\( \alpha \) Test for TwinSol Crossover Timing

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Abstract

Several methods for crossover detection are being studied by the University of Michigan group for use with the UM-UND TwinSol apparatus. An ideal test of these detection methods can be made with a radioactive \( ^{228}\text{Th} \) source of 3 \( \mu \text{Ci} \). The TwinSol magnets can be used to focus the \( \alpha \) particles from this source, creating a low count rate venue where timing resolution can be studied. Subsequent tests can then be done with much higher rate radioactive beams.

1 Overview

The geometry for the crossover detection is quite simple, employing a single low energy loss detector at the crossover point and a Silicon energy detector at the final location for the transiting particles. The final location can either be in the new large chamber beyond the water wall after the TwinSol beamline or at the smaller chamber just beyond the second solenoid. The details of the focus used for the \( ^{228}\text{Th} \) daughter \( \alpha \) decays are discussed in Section 3 Figure 1 shows the locations of each of the detectors in the setup.

![Diagram of crossover detection scheme](attachment:diagram.png)

Figure 1: Crossover detection scheme. The diagram is not to scale.

One set of data can be taken in the near chamber and one in the far chamber.
(through the water wall). Only two observables will be recorded by the data readout. These observables are the relative time between the events and the energy of the focused beam. The time will be recorded via TDC and the energy via ADC. The TDC spectrum is to be calibrated with a pulse generator while the ADC spectrum can be calibrated with the same $^{228}\text{Th}$ source, placed in the chamber facing the final energy detector.

There are several detectors that can be used for the crossover measurement. For this test these detectors only need to be capable of giving a well resolved timing signal at a rate of 10-100 counts per second. The test plans to use several crossover detector schemes including PPAC [1], thin foil + MCP, thin scintillator + phototube at some stage. It is hoped that these detectors can produce sub-nanosecond timing resolution up to counting rates of $10^5$/s or more. If this is possible one may be able to significantly increase the energy resolution with which one can measure nuclear reaction products.

It is important to estimate the expected count rate at the crossover point for the $3\ \mu\text{Ci}$ source. Since the Twinsol magnets will focus only monochromatic $\alpha$ particles, the full activity can not be utilized at the same time. The source was obtained in May of 2007. To get an idea of the $\alpha$ spectrum of this source one can turn to studies of abundances of $^{229}\text{Th}$ and $^{228}\text{Th}$ for information [2].

The source which will be used is a 1.2 year old $^{228}\text{Th}$ source. A significant amount of the original $3\ \mu\text{Ci}$ activity will have escaped into the daughter nuclei, which also have $\alpha$ decays of different energies. There is a recent measurement of the relative activities for each of these $\alpha$ lines. Therefore, if we can estimate the current integrated activity of the 5.423 MeV and the 5.340 MeV $^{228}\text{Th}$ lines, one can normalize this measured spectrum and know the activity of each line. The half life of $^{228}\text{Th}$ is 1.913 years. By the date of delivery (June 07) one can find that the source is about 1.2 years old. The integrated activity of the $^{228}\text{Th}$ lines is then 1.94 $\mu\text{Ci}$. The current spectrum of the $^{228}\text{Th}$ source is visible in Figure 3. From the data and the knowledge of the total activity from the $^{228}\text{Th}$ $\alpha$ lines, one can find the activities for all the other lines. One can then estimate the particle rate at the crossover point of the magnets assuming that one accepts forward going

<table>
<thead>
<tr>
<th>Parent</th>
<th>Energy (MeV)</th>
<th>($%$) $^{228}\text{Th}$ Activity</th>
<th>Activity ($\mu\text{Ci}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{224}\text{Ra}$</td>
<td>5.685</td>
<td>92 %</td>
<td>1.78</td>
</tr>
<tr>
<td>$^{220}\text{Rn}$</td>
<td>6.288</td>
<td>94 %</td>
<td>1.82</td>
</tr>
<tr>
<td>$^{216}\text{Po}$</td>
<td>6.778</td>
<td>93 %</td>
<td>1.80</td>
</tr>
<tr>
<td>$^{212}\text{Bi}$</td>
<td>6.051</td>
<td>32 %</td>
<td>0.62</td>
</tr>
<tr>
<td>$^{212}\text{Po}$</td>
<td>8.785</td>
<td>60 %</td>
<td>1.16</td>
</tr>
</tbody>
</table>

Table 1: $\alpha$ decay activities for the Notre Dame $^{228}\text{Th}$ source.
Figure 2: $\alpha$ decays of $^{229}$Th and $^{228}$Th with the daughters in equilibrium [2].

Particles making angles between $\theta_1 = 2^\circ$ and $\theta_2 = 6^\circ$ with the beam axis. The geometrical scale factor for the activities is then:

$$ f = \frac{2\pi \int_{\cos \theta_1}^{\cos \theta_2} d\cos \theta}{4\pi}. $$

(1)

This factor comes out to be $f=0.0024$. The count rates at the crossover point are displayed in Table 2 assuming the appropriate $\alpha$ energy is focused by the TwinSol magnets.

## 2 Procedure

With the basic idea of the measurement and count rates known, the procedure for the measurement can be written. One should do all of the steps to be sure that there is good data to use for analysis.

1. Place source at production target position and pump down.
2. Place retractable crossover detector mounts and pump down.
Figure 3: α decays of $^{228}$Th measured with the source at Notre Dame.

<table>
<thead>
<tr>
<th>Parent</th>
<th>Energy (MeV)</th>
<th>Crossover rate (p/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{224}$Ra</td>
<td>5.685</td>
<td>160</td>
</tr>
<tr>
<td>$^{220}$Rn</td>
<td>6.288</td>
<td>164</td>
</tr>
<tr>
<td>$^{216}$Po</td>
<td>6.778</td>
<td>162</td>
</tr>
<tr>
<td>$^{212}$Bi</td>
<td>6.051</td>
<td>55</td>
</tr>
<tr>
<td>$^{212}$Po</td>
<td>8.785</td>
<td>104</td>
</tr>
</tbody>
</table>

Table 2: α crossover rates for the Notre Dame $^{228}$Th source.

3. Place in back detector PSD for focus adjusting.
4. Replace PSD with standard thick Silicon energy detector at the beam spot.
5. Take energy data with crossover detector out of beam.
6. Place crossover detector in the beam and adjust focus.
7. Take energy and timing data with crossover detector in beam.
8. Change energies (magnet focus) or crossover detector and repeat.

It is important to also try to obtain a measurement of the energy loss of the α particles in the detectors. This will affect the focus which may need to be adjusted. The α particles of low energy may stop completely in the detector. In this case the measurement cannot be done with this method and one must use a heavier ion beam.

### 3 Focus

With the knowledge of the possible energies one can try to bring the appropriate α lines to a focus at the back end detector. Since from this source
roughly 100 particles per second are expected from the 8.79 MeV decay, this is the energy that will be used because it is the most similar to radioactive beam energies. The other energies can also be tuned in a similar manner. A ray tracing program developed at the University of Michigan can be used for this task [3]. The focus pictured in Figure 4 can be obtained using the TwinSol magnets. From the ray trace calculation one can see that the

![Figure 4: TwinSol focus for 8.79 MeV α particles.](image)

first solenoid should be set to a persistent current of 27.0 A and the second solenoid persistent current should be set to 24.0 A. This is a quick estimate, but careful tuning should be done to place the crossover point where the crossover detector has acceptance.

## 4 Electronics and DAQ

The electronics are fairly simple for this experiment and there are only two observables which need to be read into the computer and analyzed. First, one needs the time-of-flight of the particle from the crossover detector to the chamber Silicon energy detector. The energy deposited in the final Silicon detector is the second observable. The experiment will use a VME crate for the data readouts with CAMAC modules for the TDC and peak-sensing ADC electronic inputs.

## References
