# Using Rest Frame Discriminants to Identify Z Boson Jets

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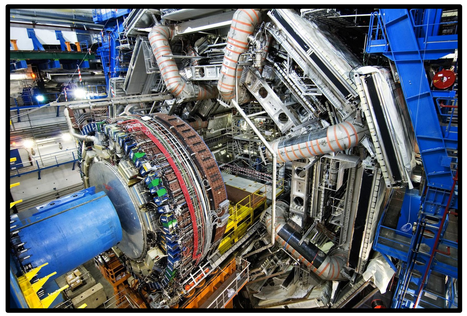
## Background

At **ATLAS** in **CERN**, beams of protons are collided, producing many elementary particles. These then decay into many more particles, where they hit detectors which measure their energy and momentum.



When quarks and gluons are produced, they decay before reaching the detector, into showers of particles called **jets**.

In this analysis, we try to distinguish jets resulting from **Z bosons** decaying into two quarks from single quark/gluon jets.

A common way to do this is by calculating **D2**:

$$D_2 = \frac{e_3}{e_2^3}$$

$$e_2 = \frac{1}{(Pt_J)^2} \sum_{1 \le i < j \le n}^{n} Pt_i Pt_j R_{ij}^{\beta}$$

$$e_3 = \frac{1}{(Pt_J)^3} \sum_{1 \le i < j < k \le n}^{n} Pt_i Pt_j Pt_k R_{ij}^{\beta} R_{jk}^{\beta} R_{ik}^{\beta}$$

This works because the two quarks each decay into showers, creating **subjets**, tighter clusters within the jet.

## Why is this important?

CERN and the ATLAS detector have been responsible for a number of important discoveries over the last 20 years.

Identifying Z boson to quark decay will improve the efficiency of finding the highest energy Z bosons, where deviations from the current standard model are most likely to occur. Challenging current theory can lead to new physics and

## Rest Frame D2

Under certain conditions, the two subjets may not be visible as they may overlap or interfere, making **D2 ineffective**.

One approach to resolve this is to construct a lorentz invariant discriminant.

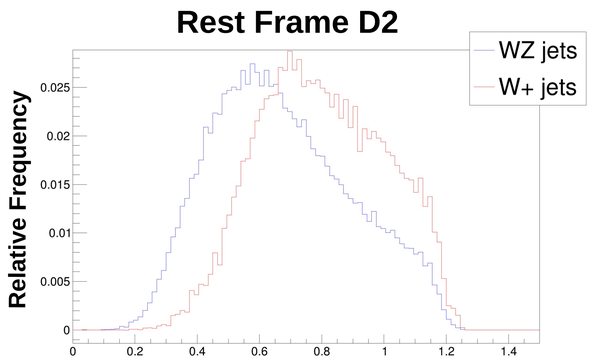
D2 can be calculated in the **rest frame** to be invariant under reference frames:

$$e_2 = \frac{1}{(E_J)^2} \sum_{1 \le i < j \le n}^{n} E_i E_j \Theta_{ij}^{\beta}$$

$$e_3 = \frac{1}{(E_J)^3} \sum_{1 \le i < j < k \le n}^{n} E_i E_j E_k \Theta_{ij}^{\beta} \Theta_{jk}^{\beta} \Theta_{ik}^{\beta}$$

## Results

Rest frame D2 had lower discriminating power than the lab frame variant, so we continued with further investigation into the relationship.




## Subjet Energy

We expect Z jets to radiate particles with most of the energy in two narrow cones, while background jets are expected to have more energy outside the two main subjets.

To measure this:
- Boost all particles into jet rest frame
- Cluster into subjets (using Antikt algorithm, R=0.6)
- Constructs a cone around the leading two subjets of a variable radius
- Measures the percent energy outside this cone

## Results

Overall, the energy fraction outside these cones provided similar discrimination to the rest frame D2 alone.

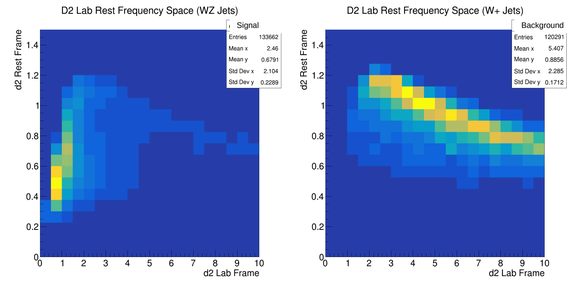
Smaller radius choices proved better at discriminating.

At this radius we are measuring subjet substructure, rather than the external energy originally predicted to work.
- Background signal were more likely to have no particles aligned so closely to the subjet

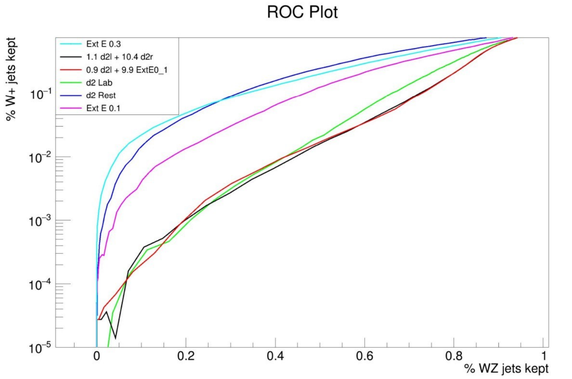
Also, these are moderately correlated with rest frame D2, implying they measure a similar phenomenon.

## 2D Analysis

Although subjet energy and rest frame D2 do not provide improvements on discriminating power alone, they can be combined to improve over current techniques.




By using a linear combination of the standard D2 with either the Rest D2 or one of the subjet energy measurements, we can improve over the lab frame D2 alone.




## Conclusions

Rest Frame discriminants can provide some advantages when combined with current techniques.

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Larkoski, A. J., Moult, I., & Neill, D. (2014). Power counting to better jet observables. Journal of High Energy Physics, 2014(12). https://doi.org/10.1007/jhep12(2014)009