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Tagging b quarks at extreme energies without tracks

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Many of the most exciting searches for new physics beyond the Standard Model, as well as further studies of the Standard Model itself, benefit from being able to identify high-energy jets containing b quarks ("b-jets"). Examples include Higgs pair production and decay via $HH \to b\bar{b}b\bar{b}$, sensitive to Higgs trilinear couplings˜\cite{Behr:2015oqq}; graviton and radion decays to heavy fermions and bosons in warped extra dimension models˜\cite{Gouzevitch:2013qca}; third-generation superpartners in supersymmetry˜\cite{Alwall:2008ag}; and indeed any new physics with preferential couplings to heavy Standard Model particles or third-generation fermions in particular.

One of the most distinctive features of a b-jet is the relatively long life (on the order of 1.5˜ps) of the B hadron, resulting in charged particle tracks displaced from the primary interaction vertex. For this reason, almost all modern collider-based particle physics experiments deploy several layers of high-granularity silicon detectors near the interaction point, and algorithms for distinguishing b-jets from jets originating from lighter quarks rely on the ability to reconstruct high-resolution tracks in these finely grained subsystems.

However, with increasingly stringent limits placed on the energy scale for new physics, distinguishing displaced tracks within increasingly energetic jets becomes simultaneously more important and more challenging. Two effects in particular make b-tagging in TeV-scale jets difficult: First, more tracks are collimated into a small angle, resulting in a higher hit density and a more ambiguous association of hits with tracks. A single mis-assignment can steer a track off-course and produce an erroneous impact parameter. Second, at extreme energies, an increasing fraction of B hadrons will decay after crossing the innermost layers of the silicon detector: in the best case scenario, this situation merely reduces the number of hits available for reconstruction and thus degrades the impact parameter resolution of the track. A worse scenario is that the track picks up a spurious hit in the densely populated inner layer.

Results on conventional b-tagger efficiencies from the LHC experiments typically are limited to momenta transverse to the beam (p_T) below roughly 500 GeV. Early simulation results indicated a falling tagging efficiency beyond approximately 150 GeV. Even with considerable optimization, results remain consistent with a falling efficiency at high energies, though obscured somewhat by the restricted momentum range published.

This article investigates a new method which, by relying only on Si detector hits rather than the reconstructed tracks, better maintains its efficiency at extreme energies,

by which we mean energies of at least 300 GeV, above which conventional
b-tagging performance degrades rapidly.

Summary

We describe a new hit-based b-tagging technique for high energy jets and study its performance with a Geant4-based simulation.
The technique uses the fact that at sufficiently high energy a B meson or baryon can live long enough to traverse the inner layers of pixel detectors such as those in the ATLAS, ALICE, or CMS experiments prior to decay.
By first defining a "jet" via the calorimeter, and then counting hits within that jet between pixel layers at increasing radii, we show it is possible to identify jets that contain b quarks by detecting a jump in the number of hits without tracking requirements.
We show that the technique maintains fiducial efficiency at TeV scale B hadron energies, far beyond the range of existing algorithms, and improves upon conventional b-taggers.

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