INTERNATIONAL MASTERCLASSES HANDS ON PARTICLE PHYSICS

Developments from QuarkNet

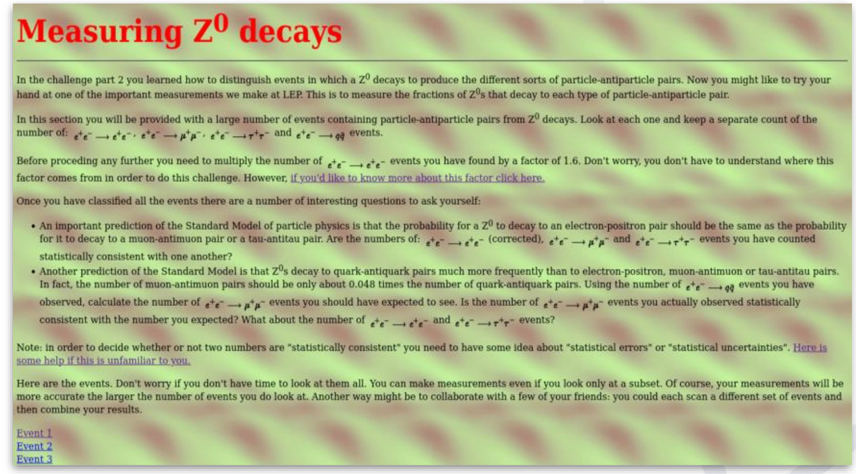
IMC Steering Group
12.11.2021, Zoom

QuarkNet

INTERNATIONAL MASTERCLASSES
hands on particle physics

OPAL masterclass

- Original OPAL masterclass: students examine event display images, learn how to identify types of events
- Original late-90s web design (last update 2003)
- Upgrade and adapt to make more modern (done)
- Slides from 21st IPPOG
- **Pedagogical purpose: Couple with LHCb recent result to investigate lepton universality**



Measuring Z^0 decays

In the challenge part 2 you learned how to distinguish events in which a Z^0 decays to produce the different sorts of particle-antiparticle pairs. Now you might like to try your hand at one of the important measurements we make at LEP. This is to measure the fractions of Z^0s that decay to each type of particle-antiparticle pair.

In this section you will be provided with a large number of events containing particle-antiparticle pairs from Z^0 decays. Look at each one and keep a separate count of the number of: $e^+e^- \longrightarrow e^+e^-$, $e^+e^- \longrightarrow \mu^+\mu^-$, $e^+e^- \longrightarrow \tau^+\tau^-$ and $e^+e^- \longrightarrow q\bar{q}$ events.

Before proceding any further you need to multiply the number of $e^+e^- \longrightarrow e^+e^-$ events you have found by a factor of 1.6. Don't worry, you don't have to understand where this factor comes from in order to do this challenge. However, if you'd like to know more about this factor click here.

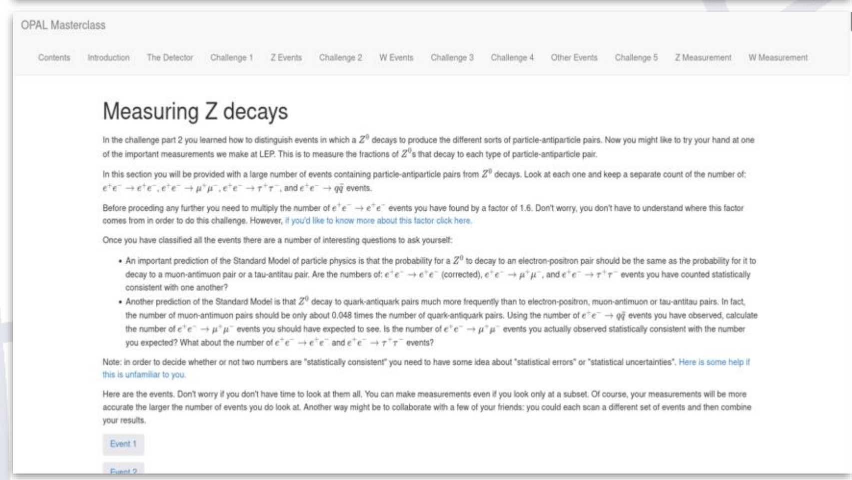
Once you have classified all the events there are a number of interesting questions to ask yourself:

- An important prediction of the Standard Model of particle physics is that the probability for a Z^0 to decay to an electron-positron pair should be the same as the probability for it to decay to a muon-antimuon pair or a tau-antitau pair. Are the numbers of: $e^+e^- \longrightarrow e^+e^-$ (corrected), $e^+e^- \longrightarrow \mu^+\mu^-$ and $e^+e^- \longrightarrow \tau^+\tau^-$ events you have counted statistically consistent with one another?
- Another prediction of the Standard Model is that Z^0s decay to quark-antiquark pairs much more frequently than to electron-positron, muon-antimuon or tau-antitau pairs. In fact, the number of muon-antimuon pairs should be only about 0.048 times the number of quark-antiquark pairs. Using the number of $e^+e^- \longrightarrow q\bar{q}$ events you have observed, calculate the number of $e^+e^- \longrightarrow \mu^+\mu^-$ events you should have expected to see. Is the number of $e^+e^- \longrightarrow \mu^+\mu^-$ events you actually observed statistically consistent with the number you expected? What about the number of $e^+e^- \longrightarrow e^+e^-$ and $e^+e^- \longrightarrow \tau^+\tau^-$ events?

Note: in order to decide whether or not two numbers are "statistically consistent" you need to have some idea about "statistical errors" or "statistical uncertainties". Here is some help if this is unfamiliar to you.

Here are the events. Don't worry if you don't have time to look at them all. You can make measurements even if you look only at a subset. Of course, your measurements will be more accurate the larger the number of events you do look at. Another way might be to collaborate with a few of your friends: you could each scan a different set of events and then combine your results.

Event 1
Event 2
Event 3



OPAL Masterclass

Contents Introduction The Detector Challenge 1 Z Events Challenge 2 W Events Challenge 3 Challenge 4 Other Events Challenge 5 Z Measurement W Measurement

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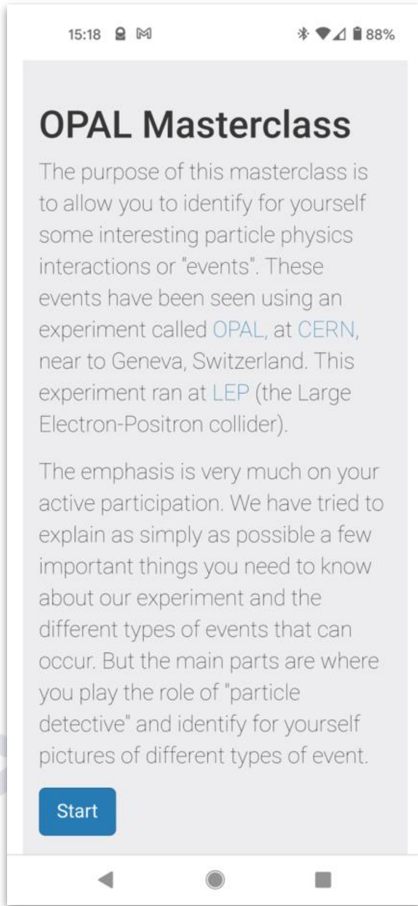
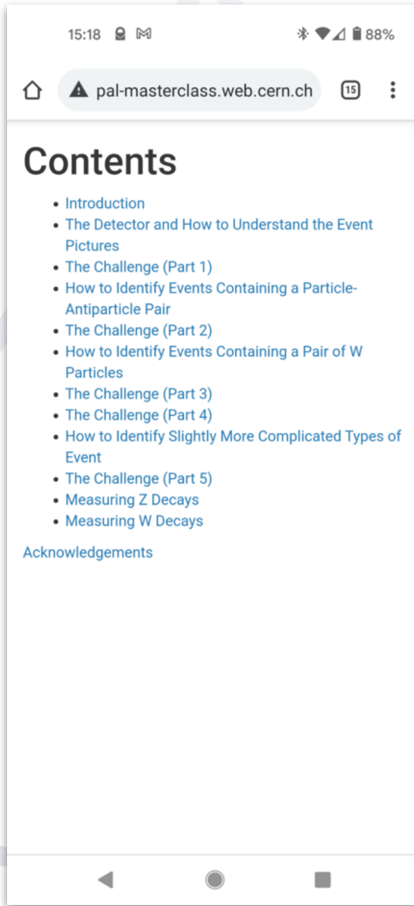
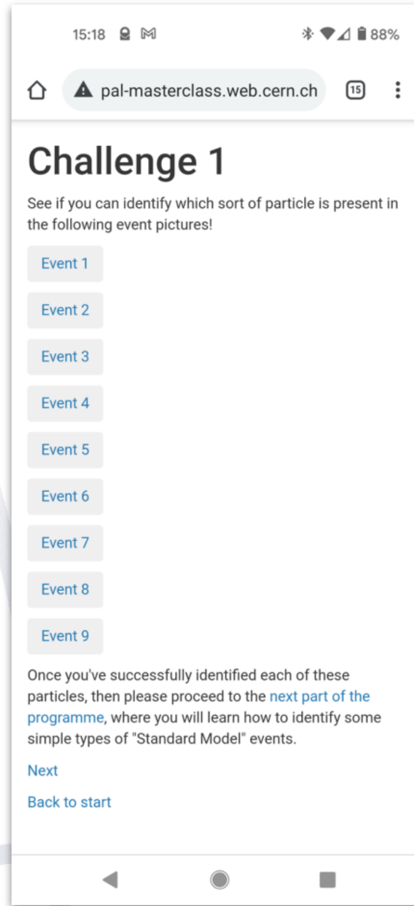
Event 1

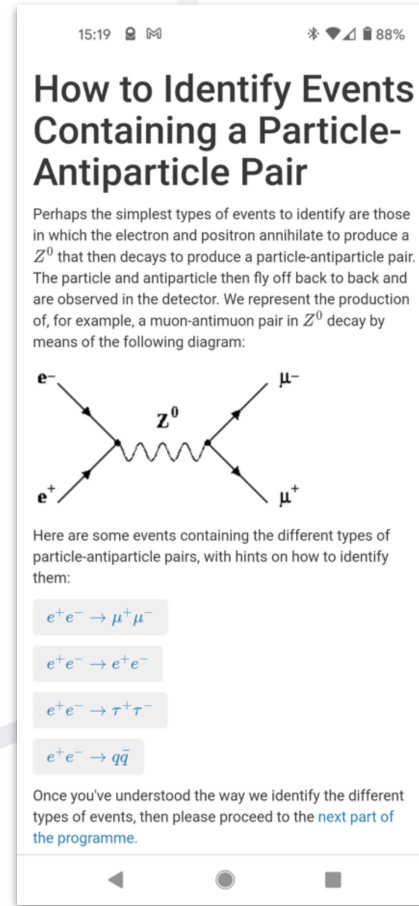
OPAL masterclass- New version

- Plan: use major structure of the original masterclass but update user interface, technology behind the scenes; run checks on data to find duplicate and missing images
- Technical details: new website built using Flask, flask-bootstrap UI, and Jinja templates; use MathJax for equation rendering
- Webpage has responsive layout e.g. runs on mobile devices
- Deployment via CERN instance of OpenShift (cloud container platform)
- GitHub repo
- Outstanding issues
- New version
- Z results: GitHub Discussions









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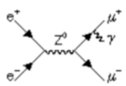
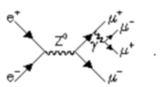
Four Fermion Events

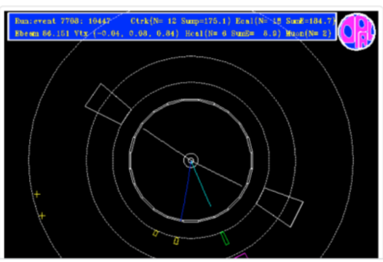
Remember the example diagram we used to represent $e^+e^- \to l^+l^-\gamma$ events:



Instead of flying out and being observed in the calorimeter, sometimes the photon produces an additional particle-antiparticle pair. Such events contain two particle-antiparticle pairs. For example:



These events go by the jargon name "four fermion" events. Here is an example event that contains electron-positron and muon-antimuon pairs:



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- Another prediction of the Standard Model is that Z^0 decay to quark-antiquark pairs much more frequently than to electron-positron, muon-antimuon or tau-antitau pairs. In fact, the number of muon-antimuon pairs should be only about 0.048

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Measuring W decays

If you've got this far then you're probably now an expert at identifying different types of Z^0 and W pair events. Here is a more difficult challenge to keep you on your toes!

In the previous challenge you measured the fractions of Z^0s that decay to each type of particle-antiparticle pair. Another important measurement is measuring the fractions of W pairs that decay into each possible class. Remember these classes are

- the four-jet events: $W^+W^- \to q\bar{q}q\bar{q}$,
- the two lepton, two neutrino events: $W^+W^- \to l^+\nu l^-\bar{\nu}$
- or the lepton-neutrino, quark-anti-quark events: $W^+W^- \to e\bar{\nu}q\bar{q}$, $W^+W^- \to \mu\bar{\nu}q\bar{q}$, $W^+W^- \to \tau\bar{\nu}q\bar{q}$.

In this challenge you are asked to look through a list of events and keep count of the various types of W pair decays. But beware! There are other types of events, such as Z^0 decays, mixed in as well. Therefore, for each event you first need to determine whether you're looking at a W pair decay or some other kind of event.

One measurement you can make is to count the total number of W pair events (having "thrown away" all the events you didn't think were W pairs). Count also the number of W pair events in each of the classes listed above. Thus you can determine the fractions of W pair events that end up in the various classes.

We expect the number of $W^+W^- \to e\bar{\nu}q\bar{q}$, $W^+W^- \to \mu\bar{\nu}q\bar{q}$, and $W^+W^- \to \tau\bar{\nu}q\bar{q}$ events each to be 0.29 times the number of $W^+W^- \to q\bar{q}q\bar{q}$ events. We also expect to observe that the total number of $W^+W^- \to l^+\nu l^-\bar{\nu}$ events to be 0.18 times the number of $W^+W^- \to q\bar{q}q\bar{q}$ events. Check your measurements

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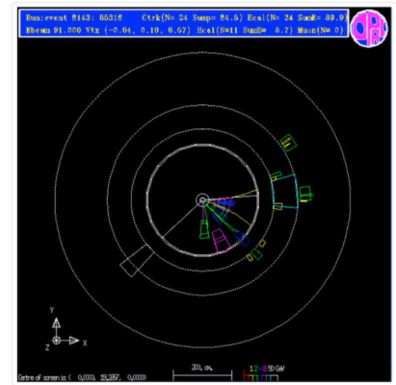
pal-masterclass.web.cern.ch

W Measurement: Event 3



Back Next

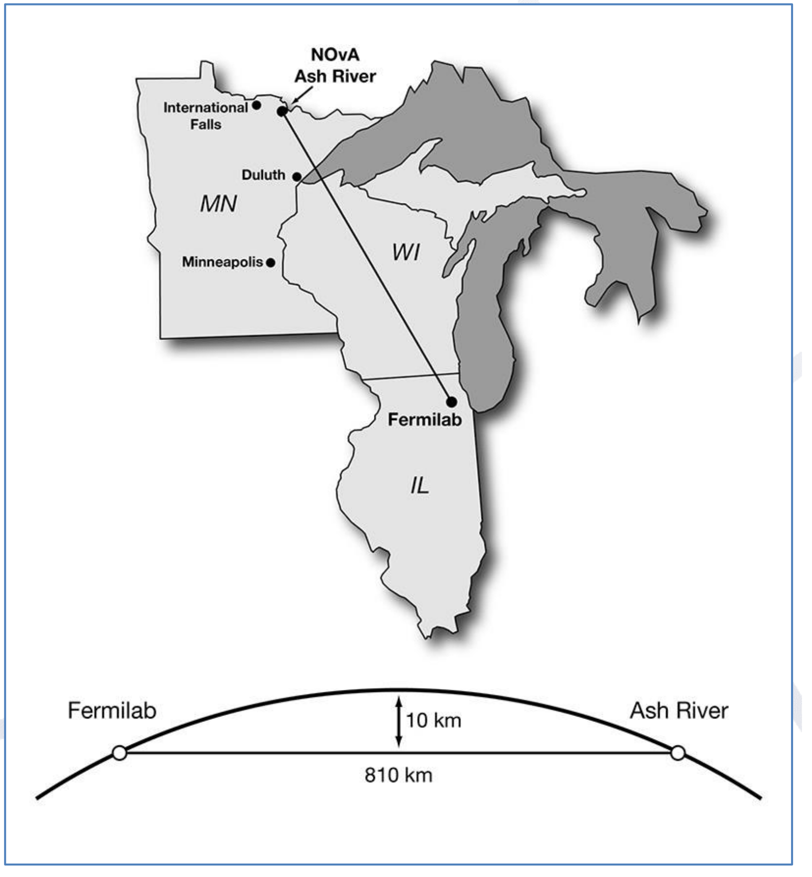
Back to event list

CMS masterclass updates

- iSpy WebGL event display
  - Upgrade of underlying WebGL library
  - Lightweight detector geometry
  - Improved picking and table views
  - New, improved view and settings controls
- CIMA
  - Improvements to histograms in development

New NOvA masterclass

- In development by Greg Pawlowski (QuarkNet mentor), Mike Plucinski (Neutrino fellow), QuarkNet staff
- Concept tested several times in QuarkNet workshops – teachers enthusiastic
- Combine event display analysis (small number) with python notebook (many events)
- NOvA (NuMI Off-axis neutrino Appearance): long baseline neutrino oscillation study



https://www.universetoday.com/109444/nova-experiment-nabs-its-first-neutrinos/

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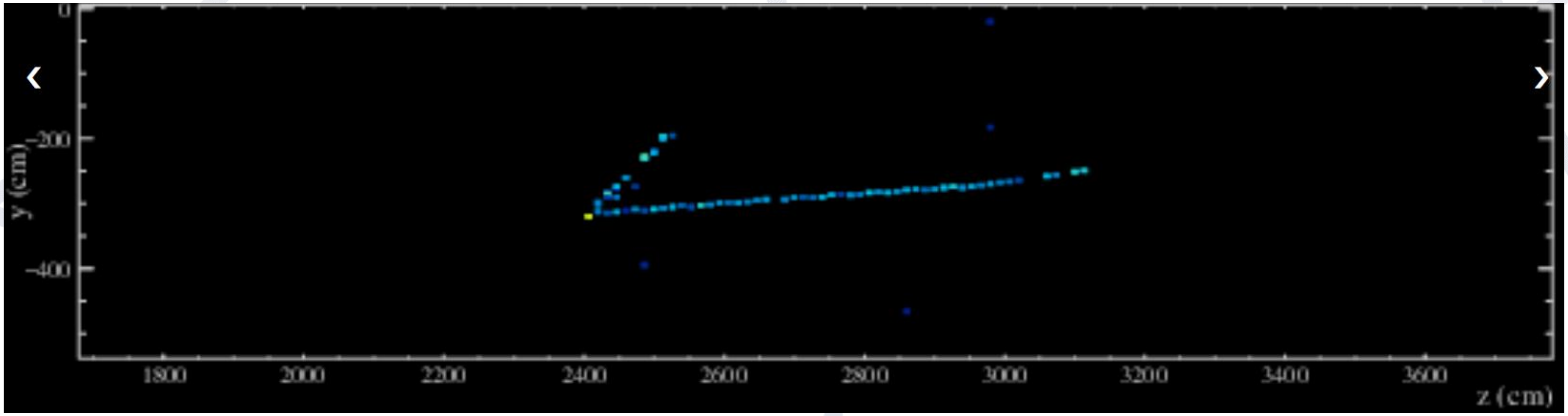
NOvA masterclass measurement

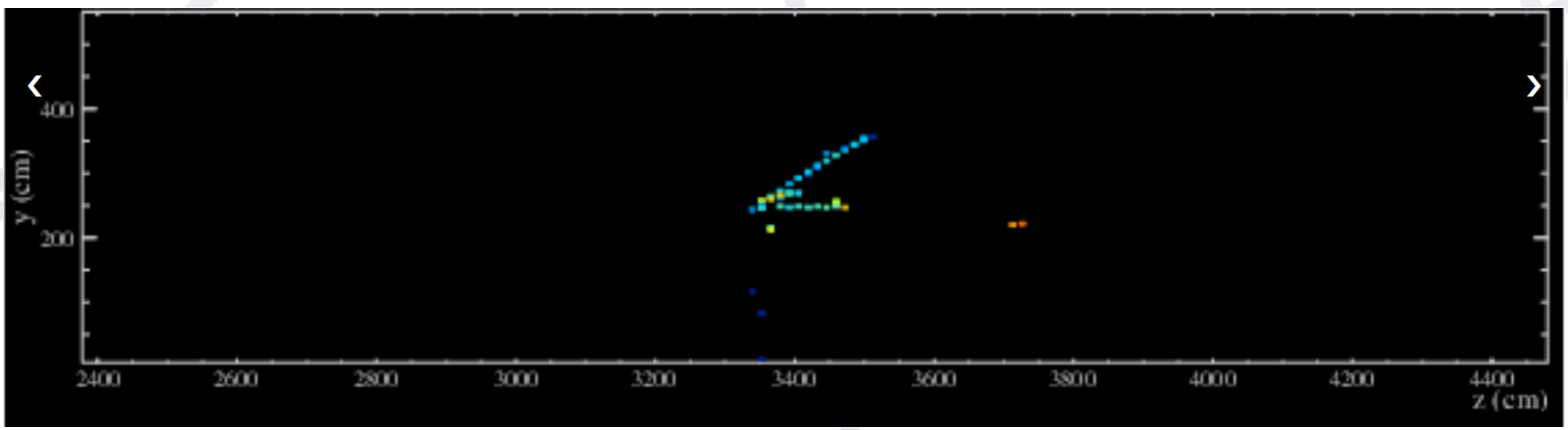
- Students study Far Detector (FD) event displays – small number due to beam spread
  - Find ratio of Neutral Current (NC) to Charged Current (CC) events
    - CC – muon neutrino (numu + n → mu + p) (W exchange)
    - NC – anything (nu + n → nu + n) (Z exchange)
  - Create quantitative criteria for detemination of CC vs NC events



CC event: muon (long) and proton (short)

NOvA masterclass measurement

- Students use python notebook and developed criteria to examine Near Detector (ND) events – many, close to beam source
  - Find ratio of Neutral Current (NC) to Charged Current (CC) events
  - Compare CC:NC in FD vs in ND → evidence of oscillations
- Still working: combination of results (we have ideas)



NC event: short tracks, multiplicities

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NOvA masterclass plans

- Current – refine measurement and procedure
- IMC 2022 – limited trial masterclasses
- Next SG – request inclusion in IMC
- Rest of 2022 – introduce in workshops
- IMC 2023 – Official rollout

```
# Importing data into a Dataframe from a web based source
# For this activity, Near NOvA Event Data can be found at this website:  https://github.com/ThePAEngineer/NOvAData
# The file you'll want to focus on is called:  NOvA-ND-Events.csv
# Once there, click on the file of interest, then copy the link from the "Raw" button, pasting it in the indicated space below

dataImported = pd.read_csv('https://raw.githubusercontent.com/ThePAEngineer/NOvAData/main/NOvA-ND-Events.csv')
dataImported.head()  # A call to the "head" function prints out the first few rows to verify the data was correctly imported

# As always, don't forget to "Run" this cell when ready!
```

	Event Number	Longest Track Length (cm)	2nd Longest Track Length (cm)	3rd Longest Track Length (cm)
0	1	99.49	0.00	0.00
1	2	343.63	227.86	167.31
2	3	1132.58	75.03	0.00
3	4	350.23	261.42	240.75
4	5	107.44	0.00	0.00