PAUL SCHERRER INSTITUT

# $t\bar{t}H$ PRODUCTION @ LHC

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I Introduction

II QCD Corrections

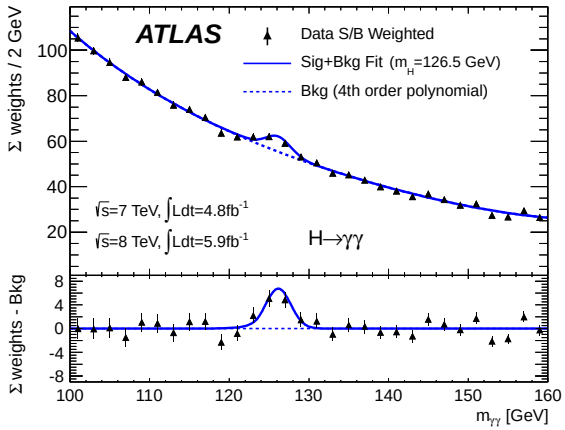
III Assessment & Improvements

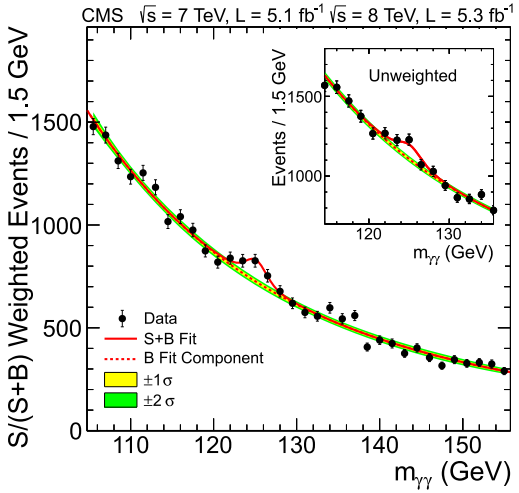
IV Conclusions

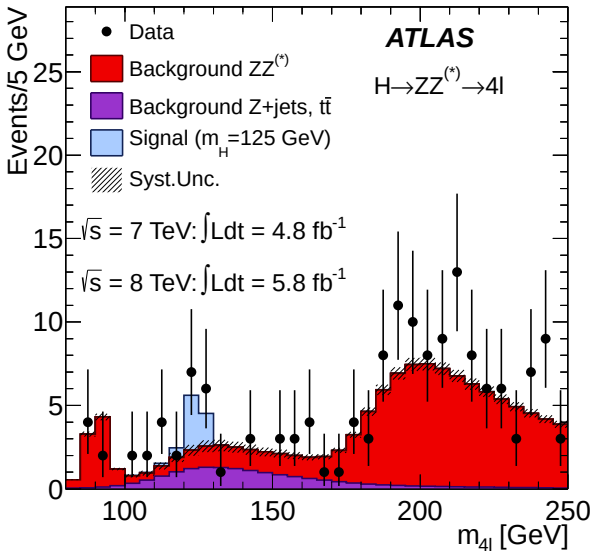
# I INTRODUCTION

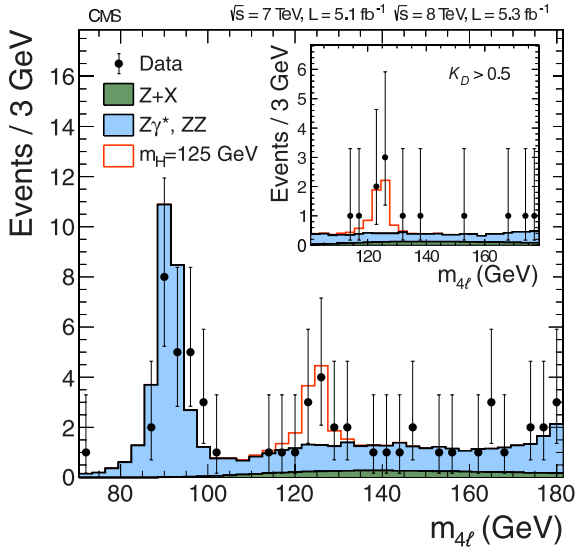
## (i) Standard Model

- we have found the Higgs: $M_H \sim 126$ GeV
- $gg \to H$ dominant

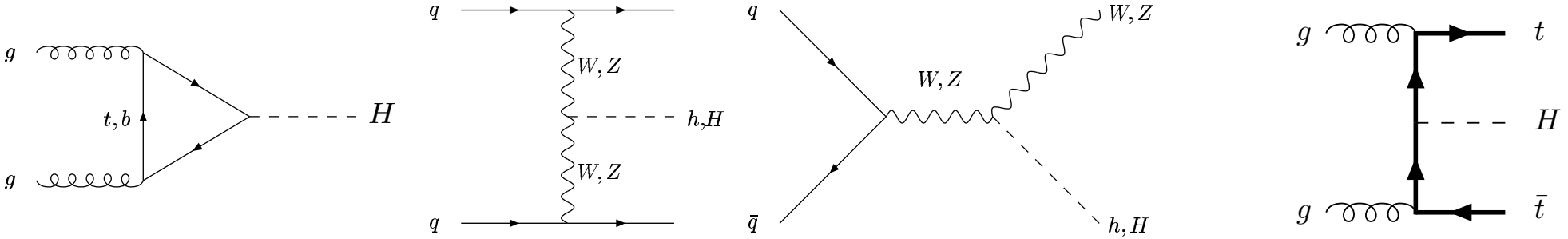


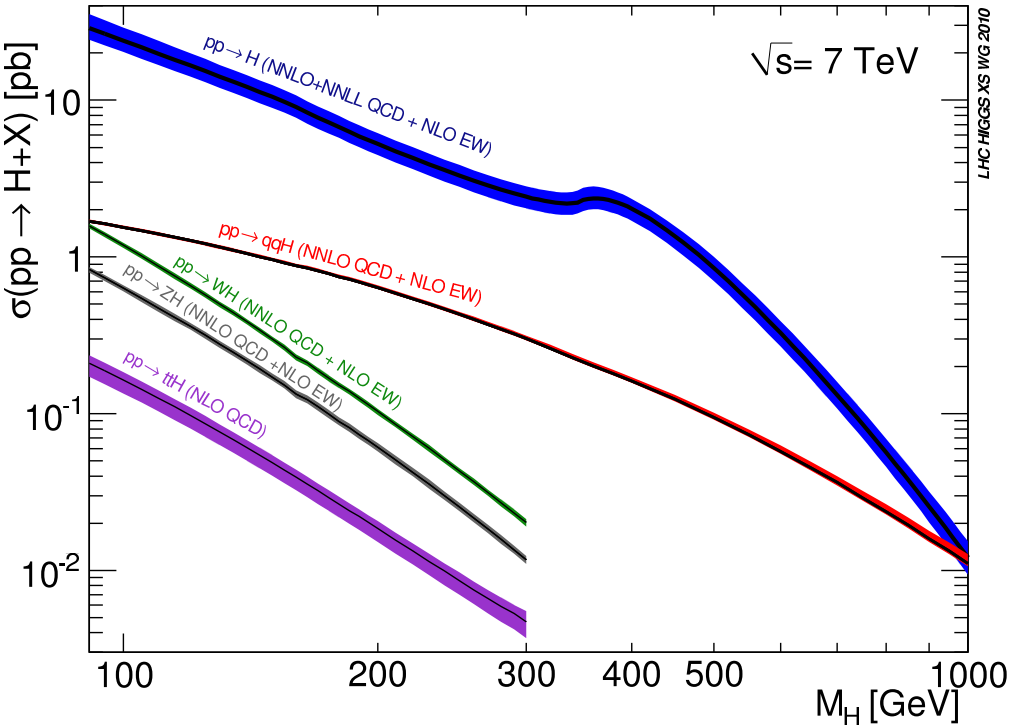



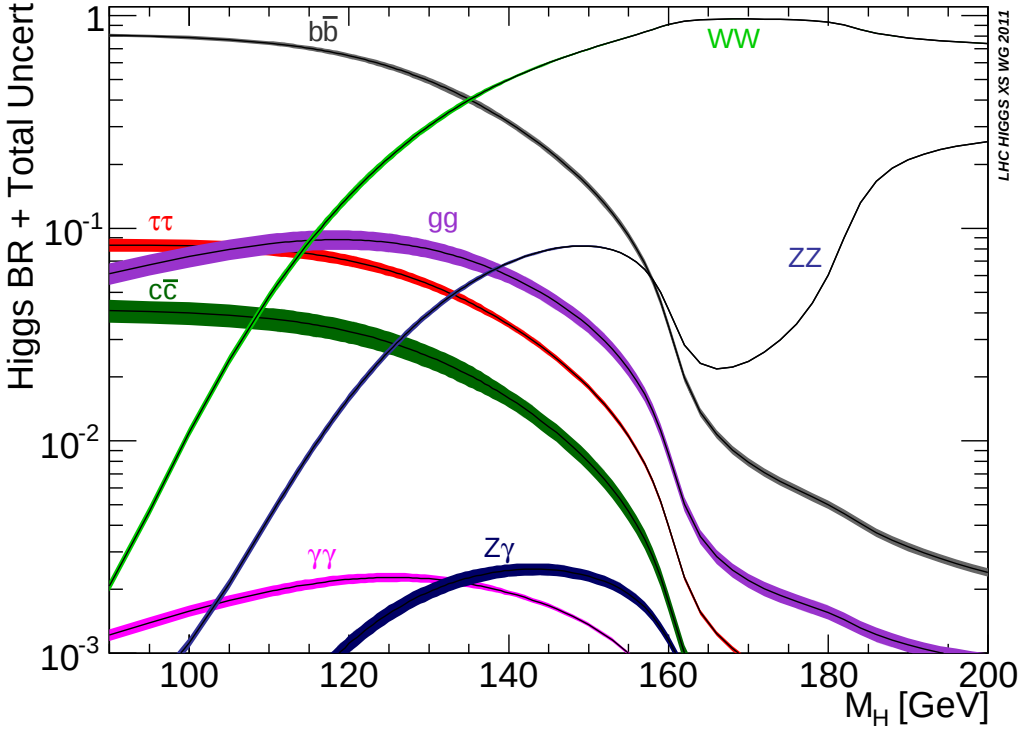



- Higgs Boson Production




LHC Higgs XS WG

- Discovery: LHC [Tevatron]

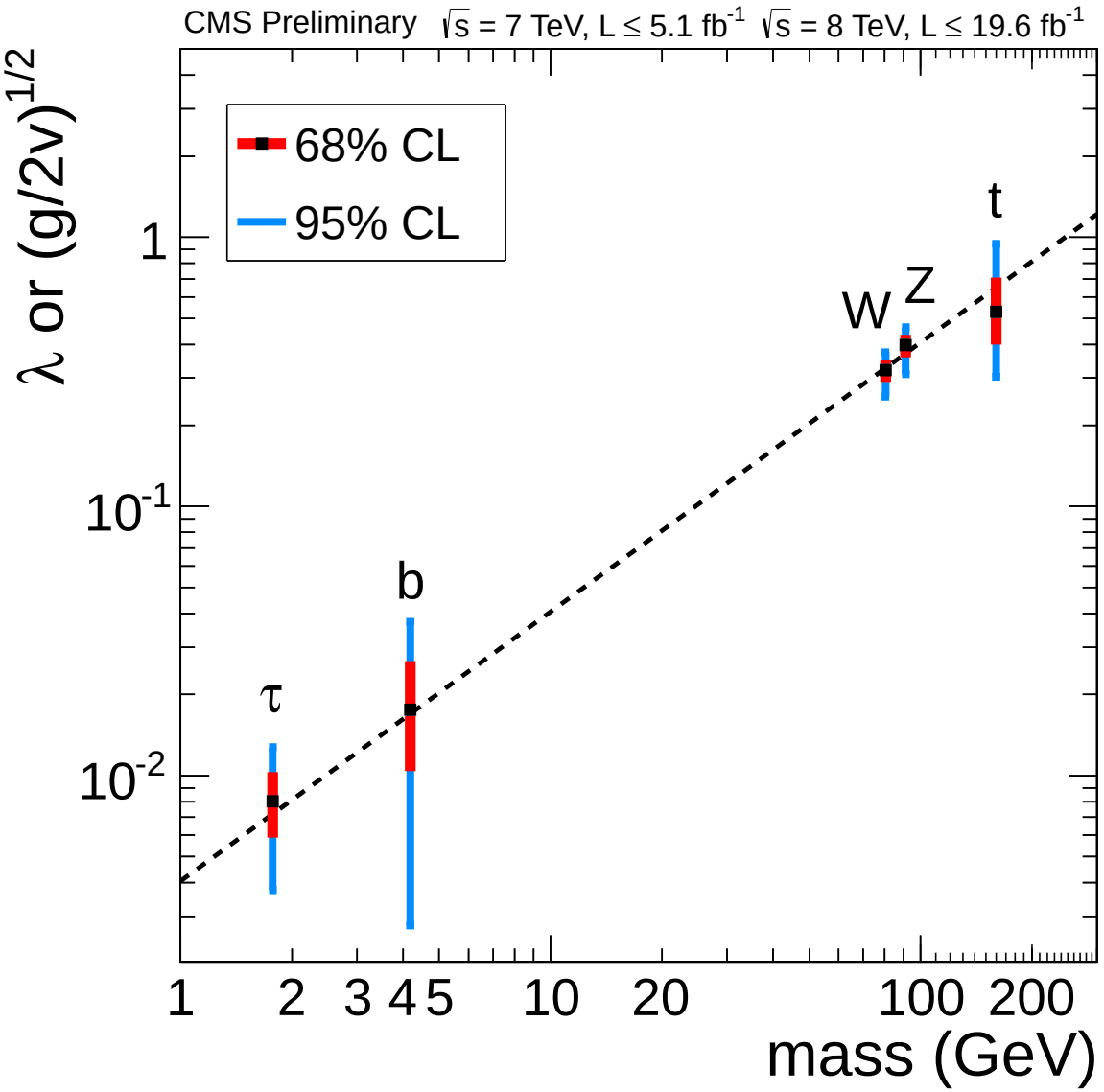
  → Higgs mass

  couplings

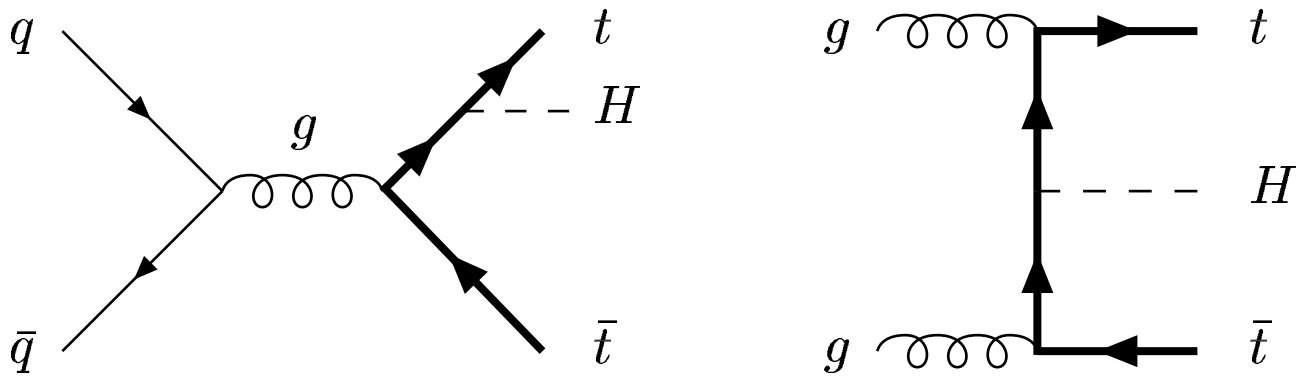
  spin

  $\mathcal{CP}$

  $\lambda$ ?




CMS




- LHC: $gg$ channel dominant, $q\bar{q}$ sizeable:

| $M_H$ [GeV] | $q\bar{q} : gg$ |
|---|---|
| 120 | 0.30 : 0.70 |
| 140 | 0.33 : 0.67 |
| 160 | 0.35 : 0.65 |
| 180 | 0.36 : 0.64 |

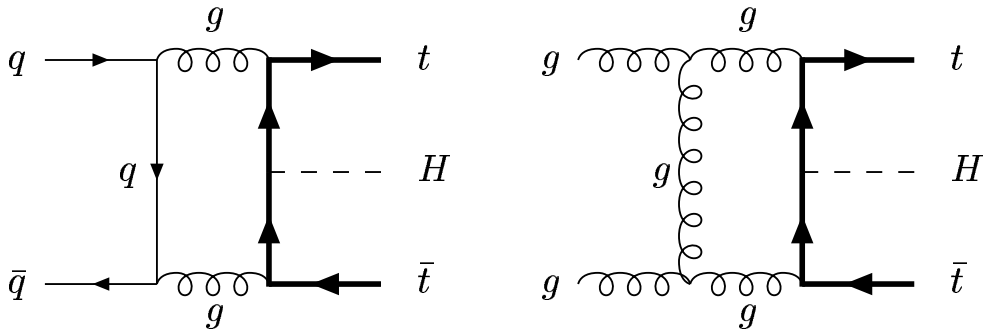
- LO: calculated a long time ago $\longrightarrow$ large scale dependence! Kunszt Gunion Marciano, Paige

$\Longrightarrow$ NLO needed

- crucial for determination of top Yukawa coupling

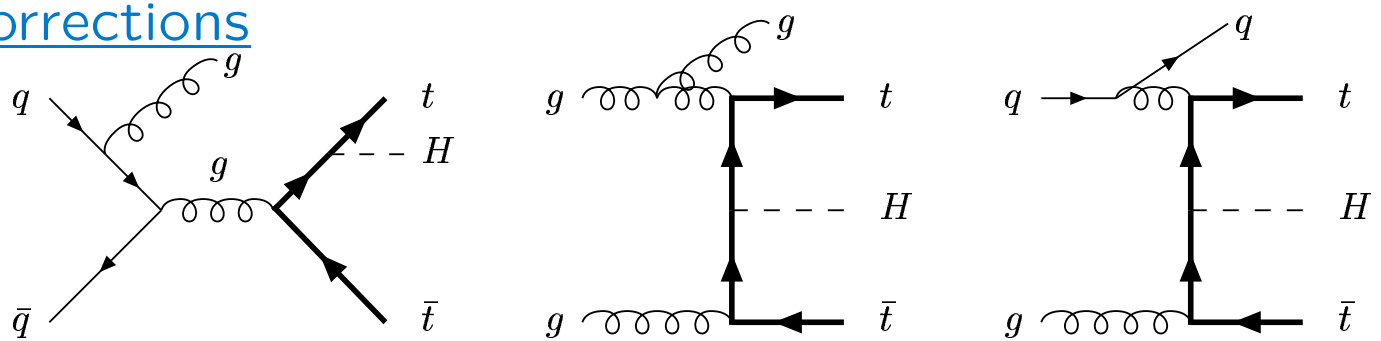
# II *QCD CORRECTIONS*

## (i) Virtual Corrections

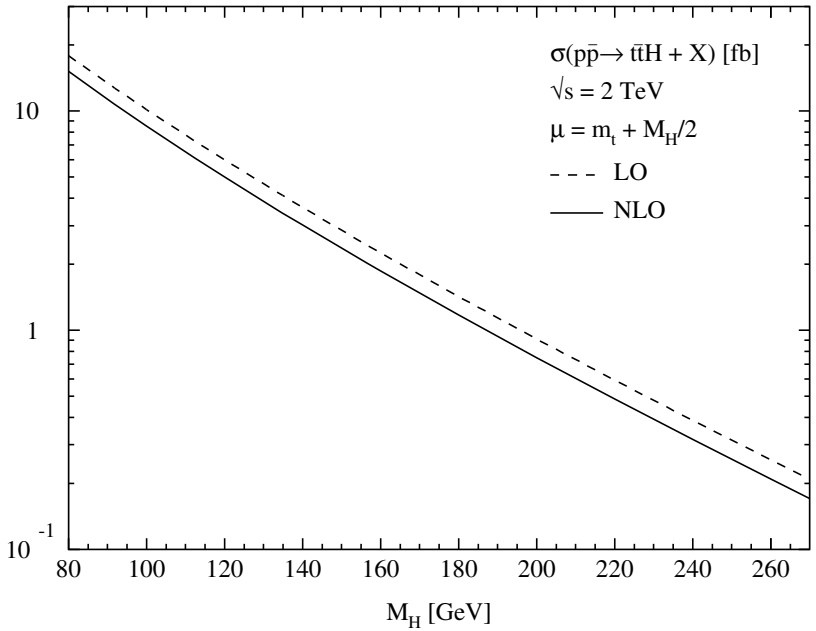



- most difficult part: Pentagon diagrams [IR and COLL divergent]
- $\alpha_s$: $\overline{\text{MS}}$ scheme [5 flavours], $m_t$: on-shell

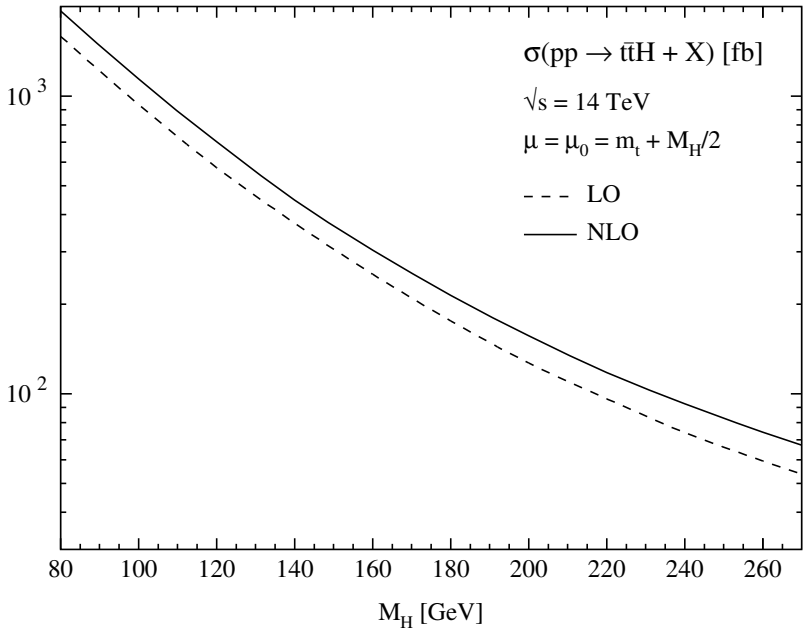
## (ii) Real Corrections



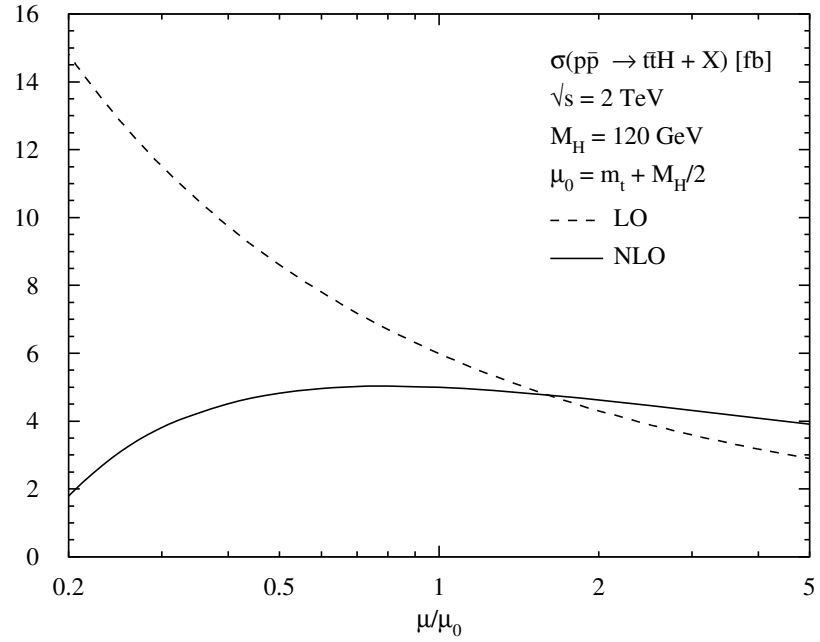

- complex matrix elements
- IR/COLL singularities $\leftrightarrow$ virt. and CTs of PDFs [mass factorization]
- PDF: $\overline{\text{MS}}$ scheme [5 flavours]

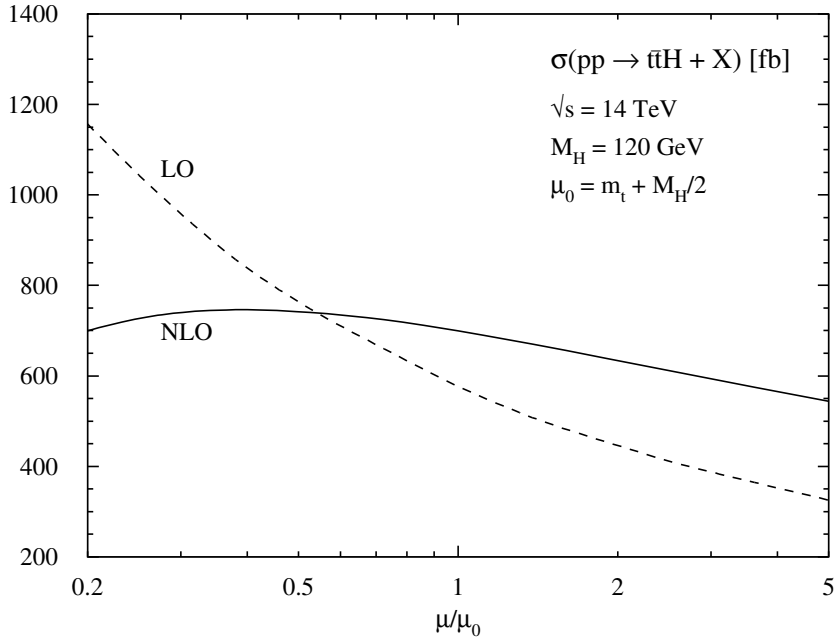



$\sim -20\%$



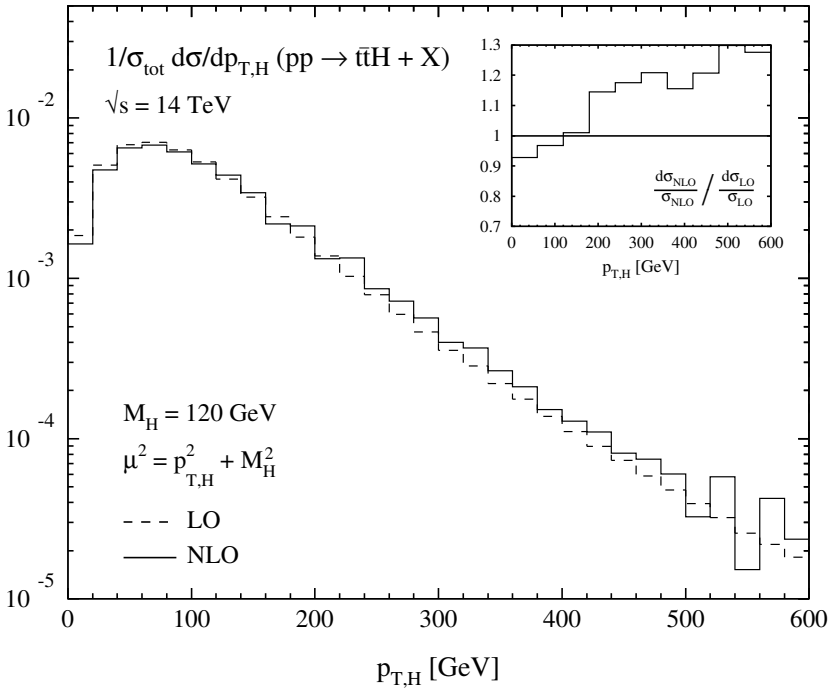

$\sim +20\%$

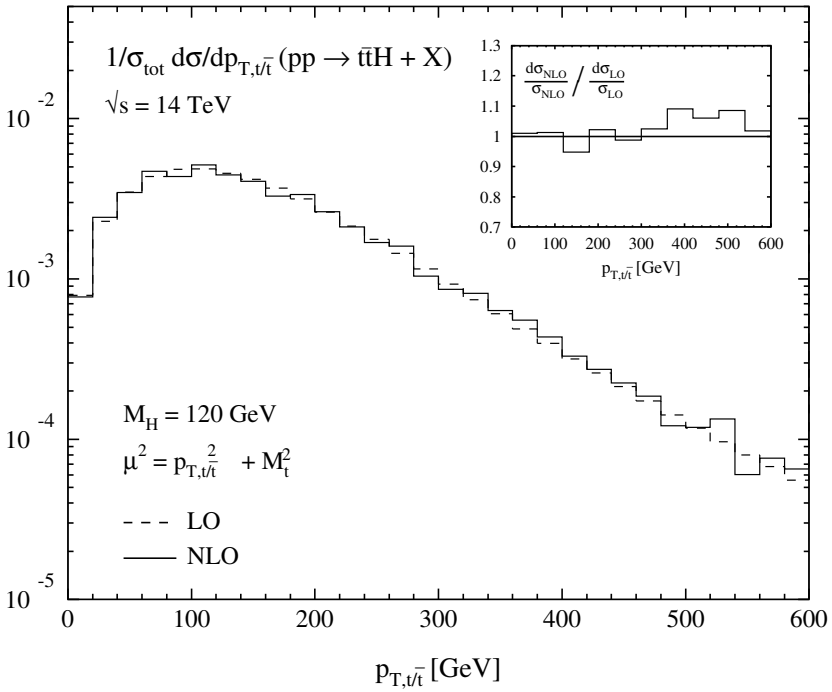


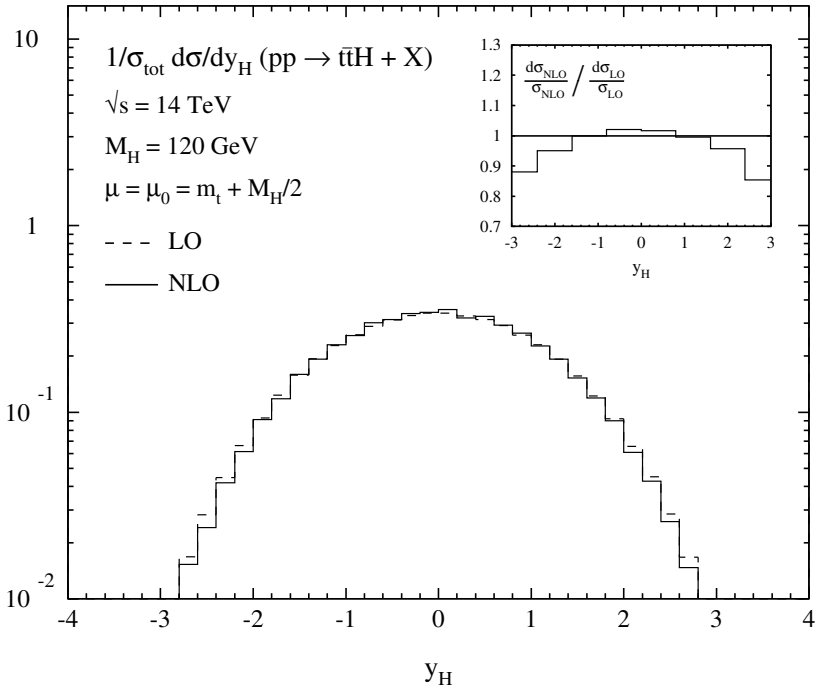

Beenakker, Dittmaier, Krämer, Plümper, S., Zerwas

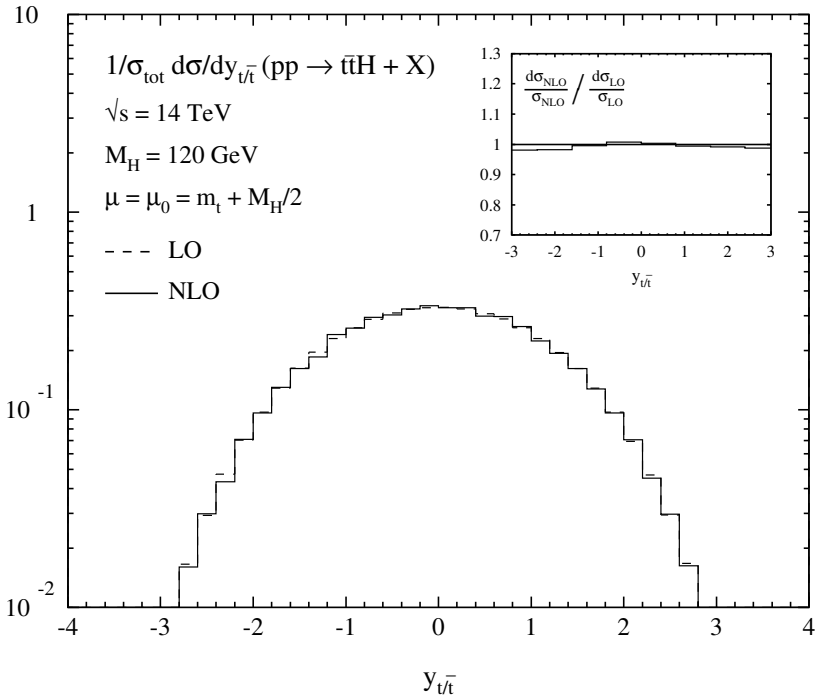
- full agreement with Dawson, Orr, Reina, Wackeroth




Beenakker, Dittmaier, Krämer, Plümper, S., Zerwas

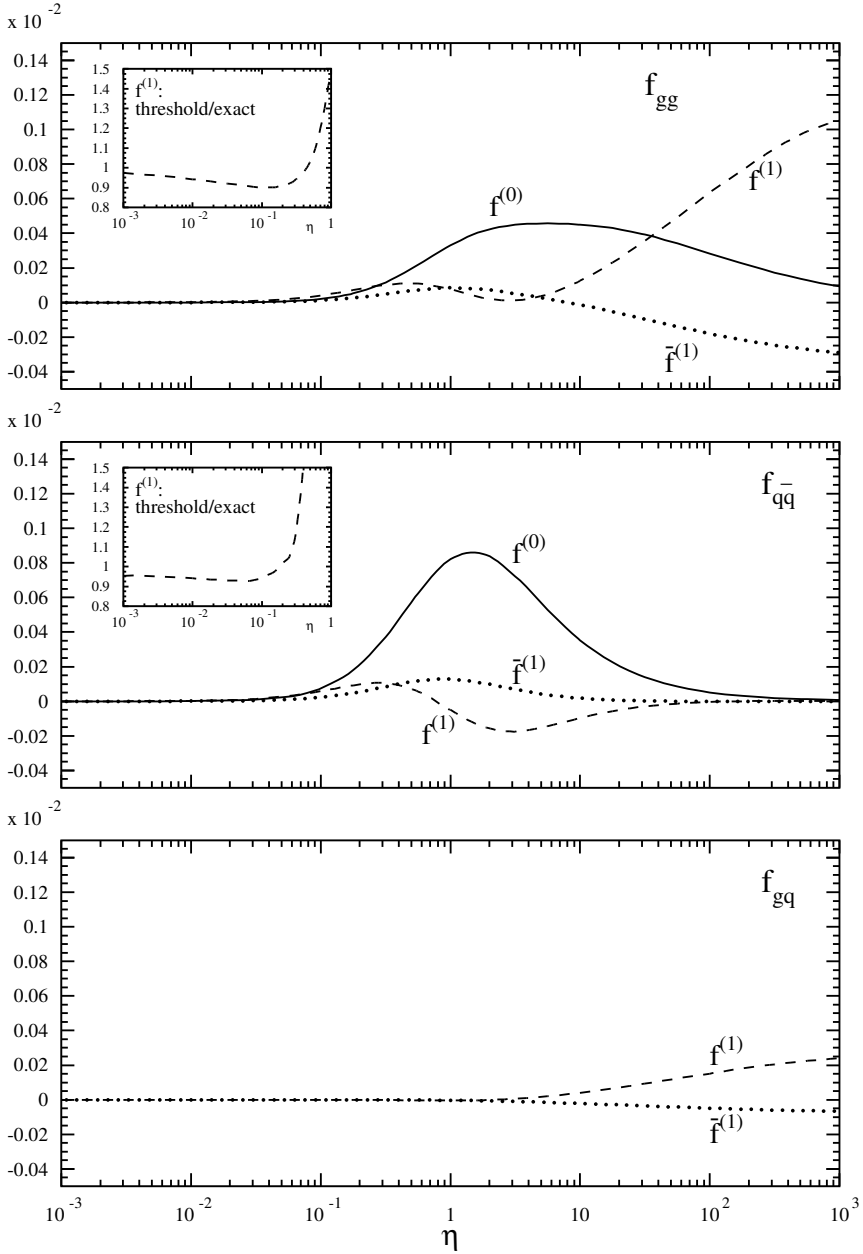



Beenakker, Dittmaier, Krämer, Plümper, S., Zerwas

Why are the corrections only of moderate size ???

$$\hat{\sigma}_{ab} = \frac{\alpha_s^2(\mu^2)}{\mu_0^2}\left\{f_{ab}^{(0)}(\eta) + 4\pi\alpha_s(\mu^2)\left[f_{ab}^{(1)}(\eta) + \bar{f}_{ab}^{(1)}(\eta)\ln\left(\frac{\mu^2}{\mu_0^2}\right)\right]\right\}$$




$$\eta = \hat{s}/4\mu_0^2 - 1$$

$$\mu_0 = m_t + M_H/2$$

$$\hat{\sigma}_{LO} \propto \beta^4 \qquad [\beta = \sqrt{1 - 4\mu_0^2/\hat{s}}]$$

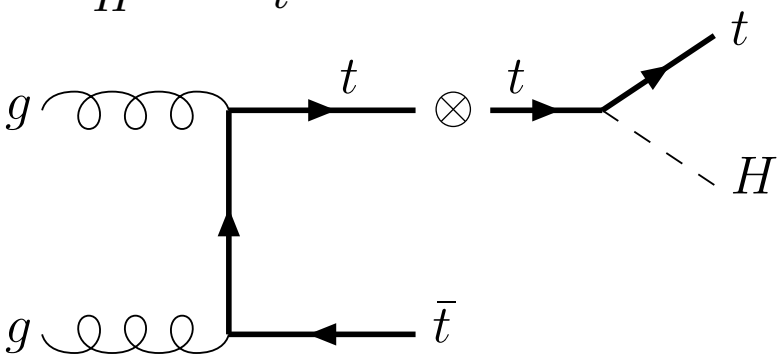
$\rightarrow$ soft gluon + Coulomb suppressed

Beenakker, Dittmaier, Krämer, Plümper, S., Zerwas

Can we find an approximation ???

- Equivalent Higgs Aproximation: $M_H^2 \ll m_t^2 \ll \hat{s}$

$\hat{\sigma}(t\bar{t}H) = (f_{H/t} + f_{H/\bar{t}}) \otimes \hat{\sigma}(t\bar{t})$




- valid within factor 2 @ LO

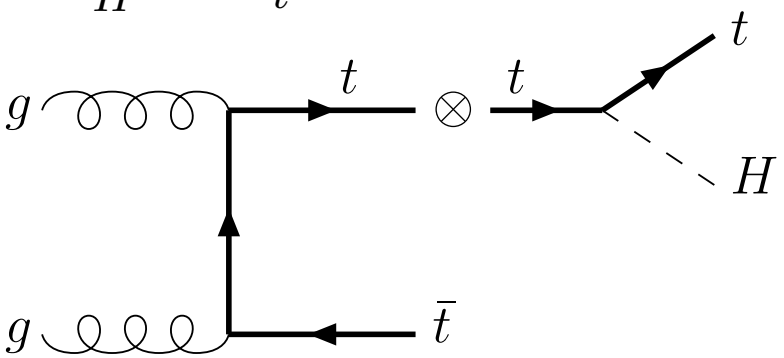
- $\delta = \delta(pp \to t\bar{t}) + \delta(t \to t + H)$ Dawson,Reina

Tevatron: $\delta(pp \to q\bar{q} \to t\bar{t}) \sim -\alpha_s/2\pi$
$\delta(t \to t + H) \sim -4\alpha_s/\pi$
$\Rightarrow K \sim 0.7 \leftrightarrow 0.8$

LHC: $\delta(pp \to gg \to t\bar{t}) \sim +11\alpha_s/\pi$
$\delta(t \to t + H) \sim -4\alpha_s/\pi$
$\Rightarrow K \sim 1.2 \leftrightarrow 1.2$

- Equivalent Higgs Aproximation: $M_H^2 \ll m_t^2 \ll \hat{s}$

$\hat{\sigma}(t\bar{t}H) = (f_{H/t} + f_{H/\bar{t}}) \otimes \hat{\sigma}(t\bar{t})$




- valid within factor 2 @ LO

- $\delta = \delta(pp \to t\bar{t}) + \delta(t \to t + H)$ Dawson,Reina

Tevatron: $\delta(pp \to q\bar{q} \to t\bar{t}) \sim -\alpha_s/2\pi$

$\delta(t \to t + H) \sim -4\alpha_s/\pi$

$\Rightarrow K \sim 0.7 \leftrightarrow 0.8$ $[\sqrt{\langle \hat{s} \rangle} \sim 650$ GeV$]$

LHC: $\delta(pp \to gg \to t\bar{t}) \sim +11\alpha_s/\pi$

$\delta(t \to t + H) \sim -4\alpha_s/\pi$

$\Rightarrow K \sim 1.2 \leftrightarrow 1.2$ $[\sqrt{\langle \hat{s} \rangle} \sim 830$ GeV$]$

$\Rightarrow$ semi-quantitative understanding

# III *ASESSMENT & IMPROVEMENTS*

(i) Asessment → LHC Higgs XS WG

- aim: (i) provide NLO cross sections (inclusive)
  (ii) theoretical errors: ren./fact. scales $[\mu_0/2, 2\mu_0]$
  ($\mu_0 = m_t + M_H/2$)
  $\alpha_s$
  PDFs
  input parameters (e.g. $m_t$)

- agreement: use $\alpha_s$ consistent with PDF set:
  MSTW2008: $\alpha_s(M_Z) = 0.120$ CTEQ6.6: $\alpha_s(M_Z) = 0.118$
  NNPDF 2.0: $\alpha_s(M_Z) = 0.119$
  use error PDFs of MSTW2008, CTEQ6.6, NNPDF 2.0 internally
  use envelope of PDFs errors PDF4LHC

MSTW2008

| $M_H$ [GeV] | LO [fb], MSTW2008 | LO [fb], CTEQ6L1 | scale [%] | PDF [%] |
|---|---|---|---|---|
| 90 | 213.17(9) | 174.15(1) | [−26.4,+39.9] | [−2.59,+2.50] |
| 100 | 162.70(7) | 132.950(7) | [−26.2,+39.8] | [−2.63,+2.59] |
| 110 | 126.06(6) | 102.808(6) | [−26.2,+39.6] | [−2.52,+2.43] |
| 120 | 98.66(4) | 80.428(5) | [−26.3,+39.8] | [−2.86,+2.29] |
| 130 | 78.09(3) | 63.62(3) | [−26.2,+39.8] | [−2.39,+2.72] |
| 140 | 62.43(3) | 50.788(3) | [−26.3,+39.9] | [−2.57,+2.62] |
| 150 | 50.35(2) | 40.940(2) | [−26.0,+39.8] | [−2.34,+2.72] |
| 160 | 40.98(2) | 33.293(2) | [−26.3,+39.6] | [−2.97,+2.16] |
| 170 | 33.62(1) | 27.30(1) | [−26.1,+39.9] | [−2.36,+2.85] |
| 180 | 27.83(1) | 22.568(1) | [−26.2,+39.7] | [−3.22,+2.28] |

differences @ LO: $\sim 20\%$

HQQ

MSTW2008 small $K$-factors!

| $M_H$ [GeV] | LO [fb] | NLO [fb] | scale [%] | $\alpha_s$ [%] | PDF [%] | PDF+$\alpha_s$ [%] |
|---|---|---|---|---|---|---|
| 90 | 213.17(9) | 224.8(3) | [−9.7%,+4.1%] | [−2.7%,+2.2%] | [−3.4%,+2.9%] | [−3.9%,+4.2%] |
| 95 | 186.11(8) | 195.6(2) | [−9.6%,+4.0%] | [−2.7%,+2.2%] | [−3.4%,+2.9%] | [−3.9%,+4.3%] |
| 100 | 162.70(7) | 170.4(2) | [−9.6%,+3.9%] | [−2.7%,+2.2%] | [−3.4%,+2.9%] | [−3.9%,+4.3%] |
| 105 | 143.06(6) | 149.0(2) | [−9.5%,+3.7%] | [−2.7%,+2.2%] | [−3.4%,+2.9%] | [−3.9%,+4.3%] |
| 110 | 126.06(6) | 130.8(2) | [−9.5%,+3.6%] | [−2.7%,+2.2%] | [−3.4%,+2.9%] | [−3.9%,+4.3%] |
| 115 | 111.38(5) | 115.0(1) | [−9.4%,+3.5%] | [−2.7%,+2.2%] | [−3.4%,+3.0%] | [−3.9%,+4.3%] |
| 120 | 98.66(4) | 101.4(1) | [−9.4%,+3.4%] | [−2.7%,+2.2%] | [−3.4%,+3.0%] | [−3.9%,+4.3%] |
| 125 | 87.66(4) | 89.8(1) | [−9.3%,+3.3%] | [−2.7%,+2.2%] | [−3.4%,+3.0%] | [−3.9%,+4.3%] |
| 130 | 78.09(3) | 79.57(8) | [−9.3%,+3.2%] | [−2.7%,+2.2%] | [−3.3%,+3.0%] | [−3.9%,+4.3%] |
| 135 | 69.71(3) | 70.75(7) | [−9.2%,+3.1%] | [−2.7%,+2.2%] | [−3.4%,+3.0%] | [−3.9%,+4.3%] |
| 140 | 62.43(3) | 63.06(6) | [−9.2%,+3.0%] | [−2.7%,+2.2%] | [−3.4%,+3.0%] | [−3.9%,+4.4%] |
| 145 | 55.96(2) | 56.50(6) | [−9.1%,+2.9%] | [−2.7%,+2.2%] | [−3.4%,+3.1%] | [−3.9%,+4.4%] |
| 150 | 50.35(2) | 50.59(6) | [−9.1%,+2.9%] | [−2.7%,+2.2%] | [−3.4%,+3.1%] | [−3.9%,+4.4%] |
| 155 | 45.37(2) | 45.49(5) | [−9.1%,+2.8%] | [−2.7%,+2.2%] | [−3.4%,+3.1%] | [−3.9%,+4.4%] |
| 160 | 40.98(2) | 41.01(4) | [−9.1%,+2.8%] | [−2.7%,+2.2%] | [−3.4%,+3.1%] | [−3.9%,+4.4%] |
| 165 | 37.09(1) | 36.99(3) | [−9.1%,+2.7%] | [−2.6%,+2.2%] | [−3.4%,+3.2%] | [−3.9%,+4.5%] |
| 170 | 33.62(1) | 33.47(3) | [−9.0%,+2.7%] | [−2.6%,+2.2%] | [−3.4%,+3.2%] | [−3.9%,+4.5%] |

MSTW2008 small $K$-factors!

| $M_H$ [GeV] | LO [fb] | NLO [fb] | scale [%] | $\alpha_s$ [%] | PDF [%] | PDF+$\alpha_s$ [%] |
|---|---|---|---|---|---|---|
| 175 | 30.56(1) | 30.31(3) | [−9.0%,+2.6%] | [−2.6%,+2.2%] | [−3.4%,+3.2%] | [−3.9%,+4.5%] |
| 180 | 27.83(1) | 27.55(3) | [−9.0%,+2.6%] | [−2.7%,+2.2%] | [−3.4%,+3.2%] | [−4.0%,+4.6%] |
| 185 | 25.38(1) | 25.09(3) | [−9.0%,+2.6%] | [−2.7%,+2.2%] | [−3.5%,+3.3%] | [−4.0%,+4.6%] |
| 190 | 23.20(1) | 22.93(3) | [−9.0%,+2.6%] | [−2.7%,+2.2%] | [−3.5%,+3.3%] | [−4.0%,+4.6%] |
| 195 | 21.247(8) | 20.94(2) | [−9.0%,+2.6%] | [−2.7%,+2.2%] | [−3.5%,+3.4%] | [−4.0%,+4.7%] |
| 200 | 19.481(8) | 19.20(2) | [−9.1%,+2.6%] | [−2.7%,+2.2%] | [−3.6%,+3.4%] | [−4.1%,+4.7%] |
| 210 | 16.492(7) | 16.23(2) | [−9.2%,+2.8%] | [−2.7%,+2.2%] | [−3.7%,+3.5%] | [−4.1%,+4.8%] |
| 220 | 14.040(6) | 13.81(1) | [−9.3%,+2.9%] | [−2.7%,+2.2%] | [−3.7%,+3.6%] | [−4.2%,+4.9%] |
| 230 | 12.037(5) | 11.86(1) | [−9.4%,+3.2%] | [−2.7%,+2.3%] | [−3.9%,+3.7%] | [−4.3%,+5.0%] |
| 240 | 10.384(5) | 10.24(1) | [−9.5%,+3.2%] | [−2.7%,+2.3%] | [−4.0%,+3.8%] | [−4.4%,+5.2%] |
| 250 | 9.011(4) | 8.899(9) | [−9.7%,+3.5%] | [−2.7%,+2.3%] | [−4.1%,+4.0%] | [−4.5%,+5.3%] |
| 260 | 7.850(4) | 7.777(10) | [−9.9%,+3.9%] | [−2.8%,+2.3%] | [−4.3%,+4.1%] | [−4.6%,+5.5%] |
| 270 | 6.888(3) | 6.866(8) | [−10.1%,+4.3%] | [−2.8%,+2.4%] | [−4.4%,+4.2%] | [−4.7%,+5.6%] |
| 280 | 6.075(3) | 6.092(9) | [−10.4%,+4.7%] | [−2.8%,+2.4%] | [−4.6%,+4.4%] | [−4.9%,+5.8%] |
| 290 | 5.376(3) | 5.405(7) | [−10.6%,+5.2%] | [−2.8%,+2.4%] | [−4.7%,+4.6%] | [−5.0%,+6.0%] |
| 300 | 4.780(3) | 4.848(7) | [−10.9%,+5.6%] | [−2.9%,+2.5%] | [−4.9%,+4.7%] | [−5.2%,+6.2%] |

# CTEQ6.6

| $M_H$ [GeV] | LO [fb] | NLO [fb] | scale [%] | $\alpha_s$ [%] | PDF [%] |
|---|---|---|---|---|---|
| 90 | 174.15(1) | 210.0(1) | [ −9.4%,+4.2%] | [−2.5%,+3.5%] | [−5.1%,+5.9%] |
| 95 | 151.903(9) | 182.49(8) | [ −9.4%,+4.1%] | [−2.5%,+3.5%] | [−5.1%,+5.9%] |
| 100 | 132.950(7) | 159.08(7) | [ −9.3%,+4.0%] | [−2.5%,+3.5%] | [−5.1%,+6.0%] |
| 105 | 116.734(7) | 139.33(6) | [ −9.2%,+3.8%] | [−2.5%,+3.5%] | [−5.2%,+6.1%] |
| 110 | 102.808(6) | 122.09(5) | [ −9.2%,+3.7%] | [−2.5%,+3.6%] | [−5.2%,+6.1%] |
| 115 | 90.806(5) | 107.50(5) | [ −9.2%,+3.6%] | [−2.5%,+3.5%] | [−5.2%,+6.2%] |
| 120 | 80.428(5) | 94.91(4) | [ −9.1%,+3.5%] | [−2.6%,+3.5%] | [−5.3%,+6.2%] |
| 125 | 71.44(3) | 83.94(4) | [ −9.1%,+3.5%] | [−2.5%,+3.6%] | [−5.3%,+6.3%] |
| 130 | 63.62(3) | 74.54(3) | [ −9.0%,+3.4%] | [−2.5%,+3.6%] | [−5.3%,+6.4%] |
| 135 | 56.77(2) | 66.32(3) | [ −9.0%,+3.3%] | [−2.5%,+3.6%] | [−5.4%,+6.4%] |
| 140 | 50.788(3) | 59.16(3) | [ −9.0%,+3.2%] | [−2.5%,+3.6%] | [−5.4%,+6.5%] |
| 145 | 45.547(2) | 52.92(2) | [ −8.9%,+3.2%] | [−2.5%,+3.6%] | [−5.5%,+6.6%] |
| 150 | 40.940(2) | 47.45(2) | [ −8.9%,+3.1%] | [−2.5%,+3.6%] | [−5.5%,+6.6%] |
| 155 | 36.879(2) | 42.60(2) | [ −8.9%,+3.1%] | [−2.5%,+3.6%] | [−5.6%,+6.7%] |
| 160 | 33.293(2) | 38.38(2) | [ −8.9%,+3.0%] | [−2.6%,+3.6%] | [−5.6%,+6.8%] |
| 165 | 30.118(2) | 34.68(2) | [ −8.9%,+3.0%] | [−2.6%,+3.7%] | [−5.7%,+6.9%] |
| 170 | 27.30(1) | 31.38(1) | [ −8.9%,+3.0%] | [−2.6%,+3.7%] | [−5.7%,+7.0%] |

differences MSTW2008 $\leftrightarrow$ CTEQ6.6 @ NLO: $7-8\%$

# CTEQ6.6

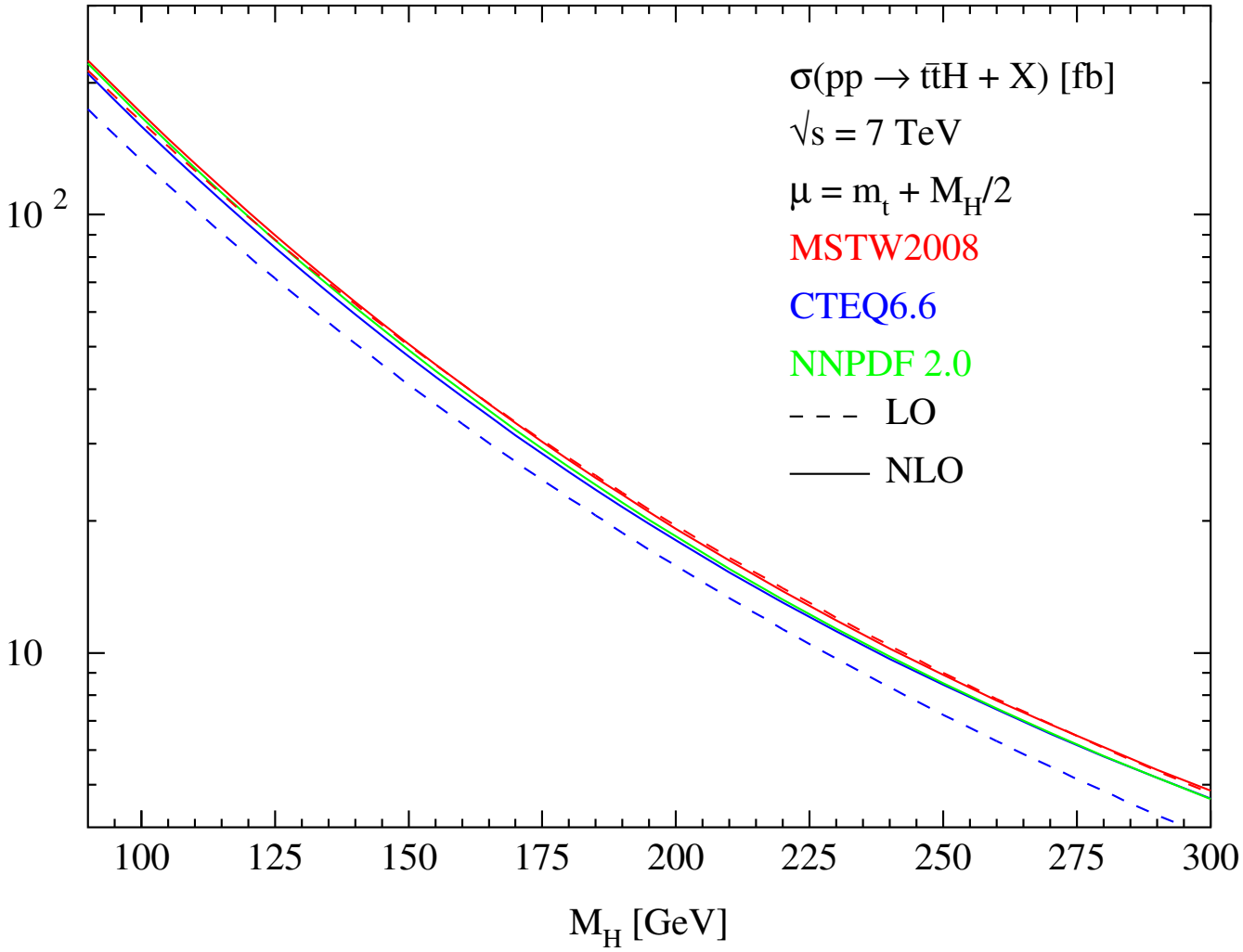
| $M_H$ [GeV] | LO [fb] | NLO [fb] | scale [%] | $\alpha_s$ [%] | PDF [%] |
|---|---|---|---|---|---|
| 175 | 24.81(1) | 28.47(1) | [ −8.9%,+3.0%] | [−2.6%,+3.7%] | [−5.8%,+7.0%] |
| 180 | 22.568(1) | 25.88(1) | [ −8.9%,+3.0%] | [−2.6%,+3.7%] | [−5.8%,+7.1%] |
| 185 | 20.577(8) | 23.56(1) | [ −8.9%,+3.0%] | [−2.6%,+3.7%] | [−5.9%,+7.2%] |
| 190 | 18.800(7) | 21.52(1) | [ −8.9%,+3.0%] | [−2.6%,+3.8%] | [−6.0%,+7.3%] |
| 195 | 17.202(7) | 19.70(1) | [ −8.9%,+3.0%] | [−2.6%,+3.8%] | [−6.0%,+7.4%] |
| 200 | 15.777(6) | 18.064(8) | [ −9.0%,+3.1%] | [−2.6%,+3.8%] | [−6.1%,+7.5%] |
| 210 | 13.329(6) | 15.272(7) | [ −9.1%,+3.2%] | [−2.6%,+3.9%] | [−6.3%,+7.8%] |
| 220 | 11.321(5) | 13.019(6) | [ −9.1%,+3.3%] | [−2.6%,+3.9%] | [−6.4%,+8.0%] |
| 230 | 9.696(4) | 11.202(5) | [ −9.3%,+3.5%] | [−2.7%,+4.0%] | [−6.6%,+8.3%] |
| 240 | 8.344(4) | 9.685(5) | [ −9.4%,+3.6%] | [−2.7%,+4.1%] | [−6.8%,+8.5%] |
| 250 | 7.227(3) | 8.450(4) | [ −9.6%,+3.9%] | [−2.7%,+4.2%] | [−7.0%,+8.8%] |
| 260 | 6.286(3) | 7.418(4) | [ −9.7%,+4.1%] | [−2.8%,+4.3%] | [−7.2%,+9.1%] |
| 270 | 5.501(2) | 6.541(4) | [ −9.9%,+4.4%] | [−2.8%,+4.4%] | [−7.4%,+9.5%] |
| 280 | 4.837(2) | 5.809(3) | [−10.1%,+4.6%] | [−2.9%,+4.5%] | [−7.7%,+9.8%] |
| 290 | 4.267(2) | 5.186(3) | [−10.3%,+4.9%] | [−2.9%,+4.6%] | [−7.9%,+10.1%] |
| 300 | 3.785(2) | 4.653(3) | [−10.5%,+5.2%] | [−3.0%,+4.7%] | [−8.2%,+10.5%] |

# NNPDF 2.0

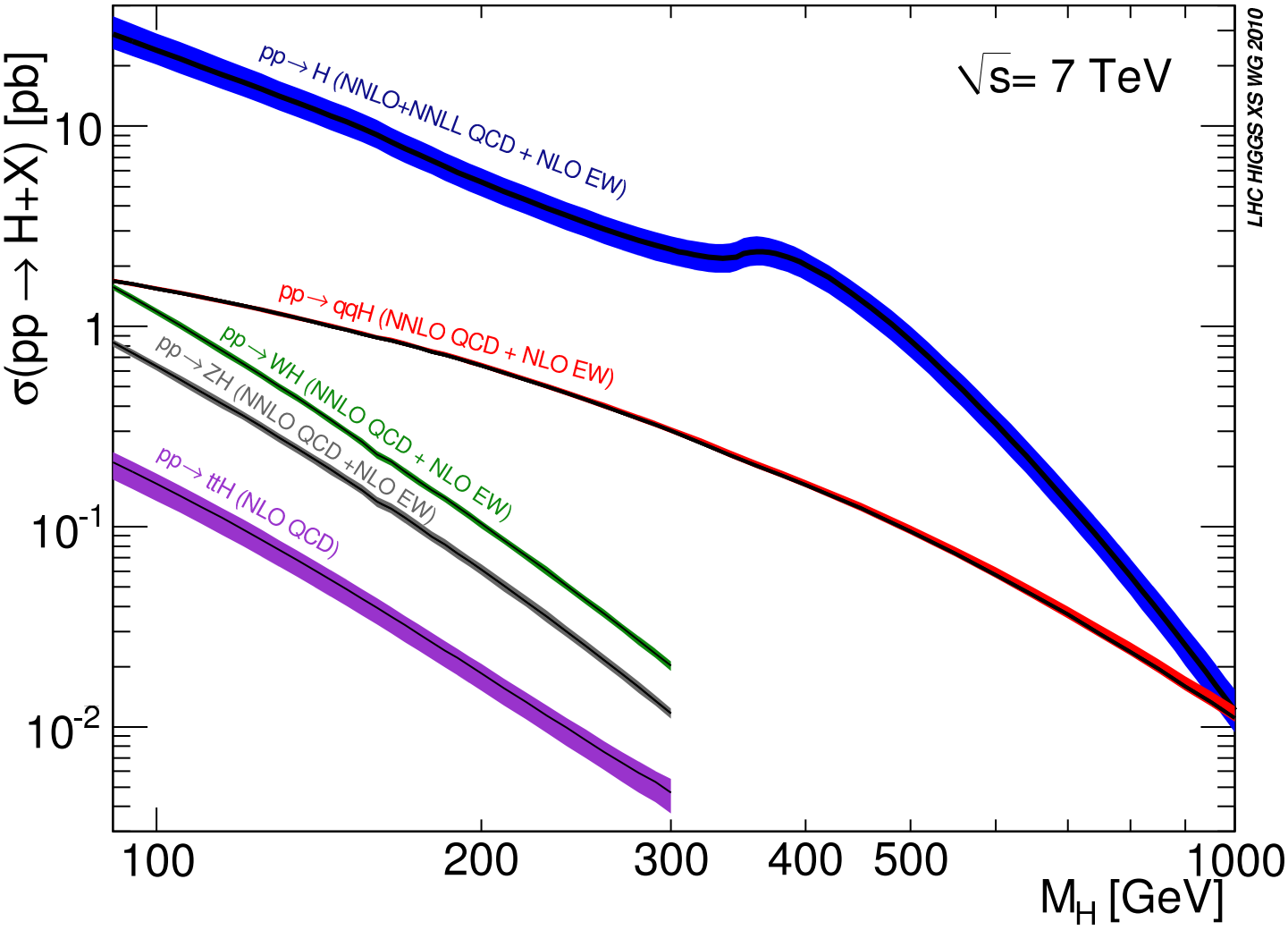
| $M_H$ [GeV] | NLO [fb] | scale [%] | $\alpha_s$ [%] | PDF [%] |
|---|---|---|---|---|
| 90 | 221.3 | [−10.7%,+4.8%] | [−2.3%,+1.6%] | [−4.1%,+4.1%] |
| 95 | 192.0 | [−10.6%,+4.7%] | [−2.3%,+1.6%] | [−4.1%,+4.1%] |
| 100 | 167.1 | [−10.6%,+4.5%] | [−2.2%,+1.6%] | [−4.1%,+4.1%] |
| 105 | 145.9 | [−10.5%,+4.4%] | [−2.2%,+1.6%] | [−4.1%,+4.1%] |
| 110 | 127.8 | [−10.4%,+4.3%] | [−2.2%,+1.6%] | [−4.2%,+4.2%] |
| 115 | 112.3 | [−10.4%,+4.2%] | [−2.2%,+1.6%] | [−4.2%,+4.2%] |
| 120 | 99.01 | [−10.3%,+4.1%] | [−2.2%,+1.6%] | [−4.2%,+4.2%] |
| 125 | 87.50 | [−10.2%,+4.1%] | [−2.2%,+1.6%] | [−4.2%,+4.2%] |
| 130 | 77.54 | [−10.2%,+4.0%] | [−2.2%,+1.6%] | [−4.2%,+4.2%] |
| 135 | 68.89 | [−10.1%,+3.9%] | [−2.1%,+1.6%] | [−4.2%,+4.2%] |
| 140 | 61.37 | [−10.1%,+3.8%] | [−2.1%,+1.6%] | [−4.3%,+4.3%] |
| 145 | 54.81 | [−10.0%,+3.8%] | [−2.1%,+1.6%] | [−4.3%,+4.3%] |
| 150 | 49.07 | [−10.0%,+3.7%] | [−2.1%,+1.6%] | [−4.3%,+4.3%] |
| 155 | 44.03 | [−9.9%,+3.7%] | [−2.1%,+1.6%] | [−4.3%,+4.3%] |
| 160 | 39.61 | [−9.9%,+3.6%] | [−2.1%,+1.6%] | [−4.4%,+4.4%] |
| 165 | 35.72 | [−9.9%,+3.6%] | [−2.1%,+1.6%] | [−4.4%,+4.4%] |
| 170 | 32.28 | [−9.9%,+3.6%] | [−2.1%,+1.6%] | [−4.5%,+4.5%] |

## NNPDF 2.0

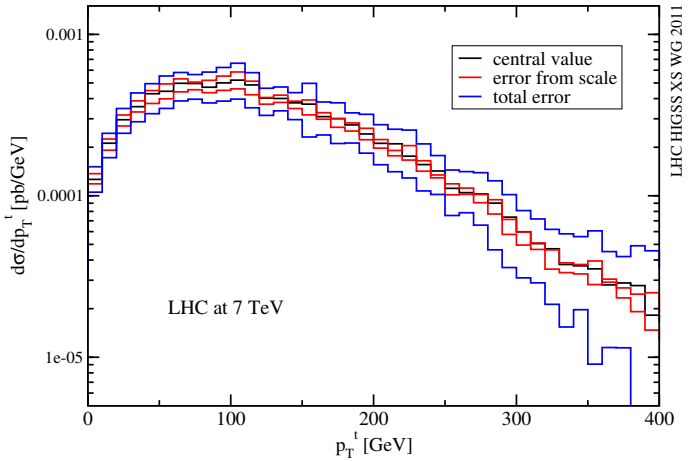
| $M_H$ [GeV] | NLO [fb] | scale [%] | $\alpha_s$ [%] | PDF [%] |
|---|---|---|---|---|
| 175 | 29.24 | [−9.9%,+3.6%] | [−2.1%,+1.6%] | [−4.5%,+4.5%] |
| 180 | 26.55 | [−9.8%,+3.6%] | [−2.1%,+1.6%] | [−4.5%,+4.5%] |
| 185 | 24.16 | [−9.8%,+3.6%] | [−2.1%,+1.6%] | [−4.6%,+4.6%] |
| 190 | 22.03 | [−9.9%,+3.6%] | [−2.0%,+1.6%] | [−4.6%,+4.6%] |
| 195 | 20.13 | [−9.9%,+3.6%] | [−2.0%,+1.6%] | [−4.7%,+4.7%] |
| 200 | 18.44 | [−9.9%,+3.7%] | [−2.0%,+1.6%] | [−4.7%,+4.7%] |
| 210 | 15.56 | [−10.0%,+3.8%] | [−2.0%,+1.6%] | [−4.9%,+4.9%] |
| 220 | 13.24 | [−10.0%,+3.9%] | [−2.0%,+1.6%] | [−5.0%,+5.0%] |
| 230 | 11.35 | [−10.1%,+4.1%] | [−2.0%,+1.6%] | [−5.2%,+5.2%] |
| 240 | 9.805 | [−10.3%,+4.3%] | [−2.0%,+1.6%] | [−5.3%,+5.3%] |
| 250 | 8.527 | [−10.4%,+4.5%] | [−2.0%,+1.6%] | [−5.5%,+5.5%] |
| 260 | 7.465 | [−10.6%,+4.8%] | [−2.1%,+1.6%] | [−5.7%,+5.7%] |
| 270 | 6.575 | [−10.7%,+5.1%] | [−2.1%,+1.6%] | [−5.9%,+5.9%] |
| 280 | 5.824 | [−10.9%,+5.4%] | [−2.1%,+1.6%] | [−6.1%,+6.1%] |
| 290 | 5.187 | [−11.1%,+5.7%] | [−2.1%,+1.5%] | [−6.4%,+6.4%] |
| 300 | 4.642 | [−11.3%,+6.0%] | [−2.1%,+1.5%] | [−6.6%,+6.6%] |

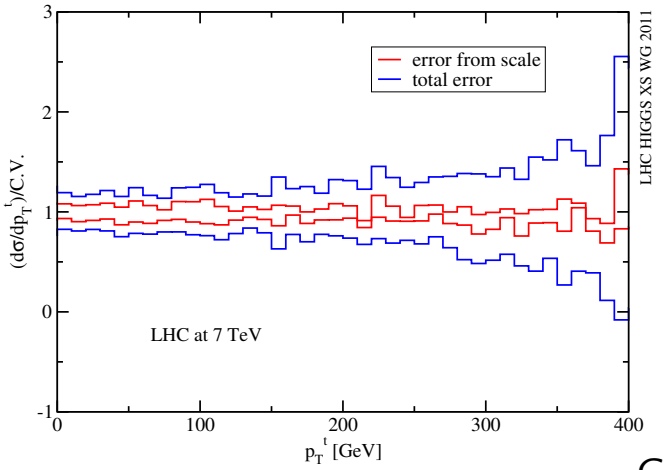



LHC Higgs XS WG

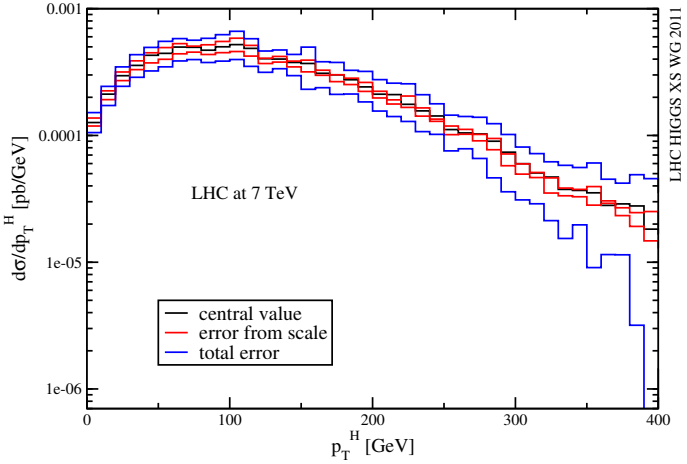


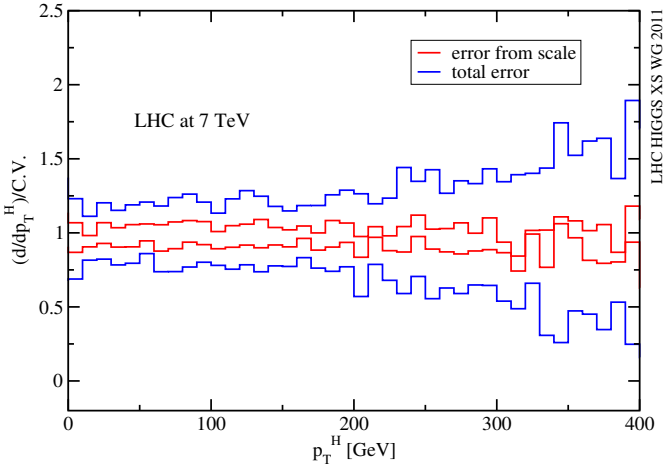

LHC Higgs XS WG

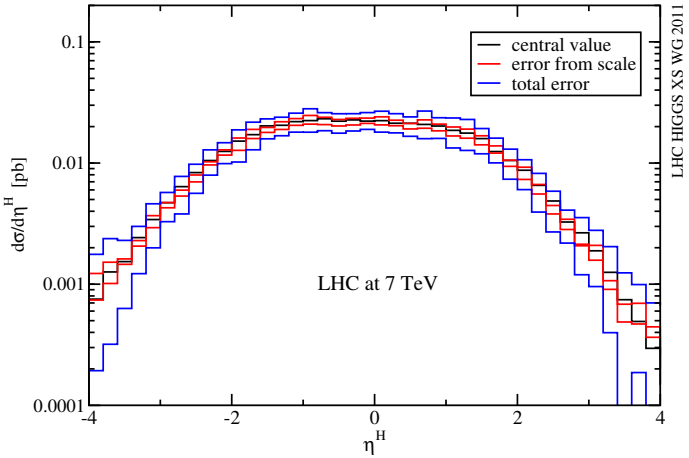


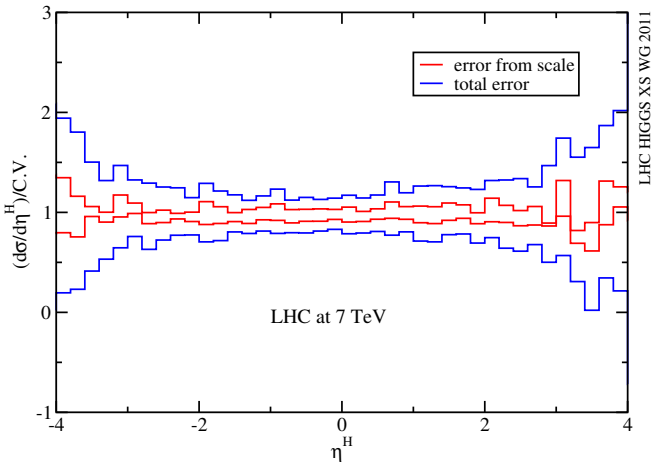




CTEQ6.6 @ 90% C.L.

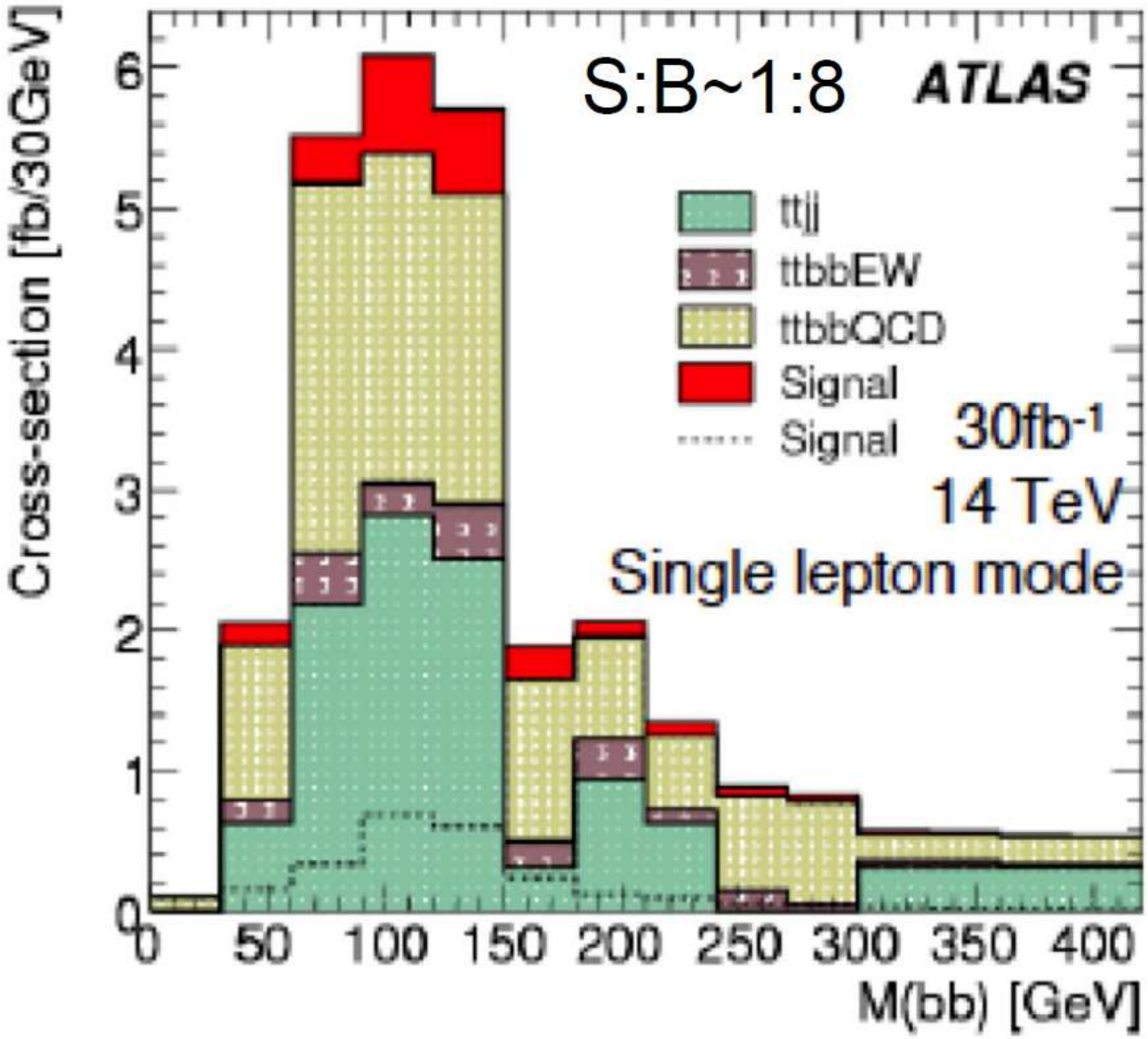



LHC Higgs XS WG



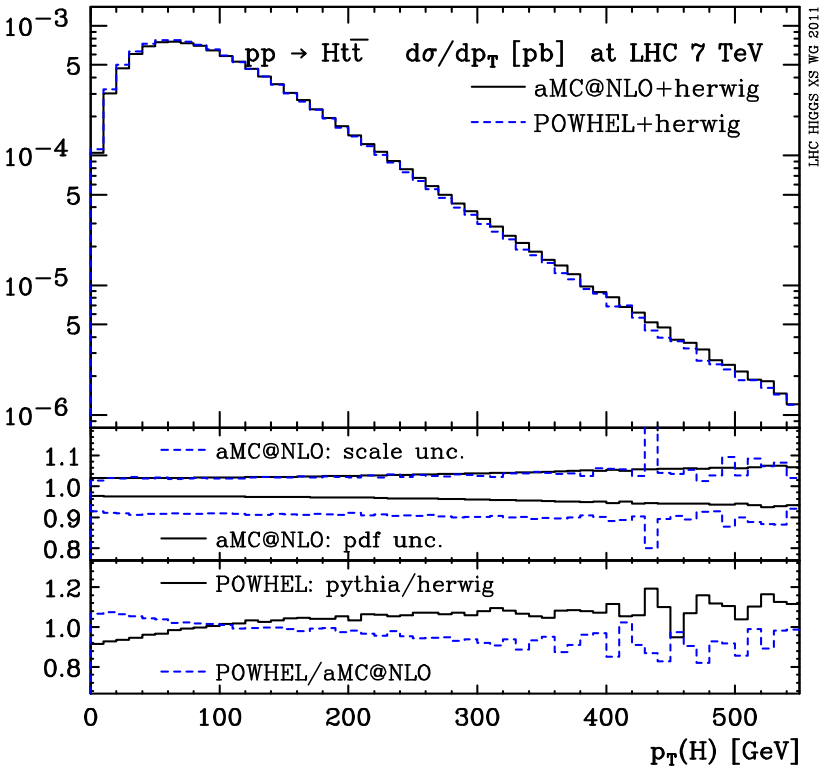

$\Rightarrow$ background: normalization & shape uncertainties?

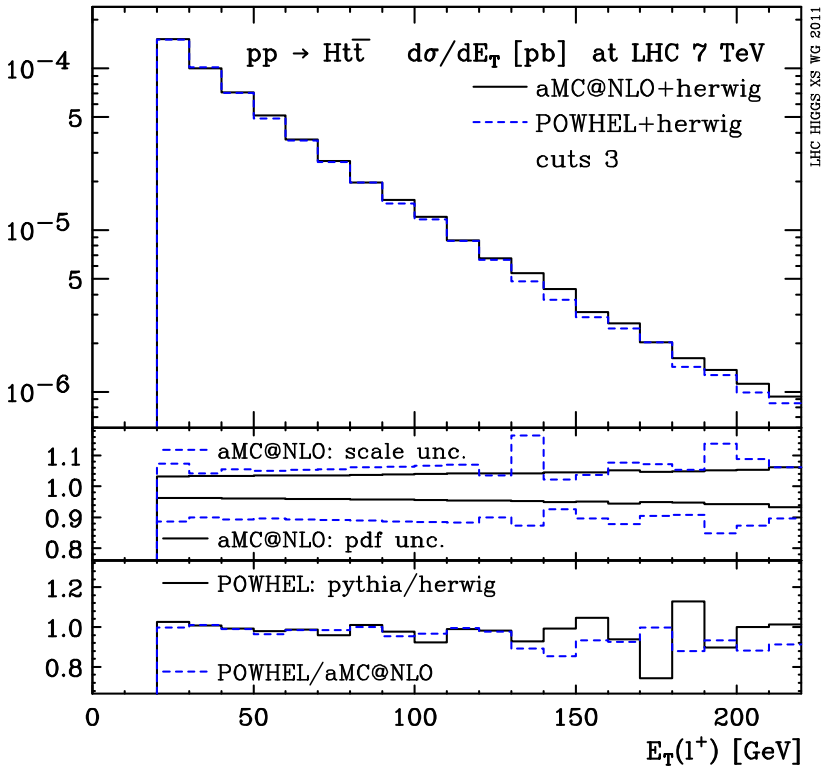
## (ii) Improvements

- matching to parton showers: aMC@NLO ($t\bar{t}H/A$), PowHel

Frederix et al.

Garzelli, Kardos, Papadopoulos, Trócsányi




- interfacing to MadSpin $\rightarrow$ spin correlations (NWA)

Artoisenet, Frederix, Mattelar, Rietkerk

$\rightarrow$ mild effects on $p_T^\ell$ distr., large effects on $\cos(\ell^+\ell^-)$ distr. ($H \leftrightarrow A$)

- backgrounds:

  $t\bar{t}b\bar{b}$:

  fixed NLO calculation

  Bredenstein, Denner Dittmaier, Pozzorini

  Bevilacqua, Czakon, Papadopoulos, Pittau, Worek (incl. signal in NWA)

  AcerMC: LO, QCD+EW

  ALPGEN: LO, QCD ME+PS (PYTHIA or HERWIG)

  SHERPA: LO, QCD ME+PS (Link to NLO OpenLoops)

  Cascioli, Maierhofer, Pozzorini

  $t\bar{t}jj$:

  fixed NLO calculation

  Bevilacqua, Czakon, Papadopoulos, Pittau, Worek

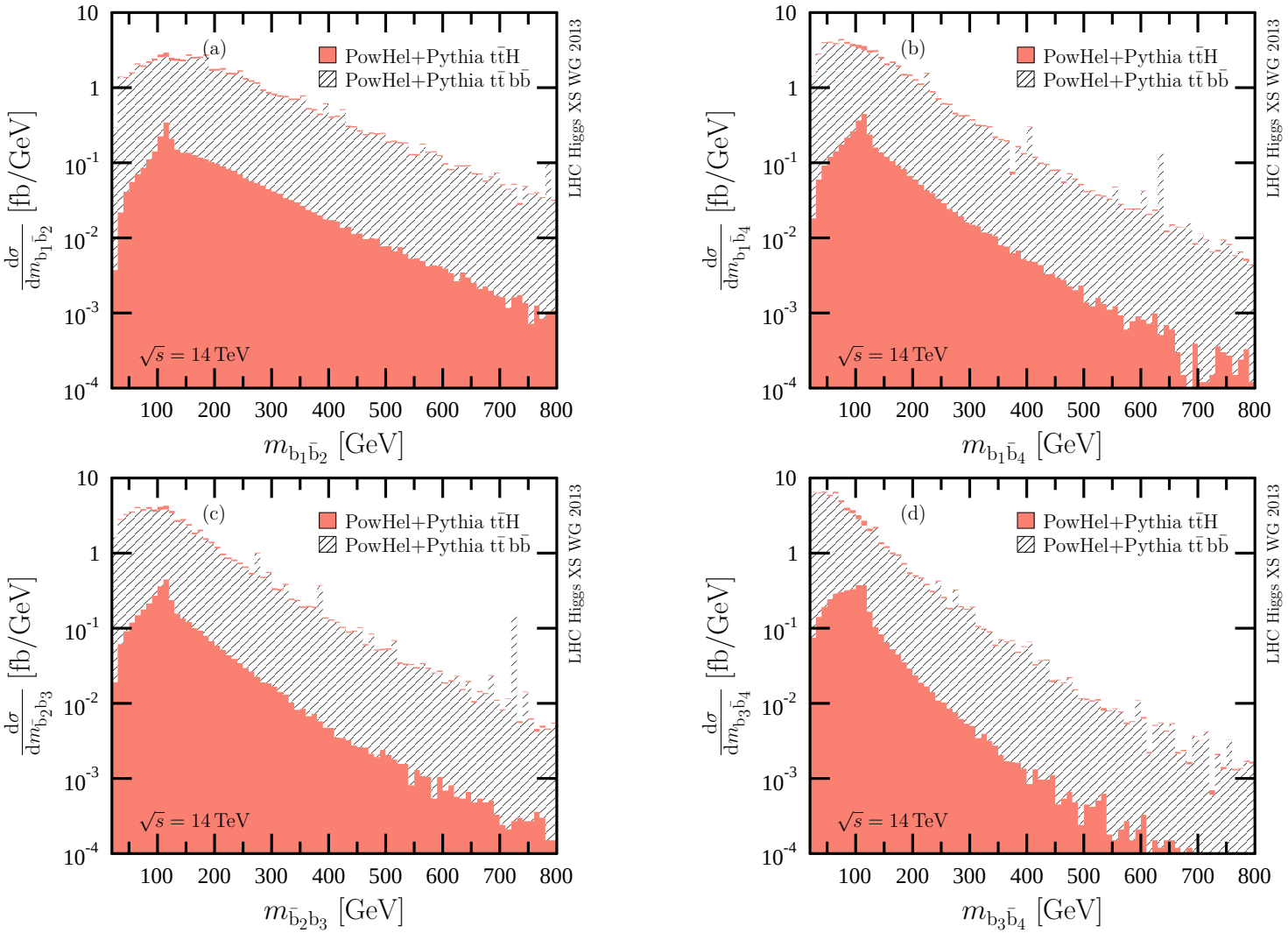
  ALPGEN: LO, QCD ME+PS (PYTHIA or HERWIG)

  SHERPA: LO, QCD ME+PS

  MC@NLO: NLO $t\bar{t}$ + PS (HERWIG)

  POWHEG: NLO $t\bar{t}j$ + PS (PYTHIA or HERWIG)

- PowHel: implementation of $t\bar{t}b\bar{b}$ @ NLO




Garzelli, Kardos, Papadopoulos, Trócsányi

# IV *CONCLUSIONS*

- $t\bar{t}H$ production important for $M_H \lesssim 130$ GeV
- direct determination of top Yukawa coupling
- QCD corrections: $\sim (20 - 40)\%$ at LHC
- strong reduction of scale dependence:
  $\Delta \lesssim 10 - 15\%$
- shape of Higgs & (anti)top $p_T$ distribution moderately affected [scale = transverse mass]
- shape of rapidity distributions hardly modified
- NLO calculations available for $t\bar{t}b\bar{b}, ttjj$ backgrounds
  $\rightarrow$ relevent modifications of shapes
- aMC@NLO, PowHel: matching NLO+PS for signal (and backgrounds)