Measuring the Magnetic Dipole Moment of the Top Quark

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The top quark is the heaviest of all fundamental particles so far discovered. One hypothesis as to why the top quark is very heavy is that it is not fundamental, but rather a composite particle made up of smaller, more fundamental building blocks. This hypothesis can be tested by looking for large deviations of the magnetic dipole moment of the top quark from the value predicted by the hypothesis that it is a fundamental particle. I set out to work on a computer simulation that plots the distribution of photons emitted by the top quark for arbitrary values of the magnetic dipole moment. Even though the project did not succeed in achieving its goal, I learned a great deal about what it takes to be a follower of Jesus as a physicist.

INTRODUCTION

As a theoretical particle physicist, I study the smallest and most fundamental particles of nature as well as the laws that govern their behavior. Everything in the visible universe is made up of atoms, which are made up of protons, neutrons, and electrons. Protons and neutrons are in turn made up of Quarks. There are 6 different quarks, one of which, called the Top quark, is the heaviest fundamental particle so far discovered by humans. It weights 172 times the mass of the proton [1], and about 75,000 times the mass of the lightest quark (the Up quark)! There in lies one of the puzzles in our current understanding of the the fundamental particles of nature; why is the top quark so much heavier than the rest? In general, the origin of masses, and especially mass hierarchies are among the most important challenges facing particle physicists.

Theorists have speculated well motivated, beautiful models to explain the heavy mass of the top quark. One of these proposals, the one I'm interested in, hypothesized that perhaps the top quark is itself not fundamental, but composite, made up of even smaller particles [2]. If history is a good guide, whenever we thought we found the most fundamental particles, we ended up realizing that they are actually made up of even smaller particles, so why not make this hypothesis?

No harm in hypothesizing, but to make the transition from hypothesis to theory, we need to test the hypothesis through experiments and find statistically significant evidence. So what kind of experiment could one conduct to test whether the top quark is composite or truly fundamental? History, again, lends us a hand. It turns out, people had faced similar challenges in the past while studying the proton and found excellent experiments that firmly established the proton's composite nature. The internal structure of composite particles can be inferred from the pattern of light that is emitted or scattered by them. A parameter called the Magnetic Dipole Moment will take very different values for two particles of the same mass and total charge depending on whether or not the respective particles have internal structure.

My task was cut out for me. I need to study, through computer simulations that I have to write myself, what the pattern of the emitted photons looks like for different values of the Magnetic Dipole Moment of the top quark. Based on the simulations, I was then to "recommend" a search to experimentalists at the Large Hadron Collider of what kind of events they should look for. If this succeeded and I made a meaningful contribution to the effort of measure the top quark's Magnetic Moment, I would find personal fulfillment in my work, science would progress, and God would be honored through my testimony.

This was the first project I took up with my adviser at the start of my third year in grad school. Then, I had just changed advisers, and was feeling a little shaky about my tenure at grad school. I put a lot of hopes in this project to fulfill what I felt was lacking so far in my career - a solid promising project.

I faced a lot of challenges, not least of which was the fact that I knew absolutely no programming. However, instead of moving to another project, I saw this as an opportunity to learn C++, something I should learn anyhow. Another significant challenge was building on a substantial amount of code that had already been written by my adviser and a grad student before me. To say the least, physicists are not the best programers. I certainly did not fully appreciate how big these difficulties were going to be. I believed that God was with me and that he will see me through. As long as I'm willing to work hard and seek his guidance, he won't let me fail, I thought.

FACING FAILURE

I slaved away at this project for two and half years. Though I worked on other side projects, this was the center piece of my efforts. Towards the end of the fall quarter of my 5th year, I had a fully functioning code. I ran several simulations, and heartbreakingly, I got gibberish results. It turns out, there is another important physics (Initial State Radiation) that needed to be incorporated in the simulation before I could get meaningful

results.

There I was at the end of my 5th year of graduate school with several failed or unfinished projects. While my cohorts were graduating and moving on to do post-docs and other jobs, I had not a single paper to my name.

It is still difficult for me to describe how those times felt. I still feel the remnants of the pain. Put simply, I felt like a big fool to have put my trust in God. This is the side of trusting God you won't hear about at church, I thought. You can trust him all you want, but He does as He pleases.

Anyone who is not me, watching my situation or hearing about it, will dismiss my case as someone who ended up where He was not meant to – a misfit. I myself was tempted to rationalize my situation as resulting from the fact that I did not have what it took, and I shouldn't be blaming God for my own failure. But then again, He could certainly have given guided me away from what I was not fit to do. Why didn't He do it? What hurt the most was the feeling of being abandoned by God. Why didn't He tell me to quit grad school? To the best of my knowledge, I was open to his guidance. If He had told me to quit grad school, I would have done it. In fact there were two significant experiences where I was the most in surrender and the most at peace and willing to do absolutely anything that God wanted. In those two moments I prayed, "Father, do you want me to quit physics?" And I got unmistakable assurance, "No, I don't want you to leave physics."

I became very bitter. The only explanation I had for my failure was that either God was enjoying seeing me miserable, or He has altogether forsaken me. There was no way in my mind that He could love me and care for me and just watch me go through this.

I seriously contemplated walking out on him. I could not see myself being able to do what Jesus asked his followers to do. I could not trust him. Any time I hear about how good He is and how good His promises are for us, I fumed and seethed in silence. Church was becoming intolerable.

I remained stuck for a while between the two insurmountable rocks of disillusionment about God and fear of godlessness. God's grace found me there one evening in the form of a simple realization. I was again fuming as usual about a promise (I believe it was in Jeremiah, I don't remember exactly). Then a thought occurred to me, following God has become simply impossible for me, it has become impossible for me to be in a relationship with him, unless I love him blindly to the exclusion of everything else happening around me. The realization did not feel nearly as stupid as it might sound to a listener who doesn't know the context. In the opposite, it gave me a new hope and direction. If I am to remain in Him, I have to first love him with full devotion disregarding what is happening to me. This is in fact exactly Jesus' calling to His followers, "whoever wants to follow me must hate himself." The force and clarity by which the thought appeared surprised me. And I recognized the moment as an open door leading homeward – back to God.

It meant that I will give up my disillusionment, my hopes, dreams, aspirations, my shame, sense of foolishness, and simply seek to love God. I realized at that moment that if I'm honest, I don't really love God at all. I knew that because it was meaningless for me to hear that He loves me. If you love a person, you will naturally be anxious to find out whether or not they love you back. If you are indifferent as to whether they love you or not, then very likely you do not love them. That is where I were, I did not care so much whether God loves me or not, what I cared about was whether He will do my bidding or not. I decided that the only way I could have any future with God was if I love him to the exclusion of everything else in life that I cared about. Unless I become a man who loves God more than himself, more than the world, more than anything in the universe, I simply will not be able to follow him. The only force strong enough to get me unstuck and free me from the ever present temptation to walk out on him was complete love to the exclusion of everything else.

Since that day, I have come a long way. I have regained my sense of self in God, and I have a direction for my career. I am going to stay in physics, as a teacher. What God wanted was for me to stay in physics, not for me to become Einstein, therefore, whatever way I find that will allow me to stay in physics, I will do it.

CONCLUSION

I know we all have testimonies of what God is doing in our research or our work. Sometimes we fall into the false thinking that unless our research does something to make the world a better place, or help the poor, end poverty, heal the sick, etc., then it is not valuable in God's Kingdom. We also tend to think that integration of faith and work means finding the worth of our work in the grand scheme of God's Kingdom. But, God works in our research in many ways, not least of which is bring us to better relationship with him. He works in our failures too, and nothing is wasted on him. Integration of work and faith could sometimes simply mean seeing God wrestle with us in the mundane and small things just as much us in the big successes and failures.

[1] J. Beringer *et al.* [Particle Data Group Collaboration], Phys. Rev. D **86**, 010001 (2012).

[2] C. T. Hill and E. H. Simmons, Phys. Rept. **381**, 235 (2003) [Erratum-ibid. **390**, 553 (2004)] [hep-ph/0203079].