Higgs production -Theory-

Higgs Hunting 2012

Robert Harlander
Bergische Universität Wuppertal

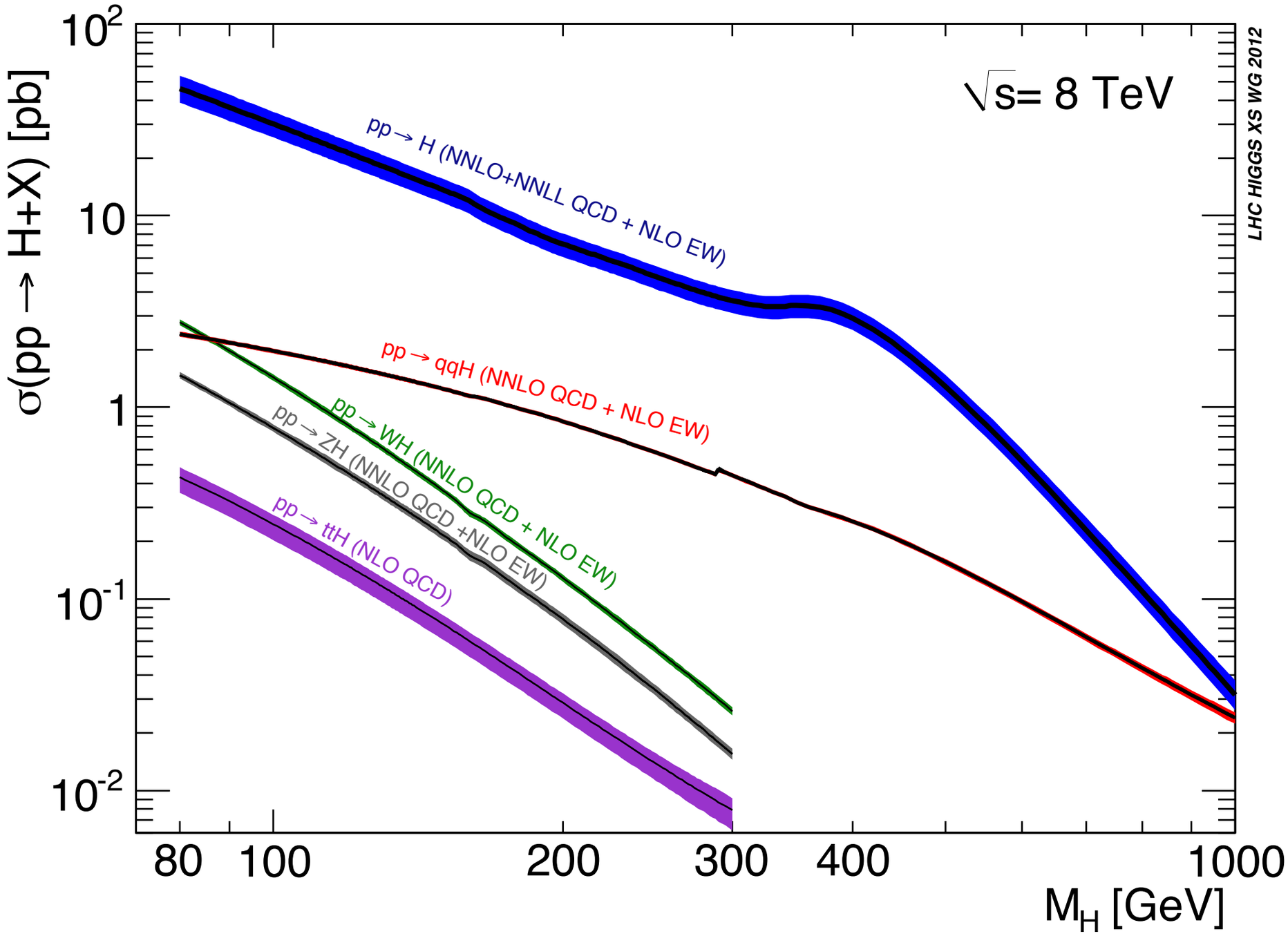
supported by

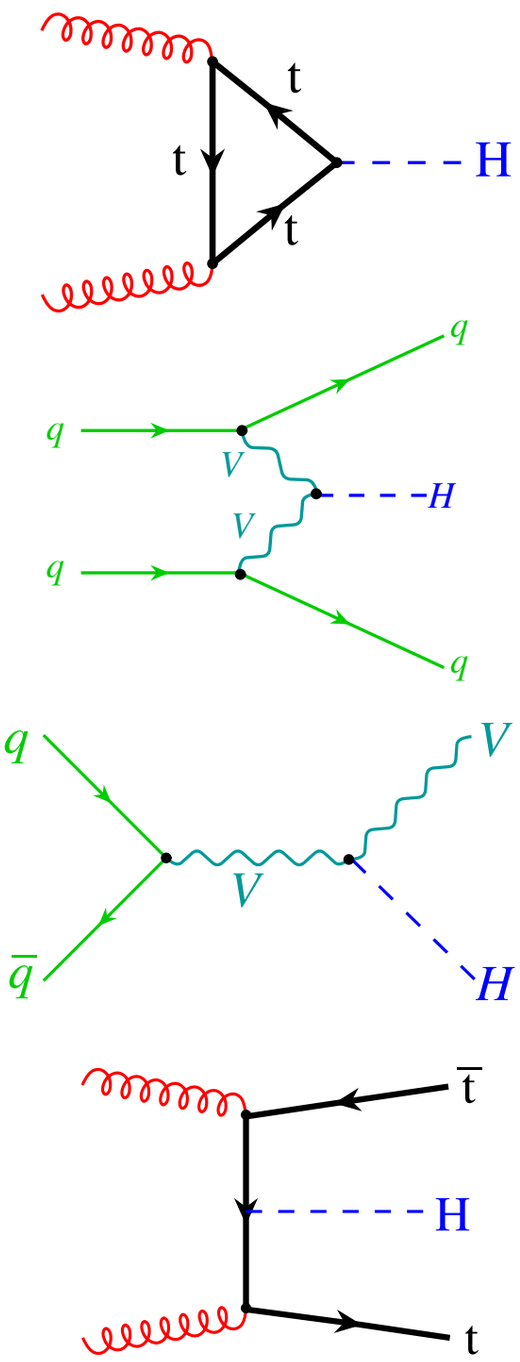
Deutsche Forschungsgemeinschaft DFG

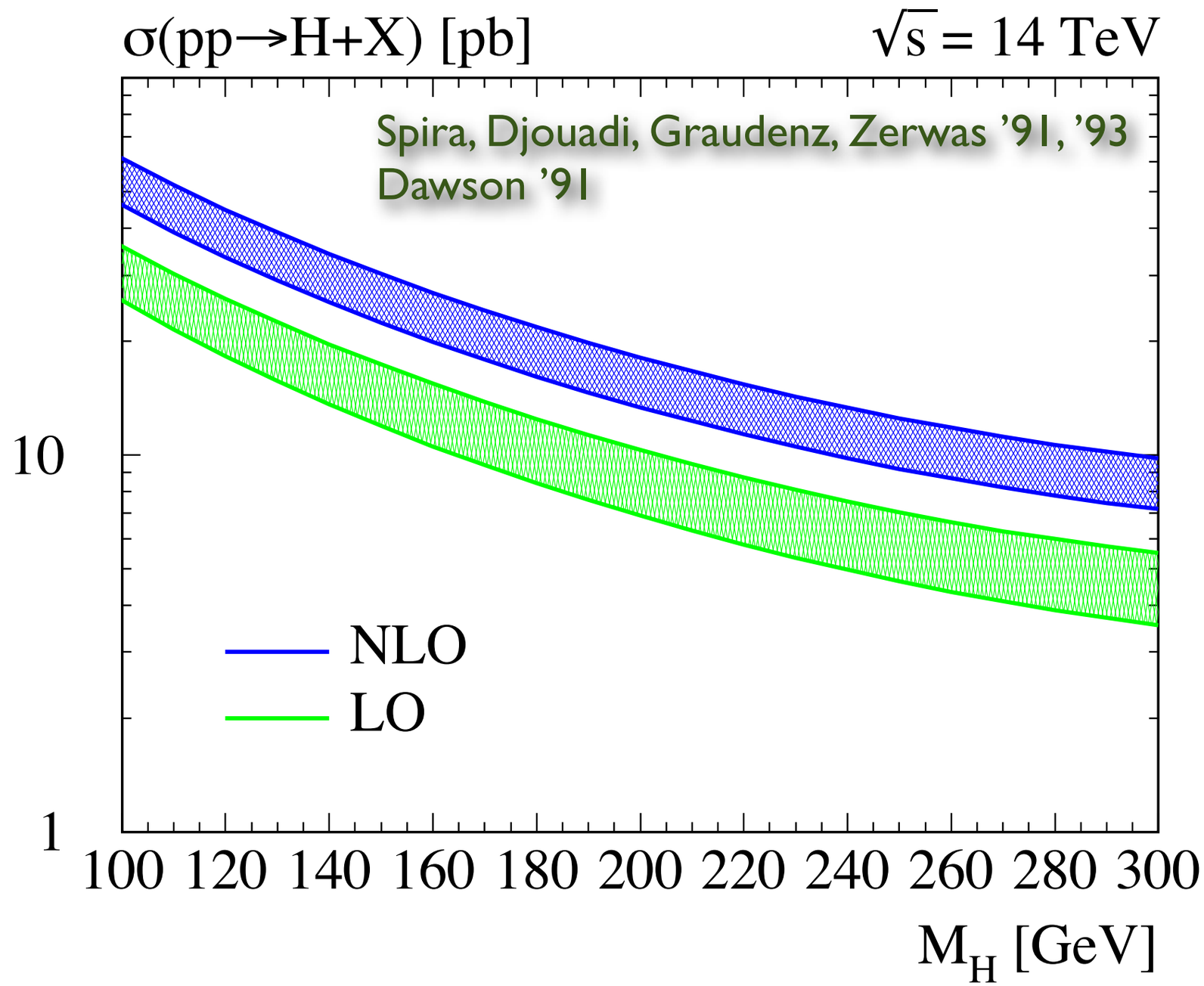
Bundesministerium für Bildung und Forschung

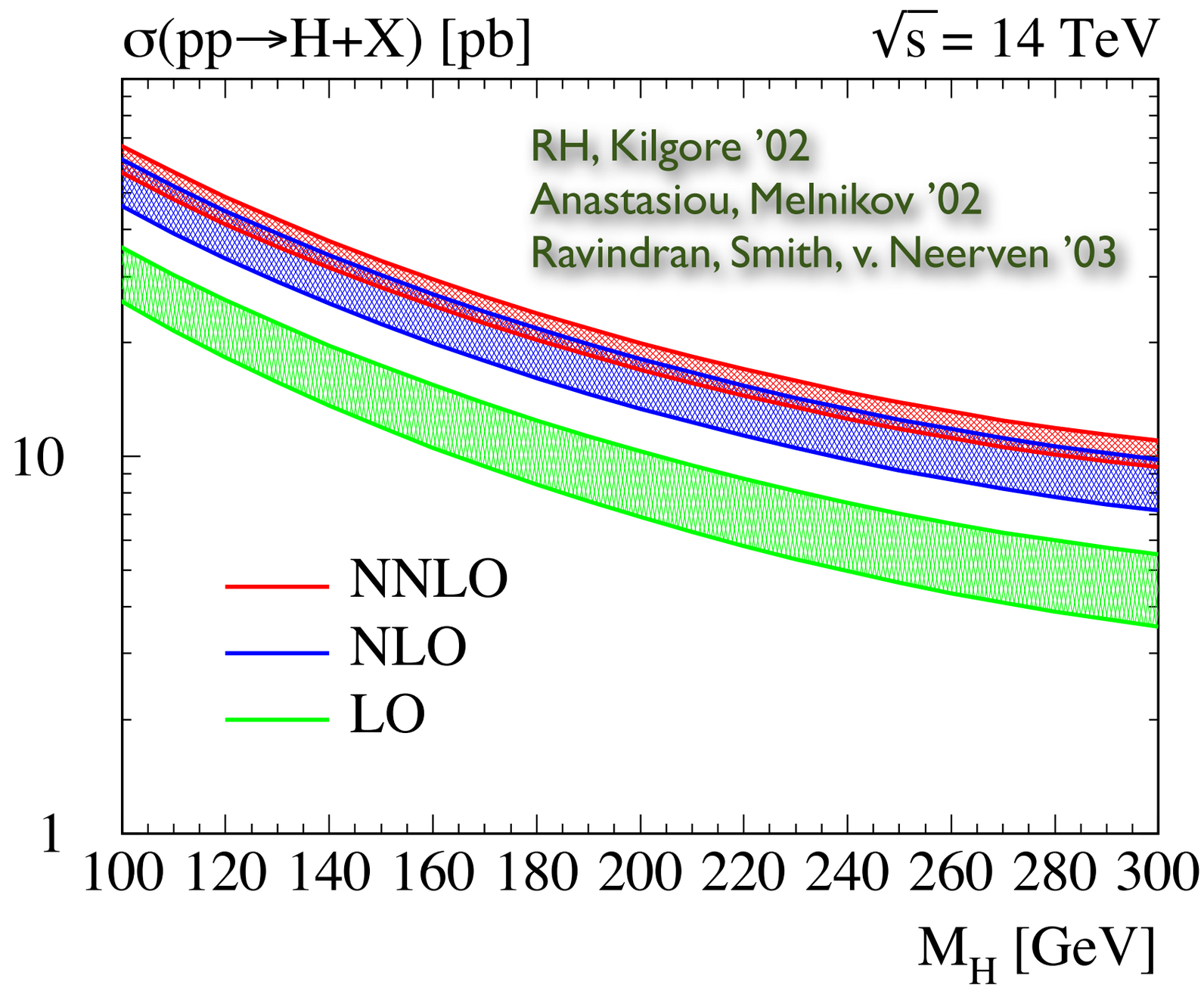
PHYSICS AT THE TERA SCALE Helmholtz Alliance

Higgs production

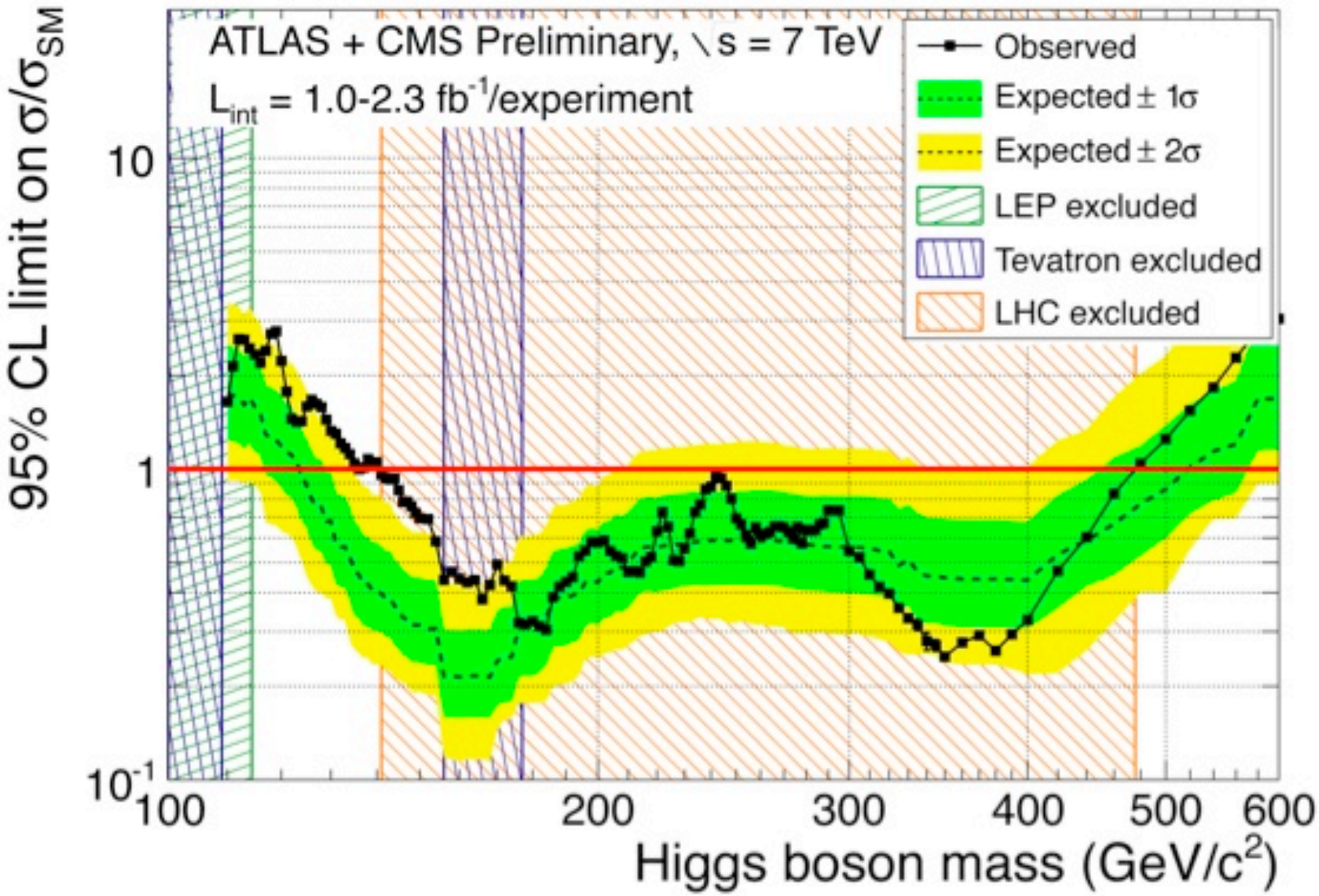




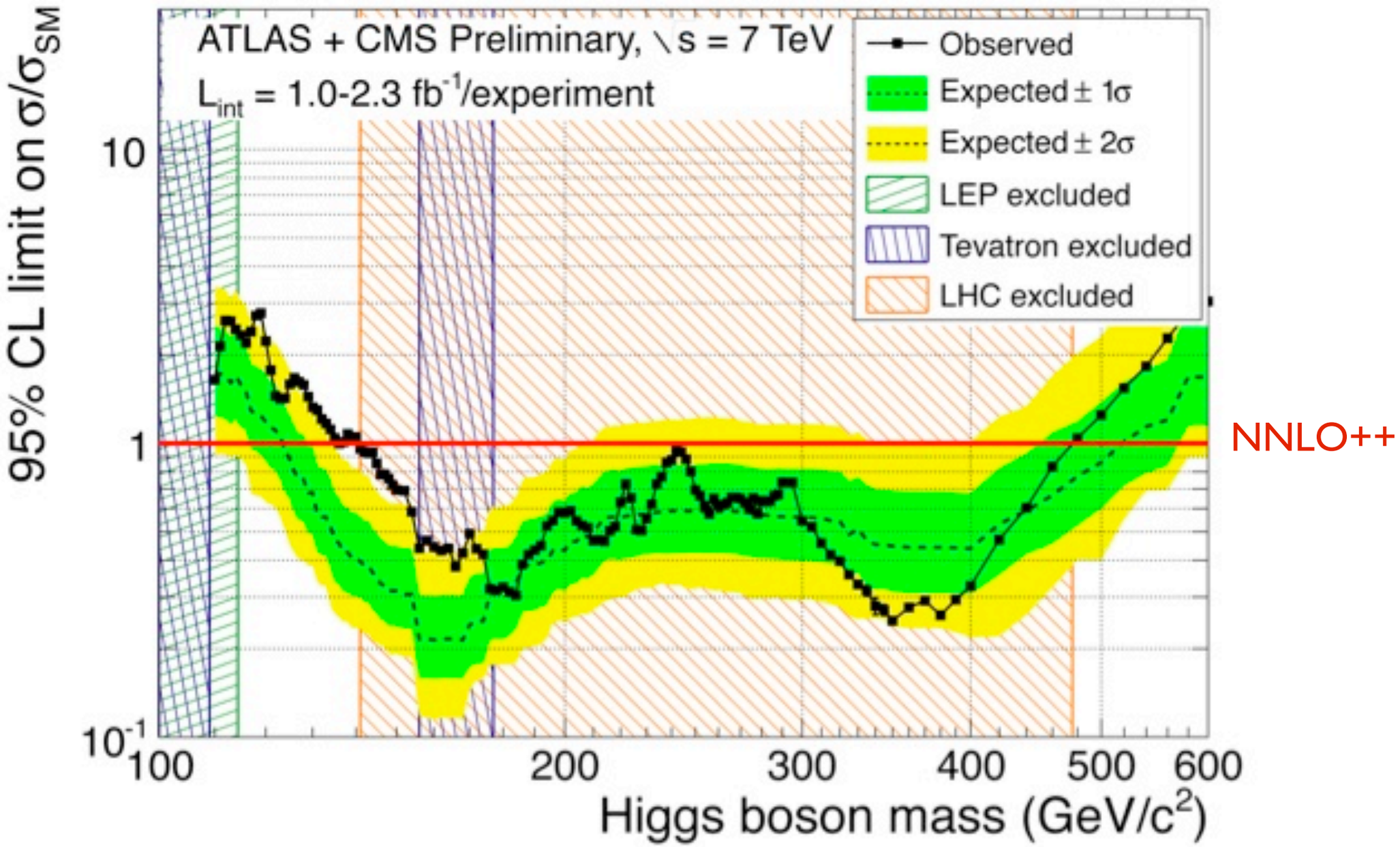

σ(pp→H+X) [pb]
√s = 14 TeV
Spira, Djouadi, Graudenz, Zerwas '91, '93
Dawson '91
NLO
LO
10
1
100 120 140 160 180 200 220 240 260 280 300
M_H [GeV]


σ(pp→H+X) [pb]
√s = 14 TeV
RH, Kilgore '02
Anastasiou, Melnikov '02
Ravindran, Smith, v. Neerven '03
NNLO
NLO
LO
10
1
100 120 140 160 180 200 220 240 260 280 300
M_H [GeV]

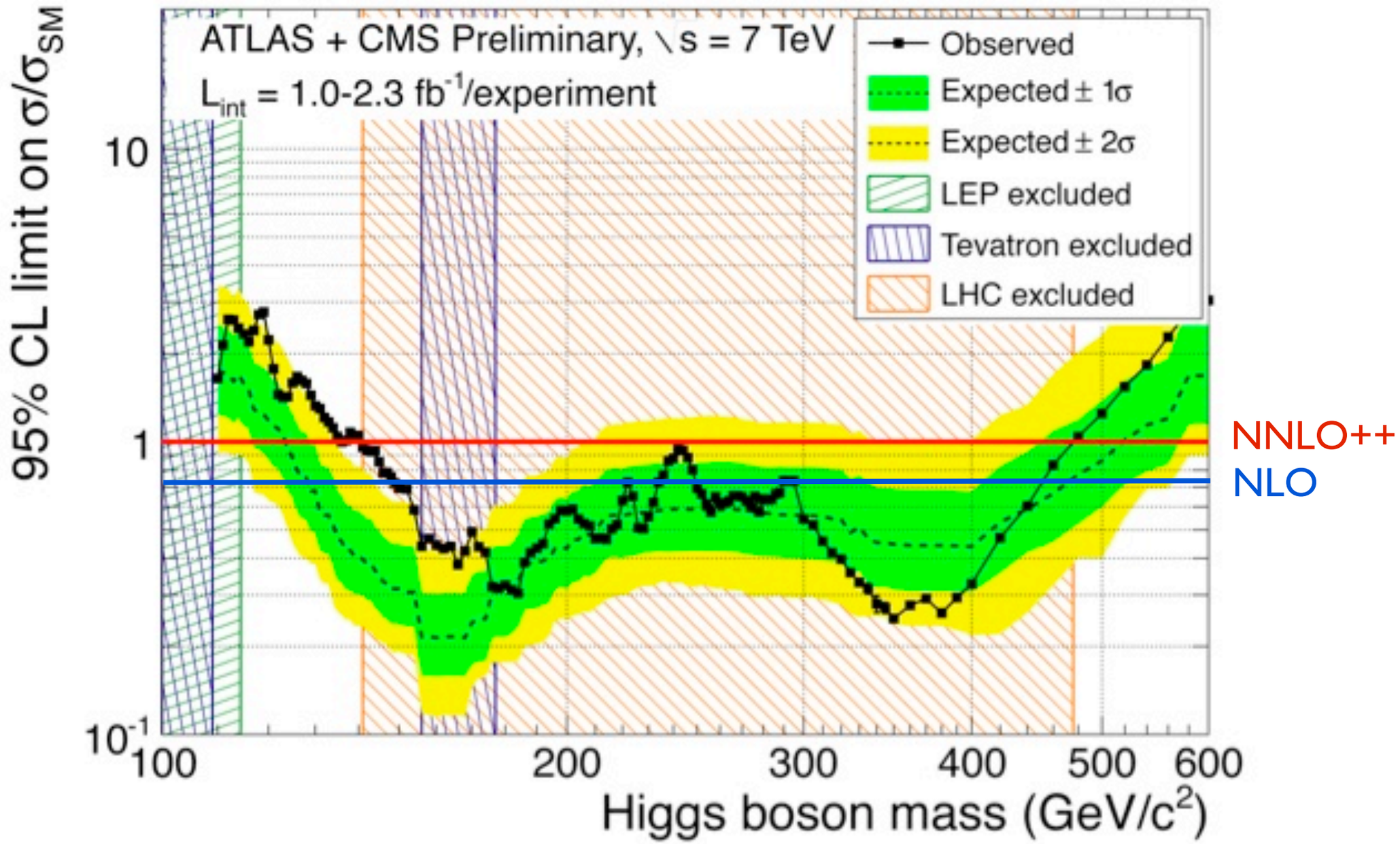
Influence of theory



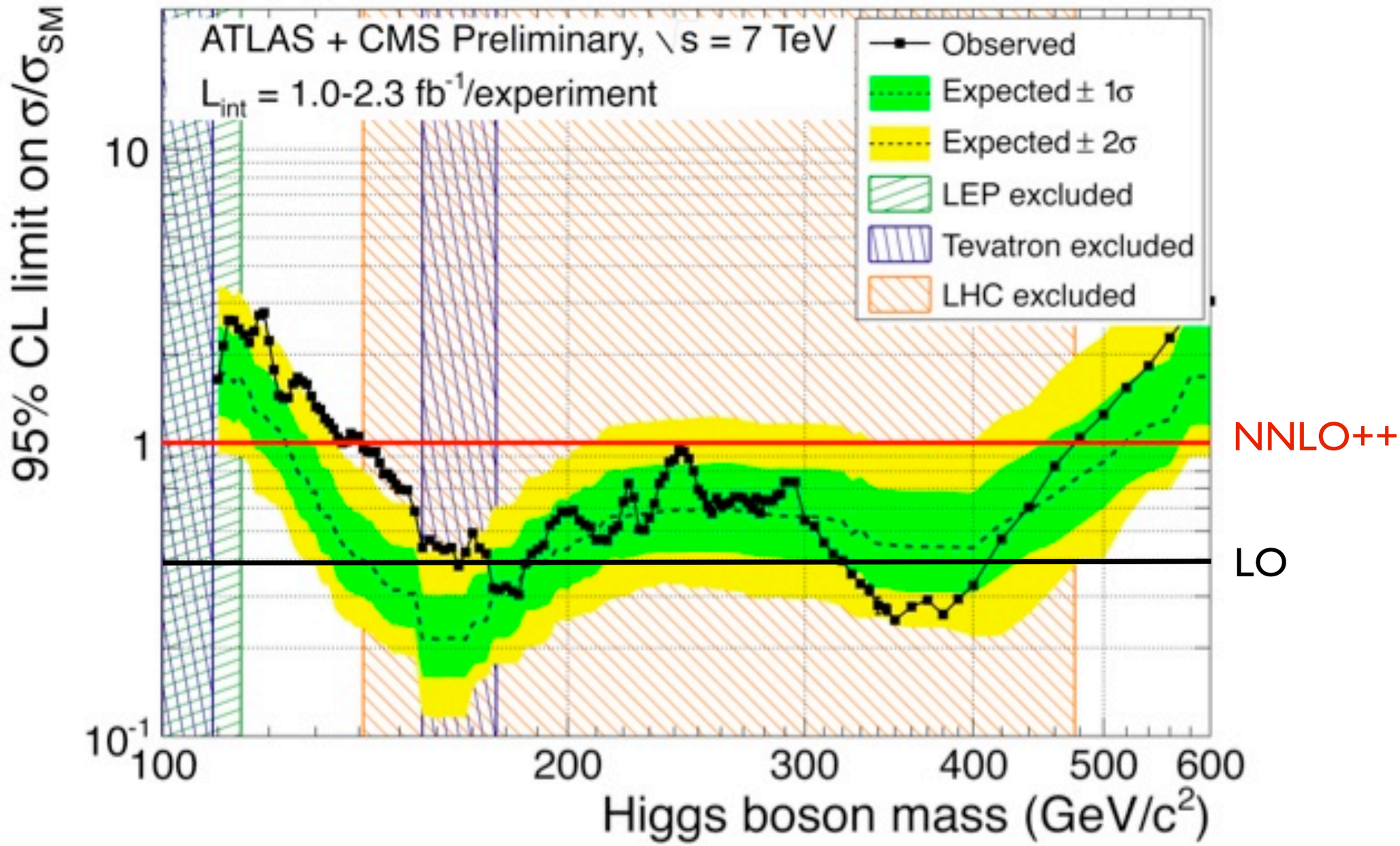
Influence of theory



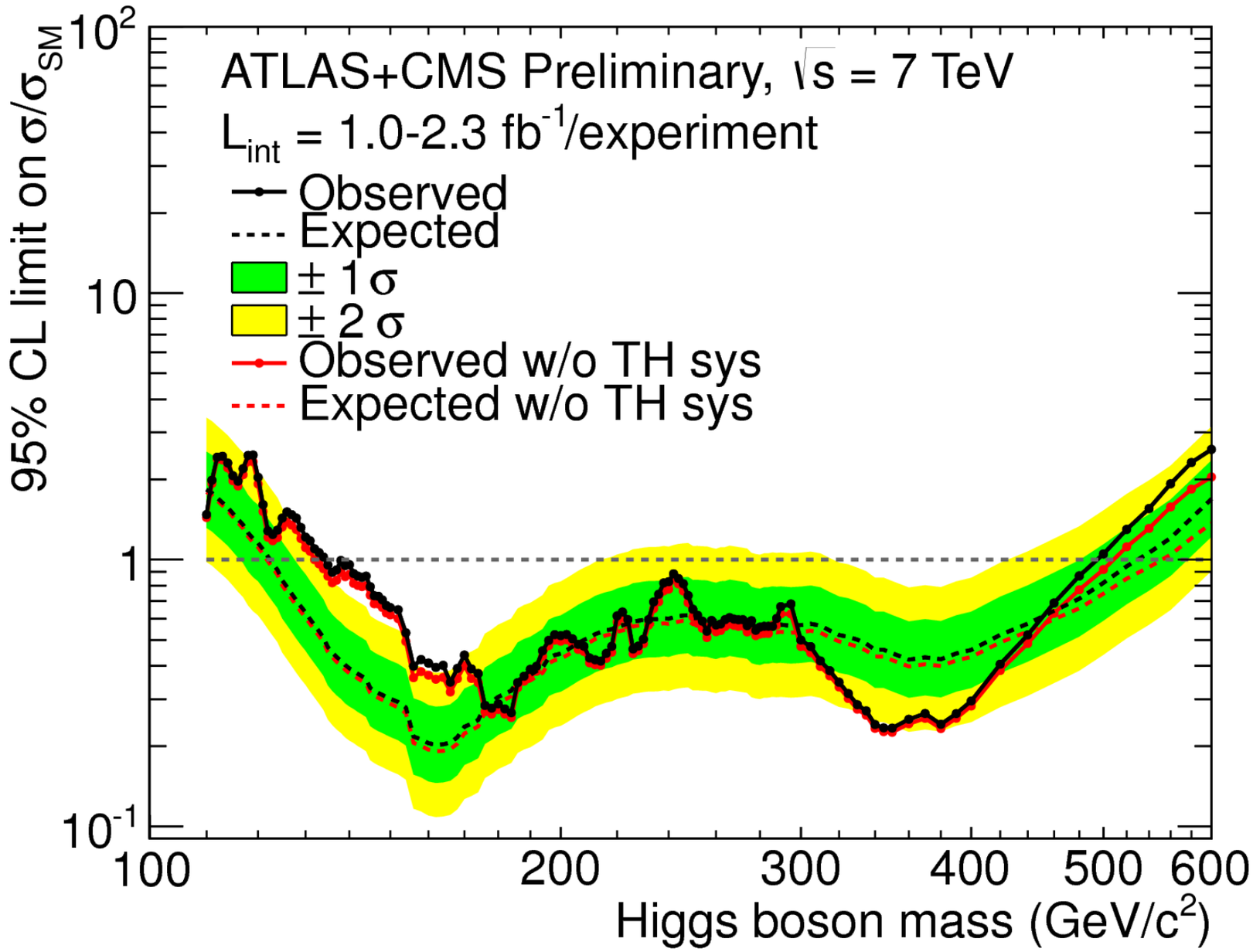
Influence of theory

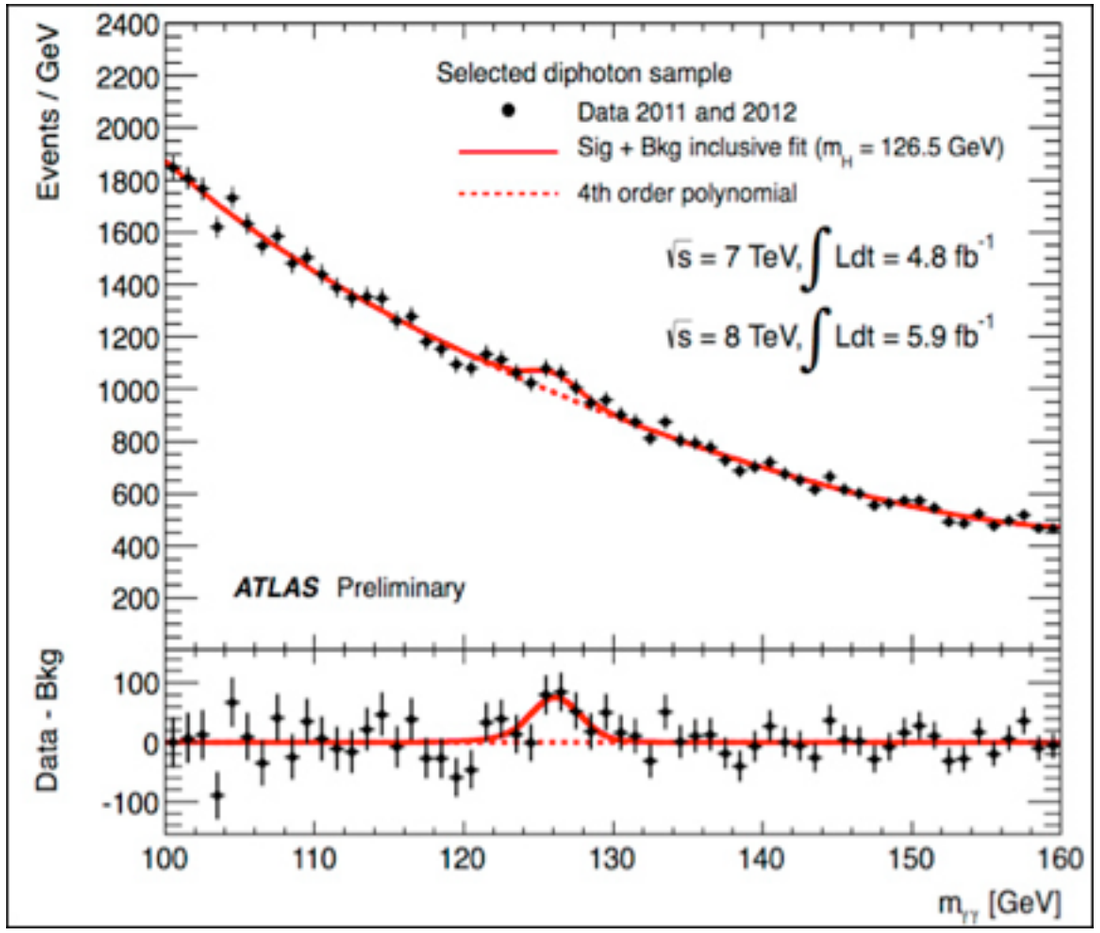


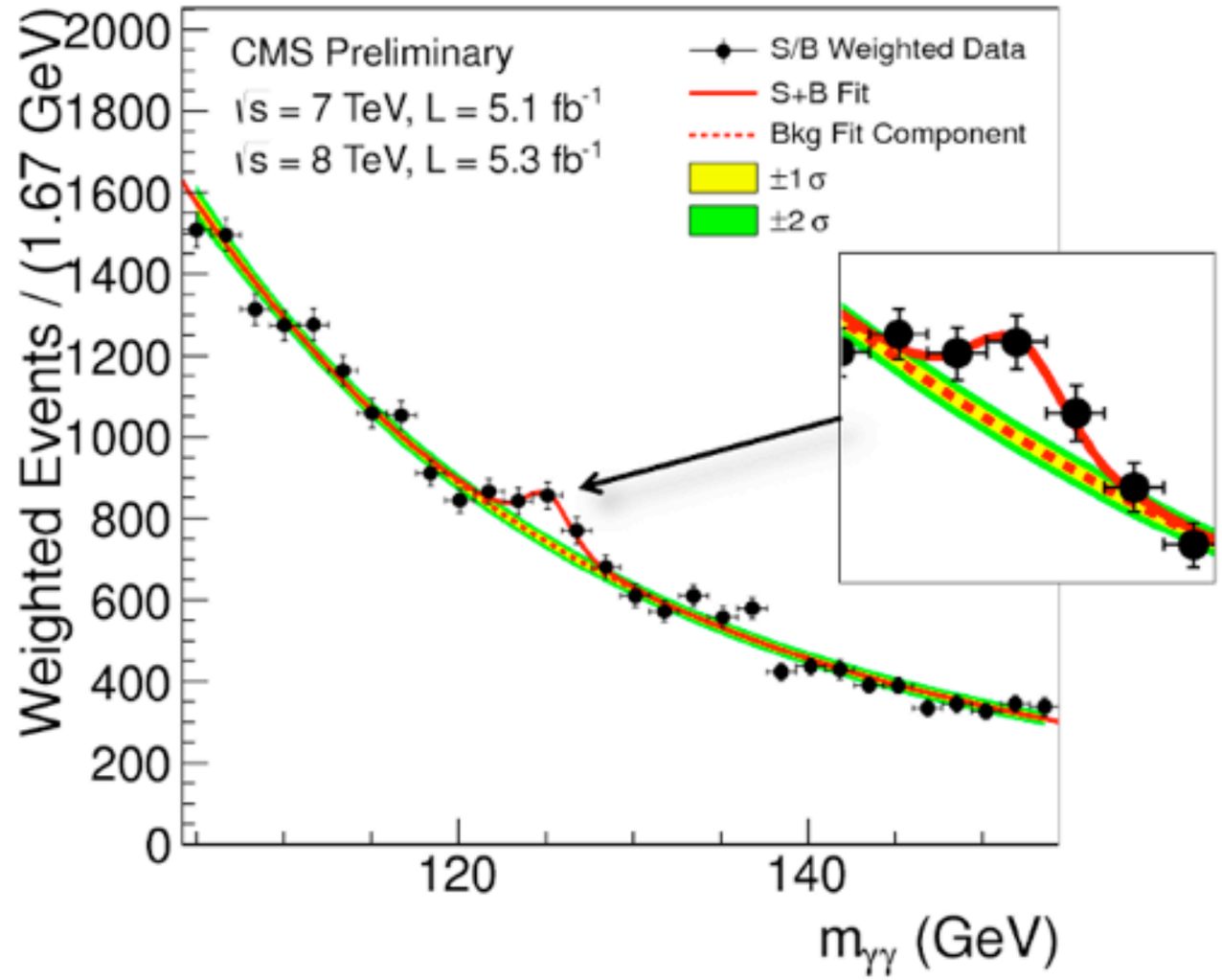
Influence of theory

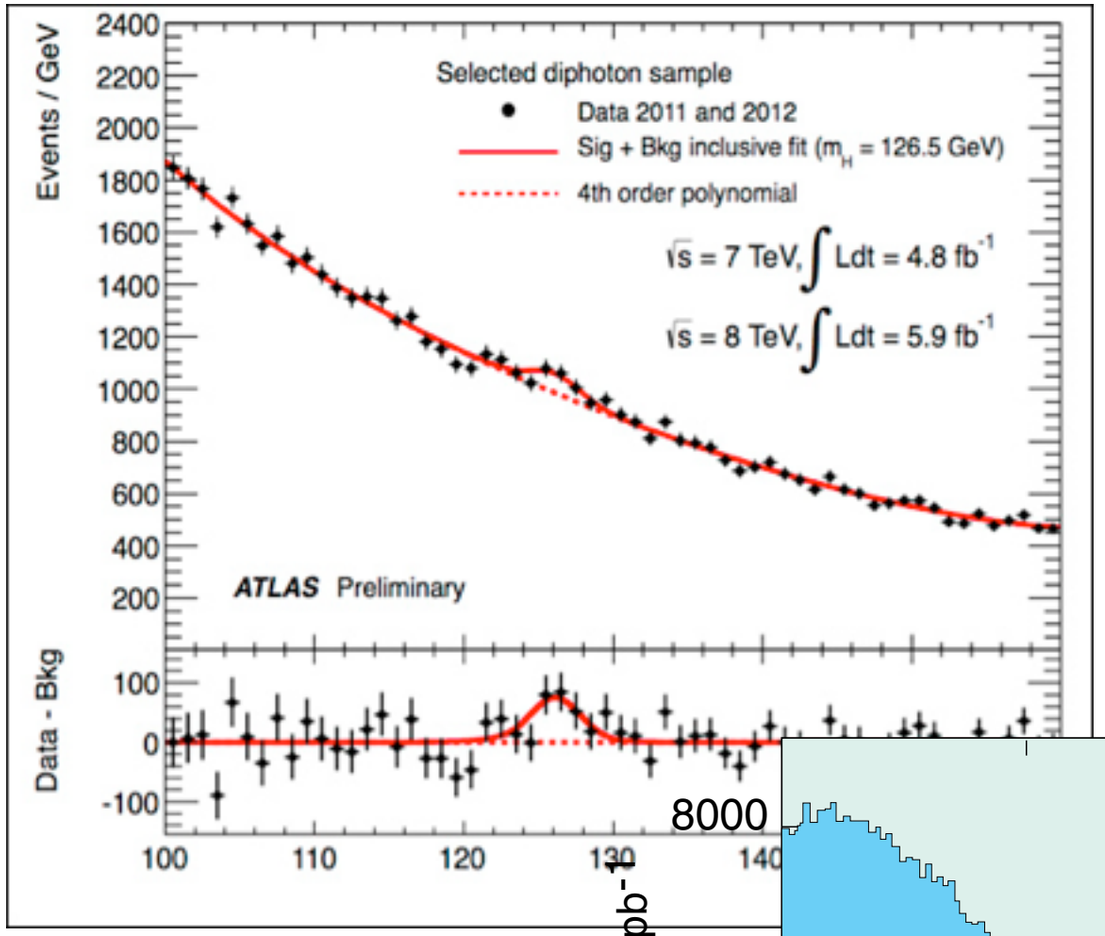


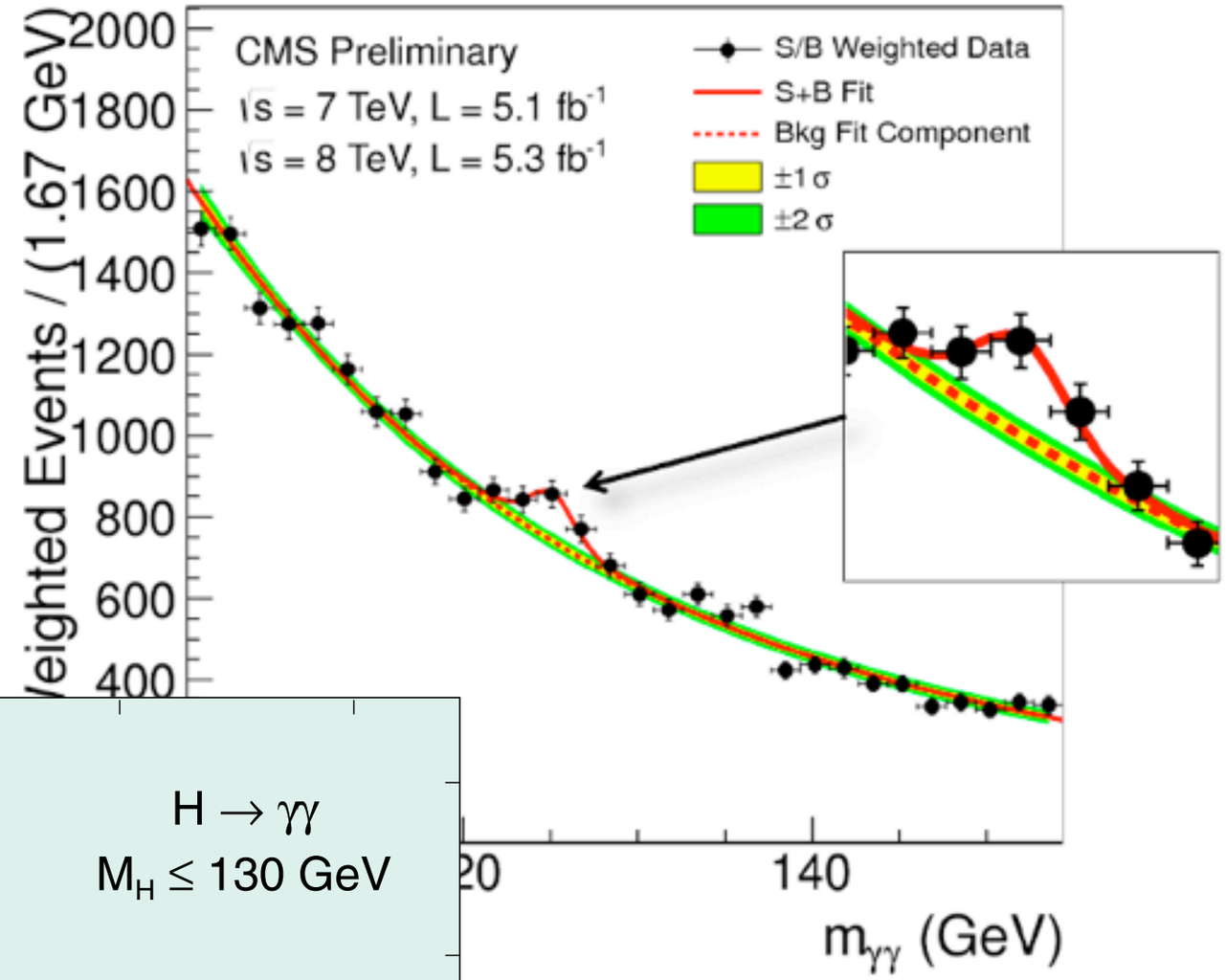
Influence of theory errors

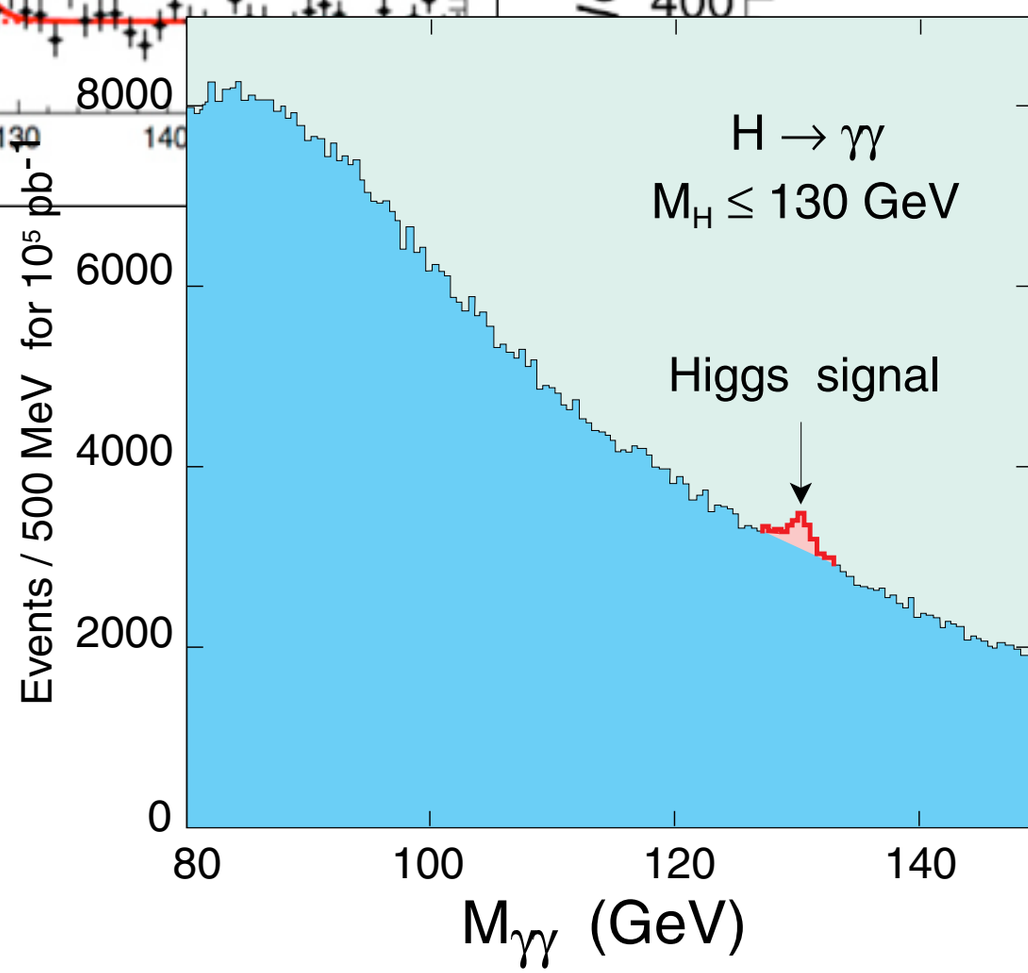


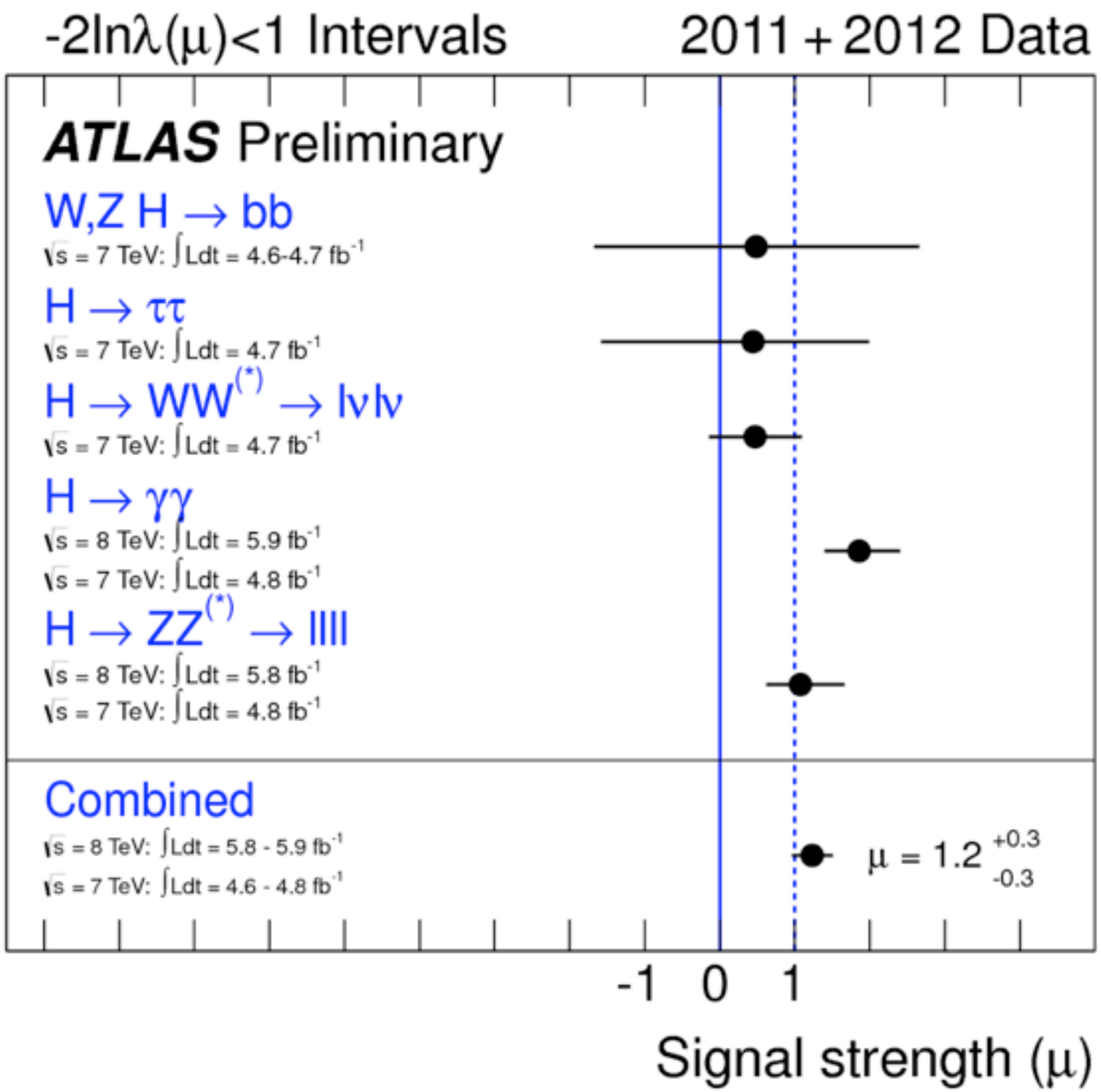

Selected diphoton sample
Data 2011 and 2012
Sig + Bkg inclusive fit (m_H = 126.5 GeV)
4th order polynomial
$\sqrt{s}$ = 7 TeV, $\int Ldt$ = 4.8 fb^{-1}
$\sqrt{s}$ = 8 TeV, $\int Ldt$ = 5.9 fb^{-1}
ATLAS Preliminary
Events / GeV
Data - Bkg
$m_{\gamma\gamma}$ [GeV]

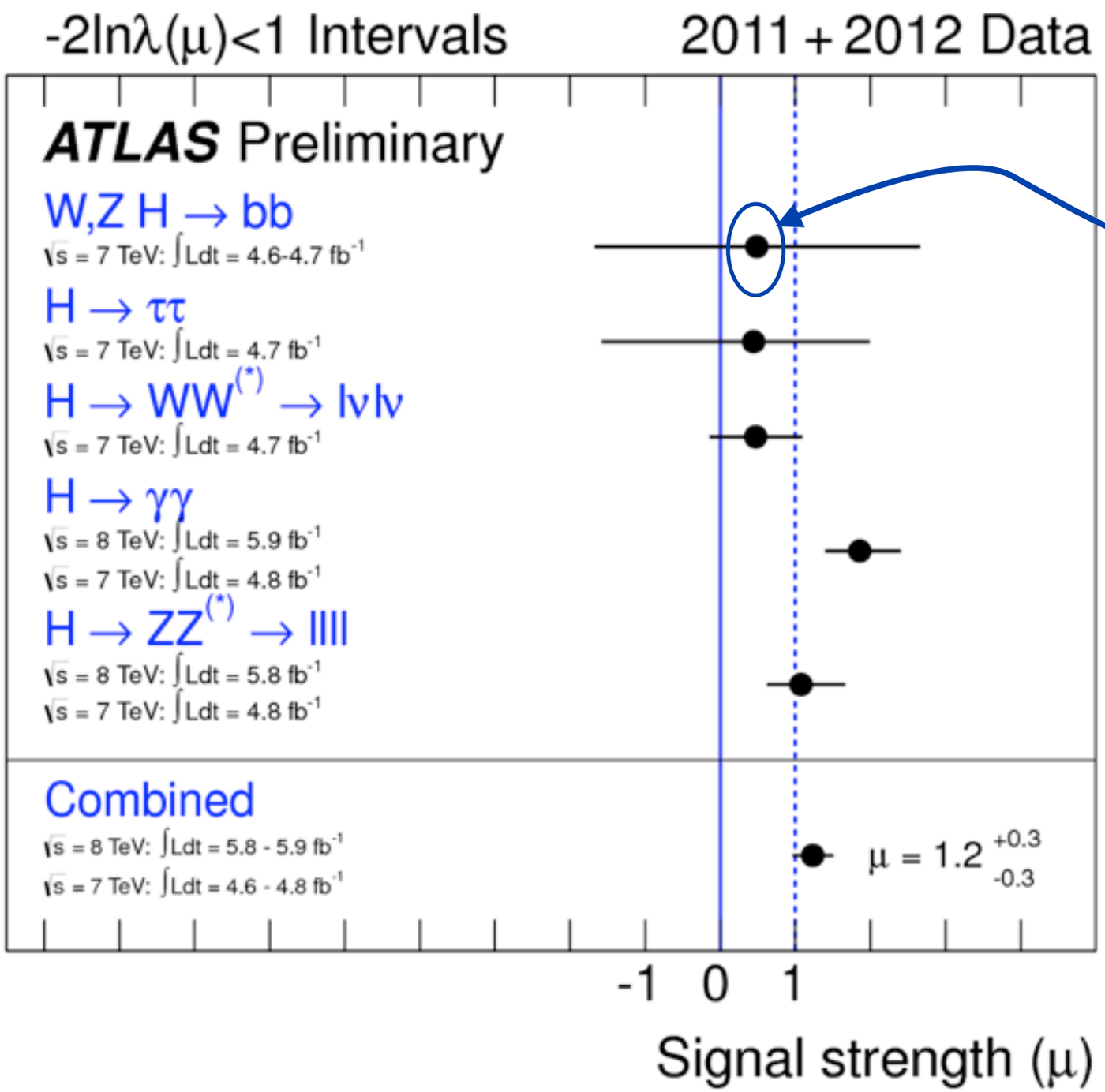

CMS Preliminary
$\sqrt{s}$ = 7 TeV, L = 5.1 fb^{-1}
$\sqrt{s}$ = 8 TeV, L = 5.3 fb^{-1}
S/B Weighted Data
S+B Fit
Bkg Fit Component
±1 σ
±2 σ
Weighted Events / (1.67 GeV)
$m_{\gamma\gamma}$ (GeV)

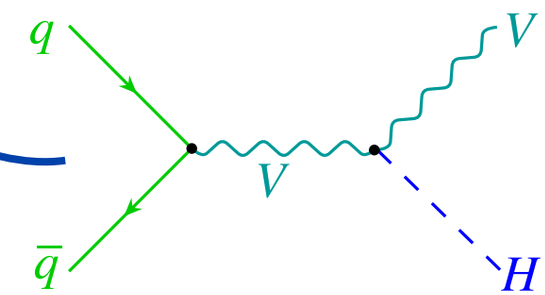

Selected diphoton sample
Data 2011 and 2012
Sig + Bkg inclusive fit (m_H = 126.5 GeV)
4th order polynomial
$\sqrt{s}$ = 7 TeV, $\int Ldt$ = 4.8 fb^{-1}
$\sqrt{s}$ = 8 TeV, $\int Ldt$ = 5.9 fb^{-1}
ATLAS Preliminary
Events / GeV
Data - Bkg

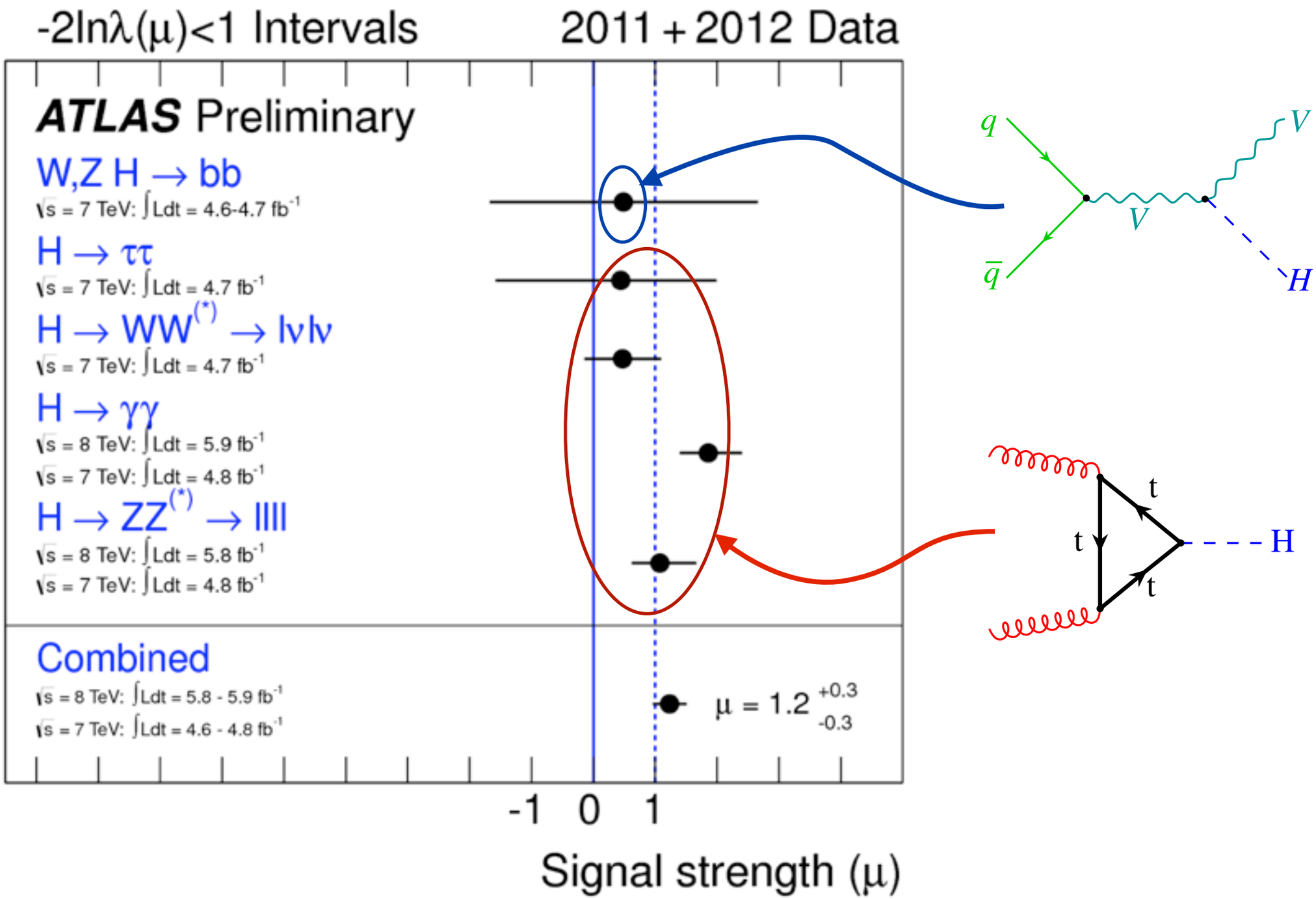

CMS Preliminary
$\sqrt{s}$ = 7 TeV, L = 5.1 fb^{-1}
$\sqrt{s}$ = 8 TeV, L = 5.3 fb^{-1}
S/B Weighted Data
S+B Fit
Bkg Fit Component
±1 σ
±2 σ
Weighted Events / (1.67 GeV)
$m_{\gamma\gamma}$ (GeV)

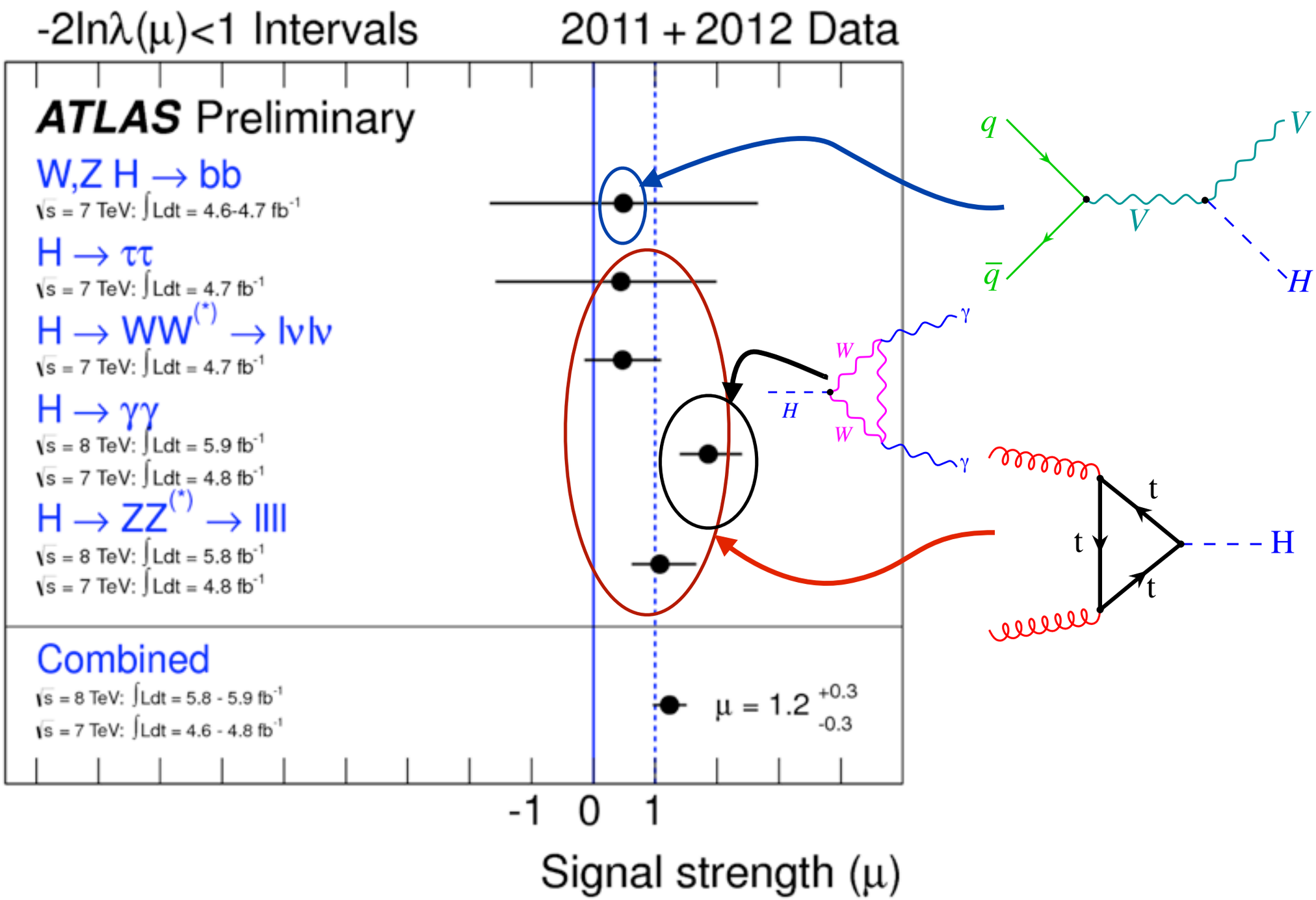

$H \rightarrow \gamma\gamma$
$M_H \leq 130$ GeV
Higgs signal
Events / 500 MeV for 10^5 pb^{-1}
$M_{\gamma\gamma}$ (GeV)


-2lnλ(μ)<1 Intervals
2011 + 2012 Data
ATLAS Preliminary
W,Z H → bb
√s = 7 TeV: ∫Ldt = 4.6-4.7 fb⁻¹
H → ττ
√s = 7 TeV: ∫Ldt = 4.7 fb⁻¹
H → WW(*) → lνlν
√s = 7 TeV: ∫Ldt = 4.7 fb⁻¹
H → γγ
√s = 8 TeV: ∫Ldt = 5.9 fb⁻¹
√s = 7 TeV: ∫Ldt = 4.8 fb⁻¹
H → ZZ(*) → llll
√s = 8 TeV: ∫Ldt = 5.8 fb⁻¹
√s = 7 TeV: ∫Ldt = 4.8 fb⁻¹
Combined
√s = 8 TeV: ∫Ldt = 5.8 - 5.9 fb⁻¹
√s = 7 TeV: ∫Ldt = 4.6 - 4.8 fb⁻¹
μ = 1.2 +0.3 -0.3
-1
0
1
Signal strength (μ)

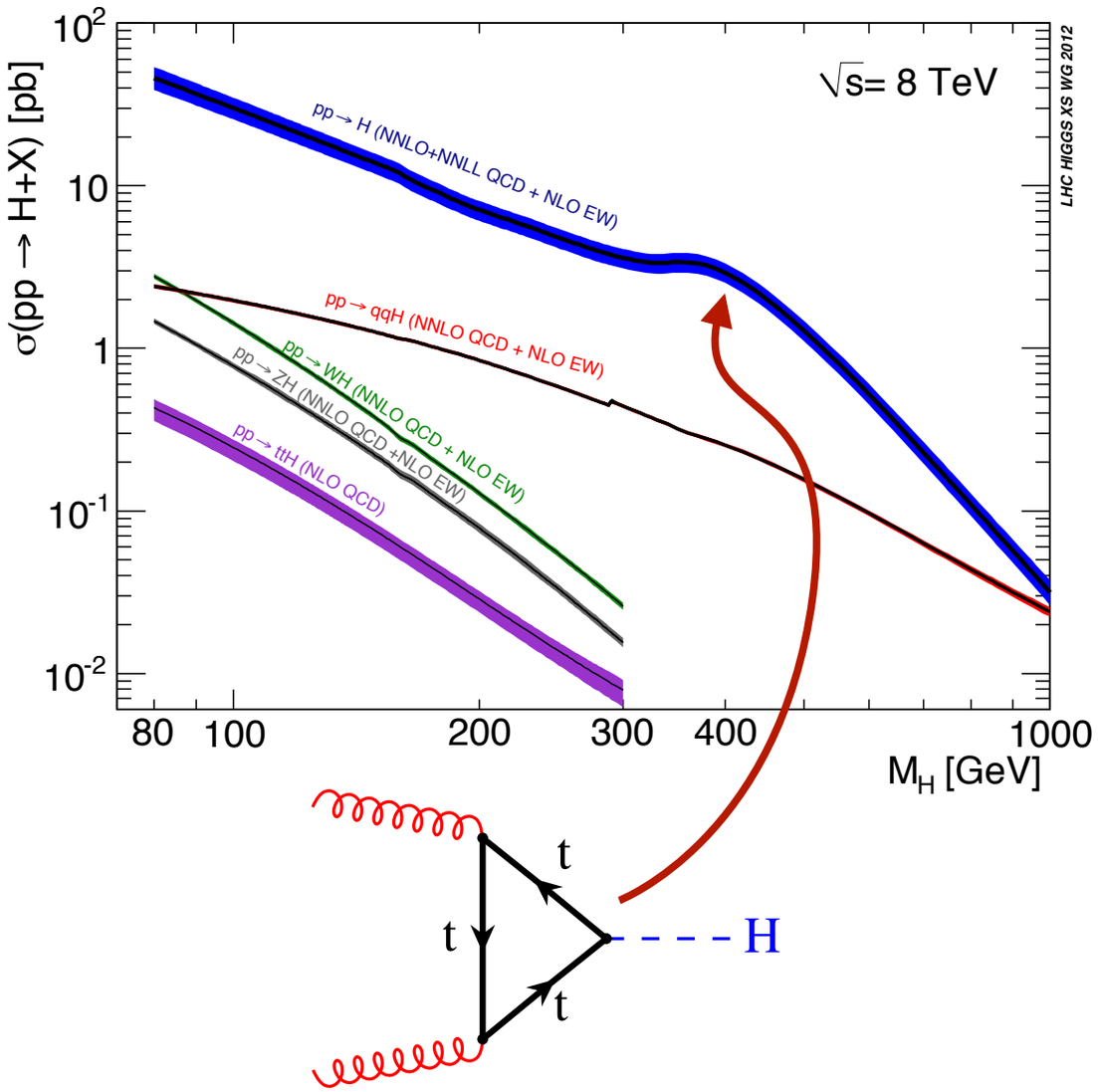

-2lnλ(μ)<1 Intervals
2011 + 2012 Data
ATLAS Preliminary
W,Z H → bb
√s = 7 TeV: ∫Ldt = 4.6-4.7 fb⁻¹
H → ττ
√s = 7 TeV: ∫Ldt = 4.7 fb⁻¹
H → WW(*) → lνlν
√s = 7 TeV: ∫Ldt = 4.7 fb⁻¹
H → γγ
√s = 8 TeV: ∫Ldt = 5.9 fb⁻¹
√s = 7 TeV: ∫Ldt = 4.8 fb⁻¹
H → ZZ(*) → llll
√s = 8 TeV: ∫Ldt = 5.8 fb⁻¹
√s = 7 TeV: ∫Ldt = 4.8 fb⁻¹
Combined
√s = 8 TeV: ∫Ldt = 5.8 - 5.9 fb⁻¹
√s = 7 TeV: ∫Ldt = 4.6 - 4.8 fb⁻¹
μ = 1.2 +0.3 -0.3
-1
0
1
Signal strength (μ)


q
q̄
V
V
H


-2lnλ(μ)<1 Intervals
2011 + 2012 Data
ATLAS Preliminary
W,Z H → bb
√s = 7 TeV: ∫Ldt = 4.6-4.7 fb⁻¹
H → ττ
√s = 7 TeV: ∫Ldt = 4.7 fb⁻¹
H → WW(*) → lνlν
√s = 7 TeV: ∫Ldt = 4.7 fb⁻¹
H → γγ
√s = 8 TeV: ∫Ldt = 5.9 fb⁻¹
√s = 7 TeV: ∫Ldt = 4.8 fb⁻¹
H → ZZ(*) → llll
√s = 8 TeV: ∫Ldt = 5.8 fb⁻¹
√s = 7 TeV: ∫Ldt = 4.8 fb⁻¹
Combined
√s = 8 TeV: ∫Ldt = 5.8 - 5.9 fb⁻¹
√s = 7 TeV: ∫Ldt = 4.6 - 4.8 fb⁻¹
μ = 1.2 +0.3 -0.3
-1
0
1
Signal strength (μ)
q
q̄
V
V
H
t
t
t
H


-2lnλ(μ)<1 Intervals
2011 + 2012 Data
ATLAS Preliminary
W,Z H → bb
√s = 7 TeV: ∫Ldt = 4.6-4.7 fb⁻¹
H → ττ
√s = 7 TeV: ∫Ldt = 4.7 fb⁻¹
H → WW(*) → lνlν
√s = 7 TeV: ∫Ldt = 4.7 fb⁻¹
H → γγ
√s = 8 TeV: ∫Ldt = 5.9 fb⁻¹
√s = 7 TeV: ∫Ldt = 4.8 fb⁻¹
H → ZZ(*) → llll
√s = 8 TeV: ∫Ldt = 5.8 fb⁻¹
√s = 7 TeV: ∫Ldt = 4.8 fb⁻¹
Combined
√s = 8 TeV: ∫Ldt = 5.8 - 5.9 fb⁻¹
√s = 7 TeV: ∫Ldt = 4.6 - 4.8 fb⁻¹
μ = 1.2 +0.3 -0.3
-1
0
1
Signal strength (μ)
q
q̄
V
V
H
W
W
γ
γ
H
t
t
t
H

Gluon fusion



NLO: Spira, Djouadi, Graudenz, Zerwas '91, '93
Dawson '91

NNLO: RH, Kilgore '02
Anastasiou, Melnikov '02
Ravindran, Smith, v. Neerven '03

Resummation:

Catani, de Florian, Grazzini, Nason '02
Ahrens, Becher, Neubert, Zhang '08

Electroweak:

Actis, Passarino, Sturm, Uccirati '08
Aglietti, Bonciani, Degrassi, Vicini '04
Degrassi, Maltoni '04
Djouadi, Gambino '94

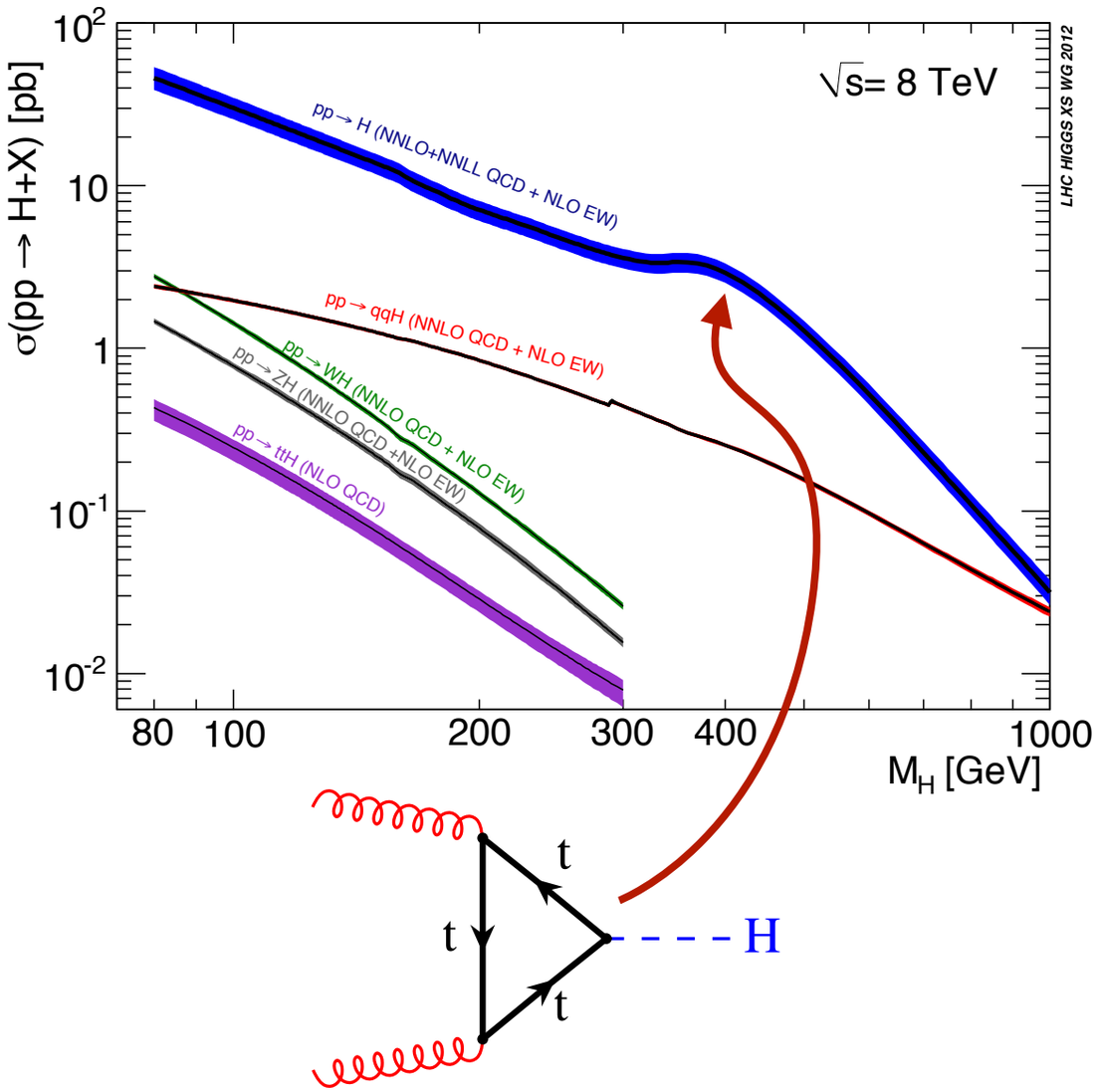
Mixed EW/QCD:

Anastasiou, Boughezal, Petriello '09

Fully differential NNLO:

Anastasiou, Melnikov, Petriello '04
Catani, Grazzini '07

Gluon fusion



NLO: Spira, Djouadi, Graudenz, Zerwas '91, '93
Dawson '91

~80%

NNLO: RH, Kilgore '02
Anastasiou, Melnikov '02
Ravindran, Smith, v. Neerven '03

Resummation:

Catani, de Florian, Grazzini, Nason '02
Ahrens, Becher, Neubert, Zhang '08

Electroweak:

Actis, Passarino, Sturm, Uccirati '08
Aglietti, Bonciani, Degrassi, Vicini '04
Degrassi, Maltoni '04
Djouadi, Gambino '94

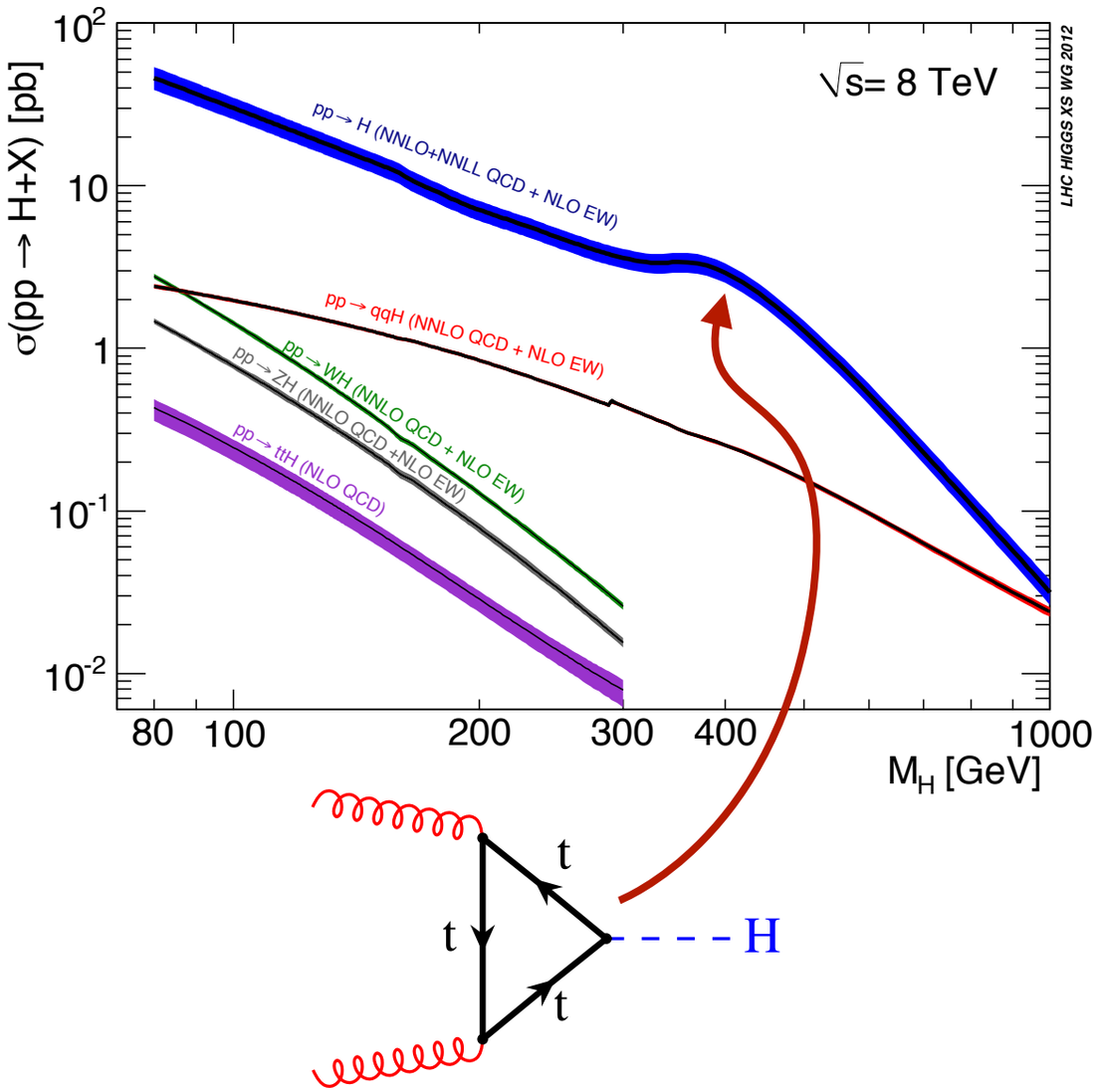
Mixed EW/QCD:

Anastasiou, Boughezal, Petriello '09

Fully differential NNLO:

Anastasiou, Melnikov, Petriello '04
Catani, Grazzini '07

Gluon fusion



NLO: Spira, Djouadi, Graudenz, Zerwas '91, '93
Dawson '91 ~80%

NNLO: RH, Kilgore '02
Anastasiou, Melnikov '02 ~30%
Ravindran, Smith, v. Neerven '03

Resummation:

Catani, de Florian, Grazzini, Nason '02
Ahrens, Becher, Neubert, Zhang '08

Electroweak:

Actis, Passarino, Sturm, Uccirati '08
Aglietti, Bonciani, Degrassi, Vicini '04
Degrassi, Maltoni '04
Djouadi, Gambino '94

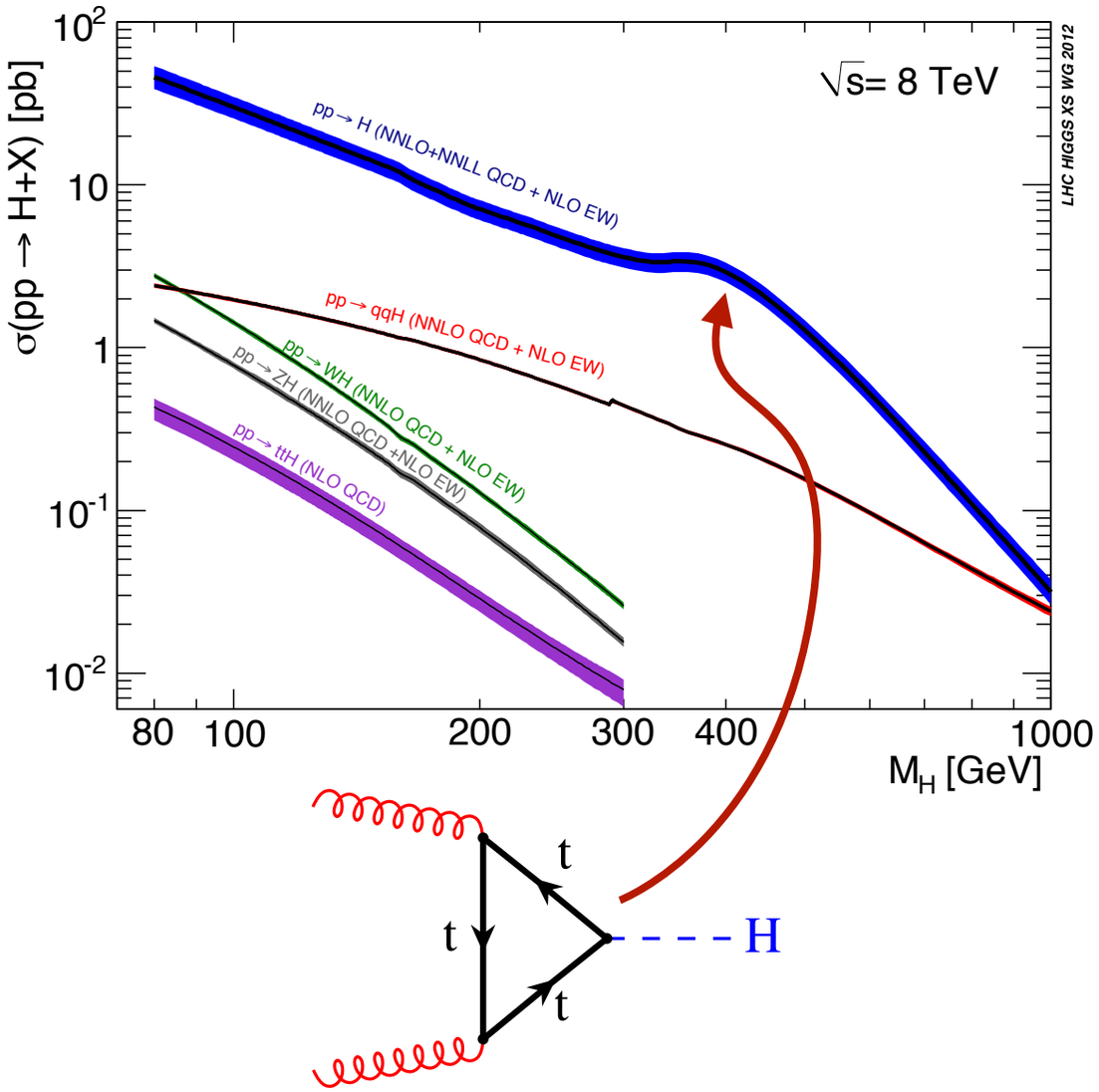
Mixed EW/QCD:

Anastasiou, Boughezal, Petriello '09

Fully differential NNLO:

Anastasiou, Melnikov, Petriello '04
Catani, Grazzini '07

Gluon fusion



NLO: Spira, Djouadi, Graudenz, Zerwas '91, '93
Dawson '91 ~80%

NNLO: RH, Kilgore '02
Anastasiou, Melnikov '02 ~30%
Ravindran, Smith, v. Neerven '03

Resummation:

Catani, de Florian, Grazzini, Nason '02
Ahrens, Becher, Neubert, Zhang '08 ~10%

Electroweak:

Actis, Passarino, Sturm, Uccirati '08
Aglietti, Bonciani, Degrassi, Vicini '04
Degrassi, Maltoni '04
Djouadi, Gambino '94

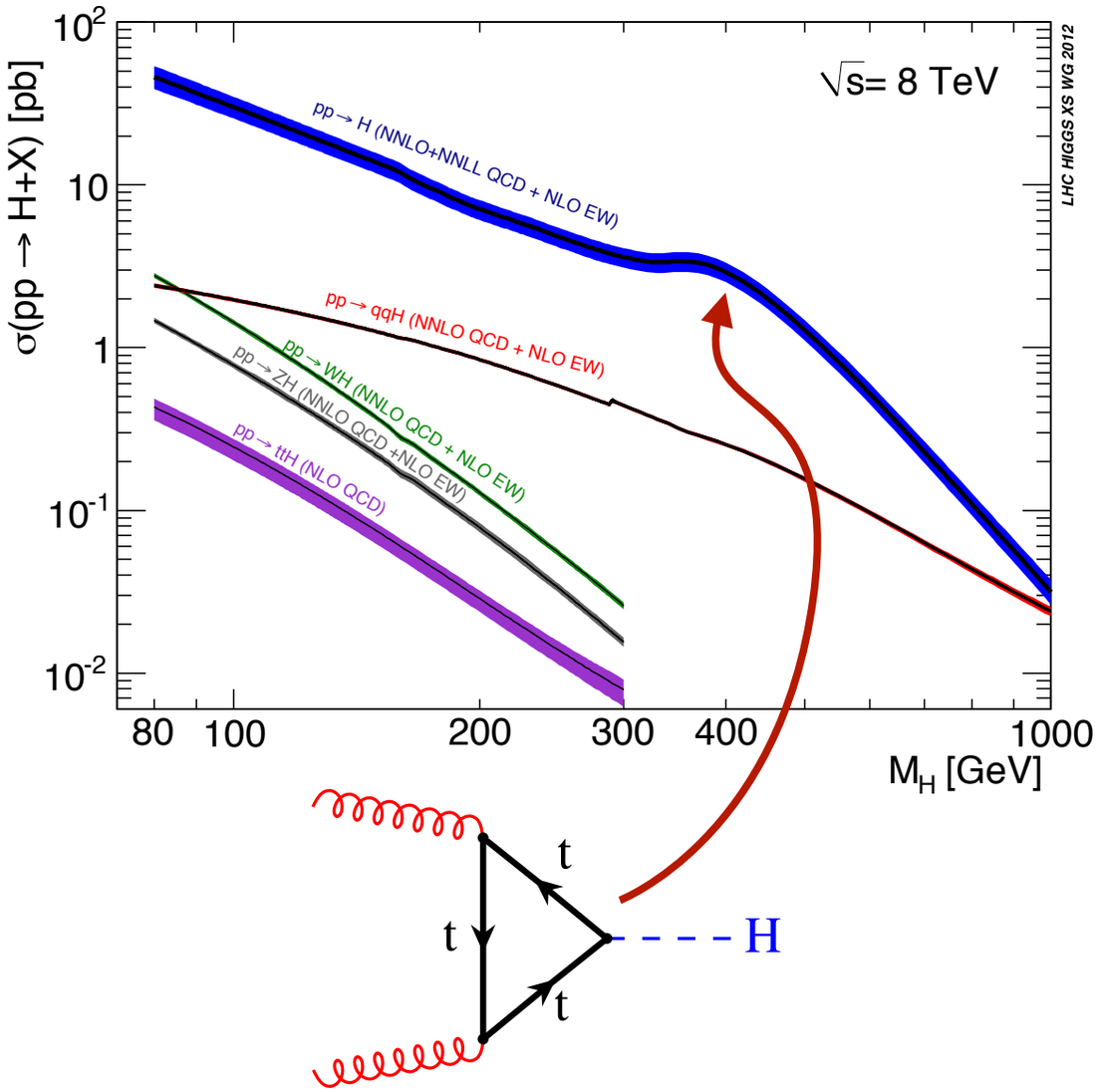
Mixed EW/QCD:

Anastasiou, Boughezal, Petriello '09

Fully differential NNLO:

Anastasiou, Melnikov, Petriello '04
Catani, Grazzini '07

Gluon fusion



NLO: Spira, Djouadi, Graudenz, Zerwas '91, '93
Dawson '91 ~80%

NNLO: RH, Kilgore '02
Anastasiou, Melnikov '02 ~30%
Ravindran, Smith, v. Neerven '03

Resummation:

Catani, de Florian, Grazzini, Nason '02
Ahrens, Becher, Neubert, Zhang '08 ~10%

Electroweak:

Actis, Passarino, Sturm, Uccirati '08
Aglietti, Bonciani, Degrassi, Vicini '04
Degrassi, Maltoni '04
Djouadi, Gambino '94 ~5%

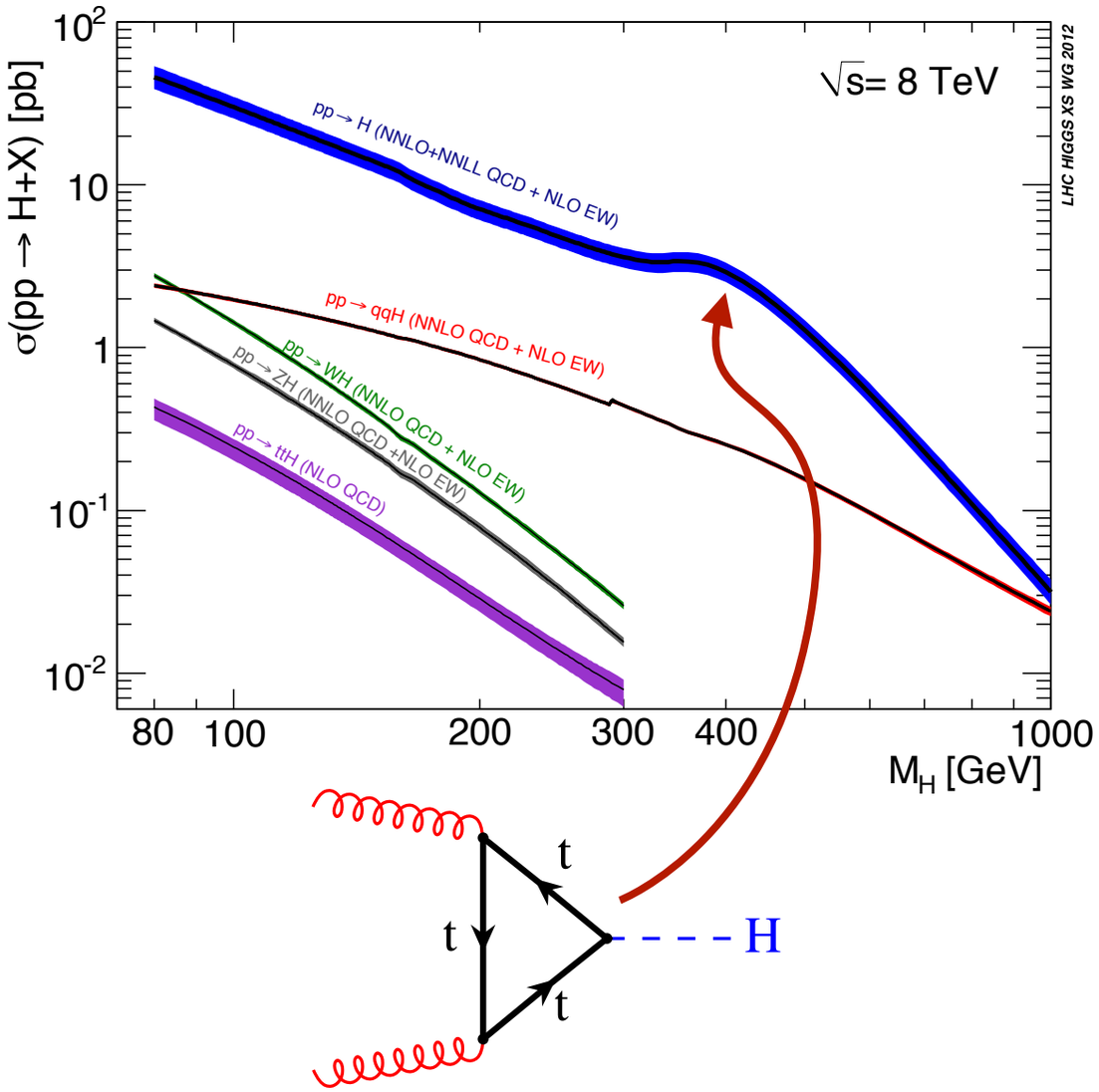
Mixed EW/QCD:

Anastasiou, Boughezal, Petriello '09

Fully differential NNLO:

Anastasiou, Melnikov, Petriello '04
Catani, Grazzini '07

Gluon fusion



$$\sigma_\infty^{\rm HO} \equiv \sigma^{\rm LO}(m_t)\left(\frac{\sigma^{\rm HO}}{\sigma^{\rm LO}}\right)_{m_t\to\infty}$$

NLO: Spira, Djouadi, Graudenz, Zerwas '91, '93
Dawson '91 ~80%

NNLO: RH, Kilgore '02
Anastasiou, Melnikov '02 ~30%
Ravindran, Smith, v. Neerven '03

Resummation:

Catani, de Florian, Grazzini, Nason '02
Ahrens, Becher, Neubert, Zhang '08 ~10%

Electroweak:

Actis, Passarino, Sturm, Uccirati '08
Aglietti, Bonciani, Degrassi, Vicini '04
Degrassi, Maltoni '04
Djouadi, Gambino '94 ~5%

Mixed EW/QCD:

Anastasiou, Boughezal, Petriello '09

Fully differential NNLO:

Anastasiou, Melnikov, Petriello '04
Catani, Grazzini '07

Gluon fusion: uncertainties

- perturbative (scale variation)
- PDF/α_s
- bottom loop/Yukawa coupling
- …

Gluon fusion: recent progress

- Higgs line shape

  Goria, Passarino, Rosco '12; Anastasiou, Buehler, Herzog, Lazopoulos '11

- Signal/Background interference

  Glover, v.d. Bij '89; Binoth, Ciccolini, Kauer, Krämer '06;
  Campbell, Ellis, Williams '11; Kauer '12; Passarino '12

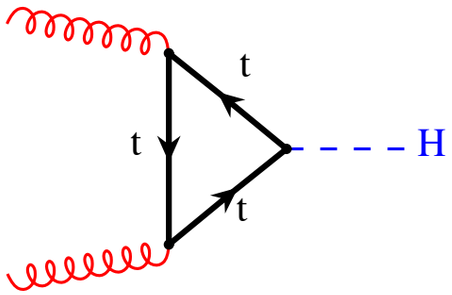
- validity of effective 1/mt theory

  RH, Mantler, Marzani, Ozeren '09; Pak, Rogal, Steinhauser '09
  Alwall, Li, Maltoni '11; Bagnasci, Degrassi, Slavich, Vicini '11
  RH, Neumann, Wiesemann '12

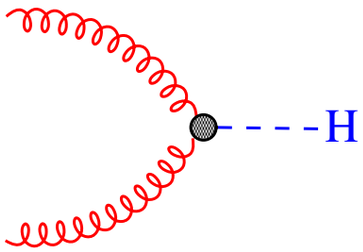
- jet veto uncertainties

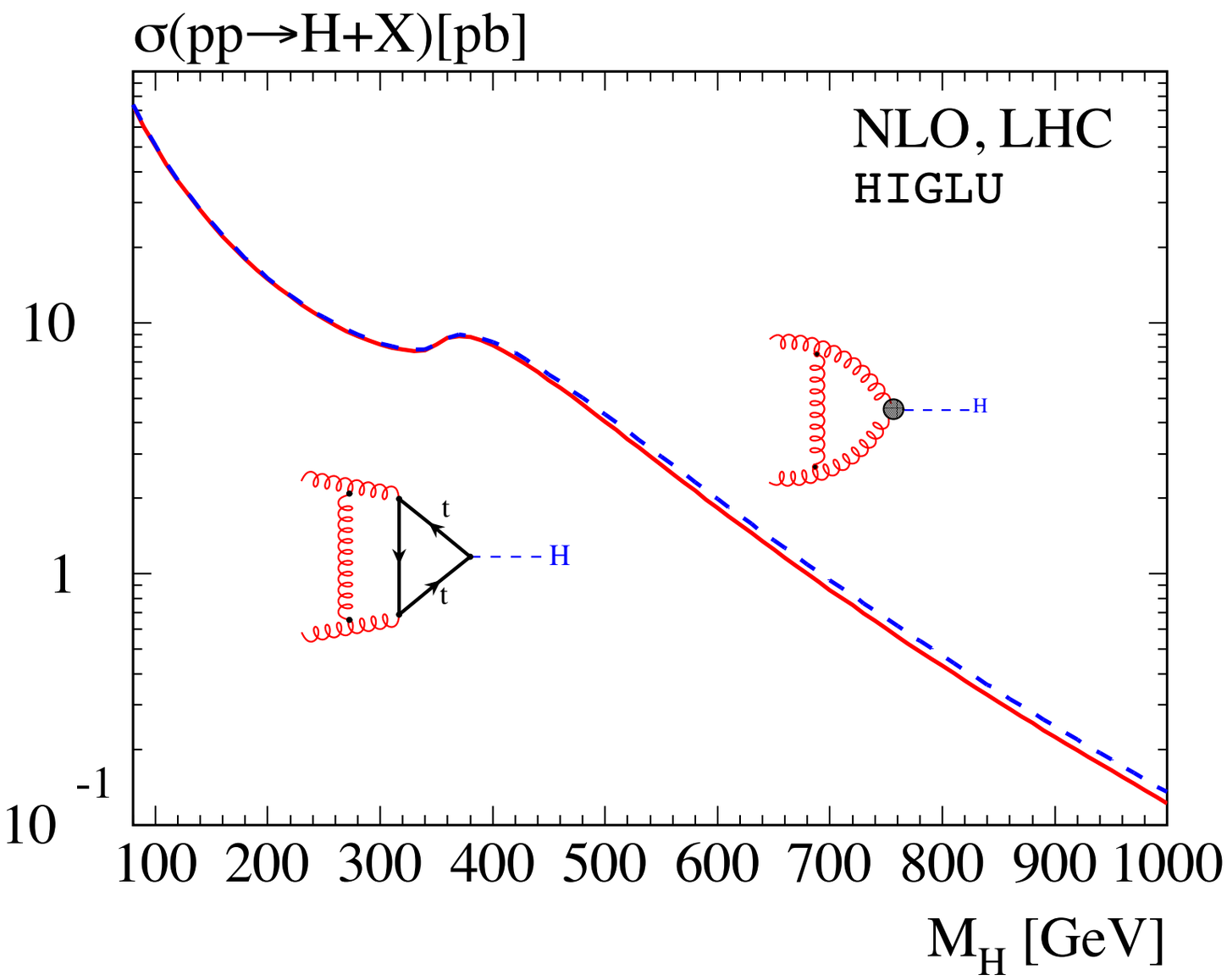
  Anastasiou, Dissertori, Grazzini, Stöckli, Webber '09
  Stewart, Tackmann '11
  Banfi, Monni, Salam, Zanderighi '12; Becher, Neubert '12
  Tackmann, Walsh, Zuberi '12

Effective Theory:



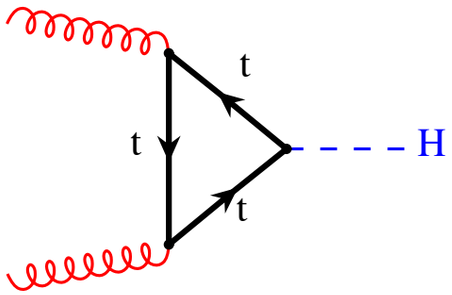
$$\xrightarrow{m_t \gg M_H} \quad C(m_t, \alpha_s) \times$$



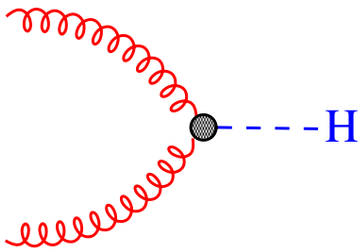


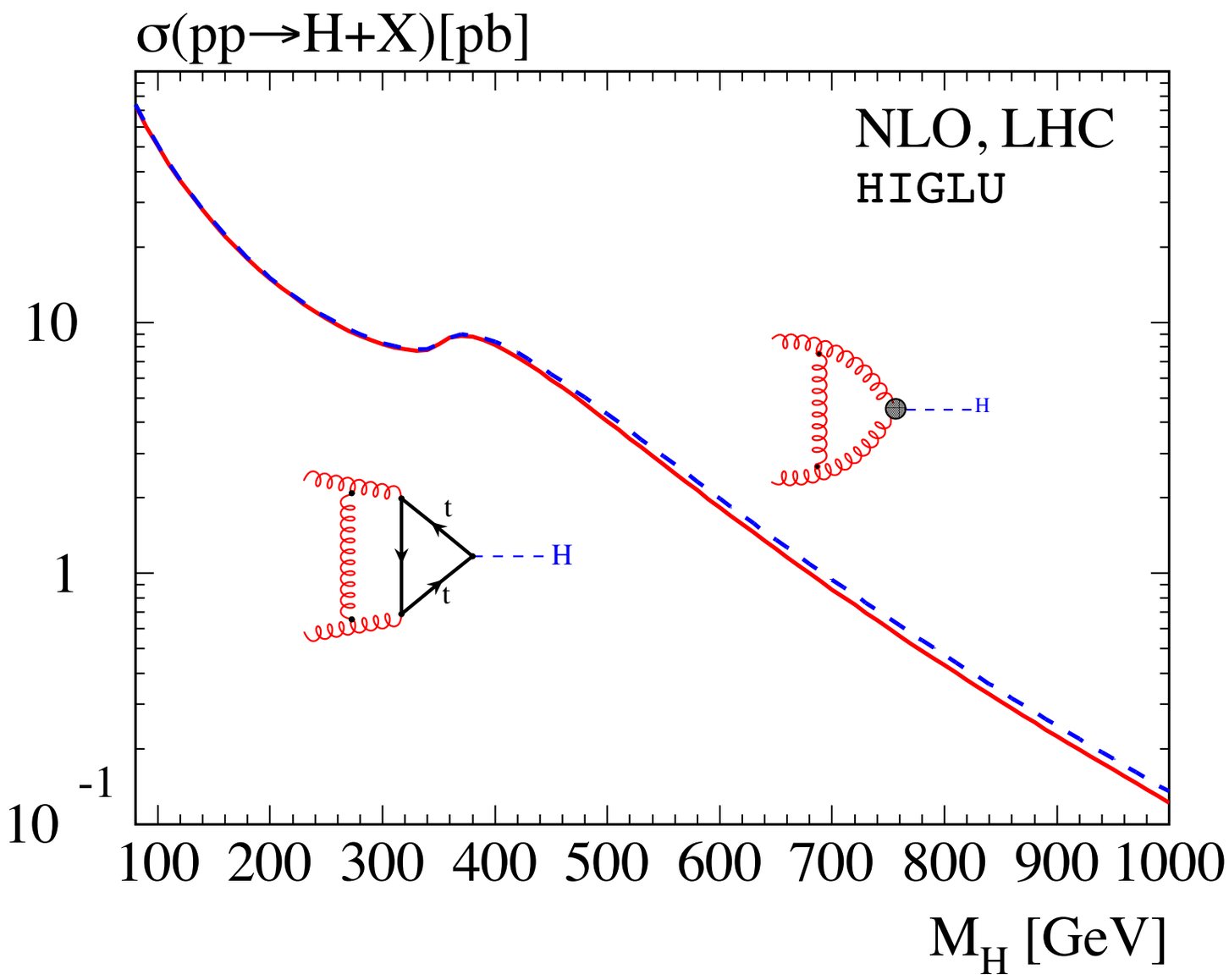
$$\sigma_\infty^{\rm HO} \equiv \sigma^{\rm LO}(m_t) \left(\frac{\sigma^{\rm HO}}{\sigma^{\rm LO}} \right)_{m_t \to \infty}$$

Effective Theory:



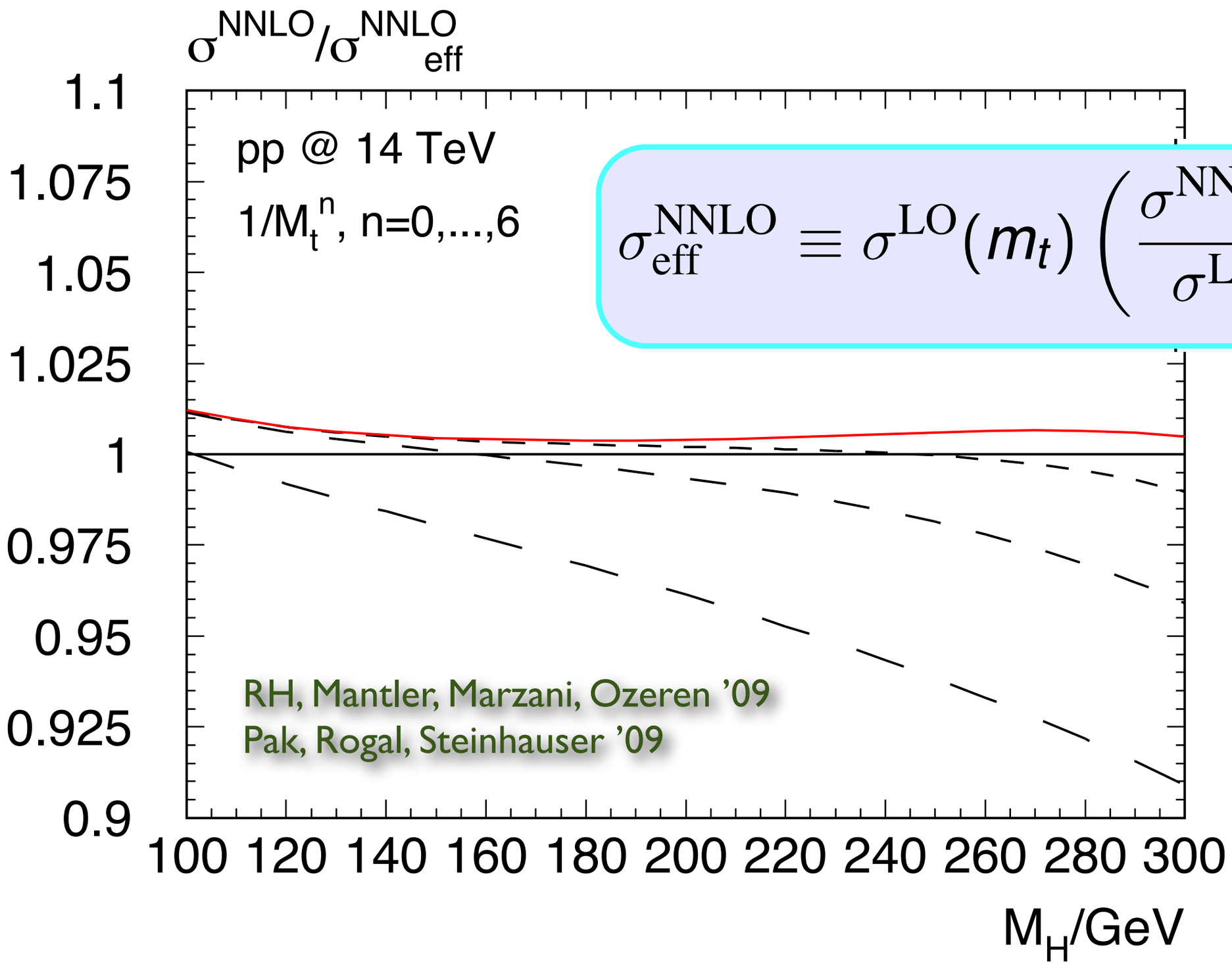
$$\xrightarrow{m_t \gg M_H} \quad C(m_t, \alpha_s) \times$$



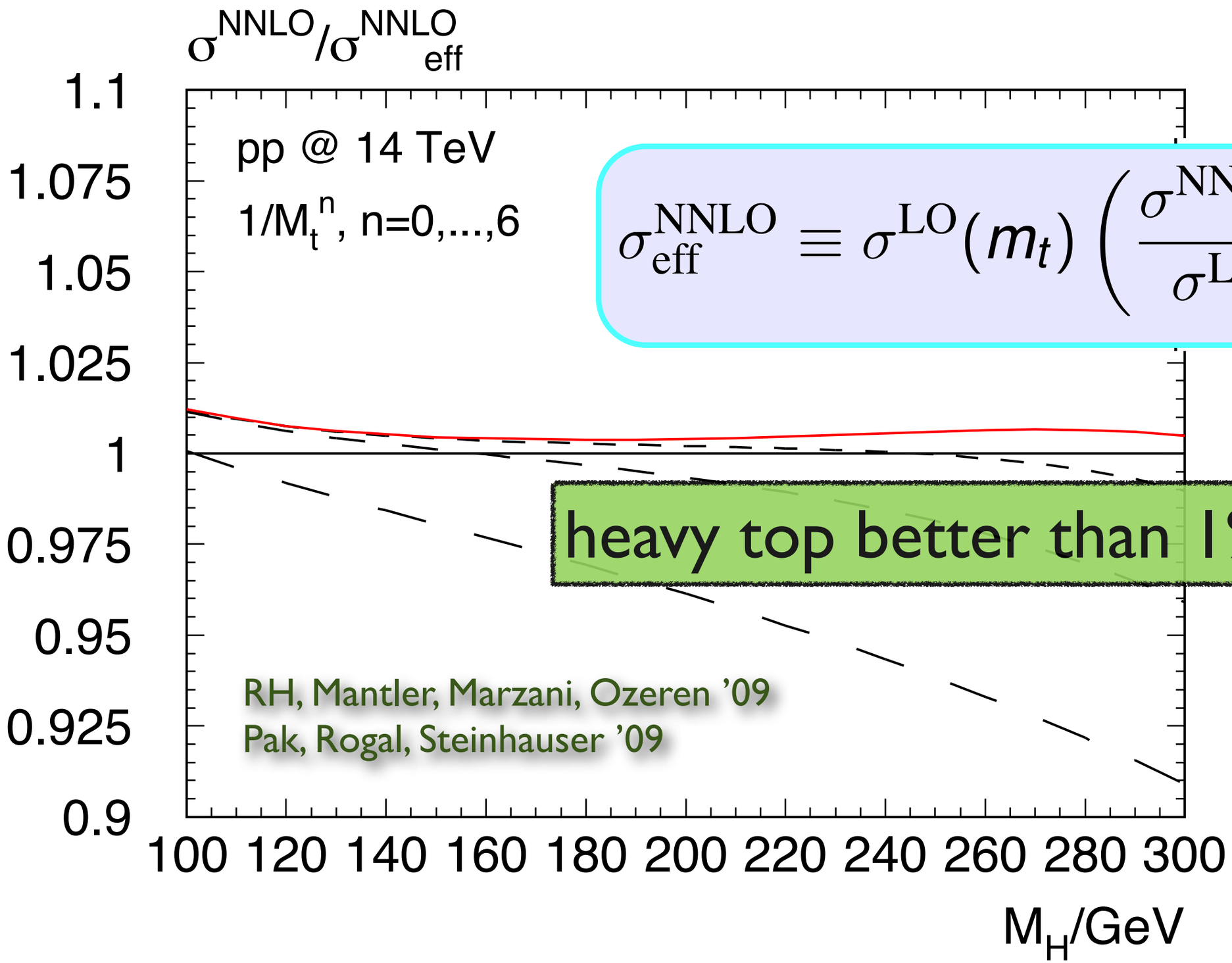


$$\sigma_\infty^{\rm HO} \equiv \sigma^{\rm LO}(m_t) \left(\frac{\sigma^{\rm HO}}{\sigma^{\rm LO}} \right)_{m_t \to \infty}$$

what about NNLO?



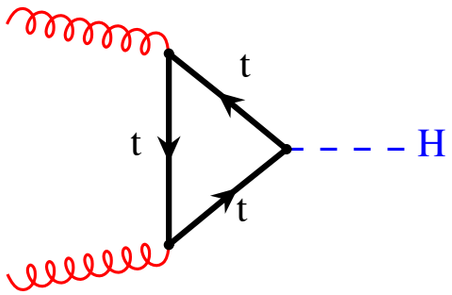
$$\sigma_{\rm eff}^{\rm NNLO} \equiv \sigma^{\rm LO}(m_t)\left(\frac{\sigma^{\rm NNLO}}{\sigma^{\rm LO}}\right)_{m_t\to\infty}$$



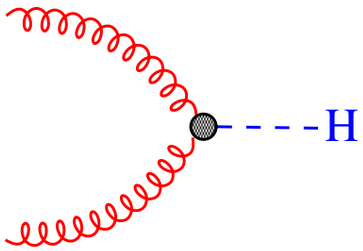
$$\sigma_{\rm eff}^{\rm NNLO} \equiv \sigma^{\rm LO}(m_t)\left(\frac{\sigma^{\rm NNLO}}{\sigma^{\rm LO}}\right)_{m_t\to\infty}$$

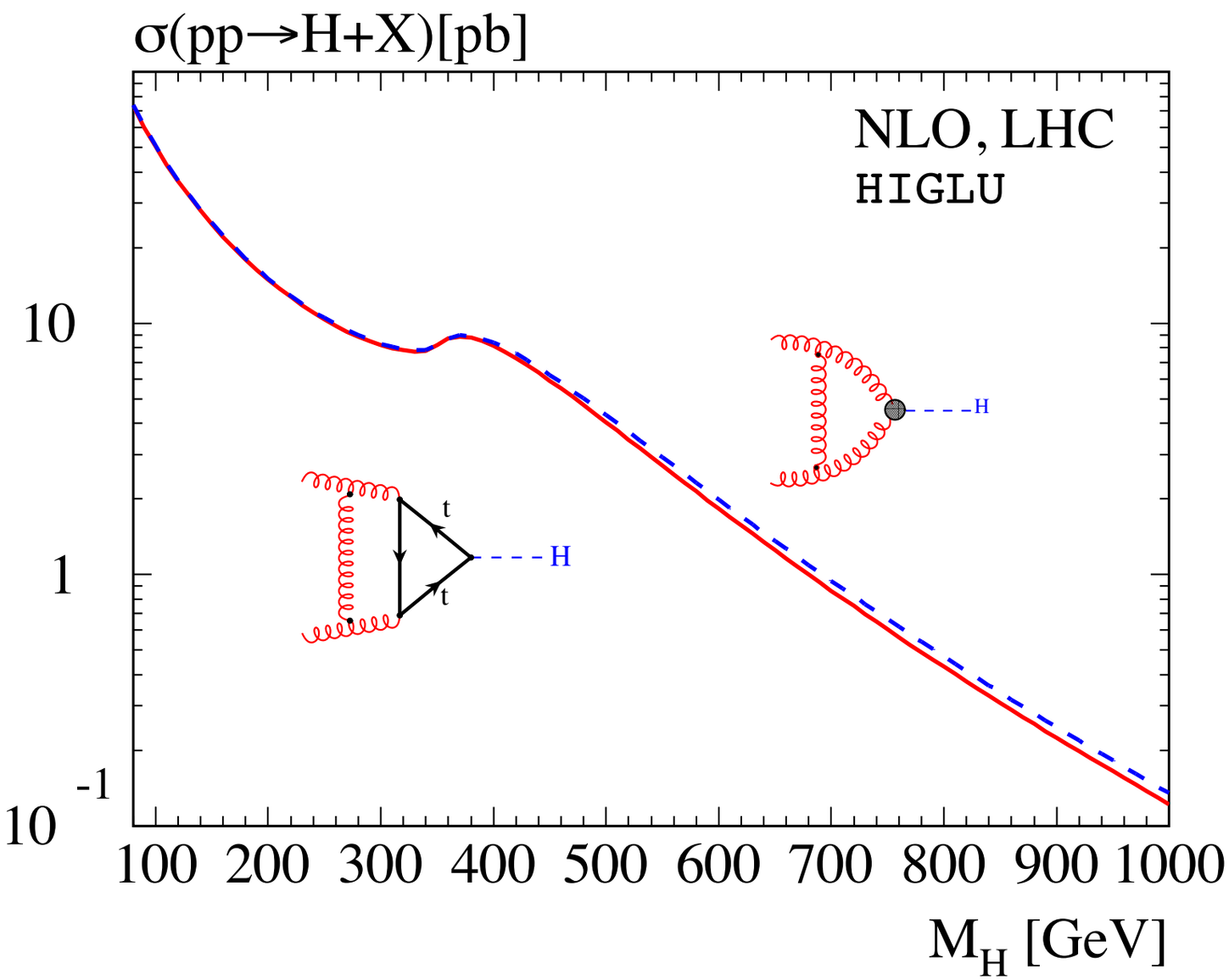
heavy top better than 1%!

RH, Mantler, Marzani, Ozeren '09
Pak, Rogal, Steinhauser '09



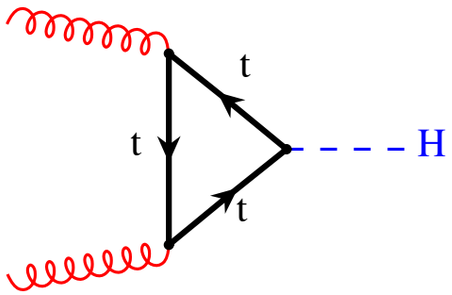
$$\xrightarrow{m_t \gg M_H} C(m_t, \alpha_s) \times$$



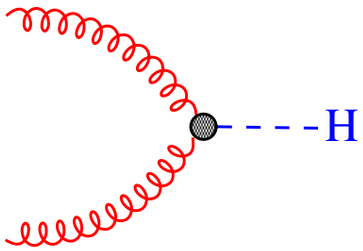


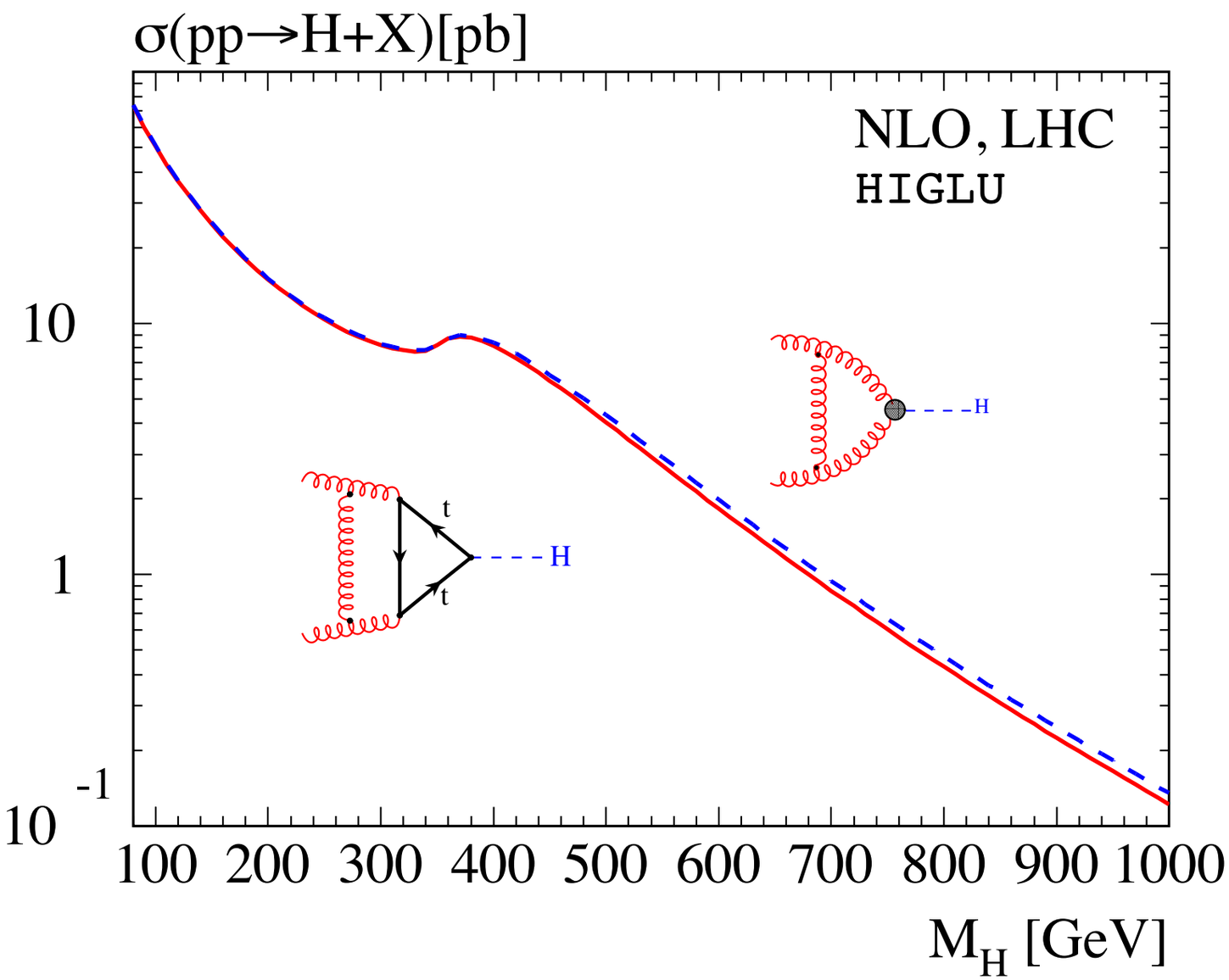
$$\sigma_\infty^{\rm HO} \equiv \sigma^{\rm LO}(m_t) \left(\frac{\sigma^{\rm HO}}{\sigma^{\rm LO}} \right)_{m_t \to \infty}$$

what about NNLO?



$$\xrightarrow{m_t \gg M_H} C(m_t, \alpha_s) \times$$

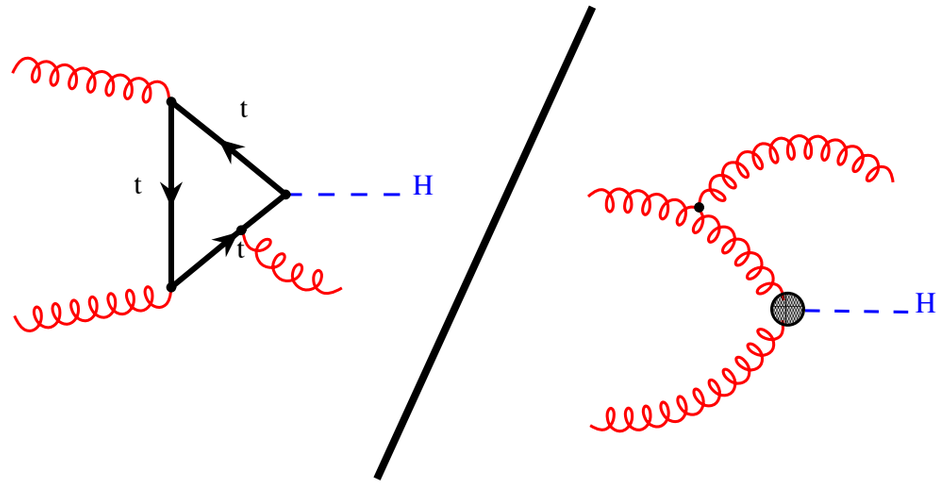


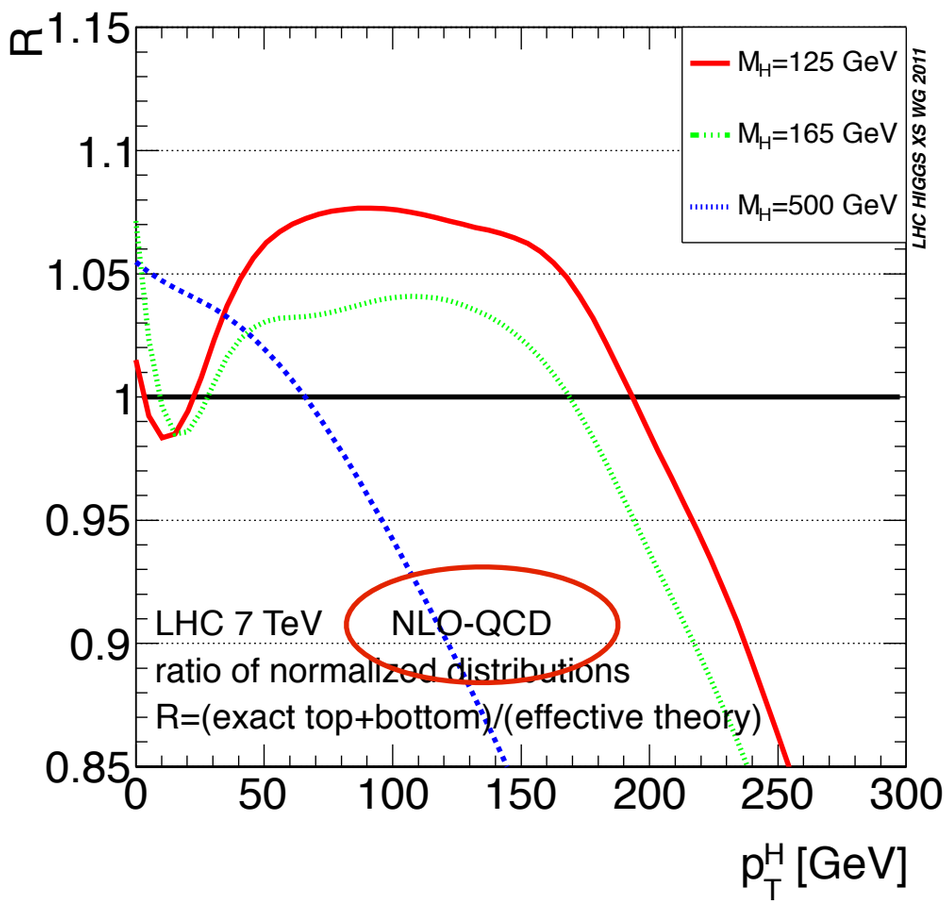


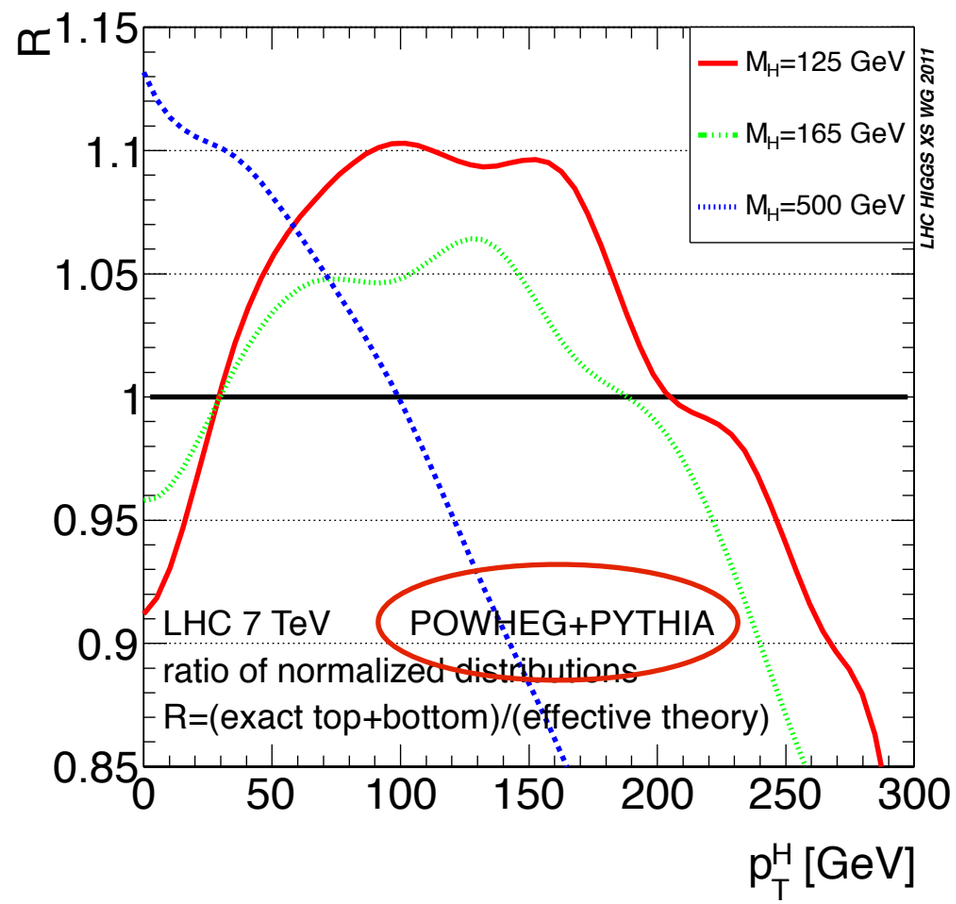
$$\sigma_\infty^{\rm HO} \equiv \sigma^{\rm LO}(m_t) \left(\frac{\sigma^{\rm HO}}{\sigma^{\rm LO}}\right)_{m_t \to \infty}$$

what about NNLO? ✓

what about distributions?

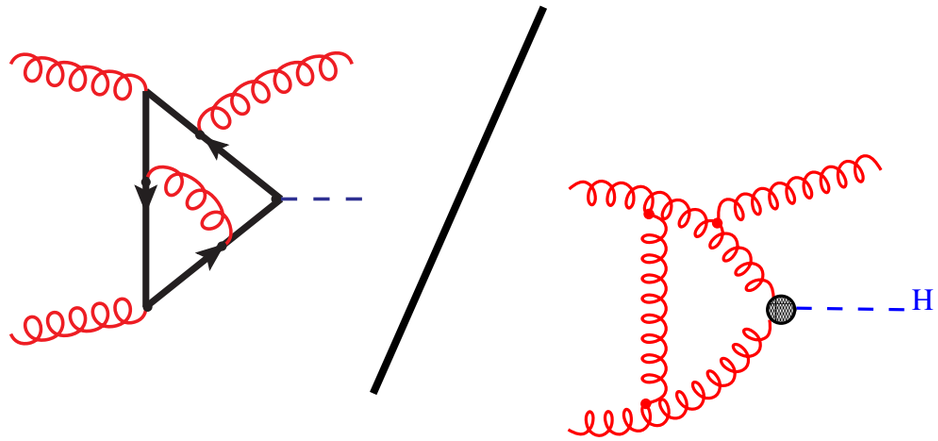


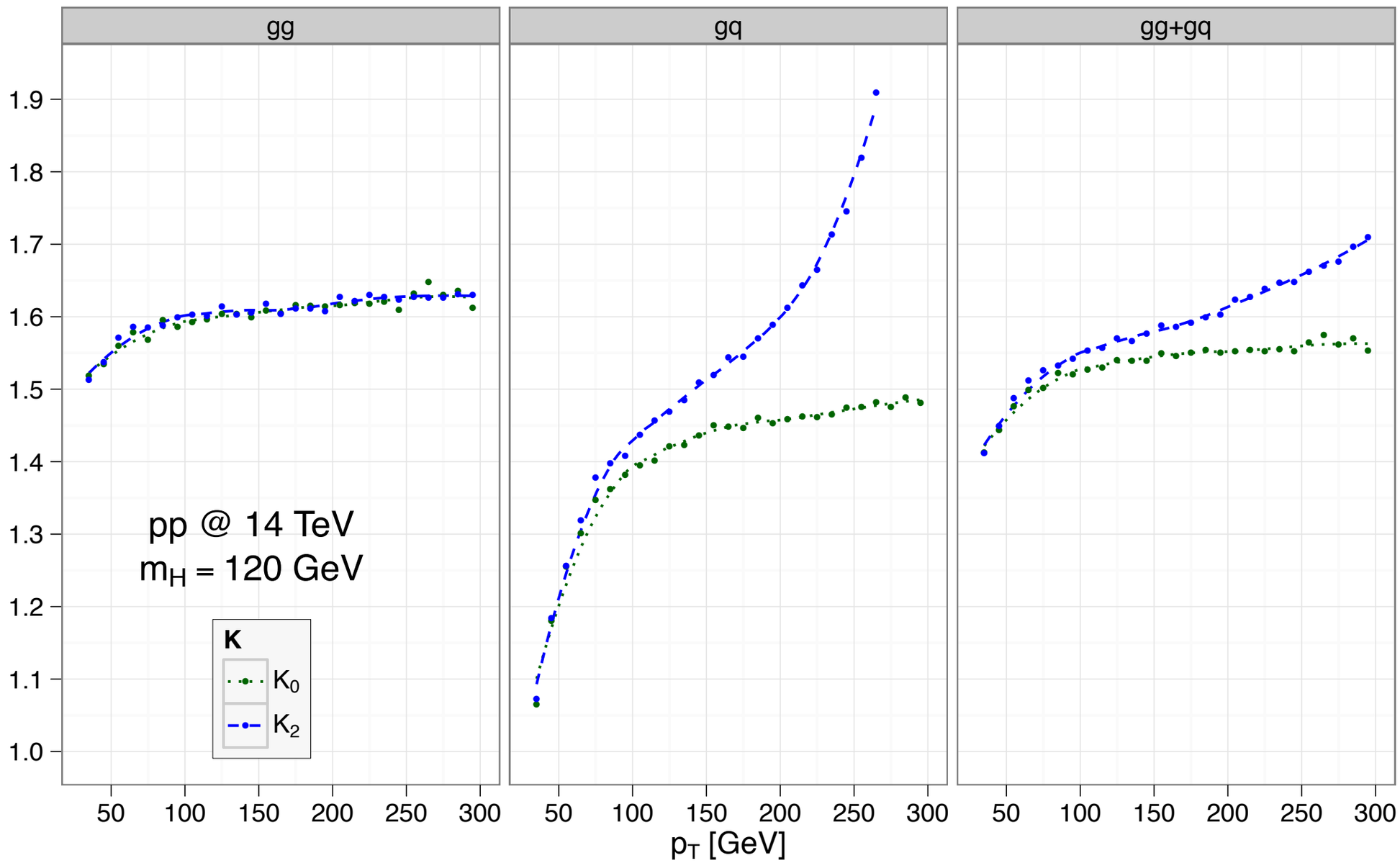




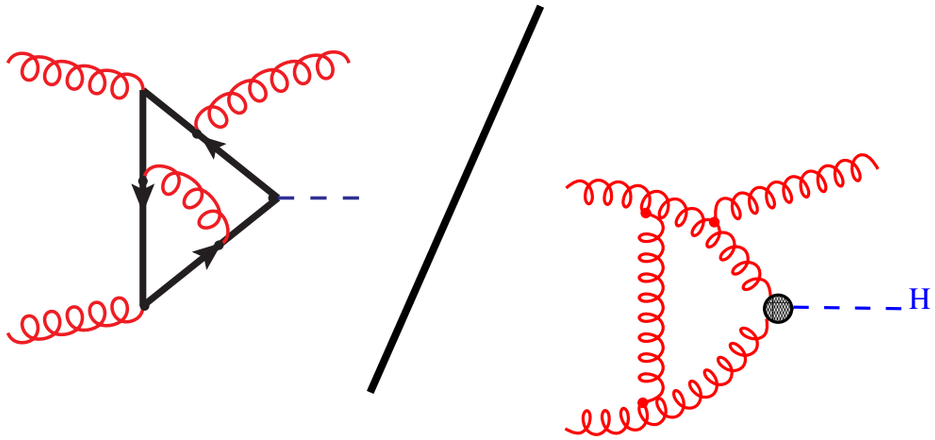
see also Spira, Djouadi, Graudenz, Zerwas '93
Keung, Petriello '09; Brein '10;
Anastasiou, Bucherer, Kunszt '09

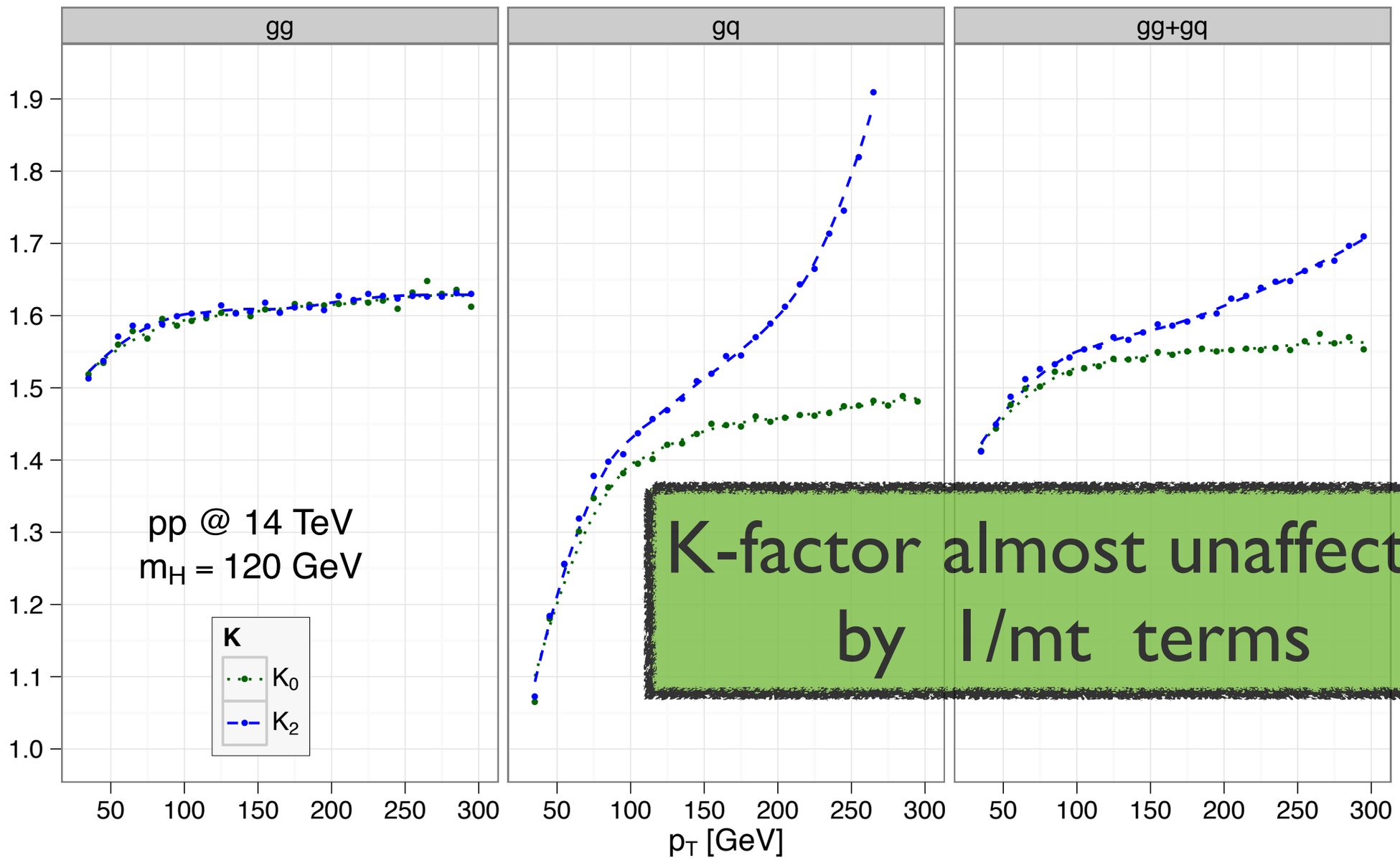
Bagnasci, Degrassi, Slavich, Vicini '11





RH, Neumann, Wiesemann '12

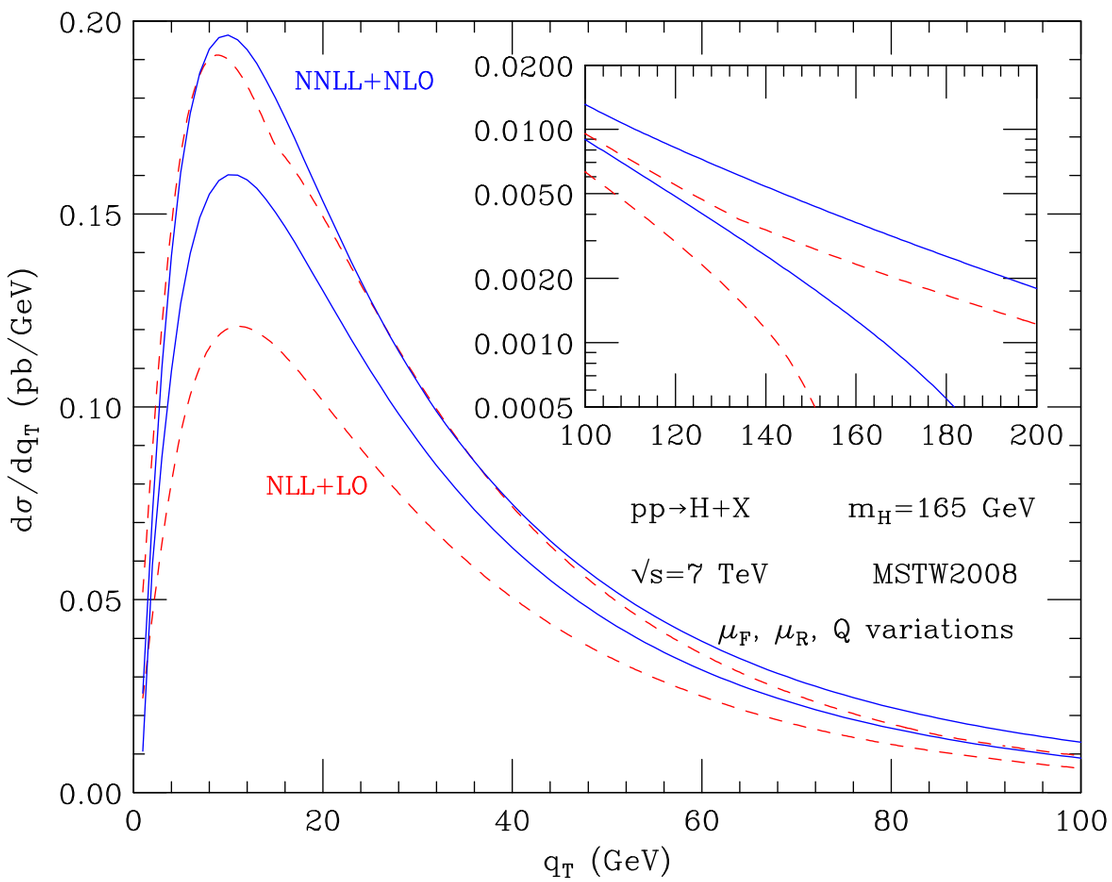




K-factor almost unaffected by 1/mt terms

RH, Neumann, Wiesemann '12

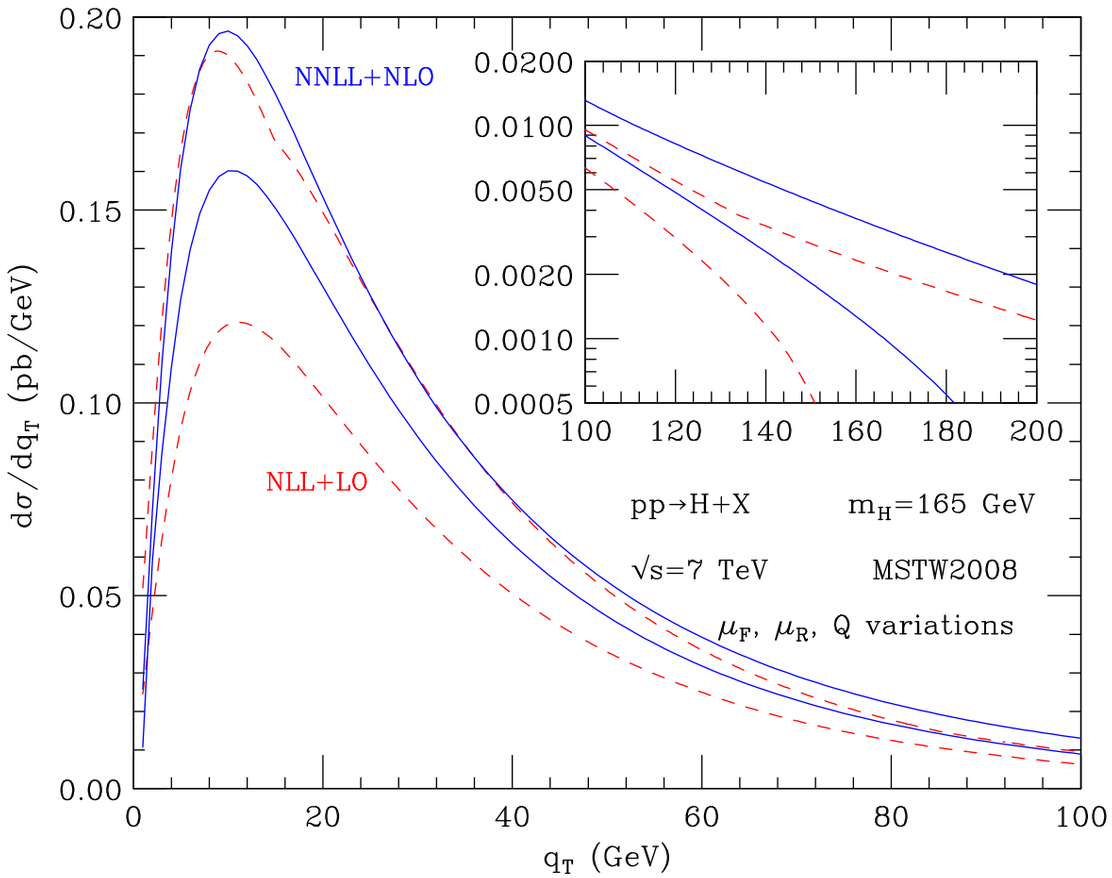
Transverse momentum:



HqT Bozzi, Catani, de Florian, Grazzini '03

see also: Mantry, Petriello '11
de Florian, Kulesza, Vogelsang '06
Kulesza, Sterman, Vogelsang '03
Berger, Qiu '03
...

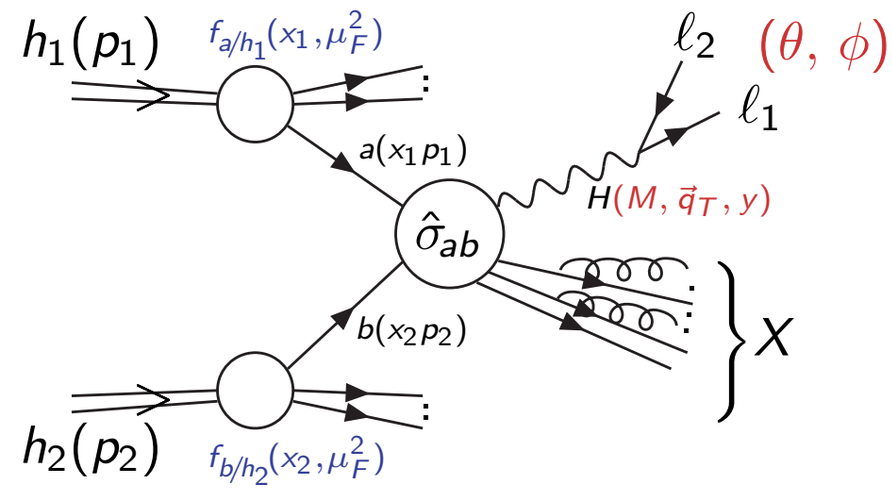
Transverse momentum:



HqT Bozzi, Catani, de Florian, Grazzini '03

see also: Mantry, Petriello '11
de Florian, Kulesza, Vogelsang '06
Kulesza, Sterman, Vogelsang '03
Berger, Qiu '03
...

including decay:



de Florian, Ferrera, Grazzini, Tommasini '11

Gluon fusion: recent progress

- Higgs line shape

  Goria, Passarino, Rosco '12; Anastasiou, Buehler, Herzog, Lazopoulos '11

- Signal/Background interference

  Glover, v.d. Bij '89; Binoth, Ciccolini, Kauer, Krämer '06;
  Campbell, Ellis, Williams '11; Kauer '12; Passarino '12

- validity of effective 1/mt theory

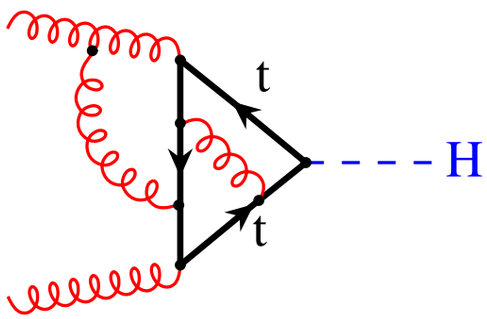
  RH, Mantler, Marzani, Ozeren '09; Pak, Rogal, Steinhauser '09
  Alwall, Li, Maltoni '11; Bagnasci, Degrassi, Slavich, Vicini '11
  RH, Neumann, Wiesemann '12

- jet veto uncertainties

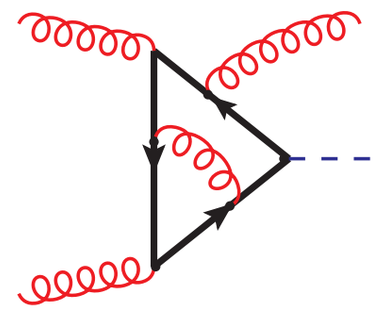
  Anastasiou, Dissertori, Grazzini, Stöckli, Webber '09
  Stewart, Tackmann '11
  Banfi, Monni, Salam, Zanderighi '12; Becher, Neubert '12
  Tackmann, Walsh, Zuberi '12

NNLO jet veto:

$$\sigma(0\text{-jet}) = \sigma(\text{total}) - \sigma(\geq 1\text{-jet})$$

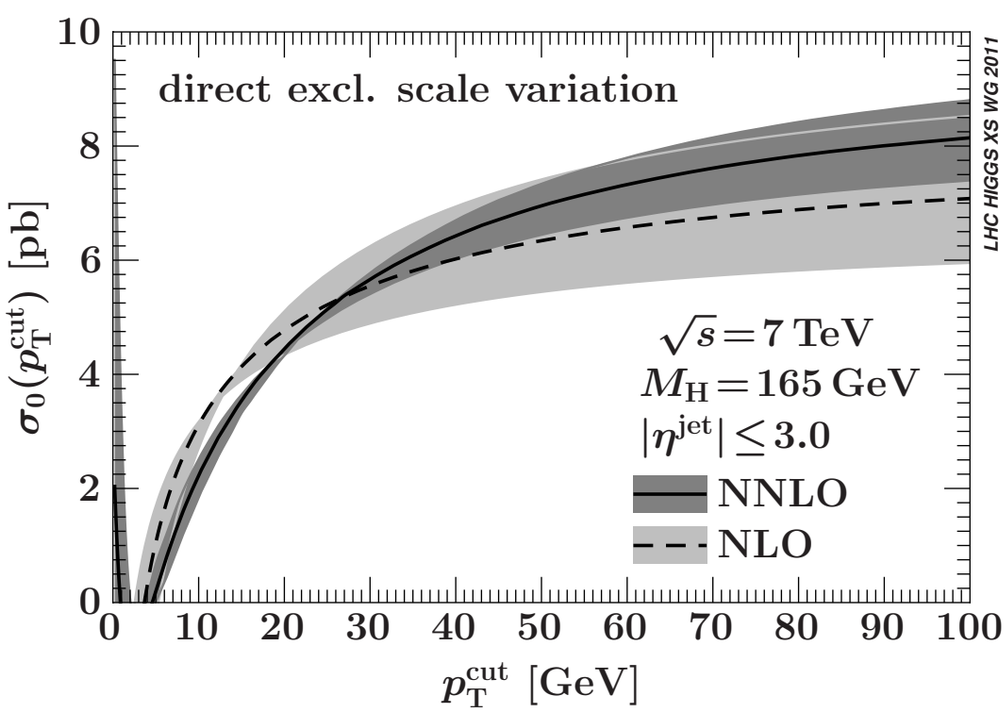


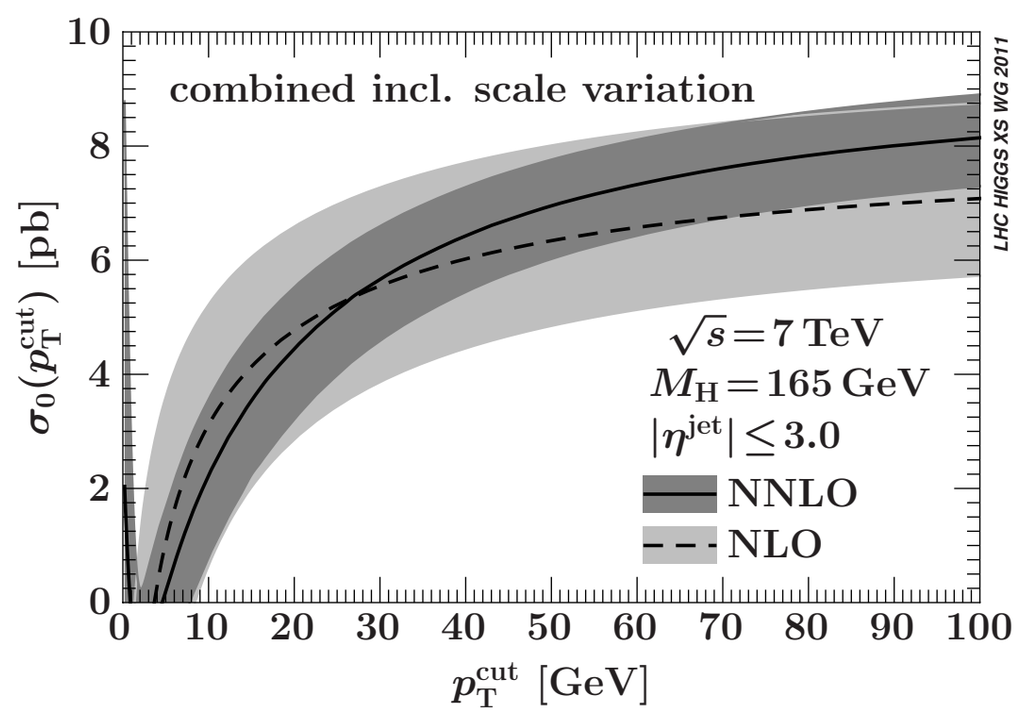
NNLO



NLO

Catani, de Florian, Grazzini '02





Anastasiou, Dissertori, Grazzini, Stöckli, Webber '09

Stewart, Tackmann '11

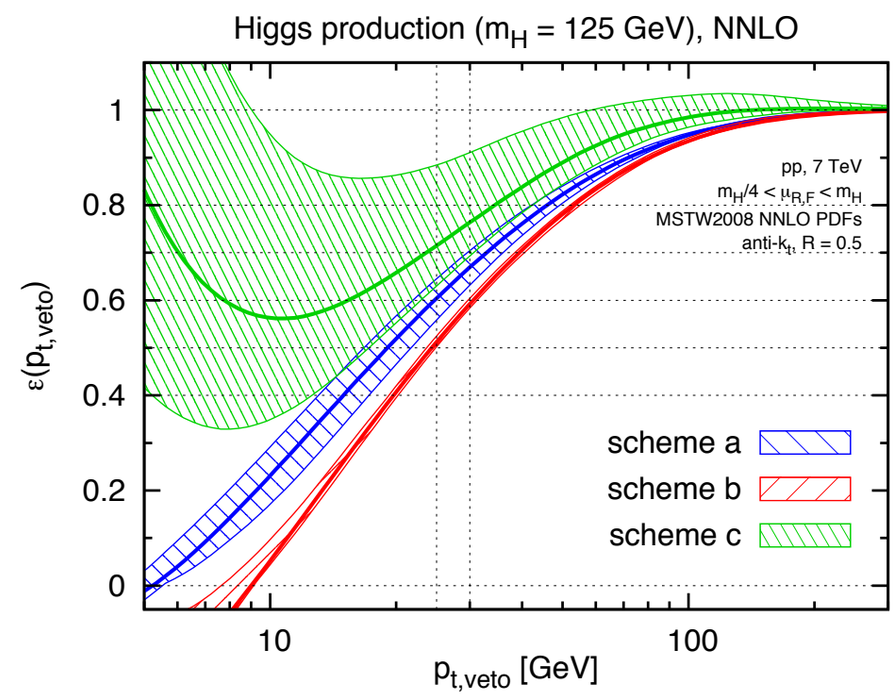
Jet veto efficiency:

$$\epsilon^{(a)}(p_{\mathrm{t,veto}}) \equiv \frac{\Sigma_0(p_{\mathrm{t,veto}}) + \Sigma_1(p_{\mathrm{t,veto}}) + \Sigma_2(p_{\mathrm{t,veto}})}{\sigma_0 + \sigma_1 + \sigma_2}$$

$$\epsilon^{(b)}(p_{\mathrm{t,veto}}) \equiv \frac{\Sigma_0(p_{\mathrm{t,veto}}) + \Sigma_1(p_{\mathrm{t,veto}}) + \bar{\Sigma}_2(p_{\mathrm{t,veto}})}{\sigma_0 + \sigma_1}$$

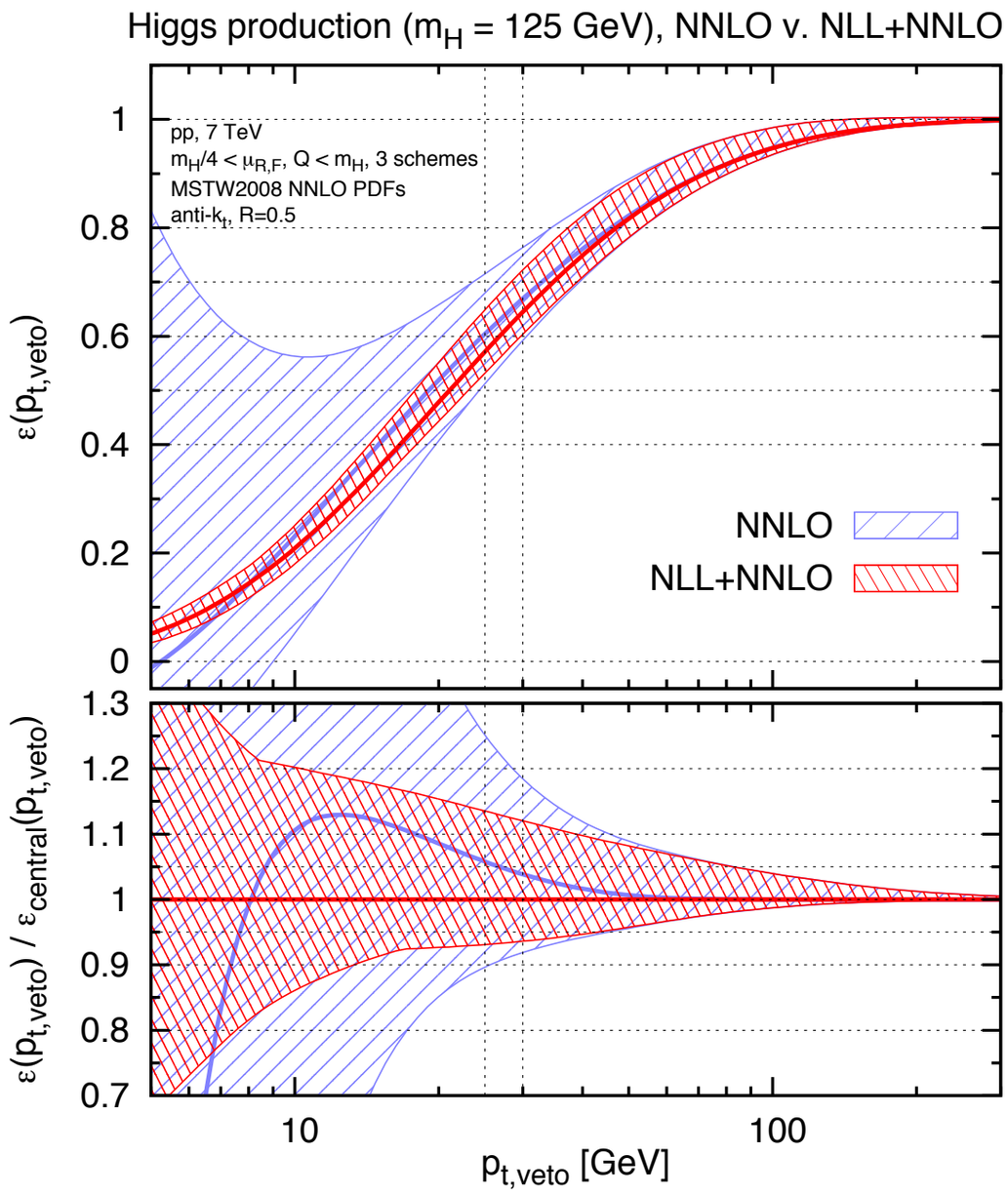
$$\epsilon^{(c)}(p_{\mathrm{t,veto}}) \equiv 1 + \frac{\bar{\Sigma}_1(p_{\mathrm{t,veto}})}{\sigma_0} + \left(\frac{\bar{\Sigma}_2(p_{\mathrm{t,veto}})}{\sigma_0} - \frac{\sigma_1}{\sigma_0^2}\bar{\Sigma}_1(p_{\mathrm{t,veto}})\right)$$

perturbatively equivalent



Banfi, Salam, Zanderighi '12

Resummation:



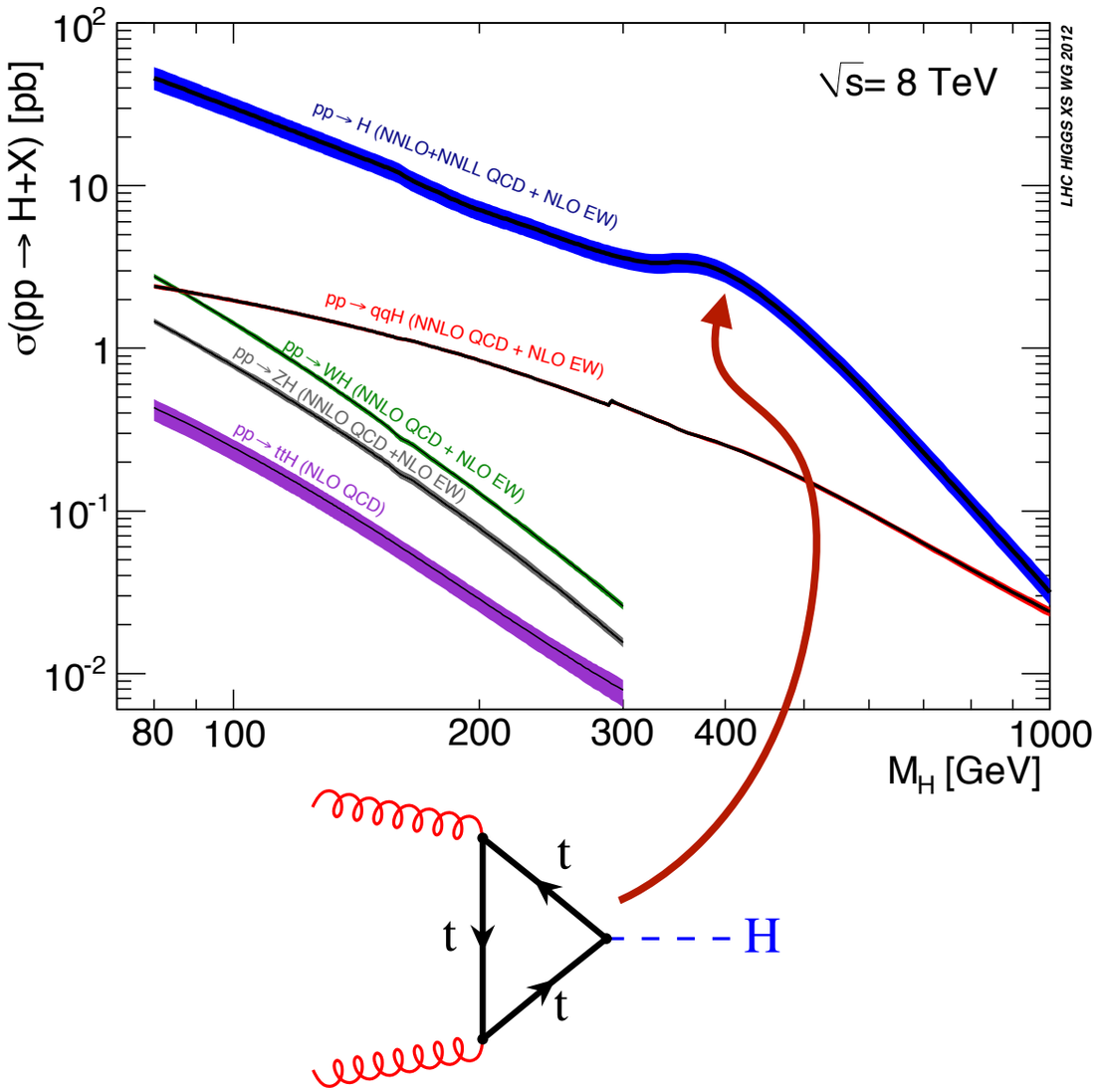
see also

Becher, Neubert '12

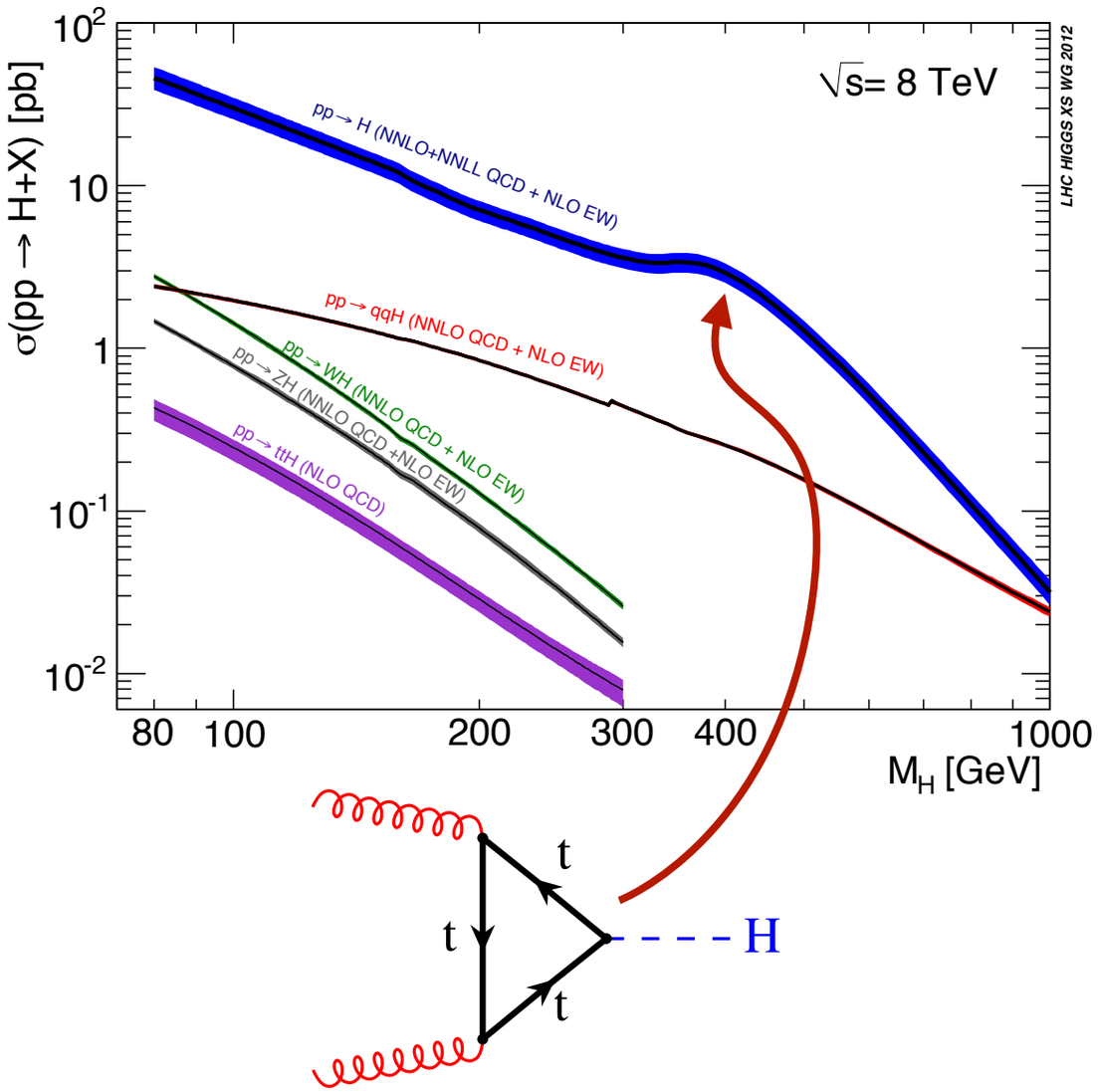
Tackmann, Walsh, Zuberi '12

Banfi, Monni, Salam, Zanderighi '12

Gluon fusion

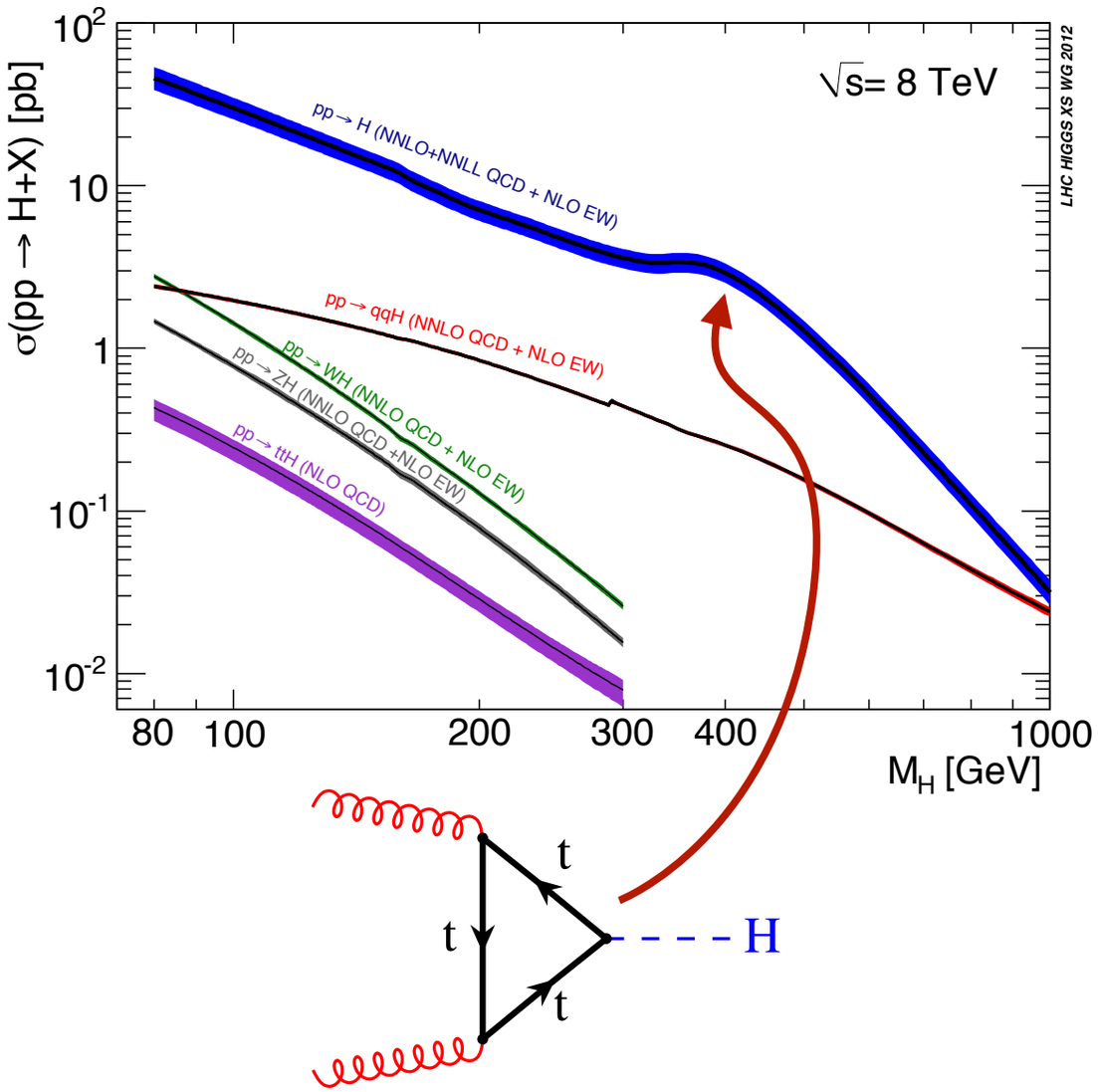


Gluon fusion



In summary

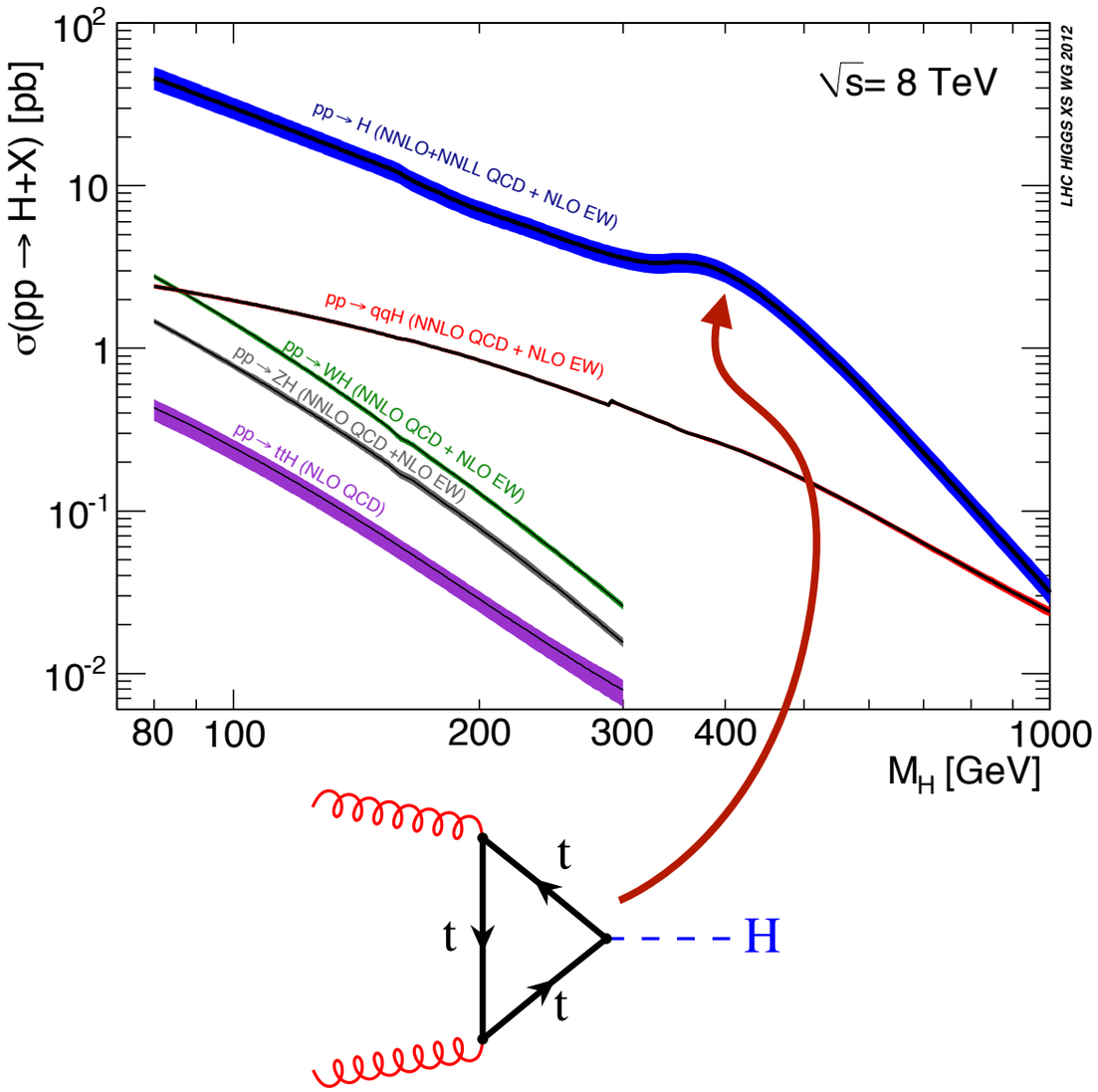
Gluon fusion



In summary

- enormous progress

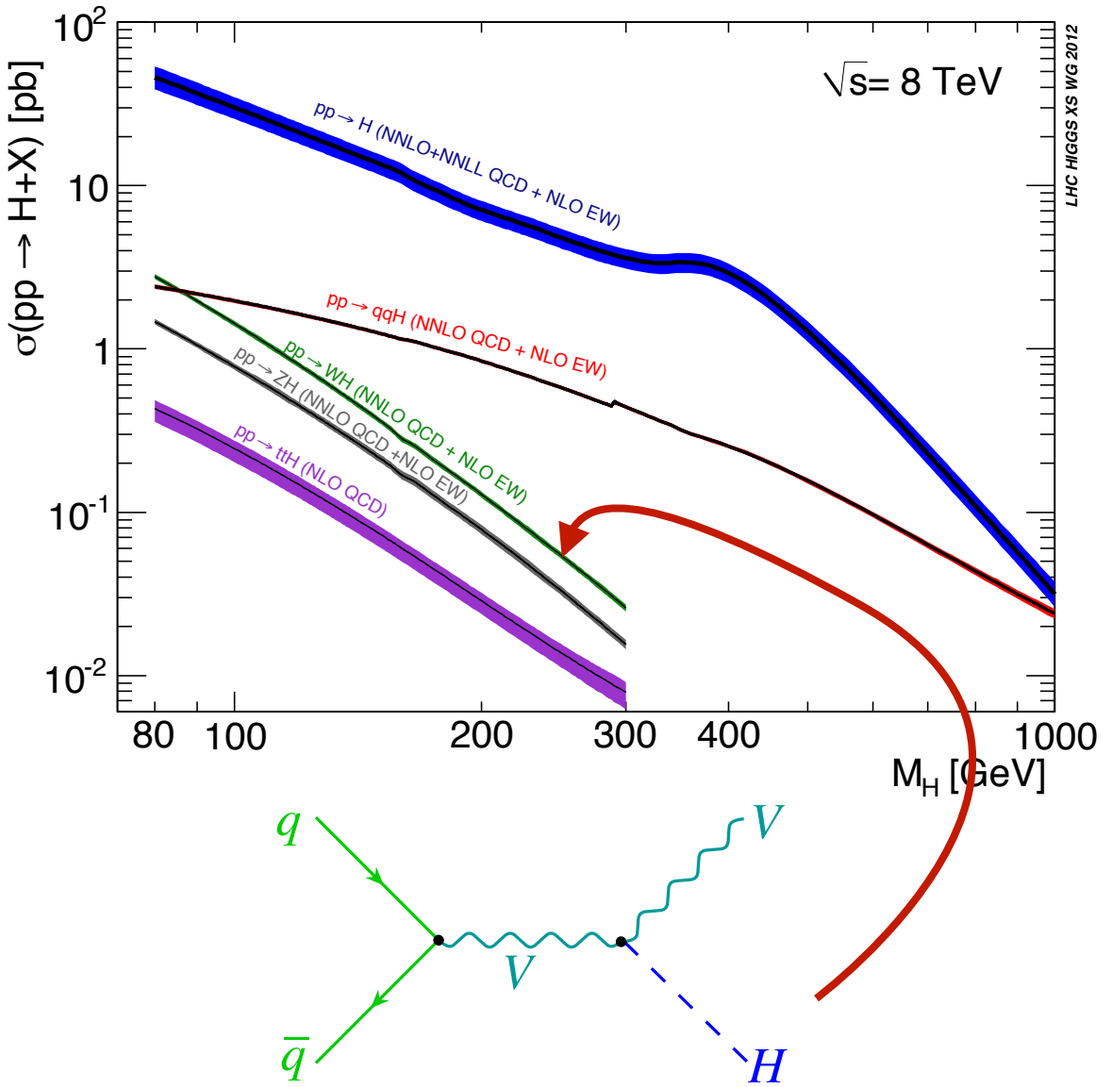
Gluon fusion



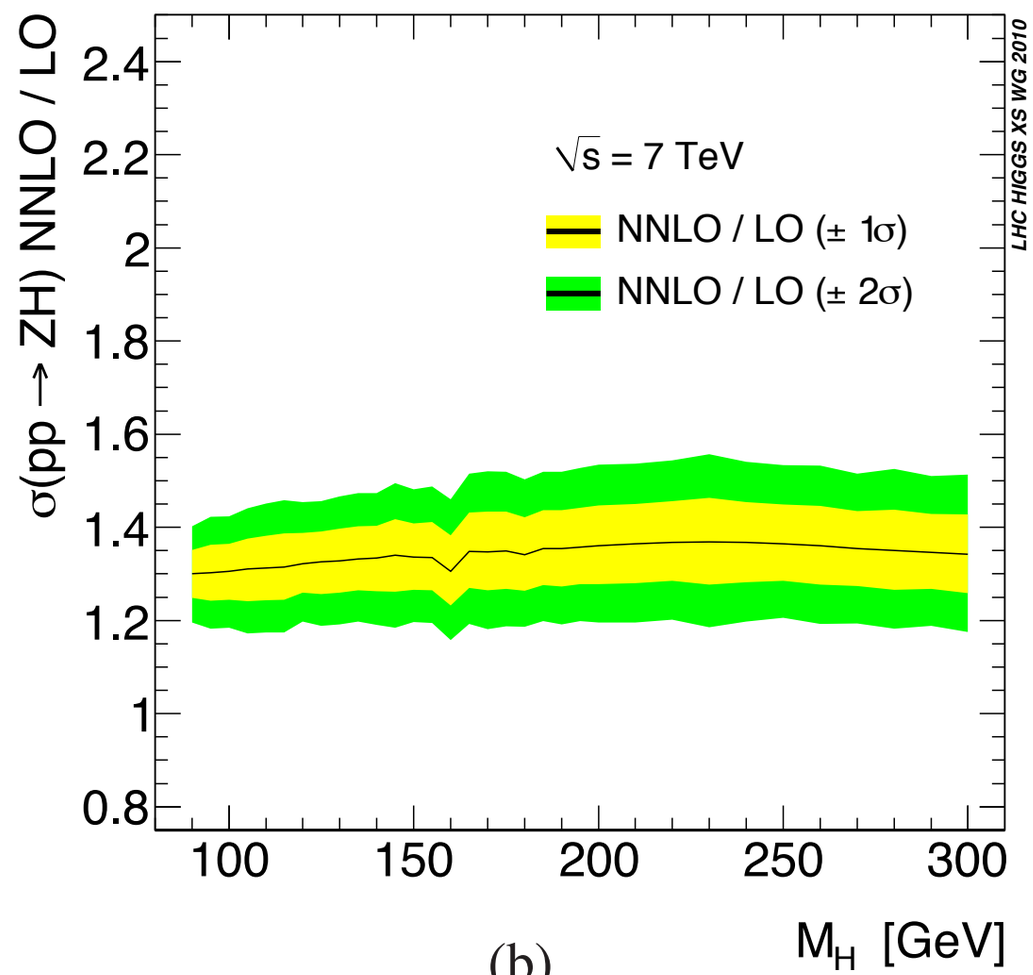
In summary

- enormous progress
- but still keeps us busy

Higgs Strahlung

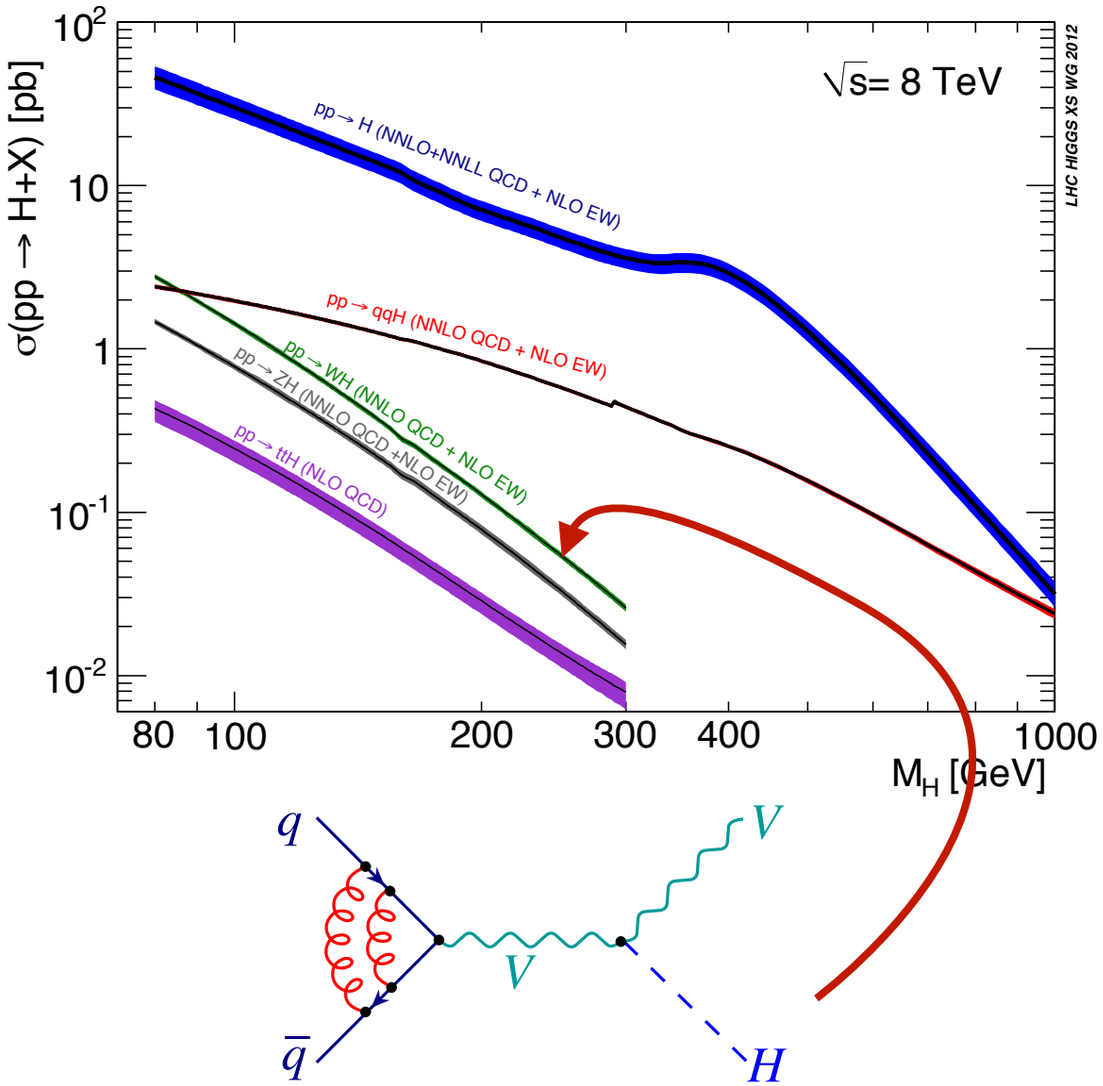


NLO: Han, Willenbrock '90
NNLO: Brein, Djouadi, RH '03 → vh@nnlo
EW: Ciccolini, Dittmaier, Krämer '03 → HAWK



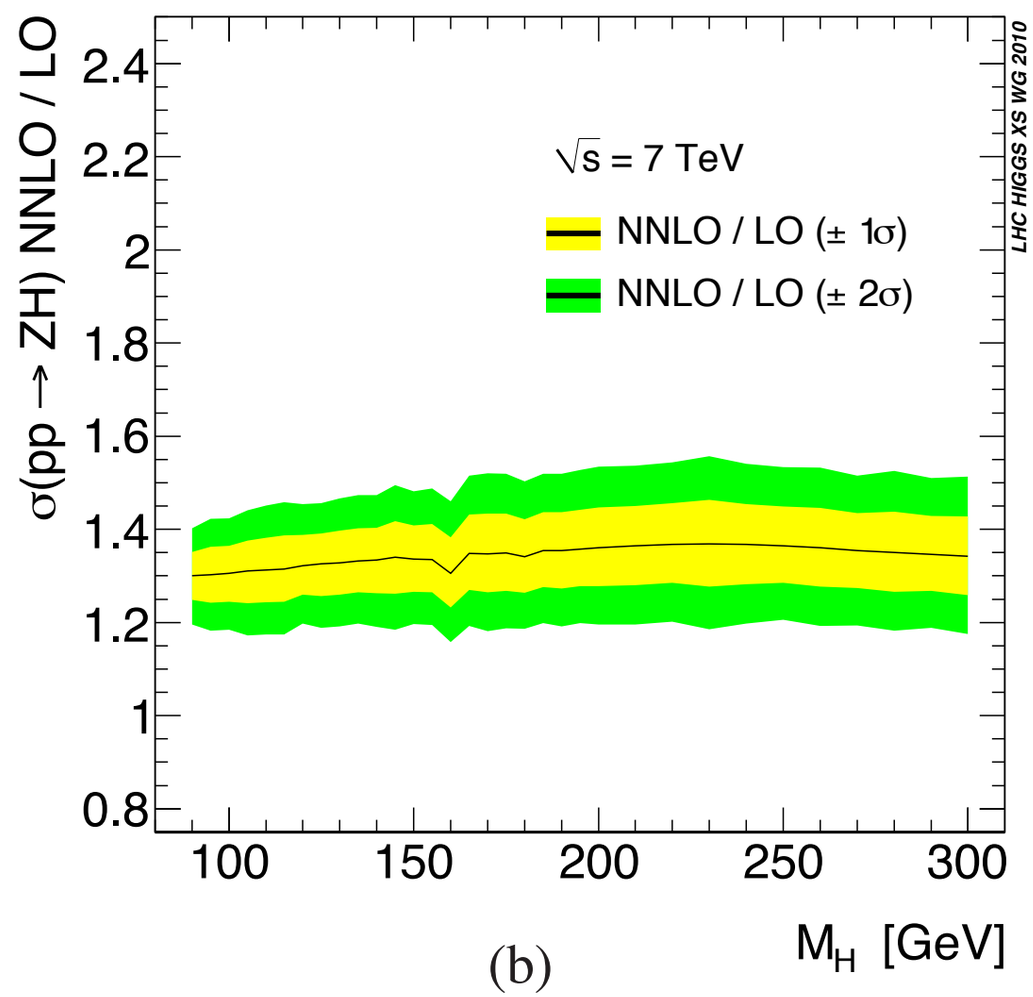
(b)

Higgs Strahlung

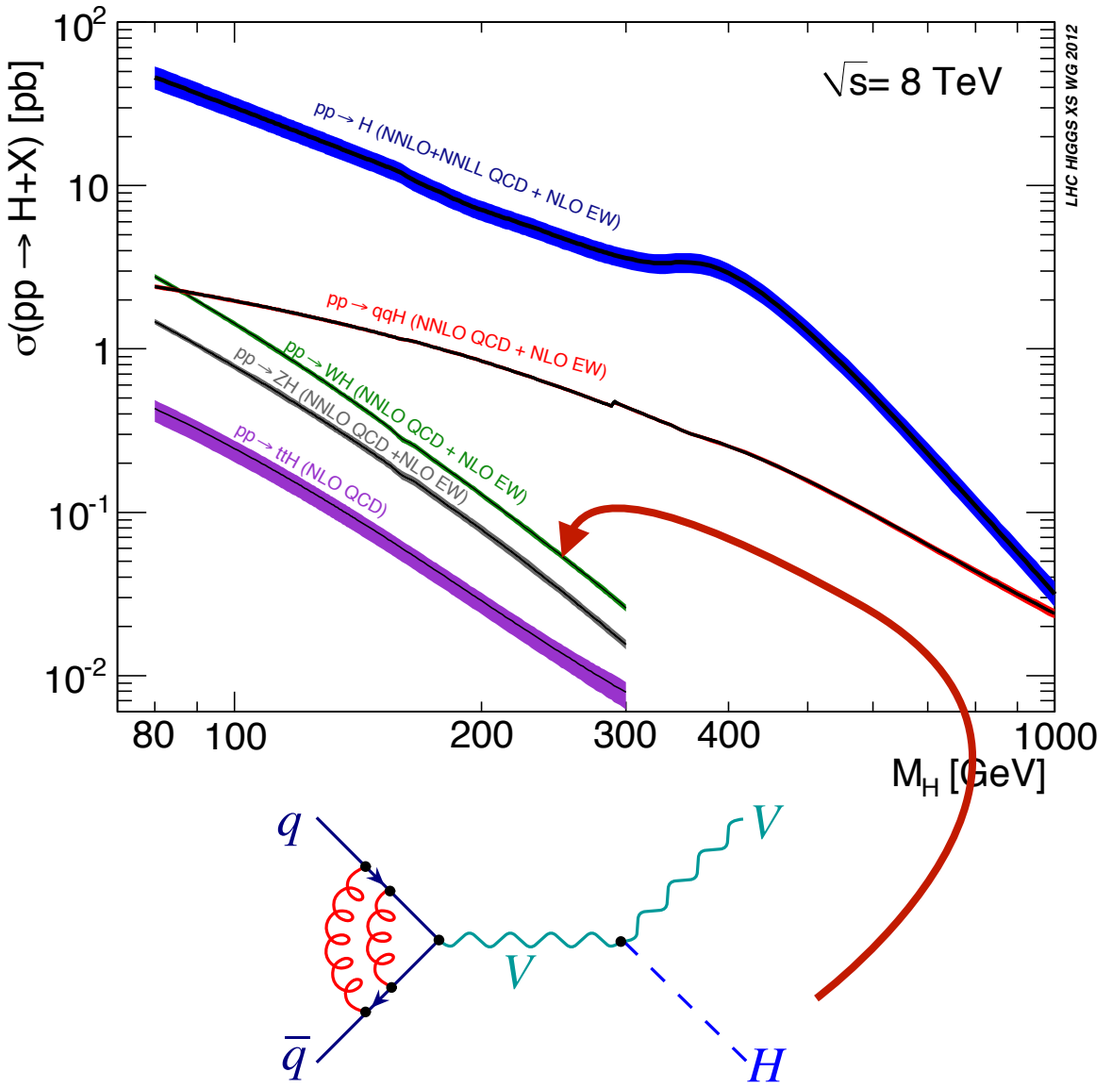


based on Hamberg, v. Neerven, Matsuura '91

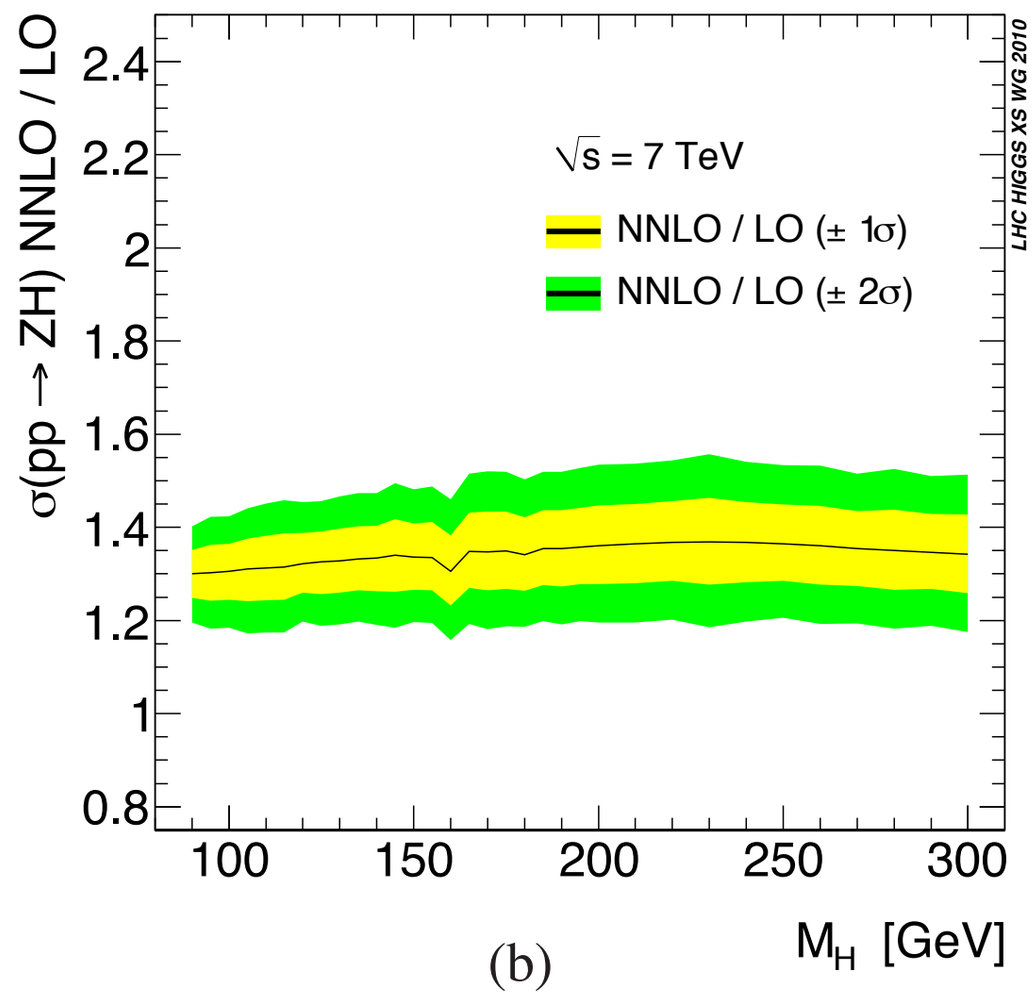
NLO: Han, Willenbrock '90
NNLO: Brein, Djouadi, RH '03 → vh@nnlo
EW: Ciccolini, Dittmaier, Krämer '03 → HAWK



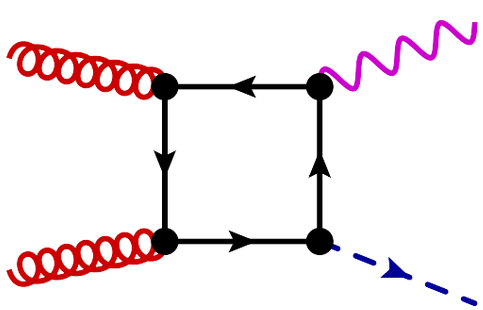
Higgs Strahlung



NLO: Han, Willenbrock '90
NNLO: Brein, Djouadi, RH '03 → vh@nnlo
EW: Ciccolini, Dittmaier, Krämer '03 → HAWK

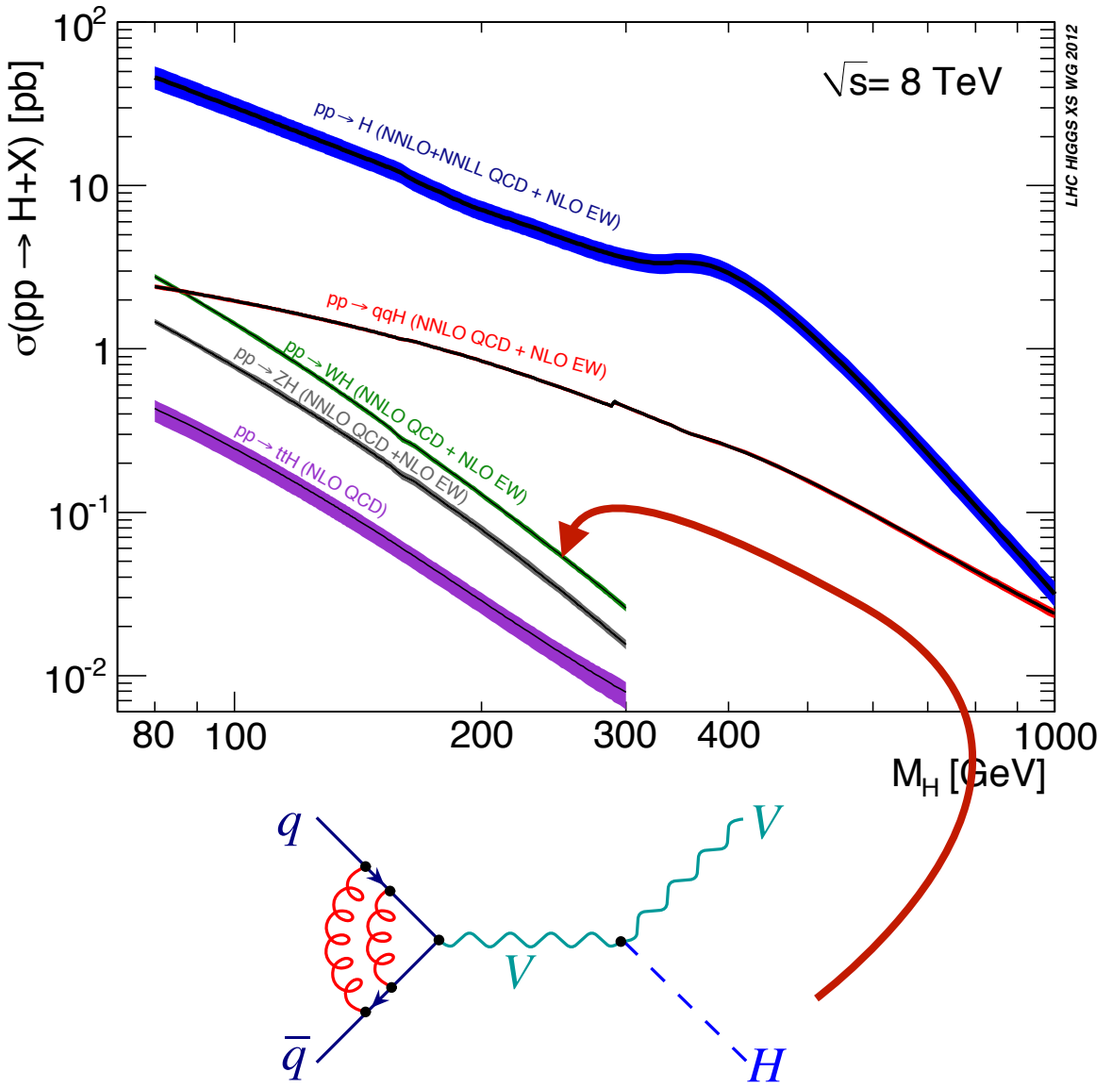


based on Hamberg, v. Neerven, Matsuura '91

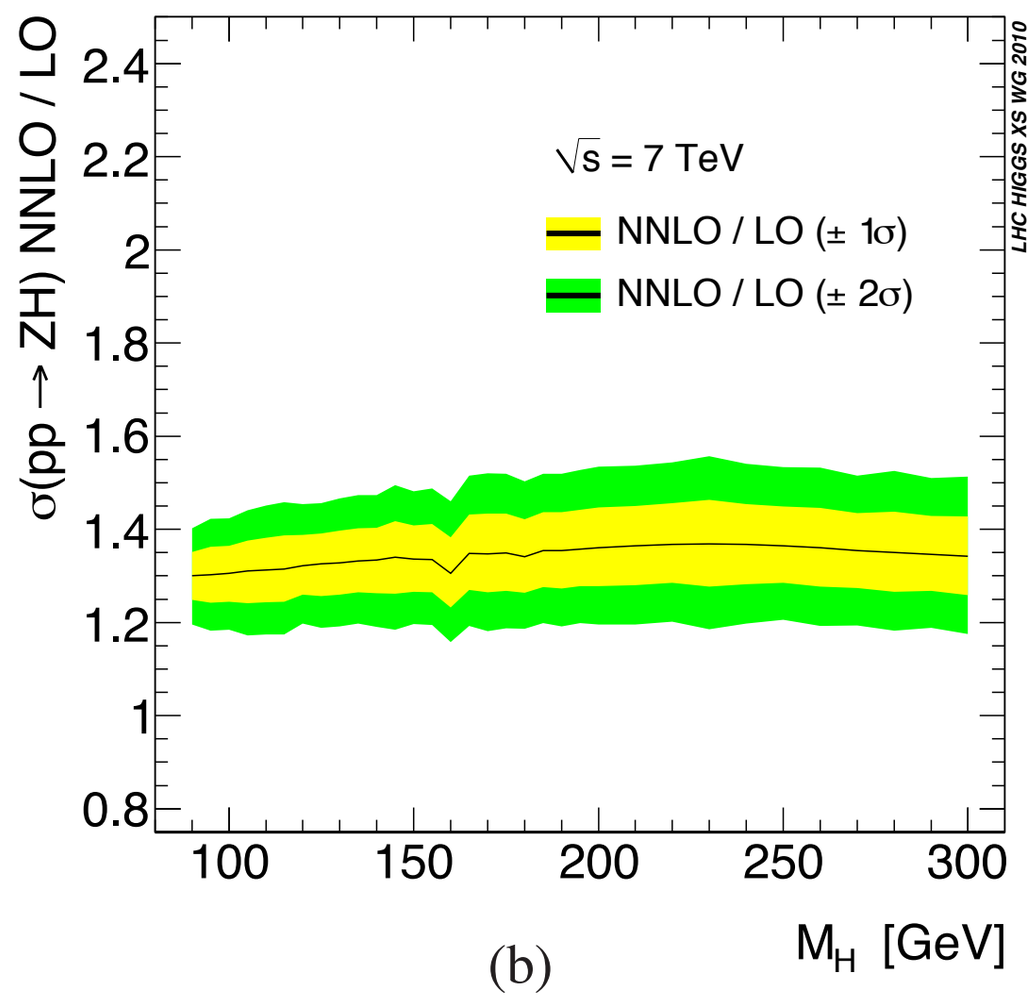


Kniehl '90

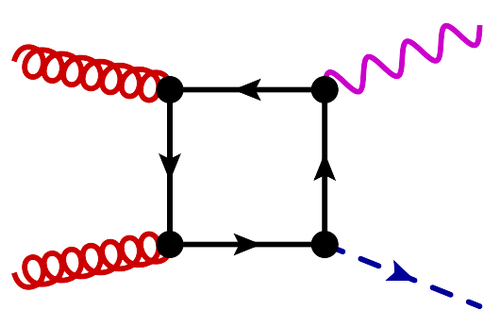
Higgs Strahlung



NLO: Han, Willenbrock '90
NNLO: Brein, Djouadi, RH '03 → vh@nnlo
EW: Ciccolini, Dittmaier, Krämer '03 → HAWK

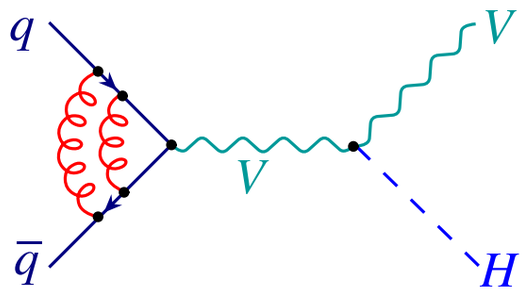


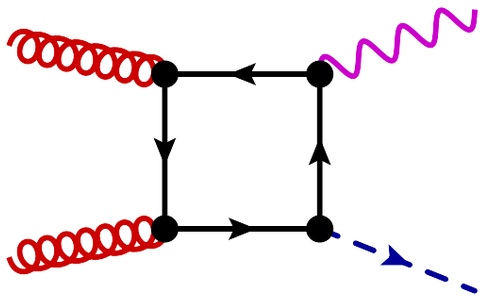
based on Hamberg, v. Neerven, Matsuura '91

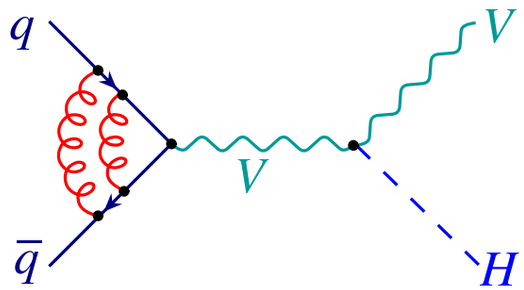


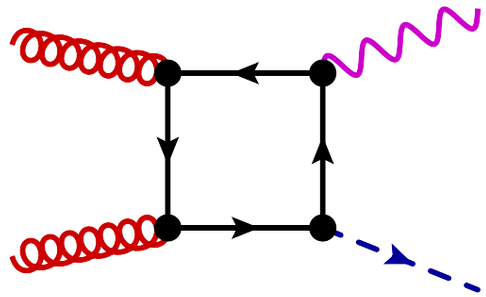
Kniehl '90

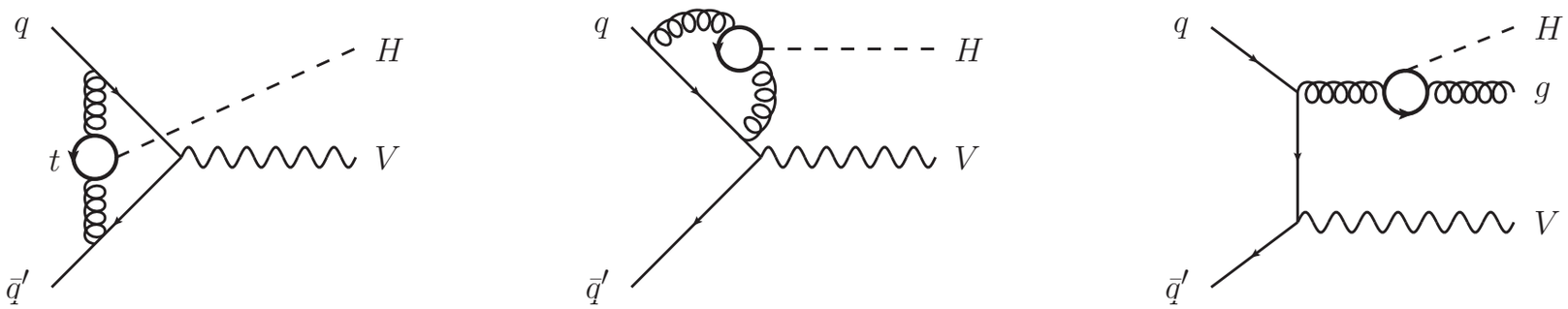
jet substructure → see talk by Gavin Salam


q
V
V
$\bar{q}$
H

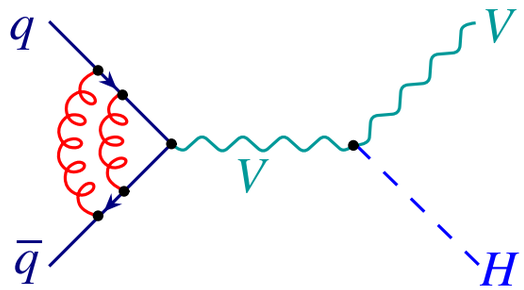


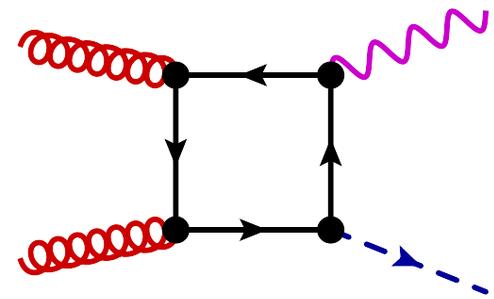


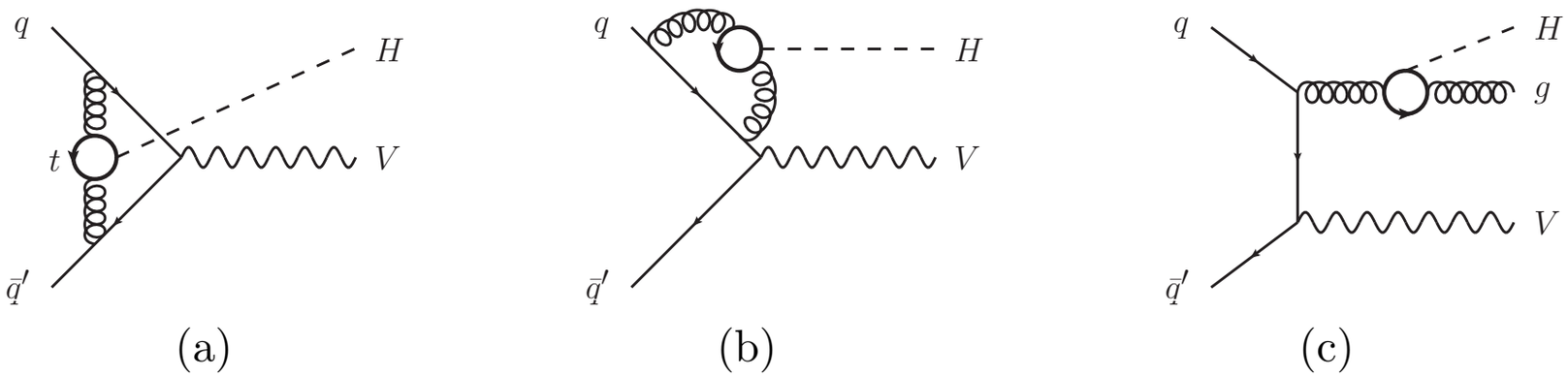


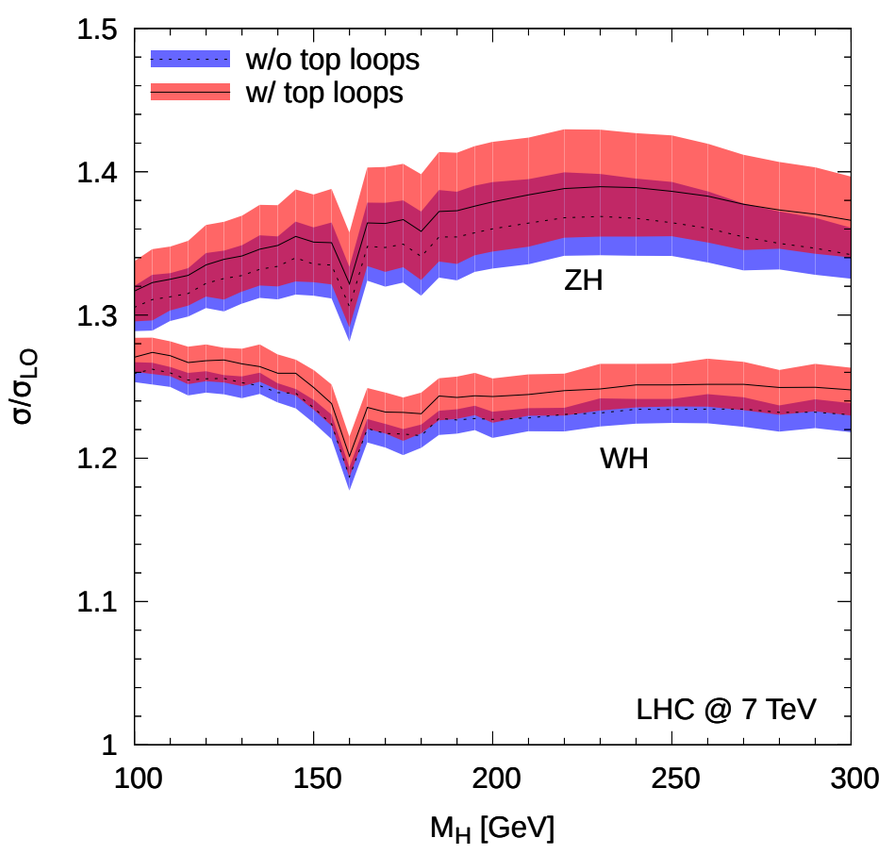


(a) (b) (c)







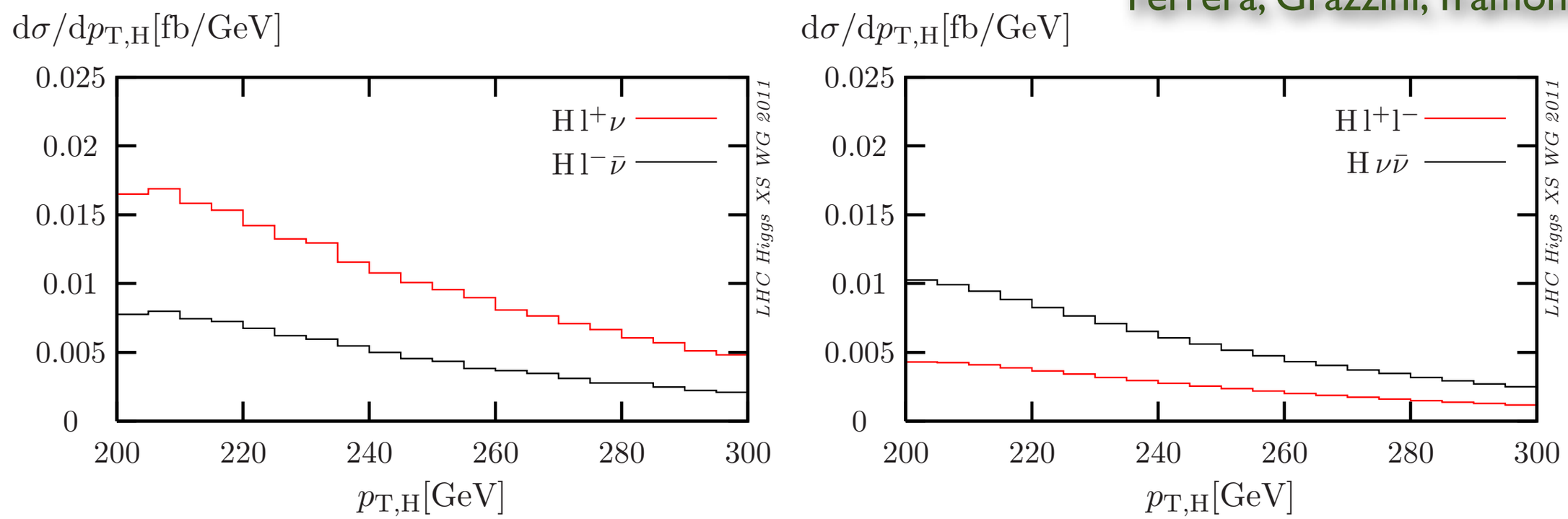


Full result at $\mathcal{O}(\alpha_s^2 G_F)$

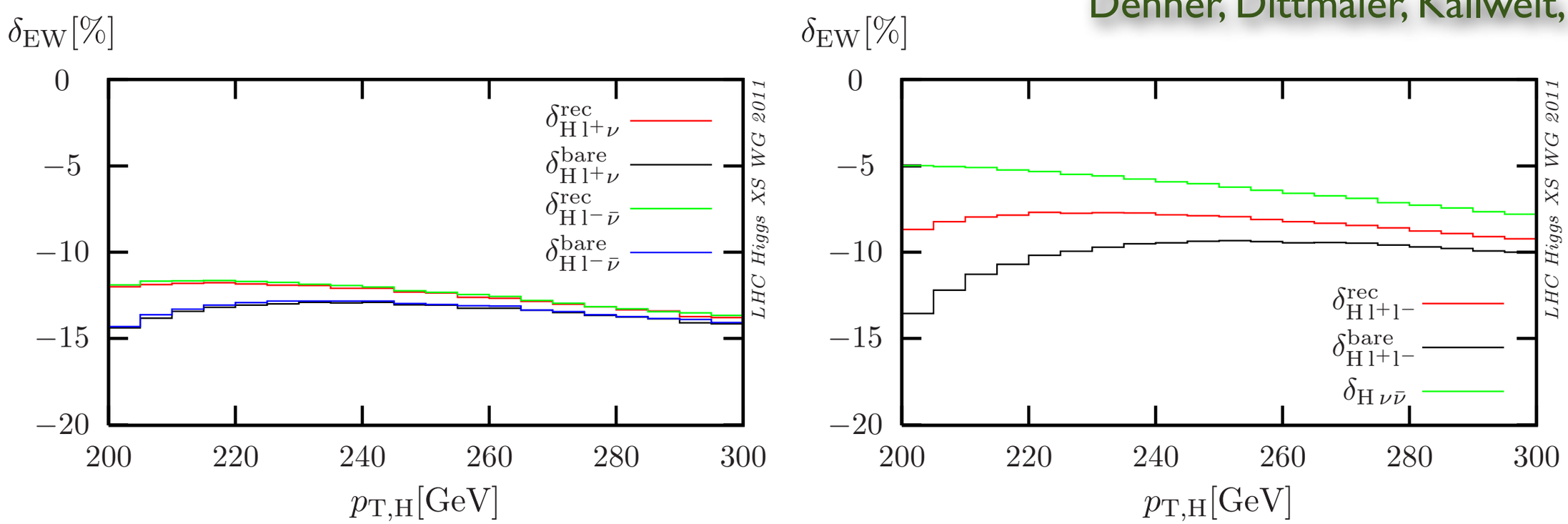
Brein, RH, Wiesemann, Zirke '11

Higgs Strahlung: fully differential NNLO

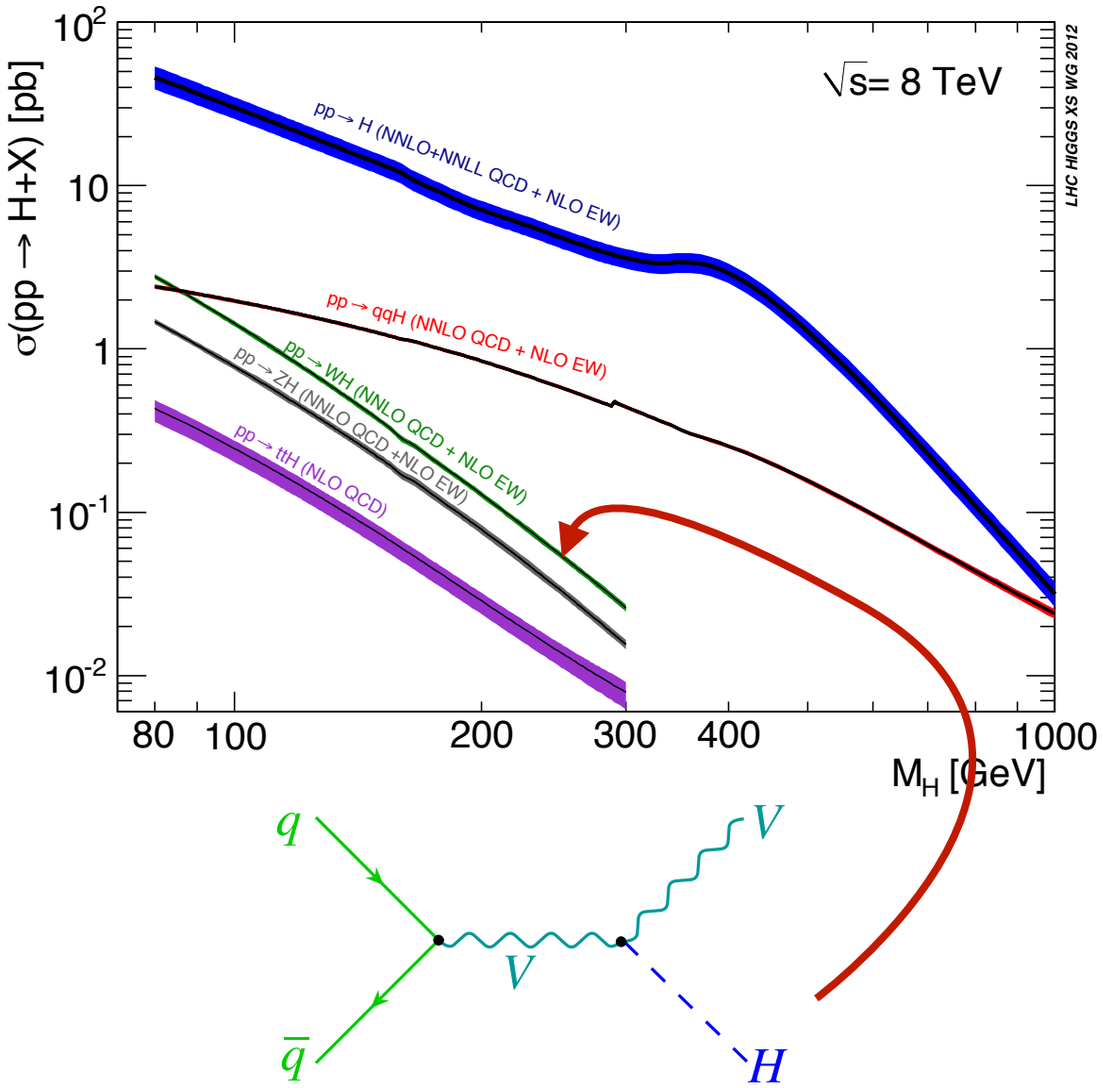
Ferrera, Grazzini, Tramontano '12



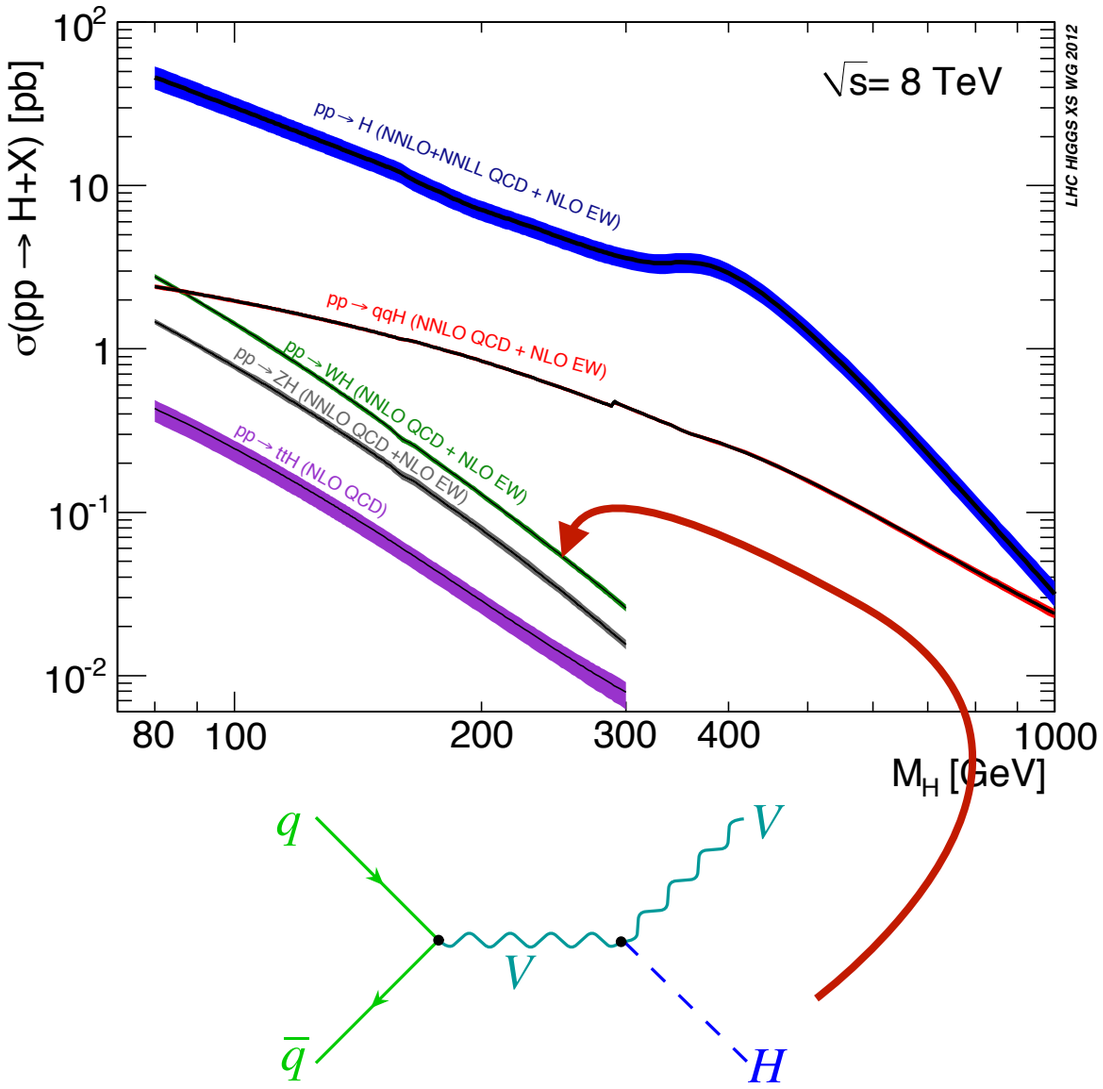
Denner, Dittmaier, Kallweit, Mück '11



Higgs Strahlung

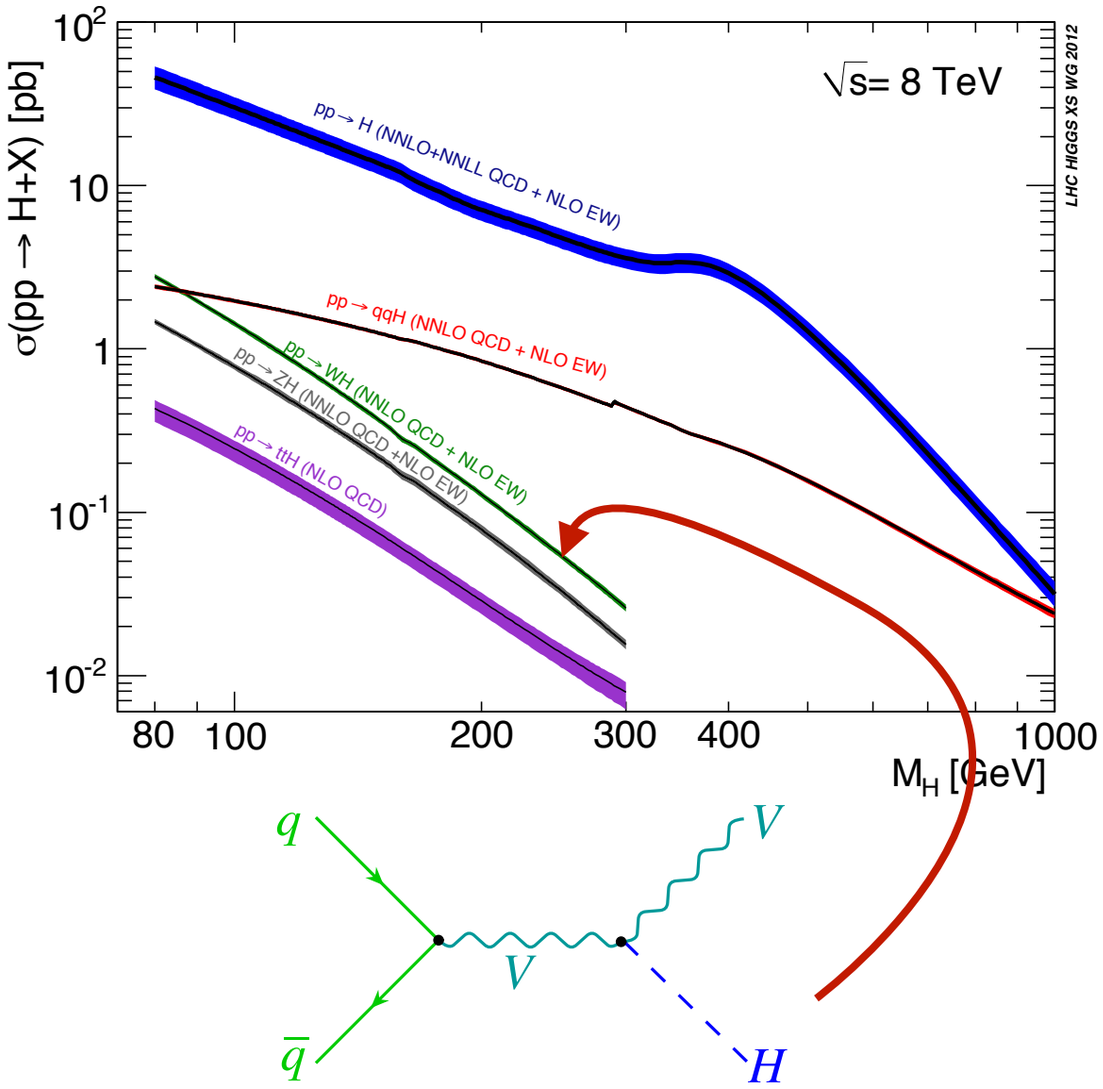


Higgs Strahlung



In summary

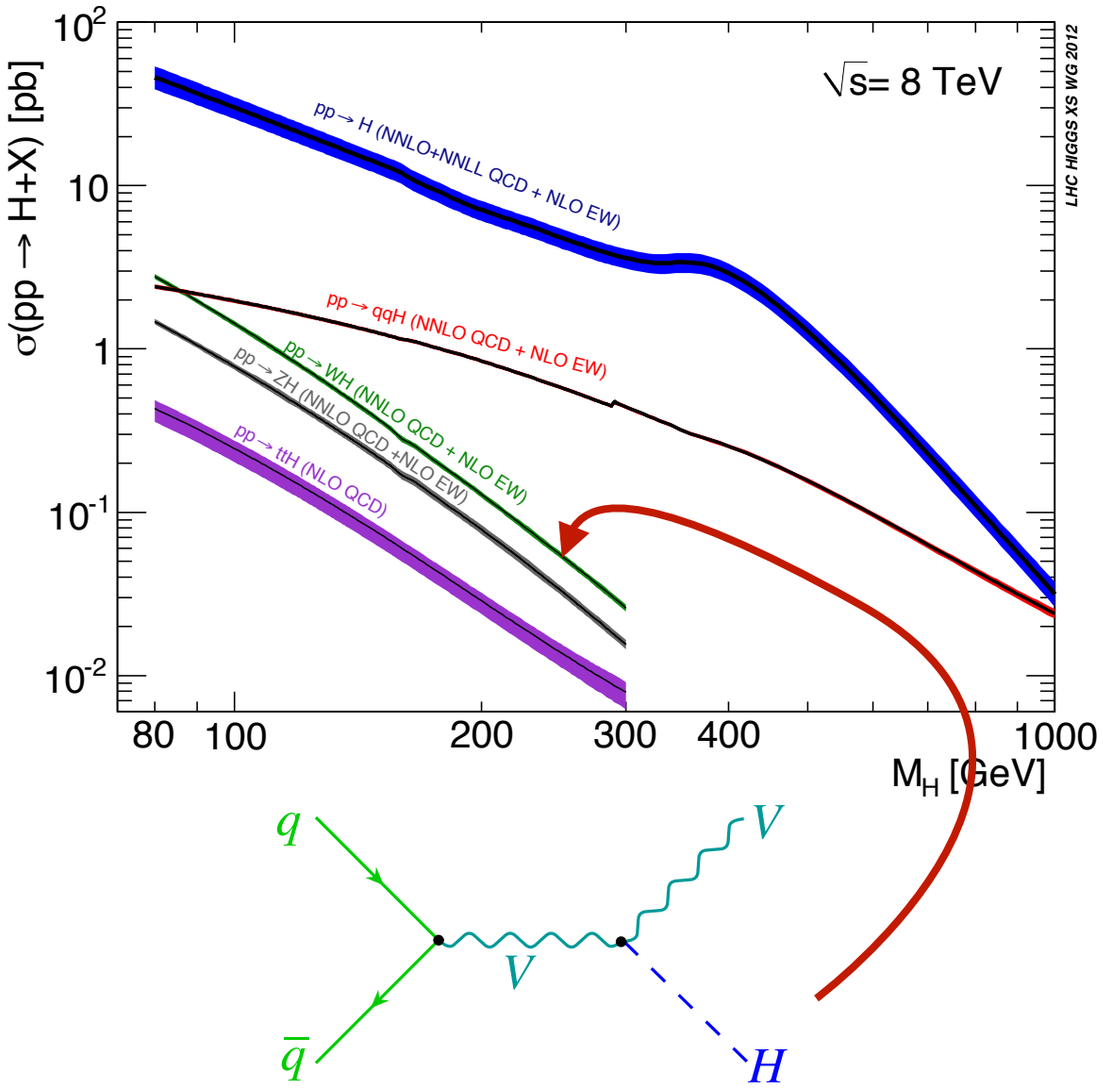
Higgs Strahlung



In summary

- under very good control

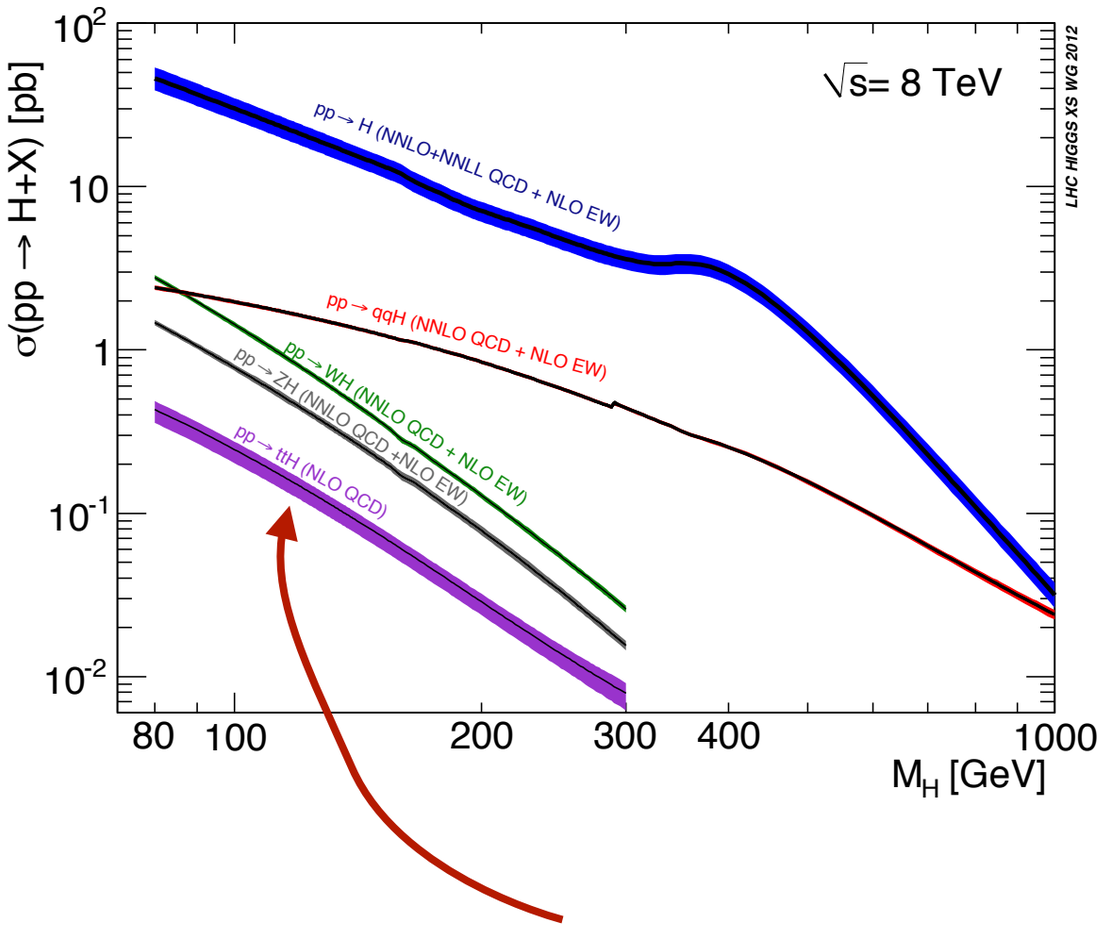
Higgs Strahlung

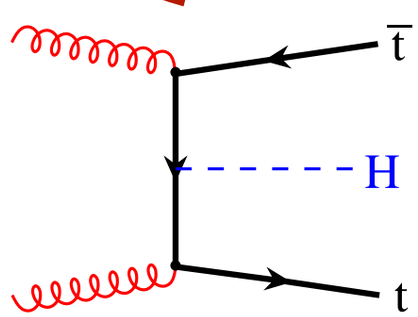


In summary

- under very good control
- high pheno potential

$t\bar{t}H$

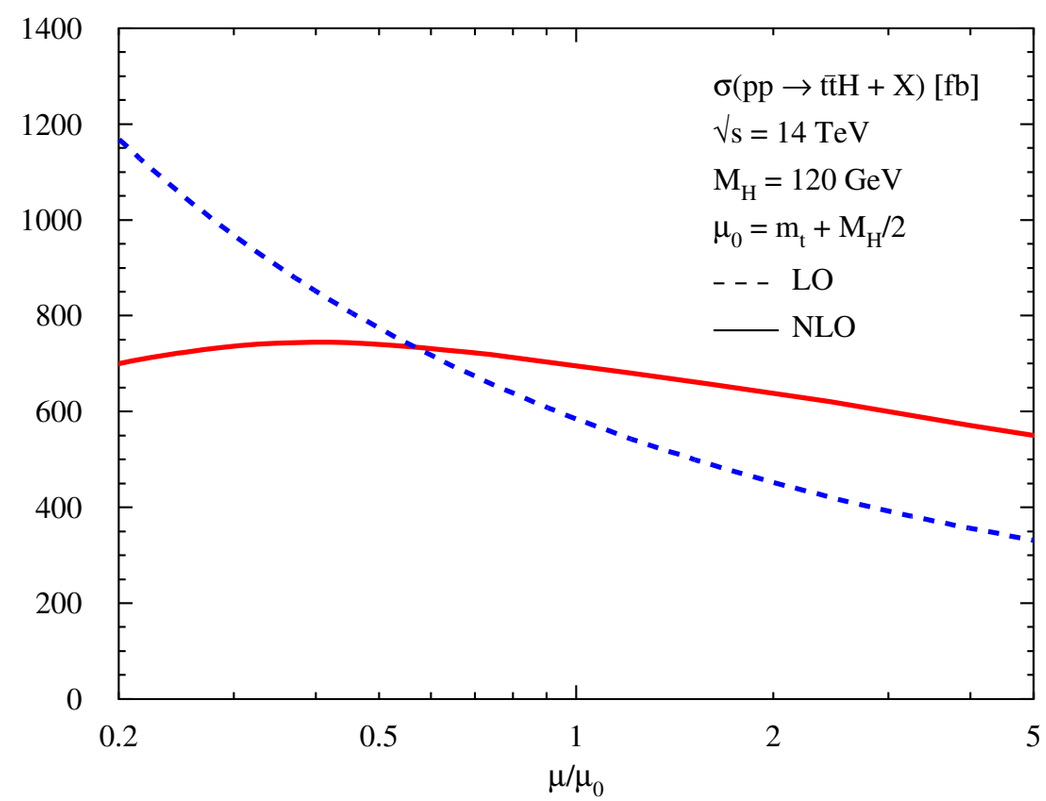




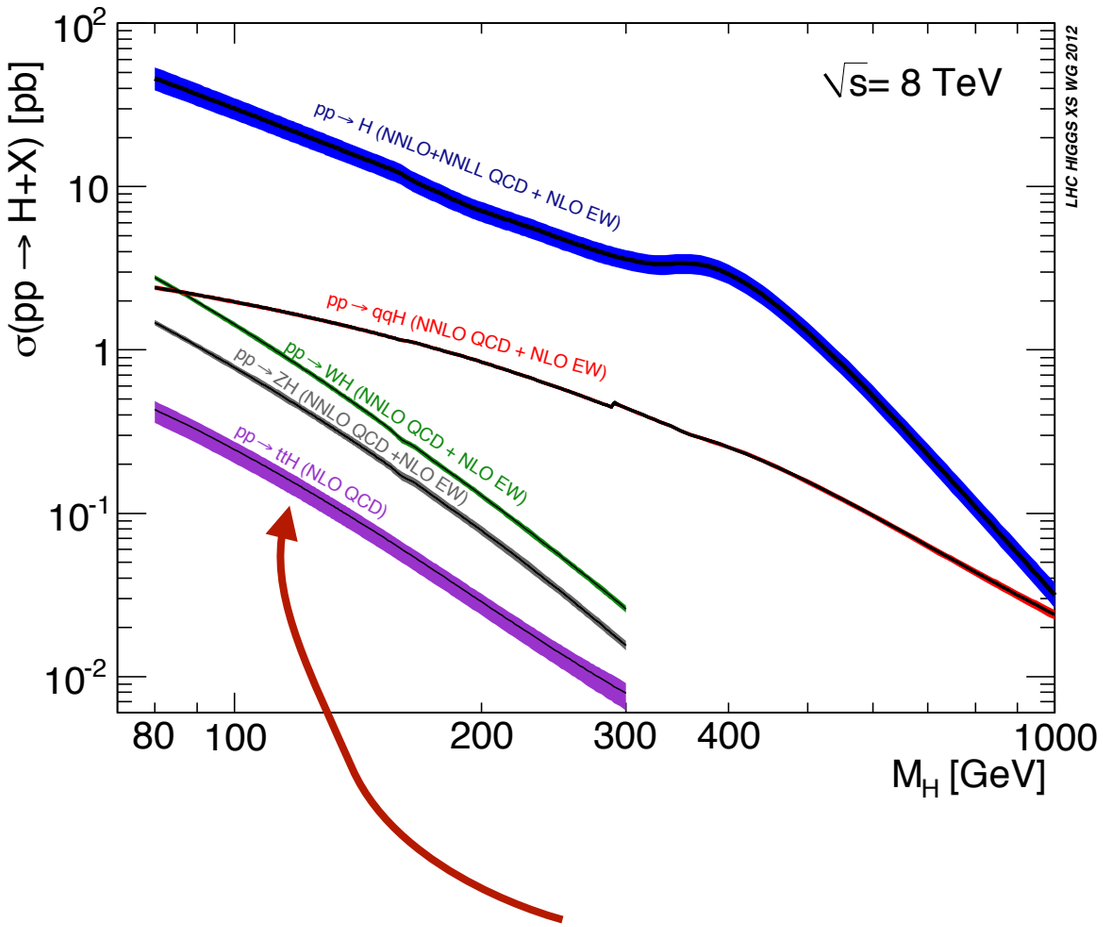
NLO:

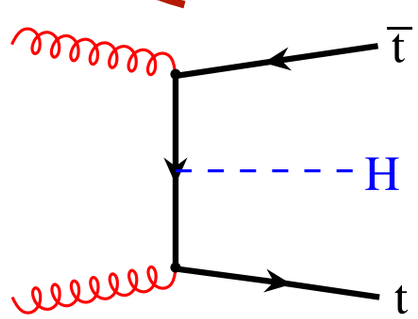
Beenakker, Dittmaier, Krämer, Plümper, Spira, Zerwas '01;

Dawson, Reina, Wackeroth, Orr, Jackson '01-'03;



$t\bar{t}H$



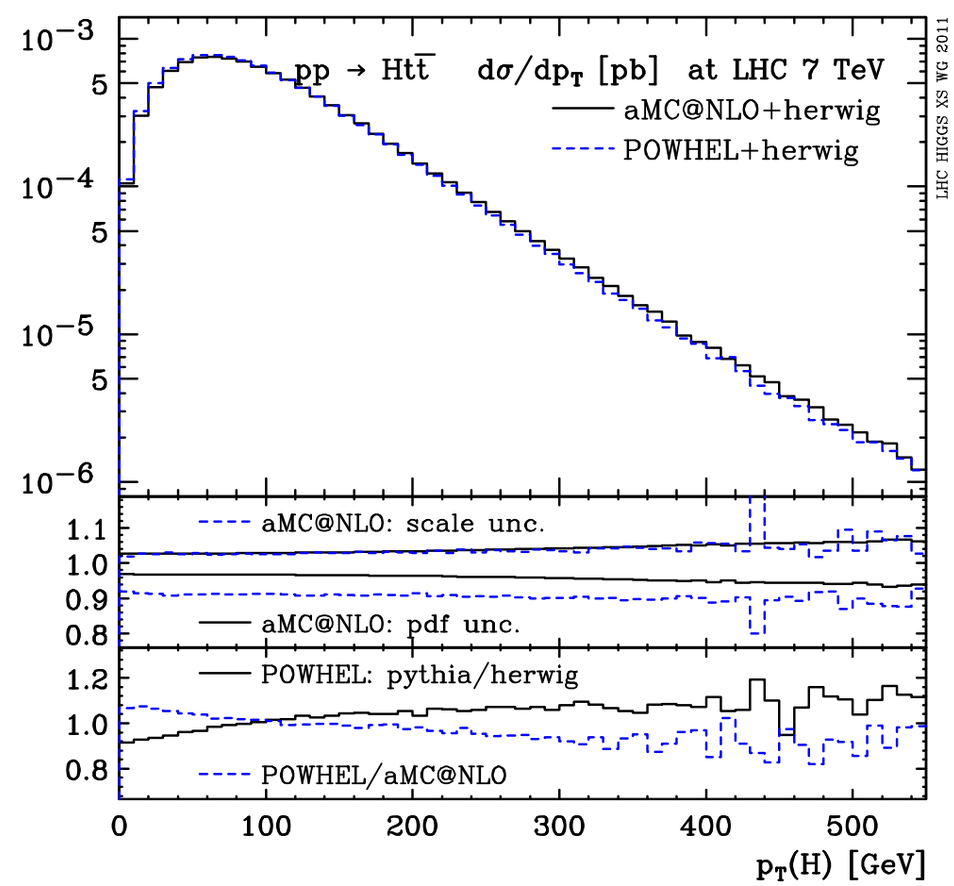


NLO:

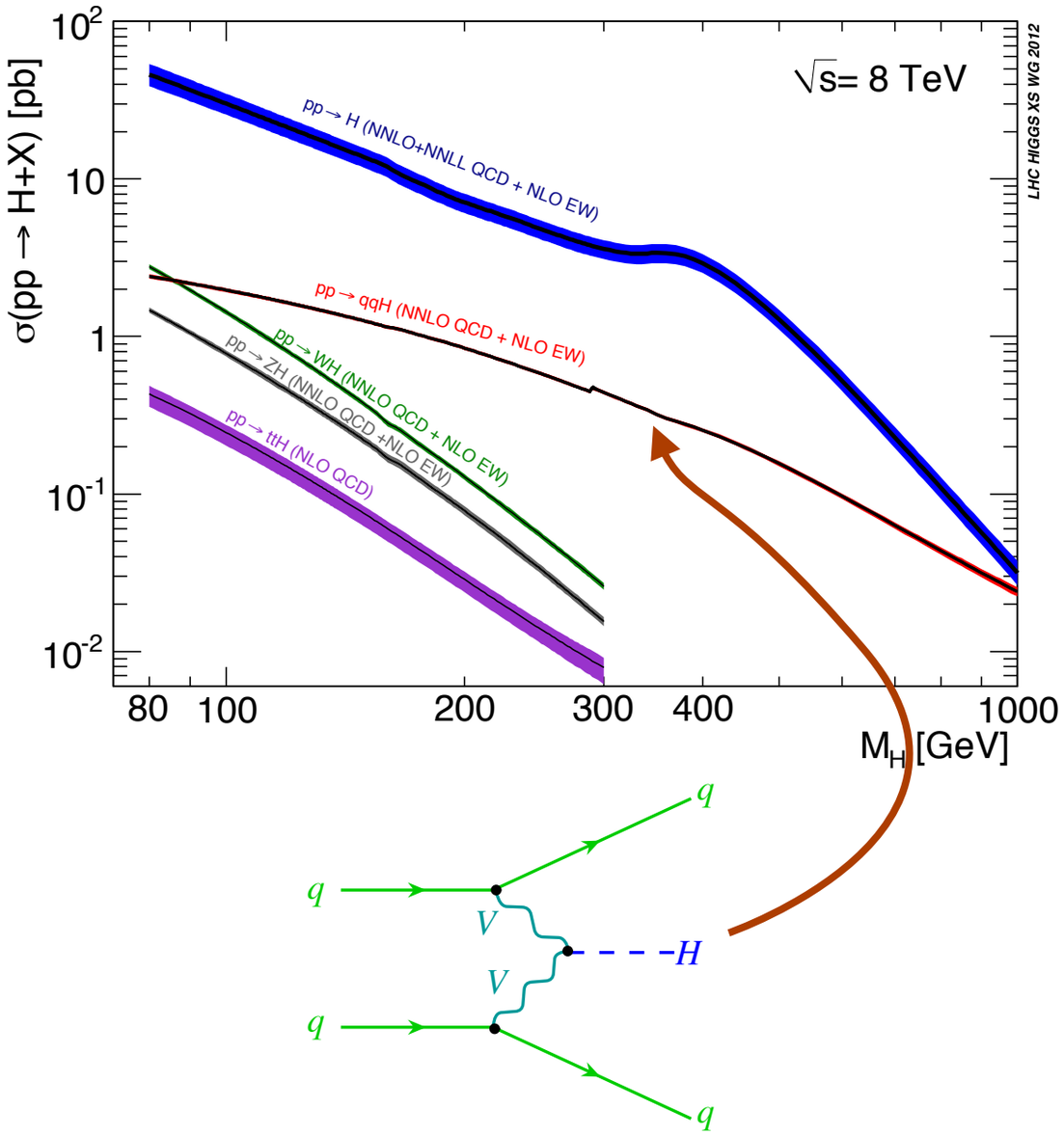
Beenakker, Dittmaier, Krämer, Plümper, Spira, Zerwas '01;
Dawson, Reina, Wackeroth, Orr, Jackson '01-'03;

NLO+PS:

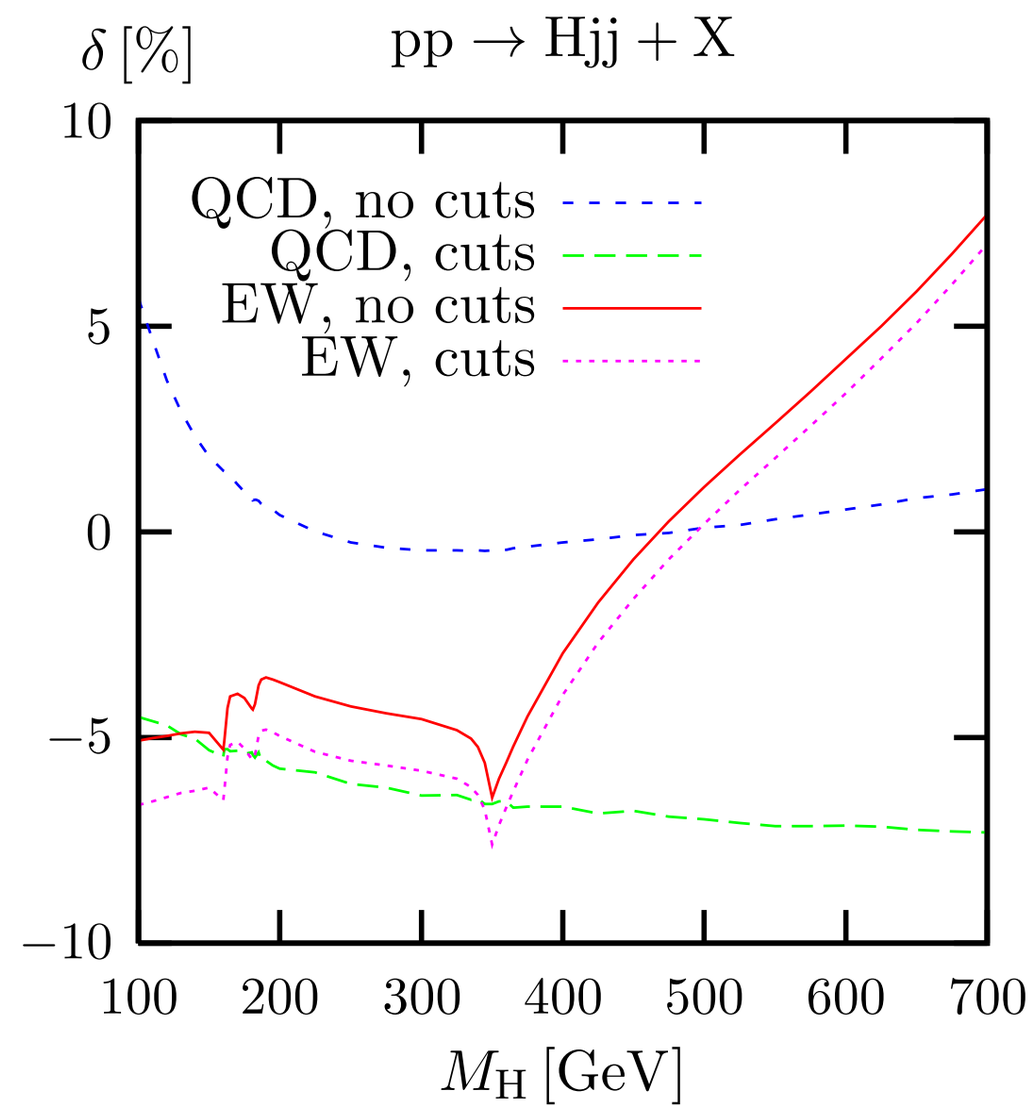
Frederix, Frixione, Hirschi, Maltoni, Pittau, Torielli '12 → aMC@NLO
Garzelli, Kardos, Papadopoulos, Trócsányi '11 → PowHel



Weak Boson Fusion

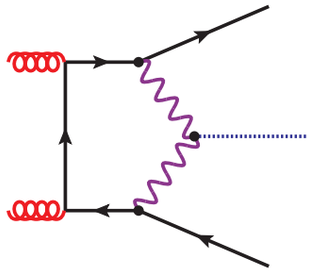


NLO QCD: Figy, Oleari, Zeppenfeld '03 → vbfnlo
NLO QCD+EW: Ciccolini, Denner, Dittmaier '08→ HAWK
NLO SUSY: Figy, Palmer, Weiglein '10



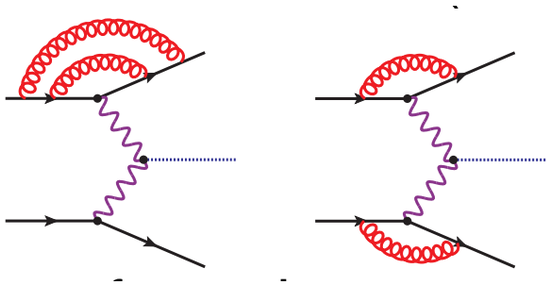
Weak Boson Fusion: Beyond-NLO

- gluon fusion/WBF interference
  Andersen, Binoth, Heinrich, Smillie '07; Bredenstein, Hagiwara, Jäger '08
- gluon induced WBF
  RH, Vollinga, Weber '08

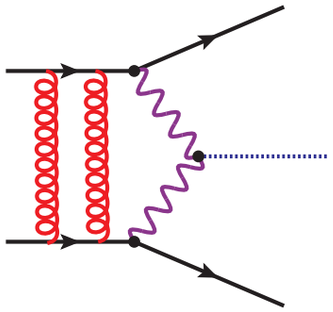


part of NNLO

- DIS-like NNLO (inclusive)
  Bolzoni, Maltoni, Moch, Zaro '11

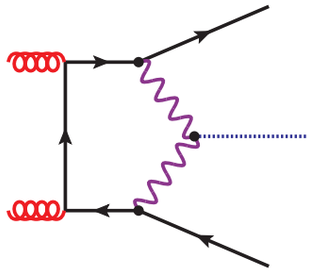


- missing:



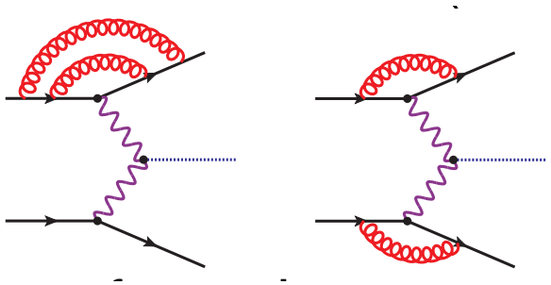
Weak Boson Fusion: Beyond-NLO

- gluon fusion/WBF interference
  Andersen, Binoth, Heinrich, Smillie '07; Bredenstein, Hagiwara, Jäger '08
- gluon induced WBF
  RH, Vollinga, Weber '08



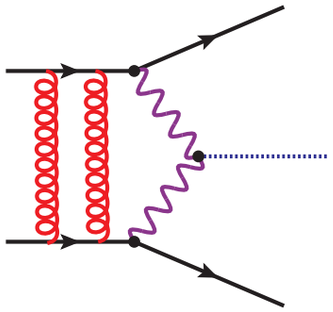
part of NNLO

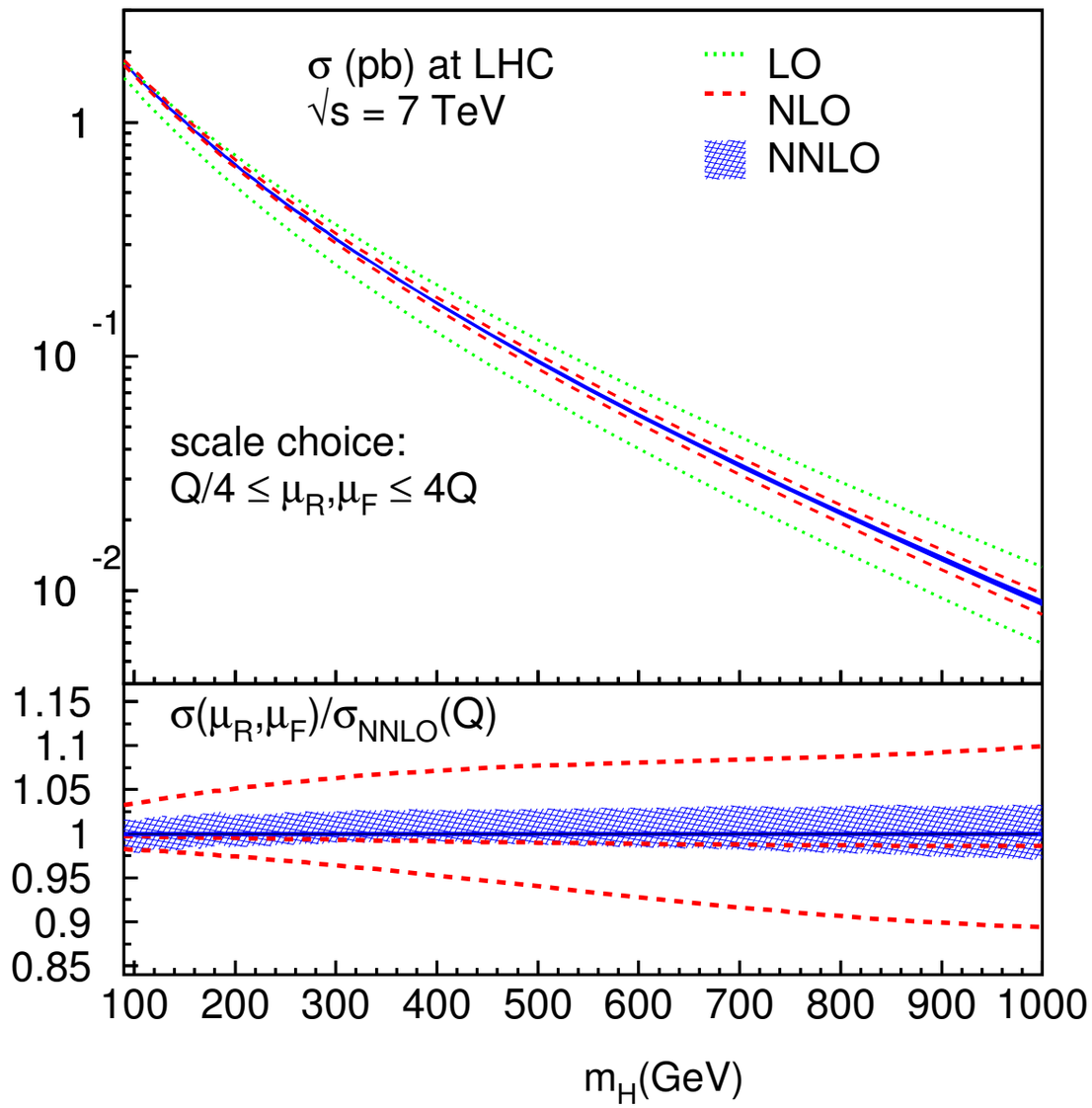
- DIS-like NNLO (inclusive)
  Bolzoni, Maltoni, Moch, Zaro '11



talk on Friday (YSF)

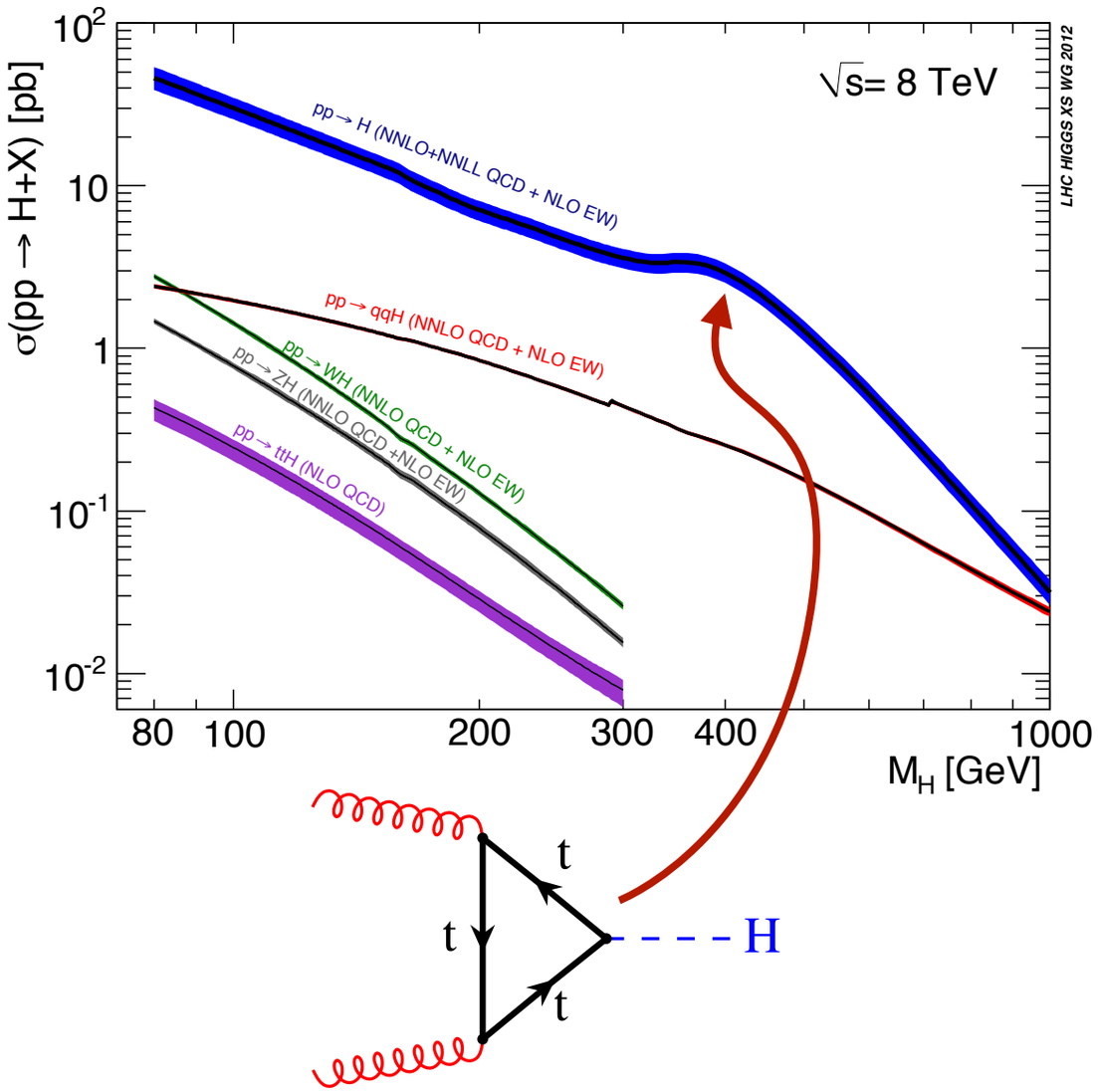
- missing:

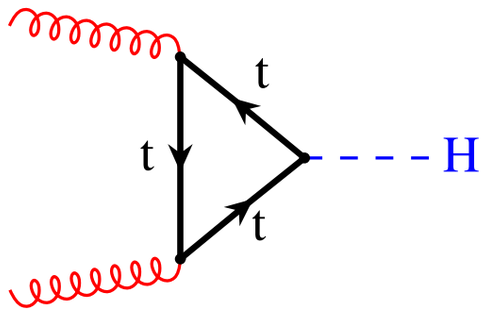




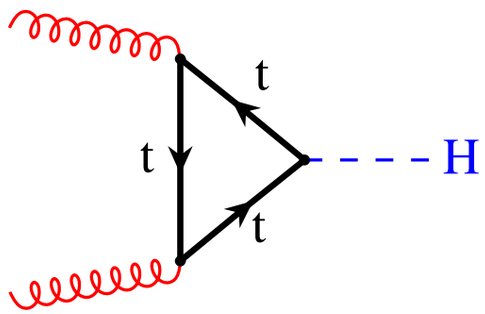
Bolzoni, Maltoni, Moch, Zaro '11

Gluon fusion



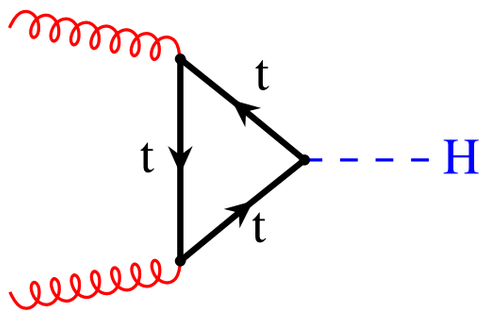


sensitive to heavy particle spectrum



sensitive to heavy particle spectrum

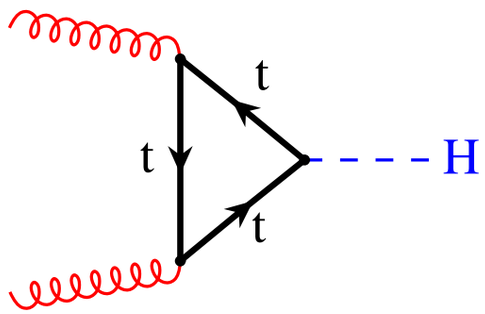
e.g. 4th generation:



sensitive to heavy particle spectrum

e.g. 4th generation:

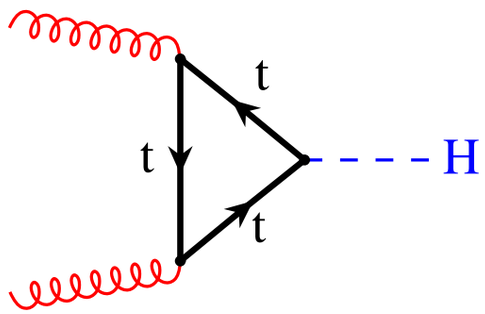
$$\sigma \overset{m_t \gg M_H}{\rightarrow} \frac{\pi}{256\sqrt{2}} \left(\frac{\alpha_s}{\pi}\right)^2 \left(\frac{y_t}{m_t}\right)^2$$



sensitive to heavy particle spectrum

e.g. 4th generation:

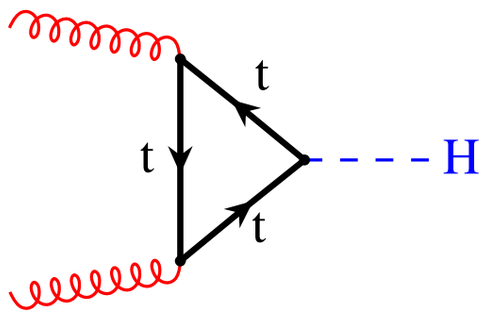
$$\sigma \overset{m_t \gg M_H}{\rightarrow} \frac{\pi}{256\sqrt{2}} \left(\frac{\alpha_s}{\pi}\right)^2 \left(\frac{y_t}{m_t} + \frac{y_{t'}}{m_{t'}} + \frac{y_{b'}}{m_{b'}}\right)^2$$



sensitive to heavy particle spectrum

e.g. 4th generation:

$$\sigma \overset{m_t \gg M_H}{\rightarrow} \frac{\pi}{256\sqrt{2}} \left(\frac{\alpha_s}{\pi}\right)^2 \left(\frac{m_t}{m_t} + \frac{m_{t'}}{m_{t'}} + \frac{m_{b'}}{m_{b'}}\right)^2$$

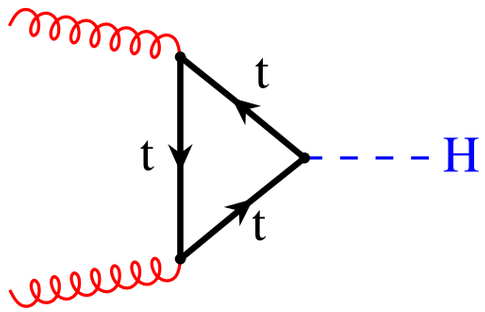


sensitive to heavy particle spectrum

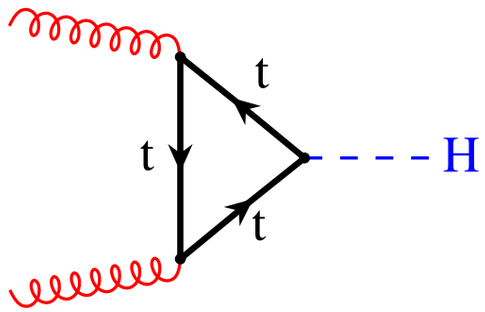
e.g. 4th generation:

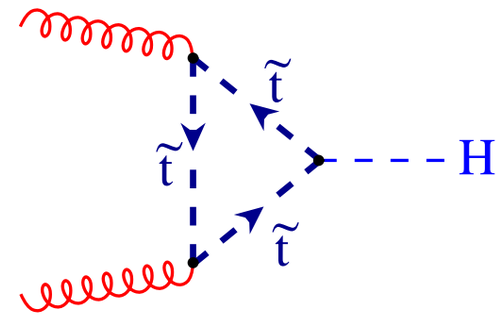
$$\sigma \overset{m_t \gg M_H}{\rightarrow} \frac{\pi}{256\sqrt{2}} \left(\frac{\alpha_s}{\pi}\right)^2 \left(\frac{m_t}{m_t} + \frac{m_{t'}}{m_{t'}} + \frac{m_{b'}}{m_{b'}}\right)^2$$

$$= 9 \frac{\pi}{256\sqrt{2}} \left(\frac{\alpha_s}{\pi}\right)^2$$

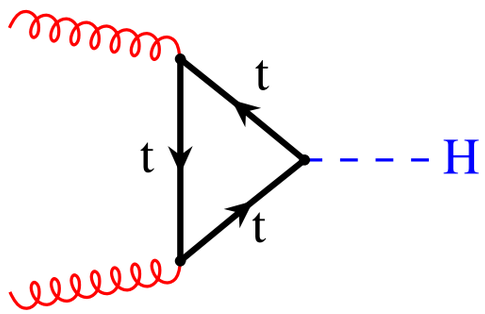


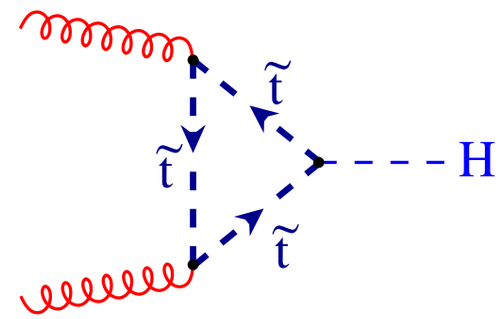
sensitive to heavy particle spectrum





sensitive to heavy particle spectrum

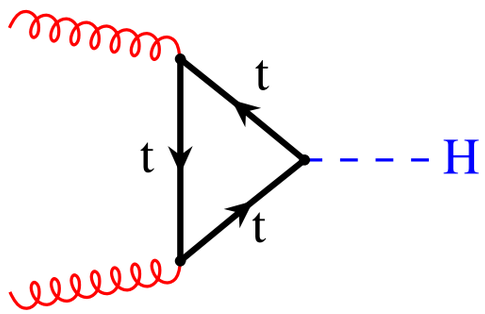


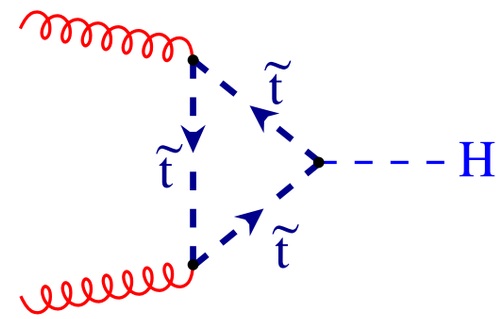


sensitive to heavy particle spectrum

LHC Higgs XS WG:

$$\sigma^{\rm MSSM}({\rm gg} \to \phi) \;=\; \left(\frac{g_{\rm t}^{\rm MSSM}}{g_{\rm t}^{\rm SM}}\right)^2 \sigma_{\rm tt}({\rm gg} \to \phi) + \left(\frac{g_{\rm b}^{\rm MSSM}}{g_{\rm b}^{\rm SM}}\right)^2 \sigma_{\rm bb}({\rm gg} \to \phi) + \frac{g_{\rm t}^{\rm MSSM}}{g_{\rm t}^{\rm SM}}\,\frac{g_{\rm b}^{\rm MSSM}}{g_{\rm b}^{\rm SM}} \sigma_{\rm tb}({\rm gg} \to \phi),$$



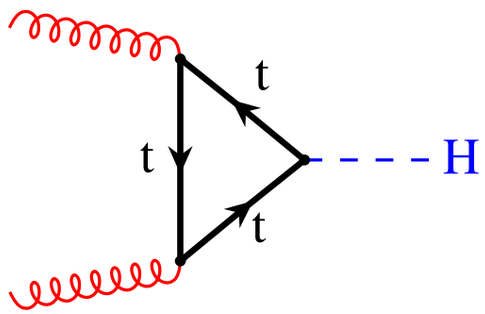


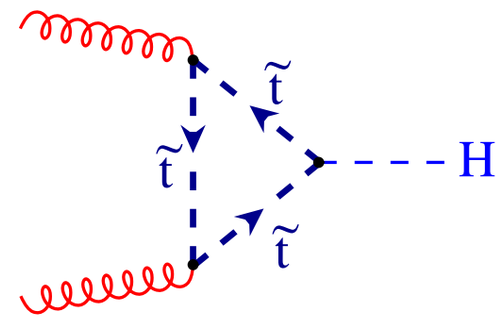
sensitive to heavy particle spectrum

LHC Higgs XS WG:

$$\sigma^{\rm MSSM}({\rm gg} \to \phi) \;=\; \left(\frac{g_{\rm t}^{\rm MSSM}}{g_{\rm t}^{\rm SM}}\right)^2 \sigma_{\rm tt}({\rm gg} \to \phi) + \left(\frac{g_{\rm b}^{\rm MSSM}}{g_{\rm b}^{\rm SM}}\right)^2 \sigma_{\rm bb}({\rm gg} \to \phi) + \frac{g_{\rm t}^{\rm MSSM}}{g_{\rm t}^{\rm SM}}\,\frac{g_{\rm b}^{\rm MSSM}}{g_{\rm b}^{\rm SM}} \sigma_{\rm tb}({\rm gg} \to \phi),$$

All contributions for NLO MSSM Higgs known:





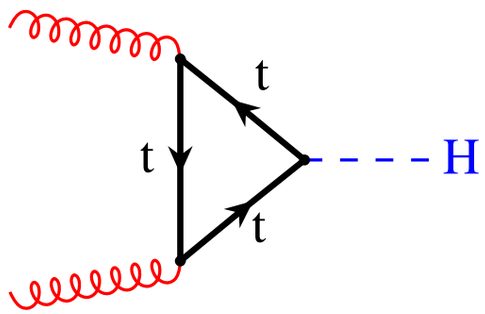
sensitive to heavy particle spectrum

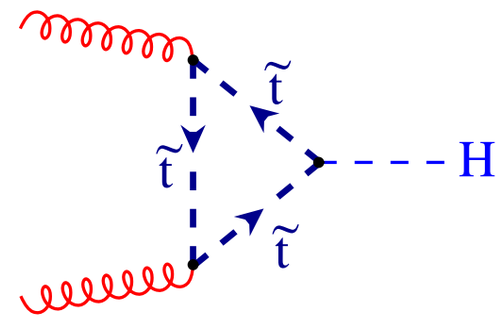
LHC Higgs XS WG:

$$\sigma^{\rm MSSM}({\rm gg}\to\phi) \;=\; \left(\frac{g_{\rm t}^{\rm MSSM}}{g_{\rm t}^{\rm SM}}\right)^2 \sigma_{\rm tt}({\rm gg}\to\phi) + \left(\frac{g_{\rm b}^{\rm MSSM}}{g_{\rm b}^{\rm SM}}\right)^2 \sigma_{\rm bb}({\rm gg}\to\phi) + \frac{g_{\rm t}^{\rm MSSM}}{g_{\rm t}^{\rm SM}}\,\frac{g_{\rm b}^{\rm MSSM}}{g_{\rm b}^{\rm SM}}\sigma_{\rm tb}({\rm gg}\to\phi),$$

All contributions for NLO MSSM Higgs known:

NLO: RH, Steinhauser '04; Anastasiou, Beerli, Daleo '08; + Bucherer, Kunszt '06; Mühlleitner, Rzehak, Spira '07/'08; Aglietti, Bonciani, Degrassi, Vicini '06; RH, Hofmann, Mantler '11; Degrassi, Slavich '08/'10; + Bagnasci, Vicini '11/'12





sensitive to heavy particle spectrum

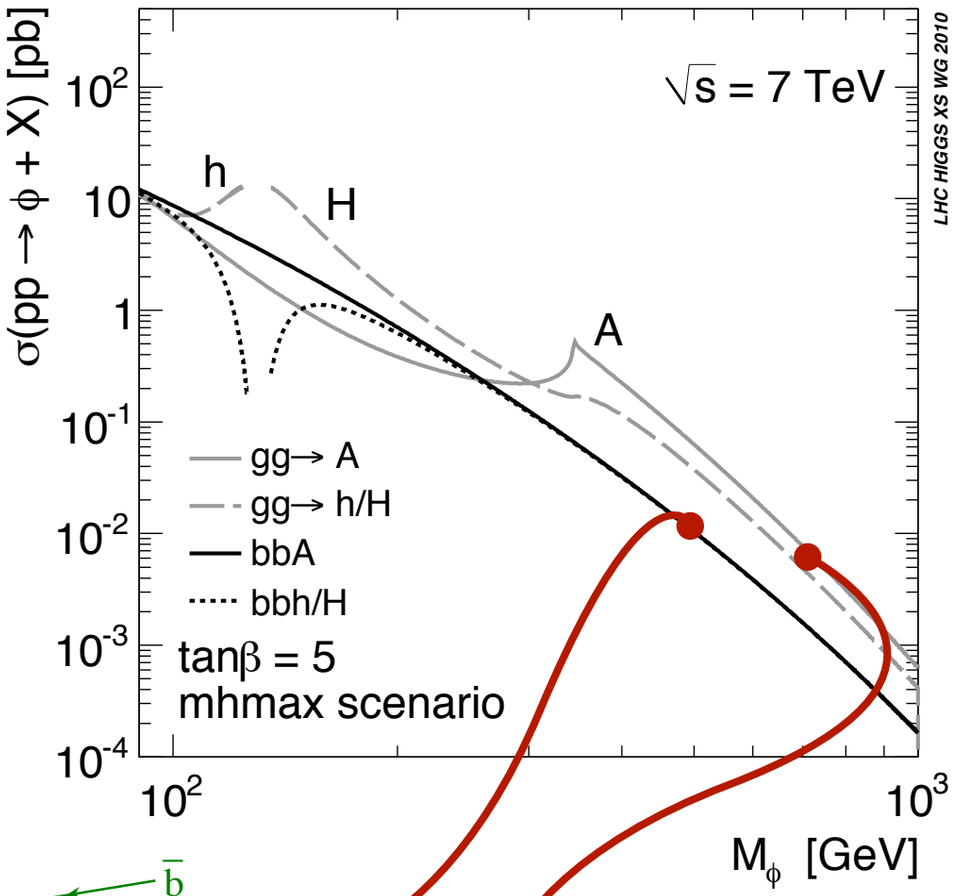
LHC Higgs XS WG:

$$\sigma^{\rm MSSM}({\rm gg}\to\phi) \;=\; \left(\frac{g_{\rm t}^{\rm MSSM}}{g_{\rm t}^{\rm SM}}\right)^2 \sigma_{\rm tt}({\rm gg}\to\phi) + \left(\frac{g_{\rm b}^{\rm MSSM}}{g_{\rm b}^{\rm SM}}\right)^2 \sigma_{\rm bb}({\rm gg}\to\phi) + \frac{g_{\rm t}^{\rm MSSM}}{g_{\rm t}^{\rm SM}}\,\frac{g_{\rm b}^{\rm MSSM}}{g_{\rm b}^{\rm SM}}\sigma_{\rm tb}({\rm gg}\to\phi),$$

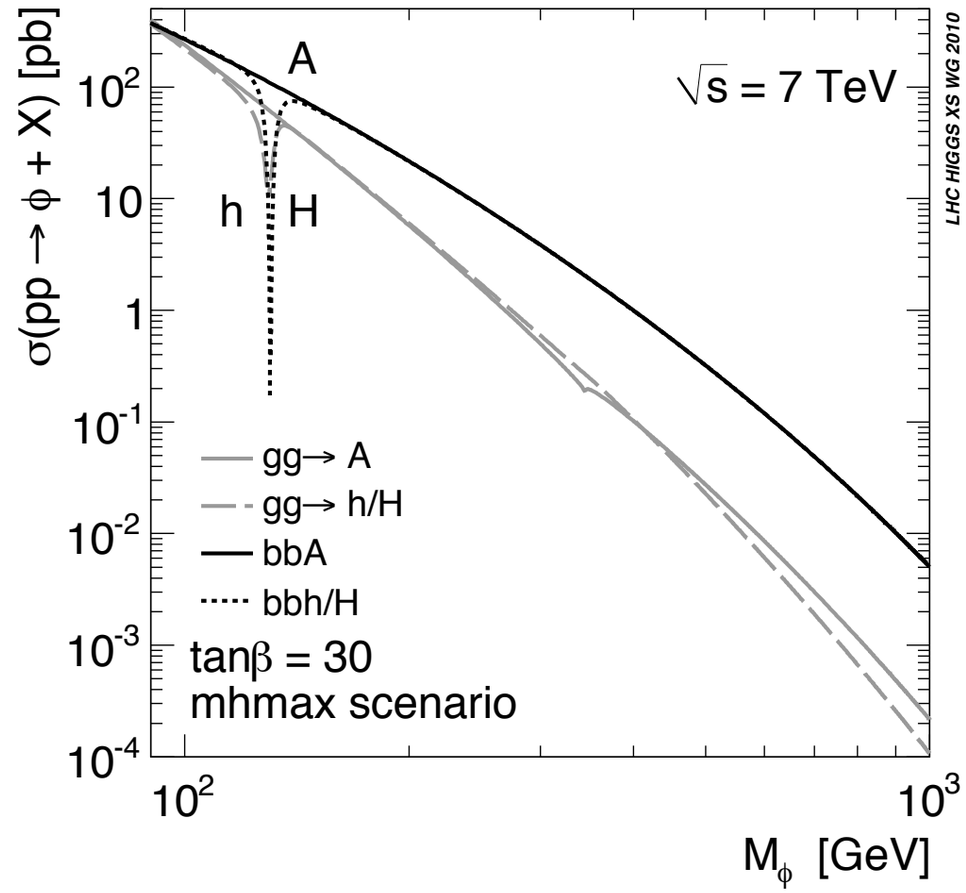
All contributions for NLO MSSM Higgs known:

NLO: RH, Steinhauser '04; Anastasiou, Beerli, Daleo '08; + Bucherer, Kunszt '06; Mühlleitner, Rzehak, Spira '07/'08; Aglietti, Bonciani, Degrassi, Vicini '06; RH, Hofmann, Mantler '11; Degrassi, Slavich '08/'10; + Bagnasci, Vicini '11/'12

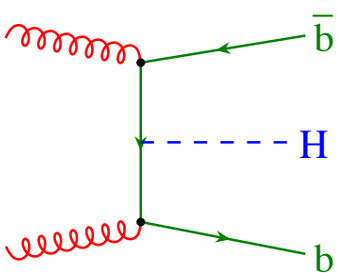
talk on Thursday (YSF)

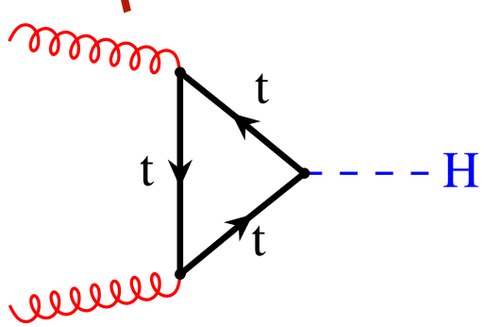

σ(pp → φ + X) [pb]
√s = 7 TeV
LHC HIGGS XS WG 2010
h
H
A
gg→ A
gg→ h/H
bbA
bbh/H
tanβ = 5
mhmax scenario
M_φ [GeV]

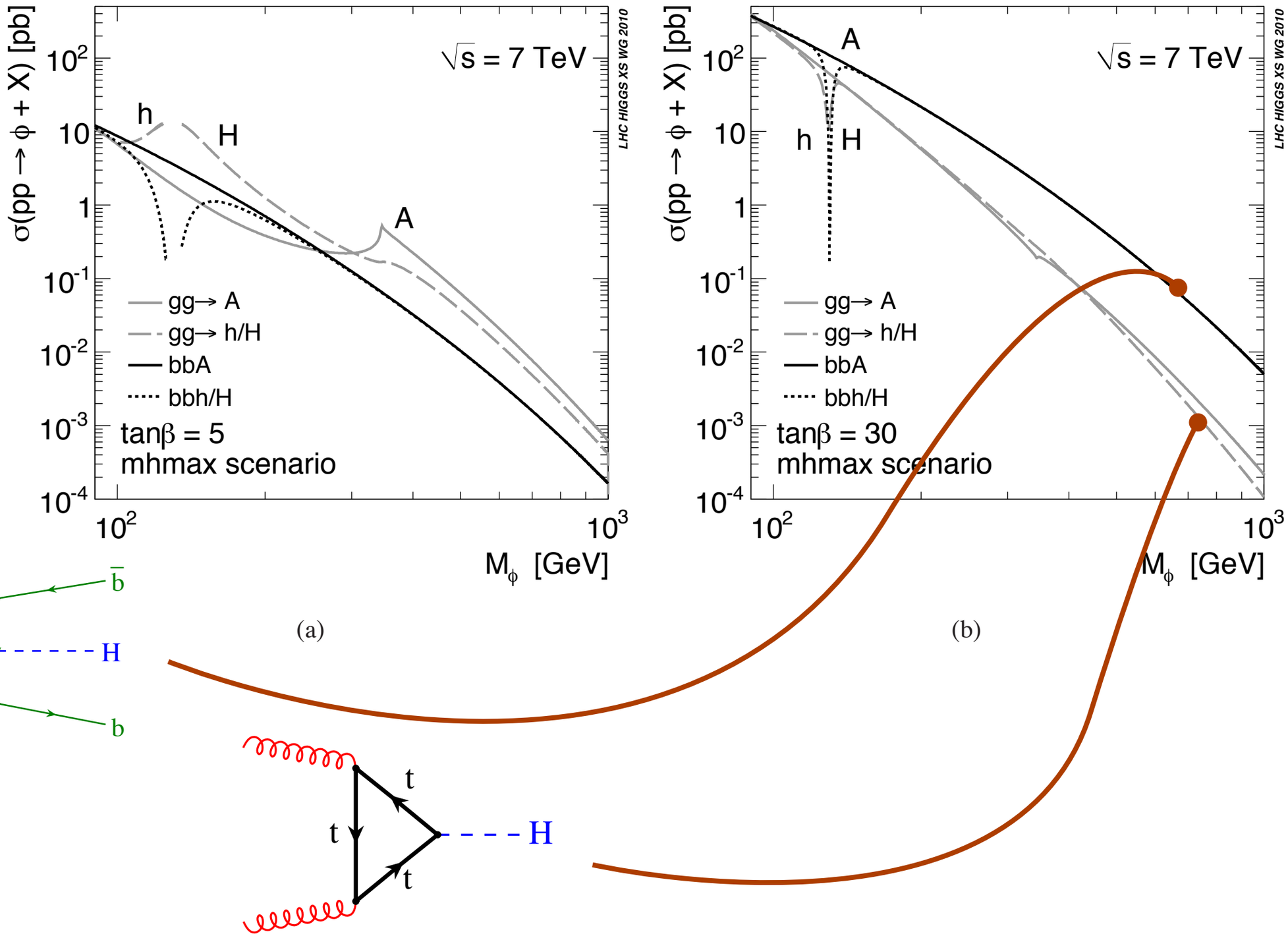
(a)

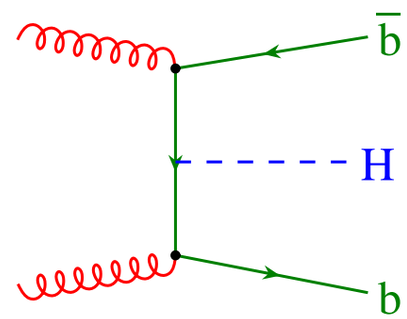

σ(pp → φ + X) [pb]
√s = 7 TeV
LHC HIGGS XS WG 2010
A
h
H
gg→ A
gg→ h/H
bbA
bbh/H
tanβ = 30
mhmax scenario
M_φ [GeV]

(b)

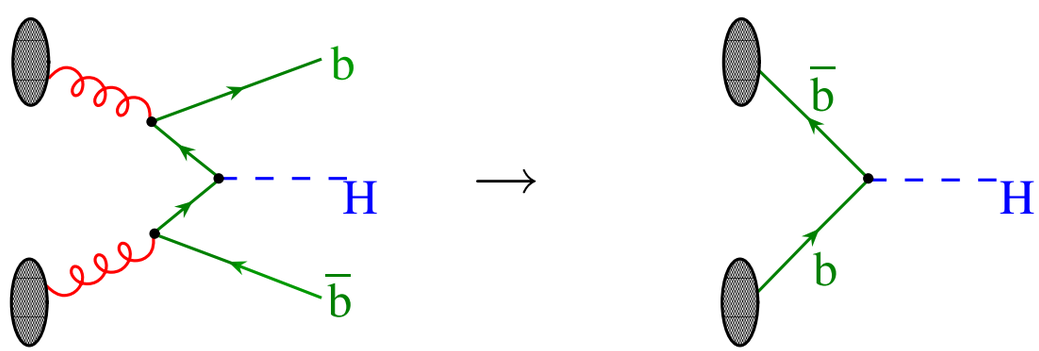

b̄
H
b


t
t
t
H

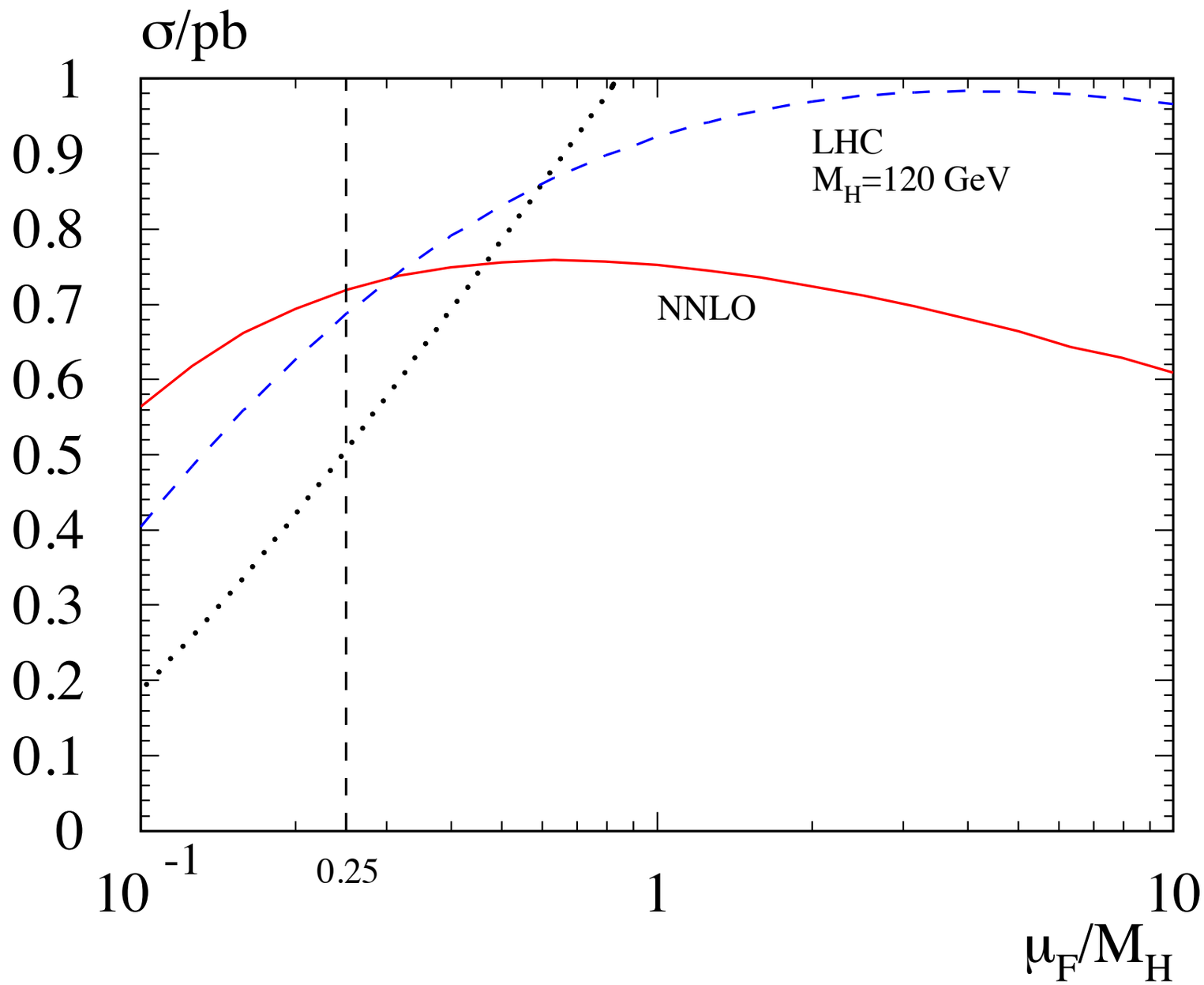

σ(pp → φ + X) [pb]
√s = 7 TeV
LHC HIGGS XS WG 2010
h
H
A
gg→ A
gg→ h/H
bbA
bbh/H
tanβ = 5
mhmax scenario
M_φ [GeV]
(a)
tanβ = 30
(b)
b̄
b
t
t
t

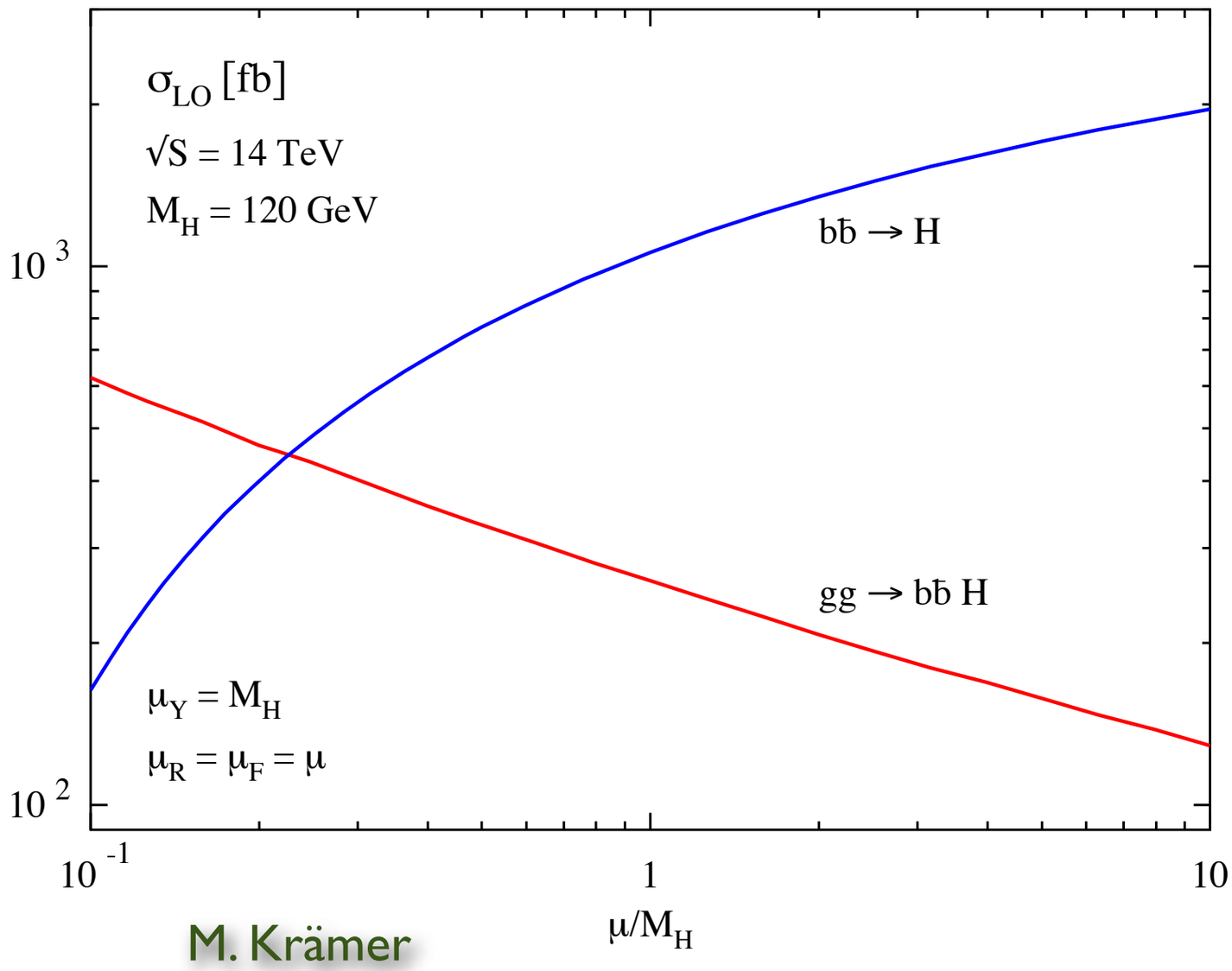


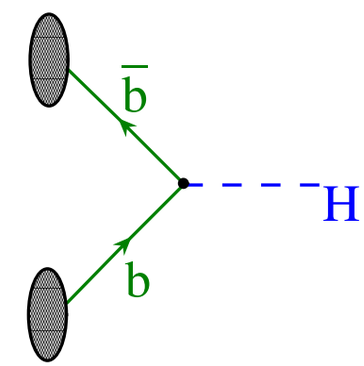
- collinear logarithms: $\sim \alpha_s \ln(m_b/M_H) \sim \alpha_s \ln(5/200)$
- resummation: bottom quarks as partons

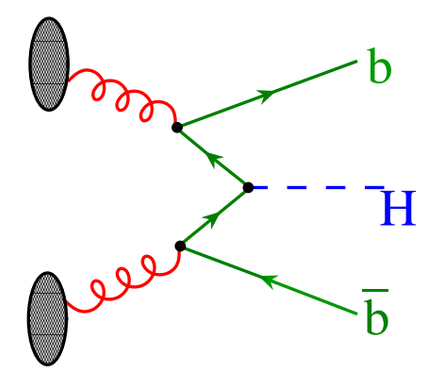


4FS 5FS

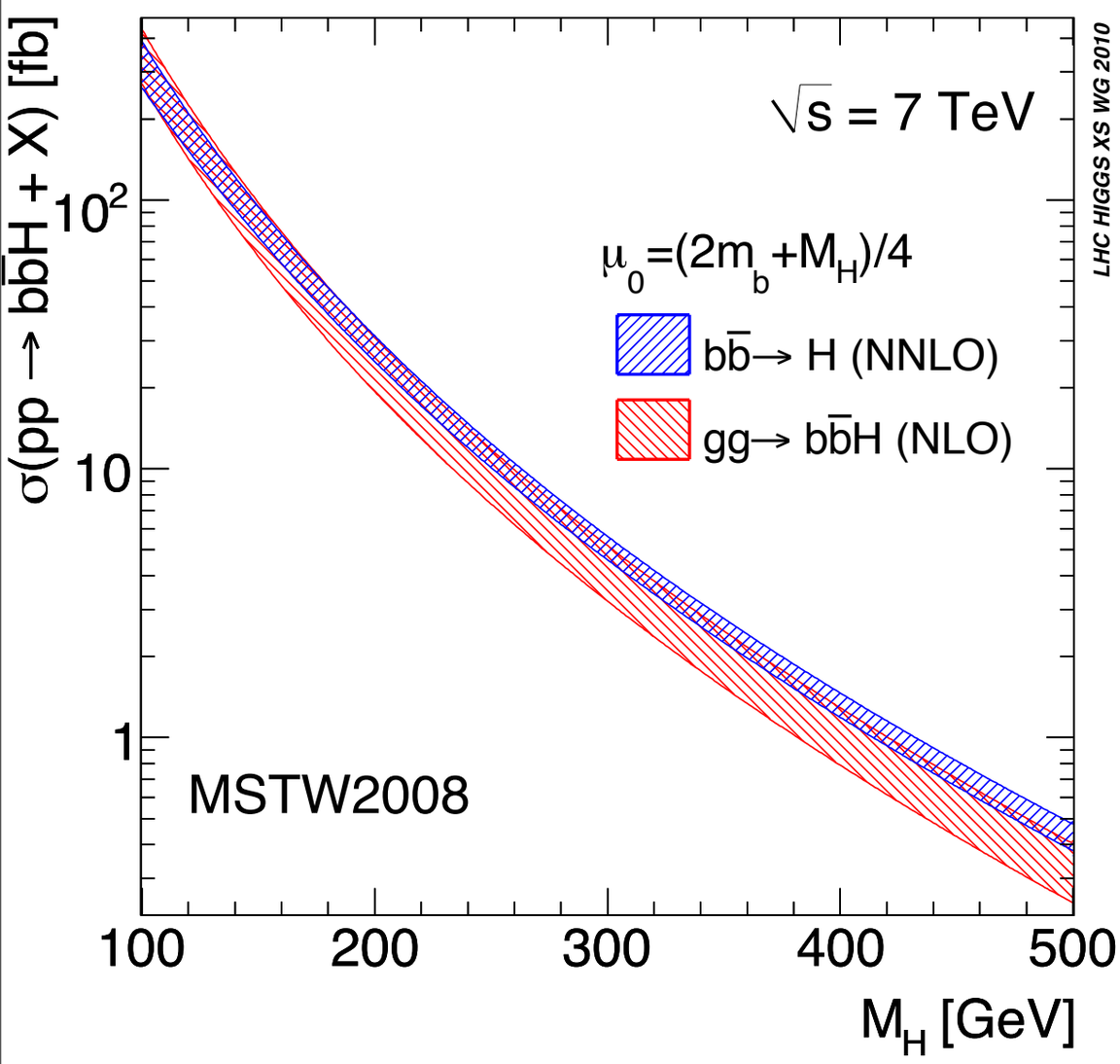

σ/pb
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
LHC
M_H=120 GeV
NNLO
10^-1
0.25
1
10
μ_F/M_H


σLO [fb]
√S = 14 TeV
MH = 120 GeV
bb̄ → H
gg → bb̄ H
μY = MH
μR = μF = μ
10 3
10 2
10 -1
1
10
μ/MH


b̄
b
H


b
H
b̄

M. Krämer



Santander matching:

$$\sigma = \frac{\sigma^{4FS} + w\sigma^{5FS}}{1+w}$$

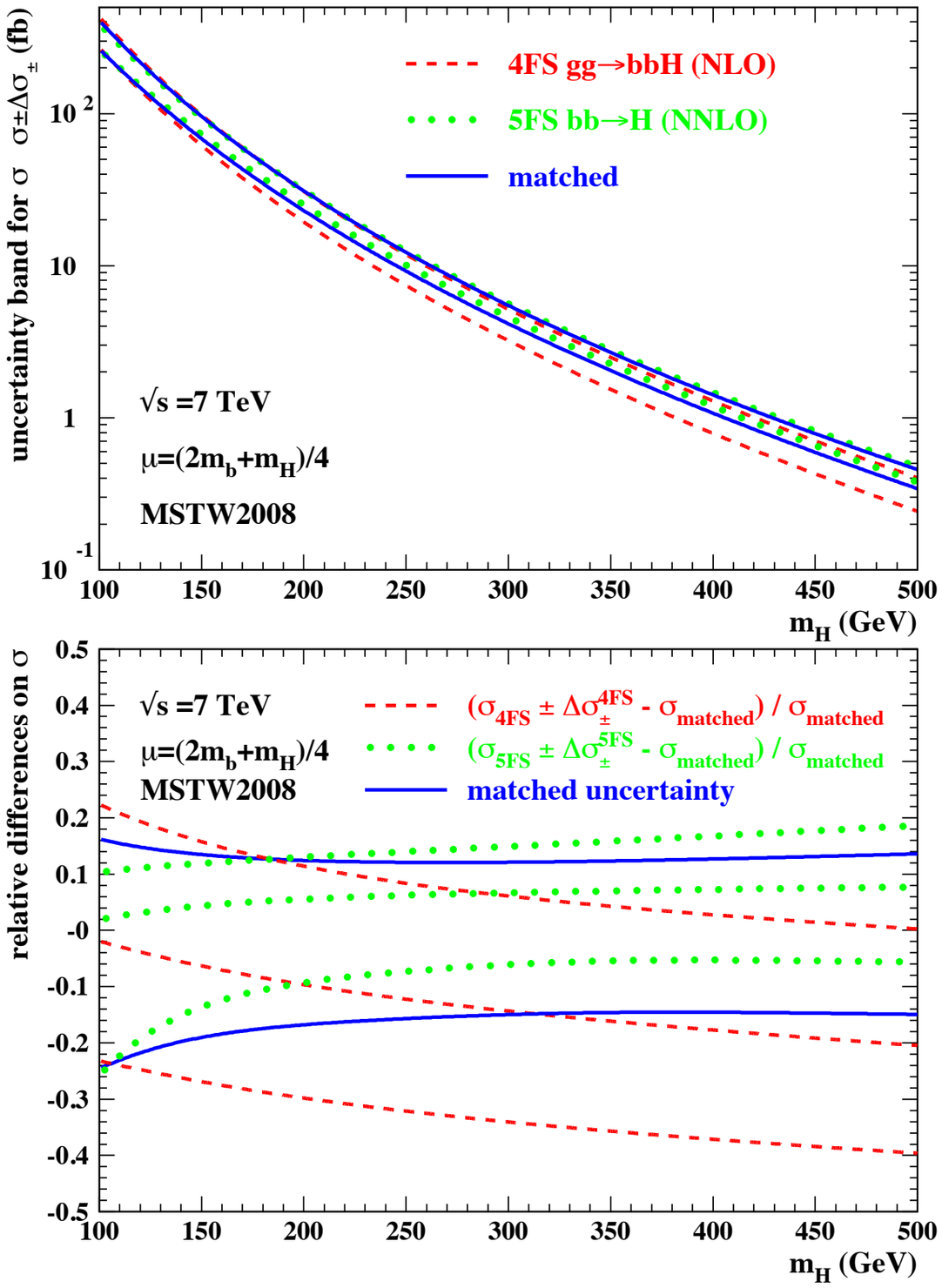
$$w = \log\frac{M_H}{m_b} - 1$$

RH, Krämer, Schumacher '11

see also
Maltoni, Ridolfi, Ubiali '12

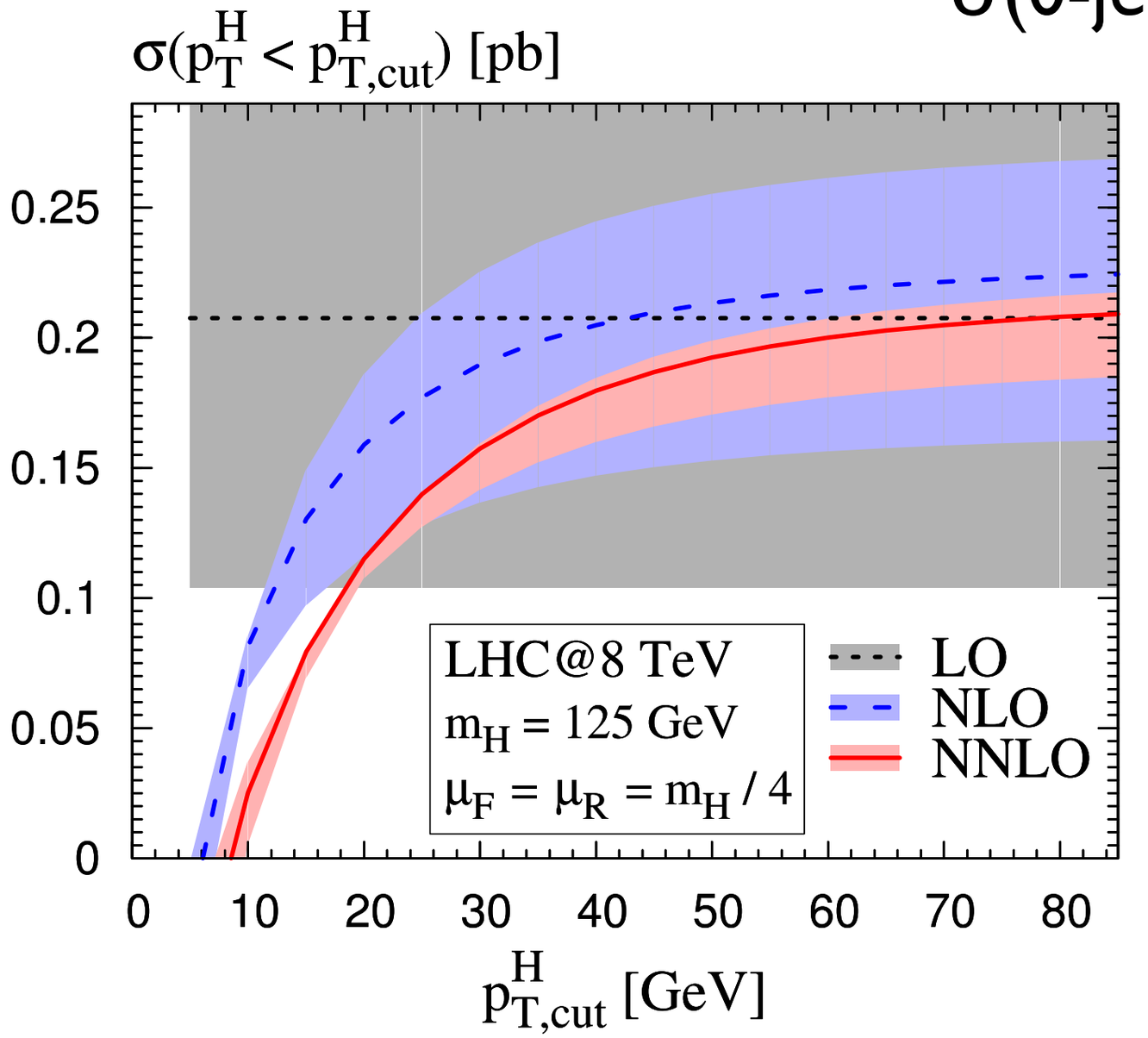
Santander matching

RH, Krämer, Schumacher '11



NNLO jet veto:

$\sigma(0\text{-jet}) = \sigma(\text{total}) - \sigma(\geq 1\text{-jet})$



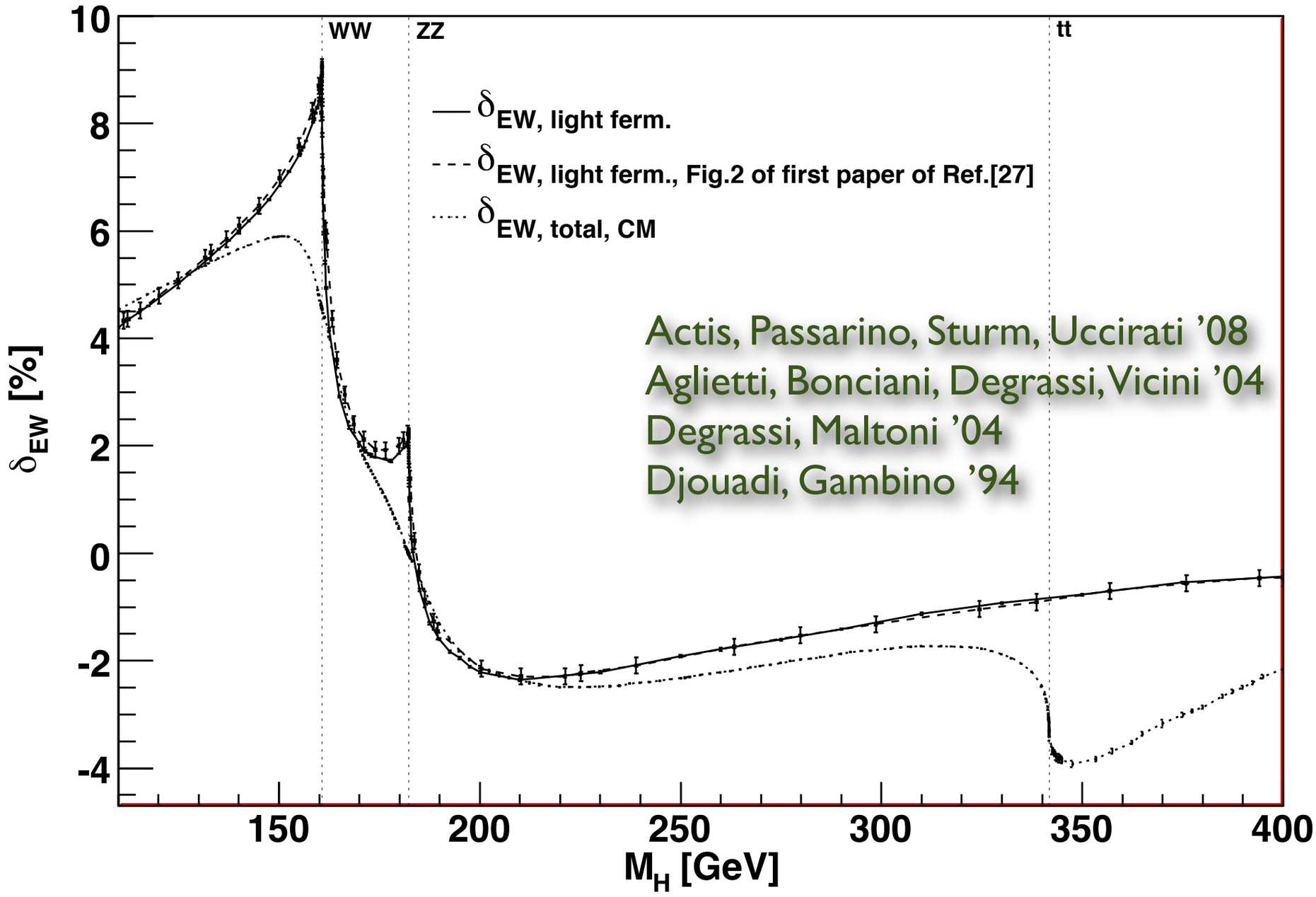
RH, Wiesemann '11; +Ozeren '09

Fully NNLO differential:

Buehler, Herzog, Lazopoulos, Mueller '12

Conclusions

- continuous theory progress
- importance of theory is being recognized
- error estimates will become crucial
- revival of precision physics?



Actis, Passarino, Sturm, Uccirati '08
Aglietti, Bonciani, Degrassi, Vicini '04
Degrassi, Maltoni '04
Djouadi, Gambino '94