# MSSM Higgs at the LHC: Impact of SUSY Parameters on the Search Reach

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Based on collaboration with *S. Gennai, S. Heinemeyer, A. Kalinowski, R. Kinnunen, S. Lehti, A. Nikitenko*, arXiv:0704.0619 [hep-ph]

- Introduction
- Analysis of the CMS discovery reach in the $b\bar{b}H, A$, $H, A \to \tau^+\tau^-$ channel
- Achievable precision of the Higgs mass measurement
- Conclusions

# Introduction

- Signatures of extended Higgs sector $\leftrightarrow$ unique evidence for BSM physics

- Higgs sector of the MSSM: physical states $h, H, A, H^{\pm}$

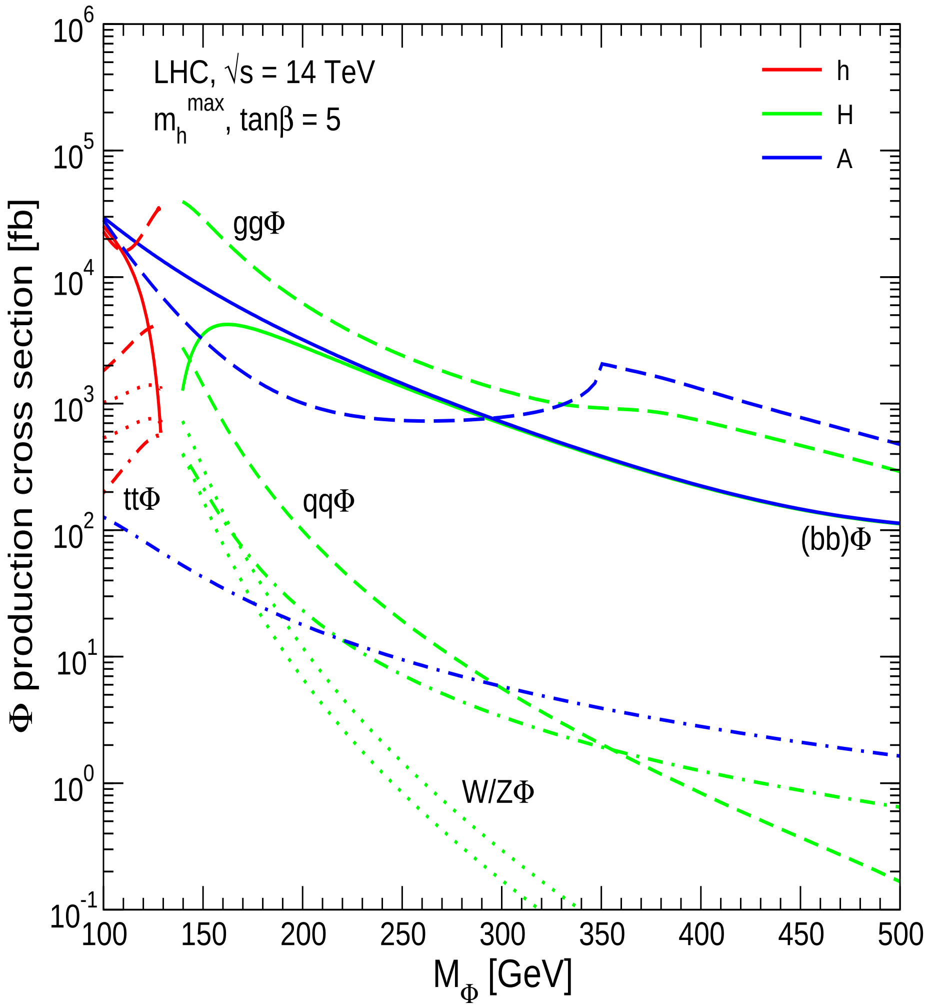
  Described by two parameters at lowest order:
  $M_{\rm A}$, $\tan\beta \equiv v_2/v_1$

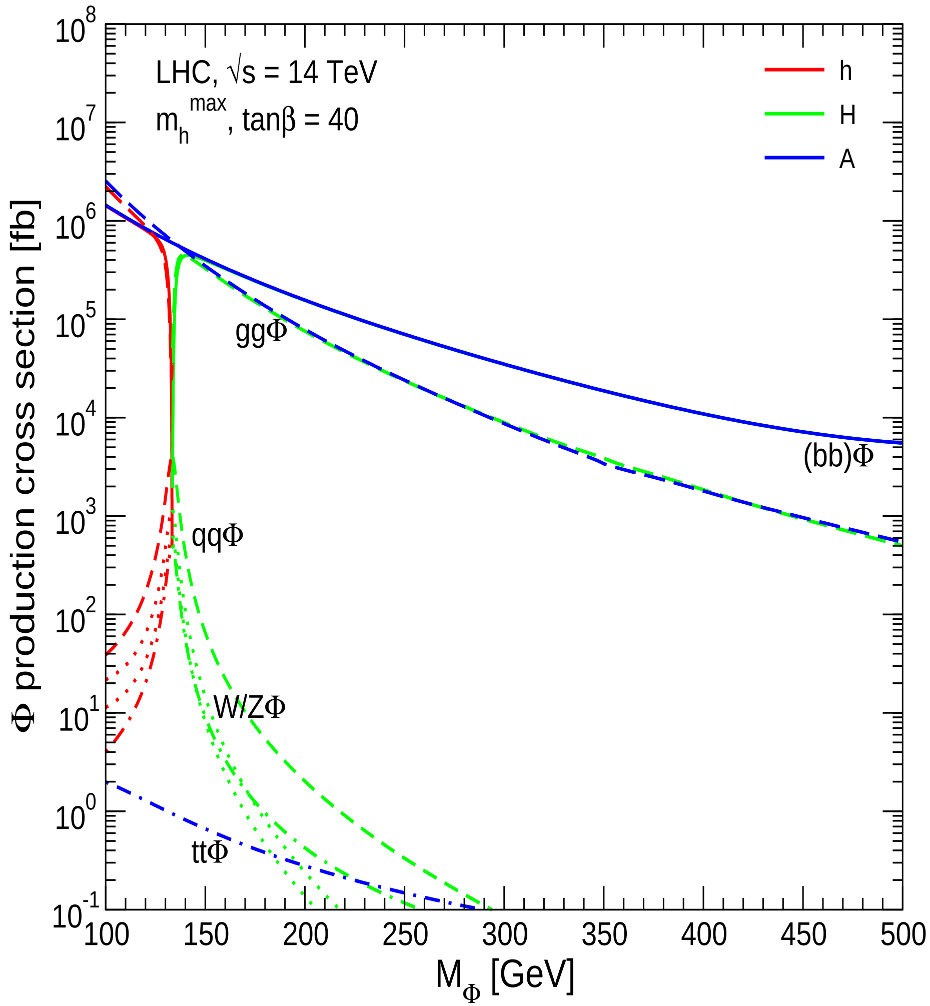
- Search for heavy MSSM Higgs bosons ($M_{\rm A}, M_{\rm H} \gg M_{\rm Z}$):
  Decouple from gauge bosons
  $\Rightarrow$ no $HVV$ coupling
  $\Rightarrow$ no Higgs production in weak boson fusion
  $\Rightarrow$ no decay $H \to ZZ \to 4\mu$

  Large enhancement of coupling to $b\bar{b}$ (and $\tau^+\tau^-$) in region of high $\tan\beta$

# *SUSY Higgs production cross sections at the LHC:* $m_\mathrm{h}^\mathrm{max}$*-scenario,* $\tan\beta = 5, 40$ **(FeynHiggs)**

$\Phi = h, H, A$ [*T. Hahn, S. Heinemeyer, F. Maltoni, G. W., S. Willenbrock '06*]




$\Rightarrow$ Large enhancement in high $\tan\beta$ region

# ***Search for SUSY Higgs bosons***

- Experimental results / future prospects are usually interpreted in the $M_\mathrm{A}$–$\tan\beta$ plane

  $\Rightarrow$ yield boundary of “LHC wedge region”, where only one SM-like Higgs can be observed at the $5\sigma$ level

- Higher-order corrections, Higgs decays into SUSY particles

  $\Rightarrow$ full structure of the SUSY model enters

  $\Rightarrow$ other parameters are fixed in certain “benchmark scenarios”

How robust is the discovery reach in the $M_\mathrm{A}$–$\tan\beta$ plane w.r.t. other SUSY effects?

# *Effect of sign of $\mu$ on Tevatron exclusion bounds from $b\bar{b}\phi$, $\phi \to b\bar{b}$ channel*

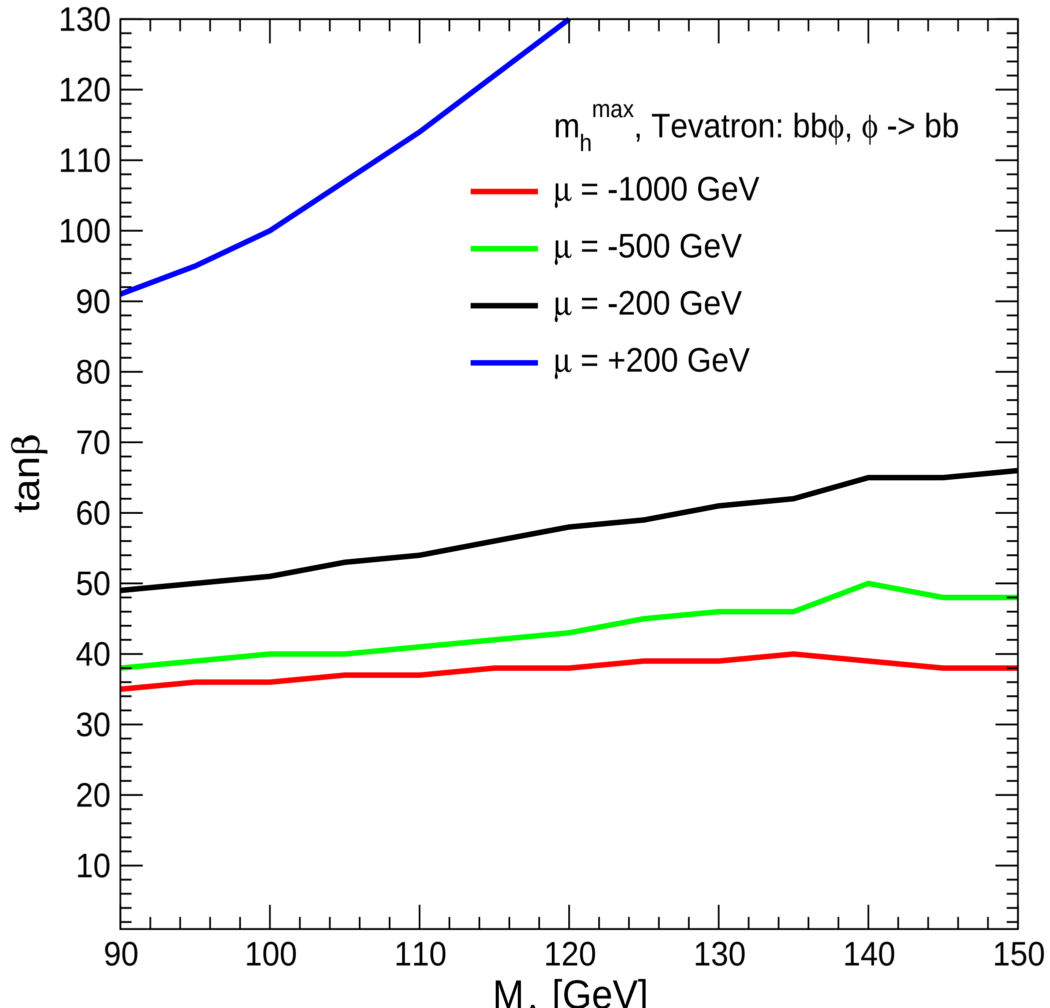
Change in the Tevatron exclusion bounds from varying $\mu$ ($m_h^{max}$ scenario) [*M. Carena, S. Heinemeyer, C. Wagner, G. W. '05*]

$\mu$: parameter in MSSM superpotential
$\mathcal{V}_{\rm MSSM} = \mu H_u H_d + \ldots$

D0 published result for $\mu = -200$ GeV in 2005 [*D0 Collab. '05*]

$\Rightarrow$ Change of sign of $\mu$ has drastic effect

Practically no exclusion for $\mu > 0$



# *Interpretation of exclusion bounds from* $b\bar{b}\phi$*,* $\phi \to b\bar{b}$ *channel*

The origin of the large sensitivity to the parameter $\mu$ is a large SUSY loop correction, $\Delta_b$:

Correction to relation between bottom mass and bottom Yukawa coupling:

$$y_b \sim \frac{m_\mathrm{b}}{1 + \Delta_b}$$

$$\Delta_b = \mu \, \tan\beta \left[ \frac{2\alpha_\mathrm{s}}{3\,\pi} m_{\tilde{\mathrm{g}}} \times I(m_{\tilde{\mathrm{b}}_1}, m_{\tilde{\mathrm{b}}_2}, m_{\tilde{\mathrm{g}}}) + \frac{\alpha_\mathrm{t}}{4\,\pi} A_\mathrm{t} \times I(m_{\tilde{\mathrm{t}}_1}, m_{\tilde{\mathrm{t}}_2}, \mu) \right]$$

$\Rightarrow$ bottom Yukawa coupling can be strongly enhanced ($\mu < 0$) or suppressed ($\mu > 0$) by the $\Delta_b$ corrections

# *Analysis of the CMS discovery reach in the* $b\bar{b}H, A$, $H, A \to \tau^+\tau^-$ *channel*

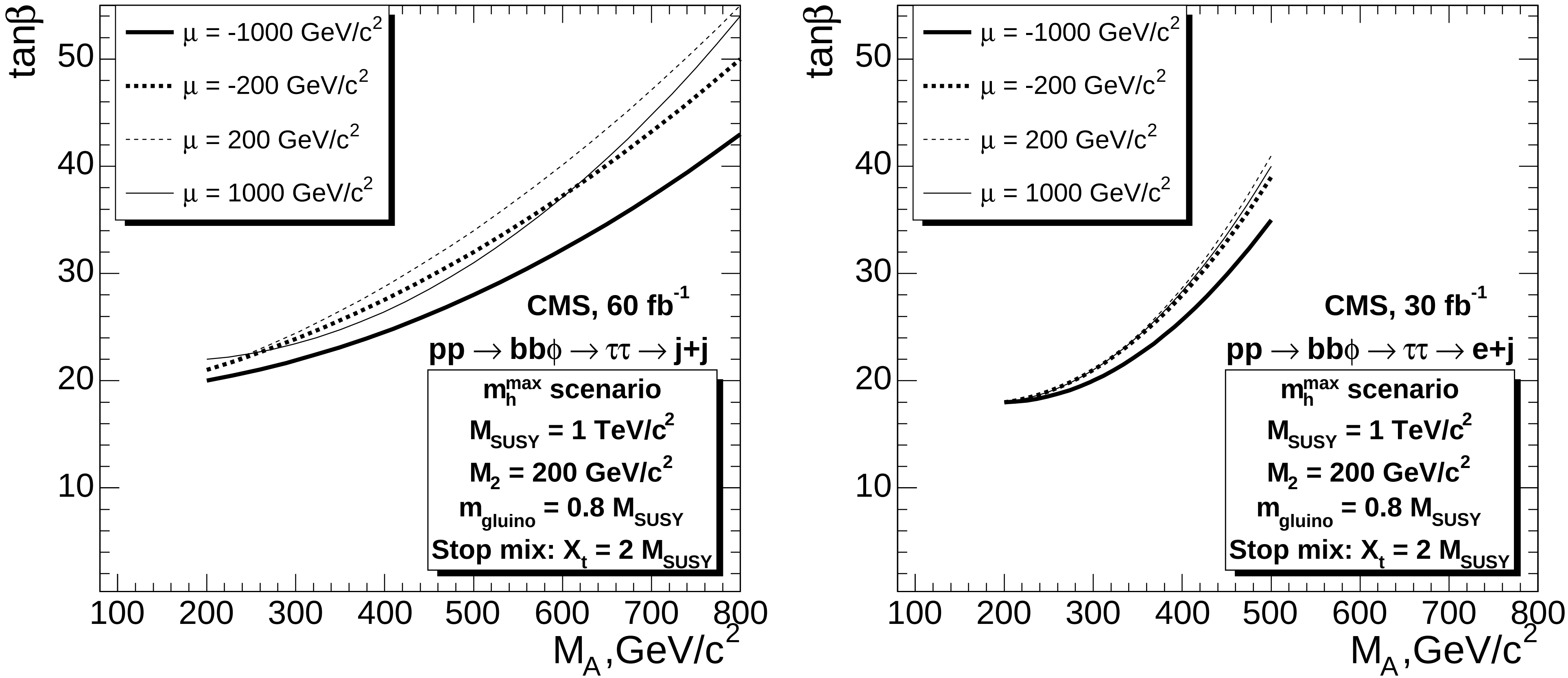
## Experimental analysis:

- Full CMS detector simulation and reconstruction
- Final states of di-$\tau$ decays: $\tau^+\tau^- \to$ jets, $\tau^+\tau^- \to e +$ jet, $\tau^+\tau^- \to \mu +$ jet, $\tau^+\tau^- \to e + \mu$
- Selection: single $b$-jet tagging
- Main backgrounds: QCD multi-jet events (for $\tau\tau \to$ jets mode), $t\bar{t}, b\bar{b}$, $Z$, $\gamma^*$, $W$+jet, $Wt$, $\tau\tau b\bar{b}$

## Theory analysis (*FeynHiggs*, *www.feynhiggs.de*):

- Detailed investigation of higher-order effects
- Impact of decays into SUSY particles

# *Variation of the $5\sigma$ discovery contours with $\mu$ ($m_h^{max}$ scen.): $\tau^+\tau^- \to$ jets (left) and $\tau^+\tau^- \to e+$ jet (right)*




$\Rightarrow$ Shift of discovery contour by up to $\Delta \tan\beta = 12$

Significant effect on “LHC wedge region”

# *Interpretation of the dependence of the discovery contours on $\mu$*

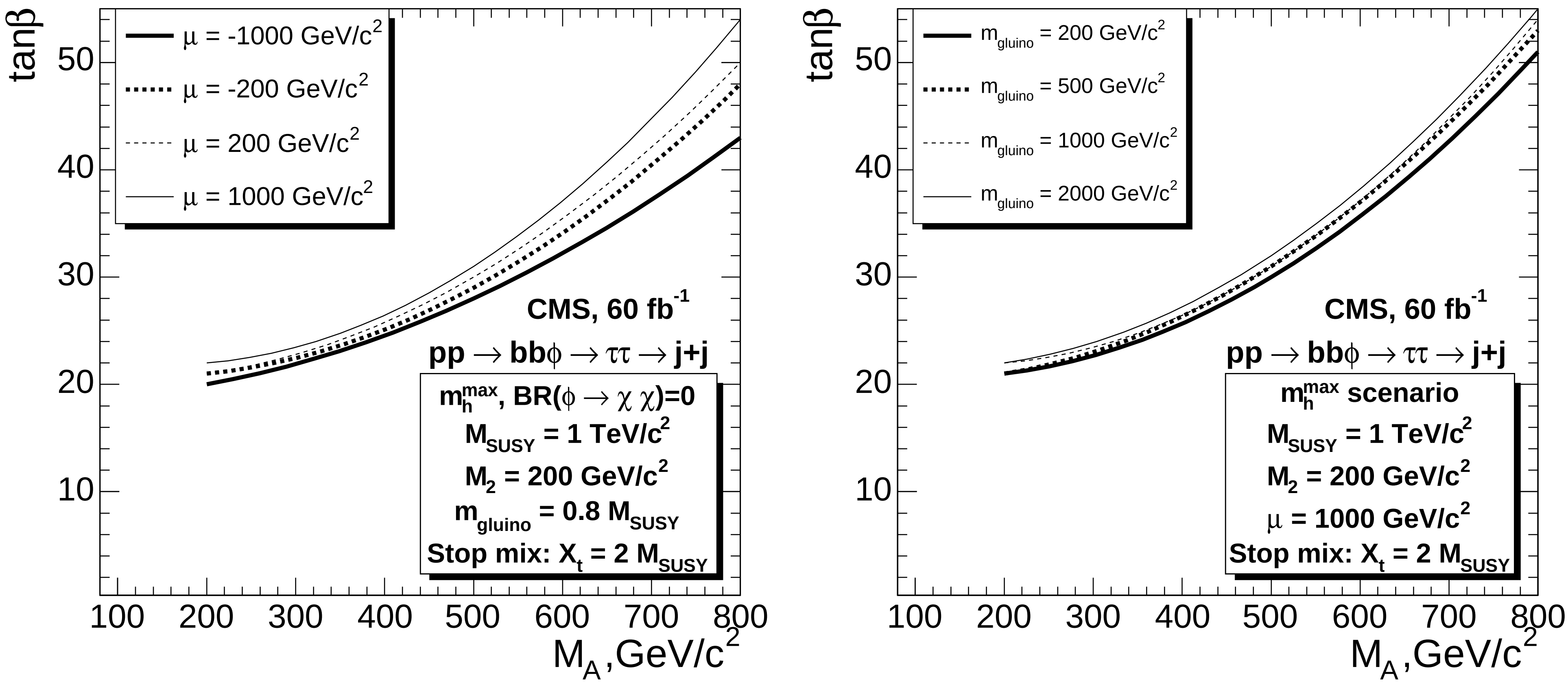
The parameter $\mu$ enters in two different ways:

- Higher-order corrections, in particular $\Delta_b$ contribution
- Supersymmetry: Higgs bosons $\leftrightarrow$ higgsinos
  $\Rightarrow$ $\mu$ enters also the mass matrix of the higgsinos
  (mass eigenstates of higgsinos and gauginos:
  charginos and neutralinos)
  $\Rightarrow$ Small $\mu \leftrightarrow$ light charginos / neutralinos

  $\Rightarrow$ For small $\mu$ Higgs decay channels into charginos and
  neutralinos can open up
  $\Rightarrow$ Suppression of BR$(H, A \to \tau^+\tau^-)$

$\Rightarrow$ Disentangle both effects $+$ study variation with gluino mass
(enters $\Delta_b$ but no effect on Higgs decay kinematics)

# $\tau^+\tau^- \to$ *jets channel: Higher-order effects induced by $\mu$ (left) and dependence on gluino mass (right)*




⇒ $\mu$: higher-order effects dominate in high $\tan\beta$ region
effects on decay kinematics dominate in small $\tan\beta$ region

⇒ Results are stable w.r.t. varying $m_{\tilde{g}}$, $\Delta \tan\beta \lesssim 4$

# *What is the impact of other SUSY parameters?*

In principle all (=105) MSSM parameters enter the prediction via higher-order effects

$\Delta_b$ is not the only source of large higher-order effects: Higgs-propagator corrections shift upper bound on light Higgs mass by 50%, ...

Impact of other parameters on Higgs decays into SUSY particles?

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We find that the results for the discovery contours are stable w.r.t. variations of the other SUSY parameters

Sizable effects on BR$(H, A \to \tau^+\tau^-)$ only in "extreme" regions of MSSM parameter space

# *Achievable precision of the Higgs mass measurement*

Statistical accuracy of mass measurement:

$$\frac{\Delta M}{M} = \frac{R_M}{\sqrt{N_{\rm S}}}$$

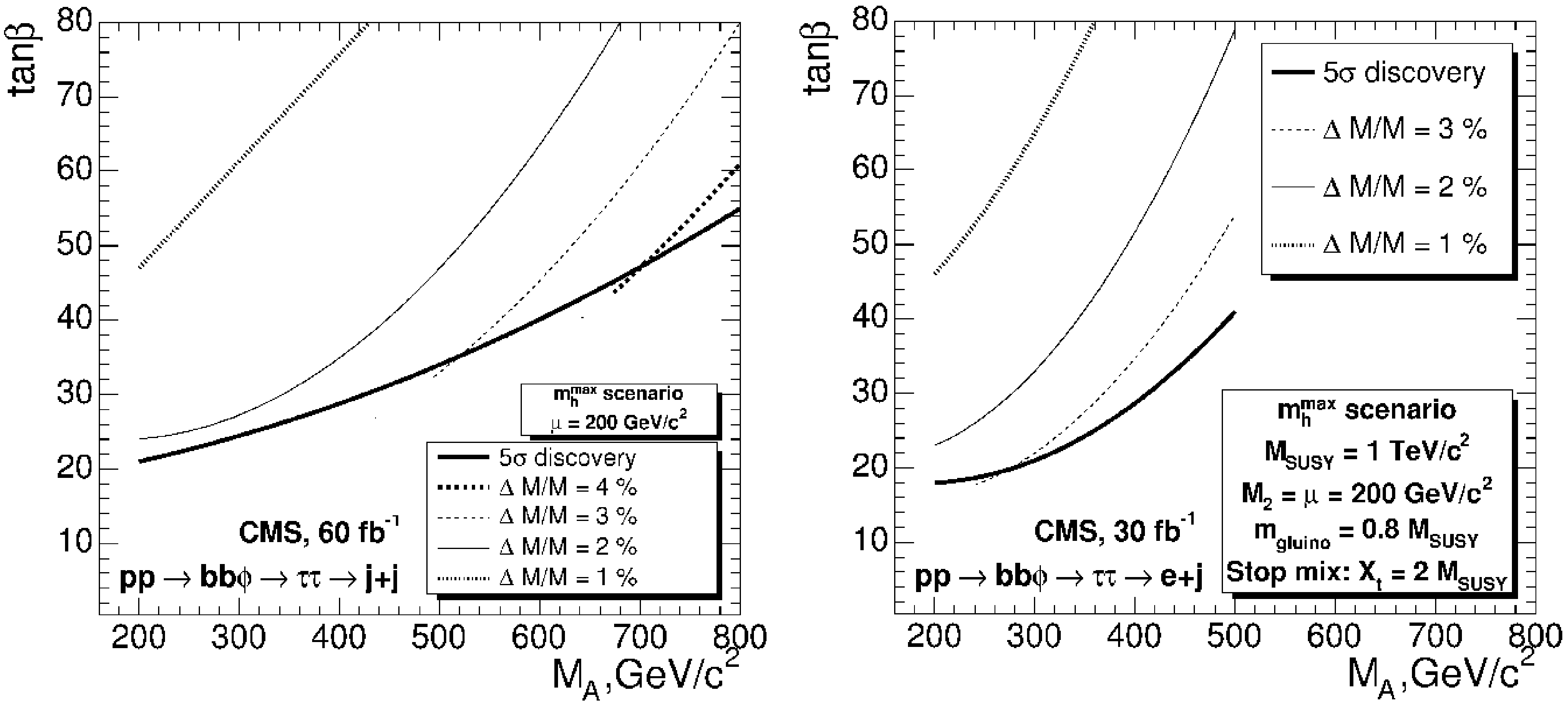
$R_M$: ratio of di-$\tau$ mass resolution to Higgs mass

$N_{\rm S}$: number of signal events

Statistical uncertainty has to be combined with uncertainties of jet and missing $E_{\rm T}$, background uncertainties, etc., but no major degradation of achievable precision expected

# *Statistical precision of Higgs-mass measurement:*

# $\tau^+\tau^- \to$ *jets (left) and* $\tau^+\tau^- \to e +$ *jet (right)*




⇒ 1–4% precision achievable in the discovery region

# *Is there a chance to resolve the $H$, $A$ signals with the mass measurement?*

$H$ and $A$ are nearly mass degenerate for $M_{\mathrm{A}} \gg M_{\mathrm{Z}}$

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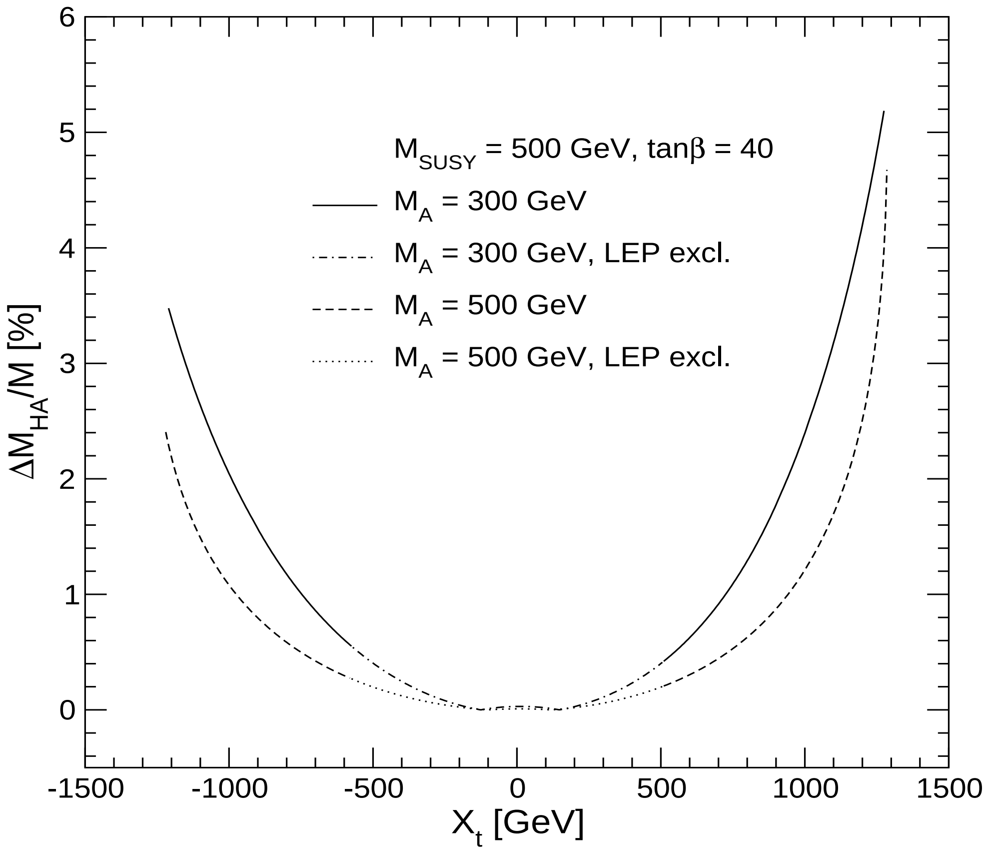


$\Rightarrow$ Distinction of $H$ and $A$ signals may be possible in favourable MSSM scenarios

# Conclusions

- Analysis of CMS discovery reach in $b\bar{b}H, A$, $H, A \to \tau^+\tau^-$
  Sensitivity to SUSY effects:
  Biggest effects from varying $\mu$, up to $\Delta \tan\beta \approx 10$
  Stable w.r.t. effects of other SUSY parameters

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- Accuracy of mass measurement of heavy SUSY Higgses:
  Statistical precision of 1–4% reachable in discovery region
  $\Rightarrow$ Chance to distinguish $H$ and $A$ signals in favourable regions of MSSM parameter space

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- Analysis for charged Higgs-boson searches is in progress