Charged Higgs Production via Bottom Partons

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– MSSM Higgs Bosons at the LHC

– Bottom Parton Description

– Charged Higgs Production at NLO

– SUSY-QCD Corrections

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 $\tan\beta \equiv v_2/v_1$

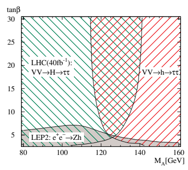
– Yukawa couplings: $(m_b \tan\beta, m_t/\tan\beta)$

LHC search channels

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

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

– mostly light scalar Higgs boson



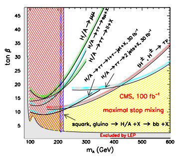
Tell it is 2HDM (MSSM?) $\Rightarrow$ look for heavy Higgs bosons

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

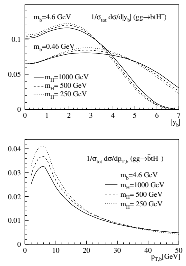
– $H^\pm \rightarrow \nu\tau, tb$ in $pp \rightarrow tH^-, W^+H^-, H^+H^-$

– apperance in SUSY cascades [Djouadi et al.]

– 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

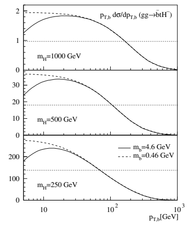
$\to$ use bottom–inclusive cross section

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

$\to$ check: plateau in exclusive cross section

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

$\to$ how large logarithms? resum!



Inclusive process $bg \to tH^-$

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

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

$\to$ usually: hard scale $\mu_{F,b} = M$

$\to$ numerical improvement in total rate?

$\to$ distributions?

Bottom Factorization Scale

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 $M = M_X = m_H + m_t$

$\to$ (1) approximate steep gluon density $\mathcal{L} = \mathcal{L}_0 / x^2$
(2) asymptotic behavior $\overline{|\mathcal{M}|^2} = S^2 \sigma_0 / Q_b^2$

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

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

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

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

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

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

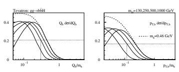
$\to$ numerical study of $gg \to \bar{b}tH^-$: $\quad \mu_{F,b} \sim M/5$

So what did we learn from exclusive process?

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

$\to$ moderate enhancement of rate

$\to$ bottom parton picture understood for heavy Higgs boson

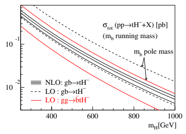


QCD Corrections to Inclusive Channel

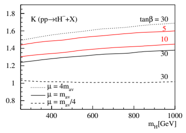
Next-to-leading Order QCD Calculation:

– leading order uncertainty large for $bg \to tH^-$
  e.g. mass definition: $\overline{MS}$ or pole mass for $y_{b,t}$?

– complete set of virtual and real QCD corrections



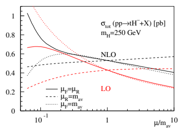
– running top and bottom Yukawa coupling
  pole mass is leading order and not conservative



$\to$ NLO correction $+30\% \cdots 40\%$ perturbatively stable [Zhu]

Scale Dependence in NLO:

– generic cancellations for $\mu_R \equiv \mu_F$ [Harlander & Kilgore]



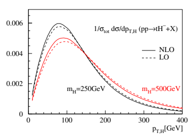
– renormalization scale dependence numerically dominant
  $\mu_R \sim (m_t + m_H)/2$ natural choice [c.f. Higgs decays, Melnikov]

– factorization scale dependene critical only for $\mu_F \sim m_b$
  $\mu_F \sim (m_t + m_H)/5$ from exclusive process

$\to$ NLO scale dependence $\pm 20\%$, good estimate for theory uncertainty

$\to$ well defined limit $\mu_F \to m_b$ returns exclusive process at NLO

Distributions in NLO:



– Higgs transverse momentum softened (gluon density)

– Higgs rapidity not symmetric (gluon splitting)

SUSY-QCD Corrections

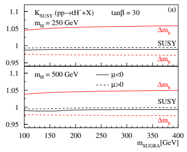
SUSY-QCD Loop Contributions:

– infrared finite but ultraviolet divergent SUSY loops

– parameterized by $K_{\mathrm{SUSY}} = 1 + \sigma_{\mathrm{SUSY}}/\sigma_{\mathrm{NLO}}$

– (1) universal corrections $y_b \to y_b/(1+\Delta m_b)$

[Carena, Garcia, Nierste, Wagner]



– (2) remaining explicit SUSY loop diagrams [Gao, Lu, Xiong, Yang]

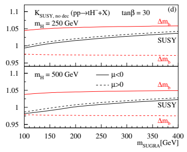
$\to$ Δm_b corrections dominant for $\tan\beta \gtrsim 10$ (dependent on sign of μ)

$\to$ explicit loop corrections negligible $\lesssim 5\%$ for generic mSUGRA

Decoupling of Running Parameters: $\alpha_s(\mu_R), y_{b,t}(\mu_R)$

– heavy SUSY particle loops ultraviolet divergent

$\to$ SUSY counter terms for Standard Model parameters



$\to$ SUSY contributions to beta functions

$\to$ explicit decoupling necessary:

$m_{b,t}(\mu_R) \to m_{b,t}(\mu_R)[1 + \alpha_s/(4\pi) C_F \log(\mu_R^2/m_{\mathrm{heavy}}^2)]$

Conclusions

– heavy Higgs bosons necessary to tell it might be the MSSM

– bottom initiated process $bg \to tH^-$ appropriate

– NLO$_1$: inclusive process well defined

NLO$_2$: $30\% \cdots 40\%$ enhancement of σ_{tot} in 2HDM

NLO$_3$: remaining scale uncertainty $\lesssim 20\%$

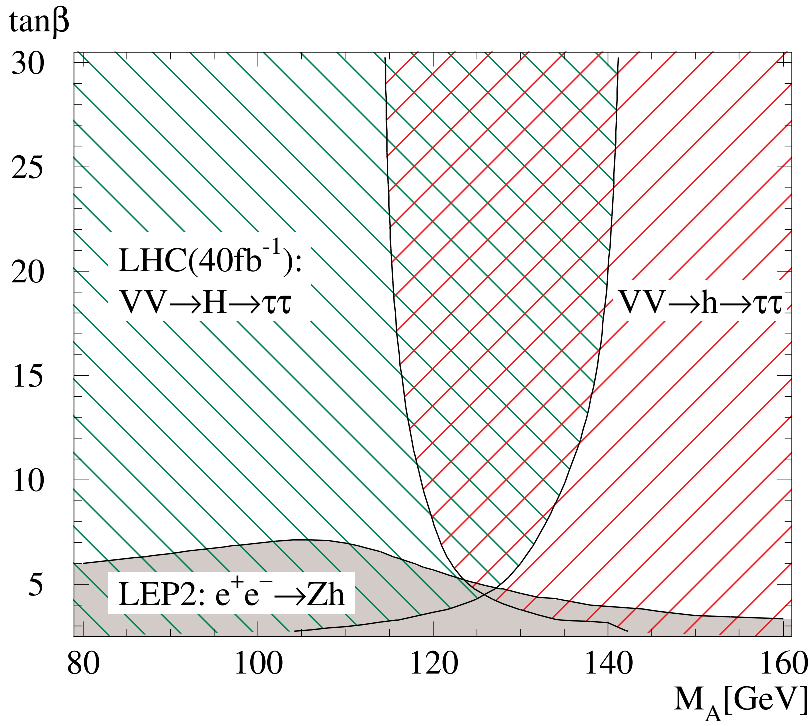
NLO$_4$: Δm_b corrections dominant in MSSM for large $\tan\beta$

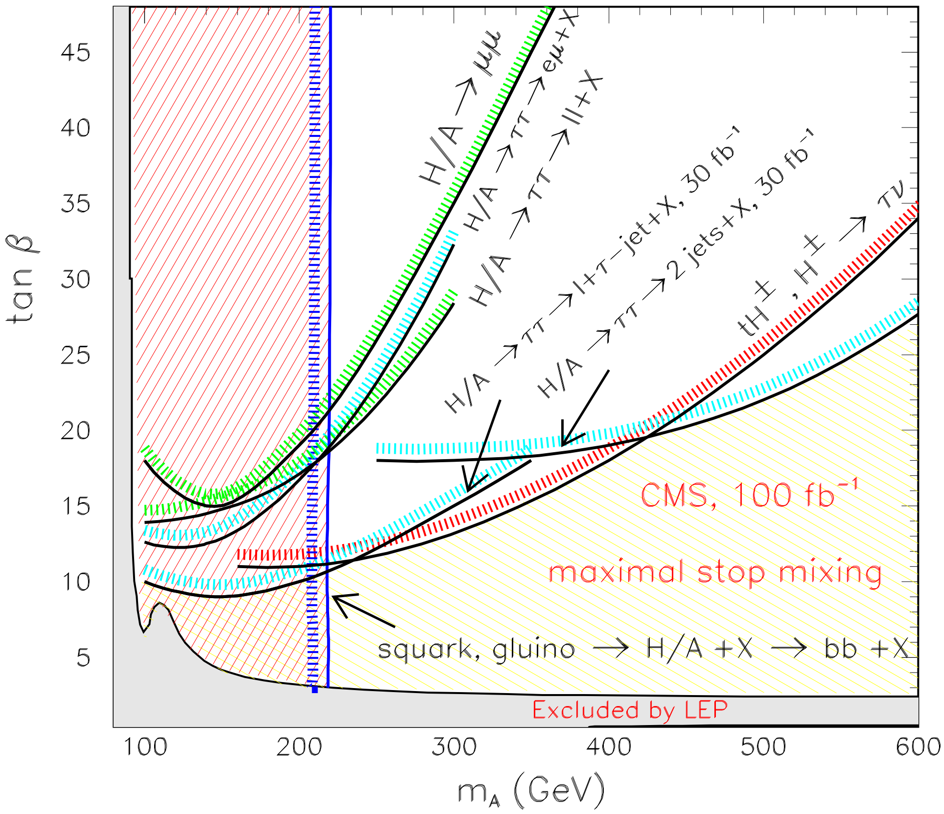
NLO$_5$: non-factorizable corrections negligible in MSSM

– to look forward to:

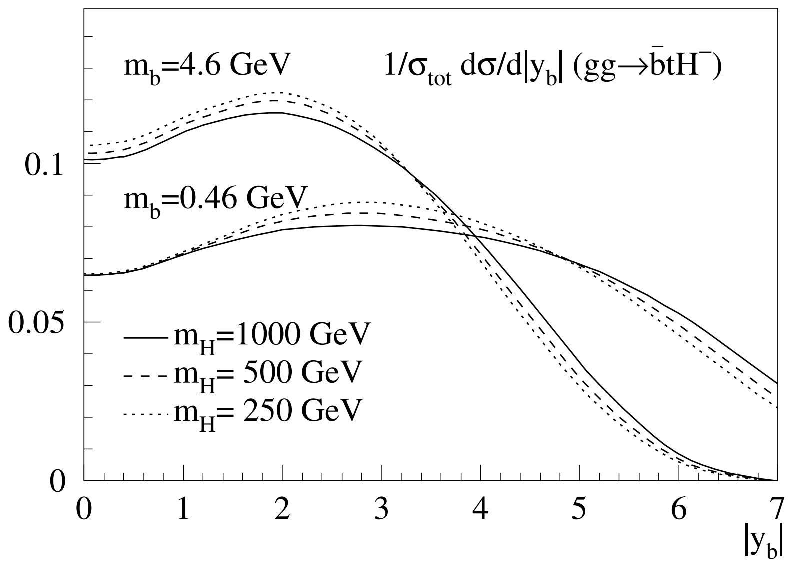
NLO$_6$: Higgs and top distributions to NLO

NLO$_7$: systematic SUSY study

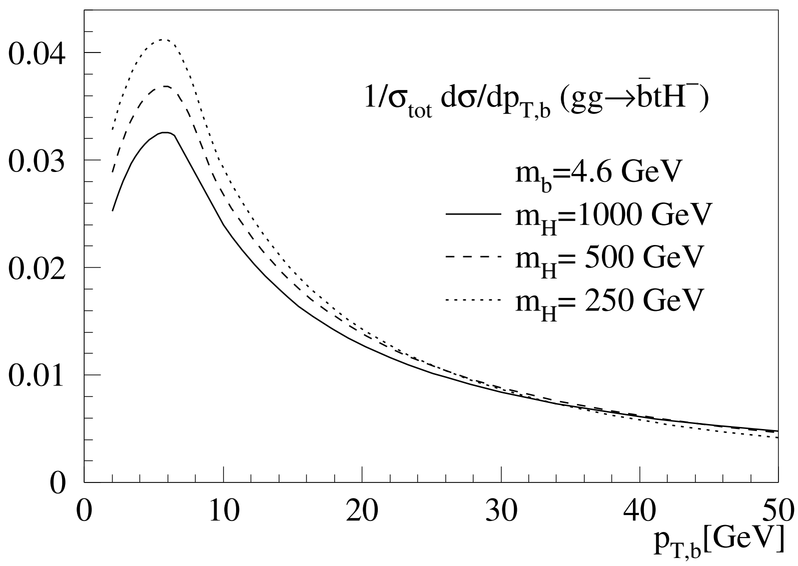

tanβ
30
25
20
15
10
5
80
100
120
140
160
M_A[GeV]
LHC(40fb^{-1}):
VV→H→ττ
VV→h→ττ
LEP2: e^+e^-→Zh



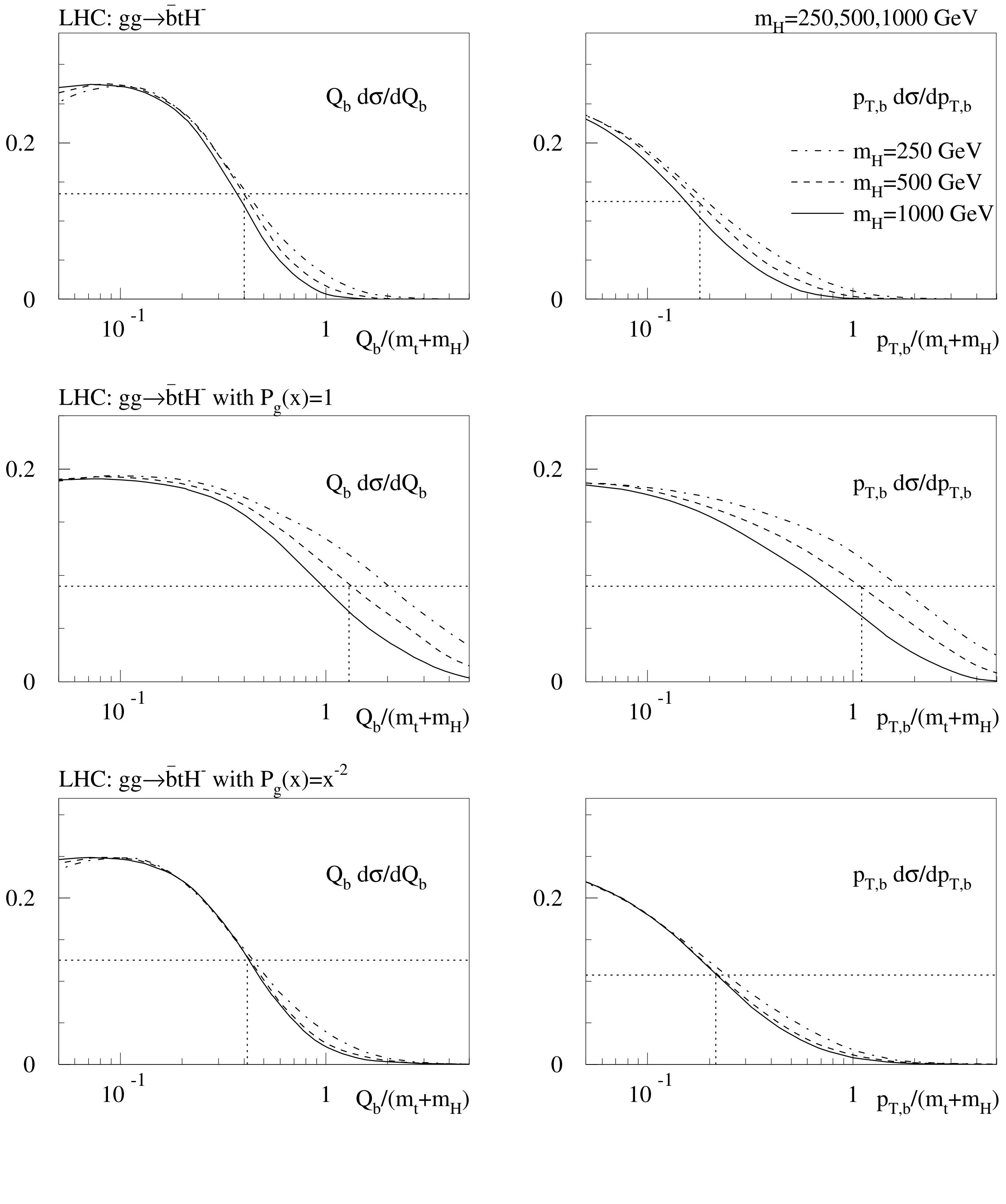
Datta, Djouadi, Guchait, Moortgat



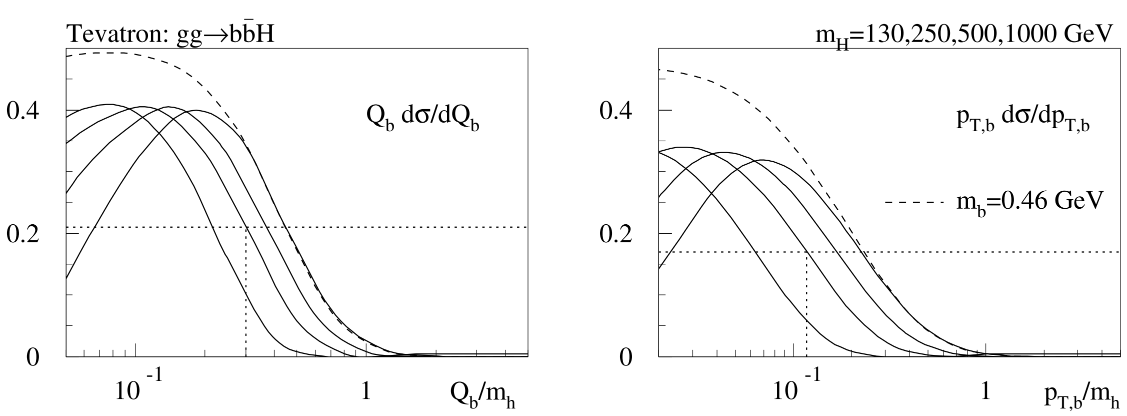
m_b=4.6 GeV
$1/\sigma_{tot}\, d\sigma/d|y_b|\ (gg\to\bar{b}tH^-)$
m_b=0.46 GeV
m_H=1000 GeV
m_H= 500 GeV
m_H= 250 GeV
0
0.05
0.1
0
1
2
3
4
5
6
7
$|y_b|$



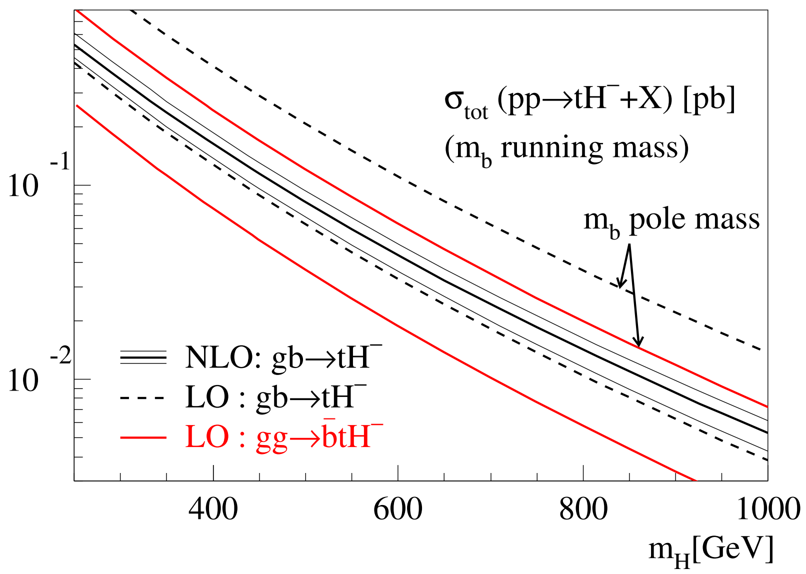
$1/\sigma_{tot}\, d\sigma/dp_{T,b}\ (gg\to\bar{b}tH^-)$
m_b=4.6 GeV
m_H=1000 GeV
m_H= 500 GeV
m_H= 250 GeV
0
0.01
0.02
0.03
0.04
0
10
20
30
40
50
$p_{T,b}$[GeV]



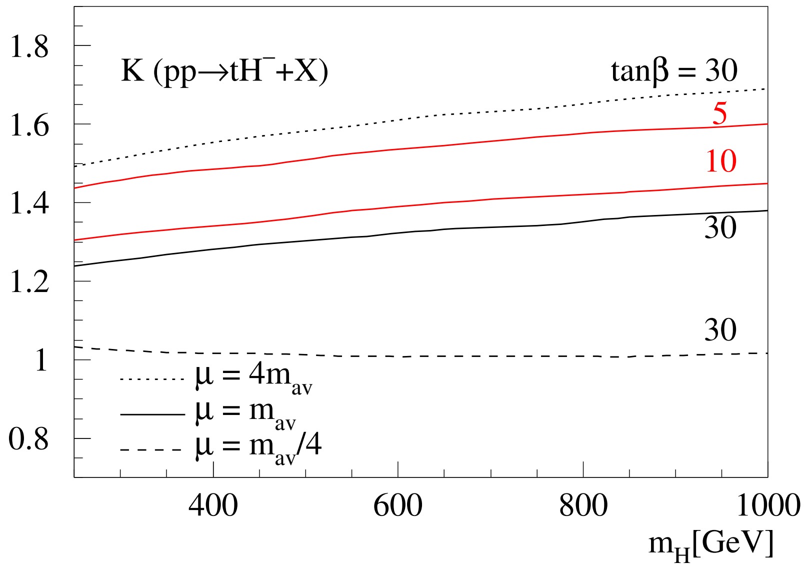
LHC: gg→b̄tH⁻
m_H=250,500,1000 GeV
Q_b dσ/dQ_b
p_T,b dσ/dp_T,b
m_H=250 GeV
m_H=500 GeV
m_H=1000 GeV
Q_b/(m_t+m_H)
p_T,b/(m_t+m_H)
LHC: gg→b̄tH⁻ with P_g(x)=1
LHC: gg→b̄tH⁻ with P_g(x)=x⁻²
0
0.2
10⁻¹
1



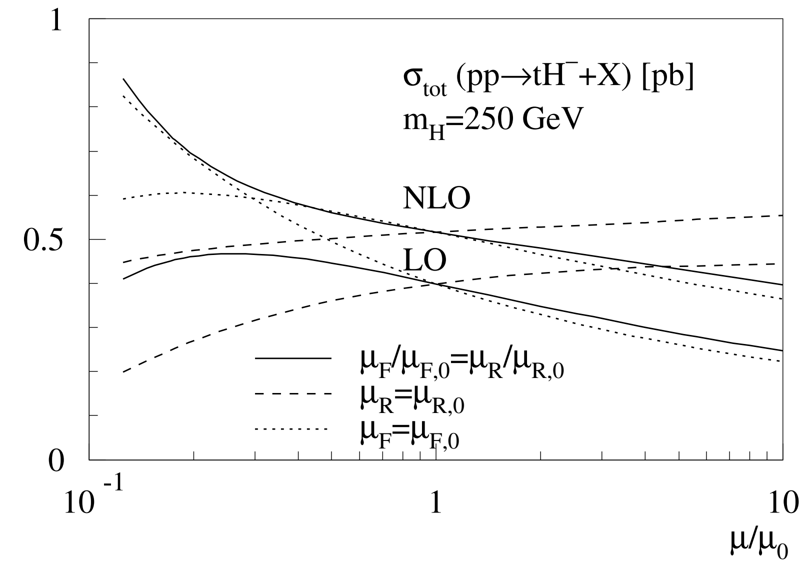
Tevatron: $gg \to b\bar{b}H$
m_H=130,250,500,1000 GeV
$Q_b\, d\sigma/dQ_b$
0.4
0.2
0
10^{-1}
1
Q_b/m_h
$p_{T,b}\, d\sigma/dp_{T,b}$
m_b=0.46 GeV
0.4
0.2
0
10^{-1}
1
$p_{T,b}/m_h$



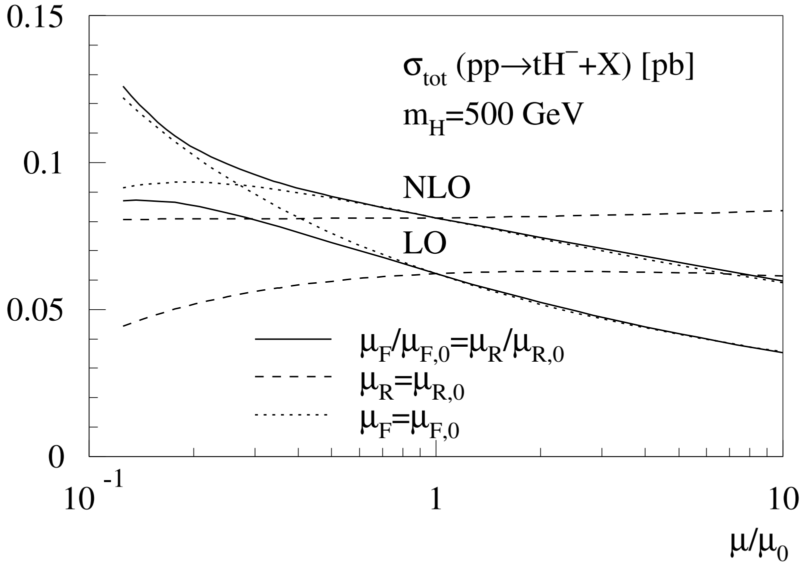
σ_{tot} (pp→tH$^-$+X) [pb]
(m_b running mass)
m_b pole mass
NLO: gb→tH$^-$
LO : gb→tH$^-$
LO : gg→$\bar{b}$tH$^-$
10^{-1}
10^{-2}
400
600
800
1000
m_H[GeV]



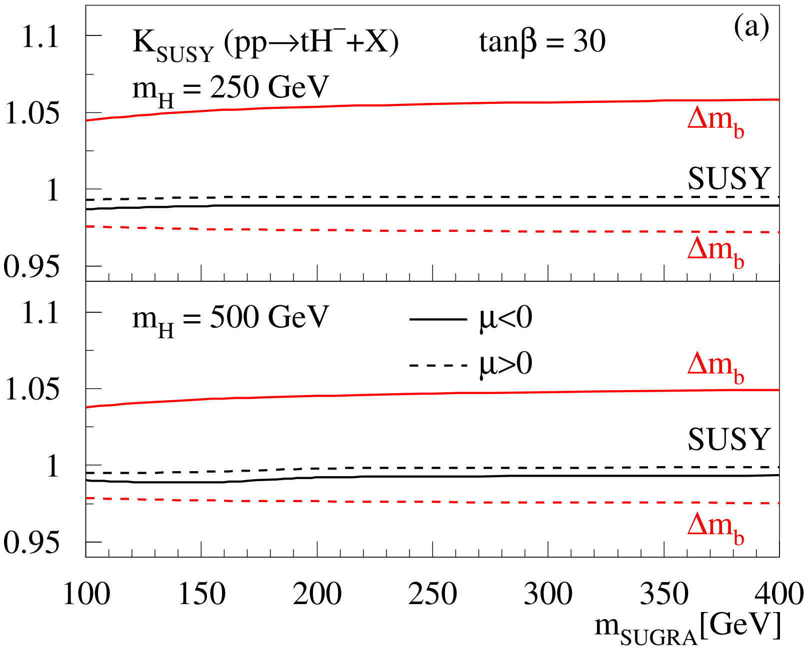
K (pp→tH$^-$+X)
tanβ = 30
5
10
30
30
μ = 4m_{av}
μ = m_{av}
μ = m_{av}/4
1.8
1.6
1.4
1.2
1
0.8
400
600
800
1000
m_H[GeV]



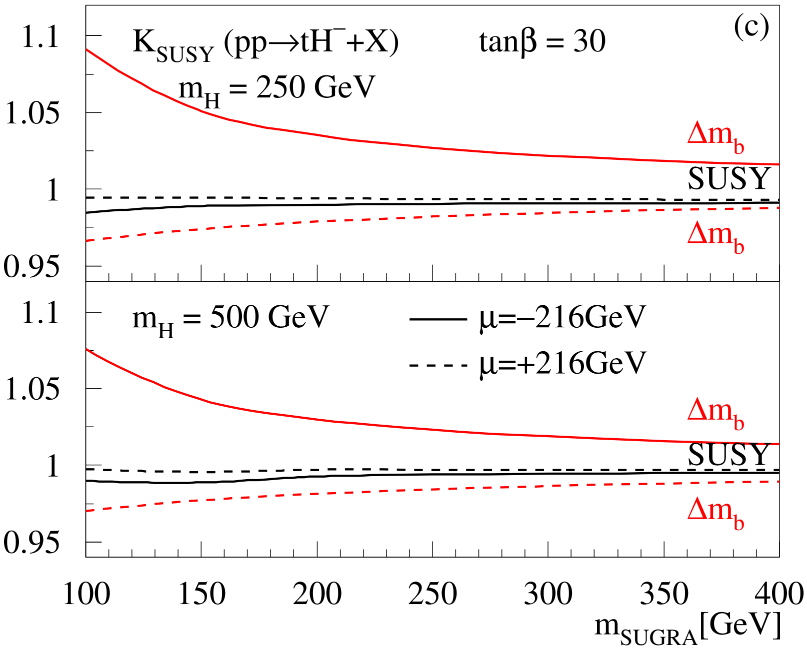
1
0.5
0
10 -1
1
10
μ/μ0
σtot (pp→tH⁻+X) [pb]
mH=250 GeV
NLO
LO
μF/μF,0=μR/μR,0
μR=μR,0
μF=μF,0



0.15
0.1
0.05
0
10 -1
1
10
μ/μ0
σtot (pp→tH⁻+X) [pb]
mH=500 GeV
NLO
LO
μF/μF,0=μR/μR,0
μR=μR,0
μF=μF,0



(a)
K_{SUSY} ($pp \to tH^- + X$)
$\tan\beta = 30$
m_H = 250 GeV
m_H = 500 GeV
$\mu<0$
$\mu>0$
Δm_b
SUSY
1.1
1.05
1
0.95
100
150
200
250
300
350
400
m_{SUGRA}[GeV]



(c)
K_{SUSY} ($pp \to tH^- + X$)
$\tan\beta = 30$
m_H = 250 GeV
m_H = 500 GeV
μ=−216GeV
μ=+216GeV
Δm_b
SUSY
1.1
1.05
1
0.95
100
150
200
250
300
350
400
m_{SUGRA}[GeV]