Squaring loops

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in collaboration with
O.Mattelaer

ERC MiniWorkshop

June 2nd, 2015

OUTLINE

- The challenges of computing loop-induced matrix-elements.
- How does MadEvent now integrate them.
- Validation and what we applied it to so far.

Loop-induced: Motivation

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There is a wide range of interest for loop-induced processes, but no general way of computing them.

Need to bring a definitive solution to this.

How NLO ME's are computed?

$$\mathcal{A}_U^{(n,1)}\Big|_{\text{non-}R_2}\mathcal{A}^{(n,0)\star} =$$

$$\sum_{\text{colour}}\sum_h \left(\sum_l \lambda_l^{(1)} \int d^d\bar{\ell}\frac{\mathcal{N}_{h,l}(\ell)}{\prod_{i=0}^{m_l-1}\bar{D}_{i,l}}\right)\left(\sum_b \lambda_b^{(0)}\mathcal{B}_{h,b}\right)^\star$$

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$$= \sum_h\sum_l\sum_b \text{Red}\left[\int d^d\bar{\ell}\frac{\mathcal{N}_{h,l}(\ell)}{\prod_{i=0}^{m_l-1}\bar{D}_{i,l}}\right]\Lambda_{lb}\mathcal{B}^\star_{h,b}$$

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$$= \sum_t \text{Red}\left[\int d^d\bar{\ell}\frac{\sum_h\sum_{l\in t}\sum_b \mathcal{N}_{h,l}(\ell)\Lambda_{lb}\mathcal{B}^\star_{h,b}}{\prod_{i=0}^{m_t-1}\bar{D}_{i,t}}\right]$$

How Loop-Induced ME's are computed

$$\left|\mathcal{A}^{LI}\right|^2 = \left|\mathcal{A}^{LI}_{\text{non-}R_2}\right|^2 + 2\Re\left(\mathcal{A}^{LI}_{\text{non-}R_2}\mathcal{A}^{LI*}_{R_2}\right) + \left|\mathcal{A}^{LI}_{R_2}\right|^2$$

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- A) The number of terms in this squaring is 'L·L' (It was 'L·B' for NLO MEs).

- B) Impossible to do reduction at the squared amplitude level in this case.
  The number of calls to Red[] scales like 'L·H' (It was 'T' for NLO MEs)

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Solution : Project onto color flows (i.e. use partial color amplitudes)

$$\lambda_l = \sum_{i=1,K} \underbrace{(\lambda_l \otimes \kappa_i)}_{\alpha_{l,i}} \kappa_i . \qquad \sum_{\text{color}} \kappa_i \kappa_j^* = K_{ij}$$

$$\left| \mathcal{A}^{LI}_{\text{non-}R_2} \right|^2 = \sum_{h=1,H} \sum_{i=1,K} \sum_{j=1,K} \left(J_{i,h} J^*_{j,h} K_{i,j} \right)$$

$$J_{j,h} := \sum_{l=1,L} \alpha_{i,l} \tilde{L}_{l,h}$$

$$\tilde{L}_{l,h} := \text{Red}\left[\frac{\mathcal{N}_{l,h}(\ell)}{\prod_{i=0}^{m_l-1} \bar{D}_{i,l}} \right]$$

Perks of color flows

- Necessary for event color assignation for loop-induced processes with MadEvent.
- Allessandro Brogio (@PSI) could use this at NLO to build SCET NLO hard functions (for t t h)
- For the matrix-element improved shower program VINCIA.
- In a matched computation when using a fixed-color ME generator such as COMIX for both reals AND subtraction terms.
- MadLoop keeps track of the 'split orders' in the partial color amplitudes, so that mixed expansions or interference computations are possible.
- The implementation of MadLoop CFA computation is now complete and tested. If there is interest for this, the next step is to provide and optimized computation of target color Flows/Configurations.
- In general, it increases MadLoop flexibility, and also,

  Prospects for pushing the Colourful FKS idea further !

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Solution B1 : Perform MC over helicity config (and stick to OPP).

Solution B2 : Use the so-called ‘open-loop’ decomposition and reduce with TIR.

$$\left\{ T^{(r),\mu_1\cdots\mu_r} \equiv \int d^d\bar{\ell}\, \frac{\ell^{\mu_1}\ldots\ell^{\mu_r}}{\prod_{i=0}^{m_{l_t}-1}\bar{D}_{i,l_t}}\,,\; C^{(r)}_{\mu_1\ldots\mu_r;h,l} \right\}_{r=0}^{r_{\max}}$$

The tensor coefficients must be computed once only and can then be recycled for all helicity configuration

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- Which one is best? It depends on:
  A) How faster OPP is w.r.t. TIR.
  B) How good is the Monte-Carlo sampling over helicity configurations

OPP vs TIR

	$gg \to hh$	$gg \to hhg$	$gg \to hhgg$	$gg \to hggg$
# loop Feynman diagrams	16	108	952	2040
# topologies	8	54	380	540
# indep. non-zero hel. configs.	2	8	16	32
Generation time	8.7s	21s	269s	1h36m
Output code size	0.5 Mb	0.7 Mb	1.8 Mb	3.2 Mb
Runtime RAM usage	4.7 Mb	20.5 Mb	102 Mb	240 Mb
Run time (OPP, single hel.)	2.6ms (81%)	40.7ms (84%)	859ms (83%)	1.27s (85%)
Run time (IREGI, single hel.)	17.5ms (97%)	1.14s (99%)	65s (100%)	70s (100%)
Run time (PJFry, single hel.)	3.2ms (85%)	190ms (96%)	29s (100%)	30s (100%)
Run time (Golem95, single hel.)	15.1ms (97%)	615ms (99%)	18s (99%)	19s (99%)
Run time (OPP, hel. summed)	5.2ms (82%)	328ms (85%)	14.7s (81%)	41s (86%)
Run time (IREGI, hel. summed)	18.4ms (95%)	1.19s (96%)	68.2s (96%)	75.6s (92%)
Run time (PJFry, hel. summed)	3.8ms (75%)	243ms (79%)	30.5s (91%)	33.7s (83%)

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- OPP with **efficient** MC over helicity configurations is clearly the dominant approach.

[Words of caution: TIR could in principle be optimized further by recycling the result for loops sharing topologies or even across topologies]

ENHANCED PARALLELIZATION

Slide by O.Mattelaer.

MadEvent

$$|M|^2 = \frac{|M_1|^2}{|M_1|^2 + |M_2|^2}|M|^2 + \frac{|M_2|^2}{|M_1|^2 + |M_2|^2}|M|^2$$

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- Iteration 2
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ENHANCED PARALLELIZATION

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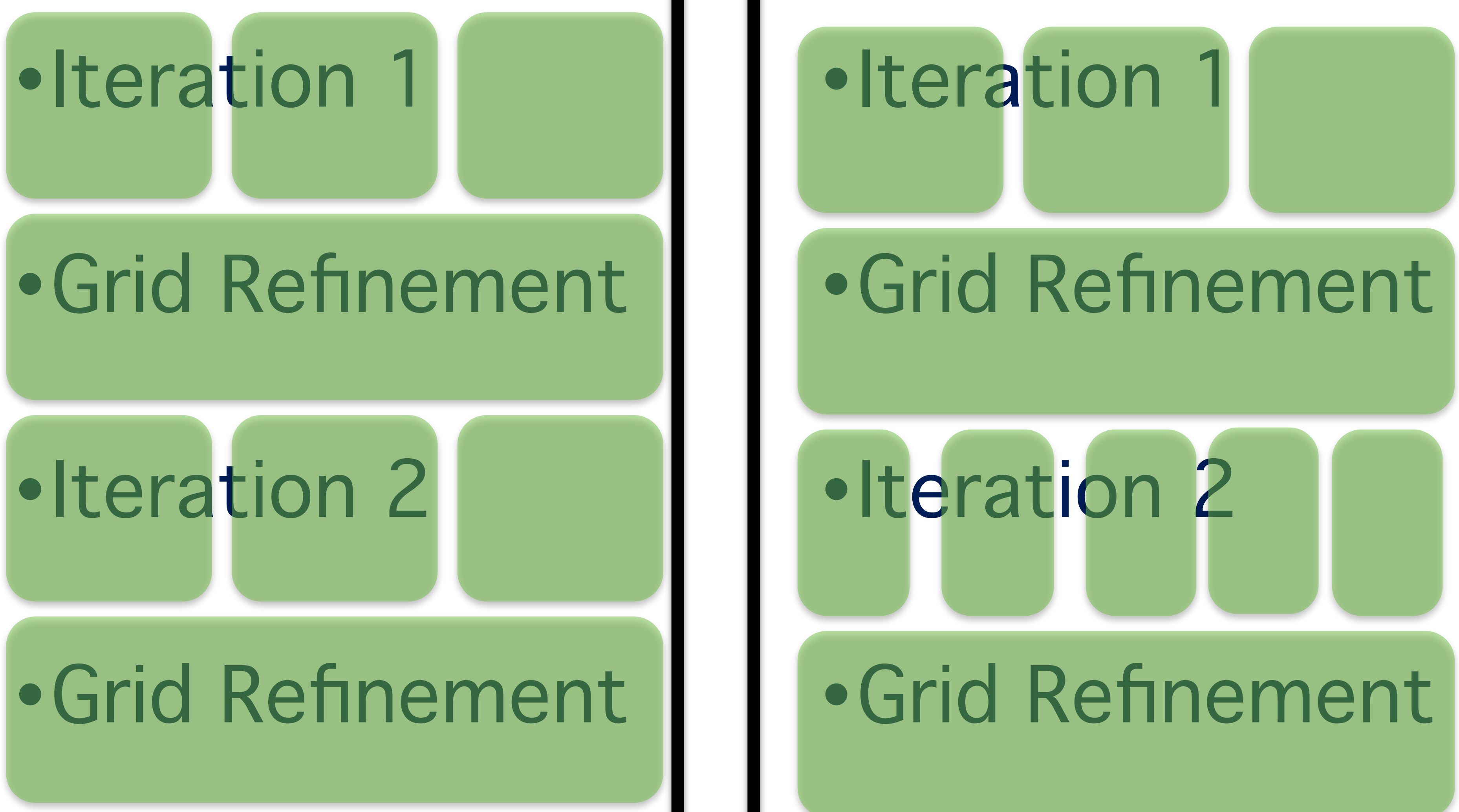
New MadEvent

$$\int |M|^2 = \int \frac{|M_1|^2}{|M_1|^2 + |M_2|^2}|M|^2 + \int \frac{|M_2|^2}{|M_1|^2 + |M_2|^2}|M|^2$$



Simplest example

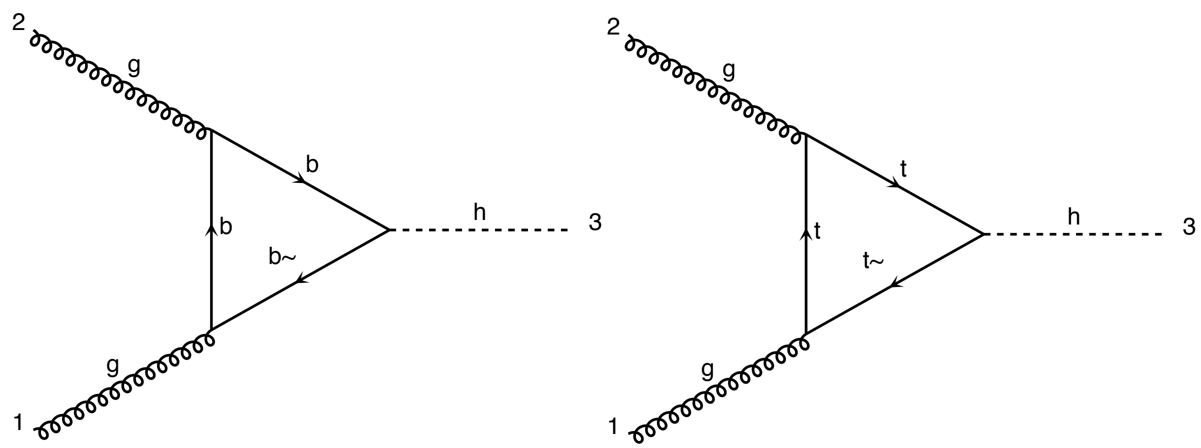
Slide by O.Mattelaer.

User Input

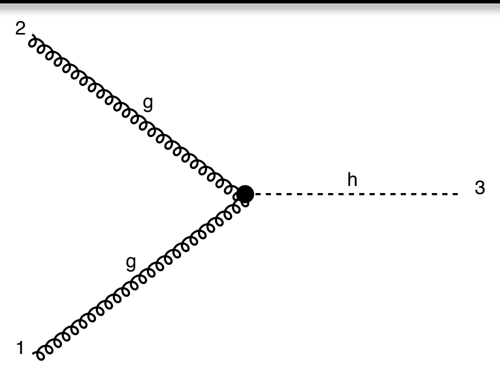
- generate g g > h [QCD]
- output
- launch

Loop Induced

$$\sigma_{loop} = 15.74(2)pb$$



HEFT



$$\sigma_{heft} = 17.63(2)pb$$

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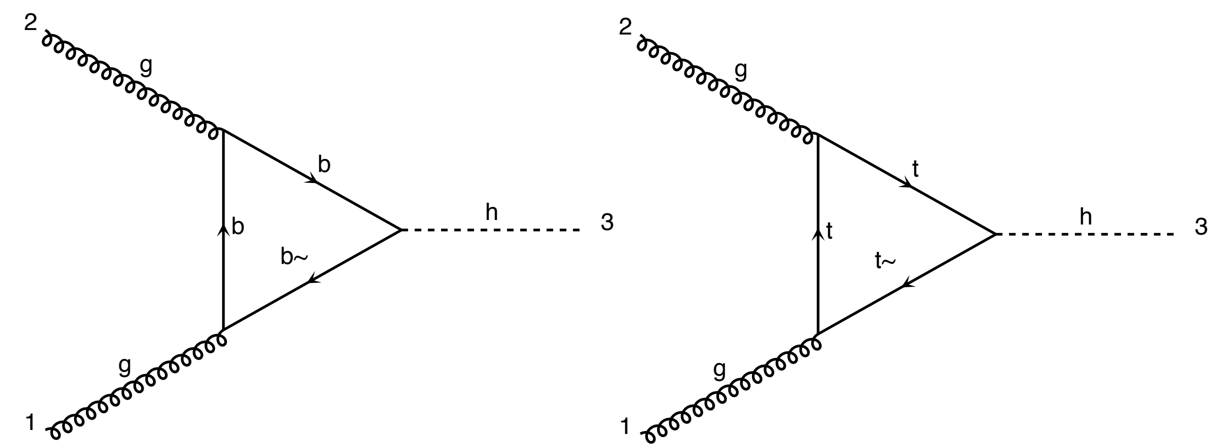
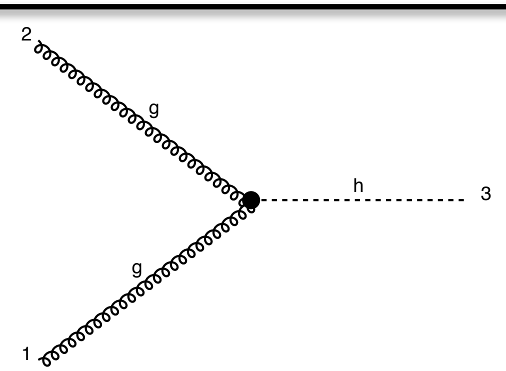
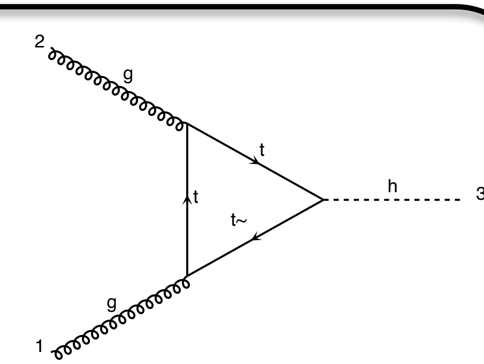


HEFT



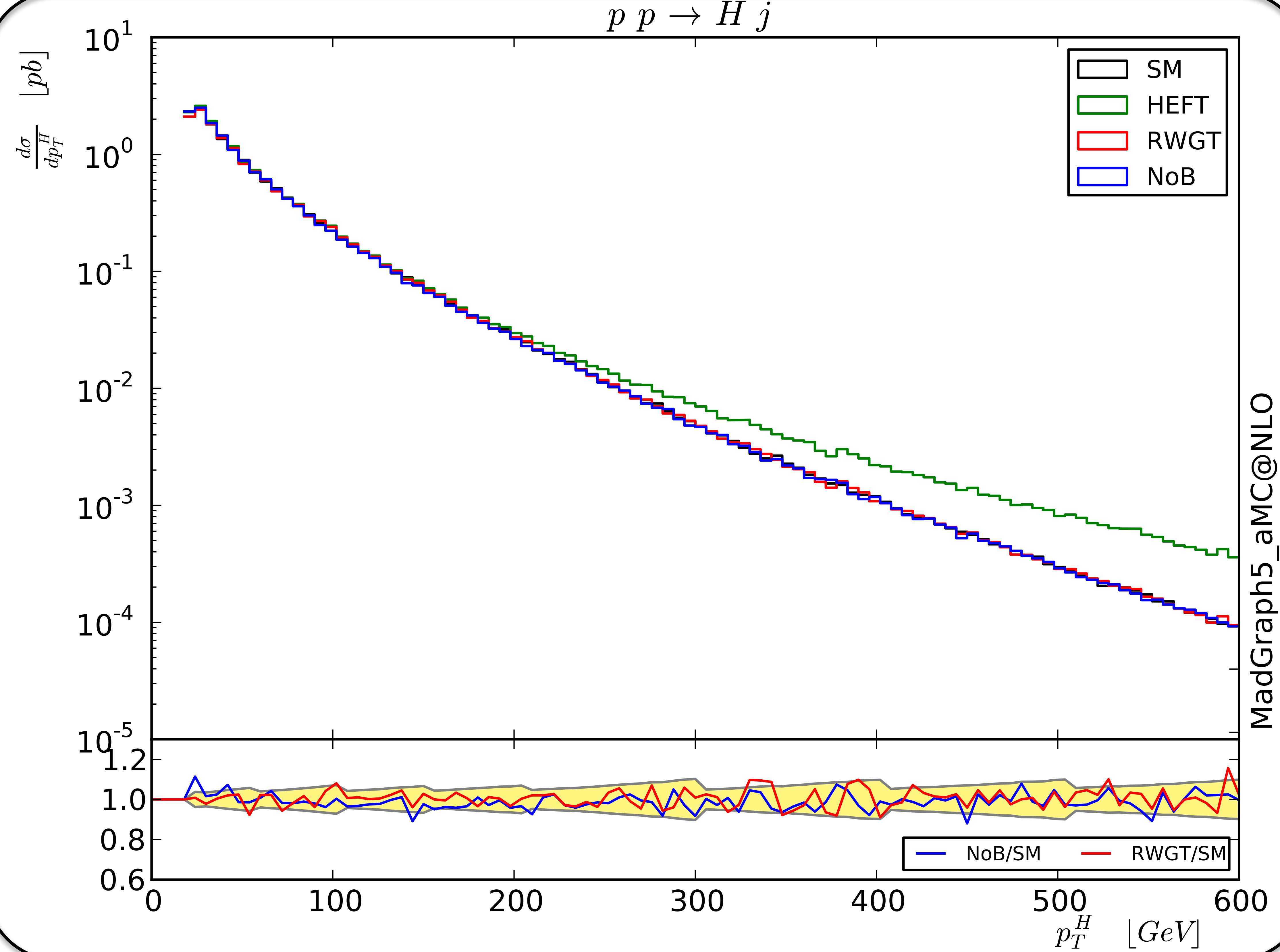
$$\sigma_{heft} = 17.63(2)pb$$

No bottom loop



$$\sigma_{toploop} = 17.65(2)pb$$

Validation p p > H j



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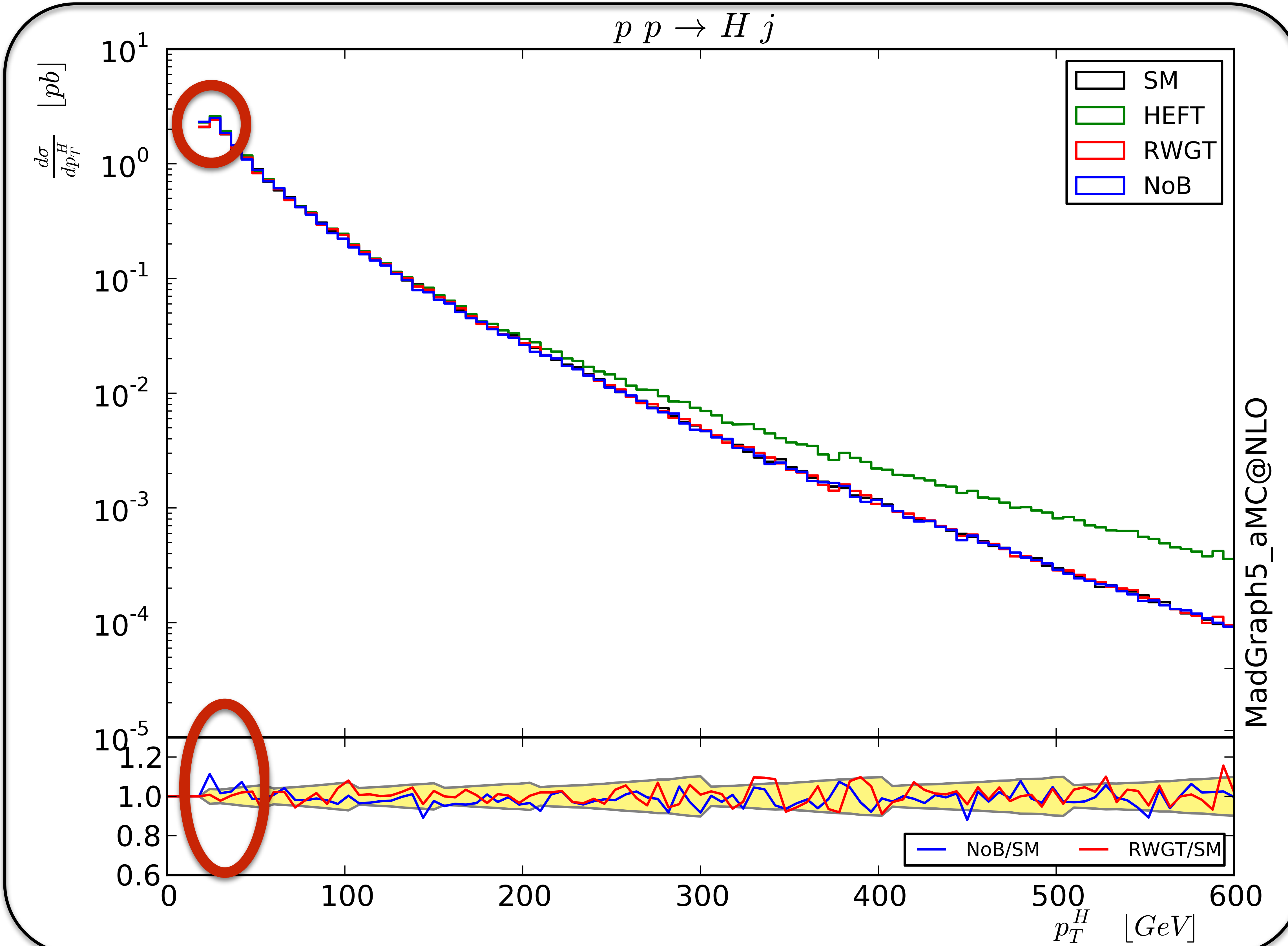

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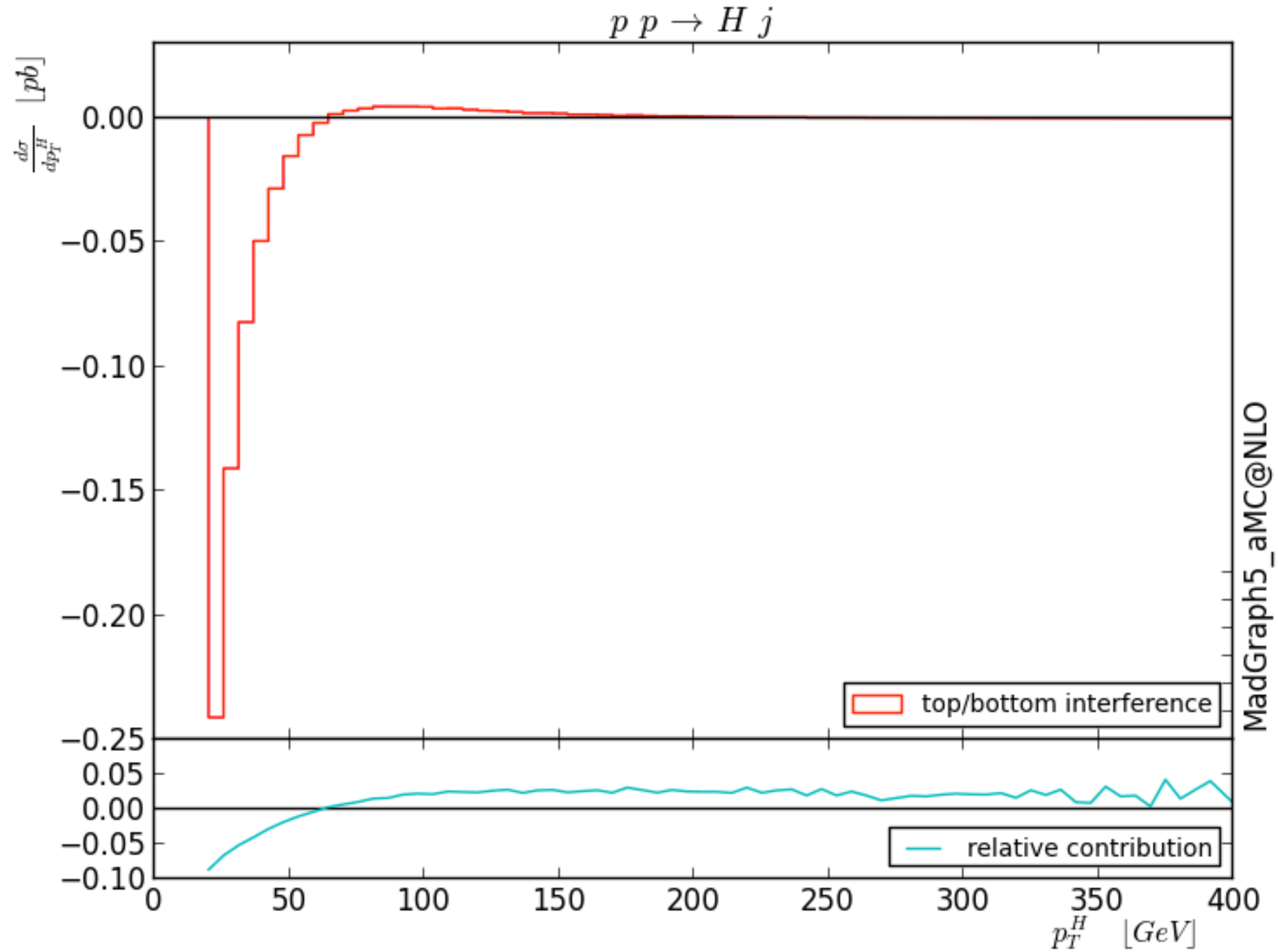
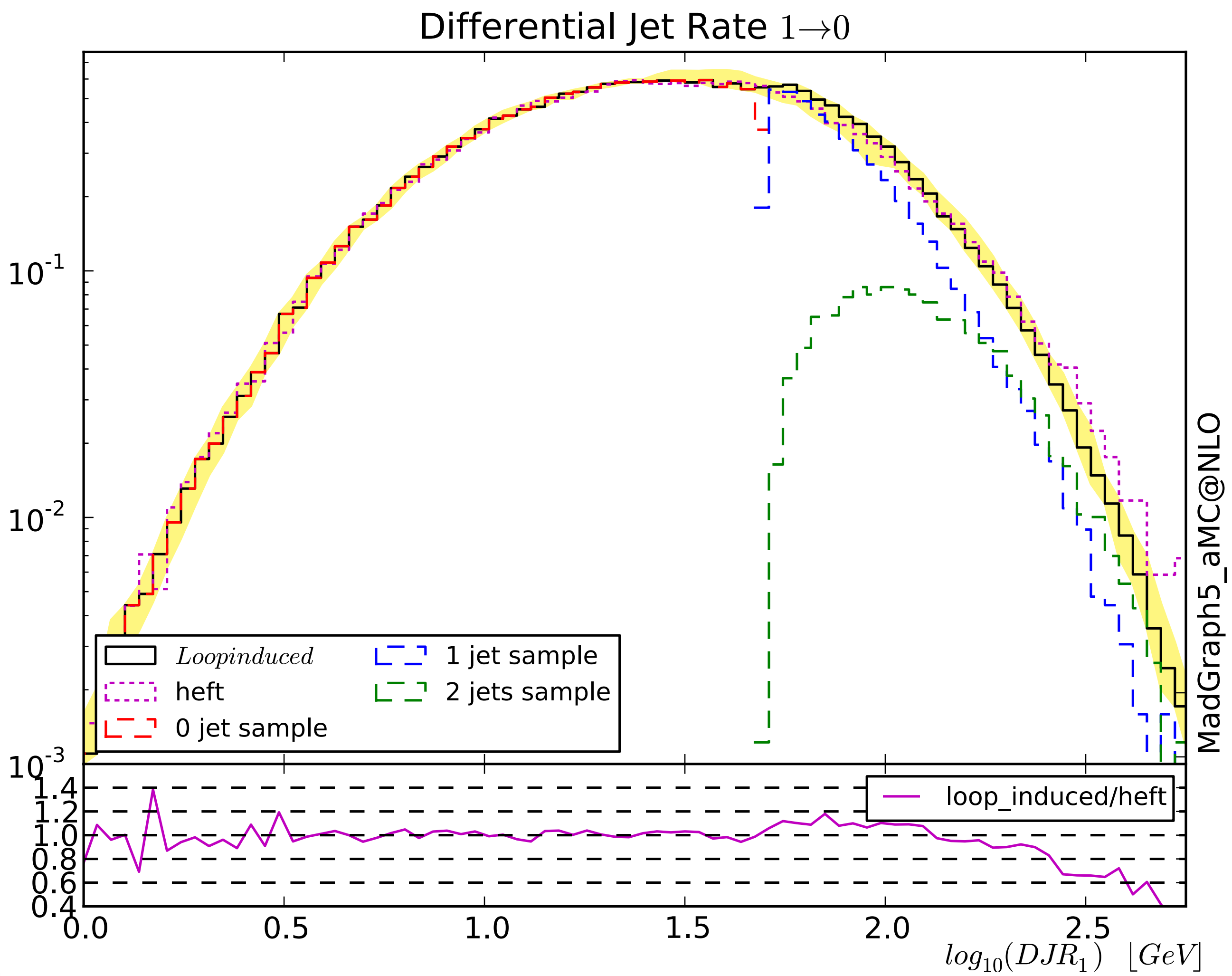
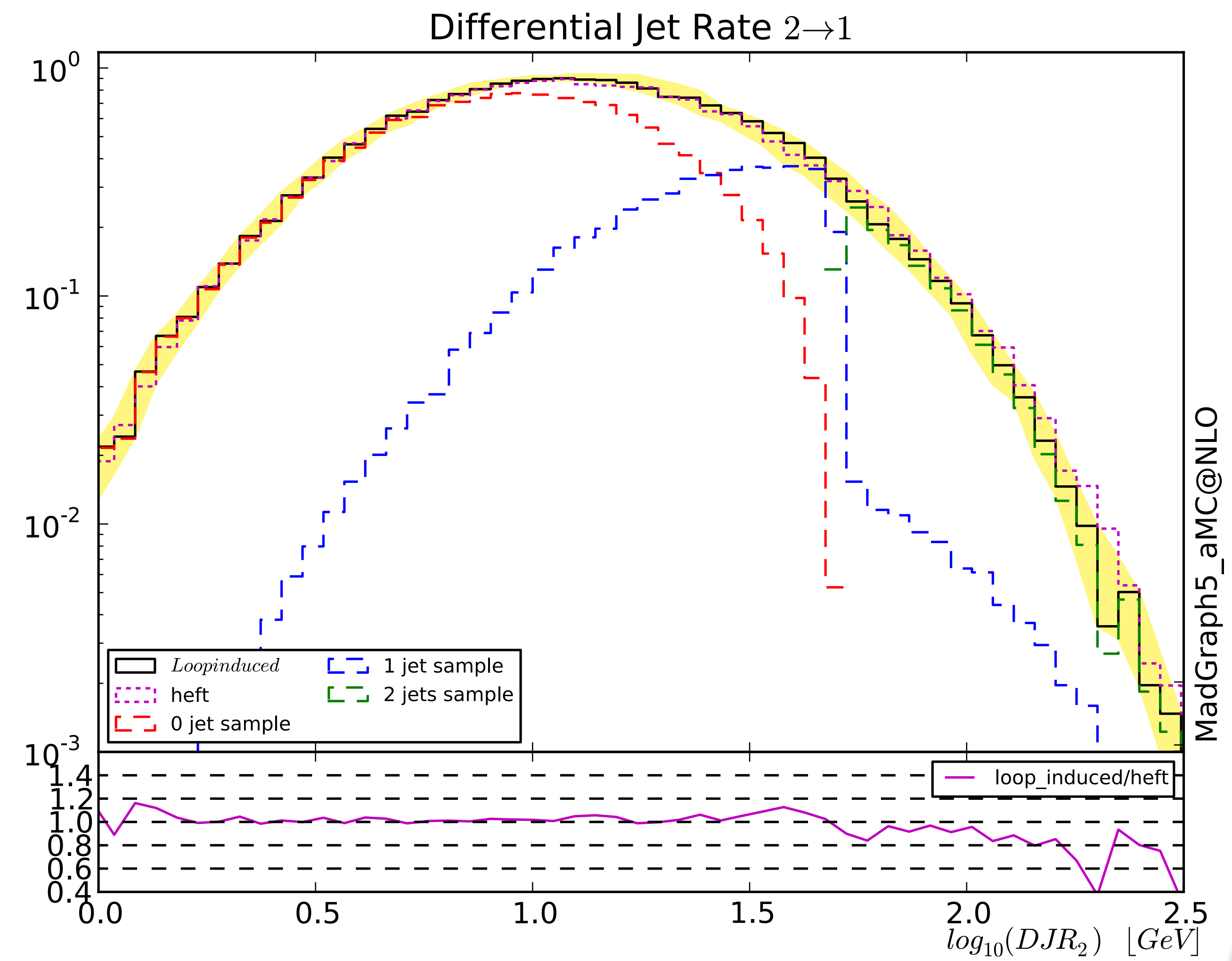


Important b-mass effects at low-pt but the expected **naive rescaling at high-pt**

Matching / Merging

KT MLM





$$Q_{match} = 50GeV$$

BSM: Z+A/H

Exact Phase-Space integration

	$gg \to Zh^0$	$gg \to ZH^0$	$gg \to ZA^0$
B1	$113.6\ ^{+28.9\%}_{-21.2\%}\ ^{+1.0\%}_{-1.2\%}$	$682.4\ ^{+29.6\%}_{-21.5\%}\ ^{+1.2\%}_{-1.2\%}$	$0.6203\ ^{+32.5\%}_{-23.0\%}\ ^{+1.9\%}_{-1.9\%}$
B2	$85.59\ ^{+29.9\%}_{-21.4\%}\ ^{+1.4\%}_{-1.1\%}$	$1545\ ^{+30.1\%}_{-21.8\%}\ ^{+1.3\%}_{-1.3\%}$	$0.8614\ ^{+33.0\%}_{-23.3\%}\ ^{+2.0\%}_{-2.0\%}$
B3	$169.9\ ^{+28.1\%}_{-19.9\%}\ ^{+1.4\%}_{-0.5\%}$	$0.8968\ ^{+31.2\%}_{-22.3\%}\ ^{+1.5\%}_{-1.6\%}$	$1317\ ^{+28.4\%}_{-20.8\%}\ ^{+1.0\%}_{-1.0\%}$

Reweighting (1503.01656)

	$gg \to Zh^0$	$gg \to ZH^0$	$gg \to ZA^0$
B1	$113\ ^{+30\%}_{-21\%}$	$686\ ^{+30\%}_{-22\%}$	$0.622\ ^{+32\%}_{-23\%}$
B2	$85.8\ ^{+30.1\%}_{-21\%}$	$1544\ ^{+30\%}_{-22\%}$	$0.869\ ^{+34\%}_{-23\%}$
B3	$167\ ^{+31\%}_{-19\%}$	$0.891\ ^{+33\%}_{-21\%}$	$1325\ ^{+28\%}_{-21\%}$

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	$gg \to Zh^0$			$gg \to ZH^0$			$gg \to ZA^0$		
B1	113.6	$^{+28.9\%}_{-21.2\%}$	$^{+1.0\%}_{-1.2\%}$	682.4	$^{+29.6\%}_{-21.5\%}$	$^{+1.2\%}_{-1.2\%}$	0.6203	$^{+32.5\%}_{-23.0\%}$	$^{+1.9\%}_{-1.9\%}$
B2	85.59	$^{+29.9\%}_{-21.4\%}$	$^{+1.4\%}_{-1.1\%}$	1545	$^{+30.1\%}_{-21.8\%}$	$^{+1.3\%}_{-1.3\%}$	0.8614	$^{+33.0\%}_{-23.3\%}$	$^{+2.0\%}_{-2.0\%}$
B3	169.9	$^{+28.1\%}_{-19.9\%}$	$^{+1.4\%}_{-0.5\%}$	0.8968	$^{+31.2\%}_{-22.3\%}$	$^{+1.5\%}_{-1.6\%}$	1317	$^{+28.4\%}_{-20.8\%}$	$^{+1.0\%}_{-1.0\%}$

Reweighting (1503.01656)

	$gg \to Zh^0$	$gg \to ZH^0$	$gg \to ZA^0$
B1	$113\ ^{+30\%}_{-21\%}$	$686\ ^{+30\%}_{-22\%}$	$0.622\ ^{+32\%}_{-23\%}$
B2	$85.8\ ^{+30.1\%}_{-21\%}$	$1544\ ^{+30\%}_{-22\%}$	$0.869\ ^{+34\%}_{-23\%}$
B3	$167\ ^{+31\%}_{-19\%}$	$0.891\ ^{+33\%}_{-21\%}$	$1325\ ^{+28\%}_{-21\%}$

BSM: Z+A/H

Exact Phase-Space integration

	$gg \to Zh^0$			$gg \to ZH^0$			$gg \to ZA^0$		
B1	113.6	$^{+28.9\%}_{-21.2\%}$	$^{+1.0\%}_{-1.2\%}$	682.4	$^{+29.6\%}_{-21.5\%}$	$^{+1.2\%}_{-1.2\%}$	0.6203	$^{+32.5\%}_{-23.0\%}$	$^{+1.9\%}_{-1.9\%}$
B2	85.59	$^{+29.9\%}_{-21.4\%}$	$^{+1.4\%}_{-1.1\%}$	1545	$^{+30.1\%}_{-21.8\%}$	$^{+1.3\%}_{-1.3\%}$	0.8614	$^{+33.0\%}_{-23.3\%}$	$^{+2.0\%}_{-2.0\%}$
B3	169.9	$^{+28.1\%}_{-19.9\%}$	$^{+1.4\%}_{-0.5\%}$	0.8968	$^{+31.2\%}_{-22.3\%}$	$^{+1.5\%}_{-1.6\%}$	1317	$^{+28.4\%}_{-20.8\%}$	$^{+1.0\%}_{-1.0\%}$

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B1	113 $^{+30\%}_{-21\%}$	686 $^{+30\%}_{-22\%}$	0.622 $^{+32\%}_{-23\%}$
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B3	167 $^{+31\%}_{-19\%}$	0.891 $^{+33\%}_{-21\%}$	1325 $^{+28\%}_{-21\%}$

[Finally, also independent cross-check against p p > (h>) z z with MadLoop+Sherpa]

SM Tables (I)

Process		Syntax	Cross section (pb)	$\Delta_{\hat{\mu}}$	Δ_{PDF}
Single boson + jets			13 TeV		
a.1	$pp \to H$	`p p > h [QCD]`	17.79 ± 0.060	$^{+31.3\%}_{-23.1\%}$	$^{+0.7\%}_{-1.0\%}$
a.2	$pp \to Hj$	`p p > h j [QCD]`	12.86 ± 0.030	$^{+42.3\%}_{-27.7\%}$	$^{+0.6\%}_{-0.9\%}$
a.3	$pp \to Hjj$	`p p > h j j QED=1 [QCD]`	6.175 ± 0.020	$^{+61.8\%}_{-35.6\%}$	$^{+0.9\%}_{-0.9\%}$
a.4	$gg \to Zg$	`g g > z g [QCD]`	43.05 ± 0.060	$^{+43.7\%}_{-28.4\%}$	$^{+0.7\%}_{-1.0\%}$
a.5	$gg \to Zgg$	`g g > z g g [QCD]`	20.85 ± 0.030	$^{+64.5\%}_{-36.5\%}$	$^{+1.2\%}_{-1.2\%}$
a.6	$gg \to \gamma g$	`g g > a g [QCD]`	75.61 ± 0.200	$^{+73.8\%}_{-41.6\%}$	$^{+0.8\%}_{-1.1\%}$
a.7	$gg \to \gamma gg$	`g g > a g g [QCD]`	14.50 ± 0.030	$^{+76.2\%}_{-40.7\%}$	$^{+0.8\%}_{-1.1\%}$

SM Tables (I)

Process Single boson + jets		Syntax	Cross section (pb) 13 TeV	$\Delta_{\hat{\mu}}$	Δ_{PDF}
a.1	$pp \to H$	`p p > h [QCD]`	17.79 ± 0.060	$^{+31.3\%}_{-23.1\%}$	$^{+0.7\%}_{-1.0\%}$
a.2	$pp \to Hj$	`p p > h j [QCD]`	12.86 ± 0.030	$^{+42.3\%}_{-27.7\%}$	$^{+0.6\%}_{-0.9\%}$
a.3	$pp \to Hjj$	`p p > h j j QED=1 [QCD]`	6.175 ± 0.020	$^{+61.8\%}_{-35.6\%}$	$^{+0.9\%}_{-0.9\%}$
a.4	$gg \to Zg$	`g g > z g [QCD]`	43.05 ± 0.060	$^{+43.7\%}_{-28.4\%}$	$^{+0.7\%}_{-1.0\%}$
a.5	$gg \to Zgg$	`g g > z g g [QCD]`	20.85 ± 0.030	$^{+64.5\%}_{-36.5\%}$	$^{+1.2\%}_{-1.2\%}$
a.6	$gg \to \gamma g$	`g g > a g [QCD]`	75.61 ± 0.200	$^{+73.8\%}_{-41.6\%}$	$^{+0.8\%}_{-1.1\%}$
a.7	$gg \to \gamma gg$	`g g > a g g [QCD]`	14.50 ± 0.030	$^{+76.2\%}_{-40.7\%}$	$^{+0.8\%}_{-1.1\%}$

Process Double bosons + jet		Syntax	Cross section (pb) 13 TeV	$\Delta_{\hat{\mu}}$	Δ_{PDF}
b.1	$pp \to HH$	`p p > h h [QCD]`	$1.641 \pm 0.002 \cdot 10^{-2}$	$^{+30.2\%}_{-21.7\%}$	$^{+1.3\%}_{-1.3\%}$
b.2	$pp \to HHj$	`p p > h h j [QCD]`	$1.758 \pm 0.003 \cdot 10^{-2}$	$^{+45.7\%}_{-29.2\%}$	$^{+1.4\%}_{-1.4\%}$
b.3	$pp \to H\gamma j$	`p p > h a j [QCD]`	$4.225 \pm 0.006 \cdot 10^{-3}$	$^{+38.6\%}_{-25.9\%}$	$^{+0.5\%}_{-0.8\%}$
b.4	$gg \to HZ$	`g g > h z [QCD]`	$6.537 \pm 0.030 \cdot 10^{-2}$	$^{+29.4\%}_{-21.3\%}$	$^{+1.2\%}_{-1.2\%}$
b.5	$gg \to HZg$	`g g > h z g [QCD]`	$5.465 \pm 0.020 \cdot 10^{-2}$	$^{+46.0\%}_{-29.4\%}$	$^{+1.5\%}_{-1.6\%}$
b.6	$gg \to ZZ$	`g g > z z [QCD]`	1.313 ± 0.004	$^{+27.1\%}_{-20.1\%}$	$^{+0.8\%}_{-1.0\%}$
b.7	$gg \to ZZg$	`g g > z z g [QCD]`	0.6361 ± 0.002	$^{+45.4\%}_{-29.1\%}$	$^{+1.2\%}_{-1.2\%}$
b.8	$gg \to Z\gamma$	`g g > z a [QCD]`	1.265 ± 0.0007	$^{+30.2\%}_{-22.2\%}$	$^{+0.9\%}_{-1.1\%}$
b.9	$gg \to Z\gamma g$	`g g > z a g [QCD]`	0.4604 ± 0.001	$^{+43.7\%}_{-28.4\%}$	$^{+0.7\%}_{-1.0\%}$
b.10	$gg \to \gamma\gamma$	`g g > a a [QCD]`	$5.182 \pm 0.010 \cdot 10^{+2}$	$^{+72.3\%}_{-43.4\%}$	$^{+1.2\%}_{-1.5\%}$
b.11	$gg \to \gamma\gamma g$	`g g > a a g [QCD]`	19.22 ± 0.030	$^{+59.7\%}_{-35.7\%}$	$^{+0.9\%}_{-1.2\%}$
b.12	$gg \to W^+W^+$	`g g > w+ w- [QCD]`	4.099 ± 0.010	$^{+26.5\%}_{-19.7\%}$	$^{+0.7\%}_{-1.0\%}$
b.13	$gg \to W^+W^-g$	`g g > w+ w- g [QCD]`	1.837 ± 0.004	$^{+45.2\%}_{-29.0\%}$	$^{+1.1\%}_{-1.1\%}$

SM Tables (II)

Process		Syntax	Cross section (pb)	$\Delta_{\hat{\mu}}$	Δ_{PDF}
Triple bosons			13 TeV		
c.1	$pp \to HHH$	`p p > h h h [QCD]`	$3.968 \pm 0.010 \cdot 10^{-5}$	$^{+31.8\%}_{-22.6\%}$	$^{+1.7\%}_{-1.7\%}$
c.2	$gg \to HHZ$	`g g > h h z [QCD]`	$5.260 \pm 0.009 \cdot 10^{-5}$	$^{+31.2\%}_{-22.2\%}$	$^{+1.6\%}_{-1.6\%}$
c.3	$gg \to HZZ$	`g g > h z z [QCD]`	$1.144 \pm 0.004 \cdot 10^{-4}$	$^{+31.1\%}_{-22.2\%}$	$^{+1.6\%}_{-1.5\%}$
c.4	$gg \to HZ\gamma$	`g g > h z a [QCD]`	$6.190 \pm 0.020 \cdot 10^{-6}$	$^{+29.3\%}_{-21.2\%}$	$^{+1.1\%}_{-1.2\%}$
c.5	$pp \to H\gamma\gamma$	`p p > h a a [QCD]`	$6.058 \pm 0.004 \cdot 10^{-6}$	$^{+30.3\%}_{-21.8\%}$	$^{+1.3\%}_{-1.3\%}$
c.6	$pp \to HW^+W^-$	`g g > h w+ w- [QCD]`	$2.670 \pm 0.007 \cdot 10^{-4}$	$^{+31.0\%}_{-22.2\%}$	$^{+1.5\%}_{-1.6\%}$
c.7	$gg \to ZZZ$	`g g > z z z [QCD]`	$6.964 \pm 0.009 \cdot 10^{-5}$	$^{+30.9\%}_{-22.1\%}$	$^{+1.5\%}_{-1.5\%}$
c.8	$gg \to ZZ\gamma$	`g g > z z a [QCD]`	$3.454 \pm 0.010 \cdot 10^{-6}$	$^{+28.7\%}_{-20.9\%}$	$^{+1.0\%}_{-1.1\%}$
c.9	$gg \to Z\gamma\gamma$	`g g > z a a [QCD]`	$3.079 \pm 0.005 \cdot 10^{-4}$	$^{+28.0\%}_{-20.9\%}$	$^{+0.9\%}_{-1.2\%}$
c.10	$gg \to ZW^+W^-$	`g g > z w+ w- [QCD]`	$8.595 \pm 0.020 \cdot 10^{-3}$	$^{+26.9\%}_{-19.5\%}$	$^{+0.7\%}_{-0.7\%}$
c.12	$gg \to \gamma W^+W^-$	`g g > a w+ w- [QCD]`	$1.822 \pm 0.005 \cdot 10^{-2}$	$^{+28.7\%}_{-20.9\%}$	$^{+0.9\%}_{-1.1\%}$

SM Tables (III)

	Process	Syntax	Cross section (pb)	$\Delta_{\hat{\mu}}$	Δ_{PDF}
Selected $2 \to 4$			13 TeV		
d.1	$pp \to Hjjj$	`p p > h j j j QED=1 [QCD]`	2.519 ± 0.005	$^{+75.1\%}_{-39.8\%}$	$^{+0.7\%}_{-0.7\%}$
d.2	$pp \to HHjj$	`p p > h h j j QED=1 [QCD]`	$1.085 \pm 0.002 \cdot 10^{-2}$	$^{+62.1\%}_{-35.8\%}$	$^{+1.5\%}_{-1.6\%}$
d.3	$pp \to HHHj$	`p p > h h h j [QCD]`	$4.981 \pm 0.008 \cdot 10^{-5}$	$^{+46.3\%}_{-29.6\%}$	$^{+1.8\%}_{-1.8\%}$
d.3	$pp \to HHHH$	`p p > h h h h [QCD]`	$1.080 \pm 0.003 \cdot 10^{-7}$	$^{+33.3\%}_{-23.4\%}$	$^{+2.2\%}_{-2.1\%}$
d.4	$gg \to e^+e^-\mu^+\mu^-$	`g g > e+ e- mu+ mu- [QCD]`	$2.022 \pm 0.003 \cdot 10^{-3}$	$^{+26.4\%}_{-19.4\%}$	$^{+1.0\%}_{-1.3\%}$
d.5	$pp \to HZ\gamma j$	`g g > h z a g [QCD]`	$4.950 \pm 0.008 \cdot 10^{-6}$	$^{+45.8\%}_{-29.3\%}$	$^{+1.5\%}_{-1.6\%}$
e^+e^- processes			$\hat{s} = 500$ GeV		
e.1	$e^+e^- \to ggg$	`e+ e- > g g g [QED]`	$2.526 \pm 0.004 \cdot 10^{-6}$	$^{+31.2\%}_{-22.0\%}$	
e.2	$e^+e^- \to HH$	`e+ e- > h h [QED]`	$1.567 \pm 0.003 \cdot 10^{-5}$	$^{+0.0\%}_{-0.0\%}$	
e.3	$e^+e^- \to HHgg$	`e+ e- > h h g g [QED]`	$6.629 \pm 0.010 \cdot 10^{-11}$	$^{+19.2\%}_{-14.8\%}$	
Miscellaneous			13 TeV		
f.1	$pp \to tt$	`p p > t t [QED]`	$4.045 \pm 0.007 \cdot 10^{-15}$	$^{+0.2\%}_{-0.8\%}$	$^{+1.1\%}_{-1.1\%}$

SM Tables (IV)
(preliminary)

Process		Syntax	Partial width (GeV)
Bosonic decays			
g.1	$H \to jj$	`h > j j [QCD]`	$1.740 \pm 0.0006 \cdot 10^{-4}$
g.2	$H \to jjj$	`h > j j j [QCD]`	$3.413 \pm 0.010 \cdot 10^{-4}$
g.3	$H \to jjjj$	`h > j j j j QED=1 [QCD]`	$1.654 \pm 0.004 \cdot 10^{-4}$
g.4	$H \to \gamma\gamma$	`h > a a [QED]`	$9.882 \pm 0.002 \cdot 10^{-6}$
g.5	$H \to \gamma\gamma jj$	`h > a a j j [QCD]`	$7.450 \pm 0.030 \cdot 10^{-13}$
g.6	$H \to \gamma\gamma\gamma\gamma$	`h > a a a a [QED]`	0.0
g.7	$Z \to ggg$	`z > g g g [QCD]`	$3.986 \pm 0.010 \cdot 10^{-6}$

SM Tables (IV)
(preliminary)

Process	Syntax	Partial width (GeV)
Bosonic decays		
g.1 $H \to jj$	`h > j j [QCD]`	$1.740 \pm 0.0006 \cdot 10^{-4}$
g.2 $H \to jjj$	`h > j j j [QCD]`	$3.413 \pm 0.010 \cdot 10^{-4}$
g.3 $H \to jjjj$	`h > j j j j QED=1 [QCD]`	$1.654 \pm 0.004 \cdot 10^{-4}$
g.4 $H \to \gamma\gamma$	`h > a a [QED]`	$9.882 \pm 0.002 \cdot 10^{-6}$
g.5 $H \to \gamma\gamma jj$	`h > a a j j [QCD]`	$7.450 \pm 0.030 \cdot 10^{-13}$
g.6 $H \to \gamma\gamma\gamma\gamma$	`h > a a a a [QED]`	0.0
g.7 $Z \to ggg$	`z > g g g [QCD]`	$3.986 \pm 0.010 \cdot 10^{-6}$

[Implementation for decays is inefficient, but sufficient for most relevant decays]

Take-home message

- Direct loop-induced process simulation with MG5_aMC@NLO finalized:
  - 2 > 2 on a laptop
  - 2 > 3 on a small size cluster
  - 2 > 4 case-by-case but typically requires a large size cluster

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- TIR needs further optimizations or a different implementation to be competitive vs OPP, thanks to an efficient MC over helicity. It however remains a great stability rescue mechanism.

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- Public version released in O (~weeks)

Thanks.