Saul Propp

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MCFM and DYNNLO for ATLAS

This summer, I spent my time working under the supervision of Dr. Qian for the ATLAS experiment at the University of Michigan, simulating cross-sections of various decay modes for the W^+, W^-, and Z^0 bosons, as well as for four diboson combinations, W^+W^-, W^+Z^0, W^-Z^0, and Z^0Z^0. The cross-sectional probability of various decay modes depended on the energy level of the simulation, so these values had to be calculated at a specified energy level. For my research, these energy levels were 8 TeV, 13 TeV, and 14 TeV, corresponding to past and future possible energy levels attainable by the LHC in Geneva. For the future energy levels, these cross-sections will be useful, as they are what the Standard Model predicts and experimental results can be compared to them, illuminating inconsistencies between theory and reality. The past energy level cross sections were useful for checking the data against experimental results.

The ATLAS experiment is one of the two general-purpose particle detectors at the Large Hadron Collider at CERN. The LHC uses a synchrotron to accelerate charged hadrons to relativistic velocities, producing extremely high-energy proton-proton collisions. By analyzing the particles produced in these collisions, ATLAS is able to provide a window into the nature of the universe at the smallest scale accessible yet. Already, work at the LHC has resulted in the discovery the long-predicted Higgs Boson, responsible for giving mass to the other particles. Currently the LHC is undergoing an upgrade, but when it turns back on at 14 TeV next summer, it will continue its quest to produce instances of new Physics beyond the Standard Model. In analyzing the data created at the LHC, ATLAS hopes to help answer many of the questions still pervasive in our physical theories, from dark matter to super symmetry.

To make sense of the experimental data created at the LHC, ATLAS needs theoretical predictions for the behavior of particles to compare data to, deviations from this indicating the existence of some phenomena outside our current understanding of Physics. However, determining what the experimental data means can be quite difficult, as it is often not the initial particles produced in the collision that are observed but the particles that they decay into. To make matters more complicated, our theories for these processes are probabilistic so observing a large number of events is necessary to understand what occurred between the collision of the two hadrons and the shower of particles observed by ATLAS. In Particle Physics, the strength or probability of a given interaction happening is called a cross-section, and is dependent on many factors including the total energy and the fine structure constant (which also depends on energy, as it is running). Calculating the cross-section of an interaction is crucial to determining whether it is present in the data, as well as to finding out if there are unexplained interactions present in the data as well. Herein lies my contribution to ATLAS.

Using terminal to access the LSA Condor Computing Cluster, I simulated the results of proton-proton collisions at 8 TeV, 13 TeV, 14 TeV, looking specifically at the cross-sections of the $W^{\pm}$ and Z^0 bosons. By creating BASH scripts, I was able to automate a great deal of the process of running simulations with varying parameters, including PDFs or Parton Density Functions which model the behavior of quarks inside the nucleus. Using MCFM for the diboson interactions and DYNNLO for the single boson interactions, I successfully calculated the needed cross sections. I was also able to check my calculations for the diboson interactions against the 8 TeV data created and published by ATLAS, which yielded theoretical predictions very similar to theirs (though a different PDF was used, causing differences up to 5%), with both theoretical predictions mostly agreeing with experiment (the WW interaction being a significant exception). Unfortunately, I was unable to do the same with the single boson interactions, as the data for 8 TeV are still unpublished.

To gain a qualitative understanding of how the theoretical predictions matched experimental results, I re-ran simulations of diboson interactions at energy levels from 1 TeV to 14 TeV, in increments of 1TeV. In ROOT I created a best-fit plot of these cross sections and also plotted the experimentally measured cross sections from CMS and ATLAS that were publically available. The analysis from this suggested that the theoretical predictions I generated in MCFM were in line with data from the LHC's two main particle detectors, ATLAS and CMS, at 7TeV and 8TeV, and yielded information about the general trend of cross sections at varying energies. These results support the accuracy of the predictions made in MCFM for higher energies, indicating that despite several shortcomings (underestimating WW cross-section, not using the ATLAS-primed PDF), these simulations do accurately model the processes in question.