DAML Project 1

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1 Introduction

Some introductory marks:

- The point of this project is to give you the opportunity to extend your work and investigations beyond the more narrow work carried out in the projects, and to bring together the ideas explored in different areas of the course.
- We do not require a full written report with pages of background material. You only need to provide a brief explanation of each step of your work. Aim to present your work clearly so that markers can easily follow your reasoning and reproduce each of your steps.
- We strongly encourage you to use Jupyter Notebooks for the project.
- Marks are available for coding style and clarity of comments.
- Please do make sure that your code is fully functional when submitted.
- If you are submitting more than one file, please do note with your submission which file is your main 'report' file and then explain in this report file at each stage which other files should be referred to.
- If you want to submit multiple files, then please 'zip' them together and submit as a single file. (If you are not familiar with this, then do make a backup copy before carrying out this step.)
- The deadline for submission of the report for this project is 3rd November at 4PM.

Some additional notes on using Jupyter Notebooks:

- You can add comments separately to code in new cells using markdown format.
- When submitting work, make sure you have saved your Jupyter Notebook.
- Do rerun the entire notebook before submitting to make sure that you are not relying on bits of code that have been over-written or changed.

2 Project Description

The report simulates making a measurement of a particle decay, from which you can measure a parameter related to the matter/antimatter asymmetry of the universe.

The signal decay, $B \to DX$ follows the following PDF:

$$p(t; \tau, \Delta m, V) \propto (1 + V \sin(\Delta m \times t)) \times \exp(-t/\tau) \tag{1}$$

where:

- t is the quantity you observe, the decay time,
- τ is a lifetime parameter,
- Δm is a parameter that leads to sinusoidal oscillations superimposed on the exponential decay,
- V is a parameter which measures the matter/antimatter asymmetry and has a value of 0 if the universe is symmetric.

The nominal values of the parameters are:

- $\tau = 1.5 \times 10^{-6}$ s,
- $\Delta m = 20.0 \times 10^{6}$ s^{-1},
- $V = 0.1$.

The experimental environment is such that we have a background process which is large for $t < 0.5 \times 10^{-6}$ seconds, such that we only choose to record events with $t > 0.5 \times 10^{-6}$ seconds. We also have a finite detector acceptance, such that if a decay happens with $t > 10 \times 10^{-6}$ seconds we do not record the decay. Note that the PDF we have given you is not yet normalised. This normalisation is important and is something you will need to think about and include.

2.1 Step 1 [6 marks]

Run pseudoexperiments to determine the expected statistical precision with which we can measure each of these parameters using a sample of 10000 events. You should:

- Generate events only in the range of decay times that are recorded by the detector.
- Generate and make a histogram of a single dataset first, to check that your generation and your fit is working. *You might wish to change some parameters when testing to make the oscillatory behaviour more noticeable.*

- Use an unbinned maximum likelihood fit and multiple pseudoexperiments to determine the precision you expect to get on each parameter. *Hint: Remember that the PDFs you use will need to be normalised correctly within the range that you consider.*
- Determine the bias (if any) on each parameter, and the precision to which you know this bias. You should provide plots that demonstrate these conclusions. *Hint: Remember to label axes of plots.*

2.2 Step 2 [10 marks]

Now we investigate the effect of a background that may be present. We want to investigate what happens to our measurement if this background is present. Assume this background follows the PDF:

$$p(t;\sigma) \propto \exp(-t^2/2\sigma^2), \tag{2}$$

where $\sigma = 0.5 \times 10^{-6}$ seconds.
You should:

- Generate pseudoexperiments where this background makes up 1%, 10% or 20% of the overall sample (which is still 10000 events). Repeat this study for each of these cases. *Hint: Remember that the detector only records events within a certain range of decay times.*
- For the cases where you do or don't include the background contribution when fitting the pseudoexperiments, how do your conclusions to Step 1 change:
  - what precision do you get for each parameter?
  - what bias do you get on each parameter, and how well known is this bias?
  - You should provide plots that demonstrate these conclusions. *Hint: Remember to label axes of plots.*
- Throughout this section when fitting you can assume that the σ parameter is well-known so that you do not need to leave it free in the fit, but do assume that the background fraction is unknown.

Hints: you will need to generate events with the background and the signal, and to fit with a PDF that is just signal, and then with a PDF that contains both signal and background. Remember to normalise your PDFs before fitting. If your fit does not include the background component then it may not converge. If your code output notes this, simply report the problem.

2.3 Coding and Comments [4 marks]

Four marks are available based on the quality of code provided, and the clarity of the comments.