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Nuclear Instruments and Methods in Physics Research A 547 (2005) 464–479
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
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# Resolving multiple particles in a highly segmented silicon array

T. Paduszynski[a], P. Sprunger[a,1], R.T. de Souza[a,*], S. Hudan[a], A. Alexander[b], B. Davin[a], G. Fleener[b], A. Mcintosh[a], C. Metelko[a], R. Moore[b], N. Peters[a], J. Poehlman[b], J. Gauthier[c], F. Grenier[c], R. Roy[c], D. Thériault[c], E. Bell[d], J. Garey[d], J. Iglio[d], A.L. Keksis[d], S. Parketon[d], C. Richers[d], D.V. Shetty[d], S.N. Soisson[d], G.A. Souliotis[d], B. Stein[d], S.J. Yennello[d]

[a]*Department of Chemistry and Indiana University Cyclotron Facility, Indiana University, Bloomington, IN 47405, USA*
[b]*Department of Chemistry, Indiana University, Bloomington, IN 47405, USA*
[c]*Département de Physique, de genie physique, et d'optique Université Laval, Québec, Canada, CA G1K 7P4*
[d]*Cyclotron Institute Texas A&M University, College Station, TX 77843, USA*

Received 24 March 2005; received in revised form 14 April 2005; accepted 15 April 2005
Available online 23 May 2005

**Abstract**

The design, construction, and performance of a new highly segmented charged particle detector array, FIRST, are described. This forward angle annular array ($2^\circ \leqslant \theta_{\rm lab} \leqslant 28^\circ$) has been developed to study peripheral and mid-central heavy-ion collisions at intermediate energies ($E/A \approx 50$ MeV). FIRST consists of three individual telescopes that each utilize ion-passivated silicon detectors in either a Si(IP)–Si(IP)–CsI(Tl) stack or a Si(IP)–CsI(Tl) stack. This array provides elemental identification for $1 \leqslant Z \leqslant 50$ with isotopic identification of lighter elements, $Z \leqslant 13$, over a wide dynamic range in energy. The high segmentation of each silicon detector provides good angular resolution in a compact geometry and allows deconvolution of multiple particles incident on a single telescope. The performance of the array in a commissioning experiment $^{64}$Zn + $^{64}$Zn, $^{209}$Bi at $E/A = 45$ MeV is shown.


*PACS:* 29.40.−n; 29.40.Wk; 29.40.Mc; 07.05.Kf

*Keywords:* Segmented silicon detector; Projectile fragmentation; Charge-splitting in semiconductor detectors; Charged particle detection; Multi-particle detection

## 1. Introduction

Understanding the properties of nuclear matter with $N/Z$ values far from stability is presently a question of considerable interest [1]. In particular,

*Corresponding author. Tel.: +1 812 855 5815; fax: +1 812 855 6645.
*E-mail address:* desouza@indiana.edu (R.T. de Souza).
[1]Present Address: Department of Physics, Oregon State University, Corvallis, Oregon.

0168-9002/$ - see front matter 
doi:10.1016/j.nima.2005.04.011

the density dependence of the asymmetry term in the nuclear equation-of-state (EOS) is relevant to the radii of neutron stars [2], as well as the ground and excited states of neutron-rich nuclei [3]. It has recently been shown that $N/Z$ equilibration in mid-central symmetric collisions of two heavy nuclei provides a probe of the density dependence of the asymmetry term [4]. Radioactive beam facilities that provide access to beams of nuclei with extreme $N/Z$ thus provide an unique opportunity to assess this important term in the nuclear EOS.

Following the peripheral collision of a projectile nucleus with a target nucleus, the excited projectile-like fragment (PLF*) undergoes decay via both charged particle and neutron emission. For neutron-rich PLF*, one expects changes in the collective properties such as level densities as compared to normal $\beta$-stable nuclei. These changes should manifest themselves in the statistical competition between charged particle and neutron emission. Coincident measurement of neutron and charged particle decay of the excited projectile-like fragment is a powerful tool in studying the properties of $N/Z$ exotic matter. At high excitation, emission of clusters ($Z \geqslant 3$) also becomes important and may signal changes in the properties of nuclear matter with changes in $N/Z$. By isotopically identifying these fragments, together with the emitted neutrons and light charged particles (LCP: $Z \leqslant 2$), and measuring their kinetic energies one can learn about the excitation and spin of the PLF* [5]. Moreover, one can also learn about the impact of the collision dynamics on fragment formation [6–8]. The internal excitation of the clusters produced can be investigated with the tool of resonance spectroscopy by examining the population of discrete states [9]. In addition, for low-lying states, multi-particle correlations can also provide information on the spin of unknown states [10]. In order to investigate the response of $N/Z$ exotic nuclear matter at modest excitation, and in particular by examining correlations, we have constructed a charged particle array FIRST (Forward Indiana Ring Silicon Telescope) that is optimized to investigate peripheral and mid-central heavy-ion collisions.

## 2. General design considerations

In order to select peripheral collisions between projectile and target nuclei, we detect the heavy decay product of the PLF*, which we designate the PLF. By measuring the $Z$ (or $A$) of this PLF, together with the magnitude of its energy damping from the beam energy, we are able to deduce the excitation of the PLF* [5]. As the angular distribution of the PLF at intermediate energies ($E/A \approx 50\,\mathrm{MeV}$) is forward peaked, it is necessary to measure at small angles ($\theta_{\mathrm{lab}} \approx 2^{\circ}$) with good angular resolution. The dynamic range of the detector at these forward angles is established by the identity of the beam $(Z, A)$, and its energy. We optimized our design for beams with $Z \leqslant 50$ and $E/A = 50$–$60\,\mathrm{MeV}$.

To allow coincident neutron detection by time-of-flight, it is essential to minimize both the size of the entire charged particle array, as well as minimize the mass in the vicinity of the target so as to reduce scattering. To achieve both goals we based our design for FIRST on three individual telescopes, each of which is highly segmented. This approach contrasts with the more conventional approach that relies on multiple detectors each with little or no segmentation [11–14]. Our choice of a few highly segmented telescopes reduces the total mass of inactive material usually associated with housing individual telescopes. A concerted effort was made to minimize the total mass of the support structure for FIRST by using a low-mass aluminum support to mount each of the telescopes. High segmentation with concurrent good energy resolution is crucial for the particle correlation measurements previously described. In addition, the measurement of multi-particle correlations demands a detection system with high geometric efficiency, particularly for low-intensity $N/Z$ exotic beams. The reduced size of the array also results in a transportable device. While use of a few highly segmented silicon detectors has clear advantages in terms of packing density, the resolution attainable in reconstructing a multi-particle event within such an array is unclear. In this work, we describe the design, construction, and performance characteristics of such a design,