Data Analysis Techniques for Micropattern Gas Polarimeters

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1. Introduction

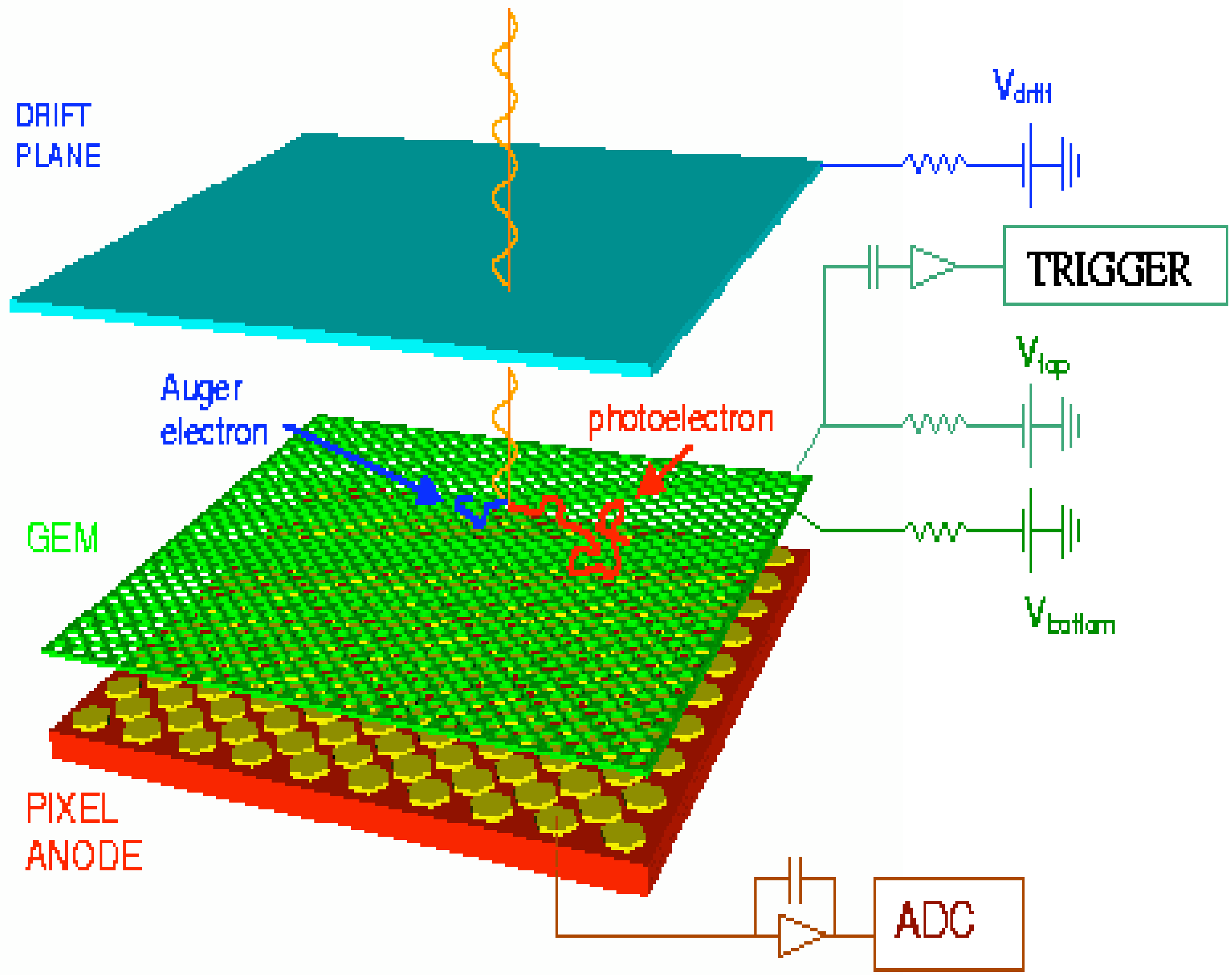
The development of the micropattern gas detector has opened new possibilities for measuring the polarization of X-rays (Costa et al. 2001, Nature 411, 662). The K-shell electron is ejected in a direction whose probability distribution depends on the polarization of the incoming X-ray. The micropattern detector is able to resolve the track of this electron as it loses energy by generating secondary electrons. However, data analysis is not straightforward since the K-shell electron is deflected by nuclei in the gas and does not follow a straight track. Secondary electron generation varies as 1/E so most of the charge is produced at the end of the track, whose orientation may not reflect the original direction of the electron. An additional complication is that some of the X-ray energy goes into an Auger electron which is emitted isotropically. The detector is illustrated schematically in figure 1.

The analysis method developed so far is to look at each event individually. The distribution of charge is used to derive the interaction position and the start of the track supplies an angle. Including the later section of the track, which contains most of the charge, increases the noise in the angle measurement. If the source is polarized then a histogram of measured angle will show a modulation (Bellazzini et al. 2003, SPIE 4843, 372).

We are investigating an alternative analysis technique which uses all the available information simultaneously. We stack all the events on top of each other and compare to a linear combination of unpolarized and polarized events. The best-fit polarization fraction and angle with their confidence regions can then be estimated using standard chi-squared methods.

In this preliminary work we have used a simplified simulation scheme. We assume a monoenergetic beam of 6 keV X-rays interacting with a detector containing neon at a pressure of 1 atmosphere. We assume that the interaction occurs at a height of 1500 microns above the anode, which has 200 micron pixels. The code to generate photoelectron and Auger electron tracks (kindly provided by Kevin Black) uses the standard Joy-Luo approximation for the energy loss and the Mott cross-section for collisions.

Figure 1: Schematic by R. Bellazzini of a micropattern gas detector



2. Determing the interaction position

In order to stack the events on top of each other we must first determine the position at which the X-ray interacts with the gas and the photoelectron and Auger electron are generated. We will then shift the tracks so they all have the same interaction position and stack them.

Figure 2 shows the mean and variance of the X pixels included in the track for 10,000 events. Note that this does not include the charge in the pixel - only whether or not there was any charge detected in that pixel. The events simulated had an identical interaction position of 8.5. There is a quadratic relation between the variance and the distance between the mean and the interaction position. Given a mean and a variance we can estimate an offset which should either be added to or subtracted from the mean to give the interaction position. If we could perfectly determine whether to add or subtract we could recover the interaction position to about 1/3 of a pixel. The best we can do at present is to also calculate the mean pixel in the track weighted by the charge in each pixel (the track barycenter). If this is greater than the pixel mean then we subtract the offset, otherwise we add it.

Figures 3 and 4 show the result of applying this algorithm. The true interaction position of all these events is (8.5, 8,5). This position is reconstructed to within +/- 0.5 pixels for almost all the events.

Figure 2: Quadratic relation between the mean and variance of the pixels in the track.

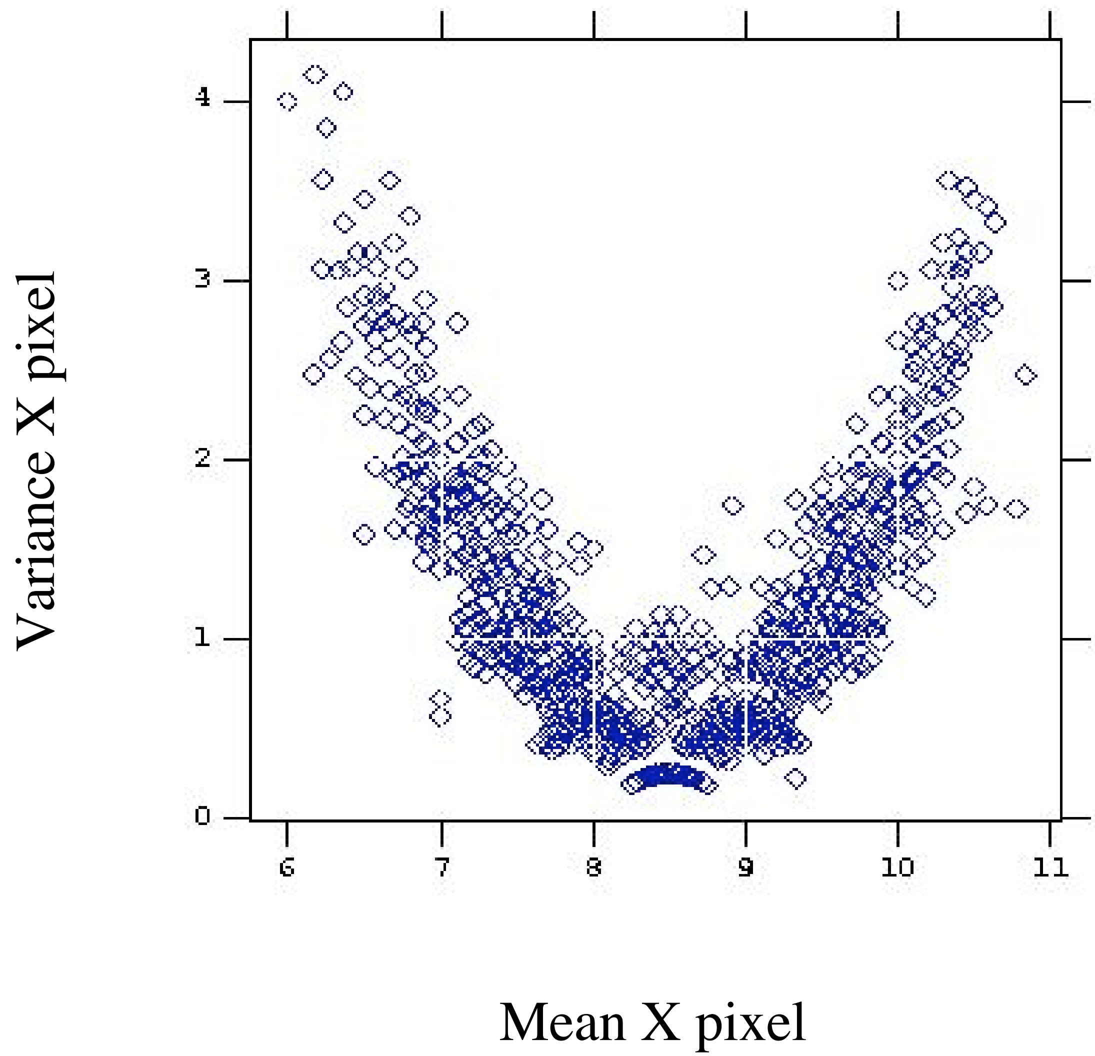


Figure 3: Reconstructed interaction positions

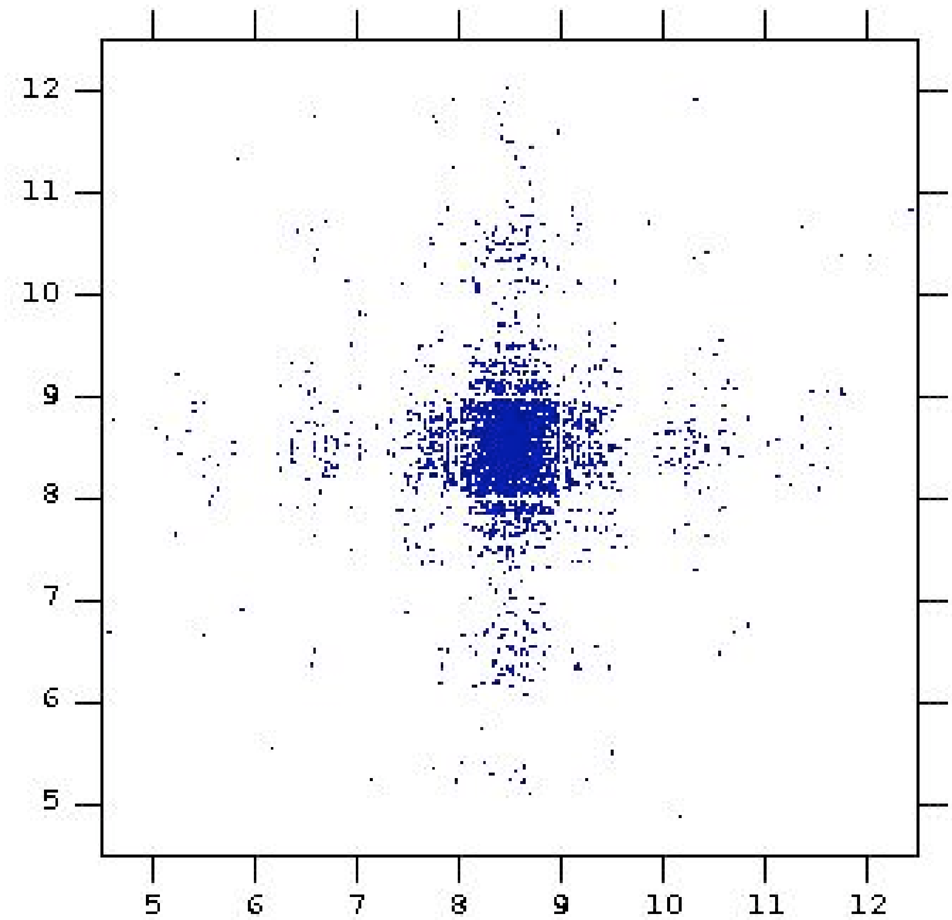
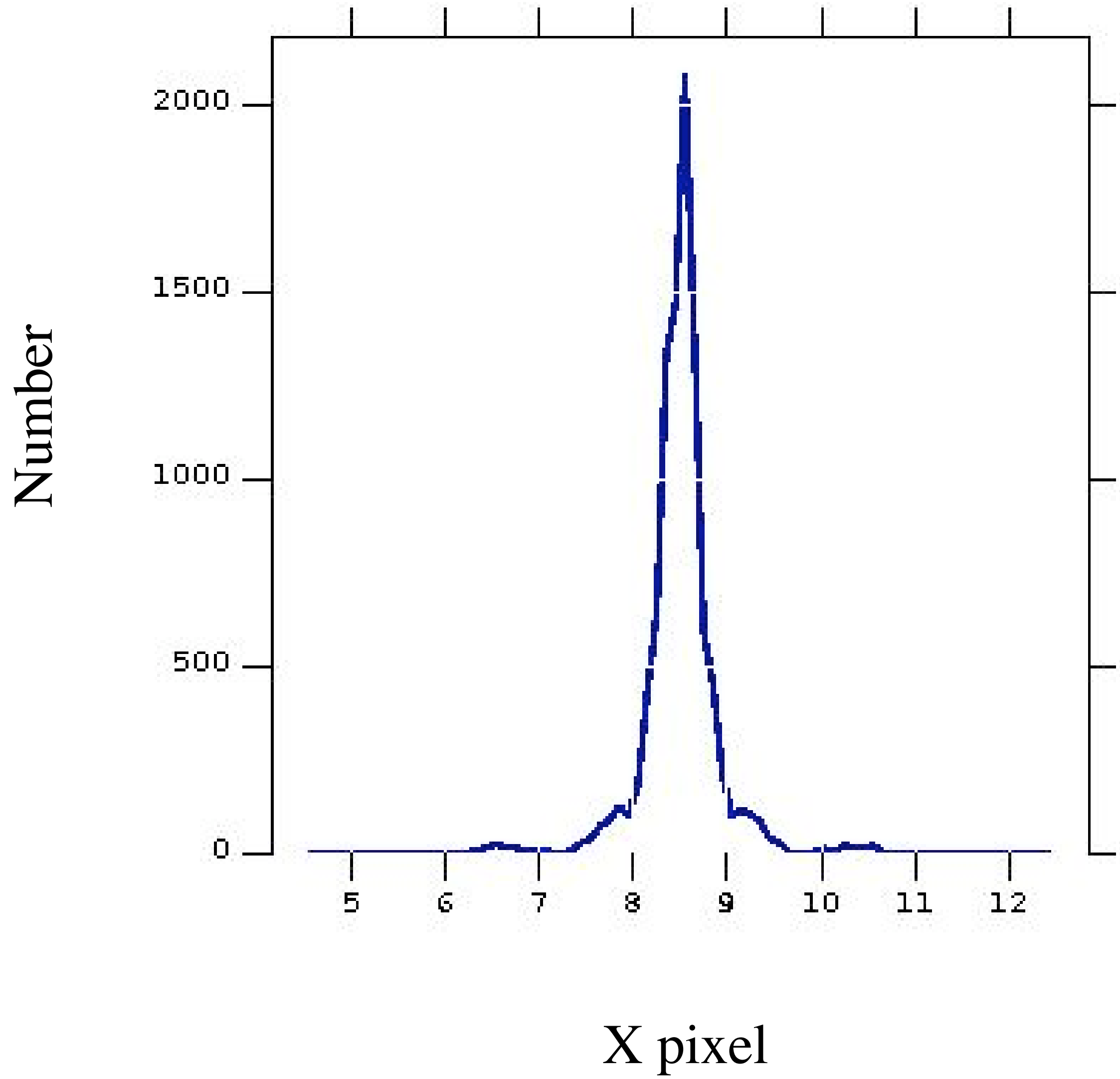


Figure 4: Histogram of calculated interaction positions.



3. Model fitting

In order to fit the stacked simulated events we also need to calculate the expected distributions for unpolarized and polarized events. These are shown in figure 5. The completely polarized version is noticeably flattened relative to the unpolarized. We repeated these simulations 100 times so that we could also calculate a variance for the charge in each pixel.

We then performed one more simulation in which half the events were assigned a fixed polarization and the other half a random polarization. We stacked the events then compared to linear combinations of the two images shown in figure 5. The free parameter is the fractional polarization. Figure 6 shows the resulting chi-squared. The input polarization is recovered with an uncertainty of approximately 10%. This is an artificially good situation because we have assumed that the polarization angle is known. A true fit would have two free parameters - the angle and fractional polarization.

Figure 5: Stacked events. The left panel is a simulation of 10,000 events with identical polarization angles (0 degrees measured from the X axis). The right panel is a simulation of 10,000 events with polarization angles randomly assigned. The colour table is logarithmic.

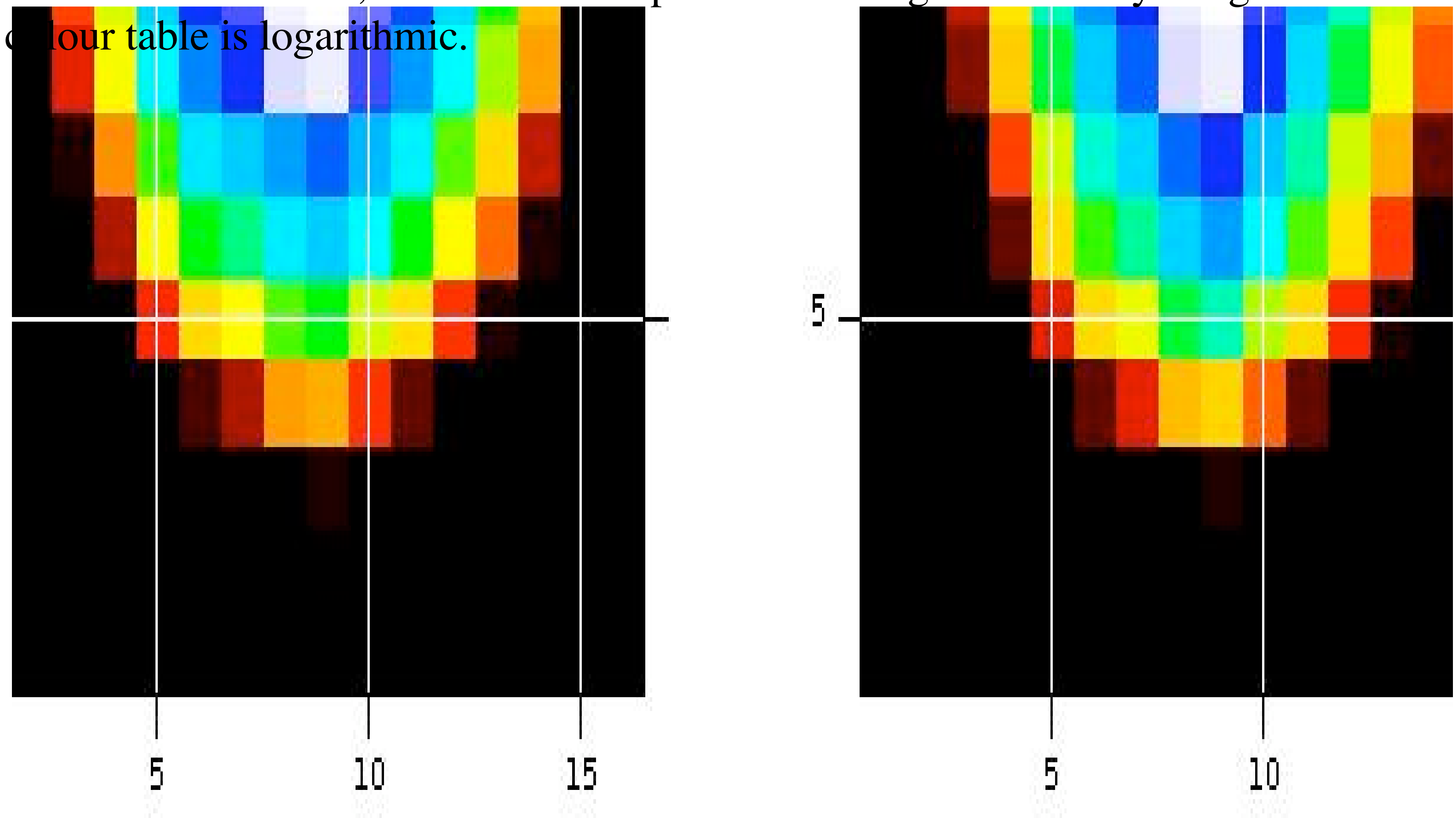
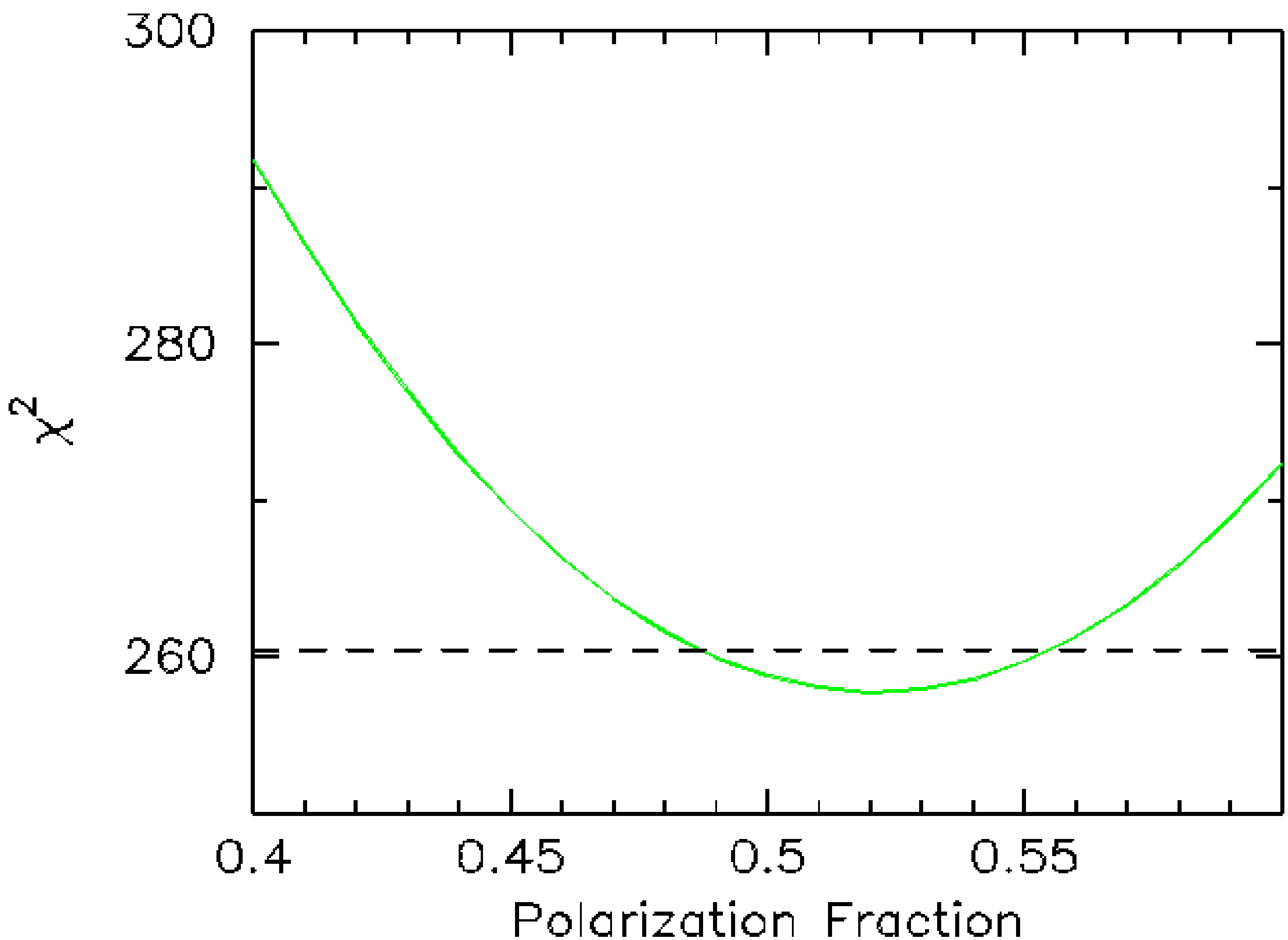


Figure 6: The green line shows the chi-squared for the simulation, which has a true polarization fraction of 0.5. The horizontal dotted line indicates the 90% confidence region on the polarization fraction.



4. Future Work

There are a number of obvious avenues to explore. Firstly, the simulation needs to be made more realistic, with the interaction depth varying. The polarization angle needs to be made a free parameter in the fitting and we need to confirm that it can be correctly recovered. We need to look for ways to improve the algorithm to determine the interaction position, particularly whether the calculated offset should be added or subtracted.

Finally, we need to compare this results with the “standard” event by event method to establish which one determines the polarization most accurately. Even with these new detectors we will be photon-starved so we need to ensure that we have the best possible algorithms to measure the polarization.