Implications of LHC Higgs and SUSY searches for MSSM

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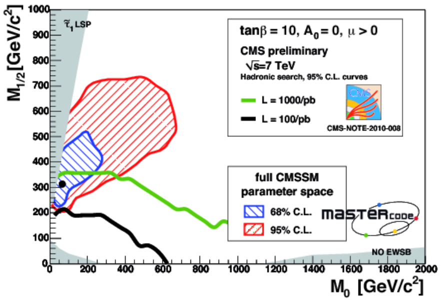
Planck 2012, 28 May - 1 June 2012, Warsaw

SUSY searches

Search for SUSY is the main focus of BSM searches in both ATLAS and CMS!

Before the start of the LHC: high expectation for an early discovery of SUSY particles

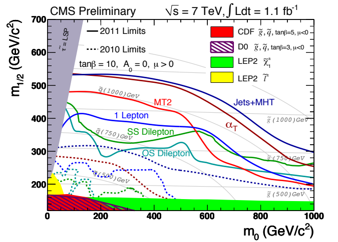


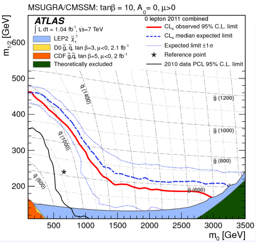
O. Buchmueller et al., JHEP 0809 (2008) 117

SUSY could be discovered even before the Higgs!

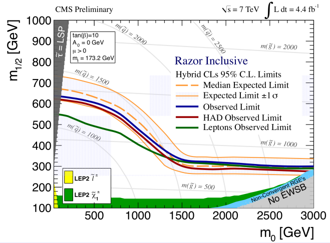
SUSY searches

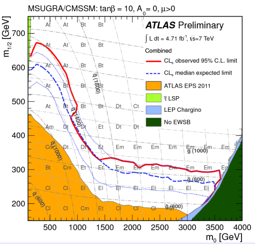
With $\sim$1 fb^{-1} of data:





With $\sim$5 fb^{-1} of data:





CMS-PAS-SUS-12-005 ATLAS-CONF-2012-033

Interpretation of SUSY limits

Two categories of studies:

- Constrained SUSY scenarios: CMSSM, mSUGRA, AMSB, GMSB, CNMSSM,...
  handful number of free parameters, useful for benchmarking,...

  $\rightarrow$ Most of the experimental limits are given for constrained MSSM scenarios

- General SUSY scenarios: pMSSM
  much richer features, signatures and phenomenology!

Limits are pushed higher and higher

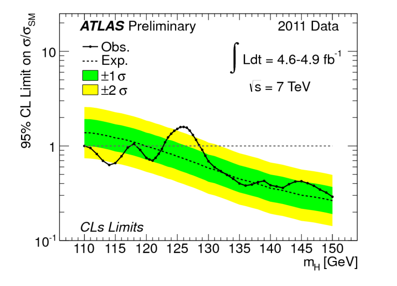
But still a lot of solutions compatible with all present bounds!

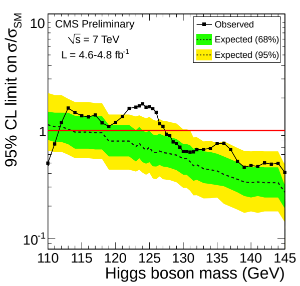
$\rightarrow$ **Not possible to falsify MSSM!**

Alternative path to tightly constrain and test the MSSM at the LHC: through the Higgs sector!

Higgs searches

ATLAS and CMS excess around 125 GeV





ATLAS-CONF-2012-019, CMS-PAS-HIG-12-008

Excess around 125 GeV seen by both ATLAS and CMS in different channels
No evidence however...

ATLAS exclusion at 95% C.L.: 110–117.5 ; 118.5–122.5 ; 129–539 GeV
CMS exclusion at 95% C.L.: 127.5–600 GeV

Allowed range is roughly 117.5 $< M_h <$ 118.5 and 122.5 $< M_h <$ 127.5 GeV!

Consequences of a 125 GeV Higgs on constrained MSSM scenarios

If the excess will be confirmed by more data, what are the consequences?

- In the SM, the Higgs mass is essentially a free parameter
- In the MSSM, the lightest CP-even Higgs particle is bounded from above:
  $M_h^{max} \approx M_Z |\cos 2\beta| +$ radiative corrections $\lesssim 110 - 135$ GeV
- Imposing M_h places very strong constraints on the MSSM parameters through their contributions to the radiative corrections

$\rightarrow$ Calculation of M_h^{max} in different constrained scenarios

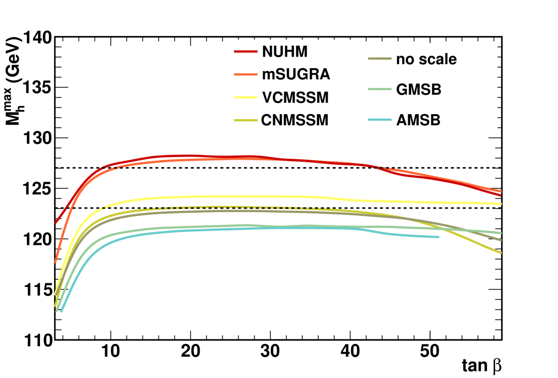
Consequences of a 125 GeV Higgs on constrained MSSM scenarios

$$M_h^2 \overset{M_A \gg M_Z}{\approx} M_Z^2 \cos^2 2\beta + \frac{3m_t^4}{2\pi^2 v^2}\left[\log\frac{M_S^2}{m_t^2} + \frac{X_t^2}{M_S^2}\left(1 - \frac{X_t^2}{12 M_S^2}\right)\right]$$

- Important parameters for MSSM Higgs mass:
  - $\tan\beta$ and M_A
  - the SUSY breaking scale $M_S = \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}}$
  - the mixing parameter in the stop sector $X_t = A_t - \mu \cot\beta$
- M_h^{max} is obtained for:
  - a decoupling regime with a heavy pseudoscalar Higgs boson, $M_A \sim \mathcal{O}(\text{TeV})$
  - large $\tan\beta$, *i.e.* $\tan\beta \gtrsim 10$
  - heavy stops, *i.e.* large M_S
  - maximal mixing scenario, *i.e.* $X_t = \sqrt{6} M_S$
- In contrast, much smaller M_h^{max} values for the no-mixing scenario, *i.e.* $X_t \approx 0$.

Consequences of a 125 GeV Higgs on constrained MSSM scenarios

Maximal Higgs mass



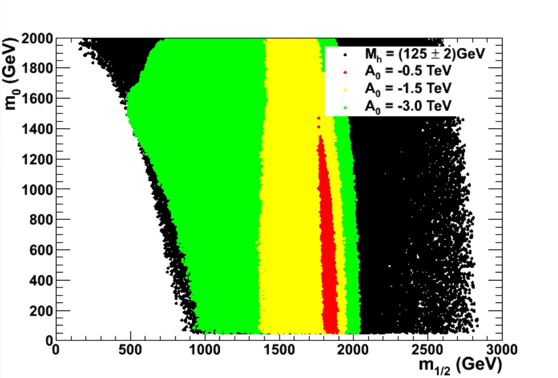
A. Arbey, M. Battaglia, A. Djouadi, F.M., J. Quevillon, Phys.Lett. B708 (2012) 162

model	AMSB	GMSB	mSUGRA	no-scale	cNMSSM	VCMSSM	NUHM
$M_h^{\max}$	121.0	121.5	128.0	123.0	123.5	124.5	128.5

End of AMSB and GMSB in their minimal versions!

Consequences of a 125 GeV Higgs on constrained MSSM scenarios

Higgs mass between 123 and 127 GeV in the CMSSM



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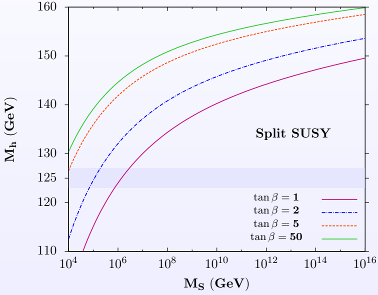
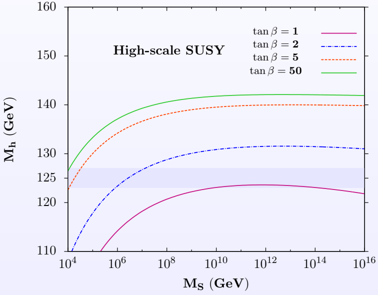
mSUGRA/CMSSM still survives, but only for negative values of A_0

Consequences of a 125 GeV Higgs on high scale SUSY scenarios





A. Arbey, M. Battaglia, A. Djouadi, F.M., J. Quevillon, Phys.Lett. B708 (2012) 162

Very strong constraints on Split-SUSY and High-scale SUSY

Going beyond constrained scenarios

Constrained MSSM

- Handful of free parameters, simple framework,...
- Useful for benchmarking, model discrimination,...
- However the mass patterns could be more complicated
- How do the conclusions change when moving to the MSSM?

Phenomenological MSSM (pMSSM)

- The most general CP/R parity-conserving MSSM
- Minimal Flavour Violation at the TeV scale
- The first two sfermion generations are degenerate
- The three trilinear couplings are general for the 3 generations

$\rightarrow$ 19 free parameters

10 sfermion masses, 3 gaugino masses, 3 trilinear couplings, 3 Higgs/Higgsino

A. Djouadi et al., hep-ph/9901246

Interplay between low energy observables, relic density,
direct dark matter searches and the LHC

Pioneering work: C.F. Berger et al., JHEP 0902 (2009) 023

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pMSSM

Flat scans over the pMSSM 19 parameters

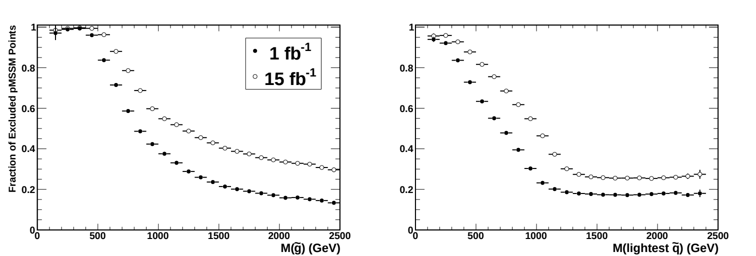
Parameter	Range (in GeV)
$\tan\beta$	[1, 60]
M_A	[50, 2000]
M_1	[-2500, 2500]
M_2	[-2500, 2500]
M_3	[50, 2500]
$A_d = A_s = A_b$	[-10000, 10000]
$A_u = A_c = A_t$	[-10000, 10000]
$A_e = A_\mu = A_\tau$	[-10000, 10000]
μ	[-3000, 3000]
$M_{\tilde{e}_L} = M_{\tilde{\mu}_L}$	[50, 2500]
$M_{\tilde{e}_R} = M_{\tilde{\mu}_R}$	[50, 2500]
$M_{\tilde{\tau}_L}$	[50, 2500]
$M_{\tilde{\tau}_R}$	[50, 2500]
$M_{\tilde{q}_{1L}} = M_{\tilde{q}_{2L}}$	[50, 2500]
$M_{\tilde{q}_{3L}}$	[50, 2500]
$M_{\tilde{u}_R} = M_{\tilde{c}_R}$	[50, 2500]
$M_{\tilde{t}_R}$	[50, 2500]
$M_{\tilde{d}_R} = M_{\tilde{s}_R}$	[50, 2500]
$M_{\tilde{b}_R}$	[50, 2500]

- Spectrum generation (SoftSusy, Suspect)
- Low energy observables (**SuperIso**)
- Dark matter (**SuperIso Relic**, Micromegas)
- SUSY and Higgs mass limits (SuperIso, HiggsBounds)
- Higgs and SUSY decays (HDECAY, Higlu, FeynHiggs, SDECAY)
- Event generation and cross sections (PYTHIA, Prospino)
- Detector simulation (Delphes)

$2.16 \times 10^{-4} < \mathrm{BR}(B \to X_s\gamma) < 4.93 \times 10^{-4}$
$\mathrm{BR}(B_s \to \mu^+\mu^-) < 1.26 \times 10^{-8}$
$0.56 < \mathrm{R}(B \to \tau\nu) < 2.70$
$4.7 \times 10^{-2} < \mathrm{BR}(D_s \to \tau\nu) < 6.1 \times 10^{-2}$
$2.9 \times 10^{-3} < \mathrm{BR}(B \to D^0\tau\nu) < 14.2 \times 10^{-3}$
$0.985 < \mathrm{R}_{\mu 23}(K \to \mu\nu) < 1.013$
$-2.4 \times 10^{-9} < \delta a_\mu < 4.5 \times 10^{-9}$
$10^{-4} < \Omega_\chi h^2 < 0.135$
+ sparticle mass upper bounds
+ Higgs search limits

Consequences on sparticle masses

Strongly Interacting Sparticle Spectra of Allowed pMSSM Points



A. Arbey, M. Battaglia, F.M., Eur.Phys.J. C72 (2012) 1847

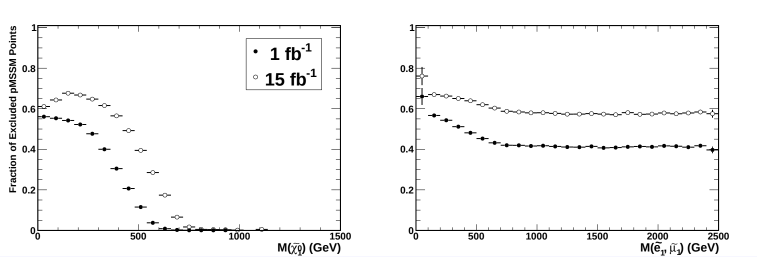
For the gluino, LHC data can exclude more than 85% of the points up to a mass of 520 (700) GeV for 1 (15) fb^{-1}

For the squarks, 85% of the points can be excluded up to mass values of 320 (510) GeV for 1 (15) fb^{-1}

Similar results also by: S. Sekmen et al., JHEP 1202 (2012) 075

Consequences on sparticle masses

Weakly Interacting Sparticle Spectra of Allowed pMSSM Points



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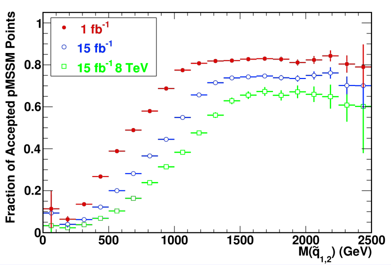
The domain of SUSY weakly-interacting particle masses above 500 GeV is relatively unaffected by the present LHC data

Consequences of a 125 GeV Higgs



With $M_h > 111$ GeV

A. Arbey, M. Battaglia, F.M., Eur.Phys.J. C72 (2012) 1847

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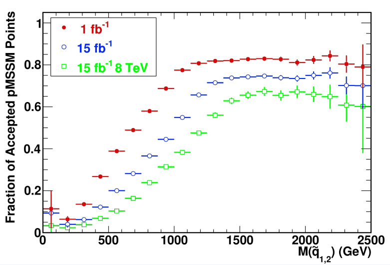

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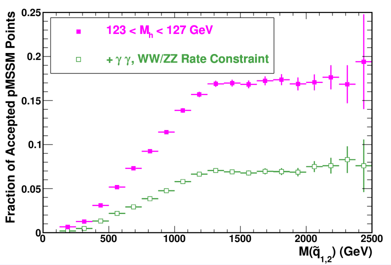

With $123 < M_h < 127$ GeV

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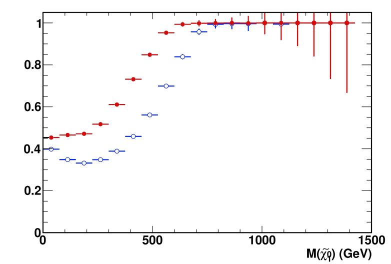

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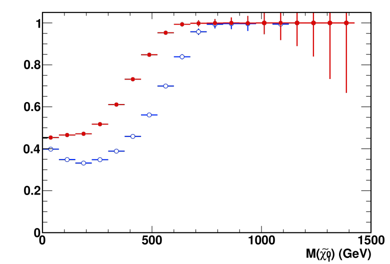

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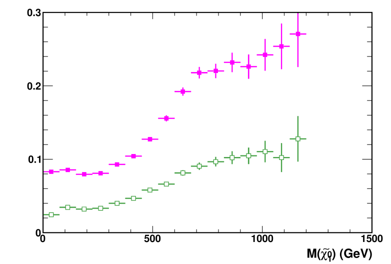

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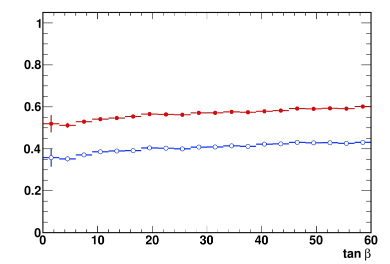

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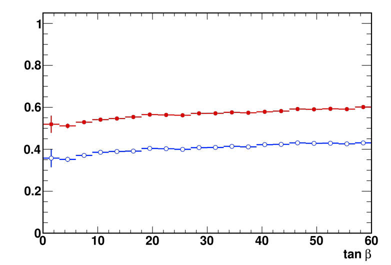

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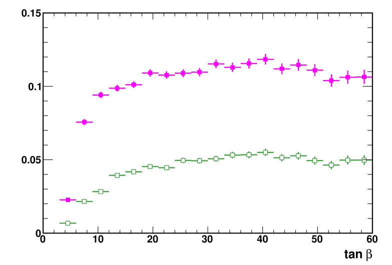

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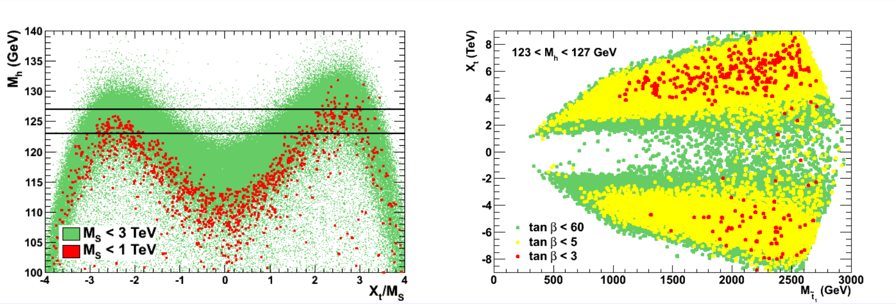

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A large part of the pMSSM still survives

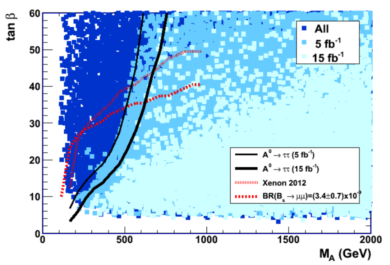
No mixing cases ($X_t \approx 0$) excluded for $M_S < 1$ TeV

Small stop masses still allowed

Consequences of a 125 GeV Higgs on pMSSM

Squeeze even more the parameter space by combining with:

- Direct $A \to \tau^+\tau^-$ search
- Constraints from BR($B_s \to \mu^+\mu^-$)
- Dark matter direct detection constraints (XENON)



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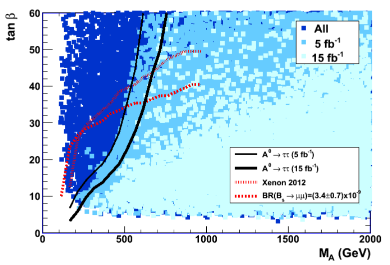

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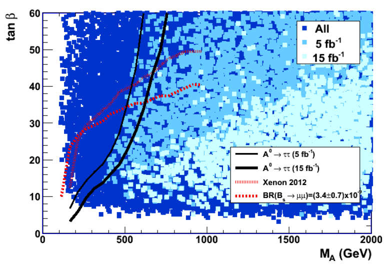

imposing in addition the h rates

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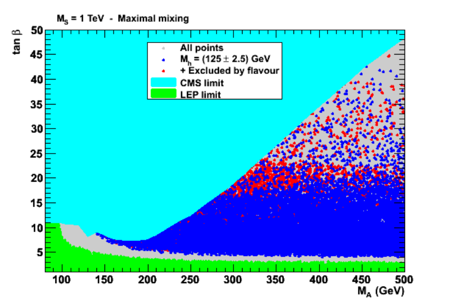
Consequences of a 125 GeV scalar

Particular benchmark scenarios

In the **maximal mixing** scenario ($X_t = \sqrt{6} M_S$):



F.M., arXiv:1205.3100 [hep-ph]

Cyan region: CMS limit from $A_0 \to \tau\tau$ with 4.6/fb

Red: flavour constraints: $b \to s\gamma$, $B \to \tau\nu$ and the recent LHCb limit on $B_s \to \mu\mu$

Very strong constraint from the neutral Higgs searches!

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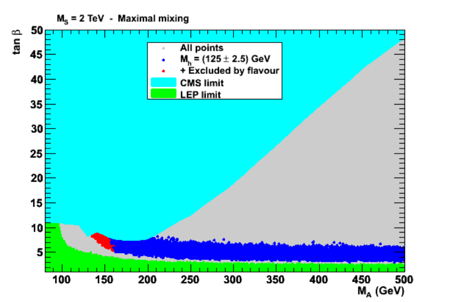

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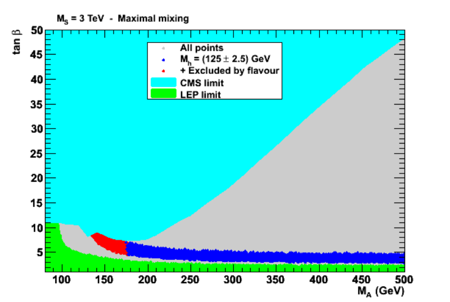

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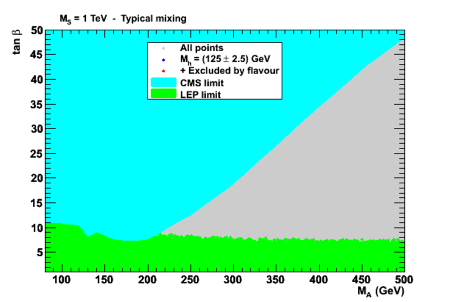

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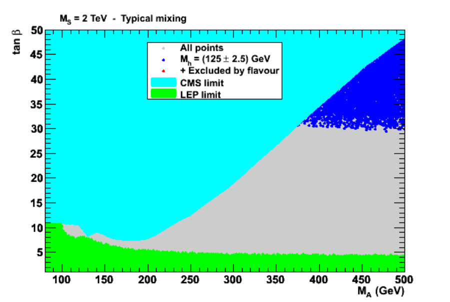

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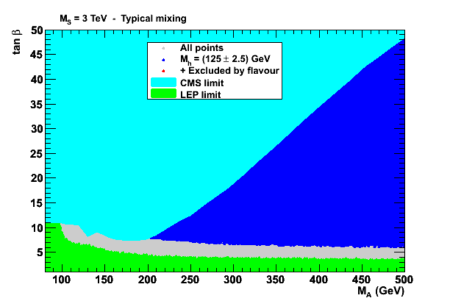

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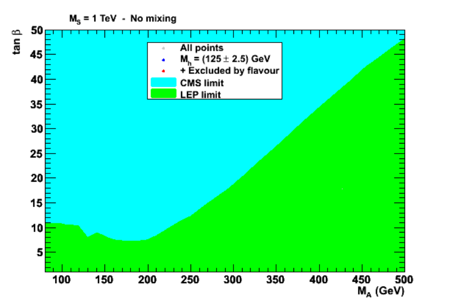

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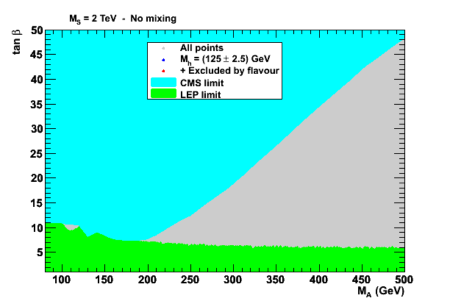

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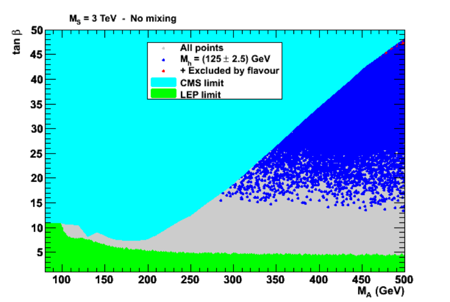
Consequences of a 125 GeV scalar

Particular benchmark scenarios

In the **no mixing** scenario ($X_t = 0$):



F.M., arXiv:1205.3100 [hep-ph]

Cyan region: CMS limit from $A_0 \to \tau\tau$ with 4.6/fb

Red: flavour constraints: $b \to s\gamma$, $B \to \tau\nu$ and the recent LHCb limit on $B_s \to \mu\mu$

Very strong constraint from the neutral Higgs searches!

Conclusion

- There still exists plenty of room for SUSY!
- Current searches are not sensitive to small mass differences, compressed spectra, ...
- The Higgs sector can play an important role in constraining SUSY
- Several constrained MSSM scenarios can be ruled out by a Higgs discovery at 125 GeV
- The CMSSM still provides viable solutions with $A_0 < 0$
- General MSSM: A lot of viable model points survive, but combining with flavour and dark matter sector information, one can squeeze the parameter space

Backup

Backup

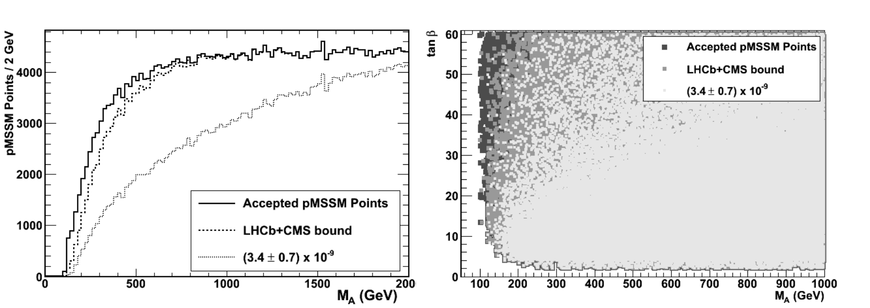
Sensitivity to M_A from $\mathrm{BR}(B_s \to \mu^+\mu^-)$

Considering 2 scenarios:

- Current bound from LHCb+CMS + estimated th syst:

$$\mathrm{BR}(B_s \to \mu^+\mu^-) < 1.26 \times 10^{-8}$$

- SM like branching ratio with estimated 20% total uncertainty



A. Arbey, M. Battaglia, F.M., Eur.Phys.J. C72 (2012)

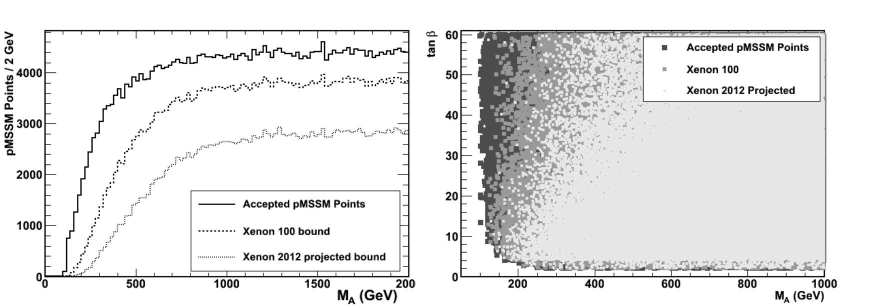
1906

Light M_A strongly constrained!

Dark matter direct detection

Considering 2 scenarios:

- Current Xenon 100 limit
- Projected 2012 90% C.L. upper limit



A. Arbey, M. Battaglia, F.M., Eur.Phys.J. C72 (2012)

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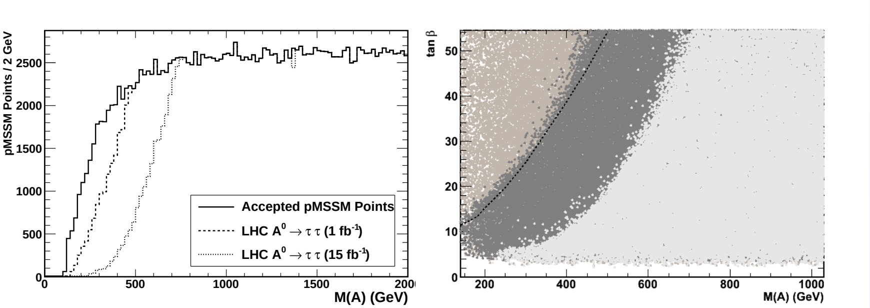
Again light M_A strongly constrained!

Higgs searches

Direct searches for $A \to \tau\tau$ CMS-PAS-HIG-11-009

Allowed region of $(M_A, \tan\beta)$ from full pMSSM scans for 1.1 and 15 fb^{-1} compared to published CMS expected limit



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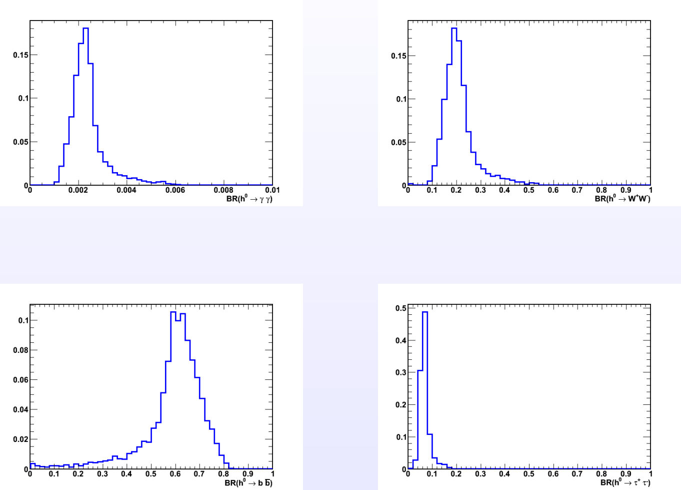
Low M_A region below 350 GeV can be explored and excluded if no signal except a narrow strip around $\tan\beta = 5$.

Higgs branching ratios



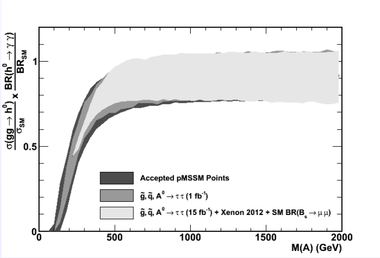
In the case of no Higgs discovery by the end of 2012

Higgs rates could be suppressed wrt the SM

- Study $\sigma\times$ BR suppression within pMSSM for $\gamma\gamma$ and WW final states assuming $M_{\chi_1^0} > 46$ GeV

- Look at suppression factor vs M_A for all accepted pMSSM points compatible with 1 fb^{-1} LHC data ($\tilde{g}, \tilde{q}$ and BR($B_s \to \mu^+\mu^-$)) and XENON 100 results

- projection for 2012 data assuming SM value for BR($B_s \to \mu^+\mu^-$).



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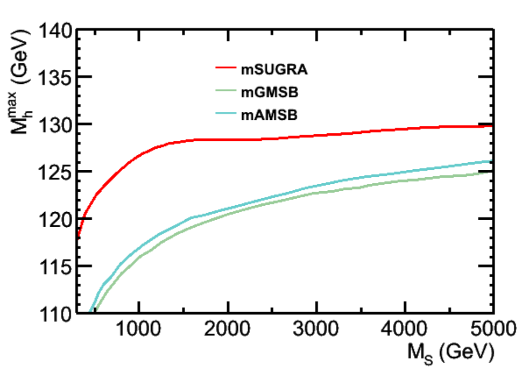
A suppression of a factor of 2 will be still possible!

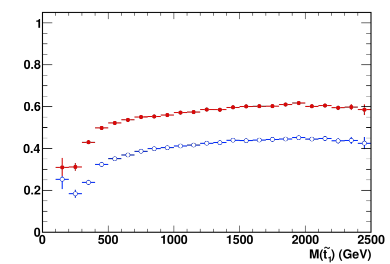
Consequences of a 125 GeV Higgs on constrained MSSM scenarios

Maximal Higgs mass



F.M., arXiv:1205.3100 [hep-ph]

Consequences of a 125 GeV Higgs



With $M_h > 111$ GeV

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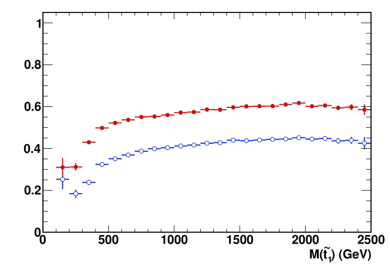
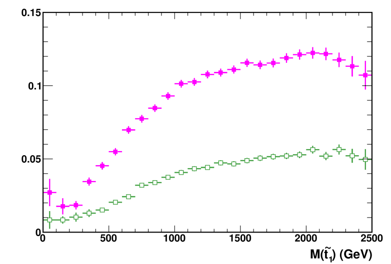
Consequences of a 125 GeV Higgs



With $M_h > 111$ GeV



With $123 < M_h < 127$ GeV

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