Les Houches Collider Workshop, May/June 2003

Associated Higgs Production at Hadron Colliders

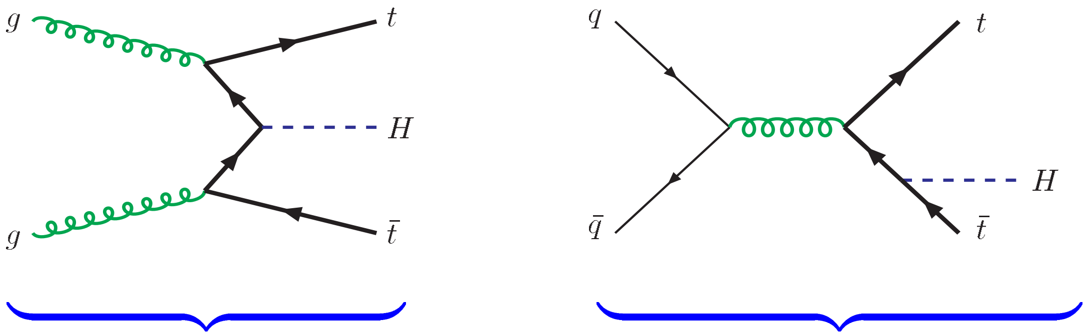
Michael Krämer

(University of Edinburgh)

- QCD corrections to $t\bar{t}H$ associated production
- QCD corrections to $b\bar{b}H$ associated production
- EWK corrections to WH and ZH associated production

$t\bar{t}H$ associated production

- at LO through gg fusion and $q\bar{q}$ annihilation



dominant at LHC　　　　dominant at Tevatron

→ Figure

- $\sigma(t\bar{t}H) \lesssim 1$ pb (LHC, $M_H > 115$ GeV)

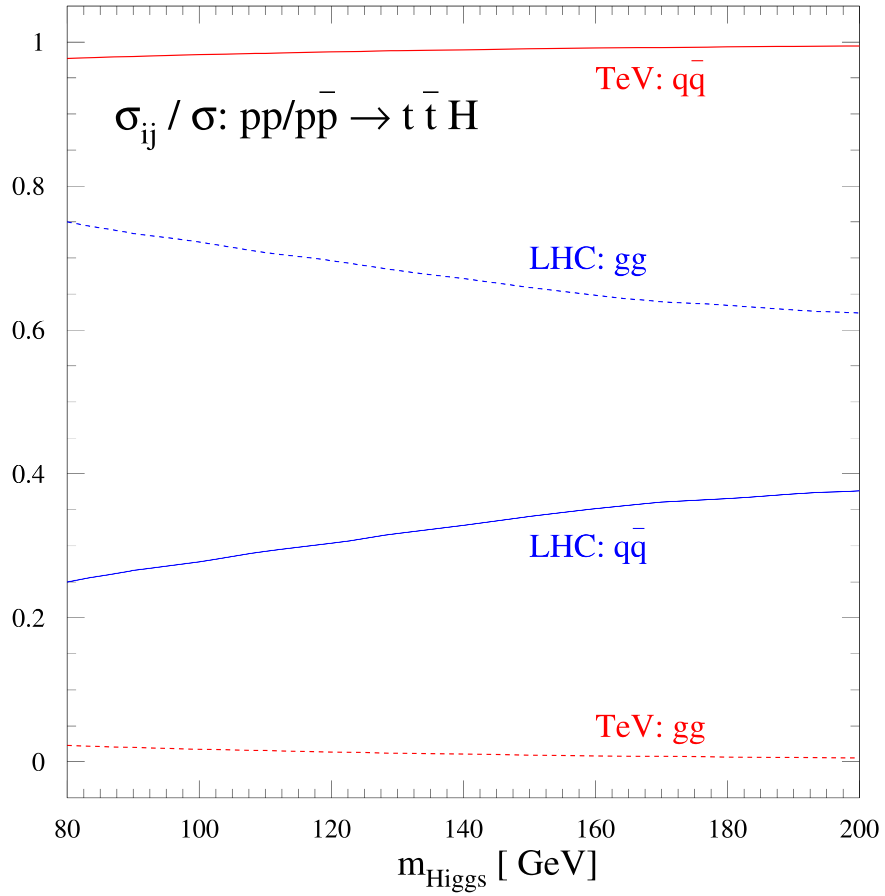
  but: distinctive final state → discovery channel for $M_H \lesssim 130$ GeV

- cross section $\propto g_{ttH}^2$

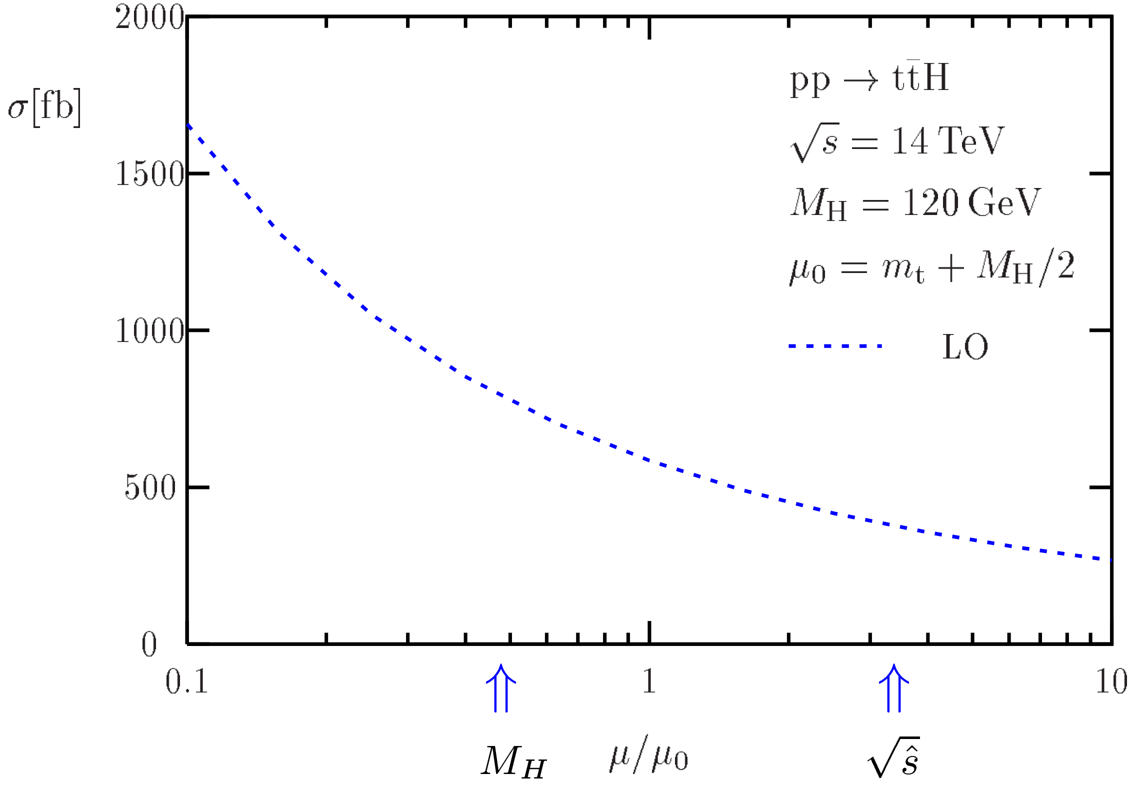
  ⇒ direct measurement of top Yukawa coupling

  $\delta g_{ttH}/g_{ttH} \approx 15\%$ (exp.)

- relative contribution of $q\bar{q}/gg$ channels



- Scale dependence of LO cross section



$$\frac{\delta\sigma_{LO}}{\sigma_{LO}} \approx 70\%$$

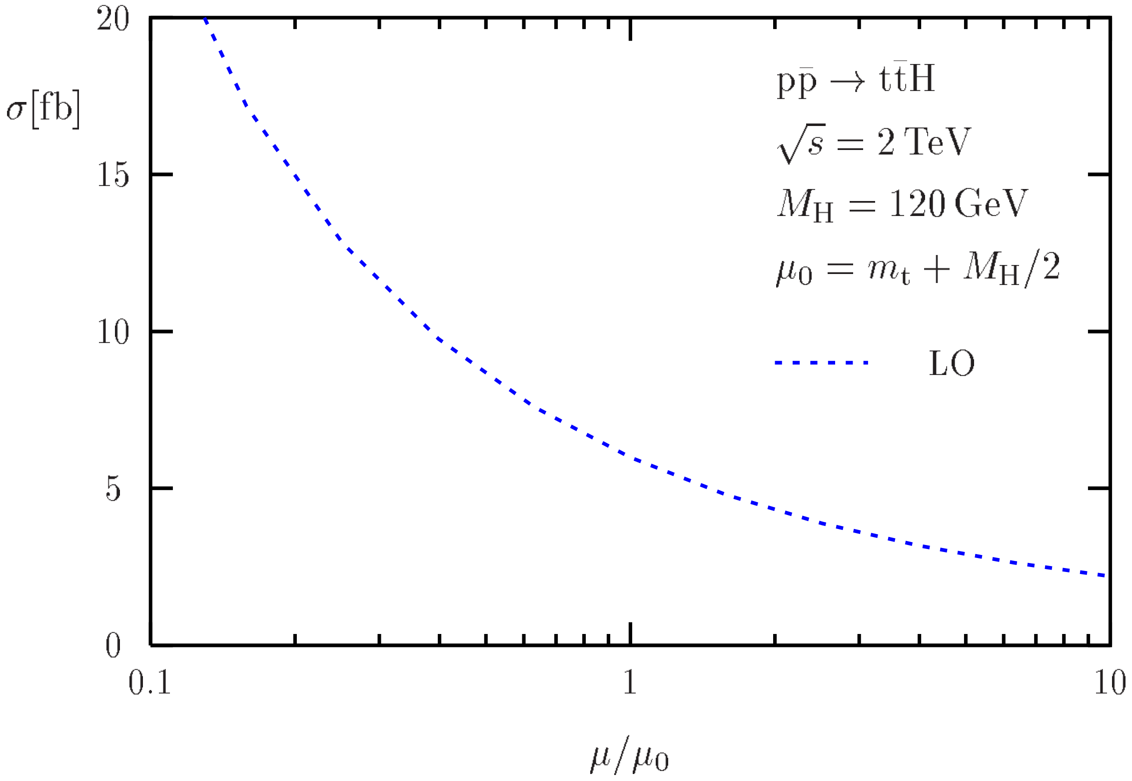
$\Rightarrow$ NLO calculation

Beenakker, Dittmaier, MK, Plümper, Spira, Zerwas '01/'02

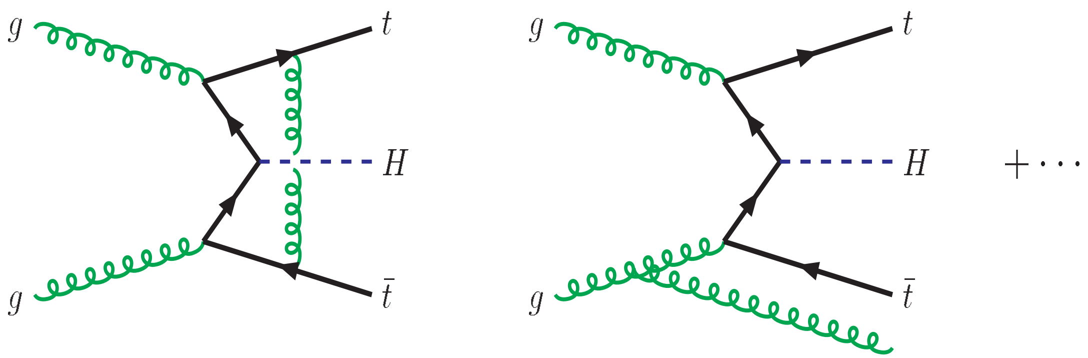
Reina, Dawson; + Wackeroth; + Orr; + Jackson '01–'03

• Scale dependence of LO cross section

at the Tevatron



NLO corrections to $q\bar{q}/gg \to t\bar{t}H$



- Pentagon diagrams: $E^{(D)} = E^{(D)}_{\text{sing}} + \left[E^{(\text{mass},D=4)} - E^{(\text{mass},D=4)}_{\text{sing}}\right]$

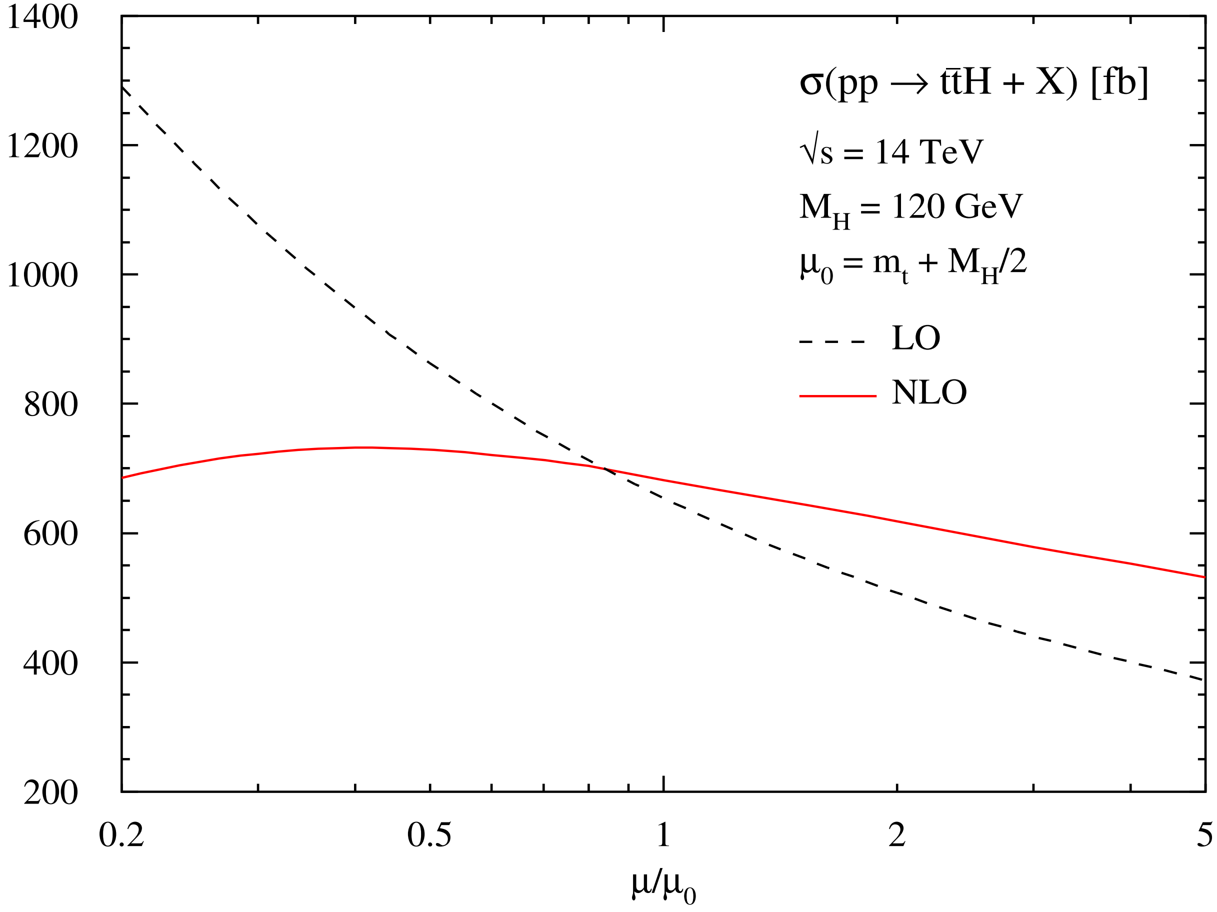
  can expressed in terms of three- and four-point functions

- Real gluon emission: soft and collinear divergences treated using dipole subtraction formalism:

$$\sigma^{\text{NLO}} = \underbrace{\int_{m+1}\left[d\sigma^{\text{real}} - d\sigma^{\text{sub}}\right]}_{\text{finite}} + \underbrace{\int_{m}\left[d\sigma^{\text{virtual}} + d\bar{\sigma}^{\text{sub}}_1\right]}_{\text{finite}} + \int_0^1 dx \underbrace{\int_m \left[d\sigma^{\text{fact}}(x) + \left(d\bar{\sigma}^{\text{sub}}(x)\right)_+\right]}_{\text{finite}}$$

$t\bar{t}H$: scale dependence at NLO

[Beenakker, Dittmaier, MK, Plümper, Spira, Zerwas]



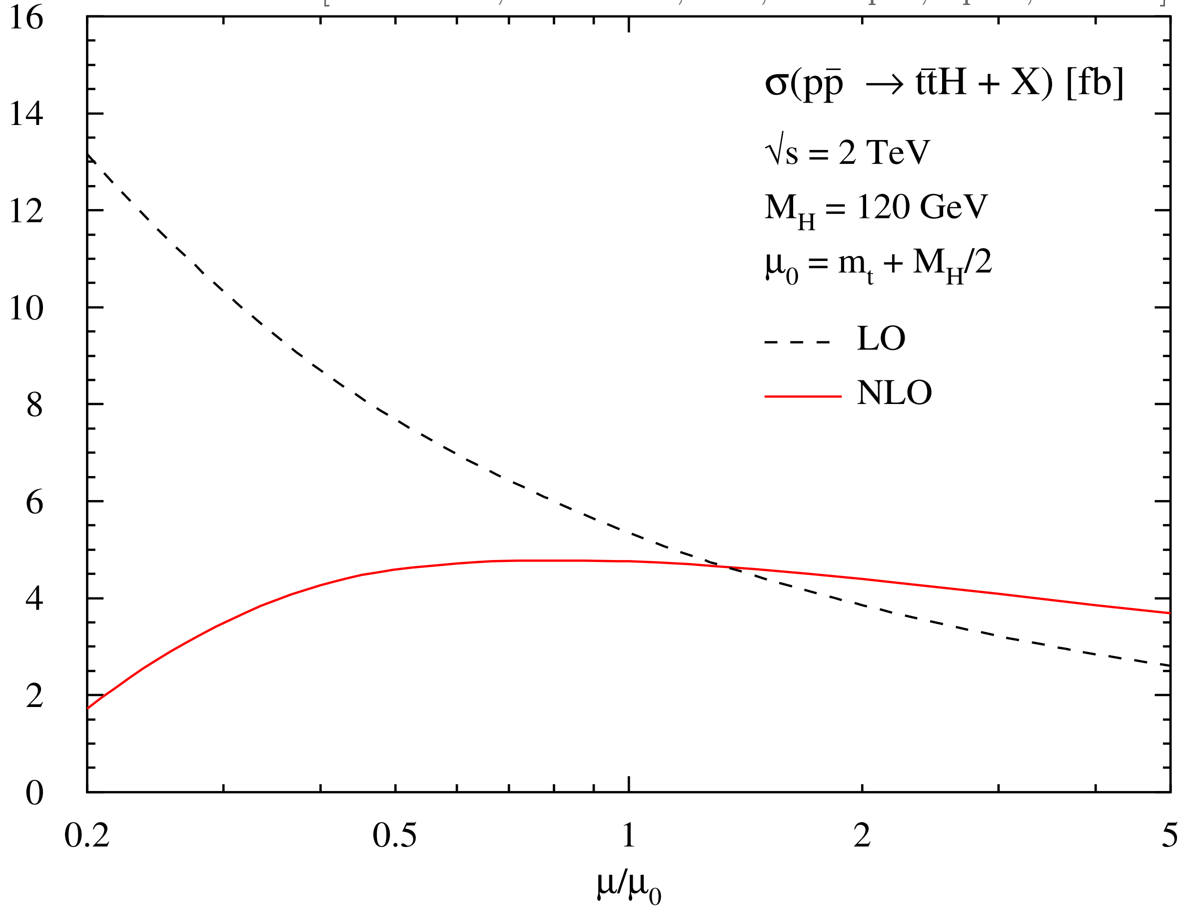
$$\frac{\delta\sigma_{\rm LO}}{\sigma_{\rm LO}} \approx 70\%$$

$$\frac{\delta\sigma_{\rm NLO}}{\sigma_{\rm NLO}} \approx 15\%$$

$t\bar{t}H$: scale dependence at NLO

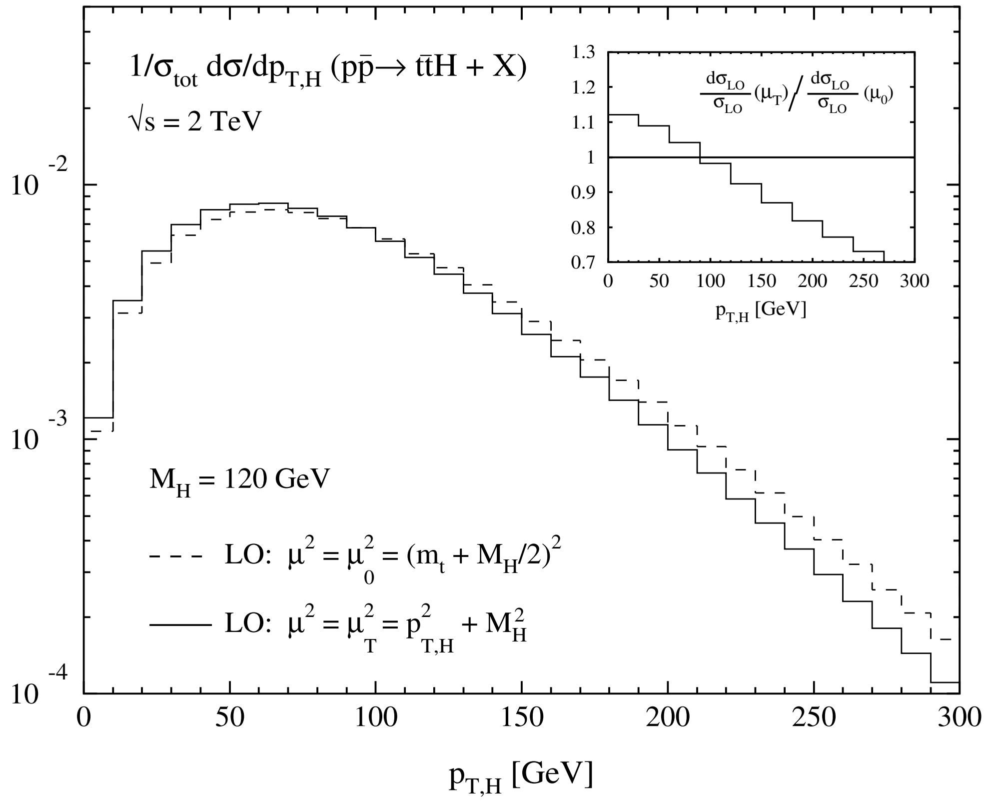
at the Tevatron:

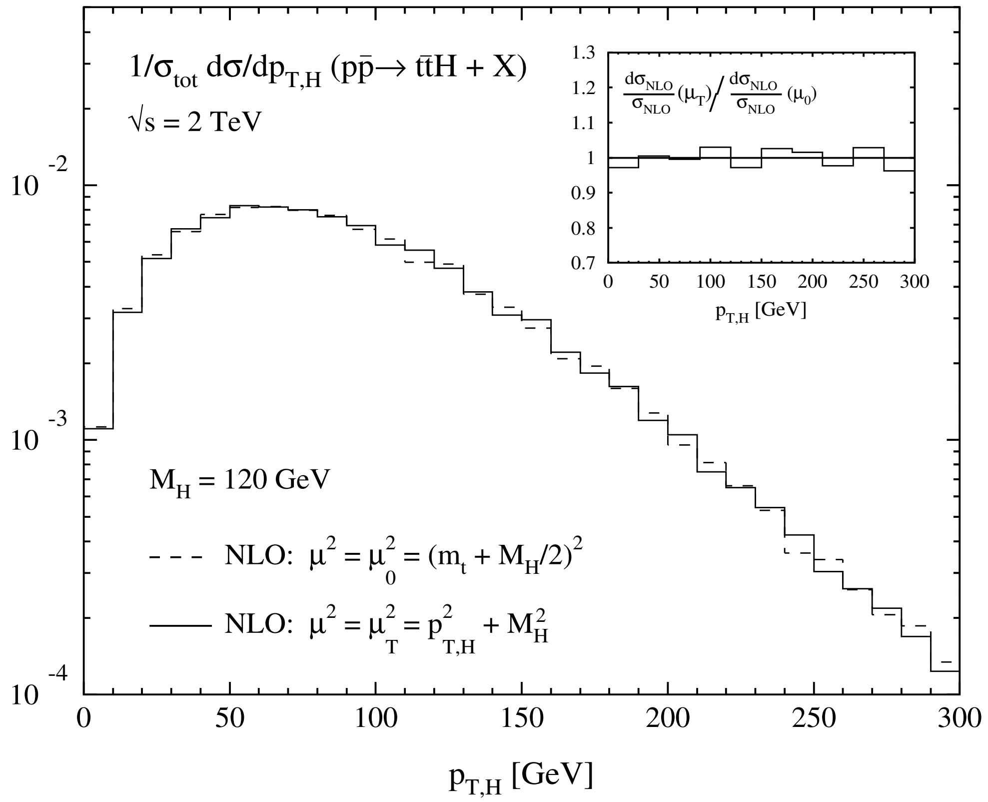
[Beenakker, Dittmaier, MK, Plümper, Spira, Zerwas]



Higgs transverse momentum distribution

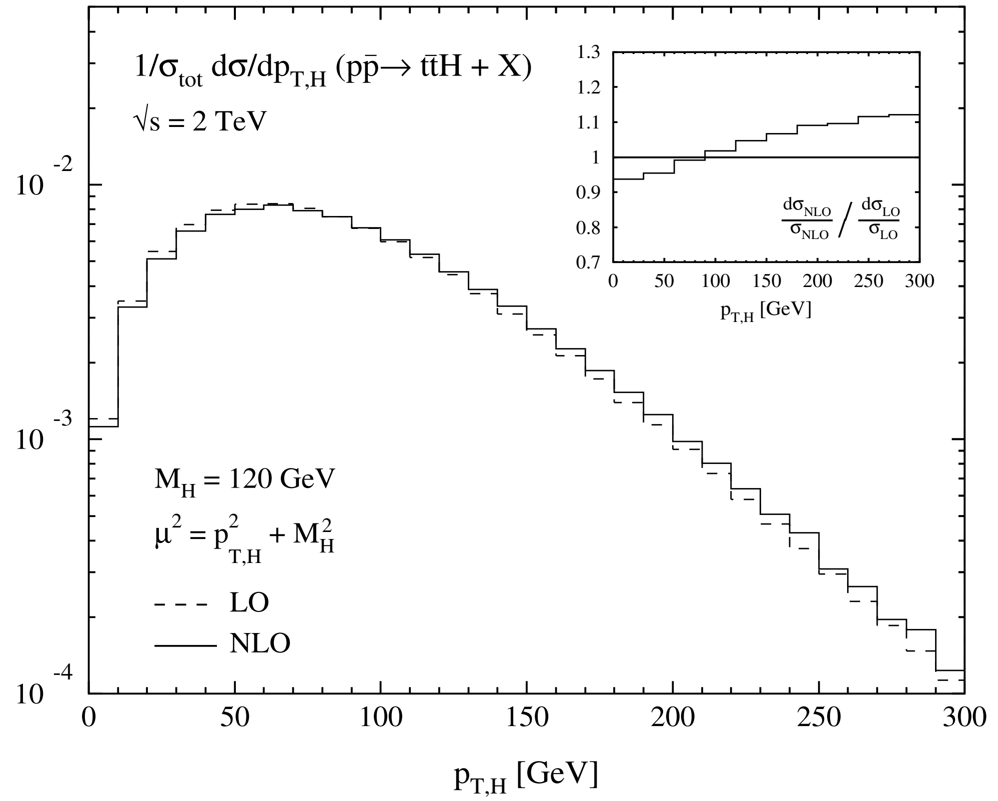
[Beenakker, Dittmaier, MK, Plümper, Spira, Zerwas]

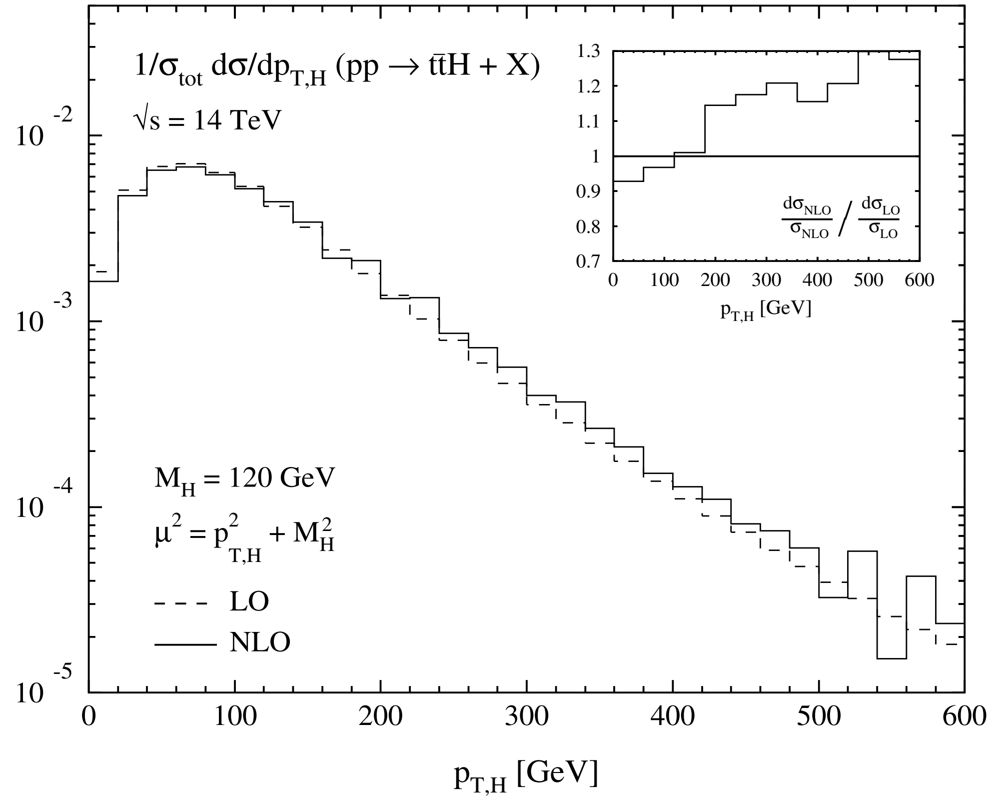




Higgs transverse momentum distribution

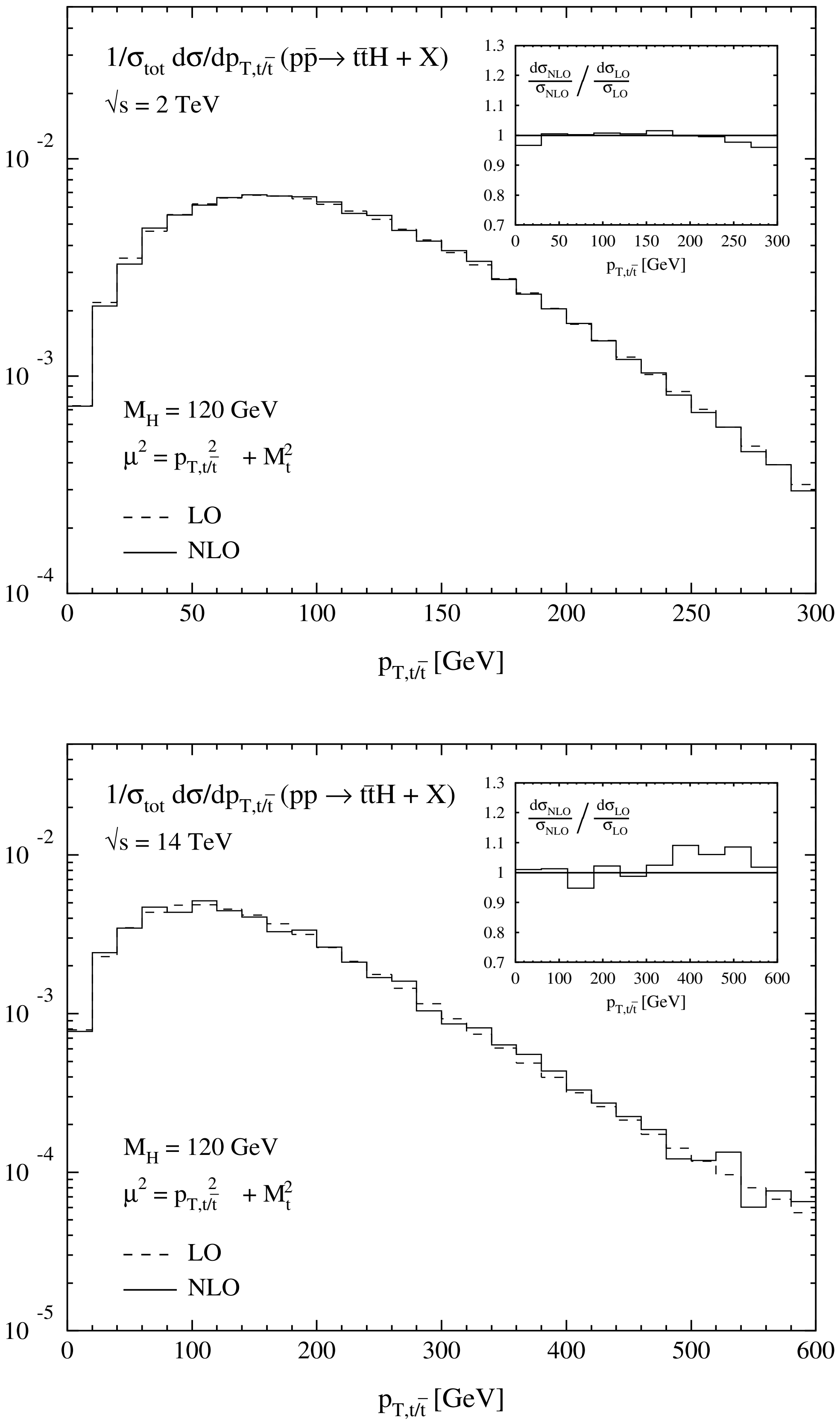
[Beenakker, Dittmaier, MK, Plümper, Spira, Zerwas]





(Anti)Top transverse momentum distribution

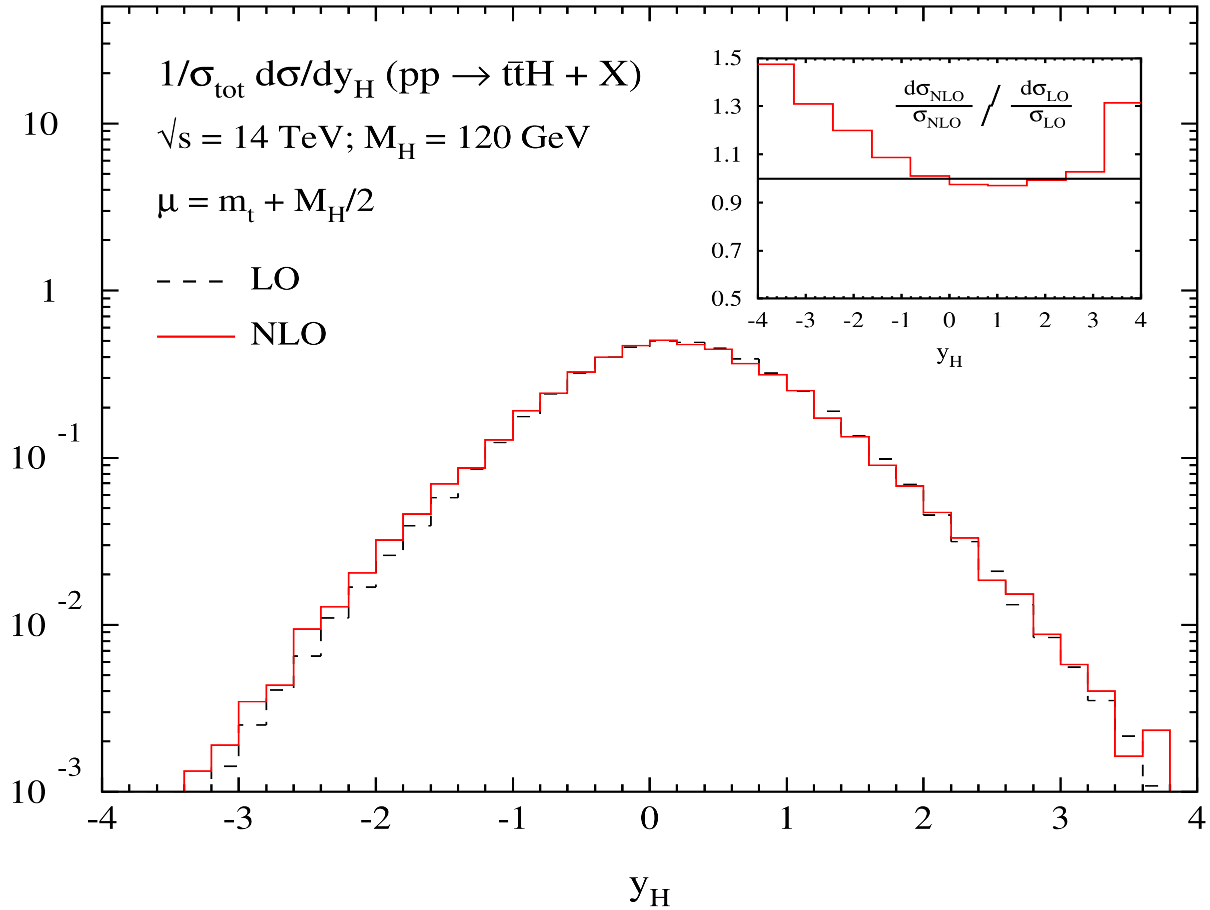
[Beenakker, Dittmaier, MK, Plümper, Spira, Zerwas]



Which distributions should we calculate?

- Eg. minimum rapidity separation between the Higgs and one of the tops

$\rightarrow$ separate signal and background in $pp \rightarrow t\bar{t}H(H \rightarrow b\bar{b})$ (Dave Rainwater)

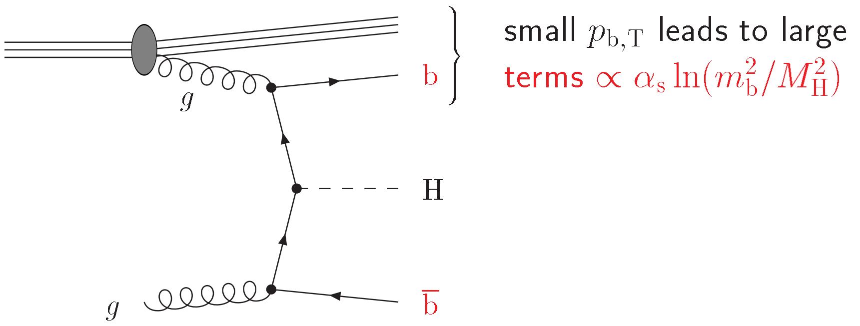


$b\bar{b}h$ Production at Hadron Colliders

- $b\bar{b}h$ coupling enhanced in SUSY models for large $\tan\beta$

- NLO corrections to $gg/q\bar{q} \to b\bar{b}h$ [Dittmaier, MK, Spira '03]
  - based on $t\bar{t}H$ calculation
  - introduce running b mass $\left(m_b^{\text{pole}} \to \overline{m}_b(\mu)(1+\alpha_s C(\mu));\ g_{bbH} \to \overline{m}_b(\mu)\sqrt{\sqrt{2}G_F}\right)$

- potential problem:

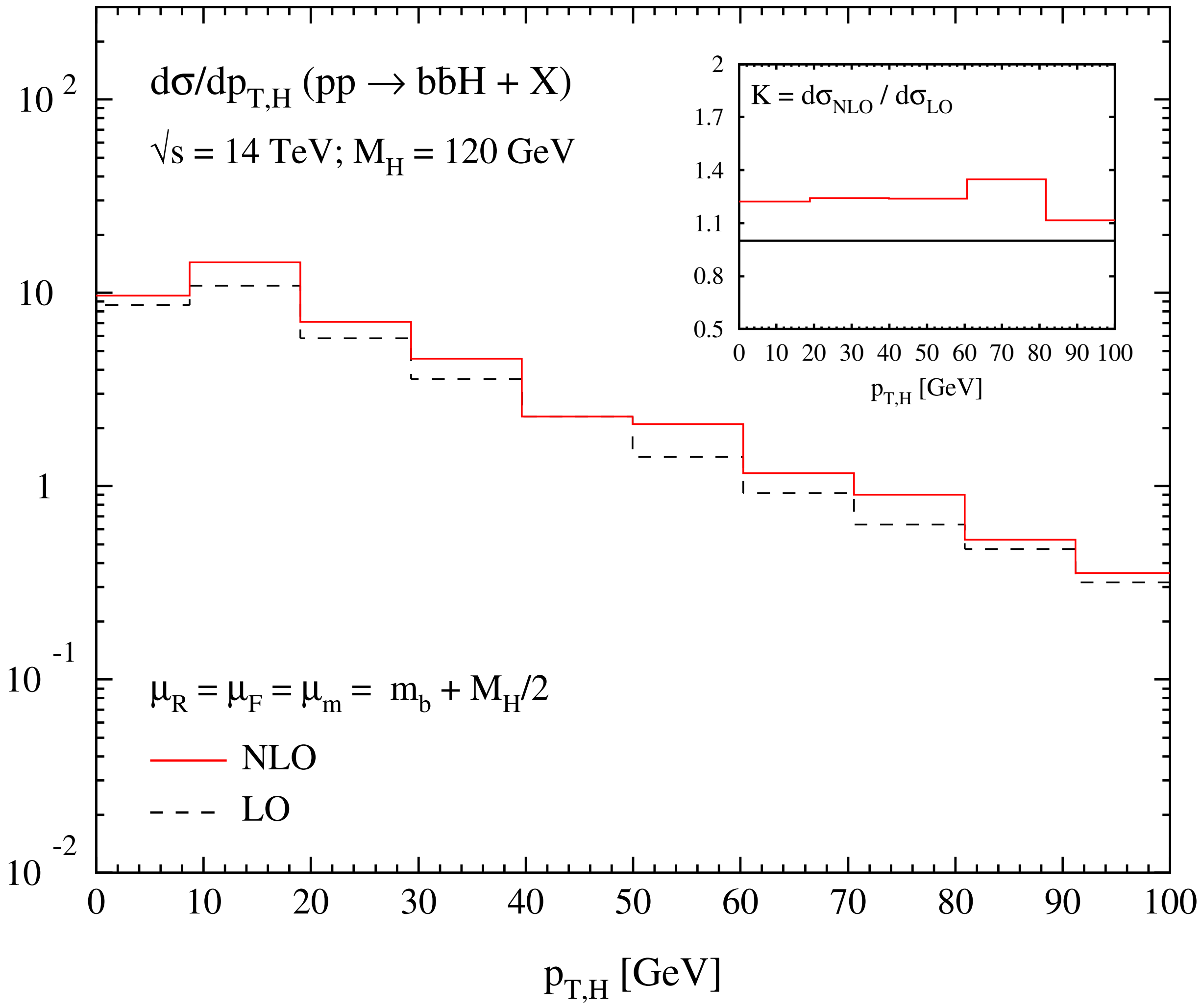


Summation of $\alpha_s \ln(m_b^2/M_H^2)$ terms by introducing b-quark density $b(x,\mu)$

$\to$ see talks by Scott Willenbrock and Michael Spira

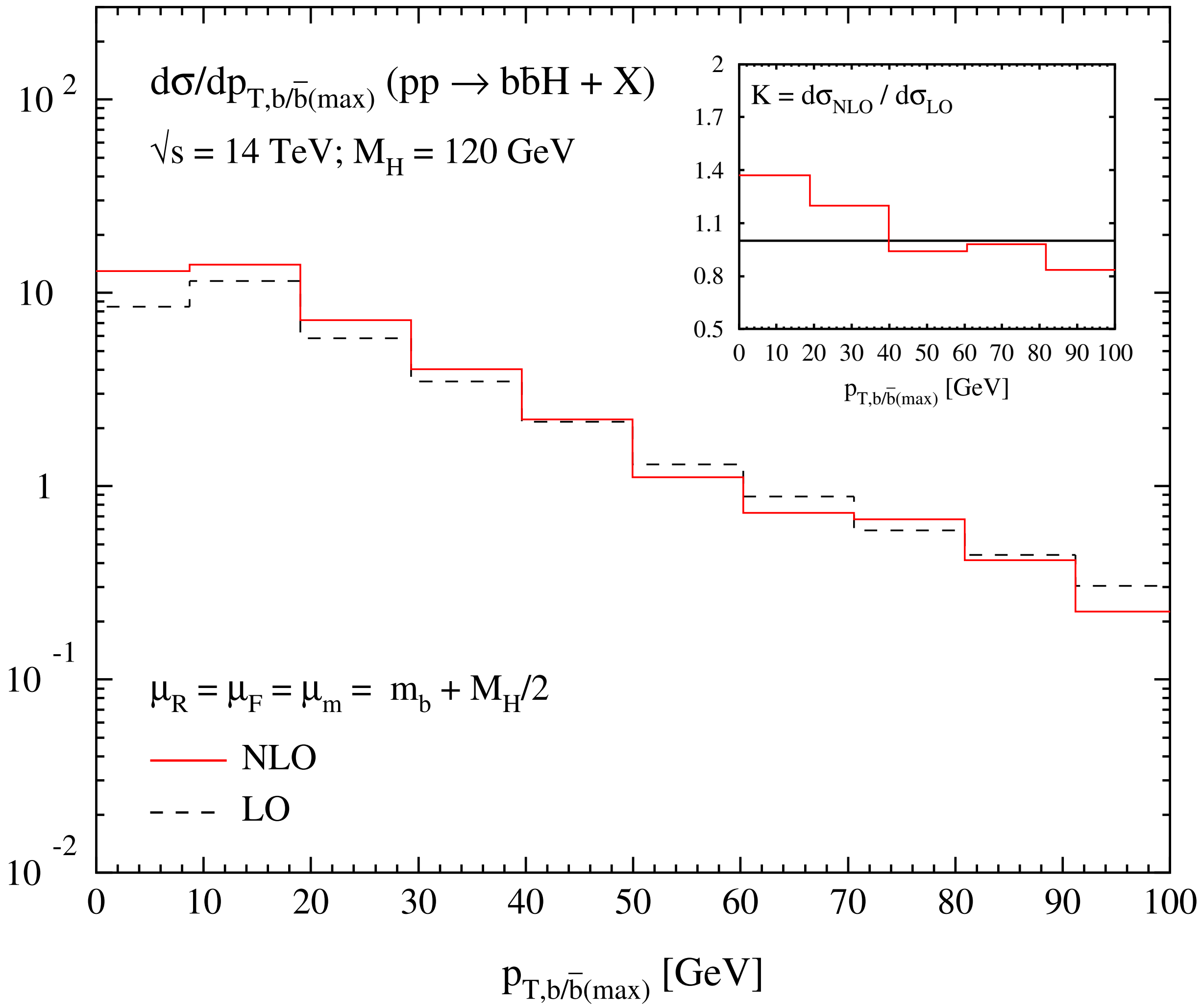
Higgs transverse momentum distribution

[Dittmaier, MK, Spira (preliminary)]



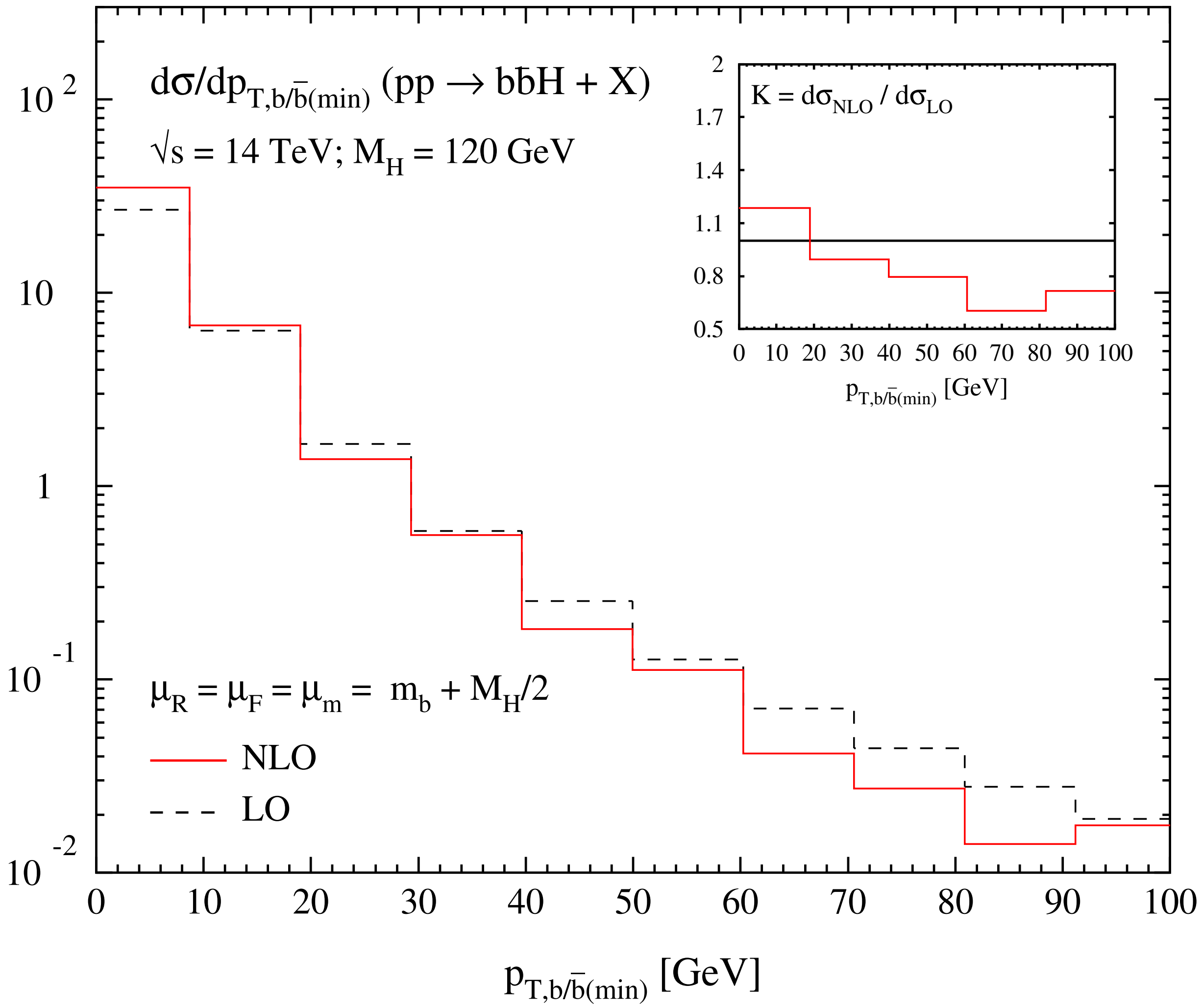
b quark transverse momentum distribution

[Dittmaier, MK, Spira (preliminary)]



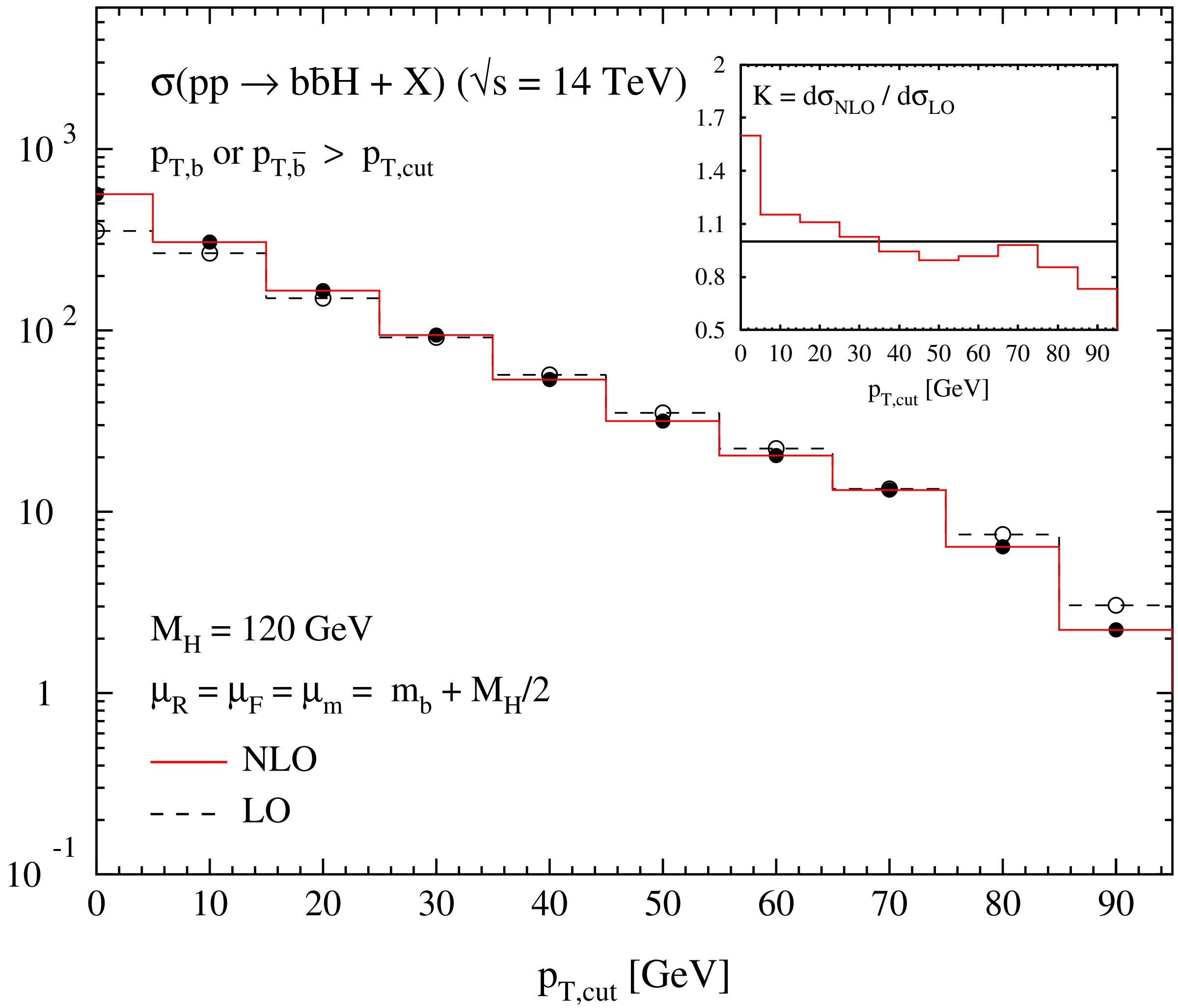
b quark transverse momentum distribution

[Dittmaier, MK, Spira (preliminary)]



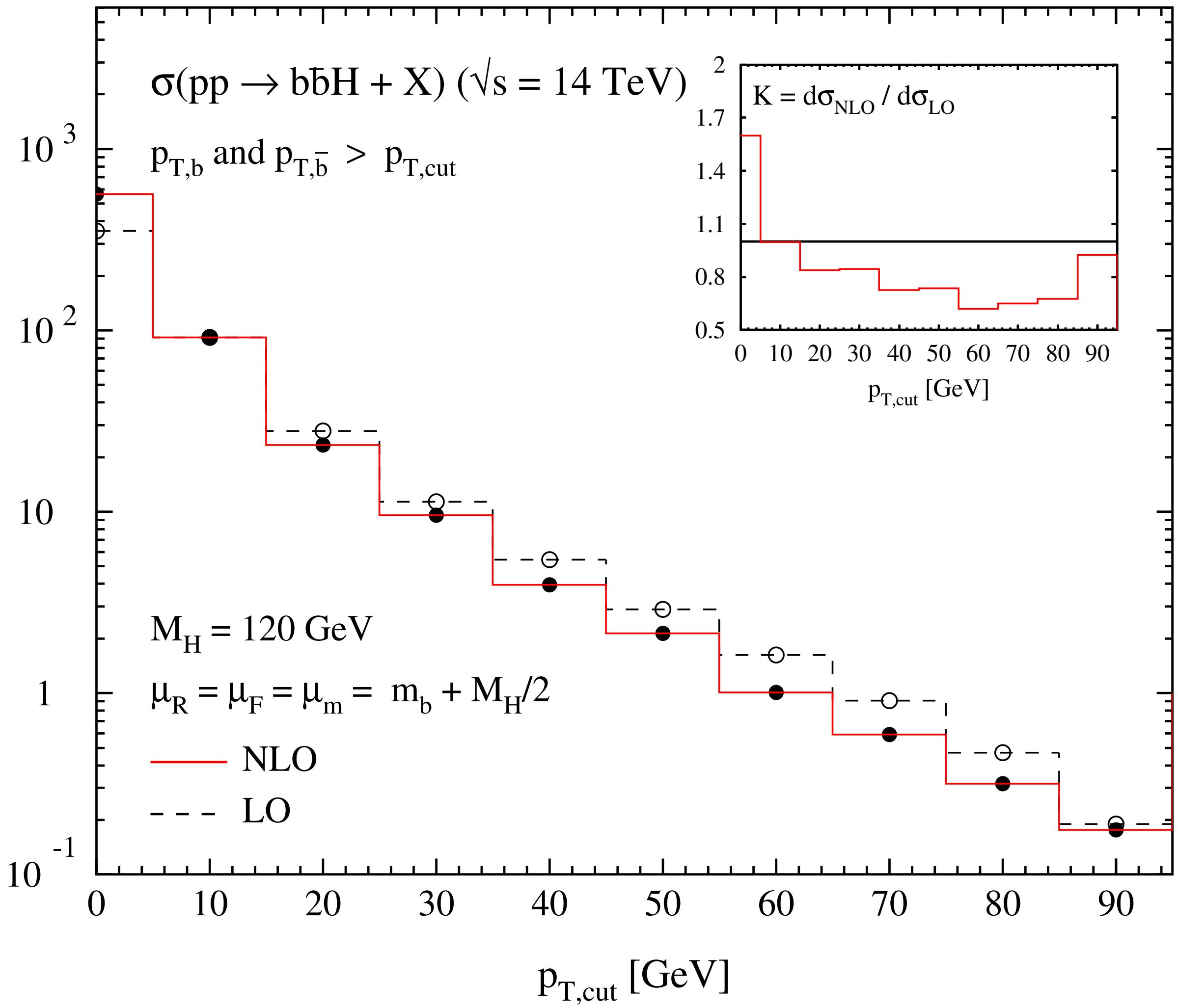
Cross section with $p_T(b)$ or $p_T(\bar{b}) > p_T(\text{cut})$

[Dittmaier, MK, Spira (preliminary)]



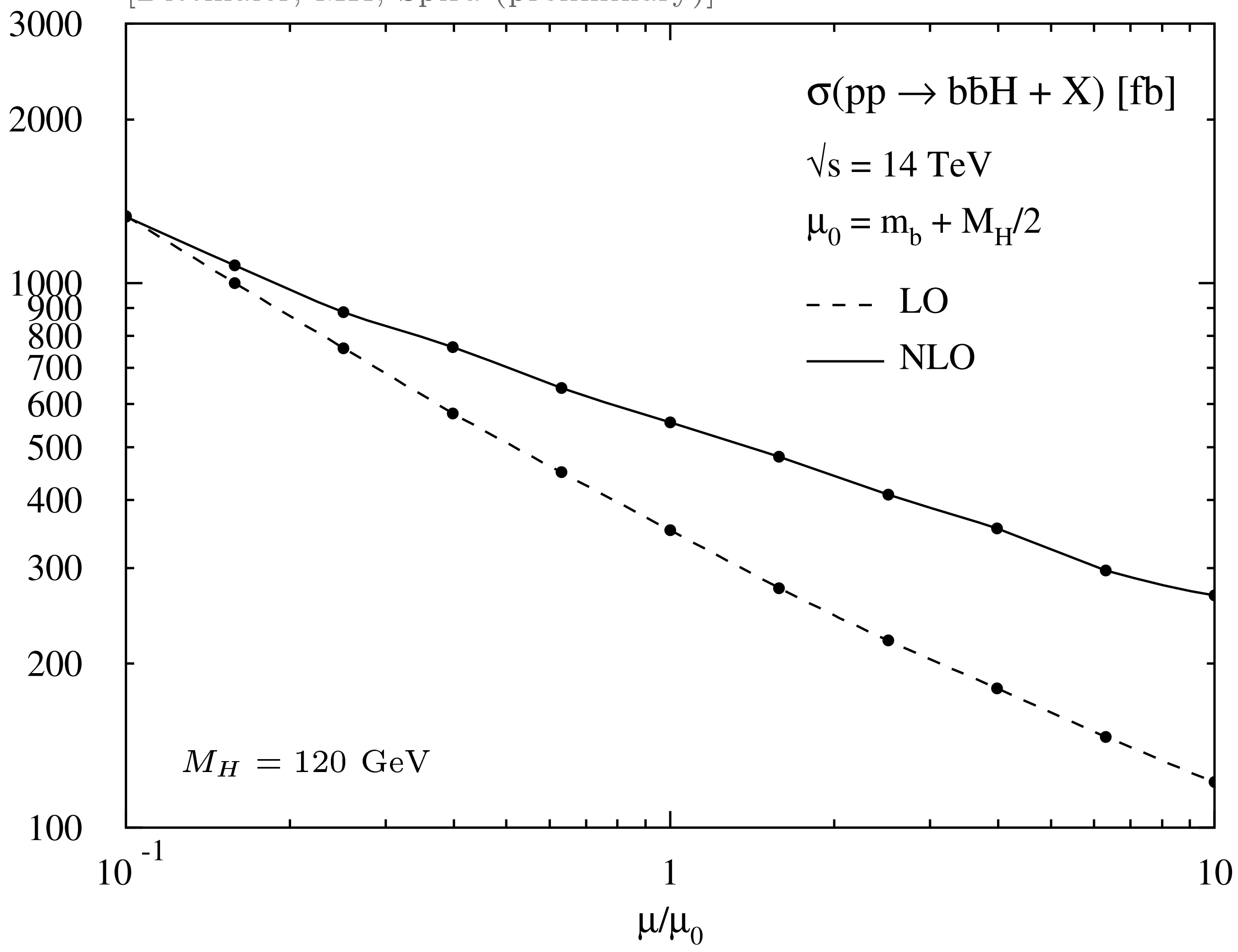
Cross section with $p_T(b)$ and $p_T(\bar{b}) > p_T(\text{cut})$

[Dittmaier, MK, Spira (preliminary)]



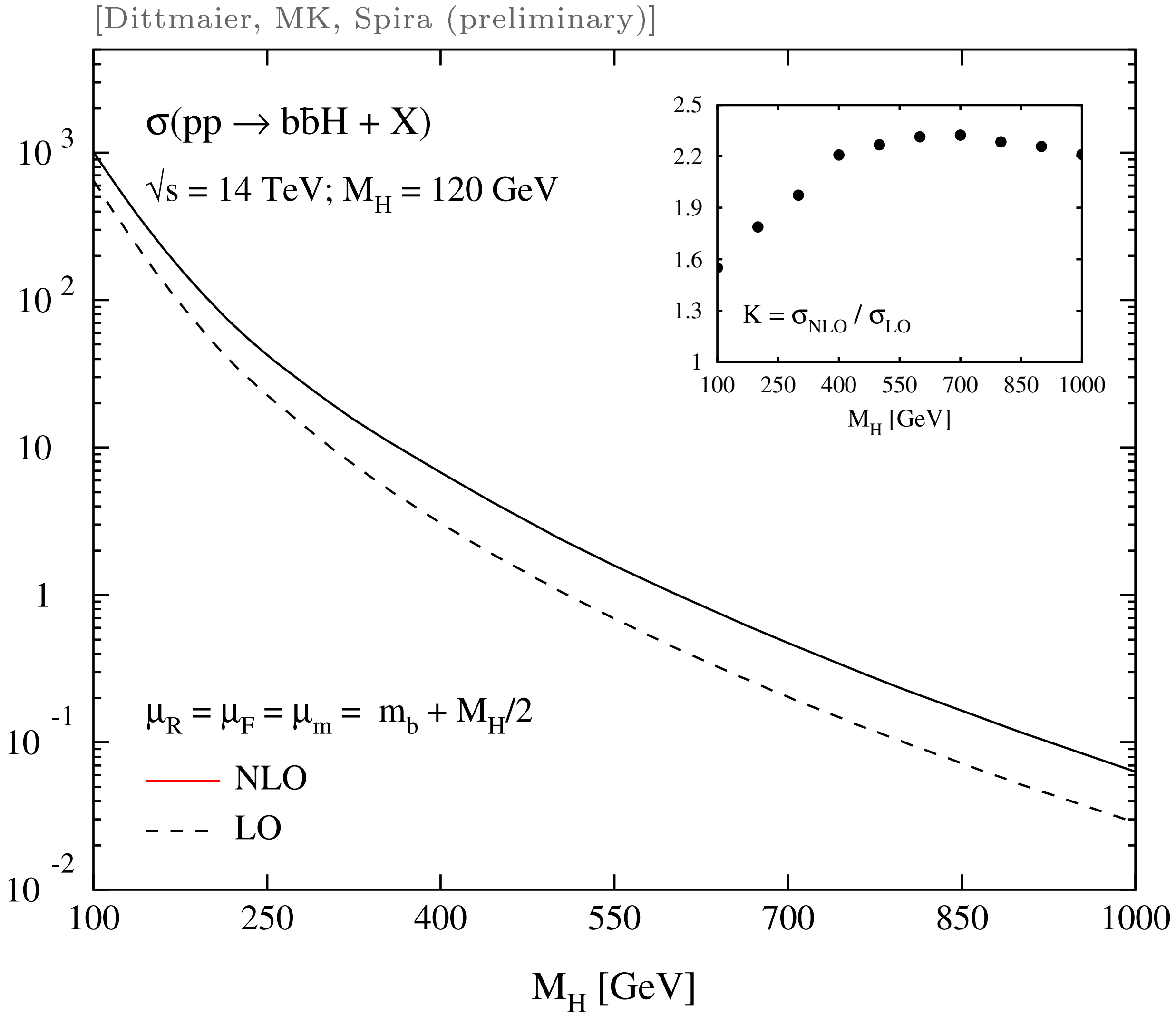
Inclusive cross section and scale dependence: LHC

[Dittmaier, MK, Spira (preliminary)]



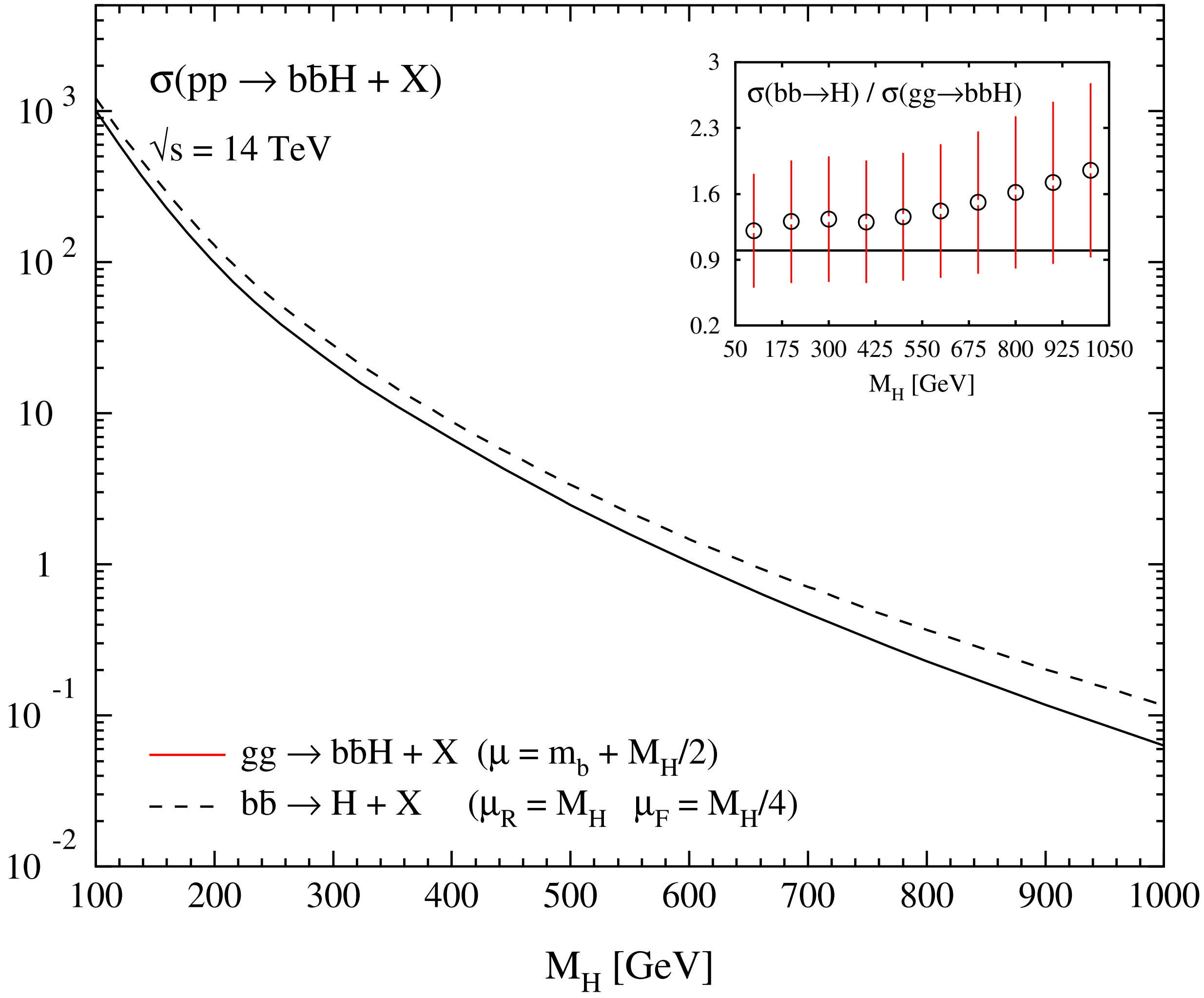
$$K(\mu_0) = \frac{\sigma_{\text{NLO}}(\mu_0)}{\sigma_{\text{LO}}(\mu_0)} \approx 1.6$$

Inclusive cross section vs M_H: LHC



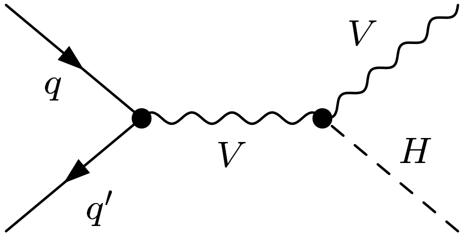
Inclusive cross section: $gg \to b\bar{b}H$ vs $b\bar{b} \to H$

[Dittmaier, MK, Spira (preliminary); Maltoni, Sullivan, Willenbrock]



EWK corrections to WH and ZH associated production

- at LO through $q\bar{q}' \to V^* \to V + H$



- most important discovery channel at Tevatron (for $M_H < 130$ GeV)
- QCD uncertainties small: $\Delta\sigma_{\text{NLO}} \lesssim 15\%$ (cf Drell-Yan)

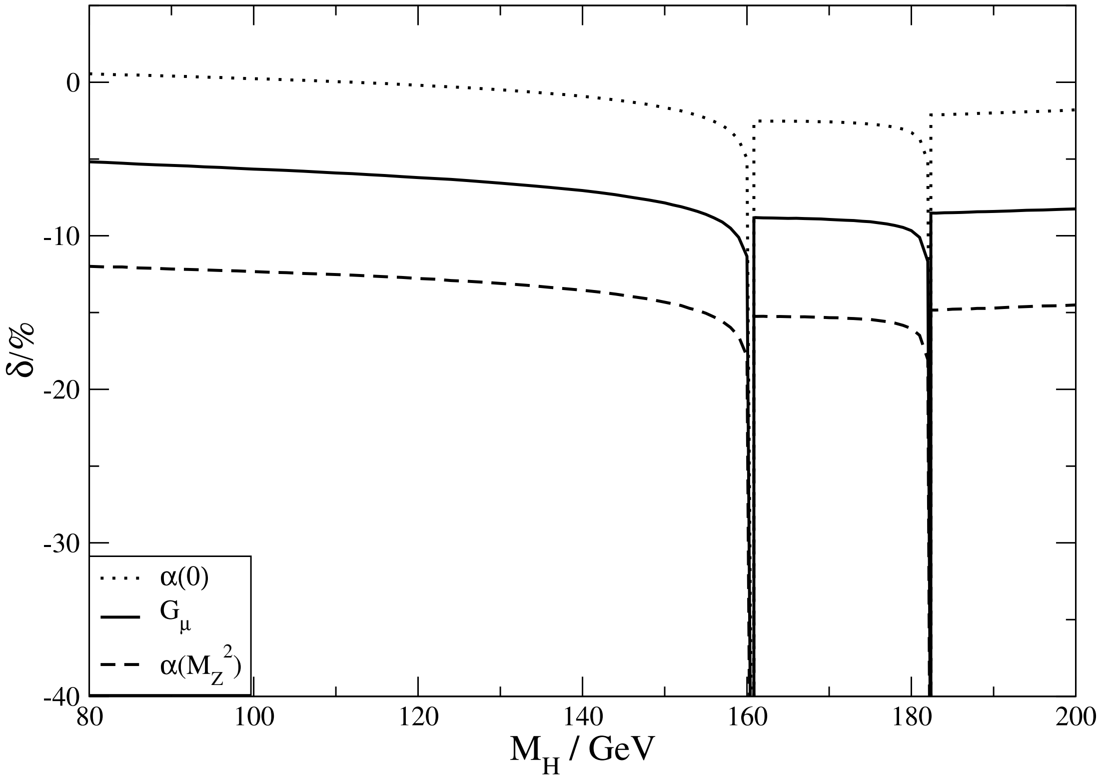
  [Han, Willenbrock; Spira, . . .]
- EWK corrections significant: $K_{\text{EWK}} \approx 0.9 - 0.95$

  [Ciccolini, Dittmaier, MK '03]

EWK corrections: input parameter schemes

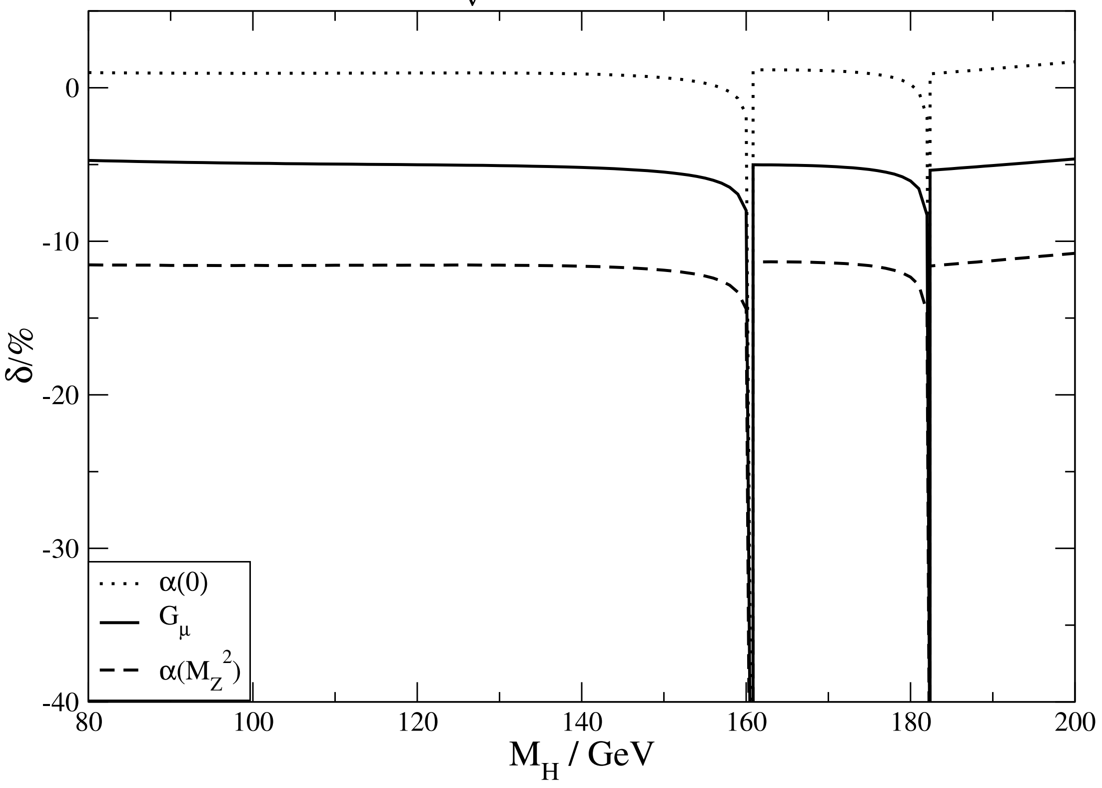
$p\,\bar{p} \rightarrow W^+ H + X$

$\sqrt{s} = 2$ TeV

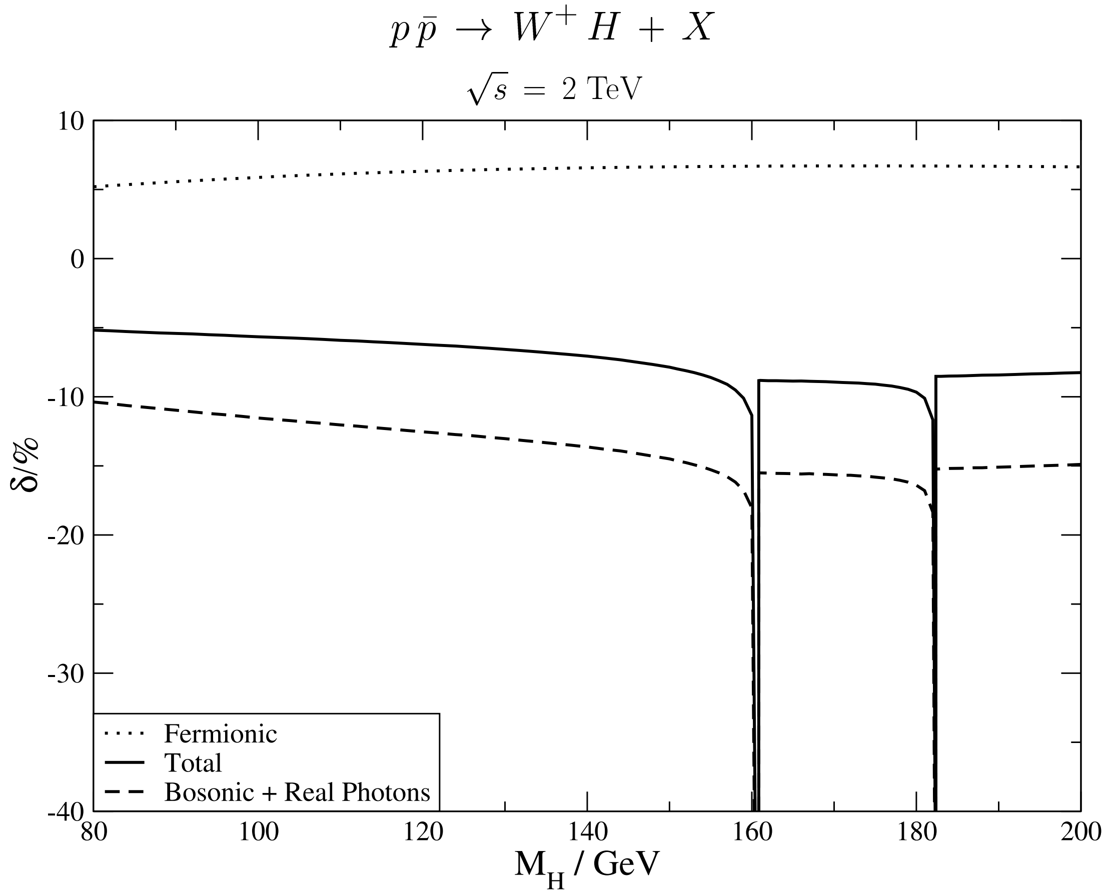


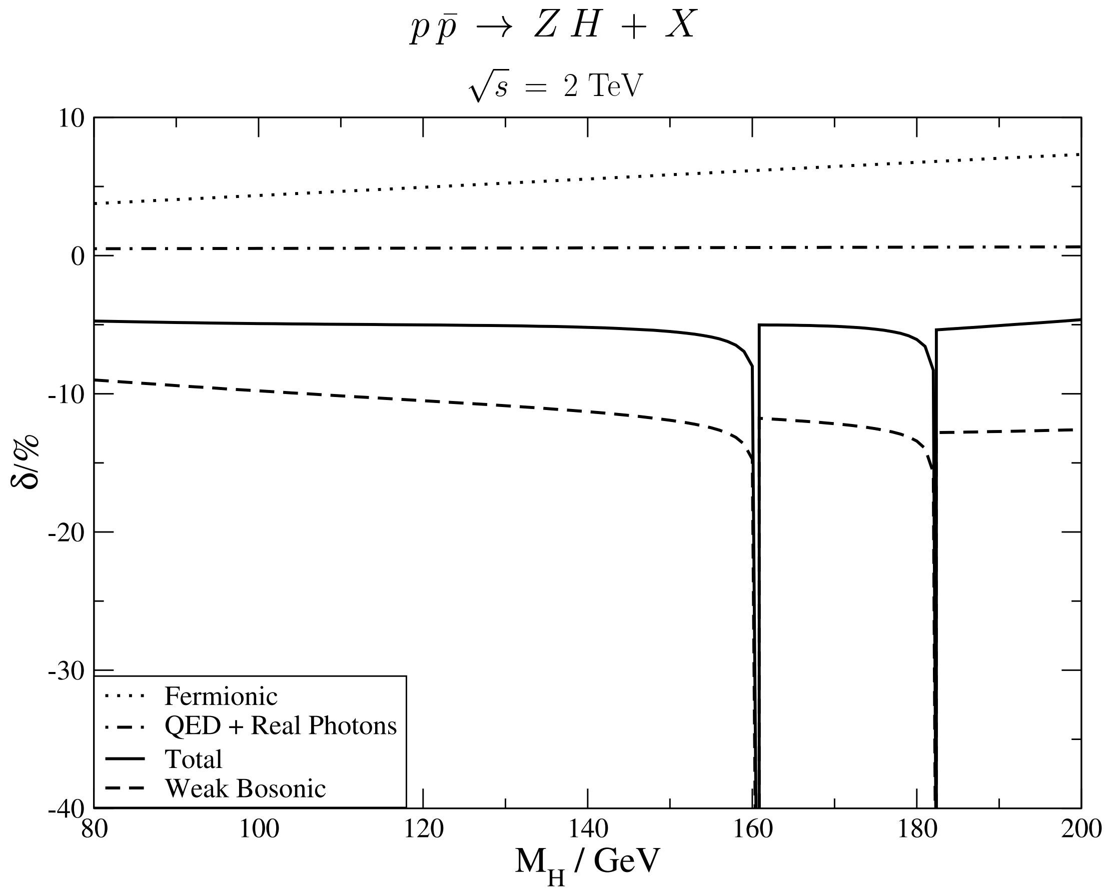
$p\,\bar{p} \rightarrow Z\,H + X$

$\sqrt{s} = 2$ TeV



EWK corrections: different contributions





NLO (QCD + EWK) cross section prediction