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Distinguishing Higgs models in $H^+ \to \tau^+\nu^- / H^+ \to t\bar{b}$

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ABSTRACT

The analysis of the ratio of branching ratio $R = BR(H^+ \to \tau^+\nu)/BR(H^+ \to t\bar{b})$ of charged Higgs boson decays as a discriminant quantity between supersymmetric and non-supersymmetric models is presented. A detailed study of the quark mass quantum corrections on this ratio, in the effective Lagrangian approach, revealed large deviations from the Standard Model values for several supersymmetric parameter combinations. Simulation for measurements of the ratio R through the analysis of signal and background for the charged Higgs production process $gb \to tbH^+$ in the context of ATLAS has been done. We found that, with a $\sim 12-14\%$ accuracy for $\tan\beta = 50, m_{H^\pm} = 300-500 GeV$ and an integrated luminosity of $300 fb^{-1}$, the LHC can discriminate between models for any scenario with $\tan\beta > 30$.

hep-ph/0402212, hep-ph/0406152

The interest of investigation of the observable ratio $R = \frac{BR(H^+\to\tau^+\nu)}{BR(H^+\to t\bar{b})}$ is many-fold.

- The discovery of a charged Higgs boson will be a clear evidence of physics Beyond the SM
- The associated production of H^+ with a top ($pp \to H^+\bar{t}+X$) is relevant at large $\tan\beta$
- The ratio receives large SUSY corrections at large $\tan\beta$ due to Δm_b and Δm_τ

$$h_f = \frac{m_f(Q)}{v\cos\beta}\frac{1}{1+\Delta m_f} \qquad (v = (v_1^2+v_2^2)^{1/2}, \tan\beta = \frac{v_1}{v_2})$$

Ex.: If all the SUSY particles are at the scale M_{SUSY},

$$\Delta m_b \simeq \text{sign}(\mu)\tan\beta\left\{\frac{\alpha_S}{3\pi} - \frac{\alpha}{16\pi s_W^2}\left(3+\frac{7s_W^2}{9c_W^2}\right) + \frac{Y_t}{8\pi}\frac{A_t}{M_{SUSY}}\right\}.$$

- While the SUSY radiative effects might be difficult to discern in the production cross-sections themselves, they will appear neatly in the relation

$$R = \frac{\sigma(pp\to H^+\bar{t}+X\to\tau^+\nu\bar{t}+X)}{\sigma(pp\to H^+\bar{t}+X\to t\bar{b}\bar{t}+X)}$$

- Sources of uncertainty from the production process (parton luminosity, unknown QCD corrections) cancel in the ratio

$$R = \frac{BR(H^+\to\tau^+\nu)}{BR(H^+\to t\bar{b})} = \frac{\Gamma(H^+\to\tau^+\nu)}{\Gamma(H^+\to t\bar{b})}$$

Experimental analysis

- Simulation for measurements of this ratio through the analysis of the H^+ production process using the two-body production cross–section subprocess

K. A. Assamagan et al, EPJDirect C4 (2002) 9, hep-ph/0203121.

$$g\bar{b} \to H^+\bar{t}; \quad H^+ \to t\bar{b}, \quad H^+ \to \tau\nu$$

- We let the t–quark decay through the standard $t \to W^+b$

- We use
  - Pythia ≡ for the signal and most of the background process
  Cross checked with Pythia of calculations of $\sigma(g\bar{b} \to H^+\bar{t})$ by T. Plehn, hep-ph/0206121, 0304034.
  - Tauola ≡ for the τ–lepton decays
  - TopRex ≡ for some background process with a custom interface to Pythia
  - ATLFAST ≡ for the detector simulation
  - Hdecay ≡ for the branching ratio of Higgs boson decays

$H^+ \to \tau\nu$

Experimental signature of the production channels under investigation is: $pp(g\bar{b}) \to H^+\bar{t} \to (\tau^+\nu)\bar{t} \to \tau^+\nu(jj\bar{b})$

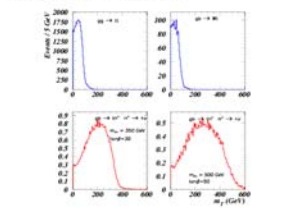
- Signal: $g\bar{b} \to H^+\bar{t}$
  - $H^+ \to \tau\nu$ and $\bar{t}$ decaying hadronically ($\bar{t} \to jj\bar{b}$)
  - Trigger: We search for 1 hadronic τ jet ($p_T^\tau > 30\,GeV$), 1 b-tagged jet ($p_T^b > 30\,GeV$), ≥ 2 light jets ($p_T^j > 30\,GeV$).
- Background: QCD backgrounds are considered
  - Top-pair production with the $W^\pm$ decaying into τν. $gg \to t\bar{t}, \bar{t} \to jj\bar{b}, t \to Wb, W \to \tau\nu$
  - $W^\pm - t$ associated production $gb \to Wt, t \to jjb, W \to \tau\nu$

★ Good signal reconstruction
★ Background free enviroment

Background Suppression

- Harder τ jets in signal compared to backgrounds
- High cut on p_T of the τ–jet: $p_T^\tau > 100 GeV$
- Small azimuthal opening angle $\Delta\phi$ between the τ-jet and the missing transverse momentum $\not{p}_T \Rightarrow$ We have the cut $\Delta\phi(\not{p}_T, p_T^\tau) > 1$.
- Transverse mass of τν: $m_T = \sqrt{2p_T^\tau \not{p}_T[1-\cos(\Delta\phi)]}$. We use a final cut $m_T > 200$ GeV for the calculations of the signal-to-background ratios and for the signal significances.

For an integrated luminosity of 30 fb^{-1}:



Signal and background cross-sections, Efficiencies and Significances

For $300 fb^{-1}$ integrated luminosity and $\tan\beta = 50$:

	$m_{H^\pm} = 350$	$m_{H^\pm} = 500$	$t\bar{t}$	$W^\pm t$
$\sigma \times BR$	99.9 fb	30.7 fb	79.1 pb	16.3 pb
Events	29958	9219	2.3×10^5	4.89×10^5
Events after cuts	174	96	17	3
Efficiency	0.6%	1%	8×10^{-5}	6×10^{-6}
S/B	7.9	4.4		
$S/\sqrt{B}$	37.1	20.5		
Poisson	23.1	14.6		

- Before cuts production rates for background are largest than for signal
- We found that the efficiences of cuts is $\sim 1\%$ for the signal but $\sim 10^{-6}$ for backgrounds
  ⇒ After cuts the number of signals events is much larger than backgrounds
- Signal are large enough to consider $H^+ \to \tau\nu$ as a "Golden channel" for the H^+ discovery at large $\tan\beta$
- After the analysis it turns out that despite the small branching ratio $BR(H^+ \to \tau^+\nu)$, the τ-lepton provides an efficient trigger to observe this channel.

$H^+ \to t\bar{b}$

Experimental signature of the production channels under investigation is: $pp(g\bar{b}) \to H^+\bar{t} \to (t\bar{b})\bar{t} \to (jj(l\nu)b)\bar{b}(l\nu(jj)\bar{b})$

- Signal: $g\bar{b} \to H^+\bar{t}$
  - $H^+ \to t\bar{b}$
  - $t \to jjb$ ≡ required to decay hadronically
  - $t \to l\nu b$ ≡ decay leptonically to provide the trigger ($l = e, \mu$)
  - Trigger: 1 isolated lepton ($p_T^e > 20\,GeV$, $p_T^\mu > 8\,GeV$), 3 b-tagged jets ($p_T^b > 30\,GeV$), ≥ 2 light jets ($p_T^j > 30\,GeV$).
- Background: Large QCD backgrounds at hadron colliders that come from $t\bar{t}q$ production with $t\bar{t} \to WbWb \to l\nu b\, jjb$

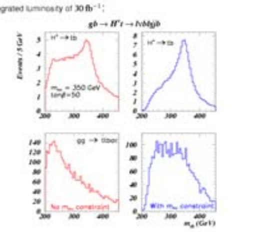
Combinatorial and Large irreducible $t\bar{t}$ background

★ Assume H^+ is discovered in $H^+ \to \tau\nu$
★ We use the $m_{H^\pm}$ constraint to improve the reconstruction in $H^+ \to t\bar{b}$

W, t and H^+ mass Reconstruction

- jj combinations such that $|m_{jj} - m_W| < 25\,GeV$
- Use m_W constraint to find the longitudinal component of the neutrino momentum in $W^\pm \to l\nu$
- Keep the best two top quarks candidates that minimize $\chi^2 \equiv (m_{jjb} - m_t)^2 + (m_{l\nu b} - m_t)^2$
- The remaining b-jet can be paired with either t to give two H^+. Use $m_{H^\pm}$ measurement from $H^+ \to \tau\nu$ to select the best candidate: min $\chi^2 = (m_{tb} - m_{H^\pm})^2$.

Integrated luminosity of 30 fb^{-1}:



- Even with $m_{H^\pm}$ constraint, some irreducible combinatorial noise still appear.
- $m_{H^\pm}$ constraint reshapes the background.

Signal and background cross-sections, Efficiencies and Significances

For $300 fb^{-1}$ integrated luminosity and $\tan\beta = 50$:

	$m_{H^\pm} = 350$	$m_{H^\pm} = 500$	$t\bar{t}q$
$\sigma \times BR$	248.4 fb	88 fb	85 pb
Events	74510	26389	2.55×10^7
Events after cuts	2100	784	59688
Efficiency	2.8%	3%	0.2%
S/B	0.035	0.013	
$S/\sqrt{B}$	8.6	3.2	

- Production rates for background are largest than for signal before cuts
- The $m_{H^\pm}$ constraint reshapes the backgrounds and in doing so the signal significance is not improved.
- Even with $m_{H^\pm}$ constraint, difficult to observe H^+ in this channel above $\sim 400\,GeV$
- For masses above $m_{H^\pm} \sim 400\,GeV$ the signal significance can be enhanced by using the kinematics of the three-body production process $gg \to H^+\bar{t}b$.
  A. Belyaev et. al., hep-ph/0210253, 0105053 ...
  S. Moretti et. al., hep-ph/9906230, 9909435 ...
- Knowledge of background shape and rate necessary!

The ratio $H^+ \to \tau\nu / H^+ \to t\bar{b}$

- Uncertainties in cross sections and luminosity cancel
- Uncertainties in the branching ratios: 5%
- $H^+ \to tb$ background uncertainty: 5%
  (Assuming background subtraction method)
- Scale uncertainties on jet and lepton energies: 1% and 0.1%

Experimental determination of the ratio for $300 fb^{-1}$ and $\tan\beta = 50$.

	$m_{H^\pm} = 350$	$m_{H^\pm} = 500$
Signals after cuts $\tau\nu/tb$	174 / 2100 = 0.08	96 / 784 = 0.12
Signals (corrected) $\tau\nu/tb$	0.18	0.16
Systematics unc.	$\sim 9\%$	$\sim 9\%$
Total unc.	12%	14%
Theory (without SUSY)	0.18	0.16

Uncertainty in the ratio are dominated by knowledge of the background shape and rate under $H^+ \to tb$.

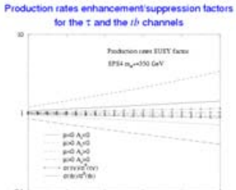
⇓

The simulation shows that the ratio can be measured with an accuracy of a $\sim 12-14\%$ for $\tan\beta = 50$, $m_{H^\pm} = 350-500\,GeV$ at an integrated luminosity of $300 fb^{-1}$.

Impact of the SUSY radiative corrections

1. By changing the value of the Yukawa coupling they change the value of the observable $R = \frac{BR(H^+\to\tau^+\nu)}{BR(H^+\to t\bar{b})}$
2. SUSY corrections can change the value of the production cross-section $\sigma(pp \to H^+\bar{t}+X)$.
   A. Belyaev et. al., hep-ph/0210253, 0203031, 0105053 ...

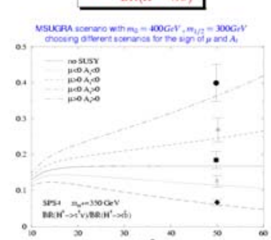
Production rates enhancement/suppression factors for the τ and the tb channels



- Production rate in the τ-channel is fairly independent of the SUSY radiative corrections. Therefore, tree-level analysis can (to a very good approximation) be kept.
- Hadronic tb production channel receives large radiative corrections. These corrections can be either positive (enhancing the signal, and therefore the significance), or negative (reducing it).
  ★ Production rate can be enhanced by a factor larger than 3 in certain scenarios, which would enhance significantly the signal, and overcome the low signal/background ratio in this channel.

$R = \frac{BR(H^+\to\tau^+\nu)}{BR(H^+\to t\bar{b})}$

MSUGRA scenario with $m_0 = 400GeV$, $m_{1/2} = 300GeV$ choosing different scenarios for the sign of μ and A_t



- The value of R only depends on $m_{H^\pm}$ through kinematical factors and the dependence is weak for $m_{H^\pm} \gtrsim 300\,GeV$.
- Experimental determination carried out and repeated for each SUSY setup.

★ Radiative SUSY effects are visible at the LHC at a large significance.

- $\mu < 0$ scenarios can easily be discriminated
  $\mu > 0$ will be more difficult to establish
  ⇒ It also provides a measurement of the sign of μ parameter

CONCLUSIONS

- We propose the measurement of the ratio
  $R = BR(H^+ \to \tau^+\nu^-)/BR(H^+ \to t\bar{b})$
  - Theoretically *clean* observable.
  - Affected by MSSM quantum contributions that do not decouple even in the heavy SUSY mass limit.
- SUSY corrections of the b and τ Yukawa couplings can be determined from this ratio.
- The determination of the sign of μ can be made with a $\sim 14\%$ measurement of this ratio for $\tan\beta > 30$.
- Simulation for measurement of this ratio have been done:
  A $\sim 12-14\%$ measurement can be achieved for $\tan\beta = 50$, $m_{H^\pm} = 300-500\,GeV$ at an integrated luminosity of $300 fb^{-1}$
- We have quantitatively shown that an LHC measurement of R can give clear evidence for, or against, the SUSY nature of charged Higgs bosons