Event generation for large Higgs transverse momentum

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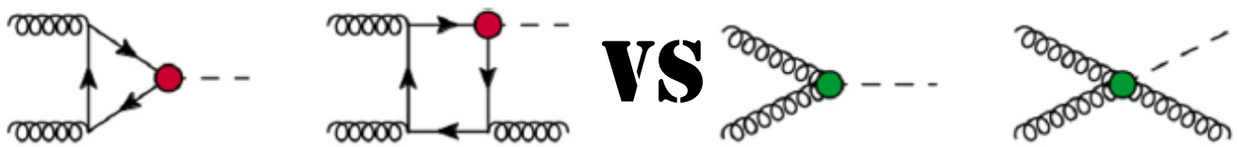
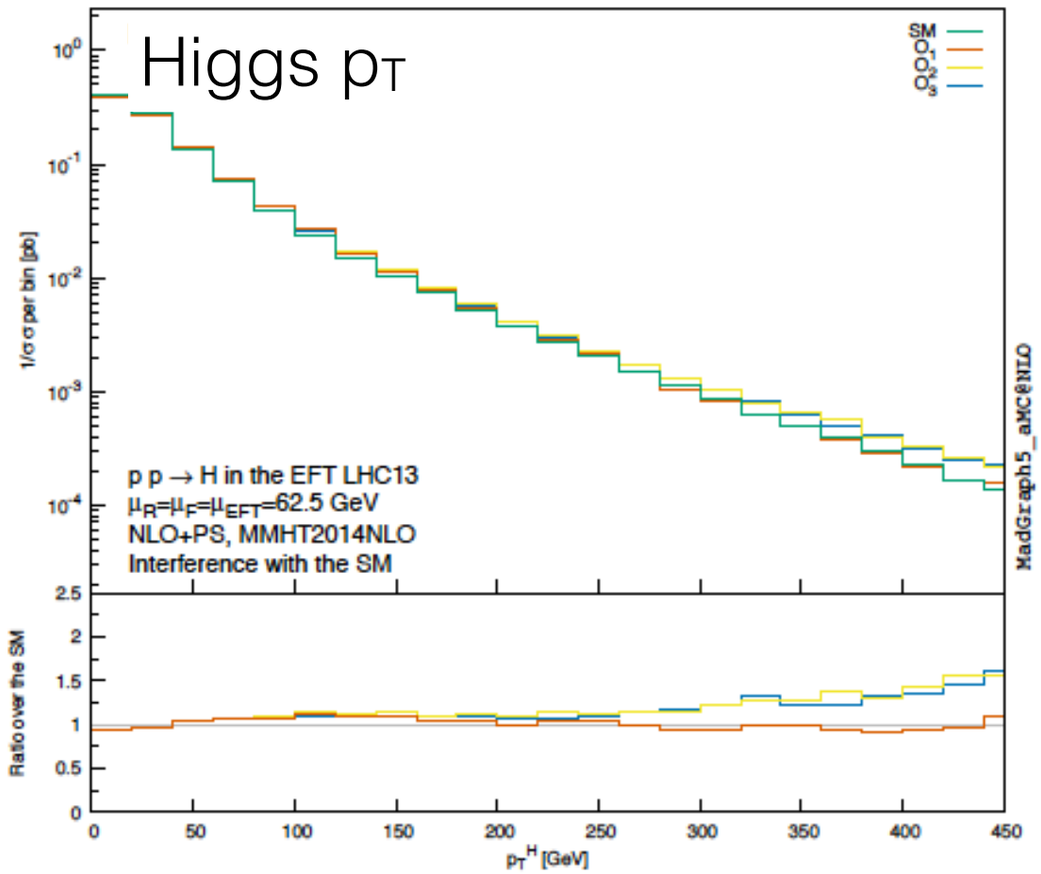
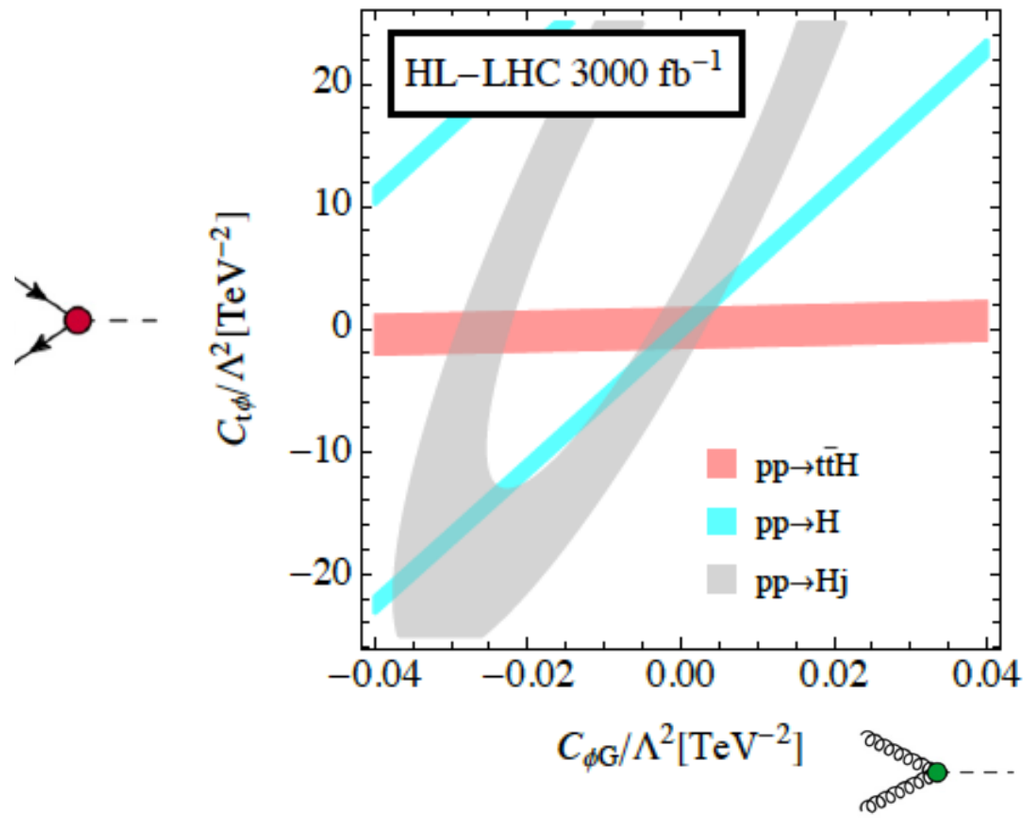
Why Higgs pT?

Probe of new interactions







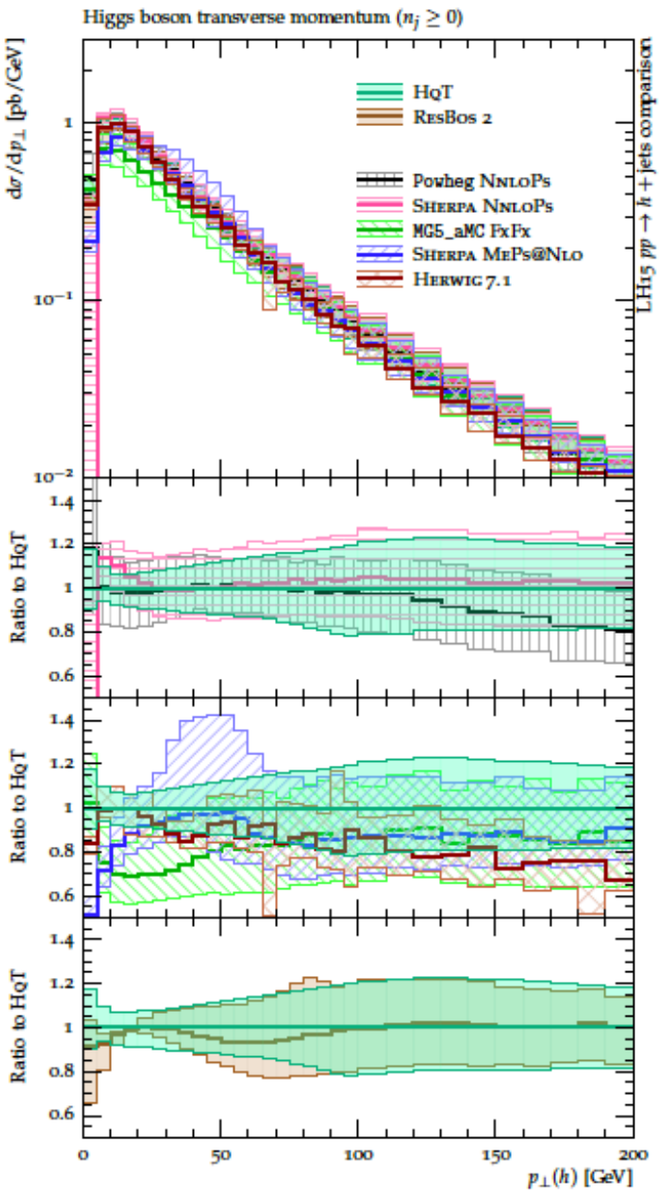
Deutschmann, Duhr, Maltoni, EV arXiv:1708.00460

See also Grazzini et al 1612.00283

14TeV projection
3000 fb^{-1}

Higgs pT early studies

Comparison of tools and calculations



Les Houches 2015 study
arXiv:1605.04692

Comparison of:

* Fixed order
* NLO+PS
* Resummation

Infinite top mass limit results
Reaching 200 GeV, differences
up to 20% but within scale uncertainties

More data coming in:

1) Need to study differences in more detail

2) Need to look at higher pTs

How to improve predictions?

Monte Carlo generators

Improvements needed for high pT region:

- Higher multiplicity samples provide better description of hard emissions which are poorly described by the parton shower
- Top mass effects important in the high pT tails

Readily available:

H+1,2… jets merging available at NLO in the infinite top mass limit: e.g. MG5_aMC and Sherpa

E.g. in MG5_aMC:

- Merging possible at NLO in MG5_aMC@NLO with FxFx (arxiv:1209.6215)
- Possibility to compute 1-loop amplitudes for H+1,2,3 jets with MadLoop

Merging at NLO and mass improvements

arXiv: 1604.03017

The idea: Use as much information as available

* Merged H+jets NLO samples with FxFx
* The exact 0j NLO result: top and bottom mass effects included exactly at one-loop and two-loop (as already implemented in aMCSusHi arXiv:1504.06625)
* Higher multiplicities at NLO in the infinite top mass limit improved by:
  * Including the exact top mass dependence in the real corrections of the higher multiplicities
  * Born-normalised HEFT virtual corrections for all higher multiplicities

How will this help? Expect better description of the tails

Impact of mass effects and merging

Setup

Computation involves reweighting of HEFT events (see 1607.00763) to include loop corrections → manageable computation time

Bias in event generation can help for high pT region generation

Inclusive level results:

	$\mathrm{FxFx_M/FxFx_{EFT}}$	$\mathrm{inc_M/inc_{EFT}}$	$\mathrm{FxFx_{MT}/FxFx_{EFT}}$	$\mathrm{inc_{MT}/inc_{EFT}}$
Total	0.994	0.994	1.056	1.060
$N_{jet} = 0$	0.970	0.974	1.067	1.067
$N_{jet} = 1$	1.034	1.037	1.045	1.050
$N_{jet} \geq 2$	1.032	1.037	1.032	1.037
$\mathrm{VBF_1}$	0.988	1.022	0.988	1.022
$\mathrm{VBF_2}$	0.968	1.038	0.968	1.038

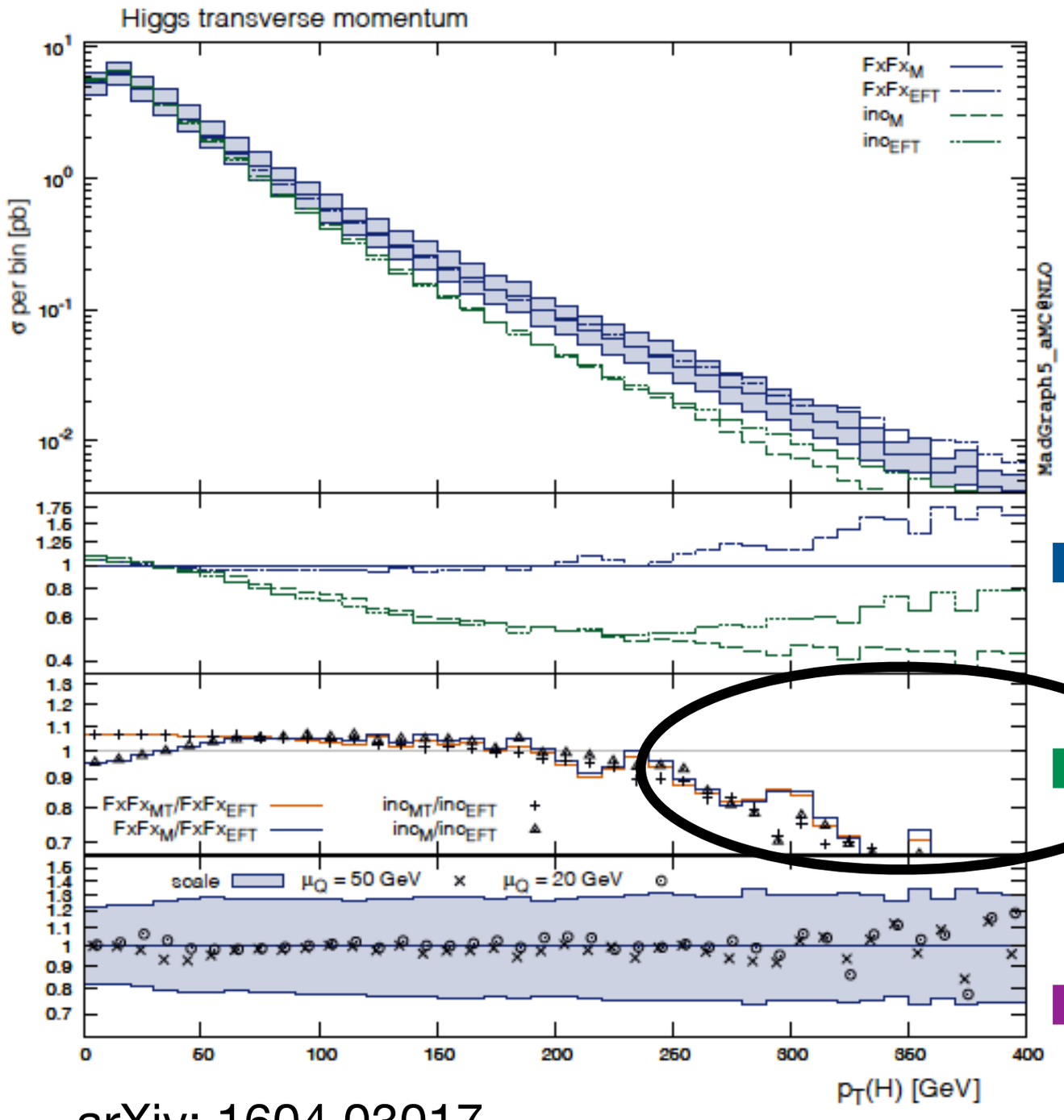
At most 3% effect compared to HEFT

Frederix, Frixione, EV, Wiesemann arXiv: 1604.03017

Very small effect of top and bottom mass corrections for inclusive quantities even in the more exclusive cases

Impact of mass effects and merging

Differential level



arXiv: 1604.03017

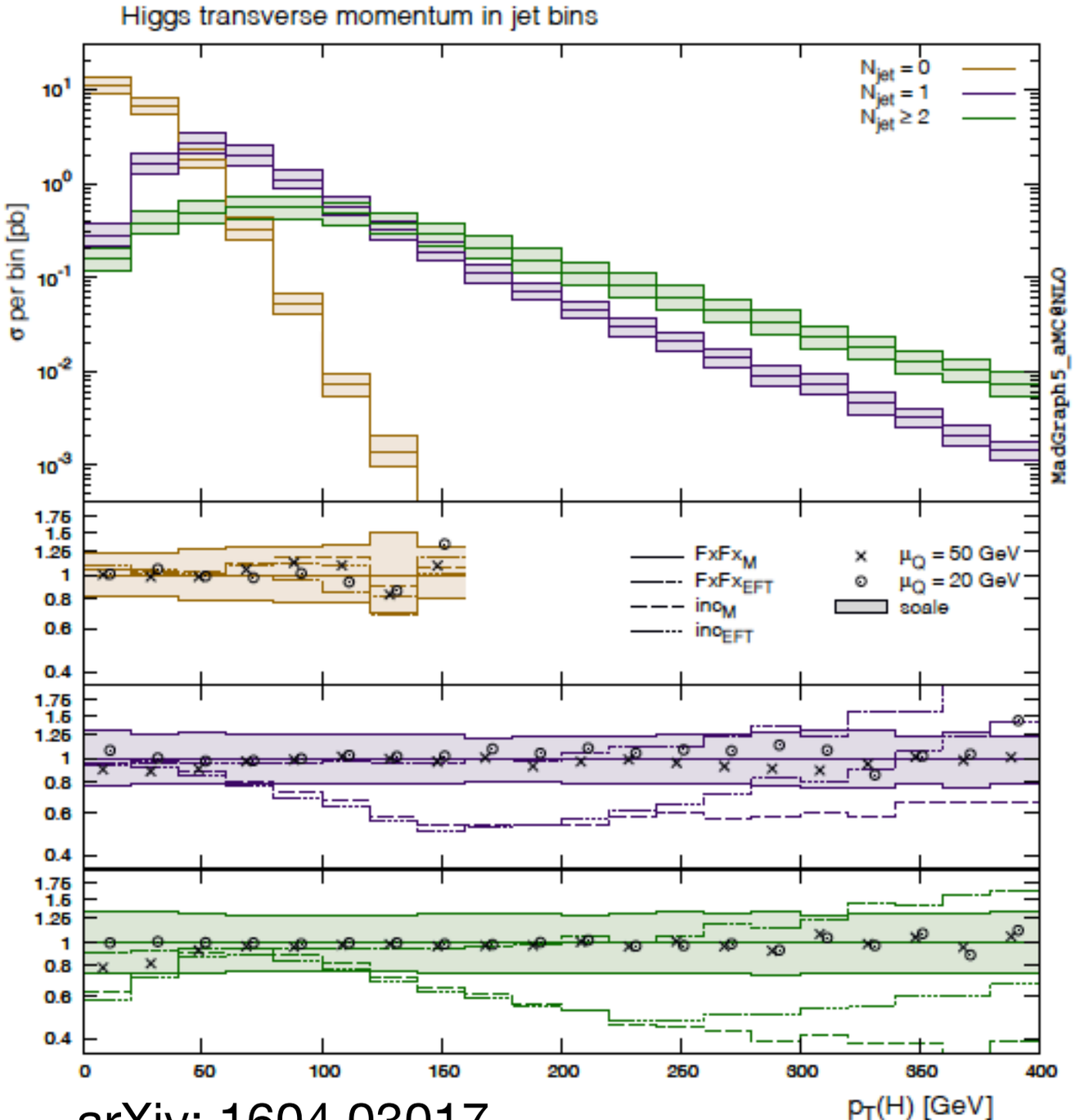
Merging impacts the distribution already at 100 GeV

Top mass corrections essential above 250 GeV

Small dependence on merging scale, well within scale uncertainty

Impact of mass corrections and merging

Jet binned cross-sections



Anti-kT jets:

$$p_T(j) > 30 \text{ GeV}\,, \qquad |\eta(j)| < 4.4$$

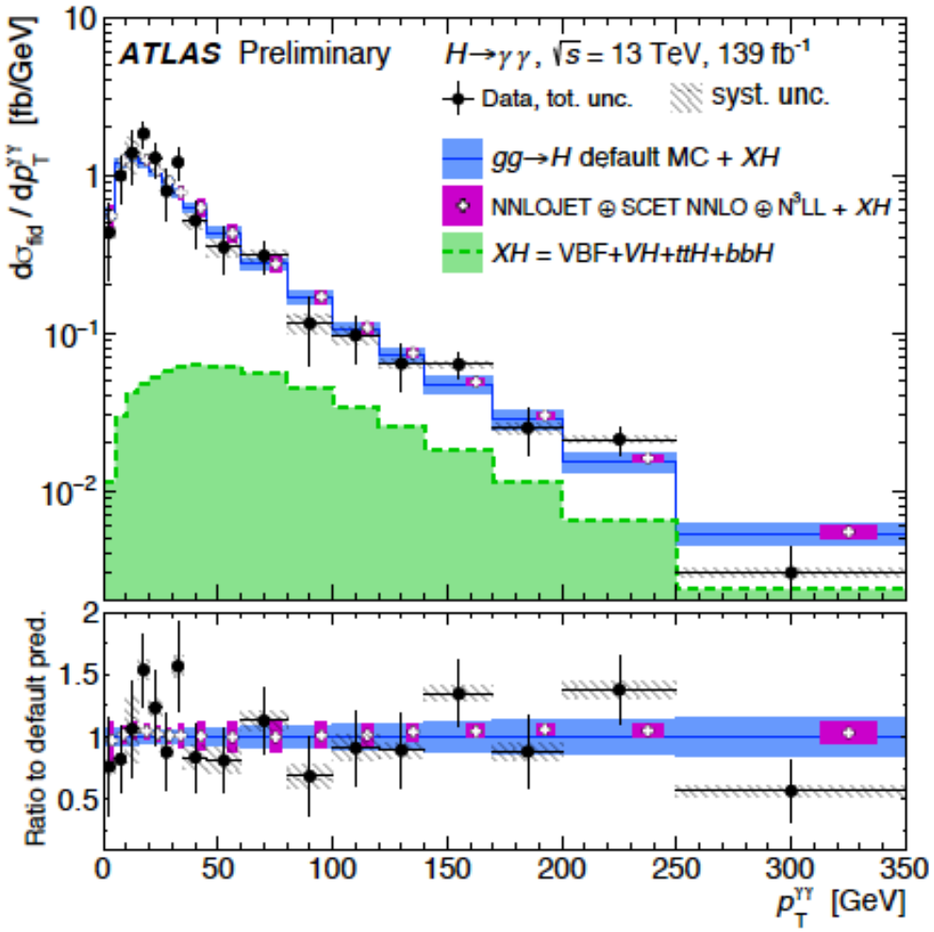
Small effects for 0-jet

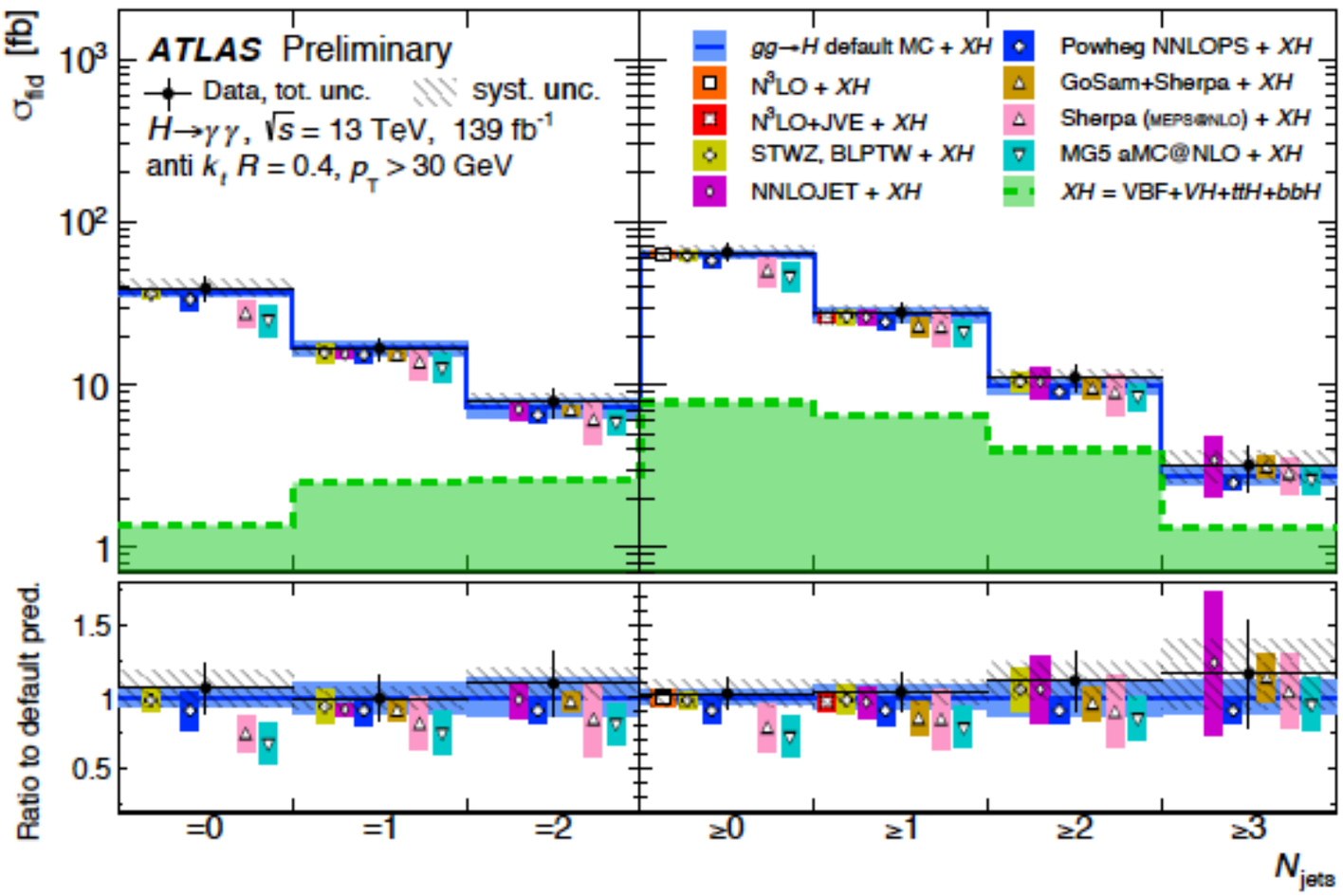
Bigger effects for higher jet multiplicities

arXiv: 1604.03017

Experimental status

e.g. ATLAS-CONF-2019-029





Higgs pT extending to 400 GeV & Jet binned cross-sections

Higgs pT calculations comparison

LHCHSWG arXiv: 2005.07762

Systematic comparison of Fixed Order and PS computations focussing on high pT region (motivated by exp needs):

Monte Carlo codes:

* POWHEG ggh Alioli et al. arXiv:0812.0578
  * NLO accurate for inclusive gluon fusion and LO in the pT spectrum.
* POWHEG HJ Campbell et al. arXiv:1202.5475:
  * NLO accurate in the Higgs pT spectrum. Calculation in the heavy-top EFT.
* HJ-MiNLO Hamilton et al. arXiv:1212.4504,1309.0017:
  * NLO for inclusive gluon fusion and NLO in the pT spectrum. Calculation in the heavy-top EFT, but finite mt effects included via a rescaling by the LO spectrum in the full SM.
* MG5_aMC based on the calculation of the previous slides arXiv: 1604.03017

MC comparison

Mass effects

Fixed order level	Total	$p_\perp^{\rm cut} > 400$ GeV	$p_\perp^{\rm cut} > 450$ GeV	$p_\perp^{\rm cut} > 500$ GeV
$\mathtt{ggh}^{\rm hfact=104}_{\rm m_t=\infty}$	$30.3^{+6.1}_{-4.7}$	$0.0829^{+0.0451}_{-0.0266}$	$0.0577^{+0.0325}_{-0.019}$	$0.0408^{+0.0236}_{-0.0137}$
HJ $m_t = \infty$, 5 GeV gen. cut	–	$0.0651^{+0.0156}_{-0.0131}$	$0.0417^{+0.01}_{-0.0084}$	$0.0279^{+0.0067}_{-0.0057}$
HJ $m_t = \infty$, 50 GeV gen. cut	–	$0.0651^{+0.0156}_{-0.0131}$	$0.0418^{+0.01}_{-0.0085}$	$0.0278^{+0.0066}_{-0.0056}$
HJ-MiNLO $m_t = \infty$	$32.1^{+11}_{-4.9}$	$0.0803^{+0.9087}_{-0.0164}$	$0.0524^{+0.0118}_{-0.0107}$	$0.0353^{+0.0078}_{-0.0072}$
HJ-MiNLO $m_t = 171.3$ GeV	$33.8^{+11.4}_{-5.2}$	$0.029^{+0.007}_{-0.006}$	$0.0161^{+0.0036}_{-0.0033}$	$0.0091^{+0.0021}_{-0.0018}$

Mass effects: more than a factor of 3

FO vs PS

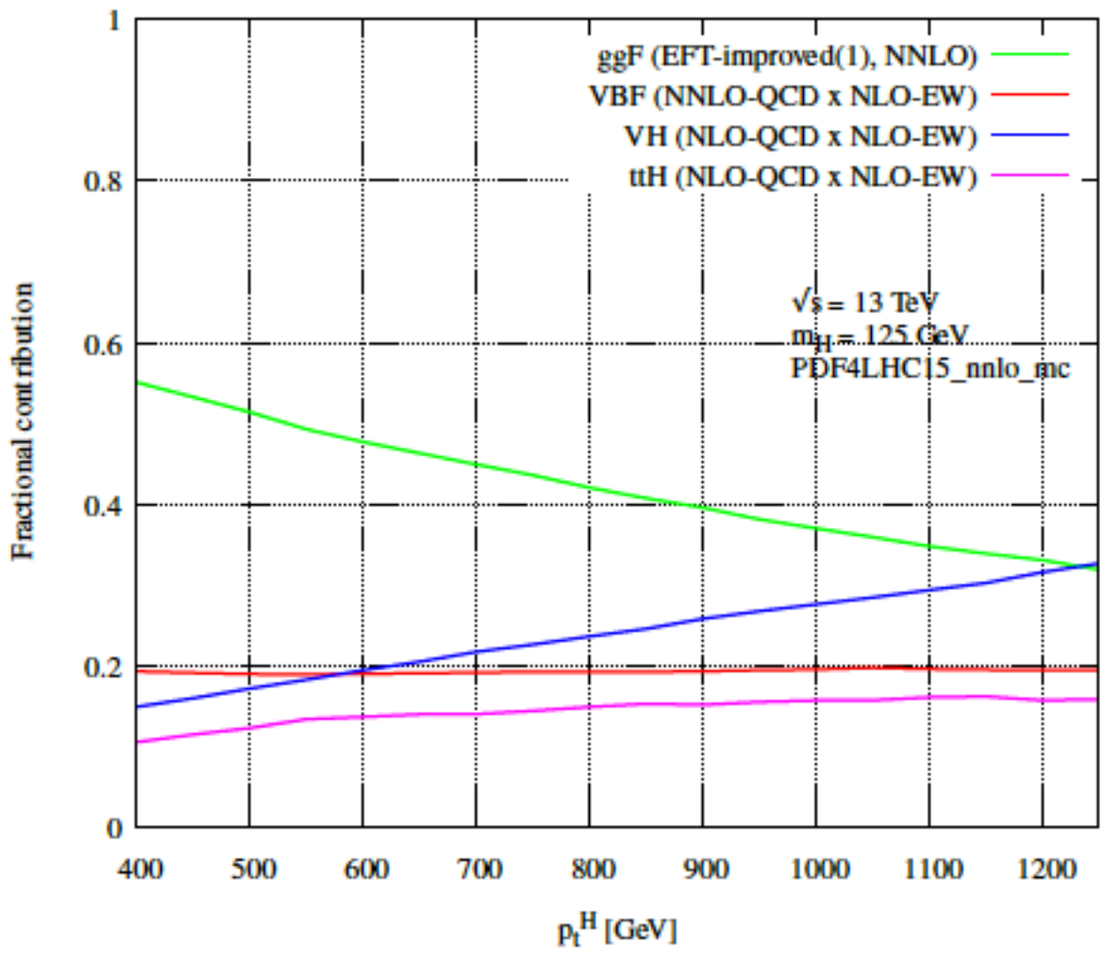
$p_\perp^{\rm cut}$	$\mathrm{NNLO}^{\rm approximate}_{\rm quad.unc.}$ [fb]	HJ-MINLO [fb]	MG5_MC@NLO [fb]
400 GeV	$33.3^{+10.9\%}_{-12.9\%}$	$29^{+24\%}_{-21\%}$	$31.5^{+31\%}_{-25\%}$
430 GeV	$23.0^{+10.8\%}_{-12.8\%}$	-	$21.8^{+31\%}_{-25\%}$
450 GeV	$18.1^{+10.8\%}_{-12.8\%}$	$16.1^{+22\%}_{-21\%}$	$17.1^{+31\%}_{-25\%}$

Good agreement between Fixed order and PS

arXiv: 2005.07762

Other Higgs production channels

Impact at high pT



arXiv: 2005.07762

Other channels become important at high pT

EW corrections are crucial in this region: known for all channels

$p_\perp^{\text{cut}}$[GeV]	VBF	VH	$t\bar{t}H$
400	−17.80%	−19.05%	−6.95%
450	−19.43%	−20.83%	−7.75%
500	−21.05%	−22.50%	−8.49%
550	−22.34%	−24.07%	−9.11%
600	−23.73%	−25.56%	−9.91%
650	−25.03%	−26.98%	−10.67%
700	−26.29%	−28.30%	−11.37%
750	−27.35%	−29.60%	−11.94%
800	−28.42%	−30.83%	−12.51%

Sherpa+OpenLoops

Conclusions

* Higgs pT measurements are crucial to search for new interactions
* Precision is needed for the SM to probe small deviations
* Monte Carlo event generation crucial for experimental analyses and comparison to data
* Improvements towards including higher jet multiplicities with merging and mass effects through the available loops, gives good agreement with higher-order fixed-order calculations.