Top-bottom interference effects in Higgs plus jet production at the LHC

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J. Lindert, K. Melnikov, L. Tancredi, CW [arXiv: 1703.03886]

ggH working group meeting, 16-03-2017

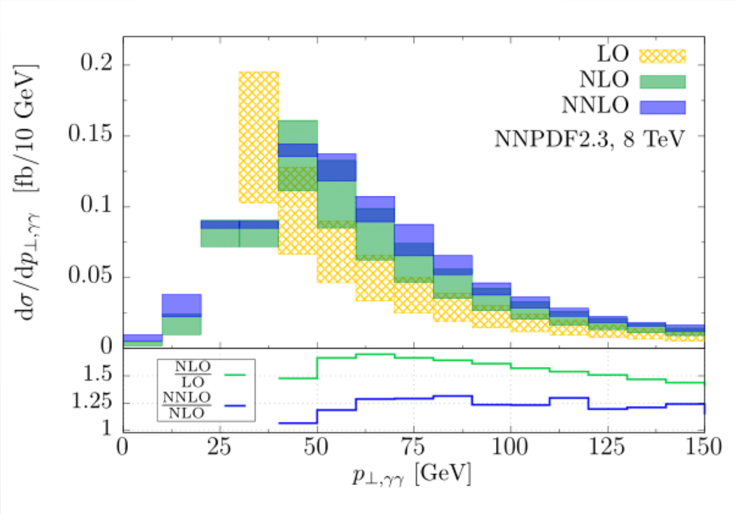
Introduction

- Higgs transverse momentum (**pTH**) distribution may be used for probing BSM models [Grazzini et al '16]
- Also may put strong constraints on light-quark Yukawa couplings at moderate pTH ~ 50 GeV [Bishara et al '16]

- Study Higgs plus jet differential cross section at LHC, which proceeds largely through quark loops

$$\mathrm{d}\sigma = \mathrm{d}\sigma_{tt} + \mathrm{d}\sigma_{tb} + \mathrm{d}\sigma_{bb}, \quad \mathrm{d}\sigma_{ij} \sim \mathcal{O}(y_i y_j)$$

- $\mathrm{d}\sigma_{tt}$ is leading contribution. Receives large NLO QCD corrections relative to LO ~ 40%
- LO top-bottom interference $\mathrm{d}\sigma_{tb}$ ~ 5% of LO $\mathrm{d}\sigma_{tt}$
- NLO correction to $\mathrm{d}\sigma_{tb}$ may be relevant for reaching percentage accuracy in diff cross section
- Top-bottom interference contains large Sudakov-like logs $\alpha_s^2(\alpha_s \log^2(p_\perp^2/m_b^2))^n$



[Caola et al '15]

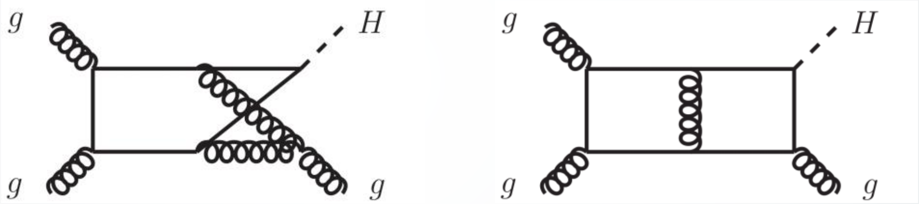
Calculation

- Real (2 to 3) and virtual (2 to 2) contributions need to be combined

Virtuals

$$d\sigma_{tb}^{\mathrm{virt}} \sim \mathrm{Re}\left[A_t^{\mathrm{LO}} A_b^{\mathrm{LO}*} + \frac{\alpha_s}{2\pi}\left(A_t^{\mathrm{NLO}} A_b^{\mathrm{LO}*} + A_t^{\mathrm{LO}} A_b^{\mathrm{NLO}*}\right)\right]$$

- At LO ~ 1-loop process, exact mass dependence known and kept
- At NLO two-loop amplitudes required $gg \to Hg$ $qg \to Hq$ $q\bar{q} \to Hg$



- Exact mass dependence in two-loop Feynman integrals currently out of reach [planar diagrams: Henn et al '16]
- Two-loop top amplitudes computed in infinite top mass limit (HEFT model)
- Two-loop bottom amplitudes computed expanded in bottom mass [Melnikov, Tancredi, CW '16-'17]

Reals

$gg \to Hgg,\ qg \to Hqg,\ q\bar{q} \to Hgg,\ \cdots$

- Reals computed with Openloops and help of Collier [Cascioli et al '12, Denner et al '03-'17]
- Exact top and bottom mass dependence

Both contributions implemented in POWHEG-BOX where IR singularities regularized via FKS

Numerical setup

- LHC 13 TeV
- PDF set and associated strong coupling constant: NNPDF3.0_lo for LO and NNPDF3.0_nlo for NLO
- Central scale is dynamical:

$$\mu_r = \mu_f = \mu_0 = H_T/2, \quad H_T = \sqrt{m_H^2 + p_\perp^2} + \sum_j p_{\perp,j}$$

$$m_H = 125\,\mathrm{GeV}, \quad m_t = 173.2\,\mathrm{GeV}$$

Theory uncertainties considered

- Scale variation: $\mu = \{1/2, 2\} * \mu_0$
- We consider also two bottom mass renormalization schemes

$$m_b^{\mathrm{OS}} = 4.75\,\mathrm{GeV}$$

$$m_b^{\overline{\mathrm{MS}}}(\mu = 100) = 3.07\,\mathrm{GeV}$$

Higgs transverse momentum distribution

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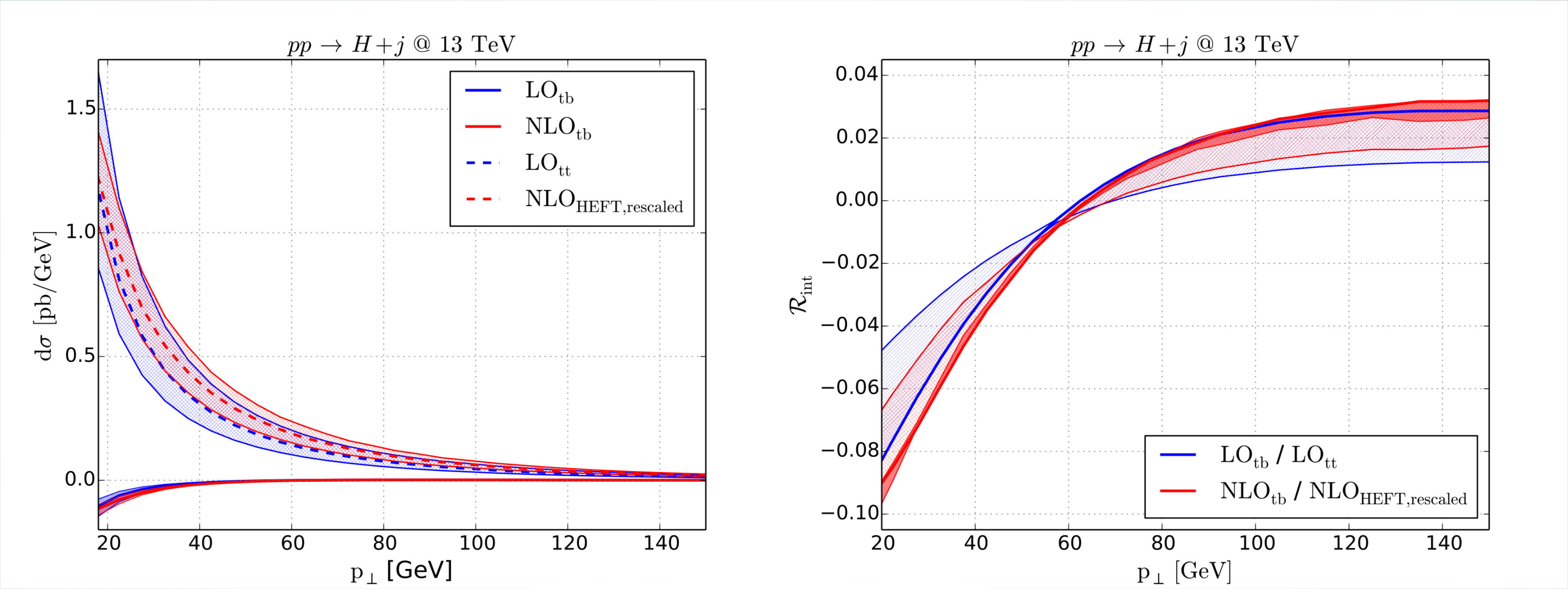
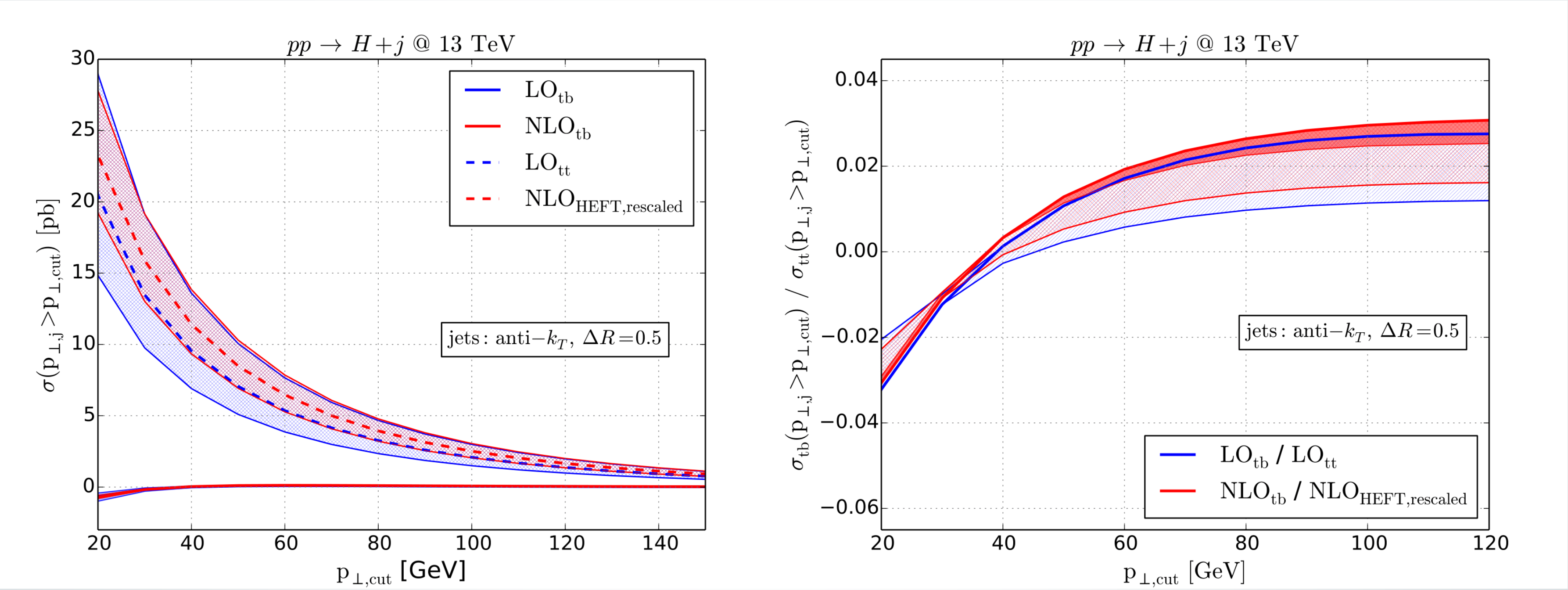


- Top-bottom interference at pTH=30 GeV: -6% @ LO and -7% @ NLO
- Relative corrections to top-bottom interference ~ relative corrections to top-top ~ large 40%
- Large mass renormalization-scheme ambiguity
- At small pTH the ambiguity is reduced by a factor of two at NLO; less pronounced at larger pTH

Total Higgs plus jet cross section

- Total cross section as function of threshold on jet pT



$$\sigma_{tb}/\sigma_{tt}(p_{T,j} > 20, 30, 40, 50)_{\rm LO} = -3.2, -1.2, +0.1, 1.1\%$$

$$\sigma_{tb}/\sigma_{tt}(p_{T,j} > 20, 30, 40, 50)_{\rm NLO} = -3.1, -1.1, +0.3, 1.3\%$$

- Total NLO top-bottom interference contributes [-3% , 3%] of NLO top-top contribution
- Strong dependence on jet pT cut

Summary

- NLO QCD corrections to top-bottom interference first time computed
- Two-loop integrals computed at first order in bottom mass expansion
- Virtuals combined with reals from Openloops
- Whenever possible, exact bottom mass dependence kept (including in reals)
- Relative NLO corrections to LO top-bottom interference similar to top-top NLO corrections ~ 40% for Higgs pTH and rapidity distributions
- On-shell vs MSbar bottom mass: large renormalization scheme ambiguity. Reduced at small pTH ~ 20-40 GeV, but unchanged at larger pTH ~ 60-100 GeV
- Total NLO top-bottom interference contributes [-3% , 3%] of NLO top-top contribution, with strong dependence on jet pT cut

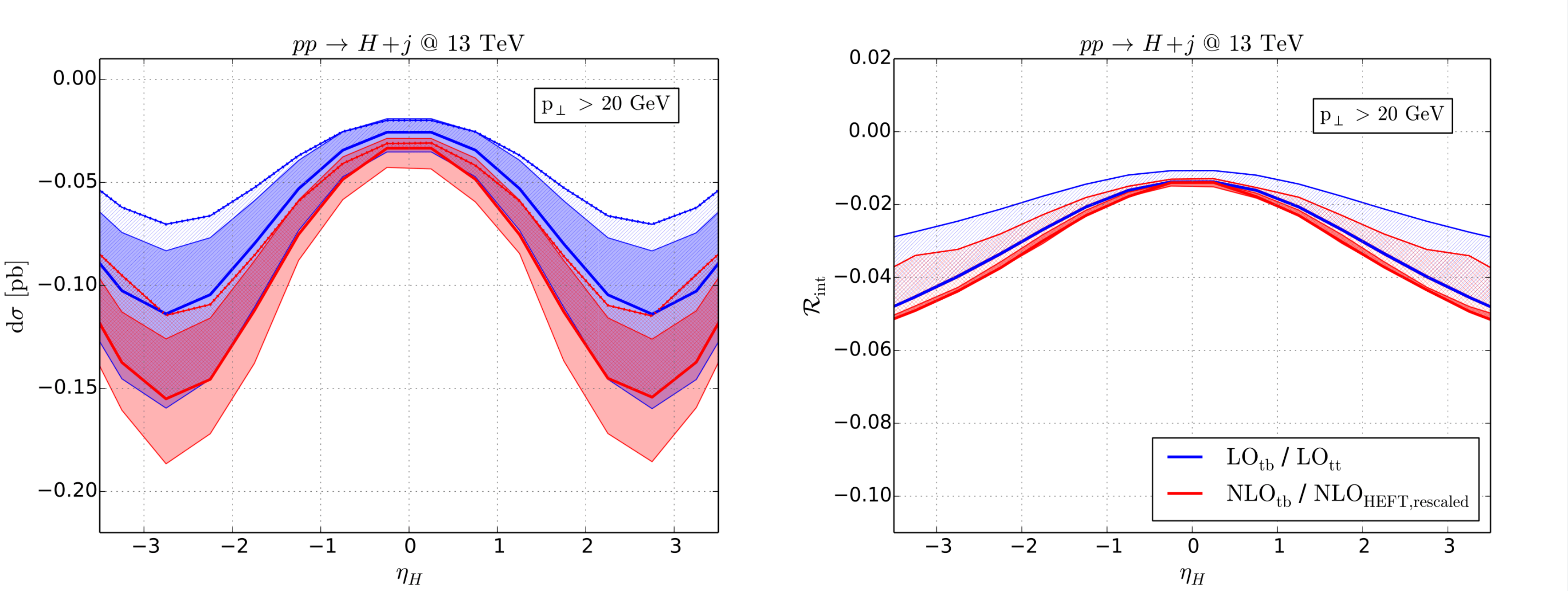
Outlook

Combine various contributions to get best H+j prediction:

- Low pTH-resummation
- NNLO HEFT corrections
- NLO top-bottom interference

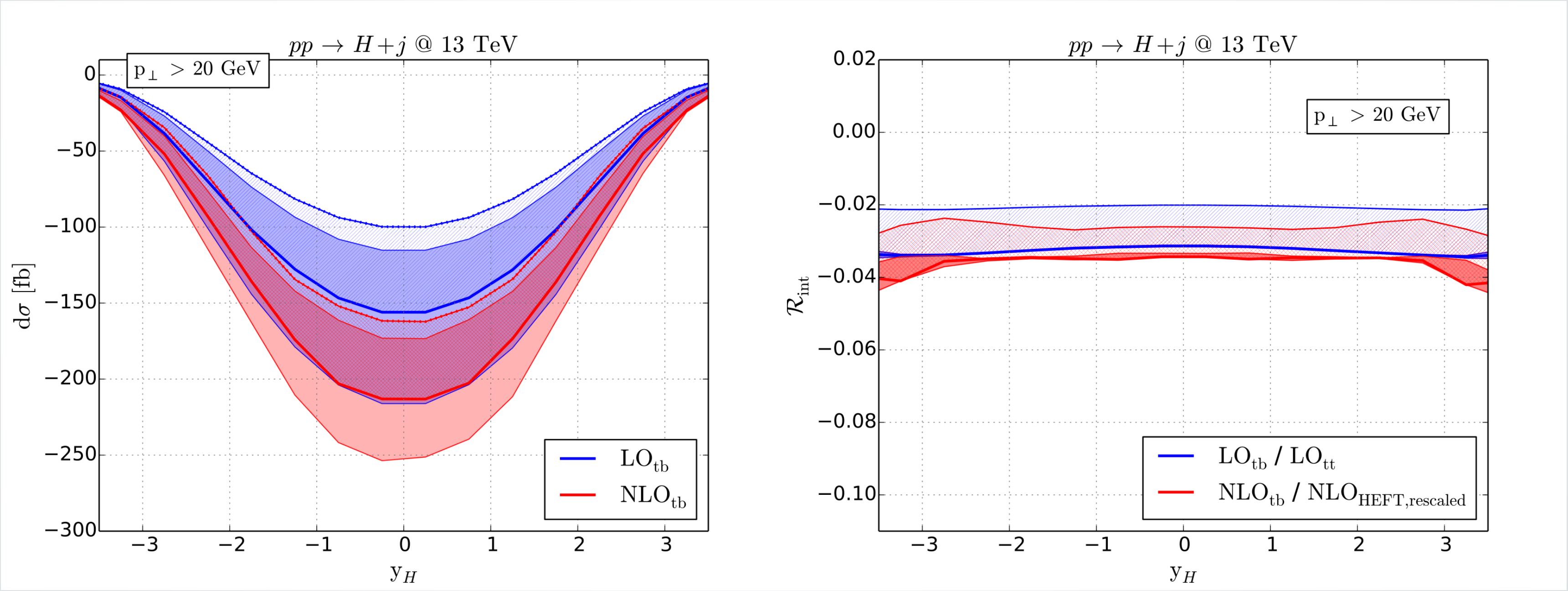
Backup slides

Higgs pseudo-rapidity distribution

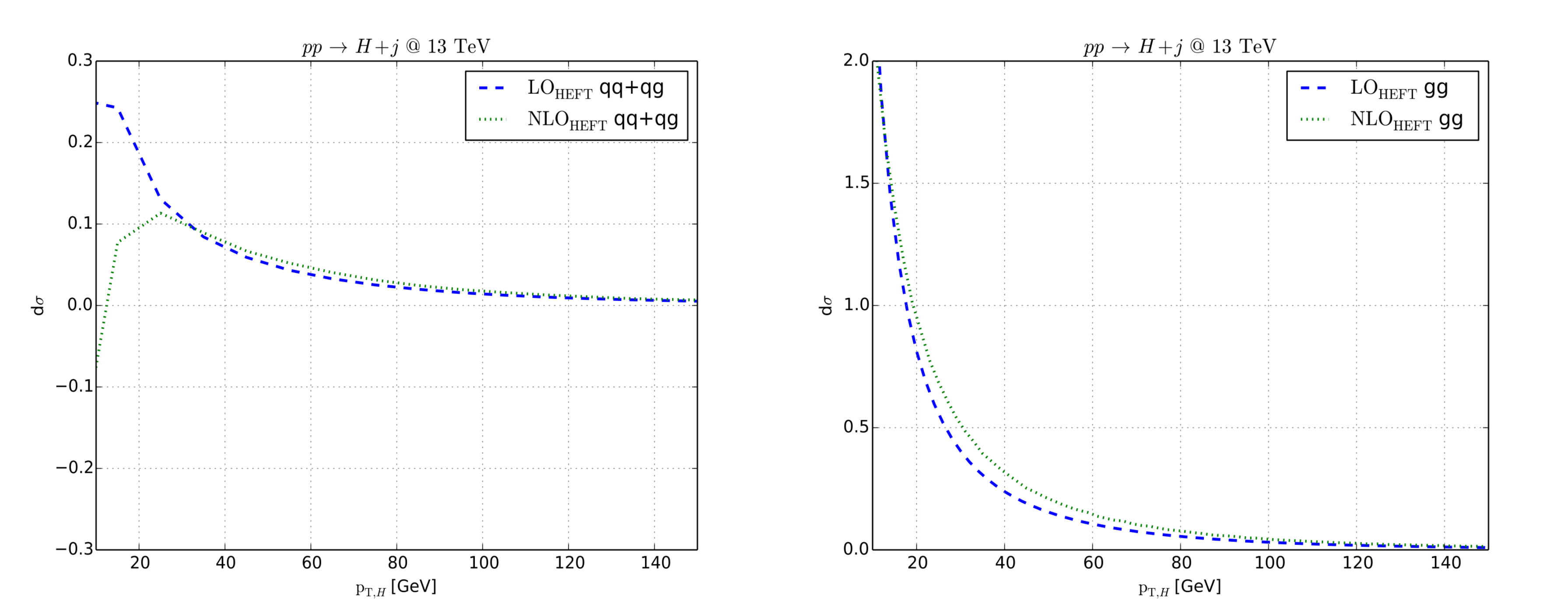


- Relative corrections to top-bottom interference ~ relative corrections to top-top
- At central rapidity (dominated by large pTH) mass scheme ambiguity similar between LO and NLO
- At larger absolute rapidity (dominated by small pTH) the mass scheme variaton band is smaller for NLO

Higgs rapidity distribution

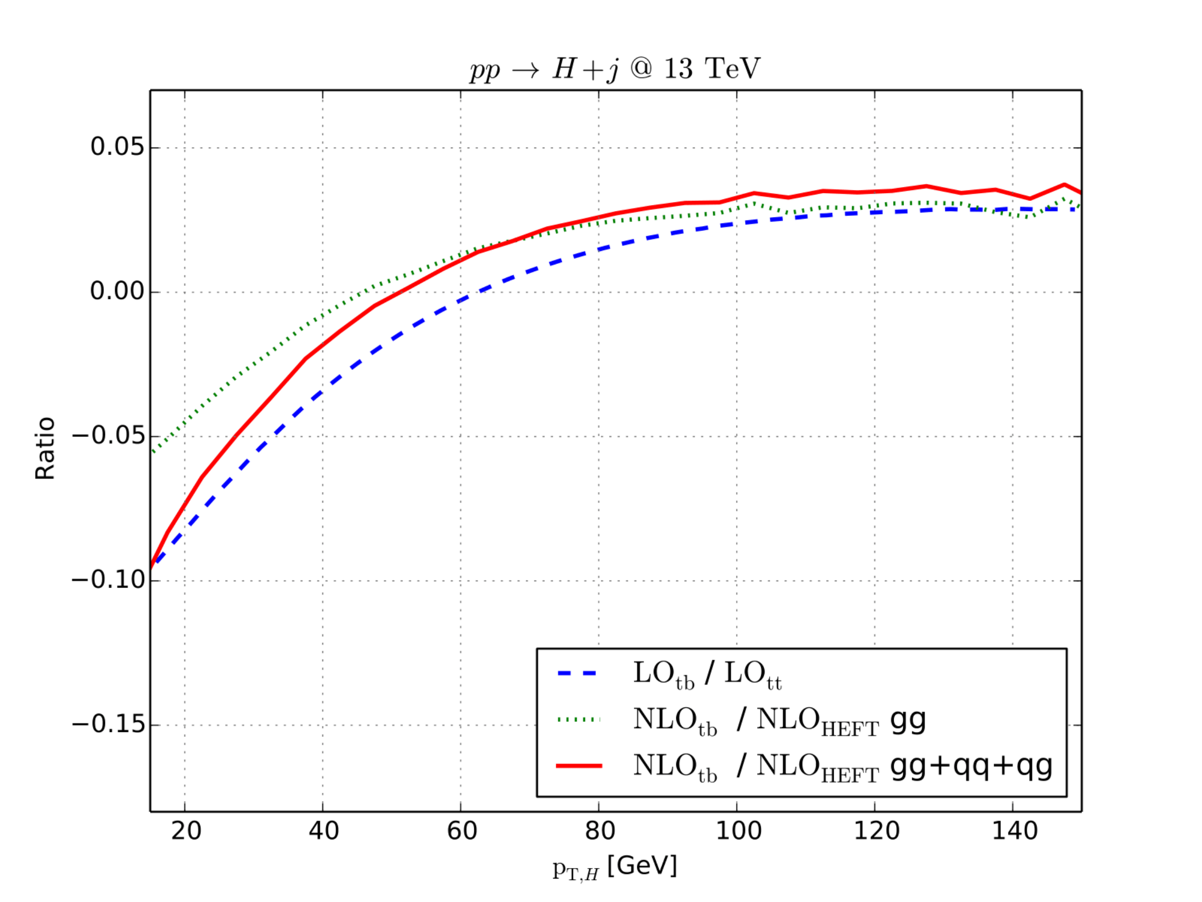


Channel contribution: tt



- gg fusion channel dominates

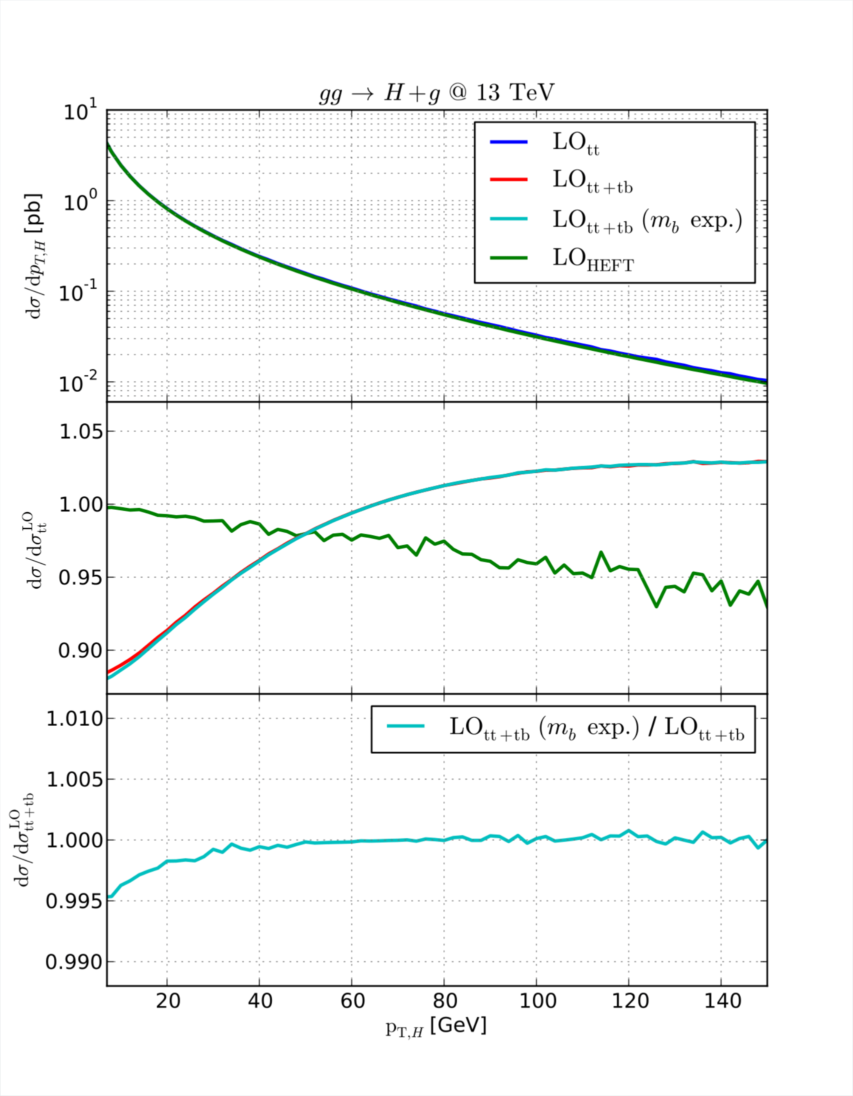
Channel contribution: tb



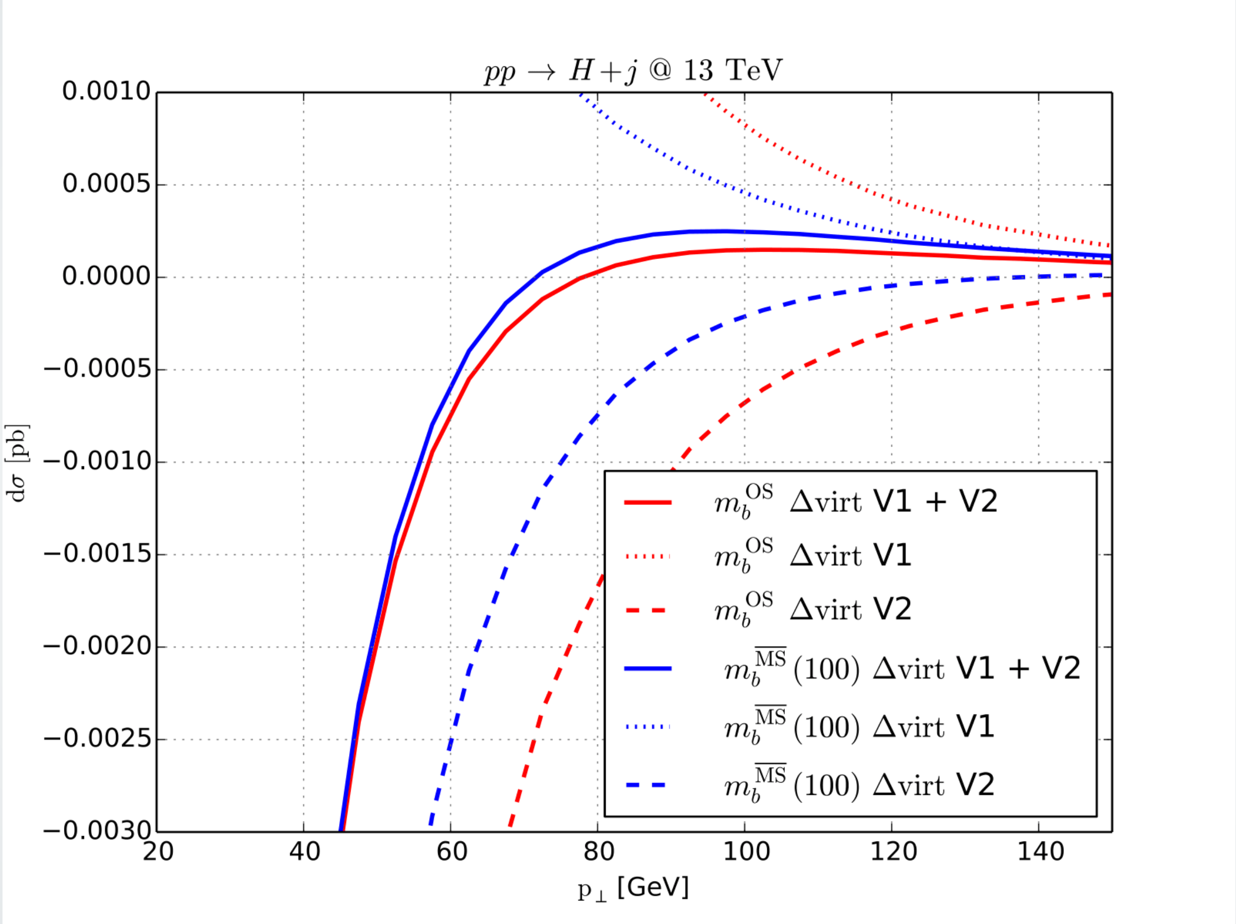
- gg fusion channel dominates

Backup

LO contributions



V1:NLO(t)xLO(b) vs V2:LO(t)xNLO(b)



- Two contributions enter with opposite signs
- V2 is dominant at low pTH ~ 20-50 GeV which reduces mass scheme ambiguity
- At large pTH V1~V2 and V1 represents LO bottom mass scheme ambiguity