Summer Research Project Journal

Exploring excited B mesons at the LHCb experiment

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Contents

1 Introduction

Over the course of my project, I regularly wrote short journal entries, discussing some of the work from the week, my experiences and how I was feeling about the project. In each subsection there is also a brief summary of the tasks, meetings and achievements from the week.

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2 Journal

2.1 First Thoughts

In the days before starting, I have been feeling a little nervous about working in a new environment, but also excited to learn more about particle physics and scientific research in general.

By the end of the project, I would like to be more experienced with coding in Python, have developed my presentation skills and confidence (in particular, get better at public speaking) and have a better idea of whether I would like to pursue a career in research. I think the project will also be a good opportunity to find out whether particle physics is an area I am interested in taking more modules in as I progress through my undergraduate degree.

2.2 Weeks 1 & 2

7th July 2023

The first two weeks of the project have been challenging at times and there has been a relatively steep learning curve, largely due to my lack of experience and familiarity with the tools and software I have been using. In particular, I am using the text/code editor "Vim" and the data analysis programming package "ROOT" (software that is ubiquitous in particle physics) both of which I have not had any previous experience with. The main focus of the start of the project has been working on simple python scripts and working with basic data structures in ROOT or performing simple fits to data to get up to speed with the sort of work I will be doing each day.

Most of the first day in the office was spent setting up accounts and getting things installed on my laptop so that I could write my own code and access previous work from other members of the group. I also followed some online tutorials on the basics of ROOT and how to use the terminal to access files. I have found it useful to always have a pen and paper by my side for jotting down commands and any useful information I need to come back to regularly. Each day things have got easier though and the frequency with which I check my notes has decreased rapidly.

On Thursday of the second week, I attended a BBQ run by the physics department for PhD students and staff. This was a nice opportunity to meet some of the academics and postgraduate students working on different projects. A large portion of the LHCb group went along and we sat with some of the people working on neutrino physics projects (e.g. JUNO, HyperK, etc. - see EPP page for more details of these experiments).

Summary:

- Setting up Ubuntu virtual machine on laptop
- Following programming tutorials for ROOT
- Python scripts
  - Plot dimuon invariant mass distribution
  - Fit model to dimuon invariant mass for different decay modes and with/without mass constraint on B_c^+
  - Comparing standard deviations (σ) for these fits
  - Fits to B_c^+ candidate mass distribution
- Background reading for the project
  - Previous papers, academic journals, etc published by the group
  - Analysis note that others in the group are currently working on
- LHCb Group Meeting
- Weekly progress meeting with supervisors

2.3 Weeks 3 & 4

21st July 2023

Towards the end of the second week and at the start of the third week, I started working on the public engagement activity for my project. Initially I had intended to write a blog on Warwick Blogs but after some discussion with other students, I decided it would be better to create something in the style of a blog (this journal and the slightly more science-heavy report) and upload it to the Physics Society website as this would be more clearly accessible to other students interested in applying for URSS projects but also to prospective university students and wider audiences outside of physics. Rather than using software I was already familiar with, I thought it would also be a good learning exercise to use the LaTeX editor Overleaf. Before starting the project I had not used Overleaf at all but I am likely to use it for writing lab reports in my third year so I was keen to start getting familiar with it.

I have treated the public engagement as work to be done outside of the office, treating it as a reflective exercise at the end of the week or in the evenings and prioritising working on code when I am in the office. Over the past two weeks, I have moved on from the basic fitting scripts I was writing in the first couple of weeks and have instead been looking for correlations between fit observables. In the event that a correlation can be seen, it is important to be able to explain its origin.

Each week (usually towards the end of it), I have a progress meeting with my supervisors (Tim and Fernando), Tom Blake and Vedanshu Mahajan. Vedanshu is completing a Masters by Research with the EPP group and works closely with Fernando on an analysis which is very similar to the work I am doing and Tom is an academic working in the rare decays group. At these meetings, I present slides with code or plots I have produced throughout the week and Tim and Tom often provide comments on my work, suggesting ideas for how to resolve problems or where to add extra details to plots or tables. Fernando was not in the office for a few days of week 3 so when I encountered some issues with what I was working on, I spoke with Tom and he helped me make significant progress. Having this support available has meant that even when the work seems quite challenging, I have never felt that I am unable to make progress or that I am out of my depth.

Summary:

- Working on online public engagement
- Python scripts
  - Plotting dimuon invariant mass against B_c^+ candidate mass in fit region
  - Fitting sideband data for dimuon invariant mass and B_c^+ candidate mass distributions
- LHCb Group Meeting
- Weekly progress meeting with supervisors

2.4 Weeks 5 & 6

4th August 2023

This section marks the halfway point of the project and I am now beginning to understand how each piece of code I have worked on contributes to the full analysis I am working on. Over the course of week 5, lots of time was spent putting all the work I have done so far into one script that would perform all the necessary fits, both for data and simulation. This was a good opportunity to clean up the code I already have and combine it into one well written script in the same style as the fitting scripts that have been used for previous analyses. In particular, I used some of Vedanshu's work as a template for my code and changed models or fit parameters where appropriate. This streamlined the process and made sure I didn't miss anything. It has also given me plenty of opportunities to do crosschecks on calculations, making sure my code produces consistent results to those found on previous analyses.

While working on a new piece of code this week, I encountered some issues with fits either not converging or converging to incorrect values. At the week 5 progress meeting, Tom and Tim offered some comments on this and ideas of things to try that may resolve the issue. After spotting some errors in my code and implementing some of these changes, my fit results were much better. This style of feedback has been quite common over the course of the project and has made it feel like I am working as part of a team rather than on a solo project.

On Thursday evening of week 5, I attended a "pizza meet up" organised by the department for physics students completing URSS projects. This was a good chance to catch up with some friends and hear about what other students had been working on. We discussed our public engagement activities and how our research was going and, of course, enjoyed the free pizza. It was interesting to hear from students working in different research groups such as Astronomy and Astrophysics, HetSys and Condensed Matter.

Most of week 6 was dedicated to working on optimisation (picking selection requirements for the data that would provide the best output results). This involved writing a few scripts in "Snakemake" which would essentially automate some of the work by running my code several times for different selection criteria with minimal input from me. In reality this meant that some days felt quite slow as they involved large amounts of time spent waiting for code to run. I spent this time working on other tasks however, or I ran code over lunch or in the evenings so that I would have results by the next time I was in the office.

Summary:

- Combining all fitting scripts and adding residuals to plots or changing axes to logarithmic scales
- Python scripts
  - Simple efficiency calculator (selection, acceptance)
  - Study of fit estimator properties (pseudoexperiments)
  - Optimisation - Multivariate Algorithm (MVA) selection criteria: Plotting variation of Punzi Figure of Merit (FoM) for coarse scan of MVA selection criteria
  - Optimisation - pion PID selection criteria: Scan on a 3D grid, looking at variation in FoM for different selection criteria
- LHCb Group Meeting
- Weekly progress meeting with supervisors

2.5 Weeks 7 & 8

18th August 2023

Although week 6 felt a bit slow, it provided the ground work for a lot of progress to be made in week 7. Having completed a coarse scan of the selection criteria using the optimisation script, I had found a smaller range of values for each of the criteria in which the quantities I was optimising seemed to peak. The next stage was doing finer scans in these ranges to get a more precise set of values for each criterion. This quickly yielded useful results so early in week 7, I already had several slides to show at the progress meeting scheduled for Friday.

The scans and some other calculations provided me with new tables of results and more importantly new checks to run to make sure that what had been found made sense and could be explained by theory or experience from other analyses. Another check I worked on was looking at how different selection requirements were having an impact on an efficiency value for the two decay modes I have been primarily looking at as, at a previous meeting, Tim had mentioned that it would be interesting to understand a discrepancy we had observed between the decay modes.

During term time, the group frequently hold seminars, often with external speakers giving talks on new research or experimental results. As my project has taken place outside of term time, these events have not been running. However in week 8, some of the group joined a seminar from Fermilab via Zoom where new results from the muon g-2 experiment were presented. This was an exciting and inspiring event and was a good showcase of what science can achieve. Several articles about the findings followed in the coming days (for instance this BBC news article).

Perhaps the most exciting part of week 8 for me was starting to put all of my work and results into an analysis note. This is a technical document, detailing the methods and results of an analysis which, after review and approval will be followed by a paper which discusses the results in a way that does not contain all the detail or jargon as it is intended for publication in scientific journals or similar. This has been an important part of the project for me as I have been able to see how I have directly contributed to the output of the group. As I continue over the next few weeks, I will not be presenting slides in progress meetings anymore but will instead be showing updates on the analysis note as further progress will be documented here.

Summary:

- Improving optimisation by doing finer scans in MVA and pion PID selection criteria where FoM value is high
- Testing how different requirements and selection cuts impact the efficiencies for each decay mode to understand a discrepancy between them
- Python scripts
  - Plotting momentum distributions for π^+, μ^+, μ^-
- Further work on study of fit estimator properties
- Putting work together in analysis note
  - Fit projections for simulation and sideband data
  - Optimisation
  - Acceptance and Selection efficiencies tables
- Weekly progress meeting with supervisors

2.6 Weeks 9 & 10

22nd September 2023

Between week 8 and week 9 of my project, I took a short break and spent some time at home with family then on holiday. Having this flexibility is a nice bonus that came with doing summer research at Warwick instead of undertaking an internship or other work experience this summer. The break was a good chance to reset and get ready for the upcoming academic year, without being too long so as to make progress slow upon returning to the office.

Much of the work I have done has warranted extra checks and more detail than what is covered in the main sections of the analysis note so I have been adding plots and tables to appendices which explain observations or conclusions we have made. Much more of the note is filling up with work I have produced which is reassuring as it is direct evidence of how much progress I have made and how much I have learnt since starting the project. In fact, a fair portion of week 8 and 9 has seen me going back to old plots from the first few weeks and making them more presentable as I now have a better appreciation for small things such as how axes should be labelled and how to add decay equations to figure legends (equations have replaced labels which had been written in a less formal way which would not be appropriate for the analysis note).

During the week 9 progress meeting, some time was spent discussing the end goal of my project and what comes after that. In particular we briefly talked about summer internships at CERN which would be a great way to get more research experience.

At the start of week 10, I carried on with some work from the week before, adding some plots and tables to the analysis note. Most of this was quite quick to do or fairly repetitive so didn't cause too much trouble. At the LHCb group meeting on Monday, there was brief mention of presenting my work to the group at the end of my project. This will be a nice way to conclude the project, summarising my work and showcasing it to the rest of the LHCb group.

Once I had finished the work that was started in week 9, I moved on to a different section of the note and started working on some new python scripts and also adapting some from earlier in the project. Throughout the second half of the project, there was a goal in mind for the final outcome of my work and the focus of the second half of week 10 was reaching this outcome. Having a clear final result to achieve made it easier to keep on track and plan out each week.

In the final few days I wrote some final thoughts about the work I had completed and reflected on the project as a whole.

Summary:

- Python scripts
  - Fit model to simulation and data for normalisation mode
  - Editing and adding to fitting script from week 5
- Finalising work for engagement activity
- Starting work on poster for showcase in November
- Analysis Note
  - Systematic uncertainties on efficiency ratio
  - Fit projections for normalisation mode and adding fit parameters to tables along with these
  - Limit extraction
  - Appendices: correlations, momentum distributions, systematics
- LHCb group meeting
- Weekly progress meeting with supervisors

2.7 Reflections on the project

Having reached the end of the 10 weeks, I think it's important to reflect on the goals set at the start of the project and what I have achieved. This experience has been useful and insightful to me as I have developed some technical skills but also improved my presentation skills and other "soft skills" that will be crucial throughout the remainder of my degree and in the workplace.

I am more proficient at coding in Python as I have not only learnt how to tackle several new problems but the daily practise has simply made me faster. For example my typing speed has increased a little and I am better at debugging programs, having picked up a few tricks from others or from what I have seen online when reading through documentation or code examples.

Using Overleaf for the analysis note and to write my journal entries has been highly beneficial as it feels very familiar to me now so will make working on lab reports and any future projects much more efficient.

When applications open, I intend to apply for a summer internship at CERN either to continue similar work to what I have already been doing or participate in a project on a different experiment, but surely applying everything I have learnt this summer.

As a closing remark, I have thoroughly enjoyed the project, even when it has been challenging, and would recommend completing a project funded by URSS to any interested student. In particular, working with the EPP group and specifically in the rare decays office has been great. It has been a comfortable and friendly environment to work in and Fernando, my supervisor, has been brilliant.

For the general reader, particle physics (or indeed physics in general) is a huge and exciting research area so I would encourage following the links scattered throughout this document but also looking beyond them as there is plenty more out there. To see other research in the physics department at Warwick go to the Department of Physics website and to read about other URSS projects see this page on the Warwick Physics society website.