ISP220 Honors Project: Analyzing LHC Collisions in the ATLAS Detector
Fall 2021

Document 1, October 10, 2021

Overall Project Due: One week before the finals week, December 7, 2021. I'll try to combine your results into one big package with the other students' work.

Exercises described in this first of two sets of directions to be done by Tuesday, November 16, 2021. This is a soft deadline, meant to help you to keep on track.

Instructions for the rest of the assignment will be provided two weeks from now. So if you get through this quickly, you can move forward.

The Aim of the Project

In this project you will analyze actual events which have been collected by the ATLAS experiment during the first data taking of the Large Hadron Collider. You'll look for the production and decay of the Z boson and look for possible production and decay of a hypothetical Z' (which I have a student at CERN doing for his PhD thesis topic), and the production of a possible Higgs Boson into two different decay modes.

These tools are from an international "master class" that is held in cities around the world. In it, high school kids and teachers assemble near universities and laboratories with particle physicists and received lectures and are taught how to use the tools that we'll use. Then in pairs the students do their work and upload their results to a central server in Norway were the results are combined. At the end, each site reports their results in a global video conference and the combined results are viewed. With that hands-on assistance the project is completed in what the organizers tell me is about 2 hours of work. It will take you a little longer since you'll be working individually, but of course you can collaborate if you like. You'll all work on your own independent datasets.

I'll refer you in this document to portions of the website that was used for training and then we'll go our own way for the actual analysis.

There are two sets of resources, besides the links that follow. This document and a talk that introduces Particle Physics (beyond where we are in class) and the data you'll use are at:

https://qstbb.pa.msu.edu/storage/ISP220_stuff/honors_project/

There you'll currently find:

ISP220_inspirationaltalk.pdf, which is about Particle Physics. Go ahead and look at this now. It's a little out of date, but still a good introduction to the ATLAS detector. Additional materials will appear, as will the datasets themselves. You'll also find a video I made that will help with the tutorial, Z_pathintro.mp4. You'll also find this memo (MinervaInstructions1_2021) and its companion (MinervaInstructions2_2021), which will arrive when you're ready. The data directory you can ignore for now.

We'll do this in phases. First, you'll do some learning on-line about the detector. Next, you'll install the program and go through some testing. Then, finally I'll point you to larger datasets that you can analyze. Let's get the bugs ironed out on Phase 1 over the next two weeks.

The Project Report

When you're done I'd like a report that will have the following sections:

1. **The LHC (2)**
   1.1. What it is (0.5)
   1.2. How it accelerates particles (0.5)
   1.3. The layout (1)
2. **The ATLAS Detector (2)**
   2.1. What it is. (0.5)
   2.2. How it detects particles (0.5)
   2.3. A cross section of the detector (1)
3. **Z Bosons (2)**
   3.1. What are they?
   3.2. How were they discovered?
   3.3. What kinds of signals do they leave in the detector?
4. **Higgs Boson (2)**
   4.1. What is it?
   4.2. What kinds of signals will the Higgs Boson leave in the detector?
5. **Data Collection**
   5.1. This will be your "logbook" for each session during which you did analysis work and your learning. Handwritten on blank sheets of paper, numbered. It's your scientific logbook, just like we all keep. I've even copied one of my own logbooks for you to use (at the end of this document). There will be two of them:

   Learning Log

   - For your "learning" part, there are two "Exercises" below which will be short tutorial sessions that you should enter into your "log," so indicate on a sheet:
     - Write the date and time,
     - what you saw in each event,
     - what choices you made, what the computer told you,
     - what you did to fix your mistakes
     - ...*A narrative of your effort, in first person singular.*

   Data-taking Log

   - When you start analyzing events, you'll keep a log just like you were in the control lab analyzing data.
   - Then each day that you work on ATLAS, document your session:
     - Write the date, time started
     - Indicate your dataset name (you'll see)
     - Indicate what event numbers you looked at
     - Write down your comments and observations...what puzzled you, what thought processes you used. You know, your logbook.
   5.2. **Results**

- Results from your Data-taking sessions will be entered into tally sheets that I'll give you

6. Summary (1)
    6.1.   Your Conclusions
    6.2.   Your Impressions

Where drawings are required (like 1.1, 1.3, 2.3, etc), I don't want graphics taken from the web. The sketches don't have to be elaborate. You can generate them on a computer drawing program, or better yet, make hand-drawn sketches. Seriously. Do it by hand, using a ruler and a curved edge so that they look neat and nice. I want the work to be through your fingers, and into your brain!

I don't want a huge paper from you. But I would like complete paragraphs and sentences. I've indicated roughly how many pages which hopefully will gauge the depth of your research and reporting.

Phase 1: The ATLAS Detector

By the time you're read this, we may have talked about the ATLAS detector and you've already seen pictures of it, and now you will see it up close. It consists of roughly 5 kinds of detectors that surround the beam in concentric, open cylinders. In class, I'll refer to a generic detector: tracking, electron calorimeter, hadron calorimeter, and muon detectors. It is more complicated than that, but you can learn it. What I've not talked about are the end sections of the detector, but the information below will complete that story.

Go to and learn about the ATLAS instrument

Start at:

https://atlas.physicsmasterclasses.org/en/index.htm

and go to the Z-Path at the top. From there you should be able to follow the instructions by following the right hand side links. There will be some practice pages with interactive responses.

Phase 2: The HYPATIA Display

1. Download the HYPATIA display

When you get to IDENTIFYING PARTICLES/Visualization with HYPATIA…don't download the program that is suggested there. There's a newer version, which is **7.4** and you should download it from:

http://hypatia.phys.uoa.gr/Downloads/

This is a JAVA program which should work on all platforms, but the MAC has become especially nervous about programs that it doesn't sanction and so this download will give you a complaint as being from an unknown source. So you need to go to your computer preferences, Security and Privacy and the General tab. You'll see at the bottom "Allow apps downloaded from:" and if you started and failed, you'll be given the opportunity to go ahead. So …go ahead.

If you have issues with using the program, refer to the D2L page, https://d2l.msu.edu/d2l/le/content/1490073/viewContent/10981913/View called Honors Project inside of the Projects tab. That's the latest in fixing-it for both macs and PCs. Both religions constantly change security protocols which sometimes interfere with installing programs from the internet, especially JAVA.

Then you can continue!

The HYPATIA display is pretty simple to use, but will require some practice. So keep reading and following instructions down to IDENTIFYING EVENTS/Practice!

Please do this, but don't miss the link (https://atlas.physicsmasterclasses.org/downloads/exercise2_Z.zip) that's in the second paragraph, kind of hidden, which downloads 10 practice events. Oh. I guess I just gave it to you.

You must make a directory, like "`HonorsProject`" or something like that and move the minerva folder inside. Neither Macs nor PCs will work from within the directory where files are naturally downloaded. When you've unpacked the HYPATIA zip file, or your computer has done it for you, you'll see the following directory structure. Double-clicking on the `HYPATIA_7.4_Masterclass.jar` file opens the program.

▼ 📁 Hypatia_7	15.6 MB	Folder	Today, 5:10 PM
▶ 📁 configuration	3.3 MB	Folder	Today, 5:10 PM
▶ 📁 events	400 KB	Folder	Today, 5:10 PM
▶ 📁 geometry	221 KB	Folder	Today, 5:10 PM
▶ 📁 help	683 KB	Folder	Today, 5:10 PM
📄 Hypatia_7.4_Masterclass.jar	2.6 MB	Java JAR file	Today, 5:10 PM
📄 HYPATIA_for_Linux.sh	50 bytes	Shell Script	Today, 5:10 PM
▶ 📁 img	1.8 MB	Folder	Today, 5:10 PM
▶ 📁 lib	6.6 MB	Folder	Today, 5:10 PM

On windows, it will look a little different, but I expect that the folders will be the same and that there will also be an `HYPATIA_7.4_Masterclass.jar` application. This is the `JAVA` application, which is a little program written in the `JAVA` language that your computer can read.

2. Test out the Hypatia display

You can find more information on the HYPATIA website at:

http://hypatia.phys.uoa.gr/Basics/

Follow the Basics and the UseHYPATIA links to get into it.

Here's a screen shot of what it looks like on my computer.

There are 4 windows that appear. On the upper left, is the end view of the central calorimeters, tracker, and the muon system. Below it is the side view. On the middle is a histogram of the energy deposited in each calorimeter cell. Here's how to think of it. Suppose the detector was a cylinder rolled up from a flat piece of paper. Unroll the paper flat and each cell in which energy could be deposited and read out would now be a little square. The amount of energy in each square is represented by a colored line (or rectangle) growing out of that cell. These are called Lego Plots, for maybe obvious reasons!

The window a the right is where you control what you see.
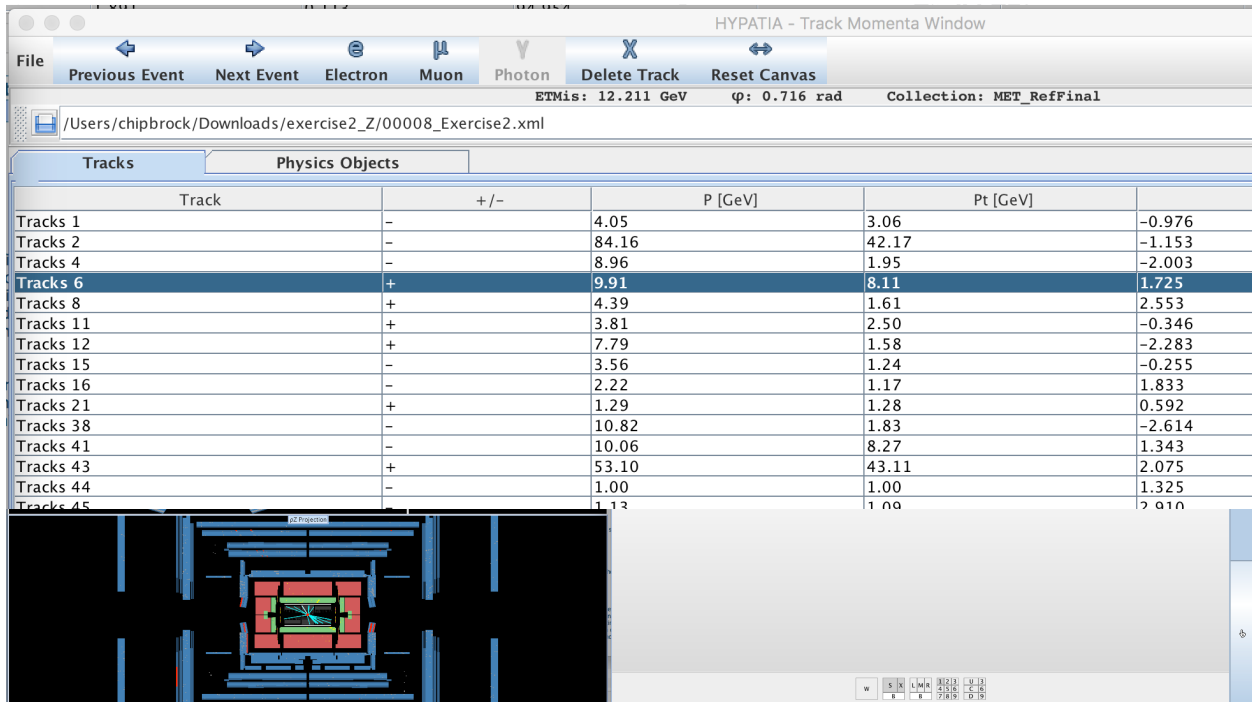
The upper right of the right hand window is blown up here. You can see the Previous Next buttons which cause the program to read the next event, or go back to the previous one.

At the top is the Invariant Mass window and it might be hard to find at the beginning. You might have to move the other windows around to locate and expand it. Here's what it looks like in the upper left hand section.
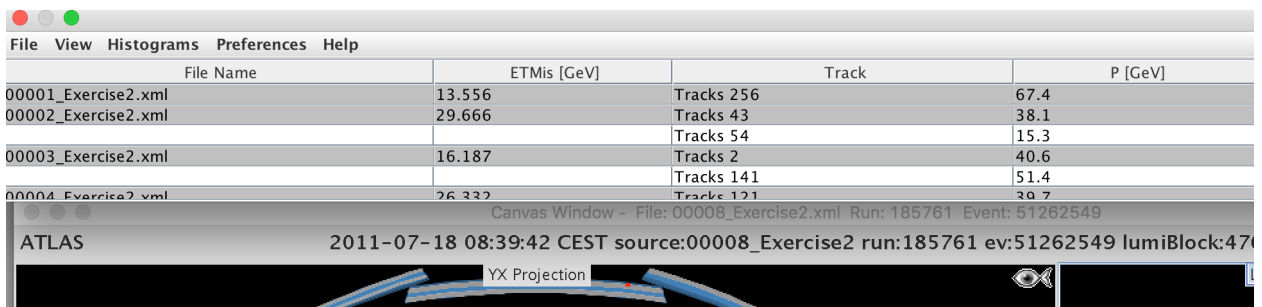

3. Another Quiz: "Exercise 2"

Your directory contains a file of practice events which are in the folder `events`. Inside that will be a zip file, events3.zip. I think you can leave this alone. (If you double click on this and your computer will unpack the file into a new directory called events4. Inside that are 10 events.) Here's a blowup of the left of the control window and you'll see the File menu, which does exactly what you'd expect.

You'll navigate it to find events for your analysis.
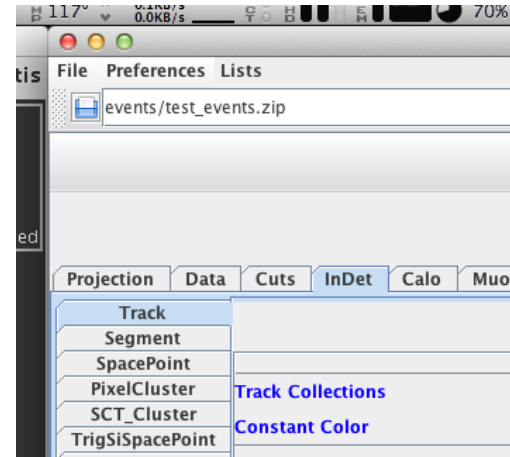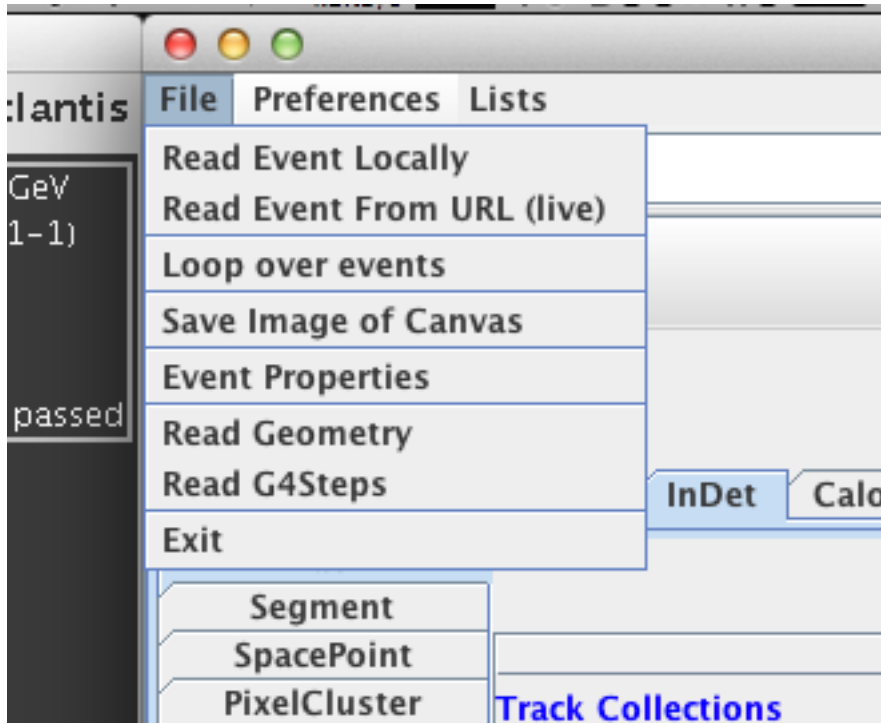
Eventually, you'll have your own data for your analysis, but for Exercise 2, when you open HYPATIA for the first time, I think it already opens the zip file and is ready to look at the events in events4.

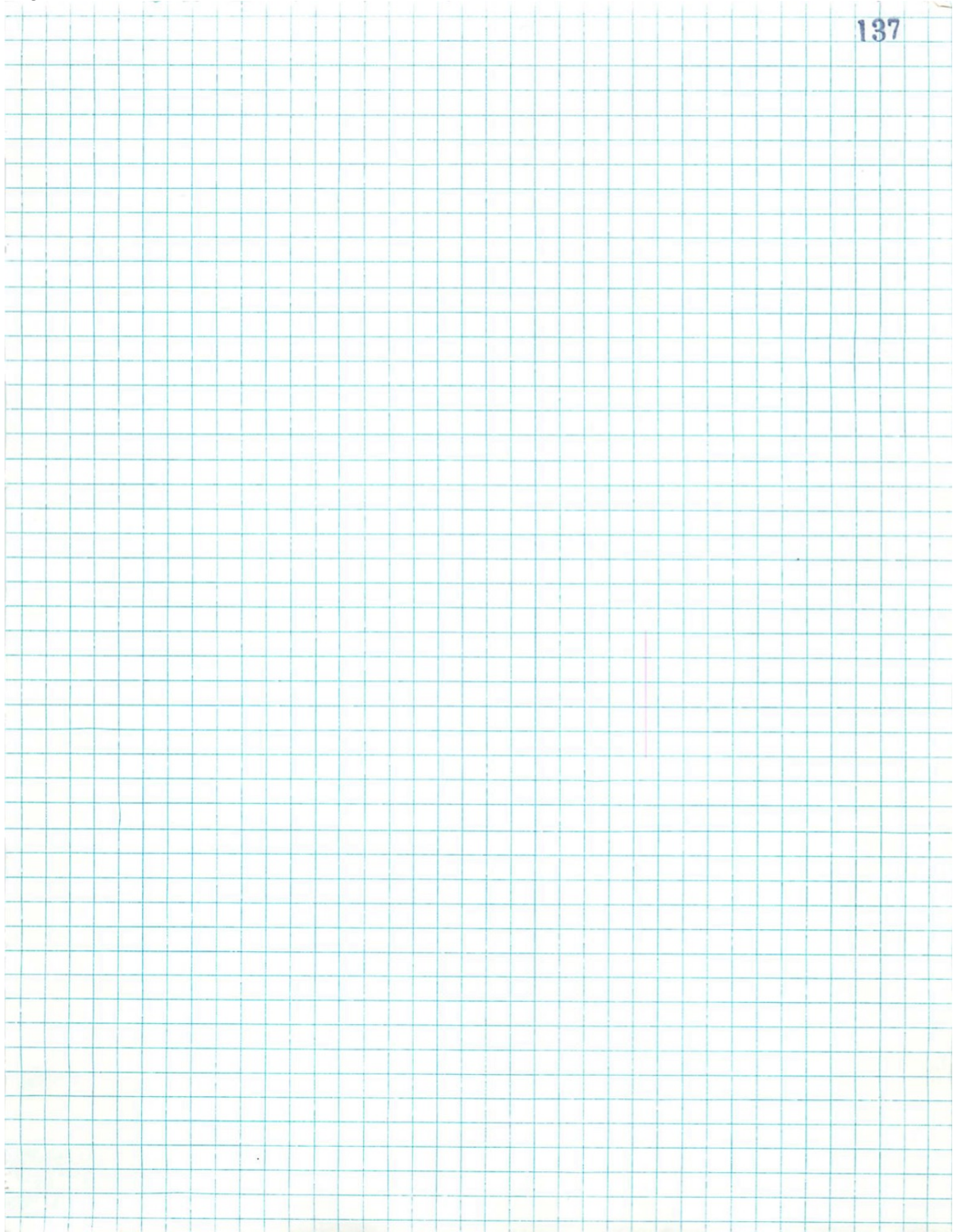If not, you can find it manually. Here's what mine looks like:
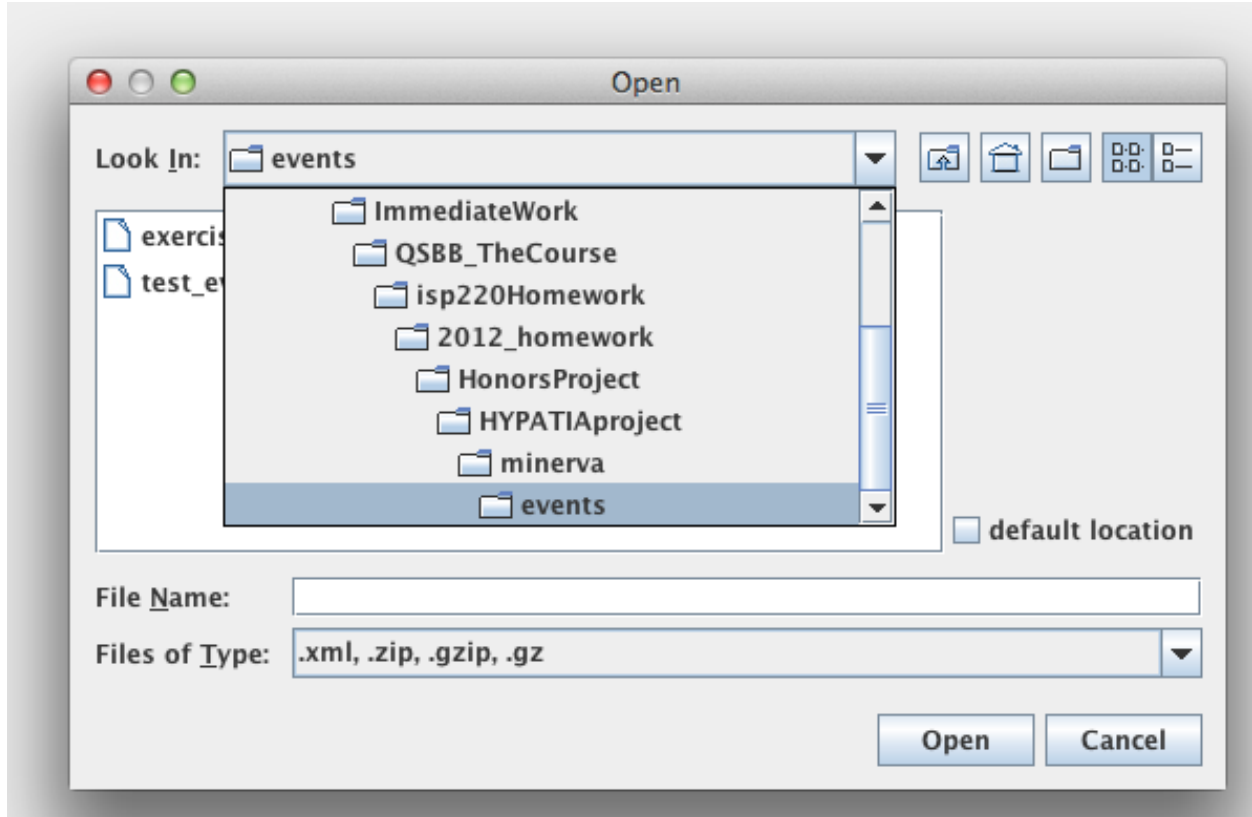
You navigate to your events folder and find the zip file. The little icon at the top left with the arrow through a folder takes you up a directory level. You'll get used to it.

Try to get this done by Friday, November 5, 2021. This is a soft deadline, only to remind you to pace yourself.

Logbook:

137

137

137

137