中国科学院高能物理研究所
Institute of High Energy Physics
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SLAC

Squaring loops in MadGraph5_aMC@NLO

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in collaboration with
Olivier Mattelaer

[arxiv:1507.00020]

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OUTLINE

- The challenges of computing loop-induced matrix-elements.
- How does MadEvent now integrate them.
- Validation and applications in Higgs physics.

Loop-induced: Motivation

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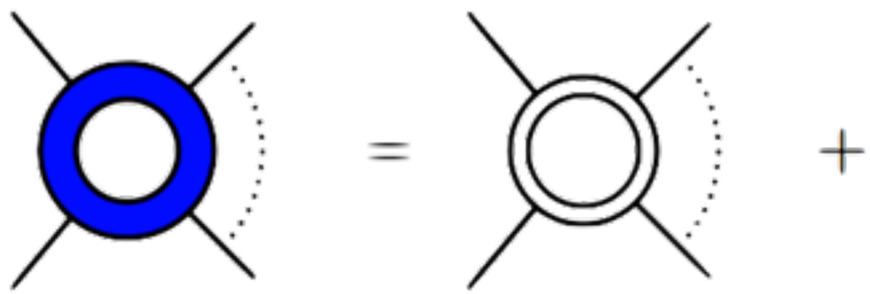
There is a wide range of interest for loop-induced processes, but no automated efficient way of **integrating** them.

Need to bring a definitive solution to this.

What is different with Loop-induced (LI) ?



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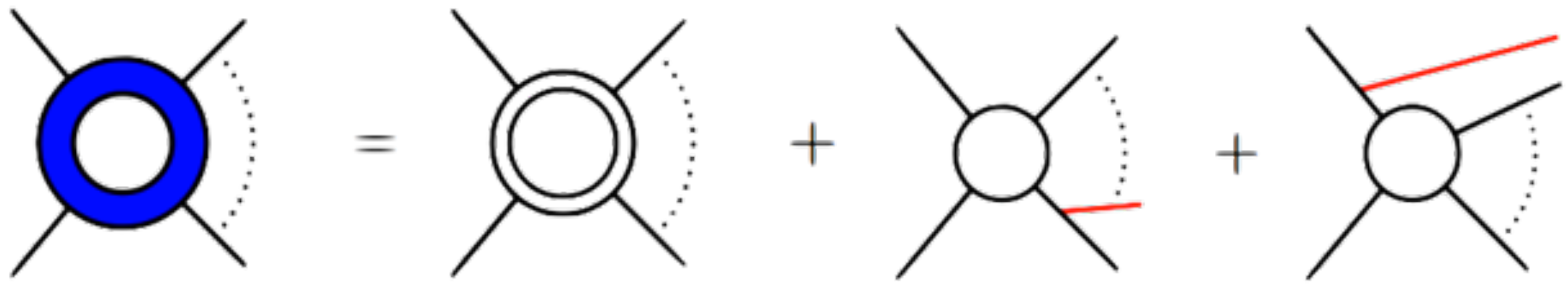

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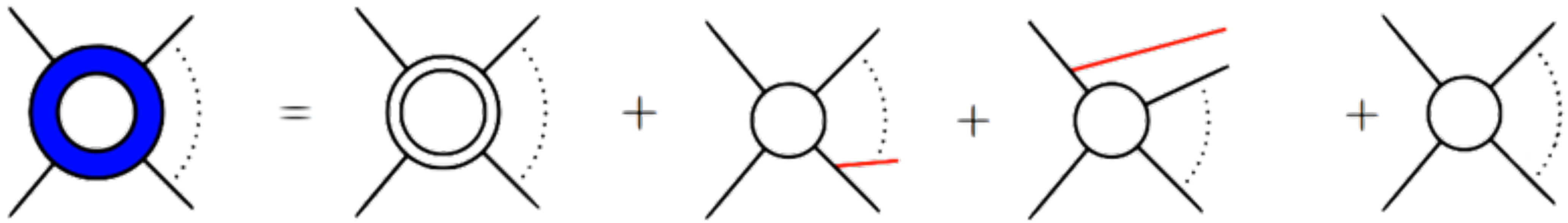

$$\sigma^{\text{NLO}} = \int_m d^{(d)}\sigma^V + \int_{m+1} d^{(d)}\sigma^R + \int_m d^{(4)}\sigma^B$$

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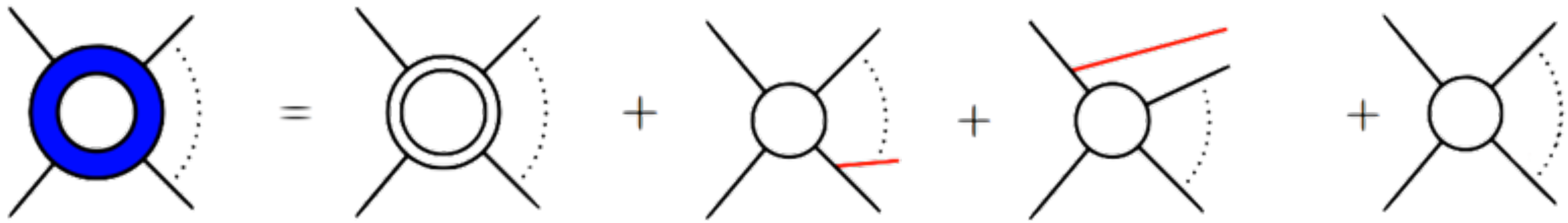

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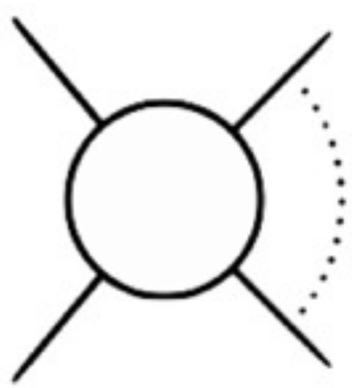
$\sigma^{\rm LI} =$ $\Big|$  $\Big|^2$ $= \int_m d^{(d)} \left|\mathcal{A}^{(1)}\right|^2$

How NLO ME's are computed?

$$\mathcal{M}^{\text{NLO,virt}} \sim \mathcal{A}_U^{(\text{loop})}\big|_{\text{non-}R_2}\mathcal{B}^\star$$

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

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

How loop-Induced ME's are computed

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

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- A) For a given helicity, 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)

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

$$\left|\mathcal{A}^{LI}_{\text{non-}R_2}\right|^2 = \sum_{h=1,H}\sum_{l_1=1,L}\sum_{l_2=1,L}\left(\text{Red}\left[\frac{\mathcal{N}_{h,l_1}(\ell)}{\prod_{i=0}^{m_{l_1}-1}\bar{D}_{i,l_1}}\right]\text{Red}\left[\frac{\mathcal{N}_{h,l_2}(\ell)}{\prod_{i=0}^{m_{l_2}-1}\bar{D}_{i,l_2}}\right]^*\underbrace{\sum_{\text{color}}\lambda_{l_1}\lambda^*_{l_2}}_{\Lambda_{l_1,l_2}}\right)$$

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

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

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

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

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

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$$\left|\mathcal{A}^{LI}_{\text{non-}R_2} \quad \ldots \quad \lambda_{l_1}\lambda^*_{l_2}\right)$$

Solu

More simply said, the projection onto the color-flow basis allows to turn

$$L_1 \cdot L_1 + L_1 \cdot L_2 + L_1 \cdot L_3 +$$
$$L_2 \cdot L_1 + L_2 \cdot L_2 + L_2 \cdot L_3 +$$
$$L_3 \cdot L_1 + L_3 \cdot L_2 + L_3 \cdot L_3 +$$

into

$$(L_1 + L_2 + L_3) \cdot (L_1 + L_2 + L_3)$$

Hence trading 9 multiplications for 1 multiplication and 6 additions!

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

Additional perks of color flows

- Necessary for event color assignation for loop-induced processes with MadEvent.
- Using NLO color partial amplitudes for SCET NLO hard functions.
- Could be used in NLO matrix-element improved showers (a.k.a Vincia)
- In a matched computation when using a fixed-color ME generator such as COMIX for both reals AND subtraction terms, i.e. Monte Carlo over colors
- MadLoop keeps track of the factorized couplings in the partial color amplitudes, so that mixed expansions or interference computations are possible.
- In general, it increases MadLoop flexibility.

- B) Impossible to do reduction at the squared amplitude level in the LI case.
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Solution B2 : Reduce with TIR whose inputs are independent on the helicity

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

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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%)
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- The modern OPP reduction algorithms SAMURAI and NINJA now available too.
- OPP with **efficient** MC over helicity configurations is the dominant approach.

ENHANCED PARALLELIZATION

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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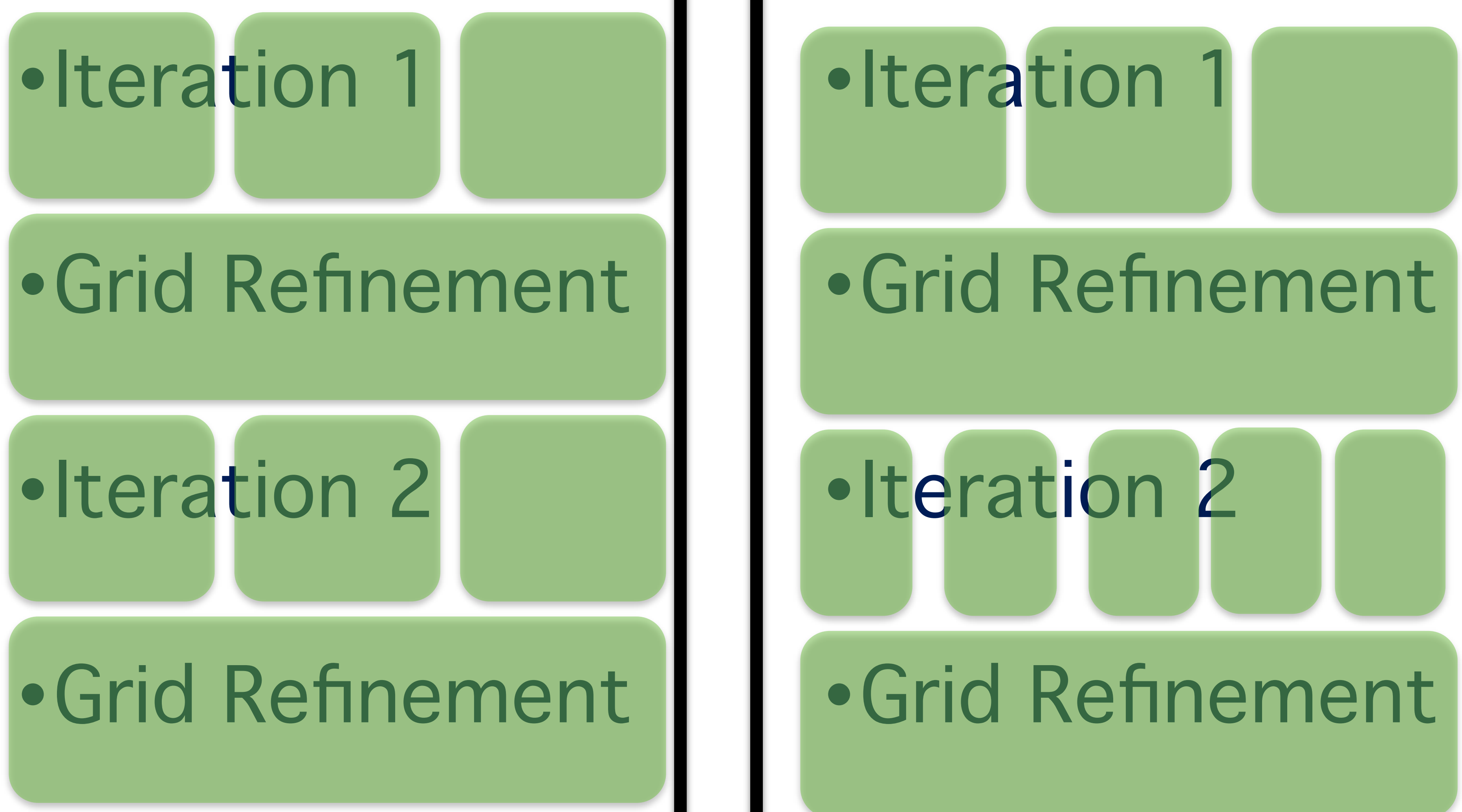
ENHANCED PARALLELIZATION

Slide by O.Mattelaer.

New MadEvent

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



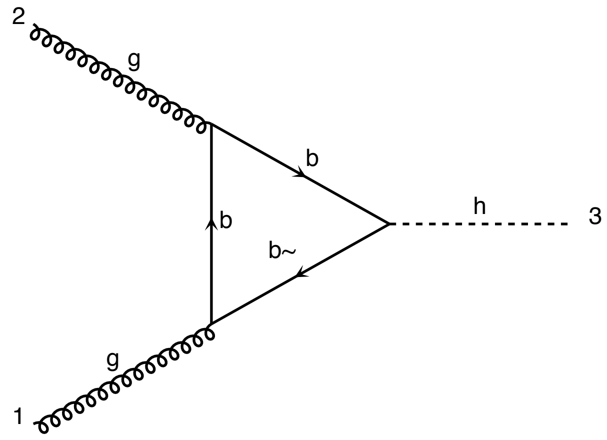
Simplest example

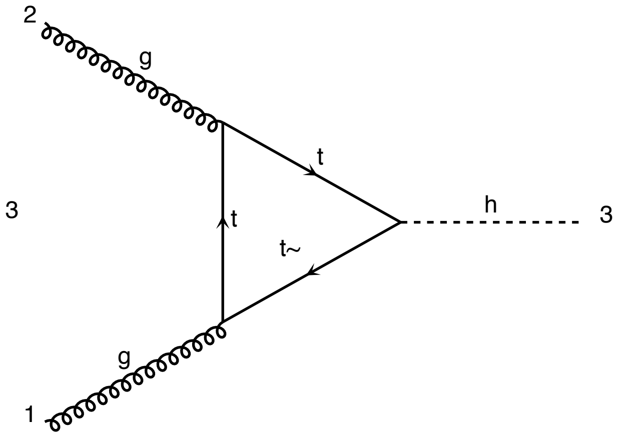
User Input

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

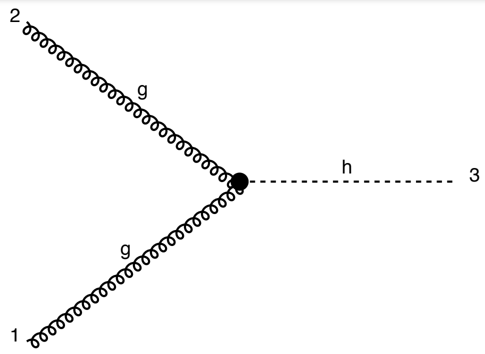
Loop Induced

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





HEFT



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

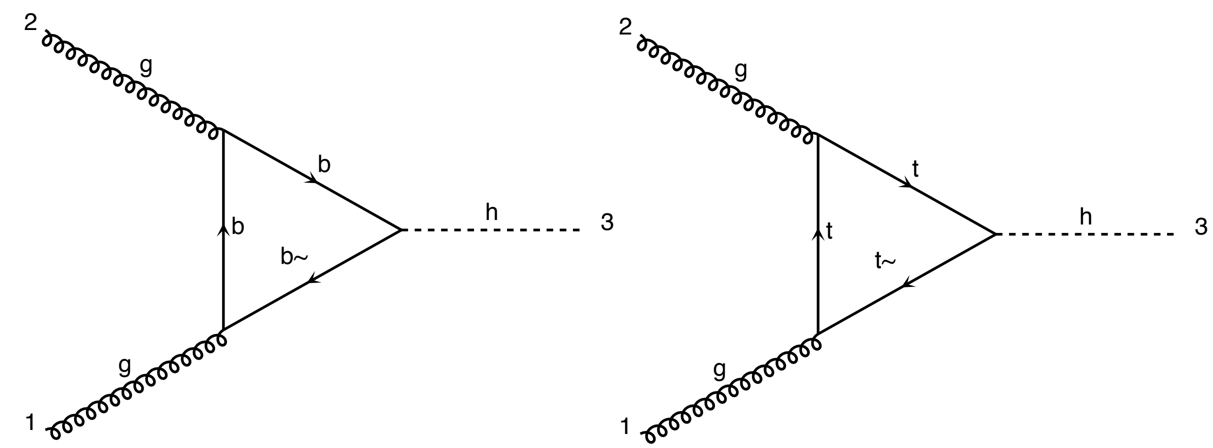
Simplest example

User Input

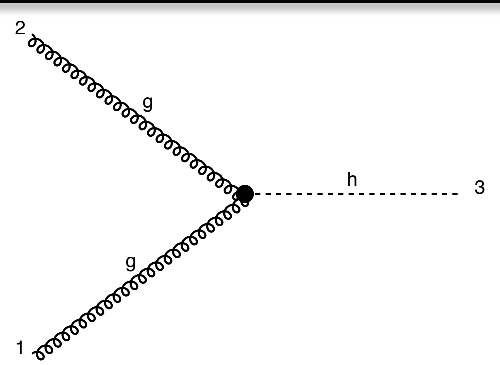
- generate g g > h [QCD]
- output
- launch

Loop Induced

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

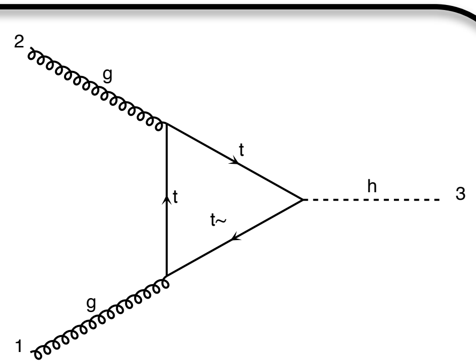


HEFT



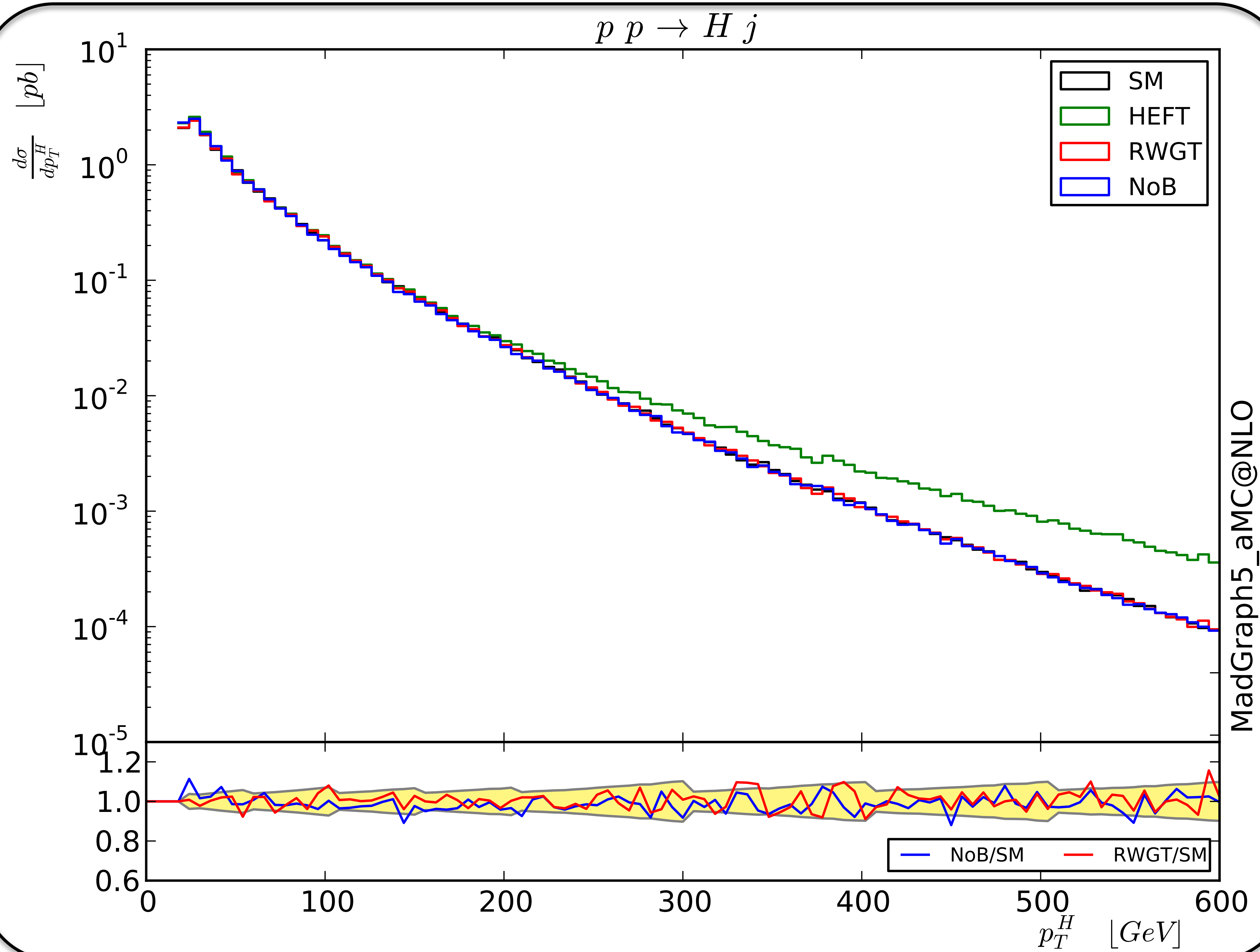
$$\sigma_{heft} = 17.63(2)pb$$

No bottom loop

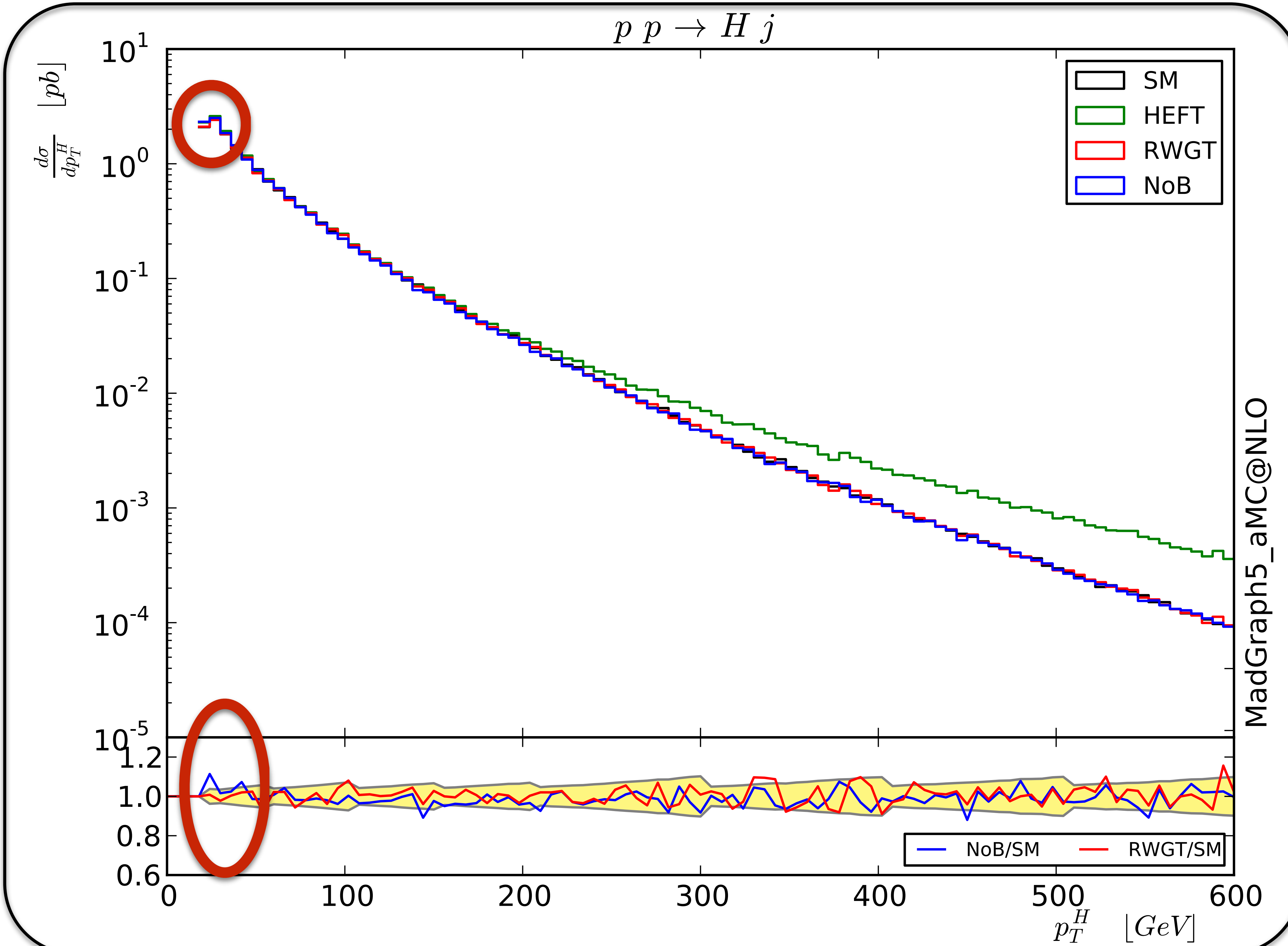


$$\sigma_{toploop} = 17.65(2)pb$$

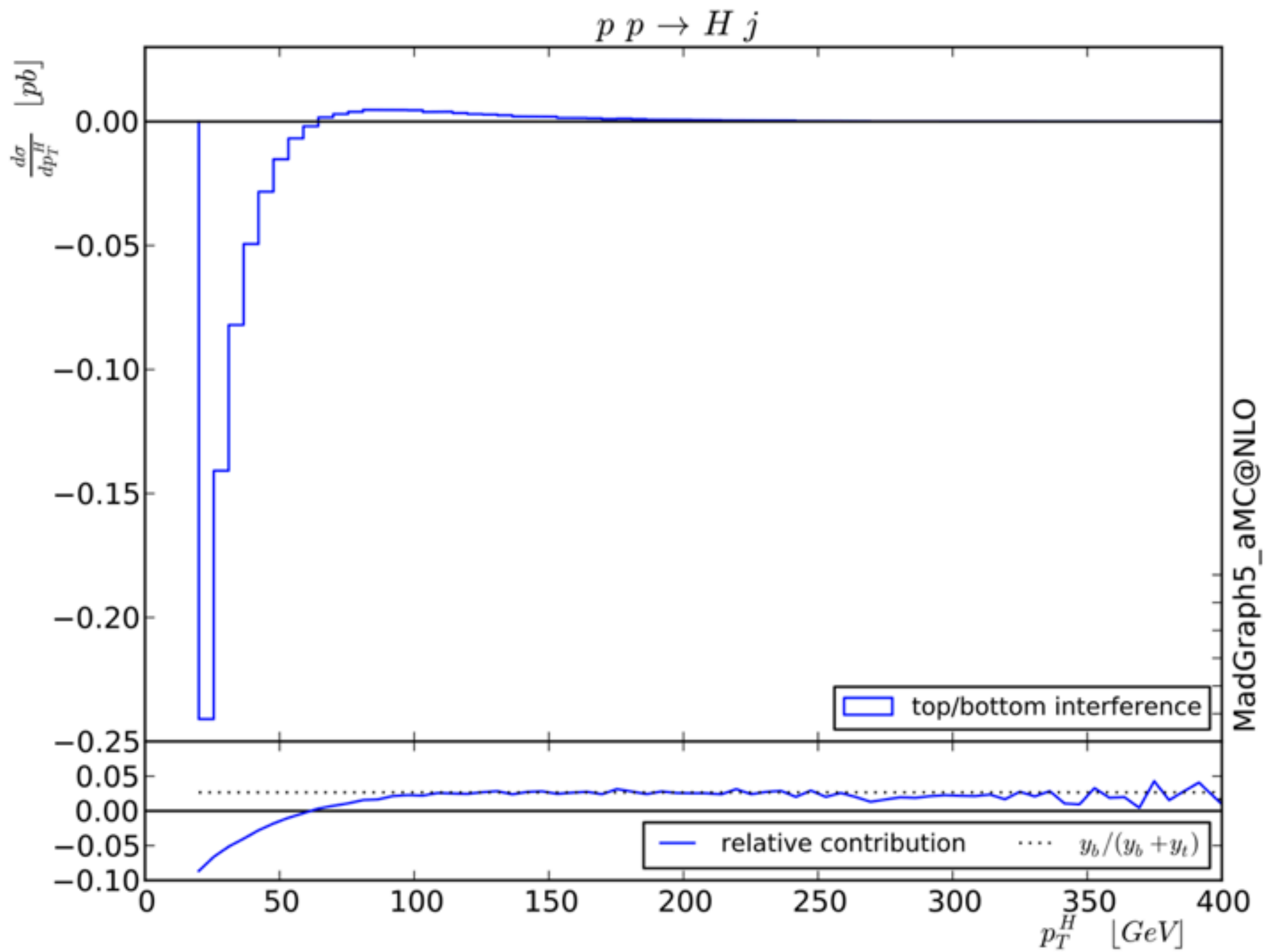
VALIDATION P P > H J



VALIDATION P P > H J



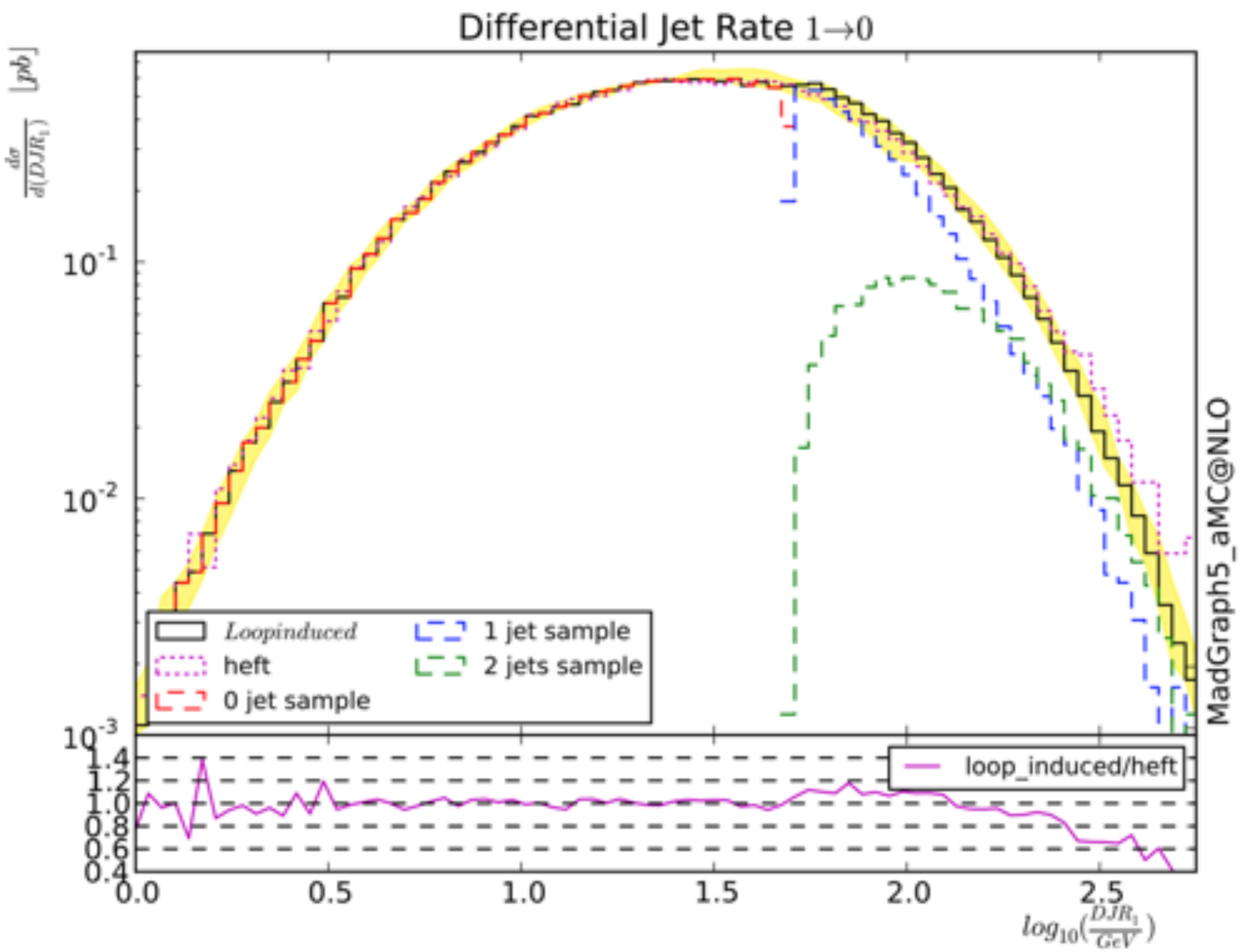
Validation p p > h j

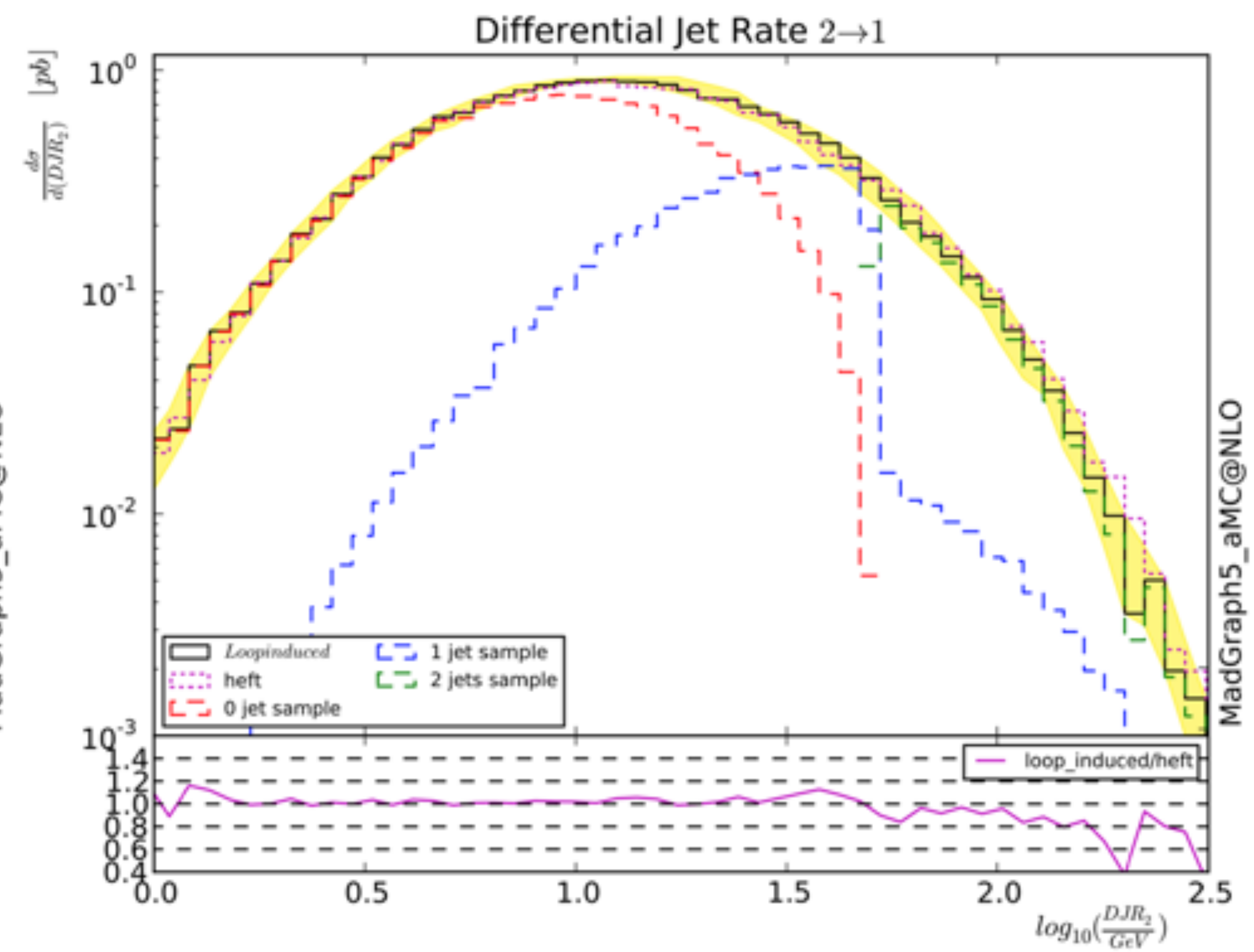


Important b-mass effects at low-pt but the expected **naive rescaling at high-pt**

Matching / Merging

K_T - MLM merging scheme





$$Q_{match} = 50GeV$$

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	$167\ ^{+31\%}_{-19\%}$	$0.891\ ^{+33\%}_{-21\%}$	$1325\ ^{+28\%}_{-21\%}$

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	$^{+32.5\%}_{-23.0\%}$	$^{+1.9\%}_{-1.9\%}$
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BSM: Z+A/H

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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	$167\,^{+31\%}_{-19\%}$	$0.891\,^{+33\%}_{-21\%}$	$1325\,^{+28\%}_{-21\%}$

[Also another independent cross-check against g g > z z with MadLoop+Sherpa]

Automation at work

SM Tables (I)

Process Single boson + jets		Syntax	Cross section (pb) $\sqrt{s}=13$ TeV	$\Delta_{\hat{\mu}}$	Δ_{PDF}
a.1	$pp \to H$	`p p > h [QCD]`	17.79 ± 0.060	$^{+31.3\%}_{-23.1\%}$	$^{+0.5\%}_{-0.9\%}$
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	$^{+61.8\%}_{-35.6\%}$	$^{+0.7\%}_{-0.9\%}$
⋆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	$^{+64.5\%}_{-36.5\%}$	$^{+1.0\%}_{-1.1\%}$
†a.6	$gg \to \gamma g$	`g g > a g [QCD]`	75.61 ± 0.200	$^{+73.8\%}_{-41.6\%}$	$^{+0.7\%}_{-1.1\%}$
†a.7	$gg \to \gamma gg$	`g g > a g g [QCD]`	14.50 ± 0.030	$^{+76.2\%}_{-40.7\%}$	$^{+0.6\%}_{-1.0\%}$

⋆ : **Not publicly** available.

† : Computed here for the **first time**.

SM Tables (II)

Process	Double bosons + jet	Syntax	Cross section (pb) $\sqrt{s}=13$ TeV	$\Delta_{\hat{\mu}}$	Δ_{PDF}
b.1	$pp \to HH$	`p p > h h [QCD]`	$1.641 \pm 0.002 \cdot 10^{-2}$	$^{+30.2\%}_{-21.7\%}$	$^{+1.1\%}_{-1.2\%}$
b.2	$pp \to HHj$	`p p > h h j [QCD]`	$1.758 \pm 0.003 \cdot 10^{-2}$	$^{+45.7\%}_{-29.2\%}$	$^{+1.2\%}_{-1.2\%}$
*b.3	$pp \to H\gamma j$	`p p > h a j [QCD]`	$4.225 \pm 0.006 \cdot 10^{-3}$	$^{+38.6\%}_{-25.9\%}$	$^{+0.4\%}_{-0.7\%}$
*b.4	$gg \to HZ$	`g g > h z [QCD]`	$6.537 \pm 0.030 \cdot 10^{-2}$	$^{+29.4\%}_{-21.3\%}$	$^{+1.0\%}_{-1.1\%}$
*b.5	$gg \to HZg$	`g g > h z g [QCD]`	$5.465 \pm 0.020 \cdot 10^{-2}$	$^{+46.0\%}_{-29.4\%}$	$^{+1.2\%}_{-1.3\%}$
b.6	$gg \to ZZ$	`g g > z z [QCD]`	1.313 ± 0.004	$^{+27.1\%}_{-20.1\%}$	$^{+0.7\%}_{-1.0\%}$
*b.7	$gg \to ZZg$	`g g > z z g [QCD]`	0.6361 ± 0.002	$^{+45.4\%}_{-29.1\%}$	$^{+1.0\%}_{-1.2\%}$
b.8	$gg \to Z\gamma$	`g g > z a [QCD]`	1.265 ± 0.0007	$^{+30.2\%}_{-22.2\%}$	$^{+0.6\%}_{-1.0\%}$
†b.9	$gg \to Z\gamma g$	`g g > z a g [QCD]`	0.4604 ± 0.001	$^{+43.7\%}_{-28.4\%}$	$^{+0.8\%}_{-1.1\%}$
b.10	$gg \to \gamma\gamma$	`g g > a a [QCD]`	$5.182 \pm 0.010 \cdot 10^{+2}$	$^{+72.3\%}_{-43.4\%}$	$^{+1.0\%}_{-1.3\%}$
*b.11	$gg \to \gamma\gamma g$	`g g > a a g [QCD]`	19.22 ± 0.030	$^{+59.7\%}_{-35.7\%}$	$^{+0.7\%}_{-1.0\%}$
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	$^{+45.2\%}_{-29.0\%}$	$^{+0.9\%}_{-1.1\%}$

$\star$: **Not publicly** available.

† : Computed here for the **first time**.

SM Tables (III)

Process		Syntax	Cross section (pb)	$\Delta_{\tilde{\mu}}$	Δ_{PDF}
Triple bosons			$\sqrt{s} = 13$ TeV		
†c.1	$pp \to HHH$	`p p > h h h [QCD]`	$3.968 \pm 0.010 \cdot 10^{-5}$	$^{+31.8\%}_{-22.6\%}$	$^{+1.4\%}_{-1.4\%}$
†c.2	$gg \to HHZ$	`g g > h h z [QCD]`	$5.260 \pm 0.009 \cdot 10^{-5}$	$^{+31.2\%}_{-22.2\%}$	$^{+1.3\%}_{-1.3\%}$
†c.3	$gg \to HZZ$	`g g > h z z [QCD]`	$1.144 \pm 0.004 \cdot 10^{-4}$	$^{+31.1\%}_{-22.2\%}$	$^{+1.2\%}_{-1.3\%}$
†c.4	$gg \to HZ\gamma$	`g g > h z a [QCD]`	$6.190 \pm 0.020 \cdot 10^{-6}$	$^{+29.3\%}_{-21.2\%}$	$^{+1.0\%}_{-1.2\%}$
†c.5	$pp \to H\gamma\gamma$	`p p > h a a [QCD]`	$6.058 \pm 0.004 \cdot 10^{-6}$	$^{+30.3\%}_{-21.8\%}$	$^{+1.1\%}_{-1.3\%}$
†c.6	$pp \to HW^+W^-$	`g g > h w+ w- [QCD]`	$2.670 \pm 0.007 \cdot 10^{-4}$	$^{+31.0\%}_{-22.2\%}$	$^{+1.2\%}_{-1.3\%}$
†c.7	$gg \to ZZZ$	`g g > z z z [QCD]`	$6.964 \pm 0.009 \cdot 10^{-5}$	$^{+30.9\%}_{-22.1\%}$	$^{+1.2\%}_{-1.3\%}$
†c.8	$gg \to ZZ\gamma$	`g g > z z a [QCD]`	$3.454 \pm 0.010 \cdot 10^{-6}$	$^{+28.7\%}_{-20.9\%}$	$^{+0.9\%}_{-1.1\%}$
†c.9	$gg \to Z\gamma\gamma$	`g g > z a a [QCD]`	$3.079 \pm 0.005 \cdot 10^{-4}$	$^{+28.0\%}_{-20.9\%}$	$^{+0.7\%}_{-1.0\%}$
†c.10	$gg \to ZW^+W^-$	`g g > z w+ w- [QCD]`	$8.595 \pm 0.020 \cdot 10^{-3}$	$^{+26.9\%}_{-19.5\%}$	$^{+0.6\%}_{-0.6\%}$
†c.12	$gg \to \gamma W^+W^-$	`g g > a w+ w- [QCD]`	$1.822 \pm 0.005 \cdot 10^{-2}$	$^{+28.7\%}_{-20.9\%}$	$^{+0.9\%}_{-1.1\%}$

⋆ : **Not publicly** available.

† : Computed here for the **first time**.

SM Tables (IV)

Process		Syntax	Cross section (pb)	$\Delta_{\hat{\mu}}$	Δ_{PDF}
Selected $2 \to 4$			$\sqrt{s} = 13$ TeV		
†d.1	$pp \to Hjjj$	`p p > h j j j QED=1 [QCD]`	2.519 ± 0.005	$^{+75.1\%}_{-39.8\%}$	$^{+0.6\%}_{-0.6\%}$
⋆d.2	$pp \to HHjj$	`p p > h h j j QED=1 [QCD]`	$1.085 \pm 0.002 \cdot 10^{-2}$	$^{+62.1\%}_{-35.8\%}$	$^{+1.2\%}_{-1.3\%}$
†d.3	$pp \to HHHj$	`p p > h h h j [QCD]`	$4.981 \pm 0.008 \cdot 10^{-5}$	$^{+46.3\%}_{-29.6\%}$	$^{+1.4\%}_{-1.4\%}$
†d.3	$pp \to HHHH$	`p p > h h h h [QCD]`	$1.080 \pm 0.003 \cdot 10^{-7}$	$^{+33.3\%}_{-23.4\%}$	$^{+1.7\%}_{-1.7\%}$
d.4	$gg \to e^+e^-\mu^+\mu^-$	`g g > e+ e- mu+ mu- [QCD]`	$2.022 \pm 0.003 \cdot 10^{-3}$	$^{+26.4\%}_{-19.4\%}$	$^{+0.7\%}_{-1.1\%}$
†d.5	$pp \to HZ\gamma j$	`g g > h z a g [QCD]`	$4.950 \pm 0.008 \cdot 10^{-6}$	$^{+45.8\%}_{-29.3\%}$	$^{+1.2\%}_{-1.3\%}$
Non-hadronic processes			$\sqrt{s} = 500$ GeV, no PDF		
†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]`	$6.629 \pm 0.010 \cdot 10^{-11}$	$^{+19.2\%}_{-14.8\%}$	
⋆e.4	$\gamma\gamma \to HH$	`a a > h h [QED]`	$3.198 \pm 0.005 \cdot 10^{-4}$	$^{+0.0\%}_{-0.0\%}$	
Miscellaneous			$\sqrt{s} = 13$ TeV		
†f.1	$pp \to tt$	`p p > t t [QED]`	$4.045 \pm 0.007 \cdot 10^{-15}$	$^{+0.2\%}_{-0.8\%}$	$^{+0.9\%}_{-1.0\%}$

⋆ : **Not publicly** available.

† : Computed here for the **first time**.

SM Tables (V)

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]`	$7.448 \pm 0.030 \cdot 10^{-13}$
*g.7	$Z \to ggg$	`z > g g g [QCD]`	$3.986 \pm 0.010 \cdot 10^{-6}$

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

$\star$: **Not publicly** available.

† : Computed here for the **first time**.

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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- Thanks to an efficient MC over helicity, OPP is competitive for loop-induced processes. TIR remains however a great stability rescue mechanism.

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- BSM-flexible and readily available on https://launchpad.net/mg5amcnlo

Thanks.