

# Detecting incident angles of radioactive particles with the Timepix 3 detector

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## **Abstract**

This project uses the Timpix 3 radiation detector, a 256x256 pixel hybrid silicon pixel detector, which can capture frames of ionising radiation incident on the detector surface. The detector simultaneously captures Time of Arrival (ToA) (the time during a capture when a pixel was triggered) and Time over Threshold (ToT) (providing information to get the energy deposited on a pixel) information which was thought may be able to be used to calculate the incident angle of a radioactive particle. It was additionally theorised that the ToA information could be used to improve the current clustering algorithm used by some institutions for other detectors in the Timepix family.

Data was collected across the country with the detector, which proved very useful for the improved clustering algorithm that was developed. An average time difference for all clusters detected was taken and used to separate clusters both by time and space (as previously they were separated by just space). This allows for more accurate particle classification. We have also shown that a single detector cannot be used in a static position to identify incident angles for most incident particles due to their energy, size and the speed at which they travel. Hence in a reasonable experimental setup, multiple detectors would be required to determine this.

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# Introduction

The Timepix 3 detector is a hybrid silicon pixel ( $256 \times 256$   $55 \mu\text{M}$  square pixels) detector capable of providing both Time of Arrival (ToA) and Time over Threshold (ToT) values for a single pixel at the same time (Poikela et al. 2014), which is an improvement over the previous Timepix generation that the author is familiar with, Timepix 1, that could only record either of the two at the same time (Llopart et al. 2007).

ToA values can tell us when in an exposure a specific pixel was triggered by a incident charged particle, and with proper calibration of the detector, ToT values (with some additional calculation) can be used to tell us the energy of the incident particle. In The Institute for Research in Schools (Parker et al. 2018), ToT values have been most useful as they can tell us the energy a satellite receives in space (Furnell et al. (2018), Hatfield et al. (2018), Baca et al. (2016) and Baca, Jilek, Vertat, Urban, Nentvich, Filgas, Granja, Inneman & Daniel (2018)) and the types of particles detected in classroom experiments (Whyntie & Parker (2013) and Whyntie et al. (2016)).

However, the new technology of the Timepix 3 detector could provide students with greater understanding of radiation - perhaps for instance the angle of incidence of a radioactive particle or the best capture time for an experiment they are conducting to minimise data gathering problems, such as limited time access to a detector. This new information may also be useful for the existing clustering algorithm, as it would allow clusters to be differ-

entiated by time and space.

The main focus for this project will be primarily on identifying the incidence angle of a radioactive particle or ray, using only a single detector. Existing methods for detecting angles of incident particles rely on multiple detectors being used in a telescope arrangement (Akiba et al. 2012), (Burian et al. 2018), or multiple detectors in a grid (as seen in the LUCID payload). Therefore, if possible, it would be particularly useful to be able to identify incident angles with only one detector to save cost, resources and complexity. Furthermore, as most Institute for Research in Schools CERN@school projects take place in the field or a classroom rather than in a laboratory, therefore needing only to use a single detector in any arrangement would be incredibly advantageous. Even if it is not possible to identify incidence angles, a direction for which a source may be located would also be useful.

Timepix detectors have been used in many applications outside the classroom and education environments - they have been used in space (Stoffle et al. (2015), Granja et al. (2016)), medical imaging (Medipix - in the same family as Timepix detectors, but used for counting hits) (Walsh et al. (2011), Ballabriga et al. (2018)), and the Large Hadron Collider (Acharya et al. (2014), Akiba et al. (2013)) so therefore, this research may have wider reaching impact should notable findings be made.

This paper describes the background data gathering process that was undertaken (Chapter 1), using the Timepix 3 detectors ToA information for clustering (Chapter 2), the difficulties that were faced with using this ToA information for angle identification (Chapter 3), other possible methods for angle identification (Chapter 4), how measurements could be automated using the Timepix 3 detector (Chapter 5) and the additions that needed to make to TAPAS (Chapter 6). This paper also discusses future work that could be completed (Chapter 7) and concludes in Chapter 8.

# Chapter 1

## Data gathering (Background)

Before any calculations with respect to angles or otherwise could be developed, sample data first needed to be gathered, due to the lack of readily available data already created with a Timepix 3 detector.

Three experimental protocols were developed for data gathering, one focused on measurements in the field (Appendix A), for background data taken around the country, and the other two (Appendices B and C) focused on a specific experiment of using a Cs-137 source at different angles to produce a dataset for the then planned angle identification algorithm.

Data was gathered in a number of locations in the UK to create a varied dataset. The locations chosen and the reasons for this are follows:

Newquay	An area with Radon gas levels that are above the national average, making it a Radon Affected Area (Miles et al. 2007)
Dungeness	The site of a nuclear power plant (Dungeness A & B) (EDF Energy 2018)
Return plane journey LGW to NQY	Radioactivity levels are measurably higher in a plane than on the ground due to a thinner atmosphere (Bagshaw 2008)
Canterbury	An area with relatively normal background radiation

Multiple readings were taken in these locations, in multiple areas to be

able to gather an average for a particular area.

Figure 1.1: Taking readings with the detector in Dungeness



Figure 1.2: Taking readings with the detector mid flight

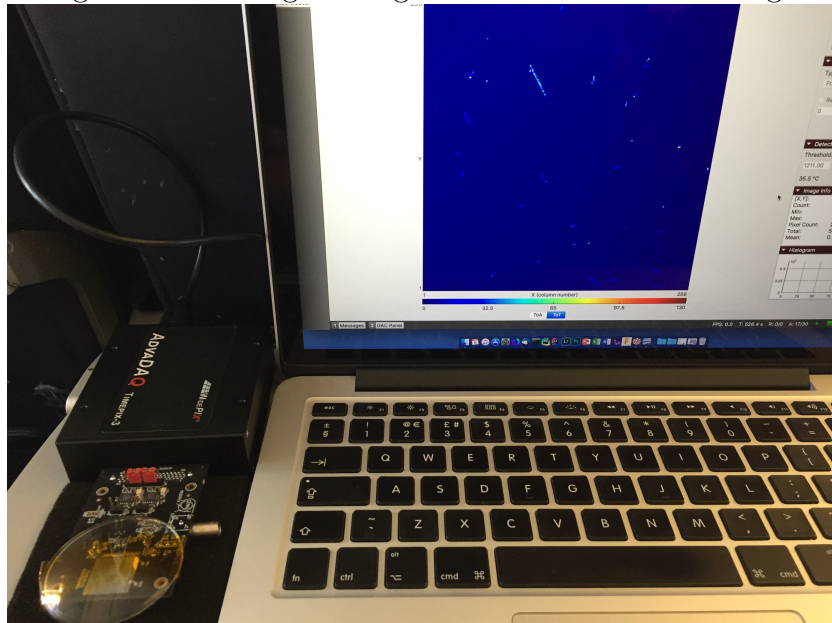


Figure 1.1 shows how readings were collected from the Timepix detector

in the environment, (in this instance Dungeness, but the same method was used everywhere else) and Figure 1.2 shows how readings were collected on board a flight from Newquay to London. The Timepix 3 detector versatility is demonstrated here, as it can be used in outdoor and laboratory environments almost equally well (the detector did need to be shaded in bright sunlight, to stop the frames being overexposed).

Full datasets that were collected are available in the corpus.

## Chapter 2

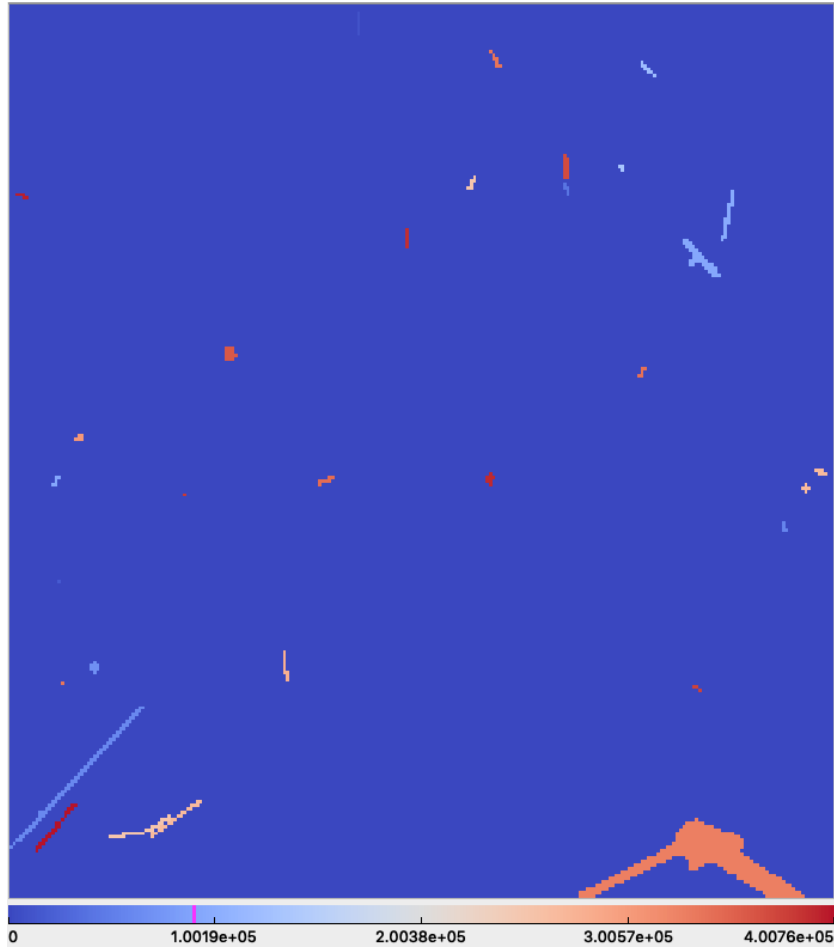
# Using ToA information for clustering

The per pixel ToA metadata that Timepix 3 provides has been used to improve the current clustering algorithm<sup>1</sup>. Previously, clusters have been identified by only considering two dimensions - hit pixels (those with a ToT value greater than 0) are identified, and a circle is drawn around them using a euclidean distance function with a user customisable radius. Now all hit pixels within this radius are added to a queue to build this cluster.

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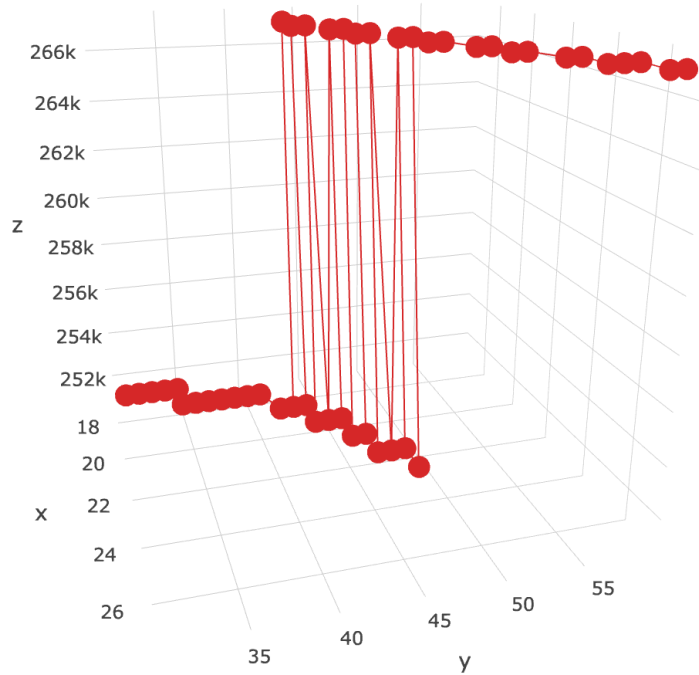
<sup>1</sup>[https://github.com/InstituteForResearchInSchools/lucid\\_utils/blob/master/lucid\\_utils/blobbing\\_energy.py](https://github.com/InstituteForResearchInSchools/lucid_utils/blob/master/lucid_utils/blobbing_energy.py)

Figure 2.1: ToA representation of a frame - different colours represent different points in time.



The main downside to this method is the fact that although two pixels may be hit and directly connected by space, they may not actually be part of the same incident particle (in time), and therefore should not be part of the same cluster! A visual representation of this (before the new clustering algorithm was applied) can be seen in Figure 2.2. The ToA representation of this whole frame can be seen in Figure 2.1.

Figure 2.2: Visual representation of a cluster identified with the current algorithm. Note: This is purely a visual representation, and is not to scale. The X and Y axes are the detector face, and the Z axis is time (arbitrary units). The straight lines show which pixels have been connected to one another.



The DBSCAN algorithm (Ester et al. 1996) and scikit-image connected component labelling (Scikit-image n.d.) were considered and tested for the clustering problem, but it was found that the existing clustering algorithm with ToA improvements produced better clusters for the input data.

The solution to this problem was to cluster using the per pixel ToA values instead of the ToT values. When checking whether a pixel is greater than 0, a check is also made to identify if the ToA value is within the range of the previous pixels ToA value  $\pm$  a constant,  $m$ .

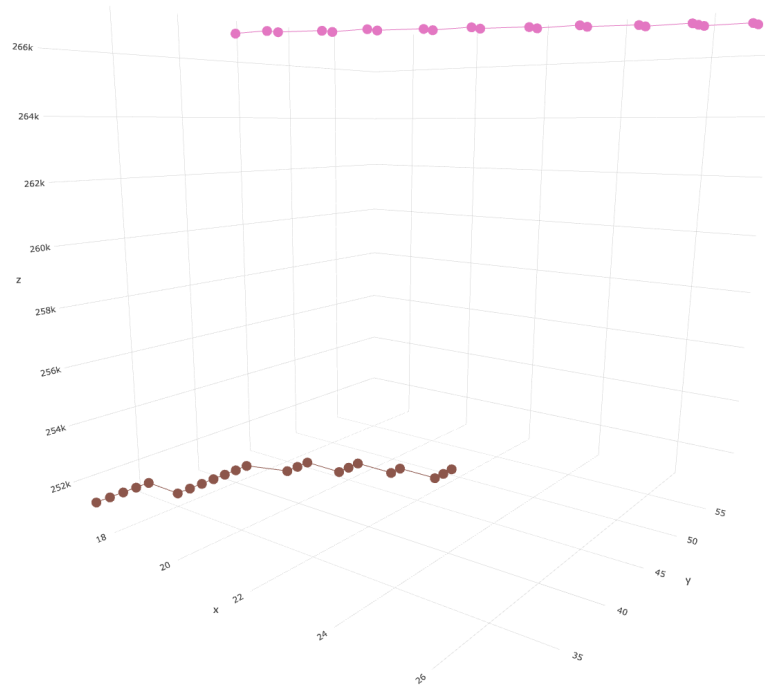
Before this solution could be implemented, the clustering algorithm first needed to return a tuple of  $x$ ,  $y$ ,  $C$  rather than just  $x$ ,  $y$ . This was rather easily implemented by returning the  $C$  value with the  $x$ ,  $y$  values in a 3-tuple.

To calculate  $m$  the following procedure was taken:

- A large number of measurements were taken around the UK using the Environmental Experimental Protocol (Appendix A) - these are measurements in the outside environment rather than a lab to provide a wide variety of different readings, allowing the final  $m$  value to better represent all files it is used on. Especially as outside measurements are most common with CERN@school projects.
- A script was run on all ToA files from the measurements. This script ran the current clustering algorithm on all these, and for each cluster an average of all the ToA values was calculated.
- Then, an overall average using all the previous averages was calculated to produce the constant.

The new clustering algorithm was then run on the same sample data set, as seen in Figure 2.3. This shows us that although pixels are next to each other in space, they are actually separated by a non-negligible amount of time, and the pixels that were previously part of the one cluster now are their own separate cluster.

Figure 2.3: Visual representation of a cluster identified with the new algorithm. Note: This is purely a visual representation, and is not to scale. The X and Y axes are the detector face, and the Z axis is time (arbitrary units)



## Chapter 3

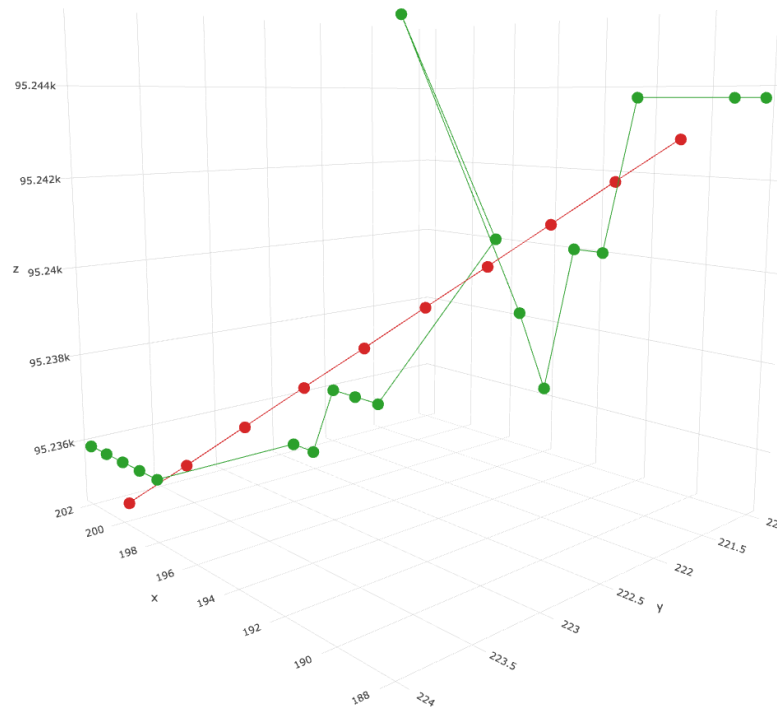
# Practicalities of using ToA information for angle identification

The original intention of the project was to use the ToA information provided by the Timepix 3 detector, to identify the incident angle of a radioactive particle relative to the detector plane - without needing to move the single detector. This would be a significant improvement on existing solutions, as a single detector could then be used where many are used (for example, in the MoEDAL project (Acharya et al. 2014), or the Matter from Light project).

Software was developed to visualise this (see Figure 3.1), with a line of best fit plotted and then used to identify the incident angle. This was accomplished using both Singular Value Decomposition and Least Squares (to test which method worked best) (Dwf & Paul 2010). However, this theory of calculating the angle was flawed due to the speed of the incident particles relative to the size of the detector, and Compton Scattering, where photons incident to the detector are scattered by the electrons in the sensor. This effect produces a track which is not truly representative of the incident Gamma ray (Compton 1923). It is most likely that both have played a part in making

the method flawed, with the speed/energy of an incident particle being the primary cause.

Figure 3.1: Visual representation of a cluster identified with the new algorithm, and a line of best fit generated using Note: This is purely a visual representation, and is not to scale. The X and Y axes are the detector face, and the Z axis is time (arbitrary units). The straight lines show which pixels have been connected to one another.



It is worth noting that an accurate "4D" representation of a particle track has been developed by Bergmann et al. (2017) to show the particle track in three dimensions and energy losses along this track - although the implementation of this is beyond the scope of this project.

The following proof shows that we cannot simply use the ToA information for incidence angles for particles that produce a small track:

We take the velocity of a gamma ray in air to be  $\gamma_{vel} = c$ , the speed of light. We also take the pixel width to be  $W_p = 0.000055m$ , the pixel length to be  $L_p = 0.000055m$  and the sensor ToA precision as  $P = 1.56e^{-9}s$  (Poikela et al. 2014). Using these, we can calculate the pixel sensitive area as  $A_{pixel} = W_p * L_p m^2 = 3.025e^{-9}m^2$  and the sensor sensitive area to be  $A_{sensor} = A_{pixel} * 65536 = 0.0001982464m^2$ .

We can now calculate the time it takes for a gamma ray to travel the length of one pixel -  $\gamma_{velp} = \frac{L_p}{\gamma_{vel}} = \frac{0.000055}{c} = 1.8346025e^{-13}s$ , and for the length of the whole detector sensitive area -  $\gamma_{vels} = \frac{L_s}{\gamma_{vel}} = \frac{0.01408}{c} = 4.6965825e^{-11}s$

Therefore, the time it takes for a gamma ray to travel across the whole detector area, should it be horizontal, is significantly smaller than the time resolution that the Timepix 3 detector can measure - which means that we are unable to use the ToA information to get an accurate representation of the track and time of a gamma ray. Higher precision ToA information would be required to calculate the incident angle. We are however able to use this method to calculate incident angles for very long tracks, such as those of the Muon that can be found in some background radiation readings and in space from cosmic rays. Unfortunately, this would require a Muon source to test the algorithm correctly - which the author does not have access to for this project.

An approach similar to how GPS is designed (but in reverse) was also considered. In this model, each pixel on the detector would be considered to be a receiver and a single emitting source would be used.

However, the main limiting factor with using this method is that due to the random nature of radioactive decay, it is not possible to accurately predict when the next particle will be emitted from a source. Without this information, the distance between the source and any of the 65536 pixels cannot be determined for certain, and therefore an incident angle cannot be calculated because at least two distance are needed, and one other angle

using the sine rule to calculate the incident angle. There is only one distance, between the two pixels, and possibly another angle, (depending on the experimental setup) that are available to use.

# Chapter 4

## Other angle identification methods

As ToA information proved unreliable to identify angles in Chapter 3, other methods were considered that may be used to identify incidence angles.

Initially, the maximum angle of incidence for the Timepix 3 detector would need to be determined. An experiment was performed using the angular protocol (Appendix B), and the experimental setup seen in Figure 4.1. Data was collected and analysed. Both the percentage occupancy of hit pixels of the detector surface (Figure 4.2) and the number of particles detected (Figure 4.3) were plotted against the angle at which they were measured. 10 frames were taken and the measurements averaged.

Figure 4.1: Experimental setup of the Timepix 3 detector. (a) the USB 3 readout interface, (b) the detector electronics, sensitive area, (c) clamp stands to hold the readout and sensitive electronics vertically, (d) ruler for measuring distance between source and detector, (e) angle measurement guide, (f) radioactive source, (g) power and data cables to control computer

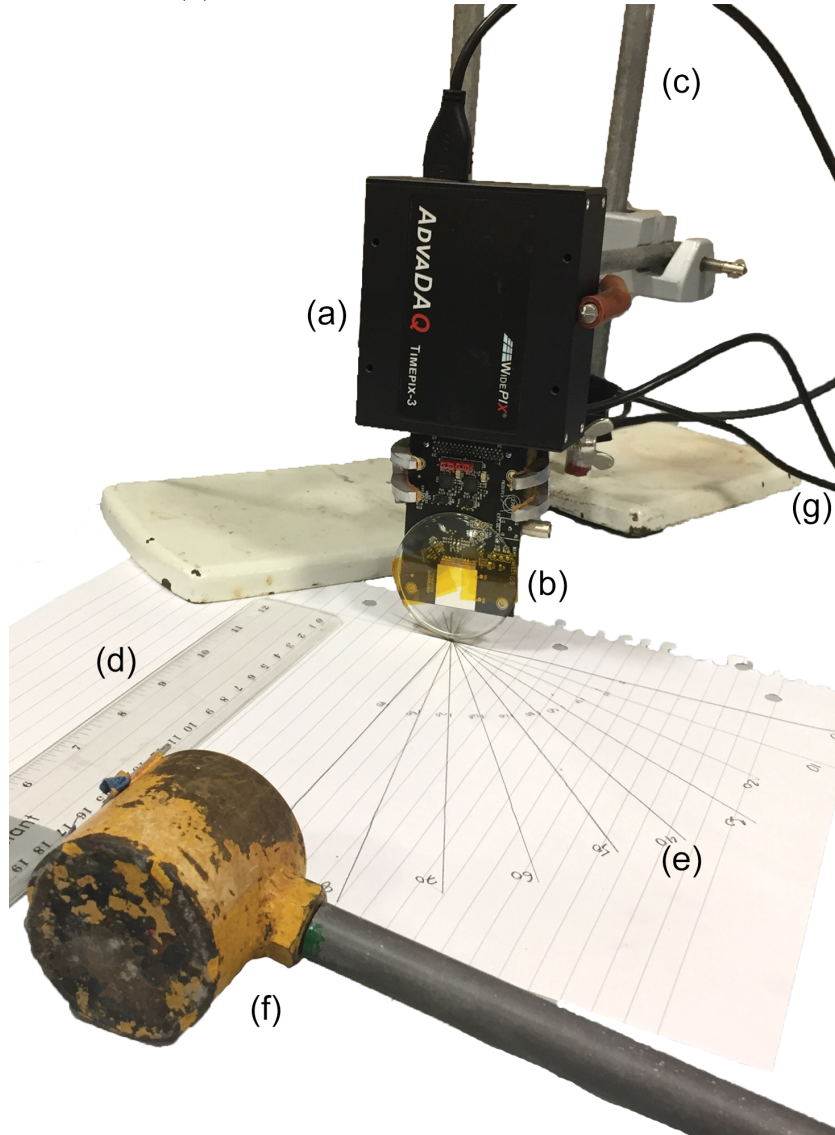


Figure 4.2: Percentage occupancy against angle graph

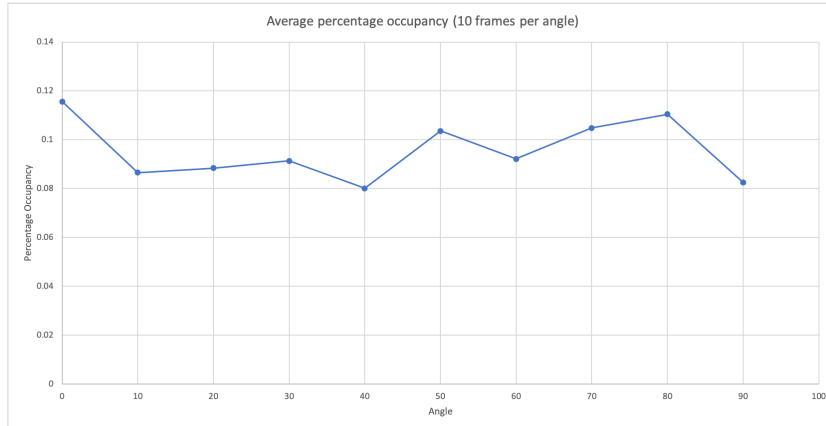
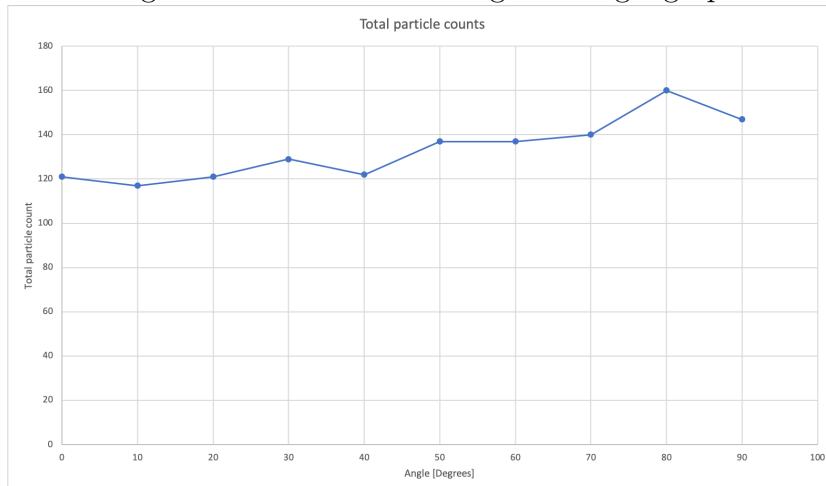


Figure 4.3: Particle count against angle graph



Interestingly, these graphs showed unexpected results - they did not show a Gaussian distribution as expected. A Gaussian distribution would show at which angle the detector no longer detects the majority of incident radioactive particles, which can then be used to identify which range of angles a source could be located. Instead the graphs actually show relatively flat distributions, which suggest that the detector is sensitive to incident particles at all angles, or as shown later, there may have been issues with the testing methodology.

For these experiments, a small script (Listing 4.1) was developed to identify the best settings to use for the detector, as it was thought that previous experimental results may have been influenced by non-ideal settings.

From visual inspection, it was found that the best settings to use were either 12.8 or 5 second exposure times, and conducted the experiment using both of these.

Listing 4.1: Python script for controlling the detector

```
devices = pixet.devicesByType(pixet.PX_DEVTYPE_TPX3)
if not devices:
    raise "No devices connected"
device = devices[0] # use the first device

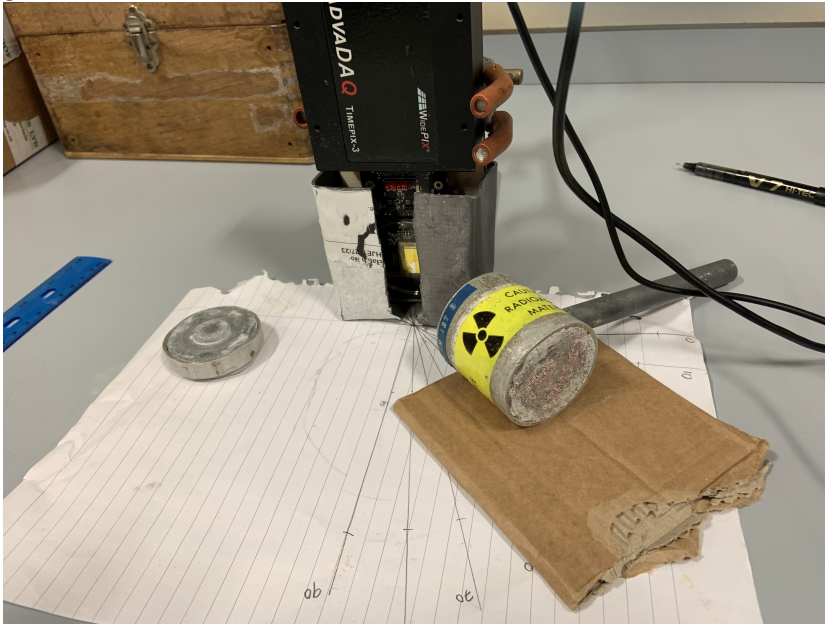
def acq_graded():
    acq_time = 0.1
    # 8 times is 25 seconds (ish) -> next step up is > 50
    ↪ seconds, so too long
    for i in range(9):
        count = 10
        current_acq_time = acq_time
        acq_time = acq_time * 2
        output_file = "/Users/will/tpx3_tests/occ_test/"
            ↪ occ_test_" + str(i) + "_" + str(acqTime) + ".txt"
        rc = device.doSimpleAcquisition(count, current_acq_time
            ↪ , pixet.PX_FTYPE_ASCII_FRAME, output_file)
        print "Acquisition: %d" % i
        print "exp_time: %f" % acqTime

acq_graded()
```

To rule out experimental errors, the experiment was performed another four times, using an updated experimental protocol (Appendix C). This time

a lead shielding iris (See Figure 4.4) was also used in half of the measurements, so a comparison could be made between lead shielding and no shielding.

Figure 4.4: Lead shielding iris attached to the detector, with a Cs-137 source pointing to it.



Like the first results that were obtained, the graph produced by these measurements shows an unexpected trend, with no significant distribution being seen. There is a slight increase at  $70^\circ$ , which the author does not have a certain idea of the cause.

We theorised that due to the source being at an angle to the detector, particle count values may be significantly different to the percentage occupancy values, as a incident particle may travel through many pixels at an angle compared to  $90^\circ$ . However, as Figures 4.5 and 4.6 show, this was not the case.

Figure 4.5: Percentage occupancy against angle for all experiments conducted

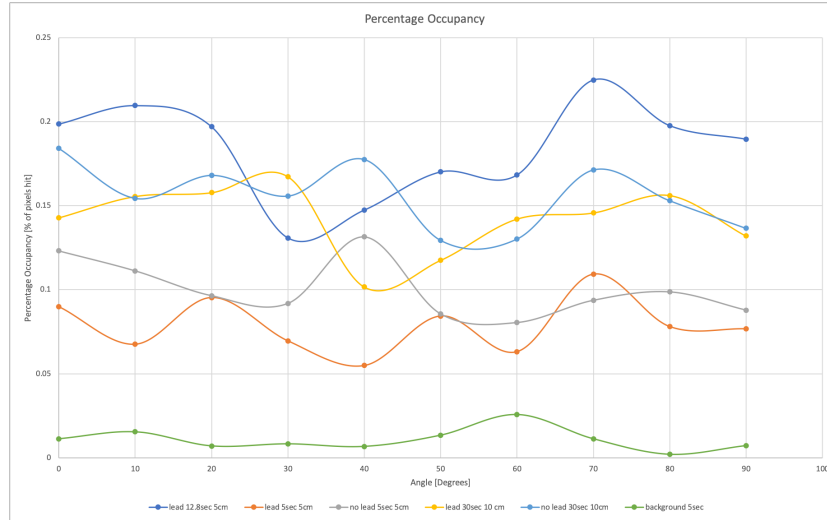
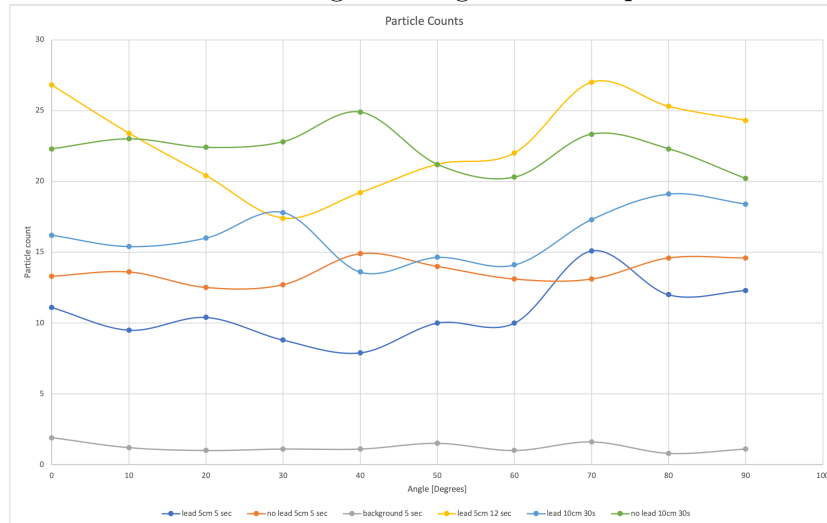


Figure 4.6: Particle count against angle for all experiments conducted



It was found that the decay energy of the Cs-137 source for  $\beta$  and  $\gamma$  is about  $0.6MeV$  (Chu et al. 1999), but the detector is only reliably sensitive to tens of  $keV$ , and this is why the experiment did not produce expected results. A lower energy source would have needed to be used to have more conclusive results (such as an X-Ray source). This is also the cause of the lead shielding showing similar results to that of no shield - the radiation be-

ing detected was simply passing through the lead! Therefore a much thicker lead shielding would be required.

Therefore, it is the case that the most appropriate method for angle identification has not been found in this project. However, chapters 5 and 7 show, once results are obtained with another source, other experiments can be conducted to improve angle of incidence detection accuracy.

# Chapter 5

## Automated measurements

Software has been written to allow Medipix detectors to be used without the use of a graphical user interface. Examples of this include 'rospix' and the 'Pixet' scripting environment. Rospix is a Robot Operating System (ROS) modular software tool that allows Timepix devices to be controlled automatically, and the data that they create processed in real time (Baca, Turecek, McEntaffer & Filgas 2018). The authors investigated the possibility of using Rospix with the Timepix 3 detector, because it would present a new opportunity for using the detector for angle identification - the detector could be mounted on a stepper motor that is controlled by another ROS module. The stepper ROS module would then publish to a topic its current position relative to a known position. While this occurs, the Timepix module would be constantly having the detector read out and process the data it is collecting, and then publish these results to another topic. A third module (or an extension to the Rospix one) could be made to correlate the data collected with the current position of the stepper motor, and identify at which location the radiation (percentage occupancy or certain particle counts) is greatest.

This information could then be used to identify in which direction a radioactive source is relative to the detecting computer system, allowing it to potentially be used for finding radioactive sources in an environment, ideally similar to the way in which a LIDAR detector can identify obstacles for

robots (Hall 2007). We note that a large collimator would be required for this method to work.

However, Rospix does currently not support reading data from Timepix 3 detectors, which means this is something that cannot be implemented at this time. Therefore, the alternative option is to use the Pixet Python scripting environment. This option is slightly more complex, as to implement the aforementioned functionality the computer system running Pixet would have needed to communicate with a second device. The second device controls and get feedback from a stepper motor (as Pixet seems to be for x86/x86\_64 systems). Additionally after exploration and testing, the Pixet scripting environment does not facilitate a live readout of captured frames, which make implementing an automated source detection system impracticable. (A script could constantly check a directory for when new ASCII frame files are created, but this approach seems like a short term 'hack' rather than long term solution and therefore would not be something that the author thinks would be a suitable implementation).

# Chapter 6

## Additions to TAPAS

To facilitate the analysis of Timepix 3 data, the web processing platform, TAPAS (The Timepix Analysis Platform At School) (Furnell 2016) needed to have minor modifications made. The web frontend was modified to allow data in the ASCII matrix format uploaded, and the analysis backend was modified to analyse this too, directly reading it into a NumPy matrix rather than converting x,y,C values to a matrix and then processing it. TAPAS was used heavily throughout chapters 1, 2, 4 to process raw data from the Timepix detector into particle counts, into CSV files that could be more easily managed.

# Chapter 7

## Further work

In the future it would be useful to perform additional experiments with the Timepix 3 detector using the angular protocol in Appendix C, and the same experiments with the Timepix 1 detector and compare them, to see if the results that have been found so far are limited to the Timepix 3 detector, or similar for all detectors in the family. Furthermore, if access to a Timepix 3 telescope is gained, then an angular identification algorithm similar to the one that was originally envisioned could be developed. This would not make a best guess to a general direction, but would use more than one detector, which would change the original goal. A different source would also be used during experimentation - such as an X-Ray source, which has much lower decay energies. Therefore, when following the Experimental Protocol in Appendix C, the results that would be found should be a Gaussian distribution, instead of those that were found in Chapter 4. This would imply that the Timepix 3 detector has frames with greater occupancy when a source is at a more direct angle to the sensor, and therefore the detector could be used multiple methods for angle identification.

Additionally, in the future, the author would like to compare results from this angular experimentation with results that (with further calculation) can

be obtained from LUCID data<sup>1</sup> and see if the angles of incidence on Earth from background radiation are significantly different to those in space.

Once the required readout drivers for the Timepix 3 detector are present in Rospix, it is hoped that the idea discussed in Chapter 5 could be developed, and the algorithm required for source/angle location could be properly developed and implemented.

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<sup>1</sup><https://tapas.researchinschools.org/view/lucid/run/>

# Chapter 8

## Conclusion

We have described and shown that using the ToA information for calculating angles of incidence, while theoretically possible, is not a feasible method for the majority of cases the Timepix 3 detector would be used in the environment and even a laboratory. Nevertheless, a method using a 3D line of best fit was attempted and could be used for Muon tracks with further testing.

We have developed experimental protocols for measurements in the environment, and angular measurements in laboratory conditions. Therefore experiments can be repeated and improved in the future.

Modifications were made to the current clustering algorithm to use the ToA information that is provided, so clusters are bound by both space and time. This allows more accurate classification of particles, as two particles that are next to each other in a frame will not be in the same cluster in most cases!

Other methods for automated measurements with the Timepix 3 detector have been discussed, using Rospix and the Pixet scripting environment, both with their respective advantages. It was found that when Rospix does support Timepix 3 it will be the better option of the two.

Additions to the TAPAS website were also shown, allowing the Timepix 3 detector and its data to be used without user conversion before uploading to the site.

Finally, we have shown that there is still much to do with the Timepix 3 detector with regards to incident angle calculation and there are potential links with other experiments such as LUCID.

# Acknowledgements

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# Appendices

Appendix C is a modified version of Appendix B, with updated instructions for gathering data and information on why the data gathering is taking place.

## Appendix A. Experimental Protocol - Outside

### Introduction

This experimental protocol details how the Timepix3 detector may be used to collect radiation measurements in the environment around you. A map of radioactivity can then be built up around the UK using these measurements. This protocol may also be used to collect data that is then used for further analysis.

The site selection is at the experimenters discretion - sites that have particular radioactive properties, e.g. a nuclear power station, may be of interest.

It is expected that the measurements that are gathered will vary depending on the environment/location of capture. In areas with a lower background rate, e.g. Kent, it is expected that the percentage occupancy of frames is lower than that of areas with higher background rate such as Cornwall. It is also expected that when measurements are taken on a plane that particles of particular interest - muons - will be detected at a greater rate than on the ground. There should also be a much higher percentage occupancy of all frames compared to ground based readings.

These measurements will provide real world data for angular measurements, allowing algorithms that are yet to be developed be tested on data that has not been produced in a laboratory environment. Therefore, problems with the algorithms can be identified, especially those relating to angular measurements of different types of particles - as alpha, beta, muons and gamma rays should be captured in some if not all the real world data.

## Method

The following method must be adhered to with each reading to ensure that control measures are put in place.

- Firstly the detector will need to be assembled, and power and USB3 cables should be connected.
- The detector will then need to be laid on a flat surface - ensure that the surface is clean of debris, dust and dirt.
- Ensure that the actual detector chip is facing the sky - this is an important step to make sure that all data is collected in the same orientation, as angular measurements may be inaccurate otherwise.
- The Pixet software on the host computer should then be opened.
- Load the configuration file for the detector in Pixet to ensure that the same bias voltage values and other settings are used for every reading.
- The operating mode should be changed to 'Frames'.
- Set the exposure time to 30 seconds.
- Set the number of frames to capture to 30. Don't enable repeats.
- Create a new folder on disk to save the frames in. This may be named at the experimenters discretion, but using the location is useful.

- The box for saving frames to disk should be checked.
- The filename for frames may be anything desired, but like the folder using the location is helpful.
- The frames must be saved in the ASCII matrix format (TXT files).
- The 'Start' button may then be clicked to initiate the capture.
- The capture may now be left to complete - however it is important to check the first two frames that have been captured for noise, if there is noise then the current capture should be aborted, and re-initiated. A cover to block visible light may need to be placed over the detector to remove noise in certain environments.
- Record the latitude and longitude of the location where data is being taken, either manually or via an online mapping service.
- Record the weather at the time of capture.
- This process may be repeated multiple times in a specific area to gather background radiation readings - the experimenter may wish to take readings inside and outside for comparison, and the experimenter may wish to take readings close to and at a distance from their site of interest.
- Once the data capture has finished, close Pixet, and pack up the detector.
- Make sure to make backups of any data that has been taken.

## **Appendix B. Experimental Protocol - Angular**

### **Introduction**

This experimental protocol is for using a Timepix3 detector to take measurements of a Cs-137 source that is placed at a range of angles from 0 to

90 degrees. This is to allow an algorithm for identifying angles of incident particles to be tested against known angular data, to identify whether the algorithm is working as expected, or is identifying angles that are not consistent with this data - and therefore may need to be modified.

It is expected that at 90 degrees, the percentage occupancy of frames will be at their highest, and decrease thereafter to its minimum at 0 degrees. It is also expected that particles incident on the detector will have the corresponding angle (in the majority of the time, except background etc.) to the angle that the source is facing towards the detector.

It is likely background radiation will also be picked up by the detector, so this has been factored into by the method, and any analysis of results will either have to disregard data that appears to be background or factor it in to the analysis by using a background reading produced before the source is used.

These measurements may also be used to further educational use of the Timepix3 detector within the Institute for Research in Schools for school students to process and analyse as they wish for their own experiments.

## **Method**

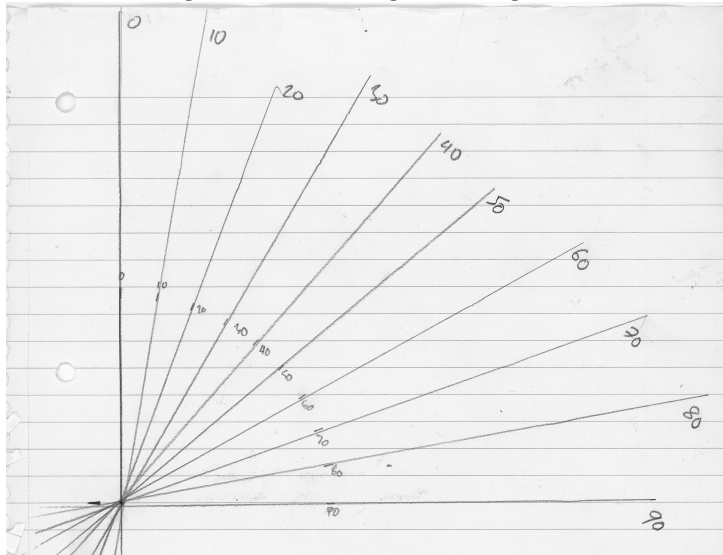
The following method must be adhered to with each reading to ensure that control measures are put in place.

- Note: Due to the use of radioactive sources, this experiment requires extreme care. A risk assessment can be found in Figure 8.
- Firstly the detector will need to be assembled, and power and USB3 cables should be connected.
- The detector will then need to be held vertically with a clamp stand, with the actual detector chip facing the experimenter straight ahead.

- Angles 0 through 90 in ten degree increments should be marked on a piece of paper using a protractor. An example of this can be seen in Figure 8.
- The paper should be placed on a flat surface, and the detector should be aligned to be on the 90 degree line, at the bottom.
- The Pixet software on the host computer should then be opened.
- Load the configuration file for the detector in Pixet to ensure that the same bias voltage values and other settings are used for every reading.
- The operating mode should be changed to 'Frames'.
- Set the exposure time to 30 seconds.
- Set the number of frames to capture to 15. Don't enable repeats.
- Create a new folder on disk to save the frames in. This may be named at the experimenters discretion, but using the angle/background is useful.
- The box for saving frames to disk should be checked.
- The filename for frames may be anything desired, but like the folder using the angle/background is helpful.
- The frames must be saved in the ASCII matrix format (TXT files).
- Before a radioactive source is used, the above settings should be used to produce a background radiation reading, so any readings with a source can be normalised against the background (ignore the following step when doing the background measurement).
- The radioactive source should be placed 20 centimetres away from the detector, facing the chip part of the detector, firstly at the 90 degree angle (directly in front of the detector).
- The 'Start' button may then be clicked to initiate the capture.

- The capture may now be left to complete - however it is important to check the first two frames that have been captured for noise, if there is noise then the current capture should be aborted, and re-initiated. A cover to block visible light may need to be placed over the detector to remove noise in certain environments.
- The experiment then should be repeated for all other angles, with the source being moved carefully each time, always 20 centimetres away. The source should always be directed towards the detector.
- Once the data capture has finished for all angles, close Pixet, and pack up the detector.
- Make sure to make backups of any data that has been taken.

Figure 1: The angular diagram.




## Risk Assessment

The following risk assessment has been conducted for using a Cs-137 source with the Timepix 3 detector in the University of Kent School of Physical

Sciences laboratories, but should be applicable to nearly all laboratory based scenarios.

Figure 2: Risk assessment for Cs-137 source.

<u>School of Physical Sciences</u>	
	UKC SPS No.
<b>Risk Assessment</b>	
<b>Task:</b>	
<b>Measuring radioactivity using a Cs-137 source and a Timepix 3 detector at different angles</b>	
<b>Hazard/Hazardous Properties:</b>	
Cs-137 emits ionizing radiation in the form of beta particles and high energy gamma rays. This could cause irradiation of parts of, or the whole, body as the result of exposure of the end of the source in the direction of a person, (or ingestion), directly resulting in burns, cell damage & mutation and in severe cases major illness.	
<b>Controls:</b>	
The radioactive source will never be pointed towards a person. The source will not be handled with bare hands – tweezers or another appropriate tool will be used to move the source. The experiment will be done in an unoccupied area of the laboratory to reduce potential exposure to others. The source will only be used for the absolute minimum amount of time required for the experiment to take place. When not in use, the source will be securely stored in a shielded container. The working area will be kept clear of any equipment/tools that are not essential to the experiment. Other users of the lab will be made aware of the ongoing experiment to reduce the chance of them coming into the area that the source is being used. When conducting the experiment, the person conducting it will stand back from the source during the data collection phase. Eating and drinking will not be allowed in the experiment area. The experiment will only be carried out under supervision by a trained person.	
<b>Risk Level: Low – if controls are followed</b>	
Name: Will Furnell	
Signature: 	Date: 30 <sup>th</sup> August 2018
Review Date:.....	
Signature of Departmental Administration:..... Date: .....	
Copy to: - Safety Coordinator: <input type="checkbox"/> Supervisor: <input type="checkbox"/> Worker: <input type="checkbox"/>	

The completed form must be sent to the Departmental Administrator.

# Appendix C. Revised Experimental Protocol - Angular

## Introduction

This experimental protocol is for using a Timepix3 detector to take measurements of a Cs-137 source that is placed at a range of angles from 0 to 90 degrees.

It is likely background radiation will be picked up by the detector, so this has been factored into by the method, and any analysis of results will factor it in to the analysis by using a background reading produced before the source is used - and subtracting the average of this from the results if necessary.

In this protocol, a lead shielding iris is used to make sure that any incident radiation only enters the detector sensitive area at a 90 degree angle. This should mean that when data is plotted (percentage occupancy against angle) a Gaussian-like distribution will be shown - unlike the results that were obtained using the previous version of this experimental protocol.

Therefore, it is expected that at 90 degrees, the percentage occupancy of frames will be at their highest, and decrease thereafter to its minimum at 0 degrees. Therefore, it is also expected that the number of discrete particles detected should decrease. This is because the lead shielding should block the beta particles and gamma rays that are emitted from the source when the source is not directly perpendicular to the detector sensitive area.

To confirm that this is the case, the experiment will be repeated with the lead iris not in place, and the same plot of percentage occupancy against angle will be conducted. This will prove that the Timepix3 detector has no

stopping power for the radioactive particles and therefore suggest why the previous experiment did not produce the expected results.

If the results obtained are not a Gaussian distribution then it suggests that the lead used is not thick enough to block radiation as intended, and therefore the experiment would need to be repeated with thicker lead. It is also possible that the lead shield was not designed correctly and further research and development would need to be undertaken to alleviate this issue.

These measurements may also be used to further educational use of the Timepix3 detector within the Institute for Research in Schools for school students to process and analyse as they wish for their own experiments.

## **Method**

The following method must be adhered to with each reading to ensure that control measures are put in place.

- Note: Due to the use of radioactive sources, this experiment requires extreme care. A risk assessment can be found in Figure 8.
- Firstly the lead shielding iris should be attached via velcro to the laser cut backplate.
- Then, the detector PCB should be attached to the FitPIX USB readout electronics. This combination should then be inserted into the iris, and the readout electronics should be screwed into the backplate - keeping everything secure.
- The detector rig will then need to be held vertically with a clamp stand, with the actual detector chip facing the experimenter straight ahead. Note: The lead rig is particularly heavy - so care should be taken to make sure it does not damage any of the sensitive electronics.

- Angles 0 through 90 in ten degree increments should be marked on a piece of paper using a protractor. An example of this can be seen in Figure 8.
- The paper should be placed on a flat surface, and the detector should be aligned to be on the 90 degree line, at the bottom.
- The Pixet software on the host computer should then be opened.
- Load the configuration file for the detector in Pixet to ensure that the same bias voltage values and other settings are used for every reading.
- The operating mode should be changed to 'Frames'.
- Set the exposure time to 30 seconds.
- Set the number of frames to capture to 15. Don't enable repeats.
- Create a new folder on disk to save the frames in. This may be named at the experimenters discretion, but using the angle/background is useful.
- The box for saving frames to disk should be checked.
- The filename for frames may be anything desired, but like the folder using the angle/background is helpful.
- The frames must be saved in the ASCII matrix format (TXT files).
- Before a radioactive source is used, the above settings should be used to produce a background radiation reading, so any readings with a source can be normalised against the background (ignore the following step when doing the background measurement).
- The radioactive source should be placed 20 centimetres away from the detector, facing the chip part of the detector, firstly at the 90 degree angle (directly in front of the detector).
- The 'Start' button may then be clicked to initiate the capture.

- The capture may now be left to complete - however it is important to check the first two frames that have been captured for noise, if there is noise then the current capture should be aborted, and re-initiated. A cover to block visible light may need to be placed over the detector to remove noise in certain environments.
- The experiment then should be repeated for all other angles, with the source being moved carefully each time, always 20 centimetres away. The source should always be directed towards the detector.
- The experiment may then be repeated more times to enable an average to be calculated.
- The whole experimental protocol should then be repeated, but without the iris present.
- Once the data capture has finished for all angles, close Pixet, and pack up the detector.
- Make sure to make backups of any data that has been taken.
- Percentage occupancy should then be plotted against angle - which should produce a distribution that appears Gaussian.

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