CMS Draft Analysis Note

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Inclusive Search for New Physics with Multiple Displaced Jets

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Abstract

This is an example of a *CMS Note* written in LaTeXusing the *cms-tdr* document class and processed using the same `tdr` perl script used in generating the CMS Physics TDRs. Instructions for producing CMS Notes and Internal Notes are given.

1 Introduction

Run I analyses by the CMS and ATLAS experiments have been highly constraining to the possible beyond the standard model parameter space. However, these analyses focus on processes where the where the visible particles of the final decay are prompt. Less explored are the scenarios of long-lived particles with lifetimes allowing decays within the detector, but outside of $c\tau_0 \simeq 500\mu m = 0.05cm$ where b-mesons dominate the background.

One analysis CMS-PAS-EXO-12-038 focused on neutral long lived particles which decay to dijets proved to have powerful sensitivity to a number long lived scenarios. Specifically, B. Tweedie et al.[CITATION] show that a phenomenological recasting of the search is most often has the best sensitivity to the considered hadronic supersymmetry motivated scenarios.

As the prompt parameter space becomes more constrained, the theoretical community continues to propose models which contain new long lived particles that decay hadronically [list references here]. The experimental interest has correspondingly grown motivating wider coverage of topolgies and signatures.

If the long lived particles are pair produced and decay to visible particles, the number of displaced objects in the final state tends to be large. For visible two-body decays there are at least 4 displaced particles.

2 Datasets

The analysis is based on the full dataset recorded by CMS in 2015 and collected by displaced dijet triggers as well as control calo H_T triggers. As this analysis does not utilze the presence of missing transverse energy the Silver JSON is used. The summary of the datasets used is given in Tab. 1.

Dataset
`/DisplacedJet/Run2015C-25ns-16Dec2015-v1/AOD`
`/DisplacedJet/Run2012D-16Dec2015-v1/AOD`
`/JetHT/Run2012D-16Dec2015-v1/AOD`

JSON
`Cert_246908-260627_13TeV_PromptReco_Collisions15_25ns_JSON_Silver_v2.txt`

Table 1: Summary of datasets used

3 Analysis Strategy

The analysis is structured as follows:

- Select events collected
- Measure the fake rate for a displaced jet tag in data.
- Calculate a per event probabability of N tags given the jet combinatorics.
- Check the agreement for the N_{tag} calculation. Comparing N_{tag}^{exp} with the true number of tags N_{tag}^{true}.
- Check the stability of the N_{tag}^{exp} prediction in the presence of signal contamination.

- We interpret the presence (or absence) of an excess in the distribution of N_{tag} within multiple simplified interpretations: XX4J, Displaced SUSY, and long-lived Neutralino

The background estimation is purely data driven and Monte Carlo is utilized for signal models in the limit setting and signal injection tests. We describe each step in the sections that follow.

4 Fake Rate Deterimination

5 N Jet Probability Derivation

$$P(N_{tags}|\{\vec{j}\}) = \sum_{config} \prod_{tagged} p(\vec{j}) \prod_{not-tagged} (1 - p\vec{j}) \quad (1)$$

6 Signal Injection Tests

7 Selection

7.1 Triggering

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's displaced vertex search [?] (with decays occurring within the detector) require the presence of another object motivated by the trigger used for the corresponding channel: jet, lepton, or MET. In 2014, CMS implemented a suite of displaced jet triggers developed by the Princeton group 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.

Currently two triggers targeting displaced jet signatures are implemented in the CMS high level trigger (HLT) menu, both seeded from L1_HTT175. Due to the L1 H_T in-efficiency at it's nominal threshold, we are constrained to at least a cut of $H_T > 350$ GeV at the high level trigger.

- `HLT_HT350_DisplacedDijet40_DisplacedTrack_v`
- `HLT_HT500_DisplacedDijet40_Inclusive_v`

Both triggers consist of an H_T requirement (the scalar sum of the transverse momentum of jets within the $|\eta| < 2.4$), two calorimeter based jets with $p_t > 40$ GeV and requirements on the tracks matched to both jets. To accomodate strict online timing constraints all tracking iterations are performed regionally (as is the strategy for b tagging not utilizing particle flow).

To enforce the entirety of the jet is contained with the tracker acceptance we require the jets to have $|\eta| < 2.0$. For both paths, the jets are required to have at most 2 "prompt" tracks. Here prompt means that the tracks have at most a 2D impact parameter of 0.05 mm. The considered tracks are constructed with regional iterative tracking `iter0`, `iter1`, and `iter2`. This requirement will be refered to as the inclusive requirements the jet. To limit the contribution of the SM diphoton cross section to the trigger rate the two jets are additionally required to have $N_{90} > 3$ and electromagnetic fraction between 1% and 99%.

For the displaced track trigger, we build on top of the inclusive requirement, and additionally require a single track matched to the jet with transverse displacement significance (2 dimensional impact parameter significance = $2DIP_{sig}$) greater than 5.0 with at least a transverse displacement of 0.05 cm. The significance is determined as the transverse track displacement L_{xy}

divided by the error on the measurement. The displaced track trigger utilizes a special iteration of tracking (`iter4`) in addition to `iter0`, `iter1`, and `iter2` designed to reconstruct tracks with 3D impact parameters as high as 20 cm.

7.2 Kinematic Cuts

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7.3 Displaced Jet Tag Definition

The displaced jet identification criteria is designed to be topologically inclusive to mixed decay toplogies of electrons and jets.

The basic requirement for the displaced jet tagging criteria is a single track with $p_t > 1GeV$ and $\chi^2 < 20$ GeV. Beyond the requirements implicitly enforced on the iterative tracking in the `generalTracks` collection, there are no further requirements (ex. total and pixel hit requirements). There are no energy composition requirements and no requirements of a reconstructed secondary vertex, both of which can exclude sensitivity to long-lived decays to electrons.

All quantities utilize 2D quantities, excluding the longitudinal dimension to prevent gross overestimations of displacement due to primary vertex mis-identification. When the signal model in question has a lifetime small on the scale of the longitudinal spread of pile up the primary vertex can still be accurately reconstructed. In contrast, as the lifetime approaches multiple centimeters the accuracy of selecting the correct primary vertex becomes highly model dependent. In fact, with beamspot constraints applied and no initial state radiation it is possible the primary vertex would not be reconstructed at all for sufficiently long lifetimes on the order of the beamspot radius.

7.3.1 Alpha Max

$$\alpha_{jet}(PV) = \frac{\sum_{i \in PV, tracks} p_t^i}{\sum_{j \in generalTracks} p_t^j} \tag{2}$$

7.3.2 The 2D Angle Θ_{2D}

The variable Θ_{2D} is utilized to characterize the recoil angle of the tracks from the flight direction of the long lived particle. Θ_{2D} is defined as the angle between 1) the 2D ray extended from the primary vertex to the inner hit of the track and 2) the track momentum vector at the inner hit of the track extended from the inner hit.

As Standard Model QCD jets do contain long lived particles and conversions, a typical jet has a very long tail in its distribution of Θ_{2D}. To minimize the affect of this tail the median value of Θ_{2D} is used (for the same reasons as it is used for $2DIP_{sig}$). Furthermore, as the typical value of Θ_{2D} spans many orders of magnitude near zero a logarithm is applied constaining typical QCD jet values of $-2.5 < \log(\text{Median}\Theta_{2D}) < -1$.

As mentioned previously, the smaller the boost of the particle, the more isotropic the decay angles. Thus, the decays of heavier long-lived particles yield larger values of Θ_{2D}. When the lifetime of the particle is small near 1 mm it becomes more difficult to resolve this angle, and as the lifetime approaches a few centimeters the signal is up to 50% efficient in a nearly background free regime. Jets capable of passing tight Θ_{2D} requirements typically consist of a single track.

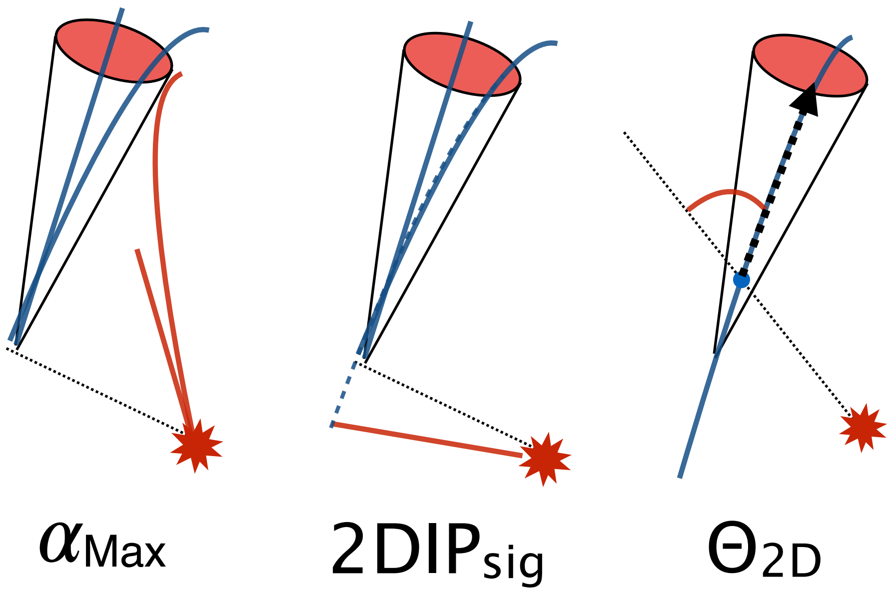

Figure 1: Diagram depicting the three variables used in the jet tagging definition. (left) the

7.3.3 Jet $2DIP_{sig}$

Variables leveraging the impact parameter information for a given jet are derived from the distribution of impact parameter significances. Fig. **??** demonstrates the improved separation of median IP significance relative to the mean (Fig. **??**). As background QCD jets contain real displaced tracks (Tab. **??**, **??**), the mean calculation is sensitive to outlier tracks with large IP significance. For truly displaced jets, all tracks have large impact parameter preserving a high median value.

7.4 Tag Definition

7.5 Signal Efficiency

8 systematics

As input to the Higgs combination tool we summarize our systematics below:

Background systematic	Value
Fake Rate Prediction	(10 - 100%)

Signal Systematic	Value
Trigger H_T cut Inefficiency	5%
Trigger Calo Jet p_T efficiency	2%
Luminosity	4%
Jet energy scale corrections	(10%)
Displaced Jet Tag efficiency	(5%)

Signal Specific Systematics	XX4J	Displaced SUSY	Neutralino
Acceptance due to PDF	1%	1%	1%

9 Results

9.1 Interpretation

In absence of a prominent excess in the N_{tag} distribution, we interpret the result of the fit procedure in terms of an exclusion limit on the parameter space of multiple simplified scenarios

9.2 Limit Setting procedure

We set the limit on a given parameter space by computing the CLs associated to each point of the parameter space. The LHC CLs calculation is performed with the Higgs Combination tool `Combine` using the Asymptotic approximation

9.2.1 XX4J

9.2.2 Displaced SUSY

9.2.3 Neutralino

10 Conclusions

References