HH production: results for YR4

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Based on arxiv:1401.7340 and 1408.6542

HH Subgroup
8/12/15

Calculation Setup

MadGraph5_aMC@NLO

PYTHIA8 for the shower for the distributions (gluon fusion)
Fixed order computation for the other channels

PDF4LHC15 sets: 100 replicas set (corrected PDF uncertainty problem)
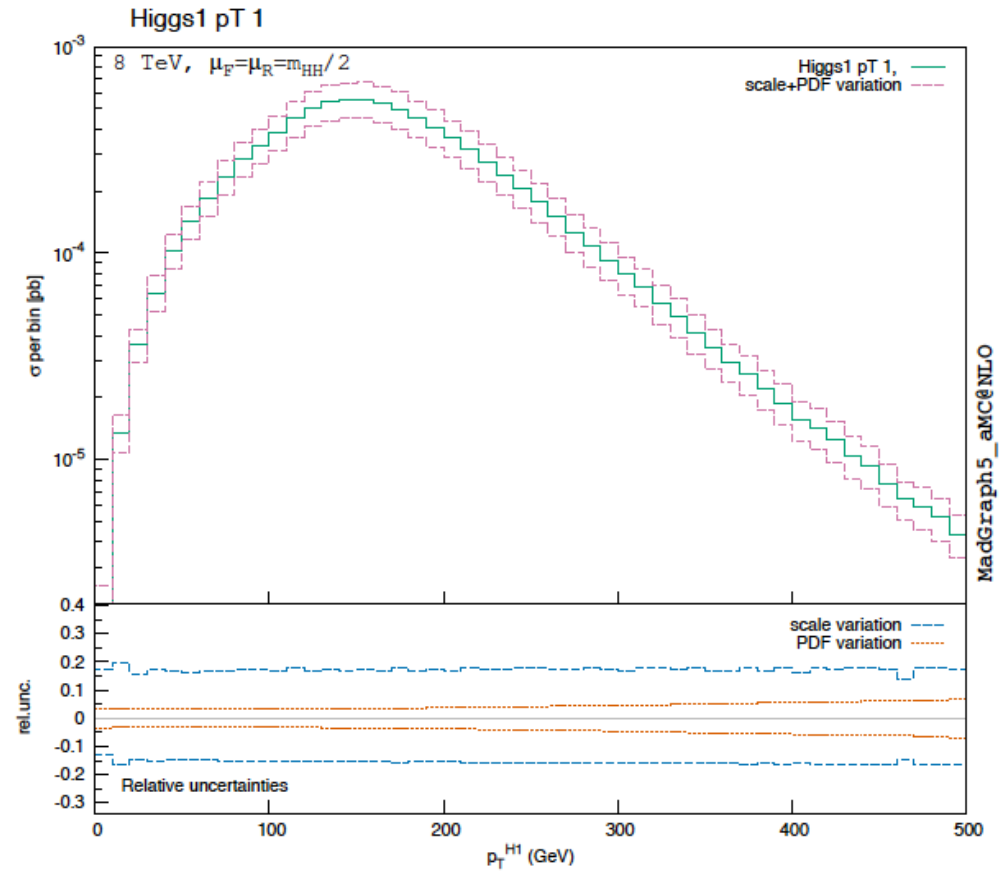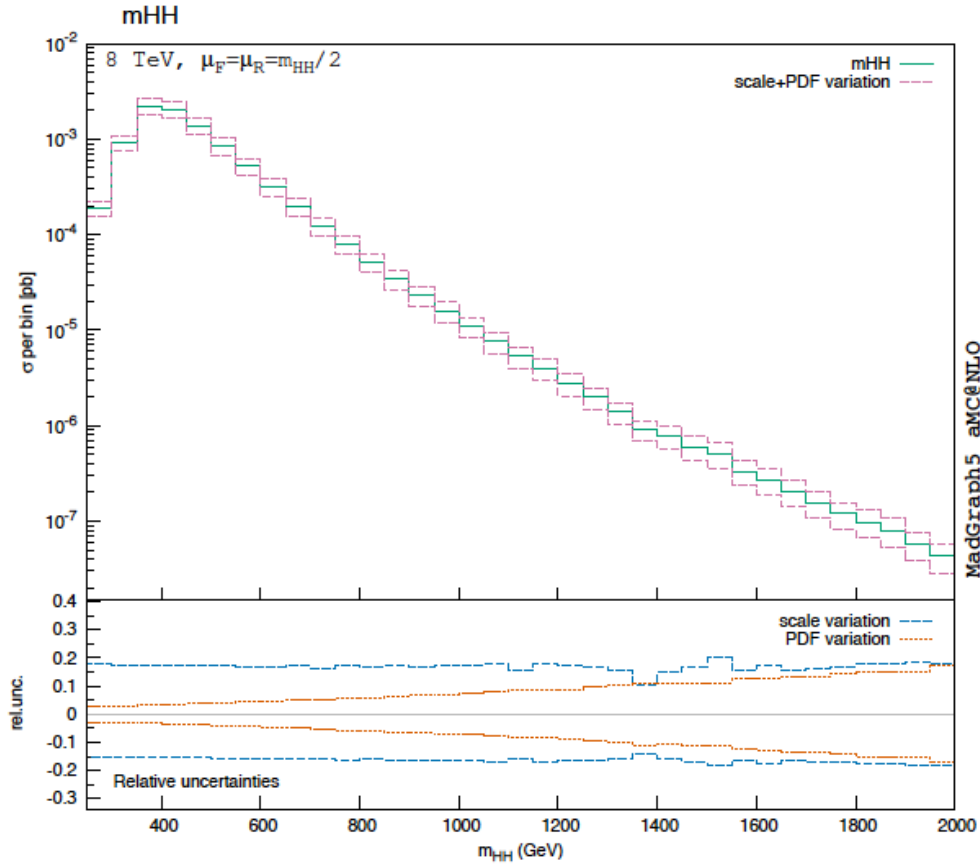
Parameters following the HXSWG recommendations:

Gluon-fusion results:

NLO-approx: Exact real emission amplitudes
                      Born-reweighted EFT for the virtual corrections
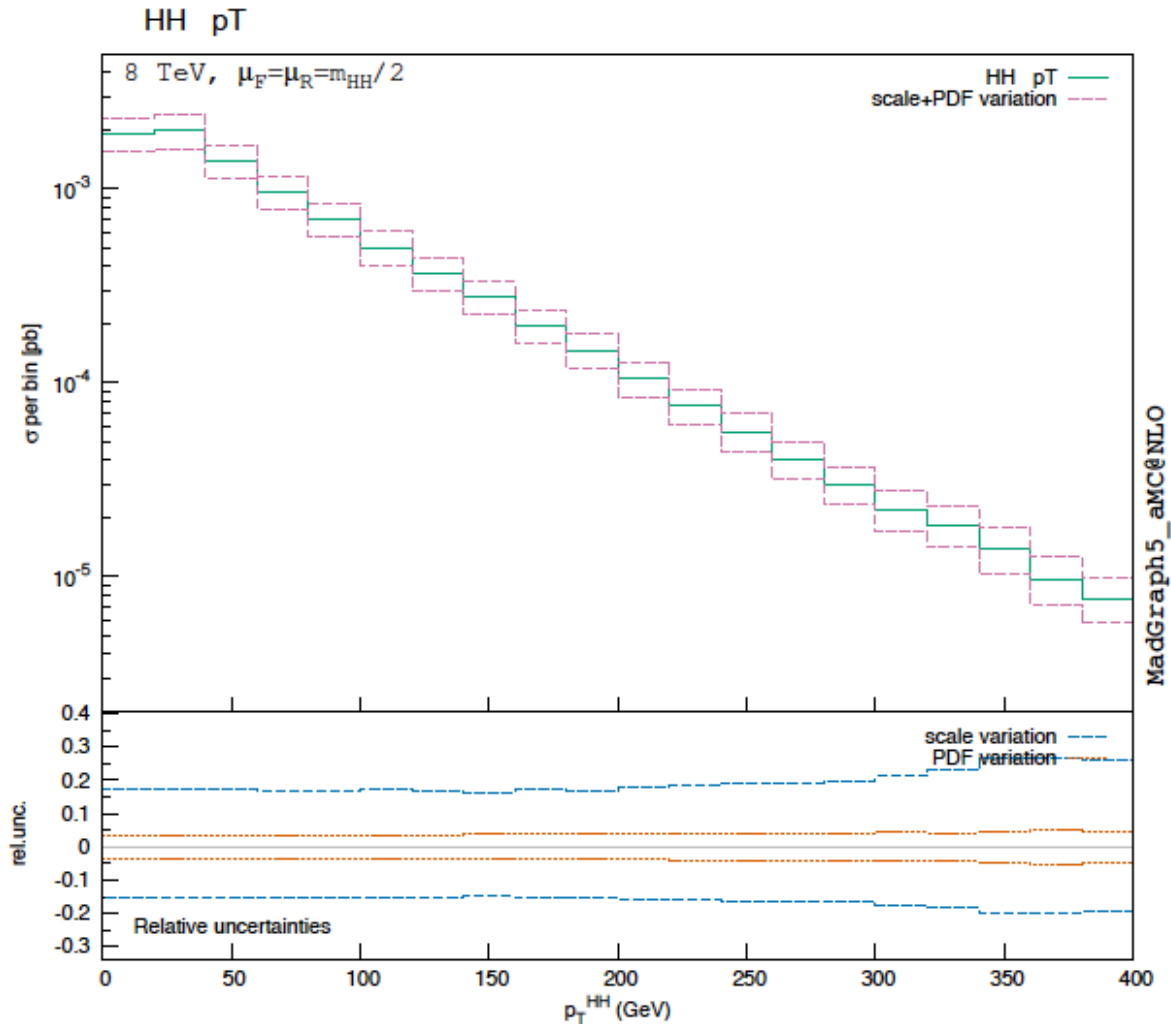
scale choices: m_{HH} and $m_{HH}/2$ for gluon fusion
                      $m_{HH}/2$ for the other channels

Results for 8 TeV
scale: $m_{HH}/2$

Scale and PDF uncertainties added linearly for upper plots
Shown separately for insets

Results for 8 TeV
scale: $m_{HH}/2$

HH pT

8 TeV, $\mu_F=\mu_R=m_{HH}/2$

HH pT
scale+PDF variation

σ per bin [pb]

MadGraph5_aMC@NLO

rel. unc.

scale variation
PDF variation

Relative uncertainties

p_T^{HH} (GeV)

Scale and PDF uncertainties added linearly for upper plots
Shown separately for insets
Other distributions can be produced if needed

4

Results for 13 TeV
scale: $m_{HH}/2$
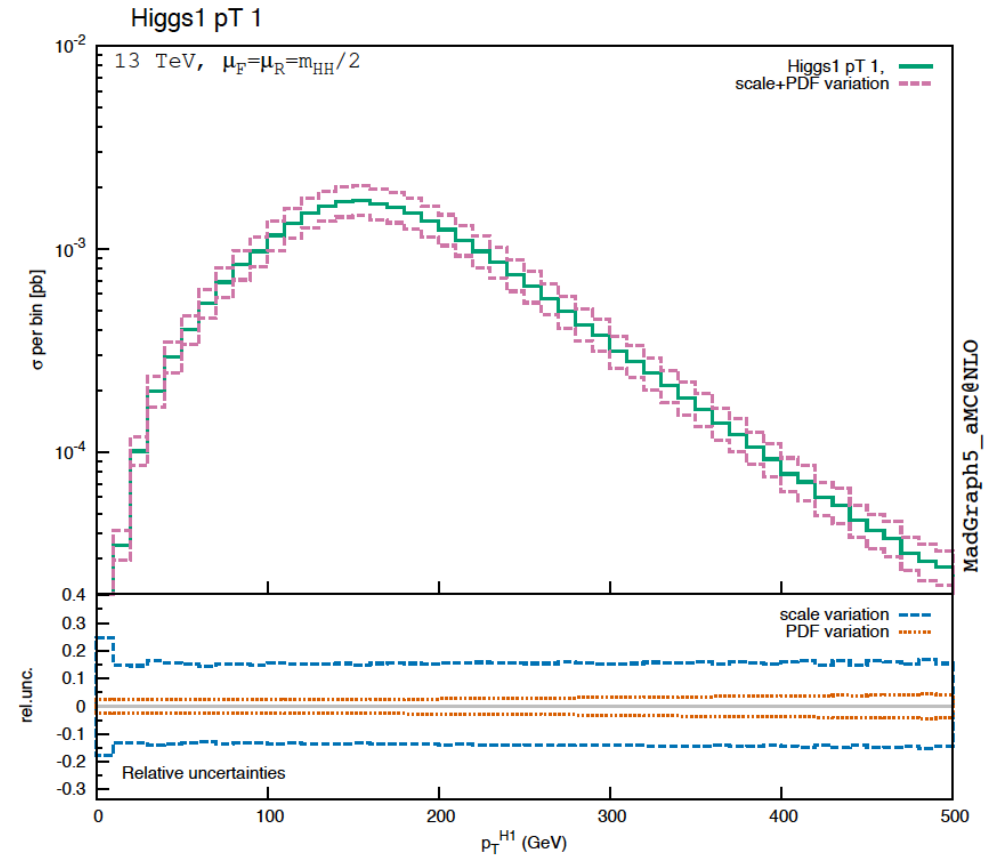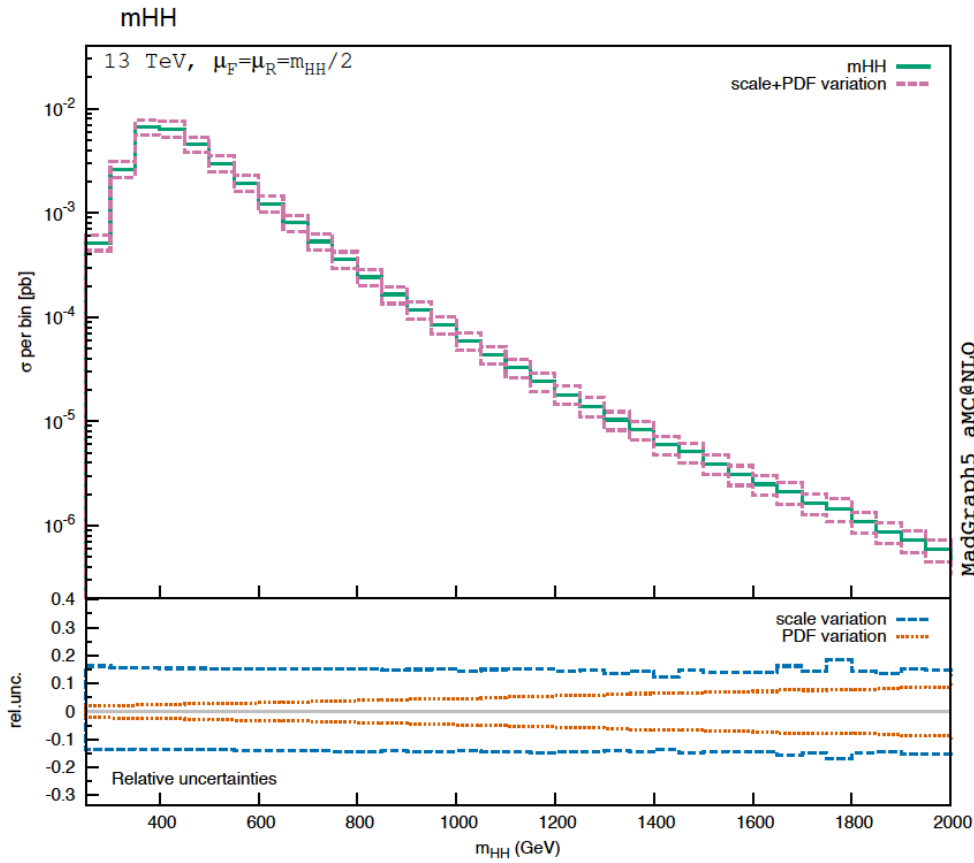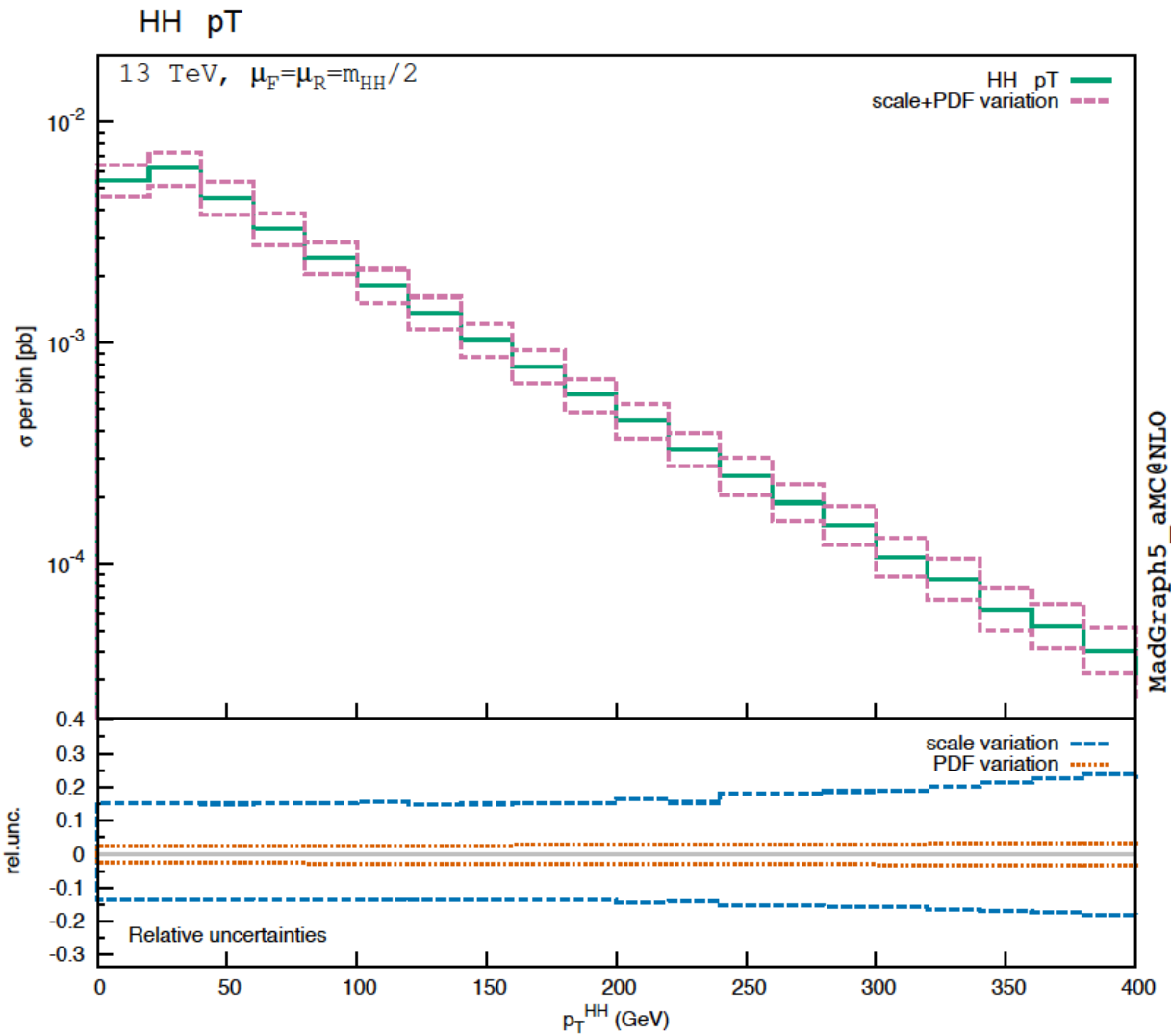

Scale and PDF uncertainties added linearly for upper plots
Shown separately for insets

Results for 13 TeV
scale: $m_{HH}/2$

Distributions for scale: m_{HH} also available

Cross sections for gluon fusion

m_H (GeV)	$\sqrt{s} = 7$ Tev	$\sqrt{s} = 8$ Tev	$\sqrt{s} = 13$ Tev	$\sqrt{s} = 14$ Tev	$\sqrt{s} = 100$ Tev
124.5	$6.17^{+17.8\%}_{-15.9\%} \pm 4.0\%$	$8.89^{+17.3\%}_{-15.4\%} \pm 3.6\%$	$29.81^{+15.5\%}_{-13.7\%} \pm 2.7\%$	$35.70^{+15.3\%}_{-13.4\%} \pm 2.6\%$	$1271^{+14.8\%}_{-14.4\%} \pm 2.1\%$
125	$6.12^{+17.7\%}_{-15.8\%} \pm 4.0\%$	$8.87^{+17.3\%}_{-15.4\%} \pm 3.6\%$	$29.76^{+15.5\%}_{-13.4\%} \pm 2.7\%$	$35.31^{+15.1\%}_{-13.4\%} \pm 2.6\%$	$1262^{+14.8\%}_{-14.4\%} \pm 2.1\%$
125.09	$6.14^{+17.7\%}_{-15.9\%} \pm 4.0\%$	$8.85^{+17.3\%}_{-15.4\%} \pm 3.6\%$	$29.75^{+15.5\%}_{-13.7\%} \pm 2.7\%$	$35.22^{+15.2\%}_{-13.4\%} \pm 2.6\%$	$1253^{+15.1\%}_{-14.5\%} \pm 2.1\%$
125.5	$6.08^{+17.8\%}_{-15.9\%} \pm 4.0\%$	$8.78^{+17.4\%}_{-15.4\%} \pm 3.6\%$	$29.69^{+15.3\%}_{-13.6\%} \pm 2.7\%$	$35.09^{+15.4\%}_{-13.5\%} \pm 2.6\%$	$1251^{+14.7\%}_{-14.3\%} \pm 2.1\%$

Table 1: Signal cross section (in fb) for $gg \to HH$ at NLO QCD.

μ_0	$\sqrt{s} = 7$ Tev	$\sqrt{s} = 8$ Tev	$\sqrt{s} = 13$ Tev	$\sqrt{s} = 14$ Tev	$\sqrt{s} = 100$ Tev
$m_{HH}/2$	$6.12^{+17.7\%}_{-15.8\%} \pm 4.0\%$	$8.87^{+17.3\%}_{-15.4\%} \pm 3.6\%$	$29.76^{+15.5\%}_{-13.4\%} \pm 2.6\%$	$35.31^{+15.1\%}_{-13.4\%} \pm 2.6\%$	$1262^{+14.8\%}_{-14.4\%} \pm 2.1\%$
m_{HH}	$5.15^{+18.9\%}_{-16.1\%} \pm 4.0\%$	$7.50^{+18.2\%}_{-15.5\%} \pm 3.6\%$	$25.70^{+15.8\%}_{-13.7\%} \pm 2.7\%$	$30.60^{+15.4\%}_{-13.4\%} \pm 2.6\%$	$1156^{+14.2\%}_{-13.3\%} \pm 2.0\%$

Table 2: Signal cross section (in fb) for $gg \to HH$ at NLO QCD for $m_H = 125$ Gev with $\mu_R = \mu_F = \mu_0$

Agreement with Javier's NLO numbers (when using the same PDF set and removing the exact exact reals ~10%):
Using the NNLO set:
For m_hh/2: 9.35fb compared to 9.32fb.
For m_hh: 7.815fb compared to 7.789fb.

HHV cross-sections
scale: $m_{HH}/2$

m_H (GeV)	$\sqrt{s} = 7$ Tev	$\sqrt{s} = 8$ Tev	$\sqrt{s} = 13$ Tev	$\sqrt{s} = 14$ Tev	$\sqrt{s} = 100$ Tev
124.5	$0.103^{+2.6\%}_{-2.2\%} \pm 2.7\%$	$0.135^{+2.4\%}_{-2.0\%} \pm 2.4\%$	$0.323^{+2.0\%}_{-1.5\%} \pm 1.8\%$	$0.364^{+2.0\%}_{-1.4\%} \pm 1.7\%$	$5.33^{+3.9\%}_{-5.8\%} \pm 1.9\%$
125	$0.102^{+2.6\%}_{-2.2\%} \pm 2.7\%$	$0.133^{+2.4\%}_{-2.0\%} \pm 2.4\%$	$0.319^{+2.1\%}_{-1.5\%} \pm 1.8\%$	$0.358^{+2.1\%}_{-1.5\%} \pm 1.7\%$	$5.28^{+3.8\%}_{-5.7\%} \pm 1.9\%$
125.09	$0.102^{+2.7\%}_{-2.4\%} \pm 2.7\%$	$0.132^{+2.7\%}_{-2.2\%} \pm 2.4\%$	$0.316^{+2.1\%}_{-1.5\%} \pm 1.8\%$	$0.357^{+1.8\%}_{-1.3\%} \pm 1.7\%$	$5.24^{+4.0\%}_{-5.8\%} \pm 1.9\%$
125.5	$0.101^{+2.5\%}_{-2.2\%} \pm 2.7\%$	$0.131^{+2.6\%}_{-2.1\%} \pm 2.4\%$	$0.314^{+2.3\%}_{-1.6\%} \pm 1.8\%$	$0.355^{+2.2\%}_{-1.6\%} \pm 1.7\%$	$5.23^{+3.9\%}_{-5.7\%} \pm 1.9\%$

Table 1: Cross section (in fb) for HHZ production at NLO QCD.

m_H (GeV)	$\sqrt{s} = 7$ Tev	$\sqrt{s} = 8$ Tev	$\sqrt{s} = 13$ Tev	$\sqrt{s} = 14$ Tev	$\sqrt{s} = 100$ Tev
124.5	$0.0531^{+2.8\%}_{-2.4\%} \pm 3.4\%$	$0.0714^{+2.4\%}_{-2.0\%} \pm 3.1\%$	$0.180^{+1.9\%}_{-1.4\%} \pm 2.3\%$	$0.205^{+1.9\%}_{-1.4\%} \pm 2.2\%$	$3.35^{+4.0\%}_{-5.7\%} \pm 2.0\%$
125	$0.0527^{+2.5\%}_{-2.2\%} \pm 3.4\%$	$0.0697^{+2.9\%}_{-2.3\%} \pm 3.1\%$	$0.177^{+1.9\%}_{-1.4\%} \pm 2.3\%$	$0.202^{+2.0\%}_{-1.4\%} \pm 2.2\%$	$3.32^{+4.1\%}_{-5.8\%} \pm 2.0\%$
125.09	$0.0524^{+2.7\%}_{-2.3\%} \pm 3.4\%$	$0.0698^{+2.7\%}_{-2.2\%} \pm 3.1\%$	$0.177^{+2.4\%}_{-1.7\%} \pm 2.3\%$	$0.201^{+2.1\%}_{-1.4\%} \pm 2.2\%$	$3.33^{+4.0\%}_{-5.7\%} \pm 2.0\%$
125.5	$0.0515^{+2.6\%}_{-2.2\%} \pm 3.4\%$	$0.0691^{+2.6\%}_{-2.1\%} \pm 3.1\%$	$0.175^{+2.3\%}_{-1.6\%} \pm 2.3\%$	$0.199^{+1.9\%}_{-1.3\%} \pm 2.2\%$	$3.25^{+3.7\%}_{-5.5\%} \pm 2.0\%$

Table 3: Signal cross section (in fb) for HHW^- at NLO QCD.

m_H (GeV)	$\sqrt{s} = 7$ Tev	$\sqrt{s} = 8$ Tev	$\sqrt{s} = 13$ Tev	$\sqrt{s} = 14$ Tev	$\sqrt{s} = 100$ Tev
124.5	$0.117^{+2.6\%}_{-2.3\%} \pm 2.8\%$	$0.149^{+2.6\%}_{-2.2\%} \pm 2.6\%$	$0.333^{+1.9\%}_{-1.3\%} \pm 2.1\%$	$0.371^{+2.0\%}_{-1.4\%} \pm 2.0\%$	$4.57^{+4.2\%}_{-5.9\%} \pm 1.9\%$
125	$0.116^{+2.5\%}_{-2.2\%} \pm 2.8\%$	$0.149^{+2.4\%}_{-2.0\%} \pm 2.6\%$	$0.330^{+1.9\%}_{-1.4\%} \pm 2.0\%$	$0.367^{+2.1\%}_{-1.5\%} \pm 2.0\%$	$4.47^{+4.1\%}_{-5.7\%} \pm 1.9\%$
125.09	$0.115^{+2.6\%}_{-2.2\%} \pm 2.8\%$	$0.147^{+2.7\%}_{-2.3\%} \pm 2.6\%$	$0.329^{+1.9\%}_{-1.4\%} \pm 2.1\%$	$0.368^{+2.1\%}_{-1.5\%} \pm 2.0\%$	$4.47^{+4.2\%}_{-5.8\%} \pm 1.9\%$
125.5	$0.114^{+2.5\%}_{-2.2\%} \pm 2.8\%$	$0.146^{+2.6\%}_{-2.2\%} \pm 2.6\%$	$0.327^{+2.3\%}_{-1.7\%} \pm 2.1\%$	$0.365^{+1.8\%}_{-1.3\%} \pm 2.0\%$	$4.44^{+3.9\%}_{-5.6\%} \pm 1.9\%$

Table 4: Signal cross section (in fb) for HHW^+ at NLO QCD.

ttHH cross-sections
scale: $m_{HH}/2$

m_H (GeV)	$\sqrt{s} = 7$ Tev	$\sqrt{s} = 8$ Tev	$\sqrt{s} = 13$ Tev	$\sqrt{s} = 14$ Tev	$\sqrt{s} = 100$ Tev
124.5		$0.176^{+2.9\%}_{-10.7\%} \pm 3.9\%$	$0.786^{+1.3\%}_{-4.5\%} \pm 3.2\%$	$0.968^{+1.7\%}_{-4.6\%} \pm 3.1\%$	$87.2^{+7.9\%}_{-7.3\%} \pm 1.6\%$
125	$0.110^{+3.5\%}_{-12.5\%} \pm 4.2\%$	$0.174^{+2.9\%}_{-10.6\%} \pm 3.9\%$	$0.775^{+1.5\%}_{-4.3\%} \pm 3.2\%$	$0.949^{+1.7\%}_{-4.5\%} \pm 3.1\%$	$82.1^{+7.9\%}_{-7.4\%} \pm 1.6\%$
125.09	$0.109^{+3.5\%}_{-12.8\%} \pm 4.2\%$	$0.174^{+2.8\%}_{-10.6\%} \pm 3.9\%$	$0.772^{+1.7\%}_{-4.5\%} \pm 3.2\%$	$0.949^{+1.8\%}_{-4.8\%} \pm 3.2\%$	$82.1^{+8.3\%}_{-7.6\%} \pm 1.6\%$
125.5	$0.107^{+3.3\%}_{-12.9\%} \pm 4.2\%$	$0.172^{+2.9\%}_{-10.4\%} \pm 4.0\%$	$0.762^{+1.3\%}_{-4.5\%} \pm 3.2\%$	$0.937^{+1.5\%}_{-4.5\%} \pm 3.1\%$	$81.9^{+8.2\%}_{-7.6\%} \pm 1.6\%$

Table 2: Cross section (in fb) for $t\bar{t}HH$ at NLO QCD.

Missing number currently running-Will be added soon

VBF cross-sections
scale: m$_{HH}$/2

m_H (GeV)	$\sqrt{s} = 7$ Tev	$\sqrt{s} = 8$ Tev	$\sqrt{s} = 13$ Tev	$\sqrt{s} = 14$ Tev	$\sqrt{s} = 100$ Tev
124.5		$0.422^{+2.3\%}_{-2.9\%} \pm 2.1\%$			
125			$1.52^{+1.6\%}_{-2.0\%} \pm 2.0\%$		
125.09			$1.51^{+1.5\%}_{-1.9\%} \pm 2.1\%$		
125.5					

Table 5: Cross section (in fb) for $HHjj$ at NLO QCD.

Missing numbers currently running-Will be added within a week

tjHH cross-sections
scale: $m_{HH}/2$

m_H (GeV)	$\sqrt{s} = 7$ Tev	$\sqrt{s} = 8$ Tev	$\sqrt{s} = 13$ Tev	$\sqrt{s} = 14$ Tev	$\sqrt{s} = 100$ Tev
124.5		$0.00551^{+5.6\%}_{-3.2\%} \pm 5.8\%$	$0.0289^{+5.4\%}_{-3.4\%} \pm 4.6\%$		$4.44^{+5.2\%}_{-5.6\%} \pm 2.3\%$
125		$0.00538^{+5.3\%}_{-3.0\%} \pm 5.6\%$	$0.0289^{+5.5\%}_{-3.6\%} \pm 4.7\%$		$4.27^{+5.0\%}_{-5.5\%} \pm 2.3\%$
125.09		$0.00540^{+5.4\%}_{-3.1\%} \pm 5.6\%$	$0.0281^{+5.2\%}_{-3.2\%} \pm 4.5\%$		
125.5		$0.00521^{+5.5\%}_{-3.4\%} \pm 5.8\%$	$0.0279^{+6.1\%}_{-4.6\%} \pm 6.4\%$		

Table 6: Signal cross section (in fb) for $HHtj$ at NLO QCD.

Missing numbers currently running-Will be added within the next week

HHH cross-sections
scale: m$_{HHH}$/2

HHH production in gluon fusion: Same setup as for HH

Exact reals-EFT virtuals

μ_0	$\sqrt{s} = 7$ Tev	$\sqrt{s} = 8$ Tev	$\sqrt{s} = 13$ Tev	$\sqrt{s} = 14$ Tev	$\sqrt{s} = 100$ Tev
$m_{HHH}/2$	$^{+\%}_{-\%} \pm \%$	$18.62^{+17.0\%}_{-15.7\%} \pm 4.8\%$	$^{+\%}_{-\%} \pm \%$	$89.15^{+14.9\%}_{-13.7\%} \pm 3.2\%$	$^{+\%}_{-\%} \pm \%$

Table 3: Signal cross section (in ab) for $gg \rightarrow HHH$ at NLO QCD for $m_H = 125$ Gev with $\mu_R = \mu_F = \mu_0$

Missing numbers currently running-Will be added within the next couple of days

Conclusions - TODO list

- Differential distributions completed
- Gluon fusion numbers in agreement with Javier's NLO numbers
- VHH, ttHH numbers complete
- VBF and single top associated production: in progress
  Should be finalised over the next week