Machine Learning methods to measure the quantum numbers of the Higgs interaction to W bosons

Supervisors: Inês Ochoa, Patrícia Muíño, Ricardo Barrué

João Moura Teixeira[1]

[1]Instituto Superior Técnico
Engineering Physics

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LABORATÓRIO DE INSTRUMENTAÇÃO
E FÍSICA EXPERIMENTAL DE PARTÍCULAS
partículas e tecnologia

- No evidence for new particles at the LHC yet
- Energy scale above LHC reach?
- Might still have visible effects in observables measurable at the LHC

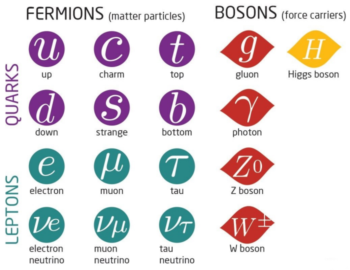


Figure: Particles of the Standard Model

Effective Field Theory (EFT)

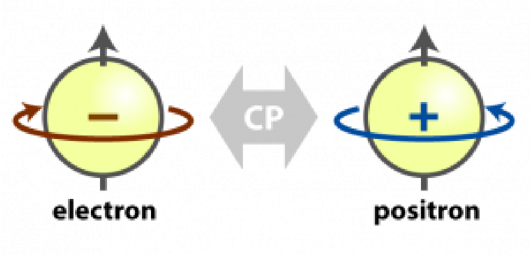
- Effective Field Theory (EFT) represents a possible approach for studying small deviations to the SM theory
- Basic principle: expand SM lagrangian with operators $O_i^{(d)}$ of dimension $d > 4$

$$\mathcal{L} = \mathcal{L}_{SM} + \sum_{d>4} \sum_{i} \frac{c_i O_i^{(d)}}{\Lambda^{d-4}} \tag{1}$$

- In which:
  - Λ = new high energy scale
  - c_i = Wilson coefficients which represent the relative strength of each mass operator, $O_i^{(d)}$
- Main advantage of using EFT: model-independent approach

Charge-Parity (CP) transformations

- Process classification on when it comes to charge-parity:
  - **CP-even process**: keeps the signal
  - **CP-odd process**: changes the signal
- It is said that a CP-symmetry violation occured in an interaction when it isn't invariant



- The Higgs interactions predicted on the SM are classified as CP-even

HWW interaction

- HWW interaction is characterized as CP-even in the SM
- So, we will recur to BSM sources to measure CP-odd terms

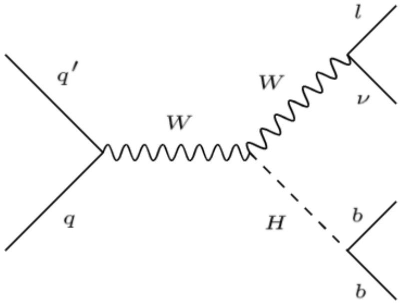


Figure: An example of HWW interaction (in this case, the topology we will study)

HWW interaction

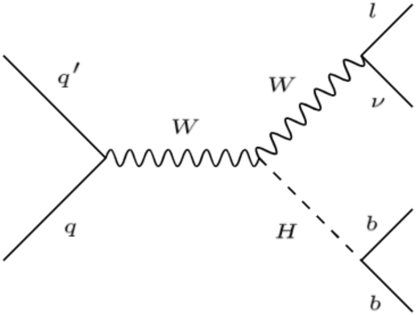
- The only dimension-6 CP-odd operator in the HWW vertex is $\tilde{\mathcal{O}}_{HW}$

$$\tilde{\mathcal{O}}_{HW} = \frac{c_{\tilde{H}W}}{\Lambda^2} H^\dagger H \tilde{W}^I_{\mu\nu} W^{I\mu\nu} = \frac{c_{\tilde{H}W}}{\Lambda^2} H^\dagger H \epsilon_{\mu\nu\rho\sigma} W^{I\rho\sigma} W^{I\mu\nu} \tag{2}$$

- Main goal of this work:
  - Study different sets of kinematic observables
  - Use the Fisher information formalism to determine the combination of observables with largest sensitivity to $c_{\tilde{H}W}$

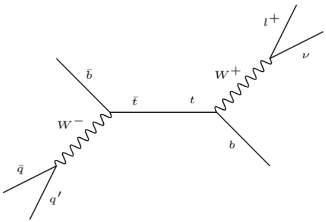
WH associated production

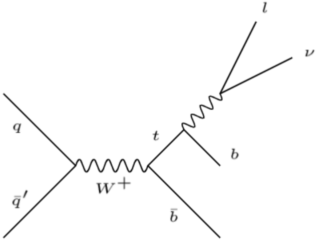
- Topology to study: associated WH production in the $W \longrightarrow l\nu$, $H \longrightarrow b\bar{b}$ final state
  - the easiness to identify the isolated high-energy lepton which will make the triggering more efficient
  - the decay of the Higgs boson to a pair of b-quarks is the one with the highest branching ratio (BR $\approx$ 58%)

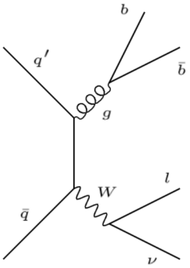


Considered backgrounds

- Main reducible backgrounds:
  - $t\bar{t}$ production in the semileptonic decay channel (left)
  - single top production in the s-channel (center)
  - associated production of a W boson and b-jets (right)







Results - I

- The variables related to the energy of the WH system are shifted to higher values
  - Expected due to BSM contributions
- The bosons' transverse momenta, p_T, have shifted distributions
- Observation: *morphing_basis_vector_1* refers to a SM sample + CP-odd coupling

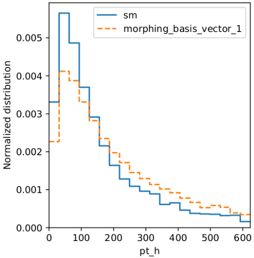


Figure: Transverse momentum of the Higgs boson, pT_H [GeV]

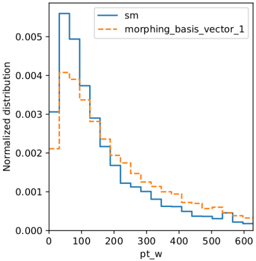


Figure: Transverse momentum of the W boson, pT_W [GeV]

Results - II

- The transverse momentum distributions of quarks and leptons will also be shifted to higher values as:
  - the Higgs decays into a pair of b-quarks
  - the W boson decays into a lepton and a neutrino

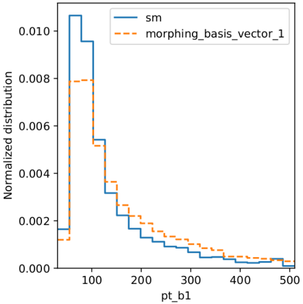


Figure: Transverse momentum of a b-quark, pT_b1 [GeV]

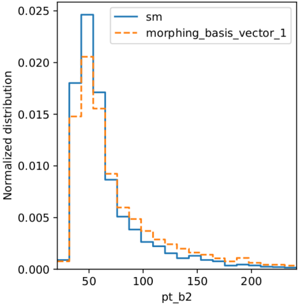


Figure: Transverse momentum of a b-quark, pT_b2 [GeV]

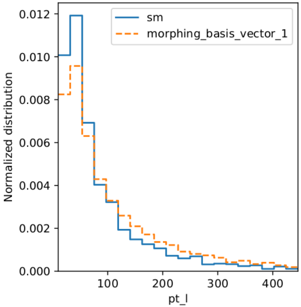


Figure: Transverse momentum of the lepton, pT_l [GeV]

Results - III

- Angular observables such as $\cos\theta^*$, $\cos\delta^+$ and $\cos\delta^-$ are relevant as they can help to distinguish CP-odd and CP-even BSM signals

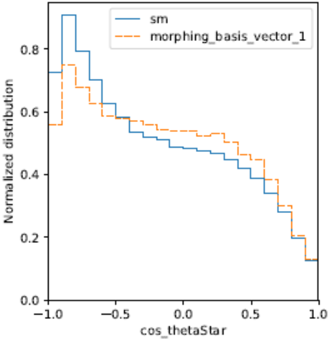


Figure: $\cos\theta^*$ distribution

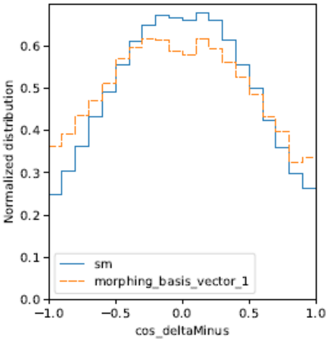


Figure: $\cos\delta^-$ distribution

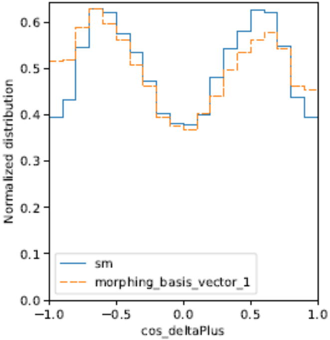
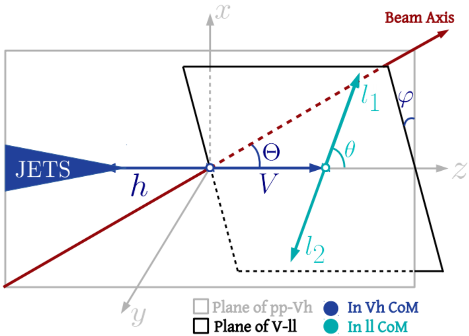


Figure: $\cos\delta^+$ distribution

Another set of angular observables

- Definition of functions for new angular observables: Θ, ϕ and θ
  - $\Theta \equiv$ angle between the W boson and the beam axis
  - $\phi \equiv$ angle between the plane of production of the VH-system and the lepton-neutrino system plane of production
  - $\theta \equiv$ angle between the W boson and one of the leptons



Results - IV

- Results weren't quite encouraging
- Statistical fluctuations $\sim$ height of each histogram bin $\implies$ observables not sensitive enough

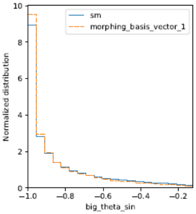


Figure: Distribution for sin Θ

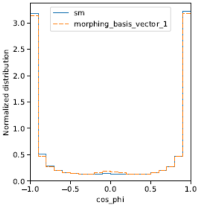


Figure: Distribution for cos ϕ

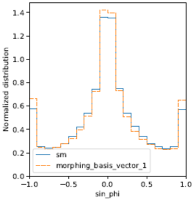


Figure: Distribution for sin ϕ

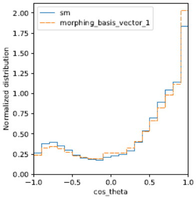


Figure: Distribution for cos θ

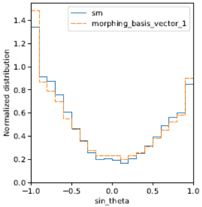
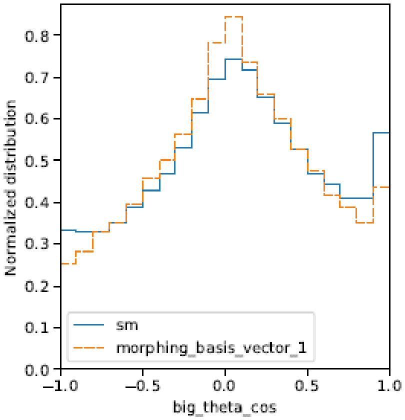


Figure: Distribution for sin θ

- However, the distribution for cos Θ led to some notorious differences between the SM and the *morphing_basis_vector_1* samples

Results - V

- Distribution for $\cos\Theta$ with a higher peak around 0



Conclusions

From the results and histograms previously shown and discussed, one can conclude that the most sensitive variables are the transverse momentum of the W candidate, p_{T_W}, and the following angular observables: $\cos\theta^*$, $\cos\delta^+$, $\cos\delta^-$ and $\cos\Theta$.

These observables are candidates for optimal variables to constrain CP-odd operators which cause the observed shift on the transverse momentum distributions.

Setup and sample generation - additional informations

- The setup and sample generation tasks of this work are made using *Madminer*.
- The samples used were generated at LO in QCD with *Madgraph5_mC@NLO*
- The SM and BSM signal samples are generated using *SMEFTsim3* and the background samples with the default SM model.
- In order to reproduce the most relevant effects from detectors, one opted to smear the parton-level b-quark energies and E_T^{miss}
- The b-jet energies are smeared by a gaussian transfer function with width $\sigma_E/E = 0.1$