Optimization of High-Energy Photon Identification at the LHC

By Ryan Kim

The Standard Model of particle physics is the theory of the observed fundamental particles and their interactions. These particles are the smallest building blocks of the visible universe, and they include six types of quarks, six types of leptons, and five types of bosons. All of these particles have been experimentally confirmed over the years, including the crowning discovery of the elusive Higgs boson in 2012. However, despite its successes, the Standard Model falls short of explaining some significant questions. First, it does not include gravity, one of the four fundamental forces. Further, it does not reveal the identity of dark matter, which makes up five times the amount of visible matter in the universe. With hopes of solving mysteries as these, particle physicists around the world attempt to improve our current understanding the Standard Model and to find physics beyond the Standard Model.

One experimental method of studying these particles in the Standard Model is with particle accelerators such as the Large Hadron Collider (LHC) located at CERN in Geneva, Switzerland. The LHC is a large circular accelerator with a 17-mile circumference that accelerates beams of protons to nearly the speed of light and collides them at one of the four detectors located throughout the ring. These detectors, including the general-purpose Compact Muon Solenoid (CMS) detector, capture the particles that ensue from the collisions of protons. The CMS Collaboration, of which the University of Notre Dame is a member, designed, built, and operates the detector and analyzes data from it. The University of Notre Dame group helped design and build the Electromagnetic and Hadronic Calorimeters and continues to have a leading role in the operation and upgrade of these detectors.

Various subsections of the detector read out data which is then analyzed by physicists to reconstruct particles and physical processes in the detector. One of these Standard Model particles that is detected by the CMS detector is a photon. Low-energy photons (50 MeV - 70 GeV) are common in the detector, and they were instrumental in the discovery of the Higgs boson, as it was the $H \rightarrow \gamma\gamma$ decay channel that was used in the discovery. A highly-accurate identification method (ID) for low-energy photons was essential.

However, this ID for low-energy photons is not appropriate for all photons, as high-energy photons (>200 GeV) can look different from low-energy photons in the detector. Though a high-energy photon ID has previously been developed for a specific kind of physical analysis, that ID is not appropriate for more general usage in multiple analyses. There are good motivations to develop a highly-accurate and more general high-energy photon ID, as high-energy photons could be key to new physics beyond the Standard Model if observed with the right physical processes.

As an example, in some theoretical models of dark matter and graviton production, there are a variety of final states that consist of a single high-energy photon and additional missing energy E_T^{miss}. All three Feynman diagrams shown in Figure 1 represent high-energy monophoton states with new physics involved. Just as the Higgs boson was discovered with a highly-accurate ID for low-energy photons, the searches for these theorized particles can only succeed with a highly-accurate ID for high-energy photons. The goal of this thesis is to develop an improved and more general ID for high-energy photons that can be utilized in multiple analyses moving forward, including these searches for new physics beyond the Standard Model.

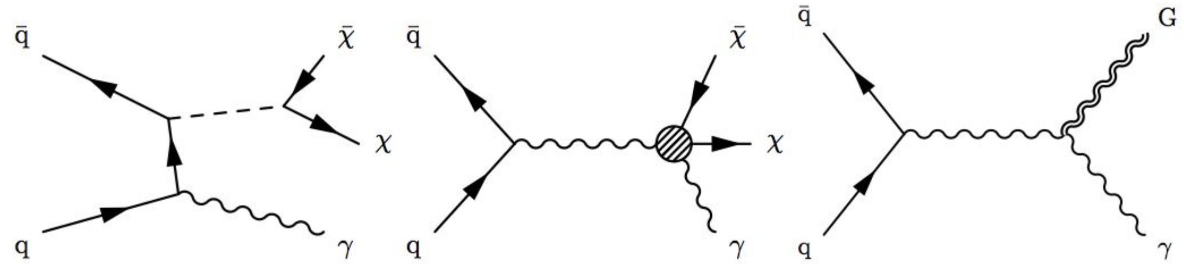

Figure 1: Theorized high-energy monophoton states with potential new physics beyond the Standard Model including dark matter models (left, middle) and a graviton model (right), where q = quark, ɣ = photon, χ = theorized dark matter particle, and G = theorized graviton particle.

To develop the high-energy photon ID, Monte Carlo simulations involving high-energy photons are used where the identity of the particles are known exactly. A selection-based approach is used for the ID, meaning that several variables characteristic of high-energy photons are taken and given a range of selection criteria. The optimal set of selection criteria demonstrates the ability to pick out high-energy photons from everything else. Once satisfactory performance is reached in simulations, the ID can be applied to data. The final results in fact show that the high-energy photon ID performs better than the low-energy photon ID. Data-to-simulation scale factors are also derived to correct for any mismodelling that may be present in the MC samples. A highly-accurate and improved high-energy photon ID has successfully been developed and is ready to be utilized in physical analyses moving forward.