Pair production of charged Higgs bosons at LHC

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8th Nordic LHC Physics Workshop
Lund, November 28 2003

Introduction

Need to understand QCD when looking for signals for new physics:

- modifications of signal due to additional radiation (parton showers) and/or soft interactions (SCI, hadronisation)
- proper treatment of initial state (when is the parton model applicable?)
- backgrounds to the signal

Vast possibilities for new physics. One common feature is additional Higgs doublets (SUSY, dimensional reconstruction).

Two Higgs doublets $\Rightarrow$ 5 Higgs bosons (h, H, A, $H^\pm$)

The discovery of charged Higgs bosons may be the first sign of new physics at LHC

Charged Higgs production processes in two Higgs Doublet Model (2HDM) under consideration in THEP Uppsala at present:

- Pair production , $gg \to H^\pm H^\mp b\bar{b}$
- Single production, $gg \to H^\pm tb$ (see talk by J. Alwall)

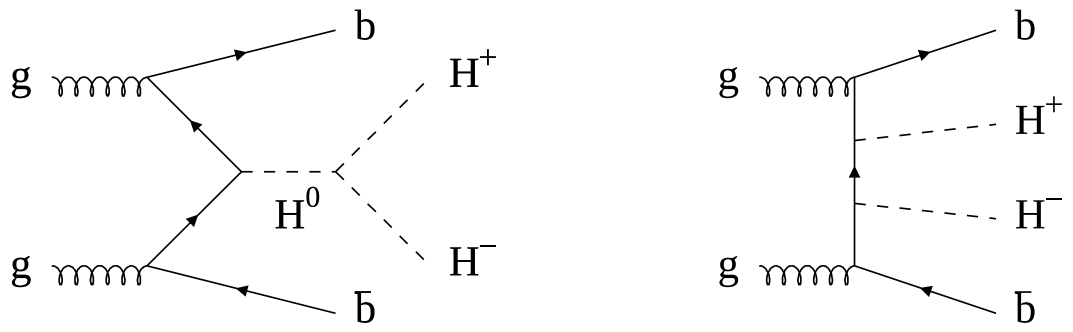
Charged Higgs pair production at LHC

(based on hep-ph/0308215, in collaboration with Stefano Moretti)

Scenario: Charged Higgs discovered with $M_{H^\pm} > m_t$ and $\tan\beta$ is large.

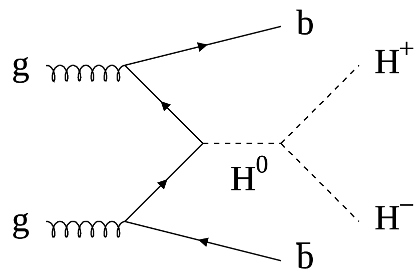
Quest: How to learn more about Higgs-sector?

Idea: Use $gg \to H^+H^-b\bar{b}$ to study magnitude of triple-Higgs coupling $g_{H^0H^+H^-}$

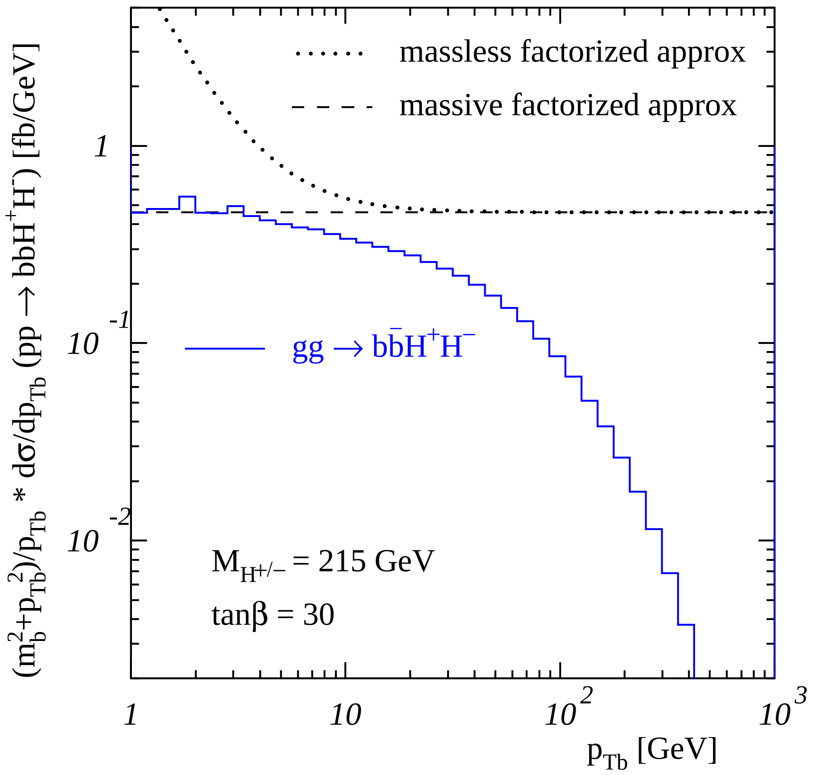


- $g_{H^0H^+H^-}$ arbitrary (up to unitarity constraints etc) in general 2HDM
- $M_{H^0} \gtrsim 2M_{H^\pm}$ is possible in general 2HDM giving extra resonant enhancement (in MSSM $M_{H^0} \approx M_{H^\pm}$)

Look at $gg \to H^+H^-b\bar{b}$ at large $\tan\beta$ in type II 2HDM



- $b\bar{b}$ pair gives well defined production process
- $b\bar{b}$ pair gives extra handle against backgrounds
- continuous transition from $M_{H^\pm} > m_t$ to $M_{H^\pm} < m_t$
- $b\bar{b} \to H^+H^-$ uncertain due to b-quark pdf and proper factorisation scale (in addition $\sigma_{b\bar{b}\to H^+H^-} \sim 5$ times larger than $\sigma_{gg\to b\bar{b}H^+H^-}$)



- b-quark density resums $[\alpha_s \log(\mu_F/m_b)]^n$
- leading log $\leftrightarrow$ plateau in $2 \to 4$ process
- extension of plateau
  $\Rightarrow \mu_F \sim 0.1(2M_{H^\pm})$ instead of $2M_{H^\pm}$
  $\Rightarrow \sigma_{b\bar{b}\to H^+H^-} \sim$ factor 2 smaller
- $\mu_F \sim m_\perp^b$ instead of $2M_{H^\pm}$
  $\Rightarrow \sigma_{gg\to b\bar{b}H^+H^-} \sim$ factor 2 larger

A general CP-conserving 2HDM

Higgs sector in MSSM is a special case of a general CP-conserving 2HDM

MSSM has two parameters: for example $\tan\beta$ and M_{A^0}

General CP-conserving 2HDM has five more parameters: for example α, $M_{H^\pm}$, M_{H^0}, M_{h^0}, $(\lambda_5 - \lambda_6)/2$ which determines the scalar potential:

$$\begin{aligned}
V(\Phi_1, \Phi_2) \quad = \quad & \lambda_1(\Phi_1^\dagger\Phi_1 - v_1^2)^2 + \lambda_2(\Phi_2^\dagger\Phi_2 - v_2^2)^2 \\
& + \lambda_3 \left[(\Phi_1^\dagger\Phi_1 - v_1^2) + (\Phi_2^\dagger\Phi_2 - v_2^2)\right]^2 \\
& + \lambda_4 \left[(\Phi_1^\dagger\Phi_1)(\Phi_2^\dagger\Phi_2) - (\Phi_1^\dagger\Phi_2)(\Phi_2^\dagger\Phi_1)\right] \\
& + \lambda_5 \left[\mathrm{Re}(\Phi_1^\dagger\Phi_2) - v_1 v_2\right]^2 + \lambda_6 \left[\mathrm{Im}(\Phi_1^\dagger\Phi_2)\right]^2
\end{aligned}$$

where $v_1^2 + v_2^2 = v^2 = 2M_W^2/g^2 \simeq (174\ \text{GeV})^2$ and $\tan\beta = v_2/v_1$

In turn this specifies all the couplings of the Higgs-sector

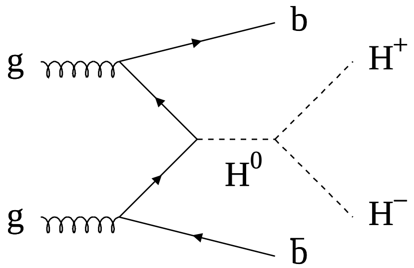
Scanning 2HDM parameter space:

Setup:

- M_{A^0} and $\tan\beta$ as input.
- MSSM mass-relations $\Rightarrow M_{H^\pm}$
- $M_{H^0}^{\mathrm{2HDM}} = 2.2 M_{H^\pm}$
- $M_{h^0} = 1.7 M_{H^\pm}$

scan remaining $(\alpha, (\lambda_5 - \lambda_6)/2)$-space for largest effective coupling:

$$g_{H^0 H^+ H^-}\, g_{H^0 b\bar{b}}$$



Conditions:

- potential bounded from below
- λ_i fulfill the unitarity constraints
- contribution to $\Delta\rho < 10^{-3}$ $(\rho = \frac{M_W^2}{M_Z^2 \cos^2\theta_W})$
- $\Gamma_{H^0} < M_{H^0}/2$

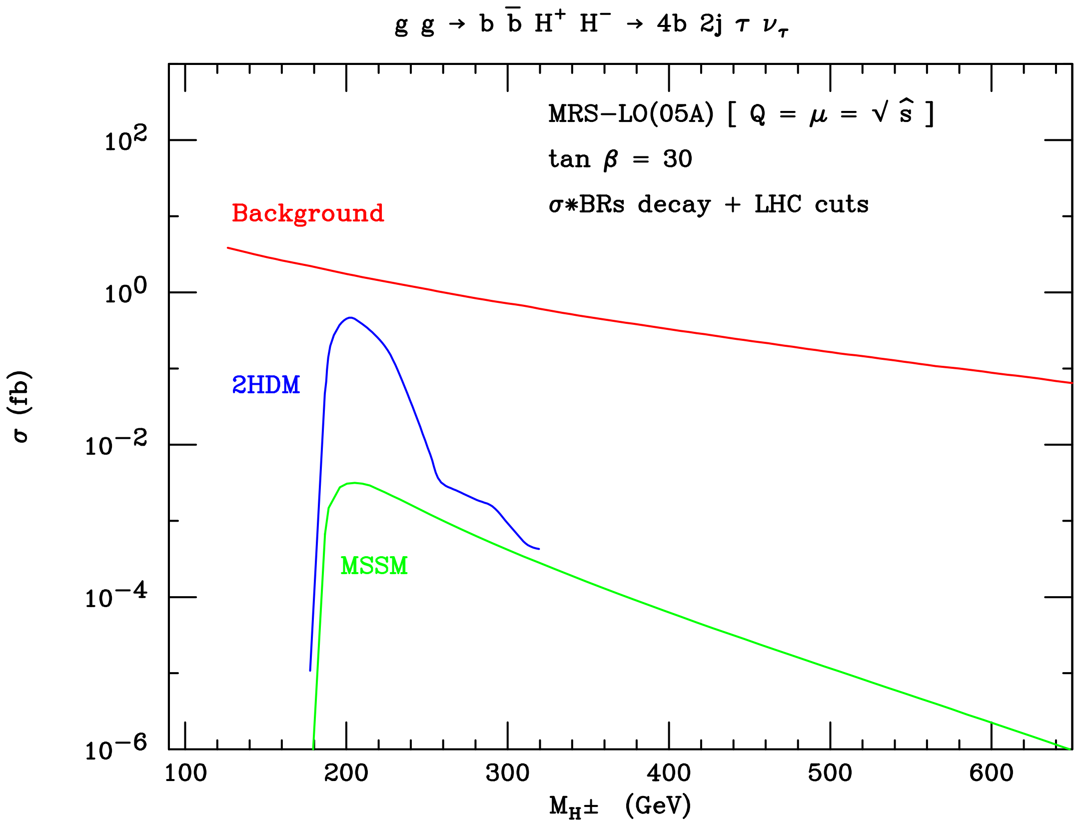
Signal

Look for one hadronic and one leptonic decay, e.g. $H^+ \to \bar{b}t \to \bar{b}bjj$ and $H^- \to \tau^-\bar{\nu}_\tau$, giving the signature:

4 b-quark jets, two light-quark jets, a τ-lepton and $p_\perp^{\rm miss}$

Cross-sections for $\tan\beta = 30$ in MSSM and general 2HDM compared to irreducible background from $gg \to t\bar{t}b\bar{b}$

$\Rightarrow$ largest cross-section around $M_{H^\pm} \sim 200$ GeV



Details of simulation

No parton showering nor hadronisation (except decay of τ)

Momenta smeared to emulate finite detector resolution:
$(\sigma(p_\perp)/p_\perp)^2 = (0.60/\sqrt{p_\perp})^2 + (0.04)^2$ for (b)jets and
$(\sigma(p_\perp)/p_\perp)^2 = (0.12/\sqrt{p_\perp})^2 + (0.01)^2$ for taujet

Basic cuts (due to detector coverage/performance):
$p_\perp^{b,j} > 20$ GeV, $p_\perp^\tau > 10$ GeV, $\eta_{b,\tau} < 2.5$, $\eta_j < 5$, $p_\perp^{\mathrm{miss}} > 60$ GeV, $\Delta R > 0.4$

Additional cut on most backward and forward b's: $m_{bb} > M_{H^\pm}$
(could remove this cut in most optimistic 2HDM scenario)

How to reconstruct a possible H^0-resonance

Mass contraints for hadronic decay $H^+ \to \bar{b}t \to \bar{b}bW^+ \to \bar{b}bjj$:

W-reconstruction: $|m_{jj} - m_W| < 15$ GeV,

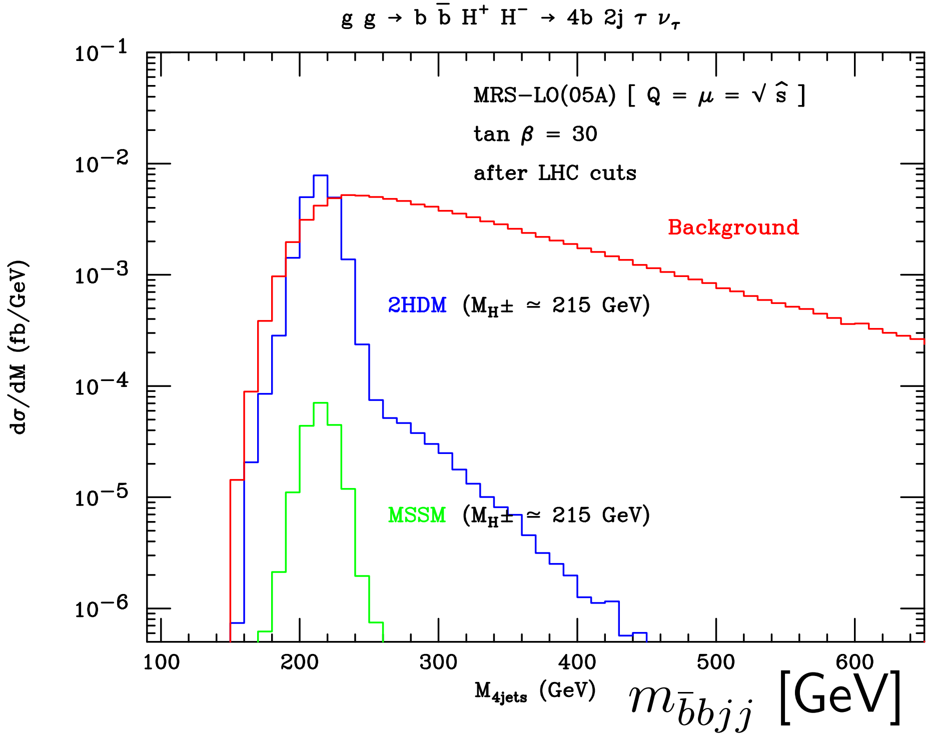
t-reconstruction: $|m_{bjj} - m_t| < 35$ GeV

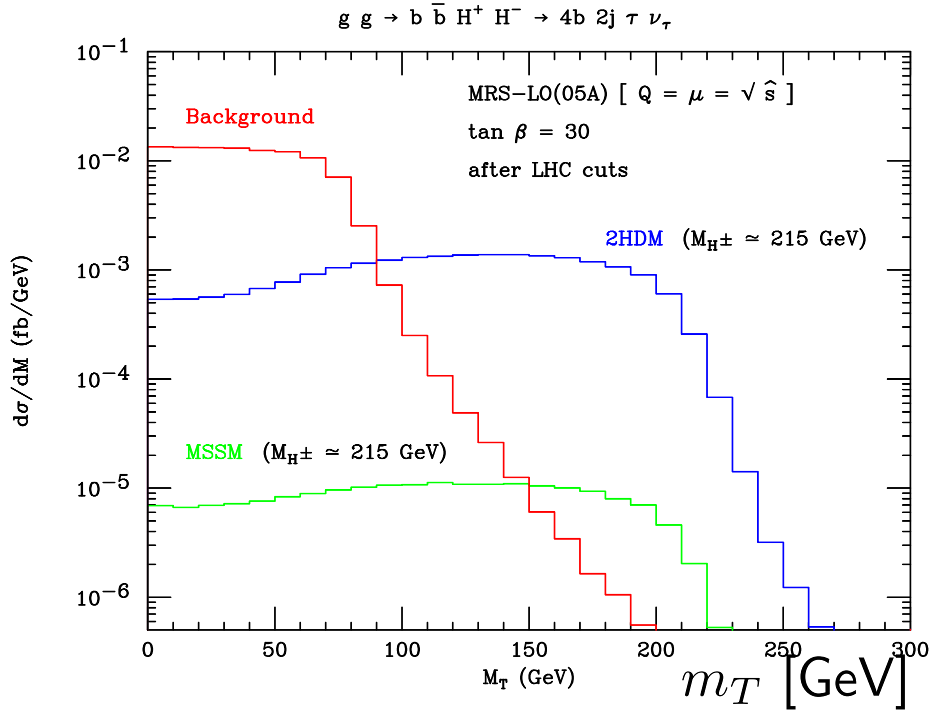
$\Rightarrow$ possible to reconstruct one of the charged Higgs bosons using $m_{\bar{b}bjj}$

Use transverse mass for leptonic decay $H^- \to \tau^- \bar{\nu}_\tau$:

$$m_T = \sqrt{2p_\perp^\tau p_\perp^{\mathrm{miss}}(1 - \cos\phi)}$$

Example: $M_{H^\pm} = 215$ GeV





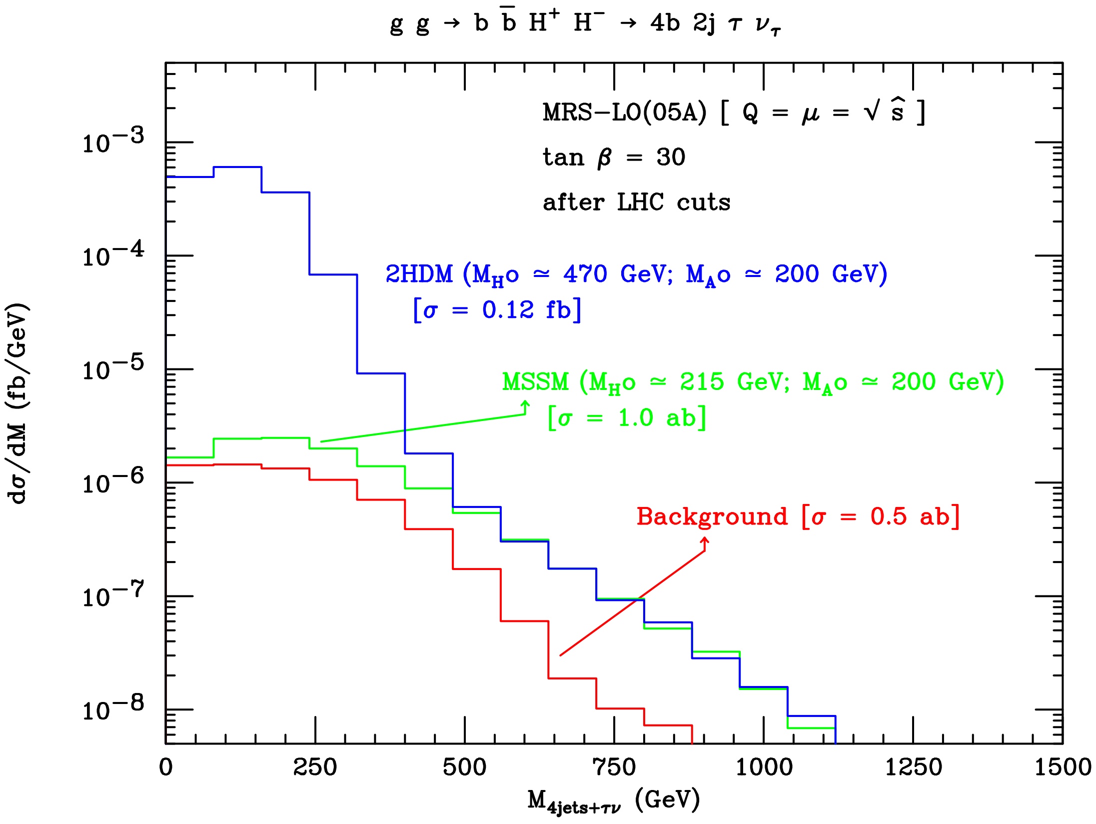
$H^+ \to \bar{b}t \to \bar{b}bjj$ $\qquad$ $H^- \to \tau^-\bar{\nu}_\tau$

Additional cuts to beat down background:

$$|m_{\bar{b}bjj} - M_{H^\pm}| < 35 \text{ GeV}, \qquad m_T = \sqrt{2p_\perp^\tau p_\perp^{\text{miss}}(1-\cos\phi)} > m_{H^\pm}/2$$

Having identified the transverse momenta of the two Higgs bosons we can look for transverse mass resonances:

Combined transverse mass $m_{\bar{b}bjj+\tau\nu}$ after applying all cuts



- Cross-section in general 2HDM can be up to 100 times larger than in MSSM
- Small cross-section in 2HDM but still viable signal at LHC ($\int\mathcal{L} \sim 100\,\mathrm{fb}^{-1}$/year)
- Significantly different shape compared to MSSM due to resonant contributions

$\Rightarrow$ Possible to determine $g_{H^0H^+H^-}$ if close to maximal but not in MSSM