Search for CP violation in HWW anomalous couplings with the ATLAS detector

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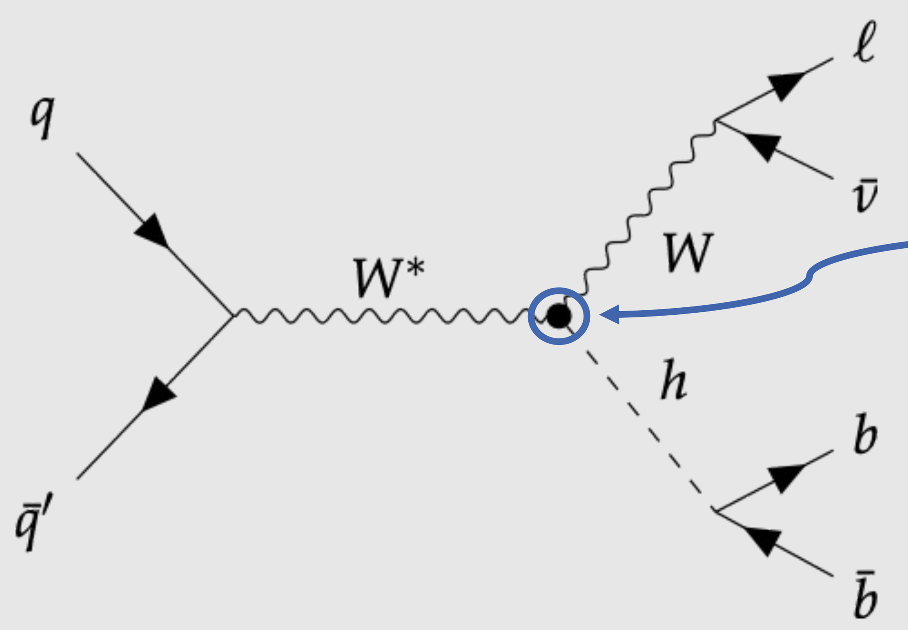
Motivation

One of the major mysteries unaddressed by the Standard Model (SM) is the observed asymmetry between matter and anti-matter.

Charge-Parity (CP) symmetry violation Beyond SM (BSM) needed!

BSM theories predict anomalous couplings in the Higgs boson interactions: natural place for new physics (NP) searches

WH production channel:



HWW interaction vertex

Effective Field Theory (EFT)

The SM can be considered as an EFT by adding to its Lagrangian operators of mass dimension > 4.

$$\mathcal{L}_{EFT} = \mathcal{L}_{SM} + \frac{1}{\Lambda}\sum_i c_i^{(5)} O_i^{(5)} + \frac{1}{\Lambda^2}\sum_j c_j^{(6)} O_j^{(6)} + \cdots$$

c_i - Wilson Coefficients

O_i - Operators with SM symmetries

Λ – NP cutoff energy scale

Only one CP-odd (changes signs under CP transformation) operator affects this interaction: $c_{H\tilde{W}}$.

Likelihood Function

Goal: Estimate the likelihood function and set limits on the Wilson coefficients. But...

$$p(x|\theta) = \int dz_d \int dz_s \int dz_p \; p(x|z_d)p(z_d|z_s)p(z_s|z_p)p(z_p|\theta)$$

Many millions of random numbers

Intractable likelihood

x - detector-level reconstructed observables

z_d - detector simulation latent variables

z_s - parton shower latent variables

z_p - parton-level latent variables (kinematics)

θ - parameter of interest (Wilson coefficients)

Two different approaches to study the likelihood: use an angular observable or machine learning

Angular Observable

Estimate the likelihood function by filling histograms of an angular variable sensitive to the CP-odd operator:

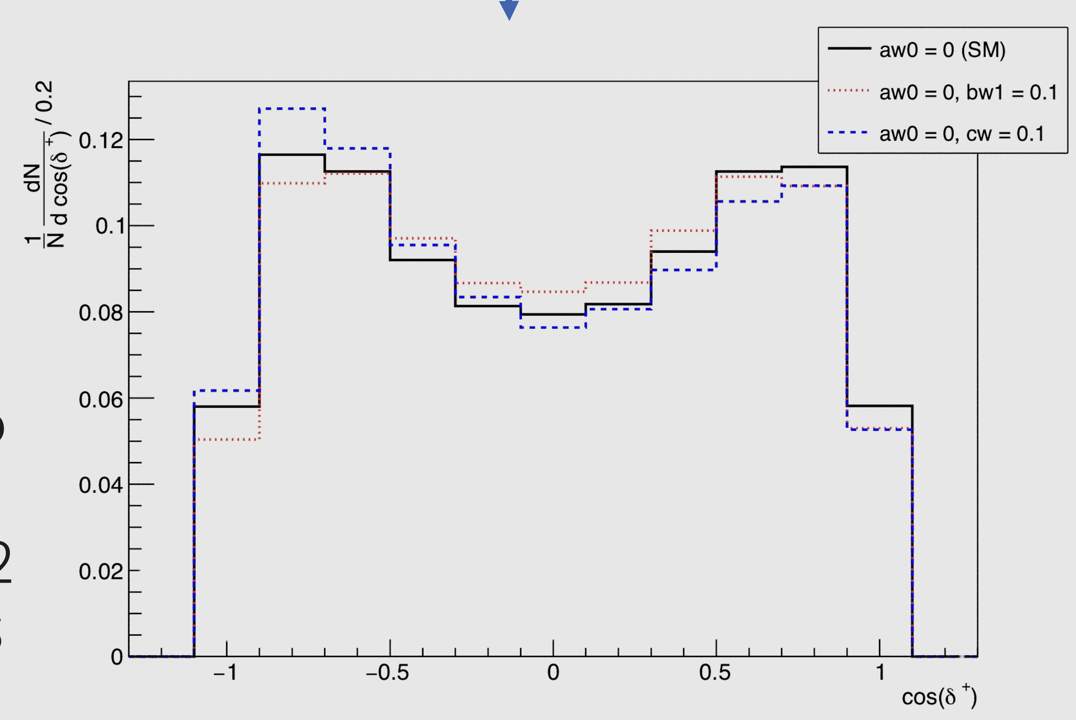
$$\cos\delta^+ = \frac{p_\ell \cdot (p_H \times p_W)}{|p_\ell||(p_H \times p_W)|}$$

p_ℓ - momentum of the lepton (ℓ)

p_H - momentum of the Higgs boson (H)

p_W - momentum of the W boson (W)

Different distribution with CP-odd contribution (cw)

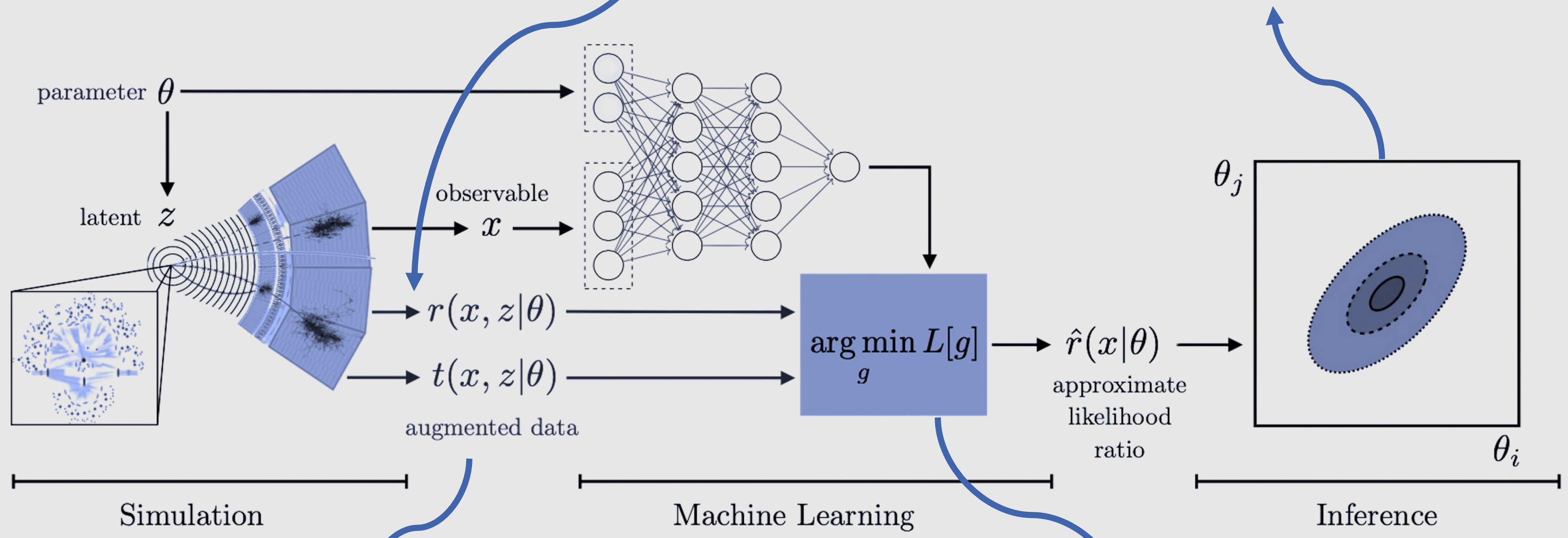


$\cos\delta^+$ will be used to study CP-violating behaviour with Run 2 data from the ATLAS experiment

Machine Learning

Train neural networks that converge to the likelihood/ likelihood ratio, using information from simulations.

Set limits on $c_{H\tilde{W}}$



Joint likelihood ratio:

$$r(x,z|\theta_0,\theta_1) = \frac{p(z_p|\theta_0)}{p(z_p|\theta_1)}$$

Joint score:

$$t(x,z|\theta) = \frac{\nabla_\theta p(z_p|\theta)}{p(z_p|\theta)}$$

Minimize a suitable loss function:

$$L[\hat{r}] = |r(x,z|\theta_0,\theta_1) - \hat{r}(x,\theta_0,\theta_1)|^2$$

This will be used to optimize Run 3 analysis of the LHC.

References

[1] Rohini Godbole et al., arXiv:1409.5449
[2] Ricardo Barrué, CERN-THESIS-2020-023
[3] Johann Brehmer et al., Phys. Rev. D 98, 052004 (2018)
[4] Johann Brehmer et al., arXiv:1907.10621

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