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Use of Anomaly Detection algorithms to unveil new physics in Vector Boson Scattering

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Motivation

So far, the search for physics beyond the Standard Model (SM) has not given any positive outcome. Therefore, the focus is now turning towards the development of model independent strategies [1].

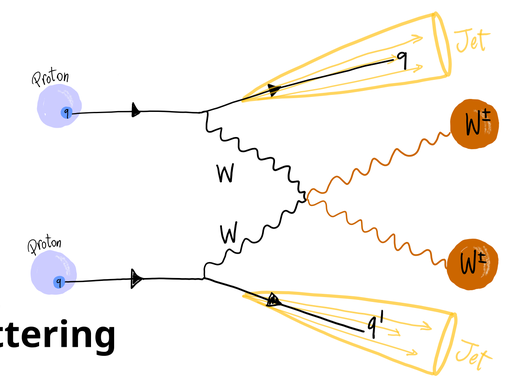
We present a **weakly supervised learning strategy to detect anomalies** in a way that is as **agnostic with respect to the assumption on new physics** as possible.

The physics usecase

Vector Boson Scattering (VBS) is ideal for new physics searches:

- Sensitive to modifications of the electroweak sector
- Deeply connected to Higgs mechanism

We use montecarlo generations (@leading order, parton level) of **same sign WW scattering with fully leptonic final state**.



The new physics model: SM Effective Field Theory (SMEFT)

SMEFT [2] serves as a general but still predictive theory that can regroup a large number of new physics processes:

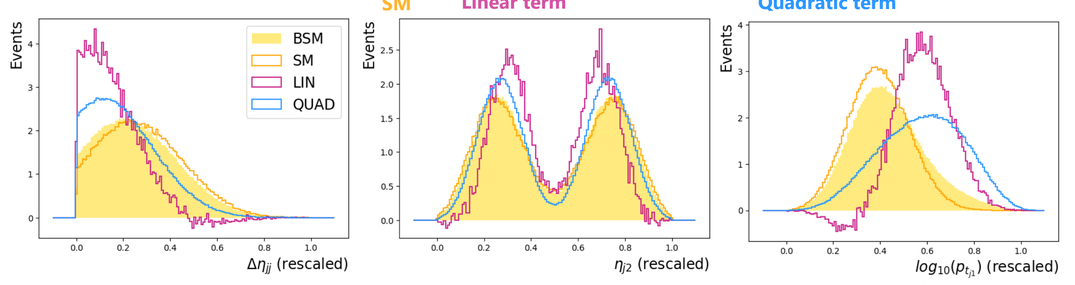
The SM is seen as a **low energy approximation of an unknown theory**, whose low energy effects are parametrized as additional terms to the SM Lagrangian:

$$\mathcal{L}_{EFT} = \mathcal{L}_{SM} + \sum_{i,d>4} \frac{c_i}{\Lambda^{d-4}} \mathcal{O}^{(d_i)}$$

- Λ – new physics scale
- $\mathcal{O}^{(d_i)}$ – EFT operator of dimension d_i
- c_i – Wilson coefficient

We focus on the effects of a chosen set of dimension 6 operators

$$|A_{EFT}|^2 = \underbrace{|A_{SM}|^2}_{\text{SM}} + \underbrace{2Re(A_{SM}A_{op}^*)}_{\text{Linear term}} + \underbrace{|A_{op}|^2}_{\text{Quadratic term}}$$

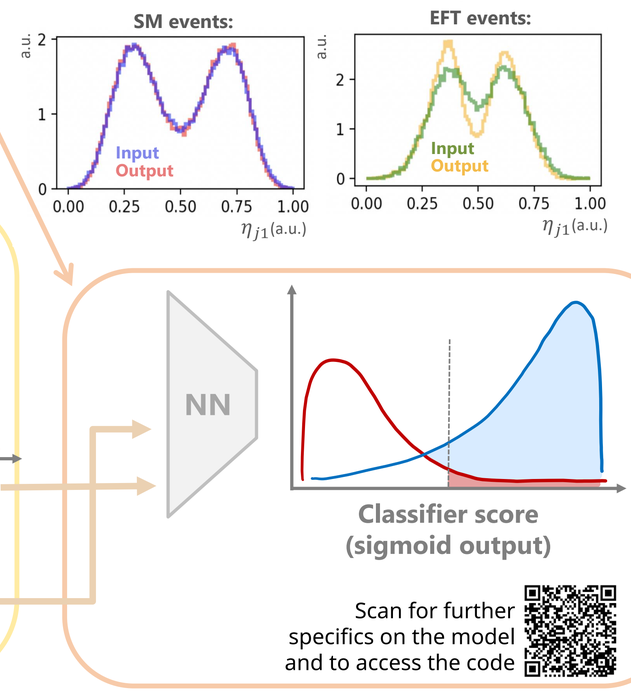


Non filled histograms: SM, LIN, QUAD distributions (normalized to 1)
Filled histogram: BSM = SM+LIN+QUAD distribution (weighted correctly with wilson coefficients)

Anomaly detection

Our model is based on a **Variational AutoEncoder (VAE)** [3] architecture followed by an **adversarial term**

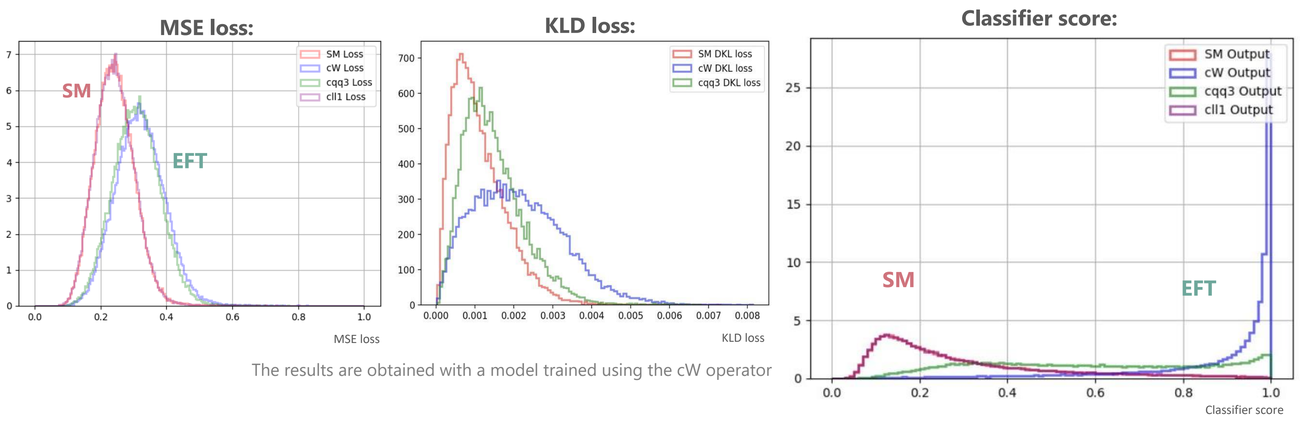
- The **VAE part is trained to reconstruct SM events** ⇨ **EFT events are then badly reconstructed** → anomalies are expected to lie in the tail of the loss function.
- The **classifier is trained on SM and EFT events** (only one operator for training) and takes as inputs the two terms of the loss functions of the VAE



Scan for further specifics on the model and to access the code

Results

- **The model is able to discriminate between SM and EFT events:**



The results are obtained with a model trained using the cW operator

- SM events are reconstructed better than EFT events
- Discrimination between SM and EFT events is best for the operator the model was trained on (cW)
- Other operators are also recognized
- Some operators are not singled out (shapes similar to SM)

Mass of the dijet system after applying tight kinematic cuts

- The model collects information from various inputs → **it provides a variable (output score) whose shape maximizes the separation between EFT and SM**, compared to a simple kinematic variable ⟶

- The model is **sensitive to various different operators**: we define a proxy metric for the significance σ, which depends on the Wilson coefficients of the operator considered during testing:

$$\sigma(c_{op}) = \frac{|BSM(c_{op}) - SM|}{\sqrt{SM}} = \frac{|LIN(c_{op}) + QUAD(c_{op}^2)|}{\sqrt{SM}}$$

We consider the model sensitive to an operator if σ reaches the value of 3:

operator	c_W	c_{qq}^1	$c_{qq}^{1,1}$	c_{qq}^3	$c_{qq}^{3,1}$	c_{Hq}^1	c_{HW}
significance	0.13	0.17	0.18	0.11	0.11	0.61	0.65

Value of the coefficient of the operators that gives $\sigma = 3$, for an integrated luminosity of $350 fb^{-1}$

Work in progress

- Test of the strategy on **fully reconstructed events** and application to **Run 2 data**
- Inclusion of the **background processes** (mainly due to QCD production and fake leptons)

[1] 10.1088/1361-6633/ac36b9 [2] 10.31526/ACP.BSM-2021.16 [3] 10.48550/arXiv.1906.02691