Parton-shower and fixed-order QCD effects in Higgs boson production in weak-boson fusion and its decays to bottom quarks

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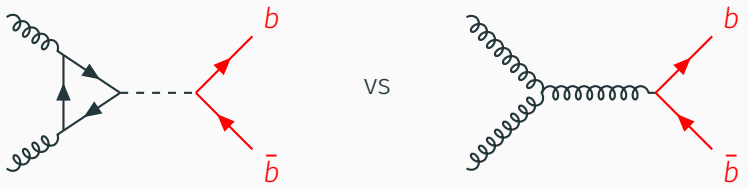
based on PRD 110 (2024) 5, 054017 [arXiv:2407.09363] and PRD 112 (2025) 7, 074033 [arXiv:2507.01448]
in collaboration with Konstantin Asteriadis, Kirill Melnikov, Ivan Novikov, Raoul Röntsch, and Giulia Zanderighi

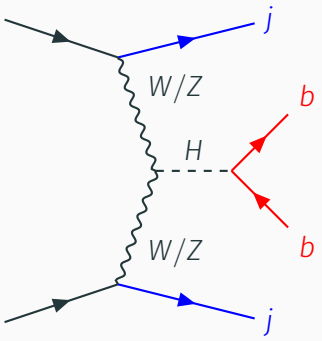
06 May 2026 – DIS2026 conference – Bologna, Italy

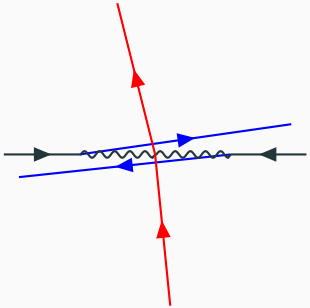
Higgs decays to bottom quark-antiquark pairs



Looking for $H \to b\bar{b}$ decays in the gluon fusion is difficult due to large QCD backgrounds.

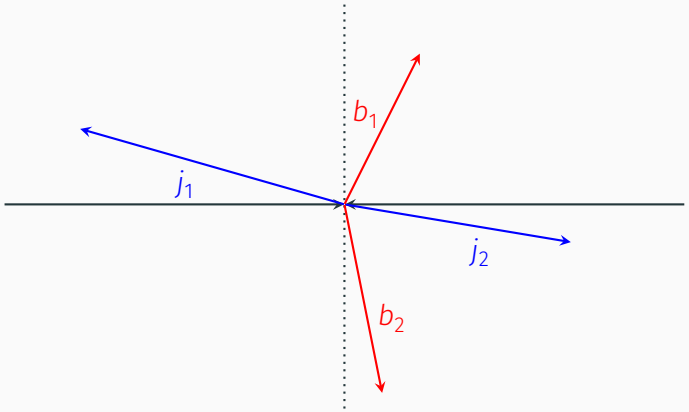
Higgs production in weak boson fusion with $H \to b\bar{b}$ decays





Higgs production in weak boson fusion adds two forward light jets that help to separate signal and background.

Fiducial cuts



- Based on ATLAS analysis
  [EPJ C 81 (2021) 6, 537]
- Find anti-k_t jets with $R = 0.4$
- We look for pair of nearly back-to-back jets with large invariant mass and two central b jets

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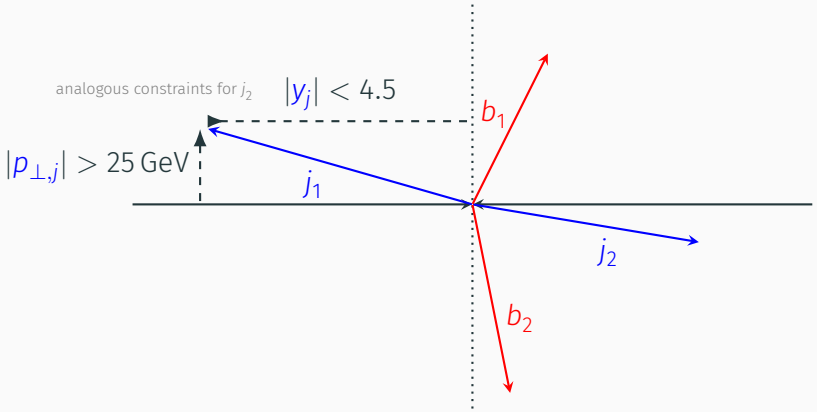

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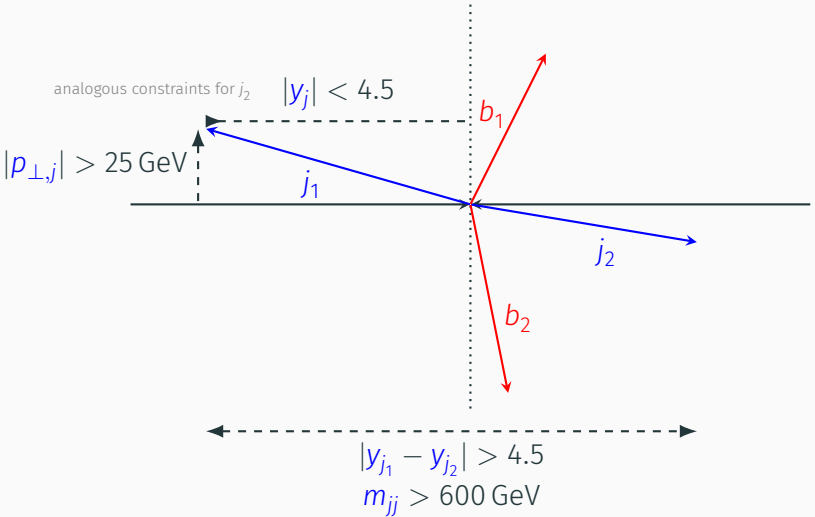

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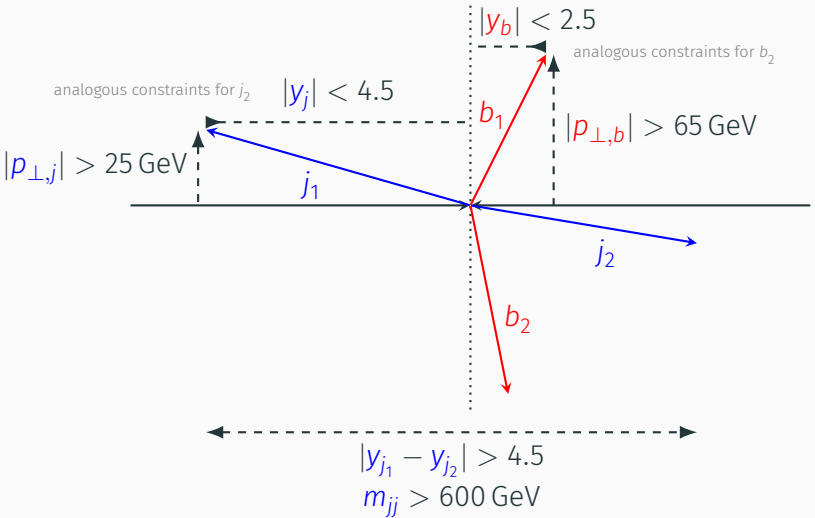

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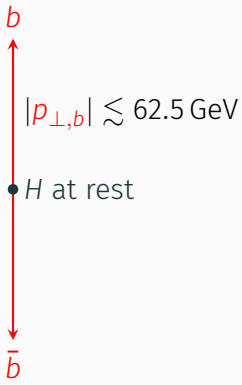
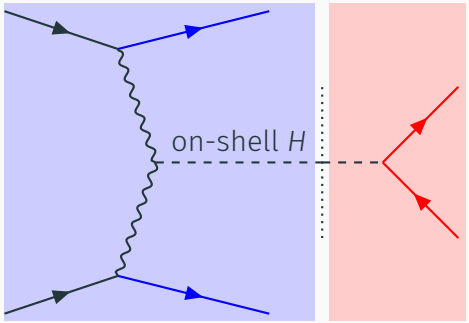
Fiducial cuts: implications for Higgs decays

Cut on b jet $p_\perp$ is rather strict

- $|p_{\perp,b}| > 65\,\text{GeV}$
- Implies that Higgs bosons decaying at rest do not pass the cut



Narrow-width approximation



Treat Higgs boson in narrow-width approximation
$\rightarrow$ factorises production and decay

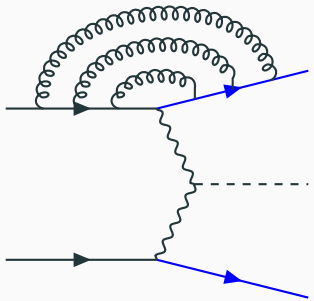
$$\mathrm{d}\sigma = \mathrm{d}\sigma_{WBF}\,\mathrm{Br}_{H\to b\bar{b}}\,\frac{\mathrm{d}\Gamma_{H\to b\bar{b}}}{\Gamma_{H\to b\bar{b}}}$$

$$\text{with } \mathrm{Br}_{H\to b\bar{b}} = \frac{\Gamma_{H\to b\bar{b}}}{\Gamma_H}$$

However, the event selection criteria introduce correlations between production and decay

Theory status: fixed-order calculations for Higgs production via weak-boson fusion

- Inclusive WBF cross section in factorised (double-DIS) approximation known up to N^{3}LO QCD [Dreyer, Karlberg '16]
  $\sigma_{\text{incl}}^{\text{N}^3\text{LO}} = 3928\,\text{fb}$



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- Fully differential calculations in factorised (double-DIS) approximation known up to NNLO QCD
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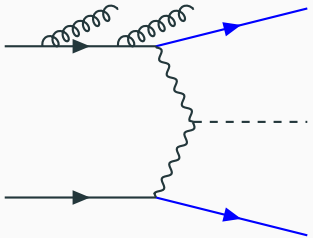

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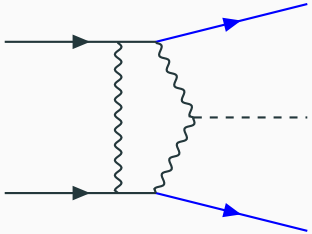

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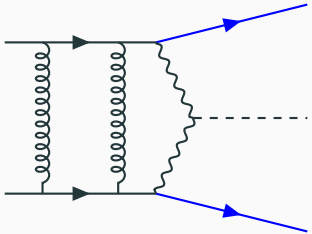

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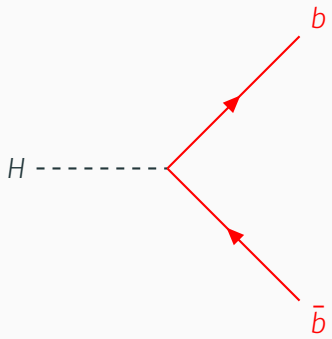
$\rightarrow$ NNLO QCD corrections to fiducial $pp \rightarrow Hjj$ production (with stable H) are roughly $\sim -11\%$

Theory status: fixed-order fully-differential calculations for $H \to b\bar{b}$ decays

- Massless b quarks: known up to N^{3}LO QCD
  [Mondini, Schiavi, Williams '19]
- Massive b quarks: known up to NNLO QCD
  [Bernreuther, Chen, Si '18] [AB, Bizon '19]

$$\Gamma^{\text{LO}}_{H\to b\bar{b}} = 1.926\,\text{MeV}$$
$$\Gamma^{\text{NLO}}_{H\to b\bar{b}} = 2.326\,\text{MeV} \quad \Big) \; 0.401\,\text{MeV}\;(+21\%)$$
$$\Gamma^{\text{NNLO}}_{H\to b\bar{b}} = 2.432\,\text{MeV} \quad \Big) \; 0.106\,\text{MeV}\;(+6\%)$$



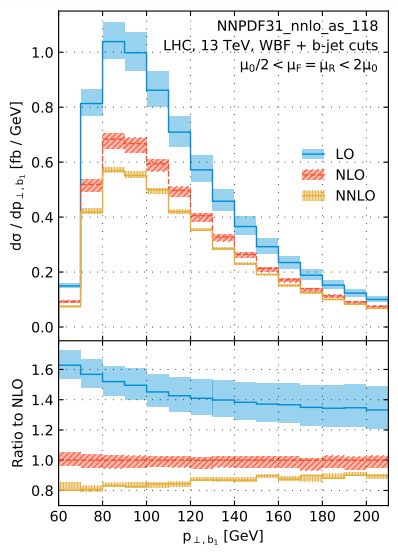
$\to$ NNLO QCD corrections to inclusive $H \to b\bar{b}$ decays are roughly $\sim +27\%$

Fixed-order NNLO QCD results

We find large corrections to fiducial cross sections and differential distributions
[Asteriadis, AB, Melnikov, Novikov, Röntsch '24]

$$\sigma_{\text{fid}}^{\text{LO}} = 75.6\,\text{fb}$$
$$\sigma_{\text{fid}}^{\text{NLO}} = 52.4\,\text{fb} \quad -31\%$$
$$\sigma_{\text{fid}}^{\text{NNLO}} = 44.6\,\text{fb} \quad -10\%$$

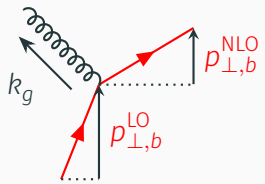
Fiducial cross section at NNLO QCD is 41% smaller than at LO



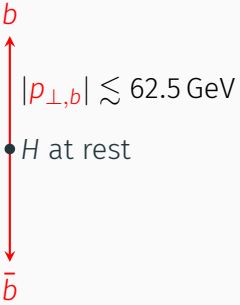
[Asteriadis, AB, Melnikov, Novikov, Rötsch '24]

What causes the large radiative corrections?

We traced the large higher-order shifts back to radiative corrections to the Higgs decay.

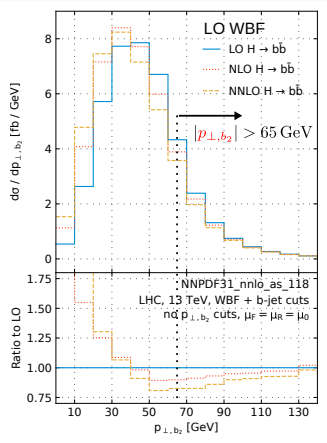


QCD radiation in $H \to b\bar{b}$ decay tends to reduce the $p_\perp$ carried by b jets

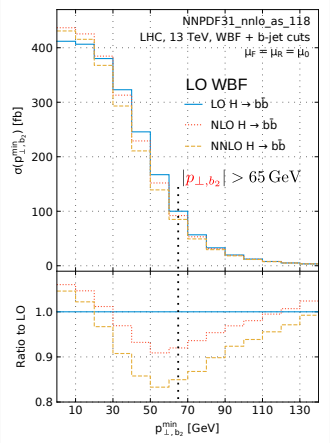


Interplay with fiducial cuts:
strict $|p_{\perp,b}| > 65\,\mathrm{GeV}$ cut reduces probability for event to survive cuts

QCD radiation effects on second hardest b jet



cumulative



[Asteriadis, AB, Melnikov, Novikov, Röntsch '24]

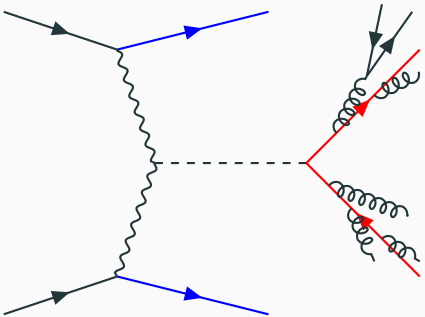
Observation: cut $p_{\perp,b} > 65\,\mathrm{GeV}$ sits on steeply falling part of spectrum

→ strongly sensitive to radiative corrections; bad apparent perturbative convergence

→ Relaxing cut could improve convergence, but might degrade purity of event sample

Follow-up study: parton shower description for Higgs decays

Large perturbative corrections caused by sensitivity to radiation in decay
→ Hypothesis: parton shower may help to improve description



We combine:

- Production: fixed-order (up to NNLO QCD)
  (using implementation based on nested soft collinear subtraction from [Asteriadis, Caola, Melnikov, Röntsch '21])
- Decay: parton shower matched calculation (LO+PS or MiNNLO+PS)
  (using `POWHEG` implementation from [Bizon, Re, Zanderighi '19] and `Pythia8.3`)

Parton shower for decay: fiducial cross sections

[AB, Melnikov, Novikov, Zanderighi '25]

σ/fb	fixed order	LO+PS	MiNNLO+PS
LO	75.6	46.6	45.2
NLO	52.4	43.6(1)	42.3
NNLO	44.6(1)	43.1(1)	41.4(1)

Monte Carlo uncertainty given in parentheses

- Already LO$\times$(LO+PS) captures much of the higher-order corrections
- NNLO result is relatively stable under inclusion of parton shower effects

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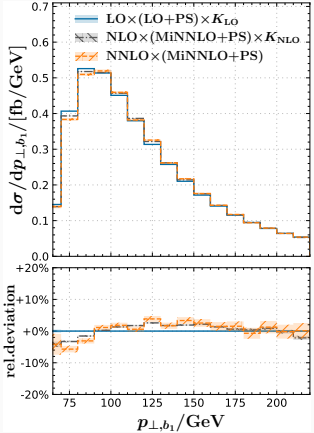
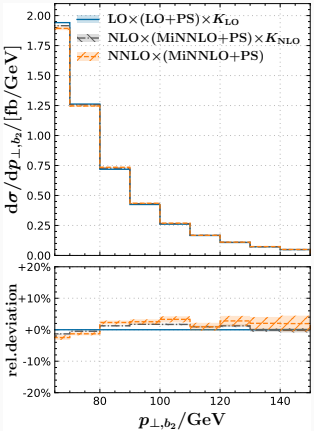
Parton shower for decay: b jet observables

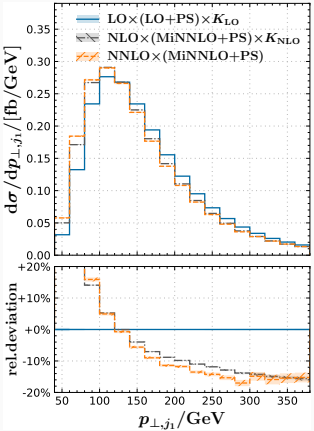


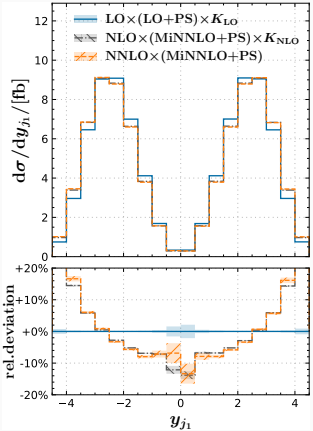


[AB, Melnikov, Novikov, Zanderighi '25]

After rescaling normalisation with K factor ($K_i = \frac{\sigma_{\text{NNLO}\times(\text{MiNNLO+PS})}}{\sigma_i}$),
b-jet observables are already well described by LO×(LO+PS) results

Parton shower for decay: WBF jet observables

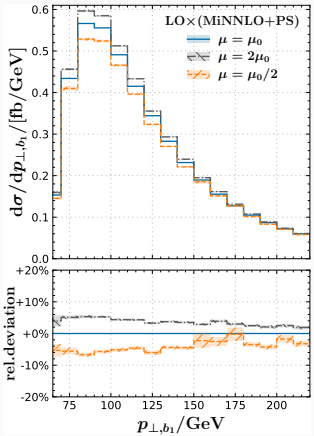


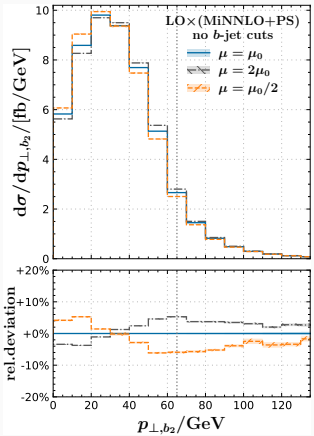


[AB, Melnikov, Novikov, Zanderighi '25]

Higher-order (fixed-order) correction are important for distributions of WBF-tagging jets

Parton shower for decay: decay scale variations





[AB, Melnikov, Novikov, Zanderighi '25]

Impact of variation of renormalisation scale used in decay process on *b*-jet distributions

$\rightarrow$ Estimate of perturbative uncertainty: $\sim 5\%$

Conclusions

- We observed large perturbative corrections for fiducial predictions for $pp \to H(b\bar{b})jj$ in fixed-order calculation ($\sim -40\%$).
- We traced back these corrections to an interplay between radiative corrections to the Higgs decay and the $p_\perp$ cuts on b jets.
- Including parton shower description matched to NNLO for the Higgs decay effectively resums these large corrections and improves perturbative convergence.
- Similar interplay between fiducial cuts, fixed order, and parton showers are also observed in di-Higgs production with decays to $b\bar{b}\gamma\gamma$ final states. [Braun, Fontes, Heinrich '25]
- Electroweak corrections are in principle known and expected to further reduce the cross section by about -5%.
- The remaining uncertainty is of order $\sim 5\%$ with the dominant source being the differential modelling of the $H \to b\bar{b}$ decays.