

Charged Higgs boson production at the LHC: NLO supersymmetric QCD corrections

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in collaboration with S. Dittmaier, M. Spira, M. Walser

Introduction: charged Higgs bosons in the MSSM

- **MSSM:** 2HDM with 5 physical Higgs particles h, H, A, H^\pm

SUSY → MSSM Higgs sector determined by M_A and $\tan \beta$ (at tree level)

mass constraint: $M_{H^\pm}^2 = M_W^2 + M_A^2$

Yukawa couplings: $g_{t\bar{b}H^-} = \frac{\sqrt{2}}{v} (m_t P_R \cot \beta + m_b P_L \tan \beta)$

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- charged Higgs searches at LEP

$$e^+ e^- \not\rightarrow H^+ H^- \Rightarrow M_{H^\pm} \gtrsim 80 \text{ GeV (95% CL)} \quad [\text{LEP Higgs WG}]$$

$$\text{MSSM: } M_{H^\pm} = \sqrt{M_W^2 + M_A^2} \gtrsim 122 \text{ GeV from } M_A \gtrsim 92 \text{ GeV} \quad [\text{LEP Higgs WG}]$$

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- charged Higgs searches at the Tevatron

$$p\bar{p} \rightarrow t(\rightarrow bH^+) \bar{t}(\rightarrow \bar{b}H^-)$$

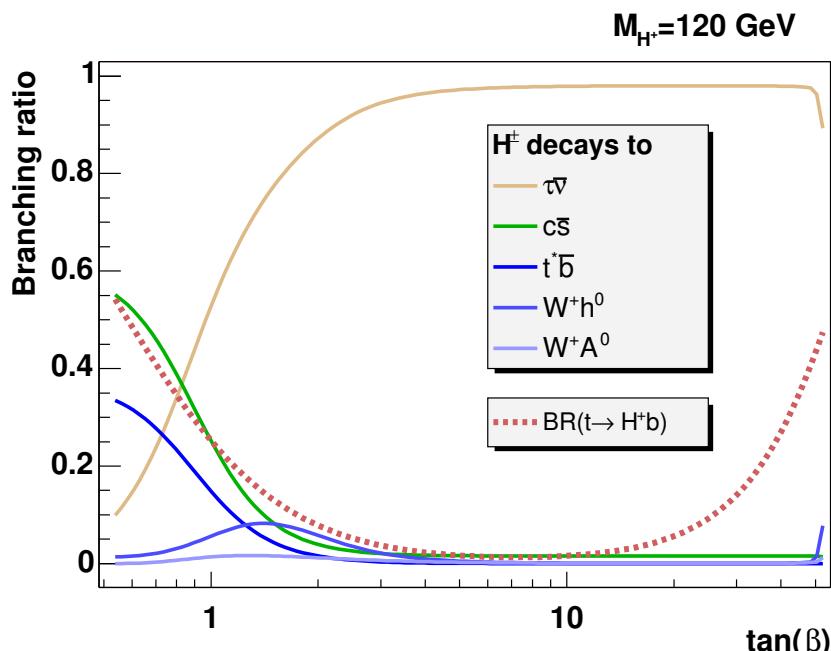
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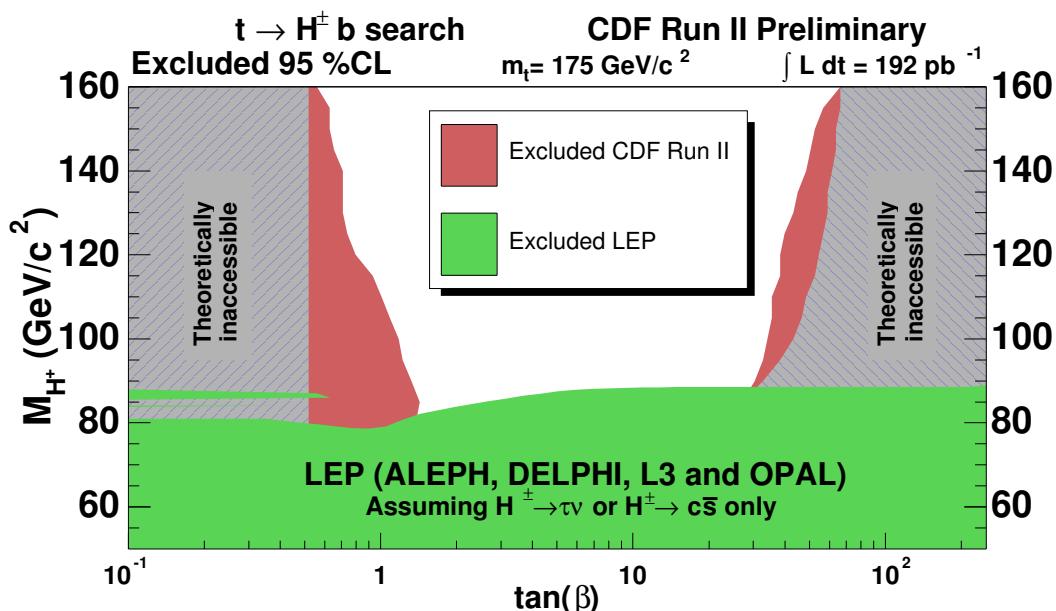
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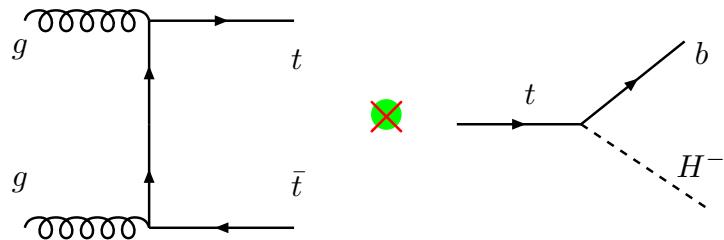
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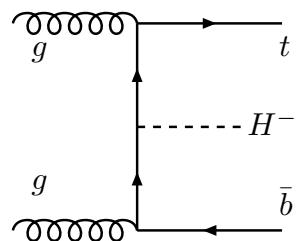


Introduction: charged Higgs boson production at the LHC

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

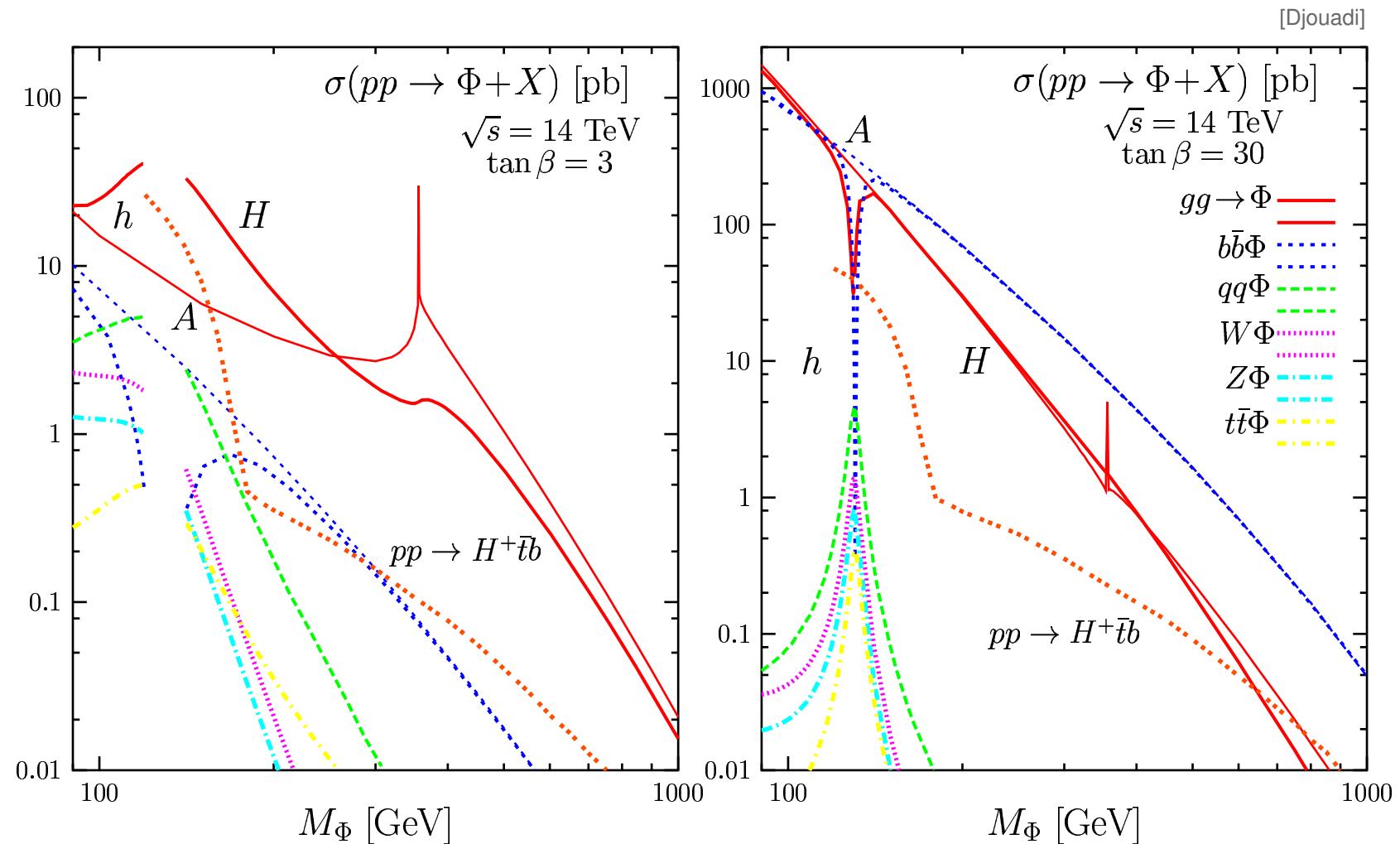


- $pp \rightarrow tbH^\pm$ for $M_{H^\pm} \gtrsim m_{\text{top}}$



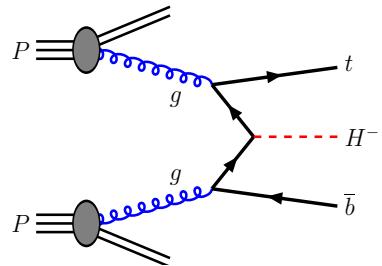
alternative production mechanisms like $q\bar{q}' \rightarrow H^\pm$, $pp \rightarrow H^\pm + \text{jet}$,
 $pp \rightarrow H^\pm W^\mp$, or Higgs pair production are suppressed...

Introduction: charged Higgs boson production at the LHC



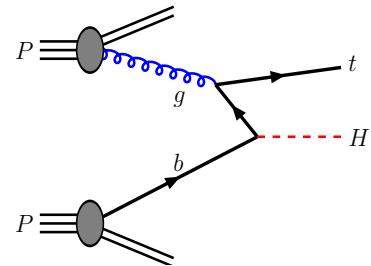
Associated tbH^\pm production: two calculational schemes

4-flavour scheme



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

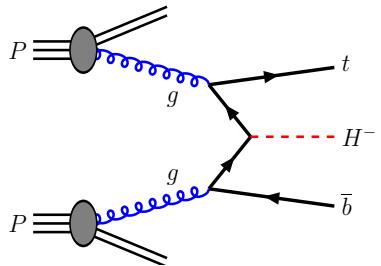
5-flavour scheme



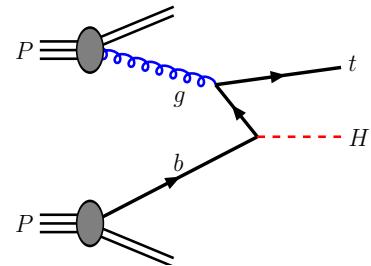
- + summation of $\ln(M_H/M_b)$ terms
- LL approximation to $g \rightarrow b\bar{b}$ splitting

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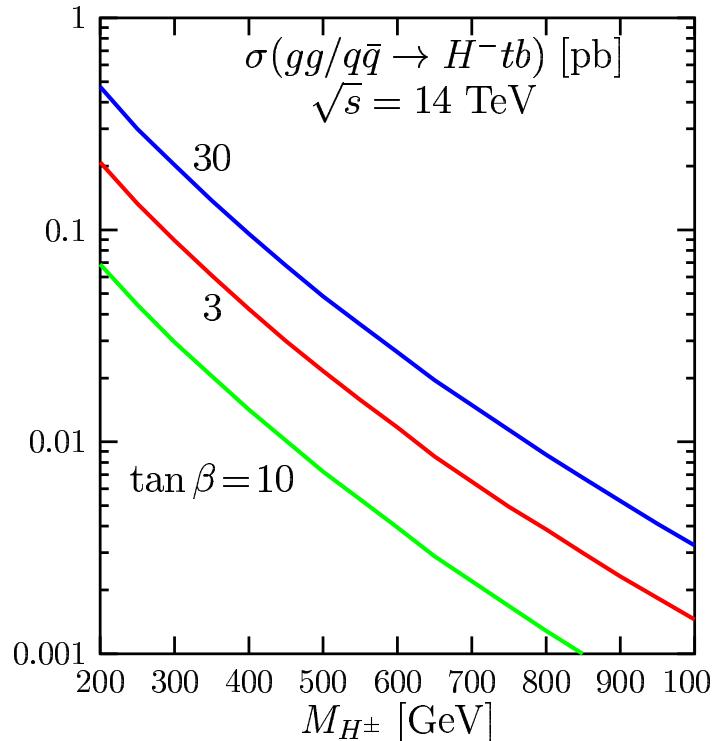
• The 4- and 5-flavour schemes

- 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

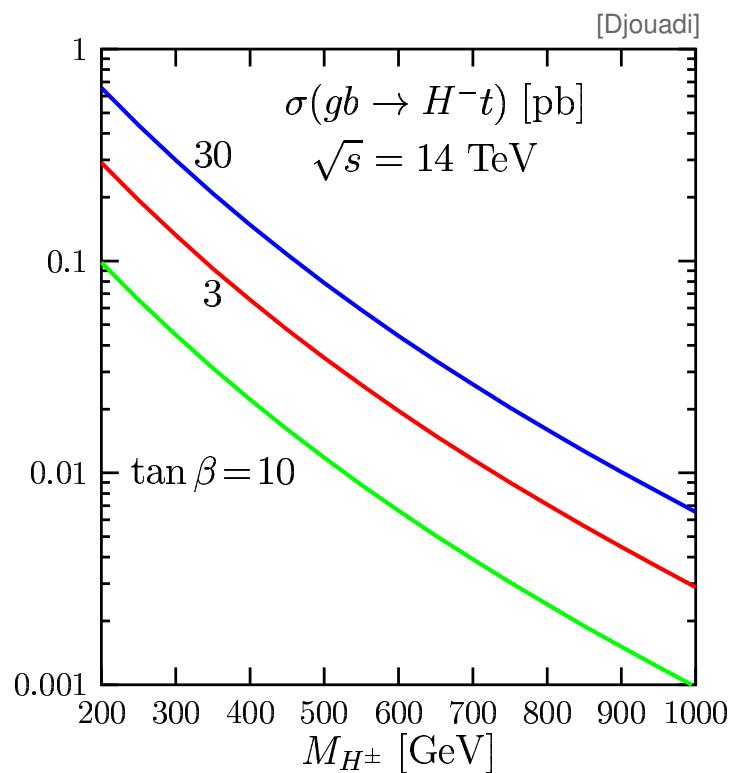
Associated tbH^\pm production: two calculational schemes

- Comparison at LO

4-flavour scheme



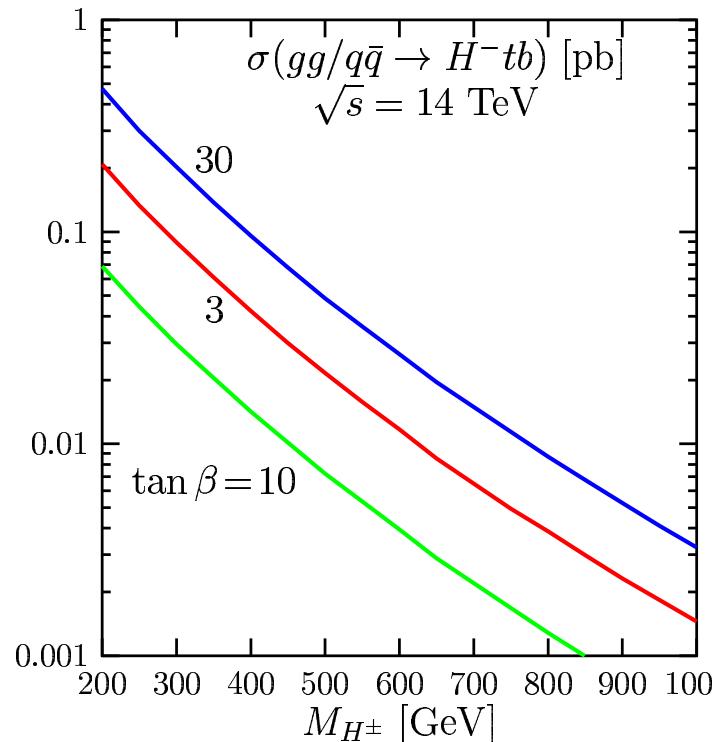
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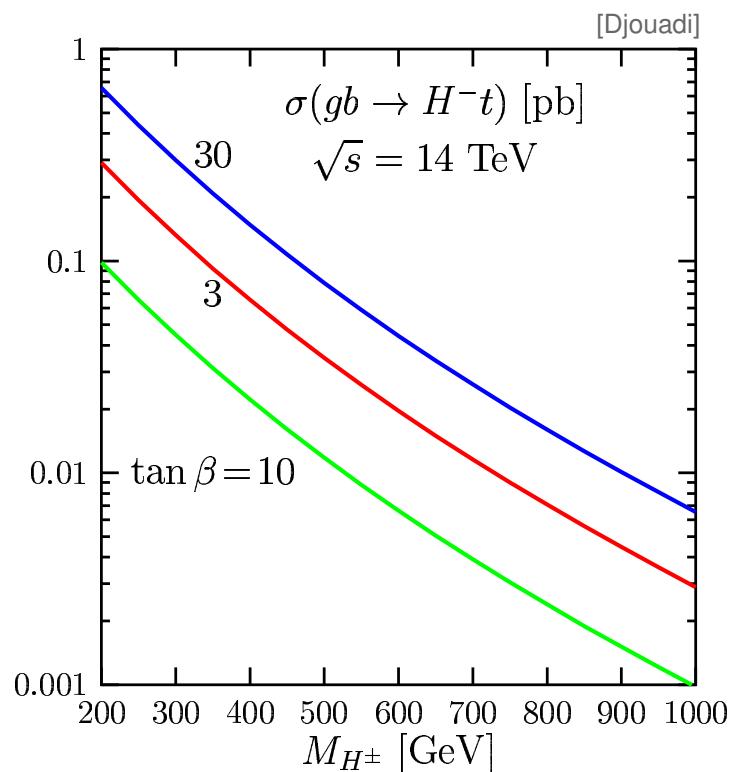
Associated tbH^\pm production: two calculational schemes

● Comparison at LO

4-flavour scheme



5-flavour scheme

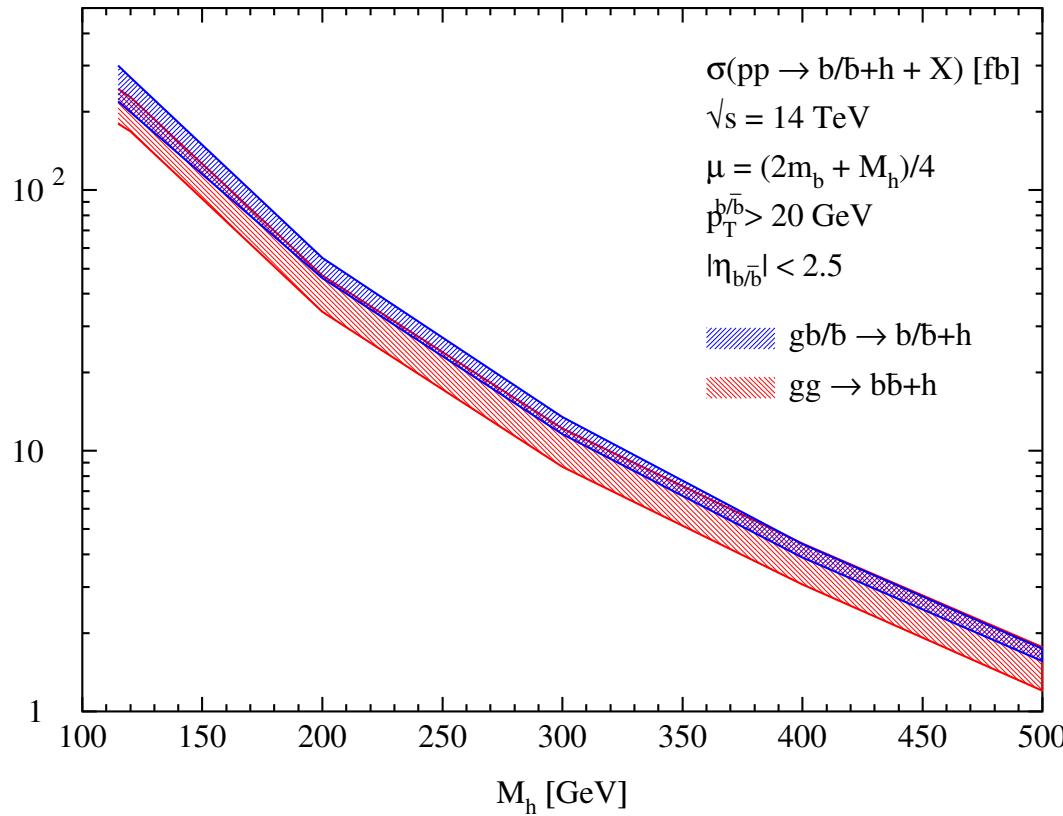


⇒ need systematic comparison of 4FNS and 5FNS beyond LO

Associated $t b H^\pm$ production: two calculational schemes

- Comparison of 4- and 5FNS for neutral Higgs plus b-jet production at NLO

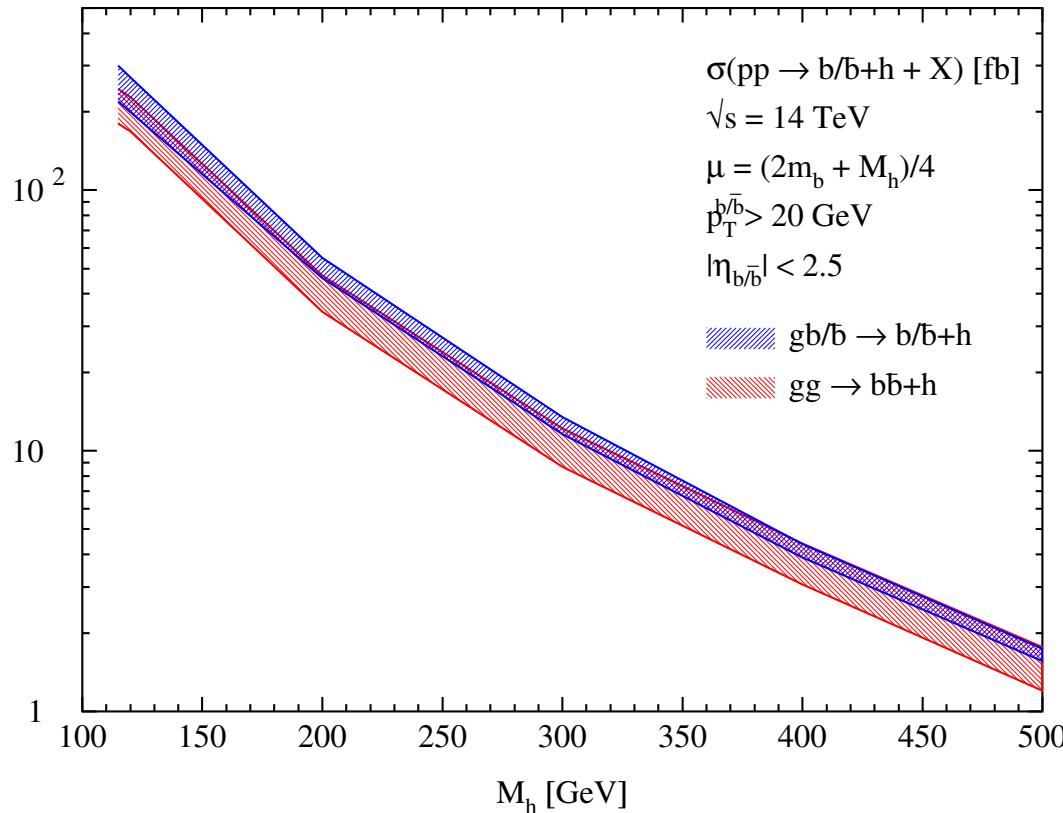
[Campbell, Ellis, Maltoni, Willenbrock; Dittmaier, MK, Spira; Dawson, Jackson, Reina, Wackerlo]



Associated $t b H^\pm$ production: two calculational schemes

- Comparison of 4- and 5FNS for neutral Higgs plus b-jet production at NLO

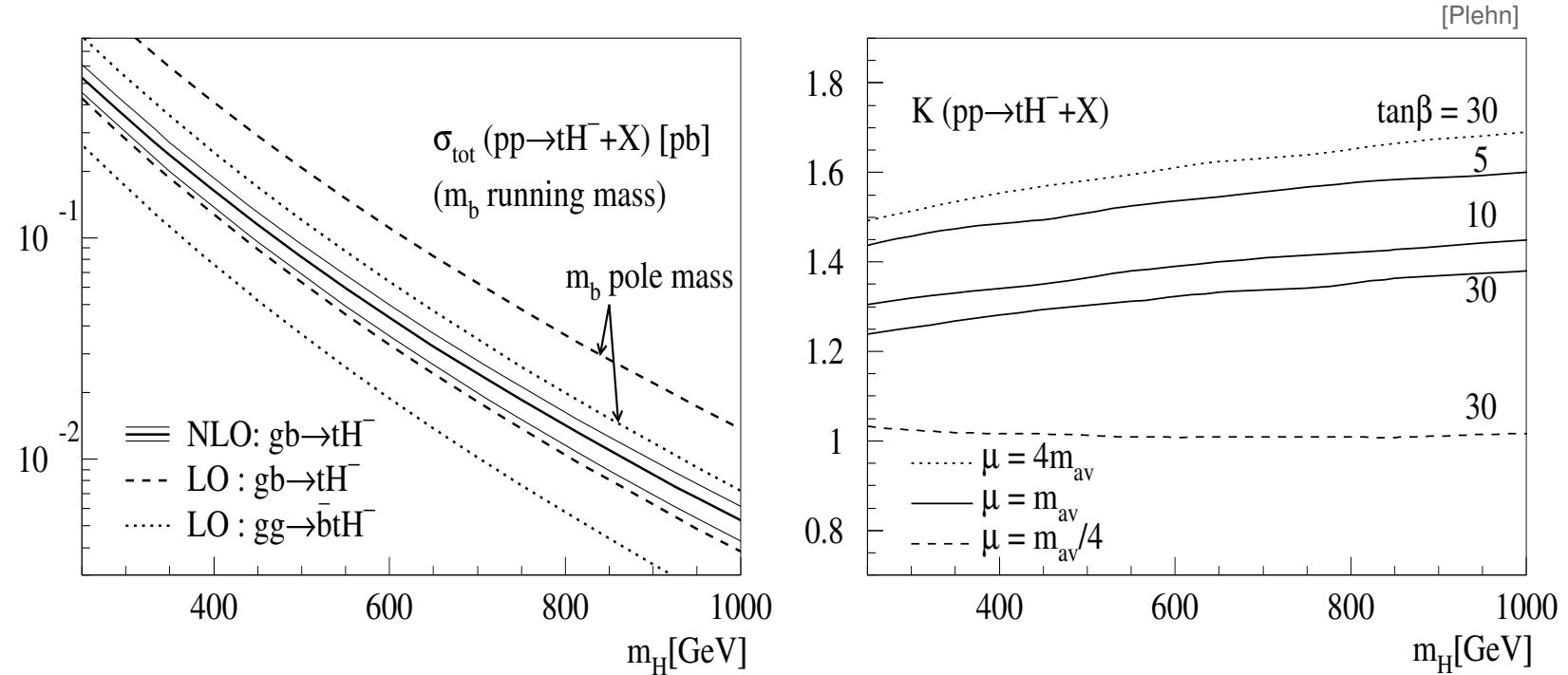
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- 4-flavour calculation includes Higgs radiation off top loops $\approx -10\%$
- calculations employ different PDF fits
- consistent comparison should reveal even better agreement

Associated $t b H^\pm$ production: 5FNS calculation at NLO

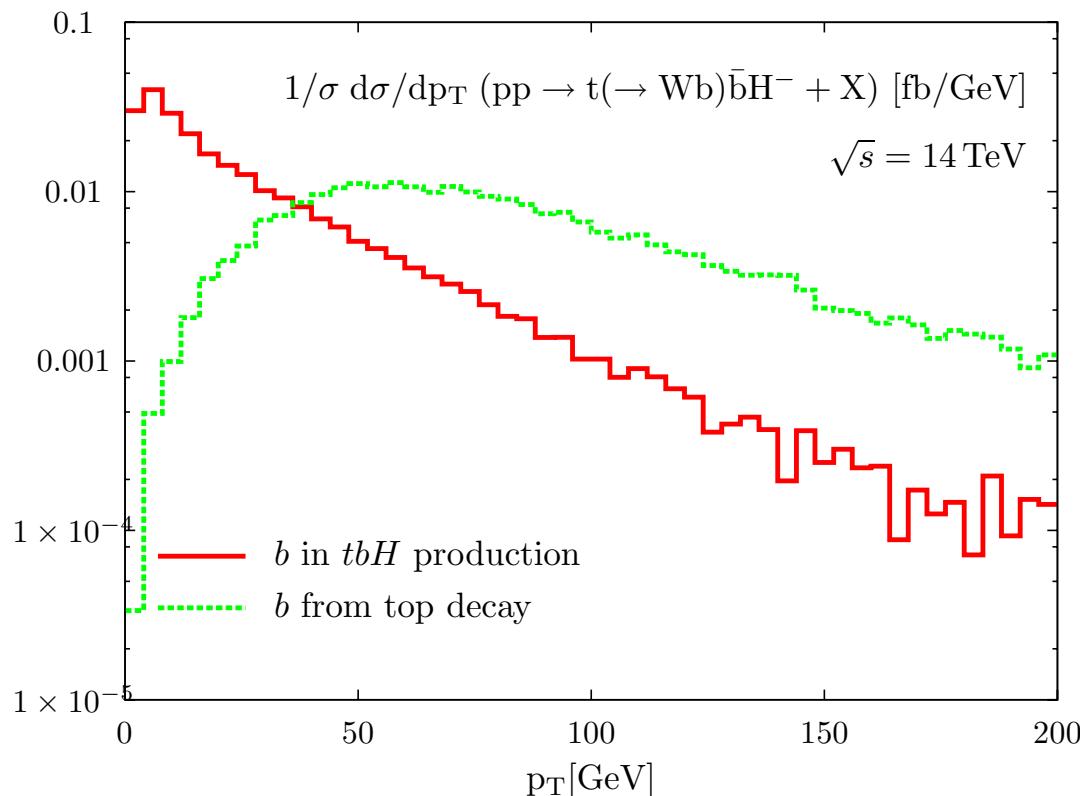
see Zhu; Gao, Lu, Xiong, Yang; Plehn; Berger, Han, Jiang, Plehn; Kidonakis



→ scale uncertainty at NLO $\approx 20\%$

Associated tbH^\pm production: 4FNS calculation

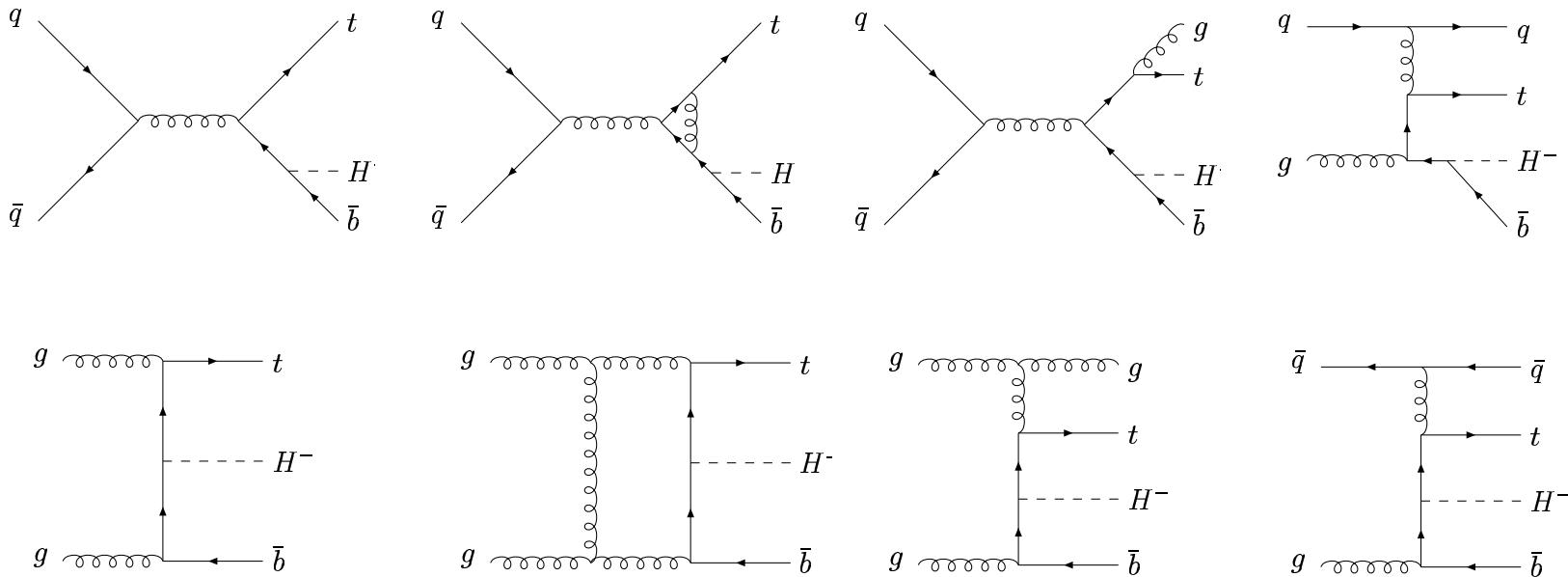
- better description of b-quark dynamics in 4FNS
 - needed for searches with additional b-tag
 - needed for event reconstruction
- contamination of top reconstruction by additional b-jets



Associated $t b H^\pm$ production: 4FNS calculation at NLO

see Peng et al.; Dittmaier, MK, Spira, Walser

- generic Feynman graphs



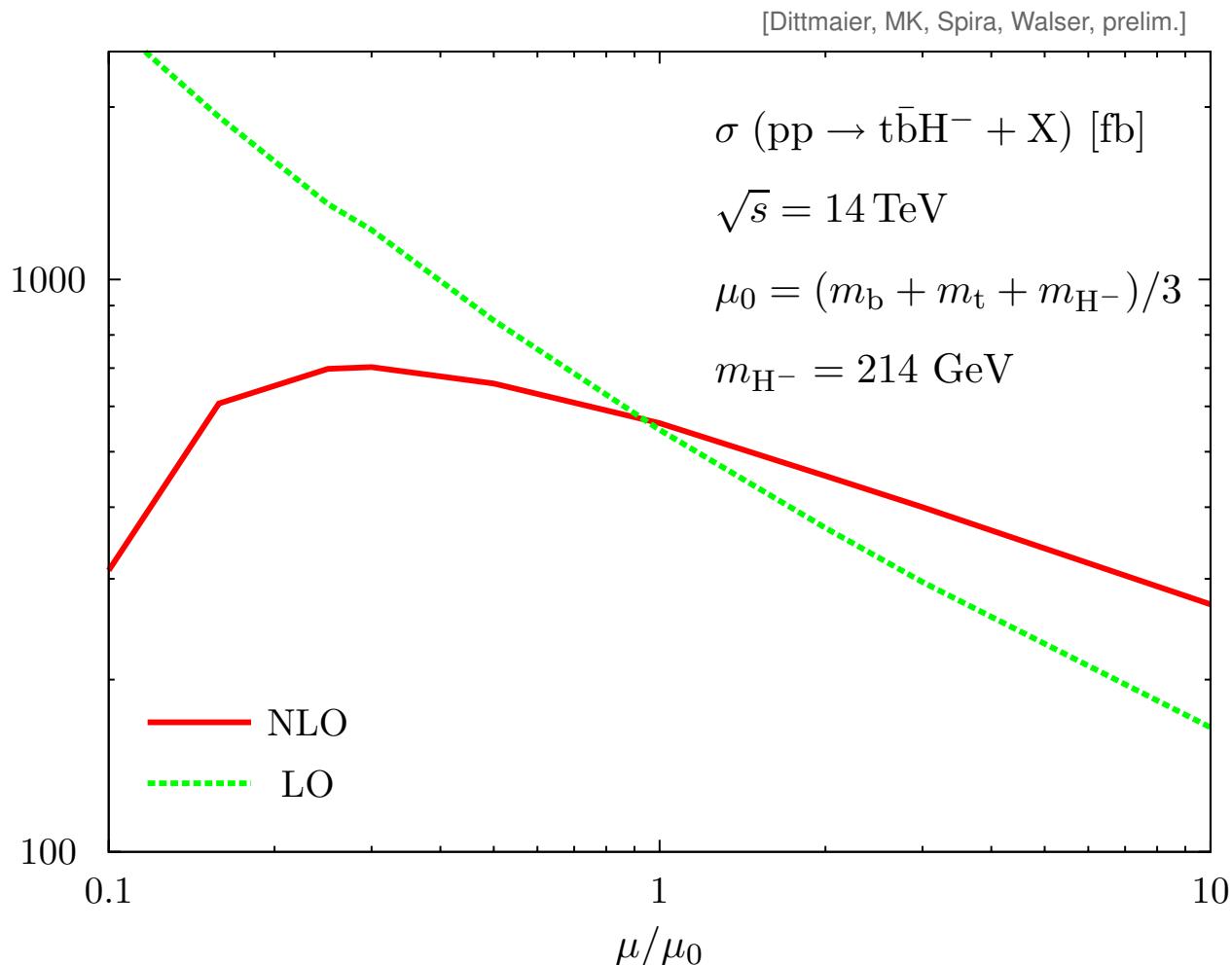
+ graphs with virtual SUSY particles...

→ calculation using standard techniques

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

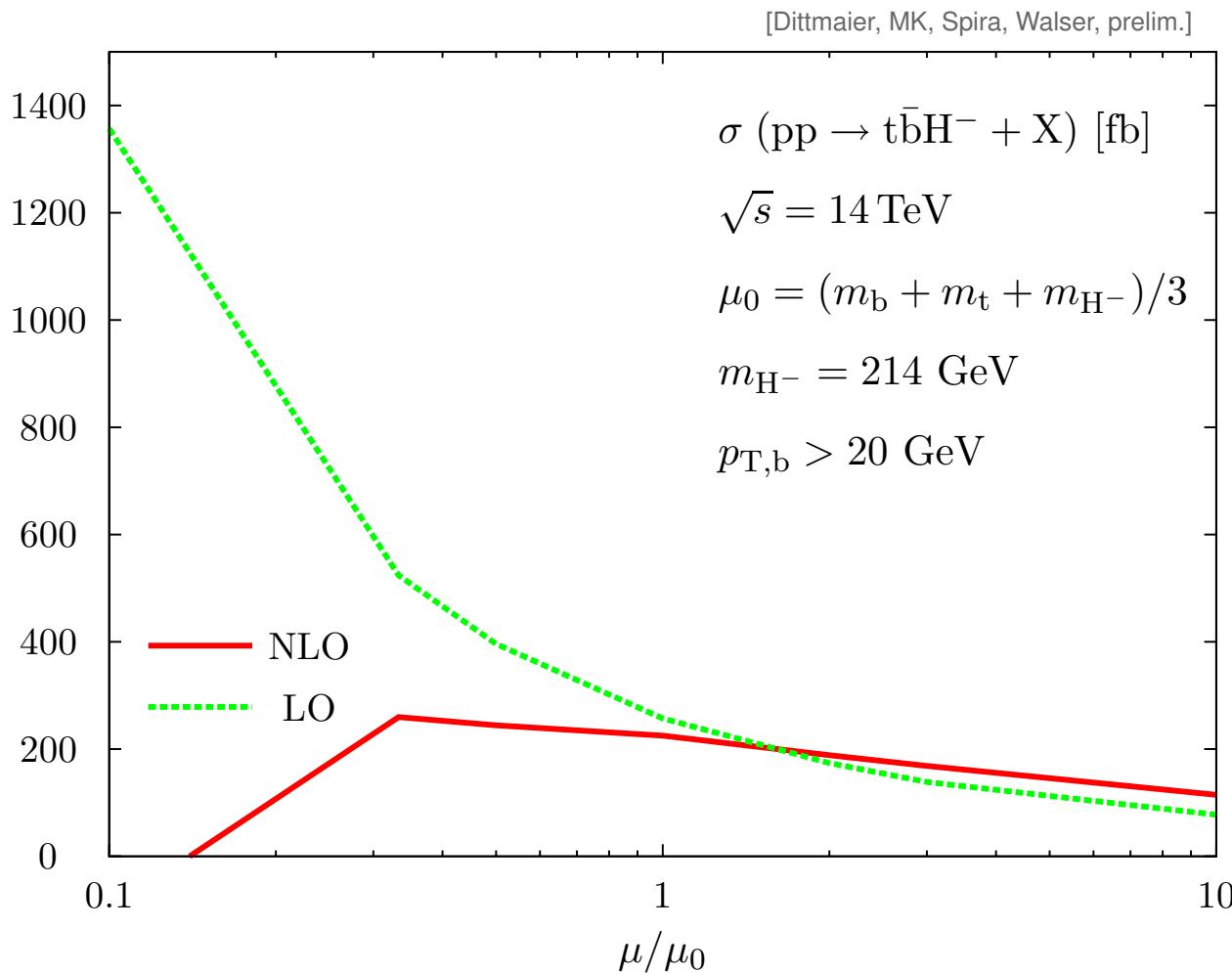
Associated $t\bar{b}H^\pm$ production: 4FNS calculation at NLO

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



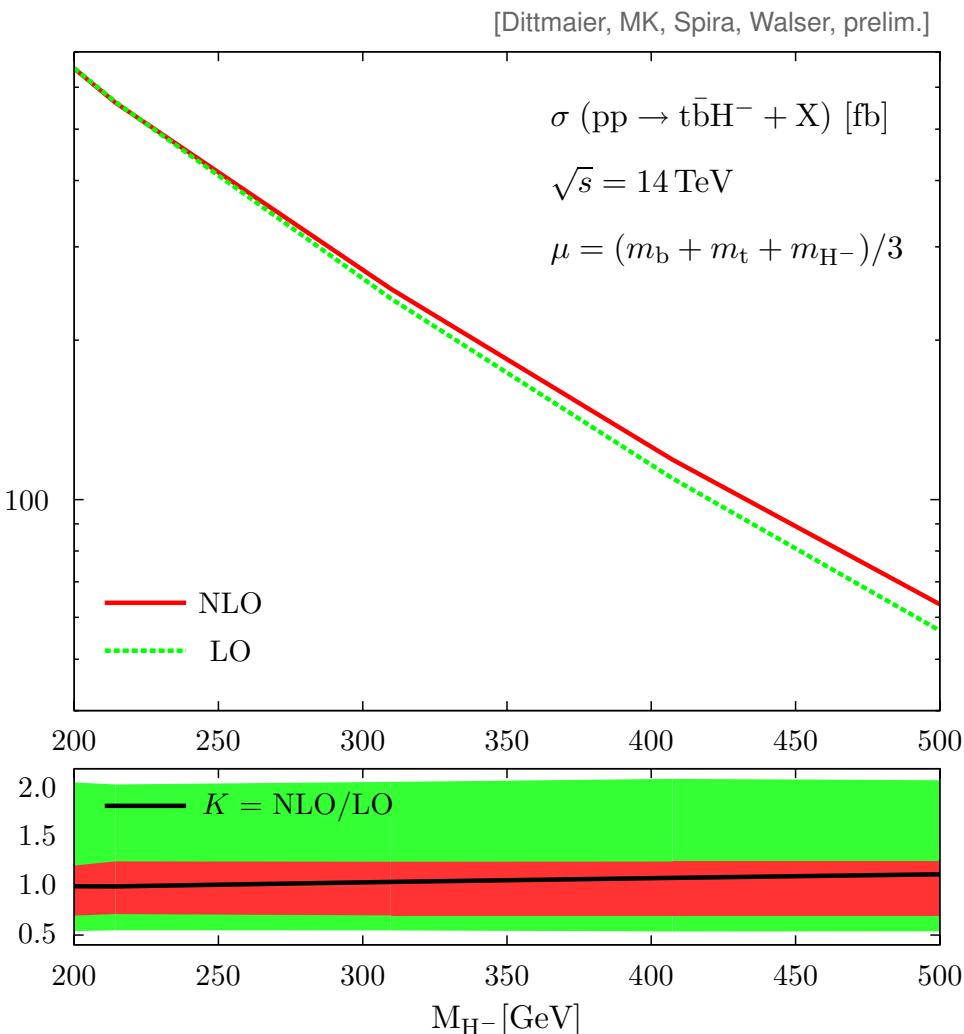
Associated $t\bar{b}H^\pm$ production: 4FNS calculation at NLO

- scale dependence exclusive cross section ($p_{T,b} > 20$ GeV)



Associated $t\bar{b}H^\pm$ production: 4FNS calculation at NLO

- total cross section



Associated $t b H^\pm$ production: 4FNS calculation at NLO

- total cross section: individual NLO contributions

M_{H^\pm} [GeV]	$\sigma_{\text{NLO}} = \sigma_0 \times (1 + \delta_{\text{SUSY-QCD}}^{\tan \beta - \text{resum.}}) \times (1 + \delta_{\text{QCD}} + \delta_{\text{SUSY-QCD}}^{\text{remainder}})$				$\sigma_{\text{NLO}}^{\text{fixed-order}}$ [fb]
	σ_0 [fb]	δ_{QCD}	$\delta_{\text{SUSY-QCD}}^{\tan \beta - \text{resum.}}$	$\delta_{\text{SUSY-QCD}}^{\text{remainder}}$	
214.28	502	0.54	-0.27	-0.001	538
309.70	219	0.58	-0.28	-0.001	243
407.33	103	0.56	-0.28	-0.0003	116

- partial cancellation between QCD and SUSY-QCD corrections
- dominant SUSY-QCD (non-decoupling) contributions from corrections to bottom-Higgs Yukawa coupling:

$$\frac{M_b \tan \beta}{v} \rightarrow \frac{M_b \tan \beta}{v} \frac{1}{1 + \Delta M_b} \quad [\text{Hall, Rattazzi, Sarid, ...; Carena, Garcia, Nierste, Wagner; ...}]$$

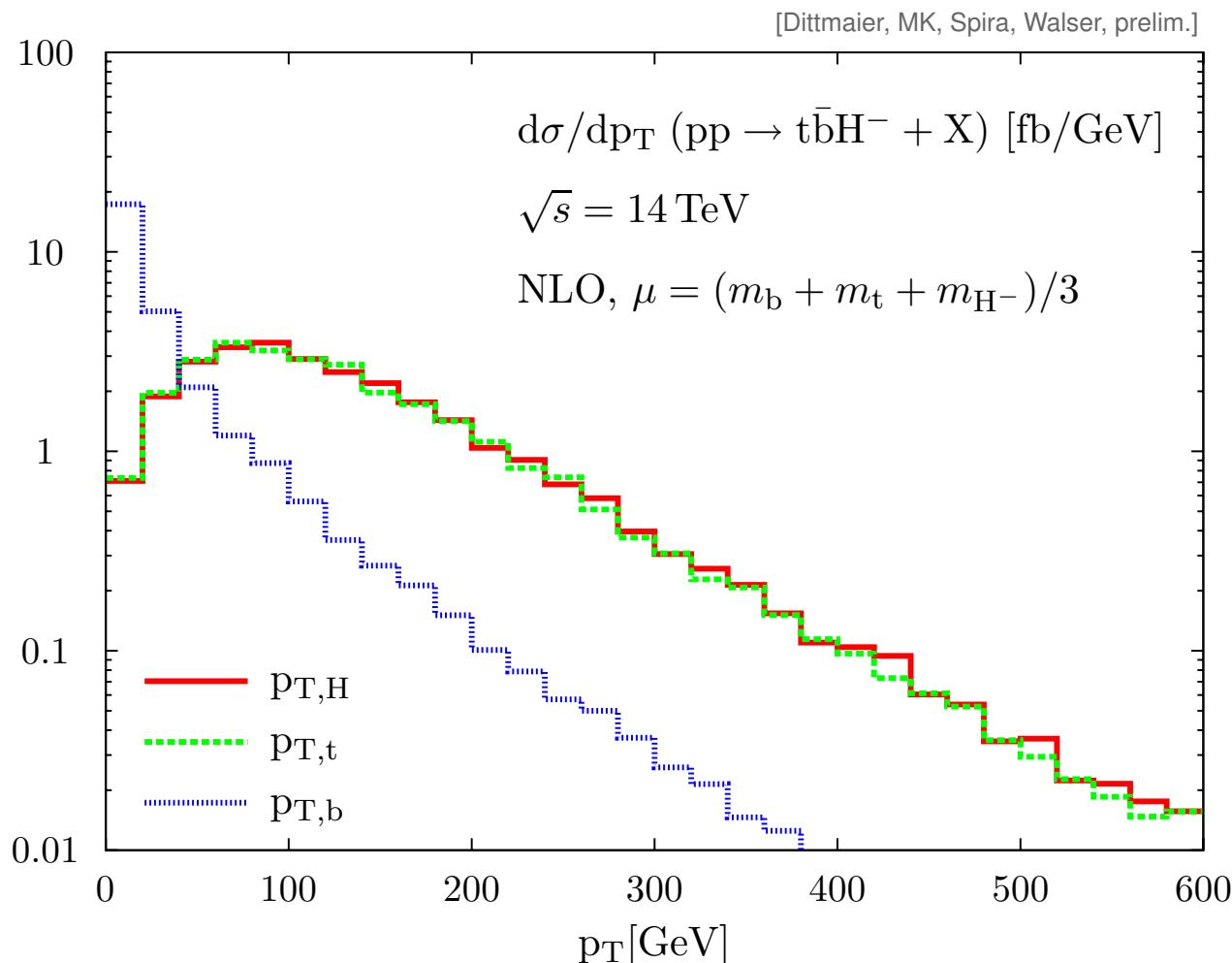
where

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

- remaining SUSY corrections negligible

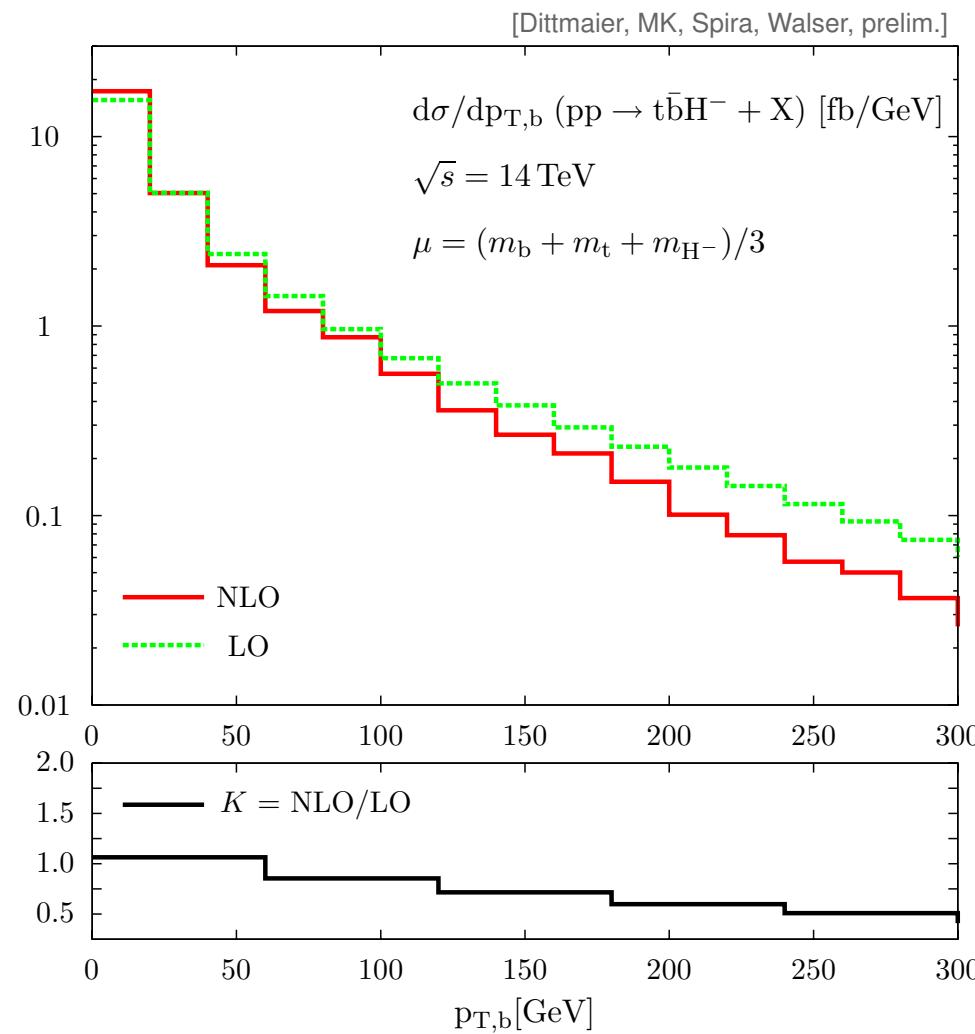
Associated $t\bar{b}H^\pm$ production: 4FNS calculation at NLO

- transverse momentum distribution



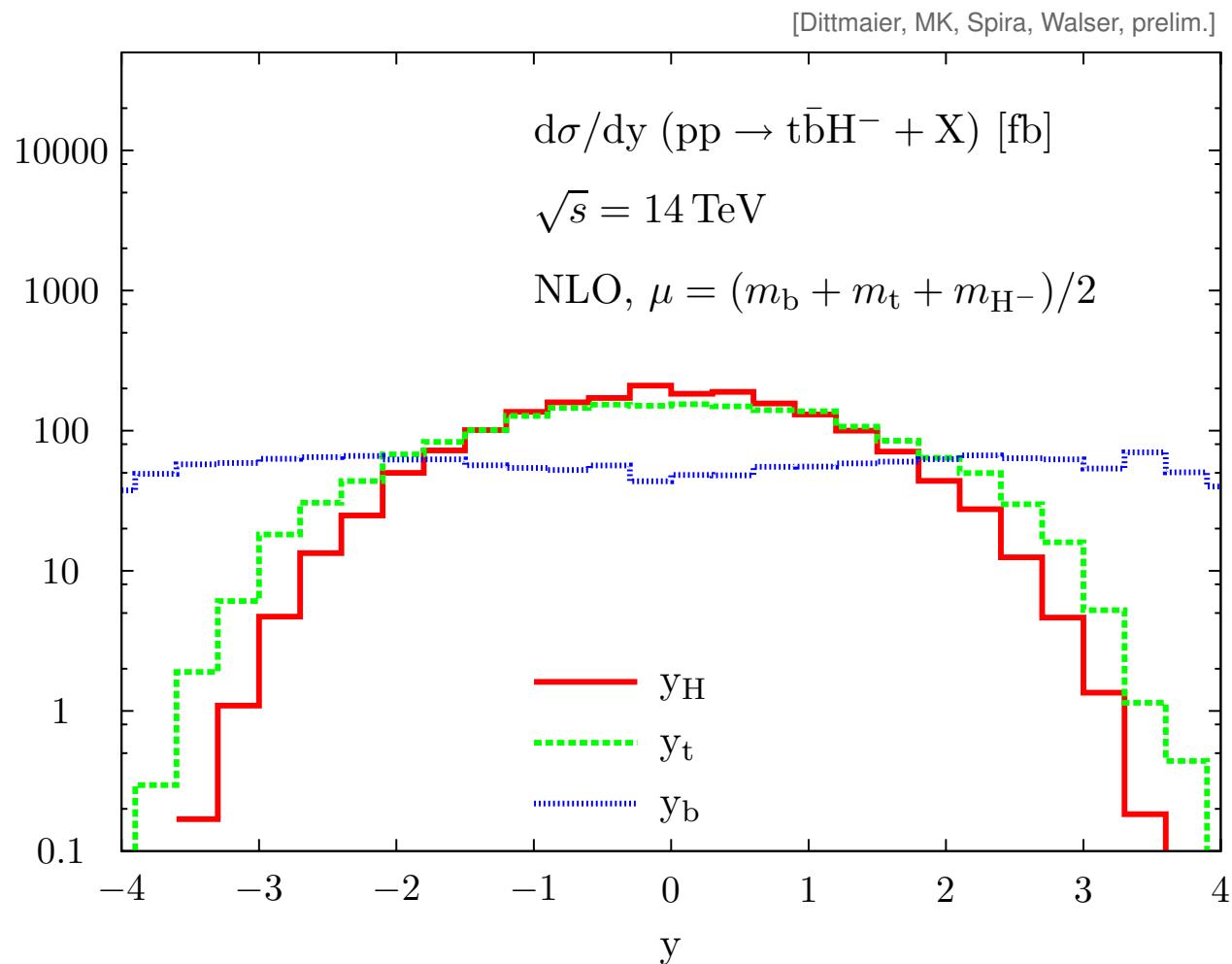
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- bottom transverse momentum distribution at LO/NLO



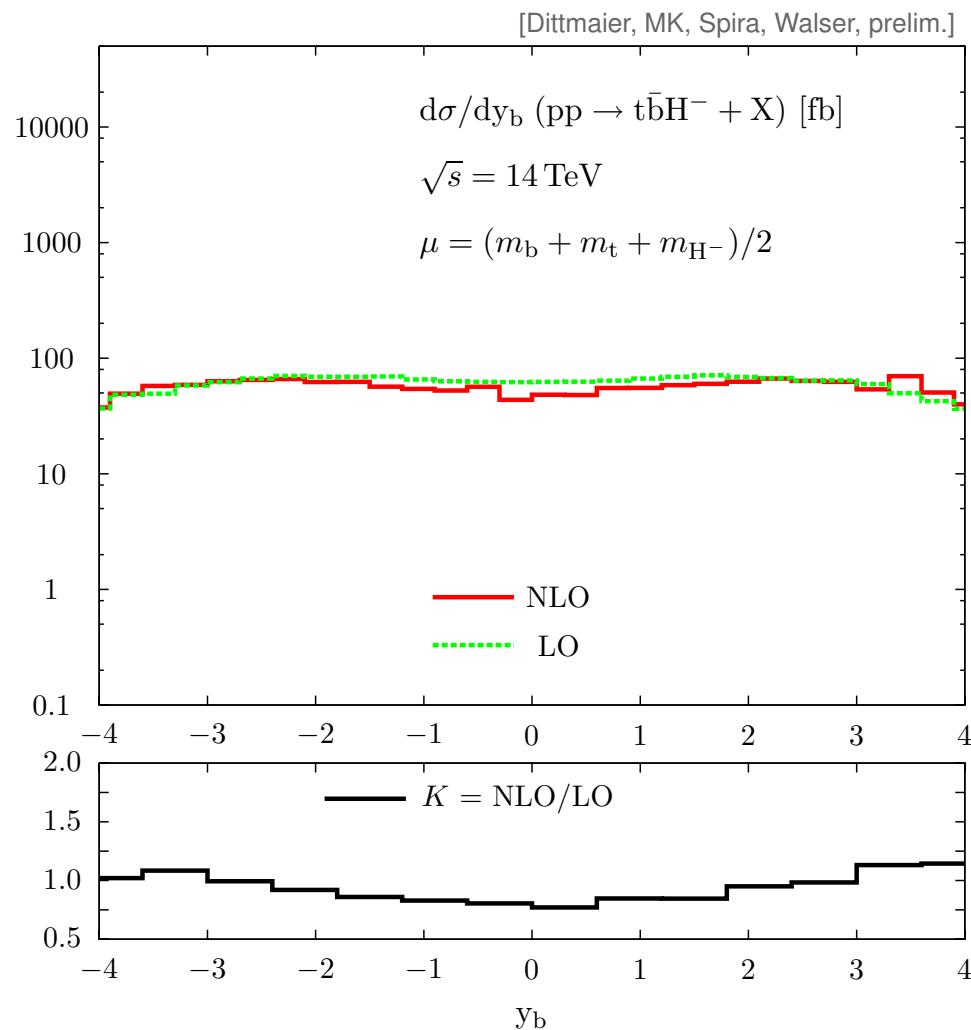
Associated $t\bar{b}H^\pm$ production: 4FNS calculation at NLO

● rapidity distribution



Associated $t\bar{b}H^\pm$ production: 4FNS calculation at NLO

- bottom rapidity distribution at LO/NLO



Search for charged MSSM Higgs bosons at the LHC

see Hashemi, Heinemeyer, Kinnunen, Nikitenko, Weiglein

→ sensitivity to MSSM parameters through ΔM_b

Consider

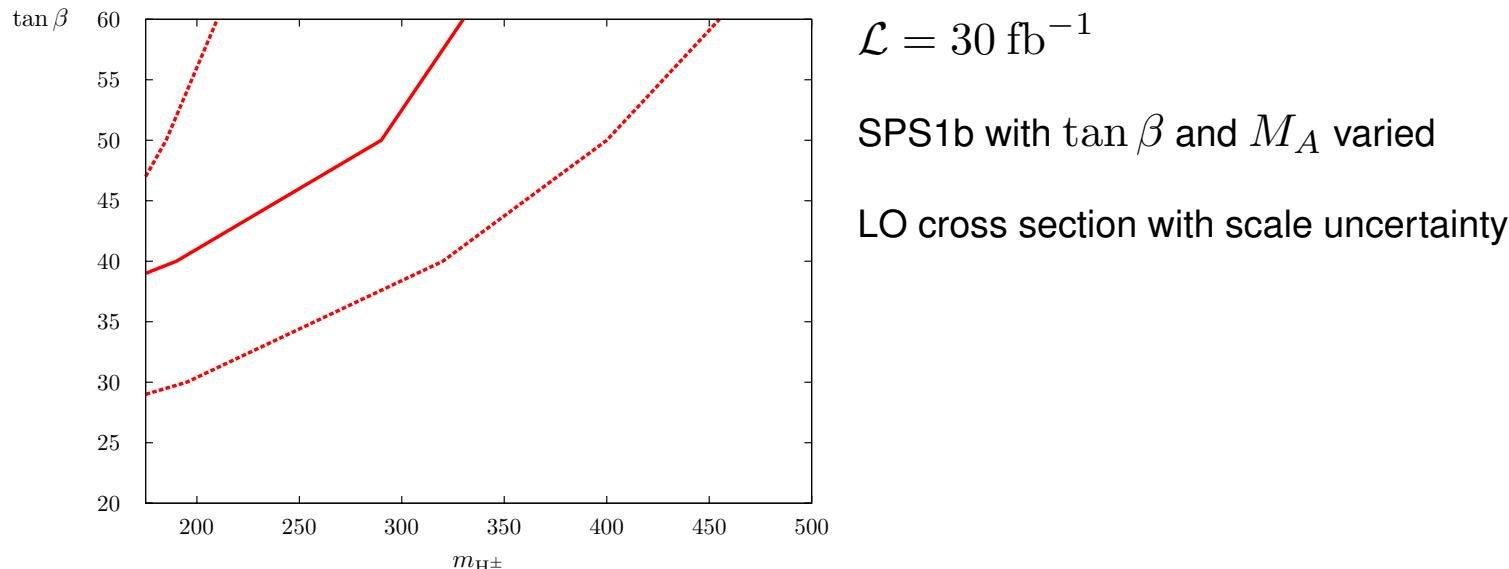
$$pp \rightarrow tH^\pm (\rightarrow \tau\nu_\tau) + X$$

and calculate number of events as

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

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

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



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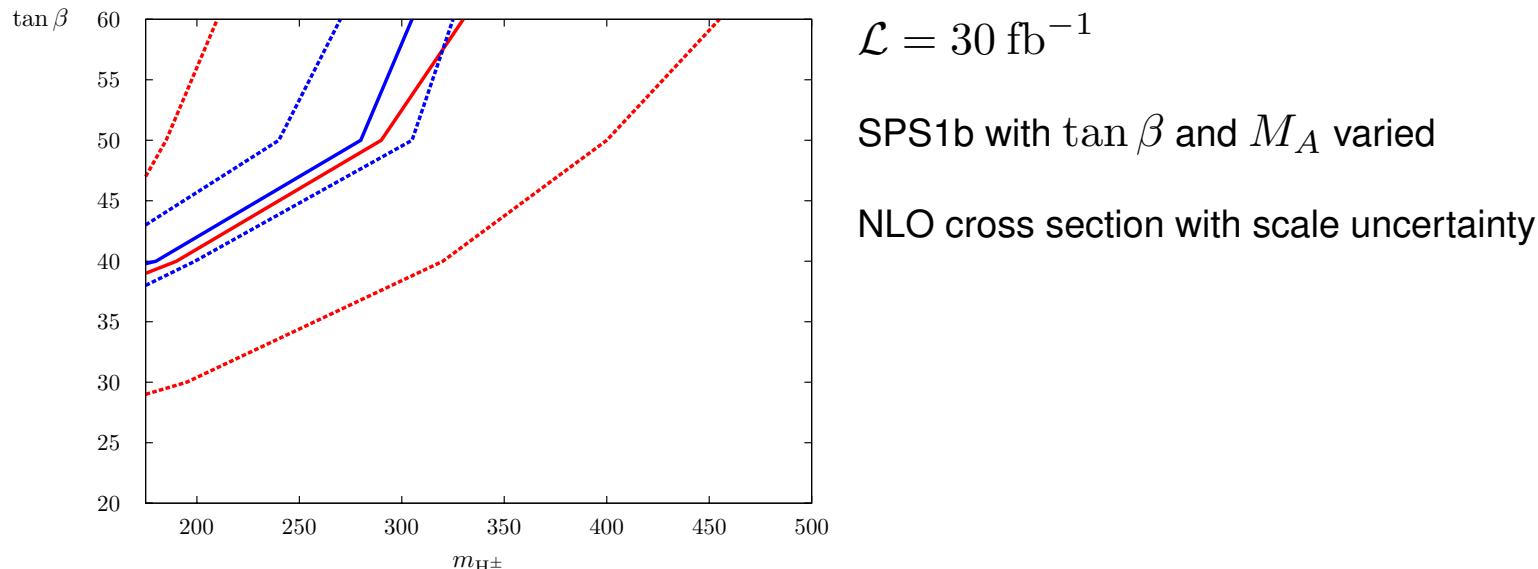
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Associated $t b H^\pm$ production: Outlook & Summary

➊ Outlook

- include leading electroweak correction through ΔM_b
- systematic NLO comparison of 4FNS and 5FNS calculations (cf. Plehn; Berger et al.)
- matching of 4FNS and 5FNS? (cf. Borzumati, Kneur, Polonsky; Alwall, Rathsman)

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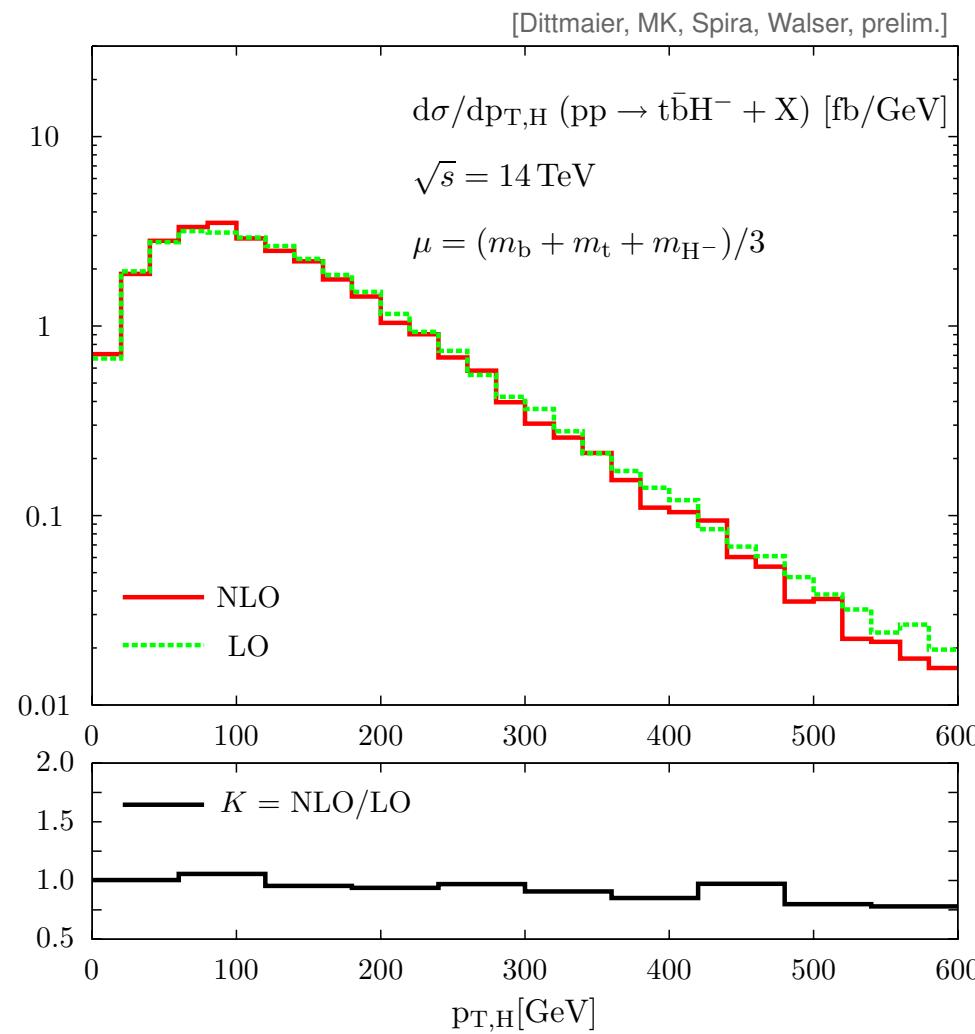
➋ Summary

- two schemes for calculating Higgs+b-jet cross sections at the LHC
→ should agree at sufficiently high order
- NLO-QCD corrections significant;
higher-order SUSY and electroweak effects can be absorbed in ΔM_b
- reliable cross section predictions are crucial for Higgs exclusion or discovery

Backup slides

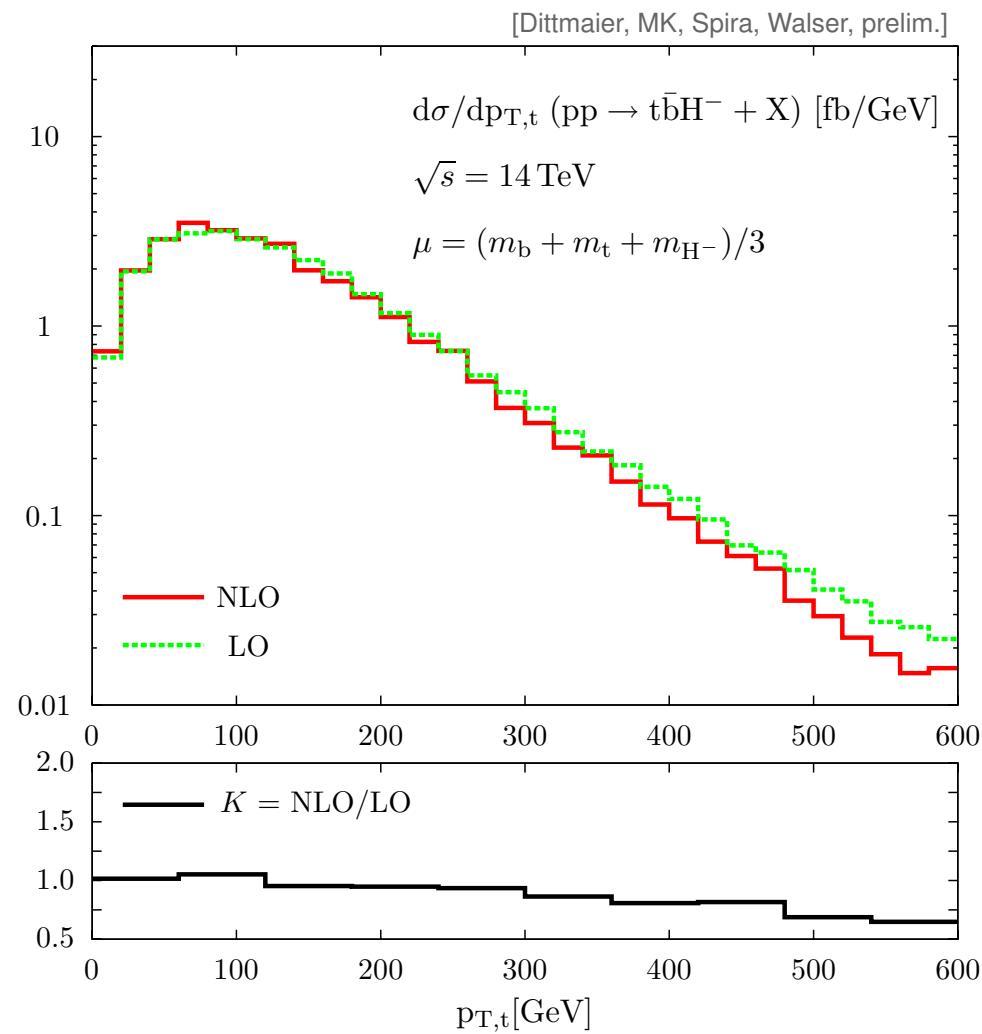
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- ➊ Higgs transverse momentum distribution at LO/NLO



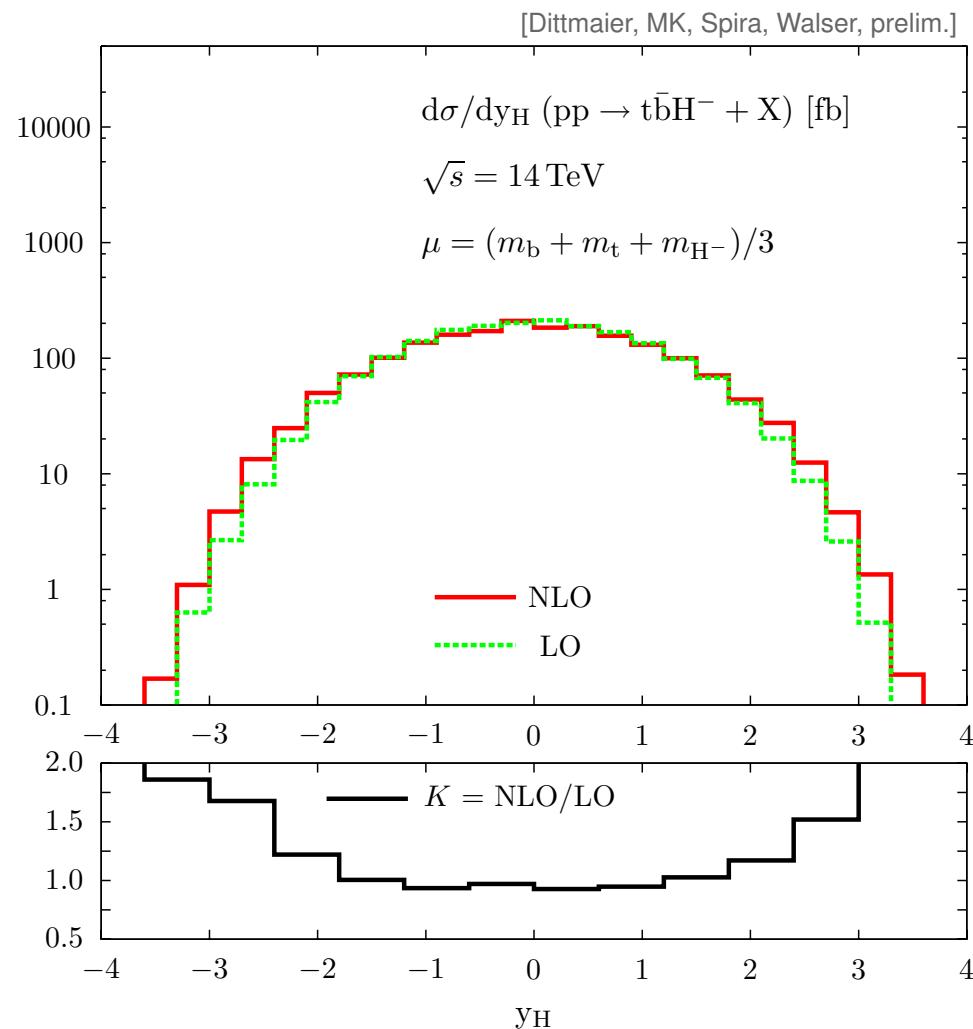
Associated $t\bar{b}H^\pm$ production: 4FNS calculation at NLO

- top transverse momentum distribution at LO/NLO



Associated $t\bar{b}H^\pm$ production: 4FNS calculation at NLO

- Higgs rapidity distribution at LO/NLO



Associated $t\bar{b}H^\pm$ production: 4FNS calculation at NLO

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