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A novel method for beam misalignment correction of an accelerated charged-particle beam

J. Rahighi*, M. Lamehi-Rachti, O.R. Kakuee

Van de Graaff Laboratory, Nuclear Science Research School, NSTRI, P.O. Box 14395-836, Tehran, Iran

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Abstract

A novel method is presented for misalignment correction of an accelerated charged-particle beam in a typical charged-particle scattering experiment employing large-solid-angle detectors. The correction method is based on Rutherford scattering and is quite straightforward to apply when a large solid angle and axially symmetric detection system is used in the experimental measurements. A Monte Carlo computer program and its formalism based on Rutherford scattering cross-section have been described. The program is used to calculate beam misalignment offline after data collection is completed. The method has been successfully applied to correct for misalignment calculated to be typically of the order of a few mm in a ^{6}He radioactive beam of 27 MeV total energy emerging from a cyclotron and produced via ^{7}Li(p,2p)^{6}He reaction.

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Keywords: Radioactive nuclear beams; Silicon strip detector; Beam misalignment

1. Introduction

In the last few decades, scattering of nuclei have been employed to determine the shapes and sizes of atomic nuclei. The spatial distributions of mass and charge (neutrons and protons) are determined through the scattering of nuclei [1].

Heavy-ion elastic scattering reactions have been a major source of information on the structure of nuclei and on the properties of nucleus–nucleus interactions [2]. Our knowledge of the nuclear chart, as a result, has significantly expanded over the last few years. Thanks to the new facilities dedicated to radioactive beams and improved large-scale detection systems. The spectroscopy of nuclear systems has moved farther away from the valley of stability and in some cases (mainly for light systems or on the proton-rich side), has reached the driplines.

In a typical nuclear particles scattering experiment, one requires a beam of particles, a target and a detection system, advantageous to subtend a large solid angle. The beam of charged particles produced by an accelerator must be highly collimated and focused. The quadrupole magnets and the dipole magnets normally placed outside scattering chamber focuses and centers the beam on the target position. The optimization is usually checked measuring the current on collimators located before the target and on small Faraday cup. The above procedure ensures precise reference direction measurement and an accurate determination of scattering angle θ and azimuthal angle φ for angular distribution. The beam intensity in a typical radioactive ion-beam experiment is significantly lower than that of a stable beam experiment. Typical beam intensities in RIB experiment vary from approximately 10^4 to 10^9 particles/s which is very low compared to stable beam facilities. It is rather difficult to achieve a good and intense beam collimation by using an aperture on the beam trajectory [3,4].

Large-solid-angle detectors are an essential part of the experimental setup in Radioactive Ion Beam (RIB) experiments in which reversed kinematics method is more advantageous because reaction products are

*Corresponding author. Fax: +98 21 88021412.
E-mail address: jrahighi@aeoi.org.ir (J. Rahighi).

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predominantly forward angled [3,4]. Due to closed target–detector geometry and the large solid angle subtended by detectors, the angular distribution of scattered particles is highly sensitive to the beam misalignment. An inaccuracy in measuring the scattering angle, accompanied by an inaccuracy of the solid angle subtended by the detectors, would result in larger errors when measuring the cross-section angular distribution. Axial symmetry of silicon strip detectors and the sensitivity of elastic scattering cross-section to the scattering angle could successfully be employed in a new technique to measure beam misalignment in the physical transverse plane.

As for detectors a wide variety of single- and double-sided silicon strip detector designs are currently used in nuclear physics applications. Some of them such as Louvain-Edinburgh Detector Array (LEDA) [5], Lampshade detector array (LAMP) [5], DINEX telescope array [6], Compact Disc double sided silicon strip detector (CD) [7], TRIUMF-UK Detector Array (TUDA) [8] are all axially symmetric detectors and can be considered as typical of the application of this kind of detector to experiment in RNB facilities.

Here, we report on a typical elastic scattering experiment in which a beam of ^{6}He is scattered by a variety of target nuclei. During data collection, a beam misalignment on the target plane relative to the beam axis ($X = 0$, $Y = 0$) was noticed. Offline misalignment correction has been successfully applied to the experimental data. The calculated misalignment was determined to be of about $X = 3$ mm and $Y = 3$ mm.

When strip detectors with axial symmetry are employed, any asymmetry in the number of counts can be related to the transverse misalignment of beam. This misalignment can be corrected after the experiment is performed. The present offline method of correction has been routinely applied to the similar beam misalignment problem as a post-process technique in experiments performed at Louvain la Neuve [6,9,10].

2. Setup of experiment

The experiment was performed using the radioactive beam facility at the cyclotron research center at Louvain la Neuve, Belgium. The ^{6}He beam used in this experiment was produced via ^{7}Li(p, 2p)^{6}He reaction in the LiF powder target contained in graphite holder [3]. ^{6}He is then ionized in an online Electron Cyclotron Resonance (ECR), ion source and after magnetic separation injected into the second cyclotron where it was accelerated to the desired energy. Post-accelerated secondary ^{6}He beam with an energy of 27 MeV and an intensity of 3×10^6 ions/s was scattered off self-supported ^{208}Pb and ^{197}Au targets of a typical 1 mg/cm^2 thickness. The reaction products were simultaneously measured in a detection system consisting of a LEDA and a LAMP-type detector described elsewhere [9–12].

LEDA detector consists of eight sectors with 16 strips on each sector (Fig. 1). The LEDA plane is perpendicular to the direction of ^{6}He beam. However, LAMP is a cone-shaped detector consisting of six sectors and 16 strips on each sector. Since each strip on LEDA and LAMP subtends a different solid angle, in order to calculate the scattering cross-section, the solid angle and the coordinates of each strip must be determined accurately (Table 1). In Fig. 2, the variables used to determine the solid angle subtended by each strip on LEDA are shown.

The solid angle subtended by the LEDA strips can be accurately determined from the equation below:

$$d\Omega = \frac{dA}{r^2} \times \cos(\theta) = \frac{\text{strip area}}{(\text{target-to-strip distance})^2} \times \cos(\theta). \quad (1)$$

As shown in Fig. 2, the center of each strip is used to calculate the target-to-detector distance [12].

In order to determine the solid angle subtended by the LAMP detector the active area of each strip is divided into

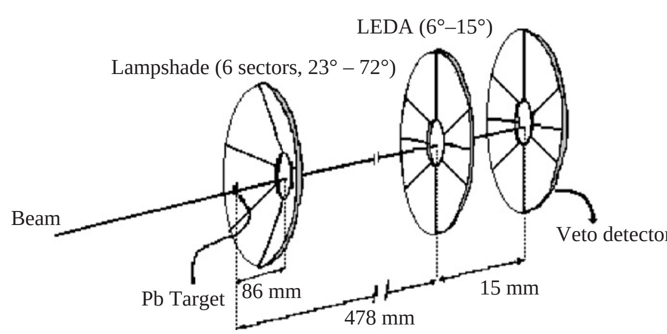

Fig. 1. Experimental setup of LEDA and LAMP detectors.

Table 1
Radial angle and the solid angle subtended by each strip of LEDA and LAMP detectors [12]

Strip no.	LEDA		LAMP	
	$\theta°$	$\Omega \times 10^{-3}$ (sr)	$\theta°$	$\Omega \times 10^{-2}$ (sr)
0	14.93	0.81	67.07	1.88
1	14.37	1.19	64.38	2.85
2	13.80	1.45	61.58	3.53
3	13.24	1.59	58.69	3.97
4	12.67	1.53	55.73	3.94
5	12.10	1.46	52.70	3.87
6	11.52	1.40	49.62	3.76
7	10.95	1.33	46.51	3.61
8	10.37	1.27	43.39	3.43
9	9.79	1.20	40.62	3.22
10	9.20	1.13	37.16	2.98
11	8.62	1.06	34.10	2.73
12	8.03	0.98	31.09	2.46
13	7.44	0.92	28.16	2.20
14	6.85	0.84	25.31	1.93
15	6.26	0.77	22.55	1.67