Identifying JeT Substructure with N-subJesseness

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Abstract

We introduce a novel observable—N-subJesseness—with the purpose of identifying and characterizing JeT substructure. This observable is empirically derived from studying the ParTonic composition of high-quality JeTs. In this work we demonstrate not only the strong correlation between large N-subJesseness and SM JeTs, but also the potential for discriminating JeTs from various NP samples. We study how several substructure observables can be combined to improve the classification of diverse physics scenarios.

1 Introduction

Detection of new physics (NP) at the Large Hadron Collider (LHC) has proved elusive [1]. This does not necessarily imply that there is no remaining possibility for discovery at the LHC, but instead suggests that NP may be hiding in previously unexplored regimes of event topology. A robust approach to discovering new physics is therefore to design searches without strong model dependence, that are sensitive to only generic characteristics of NP models. A potentially lucrative and recently revisited highly clever strategy [2–4] is then to develop tools that measure event characteristics that are fundamentally distinct from the Standard Model (SM).

The event topology of Quantum Chromodynamics (QCD) at the collider scale is characterized by its small 't Hooft coupling, therefore we primarily observe two- or three-jet events. NP events may have similar or distinct substructure; we can conceive of scenarios with strongly coupled (large 't Hooft coupling) dynamics at TeV scales that don't form jets, or models with collimated cascades of complicated decays that produce similar radiation patterns. It is therefore imperative that we understand jet substructure to be able to discriminate SM jets from NP.

The goal of this letter is the same as the previously stated overarching goal towards discovering new phenomena at the LHC, but with a slightly different approach. Here, we aim to distinguish the work of Jesse Thaler (JeT), a Scientist at MIT (SM), from that of other phenomenologists of similar UV[1] completion. We will frequently use JeT to refer to both the person and his publications. This should be easy to understand, as many of us feel no separation between our work and our essence of being. For the remainder of this letter, we will refer to the work done by other physicists as Non-Jesse Publications (NP). Thus, as promised, we aim to distinguish SM JeT samples from NP. In order to do so, we introduce a new observable that can characterize the substructure of these samples and be used as an efficient discriminant: N-subJesseness.

The outline is as follows. We begin in Sec. 2 by defining N-subJesseness and the methodology necessary for its computation. We then discuss the results of applying N-subJesseness to discrimi-

[1]UV is a common abbreviation for *university*, implying of course the PhD program, and more specifically the timing of said program.

nate between the samples in Sec. 3. In Sec. 4 we conclude, and discuss the future relevancy of this new observable.

2 Definitions and Methodology

N-subJesseness, which we write as τ_J, is constructed to probe lexical substructure of physics publications. This observable is empirical by nature, as it emerged from studying the substructure of JeTs.

As with any data-driven particle physics analysis, we first assemble a sample of the twenty highest quality—i.e. most citations—JeTs [5–24]. As a baseline, we also consider pure JeT samples, meaning single author JeTs [25,26]. We call these the multi JeT and single JeT samples respectively. Note that we remove community papers, as the true degree of JeT-iness is largely unknown.

The fundamental physics within each JeT is identified using the `Python NLTK` [27]. With this toolkit, we can cluster and enumerate the Parsed Tokens (ParTons), or words, in the JeT.

The extraction of JeT substructure information is nontrivial. Much like QCD jet events produced at the LHC, there is some due diligence required to reconstruct the underlying physics. The ParTons of a JeT do not appear in isolation; like quarks in protons, they obey the constraints of a PDF. To probe the substructure, we must be mindful of *hadronization*, or Having Difficulties Rendering ONline Information, reorganiZing arXiv-preprints as Text In Order to Numerate. The *hadronization* of JeTs potentially obfuscates some of the underlying physics of interest, but it does not substantially change the dominant substructure. Some soft ParTons may be lost or combined, but the overall analysis is robust.

After *hadronization*, the JeTs still contain auxiliary information such as symbols, equations, and generic non-ascii characters. We restrict our focus to only the highest frequency ParTons. In order to accurately understand its substructure, we must further refine the JeT and remove this lexical noise. We do so by *grooming*, or Getting Rid of Odd Misrepresentations of equatIons, Numbers, and Graphs. Once the JeTs have undergone *hadronization* and *grooming*, they are in a suitable format for us to begin the analysis.

We make several additional cuts at this stage to remove Irrelevant Reading (IR) divergences, as they have no observable affect on the phenomenology. For additional information on these cuts,

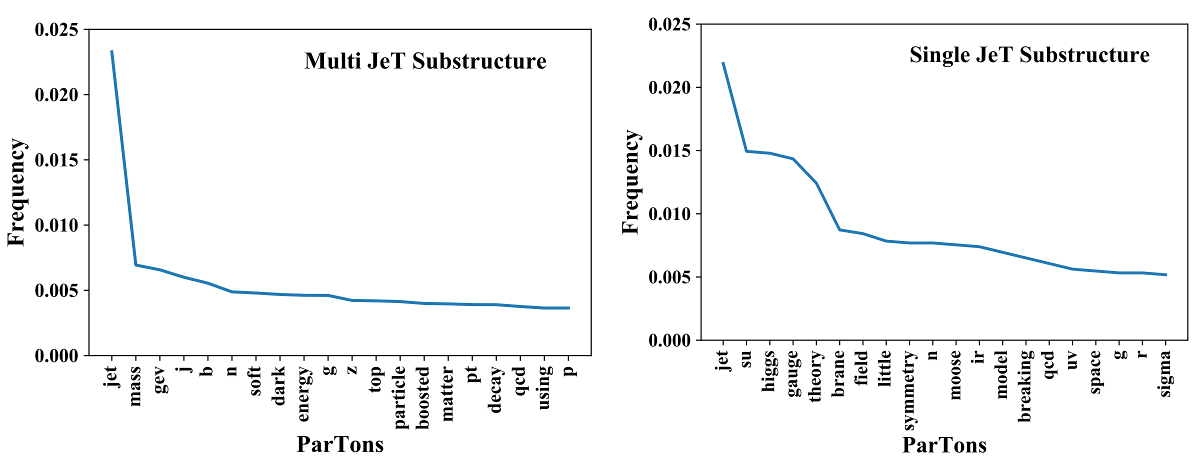

Figure 1: The relative ParTon abundance in the multi-JeT sample (left) and single-Jet sample (right). Note the obvious prevalence of *jet*.

see App. A. The output of the NLTK analysis is shown in Fig. 1.

The identifier of JeTs is clear: the high frequency of the word *jet* is a fundamental characteristic of a JeT. We therefore define N-subJesseness as

$$\tau_J \equiv \text{Freq}(jet). \tag{2.1}$$

In this letter we consider both local (per publication) as well as global (integrated over several highly-cited publications) N-subJesseness for characterization of these samples.

3 Results

Although the global τ_J of the JeT samples is striking, we cannot a priori claim that it is an efficient discriminator of SM JeT physics from NP. In this section, we first consider the substructure of various NP scenarios, and explore the discrimination efficiencies using τ_J and additional substructure observables. In all of our NP scenarios, we consider 10 high-quality samples again after *hadronization* and *grooming*.

An important NP scenario to consider is that of Arkani-Hamed [28–37]. Since the physics of this scenario had potentially strong influence on the formative stages of JeTs, it is important to compare the substructure of such physics. The ParTon distribution is shown in Fig. 2. Miraculously, even the global τ_J is exactly zero. This demands the question as to whether Arkani-Hamed was ever actually in causal contact with JeTs, but this fundamental concern is left to future work.

For other NP comparisons, we consider several scenarios constructed in the similar era. Namely, we consider Reece [38–47], Wang [7, 12, 39, 40, 48–53], Williams[2] [54–63], Slatyer [31, 64–72], Ruderman [43, 50, 53, 73–79], and Fan [39, 41–43, 46, 79–82] NP constructions. An overview of the global substructure is shown in Fig. 3. Note that while *jet* and its symbolic representation j occur in many of these scenarios, the relative abundance is still far below that of the multi JeT sample.

[2] This sample is equivalent to the LHCb NP scenario.

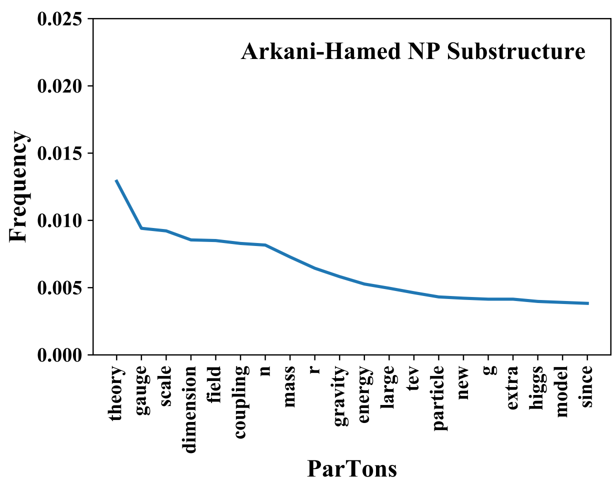

Figure 2: The relative ParTon abundance of Arkani-Hamed NP. Note that the global value of τ_J is exactly zero.

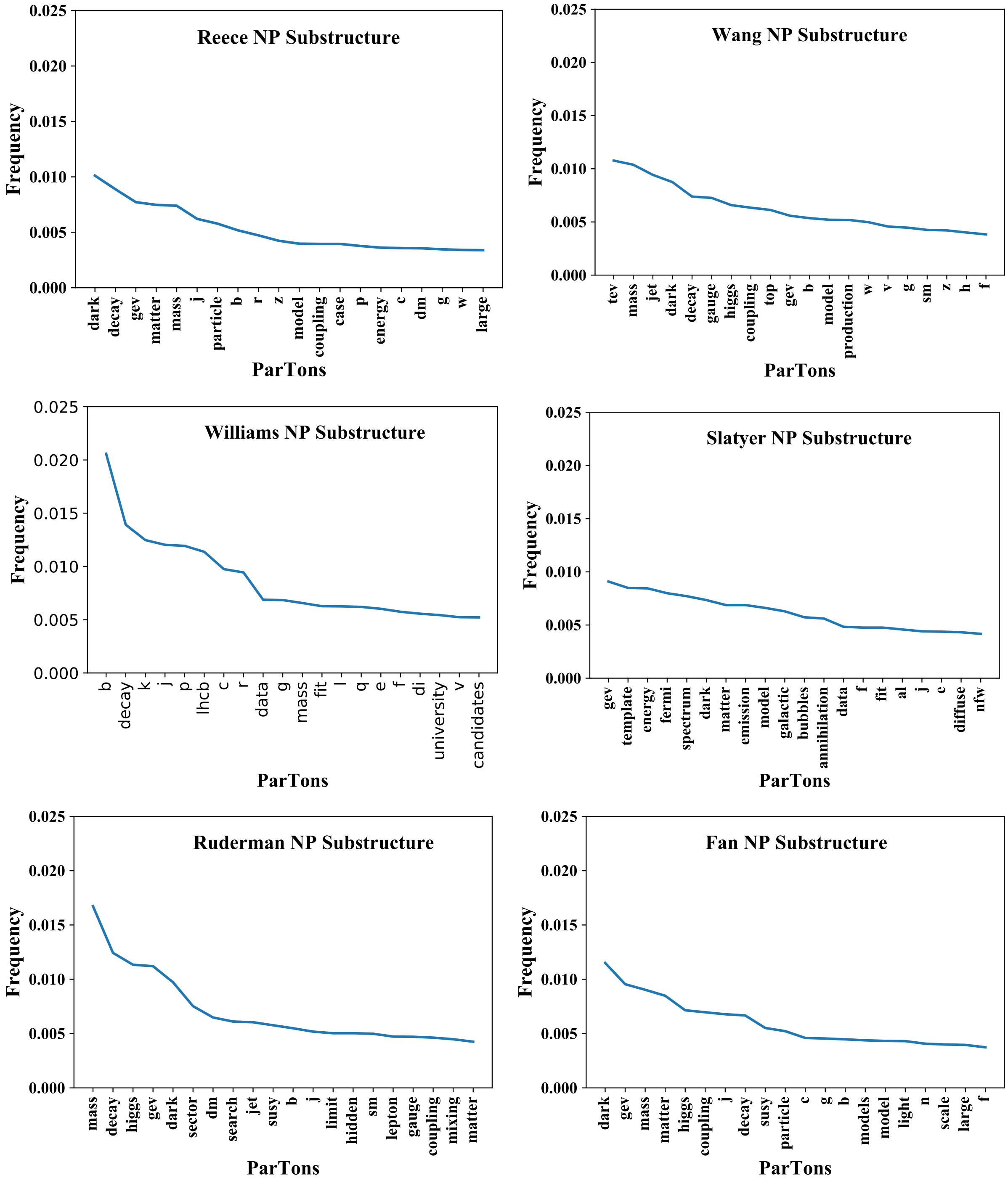

Figure 3: The relative ParTon abundance of various NP scenarios. There are several notable features of these distributions. For example, the Reece, Wang, Ruderman, and Fan scenarios all have very similar substructure. The Reece, Ruderman, and Fan samples are high in *gev*, whereas the Wang sample has a greater abundance of *tev*, suggesting that the Wang scenario can probe physics at larger energy scales. The only two scenarios that are concerned with data are the Slatyer and Williams NP, which begs the question of feasibility of the other scenarios. All scenarios have considerable abundances of *mass* and *decay*, confirming that particle physics research is being done at least at an undergraduate level.

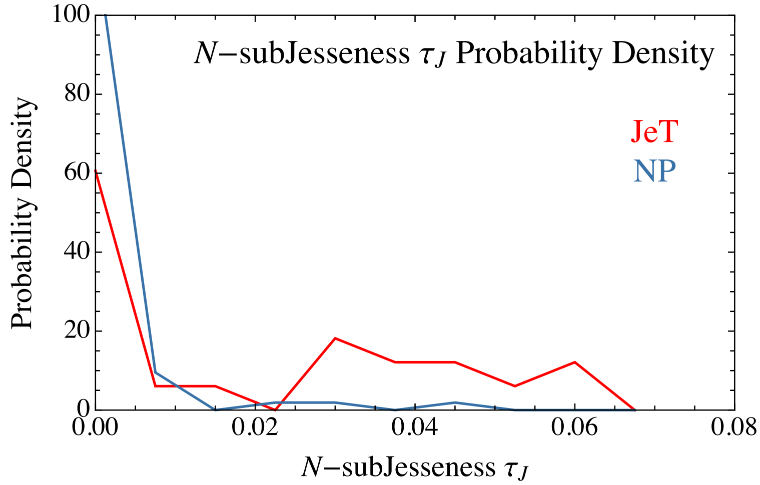

Figure 4: Probability density distribution in τ_J of the JeT (red) and NP (blue) samples.

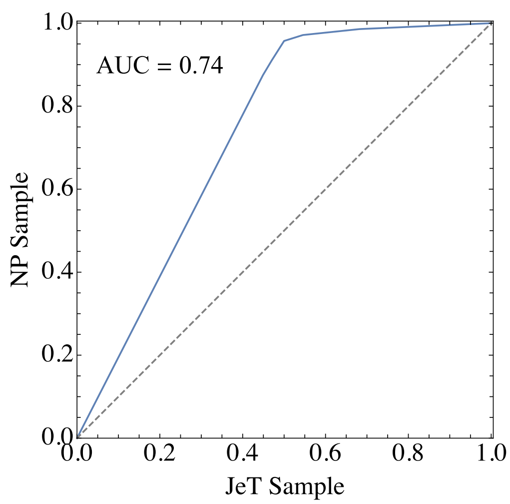

Figure 5: The ROC curve for discriminating the JeT sample from the NP sample. The AUC is 0.74, substantially better than naive random guessing.

3.1 The Discrimination Efficiency of N-subJesseness

We now aim to quantify how efficient τ_J is at discriminating between the JeT and NP scenarios. For higher statistics, we combine all of the mentioned NP samples into one larger sample, which we refer to holistically as NP. We also combine the single and multi JeT samples. The probability density in τ_J of these samples is shown in Fig. 4.

To quantify the separation of these distributions, we plot the approximate receiver operating characteristic (ROC) curve in Fig. 5 and integrate to attain the area under the curve (AUC). For reference, the worst case scenario of a constant slope ROC is drawn. This corresponds to an AUC of 0.5, which is realized for categorizing the samples by random guessing. When samples are perfectly separated, the AUC is 1.

We see that the the AUC is roughly 0.74, indicating improvement over random guessing. Therefore, even in this minimal inclusive analysis, we can use N-subJesseness as a means towards discriminating SM JeT and NP samples.

3.2 N-subJesseness and *decay* Rates

In this section we explore the potential of characterizing JeT and NP scenarios in 2d parameter space: τ_J and *decay* frequency, which we write as

$$\tau_{\text{decay}} \equiv \text{Freq}(\textit{decay}). \tag{3.1}$$

We chose *decay* as NP *decay* can often introduce novel event topologies distinct from SM JeTs. This discussion is very brief, and is only meant to introduce the concept rather than fully exhaust its potential. We therefore consider the global τ_J and τ_{decay}. The distribution of JeT samples and NP scenarios is shown in Fig. 6.

We find that generically the JeT samples occupy a distinct region of parameter space from the NP scenarios, many of which are clustered together. This suggests that one could improve the separation between the JeT and NP samples by considering several other JeT substructure observables. This is an excellent proof of concept, and we encourage others in the community to pursue more in-depth analyses using this strategy.

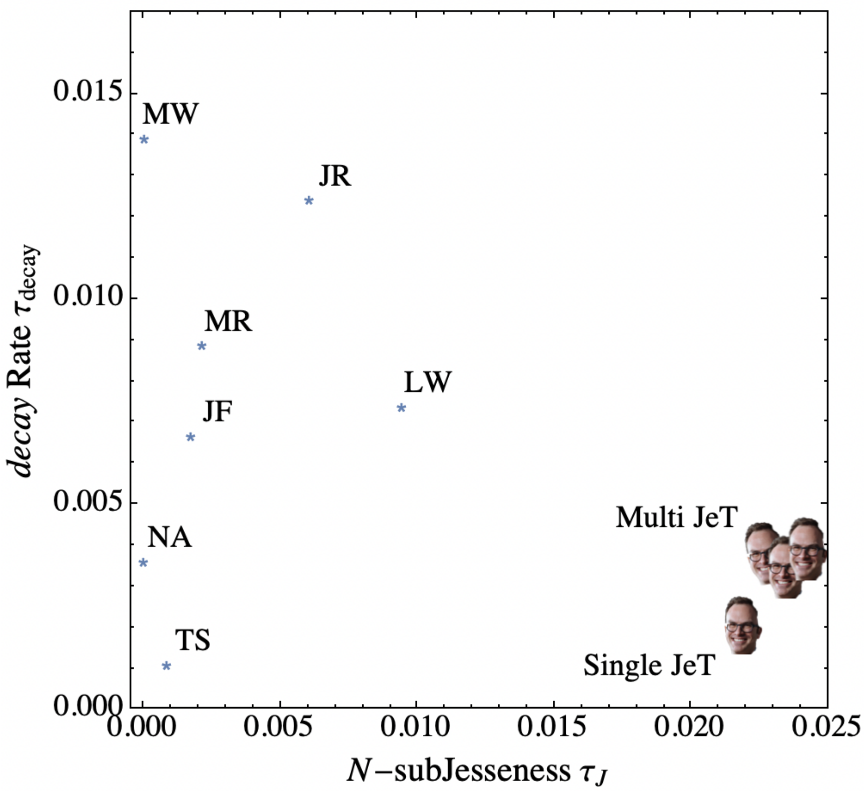

Figure 6: Distribution of JeT and NP samples in global τ_J-τ_{decay} 2d parameter space.

4 Discussion

Ultimately we have shown that N-subJesseness is an excellent identifier of SM JeTs. The substructure of a JeT is inherently much jettier than that of a generic NP scenario. This observable has strong potential to inform previous searches at the LHC, as well as hopefully future collider analyses. We would be very interested to see an application of JeT at a possible future muon collider.

The discrimination power of τ_J alone was nontrivial, but there are certainly ways it can be improved. For instance, it is tempting to want to apply machine learning techniques to further optimize the efficiency of NP vs. JeT classification. However, we find the discrimination efficiency was not improved after employing multi-level neural networks and training for an appropriate amount of CPU hours. One maybe be able to construct a more sophisticated convolutional neural network or utilize Deep Learning to improve the efficiency, but the leading methodology remains anthropic[3]. From these results, we must pose the question to the field as to whether or not machine learning is the future of identifying JeT substructure or NP, as our studies are less than promising.

To conclude, we strongly suggest the use of N-subJesseness whenever one needs to predict or understand the JeT content of a physics publication.

5 Acknowledgements

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A Further *Grooming*

In order to parse the samples in good faith, some additional grooming was needed. For example, trivial phrases that appear many times in all physics publications, such as `eq.`, `Sec.`, `JHEP` , etc. were removed as they occur with high frequency but do not contain any physics information.

Beyond these superfluous words, the issue of pluralization also required attention. Special care was taken to ensure that high-frequency words such as *theories*, *couplings*, *jets*, etc. were counted as their singular form. The `NLTK` offers a tool to automatically revert all words back to their stem, the `stemmer`, but this often over trimmed words and resulted in distributions in bizarre pseudo-words that offered much less comedic effect.

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