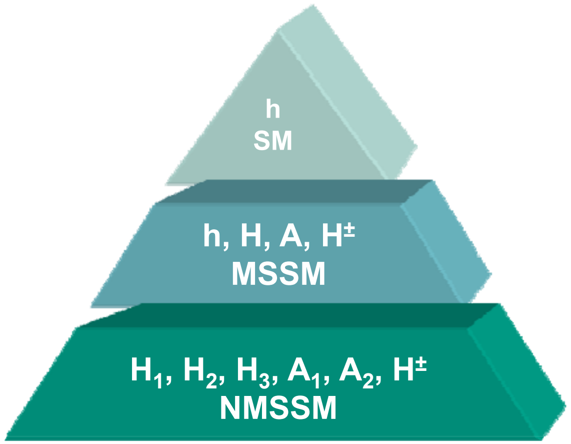
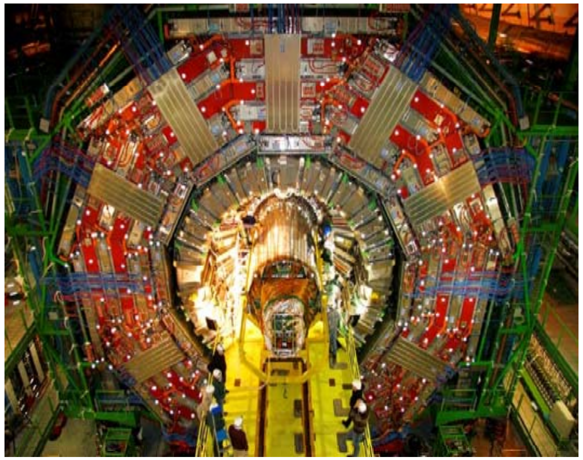
Comparison of the Higgs sectors of the MSSM and NMSSM for a 126 GeV Higgs boson using GUT scale parameters

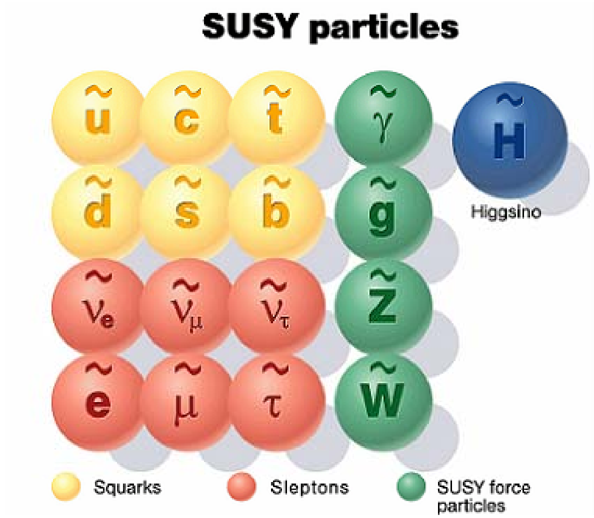
arXiv:1308.1333

C. Beskidt, W. de Boer, D. Kazakov

Institut für Experimentelle Kernphysik



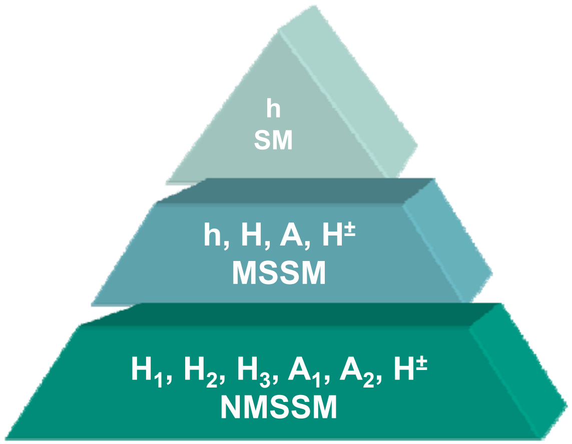




126 GeV Higgs-like Boson found at the LHC!

- **Supersymmetry predicts Higgs < 130 GeV**

- SUSY provides several Higgs bosons dependent on the model



- **Problem I:** Which Higgs boson has been found?
- **Problem II:** What do we know about the heavier/lighter Higgs bosons?

Why going to the NMSSM?

- **MSSM**

Loop corrections $X_t = m_t(A_t - \mu \cot\beta)$

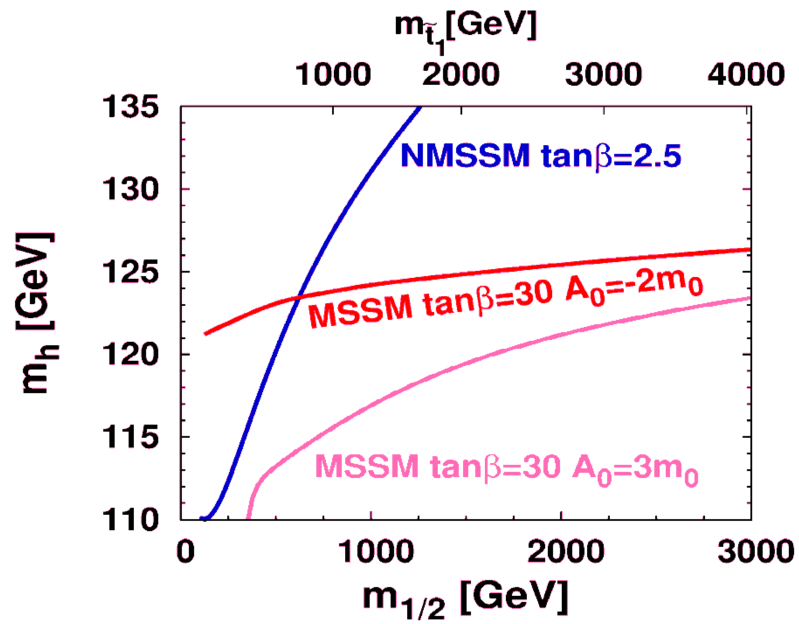
$$\underbrace{m_h^2}_{<(130\,GeV)^2} \approx \underbrace{m_Z^2 \cos^2 2\beta}_{<m_Z^2} + \frac{3}{(4\pi)^2}\frac{m_t^4}{v^2}\left[\ln\frac{m_{\tilde{t}}^2}{m_t^2} + \frac{X_t^2}{m_{\tilde{t}}^2}\left(1 - \frac{X_t^2}{12 m_{\tilde{t}}^2}\right)\right]$$

- **NMSSM: Mixing with singlet**

$$m_h^2 \approx \lambda^2 v^2 \sin^2 2\beta + M_Z^2 \cos^2 2\beta + \Delta_{rad} + \Delta_{mix}$$

Ellwanger, arXiv 1108.0157

Increases Higgs mass for large values of λ



Getting m_h=126 GeV for TeV instead of multi-TeV stops

Status of NMSSM

- Many papers on NMSSM after M_H=126 GeV and hint of non SM BR, see **arXiv: 1306.1291, arXiv:1304.5437, arXiv:1301.6437, arXiv:1301.1325, arXiv:1301.0453, arXiv:1212.5243, arXiv:1211.5074, arXiv:1211.1693, arXiv:1211.0875, arXiv:1209.5984, arXiv:1209.2115, arXiv:1208.2555, arXiv:1207.1545, arXiv:1206.6806, arXiv:1206.1470, arXiv:1205.2486, arXiv:1205.1683, arXiv:1203.5048, arXiv:1203.3446, arXiv:1202.5821, arXiv:1201.2671, arXiv:1201.0982, arXiv:1112.3548, arXiv:1111.4952, arXiv:1109.1735, arXiv:1108.0595, arXiv:1106.1599, arXiv:1105.4191, arXiv:1104.1754, arXiv:1101.1137, arXiv:1012.4490, ………..**

- Differences to other analysis comparing MSSM and NMSSM e.g.
- Comparison without GUT scale relations Cao,Heng,Yeng et al. arXiv:1202.5821
- More tight GUT scale relations in Higgs sector Kowalska, Munir, Roszkowski et al. arXiv:1211.1693

NMSSM versus MSSM

- NMSSM has one additional singlet

MSSM

$$H_1 = S_{1,d} H_d + S_{1,u} H_u + S_{1,s} S$$
$$H_2 = S_{2,d} H_d + S_{2,u} H_u + S_{2,s} S$$

NMSSM

$$H_3 = S_{3,d} H_d + S_{3,u} H_u + S_{3,s} S$$

→

MSSM	NMSSM
2 CP even	3 CP even
1 CP odd	2 CP odd

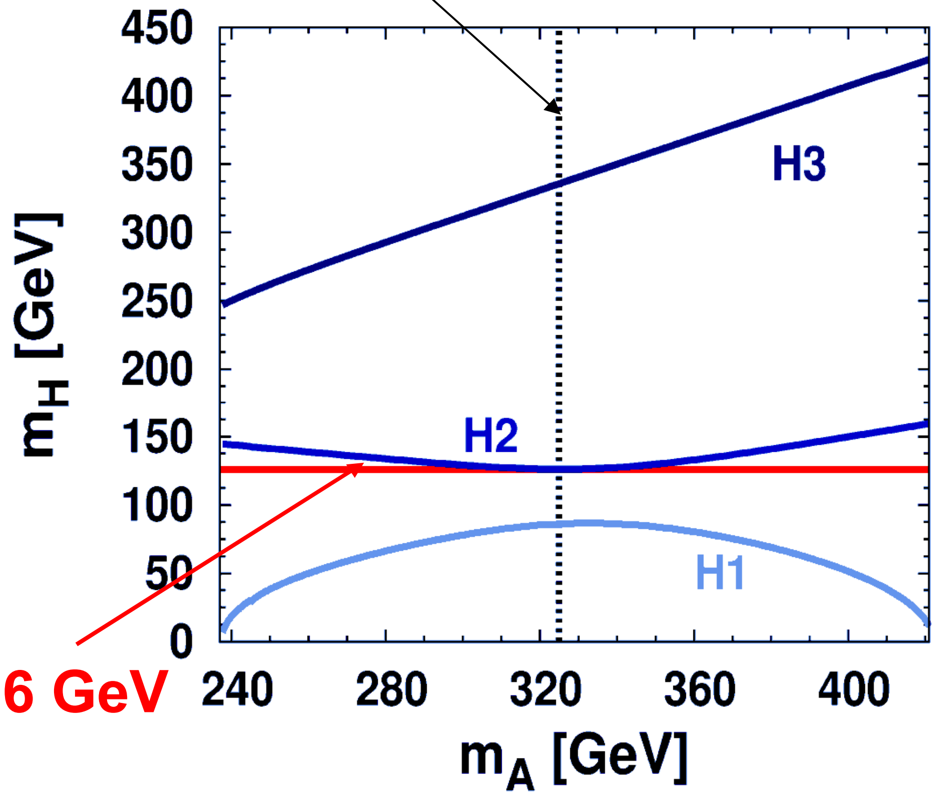
$$W_{NMSSM} = \lambda \hat{S} \hat{H}_u \cdot \hat{H}_d + \frac{\kappa}{3} \hat{S}^3 + \dots$$

- **Pros of NMSSM**
  - ✓ Increase light Higgs mass
  - ✓ Modified couplings to up-/down-type fermions (if $R_{\gamma\gamma} \neq 1$)
  - ✓ Solves μ-Problem (Kim, Nilles Phys. Lett. B 138, 150 (1984))
- **Cons**
  - ✗ **More** free parameters: couplings **λ, κ**
    trilinear couplings **A_κ, A_λ**
    mixing parameter **$\mu_{eff} = \lambda \langle S \rangle$**

  (in addition to m_0, $m_{1/2}$, A_0, tanβ) **NMSSM review:Ellwanger, Phys.Rept. 496 (2010)1**

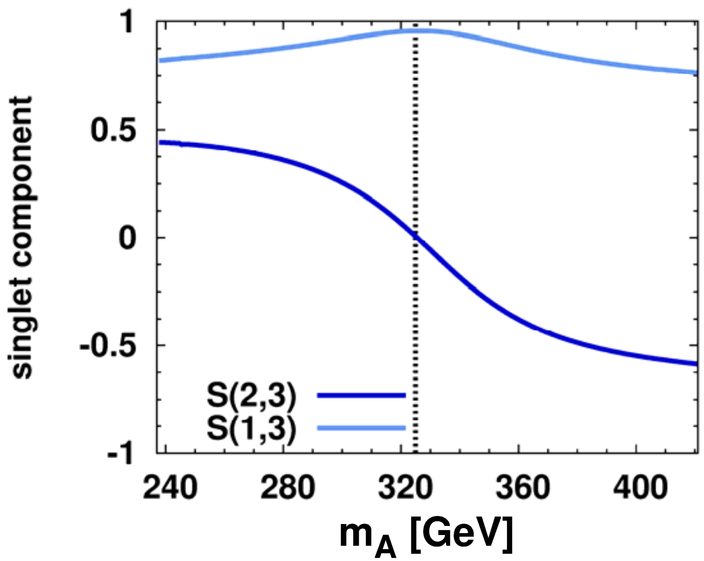
BMP I (H_2=126 GeV, H_3 mass below 0.5 TeV)

m_A for 126 GeV Higgs



126 GeV

m_A range for positive Higgs mass m_H^2



Singlet component of H_2 is minimal for m_A~320

Higgses mix as a function of m_A

Masses for scalar Higgs Bosons in NMSSM

- 3x3 Higgs mass matrix

$$M_{11}^2 = M_A^2 + (m_Z^2 - \lambda^2 v^2) \sin^2 2\beta,$$ ~H3

$$M_{12}^2 = -\frac{1}{2}(m_Z^2 - \lambda^2 v^2) \sin 4\beta,$$

$$M_{13}^2 = -\frac{1}{2}(M_A^2 \sin 2\beta + \frac{2\kappa\mu^2}{\lambda})\frac{\lambda v}{\mu} \cos 2\beta,$$

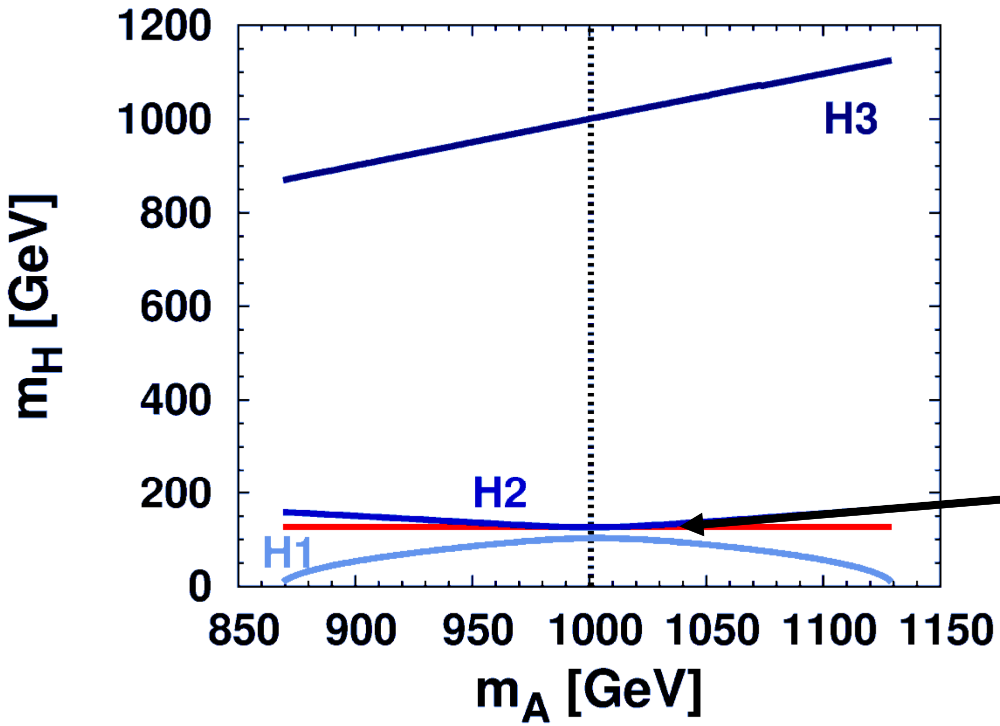
$$M_{22}^2 = m_Z^2 \cos^2 2\beta + \lambda^2 v^2 \sin^2 2\beta,$$ ~H2

$$M_{23}^2 = 2\lambda\mu v \left[1 - (\frac{M_A \sin 2\beta}{2\mu})^2 - \frac{\kappa}{2\lambda} \sin 2\beta\right],$$

$$M_{33}^2 = \frac{1}{4}\lambda^2 v^2 (\frac{M_A \sin 2\beta}{\mu})^2 + \frac{\kappa\mu}{\lambda}(A_\kappa + \frac{4\kappa\mu}{\lambda}) - \frac{1}{2}\lambda\kappa v^2 \sin 2\beta,$$ ~H1

$$M_A^2 \equiv \frac{2\mu(A_\lambda + \kappa s)}{\sin 2\beta}$$

BMP II (H_2=126 GeV, H_3 mass around 1 TeV)



$$M_{H3}^2 \propto M_A^2 \propto A_\lambda$$

High values of A_λ can give high values for H_3 mass

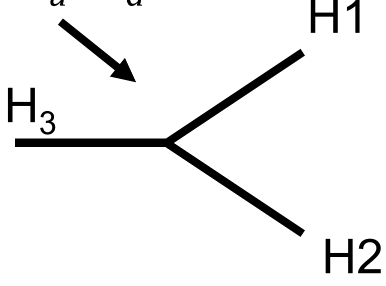
H_1/H_2 both ≈ 126 GeV, by changing parameters → shift in masses → lightest Higgs H_1 = 126 GeV

Input	m_0	$m_{1/2}$	A_0	$\tan\beta$	A_κ	A_λ	κ_{SUSY}	λ_{SUSY}	μ
MSSM	2500	2375	-4999	48.11	-	-	-	-	3339
BMP I	2400	550	-976	2.69	-848	-509	0.38	0.65	120
BMP II	2450	550	-1840	4.18	2549	1774	0.12	0.68	229

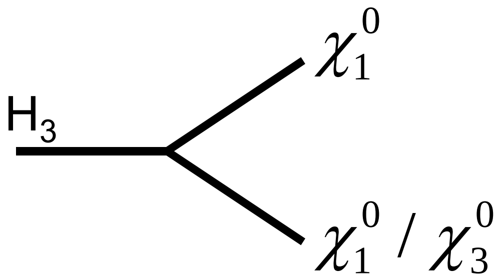
Different signatures for MSSM and NMSSM

- H_3 decays preferentially into Higgses and gauginos

$$A_\lambda \lambda S H_u H_d + \ldots$$



- LSP is mixture of higgsino and singlino



Branching Ratios [%]

	MSSM			NMSSM (BMP I)				
	h	H	A	H_1	H_2	H_3	A_1	A_2
Mass [GeV]	126	2256	2256	86	126	336	214	325
$b\bar{b}$	67.6	85.2	85.2	90.6	63.6	3.0	0.2	1.9
W^+W^-	17.7	1.7e-5	-	6.5e-7	19.6	0.2	-	-
$\tau\tau$	5.0	14.6	14.6	8.8	6.5	0.4	0.02	0.2
hh	-	8.9e-5	-	-	-	-	-	-
H_1H_2	-	-	-	-	-	41.9	-	-
A_1H_1	-	-	-	-	-	-	-	4.0
Zh	-	-	1.7e-5	-	-	-	-	-
ZH_1	-	-	-	-	-	-	0.3	26.8
$\chi_1^0\chi_1^0$	-	4.7e-5	5.3e-4	-	-	5.7	99.5	38.1
$\chi_1^0\chi_3^0$	-	-	-	-	-	20.8	-	4.2
$\chi_1^+\chi_1^-$	-	-	-	-	-	20.7	-	18.4
σ_{prod} [pb]	19.3	1.3e-5	1.3e-5	2.57	19.1	0.57	1.6e-2	0.41

Double Higgs production negligible in MSSM, but strong in NMSSM because of triple Higgs coupling

Invisible decay for A1

BRs for heavy H_3 mass → more decay channels $(t\bar{t})$

- Smaller BR for double Higgs production for higher values of H3 mass
- High masses will require high luminosity

	NMSSM (BMP II)				
Mass [GeV]	H_1 103	H_2 126	H_3 1001	A_1 91	A_2 1001
$b\bar{b}$	90.5	61.9	0.9	90.9	0.9
$t\bar{t}$	0.0	0.0	9.6	0.0	10.4
$\tau\tau$	9.1	6.4	0.1	8.8	0.1
W^+W^-	1.2e-4	20.6	1.7e-4	-	-
$\chi_1^0\chi_1^0$	-	-	10.7	-	11.8
$\chi_1^0\chi_3^0$	-	-	5.1	-	6.3
$\chi_1^+\chi_1^-$	-	-	3.2	-	5.9
H_1H_2	-	-	14.8	-	-
A_1H_2	-	-	-	-	13.5
ZA_1	-	-	12.3	-	-
ZH_1	-	-		-	13.6
A_1H_1	-	-	-	-	0.3
ZH_2	-	-	-	-	8.1e-4
σ_{prod} [pb]	0.33	19.3	1.6e-3	0.13	1.9e-3

Multistep fitting approach

- Consider not only BMPs but scan whole m_0-$m_{1/2}$ plane
- Fit to accelerator and cosmological data (see list in backup)
- Use NMSSM with 9 free GUT/SUSY scale parameter

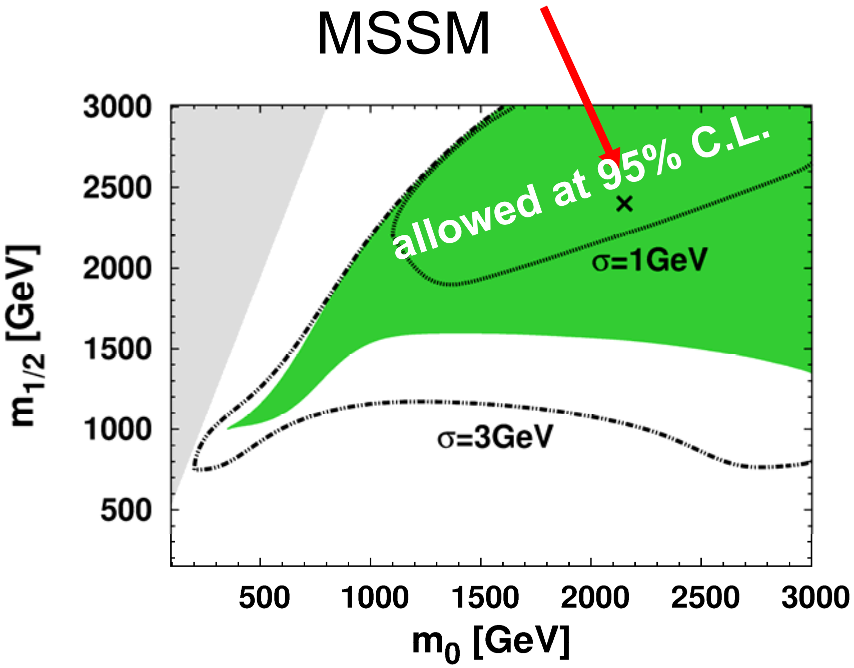
  (GUT scale parameter implies including complete rad. corr. between GUT and SUSY scale via RGEs, incl. fixed point solutions (forbids max. mixing in stop sector, so requires large values of stop masses)
- Challenging to deal with so many free parameters → multistep fitting technique: Fit the strongly correlated parameters first for fixed other parameters
- In the NMSSM case: start minimizing λ,κ and $\tan\beta$ → study influence on the lightest Higgs mass
- (assuming first m_{H2}=126 GeV)

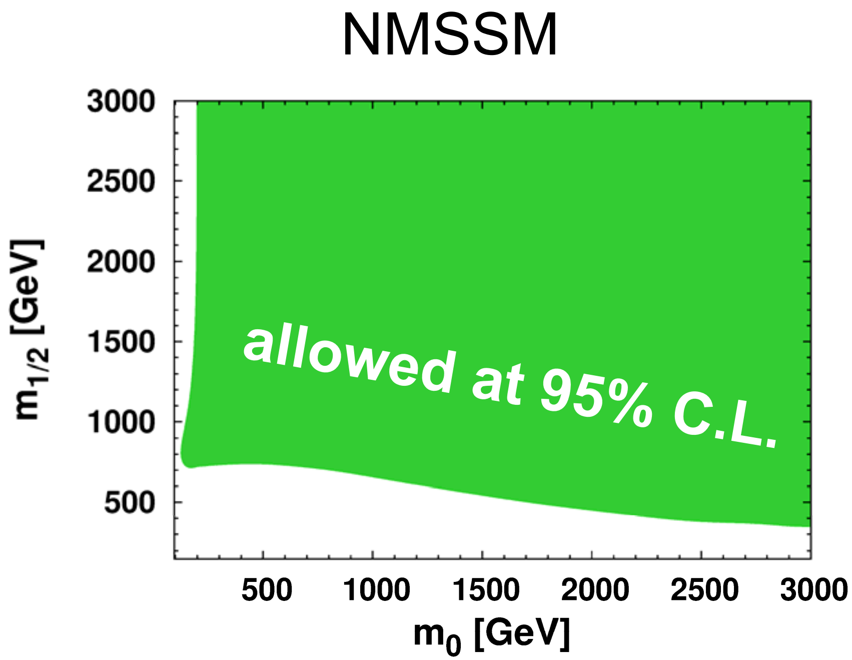
- For more details see CB et al., EPJ C
- Used Software **NMSSMTools3.2.4**, Ulrich Ellwanger, John F. Gunion, Cyril Hugonie

  MicrOMEGAs2.4.1 G. Bélanger, F. Boudjema, P. Brun, A. Pukhov, S. Rosier-Lees, P. Salati, A. Semenov

Combination of all constraints - What does this mean for m_0-$m_{1/2}$ plane? arXiv:1308.1333

Best Fit Point requiring 3.1 TeV stop mass

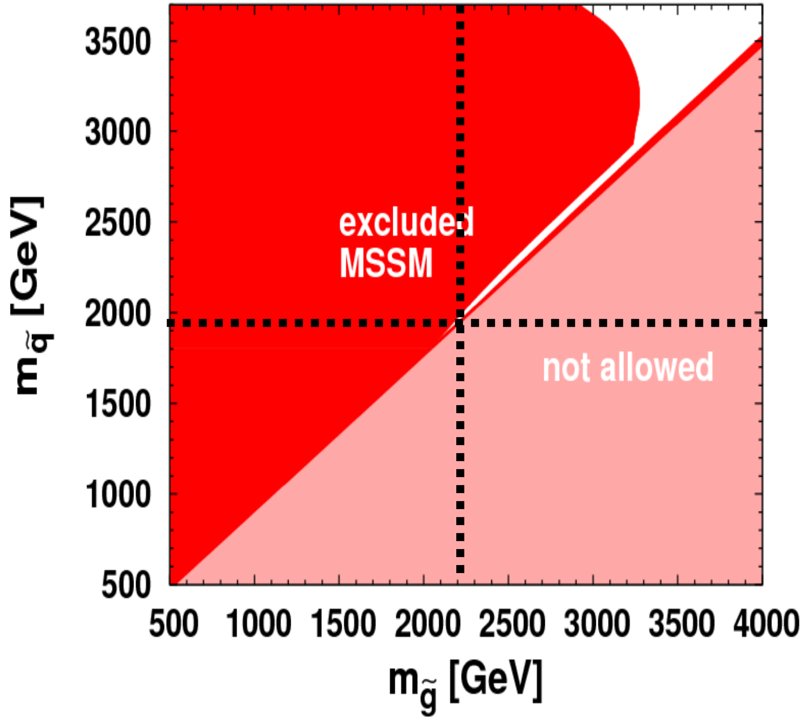


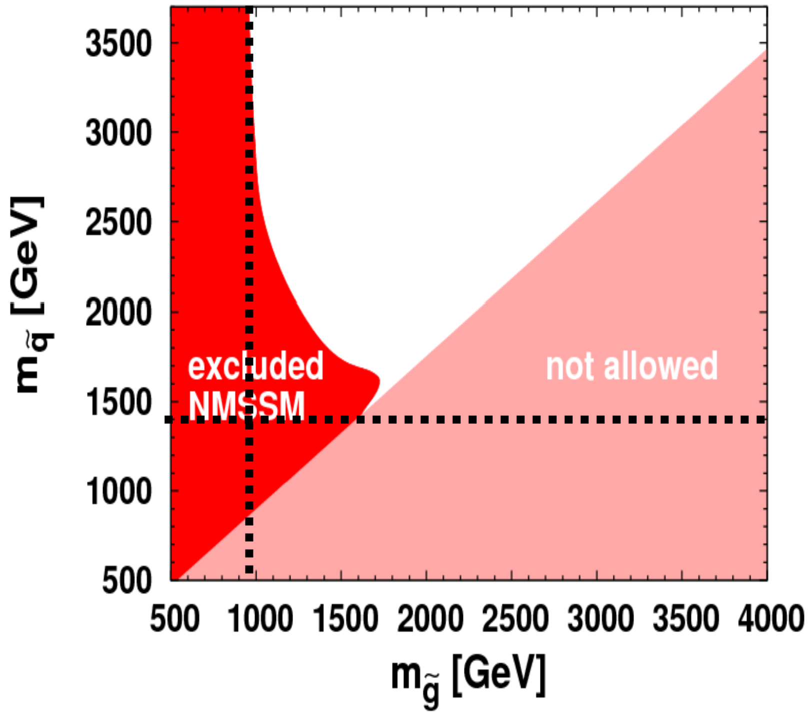


Within the MSSM the excluded region is dominated by Higgs mass (126 ± 2) GeV

Within the NMSSM the excluded region is dominated by LHC limit

What does this mean for squark and gluino masses?





Squarks	below	1.9 TeV 1.4 TeV	excluded within	MSSM NMSSM
Gluinos	below	2.3 TeV 0.95 TeV	excluded within	MSSM NMSSM

Limits on heavier/lighter Higgses

- $m_{H1} \sim A_\kappa$, but for $m_{H1} < 60$ GeV $\tilde{\chi}_1^0 \tilde{\chi}_1^0 \rightarrow ZH_1 / H_1 H_1$ kinematically allowed → Neutralino annihilation XS ↑ relic density ↓
- **Lower limit on m_{H1} because of relic density constraint** (assuming all relic density from neutralinos)

- $m_{H3} \sim A_\lambda$ → No upper limit on H_3 mass
- Lower limit for H_3 because of limit on μ_{eff} (chargino limit)

60 GeV < m_{H1} < 126 GeV

250 GeV < m_{H3}

Summary arXiv:1308.1333

- 126 GeV Higgs within the MSSM only possible for large SUSY masses
- Within the NMSSM one can get a 126 GeV Higgs for light SUSY masses because of the mixing with the additional Higgs singlet
- Excluded region is dominated by

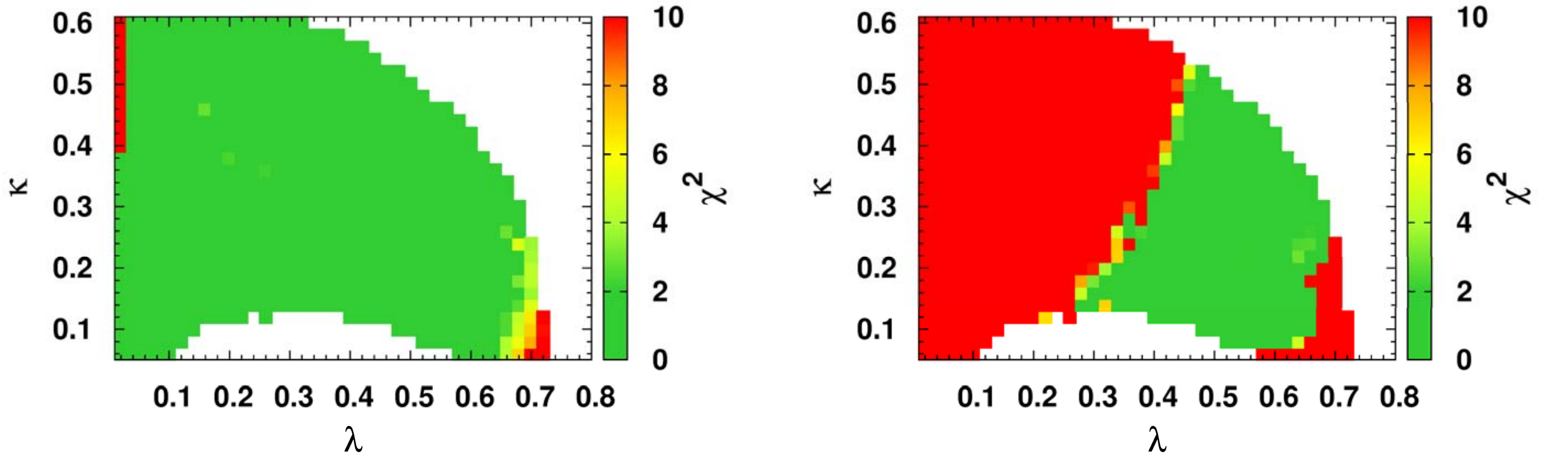
m_h in MSSM **LHC in NMSSM**

- m_{H3} allows $H_3 \rightarrow H_1 H_2$ (two Higgs bosons in ONE event!)
- H_3, $A_1 \rightarrow \chi_i \chi_j$ (invisible Higgs decays)
- Lower limit on m_{H1} because of relic density constraint

BACKUP

126 GeV Higgs within NMSSM ⇒ couplings?

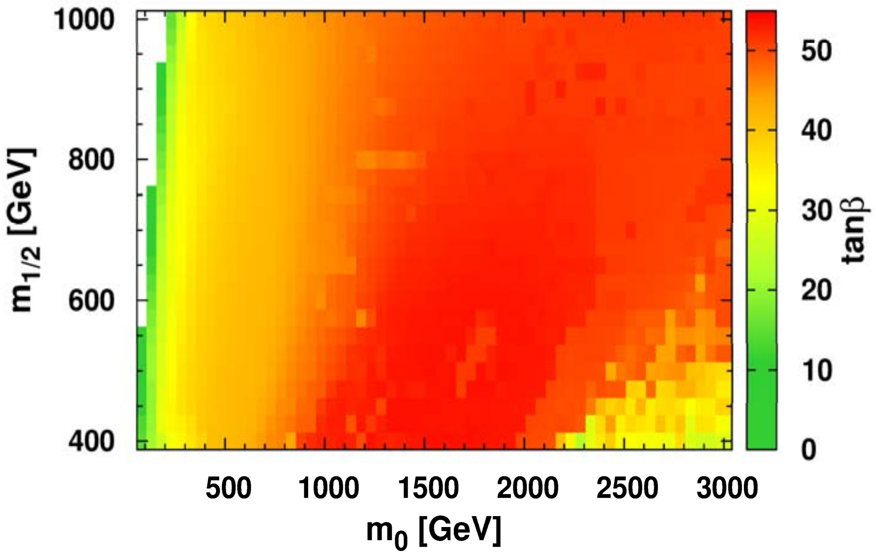
- 126 GeV allows large range of λ and κ
- LSP is typically higgsino, so annihilation cross section ($\propto 1/\Omega$) restricts couplings!

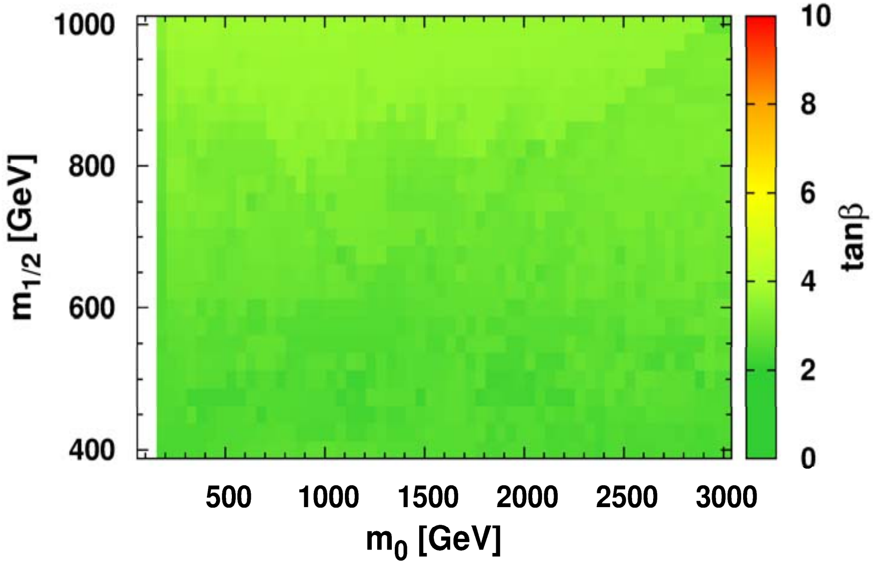


χ^2-distribution for M_2=125 GeV

χ^2-distribution for M_2=125 GeV and relic density Ωh^2 constraint

Comparison of CMSSM – NMSSM: Optimized tanβ values





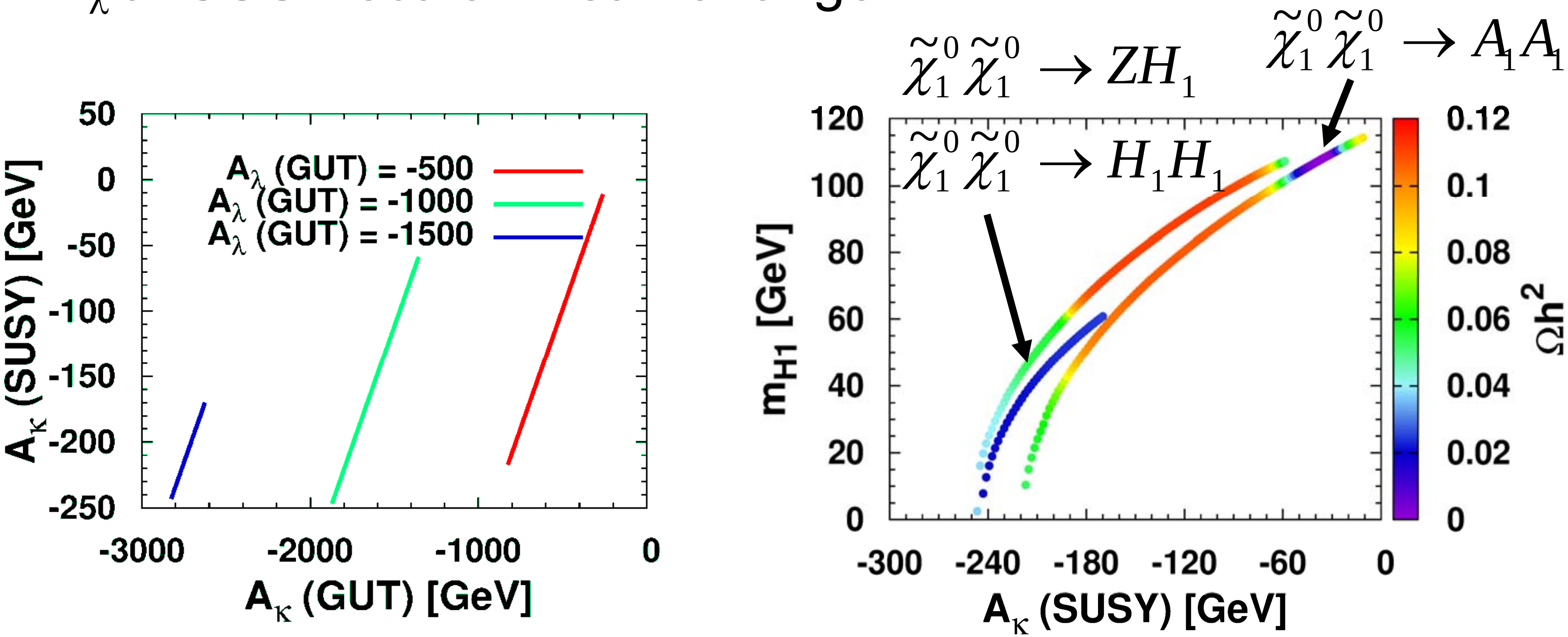
High values (except for coannihilation region) of **tanβ** needed to fulfill relic density constraint

Small values of **tanβ** are preferred to get the 126 GeV Higgs for light SUSY masses.

→ Fulfills B-physics constraints

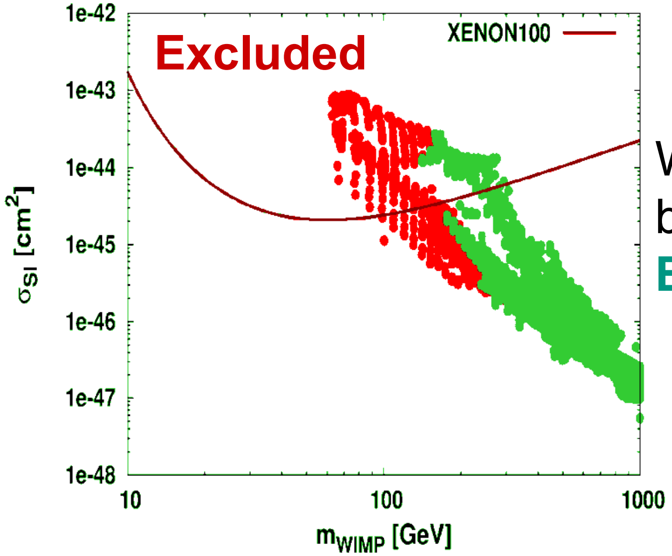
Lower limit on m_{H1} mass

- $m_{H1} \sim A_\kappa$, but one cannot choose any arbitrary value for A_κ because of radiative corrections from RGEs
- A_λ at SUSY scale → same range

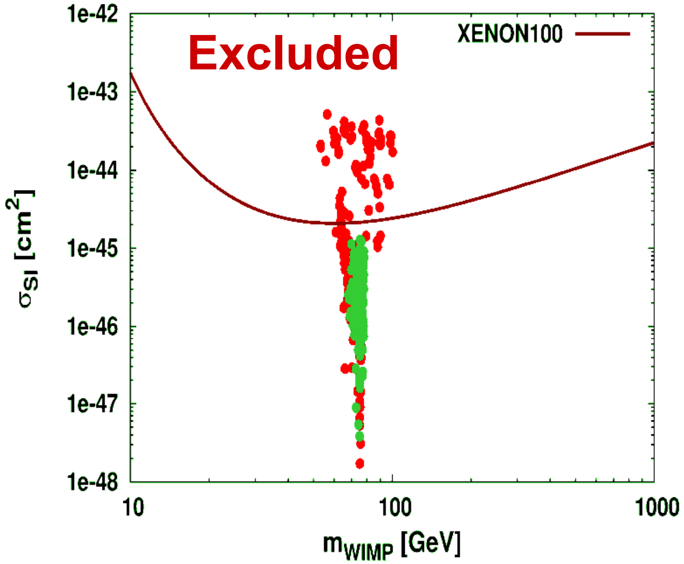


- **Lower limit on m_{H1} because of relic density constraint**

CMSSM – NMSSM: Wimp-Nucleon XS

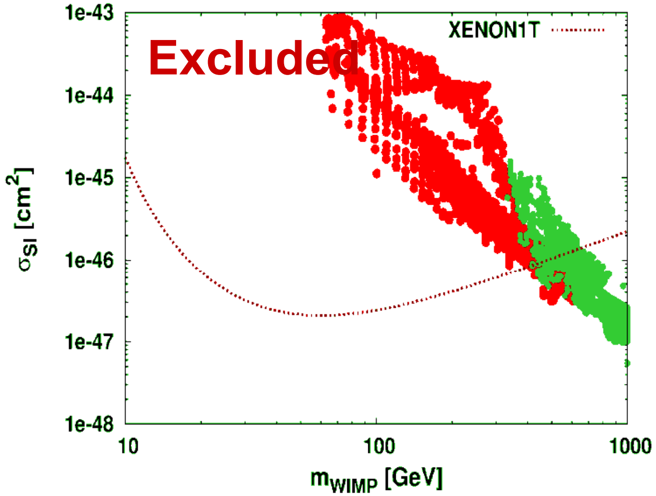


WIMP basically **Bino**

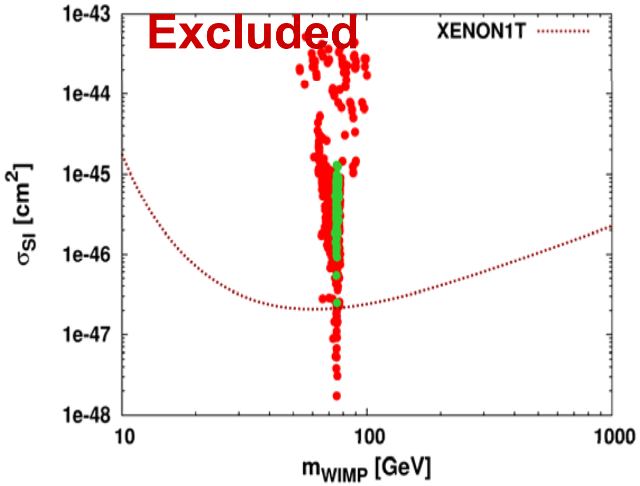


WIMP = Mixing of **Singlino** and **Higgsino**

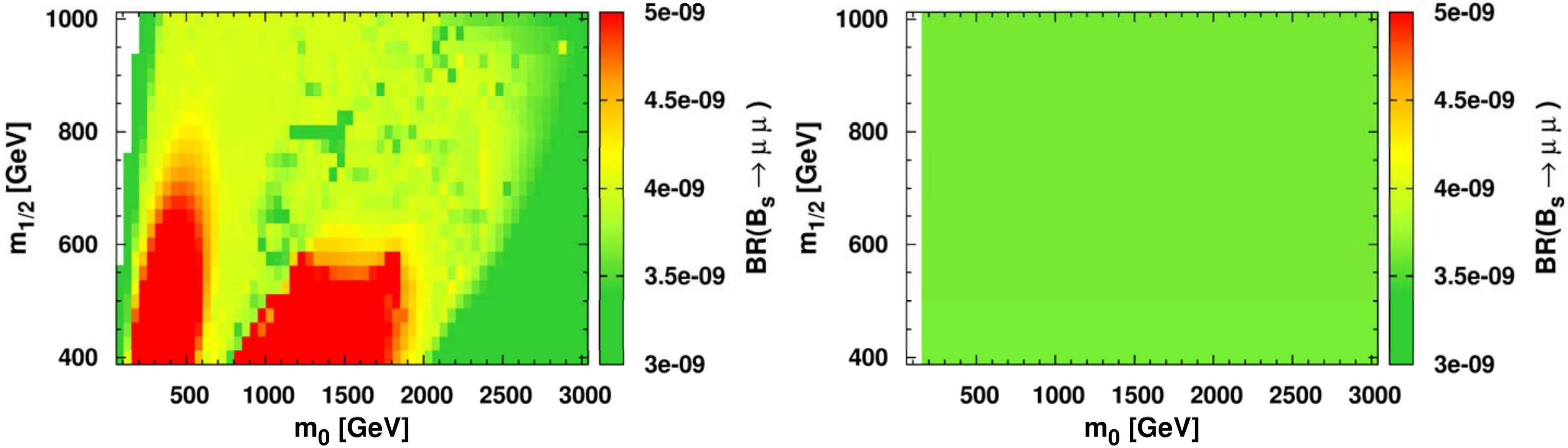
Expected sensitivity of LHC-14TeV and Xenon1T



- **LHC allowed**
- **LHC excluded**



Comparison of CMSSM – NMSSM: BR($B_s \to \mu\mu$)



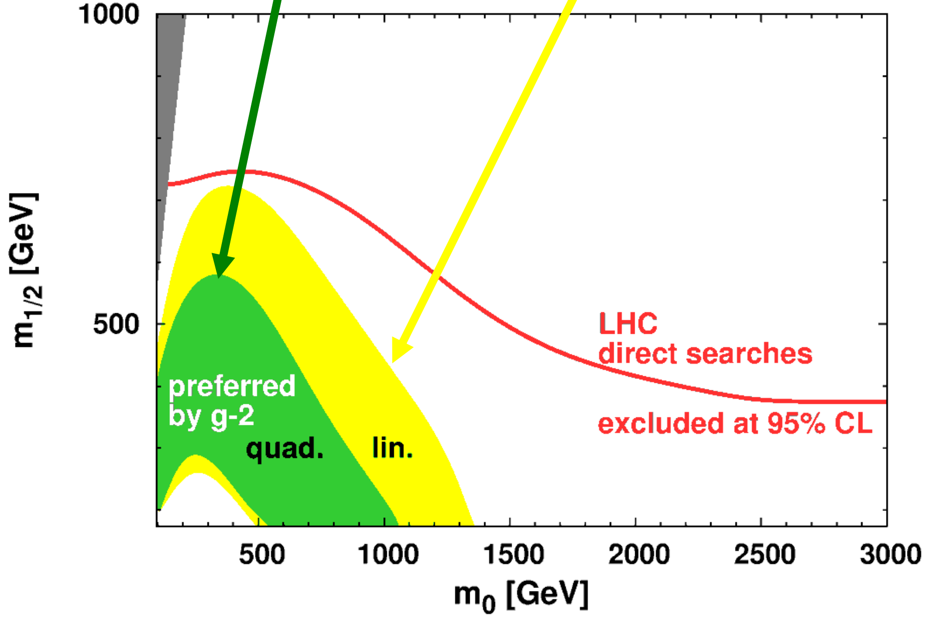
- BR^{exp}($B_s \to \mu\mu$) = $(3.2 \pm 1.2) \cdot 10^{-9}$
- BR^{theo}($B_s \to \mu\mu$) = $(3.2 \pm 0.2) \cdot 10^{-9}$

BR($B_s \to \mu\mu$) ~ tanβ^6 → Fulfilled within the NMSSM because of small tanβ

Large excluded region within the CMSSM

Influence of g-2

Preferred region by g-2 for quadratic and linear addition of the errors



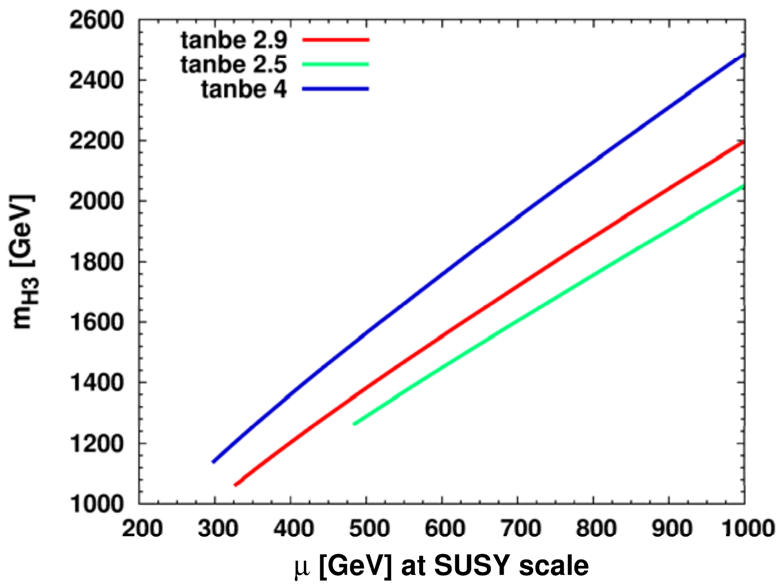
g-2 gives light preference for light SUSY masses **but light SUSY Massen are already excluded by the LHC direct searches** → errors underestimated or additional loop corrections

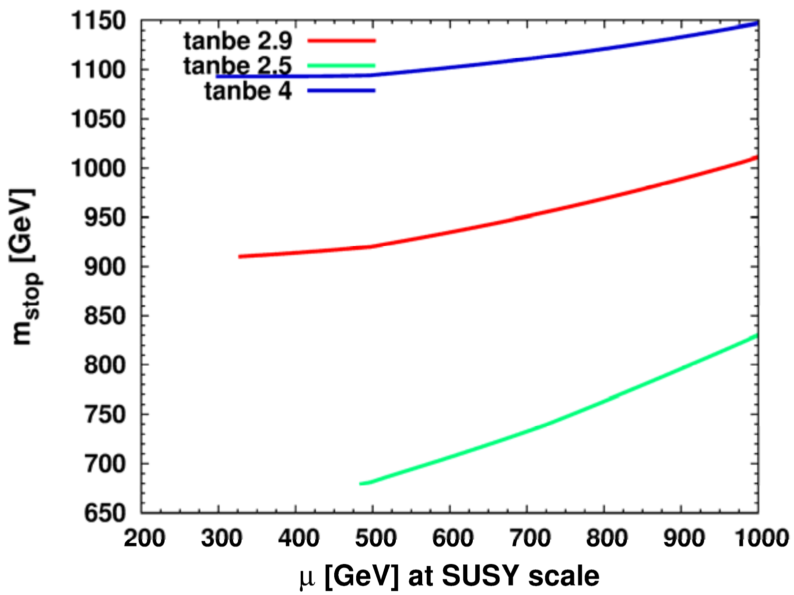
$$\left|a_\mu^{SUSY}\right| \approx 13 \cdot 10^{-10} \mu \left(\frac{100GeV}{m_{SUSY}}\right)^2 \tan\beta$$

Deviation compared to SM 2-3σ: $\chi^2 = \left(\frac{D-T}{\sigma}\right)^2 \approx 5$ for heavy m_{SUSY}

Mass range for m_{H3}

- m_{H3}: linear dependence on A_λ and μ_{eff}





- For strong deviations between A_0 and A_λ/A_κ one can get masses up to 1TeV

Other constraints (in addition to m_h=126 GeV)

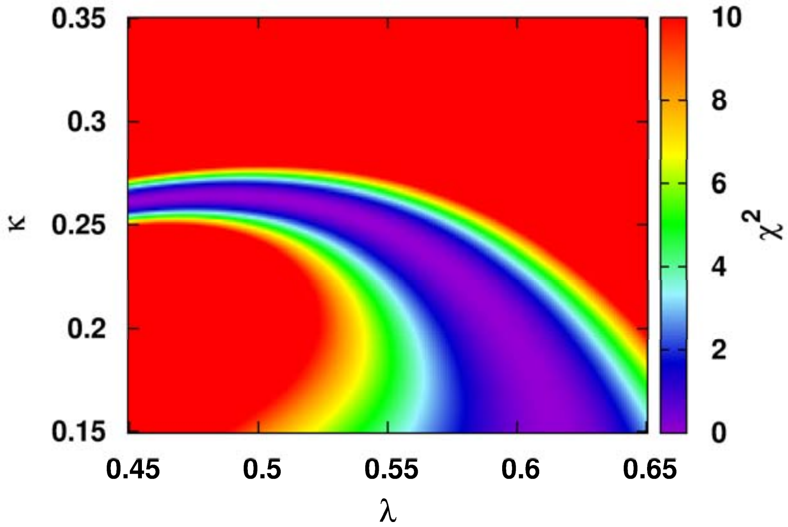
- Define χ^2-function to find the allowed parameter space

Relic density	$\Omega h^2 = 0.1131 \pm 0.0034$
$B \to \tau\nu$	$BR^{exp}(B\to\tau\nu) = (1.68 \pm 0.31)\cdot 10^{-4}$
Myon g-2	$\Delta a_\mu = (30.2 \pm 6.3 \pm 6.1)\cdot 10^{-11}$
$b \to s\gamma$	$BR^{exp}(b\to s\gamma) = (3.55 \pm 0.24)\cdot 10^{-4}$
$B_s \to \mu\mu$	$BR^{exp}(B_s\to\mu\mu) = (3.2 \pm 1.2)\cdot 10^{-9}$
LHC direct searches	$\sigma_{had} < 0.001 – 0.03$ pb
XENON100	$\sigma_{\chi N} < 1.8\cdot 10^{-45} - 6\cdot 10^{-45}$ cm^2
Pseudo-scalar Higgs m_A	$m_A > 510$ GeV für $\tan\beta \sim 50$

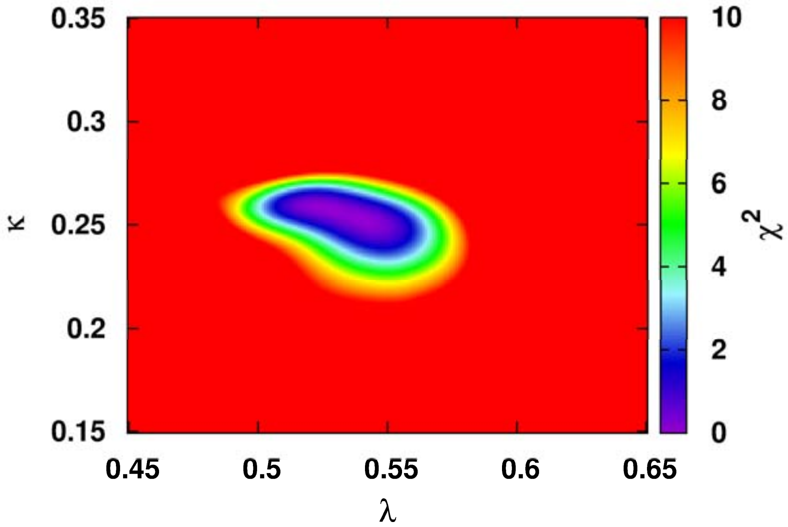
- For more details see CB et al., EPJ C
- Used Software
  MicrOMEGAs2.4.1 G. Bélanger, F. Boudjema, P. Brun, A. Pukhov, S. Rosier-Lees, P. Salati, A. Semenov
  NMSSMTools3.2.4, Ulrich Ellwanger, John F. Gunion, Cyril Hugonie

126 GeV Higgs within NMSSM

- 126 GeV Higgs within NMSSM for small SUSY masses possible for many different combinations of λ and κ
- Combined with relic density constraints possible $\lambda\kappa$ solution



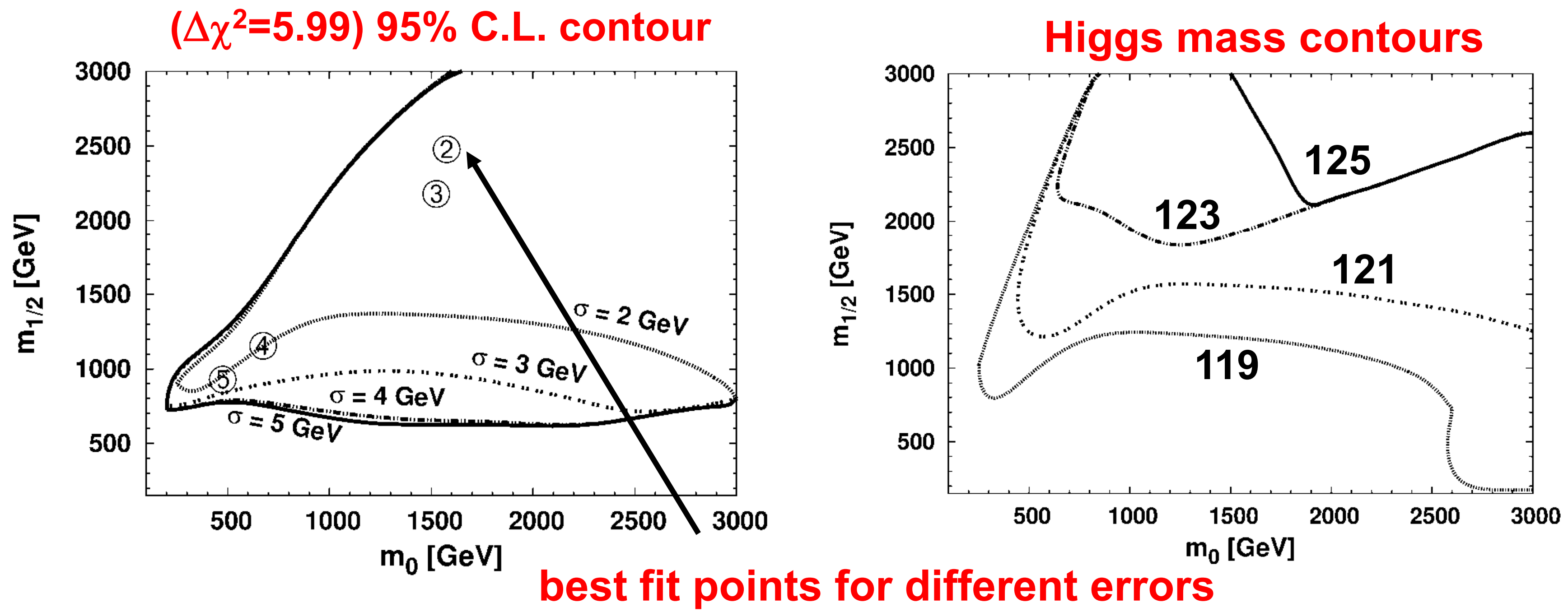
χ^2-distribution for M_2=125 GeV



χ^2-distribution for M_2=125 GeV and Ωh^2 constraint

125 GeV Higgs within the CMSSM

- A 125 GeV light Higgs is possible within the CMSSM if the SUSY masses are heavy enough and if the trilinear coupling A_0 is negative
- The allowed parameter space is largely determined by the assigned error → strong dependence on the theoretical error
- Exp. ~ 2GeV, theo. ~ 3GeV, non-Gaussian → lin. addition → 5GeV



Benchmark points in NMSSM

- Analyses have been done e.g. Ellwanger, Hugonie (arXiv:1203.5048 using GUT scale parameters), Mühlleitner et al. (arXiv:1201.2671 using low energy values of parameters)
- Benchmark points fulfill Higgs mass and couplings, but one needs very specific singlet mixing to obtain simultaneously m_H=125 GeV, large branching into $\gamma\gamma$, small branching into $\tau\tau$

E.g. Benchmark points from Ellwanger, Hugonie, arXiv:1203.5048

Input at M_{GUT} → (M_0 … A_λ); Input at M_{SUSY} ← ($\tan\beta$ … μ_{eff})

	M_0	$m_{1/2}$	A_0	A_κ	A_λ	$\tan\beta$	λ	κ	μ_{eff}
BM I	600	600	-1550	-275	-625	2.40	0.545	0.253	120
BM II	960	525	-1140	-360	-575	2.29	0.600	0.321	122

Typical Higgs masses and couplings

Lightest Higgs H_1

	BM I	II
M_{H_1}	100	121
Components of H_1		
H_d	0.39	0.50
H_u	0.34	0.74
S	0.86	0.45

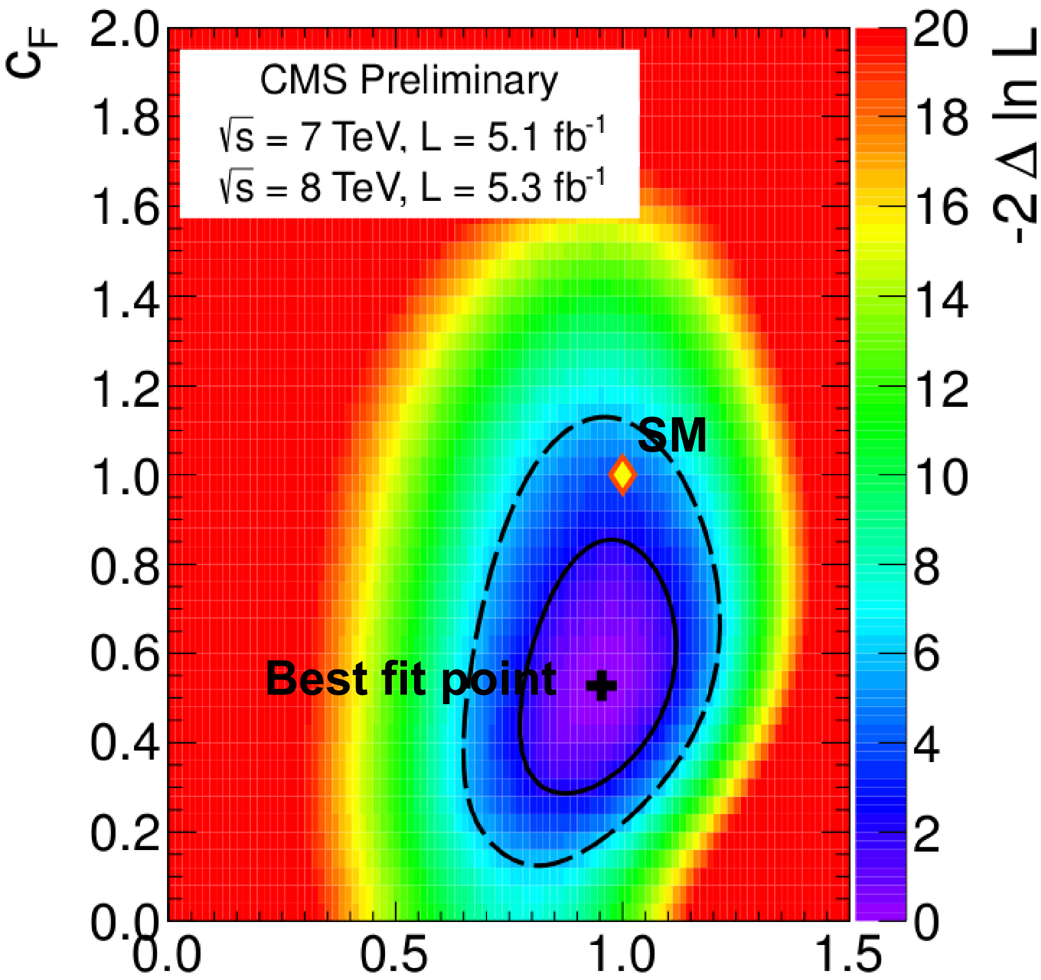
Second lightest Higgs H_2

	BM I	II
M_{H_2}	126	126
Components of H_2		
H_d	0.26	0.04
H_u	0.85	-0.54
S	-0.45	0.84

Strong mixing with singlet → $R_{\gamma\gamma}$ can be enchanced

It is possible that 126 GeV is not the lightest Higgs

Fit to SM couplings (scale factors)



(CMS-PAS-HIG-12-020)

C_F = scale factor for coupling to fermions

C_V = scale factor for coupling to vector bosons

Best fit point:
$C_F \approx 0.5$ $C_V \approx 1.0$

SM: $C_F = C_V = 1$

Details on χ^2-function

- Relic Density
- $B \rightarrow \tau\nu$
- Myon g-2
- $b \rightarrow s\gamma$

Experimental Values

Defined in a straight forward way:

$$\chi^2 = \frac{\left(X_{SUSY} - X_{\exp}\right)^2}{\sigma^2}$$

- $B_s \rightarrow \mu\mu$ — $BR^{exp}(B_s \rightarrow \mu\mu) < 4.5 \cdot 10^{-9}$
- Higgs Mass m_h — $m_h > 114.4$ GeV

- LHC direct searches — $\sigma_{had} < 0.003 - 0.03$ pb
- DDMS — $\sigma_{\chi N} < 8 \cdot 10^{-45} - 2 \cdot 10^{-44}\ cm^2$
- Pseudo-scalar Higgs m_A — $m_A > 480$ GeV for $\tan\beta \sim 50$

Details on χ^2-function?

- Relic Density — $\Omega h^2 = 0.1131 \pm 0.0034$
- $B \rightarrow \tau\nu$ — $BR^{exp}(B \rightarrow \tau\nu) = (1.68 \pm 0.31) \cdot 10^{-4}$
- Myon g-2 — $\Delta a_\mu = (30.2 \pm 6.3 \pm 6.1) \cdot 10^{-11}$
- $b \rightarrow s\gamma$ — $BR^{exp}(b \rightarrow s\gamma) = (3.55 \pm 0.24) \cdot 10^{-4}$

- $B_s \rightarrow \mu\mu$
- Higgs Mass m_h

95% CL

only added if $X_{SUSY} > X_{95\%}$

X_{SUSY} = model value of $BR(B_s \rightarrow \mu\mu)$ or m_h

$X_{95\%}$ can be determined from requirement

$\Delta\chi^2 = 5.99$ at 95% CL exclusion limit

- LHC direct searches — $\sigma_{had} < 0.003 – 0.03$ pb
- DDMS — $\sigma_{\chi N} < 8 \cdot 10^{-45} - 2 \cdot 10^{-44}$ cm^2
- Pseudo-scalar Higgs m_A — $m_A > 480$ GeV for $\tan\beta \sim 50$

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- $B_s\to\mu\mu$
- Higgs Mass m_h

- LHC direct searches
- DDMS
- Pseudo-scalar Higgs m_A

95% CL exclusion contours

Define $\chi^2=(X_{SUSY} - X_{95\%})^2/\sigma_{95\%}^2$ X_{SUSY} = model value of m_A or hadronic cross section or χN elastic scattering cross section $\sigma_{95\%}$ can be determined from 1σ band given by experiments $X_{95\%}$ determined from requirement $\Delta\chi^2=5.99$ at 95% CL exclusion contour

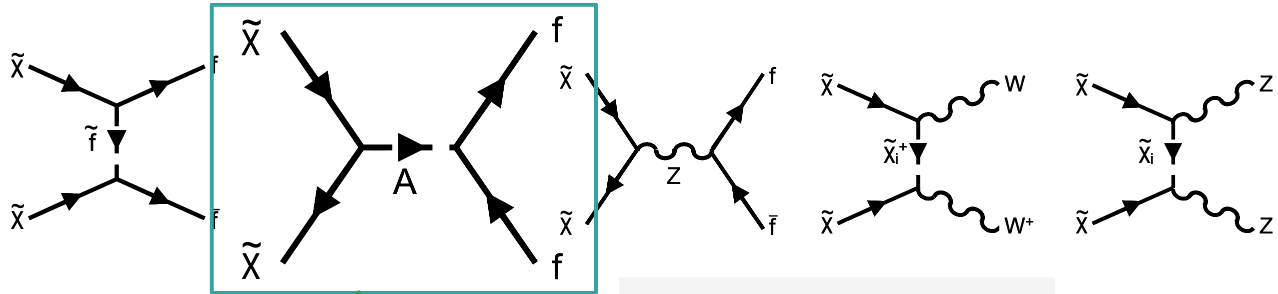
Typical Sparticle masses and LSP mixing (NMSSM)

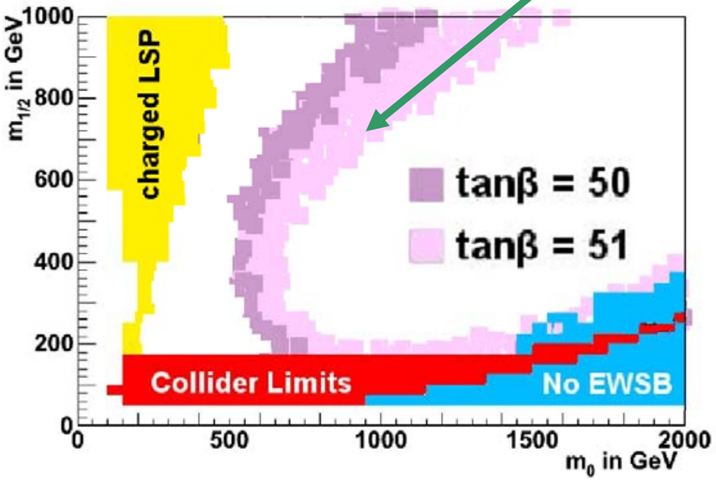
Sparticle masses	BM I	II
$m_{\tilde{g}}$	1388	1254
$m_{\tilde{q}}$	1318	1397
$m_{\tilde{t}_1}$	359	463
$m_{\tilde{b}_1}$	1001	1060
$m_{\tilde{\tau}_1}$	528	900
$m_{\chi_1^\pm}$	108	108
$m_{\chi_1^0}$	77	78

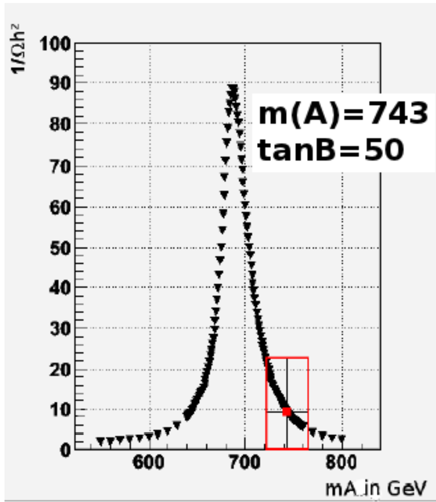
Components of χ_1^0	BM I	II
$\tilde{B}$	0.20	0.25
$\tilde{W}$	-0.16	-0.20
$\tilde{H}_d$	0.48	0.52
$\tilde{H}_u$	-0.70	-0.70
$\tilde{S}$	0.46	0.37
Ωh^2	0.10	0.10

Start with Relic Density Constraint

Problem: for excluded $m_{\tilde{q}}$ first diagram too small. Last diagram also small → can get correct relic density by m_A s-channel annihilation







$$\langle \sigma v \rangle \propto \frac{\tan\beta^2}{m_A^4}$$

$$\Rightarrow m_A \propto 2m_\chi \propto m_{1/2}$$

m_A can be tuned with tanβ for any $m_{1/2}$ → tanβ ≈ 50 (see next slide)

Relic Density Constraint – Dependence on tanβ

$$V_{tree}(H_1,H_2)=m_1^2|H_1|^2+m_2^2|H_2|^2-m_3^2(H_1H_2+h.c.)+\frac{g^2+g'^2}{8}\left(|H_1|^2-|H_2|^2\right)^2+\frac{g^2}{2}|H_1^+H_2^-|^2$$

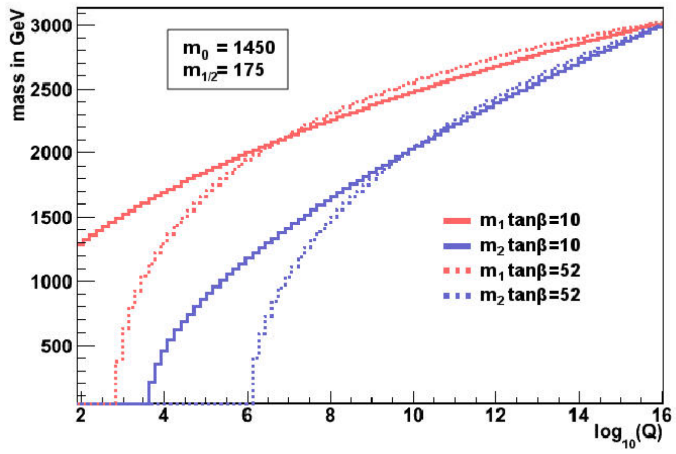
$m_A^2 = m_1^2 + m_2^2$ (Tree Level)

m_1 running $\propto h_t$

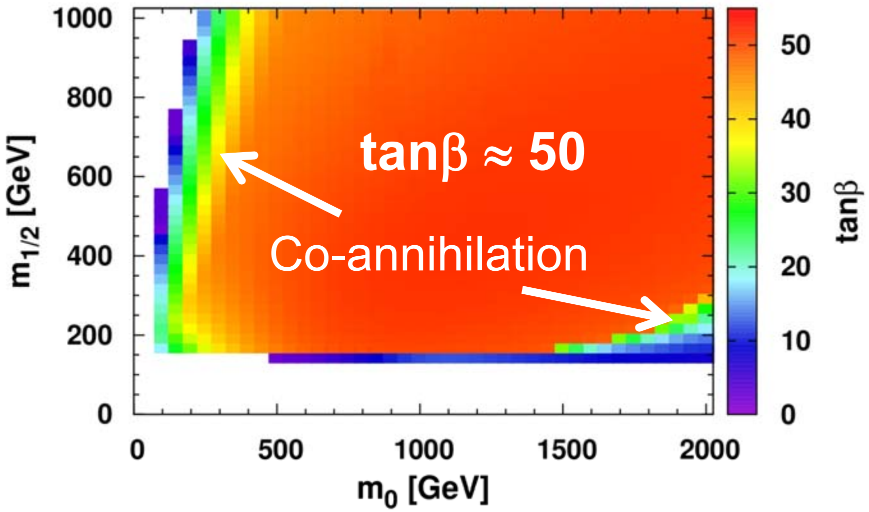
m_2 running $\propto h_b$

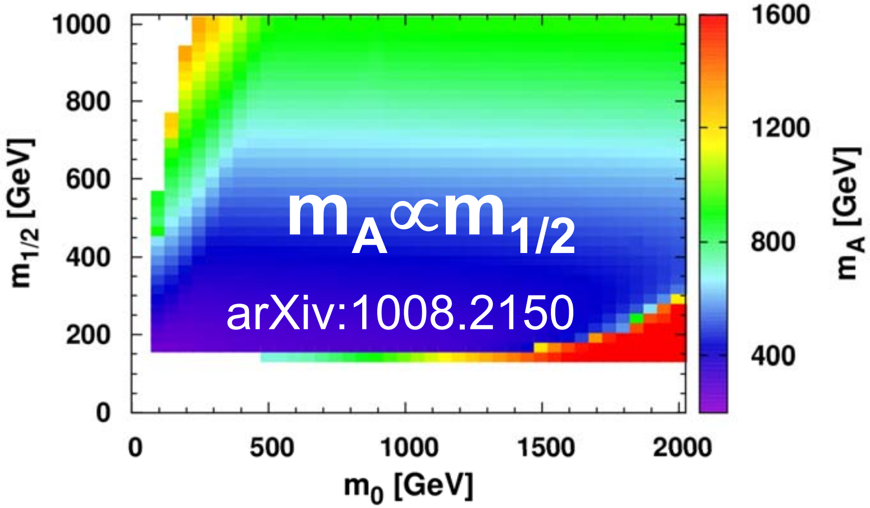
running < 0 → if h_t and h_b similar

→ small m_A for tanβ= $m_t/m_b \approx 50$

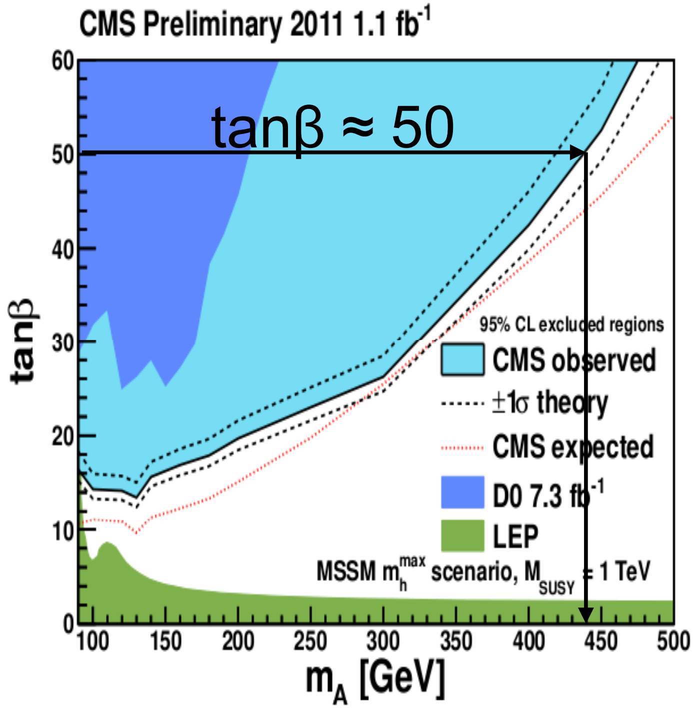


Fit of Ωh^2 determines m_A and tanβ



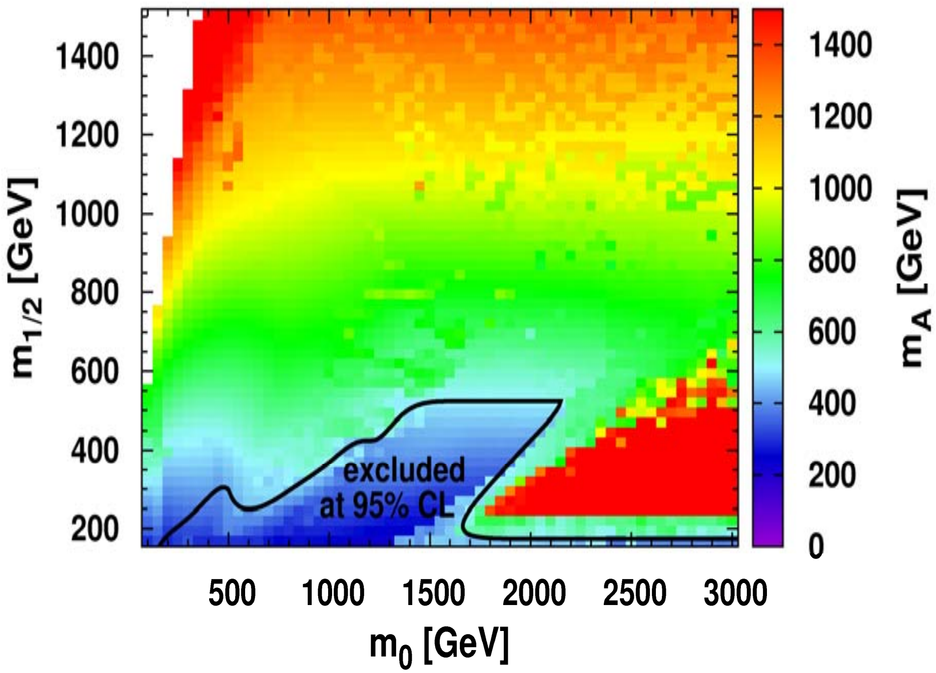


What about Higgs m_A limit?



(CMS PAS HIG-11-009)
Atlas similar

For tanβ ≈ 50
m_A > 440 GeV

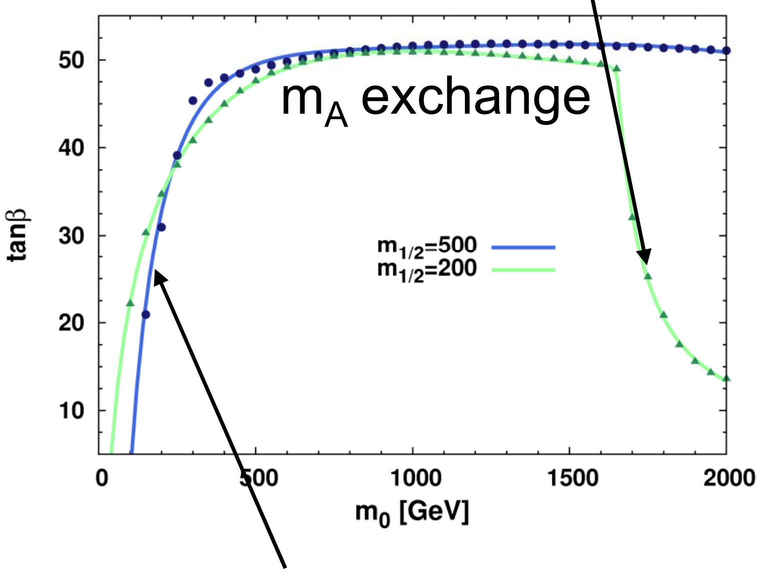


Examples for high correlation

KIT

For given m_0 only very specific values of tanβ

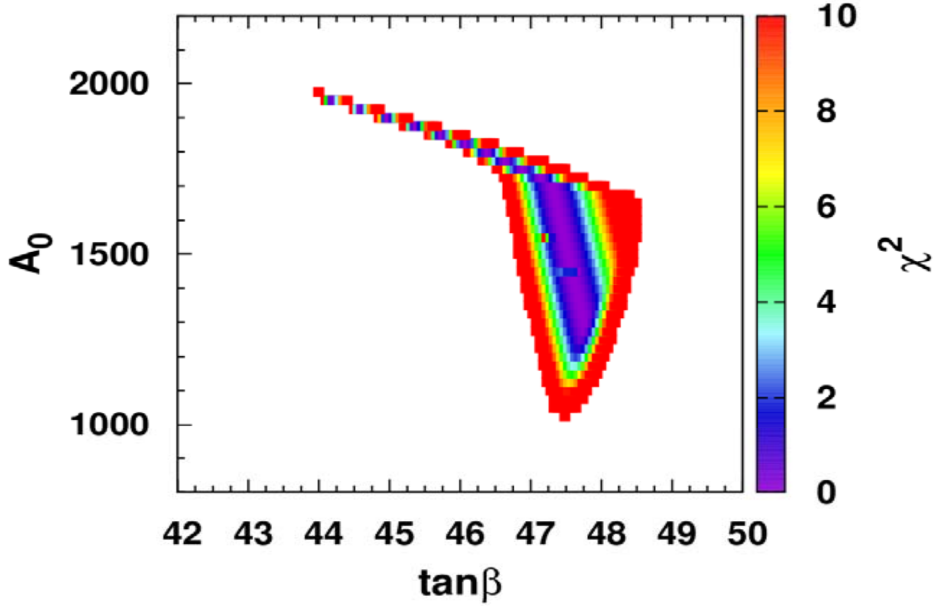
focus point region



co-annihilation region

For given tanβ only very specific values of A_0

χ^2 for $B_s \to \mu\mu$ and Ωh^2

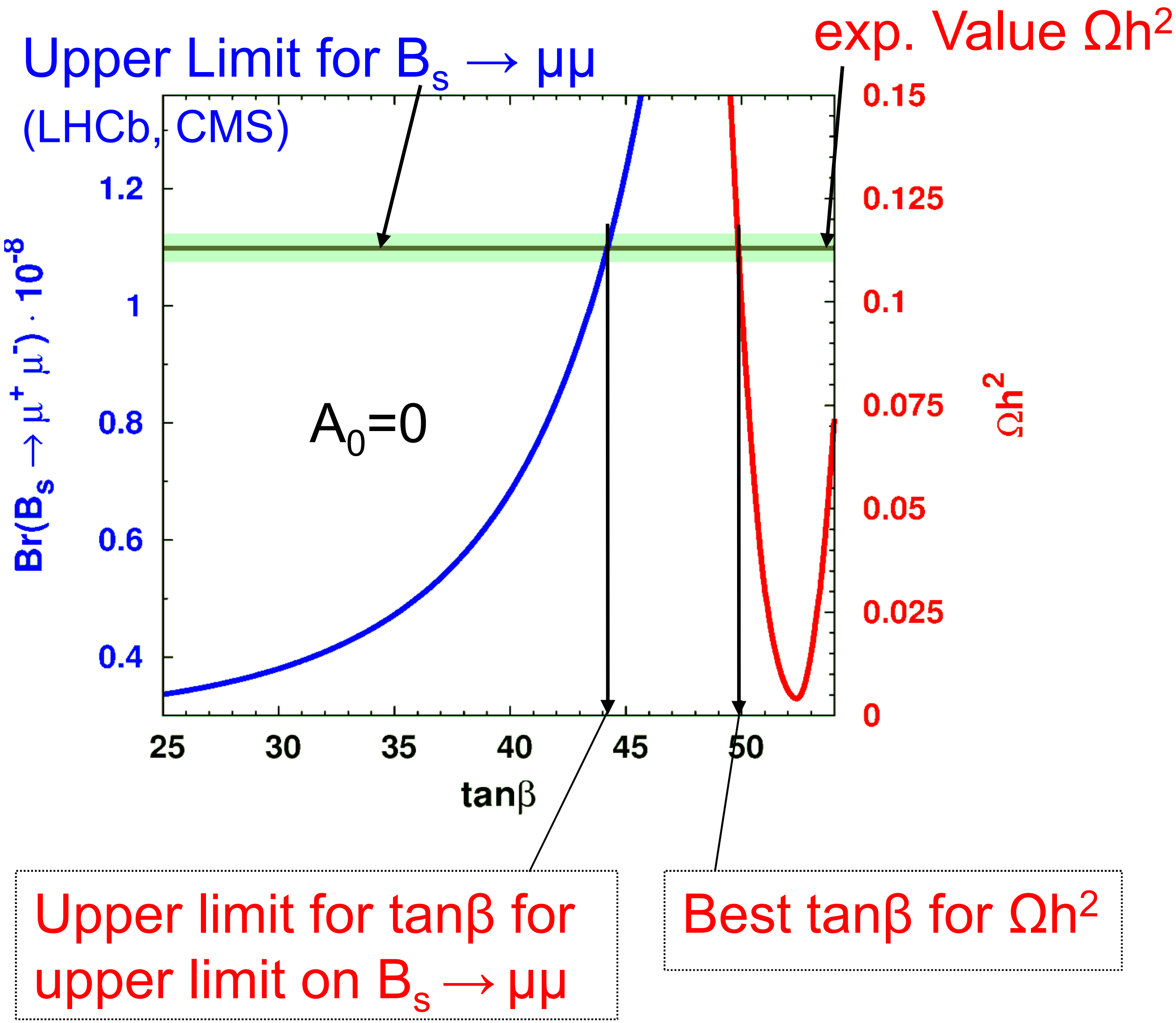


Origin of correlation:

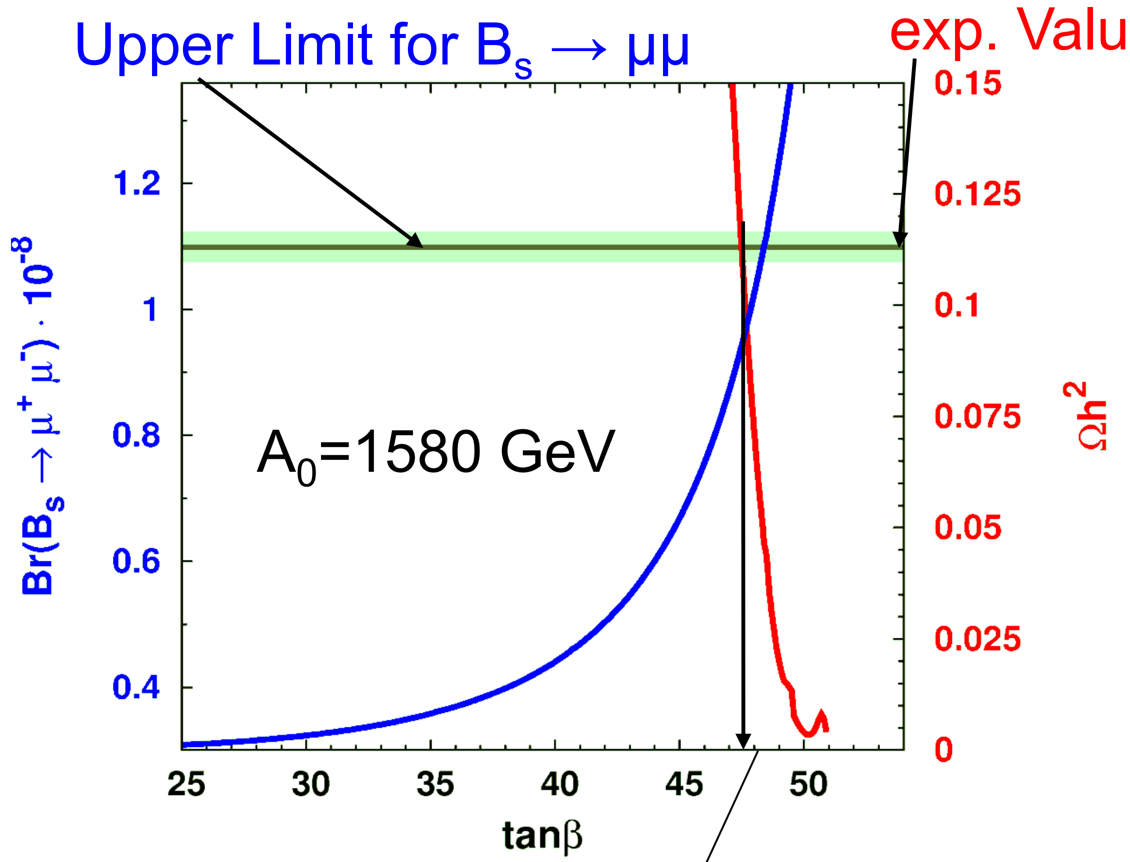
$B_s \to \mu\mu$
Ωh^2

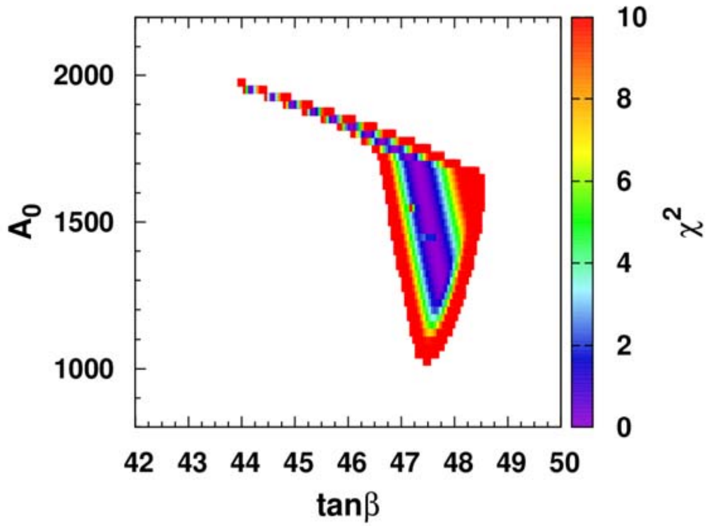
Both strongly dependent on tanβ

Origin of correlation



Origin of correlation





Common tanβ can only be found for specific A_0 value

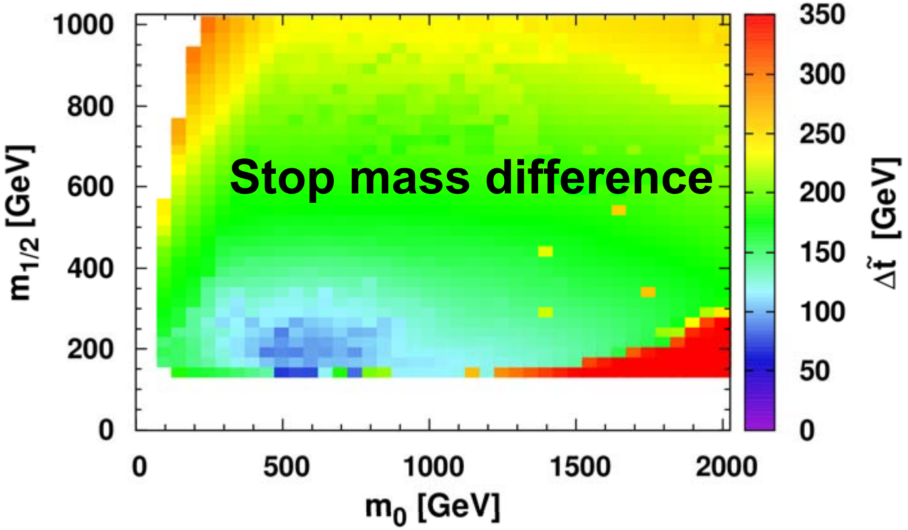
Best tanβ for $B_s \rightarrow \mu\mu$ and Ωh^2 simultaneously

Reason for strong A_0 dependence of $B_s \to \mu\mu$

arXiv:hep-ph/0203069v2

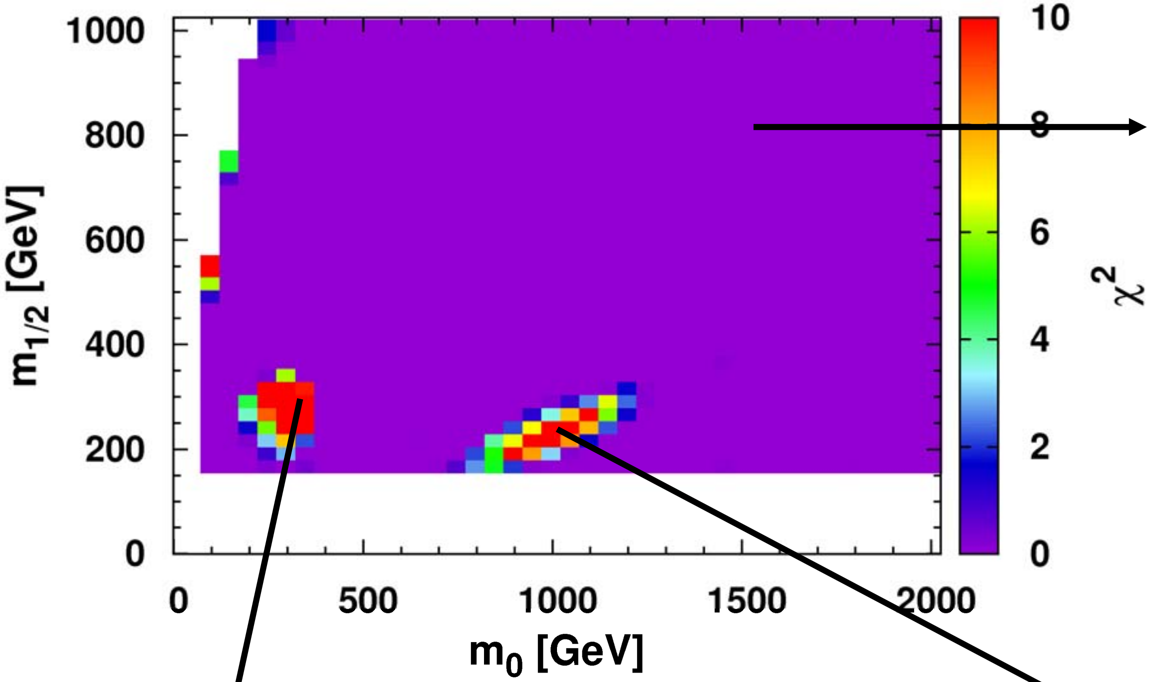
$$Br[B_s \to \mu^+\mu^-] = \frac{2\tau_B M_B^5}{64\pi} f_{B_s}^2 \sqrt{1-\frac{4m_l^2}{M_B^2}} \left[\left(1-\frac{4m_l^2}{M_B^2}\right)\left|\frac{(C_S - C_S')}{(m_b+m_s)}\right|^2 + \left|\frac{(C_P - C_P')}{(m_b+m_s)} + 2\frac{m_\mu}{M_{B_s}^2}(C_A - C_A')\right|^2\right]$$

$$C_S \simeq \frac{G_F\alpha}{\sqrt{2}\pi} V_{tb}V_{ts}^* \left(\frac{\tan^3\beta}{4\sin^2\theta_W}\right)\left(\frac{m_b m_\mu m_t \mu}{M_W^2 M_A^2}\right)\frac{\sin 2\theta_{\tilde{t}}}{2}\left(\frac{m_{\tilde{t}_1}^2 \log\left[\frac{m_{\tilde{t}_1}^2}{\mu^2}\right]}{\mu^2 - m_{\tilde{t}_1}^2} - \frac{m_{\tilde{t}_2}^2 \log\left[\frac{m_{\tilde{t}_2}^2}{\mu^2}\right]}{\mu^2 - m_{\tilde{t}_2}^2}\right)$$



Becomes small, if $\tilde{t}_1 \approx \tilde{t}_2$
can be achieved by adjusting A_t,
till mixing term ~ (A_t – μ/tanβ)
becomes small.
Important only for light SUSY masses (see blue region)

Combination of $B_s \rightarrow \mu\mu$ and Ωh^2

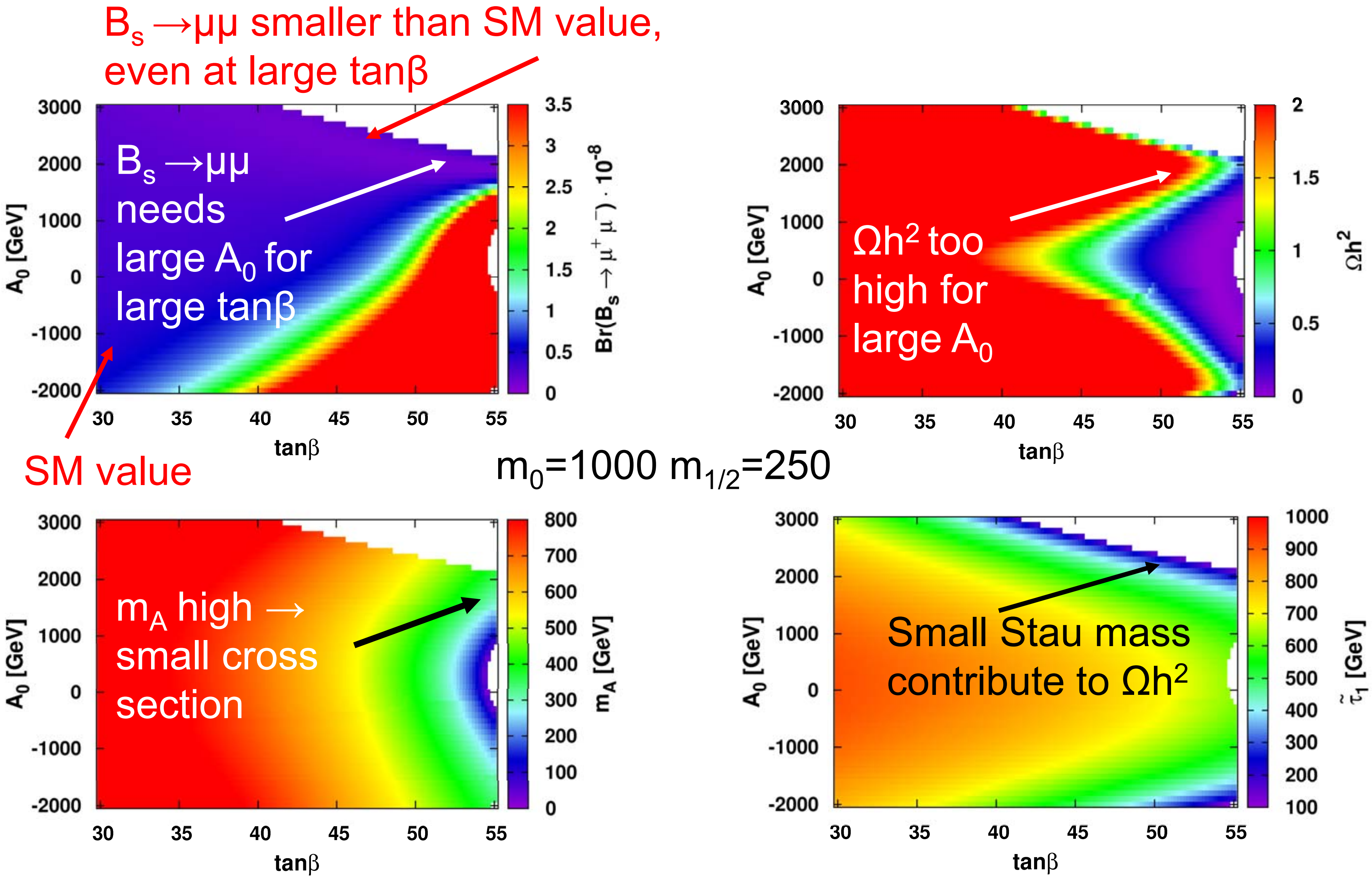


Tension at large $\tan\beta$ from $B_s \rightarrow \mu\mu$ can be removed by large A_0

Tension can't be removed by varying $A_0 \rightarrow$ because $A_0 < 3m_0$, A_0 not high enough to get small BR

Tension still there although A_0 large enough to get small BR

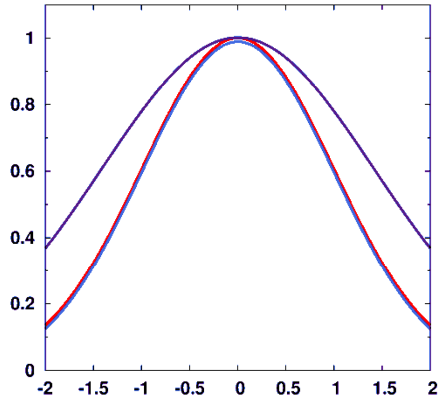
Why there's still a tension for large m_0?



How to treat theoretical errors?

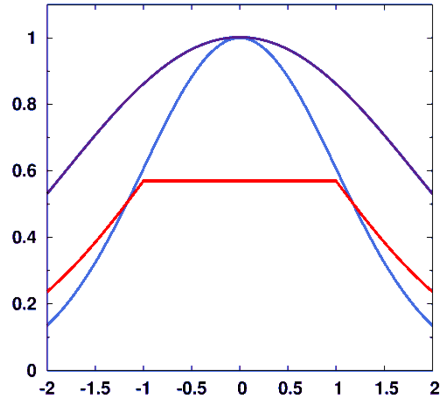
- Theoretical errors can be treated as nuisance parameters and integrated over in the probability distribution (=convolution for symm. distr.)
- If errors Gaussian, this corresponds to adding the experimental and theoretical errors in quadrature
- Assume $\sigma_{theo} \sim \sigma_{exp}$ (only then important)

Convolution of 2 Gaussians



$$\sigma_+^2 = \sigma_{theo}^2 + \sigma_{\exp}^2$$

Convolution of Gaussian + “flat top Gaussian” (expected if theory errors indicate a range)

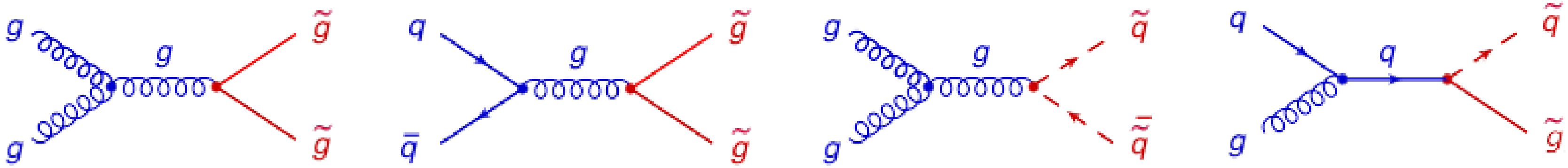


$$\sigma_+ \sim \sigma_{theo} + \sigma_{\exp}$$

Adding errors linearly more conservative approach for theory errors.

Direct searches for SUSY particles

- SUSY particles can be produced in pp collisions at the LHC

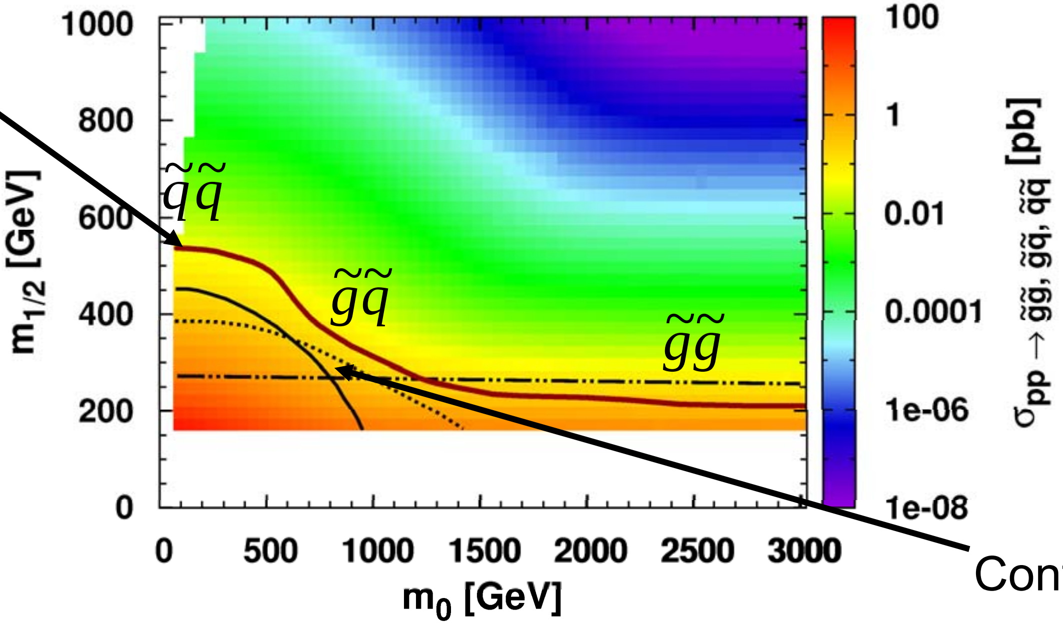


- Combination of the different cross sections of $pp \to \tilde{g}\tilde{g}, \tilde{g}\tilde{q}, \tilde{q}\tilde{q}$

95% CL exclusion by CMS + Atlas (Jets+MET)

CMS PAS SUS-11-003

arXiv:1109.6572

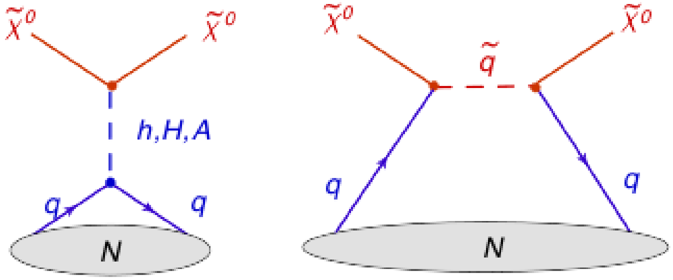


Parametrization of $\chi^2 = \sigma_{tot}^2 / \sigma_{eff}^2$ with σ_{eff}^2 that $\Delta\chi^2 = \chi^2 - \chi^2_{min} = 5{,}99$

Contribution to σ_{tot}=0,1pb

Direct search for dark matter (DDMS)

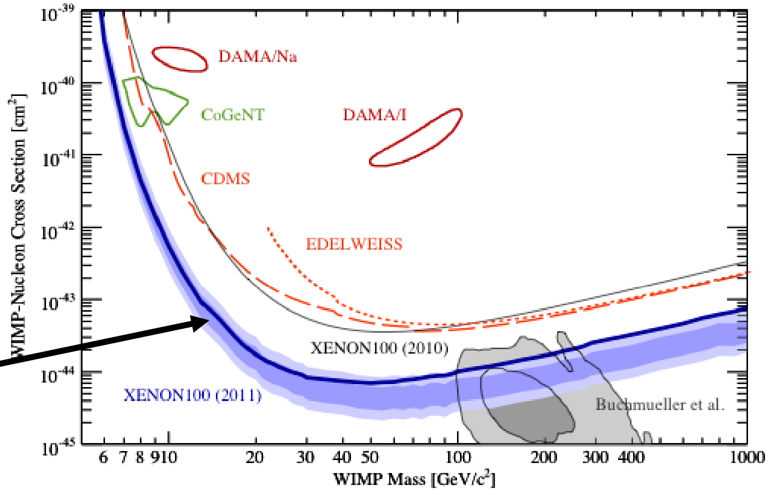
- Assume Neutralino is LSP and therefore perfect WIMP candidate
- Direct detection of WIMPs through elastic scattering on heavy nuclei



- Coherent scattering: $\sigma \sim N^2$ and effective coupling on proton/neutron f_p/f_n
- Effective coupling includes couplings of WIMPs on quarks f_q^n/f_q^p

90% CL → $\Delta\chi^2 = 4{,}21$

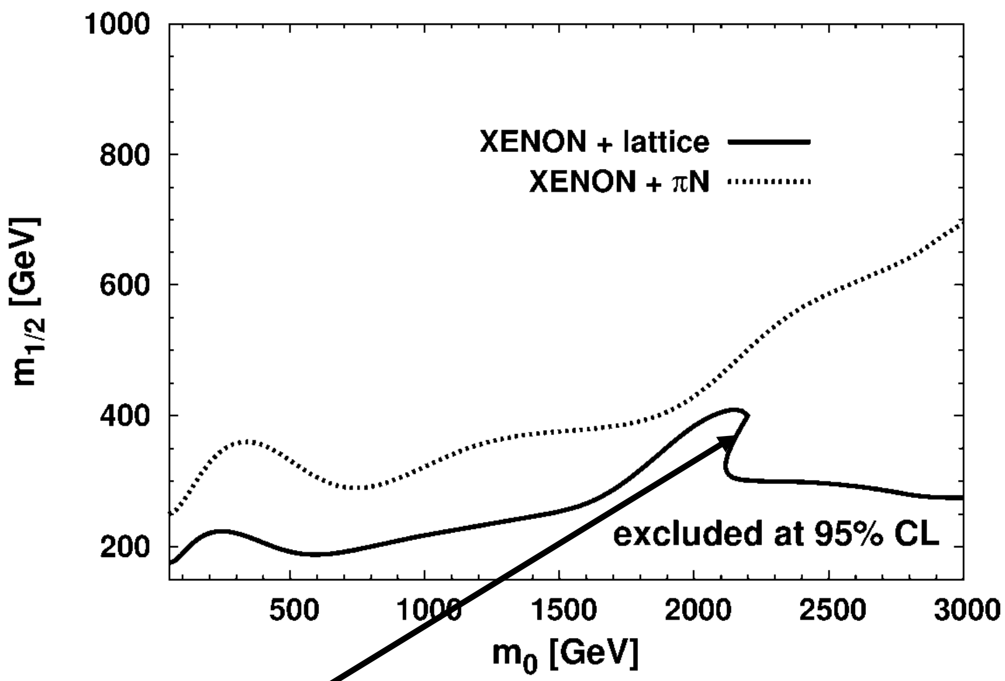
(arXiv:1005.0380)



Including DDMS constraint into χ^2

- Uncertainties
  - Local DM density (0,3/1,3 GeV/cm³)
  - Effective coupling (especially s-quark) because of different calculations

lattice	πN
$f_u^p = 0.02;$	$f_u^p = 0.023;$
$f_d^p = 0.026;$	$f_d^p = 0.033;$
$f_s^p = 0.02;$	$f_s^p = 0.26;$
$f_u^n = 0.014;$	$f_u^n = 0.018;$
$f_d^p = 0.036;$	$f_d^p = 0.042;$
$f_s^p = 0.02;$	$f_s^p = 0.26;$



conservative

Excluded parameter space by XENON100

- Scattering cross section is proportional to the product of gaugino und higgsino component → Increase of the cross section if higgsino component is increasing
- Higgsino component increases for high values of m_0 → DDMS is sensitive for high m_0 in contrast to the direct searches at the LHC