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The MINIBALL array [☆]

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Abstract

MINIBALL a highly efficient, position sensitive γ -spectrometer is under construction for upcoming radioactive-beam experiments. In contrast to high spin arrays the total full energy peak efficiency and not the resolving power is optimized with a factor of two larger efficiency for γ -ray energies up to 10 MeV and for low to medium γ -ray multiplicity events. Cluster detectors, incorporating three or four Ge crystals, will be employed to provide high flexibility and to accommodate the various demands of the experiments. © 2002 Published by Elsevier Science B.V.

For new radioactive beam experiments like REX-ISOLDE the γ -spectrometer MINIBALL is optimized to achieve primarily a high photo-peak efficiency in combination with position sensitive γ -ray detection for low to medium γ -ray multiplicity ($M_\gamma \leq 10$) events. In order to gain the efficiency the MINIBALL detectors are operated at close distance from the target. Despite large opening angles, which may cause a huge Doppler broadening, a proper Doppler correction will be performed by measuring the first interaction point of the γ -rays within the crystals. The basic element of MINIBALL is a six-fold segmented encapsulated Ge-detector of EUROBALL shape [1,2]. The array will consist of

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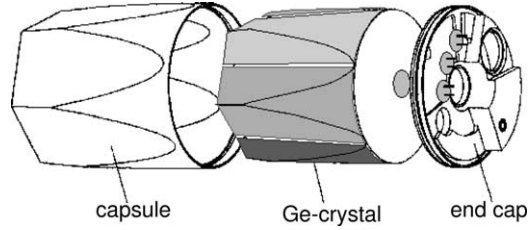


Fig. 1. Schematic drawing of the six fold segmented, encapsulated Ge-detector for the MINIBALL spectrometer.

42 segmented position sensitive Ge detectors [3]. The capsules will be used individually or packed to clusters of either three or four to provide a high level of flexibility and to accommodate the various demands of individual experiments.

The MINIBALL is designed to achieve the following goals and properties:

- (1) Ge-detectors: 42 hexagonal shaped, encapsulated EUROBALL-type detectors sixfold segmented, rel. efficiency 60% (1.3 MeV).
- (2) Full energy peak efficiency: $\epsilon_{\text{ph}} \simeq 20\%$ for 1.3 MeV γ -rays, $\epsilon_{\text{ph}} \simeq 5\%$ for 11.7 MeV γ -rays.
- (3) Energy resolution $\Delta E_{\gamma} \leq 2.3$ keV at 1.3 MeV and 10 kHz count rate.
- (4) High counting-rate capability: > 10 kHz per individual Ge-detector.
- (5) Granularity: 252 detector elements in 4π are required to be able to perform a Doppler-shift correction of γ -ray energies emitted by nuclei with velocities of typically 10% of that of light. The velocity of the γ -emitting nuclei has to be determined in addition by particle detectors.
- (6) Minimum inner free sphere for ancillary detectors: radius ≥ 10 cm.
- (7) High modularity and flexibility allowing arrangements in different geometries.
- (8) Electronics: digital pulse processing for energy, timing and pulse shape.

A drawing (Fig. 1) of the MINIBALL prototype detector shows the sixfold segmented Ge-crystal. The performance of the detectors are better than expected: the energy resolution of the central contact is typically 2.1 keV at 1.33 MeV, the resolution of the segments is < 2.5 keV at 1.33 MeV with FETs at liquid nitrogen temperature. The high capacity between detector surface and capsule wall is typically deteriorating the resolution of the segments. The energy result of the segments was surprisingly good also due to new pre-amplifiers. The segments will be used as individual channel for spectroscopy and pulse shape analysis and 294 individual electronic signals will be instrumented with high resolution electronics.

The cryostat configuration will combine subgroups of three and four Ge detectors respectively to units with a common vacuum chamber, cryostat and dewar. Different subsets of detector groups may be arranged in a very efficient way. For example, a set of 18 Ge crystals can be arranged in six groups of three detectors in a cubic geometry. The photopeak efficiency of this setup ($\epsilon \approx 10\%$) will be comparable with EUROBALL. The 18 Ge detectors (Phase I) are available for the first REX-ISOLDE experiments.

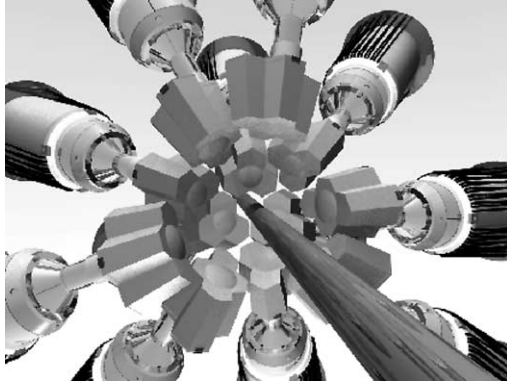


Fig. 2. 2π configuration of the MINIBALL spectrometer.

The different experiments require a large amount of flexibility for the MINIBALL mechanics. Configurations with a covering from 2π solid angle under backward angles (see Fig. 2) up to 4π in a full sphere are necessary. The 12 Ge-cryostats are mounted onto six half circular, rotatable arms. They can be moved continuously along the arms. The distance target detector is also flexible and nearly every position of the detectors with respect to the target can be arranged. The spherical setup can be moved apart in two halves to have access to the target chamber and the charged particle detectors.

A central issue for MINIBALL is its electronics, because a large number of high-resolution channels—294 in the present design—have to be processed. Starting from the pre-amplifiers the whole chain of electronic pulse processing will be done in a new and unprecedented way. The development of an improved, very small size pre-amplifier was successfully finished at the IKP, Köln. The pre-amplifier has a short rise time of 30 ns and an input capacitance of $C_E = 35$ pF (large volume Ge-detector). The noise contribution is equivalent to the best conventional large pre-amplifiers. An important achievement is the pulse shape with no over- or undershooting, a prerequisite for the pulse shape analysis.

MINIBALL will be the first γ -spectrometer which will replace the conventional analog pulse processing electronics by digital pulse processing. The pre-amplifier signal is digitized with a sampling-ADC, from the digitized values the energy and time information as well as pulse shape parameters for position determination are deduced by exploiting real time digital filter algorithms. Main advantages are: the shorter processing time intervals enable higher count rates and less dead time. The amount of electronics hardware can be reduced substantially. MINIBALL will be instrumented with an electronics module customized by X-Ray Instrumentation Associates, Mountain View (USA). The achieved energy resolution with the digital electronics module is of equal quality compared to results achieved with standard Ge electronics. Timing properties and position determination are currently investigated exploiting the digitized pulse shape information.

A data acquisition and analysis system for the MINIBALL, including also electronics of a Silicon detector array, has been completed. The new system consists of two main parts: a front-end system for data readout, event building and data transport based on GSI's

Multi-Branch System (MBS) [4] and a back-end system responsible for setup, run control, histogramming, and data analysis written within the ROOT framework [5].

As a test experiment for future REX-ISOLDE experiments, the 1n-transfer reactions $D(^{36}\text{S}, ^{37}\text{S})p$ and $D(^{36}\text{S}, ^{37}\text{Cl})n$ were investigated at MPI-K Heidelberg [6]. The beam energy was chosen to 2.2 MeV/u the maximum energy of the REX-ISOLDE accelerator. Two MINIBALL detectors and a parallel plate avalanche counter (PPAC) were included in the experimental setup. The two Ge-detectors were positioned at a distance of 10.6 cm perpendicular to the beam axis. Despite of the unfavoured observation direction of the γ -rays and the large recoil velocity of $v/c = 6.5\%$ (inverse kinematics) a remarkable improvement of the γ -linewidth could be achieved without loss in efficiency. The PPAC developed for REX-ISOLDE was placed under 0 degree. At higher beam intensities (10^5 – 10^7 s $^{-1}$) the PPAC is used in current mode as a beam monitor. At lower beam intensities ($< 10^6$ s $^{-1}$) the PPAC can be operated in a single particle mode which allows to determine the position and the arrival time for every beam particle. The time reference is necessary to suppress the background radiation in the Ge detectors. The experiment has demonstrated, that it is possible to measure inverse transfer reactions on deuterium targets at low beam intensities—expected at radioactive beam facilities—if a γ -array like MINIBALL is combined with an efficient particle detector.

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