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Identification of heavy ion reaction channels with a new CAlorimeter TElescope within RISING*

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Abstract

A newly developed CAlorimeter TElescope (CATE) is employed in the fast beam RISING γ-campaign with relativistic energies at the FRS at GSI. CATE consists of nine Si-CsI(Tl) detector telescopes for position and $\Delta E - E$ measurements. It registers the scattering angle and identifies the charge (Z) and the mass (A) of exotic heavy ions produced after secondary fragmentation or Coulomb excitation.

1. Introduction

Within the fast beam RISING [1] campaign at GSI, stable and radioactive heavy-ion beams at relativistic energies have been used, after separation by the FRS [2] and identification, to investigate fragmentation reactions and single step Coulomb excitation with secondary targets. To obtain information about the impact parameter and to distinguish the different reaction channels, a position sensitive CAlorimeter TElescope (CATE) [3] has been designed and employed. The detector system has been used for the detection of primary and secondary heavy ions from ^{54}Cr up to ^{132}Xe in the energy range between 90 and 400 MeV/u (at the detectors) with instantaneous rates between 1×10^2 and 5×10^4 p s^{-1}.

2. CATE

CATE is a chessboard-like array of nine $\Delta E - E$ telescopes. Each of them comprises a position sensitive Si-pin detector for position (x, y) and atomic number (Z) determination, and a corresponding CsI(Tl) detector coupled to a photodiode for particle mass (A) determination

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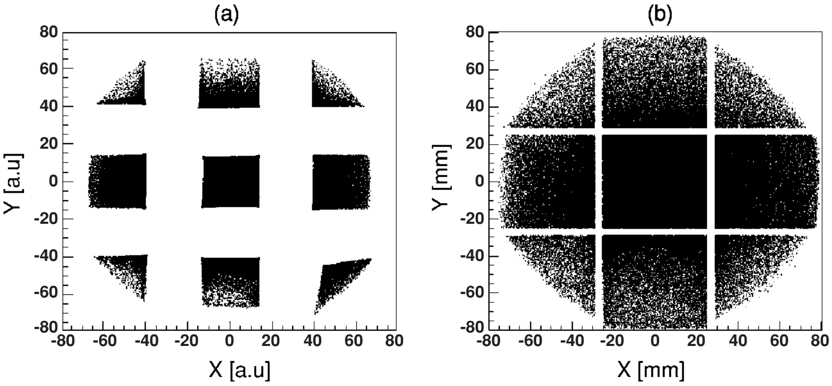


Figure 1. Position response of the CATE-Si array for ^{54}Cr ions with an energy of 170 MeV/u: (a) raw and (b) corrected spectra.

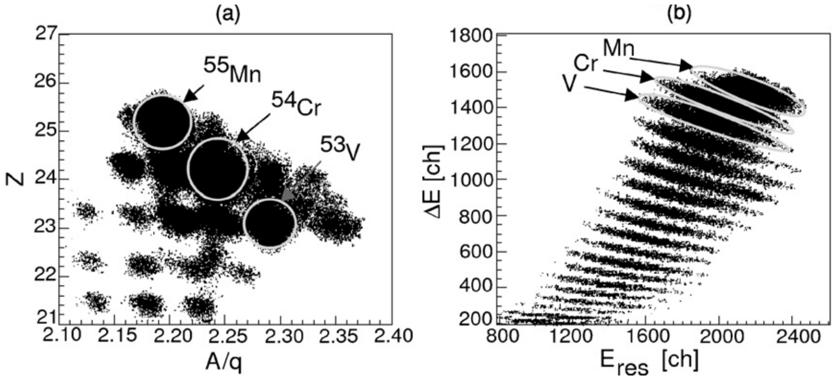


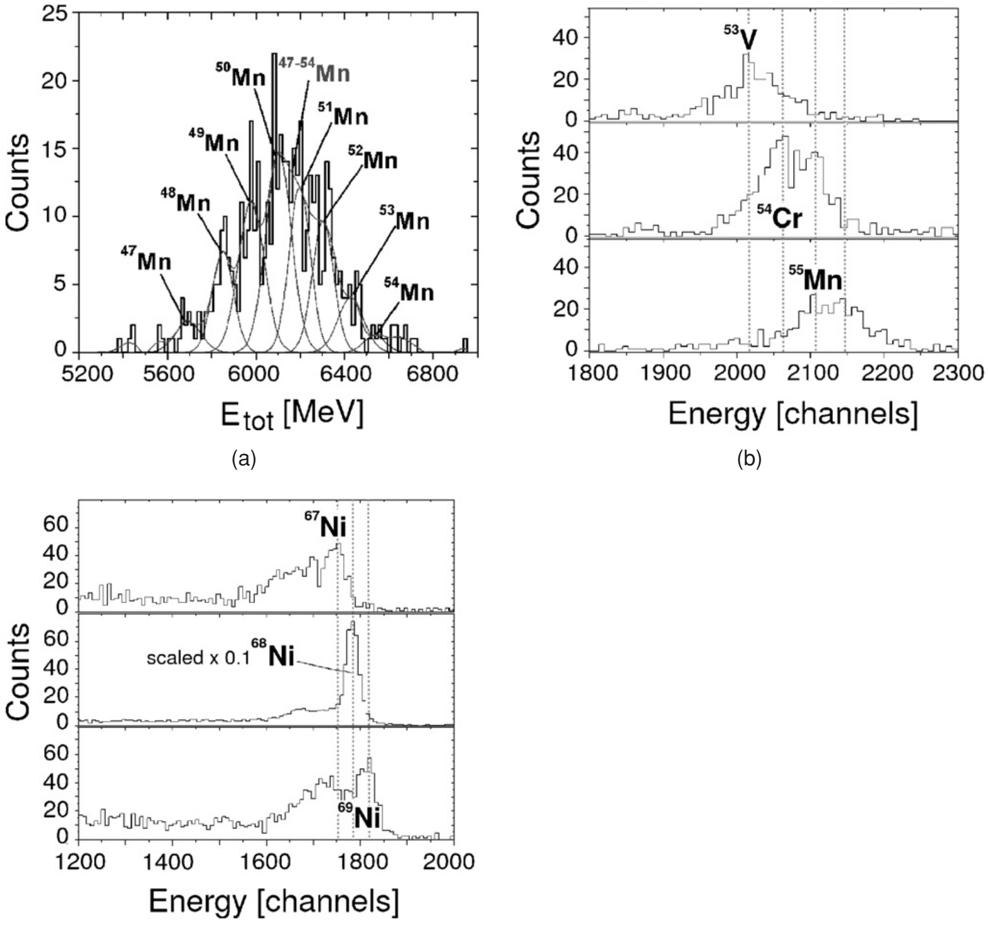
Figure 2. Identification of ^{55}Mn, ^{54}Cr and ^{53}V particles (a) before, and (b) after the secondary reaction (^{197}Au) target.

[3]. The CATE array is placed downstream from the secondary target, covering a solid angle $\theta \in [-3, 3]^\circ$, and having geometrical efficiency with respect to the incoming particles of 92%.

The position (x, y) is determined from the Si detectors via a charge division in its resistive layer (with a sheet resistance of 4–5 kΩ cm^{-2}). The resolution amounts to accuracy of better than (3×3) mm^2, tested with α-particles. The energy loss (ΔE) deposited in the Si transmission detectors, is a measure of the atomic number (Z), which is approximated to the particle charge (q) at relativistic energies [2]. The intrinsic energy resolution is about 1.5% (FWHM) for α-particles and about 2% (FWHM) for heavy ions (i.e. ^{86}Kr with an energy of 150 MeV/u and ^{58}Ni ions with an energy of 120 MeV/u). The residual energy (E_{res}) is deposited in the 25 mm thickness of the CsI(Tl) scintillators. Combined with the ΔE signal in the Si semiconductors, it is a measure of the ion mass A, under the assumption that all particles with the same mass have the same velocity. The intrinsic heavy ion energy resolution of these stop detectors is about 0.8% (FWHM), found with primary ^{86}Kr beam at an energy of 145 MeV/u and for a ^{58}Ni beam at an energy of 113 MeV/u.

3. The position sensitivity

The position, determined with the Si detectors, gives a measure of the scattering angle, and hence of the impact parameter, of the particles from the RISING secondary target. The



(a) (b)

(c)

Figure 3. The mass spectra of CATE for (a) fragmentation ^{55}Ni(^{9}Be,xn,3p) of 100 MeV/u (b) Coulex ^{53}V, ^{54}Cr, ^{55}Mn(^{197}Au,0n,0p) of 170 MeV/u and (c) Coulex ^{67}Ni, ^{68}Ni, ^{69}Ni(^{197}Au,0n,0p) of 415 MeV/u.

thickness of the secondary target is usually chosen to keep the angular straggling of the order of 10 mrad, corresponding to a position uncertainty at CATE of about 1 cm [1]. Therefore, the intrinsic position resolution and the linearity are not critical. As demonstrated in figure 1(a), the position response of the Si detectors is almost linear. Since the efficiency with respect to the incoming particles is kept, only a simple calibration, using a normalization to the detector size [4] is required to obtain the real position as shown in figure 1(b).

4. The particle identification

The energy measurement of the CATE detectors is found to be influenced by (i) the particle position, (ii) the beam rate and (iii) the velocity. The first effect is connected to the nature of the detectors and their inhomogeneity, while the rest are effects connected to the beam and depend on its irradiation and distribution. Therefore, corrections are performed for all these effects [4].

In all in-beam studies the detector response revealed a unique Z identification with extracted Z resolution of the particle cocktail of $\Delta Z \sim 0.7$–$0.8\,Z$ (FWHM). A typical example is the system (^{55}Mn, ^{54}Cr, ^{53}V on a ^{197}Au target) at 170 MeV/u. For the selected ^{55}Mn, ^{54}Cr and ^{53}V ions, separated and identified by the FRS (see figure 2(a)), the reaction channels were detected by CATE as shown in figure 2(b).

In fragmentation processes, the momentum variation of the abraded nucleons leads to a spread of the momentum, respectively, the velocity of the final fragment [5]. Therefore, the assumption of constant velocity for all secondary ion species does not hold. Consequently, without a time-of-flight measurement after the secondary target, the possible mass resolution is typically 2–3% (FWHM) at energies of about 100 MeV/u. These values were also found from the total energy ($E_{\mathrm{tot}} = \Delta E + E_{\mathrm{res}}$) of CATE in the experimental data (^{55}Ni on ^{9}Be at 100 MeV/u). The energy is obtained after an absolute energy calibration and linearization of the $\Delta E - E$ distribution [4]. As an illustration, the E_{tot} spectrum for i.e. $Z = 25$ isotopes is presented in figure 3(a) with multiple fit and deconvolution to single distributions (with reduced $\chi^2 \leqslant 5$; $\chi^2 = \chi^2/n$, where n is the number of degrees of freedom). The identification is performed by comparison of the energy centroids with simulated single mass distributions using the LISE code [6], as indicated with arrows.

In relativistic Coulomb excitation it is important to distinguish the Coulex channel from knock-out channels. For the selected isotopes in figure 2(b) the masses are obtained from the E_{res} projection (in channels) and identified by their reaction probability with the secondary target (since no energy calibration is performed). The extracted mass resolution from the difference in the energy centroids is about 2% (FWHM), as shown in figure 3(b).

In another Coulex reaction of ^{67}Ni, ^{68}Ni, ^{69}Ni on ^{197}Au at 415 MeV/u, the high energetic ^{67}Ni, ^{68}Ni and ^{69}Ni isotopes are identified in the same way and their mass resolution is determined with an accuracy of about 1–2% (FWHM) (see figure 3(c)).

5. Summary

With the newly developed $\Delta E - E$ telescope, CATE, identification of relativistic heavy ions at energies $\geqslant$100 MeV/u can be performed. The system has a good position resolution (Δx, Δy) of (3×3) mm^2 for scattering angle reconstruction, a unique charge resolution of 0.7–0.8 Z (FWHM), a mass resolution of 2–3% (FWHM) for fragmentation and 1–2% (FWHM) for Coulex channels.

Taking into account the intrinsic energy resolution, with an additional time-of-flight measurement after the secondary target, the A resolution for fragments could be improved to about 1% (FWHM).

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