Discovering Higgs Bosons with Tau Leptons and a Bottom Quark

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Kao, Dicus, Malhotra and Wang (2007)

- Introduction: Higgs Production in the MSSM
- Discovering Higgs Bosons with Muons
- Higgs Decay into Tau Leptons
- Higgs Mass Reconstruction
- Physics Background
- Discovery Potential at the LHC

Production of Higgs Bosons

A. Gluon Fusion: $gg \to \phi^0$ ($\tan\beta < 7$).

B. Bottom Quark Fusion: $b\bar{b} \to \phi^0$ ($\tan\beta > 7$)

- $\sigma(gg \to \phi^0 b\bar{b})[m_b(M_b)]$
  $\approx 3\sigma(gg \to \phi^0 b\bar{b})[m_b(M_\phi)]$, $M_\phi = 200$ GeV
- $\sigma(gg \to \phi^0 b\bar{b}) \approx \sigma(b\bar{b} \to \phi^0)$, $\mu_F = M_\phi/4$

S. Dawson, C.B. Jackson, L. Reina, D. Wackeroth (2003 & 2004);
V. Ravindran, J. Smith, and W.L. van Neerven (2003);
R.V. Harlander & W.B. Kilgore (2002); C. Anastasiou & K. Melnikov (2002).
M. Spira, A. Djouadi, D. Graudenz, P.M. Zerwas (1995).
T. Plehn (2002); F. Maltoni, Z. Sullivan and S. Willenbrock (2003);
E. Boos and T. Plehn (2003); R.V. Harlander and W.B. Kilgore (2003).
B. Plumper, DESY-THESIS-2002-005.
J. Campbell *et al.*, arXiv:hep-ph/0405302.

Higgs Boson Production via Bottom-Quark Fusion

- The dominant subprocess for the production of a Higgs boson in association with bottom quarks is bottom-quark fusion $b\bar{b} \to \phi^0$.
- If we require one bottom quark at high p_T from the production process, the leading-order subprocess should become $bg \to b\phi^0$.
- For the production of the Higgs boson accompanied by two high p_T b quarks, the leading subprocess should be $gg, qq \to b\bar{b}\phi^0$.

Campbell, Ellis, Maltoni and Willenbrock (2003);
S. Dawson, C.B. Jackson, L. Reina, D. Wackeroth (2003 & 2004);
Hou, Ma, Zhang, Sun, and Wu (2003); C.S. Huang and S.H. Zhu (1999); Choudhury, Datta and Raychaudhury (1998).

Higgs Boson Production via Bottom-Quark Fusion

There were two puzzling aspects in the NLO calculations of bottom quark fusion:

- The independent corrections of order α_s and $1/\ln(m_h/m_b)$ are both large and of opposite sign.
- The cross section in hadron collisions via $gg \to b\bar{b}\phi^0$ is an order of magnitude smaller than that obtained from $b\bar{b} \to \phi^0$.

One simple solution: $\mu_{\text{Factorization}} = m_{\phi/4}$.

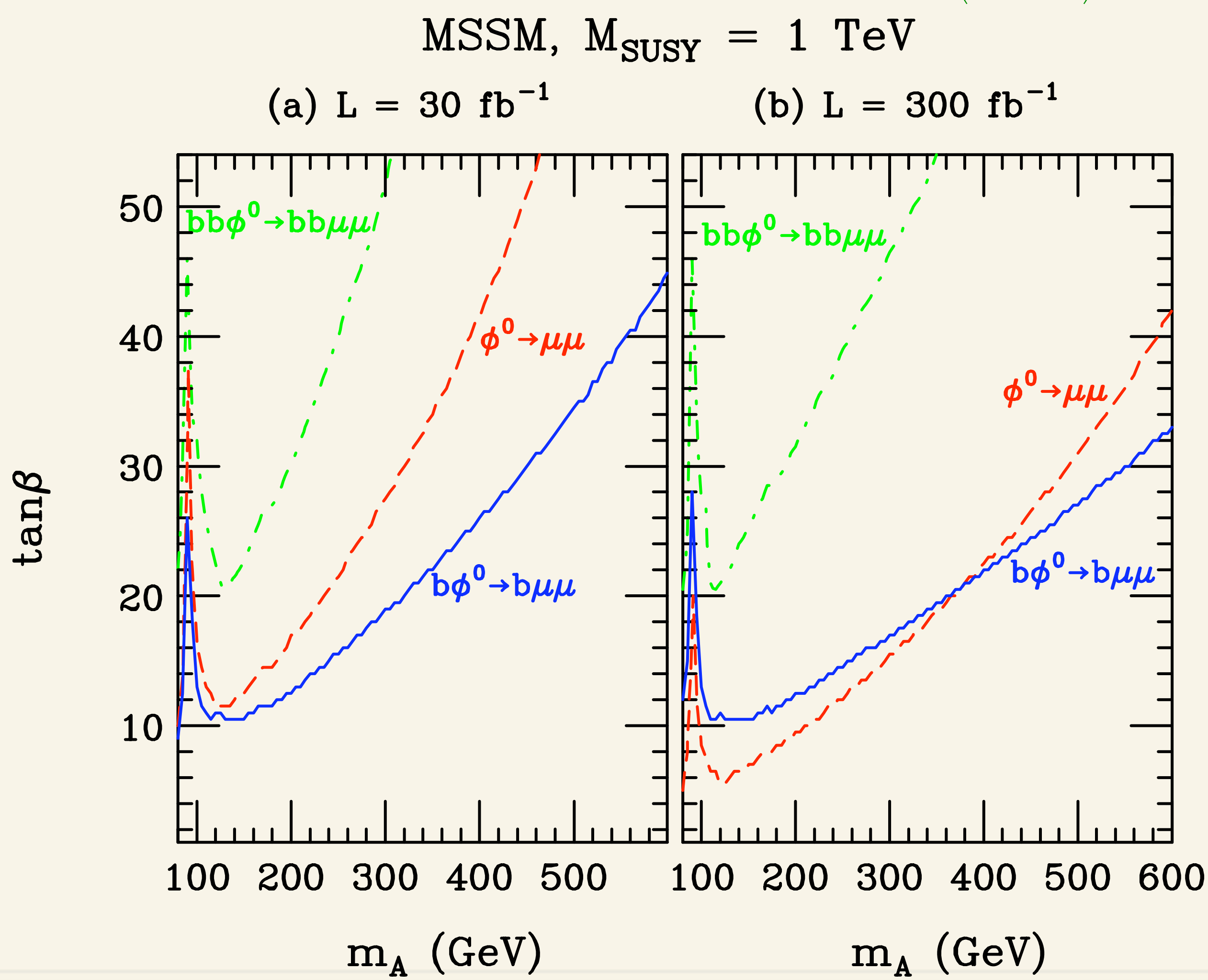
F. Maltoni, Z. Sullivan, and S. Willenbrock, Phys. Rev. D **67**, 093005 (2003).

Discovering Higgs Bosons with Muons

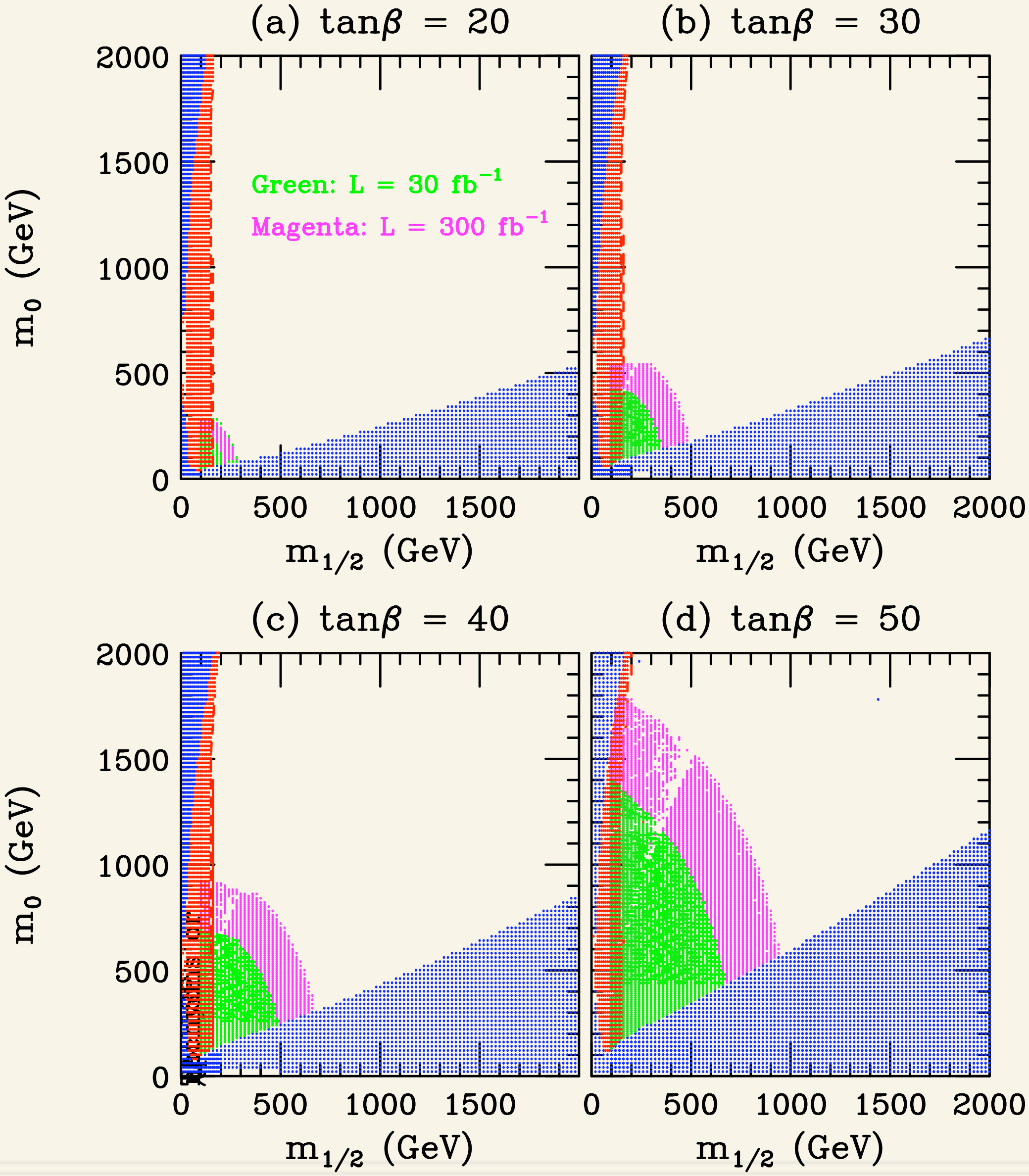
- The discovery channel of $b\phi^0 \to b\mu^+\mu^-$ offers great promise to discover the A^0 and the H^0 at the LHC for $\tan\beta > 10$, $m_A < 650$ GeV with $L = 30\ \mathrm{fb}^{-1}$.
- A higher luminosity of 300 fb^{-1} can improve the discovery reach in m_A up to $m_A = 800$ GeV.
- The $b\phi^0$ channel greatly improves the discovery potential beyond the reach of the associated mode with two bottom quarks $pp \to b\bar{b}\,\phi^0 \to b\bar{b}\,\mu^+\mu^- + X$, and even the inclusive channel $pp \to \phi^0 \to \mu^+\mu^- + X$.
- The muon discovery channels might provide good opportunities to precisely reconstruct the Higgs mass as well as to measure $\tan\beta$ and the Yukawa couplings.

Discovering Higgs Bosons with Muons

Dawson, Dicus, Kao, and Malhotra (2004)



Minimal Supergravity Model



Higgs Decay into Tau Leptons

- For $\tan\beta \geq 10$ and $M_A < 2mt$,
  $B(A^0 \to bb) \sim 0.89$,
  $B(A^0 \to \tau\tau) \sim 0.10$.
- It is very promising to search for neutral Higgs bosons ($\phi^0 = h^0$, H^0, and A^0) via their decays into tau leptons, $\phi^0 \to \tau^+\tau^-$, at the LHC.
- If the taus are not back-to-back, we can reconstruct the Higgs mass as the invariant mass of the tau pairs.
- At the LHC, the tau pair mass resolutions is $\Delta M \cong 0.15 \times M_\phi$.

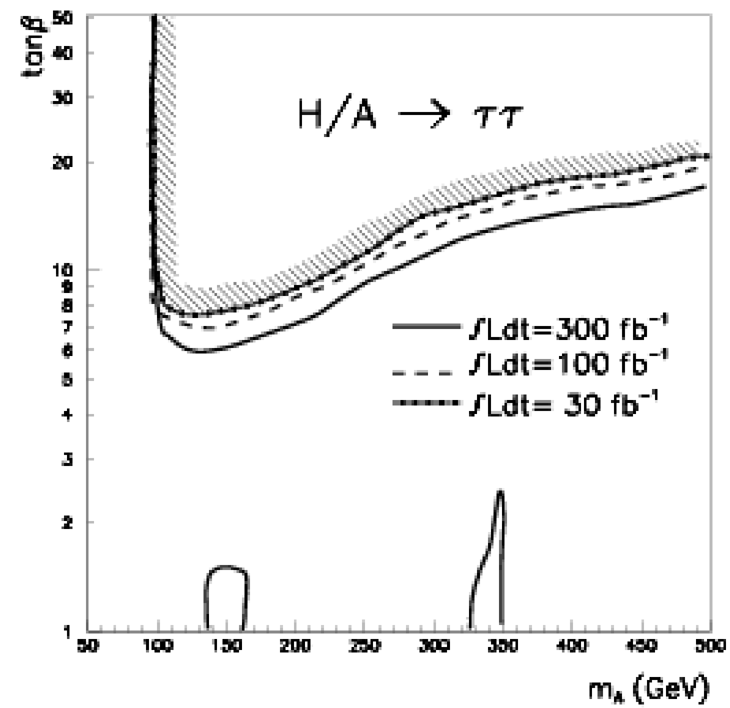


Figure 19-62 For integrated luminosities of 30 fb^{-1}, 100 fb^{-1} and 300 fb^{-1}, 5σ-discovery contour curves for the $H/A \rightarrow \tau\tau$ channel in the (m_A, tanβ) plane.

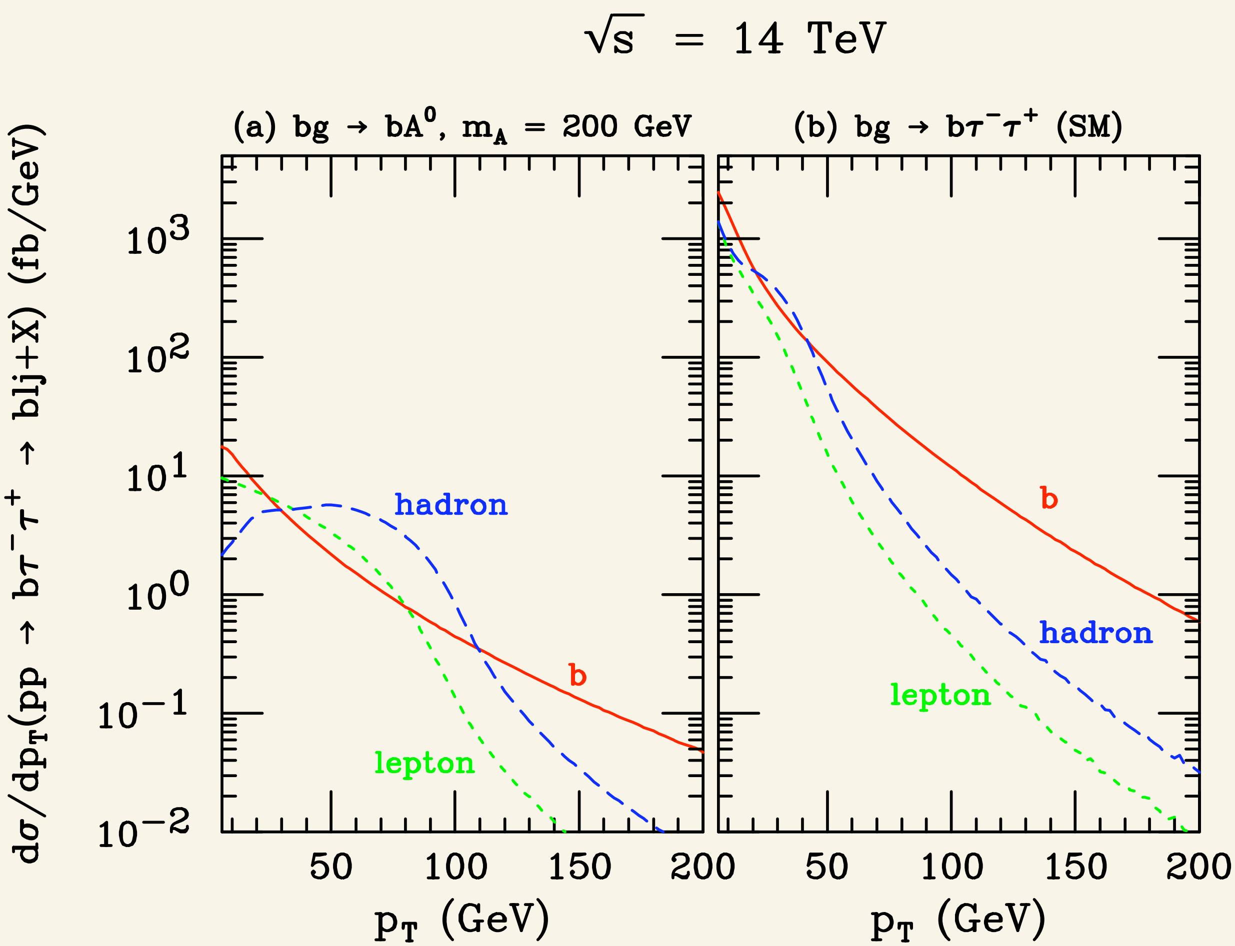
ATLAS Technical Design Report (1999);
R. Kinnunen & A. Nikitenko (2003).

Higgs Signature of Tau Leptons and a Bottom Quark

Kao, Dicus, Malhotra, and Wang (2007)

- We consider the associated production of a Higgs boson with one bottom quark followed by the Higgs decay into a pair of tau leptons
  $bg \to b\phi^0 \to b\tau^+\tau^-$.
- One tau decays into a lepton plus neutrinos and the other decays into a hadron plus neutrino.
- The signal is
  $pp \to b\phi^0 \to b\tau^+\tau^- \to blj + E_T(\text{miss}) + X$.
- We have applied the collinear approximation for the tau decays.
  Tau decays: Hagiwara, Martin, Zeppenfeld (1990).
  SM Higgs boson: Rainwater, Zeppenfeld and Hagiwara (1999).

Transverse Momentum Distributions



Higgs Mass Reconstruction

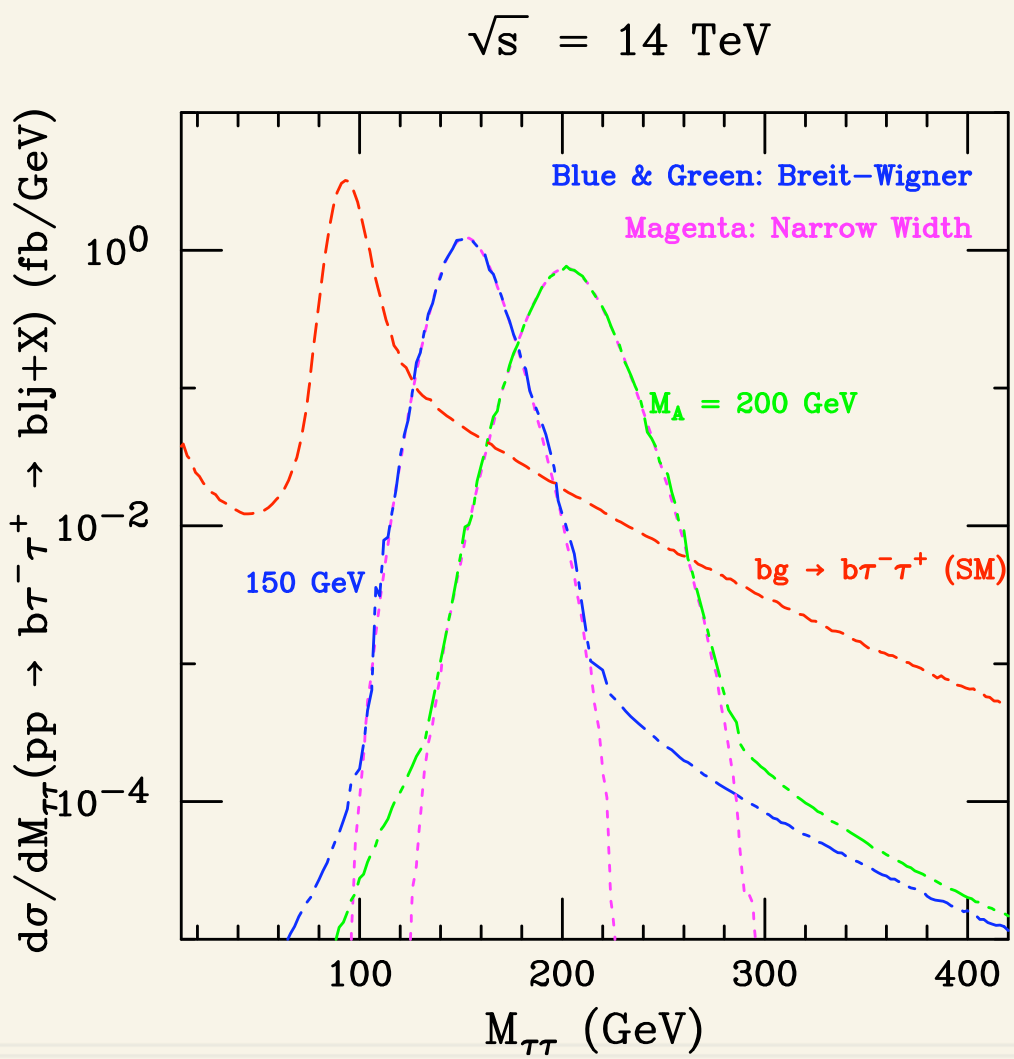
- We consider the final state with one tau decaying into a lepton and the other decaying into a hadron (π, ρ or a1).

- $B(\tau \to e\nu\nu + \mu\nu\nu) = 0.352$
- $B(\tau \to \pi\nu) = 0.111$
- $B(\tau \to \rho\nu) = 0.254$
- $B(\tau \to a_1\nu) = 0.183$

- Applying (a) the collinear approximation for the tau decays and (b) the relations among the momenta of visible particles, we can reconstruct the momenta for the tau leptons, then reconstruct the Higgs mass as the invariant mass of the taus.

- R.K. Ellis, I. Hinchliffe, M. Soldate, J.J. van der Bij (1988).

Invariant Mass of Tau Pairs

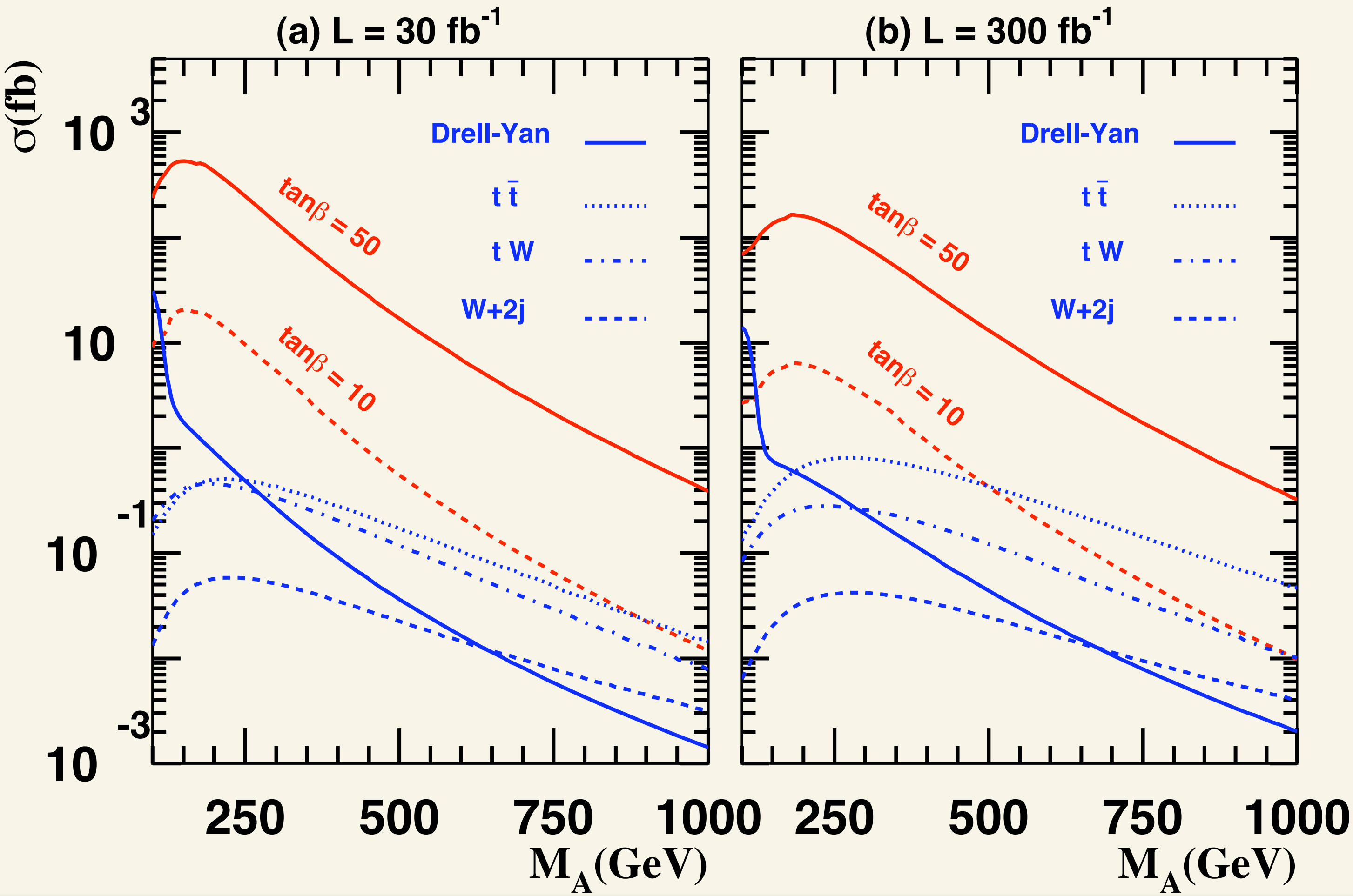


Physics Background

- We take the following efficiencies for tagging and mis-tagging:
  $\varepsilon_\tau = 0.26$, $\varepsilon_{\tau j} = 1/400$, $\varepsilon_{\tau b} = 1/700$, $j = q, g$;
  $\varepsilon_b = 0.6$ (LL)or 0.5(HL), $\varepsilon_c = 0.14$, $\varepsilon_j = 0.01$,
  $j = u, d, s$ or g.

- We have considered dominant background from
  1. $bg \to b\tau^+\tau^-$
  2. $qg \to q\tau^+\tau^-$
  3. $qq \to g\tau^+\tau^-$
  4. $gg, qq \to tt \to bbW^+W^-$
  5. $bg \to tW \to bW^+W^-$
  6. Wjj

Signal Versus Physics Background



Conclusions

- The tau pair decay mode is a promising channel for the discovery of the neutral Higgs bosons in the minimal supersymmetric model at the LHC.
- The associated final state of $b\phi^0 \to b\tau^+\tau^-$ could discover the A^0 and the H^0 at the LHC with an integrated luminosity of 30 fb^{-1} if $M_A \leq 800$ GeV.
- At a higher luminosity of 300 fb^{-1}, the discovery region in M_A is easily expanded up to $M_A \leq 1$ TeV for $\tan\beta \cong 50$.
- The discovery of both $\phi^0 \to \tau^+\tau^-$ and $\phi^0 \to \mu^+\mu^-$ will allow us to understand the Higgs Yukawa couplings with the leptons.

Discovery Contours at the LHC