VH: theory

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CERN & LAPTh Annecy

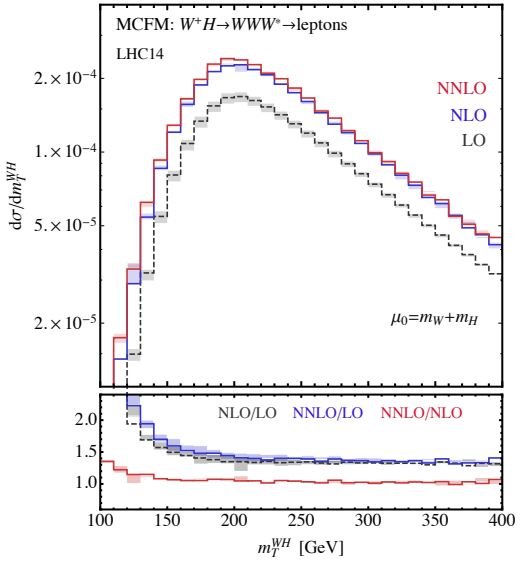
The 14th Workshop of the LHC Higgs Cross Section Working Group
CERN, 26 March 2018

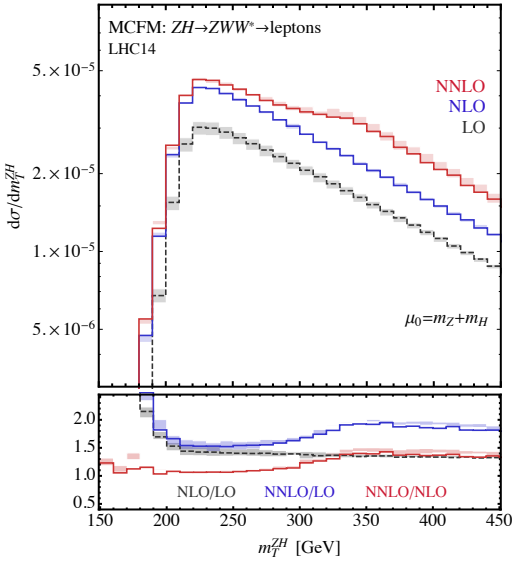
1. *overview of recent results*

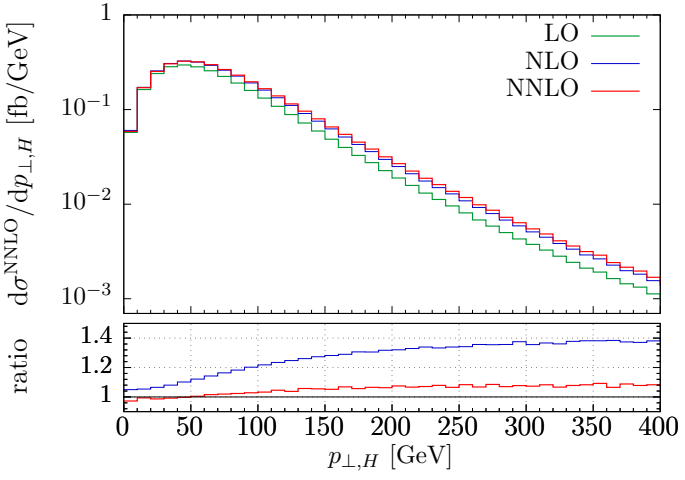
2. *planned future studies*

$pp \to VH$: production

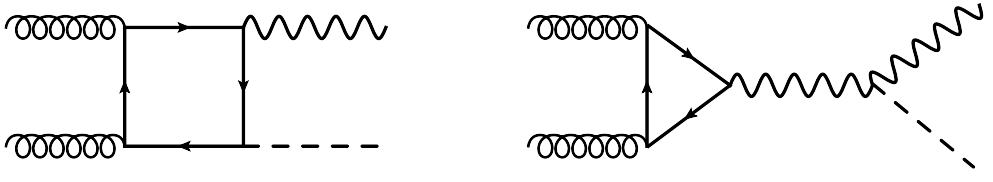
- QCD NNLO correction
  - inclusive: `vh@nnlo` [Brein et al.]
  - differential: 3 groups [Ferrera et al. '11-'17, Campbell et al. '16, Caola et al. '17]
  - publicly available in `MCFM`







- in general, NNLO corrections moderate
- $gg \to HZ$ (NNLO) term sizeable above $t\bar{t}$ threshold



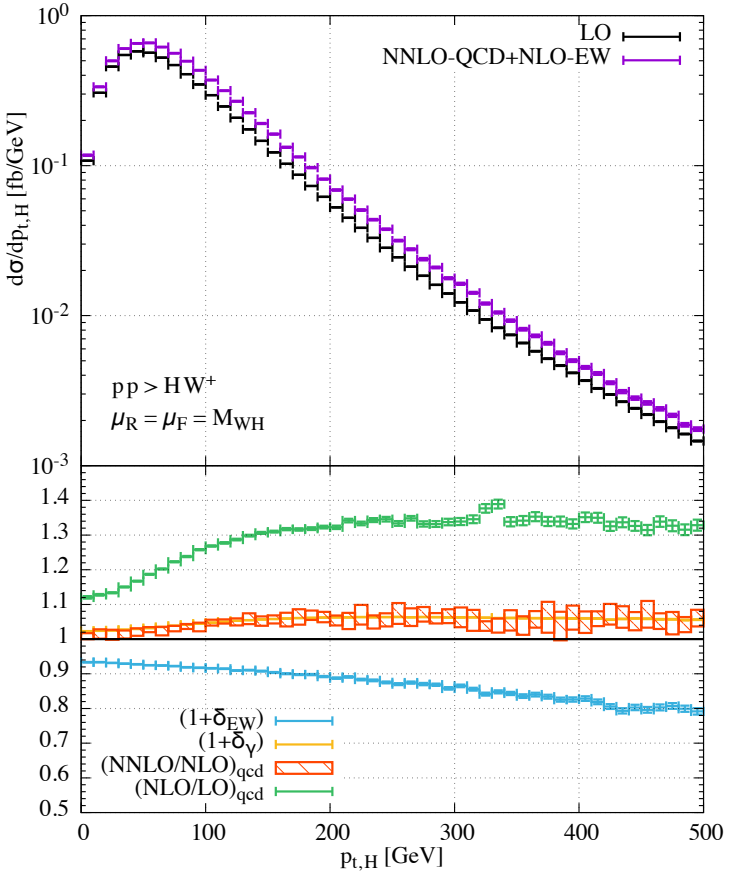
$pp \to VH$: production

- EW (+ QCD) NLO correction
  - HAWK
  - possible also with other automated tools (see later)

[Denner et al.]

- study in YR4 on combination of QCD NNLO and EW NLO

$$\begin{aligned} \sigma^{\mathrm{WH}} &= \sigma^{\mathrm{WH,DY}}_{\mathrm{NNLOQCD}}(1+\delta_{\mathrm{EW}}) + \sigma_{\text{t-loop}} + \sigma_{\gamma}, \\ \sigma^{\mathrm{ZH}} &= \sigma^{\mathrm{ZH,DY}}_{\mathrm{NNLOQCD}}(1+\delta_{\mathrm{EW}}) + \sigma_{\text{t-loop}} + \sigma_{\gamma} + \sigma^{\mathrm{ggZH}}, \end{aligned}$$



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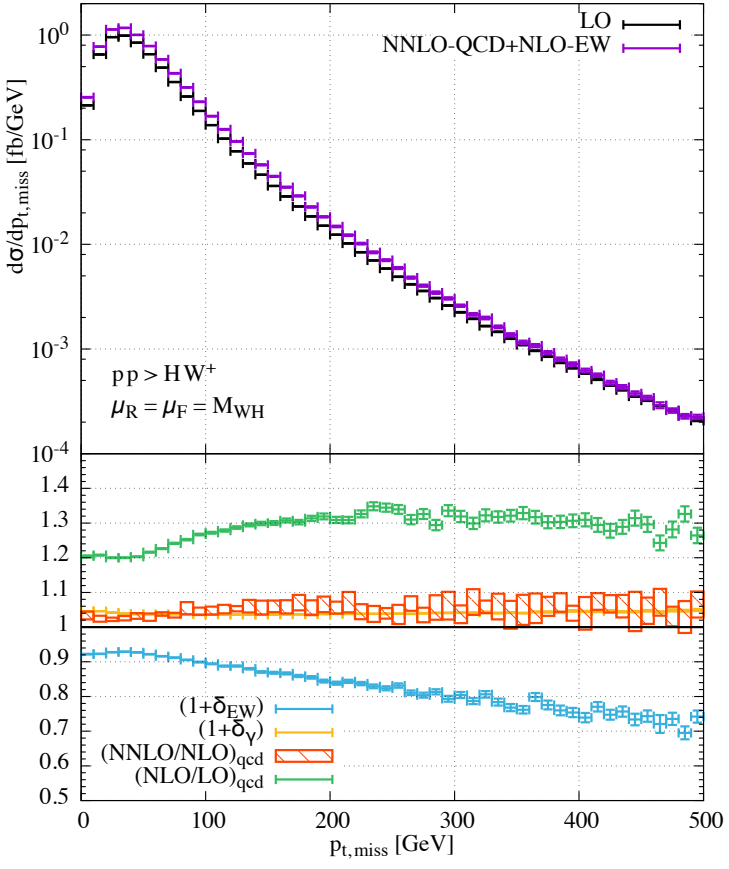

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$pp \to VH$: the $H \to b\bar{b}$ decay

- NNLO QCD corrections to $H \to bb$: 2 groups, massless b-quarks

  [Anastasiou et al. '12, Del Duca et al. '15]

- More recently, included in fully-differential NNLO computation (NNLO QCD for production and decay)

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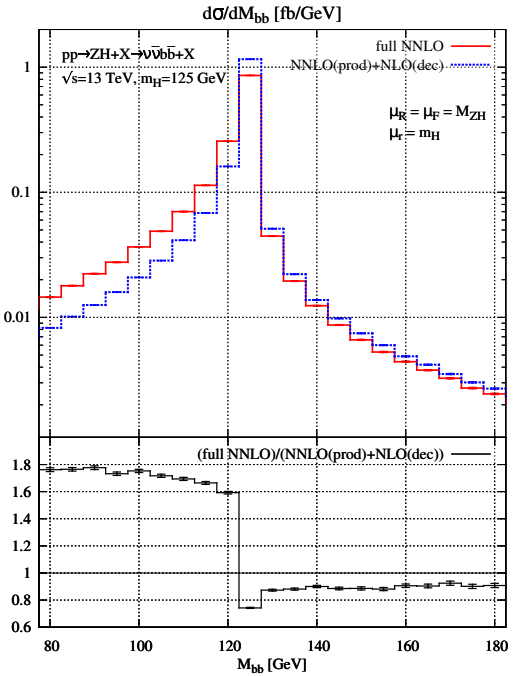

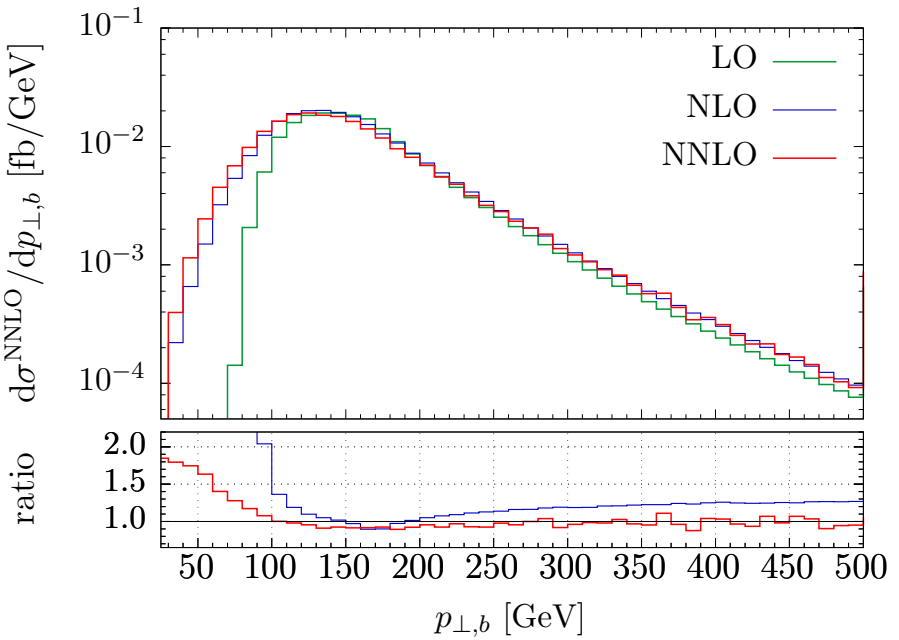

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  ($\to$ K-factors depend on cuts. Dominated by extra emissions in decay, PS expected to do a good job.)
- there's ongoing work to compute NNLO corrections to the decay with massive b-quarks

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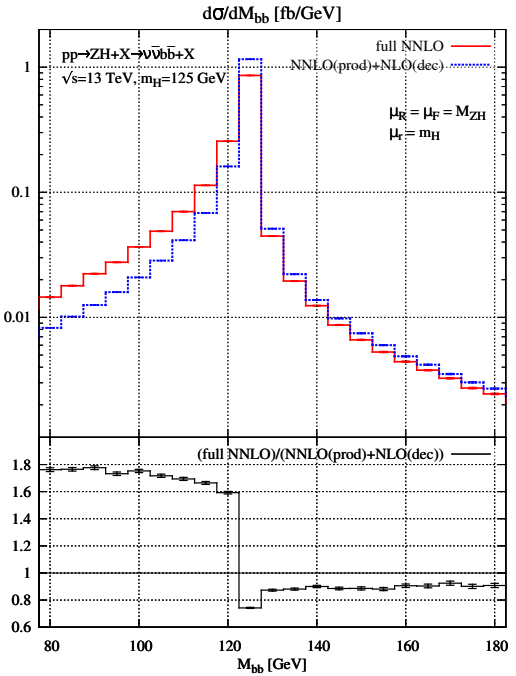

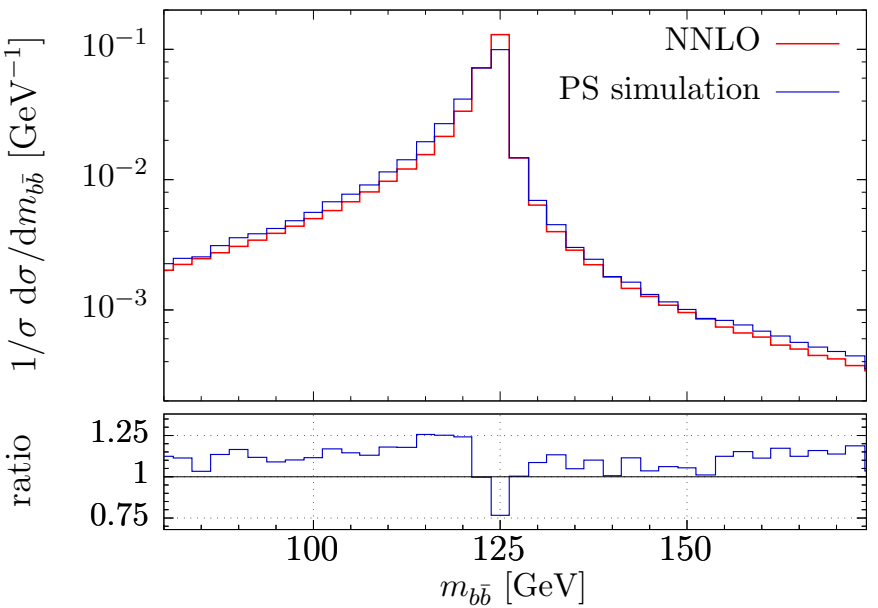

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event generators

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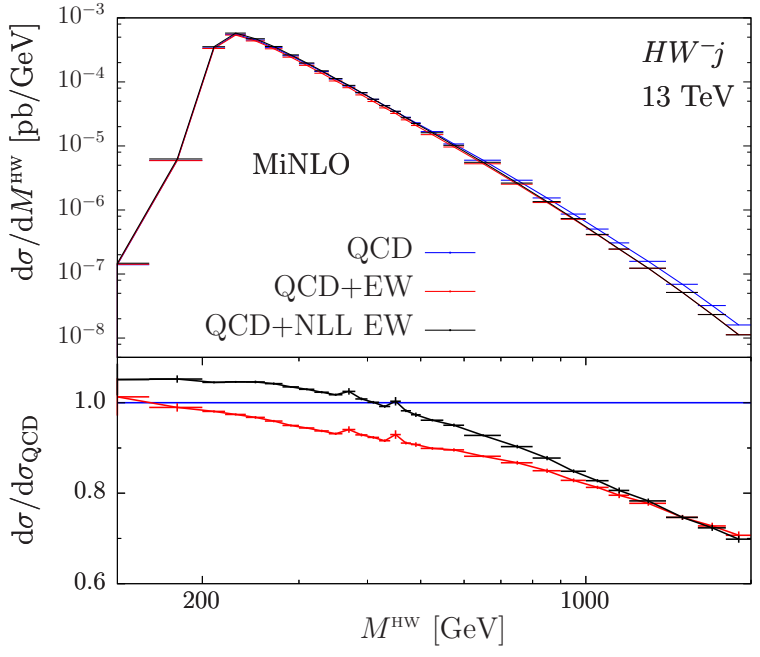
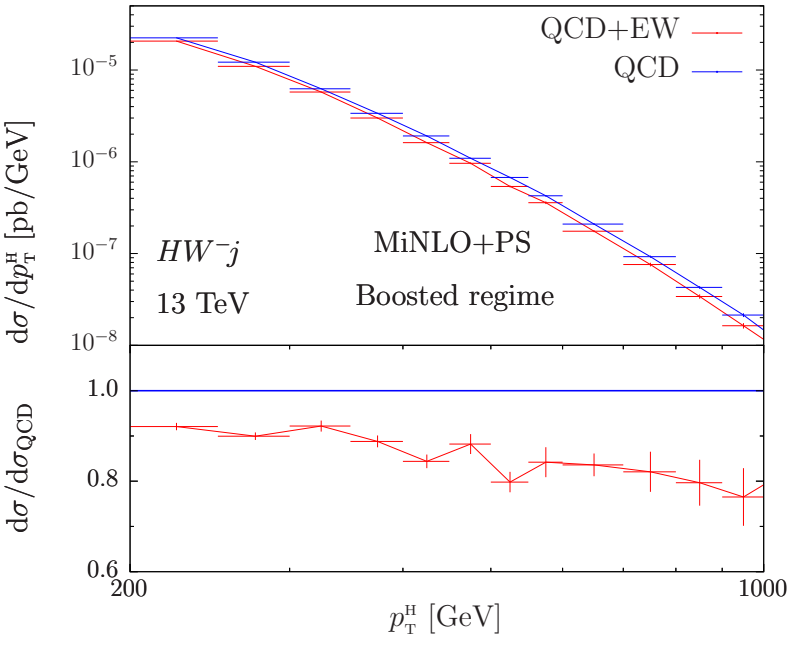
- it's known that EW corrections are important at large p_T / large invariant masses
- VH and VH+jet: NLO QCD + NLO EW + PS [Granata et al. '17]



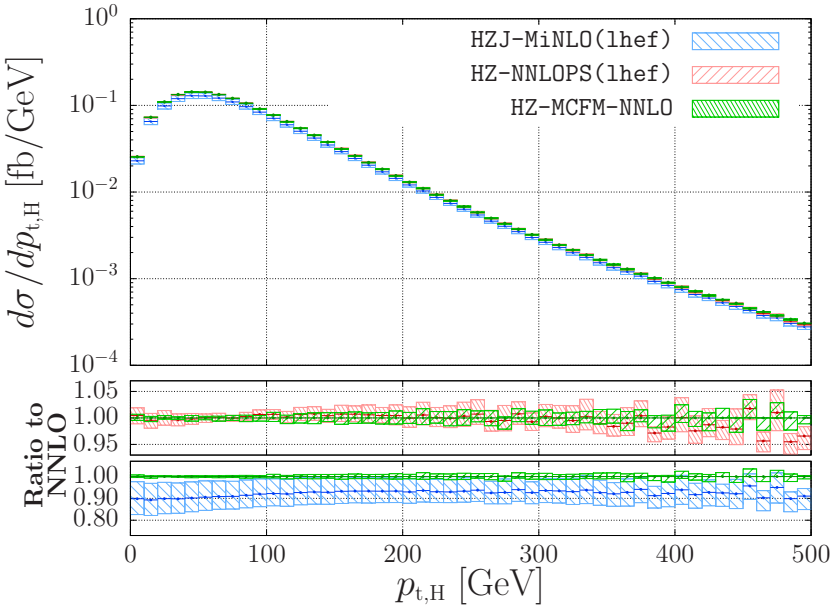


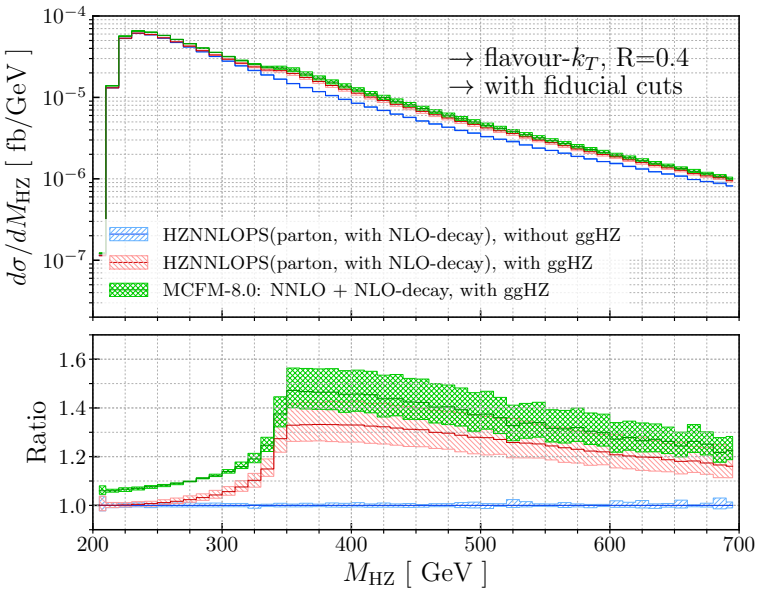
. built using OpenLoops and Madgraph4

. available in POWHEG-BOX

event generators

- NNLO+PS [Astill et al. '16-'18]
  - currently finishing a project where we also include NLO corrections to the decay (NNLO+PS, with NLO+PS `POWHEG` matching also for the decay)
  - `MCFM` as input for NNLO ; `POWHEG-BOX-RES` (with `MiNLO`) to deal with NLO corrections in production and decay.





  - as soon as possible both ZH and WH available in `POWHEG-BOX`, with NLO $H \to b\bar{b}$ decay.
  - $gg \to HZ$ included (with m_t-dependence, but just at LO, no extra partons in fixed-order part)

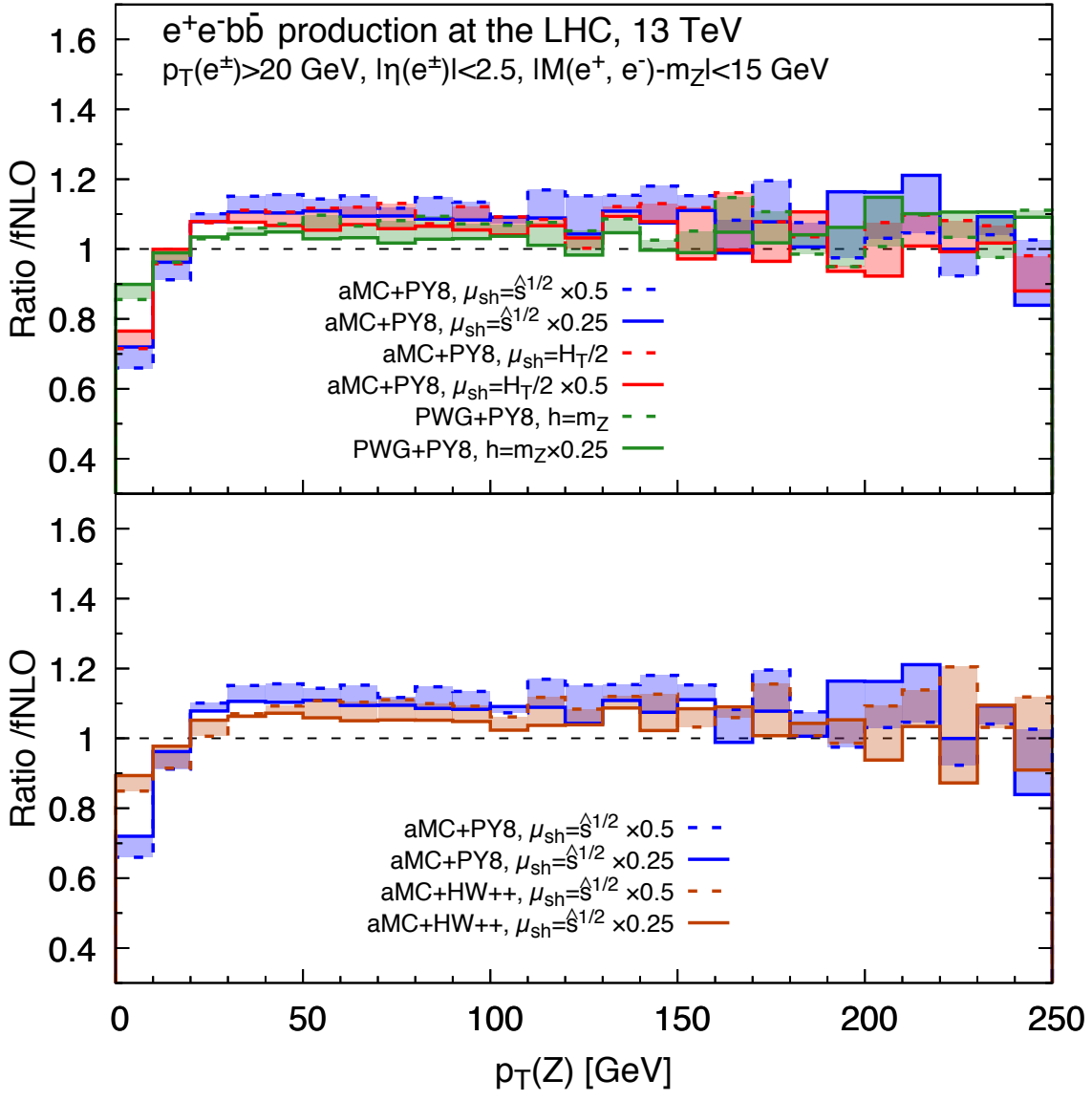
1. *overview of recent results*

2. *planned future studies*

$pp \to V + b\bar{b}$

- V + heavy flavour production is one of the main backgrounds to $pp \to VH(\to b\bar{b})$.
- as mentioned in previous talk, it'd be desirable to study more precisely its impact (and uncertainties thereof) in the signal region
- we will perform a MC comparison between the currently-used tools, and several, more accurate, predictions.
  - for instance, currently in ATLAS:
    `Sherpa MEPS@NLO (5FS)` vs. `MG+PY8 (5FS, CKKW)`
  - positive reply from all people contacted:
    - `POWHEG+MiNLO` for $Wb\bar{b}j$, 4FS [Luisoni et al. '15]
    - `Sherpa V+HF`: 4/5 FS, at NLO+PS, with jet merging at NLO [Krauss et al. '16]
    - `Herwig7` [Bellm et al.]
    - `MG5_aMC@NLO` / `POWHEG`: very recent study [Bagnaschi et al. '18]
    - if possible, `Blackhat + Sherpa`: NLO 4FS, up to $Vb\bar{b}$ + 3 jets [Anger et al. '17]
    - have we missed anyone ?

- an example taken from the more recent result [Bagnaschi et al. '18]

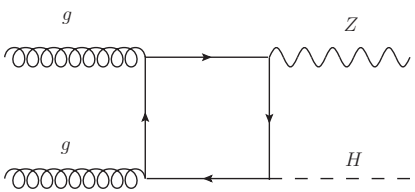


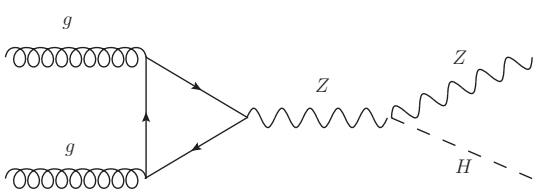
- goal(s):
  - establish if tools used nowadays are reliable enough in describing the signal region, or relevant differences are found.
  - quantify what is, currently, the “theory uncertainty”
    (not only due to μ_R/μ_F variations, but also PS uncertainties, etc, as now the tools are available)
  - ideally, if possible, give a guideline
  - as a byproduct, this will also allow for a comparison among different modern tools (already started in LH 15)

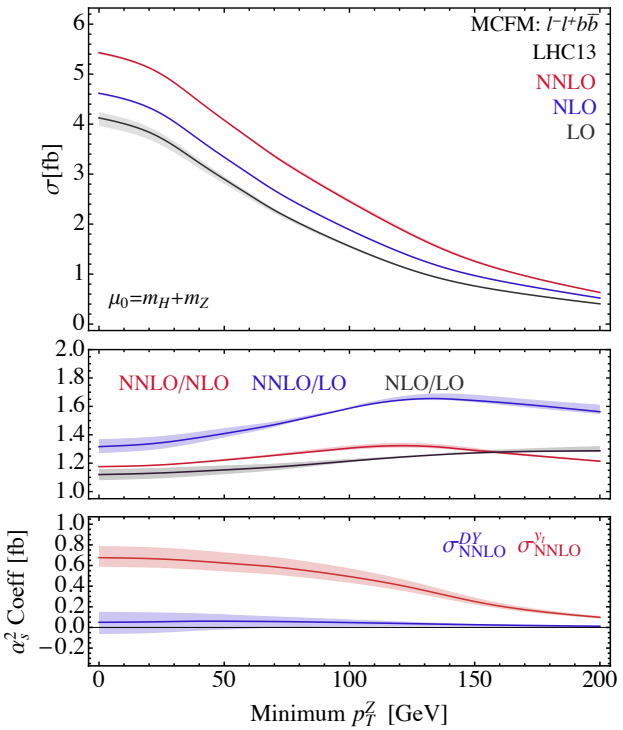
- timescale: Fall 2018

$gg \to HZ$

- at NNLO, the $gg \to HZ$ contribution is effectively a "LO" term
- nevertheless, it's quite relevant, especially in boosted regime



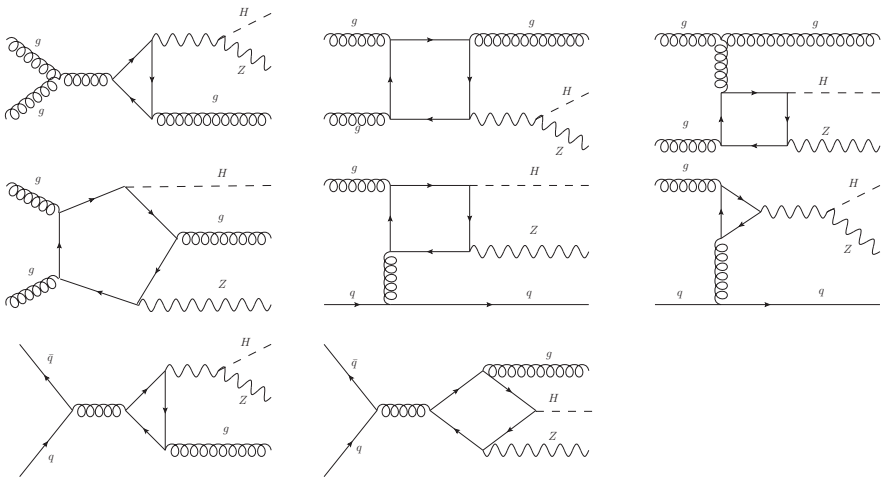


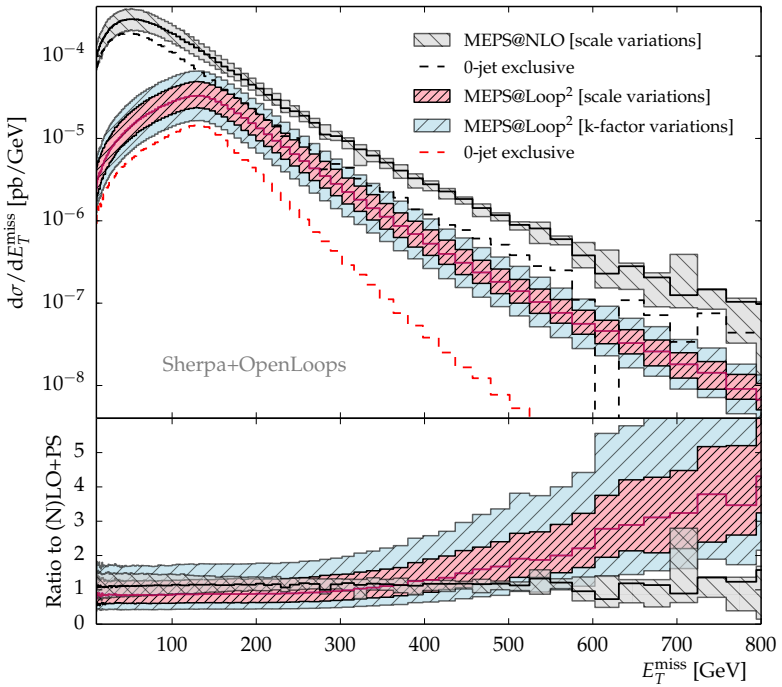


- currently this is included in EXP analysis at LO (with m_t dependence), and the total cross-section is rescaled to an approximate NLO+NLL results (fully inclusive, $m_t \to \infty$)
  [Altenkamp et al. '12, Harlander et al '14]

$gg \to HZ$

- more differential results exist, where 0 and 1 jet merging is performed at LO





- goal:
  - compare current result against LO merging of the 0 and 1 jet (loop-induced) processes
    - `Sherpa` [Goncalves et al. '15]
    - `MG5` [Hespel et al. '15]
    - ...
- timescale: mid-Summer 2018
- ultimately, the "final result" should come from an exact NLO computation, which might be not too far(?), given the results recently achieved for HH and $H + j$ production.

conclusions

- we have identified a few studies and we plan to focus our efforts on those for the forthcoming ~ 6 months.
  At least for some of them, depending on the outcome, we plan to also produce a public document.
- we'll also address the request about producing reference results for $pp \to VH$ at 27 TeV.
- of course, we are open to suggestions, in case further issues arise.

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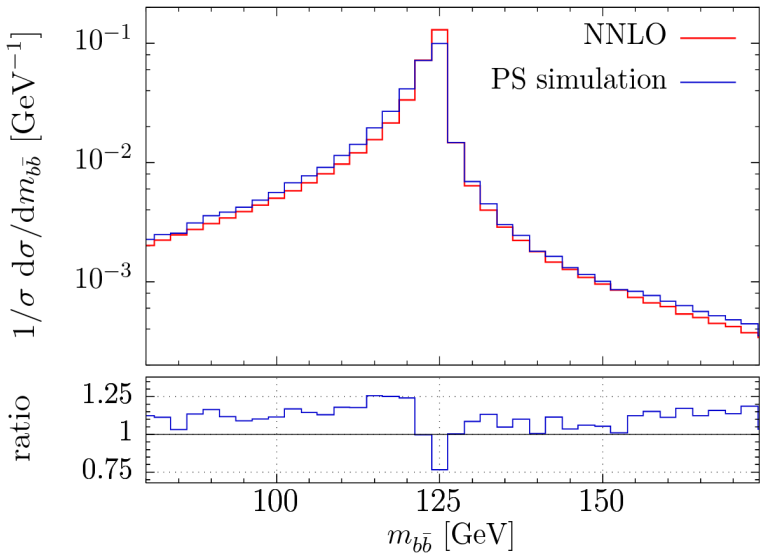
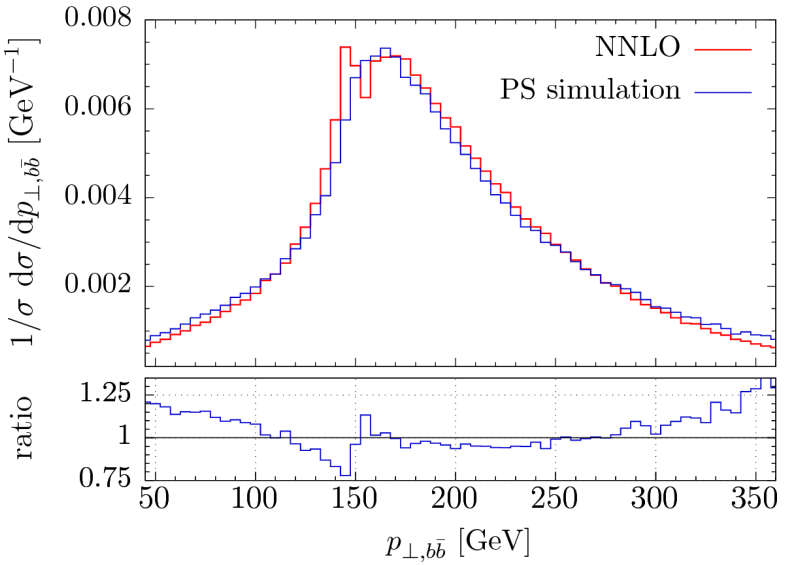
Thanks for your attention

Extra slides

Parton showers

Note: normalized distributions.





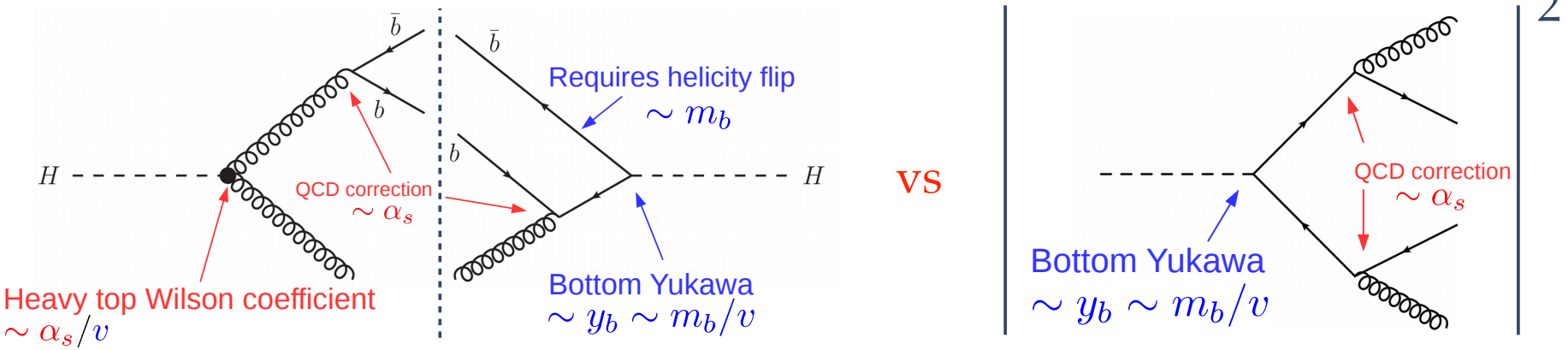
- Generally good description of NNLO shape.
- PS predicts more events in tails, fewer in peak.

- Generally good description of NNLO shape, except in **tails** – PS predicts more events.
- PS removes Sudakov shoulder (as expected).

slide from R. Roentsch talk; VH meeting

H→bb decay@NNLO: a theoretical issue

- Why is this a problem? We require helicity flip → after factoring out one power of m_b, amplitude acquires SUB-LEADING-POWER DIVERGENCES, not regulated by flavor jet algorithm



$\sigma \sim \alpha_s^2\, m_b^2/v^2\, \mathrm{Ln}^k(m_b/m_H)$ *[k≤2]*

$\sigma \sim \alpha_s^2\, m_b^2/v^2\, [1 + O(m_b^2/m_H^2)]$

Log-enhanced, cannot set $m_b \to 0$

slide from F. Caola talk at Moriond QCD