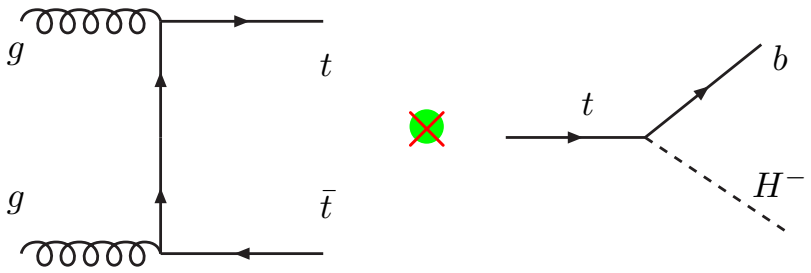
Charged Higgs boson production at the LHC: NLO SUSY-QCD corrections

Michael Krämer (CERN-TH & RWTH Aachen)

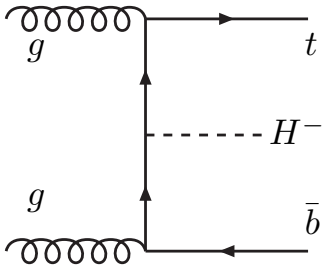
with Stefan Dittmaier, Michael Spira and Manuel Walser (arXiv:0906.2648)

Introduction: charged Higgs production at the LHC

- $pp \to t\bar{t}$ with $t \to bH^{\pm}$ for $M_{H^{\pm}} \lesssim m_{\text{top}}$



- $pp \to tbH^{\pm}$ for $M_{H^{\pm}} \gtrsim m_{\text{top}}$



alternative production mechanisms like $q\bar{q}' \to H^{\pm}$, $pp \to H^{\pm} + \text{jet}$, $pp \to H^{\pm}W^{\mp}$, or Higgs pair production are suppressed...

Status of (MSSM) calculations

- 5FS NLO SUSY-QCD [Plehn; Berger et al.]
- 5FS in MC@NLO [Weydert et al.] → talk by T. Plehn
- 5FS NNLL/NNLO$_{\text{approx.}}$ [Kidonakis]
- 5FS SUSY-EWK [Jin et al., Belyaev et al., Beccaria et al.]

  → talk by C. Verzegnassi

- 4FS NLO SUSY-QCD [Peng et al.; Dittmaier et al.]

- LO 4FS and 5FS matched [Borzumati et al.; Alwall, Rathsman]

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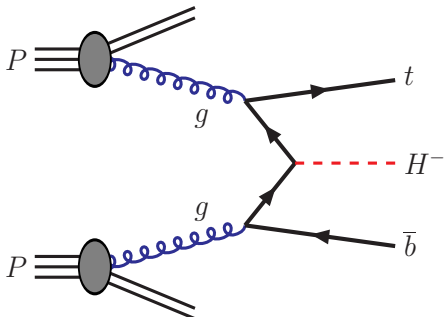
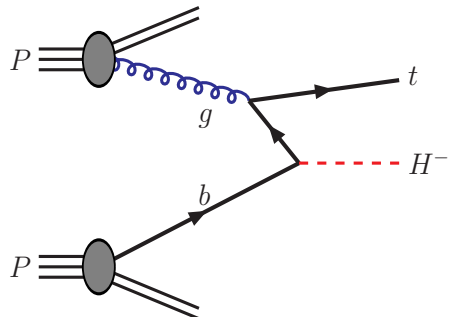
Associate $tbH^{\pm}$ production: two calculational schemes

4-flavour scheme



+ exact $g \to b\bar{b}$ splitting & mass effects
− no summation of $\ln(M_H/M_b)$ terms

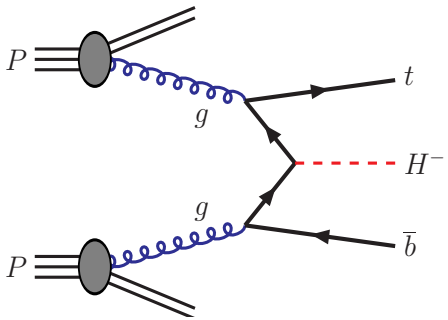
5-flavour scheme



+ summation of $\ln(M_H/M_b)$ terms
− LL approximation to $g \to b\bar{b}$ splitting

Associate $tbH^{\pm}$ production: two calculational schemes

4-flavour scheme



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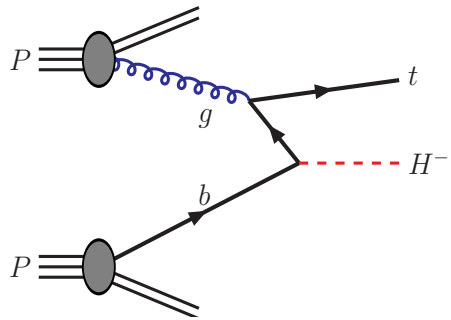


+ summation of $\ln(M_H/M_b)$ terms
− LL approximation to $g \to b\bar{b}$ splitting

The 4- and 5-flavour schemes

- are both theoretically consistent & well-defined
- represent different ways of ordering perturbation theory
- should agree at sufficiently high order
- do not match exactly at finite order

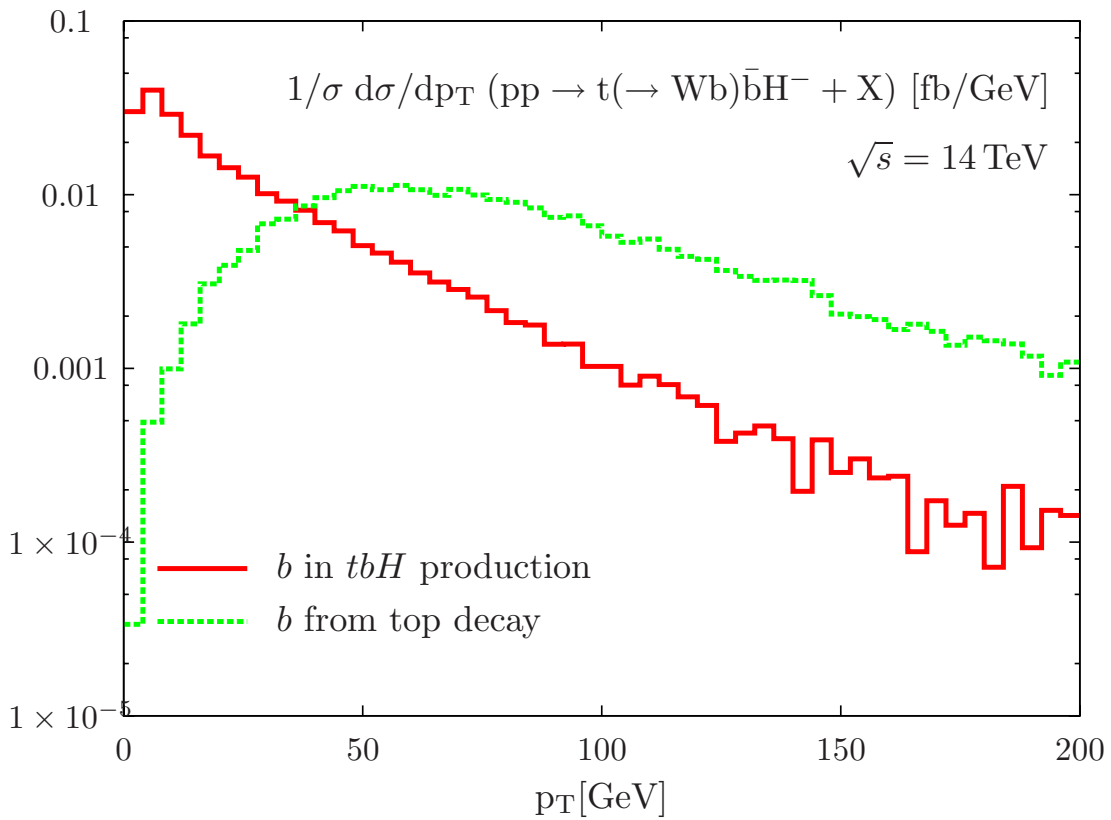
Associate $tbH^{\pm}$ production: 4FS calculation

- better description of b-quark dynamics in 4FS

  $\longrightarrow$ needed for searches with additional b-tag

  $\longrightarrow$ needed for event reconstruction

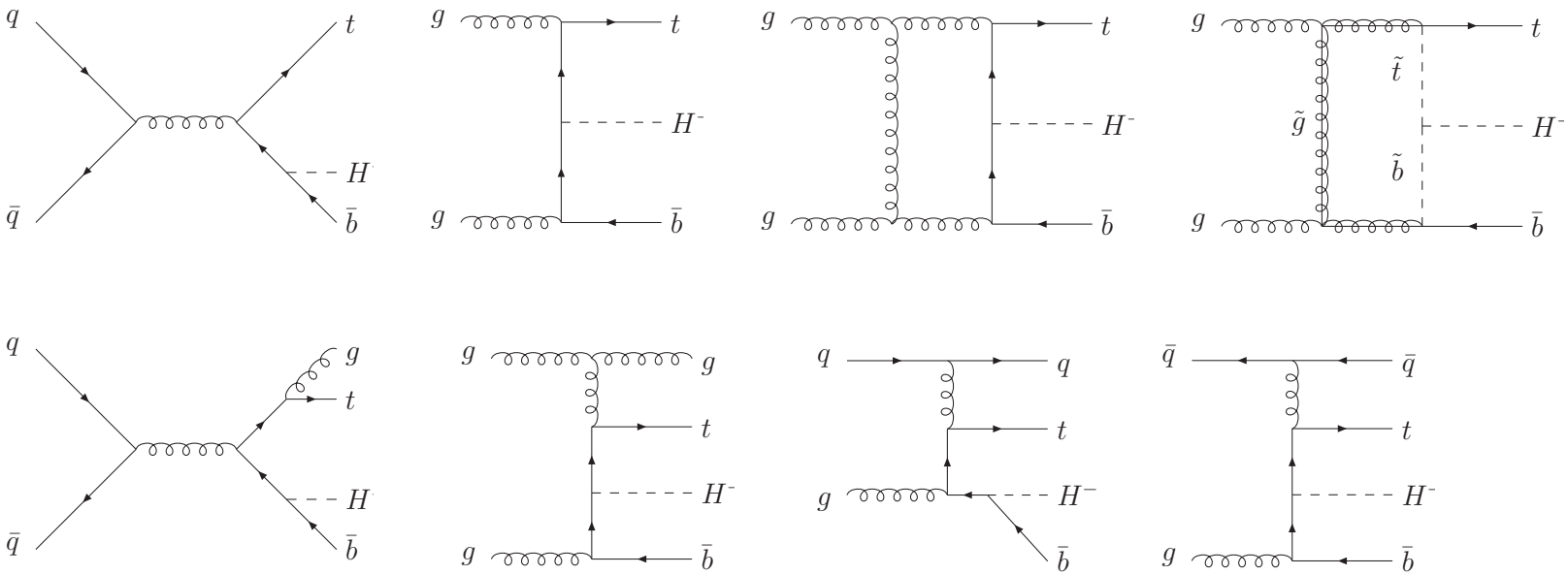
contamination of top reconstruction by additional b-jets



Associate $tbH^{\pm}$ production: 4FS calculation at NLO

see Dittmaier, MK, Spira, Walser (arXiv:0906.2648)

- some generic Feynman graphs

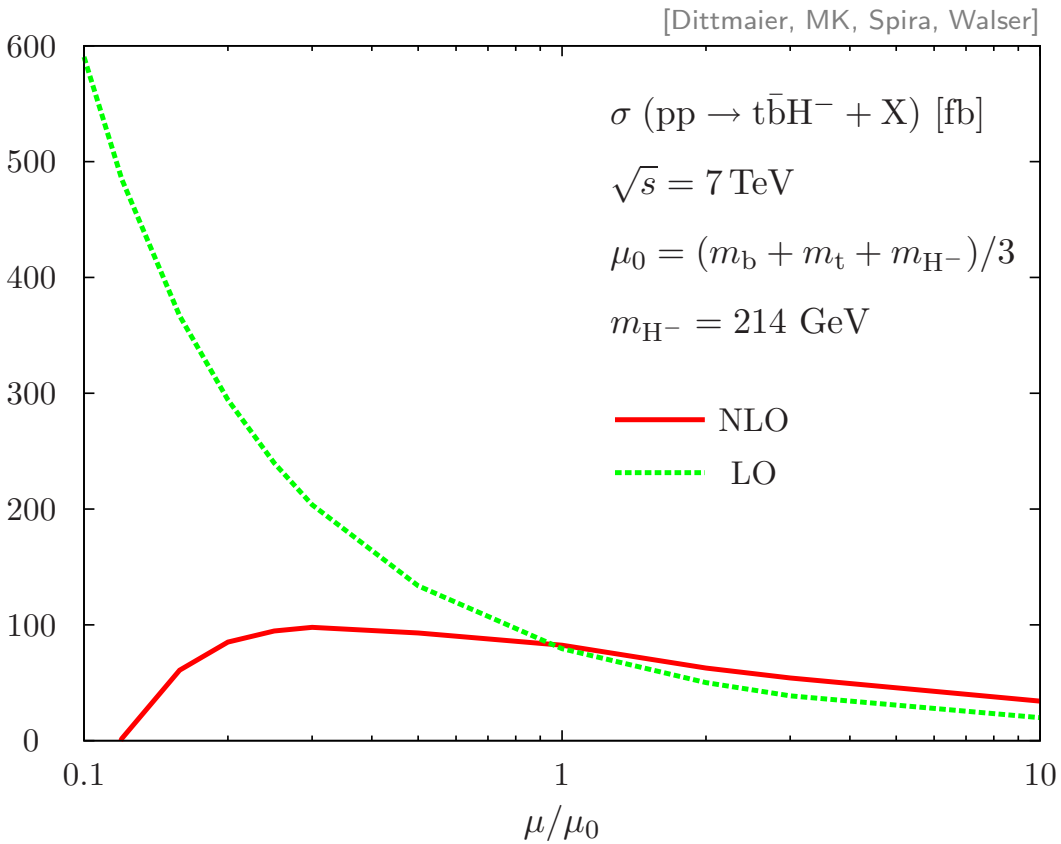


- calculation using standard techniques

  FeynArts, LoopTools, dipole subtraction, Denner/Dittmaier tensor reduction, MadGraph...

Associate $tbH^{\pm}$ production: 4FS calculation at NLO

- scale dependence at 7 TeV (here and in the following we use SPS1b)



$\longrightarrow$ choose $\mu_0 = (m_\mathrm{b} + m_\mathrm{t} + m_\mathrm{H})/3$ with scale variation $\mu/3 \leq \mu \leq 3\mu_0$

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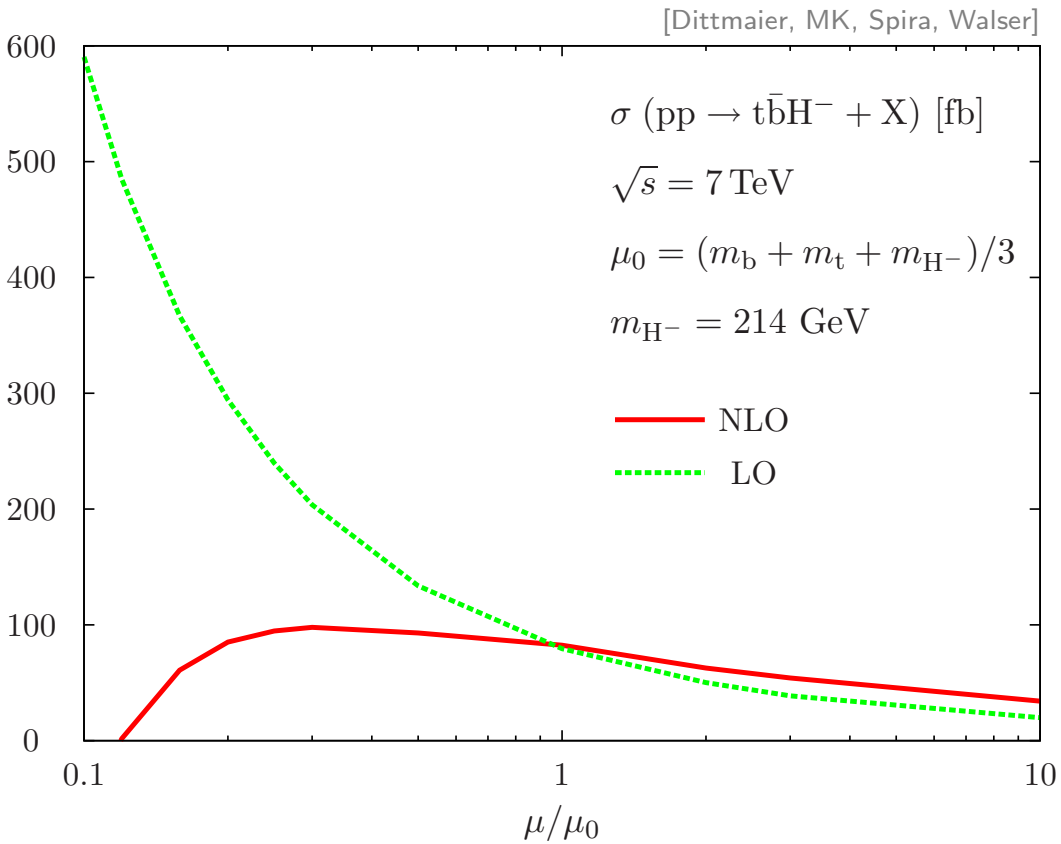
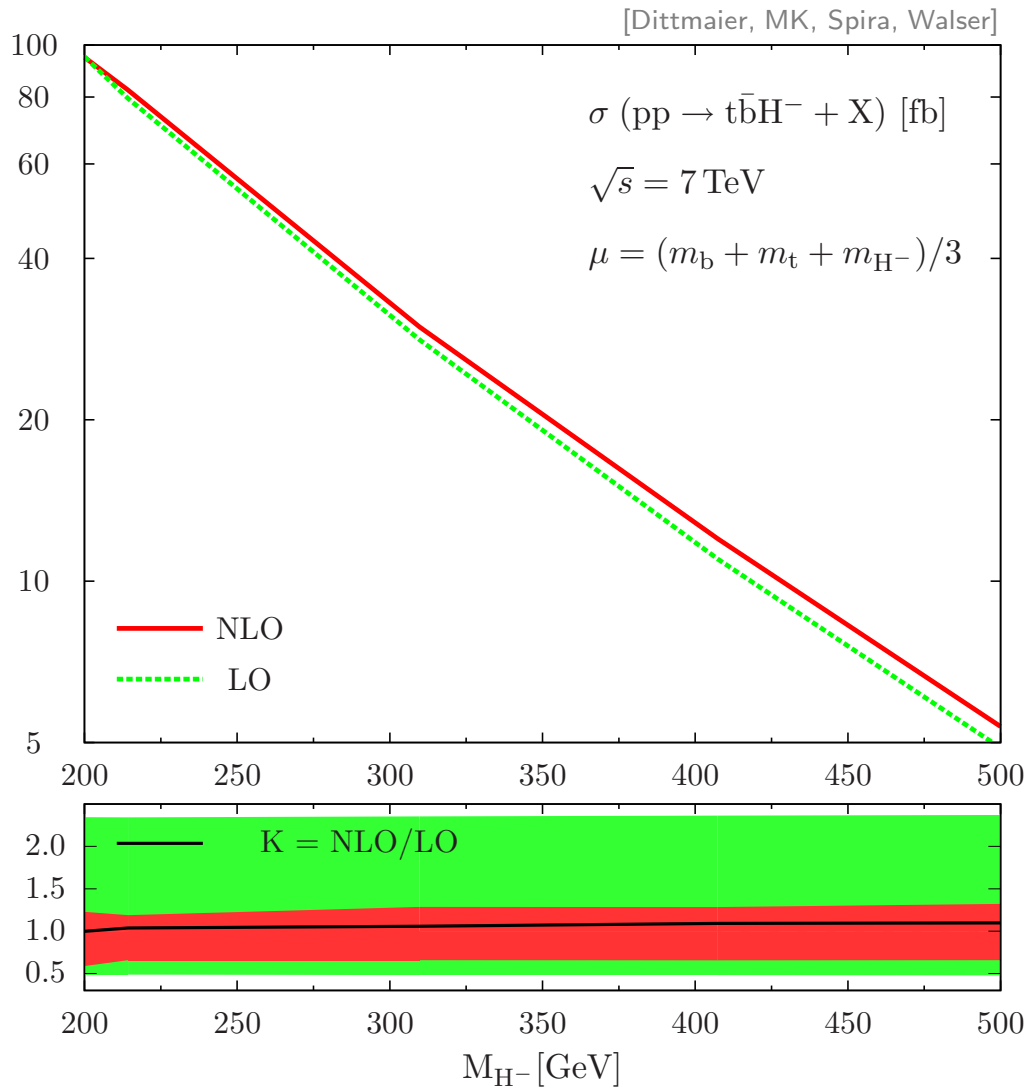


$\rightarrow \Delta\sigma = \pm$ 100% (LO) and $\pm$ 25% (NLO)

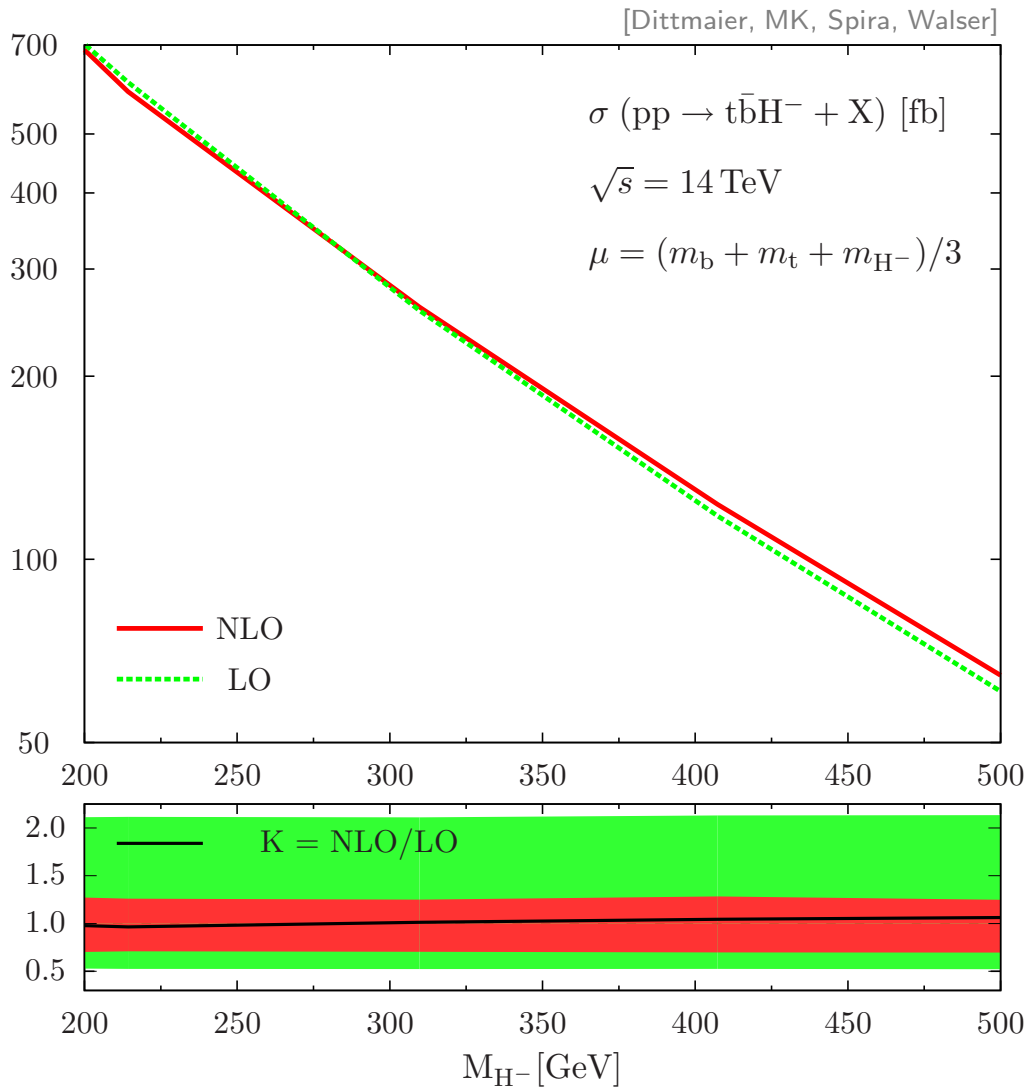
Associate $tbH^{\pm}$ production: 4FS calculation at NLO

- total cross section at 7 TeV



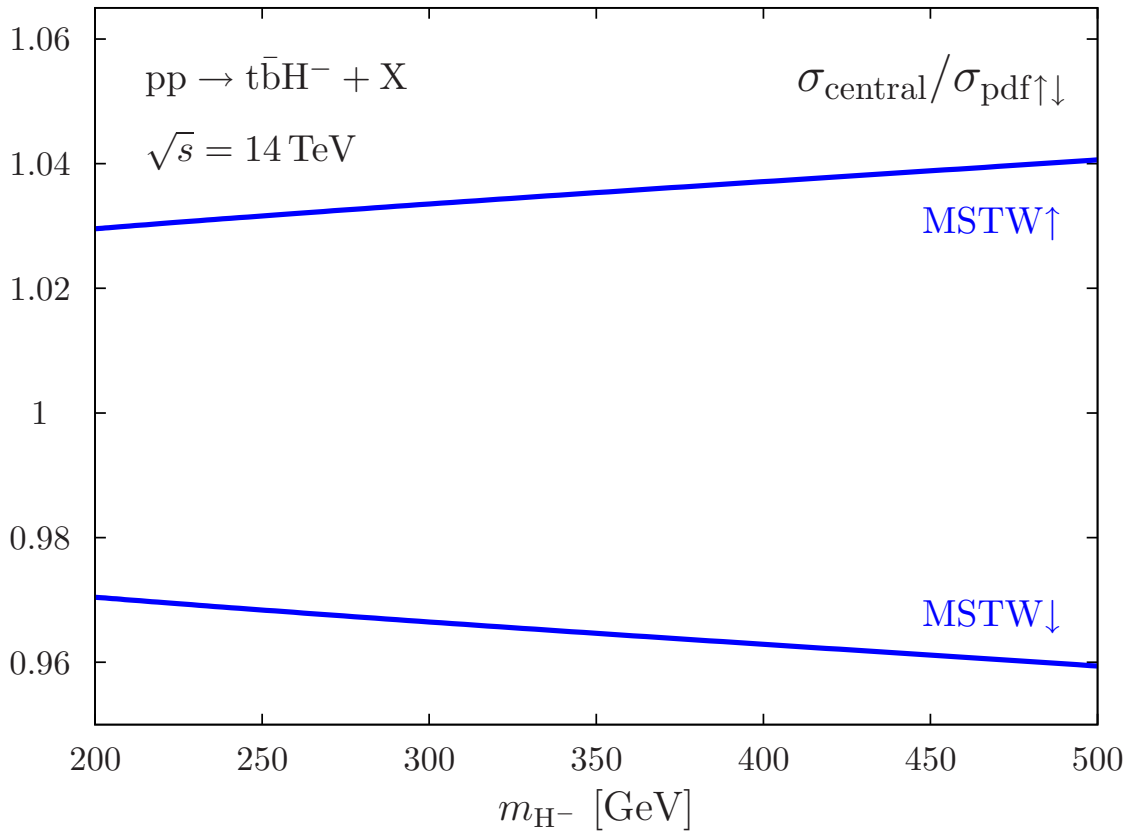
Associate $tbH^{\pm}$ production: 4FS calculation at NLO

- total cross section at 14 TeV



Associate $tbH^{\pm}$ production: 4FS pdf uncertainty

- total cross section with MSTW08 4FS pdf



$\rightarrow \Delta\mathrm{pdf} \lesssim 5\%$

Associate $tbH^{\pm}$ production: 4FS calculation at NLO

- total cross section (14 TeV): individual NLO contributions

$$\sigma_{\mathrm{NLO}} = \sigma_0 \times (1 + \delta^{\tan\beta-\mathrm{resum.}}_{\mathrm{SUSY-QCD}}) \times (1 + \delta_{\mathrm{QCD}} + \delta^{\mathrm{remainder}}_{\mathrm{SUSY-QCD}})$$

$M_{\mathrm{H}^{\pm}}$ [GeV]	σ_0 [fb]	δ_{QCD}	$\delta^{\tan\beta-\mathrm{resum.}}_{\mathrm{SUSY-QCD}}$	$\delta^{\mathrm{remainder}}_{\mathrm{SUSY-QCD}}$
214	545	0.57	−0.30	−0.002
310	234	0.61	−0.30	−0.002
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- partial cancellation between QCD and SUSY-QCD corrections

Associate $tbH^{\pm}$ production: 4FS calculation at NLO

- total cross section (14 TeV): individual NLO contributions

$$\sigma_{\rm NLO} = \sigma_0 \times (1 + \delta^{\tan\beta-{\rm resum.}}_{\rm SUSY-QCD}) \times (1 + \delta_{\rm QCD} + \delta^{\rm remainder}_{\rm SUSY-QCD})$$

$M_{\rm H^{\pm}}$ [GeV]	σ_0 [fb]	$\delta_{\rm QCD}$	$\delta^{\tan\beta-{\rm resum.}}_{\rm SUSY-QCD}$	$\delta^{\rm remainder}_{\rm SUSY-QCD}$
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- partial cancellation between QCD and SUSY-QCD corrections
- dominant SUSY-QCD (non-decoupling) contributions from corrections to bottom-Higgs Yukawa coupling:

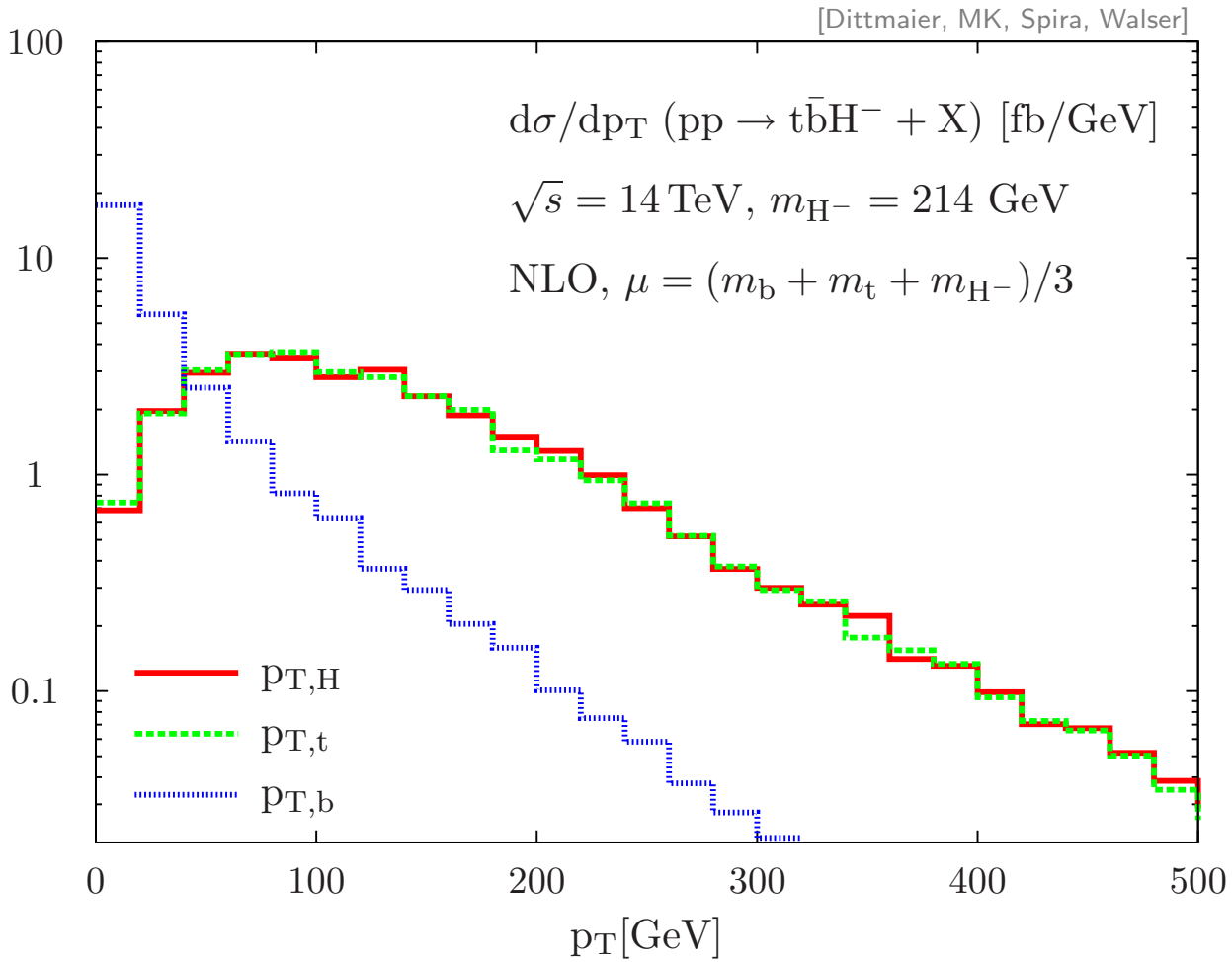
$$\frac{M_b \tan\beta}{v} \rightarrow \frac{M_b \tan\beta}{v} \frac{1}{1 + \Delta M_b}$$

where $\Delta M_b = \frac{C_F}{2} \frac{\alpha_s}{\pi} m_{\tilde{g}} \mu \tan\beta \times I(m_{\tilde{b}_1}, m_{\tilde{b}_2}, m_{\tilde{g}})$

[Hall, Rattazzi, Sarid, ...; Carena, Garcia, Nierste, Wagner;...Noth, Spira]

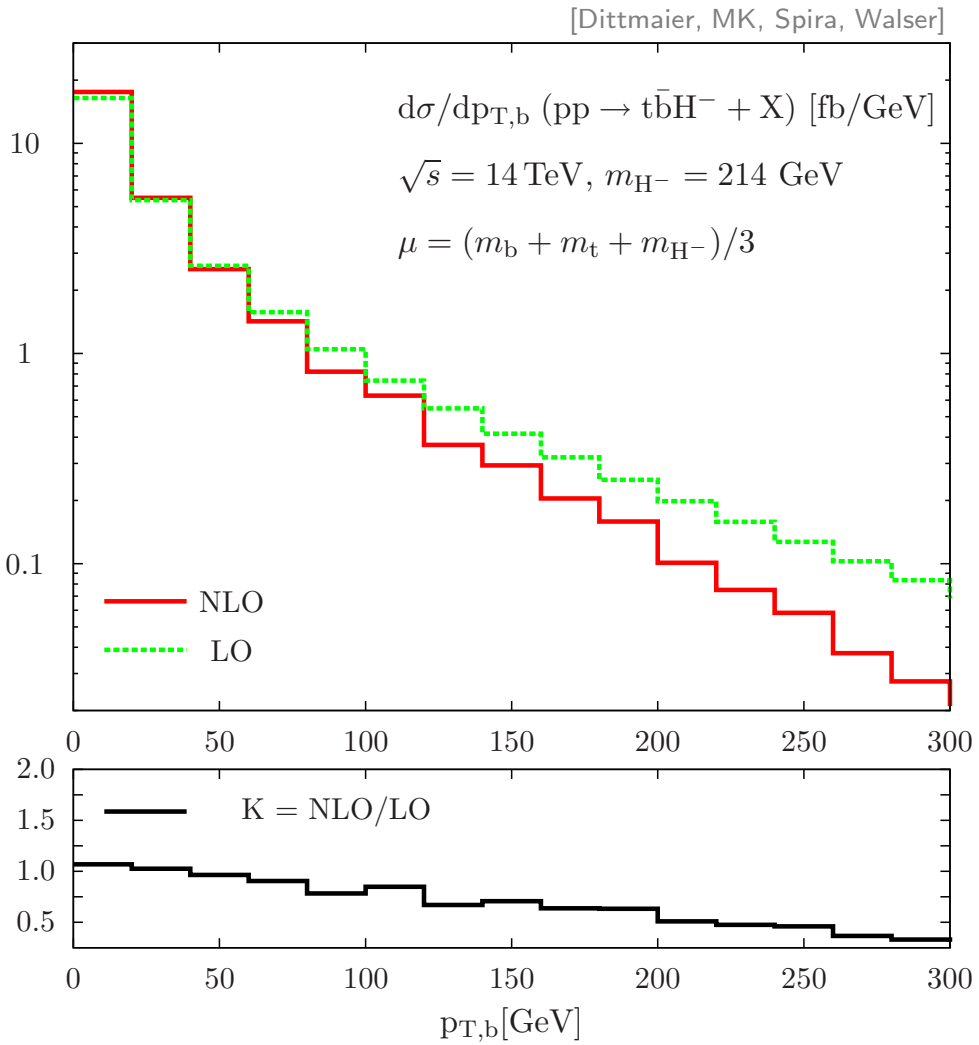
Associate $tbH^{\pm}$ production: 4FS calculation at NLO

- transverse momentum distribution



Associate $tbH^{\pm}$ production: 4FS calculation at NLO

- bottom transverse momentum distribution at LO/NLO



Comparison of 4 and 5FS calculations at NLO

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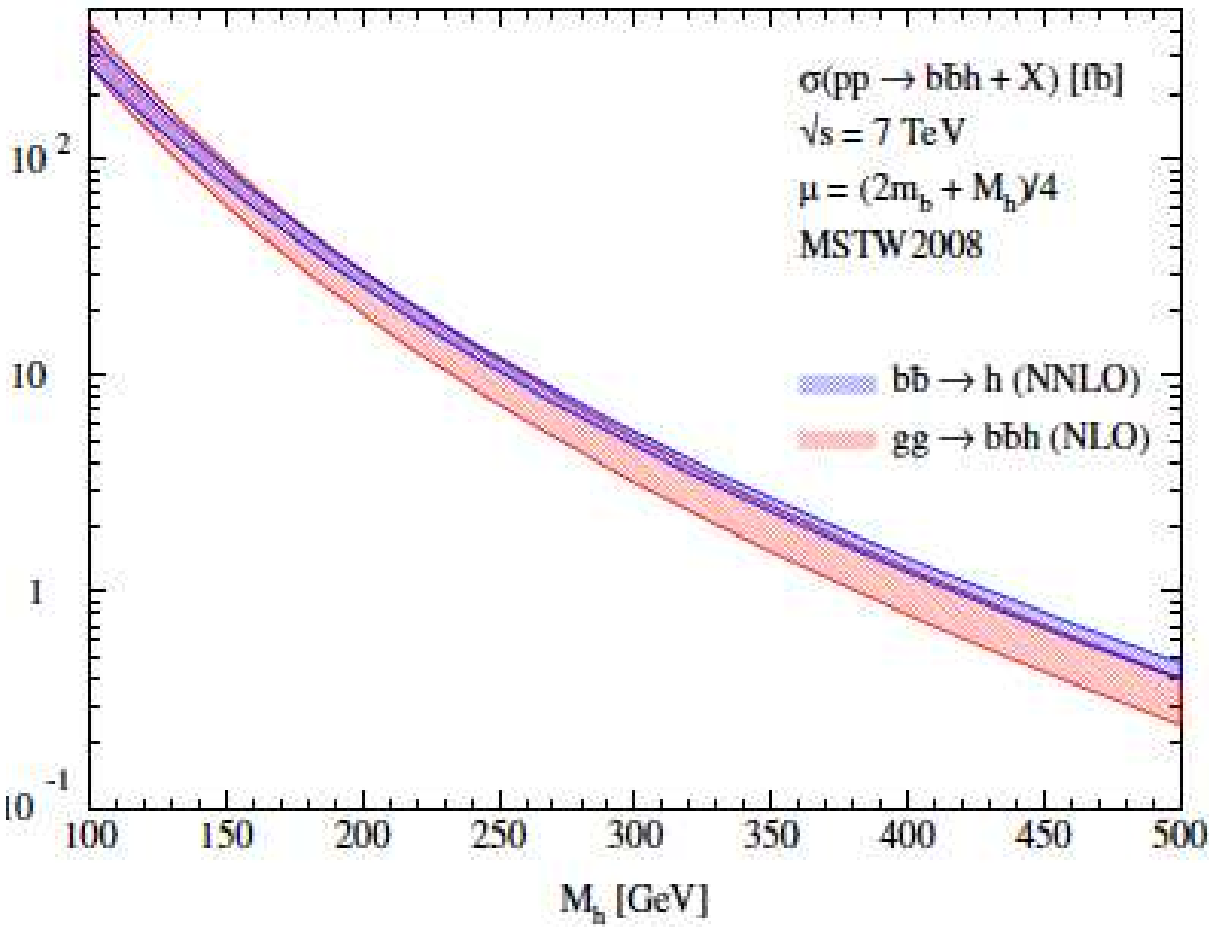
- Look first at $b\bar{b}H$ associated production at NLO/NNLO

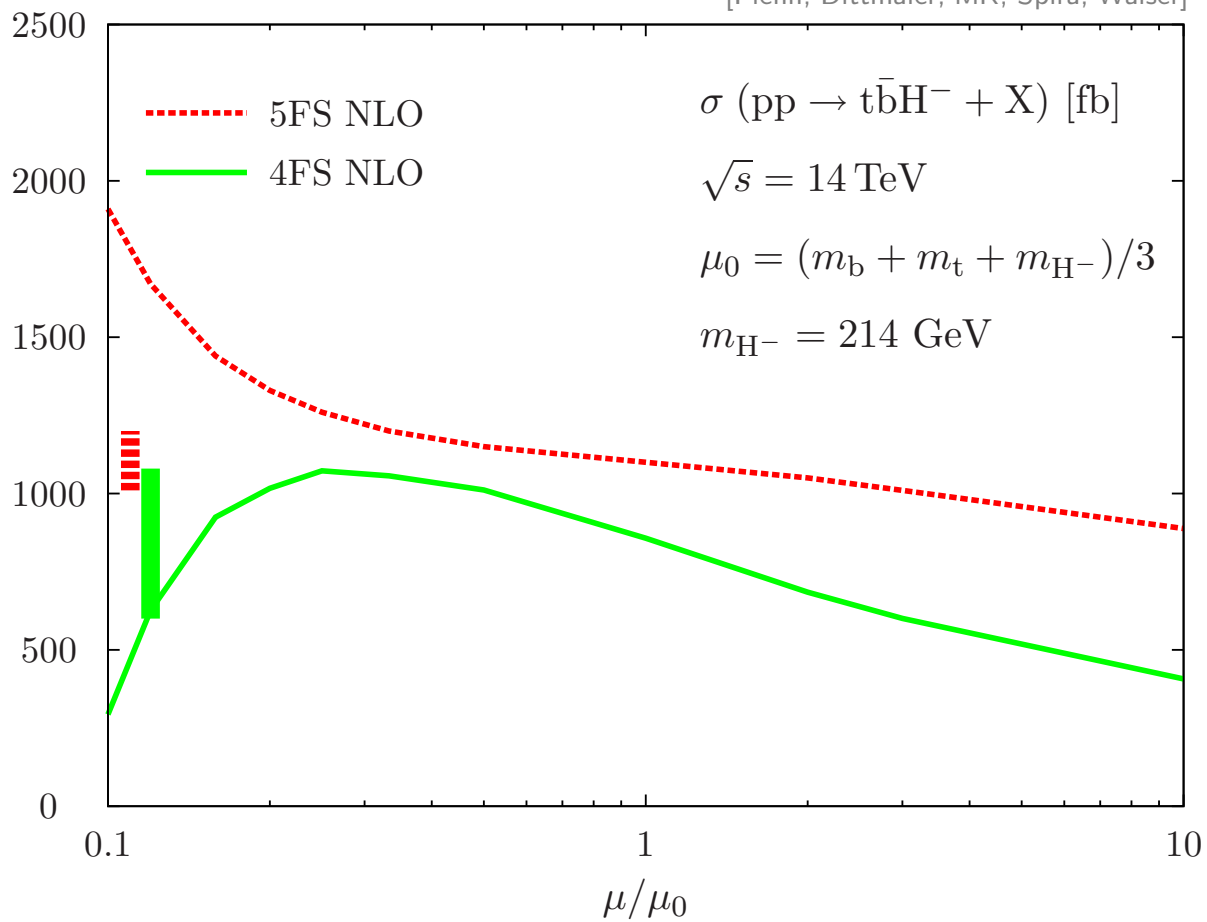
[Harlander, Kilgore; Dittmaier, MK, Spira]



Comparison of 4 and 5FS calculations at NLO

- NLO scale dependence

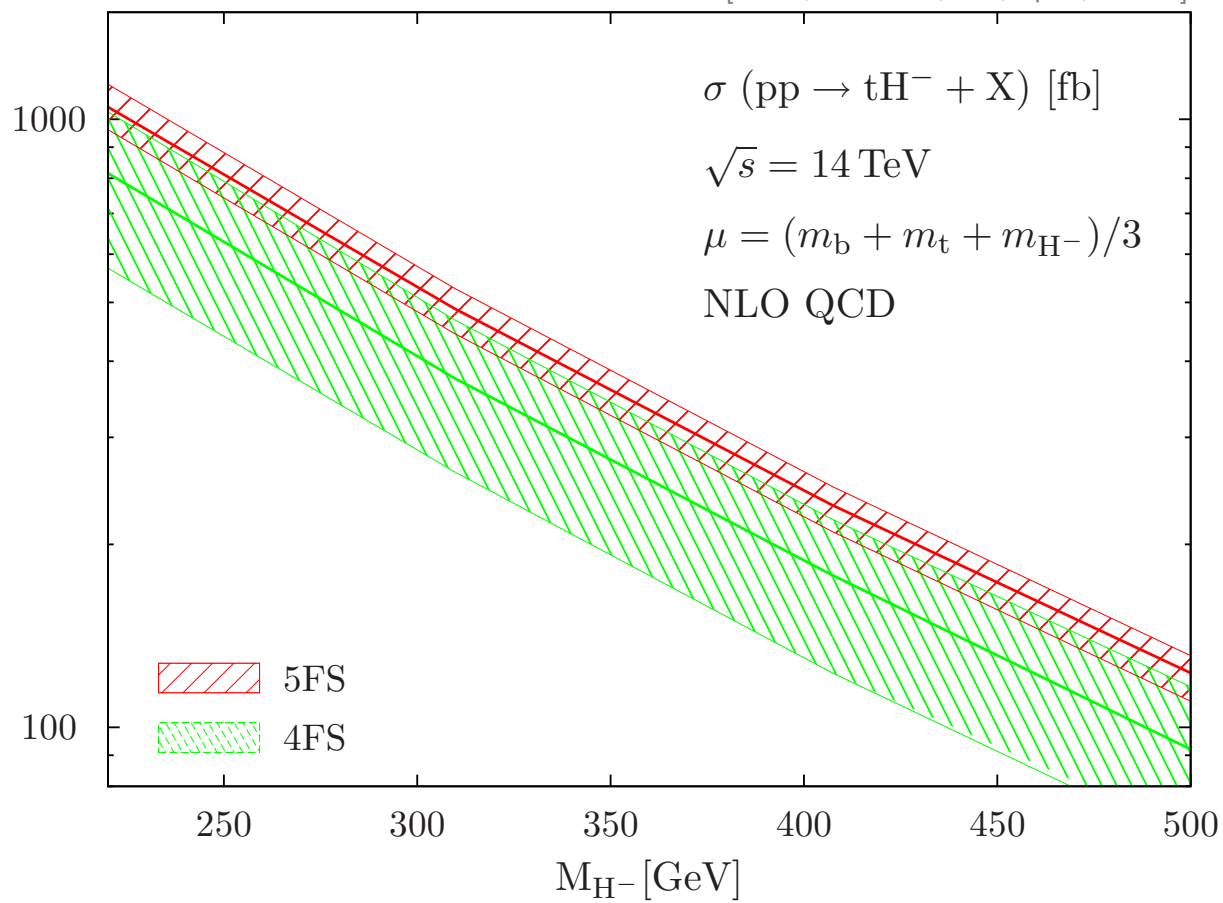
[Plehn; Dittmaier, MK, Spira, Walser]



Comparison of 4 and 5FS calculations at NLO

- total cross section

[Plehn; Dittmaier, MK, Spira, Walser]



Associate $tbH^{\pm}$ production: Outlook

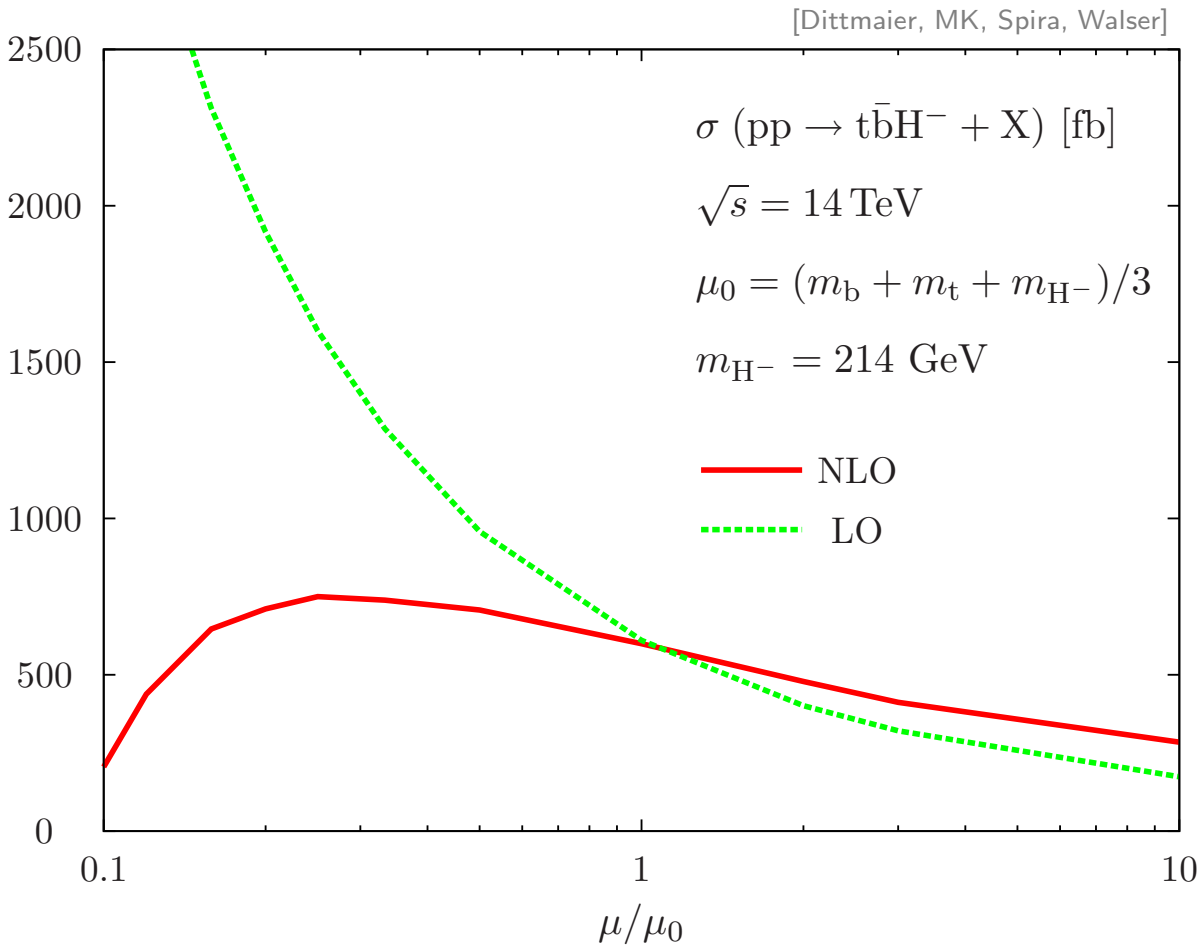
We should

- complete the pdf and α_{s} uncertainty analysis;
- study the factorization of SUSY corrections for a wider range of scenarios;
- pursue the comparison of 4FS and 5FS calculations for distributions;
- combine the NLO SUSY-QCD and EWK corrections;
- match the 4FS calculation with parton showers;
- include the decay of the Higgs and the top.
- consider the transition region where $m_H \approx m_{\mathrm{top}}$;

backup

Associate $tbH^{\pm}$ production: 4FS calculation at NLO

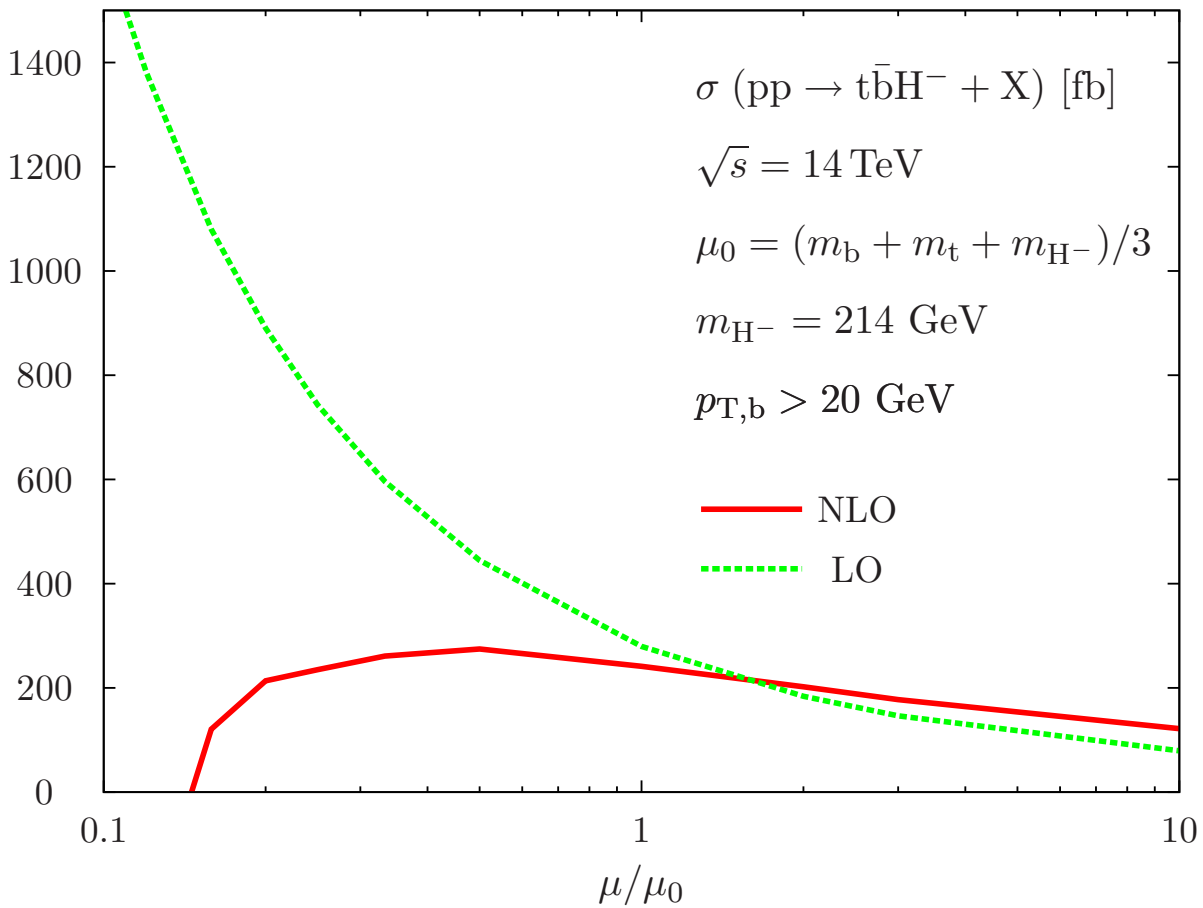
- scale dependence at 14 TeV



Associate $tbH^{\pm}$ production: 4FS calculation at NLO

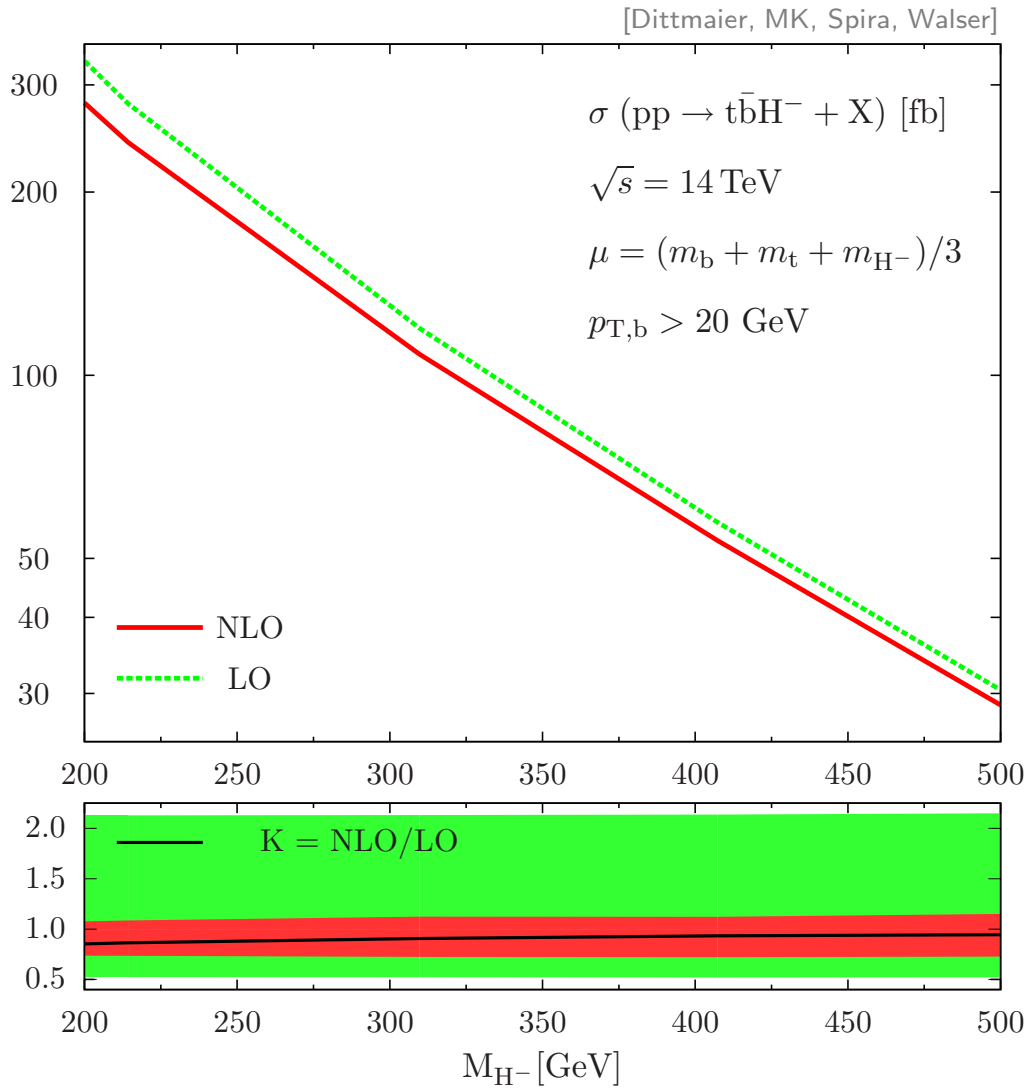
- scale dependence with $p_{\mathrm{T,b}}$-cut

[Dittmaier, MK, Spira, Walser]



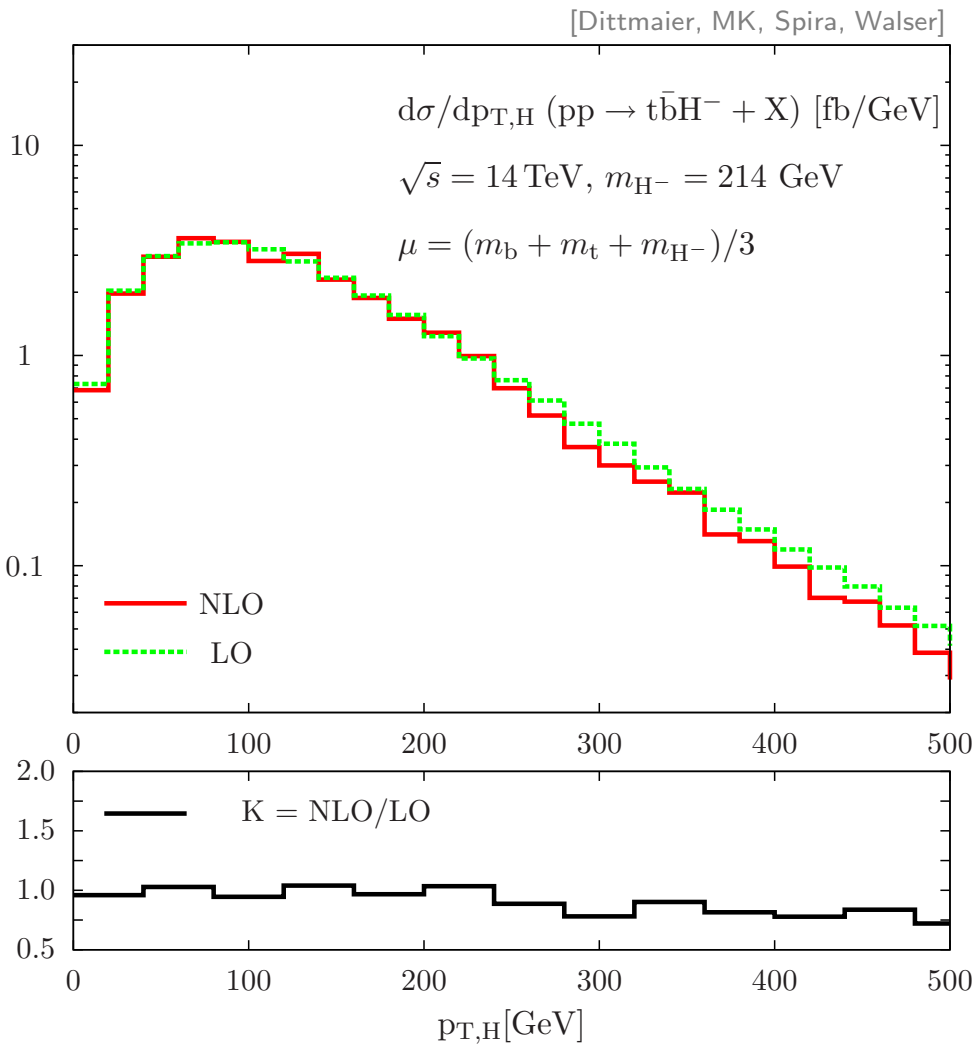
Associate $tbH^{\pm}$ production: 4FS calculation at NLO

- cross section with $p_{\mathrm{T,b}}$-cut



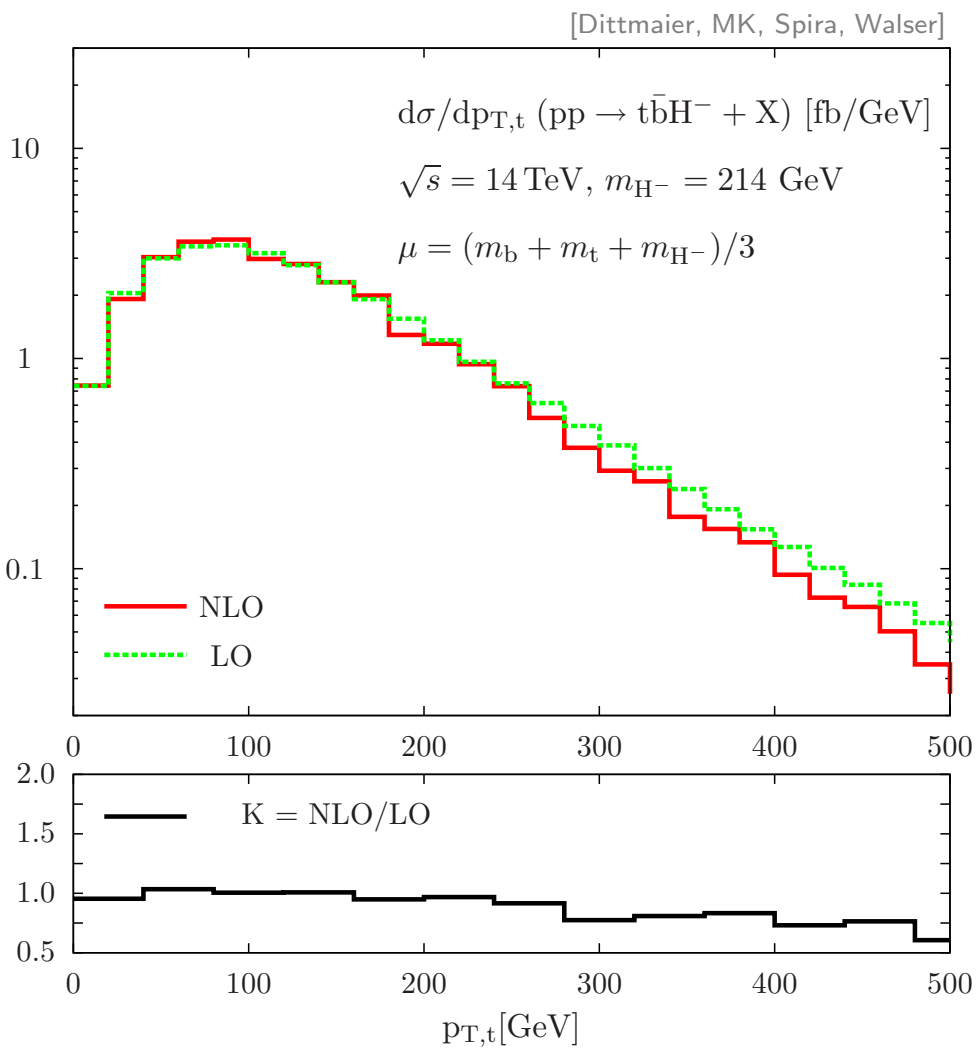
Associate $tbH^{\pm}$ production: 4FS calculation at NLO

- Higgs transverse momentum distribution at LO/NLO



Associate $tbH^{\pm}$ production: 4FS calculation at NLO

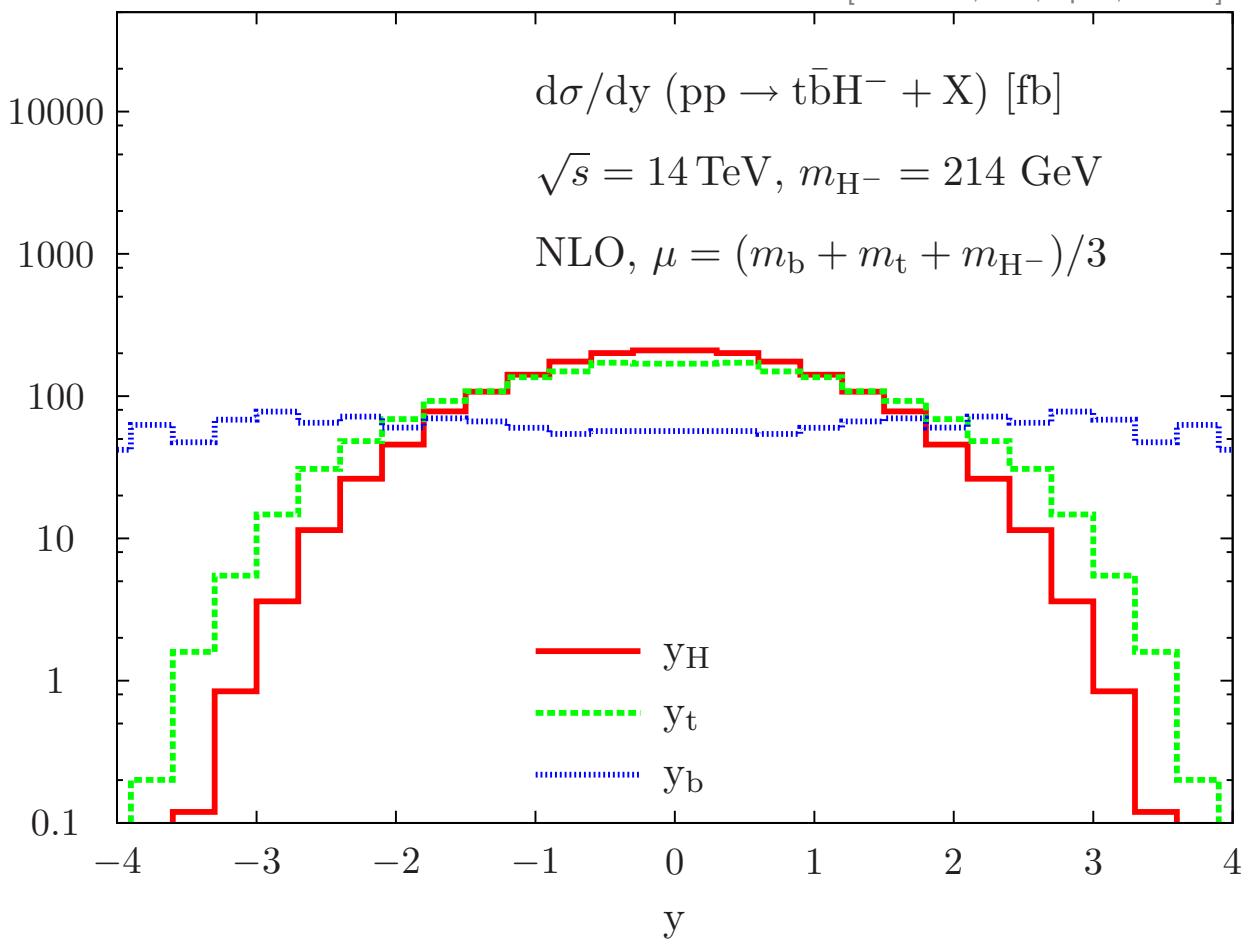
- top transverse momentum distribution at LO/NLO



Associate $tbH^{\pm}$ production: 4FS calculation at NLO

- rapidity distribution

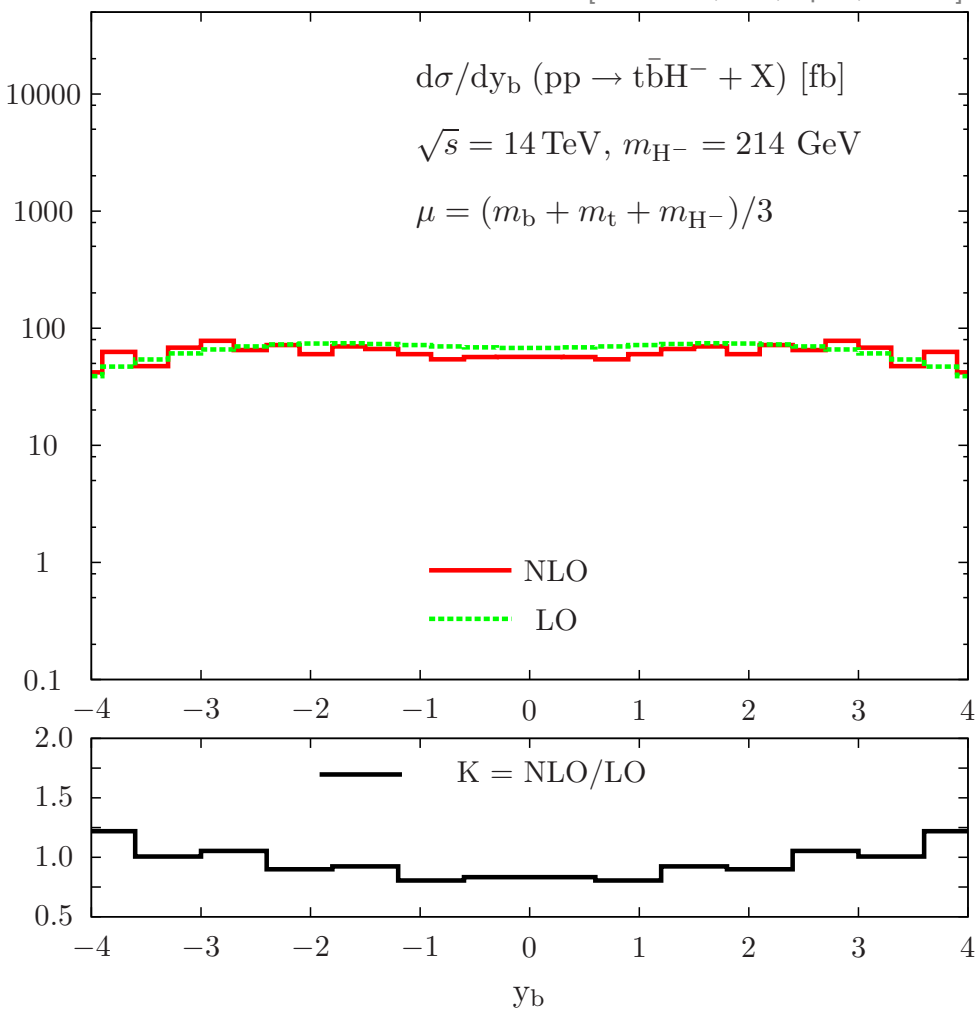
[Dittmaier, MK, Spira, Walser]



Associate $tbH^{\pm}$ production: 4FS calculation at NLO

- bottom rapidity distribution at LO/NLO

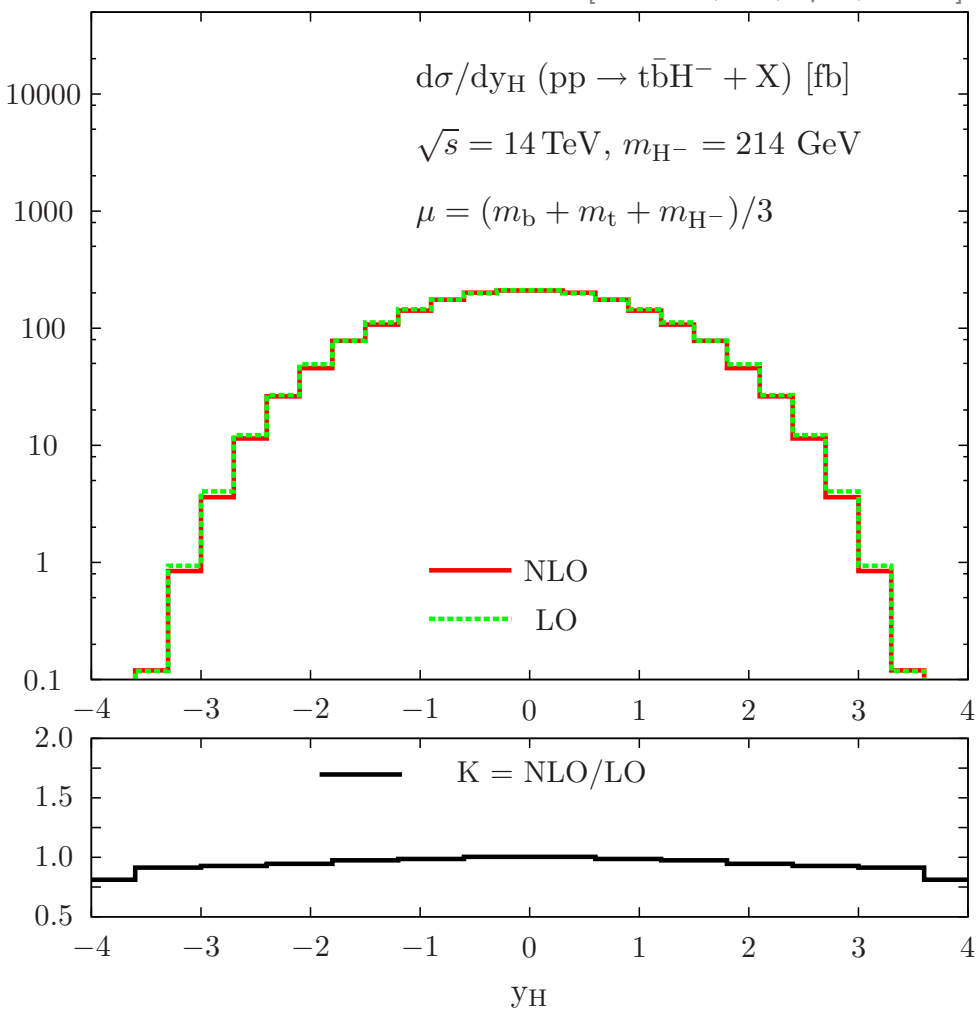
[Dittmaier, MK, Spira, Walser]



Associate $tbH^{\pm}$ production: 4FS calculation at NLO

- Higgs rapidity distribution at LO/NLO

[Dittmaier, MK, Spira, Walser]



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- top rapidity distribution at LO/NLO

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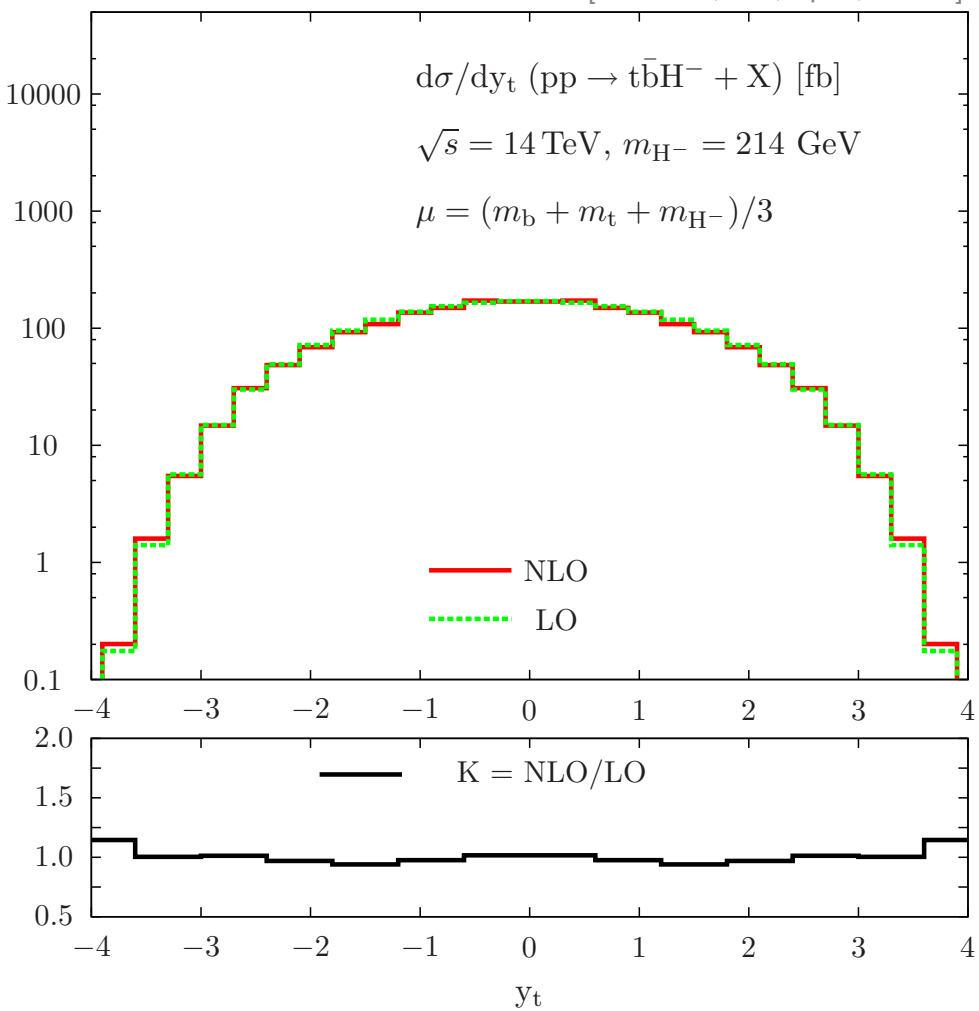
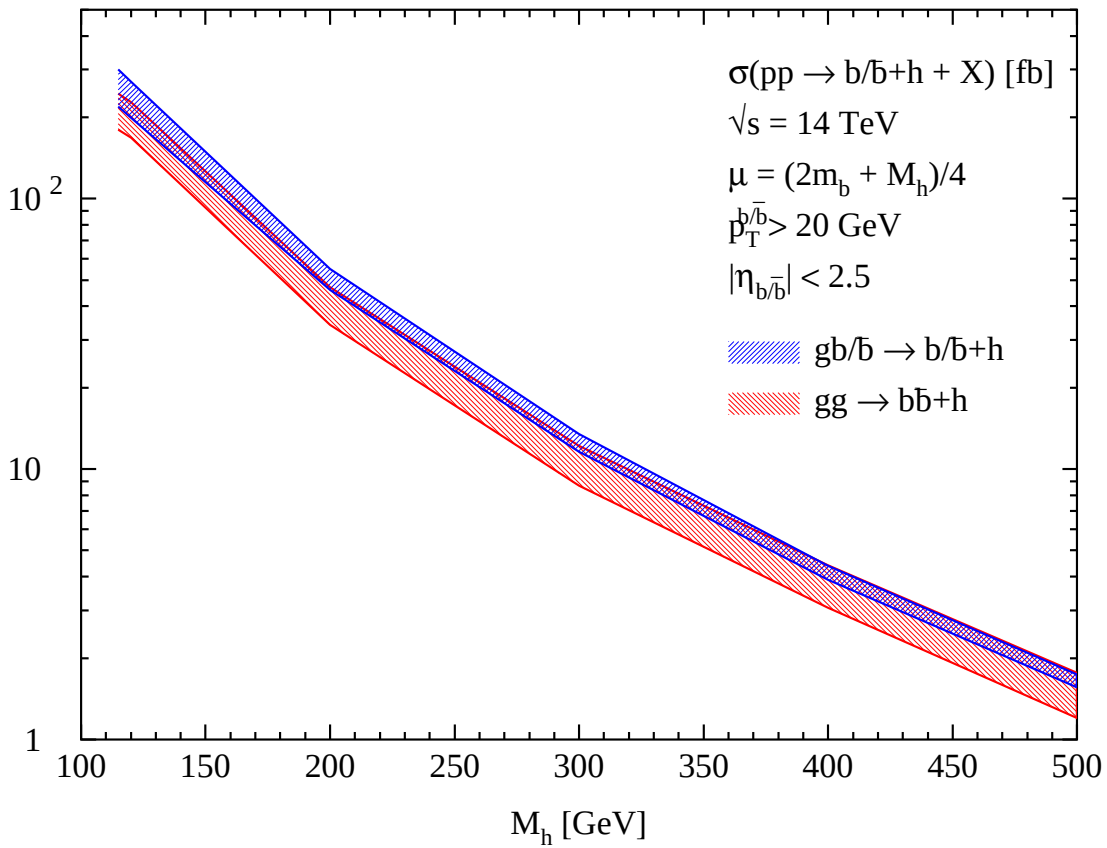


Associate $tbH^{\pm}$ production: two calculational schemes

NLO comparison of 4FS and 5FS for $pp \to b/\bar{b} + h$

[Campbell, Ellis, Maltoni, Willenbrock; Dittmaier, MK, Spira; Dawson, Jackson, Reina, Wackeroth]



Note: consistent treatment of pdf and Higgs radiation off top should lead to even better agreement

Search for charged MSSM Higgs bosons at the LHC

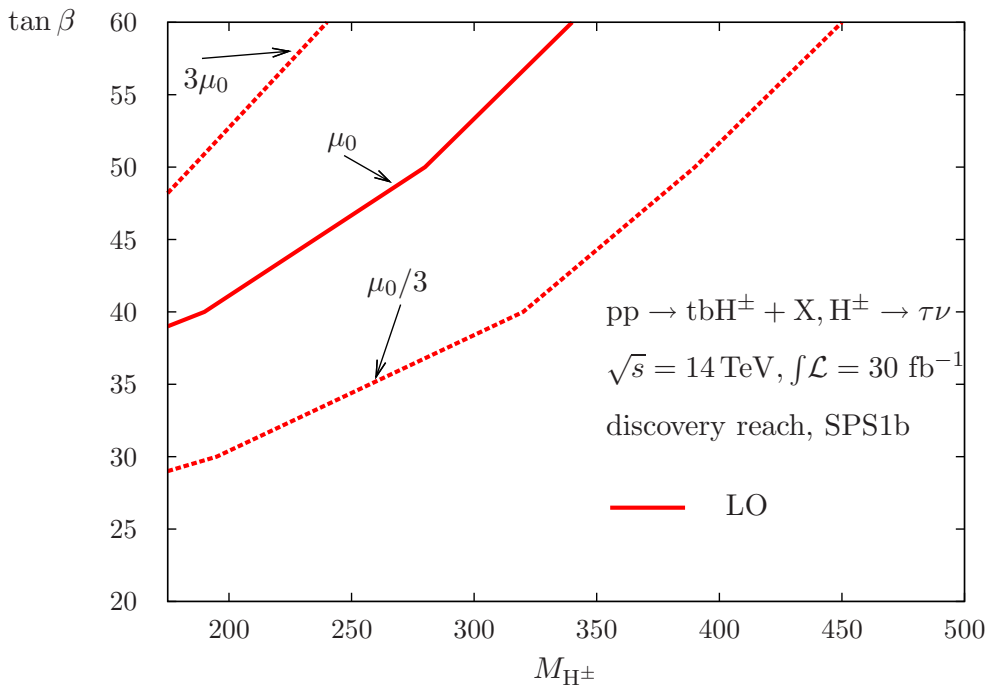
cf. Hashemi, Heinemeyer, Kinnunen, Nikitenko, Weiglein

Consider $pp \to tH^{\pm}(\to \tau\nu_\tau) + X$ and calculate number of events as

$$N_{\text{events}} = \mathcal{L} \times \sigma(pp \to H^{\pm} + X) \times \text{BR}(H^{\pm} \to \tau + \nu_\tau) \times \text{BR}(\tau \to \text{hadrons}) \times \text{exp. eff.}$$

(experimental efficiency from CMS 2006/100 (Kinnunen))

$\to$ 5σ discovery contours in $(\tan\beta, M_{H^{\pm}})$ plane



$\mathcal{L} = 30\ \text{fb}^{-1}$

SPS1b with $\tan\beta$ and M_A varied

LO cross section

with scale uncertainty

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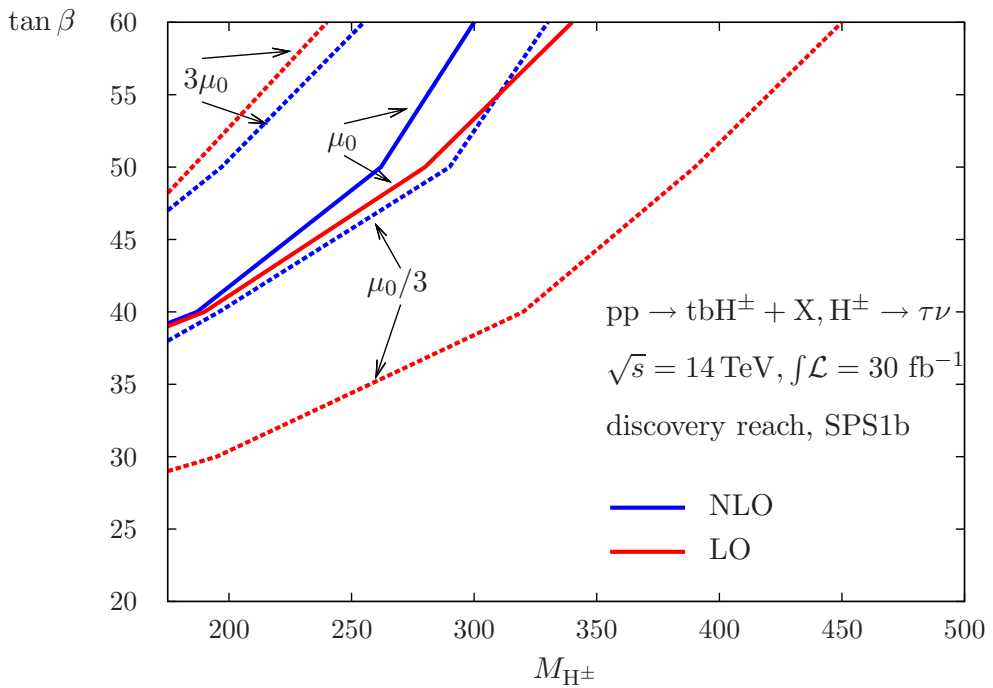

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LO/NLO cross section

with scale uncertainty