Introduction

Dependence of the “LHC wedge region” on the SUSY scenario and analysis of the prospective precision for the masses of heavy SUSY Higgs bosons

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Prospects for SUSY Higgses in diffractive Higgs production

with S. Heinemeyer, V.A. Khoze, M. Ryskin, W. Stirling, M. Tasevsky

Conclusions
Introduction

- Signatures of extended Higgs sector ↔ unique evidence for BSM physics

- Higgs sector of the MSSM: physical states $h, H, A, H^\pm$
  
  Described by two parameters at lowest order:
  
  $M_A, \tan \beta \equiv v_2/v_1$

- Search for heavy MSSM Higgs bosons ($M_A, M_H \gg M_Z$):
  
  Decouple from gauge bosons
  
  ⇒ no $HVV$ coupling
  
  ⇒ no Higgs production in weak boson fusion
  
  ⇒ no decay $H \rightarrow ZZ \rightarrow 4\mu$

  Large enhancement of coupling to $b\bar{b}$ (and $\tau^+\tau^-$) in region of high $\tan \beta$
SUSY Higgs production cross sections at the Tevatron: $m_h^{\text{max}}$-scenario, $\tan \beta = 5, 40$ (FeynHiggs)

$\Rightarrow$ Large enhancement in high $\tan \beta$ region
Search for SUSY Higgs bosons

- Experimental results / future prospects are usually interpreted in the $M_A - \tan \beta$ plane
  - 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
  - full structure of the SUSY model enters
  - other parameters are fixed in certain “benchmark scenarios”

How robust is the discovery reach in the $M_A - \tan \beta$ plane w.r.t. other SUSY effects?
Effect of sign of $\mu$ on Tevatron exclusion bounds from $b\bar{b}\phi, \phi \rightarrow b\bar{b}$ channel

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

$\mu$: parameter in MSSM superpotential

$V_{\text{MSSM}} = \mu H_u H_d + \ldots$

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 $b\bar{b}\phi$, $\phi \rightarrow b\bar{b}$ 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:

$$y_b \sim \frac{m_b}{1 + \Delta_b}$$

$$\Delta_b = \frac{2\alpha_s}{3\pi} m_{\tilde{g}} \mu \tan \beta \times I(m_{\tilde{b}_1}, m_{\tilde{b}_2}, m_{\tilde{g}}) + \frac{\alpha_t}{4\pi} A_t \mu \tan \beta \times I(m_{\tilde{t}_1}, m_{\tilde{t}_2}, \mu)$$

$\Rightarrow$ bottom Yukawa coupling can be strongly enhanced ($\mu < 0$) or suppressed ($\mu > 0$) by the $\Delta_b$ corrections
Search for SUSY Higgses at the Tevatron:

\[ p\bar{p} \rightarrow \phi \rightarrow \tau^+ \tau^- \] channel, CDF vs. D0 results

\[ CDF \text{ Collab. '07} \]

\[ m_A \text{ (GeV/c}^2) \]

\[ \tan \beta \]

\[ m_h \text{ (max)} \]

\[ m_{\tilde{\mu}} = +200 \text{ GeV}, M = 200 \text{ GeV}, m = 0.8 M_{\text{SUSY}} \]

\[ M_{\text{SUSY}} = 1 \text{ TeV}, X_t = \sqrt{6} M_{\text{SUSY}} \]

\[ m_{\text{SUSY}} = 2 \text{ TeV}, X_t = 0 \text{ (no-mixing)} \]

CDF Run II 1 fb^{-1}

MSSM \phi \rightarrow \tau\tau \text{ Search Preliminary}

\[ \Rightarrow \approx 2 \sigma \text{ excess} \]
Search for SUSY Higgses at the Tevatron:

\( p\bar{p} \rightarrow \phi \rightarrow \tau^+\tau^- \) channel, CDF vs. D0 results

\[ m_{h_{\text{max}}}^\mu > 0 \]

CDF Run II 1 fb\(^{-1} \)

MSSM \( \phi \rightarrow \tau\tau \) Search Preliminary

\[ m_{h_{\text{max}}}^\mu > 0 \]

D0 Preliminary, 1.0 fb\(^{-1} \)

No-mixing, \( \mu > 0 \)

\( \Rightarrow \approx 2 \sigma \) excess

\( \Rightarrow \) no excess,
Search for SUSY Higgses at the Tevatron:

$pp \rightarrow \phi \rightarrow \tau^+\tau^-$ channel, CDF vs. D0 results

[CDF Collab. ’07]

$\mu = +200 \text{ GeV, } M_{\phi} = 200 \text{ GeV, } m_\chi = 0.8 \text{ } M_{\text{SUSY}}$

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CDF

expected

observed

$no\ mixing$

max

CDF Run II 1 fb$^{-1}$

MSSM $\phi \rightarrow \tau\tau$ Search Preliminary

[DO Collab. ’07]

$m_{h_{\text{max}}}^\mu > 0$

no-mixing, $\mu > 0$

$\Rightarrow \approx 2 \sigma$ excess

$\Rightarrow no\ excess, \ but\ where\ are\ the\ Z’s?$
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 $\mu$ ($m_h^{\text{max}}$ scen.):

$\tau^+\tau^- \rightarrow $ jets (left) and $\tau^+\tau^- \rightarrow e + $ jet (right)

⇒ 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 $\text{BR}(H, A \rightarrow \tau^+\tau^-)$

  $\Rightarrow$ Disentangle both effects + study variation with gluino mass
  
  (enters $\Delta_b$ but no effect on Higgs decay kinematics)
$\tau^+\tau^- \rightarrow \text{jets channel: Higher-order effects induced by } \mu \text{ (left) and dependence on gluino mass (right)}$

$\Rightarrow \mu$: higher-order effects dominate in high $\tan\beta$ region

effects on decay kinematics dominate in small $\tan\beta$ region

$\Rightarrow$ 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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Impact of other parameters on Higgs decays into SUSY particles?

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

Sizable effects on $\text{BR}(H, A \rightarrow \tau^+\tau^-)$ only in “extreme” regions of MSSM parameter space.
Achievable precision of the Higgs mass measurement

Statistical accuracy of mass measurement:

\[
\frac{\Delta M}{M} = \frac{R_M}{\sqrt{N_S}}
\]

- \(R_M\): ratio of di-\(\tau\) mass resolution to Higgs mass
- \(N_S\): number of signal events

Statistical uncertainty has to be combined with uncertainties of jet and missing \(E_T\), background uncertainties, etc., but no major degradation of achievable precision expected.
Statistical precision of Higgs-mass measurement:

$\tau^+\tau^- \rightarrow jets \ (left) \ and \ \tau^+\tau^- \rightarrow e + jet \ (right)$

$\Rightarrow$ 1–4% precision achievable in the discovery region

SUSY Higgs bosons at the LHC, Georg Weiglein, Moriond QCD, La Thuile 03/2007 – p.14
Is there a chance to resolve the $H$, $A$ signals with the mass measurement?

$H$ and $A$ are nearly mass degenerate for $M_A \gg M_Z$

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$H$ and $A$ are nearly mass degenerate for $M_A \gg M_Z$

$\Rightarrow$ need high precision of mass measurement

$\Rightarrow$ Distinction of $H$ and $A$ signals may be possible in favourable MSSM scenarios
Central exclusive diffractive (CED) Higgs production at the LHC, $pp \rightarrow p + H + p$

Protons remain undestroyed

exchange of colour-singlet

large rapidity gaps:

no hadronic activity between outgoing protons and Higgs decay products

$J_z = 0$ selection rule

⇒ Need forward proton tagging in “roman pot” detectors

⇒ Good mass resolution, access to $H \rightarrow b\bar{b}$ decay mode

Main experimental challenge: pile-up, in particular at high lumi
$5\sigma$ contours in the MSSM for the $H \rightarrow b\bar{b}$ channel in CED production for $\mu = 200$ GeV

For heavy MSSM Higgs $H$: huge enhancement of CED $H \rightarrow b\bar{b}$ channel for high $\tan \beta$, up to factor 400 compared to SM

⇒ promising reach with high luminosity
$\text{5}\sigma$ contours in the MSSM for the $H \rightarrow b\bar{b}$ channel in CED production for $\mu = -500$ GeV

For heavy MSSM Higgs H: huge enhancement of CED $H \rightarrow b\bar{b}$ channel for high $\tan\beta$, up to factor 2000 compared to SM

$\Rightarrow$ promising reach with high luminosity
5σ contours for CED production of the light MSSM Higgs boson at the LHC with \( h \rightarrow b\bar{b} \)

\[ S. \ Heinemeyer, \ V.A. \ Khoze, \ M.G. \ Ryskin, \ W.J. \ Stirling, \ M. \ Tasevsky, \ G. \ W. \ (prel.) \]

\[ m_h = 115 \text{ GeV} \]

\[ m_h = 125 \text{ GeV} \]

\[ m_h = 130 \text{ GeV} \]

\[ m_h = 131 \text{ GeV} \]

⇒ almost complete coverage with \( 600 \text{ fb}^{-1} \)
Conclusions

- Analysis of CMS discovery reach in $b\bar{b}H, A, H, A \rightarrow \tau^+\tau^-$

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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- Diffractive Higgs production at the LHC:
  Good prospects for $pp \rightarrow p + H/h + p, H/h \rightarrow b\bar{b}$ channels
  $\Rightarrow$ Deserves further experimental effort to make it work at high luminosity