

11. Additional detectors for EUROBALL

11.1. DIAMANT-III: the upgraded 4π light charged-particle detector array^{*}

Abstract

Diamant-III is an upgraded version of the ancillary detector developed in CENBG, Bordeaux, for use in large gamma-ray spectrometers to identify the light charged particles emitted in heavy-ion induced reactions. It has 84 CsI(Tl) detectors, with improved light collection, which are equipped with preamplifiers working in vacuum. The processing of signals coming from the particle detectors is performed now entirely by VXI electronics. The newly designed VXI card is fully compatible with the existing signal processing system of Euroball. For each detector three types of signals are derived: the energy and the type of the particle, and a time-reference signal related to the time instance of the particle–gamma coincidence. For deriving the particle type information the zero-crossing method, the ballistic deficit method or the combination of these two, giving the best figure of merit for the particle discrimination, can be used. Data readout is managed using the G.I.R general-purpose readout interface card developed in CSNSM, Orsay. Typical result from experiments with the Euroball IV are used to illustrate the performance of the new ensemble.

The DIAMANT array [6], serving as an ancillary detector in large gamma-ray spectrometers like EUROGAM [3] and EUROBALL [1], has recently been upgraded within a Bordeaux-Debrecen-Napoli collaboration. This system, having detectors made of CsI(Tl) scintillation crystals coupled to *pin*-photodiodes by 5 mm plexiglass light guide, is used to identify light charged particles. The detectors are arranged in a polyhedron geometry made of 18 square and 8 triangle planes which are formed by single triangle detectors (with 10mm thick light guide) and sets of 4 square detectors with maximum dimension of $14.5 \times 14.5 \text{ mm}^2$. The distance of the square planes from the target is 32 mm, except the one in forward direction, which is replaced by a plane of 8 detectors arranged as a 3×3 array at a distance of 49 mm. The 3 mm thick detectors, able to fully

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stop protons up-to an energy of about 25 MeV, have over 70% light-collection efficiency due to our newly developed special wrapping technique.

The CsI detectors are equipped with special charge-sensitive preamplifiers [306] of low heat dissipation. They are mounted on the detectors inside the vacuum chamber. The signals from these *first-stage* preamplifiers are connected by flat ribbon cables, via vacuum feed-through, to a set of *second-stage* preamplifiers, which are used as line-drivers to send the signals through coaxial cables to the signal processing electronics.

The signal processing of DIAMANT is now done by new VXI electronics [307]. The D-size VXI card, developed in Debrecen, contains eight complete electronic channels, each of which produces three signals: energy, particle type and time reference. To reach full compatibility with the EUROBALL electronics, and to further improve the performance of DIAMANT, some new techniques have been used for signal processing. The *energy* signal is produced by a *delay-switched gated integrator* [308,309]. The integration time is adjustable from the software (3-12 μ s), and it determines the signal processing time. The *time reference* for particle–gamma coincidence is derived by *non-delay-line* CFD-s [307,310] using a 600ns time window. The *particle-type* information is obtained using two pulse shape discrimination techniques: the *ballistic deficit method* [309,311] and the *zero-crossing method* [312]. Any of these or a combination of them, the *mixed method*, can be selected. The latter one gives the best figure of merit for α –proton discrimination. Although CsI detectors are slow relative to the Ge detectors, signal rise-times are 1600-2000 ns (for charged particles) and 100-200 ns, respectively, with these new solutions the readout electronics of the particle-detector array can complete the data treatment within the same time necessary for the Ge detectors, while both good *energy resolution* and *particle separation* is achieved. The short integration time enables particle detection up-to high count rates. Pile-up events are marked during data collection. The card generates also a *sumbus* signal in each channel if a particle is detected, so particle multiplicity can also be derived. For the coding of the *energy*, *particle type* and *time reference* signals three independent ADCs of the same type as used for the Ge detectors are applied. Data readout is managed using the G.I.R general-purpose readout interface card developed in CSNSM, Orsay [313].

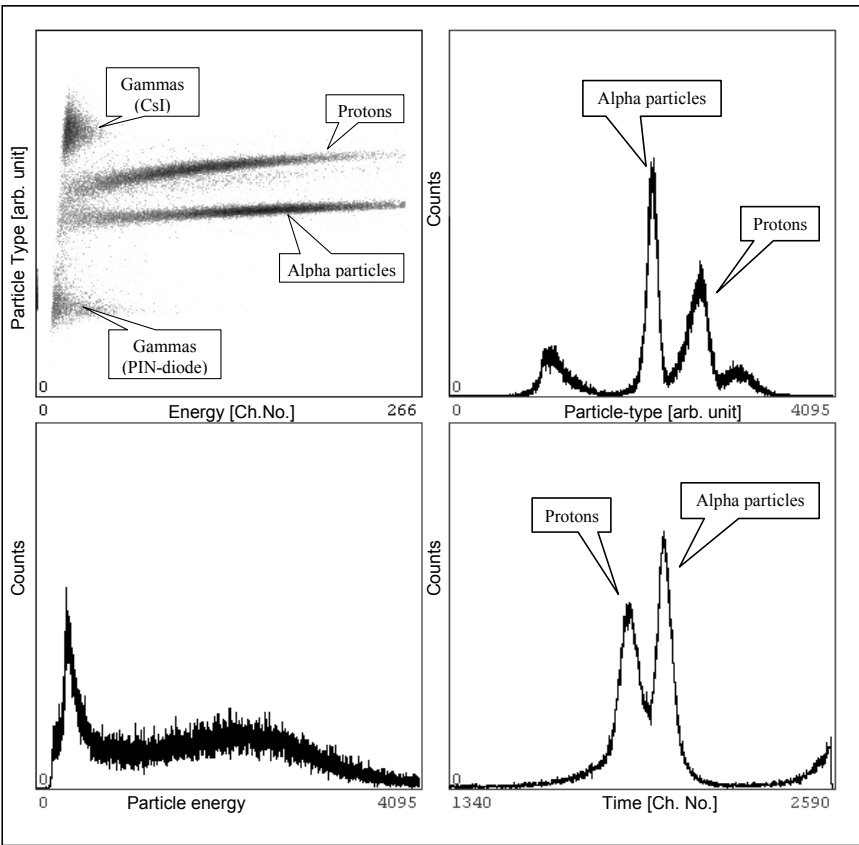


Figure 11.1: Illustrative spectra obtained for a DIAMANT CsI detector using VXI electronics: **(a)** Particle type vs. energy plot generated from correlated events shown in panels (b) and (c), respectively, after compressing these by factors of 16. The labels indicate the type of particles. **(b)** Original Particle-type and **(c)** Energy spectrum, including detected particles and gammas. **(d)** A 600 ns wide window of the Time reference spectrum.

The VXI cards are integrated into the VXI environment [301] of EUROBALL. For the synchronisation of data processing two global trigger signals, the *Fast Trigger* (FT) and the *Validation* (VAL) generated by the Master Trigger Unit are used. On each channel a Local Trigger (LT) controls, if the signal from the CsI detector is in coincidence with a delayed FT signal. If so, the channel is involved in a particle-gamma coincidence. Data readout occurs only, if a validation signal arrives. LT can operate in slave, test or master mode, the last two mainly useful for test or stand-alone operation. The set-up and control of the VXI cards are managed using a special user interface of the MIDAS software [303].

In nuclear structure studies, data acquisition with DIAMANT can be maintained in two main operating modes: when DIAMANT alone is involved in the *validation*, or when DIAMANT is also involved in the *validation*, in which case

either the Ge array or the CsI array can validate an event. In the first case only (HI, particle-xn) channels, in the second one both (HI, particle-xn) channels and (HI, xn) channels are collected.

The measured performance of the present version is as follows: The typical energy resolution at 5 MeV measured with an alpha-source is 2%, the low-energy thresholds for proton-alpha discrimination is around 2 MeV (proton) and 4 MeV (alpha). The array's gamma absorption is to be considered only if detection of gammas below 200 keV is important (see Ref. [314]). The overall time resolution for particles has improved from 70ns to 20ns (without any correction). The measured efficiency for detecting one proton is ~70%. The presence of the CsI array does practically not affect the peak-to-total ratio of the Ge detectors, with a typical value of 0.55 for a ^{137}Cs source.

The type and quality of data, which can be obtained with DIAMANT after the upgrade, are illustrated in Figure 11.1. Putting 2-dimensional gates on spectra like the one shown in Figure 11.1a, very good enhancement can be achieved in selecting gamma-rays related to reaction channels with particle emission. Some illustrative spectra can also be seen in our contribution (B.M. Nyakó et al., A step forward in...) to the EUROBALL Booklet on the Euroball workshop held in Orsay, March 2002. With different combinations of gates put on *Time-reference vs. Energy*, *Time-reference vs. Particle-type* and/or just on the *time reference* data alone, a further cleaning of the random events is possible.

Acknowledgements

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11.2. The EUCLIDES array^{*}

Array description

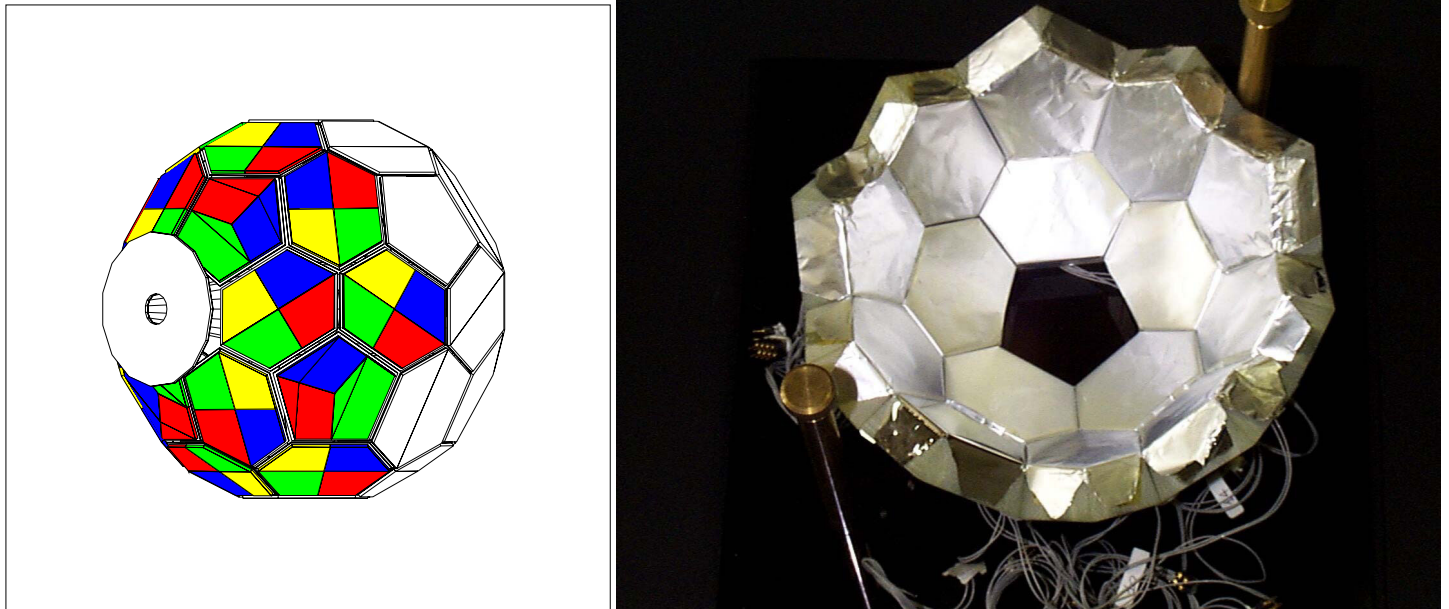


Figure 11.2 (Left panel): Schematic design of the EUCLIDES detector array from the GEANT3 Monte-Carlo simulations. **(Right panel):** The first two rings of EUCLIDES with the UPILEX and aluminium protection in front of the ΔE detector.

The EUCLIDES array is a charged-particle detector array developed and built within a collaboration of the INFN laboratories in Legnaro, Padova and Firenze as well as the University of Liverpool and the Daresbury laboratory. EUCLIDES is composed of 40 ΔE -E Si telescopes ($130\text{ }\mu\text{m} + 1000\text{ }\mu\text{m}$ thick) arranged in the same geometry as the ISIS Si-ball [4] (see Figure 11.2).

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The five forward elements are electrically segmented in four parts and there are plans to segment the following ten elements in two parts. The ΔE detector is mounted in a reversed configuration, enabling charged particle discrimination with pulse shape techniques [315]. The front-end electronics is composed of charge-sensitive preamplifiers and of specially designed single-unit CAMAC modules, called Silicon Shaper Analyser, which provide linear (gaussian and stretched) and logic (fast timing and crossover timing for pulse shape analysis) outputs. Data are collected through FERA ADCs and TDCs and sent to the EUROBALL data acquisition via the Fera-VXI interface.

Status

At the beginning of its operation, EUCLIDES suffered from various problems. Part of these problems is related to a faulty detector design, which has been solved by the manufacturer (Micron Semiconductors Ltd). Most of the faulty telescopes have been replaced, however this slowed down the production of segmented detectors and at the time of writing only the five forward telescopes on the array are segmented. Also the front-end electronics suffered from various bugs which took quite a long time to fix. This precluded the required development work on the pulse shape part, which remains the major missed goal of the project. The performance of EUCLIDES as a standard ΔE -E array is very satisfactory. The discrimination capability is excellent, since less than 0.01% of the detected particles are misidentified. The detection efficiency depends strongly on the reaction and on the absorbers used to stop the scattered beam ions; values of $\epsilon \sim 60\%$ for protons and $\epsilon \sim 40\%$ for α particles can be obtained.

EUROBALL experiments

EUCLIDES has been used in 24 experiments (including three commissioning runs), for a total of 141 days of beam time, in a stand-alone configuration or together with other ancillary devices:

stand-alone: 1 experiment, 5 days

Neutron Wall: 1 commissioning run, 10 experiments, 69 days

Neutron Wall + Isomer tagging: 2 experiments, 16 days

Köln plunger device: 1 commissioning run, 2 experiments, 16 days

INNER BALL: 1 commissioning run, 4 experiments, 23 days

HECTOR + INNER BALL: 1 experiment, 6 days

RFD : 1 experiment, 6 days

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11.3. The HECTOR array^{*}

Abstract

The large volume BaF₂ detectors of the HECTOR array have been used in one measurement on ¹⁴³Eu made in the Legnaro (see references [95,134]) and more recently during spring 2002 in 3 measurements at Strasbourg. At variance from the Legnaro measurement, in Strasbourg also 3/4 of the INNER BALL was present and for one measurement also the Silicon ball EUCLIDES has been used to measure charged particles. Here below we give more details on the Strasbourg measurements whose data are presently being analysed.

EUROBALL experiments in Strasbourg with HECTOR

The part of the HECTOR array [11] used in the Strasbourg measurement consisted of 8 large volume BaF₂ detectors and 4 small BaF₂ detectors. These detectors were incorporated into the EUROBALL array, in order to measure the high-energy gamma rays from the decay of Giant Dipole resonance in coincidence with discrete lines from the residual nuclei. The large volume BaF₂ detectors were mounted in the forward hemisphere replacing the Phasel detectors (detectors with green housing in Figure 11.3). As the forward part of the EUROBALL INNER BALL (consisting of BGO

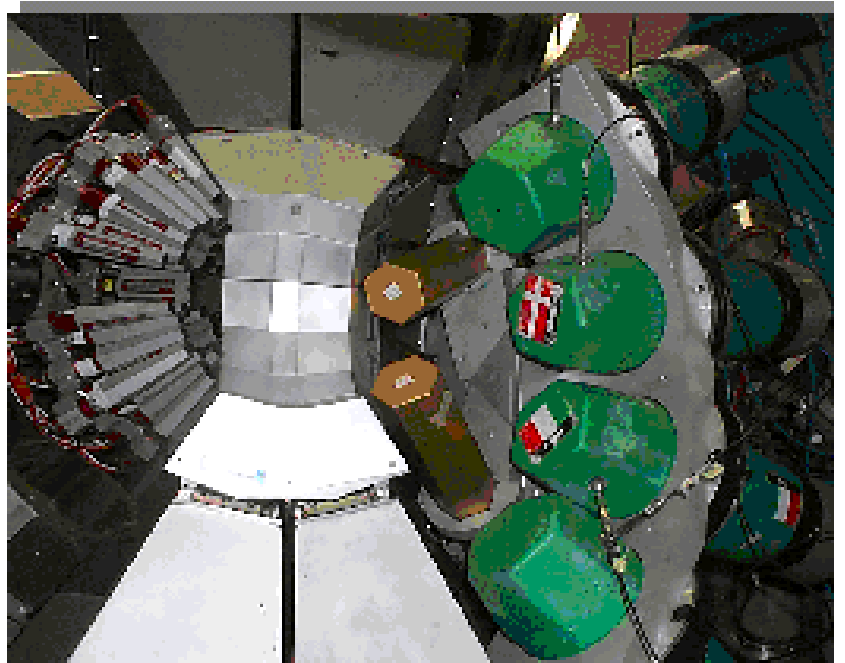
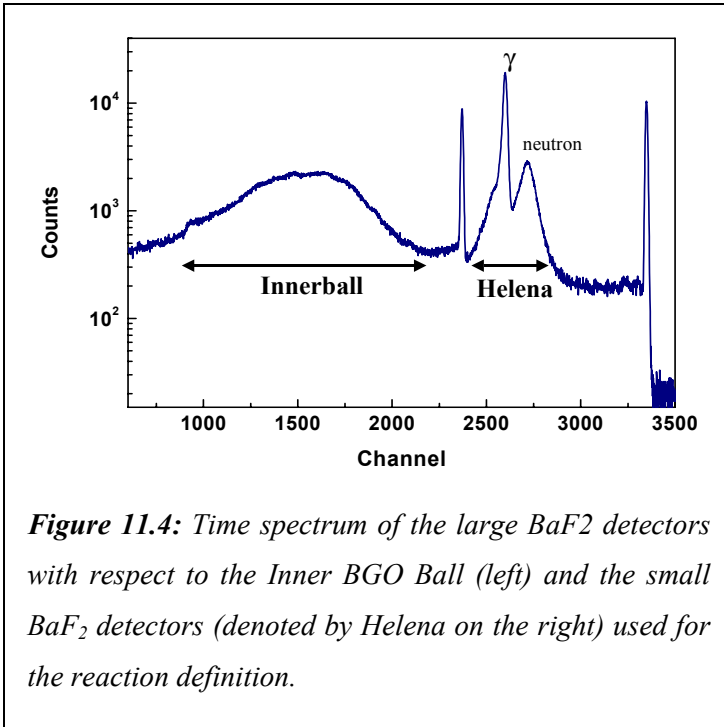


Figure 11.3: *The HECTOR experimental setup at Strasbourg.*

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crystals) had to be also removed, there was room to place very close to the reaction chamber, 4 small BaF₂ crystals from HECTOR's multiplicity filter (detectors with yellow housing in Figure 11.3). They were used to obtain the reaction time definition. Figure 11.4 shows the time spectrum of the large BaF₂ detector with respect to the EUROBALL INNER BALL (left part) and the small BaF₂ crystals (appearing on the right part of the figure and denoted by Helena). The time resolution when the BaF₂ detectors fired was 1.6 ns, allowing, as can be seen in the figure, for clean separation between gamma and neutron induced events. In contrast, when the time was defined by the Inner Ball it produced a distribution with a width of 35 ns which did not allowed for gamma-neutron separation.



Therefore, in the performed experiments the inner ball was used only as the multiplicity filter, while the reaction time was defined by the 4 small BaF₂ Helena detectors for all the events in which a high energy gamma-ray was detected.

The HECTOR electronics consisted of standard NIM modules and VME ADC and TDC (from CAEN). The coupling of the VME electronics to the VXI electronics of EUROBALL ACQ system was made using the ATTIC module from the Neutron Wall system. In the experiment in which the array of Si telescopes (EUCLIDES) was used, the coupling of its electronics was done via the FVI module.

The three performed experiments were intended to address three different physical issues. One was that of the investigation of the gamma decay of the giant dipole

resonance in the feeding of superdeformed structures and this experiment concerned the ¹⁹⁶Pb nucleus. An experiment aiming at searching for hyperdeformed structures in ¹²⁶Ba was made and there the gating with high energy gamma-rays could help in this search.

The other very interesting problem addressed in the third experiment is that of the identification of the expected Jacobi transition of nuclear shapes (namely that from oblate to very extended prolate occurring in rotating objects at very high rotational frequency). The performed experiment focused in particular on the ^{46}Ti nucleus for which such a transition is expected to be at $I \approx 30\hbar$ and used a 100 MeV ^{18}O beam impinging on a ^{28}Si target. The main experimental signature of this Jacobi shape change phenomenon is expected to be the large splitting of the GDR components corresponding to vibrations along the different symmetry axes. Indications of such feature in the GDR spectra in this mass region were earlier obtained both by the Seattle group [316] and by the HECTOR group [317]. However these experiments were not exclusive enough to exclude other possible explanations as for example contaminations from fission. In contrast, the GDR spectra measured by HECTOR in coincidence with the discrete lines of specific residual nuclei, measured in the germanium detectors of EUROBALL, correspond uniquely to the fusion-evaporation channel. Other indications of the Jacobi transition are the expected Giant Backbend of the E2 transitions [318] and the change of the angular distribution of the evaporated charged particles, quantities that can be simultaneously studied in the present measurement because of the presence of the EUROBALL clusters detectors and of the EUCLIDES array, respectively.

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11.4. The Internal Conversion Electron Mini-Orange Spectrometer (ICEMOS) ^{*}

Gamma-ray spectroscopy is the most powerful tool to study the structure of excited states in nuclei. But in some cases the information that is available through γ -ray detection alone is too limited in order to investigate important nuclear structure aspects. One example are electric-monopole (E0) transitions, which can not proceed via the emission of (single) γ rays, but proceed instead by internal conversion, i.e. the emission of electrons from (inner) atomic shells. Pure γ -ray spectroscopy must then be replaced by electron-gamma coincidence spectroscopy. A second important aspect of conversion-electron spectroscopy is the possibility to determine the electro-magnetic multipolarity of the emitted radiation via measurements of conversion coefficients. This method is complementary to the combined measurement of γ -ray angular distributions (sensitive to the multipole order) and of the linear polarisation (sensitive to the electromagnetic character, E or M). Finally, in heavy nuclei and/or for higher multipolarities where the conversion probabilities is large, conversion-electron spectroscopy may be the only way to identify the transitions.

In-beam conversion-electron detection is severely impaired by the atomic background of low- energy δ electrons, which are created with extremely high cross sections in heavy-ion induced reactions. In our approach, Mini-Orange spectrometers [319] are used to suppress most of this background. They consist of wedges of permanent magnets arranged to create a thoroidal field focusing electrons of a given energy on a detector placed at the focal point of this magnetic lens (see figure 11.5). Different from a large (iron-free) Orange spectrometer the radial and azimuthal variation of the magnetic field strength gives rise to a certain range of electron momenta that are transported to the detector (“transmission window”). A liquid-nitrogen cooled Si(Li) detector (of up to 6 mm thickness) measures the electron energy with high resolution. The setup is very compact and can be installed inside the scattering chamber of a large γ -ray spectrometer.

The transmission window of the Mini-Orange spectrometers can be adjusted through the number of magnets, their strength and by the distances between target, magnets and detector. Depending on the experimental conditions the peak position and

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width of the transmission curve can be changed. For a peak efficiency of $\sim 5\%$ at electron energies of ~ 600 keV the width is typically a few hundred keV. The Si(Li) detectors are located in their own vacuum chamber behind the Mini Oranges and are separated from the vacuum of the beam line by (thin) Carbon or Mylar foils, in order to protect their surfaces from

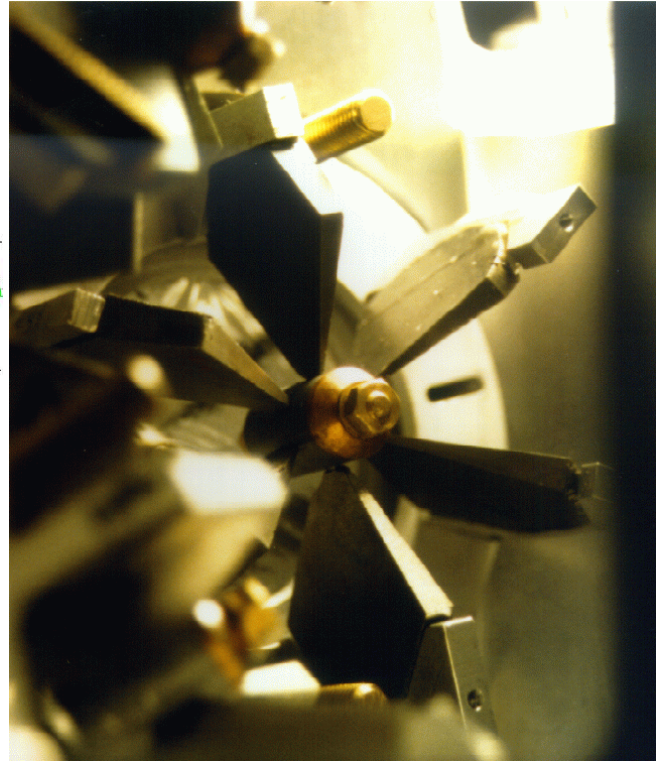
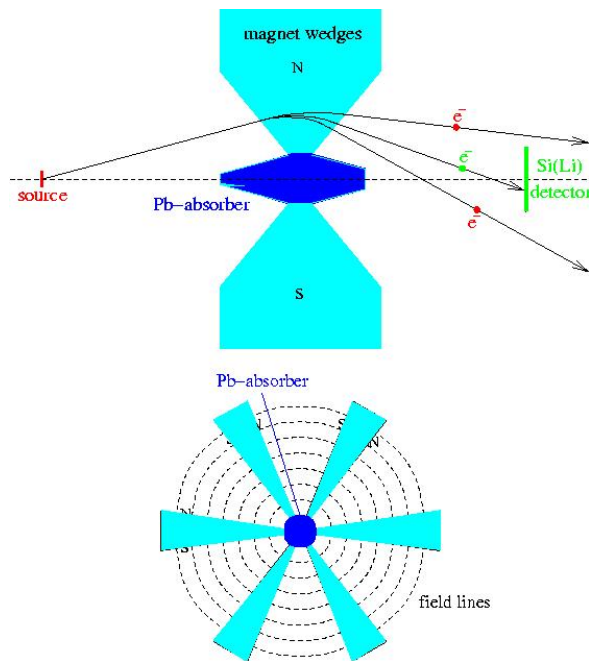


Figure 11.5: Principle (left) and picture (right) of a Mini-Orange spectrometer. Electrons emitted within the solid angle covered by an array of permanent magnets are deflected in the thoroidal field and focused on a large area Si(Li) detector. The transmission window can be adjusted by the field strength and by the geometrical arrangement of the source, magnets and detectors. A lead absorber paced in between the source and the detector excludes its direct illumination.

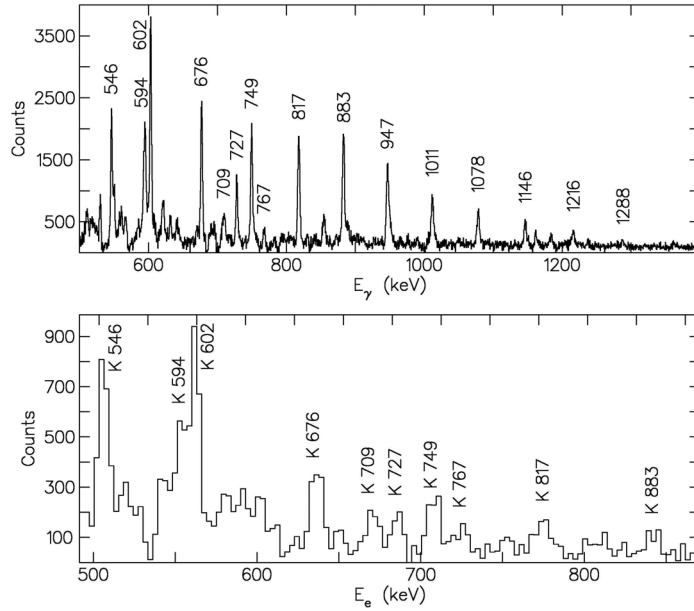


Figure 11.6: Spectra from the gamma-ray (upper part) and conversion electron (lower part) decay of ^{135}Nd . Both spectra are single gated on transitions in the highly deformed band in that nucleus. Besides the regularly spaced E2 transitions within the band, some of the transitions linking the band to lower lying states are also observed.

spectrometer has been very successfully used in combination with several smaller Ge detector arrays. A typical in-beam spectrum from a heavy-ion reaction taken in coincidence with γ -rays from ^{135}Nd is shown in figure 11.6 and demonstrates the feasibility of the technique. In this pre-EUROBALL experiment at the MPI Heidelberg four Cluster detectors were used at a rather small distance to the target. From this experiment the spin and parities of the yrast SD band in ^{135}Nd could be determined [320].

contamination. The thin foil further reduces the remaining δ -electron background, especially for the very lowest energies.

Experiments to obtain spectroscopic information from *electron-gamma coincidence spectroscopy* are best done by having large, comparable efficiencies for both conversion-electron and gamma-ray detection. By replacing the forward EUROBALL sector of individual Ge detectors with a Three-Mini-Orange conversion-electron spectrometer, an efficiency of $\sim 5\%$ for electrons (in the peak of the transmission curve) can be reached, similar to the γ -ray photo-peak efficiency (at 1.3 MeV) of the remaining Clover and Cluster detectors. Experiments with ICEMOS at EUROBALL allow for the first time electron- γ coincidence spectroscopy of weakly populated nuclei.

Before being used at EUROBALL the ICEMOS

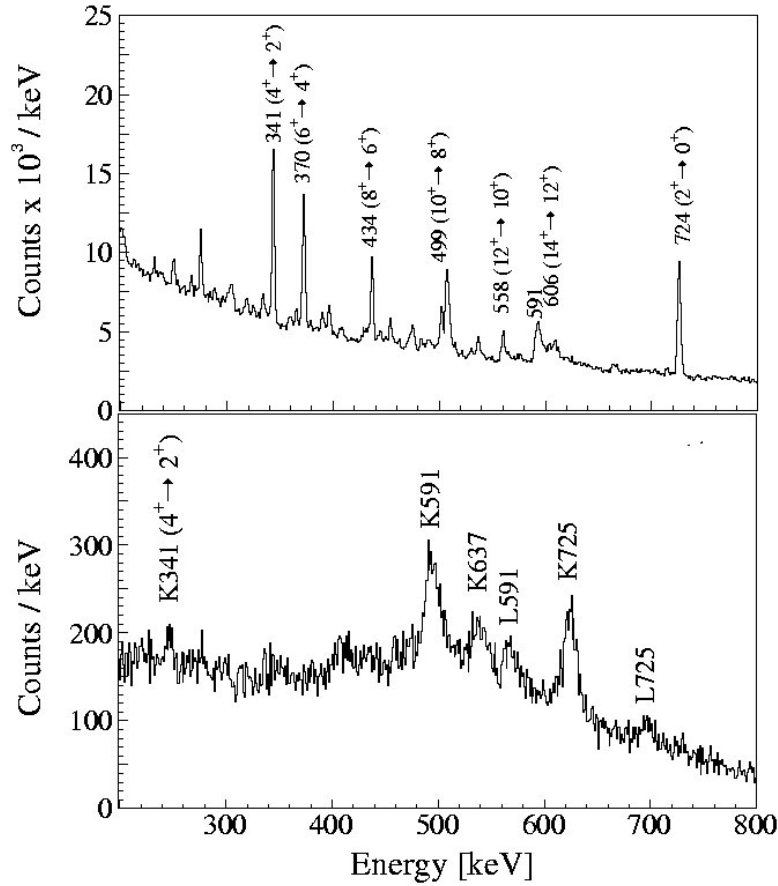


Figure 11.7: Gamma-ray (upper part) and conversion-electron (lower part) decay in ^{188}Pb ; both spectra are singles spectra, but gated on the detection of a fusion-evaporation residue in the RITU gas-filled separator, discriminating against the strong fission background. The strong lines in the CE spectrum labelled K591 and K725 correspond to E0 transitions of excited 0^+ states at these energies and are interpreted as evidence for a triple shape coexistence in that nucleus.

consisting of four segmented Clover detectors coupled to the gas-filled separator RITU. In order to maximise the gamma efficiency the Ge detectors were placed again at a relatively small distance to the target. In figure 11.7 the result from an experiment on ^{188}Pb are shown; in the electron spectra E0 decays from two new 0^+ states were observed giving evidence for a unique triple shape coexistence in this isotope [321]. In this case the production cross section is too small to measure CE- γ coincidences. This type of spectroscopy will clearly benefit from a larger Ge detector array.

In the first experimental campaign at EUROBALL we have tried to search for an E0 competition in the decay out of superdeformed bands. Unfortunately, these experiments were not successful, mainly due to experimental problems related to the electronics and DAQ system. An additional complication arose from the mounting of the Mini-Oranges at forward angles, where the δ -electron background is higher and due to scattering of the beam halo into our detectors. In the future we plan to repeat these very interesting but extremely difficult experiments with Ge detectors from the pool of EUROBALL resources.

11.5. The EUROBALL Neutron Wall detector^{*}

The EUROBALL Neutron Wall detector array [7] is designed, built and managed by groups from Sweden, Germany, UK, and Poland. It is mounted in the forward hemisphere of EUROBALL, replacing the tapered Ge spectrometers and covering a solid angle of about 1π (see Figure 11.8).

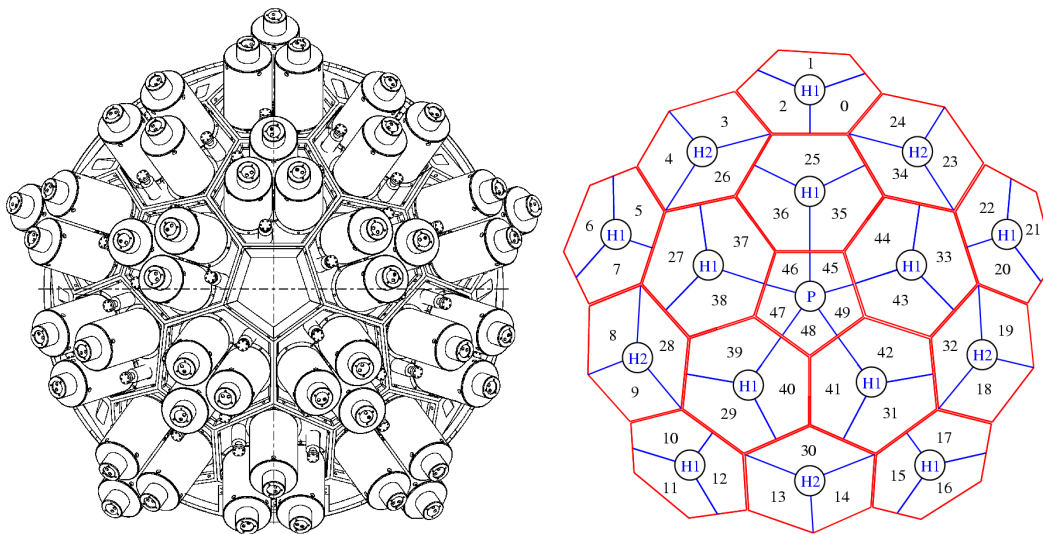


Figure 11.8: The Neutron Wall detector array as viewed from the downstream side of Euroball. The central pentagonal detector is not included in the figure on the left. The detector numbering is shown on the right side.

The array consists of 15 pseudo-hexagonal detector units in three rings and a central pentagonal unit. Each hexagonal unit is subdivided into three hermetically separated segments, each viewed by a 130 mm diameter PMT (Philips XP4512PA). The subdivision is made in two ways, giving two types of hexagonal detector units (H1 and H2), each with a volume of 9.70

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litres. The central pentagonal unit (P) has a volume of 5.37 liter and is subdivided into five hermetically separated segments, each viewed by a 75 mm diameter PMT (Philips XP4313B). This amounts to a total granularity of 50 segments and a total volume of 151 liters. The scintillation liquid used is BC501A. The distance from the focal point to the front face of the detectors is 510 mm.

Integrated front-end electronics has been designed and built for the NEUTRON WALL by SINS, Swierk, Poland. It consists of hardware for pulse shape analysis of the anode signals from the PMT's, and was implemented as a dual channel pulse-shape discriminator (PSD) unit built in NIM. Each PSD channel has a CFD, a bipolar shaping amplifier with a zero-crossover (ZCO) detector, two time-to-amplitude converters (TAC), and a charge-to-voltage Converter (QVC).

Neutron- γ discrimination is made by using a combination of the ZCO time signal and the difference in measured time of flight of neutrons and γ rays. Neutrons interact in the detectors mainly by elastic scattering against the protons of the scintillation liquid. When the recoiling protons are slowed down in the liquid, they give rise to a larger proportion of the slow component of the scintillation light than the recoiling electrons, which are produced by γ -ray interactions. This gives rise to a difference in the pulse shape of the anode signal, a difference which is observed as a delayed ZCO time signal for neutrons interacting in the detector compared to γ rays. In the Neutron Wall set up, neutron- γ discrimination works very well down to a recoil electron energy of at least 100 keV, which corresponds to a neutron energy of about 0.5 MeV.

One of the TAC units of the PSD is used for time of flight (TOF) measurements. It is started by the internal CFD signal and stopped by an external time reference signal. The other TAC unit is started by the internal ZCO signal and stopped either by the internal CFD (usual mode of operation) or by the external time reference signal. The charge of the anode signal from the PMT is integrated in the QVC, to give a signal whose amplitude is proportional to the energy deposited in the detector. The outputs of the two TAC units (TOF, ZCO) and of the QVC unit are sent to peak sensitive ADC for digitisation and readout.

The external time reference signal, needed for the TOF measurement, is usually made as a precisely time aligned OR of all the Neutron Wall CFD signals (self-timing mode), or taken from the RF system of a pulsed beam.

Logic neutron and γ -ray signals are produced in the PSD units from the time information of the ZCO signal. These logic signals indicate if a neutron or a γ ray was detected. The neutron logic signals from all neutron detectors are OR-ed together and sent to the EUROBALL trigger system, which then can select events for readout in which at least one neutron was detected.

A completely new VME based readout system was built for the Neutron Wall. It consists of five 32 channel peak sensitive ADCs (Caen V785), a trigger and control unit (ATTIC), a VME to DT32 bus interface and readout card (V2DT), all controlled by a PowerPC (Motorola MVME2431) running LynxOS. The ATTIC and V2DT cards, as well as the software for control and readout, were developed by Daresbury Laboratory. The Neutron Wall readout system has been used also by other ancillary detectors of EUROBALL, e.g. RFD and HECTOR.

An example of the excellent neutron- γ separation achieved is shown in Figure 11.9. The data shown was obtained during the Neutron Wall commissioning run, performed at the IReS, Strasbourg in February 2001. The reaction used in this experiment was ^{58}Ni (220 MeV) + ^{56}Fe . The time reference for the TOF measurement in Figure 11.9 was the RF signal of the pulsed beam (pulsing frequency 3 MHz). The resolution of the prompt γ -ray time peak in Figure 11.9 is FWHM = 5.3 ns. Using the self-timing mode, i.e. the OR of the Neutron Wall CFD signals as time reference, a time resolution of FWHM \sim 2 ns is obtained. The disadvantage of using the CFD OR signal as a time reference is however that, for events where no prompt γ rays are detected, usually a neutron produces the time reference signal. In such events the neutron TOF signal cannot be used for neutron- γ discrimination, which then only relies on the ZCO signal and leads to a somewhat reduced discrimination.

The measured total neutron efficiency, i.e. the probability of detecting and identifying one neutron out of one emitted, in coincidence with γ rays detected by the Ge spectrometers of EUROBALL, is \sim 25-30% for symmetric reactions with compound nuclei in the A \sim 100 region.

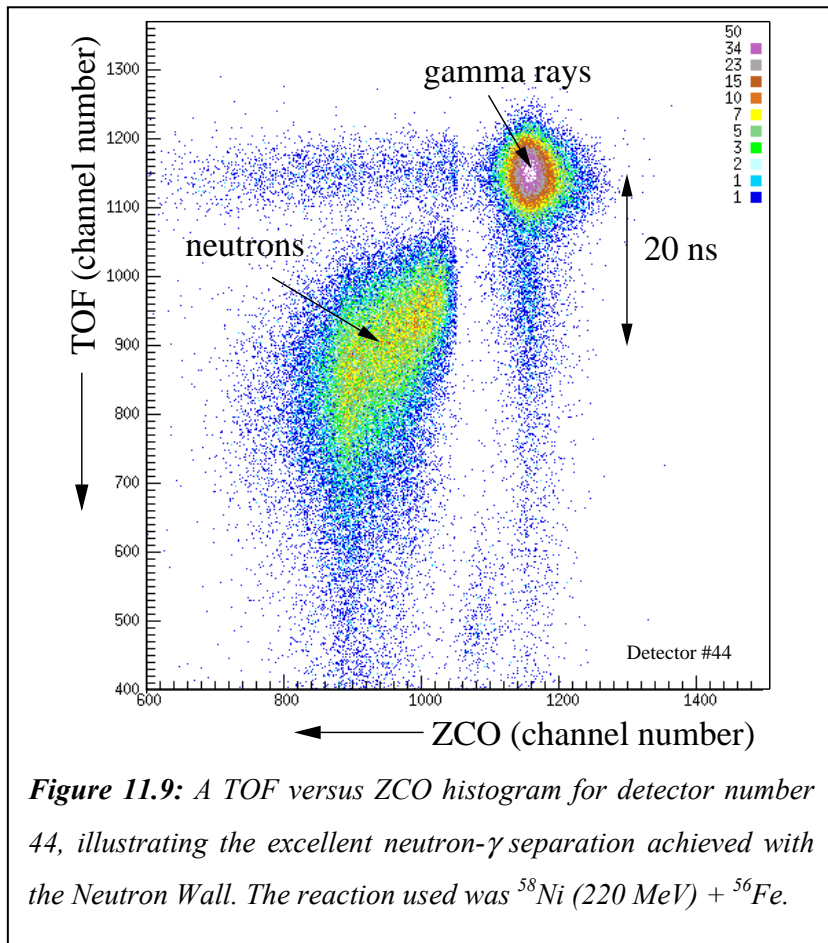


Figure 11.9: A TOF versus ZCO histogram for detector number 44, illustrating the excellent neutron- γ separation achieved with the Neutron Wall. The reaction used was ^{58}Ni (220 MeV) + ^{56}Fe .

For studies of the most neutron deficient nuclei, reaction channels in which more than one neutron is evaporated are most interesting. The major problem of clearly identifying such reactions, with a closely packed neutron detector array, is the scattering of neutrons. In the NEUTRON WALL the scattering probability, i.e. the probability that one neutron is detected as two or more neutrons, is about 7%. If nothing is done to identify scattered neutrons, the 2n gated γ spectra would be completely dominated by peaks from the 1n reaction channels.

A large part of the scattered neutrons can be identified by using a correlation between the distance between the two detectors that have registered a neutron and the difference in their TOF values (ΔTOF). For scattered neutrons, ΔTOF is large for large distances between the two detectors, and vice versa for short distances, while for real 2n events there is no such correlation. Extensive Monte Carlo

simulations of the Neutron Wall have been done with Geant4, to study the effect of scattering [322]. The simulations were compared to data from the Neutron Wall commissioning run. It was found that using the ΔTOF -distance correlation, peaks from real 2n reactions compared to peaks from scattered 1n reactions could be enhanced by a factor of ~ 30 , with a loss of real 2n events of about 70%. The Monte Carlo simulation also showed the importance of the neutron- γ separation when

trying to identify scattered neutrons. Misinterpreted γ rays makes identification of scattered neutrons much more difficult. Further information concerning the Neutron Wall can be found at the URL <http://www.nsg.tsl.uu.se/nwall>.

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11.6. A Plunger apparatus for EUROBALL^{*}

A special plunger apparatus for EUROBALL III and IV has been built in Cologne following closely the design of a plunger apparatus previously built at the IKP of the University of Cologne which is described in Ref. [291]. Like the previous version also the new plunger is especially suited for coincidence recoil distance measurements (RDM). It meets the geometrical conditions defined by the different EUROBALL set-ups. Figure 11.10 shows the plunger mounted in EUROBALL IV.

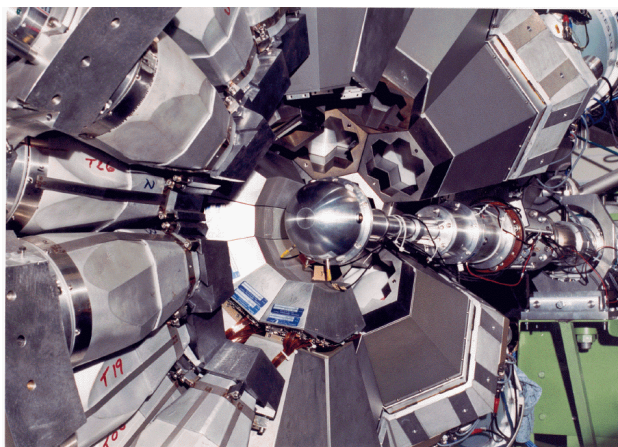


Figure 11.10: Plunger mounted in EUROBALL IV

It consists of a spherical target chamber and a cylindrical actuator housing. Both parts are connected by a tube which houses another tube held by bearings enabling precise axial movements. This inner tube is used to transmit the movements of a linear motor to the target.

The target chamber itself and the target and stopper frames were built such that a minimal amount of absorbing material for γ -rays is used in forward direction up to a polar angle of $\theta=60^\circ$ with respect to the beam and in backward direction between the polar angles $\theta=300^\circ - 343^\circ$.

The beam axis is fixed by two lead diaphragms with a 3 mm and 10 mm hole placed at the entrance of the target chamber and the actuator housing, respectively. An inductive transducer is mounted off-axis in the target chamber measuring the target-stopper distances with an accuracy up to $0.1 \mu\text{m}$. The target chamber consists of two hemispheres. It can be opened completely to achieve an easy mounting and adjustment of the target and stopper foils.

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A piezoelectric linear motor (called Inchworm) is used as an actuator. The spindle of the motor is connected via a piezoelectric crystal with the inner tube which, is connected to the target supporting frame. This crystal allows for small variations (0-30 μm) of the target-stopper distance and is part of the automatic feedback system described below.

Piezo-feedback system

In order to compensate for slow variations of the actual target-stopper distance, e.g., when the system is heated by the beam, the plunger is equipped with a piezo-feedback system. The actual target-stopper distance is monitored permanently, in particular in-beam, by measuring the target-stopper capacitance. This signal is used to record the target-stopper displacements and to generate a DC voltage for the piezo-crystal to compensate for these displacements. Recently the software of the feedback system was renewed and is now based on the LabView system (National Instruments) under LINUX.

Technical data

target-stopper separation: 0 - 8 mm

magnetic transducer range (accuracy) in [μm] : 20(0.1); 200(1); 1000(10)

Inchworm: travel distance: 25 mm,

mechanical stability : 0.004 μm

optical encoder, range (resolution): 25 mm (0.5 μm)

Plunger in combination with EUCLIDES

The new plunger apparatus provides the possibility of being used in combination with other ancillary detectors like the particle Si detector array EUCLIDES.

This can be achieved by removing the end cap of the plunger target chamber and mounting a special adapting ring instead, to which one half of the standard EUCLIDES vacuum chamber can be screwed on.

Experiments at Legnaro with EUROBALL III:

Investigation of magnetic rotation in ^{196}Pb :

G. Kemper, PhD thesis, University of Köln, 2000

G. Kemper et al., Eur. Phys. J. A11 (2001) 121

Decay out the SD band in ^{135}Nd :

R. Peusquens, PhD Thesis, University of Köln, 2000

Lifetime measurements with the EUROBALL spectrometer

A. Dewald et al., International Symposium on Nuclear Structure Physics; Editors: R. F. Casten, J. Jolie, U. Kneissel, K.P. Lieb, Göttingen, 2001

Experiments at IReS Strasbourg with EUROBALL IV:

Investigation of magnetic rotation in ^{124}Xe :

Investigations of nuclear structures using transition probabilities

A. Dewald, XIV International School on Nuclear Physics, Neutron Physics and Nuclear Energy, Varna, 2001

B. Saha, PhD thesis, University of Köln, in preparation

Test experiment EUCLIDES+Plunger: ^{114}Xe , ^{113}I

G. de Angelis et al., Phys. Lett. B535 (2002) 92

Isospin mixing in ^{46}V (EUCLIDES-Plunger)

Data analysis in progress

Isospin mixing in ^{64}Ge (EUCLIDES+Plunger)

E. Farnea et al. Phys. Lett. B551 (2003) 56

11.7. The Recoil Filter Detector for EUROBALL*

In-beam nuclear spectroscopy based on fusion evaporation reactions with both light and heavy ions has been one of the major tools in nuclear structure research for more than 30 years. At bombarding energies not too high above the Coulomb barrier, the fusion evaporation reactions are usually dominant, with cross sections ranging from about 0.1 barn to 1 barn. Often, it happens that, out of several reaction channels, one dominates and a single nucleus is populated preferentially. It is therefore satisfactory to perform only γ -ray measurements and usually γ - γ double coincidences are sufficient to obtain high quality data. This is not the case, however, if one wants to study heavy nuclei, even roughly beyond Pb, where the compound nuclei mostly undergo fission and particle evaporation, which leads to nuclei of interest, becomes weak. When going to very heavy nuclei with $Z \sim 100$, the situation is even worse. To perform spectroscopic studies in that region, it is necessary to make an identification and selection of γ - rays from the desired, rarely occurring evaporation residues.

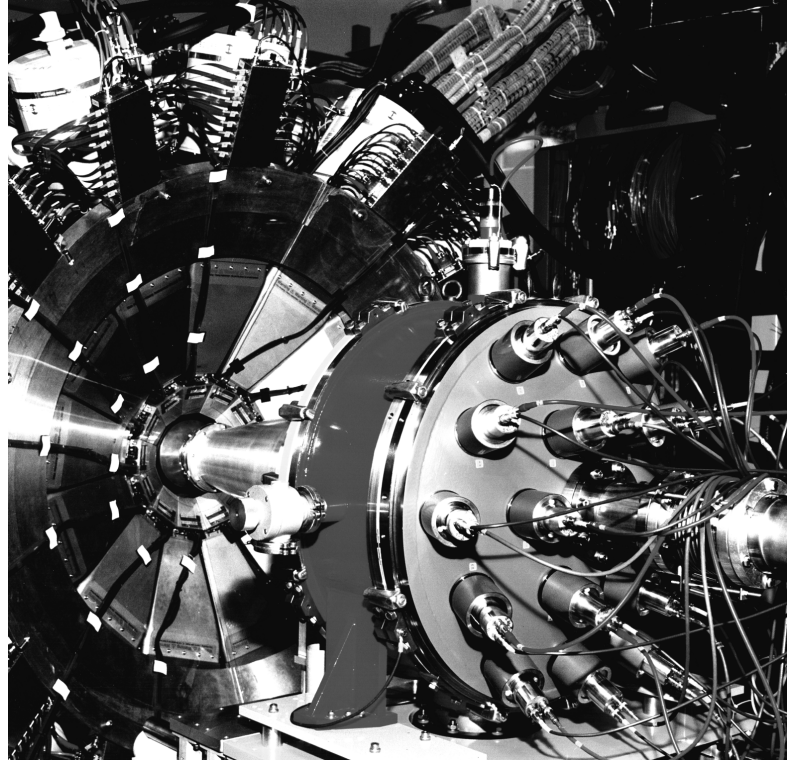


Figure 11.11 : The Recoil Filter Detector (RFD) coupled to EUROBALL.

* Contact person : W. Meczynski (witold.meczynski@ifj.edu.pl)

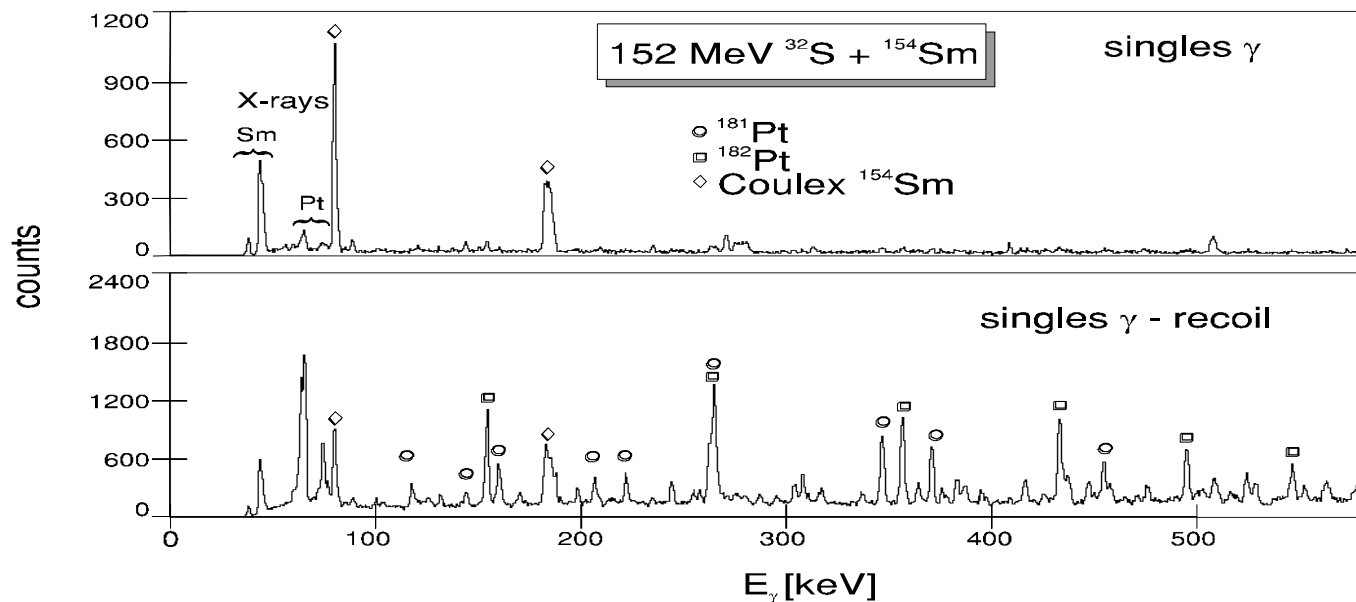


Figure 11.12: The singles γ -spectrum and the singles γ -recoil coincidence spectrum (not normalized) measured with one Ge-detector and the Recoil Filter Detector. A 152 MeV ^{32}S pulsed beam with a 400 ns repetition time from the VIVITRON accelerator bombarded a 0.7 mg/cm² thick ^{154}Sm target.

For that purpose and to overcome the aforementioned difficulties, we have built a Recoil Filter Detector (RFD) [8]. It was intended to be used only in coincidence with γ -spectrometers (multidetector arrays) such as EUROBALL (see Figure 11.11).

The RFD measures evaporation residues in coincidence with γ -rays detected in the Ge detector array. The recoil selection by time-of-flight techniques discriminates against other reaction channels. Therefore, the background is significantly reduced (Figure 11.12) and spectroscopic studies in reactions with low cross section become feasible.

Moreover, the granularity of the RFD system allows for “tracking” the reaction product, thus allowing for its velocity vector determination. This strongly reduces the Doppler broadening of the γ -lines emitted by the recoil in flight. This is especially important for light, or medium-light nuclei (Figure 11.13) for which the recoil velocity can be high when produced in fusion-evaporation reactions with energetic, heavy projectiles.

The above properties, when the RFD is coupled to the very efficient EUROBALL array equipped with the silicon ball EUCLIDES and the multiplicity filter, make such a combined system a very powerful tool for various spectroscopic studies in light, medium or in very heavy nuclei. Moreover, the use of the silicon ball and/or the multiplicity filter provides a proper information on a true reaction event having occurred in the target. This signal can then be used as a start for the RFD instead

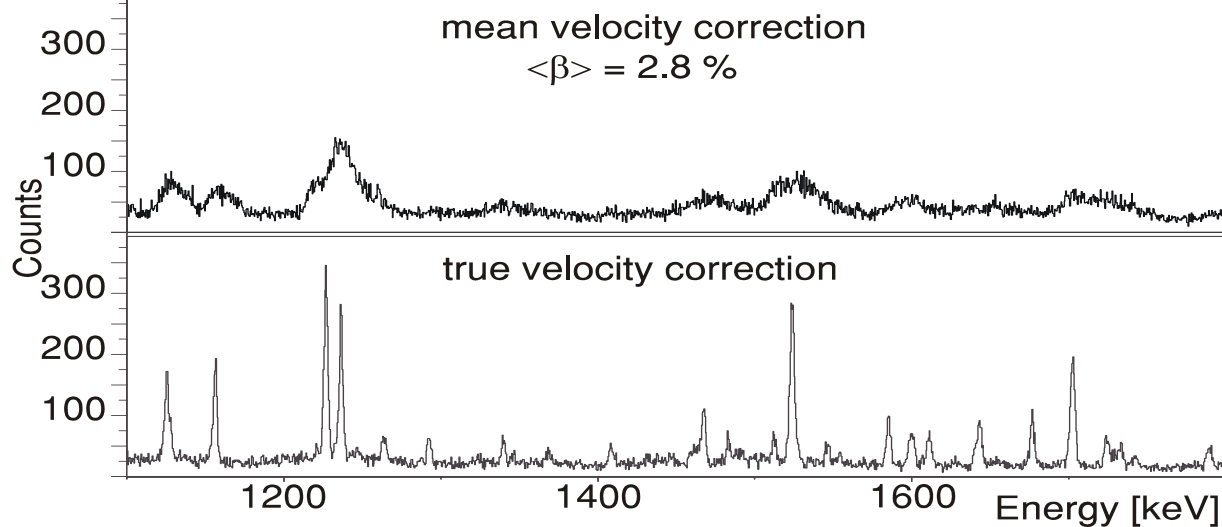


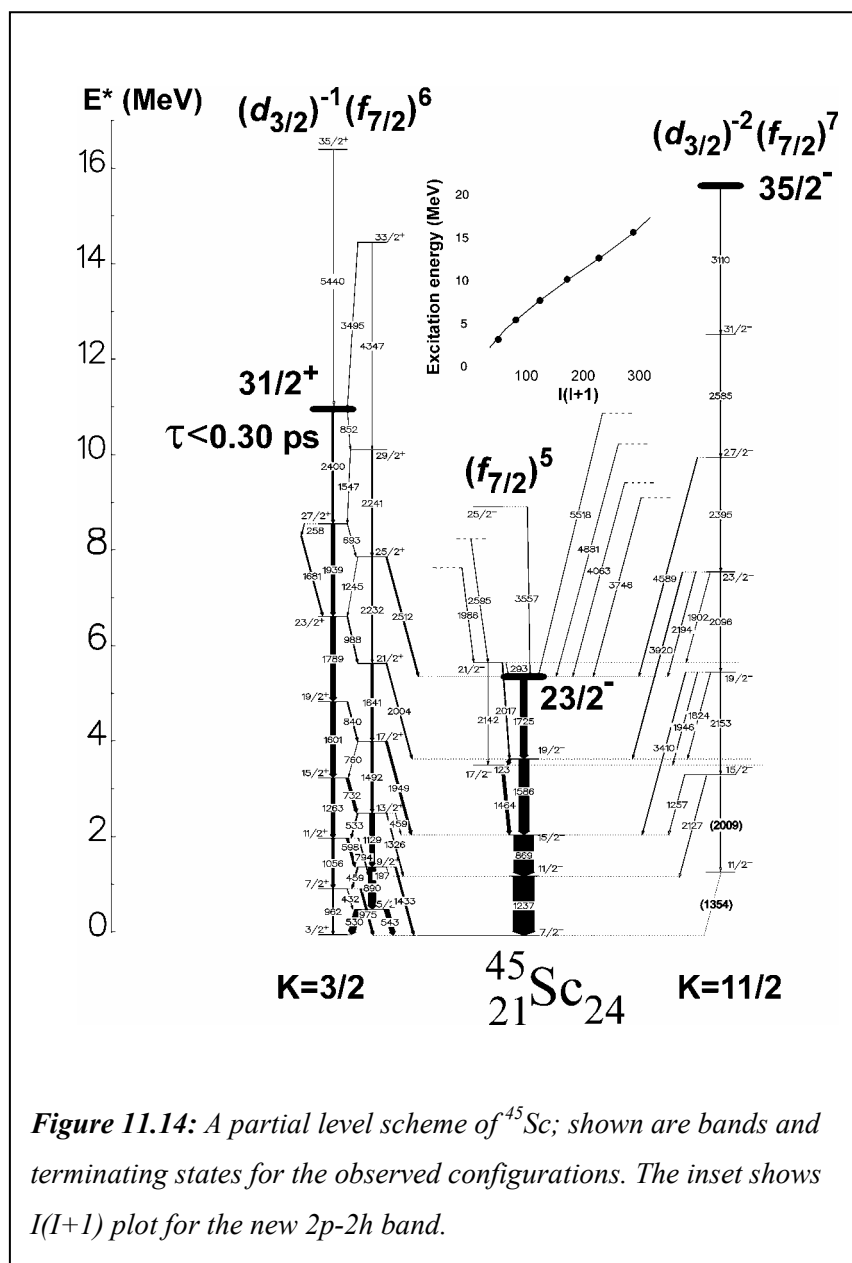
Figure 11.13: Gamma spectra of a single cluster detector of the EUROBALL IV: upper – corrected for a mean recoil velocity; lower – corrected for the true recoil velocity vector measured with the RFD for $A = 45$. The γ -lines width is 4 keV at 1.5 MeV energy.

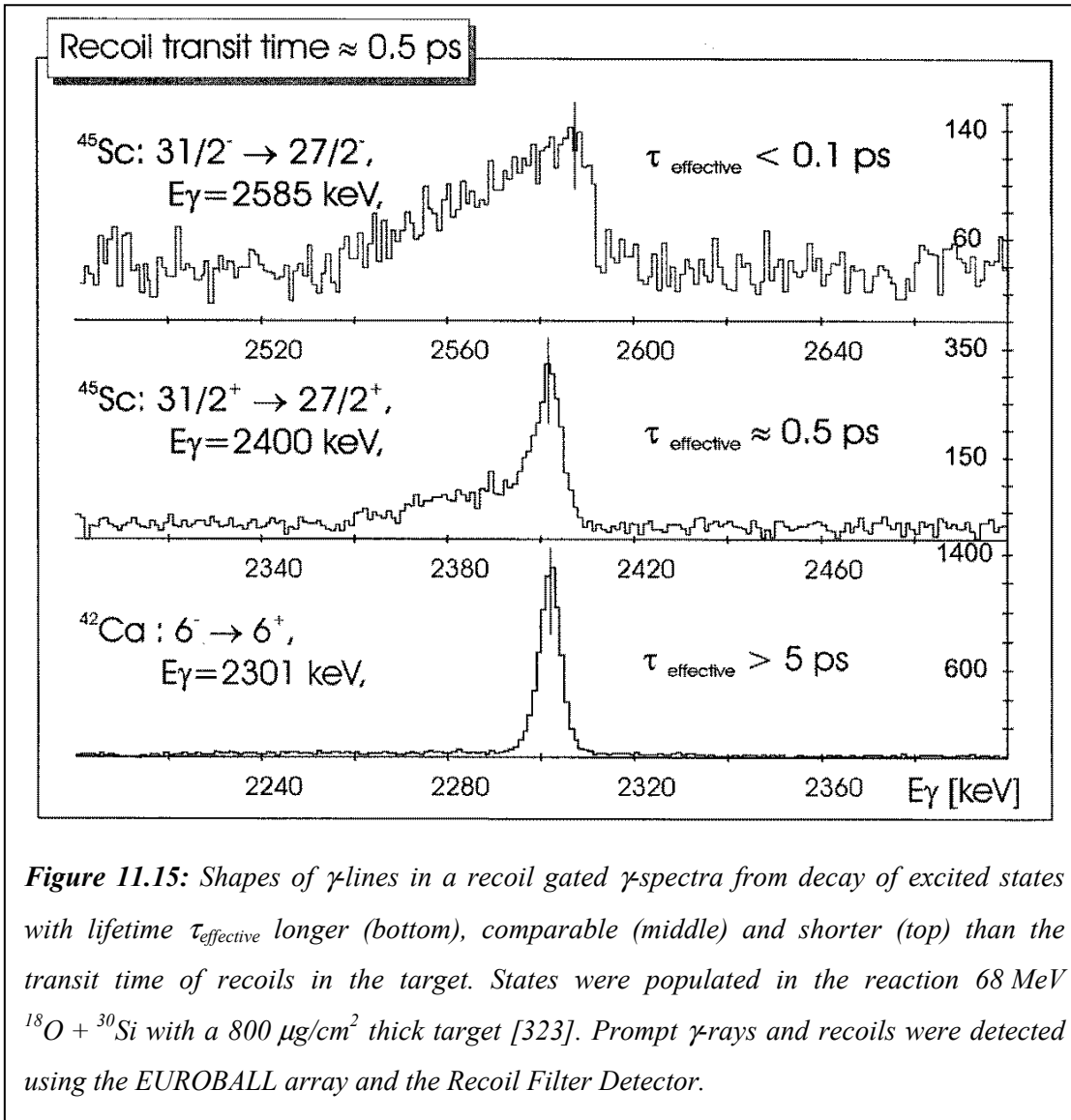
of the beam pulse. This allows working with a *continuous beam* instead of pulsed beam. This is important for studies in the region of very heavy nuclei where, because of low reaction cross sections, one needs high beam currents whereas the long flight-time of a heavy system needs slow pulsing.

Search for highly excited states (beyond band termination) in light nuclei

Superdeformed bands

Highly excited states in light nuclei commonly decay via high-energy γ -transitions (of several MeV). A huge Doppler broadening of the γ -lines severely hampered the investigations of the decay of those states (Figure 11.13). The combination of EUROBALL and the RFD allows now such studies. Two experiments have been performed to investigate nuclei close to ^{40}Ca and ^{50}Cr . The data for the latter are under evaluation. In many nuclei in the vicinity of ^{40}Ca new excited states have been observed. The new data provide valuable information on the evolution of the nuclear deformation along the observed bands. Partial data





for ^{45}Sc are shown in Figure 11.14. The positive parity 1p-1h signature partner bands loose gradually the collectivity and terminates at spin $31/2^+$ [323]. Still higher energy transitions are observed above, likely to continue the bands. A new excited 2p-2h negative parity band has been found with a high deformation parameter $\beta \sim 0.4$. New data have also been obtained for ^{44}Ca [324] and ^{42}Ca [325]; a weak band with fast E2 transitions observed in ^{42}Ca resembles properties of the superdeformed band recently observed in ^{40}Ca .

The capability of the RFD to measure the velocity vector of the recoiling nucleus,

allows for lifetime determination (or estimate lifetime limits) of excited states, as the experiments require use of thin targets

(of the order of $200\mu\text{g}/\text{cm}^2$). If the feeding time of an excited state as well as its lifetime is much longer than the transit time of the recoil through the target (typically 0.1 ps) such state decays mostly outside the target when the recoiling nucleus has already a well-defined velocity. In this case, the recoil velocity vector can be precisely measured by the RFD and the width of the γ -line can be significantly reduced (bottom panel of Figure 11.15). If, however, the lifetime of a state is comparable to or much shorter than the transit time, the recoiling nuclei in this state decay partly or entirely inside the target. Therefore, they can undergo further straggling after the γ -rays have been emitted, and consequently, the recoil velocity vector at the point of the γ -ray emission cannot be measured ‘correctly’ by the RFD. The application of such measured velocity vector *does not reduce* the broadening of the γ -lines, as shown in the middle and top panels of Figure 11.15.

It can be proven that the ratio of the ‘uncorrected’ part of the γ -line to the ‘corrected’ one is expressed by the ratio of the lifetime of the state to the recoil transit time through the target. In this way, if the transit time of the recoil through the target material is known the lifetime of highly excited, short-lived states can be estimated.

Perspectives in superdeformed band decay studies in nuclei with $A \sim 150$ –

Search for decay modes and linking transitions

Superdeformation in atomic nuclei has been extensively studied during the past two decades. SD bands have been found in many nuclei throughout the nuclear chart. However, neither feeding nor decay of the SD bands has been well understood. In few cases only, the ‘linking’ transitions connecting the highly excited SD bands to low lying states have been observed. Much less on those transitions is known in rare earth nuclei where the SD bands have been originally discovered. Again, those transitions are of rather high energy. First, to get peaks emerging from the background corresponding to those transitions, one needs to make use of high-fold coincidence spectra. This procedure reduces severely the statistics in the high energy part of the spectra. Moreover, the linking high energy γ -transitions emitted from short-lived SD states suffer the Doppler effect and the peaks can be severely broadened. This, together with the aforementioned lowering of statistics due to high-folds coincidence requirements may hamper the search of the SD bands decay.

Still unclear remains whether the decay from SD states may (partially) occur via fission from the second well of the double-humped barrier in competition to the γ -decay via linking transitions. EUROBALL plus the RFD and the Multiplicity Filter has been employed in the reaction $^{124}\text{Sn}(^{31}\text{P},5\text{n})^{150}\text{Tb}$ as an efficient way to study the SD decay. The precise selection of the recoils provides very clean spectra of γ -ray in coincidence with recoils only. The obvious precise Doppler effect correction makes possible to ‘narrow’ the high energy peaks and facilitate their observation. The RFD measures the fusion evaporation recoils which reach the detector after several tenths of nanoseconds. If the nucleus produced in such reaction undergoes immediate fission from the SD states, then it does not reach the RFD and will not be detected. Therefore, a careful intensity analysis of SD spectra measured with and without the RFD may provide information on the decay mode from SD states. An experiment searching for superdeformed bands in ^{209}Po in the $^{176}\text{Yb}(^{30}\text{Si},6\text{n})$ reaction may elucidate on the above question, but this data are still under analysis.

Spectroscopic studies for very heavy nuclei

Studies of very heavy and superheavy nuclei are a very challenging question of the present day’s nuclear spectroscopy. However, superheavy nuclei remain so far unreachable for spectroscopic studies as they are produced with cross sections in the range of picobarns. Lower mass nuclei, however, can be produced with cross sections as high as 100nb – 10 μb and thus offer a possibility for spectroscopic studies in some special conditions. Pioneering experiments for $^{252,253,254}\text{No}$ [55,326,327] and ^{255}Lr [328] provided first systematic sets of in-beam spectroscopic data on very heavy, transfermium nuclei. These are only few cases which already give some hints to the importance of such studies. Therefore, new data on other heavy systems is highly desirable. An experiment with the EUROBALL plus RFD set-up provided recently encouraging results for spectroscopic studies for a lighter system, the ^{252}Fm nucleus.

Acknowledgements:

The following people have been involved in developing the RFD for EUROBALL experiments: W. Meczynski, J. Styczen, P. Bednarczyk, J. Grebosz, M. Lach, M. Zieblinski, IFJ Krakow.

11.8. The SAPHIR detector*

SAPHIR (Saclay Acquitaine Photovoltaic cells for Isomer Research) is a solar-cell array used for the detection of fission fragments [9]. Since the development of large γ -ray detectors, the association of ancillary detectors is continuously growing. Impressive results on the spectroscopy of neutron-rich nuclei produced by spontaneous or induced fission have been obtained (see Section 0 of this report). The detection of fission fragments provides additional selectivity on the fragment mass, information on the fission mechanism (energy released in the fission process) and momentum for Doppler correction.

The SAPHIR array is able to measure the energy, mass, angle of the fragments and has many advantages compared to other

detectors like PPAC or Si surface barrier detectors. In particular, the geometry is very versatile and can be easily adapted to the kinematics of the reaction. Moreover, the lifetime of the solar cells is long compared to surface barrier detectors.

The first experiment with SAPHIR coupled to a large γ -ray detector was performed in 1995 with EUROGAM II installed at Strasbourg. Two photovoltaic cells were used to tag isomeric states in the fragments produced by the ^{252}Cf spontaneous fission [329]. After this successful experiment, the induced fission $p+^{232}\text{Th}$ reaction has been used with EUROGAM II coupled to an array of 10 solar cells. Soon after this, a larger array coupled to EUROBALL III and IV was considered and it became urgent to design an electronics able to handle a large number of detectors and compatible with EUROBALL .

In order to have a compact electronics, fully compatible to the EUROBALL standard, a VXI D-size card has been designed for SAPHIR handling 16 channels per card (energy and time). There is the possibility to by-pass the internal linear amplifier and to inject a (positive or negative) signal directly in the ADC. The VXI electronics could therefore also be used for other Ge

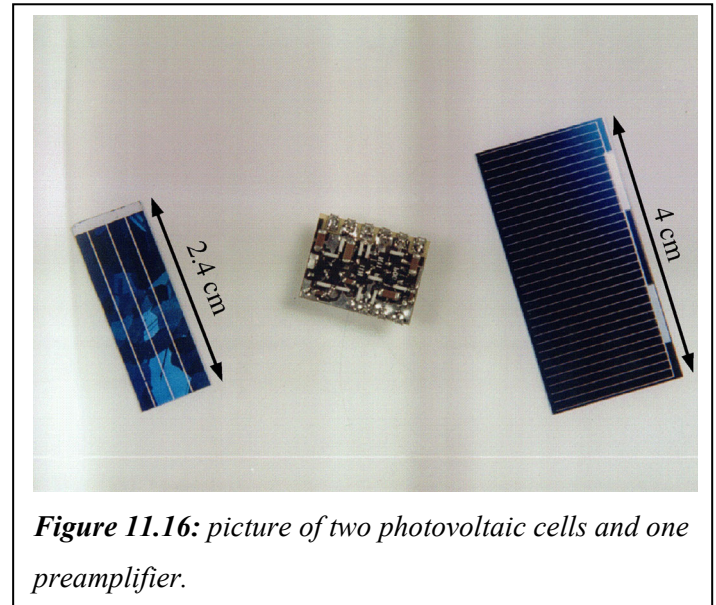


Figure 11.16: picture of two photovoltaic cells and one preamplifier.

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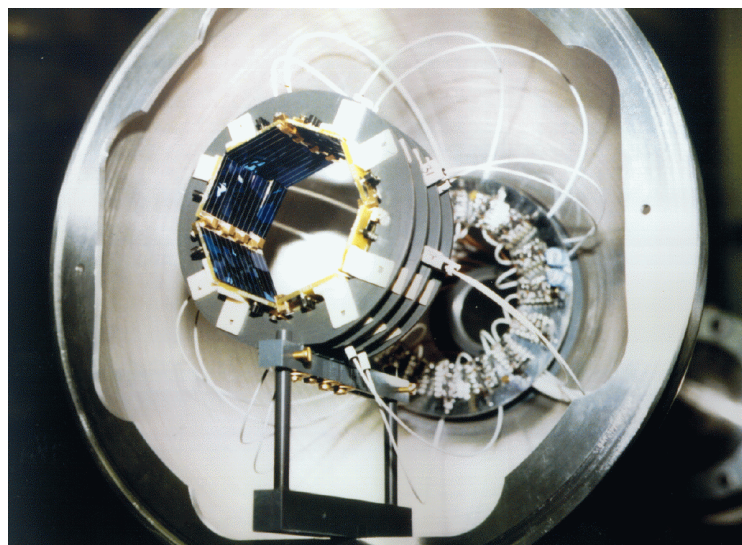


Figure 11.17: The SAPHIR array used in EUROBALL at Legnaro.

and Si detectors, for example at EXOGAM during the early implementation phase (segmented clover inner and outer contacts, anti-Compton shield) and during the first SPIRAL $^{74,76}\text{Kr}$ Coulomb excitation experiment in 2002 instrumenting a 64 channel Si strip detector. Two types of solar cells

are being used: see Figure 11.16. They are made from a polycrystalline (type 1, left) or mono-crystalline (type 2, right) silicon p-type wafers with a thickness of 300 μm [9]. The front face of the cells consists of an Ag grid covered with a thin antireflection titanium-oxide layer. The charge collection is done through a

thin Ag backing evaporated on the rear side of the wafer. The detectors are able to detect charged particles (as standard surface-barrier detectors), but a limitation arises from the large capacitance. The cells have been tested to work well for heavy particles with $A > 50$ and $E > 30$ MeV.

EUROBALL experiments:

Structure of neutron-rich isotopes produced by the $^{12}\text{C}+^{238}\text{U}$ induced fission

The SAPHIR setup consisted of 32 cells in a barrel geometry with a geometric efficiency of $\sim 50\%$: see Figure 11.17. The aim of the experiment was to study isomeric states in the range from a few ns to a few μs . Fission fragments were stopped in the array and isomeric decays occurred at rest without Doppler shift. SAPHIR provided a clear signature of the fission process as well as a time reference for lifetime measurement. From the analysis, we have identified 46 isomeric level schemes; 18 of them are new [218,222].

Lifetime measurements in fission fragments

The aim of experiments performed at EUROBALL IV was to measure lifetimes of short-lived excited states in fission

fragments emitted by a ^{252}Cf source [231]. Fission fragments emanating from the source at angles less than 50° to the EUROBALL axis passed through a stretched Au foil of 3 mg cm^{-2} thickness before being detected in the SAPHIR array. The special configuration of SAPHIR used in this work consists of 48, 12 mm square, solar cells arranged on a frame at a distance of 8.0 cm from the center of the EUROBALL array (Figure 11.18). The Au foil, fixed at the array center, served to degrade the fission-fragment energies by roughly a factor of two.

Therefore, a fission fragment detected in SAPHIR will have associated γ -ray data corresponding to two possible Doppler shifts, namely, the full one (when emitted before the degrader foil) and the partial one (when emitted after having passed the degrader foil). In this way lifetimes in the range from 1ps to 1ns can be measured by examining the count rate in the fully and partially Doppler-shifted γ -ray peaks as a function of the gap between the source and the degrader foil.

Since the first experiment performed with two cells at EUROGAM II, large progress in the development have been made. The attractive performance of SAPHIR has lead many laboratories to develop solar cells array (Cape Town, Munich, Bonn). Solar cells are also used for fission cross section measurement in the framework of the French nuclear waste management project.

The VXI electronics developed initially for the coupling with EUROBALL has been and will be intensively used at EXOGAM and with various other detectors when being integrated into a VXI system. More information can be found on the following web site: <http://www-dapnia.cea.fr/Phys/Sphn/Deformes>

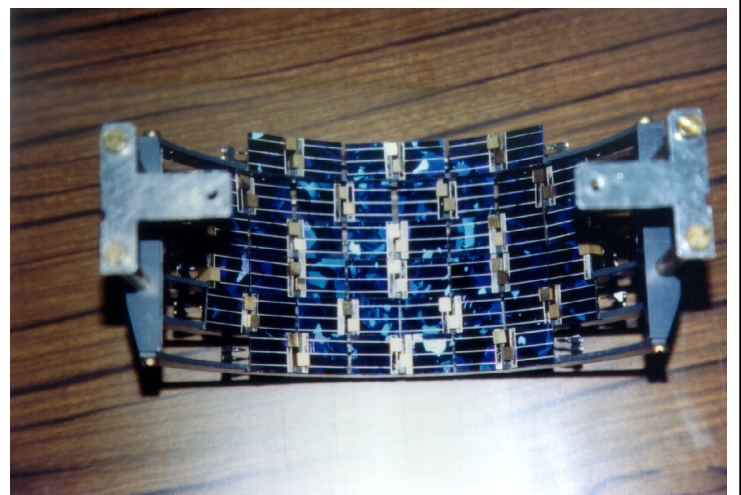


Figure 11.18: SAPHIR configuration used for the plunger experiment.

11.9. The BRS Binary Reaction Trigger Spectrometer for EUROBALL IV*

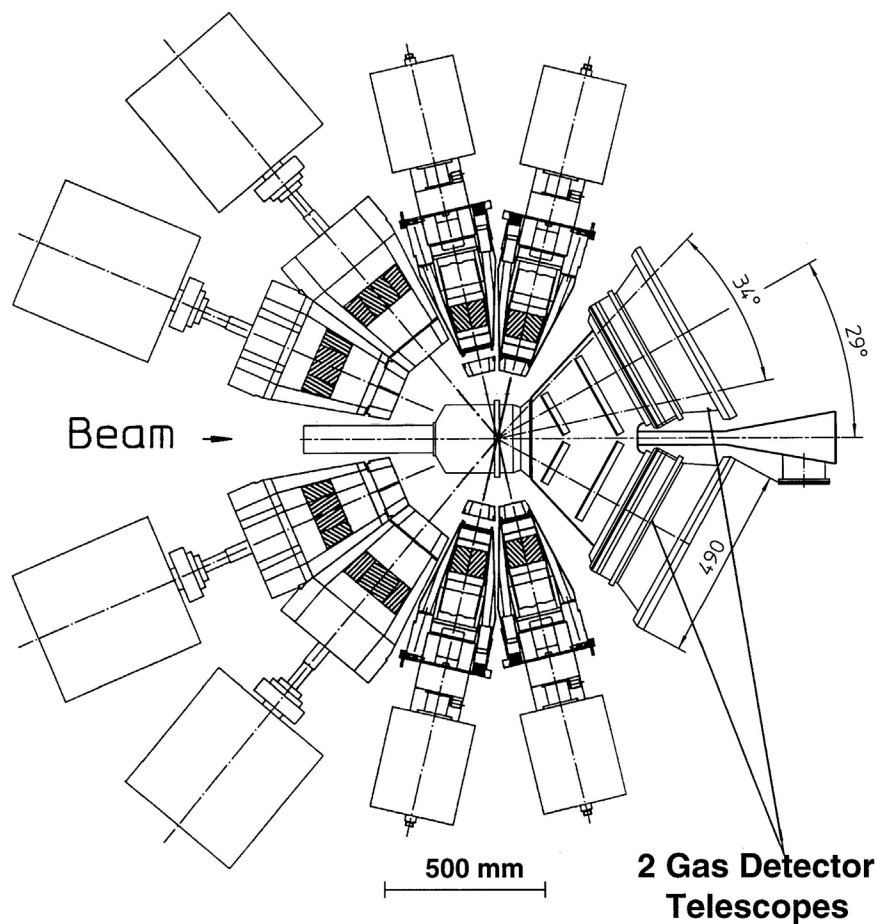


Figure 11.19: Vertical cut through the BRS setup for EUROBALL IV. At forward angles the two BRS gas detector telescopes, at angles around 90° the two rings of Clover Ge detectors and at backward angles the Cluster Ge detectors of EUROBALL are depicted.

* Contact person B. Gebauer (gebauer@hmi.de)

Compared to fusion-evaporation reactions with stable projectile and target nuclei, binary reaction channels have the potential to open up new regions of the nuclear chart for γ -ray spectroscopy. For instance, nuclei on the neutron-rich side of the valley of stability can be studied by multi-nucleon transfer or deep-inelastic reactions, and high-spin states, e.g. belonging to highly deformed configurations in α -cluster nuclei, can be populated and detected very selectively by multiple α -transfer and fusion-fission exit channels. In addition, nuclear reaction studies can gain qualitatively new insights by a clean selection of a certain reaction channel, separating the γ -ray transitions from individual channels. A complete separation of the different reaction channels can be achieved, in favourable cases, by using thin targets and powerful particle trigger systems. In addition, the entry points of the γ -ray cascades and an optimal Doppler-shift correction of the resulting low background γ -ray spectra can be obtained. These are the fields of applications of the **B**inary **R**eaction **T**rigger **S**pectrometer (**BRS**) for EUROBALL.

By obtaining a complete reaction channel resolution in the BRS in the kinematical coincidence mode, the observational limits of EUROBALL can be considerably improved. In favorable cases a unique channel separation can already be achieved by the trigger detector and multi-fold γ -ray detection is not needed to reduce the background in the γ -ray spectra. The detection of two-fold γ -ray coincidences is, however, needed in order to identify specific γ -ray sequences.

Features of the Trigger Spectrometer

The BRS for EUROBALL combines as essential detection elements two large-area logarithmic heavy-ion gas-detector telescopes in a kinematical coincidence setup at forward angles. In addition, six eight-fold segmented silicon detectors providing particle identification by pulse-shape discrimination, which can be integrated into the setup at forward angles, have been prepared as an option. In the EUROBALL IV setup (cf. Fig. 11.19) the two detectors are mounted symmetrically on either side of the beam axis, covering each the forward scattering angle range $12.5^\circ < \theta < 45.5^\circ$, i.e. $\theta = 29^\circ \pm 16.5^\circ$. Therefore, the 30 tapered Ge detectors of EUROBALL must be taken out, thus reducing the total photo-peak efficiency of EUROBALL by a small amount. In this geometry, the case of inverse kinematics offers best conditions, i.e. if the projectiles are heavier than

the targets and/or the reaction Q-values are sufficiently negative, both ejectiles of a binary reaction can be detected in exclusive kinematical coincidence measurements.

Each gas-detector telescope comprises two consecutive gas volumes containing a two-dimensional position sensitive low-pressure multi-wire chamber (MWC) and a Bragg-curve ionization chamber (BIC), respectively. All detection planes are four-fold subdivided in order to increase the counting rate capability and the resolution. Thus the following correlations between two heavy ejectiles can be measured with high resolution:

In the MWCs the in-plane and out-of-plane scattering angles θ and ϕ , derived from the position measurement and the time of flight (TOF) are measured with position and time resolutions of ~ 0.5 mm and ~ 200 ps, respectively. If the accelerator pulsing gives a sufficiently good time resolution (~ 1 ns) for non-binary exit channels the measurement of TOF versus the beam pulse for two heavy ejectiles can be used. Usually the better time resolution of the MWCs is utilized to measure the ejectile masses, more precisely the mass asymmetry in the binary channels, by measuring the time-of-flight differences between the two ejectiles detected in the two telescopes. In exclusive kinematical coincidence measurements masses and binary Q-values can be with a resolution of $< 1-2$ MeV, which is dependent on target thickness.

In the BICs the Bragg-Peak height (BP), Range (R) and rest Energy (E) are measured. BP delivers in BP/R and BP/E correlations a fairly mass-independent Z signal. Since the Bragg-peak width is mass dependent, whereas its height BP is not a limited mass resolution can be obtained. By measuring the Z and E correlations of two heavy ejectiles the reaction channel dynamics of binary reaction channels can be unambiguously identified and non-binary events are suppressed very effectively. These can be further suppressed using the ϕ - ϕ correlation measured in the two MWCs, i.e. applying the coplanarity condition.

Furthermore, if a pulsed beam of about 1 ns (FWHM) time resolution is available from the accelerator (e.g. VIVITRON post-pulsing system), kinematically complete inclusive measurements of three-body exit channels can be performed by detection of two heavy residues in the BRS. In this case the achievable resolution is limited by the time resolution of the pulsing system.

By measuring (θ/ϕ), TOF, E, R and Z correlations for two heavy ejectiles in the BRS gas detector telescopes alone, the reaction dynamics of quasi-elastic, deeply-inelastic and fusion-fission channels can be determined for masses, which are not too heavy and the Doppler-shifts of γ -rays emitted from the ejectiles can be corrected for. In many cases, sufficient characterization can already be achieved by measuring these quantities for one ejectile in one-arm experiments, usually for the lighter one. In this mode of operation, normal kinematics can be used, detecting the lighter nucleus in the BRS.

Dynamical Ranges

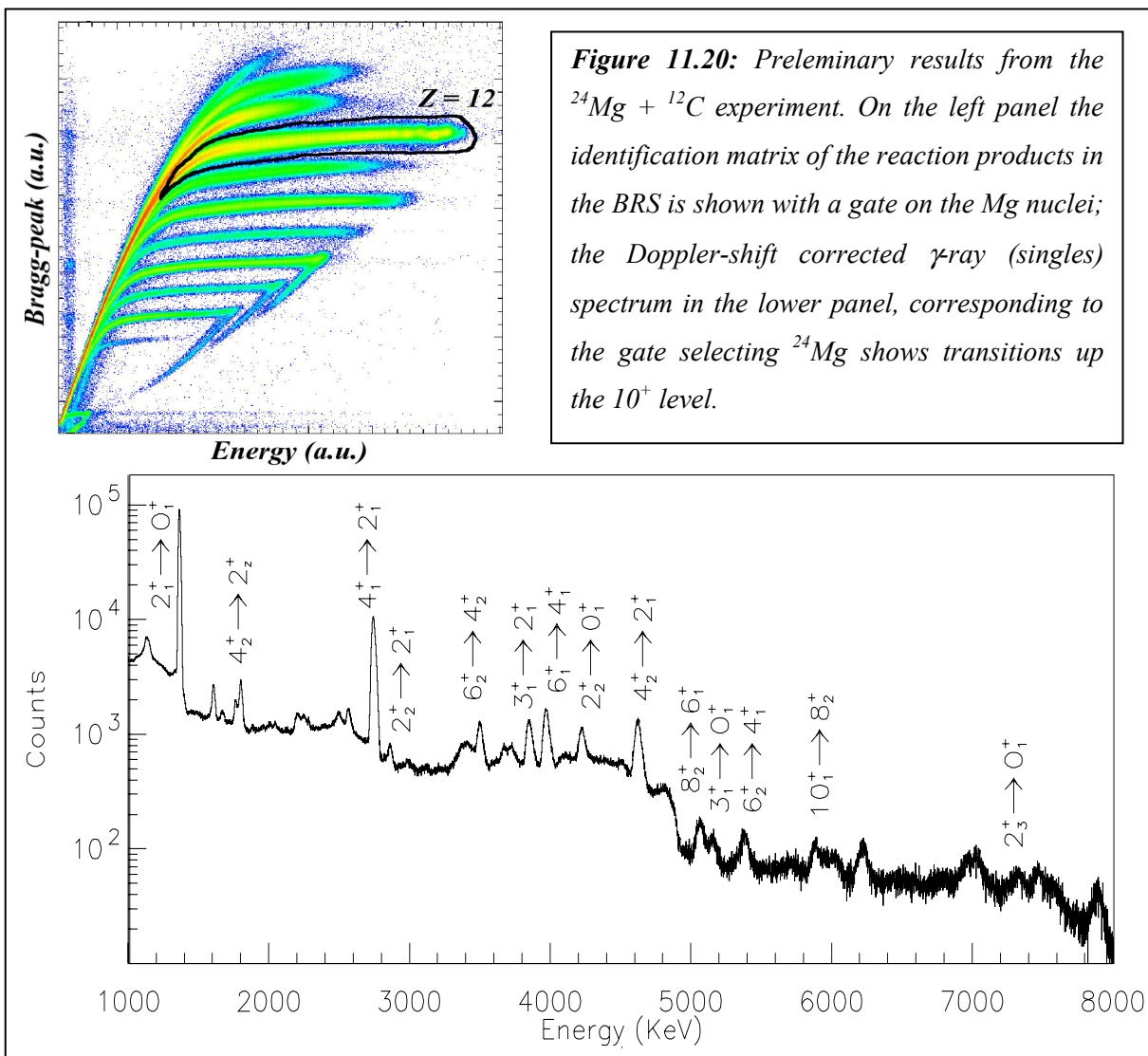
The most stringent restrictions in the dynamical ranges result from the fixed-angle settings and the limited opening angles of the detector telescopes in comparison with the kinematics. The lightest particles, which can be identified adequately in the BRS gas telescopes, are low-energy α particles (<5 MeV/u can be stopped). In the MWCs the low-energy thresholds are <0.1 MeV/u. In the BICs adequate Z resolution can only be achieved for kinetic energies at or above the Bragg-maximum. In cases where the correlation angles are too large for detection of two correlated ejectiles or the kinetic energy of one of the ejectiles is too low for detection, the measurement of the faster ejectile will often deliver a good trigger for γ -ray spectroscopy. In this case the detected ejectile must be stopped in the ionization chamber. With BICs of 125 mm active depth this is possible, for example, for 6 MeV/u ^{16}O , 7.5 MeV/u ^{28}Si , 8.5 MeV/u ^{40}Ca or 9 MeV/u ^{58}Ni with a pressure of 400 mbar of the CF_4 gas. At energies well above the Bragg maximum, ejectile nuclear charges should be separable at least up to $Z=30$.

Experiments performed at EUROBALL

In October 1998 the first experiment with the BRS and EUROBALL III was performed at the Legnaro National Laboratory (*“Search for γ -ray Transitions in Hyperdeformed 4N-nuclei $A=36-44$ ”*) using the reaction $^{32}\text{S} + ^{24}\text{Mg}$ at a beam energy of 163 MeV. At this time only a one arm-experiment could be performed. However, due to the good pulsing system of the LNL accelerator the TOF could be used for the determination of the velocity vectors and for Doppler-shift corrections.

Results of previous measurements with the BRS and some results of this experiment are published in

S. Thummerer et al. Il Nuovo Cimento Vol.111A (1998) 1077, and S. Thummerer et al. Physica Scripta T88 (2000) 114.



In September 2002 the BRS was installed for a commissioning run at EUROBALL IV at IReS Strasbourg, and later two experiments (W. von Oertzen (Berlin) et al. “Search for rare γ -decays in the strongly deformed light neutron rich isotopes $^{10-12}\text{Be}$ and $^{13-16}\text{C}$ ” and Ch. Beck (Strasbourg), W. von Oertzen (Berlin) et al. “Search for gamma-ray transition from SD and HD states in ^{24}Mg in the ^{24}Mg on ^{12}C reaction”) were successfully performed in October 2002. Later on two further experiments (B. Gebauer (Berlin) et al. “Search for gamma-ray transition in the HD 4N-nuclei with $A=36-46$ ” and X. Liang (Paisley), F. Haas (Strasbourg) et al. “Search for excited states in the neutron-rich Na and Mg nuclei around $N=20$ using deep inelastic processes”) had successful beam times at the VIVITRON in April 2003. The data are processed by four different groups at IReS (Strasbourg), HMI (Berlin); FLNR (Dubna) and Paisley (UK).

In Figure 11.20 preliminary results from the $^{24}\text{Mg} + ^{12}\text{C}$ experiment (EB-01/5) are shown. The upper panel shows the identification of the reaction products in the BRS with a gate on the Mg nuclei, the lower panel the corresponding Doppler-shift corrected γ -ray (singles) spectrum of the gate selecting ^{24}Mg .

Acknowledgements

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