Charged Higgs Bosons Production in Bottom-Gluon Fusion

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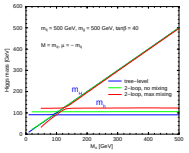
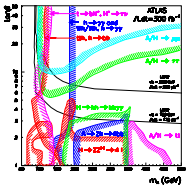
- MSSM Higgs Bosons at the LHC
- Why Bottom Parton Description?
- QCD Corrections
- SUSY-QCD Corrections

MSSM Higgs Bosons at the LHC



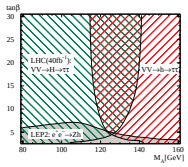
MSSM Higgs Sector:

- two doublets, coupling to up and down type fermions
  - → five physical states $h^o, H^o, A^o, H^\pm$
  - → mixing of scalars to mass eigenstates [mixing angle α]
  - → more predictive than Standard Model
    (2-loop limits on h^o mass: S. Heinemeyer et al., R. Zhang)
- conveniently expressed as function of m_A and $\tan\beta \equiv v_2/v_1$
- charged Higgs Yukawa coupling $(m_b \tan\beta + m_t/\tan\beta)$



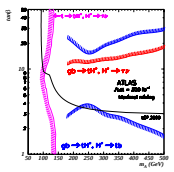
LHC Search Channels:

- multitude of channels in ATLAS TDR (pre-LEP2)
- no-lose theorem in WBF $h \to \tau\tau$
- mostly light scalar Higgs boson

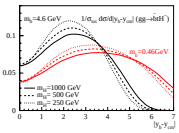


Tell it is 2HDM (MSSM?) ⇒ look for heavy Higgs bosons:

- $H^0, A^0 \to \tau\tau, \mu\mu$ in gluon fusion
- $H^\pm \to \nu\tau, tb$ in $pp \to tH^-, W^+H^-, H^+H^-$ [e.g. D.P.Roy]
- There is no other conclusive way but to find these particles!



Bottom Parton Description



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

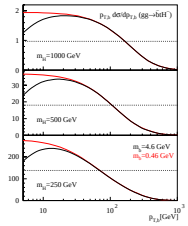
$\to$ collinear bottom jets from gluon splitting, regularized by m_b

$\to$ large logarithms in total cross section $\log(p_{T,b}/m_b)$

$\to$ asymptotic cross section behavior $d\sigma/dp_{T,b} \propto p_{T,b}/m_{T,b}^2$

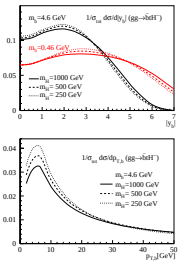
$\to$ solve for factorization scale $p_{T,b}^{\max} \sim \mu_F$

$\to$ plateau in hadronic vs. partonic cross section
(limitations by gluon parton density at LHC)



Why the Inclusive Process $bg \to tH^-$?

– bottom jet at large rapidity (collinear)
bottom jet with low transverse momentum (soft)



$\to$ hard to see or even tag $\Rightarrow$ analysis $gg \to tH^- + X$

$\to$ resum above logarithms for numerical improvement

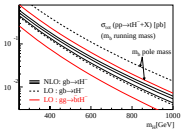
$\to$ remaining error $\mathcal{O}(m_b^2/M^2)$ [Campbell, Ellis, Maltoni, Willenbrock]

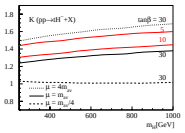
$\to$ n.b.: NLO calculation to interpolate between $gg \to \bar{b}tH^-$ and $bg \to tH^-$

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 SUSY corrections
- running top and bottom Yukawa coupling

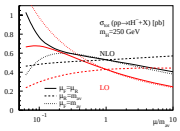




→ NLO correction $+30\% \cdots 40\%$ perturbatively stable [Zhu]

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]



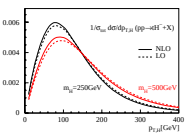
- factorization scale dependene critical for $\mu_F \sim m_b$
  $\mu_F \sim 1/3 \times (m_t + m_H)/2$ from exclusive process

→ NLO scale dependence $\pm 20\%$

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

Distributions in NLO:

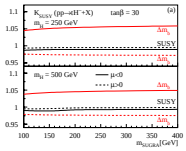
- Higgs transverse momentum softened (gluon density)
- Higgs rapidity not symmetric (gluon splitting)



SUSY-QCD Corrections

SUSY-QCD Loop Contributions:

- infrared finite but ultraviolet divergent SUSY loops
- parameterized by $K_{\rm SUSY} = 1 + \sigma_{\rm SUSY}/\sigma_{\rm NLO}$
- (1) universal corrections $y_b \to y_b/(1 + \Delta m_b)$
  [Carena, Garcia, Nierste, Wagner]



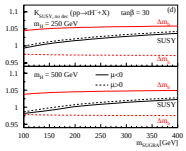
- (2) remaining explicit SUSY loop diagrams [Gao, Lu, Xiong, Yang]

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

Conclusions

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

– charged Higgs boson production promising at LHC for large $\tan\beta$

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

– NLO_1: inclusive process well defined

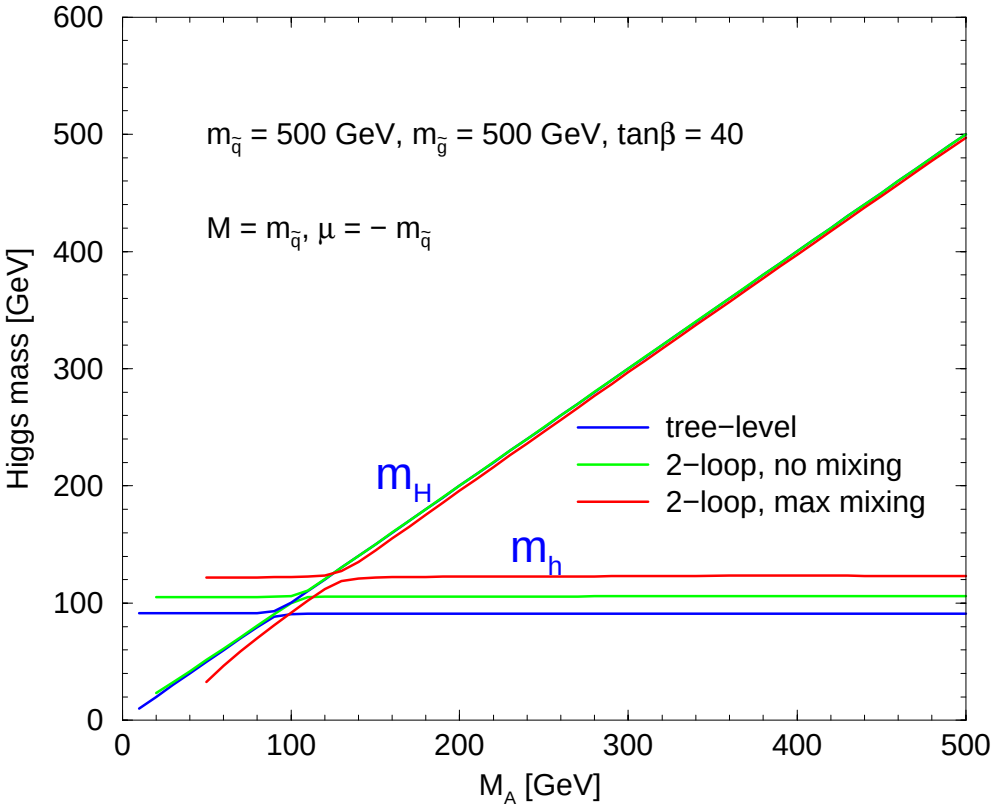
– NLO_2: $30\% \cdots 40\%$ enhancement of σ_{tot} in 2HDM

– NLO_3: remaining scale uncertainty $\lesssim 20\%$

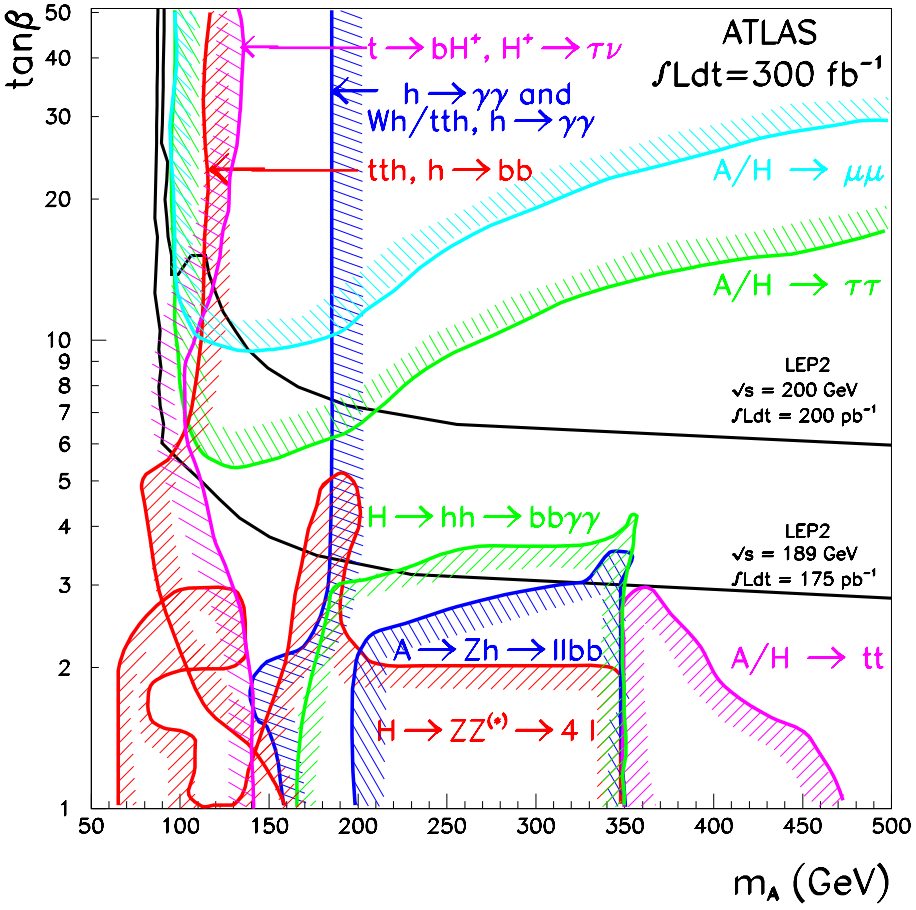
– NLO_4: Δm_b corrections dominant in MSSM for large $\tan\beta$

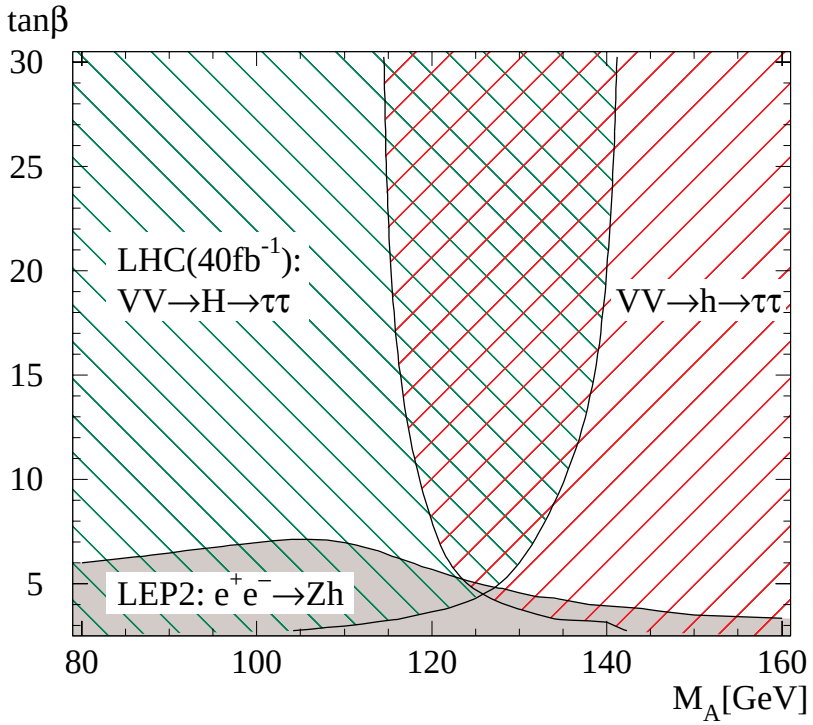
– NLO_5: non-factorizable corrections negligible in MSSM

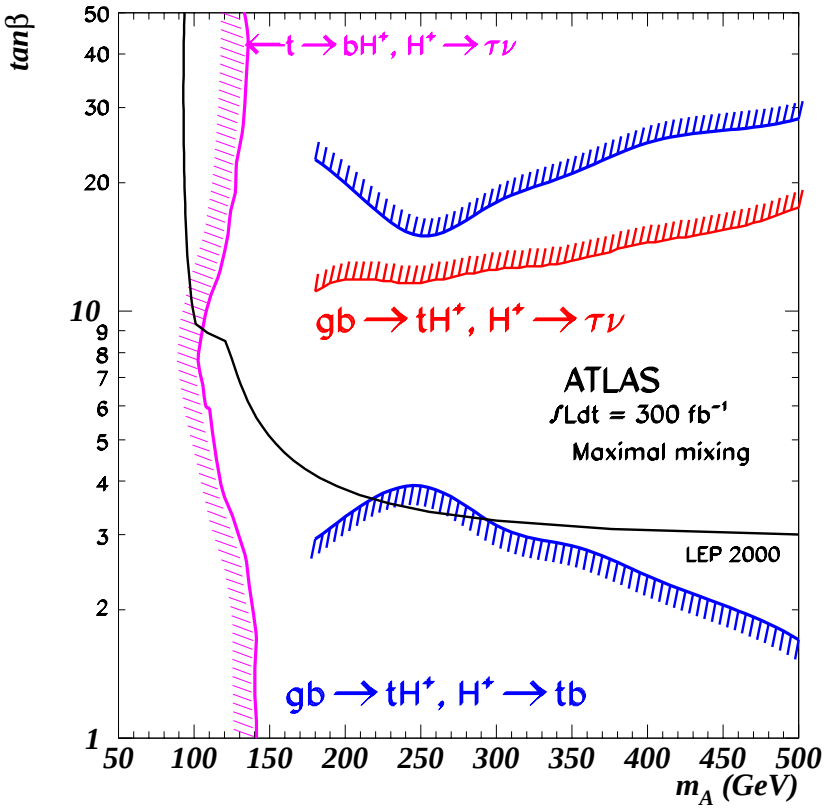
– Let's go and get data!



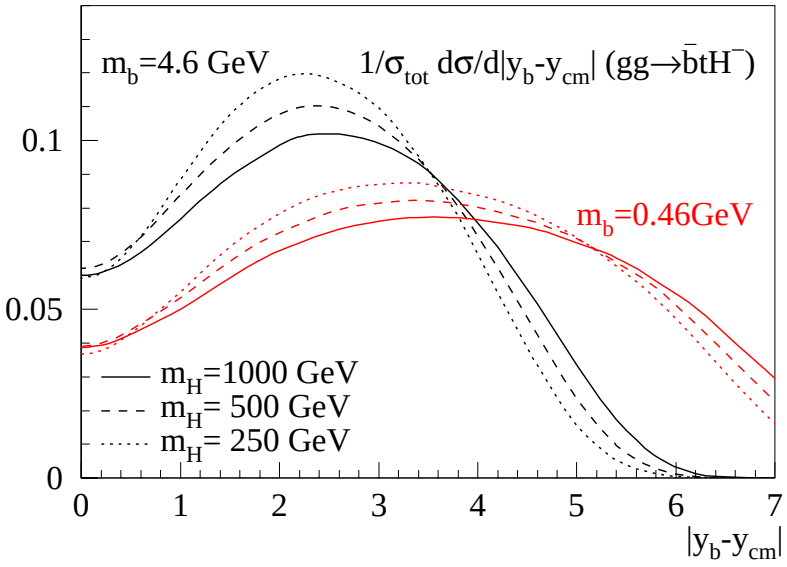
Heinemeyer, Hollik, Weiglein

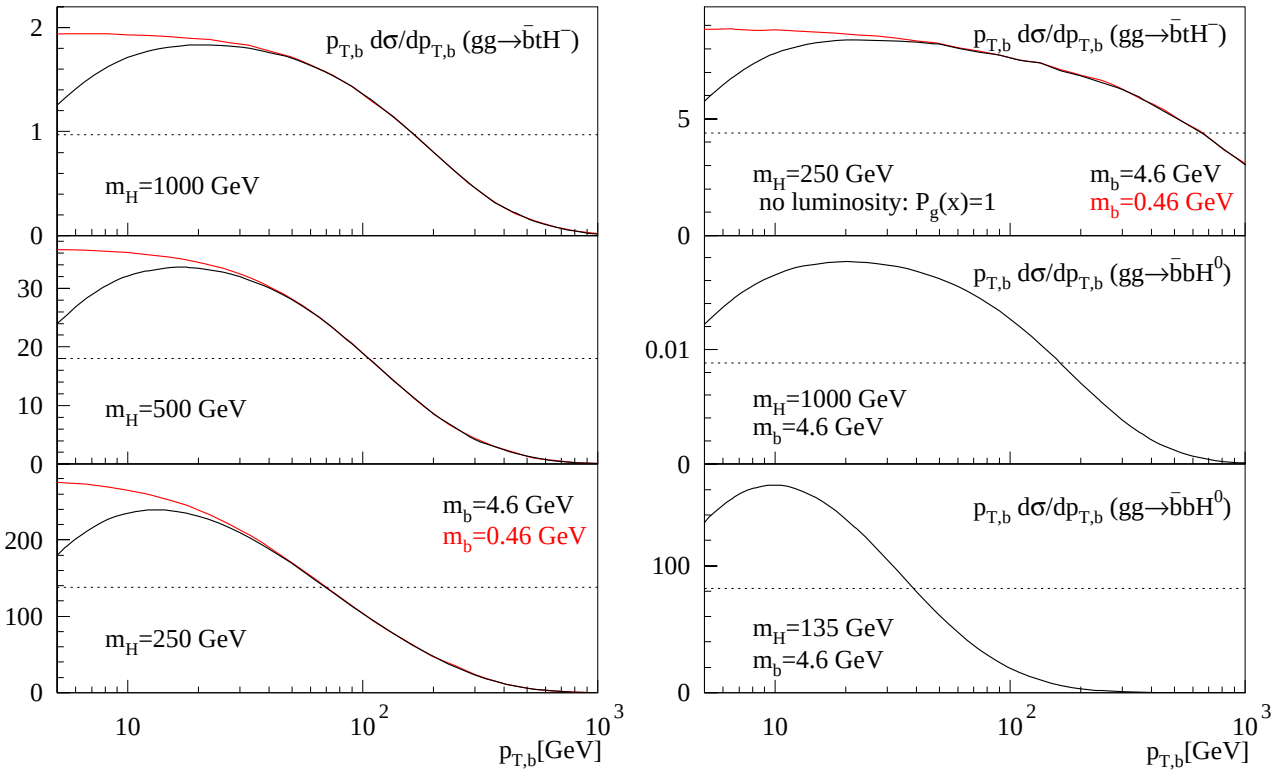

tanβ
50
40
30
20
10
9
8
7
6
5
4
3
2
1
50
100
150
200
250
300
350
400
450
500
m_A (GeV)
ATLAS
∫Ldt=300 fb⁻¹
t → bH⁺, H⁺ → τν
h → γγ and
Wh/tth, h → γγ
tth, h → bb
A/H → μμ
A/H → ττ
LEP2
√s = 200 GeV
∫Ldt = 200 pb⁻¹
H → hh → bbγγ
LEP2
√s = 189 GeV
∫Ldt = 175 pb⁻¹
A → Zh → llbb
A/H → tt
H → ZZ(*) → 4 l

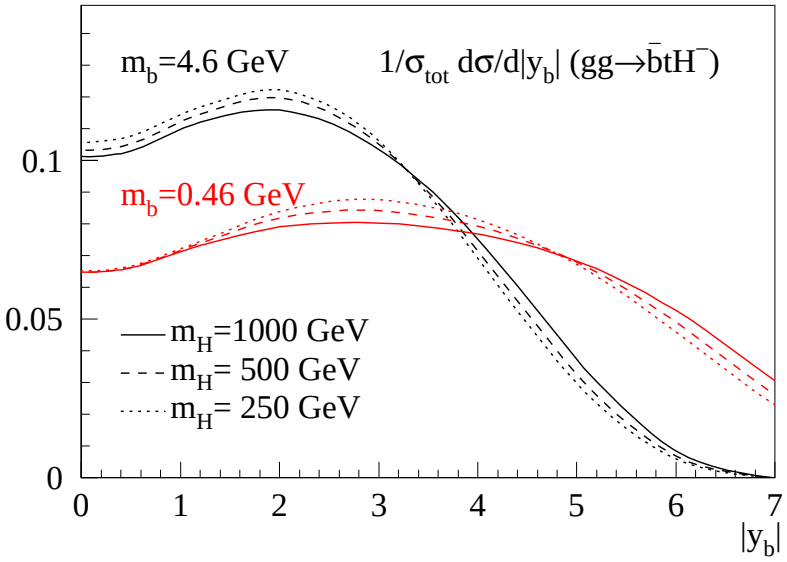

tanβ
30
25
20
15
10
5
LHC(40fb-1):
VV→H→ττ
VV→h→ττ
LEP2: e+e−→Zh
80
100
120
140
160
MA[GeV]

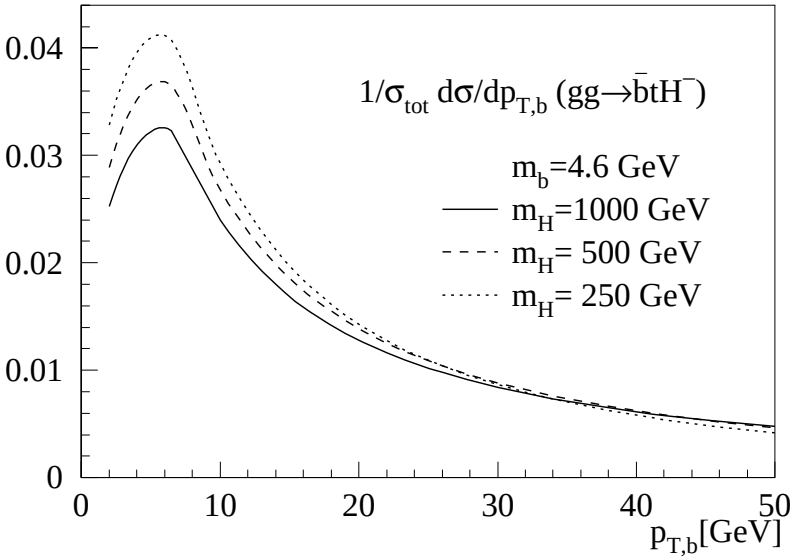


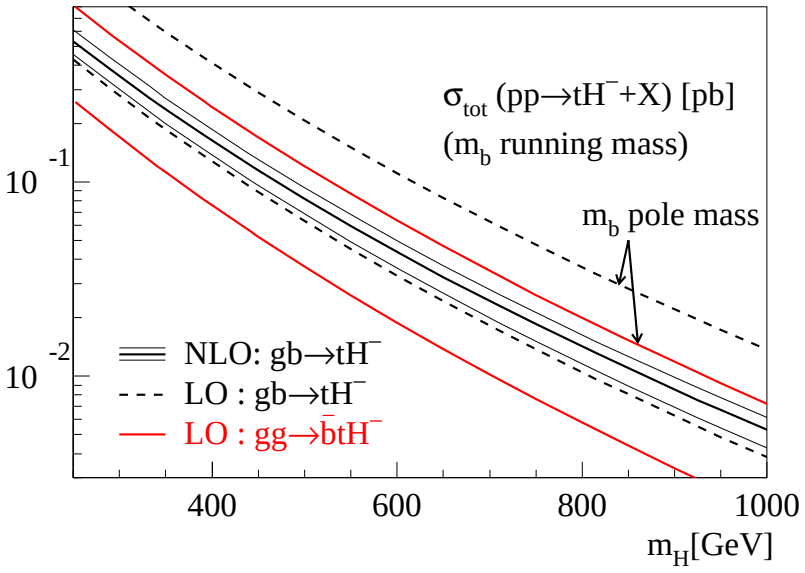
Assamagan, Coadou, Deandrea

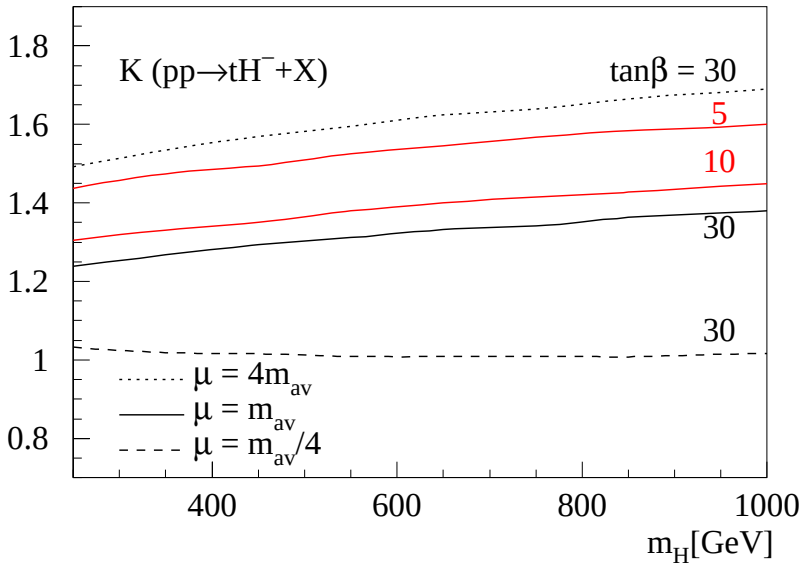

m_b=4.6 GeV
1/σ_tot dσ/d|y_b-y_cm| (gg→b̄tH⁻)
m_b=0.46GeV
m_H=1000 GeV
m_H= 500 GeV
m_H= 250 GeV
0.1
0.05
0
0
1
2
3
4
5
6
7
|y_b-y_cm|

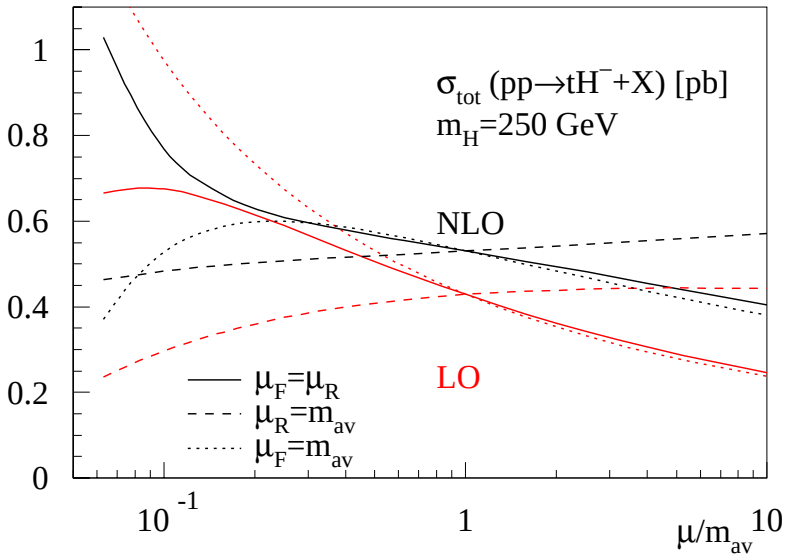

$p_{T,b}\, d\sigma/dp_{T,b}$ ($gg \to \bar{b}tH^-$)
m_H=1000 GeV
m_H=500 GeV
m_b=4.6 GeV
m_b=0.46 GeV
m_H=250 GeV
$p_{T,b}$[GeV]
$p_{T,b}\, d\sigma/dp_{T,b}$ ($gg \to \bar{b}tH^-$)
m_H=250 GeV
no luminosity: $P_g(x)$=1
m_b=4.6 GeV
m_b=0.46 GeV
$p_{T,b}\, d\sigma/dp_{T,b}$ ($gg \to \bar{b}bH^0$)
m_H=1000 GeV
m_b=4.6 GeV
$p_{T,b}\, d\sigma/dp_{T,b}$ ($gg \to \bar{b}bH^0$)
m_H=135 GeV
m_b=4.6 GeV
$p_{T,b}$[GeV]

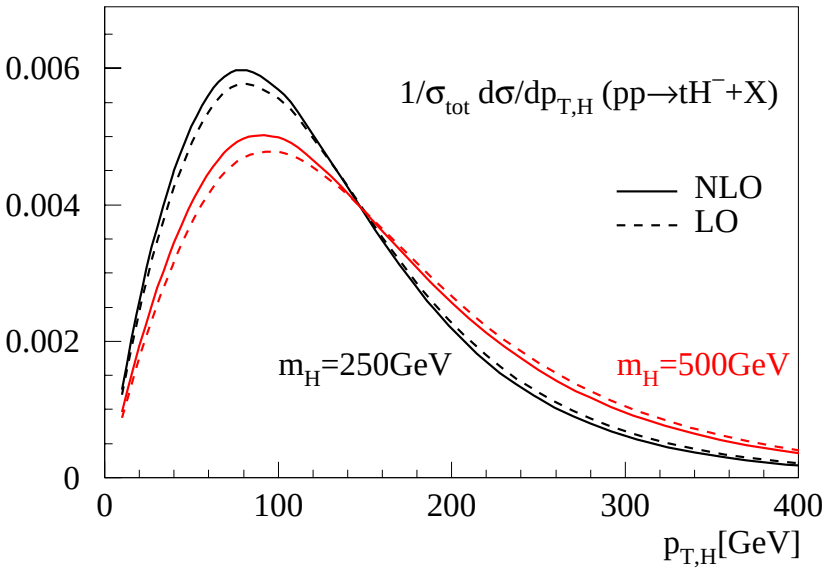

m_b=4.6 GeV
1/σ_tot dσ/d|y_b| (gg→b̄tH⁻)
m_b=0.46 GeV
m_H=1000 GeV
m_H= 500 GeV
m_H= 250 GeV
0.1
0.05
0
0
1
2
3
4
5
6
7
|y_b|

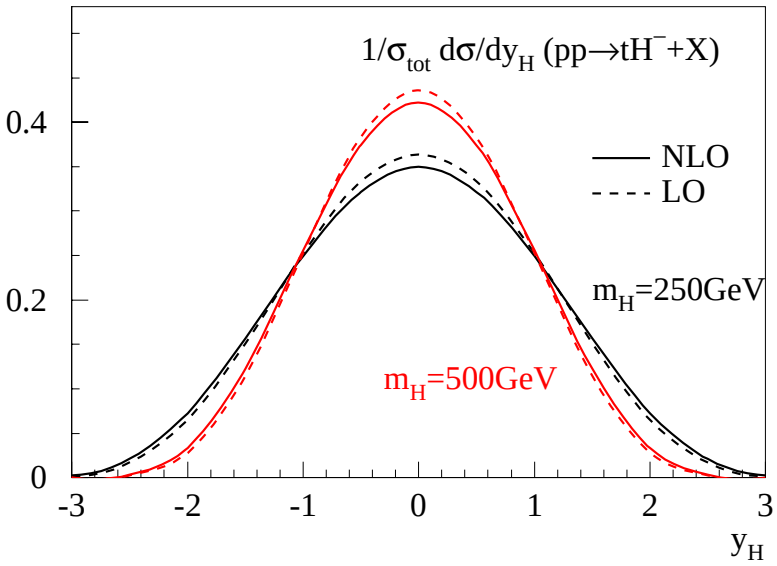

1/σ_tot dσ/dp_T,b (gg→b̄tH⁻)
m_b=4.6 GeV
m_H=1000 GeV
m_H= 500 GeV
m_H= 250 GeV
0.04
0.03
0.02
0.01
0
0
10
20
30
40
50
p_T,b[GeV]

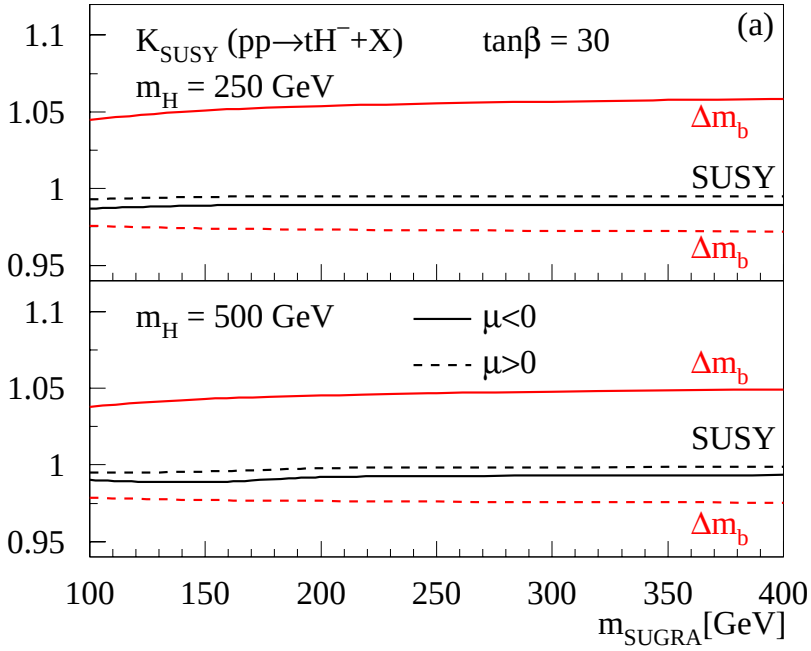

σ_{tot} (pp→tH$^-$+X) [pb]
(m_b running mass)
m_b pole mass
NLO: gb→tH$^-$
LO : gb→tH$^-$
LO : gg→$\bar{b}$tH$^-$
10^{-1}
10^{-2}
400
600
800
1000
m_H[GeV]

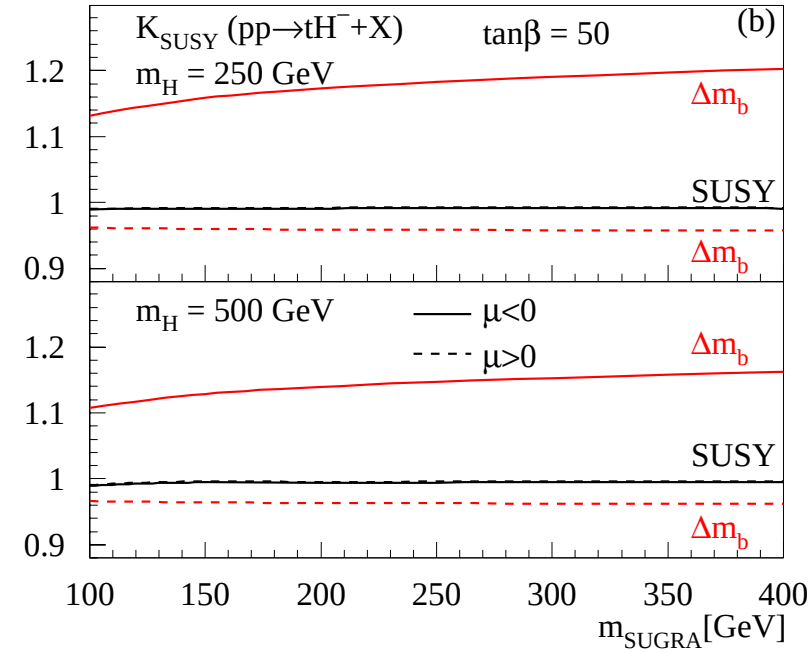

K (pp→tH$^-$+X)
tanβ = 30
5
10
30
30
μ = 4m_{av}
μ = m_{av}
μ = m_{av}/4
1.8
1.6
1.4
1.2
1
0.8
400
600
800
1000
m_H[GeV]

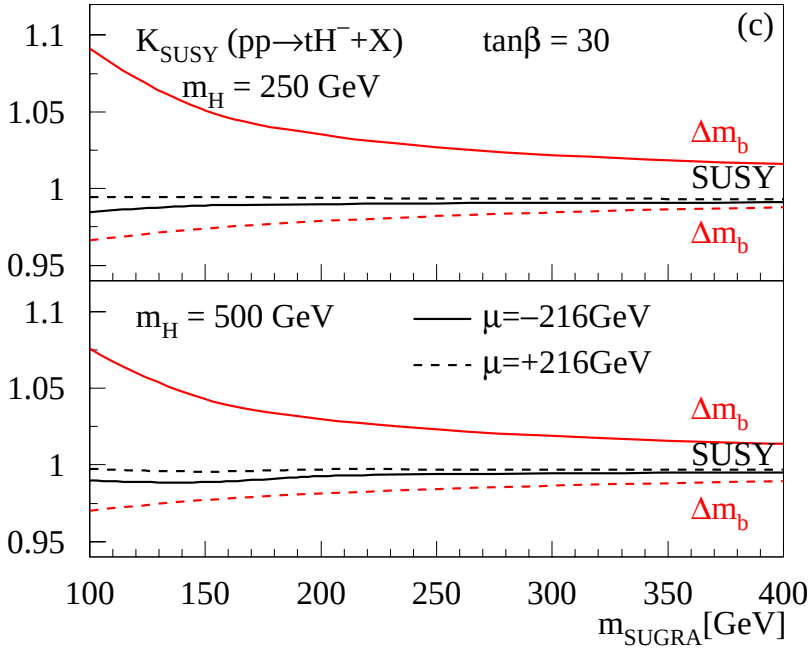

1
0.8
0.6
0.4
0.2
0
10^{-1}
1
10
μ/m_{av}
σ_{tot} (pp→tH$^-$+X) [pb]
m_H=250 GeV
NLO
LO
$\mu_F=\mu_R$
$\mu_R=m_{av}$
$\mu_F=m_{av}$

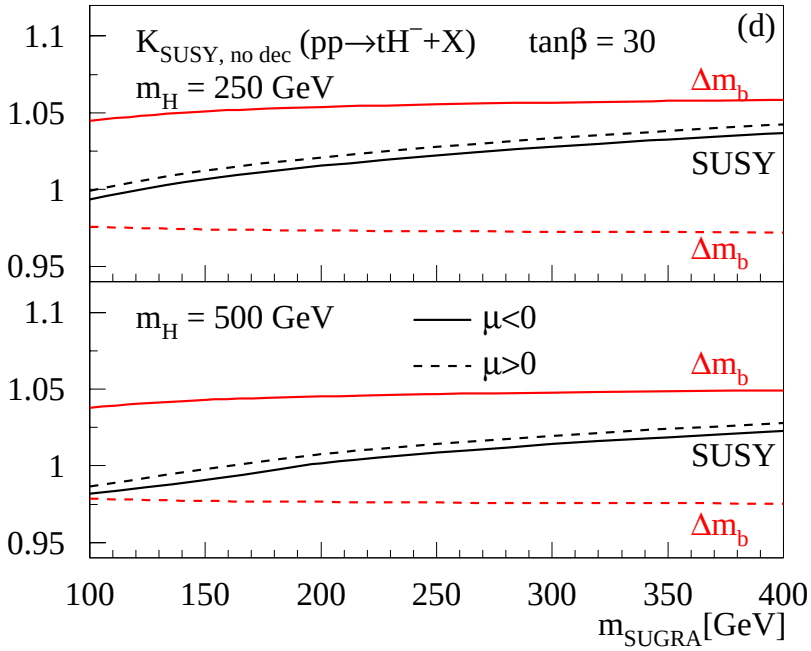

0.006
0.004
0.002
0
0
100
200
300
400
$p_{T,H}$[GeV]
$1/\sigma_{tot}\ d\sigma/dp_{T,H}\ (pp\rightarrow tH^{-}+X)$
NLO
LO
m_H=250GeV
m_H=500GeV


0.4
0.2
0
-3
-2
-1
0
1
2
3
y_H
$1/\sigma_{tot}\ d\sigma/dy_H\ (pp\rightarrow tH^{-}+X)$
NLO
LO
m_H=250GeV
m_H=500GeV


(a)
K_{SUSY} (pp→tH⁻+X)
tanβ = 30
m_H = 250 GeV
Δm_b
SUSY
Δm_b
m_H = 500 GeV
μ<0
μ>0
Δm_b
SUSY
Δm_b
1.1
1.05
1
0.95
100
150
200
250
300
350
400
m_{SUGRA}[GeV]


(b)
K_{SUSY} (pp→tH⁻+X)
tanβ = 50
m_H = 250 GeV
Δm_b
SUSY
Δm_b
m_H = 500 GeV
μ<0
μ>0
Δm_b
SUSY
Δm_b
1.2
1.1
1
0.9
100
150
200
250
300
350
400
m_{SUGRA}[GeV]


(c)
K_{SUSY} (pp→tH⁻+X)
tanβ = 30
m_H = 250 GeV
Δm_b
SUSY
Δm_b
m_H = 500 GeV
μ=−216GeV
μ=+216GeV
Δm_b
SUSY
Δm_b
1.1
1.05
1
0.95
100
150
200
250
300
350
400
m_{SUGRA}[GeV]


(d)
$K_{SUSY, no\ dec}$ (pp→tH⁻+X)
tanβ = 30
m_H = 250 GeV
Δm_b
SUSY
Δm_b
m_H = 500 GeV
μ<0
μ>0
Δm_b
SUSY
Δm_b
1.1
1.05
1
0.95
100
150
200
250
300
350
400
m_{SUGRA}[GeV]