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HERACLES : a multidetector for heavy-ion collisions at TRIUMF

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Abstract HERACLES is a multidetector that has been modified to study heavy-ion collisions, using an ion beam with an energy range between 8 to 15 MeV per nucleon. It has 78 detectors axially distributed around the beam axis in 6 rings allowing detection of multiple charged fragments from nuclear reactions. HERACLES has 4 different types of detectors, BC408/BaF_2 phoswich, Si/CsI(Tl) telescope, BC408/BC444 phoswich and CsI(Tl) detectors. $^{25}Na + ^{12}C$, $^{25}Na + ^{27}Al$, $^{25}Mg + ^{12}C$ and $^{25}Mg + ^{27}Al$ reactions have been used to characterize the multidetector. Element identification up to Z = 12 is achieved with the BC408/BaF_2 phoswich detectors, up to Z = 15 with the Si/CsI(Tl) telescopes and up to Z = 12 with the BC408/BC444 phoswich detectors. Isotopic identification is reached with the CsI(Tl) detector up to Z = 2.

Keywords Nuclear fragmentation · Multidetector · Heavy-ion reactions · ISAC-II · TRIUMF

1 Introduction

Properties of the nuclear matter at high density and temperature are not well known. Heavy-ion collisions give the possibility to study nuclear matter at high density and temperature. The recent availability of radioactive ion beams gives new possibilities to study collisions of nuclei with different isospin [1]. With the ISAC II facility at TRIUMF, radioactive ion beams are available with energies up to 15 MeV per nucleon (AMeV). HERACLES is a multidetector that has been used to study heavy-ion collisions at intermediate energy over 25 AMeV [2–5]. To use

ISAC and ARIEL: The TRIUMF Radioactive Beam Facilities and the Scientific Program.

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HERACLES efficiently at ISAC II, we had to modify greatly the multidetector. In fact, every detector in the new version of HERACLES has been modified to lower the energy threshold required for particle identification. In Section 2, an experiment at ISAC II with the new HERACLES is described. Section 3 gives the multidetector's characteristics and first results.

2 Experiment

The main goal of experiment S1067 at TRIUMF is to study the nuclear symmetry energy using radioactive ion beams with different neutron-to-proton values (N/Z). For the July 2011 experiment, three ion beams were used. A radioactive ion beam of ^{25}Na at 9.23 AMeV, a stable ion beam of ^{25}Mg at 9.23 AMeV and a mixed beam with ^{4}He, ^{12}C and ^{16}O at 6.563 AMeV for energy calibration. The reactions used were $^{25}Na +^{12} C$, $^{25}Na +^{27} Al$, $^{25}Mg +^{12} C$ and $^{25}Mg +^{27} Al$.

3 Experimental setup

HERACLES is composed of 6 rings of detectors centered on the beam axis with polar angles (θ) between 4.8° and 46°. Ring 0 ($4.8° < \theta < 6°$) is composed of 6 BC408/BaF_2 scintillators in phoswich mode. Ring 1 ($6° < \theta < 10°$) is composed of 8 telescopes with 50 μm thick silicon detectors and CsI(Tl) scintillators. Ring 2 ($10.5° < \theta < 16°$) and ring 3 ($16° < \theta < 24°$) are each composed of 16 BC408/BC444 scintillators in phoswich mode. Ring 4 ($24° < \theta < 34°$) and ring 5 ($34° < \theta < 46°$) are each composed of 16 CsI(Tl) scintillators (see Table 1).

3.1 BC408/BaF_2 detectors

The BC408/BaF_2 phoswich detector is made of a fast plastic scintillator of 100 μm thick and a BaF_2 crystal scintillator. The thin BC408 100 μm plastic scintillator provides a low energy threshold from 2.2 AMeV for He to 5.5 AMeV for Mg. A pulse shape analysis of the signal from the detectors gives element identification, obtained with a fast-slow representation. The fast component is from the BC408 and the slow component is from the BaF_2. The BC408/BaF_2 phoswich detectors are designed for mass identification from $A = 1$ up to $A = 12$ using time of flight measurements. BC408/BaF_2 detectors are placed at a distance of 1.45 m from the target.

Performance A time resolution of less than 1 ns is necessary to obtain mass identification using time of flight measurements. For the July 2011 experiment at 9.23 AMeV, a beam buncher was not available on the ISAC-II beamline; the time resolution was estimated at 3 ns. Therefore, there was no mass identification using BC408/BaF_2 detectors for that experiment. The analysis of the fast-slow representation provides element identification up to $Z = 12$ (see Fig. 1).

3.2 Si/CsI(Tl) detectors

The Si/CsI(Tl) telescope detector is made of a 50 μm thick silicon detector and a CsI(Tl) crystal scintillator. The thin 50 μm silicon detector has a low threshold from

Table 1 Configuration of detectors in HERACLES

Ring No.	ΔE detector	E detector	θ_{min} (°)	θ_{max} (°)	N	$\Delta\phi$ (°)	ΔE thickness (μm)
0	BC408	BaF_2	4.8	6	6	15	100
1	Si	CsI(Tl)	6	10	8	18	50
2	BC408	BC444	10.5	16	16	22.5	100
3	BC408	BC444	16	24	16	22.5	100
4	–	CsI(Tl)	24	34	16	22.5	–
5	–	CsI(Tl)	34	46	16	22.5	–

θ is the polar angle from the beam axis, N is the number of detectors per ring, ϕ is the azimuthal angle

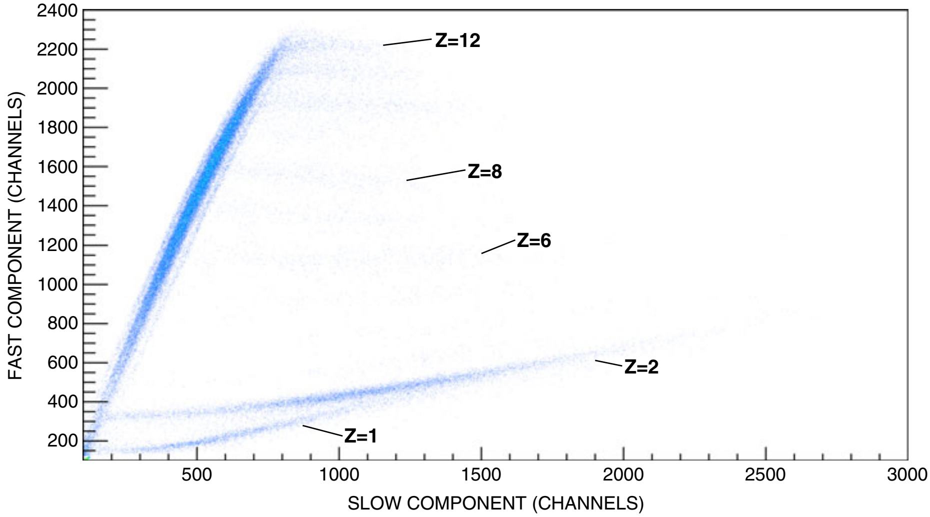

Fig. 1 Fast-slow representation of a $BC408/BaF_2$ phoswich detector for $^{25}Mg + ^{12}C$ at 9.23 AMeV

2 AMeV for He to 5 AMeV for Mg. Fragment identification is done with a ΔE-E representation, the ΔE component coming from the Si and the E component, from the CsI(Tl).

Performance The analysis of the ΔE-E representation provides element identification up to Z = 15. Isotopic identification is reached for ^{1}H, ^{2}H, ^{3}H, ^{4}He, ^{7}Be and ^{9}Be (see Figs. 2 and 3).

3.3 BC408/BC444 detectors

The BC408/BC444 phoswich detector has the same fast plastic scintillator as the $BC408/BaF_2$ detector, but the second stage of detection is BC444, a slow plastic scintillator. A pulse shape analysis of the signal from the detector gives element identification.

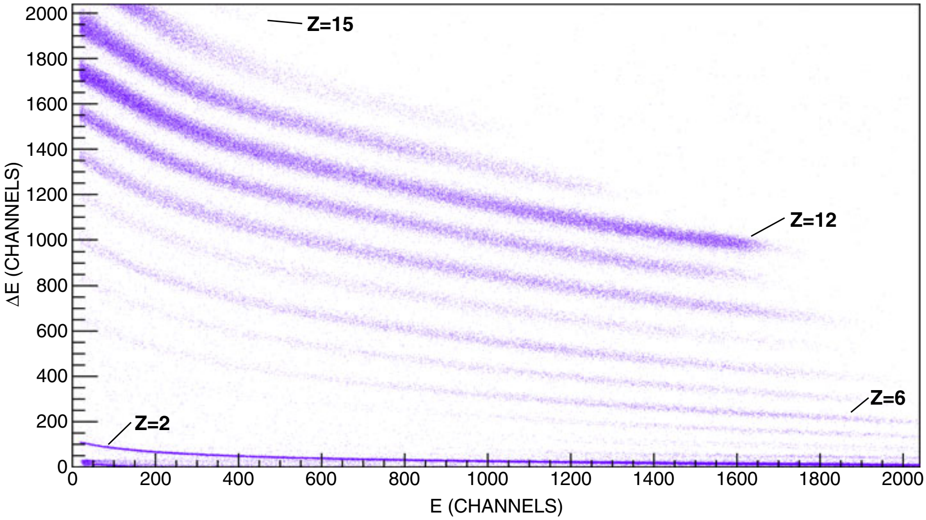

Fig. 2 ΔE-E representation of a Si/CsI(Tl) detector for $^{25}Mg + ^{12}C$ at 9.23 AMeV

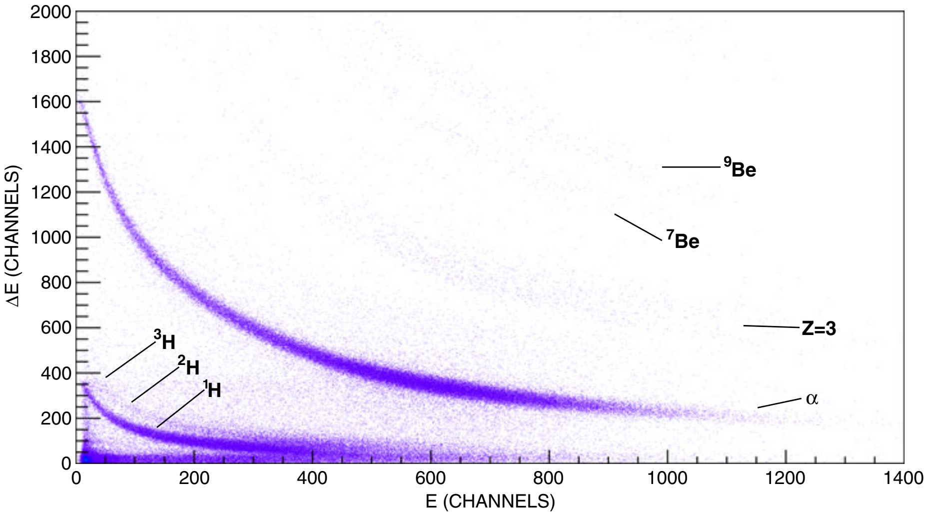

Fig. 3 ΔE-E representation of a high gain Si/CsI(Tl) detector for $^{25}Mg + ^{12}C$ at 9.23 AMeV

Performance The analysis of the fast-slow representation provides element identification up to Z = 12 (see Fig. 4).

3.4 CsI(Tl) detectors

The CsI(Tl) detector has only one stage of detection, the CsI(Tl) scintillator. The threshold is lower than for the other detectors of HERACLES. The decay time of

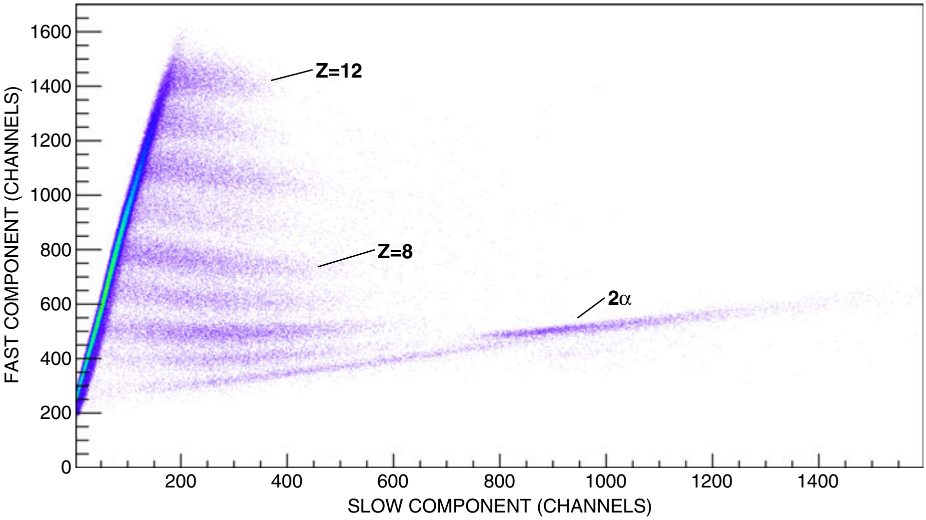

Fig. 4 Fast-slow representation of a BC408/BC444 detector for $^{25}Mg + ^{12}C$ at 9.23 AMeV

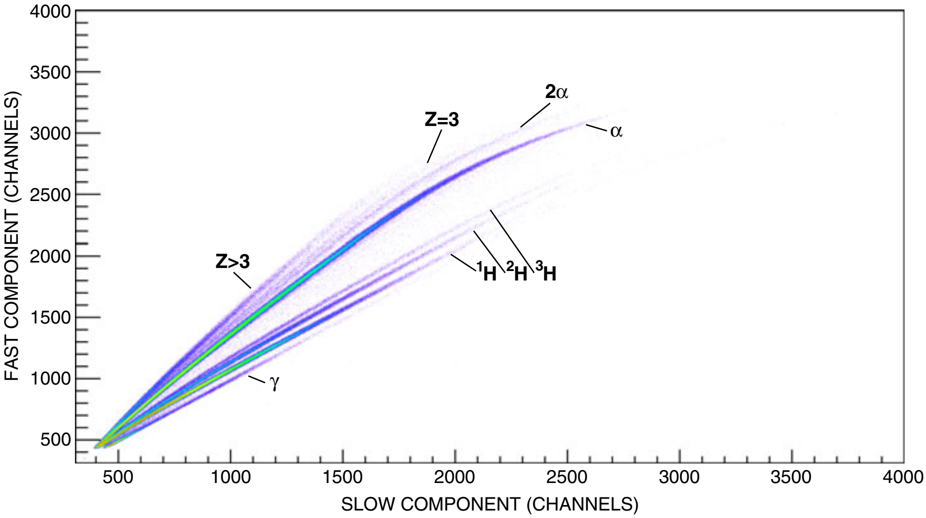

Fig. 5 Fast-slow representation of a CsI(Tl) detector for $^{25}Mg + ^{12}C$ at 9.23 AMeV

CsI(Tl) scintillators has two components, one fast (0.6 μs) and one slow (3.5 μs). A pulse shape analysis of the signal from the fast and slow components gives the identification.

Performance The analysis of the fast-slow representation provides isotopic identification for ^1H, ^2H, ^3H, ^4He with energy per nucleon greater than 4 AMeV and element identification up to $Z = 3$ (see Fig. 5).

4 Conclusion

HERACLES has been modified for heavy-ion collisions for low energies between 8 and 15 AMeV. The first results show element identification in rings 0, 1, 2 and 3 and mass identification for $Z < 3$ in rings 4 and 5. A better time resolution of the beam should provide mass identification in ring 0.

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