Note

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1 Higgs Production

We want to apply the deep learning methods in distinguishing vector boson fusion (VBF) from gluon-gluon fusion (GGF) Higgs production at the LHC.

We want to apply the CWoLa methods, then can use the real data without knowing the true label.

2 Sample Preparation

2.1 Monte Carlo samples

We consider Standard Model (SM) di-photon Higgs events produced via GGF and VBF channels at a center-of-mass energy of $\sqrt{s} = 14$ TeV. The Higgs boson events are generated using `MadGraph 3.3.1` [1] for both GGF and VBF production. The Higgs decays into the di-photon final state, and the parton showering and hadronization are simulated using `Pythia 8.306` [2]. The detector simulation is conducted by `Delphes 3.4.2` [3]. Jet reconstruction is performed using `FastJet 3.3.2` [4] with the anti-k_t algorithm [5] and a jet radius of $R = 0.4$. These jets are required to have transverse momentum $p_{\mathrm{T}} > 25$ GeV.

The following `MadGraph` scripts are used to generate Monte Carlo samples for each production channel.

GGF Higgs Sample Generation

```
generate p p > h QCD<=99 [QCD]
output GGF_Higgs
launch GGF_Higgs

shower=Pythia8
detector=Delphes
```

```
analysis=OFF
madspin=OFF
done

set run_card nevents 100000
set run_card ebeam1 7000.0
set run_card ebeam2 7000.0

set run_card use_syst False

set pythia8_card 25:onMode = off
set pythia8_card 25:onIfMatch = 22 22
done
```

VBF Higgs Sample Generation

```
define v = w+ w- z
generate p p > h j j $$v
output VBF_Higgs
launch VBF_Higgs

shower=Pythia8
detector=Delphes
analysis=OFF
madspin=OFF
done

set run_card nevents 100000
set run_card ebeam1 7000.0
set run_card ebeam2 7000.0

set run_card use_syst False

set pythia8_card 25:onMode = off
set pythia8_card 25:onIfMatch = 22 22
done
```

2.2 Event selection

The selection cuts after the `Delphes` simulation:

- n_γ cut: The number of photons should be at least 2.
- n_j cut: The number of jets should be at least 2.
- $m_{\gamma\gamma}$ cut: The invariant mass of two leading photons $m_{\gamma\gamma}$ are required 120 GeV $\leq m_{\gamma\gamma} \leq$ 130 GeV.

Table 1 summarizes the cutflow number at different selection cuts.

Table 1: Number of passing events and passing rates for GGF and VBF Higgs production at different selection cuts.

Cut	GGF	pass rate	VBF	pass rate
Total	100000	1	100000	1
n_γ cut	48286	0.48	53087	0.53
n_j cut	9302	0.09	42860	0.43
$m_{\gamma\gamma}$ cut	8864	0.09	40694	0.41

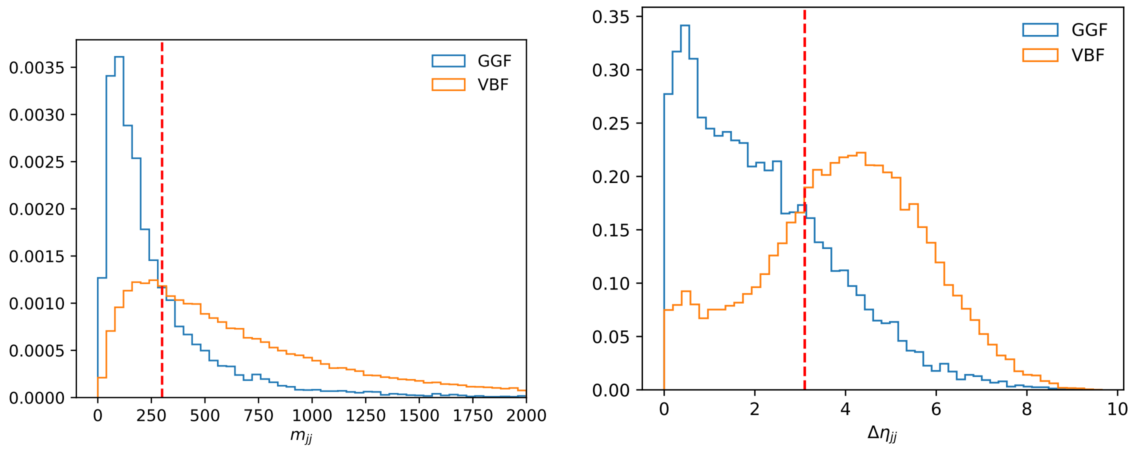
Figure 1 shows the distributions of m_{jj} (the invariant mass of the two leading jets) and $\Delta\eta_{jj}$ (the pseudorapidity difference between the two leading jets). The scatter plot of m_{jj} versus $\Delta\eta_{jj}$ is presented in Figure 2.

References

[1] J. Alwall, R. Frederix, S. Frixione, V. Hirschi, F. Maltoni, O. Mattelaer, H. S. Shao, T. Stelzer, P. Torrielli, and M. Zaro, "The automated computation of tree-level and next-to-leading order differential cross sections, and their matching to parton shower simulations," *JHEP*, vol. 07, p. 079, 2014.

[2] T. Sjöstrand, S. Ask, J. R. Christiansen, R. Corke, N. Desai, P. Ilten, S. Mrenna, S. Prestel, C. O. Rasmussen, and P. Z. Skands, "An introduction to PYTHIA 8.2," *Comput. Phys. Commun.*, vol. 191, pp. 159–177, 2015.

[3] J. de Favereau, C. Delaere, P. Demin, A. Giammanco, V. Lemaître, A. Mertens, and M. Selvaggi, "DELPHES 3, A modular framework for fast simulation of a generic collider experiment," *JHEP*, vol. 02, p. 057, 2014.



(a) m_{jj} distribution (b) $\Delta\eta_{jj}$ distribution

Figure 1: Distributions of the invariant mass m_{jj} and pseudorapidity difference $\Delta\eta_{jj}$ of the two leading jets. Red dashed lines are selection cuts used to construct mixed datasets.

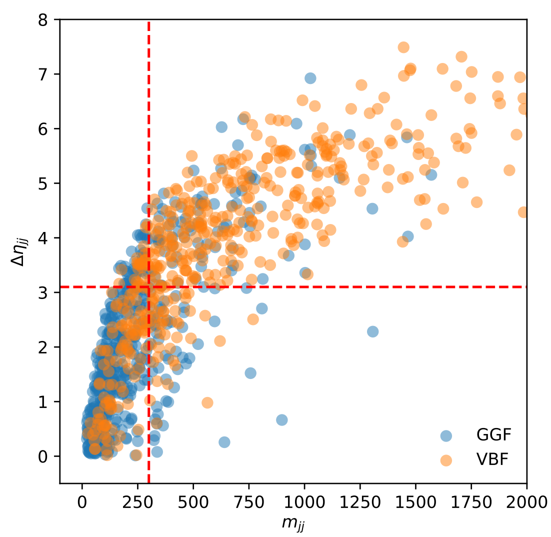


Figure 2: Scatter plot of m_{jj} versus $\Delta\eta_{jj}$. Red dashed lines are selection cuts used to construct mixed datasets.

[4] M. Cacciari, G. P. Salam, and G. Soyez, "FastJet User Manual," *Eur. Phys. J. C*, vol. 72, p. 1896, 2012.

[5] M. Cacciari, G. P. Salam, and G. Soyez, "The anti-k_t jet clustering algorithm," *JHEP*, vol. 04, p. 063, 2008.