Week 5

This week, for the computational and theoretical component of my research, I was tasked with investigating the kinematical behavior of particle interactions in collider experiments where both particles are being accelerated towards each other in the laboratory frame. In many instances, particle accelerators are configured to have a material - typically a particle-rich material, for example in the case of electron-proton scattering, liquid hydrogen is often used as a proton-dense material for ep interactions - fixed, while an electron beam, for example, is accelerated towards it, where then interactions are observed by a detector. In my previous investigations, it was implicit that the interactions I was analyzing were fixed target experiments. Thus, the kinematic derivations were for fixed-target experiments, meaning that in the laboratory frame, one of the particles was at rest. Now, what do I mean by the laboratory frame? Essentially, the lab frame, when discussing particle interactions, is the frame in which the target particle of the interaction is fixed. This is not the only way to evaluate a particle interaction, however. Oftentimes, in scattering and similar two-body problems, one could evaluate the interaction in the center of mass or center of momentum frame. In this case, the total momentum is zero. Thus, for a fixed target experiment in the CM frame, two particles are directed towards each other with equal and opposite momenta. But what about when we have the target particle moving in the lab frame? In this case, things are a bit trickier but there are some nifty definitions to smooth things out qualitatively, so let me transition into my main focus of theoretical research this week, which was Deep Inelastic Scattering.

In a DIS experiment, a high energy lepton (electron) is scattering off quarks inside the nucleon (proton), leading to its break-up into a hadronic system. The interaction is described by the emission and absorption of a virtual photon, which is essentially the mediator of the interaction in quantum field theory. Let’s investigate this phenomenon for a fixed proton target and moving proton target in the lab frame. In writing the 4-momenta, I’ve set c=1 for high-energy conventions. Evidently, the proton only has a time component, while the electron is traveling in the +z direction by convention. As we can see, we can write the components for the momenta after the collision in terms of measurable parameters. We can do the same for a moving target, but instead the proton has non-zero spatial momentum. Now, we can define some important measurable kinematic variables that can characterize the interaction. These quantities are dependent and can be rewritten in terms of each other. Using these, physicists can perform kinematic reconstruction, which essentially means, because of these dependencies, we can measure a subset of these quantities and use that to determine the rest of the kinematics of the interaction. For example, there has been one accelerator site that has done electron-proton collisions, HERA, and it most notably revealed (at the time) the highest precision measurements of the structure function which alludes to the distribution of quark momenta in the nucleons.

Experimentally, Casey, Joshua, and I worked on setting up an experiment for testing cosmic muon showers using the scintillation properties of plastic scintillators and a scintillating glass sample. Essentially, the set-up is as follows: we set up two plastic scintillators (second not shown) which will act as our triggers when a muon is in coincidence with both of them. In order to ensure that we don’t measure accidental coincidences, essentially when two different muon events strike the scintillators simultaneously, we minimize the cross-section area at which a muon can strike. To do this, and to ensure our muon events also strike the scintillating glass we align one longitudinally along the glass and one perpendicular below it. This helps ensure that when we run our experiment, our muon events pass through all three scintillators (although it is not full-proof). When our plastic scintillators are in coincidence, it triggers our DAQ for readouts from the scintillating glass. Here, we have two ultra-fast PMT’s that can read out the initial Cherenkov radiation that occurs from the muons in our sample, as well as the subsequent scintillation light. However, while we had success in establishing the electronics in the correct configurations to take data samples, there were some complications in the timing mechanisms between our trigger scintillators and the signal being received from the ultra-fast PMTs. Essentially, we were receiving signals from our scintillating glass sample before the trigger window from the plastic trigger scintillators. Before determining this, we ran an overnight sampling where our DAQ rendered indiscernible results for the glass signal response. Today, we look to resolve this timing issue and run a full experiment where I can hopefully present the results next week. These results will give insight into the flux of muons at this particular altitude, latitude, and particular cross-sectional area we’ve chosen. It will also give insight into the material properties of our scintillating glass and its response to highly relativistic charged particles.

Looking forward, I look to understand these cosmic particle showers and analyze how they are impacted by the density and composition of the atmosphere and more generally the medium that they travel in. After a successful cosmic muon run, our group would like to formulate and test new experimental set-ups to get a better evaluation of our scintilating glass sample.