Higgs Bosons and b Quarks

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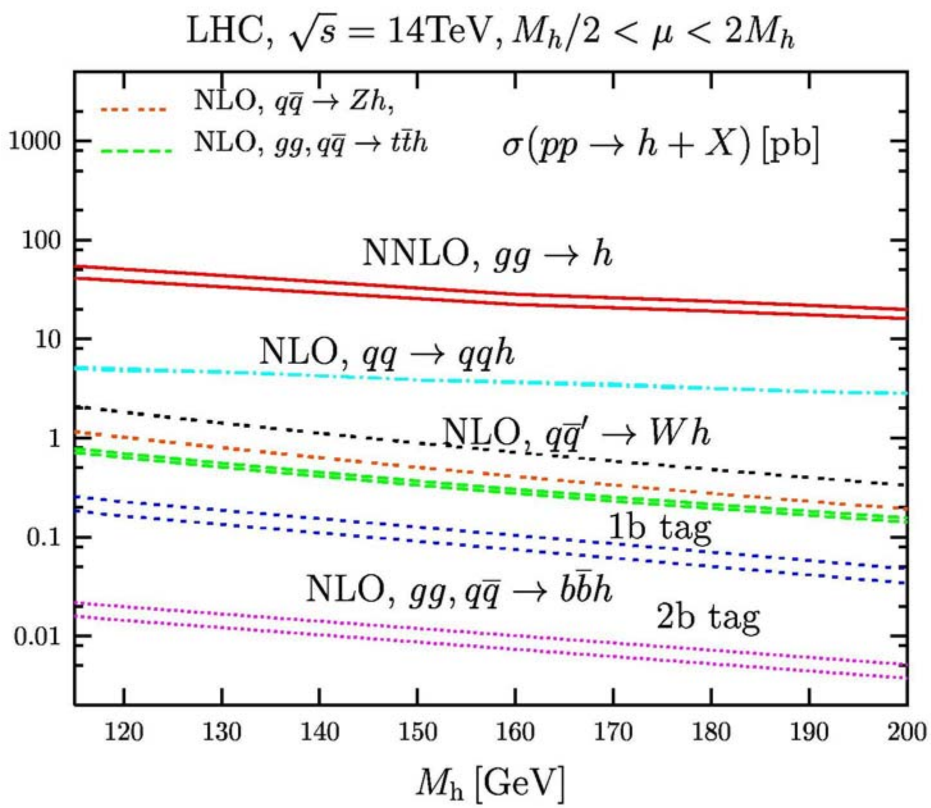
SM Production Mechanisms at LHC



Production with b's very small in SM

- In SM, Information about $b\bar{b}h$ coupling must come from decays

- Progress in extracting $h \to b\bar{b}$ from boosted Higgs techniques

Higgs in the MSSM

- MSSM has 2 Higgs doublets: H_d and H_u

$$H_d = \begin{pmatrix} \varphi_d^+ \\ \varphi_d^0 \end{pmatrix} \qquad H_u = \begin{pmatrix} \phi_u^0 \\ -\phi_u^- \end{pmatrix}$$

$$\phi_d^0 = \frac{1}{\sqrt{2}}\left(v_1 + h_d^0\right)$$

$$\phi_u^0 = \frac{1}{\sqrt{2}}\left(v_2 + h_u^0\right)$$

$$\tan\beta = \frac{v_2}{v_1}$$

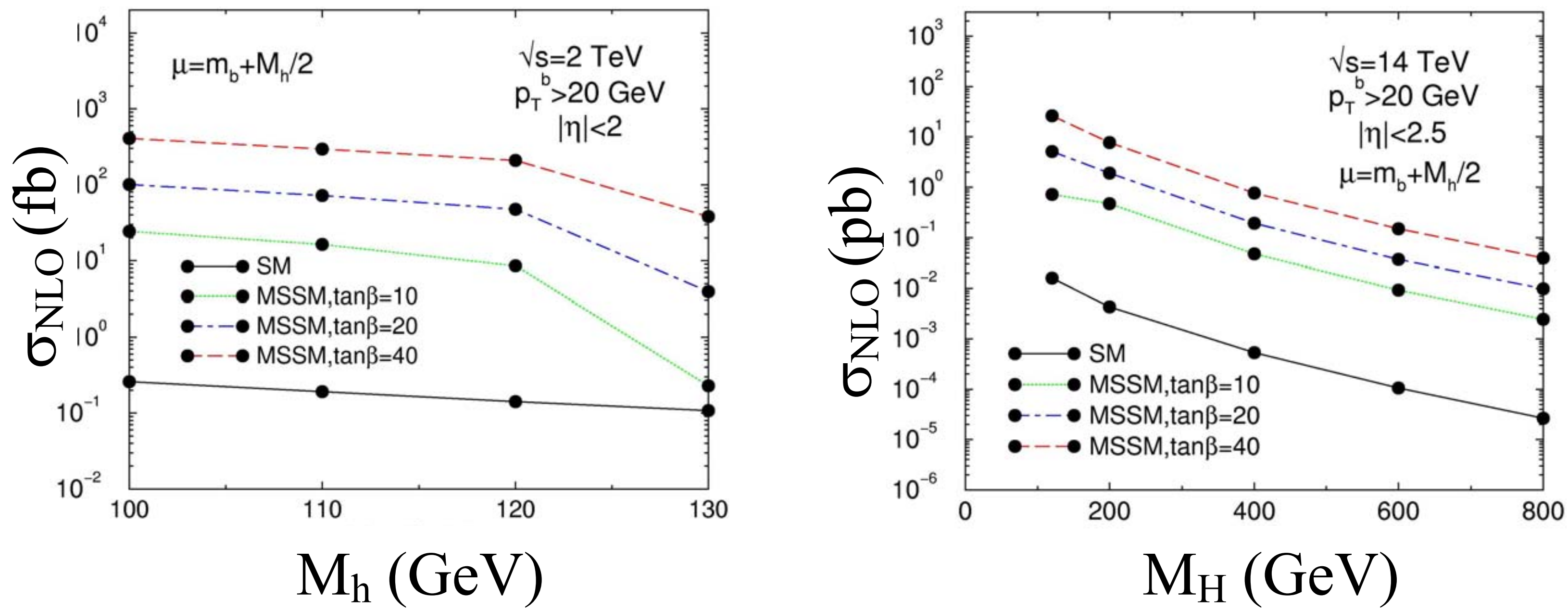
- Physical CP-Even Higgs bosons

$$\begin{pmatrix} h^0 \\ H^0 \end{pmatrix} = \begin{pmatrix} c_\alpha & -s_\alpha \\ s_\alpha & c_\alpha \end{pmatrix} \begin{pmatrix} h_u{}^0 \\ h_d{}^0 \end{pmatrix}$$

- Pseudoscalar, A^0, and two charged Higgs, $H^\pm$
- At tree level, $$g_{hbb} \equiv \frac{m_b}{v_{SM}}\left(-\frac{\sin\alpha}{\cos\beta}\right)$$

$MSSM: \quad pp, p\bar{p} \rightarrow b\bar{b}\Phi$

Rates large even at relatively small tan β



H, A couplings to d, s, b enhanced at large tan β

h couplings to d, s, b enhanced at large tan β for small M_A

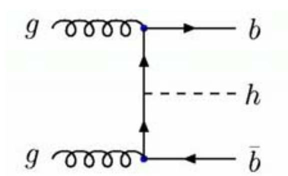
Theoretical Issues in $b\bar{b}\Phi$ production

Reduced ↓ Background

- Inclusive mode: No tagged b's
- Semi-inclusive mode: At least one tagged b
- Exclusive mode: Two tagged b's

Larger ↑ Signal

- Treating b quarks inclusively leads to large collinear logarithms from integration over phase space



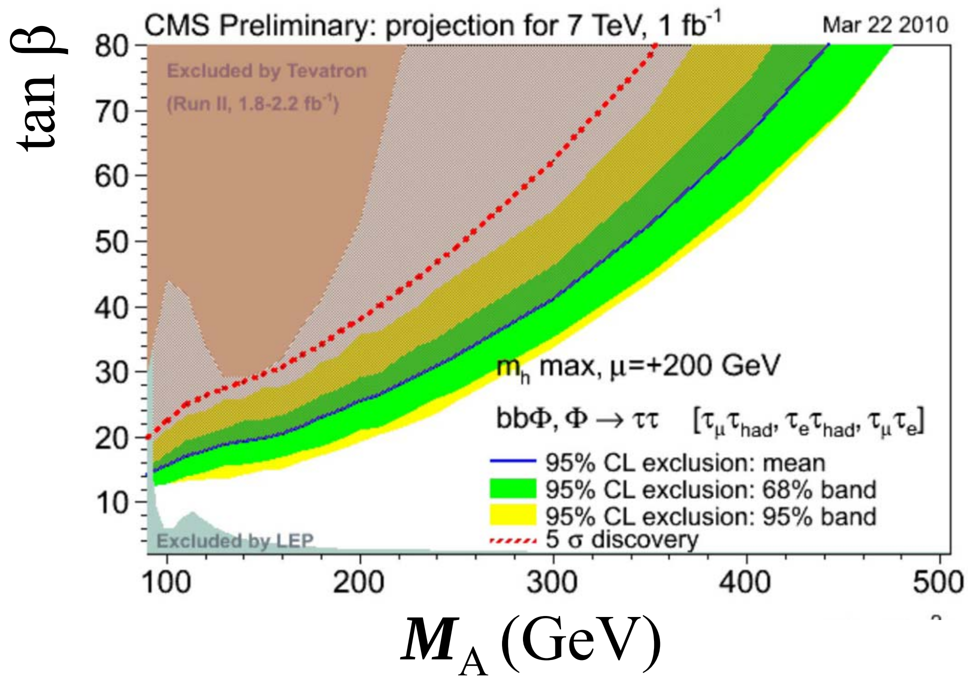
$$\ln\left(\frac{\mu_F^2}{m_b^2}\right), \qquad \mu_F \approx M_h$$

- Expansion parameter becomes $\alpha_s \log(m_b/M_h)$
- Absorb large logs into b PDFS
  - Relevant process is then $bg \rightarrow b\Phi$ or $b\bar{b} \rightarrow \Phi$

Focus on bΦ Production

- Significant rate in MSSM
  - Discovery channel at both LHC and Tevatron
  - Sensitive to $b\bar{b}\Phi$ Yukawa couplings
  - Interesting theoretical questions about b PDFs
- Rate known to NLO QCD
  - Uncertainties from PDFs, renormalization /factorization scale variation
  - Inclusion of SUSY loops: squarks/gluinos
  - Inclusion of EW effects

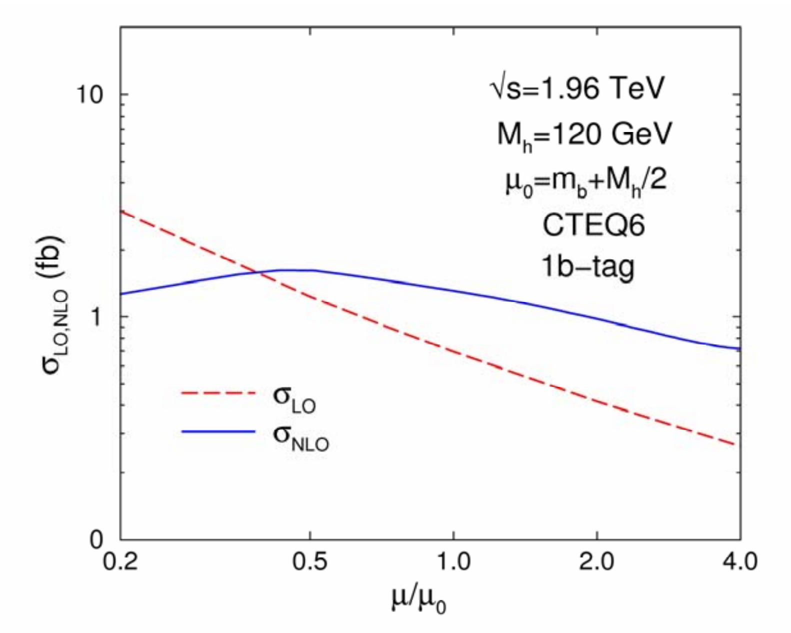
LHC Expectations

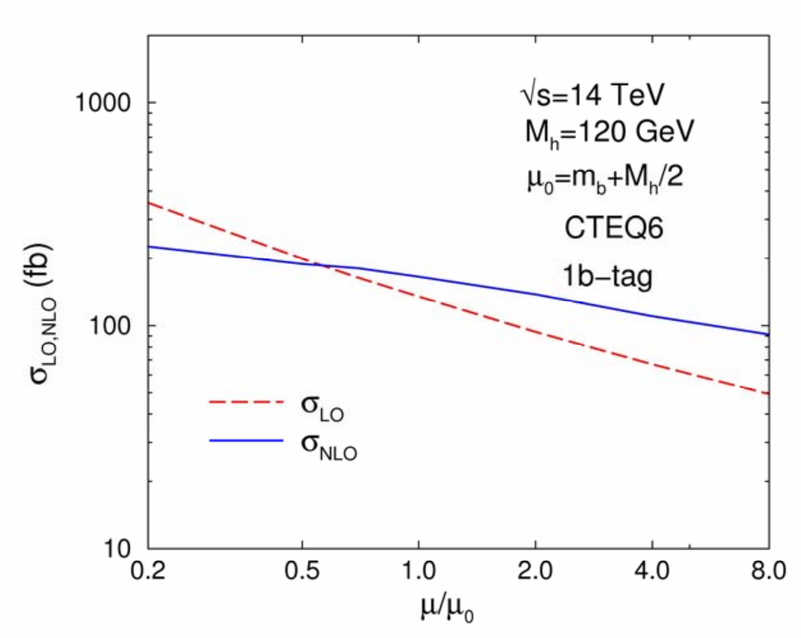


➢Higgs Discovery Channel

QCD Corrections Important

- NLO corrections improve scale dependence
- NLO QCD corrections large (can't neglect them!)
- Standard Model bh production:





Dawson, Jackson, Reina, Wackeroth, [hep-ph/0408077,0508293]

Dittmaier, Kramer, Spira, [hep-ph/0309204]

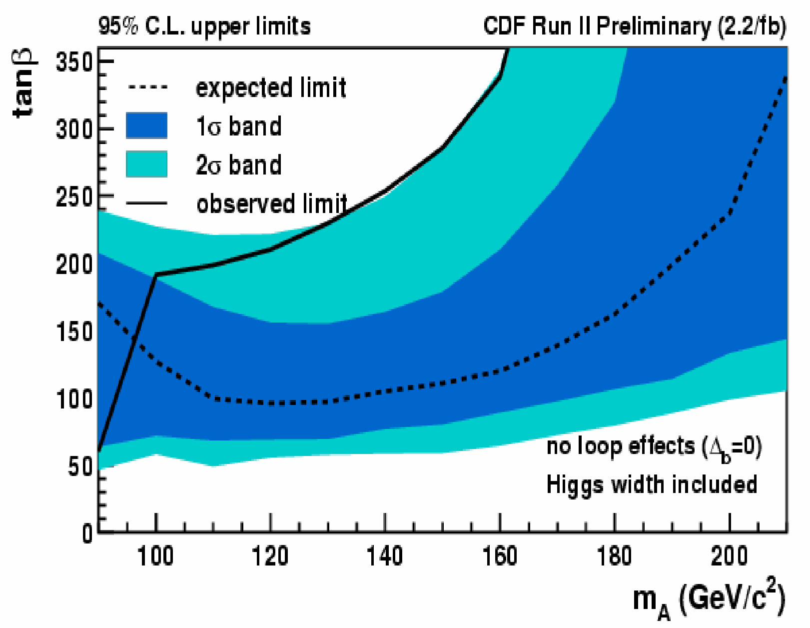
Calculate SUSY QCD Corrections to bg→bΦ

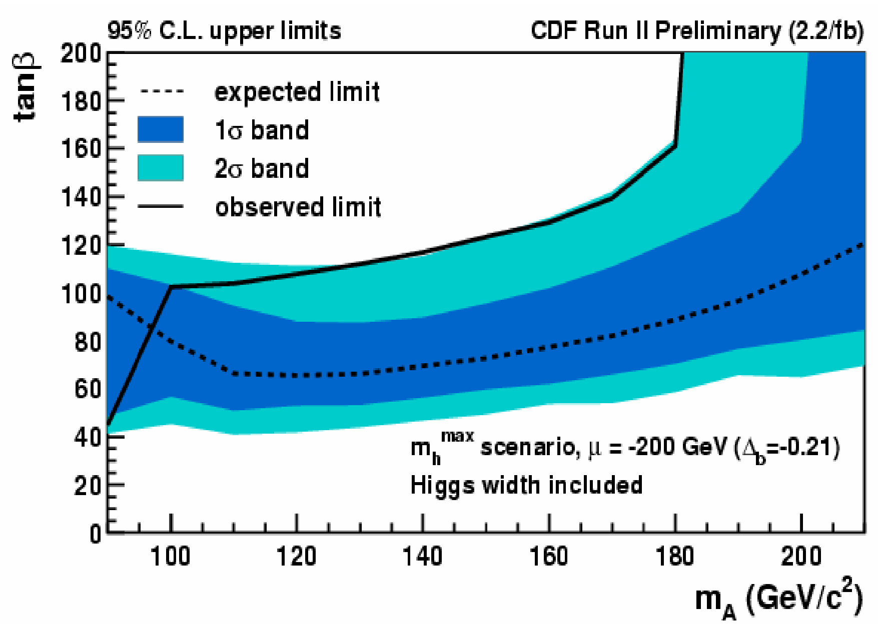
- Approach 1: Improved Born Approximation (Δm_b)
  - This is simply rescaling of on-shell $b\bar{b}\Phi$ vertex
  - Approximation extensively used
  - Excellent approximation for $b\bar{b}\to\Phi$

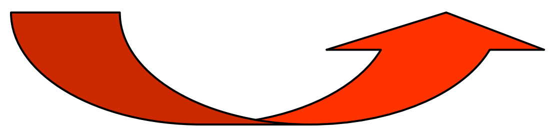
$$\sigma_{IBA} = \left(\frac{g_{hbb}}{g_{hbb}^{Tree}}\right)^2 \sigma$$

$$g_{hbb} \equiv \frac{m_b}{v_{SM}}\left(\frac{1}{1+\Delta m_b}\right)\left(-\frac{\sin\alpha}{\cos\beta}\right)\left(1-\frac{\Delta m_b}{\tan\beta\tan\alpha}\right)$$

Limits from Tevatron



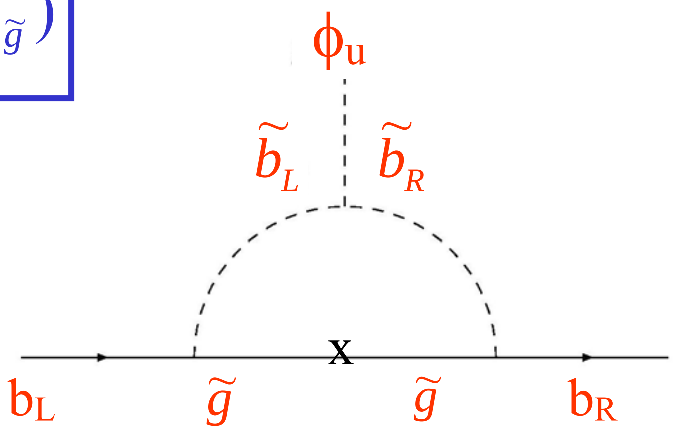




Note dependence of limits on assumptions about loop (Δm_b) effects

b's Couple to Both Higgs at 1-Loop

$$\Delta m_b = \frac{2\alpha_s}{3\pi} m_{\tilde{g}} \mu I(m_{\tilde{b}_1}, m_{\tilde{b}_2}, m_{\tilde{g}})$$



Non-decoupling Effect:

$$m_{\tilde{g}}, m_{\tilde{b}_1}, m_{\tilde{b}_2}, \mu >> M_h, M_Z$$

$$\Delta m_b^{SQCD} = -sign(\mu)\frac{\alpha_s}{3\pi}\left(\frac{\mu m_{\tilde{g}}}{M_{SUSY}^2}\right)(\tan\beta + \cot\alpha)$$

Slow Decoupling for large tan β

- Approach to decoupling slowed for large tan β
- If M_A also large, decoupling recovered

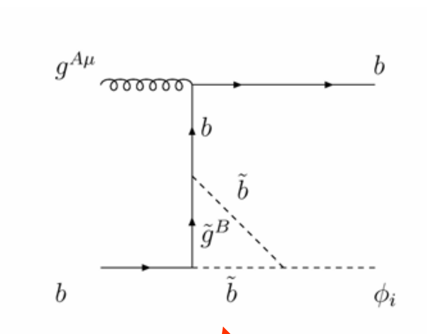
$$\Delta m_b^{SQCD} = -sign(\mu)\frac{\alpha_s}{3\pi}\left(\frac{\mu m_{\tilde{g}}}{M_{SUSY}^2}\right)(\tan\beta + \cot\alpha)$$

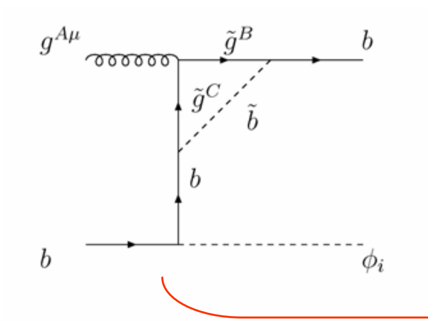
$$\tan\beta + \cot\alpha \rightarrow -\frac{2M_Z^2}{M_A^2}\tan\beta\cos 2\beta$$

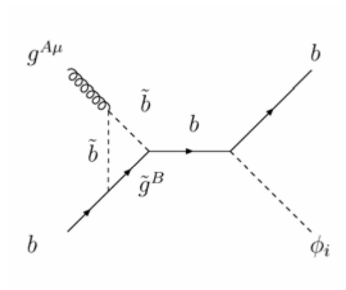
- Same slow decoupling in $gb \rightarrow b\Phi$

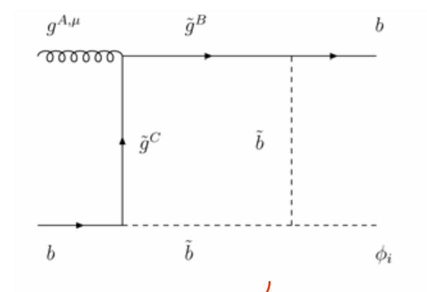
Calculate SUSY QCD Corrections to bg→bΦ

- $O(\alpha_s^2)$ NLO SUSY QCD calculation
  - Use g_{hbb} as above, so subtract off double counting
  - Include all contributions from squark/gluino loops









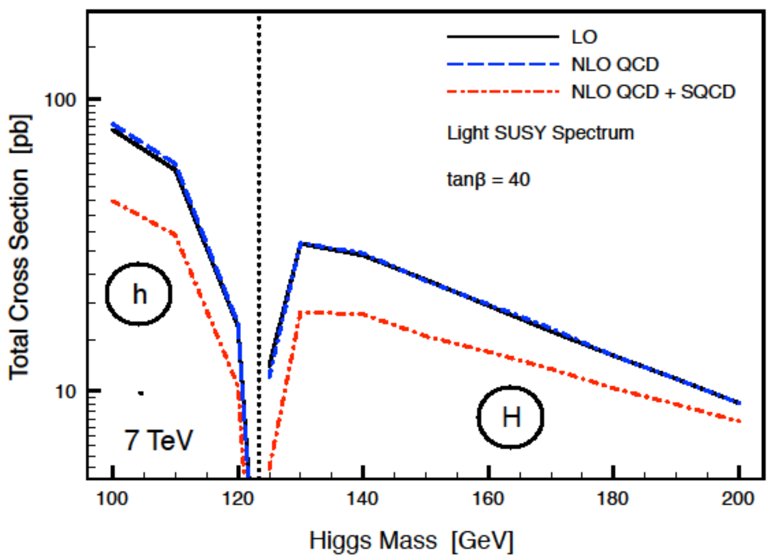
Δm_b approximation puts bbΦ vertex on shell

Many contributions not included in IBA

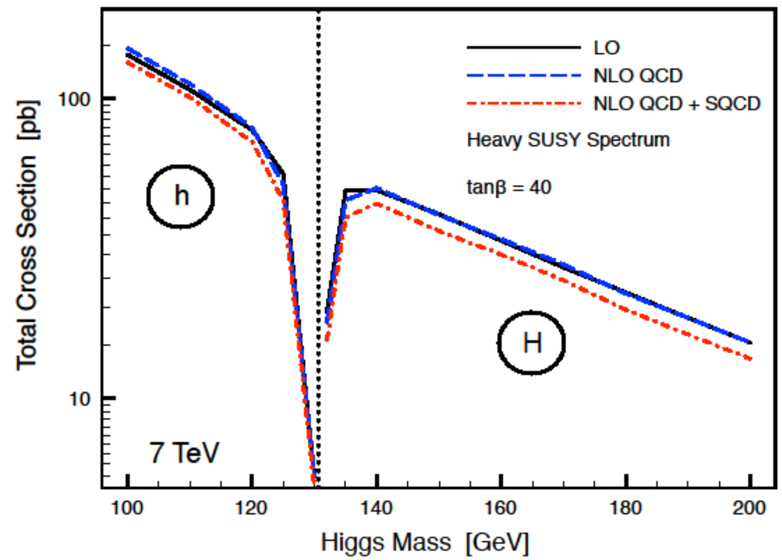
Jackson, Dawson

Can't neglect SQCD Effects on bg→bΦ

$\sqrt{s}$ = 7 TeV



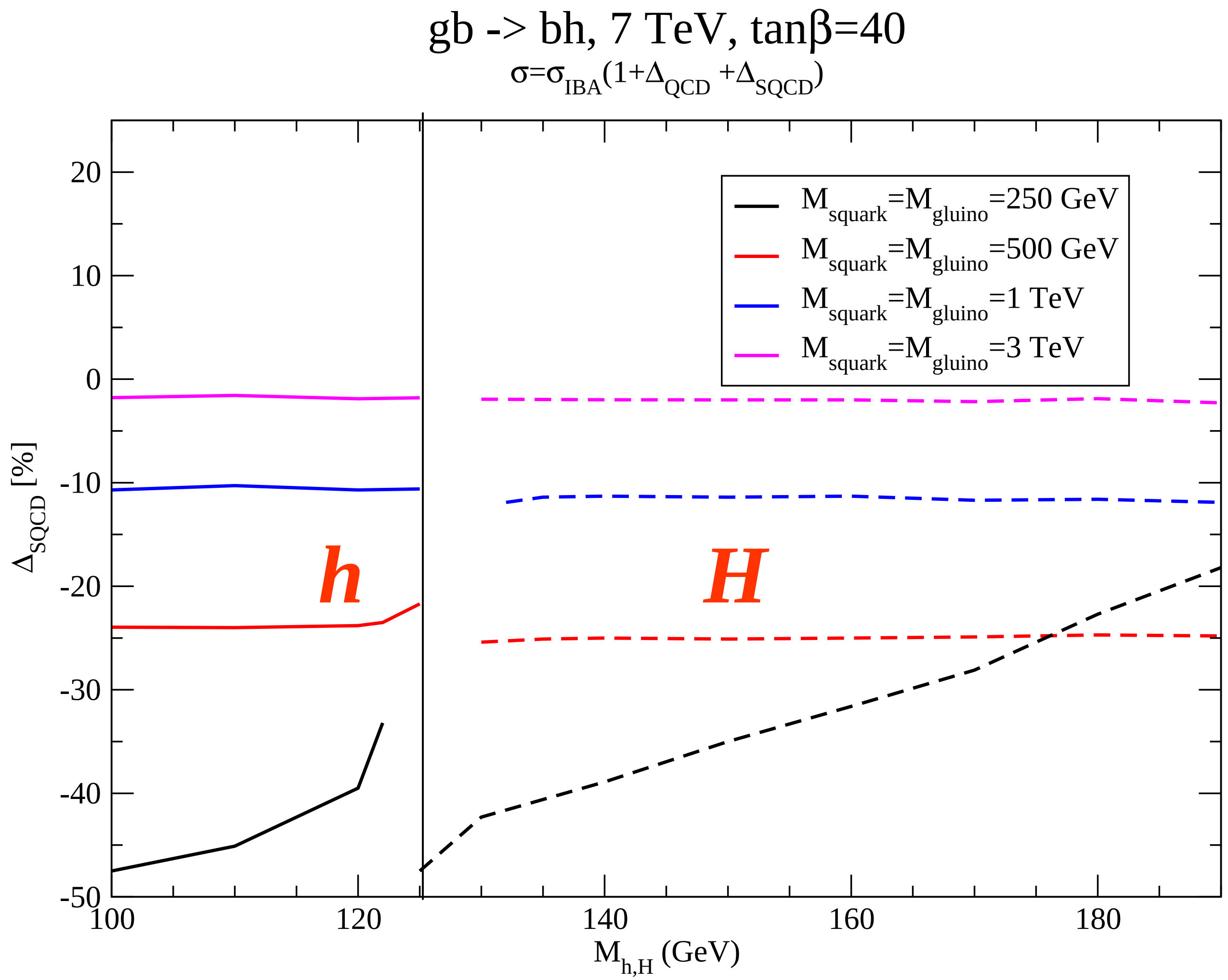
$M_{squark}=M_{gluino}$=250 GeV



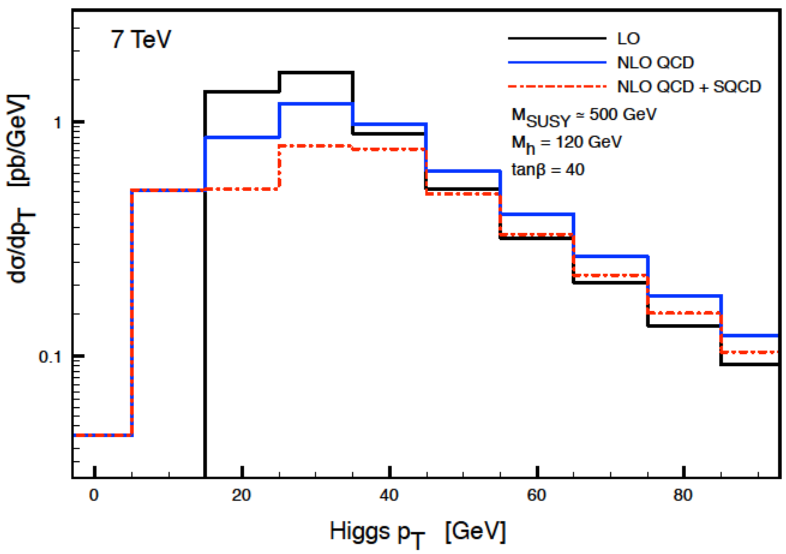
$M_{squark}=M_{gluino}$=1 TeV

SQCD effects large for light SUSY and large tan β

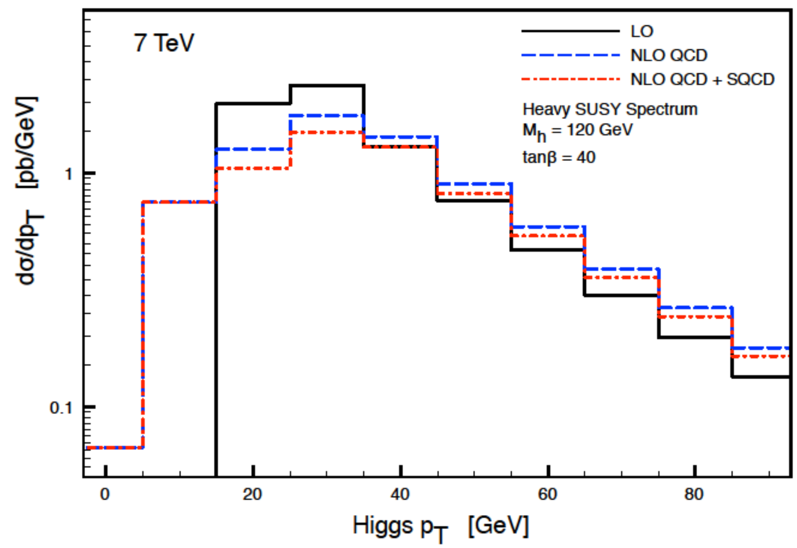
Slow Decoupling of SQCD Effects



Non-Decoupling of SQCD for Light SUSY
$(pp \rightarrow bh)$



$$\tilde{m}_g = \tilde{m}_b = 500\,GeV$$



$$\tilde{m}_g = \tilde{m}_b = 1\,TeV$$

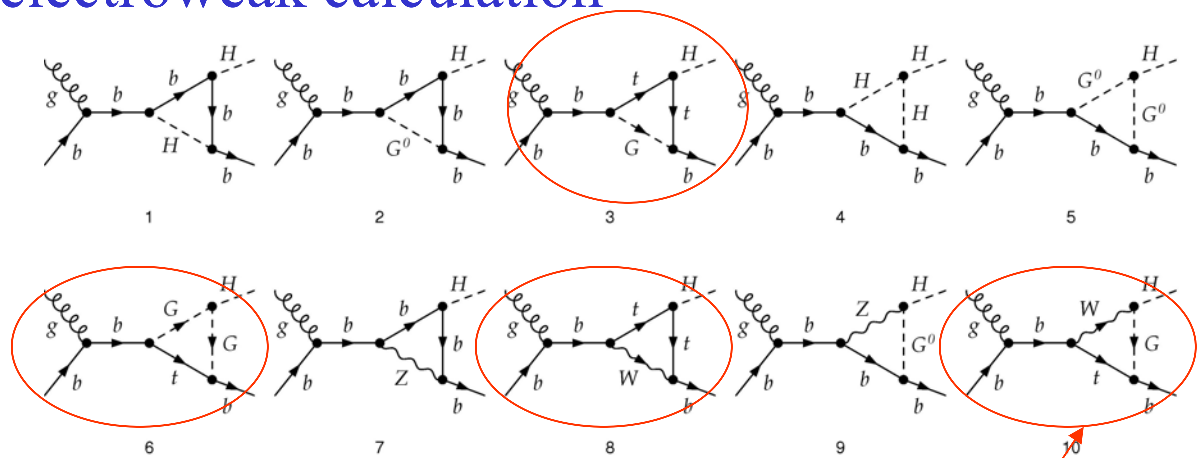
Improved Born Approximation fails for light SUSY particles

Light SUSY particles numerically important

Jackson, Dawson

Do Electroweak Corrections Matter?

- Lowest order rate for bg→bh vanishes for m_b=0
- At 1-loop, there are diagrams which do NOT vanish in m_b=0 limit
- Full electroweak calculation



Proportional to m_t not m_b

Plus many more diagrams…..

Electroweak Corrections

- Compare full Standard Model calculation for gb→bh with Improved Born approximation (IBA) for EW corrections
  - IBA includes on-shell $b\bar{b}h$ vertex contributions
  - IBA is excellent approximation for EW contributions to $b\bar{b}\to\Phi$

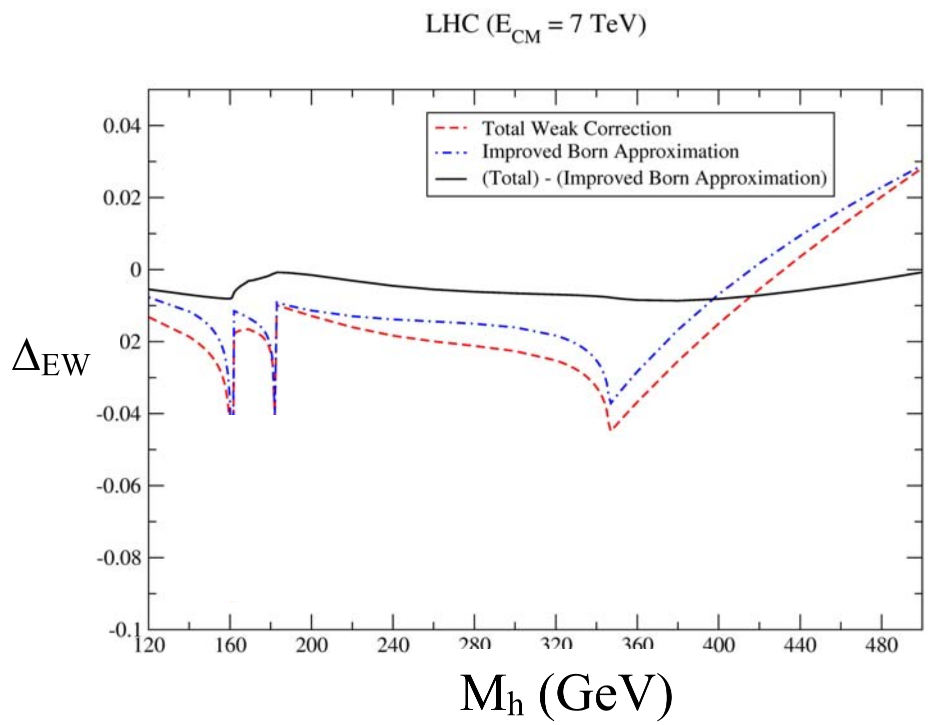
Dittmaier, Kramer, Muck, Schluter, [hep-ph/0611353]

Standard Model: EW Corrections to pp → b h

$$\sigma(pp \to bh) = \sigma_0 \left(1 + \Delta_{QCD} + \Delta_{EW}\right)$$

For M_h ~ 400 GeV corrections 2-4%

IBA captures weak corrections accurately



Dawson, Jaiswal [arXiv:1002.2672]

EW Corrections in Large M_h Limit

- Dominant contributions from $b\bar{b}h$ vertex
  - No contributions which grow with M_h from triangle or box diagrams

$$\sigma(bg \to bh) \approx \sigma_0 \left(1 + \frac{M_h^2}{32\pi v^2} \left[13 - 2\pi\sqrt{3} \right] \right)$$

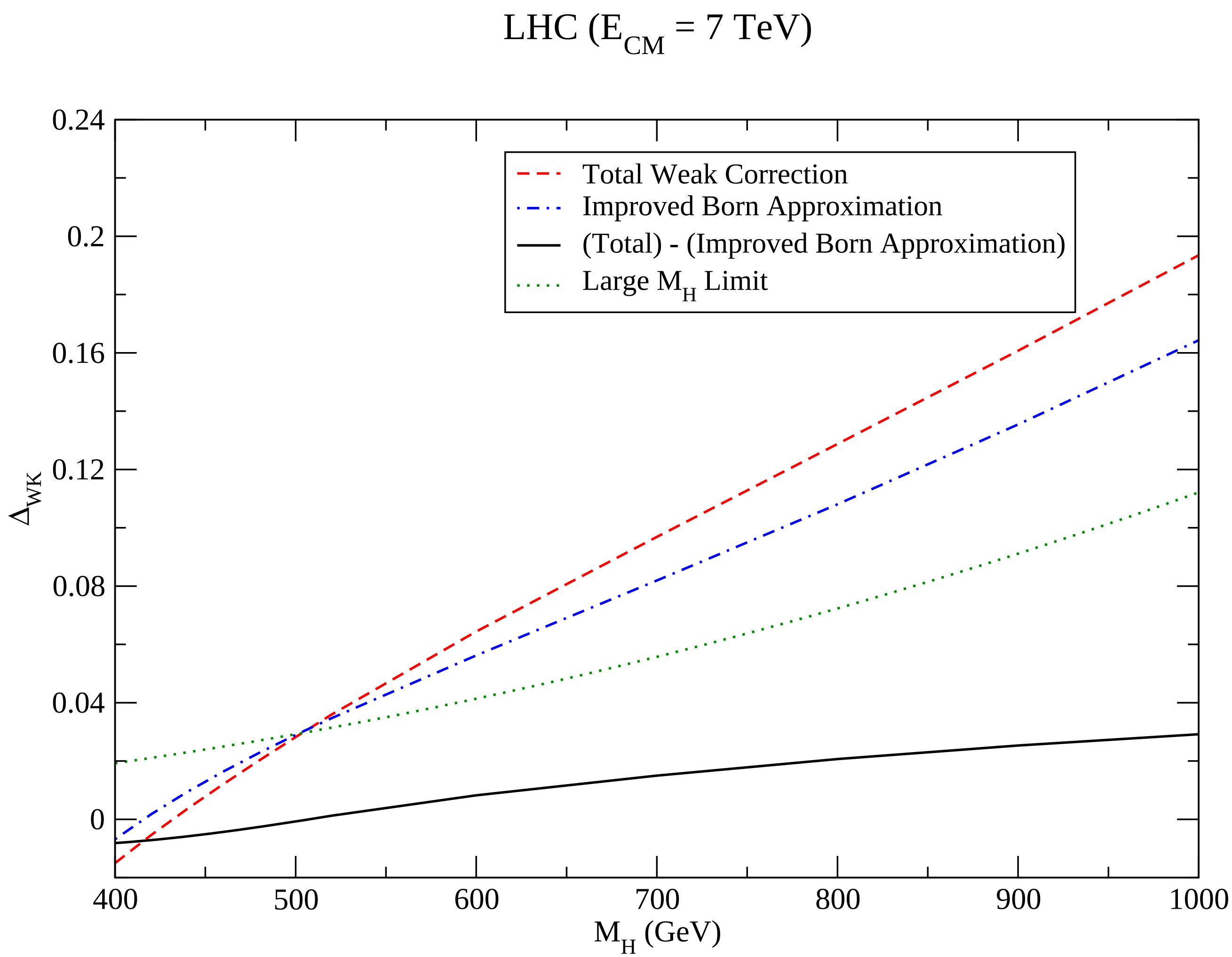
• Need log(M_h) pieces to reproduce full calculation

•Corrections O(18%) for M_h~1 TeV

•Corrections O(3%) for M_h~500 GeV

Dawson, Jaiswal, [hep-ph, arXiv:1002.2672]

Weak Corrections large for Heavy Higgs



Conclusions

- b Higgs production is a discovery channel
- SUSY QCD corrections can be important for light SUSY
  - For heavy SUSY can include SQCD in effective Lagrangian
  - Improved Born Approximation (Δm_b) approximation doesn't work for light SUSY $\Rightarrow$ Need full calculation
- EW corrections important at large M_h
  - EW corrections accurately approximated by effective vertex corrections in Standard Model
  - EW corrections small for light Higgs