# Experimental 2 Report: Positron Emission Tomography

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## 1 Summary of Apparatus Capabilities

### 1.1 Conversion Factors

In order to determine the distance in centimeters that corresponds to each motor step, a conversion factor was measured using a linear scan of the apparatus. To do this, the platform was set to move 30,000 steps. The beginning and ending positions of the platform were marked on the linear stage and this distance was measured with a caliper. 30,000 steps is one third of the full distance the platform is able to move. A large step count was used to mitigate error through dividing by more steps, however larger step counts $>$ 30,000 became more difficult to measure precisely due to the physical space of the motor and limitation of the caliper. Therefore, a distance of 30,000 steps was chosen as a medium value to minimize error. The measured distance the platform moved in the 30,000 steps was 7.224 $\pm$ 0.001. Uncertainty was determined by the limitation of the caliper. This makes the final conversion factor:

$$30,000 \text{ steps} = 7.224 \pm 0.001 \text{ cm}$$

$$\delta y = \frac{\delta x}{x} y = \frac{0.001}{7.224} * 4152.8 = 0.57$$

$$\frac{30,000 \text{ steps}}{7.224 \pm 0.001 \text{ cm}} = 4152.8 \pm 0.57 \text{ steps/cm}$$

The conversion factor for angle was given through the lab wiki. It relates 25600 motor steps as one full rotation. This defines:

$$\frac{25600}{360} = 71.11 \text{ steps/degree}$$

## 1.2 1D Spatial Resolution

The 1D spatial resolution was determined using a single scan across the entire range of the apparatus (90,000 steps). The linear scan was done using 90 collections, meaning they were each 1,000 steps apart, or 0.24 cm. The scans lasted 10 seconds each. With these parameters, the final linear scan gave the following results:

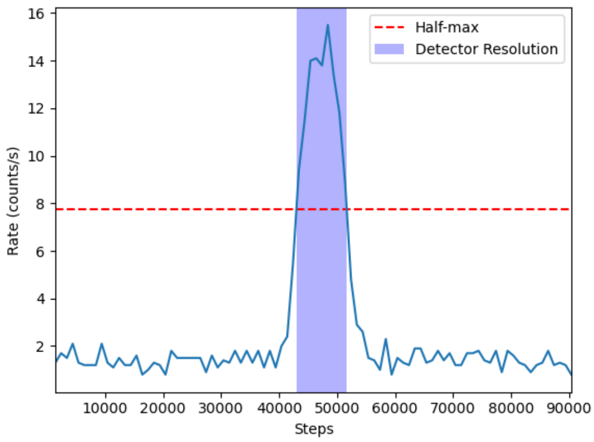


Figure 1: 1D spatial resolution of detector

The resolution of the detectors was found through the full-width half-max method. First, the half of the maximum value of the plot was found to be 7.9 ± 0.5 counts/s. The uncertainty of the maximum was found by averaging the difference in rate of the closest two data-points. Next the x-values where the data intersects the half-max were found, as seen on Figure 1. The points of intersection were found directly by calculating the equation of the line between the two points nearest the half-max value, then determining the step value that corresponds to the intersecting point. The intersection points then act as the bounds of our resolution. Error in the intersection point was propagated with the parameters of the regression and the uncertainty of the half-max value. The full range is 8,685 steps ± 0.2 or 2.09 ± 0.6 cm. The middle point of this range is then cited as the center point of the apparatus, with the center point being at 47,319.5 steps ± 0.2 steps .

## 1.3 Two-Source Resolution

The two source resolution, or the distance at which the detectors can no longer distinguish between two separate sources, must also be determined as a measure of apparatus capability. This is important in interpreting the results from the detectors, as we can only claim certainty of the separation of two sources to a certain threshold. In order to determine the two-source resolution, our method consisted of conducting various runs of two sources, separating them by small increments and re scanning until a separate peak appears on the plot of rate/position gathered from the detector.

This data was gathered across the entire length of the apparatus, with 30 instances of data collection, each scan lasting 10 seconds. This means data was collected every 3,000 step lengths, or every 0.72 ± 0.056 cm. Rather than using the 90 collections we used previously for the 1D spatial revolution, to limit the amount of running time, we used 30 collections instead. This decision can result in a less precise final measurement than if all 90 steps were used.

The two sources were measured from their center point starting at a separation distance of 0 cm (two sources were overlapping). Then, a larger distance of 2.5 cm was used for separation. This distance was narrowed and re-scanned until the distances between the sources varied by 0.3 cm.

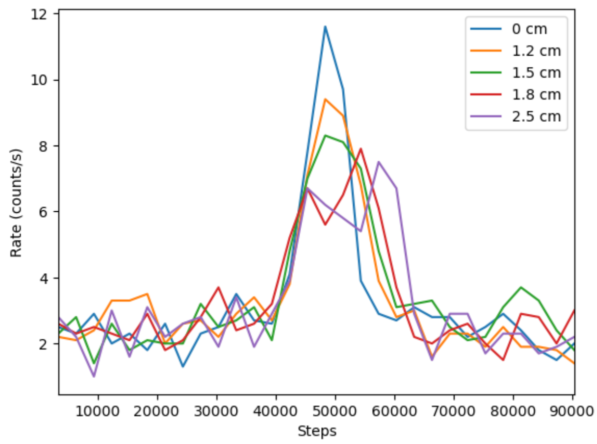


Figure 2: Two-Source Spatial Resolution

As we can see from the data, we still do not get any notable separation of the two sources at a 1.5 cm distance, however when it is increased to 1.8 cm we begin to see a dip in the peak of the plot, denoting two separate sources. Therefore, taking into consideration our scan parameters (30 scans across 90,000 steps), the detectors can distinguish between two sources outside of a $0.3 \pm 0.001$ cm range (0.001 cm uncertainty is determined by caliper through measurement of distance between the sources).

# 2 Interpretation of Unknown Sample

Our unknown sample was run using 45 rotations, each of 8 degrees or 568.88 motor pulses. Each scan was conducted for 10 seconds with 90 lateral steps, each of 1,000 motor steps. These parameters were chosen in order to get the maximum definition in our final data, while staying under the limit of an 11 hour total scan.

When analyzing our results using the pet plotting notebook, the sinogram we get from the data shows:

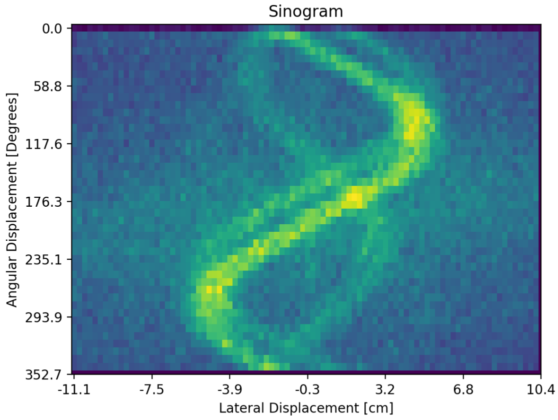


Figure 3: Two-Source Spatial Resolution

From this plot we can observe the lateral displacement for every angle of rotation that was run. Reconstructing the image requires overlaying many of these images to achieve an image that resembles the original configuration of sources. The final reconstruction images are shown in Figure 4.

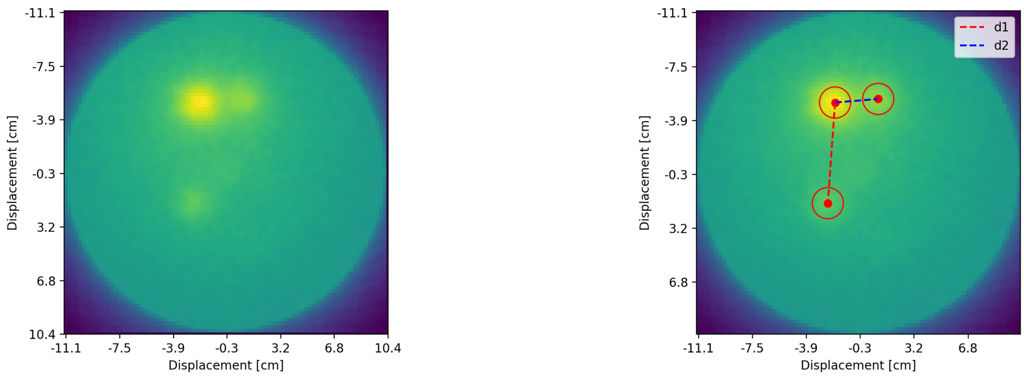


Figure 4: Final Reconstruction of Source Configuration

From the plot, the center sources were picked by determining the maximum value within a region of interest as the center-point of the source signal. The regions of interest were manually selected. The calculations were not done in centimeters, instead using the number of steps the data was collected in, resulting in a (90,90) matrix. The final distances were then calculated geometrically using the center-points. Because of the limitation of choosing exact data points when identifying the center points, and because each data point represents 1,000 steps, an additional uncertainty of 500 steps is added to the distance measurement. The distance in steps is then converted to centimeters and the uncertainty propagated (see Figure 6).

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \tag{1}$$

Figure 5: Distance Between two Centerpoints

$$\frac{\delta \text{Dist (cm)}}{\text{Dist (cm)}} = \sqrt{\left(\frac{\delta 0.57}{4152.8}\right)^2 + \left(\frac{\delta 500}{\text{Dist}}\right)^2} \tag{2}$$

Figure 6: Error Propagation of Final Distance

The final distances in steps and centimeters are shown below:

| | Distance (steps) | Distance (cm) |
|---|---|---|
| d1 | 28070 ± 500 | 6.76 ± 0.110 |
| d2 | 12040 ± 500 | 2.90 ± 0.116 |

The most intense center node reaches an count rate of 26 where the other two sources see rates of 21 and 19 respectively.

# 3 Challenge Task Summary

For the challenge task, the parameters were chosen with a 30 minute limit. To reduce our scan time within the limit, we sought to limit the amount of rotations to 5, assuming there could be 3 or more sources in the unknown configuration, 5 was on the minimal end in which a reasonable amount of sources could be independently scanned.

Our final scan consisted of 24 lateral steps, moving 3,750 motor steps each, and 5 rotations spanning 360 degrees. Each angular movement spanned 5,120 motor pulses, or 72 degrees. The collection time was set to 8 seconds. The reduction of the collection time from 10 to 8 second was necessary in order to keep the total scan time under 30 minutes. When doing the challenge, we were most hesitant about reducing the scan time, as we suggested a higher count number would create higher contrast in our plots that make them easier to interpret. We were also hesitant about reducing the number of rotations as we hypothesized that it would have a greater impact than reducing the number of linear movements. We therefore reduced the number of lateral scans from 90 to 24, reduced the number of rotations from 45 to 5 and the scan time from 10 to 8. Our resulting sinogram shows as follows:

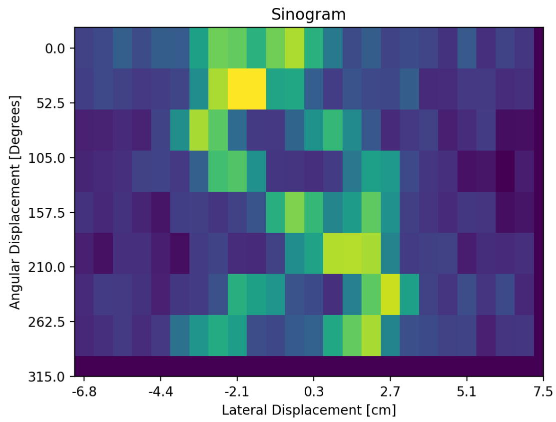


Figure 7: Two-Source Spatial Resolution

The reconstructed sources were analyzed the same way as for the unknown sample in the previous section. From the data above we can visually see two nodes of stronger intensity. The most intense done being at -0.3cm on the x axis and 2.7 cm in the y axis, reaching an count rate intensity of 35 while the second source reaches an intensity of 30. The limit of rotations makes them much less distinct than in the previous section. Like the previous analysis, the point of maximum intensity in each region of interest was found, acting as the source center point.

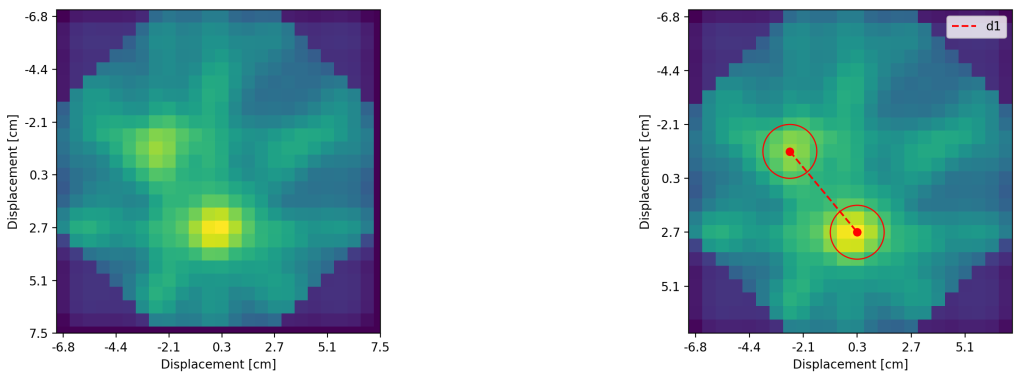


Figure 8: Final Reconstruction of Source Configuration

| | Distance (steps) | Distance (cm) |
|---|---|---|
| d1 | 29288.4 $\pm$ 1875 | 7.05 $\pm$ 0.42 |

The calculations and uncertainty for the final value in centimeters was done in the same manner as the previous section, however due to the reduction in the number of scans, the uncertainty in point distance is raised from 500 to 1,875. This value reflects half of the number of motor steps each data collection spans (1,000 in a 90 collection scan and 3,750 in a 24 collection scan).

If we were to repeat the experiment, I believe increasing the number of rotations and decreasing the collection time slightly would be a beneficial change. The low amount of rotations caused overlapping lines in the reconstruction that make it difficult to pinpoint the locations of the sources/ what are the true sources. It is worth noting that from the data we collected there is much less certainty on if there were only two sources, and the existence of more sources in the tertiary intense nodes is possible. From what we have observed in the first Unknown sample collection and this challenge, changing scan time from 10 to 8 seconds does not have a visible significance on the contrast in the plot. In the future, I believe this parameter can be lowered even further without compromising the readability of the plot.