powhegbox.mib.infn.it

SMEFT in the POWHEG-BOX

Simone Alioli

MILANO-BICOCCA UNIVERSITY & INFN

LHC EFT WG MEETING 14/12/2020

The POWHEG-BOX is both a code for the calculation of NLO QCD corrections and their matching to Parton Showers and library where authors can implement their own codes, which can then be made available via a SVN repo as process subfolders.

The first version V1 is no longer actively developed, V2 is the new version of choice (supports parallelization, more processes, etc).

75+ process subfolders: process authors are the primary responsible for their maintenance.

Newer POWHEG-BOX-RES version able to handle radiation from colored resonances. Only 7 processes implemented so far.

SMEFT processes have only be made available in V2 for now.

SMEFT in POWHEG-BOX

Different processes based on certain class of dimension 6 operators are available

- Dark-Matter + Monojet with POWHEG, U. Haisch, F, Kahlhoefer, E. Re, arXiv:1310.4491 [paper]. Code in version 2.

  User-Processes-V2/DMV
  User-Processes-V2/DMGG
  User-Processes-V2/DMS

- Scalar and pseudoscalar monojet production, exact top-quark mass effects included (at LO). U. Haisch, E. Re, arXiv:1503.00691 [paper]. Code in version 2.

  User-Processes-V2/DMS_tloop

- Higgs production in association with a vector boson at NLO QCD including SM EFT effects, K. Mimasu, V. Sanz and C. Williams, JHEP 1608 (2016) 039, arXiv:1512.02572 [paper]. Code in version 2.

  User-Processes-V2/WHanom
  User-Processes-V2/ZHanom

- NLO Effects in EFT Fits to W+W- Production at the LHC, J. Baglio, S. Dawson, I.M. Lewis, Phys. Rev. D 99, 035029 (2019), arXiv:1812.00214 [paper]
  Code in version 2.

  User-Processes-V2/WWanomal

- QCD Corrections in SMEFT Fits to WZ and WW Production, J. Baglio, S. Dawson, and S. Homiller, arXiv:1909.11576 [paper]
  Code in version 2.

  User-Processes-V2/WZanomal

In the following I will focus on these two implementations

- NLO QCD corrections to SM-EFT dilepton and electroweak Higgs boson production, matched to parton shower in POWHEG, S. Alioli, W. Dekens, M.Girard, E. Mereghetti, JHEP 1808 (2018) 205, arXiv:1804.07407 [paper] and
  Right-handed charged currents in the era of the Large Hadron Collider, S. Alioli, V. Cirigliano, W. Dekens, J. de Vries, E. Mereghetti, arXiv:1703.04751 [paper].
  Code in version 2.

  User-Processes-V2/Z_smeft
  User-Processes-V2/W_smeft
  User-Processes-V2/HZ_smeft
  User-Processes-V2/HW_smeft
  User-Processes-V2/VBF_H_smeft

- An interface between the POWHEG BOX and MadGraph5_aMC@NLO, P. Nason, C. Oleari, M. Rocco, M. Zaro, arXiv:2008.06364 [paper].

  Code for version 2.

- Scalar X0 production plus two jets: Higgs-like boson production + 2 jets with CP-violating couplings, P. Nason, C. Oleari, M. Rocco, M. Zaro, arXiv:2008.06364 [paper].

  INSTALLATION instructions can be found here.

  Script to clean the directory BEFORE the svn checkout (see the INSTALLATION instructions) can be found here.

  User-Processes-V2/X0jj

NC and CC dim6 Drell-Yan production @NLO+PS

$$\mathcal{L} = \mathcal{L}_{X^2\varphi^2} + \mathcal{L}_{\psi^2 X\varphi} + \mathcal{L}_{\psi^2\varphi^2 D} + \mathcal{L}_{\psi^2\varphi^3} + \mathcal{L}_{\psi^4}.$$

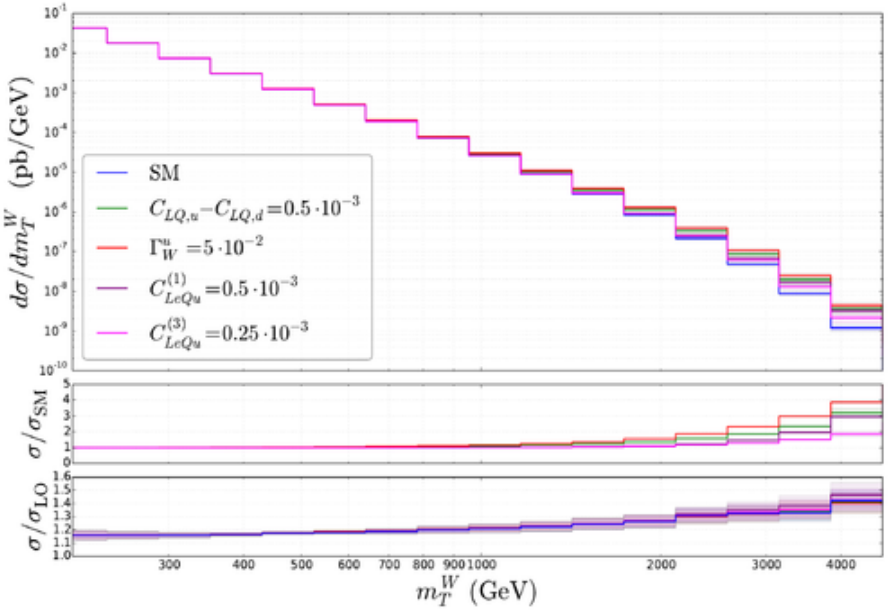
SA et al. 1804.07047

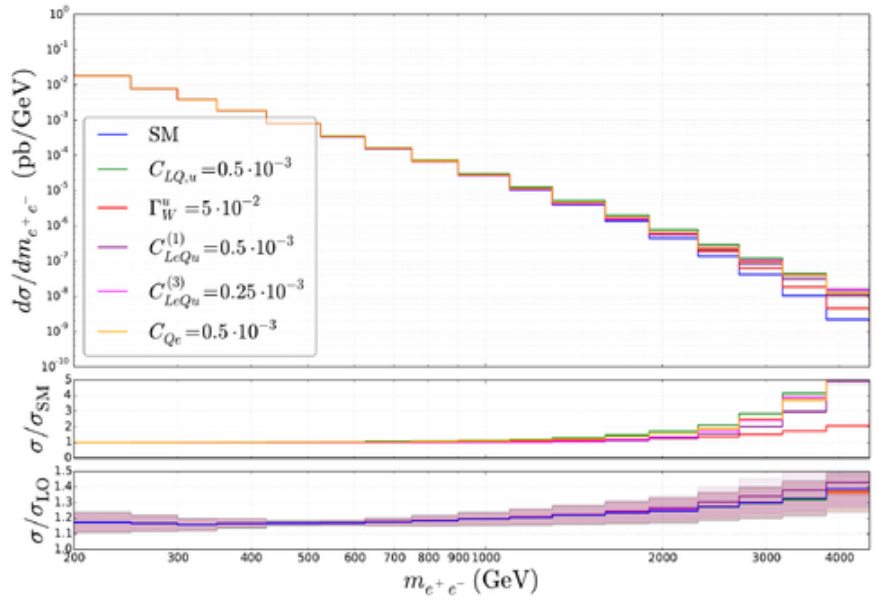
Including all dim6 terms with nonvaninishing tree-level interfence $\mathcal{O}(1/\Lambda^2)$

Also dim6 non-interfering $\mathcal{O}(1/\Lambda^4)$

Relations between SM couplings updated accordingly

	Operator			Operator	
$C_{\varphi W,\varphi B,\varphi WB}$,	CC_ww, CC_bb, CC_wb		$C_{\varphi\tilde{W},\varphi\tilde{B},\varphi\tilde{W}B}$	CC_wwt, CC_bbt, CC_wbt	
Γ^u_W	ReGUw_ik ImGUw_ik		Γ^d_W	ReGDw_jl ImGDw_jl	
Γ^u_γ	ReGUe_ik ImGUe_ik		Γ^d_γ	ReGDe_jl ImGDe_jl	
Γ^e_W	ReGEw, ImGEw		Γ^e_γ	ReGEe, ImGEe	
$c_{Q\varphi,U}$ $c_{U\varphi}$ ξ	QphiU_ik Uphi_ik ReXi_ ij ImXi_ij	$i \geq k$ $i \geq k$	$c_{Q\varphi,D}$ $c_{D\varphi}$	QphiD_jl Dphi_jl	$j \geq l$ $j \geq l$
Y'_u	ReYu_ik ImYu_ik		Y'_d	ReYd_jl ImYd_jl	
$C_{LQ,U}$ C_{eu} C_{Lu} $C^{(3)}_{LeQu}$ $C^{(1)}_{LeQu}$	QLu_ik Ceu_ik CLu_ik ReLeQu3_ik ImLeQu3_ik ReLeQu_ik ImLeQu_ik	$i \geq k$ $i \geq k$ $i \geq k$	$C_{LQ,D}$ C_{ed} C_{Ld} C_{Qe} C_{LedQ}	QLd_jl Ced_jl CLd_jl Qe_jl ReLedQ_jl ImLedQ_jl	$j \geq l$ $j \geq l$ $j \geq l$ $j \geq l$

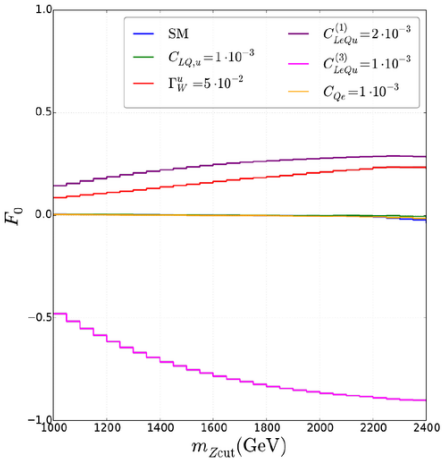


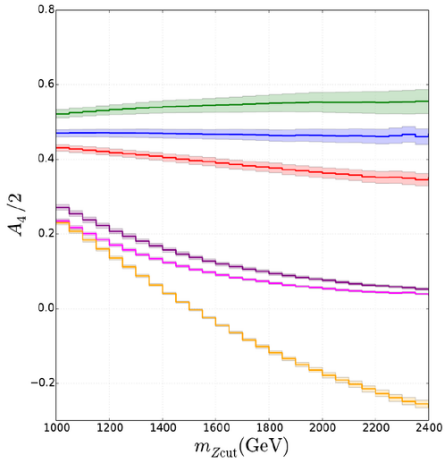


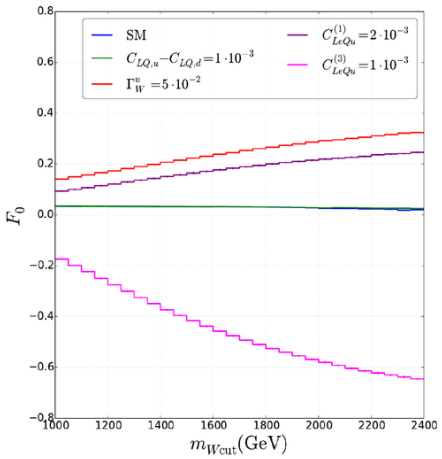
NLO QCD + PS corrections to Dim 6 effects in DY production.

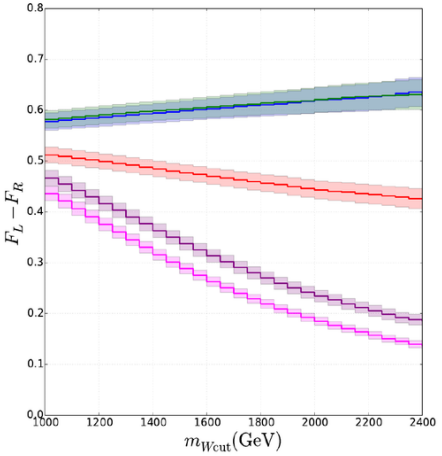
- Effects due to different operators can be disentangled looking at angular or polarization coefficients

$$F_0 = \frac{A_0}{2}\,, \qquad F_L = \frac{1}{4}(2 - A_0 \mp A_4)\,, \qquad F_R = \frac{1}{4}(2 - A_0 \pm A_4)$$









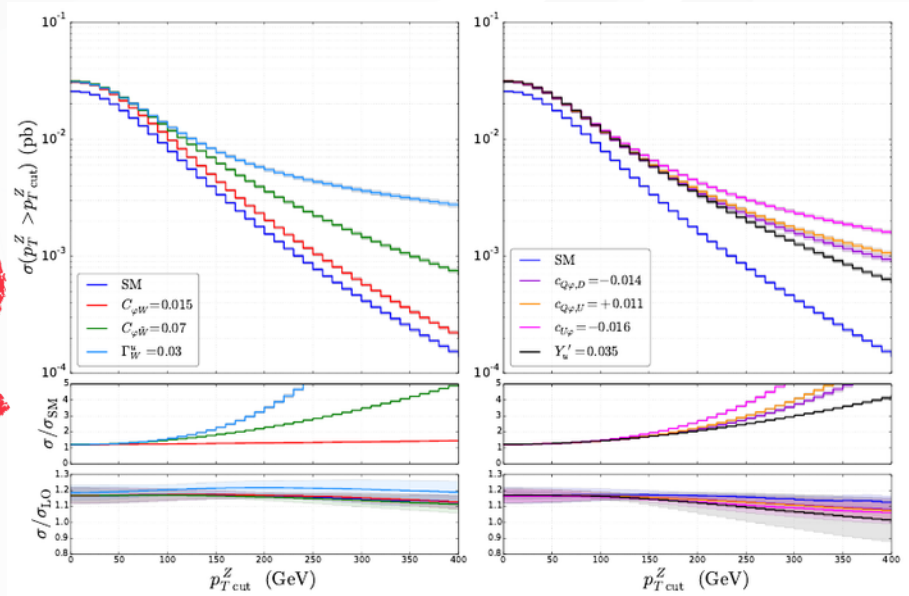
- No new angular dependence in A_i's induced by QCD corrections since the spin-1 current attached to the leptons is not affected.

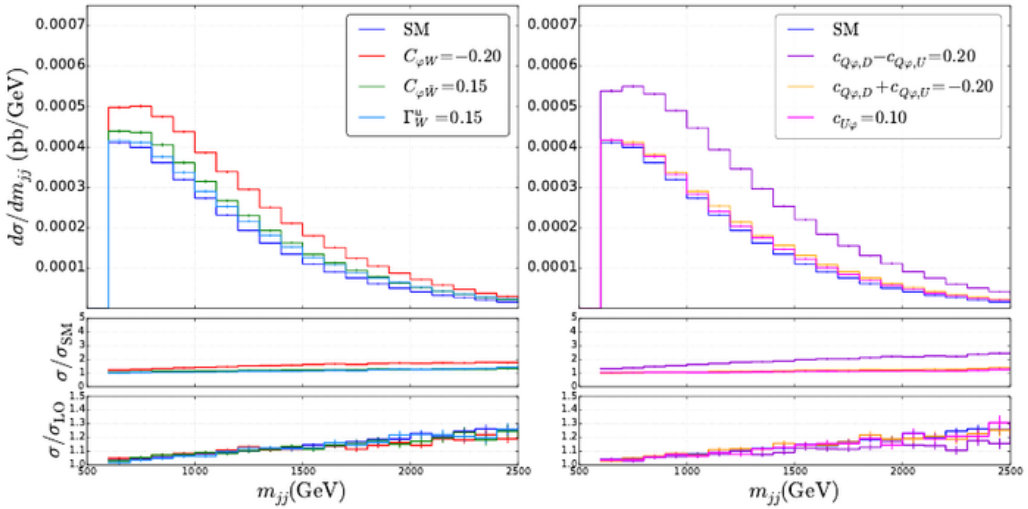
$$< f(\theta^*, \phi^*) >= \int_{-1}^{1} d(\cos\theta^*) \int_0^{2\pi} d\phi^* \frac{1}{\sigma} \frac{d\sigma}{d(\cos\theta^*) d\phi^*} f(\theta^*, \phi^*)$$

$$A_0 = 4 - < 10\cos^2\theta^* >, \quad A_1 = < 5\sin 2\theta^* \cos\phi^* >, \quad A_2 = < 10\sin^2\theta^* \cos 2\phi^* >,$$
$$A_3 = < 4\sin\theta^* \cos\phi^* >, \quad A_4 = < 4\cos\theta^* >, \quad A_5 = < 5\sin^2\theta^* \sin 2\phi^* >,$$
$$A_6 = < 5\sin 2\theta^* \sin\phi^* >, \quad A_7 = < 4\sin\theta^* \sin\phi^* > .$$

NLO QCD + PS corrections to Dim 6 effects in EWK Higgs boson production.

Higgstrahlung





VBF

UNIVERSITÀ DEGLI STUDI DI MILANO BICOCCA

Progress towards inclusion of dim8 effects

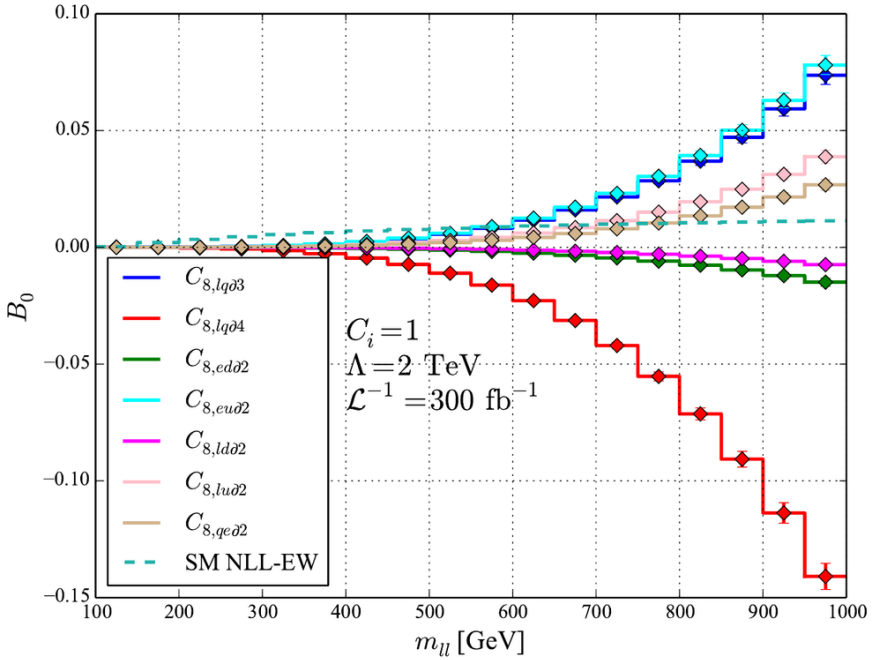
- Since we include dim-6 squared $\mathcal{O}(1/\Lambda^4)$ contributions in our analysis, we should also include dim-8 interference with the SM. This could:
  - Weaken the competitive bounds we get on scalar and tensor currents
  - Pollute the clear separation we observe in angular distributions
  - Provide an estimate for the uncertainty in the EFT expansion parameter Λ.
- In order to address these issues we started looking into dim-8 effects to CC and NC Drell-Yan.

Basis for dim8 are now available, stay tuned for inclusion of dim8 effects in POWHEG

Novel dim8 effects on angular distributions

SA et al.
2003.11615

$$\mathcal{O}_{8,lq\partial 3} = (\bar{l}\gamma_\mu \overleftrightarrow{D}_\nu l)(\bar{q}\gamma^\mu \overleftrightarrow{D}^\nu q),$$
$$\mathcal{O}_{8,lq\partial 4} = (\bar{l}\tau^I\gamma_\mu \overleftrightarrow{D}_\nu l)(\bar{q}\tau^I\gamma^\mu \overleftrightarrow{D}^\nu q)$$



$$\Delta|\mathcal{M}_{u\bar{u}}|^2 = -\frac{C_{8,lq\partial 3}}{\Lambda^4}\hat{c}_\theta(1+\hat{c}_\theta)^2\frac{\hat{s}^2}{6}\left[e^2Q_uQ_e + \frac{g^2 g_L^u g_L^e \hat{s}}{c_W^2(\hat{s}-M_Z^2)}\right]$$

$$\frac{d\sigma}{dm_{ll}^2 dy d\Omega_l} = \frac{3}{16\pi}\frac{d\sigma}{dm_{ll}^2 dy}\Big\{(1+c_\theta^2) + \frac{A_0}{2}(1-3c_\theta^2)$$
$$+A_1 s_{2\theta}c_\phi + \frac{A_2}{2}s_\theta^2 c_{2\phi} + A_3 s_\theta c_\phi + A_4 c_\theta$$
$$+A_5 s_\theta^2 s_{2\phi} + A_6 s_{2\theta}s_\phi + A_7 s_\theta s_\phi$$
$$+B_3^e s_\theta^3 c_\phi + B_3^o s_\theta^3 s_\phi + B_2^e s_\theta^2 c_\theta c_{2\phi}$$
$$+B_2^o s_\theta^2 c_\theta s_{2\phi} + \frac{B_1^e}{2}s_\theta(5c_\theta^2-1)c_\phi$$
$$+\frac{B_1^o}{2}s_\theta(5c_\theta^2-1)s_\phi + \frac{B_0}{2}(5c_\theta^3-3c_\theta)\Big\}$$

- B_i^e are even and B_i^o are odd under T-reversal.
- B_0 is already populated at LO.
- B_i's with $i > 0$ start to be populated at $\mathcal{O}(\alpha\alpha_S)$ or $\mathcal{O}(\alpha^2)$. Depending on ϕ they need both a spin-2 current and a non-zero transverse momentum.
- In the SM EW corrections affect B_0 starting at NLL.

MG5aMC-PWG: an interface between MG5_aMC@NLO and POWHEG-BOX

Nason et al. 2008.06364

Plugin of MG5_aMC, providing matrix elements, including NLO QCD corrections

```
https://code.launchpad.net/~mg5amc-pwg-team/mg5amc-pwg/v0
```

This allows separate developments, but full access to MG5 amplitudes, including UFO, counter terms, MADLOOP …

Only need to copy the MG5_aMC_PWG folder inside PLUGIN

Load it with

```
#./bin/mg5_aMC —mode=MG5aMC_PWG
#generate p p > X Y Z [QCD]
#output folder_name
```

This checks POWHEG-BOX-V2 is present and produces the necessary files, which can be further modified by the user

MG5aMC-PWG

Files that need attentions are:

`Born.f, real.f, virtual.f` ready to go

`Born_phsp.f` including `born_suppression` routine

`init_couplings.f` read couplings from `Cards/param_card.dat` in MG5

`init_processes.f` all physical parameters should be set by MG5 ones

The interface also produce the

`#./prepare_run_dir folder_name`

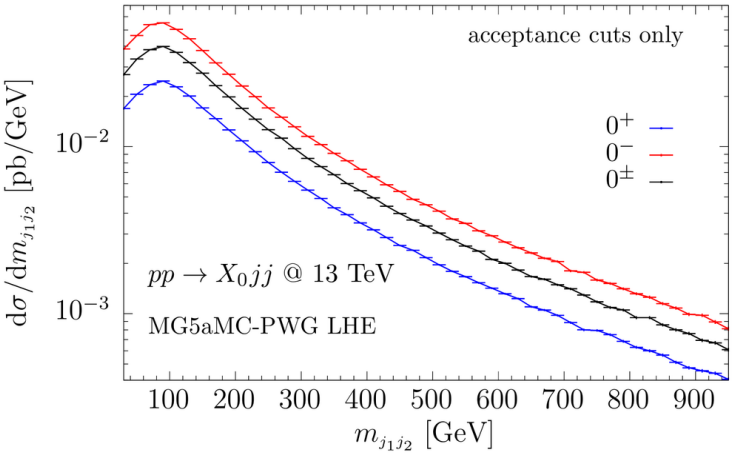
script that creates a run directory with the appropriate POWHEG input card.

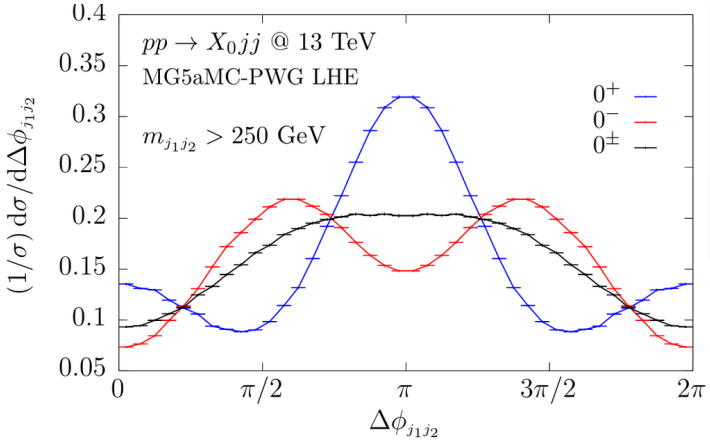
At this point one can use all V2 improvements, like parallelization of runs, MiNLO to regulate Born divergencies, damping to separate the real contributions, etc.

Case study: $X_0 jj$ with CP-violating couplings

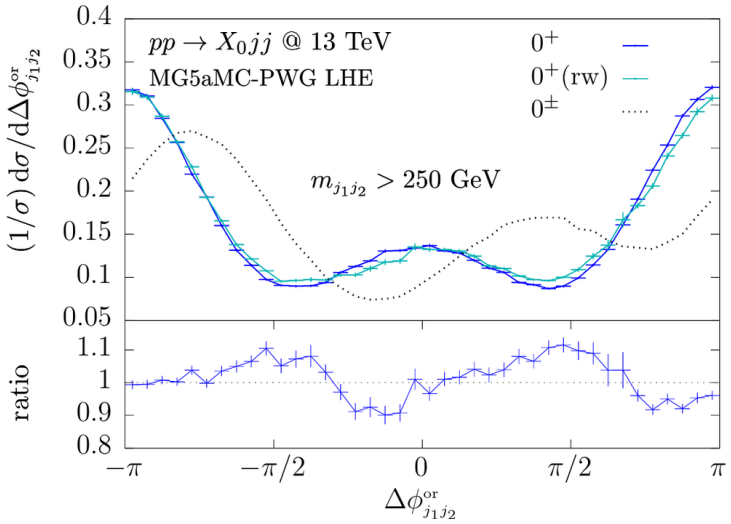
Based on *Higgs Characterization* framework using UFO model `HC_NLO_X0`. Phase space, suppression factors, etc taken from Hjj in POWHEG.

$$\mathcal{L}_{0,g}^{\text{loop}} = -\frac{1}{4}\left(k_{Hgg}\, g_{Hgg}\, \cos\alpha\, G^a_{\mu\nu} G^{a,\mu\nu} + k_{Agg}\, g_{Agg}\, \sin\alpha\, \epsilon^{\mu\nu\rho\sigma} G^a_{\mu\nu} G^a_{\rho\sigma}\right) X_0$$





Reweighting possible but needs attention



$$\Delta\phi^{\text{or}}_{j_1 j_2} \equiv \frac{(\hat{\mathbf{p}}_{\mathrm{T}}^{j_1} \times \hat{\mathbf{p}}_{\mathrm{T}}^{j_2}) \cdot \hat{z}}{|(\hat{\mathbf{p}}_{\mathrm{T}}^{j_1} \times \hat{\mathbf{p}}_{\mathrm{T}}^{j_2}) \cdot \hat{z}|} \frac{(\mathbf{p}^{j_1} - \mathbf{p}^{j_2}) \cdot \hat{z}}{|(\mathbf{p}^{j_1} - \mathbf{p}^{j_2}) \cdot \hat{z}|} \arccos\left(\hat{\mathbf{p}}_{\mathrm{T}}^{j_1} \cdot \hat{\mathbf{p}}_{\mathrm{T}}^{j_2}\right)$$

UNIVERSITÀ DEGLI STUDI DI MILANO BICOCCA

Conclusions

Several implementations for SMEFT dim6 processes are available in the POWHEG-BOX-V2

Recently an interface to MG5_aMC@NLO has been presented, allowing to in principle implement any process for which a corresponding UFO models exists.

Extensions towards dim8 are being actively investigated

Thanks for your attention.