ATLAS NOTE

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Performance of the ATLAS Secondary Vertex *b*-tagging Algorithm in 900 GeV Collision Data

The ATLAS collaboration

Abstract

In December 2009, the ATLAS experiment recorded approximately 400,000 collision events, at a centre-of-mass energy of 900 GeV, with the tracking detectors and the solenoid magnet fully operational. This note describes performance studies of a secondary vertex *b*-tagging algorithm using collision data. The analysis is based on approximately 10,000 jets with pseudorapidity $|\eta| < 2.5$. As very few jets are expected to be tagged as *b*-jet candidates using the standard algorithm configuration, track selection criteria have been loosened to allow for more light-flavour jets to be tagged. In particular, the veto of tracks consistent with coming from decays of K_s^0 mesons, Λ^0 baryons, photon conversions and hadronic interactions has been removed. With these looser selections, 70 secondary vertices with a positive decay length significance are reconstructed, and the vast majority of them are consistent with originating from decays of K_s^0 mesons. The rate of reconstructed secondary vertices is consistent with expectations from simulated events, as are the properties of these vertices.

1 Introduction

In December 2009, the ATLAS experiment recorded approximately 400,000 collision events, at a centre-of-mass energy of 900 GeV, with the tracking detectors and the solenoid magnet fully operational. This note describes performance studies of the SV0 algorithm that is designed to reconstruct secondary vertices from long-lived *b*-hadrons and is envisaged to be used for early *b*-tagging analyses. The identification of jets originating from *b*-quarks is an important part of the LHC physics program. In precision measurements in the top quark sector as well as in the search for the Higgs boson and new phenomena, the suppression of background processes containing predominantly light-flavour jets using *b*-tagging is of great use.

Section 2 of the note briefly describes the ATLAS detector with a focus on the detector elements central to this analysis. Section 3 describes the SV0 tagging algorithm and the selection criteria applied to tracks and vertices within this algorithm. In Section 4, the samples of data and simulated events used in this study are defined, and the selection criteria applied to events and jets are discussed.

As the amount of heavy-flavour jets produced in the data analyzed is expected to be very low, it is not possible to study the performance of the SV0 algorithm itself using standard selection criteria. To demonstrate that the secondary vertex algorithm can find decay vertices from long-lived particles, the selection criteria made in the SV0 algorithm are loosened to allow for more light-flavour jets to be *b*-tagged. The properties of the tracks in jets, which are input to the SV0 tagging algorithm, as well as the reconstructed secondary vertices are shown in Section 5.

2 The ATLAS Detector

The ATLAS detector [1] is one of the general purpose detectors built to study the LHC proton-proton collisions. It consists of an Inner Detector, a lead/liquid argon electromagnetic calorimeter, a steel/scintillator hadronic calorimeter and a system of muon chambers. The whole Inner Detector is immersed in a 2 T solenoidal magnetic field while a toroidal magnetic field allows for momentum measurements in the muon system.

The Inner Detector reconstructs the tracks of charged particles up to pseudorapidities of $|\eta| < 2.5$. It consists of three subdetectors: the Pixel detector, the silicon strip detector (SCT) and the transition radiation tracker (TRT). The Pixel detector is built up of three barrel layers and an additional three disks on each side of the barrel. It has a position resolution of approximately 10 μm in the transverse plane. The SCT barrel consists of 4 layers while 9 disks on each side of the barrel make up the endcaps. The TRT contributes with up to 73 layers of straws in the barrel region and 160 straw planes in each endcap.

The ATLAS detector has a three-level trigger system: Level 1 (L1), Level 2 (L2) and the Event Filter (EF). In this analysis, the trigger decision was based on the Beam Pickup Timing devices (BPTX) and the Minimum Bias Trigger Scintillators (MBTS). The BPTX are beam pickup devices attached to the beampipe at $z = \pm 175$ m. The MBTS are scintillators mounted on each side of the interaction point in front of the liquid-argon endcap calorimeter cryostats at $z = \pm 3.56$ m, covering the pseudorapidity range $2.09 < |\eta| < 3.84$.

3 The SV0 Tagging Algorithm

The SV0 tagging algorithm is a lifetime-based *b*-tagger which explicitly reconstructs secondary vertices from tracks associated with a jet. The operation of the tagging algorithm involves placing a cut on the signed decay length significance of the reconstructed secondary vertex. The sign of the decay length significance is given by the sign of the projection of the decay length vector on the jet axis. An illustration of a SV0-tagged jet is shown in Fig. 1.

As input, the tagging algorithm is given a list of tracks associated to the calorimeter jet. The track-to-jet association is done using a ΔR matching between the tracks and the jet axis. A track is not allowed to be associated to multiple jets, but only to the closest one. For this analysis, a cone size of $\Delta R = 0.4$ was used. Only tracks in jets fulfilling the criteria listed in Table 1 are used in the secondary vertex fit. These tracks are referred to as loose or standard SV0 tracks.

With a collection of SV0 input tracks the SV0 algorithm starts by reconstructing two-track vertices significantly displaced (in three dimensions) from the primary vertex. Tracks are considered for the two-track vertices if $dca/\sigma(dca) > 2.3$, where $dca/\sigma(dca)$ is the impact parameter significance of the track in three dimensions with respect to the primary vertex. Furthermore, the sum of the impact parameter significances of the two tracks has to be greater than 6.6. Two-track vertices must have a $\chi^2 < 4.5$ and be incompatible with the primary vertex by requiring the χ^2 of the distance between the primary and secondary vertex, computed in three dimensions, to be greater than 6.25.

The standard version of the algorithm then removes two-track vertices with a mass consistent with a K_s^0 meson, a Λ^0 baryon or a photon conversion. In addition, two-track vertices at a radius consistent with the radius of one of the three Pixel detector layers are removed, as these vertices are likely to originate from material interactions. In the present loose version of the tagging algorithm the vetoes against vertices from long-lived particles and material interactions are not applied.

From the tracks in all surviving two-track vertices, the algorithm fits an inclusive secondary vertex. In an iterative process it removes the track with the largest χ^2 contribution to the common vertex until the fit probability of the vertex is greater than 0.001, the vertex mass is less than 6 GeV and the largest χ^2 contribution from any one track is 7 or less. Finally it tries to re-incorporate the tracks failing the selections made during the formation of two-track vertices into the vertex fit.

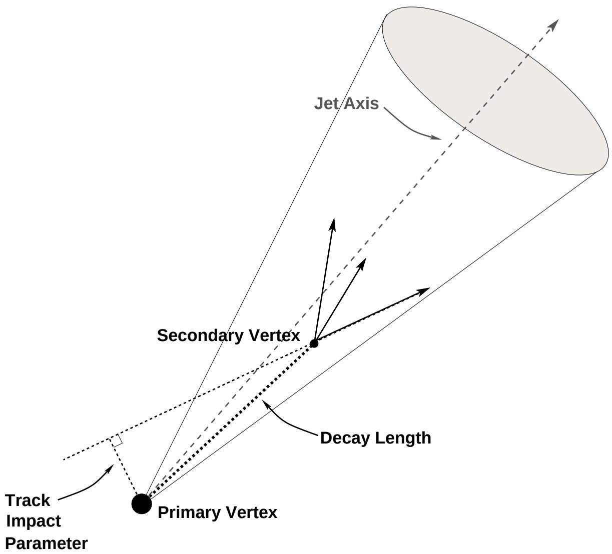


Figure 1: A secondary vertex with a significant decay length indicates the presence of a long-lived particle in the jet. The secondary vertex is reconstructed from tracks with a large impact parameter significance with respect to the primary vertex.

	Standard	Loose
p_T	> 0.5 GeV	> 0.5 GeV
d_0^{PV}	< 2 mm	< 10 mm
$z_0^{PV} \sin\theta$	< 2 mm	< 50 mm
$\sigma(d_0^{PV})$	< 1 mm	< 1 mm
$\sigma(z_0^{PV})$	< 5 mm	< 5 mm
χ^2/ndof	< 3	< 6
Number of Pixel hits	≥ 2	≥ 2
Number of SCT hits	≥ 4	≥ 4
Number of Pixel+SCT hits	≥ 7	≥ 7

Table 1: Track selection criteria used by the SV0 tagging algorithm, where d_0^{PV} and z_0^{PV} denote the impact parameters of the track in the transverse and longitudinal directions, derived with respect to the reconstructed primary vertex, and the χ^2/ndof is that of the track fit. Tracks in jets passing the loose (standard) selection criteria are used as input to the loose (standard) version of the SV0 tagging algorithm.

4 Data Samples and Selections

The data sample used in this analysis corresponds to approximately 9 μb^{-1} of 900 GeV collision data collected by the ATLAS experiment in December 2009. The data are compared to 10 million non-diffractive minimum bias events generated with PYTHIA 6.4.21 [2] using the MRST LO* parton distribution functions [3]. To simulate the detector response, the generated events were processed through a GEANT4 [4] simulation of the ATLAS detector. The simulated events use the nominal ATLAS alignment constants.

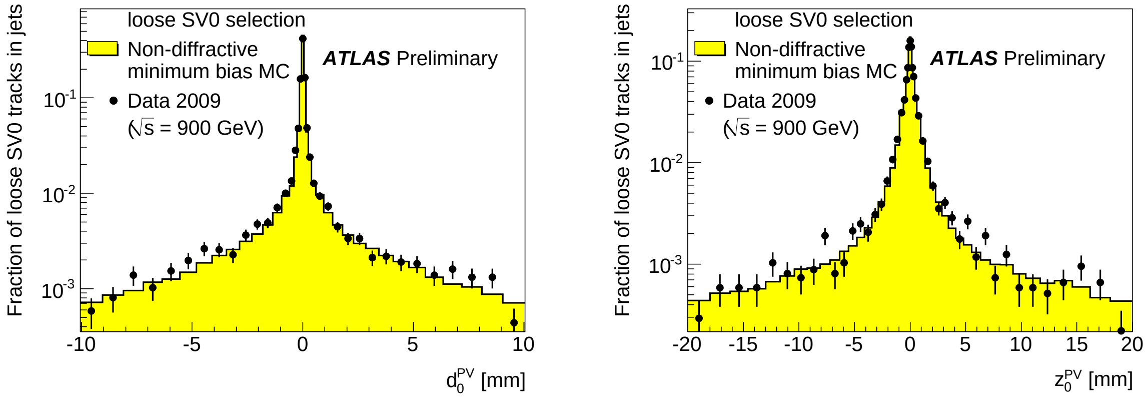
Only data-taking periods where the Pixel and SCT detectors pass certain data quality criteria, to ensure they are fully operational, are used in this analysis. In addition, the solenoid magnet is required to be on. Events were triggered by requiring at least one hit in any of the MBTS detectors in coincidence with a BPTX signal. The events are required to have a reconstructed primary vertex containing at least two tracks [5]. The jets used in this note are reconstructed from topological clusters of energy in the calorimeters, using an anti-K_T algorithm [6], and are required to have $|\eta| < 2.5$.

5 Displaced Vertices in Jets

In approximately 400,000 events of 900 GeV collision data, there are only 9 secondary vertices with positive decay length observed when using the standard version of the SV0 tagging algorithm. Thus some of the requirements made in the standard tagging algorithm are relaxed to gain statistics to allow for an examination of the performance of the algorithm even with this limited data set. Compared to the standard SV0 algorithm, the loose version of the tagging algorithm uses the loose rather than the standard track selection, as defined in Table 1. In addition, tracks consistent with originating from long-lived particles and material interactions are allowed to contribute to the secondary vertex. The loosened requirements are designed to reconstruct secondary vertices from long-lived particles such as K_S^0 mesons, which are more abundant in the data than b-hadron decays and mistags.

As described in Section 3, the secondary vertex algorithm uses good-quality tracks associated to calorimeter jets. For a good understanding of the tagging algorithm performance it is therefore of great importance to study this set of tracks closely, and to ensure that their properties are well modelled by the simulation. Tracks with selection criteria very close to those used by the standard SV0 algorithm are studied elsewhere [7], and the agreement between data and simulation is found to be very good.

Figure 2 shows the impact parameter distributions with respect to the primary vertex in both the transverse and longitudinal plane for tracks fulfilling the loose selection criteria, as given in Table 1. There is a good agreement between data and simulation both in the core as well as in the tails of the distributions. As the loose track selection efficiency in data events is about 10% lower than in the simulated events, the distributions in Fig. 2 are normalized to unit area to allow for shape comparisons.



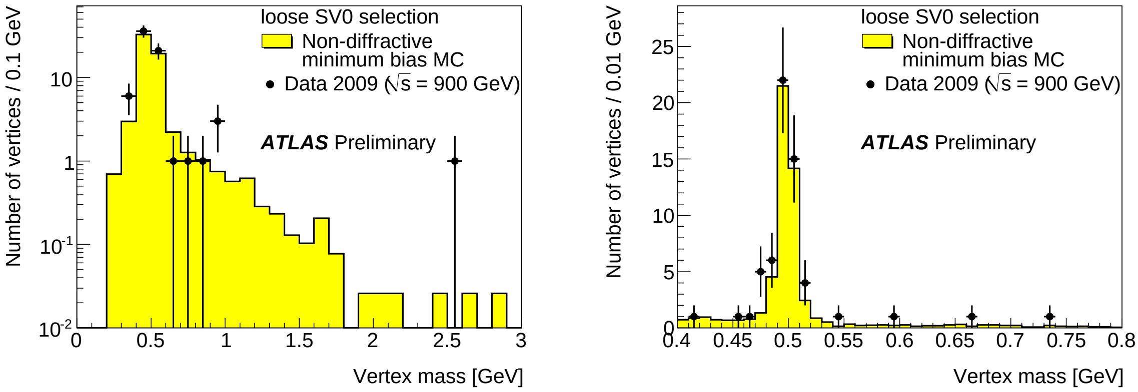
(a) (b)

Figure 2: d_0 (a) and z_0 (b) with respect to the reconstructed primary vertex for all loose SV0 tracks in jets. The distributions are normalized to unit area to allow for shape comparisons. The width of the bins is varying from 0.1 mm in the core region to 1 mm (d_0) and 2 mm (z_0) in the tails of the distributions.

If not stated otherwise, the following figures show the properties of the secondary vertices with positive decay length reconstructed in data events and simulated events. The results are shown for vertices which are reconstructed using the loose version of SV0, as described in Section 3. With these selections there are 70 jets in the data having a secondary vertex with a positive decay length. This is in good agreement with the 63 ± 1 vertices expected from the same number of jets in simulated events (the uncertainty is statistical only). Out of the 63 tagged jets expected, 2.4 originate from *b*-quarks with a transverse momentum larger than 5 GeV. All distributions of vertex properties are normalized to the number of jets in data, making them sensitive to the absolute number of secondary vertices reconstructed per jet.

Figure 3 shows the mass of all reconstructed secondary vertices with positive decay length. The vertex mass is defined as the invariant mass of the charged particles associated to the reconstructed secondary vertex, where the associated particles are all assumed to have pion masses. A clear peak is observed at the mass of the K_s^0. The agreement between data and simulation is good, both within the K_s^0 mass peak and outside of it. Figure 4 shows the signed decay length significance for all reconstructed secondary vertices. Many vertices have a very large positive decay length significance, consistent with the presence of K_s^0 mesons. The shape of the distribution is well modelled by the simulation. Figure 5 shows the number of tracks associated to the reconstructed secondary vertices with positive decay length. Most vertices have two tracks, which is characteristic of vertices from K_s^0 decays. Figure 6 shows the impact parameter in the transverse and longitudinal directions of the tracks associated to the secondary vertices. Again, the agreement between data and simulation is good.

The SV0 tagging algorithm was also run in the standard configuration on the data events, resulting in 9 reconstructed secondary vertices with positive decay length significance. This is in good agreement with the 8.9 ± 0.5 vertices expected from the same number of jets in simulated events (the uncertainty is statistical only). The vertices reconstructed with the standard version of the tagging algorithm are predominantly those with higher masses. The majority of the vertices consistent with originating from



(a) (b)

Figure 3: The vertex mass distribution for all secondary vertices with positive decay length in data events. The expectation from simulated events, normalized to the number of jets in the data, is superimposed. Figure (a) shows the entire mass range, while (b) only shows vertices with a mass close to the K_s^0 meson.

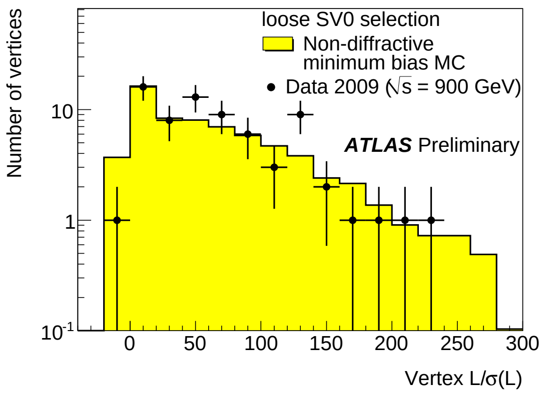


Figure 4: The three-dimensional decay length significance, signed with respect to the calorimeter jet axis, for all secondary vertices reconstructed in data events. The expectation from simulated events, normalized to the number of jets in the data, is superimposed.

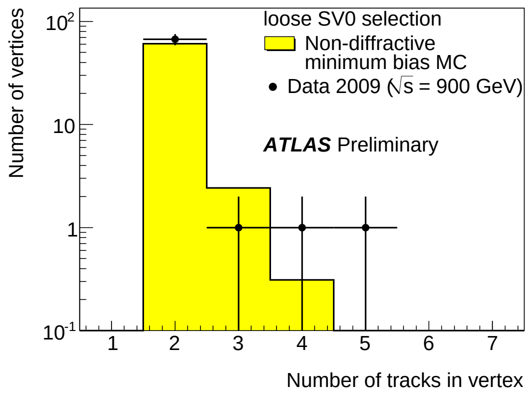


Figure 5: The number of tracks in secondary vertices with positive decay length reconstructed in data events. The expectation from simulated events, normalized to the number of jets in the data, is superimposed.

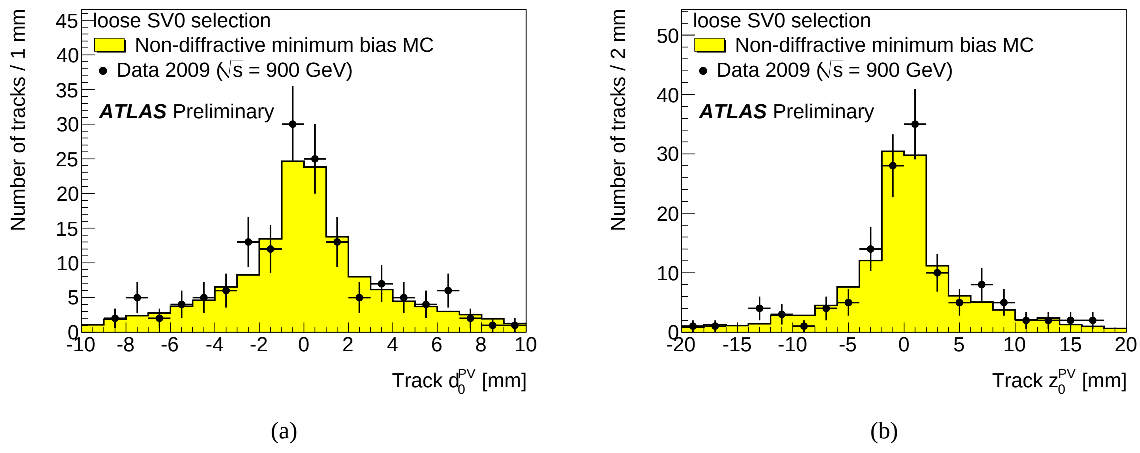


Figure 6: d_0 (a) and z_0 (b) with respect to the reconstructed primary vertex for all tracks in secondary vertices with positive decay length reconstructed in data events. The expectation from simulated events, normalized to the number of jets in the data, is superimposed.

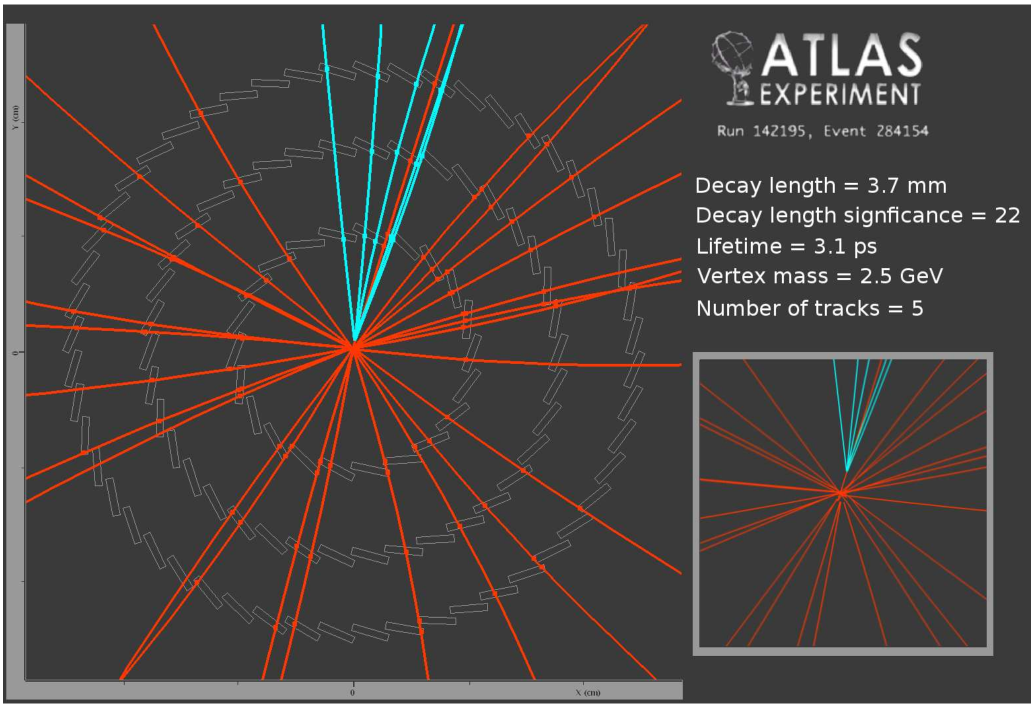


Figure 7: Event display of a b-jet candidate event. Only tracks in the barrel region with $p_T > 500$ MeV are displayed. The detector elements shown are the three barrel layers of the Pixel detector.

the decay of a K_s^0 meson, which are reconstructed with the loose version of the tagging algorithm, are now suppressed as the standard algorithm includes the removal of vertices consistent with long-lived particles and material interactions, as discussed in Section 3. Figure 7 shows an event display of one of the events which is b-tagged with the standard version of the SV0 tagging algorithm. The secondary vertex consists of five tracks and has a mass of 2.5 GeV. The vector sum of the momenta of the tracks making up the secondary vertex is 9.8 GeV. The vertex is significantly displaced from the primary vertex, with a signed decay length significance $L/\sigma(L) = 22$. The three-dimensional distance between the primary and secondary vertices is 3.7 mm, which corresponds to a lifetime of 3.1 ps. As the mean lifetime of a b-hadron is approximately 1.5 ps, the vertex is consistent with a b-hadron decay. The heavy-flavour origin of this vertex is also supported by its large track multiplicity and high mass. Moreover, the same jet is found to be consistent with originating from a b-quark according to the JetProb tagging algorithm [8] which assigns a light-jet probability based on the impact parameter significances of the tracks associated with jets. In addition to the jet with the highly displaced secondary vertex, there is a second jet in the same event. The two jets are in a back-to-back configuration with $\Delta\phi(\text{jet},\text{jet}) = 3.0$. The second jet also contains a reconstructed secondary vertex, with a three-dimensional distance between the primary and secondary vertices of 0.5 mm and a signed decay length significance of 0.9.

6 Conclusions

In this note, data-to-simulation comparisons of quantities relevant for the secondary vertex tagging algorithm SV0 have been presented. The SV0 tagging algorithm, used to identify jets originating from b-quarks, is one of the tagging algorithms that will be used for early data measurements. By allowing larger impact parameters of the input tracks, and by removing the veto of tracks likely to originate from

K_s^0 mesons, Λ^0 baryons and material interactions, the algorithm's ability to reconstruct vertices from long-lived particles has been demonstrated. The properties of the reconstructed secondary vertices are found to be in good agreement with the expectations from simulated events.

References

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