Neutrino Oscillations Activity Worksheet

In this activity you are going to have a go at classifying simulated events for the Super-Kamiokande experiment. You will then determine whether there is evidence of oscillation in your data set.

There are 10 data sets with 50 events in each – that is 500 events in total but you don't have to analyse all of them. One approach is for the class to split into groups and each group work on a different data set. Don't worry if you don't get through the whole set – just record the range of events you looked at and the total number.

The events are randomly distributed so you will see variation between the data sets, but the more data you examine, the more accurate your result should be so we suggest combining the results across groups at the end.

Step 1

Watch these videos and then try to answer the following questions.
What is a neutrino?[*]
Atmospheric neutrinos[†]

What ratio of muon-like to electron-like neutrinos do we expect (in the absence of neutrino oscillations)?

Your answer:

Which neutrinos travel further, upwards or downwards going ones?

Your answer:

Why might you expect the ratio to be different for upwards and downwards events?

Your answer:

Step 2

[*] https://media.kcl.ac.uk/media/What%20is%20a%20neutrino/1_z9q1hug7
[†] Measuring atmospheric neutrinos - King's College London

Now watch this video[‡] which talks about neutrino event displays.

Using the online event display[§], work through a range of events and try to classify them into one of the five categories:

- Incoming background (hits in the outer detector)
- Muon-like (sharp-ring) Upwards going
- Muon-like (sharp-ring) Downwards going
- Electron-like (fuzzy ring) Upwards going
- Electron-like (fuzzy ring) Downwards going

There are 10 data sets with 50 events in each – that is 500 events in total - but don't worry, you don't have to analyse all of them. Just record the range of events you looked at and the total number.

Mark the data set, event range and total number of events you classify at the top of the table on page 3 (applicable if you are sharing the task across groups in the class).

Mark each Event ID number in the relevant box in the provided Results Table on page 3.

Step 3

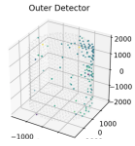
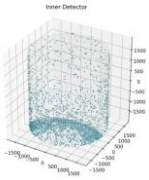
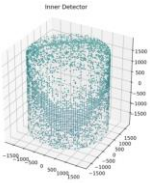
When you have finished, count up the number of events in each classification and record it in the Results Table.

Step 4

Now calculate the ratio of muon to electron type for Downwards events and for Upwards events and record these at the bottom of your Results Table.

[‡] https://media.kcl.ac.uk/media/Reading%20the%20event%20display/1_6i5j9v0j
[§] URL: https://nms.kcl.ac.uk/jeanne.wilson/Outreach/wc_evd/

Results table

<table>
<tr><td colspan="2">Data set analysed:</td><td>Total event number (N):</td></tr>
<tr><td colspan="3">Events classified as Background:
(hits in outer detector)
 
</td></tr>
<tr><td colspan="2"></td><td>Total background events:</td></tr>
<tr><td rowspan="2">Events Classified as muon-like (sharp ring)
  </td><td>Upwards:</td><td>Downwards:</td></tr>
<tr><td>Total Upward muon events:</td><td>Total Downward muon events:</td></tr>
<tr><td rowspan="2">Events classified as electron-like (fuzzy ring)
  </td><td>Upwards:</td><td>Downwards:</td></tr>
<tr><td>Total Upward electron events:</td><td>Total Downward electron events:</td></tr>
</table>

$$Downwards\ ratio = \frac{Number\ of\ downward\ muon\ events}{Number\ of\ downward\ electron\ events} = \_\_\_\_ =$$

$$Upwards\ ratio = \frac{Number\ of\ upward\ muon\ events}{Number\ of\ upward\ electron\ events} = \_\_\_\_ =$$

Step 5

Do your two ratios agree with what you expected?

Do your two ratios agree with each other?

Step 6

If you shared the task between groups – collect up the total number of events in each category in this table now:

Data Set:	1	2	3	4	5	6	7	8	9	10	Total
Upwards Muon											
Downwards Muon											
Upwards Electron											
Downwards Electron											
Background											

Step 7

Add up the totals and record in the final column of the above table.

Calculate the total values for:

$$Downwards\ ratio = \frac{Number\ of\ downward\ muon\ events}{Number\ of\ downward\ electron\ events} = \_\_\_\_ =$$

$$Upwards\ ratio = \frac{Number\ of\ upward\ muon\ events}{Number\ of\ upward\ electron\ events} = \_\_\_\_ =$$

Step 8

What can you conclude from this? Discuss as a class.