Pigeons love doves

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Abstract

Something to do with b-tagging, I presume. I will write this after its all written, I think this is the best way of doing an abstract! Filling in some space now so I can see what it looks like.

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1 Introduction

In high energy proton collisions, narrow beams of propagating high energy hadrons, known as jets, are produced by an interaction that contains free quarks or gluons in its final state. Flavour tagging is the identification of b-jets, c-jets and light-flavoured jets, which are defined as jets containing a b-hadrons, charmed-hadrons and only light hadrons (only containing u,d and s quarks) respectively. Flavour tagging is achieved by utilising the large lifetimes of the b-hadrons and charmed-hadrons (of the order 1.5 ps and 0.4-1 ps respectively), due to the fact that they can only decay through the flavour changing weak interaction. The large lifetimes of the heavy flavour hadrons means that the they will decay a measurable distance from the primary vertex, the point where the hard-scatter collision occurs, and hence the flavour can be infered from the prescence of particles that originate from a point offset from the primary vertex.

Flavour tagging of b-quarks (b-tagging) is important for many analyses, as the b-quark is the 2nd most massive quark in the standard model ($m_b \sim 5$ GeV) and as a third generation quark, partners the most massive quark, the top quark. Two analyses where these properties mean that b-tagging features strongly are $t\bar{t}$ analyses and searches for a Higgs boson decaying to $b\bar{b}$. In the former, as the top decays to a W-boson and a b-quark with a branching ratio of close to 100%, $t\bar{t}$ typically require a b-tagged jet. In the latter, the Higgs boson coupling in proportional to mass squared, hence the large mass of the b-quark means that $H \to b\bar{b}$ is the decay of the Higgs boson with the largest branching-ratio (the top quark's mass is too large for a Higgs boson to decay into $t\bar{t}$), which means that it is the best channel to make the first observation of the Higgs boson coupling to fermions. b-tagging is also important for a number of exotic and super-symmetry searches due to the properties of the b-quark mentioned above.

1.1 The ATLAS detector at the LHC

The standard model of particle physics is a theory that describes interactions of fundamental physics with great success. However, there are a number of observed problems with current theory. One of the most important is that the mass profiles of galaxies, measured from their rotation curves, show that there must be more matter in the universe that is within the standard model; this missing mass is known as 'dark matter'. Many of the models that have been proposed as dark matter candidates result in predictions of new particle on the TeV energy scale.

High energy proton-proton collisions are an effective way of probing the high-energy frontier for resonances, which repesent the decay of heavy particles. The LHC is a synchotron, 27km in circumference, where protons are accelerated and then collided at a centre-of-mass energy of 13 TeV, $\sqrt{s}$. This centre-of-mass energy is the highest collision energy ever achieved, and allows the exploration of new regions of phase space for beyond standard model physics.

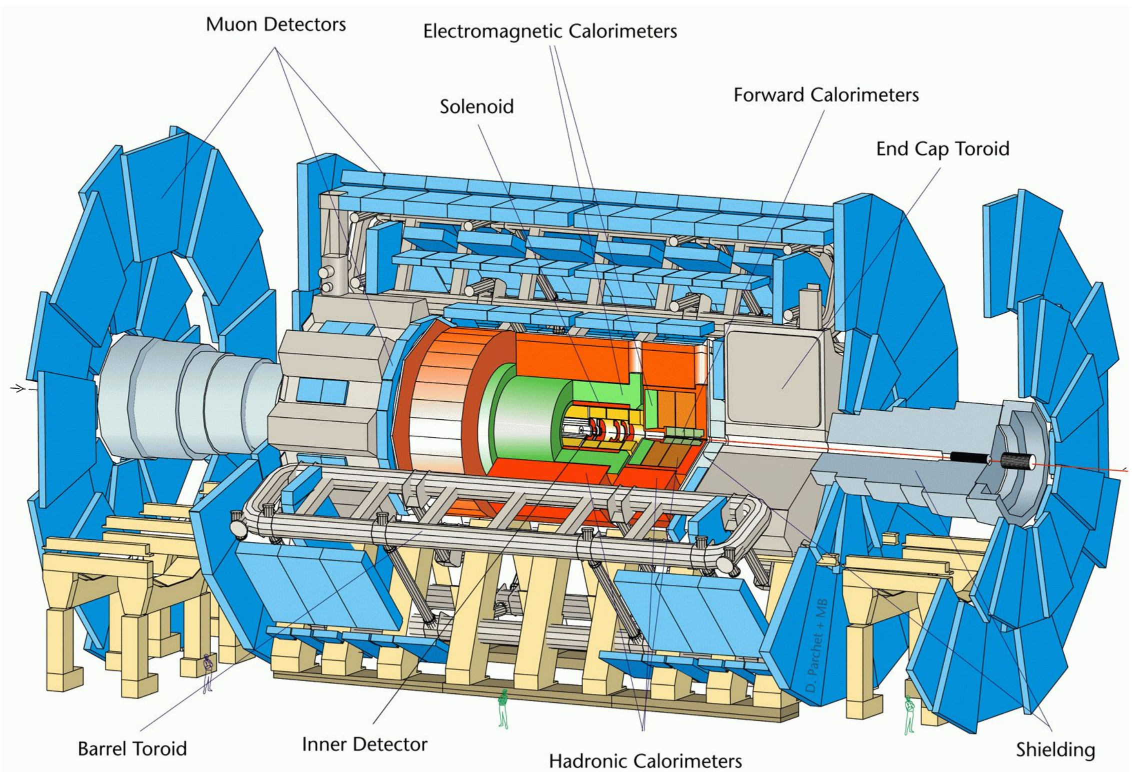

Figure 1: A diagram that shows the key features of the ATLAS detector.

ATLAS, shown in Figure 1 is a general purpose particle detector, which observes collisions of protons accelerated by the LHC. The detector is built in many layers around the beam-pipe where the proton-proton collisions occur; first the Inner Detector, which creates tracks showing the trajectories of charged particles, then the EM and Hadronic calorimeters, which measure the energy of many of the particles and then the muon chamber which measures the properties of muons. The solonoids causes a magnetic field throughout ATLAS which causes charged particles to curve which aids particle identification as well as measurements of energy and momentum.

The Inner Detector is the most important part of the detector for flavour tagging. The Inner Detetector is made of ... silicon layers which sit at ?-? mm from the beam pipe, followed by a section of straw trackers which sit at ??-??m. Charged particles leave a small but detectable amount of energy in each layer, called a hit. The pattern of hits in the layers is then analysed to reconstruct tracks that represent the trajectories of particles as they pass through the layers. The reconstructed tracks are then used to search for particles that are coming from an offset vertex.

1.2 Flavour Tagging Algorithms

There are three main base flavour tagging algorithms used at ATLAS, each of which utilise the extended lifetimes of the heavy hadrons by searching for tracks, reconstructed in the inner detector, that show that there are particles coming from a decay offset from the primary vertex. Then the three base algorithms are then combined to create a multivariate tagger, which has the most optimal flavour-tagging peformance. Figure 2 illustrates the key features of the three algorithms.

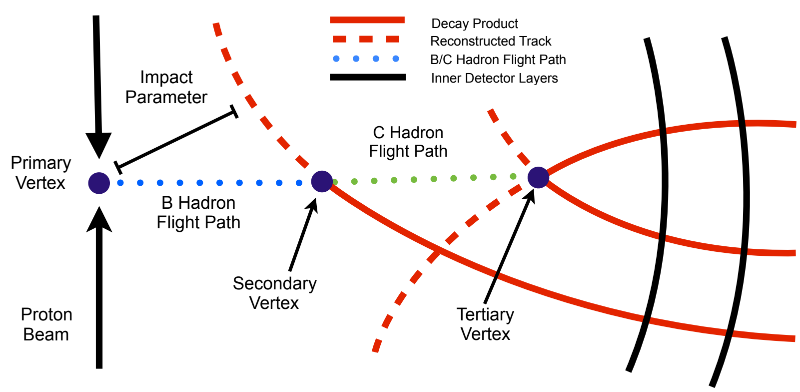

Figure 2: A diagram to illustrate the key features in a b-jet that are used by the base flavour-tagging algorithms.

1.2.1 Impact Parameter Based: IPxD

The IP3D algorithm is an impact parameter based flavour tagging tool. In this algoritm, for all tracks associated to a jet, the distance of closest approach, known as the impact parameter, is calculated in both the transverse (perpindicular to beam-pipe) and longitudinal(parallel to beam-pipe) direction, which are labelled as d_0 and z_0. Then the IP3D algorithm calculates a likelihood of the jet having a specific flavour, based on the distributions of the impact paremeters (d_0, z_0), and the distributions of their significances (d_0/σ_{d0} and z_0/σ_{z0}) of tracks inside the jet. Another similar algorithm, IP2D, also calculates the likelihood of flavour from just the transverse distributions, (d_0 and d_0 significance), which is more robust to pile-up, which is likely to have a large z_0 value.

1.2.2 Secondary Vertex: SV1

The SV1 algorithm aims to reconstruct a secondary vertex of two or more intersecting tracks, corrosponding to the decay of a heavy-flavour hadron. Properties of the reconstructed secondary vertex that show flavour discrimination are, for example; vertex invariant mass and energy fraction (fraction of jet energy contained in the secondary vertex) which will be large for b-jets due to the heavy mass of the b-hadron, the distance in the transverse plane between the primary vertex and the secondary vertex (2D fligh path L_{XY}), which will be large for b-jets due to the long lifetime of the b-hadron and the number of tracks at the secondary vertex, which will be large for well constructed secondary vertices, which are more likely in b-jets.

1.2.3 Multi-Vertex: JetFitter

The JetFitter algorithm (JF) attempts to reconstruct the full decay chain of the b-hadron into a charmed-hadron and then into light-hadrons by constructing. This is done by assuming that all vertices lie on a common b-flight axis, and then constructing vertices from the intersection of one or more tracks and the flight axis. Discriminating variables of JF, similarly to SV1, are vertex mass, energy fraction, number of vertices with two or more tracks and number of one track vertices.

1.2.4 Multi-Variate Algorithms: MV2

The three base algorithms are combined in a boosted decision tree (BDT), which is machine-learning technique for combining many flavour-discriminating variables. As shown in Figure 3, MV2 combines the likelihood output of IP3D and IP2D,

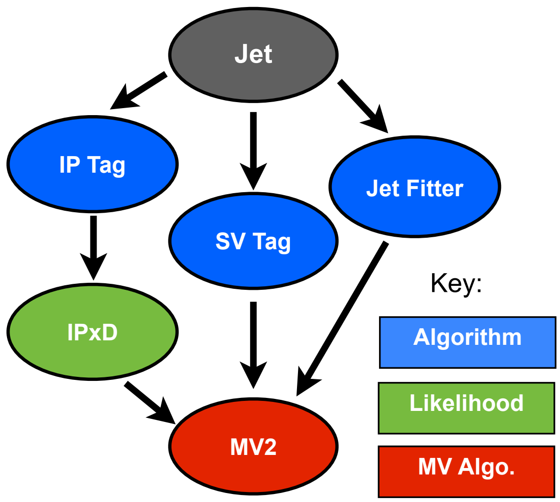

Figure 3: A diagram to show the flow of information used in MV2 flavour-tagging algorithm.

with the discriminating variables of SV1 and JF discussed above. For Run 2 the recommended b-tagging tool is MV2c20 which has been trained on sample containing 20% charm, to give strong light- and c-rejection rates.