Higgs Bosons and b Quarks

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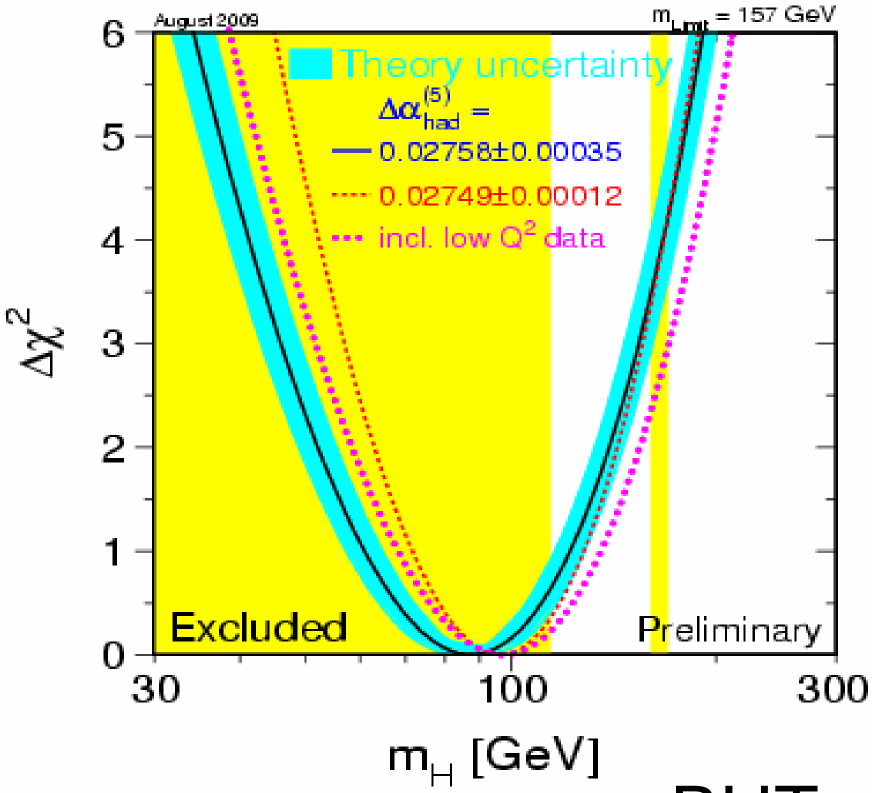
Plan:

- Lightning review of SM & MSSM Higgs physics
- QCD corrections to $bg \rightarrow bh$ (review)
  - Discussion of $gg \rightarrow b\bar{b}h$ vs $bg \rightarrow bh$
- MSSM results for $bg \rightarrow bh$
  - Status of current limits
- Effects of SUSY QCD (SQCD) and EW corrections on $bg \rightarrow bh$
  - Why are these effects interesting?
  - Does the effective Lagrangian approach work here?
  - What about decoupling for heavy SUSY particles?

EW measurements suggest light Higgs

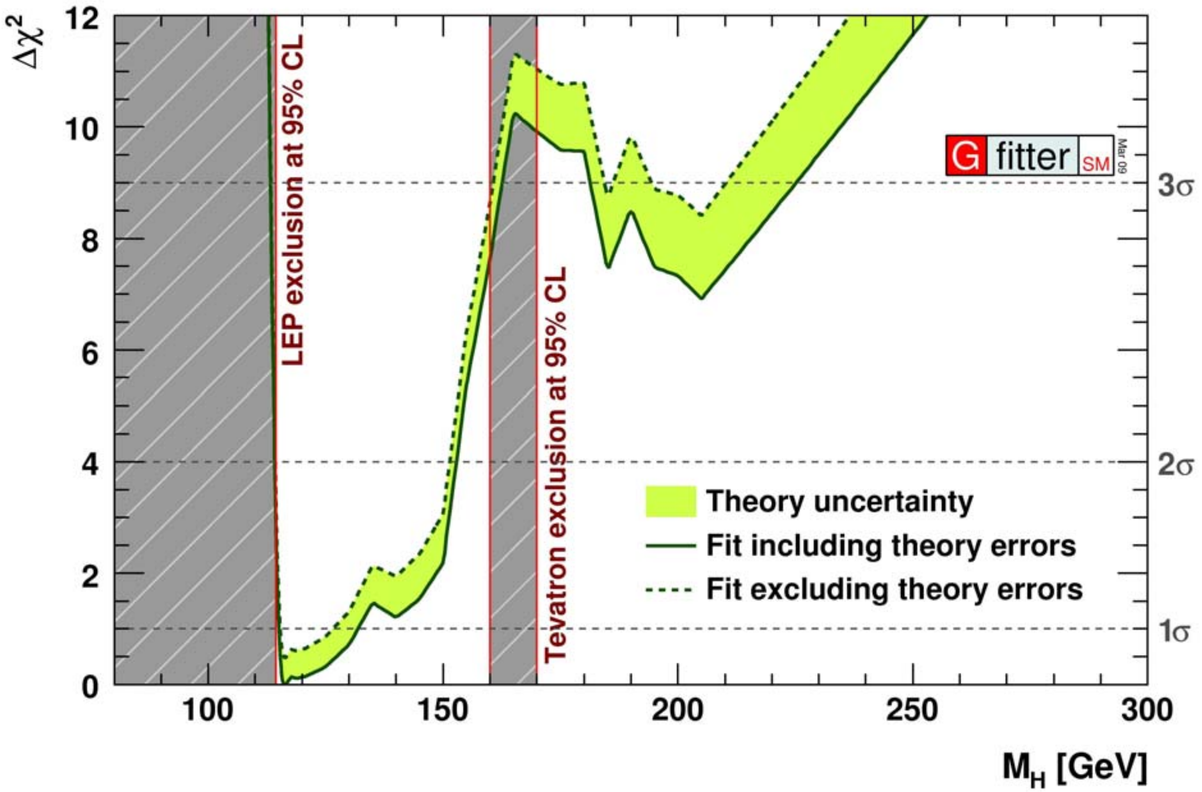


- $M_H = 87^{+35}_{-26}$ GeV (68% CL)
- $M_H < 186$ GeV (Precision measurements plus direct search limit)

BUT…..Fits assume SM with weakly interacting Higgs boson

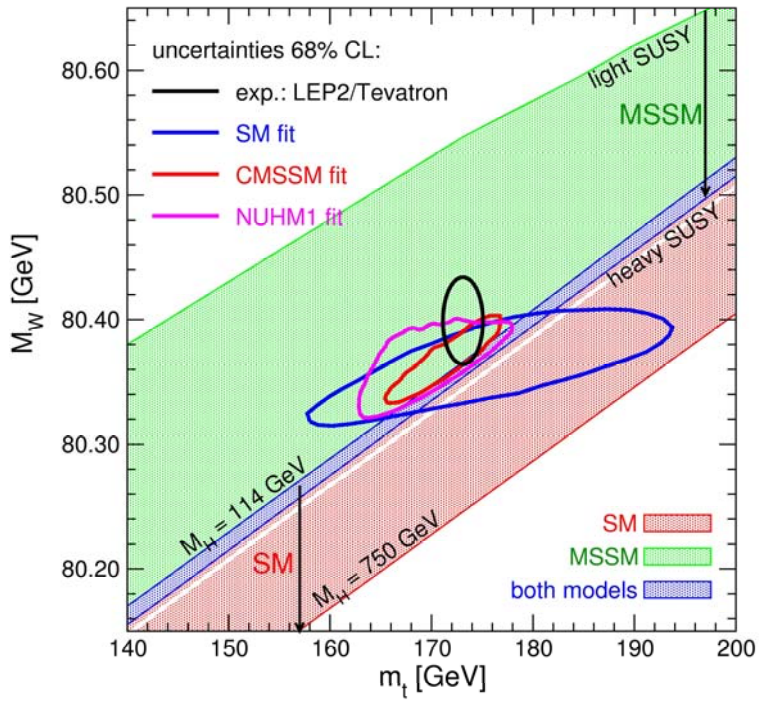
GFITTER Approach

- Includes direct search limits from Fermilab
- Includes estimate of theoretical uncertainties



SUSY is favorite alternative

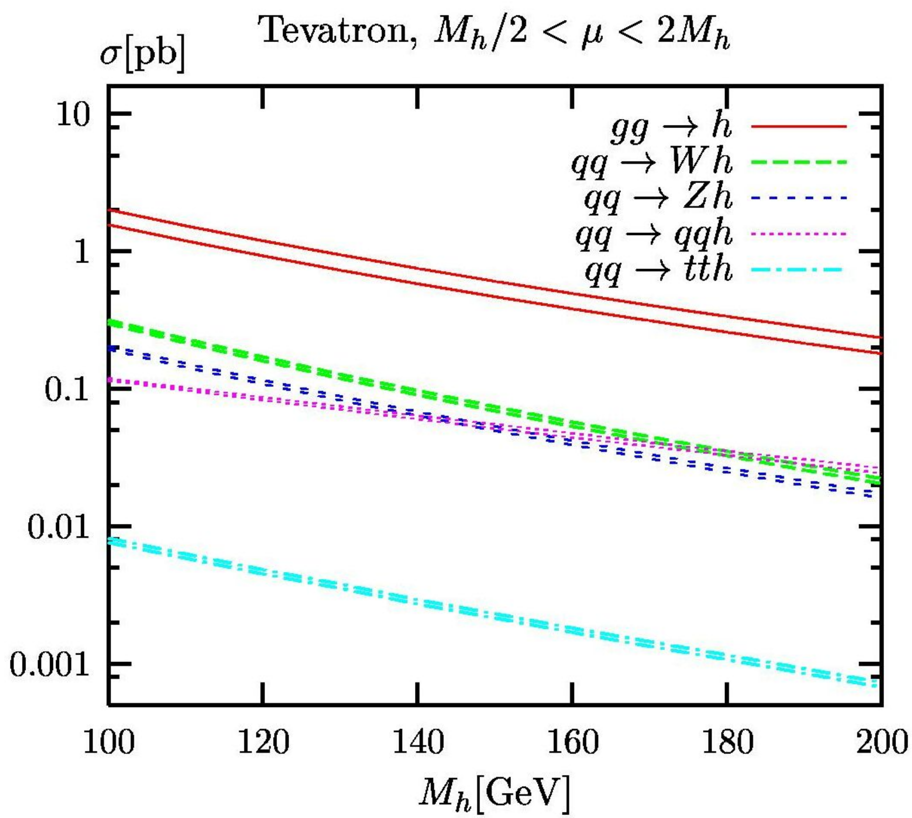
- SUSY: No quadratic divergences, large top Yukawa can give EWSB, dark matter candidate, good fit to EW data ….



SUSY is slightly better fit than SM

Buchmueller et al, arXiv:0912.1036

Producing the Higgs at the Tevatron

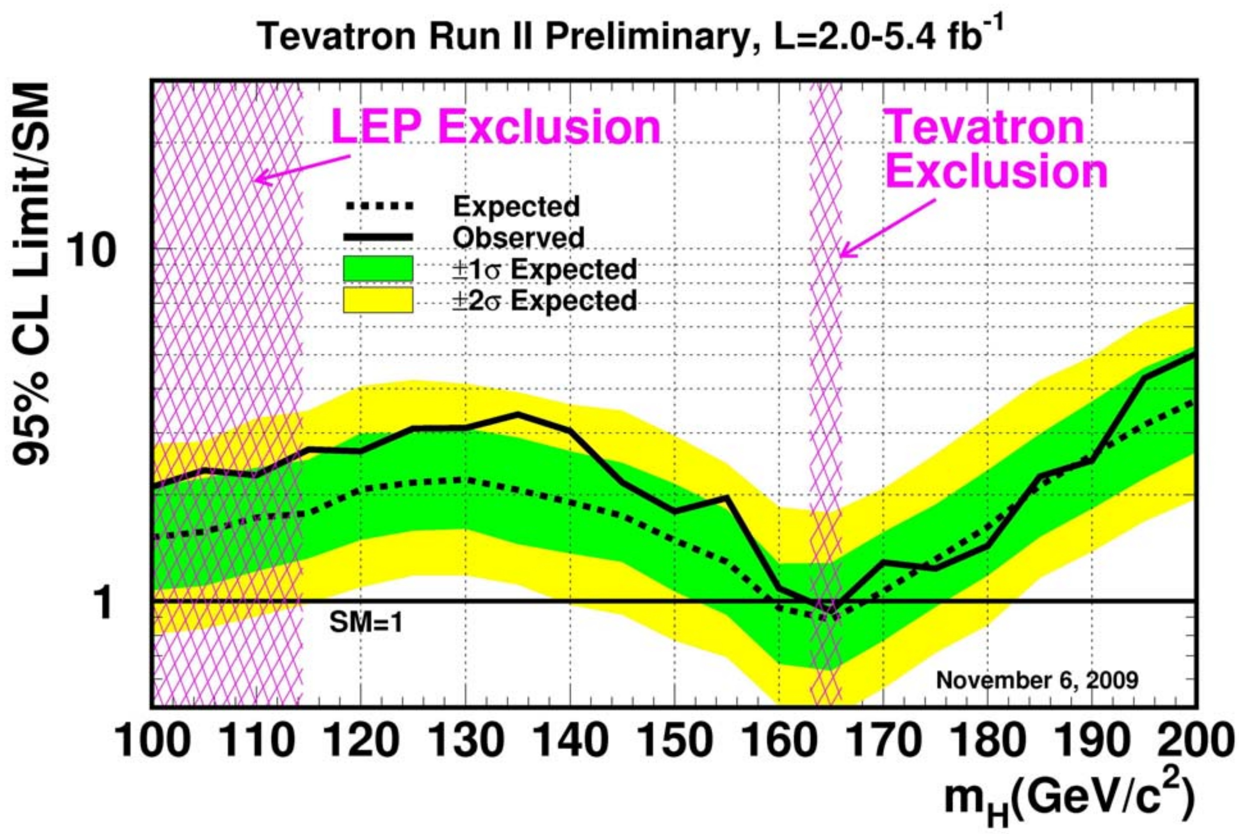


- SM Higgs production with b's not relevant
- $\lambda_b = m_b/v$

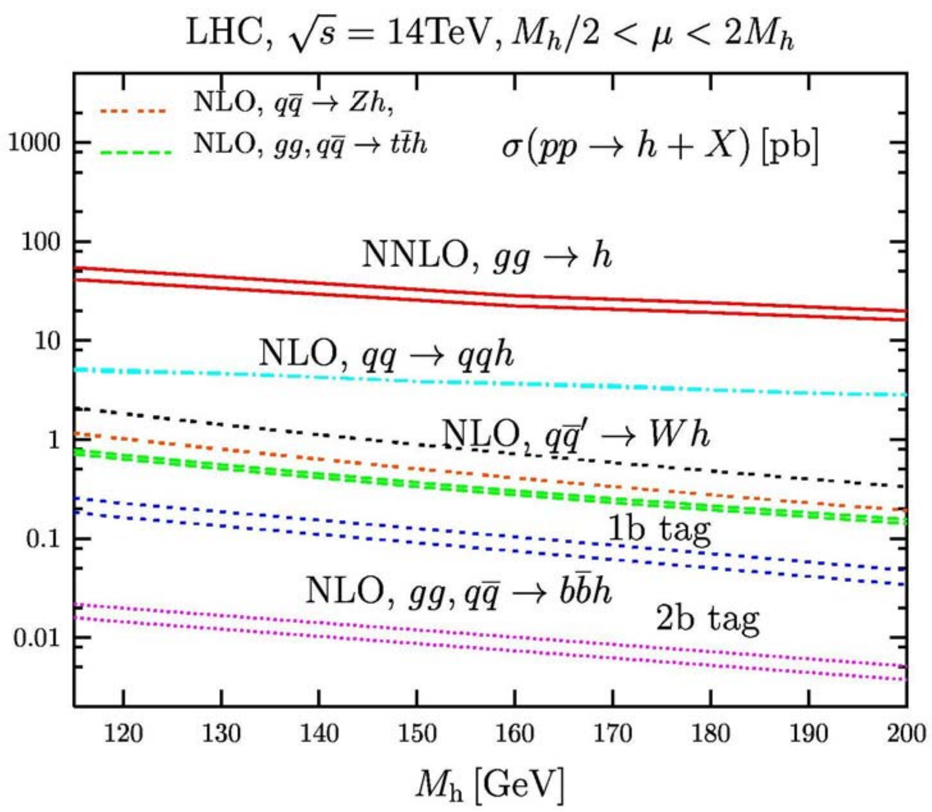
NNLO or NLO rates

$M_h/2 < \mu < M_h/4$

SM Higgs Searches at Tevatron



SM Production Mechanisms at LHC



Bands show scale dependence

All important channels calculated to NLO or NNLO

Production with b's very small in SM

Higgs in the MSSM

- MSSM has 2 Higgs doublets: H_d and H_u

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

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

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

$\tan\beta = v_1/v_2$

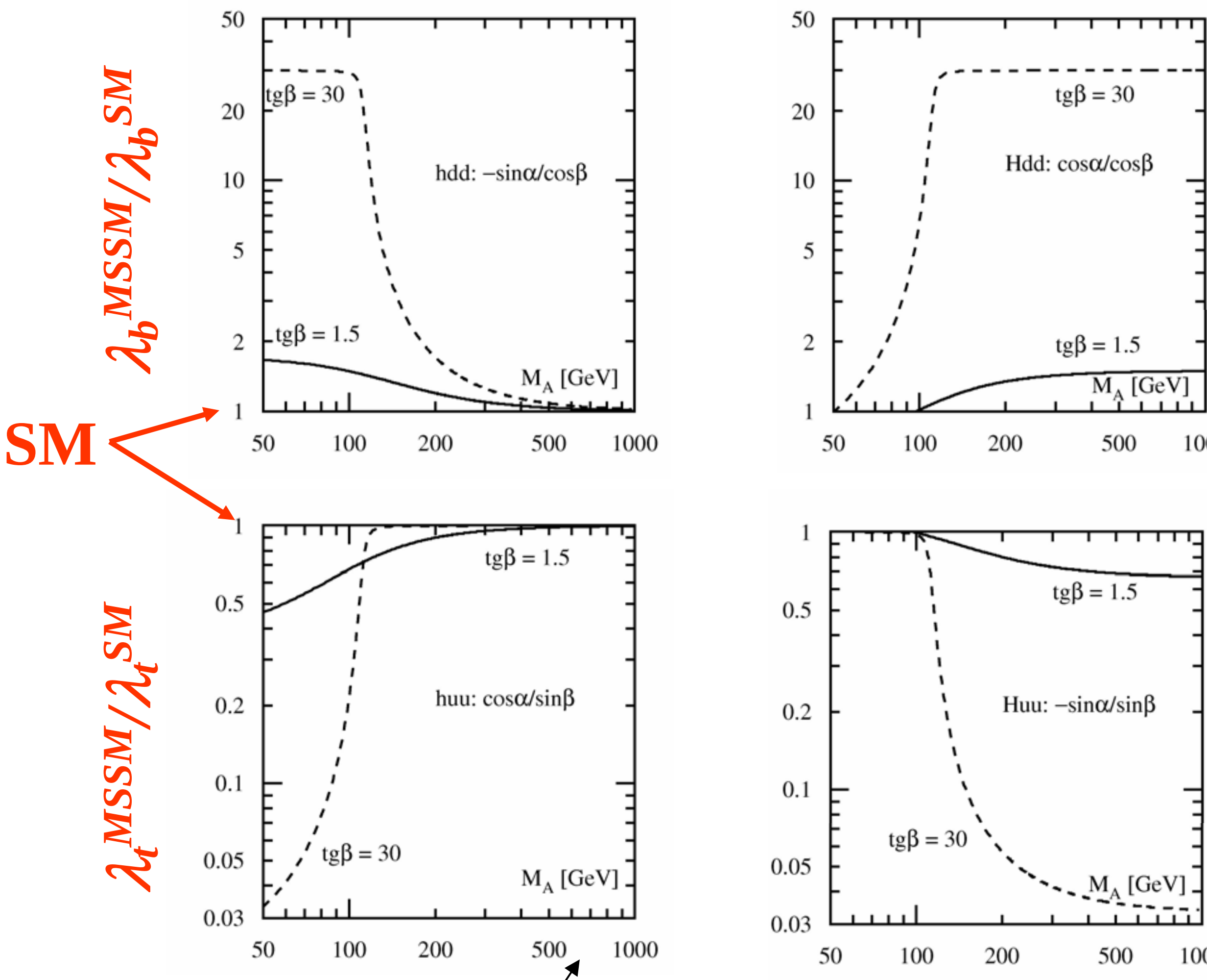
- Physical CP-Even Higgs bosons

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

- Pseudoscalar, A^0, and two charged Higgs, $H^\pm$

Higgs Couplings very different in MSSM

Light Higgs **Heavy Higgs**

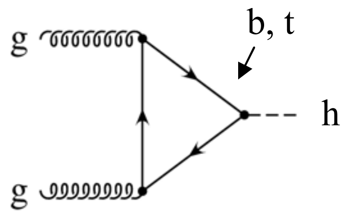


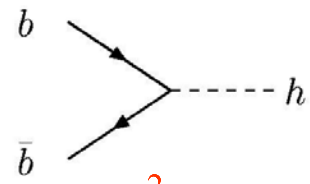
Couplings to d, s, b enhanced at large tan β

Couplings to u, c, t suppressed at large tan β

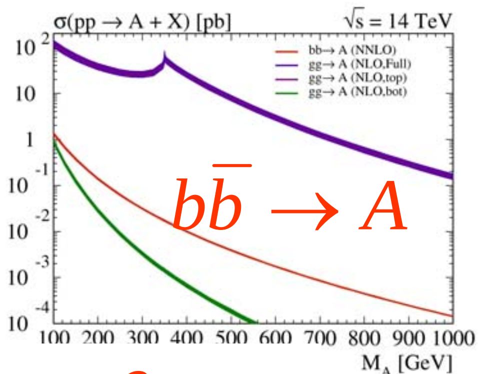
Decoupling limit: Higgs couplings go to SM limit for $M_A \to \infty$

Large tan β Changes Relative Importance of Production Modes

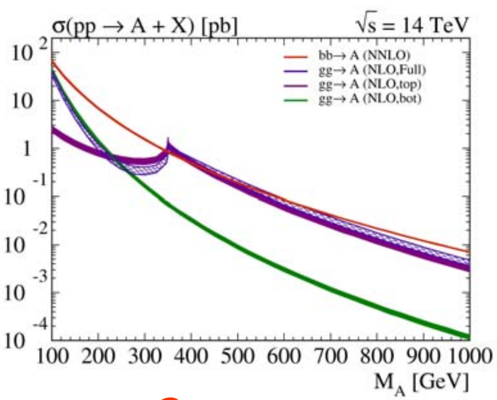




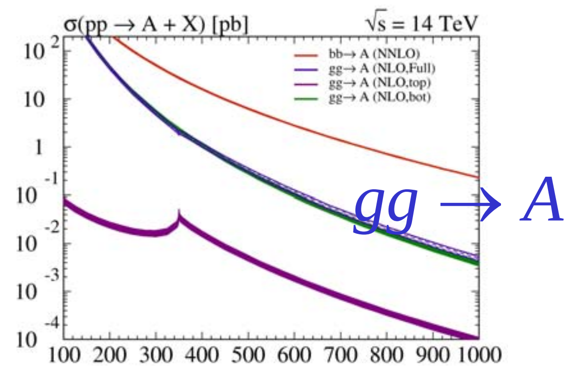
$$\sigma_{gg} = \frac{1}{M_h^2}\left(c_1 \cot^2\beta + c_2 \frac{m_b^2}{M_h^2} + c_3 \frac{m_b^4}{M_h^4} \tan^2\beta \right) \qquad \sigma_{bb} = \frac{m_b^2}{M_h^4} c_4 \tan^2\beta$$



tanβ=1



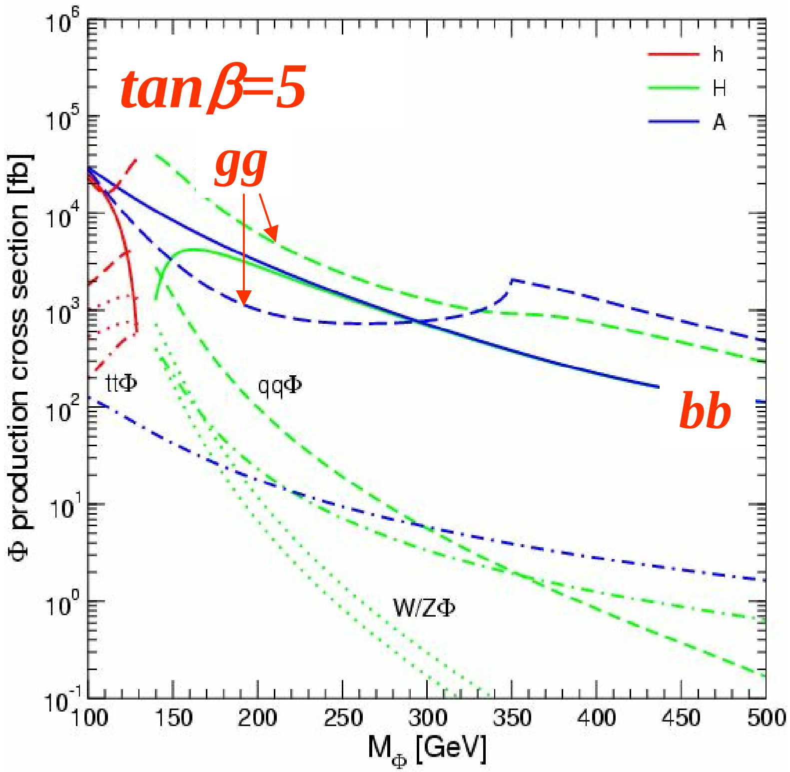
tanβ=7

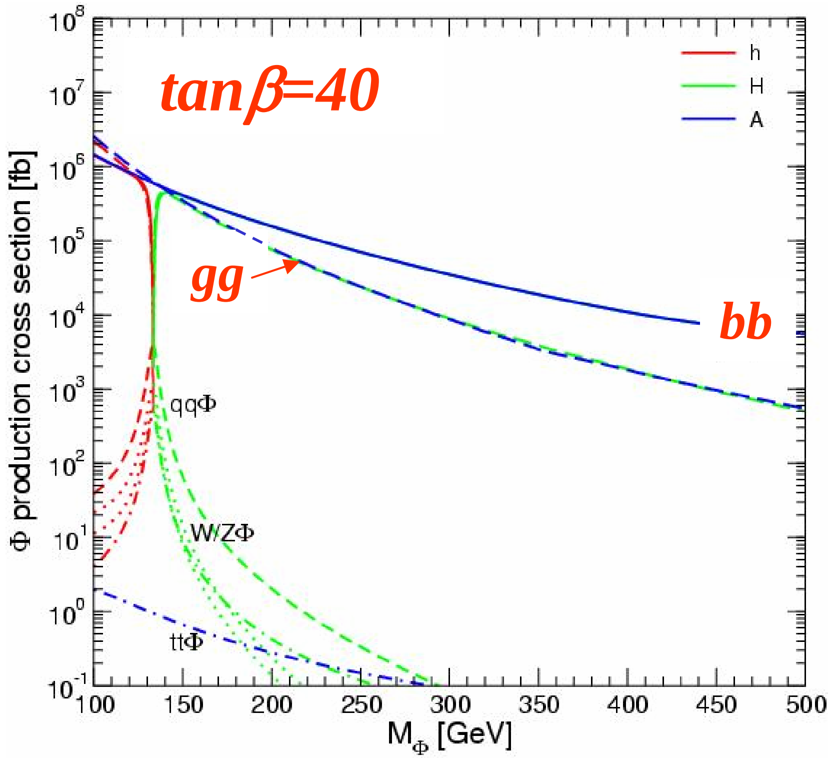


tanβ=40

tanβ ≥ 7, $b\bar{b}$ production mode larger than gg

SUSY Higgs Rates at the LHC



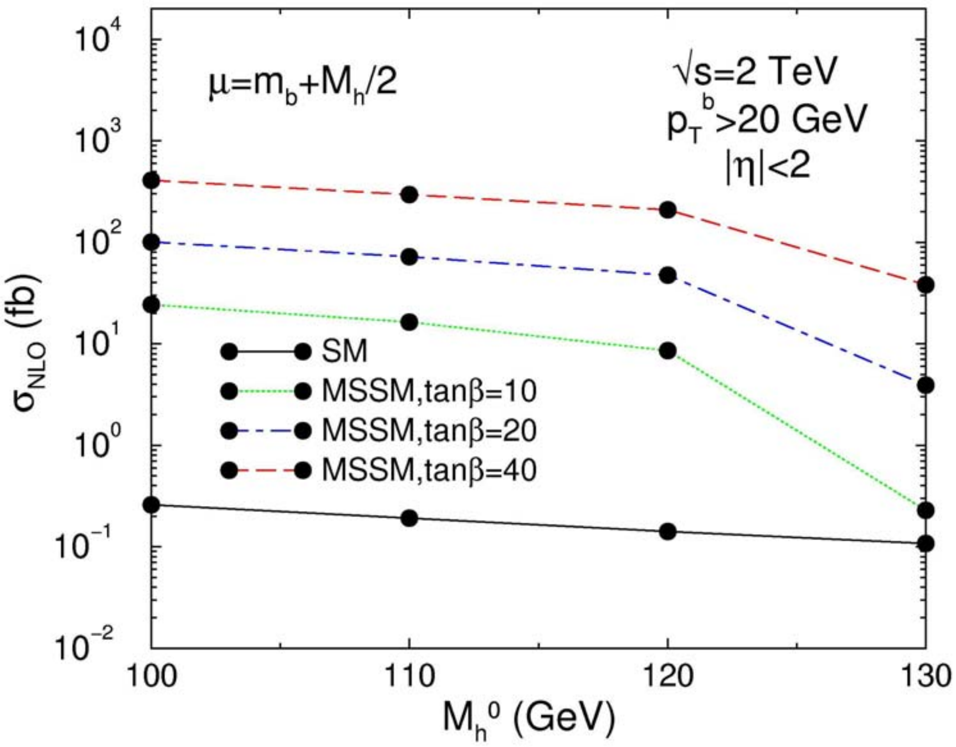


- For large tan β, dominant production mechanism is with b's
- bbh can be 10x's SM Higgs rate in SUSY for large tan β

  $\sigma_{SM}^{gg}(M_h=200\text{ GeV}) \sim 1.5 \times 10^4$ fb

TeV4LHC Report

$gg \to b\bar{b}h$ in SUSY Models at Tevatron

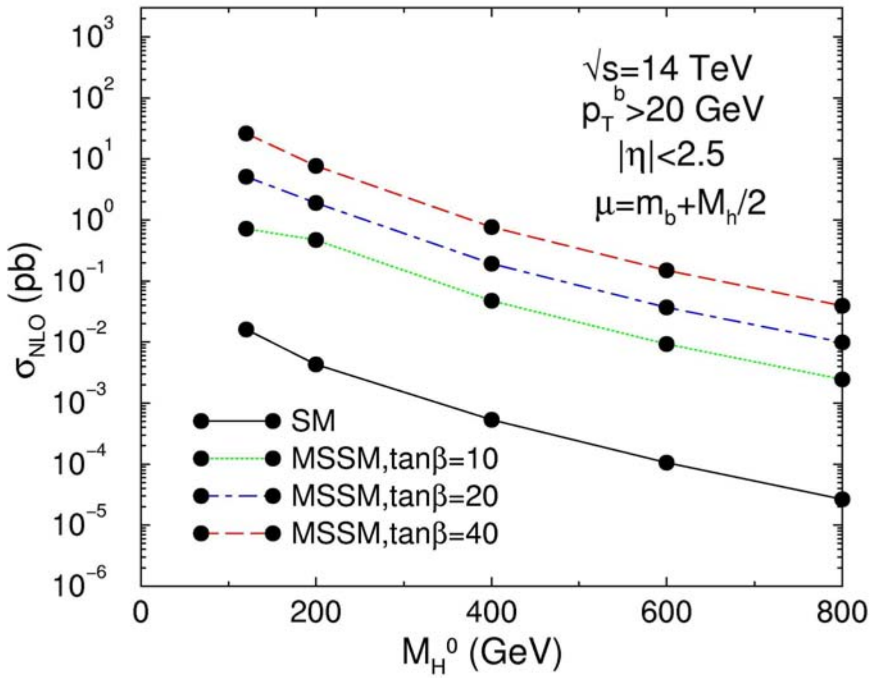


Huge enhancements in SUSY from SM Rate

Couplings/masses with FeynHiggs

$pp, p\bar{p} \to b\bar{b}H$ Enhancement in MSSM

Note log scale!



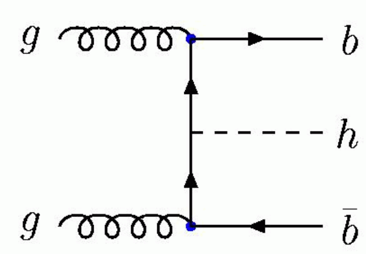
This is why the calculation is interesting!

α_{eff} from FeynHiggs with $M_{SUSY}=M_g=\mu=M_2=1$TeV, $A_b=A_t=25$ GeV

Can observe heavy MSSM scalar Higgs boson

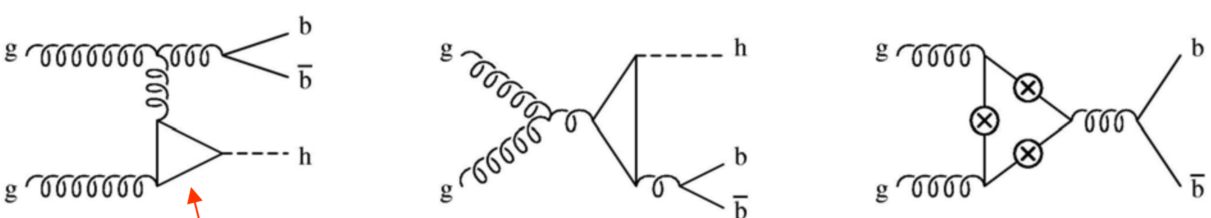
$pp \to b\bar{b}h$

- Why is $b\bar{b}h$ interesting?
  - Higgs discovery mode in SUSY models at large tan β
  - Direct measurement of b quark Yukawa coupling (enhanced in MSSM at large tan β)
  - Theoretical questions about b quark parton distribution functions (PDFs)
- Why do NLO corrections?
  - Improved theoretical reliability
  - Often find large numerical results



pp → $b\bar{b}h$ at NLO in QCD

- Almost identical calculation to pp→$t\bar{t}h$ calculation
  - Dominant contribution at both Tevatron and LHC is gg initial state
  - Virtual + real corrections computed numerically using phase space slicing
  - b quark mass included everywhere
  - Differences: closed loops with top quarks, numerical problems from large $\log(m_b/M_h)$



This can be a top quark

General Approach

- NLO total cross section

$$\sigma_{NLO} = \sum_{i,j} \int dx_1 dx_2 F_i^{p}(x_1,\mu) F_j^{p,\bar{p}}(x_2,\mu) \hat{\sigma}_{ij}(x_1,x_2,\mu)$$

- NLO corrections contain:

$$\hat{\sigma}_{ij}^{NLO} = \hat{\sigma}_{ij}^{LO} + \frac{\alpha_s}{4\pi} \delta\hat{\sigma}_{ij}^{NLO}$$

$$\boxed{\delta\hat{\sigma}_{ij}^{NLO} = \hat{\sigma}_{ij}^{virt} + \hat{\sigma}_{ij}^{real}}$$

$\hat{\sigma}_{ij}^{virt}$: One loop virtual corrections to $q\bar{q}, gg \rightarrow b\bar{b}h$

$\hat{\sigma}_{ij}^{real}$: One gluon real emission $q\bar{q}, gg \rightarrow b\bar{b}h + g,\ qg \rightarrow b\bar{b}hq$

→ Renormalize UV divergences (d=4-2ε)

→ Cancel IR divergences in virtual + real contributions

→ Check μ dependence

Virtual Corrections

- Reduce each diagram in terms of scalar integrals of the form:

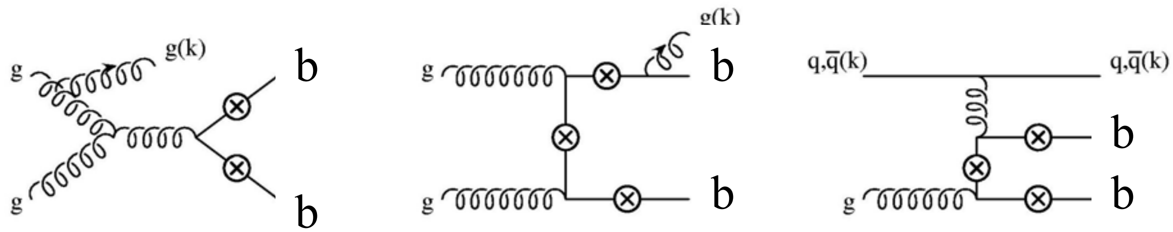
$$\int \frac{d^n k}{(2\pi)^n} \frac{1}{[(k^2 - m_1^{\;2})((k+p_1)^2 - m_2^{\;2})....]}$$

  - Three external massive particles (keep b mass everywhere)
  - Several massive internal propagators
- Finite integrals: use existing libraries/packages
- UV divergent integrals: analytic (easy)
- IR divergent integrals: analytic (hard)
- Most challenging part: pentagons with 3 mass scales

This calculation at the limit of what can be done by brute force

Real Corrections

- Real gluon emission: IR singularities for $2\rightarrow4$ process



- Phase Space Slicing$\rightarrow$isolate the region of phase space where $s_{ig}\rightarrow0$

$$s_{ig}=2p_i\bullet p_j=2E_iE_g(1-\beta\cos\theta_{ig})$$

$\rightarrow$ Two cut-off method:

  - δ_s ($E_g<\delta_s\sqrt{s}/2$) Soft singularities
  - δ_c ($1-\cos\theta_{ig}<\delta_c$) Collinear singularities

$\boxed{\text{Final result is independent of cut-offs}}$

Two Cutoff Method (δ_s,δ_c):

$$\boxed{\hat{\sigma}_{real}(ij \to b\bar{b}h + g) = \hat{\sigma}_{soft} + \hat{\sigma}_{hard}}$$

Divide gluon phase space: $\hat{\sigma}_{soft} \to E_g < \frac{\sqrt{s}}{2}\delta_s \qquad \hat{\sigma}_{hard} \to E_g > \frac{\sqrt{s}}{2}\delta_s$

In the soft limit ($E_g \to 0$):

$$d(PS)_4 \to d(PS)_3 d(PS)_g = d(PS_3)\frac{d^{n-1}k}{(2\pi)^{n-1}(2E_g)}$$

$$\left|A_{real}(ij \to b\bar{b}h + g)\right|^2 \to (4\pi\alpha_s)\left|A_{LO}\right|^2 \phi_{eik}$$

Eikonal factor contains soft poles: $\phi_{eik} = \sum_{ij}\left(\frac{s_{ij}}{s_{ig}s_{jg}} - \frac{m_i^2}{s_{ig}^2} - \frac{m_j^2}{s_{jg}^2}\right)$

σ_{soft} computed analytically: $\hat{\sigma}_{soft} = (4\pi\alpha_s)\int d(PS_3)\left|A_{LO}\right|^2 \int_{soft} d(PS)_g \phi_{eik}$

Hard gluon phase space further divided: $\hat{\sigma}_{hard} = \hat{\sigma}_{hard/coll} + \hat{\sigma}_{hard/not-coll}$

In collinear limit: $i \rightarrow i'g$; $p_{j'}=zp_i$, $p_g=(1-z)p_i$

$$\left| A_{real}(ij \rightarrow b\bar{b}h + g) \right|^2 \rightarrow (4\pi\alpha_s) \left| A_{LO} \right|^2 \frac{2P_{ii'}(z)}{zs_{ig}}$$

$$d(PS_4)(ij \rightarrow b\bar{b}h + g) \rightarrow d(PS_3)(i'j \rightarrow b\bar{b}h) z d(PS_g)$$

Compute hard/collinear σ analytically

$$\hat{\sigma}_{hard/coll} \approx \int d(PS_3) \int_{coll} d(PS_g) \sum_i \frac{P_{ii'}}{s_{ig}} \left| A_{LO} \right|^2$$

σ hard/not collinear is finite: compute numerically

Use $\overline{\text{MS}}$ Renormalization

- Compute the O(α_s) corrections:

$$\Gamma_1(h \to b\bar{b}) = \frac{3M_h}{8\pi}\left(\frac{m_b}{v}\right)^2 \left\{1 + \frac{2\alpha_s}{3\pi}\left[\frac{9}{2} - 3\log\left(\frac{M_h^2}{m_b^2}\right)\right]\right\}$$

- Define the running b mass

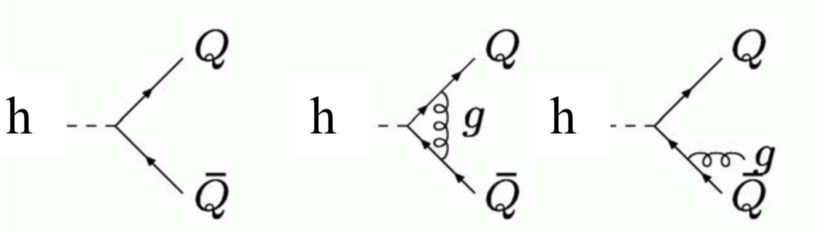
$$\overline{m}_b(\mu) = m_b\left[1 - \frac{\alpha_s}{3\pi}\left(4 + 3\ln\left\{\frac{\mu^2}{m_b^2}\right\}\right)\right]$$

- Large logarithms absorbed to 2-loops

$$\Gamma(h \to b\bar{b}) = \Gamma_0\left\{1 + 5.67\frac{\alpha_s(M_h)}{\pi} + (36 - 1.4n_{lf})\frac{\alpha_s(M_h)^2}{\pi^2}\right\}$$

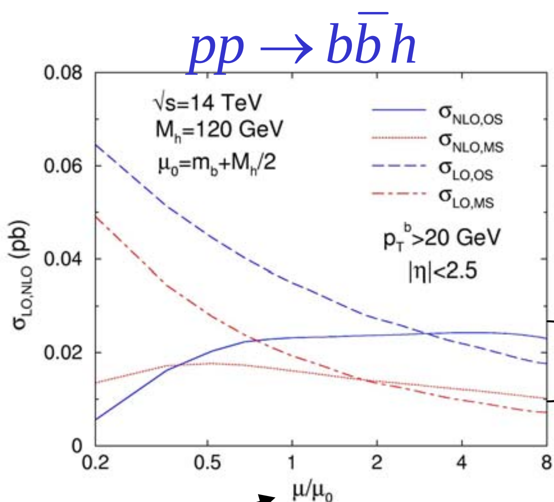
$$\Gamma_0(h \to b\bar{b}) = \frac{3M_h}{8\pi}\left(\frac{\overline{m}_b(M_h)}{v}\right)^2$$

Lore: $\overline{\text{MS}}$ is best!



Scale and Scheme Dependence at NLO

- NLO calculations improve scale dependence
  - Scale dependence enters in running of $\alpha_s(\mu)$ and PDFs, $g(\mu)$, as well as $\alpha_s^3 \log(\mu)$ contributions
  - Formally, scale dependence is $O(\alpha_s^4)$ but may be numerically large



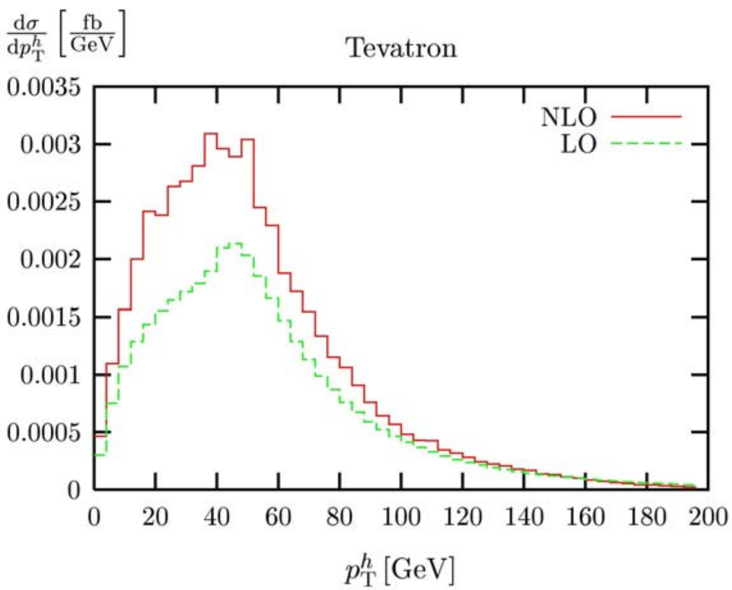
Scheme dependence

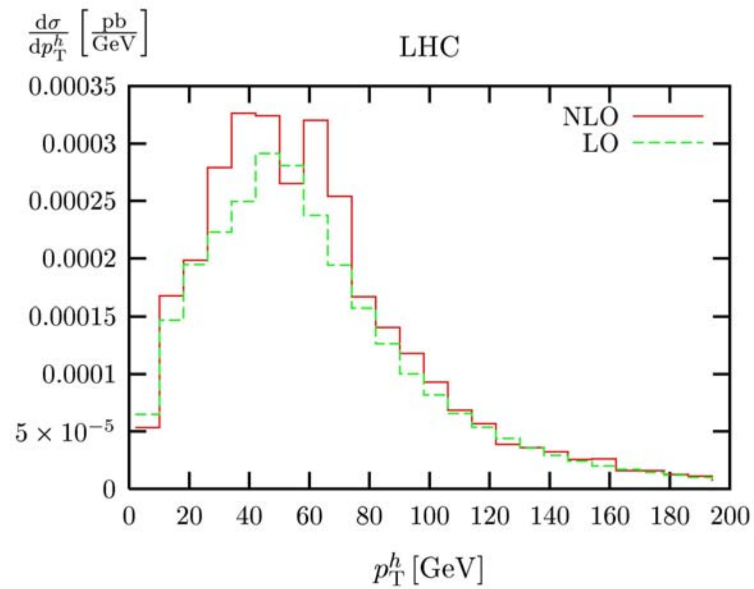
Scale dependence

> - Large remaining scheme dependence between OS and MS at NLO
> - Effect ≈ 10-20%

Distributions for $b\bar{b}h$ production

M_h=120 GeV





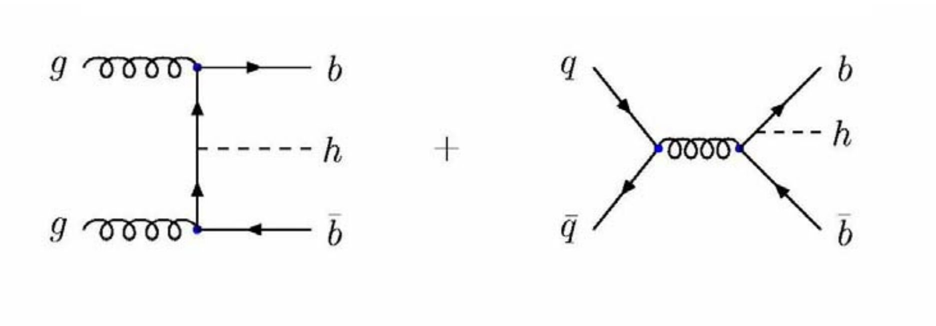
p_T^b> 20 GeV

$|\eta|$ < 2 (Tevatron), 2.5 (LHC)

ΔR > 0.4

Dawson, Jackson, Reina, Wackeroth

What is the dominant process for Higgs + b Production?



- Answer depends on whether you tag outgoing b's

- Is there double counting when including b initial state?

The b quark as a parton

Phase space factorizes in collinear limit:

$$(PS)_3 \to (PS)_2(\cdots)\int \frac{dE_b}{E_b}$$

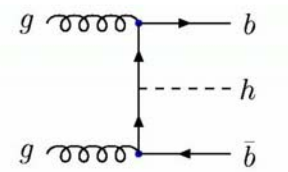
- Integration over b phase space gives large log
- Absorb log into b quark distribution

$$b(x,\mu) = \frac{\alpha_s}{2\pi}\ln\left(\frac{\mu^2}{m_b{}^2}\right)\int_x^1 \frac{dz}{z}P_{bg}\left(\frac{x}{z}\right)g(z,\mu)$$

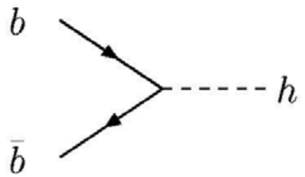
- Altarelli-Parisi evolution of PDFs sums $\alpha_s{}^n \ln^n(\mu^2/m_b{}^2)$
- b quark PDF $\approx \alpha_s \ln(\mu^2/m_b{}^2)$ relative to gluon PDF

Two Schemes for PDFs:

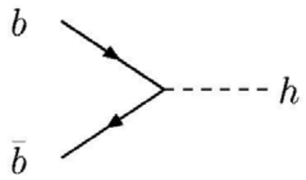
- 4 flavor number scheme (also called fixed flavor number scheme)
  - No b quarks in initial state
  - Lowest order process involving Higgs and b's is $gg \rightarrow b\bar{b}h$
- 5 flavor number scheme (also called variable flavor number scheme)
  - Define b quark PDFs (absorbs large logarithms)
  - Higgs produced with no p_T at lowest order ($b\bar{b} \rightarrow h$)
  - Higgs p_T generated at higher orders in expansion



VS

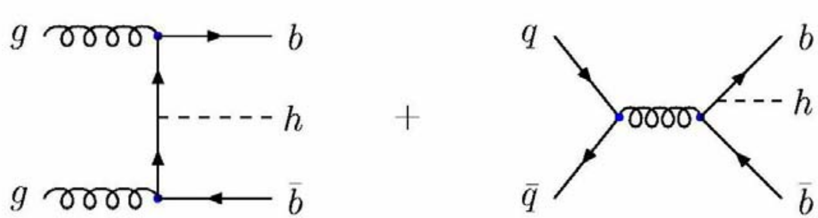


Counting Rules with b PDFs: Reordering of perturbation expansion



$(\alpha_s \ln(M_h^2/m_b^2))^2 \approx .4$

$\alpha_s^2 \ln(M_h^2/m_b^2) \approx .06$



$\alpha_s^2 \approx .01$

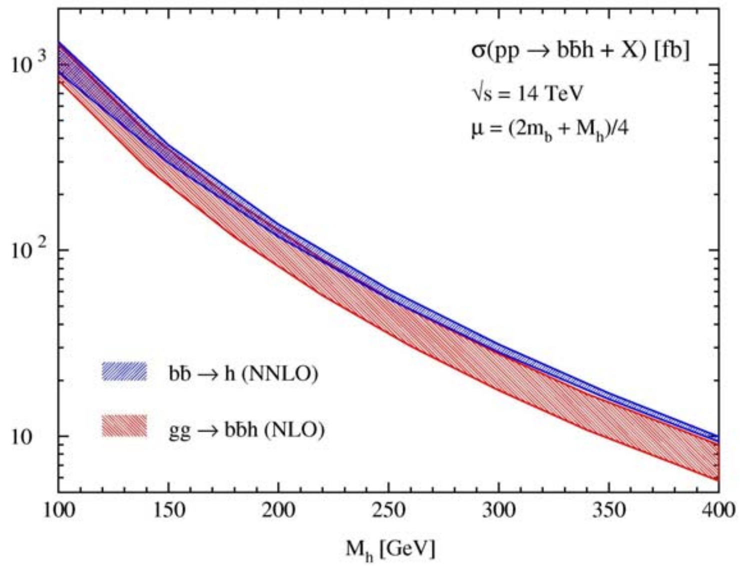
Re-ordering of Perturbation Theory

- 0 b tag process in 5FNS:
  - LO: $b\bar{b} \to h$ $O(\alpha_s^2 \Lambda_b^2)$
  - NLO: Virtual+real corrections $O(\alpha_s^3 \Lambda_b^2)$
  - NLO: $bg \to bh$ $O(\alpha_s^2 \Lambda_b)$, correction of $O(1/\Lambda_b)$ to tree level
  - NNLO: $gg \to b\bar{b}h$ $O(\alpha_s^2)$, correction of $O(1/\Lambda_b^2)$ to tree level

- 1 b tag process in 5FNS:
  - LO process is $bg \to bh$: Tree level, $O(\alpha_s^2 \Lambda_b)$
  - NLO includes new subprocess: $gg \to b\bar{b}h$, $O(1/\Lambda_b)$ correction to LO

$$\boxed{\Lambda_b = \log(M_h^2/m_b^2)}$$

Inclusive Cross Section for $b\bar{b} \rightarrow h$: 0 b tags

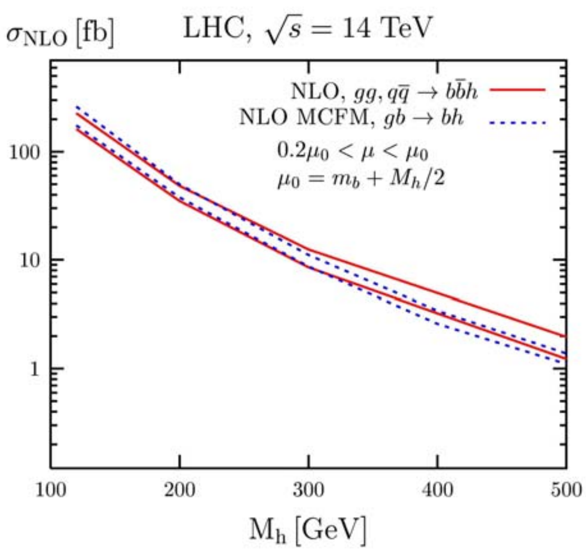


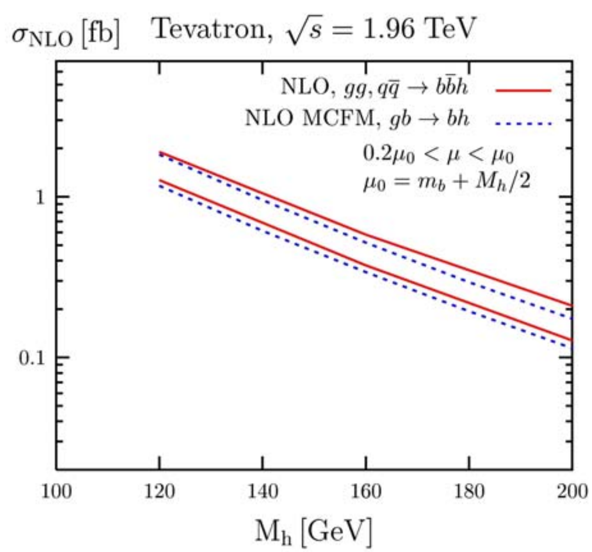
$b\bar{b} \rightarrow h$ vs $gg \rightarrow b\bar{b}h$

Agreement best at low M_h

Exclusive cross section for pp→ $b\bar{b}h$: 1 b tag

- Compare *5 flavor number scheme* (b PDFs) with *4 flavor number scheme* (no b PDFs) for total rates
- Consistent results in two schemes

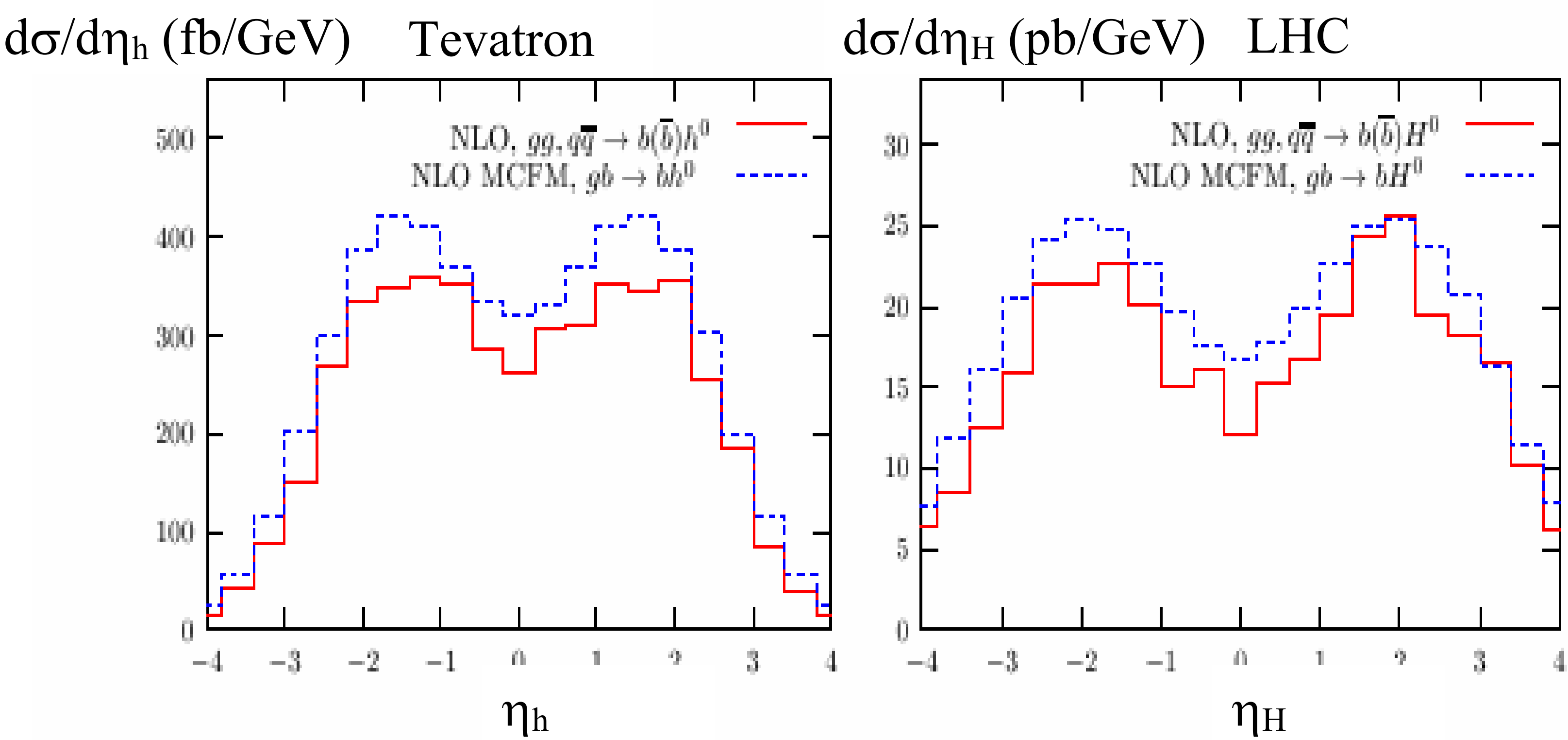




It doesn't matter which scheme you use !

This is SM—Note smallness of rates

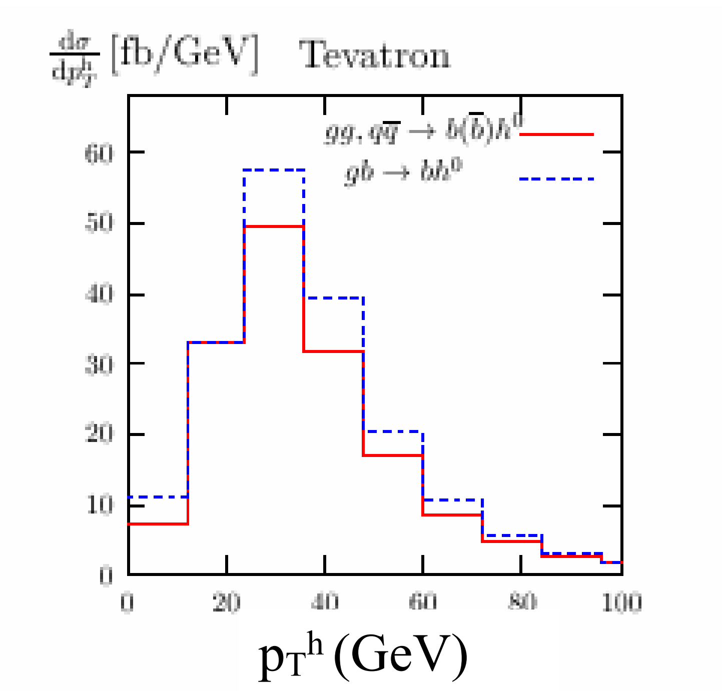
Compare Distributions: Single b Tag

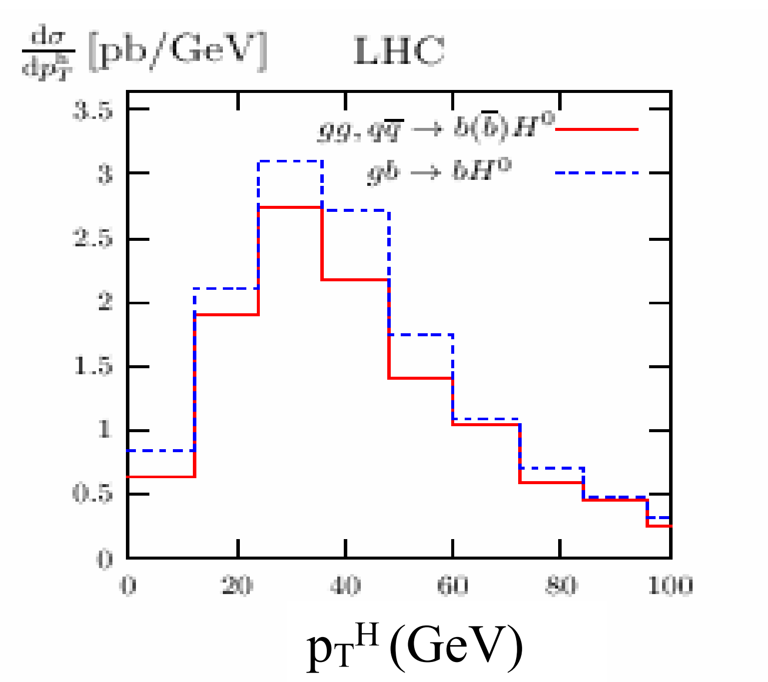


MSSM with M_h=M_H=120 GeV, tan β=40

Single b tag

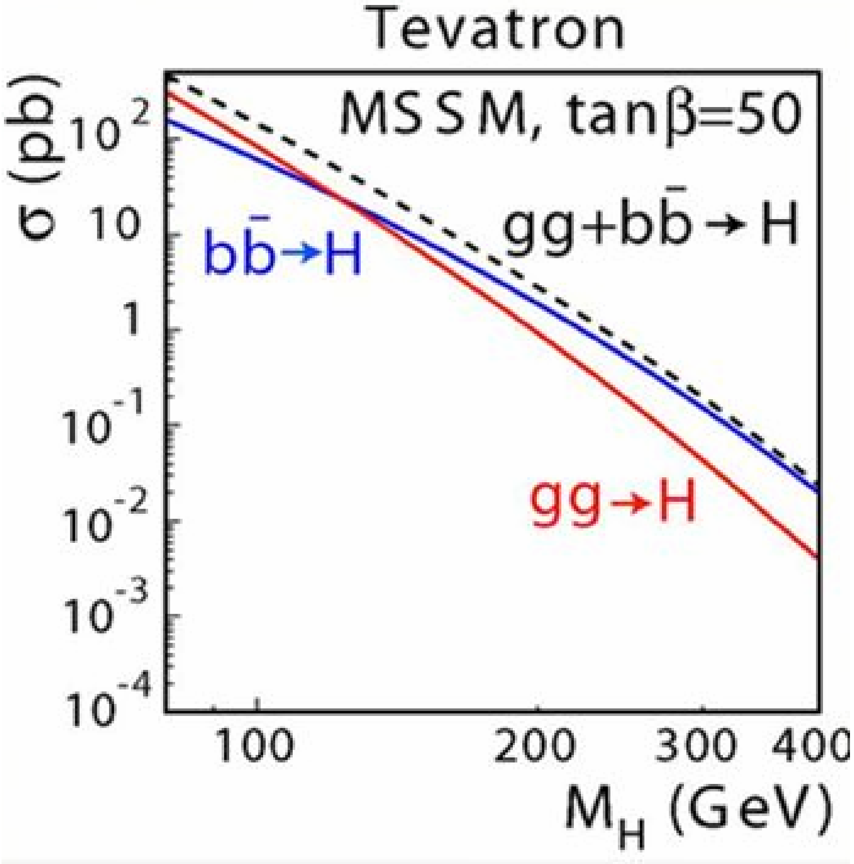
NLO





MSSM with M_h=M_H=120 GeV, tan β=40

Tevatron Limits From bbh

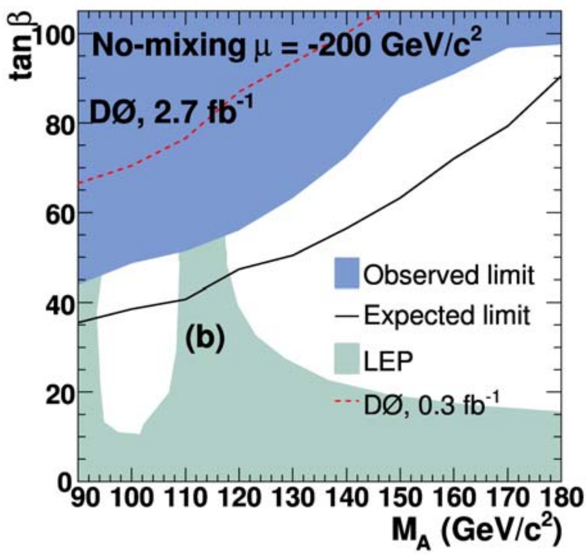


Higgs decays:

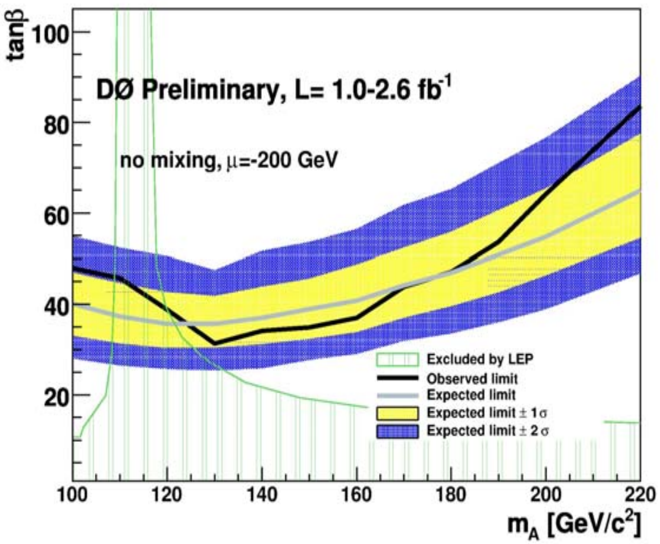
- bb (~90%)
- ττ (~9%)

MSSM limits from bg→bh and bb →h

- ➢Larger rate than bbh process
- ➢Extra b tag and Higgs transverse momentum improve detection efficiency from 0-b tag process (bb→h)



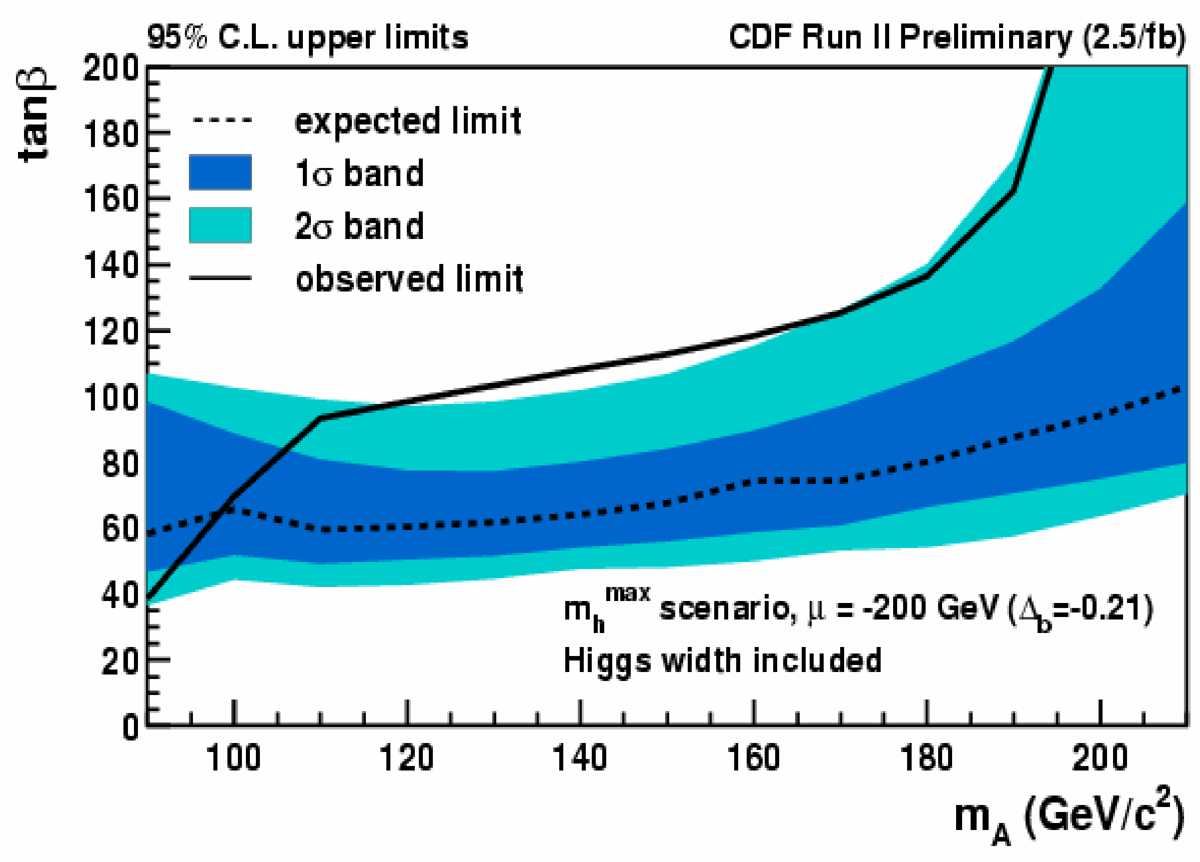
bg →hb, h →ττ



bg →hb, h →ττ, bb

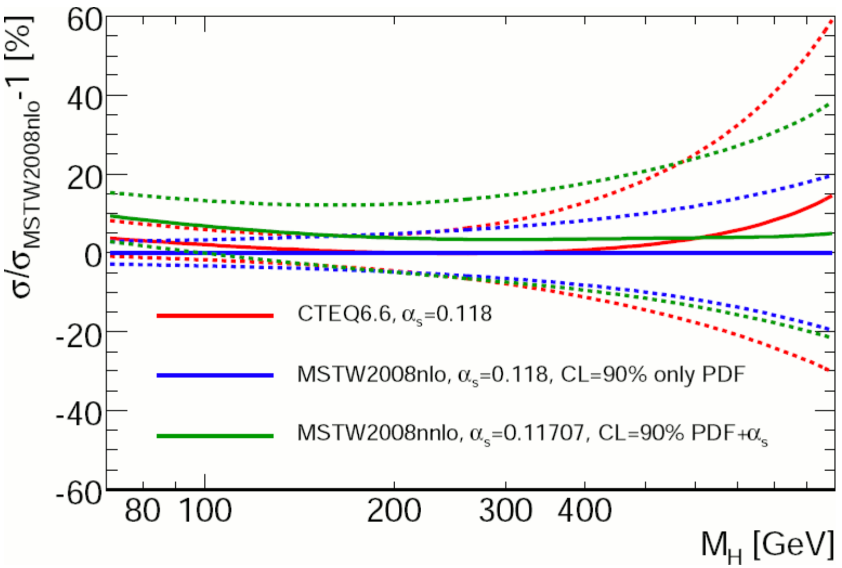
bb →h, h →ττ

New CDF Limits



A Reliable Prediction?

- $b\bar{b} \to h$ at QCD NNLO
- We have $bg \to bh$ at QCD NLO
  - Large PDF uncertainties
  - Arise from gluons at large x



Higgs Couplings to Fermions

- At tree level, H_d couples to charge -1/3 quarks, and H_u couples to charge 2/3 quarks

$$L = -\lambda_b \overline{\psi}_L H_d b_R - \lambda_t \overline{\psi}_L H_u t_R + hc \qquad \psi_L = \begin{pmatrix} t_L \\ b_L \end{pmatrix}$$

- Since up and down quark sectors are diagonalized independently, Higgs interactions are flavor diagonal

- Trilinear couplings couple both Higgs to charge -1/3 and charge 2/3 squarks

$$L = \tilde{t}_L^{\,*} \lambda_t \left(A_t H_u - \mu^* H_d \right) \tilde{t}_R + \tilde{b}_L^{\,*} \lambda_b \left(A_b H_d - \mu^* H_u \right) \tilde{b}_R + h.c.$$

Couples "wrong" Higgs

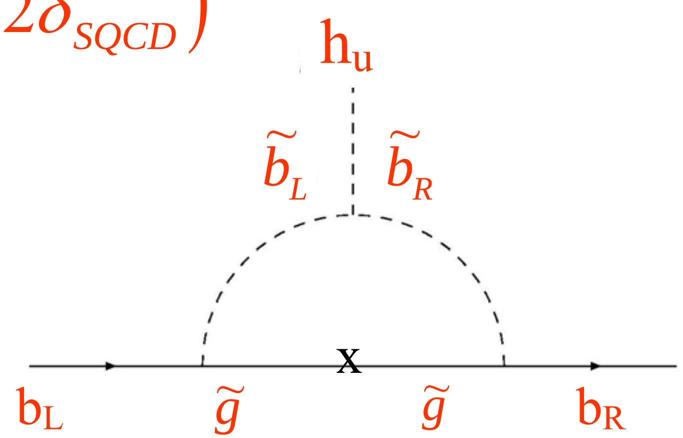
b quarks couple to both Higgs at 1-Loop

Calculate squark/gluino contributions to $h \to b\bar{b}$

$$\Gamma(h \to b\bar{b}) = \Gamma_0 \left(1 + 2\delta_{QCD} + 2\delta_{SQCD}\right)$$

Non-decoupling Effect:

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



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

(+WF and CTs)

$h \rightarrow b\bar{b}$

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

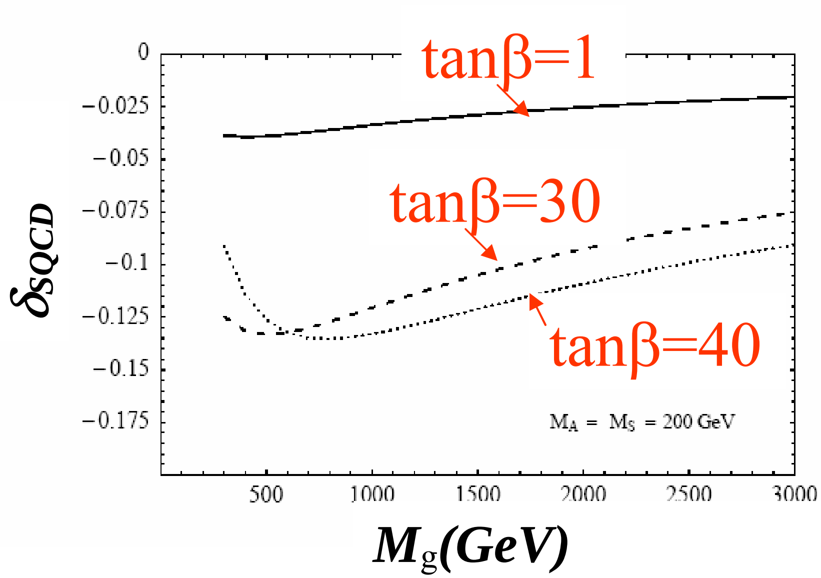
$$\boxed{\delta_{SQCD} = -sign(\mu)\frac{\alpha_s}{3\pi}\left(\frac{\mu m_{\tilde{g}}}{M_{SUSY}^2}\right)(\tan\beta + \cot\alpha)}$$

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

Decoupling very slow for large gluino mass

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

$$\boxed{\delta_{SQCD} = -sign(\mu)\frac{2\alpha_s}{3\pi}\left(\frac{\mu}{\tilde{m}_g}\right)(\tan\beta + \cot\alpha)\left(1 - \log\left(\frac{\tilde{m}_g{}^2}{\tilde{m}_b^2}\right)\right)}$$



For large tan β, effects ~10-15%

Effective Lagrangian Approach

- No tree level $H_u b\bar{b}$ coupling in MSSM, but it arises at 1-loop

$$\boxed{L_{eff} = -\lambda_b \bar{b}_R \left(\phi_d^0 + \frac{\Delta m_b}{\tan\beta} \phi_u^{0*} \right) b_L + hc}$$

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

- At tree level, $m_b = \lambda_b v_1/\sqrt{2}$

- At one loop: $m_b \equiv \lambda_b v_1 (1+\Delta m_b)/\sqrt{2}$

- Yukawa coupling shifted:

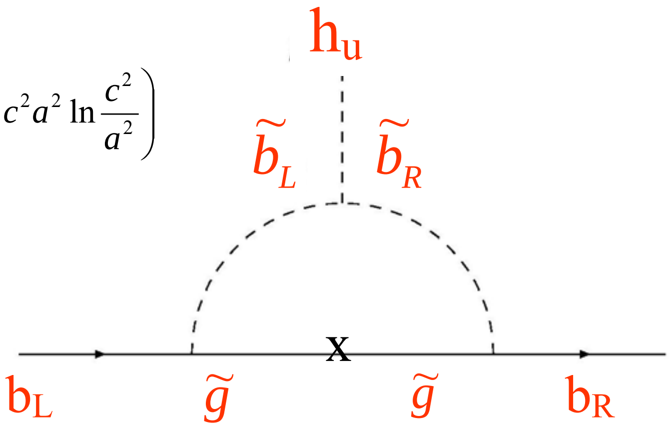
$$\boxed{L_{eff} = \frac{m_b}{v_{SM}} \left(\frac{1}{1+\Delta m_b} \right) \left(-\frac{\sin\alpha}{\cos\beta} \right) \left(1 - \frac{\Delta m_b}{\tan\beta \tan\alpha} \right) \bar{b} b h^0}$$

Define Effective Yukawa Couplings

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

Assumes $M_h << M_{SUSY}$

$$I(a,b,c) = \frac{1}{(a^2-b^2)(b^2-c^2)(a^2-c^2)}\left(a^2b^2 \ln\frac{a^2}{b^2} + b^2c^2 \ln\frac{b^2}{c^2} + c^2a^2 \ln\frac{c^2}{a^2}\right)$$

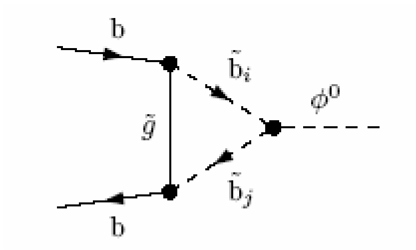


$$\boxed{g_{hbb} \equiv \frac{m_b}{v_{SM}}\left(\frac{1}{1+\Delta m_b}\right)\left(-\frac{\sin\alpha}{\cos\beta}\right)\left(1-\frac{\Delta m_b}{\tan\beta\tan\alpha}\right)}$$

Effective Lagrangian approach neglects momentum dependence of 3-pt function

Squark/Gluino Contributions to $b\bar{b} \rightarrow h$

- Just calculate it….
- Compare with tree level rescaled by effective Yukawa couplings
- Squark/gluino effects almost completely described by *Improved Born Approximation (IBA)*
- SQCD effects not contained in IBA are 1-2%



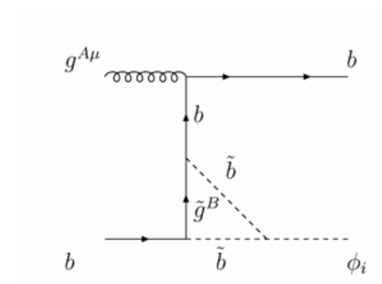
Dittmaier et al, hep-ph/0611353

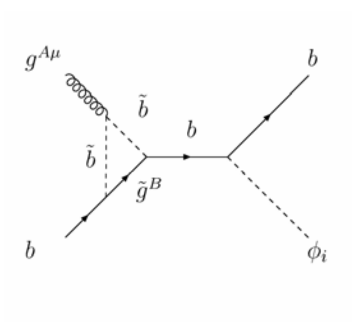
Calculate SUSY QCD Corrections to bg→bh

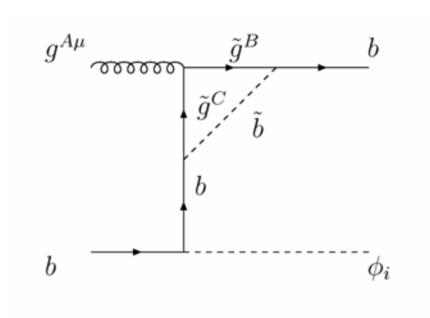
- Approach 1: "Improved Born Approximation"

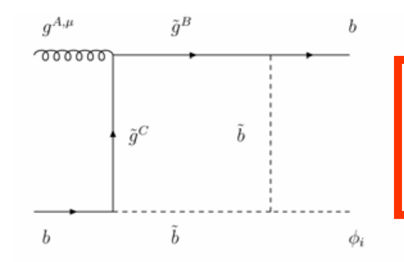
$$\boxed{g_{hbb} \equiv \frac{m_b}{v_{SM}}\left(\frac{1}{1+\Delta m_b}\right)\left(-\frac{\sin\alpha}{\cos\beta}\right)\left(1-\frac{\Delta m_b}{\tan\beta\tan\alpha}\right)} \qquad \sigma_{IBA} = \left(\frac{g_{hbb}}{g_{hbb}^{SM}}\right)^2 \sigma_{LO}$$

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



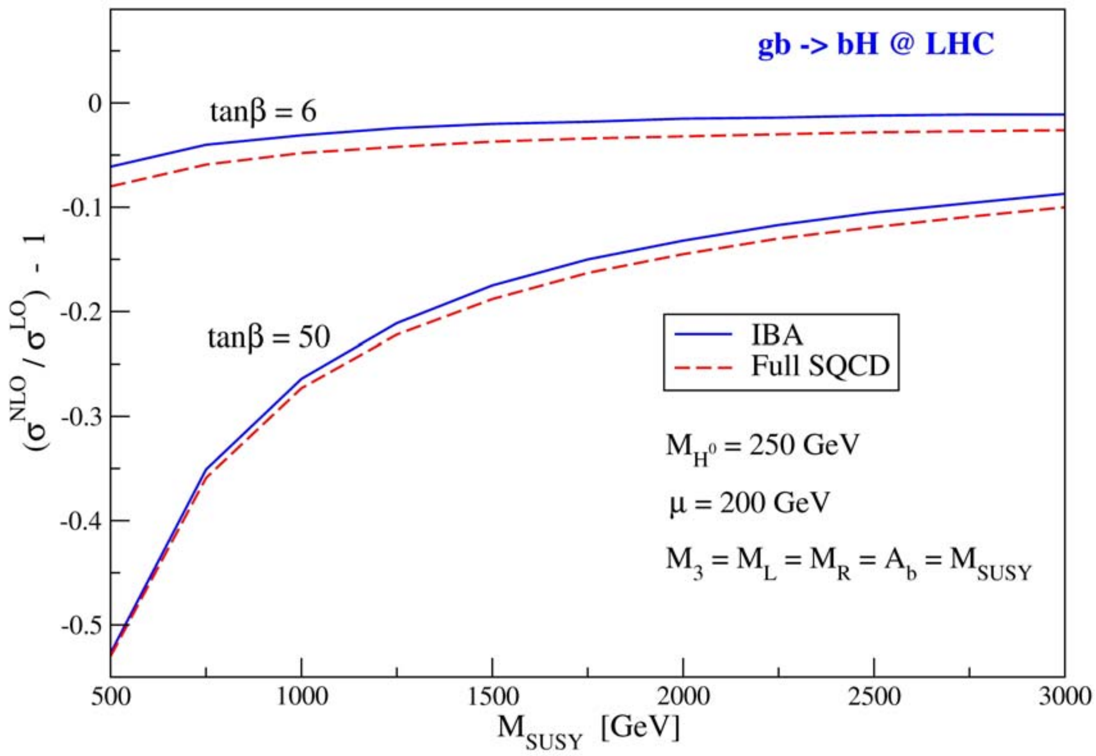






Many contributions not included in IBA

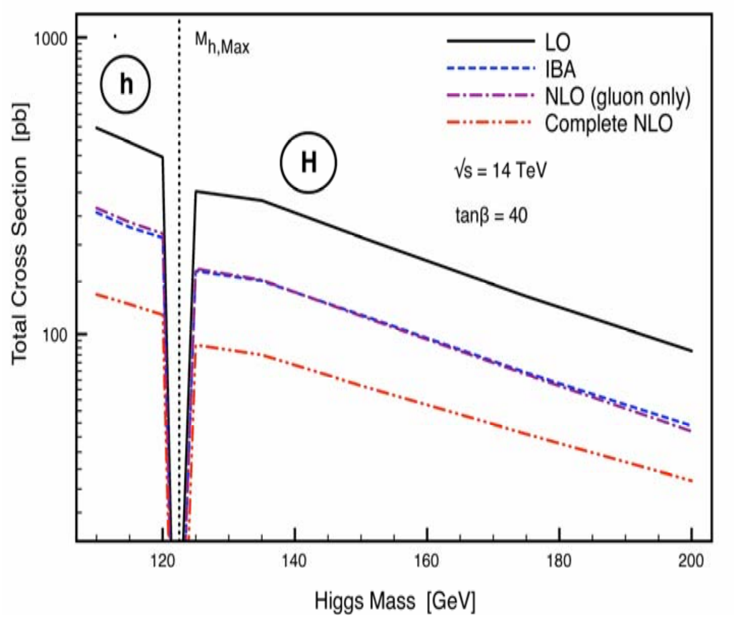
IBA (Effective L approach) works

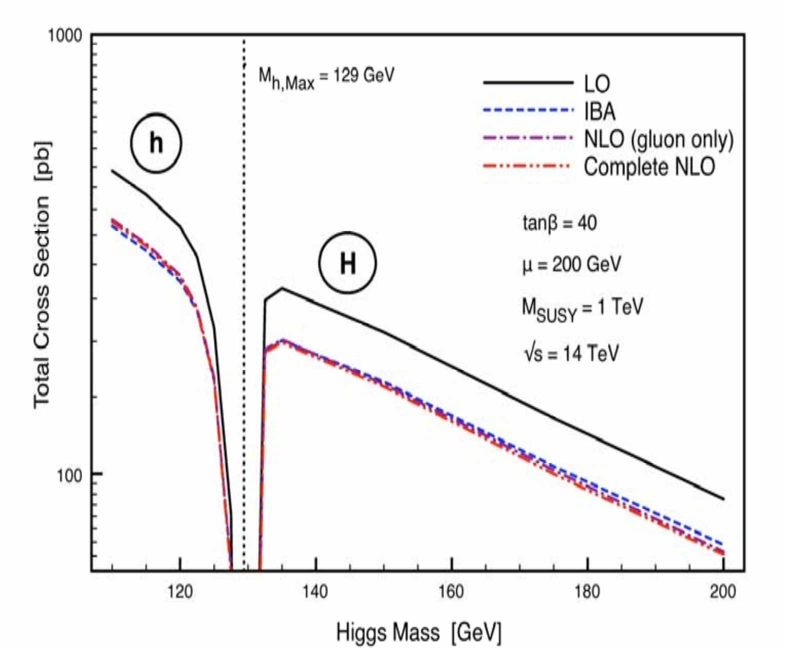


- Note slow approach to decoupling limit for large tanβ

Dawson & Jackson, arXiv:0709.4519 [hep-ph]

Non-Decoupling of SQCD for Moderate M_{SUSY} ($bg \rightarrow bh$)



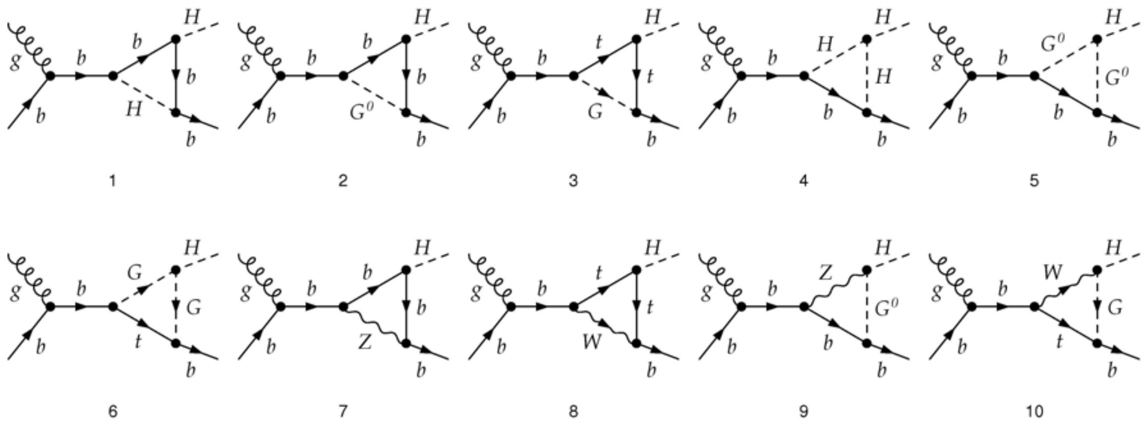


$m_g = m_b = 250$ GeV

$m_g = m_b = 1$ TeV

Do Electroweak Corrections Matter?

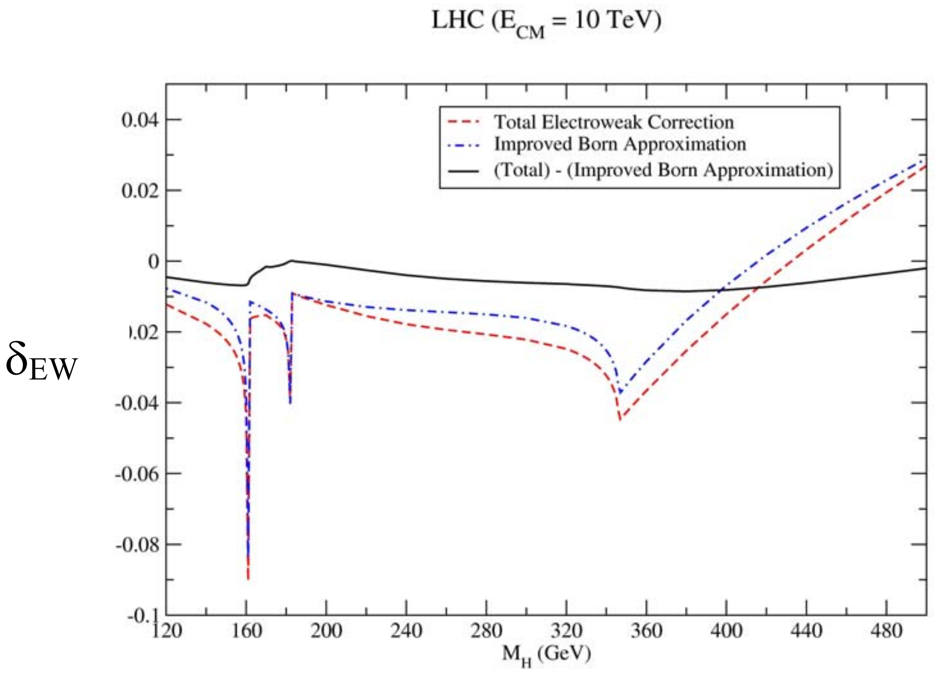
- Full EW calculation
- At 1-loop, there are diagrams which do NOT vanish in m_b=0 limit



Plus many more…..

EW Corrections to bg→bh

$$\Gamma(h \to b\bar{b}) = \Gamma_0\left(1 + 2\delta_{QCD} + 2\delta_{SQCD} + 2\delta_{EW}\right)$$

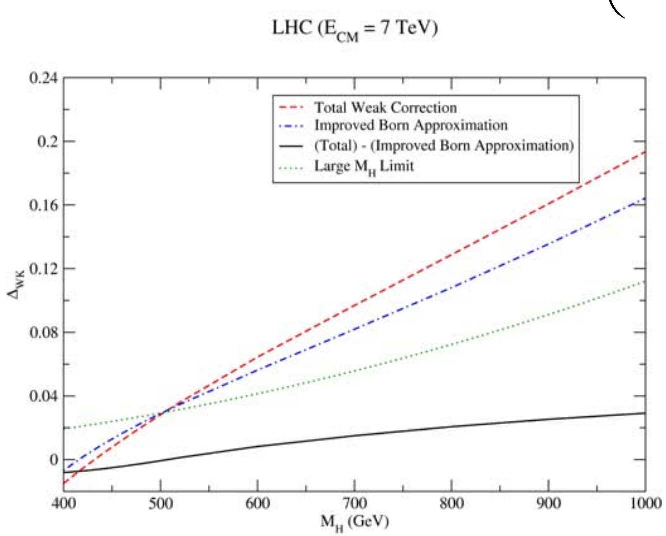


Dawson & Jaiswal,
arXiv:1002.2672

EW corrections in large M_H limit

- Dominant contributions from bbH Vertex
  - No contributions which grow with M_h from triangle or box diagrams

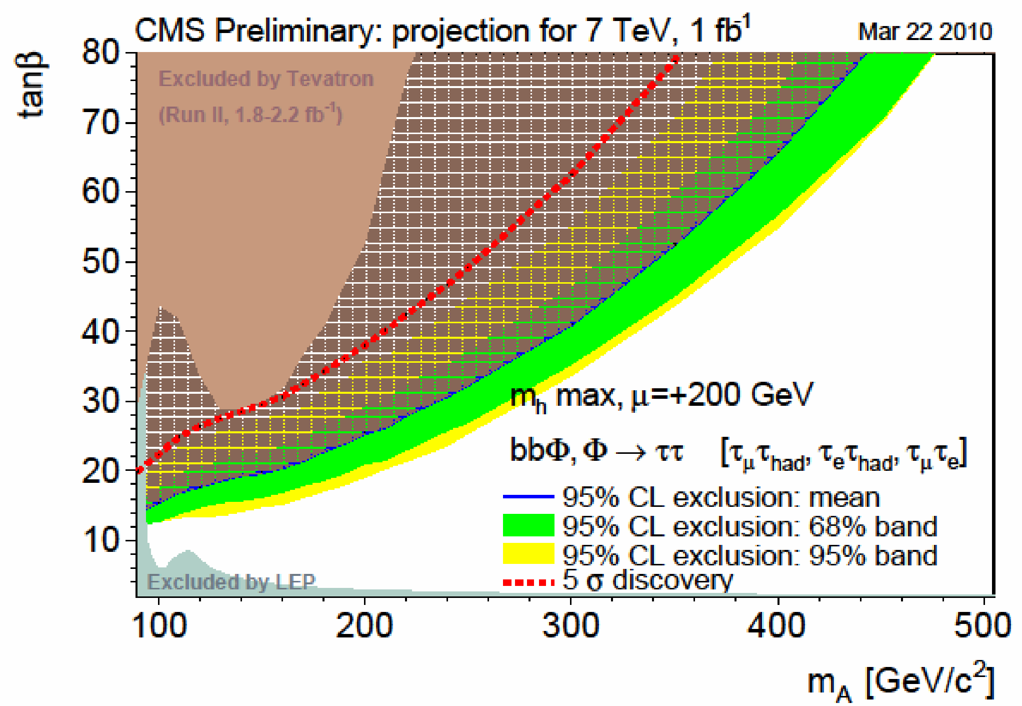
$$\sigma(bg \to bh) \approx \sigma_0 \left(1 + \frac{M_h^2}{32\pi v^2} \left[13 - 2\pi\sqrt{3} \right] \right)$$



Need log(M_h) pieces

LHC Expectations

$(b)bH,\ H \to \tau\tau$



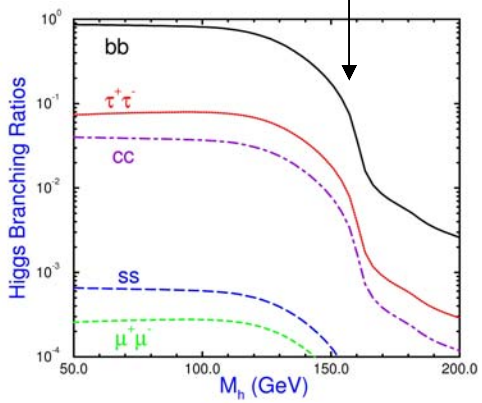
Conclusions

- In the MSSM Higgs and b quarks go together at large tan β
- Higgs production with b's is dominant mechanism for tan $\beta > 7$
- Theoretical understanding of b PDFs: compatible answers in 4FNS and 5FNS for PDFs
- EW corrections important at large M_h
- SUSY QCD corrections can be important
  - Decoupling only occurs for $M_A \rightarrow \infty$
  - SUSY QCD has slow decoupling for large tan β

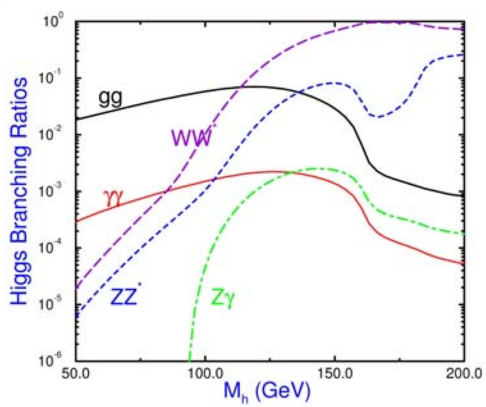
Backup

Higgs Decays also affected at large tan β

- SM: Higgs branching rates to bb and $\tau^+\tau^-$ turn off as rate to W^+W^- turns on (M_h > 160 GeV)

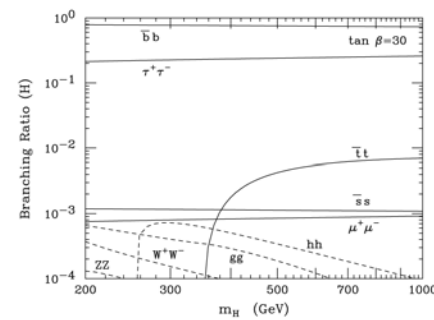


SM



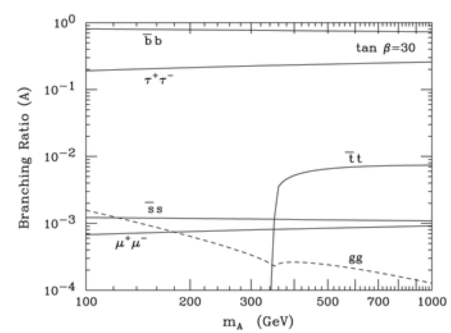
•MSSM: At large tan β, rates to bb and $\tau^+\tau^-$ stay large

Heavy H^0 MSSM BRs



Rate to bb and $\tau^+\tau^-$ almost constant in MSSM

A^0 MSSM BRs



New Logs in Production Processes

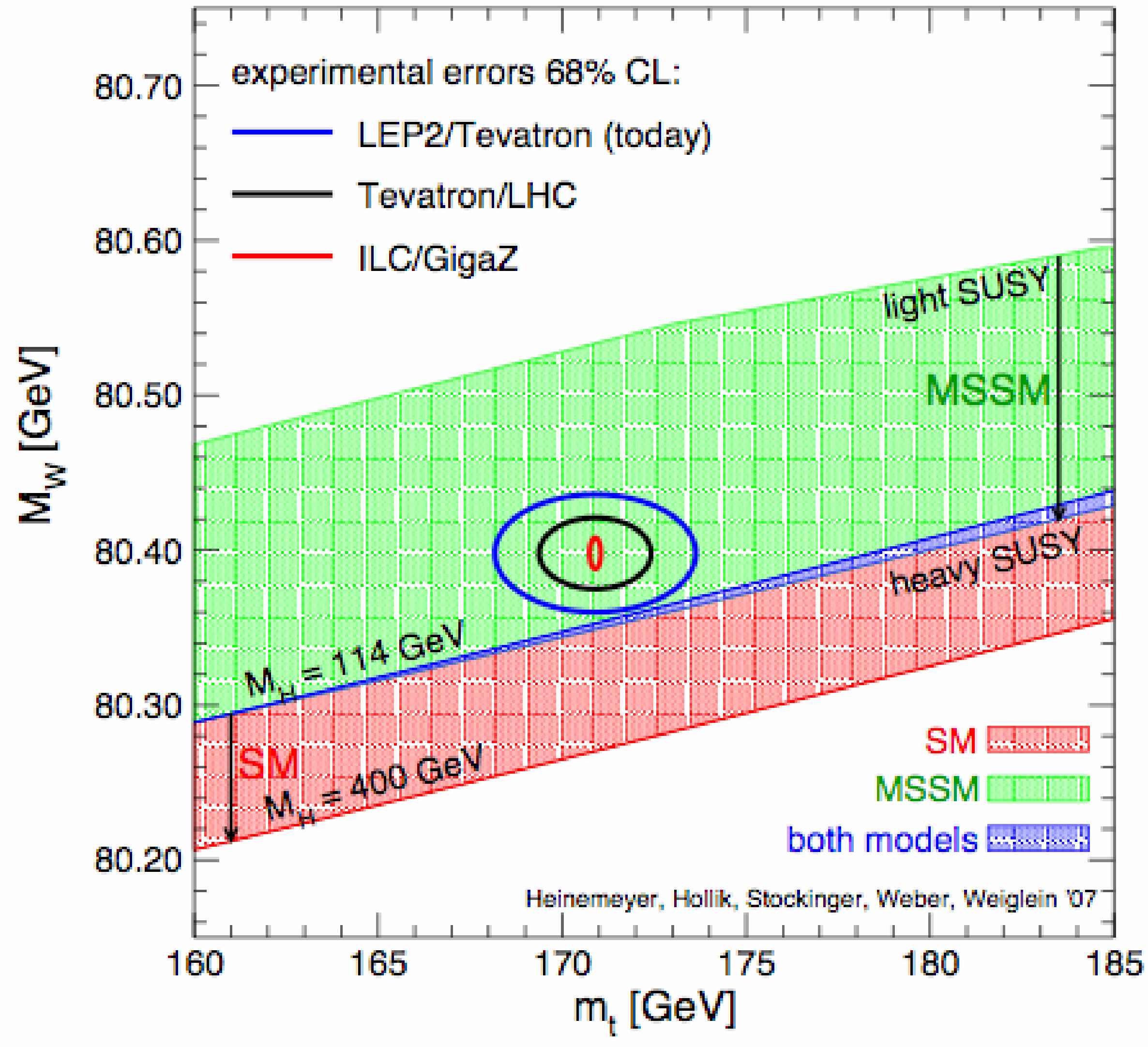
- At NLO:

$$\sigma(b\bar{b} \to h)_{NLO} \approx \sigma_0 \begin{pmatrix} 1 + C_F \dfrac{\alpha_s}{2\pi} \left[.... - 3\log \dfrac{M_h{}^2}{\mu^2} \right] \delta(1-z) \\ + P_{qq}(z) \log \dfrac{M_h{}^2}{\mu_F{}^2} + ... \end{pmatrix}$$

$\mu \approx M_h$ associated with renormalization of α_s

$\mu_F \approx m_b$ associated with PDFs

- Logs not neatly absorbed into running b mass


experimental errors 68% CL:
LEP2/Tevatron (today)
Tevatron/LHC
ILC/GigaZ
light SUSY
MSSM
heavy SUSY
M_H = 114 GeV
SM
M_H = 400 GeV
SM
MSSM
both models
Heinemeyer, Hollik, Stockinger, Weber, Weiglein '07
80.70
80.60
80.50
80.40
80.30
80.20
M_W [GeV]
160
165
170
175
180
185
m_t [GeV]