Discovering Higgs Bosons with Leptons and Bottom Quarks

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Discovering Higgs Bosons with Leptons and Bottom Quarks

Dawson, Dicus, Kao and Malhotra (2004)
Kao, Dicus, Malhotra and Wang (2007)
Kao, Sachithanandam, Sayre and Wang (2009)

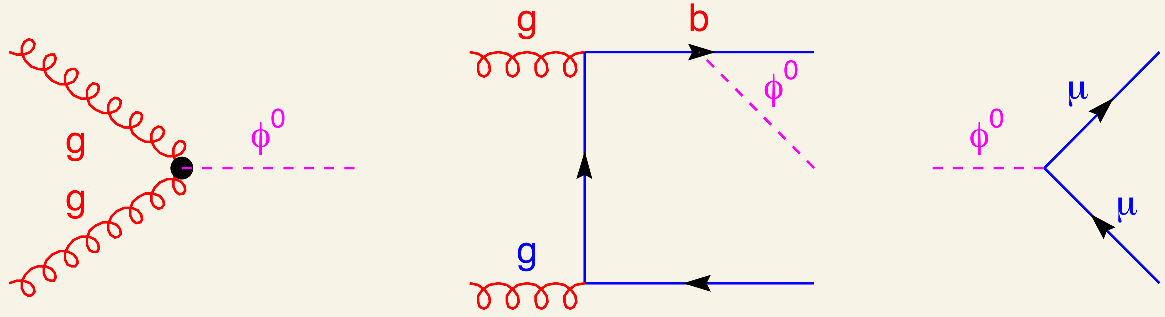
- Introduction
- Discovering Higgs Bosons with Muons
- Discovering Higgs Bosons with Tau Leptons
- Higgs Decay into Bottom Quarks
- Discovery Potential at Hadron Colliders
- Comparison with Results from MG_ME
- Challenges

Higgs Boson Production Involving Bottom Quarks

- 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 $gg, q\bar{q} \to b\bar{b}\phi^0$.

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).

Discovering the Higgs Bosons with Muons



- The A^0 and the H^0 might be observable in a large region of parameter space with $\tan\beta \geq 10$.
- This discovery channel of $\mu^+\mu^-$ will allow precise reconstruction for the Higgs boson masses.
- Kao and Stepanov (1995);
  Barger and Kao (1998);
  Dawson, Dicus and Kao, Phys. Lett. **B545**, 132 (2002).

Cross Section in the MSSM

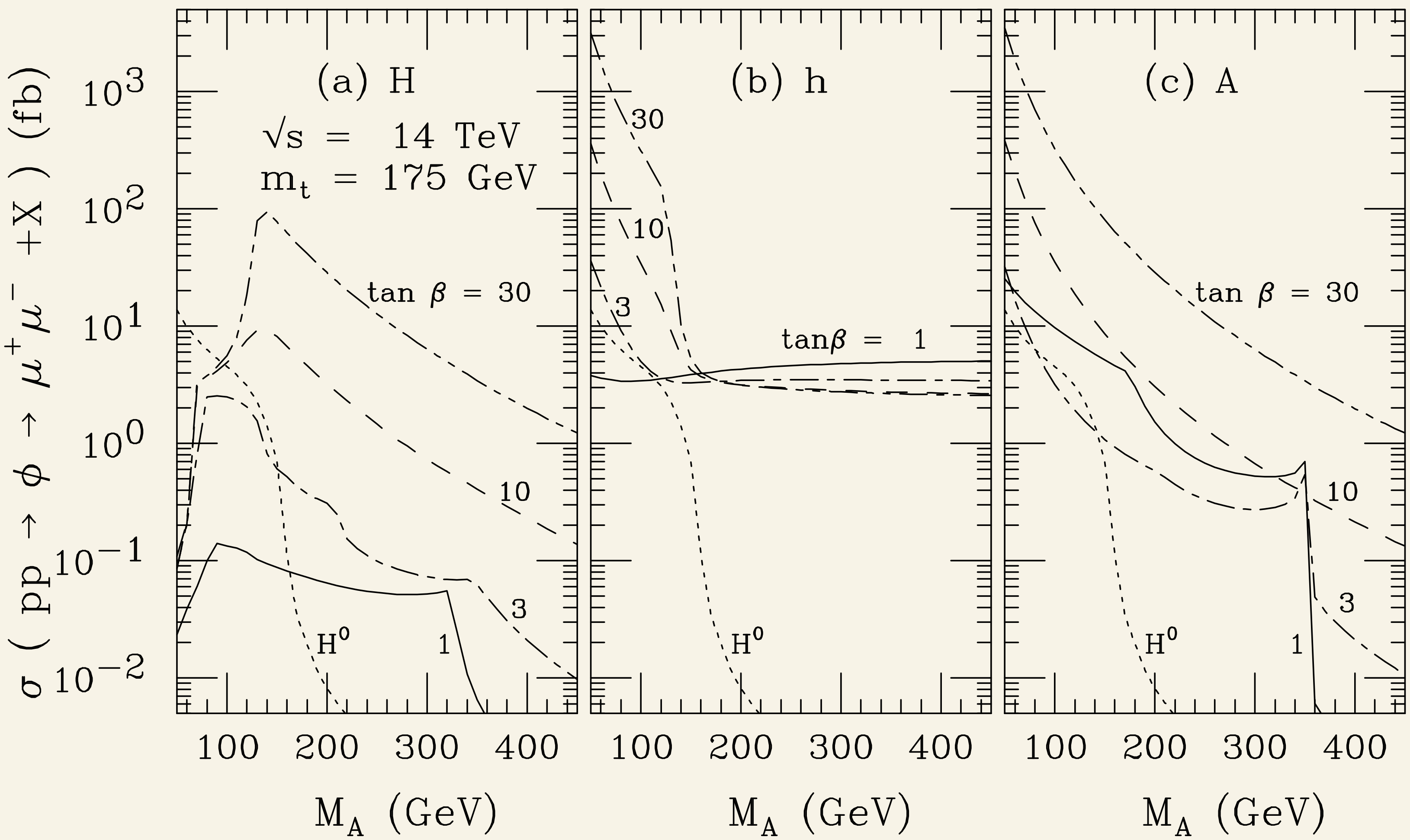
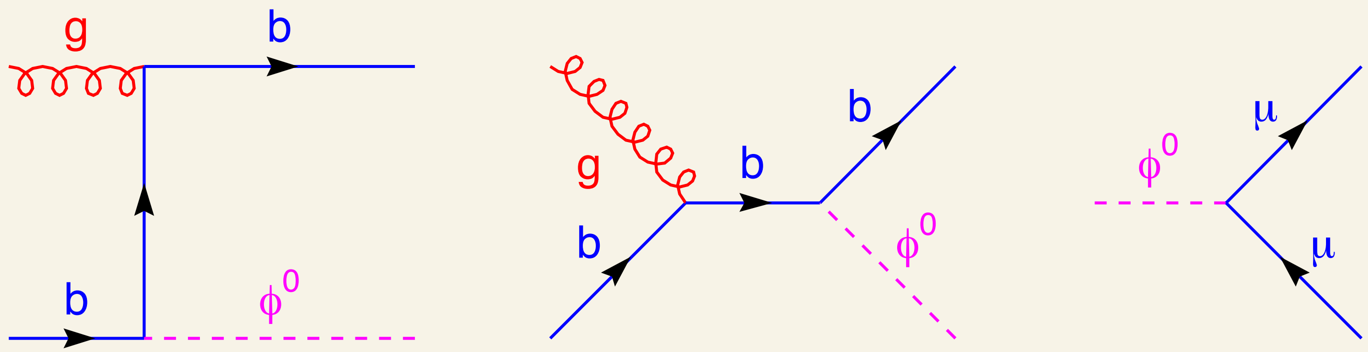


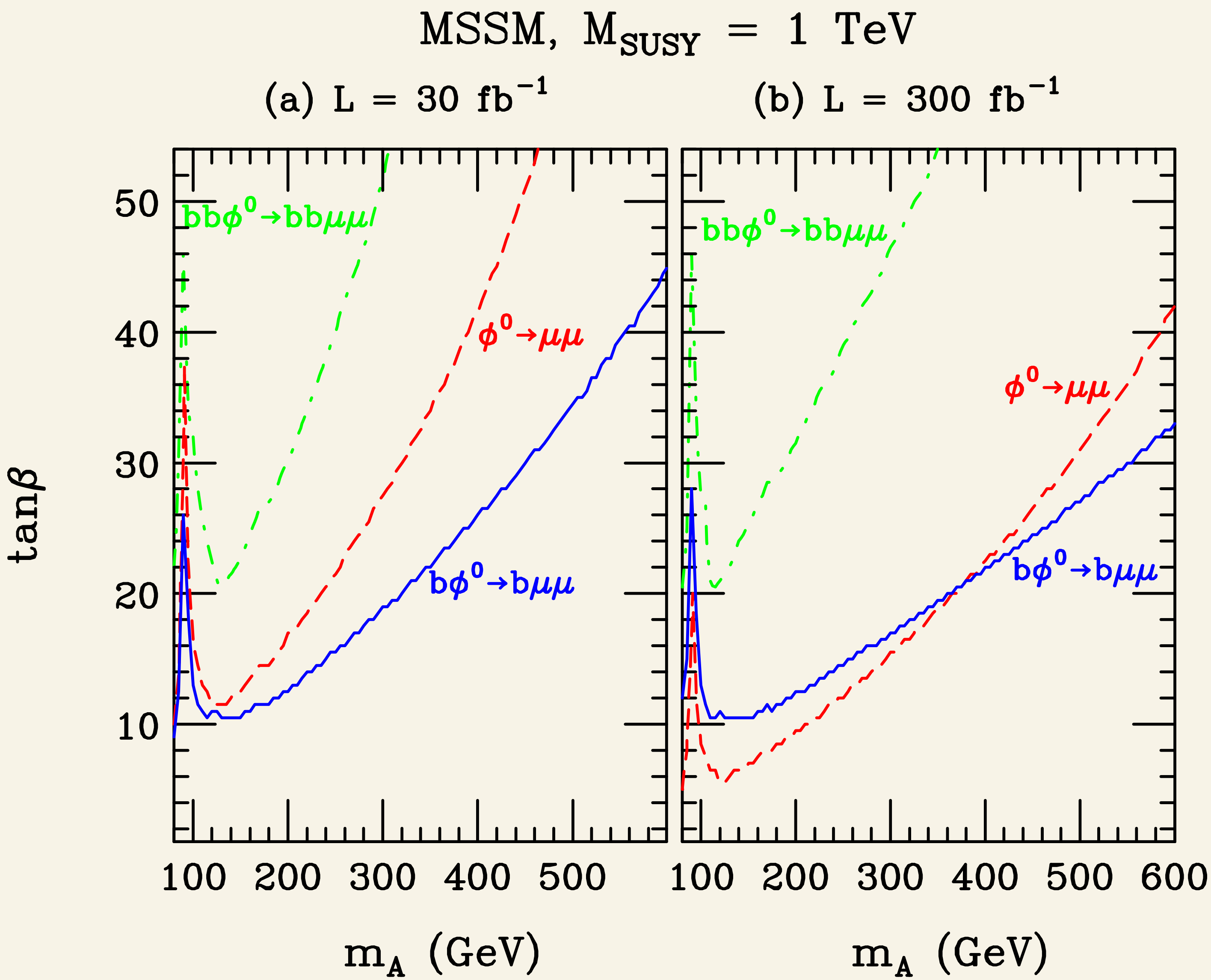
FIG 1/Kao and Stepanov

Discovering Higgs Bosons with Muons and a Bottom Quark



S. Dawson, D. Dicus, C. Kao and R. Malhotra, Phys. Rev. Lett. 92, 241801 (2004). S. Dawson, D. Dicus, and C. Kao, Phys. Lett. B **545**, 132 (2002);
V. Barger and C. Kao, Phys. Lett. B **424**, 69 (1998);
C. Kao and N. Stepanov, Phys. Rev. D **52,** 5025 (1995).

Discovery Potential at the LHC



Summary for Higgs Decay into 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 $L = 30$ 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 inclusive channel $pp \to \phi^0 \to \mu^+\mu^- + X$.
- This discovery channel might provide good opportunities to measure important parameters such as the Higgs masses, $\tan\beta$, and Higgs couplings with bottom quarks and leptons.

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).

Collinear Approximation of Tau Decays

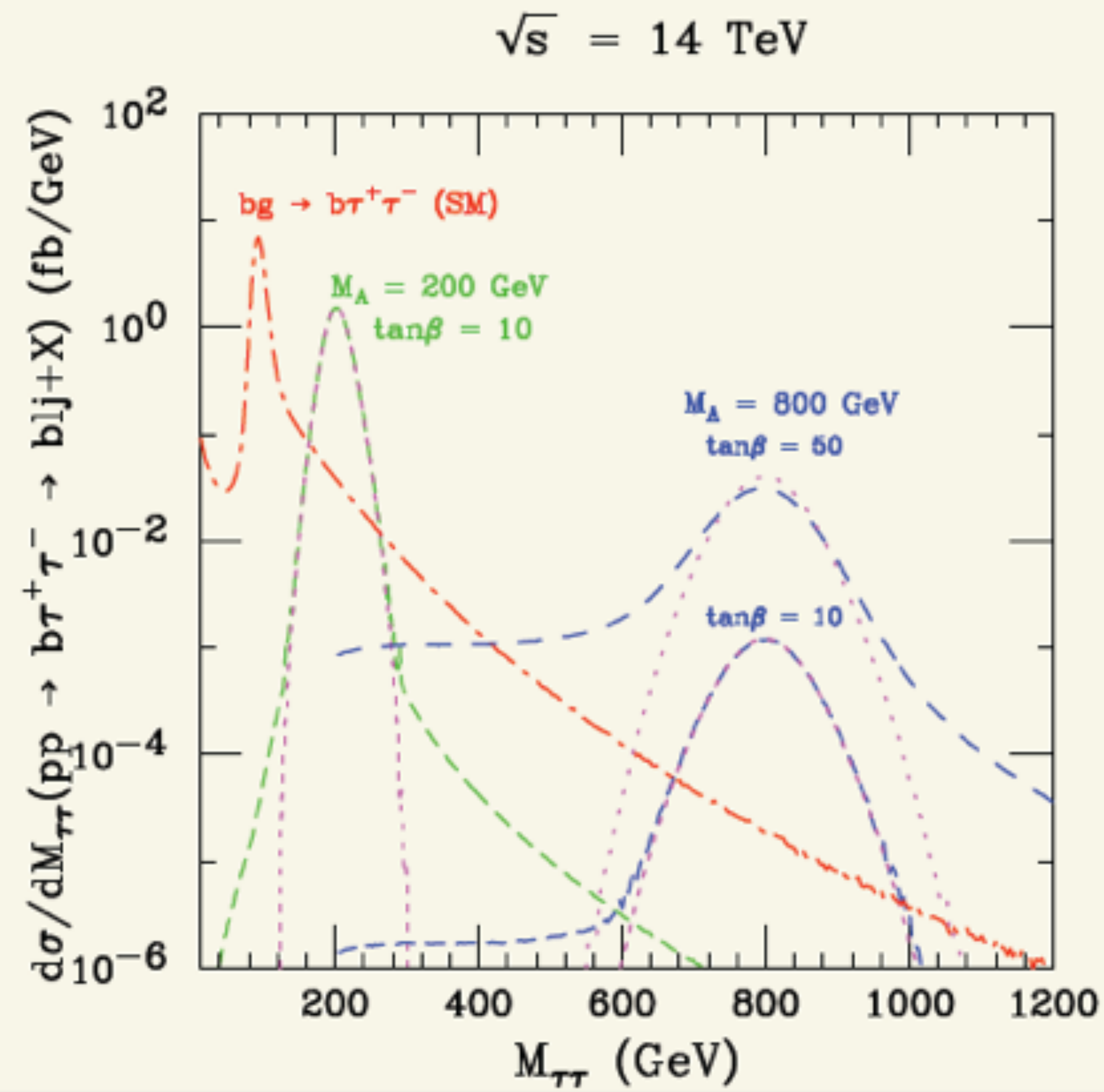
Hagiwara, Martin and Zeppenfeld (1990);
Rainwater, Zeppenfeld and Hagiwara (1999)

$$\frac{1}{\Gamma_\ell}\frac{d\Gamma_\ell}{dz} = \frac{1}{3}(1-z)[(5+5z-4z^2)+\chi_\tau(1+z-8z^2)]. \tag{2}$$

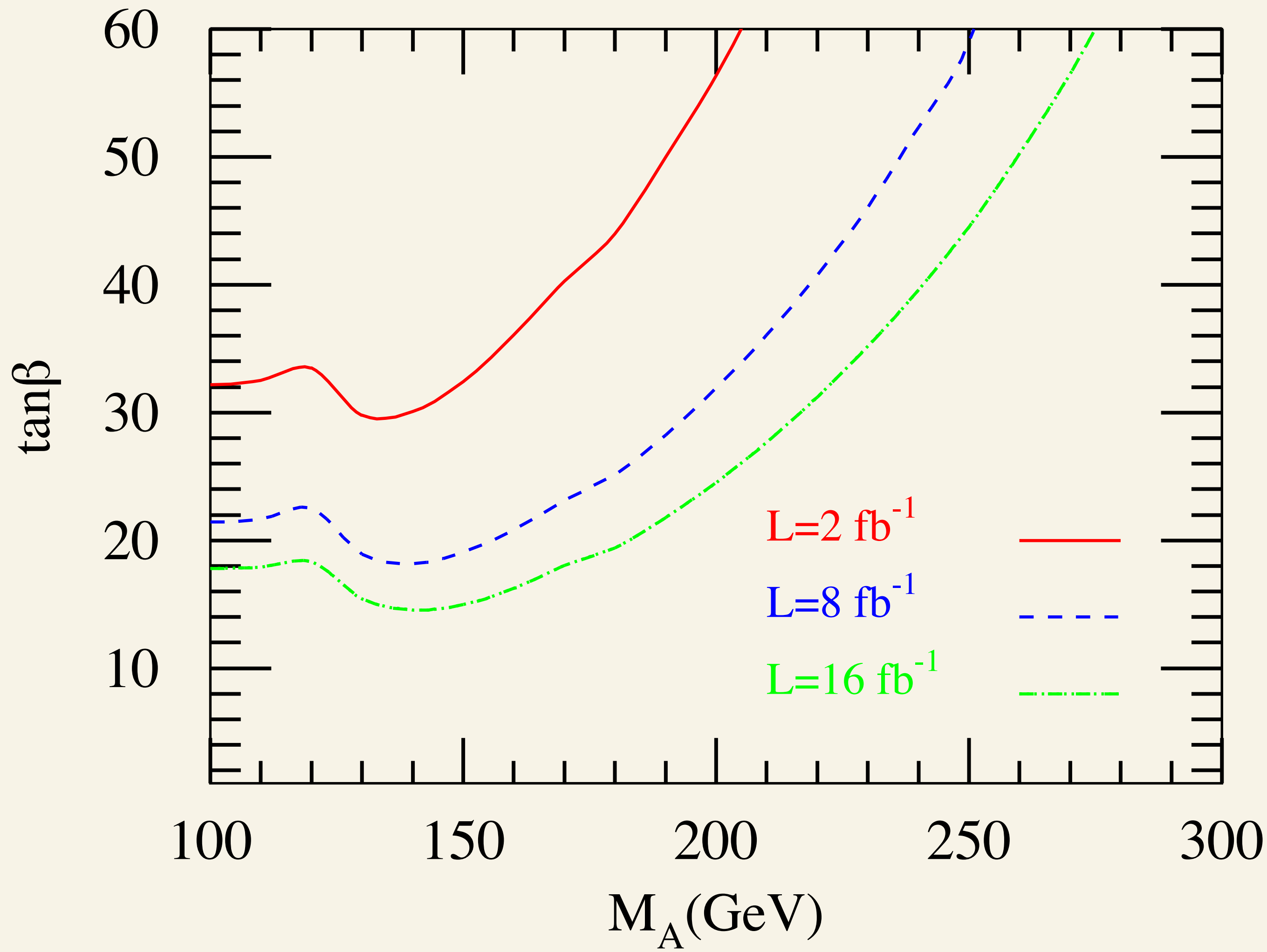
Here χ_τ denotes the chirality of the decaying τ (which, for a negative helicity τ^- or positive helicity τ^+, is given by $\chi_\tau = -1$ in the collinear limit). Similarly the pion spectrum for $\tau^\pm \to \pi^\pm \nu_\tau$ decays is given by

$$\frac{1}{\Gamma_\pi}\frac{d\Gamma_\pi}{dz} \simeq 1+\chi_\tau(2z-1). \tag{3}$$

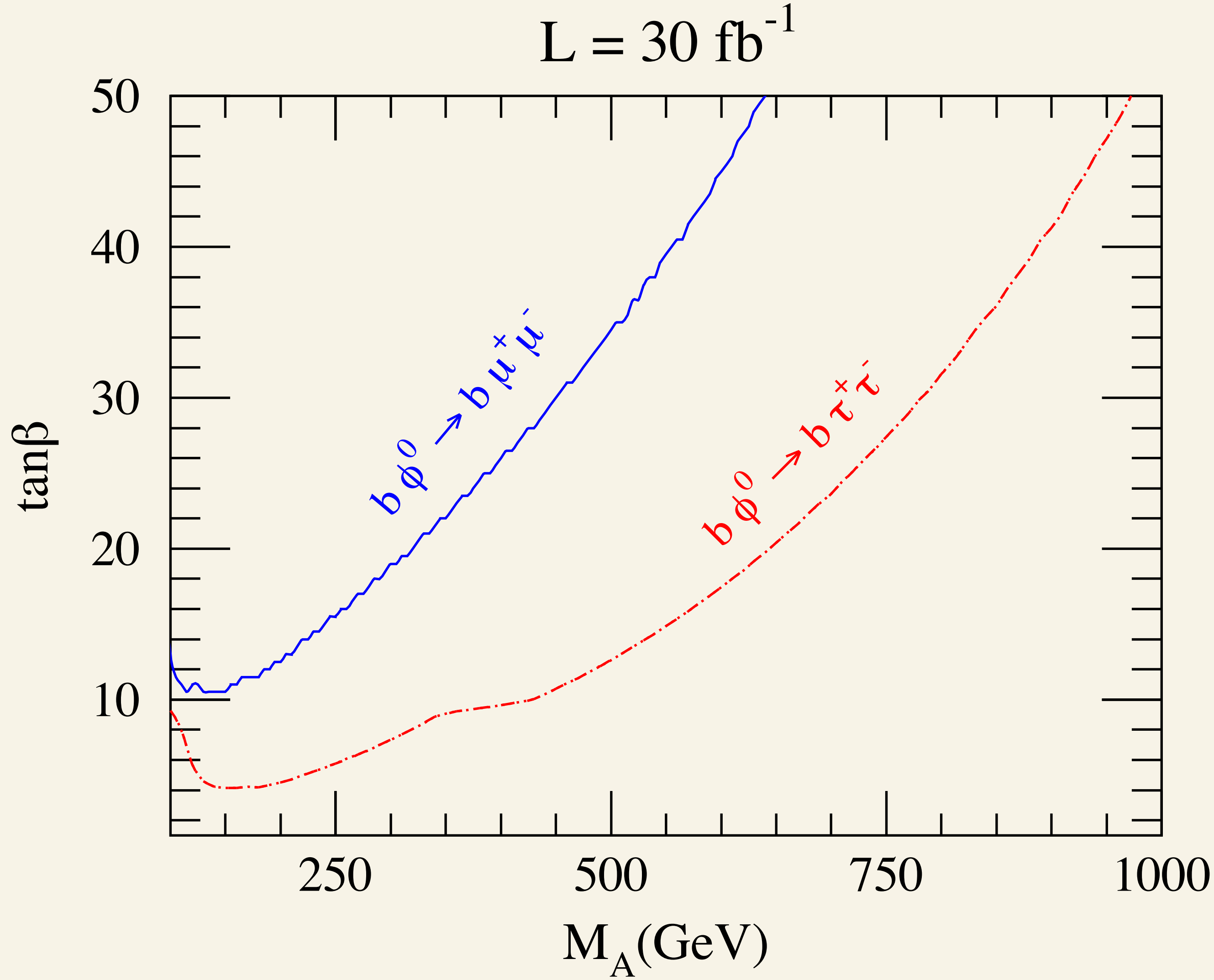
Invariant Mass Distribution



Discovery Potential at the Tevatron



Higgs Decays into Leptons



Summary for Higgs Decay into Leptons

- 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.

Discovering Higgs Bosons with Bottom Quarks

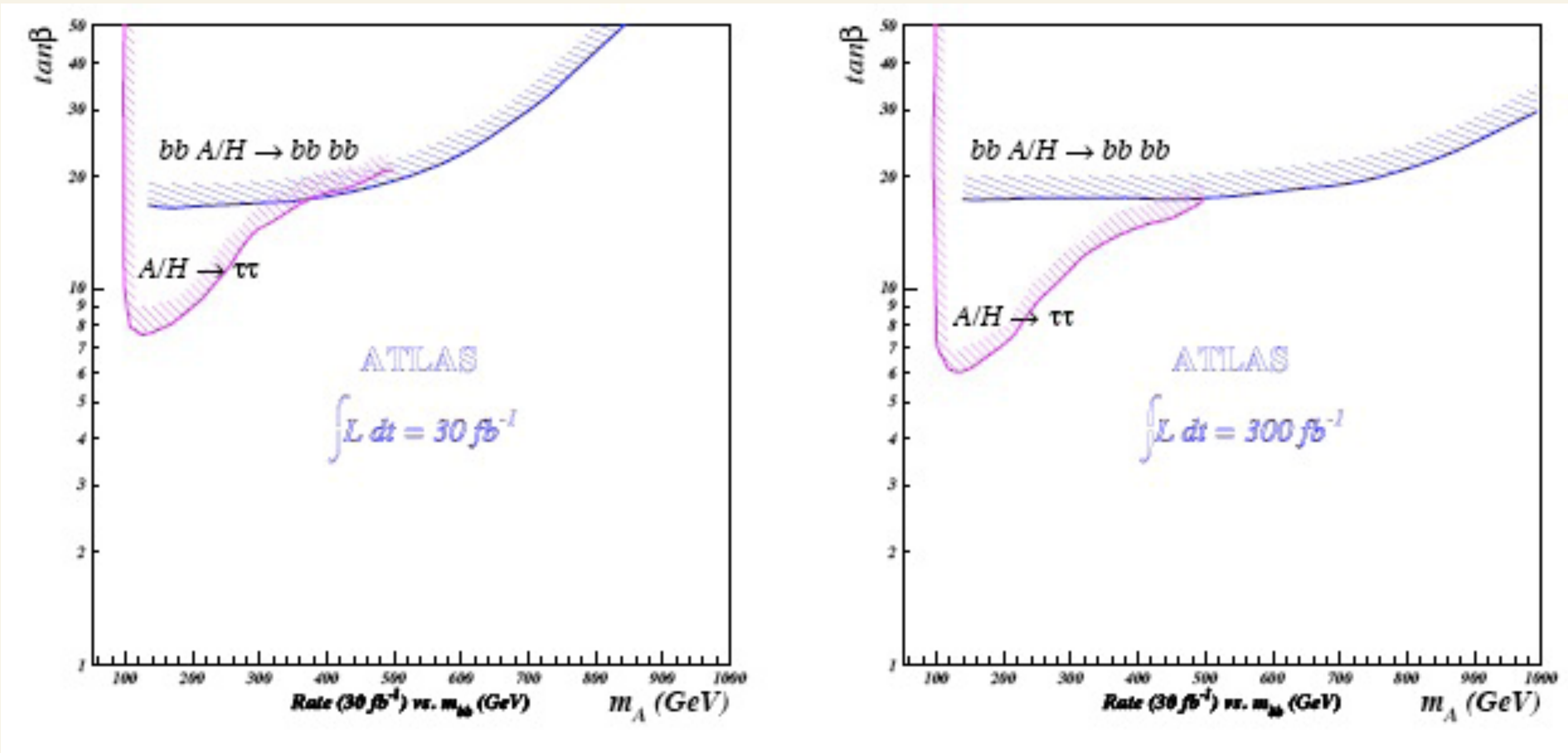
Kao, Sachithanandam, Sayre and Wang (2009)

- For a large value of tan(beta), the branching ratio of A^0 or H^0 to bb is approximately 89%.
- The inclusive channel of H to bb is overwhelmed by the QCD background.
- The associated channel of bbH to bbbb has two sepctator b's such that 95% of the signal and backround are removed by acceptance cuts.
- The associate channel of bH to bbb offers the best promise for Higgs search at hadron colliers.

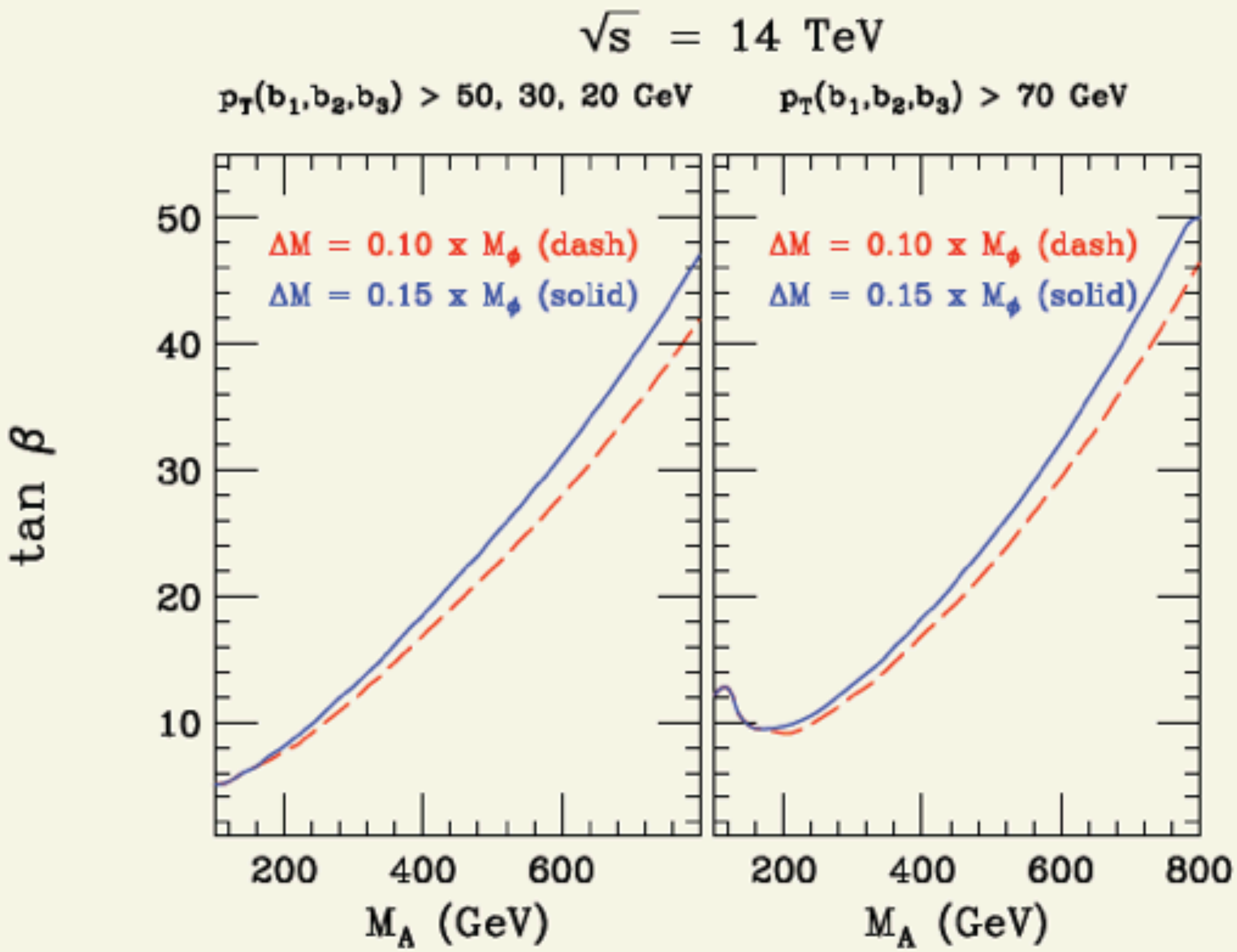
Associate Discovery Channel of bbH to bb bb

- Dai, Gunion and Vega (1994, 1996)
- Balazs, Diaz-Cruz, He, Tait and Yuan (1999)
- ATLAS TDR (1999), ATLAS Thesis (2002), ATLAS Report (arXiv:0901.0512/hep-ex, 2009)
- CMS TDR (2007)
- 3 jet trigger: $P_T > 70$ GeV (CMS) or $P_T > 75$ GeV (ATLAS)

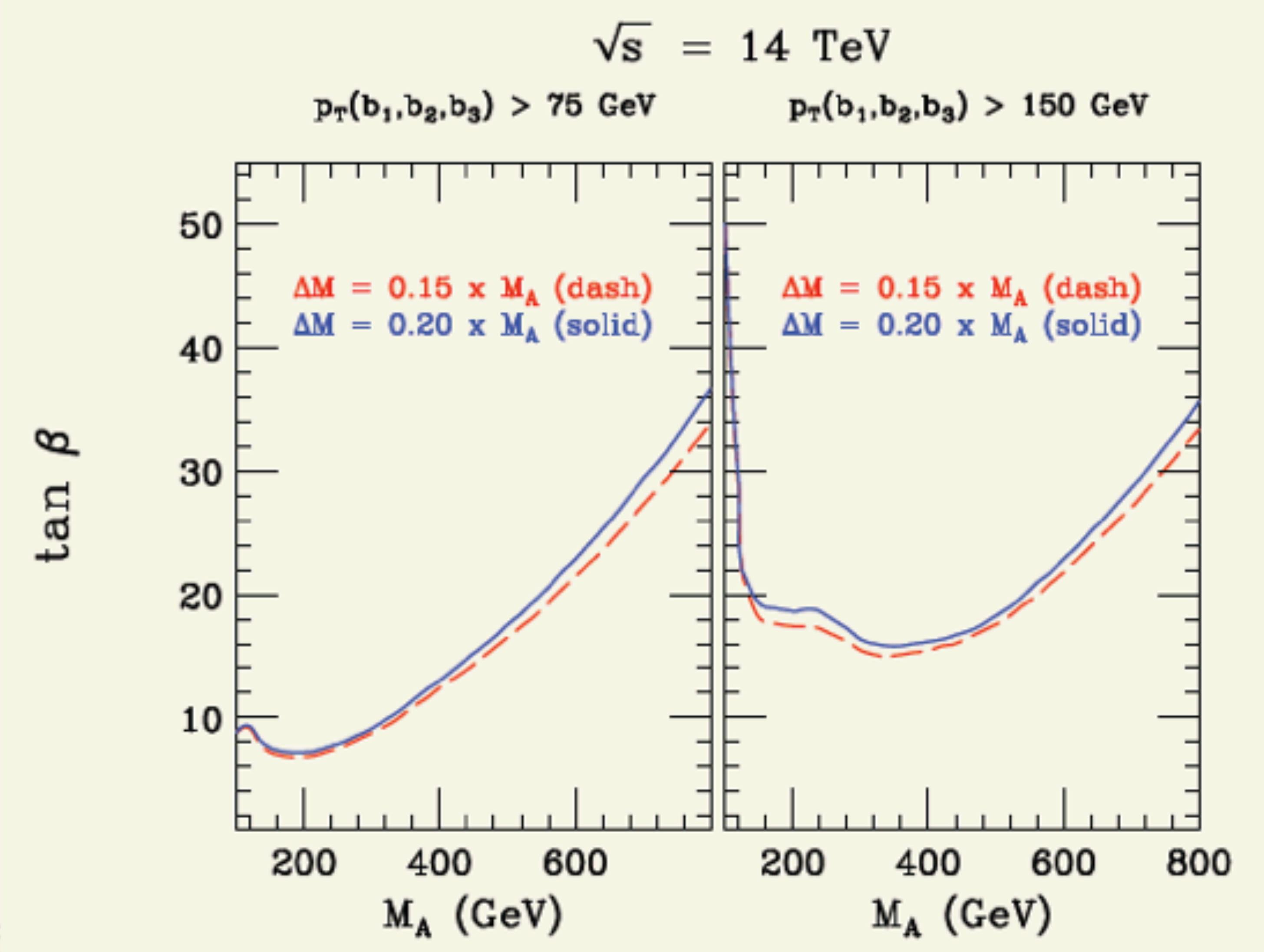
Discovery Potential at the ATLAS



Discovery Potential at the LHC with L = 30 fb^{-1}



Discovery Potential at the LHC with L = 300 fb^{-1}



Conclusions

- The tau pair discovery channel is the most promising mode to discover MSSM Higgs bosons up to 1 TeV at the LHC.
- The muon pair channel will provide an excellent opportunity to reconstruct Higgs boson mass with high precision.
- The bottom quark pair channel has large QCD background. With suitable cuts, the 3b final state will be promising at the LHC.
- In concert, this family of channels may provide an excellent window on the Yukawa sector of the MSSM or type II two-Higgs-doublet models.

Comparison with Results from MG_ME at the Parton Level for tan(b) = 10 with Basic Cuts: pT > 50 GeV, |eta| < 2.5

M_A (GeV)		σ_{PM}(fb)	σ_{MGME}(fb)
150		1483	1528
200		1109	1102
250		663	653

Results with PYTHIA and PGS

M_A (GeV)		σ_{PM}(fb)	σ_{MGME}(fb) (PGS)
150		61.39	6.22
200		76.63	16.50
250		65.43	16.85

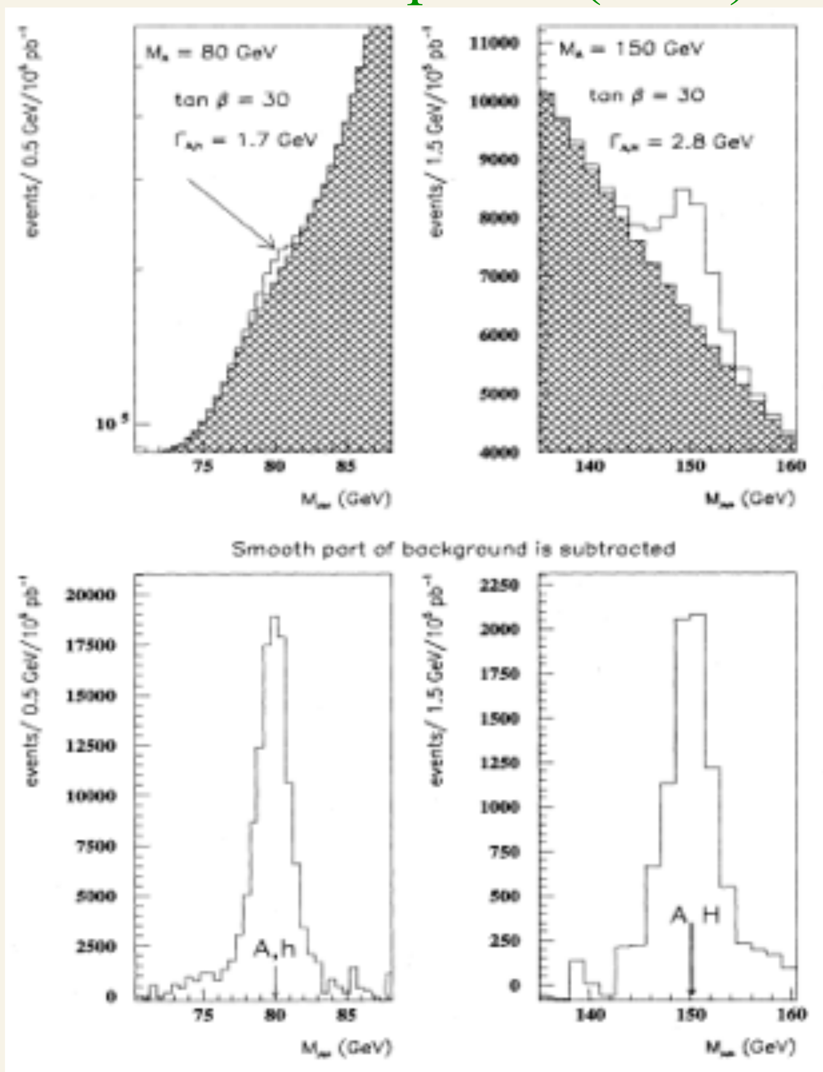
Results from PGS with eps(b) = 0.6

- ** Chain contains 40000 events
- 3 or more jets 37511
- less than 3-bs 29170
- 3 b-tags 8341
- PT/eta cuts 7652
- all cuts 588
- sigma = 16.2049 fb

Invariant Mass Distribution

A^0,h^0,H^0 to mu mu with PYTHIA and CMSJET

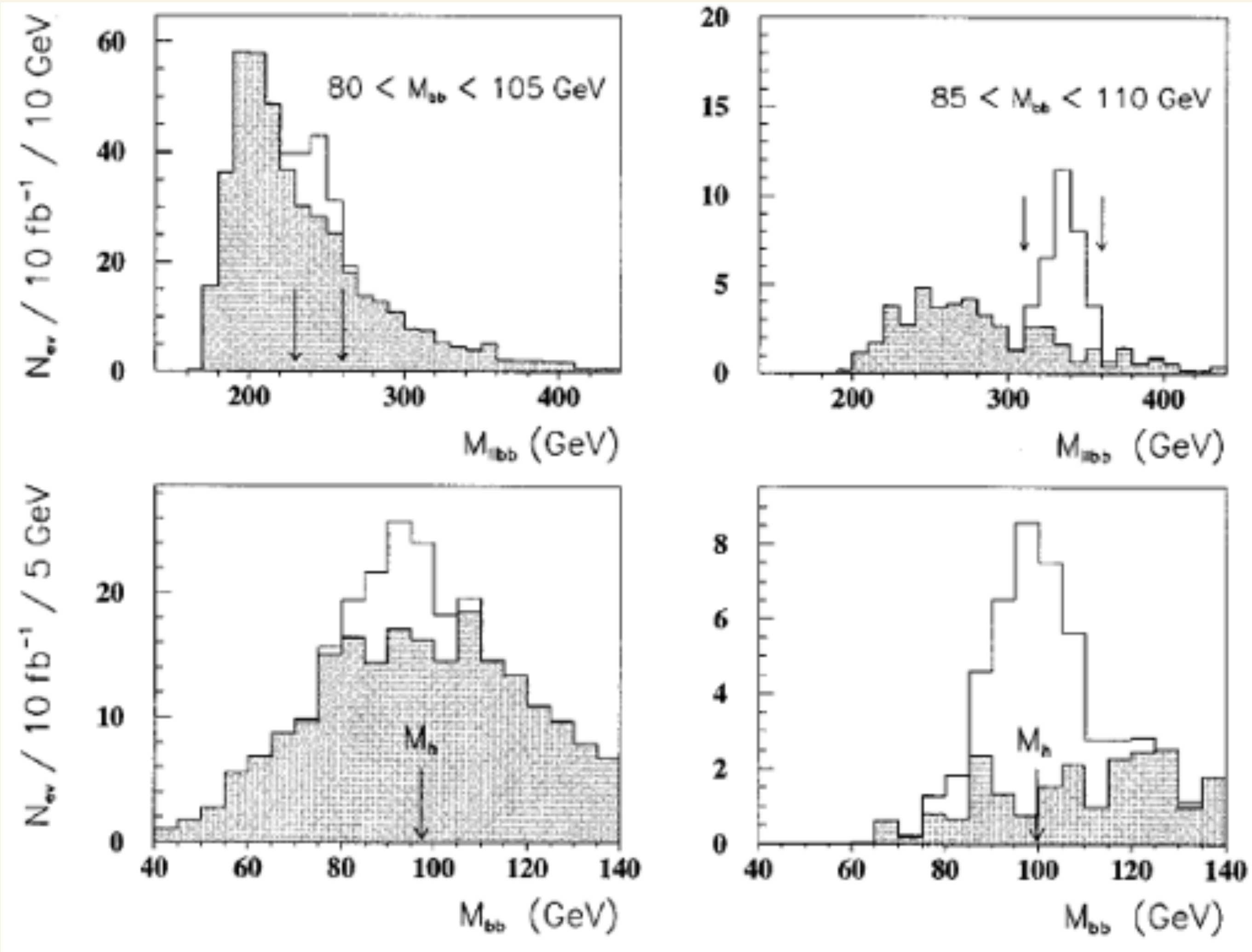
Kao and Stepanov (1995)



Invariant Mass Distribution

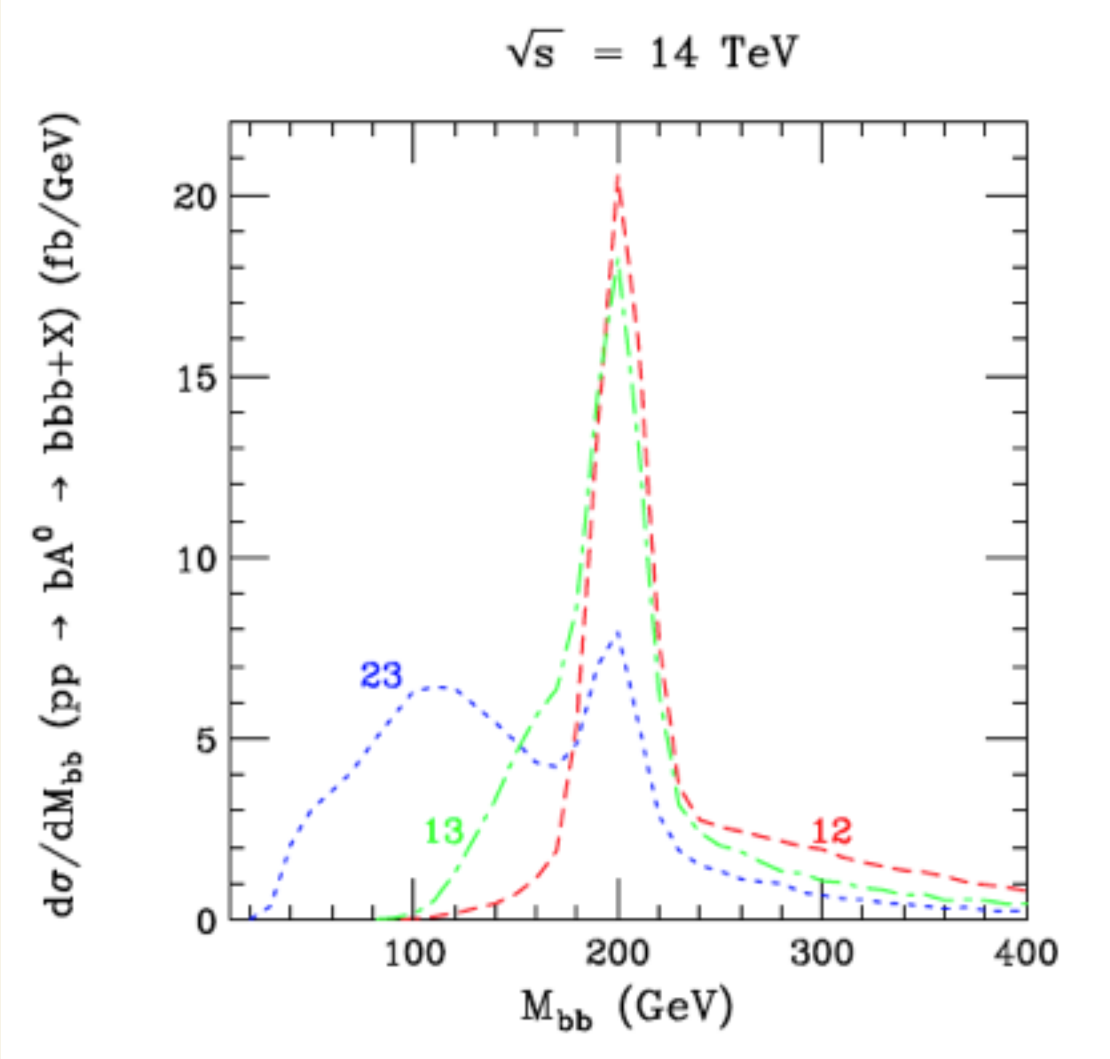
A^0 to Zh^0 to llbb with PYTHIA and CMSJET

Abdullin, Baer, Kao, Stepanov, and Tata (1996)



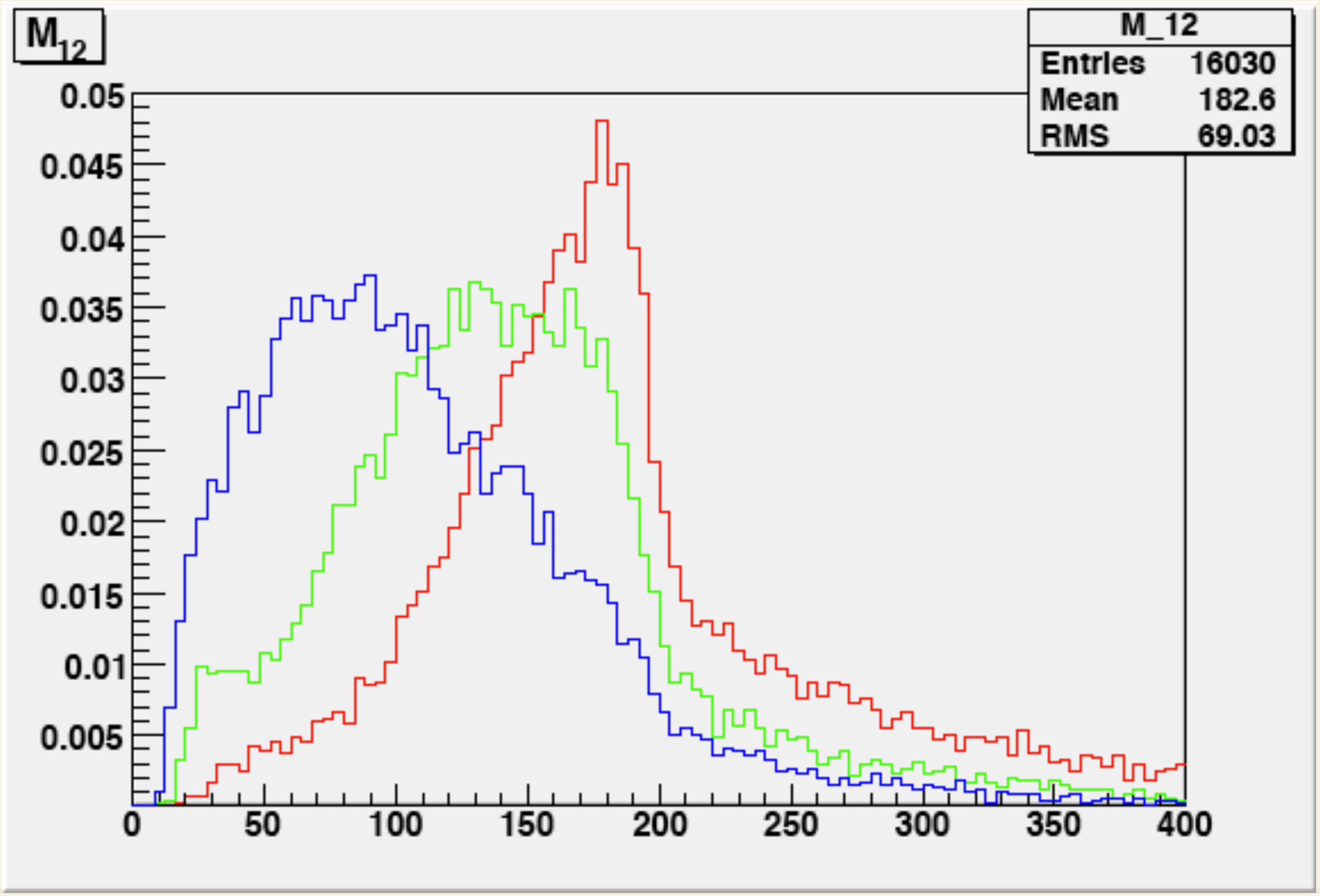
Invariant Mass Distribution

bA^0 to bbb at the Parton Level



Invariant Mass Distribution

bA^0 to bbb with PYTHIA and PGS



Challenges

- Phenomenologists build bridges between interesting Theoretical Models and Experiments.
- How do we compare experimental data with theoretical predictions or expectations, especially when there are b's, tau's and jets?
- How do we analyze experimental data to determine 'correct' model parameters?
- Cacciari, Rojo, Salam and Soyez (2008);
  Cacciari, Salam and Soyez (2008);
  talks by G. Salam and G. Soyez.
- Many thanks to Josh Sayre and Peter Skands!