Bottom–Parton Induced Higgs Production

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– MSSM Higgs Bosons at the LHC

– Bottom Parton Description

– Bottom Factorization Scale

– Impact on LHC Searches

MSSM Higgs Bosons at the LHC

MSSM Higgs Sector

– two doublets, coupling to up and down type fermions
$\rightarrow$ five physical states $h^o, H^o, A^o, H^\pm$
$\rightarrow$ mixing of scalars to mass eigenstates (mixing angle α)
$\rightarrow$ more predictive than Standard Model (upper h^o mass limit)

– conveniently expressed as function of m_A and $\tan\beta \equiv v_2/v_1$

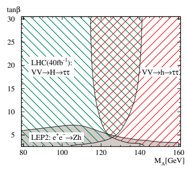
– Yukawa couplings: $(m_b \tan\beta, m_t/\tan\beta)$

LHC search channels

– multitude of channels [ATLAS TDR (pre-LEP2)]

– complete coverage by WBF $h \to \tau\tau$ [TP, Rainwater, Zeppenfeld]

– mostly light scalar Higgs boson

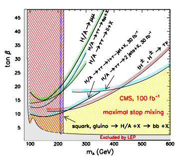


Tell it is 2HDM (MSSM?) $\Rightarrow$ look for heavy Higgs bosons

– $H^0, A^0 \to \tau\tau, \mu\mu$ inclusive $gg \to \Phi$ and $gg \to b\bar{b}\Phi$

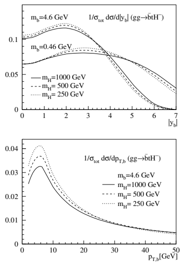
– $H^\pm \to \nu\tau, tb$ in $pp \to tH^-, W^+H^-, H^+H^-$

– apperance in SUSY cascades [Djouadi et al.]



– There is no other conclusive way but to find these particles!

Bottom-Inclusive Cross Sections



Exclusive production $gg \to \bar{b}tH^-$

– simple example, only one final state bottom jet

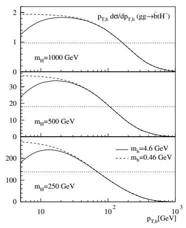
$\to$ collinear bottom jets from gluon splitting, regularized by m_b

$\to$ experiment: forward jets, $p_{T,b}$ peaked at m_b

$\to$ use bottom–inclusive cross section

$\to$ possibly large logarithms $\log(p_{T,b}/m_b)$
asymptotic cross section behavior $\quad d\sigma/dp_{T,b} \propto p_{T,b}/m^2_{T,b}$

$\to$ check: plateau in exclusive cross section



$\to$ impact on inclusive rate $\quad \sigma \propto \log[(p^{\max}_{T,b}/m_b)^2 + 1]$

$\to$ see how large the logarithms can become

Inclusive process $bg \to tH^-$

– large logarithms $\log(p_{T,b}/m_b)$ can be resummed

$\to$ equivalent to bottom parton density
$\mu_{F,b}$ ‘transverse momentum size’ of bottom parton $\quad (\mu_{F,b} \equiv p^{\max}_{T,b})$

$\to$ inclusive cross section: hard scale $\mu_{F,b} = M$

$\to$ huge enhancement in case of $b\bar{b} \to h$

$\to$ numerical improvement or overestimate?
how large are these logs, really?

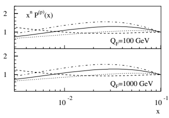
Bottom Jet Virtuality

Two steps: bottom virtuality $Q_b^{\max}$, then transverse momentum $p_{T,b}^{\max}$

– effective $2 \to 2$ cross section: $gg \to \bar{b}X$

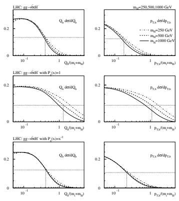
hard scale for threshold production $M = M_X = m_H + m_t$

$$\sigma = \frac{1}{16\pi}\frac{1}{S}\int_0^{S-M^2} dQ_b^2 \int_{Q_b^2+M^2}^{S} ds \int_{\frac{1}{2}\log\frac{s}{S}}^{-\frac{1}{2}\log\frac{s}{S}} dy\; \mathcal{L}_{gg}\, \frac{1}{s^2}\, \overline{|\mathcal{M}|^2}$$



$\to$ (1) approximate steep gluon density $\mathcal{L} = \mathcal{L}_0/x^2$

(2) asymptotic behavior $\overline{|\mathcal{M}|^2} = S^2\sigma_0/Q_b^2$



$$\sigma = \frac{2\sigma_0\mathcal{L}_0}{16\pi}\int_0^{S-M^2}\frac{dQ_b}{Q_b}\,F(Q_b)$$

$\to$ $F(Q_b)$ correction to asymptotic behavior $\;d\sigma/dQ_b \sim 1/Q_b$

(analogy $Q_b \leftrightarrow p_{T,b}$)

$\to$ turning point $d^2F(Q_b)/d(\log Q_b)^2 = 0\;$ at $Q_b^{\max}$

$\to$ $Q_b^{\max} \sim M/2\quad$ (hard scale argument $Q_b^{\max} \propto M$, nothing more!)

Valid in general

– gg initiated exclusive process

– hard scale plus bottom jet $\sqrt{S} \gg M \gg m_b$

– threshold dominated (otherwise M typical invariant mass)

Bottom Factorization Scale

Second step: transverse momentum $p_{T,b}^{\max}$

– no simple phase space parametrization

– check explicitly: $Q_b \sim Q_b^{\max}$ also yields $p_{T,b} \sim p_{T,b}^{\max}$

$\to$ translate Q_b into $p_{T,b}$ point by point

$\to$ mostly transverse momentum at threshold $(\rho \equiv p_{z,b}/p_{T,b} \ll 1)$

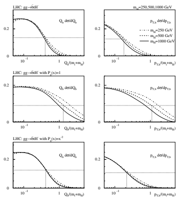
$$\frac{Q_b^2}{M^2} = \frac{p_{T,b}\sqrt{s}}{M^2}\left(\sqrt{1+\rho^2}-\rho\right) \sim \frac{p_{T,b}}{M}$$

$\to$ $p_{T,b}^{\max}/Q_b^{\max} \sim Q_b^{\max}/M$

$\to$ $\mu_{F,b} \equiv p_{T,b}^{\max} \sim Q_b^{\max}/2 \sim M/4$

$\to$ numerical study of $gg \to \bar{b}tH^-$: $\mu_{F,b} \sim M/5$

(not quite as easy, detailed discussion with same result)



What did we learn from exclusive process?

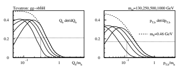
– 'large logs' $\log(p_{T,b}/m_b)$ after integrating over bottom jet

– hard scale for inclusive process: $\mu_{F,b} \propto M$

– gg and bg processes: $\mu_{F,b} \sim M/4$ from partonic phase space

– inclusive logs at maximum $\log(M/(4m_b))$

– valid for Tevatron and LHC



Instead of Conclusions

Neutral Higgs boson production

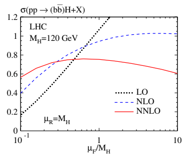
– $gg \to b\bar{b}h$ exclusive as $gg \to \bar{b}X$
  $bg \to bh$ exclusive as $bg \to bX$

– hard scale $\mu_{F,b} \sim M/5 = m_h/5$

– exclusive vs. inclusive total rate [Maltoni, Sullivan, Willenbrock]

Scales	$\sigma(b\bar{b} \to h)$	$\sigma(gg \to b\bar{b}h)$	$\sigma(b\bar{b} \to h)/\sigma(gg \to b\bar{b}h)$
$\mu_F = \mu_R = m_h$	26.6 fb	3.1 fb	8.5
$\mu_F = \mu_R = m_h/4$	20.8 fb	9.2 fb	2.3

– $b\bar{b} \to h$ NNLO [Harlander & Kilgore]
  $\mu_{R,b}$ variation for fixed $\mu_{F,b} \sim m_h/4$ well under control
  $\mu_{F,b}$ variation for fixed $\mu_{R,b} \sim m_h$ almost fixed point



Single top production $qg \to \bar{b}tq'$ [Willenbrock et al]

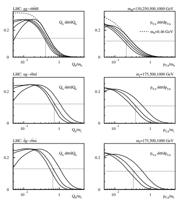
– less steep quark densities, $x_1 \neq x_2$

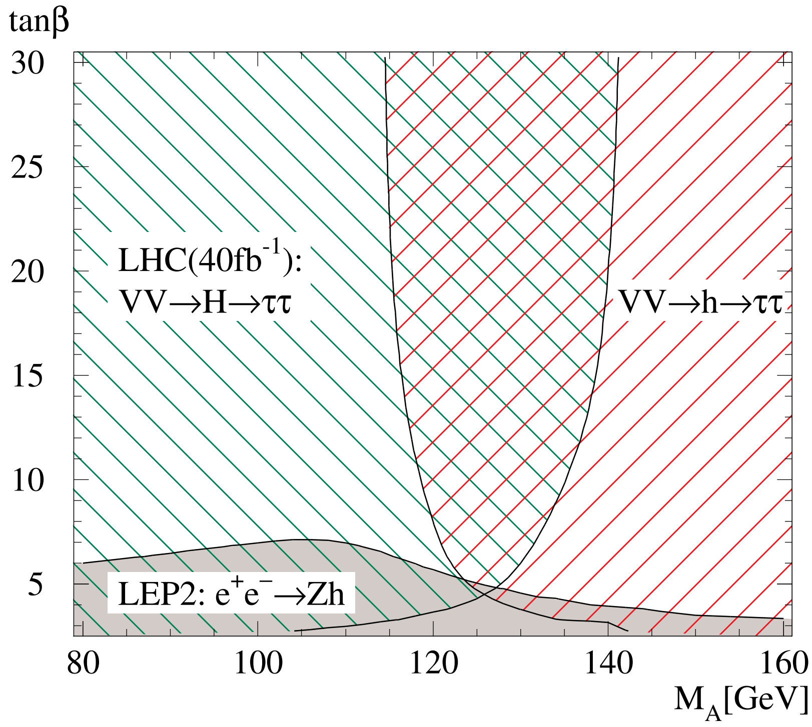
– production above threshold

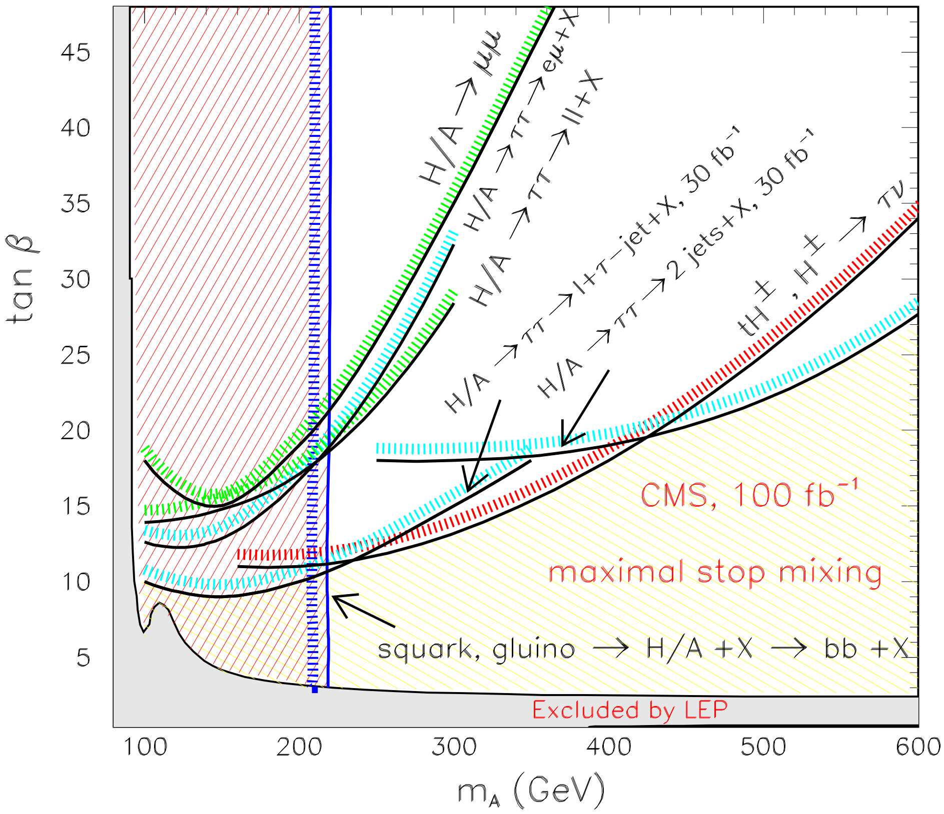
$\to$ $Q_b^{\max} \sim m_t$

– generally $p_{T,b}^{\max} \sim Q_b^{\max}/2$

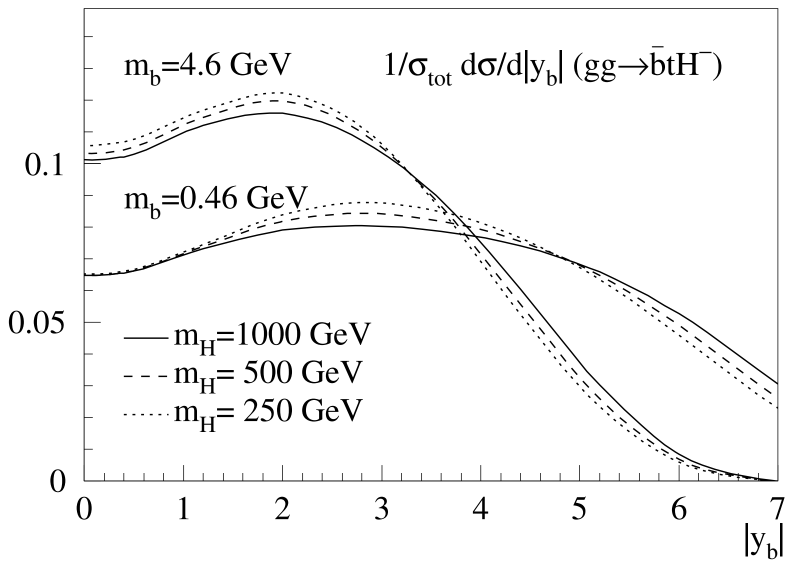
$\to$ $\mu_{F,b} \sim m_t/2$ covered by quoted theoretical uncertainty



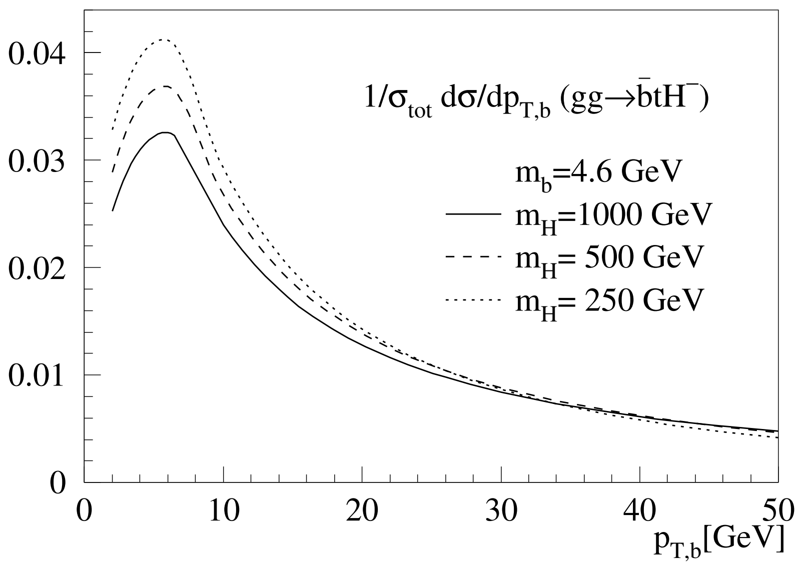

tanβ
30
25
20
15
10
5
80
100
120
140
160
M_A[GeV]
LHC(40fb^-1):
VV→H→ττ
VV→h→ττ
LEP2: e^+e^-→Zh



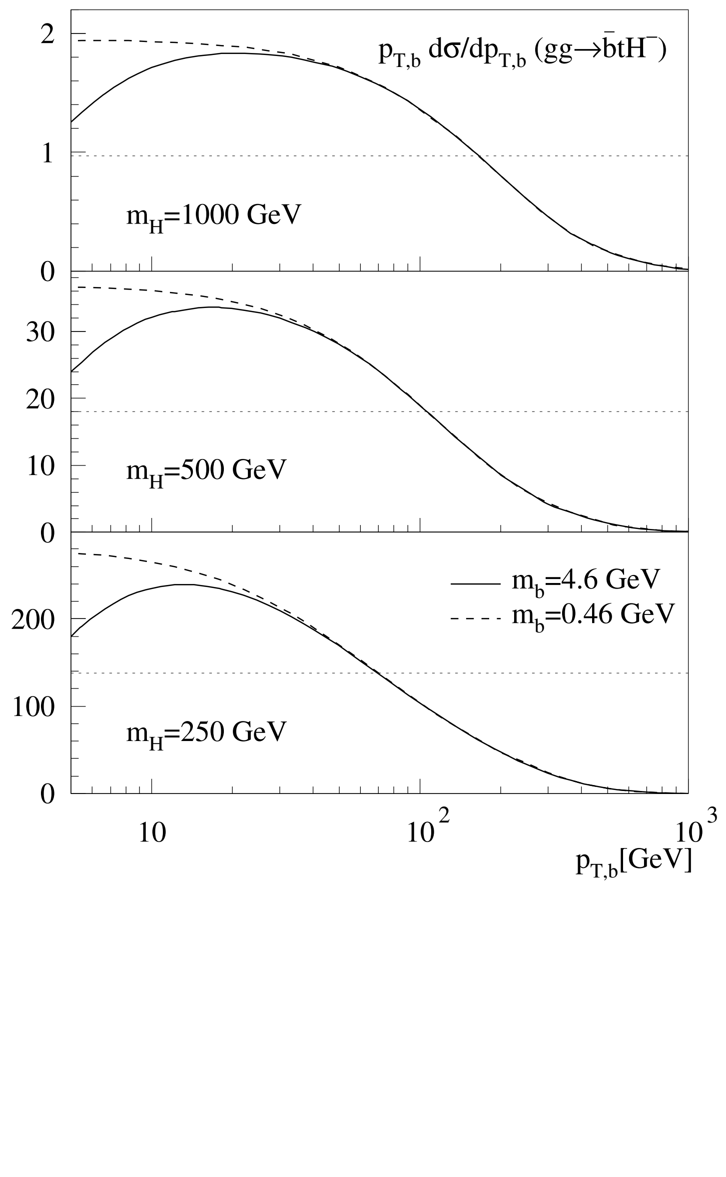
Datta, Djouadi, Guchait, Moortgat



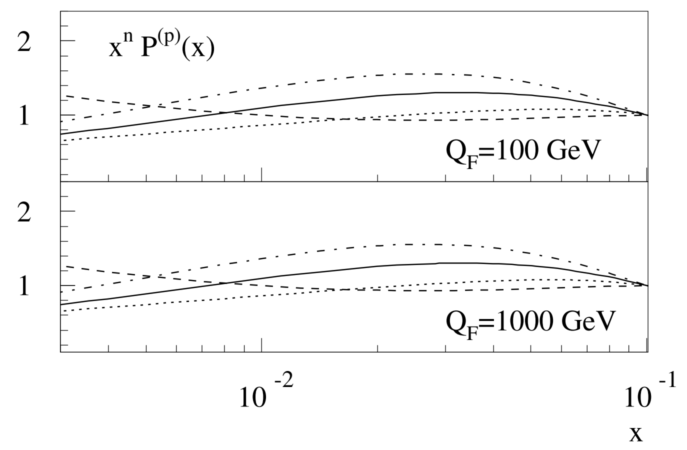
m_b=4.6 GeV
$1/\sigma_{tot}\ d\sigma/d|y_b|\ (gg\rightarrow\bar{b}tH^-)$
m_b=0.46 GeV
m_H=1000 GeV
m_H= 500 GeV
m_H= 250 GeV
0
0.05
0.1
0 1 2 3 4 5 6 7
$|y_b|$

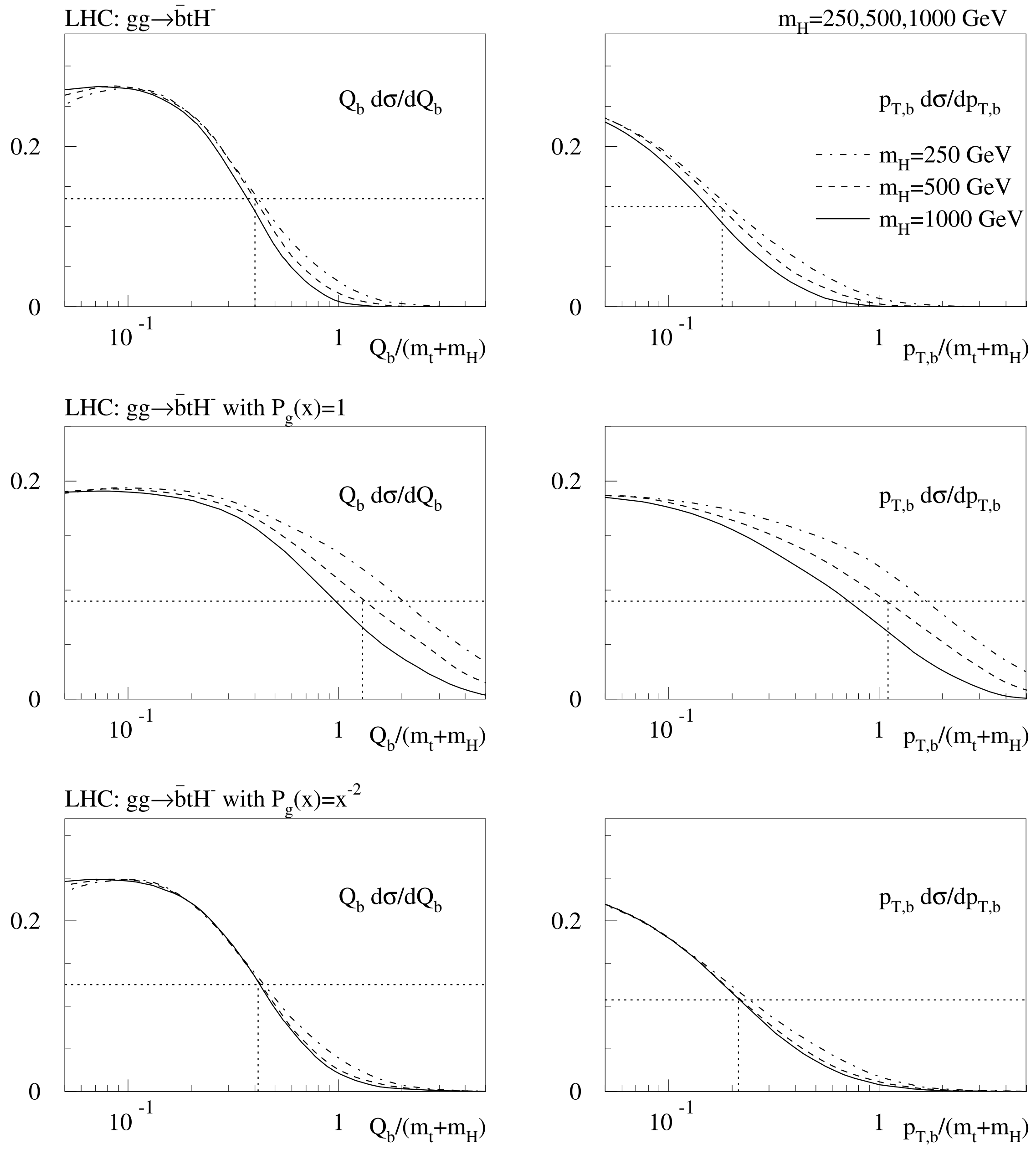


$1/\sigma_{tot}\ d\sigma/dp_{T,b}\ (gg\rightarrow\bar{b}tH^-)$
m_b=4.6 GeV
m_H=1000 GeV
m_H= 500 GeV
m_H= 250 GeV
0
0.01
0.02
0.03
0.04
0 10 20 30 40 50
$p_{T,b}$[GeV]

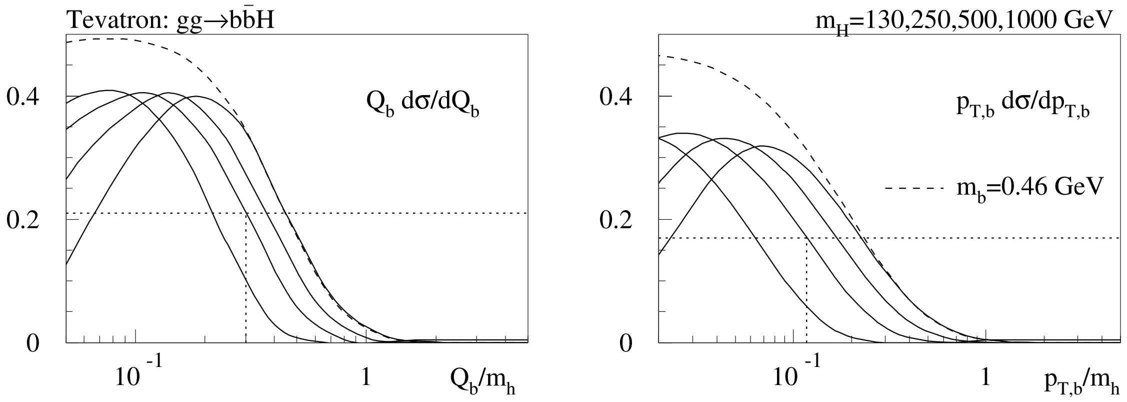


$p_{T,b}\ d\sigma/dp_{T,b}\ (gg\to\bar{b}tH^-)$
m_H=1000 GeV
m_H=500 GeV
m_H=250 GeV
m_b=4.6 GeV
m_b=0.46 GeV
$p_{T,b}$[GeV]

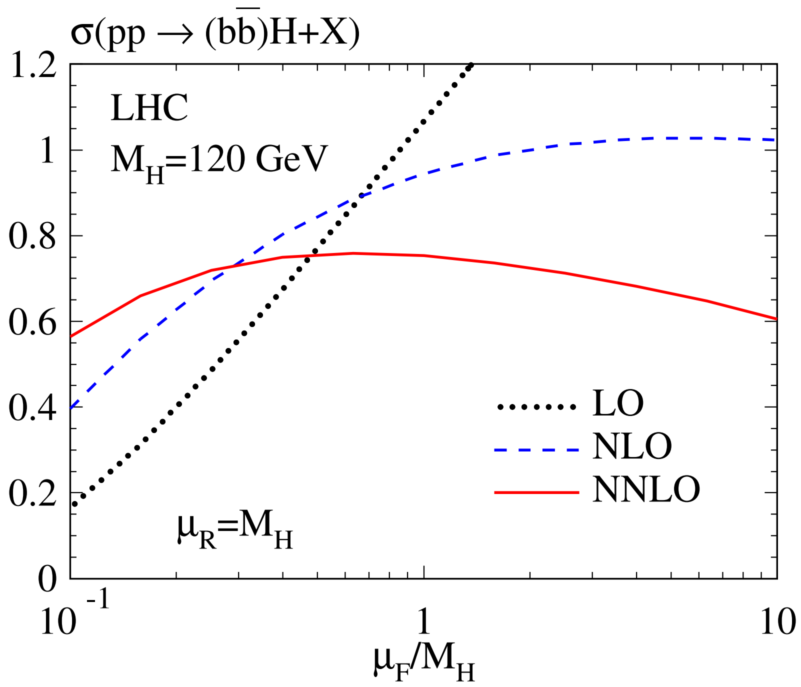

x^n P^(p)(x)
2
1
Q_F=100 GeV
2
1
Q_F=1000 GeV
10^-2
10^-1
x



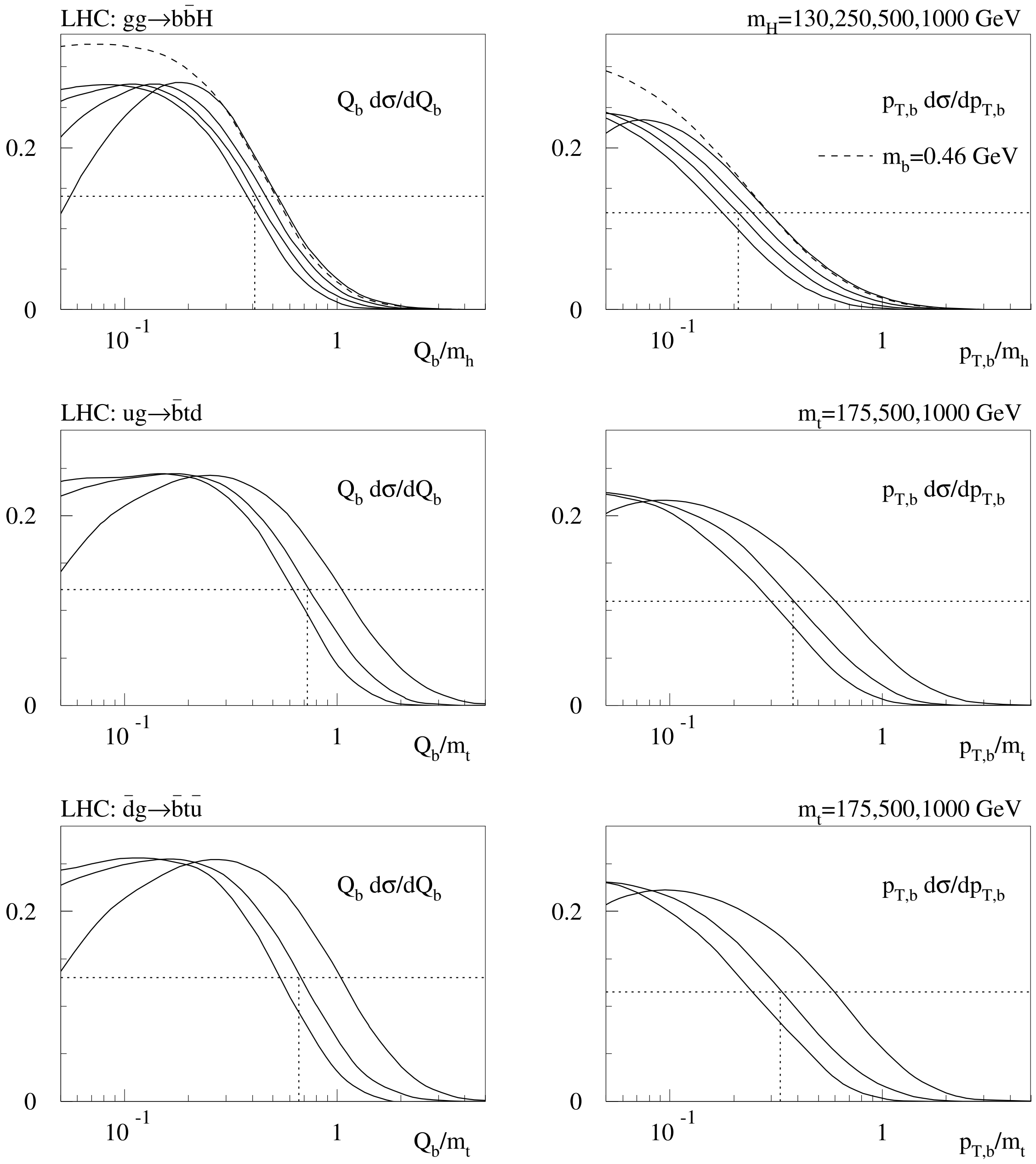
LHC: gg→b̄tH⁻
m_H=250,500,1000 GeV
Q_b dσ/dQ_b
p_T,b dσ/dp_T,b
m_H=250 GeV
m_H=500 GeV
m_H=1000 GeV
Q_b/(m_t+m_H)
p_T,b/(m_t+m_H)
LHC: gg→b̄tH⁻ with P_g(x)=1
LHC: gg→b̄tH⁻ with P_g(x)=x^-2
0
0.2
10^-1
1



Tevatron: gg→bb̄H
m_H=130,250,500,1000 GeV
0.4
0.2
0
Q_b dσ/dQ_b
10^-1
1
Q_b/m_h
p_T,b dσ/dp_T,b
m_b=0.46 GeV
p_T,b/m_h



Harlander, Kilgore



LHC: $gg \to b\bar{b}H$
m_H=130,250,500,1000 GeV
$Q_b\ d\sigma/dQ_b$
$p_{T,b}\ d\sigma/dp_{T,b}$
m_b=0.46 GeV
0.2
0
10^{-1}
1
Q_b/m_h
$p_{T,b}/m_h$
LHC: $ug \to \bar{b}td$
m_t=175,500,1000 GeV
Q_b/m_t
$p_{T,b}/m_t$
LHC: $\bar{d}g \to \bar{b}t\bar{u}$
m_t=175,500,1000 GeV