Beyond the Standard Model Higgs Searches at ATLAS

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Outline

Introduction

Beyond SM Higgs Boson

Neutral Higgs Boson

$$A/H/h \rightarrow \tau^+ \tau^- \rightarrow \ell^+ \ell^- 4\nu$$

$$A/H/h \rightarrow \mu^+ \mu^-$$

Charged Higgs Boson

Background Analysis and Uncertainties

Light $H^\pm$

Heavy $H^\pm$

Combined Sensitivity

Conclusions

MSSM Higgs Boson at ATLAS

- Non-SM Higgs Boson efforts at ATLAS currently focused on MSSM Higgs bosons.
- MSSM provides two Higgs doublets, resulting in five physical Higgs bosons.
 - Neutral (h , H , and A) and charged (H^+ and H^-).
- Several SUSY parameter benchmark scenarios (small- α , no mixing, etc.)
 - Two DOF left to vary at tree level, m_A and $\tan\beta$
($\tan\beta$ is ratio of vacuum expectation values of the two Higgs doublets).
- Results shown here use point: “ m_h -max”.
 - $m_t = 170$ GeV
 - $M_{SUSY} = 1000$ GeV
 - $X_t = 2000$ GeV
 - $\mu = 200$ GeV
 - $M_2 = 200$ GeV
 - $M_3 = 800$ GeV
- Large $\tan\beta$ enhancement: primary decay channel is to 3rd gen fermions.

ATLAS MSSM Higgs Boson Sensitivity Studies

- **Talk focus:** ATLAS sensitivity to MSSM Higgs Boson
 - Results from recent “Computer Systems Commissioning” (CSC) studies.
 - Detailed in: CERN-OPEN-2008-020 (arXiv:0901.0512)
 - Several studies are still in progress only briefly mentioned or absent here.
- **Two major search categories:** Neutral Higgs Boson and Charged Higgs Boson
- Based on most recent theoretical Monte Carlo generation
- Utilize detailed detector simulation
- Detailed consideration of systematic uncertainties go into shown results
- Pileup not taken into account

Neutral Higgs Boson

Production ($\Phi = H, h, \text{ or } A$)

Direct Production

Associated b Production
(Dominates at large $\tan\beta$)

Investigated Decay Channels

- $\Phi \rightarrow \tau^+ \tau^- \rightarrow \ell^+ \ell^- 4\nu$
 - Semileptonic channel study ongoing, finished soon.
- $\Phi \rightarrow \mu^+ \mu^-$

Mass Degeneracy

- For most of the parameter space the A and H masses are degenerate.
- Handled by summing their cross sections

$A/H/h \rightarrow \tau^+\tau^- \rightarrow \ell^+\ell^- 4\nu$ with associated b -jets

Analysis

- $\Phi \rightarrow \tau\tau$ is significant decay of neutral Higgs Boson ($\Phi = A, H$, or h .)
- Only channels with associated b investigated.
- Make lepton kinematic cuts and require $b(b\bar{b})$ jet(s).
- Reconstruct $m_{\tau\tau}$ using “Collinear Approximation”.

- $m_{\tau\tau} = \frac{m_{\ell\ell}}{\sqrt{x_1 x_2}}$
- $x_i = \frac{p_T \ell_i}{p_T \tau_i}$ = fraction of τ momentum carried by its visible decay products.

Cross Section vs. Collinear $m_{\tau\tau}$

Backgrounds for $A/H/h \rightarrow \tau^+\tau^- \rightarrow \ell^+\ell^-4\nu$

- $Z \rightarrow ee$ and $Z \rightarrow \mu\mu$
 - Require $m_{\ell\ell}$ well below m_Z
- $t\bar{t}$: Important for $m_A \geq 200$ GeV
 - Require $N_{jets} \leq 2$
- $Z \rightarrow \tau\tau$: Dominant for $m_A < 200$ GeV
 - Irreducible background
 - Shape and normalization estimated from data.
 - Scale energy of $Z \rightarrow \mu\mu$ in sideband region to match $Z \rightarrow \tau\tau$ events.
 - Project to peak region.
 - Systematic uncertainty is 2.6%, primarily from energy scale, efficiency, and resolution of ℓ and μ .

Results for $A/H/h \rightarrow \tau^+\tau^- \rightarrow \ell^+\ell^- 4\nu$

5 σ Discovery

95% Exclusion

- Experimental systematic uncertainties primarily from jet resolution, jet energy scale, and b -tagging.
- High $\tan\beta$, low m_A regions well covered at 30 fb $^{-1}$.

$$A/H/h \rightarrow \mu^+ \mu^-$$

Motivation

- $\mu\mu$ is a cleaner signal than $\tau\tau$.
- Excellent mass resolution: **3%** versus $\tau\tau$'s **20%**.
- **Tradeoff**: Approximately 300% smaller branching ratio than $\tau\tau$ channel.

$A/H/h \rightarrow \mu^+\mu^-$ Analysis

B-Tag Requirement

Separate handling of two event types

- 0 b -jets
 - Suppresses $t\bar{t}$ background
- ≥ 1 b -jets
 - Suppresses Z background
 - Additional cuts needed to filter out $t\bar{t}$

Background

- Major backgrounds are $Z + \text{jet}$ and $t\bar{t}$
- Background estimated from data using:
 1. Background enriched control sample. Primarily useful for $t\bar{t}$.
 2. e^+e^- and $e^\pm\mu^\mp$ control samples with same shape as $\mu^+\mu^-$ background.

Results for $A/H/h \rightarrow \mu^+\mu^-$

- Less coverage than $\tau\tau$ analysis, but can contribute to combined sensitivity.
- Systematic on signal are $\sim 5\% - 10\%$.
 - Due primarily to the jet energy scale and b -tagging
- Systematic uncertainties degrade signal significance by up to 20% at large $\tan\beta$.

MSSM Charged Higgs Boson

Dominant charged Higgs boson production channels vary greatly on $m_{H^\pm}$

Light $H^\pm$ ($m_{H^\pm} < m_{top}$)

1. $t\bar{t} \rightarrow bH^\pm bW \rightarrow b\nu\tau(had)bqq$
2. $t\bar{t} \rightarrow bH^\pm bW \rightarrow b\nu\tau(lep)bqq$
3. $t\bar{t} \rightarrow bH^\pm bW \rightarrow b\nu\tau(had)bl\nu$

Heavy $H^\pm$ ($m_{H^\pm} > m_{top}$)

Production:

1. $gg \rightarrow H^\pm tb$
2. $gb \rightarrow H^\pm t$

Decay:

1. $H^\pm t \rightarrow \nu\tau(had)bqq$
2. $H^\pm t \rightarrow tbt \rightarrow bWbbW \rightarrow bqqbb\nu$

Major $H^\pm$ backgrounds

- $t\bar{t}$ (primary)
- QCD dijet
- single top
- W + jets

Branching Ratio vs $m_{H^\pm}$

$H^\pm$ Background Analysis and Uncertainties

Data Driven $t\bar{t}$ Background Subtraction

- $t\bar{t}$ is dominant background for all $H^\pm$ analyses.
- Relative contribution from different jet multiplicities unknown.
- Need data driven technique.
- Control samples of $t\bar{t} \rightarrow WbWb \rightarrow \mu\nu b\mu\nu b / \mu\nu bqqb$.
- Replace μ 's with τ 's, scaling the 4-momenta to correct for the mass.
- Simulate decay of τ 's

Uncertainties

- Dominant systematic uncertainty:
 - jet energy scale (10% to 30%).
- Systematic uncertainty varies 15% to 40% for signals.

Scaled & Real Transverse Mass

Ratio Scaled / Real

Light $H^\pm$

Channel 1 | $t\bar{t} \rightarrow bH^\pm bW \rightarrow b\nu\tau(had)bqq$

- Relatively high cross section compared to other decay channels.
- Challenging because:
 - No leptons.
 - High hadronic activity.
- Channel with best coverage in tan β / m_{H^+} plane.

Light $H^\pm$

Channel 2 | $t\bar{t} \rightarrow bH^\pm bW \rightarrow b\nu\tau(\text{lep})bqq$

- Leptonic τ decay gives signal a characteristic isolated lepton (ℓ).
- Excess of ν 's make full reconstruction impossible.
 - Can reconstruct “generalized transverse mass” that satisfies
$$m_{H^\pm} < m_T^{H^\pm} < m_t.$$
- Look for expected charge and angle correlations between b 's and associated particles.
- Suppress background with $W \rightarrow \ell\nu$ by cutting on angle between t and ℓ .

Light $H^\pm$

Channel 3 | $t\bar{t} \rightarrow bH^\pm bW \rightarrow b\nu\tau(had)b\nu$

- Leptonic W decay gives characteristic isolated lepton (ℓ).
- Excess ν 's make reconstructing entire event impossible.
- Requiring τ jet removes $\geq 95\%$ of $t\bar{t}$ background, while leaving $\geq 25\%$ of signal.
- The τ from $H^\pm$ is harder than τ from W , making p_T^τ and E_T^{miss} good variables to cut on.

Heavy $H^\pm$

Production from $gg \rightarrow H^\pm tb$ or $gb \rightarrow H^\pm t$. Analysis varies depending on decay from $H^\pm$ and t .

- **Channel 1:** $H^\pm t \rightarrow \nu \tau(had) bqq$

- Cut on quality of reconstructed W boson and top quark
- Likelihood background discrimination based on τ 's and E_T^{miss} .

- **Channel 2:** $H^\pm t \rightarrow tb \rightarrow bWbbW \rightarrow bqbbbl\nu$

- Jet assignment combinatorics makes this a difficult analysis.
- Background reduction by reconstruction of W and top quark
- Combinatorial likelihood analysis.

Charged Higgs Boson Combined Sensitivity

- Good sensitivity for high $\tan\beta$ and low $m_{H^\pm}$.
- $H^\pm$ invisible in so-called “wedge region” of intermediate $\tan\beta$, where $H^\pm$ cross section is at minimum.

MSSM $H^\pm \rightarrow \tilde{\chi}^\pm \tilde{\chi}^0 \rightarrow 3 \text{ lep} + E_T^{\text{miss}}$

- So far presented “well-exercised” analyses.
- Others under development which may increase discovery range.

EXAMPLE: $H^\pm \rightarrow \tilde{\chi}^\pm \tilde{\chi}^0$

- SM $H^\pm$ decays do not provide good coverage in so called “wedge region”.
- It has been shown that a $H^\pm \rightarrow \tilde{\chi}^\pm \tilde{\chi}^0$ decay chain ending in a trilepton final state exhibits promise in this region.
 - Detailed in Hansen C et al. (arXiv:hep-ph/0504216)
- Recent new effort on this decay channel.

Overall Sensitivity, SM Studies

$H^\pm$ MSSM Decay to 3ℓ Final State

Conclusions

Neutral Higgs Boson

- $h/H/A \rightarrow \tau^+ \tau^- \rightarrow \ell^+ \ell^- 4\nu$
 - With 30 fb^{-1} have good discovery potential for high $\tan\beta$ and low m_A .
 - Best sensitivity (of those channels covered).
- $h/H/A \rightarrow \mu^+ \mu^-$
 - Helps to increase discovery range.
 - Will give sharp Higgs boson mass resolution.
- Other channels (e.g. $\tau\tau$ semileptonic and fully hadronic decays) still under investigations. Results soon.

Charged Higgs Boson

- Decay mode with $H^\pm \rightarrow \tau\nu$ gives best sensitivity for both light and heavy $H^\pm$.
- Other channels being investigated, such as $H^\pm$ MSSM decays to 3ℓ final state.

Backup Slides

Charged Higgs Boson Scenarios

Two scenarios were studied for charged higgs. All results in main slides for scenario B.

Scenario A

H^+ SUSY decays suppressed

- $m_t = 175$ GeV
- $M_{SUSY} = 500$ GeV
- $\mu = 200$ GeV
- $M_2 = 1000$ GeV
- $M_3 = 1000$ GeV
- $A_t = 1000$ GeV

Scenario B (m_h -max)

Mass of h_0 maximized

- $m_t = 170$ GeV
- $M_{SUSY} = 1000$ GeV
- $\mu = 200$ GeV
- $M_2 = 200$ GeV
- $M_3 = 800$ GeV
- $X_t = 2000$ GeV, $A_t = X_t + \mu/\tan\beta$

Parameter Definitions

- M_{SUSY} = soft SUSY-breaking mass parameter
- $m_t X_t$ = off-diagonal entry in stop mass matrix
- μ = Higgsino mixing parameter
- M_2, M_3 = SU(2) & SU(3) soft SUSY-breaking mass parameter

Sensitivity For Scenarios A and B