Summary of MC generator used by ATLAS and CMS collaborations in Run 2

Stefano Manzoni (CERN)

Nan Lu (University of Science and Technology of China)

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Summary of Run 2 settings

	ggHH		VBFHH		VHH		ttHH	
	ATLAS	CMS	ATLAS	CMS	ATLAS	CMS	ATLAS	CMS
Generator	Powheg+FT	Powheg+FT	MG5@LO	MG5@LO	MG5@LO	MG5@LO		MG5@LO
Showering	Pythia 8.2	Pythia 8.2	Pythia 8.2	Pythia 8.2	Pythia 8.2	Pythia 8.2		Pythia 8.2
PDF	PDFLHC15	NNPDF 3.0 (2016) NNPDF 3.1 (2017-2018)	NNPDF3.0nlo	NNPDF 3.0 (2016) NNPDF 3.1 (2017-2018)	NNPDF2.3lo	NNPDF 3.1		NNPDF 3.1

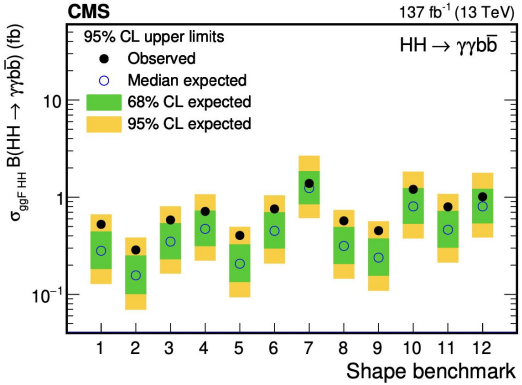
CMS EFT studies

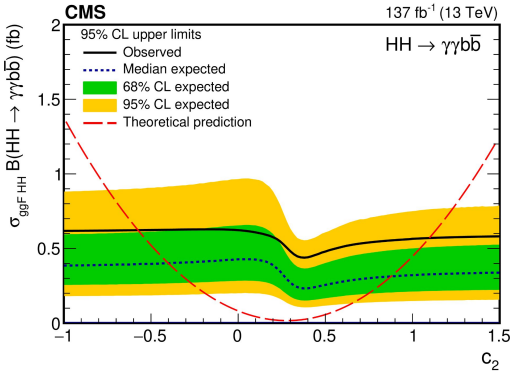
- HEFT ggF cross section modeling with three new contact interactions (couplings): ttHH (C2), ggHH (C2g) and ggH (Cg)

- Run 2: EFT Benchmarks in JHEP04(2016)126 generated at LO in QCD using Madgraph

	1	2	3	4	5	6	7	8	9	10	11	12	SM
κ_λ	7.5	1.0	1.0	−3.5	1.0	2.4	5.0	15.0	1.0	10.0	2.4	15.0	1.0
κ_t	1.0	1.0	1.0	1.5	1.0	1.0	1.0	1.0	1.0	1.5	1.0	1.0	1.0
c_2	−1.0	0.5	−1.5	−3.0	0.0	0.0	0.0	0.0	1.0	−1.0	0.0	1.0	0.0
c_g	0.0	−0.8	0.0	0.0	0.8	0.2	0.2	−1.0	−0.6	0.0	1.0	0.0	0.0
c_{2g}	0.0	0.6	−0.8	0.0	−1.0	−0.2	−0.2	1.0	0.6	0.0	−1.0	0.0	0.0

JHEP03(2021)257





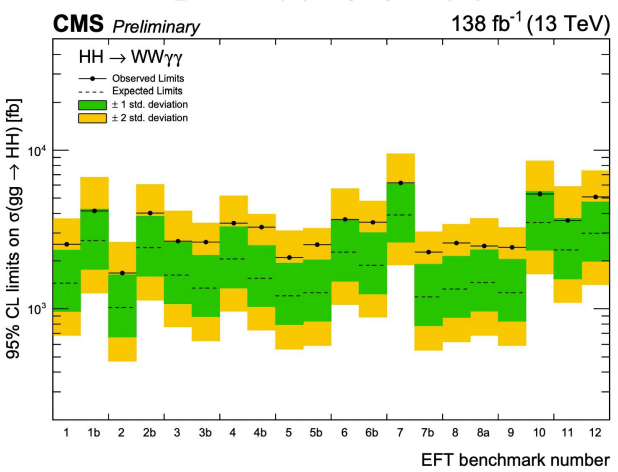
CMS EFT studies

Run 2: using reweighting method to get the HEFT benchmarks at NLO in QCD [JHEP 09 (2018) 057,JHEP 04 (2016) 126,JHEP 03 (2020) 091]

Run 3 plans:

- generate HEFT benchmarks at NLO in QCD using User-Processes-V2/ggHH @ https://powhegbox.mib.infn.it/ for Run 3 [JHEP20(2020)21]
- SMEFT interpretation

CMS-PAS-HIG-21-014



JHEP04(2016)126 + JHEP09(2018)057

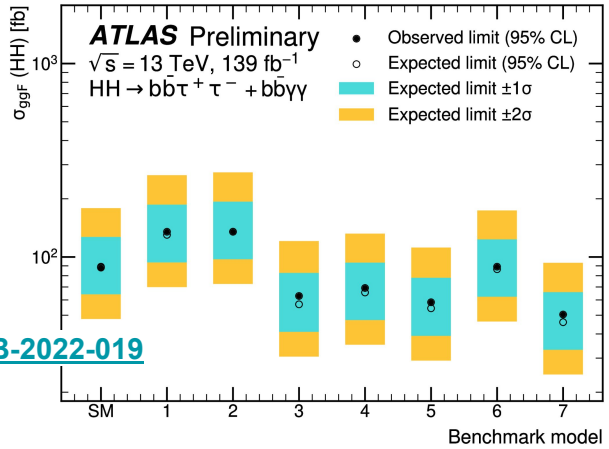
Benchmark	c_{hhh}	c_t	c_{tt}	c_{ggh}	c_{gghh}
1	7.5	1.0	−1.0	0.0	0.0
2	1.0	1.0	0.5	$-\frac{1.6}{3}$	−0.2
3	1.0	1.0	−1.5	0.0	$\frac{0.8}{3}$
4	−3.5	1.5	−3.0	0.0	0.0
5	1.0	1.0	0.0	$\frac{1.6}{3}$	$\frac{1.0}{3}$
6	2.4	1.0	0.0	$\frac{0.4}{3}$	$\frac{0.2}{3}$
7	5.0	1.0	0.0	$\frac{0.4}{3}$	$\frac{0.2}{3}$
8a	1.0	1.0	0.5	$\frac{0.8}{3}$	0.0
9	1.0	1.0	1.0	−0.4	−0.2
10	10.0	1.5	−1.0	0.0	0.0
11	2.4	1.0	0.0	$\frac{2.0}{3}$	$\frac{1.0}{3}$
12	15.0	1.0	1.0	0.0	0.0
SM	1.0	1.0	0.0	0.0	0.0

JHEP03(2020)091

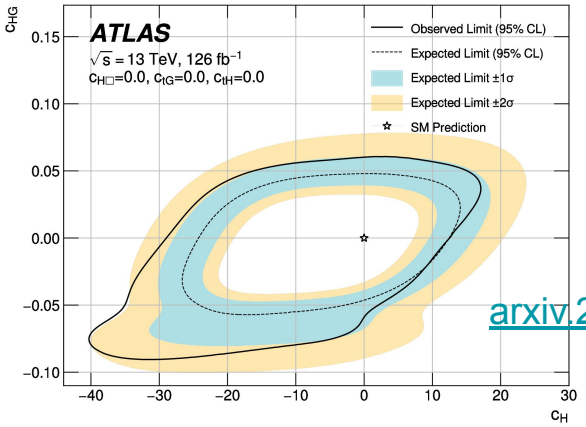
benchmark	c_t	c_{hhh}	c_{tt}	c_{ggh}	c_{gghh}
1	0.94	3.94	$-\frac{1}{3}$	0.5	$\frac{1}{3}$
2	0.61	6.84	$\frac{1}{3}$	0.0	$-\frac{1}{3}$
3	1.05	2.21	$-\frac{1}{3}$	0.5	0.5
4	0.61	2.79	$\frac{1}{3}$	−0.5	$\frac{1}{6}$
5	1.17	3.95	$-\frac{1}{3}$	$\frac{1}{6}$	−0.5
6	0.83	5.68	$\frac{1}{3}$	−0.5	$\frac{1}{3}$
7	0.94	−0.10	1	$\frac{1}{6}$	$-\frac{1}{6}$

ATLAS EFT benchmarks

- Study done for HEFT benchmarks and couplings **ATL-PHYS-PUB-2022-019**
  - NLO HH Generation at true level using Powheg arxiv.2006.16877
  - Reweighting applied to SM generated sample to get any coupling combinations
- SMEFT interpretation include in HH->4b analysis arxiv.2301.03212:
  - SMEFT@NLO (LO in HH) Generation using MG5 Reweighting applied to SM generated sample to get any coupling combinations



ATL-PHYS-PUB-2022-019



arxiv.2301.03212

CMS Resonant X→HH and X→YH samples

X→HH: Warped extra dimension (WED) model. Radion (Spin-0) and Bulk Gravtion (spin-2) resonances decaying into two SM Higgs bosons.

X→YH: Next-to-minimal Supersymmetric Standard Model (NMSSM): X (Spin-0) resonance decaying into an SM Higgs boson and a Y scalar

➢ Assuming resonances with narrow decay widths ○ No interference effects

Generator	Madgraph
Showering	Pythia 8.2
PDF	NNPDF 3.0 (2016) NNPDF 3.1 (2017-2018)

More about resonant searches by CMS talk by Fabio Monti and Alexandra Carvalho in Sept 2022 HH cross group meeting

ATLAS Resonant X→HH

X→HH: Heavy Spin-0 resonance with narrow width (much smaller than detector resolution) and Kaluza–Klein graviton with $k/M_{\mathrm{Pl}} = 1$ (spin-2) resonances decaying into two SM Higgs bosons.

- Generator: MG5@LO
- Showering: Herwig 7.1 and Pythia 8.1
- Pdf: NNPDF23LO

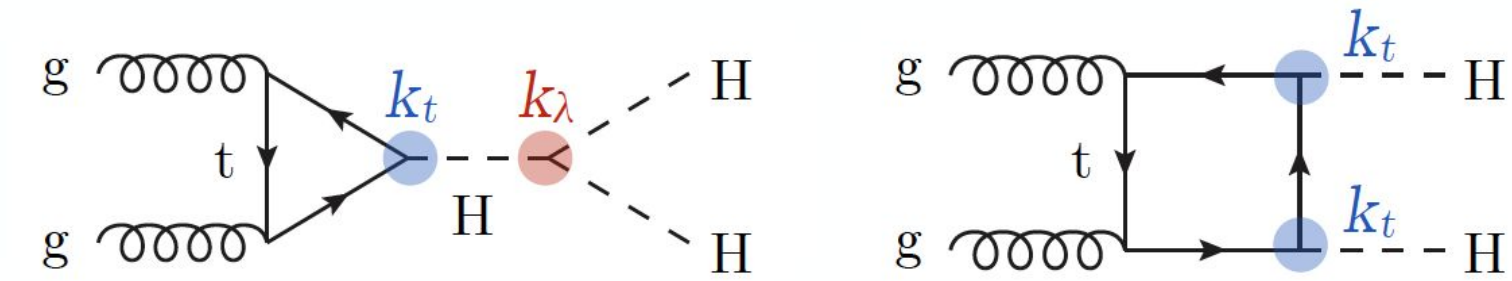
Conclusion, next steps and TODOs

- Similar setup from ATLAS and CMS in Run 2 (not many setup available for the generation)
- VBFHH, VHH, ttHH non Resonant production at NLO (https://arxiv.org/abs/1401.7340):
  - SM already available
  - Possibility to obtain BSM distribution hacking the code by hand
  - An integration with a proper EFT (HEFT) model would be preferable ->TODO for LHC-HH group: shared repository of UFO EFT models?
- For resontant searches:
  - What about VBFHH resonances arxiv.2007.07295?

backup

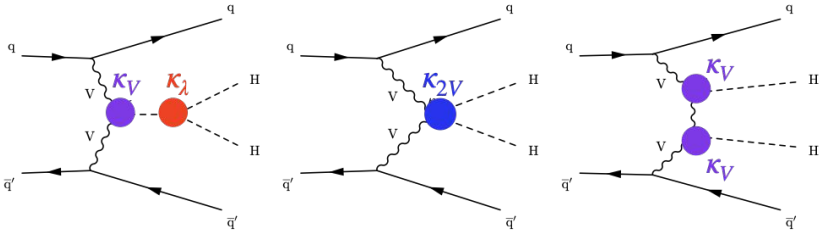
Gluon fusion - CMS

Run 2: samples (κ_λ κ_t) = (0, 1), (1, 1), (2.45, 1), (5, 1): base of 3 samples + (0, 1) sample for validation)



VBF HH - CMS

qqHH_CV_1_C2V_1_kl_1 qqHH_CV_1_C2V_1_kl_0
qqHH_CV_1_C2V_1_kl_2 qqHH_CV_1_C2V_0_kl_1
qqHH_CV_1_C2V_2_kl_1 qqHH_CV_0p5_C2V_1_Rl_1
qqHH_CV_1p5_C2V_1_kl_1



Run 2: Madgraph using the model privately by R. Contino
https://cms-project-generators.web.cern.ch/cms-project-generators/SM_HEL_UFO_noLightYukawa_HH_VBF.tar.gz

p p > h h j j $$ z w+ w- / a j QED=4

Run 3:

- Optimization of the base points ongoing
- Plan to explore the possibility to generate MC events at NLO in QCD: the SM point is straightforward. For non-SM couplings, need to change the code by hand suggested by Marco Zaro

Kλ	K2V	KV
1	1	1
1	2	1
2	1	1
0	1	1
1	1	1.5
1	0	1
1	1	0.5

Base samples

validation sample

VHH - CMS

ZHH and WHH generated separately in Run 2

VHH_CV_1_C2V_1_kl_1
VHH_CV_1_C2V_1_kl_2
VHH_CV_1_C2V_0_kl_1
VHH_CV_1_C2V_2_kl_1
VHH_CV_0p5_C2V_1_kl_1
VHH_CV_1p5_C2V_1_kl_1
VHH_CV_1_C2V_1_kl_0
VHH_CV_1_C2V_1_kl_20

ttHH - CMS

- HEFT ttHH model (LO UFO model) provided by Gerard Buchalla and Gudrun Heinrich

- Samples with different couplings are generated: (kl,kt,c2) = [(0.5, 1, 1), (1, 1, 0), (1, 2, 0), (3, 1, 0), (1, 1, -1), (1, 1, 6)]