Fully differential N^{3}LO predictions for boosted Higgs-strahlung

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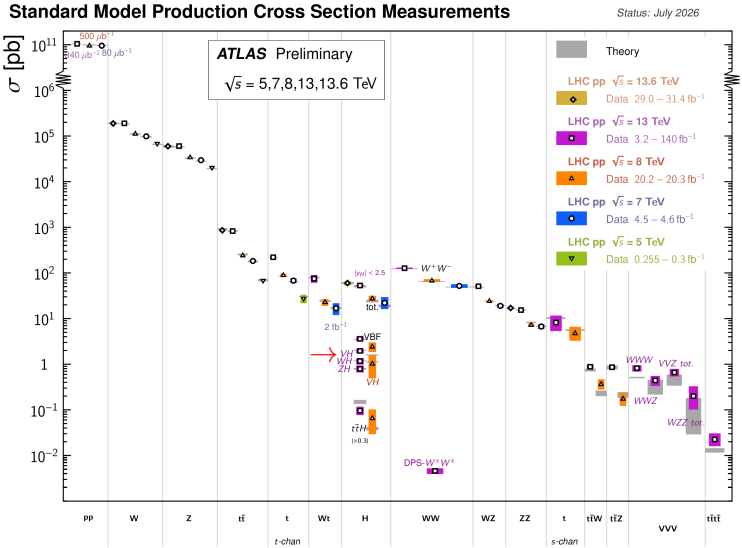
Based on 2606.31286, with A. Gehrmann-De Ridder, Alexander Huss, Matteo Marcoli, Pier Francesco Monni, Emanuele Re, Luca Rottoli and Paolo Torrielli



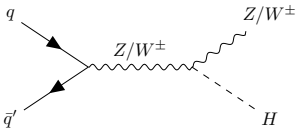


Higgs-strahlung at the LHC



- Third Higgs production at the LHC

  $\sigma_{VH} < \sigma_{\mathrm{VBF}} < \sigma_{ggH}$
- Direct probe of Higgs–vector boson coupling
- Access to Yukawa couplings

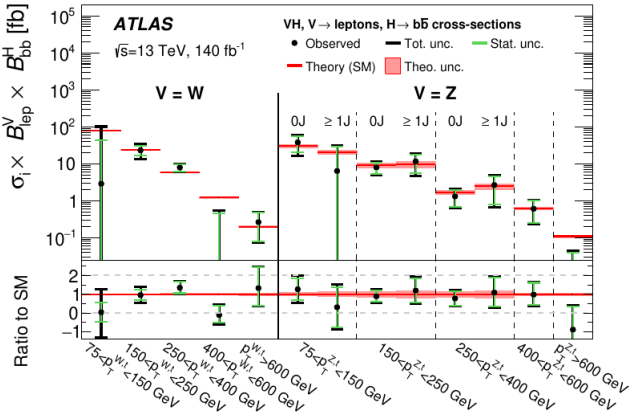


The boosted-Higgs regime

Selecting a high-p_T^H Higgs trades signal rate for improved background discrimination.

→ Butterworth, Davison, Rubin, Salam 0802.2470

ATLAS: $V \to$ leptons , $H \to b\bar{b}$ JHEP 04 (2025) 075

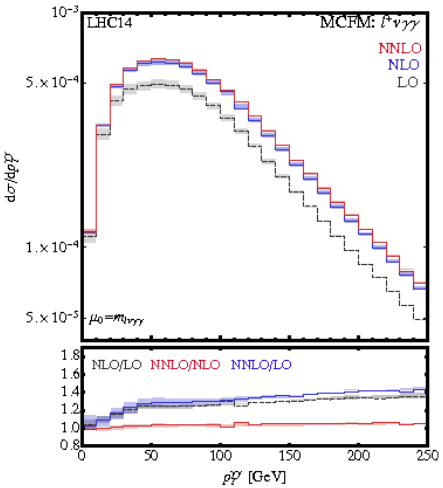


$$\Delta R_{b\bar{b}} \sim \frac{2m_H}{p_T^H}$$

- Collimated $b\bar{b}$ decay: large-R jet reconstruction and tagging.
- High-momentum spectra probe energy-growing SMEFT contributions.
- High-p_T bins are statistically limited (but will not at HL-LHC).

The boosted-Higgs regime

Campbell, Ellis, Williams 1601.00658v2



Drell-Yan like inclusive QCD corrections known to N^{3}LO.

Baglio, Duhr, Mistlberger, Szafron 2209.06138

Differential predictions relevant for fiducial analyses were previously up to NNLO were studied extensively.

→ Ferrera, Grazzini, Tramontano 1107.1164

→ Astill, Bizon, Re, Zanderighi 1603.01620

Many other approaches for higher-order QCD, see C. Signorile-Signorile's talk .

NNLO $\longrightarrow$ N^{3}LO via q_T slicing for W^+H

- First fully differential N^{3}LO prediction for boosted W^+H.
- Fiducial cross sections and p_T^H spectra.
- Explore size of residual QCD uncertainty.

q_T slicing: idea

Catani, Grazzini 0703012

$$\mathrm{d}\sigma = \int_{q_T<q_T^{\mathrm{cut}}} \mathrm{d}\sigma^{\mathrm{singular}} + \int_{q_T>q_T^{\mathrm{cut}}} \mathrm{d}\sigma^{\mathrm{regular}} + \mathcal{O}\big((q_T^{\mathrm{cut}}/Q)^p\big)$$

- In the unresolved region, (small-)q_T structure of color-singlet production is universal .
- The resolved region is a higher-multiplicity fixed-order calculation.
- The cut must be small enough for power corrections, but not so small that the real-emission calculation becomes unstable.

see also R. Poncelet's talk from yesterday

q_T slicing: idea

Catani, Grazzini 0703012

$$\mathrm{d}\sigma^{F}_{\mathrm{N^{(k+1)}LO}} = \mathcal{H}^{F}_{\mathrm{N^{(k+1)}LO}} \otimes \mathrm{d}\sigma^{F}_{\mathrm{LO}} + \int_{q_T > q_T^{\mathrm{cut}}} \left[\mathrm{d}\sigma^{F+1\mathrm{jet}}_{\mathrm{N^{k}LO}} - \mathrm{d}\sigma^{F,\mathrm{CT}}_{\mathrm{N^{(k+1)}LO}}\right] + \mathcal{O}\big((q_T^{\mathrm{cut}}/Q)^p\big)$$

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q_T slicing: execution

RadISH

- Direct-space resummation of q_T up to N^{3}LL'

  Monni, Re, Torrielli 1604.02191

  Bizon, Monni, Re, Rottoli, Torrielli 1705.09127

- Similar strategy previously applied to fiducial Drell-Yan

  Chen, Gehrmann, Glover et al. 2203.01565

We consider $pp \to W^+(\to e^+\nu_e)H$

$$\mathrm{d}\sigma = \underbrace{\mathrm{d}\sigma_{\alpha_s^3}}_{q_T \text{ slicing}} + \underbrace{\mathrm{d}\sigma_{\alpha_s^{0,1,2}} + \mathrm{d}\sigma_{y_t\alpha_s^2}}_{\texttt{NNLOJET local subtraction}}$$

NNLOJET

- Parton-level Monte Carlo event generator based on antenna subtraction

  Gehrmann–De Ridder, Gehrmann, and Glover 0505111

  Currie, Glover, and Wells 1301.4693

  NNLOJET 2503.22804

- Studies of $VH + 1\,\mathrm{jet}$ @ NNLO

  Gauld, Gehrmann-De Ridder et al. 2009.14209, 2110.12992

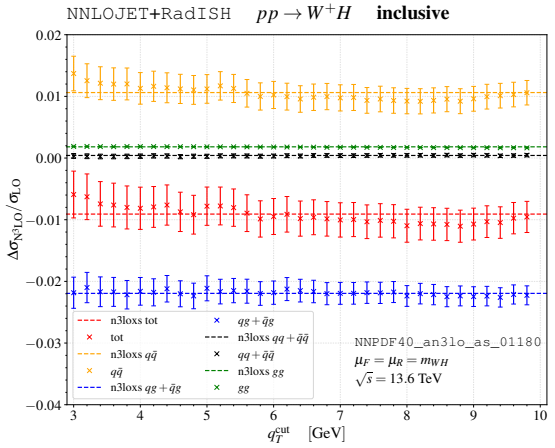
- 1-loop real-virtual amplitudes provided by OpenLoops2

  Buccioni, Lang, Lindert et al. 1907.13071

- Contributions from top loops are included separately.

  Brein, Harlander, Wiesemann, Zirke 1111.0761

Validation: inclusive W^+H production



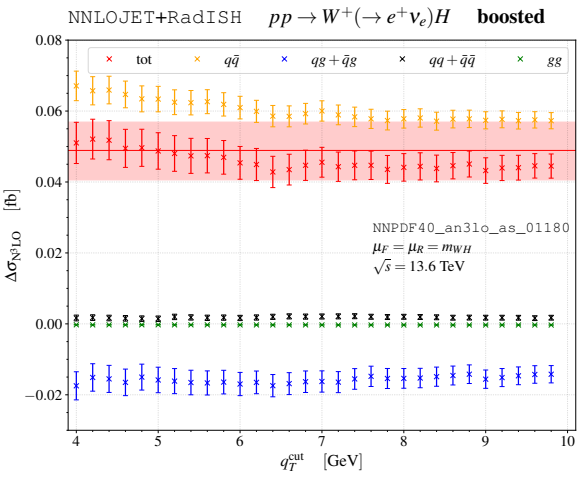
- No p_T cuts, on shell W^+.
- Benchmark slicing against `n3loxs` N^{3}LO result.

  Baglio, Duhr, Mistlberger, Szafron 2209.06138
- Agreement is found channel by channel for

$$q\bar{q}, \quad qg + \bar{q}g, \quad qq + \bar{q}\bar{q}, \quad gg.$$

- The result is stable for approximately $3\ \mathrm{GeV} \lesssim q_T^{\mathrm{cut}} \lesssim 10\ \mathrm{GeV}$.

Controlling the slicing uncertainty



- Partial cancellation $q\bar{q}$ and $qg + \bar{q}g$ contributions to reduced accuracy on combintion.
- fiducial cuts are staggered: no linear power corrections

$$\delta\sigma \sim \mathcal{O}\big((q_T^{\mathrm{cut}}/Q)^2\big).$$

- $q_T^{\mathrm{cut}} = 5$ GeV is safely above the numerical-instability region and small enough to suppress power corrections.
- Error band is estimated from envelope of $q_T^{\mathrm{cut}} \pm (1\mathrm{GeV})$ variations and Monte Carlo errors.

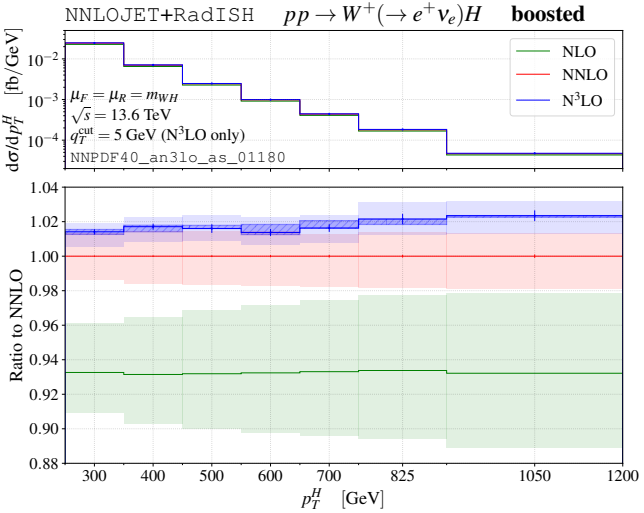
Fiducial cross sections

σ [fb]	Boosted $p_T^H \geq 250\,\text{GeV}$	Boosted $p_T^H \geq 400\,\text{GeV}$	"STXS" $p_T^H \geq 400\,\text{GeV},\ p_T^W \geq 250\,\text{GeV}$
LO	$2.457^{+2.5\%}_{-2.5\%}$	$0.4639^{+4.7\%}_{-4.4\%}$	$0.4639^{+4.7\%}_{-4.4\%}$
NLO	$3.324^{+3.3\%}_{-2.8\%}$	$0.6368^{+4.0\%}_{-3.5\%}$	$0.5858^{+2.8\%}_{-2.5\%}$
NNLO	$3.564^{+1.4\%}_{-1.4\%}$	$0.6835^{+1.4\%}_{-1.7\%}$	$0.6116^{+0.7\%}_{-1.0\%}$
N^{3}LO	$(3.62 \pm 0.01)^{+0.5\%}_{-0.8\%}$	$(0.694 \pm 0.002)^{+0.7\%}_{-0.7\%}$	$(0.621 \pm 0.002)^{+0.6\%}_{-0.5\%}$

Highlights:

- **Boosted**: N^{3}LO adds about $+1.5\%$ and reduces the scale band below 1%.
- **"STXS"**: The correction is again about $+1.5\%$, despite a small NNLO scale band.
- **Effect of fiducial cuts**: the inclusive N^{3}LO correction is negative, while the boosted one is positive.

Boosted p_T^H spectrum

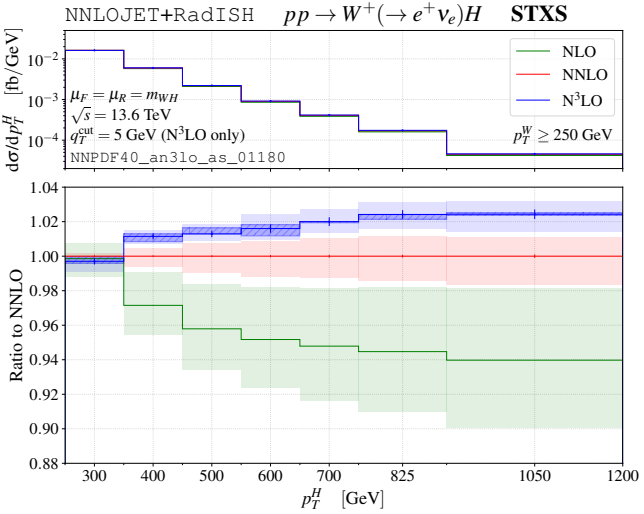


- First p_T^H N^{3}LO prediction for boosted W^+H.
- The N^{3}LO shift is positive and remarkably stable:

$$\Delta_{N^3\mathrm{LO}} \simeq +1.5\%\text{–}2\%$$

  across the displayed p_T^H range.
- Scale uncertainty is about 1% near $p_T^H = 300$ GeV and grows in the tail.
- Small slicing variation $\rightarrow$ negligible power corrections.

STXS p_T^H spectrum



- The additional p_T^W cut changes the correction near threshold.
- Small negative shift around $p_T^H \simeq 250$ GeV, followed by a 2–3% positive correction in the tail.
- Large p_T^H bins are less sensitive to the p_T^W cut $\rightarrow$ the two setups become more similar.
- The first bin is dominated by symmetric cut configuration. linear power corrections are calculated and included explicitly.

Conclusions

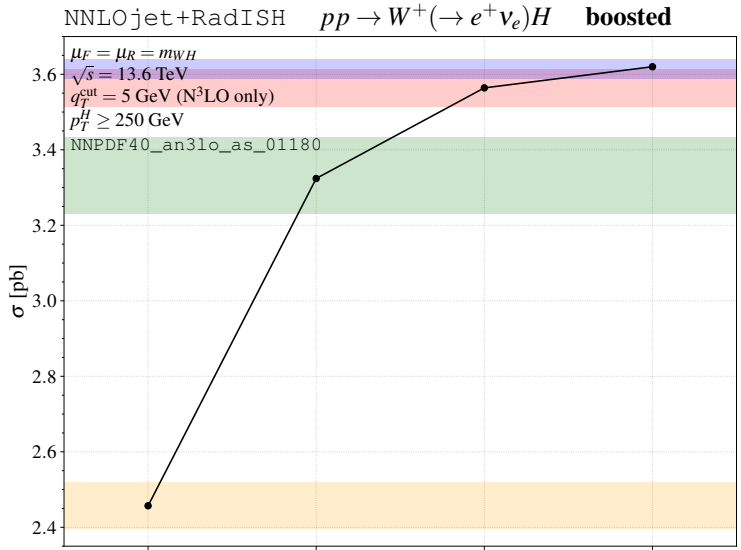
- Boosted W^+H production is a precision probe of Higgs interactions at the LHC and HL-LHC.
- q_T slicing through `RadISH+NNLOJET` enables the first fully **differential** N^{3}LO prediction for W^+H.
  1. **The perturbative series is not yet fully stable** in the boosted region.
  2. **N^{3}LO corrections are phenomenologically relevant in face of future experimental precision.**
     - They are of order 1–2%, comparable to the NNLO scale uncertainty.
     - Top-Yukawa-induced terms are also about the same size.
  3. **Scale uncertainty is reduced to around, or below, one percent in p_T^H tail.**
- The same strategy also applies to boosted ZH, with the separate addition of loop-induced $gg \to ZH$.

Thank you

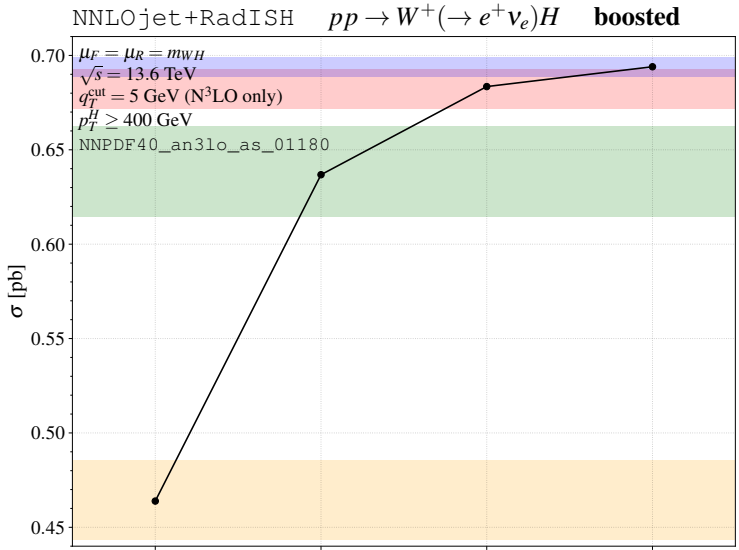
question time?

Backup

convergence plots



convergence plots



convergence plots

