Honors Research Reflection Essay

The research project we did this semester was to delve deep into calculating corrections to leading-order results that we have been doing in previous semesters. Leading-order calculations are really good in many instances, but of course, as technology and data acquisition get better and better, it is in our interest as theorists to push our own precision in calculations to match or even exceed that of experiment. Leading order corrections are the first step in doing so, and open a pandora's box of new mathematical techniques to handle the increased complexity of the expressions we find.

For instance, when we go to calculate an amplitude for a process that contains an internal photon/gluon loop, we need to integrate over all possible momenta that the boson can have, since it is not constrained by the known momenta of the external particles. However, in doing the calculation, we find that the integral actually results in infinity, which is of course very bad news. We studied two steps to remedy this and get reasonable results that we can use to improve our calculational precision: regularization and renormalization. The first step, regularization, involves a number of mathematical tricks to essentially map the infinite integral into poles of $1/\varepsilon$, where ε goes to zero. With this, are able to isolate out the problematic terms much more easily. This step is very long and physicists many decades ago invented new mathematical techniques in order to do these calculations.

The final step is renormalization, which is a more simple step that simply involves absorbing the isolated infinite terms into known physical quantities, called "bare" quantities. The motivation for doing this is that, as an example, the charge of the electron would be infinite if we were to be able to view it from infinitely close up. However, since that is impossible as it would require infinite energy, we can effectively "ignore" the infinite part and calculate only the visible part. With all of this, then, we have eliminated the infinite terms, and the leftover terms are the ones that provide the corrections/improvements that we were originally looking for.

We also covered a couple of other concepts that were more directly related to what my professor, Dr. Guzzi, works on, that being the DGLAP equations. Essentially, we have models for protons that can give the momentum fraction that its constituent quarks will have at any given energy, but those models aren't calculatable from first principles, meaning we have to get it from data. However, the DGLAP equations *are* calculatable from first principles, and they describe how the models change when the energy scale changes. We are also interested in calcuating corrections to this, as well as improving the computational algorithms that are used.

As with the previous reflection I made, we are still doing preliminary learning and studying in order to be fully prepared to take on a full project, meaning we didn't directly impact the field by providing some novel research. Next semester, however, I am no longer going to be doing the credited "Directed Methods" class and will be hired as a full Research Assistant under my professor, because we will finally be ready to start working on some of his projects. One candidate project is the aforementioned improvements to the computational methods for the DGLAP equations. There are some others, but I don't know enough details to confidentally state them in this report. Either way, next semester's report will more than likely contain some novel research.

Our goals were to completely study the basics of regularization and renormalization, and apply it to some more simple processes and calculate the final result. We did this through a few projects in which we just exactly that: just a bunch of calculations and comparisons with results from the literature. Our other goal was to be introduced to the DGLAP equations and study their use cases a little bit. This was largely achieved, though with the hurricane and other things, we ended up a bit behind schedule and had to rush at the end, but we still largely achieved all of these goals that we set out to accomplish.

I absolutely grew during this experience. This knowledge is absolutely indispensible for any physicist, and the number of mathematical and physics concepts I learned throughout this semester were very large. On top of these specific NLO and DGLAP concepts, we also inadvertently (sometimes it was intented) filled in some of the gaps I had in my own knowledge along the way. Many missing pieces were finally connected and I feel like I have a massively improved understanding of not only basic quantum field theory concepts but also more advanced QFT concepts such as NLO calculations and the DGLAP equations.

In terms of how this can be applied to other coursework, there likely won't be much, except in next semester's Quantum Mechanics II taught by this same professor I work under. In general, though, the content was far above anything else I'll cover, and I think that my work ethic, time management, and so on were already more than satisfactory. (they had to be, else I wouldn't have made it this far!)

Critical thinking was without a doubt the main Honors foundation we focused on. Our professor did really well at providing just enough context and information to get us going but didn't give away the answer, meaning we had to think and find some new/creative ways to solve these problems that up until then we had never done before. As I said before, physicists themselves invented techniques to handle these very calculations; of course he didn't expect us to rederive them ourselves, but he provided enough of a boost for us to figure things out ourselves, which allowed us to gain a better understanding and a higher level of skill for these concepts.

In general, this was a fantastic experience. The previous semester of work under this professor was great, but there were a lot of allusions to NLO calculations, and many QFT books cover it, so in our preliminary reading there was a lot of discussion on these concepts, so finally being able to get our hands dirty and do some cool (albeit insane) calculations was fantastic.

I also wanted to add (since it wasn't explicitly a question in the prompt) that I was fortunate enough to get to present my research at the SESAPS (Southeastern Section of the American Physical Society) conference at the end of October. It wasn't research I did with this professor, rather it was research I did at CERN over the summer, but it was closely related. Further, I wouldn't have had the opportunity to do the internship over the summer without the advanced knowledge I gained through working with the professor, so I would definitely credit the research and the appearance at the conference to this research.