HH production modes in MadGraph5_aMC@NLO

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LPTHE - UPMC Paris VI

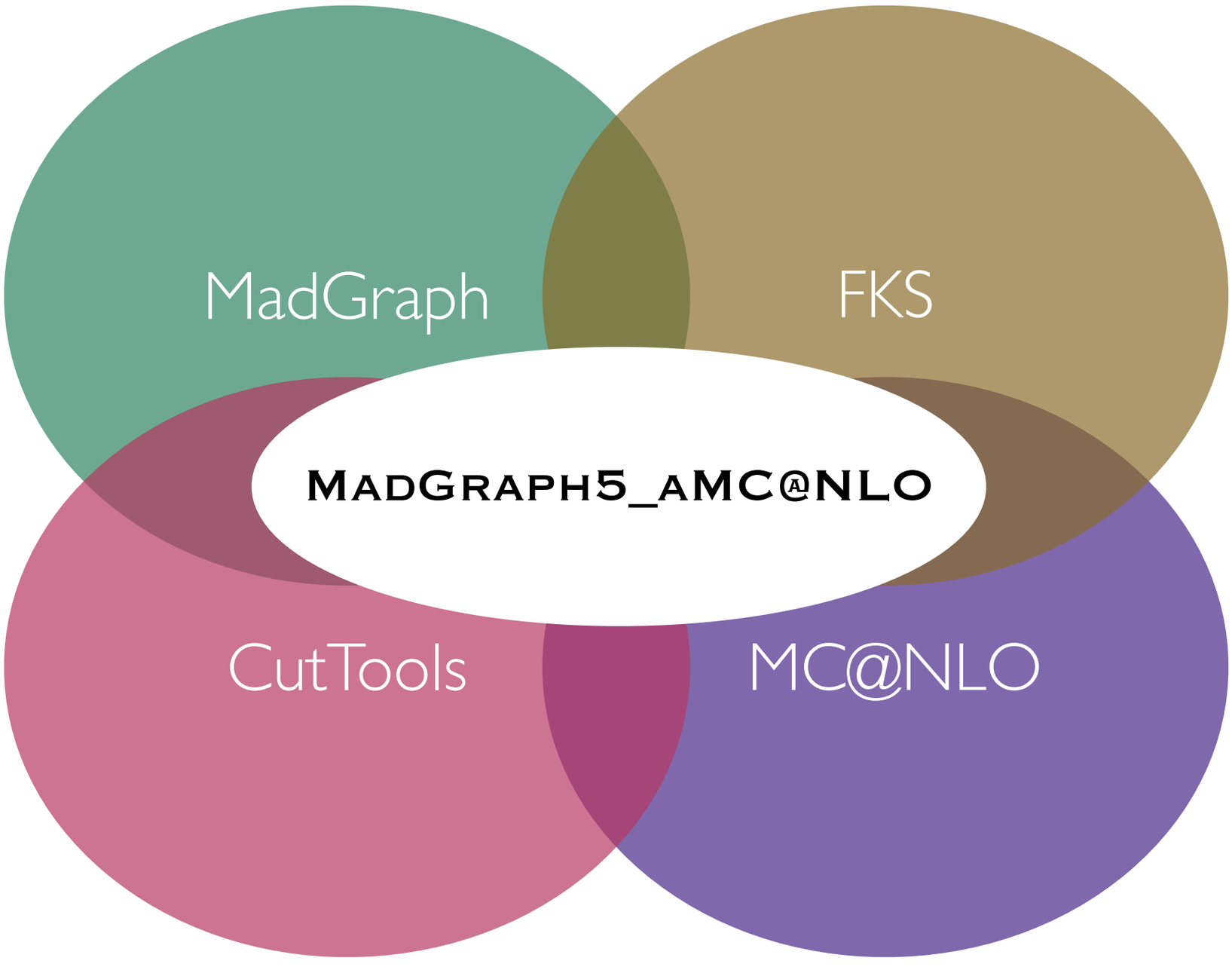
LHC Higgs XS HH subgroup meeting

November 20, 2014

LHCPhenoNet

MadGraph5_aMC@NLO

Alwall, Frederix, Frixione, Maltoni, Mattelaer, Shao, Stelzer, Torrielli, Hirschi, MZ arXiv:1405.0301



Full automation (and extreme simplicity)

- Start the MG5/aMC@NLO shell

```
$./bin/mg5_aMC
```

- Generate the process

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

- Write the code

```
> output my_ttHH_nlo
```

- Launch the event generation/fixed order computation

```
> launch
```

HH in aMC@NLO

R. Frederix, S. Frixione, F. Maltoni, O. Mattelaer, P. Torrielli, E. Vryonidou, MZ

arXiv:1401.7340,

- The code for all channels (but gg→HH) can be generated automatically including NLO+PS effects

Process		Syntax	Cross section (pb)			
Single Higgs 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	$pp \to HHZ$	`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.5	$pp \to HHt\bar{t}$	`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.6	$pp \to HHtj$	`p p > h h tt j`	$1.844 \pm 0.008 \cdot 10^{-5}$	$^{+0.0\%}_{-0.6\%}$ $^{+1.8\%}_{-1.8\%}$	$2.444 \pm 0.009 \cdot 10^{-5}$	$^{+4.5\%}_{-3.1\%}$ $^{+2.8\%}_{-3.0\%}$

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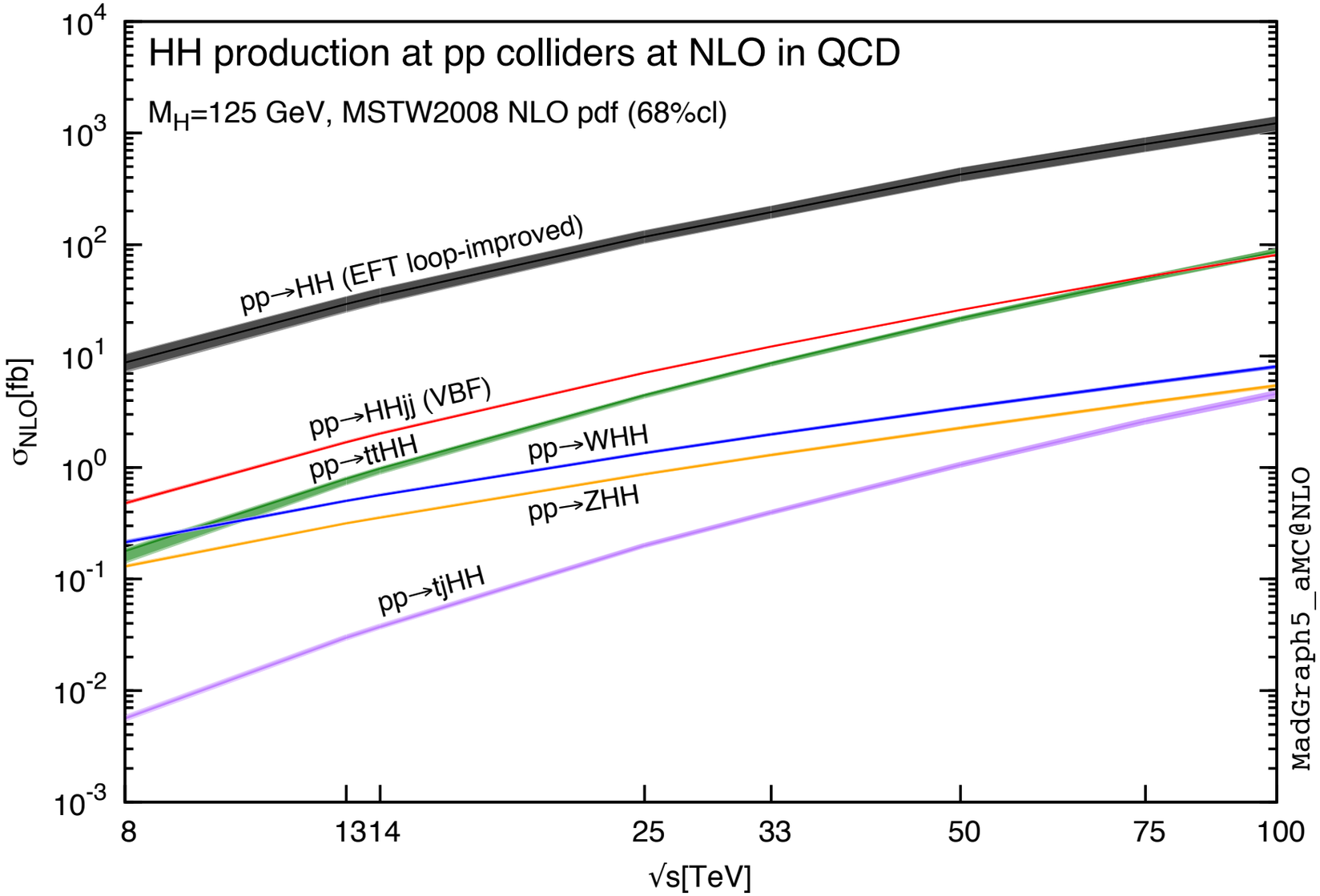
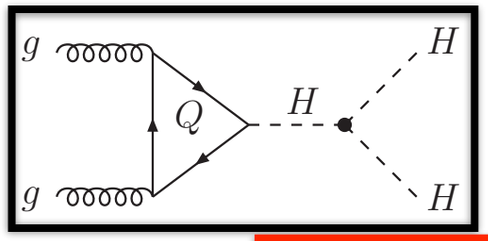
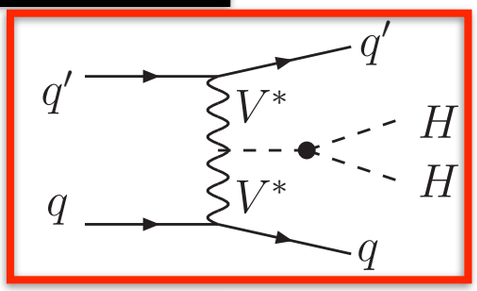
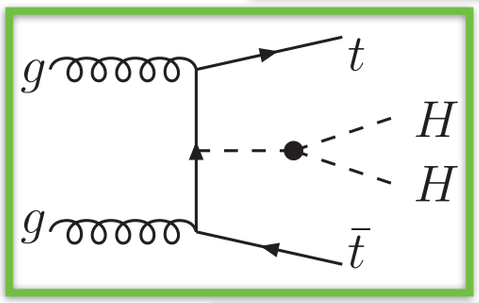
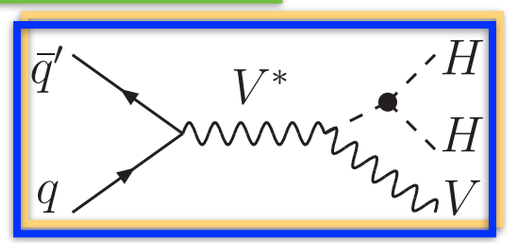


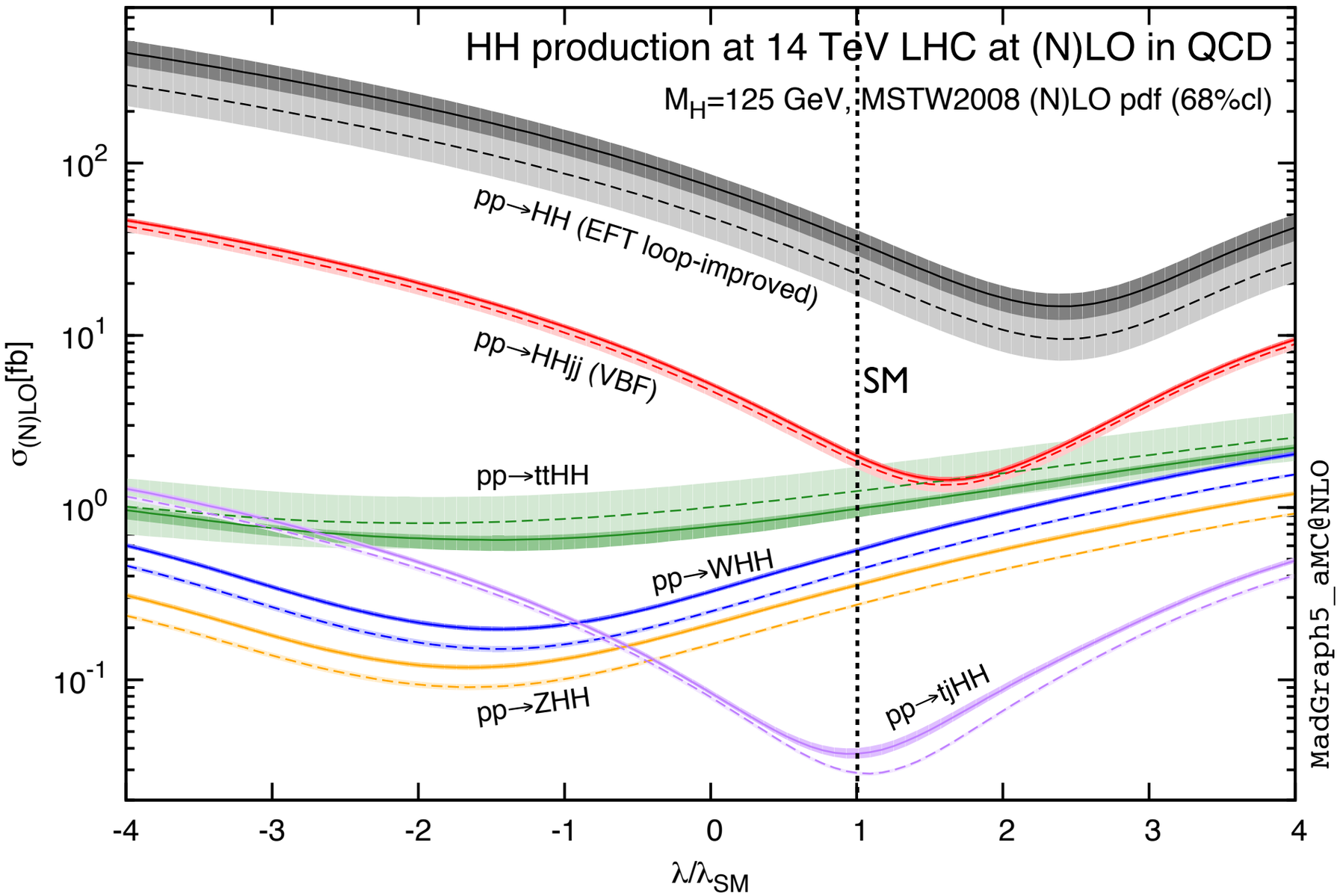


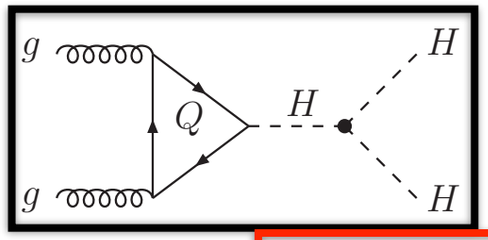


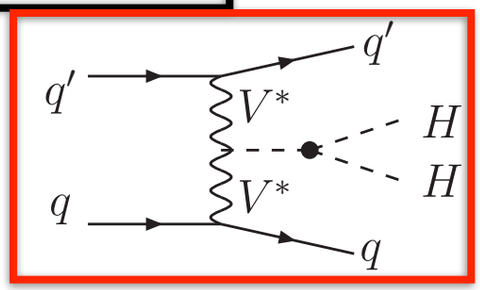


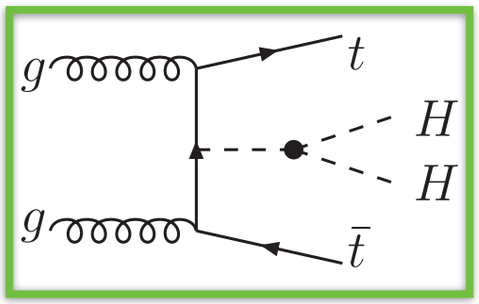


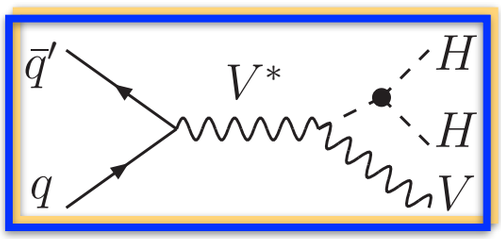
λ_{HHH} dependence







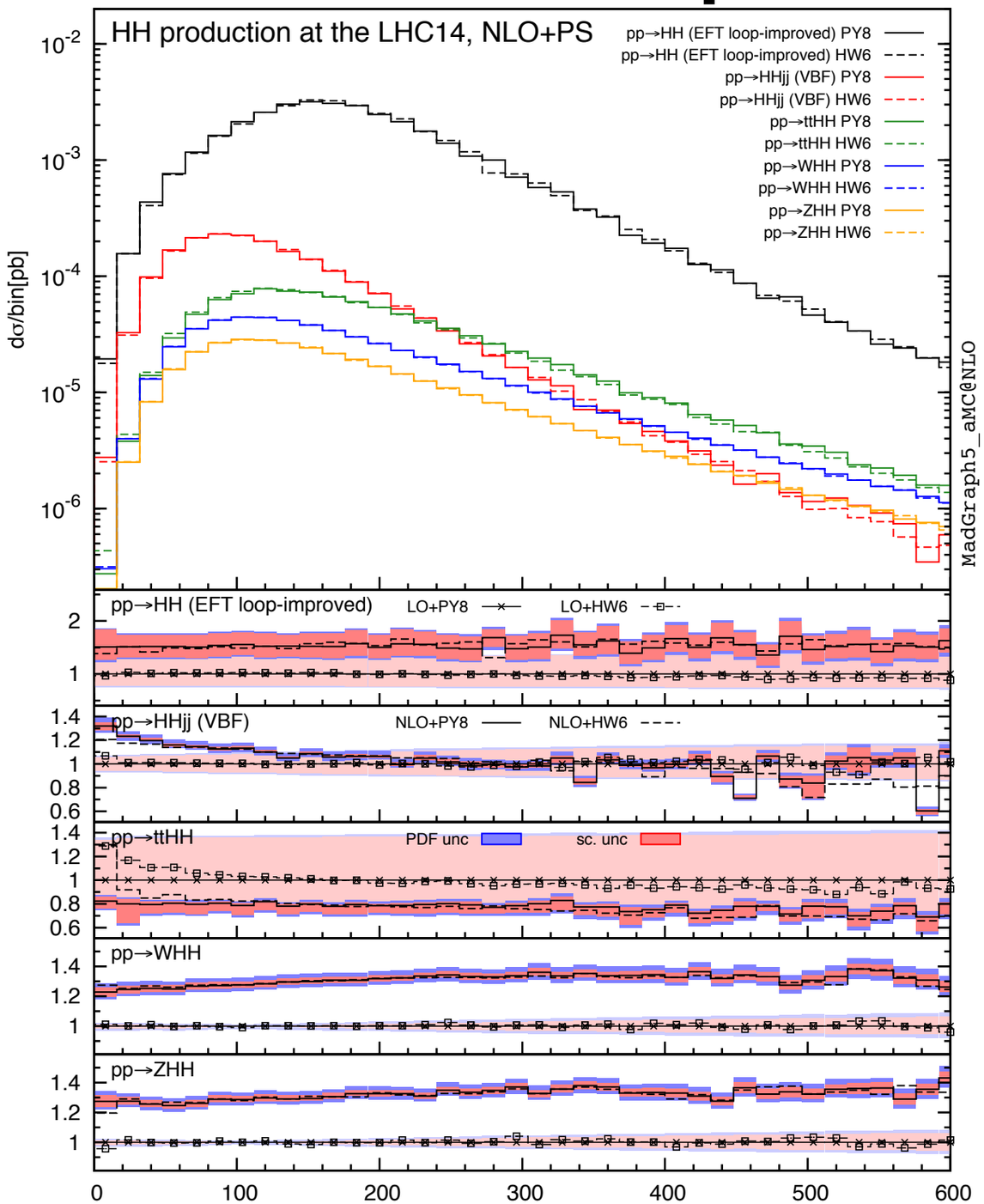


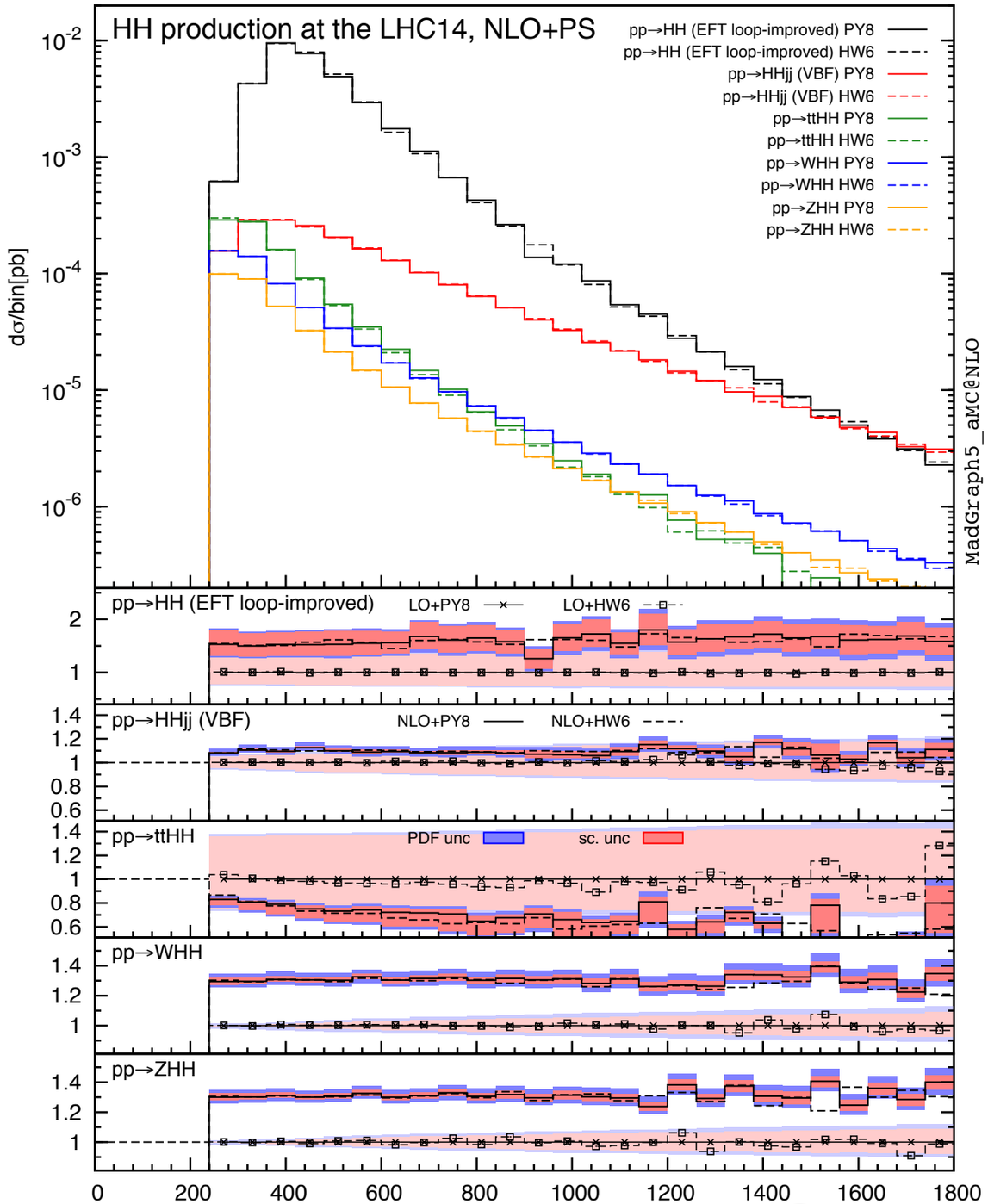


Beyond total rates

- More than total rates needed for realistic pheno studies
  - Selection/acceptance cuts are imposed on particles in the final state
  - One may want to look to specific differential distributions
- Accurate (i.e. at $N^{\geq 1}LO$) and realistic (i.e. matched with PS) fully differential predictions are necessary!

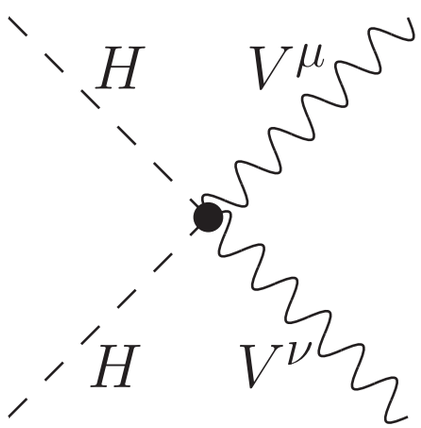
Fully differential predictions for HH production in the SM



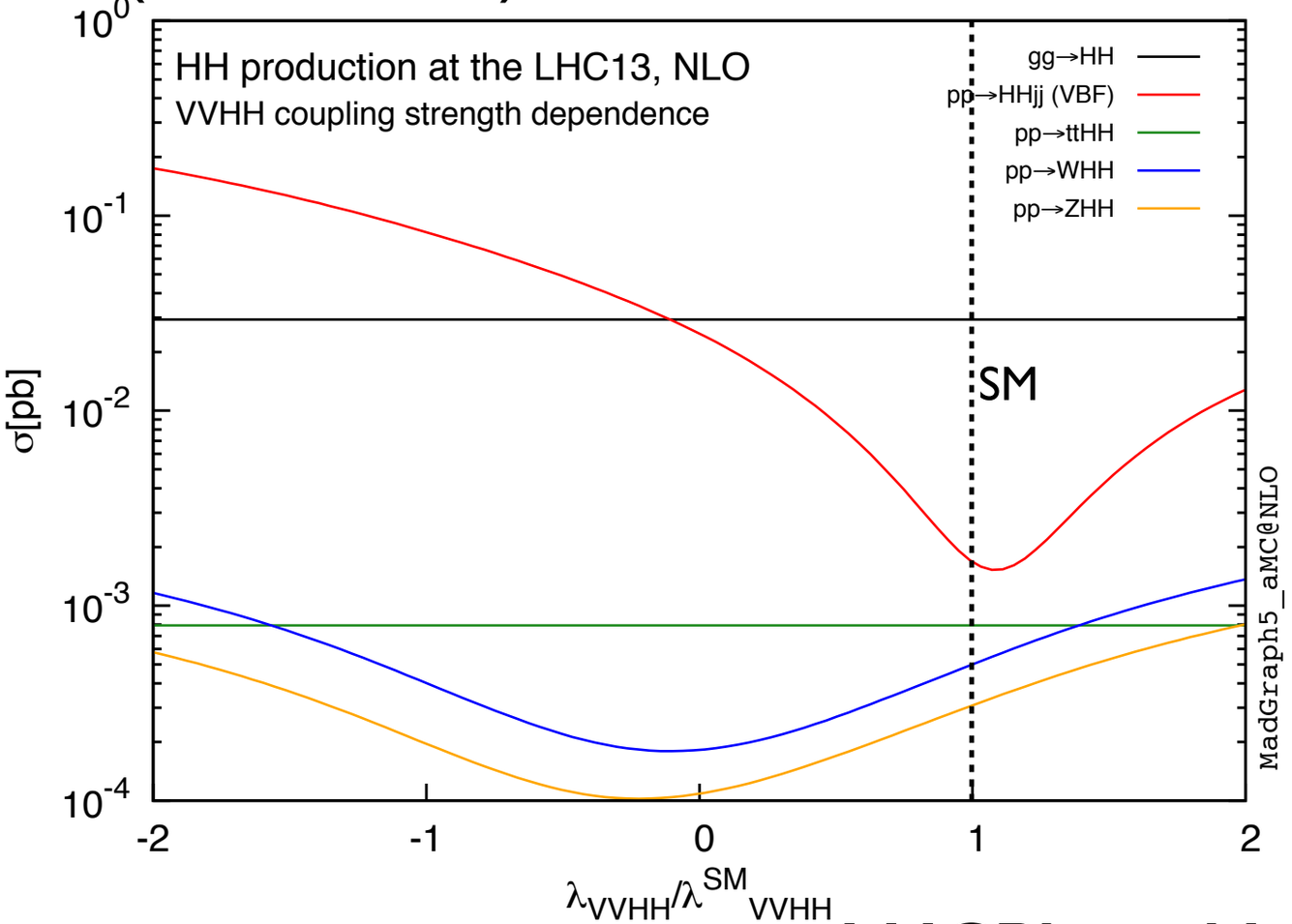


What can we learn from subdominant HH production modes?

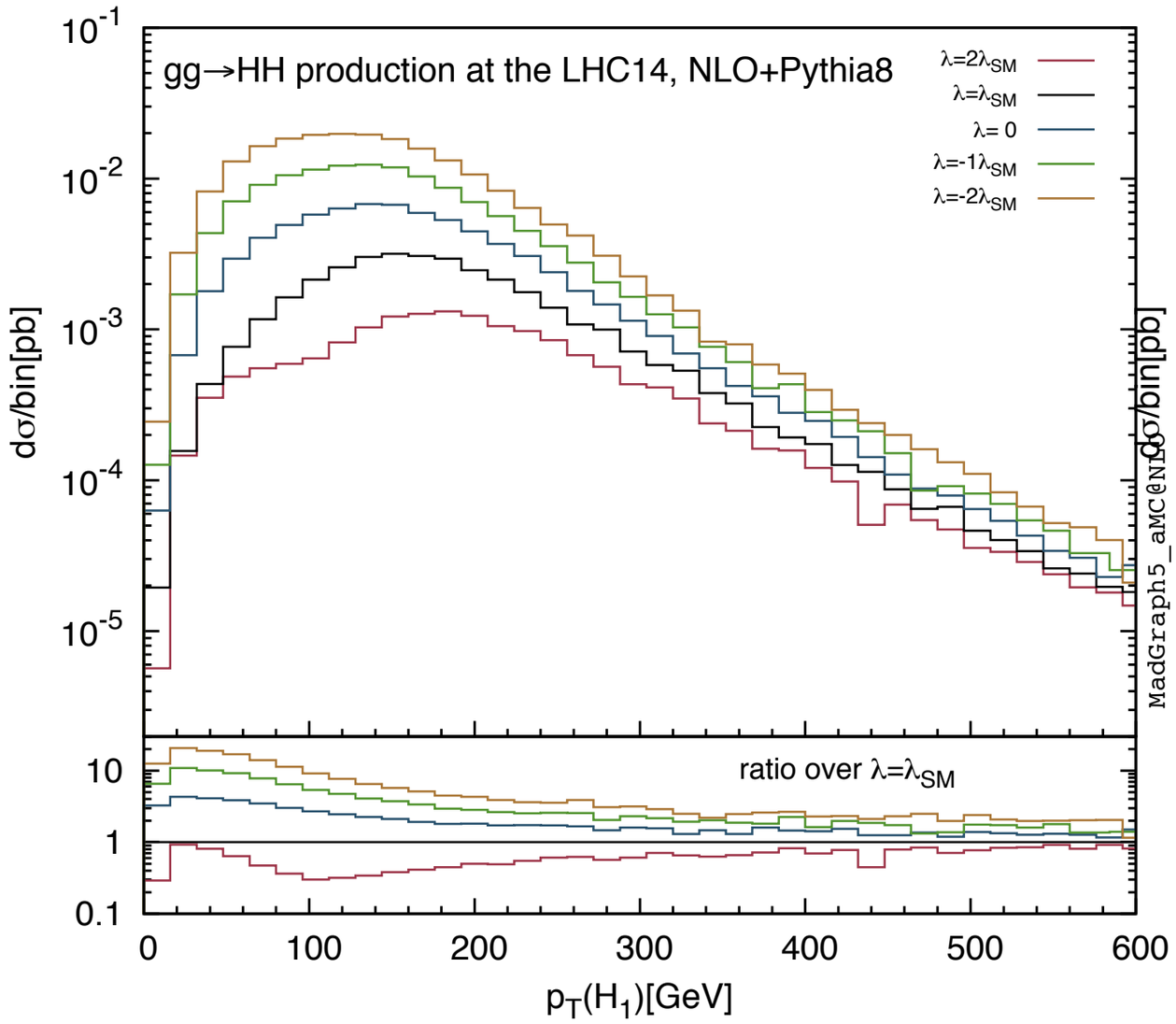
- Complimentary information on the Higgs self coupling
- Extra information on other SM interactions:
  - E.g.: VVHH vertex in VBF (and VHH)

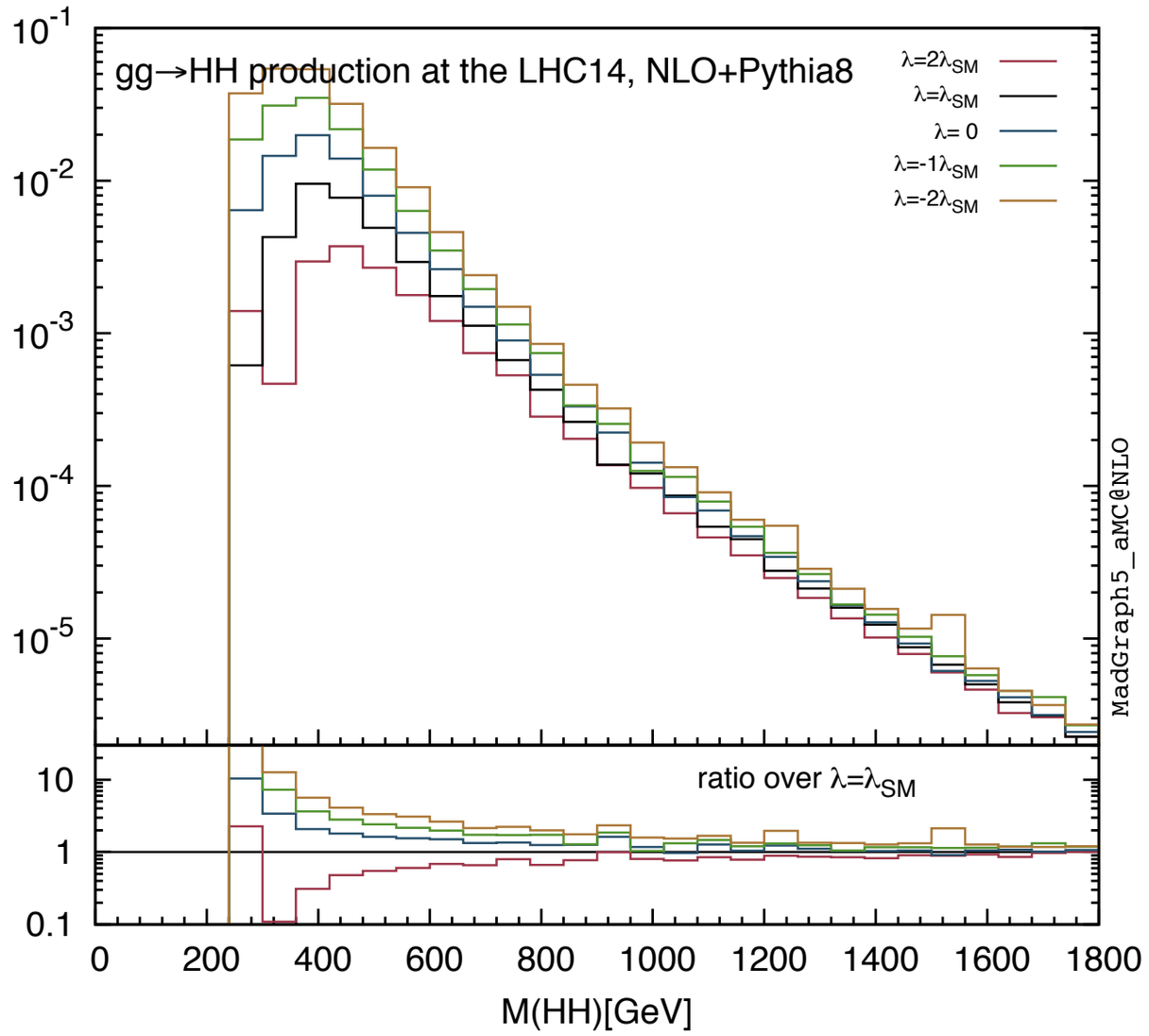


$$= -2ig^{\mu\nu} M_V^2 / v^2$$

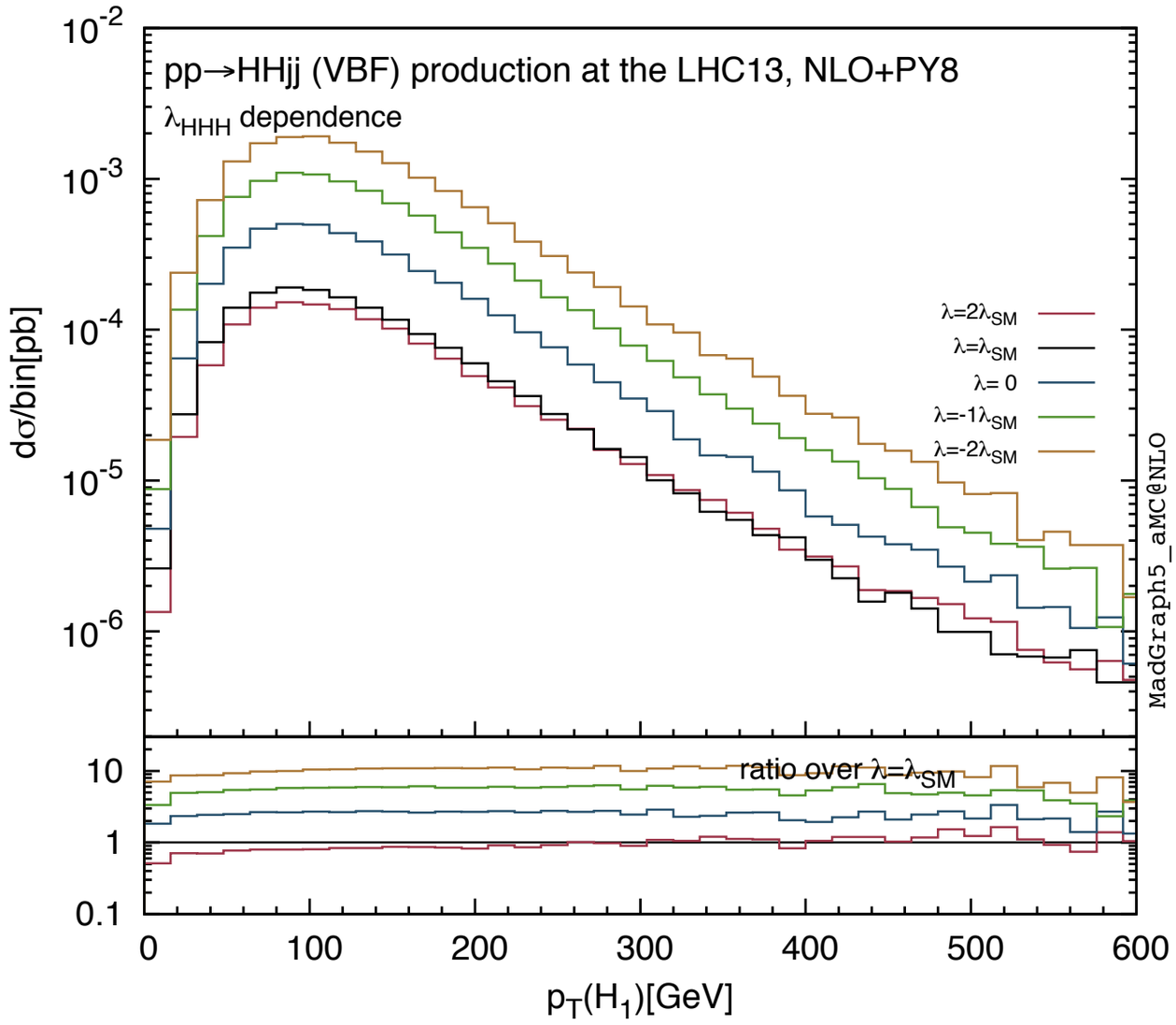


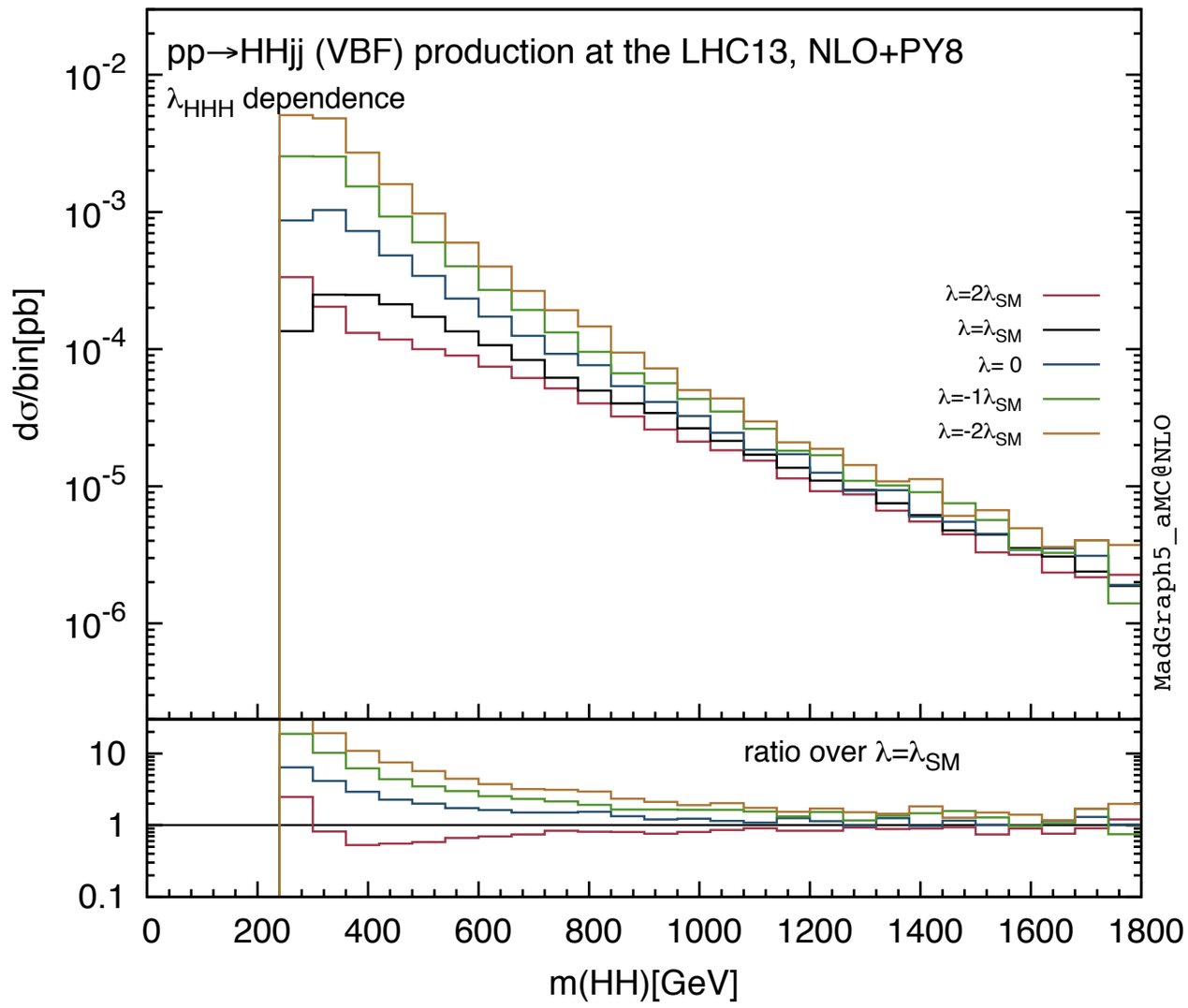
λ_{HHH} dependence in gg→HH



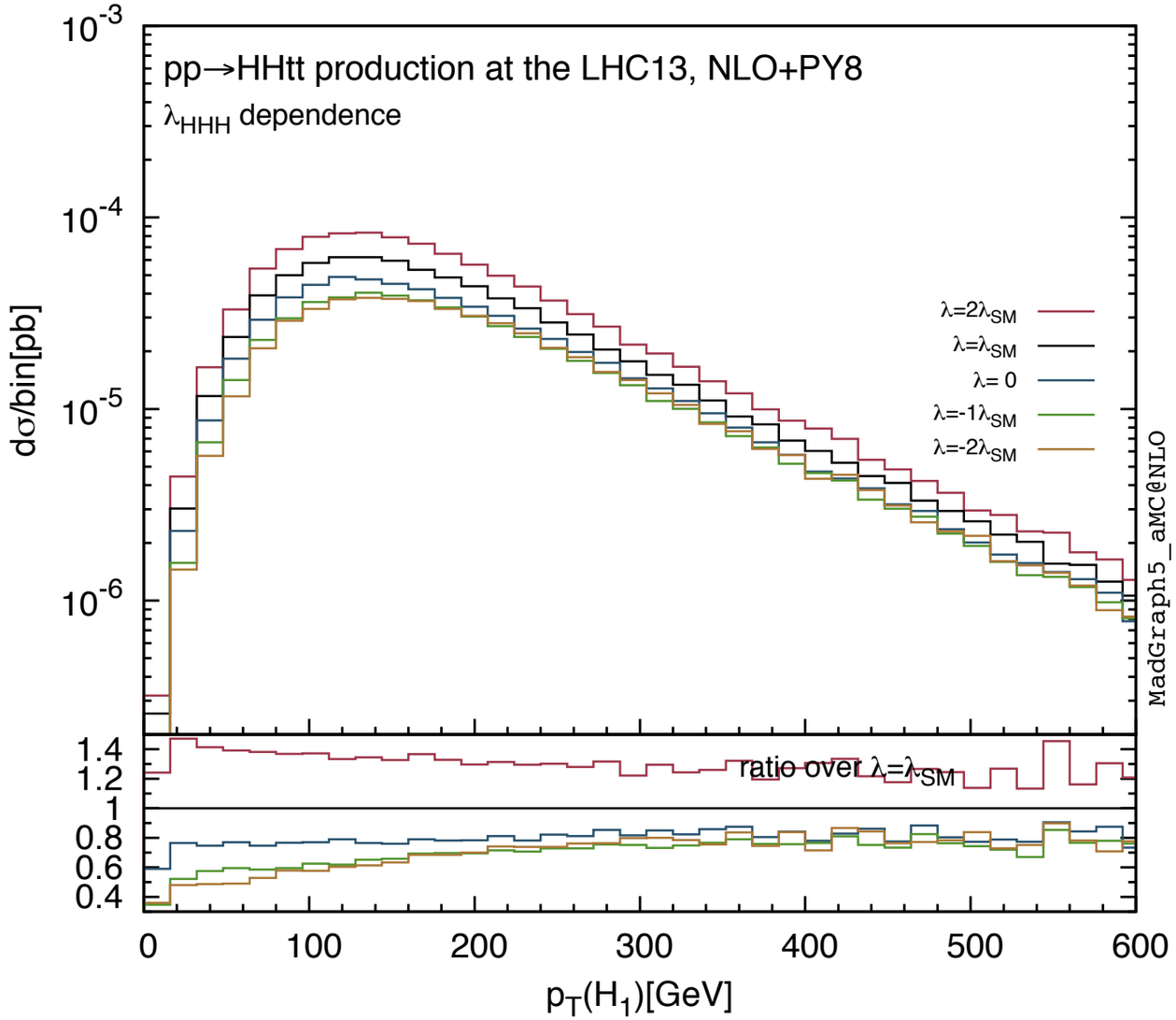


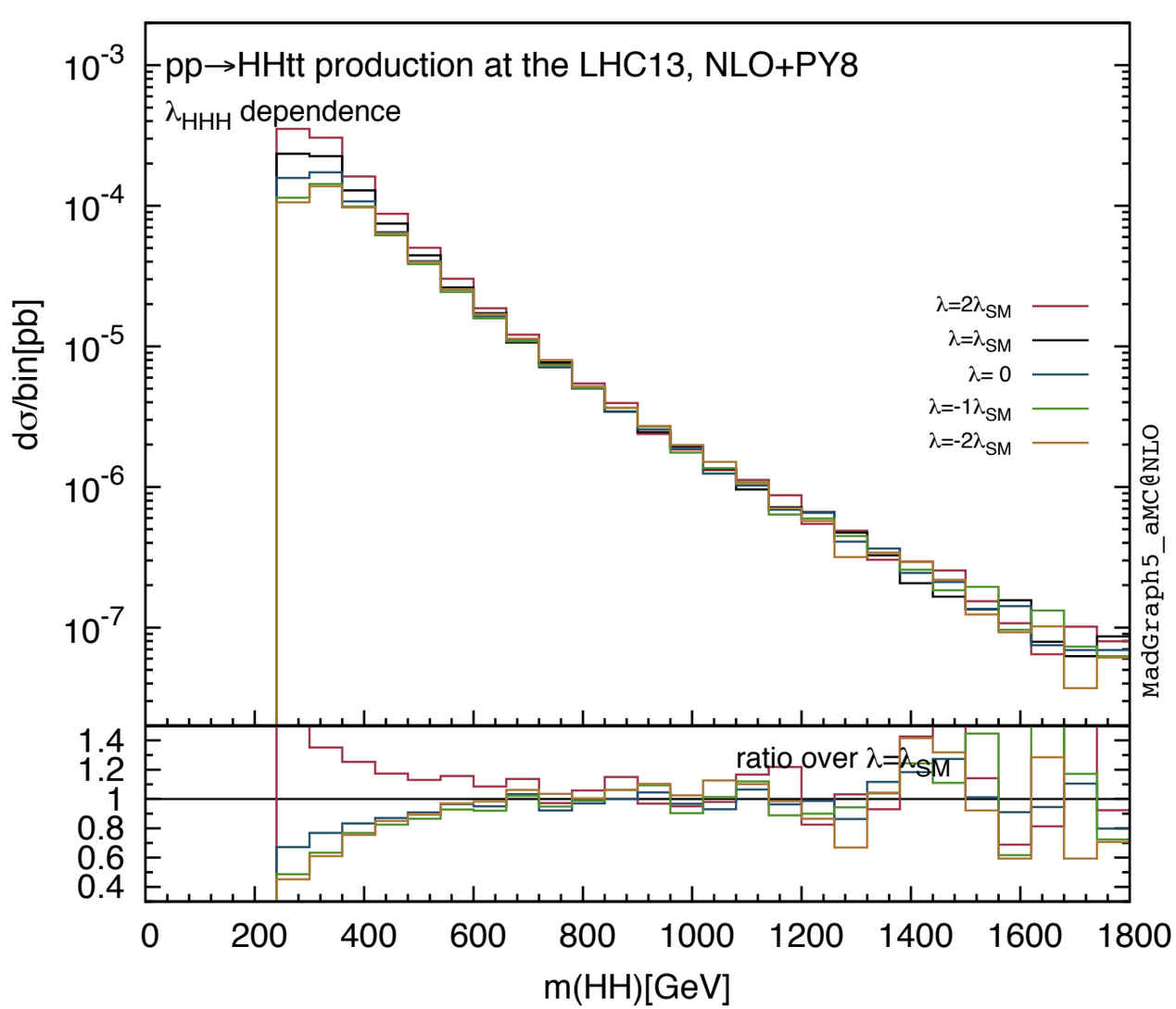
λ_{HHH} dependence in VBF



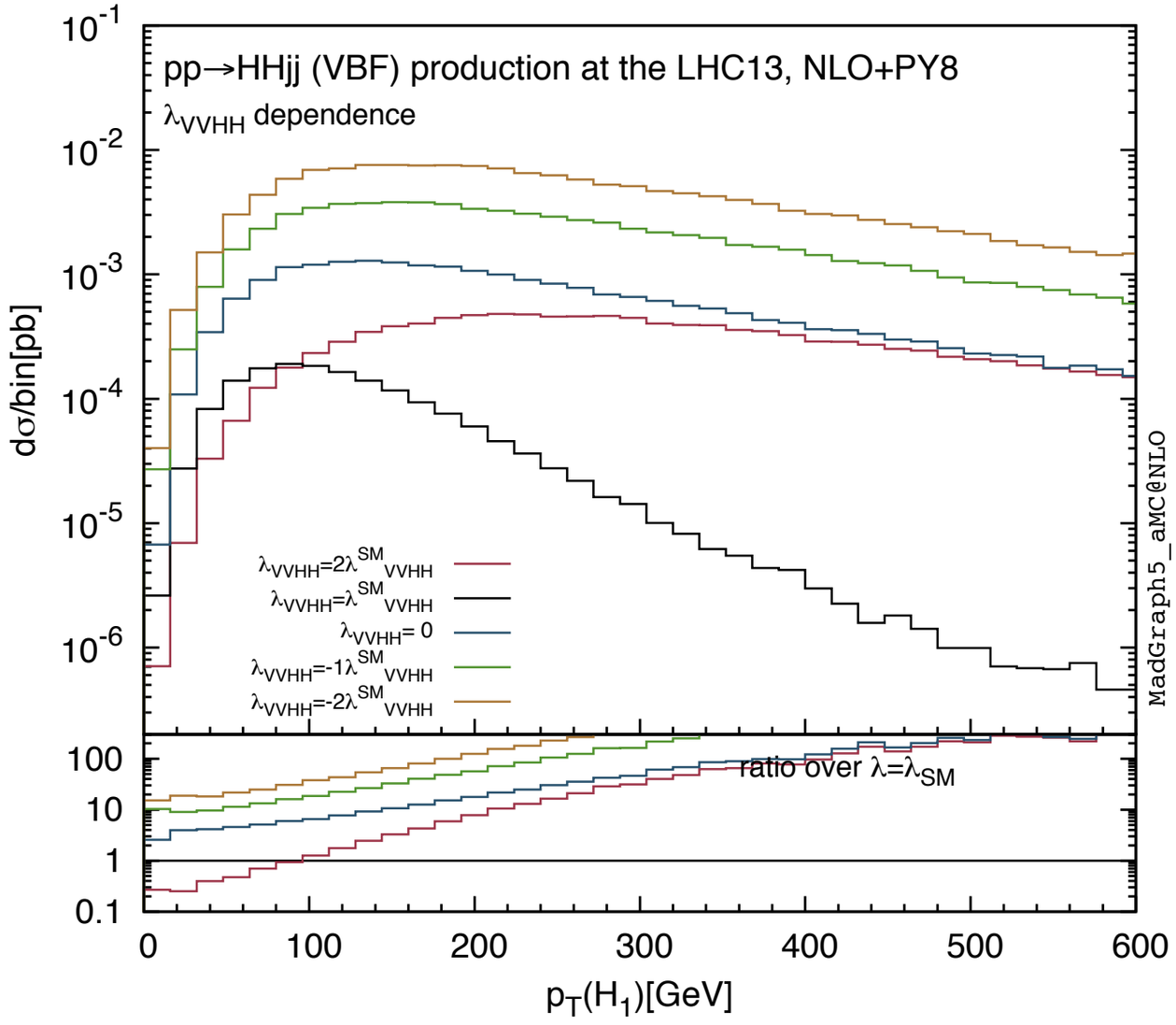


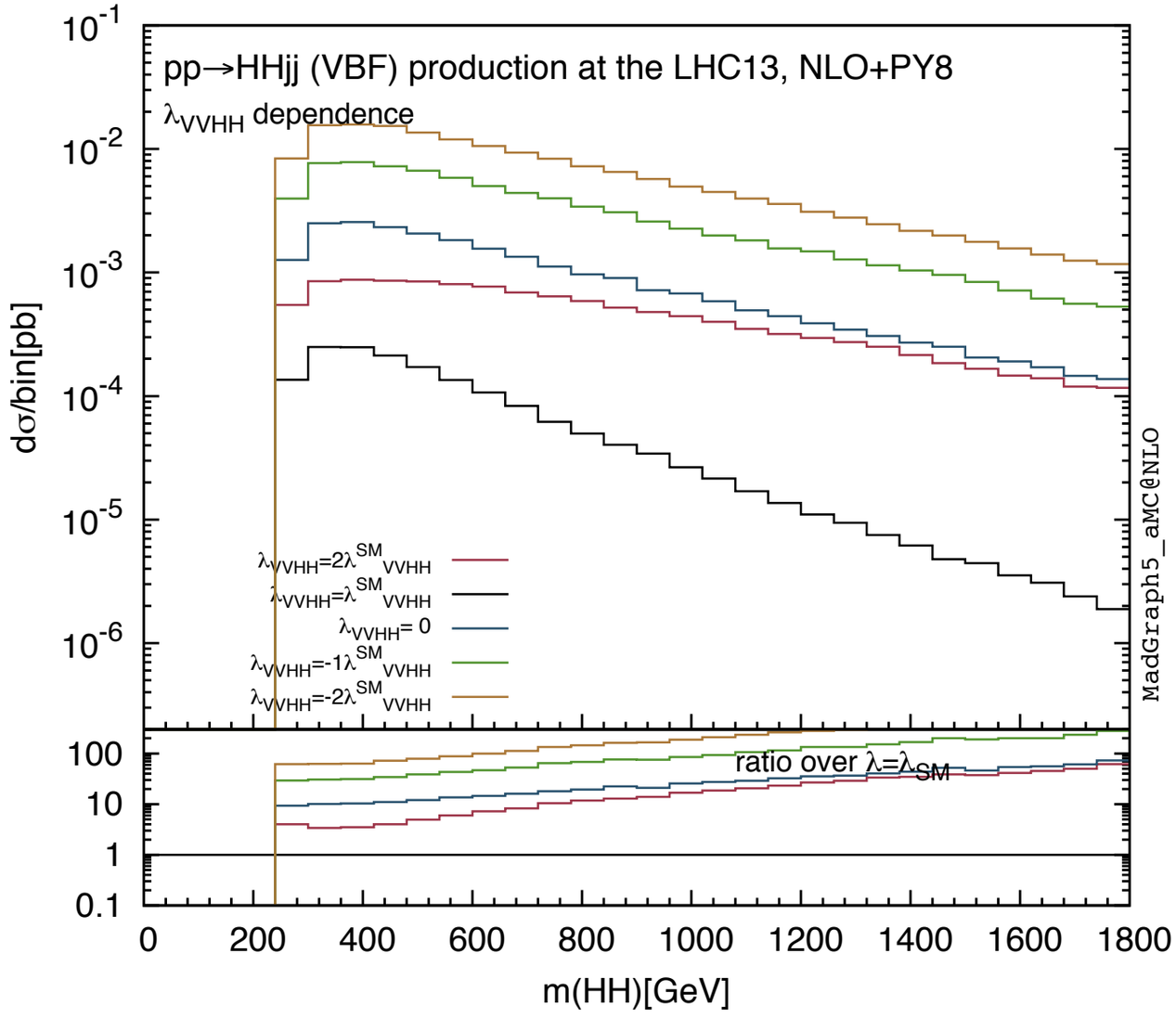
λ_{HHH} dependence in $t\bar{t}HH$





λ_{VVHH} dependence in VBF



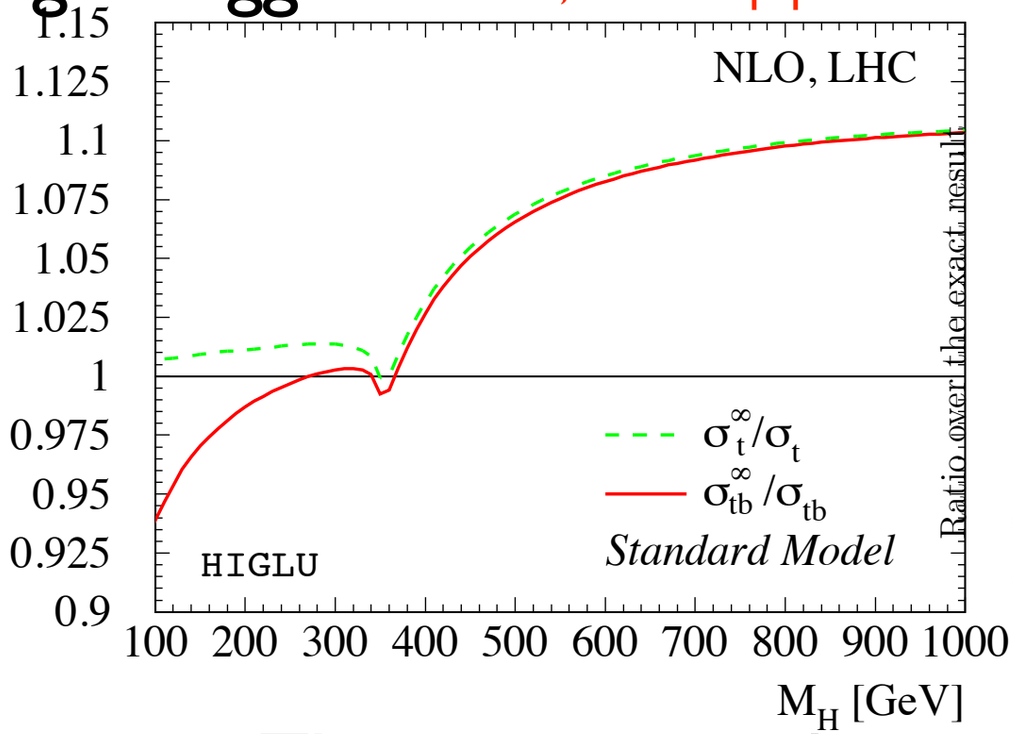


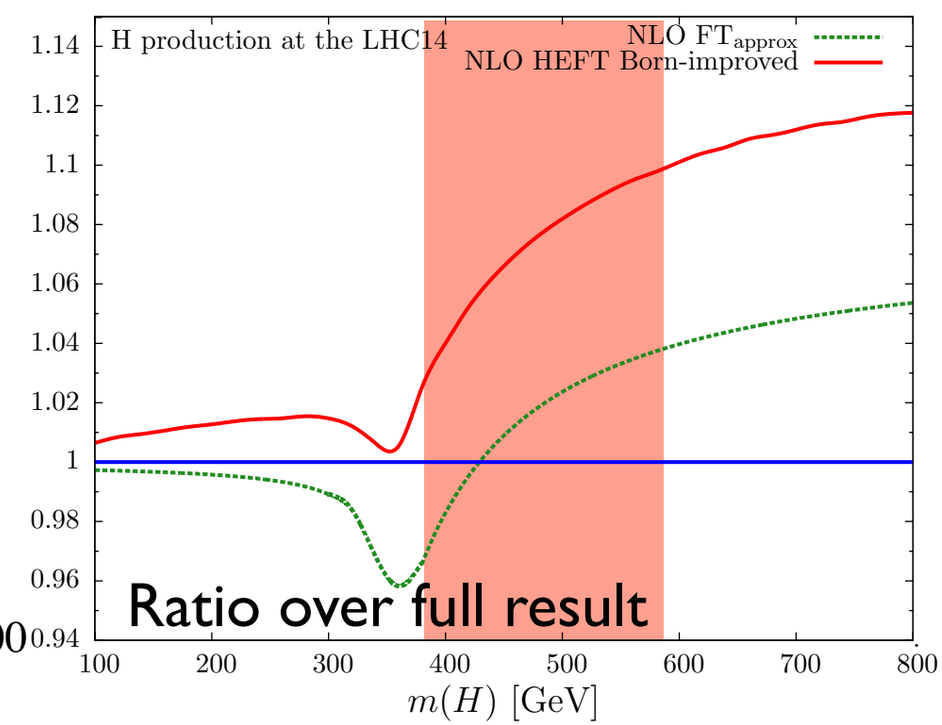
- λ_{VVHH} changed in a custodial way (same scaling factor for W and Z)

More on the inclusion of top-mass effects

from Maltoni, Vryonidou, Zaro, arXiv:1408.6542

- Does the inclusion of the exact m_t dependence in the reals spoil cancelations between reals and virtuals?
  - Single Higgs Harlander, arXiv:hep-ph/0311005





There is a cancelation at the $t\bar{t}$ threshold

Total cross-section for HH is dominated by higher invariant masses

FT_{approx} is closer to the exact value (at least for single Higgs)

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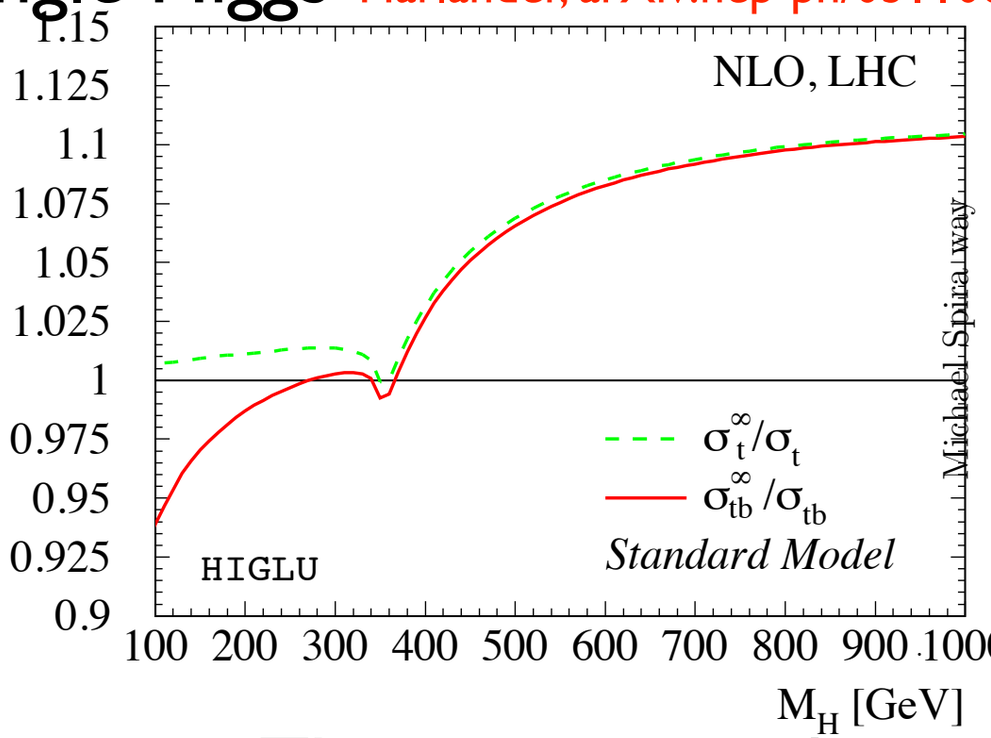

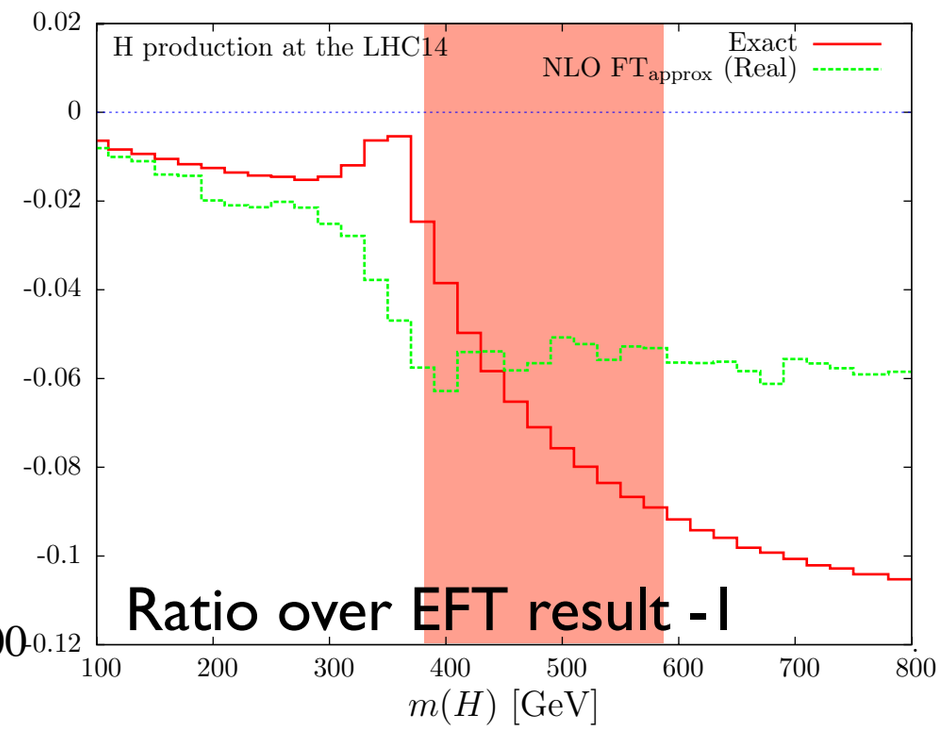

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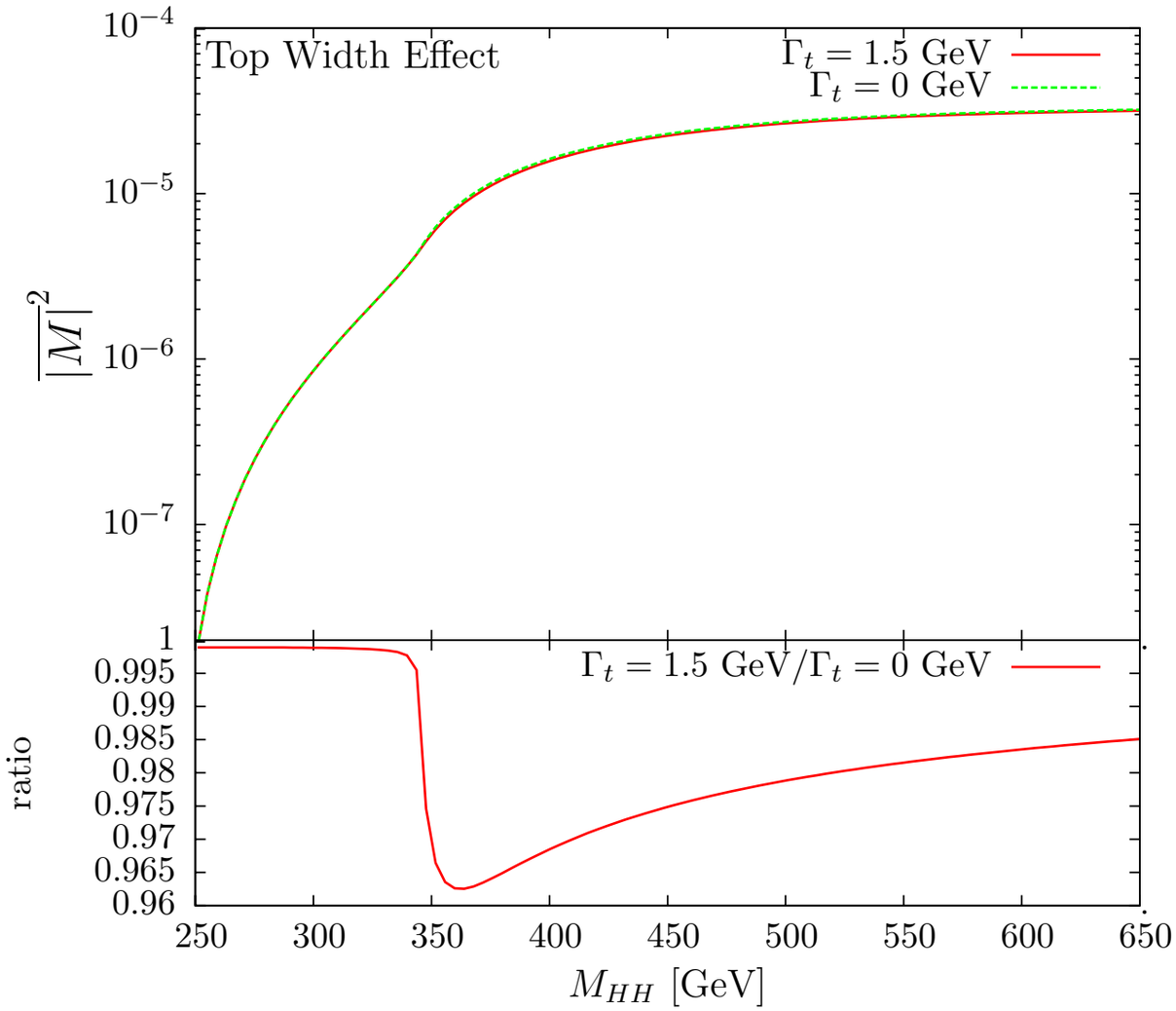
m_t uncertainties in gg→HH

- Top-mass uncertainty (in m_t and y_t) at LO and NLO:

$$\frac{\Delta\sigma}{\sigma} \simeq 0.6\% \frac{\Delta m_t}{1\text{GeV}}$$

- Beware! Width effects: -3% at the LO



Conclusions

- All HH production modes available at NLO+PS accuracy in MadGraph5_aMC@NLO
  - Codes publicly available for *all* channels
- Subdominant production modes can provide precious complimentary information on SM parameters not constrained so far: λ_{HHH}, λ_{VVHH}, …