I would like to focus my graduate work on jet reconstruction in the field of experimental high-energy physics. This work will be used for experiments using the Large Hadron Collider (LHC) at the European Organization for Nuclear Research (CERN). The LHC is scheduled to commence running at $\sqrt{s} = 13\,\text{TeV}$ for p-p collisions and $\sqrt{s} = 5.5\,\text{TeV}$ for Pb-Pb collisions from 2015 through 2017. During this time, I plan to be attending graduate school.

Current jet reconstruction algorithms are still being developed and considered for the most recent LHC run. However, the next run will feature environments requiring more aggressive grooming of the quark and gluon jets, while keeping the jet substructure intact. Measuring accurate jet characteristics is imperative if researchers hope to observe any new particles.

Intellectual Merit

Current State of Jet Reconstruction

Jet reconstruction has become a more complex field since the design process of the LHC. In previous facilities, such as the Tevatron, there was significantly less event pileup, averaging a number of primary vertices (NPV) per bunch crossing of 2.5. During the most recent run of the LHC, the average NPV was approximately 21. This leads to significantly more overlap of the jets, requiring grooming for accurate characterization of events.

Recent jet comparisons have been made between various cone sizes and grooming algorithms using the common benchmark process of $t\bar{t} \rightarrow b\bar{b}W^+W^- \rightarrow b\bar{b}\mu\nu_\mu qq'$ in simulated LHC environments. Jets were used to observe the hadronic W boson in a resonance of the dijet system mass. Defining $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$, jet cone sizes ranging from $\Delta R = 0.3$ to $\Delta R = 1.0$, with a resolution of 0.1, were compared. The current CMS default small cone size of $\Delta R = 0.5$ consistently gave uncorrected dijet masses closer to the actual mass of the W boson. However, the ATLAS default small cone size of $\Delta R = 0.4$ consistently gave a better mass resolution, where the figure of merit for resolution was the resonance width divided by its mean. The smaller cone size of $\Delta R = 0.3$ subsequently competed with the $\Delta R = 0.4$ cones in resolution. This was a surprising result that still needs to be understood since the smaller cone sizes also tend to leak an excess of radiation.

The grooming algorithms compared were pruning, trimming, and filtering. The current CMS default is pruning, which was found to be overly aggressive in those events with lower pileup and W momentum. Pruning also consistently had the worst mass resolution. Recent studies suggest changing to either filtering or trimming using smaller sub-cone sizes.

Proposed Work on Jet Reconstruction

The next step to take is to analyze the efficiency of selecting the correct jets using N-subjettiness cuts. N-subjettiness is a new substructure identifier designed with the purpose of identifying particles with high momentum that decay into jets. By identifying these cuts, jet taggers based on N-subjettiness can be used alongside mass resonances. These cuts will be determined for all of the different grooming algorithms, with a new grooming algorithm called mass drop, and a number of grooming parameter sets. Comparing the efficiencies using this cut between different algorithms will reveal the effect of grooming on jet substructure.

Much of this will be done in the near future, preparing the approach for the next LHC run. For future runs, the pileup is expected to jump from 21 NPV to 25 NPV during the beginning of the next run and eventually reach 50 NPV. Being able to handle the NPV increase will

maximize the experiments' luminosity and gather as much data as possible during the LHC's useful lifetime. While necessary to observe low cross-section interactions, this will complicate the analysis in many channels. There is another prominent effect expected to increase the need for new jet reconstruction algorithms. Cross sections for production of many particles will increase with energy. Jet production cross sections are expected to increase by at least an order of magnitude after increase the energy from 7 TeV to 13 TeV for p-p collisions. It will be more difficult to correctly identify which jets are from a certain parent particle of interest. Aggressive grooming algorithms that also retain the jet substructure will be needed.

Broader Impacts

Scientific Impacts

Accurate jet reconstruction is a means to an end. Many currently studied and hypothesized interactions have final states that include jets. The following are just three examples of processes that will require accurate jet reconstruction to study in the next run.

The first study that can be improved is studying top quark properties. Some theories predict that top quarks are composite, and when excited would emit a characteristic gluon. To find this in high pileup environments, the gluon jets need to be cleanly separated from the quark jets. In addition, current theories predict a vacuum that is close to instability. Stability depends on the mass of the Higgs boson and the mass of the top quark. Better resolution of the top quark could result in an unstable model, which is within current uncertainties. If this happens, new models outside the Standard Model will be required.

The second application would be the search for dark matter. The supersymmetry (SUSY) model predicts dark matter to be in the form of massive squarks. Even if the SUSY model is not accurate, dark matter exists, and recent observations from the AMS experiment suggest that it may be possible to find dark matter using the LHC. In this case, dark matter will be in the form of missing energy. Accurate reconstruction of all particles from the same vertex is needed to characterize missing energy, with the most difficult reconstruction from jets.

The third application of jet physics, heavy ion collisions, is where the results are the most difficult to anticipate. Jets are abundant in heavy ion reactions, making reconstruction much more difficult than in proton collisions. Currently, there are relatively few fundamental questions being investigated by heavy ion experiments compared to the information that might be available. The energy increase from 2.76 GeV to 5.5 GeV will make the analysis much more difficult, but it will certainly yield the possibility for more exciting results.

Societal Impacts

A significant portion of the public is excited by the activities at the LHC. Understandable descriptions of the Higgs boson were requested after its presence was confirmed. This portion of the public would be excited by new discoveries, such as the generation of dark matter. Furthermore, heavy ion experiments may lead to increased understanding of the early universe, another topic of interest to much of the public. Finally, one of the most fantastic parts about research at CERN is the international collaboration among the scientists. CERN is considered by some to be an ideal model for a global civilization. However, if the upcoming experiments are unsuccessful in identifying new phenomena, it will be difficult to fund such endeavors in the future. To continue that kind of collaboration, CERN needs to push the boundaries of physics during the LHC's final runs.