Stefano Frixione

Status of MadGraph5_aMC@NLO

ATLAS NLO MC meeting
CERN, 17/12/2014

Developers of the core code

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Rikkert Frederix
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Marco Zaro

I am speaking on their behalf

Other very important contributors

MadSpin(spin corr) Pierre Artoisenet, Robbert Rietkerk

HW++, PY8, and NLO merging Andreas Papaefstathiou,
Stefan Prestel

aMCfast(fast NLO for PDFs) Valerio Bertone, Juan Rojo

w/SusHi($gg \to H$ 2HDM/MSSM) Marius Wiesemann

EW corrections Davide Pagani, Stefano Carrazza

Others(EFT, BSM, loop-induced, ...) Benjamin Fuks, Eleni Vryonidou,
Andrew Papanastasiou, Kentarou Mawatari, Cen Zhang

A significant help from the CMS MC conveners, and from
Josh Bendavid in particular

Please bear in mind that *both* MadGraph5 *and* aMC@NLO have been superseded by:

MadGraph5_aMC@NLO

Regardless of whether one is interested in LO or NLO simulations, one must use the latter code, not the former ones

It is a *single code*: switch from LO to NLO through input parameters.
Main reference (and many physics applications): 1405.0301

The basic philosophy, common to LO and NLO:

Given a Lagrangian, transform it in a set of rules (eg with `FeynRules`): this is what is called a (UFO) `model`. MadGraph5_aMC@NLO imports the model, and carries out computations according to its rules

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- ♦ Such NLO-specific information *used* to be computed by hand. This is fine with the SM, but untenable beyond that.
  New in 2014: now automated (`NLOCT`: Degrande, 1406.3030)
  (more on this later)

In practice:

```
> ./bin/mg5_aMC

MG5_aMC> generate p p > t t~ h [QCD]

MG5_aMC> output MY_TTH_DIR

MG5_aMC> launch
```

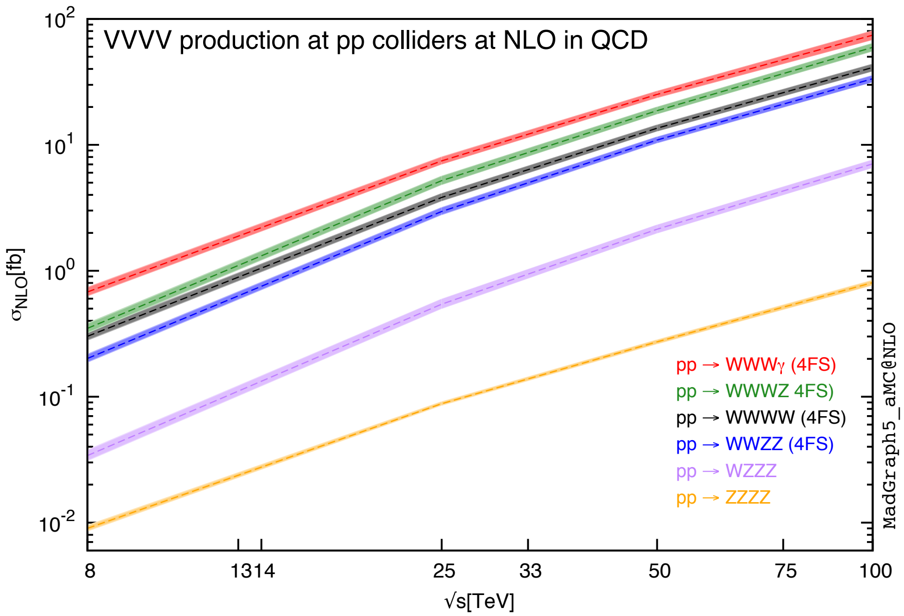
An NLO model is imported automatically, which corresponds to QCD corrections to SM processes, as in this example relevant to $t\bar{t}H$ production

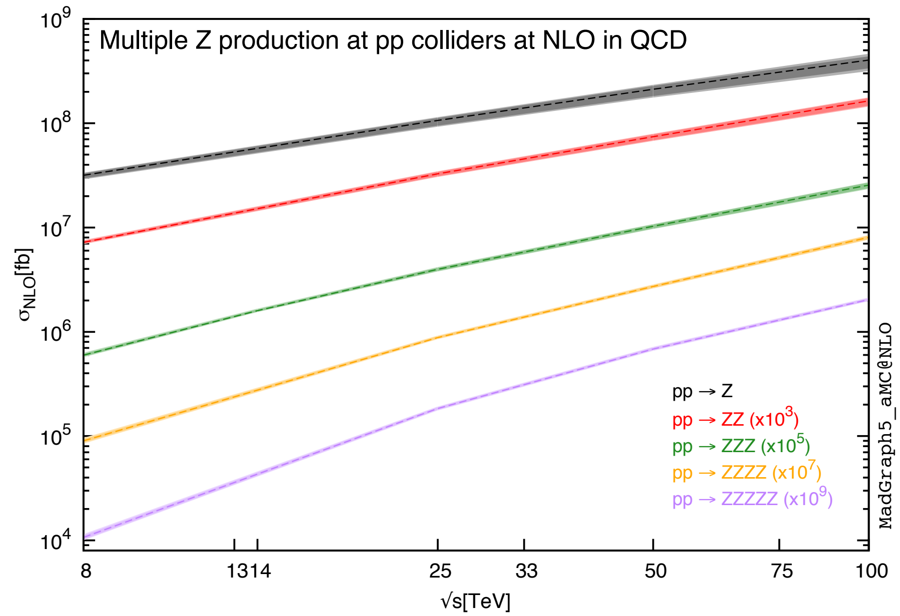
Alternatively $\longrightarrow$

For EW corrections:

```
> ./bin/mg5_aMC
MG5_aMC> import model loop_qcd_qed_SM
MG5_aMC> generate p p > t t~ h [QED]
MG5_aMC> output MY_TTH_DIR_QED
MG5_aMC> launch
```

One may push the code rather far. For example:





SM at NLO: thickness of lines is scale+PDF uncertainties

arXiv:1407.1623 [hep-ph]

(Paolo Torrielli)

Given the aim and scope of this workshop, I shall discuss only (some of) NLO-related features, mostly biased towards Higgs production.
Bear in mind that LO capabilities have been significantly extended and improved wrt those of MadGraph5

Crucial characteristics, some of which achieved in 2014

- NLO matching to Pythia8, Herwig$++$, Pythia6(Q^2), Herwig6, and Pythia6(p_T, ISR only)

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An aside on scale and PDF uncertainties

MadGraph5_aMC@NLO associates with each event $N^2_{\rm scales} + N_{\rm PDF}$ weights that allow one to compute the corresponding theoretical uncertainties at no extra CPU cost

These weights are stored in hard-event files in a way compliant with the Les Houches Accord 3

Software in experiments and/or MCs may or may not be compliant with LHA3, but given the universality of the format it is not difficult to devise an ad-hoc solution (as done by CMS)

These weights carry very significant information: the inability to exploit them fully is an immense waste of resources

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- NLO matching to Pythia8, Herwig++, Pythia6(Q^2), Herwig6, and Pythia6(p_T, ISR only)
- Scale and PDF uncertainties without recomputation
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- Loop-induced processes

NLO merging

Terminology

- An NLO *matching* procedure is MC@NLO or POWHEG
- An LO *merging* procedure is CKKW or MLM

Hence, with NLO merging I mean the extension of techniques such as CKKW or MLM to simulations whose individual results are accurate to NLO. There may thus exist different NLO mergings for the same matching strategy, and not only for different types of matching

NLO mergings in MadGraph5_aMC@NLO

Now fully automated for HW++ and PY8 (new in 2014)

- FxFx (Frederix, SF) 1209.6215
- UNLOPS (Lönnblad, Prestel) 1211.7278

Require companion routines in MCs: included in Pythia v8.2 or higher, and as user's library in HW++ (templates public in $\sim$ Jan 2015)

In practice:

```
MG5_aMC> generate p p > e+ ve [QCD] @ 0
MG5_aMC> add process p p > e+ ve j [QCD] @ 1
MG5_aMC> add process p p > e+ ve j j [QCD] @ 2
```

with:

```
3 = ickkw !  0 no merging, 3 FxFx merging, 4 UNLOPS
```

in the input card `run_card.dat`

- The commands above result in a *single file* of unweighted events. A-posteriori recombination of files is not necessary

Validation: $W/Z+$jets

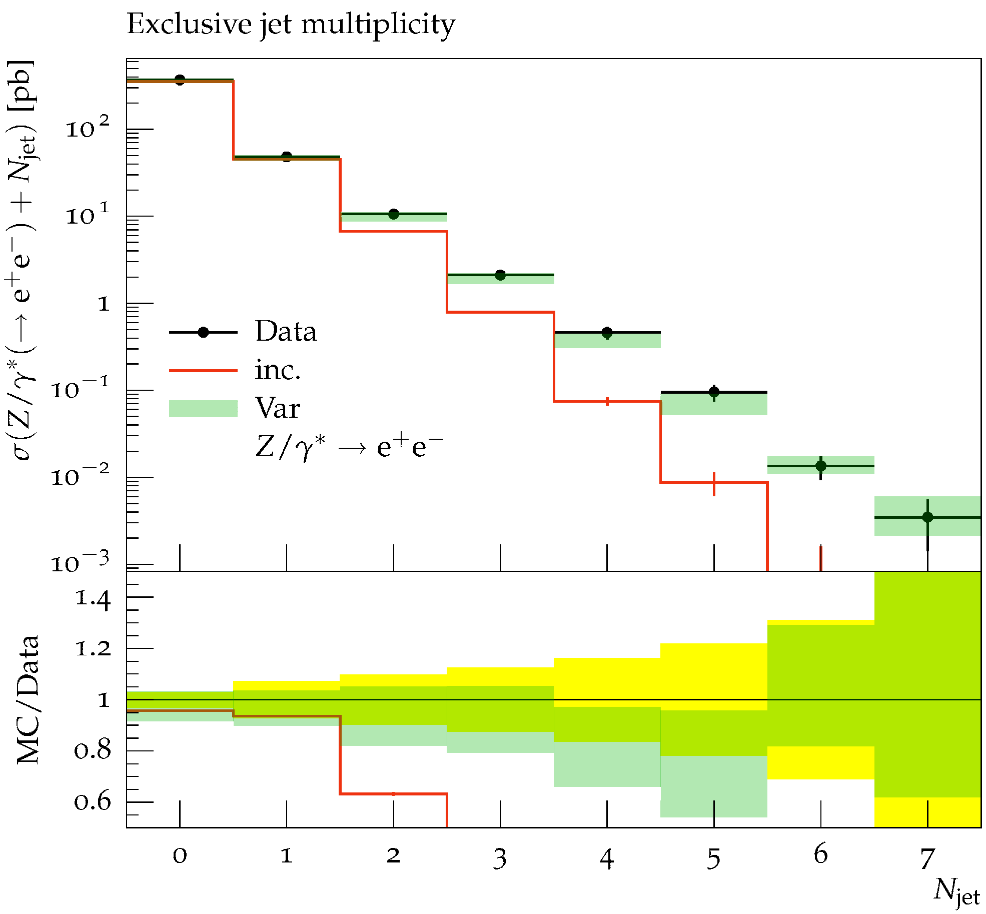
(preliminary)

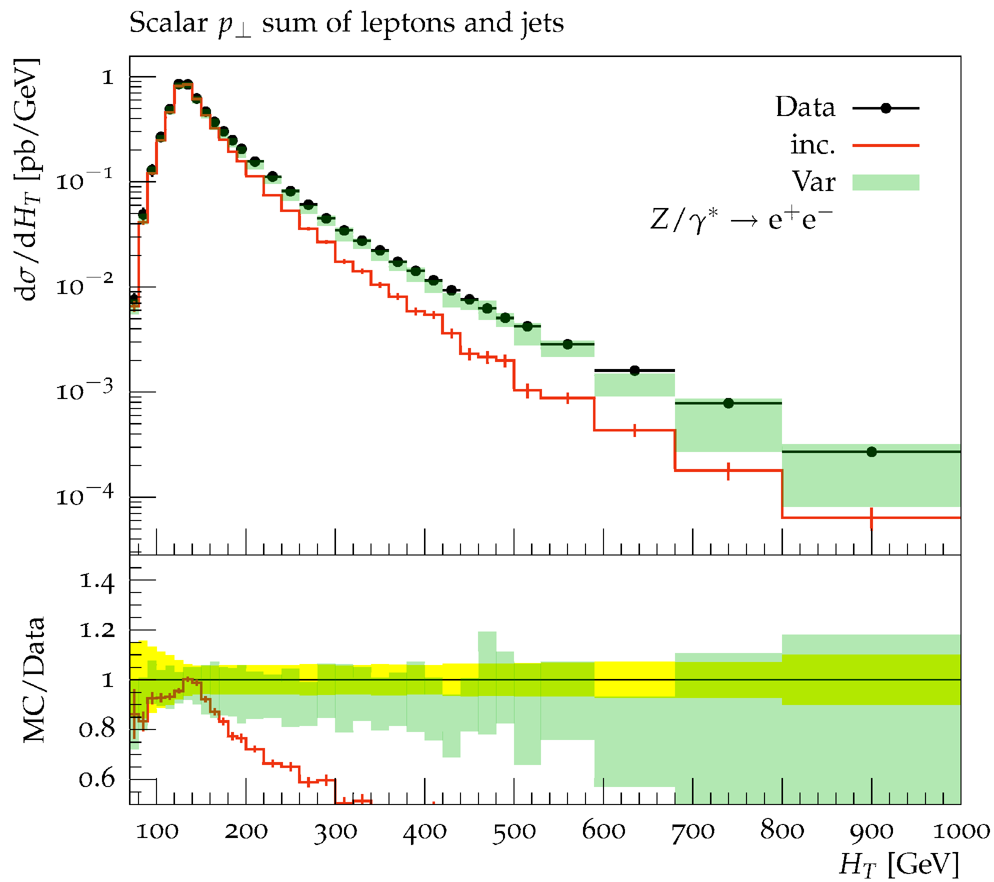
- Comparisons to ATLAS and CMS data associated with a public Rivet analysis
- The following plots: FxFx with HW++ (tune UE-EE-3-CTEQ6L1)
- 0-, 1-, and 2-parton samples, all NLO
- Native normalisation: no rescaling to NNLO
- Green band: envelope of the scale and (NNPDF) PDF uncertainties relevant to three merging scales: 15, 25, 45 GeV
- Red histogram: unmerged sample (ie $W/Z + 0j$@NLO)

These plots courtesy of A. Papaefstathiou and P. Torrielli, in the context of

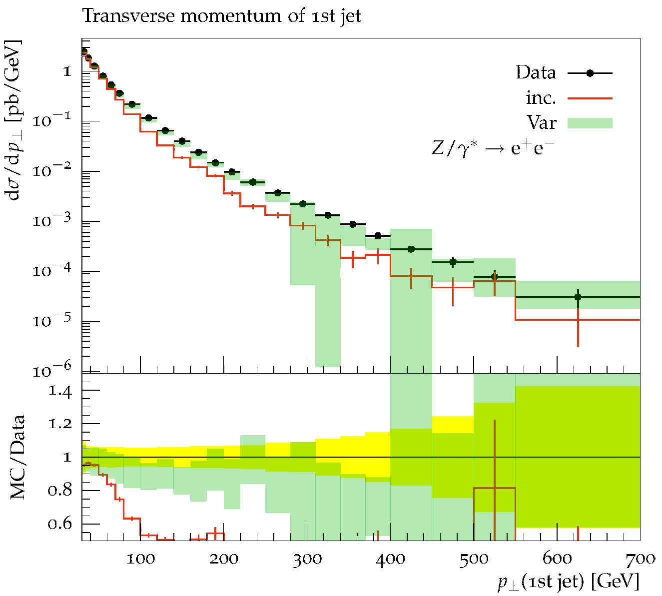
Frederix, Papaefstathiou, Prestel, Torrielli, SF, in preparation

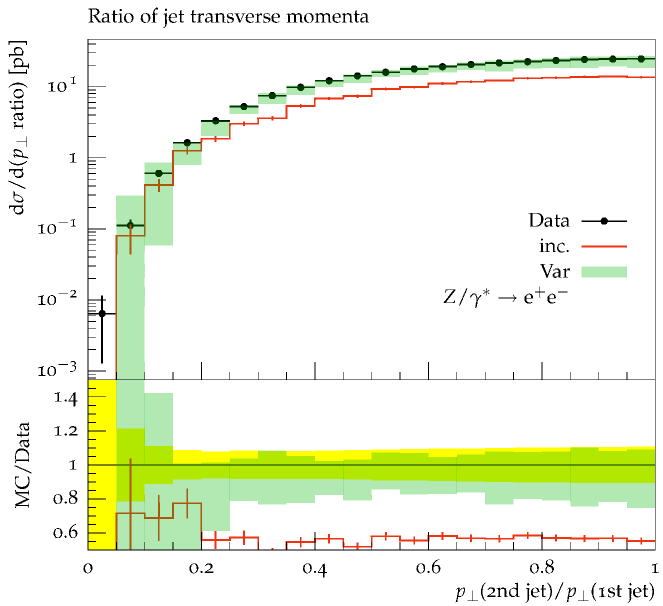
1304.7098 [ATLAS, Z+jets]

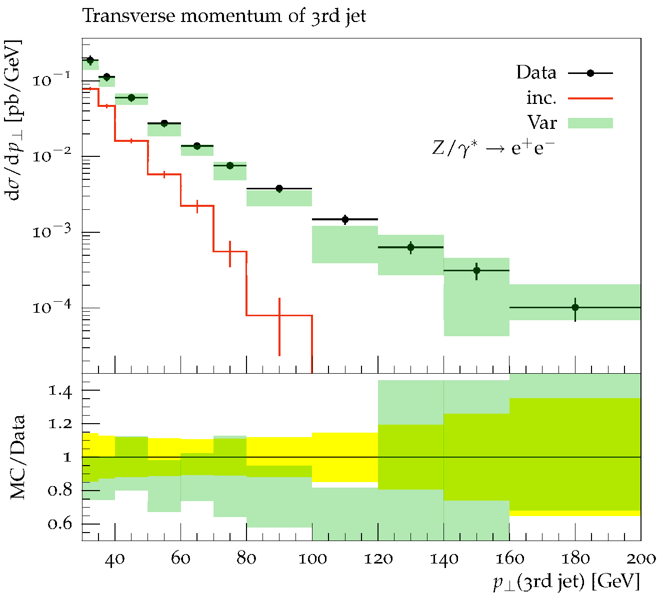




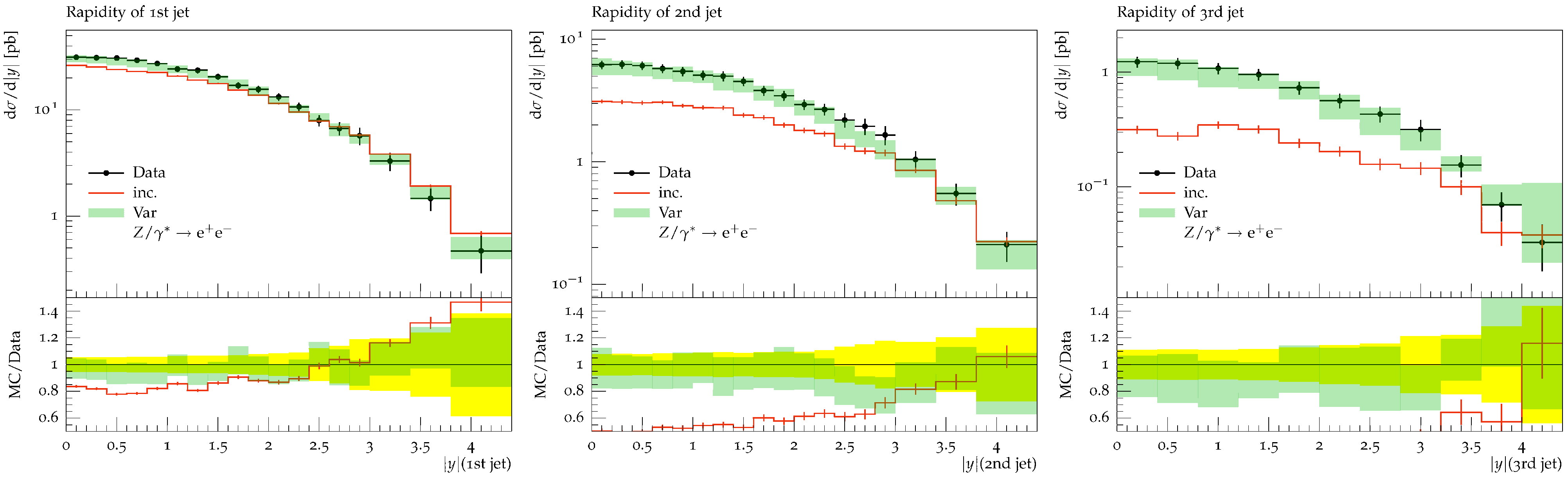
1304.7098 [ATLAS, Z+jets]



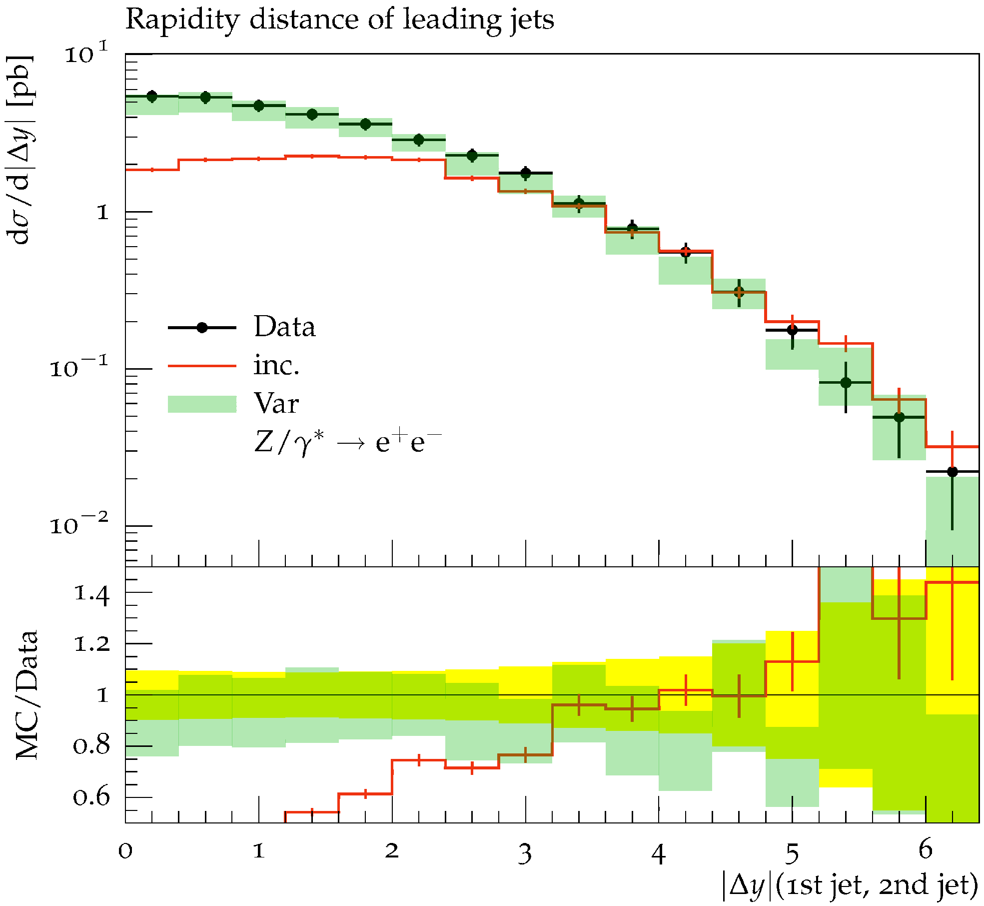


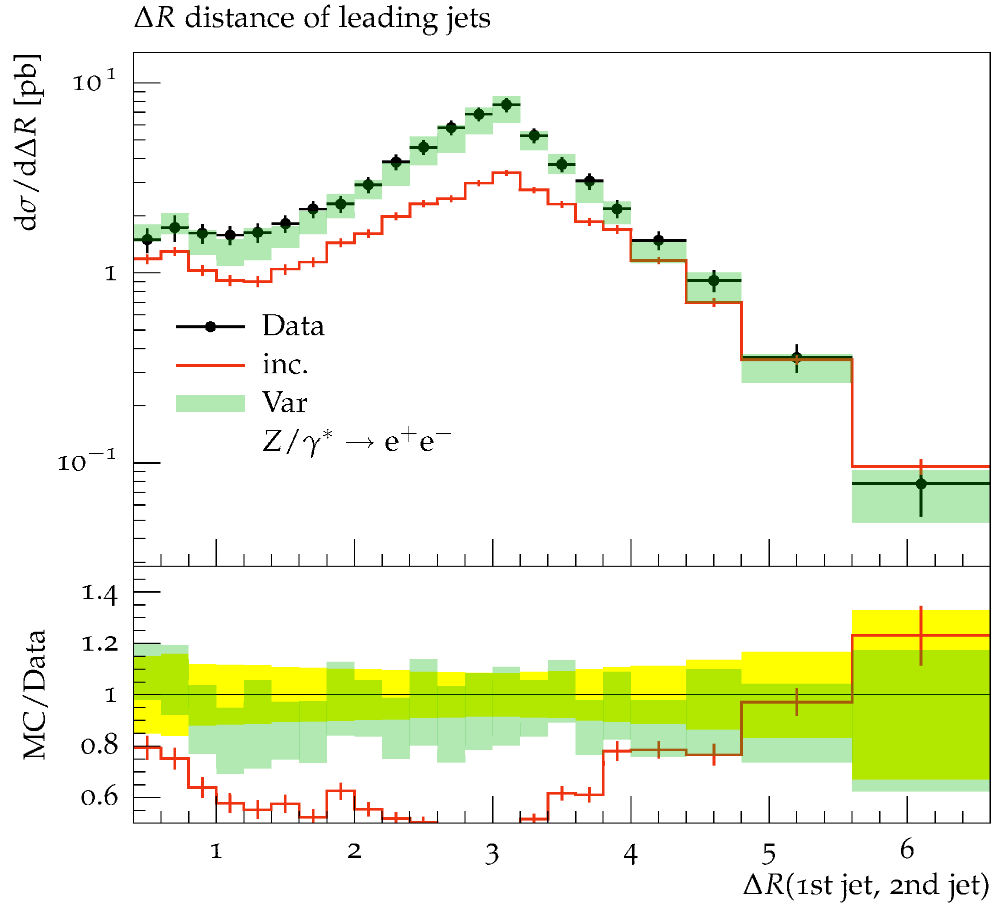


1304.7098 [ATLAS, Z+jets]

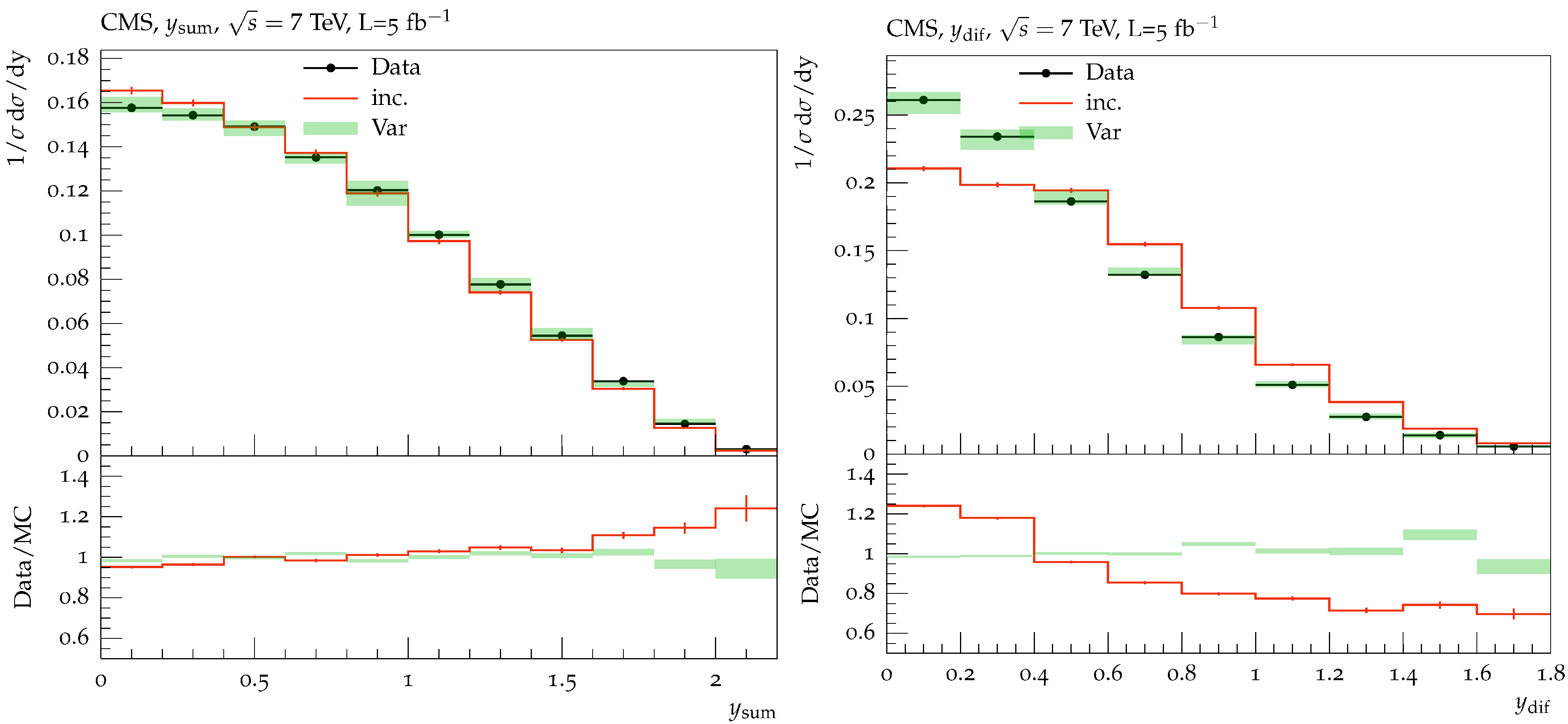


1304.7098 [ATLAS, Z+jets]

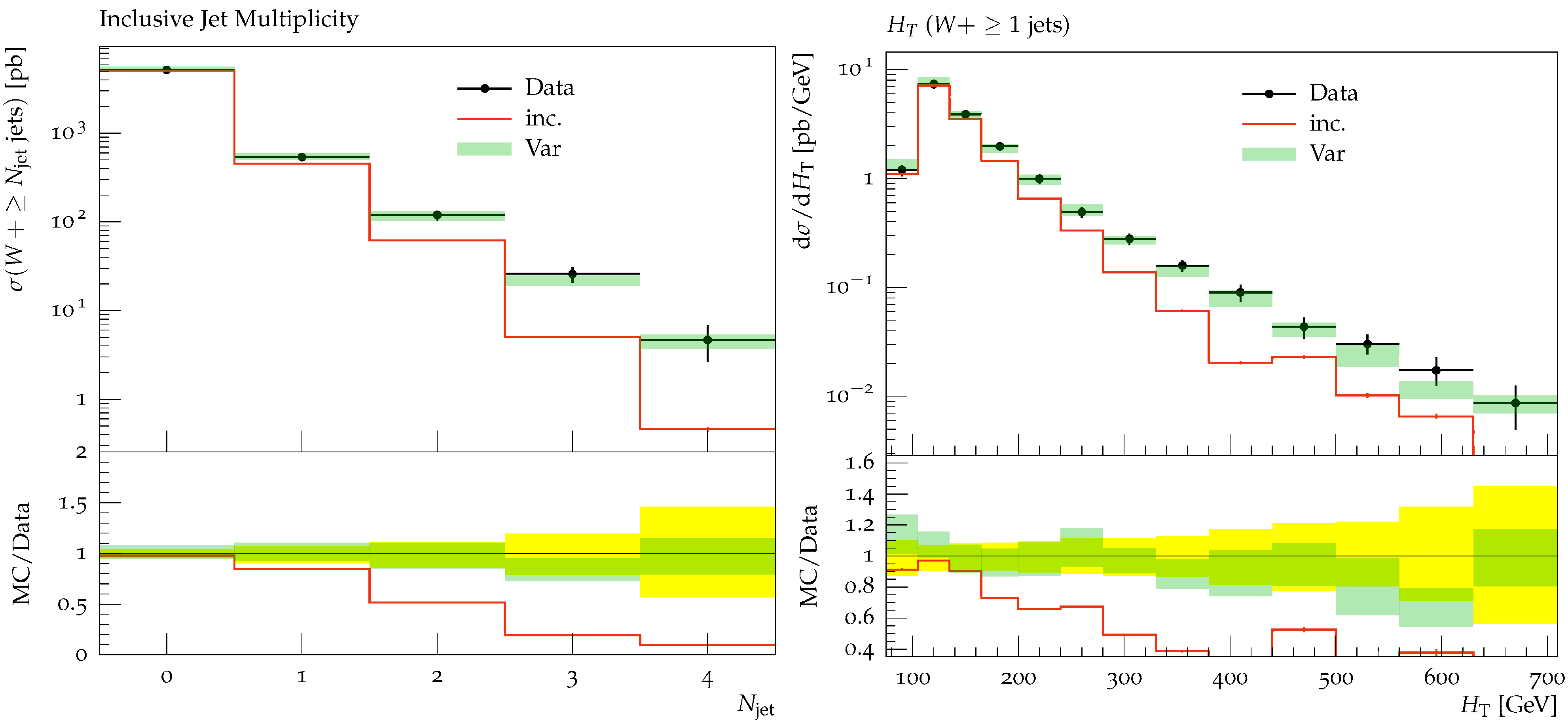




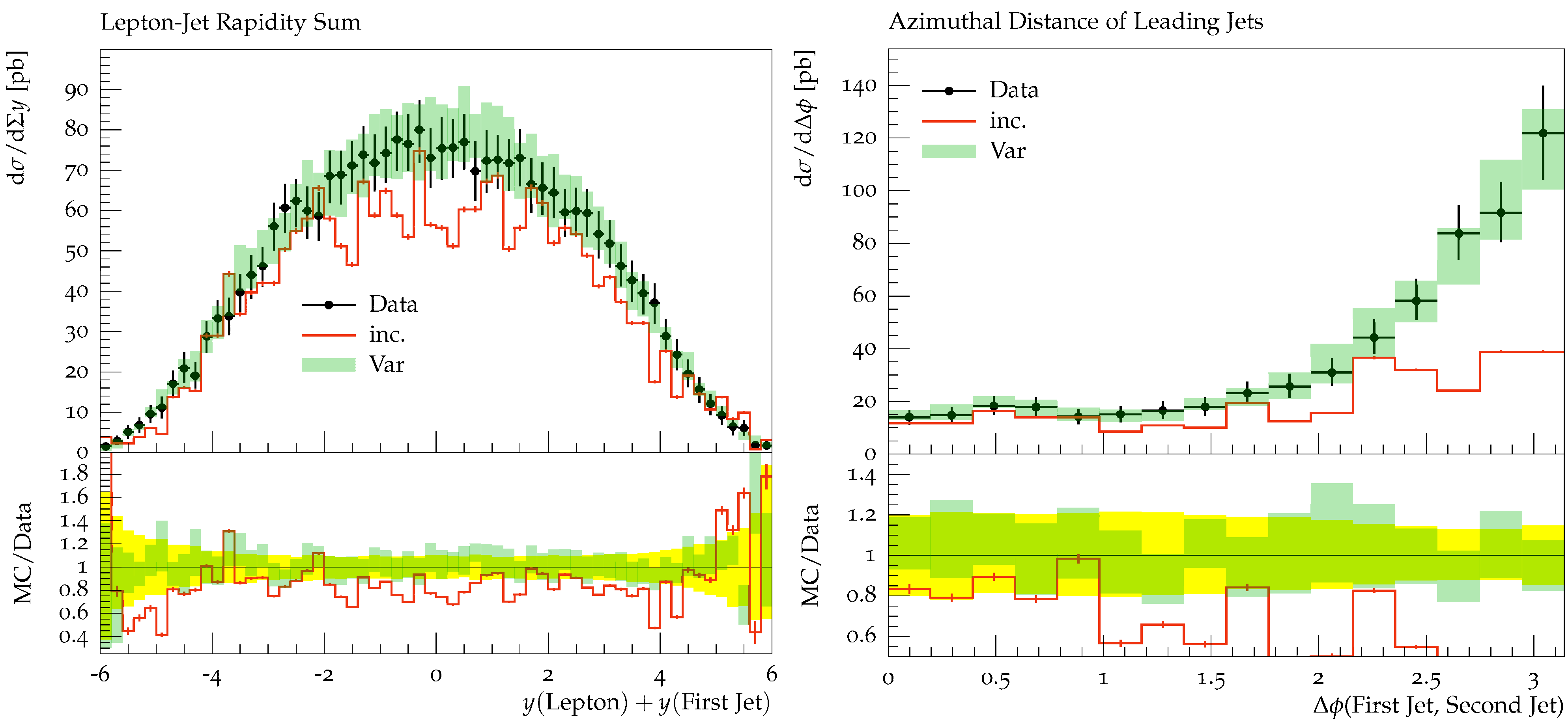
1310.3082 [CMS, Z+jets]



1201.1276 [ATLAS, W+jets]



1201.1276 [ATLAS, W+jets]



Short summary of $W/Z+$ jets validation

- The agreement data/theory is quite good, especially in view of the fact that the largest multiplicity generated is $V+2$ partons
- Slight increase of rate in the case of $Z+$jets (FxFx has no unitary contraint); improves description of data
- Data slightly harder than theory, especially in $Z+$jets: impact of 3-parton samples and different hard scales to be investigated
- Immense improvement wrt unmerged 0jets simulations (which are not particularly sensible for these observables, but...)
- Must check what happens with Pythia8 (both FxFx and UNLOPS)

One technical issue: scale/PDF uncertainties in Rivet

Aside: Rivet and theory uncertainties

We could not find a way to tell Rivet to treat simultaneously the $N^2_{\rm scales} + N_{\rm PDF}$ weights relevant to scale and PDF uncertainties

The solution (Prestel, Papaefstathiou) we have adopted creates $N^2_{\rm scales} + N_{\rm PDF}$ parallel instances of Rivet

It works technically, but it is a waste of time: each instance runs the analysis, while it would only be necessary to fill multiple histograms

Upgrade of Rivet highly desirable

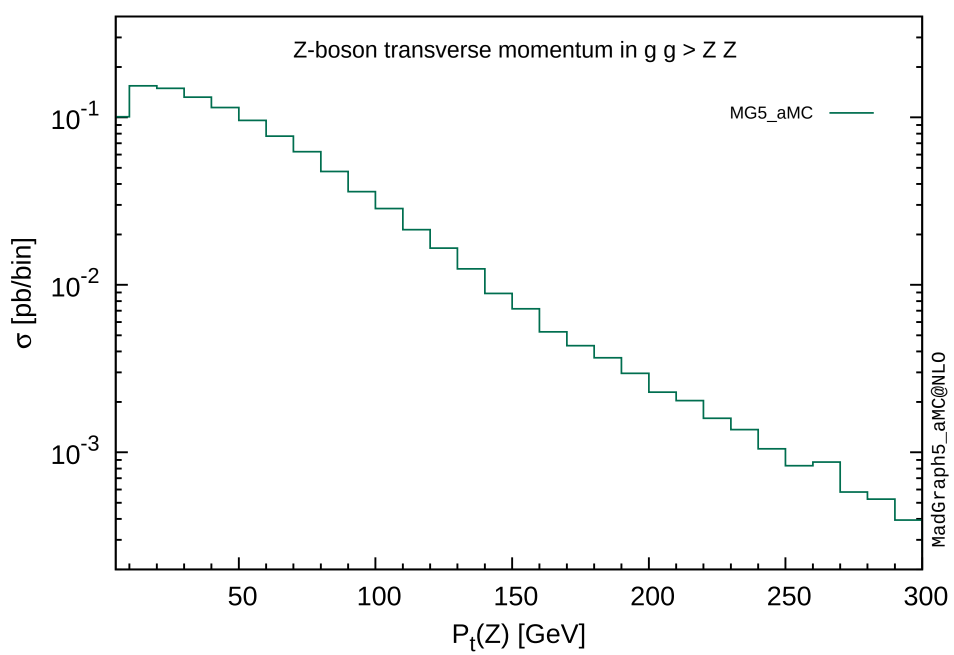
Loop-induced processes in MadGraph5_aMC@NLO

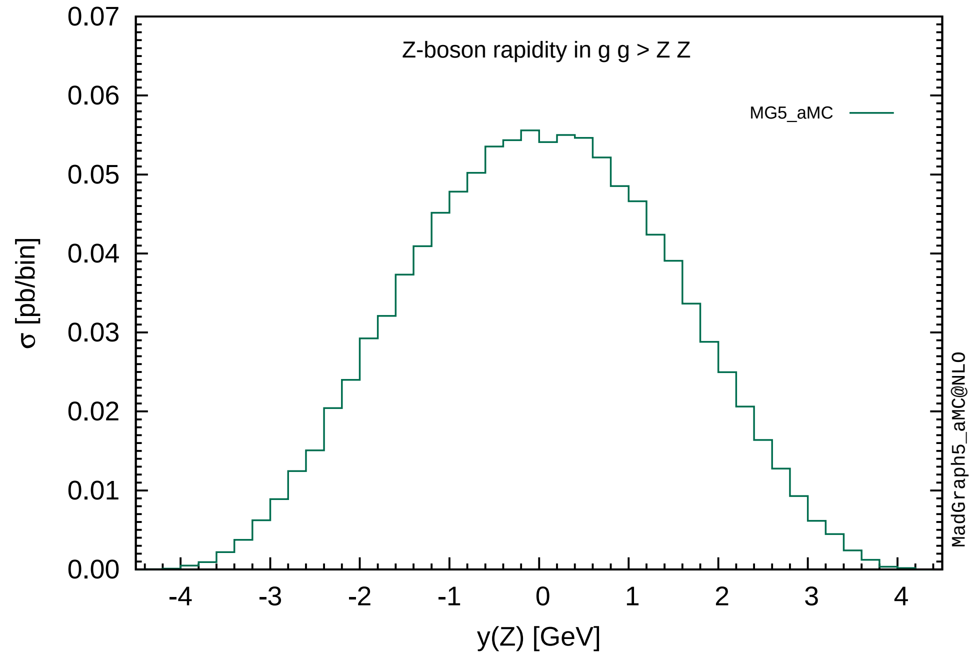
By loop-induced I mean a process whose LO contribution is given by the square of a (IR finite) one-loop amplitude

Now fully automated (new in 2014; Hirschi and Mattelaer); to be released in the near future

Examples $\longrightarrow$

Diboson production (LHC13)

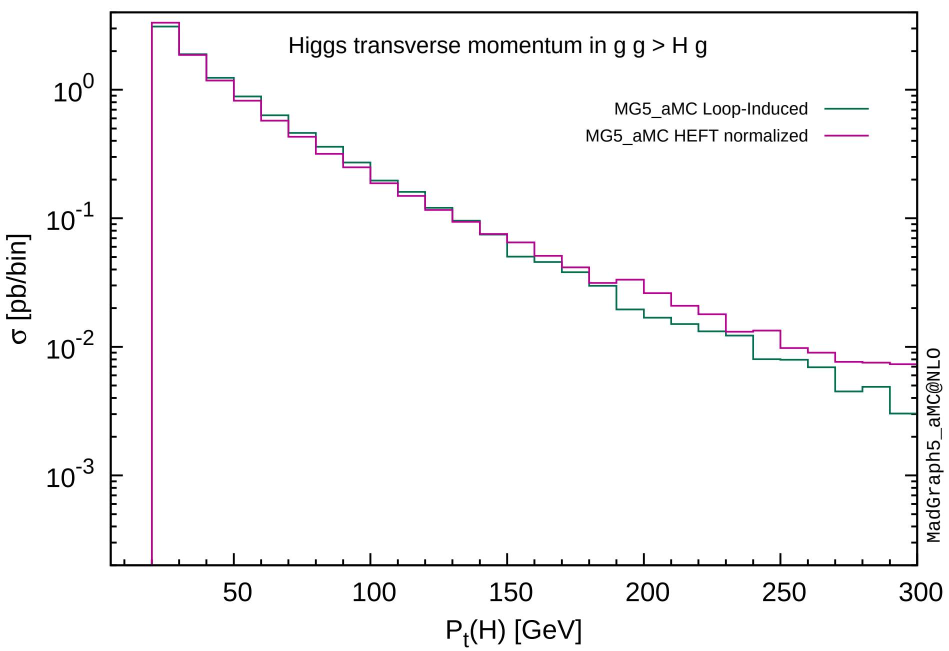


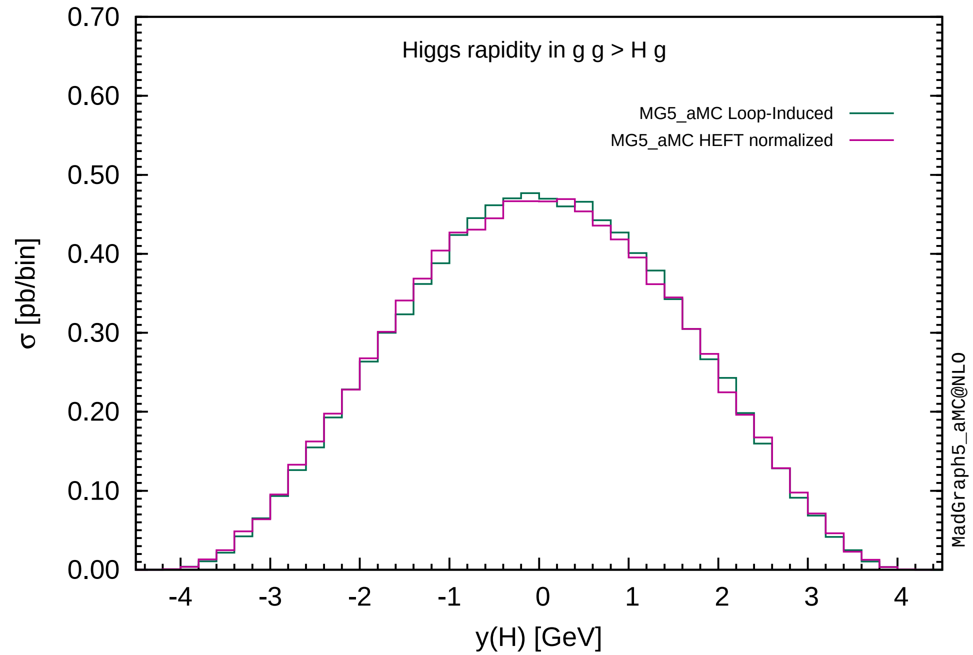



```
MG5_aMC> generate g g > z z [QCD]
```

Do not be misled by the syntax: plots do include the convolution with parton luminosity

Higgs+jet production (LHC13)






```
MG5_aMC> generate g g > h g [QCD]
```

$$\sigma_{\rm LI} = 9.784 \pm 0.008 \; pb \,, \qquad \sigma_{\rm ETF} = 10.6 \pm 0.004 \; pb$$

Higgs physics

The capabilities of the code are illustrated by the results for single- and di-Higgs total rates reported in 1405.0301:

Process		Syntax	Cross section (pb)			
Single Higgs production			LO 13 TeV		NLO 13 TeV	
g.1	$pp \to H$ (HEFT)	`p p > h`	$1.593 \pm 0.003 \cdot 10^{1}$	$^{+34.8\%}_{-26.0\%}\ ^{+1.2\%}_{-1.7\%}$	$3.261 \pm 0.010 \cdot 10^{1}$	$^{+20.2\%}_{-17.9\%}\ ^{+1.1\%}_{-1.6\%}$
g.2	$pp \to Hj$ (HEFT)	`p p > h j`	$8.367 \pm 0.003 \cdot 10^{0}$	$^{+39.4\%}_{-26.4\%}\ ^{+1.2\%}_{-1.4\%}$	$1.422 \pm 0.006 \cdot 10^{1}$	$^{+18.5\%}_{-16.6\%}\ ^{+1.1\%}_{-1.4\%}$
g.3	$pp \to Hjj$ (HEFT)	`p p > h j j`	$3.020 \pm 0.002 \cdot 10^{0}$	$^{+59.1\%}_{-34.7\%}\ ^{+1.4\%}_{-1.7\%}$	$5.124 \pm 0.020 \cdot 10^{0}$	$^{+20.7\%}_{-21.0\%}\ ^{+1.3\%}_{-1.5\%}$
g.4	$pp \to Hjj$ (VBF)	`p p > h j j $$ w+ w- z`	$1.987 \pm 0.002 \cdot 10^{0}$	$^{+1.7\%}_{-2.0\%}\ ^{+1.9\%}_{-1.4\%}$	$1.900 \pm 0.006 \cdot 10^{0}$	$^{+0.8\%}_{-0.9\%}\ ^{+2.0\%}_{-1.5\%}$
g.5	$pp \to Hjjj$ (VBF)	`p p > h j j j $$ w+ w- z`	$2.824 \pm 0.005 \cdot 10^{-1}$	$^{+15.7\%}_{-12.7\%}\ ^{+1.5\%}_{-1.0\%}$	$3.085 \pm 0.010 \cdot 10^{-1}$	$^{+2.0\%}_{-3.0\%}\ ^{+1.5\%}_{-1.1\%}$
g.6	$pp \to HW^{\pm}$	`p p > h wpm`	$1.195 \pm 0.002 \cdot 10^{0}$	$^{+3.5\%}_{-4.5\%}\ ^{+1.9\%}_{-1.5\%}$	$1.419 \pm 0.005 \cdot 10^{0}$	$^{+2.1\%}_{-2.6\%}\ ^{+1.9\%}_{-1.4\%}$
g.7	$pp \to HW^{\pm}j$	`p p > h wpm j`	$4.018 \pm 0.003 \cdot 10^{-1}$	$^{+10.7\%}_{-9.3\%}\ ^{+1.2\%}_{-0.9\%}$	$4.842 \pm 0.017 \cdot 10^{-1}$	$^{+3.6\%}_{-3.7\%}\ ^{+1.2\%}_{-1.0\%}$
g.8*	$pp \to HW^{\pm}jj$	`p p > h wpm j j`	$1.198 \pm 0.016 \cdot 10^{-1}$	$^{+26.1\%}_{-19.4\%}\ ^{+0.8\%}_{-0.6\%}$	$1.574 \pm 0.014 \cdot 10^{-1}$	$^{+5.0\%}_{-6.5\%}\ ^{+0.9\%}_{-0.6\%}$
g.9	$pp \to HZ$	`p p > h z`	$6.468 \pm 0.008 \cdot 10^{-1}$	$^{+3.5\%}_{-4.5\%}\ ^{+1.9\%}_{-1.4\%}$	$7.674 \pm 0.027 \cdot 10^{-1}$	$^{+2.0\%}_{-2.5\%}\ ^{+1.9\%}_{-1.4\%}$
g.10	$pp \to HZj$	`p p > h z j`	$2.225 \pm 0.001 \cdot 10^{-1}$	$^{+10.6\%}_{-9.2\%}\ ^{+1.1\%}_{-0.8\%}$	$2.667 \pm 0.010 \cdot 10^{-1}$	$^{+3.5\%}_{-3.6\%}\ ^{+1.1\%}_{-0.9\%}$
g.11*	$pp \to HZjj$	`p p > h z j j`	$7.262 \pm 0.012 \cdot 10^{-2}$	$^{+26.2\%}_{-19.4\%}\ ^{+0.7\%}_{-0.6\%}$	$8.753 \pm 0.037 \cdot 10^{-2}$	$^{+4.8\%}_{-6.3\%}\ ^{+0.7\%}_{-0.6\%}$
g.12*	$pp \to HW^{+}W^{-}$ (4f)	`p p > h w+ w-`	$8.325 \pm 0.139 \cdot 10^{-3}$	$^{+0.0\%}_{-0.3\%}\ ^{+2.0\%}_{-1.6\%}$	$1.065 \pm 0.003 \cdot 10^{-2}$	$^{+2.5\%}_{-1.9\%}\ ^{+2.0\%}_{-1.5\%}$
g.13*	$pp \to HW^{\pm}\gamma$	`p p > h wpm a`	$2.518 \pm 0.006 \cdot 10^{-3}$	$^{+0.7\%}_{-1.4\%}\ ^{+1.9\%}_{-1.5\%}$	$3.309 \pm 0.011 \cdot 10^{-3}$	$^{+2.7\%}_{-2.0\%}\ ^{+1.7\%}_{-1.4\%}$
g.14*	$pp \to HZW^{\pm}$	`p p > h z wpm`	$3.763 \pm 0.007 \cdot 10^{-3}$	$^{+1.1\%}_{-1.5\%}\ ^{+2.0\%}_{-1.6\%}$	$5.292 \pm 0.015 \cdot 10^{-3}$	$^{+3.9\%}_{-3.1\%}\ ^{+1.8\%}_{-1.4\%}$
g.15*	$pp \to HZZ$	`p p > h z z`	$2.093 \pm 0.003 \cdot 10^{-3}$	$^{+0.1\%}_{-0.6\%}\ ^{+1.9\%}_{-1.5\%}$	$2.538 \pm 0.007 \cdot 10^{-3}$	$^{+1.9\%}_{-1.4\%}\ ^{+2.0\%}_{-1.5\%}$
g.16	$pp \to Ht\bar{t}$	`p p > h t t~`	$3.579 \pm 0.003 \cdot 10^{-1}$	$^{+30.0\%}_{-21.5\%}\ ^{+1.7\%}_{-2.0\%}$	$4.608 \pm 0.016 \cdot 10^{-1}$	$^{+5.7\%}_{-9.0\%}\ ^{+2.0\%}_{-2.3\%}$
g.17	$pp \to Htj$	`p p > h tt j`	$4.994 \pm 0.005 \cdot 10^{-2}$	$^{+2.4\%}_{-4.2\%}\ ^{+1.2\%}_{-1.3\%}$	$6.328 \pm 0.022 \cdot 10^{-2}$	$^{+2.9\%}_{-1.8\%}\ ^{+1.5\%}_{-1.6\%}$
g.18	$pp \to Hb\bar{b}$ (4f)	`p p > h b b~`	$4.983 \pm 0.002 \cdot 10^{-1}$	$^{+28.1\%}_{-21.0\%}\ ^{+1.5\%}_{-1.8\%}$	$6.085 \pm 0.026 \cdot 10^{-1}$	$^{+7.3\%}_{-9.6\%}\ ^{+1.6\%}_{-2.0\%}$
g.19	$pp \to Ht\bar{t}j$	`p p > h t t~ j`	$2.674 \pm 0.041 \cdot 10^{-1}$	$^{+45.6\%}_{-29.2\%}\ ^{+2.6\%}_{-2.9\%}$	$3.244 \pm 0.025 \cdot 10^{-1}$	$^{+3.5\%}_{-8.7\%}\ ^{+2.5\%}_{-2.9\%}$
g.20*	$pp \to Hb\bar{b}j$ (4f)	`p p > h b b~ j`	$7.367 \pm 0.002 \cdot 10^{-2}$	$^{+45.6\%}_{-29.1\%}\ ^{+1.8\%}_{-2.1\%}$	$9.034 \pm 0.032 \cdot 10^{-2}$	$^{+7.9\%}_{-11.0\%}\ ^{+1.8\%}_{-2.2\%}$

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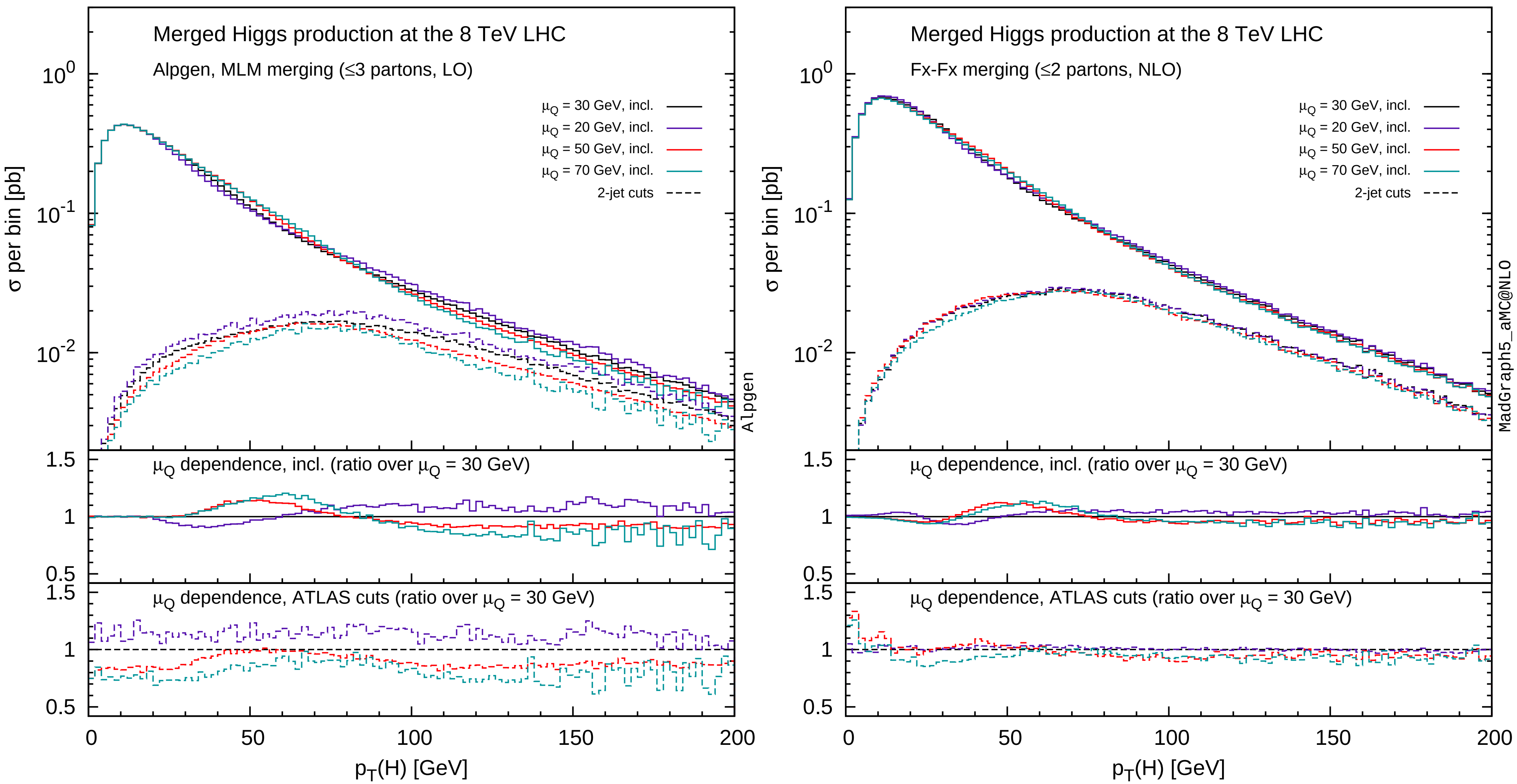
	Process	Syntax	Cross section (pb)			
	Higgs pair production		LO 13 TeV		NLO 13 TeV	
h.1	$pp \to HH$ (Loop improved)	`p p > h h`	$1.772 \pm 0.006 \cdot 10^{-2}$	$^{+29.5\%}_{-21.4\%}$ $^{+2.1\%}_{-2.6\%}$	$2.763 \pm 0.008 \cdot 10^{-2}$	$^{+11.4\%}_{-11.8\%}$ $^{+2.1\%}_{-2.6\%}$
h.2	$pp \to HHjj$ (VBF)	`p p > h h j j $$ w+ w- z`	$6.503 \pm 0.019 \cdot 10^{-4}$	$^{+7.2\%}_{-6.4\%}$ $^{+2.3\%}_{-1.6\%}$	$6.820 \pm 0.026 \cdot 10^{-4}$	$^{+0.8\%}_{-1.0\%}$ $^{+2.4\%}_{-1.7\%}$
h.3	$pp \to HHW^{\pm}$	`p p > h h wpm`	$4.303 \pm 0.005 \cdot 10^{-4}$	$^{+0.9\%}_{-1.3\%}$ $^{+2.0\%}_{-1.5\%}$	$5.002 \pm 0.014 \cdot 10^{-4}$	$^{+1.5\%}_{-1.2\%}$ $^{+2.0\%}_{-1.6\%}$
h.4*	$pp \to HHW^{\pm}j$	`p p > h h wpm j`	$1.922 \pm 0.002 \cdot 10^{-4}$	$^{+14.2\%}_{-11.7\%}$ $^{+1.5\%}_{-1.1\%}$	$2.218 \pm 0.009 \cdot 10^{-4}$	$^{+2.7\%}_{-3.3\%}$ $^{+1.6\%}_{-1.1\%}$
h.5*	$pp \to HHW^{\pm}\gamma$	`p p > h h wpm a`	$1.952 \pm 0.004 \cdot 10^{-6}$	$^{+3.0\%}_{-3.0\%}$ $^{+2.2\%}_{-1.6\%}$	$2.347 \pm 0.007 \cdot 10^{-6}$	$^{+2.4\%}_{-2.0\%}$ $^{+2.1\%}_{-1.6\%}$
h.6	$pp \to HHZ$	`p p > h h z`	$2.701 \pm 0.007 \cdot 10^{-4}$	$^{+0.9\%}_{-1.3\%}$ $^{+2.0\%}_{-1.5\%}$	$3.130 \pm 0.008 \cdot 10^{-4}$	$^{+1.6\%}_{-1.2\%}$ $^{+2.0\%}_{-1.5\%}$
h.7*	$pp \to HHZj$	`p p > h h z j`	$1.211 \pm 0.001 \cdot 10^{-4}$	$^{+14.1\%}_{-11.7\%}$ $^{+1.4\%}_{-1.1\%}$	$1.394 \pm 0.006 \cdot 10^{-4}$	$^{+2.7\%}_{-3.2\%}$ $^{+1.5\%}_{-1.1\%}$
h.8*	$pp \to HHZ\gamma$	`p p > h h z a`	$1.397 \pm 0.003 \cdot 10^{-6}$	$^{+2.4\%}_{-2.5\%}$ $^{+2.2\%}_{-1.7\%}$	$1.604 \pm 0.005 \cdot 10^{-6}$	$^{+1.7\%}_{-1.4\%}$ $^{+2.3\%}_{-1.7\%}$
h.9*	$pp \to HHZZ$	`p p > h h z z`	$2.309 \pm 0.005 \cdot 10^{-6}$	$^{+3.9\%}_{-3.8\%}$ $^{+2.2\%}_{-1.7\%}$	$2.754 \pm 0.009 \cdot 10^{-6}$	$^{+2.3\%}_{-2.0\%}$ $^{+2.3\%}_{-1.7\%}$
h.10*	$pp \to HHZW^{\pm}$	`p p > h h z wpm`	$3.708 \pm 0.013 \cdot 10^{-6}$	$^{+4.8\%}_{-4.5\%}$ $^{+2.3\%}_{-1.7\%}$	$4.904 \pm 0.029 \cdot 10^{-6}$	$^{+3.7\%}_{-3.2\%}$ $^{+2.2\%}_{-1.6\%}$
h.11*	$pp \to HHW^{+}W^{-}$ (4f)	`p p > h h w+ w-`	$7.524 \pm 0.070 \cdot 10^{-6}$	$^{+3.5\%}_{-3.4\%}$ $^{+2.3\%}_{-1.7\%}$	$9.268 \pm 0.030 \cdot 10^{-6}$	$^{+2.3\%}_{-2.1\%}$ $^{+2.3\%}_{-1.7\%}$
h.12	$pp \to HHt\bar{t}$	`p p > h h t t~`	$6.756 \pm 0.007 \cdot 10^{-4}$	$^{+30.2\%}_{-21.6\%}$ $^{+1.8\%}_{-1.8\%}$	$7.301 \pm 0.024 \cdot 10^{-4}$	$^{+1.4\%}_{-5.7\%}$ $^{+2.2\%}_{-2.3\%}$
h.13	$pp \to HHtj$	`p p > h h tt j`	$1.844 \pm 0.008 \cdot 10^{-5}$	$^{+0.0\%}_{-0.6\%}$ $^{+1.8\%}_{-1.8\%}$	$2.444 \pm 0.009 \cdot 10^{-5}$	$^{+4.5\%}_{-3.1\%}$ $^{+2.8\%}_{-3.0\%}$
h.14*	$pp \to HHb\bar{b}$	`p p > h h b b~`	$7.849 \pm 0.022 \cdot 10^{-8}$	$^{+34.3\%}_{-23.9\%}$ $^{+3.1\%}_{-3.7\%}$	$1.084 \pm 0.012 \cdot 10^{-7}$	$^{+7.4\%}_{-10.8\%}$ $^{+3.1\%}_{-3.7\%}$

.

A couple of key messages:

- These total rates are given as *examples*: the primary aim of the code is actually that of predicting differential distributions, with or without matching to parton showers
- Likewise, one can merge different samples at (N)LO+PS accuracy: for example, HV, HVj, $HVjj$

NLO merging for $gg \to H$: from 1405.0301



Left: LO (Alpgen). Right: NLO (FxFx in MadGraph5_aMC@NLO)

A couple of key messages:

- These total rates are given as *examples*: the primary aim of the code is actually that of predicting differential distributions, with or without matching to parton showers
- Likewise, one can merge different samples at (N)LO+PS accuracy: for example, HV, HVj, $HVjj$

There is apparently a common misconception: that if we do not write a paper about process $pp \to xyz$, that process cannot be computed

We simply cannot write a paper on each interesting signal or background process, that's it. If you don't dare to run the code for a "new" process, drop us an email. And do check sect. 4 of 1405.0301

Having said that, we did write a few papers on Higgs production.
Here is the 2013–2014 list (*all results are differential NLO(+PS)*):

1304.7927 $H_{\rm SM}$ in VBF (SF, Torrielli, Zaro)

1306.6464 $gg/q\bar{q}\to X_{J^P}$, $J^P = 0^\pm, 1^\pm, 2^+$ (Higgs Characterisation) (Artoisenet etal)

1311.1829 $X_{0^\pm}$ in VBF and $+Z/W$ (HC) (Maltoni, Mawatari, Zaro)

1401.7340 $H_{\rm SM}H_{\rm SM}$ (six largest channels) (Frederix etal)

1407.0281 $gg \to HH$ in 2HDM (Hespel, Lopez-Val, Vryonidou)

1407.0823 weak corrections to $t\bar{t}H$ (Hirschi, Pagani, Shao, Zaro, SF)

1407.5089 $t\bar{t}X_{0^\pm}$ in (HC) (Demartin, Maltoni, Mawatari, Page, Zaro)

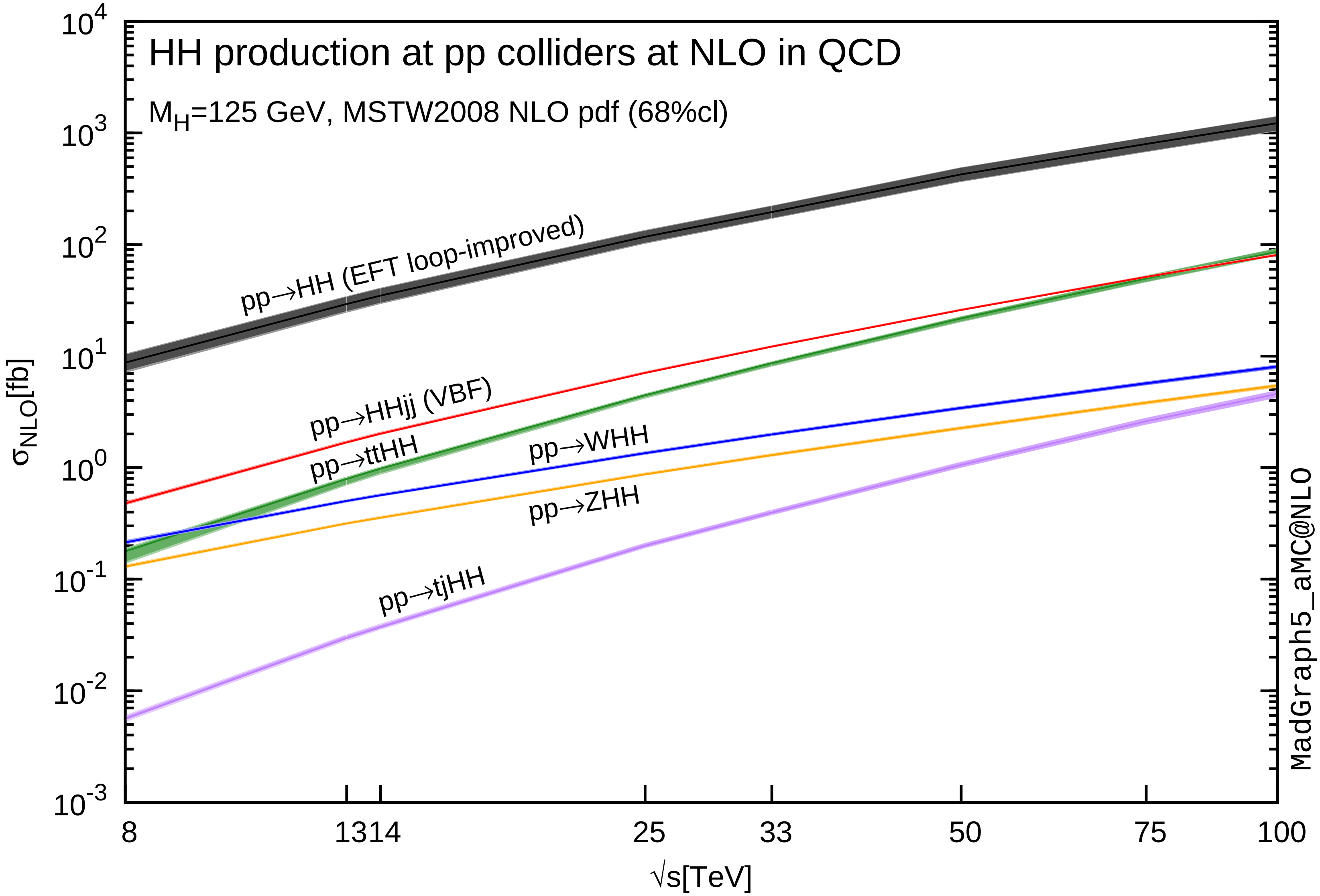
1408.6542 $gg \to H_{\rm SM}H_{\rm SM}/H_{\rm SM}H_{\rm SM}H_{\rm SM}$ (Maltoni, Vryonidou, Zaro)

1409.5301 $b\bar{b}H$ 4FS and 5FS (Wiesemann, Frederix, Hirschi, Maltoni, Torrielli, SF)

There is a lot of involved SM and BSM physics in these papers, which is a testament to the immense scope of automated techniques

Equally important, during the course of their writing a technical watershed has been crossed. The earlier papers relied on NLO models computed by hand; in the later papers this preliminary phase has been taken care of automatically (`NLOCT`: Degrande, 1406.3030)

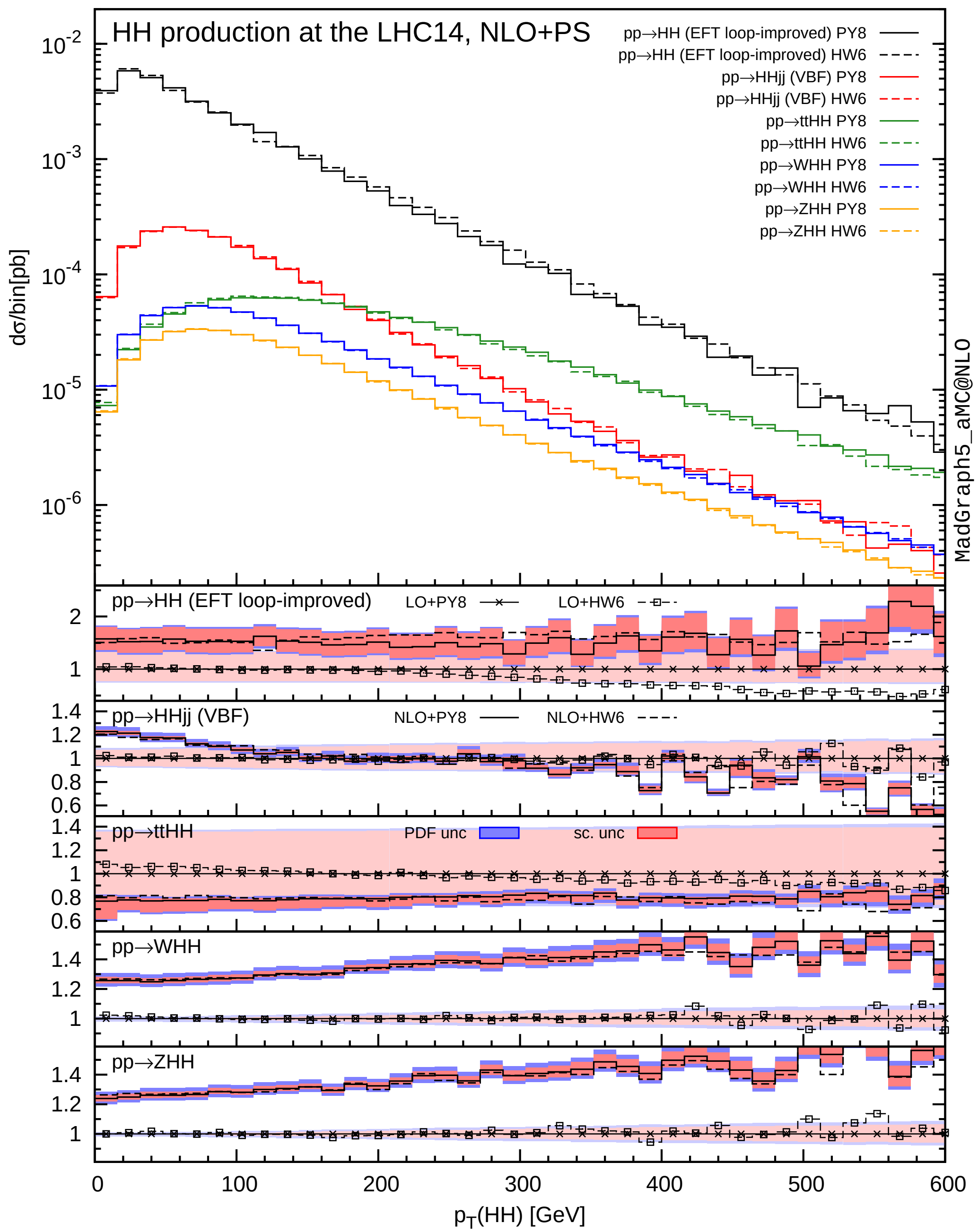
I reiterate the message: this is not particularly important for the SM, but it is crucial beyond it. ETFs (such as the HC model) are an excellent example



SM at NLO: thickness of lines is scale+PDF uncertainties

arXiv:1401.7340 [hep-ph]

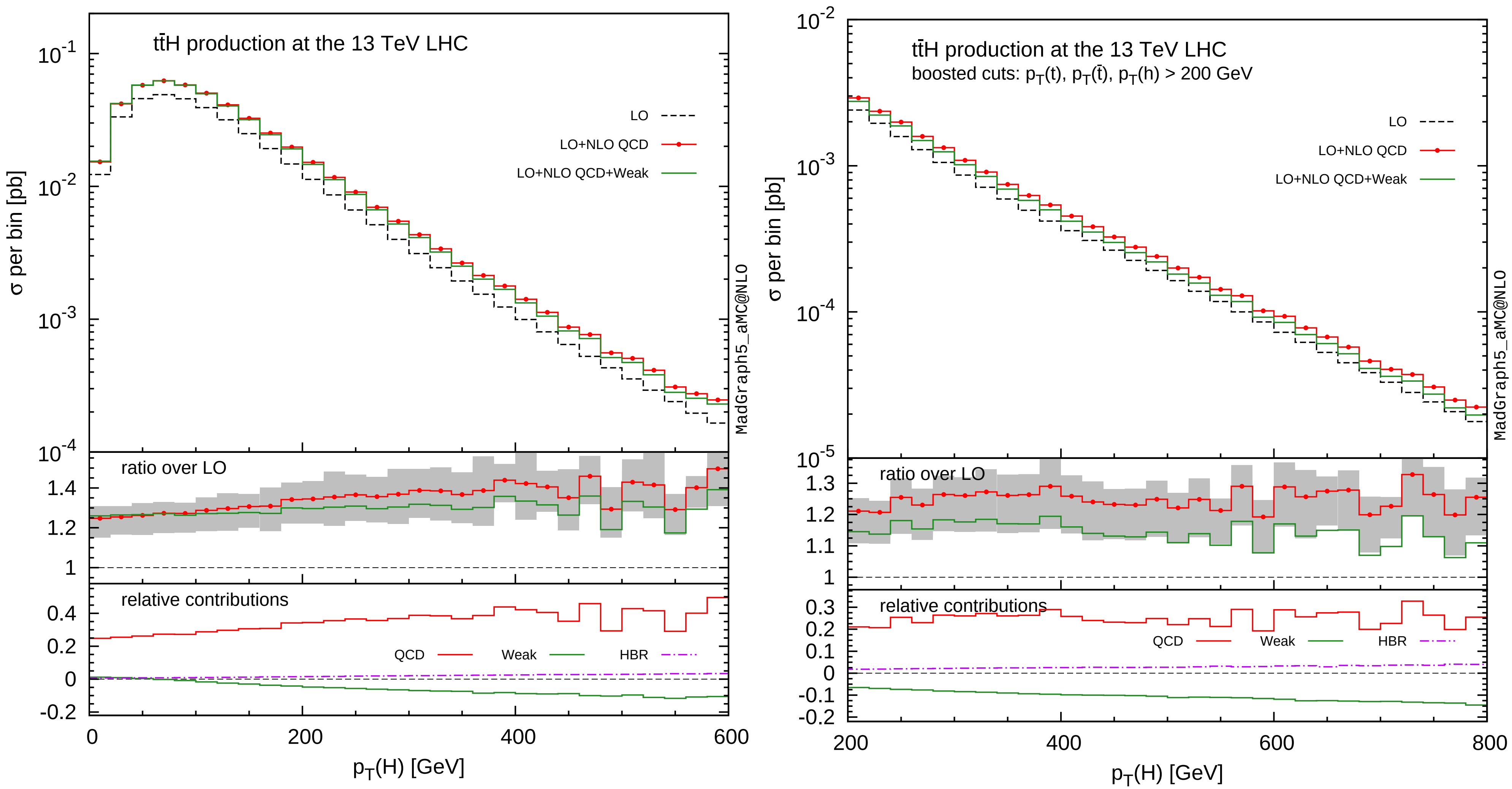
(Frederix, SF, Hirschi, Maltoni, Mattelaer, Torrielli, Vryonidou, Zaro)



arXiv:1401.7340 [hep-ph]

NLO+PS: *all channels, all public*

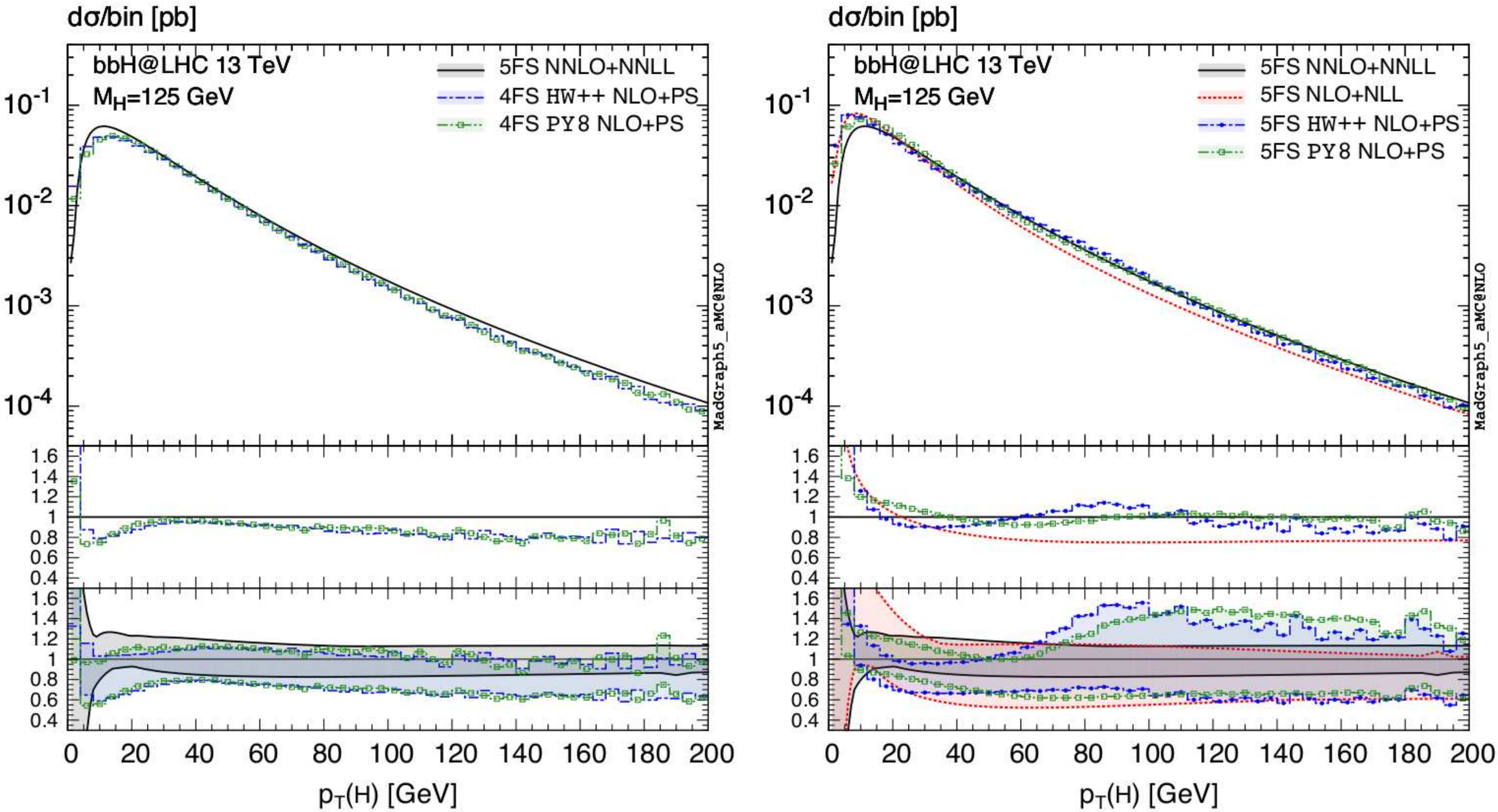
All results include scale and PDF uncertainties



Weak (and QCD) NLO corrections to $t\bar{t}H$ production

arXiv:1407.0823 [hep-ph]

(SF, Hirschi, Pagani, Shao, Zaro)



Fully differential NLO+PS $b\bar{b}H$ predictions, 4FS and 5FS

arXiv:1409.5301 [hep-ph] ⟶ Wiesemann's talk on friday

(Wiesemann, Frederix, SF, Hirschi, Maltoni, Torrielli)

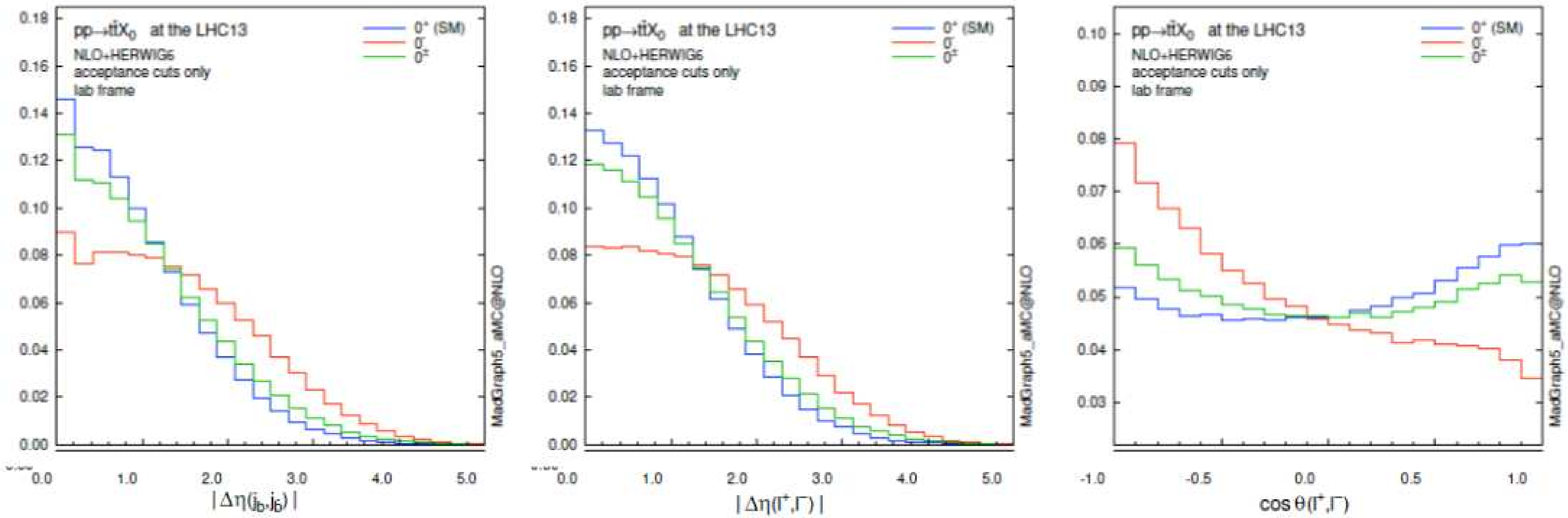
$$\mathcal{L}_0^V = \Bigg[c_\alpha \kappa_{\rm SM} \big[\frac{1}{2} g_{HZZ}\, Z_\mu Z^\mu + g_{HWW}\, W_\mu^+ W^{-\mu} \big]$$
$$- \frac{1}{4} \big[c_\alpha \kappa_{H\gamma\gamma} g_{H\gamma\gamma}\, A_{\mu\nu} A^{\mu\nu} + s_\alpha \kappa_{A\gamma\gamma} g_{A\gamma\gamma}\, A_{\mu\nu} \widetilde{A}^{\mu\nu} \big]$$
$$- \frac{1}{2} \big[c_\alpha \kappa_{HZ\gamma} g_{HZ\gamma}\, Z_{\mu\nu} A^{\mu\nu} + s_\alpha \kappa_{AZ\gamma} g_{AZ\gamma}\, Z_{\mu\nu} \widetilde{A}^{\mu\nu} \big]$$
$$- \frac{1}{4} \big[c_\alpha \kappa_{Hgg} g_{Hgg}\, G_{\mu\nu}^a G^{a,\mu\nu} + s_\alpha \kappa_{Agg} g_{Agg}\, G_{\mu\nu}^a \widetilde{G}^{a,\mu\nu} \big]$$
$$- \frac{1}{4} \frac{1}{\Lambda} \big[c_\alpha \kappa_{HZZ}\, Z_{\mu\nu} Z^{\mu\nu} + s_\alpha \kappa_{AZZ}\, Z_{\mu\nu} \widetilde{Z}^{\mu\nu} \big]$$
$$- \frac{1}{2} \frac{1}{\Lambda} \big[c_\alpha \kappa_{HWW}\, W_{\mu\nu}^+ W^{-\mu\nu} + s_\alpha \kappa_{AWW}\, W_{\mu\nu}^+ \widetilde{W}^{-\mu\nu} \big]$$
$$- \frac{1}{\Lambda} c_\alpha \big[\kappa_{H\partial\gamma}\, Z_\nu \partial_\mu A^{\mu\nu} + \kappa_{H\partial Z}\, Z_\nu \partial_\mu Z^{\mu\nu} + (\kappa_{H\partial W}\, W_\nu^+ \partial_\mu W^{-\mu\nu} + h.c.) \big] \Bigg] X_0$$

[Artoisenet, et al., 1306.6464]

$$\mathcal{L}_0^f = - \sum_{f=t,b,\tau} \bar\psi_f \big(c_\alpha \kappa_{Hff} g_{Hff} + i s_\alpha \kappa_{Aff} g_{Aff}\, \gamma_5 \big) \psi_f X_0$$

The HC Lagrangian (EFT below the EWSB scale) is a paradigm of what can be achieved with `FeynRules` – `NLOCT` – MadGrapgh5_aMC@NLO

EFT@NLO above the EWSB scale is progress $\longrightarrow$ see V. Sanz's talk



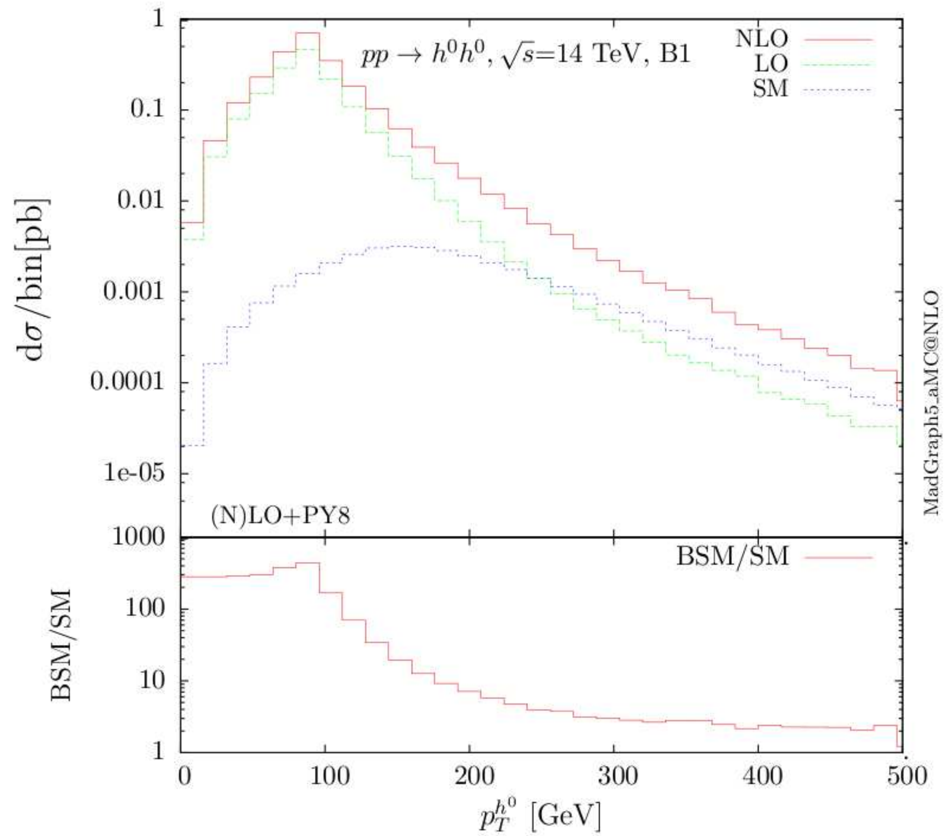
ttX_0 production (HC): angular correlations sensitive to CP mixing (NLO+PS)

arXiv:1407.5089 [hep-ph]

(Demartin, Maltoni, Mawatari, Page, Zaro)

Benchmark B1

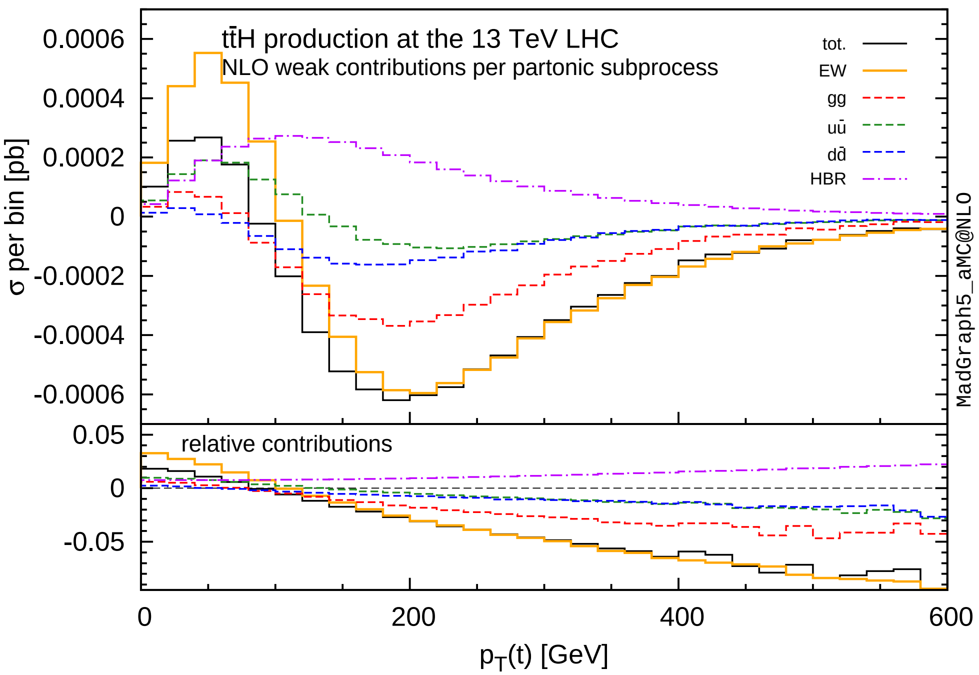
gg–channels	LO	NLO–loop improved	NLO–Born improved	K–factor
h^0h^0	$1480^{+29.8+1.5\%}_{-21.6-2.1\%}$	$2400^{+17.9+1.6\%}_{-14.4-1.9\%}$	$2500^{+19.2+1.6\%}_{-15.0-1.9\%}$	1.62
h^0H^0	$10.5^{+33.5+2.3\%}_{-23.5-2.5\%}$	$16.1^{+15.2+2.3\%}_{-13.7-2.8\%}$	$17.9^{+18.5+2.3\%}_{-15.3-2.8\%}$	1.54
H^0H^0	$0.550^{+35.3+2.8\%}_{-24.4-2.9\%}$	$0.859^{+14.7+2.8\%}_{-13.8-3.6\%}$	$0.936^{+17.6+2.8\%}_{-15.3-3.5\%}$	1.56
h^0A^0	$5.22^{+34.4+2.5\%}_{-23.9-2.7\%}$	$8.68^{+17.1+2.5\%}_{-14.8-3.1\%}$	$8.90^{+17.9+2.5\%}_{-15.2-3.1\%}$	1.66
H^0A^0	$0.457^{+36.4+3.1\%}_{-24.9-3.2\%}$	$0.727^{+15.2+3.3\%}_{-14.3-4.1\%}$	$0.798^{+17.8+3.2\%}_{-15.5-4.0\%}$	1.59
A^0A^0	$0.221\ ^{+37.3+3.4\%}_{-25.4-3.5\%}$	$0.352^{+14.8+3.7\%}_{-14.2-4.6\%}$	$0.382^{+17.4+3.7\%}_{-15.5-4.6\%}$	1.59
H^+H^-	$0.321^{+37.3+3.4\%}_{-25.4-3.5\%}$	$0.531^{+16.1+3.7\%}_{-14.9-4.6\%}$	$0.559^{+17.7+3.7\%}_{-15.7-4.6\%}$	1.65

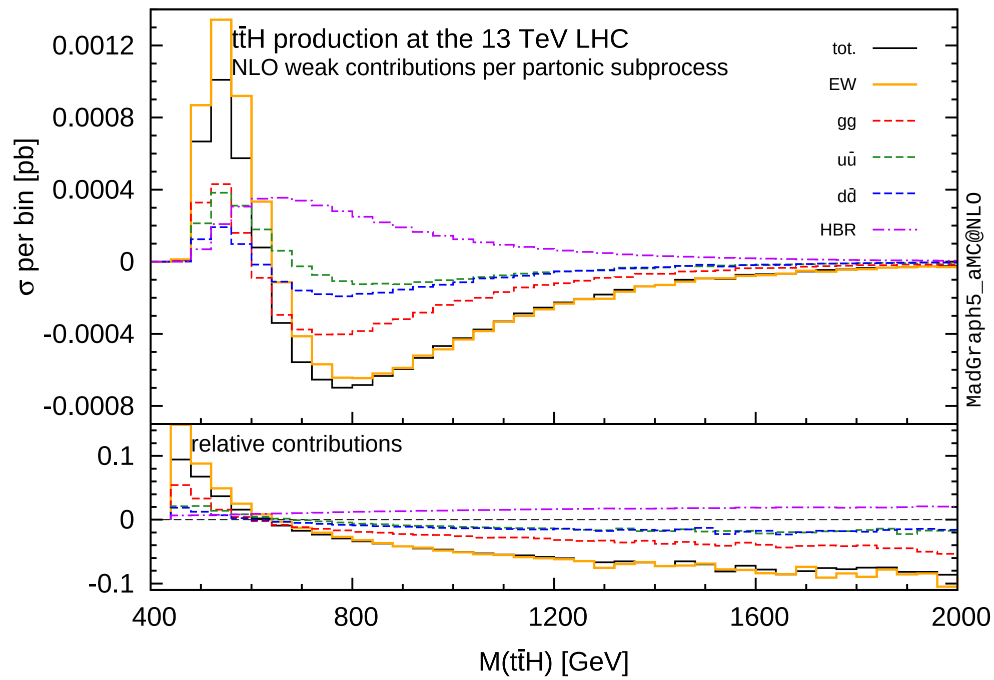


HH production (2HDM)

arXiv:1407.0281 [hep-ph]

(Hespel, Lopez-Val, Vryonidou)



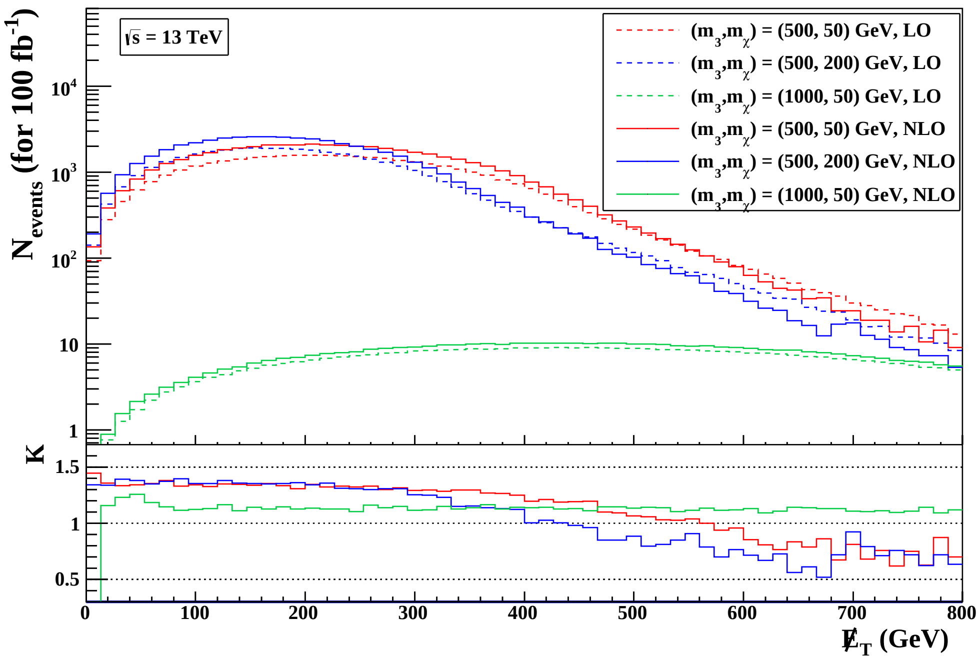


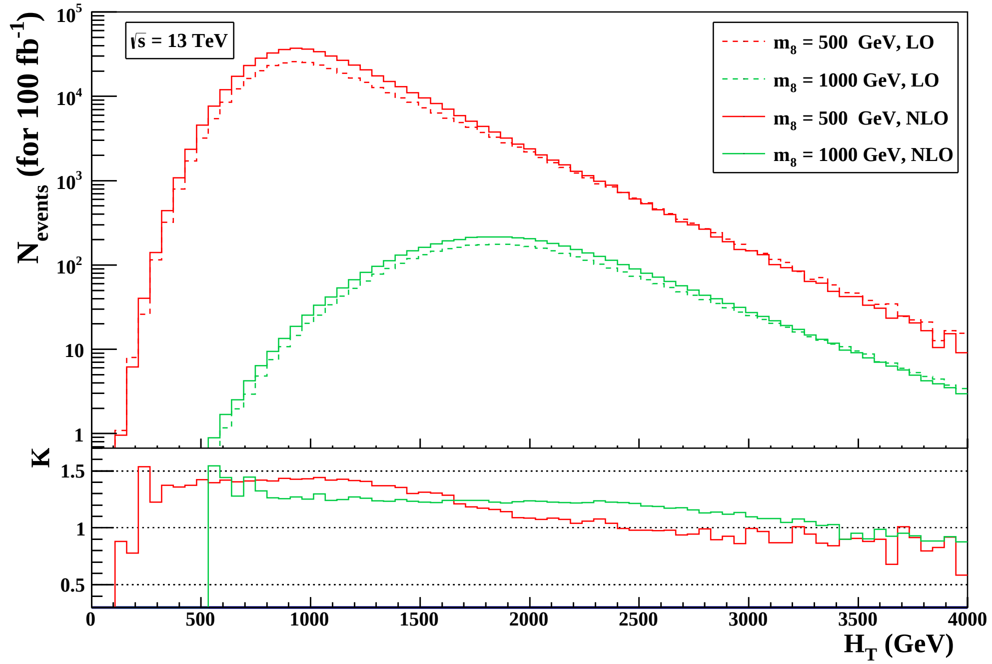
NEW (to appear) $t\bar{t}H$ production (SM): QED+weak NLO corrections

NLO corrections, in absolute value and relative to LO

Black: weak only; yellow: QED+weak

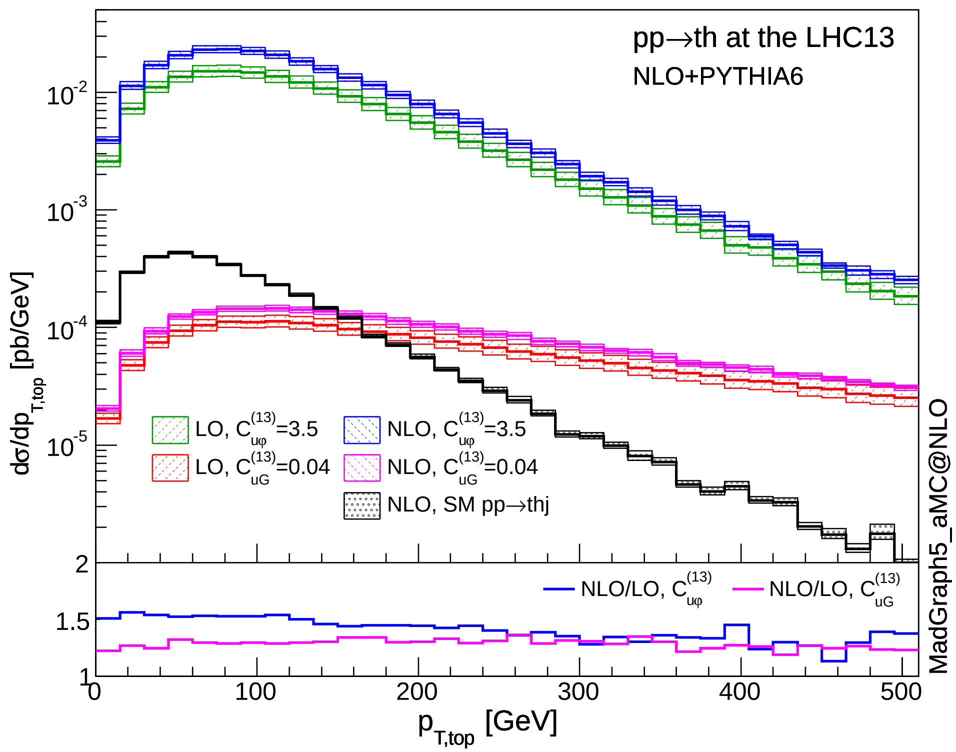
Plots: D. Pagani, M. Zaro

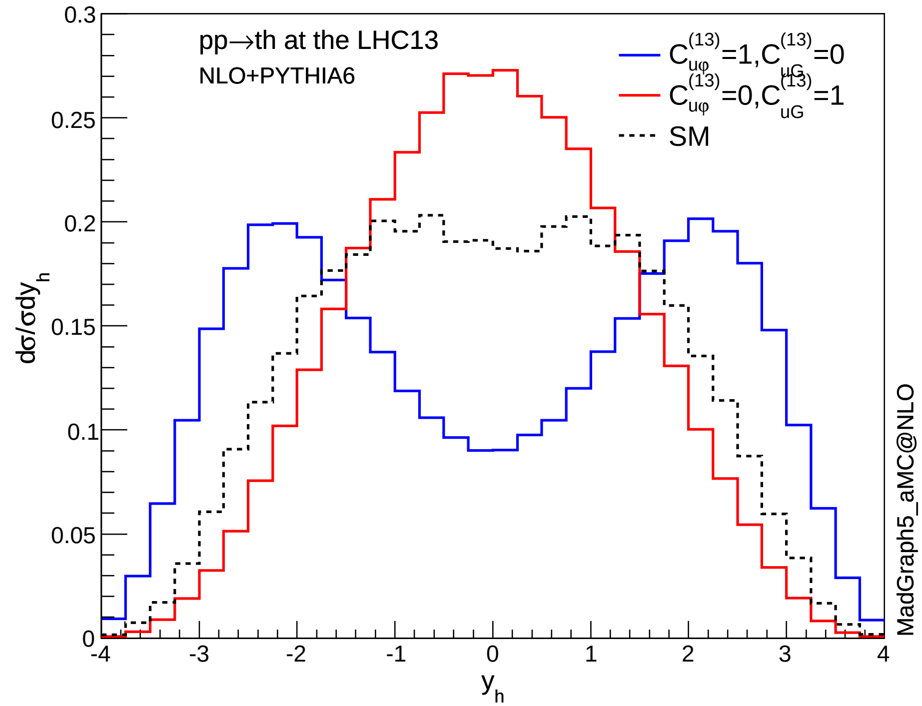




NEW (to appear) stop and sgluon pair production (simplified SUSY): NLO+PS

(Degrande, Fuks, Hirschi, Proudom, Shao, 1412.XXXX)





NEW (to appear) $tH(+j)$ production (FCN dim-6 operators): NLO+PS

(Degrande, Maltoni, Wang, Zhang, 1412.YYYY)

Conclusions

- MadGraph5_aMC@NLO is public and open-ended
- NLO and LO basically on the same footing
- Features:

  fixed-order and MC-matched results

  matching to several MCs

  multi-parton mergings

  spin correlations

  loop-induced processes

  scale and PDF uncertainties at no CPU cost

  . . .