

MG5_aMC@NLO

looping up to be mad!

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IPPP/Durham

based on 1401.7340 and 1405.0301
Work in progress with V. Hirschi

- What is MadGraph5_aMC@NLO
- Loop-Induced processes

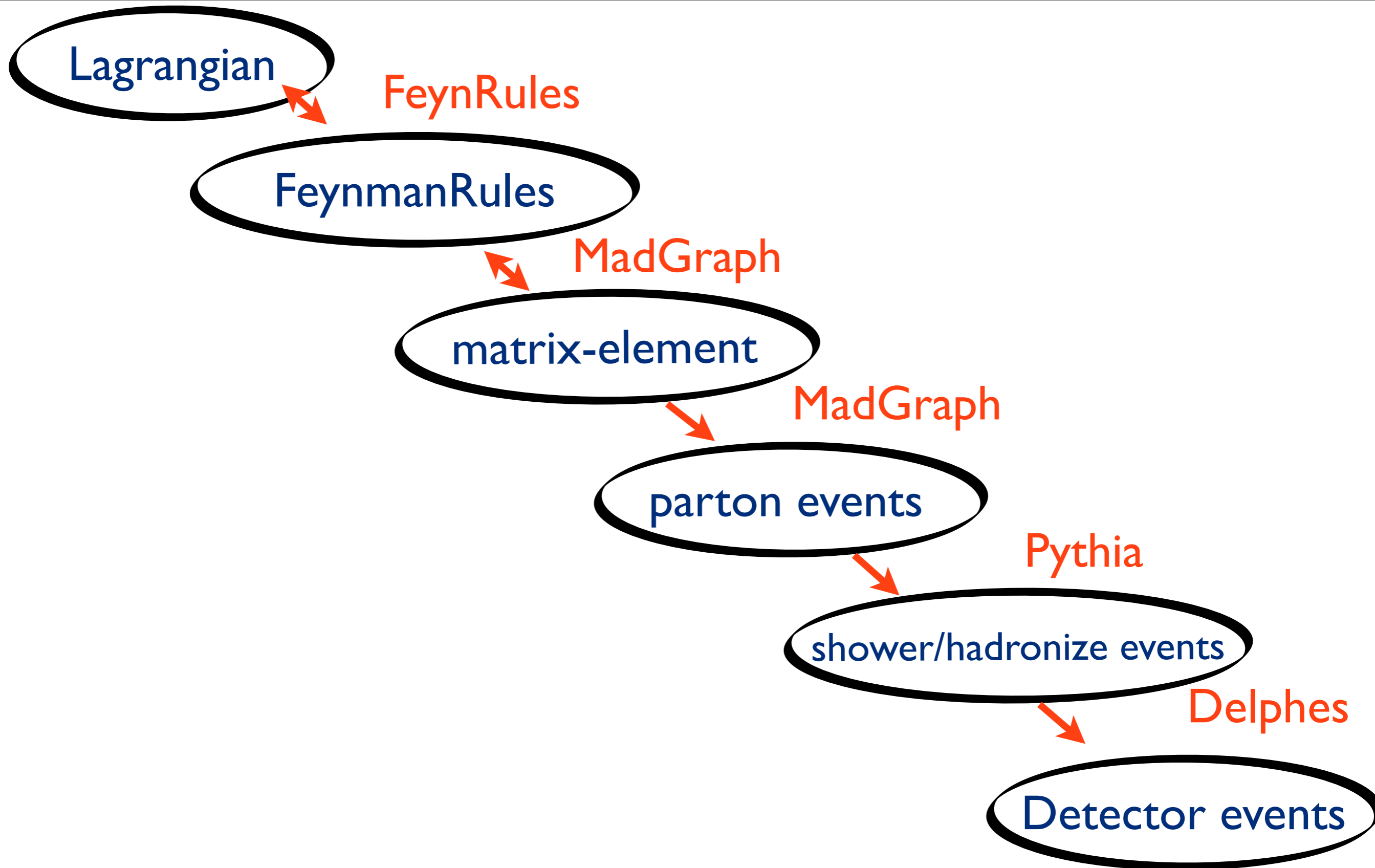


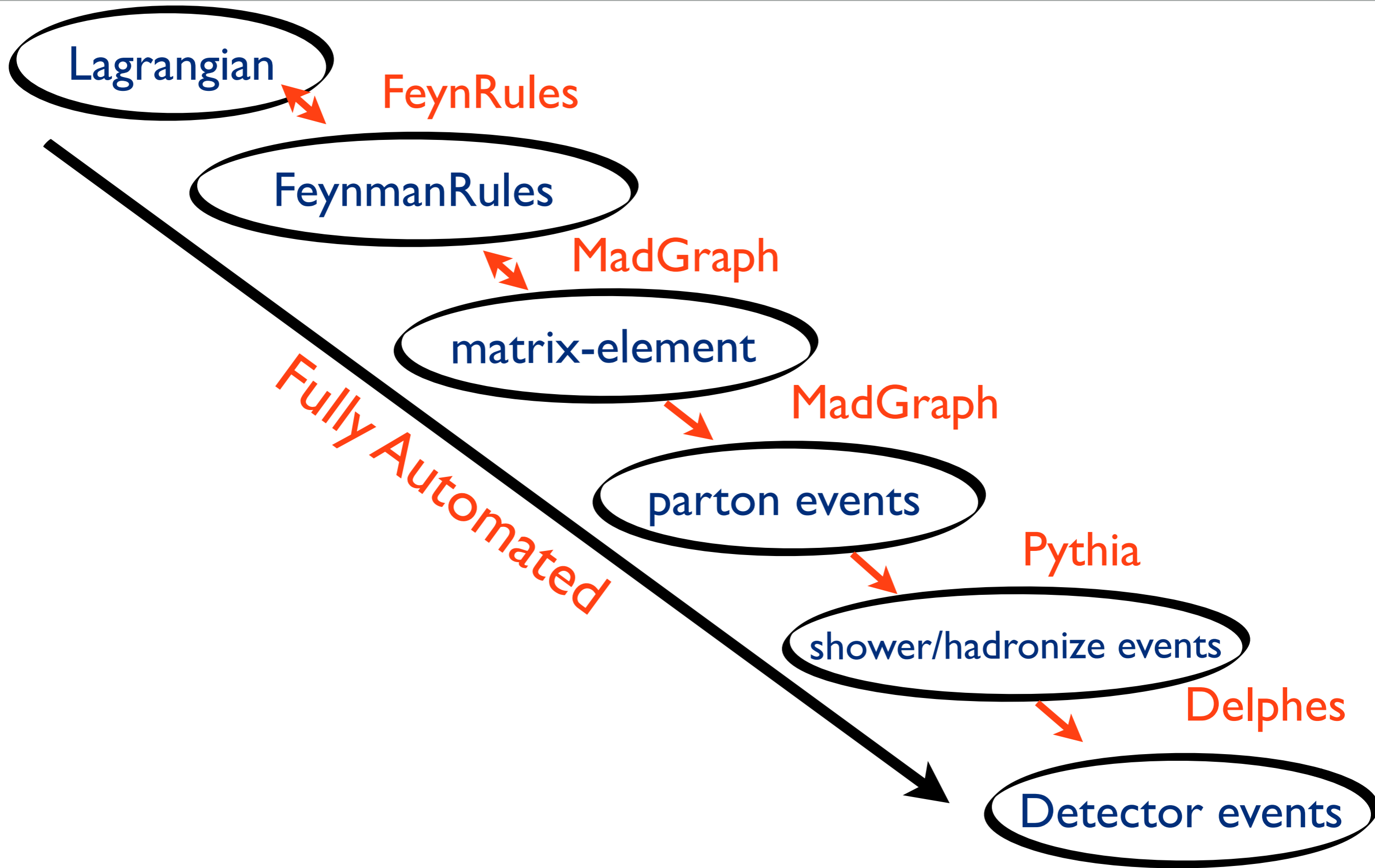
- What is MadGraph5_aMC@NLO
- Loop-Induced processes

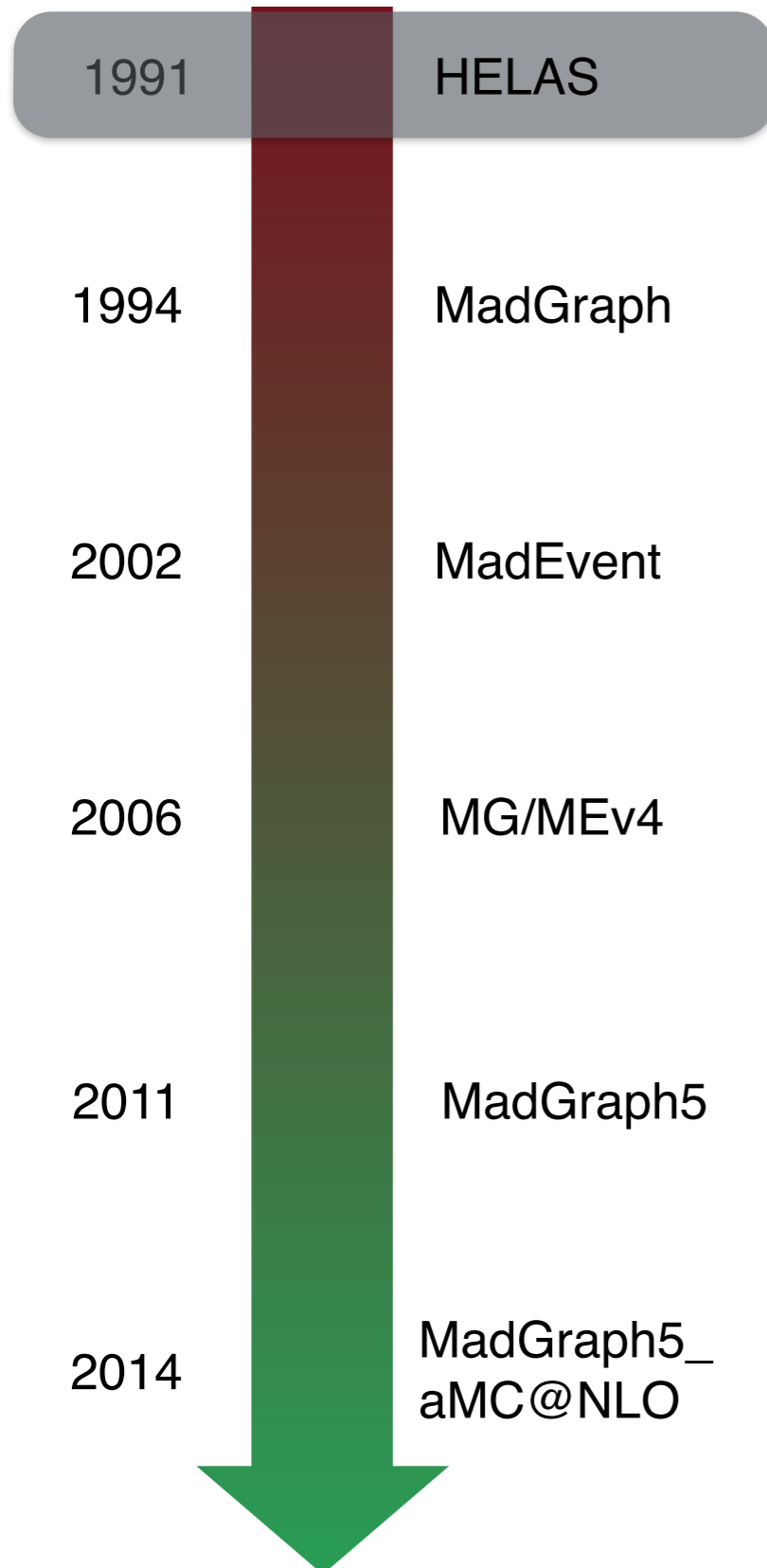


Lagrangian

Detector events







1991

HELAS



1994

MadGraph

2002

MadEvent



2006

MG/MEv4

2011

MadGraph5



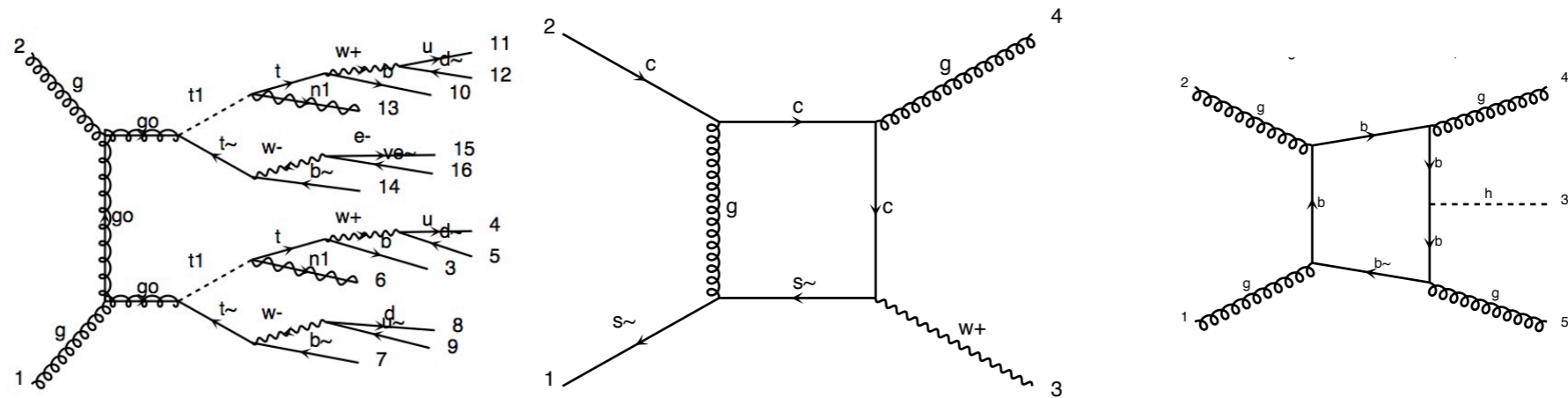
2014

MadGraph5_ aMC@NLO



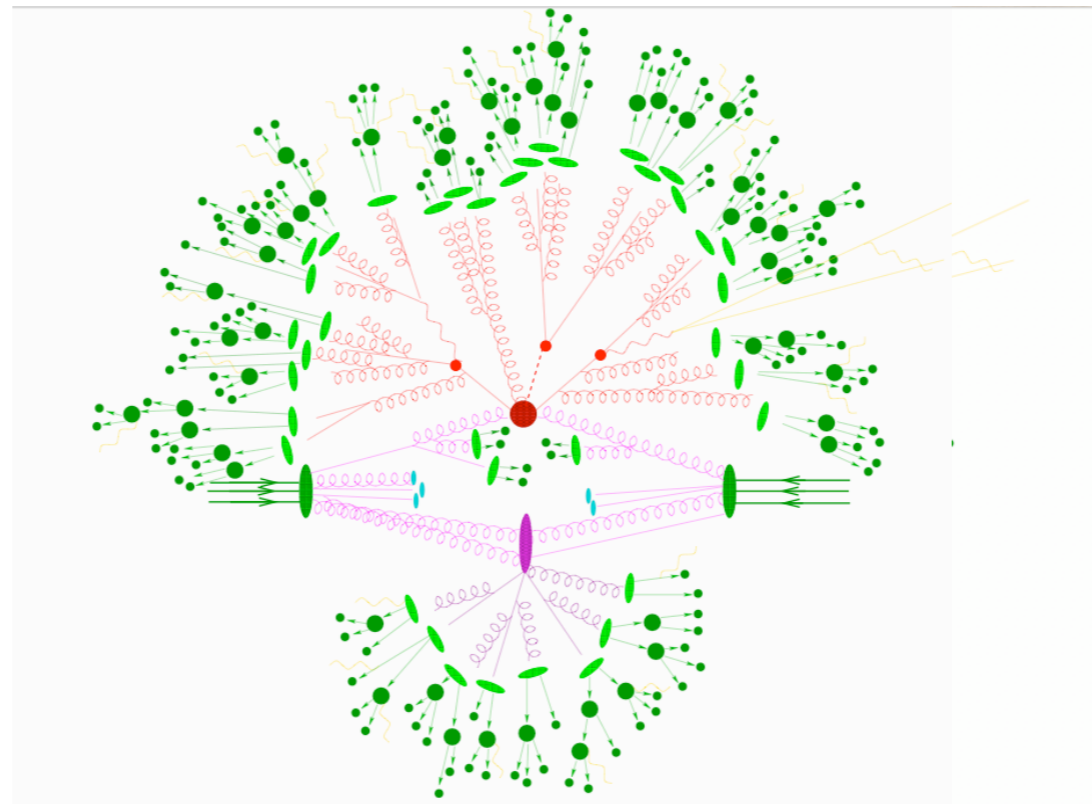
Type of generation

Fix Order



Fix Order

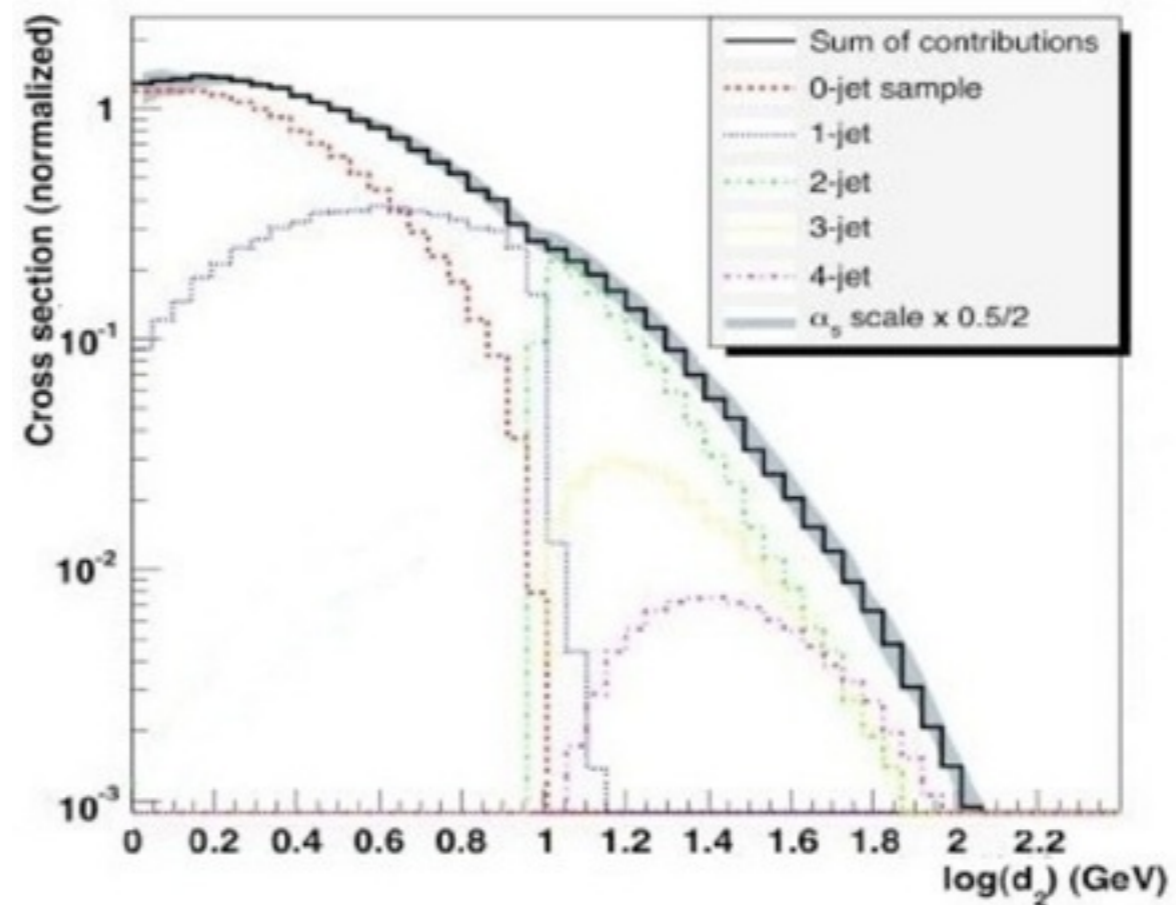
+Parton Shower












Fix Order










+Parton Shower











Merged Sample


















	Tree (SM)
Fix Order	
+Parton Shower	
Merged Sample	

	Tree (SM)	Tree (BSM)
Fix Order		
+Parton Shower		
Merged Sample		

	Tree (SM)	Tree (BSM)	NLO (QCD) (SM)
Fix Order			
+Parton Shower			
Merged Sample			

	Tree (SM)	Tree (BSM)	NLO (QCD) (SM)	NLO (QCD) (BSM)
Fix Order				
+Parton Shower				
Merged Sample				

	Tree (SM)	Tree (BSM)	NLO (QCD) (SM)	NLO (QCD) (BSM)	NLO (EW) (SM)
Fix Order					
+Parton Shower					
Merged Sample					

	Tree (SM)	Tree (BSM)	NLO (QCD) (SM)	NLO (QCD) (BSM)	NLO (EW) (SM)	NLO (EW) (BSM)
Fix Order	✓	✓	✓	✓	✓	?
+Parton Shower	✓	✓	✓	✓	✓	?
Merged Sample	✓	✓	✓	✓	✓	?

	Tree (SM)	Tree (BSM)	NLO (QCD) (SM)	NLO (QCD) (BSM)	NLO (EW) (SM)	NLO (EW) (BSM)	Loop Induced
Fix Order	✓	✓	✓	✓	✓	?	✓
+Parton Shower	✓	✓	✓	✓	✓	?	✓
Merged Sample	✓	✓	✓	✓	✓	?	✓

Process	Syntax	Cross section (pb)					
		LO 13 TeV			NLO 13 TeV		
Vector-boson pair +jets							
b.1	$pp \rightarrow W^+W^-$ (4f)	p p > w+ w-	$7.355 \pm 0.005 \cdot 10^1$	+5.0% +2.0%	$1.028 \pm 0.003 \cdot 10^2$	+4.0% +1.9%	
b.2	$pp \rightarrow ZZ$	p p > z z	$1.097 \pm 0.002 \cdot 10^1$	-6.1% -1.5%	$1.415 \pm 0.005 \cdot 10^1$	-4.5% -1.4%	
b.3	$pp \rightarrow ZW^\pm$	p p > z wpm	$2.777 \pm 0.003 \cdot 10^1$	+4.5% +1.9%	$4.487 \pm 0.013 \cdot 10^1$	+3.1% +1.8%	
b.4	$pp \rightarrow \gamma\gamma$	p p > a a	$2.510 \pm 0.002 \cdot 10^1$	-5.6% -1.5%	$6.593 \pm 0.021 \cdot 10^1$	-3.7% -1.4%	
b.5	$pp \rightarrow \gamma Z$	p p > a z	$2.523 \pm 0.004 \cdot 10^1$	+3.6% +2.0%	$3.695 \pm 0.013 \cdot 10^1$	+4.4% +1.7%	
b.6	$pp \rightarrow \gamma W^\pm$	p p > a wpm	$2.954 \pm 0.005 \cdot 10^1$	-4.7% -1.5%	$7.124 \pm 0.026 \cdot 10^1$	-4.4% -1.3%	
b.7	$pp \rightarrow W^+W^-j$ (4f)	p p > w+ w- j	$2.865 \pm 0.003 \cdot 10^1$	+22.1% +2.4%	$3.730 \pm 0.013 \cdot 10^1$	+17.6% +2.0%	
b.8	$pp \rightarrow ZZj$	p p > z z j	$3.662 \pm 0.003 \cdot 10^0$	-22.4% -2.1%	$4.830 \pm 0.016 \cdot 10^0$	-18.8% -1.9%	
b.9	$pp \rightarrow ZW^\pm j$	p p > z wpm j	$1.605 \pm 0.005 \cdot 10^1$	+9.9% +2.0%	$2.086 \pm 0.007 \cdot 10^1$	+5.4% +1.8%	
b.10	$pp \rightarrow \gamma\gamma j$	p p > a a j	$1.022 \pm 0.001 \cdot 10^1$	-11.2% -1.6%	$2.292 \pm 0.010 \cdot 10^1$	-7.1% -1.4%	
b.11*	$pp \rightarrow \gamma Zj$	p p > a z j	$8.310 \pm 0.017 \cdot 10^0$	+9.5% +2.0%	$1.220 \pm 0.005 \cdot 10^1$	+9.7% +1.5%	
b.12*	$pp \rightarrow \gamma W^\pm j$	p p > a wpm j	$2.546 \pm 0.010 \cdot 10^1$	-11.0% -1.7%	$3.713 \pm 0.015 \cdot 10^1$	-9.9% -1.3%	
b.13	$pp \rightarrow W^+W^+jj$	p p > w+ w+ j j	$1.484 \pm 0.006 \cdot 10^{-1}$	+11.6% +1.0%	$2.251 \pm 0.011 \cdot 10^{-1}$	+4.9% +1.1%	
b.14	$pp \rightarrow W^-W^-jj$	p p > w- w- j j	$6.752 \pm 0.007 \cdot 10^{-2}$	-10.0% -0.8%	$1.003 \pm 0.003 \cdot 10^{-1}$	-4.9% -0.8%	
b.15	$pp \rightarrow W^+W^-jj$ (4f)	p p > w+ w- j j	$1.144 \pm 0.002 \cdot 10^1$	+10.9% +1.0%	$1.396 \pm 0.005 \cdot 10^1$	+5.0% +1.1%	
b.16	$pp \rightarrow ZZjj$	p p > z z j j	$1.344 \pm 0.002 \cdot 10^0$	-9.3% -0.8%	$1.706 \pm 0.011 \cdot 10^0$	-4.8% -0.9%	
b.17	$pp \rightarrow ZW^\pm jj$	p p > z wpm j j	$8.038 \pm 0.009 \cdot 10^0$	+11.6% +0.9%	$9.139 \pm 0.031 \cdot 10^0$	+4.9% +0.9%	
b.18	$pp \rightarrow \gamma\gamma jj$	p p > a a j j	$5.377 \pm 0.029 \cdot 10^0$	-10.0% -0.7%	$7.501 \pm 0.032 \cdot 10^0$	-4.8% -0.7%	
b.19*	$pp \rightarrow \gamma Zjj$	p p > a z j j	$3.260 \pm 0.009 \cdot 10^0$	+20.3% +1.2%	$4.242 \pm 0.016 \cdot 10^0$	+17.2% +1.0%	
b.20*	$pp \rightarrow \gamma W^\pm jj$	p p > a wpm j j	$1.233 \pm 0.002 \cdot 10^1$	-17.7% -1.5%	$1.448 \pm 0.005 \cdot 10^1$	-15.1% -1.4%	
				+14.5% +1.0%		+7.3% +0.9%	
				-12.8% -1.0%		-7.4% -0.9%	
				+13.7% +0.9%		+7.2% +0.9%	
				-12.1% -1.0%		-7.1% -1.0%	
				+25.4% +2.1%		+10.5% +2.2%	
				-18.9% -1.5%		-10.6% -1.6%	
				+25.4% +2.4%		+10.1% +2.5%	
				-18.9% -1.7%		-10.4% -1.8%	
				+27.2% +0.7%		+5.0% +0.7%	
				-19.9% -0.5%		-6.8% -0.6%	
				+26.6% +0.7%		+5.8% +0.8%	
				-19.6% -0.6%		-7.2% -0.6%	
				+26.7% +0.7%		+3.1% +0.7%	
				-19.7% -0.5%		-5.1% -0.5%	
				+26.2% +0.6%		+8.8% +0.6%	
				-19.8% -1.0%		-10.1% -1.0%	
				+24.3% +0.6%		+6.5% +0.6%	
				-18.4% -0.6%		-7.3% -0.6%	
				+24.7% +0.6%		+3.6% +0.6%	
				-18.6% -0.6%		-5.4% -0.7%	

Process	Syntax	Cross section (pb)				
		LO 13 TeV		NLO 13 TeV		
Three vector bosons + jet						
c.1	$pp \rightarrow W^+W^-W^\pm (4f)$	$p p > w^+ w^- wpm$	$1.307 \pm 0.003 \cdot 10^{-1}$	$+0.0\% +0.0\%$	$2.109 \pm 0.006 \cdot 10^{-1}$	$+5.1\% +1.6\%$
c.2	$pp \rightarrow ZW^+W^- (4f)$	$p p > z w^+ w^-$	$9.658 \pm 0.085 \cdot 10^{-2}$	$-0.2\% -1.2\%$	$1.679 \pm 0.005 \cdot 10^{-1}$	$-4.1\% -1.2\%$
c.3	$pp \rightarrow ZZW^\pm$	$p p > z z wpm$	$2.996 \pm 0.016 \cdot 10^{-2}$	$+1.0\% +0.0\%$	$5.550 \pm 0.020 \cdot 10^{-2}$	$+4.8\% +3.0\%$
c.4	$pp \rightarrow ZZZ$	$p p > z z z$	$1.085 \pm 0.002 \cdot 10^{-2}$	$+0.0\% +0.0\%$	$1.417 \pm 0.005 \cdot 10^{-2}$	$+3.7\% +3.6\%$
c.5	$pp \rightarrow \gamma W^+W^- (4f)$	$p p > a w^+ w^-$	$1.427 \pm 0.011 \cdot 10^{-1}$	$-1.5\% -1.8\%$	$2.581 \pm 0.008 \cdot 10^{-1}$	$-4.3\% -1.1\%$
c.6	$pp \rightarrow \gamma\gamma W^\pm$	$p p > a a wpm$	$2.681 \pm 0.007 \cdot 10^{-2}$	$+4.0\% +1.7\%$	$8.251 \pm 0.032 \cdot 10^{-2}$	$+7.6\% +1.0\%$
c.7	$pp \rightarrow \gamma ZW^\pm$	$p p > a z wpm$	$4.994 \pm 0.011 \cdot 10^{-2}$	$+0.9\% +1.9\%$	$1.117 \pm 0.004 \cdot 10^{-1}$	$+7.2\% +2.2\%$
c.8	$pp \rightarrow \gamma ZZ$	$p p > a z z$	$2.320 \pm 0.005 \cdot 10^{-2}$	$+1.0\% +1.9\%$	$3.118 \pm 0.012 \cdot 10^{-2}$	$+3.9\% +1.9\%$
c.9	$pp \rightarrow \gamma\gamma Z$	$p p > a a z$	$3.078 \pm 0.007 \cdot 10^{-3}$	$+0.9\% +1.9\%$	$4.634 \pm 0.020 \cdot 10^{-3}$	$+4.0\% +1.7\%$
c.10	$pp \rightarrow \gamma\gamma\gamma$	$p p > a a a$	$1.269 \pm 0.003 \cdot 10^{-3}$	$+0.8\% +2.0\%$	$3.441 \pm 0.012 \cdot 10^{-3}$	$+11.6\% +1.4\%$
Four vector bosons						
c.11	$pp \rightarrow W^+W^-W^\pm j (4f)$	$p p > w^+ w^- wpm j$	$9.167 \pm 0.010 \cdot 10^{-2}$	$+15.0\% +1.0\%$	$1.197 \pm 0.004 \cdot 10^{-1}$	$+5.3\% +1.0\%$
c.12	$pp \rightarrow ZW^+W^- j (4f)$	$p p > z w^+ w^- j$	$8.340 \pm 0.010 \cdot 10^{-2}$	$+15.0\% +1.0\%$	$1.066 \pm 0.003 \cdot 10^{-1}$	$+4.5\% +1.0\%$
c.13	$pp \rightarrow ZZW^\pm j$	$p p > z z wpm j$	$2.810 \pm 0.004 \cdot 10^{-2}$	$+15.0\% +1.0\%$	$3.660 \pm 0.013 \cdot 10^{-2}$	$+4.8\% +1.0\%$
c.14	$pp \rightarrow ZZZ j$	$p p > z z z j$	$4.823 \pm 0.011 \cdot 10^{-3}$	$+14.8\% +1.4\%$	$6.341 \pm 0.025 \cdot 10^{-3}$	$+4.9\% +1.0\%$
c.15	$pp \rightarrow \gamma W^+W^- j (4f)$	$p p > a w^+ w^- j$	$1.182 \pm 0.004 \cdot 10^{-1}$	$+18.4\% +0.5\%$	$1.233 \pm 0.004 \cdot 10^{-1}$	$+18.9\% +1.0\%$
c.16	$pp \rightarrow \gamma\gamma W^\pm j$	$p p > a a wpm j$	$4.107 \pm 0.015 \cdot 10^{-2}$	$+11.8\% +0.6\%$	$5.807 \pm 0.023 \cdot 10^{-2}$	$+9.8\% +0.7\%$
c.17	$pp \rightarrow \gamma ZW^\pm j$	$p p > a z wpm j$	$5.833 \pm 0.023 \cdot 10^{-3}$	$+14.4\% +0.7\%$	$7.764 \pm 0.025 \cdot 10^{-3}$	$+8.1\% +0.6\%$
c.18	$pp \rightarrow \gamma ZZ j$	$p p > a z z j$	$9.995 \pm 0.013 \cdot 10^{-3}$	$+12.8\% +1.2\%$	$1.371 \pm 0.005 \cdot 10^{-2}$	$+8.6\% +1.2\%$
c.19	$pp \rightarrow \gamma\gamma Z j$	$p p > a a z j$	$1.372 \pm 0.003 \cdot 10^{-3}$	$+10.9\% +1.0\%$	$2.051 \pm 0.011 \cdot 10^{-3}$	$+7.0\% +1.0\%$
c.20	$pp \rightarrow \gamma\gamma\gamma j$	$p p > a a a j$	$1.031 \pm 0.006 \cdot 10^{-3}$	$+14.3\% +0.9\%$	$2.020 \pm 0.008 \cdot 10^{-3}$	$+12.8\% +0.8\%$

Process	Syntax	Cross section (pb)				
		LO 13 TeV		NLO 13 TeV		
c.21*	$pp \rightarrow W^+W^-W^+W^- (4f)$	$p p > w^+ w^- w^+ w^-$	$5.721 \pm 0.014 \cdot 10^{-4}$	$+3.7\% +2.3\%$	$9.959 \pm 0.035 \cdot 10^{-4}$	$+7.4\% +1.7\%$
c.22*	$pp \rightarrow W^+W^-W^\pm Z (4f)$	$p p > w^+ w^- wpm z$	$6.391 \pm 0.076 \cdot 10^{-4}$	$+4.4\% +2.4\%$	$1.188 \pm 0.004 \cdot 10^{-3}$	$+8.4\% +1.7\%$
c.23*	$pp \rightarrow W^+W^-W^\pm \gamma (4f)$	$p p > w^+ w^- wpm a$	$8.115 \pm 0.064 \cdot 10^{-4}$	$+2.5\% +2.2\%$	$1.546 \pm 0.005 \cdot 10^{-3}$	$+7.9\% +1.5\%$
c.24*	$pp \rightarrow W^+W^-ZZ (4f)$	$p p > w^+ w^- z z$	$4.320 \pm 0.013 \cdot 10^{-4}$	$+4.4\% +2.4\%$	$7.107 \pm 0.020 \cdot 10^{-4}$	$+7.0\% +1.8\%$
c.25*	$pp \rightarrow W^+W^-Z\gamma (4f)$	$p p > w^+ w^- z a$	$8.403 \pm 0.016 \cdot 10^{-4}$	$+3.0\% +2.3\%$	$1.483 \pm 0.004 \cdot 10^{-3}$	$+7.2\% +1.6\%$
c.26*	$pp \rightarrow W^+W^- \gamma\gamma (4f)$	$p p > w^+ w^- a a$	$5.198 \pm 0.012 \cdot 10^{-4}$	$+0.6\% +2.1\%$	$9.381 \pm 0.032 \cdot 10^{-4}$	$+6.7\% +1.4\%$
c.27*	$pp \rightarrow W^\pm ZZZ$	$p p > wpm z z z$	$5.862 \pm 0.010 \cdot 10^{-5}$	$+5.1\% +2.4\%$	$1.240 \pm 0.004 \cdot 10^{-4}$	$+9.9\% +1.7\%$
c.28*	$pp \rightarrow W^\pm ZZ\gamma$	$p p > wpm z z a$	$1.148 \pm 0.003 \cdot 10^{-4}$	$-3.5\% +2.2\%$	$2.945 \pm 0.008 \cdot 10^{-4}$	$+10.8\% +1.3\%$
c.29*	$pp \rightarrow W^\pm Z\gamma\gamma$	$p p > wpm z a a$	$1.054 \pm 0.004 \cdot 10^{-4}$	$+1.7\% +2.1\%$	$3.033 \pm 0.010 \cdot 10^{-4}$	$+10.6\% +1.1\%$
c.30*	$pp \rightarrow W^\pm \gamma\gamma\gamma$	$p p > wpm a a a$	$3.600 \pm 0.013 \cdot 10^{-5}$	$+0.4\% +2.0\%$	$1.246 \pm 0.005 \cdot 10^{-4}$	$+9.8\% +0.9\%$
c.31*	$pp \rightarrow ZZZZ$	$p p > z z z z$	$1.989 \pm 0.002 \cdot 10^{-5}$	$+3.8\% +2.2\%$	$2.629 \pm 0.008 \cdot 10^{-5}$	$+3.5\% +2.2\%$
c.32*	$pp \rightarrow ZZZ\gamma$	$p p > z z z a$	$3.945 \pm 0.007 \cdot 10^{-5}$	$+1.9\% +2.1\%$	$5.224 \pm 0.016 \cdot 10^{-5}$	$+3.3\% +2.1\%$
c.33*	$pp \rightarrow ZZ\gamma\gamma$	$p p > z z a a$	$5.513 \pm 0.017 \cdot 10^{-5}$	$-0.3\% +1.6\%$	$7.518 \pm 0.032 \cdot 10^{-5}$	$-2.6\% +1.5\%$
c.34*	$pp \rightarrow Z\gamma\gamma\gamma$	$p p > z a a a$	$4.790 \pm 0.012 \cdot 10^{-5}$	$+2.3\% +2.0\%$	$7.103 \pm 0.026 \cdot 10^{-5}$	$+3.4\% +1.6\%$
c.35*	$pp \rightarrow \gamma\gamma\gamma\gamma$	$p p > a a a a$	$1.594 \pm 0.004 \cdot 10^{-5}$	$+4.7\% +1.9\%$	$3.389 \pm 0.012 \cdot 10^{-5}$	$+7.0\% +1.3\%$

Process	Syntax	Cross section (pb)				
		LO 13 TeV		NLO 13 TeV		
Heavy quarks and jets						
d.1	$pp \rightarrow jj$	$p p > j j$	$1.162 \pm 0.001 \cdot 10^6$	$+24.9\% +0.8\%$	$1.580 \pm 0.007 \cdot 10^6$	$+8.4\% +0.1\%$
d.2	$pp \rightarrow jjj$	$p p > j j j$	$8.940 \pm 0.021 \cdot 10^4$	$+43.8\% +1.2\%$	$7.791 \pm 0.037 \cdot 10^4$	$+2.1\% +1.1\%$
d.3	$pp \rightarrow b\bar{b} (4f)$	$p p > b b \sim$	$3.743 \pm 0.004 \cdot 10^3$	$+26.2\% +1.0\%$	$6.438 \pm 0.028 \cdot 10^3$	$+15.9\% +1.0\%$
d.4*	$pp \rightarrow b\bar{b}j (4f)$	$p p > b b \sim j$	$1.050 \pm 0.002 \cdot 10^3$	$+16.9\% +1.0\%$	$1.327 \pm 0.007 \cdot 10^3$	$+13.3\% +1.7\%$
d.5*	$pp \rightarrow b\bar{b}jj (4f)$	$p p > b b \sim j j$	$1.852 \pm 0.006 \cdot 10^2$	$+28.5\% +1.8\%$	$2.471 \pm 0.012 \cdot 10^2$	$+11.6\% +1.8\%$
d.6	$pp \rightarrow b\bar{b}bb (4f)$	$p p > b b \sim b b \sim$	$5.050 \pm 0.007 \cdot 10^{-1}$	$+81.8\% +2.1\%$	$8.736 \pm 0.034 \cdot 10^{-1}$	$+8.2\% +2.0\%$
d.7	$pp \rightarrow t\bar{t}$	$p p > t t \sim$	$4.584 \pm 0.003 \cdot 10^2$	$+35.6\% +2.4\%$	$8.736 \pm 0.034 \cdot 10^{-1}$	$+20.9\% +2.9\%$
d.8	$pp \rightarrow t\bar{t}j$	$p p > t t \sim j$	$3.135 \pm 0.002 \cdot 10^2$	$+11.7\% +2.9\%$	$4.106 \pm 0.015 \cdot 10^2$	$+16.4\% +2.3\%$
d.9	$pp \rightarrow t\bar{t}jj$	$p p > t t \sim j j$	$1.361 \pm 0.001 \cdot 10^2$	$+29.0\% +2.8\%$	$1.795 \pm 0.006 \cdot 10^2$	$+12.2\% +2.8\%$
d.10	$pp \rightarrow t\bar{t}tt$	$p p > t t \sim t t \sim$	$4.505 \pm 0.005 \cdot 10^{-3}$	$+61.4\% +2.0\%$	$9.201 \pm 0.028 \cdot 10^{-3}$	$+9.8\% +2.4\%$
d.11	$pp \rightarrow t\bar{t}bb (4f)$	$p p > t t \sim b b \sim$	$6.119 \pm 0.004 \cdot 10^0$	$+19.2\% +0.4\%$	$1.452 \pm 0.005 \cdot 10^1$	$+30.9\% +3.9\%$

d.1b $pp \rightarrow W^+W^-jj (4f) p p > w^+ w^- j j$

Process	Syntax	Cross section (pb)				
		LO 13 TeV		NLO 13 TeV		
Single-top						
f.1	$pp \rightarrow tj (t\text{-channel})$	$p p > tt j \bar{q} w^+ w^-$	$1.520 \pm 0.001 \cdot 10^2$	$+9.4\% +0.4\%$	$1.563 \pm 0.005 \cdot 10^2$	$+1.4\% +0.4\%$
f.2	$pp \rightarrow tj (t\text{-channel})$	$p p > tt a j \bar{q} w^+ w^-$	$9.956 \pm 0.014 \cdot 10^{-1}$	$+11.9\% +0.8\%$	$1.017 \pm 0.003 \cdot 10^0$	$+1.3\% +0.8\%$
f.3	$pp \rightarrow tZj (t\text{-channel})$	$p p > tt z j \bar{q} w^+ w^-$	$6.967 \pm 0.007 \cdot 10^{-1}$	$+8.8\% +1.0\%$	$6.993 \pm 0.021 \cdot 10^{-1}$	$+1.2\% +0.9\%$
f.4	$pp \rightarrow thj (t\text{-channel}, 4f)$	$p p > tt bb j \bar{q} w^+ w^-$	$1.003 \pm 0.000 \cdot 10^0$	$+18.9\% +0.4\%$	$1.219 \pm 0.003 \cdot 10^0$	$+9.8\% +0.4\%$
f.5*	$pp \rightarrow thj (t\text{-channel}, 4f)$	$p p > tt bb j a \bar{q} w^+ w^-$	$6.293 \pm 0.006 \cdot 10^{-1}$	$+11.8\% +0.8\%$	$8.612 \pm 0.025 \cdot 10^{-1}$	$+16.2\% +0.8\%$
f.6*	$pp \rightarrow thjZ (t\text{-channel}, 4f)$	$p p > tt bb j z \bar{q} w^+ w^-$	$3.934 \pm 0.002 \cdot 10^{-1}$	$+18.7\% +1.0\%$	$5.657 \pm 0.014 \cdot 10^{-1}$	$+17.7\% +0.9\%$
f.7	$pp \rightarrow tb (s\text{-channel}, 4f)$	$p p > w^+ w^- t b, p p > w^- w^- t \bar{b}$	$7.489 \pm 0.007 \cdot 10^0$	$+3.3\% +1.9\%$	$1.001 \pm 0.004 \cdot 10^1$	$+3.7\% +1.9\%$
f.8*	$pp \rightarrow tbj (s\text{-channel}, 4f)$	$p p > w^+ w^- t b a, p p > w^- w^- t \bar{b} a$	$1.490 \pm 0.001 \cdot 10^{-2}$	$+1.3\% +1.9\%$	$1.932 \pm 0.007 \cdot 10^{-2}$	$+3.6\% +1.7\%$
f.9*	$pp \rightarrow tbZ (s\text{-channel}, 4f)$	$p p > w^+ w^- t b a, p p > w^- w^- t \bar{b} a$	$1.072 \pm 0.001 \cdot 10^{-2}$	$+1.3\% +1.9\%$	$1.539 \pm 0.005 \cdot 10^{-2}$	$+3.6\% +1.7\%$

Process	Syntax	Cross section (pb)				
		LO 13 TeV		NLO 13 TeV		
Heavy quarks+vector bosons						
e.1	$pp \rightarrow W^\pm b\bar{b} (4f)$	$p p > wpm b b \sim$	$3.074 \pm 0.002 \cdot 10^2$	$+42.3\% +2.0\%$	$8.162 \pm 0.034 \cdot 10^2$	$+29.8\% +1.5\%$
e.2	$pp \rightarrow Z b\bar{b} (4f)$	$p p > z b b \sim$	$6.993 \pm 0.003 \cdot 10^2$	$+33.5\% +1.0\%$	$1.235 \pm 0.004 \cdot 10^3$	$+19.9\% +1.0\%$
e.3	$pp \rightarrow \gamma b\bar{b} (4f)$	$p p > a b b \sim$	$1.731 \pm 0.001 \cdot 10^3$	$+51.9\% +1.6\%$	$4.171 \pm 0.015 \cdot 10^3$	$+33.7\% +1.4\%$
e.4*	$pp \rightarrow W^\pm b\bar{b}j (4f)$	$p p > wpm b b \sim j$	$1.861 \pm 0.003 \cdot 10^2$	$+42.5\% +0.7\%$	$3.957 \pm 0.013 \cdot 10^2$	$+27.0\% +0.7\%$
e.5*	$pp \rightarrow Z b\bar{b}j (4f)$	$p p > z b b \sim j$	$1.604 \pm 0.001 \cdot 10^2$	$+27.7\% -0.7\%$	$2.805 \pm 0.009 \cdot 10^2$	$+21.0\% +0.8\%$
e.6*	$pp \rightarrow \gamma b\bar{b}j (4f)$	$p p > a b b \sim j$	$7.812 \pm 0.017 \cdot 10^2$	$+24.4\% -1.4\%$	$1.233 \pm 0.004 \cdot 10^3$	$+17.6\% -1.0\%$
e.7	$pp \rightarrow t\bar{t}W^\pm$	$p p > t t \sim wpm$	$3.777 \pm 0.003 \cdot 10^{-1}$	$+23.9\% +2.1\%$	$5.662 \pm 0.021 \cdot 10^{-1}$	$+11.2\% +1.7\%$
e.8	$pp \rightarrow t\bar{t}Z$	$p p > t t \sim z$	$5.273 \pm 0.004 \cdot 10^{-1}$	$+18.0\% -1.6\%$	$7.598 \pm 0.026 \cdot 10^{-1}$	$+10.6\% -1.3\%$
e.9	$pp \rightarrow t\bar{t}\gamma$	$p p > t t \sim a$	$1.204 \pm 0.001 \cdot 10^0$	$+30.5\% +1.8\%$	$1.744 \pm 0.005 \cdot 10^0$	$+9.7\% +1.9\%$
e.10*	$pp \rightarrow t\bar{t}W^\pm j$	$p p > t t \sim wpm j$	$2.352 \pm 0.002 \cdot 10^{-1}$	$+29.6\% +1.6\%$	$1.744 \pm 0.005 \cdot 10^0$	$+9.8\% +1.7\%$
e.11*	$pp \rightarrow t\bar{t}Zj$	$p p > t t \sim z j$	$3.953 \pm 0.004 \cdot 10^{-1}$	$-21.3\% -1.8\%$	$1.744 \pm 0.005 \cdot 10^0$	$-11.0\% -2.6\%$
e.12*	$pp \rightarrow t\bar{t}\gamma j$	$p p > t t \sim a j$	$8.726 \pm 0.010 \cdot 10^{-1}$	$+40.9\% +1.3\%$	$3.404 \pm 0.011 \cdot 10^{-1}$	$+11.2\% +1.2\%$
e.13*	$pp \rightarrow t\bar{t}W^-W^+ (4f)$	$p p > t t \sim w^+ w^-$	$6.675 \pm 0.006 \cdot 10^{-3}$	$+40.9\% +1.3\%$	$9.904 \pm 0.026 \cdot 10^{-3}$	$+10.9\% +2.1\%$
e.14*	$pp \rightarrow t\bar{t}W^\pm Z$	$p p > t t \sim wpm z$	$2.404 \pm 0.002 \cdot 10^{-3}$	$-27.1\% -1.0\%$	$3.404 \pm 0.011 \cdot 10^{-1}$	$-14.0\% -0.9\%$
e.15*	$pp \rightarrow t\bar{t}W^\pm \gamma$	$p p > t t \sim wpm a$	$2.718 \pm 0.003 \cdot 10^{-3}$	$+46.2\% +2.7\%$	$5.074 \pm 0.016 \cdot 10^{-1}$	$+7.0\% +2.5\%$
e.16*	$pp \rightarrow t\bar{t}ZZ$	$p p > t t \sim z z$	$1.349 \pm 0.014 \cdot 10^{-3}$	$+26.6\% +2.5\%$	$1.135 \pm 0.004 \cdot 10^0$	$+12.3\% -2.9\%$
e.17*	$pp \rightarrow t\bar{t}Z\gamma$	$p p > t t \sim z a$	$2.548 \pm 0.003 \cdot 10^{-3}$	$-19.6\% -1.8\%$	$1.840 \pm 0.007 \cdot 10^{-3}$	$-9.9\% -1.5\%$
e.18*	$pp \rightarrow t$					

Process	Syntax	Cross section (pb)				
		LO 13 TeV		NLO 13 TeV		
Single Higgs production						
g.1	$pp \rightarrow H$ (HEFT)	$p p > h$	$1.593 \pm 0.003 \cdot 10^1$	+34.8% +1.2%	$3.261 \pm 0.010 \cdot 10^1$	+20.2% +1.1%
g.2	$pp \rightarrow H_j$ (HEFT)	$p p > h j$	$8.367 \pm 0.003 \cdot 10^0$	+39.4% +1.2%	$1.422 \pm 0.006 \cdot 10^1$	+18.5% +1.1%
g.3	$pp \rightarrow H_{jj}$ (HEFT)	$p p > h j j$	$3.020 \pm 0.002 \cdot 10^0$	+59.1% +1.4%	$5.124 \pm 0.020 \cdot 10^0$	+20.7% +1.3%
g.4	$pp \rightarrow H_{jj}$ (VBF)	$p p > h j j \ \$\$ w^+ w^- z$	$1.987 \pm 0.002 \cdot 10^0$	+1.7% +0.9%	$1.900 \pm 0.006 \cdot 10^0$	+0.8% +0.0%
g.5	$pp \rightarrow H_{jjj}$ (VBF)	$p p > h j j j \ \$\$ w^+ w^- z$	$2.824 \pm 0.005 \cdot 10^{-1}$	+16.7% +1.0%	$3.085 \pm 0.010 \cdot 10^{-1}$	+2.0% +1.3%
g.6	$pp \rightarrow HW^\pm$	$p p > h vpm$	$1.195 \pm 0.002 \cdot 10^0$	+3.5% +1.9%	$1.419 \pm 0.005 \cdot 10^0$	+2.1% +1.9%
g.7	$pp \rightarrow HW^\pm j$	$p p > h vpm j$	$4.018 \pm 0.003 \cdot 10^{-1}$	+10.7% +1.3%	$4.842 \pm 0.017 \cdot 10^{-1}$	+2.0% +1.4%
g.8*	$pp \rightarrow HW^\pm jj$	$p p > h vpm j j$	$1.198 \pm 0.016 \cdot 10^{-1}$	+36.1% +0.8%	$1.574 \pm 0.014 \cdot 10^{-1}$	+5.0% +0.8%
g.9	$pp \rightarrow HZ$	$p p > h z$	$6.468 \pm 0.008 \cdot 10^{-1}$	+3.8% +1.9%	$7.674 \pm 0.027 \cdot 10^{-1}$	+2.0% +1.9%
g.10	$pp \rightarrow HZ j$	$p p > h z j$	$2.225 \pm 0.001 \cdot 10^{-1}$	+10.6% +1.1%	$2.667 \pm 0.010 \cdot 10^{-1}$	+3.5% +1.1%
g.11*	$pp \rightarrow HZ jj$	$p p > h z j j$	$7.262 \pm 0.012 \cdot 10^{-2}$	+26.2% +0.7%	$8.753 \pm 0.037 \cdot 10^{-2}$	+4.8% +0.7%
g.12*	$pp \rightarrow HW^+W^-$ (4f)	$p p > h w^+ w^-$	$8.325 \pm 0.139 \cdot 10^{-3}$	+0.0% +2.0%	$1.065 \pm 0.003 \cdot 10^{-2}$	+2.0% +2.0%
g.13*	$pp \rightarrow HW^\pm \gamma$	$p p > h vpm a$	$2.518 \pm 0.006 \cdot 10^{-3}$	+0.7% +1.9%	$3.309 \pm 0.011 \cdot 10^{-3}$	+2.7% +1.7%
g.14*	$pp \rightarrow HZW^\pm$	$p p > h z vpm$	$3.763 \pm 0.007 \cdot 10^{-3}$	+1.1% +2.0%	$5.292 \pm 0.015 \cdot 10^{-3}$	+3.9% +1.8%
g.15*	$pp \rightarrow HZZ$	$p p > h z z$	$2.093 \pm 0.003 \cdot 10^{-3}$	+0.1% +1.9%	$2.538 \pm 0.007 \cdot 10^{-3}$	+1.9% +2.0%
g.16	$pp \rightarrow Ht\bar{t}$	$p p > h t t\bar{t}$	$3.579 \pm 0.003 \cdot 10^{-1}$	+30.0% +1.7%	$4.608 \pm 0.016 \cdot 10^{-1}$	+5.7% +5.0%
g.17	$pp \rightarrow Htj$	$p p > h tt j$	$4.994 \pm 0.005 \cdot 10^{-2}$	+9.4% +1.3%	$6.328 \pm 0.022 \cdot 10^{-2}$	+9.9% +1.5%
g.18	$pp \rightarrow Hb\bar{b}$ (4f)	$p p > h b b\bar{b}$	$4.983 \pm 0.002 \cdot 10^{-1}$	+26.1% +1.0%	$6.085 \pm 0.026 \cdot 10^{-1}$	+7.5% +1.9%
g.19	$pp \rightarrow Htj$	$p p > h t t\bar{t} j$	$2.674 \pm 0.041 \cdot 10^{-1}$	+45.0% +2.0%	$3.244 \pm 0.025 \cdot 10^{-1}$	+3.5% +2.5%
g.20*	$pp \rightarrow Hb\bar{b}j$ (4f)	$p p > h b b\bar{b} j$	$7.367 \pm 0.002 \cdot 10^{-2}$	+45.0% +1.8%	$9.034 \pm 0.032 \cdot 10^{-2}$	+7.9% +1.8%

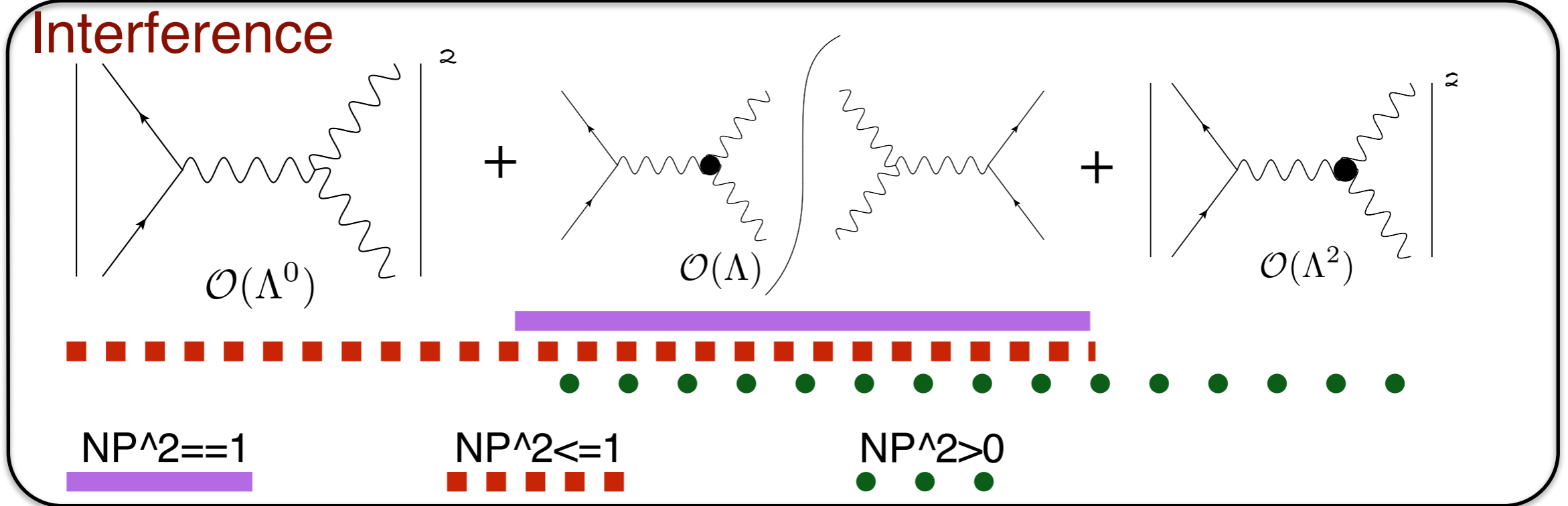
Process	Syntax	Cross section (pb)				
		LO 13 TeV		NLO 13 TeV		
Higgs pair production						
h.1	$pp \rightarrow HH$ (Loop improved)	$p p > h h$	$1.772 \pm 0.006 \cdot 10^{-2}$	+29.5% +2.1%	$2.763 \pm 0.008 \cdot 10^{-2}$	+11.4% +2.1%
h.2	$pp \rightarrow HHjj$ (VBF)	$p p > h h j j \ \$\$ w^+ w^- z$	$6.503 \pm 0.019 \cdot 10^{-4}$	+7.9% +2.8%	$6.820 \pm 0.026 \cdot 10^{-4}$	+0.8% +2.8%
h.3	$pp \rightarrow HHW^\pm$	$p p > h h vpm$	$4.303 \pm 0.005 \cdot 10^{-4}$	+0.9% +1.6%	$5.002 \pm 0.014 \cdot 10^{-4}$	+1.5% +3.0%
h.4*	$pp \rightarrow HHW^\pm j$	$p p > h h vpm j$	$1.922 \pm 0.002 \cdot 10^{-4}$	+14.2% +1.6%	$2.218 \pm 0.009 \cdot 10^{-4}$	+2.7% +1.6%
h.5*	$pp \rightarrow HHW^\pm \gamma$	$p p > h h vpm a$	$1.952 \pm 0.004 \cdot 10^{-6}$	+8.0% +2.9%	$2.347 \pm 0.007 \cdot 10^{-6}$	+2.4% +2.1%
h.6	$pp \rightarrow HHZ$	$p p > h h z$	$2.701 \pm 0.007 \cdot 10^{-4}$	+0.9% +1.6%	$3.130 \pm 0.008 \cdot 10^{-4}$	+2.0% +1.6%
h.7*	$pp \rightarrow HHZj$	$p p > h h z j$	$1.211 \pm 0.001 \cdot 10^{-4}$	+14.1% +1.4%	$1.394 \pm 0.006 \cdot 10^{-4}$	+2.7% +1.4%
h.8*	$pp \rightarrow HHZ\gamma$	$p p > h h z a$	$1.397 \pm 0.003 \cdot 10^{-6}$	+2.4% +2.2%	$1.604 \pm 0.005 \cdot 10^{-6}$	+1.4% +2.3%
h.9*	$pp \rightarrow HHZZ$	$p p > h h z z$	$2.309 \pm 0.005 \cdot 10^{-6}$	+3.9% +2.2%	$2.754 \pm 0.009 \cdot 10^{-6}$	+2.3% +2.3%
h.10*	$pp \rightarrow HHZW^\pm$	$p p > h h z vpm$	$3.708 \pm 0.013 \cdot 10^{-6}$	+4.8% +2.3%	$4.904 \pm 0.029 \cdot 10^{-6}$	+3.7% +2.2%
h.11*	$pp \rightarrow HHW^+W^-$ (4f)	$p p > h h w^+ w^-$	$7.524 \pm 0.070 \cdot 10^{-6}$	+3.5% +2.3%	$9.268 \pm 0.030 \cdot 10^{-6}$	+2.9% +2.3%
h.12	$pp \rightarrow HHt\bar{t}$	$p p > h h t t\bar{t}$	$6.756 \pm 0.007 \cdot 10^{-4}$	+30.2% +1.8%	$7.301 \pm 0.024 \cdot 10^{-4}$	+1.4% +2.2%
h.13	$pp \rightarrow HHtj$	$p p > h h tt j$	$1.844 \pm 0.008 \cdot 10^{-6}$	+0.0% +1.8%	$2.444 \pm 0.009 \cdot 10^{-6}$	+4.5% +2.8%
h.14*	$pp \rightarrow HHb\bar{b}$	$p p > h h b b\bar{b}$	$7.849 \pm 0.022 \cdot 10^{-8}$	+34.3% +3.1%	$1.084 \pm 0.012 \cdot 10^{-7}$	+7.4% +3.1%
$\eta \rightarrow \gamma\gamma\gamma$		$p p > z z a a$	$3.015 \pm 0.011 \cdot 10^{-5}$	-0.3% -1.6%	$1.015 \pm 0.032 \cdot 10^{-5}$	-2.6% -1.5%
$\eta \rightarrow Z\gamma\gamma$		$p p > z a a a$	$4.790 \pm 0.012 \cdot 10^{-5}$	+2.3% +2.0%	$7.103 \pm 0.026 \cdot 10^{-5}$	+3.4% +1.6%
$\eta \rightarrow \gamma\gamma\gamma$		$p p > a a a a$	$1.594 \pm 0.004 \cdot 10^{-5}$	+4.7% +1.9%	$3.389 \pm 0.012 \cdot 10^{-5}$	+7.0% +1.3%

Process	Syntax	Cross section (pb)				
		LO 1 TeV		NLO 1 TeV		
Heavy quarks and jets						
i.1	$e^+e^- \rightarrow jj$	$e^+ e^- > j j$	$6.223 \pm 0.005 \cdot 10^{-1}$	+0.0%	$6.389 \pm 0.013 \cdot 10^{-1}$	+0.2%
i.2	$e^+e^- \rightarrow jjj$	$e^+ e^- > j j j$	$3.401 \pm 0.002 \cdot 10^{-1}$	+9.6%	$3.166 \pm 0.019 \cdot 10^{-1}$	-0.2%
i.3	$e^+e^- \rightarrow jjjj$	$e^+ e^- > j j j j$	$1.047 \pm 0.001 \cdot 10^{-1}$	+20.0%	$1.090 \pm 0.006 \cdot 10^{-1}$	+0.0%
i.4	$e^+e^- \rightarrow jjjjj$	$e^+ e^- > j j j j j$	$2.211 \pm 0.006 \cdot 10^{-2}$	+31.4%	$2.771 \pm 0.021 \cdot 10^{-2}$	+4.4%
i.5	$e^+e^- \rightarrow t\bar{t}$	$e^+ e^- > t t\bar{t}$	$1.662 \pm 0.002 \cdot 10^{-1}$	+0.0%	$1.745 \pm 0.006 \cdot 10^{-1}$	+0.4%
i.6	$e^+e^- \rightarrow t\bar{t}j$	$e^+ e^- > t t\bar{t} j$	$4.813 \pm 0.005 \cdot 10^{-2}$	+9.3%	$5.276 \pm 0.022 \cdot 10^{-2}$	+1.3%
i.7*	$e^+e^- \rightarrow t\bar{t}jj$	$e^+ e^- > t t\bar{t} j j$	$8.614 \pm 0.009 \cdot 10^{-3}$	+19.4%	$1.094 \pm 0.005 \cdot 10^{-2}$	+5.0%
i.8*	$e^+e^- \rightarrow t\bar{t}jjj$	$e^+ e^- > t t\bar{t} j j j$	$1.044 \pm 0.002 \cdot 10^{-3}$	+30.5%	$1.546 \pm 0.010 \cdot 10^{-3}$	+10.6%
i.9*	$e^+e^- \rightarrow t\bar{t}t\bar{t}$	$e^+ e^- > t t\bar{t} t\bar{t}$	$6.456 \pm 0.016 \cdot 10^{-7}$	+19.1%	$1.221 \pm 0.005 \cdot 10^{-6}$	+13.2%
i.10*	$e^+e^- \rightarrow t\bar{t}t\bar{t}j$	$e^+ e^- > t t\bar{t} t\bar{t} j$	$2.719 \pm 0.005 \cdot 10^{-8}$	+29.9%	$5.338 \pm 0.027 \cdot 10^{-8}$	+18.3%
i.11	$e^+e^- \rightarrow b\bar{b}$ (4f)	$e^+ e^- > b b\bar{b}$	$9.198 \pm 0.004 \cdot 10^{-2}$	+0.0%	$9.282 \pm 0.031 \cdot 10^{-2}$	+0.0%
i.12	$e^+e^- \rightarrow b\bar{b}j$ (4f)	$e^+ e^- > b b\bar{b} j$	$5.029 \pm 0.003 \cdot 10^{-2}$	+9.5%	$4.826 \pm 0.026 \cdot 10^{-2}$	-0.5%
i.13*	$e^+e^- \rightarrow b\bar{b}jj$ (4f)	$e^+ e^- > b b\bar{b} j j$	$1.621 \pm 0.001 \cdot 10^{-2}$	+20.0%	$1.817 \pm 0.009 \cdot 10^{-2}$	+0.0%
i.14*	$e^+e^- \rightarrow b\bar{b}jjj$ (4f)	$e^+ e^- > b b\bar{b} j j j$	$3.641 \pm 0.009 \cdot 10^{-3}$	+31.4%	$4.936 \pm 0.038 \cdot 10^{-3}$	+4.8%
i.15*	$e^+e^- \rightarrow b\bar{b}b\bar{b}$ (4f)	$e^+ e^- > b b\bar{b} b\bar{b}$	$1.644 \pm 0.003 \cdot 10^{-4}$	+19.9%	$3.601 \pm 0.017 \cdot 10^{-4}$	+15.2%
i.16*	$e^+e^- \rightarrow b\bar{b}b\bar{b}j$ (4f)	$e^+ e^- > b b\bar{b} b\bar{b} j$	$7.660 \pm 0.022 \cdot 10^{-5}$	+31.3%	$1.537 \pm 0.011 \cdot 10^{-4}$	+17.9%
i.17*	$e^+e^- \rightarrow t\bar{t}b\bar{b}$ (4f)	$e^+ e^- > t t\bar{t} b\bar{b}$	$1.819 \pm 0.003 \cdot 10^{-4}$	+19.5%	$2.923 \pm 0.011 \cdot 10^{-4}$	+9.2%
i.18*	$e^+e^- \rightarrow t\bar{t}b\bar{b}j$ (4f)	$e^+ e^- > t t\bar{t} b\bar{b} j$	$4.045 \pm 0.011 \cdot 10^{-5}$	+30.5%	$7.049 \pm 0.052 \cdot 10^{-5}$	+13.7%

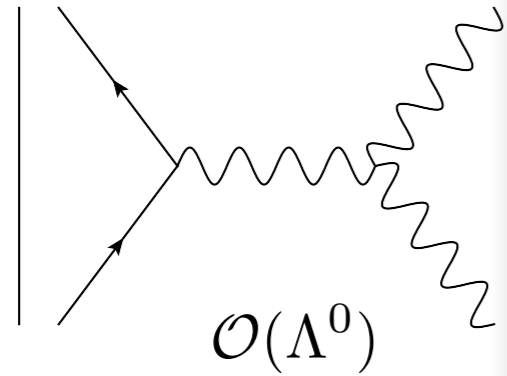
Process	Syntax	Cross section (pb)				
		LO 1 TeV		NLO 1 TeV		
Heavy quarks+vector bosons						
j.1	$e^+e^- \rightarrow t\bar{t}H$	$e^+ e^- > t t\bar{t} h$	$2.018 \pm 0.003 \cdot 10^{-3}$	+0.0%	$1.911 \pm 0.006 \cdot 10^{-3}$	+0.4%
j.2*	$e^+e^- \rightarrow t\bar{t}Hj$	$e^+ e^- > t t\bar{t} h j$	$2.533 \pm 0.003 \cdot 10^{-4}$	+9.2%	$2.658 \pm 0.009 \cdot 10^{-4}$	+0.5%
j.3*	$e^+e^- \rightarrow t\bar{t}Hjj$	$e^+ e^- > t t\bar{t} h j j$	$2.663 \pm 0.004 \cdot 10^{-5}$	+19.3%	$3.278 \pm 0.017 \cdot 10^{-5}$	+4.0%
j.4*	$e^+e^- \rightarrow t\bar{t}\gamma$	$e^+ e^- > t t\bar{t} a$	$1.270 \pm 0.002 \cdot 10^{-2}$	+0.0%	$1.335 \pm 0.004 \cdot 10^{-2}$	+0.5%
j.5*	$e^+e^- \rightarrow t\bar{t}\gamma j$	$e^+ e^- > t t\bar{t} a j$	$2.355 \pm 0.002 \cdot 10^{-3}$	+9.3%	$2.617 \pm 0.010 \cdot 10^{-3}$	+1.0%
j.6*	$e^+e^- \rightarrow t\bar{t}\gamma jj$	$e^+ e^- > t t\bar{t} a j j$	$3.103 \pm 0.005 \cdot 10^{-4}$	+19.5%	$4.002 \pm 0.021 \cdot 10^{-4}$	+3.4%
j.7*	$e^+e^- \rightarrow t\bar{t}Z$	$e^+ e^- > t t\bar{t} z$	$4.642 \pm 0.006 \cdot 10^{-3}$	+0.0%	$4.949 \pm 0.014 \cdot 10^{-3}$	+0.6%
j.8*	$e^+e^- \rightarrow t\bar{t}Zj$	$e^+ e^- > t t\bar{t} z j$	$6.059 \pm 0.006 \cdot 10^{-4}$	+9.3%	$6.940 \pm 0.028 \cdot 10^{-4}$	+2.0%
j.9*	$e^+e^- \rightarrow t\bar{t}Zjj$	$e^+ e^- > t t\bar{t} z j j$	$6.351 \pm 0.028 \cdot 10^{-5}$	+19.4%	$8.439 \pm 0.051 \cdot 10^{-5}$	+5.8%
j.10*	$e^+e^- \rightarrow t\bar{t}W^\pm jj$	$e^+ e^- > t t\bar{t} vpm j j$	$2.400 \pm 0.004 \cdot 10^{-7}$	+19.3%	$3.723 \pm 0.012 \cdot 10^{-7}$	+9.3%
j.11*	$e^+e^- \rightarrow t\bar{t}HZ$	$e^+ e^- > t t\bar{t} h z$	$3.600 \pm 0.006 \cdot 10^{-5}$	+0.0%	$3.579 \pm 0.013 \cdot 10^{-5}$	+0.1%
j.12*	$e^+e^- \rightarrow t\bar{t}\gamma Z$	$e^+ e^- > t t\bar{t} a z$	$2.212 \pm 0.003 \cdot 10^{-4}$	+0.0%	$2.364 \pm 0.006 \cdot 10^{-4}$	+0.6%
j.13*	$e^+e^- \rightarrow t\bar{t}\gamma H$	$e^+ e^- > t t\bar{t} a h$	$9.756 \pm 0.016 \cdot 10^{-5}$	+0.0%	$9.423 \pm 0.032 \cdot 10^{-5}$	+0.3%
j.14*	$e^+e^- \rightarrow t\bar{t}\gamma\gamma$	$e^+ e^- > t t\bar{t} a a$	$3.650 \pm 0.008 \cdot 10^{-4}$	+0.0%	$3.833 \pm 0.013 \cdot 10^{-4}$	+0.4%
j.15*	$e^+e^- \rightarrow t\bar{t}ZZ$	$e^+ e^- > t t\bar{t} z z$	$3.788 \pm 0.004 \cdot 10^{-5}$	+0.0%	$4.007 \pm 0.013 \cdot 10^{-5}$	+0.5%
j.16*	$e^+e^- \rightarrow t\bar{t}HH$	$e^+ e^- > t t\bar{t} h h$	$1.358 \pm 0.001 \cdot 10^{-5}$	+0.0%	$1.206 \pm 0.003 \cdot 10^{-5}$	-0.5%
j.17*	$e^+e^- \rightarrow t\bar{t}W^+W^-$	$e^+ e^- > t t\bar{t} w^+ w^-$	$1.372 \pm 0.003 \cdot 10^{-4}$	+0.0%	$1.540 \pm 0.006 \cdot 10^{-4}$	+1.0%



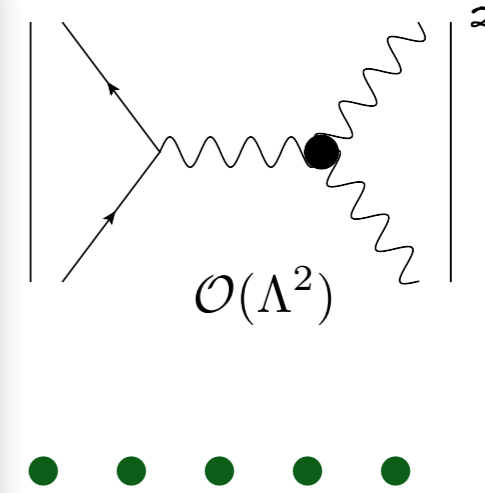
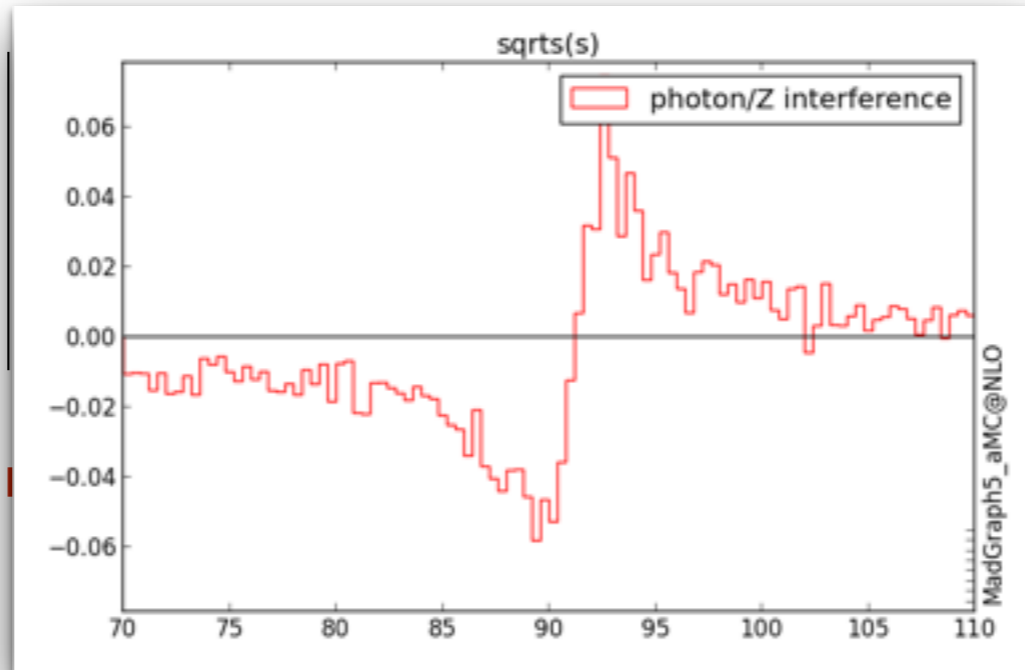
- MadWidth: Computation of the width
- MadSpin: Decay with full-spin correlation
- MadAnalysis5: Plotting interface
- SysCalc: Computation of uncertainty
- MadWeight: Matrix-Element Method
-



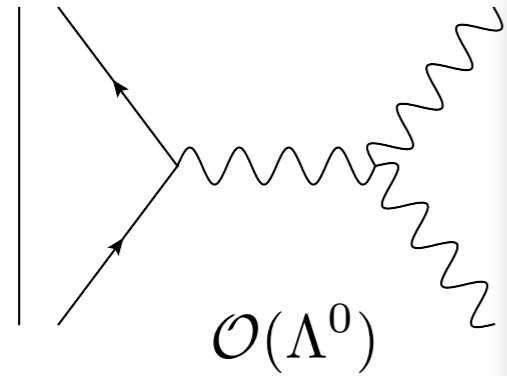
Interference



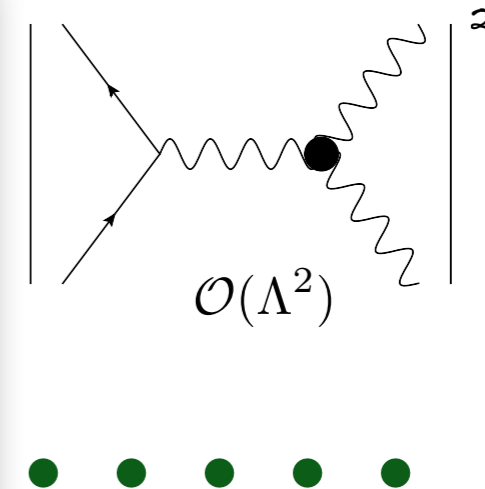
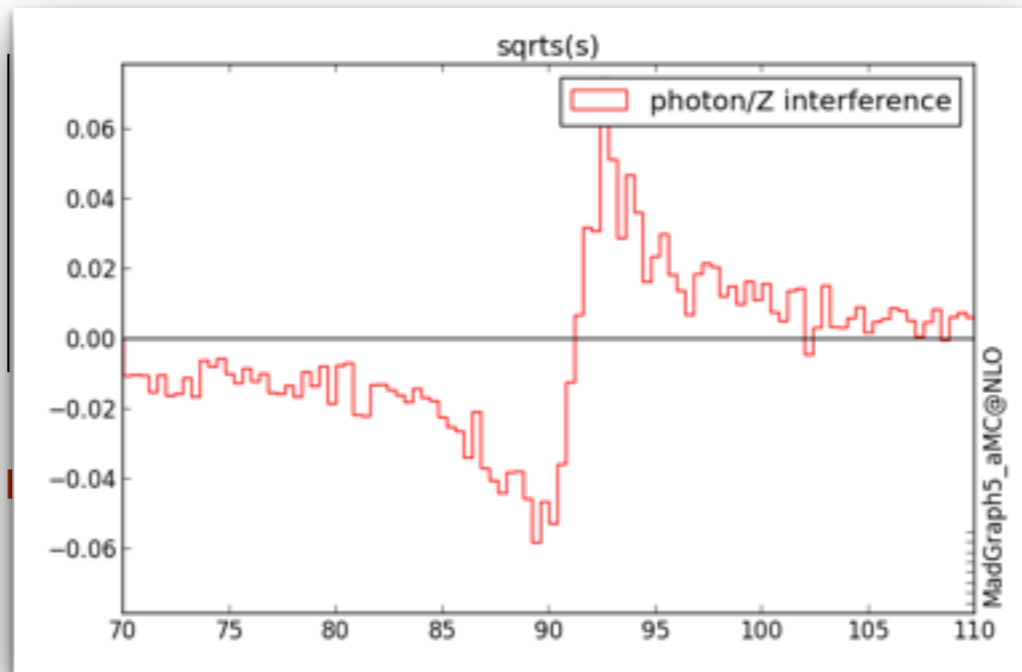
$NP^2 == 1$



Interference

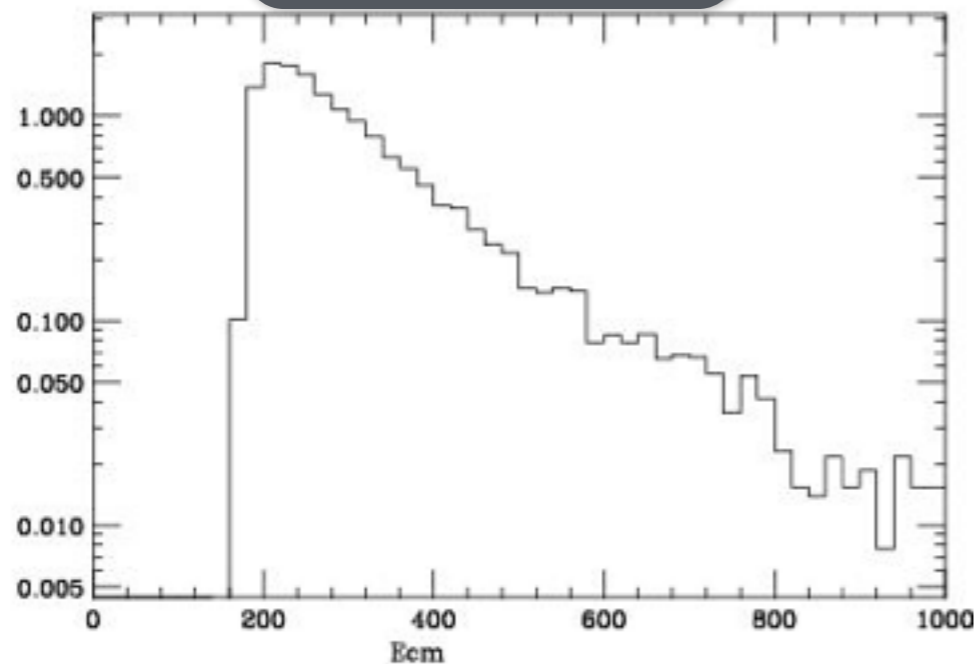


NP²==1



Re-Weighting

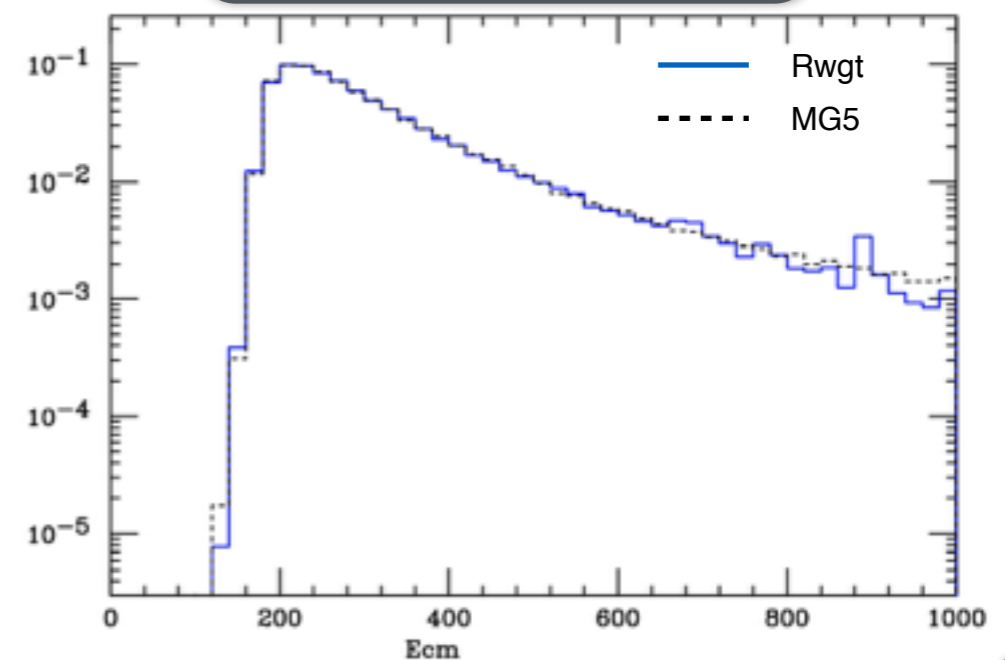
Original



$$\frac{|M_{new}|^2}{|M_{old}|^2}$$

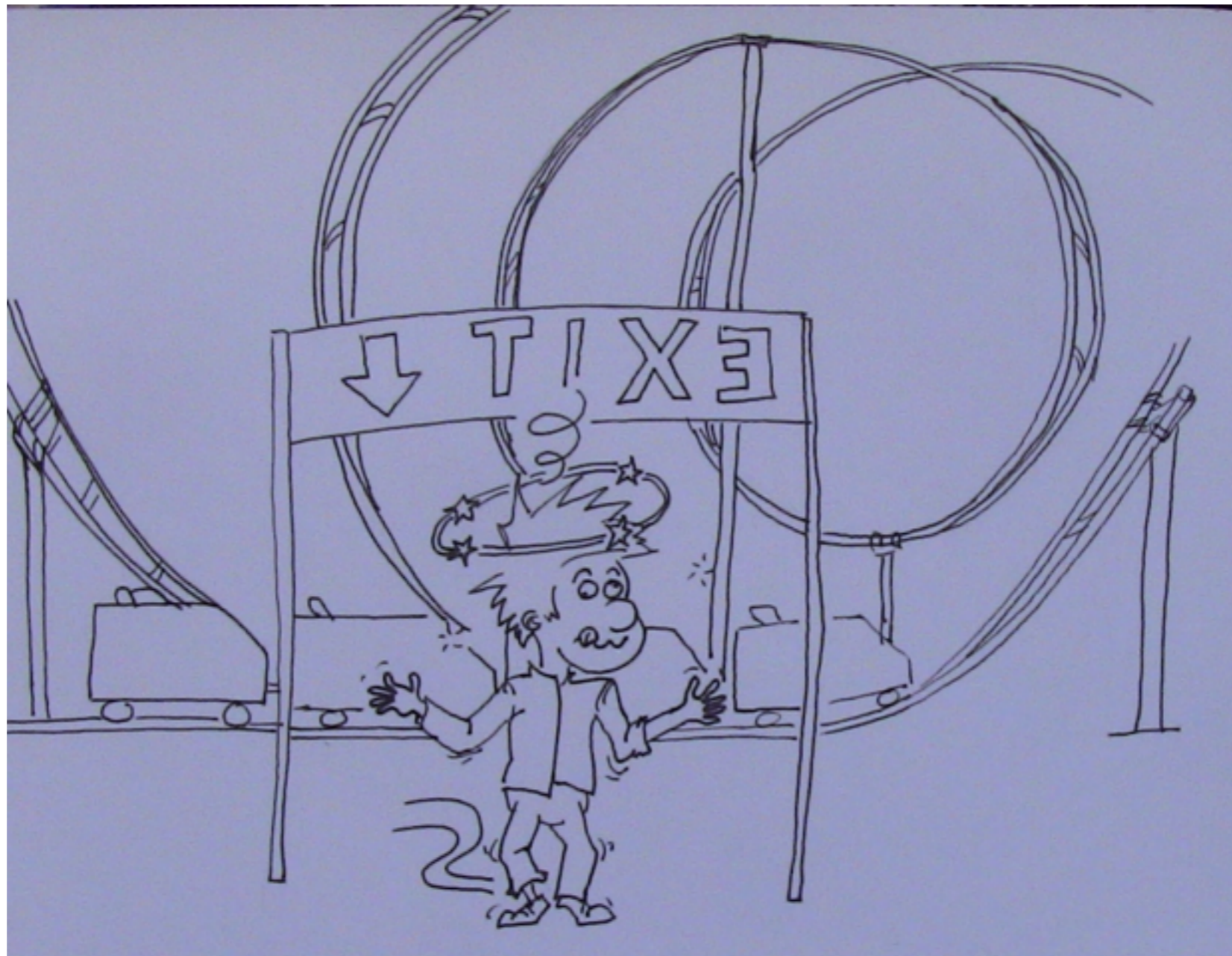


Reweighted



- What is MadGraph5_aMC@NLO
- Loop-Induced processes

- What is MadGraph5_aMC@NLO
- Loop-Induced processes



Why?

- Main production mechanism for Higgs & Higgs associated processes
- Contribution for NNLO computation
- Correction to shape of observables

Difficulties?

- The phase-space integration is based on the born diagram
- Loop evaluation are extremely slow
- Need Leading Color information for writing Events associated to the loop

Difficulties?

- The phase-space integration is based on the born diagram
- Loop evaluation are extremely slow
- Need Leading Color information for writing Events associated to the loop

Solution

- Use Effective Field Theory (\Rightarrow Tree)
- And correct the mass effect

$$W_{new} = \frac{|M_{new}|^2}{|M_{old}|^2} * W_{old}$$

- Difficult control on numerical uncertainty
- Wrong Leading Color information/helicity
- Not generic

Difficulties?

- The phase-space integration is based on the born diagram
- Loop evaluation are extremely slow
- Need Leading Color information for writing Events associated to the loop

Solution

- Contract the loop to have tree-level diagrams which drive the integration multi-channel
- Use Monte-Carlo over helicity
- Increase parallelization
- Compute the loop with the color flow algebra

Difficulties?

- The phase-space integration is based on the born diagram
- Loop evaluation are extremely slow
- Need Leading Color information for writing Events associated to the loop

Solution

- Contract the loop to have tree-level diagrams which drive the integration in a single channel
- Use MadGraph5 to generate the loop diagrams
- Use MadGraph5 to compute the loop with the color flow algebra

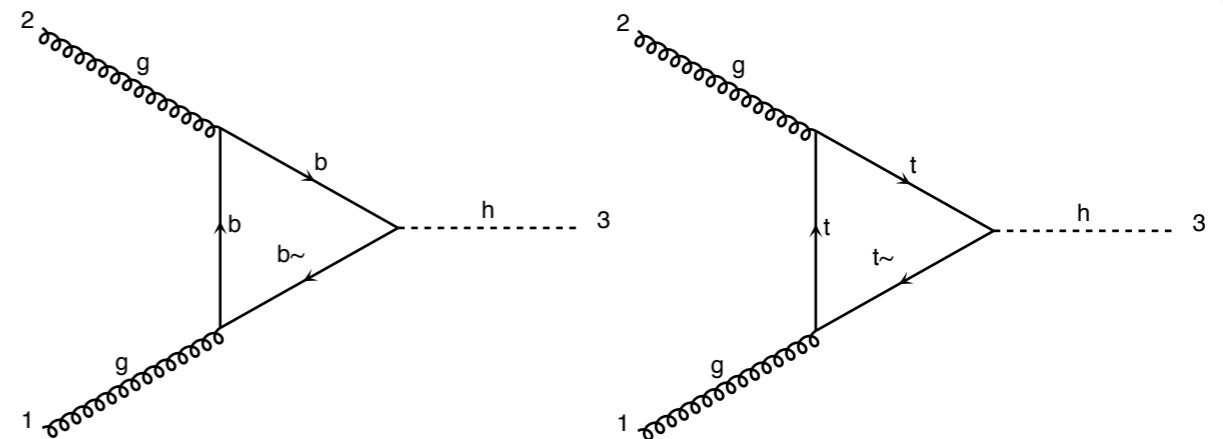
WARNING: WORK IN PROGRESS
Temporary Result

User Input

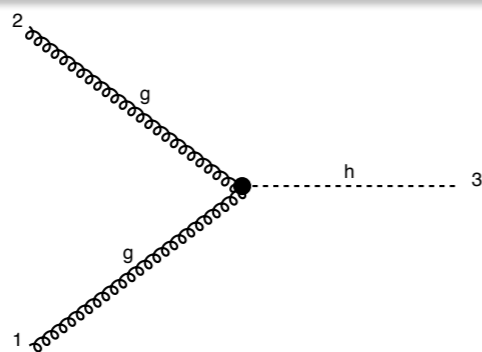
- generate $g g \rightarrow h$ [QCD]
- output
- launch

Loop Induced

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



HEFT



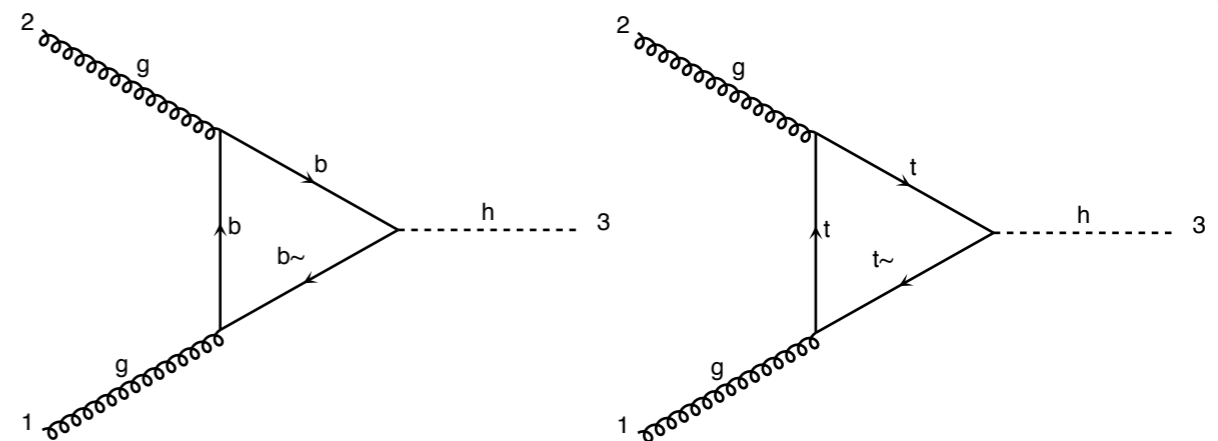
$$\sigma_{heft} = 17.63(2)pb$$

User Input

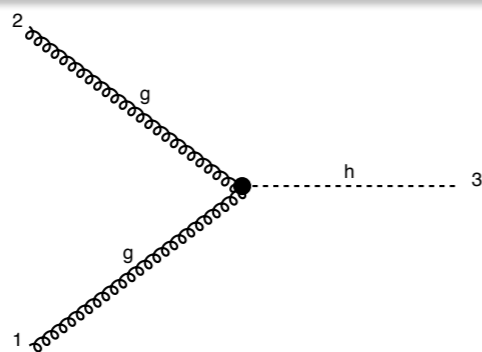
- generate $g g \rightarrow h$ [QCD]
- output
- launch

Loop Induced

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

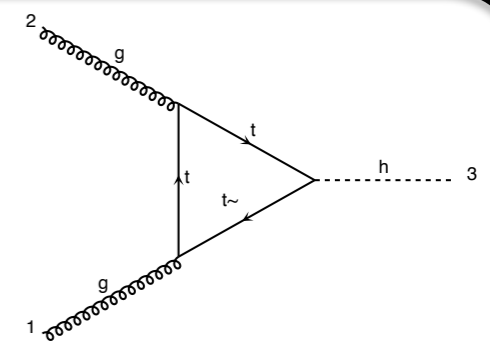


HEFT



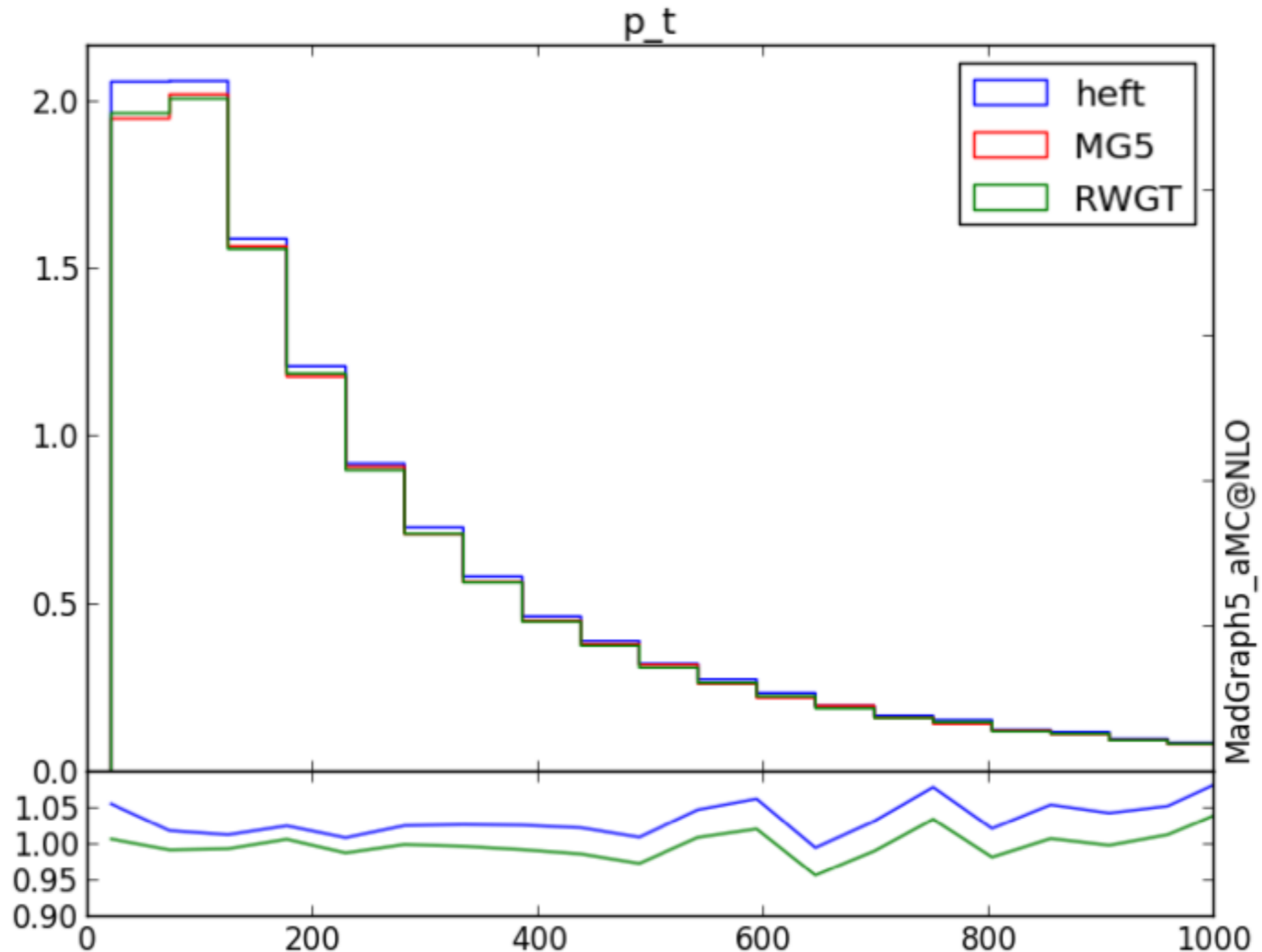
$$\sigma_{heft} = 17.63(2)pb$$

No bottom loop

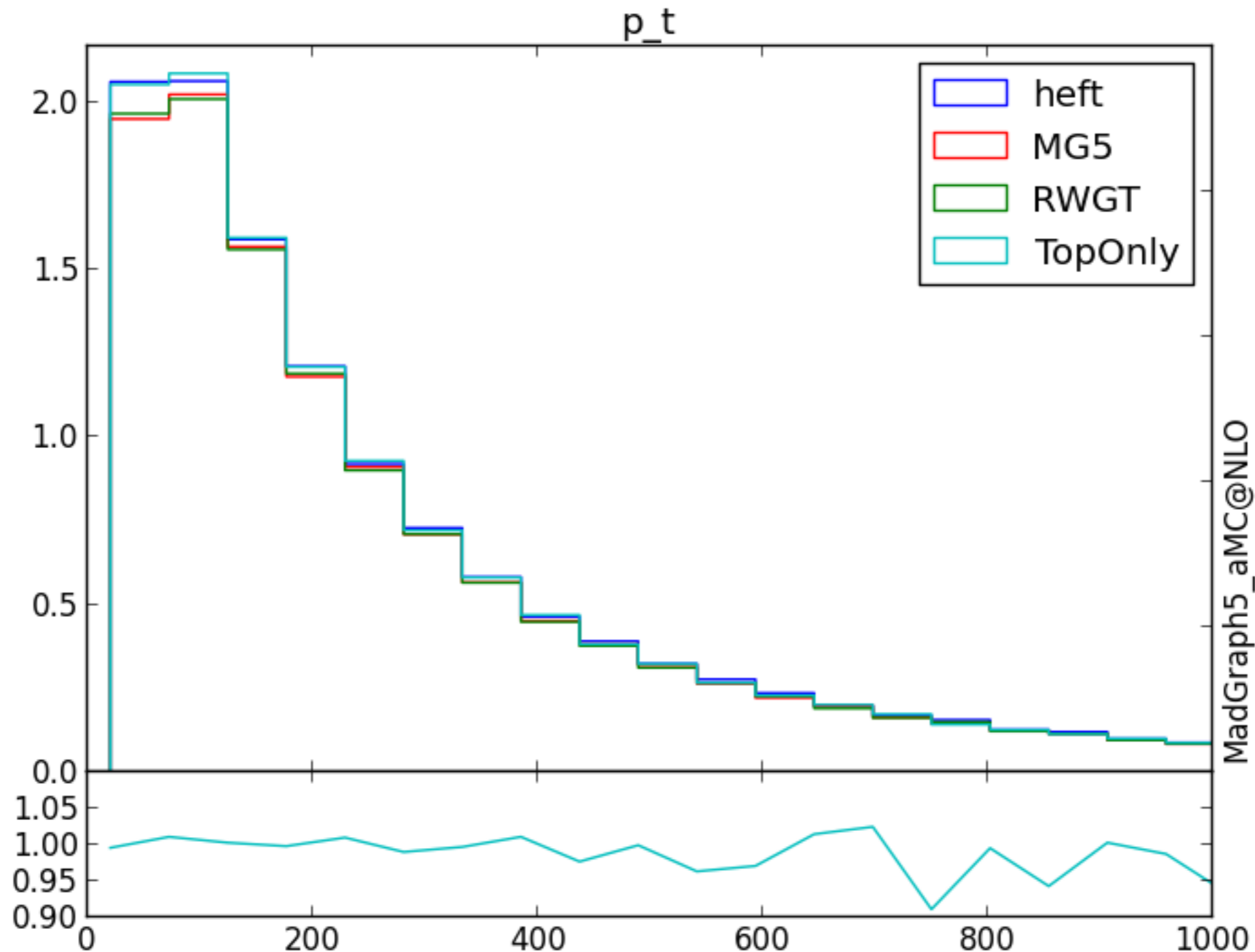


$$\sigma_{toploop} = 17.65(2)pb$$

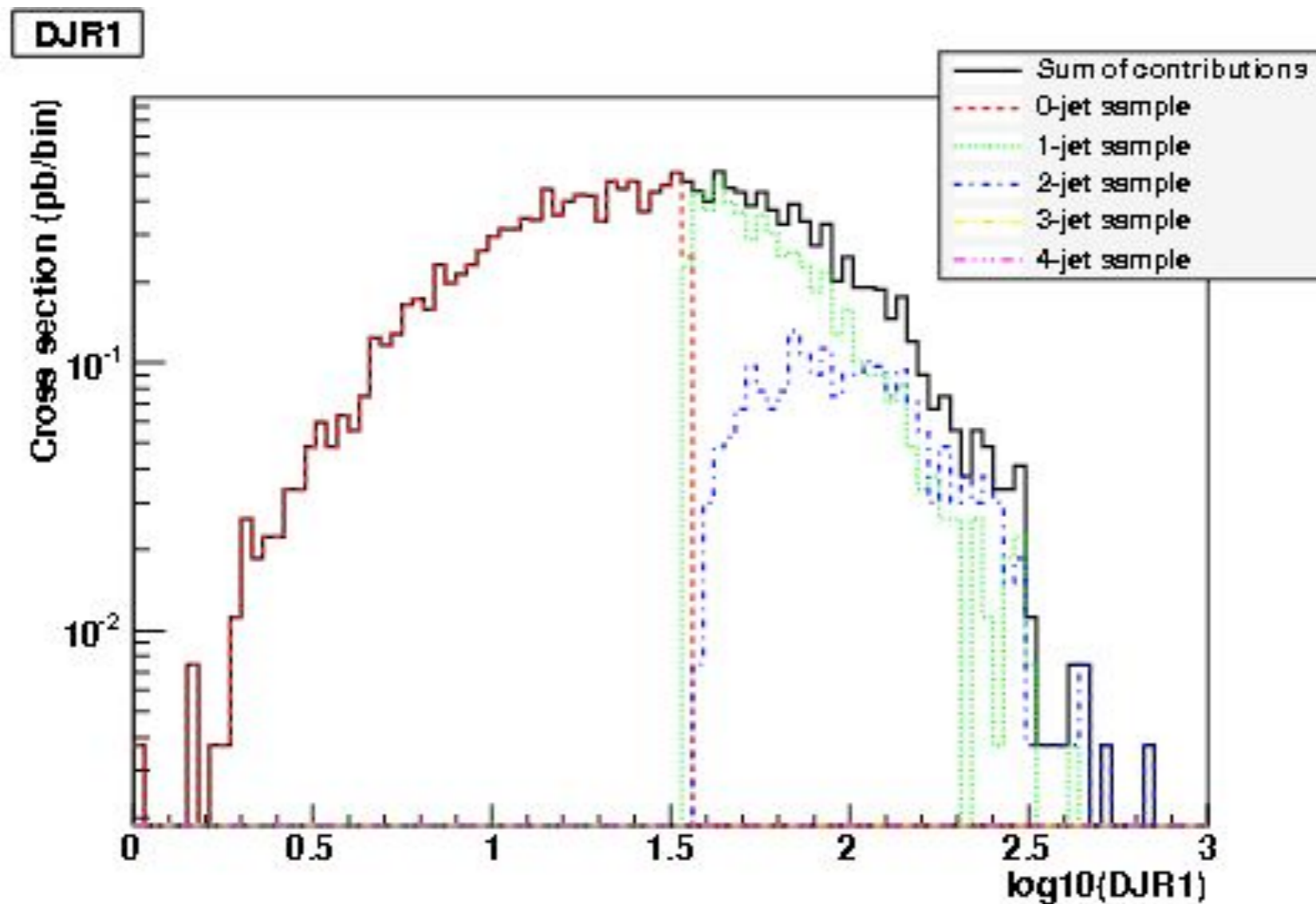
- Comparison for $g g > h g$



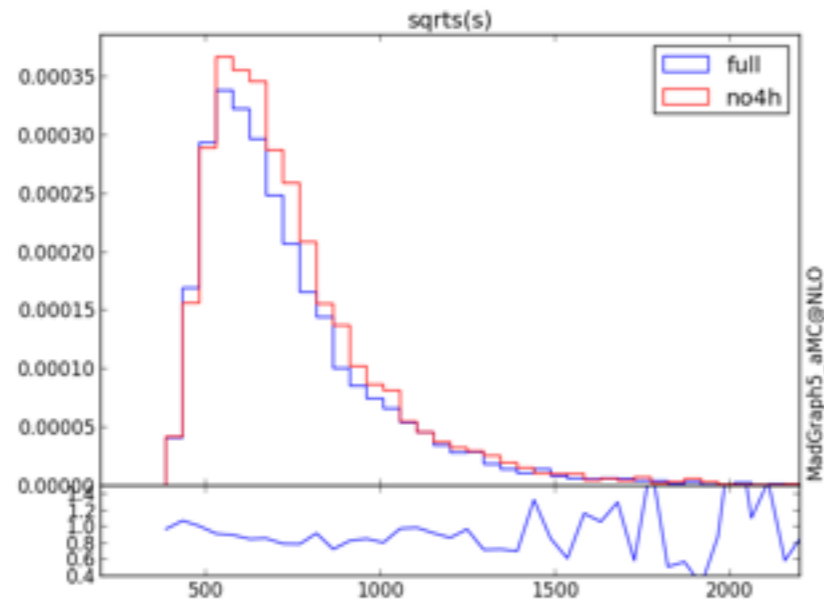
- Comparison for $g g > h g$



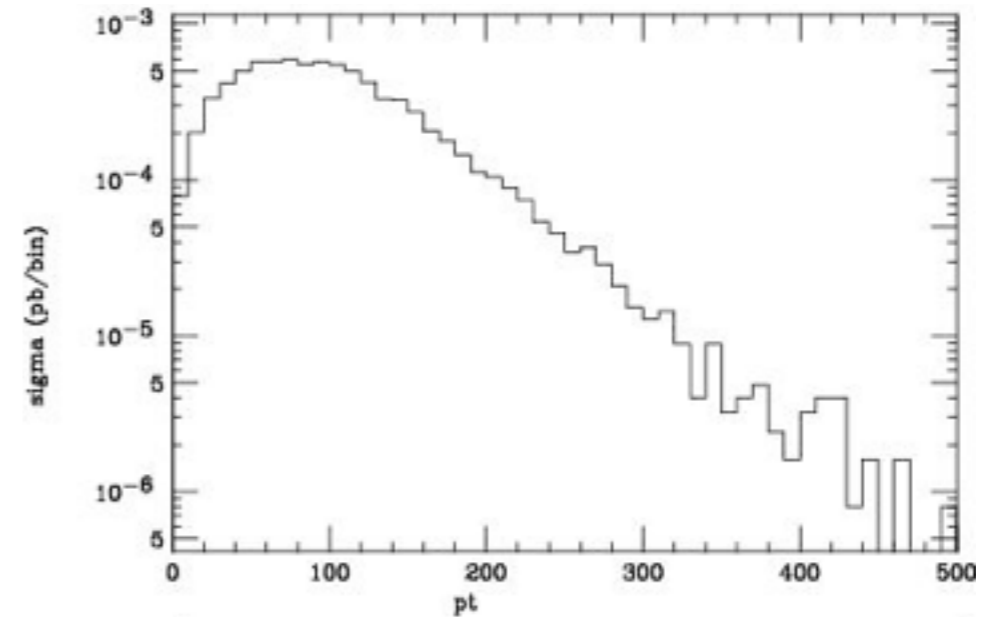
- Higgs Production up to two loop
 - ➔ not considering the VBS production



Triple Higgs @ 100TeV

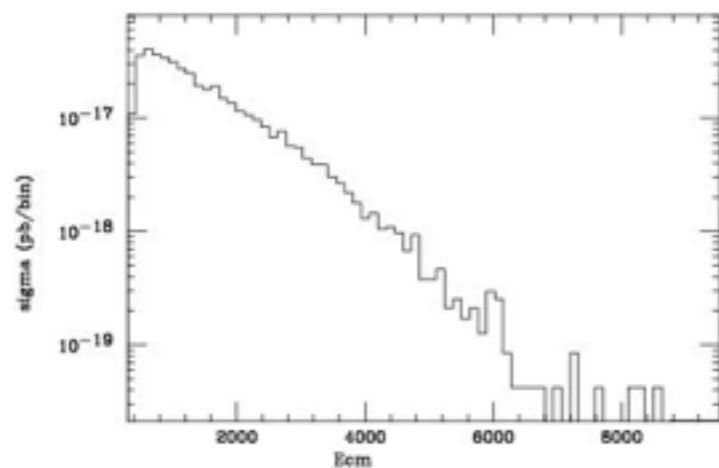


Charge Pair Production

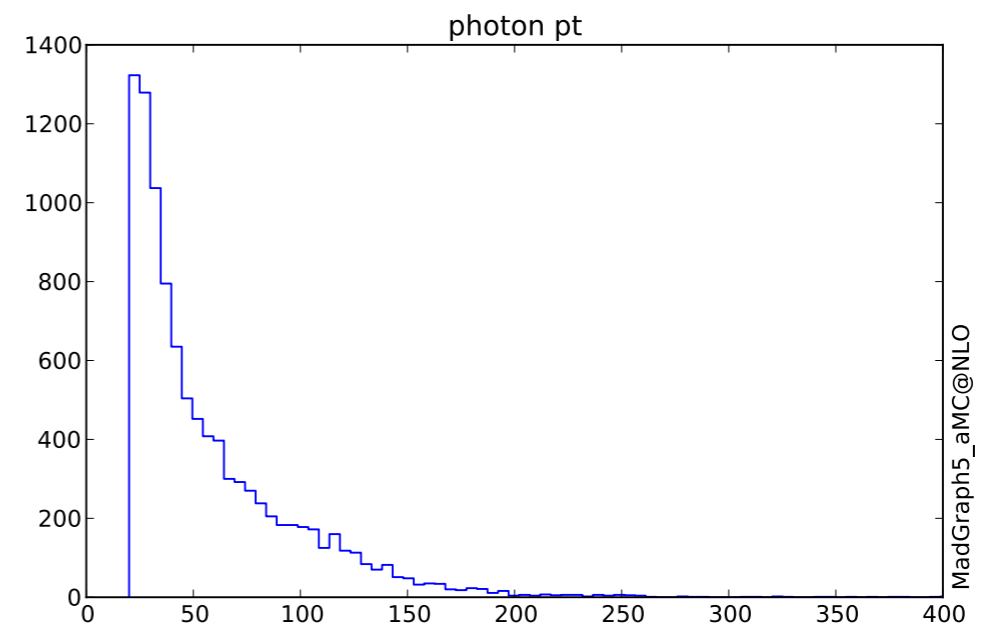


Same Sign Top

$$\sigma_{loop} = 2.23(1)10^{-15} pb$$



gg > ga & gg > gga



- 2 to 2 processes: OK on a laptop
- 2 to 3 processes: OK on a small size cluster
- 2 to 4 processes: Specific case

Process	Syntax	Cross section (pb)		
Single boson + jets		13 TeV		
a.1 $pp \rightarrow H$	<code>p p > h [noborn=QCD]</code>	17.77 ± 0.060	+31.3%	+0.7%
a.2 $pp \rightarrow H j$	<code>p p > h j [noborn=QCD]</code>	14.82 ± 0.010	-23.1%	-1.0%
a.3 $pp \rightarrow H j j$	<code>p p > h j j [noborn=QCD]</code>	8.807 ± 0.010	+43.9%	+0.6%
a.4 $gg \rightarrow Z g$	<code>g g > z g [noborn=QCD]</code>	51.80 ± 0.050	-28.4%	-0.9%
a.5 $gg \rightarrow Z g g$	<code>g g > z g g [noborn=QCD]</code>	0.0	+65.3%	+0.8%
a.6 $gg \rightarrow \gamma g$	<code>g g > a g [noborn=QCD]</code>	0.0	-36.9%	-1.0%
a.7 $gg \rightarrow \gamma g g$	<code>g g > a g g [noborn=QCD]</code>	0.0	0% 0%	0% 0%

Process	Syntax	Cross section (pb)		
Triple bosons		13 TeV		
c.1 $pp \rightarrow H H H$	<code>p p > h h h [noborn=QCD]</code>	0.0	0% 0%	0% 0%
c.2 $gg \rightarrow H H Z$	<code>g g > h h z [noborn=QCD]</code>	0.0	0% 0%	0% 0%
c.3 $gg \rightarrow H Z Z$	<code>g g > h z z [noborn=QCD]</code>	0.0	0% 0%	0% 0%
c.4 $gg \rightarrow H Z \gamma$	<code>g g > h z a [noborn=QCD]</code>	0.0	0% 0%	0% 0%
c.5 $pp \rightarrow H \gamma \gamma$	<code>p p > h a a [noborn=QCD]</code>	0.0	0% 0%	0% 0%
c.6 $pp \rightarrow H W^+ W^-$	<code>g g > h w+ w- [noborn=QCD]</code>	0.0	0% 0%	0% 0%
c.7 $gg \rightarrow Z Z Z$	<code>g g > z z z [noborn=QCD]</code>	0.0	0% 0%	0% 0%
c.8 $gg \rightarrow Z Z \gamma$	<code>g g > z z a [noborn=QCD]</code>	0.0	0% 0%	0% 0%
c.9 $gg \rightarrow Z \gamma \gamma$	<code>g g > z a a [noborn=QCD]</code>	0.0	0% 0%	0% 0%
c.10 $gg \rightarrow Z W^+ W^-$	<code>g g > z w+ w- [noborn=QCD]</code>	0.0	0% 0%	0% 0%
c.11 $gg \rightarrow \gamma \gamma \gamma$	<code>g g > a a a [noborn=QCD]</code>	0.0	0% 0%	0% 0%
c.12 $gg \rightarrow \gamma W^+ W^-$	<code>g g > a w+ w- [noborn=QCD]</code>	0.0	0% 0%	0% 0%

Process	Syntax	Cross section (pb)		
Double bosons + jet		13 TeV		
b.1 $pp \rightarrow H H$	<code>p p > h h [noborn=QCD]</code>	$1.547 \pm 0.002 \cdot 10^{-2}$	+29.5%	+1.3%
b.2 $pp \rightarrow H H j$	<code>p p > h h j [noborn=QCD]</code>	0.0	-21.4%	-1.3%
b.3 $pp \rightarrow H \gamma j$	<code>p p > h a j [noborn=QCD]</code>	0.0	0% 0%	0% 0%
b.4 $gg \rightarrow H Z$	<code>g g > h z [noborn=QCD]</code>	$6.180 \pm 0.010 \cdot 10^{-2}$	+28.7%	+1.1%
b.5 $gg \rightarrow H Z g$	<code>g g > h z g [noborn=QCD]</code>	0.0	-20.9%	-1.2%
b.6 $gg \rightarrow Z Z$	<code>g g > z z [noborn=QCD]</code>	1.182 ± 0.003	0% 0%	0% 0%
b.7 $gg \rightarrow Z Z g$	<code>g g > z z g [noborn=QCD]</code>	0.0	+26.5%	+0.7%
b.8 $gg \rightarrow Z \gamma$	<code>g g > z a [noborn=QCD]</code>	1.211 ± 0.006	-19.8%	-1.0%
b.9 $gg \rightarrow Z \gamma g$	<code>g g > z a g [noborn=QCD]</code>	0.0	+29.2%	+0.8%
b.10 $gg \rightarrow \gamma \gamma$	<code>g g > a a [noborn=QCD]</code>	$5.119 \pm 0.007 \cdot 10^{+2}$	-21.7%	-1.1%
b.11 $gg \rightarrow \gamma \gamma g$	<code>g g > a a g [noborn=QCD]</code>	0.0	+68.8%	+1.1%
b.12 $gg \rightarrow W^+ W^+$	<code>g g > w+ w- [noborn=QCD]</code>	3.698 ± 0.010	-42.0%	-1.5%
b.13 $gg \rightarrow W^+ W^- g$	<code>g g > w+ w- g [noborn=QCD]</code>	0.0	+26.0%	+0.7%

Process	Syntax	Cross section (pb)		
Selected 2 \rightarrow 4		13 TeV		
d.1 $pp \rightarrow H j j j$	<code>p p > h j j j [noborn=QCD]</code>	0.0	0% 0%	0% 0%
d.2 $pp \rightarrow H H j j$	<code>p p > h h j j [noborn=QCD]</code>	0.0	0% 0%	0% 0%
d.3 $gg \rightarrow e^+ e^- \mu^+ \mu^-$	<code>g g > e+ e- mu+ mu- [noborn=QCD]</code>	0.0	0% 0%	0% 0%
d.4 $pp \rightarrow H Z \gamma j$	<code>g g > h z a g [noborn=QCD]</code>	0.0	0% 0%	0% 0%
d.5 $gg \rightarrow W^+ W^- W^+ W^-$	<code>g g > w+ w- w+ w- [noborn=QCD]</code>	0.0	0% 0%	0% 0%
$e^+ e^-$ processes		$\hat{s} = 500$ GeV		
e.1 $e^+ e^- \rightarrow g g g$	<code>e+ e- > g g g [noborn=QED]</code>	0.0	0% 0%	0% 0%
e.2 $e^+ e^- \rightarrow H H$	<code>e+ e- > h h [noborn=QED]</code>	0.0	0% 0%	0% 0%
e.3 $e^+ e^- \rightarrow H H g g$	<code>e+ e- > h h g g [noborn=QED]</code>	0.0	0% 0%	0% 0%

- MadGraph5_aMC@NLO
 - ➔ Framework for LO and NLO computation
 - ➔ Fixed order or matched to the shower
 - ➔ Merging possible
- Loop-Induced
 - ➔ Code Ready
 - ➔ Full Validation in progress (and fine tuning)
 - ➔ Will be released soon