Testing of time of flight diamond detectors at TAMU cyclotron: 31st March - 2nd April 2010

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A project is under way in the UK, led by the Universities of York and Surrey, to develop diamond detectors for time of flight measurements as part of the LYCCA array (Lund-York-Cologne-Calorimeter), designed to identify and track the many fragments to be generated in the Super FRS at GSI. This array will form part of the NuSTAR project at FAIR, and in particular the HISPEC project which will concentrate on in-beam gamma-ray spectroscopy of exotic fragments at 100 – 200 MeV/u [1].

A commissioning run for the prototype of the LYCCA array, LYCCA-0, is planned to take place toward the end of June 2010 in which diamond detectors (used as start time of flight) shall be tested. In order to be able to distinguish between fragments with mass differences of only 1 u, the timing resolution of the diamond detectors must be less than 100 ps, and preferably close to 50 ps for a flight path of only 3.4 m [2].

Up until the beam time at Texas A&M University (TAMU) cyclotron institute, timing resolutions of, at best, ~300 ps per diamond detector had been attained. This was primarily due to a lack of understanding of how the electronic setup (CFD/leading edge thresholds, bias, PCB's, cables etc.) affected the resolution, as well as the fact that tests could only be made with 20-30 MeV deposited in the detectors in the UK.

The beam time at the cyclotron institute enabled us to take measurements with energy deposits of around 500 MeV in the front detector and 800 MeV in the back detector, which was essential to create pulses with a good signal to noise ratio and is far more like the energies that shall be deposited in the detectors during the HISPEC project. Beam time prior to the commissioning run was vital in order to understand and optimise the electronics associated with fast timing. Diamond detectors have been used as timing detectors before, but never with a surface area as large as that of the LYCCA-0 diamond detectors. It was therefore important to change and test variables in a systematic way so that the principles of their operation could be well understood.

Experimental Setup

Two polycrystalline diamond wafers with dimensions 20 mm x 20 mm x 0.3 mm were placed one above the other onto an impedance-controlled PCB, one wafer having an Aluminium contact, the other a Gold contact. The front contacts of the wafers were divided into four strips of 20 mm x 5 mm, each strip acting as an individual timing detector. An identical PCB with identical diamond wafers and contacts was placed 15 mm behind the first PCB in transmission geometry, inside a vacuum chamber at the end of the MARS separator. This provided sixteen channels of timing signals which could be used for coincidence measurements between front and back PCBs.

DBA-IV preamplifiers, specially designed for use with diamond, were used to shape and amplify the current pulse from the diamond detectors. This pulse was then sent through a variety of conventional electronic modules, including either leading edge or constant fraction discriminators, before the data was acquired using Caen V1290 TDC.

The detectors were placed in a secondary beam consisting mainly of 35 MeV/u ^{40}Ar and the first front detector pulses, viewed on an oscilloscope outside the cave, looked extremely encouraging. The pulses were large, ~ 2 V, well above the noise which was found to be around 40 mV, and pulse heights varied far less than expected. Pulses from the back detectors did not look quite as high-quality, but a few of the strips were more than good enough to make worth-while coincident measurements between.

Optimum settings were found by systematically increasing the bias on the detectors and lowering the thresholds of the leading edge discriminators and CFD's, something that we have never been able to do before. From initial data analysis, a total timing resolution of 124 ± 12 ps has been measured (Fig. 1), from which, assuming equal contributions, a resolution of 88 ± 11 ps for each detector results. This is far better than any previous tests with these diamond detectors, and is less than 100 ps as desired.

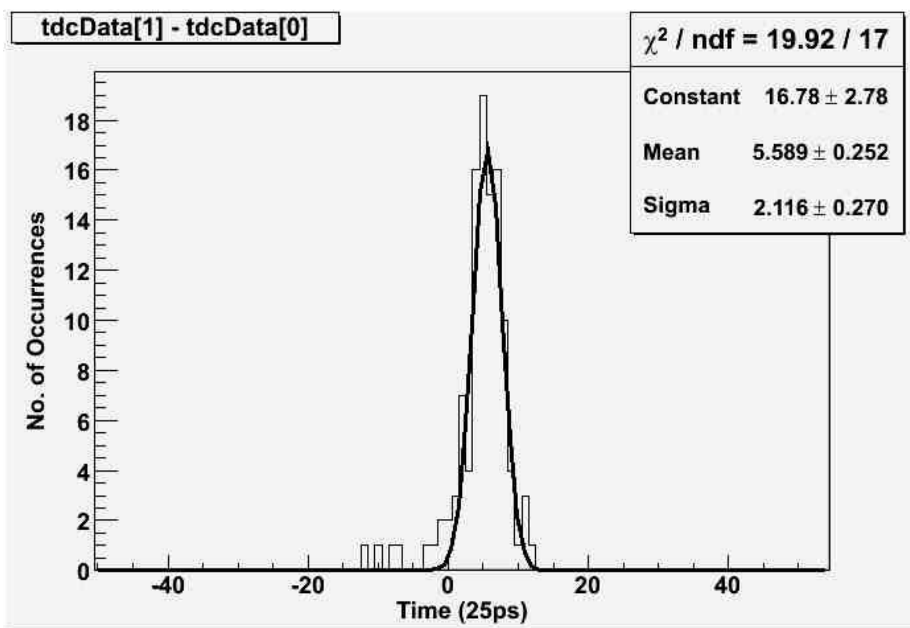

FIG. 1. Histogram of best timing resolution of sigma=2.116, which corresponds to 88 ps for each detector.

The primary beam was then changed to 25 MeV/u ^{20}Ne in order to observe how decreasing the energy deposited in the detectors affects the timing resolution. The data acquired for the first few runs with this beam showed two peaks in the time resolution histogram, separated by ~6 channels, which corresponds to 150 ps (25 ps per channel). It was suggested that this second peak may be caused by the presence of ^{16}O in the secondary beam. To verify this, MARS settings were changed to eliminate any ^{16}O in the beam, and as expected, the second peak in the time resolution histogram disappeared, suggesting that we were in fact viewing two different species in the beam.

For further confirmation, the beam was adjusted to its original settings and an extra spacer was inserted between the front and back PCB's, increasing the distance from 14.5 mm to 29.5 mm. This should cause the peaks in the time resolution histogram to shift and increase the distance between them by an approximate factor of two. As can be seen in Figs 2(a) and (b), this is exactly what happened. Fig. 2(a) shows the peaks with a 14.5 mm gap between PCB's, and 2(b) shows the peaks with a gap of 29.5

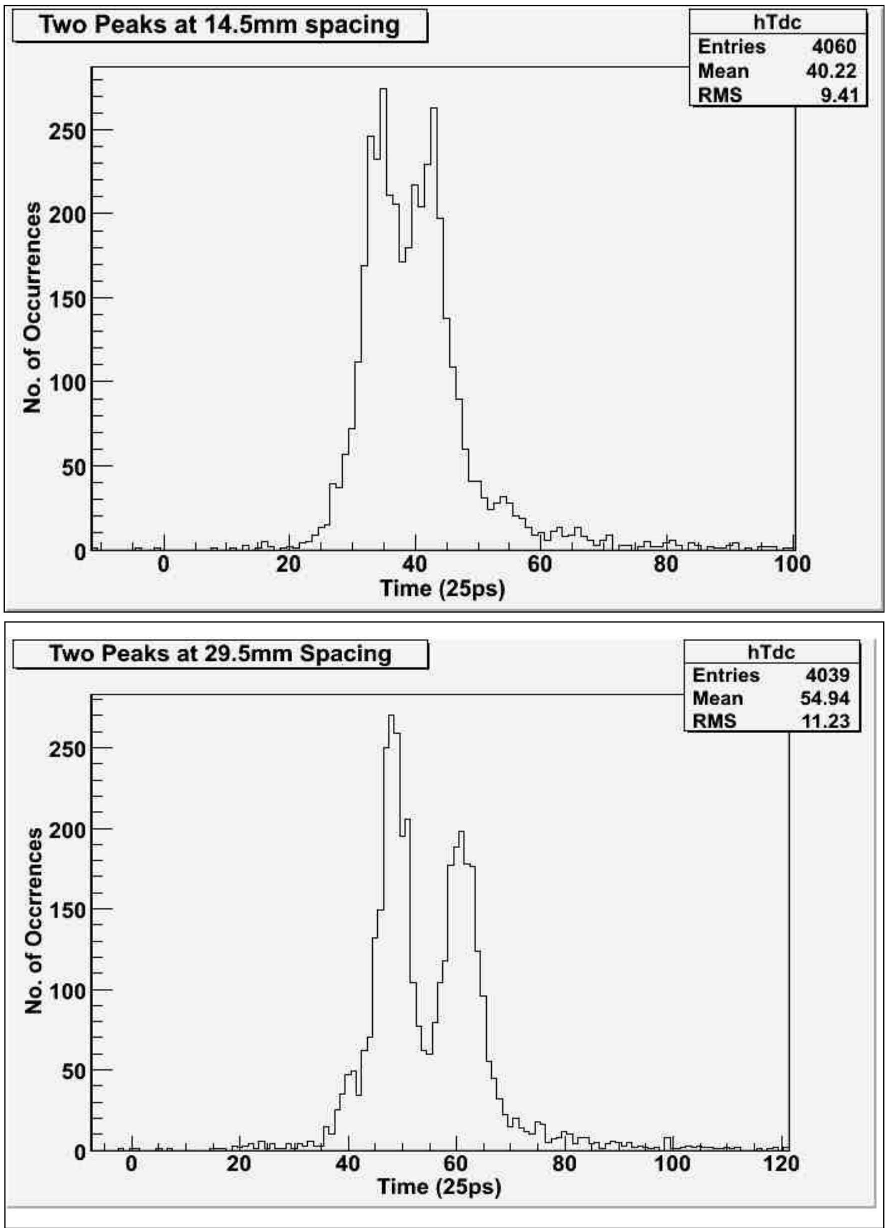

FIG. 2. Timing histograms before and after addition of spacer. (a) Two peaks of O-16 and Ne-20 at 14.5mm spacing. Peaks ~6 channels apart. (b) Same two peaks at 29.5mm spacing. Peaks now ~12 channels apart.

mm. The two peaks clearly separate further in Fig. 2(b), and the distance between these peaks are now found to be ~12 channels (300 ps), which is a factor of two increase as expected.

With proof that the diamond detectors could distinguish between different species within the beam, consideration then had to be made to the fact that both ^{39}Ar and ^{40}Ar were present in the first ^{40}Ar beam. Physical calculations found that the time difference between the two Ar species over a flight path of 14.5 mm would be around 14ps, which wouldn't be distinguishable on the timing histograms, but would certainly cause a widening of the timing peak. It is therefore possible that the timing resolution of the diamond detectors may, in fact, be better than initial analysis indicates.

In conclusion, the beam time at Texas A&M cyclotron institute not only allowed optimum electronic settings to be found and understood, but we were also able to measure sub 100 ps timing resolutions with the diamond detectors (88 ± 11 ps), something we have never been able to obtain prior to these runs. This proves that the diamond detectors will certainly provide a good solution to large area time of flight measurements, which is a major step forward in the project. The detectors were also able to distinguish between ^{20}Ne and ^{16}O over only a 14.5 mm flight path. This is in fact the very first use of time of flight measurements for particle identification using large-area diamond detectors.

[1] D. Rudolph *et al*, *LYCCA – the Lund-York-Cologne-Calorimeter: Identification of reaction products in HISPEC_DESPEC@NuSTAR*, Technical Report V1.2, (June 2009).

[2] M.A. Bentley *et al, Commissioning of the LYCCA Spectrometer: Preparation for exotic nuclear spectroscopy at HISPEC*, GSI Experimental Proposal, (2009).