

$gg \rightarrow ZH$ at NLO

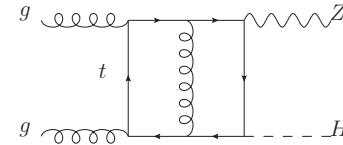
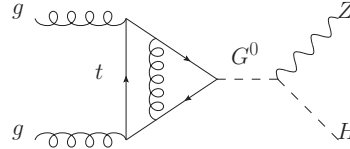
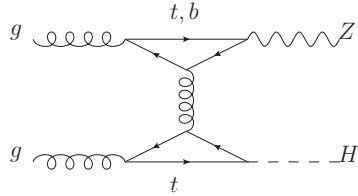
Marco Vitti (Karlsruhe Institute of Technology, TTP and IAP)

VH subgroup meeting: Plans for YR5 – 24.10.24

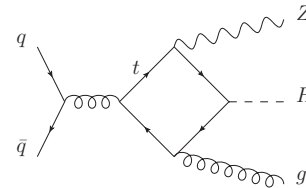
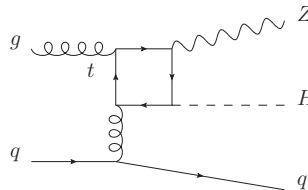
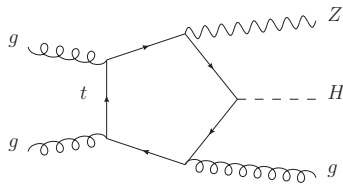


$gg \rightarrow ZH$ @ NLO in QCD - Ingredients

Virtual corrections ($2 \rightarrow 2$, two loops) - interference with LO



Real emission ($2 \rightarrow 3$, one loop) - squared amplitudes



Complete NLO Predictions

■ Sector decomposition \oplus High-Energy expansion

[Chen, Davies, Heinrich, Jones, Kerner, Mishima, Schlenk, Steinhauser - 2204.05225]

Virtual corrections

- ◆ pySecDec for $p_T < 200$ GeV
- ◆ HE exp for $p_T > 200$ GeV

Real emission

- ◆ GoSam & in-house C++ code

■ pT expansion \oplus High-Energy expansion [Degrassi, Gröber, MV, Zhao - 2205.02769]

Virtual corrections

- ◆ pT exp for $|\hat{t}| < 4m_t^2$
- ◆ HE exp for $|\hat{t}| > 4m_t^2$

Real emission

- ◆ RECOLA2 [Denner, Lang, Uccirati - 1711.07388]
- ◆ MadGraph5 [Alwall et al. - 1405.0301]

Plan

- Validation of predictions when same parameters are used
 - Once agreement is found, the “pT exp \oplus High-Energy exp” implementation should be adapted to inputs and recommendations from VH subgroup
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Real Emission

■ Overall agreement for prediction w/o Z-radiated diagrams **DONE**

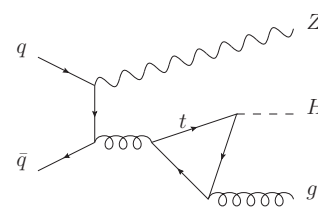
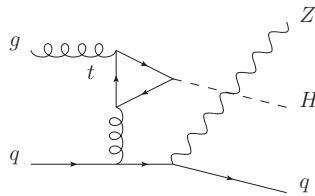
Agreement below 0.1% for real emission in gg-channel

Better agreement for qq- and qq- channels

■ Comparison when Z-radiated diagrams are included **TO BE COMPLETED**

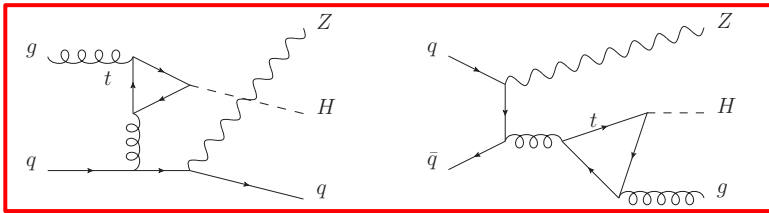
Good agreement for qq- and qq- channels

Discrepancies in gg-channel (not affected by Z-radiation...)



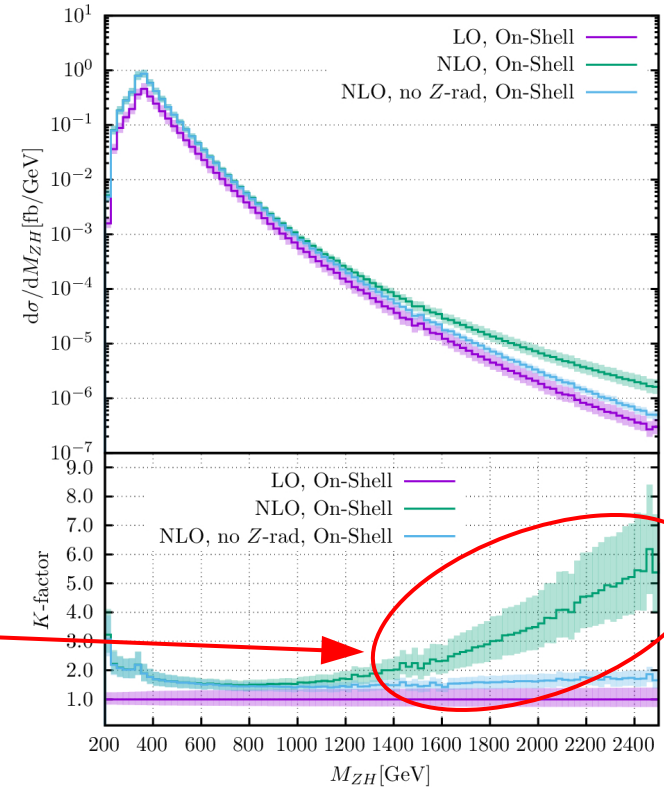
High-Energy Tails – Z Radiation

- K-factor rapidly increasing for $M_{ZH} > 1 \text{ TeV}$
- Effect due to real-emission diagrams where the Z is radiated from an open fermion line
- Not included in [\[Wang, Xu, Xu, Yang - 2107.08206\]](#)
[\[Chen et al. - 2204.05225\]](#)



Dominant

PDF suppressed

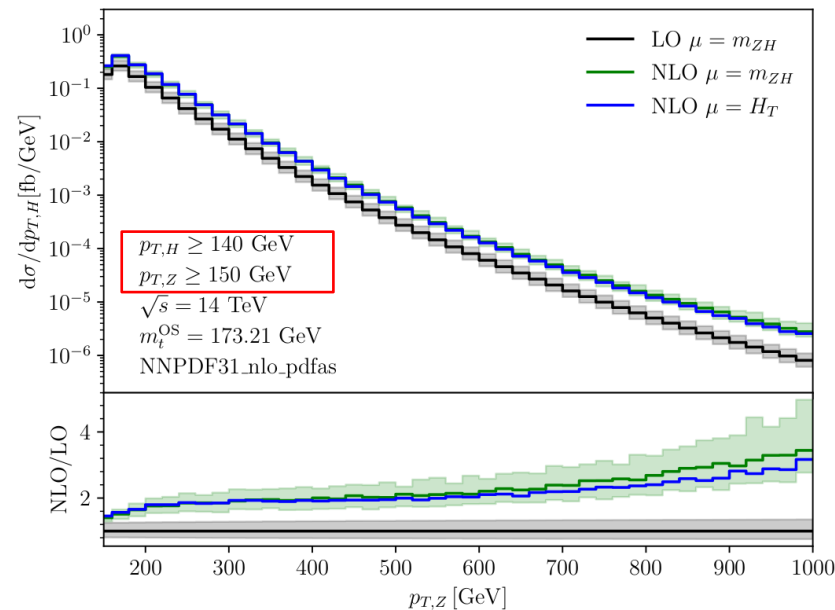
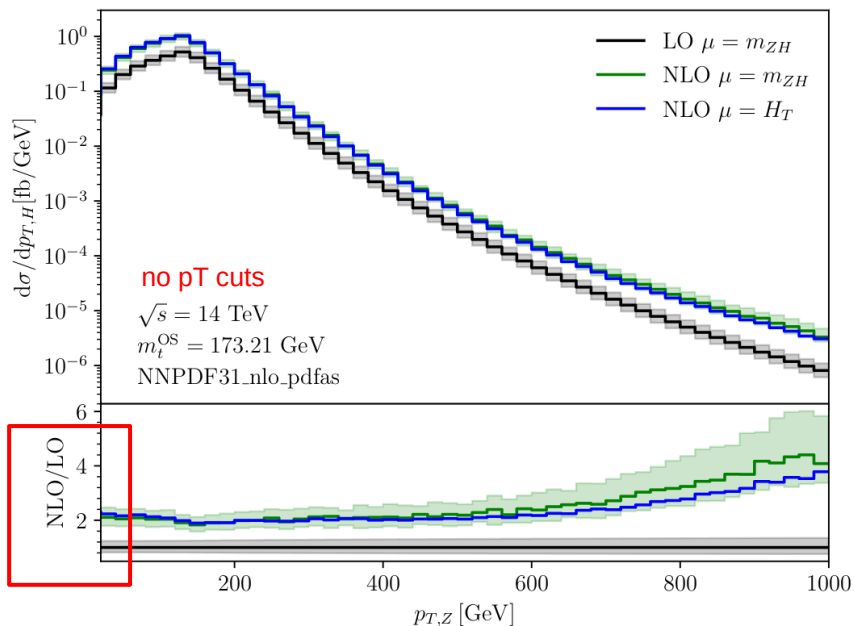


[\[Degrassi, Gröber, MV, Zhao - 2205.02769\]](#)

High-Energy Tails – pT Distributions

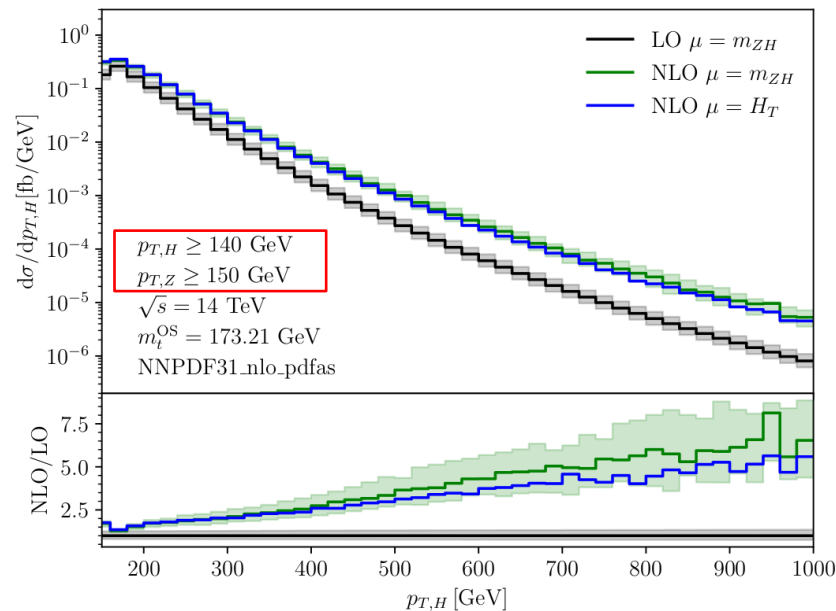
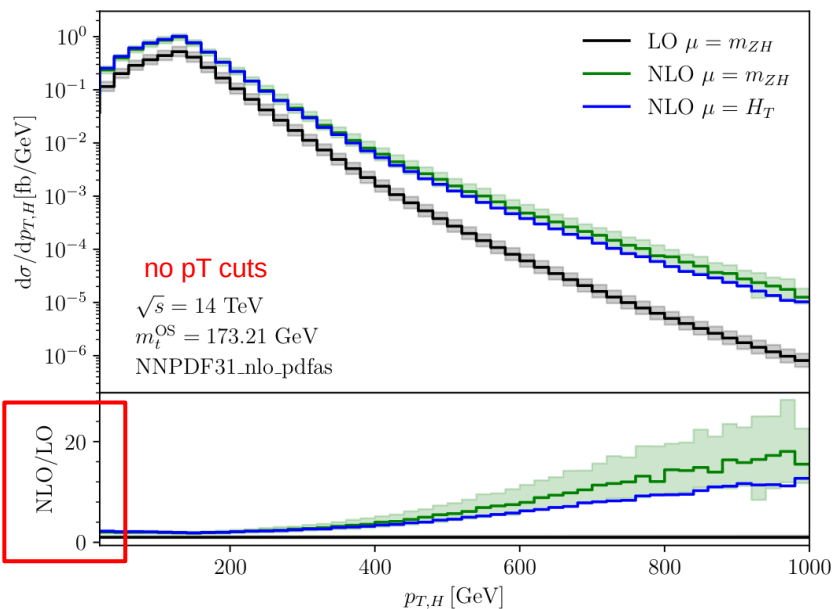
■ K-factor increasing for $p_{T,Z} > 600$ GeV

■ Not very sensitive to pT cuts



High-Energy Tails – pT Distributions

- Very large NLO corrections for $p_{T,H} > 400$ GeV
- Still K-factor of ~ 5 after pT cuts



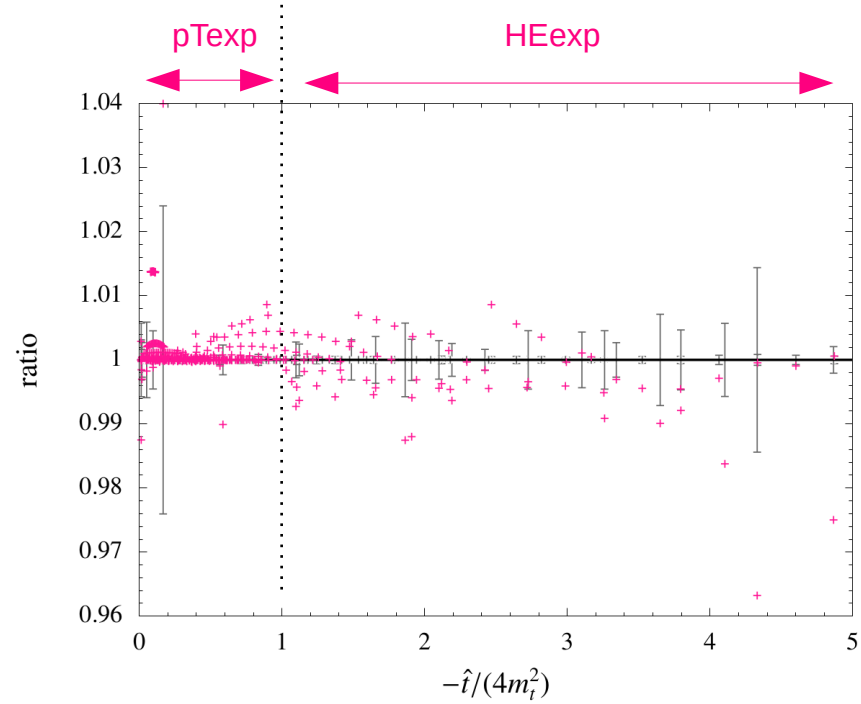
Virtual corrections

Comparison at the level of IR-subtracted \mathcal{V}_{fin}

pT+HE expansion vs pySecDec+HE exp

Overall agreement at % level

TODO: understand better deviations at low $|t|/4m_t^2$



[Plot: Ramona]

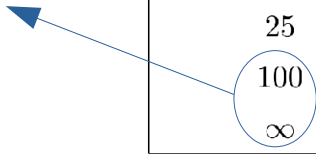
Top Mass Scheme Uncertainty

- Envelope of deviations of $\overline{M_S}$ schemes wrt OS result
Same method already used for HH production
[Baglio et al. - 1811.05692, 2003.03227]

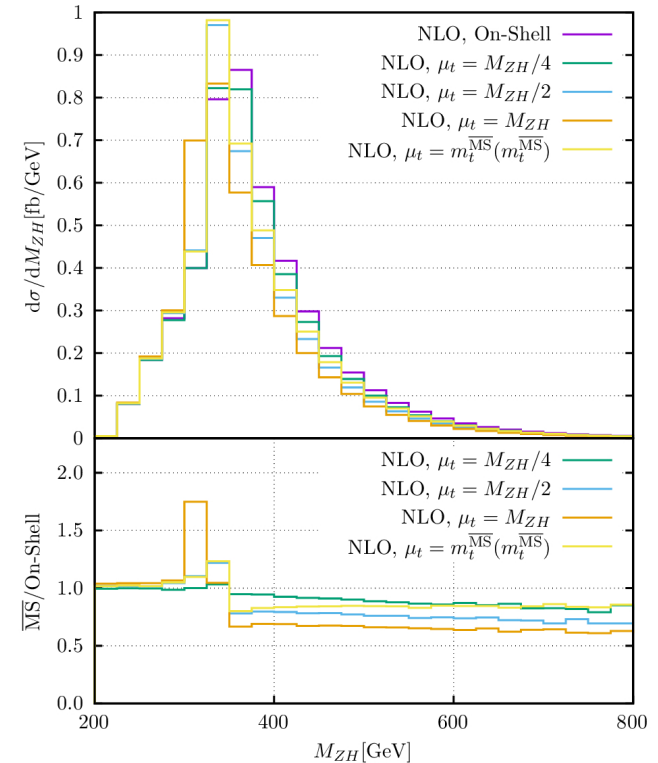
- Uncertainty sensitive to the binning of top-pair threshold peak

| Bin Width [GeV] | LO | NLO |
|-----------------|-----------------------------------|-----------------------------------|
| 1 | 64.01 ^{+15.6%} -35.9% | 118.6 ^{+17.2%} -27.0% |
| 5 | 64.01 ^{+15.3%} -35.6% | 118.6 ^{+14.7%} -24.9% |
| 25 | 64.01 ^{+14.0%} -33.1% | 118.6 ^{+10.9%} -20.8% |
| 100 | 64.01 ^{+2.0%} -25.3% | 118.6 ^{+0.6%} -13.7% |
| ∞ | 64.01 ^{+0%} -23.1% | 118.6 ^{+0%} -12.9% |

Avoid overestimate of uncertainty



- Top-mass uncertainty \sim scale uncertainty
- Agreement with [Chen et al. - 2204.05225] for $M_{ZH} > 400$ GeV
(Predictions for different schemes available only in this region for both papers)



[Degrassi, Gröber, MV, Zhao - 2205.02769]

Status summary

- Real and virtual corrections for both setups in general agreement

TODO

- Extend validation at the level of differential distributions
- Numbers for inclusive $gg \rightarrow ZH$
- Single-differential distributions (invariant mass, p_T)

To be discussed

- Binning and top-mass-scheme uncertainties
 - Possibility of multi-differential distributions?
 - Better understanding of high-energy tails:
 - Include Z-radiated diagrams? Present predictions w/ and w/o Z-radiated?
 - Interplay between fiducial cuts and large K-factors
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