Tools for EFTs@NLO

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HXSWG MC@(N)NLO for Run2

New Physics and EFTs

also Contino's talk

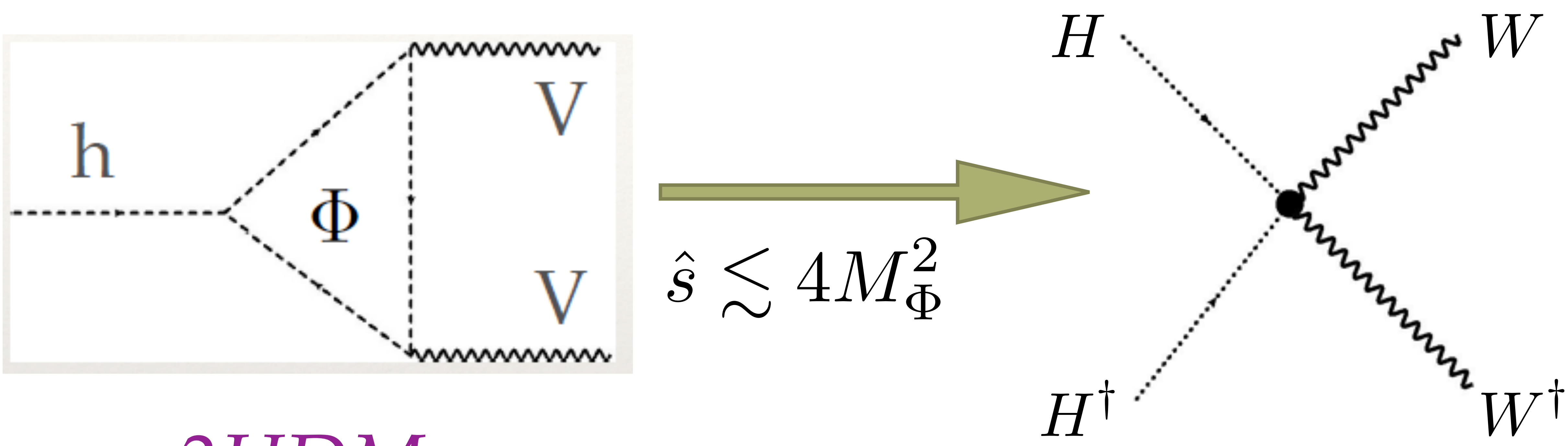
The guide to discover New Physics may come from precision, and not through direct searches

New Physics could be heavy

as compared with the channel we look at

Effective Theory approach

Example.



2HDMs

$$(H^\dagger \sigma^a D^\mu H)\, D^\nu W^a_{\mu\nu}$$

EFT

Bottom-up approach

operators w/ SM particles and symmetries, plus the newcomer, the Higgs

Buchmuller and Wyler. NPB (86)

$$\mathcal{L}_{BSM} = \mathcal{L}_{SM} + \mathcal{L}_{d=6} + \ldots$$

HDOs

modification of couplings of SM particles

Many such operators, but few affect the searches we do

EFT

Bottom-up approach

operators w/ SM particles and symmetries, plus the newcomer, the Higgs

Many such operators but few affect the searches we do

Example 1. LEP physics

Operator
$\mathcal{O}_W = \frac{ig}{2}\left(H^\dagger \sigma^a \overleftrightarrow{D}^\mu H\right) D^\nu W^a_{\mu\nu}$ + $\mathcal{O}_B = \frac{ig'}{2}\left(H^\dagger \overleftrightarrow{D}^\mu H\right) \partial^\nu B_{\mu\nu}$
$\mathcal{O}_T = \frac{1}{2}\left(H^\dagger \overleftrightarrow{D}_\mu H\right)^2$
$\mathcal{O}_{LL}^{(3)\,l} = (\bar{L}_L \sigma^a \gamma^\mu L_L)(\bar{L}_L \sigma^a \gamma_\mu L_L)$
$\mathcal{O}_R^e = (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{e}_R \gamma^\mu e_R)$
$\mathcal{O}_R^u = (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{u}_R \gamma^\mu u_R)$
$\mathcal{O}_R^d = (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{d}_R \gamma^\mu d_R)$
$\mathcal{O}_L^{(3)\,q} = (iH^\dagger \sigma^a \overleftrightarrow{D}_\mu H)(\bar{Q}_L \sigma^a \gamma^\mu Q_L)$
$\mathcal{O}_L^q = (iH^\dagger \overleftrightarrow{D}_\mu H)(\bar{Q}_L \gamma^\mu Q_L)$

EFT

Bottom-up approach

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Many such operators but few affect the searches we do

Operator
$\mathcal{O}_W = \frac{ig}{2}\left(H^\dagger \sigma^a \overleftrightarrow{D}^\mu H\right) D^\nu W^a_{\mu\nu}$ $\mathcal{O}_B = \frac{ig'}{2}\left(H^\dagger \overleftrightarrow{D}^\mu H\right) \partial^\nu B_{\mu\nu}$
$\mathcal{O}_{HW} = ig(D^\mu H)^\dagger \sigma^a (D^\nu H) W^a_{\mu\nu}$
$\mathcal{O}_{HB} = ig'(D^\mu H)^\dagger (D^\nu H) B_{\mu\nu}$
$\mathcal{O}_{3W} = \frac{1}{3!} g \epsilon_{abc} W^{a\,\nu}_{\mu} W^b_{\nu\rho} W^{c\,\rho\mu}$
$\mathcal{O}_g = g_s^2 \lvert H\rvert^2 G^A_{\mu\nu} G^{A\mu\nu}$
$\mathcal{O}_\gamma = g'^2 \lvert H\rvert^2 B_{\mu\nu} B^{\mu\nu}$
$\mathcal{O}_H = \frac{1}{2}(\partial^\mu \lvert H\rvert^2)^2$
$\mathcal{O}_f = y_f \lvert H\rvert^2 \bar{F}_L H^{(c)} f_R + \text{h.c.}$

Example 2. LHC physics

operators **not** constrained by LEP

Run1: Ellis, VS, You. 1410.7703

Higgs couplings vs EFT

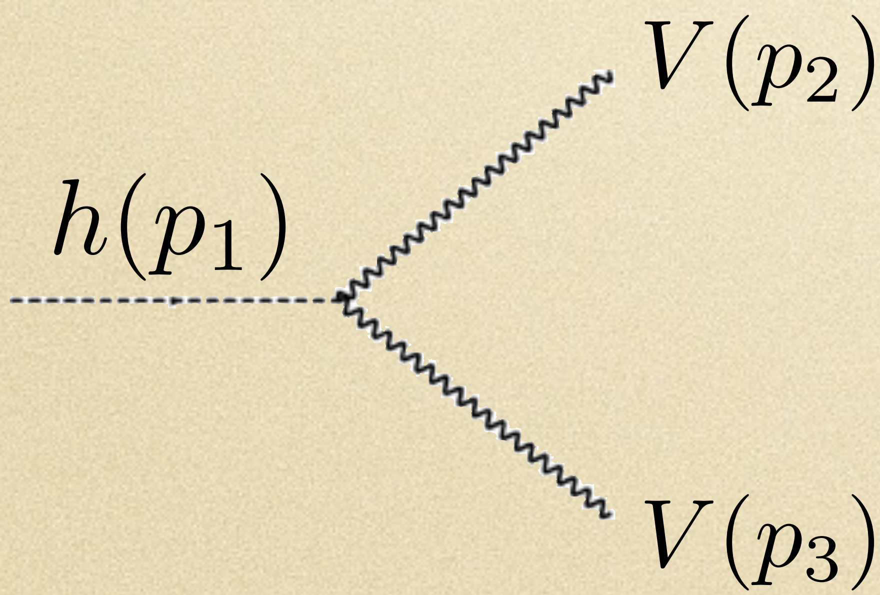
also Frixione's talk

EFTs generate HVV interactions with more derivatives parametrization in terms of anomalous couplings

Example. Higgs anomalous couplings

$$-\frac{1}{4} h\, \underline{g^{(1)}_{hVV}} V_{\mu\nu} V^{\mu\nu} \qquad -h\, \underline{g^{(2)}_{hVV}} V_{\nu} \partial_{\mu} V^{\mu\nu} \qquad -\frac{1}{4} h\, \underline{\tilde{g}_{hVV}} V_{\mu\nu} \tilde{V}^{\mu\nu}$$

Feynman rule for mh>2mV



$$i\eta_{\mu\nu} \left(\underline{g^{(1)}_{hVV}} \left(\frac{\hat{s}}{2} - m_V^2 \right) + 2 \underline{g^{(2)}_{hVV}} m_V^2 \right)$$

$$-i \underline{g^{(1)}_{hVV}} p_3^{\mu} p_2^{\nu}$$

$$-i \underline{\tilde{g}_{hVV}} \epsilon^{\mu\nu\alpha\beta} p_{2,\alpha} p_{3,\beta}$$

EFTs generate HVV interactions with more derivatives parametrization in terms of anomalous couplings

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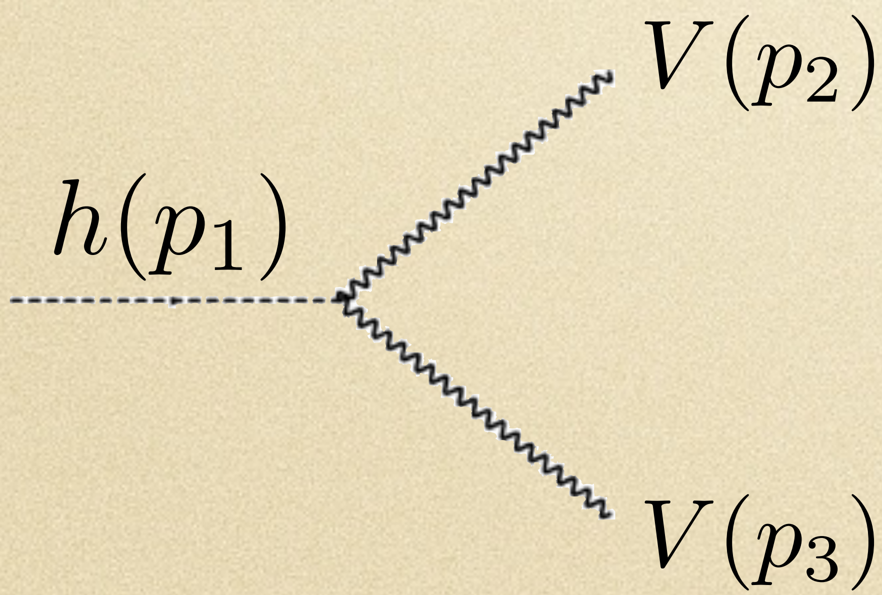


total rates, COM, angular, inv mass and pT distributions

Translation between EFT and Anomalous couplings

$\mathcal{L}_{3h}$ Couplings *vs* $SU(2)_L \times U(1)_Y$ $(D \leq 6)$ Wilson Coefficients

$$g^{(1)}_{hhh} = 1 + \tfrac{5}{2}\,\bar{c}_6 \quad , \quad g^{(2)}_{hhh} = \tfrac{g}{m_W}\,\bar{c}_H \quad , \quad g_{hgg} = g^{\rm SM}_{hgg} - \tfrac{4\,g_s^2\,v\,\bar{c}_g}{m_W^2} \quad , \quad g_{h\gamma\gamma} = g^{\rm SM}_{h\gamma\gamma} - \tfrac{8\,g\,s_W^2\,\bar{c}_\gamma}{m_W}$$

$$g^{(1)}_{hww} = \tfrac{2g}{m_W}\bar{c}_{HW} \quad , \quad g^{(1)}_{hzz} = g^{(1)}_{hww} + \tfrac{2g}{c_W^2\,m_W}\Big[\bar{c}_{HB}s_W^2 - 4\bar{c}_\gamma s_W^4\Big] \quad , \quad g^{(2)}_{hww} = \tfrac{g}{2\,m_W}\Big[\bar{c}_W + \bar{c}_{HW}\Big]$$

$$g^{(2)}_{hzz} = 2\,g^{(2)}_{hww} + \tfrac{g\,s_W^2}{c_W^2\,m_W}\Big[(\bar{c}_B + \bar{c}_{HB})\Big] \quad , \quad g^{(3)}_{hww} = g\,m_W \quad , \quad g^{(3)}_{hzz} = \tfrac{g^{(3)}_{hww}}{c_W^2}(1 - 2\,\bar{c}_T)$$

$$g^{(1)}_{haz} = \tfrac{g\,s_W}{c_W\,m_W}\Big[\bar{c}_{HW} - \bar{c}_{HB} + 8\,\bar{c}_\gamma\,s_W^2\Big] \quad , \quad g^{(2)}_{haz} = \tfrac{g\,s_W}{c_W\,m_W}\Big[\bar{c}_{HW} - \bar{c}_{HB} - \bar{c}_B + \bar{c}_W\Big]$$

$$-\frac{1}{4}h\,g^{(1)}_{hVV}V_{\mu\nu}V^{\mu\nu} \quad -h\,g^{(2)}_{hVV}V_\nu\partial_\mu V^{\mu\nu} \quad -\frac{1}{4}h\,\tilde{g}_{hVV}V_{\mu\nu}\tilde{V}^{\mu\nu}$$

for a dictionary between anomalous couplings and EFT operators see

Alloul, Fuks, VS. 1310.5150

Gorbahn, No, VS. In preparation

Translation between EFT and Anomalous couplings

Within the EFT there are relations among anomalous couplings, e.g. TGCs and Higgs physics

$\mathcal{L}_{3V}$ **Couplings** *vs* $SU(2)_L \times U(1)_Y$ $(D \leq 6)$ **Wilson Coefficients**

$$g_1^Z = 1 - \frac{1}{c_W^2}\left[\bar{c}_{HW} - (2s_W^2 - 3)\bar{c}_W\right] \quad , \quad \kappa_Z = 1 - \frac{1}{c_W^2}\left[c_W^2\bar{c}_{HW} - s_W^2\bar{c}_{HB} - (2s_W^2 - 3)\bar{c}_W\right]$$

$$g_1^\gamma = 1 \quad , \quad \kappa_\gamma = 1 - 2\,\bar{c}_W - \bar{c}_{HW} - \bar{c}_{HB} \quad , \quad \lambda_\gamma = \lambda_Z = 3\,g^2\,\bar{c}_{3W}$$

similarly for QGCs: also function of the same HDOs

Alloul, Fuks, VS. 1310.5150

Gorbahn, No, VS. In preparation

Translation between EFT and Anomalous couplings

CP conserving anomalous couplings

hZZ
hW^+W^-
$h\gamma\gamma$
$h\gamma Z$
$TGCs$

13 couplings

EFT

7 operators -
2 LEP constraints =
5 coefficients

Recommendation: analysis in terms of anomalous couplings
BUT add interpretation within EFTs

MC Tools for EFTs @NLO

Higgs BRs eHDECAY

Contino et al. 1303.3876

Spira's talk

Production rates and kinematic distributions

depend on cuts

need radiation and detector effects

Simulation tools

coefficients

$$\mathcal{L}_{eff} = \sum_i \frac{f_i}{\Lambda^2} \mathcal{O}_i$$

Collider simulation

observables

Limit coefficients
= new physics

In this talk I present progress in

1. Feynrules   EFT involving Higgs and TGCs

Alloul, Fuks, VS. 1310.5150

links to CalcHEP, LoopTools, Madgraph...

EFT->Madgraph-> Pythia... -> FastSim/FullSim

2. QCD NLO   EFT involving Higgs and TGCs

MCFM and POWHEG

VS and Williams. In prep.

MC@NLO

de Grande, Fuks, Mawatari, Mimasu, VS. In prep.

Pythia, Herwig... -> FastSim/FullSim

What is available right now

Alloul, Fuks, VS. 1310.5150

Feynrules model with

Higgs (SILH)
TGCs
Higgs + fermions
Higgs+gauge+fermions
CP conserving and violating terms

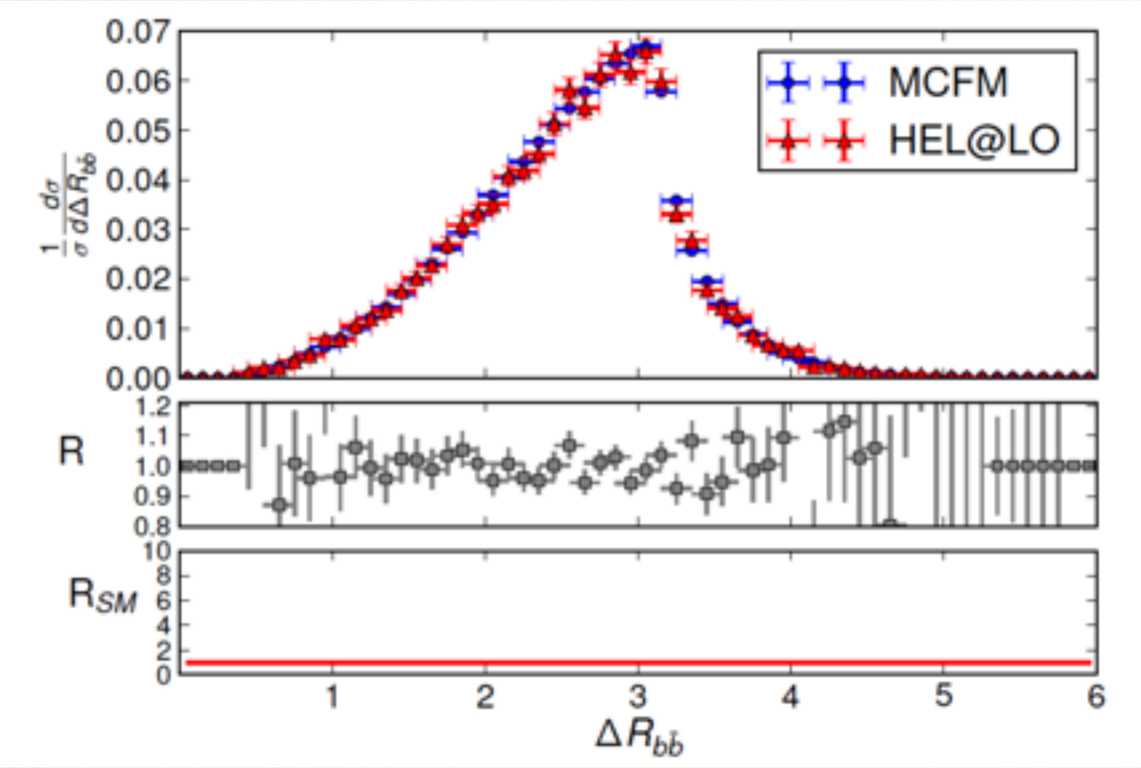
feynrules webpage

FR model (modifiable)
UFO model (for Madgraph)
CalcHEP model

Using this tool in MG in a nutshell

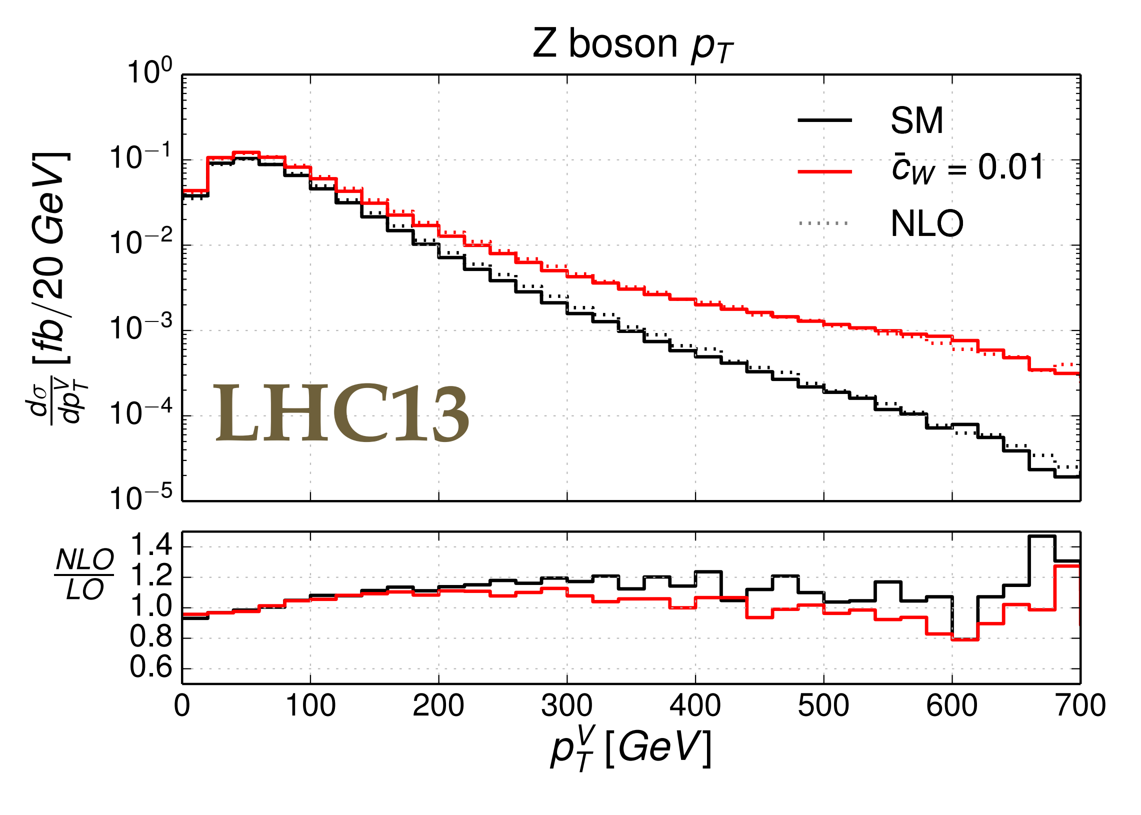
1. download UFO folder from webpage
2. place the UFO folder in models/
3. run Madgraph as usual
   import model HEL
   generate processes with NP=1
4. In the param_card, modify the values of the EFT coefficients
5. run as usual incl pythia/herwig… > fastsim/fullsim

In progress



A. Comparison MCFM vs MG5 at LO

very good agreement, as expected



B. Test of NLO MCFM and POWHEG

Plans for next 2/3 months

1. Comparison MCFM vs MC@NLO at NLO
2. Comparison Higgs couplings vs EFT within MC@NLO
3. Comparison POWHEG vs MC@NLO at LO/NLO test differences in showering
4. Add automatic switch from SILH to other basis in MC@NLO tool

Conclusions

Absence of hints in direct searches
EFT approach to searching for New Physics

* Effect of EFTs: rates but also kinematic distributions (most sensitive)

* Need MC tools to apply realistic cuts, account for hadronization/showering and detector effects
LO tool already available and used to exploit LHC8 data

* Analyses in terms of Higgs couplings should be re-interpreted within the EFT (more constrained)

* Use of Run2 requires MC at NLO
two tools (MCFM/POWHEG and MC@NLO)
allows comparison of showering and matching

* Expect release before summer
we can start working with you **now,** with beta versions

* SM precision crucial: excess as genuine new physics