NLO $bg \to tH^-$ AT THE LHC

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* Heavy Higgs Search

* Bottom Parton Description

* QCD/SUSY-QCD Corrections

* Summary

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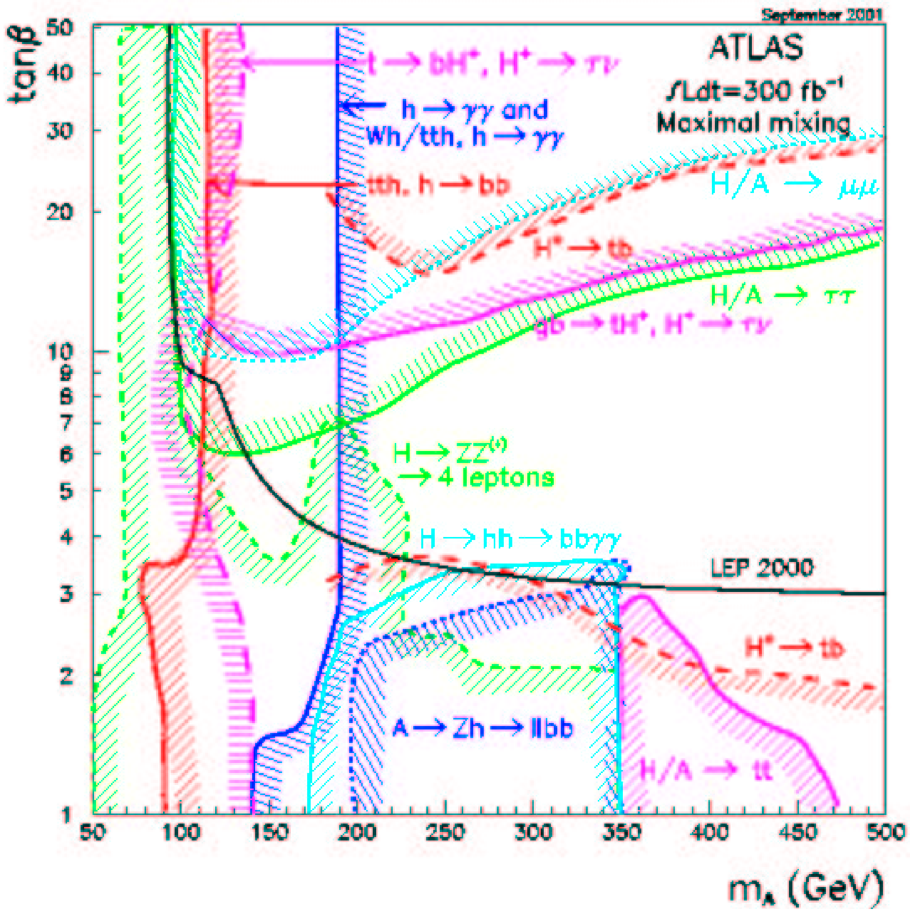
MSSM Higgs Bosons

MSSM Higgs Sector:

* two doublets, coupling to up and down type fermions
  - five physical states h^0, H^0, A^0, $H^\pm$
  - mixing of scalars to mass eigenstates
  - more predictive than the SM,
    2-loop limits on h^0 mass [Heinemeyer et al.; Zhang]
* conveniently expressed as function of m_A and $\tan\beta = v_2/v_1$
* charge Higgs Yukawa coupling $(m_b \tan\beta + m_t \cot\beta)$

LHC Search Channels:

* multitude of channels in ATLAS TDR
* mostly for light scalar Higgs bosons

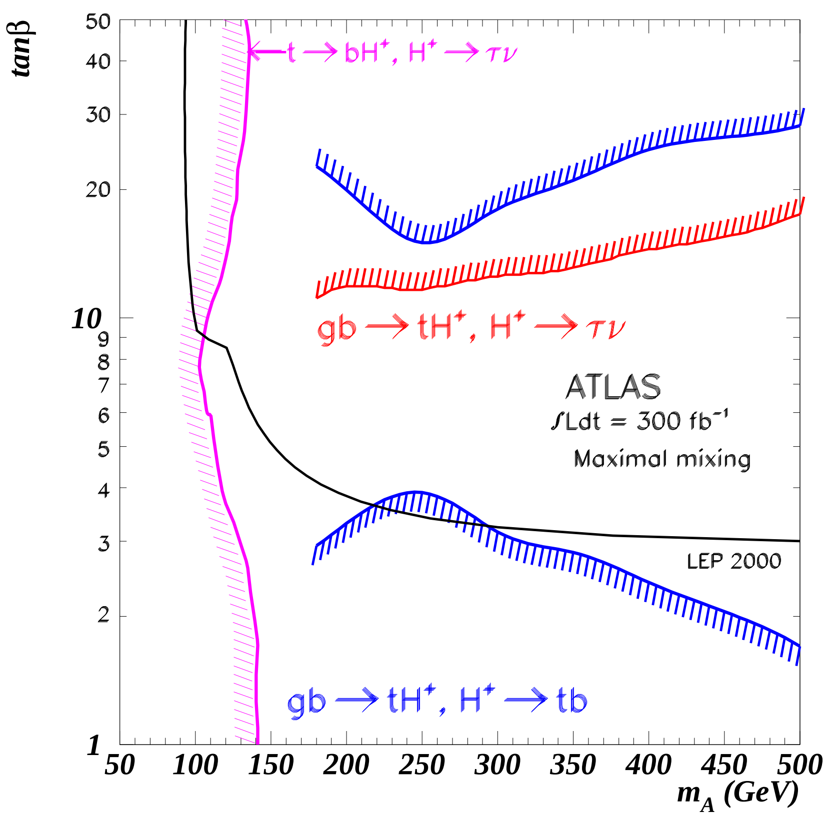


September 2001
ATLAS
∫Ldt=300 fb⁻¹
Maximal mixing
t → bH⁺, H⁺ → τν
h → γγ and
Wh/tth, h → γγ
tth, h → bb
H/A → μμ
H⁺ → tb
H/A → ττ
gb → tH⁺, H⁺ → τν
H → ZZ⁽*⁾
→ 4 leptons
H → hh → bbγγ
LEP 2000
H⁺ → tb
A → Zh → llbb
H/A → tt
tanβ
m_A (GeV)

Heavy Higgs at LHC

Search for heavy Higgs bosons is the conclusive way to tell if it is 2HDM:

* $H^0, A^0 \to \tau\tau, \mu\mu$ in gluon fusion
* $H^\pm \to \nu\tau, tb$ in $pp \to tH^-, W^+H^-, H^+H^-$



tH^- production the most promising search mode [e.g. Bawa, Kim and Martin]

m_T^τ provides fairly good estimate of $H^\pm$ mass [Roy]

HEAVY HIGGS AT LC

Neutral Heavy Higgs:

* at decoupling limit H^0VV coupling is highly suppressed, A^0VV loop-suppressed
* radiatively corrected cross sections for ZH^0, H^0A^0, h^0A^0 [Heinemeyer et al.]
* in $\gamma\gamma$ collisions, the s-channel resonant production of H^0 and A^0 [e.g. Gunion, Haber]
* $b\bar{b}\phi$ extend the mass reach of the heavier neutral Higgs states [e.g. Cotti et al.]

Charged Heavy Higgs:

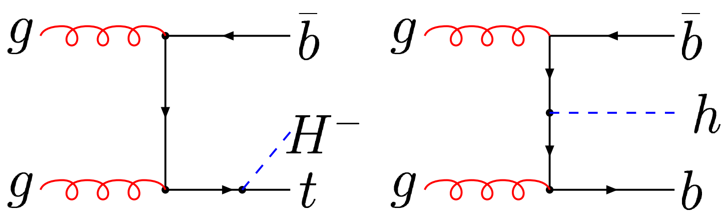
* $t\bar{b}H^-$ enhanced by $\tan\beta^2$, large phase-space suppression due to final state top quark [He et al.]
* loop-induced W^+H^- production enhanced over most of the SUSY parameter space [e.g. Logan, Su]

Bottom Parton Description

[Campbell et al.; Plehn; Boos, Plehn; Maltoni et al.]

Summation of log into parton distribution [e.g. Olness, Tung]

* the integration over final state bottom quark gives rise to large logarithms
* switching to a bottom quark parton description corresponds to a summation of the potentially large logarithms

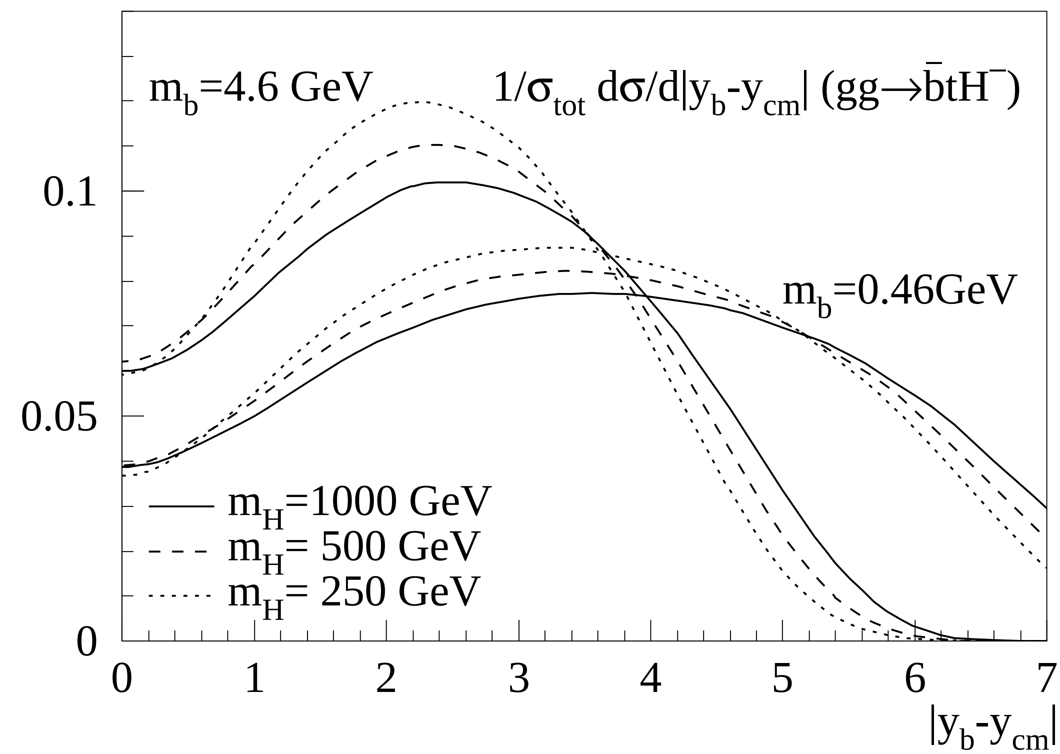


$\bar{b}tH^-$ vs. $\bar{b}bh$

* charged Higgs boson production involves only one incoming bottom quark

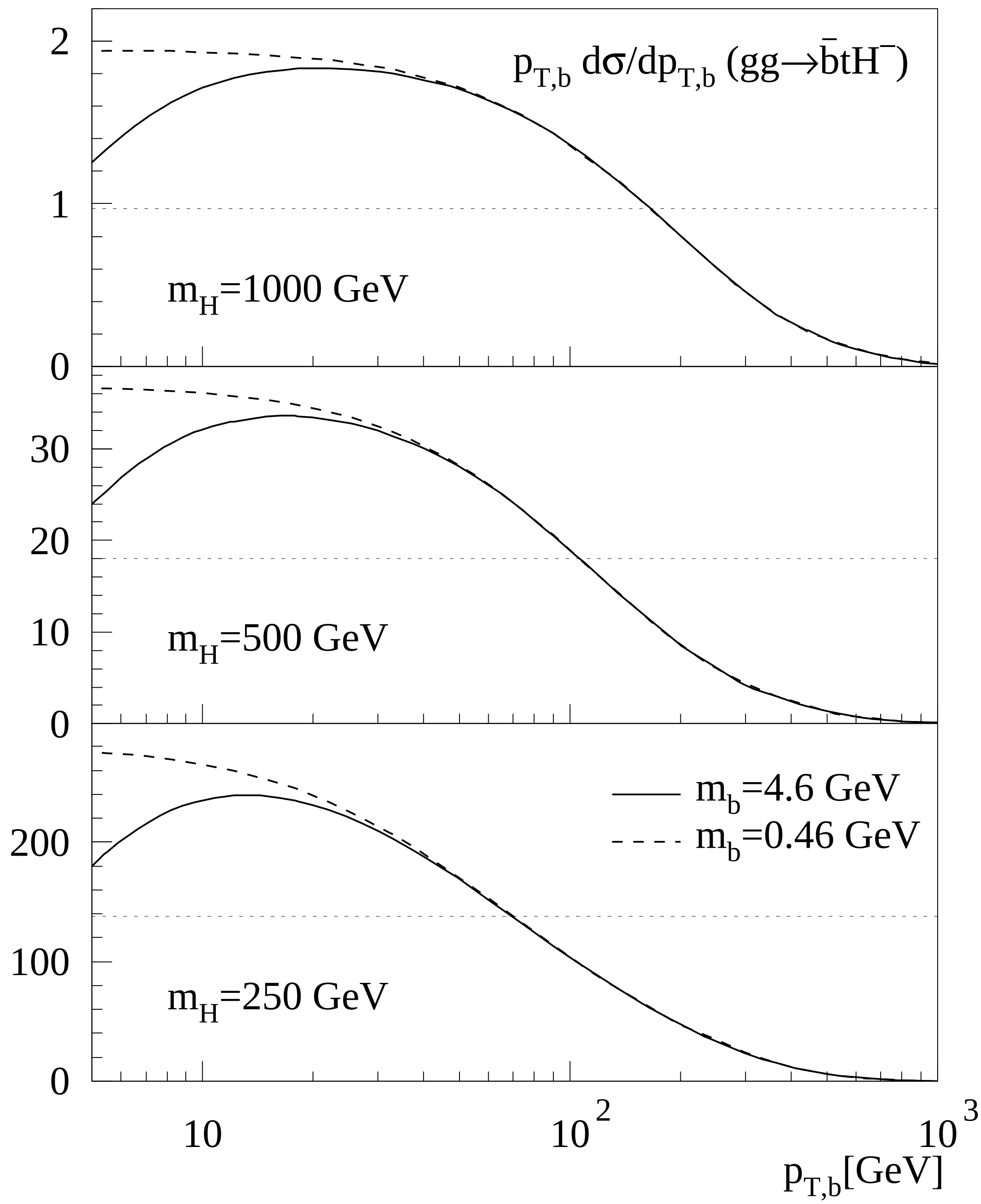
Exclusive Production Process $gg \to \bar{b}tH^-$

* collinear bottom jets from gluon splitting, regularized by m_b
* large logarithms in total cross section $\log(p_{T,b}/m_b)$
* asymptotic cross section behavior $d\sigma/dp_{T,b} \propto p_{T,b}/m_{T,b}^2$
* solve for factorization scale $p_{T,b}^{max} \sim \mu_F$
* plateau in hadronic vs. partonic cross section



m_b=4.6 GeV
1/σ_tot dσ/d|y_b-y_cm| (gg→b̄tH⁻)
m_b=0.46GeV
m_H=1000 GeV
m_H= 500 GeV
m_H= 250 GeV
0.1
0.05
0
0
1
2
3
4
5
6
7
|y_b-y_cm|

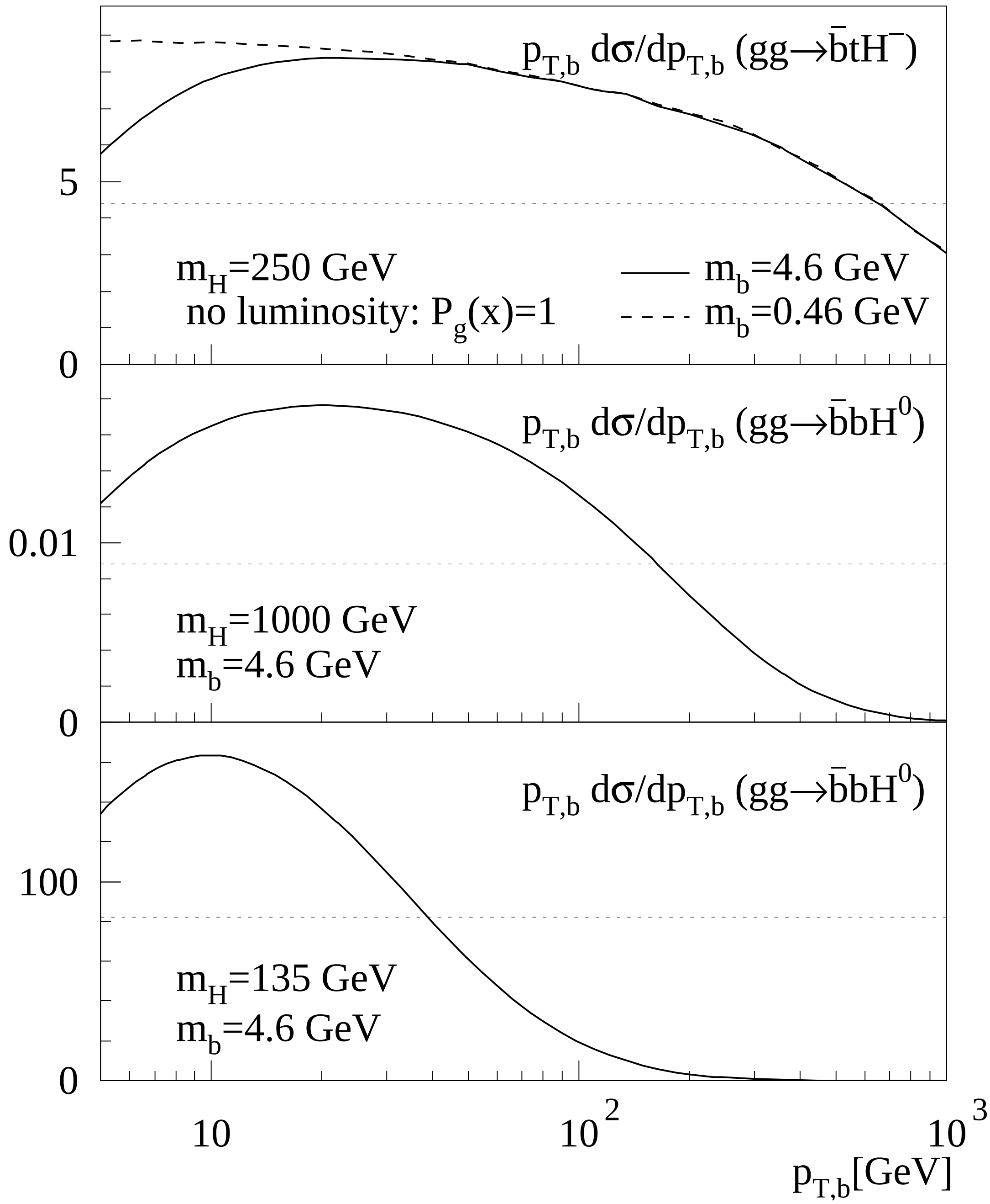
$$\left.\frac{d\sigma}{dp_{T,b}}\right|_{\text{asympt}} \propto \frac{p_{T,b}}{p_{T,b}^2 + m_b^2} \qquad \left.\sigma\right|_{\text{asympt}} \propto \log\left[\left(\frac{p_{T,b}^{\max}}{m_b}\right)^2 + 1\right]$$



naive choice of $\mu_F \sim p_{T,b}^{max}$ would be $m_{av} = (m_t + m_H)/2$

$$\mu_F \sim C\frac{m_t + m_H}{2} \text{ with } C \sim \frac{1}{3}$$

the reason: falling gluon density

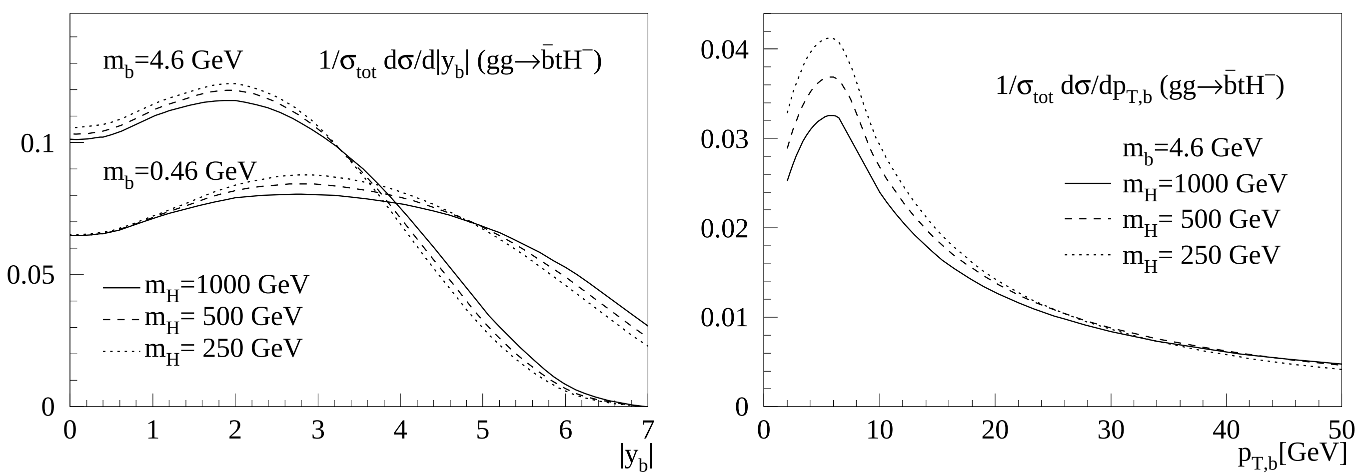


apply the same analysis to the $b\bar{b}H^0$

Bottom Parton Description Ctn.

Inclusive Process $bg \to tH^-$

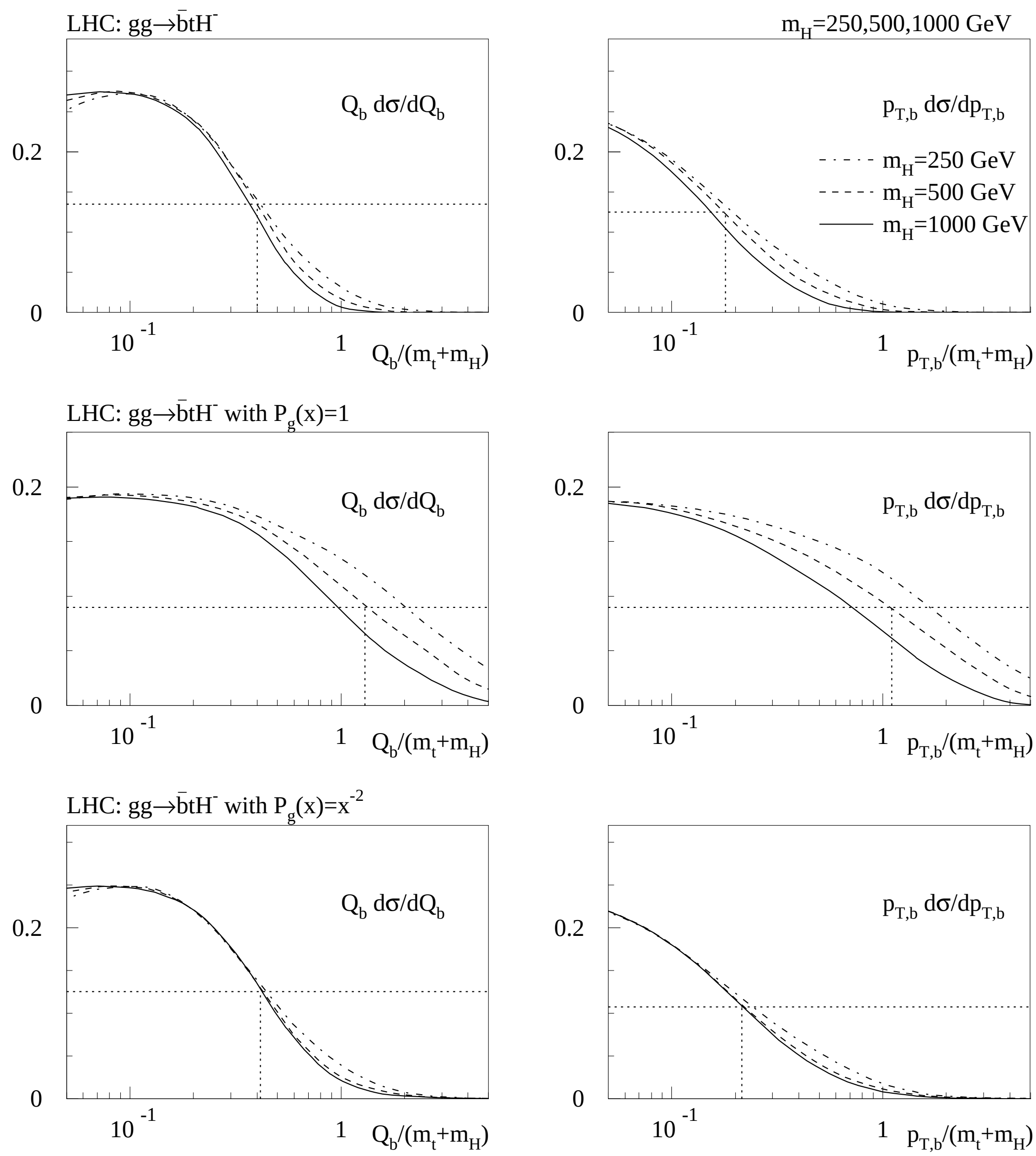
* bottom jet at large rapidity(collinear) and with low transverse momentum(soft)
* hard to see or tag
* resum logarithms for numerical improvement
* remaining error $\mathcal{O}(m_b^2/M^2)$



bottom parton distribution with an appropriate choice of μ_F improves numerical prediction

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

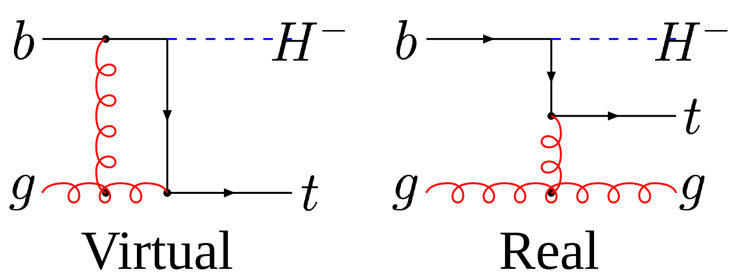
$$\left.\frac{d^2F(\tau(Q_b^2))}{d(\log Q_b)^2}\right|_{Q_b^{\max}} = 0$$



QCD CORRECTION

Next-to-leading Order QCD Calculation:

* leading order uncertainty large for $bg \to tH^-$
  e.g. mass definition: $\overline{\mathrm{MS}}$ or pole mass for $y_{b,t}$?
* LO cross section has large scale dependence
* complete set of virtual and real corrections
* running top and bottom Yukawa coupling

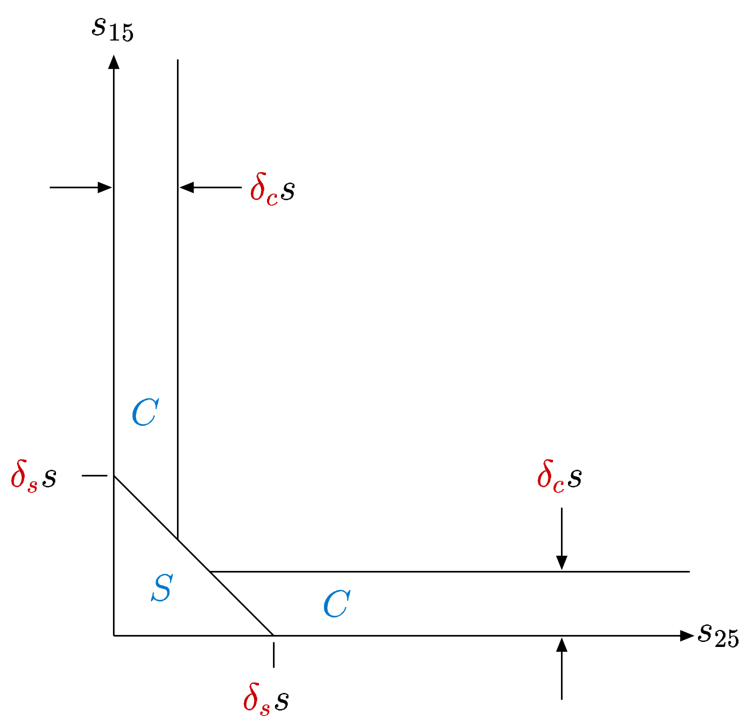


* UV singularity absorbed in renormalization
* soft divergences cancel between virtual and real diagrams
* collinear divergence removed by factorization

2 CUT-OFF PHASE SPACE SLICING

Two cutoff parameters serve to separate out the regions of phase space containing the soft and collinear singularities

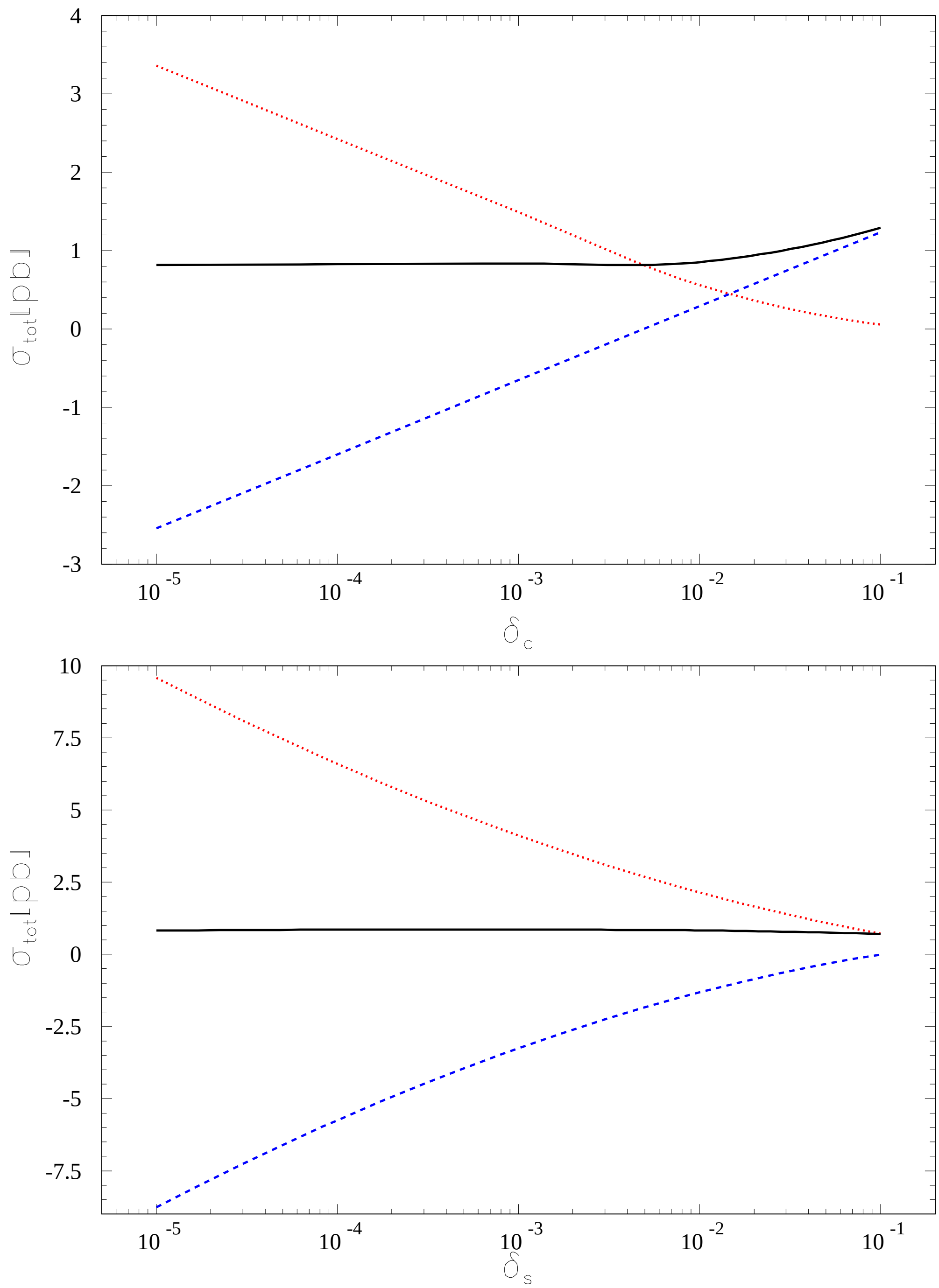
[Harris, Owens]



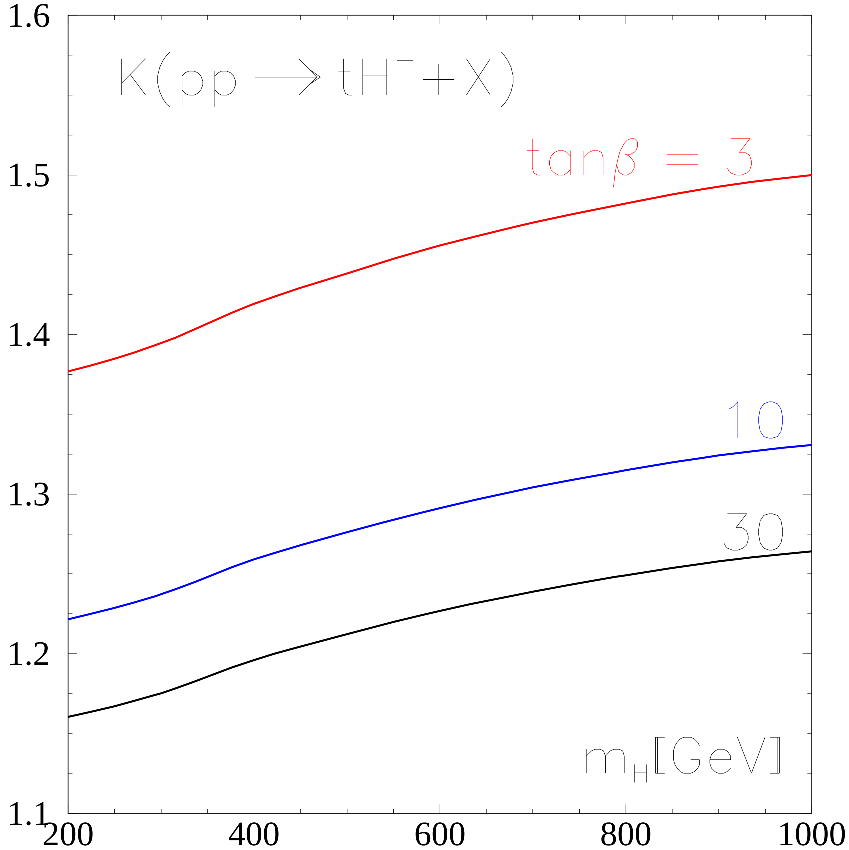
$$\sigma_{Real} = \sigma_S + \sigma_{HC} + \sigma_{H\overline{C}}$$

The advantage of 2CPSS is that it preserves information in terms of final state momenta

The cancellation of the δ_s and δ_c dependences provides a crucial test of the calculation



QCD Correction Ctn.



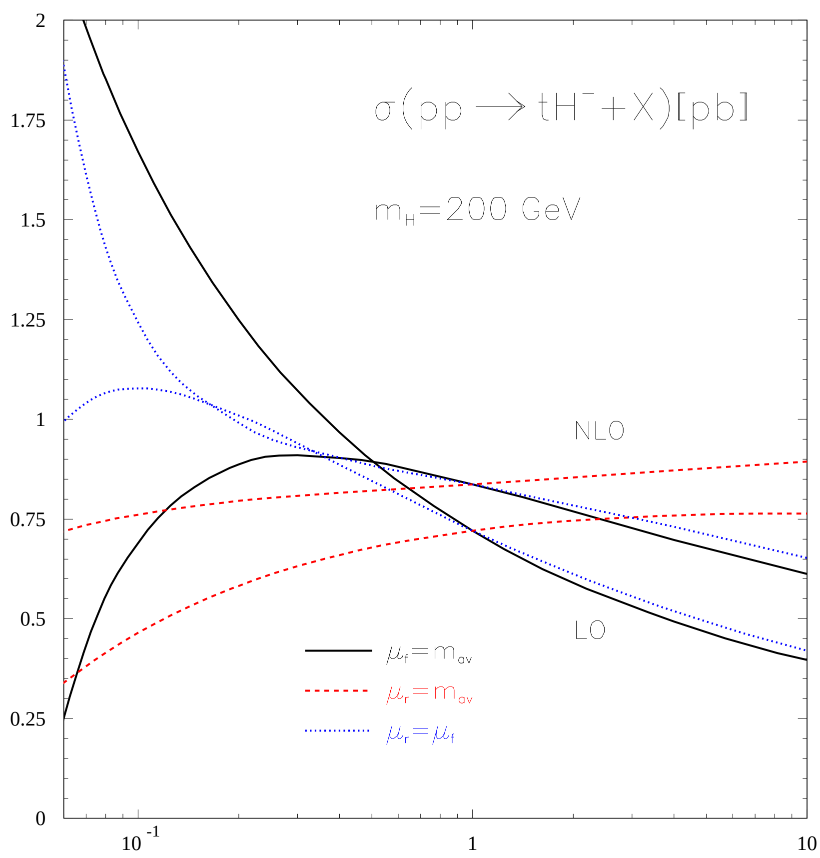
K-factor for the total cross section is $1.2 \sim 1.5$ [Zhu; Plehn]

Scale Dependence at NLO:

* generic cancellations for $\mu_R = \mu_F$ [Harlander & Kilgore]

* renormalization scale dependence numerically dominant
  $\mu_R \approx (m_t + m_H)/2$ natural choice [Melnikov]

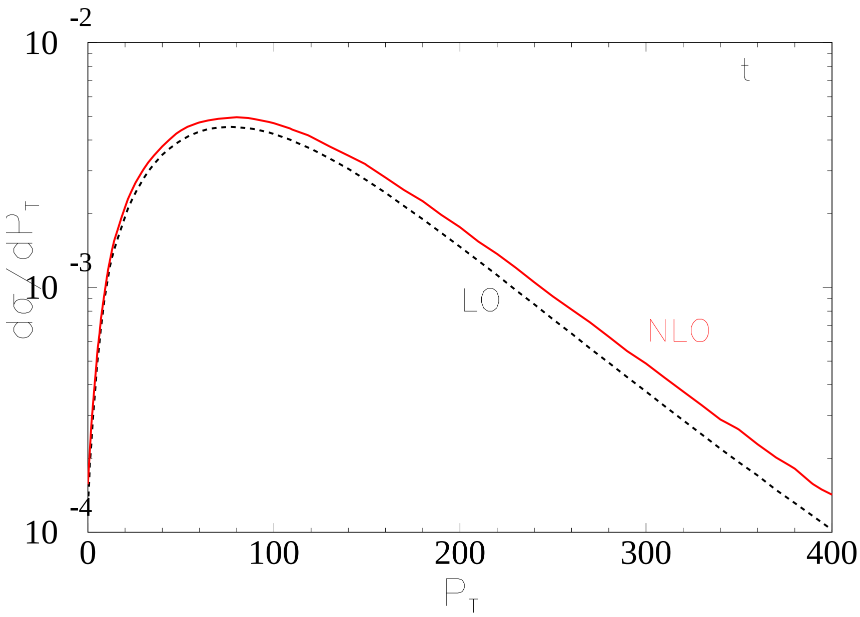
* NLO scale dependence 20%

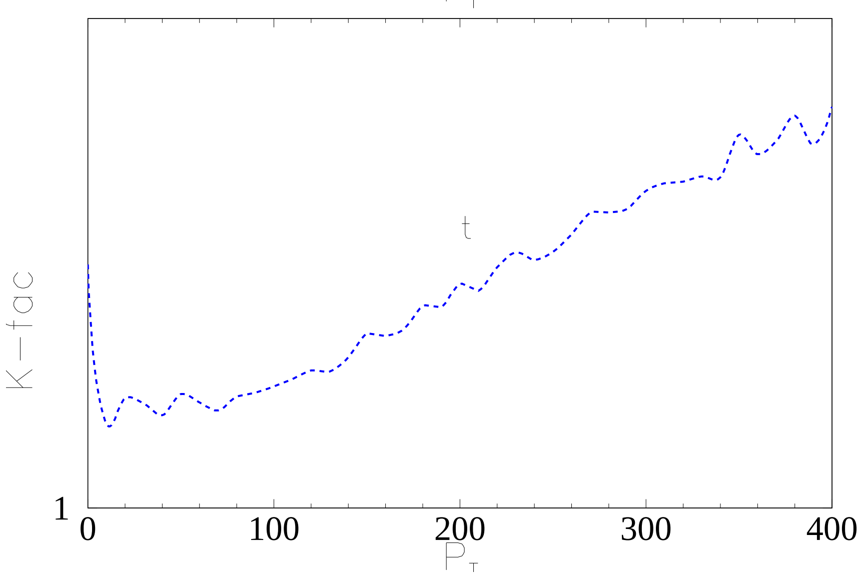


NLO calculation interpolates between $gg \to \bar{b}tH^-$ and $bg \to tH^-$

DISTRIBUTIONS AND CORRELATIONS

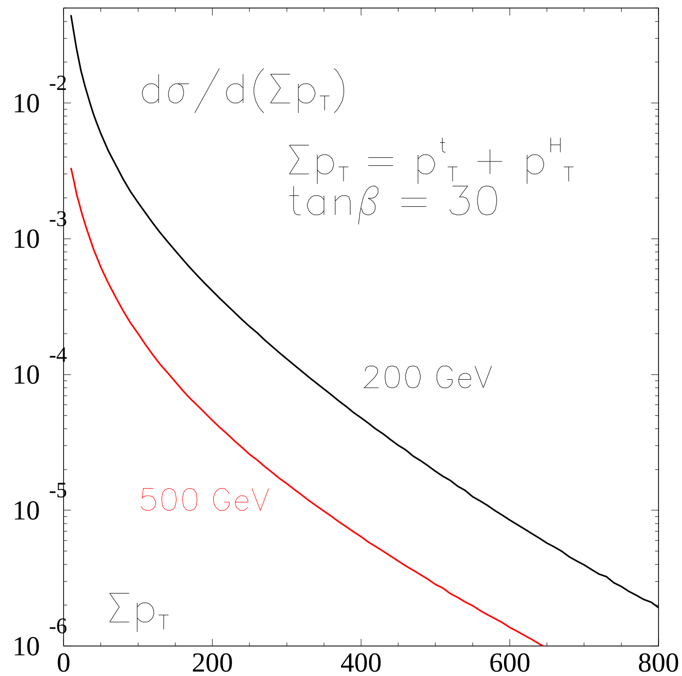
p_T distributions:



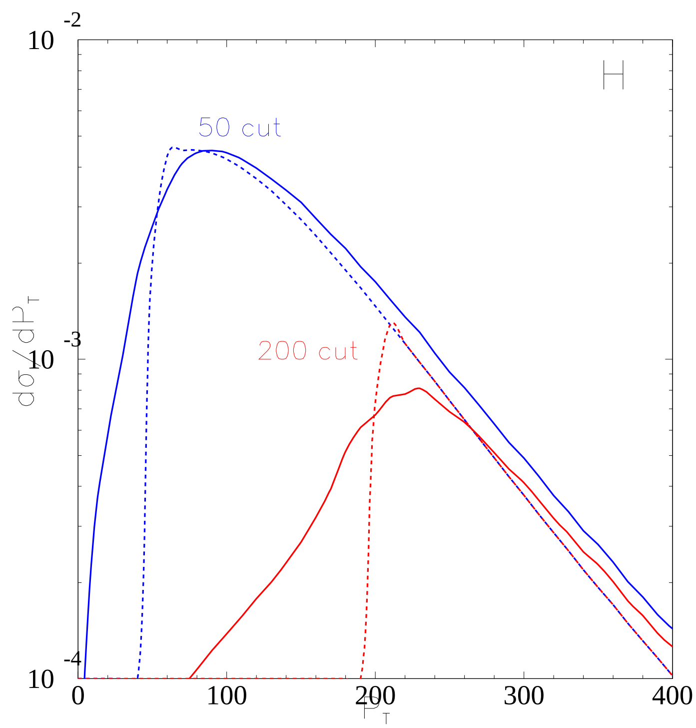


K-factor for different p_T of top ranges from 1.1 - 1.4

$\Sigma p_T = p_T^t + p_T^H$ is 0 at LO but has a broader distribution at NLO:



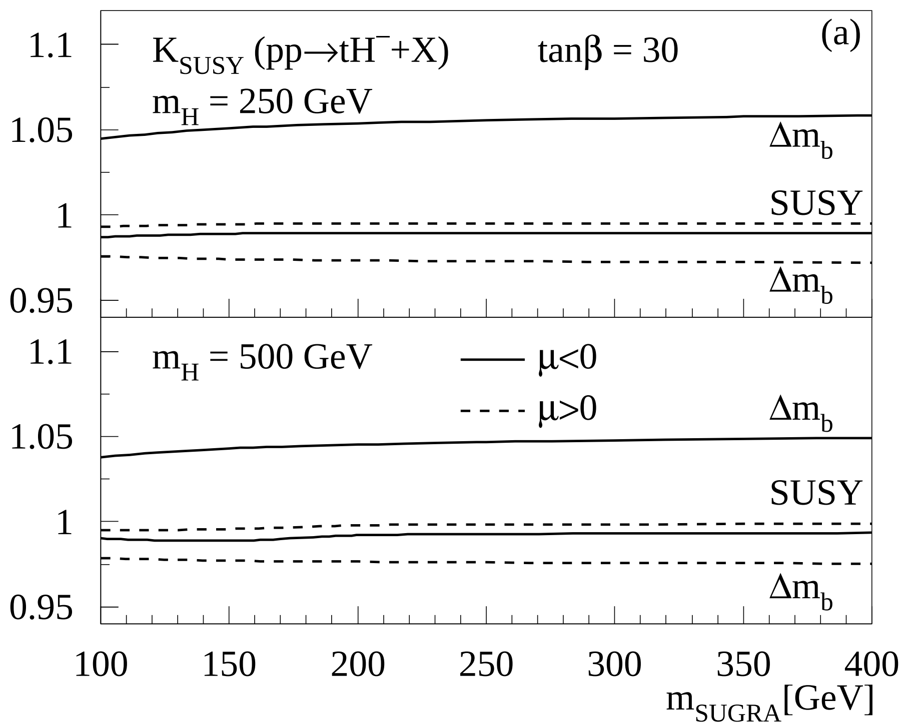
The p_T distribution of H after applying 50 GeV or 200 GeV cut on p_T of top quark



SUSY-QCD CORRECTIONS

SUSY-QCD Loop Contributions:

* infrared finite but ultraviolet divergent SUSY loops
* universal correction $y_b \to y_b/(1+\Delta m_b)$ [Carena, Garcia, Nierste, Wagner]
* remaining explicit SUSY loop diagrams [Gao, Lu, Xiong, Yang]
* parametrized by $K_{SUSY} = 1 + \sigma_{SUSY}/\sigma_{NLO}$



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

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

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

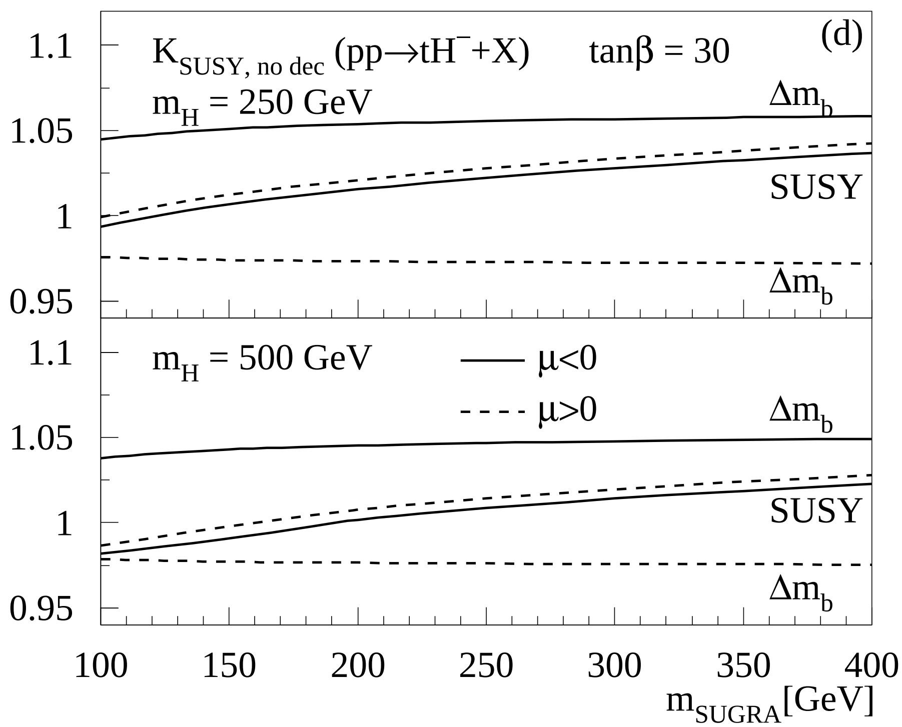
* heavy SUSY particle loops UV divergent

* SUSY counter-terms for SM parameters

* SUSY contribution to beta functions

* explicit decoupling

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



SUMMARY

* heavy charged Higgs bosons necessary to tell if it is 2HDM
* charged Higgs boson production promising at LHC for large $\tan\beta$
* bottom parton distribution with an appropriate choice of factorization scale improve numerics
* $20\% \sim 50\%$ NLO correction
* remaining scale uncertainty $\lesssim 20\%$
* 2CPSS enables us to explore interesting distributions and correlations
* Δm_b corrections dominant in MSSM for large $\tan\beta$
* remaining SUSY loop corrections negligible