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Determining Detector Threshold and Material Thickness Using an Alpha-Emitter Source

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Abstract: Double-Sided Silicon Strip Detectors of the High-Resolution Array (HiRA), recently used in a heavy ion experiment at the National Superconductive Cyclotron Laboratory (Michigan State University), have been calibrated using a uranium-232 radioactive source. Parameters important for the analysis of the experiment, such as the thickness of a Sn-Pb foil used to protect the Si detectors from radiation damage and the detector electronic thresholds, have been inferred using radioactive source data.

Keywords: *Silicon Strip Detectors, HiRA, Radiation damage*

1. INTRODUCTION

A recent experiment was conducted at the National Superconducting Cyclotron Laboratory (NSCL) to study the Equation of State (EoS) of nuclear matter. The properties of the nuclear EoS are fundamental not only to our understanding of nuclei, but also to correctly describe complex astrophysical objects such as Neutron Stars [1]. To this end, the experiment aimed to measure the ratio of neutron to proton energy spectra emitted in the isotopes of Ca+Sn and Ca+Ni nuclear collisions at E/A=56-140 MeV, which is predicted to be sensitive to the properties of the nuclear EoS and is needed to constraint Neutron Stars observables. To detect neutrons and charged particles in a single experiment, a complex coupling of several nuclear physics detectors (as shown in Fig. 1) was implemented, including two Neutron Walls (NWs), the Veto Wall (VW), the Forward Array (FA), the Microball, and the High-Resolution Array (HiRA). While the combination of FA, VW and NWs (the latter constituted by large arrays of bars containing a liquid scintillator) allows to measure neutrons, HiRA (located at the right side of the vacuum chamber in Fig. 1), is used to detect, with high precision, charged particles and fragments [2].

This paper spotlights HiRA and the various elements of the detector. The paper focuses, in particular, on the procedure used to obtain energy calibration of the Double-Sided Silicon Strip Detectors (DSSSDs) in HiRA, the analysis of the electronic detection thresholds, and the study of the thickness of a material absorber placed at the entrance widows of the detectors during the experiment.

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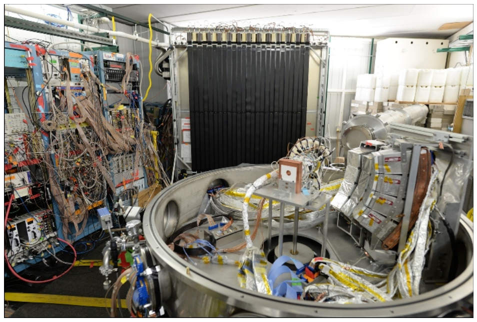

Figure 1: A photograph of the experimental setup at the National Superconducting Cyclotron Laboratory. A circular vacuum chamber (of around 50 cm radius) contains the experiment target, lying in the center of the chamber inside the Microball, and a cluster of 12 HiRA telescopes placed at the right side at a distance of around 35 cm from the target. The beam direction is from bottom left to top right of the picture. The first NW is placed at around 4 m from the target.

2. EXPERIMENTAL DETAILS

2.1 The High Resolution Array

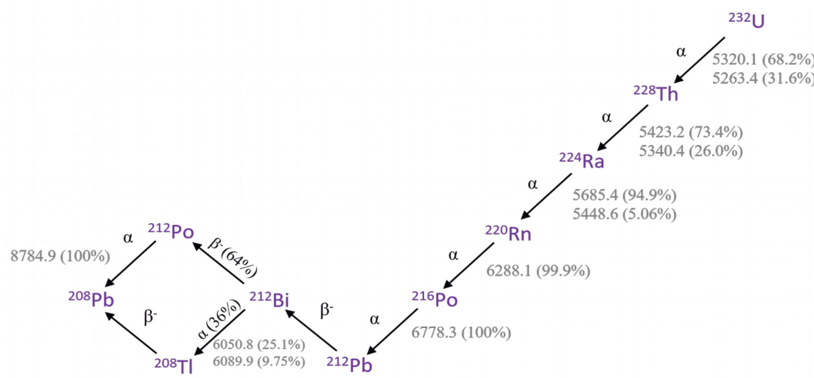

Figure 2: The decay scheme of ^{232}U. Alpha and beta decays are indicated. In the case of the alpha-decay, kinetic energies (MeV) of the emitted alphas and the corresponding emission probabilites are shown. The decay chain ends with ^{208}Pb.

HiRA is an array of highly segmented detectors for charged particles which combine detectors based on semiconducting material and scintillators [3]. HiRA provides exceptional energy resolution that is fundamental for the advancement of our exploration of the Equation of State. It is composed of modular telescopes, 12 telescopes are used in the present experiments arranged in the configuration 4x3 shown in Fig. 1, each containing two separate detection stages: a silicon detector as the first stage (around 1500 μm thick, ΔE) and four (4) Cesium-Iodide (CsI) Crystals used as the second detection stage (with a thickness of 10 cm in order to stop most particles, E). When a particle strikes a HiRA telescope, the combination of

ΔE, the energy deposited by the particle in the first detection stage, and E, the residual energy released in one of the CsI detectors, is used to identify the type of particle (via the so-called ΔE-E technique) and its kinetic energy (as the sum ΔE+E). Additionally, the impact point on the surface of the telescope, which allows to obtain the emission direction of the particle from the experiment target (where it is produced), is deduced from the segmentation in vertical and horizontal *strips* of the electrode used to collect the charge from the silicon detection stage. The latter, is a square silicon piece of dimensions 7.5 cm x 7.5 cm and a thickness of around 1500 μm. An ultra-thin aluminium layer (≈0.59 μm), used as ohmic contact to connect the silicon to a detection circuit, is deposited on front and back faces of the silicon to measure the number of electron-hole pairs produced in the silicon by the incident particle. Such number is proportional to the energy released by the particle in the material, being ≈3.62 eV, the energy required to produce one of such pairs [3]. To provide information on the impact point of the particle on the surface of the silicon, as mentioned above, the aluminium layer is segmented in 32 vertical strips on the front face and 32 horizontal strips on the back face, with a width of 2 mm, which provide 32 independent electric contacts on both sides to form 1024 detection pixels.

2.2 Energy Calibrations of DSSSDs

To individually calibrate each of the strips of HiRA DSSSDs, we used a Uranium-232 radioactive alpha-source. This source consists in a metallic disc on which the radioactive material is deposited, covered with a thin gold layer (0.093 μm). ^{232}U is a natural alpha-emitter that decays, with a life-time $T_{1/2}$=68.9 years, to ^{228}Th emitting an alpha-particle (2 protons and 2 neutrons, a nucleus of ^{4}He) of an energy around 5.3 MeV. The decay chain is made by subsequent alpha and beta decays of the daughter nucleus, ^{228}Th, terminating with ^{208}Pb as shown, schematically, in Fig. 2. Each transition between isotopes in the decay scheme of ^{232}U is identified in Fig. 3, where the alpha energy spectrum obtained from one strip of HiRA is shown as a histogram of counts. Here, the x-axis is in Analog to Digital Converter (ADC) channels, the “raw” information collected by the acquisition system. Peaks, of well-known energy, identified in this plot, allow to calibrate the strip with a linear calibration. We used four of the peaks identified in Fig. 3, and labelled in green, since they are the only peaks isolated in the detected spectrum. This procedure has been performed, individually, for each strip (front and back) of each HiRA telescope.

Once the raw data is received in ADC channels for one of the detection strips, it can be converted into MeV by using the corresponding linear calibration. A spectrum, analogous to the one shown in Fig. 3 is shown in Fig. 4 with the blue line. To increase statistics, we have combined data from all the strips of a single telescope after calibration. Peaks identified in Fig. 3, and relative to each particular alpha-transition, are well visible in the calibrated spectrum, testifying the good quality of our calibrations.

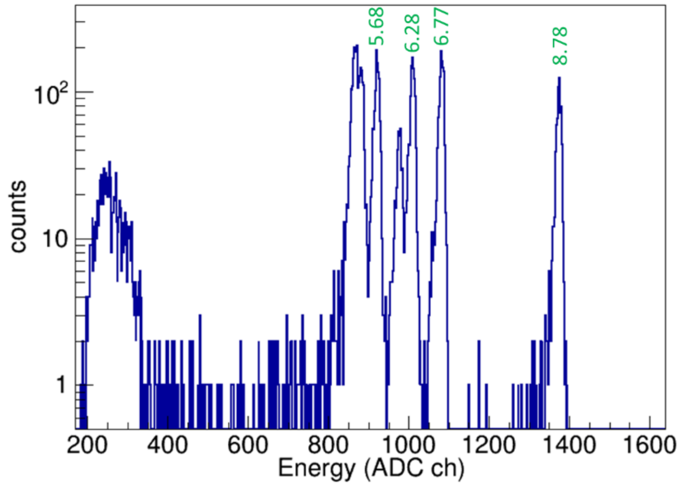

Figure 3*: Alpha spectrum of a uranium-232 radioactive source detected with one strip of HiRA (telescope 0). Alpha-particles in this energy range are completely stopped in the first detection stage of HiRA. Data is reported in uncalibrated ADC channels. Peaks correspond to well-identified alpha-transitions. The peak at around 300 ch is caused by gamma-rays emitted by the source.*

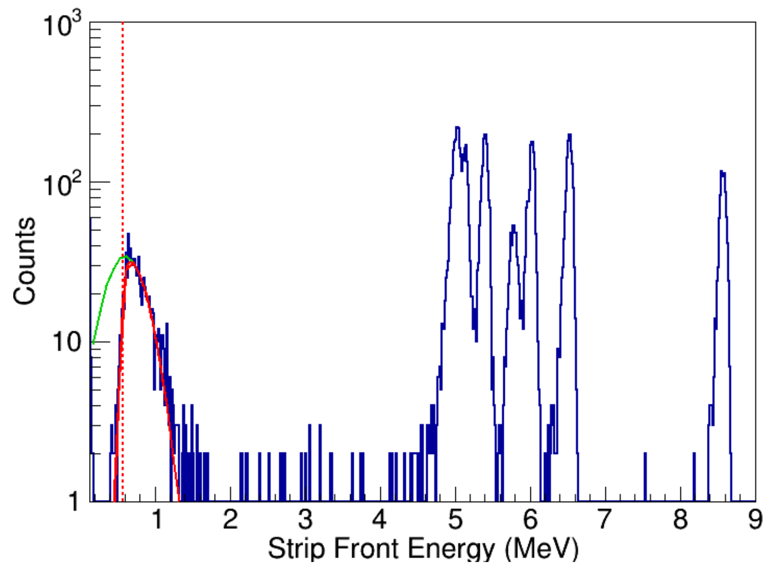

Figure 4: Fit of the gamma-peak observed with one front strip of HiRA. The fit is obtained with the combination of a Gaussian and a Fermi function (to simulate the effect of the detection threshold). The green curve shows the Gaussian function only as resulted from the fit. The red line is the global fit function. A red dashed line indicates the position of the deduced threshold. The example is produced by using data of a typical strip from telescope 0.

3. THRESHOLD ANALYSIS

The alpha-spectrum shown in Fig. 3 exhibits a peak at low ADC channels (around 300 ch), corresponding to energies lower than 1 MeV. Such peak is caused by gamma-rays emitted by the ^{232}U-source and detected by the silicon detectors. The gamma peak appears slightly distorted in its low energy tail, indicating that it lies around the detection threshold, i.e. the minimum energy that a particle must release in the silicon and overcome the electronic circuit to trigger the acquisition of the corresponding signal. This thresholds are normally difficult to pin-point with experimental data due to the low pulses coming from noise of the electronic circuits. Knowledge of the Si detector thresholds is important for the determination of the highest energy of the protons detected in the telescopes.

A study of the shape of the gamma peak can therefore provide useful evidence of the location of such threshold. By fitting it with the product of a Gaussian function G(x) = a*exp[(x-b)^2/2c^2] where a, b and c are free parameters, to simulate an ideal gamma peak unaffected by threshold, and a Fermi function $F(x)=\frac{d}{1+\exp\left(\frac{x-E_{thr}}{\Delta E_{thr}}\right)}$, where d is a free parameter and $E_{thr} \pm \Delta E_{thr}$ is the detection threshold, to simulate the fall of the left tail due to threshold effects, one can analyze the rise of this peak to infer the threshold value strip-by-strip. An example of this fit obtained for one of the front strips of HiRA is shown in Figure 5. The red curve is the result of the fit, while the green curve corresponds to the Gaussian function, resulted from the fit, as one would observe if a threshold effect was not present. A dashed red curve indicates the obtained threshold value. Figure 6 shows the threshold in MeV by telescope for all of the front strips, obtained with the method here described. The electronic thresholds for most telescopes are around 0.5 MeV. In the case of Telescope 2, due to noise in the electronics for that telescope, the threshold is slightly higher to 0.8 MeV.

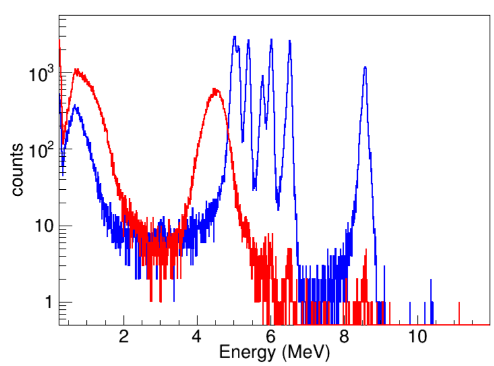

Figure 5: Calibrated alpha-particle spectrum obtained by combining data of HiRA strips of an entire telescope (32 strips, telescope 0 in our array). The blue spectrum is obtained without the use of the Sn/Pb absorber, while the red one is obtained when the Sn/Pb absorber is placed at the entrance window of the telescope. The latter is affected by straggling effects, broadening the observed peaks.

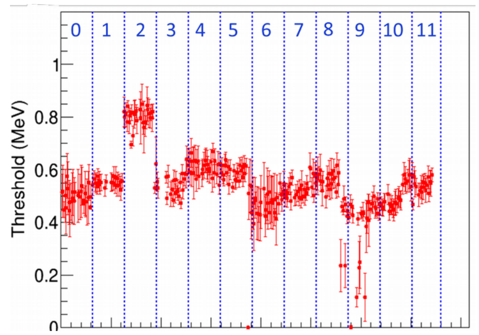

Figure 6: Threshold values in MeV for each of the strip front of HiRA. Dashed vertical blue lines indicate the limits of each of the 12 telescopes.

4. STUDY OF ABSORBER THICKNESS

Each of the 12 telescopes is covered with three (3) layers of tin-lead (Sn-Pb) foils, placed in front of the DSSSDs, to protect detectors from damage caused by the intense flux of electrons that is usually emitted in nuclear collisions involving heavy ions at these energies. Each foil has a thickness of approximately six (6) microns based on the information from the manufacturer resulting in a total of about18 micron thick foil at the entrance window of each telescope. This acts as an absorber as it completely stops electrons, but also degrades the energy particles carry prior to reach the detectors. For this reason, the energy measured by detectors is not the actual energy carried by particles as they are emitted from the target. As an example, after passing through the 18 μm absorber foil, the theoretical E_{final} of an alpha-particle emitted with an initial energy $E_{initial}=8.78\,MeV$, results to be around 4.9 MeV. The effect of the interaction with a material of a heavy charged particle can be universally parametrized by the Bethe formula. This relates the stopping power $\frac{dE}{dx}$ of an incident heavy ion, which corresponds to the energy lost by the particle per unit of length traveled in the material, to energy, charge and mass of the particles and the properties of the material:

$$\frac{-dE}{dx}=4\pi N_e r_e^2 m_e c^2 \frac{Z^2}{\beta^2}\left(\ln\frac{2m_e c^2\beta^2\gamma^2}{I}-\beta^2-\frac{\delta(\gamma)}{2}\right) \qquad [1]$$

Here, the properties of the material are represented by I, the material ionization potential, and N_e, the electron density per unit of volume, while the properties of the incident particle are charge Z and speed β. $\delta(\gamma)$ is a relativistic correction term that depends on the Lorentz factor γ of the incident particle. The Bethe formula can be used to infer the thickness of the Sn-Pb absorber by using alpha-particles emitted by the ^{232}U source interacting with the Sn-Pb foil.

While the relative uniformity of the foil is very good, the thickness, on the other hand, has a slight error. This uncertainty has a significant impact on the reconstructed incident energy of particles passing through the material. A larger thickness corresponds to a greater energy loss, according to equation 1.

In order to perform an accurate correction of detected energy for the energy loss in the absorber, it is important to accurately determine the thickness of the absorber over each of the 12 telescopes. This can be achieved by measuring the residual energy of alpha-particle of well-known energy, after passing through the absorber. The corresponding spectrum, calibrated in MeV, is shown with the red line in Fig. 4, compared to the one obtained without the absorber (the blue line). After passing through the absorbers, only two broad peaks are visible on the spectrum. Between these two peaks there is a relatively large gap indicating that the 8.78 MeV alpha peak is isolated from possible contaminations caused by neighbour peaks. The 8.78 MeV energy peak of the ^{232}U source appears at an energy around 4 MeV in the absorbed spectrum in Fig. 4.

By extracting the energy position of this peak for each strip, one can obtain the value that corresponds to the energy deposited in the detector by the alpha-particle particle. This value can then be used to calculate, by means of the equation 1, the energy loss by the particle in the Sn/Pb foil, and deduce the thickness of the foil itself. This calculation has been performed by means of the software LISE++ [4]. The vast majority of the strips recorded an energy that was less than 4.9 MeV (the energy predicted for a nominal 18 microns thickness of the absorber). With this information, it is evident that the thickness of the foils are all greater than the nominal thickness provided by the manufacturer because more energy is being lost after passing through the absorber. Thickness values obtained with a strip-by-strip analysis have been averaged within each telescope of HiRA to generate the thickness mapping in Fig. 7, they range from around 18.2 μm to 21 μm. This analysis is particularly important to correct the detected energy for the absorber material that they punch-through before reaching the detectors.

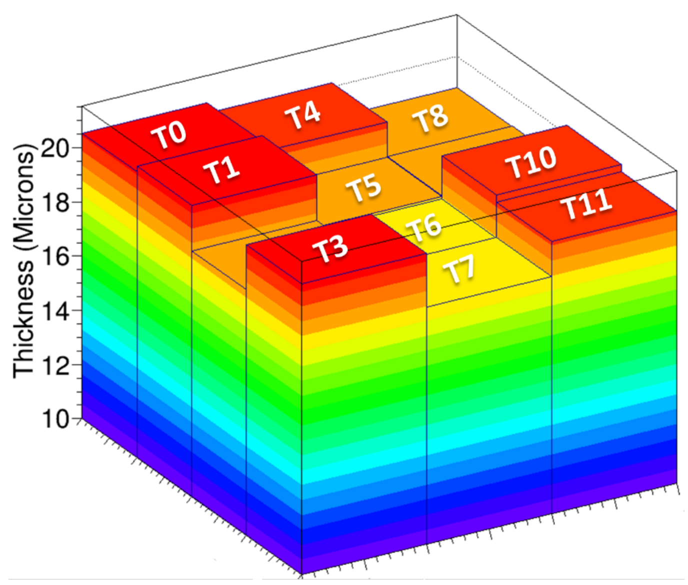

Figure 7: Thickness mapping of the Sn/Pb foils (for each telescope) obtained by means of the described analysis. Telescopes are numbered from 0 to 11 as shown by the labels.

5. CONCLUSIONS

In conclusion, energy calibration and detector characterization of HiRA DSSSDs and its electronic thresholds have been obtained by analyzing alpha emitted from a uranium-232 radioactive source. The energy calibration has been performed by means of a linear function using four well-known alpha-transitions observed in the obtained energy spectra, strip-by-strip. A precise study of detection threshold was possible using a low-energy gamma peak observed in the alpha spectrum. The product of a Gaussian function and a Fermi function was used to consistently fit the shape of this peak and infer the position in energy of the detection threshold in the electronics. Threshold values have been found to lie from 0.5 to 0.8 MeV. Finally, a study of the energy degradation of alpha-particles that punch through a Sn-Pb absorber (placed in front of the HiRA telescopes during the experiment) has been carried out to infer the thickness of the Sn-Pb absorber foil. This analysis is important since it allows measurement of the absorber thicknesses, telescope-by-telescope. We found thickness values ranging from 18.2 μm to 21 μm, instead of a nominal thickness of 18 μm for all the foils with the error given by the manufacturer. The accurate foil thicknesses allows consistently correct the energy of detected particles in HiRA.

6. ACKNOWLEDGEMENTS

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