This will be an empty chapter and I will put some text here

$$\sum_{i=0}^{\infty} a_i x^i \tag{1}$$

The equation 1 shows a sum that is divergent. This formula

For further references see Something Linky or go to the next url: `http://www.sharelatex.com` or open the next file File.txt

It's also possible to link directly any word or any sentence in your document.

Terry Wyatt is inviting you to a scheduled Zoom meeting at 9:00 on Tuesday 6th October.
Topic: Terry Wyatt's ATLAS Lab. Experiment Zoom Meeting
Join Zoom Meeting
https://zoom.us/j/92221091854
Meeting ID: 922 2109 1854
Passcode: 061020

1 Aims

- To gain appreciation of the physics processes that can occur in high energy proton-proton collisions at the LHC
- To be introduced to event selection and measurement methods used in particle physics data analysis.

2 Objectives

-
- Compare real data collected by the ATLAS experiment with computer-simulated "Monte Carlo" data.
- Measure the cross sections for the production of the Z, W, and Higgs bosons at the LHC and estimate statistical and systematic uncertainties of the results.
- Gain experience of using *ROOT*
- Extend the event selections to other sources of events at the LHC, such as:

  Higgs decaying to two photons

  events containing tau leptons, pairs of vector bosons, top quarks

  potential sources of new physics from "Beyond the standard model".

3 Background Reading

3.1 A femto-course in particle physics

3.1.1 Leptons

Leptons = spin-$\frac{1}{2}$ fundamental particles
Charges of $-1, 0, +1$
Each generation has a flavour - electron, muon, tau

3.1.2 Quarks

Quarks = spin-$\frac{1}{2}$ fundamental particles
Up-type = charge $+\frac{2}{3}$
Down-type = charge $-\frac{1}{3}$
Bind together via the strong interaction to form Hadrons
Baryons = 3 quarks
Mesons = quark + anti-quark

3.1.3 Gauge Bosons

Responsible for mediating forces

3.1.4 Higgs Boson

Does NOT directly mediate a force.
It's an excitation of the Higgs field
Field gives rise to the masses of the Z & W bosons.

3.1.5 Parton

Parton = any constituent of a hadron (q, $\bar{q}$, g)

Main interaction of interest for this experiment = the production & decay of Z, W and Higgs.
Most easily identified decay:

$$Z \to l^{+}l_{-} \tag{2}$$

$$W^{-} \to l^{-}\bar{\nu}_{l} \tag{3}$$

$$H \to ZZ^{(*)} \to llll \tag{4}$$

4 Getting Started

Start a Jupyter notebook server running on the lab machine. Can then connect to this server using a web browser from anywhere.

4.1 Logging into the Lab machine

1. Open terminal
2. *ssh atlaslab[lab machine #]@atlaslab[lab machine #].blackett.manchester.ac.uk*
3. Answer yes
4. Enter the password for the specific machine

4.2 Setting up the code - TODO once at the start of the experiment

A skeleton version of the code is providied.
To work in python: *cp -r /opt/ATLAS-Project-py ATLAS-Project*
Then type in:

- *cd ATLAS-Project*
- *mkdir outputPlots*
- *ls -l*

Can then log out using *exit*

4.3 Starting up the Jupyter notebook server

Need to be followed at the beginning of each lab day.
Uses Singularity to run a Jupyter notebook server on the lab machine.

1. Log into the lab machine using 4.2
2. Configure Singularity

   export SINGULARITY_TMPDIR=$HOME.singularity/tmp - sets up the scratch directory
   singularity run -B /data/ATLAS:$HOME/ATLAS-Project/ATLAS $HOME/root_6.22.00-conda.sif bash

   Should see **INFO: Convert SIF file to sandbox...** and then after about a minute **Singularity>**

3. Start the Jupyter Notebook

   jupyter-notebook –no-browser –port=8888

4. Should expect text that looks like:

   Writing notebook server cookie secret to /home/atlaslab16/.local/share/jupyter/runtime/notebook cookie secret Loading IPython parallel extension Serving notebooks from local directory: /home/atlaslab16 The Jupyter Notebook is running at: http://localhost:8888/?token=a7ea520d2f4d6f62ea2026ac0aa1edd0a48e935b03539b or http://127.0.0.1:8888/?token=a7ea520d2f4d6f62ea2026ac0aa1edd0a48e935b03539bc4 Use Control-C to stop this server and shut down all kernels (twice to skip confirmation). . To access the notebook, open this file in a browser: file:///home/atlaslab16/.local/share/jupyter/runtime/nbserver-15700-open.html Or copy and paste one of these URLs: http://localhost:8888/?token=a7ea520d2f4d6f62ea2026ac0aa1edd0a48e935b0353 or http://127.0.0.1:8888/?token=a7ea520d2f4d6f62ea2026ac0aa1edd0a48e935b03539bc4

   Need to keep this terminal window open.

5. Open another terminal window:

   ssh -N -L localhost:1234:localhost:8888 atlaslab[MACHINE NUMBER]@atlaslab[MACHINE NUMBER].blackett.manchester.ac.uk

6. Enter the machine password
   Also keep this terminal window open.
7. Use any browser to connect to

   localhost:1234

8. Should be presented with a Jupyter page asking for a **token** to be entered at the top of the page in the **token or password** box.

9. Use the token given in the terminal window from a couple of steps ago.

4.4 Closing the Jupyter Notebook and Logging out of the lab machine

1. **ctrl+C** on both terminal windows.

2. then enter

   y — Close down the Jupyter notebook server
   exit — Closes Singularity
   exit — Logs out from the lab machine.

4.5 Using Analysis.py

Add names and date to the top of **Analysis.py** in a comment.
lep_n: Int = Number of leptons identified in each event.
lep_pt: Vect = vector of the lepton momenta in the plane transverse (perpendicular) to the beam direction (the z coordinate points along the beam).
All available data sets: http://opendata.atlas.cern/release/2020/documentation/datasets/dataset13.html

Values of energies and momenta are given in units of **MeV**.

4.6 Running the Skeleton code and examining the produced kistograms

Page 13 (14) for Monte Carlo data sets with string code. (String code = What is typed in Run-Analysis.py)
Full list ccan be found in the file **backend/dataSets.py**

Remember to select *Save and Checkpoint* from *File* drop-down. Can then *Revert to Checkpoint* from *File* drop-down.

The file *Analysis.py* contains a single function, *Analyse*. It is called once per data set analysed. In this function, will:

- select events
- plot histograms
- set histogram styles
- write plotted histograms to an output file.

5 Analysis

Selection cut to select a sample of events corresponding to the desired particular physics processes.
There is a trade off between the conflicting aims of achieving as high as possible a selection efficiency for the signal and rejecting as much as possible of the "background" from other physics processed.
It's more important to make estimates of the selection efficiency and the level of residual background. And to come up with credible statistical and systematic uncertainties on these estimates.

Note that the generated particles are not always actually observed in the ATLAS detector.

Note that the events may contain additional particles (e.g. jets of hadrons produced by radiation from the incoming partons before the annihilation that produced the Z boson)

5.1 Analysing Z bosons

ATLAS uses a right-handed coordinate system. Origin at the nominal interaction point in the centre of the detector and the z-axis along the beam pipe. The x-axis points from the interaction point to the centre of the LHC ring. y-axis upwards.

In the data, the kinematic variables given for each lepton are:

- transverse (perpendicular) momentum - p_T
- azimuthal angle ϕ between p_T and the x-axis
- pseudorapidity η

Pseudorapitdity is a spatial coordinate describing the angle of a particle relative to the beam axis defined as

$$\eta = -ln\left(\tan\left(\frac{\theta}{2}\right)\right) \tag{5}$$

where $theta$ = the polar angle
When high (small angle) the parricle is usually along the beam exis (often lost) For massless particles, this is equivalent to the rapidity (y) defined as

$$y = \frac{1}{2}\ln\left(\frac{|\vec{p}| + p_L}{|\vec{p}| - p_L}\right) \tag{6}$$

where p_L is the longitudinal momentum and $\vec{p}$ is the 3-momentum of the particle.

5.1.1 Excercise 6.2

Derive an expression for m_{ll} for the decay $Z \to \mu^+\mu^-$

The invarient mass of the system can be expressed directly using....

$$m_{ll}^2 = 2p_{T1}p_{T2}\left(\cosh(\eta_1 - \eta_2) - \cos(\phi_1 - \phi_2)\right) \tag{7}$$

5.2 Making event selction cuts

Selection criteria/cuts on each event - e.g. only interested in events with oppositely charged leptons of the same type/flavour.
Can restrict the events plotted by using the p_T of the leptons. In general, always want to use the particles with the highest p_T.

5.2.1 Exercise 6.6

Leptons produced in the decay of Z and W bosons tend to be "isolated" from other particles produced in p-p collisions.
Leptons from "background" processes (e.g. decay of b quarks) tend to be accompanied by a jet of other particles.

5.2.2 The Isolation Variables - ptcone30 and etcone20

ptcone30 (ntuple) = a sum over the p_T of all tracks contained within a cone of half-width 0.3 in δR around the lepton direction

$$\Delta R = \sqrt{\Delta\phi^2 0} \tag{8}$$

etcone20 (ntuple) = contains a sum over the p_T cone

5.3 Event weights for Monte Carlo data sets

The used ATLAS datasets correspond to an "integrated luminosity" $\int Ldt = 10.064\text{fb}^{-1}$ ("inverse femtobarns").
= a measure of the number of the p=p collisions in ATLAS.
The Monte Carlo

Integral corresponds to the sum of all weights for all the calls of *Fill* for which the plotted value lies between the lower and upper bounds of the histogram. It is *Intergral* that should be compared NOT *Entries* (when comparing histograms of ATLAS and MC data).

5.4 Cross Sections, backgrounds, and efficiencies

Cross section σ for a given process such as $Z \to ll$:

$$\sigma(pp \to Z \to ll) = \frac{N^{selected} - N^{background}}{\epsilon \int Ldt} \tag{9}$$

$$\tag{10}$$

$$N^{\text{selected}} = \text{ total number of events in the ATLAS data that pass the final selection cuts} \tag{11}$$

$$N^{\text{background}} = \text{ estimate of the number of background events in the selected data sample} \tag{12}$$

$$N^{selected} - N^{background} = \text{estimate of the number of "signal" events in the ATLAS data for the targeted physics process} \tag{13}$$

To get the sum of weights for all generated $Z \to ll$ signal MC events:

$$\textbf{python3.4 TotExpected.py} \tag{14}$$

$$\textbf{Zee} \tag{15}$$

Fractional uncertainty on $\int Ldt = 1.7\%$
Other systematic uncertainties may arise, for example, from:

- backgrounds not accounted for
- disagreements between simulation and real data

Possible catch all to estimate the size of such effects = to re-calculate the cross section having changed your event selection cuts

5.5 Re-discovering the Higgs boson

Simplest Higgs decay mode:

$$H \to ZZ^{(*)} \to llll \tag{16}$$

- Look at events producing 4 leptons
- 2 same-flavour, opposite-charge pairs.

5.6 Analysing W bosons