EURONS JRA4- DLEP, Detection of Low Energy Particles

Progress Report: **September-December 2006**
by: **Hans Henrik Knudsen, University of Aarhus, Denmark**
John McGrath, University of York, UK.
Performed at: ***Consejo Superior de Investigaciones Científicas (CSIC***
Centro de Microanalisis de Materiales (CMAM) Madrid, Spain

Chapter 1

1.1 Introduction

This report describes the DLEP project and outlines the work achieved by Hans Henrik Knudsen, University of Aarhus, Denmark and John McGrath, University of York, UK. Both are PhD students working within the DLEP project, autumn 2006, CSIC Madrid. The project outline is presented here in the first chapter, the second chapter introduces the facilities and the equipment to be used, in the third chapter we describe our work in Madrid to achieve this and finally the fourth chapter contains our planned future work from January and onwards.

DLEP - ***Detection of Low Energy Particles from Exotic β-decays*** [1] is a development project aiming to improve the Infrastructure at the European Large Scale Facilities through developments of new schemes for low energy particle detection. This Joint Research Activity (JRA) will investigate a new approach to simultaneously detect the mass and charge of particles impinging upon a Si-detector, made possible by the advent of fast digitisation circuits [2]. This involves recording the full waveform of the detector signal for subsequent analysis.

It has been long understood that the pulse shapes generated in a silicon detector contains information about the particle type [5]. However, limits on electronic processing speed have meant, until recently, this information could not be recorded [6], since the rise time for a low energy charged particle in silicon is in the region of 10 nanoseconds.

1.2 The Aim

The ultimate aim of this project will be to identify different charged particles stopped in silicon detectors in multiple channels and at a high count rate. It is hoped to identify these charged particles by distinguishing the different pulse shapes each generates in a detector through the creation of electron-hole pairs. Concurrently, the techniques used on silicon detectors will also be applied to CZT where the aim is to improve energy resolution.

The task of constructing such a system has been split up into various sub tasks. Firstly a system needs to be designed which can capture, digitise and subsequently store individual pulses or waveforms. Secondly, analysis of these waveforms will determine which parameter(s), if any, can be used to distinguish different particles with the same energy in silicon and depth-information in CZT. The concept of identification rests on the assumption that the signal waveform is solely defined by particle and detector and not by the electronics between detector and digitisation. Therefore, preamplifiers used in this project have to process the signal faster than the detector can discharge, so as not to distort the output by integrating the signal

Once a comprehensive knowledge is learnt of how the pulse shapes depend on particle and detector types a system for real-time particle identification will have to be devised. Firstly for one or two channels using existing electronics but ultimately designing a system capable of working with hundreds of channels in dedicated VME modules.

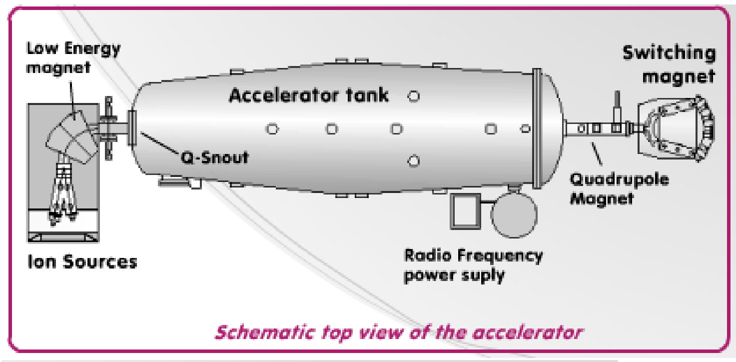
Chapter 2

2.1 Implementation

In constructing this system a wide range of equipment is needed. We discuss here the essential parts of our set-up. The three main parts to perform Pulse Shape Analysis (PSA) and identify particles by waveform in silicon detectors are a source of various particles of different energies, different detectors and system to record and subsequently analyse waveforms.

2.2 CMAM Particle Accelerator

Aside from alpha sources our particles will be provided by the CMAM (Centro de Microanalisis de Materiales) particle accelerator. Located just outside Madrid at Universidad Autonoma, the CMAM Accelerator is a 5MV Tandetron. The 5MV is generated by a Cockroft-Walton based solid state generator [3]. The advantage being no moving parts and lower voltage fluctuations than in the more frequently used Van de Graft generator. Using two different ion sources a beam of practically any particle can be produced. One ion source is mainly used for Helium and the other for other particles. The ions produced are focused by einzel-lenses steered by electrostatic and magnetic deflectors. At the entrance of the accelerator tube the beam is further manipulated by an electrostatic lens, which helps to optimise beam transmission across the whole system for a very wide range of output beam energies. A 5MV tandetron is well suited for Ion Beam Analysis techniques applied to Materials Science, Archaeometry, Environmental Science, etc., but also Positron Emission Tomography (PET), deep-level light-ion implants in semiconductors, or Accelerator Mass Spectrometry (AMS) of various elements. The CMAM accelerator is used for a wide range of purposes within these fields. Furthermore the Nuclear Physics group at CSIC has a dedicated beam line for use with their experiments which include light nuclear reactions and decay studies. The tandetron is an ideal machine for these studies as the energy is kept stable in the full range and thus reduces uncertainties in the experimental results. It also is a very useful facility to test our development in detector, electronics and DAQ's since it's readily accessible.



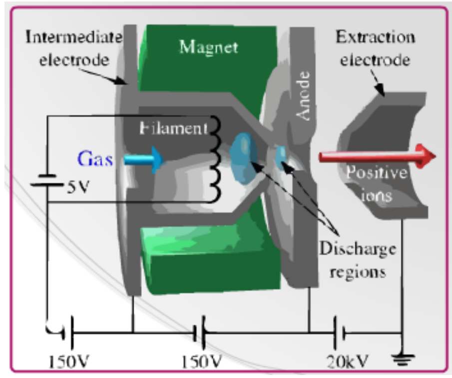


Figure 1 (left), *Schematic View of the Tandetron Accelerator at CMAM.* **Figure 2 (right),** *The Ion-source.*

2.3 Semiconductor Radiation Detectors

Our work focuses on two different types of semi-conductor detector, CZT and silicon. The operating principle of both detectors is the creation of electron-hole pairs when irradiated by ionising radiation. These electron-hole pairs are extracted by a bias voltage applied over the detector and are the output signal. As already mentioned the motivation for PSA in CZT differs from that of silicon detectors.

Because of poor electron-hole mobility within the CZT crystal, it is advantageous to improve the energy resolution. PSA would enable corrections for the interaction depth to be implemented as well as possibly differentiating between gamma induced and other charged particle events. CZT detectors are being used in the search for neutrinoless double beta decay [4], because of the rare nature of this decay any improvement in the detection technique are vital.

Unlike CZT, silicon doesn't have electron-hole mobility problems. Silicon detectors are used in a wide range of Low Energy Nuclear Reaction and Decay Experiments where a common feature is the emission of a range of different charged particles at varying energies. In order to interpret the experimental data it is vital to identify the charged particles in the data analysis process. Usually this is done by the conventional DE-E method where the particles pass through a thin (silicon) detector before stopping in a thick one. This has the obvious disadvantage of a low energy cut-off for particles that do not transverse the thin detector and can be rather large for heavier particles. This project aims to be able to identify the charged particles stopping in the thin detector by PSA.

Our project will test various silicon detectors and a CZT crystal in different conditions. The range of detectors used are two planar silicon detectors, one Double Sided Silicon Strip Detector (DSSSD) and a CZT crystal. The two planar silicon detectors each have an active area of about $3cm^2$ and different thickness in the order of 100s microns. The thicker of the two has been labelled the CSIC detector and the other thinner one the CMAM detector. The DSSSD is 60 micron thick, 16x16 strip, thick dead layer model with an active area of $25cm^2$. The CZT detector is a $1cm^3$ crystal with coplanar anodes.

2.4 Preamplifiers

As mentioned in section 1.2 a crucial part of the silicon setup is the preamplifier. It is vital that the preamplifier used for PSA is fast with a low noise level so as not to disturb or distort the pulse shape. A wide selection of both standard and fast preamplifiers has been and are to be used in our work. For basic setup and testing the standard Mesytec MPR-1 (1 channel) and MPR-16 (16 channel) preamps are used. On the test bed we have an old Ortec with unknown specifications and a newly purchased 9326A fast Ortec preamp. A preamp designed by Rutherford Appleton Laboratory (RAL) is currently being upgraded for our use.

2.5 DAQ

The heart of our system and the key to particle identification is the Data Acquisition System. Such a system consists of a fast Analogue-Digital Converter capable of capturing pulse shapes and a way of digitally storing, analysing and possibly plotting the waveforms. The final ambition would be to implement all of the above including particle identification into a single module capable of multi-channel acquisition. However, presently our DAQ system is split into two separate units, each to fulfil a different purpose.

2.5.1 Lecroy WavePro 7000 DDA5005A Digital Oscilloscope

The Lecroy oscilloscope is capable of sampling a signal at 40GSamples/s over 4 channels and storing the acquired waveforms. The scope is also a fully functional PC with many features to help on-line data analysis, it is for instance able to histogram data in real-time. For initial testing this scope is ideal as it requires little operating knowledge and programming in order to achieve its main functions. At the same time its sampling rate is faster than any other equipment we have access to. It is therefore very useful as a tool to gain detailed knowledge about signal waveforms. This scope will be used for our initial tests and to build a substantial library of various pulse shapes to be analysed off-line.

2.5.2 Acqiris DC440 ADC

The Acqiris system consists of a fast ADC in a separate unit connected to a Linux PC by a dedicated PCI card. It is capable of sampling at a rate of 880MSamples/second over 2 channels, which is a factor of 25 slower than the Lecroy scope. The interface for the Acqiris system is based on C++ code and is thus completely customisable but also rather complicated to work with under changing circumstances. Once the different characteristics of particle waveforms are known from the initial tests with the Lecroy scope it is thought that the Acqiris system will perform on-line particle identification, even though it runs at a much slower sampling rate.

Chapter 3

3.1 Work done at CMAM

The initial goal was to do a test run at CMAM on all detectors at the end of November. For that reason we began setting up our chamber with detectors at CMAM and moved all of our electronics from CSIC to the facility in the middle of November. This entailed thorough testing of all detectors and electronics and generally getting ready for the run. The accelerator schedule was for one day with protons and one day with alphas. Both the proton and alpha beams would be scattered at different energies on a heavy target (gold or lead) thus giving us two different particle types at different known energies in our detector. Also an attempt would be made to scatter on a deuterated polyethylene target in order to see deuterons at a semi-known energy. Due to unforeseen circumstances the accelerator wasn't functioning and unfortunately the run had to be delayed until January 2007. However, the setup continued in preparation for the tests next year and chamber and electronics are still at CMAM.

3.2 Detector and Preamp Status

Before going to CMAM all of our silicon detectors were mounted and tested in a setup at CSIC. Two different alpha-sources were used to irradiate the detectors and the rise time and resolution of different detector-preamp combinations was estimated. Most of our tests were based around the CSIC planar silicon detector, due to its simplicity compared to the DSSSD.
Basic setup at CSIC was our very first task, and once we had a fully functioning setup our priority was to test our Ortec 9326 fast preamplifier. We discovered, however, that it only amplifies the signal 20 times, which is negligible compared to the slower Mesytec MPR-1 preamp which was initially used and amplifies 500 times. That severely restricted our possibility of getting any usable signals from the fast preamp. An attempt was made to run the preamp signal through a fast Ortec Quad amplifier (10ns rise-time) and that resulted in a signal but whether this is usable is unlikely since the signal to noise ratio was small, and the rise time of the amplifier is comparable to the expected detector rise time.

In our attempts to get a usable signal out the fast preamp, a lot of effort and tinfoil was spent on noise reduction. Calculating back from the slow Mesytec preamp the signal directly from the detector for a 3.8MeV alpha particle seems to be around 1mV. The white noise from cables, electronics, etc. was seen in the scope initially to be around 20mV after reducing cable lengths and applying copious amounts of tinfoil the noise was reduced to around 3mV.

The performance of the old Ortec preamp with unknown specifications was similar to that of the Mesytec MPR-1 and is thus of no use to us in this context. The RAL preamp, as mentioned before, is still undergoing modifications to its power supply and its performance is therefore as yet unknown.

At the moment the best possibility for this part of the setup seems to be to use another preamplifier, e.g. the Ortec VT120, which can amplify at 200 times and has the same rise-time performance.

Concurrent to our work with different pre-amps we have attempted to get a single channel signal from a DSSSD. This is not at all trivial since the entire DSSSD has to be biased and the 16 channel Mesytec MPR-16 preamp has no easy way of extracting single channel signals before amplification. We tried to extract the detector signal by pinching directly from the cable and passing it through a selection of our preamps. Unfortunately this produced no result and we will have to find another solution for looking at the DSSSD signals.

3.3 Lecroy Scope Status

For our initial data acquisition as mentioned before, instead of the using the rather cumbersome Acqiris Digitiser, we will use our Lecroy oscilloscope. After acquainting ourselves with the basic functionality of the scope it was used as the DAQ for our test runs at CSIC. Asides from its performance as an oscilloscope the Lecroy can also histogram waveform parameters, e.g. rise time, amplitude etc., in real time. It is also capable of storing entire or partial waveforms either to its own internal hard-drive or to an externally connected USB-drive. In our setup an external drive is used so we are able to transfer the waveforms for subsequent analysis on a PC. The frequency with which the scope can store waveforms depends heavily on the number of points sampled, for a 100ns interval the raw data size is around 50kbyte and the rate of storage is around 100Hz.

Even though the Lecroy scope is also a fully functioning (windows) PC in itself, it is not practical for analysis of the waveforms, nor is it feasible to use it for real-time particle identification. As previously mentioned its main function will be to record the waveforms in our first test runs at CMAM.

3.4 Acqiris ADC Status

To attempt real time particle identification we will have to use the Acqiris system. Although it has a much lower sampling rate then the Lecroy scope, it is very adaptable due to its C++ interface that allows complete customisation.

Initial installation of the Acqiris ADC hardware and its drivers were performed at CSIC and the basic operation of the unit was then tested using the limited bundled software. After thorough investigation into the abilities of the digitiser from the hardware documentation, the bundled C++ digitiser interface program was compiled and run. This very simple program then became the foundation of our development work. Initially the program loaded a standard configuration, calibrated the scope and acquired one waveform with no usable output or communication with the user. This has since been modified and vastly expanded in such a way that we are now able to;

- Easily change the configuration of the digitiser
- Output relevant information to the user while running (i.e. the loaded configuration)
- Acquire any number of pulses from one or both channels
- Save these pulses in ASCII-format with user defined filenames

Besides working on the interface program, subsequent work has also been undertaken to show graphical plots of the waveforms and on a waveform analysis program, which can output rise time, falltime, integration and amplitude. The waveforms are plotted using 'gnuplot', for which a simple script can produce the desired output. The analysis program is so far an independent offline C++ program that uses the saved ASCII-waveforms from the interface program and outputs to a user specified file and to the screen. Both interface and analysis program can be run for an arbitrary number of pulses, with a user-friendly interface.

3.5 Particle Identification by Neural Network

In addition to the above mentioned attempts at particle identification a python based neural network package is being developed by our colleagues at CSIC. This will enable a more sophisticated way to distinguish between pulse shapes and should be more resistant to changes in preamps and detectors. From our present setup differing waveforms from a pulse generator have been saved and their output values recorded for analysis by the neural network package. This is being run as a test to see whether it can achieve our demands.

Chapter 4

4.1 Planned Work

Our participation in the project extends only into January 2007. The planned beam time at CMAM will hopefully take place at the end of that month. During this time we hope to record a large number of waveforms from different particles using our different detectors and different (hopefully fast) preamps.

As mentioned we'll try and get a usable signal from the fast Ortec preamp and in any case compare these signals to the slow preamp signals and to each other. Should the fast preamp not produce any usable signal then we shall try and run the fast preamp through the fast amplifier and compare these signals, even though it is highly doubtful that these pulses will be of any use. As a possible remedy to our preamp troubles we have the RAL preamp underway. However, we don't know how fast it may be nor its amplification.

One of the techniques that could be of interest for particle identification in the DSSSD is to compare the signal from the front- and backside of the detector. Since particles with the same energy but different mass will stop at different positions inside the detector (the heavier one stops sooner), this could be a particle signature. We will attempt this technique in the CMAM run with whatever preamps are available.

Hopefully, there is also time to run a collimated Cs-137 gamma source for the CZT detector during beam time as well.

4.2 Limits and outlook

The main obstacle holding progress back at the moment is the lack of a proper fast preamplifier. It is vital for the continuation of this project that this is rectified by acquiring a new preamp. With our current knowledge about the preamps at our disposal it is doubtful that a test run at CMAM would produce any results of fruition.

Another complication is our inability to see a signal from a single channel in the DSSSD. Since this is the detector of preference a viable solution must be found, this might be rectified once the RAL preamp is functioning.

Once the technical difficulties mentioned above have been overcome, the next logical step is to test the entire setup with a range of particles at CMAM. With the recorded waveforms from such a run all the information needed to make a thorough analysis of particle signatures in the pulse shapes will be available.

Our final step in this project will then be to implement a suitable code for particle identification in the Acqiris software and to try and run this software online.

References

[1] JRA-4 Eurons Proposal, DLEP.
[2] L. Bardelli et al. Nuclear Instruments & Methods A491 (2002) 244.
[3] www.rtftechnologies.org
[4] K. Zuber, Contemporary Physics, 491 (2004).
[5] H. Hamrita et al. Nuclear Instruments & Methods A531 (2004) 607.
[6] L. Bardelli et al. Nucear Instruments & Methods A560 (2006) 517.
[7] Fast Preamplifer 9326, Ortec Co-operation, US.

Acknowledgments

We would like to thank the support from the EU: EURONS-DLEP 506065 and support from the bilateral agreement between CSIC (Instituto de Estructura de la Materia) - Royal Society 2005GB0081.