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A novel Calorimeter Telescope for identification of relativistic heavy-ion reaction channels

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Abstract

A novel Calorimeter Telescope (CATE) is employed in the fast beam Rare Isotope Investigations at GSI (RISING) γ-campaign with relativistic energies at the Fragment Separator (FRS) at GSI. CATE consists of nine modular Si$-$CsI(Tl) detector telescopes for position and $\Delta E - E_{\text{res}}$ 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.

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1. Introduction and motivation

The FRS facility [1] at GSI provides a unique opportunity to separate a variety of relativistic heavy-ion beams which are produced at a primary target and transported to a final focus, where a secondary target is located. The FRS allows an isotope separation using the Bρ-ΔE-Bρ technique [1] and an identification using a system of tracking detectors (see Fig. 1) before the secondary reaction target.

At this position the RISING [2] spectrometer is situated, utilizing fifteen of the ex-EUROBALL [3] Ge-Cluster detectors [4]. Within the first, ''fast beam'' phase, the RISING experiments aimed at γ-ray spectroscopy of secondary isotopes, produced in nucleon knockout and fragmentation reactions or relativistic Coulomb excitation at the secondary target, yielding unique nuclear structure information which cannot be obtained by other techniques.

In order to obtain information about the excited residues, channel selection after the reaction target is needed. Here, the energy loss (ΔE) combined with a residual energy (E_{res}) measurement, known as $\Delta E - E_{\text{res}}$ method is favored for identification of the secondary reaction products and to measure their scattering angle (for kinematics reconstruction). Detector systems utilizing this type of energy measurement have shown a large and simple applicability in a wide range of experimental conditions in

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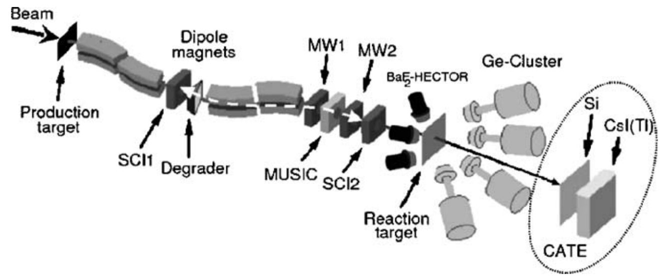

Fig. 1. Schematic layout of the RISING experimental setup for the fast beam campaign. The identification detectors consist of two Multi Wire detectors (MW1 and MW2) for position (x, y) measurement, an Ionization Chamber (MUSIC) for energy loss (respectively Z) measurement and two plastic scintillators (SCI1 and SCI2) for Time-of-Flight, ToF (respectively velocity β) measurement. The identification after the secondary target is performed with the new Calorimeter Telescope CATE.

many laboratories [5–12]. However, a $\Delta E - E_{\rm res}$ detector system has not been employed for a relativistic heavy-ion identification so far. The present paper reports on a novel calorimeter telescope constructed for this purpose. In order to design such a new system, several investigations have been performed for the selection of particle detectors for ΔE and $E_{\rm res}$ measurements. Based on these experimental studies, a new position sensitive $\Delta E - E_{\rm res}$ Calorimeter Telescope (CATE) [13] has been built, consisting of a Si and a CsI(Tl) detector arrays.

The position sensitive Si detector array measures the particle's (x, y) position and is used for the reconstruction of the scattering angle after the secondary target. From the energy loss, detected in the Si (ΔE) and CsI(Tl) $(E_{\rm res})$ detectors, the ion charge Z and mass A are derived, respectively. The CATE detector system has been used within the RISING fast beam campaign for the detection of primary and secondary heavy ions from ^{53}V up to ^{132}Xe in the energy range between 90 and 400 A MeV (at the detectors) with instantaneous rates between 10^2 and 10^4 pps.

2. Calorimeter Telescope—CATE

CATE is a chessboard-like array of nine $\Delta E - E_{\rm res}$ telescopes. Each of them comprises a position sensitive Si-pin detector and a corresponding CsI(Tl) detector coupled to a photodiode [13]. It is placed 1.4 m downstream from the secondary target (see Fig. 1) in order to have sufficient angular coverage for impact parameter measurements in the relativistic Coulomb excitation reactions. Thus, the opening angles are $\theta \in [-3.2, 3.2]^\circ$ and $\phi \in [-180, 180]^\circ$. Taking into account the solid angle coverage of the detectors in the array (see Fig. 2(a,b)), the efficiency with respect to the incoming particles amounts to 92%.

2.1. CATE-Si array

Two types of Si-pin detectors have been used for the CATE-Si array. These are a Si-IPP type semiconductor (model: $IPP2D50x50-300-SPE$) [14] and a Si-PIPS[4] type semiconductor (model: $PF50x50-300EB-L$) [15]. They differ slightly by their thickness, and significantly, by the resistivity of the resistive layer.

Each Si-ΔE counter has a size of $(50 \times 50)\,\text{mm}^2$ and a thickness of 0.30 mm (for the Si-IPP) and 0.32 mm (for the Si-PIPS). A resistive carbon layer with a sheet resistance of $1-2\,\text{k}\Omega/\text{cm}^2$ (for the Si-IPP) and $4-5\,\text{k}\Omega/\text{cm}^2$ (for the Si-PIPS) serves as a front contact. This layer is used as a charge divider with four contact electrodes at the four corners. By comparing the relative pulse heights, obtained at these four electrodes, the position is calculated (see Section 3). Each corner contact has in addition a resistor of $1-1.5\,\text{k}\Omega$ (for the Si-IPP) and $1.5-1.6\,\text{k}\Omega$ (for the Si-PIPS) to reduce nonlinearities in the position determination as described i.e. in Refs. [16,17]. All detectors are placed in separate frames with size $(54 \times 54)\,\text{mm}^2$ and altogether on a motherboard, as shown in Fig. 2(a,c).

The energy, ΔE, deposited by the incident particle, is measured by the back-side contact and the signal is proportional to the total charge created. From the energy loss in the detector (ΔE), the charge Z of the impinging particle is obtained (see Section 5.1).

An α-test measurement with a ^{241}Am source revealed the intrinsic position resolution $(\Delta x, \Delta y)$ of these detectors. It is better than $(5 \times 5)\,\text{mm}^2$ for the Si-IPP detectors and better than $(3 \times 3)\,\text{mm}^2$ for the Si-PIPS detectors. The intrinsic energy resolution for 5.5 MeV α-particles stopped inside the detector is better than 1.5% (FWHM) for both Si types. In-beam, the intrinsic energy resolution of both Si types, acting as transmission detectors, is found to be about 2.0% (FWHM) with primary ^{86}Kr ions with an energy of 150 A MeV and ^{58}Ni ions with an energy of 120 A MeV.

2.2. CATE-CsI(Tl) array

The CsI(Tl) array (see Fig. 2(d)) is placed about 40 mm behind the Si array in the CATE detector chamber to yield the residual energy, $E_{\rm res}$, of the fragments. Each CsI(Tl) scintillator (model: $V52P25/18M-E2-$Cs$-X(SSX848)$) [18] has a truncated pyramidal shape (see right-bottom part of Fig. 2(d)) with a base size of $(54 \times 54)\,\text{mm}^2$, a minimal height of 10 mm and a maximal height of 25 mm. In 10 mm thickness all heavy ions with $Z \geqslant 7$ and $A \geqslant 14$ with an energy of $\leqslant 100$ A MeV are fully stopped [19]. For readout a photodiode with size of $(18 \times 18)\,\text{mm}^2$ is attached at the smaller base, together with an integrated appropriate preamplifier [20]. The detectors are covered by 2 μm thick Mylar,[5] to protect the crystal, and to assure good light collection. All detectors are mounted in a very close geometry and separated in front by an Al holder frame, which covers a spacing of 4 mm between each two of them, thus reproducing the geometrical efficiency of the Si array.

[4]PIPS is a Trademark of Canberra.
[5]Mylar is a Trademark of DuPont.