The Case for an Exotic Physics Object Definition and Related Online Iterative Tracking Improvements

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Introduction

Physics as with any evolving discipline is built upon the previous generation's knowledge and tools to innovate new techniques. B-quark tagging (b-tagging) techniques were developed and successfully utilized for the discovery of the top quark. Today, b-tagging is a tool for studying the Higgs and searching for beyond the standard physics. In difficult all hadronic topologies with limited missing energy, b-tagging can be one of few important handles on discovering new physics. Since its inception, b-tagging has evolved with the implementation of particle flow, refined secondary vertex algorithms, and advanced multivariate techniques. Naturally, this sophistication is extended to the trigger level with the necessary refinements to function within tight online timing constraints.

The strength of b-tagging is not restricted to its signal background differentiation, but the community sized impact enabled by the wide support of a singular physics object definition. The b-tagging algorithms are publicly documented with corresponding working points and data/mc factors derived by the physics object group (POG). The algorithms are integrated directly into the experiment software allowing fast adoption of subsequent improvements. The object can then be used interchangely as part of a large toolkit of jets, leptons, taus, photons, and missing energy.

Analogous to b-tagging, CMS can benefit from a background motivated exotic physics object definition, specifically a displaced jet tag. The jet is considered displaced in the sense that the jet is comes from a decay vertex measurably separated from the primary vertex of the event. As the prompt BSM parameter space becomes increasingly small, theorists continue to propose new models containing particles with detector scale lifetimes. These long lived particles generate striking signatures, with high discrimination power for visibly convincing discoveries. Unfortunately, these events can be easily cleaned out in prompt analyses or inefficient at the trigger level. A documented and CMSSW implementation of a displaced jet tag would serve as the foundation of further sophistication and topological specificity.

It is the aim of this research proposal to use Princeton's experience studying displaced jets, to create and support a displaced jet tag for initial use within multiple long lived analyses. The implementation would be performed with the intent of making the definition available wider within the experiment. With this object definition in mind, this proposal also aims to improve the timing for iterative tracking at the HLT through collaboration with the tracking POG.

Motivation

A standalone displaced jet tag would reduce the duplication of work related to long lived searches and enable a straightforward expansion of both prompt and long-lived searches. For instance, the displaced susy analysis [citation] performed a search for pair-produced long-lived RPV stops decaying to a b quark and lepton. The analysis focused on the two leptons and can benefit from the two long lived jets in the event. Additionally, inclusive prompt searches like mono-jet could investigate using a single displaced jet.

The CMS experiment has an advantage over ATLAS to collect data sensitive to displaced topologies at 13 TeV given the trigger coordination's flexible stance on allowing analyzers to develop specialized triggers. ATLAS displaced searches (with decays occurring within the detector) must require the presence of another object "X" motivated by the trigger used for the corresponding channel: dijet, lepton, MET [citation displaced vertex + X]. In 2014, a suite of displaced jet triggers was developed in coordination with the trigger studies group and iterative tracking experts. The goal of these triggers was to gain sensitivity to softer kinematics while remaining highly efficient to a variety of kinematic regimes and lifetimes. Two triggers are seeded at the L1 by an HT seed and two by a VBF seed specially targeting higgs decays. Two of the triggers utilize a specialized tracking iteration unique to displaced jet paths.

After the trigger development, a set of lifetime inclusive tagging variables were investigated in 25ns data. Building on the philosophy of the trigger strategy, the variables are background motivated and mostly utilize tracking quantities to reject "prompt" qualities. In example, summing the jet scalar sum p_t contribution

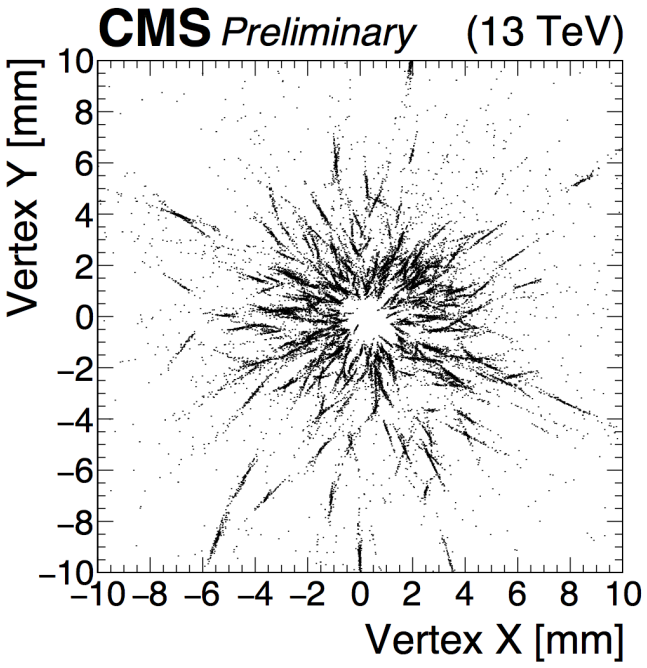

FIGURE 1. Displaced Jet signal events where an neutral 300 GeV X with a lifetime of $c\tau = 1$mm decays to a di-jet pair. For each jet, combinatorial vertices are fitted to pairs of tracks. Clustering combinatorial vertices gives visibly distinct displaced double and single jet vertices.

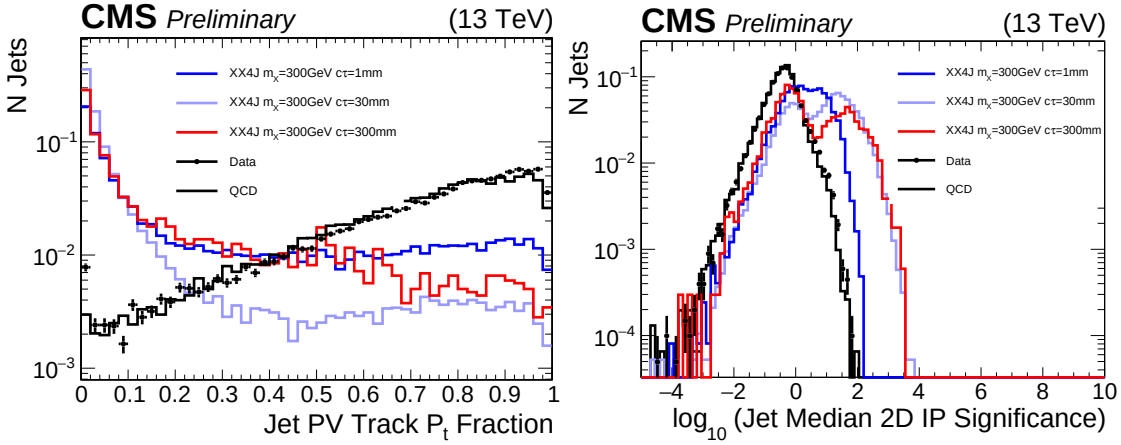

FIGURE 2. Candidate inclusive displaced jet identification criteria. The XX4J events consist of 2 long lived neutral X decay to di-jet pairs with varied lifetime.

from tracks included in the primary vertex fit. For displaced jets this fraction should be small. This strategy allows inclusive coverage of particles with long lifetimes with minimal model dependence. A corresponding displaced jet reconstruction note is in preparation based on early data.

To study clean samples of displaced jets, the particle gun interface utilized by object groups for performance studies (jet calibration, single pion, ect) was modified to generate a long lived particle gun decaying to two jets. This modification gives finer control of event kinematics and the distribution of particle lifetimes.

Additionally, there is certainty that all reconstructed tracks in an event are generated by the displaced vertex without performing track by track matching.

Timeline

The current state of displaced jet reconstruction studies is naturally aligned with the timeline of the CMS FPS Fellowship. Preliminary studies have been performed showing the strength of a displaced jet tag, a specialized suite of displaced jet triggers have been implemented online, and a note is in preparation on the variables that will enter the definition. What remains is finalizing the definition to provide a clean, well documented implementation for current and future analyzers. Once documented, the remainder of the fellowship will be spent improving iterative tracking timing at the HLT.

The first 4-5 months of the fellowship tenure would be dedicated to finalizing a definition of the displaced jet tag and the continued study of the SM background due to nuclear interactions within the detector material and tracks from long lived Standard Model particles. During the summer I would like to work with a summer student generating the proper documentation and improving the code for wider distribution. The final months of the fellowship would be spent working on online iterative tracking improvements.

Project Impact

I have been fortunate to have received a National Science Foundation Graduate Research Fellowship. The fellowship finances the majority of the cost of being stationed at CERN, however, the funding ends after 3 academic years. The CMS FPS fellowship's supplemental income would allow me maintain my presence at CERN for the next year without finding external support. The opportunity to work at CERN without a 6 hour time difference and face to face with the involved parties (tracking POG, long lived sub conveners, summer students, and analyzers) is essential to this project's success. The fellowship award would aide in generating interest from the experiment, leading to wider use of the exotic object definition as well as a improved performance and implementation resulting from wider collaboration.

Conclusion

This propsal represents a *novel* approach to searching for beyond the Standard Model physics with displaced vertices by creating an exotic physics object. This strategy to-do list can be summarized as:

- Develop a fixed version of displaced jet tags
- Develop supporting documentation and CMSSW implementation with a summer student for current and future analyzers.
- Initially support the object within the Long-Lived group, with the intent of expanding outside of the group.
- Improve iterative tracking timing at the HLT with the intent of improving displaced jet triggering

References

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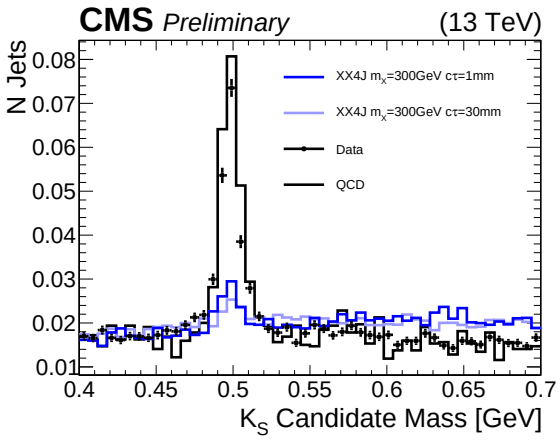
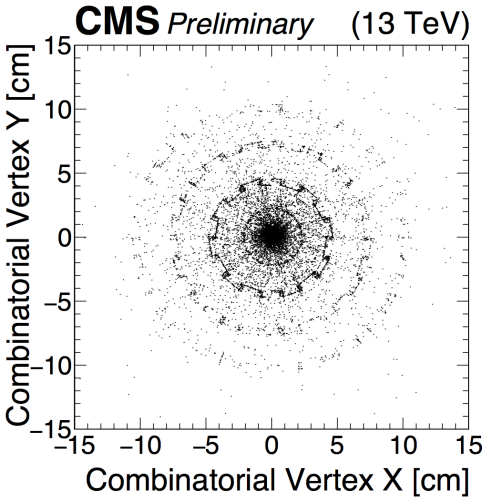
A1. Jet Tagging Background Sources





There are a large number of particles in the standard Model with detector sized lifetimes. The most relevant to displaced jet identification are neutral particles that have no corresponding track pointing to the primary vertex such as the $\Lambda^0 \to p\pi^-$ and $K_s^0 \to \pi^+\pi^-$. These particles are an irreducible background containing truly displaced tracks with large impact parameters. By taking combinatorial pairs of tracks in jets, it is possible to tag these candidates by applying the corresponding mass hypothesis. Once identified, these tracks can be individually removed from the related impact parameter calculations.

Displaced vertices can result from nuclear interactions with the beampipe and detector material. By fitting all combinatorial vertices in a jet we can check the spatial distribution of the vertices. High multiplicities of vertices with large significance can be seen in the beam pipe and the first few pixel layers. As this can occur for both signal and background, it is important that the cluster vertex momentum be high relative to the track momentum of the jet.

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