The Uniformity of Cesium Iodide Crystals

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Abstract

The LASSA detector array has very high energy resolution requirements. These requirements necessitated the application of several different correction methods. These correction methods were all somewhat thwarted by the discovery of relatively large local variations of light output from the crystals. These local variations could not be globally corrected, and therefore the general correction methods used were not as effective as they could have been. These local variations will have to be mastered and understood before the optimum energy resolution can be achieved.

Introduction:

The LASSA (Large Area Silicon Strip Array) uses Cesium Iodide crystals, which are scintillators, for energy measurements. This array has very high energy resolution requirements. The resolution and therefore the uniformity of these crystals is very important. This is because the Cesium Iodide crystals are the primary method of determining the energy of the incident particles. Only crystals with uniformity variations under 1 percent are used in this array.

There are nine telescopes in the LASSA array. Each telescope is composed of two Silicon Strip detectors followed by four Cesium Iodide crystals behind them (see figure 1). The second of the two Silicon Strip detectors is 500 μm thick and has two perpendicular sets of strips. The EF strips provide x positional resolution and the EB strips provide y positional resolution. Both sets of strips have a width of about three millimeters. There are sixteen strips in both sets and this yields 256 “pixels” which are the x and y coordinates of the point where the particle enters the Cesium Iodide crystals. As there are four Cesium Iodide crystals, there are sixty-four of these pixels in each crystal. When the detectors are bombarded with a beam of known energy, one obtains sixty-four measurements of the variation in the light output as a function of position in the crystal

It is important to understand how a Cesium Iodide crystal in order to understand why each crystal is not actually uniform. Cesium Iodide crystals exploit the fact that when an ion passes through a solid medium it will give energy over to some of the electrons. This will excite them out of the valence band into the conduction band (using the band theory of solids). Cesium Iodide crystals are insulators, this means that their energy gaps are big enough that when one of these electrons deexcites it will emit a photon in the ultraviolet spectrum. This is not the optimal wavelength for collecting data from the crystal. To correct this the crystal is doped with Thallium. Thallium acts as an activation center in the crystal. The electrons excite the activation center and when the activation center deexcites it will emit a photon in the visible light spectrum. This is very good for converting over into an electronic signal. The number of photons will

determine the strength of the signal and the number of photons is proportional to the concentration of activation centers where the ion actually entered the crystal.

This means that even if two ions enter the crystal with the same energy they might register as having different energies. This is because one might end up giving most of its energy up in an area with lots of these activation centers producing lots of photons, whereas the other ion may end up giving up most of its energy up in an area where there are fewer of these activation centers so it will actually look like it had less energy. This implies that if these activation centers are not uniformly distributed throughout the crystal then there will have to be a positional correction to the energy reading to get the optimum energy resolution.

Experimental:

The data, which was analyzed, was taken from an earlier experiment. A beam of 240 MeV α particles was shot directly into each detector. This yielded quite a few statistics so that corrections could be made to the crystals and the effectiveness of the corrections ascertained. The originally proposed corrections were very global in nature. They resulted from the data taken during the uniformity tests performed upon the crystals when they were purchased.

The uniformity test was performed with a 5.486 MeV α particles from a collimated ^{241}Am source. The nine different points in the crystal, which were irradiated with the source, had a diameter of approximately six millimeters. There were actually three measurements of the middle point to insure that there were no long-term drifts influencing the resolution during the test. The nine positionally different measurements made it look like there was a linear gradient in the doping for most of the crystals. This meant that only a simple correction applied to the data would compensate for this and improve the resolution quite a bit.

It actually turned out that there are some local variations in the crystals. These local variations are large, when they are compared to the total variation of the crystal. They are usually about one-half to one-third the size of the total variation in the crystal. These local variations came as quite a bit of a surprise as they were definitely not expected. They can be rather large, usually on the order of a few tenths of a percent, which translates to a few tenths of a percent worse energy resolution (see figure 2).

These local variations could be caused by quite a number of factors. The first possible explanation is that a relatively large and dense packet of activation centers causes localized peaks. This concentration of activation centers would result in a larger light output at that point, which translates to a larger energy reading. A relatively diffuse region of activation centers would then cause localized valleys. Of course, these regions would have to be small, on the order of a few millimeters in cross-section at most. The localized valleys could also have been caused by defects in the crystal, but these defects should be visible to the eye.

Another factor that might cause some of the local variations would be nonuniform light collection due to a bad crystal surface or bad wrapping with poor reflectivity. The influence of such a region would be proportional to the solid angle the region presents to the ionization region where the light is produced. For this reason, most of the analysis of the pixels containing the local variations was conducted for pixels that reside near the

center of the crystal. This should minimize any effects from light bleeding from other crystals or bad reflections off of the wrapping of the crystals. Since the variations are very localized, usually consisting of about nine pixels, arranged in a three by three matrix and over this small region, the solid angle of a bad place on the edge of the crystal would have only a small effect. A much bigger effect would have been observed near the edge of the crystal, but no such effects were present at the required level. We concluded that the local light output variations were the result of the manufacturing process.

In addition to the local variations in the crystals, there also exist global trends. The most interesting characteristic of these is the fact that they appear to be independent of the depth of the crystal being examined. The global trends were present in the α source measurement and the corrections based upon them were valid in the sense that the corrections improved the resolution of the entire detector. The fact that these variations appear throughout the crystal suggests that this might be a consequence of the manufacturing process. The relative simplicity of the trend, and the fact that the trend is depth independent suggests that there might be a linear gradient to the activation centers that would explain this.

A linear correction based upon the α source tests was developed and applied to the data from the α beam. This correction is based upon the trends that can be found in the data from the uniformity test. The nine points are divided into six different lines, three in the x-axis and three in the y-axis. These lines all contain three points. The slopes and the y-intercepts of the lines along each axis are averaged together, (i.e. all of the lines which go along the x-axis are averaged together to get one line). The average line is taken as the general trend of the crystal, and offsets are applied to the data from the α beam based upon where each pixel lies along the line. These offsets attempt to make all of the centroids of the peaks of the pixels correspond to the average centriod of the detector

This correction ignored the local variations completely, which impaired its effectiveness. To see whether the problem was with the α source data a new correction based upon the α beam data was developed. This new correction basically looked for linear trends in the α beam data and then removed them. This was done by running eight lines down the x-axis and eight along the y-axis, (these lines had eight points). Then the average slopes and average y-intercepts of these two sets of lines were calculated. Finally, a check was made to make sure all of the component slopes were with in a certain tolerance of the average slope to insure that a local variation could not be interpreted as a global trend very easily. When this correction was applied the increase in energy resolution was comparable to that of the α source correction.

Results and Discussion:

The energy resolution of the crystals was improved by applying either of the linear corrections. The actual improvement was around six percent. A resolution of 1.246 MeV was achieved for the corrected crystal as opposed to 1.340 MeV for the uncorrected crystal in the case of the 240 MeV α beam. These resolutions are extraordinarily good corresponding to .533 percent and .570 percent respectively. The improvement in the energy resolution is a result of applying the offsets to each pixel, which in effect shifts the centroid a few channels. This means that the entire peak for each pixel shifts a few channels, so if all of the peaks are summed up for the entire

detector and if the correction is valid then the peak will have a width smaller then the width of the uncorrected peak. Actually, the energy resolution of the crystals is almost directly related to the width of the peak as compared to its position. The corrections were not as effective as they could have been because of the local variations, (see figure 3).

The corrections actually have an upper limit past which it is impossible to increase the resolution any more. The best correction possible that of a pixel by pixel correction which makes the average of the spectrum of each pixel exactly equal to the average global spectrum. This yields an energy resolution of about 912 keV for the 240 MeV α beam. This is the limiting resolution of the detector and this resolution is about two times larger then the noise width of 400 keV. This resolution is based upon the widths of the peaks within each pixel.

The pixel by pixel correction is not valid for any depth besides where it was performed because of the local variation. This correction could not be applied for a 200 MeV α beam, as that beam would actually be stopped prior to where the 240 MeV α beam was stopped, and as of now the depth dependence of these local variations is not known. It would seem very likely that these local variations are depth dependent. This means that unless calibration runs like the 240 MeV α beam run are performed throughout the crystal and the actual stopping place of the particle in question is known then this is not really a valid correction for anything besides finding the limiting resolution of the detector.

Conclusions:

The energy resolution of the Cesium Iodide crystals can be improved by applying some of the linear corrections to correct for general trends. The local variations, which came as a big surprise, limit the effectiveness of these corrections and can even lead to a badly applied correction at times. These variations and their causes will have to be mastered before significantly better energy resolution can be achieved. Different manufacturing techniques may actually be able to get rid of these local variations, as they seem to be a consequence of the doping methods.

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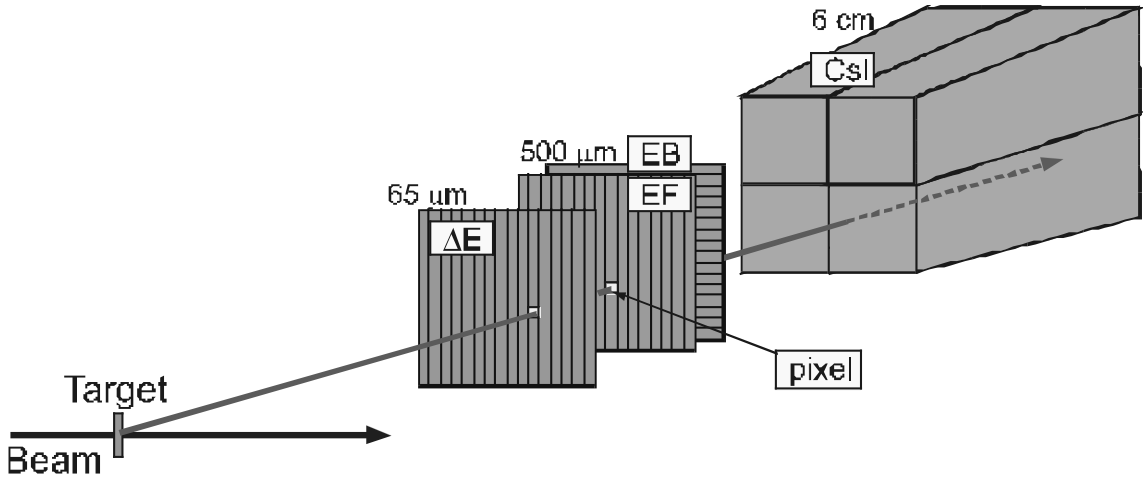


Figure 1
A schematic diagram of a typical telescope of the LASSA array.

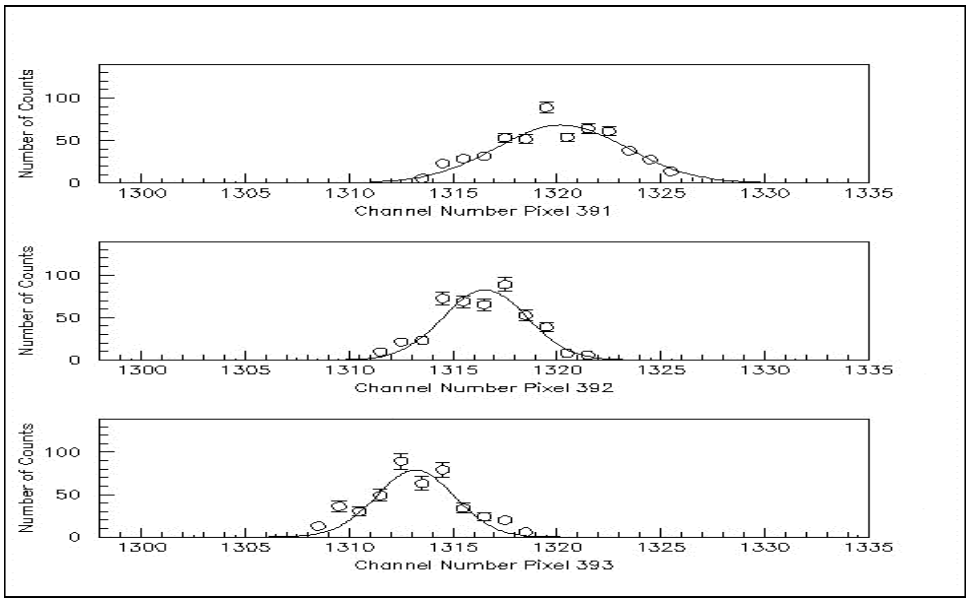
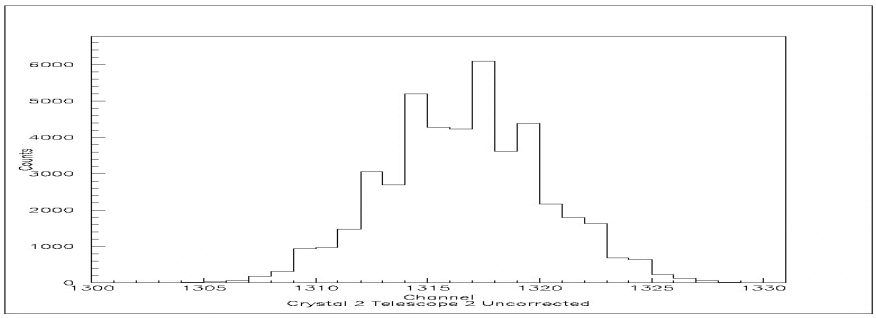


Figure 2
The energy spectrum for three pixels right next to each other. This is the trailing end of a local peak in the light output of the crystal.



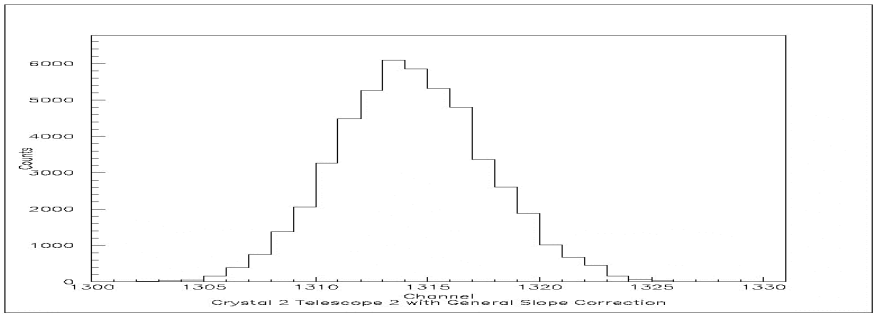


Figure 3: A comparison of the uncorrected energy spectrum for the detector (top) and the corrected, using the α beam data correction, energy spectrum for the detector (bottom).
The top spectrum has a resolution of about 1.34 MeV and the bottom one has a resolution of about 1.25 MeV.