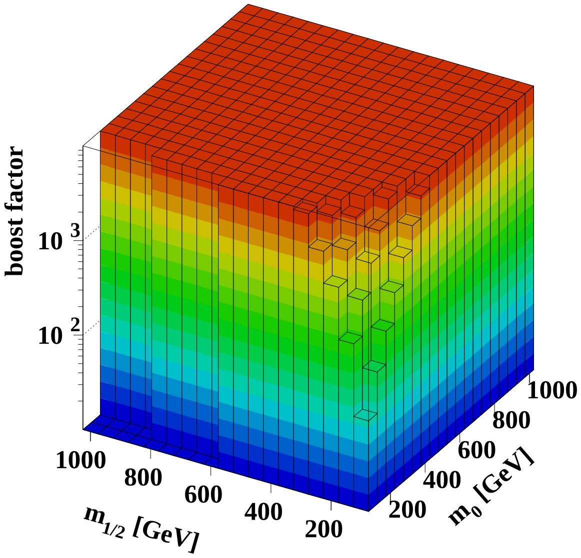
Boost factor for HEAT Data

$\tan\beta = 1.6$

$\tan\beta = 5$



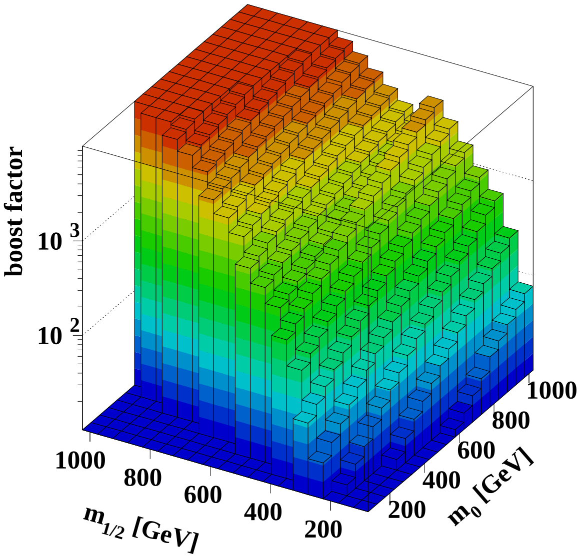
boost-factor (best fit)



boost-factor (best fit)

$\tan\beta = 20$

$\tan\beta = 35$



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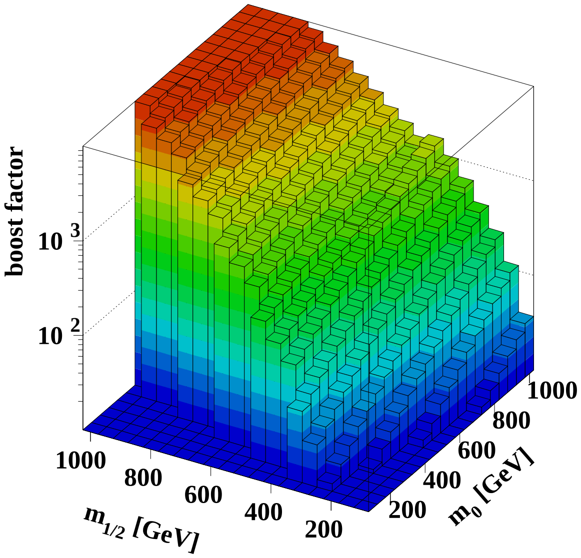
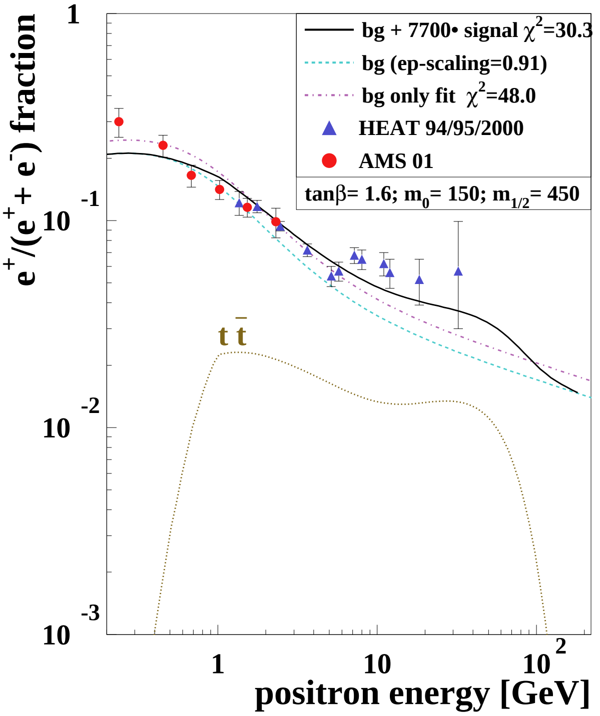
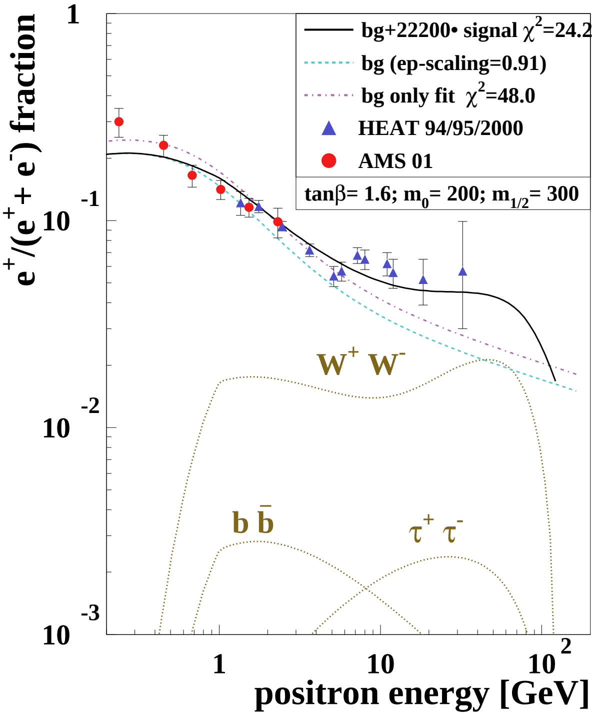


boost-factor (best fit)

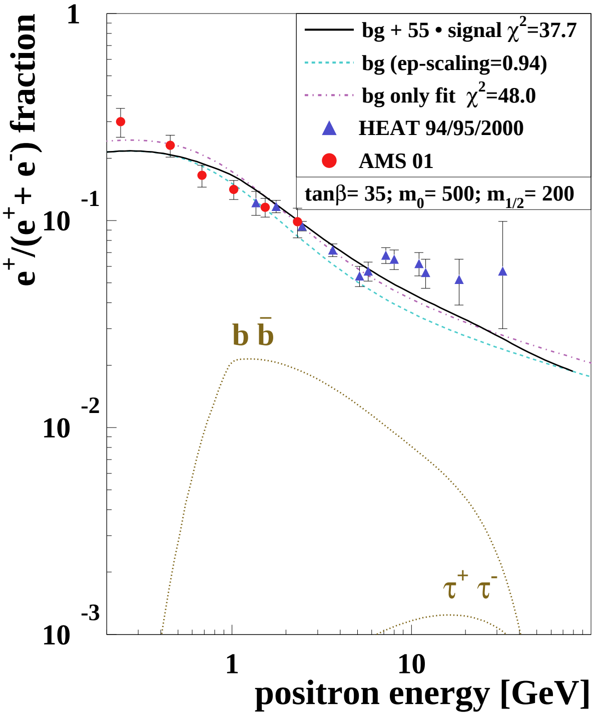
Typical Fits to HEAT Data

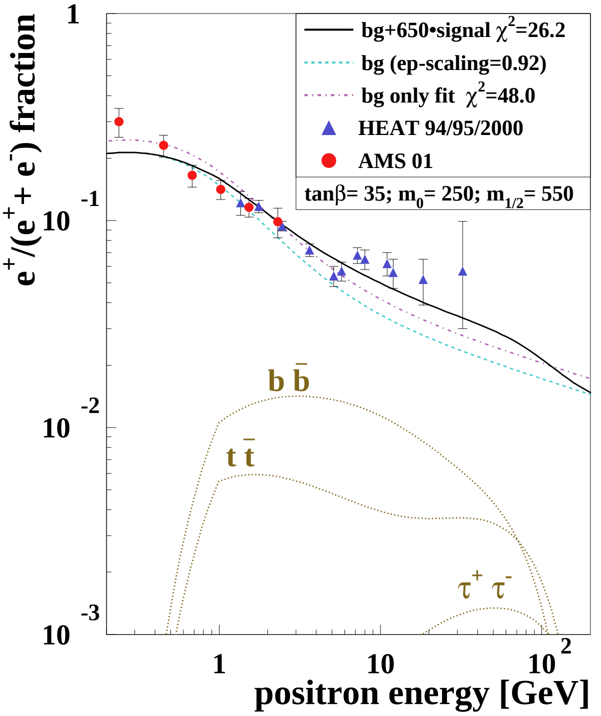
$\tan\beta = 1.6\ m_\chi^0 = 190$ $\tan\beta = 1.6\ m_\chi^0 = 120$





$\tan\beta = 35\ m_\chi^0 = 60$ $\tan\beta = 35\ m_\chi^0 = 230$





Summary

Low values of ($\tan\beta < 4.3$) excluded by LEP Higgs Limit of 114 GeV

At larger values of $\tan\beta$ $b\bar{b}$ DOMINANT FINAL STATE

$b\bar{b}$ FINAL STATE has orders of magnitude larger x-section than W^+W^- final states

$b\bar{b}$ FINAL STATE fits the HEAT data as well as the W^+W^- final states

Supersymmetry is excellent candidate to explain Dark Matter in the universe