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ATLAS NOTE

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Search for Higgs pair production with decays to WW(jjjj) and $\gamma\gamma$ in 22.1 fb^{-1} proton-proton collision data at 13 TeV in the ATLAS detector

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Abstract

A search is performed for resonant and non-resonant Higgs pair production with one Higgs boson decaying to full hadronic WW and the other to $\gamma\gamma$ using proton-proton collision data corresponding to an integrated luminosity of 22.1 fb^{-1} at a 13 TeV centre-of-mass energy recorded with the ATLAS detector. No deviation from the Standard Model prediction is observed. The observed (expected) upper limit at 95% confidence level on the cross section for $gg \rightarrow hh$ is XXX pb (XXX pb) for the non-resonant Higgs pair production. For resonant Higgs pair production, the observed (expected) upper limits at 95% confidence level on cross section times the branching ratio of $X \rightarrow hh$ range from XXX pb (XXX pb) to XXX pb (XXX pb) as a function of the resonant mass from 260 GeV to 500 GeV assuming that the narrow-width approximation holds.

Contents

1 Statements

1.1 version 0.0

2 Data and Monte Carlo samples

3 Object definition

The object definition is similar to what is used by the HGam group. The analysis framework of $hh \rightarrow \gamma\gamma WW$ is based on the HGamAnalysisFramework that is centrally developed by HGam group. The tag of the framework is HGamAnalysisFramework-00-02-55-11 which is used to produce official MxAOD samples of version h013a.

3.1 Photons

- The p_T of leading (sub-leading) photon is required to be larger than 25 GeV.
- The $|\eta|$ of photon is considered up to 2.37, vetoing the crack region $1.37 < |\eta| < 1.52$.
- Tight photons are required as is the default in HGam group. The photon identification algorithm is based on the lateral and longitudinal energy profiles of the shower measured in the electromagnetic calorimeter.
- The isolation working point FixedCutLoose is used. It is one of the recommended points from the isolation forum. Photons are required to pass both calorimeter-based and track-based isolation requirements.

3.2 Jets

- The Anti-k_t algorithm [1] with the distance parameter of $R = 0.4$ is used.
- Jets are required to have $p_T > 25$ GeV and $|\eta| < 2.5$.
- Jets from pileup are rejected by applying a JVT (Jet Vertex Tagger) cut. The jet is rejected if JVT< 0.59 for $p_T < 60$ GeV and $|\eta| < 2.4$.
- Events with a jet passing the LooseBad cut are rejected. The LooseBad jet quality requirement is designed to reject fake jets caused by detector readout problems and non-collision backgrounds.

3.3 Electrons

Electrons are reconstructed from energy clusters in the EM calorimeter matched with tracks reconstructed in the inner detector.

- p_T is required to be larger than 10 GeV.
- $|\eta|$ is required to be less than 2.47 vetoing the transition region with $1.37 < |\eta| < 1.52$.
- The $|d_0|$ significance ($d_0/\sigma(d_0)$) with respect to the primary vertex in the event is required to be less than 5.
- The $|z_0|$ with respect to the primary vertex in the event is required to be less than 0.5mm.
- Identification: Medium quality electrons are used.
- Isolation: Loose electrons are used.

3.4 Muons

Muons are reconstructed from tracks in the inner detector and the muon spectrometer.

- p_T is required to be larger than 10 GeV.
- $|\eta|$ is required to be less than 2.7.
- The $|d_0|$ significance with respect to the primary vertex in the event is required to be less than 3.
- The $|z_0|$ with respect to the primary vertex in the event is required to be less than 0.5mm.
- Identification: Medium quality muons are used.
- Isolation: GradientLoose is used.

3.5 Overlap removal

Since objects are reconstructed with different algorithms in parallel, i.e. no check to see if a same set of clusters or tracks are used for reconstructing two different object, one needs to implement a set of rules to remove objects close to each other to avoid double counting. The rule is defined as below:

- The two leading photons are always kept.
- Electrons with $\Delta R(e, \gamma) < 0.4$ are removed.
- Jets with $\Delta R(jet, \gamma) < 0.4$ are removed.
- Jets with $\Delta R(jet, e) < 0.2$ are removed.
- Muons with $\Delta R(\mu, \gamma) < 0.4$ or $\Delta R(\mu, jet) < 0.4$ are removed
- Electrons with $\Delta R(e, jet) < 0.4$ are removed.

4 Event selection

4.1 Selection and efficiency

The event selection procedure identifies two photons and then applies requirements on the multiplicities of jets in order to increase the signal purity and background rejection for events with multi-jets. The event selection for the analysis starts with the full di-photon selection from the $h \to \gamma\gamma$ analysis in RUN II to select two high p_T isolated photons.

- **Trigger**: di-photon trigger $HLT\_g35\_loose\_g25\_loose$ or $HLT\_g35\_medium\_g25\_medium$ or HLT_2g50_loose or HLT_2g20_tight is used.

- **Good Run List and Detector Quality**: Events must belong to the luminosity blocks specified in the Good Run Lists:

  - data15_13TeV.periodAllYear_DetStatus-v79-repro20-02_DQDefects-00-02-02_PHYS_StandardGRL_All_Good_25ns.xml for 2015 data
  - data16_13TeV.periodAllYear_DetStatus-v82-pro20-12_DQDefects-00-02-04_PHYS_StandardGRL_All_Good_25ns.xml for 2016 data

  Events with data integrity errors in the calorimeters and incomplete events where some detector information is missing are rejected, as well as events which are corrupted due to power supply trips in the tile calorimeter.

- **Primary Vertex**: The primary vertex is selected using the neural network algorithm from HGam group. The photons' four momenta, JVT and track isolation are corrected with respect to this origin, and the mass of the diphoton system is accordingly recalculated.

- **2 loose photons**: At least two loose photons with $E_T > 25$ GeV and within the detector acceptance are selected.

- The other cuts on photons involving **Identification (tight ID), Isolation, Rel.Pt cuts**. The relative p_T cut requires the p_T of leading (sub-leading) photon is larger than 0.35(0.25) of diphoton invariant mass. $m_{\gamma\gamma} \in [105, 160]$ **GeV** is also required.

- **Number of jets**: Considering the jet p_T at truth level, the two categories are defined by exact 3 jets or at least 4 jets to enlarge signal efficiency. Figure **??** shows the truth jet p_T from on-shell and off-shell W boson.

- **b-veto**: In order to suppress bacgkrounds with top quarks and keep orthogonality to other hh channels $bb\gamma\gamma$, $bbbb$, $bb\tau\tau$ etc, the event is rejected if there is any b-jet. The b-tagger is MV2c10 with a b-tagging efficiency of 70%.

The efficiencies of event selection are listed in Table 1. These efficiencies are derived for signals from simulated samples. After the selection of the two photons, the signal efficiencies range from 38.0% to 43.0%, while after the additional selection on the jets, the leptons and the tight mass window on the di-photon, the signal efficiencies range from 5.65% to 10.7%, for a resonant mass from 260 and 500 GeV.

	SM	Resonant			
	Higgs pair	260 GeV	300 GeV	400 GeV	500 GeV
All Events	100.0%	100.0%	100.0%	100.0%	100.0%
Duplicate	100.0%	100.0%	100.0%	100.0%	100.0%
GRL	100.0%	100.0%	100.0%	100.0%	100.0%
Pass Trigger	73.7%	68.5%	69.6%	71.9%	74.6%
Detector Quality	73.7%	68.5%	69.6%	71.9%	74.6%
has PV	73.7%	68.5%	69.6%	71.9%	74.6%
2 loose photons	59.3%	56.9%	56.5%	57.6%	59.7%
Trig Match	59.0%	56.6%	56.3%	57.3%	59.9%
Tight ID	49.8%	46.8%	46.2%	48.1%	50.8%
Isolation	45.2%	40.2%	40.2%	43.4%	46.5%
Rel.Pt cuts	41.7%	37.5%	36.4%	39.4%	43.0%
$105 < m_{\gamma\gamma} < 160$ GeV	41.6%	37.4%	36.3%	39.2%	42.8%

Table 1: Efficiencies for event selection

5 Selection optimizations

6 Signal and background estimations

7 Systematic uncertainties

8 Statistical interpretation

9 Unblinded result

10 Summary

References

[1] M. Cacciari, G. P. Salam, and G. Soyez, *The anti- k t jet clustering algorithm*, Journal of High Energy Physics **2008** (2008) no. 04, 063.

Appendices