MC(NET) ACTIVITIES @ UCLOUVAIN

Fabio Maltoni
Centre for Cosmology, Particle Physics and Phenomenology
Université catholique de Louvain

CERN
31 March 2014

CP3 AT UCLOUVAIN

Connecting

People

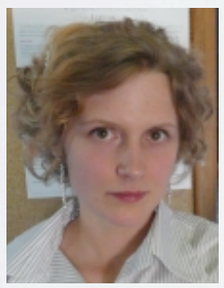
and Physics

Projects

PHD STUDENTS @ CP3

Ioannis Tsinikos

ttV, ttVV



Elisa Mariani

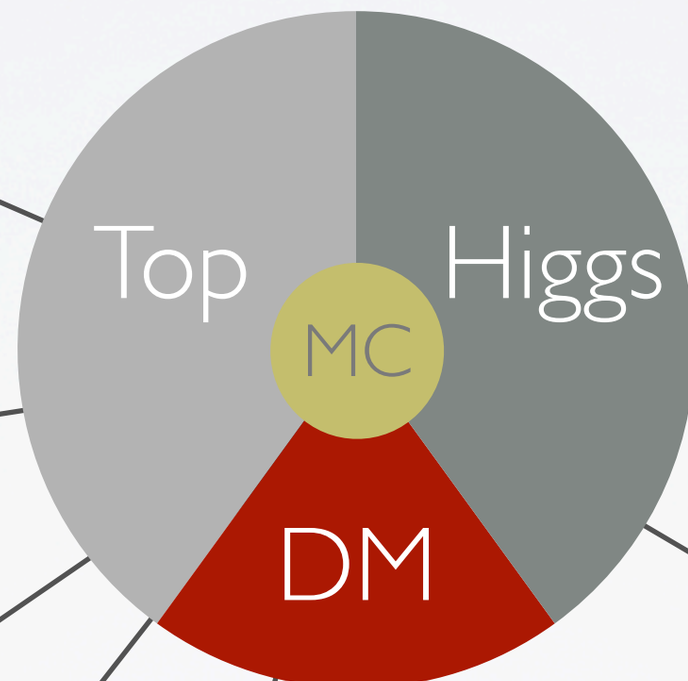
single top

Mathieu Buchkremer

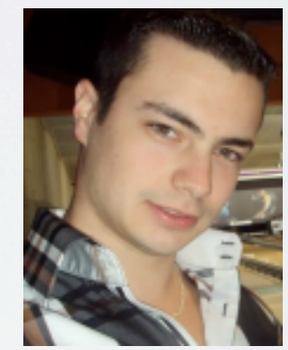
top partners

Gauthier Durieux

top BSM

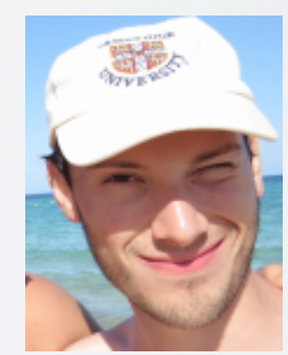


Benoit Hespel



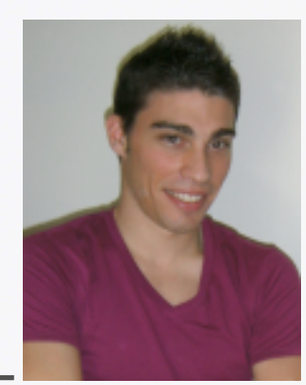
HH in BSM

Federico Demartin



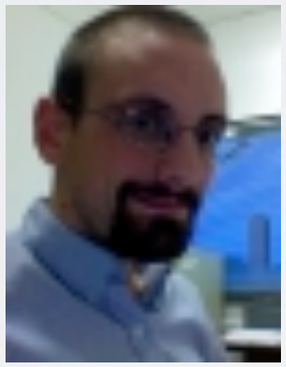
H properties

MadDM



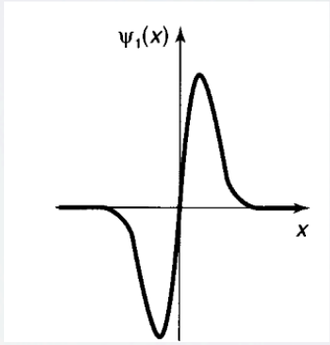
Antony Martini

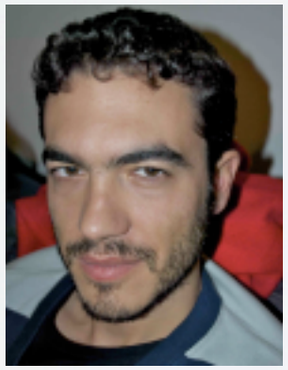
POST-DOCS @ CP3



Olivier Mattelaer, "The wave"

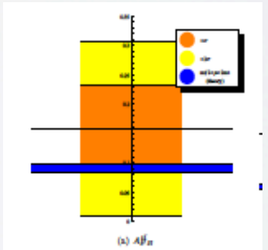
MadGraph5_aMC@NLO development
MadSpin, CMS, ALOHA, Matrix Element Methods





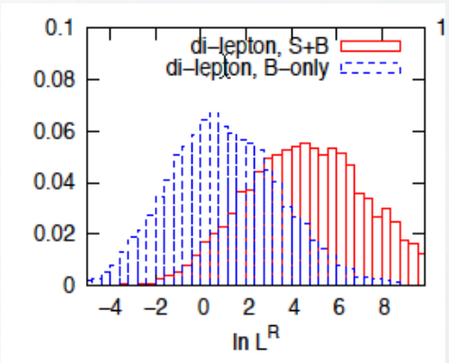
Davide Pagani

Electroweak corrections in SM and BSM



Pierre Artoisenet

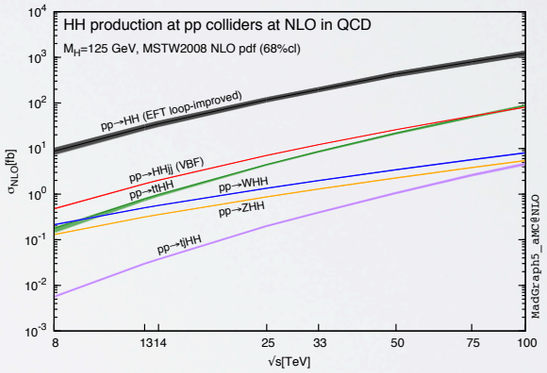
QCD, Quarkonium, Matrix Element Methods



POST-DOCS @ CP3

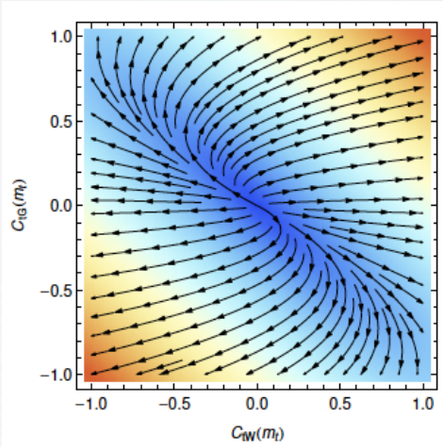
Eleni Vryonidou

Loop induced processes in the SM and BSM



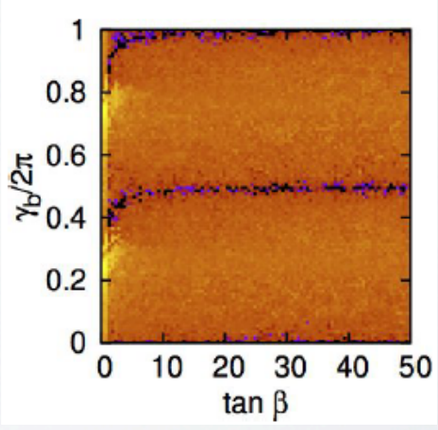
Cen Zhang

Effective field theories at NLO in particular Higgs and top quark



David Lopez-Val

Higgs SM and BSM, 2HDM, MadGolem



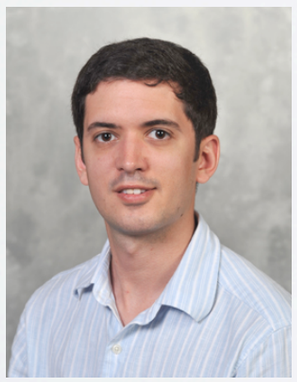
POST-DOCS AT CP3 : IN AND OUT

Diogo Buarque Franzosi

CP3-UCLouvain → CP3-Origins (Odense)

Heavy Higgs production in 2HDM, Complex mass scheme implementation in MG5_aMC

Mihailo Backovic



CP3-UCLouvain ← Weiszmann

Dark Matter Phenomenology in MadDM, direct, indirect, collider production

THE BRUXELLES TEAM AT VUB

Bettina Oexl

Kentarou Mawatari

Karen de Causmaecker

- MadGolem
- AsperGe
- GMSB Pheno
- Spin 3/2 and Gravitino Phenomenology
- ILC
- Higgs EFT and Characterisation

THE ILLINOIS CONNECTION

Tim Stelzer

MadGraph since 1992

Neil Christiensen

BSM, Galileo, FeynRules, CalcHEP

THE DESY CONNECTION

Stefan Prestel

Pythia8, CKKW-L, UNLOPS, Merging interfaces,FxFx, 4F vs 5F more....

Andrew Papanastasiou

Single-top and unstable particle treatment in NLO+PS

Simon Platzer

HERWIG
MatchBox interface

Alexis Kalogeropoulos

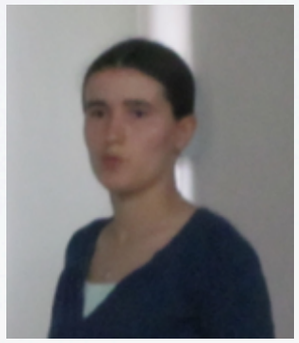
Large scale event production, systematic uncertainties,...

THE DURHAM CONNECTION

Claude Duhr

- FeynRules
- NNLO
- Consultant

Celine Degrande

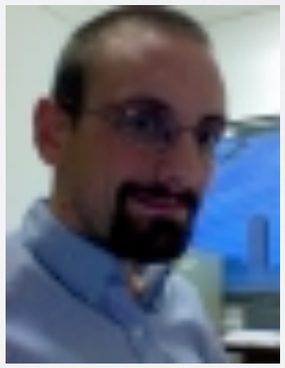


- FeynRules NLO
- EFT

Dorival G. Netto

- MadGolem

The wave

()

- MG5_aMC
- MEM

THE FAR EAST CONNECTIONS

Sariska Palace,
MC@NLO school 2011

Mandal, Mathew, Ravindram,...

- NLO in SM and BSM

Taiwan,
2nd Taipei MG school, 2013

Johan Alwall, Kaoru Hagiwara, Junichi

- roots and blue sky

THE CERN CONNECTION

Benjamin Fuks

MA5, FR, SUSY, PHENO

Rikkert Frederix

NLO, NLO+PS, FxFx

Stefano Frixione

NLO, aMC@NLO, FxFx

Simon de Visscher

CMS, Pythia and Pythia8 merging

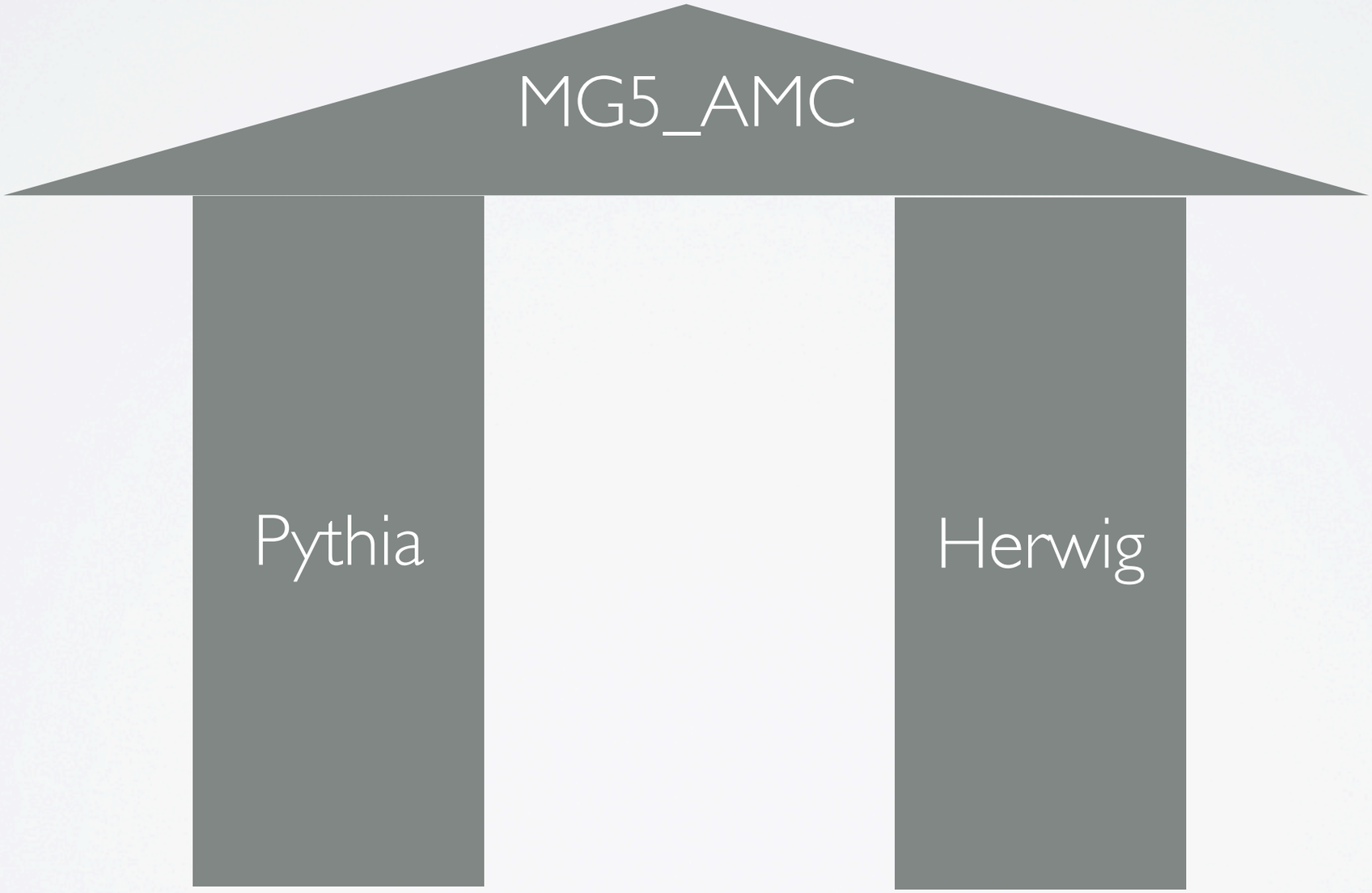
MLMv_Iron Man

Support + Inspiration + ...

OTHER ACTIVITIES SUPPORTED BY LOUVAIN

- MadAnalysis 5 [Conte et al.] **Fully-fledged analysis station**
- FeynRules [Alloul et al.] **Web site hosting**
- DELPHES [de Favereau et al.] **Detector simulation package**
- MadWeight [Artoisenet et al.] **Matrix element reweighting**
- MadGPU's [Hagiwara et al.] **MadGraph on GPU's**

MADGRAPH5_AMC@NLO



MADGRAPH5_AMC@NLO

Tim Stelzer

Olivier Mattelaer

Paolo Torrielli

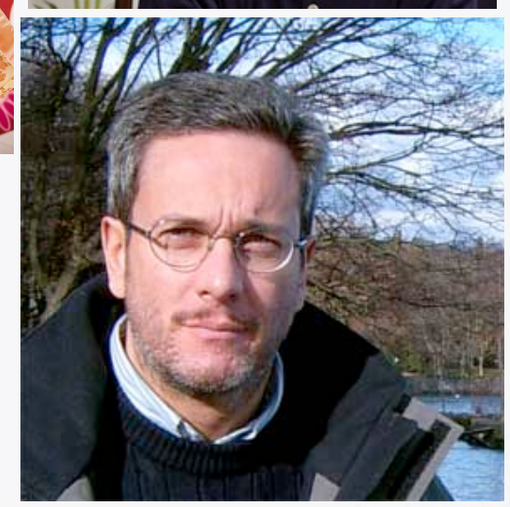
Marco Zaro

Valentin Hirschi

Rikkert Frederix

Hua-Sheng Shao

Johan Alwall



Stefano Frixione

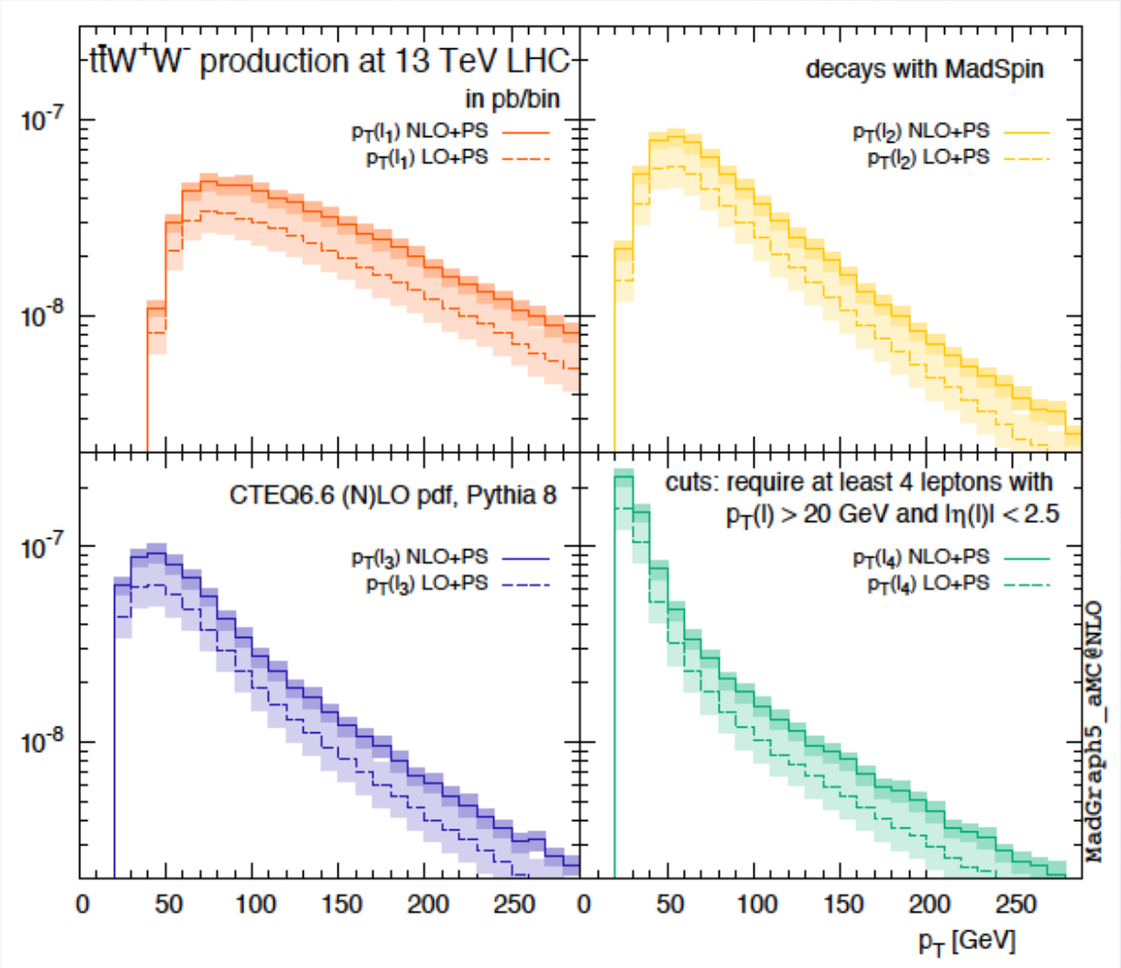
+....

AUTOMATIC MC'S AT NLO

Suppose now you are interested in multi-lepton backgrounds to SUSY. You might want to check:

```
./bin/mg5_aMC
> generate p p > t t~ W+ W- [QCD]
> output ttw
> launch
```

where heavy states can also be decayed keeping spin correlations.



AUTOMATIC NLO IN SM (2014)

- ~15 NLO publications since 2011
- Public release of MadGraph5_aMC@NLO 16 Dec 2013
- Improved functionalities (OpenLoops method, automatic uncertainties, Pythia8 interface, speed-up)
- Running/validating now a WIDE range of SM processes up to 4 final states (150 here...)

Process		Syntax	Cross section (pb)			
Vector boson +jets			LO 13 TeV		NLO 13 TeV	
a.1	$pp \to W^{\pm}$	`p p > wpm`	$1.375 \pm 0.002 \cdot 10^5$	$^{+15.4\%}_{-16.6\%}$ $^{+2.0\%}_{-1.6\%}$	$1.773 \pm 0.007 \cdot 10^5$	$^{+5.2\%}_{-9.4\%}$ $^{+1.9\%}_{-1.6\%}$
a.2	$pp \to W^{\pm}j$	`p p > wpm j`	$2.045 \pm 0.001 \cdot 10^4$	$^{+19.7\%}_{-17.2\%}$ $^{+1.4\%}_{-1.1\%}$	$2.843 \pm 0.010 \cdot 10^4$	$^{+5.9\%}_{-8.0\%}$ $^{+1.3\%}_{-1.1\%}$
a.3	$pp \to W^{\pm}jj$	`p p > wpm j j`	$6.805 \pm 0.015 \cdot 10^3$	$^{+24.5\%}_{-18.6\%}$ $^{+0.8\%}_{-0.7\%}$	$7.786 \pm 0.030 \cdot 10^3$	$^{+2.4\%}_{-6.0\%}$ $^{+0.9\%}_{-0.8\%}$
a.4	$pp \to W^{\pm}jjj$	`p p > wpm j j j`	$1.821 \pm 0.002 \cdot 10^3$	$^{+41.0\%}_{-27.1\%}$ $^{+0.5\%}_{-0.5\%}$	$2.005 \pm 0.008 \cdot 10^3$	$^{+0.9\%}_{-6.7\%}$ $^{+0.6\%}_{-0.5\%}$
a.5	$pp \to Z$	`p p > z`	$4.248 \pm 0.005 \cdot 10^4$	$^{+14.6\%}_{-15.8\%}$ $^{+2.0\%}_{-1.6\%}$	$5.410 \pm 0.022 \cdot 10^4$	$^{+4.6\%}_{-8.6\%}$ $^{+1.9\%}_{-1.5\%}$
a.6	$pp \to Zj$	`p p > z j`	$7.209 \pm 0.005 \cdot 10^3$	$^{+19.3\%}_{-17.0\%}$ $^{+1.2\%}_{-1.0\%}$	$9.742 \pm 0.035 \cdot 10^3$	$^{+5.8\%}_{-7.8\%}$ $^{+1.2\%}_{-1.0\%}$
a.7	$pp \to Zjj$	`p p > z j j`	$2.348 \pm 0.006 \cdot 10^3$	$^{+24.3\%}_{-18.5\%}$ $^{+0.6\%}_{-0.6\%}$	$2.665 \pm 0.010 \cdot 10^3$	$^{+2.5\%}_{-6.0\%}$ $^{+0.7\%}_{-0.7\%}$
a.8	$pp \to Zjjj$	`p p > z j j j`	$6.314 \pm 0.008 \cdot 10^2$	$^{+40.8\%}_{-27.0\%}$ $^{+0.5\%}_{-0.5\%}$	$6.996 \pm 0.028 \cdot 10^2$	$^{+1.1\%}_{-6.8\%}$ $^{+0.5\%}_{-0.5\%}$
a.9	$pp \to \gamma j$	`p p > a j`	$1.964 \pm 0.001 \cdot 10^4$	$^{+31.2\%}_{-26.0\%}$ $^{+1.7\%}_{-1.8\%}$	$5.218 \pm 0.025 \cdot 10^4$	$^{+24.5\%}_{-21.4\%}$ $^{+1.4\%}_{-1.6\%}$
a.10	$pp \to \gamma jj$	`p p > a j j`	$7.815 \pm 0.008 \cdot 10^3$	$^{+32.8\%}_{-24.2\%}$ $^{+0.9\%}_{-1.2\%}$	$1.004 \pm 0.004 \cdot 10^4$	$^{+5.9\%}_{-10.9\%}$ $^{+0.8\%}_{-1.2\%}$
a.11	$pp \to \gamma jjj$	`p p > a j j j`		running		

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

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Three vector bosons +jet			LO 13 TeV			NLO 13 TeV		
c.1	$pp \to W^+W^-W^\pm$ (4f)	`p p > w+ w- wpm`	$1.307 \pm 0.003 \cdot 10^{-1}$	$^{+0.0\%}_{-0.3\%}$	$^{+2.0\%}_{-1.5\%}$	$2.109 \pm 0.006 \cdot 10^{-1}$	$^{+5.1\%}_{-4.1\%}$	$^{+1.6\%}_{-1.2\%}$
c.2	$pp \to ZW^+W^-$ (4f)	`p p > z w+ w-`	$9.658 \pm 0.065 \cdot 10^{-2}$	$^{+0.8\%}_{-1.1\%}$	$^{+2.1\%}_{-1.6\%}$	$1.679 \pm 0.005 \cdot 10^{-1}$	$^{+6.3\%}_{-5.1\%}$	$^{+1.6\%}_{-1.2\%}$
c.3	$pp \to ZZW^\pm$	`p p > z z wpm`	$2.996 \pm 0.016 \cdot 10^{-2}$	$^{+1.0\%}_{-1.4\%}$	$^{+2.0\%}_{-1.6\%}$	$5.550 \pm 0.020 \cdot 10^{-2}$	$^{+6.8\%}_{-5.5\%}$	$^{+1.5\%}_{-1.1\%}$
c.4	$pp \to ZZZ$	`p p > z z z`	$1.085 \pm 0.002 \cdot 10^{-2}$	$^{+0.0\%}_{-0.5\%}$	$^{+1.9\%}_{-1.5\%}$	$1.417 \pm 0.005 \cdot 10^{-2}$	$^{+2.7\%}_{-2.1\%}$	$^{+1.9\%}_{-1.5\%}$
c.5	$pp \to \gamma W^+W^-$ (4f)	`p p > a w+ w-`	$1.427 \pm 0.011 \cdot 10^{-1}$	$^{+1.9\%}_{-2.6\%}$	$^{+2.0\%}_{-1.5\%}$	$2.581 \pm 0.008 \cdot 10^{-1}$	$^{+5.4\%}_{-4.3\%}$	$^{+1.4\%}_{-1.1\%}$
c.6	$pp \to \gamma\gamma W^\pm$	`p p > a a wpm`	$2.681 \pm 0.007 \cdot 10^{-2}$	$^{+4.4\%}_{-5.6\%}$	$^{+1.9\%}_{-1.6\%}$	$8.251 \pm 0.032 \cdot 10^{-2}$	$^{+7.6\%}_{-7.0\%}$	$^{+1.0\%}_{-1.0\%}$
c.7	$pp \to \gamma ZW^\pm$	`p p > a z wpm`	$4.994 \pm 0.011 \cdot 10^{-2}$	$^{+0.8\%}_{-1.4\%}$	$^{+1.9\%}_{-1.6\%}$	$1.117 \pm 0.004 \cdot 10^{-1}$	$^{+7.2\%}_{-5.9\%}$	$^{+1.2\%}_{-0.9\%}$
c.8	$pp \to \gamma ZZ$	`p p > a z z`	$2.318 \pm 0.004 \cdot 10^{-2}$	$^{+2.0\%}_{-2.8\%}$	$^{+1.9\%}_{-1.5\%}$	$3.177 \pm 0.015 \cdot 10^{-2}$	$^{+3.1\%}_{-2.9\%}$	$^{+1.8\%}_{-1.4\%}$
c.9	$pp \to \gamma\gamma Z$	`p p > a a z`	$3.077 \pm 0.008 \cdot 10^{-2}$	$^{+5.7\%}_{-6.8\%}$	$^{+1.9\%}_{-1.6\%}$	$4.571 \pm 0.017 \cdot 10^{-2}$	$^{+4.2\%}_{-4.8\%}$	$^{+1.7\%}_{-1.4\%}$
c.10	$pp \to \gamma\gamma\gamma$	`p p > a a a`	$1.269 \pm 0.003 \cdot 10^{-2}$	$^{+9.8\%}_{-11.0\%}$	$^{+2.0\%}_{-1.8\%}$	$3.441 \pm 0.012 \cdot 10^{-2}$	$^{+11.8\%}_{-11.6\%}$	$^{+1.4\%}_{-1.5\%}$
c.11*	$pp \to W^+W^-W^\pm j$ (4f)	`p p > w+ w- wpm j`	$9.167 \pm 0.010 \cdot 10^{-2}$	$^{+15.0\%}_{-12.2\%}$	$^{+1.0\%}_{-0.7\%}$	$1.197 \pm 0.004 \cdot 10^{-1}$	$^{+5.2\%}_{-5.6\%}$	$^{+1.0\%}_{-0.8\%}$
c.12*	$pp \to ZW^+W^-j$ (4f)	`p p > z w+ w- j`	$8.340 \pm 0.010 \cdot 10^{-2}$	$^{+15.6\%}_{-12.6\%}$	$^{+1.0\%}_{-0.7\%}$	$1.066 \pm 0.003 \cdot 10^{-1}$	$^{+4.5\%}_{-5.3\%}$	$^{+1.0\%}_{-0.7\%}$
c.13*	$pp \to ZZW^\pm j$	`p p > z z wpm j`	$2.810 \pm 0.004 \cdot 10^{-2}$	$^{+16.1\%}_{-13.0\%}$	$^{+1.0\%}_{-0.7\%}$	$3.660 \pm 0.013 \cdot 10^{-2}$	$^{+4.8\%}_{-5.6\%}$	$^{+1.0\%}_{-0.7\%}$
c.14*	$pp \to ZZZj$	`p p > z z z j`	$4.823 \pm 0.011 \cdot 10^{-3}$	$^{+14.3\%}_{-11.8\%}$	$^{+1.4\%}_{-1.0\%}$	$6.341 \pm 0.025 \cdot 10^{-3}$	$^{+4.9\%}_{-5.4\%}$	$^{+1.4\%}_{-1.0\%}$
c.15*	$pp \to \gamma W^+W^-j$ (4f)	`p p > a w+ w- j`	$1.182 \pm 0.004 \cdot 10^{-1}$	$^{+13.4\%}_{-11.2\%}$	$^{+0.8\%}_{-0.7\%}$	$1.233 \pm 0.004 \cdot 10^{3}$	$^{+18.9\%}_{-19.9\%}$	$^{+1.0\%}_{-1.5\%}$
c.16	$pp \to \gamma\gamma W^\pm j$	`p p > a a wpm j`	$4.107 \pm 0.015 \cdot 10^{-2}$	$^{+11.8\%}_{-10.2\%}$	$^{+0.6\%}_{-0.8\%}$	$5.807 \pm 0.023 \cdot 10^{-2}$	$^{+5.8\%}_{-5.5\%}$	$^{+0.7\%}_{-0.7\%}$
c.17*	$pp \to \gamma ZW^\pm j$	`p p > a z wpm j`	$5.833 \pm 0.023 \cdot 10^{-2}$	$^{+14.4\%}_{-12.0\%}$	$^{+0.7\%}_{-0.6\%}$	$7.764 \pm 0.025 \cdot 10^{-2}$	$^{+5.1\%}_{-5.5\%}$	$^{+0.8\%}_{-0.6\%}$
c.18*	$pp \to \gamma ZZj$	`p p > a z z j`	$9.995 \pm 0.013 \cdot 10^{-3}$	$^{+12.5\%}_{-10.6\%}$	$^{+1.2\%}_{-0.9\%}$	$1.371 \pm 0.005 \cdot 10^{-2}$	$^{+5.6\%}_{-5.5\%}$	$^{+1.2\%}_{-0.9\%}$
c.19*	$pp \to \gamma\gamma Zj$	`p p > a a z j`	$1.372 \pm 0.003 \cdot 10^{-2}$	$^{+10.9\%}_{-9.4\%}$	$^{+1.0\%}_{-0.9\%}$	$2.051 \pm 0.011 \cdot 10^{-2}$	$^{+7.0\%}_{-6.3\%}$	$^{+1.0\%}_{-0.9\%}$
c.20*	$pp \to \gamma\gamma\gamma j$	`p p > a a a j`	$1.031 \pm 0.006 \cdot 10^{-2}$	$^{+14.3\%}_{-12.6\%}$	$^{+0.9\%}_{-1.2\%}$	$2.020 \pm 0.008 \cdot 10^{-2}$	$^{+12.8\%}_{-11.0\%}$	$^{+0.8\%}_{-1.2\%}$

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Four vector bosons			LO 13 TeV			NLO 13 TeV	
c.21*	$pp \to W^+W^-W^+W^-$ (4f)	`p p > w+ w- w+ w-`	$5.721 \pm 0.014 \cdot 10^{-4}$	$^{+3.7\%}_{-3.5\%}$	$^{+2.3\%}_{-1.7\%}$	$9.959 \pm 0.035 \cdot 10^{-4}$	$^{+7.4\%}_{-6.0\%}$ $^{+1.7\%}_{-1.2\%}$
c.22*	$pp \to W^+W^-W^\pm Z$ (4f)	`p p > w+ w- wpm z`	$6.391 \pm 0.076 \cdot 10^{-4}$	$^{+4.4\%}_{-4.1\%}$	$^{+2.4\%}_{-1.8\%}$	$1.188 \pm 0.004 \cdot 10^{-3}$	$^{+8.4\%}_{-6.8\%}$ $^{+1.7\%}_{-1.2\%}$
c.23*	$pp \to W^+W^-W^\pm\gamma$ (4f)	`p p > w+ w- wpm a`	$8.115 \pm 0.064 \cdot 10^{-4}$	$^{+2.5\%}_{-2.5\%}$	$^{+2.2\%}_{-1.7\%}$	$1.546 \pm 0.005 \cdot 10^{-3}$	$^{+7.9\%}_{-6.3\%}$ $^{+1.5\%}_{-1.1\%}$
c.24*	$pp \to W^+W^-ZZ$ (4f)	`p p > w+ w- z z`	$4.320 \pm 0.013 \cdot 10^{-4}$	$^{+4.4\%}_{-4.1\%}$	$^{+2.4\%}_{-1.7\%}$	$7.107 \pm 0.020 \cdot 10^{-4}$	$^{+7.0\%}_{-5.7\%}$ $^{+1.8\%}_{-1.3\%}$
c.25*	$pp \to W^+W^-Z\gamma$ (4f)	`p p > w+ w- z a`	$8.403 \pm 0.016 \cdot 10^{-4}$	$^{+3.0\%}_{-2.9\%}$	$^{+2.3\%}_{-1.7\%}$	$1.483 \pm 0.004 \cdot 10^{-3}$	$^{+7.2\%}_{-5.8\%}$ $^{+1.6\%}_{-1.2\%}$
c.26*	$pp \to W^+W^-\gamma\gamma$ (4f)	`p p > w+ w- a a`	$5.198 \pm 0.012 \cdot 10^{-4}$	$^{+0.6\%}_{-0.9\%}$	$^{+2.1\%}_{-1.6\%}$	$9.381 \pm 0.032 \cdot 10^{-4}$	$^{+6.7\%}_{-5.3\%}$ $^{+1.4\%}_{-1.1\%}$
c.27*	$pp \to W^\pm ZZZ$	`p p > wpm z z z`	$5.862 \pm 0.010 \cdot 10^{-5}$	$^{+5.1\%}_{-4.7\%}$	$^{+2.4\%}_{-1.8\%}$	$1.240 \pm 0.004 \cdot 10^{-4}$	$^{+9.9\%}_{-8.0\%}$ $^{+1.7\%}_{-1.2\%}$
c.28*	$pp \to W^\pm ZZ\gamma$	`p p > wpm z z a`	$1.148 \pm 0.003 \cdot 10^{-4}$	$^{+3.6\%}_{-3.5\%}$	$^{+2.2\%}_{-1.7\%}$	$2.945 \pm 0.008 \cdot 10^{-4}$	$^{+10.8\%}_{-8.7\%}$ $^{+1.3\%}_{-1.0\%}$
c.29*	$pp \to W^\pm Z\gamma\gamma$	`p p > wpm z a a`	$1.054 \pm 0.004 \cdot 10^{-4}$	$^{+1.7\%}_{-1.9\%}$	$^{+2.1\%}_{-1.7\%}$	$3.033 \pm 0.010 \cdot 10^{-4}$	$^{+10.6\%}_{-8.6\%}$ $^{+1.1\%}_{-0.8\%}$
c.30*	$pp \to W^\pm\gamma\gamma\gamma$	`p p > wpm a a a`	$3.600 \pm 0.013 \cdot 10^{-5}$	$^{+0.4\%}_{-1.0\%}$	$^{+2.0\%}_{-1.6\%}$	$1.246 \pm 0.005 \cdot 10^{-4}$	$^{+9.8\%}_{-8.1\%}$ $^{+0.9\%}_{-0.8\%}$
c.31*	$pp \to ZZZZ$	`p p > z z z z`	$1.989 \pm 0.002 \cdot 10^{-5}$	$^{+3.8\%}_{-3.6\%}$	$^{+2.2\%}_{-1.7\%}$	$2.629 \pm 0.008 \cdot 10^{-5}$	$^{+3.5\%}_{-3.0\%}$ $^{+2.2\%}_{-1.7\%}$
c.32*	$pp \to ZZZ\gamma$	`p p > z z z a`	$3.945 \pm 0.007 \cdot 10^{-5}$	$^{+1.9\%}_{-2.1\%}$	$^{+2.1\%}_{-1.6\%}$	$5.224 \pm 0.016 \cdot 10^{-5}$	$^{+3.3\%}_{-2.7\%}$ $^{+2.1\%}_{-1.6\%}$
c.33*	$pp \to ZZ\gamma\gamma$	`p p > z z a a`	$5.513 \pm 0.017 \cdot 10^{-5}$	$^{+0.0\%}_{-0.3\%}$	$^{+2.1\%}_{-1.6\%}$	$7.518 \pm 0.032 \cdot 10^{-5}$	$^{+3.4\%}_{-2.6\%}$ $^{+2.0\%}_{-1.5\%}$
c.34*	$pp \to Z\gamma\gamma\gamma$	`p p > z a a a`	$4.790 \pm 0.012 \cdot 10^{-5}$	$^{+2.3\%}_{-3.1\%}$	$^{+2.0\%}_{-1.6\%}$	$7.103 \pm 0.026 \cdot 10^{-5}$	$^{+3.4\%}_{-3.2\%}$ $^{+1.6\%}_{-1.5\%}$
c.35*	$pp \to \gamma\gamma\gamma\gamma$	`p p > a a a a`	$1.594 \pm 0.004 \cdot 10^{-5}$	$^{+4.7\%}_{-5.7\%}$	$^{+1.9\%}_{-1.7\%}$	$3.389 \pm 0.012 \cdot 10^{-5}$	$^{+7.0\%}_{-6.7\%}$ $^{+1.3\%}_{-1.3\%}$

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Process		Syntax	Cross section (pb)				
Heavy quarks and jets			LO 13 TeV			NLO 13 TeV		
d.1	$pp \to jj$	`p p > j j`	$1.162 \pm 0.001 \cdot 10^6$	$^{+24.9\%}_{-18.8\%}$	$^{+0.8\%}_{-0.9\%}$	$1.580 \pm 0.007 \cdot 10^6$	$^{+8.4\%}_{-9.0\%}$	$^{+0.7\%}_{-0.9\%}$
d.2	$pp \to jjj$	`p p > j j j`	$8.940 \pm 0.021 \cdot 10^4$	$^{+43.8\%}_{-28.4\%}$	$^{+1.2\%}_{-1.4\%}$	$7.791 \pm 0.037 \cdot 10^4$	$^{+2.1\%}_{-23.2\%}$	$^{+1.1\%}_{-1.3\%}$
d.3	$pp \to b\bar{b}$	`p p > b b~`	$3.743 \pm 0.004 \cdot 10^3$	$^{+25.2\%}_{-18.9\%}$	$^{+1.5\%}_{-1.8\%}$	$6.438 \pm 0.028 \cdot 10^3$	$^{+15.9\%}_{-13.3\%}$	$^{+1.5\%}_{-1.7\%}$
d.4*	$pp \to b\bar{b}j$	`p p > b b~ j`	$1.050 \pm 0.002 \cdot 10^3$	$^{+44.1\%}_{-28.5\%}$	$^{+1.6\%}_{-1.8\%}$	$1.327 \pm 0.007 \cdot 10^3$	$^{+6.8\%}_{-11.6\%}$	$^{+1.5\%}_{-1.8\%}$
d.5*	$pp \to b\bar{b}jj$	`p p > b b~ j j`	$1.852 \pm 0.006 \cdot 10^2$	$^{+61.8\%}_{-35.6\%}$	$^{+2.1\%}_{-2.4\%}$	$2.471 \pm 0.012 \cdot 10^2$	$^{+8.2\%}_{-16.4\%}$	$^{+2.0\%}_{-2.3\%}$
d.6	$pp \to b\bar{b}b\bar{b}$	`p p > b b~ b b~`	$5.050 \pm 0.007 \cdot 10^{-1}$	$^{+61.7\%}_{-35.6\%}$	$^{+2.9\%}_{-3.4\%}$	$8.736 \pm 0.034 \cdot 10^{-1}$	$^{+20.9\%}_{-22.0\%}$	$^{+2.9\%}_{-3.4\%}$
d.7	$pp \to t\bar{t}$	`p p > t t~`	$4.584 \pm 0.003 \cdot 10^2$	$^{+29.0\%}_{-21.1\%}$	$^{+1.8\%}_{-2.0\%}$	$6.741 \pm 0.023 \cdot 10^2$	$^{+9.8\%}_{-10.9\%}$	$^{+1.8\%}_{-2.1\%}$
d.8	$pp \to t\bar{t}j$	`p p > t t~ j`	$3.135 \pm 0.002 \cdot 10^2$	$^{+45.1\%}_{-29.0\%}$	$^{+2.2\%}_{-2.5\%}$	$4.106 \pm 0.015 \cdot 10^2$	$^{+8.1\%}_{-12.2\%}$	$^{+2.1\%}_{-2.5\%}$
d.9	$pp \to t\bar{t}jj$	`p p > t t~ j j`	$1.361 \pm 0.001 \cdot 10^2$	$^{+61.4\%}_{-35.6\%}$	$^{+2.6\%}_{-3.0\%}$	$1.795 \pm 0.006 \cdot 10^2$	$^{+9.3\%}_{-16.1\%}$	$^{+2.4\%}_{-2.9\%}$
d.10	$pp \to t\bar{t}t\bar{t}$	`p p > t t~ t t~`	$4.505 \pm 0.005 \cdot 10^{-3}$	$^{+63.8\%}_{-36.5\%}$	$^{+5.4\%}_{-5.7\%}$	$9.201 \pm 0.028 \cdot 10^{-3}$	$^{+30.8\%}_{-25.6\%}$	$^{+5.5\%}_{-5.9\%}$
d.11	$pp \to t\bar{t}b\bar{b}$	`p p > t t~ b b~`	$6.119 \pm 0.004 \cdot 10^0$	$^{+62.1\%}_{-35.7\%}$	$^{+2.9\%}_{-3.5\%}$	$1.452 \pm 0.005 \cdot 10^1$	$^{+37.6\%}_{-27.5\%}$	$^{+2.9\%}_{-3.5\%}$

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Process		Syntax	Cross section (pb)					
Heavy quarks+vector bosons			LO 13 TeV			NLO 13 TeV		
e.1	$pp \to W^{\pm} b\bar{b}$	`p p > wpm b b~`	$3.074 \pm 0.002 \cdot 10^{2}$	$^{+42.3\%}_{-29.2\%}$	$^{+2.0\%}_{-1.6\%}$	$8.162 \pm 0.034 \cdot 10^{2}$	$^{+29.8\%}_{-23.6\%}$	$^{+1.5\%}_{-1.2\%}$
e.2	$pp \to Z b\bar{b}$	`p p > z b b~`	$6.993 \pm 0.003 \cdot 10^{2}$	$^{+33.5\%}_{-24.4\%}$	$^{+1.0\%}_{-1.4\%}$	$1.235 \pm 0.004 \cdot 10^{3}$	$^{+19.9\%}_{-17.4\%}$	$^{+1.0\%}_{-1.4\%}$
e.3	$pp \to \gamma b\bar{b}$	`p p > a b b~`	$1.731 \pm 0.001 \cdot 10^{3}$	$^{+51.9\%}_{-34.8\%}$	$^{+1.6\%}_{-2.1\%}$	$4.171 \pm 0.015 \cdot 10^{3}$	$^{+33.7\%}_{-27.1\%}$	$^{+1.4\%}_{-1.9\%}$
e.4*	$pp \to W^{\pm} b\bar{b} j$	`p p > wpm b b~ j`	$1.861 \pm 0.003 \cdot 10^{2}$	$^{+42.5\%}_{-27.7\%}$	$^{+0.7\%}_{-0.7\%}$	$3.957 \pm 0.013 \cdot 10^{2}$	$^{+27.0\%}_{-21.0\%}$	$^{+0.7\%}_{-0.6\%}$
e.5*	$pp \to Z b\bar{b} j$	`p p > z b b~ j`	$1.604 \pm 0.001 \cdot 10^{2}$	$^{+42.4\%}_{-27.6\%}$	$^{+0.9\%}_{-1.1\%}$	$2.805 \pm 0.009 \cdot 10^{2}$	$^{+21.0\%}_{-17.6\%}$	$^{+0.8\%}_{-1.0\%}$
e.6*	$pp \to \gamma b\bar{b} j$	`p p > a b b~ j`	$7.812 \pm 0.017 \cdot 10^{2}$	$^{+51.2\%}_{-32.0\%}$	$^{+1.0\%}_{-1.5\%}$	$1.233 \pm 0.004 \cdot 10^{3}$	$^{+18.9\%}_{-19.9\%}$	$^{+1.0\%}_{-1.5\%}$
e.7	$pp \to t\bar{t} W^{\pm}$	`p p > t t~ wpm`	$3.777 \pm 0.003 \cdot 10^{-1}$	$^{+23.9\%}_{-18.0\%}$	$^{+2.1\%}_{-1.6\%}$	$5.662 \pm 0.021 \cdot 10^{-1}$	$^{+11.2\%}_{-10.6\%}$	$^{+1.7\%}_{-1.3\%}$
e.8	$pp \to t\bar{t} Z$	`p p > t t~ z`	$5.273 \pm 0.004 \cdot 10^{-1}$	$^{+30.5\%}_{-21.8\%}$	$^{+1.8\%}_{-2.1\%}$	$7.598 \pm 0.026 \cdot 10^{-1}$	$^{+9.7\%}_{-11.1\%}$	$^{+1.9\%}_{-2.2\%}$
e.9	$pp \to t\bar{t} \gamma$	`p p > t t~ a`	$1.204 \pm 0.001 \cdot 10^{0}$	$^{+29.6\%}_{-21.3\%}$	$^{+1.6\%}_{-1.8\%}$	$1.744 \pm 0.005 \cdot 10^{0}$	$^{+9.8\%}_{-11.0\%}$	$^{+1.7\%}_{-2.0\%}$
e.10*	$pp \to t\bar{t} W^{\pm} j$	`p p > t t~ wpm j`	$2.352 \pm 0.002 \cdot 10^{-1}$	$^{+40.9\%}_{-27.1\%}$	$^{+1.3\%}_{-1.0\%}$	$3.404 \pm 0.011 \cdot 10^{-1}$	$^{+11.2\%}_{-14.0\%}$	$^{+1.2\%}_{-0.9\%}$
e.11*	$pp \to t\bar{t} Z j$	`p p > t t~ z j`	$3.953 \pm 0.004 \cdot 10^{-1}$	$^{+46.2\%}_{-29.5\%}$	$^{+2.7\%}_{-3.0\%}$	$5.074 \pm 0.016 \cdot 10^{-1}$	$^{+7.0\%}_{-12.3\%}$	$^{+2.5\%}_{-2.9\%}$
e.12*	$pp \to t\bar{t} \gamma j$	`p p > t t~ a j`	$8.726 \pm 0.010 \cdot 10^{-1}$	$^{+45.4\%}_{-29.1\%}$	$^{+2.3\%}_{-2.6\%}$	$1.135 \pm 0.004 \cdot 10^{0}$	$^{+7.5\%}_{-12.2\%}$	$^{+2.2\%}_{-2.5\%}$
e.13*	$pp \to t\bar{t} W^{-} W^{+}$ (4f)	`p p > t t~ w+ w-`	$6.675 \pm 0.006 \cdot 10^{-3}$	$^{+30.9\%}_{-21.9\%}$	$^{+2.1\%}_{-2.0\%}$	$9.904 \pm 0.026 \cdot 10^{-3}$	$^{+10.9\%}_{-11.8\%}$	$^{+2.1\%}_{-2.1\%}$
e.14*	$pp \to t\bar{t} W^{\pm} Z$	`p p > t t~ wpm z`	$2.404 \pm 0.002 \cdot 10^{-3}$	$^{+26.6\%}_{-19.6\%}$	$^{+2.5\%}_{-1.8\%}$	$3.525 \pm 0.010 \cdot 10^{-3}$	$^{+10.6\%}_{-10.8\%}$	$^{+2.3\%}_{-1.6\%}$
e.15*	$pp \to t\bar{t} W^{\pm} \gamma$	`p p > t t~ wpm a`	$2.718 \pm 0.003 \cdot 10^{-3}$	$^{+25.4\%}_{-18.9\%}$	$^{+2.3\%}_{-1.8\%}$	$3.927 \pm 0.013 \cdot 10^{-3}$	$^{+10.3\%}_{-10.4\%}$	$^{+2.0\%}_{-1.5\%}$
e.16*	$pp \to t\bar{t} Z Z$	`p p > t t~ z z`	$1.349 \pm 0.014 \cdot 10^{-3}$	$^{+29.3\%}_{-21.1\%}$	$^{+1.7\%}_{-1.5\%}$	$1.840 \pm 0.007 \cdot 10^{-3}$	$^{+7.9\%}_{-9.9\%}$	$^{+1.7\%}_{-1.5\%}$
e.17*	$pp \to t\bar{t} Z \gamma$	`p p > t t~ z a`	$2.548 \pm 0.003 \cdot 10^{-3}$	$^{+30.1\%}_{-21.5\%}$	$^{+1.7\%}_{-1.6\%}$	$3.656 \pm 0.012 \cdot 10^{-3}$	$^{+9.7\%}_{-11.0\%}$	$^{+1.8\%}_{-1.9\%}$
e.18*	$pp \to t\bar{t} \gamma\gamma$	`p p > t t~ a a`	$3.272 \pm 0.006 \cdot 10^{-3}$	$^{+28.4\%}_{-20.6\%}$	$^{+1.3\%}_{-1.1\%}$	$4.402 \pm 0.015 \cdot 10^{-3}$	$^{+7.8\%}_{-9.7\%}$	$^{+1.4\%}_{-1.4\%}$

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Process		Syntax	Cross section (pb)	
	Single-top		LO 13 TeV	NLO 13 TeV
f.1	$pp \to tj$ (t-channel)	`p p > tt j $$ w+ w-`	$1.520 \pm 0.001 \cdot 10^{2}$ $^{+9.4\%}_{-11.9\%}$ $^{+0.4\%}_{-0.6\%}$	$1.563 \pm 0.005 \cdot 10^{2}$ $^{+1.4\%}_{-1.8\%}$ $^{+0.4\%}_{-0.6\%}$
f.2	$pp \to t\gamma j$ (t-channel)	`p p > tt a j $$ w+ w-`	$9.956 \pm 0.014 \cdot 10^{-1}$ $^{+6.4\%}_{-8.8\%}$ $^{+0.9\%}_{-1.0\%}$	$1.017 \pm 0.003 \cdot 10^{0}$ $^{+1.3\%}_{-1.2\%}$ $^{+0.8\%}_{-0.9\%}$
f.3	$pp \to tZj$ (t-channel)	`p p > tt z j $$ w+ w-`	$6.967 \pm 0.007 \cdot 10^{-1}$ $^{+3.5\%}_{-5.5\%}$ $^{+0.9\%}_{-1.0\%}$	$6.993 \pm 0.021 \cdot 10^{-1}$ $^{+1.6\%}_{-1.1\%}$ $^{+0.9\%}_{-1.0\%}$
f.4	$pp \to tbj$ (t-channel)	`p p > tt bb j $$ w+ w-`	$1.003 \pm 0.000 \cdot 10^{2}$ $^{+13.8\%}_{-11.5\%}$ $^{+0.4\%}_{-0.5\%}$	$1.319 \pm 0.003 \cdot 10^{2}$ $^{+5.8\%}_{-5.2\%}$ $^{+0.4\%}_{-0.5\%}$
f.5*	$pp \to tbj\gamma$ (t-channel)	`p p > tt bb j a $$ w+ w-`	$6.293 \pm 0.006 \cdot 10^{-1}$ $^{+16.8\%}_{-13.5\%}$ $^{+0.8\%}_{-0.9\%}$	$8.612 \pm 0.025 \cdot 10^{-1}$ $^{+6.2\%}_{-6.6\%}$ $^{+0.8\%}_{-0.9\%}$
f.6*	$pp \to tbjZ$ (t-channel)	`p p > tt bb j z $$ w+ w-`	$3.934 \pm 0.002 \cdot 10^{-1}$ $^{+18.7\%}_{-14.7\%}$ $^{+1.0\%}_{-0.9\%}$	$5.657 \pm 0.014 \cdot 10^{-1}$ $^{+7.7\%}_{-7.9\%}$ $^{+0.9\%}_{-0.9\%}$
f.7	$pp \to tb$ (s-channel)	`p p > w+ > t b~, p p > w- > t~ b`	$7.489 \pm 0.007 \cdot 10^{0}$ $^{+3.5\%}_{-4.4\%}$ $^{+1.9\%}_{-1.4\%}$	$1.001 \pm 0.004 \cdot 10^{1}$ $^{+3.7\%}_{-3.9\%}$ $^{+1.9\%}_{-1.5\%}$
f.8*	$pp \to tb\gamma$ (s-channel)	`p p > w+ > t b~ a, p p > w- > t~ b a`	$1.490 \pm 0.001 \cdot 10^{-2}$ $^{+1.2\%}_{-1.8\%}$ $^{+1.9\%}_{-1.5\%}$	$1.952 \pm 0.007 \cdot 10^{-2}$ $^{+2.6\%}_{-2.3\%}$ $^{+1.7\%}_{-1.4\%}$
f.9*	$pp \to tbZ$ (s-channel)	`p p > w+ > t b~ z, p p > w- > t~ b z`	$1.072 \pm 0.001 \cdot 10^{-2}$ $^{+1.3\%}_{-1.5\%}$ $^{+2.0\%}_{-1.6\%}$	$1.539 \pm 0.005 \cdot 10^{-2}$ $^{+3.9\%}_{-3.2\%}$ $^{+1.9\%}_{-1.5\%}$

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Process		Syntax	Cross section (pb)	
Single Higgs production			LO 13 TeV	NLO 13 TeV
g.1	$pp \to H$ (HEFT)	`p p > h`		$3.261 \pm 0.010 \cdot 10^{1}$ $^{+20.2\%}_{-17.9\%}$ $^{+1.1\%}_{-1.6\%}$
g.2	$pp \to Hj$ (HEFT)	`p p > h j`		$1.422 \pm 0.006 \cdot 10^{1}$ $^{+18.5\%}_{-16.6\%}$ $^{+1.1\%}_{-1.4\%}$
g.3	$pp \to Hjj$ (HEFT)	`p p > h j j`		$5.124 \pm 0.020 \cdot 10^{0}$ $^{+20.7\%}_{-21.0\%}$ $^{+1.3\%}_{-1.5\%}$
g.4	$pp \to Hjj$ (VBF)	`p p > h j j $$ w+ w- z`		$1.900 \pm 0.006 \cdot 10^{0}$ $^{+0.8\%}_{-0.9\%}$ $^{+2.0\%}_{-1.5\%}$
g.5	$pp \to Hjjj$ (VBF)	`p p > h j j j $$ w+ w- z`		$3.085 \pm 0.010 \cdot 10^{-1}$ $^{+2.0\%}_{-3.0\%}$ $^{+1.5\%}_{-1.1\%}$
g.6	$pp \to HW^{\pm}$	`p p > h wpm`		$1.419 \pm 0.005 \cdot 10^{0}$ $^{+2.1\%}_{-2.6\%}$ $^{+1.9\%}_{-1.4\%}$
g.7	$pp \to HW^{\pm}j$	`p p > h wpm j`		$4.842 \pm 0.017 \cdot 10^{-1}$ $^{+3.6\%}_{-3.7\%}$ $^{+1.2\%}_{-1.0\%}$
g.8*	$pp \to HW^{\pm}jj$	`p p > h wpm j j`		$1.574 \pm 0.014 \cdot 10^{-1}$ $^{+5.0\%}_{-6.5\%}$ $^{+0.9\%}_{-0.6\%}$
g.9	$pp \to HZ$	`p p > h z`		$7.674 \pm 0.027 \cdot 10^{-1}$ $^{+2.0\%}_{-2.5\%}$ $^{+1.9\%}_{-1.4\%}$
g.10	$pp \to HZj$	`p p > h z j`		$2.667 \pm 0.010 \cdot 10^{-1}$ $^{+3.5\%}_{-3.6\%}$ $^{+1.1\%}_{-0.9\%}$
g.11*	$pp \to HZjj$	`p p > h z j j`		$8.753 \pm 0.037 \cdot 10^{-2}$ $^{+4.8\%}_{-6.3\%}$ $^{+0.7\%}_{-0.6\%}$
g.12*	$pp \to HW^{+}W^{-}(4f)$	`p p > h w+ w-`		$1.065 \pm 0.003 \cdot 10^{-2}$ $^{+2.5\%}_{-1.9\%}$ $^{+2.0\%}_{-1.5\%}$
g.13*	$pp \to HW^{\pm}\gamma$	`p p > h wpm a`		$3.309 \pm 0.011 \cdot 10^{-3}$ $^{+2.7\%}_{-2.0\%}$ $^{+1.7\%}_{-1.4\%}$
g.14*	$pp \to HZW^{\pm}$	`p p > h z wpm`		$5.292 \pm 0.015 \cdot 10^{-3}$ $^{+3.9\%}_{-3.1\%}$ $^{+1.8\%}_{-1.4\%}$
g.15*	$pp \to HZZ$	`p p > h z z`		$2.538 \pm 0.007 \cdot 10^{-3}$ $^{+1.9\%}_{-1.4\%}$ $^{+2.0\%}_{-1.5\%}$
g.16	$pp \to Ht\bar{t}$	`p p > h t t~`		$4.608 \pm 0.016 \cdot 10^{-1}$ $^{+5.7\%}_{-9.0\%}$ $^{+2.0\%}_{-2.3\%}$
g.17	$pp \to Htj$	`p p > h tt j`		$6.328 \pm 0.022 \cdot 10^{-2}$ $^{+2.9\%}_{-1.8\%}$ $^{+1.5\%}_{-1.6\%}$
g.18	$pp \to Hb\bar{b}$	`p p > h b b~`	$4.983 \pm 0.002 \cdot 10^{-1}$ $^{+28.1\%}_{-21.0\%}$ $^{+1.5\%}_{-1.8\%}$	$6.085 \pm 0.026 \cdot 10^{-1}$ $^{+7.3\%}_{-9.6\%}$ $^{+1.6\%}_{-2.0\%}$
g.19	$pp \to Ht\bar{t}j$	`p p > h t t~ j`		$3.244 \pm 0.025 \cdot 10^{-1}$ $^{+3.5\%}_{-8.7\%}$ $^{+2.5\%}_{-2.9\%}$
g.20*	$pp \to Hb\bar{b}j$	`p p > h b b~ j`		

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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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Process		Syntax	Cross section (pb)			
Top quarks +bosons			LO 1 TeV		NLO 1 TeV	
j.1	$e^+e^- \to t\bar{t}H$	`e+ e- > t t~ h`	$2.018 \pm 0.003 \cdot 10^{-3}$	$^{+0.0\%}_{-0.0\%}$	$1.911 \pm 0.006 \cdot 10^{-3}$	$^{+0.4\%}_{-0.5\%}$
j.2	$e^+e^- \to t\bar{t}Hj$	`e+ e- > t t~ h j`	$2.533 \pm 0.003 \cdot 10^{-4}$	$^{+9.2\%}_{-7.8\%}$	$2.658 \pm 0.009 \cdot 10^{-4}$	$^{+0.5\%}_{-1.5\%}$
j.3	$e^+e^- \to t\bar{t}Hjj$	`e+ e- > t t~ h j j`	$2.663 \pm 0.004 \cdot 10^{-5}$	$^{+19.3\%}_{-14.9\%}$	$3.278 \pm 0.017 \cdot 10^{-5}$	$^{+4.0\%}_{-5.7\%}$
j.4	$e^+e^- \to t\bar{t}\gamma$	`e+ e- > t t~ a`	$1.270 \pm 0.002 \cdot 10^{-2}$	$^{+0.0\%}_{-0.0\%}$	$1.335 \pm 0.004 \cdot 10^{-2}$	$^{+0.5\%}_{-0.4\%}$
j.5	$e^+e^- \to t\bar{t}\gamma j$	`e+ e- > t t~ a j`	$2.355 \pm 0.002 \cdot 10^{-3}$	$^{+9.3\%}_{-7.9\%}$	$2.617 \pm 0.010 \cdot 10^{-3}$	$^{+1.6\%}_{-2.4\%}$
j.6	$e^+e^- \to t\bar{t}\gamma jj$	`e+ e- > t t~ a j j`	$3.103 \pm 0.005 \cdot 10^{-4}$	$^{+19.5\%}_{-15.0\%}$	$4.002 \pm 0.021 \cdot 10^{-4}$	$^{+5.4\%}_{-6.6\%}$
j.7	$e^+e^- \to t\bar{t}Z$	`e+ e- > t t~ z`	$4.642 \pm 0.006 \cdot 10^{-3}$	$^{+0.0\%}_{-0.0\%}$	$4.949 \pm 0.014 \cdot 10^{-3}$	$^{+0.6\%}_{-0.5\%}$
j.8	$e^+e^- \to t\bar{t}Zj$	`e+ e- > t t~ z j`	$6.059 \pm 0.006 \cdot 10^{-4}$	$^{+9.3\%}_{-7.8\%}$	$6.940 \pm 0.028 \cdot 10^{-4}$	$^{+2.0\%}_{-2.6\%}$
j.9	$e^+e^- \to t\bar{t}Zjj$	`e+ e- > t t~ z j j`	$6.351 \pm 0.028 \cdot 10^{-5}$	$^{+19.4\%}_{-15.0\%}$	$8.439 \pm 0.051 \cdot 10^{-5}$	$^{+5.8\%}_{-6.8\%}$
j.10	$e^+e^- \to t\bar{t}W^{\pm}jj$	`e+ e- > t t~ wpm j j`	$2.400 \pm 0.004 \cdot 10^{-7}$	$^{+19.3\%}_{-14.9\%}$	$3.723 \pm 0.012 \cdot 10^{-7}$	$^{+9.6\%}_{-9.1\%}$
j.11	$e^+e^- \to t\bar{t}HZ$	`e+ e- > t t~ h z`	$3.600 \pm 0.006 \cdot 10^{-5}$	$^{+0.0\%}_{-0.0\%}$	$3.579 \pm 0.013 \cdot 10^{-5}$	$^{+0.1\%}_{-0.0\%}$
j.12	$e^+e^- \to t\bar{t}\gamma Z$	`e+ e- > t t~ a z`	$2.212 \pm 0.003 \cdot 10^{-4}$	$^{+0.0\%}_{-0.0\%}$	$2.364 \pm 0.006 \cdot 10^{-4}$	$^{+0.6\%}_{-0.5\%}$
j.13	$e^+e^- \to t\bar{t}\gamma H$	`e+ e- > t t~ a h`	$9.756 \pm 0.016 \cdot 10^{-5}$	$^{+0.0\%}_{-0.0\%}$	$9.423 \pm 0.032 \cdot 10^{-5}$	$^{+0.3\%}_{-0.4\%}$
j.14	$e^+e^- \to t\bar{t}\gamma\gamma$	`e+ e- > t t~ a a`	$3.650 \pm 0.008 \cdot 10^{-4}$	$^{+0.0\%}_{-0.0\%}$	$3.833 \pm 0.013 \cdot 10^{-4}$	$^{+0.4\%}_{-0.4\%}$
j.15	$e^+e^- \to t\bar{t}ZZ$	`e+ e- > t t~ z z`	$3.788 \pm 0.004 \cdot 10^{-5}$	$^{+0.0\%}_{-0.0\%}$	$4.007 \pm 0.013 \cdot 10^{-5}$	$^{+0.5\%}_{-0.5\%}$
j.16	$e^+e^- \to t\bar{t}HH$	`e+ e- > t t~ h h`	$1.358 \pm 0.001 \cdot 10^{-5}$	$^{+0.0\%}_{-0.0\%}$	$1.206 \pm 0.003 \cdot 10^{-5}$	$^{+0.9\%}_{-1.1\%}$
j.17	$e^+e^- \to t\bar{t}W^+W^-$	`e+ e- > t t~ w+ w-`	$1.372 \pm 0.003 \cdot 10^{-4}$	$^{+0.0\%}_{-0.0\%}$	$1.540 \pm 0.006 \cdot 10^{-4}$	$^{+1.0\%}_{-0.9\%}$

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Heavy quarks and jets			LO 1 TeV		NLO 1 TeV	
i.1	$e^+e^- \to jj$	`e+ e- > j j`	$6.223 \pm 0.005 \cdot 10^{-1}$	$^{+0.0\%}_{-0.0\%}$	$6.389 \pm 0.013 \cdot 10^{-1}$	$^{+0.2\%}_{-0.2\%}$
i.2	$e^+e^- \to jjj$	`e+ e- > j j j`	$3.401 \pm 0.002 \cdot 10^{-1}$	$^{+9.6\%}_{-8.0\%}$	$3.166 \pm 0.019 \cdot 10^{-1}$	$^{+0.2\%}_{-2.1\%}$
i.3	$e^+e^- \to jjjj$	`e+ e- > j j j j`	$1.047 \pm 0.001 \cdot 10^{-1}$	$^{+20.0\%}_{-15.3\%}$	$1.090 \pm 0.006 \cdot 10^{-1}$	$^{+0.0\%}_{-2.8\%}$
i.4	$e^+e^- \to jjjjj$	`e+ e- > j j j j j`	$2.201 \pm 0.021 \cdot 10^{-2}$	$^{+31.4\%}_{-22.1\%}$	$2.851 \pm 0.041 \cdot 10^{-2}$	$^{+5.7\%}_{-9.3\%}$
i.5	$e^+e^- \to t\bar{t}$	`e+ e- > t t~`	$1.662 \pm 0.002 \cdot 10^{-1}$	$^{+0.0\%}_{-0.0\%}$	$1.745 \pm 0.006 \cdot 10^{-1}$	$^{+0.4\%}_{-0.4\%}$
i.6	$e^+e^- \to t\bar{t}j$	`e+ e- > t t~ j`	$4.813 \pm 0.005 \cdot 10^{-2}$	$^{+9.3\%}_{-7.8\%}$	$5.276 \pm 0.022 \cdot 10^{-2}$	$^{+1.3\%}_{-2.1\%}$
i.7	$e^+e^- \to t\bar{t}jj$	`e+ e- > t t~ j j`	$8.614 \pm 0.009 \cdot 10^{-3}$	$^{+19.4\%}_{-15.0\%}$	$1.094 \pm 0.005 \cdot 10^{-2}$	$^{+5.0\%}_{-6.3\%}$
i.8	$e^+e^- \to t\bar{t}jjj$	`e+ e- > t t~ j j j`	$1.044 \pm 0.002 \cdot 10^{-3}$	$^{+30.5\%}_{-21.6\%}$	$1.546 \pm 0.010 \cdot 10^{-3}$	$^{+10.6\%}_{-11.6\%}$
i.9	$e^+e^- \to t\bar{t}t\bar{t}$	`e+ e- > t t~ t t~`	$6.456 \pm 0.016 \cdot 10^{-7}$	$^{+19.1\%}_{-14.8\%}$	$1.221 \pm 0.005 \cdot 10^{-6}$	$^{+13.2\%}_{-11.2\%}$
i.10	$e^+e^- \to t\bar{t}t\bar{t}j$	`e+ e- > t t~ t t~ j`	$2.719 \pm 0.005 \cdot 10^{-8}$	$^{+29.9\%}_{-21.3\%}$	$5.338 \pm 0.027 \cdot 10^{-8}$	$^{+18.3\%}_{-15.4\%}$
i.11	$e^+e^- \to b\bar{b}$	`e+ e- > b b~`	$9.198 \pm 0.004 \cdot 10^{-2}$	$^{+0.0\%}_{-0.0\%}$	$9.282 \pm 0.031 \cdot 10^{-2}$	$^{+0.0\%}_{-0.0\%}$
i.12	$e^+e^- \to b\bar{b}j$	`e+ e- > b b~ j`	$5.029 \pm 0.003 \cdot 10^{-2}$	$^{+9.5\%}_{-8.0\%}$	$4.826 \pm 0.026 \cdot 10^{-2}$	$^{+0.5\%}_{-2.5\%}$
i.13	$e^+e^- \to b\bar{b}jj$	`e+ e- > b b~ j j`	$1.621 \pm 0.001 \cdot 10^{-2}$	$^{+20.0\%}_{-15.3\%}$	$1.817 \pm 0.009 \cdot 10^{-2}$	$^{+0.0\%}_{-3.1\%}$
i.14	$e^+e^- \to b\bar{b}jjj$	`e+ e- > b b~ j j j`	$3.641 \pm 0.009 \cdot 10^{-3}$	$^{+31.4\%}_{-22.1\%}$	$4.936 \pm 0.038 \cdot 10^{-3}$	$^{+4.8\%}_{-8.9\%}$
i.15	$e^+e^- \to b\bar{b}b\bar{b}$	`e+ e- > b b~ b b~`	$1.644 \pm 0.003 \cdot 10^{-4}$	$^{+19.9\%}_{-15.3\%}$	$3.601 \pm 0.017 \cdot 10^{-4}$	$^{+15.2\%}_{-12.5\%}$
i.16	$e^+e^- \to b\bar{b}b\bar{b}j$	`e+ e- > b b~ b b~ j`	$7.660 \pm 0.022 \cdot 10^{-5}$	$^{+31.3\%}_{-22.0\%}$	$1.537 \pm 0.011 \cdot 10^{-4}$	$^{+17.9\%}_{-15.3\%}$
i.17	$e^+e^- \to t\bar{t}b\bar{b}$	`e+ e- > t t~ b b~`	$1.819 \pm 0.003 \cdot 10^{-4}$	$^{+19.5\%}_{-15.0\%}$	$2.923 \pm 0.011 \cdot 10^{-4}$	$^{+9.2\%}_{-8.9\%}$
i.18	$e^+e^- \to t\bar{t}b\bar{b}j$	`e+ e- > t t~ b b~ j`	$4.045 \pm 0.011 \cdot 10^{-5}$	$^{+30.5\%}_{-21.6\%}$	$7.049 \pm 0.052 \cdot 10^{-5}$	$^{+13.7\%}_{-13.1\%}$

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