Calculation of the relation between counts and electrons in the DES CCDs using traces of cosmic rays.

L.Galbany and M.Martinez DES-IFAE

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1 Introduction

We want to measure the correspondence between electrons and counts in the DES-Spain CCD readout setup using an image of a cosmic ray taken with a DES CCDs. Cosmic rays reaching Earths surface are predominantly muons. Therefore, we will compare the expected ionization charge released by muons in Silicon with the number of counts observed in the pixels where the muon has passed after subtracting the counts of the dark pixels (pedestal).

For minimum-ionizing particles (mip), such as the muon, the most probable charge deposition in a 300 μm thick silicon detector is about 22000 e^- (Review of Particle Physics, p. 238). This is so because in Silicon the most probable ionization energy loss by a particle in the mip regime is about 270 $eV/\mu m$ and the energy needed to create an electron-hole pair is about 3.6 eV (Review of Particle Physics). It is important to stress that these are not mean values

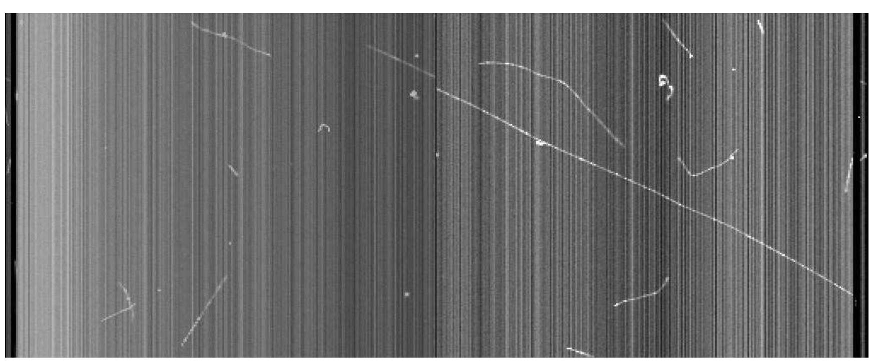

Figure 1: The complete muon trace

but the most probable ones, because the energy deposition curve is actually a Landau distribution with a long tail and not a Gaussian. For instance, in 160 μm of Silicon the most probable values for the deposited energy or charge is about 0.70 times smaller than the corresponding mean values, whereas for 80 μm is about 0.60.

Then, as we have squared pixels of 15 μm, we should find about 1100 e^-. Taking into account the impact angle, this value can be a little bit larger. The trajectory has an angle of 29.3° from horizontal, and then the muon travels 17.2 μm for each pixel, leaving about 1260 e^-.

We don't take into account the width of the silicon detector, because it is 0.260 μm, and it wouldn't change too much the final value of the trajectory (2 nm).

The difference in the number of counts between a pixel where the muon has passed and another one where it hasn't (dark), will give us the number of counts equivalent to 1260 e^-. We find ourselves facing a small problem, because the muon could have passed by more than one pixel in the same column, dividing the charge that it leaves in them. Due to the geometry of the CCD and to the impact angle, the muon can only pass by two pixels of the same column.

2 Measuring the energy loss of the muon

When the time comes for analyzing the CCD we see that each column of pixels in the CCD has its own contrast. The number of counts of each pixel can only be compared to the counts of the pixels on its column. We also clearly see that all the pixels on the left side of the CCD have more counts than on the right side. This can be due to either the CCD electronics or the Monsoon video amplifiers.

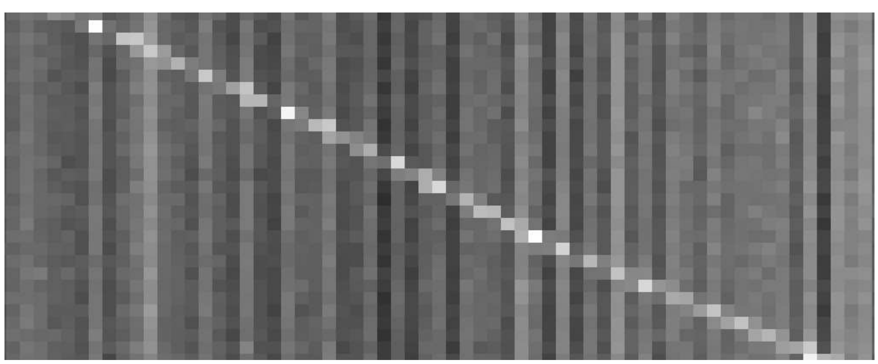

Figure 2: Amplied image of the muon trace in the right CCD side.

In order to do a good measurement, we would have to take the difference between the number of counts of the pixels where the muon has passed and the pedestal counts, for each column. After that we would have to measure statistically how many counts per pixel leaves the muon. But in this note we only want to make a rough estimate of this value, and we'll only take a small sample of these pixels where the muon has passed.

Table 1: Number of counts in some pixels of the right CCD side. n is the road index for the pixel crossed by μ^-.

n-2	n-1	n	n+1	n+2
76797	76794	78266	76745	76884
77189	77440	78402	77100	77177
76398	76503	78192	76576	76620
76154	76351	77913	76163	76338
76618	77005	78511	76439	76489

We have selected 5 columns on the right side where we can clearly see that the muon has only passed through one pixel. We have subtracted the counts of the contiguous pixels from the count of the middle one and we have checked that the contiguous had a similar number of counts than the following ones. Finally, we can see that the chosen pixels where the muon has passed have 1568 more counts than the pixels where it hasn't, in average.

We make the same calculus on the left side. But this time, we find some cases where the charge left by the muon is spread in 3 pixels of the same column,

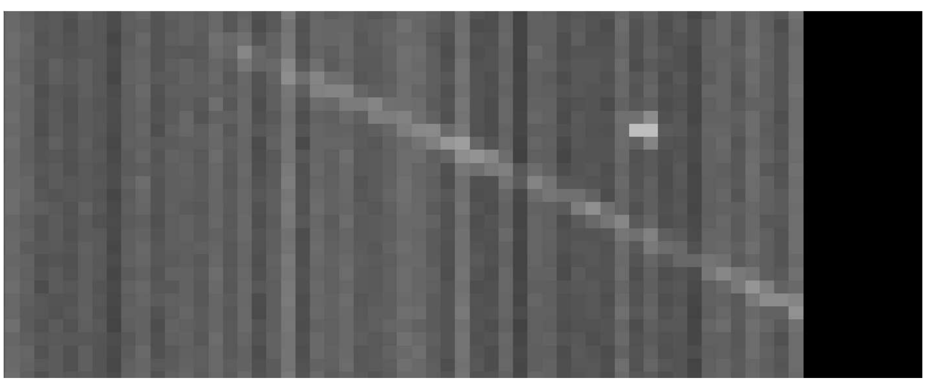

Figure 3: The muon trace in the left CCD side.

Table 2: Number of counts in some pixels of the left CCD side.

n-2	n-1	n	n+1	n+2
83975	84208	84896	84305	84006
83959	84263	84957	84396	83935
83941	84326	84996	84267	83931
84162	84395	84719	84340	84198
84240	84468	84983	84564	84323

although geometrically it's not possible. The middle one is more illuminated than the contiguous, which are more illuminated than the following ones. This can be due to the voltage which produces the potential wells for each pixel. We think that the wells might not be deep enough and this could allow the charge to spread among pixels. Taking the number of counts of these last pixels as the pedestal, we subtract it from the counts of the middle one pixel and the contiguous. Summing the remainder, we have the counts per pixel left by the muon. The final value we find is 1408.

Taking the mean value of the counts per pixel and of the electrons per pixel, we find that the relation between them is roughly about 1.2 counts per electron.

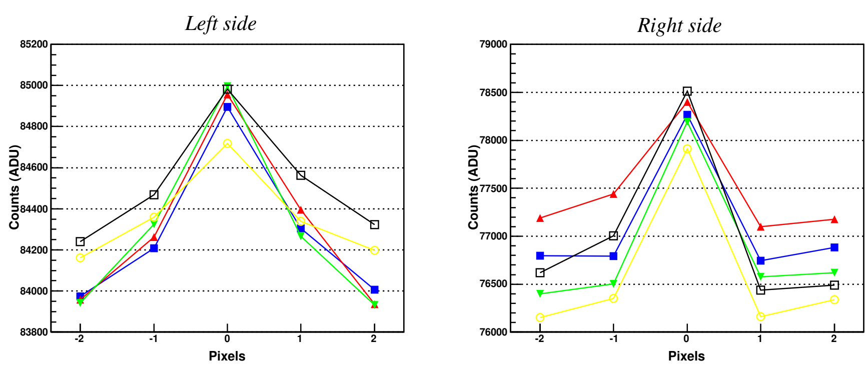

Figure 4: We can see the charge spread in the neighbour pixels compared to the following ones. We can also see that in the right side the image is sharper than in the left one.