Detecting a Higgs Pseudoscalar with a Z Boson Produced in Bottom Quark Fusion

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*Presented at the 13th International Conference on *Supersymmetry and Unification of Fundamental Interactions*, *July 18-23, 2005, IPPP Durham,* United Kingdom

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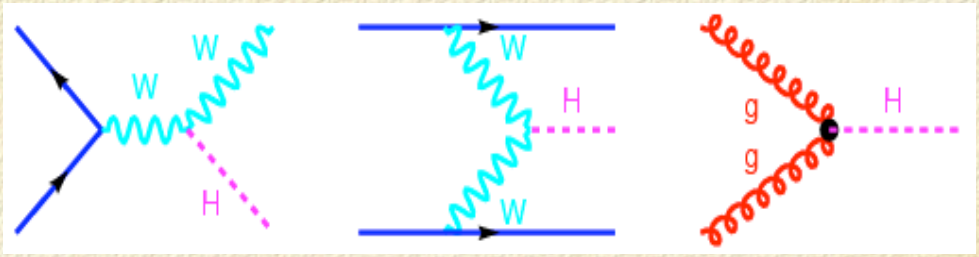
- Introduction: The Standard Model
- Two Higgs Doublet Models
- The Minimal Supersymmetric Model
- Associated Production of ZA^0 at the LHC
  - ❖ $gg \rightarrow ZA^0$
  - ❖ $b\bar{b} \rightarrow ZA^0$
- Discovery Potential at the LHC

C. Kao, G. Lovelace and L. Orr, Phys. Lett. **B567**, 259 (2003).
C. Kao and S. Sachithanandam, to appear in Phys. Lett. B.

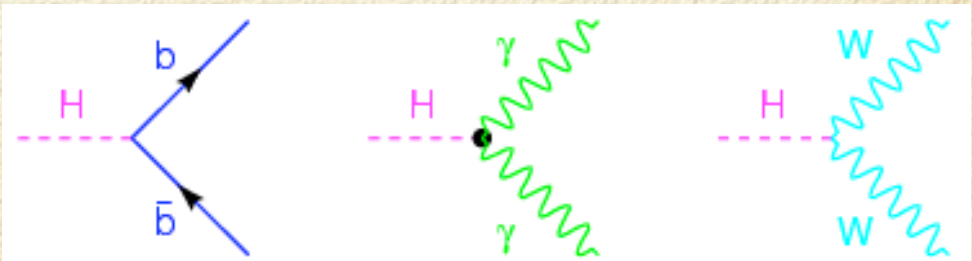
The Standard Model Higgs Boson

- In the SM, there is one Higgs doublet and a spin-0 particle: the Higgs boson (H).

It can be produced at colliders:



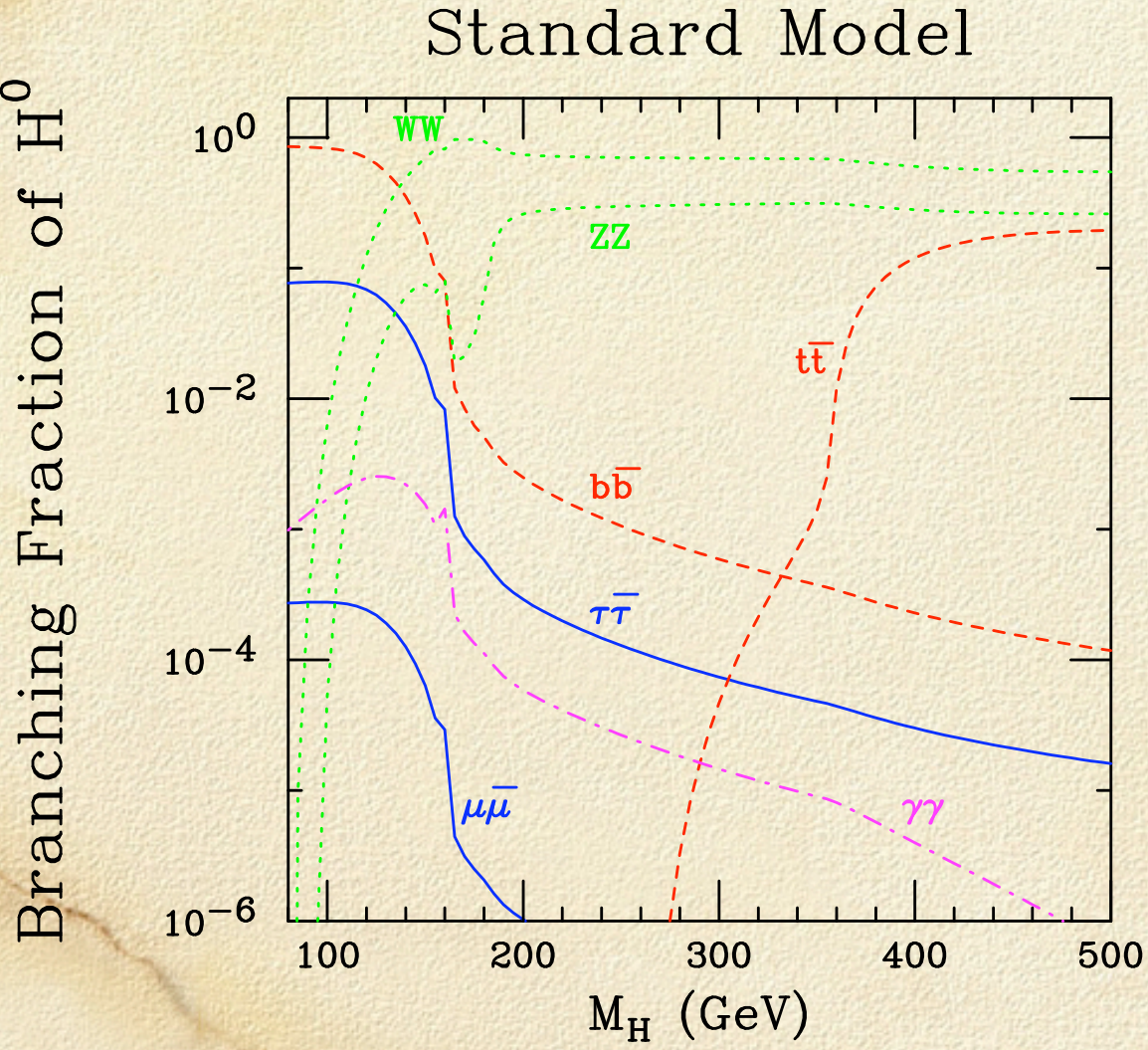
Its decays are well known:



Why has't it been discovered yet?

We need higher energy and higher luminosity!

Branching Fractions of the Higgs Boson



Two Higgs Doublet Models

- In two Higgs doublet Models (2HDMs), there are five physical Higgs bosons: a pair of charged Higgs bosons, two scalars H^0 (heavier) and h^0 (lighter) and a pseudoscalar A^0.
- There are two channels to search for a Higgs scalar and a Higgs pseudoscalar simultaneously:

(i) $A^0 \rightarrow Zh^0 \rightarrow l^+l^- \tau^+\tau^-, l^+l^- b\bar{b}$;

Baer, Kao and Tata (1993); Abdullin, Baer, Kao, Stepanov and Tata (1996); Richter-Was, Froidevaux, Gianotti, Poggioli, and Resconi, (1998); CMS (1994); ATLAS (1999).

(ii) $H^0 \rightarrow ZA^0 \rightarrow l^+l^- \tau^+\tau^-, l^+l^- b\bar{b}$.

The Minimal Supersymmetric Model

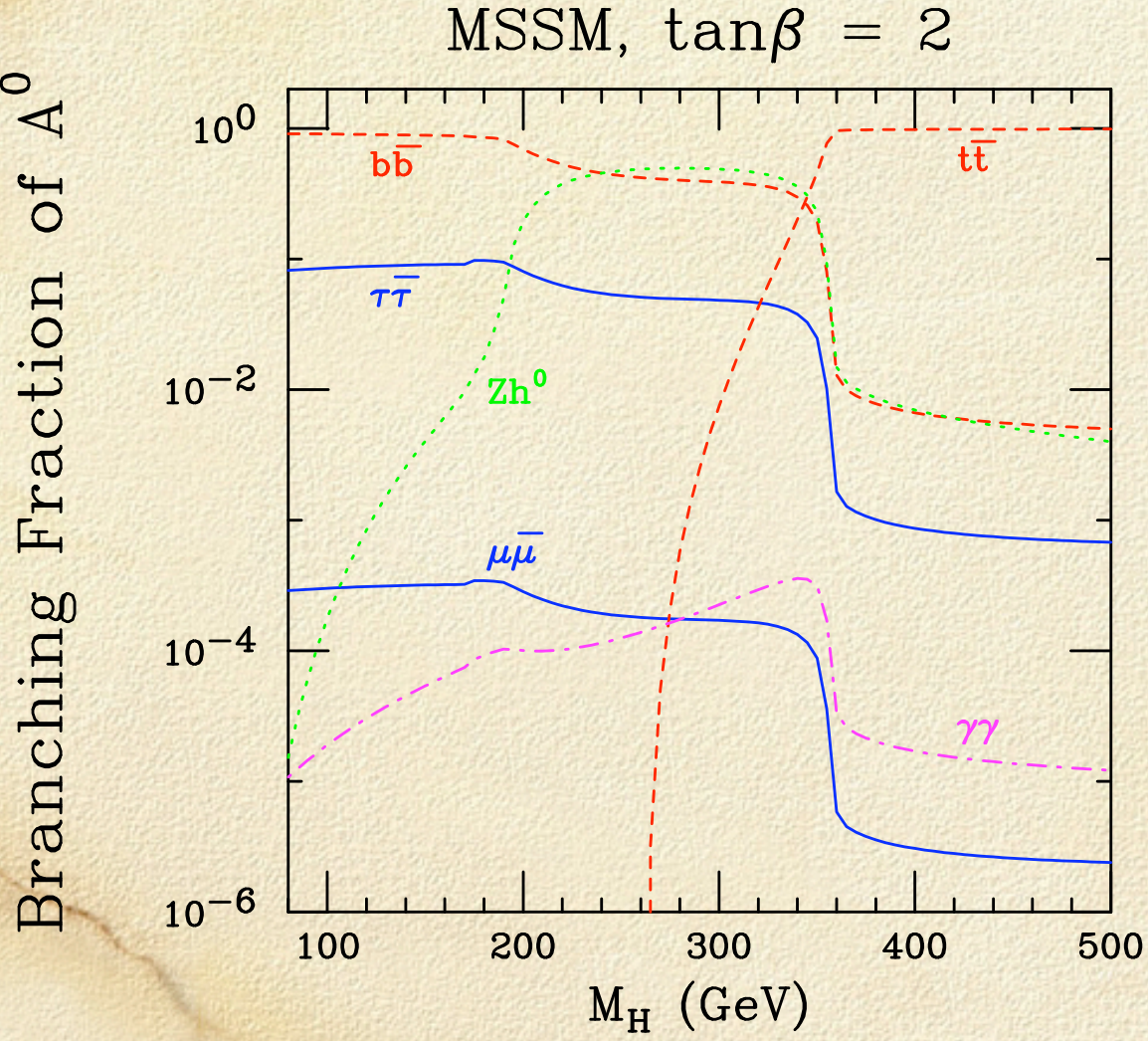
- In the minimal supersymmetric model (MSSM), there are two Higgs doublets with vacuum expectation value (VEVs) v_1 and v_2. We often choose m_A and $\tan\beta \equiv v_2/v_1$ to be the free parameters.

- The Higgs pseudoscalar does not couple to the guage bosons, while the Higgs couplings with the bottom quark and leptons are greatly enhance by a large $\tan\beta$.

- At the tree level, $m_h \leq M_Z$ 91 GeV $< m_H$. With radiative corrections, m_h can be in the range125 GeV $\leq m_h \leq$ 135 GeV.

- For $\tan\beta > 10$ and $m_A > 150$ GeV, h^0 becomes like the Higgs boson in the Standard Model.

Branching Fractions of the Higgs Pseudoscalar in the MSSM

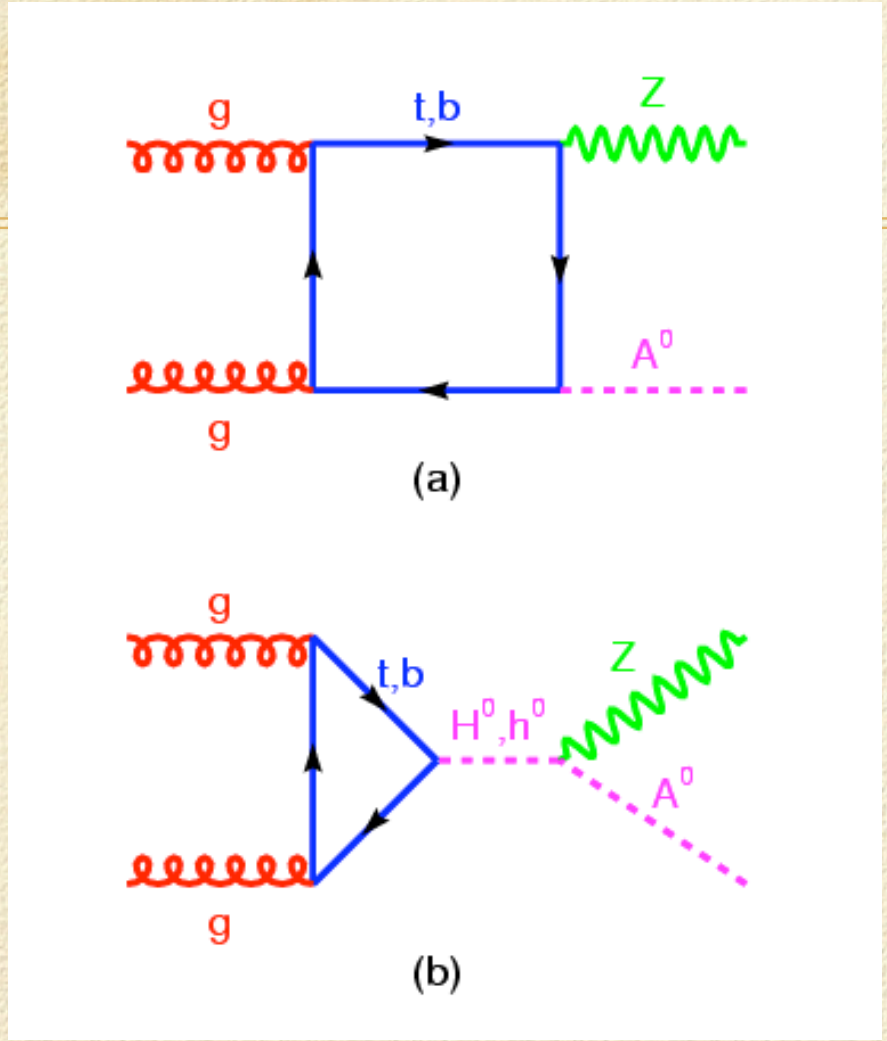


Production of ZA^0 via Gluon Fusion

- In 2HDMs, gluon fusion can be a significant source to produce a Higgs pseudoscalar (A^0) and a Z boson ($gg \rightarrow ZA^0$) via triangle and box diagrams with the third generation quarks.
- Kao (1992); Yin, Ma, Zhang and Hou (2002).

- The triangle and box diagrams can be expressed in terms of the Spence functions.
- 't Hooft and Veltman (1979); Passarino and Veltman (1979).

- We have evaluated the loop integrals with a FORTRAN code developed for one-loop diagrams.
- LOOP, Kao and Dicus (1991).



Feynman Diagrams of $gg \rightarrow ZA^0$

Kao (1992); Yin, Ma, Zhang and Hou (2002)

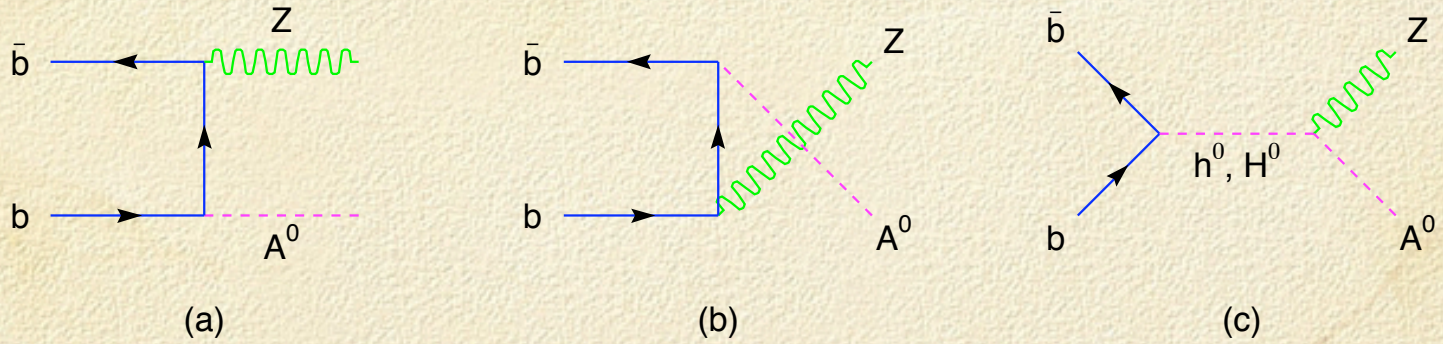
Higgs Boson Production via Bottom-Quark Fusion

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

J. Campbell et al., hep-ph/0405302; S. Dawson, C.B. Jackson, L. Reina, D. Wackeroth (2003 & 2004); T. Plehn (2002); F. Maltoni, Z. Sullivan and S. Willenbrock (2003); Campbell, Ellis, Maltoni and Willenbrock (2003); Hou, Ma, Zhang, Sun, and Wu (2003); C.S. Huang and S.H. Zhu (1999); Choudhury, Datta and Raychaudhury (1998).

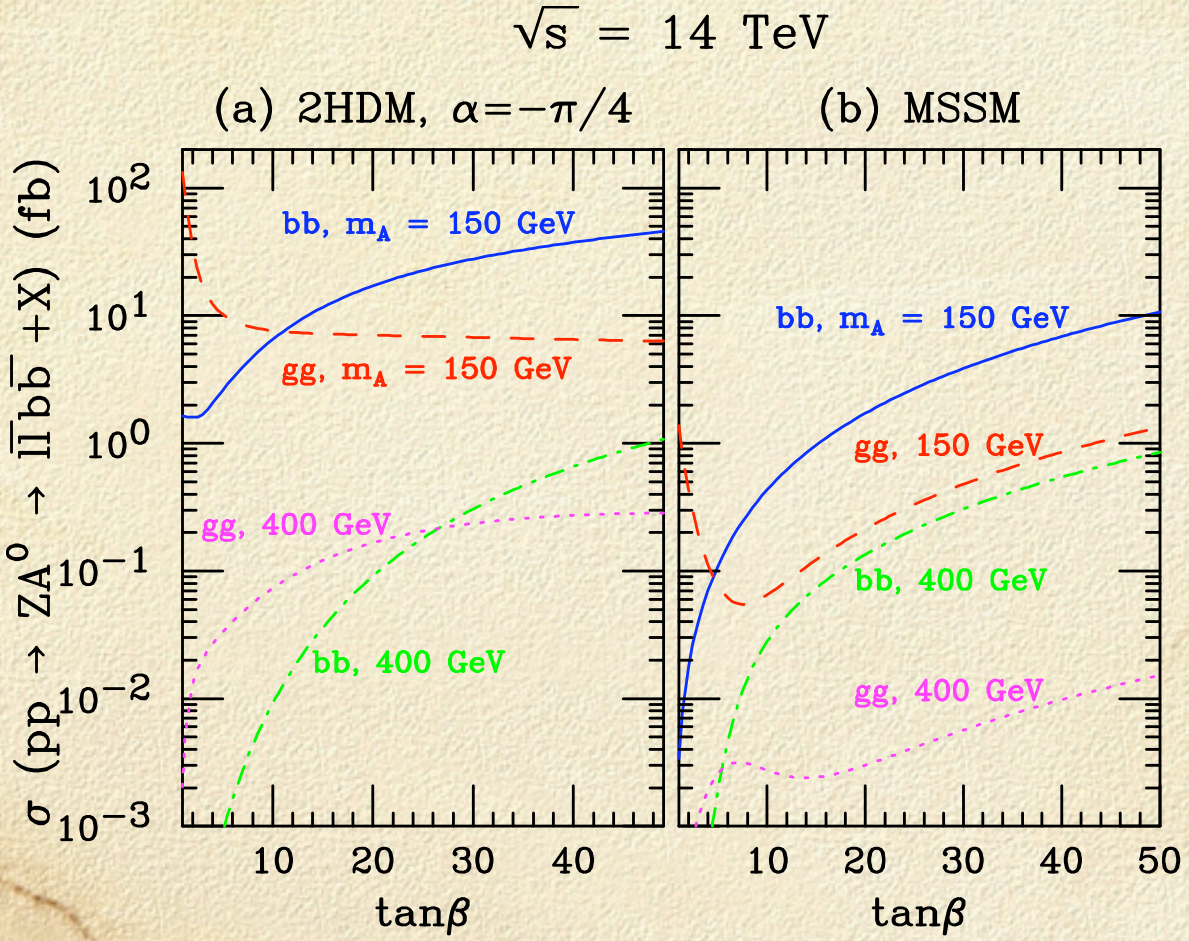
Production of a Higgs Pseudoscalar with a Z Boson in Bottom Quark Fusion

$$\text{Signal}: \quad pp \to Z A^0 \to \ell^+ \ell^- b\bar{b} + X$$



Kao and Sachithanandam (2004), to appear in Phys. Lett. B.
NLO: Li, Li, Liu, Jin, and Yuan, e-Print Archive: hep-ph/0501070.

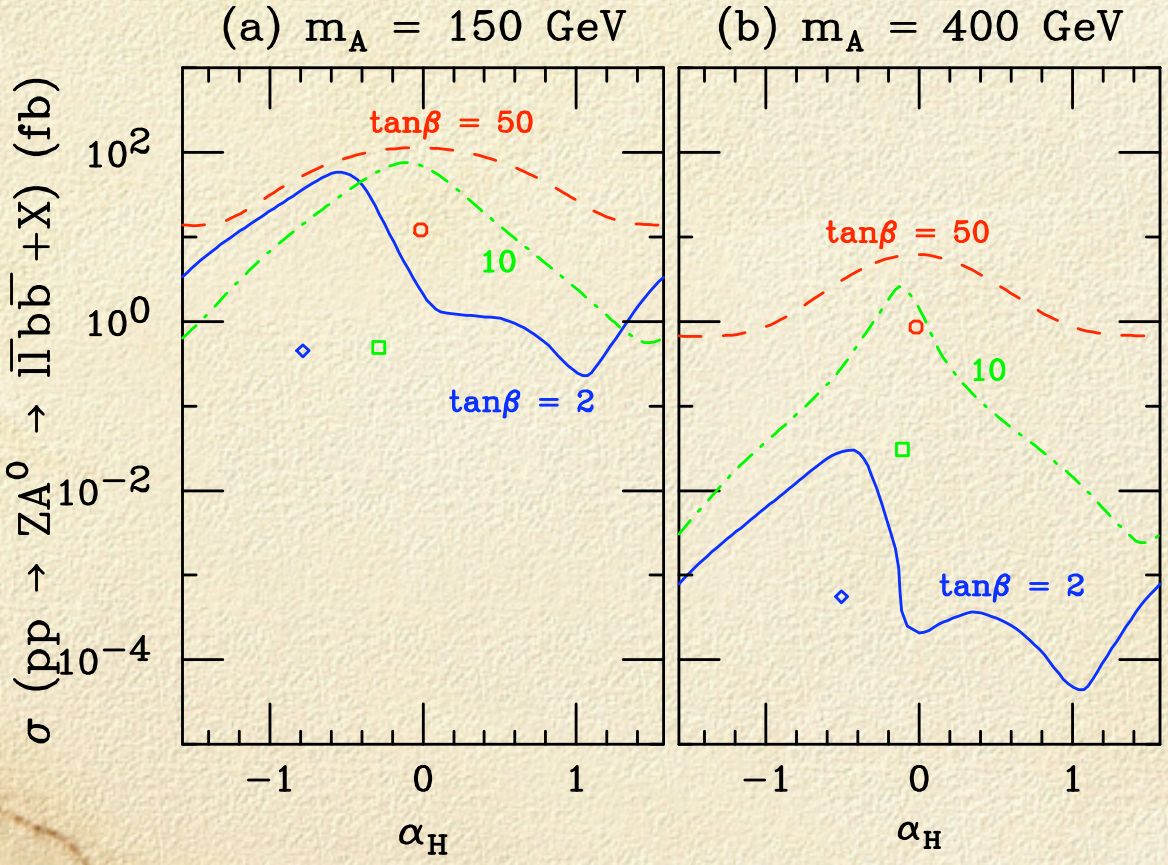
Bottom Quark Fusion and Gluon Fusion



MSSM versus 2HDM

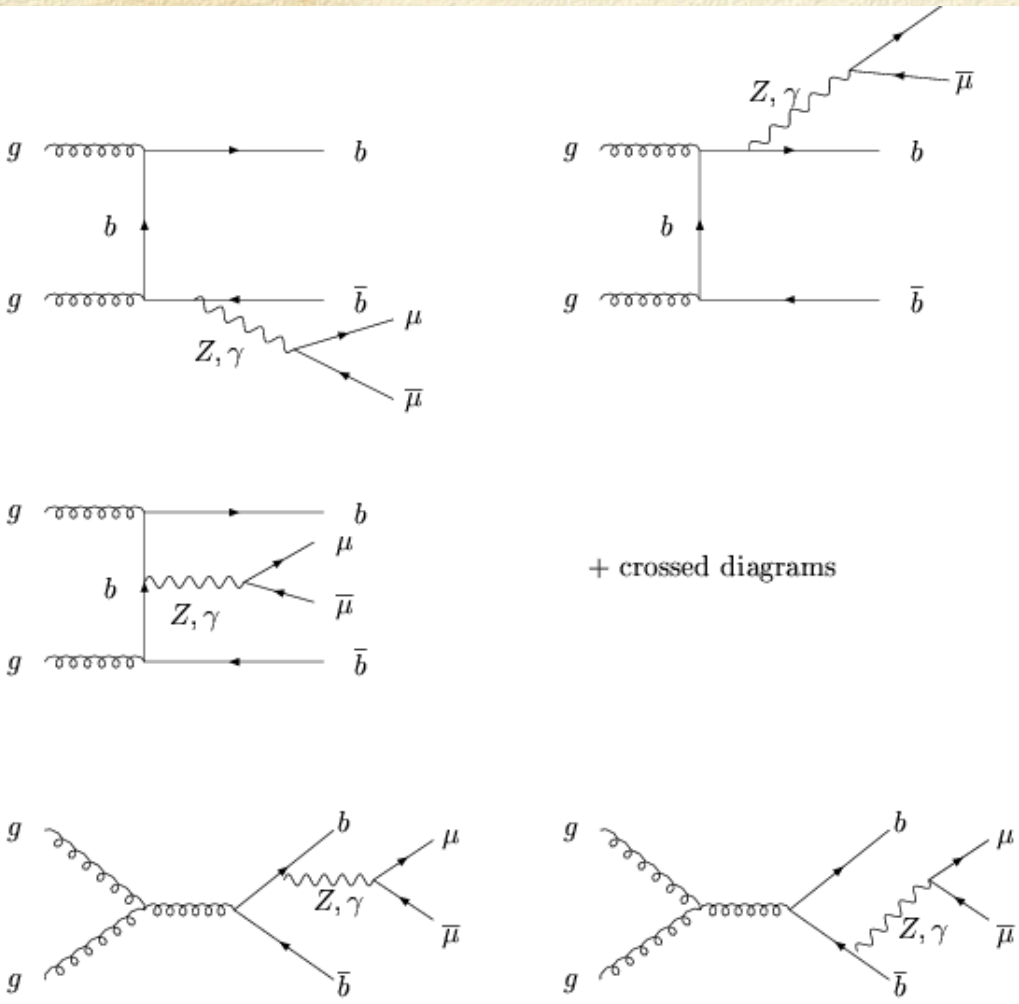
MSSM	2HDM
Two free parameters: tanβ and m_A	6 free parameters: tanβ, 4 Higgs masses, and α_H
$m_H \sim m_A$	m_H and m_A are free parameters
λ_{ZHA}: $\sin(\beta-\alpha) \sim 1$ for $m_A > 150$ GeV	tanβ and α_H are free parameters

MSSM versus 2HDM



The Physics Background

- For the final state of $ZA^0 \rightarrow l^+l^-b\bar{b}$, the dominant physics background comes from $pp \rightarrow l^+l^-b\bar{b} + X$ via $gg, q\bar{q} \rightarrow l^+l^-b\bar{b}$.
- Additional contributions come from production of $W^+W^-b\bar{b}$, and l^+l^- jj, j = g, u, d, s, or c.
- We take the b tagging efficiency to be
  $\varepsilon_b = 0.6$ (LL = 30 fb^{-1}) or 0.5 (HL = 300 fb^{-1}),
  $\varepsilon_c = 0.10$ = probability of c misidentified as b,
  $\varepsilon_j = 0.01$ = probability of jets mistagged as b.
- ATLAS Technical Design Report (1999).



Feynman Diagrams of $gg \rightarrow \mu^+\mu^- b\bar{b}$

The Discovery Potential at the LHC

- To study the discovery potential of

  $pp \rightarrow ZA^0 \rightarrow l^+l^- b\bar{b} + X$

  we calculate the SM background from

  $pp \rightarrow l^+l^- b\bar{b} + X$,

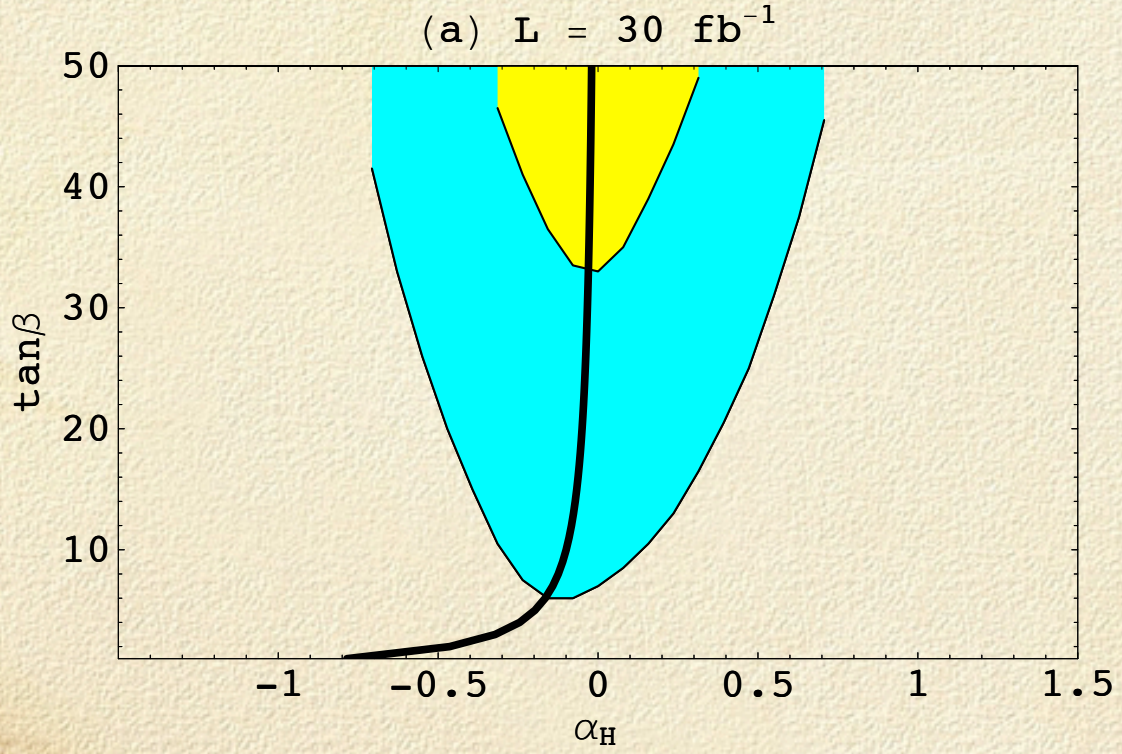
  $pp \rightarrow W^+W^- b\bar{b} \rightarrow l^+l^- b\bar{b} + X$, and

  $pp \rightarrow l^+l^- jj + X$

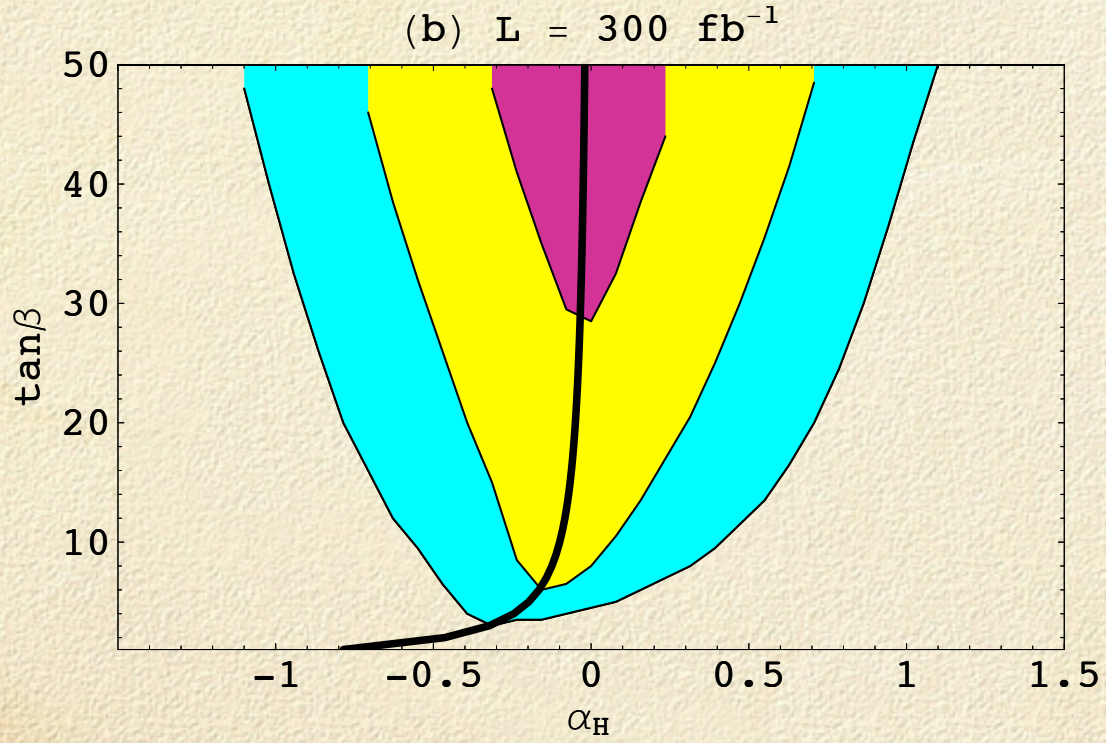
  in the mass window of $m_A \pm \Delta M_{bb}$.

- $\Delta M_{bb} = 22$ GeV

Discovery Contours for L = 30 fb^{-1}



Discovery Contours for L = 300 fb^{-1}



Summary for $b\bar{b} \rightarrow Z A^0$

- We have found promising results in two Higgs doublet models at the LHC with L = 300 fb^{-1} for $M_H = m_A + 100$ GeV, $m_A < 260$ GeV, $\tan\beta \sim 2$ (gg), or $m_A < 400$ GeV for $\tan\beta \sim 50$ (bb).

- This discovery channel might lead to new physics beyond the Standard Model and the minimal supersymmetric model since its cross section is usually small in the MSSM.

- We might be able to discover two Higgs bosons simultaneously if the heavier Higgs scalar (H^0) can decay into a Z boson and a Higgs pseudoscalar (A^0).