Fiducial and Differential Properties of Higgs from NNLOJET

WG1 ggF subgroup meeting: uncertainties in kinematic regions

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NNLOJET: NNLO tool with Antenna subtraction

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*                                                                     *
* NNLOJET: A multiprocess parton level event generator at O(alpha_s^3)*
*                                                                     *
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XC, J. Cruz-Martinez, J. Currie, A. Gehrmann-De Ridder, T. Gehrmann, N. Glover, A. Huss, M. Jaquier, T. Morgan, J. Niehues, J. Pires

✔	$pp \to H + 0, 1$ jet (ggF)	1408.5325, 1604.04085, 1607.08817
✔	$pp \to H + 2$ jet (VBF)	comming soon
✔	$pp \to Z(W) + 0, 1$ jet	1507.02850, 1601.04569, 1605.04295, 1610.01843
✔	$pp \to 2$ jets	1310.3993, 1407.5558
✔	$pp \to 1$ jet	1611.01460
✔	$ep \to e + 1, 2$ jets	1606.03991
✔	$e + e- \to 1, 2, 3$ jets	0710.0346, 0711.4711
✔	$\cdots$	all process @NNLO

NNLOJET: application in $pp \to H + jet$

- $pp \to H + jet$
  - Higgs production via gluon fusion in EFT
  - NNLO accuracy for one-jet bin in fiducial cross section
  - Precise study for p_T^H distribution (Boosted Higgs with NNLO accuracy)
  - Excellent agreement in inclusive H($\gamma\gamma$)+Jet final states (RUN II data)
- One of the first NNLO processes done with three different subtraction schemes
  - pp $\to$ H + J Antenna subtraction. XC, Gehrmann, Glover and Jaquier 1408.5325, 1604.04085, 1607.08817 [hep-ph]
  - pp $\to$ H + J Sector Improved Decomposition subtraction (without quark-quark channel). Boughezal, Caola, Melnikov, Petriello, Schulze 1302.6216, 1504.07922, 1508.02684 [hep-ph]
  - pp $\to$ H + J N-jettiness subtraction. Boughezal, Focke, Giele, Liu, Petriello 1505.03893 [hep-ph]
- Results in YR4 were calculated with the following cuts:

$\sqrt{s}$	13 TeV
PDF set	PDF4LHC15_nnlo_30
Scale choices	$\mu_R = \mu_F = [1, 1/2, 2] \times m_H$
anti-k_T jets	$R = 0.4$
	$p_T^j > 30$ GeV
Parton channels	$all@NNLO$
Wilson correction	Same order of α_s
m_t effects	N/A

Recap of NNLOJET in YR4

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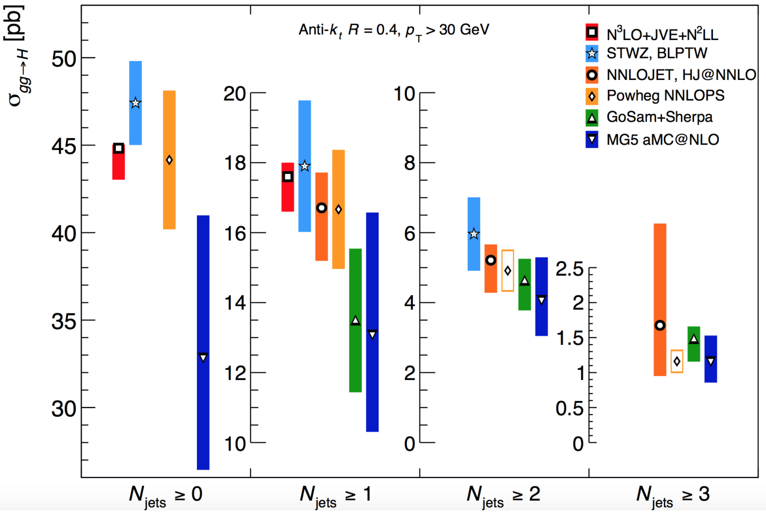
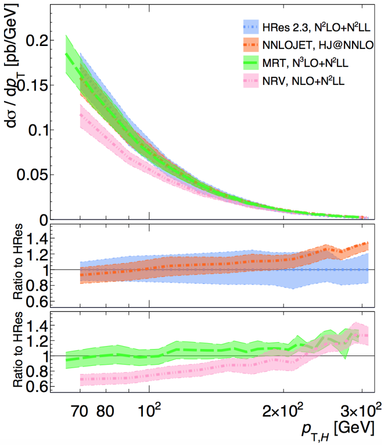
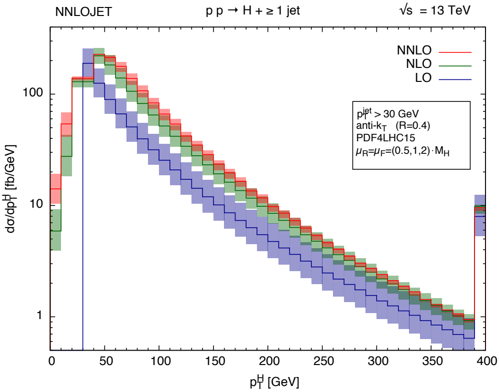
- Jet-bin comparison using CERN-LHCHXSWG recommend cuts:



Recap of NNLOJET in YR4

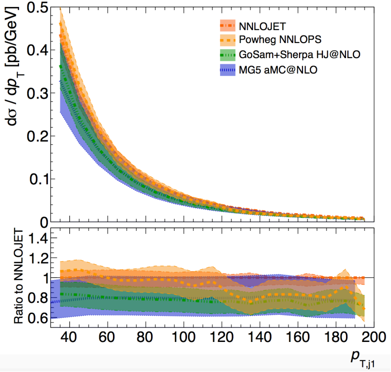
- Differential distribution of p_H^T in YR4:

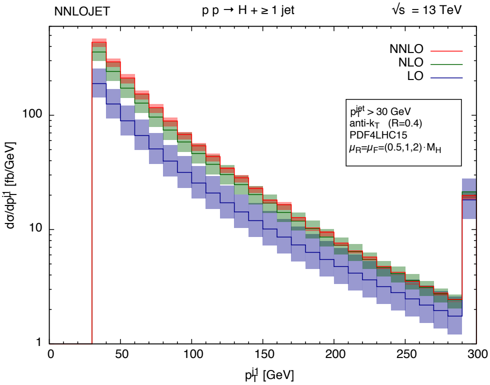




Recap of NNLOJET in YR4

- Suitable as benchmark reference for p^T_{j1} in YR4:

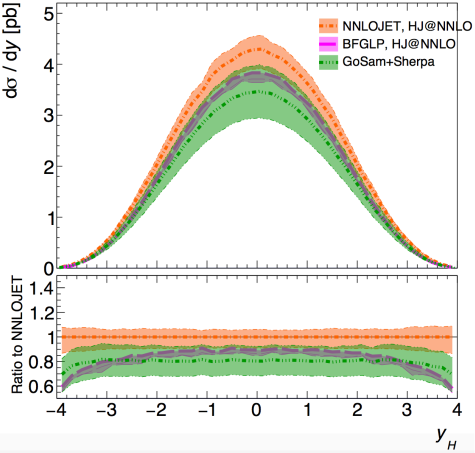




Recap of NNLOJET in YR4

- Cross-checking is important (more details later):

- Substantial difference in the shape and scale variation in $\mathrm{y_H}$ distributions
- Using different PDF sets
- Need information about self-consistence check: safety cut, N-jettiness cut etc.
- Need information about channel break down, integration error etc.



Finite quark mass effect

Finite quark mass effect in p_T^H

- Precision study for p_T^H distribution (no jet cut)

- The heavy particle loop is resolved by the large momentum transfer flowing through it
- Currently only LO mass effect is known for Higgs + 3 parton
- Including Top, Bottom and Charm quark masses (and interference terms)
- Define differential reweighing function to estimate the effect at NLO and NNLO:

$$R = \sigma_{\mathrm{LO}}^{M} / \sigma_{\mathrm{LO}}^{\mathrm{EFT}}$$

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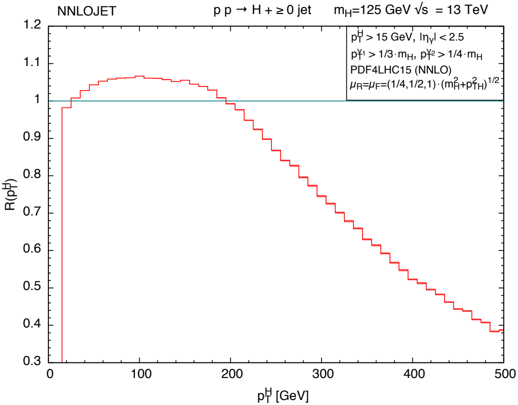
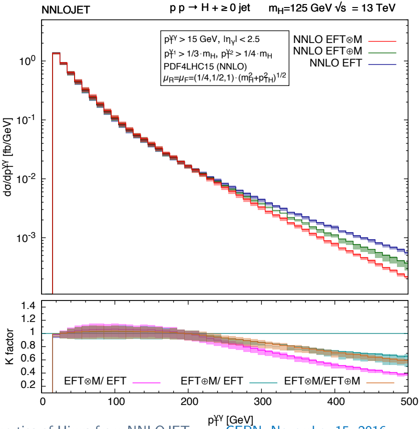


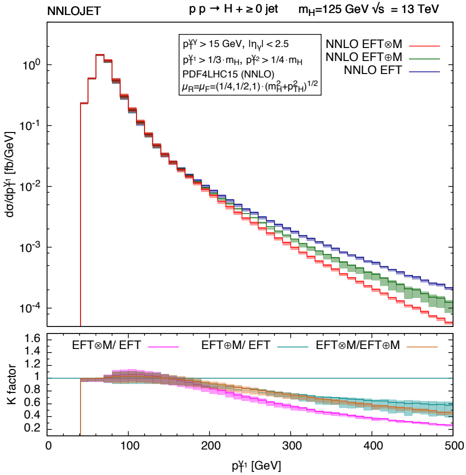
Finite quark mass effect in p_T^H

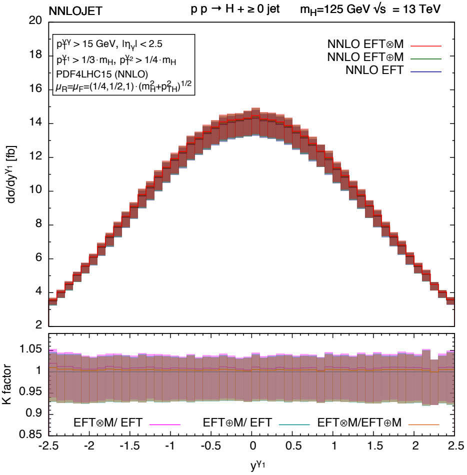
- Precision study for p_T^H distribution (no jet cut)
  - EFT⊗M reweighting $\frac{d\sigma^{EFT\otimes M}_{NNLO}}{dp_T^H} \equiv R(p_T^H)\left(\frac{d\sigma^{EFT}_{NNLO}}{dp_T^H}\right)$
  - EFT⊕M reweighting $\frac{d\sigma^{EFT\oplus M}_{NNLO}}{dp_T^H} \equiv \left(\frac{d\sigma^{EFT}_{NNLO}}{dp_T^H}\right) + (R(p_T^H)-1)\left(\frac{d\sigma^{EFT}_{LO}}{dp_T^H}\right)$
- The spread serves to quantify the systematic uncertainty
- Mass correction within scale uncertainties for $p_T^H < 250$ GeV
- Corrections in high p_T^H region $(400 \sim 500$ GeV) could be $40\% \sim 70\%$
- Would need NLO mass effect for further constrain



Finite quark mass effect in γ_1

- Apply CMS cuts at 13 TeV in $H \to \gamma\gamma$ channel, γ_1 is the leading photon
- $p_T^{\gamma_1}$ and y^{γ_1} distributions with two reweighting schemes :





Cross check of $pp \to H + jet$ @ NNLO

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- One of the first NNLO processes done with three different subtraction schemes
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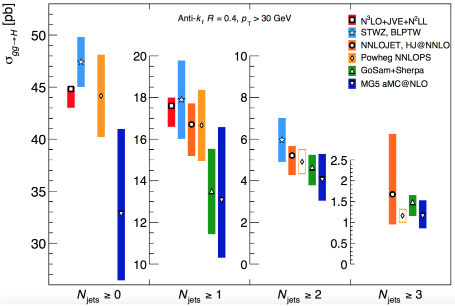
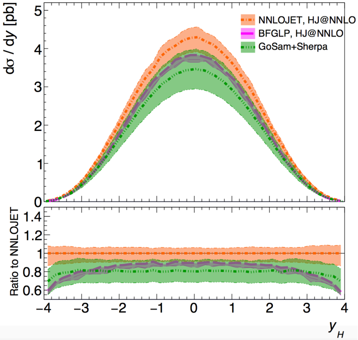
- NNLL effects are included in jet-bin analysis → direct comparison not available
- Rapidity distribution of Higgs show tension between N-jettiness and NNLOJET
- NNLOJET repeat three sets of calculations for cross check (next slides)





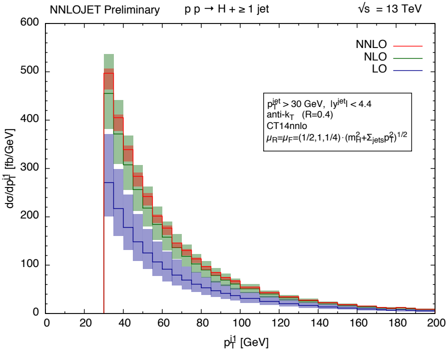
Cross check of $pp \to H + jet$ @ NNLO

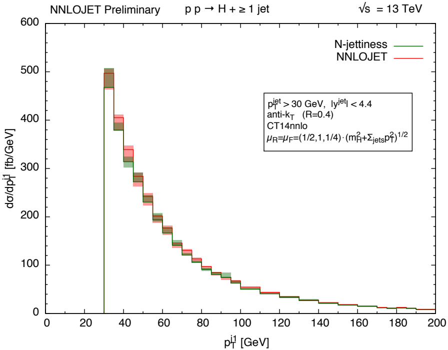
$\sqrt{s}$	8 TeV	13 TeV	8 TeV
PDF set	NNPDF23_nnlo	PDF4LHC15_nnlo_30	NNPDF23_nnlo
Central scales	$\mu_R = \mu_F = m_H$	$\mu_R = \mu_F = m_H$	$\mu_R = \mu_F = m_H$
anti-k_T jets	$R = 0.4$	$R = 0.4$	$R = 0.5$
	$\lvert\eta_j\rvert < 4.4$	-	$\lvert\eta_j\rvert < 2.5$
	$p_T^j > 30$ GeV	$p_T^j > 30$ GeV	$p_T^j > 30$ GeV
leading photon	$\lvert\eta_{\gamma_1}\rvert < 2.37$	-	-
	$p_T^{\gamma_1} > 0.35\, m_H$	-	-
sub-leading photon	$\lvert\eta_{\gamma_2}\rvert < 2.37$	-	-
	$p_T^{\gamma_2} > 0.25\, m_H$	-	-
Parton channels	$gg{+}qg{+}q\bar{q}$(NLO)	$gg{+}qg{+}q\bar{q}$(NLO)	all channels (NNLO)
	$\sigma^{EFT}_{H(\to\gamma\gamma)+\geq 1jet,\mathrm{NNLO}}$	$\sigma^{EFT}_{H+\geq 1jet,\mathrm{NNLO}}$	$\sigma^{EFT}_{H+\geq 1jet,\mathrm{NNLO}}$
NNLOJET	$9.44^{+0.59}_{-0.85}$ fb	$16.8^{+0.9}_{-1.5}$ pb	$5.81^{+0.51}_{-0.62}$ pb
STRIPPER 1508.02684	$9.45^{+0.58}_{-0.82}$ fb	-	-
STRIPPER 1511.02886	-	$16.7^{+1.0}_{--}$ pb	-
N-jettiness 1505.03893	-	-	$5.5^{+0.3}_{-0.4}$ pb

- In-depth comparison with 1508.02684 also for differential distributions
- Unable to confirm the N-jettiness results
- More comparison using Les Houches setup on the way

Cross check of $pp \to H + jet$ @ NNLO

- Preliminary comparison using Les Houches 2015 setup [1605.04692]
  - Same choices of scale, PDFs, jet algorithm and etc.
  - Tension in both fiducial and differential cross sections
    $\sigma^{NNLOJET}_{H+\geq 1jet,\mathrm{NNLO}} = 17.4^{+0.28}_{-1.22}(\mathrm{pb})$, $\sigma^{N-jettiness}_{H+\geq 1jet,\mathrm{NNLO}} = 16.4^{+0.0}_{-0.9}(\mathrm{pb})$





Summary

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  - NNLO corrections is important for H+J
    - Increase total cross sections and reduce scale uncertainties
    - Change the normalisation and the shape in differential distributions
    - Provide p_T^H distributions at NNLO accuracy
  - To improve from YR4
    - Finite quark mass effects are important for p_T^H, NLO corrections needed
    - Cross check between different groups are needed
    - Different decay channels not yet well studied
  - Future work
    - More process and more functions in NNLOJET
    - Require resummation for certain observables
    - Closer collaboration with experimental analysis for LHC Run 2.

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THANK YOU!

BACK UP

Recap of NNLOJET in YR4

- y_H distributions: