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MINIBALL
A Ge Detector Array for Radioactive Ion Beam Facilities

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Abstract

Dedicated Ge-detector arrays are being developed for the investigation of rare γ decays with low γ-ray multiplicity at the upcoming radioactive ion beam facilities . These arrays are optimized for the high full-energy peak efficiency and angular resolution of the γ-ray detection needed for a proper Doppler correction of the γ-rays emitted by fast recoiling nuclei. MINIBALL will consist of 40 six-fold segmented, encapsulated Ge detectors which are clustered in eight cryostats with three detectors each and four cryostats with four detectors, respectively. The individual components - the six-fold segmented Ge detector, the cryostats, the fast preamplifier, the digital pulse-processing electronics and the mechanical frame - and their properties are described. The results of test measurements with the first MINIBALL cluster detector using a ^{137}Cs source and the in-beam reaction D(^{37}Cl, n) ^{38}Ar are presented. It is shown that from pulse-shape analysis of the events within a detector segment the effective granularity of the MINIBALL array can be enhanced from 240 to $\sim$ 4000. The specifications of MINIBALL are compiled on the basis of experimental data. First results with a 12-fold segmented, encapsulated detector are discussed with respect to the feasibility of future γ-ray tracking arrays.

1 Introduction

The most powerful gamma spectrometers to date are GAMMASPHERE and EUROBALL [1]. Both instruments are optimized to study the nuclear structure at high spins with heavy-ion induced fusion-evaporation reactions. The fact that, in these experiments, the nucleus is populated at maximum angular momentum results in a γ-multiplicity of an event of $M_\gamma \sim 30$. In order to detect as many γ-rays as possible out of the 30 emitted coincident γ-rays a high total-absorption efficiency of the array and a high single-hit probability of the individual Ge detectors are needed. Fig.1 shows a cross section of the EUROBALL spectrometer. It consists of 15 Cluster detectors (each of which is composed of seven encapsulated Ge detectors)

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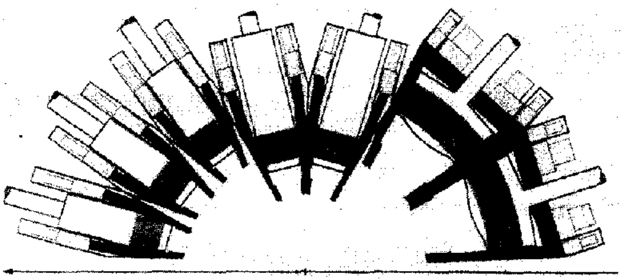

Figure 1: *Arrangement of the EUROBALL detectors*

at backward angles, 26 Clover detectors (each composed of four detectors in one cryostat) in the central part and 30 standard Ge detectors at forward angles. Each type of detector is surrounded by a BGO shield which suppresses the Compton-escaped γ-rays; at the same time these BGO shields act as collimators to prevent the scattering of γ-rays from one Ge detector to another which would result in background events.

EUROBALL and GAMMASPHERE have enabled an impressive progress in nuclear-structure physics during their 4 - 5 years of operation so far. For recent results achieved with EUROBALL we refer to the contribution by S. Lunardi in this volume [2].

In order to answer the open questions in nuclear-structure physics the interest is moving more and more to nuclei with extraordinary N/Z ratio close to the proton and neutron drip lines. It has been shown that more than 1000 new nuclei can be produced with heavy-ion induced fragmentation reactions (MSU, RIKEN, GSI) or with the ISOL technique (REX-ISOLDE, MAFF, SPIRAL)[3]. New facilities for the production and acceleration of unstable beams are planned in Europe (EURISOL) and in the USA (RIA). These facilities will allow the detailed study of a variety of phenomena, e.g. neutron skins, neutron halos and the melting of shell effects in neutron-rich nuclei, the effects of T=0 proton-neutron pairing in selfconjugate nuclei up to ^{100}Sn and the detection of waiting points in the r- and rp-process during nucleosynthesis.

The new exciting experimental perspectives at the RNB facilities have triggered development programmes in Europe and in the USA for γ-ray detector arrays with several orders of magnitude improvement in resolving power compared to their predecessors. The new concept is based on γ-ray tracking. The target is surrounded by a 4π shell of 100 - 150 Ge position-sensitive detectors. The position sensitivity of the detectors is achieved by segmentation of the outer contact and by analysing the charge drift times within a segment and the mirror charges induced in the neighbouring segments. Thus, one will be able to determine the individual interaction points of a γ-ray being Compton-scattered and finally absorbed in the Ge detectors. Reconstructing the track of the γ-ray and comparing with the Klein-Nishina formula makes it possible to decide whether the γ-ray was emitted from the target and fully absorbed in the Ge shell. From Monte-Carlo simulations one expects that a Ge tracking array will have a high efficiency (maximum coverage of the solid angle with Ge detectors), excellent performance for the correction of Doppler effects (angle of the emission of the γ-ray determined from the first interaction point in the Ge detector) and a very good peak-to-total ratio (by distinguishing between fully and partially absorbed events).

Two Ge detector arrays are under construction now which use, for the first time, position-sensitive Ge detectors. MINIBALL is designed for the radioactive-beam programme of REX-ISOLDE and MAFF while EXOGAM is designed for use at the SPIRAL facility at GANIL. The physics programme at these RNB facilities will concentrate on reactions with low γ-multiplicities, e.g. Coulomb excitation of exotic nuclei and inverse d,p and d,n reactions. The experiments require a high efficiency because of the low event rates expected and a high effective granularity in order to improve the final resolution by Doppler correction.

MINIBALL will consist of 40 six-fold segmented, encapsulated Ge detectors while 16 four-fold segmented CLOVER detectors will be used for EXOGAM. Both types of detectors are segmented longitudinally which allows the localisation of the main interaction of the γ-ray in two dimensions for Doppler correction, but are not capable of a full γ-ray tracking because they lack segmentation in depth. In this sense, MINIBALL and EXOGAM are dedicated arrays for experiments with low γ-multiplicities but will explore the technique of pulse-shape analysis with segmented detectors needed for future γ-ray tracking arrays.

In this contribution, we will describe the MINIBALL components and their properties in detail and we will present the final specifications of MINIBALL as extracted from in-beam experiments with the first detectors and digital pulse-processing electronics.

2 The components of the MINIBALL array

The development programme to realize the MINIBALL array covered all components of the spectrometer chain: the encapsulation technology of Ge detectors had to be extended to segmented detectors, a cryostat capable of cooling up to four 6-fold segmented Ge detectors with 28 cold FET's had to be constructed, a fast preamplifier transferring the full information of the Ge detector pulse had to be developed as well as digital electronics for pulse-shape analysis and a very flexible mechanical frame had to be constructed in order to be adaptable for the different experimental conditions at the RNB facilities.

2.1 The 6-fold segmented encapsulated Ge detector

The development is a continuation of the encapsulation technology used for the EUROBALL-Cluster detector [4]. Encapsulation has proved to enhance the reliability of Ge detectors considerably. The failure rate of the 122 encapsulated EUROBALL detectors produced since 1993 is less than 4%. All detectors have been annealed several times, after neutron damage in the users' lab, without any failure. From our experience we believe that this encapsulation technology is needed in order to build complex detector arrays with position-sensitive Ge detectors. Segmented Ge detectors are more sensitive to the contamination of the passivated intrinsic surfaces, especially at the separation lines between the segments. Encapsulation will help to preserve the properties of the detectors over many years. Even more important is the fact that, in systems using encapsulated detectors, the vacuum of the detectors is separated from the vacuum of the cryostat containing the cold parts of the preamplifiers. It has turned out that the position of the cold electronic components, the shielding between the components and the wiring is crucial to prevent oscillation of the preamplifiers and crosstalk between segments. Usually, the cryostat has to be opened several times before a perfect performance of the system is achieved. This procedure and also repairs of the electronics can only be performed on systems with encapsulated detectors without running the risk of damaging the Ge detectors. Fig. 2 shows the 6-fold segmented MINIBALL detector. An AC-coupled preamplifier is used to read out the total signal of the detector from the core and six DC-coupled preamplifiers to read out the segment information. All cold parts of the seven preamplifiers are mounted on top of the capsule.

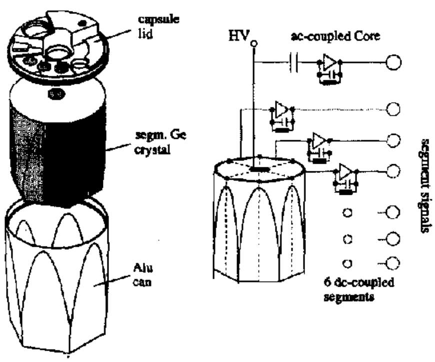

Figure 2: *The encapsulated MINIBALL detector*

The typical performance of one of the 22 detectors delivered so far by Eurisys Mesure is summarized in table 1. The energy resolution measured at the core is typical for a large Ge detector; the resolution of the segments is 200-300 eV worse due to the additional capacitance between the Ge surface and the wall of the capsule.

	Core	Seg1	Seg2	Seg3	Seg4	Seg5	Seg6
@122keV	1.30	1.65	1.52	1.63	1.89	1.71	1.76
@1.3MeV	2.22	2.41	2.44	2.44	2.59	2.45	2.53

Table 1: energy resolution of core and segments in [keV] for one MINIBALL detector

2.2 The MINIBALL-Cluster cryostat

Fig. 3 shows a photograph of a MINIBALL Triple-Cluster cryostat which has been developed at the University of Cologne. Up to 28 preamplifiers are mounted on a circular motherboard below the dewar. The detector endcap can be exchanged to house three or four 6-fold segmented detectors. MINIBALL will consist of 40 detectors clustered in eight cryostats with three detectors each and four cryostats with four detectors each. These two types of cryostats are chosen to get an optimum coverage with Ge in a 4π arrangement of the detectors. The holding time for liquid nitrogen in the dewar is 12 hours.

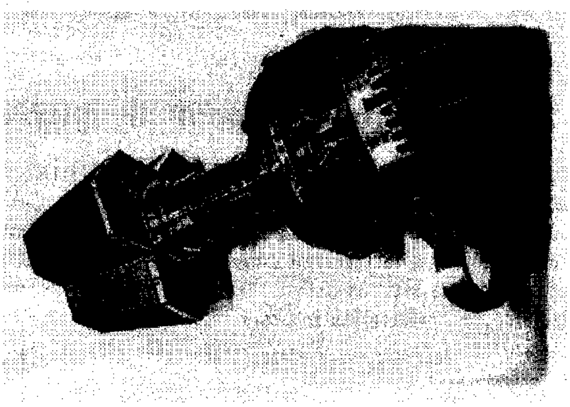

Figure 3: *The MINIBALL cryostat*

2.3 The MINIBALL frame

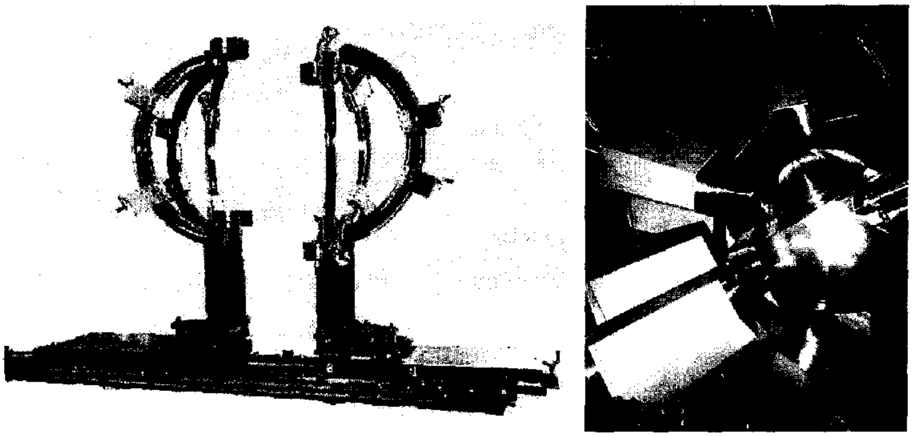

Figure 4: *Photographs of the MINIBALL frame*

Existing large 4π arrays like GASP, GAMMASPHERE and EUROBALL use rigid mechanical structures which limit the positions of the Ge detectors with their BGO suppression shields to a fixed geometry. As MINIBALL will be used at various RNB facilities (REX-ISOLDE, MAFF, GSI, ..) for a variety of different types of experiments more mechanical flexibility is needed, e.g. to change the arrangement from a 2π setup to a 4π setup without dismounting all the detectors. Such a flexible construction (Fig. 4) has been developed by a collaboration of the University of Cologne, the IRES Strasbourg and the University of Göttingen. The MINIBALL-Cluster detectors are mounted on six arcs which can be turned around the target. The detectors can be moved along the arcs, the distance to the target can be varied and the detectors can be rotated about their axis to allow for optimum package of the detectors. With the exception of the two positions above and below the target, excluded by the bearings of the arcs, the detectors can be moved to all angles of the sphere. Each arc can carry the weight of three MINIBALL cluster detectors including optional BGO shields. In order to get full access to the target chamber the two halves of MINIBALL can be moved perpendicular to the beam axis by one metre on each side. Fig. 4 shows the opened MINIBALL frame and a setup consisting of four MINIBALL detectors.

2.4 Electronics

The position sensitivity of the MINIBALL detector is based on the segmentation of the detector and the analysis of the pulse shape of the core signal for the radial position and of the mirror charges induced in the segments for the azimuthal position. This requires a large bandwidth of the preamplifiers in order to transfer the full information of the Ge detector signal; on the other hand, the need for a compact cryostat, housing up to 28 preamplifier, places a constraint on the size of the preamplifier. Such a preamplifier has been developed by the University of Cologne and the MPI-K Heidelberg. Fig. 5 shows a photo of the board and the most important specifications. The preamplifier has a fast rise time and an excellent noise performance; by the use of SMD components the size could be limited to 25 x 40 mm. There are adjustments for pole zero, DC offset and the drain current of the FET. For easy exchange, the preamplifiers are plugged into a motherboard mounted in the cryostat.

Figure 5: *The SMD-Preamplifier. Gain:* $175mV/MeV$; *Noise:* $0.6keV + 0.17keV/pF$; *Rise Time:* $15ns + 0.3ns/pF$

For pulse processing, MINIBALL uses the CAMAC module DGF-4C supplied by the company XIA, Newark (CA), USA. Each single-width CAMAC module comprises four complete Ge channels for energy spectroscopy and pulse-shape analysis. A block diagram of one channel is shown in fig. 6. The analogue part contains a gain adjustment via a 14 bit DAC and a Nyquist filter for high frequencies. The signal then is digitized by a 12 bit, 40 Mhz ADC; the result is transferred to a FIFO and a FPGA (Field Programmable Gate Array). From the FIFO the trace can be read out to a host computer for off-line analysis or it can be analyzed on-board by a DSP. The FPGA extracts the γ-energy in real-time by a software filter; it can also apply simple algorithms for pulse-shape analysis in real-time. Four γ-ray singles spectra of $32K$ length each are stored in on-board RAM. In order to overcome the limitations in transfer rates imposed by the CAMAC standard the board has an additional Firewire readout (IEEE 1394) with a maximum transfer rate of 16 Mwrds/s. A multiplicity bus and readout with adjustable threshold, busy and synchronization lines and inputs for first- and second-level triggers make it possible to incorporate the modules in complex coincidence systems.

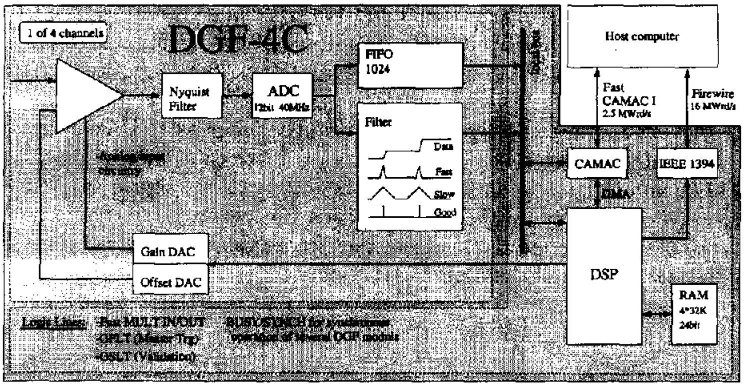

Figure 6: *Block diagram of the DGF-4C*

The energy resolution obtained for the MINIBALL detectors with DGF-4C is comparable or better than the resolution measured with conventional analogue spectroscopy amplifiers. The performance of the pulse-shape analysis is discussed in the next section.

3 Position sensitivity of the six-fold segmented MINIBALL detectors

In most experiments at RNB facilities planned with MINIBALL the γ-rays will be emitted from fast-moving nuclei. In these cases the energy of the γ-ray depends on the angle of observation with respect to the velocity vector of the emitting nucleus due to the Doppler effect. For an optimum Doppler correction the angle of observation has to be known within several degrees depending on the velocity of the emitter. In order to achieve a high detection efficiency with a limited amount of Ge the MINIBALL detectors will be operated at distances of 10 - 19 cm from target. At these close distances the granularity of the detector by six-fold segmentation alone, yields an inadequate Doppler correction. We therefore will use pulse-shape analysis to determine the first interaction point of the γ-ray within a detector segment and thus, try to enhance the effective granularity of the detector. For the analysis, we use the assumption that the main interaction within a segment, i.e. the main contribution to the pulse height, is identical to the first interaction. This assumption is always valid if the γ-ray is absorbed directly via a photoeffect interaction. But for energies greater than $200keV$ an absorption via a chain of Compton-scattering interactions terminated by a photoeffect interaction is common. In the case of small-angle scattering, the assumption is still quite good. For large-angle Compton scattering, in most cases the majority of the energy is deposited, or the mean free path of the scattered γ-ray is so small, that it will be totally absorbed nearby. The radial position of the main interaction is derived from the charge-collection time of the electrons measured from the core signal. The current signal of the core, i.e. the derivative of the charge signal, has its steepest slope at the time when all electrons are collected. We use this time as measure of the radial position

The azimuthal position of the main interaction within a segment is extracted from the amplitude of mirror charges induced in the two neighbouring segments. These mirror charges are only induced while the electrons and holes are moving in the segment of the main interaction. Mirror charges and net-charges result in very different pulse shapes. The net-charge pulse measured at the core has a rise time given by the collection time of the electrons and holes and a fall of $50\mu s$ given by the time constant of the preamplifier. The mirror charge signal has a maximum pulse height while electrons and holes of the net charge are moving and the signal returns to zero again when all net charges have been collected. Thus, it is rather easy to deconvolute the mirror charge signal and the net charge signal for the case of Compton scattering from one segment to its neighbour. The amplitude of the mirror charge signal depends as well from the distance of the main interaction from the separation to the neighbour as from the radial position of the main interaction. Mirror-charge signals are positive for interactions close to the core where mainly holes are moving and negative for interactions in the outer part of the detector where the net-charge signal is dominated by the collection of electrons. If we calculate the quantity $A = (Q_l - Q_r)/(Q_l + Q_r)$, where Q_l and Q_r are the amplitudes of the mirror charge signals in the left and in the right neighbour, respectively, the effect of the radial position cancels out to first order and A will depend only on the distance of the main interaction from the two neighbours. We will use the quantity A to determine the azimuthal position of the main interaction.

Fig. 7 shows an example of the pulse shapes measured at the core and at the six segments, respectively, for a selected interaction which was produced with a collimated ^{137}Cs source in segment 4. The signal from segment 4 has the same pulse height as the core signal, i.e the whole energy was deposited in segment 4. The neighbouring segments 3 and 5 show a positive mirror-charge signal, i.e. the main interaction occurred in segment 4 close to the core. The pulse height of the mirror charge in segment 3 is larger than in segment 5, i.e. the interaction in segment 4 occurred closer to its neighbour 3.

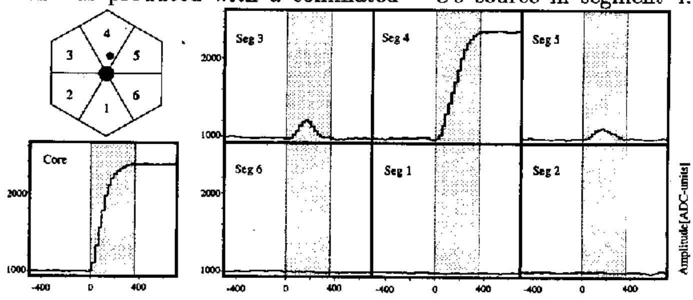

Figure 7: *Signals of the core and segments for an event fully absorbed in segment 4*

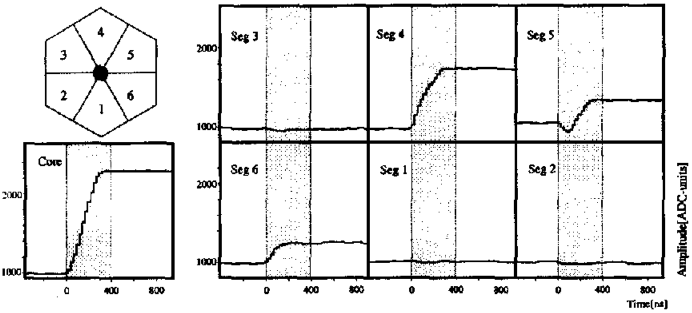

Figure 8: *Signals of the core and segments for an event scattered from segment 4 to segments 5 and 6*

Fig. 8 gives another example of a collimated γ-ray hitting segment 4 at a larger radius close to segment 5. The main part of the energy is deposited in segment 4, but also in segment 5 and segment 6 a net charge is detected. Obviously, this is a Compton-scattering event where the main part of the energy is deposited in the first interaction, then the γ-ray had a second Compton scattering in segment 5 and the remaining energy was absorbed in segment 6. A negative mirror charge is clearly visible in segment 5 and almost no mirror charge is detected in segment 3, i.e. the main interaction took place in segment 4 at a large radius close to the edge of segment 5. The two examples demonstrate the clear information contained in the pulse shape of the core and segment signals, and also the quality of the signals transferred by the preamplifiers and digitized by the XIA electronics. Many preamplifiers used so far with Ge detectors show an overshoot of the signal by a damped oscillation; this does not influence the energy resolution but it disturbs the proper interpretation of mirror-charge effects.

3.1 Response of the MINIBALL detector to a collimated γ-ray source

In the first experiment the position sensitivity of the MINIBALL detector was studied with a collimated ^{137}Cs source. The collimator was $10cm$ long with a diameter of 2 mm. The detector was scanned in two dimensions in steps of $2.5mm$ with the collimated γ-rays hitting the detector perpendicularly to its front surface. The collimation of the ^{137}Cs source reduced the count rate to $35 counts/s$, so the detector had to be shielded with low-level lead, to bring the count rate from the natural background down to $5 counts/s$. The digitized signals of the core and of the six segments were written to a magnetic disc for off-line analysis of the pulse shapes.

The right part of Fig. 9 shows the result of a radial scan with five positions of the collimator separated by 5 mm. For each position the number of counts is plotted versus the time to the steepest slope of the current signal measured at the core. The peaks for the five positions are clearly separated. The tails to longer charge collection times are probably due to regions of weak electric fields in the front part of the detector which is common for a semi-coaxial detector. The left part of Fig. 9 gives the results of a scan perpendicular to the middle radius of one segment for six points separated by 5 mm as indicated in the figure. The number of counts is plotted versus the asymmetry $A = (Q_l - Q_r)/(Q_l + Q_r)$ where Q_l and Q_r are the amplitudes of the mirror charge signals as detected in the left and the right neighbour segment, respectively. Again the peaks for the six positions can be well distinguished.

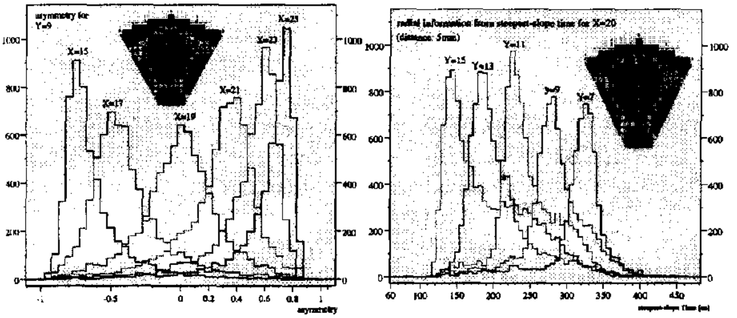

Figure 9: *The Asymmetry of the mirror charges (left) and the time of the steepest slope of the current pulse (right) for various collimator postions*

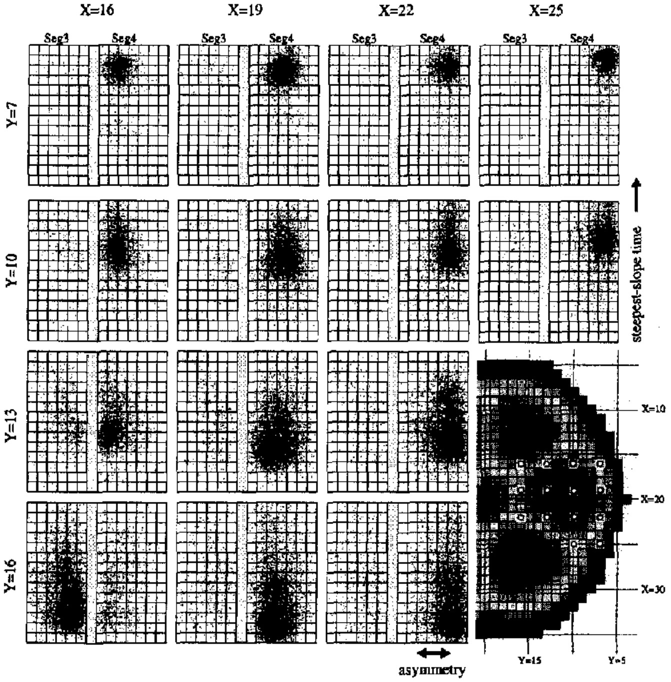

Figure 10: *2-dimensional position response of segment 3 and 4. The collimator positions (separated by 7.5mm) are indicated in the right lower corner.*

Fig. 10 summarizes the results of the 2-dimensional scan. For each of the 14 collimator positions, indicated in the figure, the time to the steepest slope of the core-current pulse is plotted vs. the asymmetry A, extracted from the mirror charges detected in the neighbouring segments. For each position the matrices of the central segment and its left neighbour are given. From a survey of all results we conclude that one can distinguish between 16 positions in one segment. Thus, the effective granularity of one MINIBALL detector is enhanced from 6 due to segmentation to $6 \times 16 \approx 100$ by the additional pulse analysis. The effective granularity of the MINIBALL array with 40 detectors will be $\approx$ 4000, compared to a granularity of 150 – 240 for GAMMASPHERE or EUROBALL. These results validate the concept of the MINIBALL array which aims at a high detection efficiency by operating a limited number of Ge detectors close to the target and at a high effective granularity needed for Doppler correction by using position-sensitive Ge detectors.

3.2 Doppler correction of in-beam data measured with the MINIBALL-Cluster detector

The performance of the MINIBALL-Cluster detector was studied in an in-beam experiment at the Cologne tandem accelerator. A ^{37}Cl beam of $70MeV$ in a deuteron target induced the reactions $D(^{37}Cl,p)^{38}Cl$ and $D(^{37}Cl,n)^{38}Ar$. The target consisted of a deuterated Ti-foil of $200\mu g/cm^2$ thickness with a Cu backing of $200\mu g/cm^2$ thickness. The reaction was chosen because this type of pickup reaction with inverse kinematics will be used at REX-ISOLDE to study the single-particle properties of exotic nuclei with radioactive beams. On the other hand, the high recoil of $v/c = 5.6\%$ of the reaction products are a crucial test for the Doppler-correction capability of the MINIBALL detector.

A MINIBALL-Cluster detector was positioned at 90^o with respect to the beam axis at a distance of $11cm$ from the target. For each γ-ray interaction in one MINIBALL detector the digitized signal of the core and the 6 segments were stored in list-mode for later off-line analysis. A second standard Ge detector was positioned at 165^o with respect to the beam axis at a greater distance of $30cm$. As the direction of the emitted reaction products was not measured, the γ line shape in the MINIBALL detector was effected by two contributions, namely the Doppler broadening due to the effective solid angle of detection and the angular spread of the recoiling nuclei. Due to the large distance to the target the effect of the solid angle for detection could be neglected for the monitor detector. Thus, the monitor detector could be used to measure the contribution to the line shape due to the kinematics of the reaction.

Table 2: Specifications of MINIBALL for different setups. Resolutions of $1MeV$ γ-rays are given for different recoil velocities and detection angles.

	coverage	No. of detectors	distance to target	P_{Ph}	FWHM @5% c		FWHM @15% c	
					at 90°	at 30°	at 90°	at 30°
Phase I	2π	18	$13.5cm$	5.1%	$3.1keV$	$2.3keV$	$7.3keV$	$4.6keV$
	4π	18	$9.5cm$	10.3%	$3.9keV$	$2.6keV$	$10.1keV$	$6.2keV$
Phase II	2π	40	$18.5cm$	6.4%	$2.7keV$	$2.2keV$	$5.6keV$	$3.7keV$
	4π	40	$11.5cm$	16.5%	$3.4keV$	$2.4keV$	$8.6keV$	$5.3keV$

Fig. 11 shows the line shape of the $2167keV$-transition in ^{38}Ar: Without using any position information the half width of the line is $35keV$. The narrow peak on top of the broad line results from the population of the $2167keV$-level of ^{38}Ar in the β-decay of ^{38}Cl produced in the same reaction. This peak has the original resolution of the detector and is not broadened by Doppler effects. Using for Doppler correction the angle of the segment where the main interaction was detected results in the spectrum with the resolution of $14keV$. Applying, in addition, the information from the pulse-shape analysis for the Doppler corrections improves the resolution to $10.2keV$. We found during the analysis that a division of one segment into up to 16 pixels improves the resolution, which in a way is consistent with the result extracted from the scan with the collimated ^{137}Cs source.

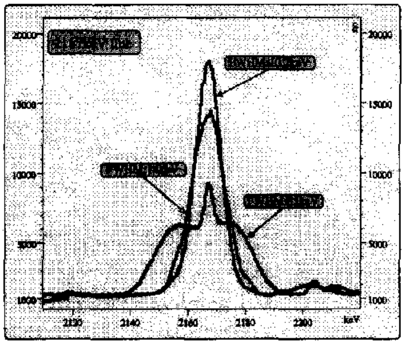

Figure 11: *Shape of the 2167keV line before and after Doppler correction (see text).*

As mentioned above, this final in-beam result is effected by the angular spread of the recoiling nuclei as by the effective solid angle of detection in the MINIBALL detector. The contribution of the kinematics of the reaction measured with the monitor detector was found to be $7.8keV$; a Monte Carlo simulation of the kinematics predicts a contribution of $7.5keV$ in good agreement with the experimental result. The measured energy resolution is given by the contribution of the detector, the kinematics of the reaction and the effective angle of detection: $\Delta E_{measured}{}^2 = \Delta E_{detector}{}^2 + \Delta E_{kinematics}{}^2 + \Delta E_{\Delta\Theta}{}^2$. Using this relation we extract a value for the contribution of the detection angle $\Delta E_{\Delta\Theta} = 6.2keV$, which corresponds to an effective detection angle of $\Delta\Theta = 2.9^o$.

4 Specifications of MINIBALL

The experiments described in chapter 3 enable us to compile the specifications of the MINIBALL array for the first time from experimental data. Table 2 gives the total-absorption efficiencies for different geometries and numbers of detectors. The expected energy resolution after Doppler correction for $E_\gamma = 1MeV$ is calculated for detection angles of 30° and 90° and recoil velocities of 5% and 15% of the velocity of light. In the experiments planned at REX-ISOLDE the recoil velocities will be in the region of $3 - 5\%$ c. Under these experimental conditions the average energy resolution of MINIBALL at $E_\gamma = 1MeV$ is expected to be $\Delta E = 2.5 - 2.7keV$ which is close to the intrinsic resolution of the Ge detector and which demonstrates the gain in resolution by the high effective granularity of MINIBALL. MINIBALL Phase I with 18 detectors will be ready for experiments by the end of 2000; commissioning of the final components has been started at the Cologne tandem accelerator. The full set of 40 detectors for Phase II will be available by the end of 2001.

5 Conclusion

The development of MINIBALL started in 1995 just after the experimental campaigns with six EUROBALL- Cluster detectors at MPI-K Heidelberg and GSI which convincingly demonstrated the power of an highly efficient, compact γ-ray array. Major developments in Ge detector technology, cryostats, pulse-processing electronics and mechanical construction had to be performed in order to achieve the specifications of MINIBALL as presented. Especially the results of the pulse-shape analysis are much better than estimated in the beginning. This fact gives a more optimistic view of the feasibility of a γ-ray tracking array for the next generation of high-spin spectrometers. The position resolution of the MINIBALL detectors is limited due to missing segmentation in depth. Recently, we received a 12-fold segmented, encapsulated detector which is shown together with its specifications in Fig. 12. It has the same geometry as the MINIBALL detector with the difference that the first third of the detector is separated by segmentation from true coaxial part. Experiments have been started to investigate the improvement in position resolution by the additional segmentation. This detector uses a new technology for the segment contacts which is suited to encapsulate highly-segmented detectors. The Berkeley group has shown recently [5] that a position sensitivity of less than 1 mm can be achieved with a 36-fold segmented detector in a standard cryostat. However, the feasibility of γ-ray tracking has still to be demonstrated experimentally and further effort in Ge detector technology, pulse-processing electronics and real-time computing power is needed until a γ-ray tracking array can be realized.

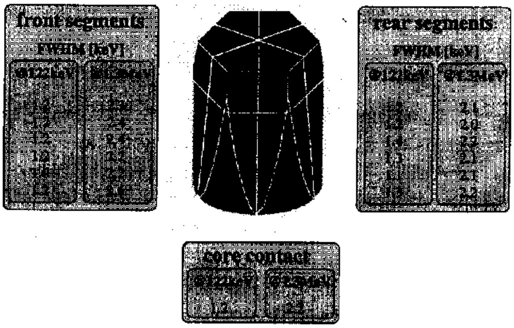

Figure 12: *The 12-fold segmented, encapsulated detector*

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