MadGraph5_aMC@NLO for linear colliders

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on behalf of the MG5_aMC collaboration

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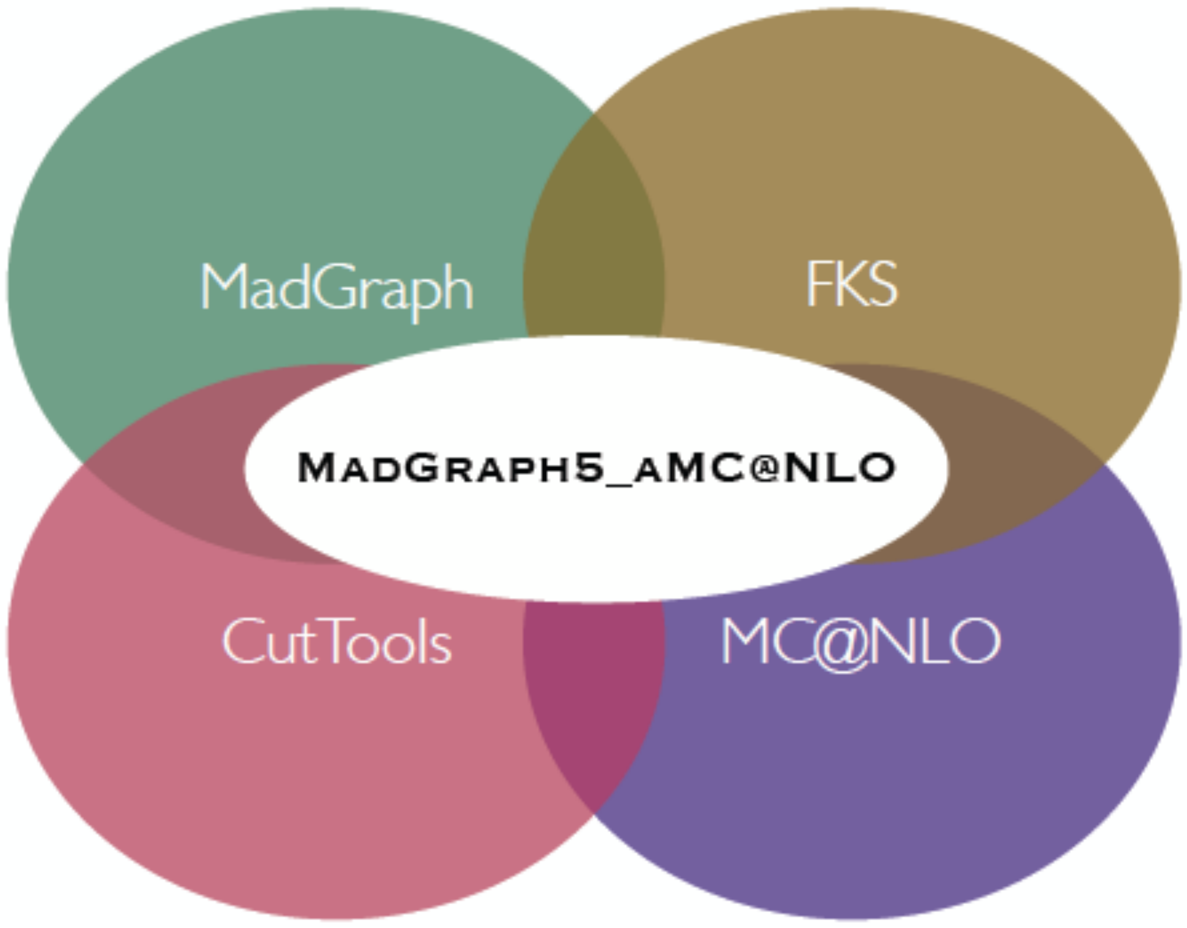
Outlines

- MadGraph5_aMC@NLO
- Simulation chain for new physics
  - e.g. Mono-photon + missing energy
  - 3-min MG5_aMC tutorial
- Summary and outlooks

MadGraph5_aMC@NLO in a nutshell

MG5_aMC: https://launchpad.net/mg5amcnlo



- is written in python.
- is widely used both by theorists (like me) and experimentalists (e.g ATLAS and CMS).
- performs automatic computations of tree-level and NLO differential cross sections.
- matches LO and NLO calculations to parton shower (PS) via the MC@NLO method.
- can compute any SM processes (up to $2 \to 4$ for hh and $2 \to 5$ for ee, tree-level born) at NLO QCD+PS fully automatically.

e.g. jets with heavy quarks (hh)

MG5_aMC [1405.0301]

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	$pp \to b\bar{b}$ (4f)	`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*	$pp \to b\bar{b}j$ (4f)	`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*	$pp \to b\bar{b}jj$ (4f)	`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	$pp \to b\bar{b}b\bar{b}$ (4f)	`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	$pp \to t\bar{t}b\bar{b}$ (4f)	`p p > t t~ b b~`	$6.119 \pm 0.004 \cdot 10^{0}$	$^{+62.1\%}_{-35.7\%}$	$^{+2.9\%}_{-3.5\%}$	$1.452 \pm 0.005 \cdot 10^{1}$	$^{+37.6\%}_{-27.5\%}$	$^{+2.9\%}_{-3.5\%}$

integration error — scale uncertainty — PDF uncertainty

e.g. jets with heavy quarks (ee)

MG5_aMC [1405.0301]

Process		Syntax	Cross section (pb)			
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`	$2.211 \pm 0.006 \cdot 10^{-2}$	$^{+31.4\%}_{-22.0\%}$	$2.771 \pm 0.021 \cdot 10^{-2}$	$^{+4.4\%}_{-8.6\%}$
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	$e^+e^- \to b\bar{b}$ (4f)	`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	$e^+e^- \to b\bar{b}j$ (4f)	`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*	$e^+e^- \to b\bar{b}jj$ (4f)	`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*	$e^+e^- \to b\bar{b}jjj$ (4f)	`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*	$e^+e^- \to b\bar{b}b\bar{b}$ (4f)	`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*	$e^+e^- \to b\bar{b}b\bar{b}j$ (4f)	`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*	$e^+e^- \to t\bar{t}b\bar{b}$ (4f)	`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*	$e^+e^- \to t\bar{t}b\bar{b}j$ (4f)	`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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e.g. top quarks with bosons (hh)

MG5_aMC [1405.0301]

Process		Syntax	Cross section (pb)			
Heavy quarks+vector bosons			LO 13 TeV		NLO 13 TeV	
e.1	$pp \to W^{\pm} b\bar{b}$ (4f)	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	$pp \to Z b\bar{b}$ (4f)	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	$pp \to \gamma b\bar{b}$ (4f)	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*	$pp \to W^{\pm} b\bar{b} j$ (4f)	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*	$pp \to Z b\bar{b} j$ (4f)	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*	$pp \to \gamma b\bar{b} j$ (4f)	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*	$pp \to t\bar{t} ZZ$	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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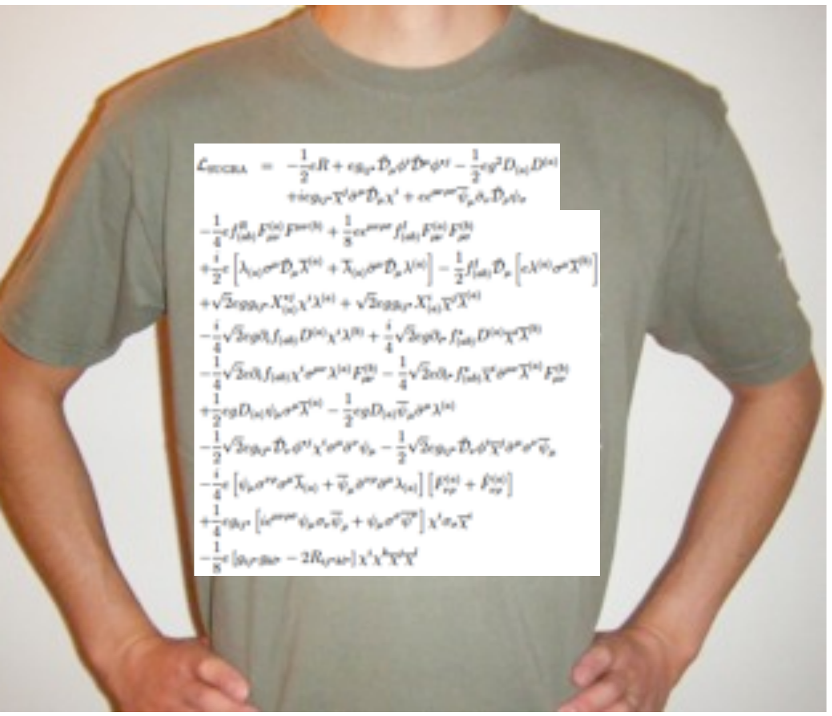
e.g. top quarks with bosons (ee)

MG5_aMC [1405.0301]

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	$2.533 \pm 0.003 \cdot 10$			
j.3*	$e^+e^- \to t\bar{t}Hjj$	e+ e- > t t~ h j j	$2.663 \pm 0.004 \cdot 10$			
j.4*	$e^+e^- \to t\bar{t}\gamma$	e+ e- > t t~ a	$1.270 \pm 0.002 \cdot 10$			
j.5*	$e^+e^- \to t\bar{t}\gamma j$	e+ e- > t t~ a j	$2.355 \pm 0.002 \cdot 10$			
j.6*	$e^+e^- \to t\bar{t}\gamma jj$	e+ e- > t t~ a j j	$3.103 \pm 0.005 \cdot 10$			
j.7*	$e^+e^- \to t\bar{t}Z$	e+ e- > t t~ z	$4.642 \pm 0.006 \cdot 10$			
j.8*	$e^+e^- \to t\bar{t}Zj$	e+ e- > t t~ z j	$6.059 \pm 0.006 \cdot 10$			
j.9*	$e^+e^- \to t\bar{t}Zjj$	e+ e- > t t~ z j j	$6.351 \pm 0.028 \cdot 10$	-15.0%	[illegible]	-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-	$1.372 \pm 0.003 \cdot 10^{-4}$	$^{+0.0\%}_{-0.0\%}$	$1.540 \pm 0.006 \cdot 10^{-4}$	$^{+1.0\%}_{-0.9\%}$

```
Summary:
Process e+ e- > t t~ x0 [QCD]
Run at l-l collider (500 + 500 GeV)
Total cross-section: 1.853e-03 +- 3.5e-06 pb
Ren. and fac. scale uncertainty: +0.5% -0.6%
Number of events generated: 10000
Parton shower to be used: HERWIG6
Fraction of negative weights: 0.09
Total running time : 2m 33s
```

Simulation chain for new physics



FeynRules

UFO (Universal FeynRules Output) model file

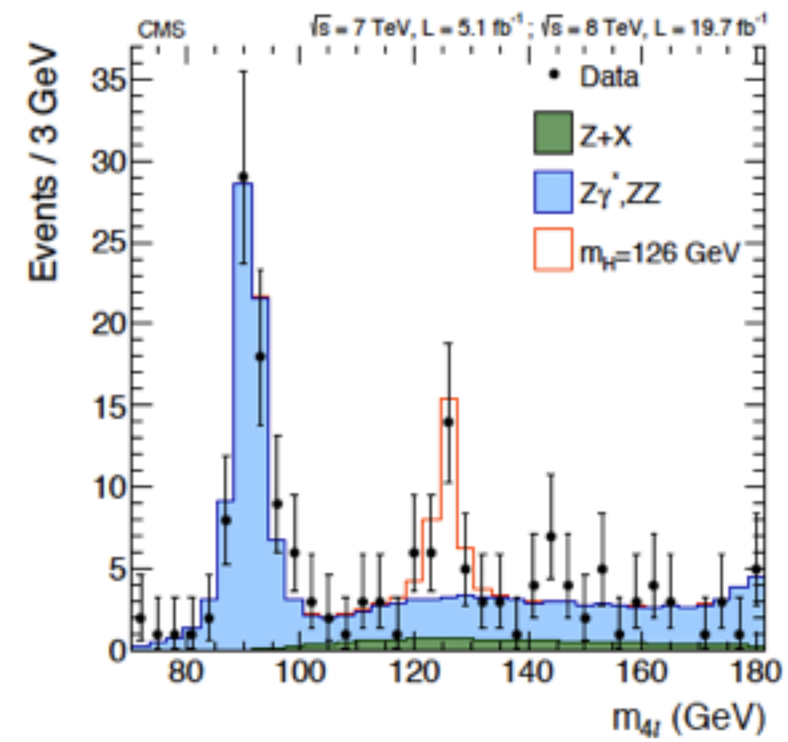
MadGraph5_aMC@NLO
(Herwig, Pythia)

StdHep event file

Delphes

LHCO event file

MadAnalysis5



e.g. New physics in mono-photon signals

Photon Events with Missing Energy in e^+e^- Collisions at $\sqrt{s} = 130$ to 209 GeV

hep-ex/0406019

DELPHI Collaboration

The production of single- and multi-photon events has been studied in the reaction $e^+e^- \rightarrow \gamma(\gamma) + invisible\ particles$. The data collected with the DELPHI detector during the years 1999 and 2000 at centre-of-mass energies between 191 GeV and 209 GeV was combined with earlier data to search for phenomena beyond the Standard Model. The measured number of light neutrino families was consistent with three and the absence of an excess of events beyond that predicted by the Standard Model processes was used to set limits on new physics. Both model-independent searches and searches for new processes predicted by supersymmetric and extra-dimensional models have been made. Limits on new non-standard model interactions between neutrinos and electrons were also determined.

Gravitino mass limits from mono-photon

Citation: K.A. Olive *et al.* (Particle Data Group), Chin. Phys. **C38**, 090001 (2014) (URL: http://pdg.lbl.gov)

LIGHT $\tilde{G}$ (Gravitino) MASS LIMITS FROM COLLIDER EXPERIMENTS

The following are bounds on light ($\ll$ 1 eV) gravitino indirectly inferred from its coupling to matter suppressed by the gravitino decay constant.

Unless otherwise stated, all limits assume that other supersymmetric particles besides the gravitino are too heavy to be produced. The gravitino is assumed to be undetected and to give rise to a missing energy ($\not{E}$) signature.

VALUE (eV)	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$> 1.09 \times 10^{-5}$	95	[1] ABDALLAH	05B	DLPH	$e^+e^- \to \tilde{G}\tilde{G}\gamma$
$> 1.35 \times 10^{-5}$	95	[2] ACHARD	04E	L3	$e^+e^- \to \tilde{G}\tilde{G}\gamma$
$> 1.3 \times 10^{-5}$		[3] HEISTER	03C	ALEP	$e^+e^- \to \tilde{G}\tilde{G}\gamma$
$> 11.7 \times 10^{-6}$	95	[4] ACOSTA	02H	CDF	$p\overline{p} \to \tilde{G}\tilde{G}\gamma$
$> 8.7 \times 10^{-6}$	95	[5] ABBIENDI,G	00D	OPAL	$e^+e^- \to \tilde{G}\tilde{G}\gamma$
$> 10.0 \times 10^{-6}$	95	[6] ABREU	00Z	DLPH	$e^+e^- \to \tilde{G}\tilde{G}\gamma$
$> 11 \times 10^{-6}$	95	[7] AFFOLDER	00J	CDF	$p\overline{p} \to \tilde{G}\tilde{G}$ +jet
$> 8.9 \times 10^{-6}$	95	[8] ACCIARRI	99R	L3	$e^+e^- \to \tilde{G}\tilde{G}\gamma$
$> 7.9 \times 10^{-6}$	95	[9] ACCIARRI	98V	L3	$e^+e^- \to \tilde{G}\tilde{G}\gamma$
$> 8.3 \times 10^{-6}$	95	[9] BARATE	98J	ALEP	$e^+e^- \to \tilde{G}\tilde{G}\gamma$

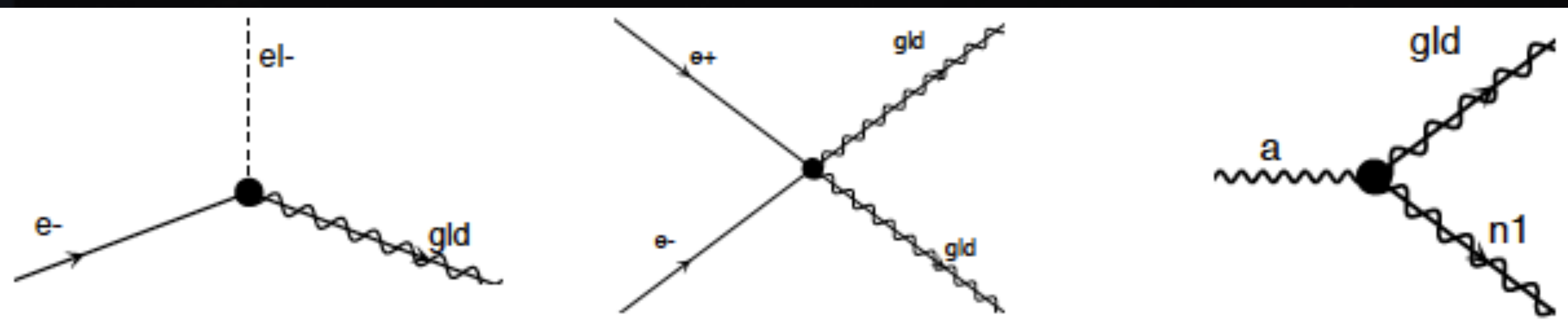
FeynRules in a nutshell

Alloul, Christensen, Degrande, Duhr, Fuks [arXiv:1310.1921]
FeynRules: http://feynrules.irmp.ucl.ac.be/

- a Mathematica package that allows to derive Feynman rules from a Lagrangian.
- allows to export the Feynman rules to various matrix element generators, e.g. CalcHEP, FeynArts, MadGraph, Sherpa, Whizard, ...

$$\mathcal{L}_{\rm int} = -\sum_{i=L,R} \frac{m^2_{\tilde{e}_i}}{F^2} \int d^4\theta\, X^\dagger X \Phi_i^\dagger \Phi_i - \left(\frac{m_\lambda}{2F} \int d^2\theta\, X W^\alpha W_\alpha + \text{h.c.} \right)$$

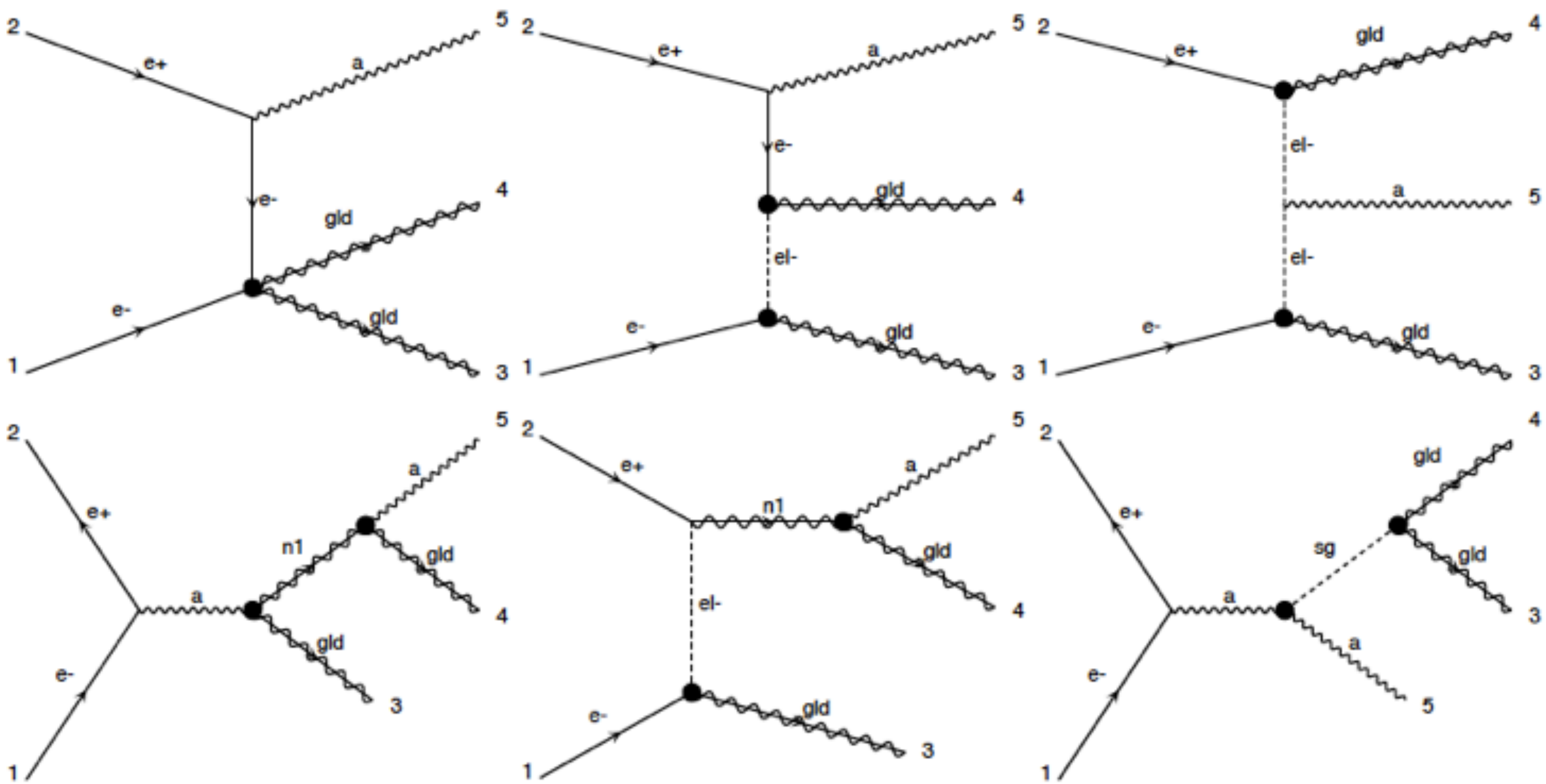
```
Lsoftm := -Mel^2/Fsusy^2 Theta2Thetabar2Component[GLbar GL ELbar EL] -
          Mer^2/Fsusy^2 Theta2Thetabar2Component[GLbar GL ERbar ER];

Lsoftg := -Mn1/(2 Fsusy) Theta2Component[nc[GL, SuperfieldStrengthL[ASF, sp4], SuperfieldStrengthL[ASF, sp3]] Ueps[sp3, sp4]] -
          Mn1/(2 Fsusy) Thetabar2Component[HC[nc[GL, SuperfieldStrengthL[ASF, sp4], SuperfieldStrengthL[ASF, sp3]] Ueps[sp3, sp4]]];
```



3-min MadGraph5_aMC@NLO tutorial

```
./bin/mg5_aMC
>import model mssm-goldstino
>generate e- e+ > gld gld a
>output JCL3demo
>launch
```

- Start the MG5_aMC shell
- Import the model
- Generate the process
- Write the code (including html)
- Generate the LO/NLO events



3-min MadGraph5_aMC@NLO tutorial

```
Do you want to edit a card (press enter to bypass editing)?
  1 / param       : param_card.dat
  2 / run         : run_card.dat
  3 / madspin     : madspin_card.dat
  4 / shower      : shower_card.dat
 [0, done, 1, param, 2, run, 3, madspin, 4, enter path, ... ]
>
```

param_card.dat

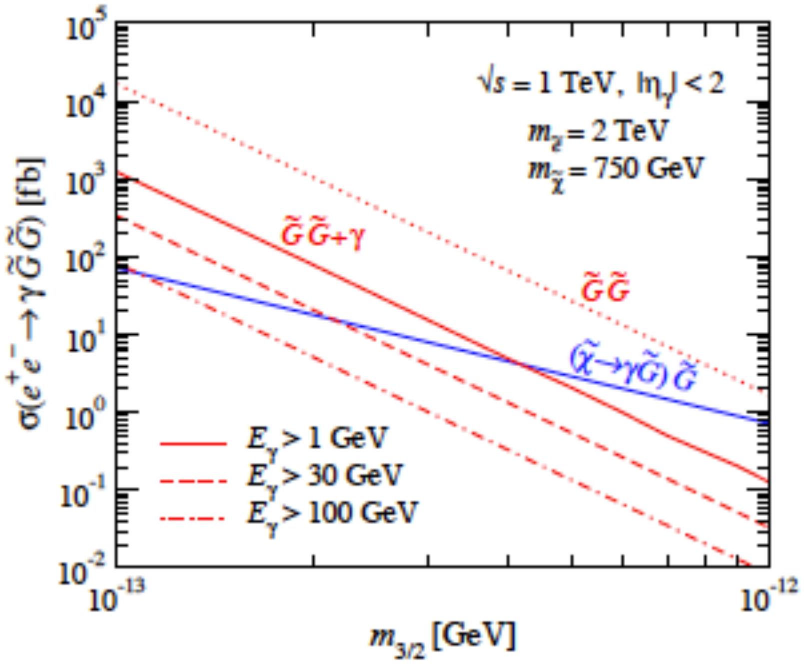
```
1000001 1.120229e+03 #  msd1
1000002 1.117576e+03 #  msu1
1000003 1.120229e+03 #  msd2
1000004 1.117576e+03 #  msu2
1000005 1.056743e+03 #  msd3
1000006 9.756224e+02 #  msu3
1000011 3.582292e+02 #  msl1
1000012 3.490483e+02 #  msn1
1000013 3.582292e+02 #  msl2
1000014 3.490483e+02 #  msn2
1000015 1.738053e+02 #  msl3
1000016 3.482844e+02 #  msn3
1000021 8.345774e+02 #  mgo
```

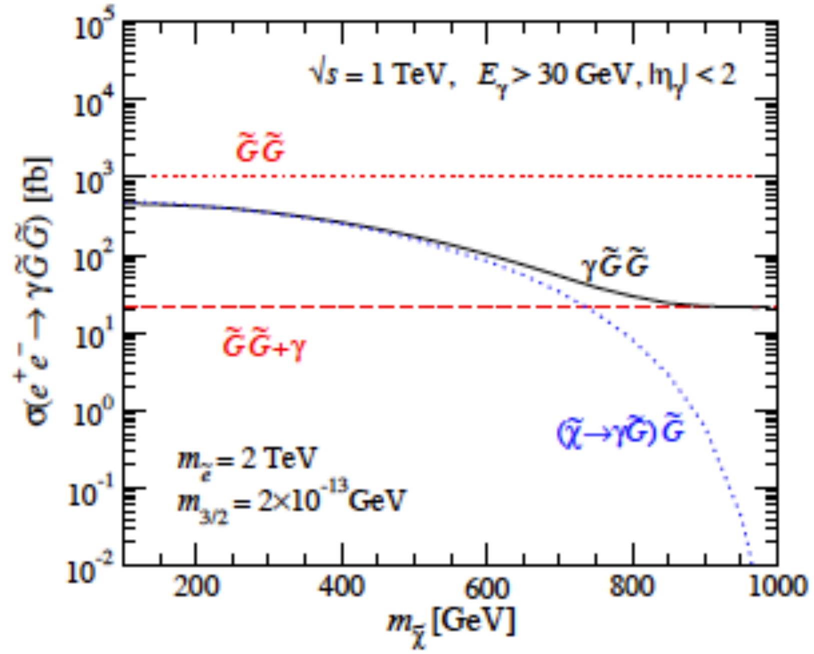
run_card.dat

```
  10000 = nevents ! Number of unweighted events requested
      0       = iseed   ! rnd seed (0=assigned automatically=default))
#*********************************************************************
# Collider type and energy                                           *
# lpp: 0=No PDF, 1=proton, -1=antiproton, 2=photon from proton,      *
#                                        3=photon from electron      *
#*********************************************************************
        0       = lpp1    ! beam 1 type
        0       = lpp2    ! beam 2 type
      500       = ebeam1  ! beam 1 total energy in GeV
      500       = ebeam2  ! beam 2 total energy in GeV
#*********************************************************************
# Beam polarization from -100 (left-handed) to 100 (right-handed)    *
#*********************************************************************
        0       = polbeam1 ! beam polarization for beam 1
        0       = polbeam2 ! beam polarization for beam 2
```

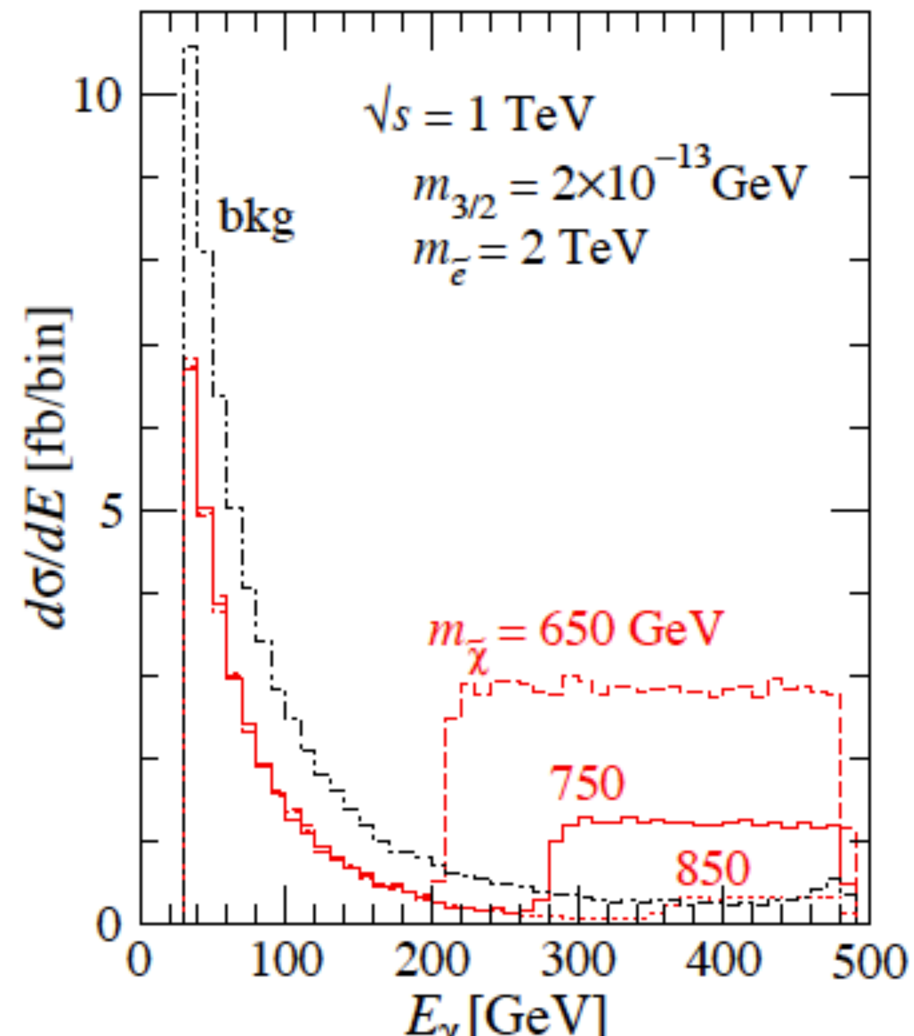
Mono-photon signals from light gravitino production

KM, Oexl [1402.3223]





(P_{e^-}, P_{e^+})	$m_{\tilde{\chi}}$ [GeV]	$\tilde{\chi}\tilde{G}$	$\tilde{G}\tilde{G}$	SM bkg
(0, 0)	650	49.2	21.1	1452
	750	15.8		
	850	2.5		
(0.9, −0.6)	650	75.8	32.7	64.9
	750	24.3		
	850	3.4		



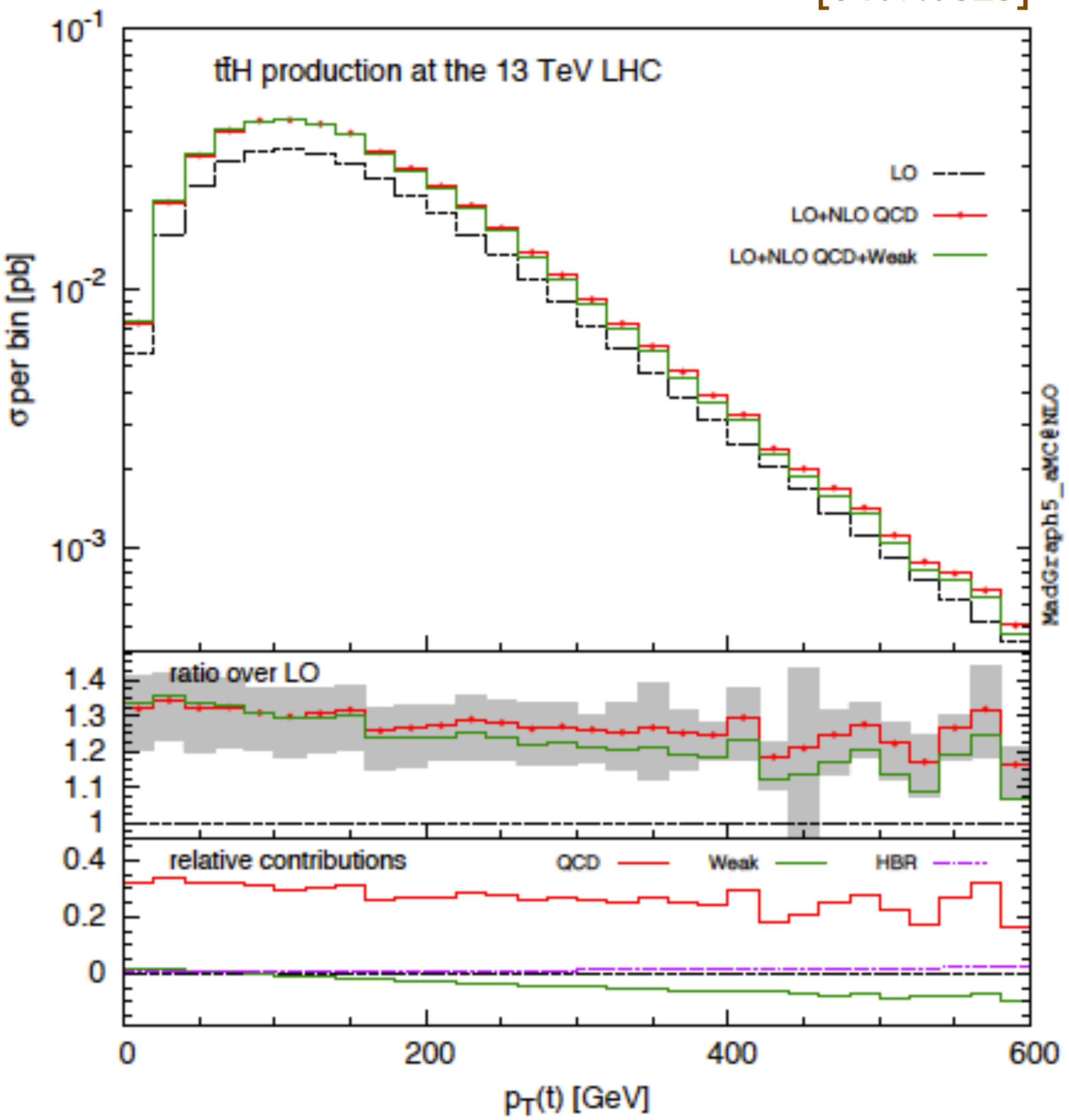
Summary and outlook

- MadGraph5_aMC@NLO is one of the event generators not only for SM but also for BSM at the tree-level as well as at the NLO QCD.
- Most of the efforts for the last few years have been devoted to LHC, especially for NLO QCD automation. However, the framework is flexible enough to be adapted to e+e- physics.
- Automation of EW corrections is in progress, which is very important for e+e- physics.
- Automation of NLO corrections for BSM is also on-going.

Automation for EW corrections in progress

slide from Davide Pagani
@ ERC miniworkshop

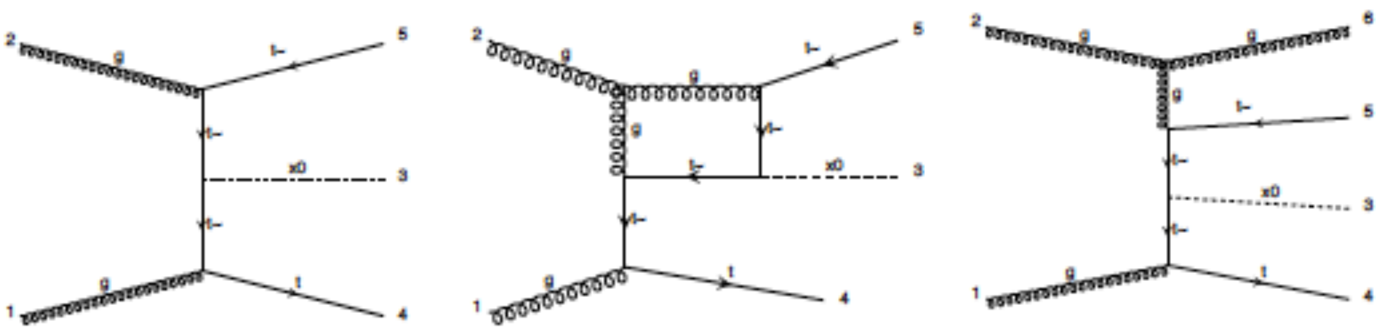
Frixione, Hirschi, Pagani, Shao, Zaro
[1407.0823]



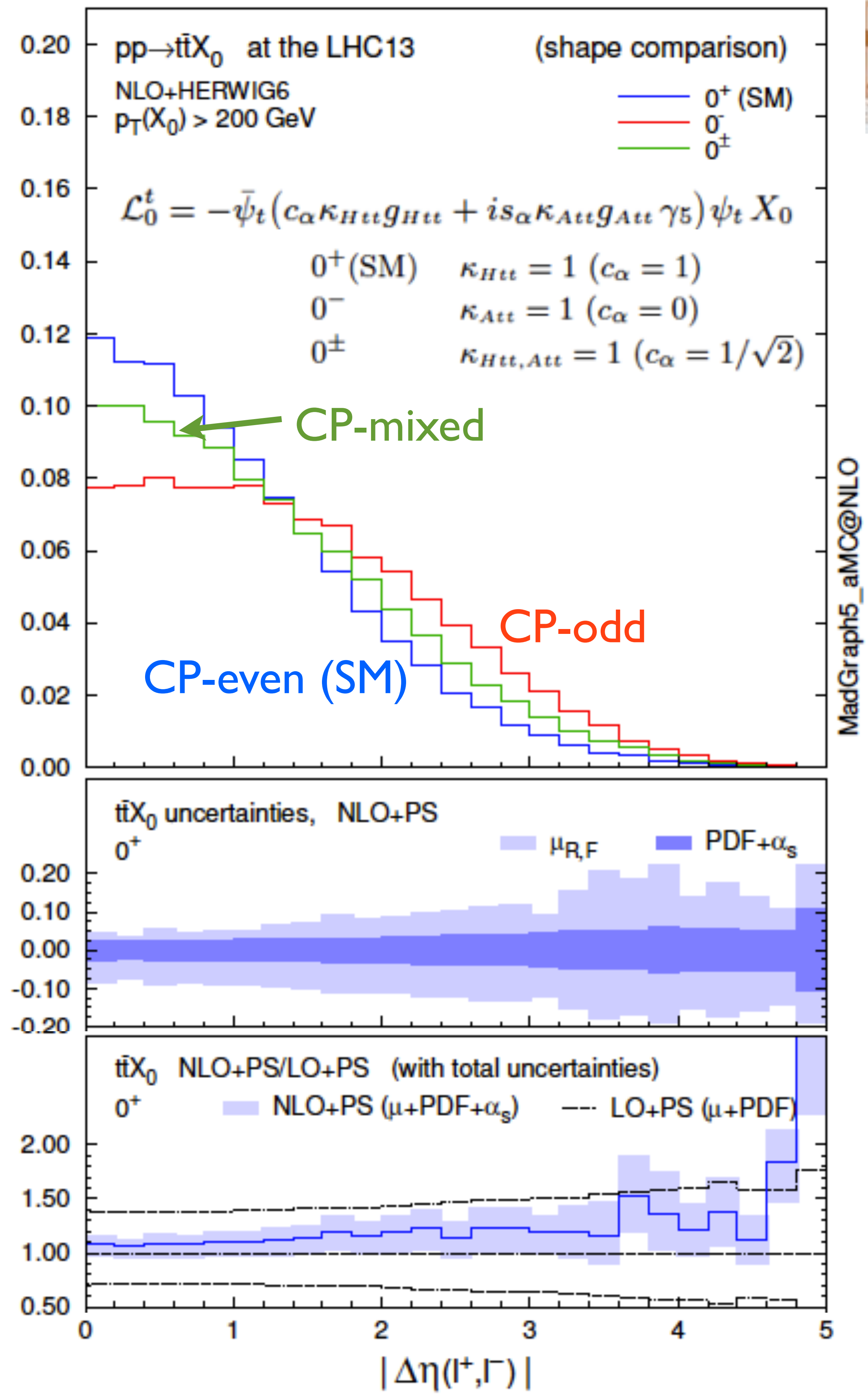
Higgs characterisation in ttH

Demartin, Maltoni, KM, Page, Zaro [1407.5089]

```
./bin/mg5_aMC
>import model HC_NLO_X0
>generate p p > x0 t t~ [QCD]
>output
>launch
```



scenario		σ_{LO} (fb)	σ_{NLO} (fb)	K
LHC 13 TeV	0^+	$468.6(4)\ ^{+32.8}_{-22.8}\ \pm4.5\%$	$525.1(7)\ ^{+5.7}_{-8.7}\ \pm2.1\%$	1.12
	0^-	$196.8(2)\ ^{+37.1}_{-25.2}\ \pm7.5\%$	$224.3(3)\ ^{+6.8}_{-10.5}\ \pm3.2\%$	1.14
	$0^\pm$	$332.4(3)\ ^{+34.0}_{-23.5}\ \pm5.4\%$	$374.1(5)\ ^{+6.0}_{-9.3}\ \pm2.5\%$	1.13



back-up

Effective Lagrangian -- spin0

$$\mathcal{L}_0^f = -\sum_{f=t,b,\tau} \bar\psi_f\big(c_\alpha\kappa_{Hff}g_{Hff} + is_\alpha\kappa_{Aff}g_{Aff}\,\gamma_5\big)\psi_f X_0$$

HC1: [1306.6464]

$$\begin{aligned}\mathcal{L}_0^V = \Big\{ & c_\alpha\kappa_{\rm SM}\big[\tfrac{1}{2}g_{HZZ}\,Z_\mu Z^\mu + g_{HWW}\,W^+_\mu W^{-\mu}\big] \\ & -\frac{1}{4}\big[c_\alpha\kappa_{H\gamma\gamma}g_{H\gamma\gamma}\,A_{\mu\nu}A^{\mu\nu} + s_\alpha\kappa_{A\gamma\gamma}g_{A\gamma\gamma}\,A_{\mu\nu}\widetilde{A}^{\mu\nu}\big] \\ & -\frac{1}{2}\big[c_\alpha\kappa_{HZ\gamma}g_{HZ\gamma}\,Z_{\mu\nu}A^{\mu\nu} + s_\alpha\kappa_{AZ\gamma}g_{AZ\gamma}\,Z_{\mu\nu}\widetilde{A}^{\mu\nu}\big] \\ & -\frac{1}{4}\big[c_\alpha\kappa_{Hgg}g_{Hgg}\,G^a_{\mu\nu}G^{a,\mu\nu} + s_\alpha\kappa_{Agg}g_{Agg}\,G^a_{\mu\nu}\widetilde{G}^{a,\mu\nu}\big] \\ & -\frac{1}{4}\frac{1}{\Lambda}\big[c_\alpha\kappa_{HZZ}\,Z_{\mu\nu}Z^{\mu\nu} + s_\alpha\kappa_{AZZ}\,Z_{\mu\nu}\widetilde{Z}^{\mu\nu}\big] \\ & -\frac{1}{2}\frac{1}{\Lambda}\big[c_\alpha\kappa_{HWW}\,W^+_{\mu\nu}W^{-\mu\nu} + s_\alpha\kappa_{AWW}\,W^+_{\mu\nu}\widetilde{W}^{-\mu\nu}\big] \\ & -\frac{1}{\Lambda}c_\alpha\big[\kappa_{H\partial\gamma}\,A_\nu\partial_\mu A^{\mu\nu} + \kappa_{H\partial Z}\,Z_\nu\partial_\mu Z^{\mu\nu} \\ & \qquad + \big(\kappa_{H\partial W}W^+_\nu\partial_\mu W^{-\mu\nu} + h.c.\big)\big]\Big\}X_0\end{aligned}$$

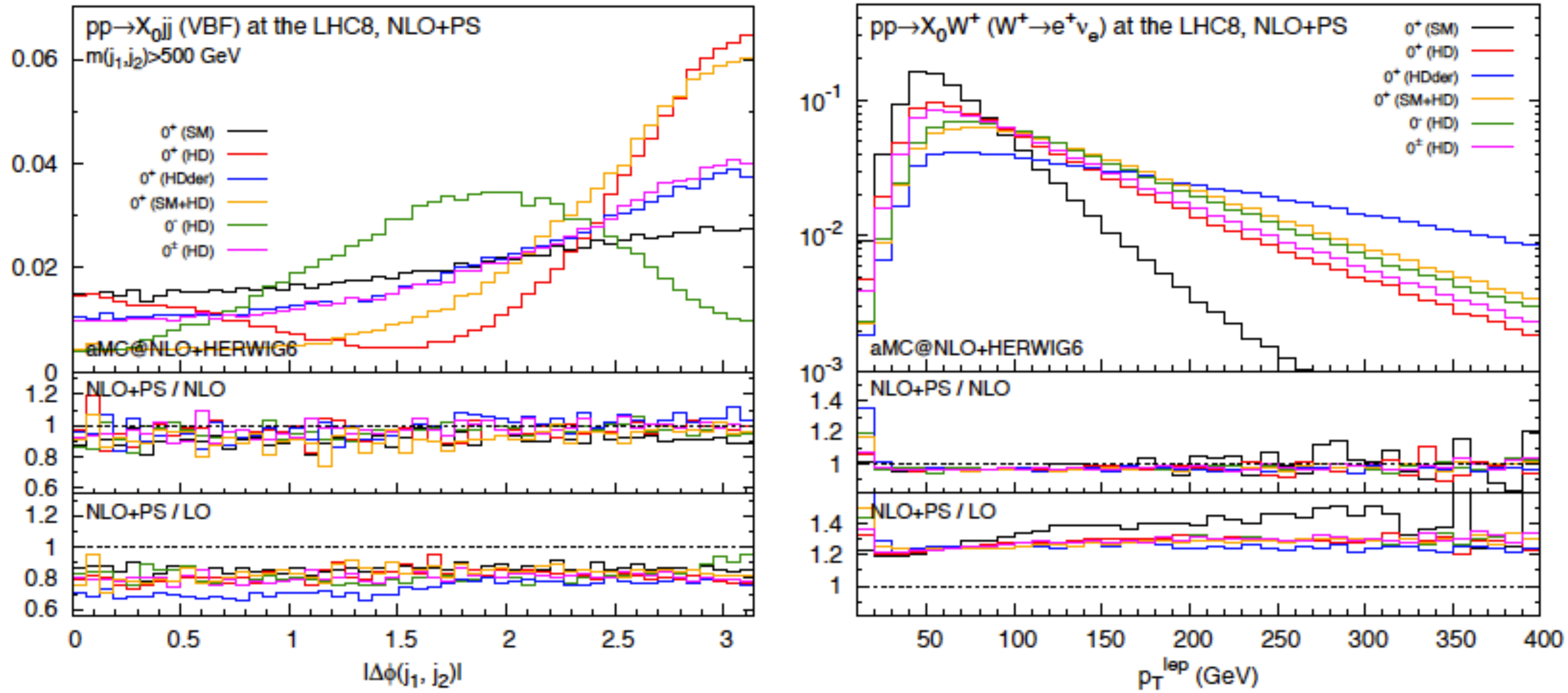
parameter	description
Λ [GeV]	cutoff scale
$c_\alpha\ (\equiv\cos\alpha)$	mixing between 0^+ and 0^-
κ_i	dimensionless coupling parameter

param_card.dat

```
######################################
## INFORMATION FOR FRBLOCK
######################################
Block frblock
    1 1.000000e+03 # Lambda
    2 1.000000e+00 # ca
    3 1.000000e+00 # kSM
    4 1.000000e+00 # kHtt
    5 1.000000e+00 # kAtt
    6 1.000000e+00 # kHbb
    7 1.000000e+00 # kAbb
    8 1.000000e+00 # kHll
    9 1.000000e+00 # kAll
   10 1.000000e+00 # kHaa
   11 1.000000e+00 # kAaa
   12 1.000000e+00 # kHza
   13 1.000000e+00 # kAza
   14 1.000000e+00 # kHgg
   15 1.000000e+00 # kAgg
   16 0.000000e+00 # kHzz
   17 0.000000e+00 # kAzz
   18 0.000000e+00 # kHww
   19 0.000000e+00 # kAww
   20 0.000000e+00 # kHda
   21 0.000000e+00 # kHdz
   22 0.000000e+00 # kHdwR
   23 0.000000e+00 # kHdwI
```

Higgs characterisation in VBF and VH

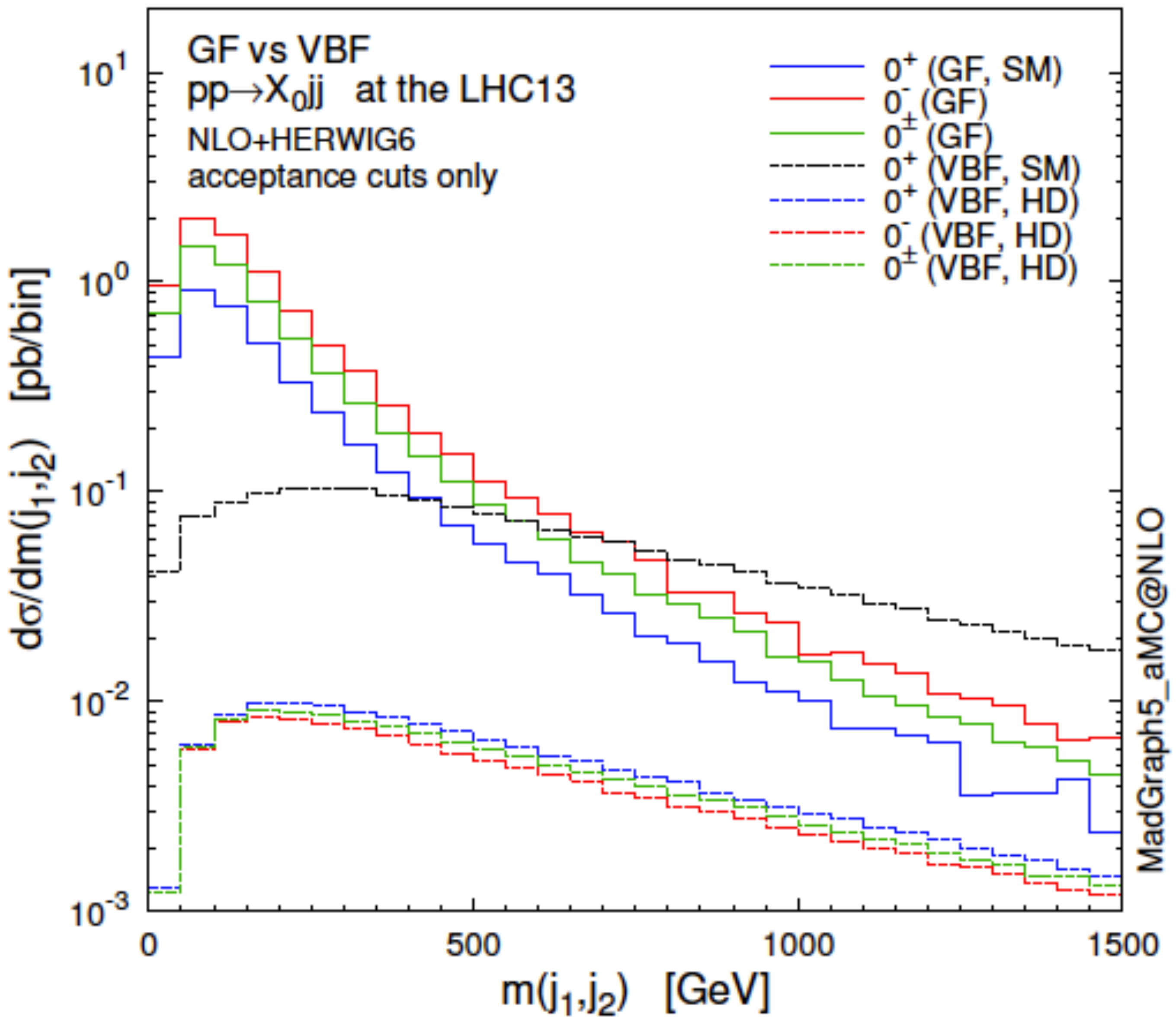
HC2: Maltoni, KM, Zaro [1311.1829]

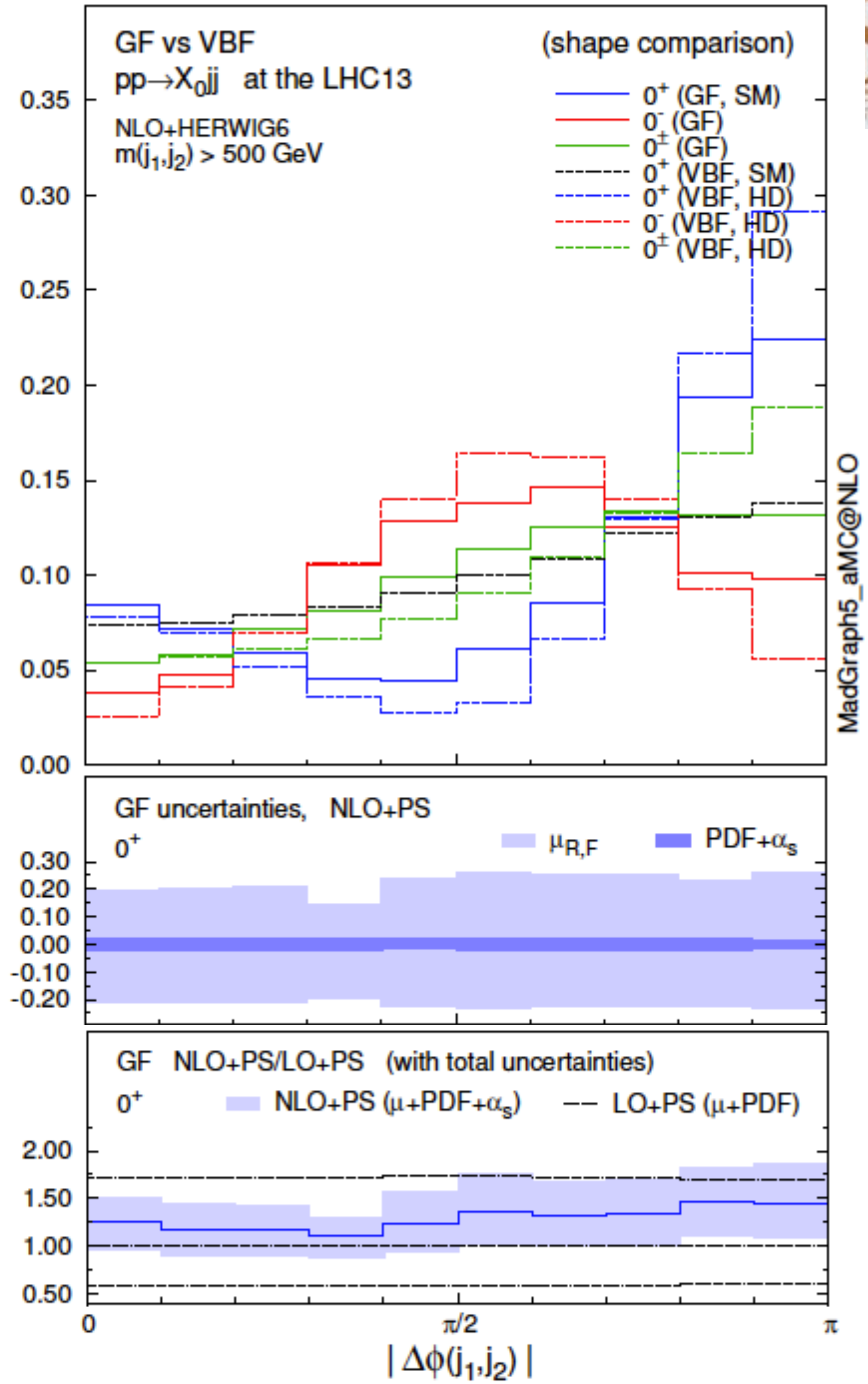


Some observables are sensitive to the structure (CP-even/odd and/or higher dimension (HD)) of the HVV interaction.

Higgs characterisation in GF

HC3: Demartin, Maltoni, KM, Page, Zaro [1407.5089]





- Di-jet correlations are still sensitive probes of the CP mixing of the Higgs boson even after PS.