Calibrating the position of a double-sided silicon strip (DSSSD) array using the elastic scattering channel

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In order to probe the structure of ^{24}Ne, we consider the ^{23}Ne (d, p) ^{23}Ne elastic scattering reaction. To evaluate the cross section of such a reaction, the detector SHARC (Silicon Highly-segmented Array for Reactions and Coulex) needs to provide the perfect scattering angle θ. Its calibration needs to be very precise. The goal of this paper is to provide an algorithm calculating the right position of the detector according to the theory.

MOTIVATION

In addition to probing the structure of ^{24}Ne, the (d, p) transfer reaction can also provide an indirect measurement of the astrophysical reaction ^{23}Al(p, γ)^{24}Si. It has been shown [6] that the astrophysical spectroscopic factor of a proton capture on a nucleus of proton number Z, and neutron number N, can be related to the spectroscopic factor of its mirror nucleus (proton number N, and neutron number Z) for a neutron capture. This means that by measuring the spectroscopic factors for different states in ^{24}Ne, which has Z=10 and N=14, it is possible to evaluate the spectroscopic factors of the ^{24}Si which has Z=14 and N=10.

$$\frac{\mathbf{d}\sigma}{\mathbf{d\Omega}} = \frac{\dot{\mathbf{N}}_{\mathbf{det}}}{\dot{\mathbf{N}}_{\mathbf{f}} \times \mathbf{N}_{\mathbf{target/cm^2}}} \qquad \text{[Eq.1]}$$

The problem is that we are not able to calculate the cross section [Eq.1] of such transfer reaction because we are not able to calculate the denominator. In fact the lattest value is the same for the elastic scattering reaction ^{23}Ne (d, d) ^{23}Ne and for this reaction we can compute the differential cross section if we know exactly the angle θ and then calculate the denominator and finally get the value of the cross section of the transfer reaction. In other words we have to perfectly calibrate θ for the elastic scattering reaction.

EXPERIMENTAL OVERVIEW

We consider in this work the ^{23}Ne (d, d) ^{23}Ne elastic scattering reaction. Due to the short half life of ^{23}Ne (37, 24 s) it is impossible to use it as a target for the duration of experiment. It's why the experiment described here was performed in inverse kinematics. It means the beam particle is heavier than the target particle which allows us to probe the structure of unstable nuclei without problem.

The light ejected deutrons were detected by the SHARC (Silicon Highly-segmented Array for Reactions and Coulex) detector array which is designed to have a very high angular resolution. This was done with 12 double-sided silicon strip detectors (DSSSDs). The Elastically scattered deutrons were detected at angles less than 90° to use after for the normalization of the cross section.

SHARC is an array made up of several DSSSD detectors (up to 16), we usually use it to detect particles from transfer reactions in inverse kinematics. SHARC device consists of 2 box detectors upstream of target and downstream one. Each DSSSD in the downstream box is segmented into pixels when a pixel is the intersection between a front strip and a back one (we have for each detector 24 front strips and 49 back strips).

METHOD AND PROGRAMMING

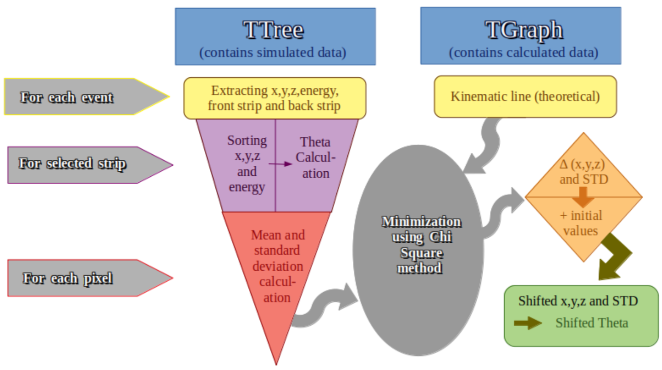

Figure 1: A diagram summarizing the programming structure.

The principle aim of our work is to obtain an optimal fitting of the simulated data [4] to theoretical data [5]. To do that we need to shift theta values the best way to reach the theoretical line. We know that for each event we have a position (x, y, z), energy and angle θ which depends on the position. Therefore to shift theta we have to shift the detector position. It is tricky to study each event. It's why we select one strip, calculate the mean position and standard deviation for each pixel on the strip, get shifted position after the minimization and finally calculate shifted θ and compare it with the theoretical line.

In order to generate a code solving our problem we used ROOT [3]. Our beam was at kinetic energy 181.39 Mev. A diagram of our work is represented in Figure 1.

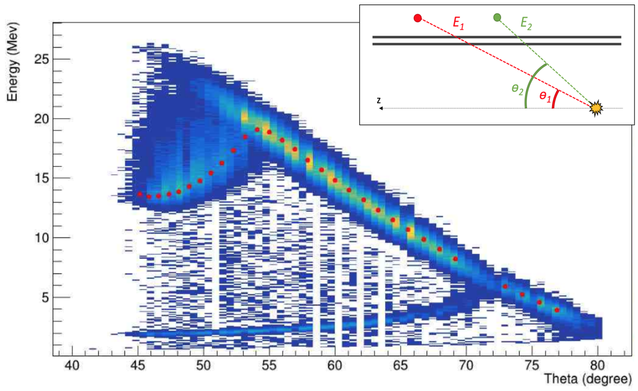

Figure 2: Energy(Mev) VS θ (°). The up figure shows example of angles with their specific energy.

In Figure 2 the energy for all events vs the θ angle is showed as a cloud, the set of red points represents the front strip 12. Each red point represents mean energy and mean θ for each pixel on the strip.

RESULTS

The minimization algorithm returns the shifts needed on the initial data (x, y and z) to fit the kinematic line. The shifts applied manually are $\Delta x = 0mm$, $\Delta y = 0mm$ and $\Delta z = 2mm$. The results on shifts obtained for the front strip 12 are : Chi^2=0.0411107 $\Delta x = 0.725211mm \pm 1.0923$, $\Delta y = -0.918672mm \pm 1.03565$ and $\Delta z = 2.20155mm \pm 0.615149$. The figure 3 illustrates these results. Each point represents the value of the mean on energy according to the discrete angle θ collected on each pixel along the front strip 12. An example of distribution of the energy is plotted on up figure 3 where it's possible to see the mean collected and their standard deviation.

DISCUSSION

A sorting has been performed on data. As we can see on figure 2, noise is present. It is due to the way the energy is deposited into the detector. In order to remedy it, a "cleaning" of data has been performed according to the strips taken or not into the algorithm.

All previous data are plotted for a specific strip (Front strip 12 here)and specific detector 12, centered along z-axis. It is interesting to see fluctuations in results when data are taken from another strip, at the border of the detector. For example, the border strip (Front strip 19) has been chosen. The results obtained on shifts are Chi^2=0.242327 $\Delta x = 0.452645mm \pm 1.27368$, $\Delta y = -0.810478mm \pm 1.2875$ and $\Delta z = 2.22003mm \pm 0.589602$. The FrontStrip 19 gives worse results (larger Chi^2). Indeed, hits are concentrated along the z-axis which gives a more representative statistics on data.

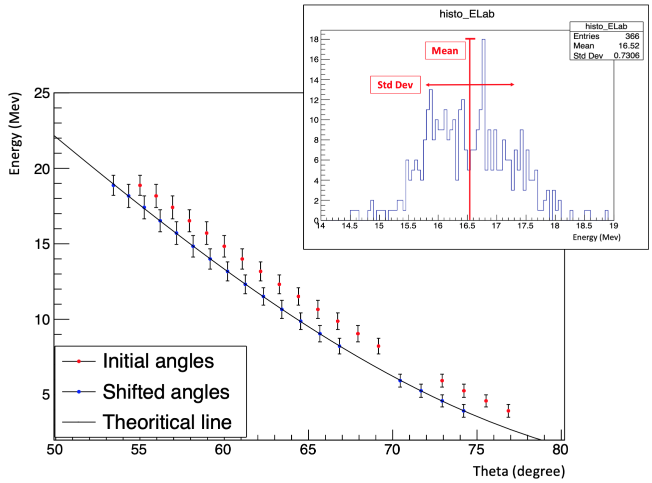

Figure 3: Initial theta with/without the addition of shifts obtained by the minimization algorithm. On the up figure, the distribution of energy from the pixel (intersection of front strip 12 and back strip 30) is plotted.

Another choice is to take a strip according to the x-axis. It would recover a smaller range of θ but containing all the statistics. Here are results obtained for Back strip 30, Chi^2=0.0643924 $\Delta x = 0.205991mm \pm 1.10796$, $\Delta y = -0.0375938mm \pm 0.769288$ and $\Delta z = 1.86662mm \pm 1.3346$.

In order to improve the fitting and the minimization of initial data, an attempt to find a known function (Gauss mainly) fitting the histogram of the distributions of the initial parameters, x, y, z and $ELab$, have been tried out. Unfortunately, none has been found, it seems data are distributed in an unknown way (see up figure 3).

[1] SHARC: Silicon Highly-segmented Array for Reactions and Coulex used in conjunction with the TIGRESS γ-ray spectrometer, C.Aa. Diget (2011).
[2] Structure of ^{25}Na measured using $d(^{24}\mathrm{Na}, p)^{25}$Na with a radioactive ^{24}Na beam, Andrew Knapton, University of Surrey (2017).
[3] ROOT CERN, `https://root.cern.ch/`.
[4] GEANT4, `https://geant4.web.cern.ch/`.
[5] Skisickness calculator, `http://skisickness.com/2010/04/relativistic-kinematics-calculator/`.
[6] Phys. Rev. Lett., 91:232501, (2003).