The performance of diphoton primary vertex reconstruction methods in H→γγ+Met channel of ATLAS experiment

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Abstract. The search for new physics in the H→γγ+met relies on how well the missing transverse energy is reconstructed. The Met algorithm used by the ATLAS experiment in turns uses input variables like photon and jets which depend on the reconstruction of the primary vertex. This document presents the performance of di-photon vertex reconstruction algorithms (hardest vertex method and Neural Network method). Comparing the performance of these algorithms for the nominal Standard Model sample and the Beyond Standard Model sample, we see the overall performance of the Neural Network method of primary vertex selection performed better than the Hardest vertex method.

1. Introduction
The reconstruction of the physics process (H→γγ) of this analysis requires precise measurement of the primary vertex (PV) [1]. Reconstructed interaction vertices are used by algorithm [2] that distinguishes measurements from the hard-scattering collision (signal) and additional collision ("pileup"). The Jet-Vertex-Tagger (JVT) also relies on precise reconstruction of the interaction vertices [3]. The common approach used for vertex interaction point is to identify the primary vertex with the highest scalar sum of transverse momenta (∑p_T) of tracks (choice of most ATLAS analyses), this method is sub-optimal with photon because photons often do not leave tracks in the inner detector. A more efficient way of reconstructing photon vertex interaction point is to take advantage of the longitudinal segmentation of the electromagnetic calorimeter (this method is often referred to as ”pointing”) [1]. Interaction vertices are reconstructed using signatures from the inner detector (see Sec 2) In preparation for Run-II a Neural network algorithm (NN algorithm as soon known as pointing method) was developed, this algorithm combines the two approaches to a framework that discriminates between the hard-scatter vertex (signal) and vertices associated with additional collision in same bunch crossing(in-time pileup).

H→γγ analysis.

2. ATLAS Tracking System
The ATLAS experiment uses the Inner detector (ID) system (see Figure 1) as the major tracking system which is made up of a silicon pixel detector, a silicon microstrip detector (SCT), the straw tubes of the transition radiation tracker (TRT), and the insertable B-layer (IBL) recently added
Figure 1. Sketch of the ATLAS inner detector showing all its components, including the new insertable B-layer (IBL). The distances to the interaction point are also shown.

Figure 2. Vertex topologies in ATLAS primary and pile up vertices from conversions and long-lived particles, vertices in jets and vertices from chain decay.

to ATLAS detector. The ID is designed to measure the trajectories and momentum of charged particle in the region of $\eta < 2.5$\textsuperscript{1} [4].

3. Vertex topologies in ATLAS Detector

Several different vertex topologies arise from the collision of bunches of proton in the LHC at the center-of-mass energy of 13 TeV as shown in Fig 2. In a typical collision event, several primary vertices along the beam and decay of long-lived particles, photon conversion, vertices in jets and vertices from decay chains are produced. Hence, the reconstruction of these vertices from processes and distinguished by their different topology are very important. The photon conversion vertices is particularly important to the analysis in $H \rightarrow \gamma \gamma$ decay channel [2].

There are different types of photon conversion considered for the $H \rightarrow \gamma \gamma$ analysis [5]. Double track photon conversions are photons that convert early in the inner detector with separated trajectories, for the photon which conversion occurs at higher radius or if reconstruction of two separate tracks fails the photon is referred to as single track conversion. The TRT standalone (TRTSA) conversion are photons which converted at the TRT with imprecise $z$

\textsuperscript{1} ATLAS coordinated with respect to the interaction point (IP) is such that: the z-axis is along the beam pipe. The x-axis points from the IP to the center of the LHC ring and the y-axis points upward. The ATLAS transverse plan uses Cylindrical coordinates ($r, \phi$), $\phi$ is azimuthal angle around the z-axis, the pseudorapidity ($\eta$) is defined as $-\ln \tan(\theta/2)$, where $\theta$ is the polar angle. Angular distance is measured in the unit od $\Delta = \sqrt{\Delta^2 + \phi^2}$.
and \( R \) measurement in the barrel and endcap respective. TRTSA photons are reconstructed using direction information from the electromagnetic calorimeter \[2\]. The global strategy and the method to be used as a function of the nature of photon is shown in Fig. 3.

4. Selection of \( \gamma \gamma \) production vertex using multivariate technique

The motivation for developing this techniques is the increase in pileup events due to high luminosity of the LHC collision, the increase in luminosity increases the number of interaction in the same bunch crossing. Different discriminant (artificial neural network, boosted decision trees, k-Nearest Neighbors and likelihood) algorithm were trained on simulated samples (sample containing pileup with 50 ns bunch spacing) containing Higgs bosons produced through gluon-gluon fusion and decay into two photons (\( H \rightarrow \gamma \gamma \)), the performance of the algorithms was cross-validated and evaluated using samples with 25 ns pileup. The algorithms were trained to distinguished:

- At least one photon converted into \( e^+e^- \) pairs and with track associated with the primary vertex.
- At least one converted photo with the track containing hit the in the silicon detector.
- Both photon unconverted or associated to track with a hit in the TRT.

The following inputs are used in the discriminants:

- \( (z_{\text{common}} - z_{\text{vertex}})/\sigma_z \) (\( z_{\text{vertex}} \) position of primary vertex) and \( z_{\text{common}} \) (intersection of the extrapolated photon trajectories from the calorimeter (“pointing”))
- \( \log_{10}(\sum pt) \), the scalar sum of transverse momenta of the tracks associated to the vertex.
- \( \log_{10}(\sum pt^2) \), idem with \( p^2 \) variable transformed to ensure the convergence of minimizer.
- \( \Delta \phi(\gamma \gamma, \text{vertex}) \): the angular difference between the diphoton system and system defined by the vector sum of the tracks associated to the vertex.

The neural network discriminant was chosen because it has the best efficiency \[1\]. Hence the neural network method will be refereed to as the pointing method in this document.

5. Sample and Event Selection

The event selection used for this studies is based on the \( H \rightarrow \gamma \gamma \) nominal selection \[3\] with additional missing transverse momentum (MET) requirement, two photon selection with transverse momentum of the leading and sub-leading photon to be greater than 0.35 and 0.25 respectively. The heavy scalar signal sample is used for this analysis, the sample has process that models the production of Higgs boson through gluon-gluon fusion.
1.2

The efficiency of identifying correct vertex is calculated for reconstructed vertex which matches the truth vertex with a z-direction of < 0.3 mm.

6. Result

The efficiency of identifying correct vertex is calculated for reconstructed vertex which matches the truth vertex with a z-direction of < 0.3 mm. The efficiency is calculated as the ratio of the number of events that pass this criteria to the total number of events ($\epsilon = \frac{N_{\text{pass}}}{N_{\text{tot}}}$). Figure 4 to 5 show the efficiency selecting correct vertex for photon pointing method and hardest vertex method as a function of Number of primary vertex, missing transverse energy ($E_T^{\text{miss}}$), truth photon leading momentum (Truth $p_T^{\gamma}$), angular distance between the diphoton system and the jet system are affected by pileup jets. Photon

Figure 4. Efficiency for selecting the corrected primary vertex as a function of $\Delta\phi(\gamma\gamma, E_T^{\text{miss,photon}})$, $E_T^{\text{miss}}$, Truth Jet Multiplicity and number of primary vertex when considering the hardest vertex or neural network algorithm.

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From Fig. 4 the efficiency of the photon pointing method and hardest vertex method decreases as a function of angular distance between the $E_T^{\text{miss}}$ energy and diphoton system, a similar distribution is observed for the number of primary vertex. And from the $E_T^{\text{miss}}$ plot, we see higher efficiency of photon pointing method for low $E_T^{\text{miss}}$ ($E_T^{\text{miss}} < 100(\text{GeV})$), efficiency are close at higher $E_T^{\text{miss}}$. Both methods have similar distribution for the Truth Jet multiplicity. From Fig. 5 the efficiencies increase with increase in the variables (Truth $p_T^{\gamma}$, $|E_T^{\text{miss,photon}} - p_T^{\gamma}|/p_T^{\gamma}$, sum of $p_T$ and sum of $p_T^2$). The efficiencies become constants and comparable at high Truth $p_T^{\gamma}$, sum of $p_T$ and sum of $p_T^2$ for both methods.

7. Conclusions

The search for Higgs in association with missing transverse energy relies on precise measurement of missing energy, the missing transverse algorithm uses physics objects like the diphoton system and jets as input. Diphoton systems are often contaminated by ambiguity in distinguishing the unconverted photon and electron likewise the jet system are affected by pileup jets. Photon
isolation and jet vertex tagging methods are ways the ATLAS experiment uses to reduce this effect in most analysis. From Figure 4 to 5 we see the photon pointing method in selecting correct vertex outperforms the hardest vertex method. The photon pointing method has been recommended for most analysis in ATLAS experiment. And based on this study it is the most efficiency method or the search for Higgs boson in association with intermediate missing energy.

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