Heavy MSSM Higgses at the LHC

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Outline

- LHC, Atlas and CMS
- A, H
- H^+
- Conclusions
**LHC schedule**

- **April 2007**: first collisions
- **August 2007 - February 2008**:  
  \[ L = 5 \times 10^{32} \rightarrow 2 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1} \]  
  \[ L_t = 10 \text{ fb}^{-1} \]
- **2008**  
  \[ L = 10^{34} \text{ cm}^{-2}\text{s}^{-1} \]  
  \[ L_t = 100 \text{ fb}^{-1} / \text{year} \]

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**Atlas and CMS**

- construction well under way
- **design parameters:**
  - \( e, \mu, \gamma \):  \( \sigma_{E/E} \sim 1\% @ 100 \text{ GeV} \)
  - calorimeter coverage  |\( \eta \)\| \( \leq 5 \)
  - tracking coverage  |\( \eta \)\| \( \leq 2.5 \)

\[ \eta = -\ln \tan(\theta/2) \]

- **event rate:**
  - \~100 kHz from L1 trigger
  - \~100 Hz stored for offline analysis
Heavy neutral Higgses A, H

Production cross-sections

High tanβ:
- Hbb, Hτ⁺τ⁻, Hμ⁺μ⁻ enhanced
- gg→bbH/A dominating

Monte-Carlo’s:
- A/H: HIGLU, HQQ (full lines) / Pythia6.1 (dashed)
- SUSY loop corrections: from partial decay widths from HDECAY

No stop mixing, M_{SUSY} = 1 TeV
Important decay modes: \( A/H \rightarrow \tau^+\tau^- \), \( \mu^+\mu^- \), \( bb \), \( \chi\chi \)

\[ \sigma(A+H)\times\text{BR}(\tau^+\tau^-) \]

\[ \sigma(bbA+bbH)\times\text{BR}(\tau^+\tau^-) \]

\( m_A \geq 150 \text{ GeV}: \ A, H \) unresolved

3 final states: \( l+l+\nu's \): BR ~ 12 %, \( l+\tau\text{-jet}+\nu's \): BR ~ 35 % (see R.Kinnunen)

\( 2\tau\text{-jets}+2\nu \): BR ~ 25 % (1+1 prong), ~ 44 % (1+3 prong)

Use of b-tagging to improve significance

large background, studies going on
Main backgrounds:

- QCD jets:
  - rate overwhelming
    - L1 trigger jet (di-jet) thresholds: $E_T \geq 120 \ (90) \ \text{GeV} \ (\text{CMS})$
    - efficiency for light $A, H$ too low
    - need dedicated $\tau$-jet trigger
- $W$+jets with $W \rightarrow \tau\nu$, jet faking $\tau$
- $Z/\gamma^* \rightarrow \tau\tau, \ tt$ with $W \rightarrow \tau\nu$

**Atlas $\tau$-trigger**

- L1+L2 CALO $\tau$-jet
  - narrow + narrower EM deposit in $\Delta\eta \times \Delta\phi = 0.4 \times 0.4$
  - calo trigger tower
- L2 tracking
  - $1 \leq N_{tk} \leq 3$ in cone

**CMS $\tau$-trigger**

- L1 CALO $\tau$-jet
  - narrow + isolated
  - L1 $\tau$-jet: $E_T \geq 100 \ (67) \ \text{GeV}$; $\varepsilon = 76\%$ for $m_A = 200 \ \text{GeV}$
- L2 ECAL isolation
- Tracking (pixel detector)
  - $1 \leq N_{tk} \leq 3$ in narrow cone

NB: $H^+ \rightarrow \tau\nu$: trigger requires full tracking
A, H $\rightarrow \tau^+\tau^- \rightarrow 2 \tau$-jets + 2$\nu$ (cont.)

**Analysis**
- $\tau$-jet identification $\gg$ fake $\tau$-jets from QCD, $W$+jets...
  - $E_T^{\text{jet}} > 60$ GeV
  - Hard track with $p_T > 40$ GeV/c within $\Delta R = 0.1$ from CALO jet axis
  - **Isolation**: no track with $p_T > 1$ GeV/c within $0.03 < \Delta R < 0.4$ from hard track

**Diagram**
- **QCD jets**
  - 1 prong selection
  - 1/3 prong selection

**Graph**
- $\varepsilon(m_A = 500\text{GeV}) = 34\%$
- $\varepsilon(m_A = 500\text{GeV}) = 17\%$

**Note**
- $\varepsilon$ QDC jets **CMS**
  - $\leq 50\%$ uncertainty from jet fragmentation

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Analysis (cont.)

- \( \tau \)-tagging \( \sim \) QCD, Z\( \rightarrow \)ll, tt...
  - impact parameter, secondary vertex
- central non-\( \tau \) jet veto \( \sim \) tt
- \( E_t^{\text{miss}} > 40 \text{ GeV} \) (60 GeV for \( m_A = 500 \text{ GeV} \))
- b-tagging \( \sim \) Z/\( \gamma^* \), QCD
  - soft b-jets, flat \( \eta \) distribution
    - CMS: \( \varepsilon_b = 35\% \) with 1\% mistag per Z/\( \gamma^* \)-event

- Mass reconstruction
  - assume \( \nu_i \) collinear to visible \( \tau_i \)
  - project \( E_t^{\text{miss}} \)
  - \( \sigma(m) \sim \sigma(E_t^{\text{miss}}/\sin(\phi_{\tau\tau})) \) while \( \tau \)'s tend to be back-to-back

\( \text{Atlas, } \phi_{\tau\tau} < 165^\circ \)

fast simulation
5σ discovery reach for $A, H \rightarrow \tau^+\tau^-$

$M_2 = 200 \text{ GeV, } \mu = -200 \text{ GeV, } M_g = 800 \text{ GeV, }$
$M_{q,\tau} = 1 \text{ TeV, } A_t = 2.4 \text{ TeV}$

Sensitivity to MSSM parameters:

- $\sigma*\text{BR}$ insensitive to stop mixing
- SUSY loops only affect $gg\rightarrow H$
- light SUSY spectrum $\Rightarrow \text{BR}(H/A\rightarrow\tau\tau)$ can be reduced at high masses
- large $\mu \Rightarrow \text{BR}(H/A\rightarrow\tau\tau)$ can be enhanced at high masses
A, H → χχ

Decay into sparticles
- MSSM, RG relation $M_2 = 2M_1$
- large $|\mu| > M_2$ (favoured if $\chi^0_1$ dark matter)
  - $m(\chi^0_1) \approx M_1; m(\chi^0_2) \approx M_2$
- sleptons light
- $A, H \rightarrow \chi^0_2 \chi^0_2 \rightarrow 4l^\pm + X$

Analysis
- SM backgrounds: ZZ, ZW, Zbb, Zcc, Wtb, tt
- MSSM backgrounds: $q/\bar{q}, l\bar{l}, \nu\bar{\nu}, q\chi, \chi\chi$
  - 2 pairs of isolated leptons
  - jet veto, Z veto
Signal and total background
\( m_A = 350 \text{ GeV}, \tan \beta = 5, M_2 = 120 \text{ GeV}, \mu = -500 \text{ GeV}, M_1 = 250 \text{ GeV}, M_{\tilde{q}, \tilde{g}} = 1 \text{ TeV} \)

\[ A, H \rightarrow \chi^0_2 \chi^0_2 \rightarrow 4l^+ - \chi^0_1 \chi^0_1 \]

Sensitivity to MSSM parameters:
- sensitive to \( M_1, M_2, \mu, m_{\tilde{t}} \)
- small \( M_1, M_2, m_{\tilde{t}} \); large \( \mu \) favourable

5\( \sigma \) discovery contours
\( \mu = -500 \text{ GeV}, M_1 = 250 \text{ GeV}, M_{\tilde{q}, \tilde{g}} = 1 \text{ TeV} \)

Maximal stop mixing

100 fb\(^{-1} \)
Charged Higgs $H^+$

**Production**
- $gg \rightarrow tbH^+, \ gb \rightarrow tH^+, \ qq' \rightarrow H^+$
- smaller rate from $pp \rightarrow H^+H^-+X, \ \rightarrow H^+W$
(see next talks)
- $1\text{pb} @ m_{H^+} = 400 \ \text{GeV}$

**Most promising decay channels**
- $\tau\nu$
  - $\text{BR}=10\%$ at high $\tan\beta$
  - harder $p_{\pi}/E_{\tau-jet}$ in $H^+ \rightarrow \tau\nu$ than in $tt$ bkg with $W \rightarrow \tau\nu$ (simulation with TAUOLA)
  - $m_\tau$ reconstruction
- $tb$
  - discovery could be possible for small ($<3$) and large $\tan\beta$ ($>20$)
H+ in cascade decays looks promising

\[ m(H^+) > m(t) \]

\[ tH^+, H^+ \rightarrow tb \]

**Intermediate tan\( \beta \)?

- \( H^+ \) in cascade decays looks promising

**CMS, 30 fb\(^{-1} \)

**ATLAS, 300 fb\(^{-1} \)**

**Same shape as signal**

**Good control of bkg mandatory**
Conclusions

- The discovery range for heavy MSSM Higgses at the LHC is studied in a large fraction of the parameter space (not all channels shown)
- The intermediate $\tan\beta$ region remains difficult
  - complementarity from decays into SUSY particles, new ideas welcome
- Work is ongoing on techniques to measure Higgs parameters at the LHC (masses, widths, $\tan\beta$, couplings)

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