SAPhIR : A FISSION-FRAGMENTS DETECTOR

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Abstract. SAPhIR is the acronym for Saclay Aquitaine Photovoltaic cells for Isomer Research. It consists of solar cells, used for fission-fragment detection. It is a collaboration between 3 laboratories : CEA Saclay, CENBG Bordeaux and CEA Bruyères le Châtel. The coupling of a highly efficient fission-fragment detector like SAPhIR with EUROBALL will provide new insights in the study of very deformed nuclear matter and in the spectroscopy of neutron-rich nuclei.

MOTIVATIONS

Since a few years, the association of large γ-ray detectors with additional neutron or charged particle detectors is under development (see for example [1]). The addition of these "ancillary" detectors provides additional information complementary to γ-ray spectroscopy.

The physics we want to address with SAPhIR should be manifold when used with the already existing large arrays for γ ray detection like EUROBALL.

- Reaction mechanism
  - Fission dynamics and nuclear dissipation.
  - Stability against fission of highly deformed states.
- Nuclear structure and spectroscopy

– Actinide region : search for superdeformed states of $J > 8\hbar$ built on fission isomers. SAPhIR is then used as a filter for delayed fission events.

– Lead-Thorium region : Very few superdeformed states at the border of this region are known. Because of the competition between fission and fusion-evaporation, SAPhIR can be used as a veto against fission. In this case a 4π geometry is necessary.

– Fission-fragment spectroscopy of very neutron-rich nuclei produced in induced or spontaneous fission. The production of fission fragments is a good way to explore the neutron-rich nuclei region, fission giving fragments which are for the most part accessible in no other manner and which are formed in various states of excitation energy, spins and deformations. A renewal of interest in fission-fragment spectroscopy occurred with the elaboration of Ge detector arrays such as EUROGAM or GAMMASPHERE. Detailed experiments have been recently performed on the γ decay paths of excited fission fragments and thus have enhanced the possibilities to gain insights in nuclear behavior (see for example [2,3]). For these kind of studies, SAPhIR is then used for mass identification, trigger and kinematic reconstruction of the fission events (Doppler correction).

To face the preceding items, SAPhIR has been designed to meet the following requirements :

- good fission-channel selectivity with the possibility to detect the 2 fission fragments in coincidence.
- large efficiency and good granularity together with a size suitable to fit into the scattering chamber of the γ-ray detector.
- weak absorption of γ rays in order to preserve the peak-to-total ratio and hence the sensitivity of the γ-ray detector.

DESCRIPTION OF THE PHOTOVOLTAIC CELLS

Usually, surface-barrier detectors or gas-avalanche counters are used to detect fission fragments, but they exhibit severe radiation-damage problems and the cost of building a large array with surface-barrier detectors is high. On the other hand, gas detectors are more difficult to handle and require special care because of the thin window. We have tested with success solar cells, the capabilities of which have been demonstrated by G. Siegert in 1979. A few other studies on these cells have been reported so far [4–6].

We are using two types of solar cells : see figure 1. They are made from a polycrystalline silicon p-type wafer with a thickness of 300 μm. The front face of the cell 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. Large cells (type 2) have a smaller capacity and a better resolution compared to smaller ones (type 1).

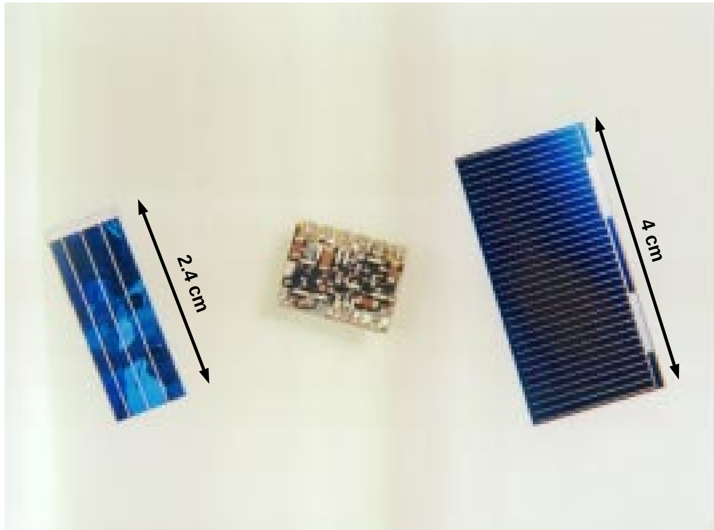


FIGURE 1. Picture of two photovoltaic cells (type 1 at left and type 2 at right) and one SAPhIR preamplifier (middle).

The semi-conductor structure pn+ junction is similar to those of surface-barrier detectors. Owing to the low resistivity of the substrate ($< 3\Omega/\mathrm{cm}^2$), the depletion depth does not exceed 0.1 μm and the solar cell hence operates without any bias voltage. Therefore, light charged particles (e, p and α...) loose only a small energy in the depletion zone. The charge collection is performed through a complex mechanism (the funneling [7]) that we will not describe here. This process depends strongly on the specific ionisation (dE/dx) so that the response of the solar cells to heavy ionizing particles is enhanced compared to light charged particles.

The detectors are able to detect charged particles (as standard surface-barriers), but a limitation arises from the large capacitance ($\simeq$ 30nF/cm^2) : the signal extracted from the preamplifiers is small and light particles cannot be distinguished from the noise. The cells have been tested to work well for heavier particles with $A > 50$ and $E > 30$ MeV.

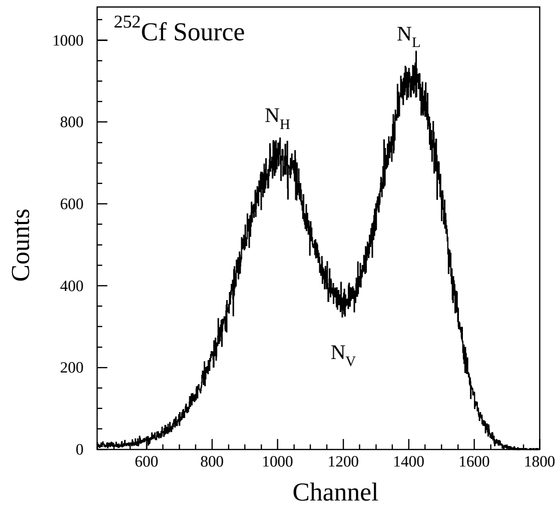
Due to the well known pulse-height defect, the particle energy E is related to the measured signal x by the relation :

$$E = (a + a'M)x + (b + b'M). \qquad (1)$$

a, a', b, b' are extracted from the "Schmitt calibration" method [8]. A calibration has been performed in 1997 at Institute Laue Langevin with the Lohengrin spectrometer to precisely determine the four coefficients of the Schmitt calibration.

PERFORMANCE OF THE PHOTOVOLTAIC CELLS

The response of the solar cells to fission fragments has been studied by using a thin open source of the spontaneously fissioning isotope ^{252}Cf widely used to study the performances of heavy-ion detectors. A careful comparison has been made with a standard surface-barrier detector.



ratio	Cell type 1	Cell type 2	surface barrier	Recommended value
N_L/N_V	2.09	2.63	2.7	> 2.85
N_H/N_V	1.68	2.04	2.1	2.20
N_L/N_H	1.24	1.28	1.3	1.30

FIGURE 2. ^{252}Cf spectrum obtained with a photovoltaic cell of type 2. The values of peak-to-valley ratios are summarized in the table, for 2 different types of solar cells, one surface barrier, and the values recommended by Schmitt and Pleasanton (see for example [9]).

The mass resolution expected from a typical double-energy measurement with a surface-barrier detector is around 4 to 5 a.m.u : this includes intrinsic energy resolution, quality of the target and its backing as well as prompt neutron emission from the fragments. The mass resolution using solar cells has been estimated to 7-8 a.m.u. with the present techniques.

The energy resolution has been measured at the Institute Laue Langevin with the Lohengrin spectrometer to be about 2 % in the energy range of fission fragments. The detection efficiency has been found to be $\simeq 1$. The time resolution is around 20 ns. The detectors are usually used on an epoxy support. Only X-rays are attenuated in this configuration while γ-ray transmission above 100 keV is near 100 %.

GEOMETRY OF SAPHIR

The geometrical arrangement is as versatile as possible keeping in mind that it should be small enough to fit inside a EUROBALL scattering chamber. The simplicity and low cost of the solar cells will allow to face various experimental situations depending on the kinematics of the reaction : large solid-angle coverage to maximize fission-fragment detection efficiency, good granularity for Doppler correction, etc... Moreover, the cells can be cut in any shape for any geometry and even a hole can be made into the cells, for example in the beam axis.

EXPERIMENT PERFORMED AT EUROGAM II - EUROBALL III

Spontaneous fission of ^{252}Cf

An experiment using the spontaneous fission of ^{252}Cf has been performed in 1995 at EUROGAM II installed at IReS Strasbourg. For this experiment, we have used two photovoltaic cells placed at both sides of the source. Fission fragments were stopped in the photovoltaic cells, from where delayed γ-ray transitions ($\tau > 1$ns) were emitted and detected by the EUROGAM array. The trigger condition for the whole setup (SAPhIR and EUROGAM) was that the two cells responded. The efficiency of the setup for fission detection was $\simeq$25 %.

In this experiment, we have identified more than 50 isomeric levels. Some of them were not identified before. We have in particular identified new K-isomers in neutron-rich Nd and Sm nuclei. The interpretation of these structures was done with the help of the Hartree-Fock-Bogoliubov formalism using D1S Gogny effective interaction [10].

Induced fission of ^{238}U by ^{12}C.

More recently, we have performed an experiment at EUROBALL III. This detector currently installed at Legnaro (Italy) consists of 239 Germanium Crystals.

Fission fragments were produced by the induced-fission reaction ^{238}U + ^{12}C at a bombarding energy of 90 MeV. Fission fragments were detected by SAPhIR in a barrel geometry (32 cells in 4 ring of 8 cells). For details concerning this experiment, see the contribution of M. Houry in these proceedings.

TECHNICAL DEVELOPMENTS

Preamplifier

Photovoltaic cells have a large capacity without polarization (20-30 nF/cm^2) for a thickness of 300 μm. A small polarization induces a current who will generate a huge noise level. Moreover, the cells deliver a very small current pulse (a few μA) which is fast (a few ns) and has a dynamical factor of 10 (from 20 MeV to 200 MeV). From an electrical point of view, these constraints lead to adopt a preamplifier with a transfer function homogeneous to an impedance i.e. the output voltage is proportional to the input current. The current-voltage conversion allows to keep a fast rise time of the output signal ($\simeq$ 10 ns with a detector capacitance C_d of 100 nF). To minimize pick-up and noise pile-up, the newly developed preamplifiers (2*2 cm^2) are housed inside the scattering chamber nearby the solar cells.

VXI electronics

In order to have a compact electronics, fully compatible to the EUROBALL standard, new VXI D-size cards have been designed. The advantage of this standard is to allow a modification of parameters (like CFD threshold, Pole Zero adjustment, delays...) by remote control from the control room. Inspection lines can also be software selected and sent to an oscilloscope. Moreover, a Digital Signal Processor (DSP) allows spectrum creation and calculation for an on-line monitoring of the experiment.

The VXI card developed for SAPhIR has 16 channels per card. Every channel is composed of one energy channel (linear amplifier, peak detector and stretcher, ADC), time channel (timing filter amplifier, constant fraction discriminator, time to amplitude converter, ADC) and one local trigger. Two trigger signals are built into the card : ‘Or’ between all channels and sum bus (multiplicity signal).

There is also the possibility to by-pass the internal linear amplifier and to inject directly a signal (positive or negative) in the stretcher. This is for example the case for other Si detectors, e.g. used in a conversion-electron spectrometer, which can also use the SAPhIR card.

FUTURE EXPERIMENTS

We present in this section some examples of experiments we plan to perform with SAPhIR in association with γ-ray detectors.

Intermediate energy neutron induced fission

The first example concerns neutron-induced fission at intermediate energy. Neutrons will be produced by the WNR of the Los Alamos Neutron Science Center

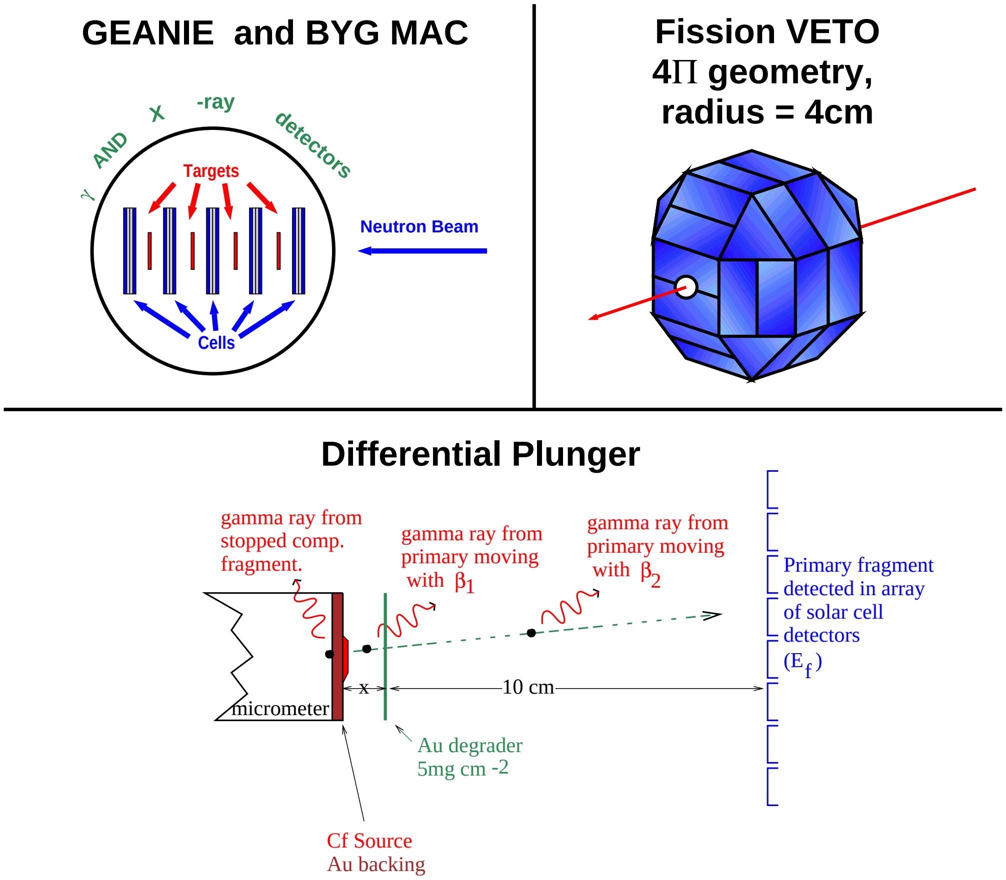


FIGURE 3. Geometry of SAPhIR for three different experiments : Top left : intermediate energy neutron induced fission. Top right : superdeformation for $Z > 82$. bottom : lifetime measurements in fission fragments.

(LANSCE). The aim of the experiment is to obtain fission-fragment yields as function of neutron energy above 14 MeV. It is well known that the peak-to-valley ratio decreases with increasing excitation energy, and there is an urgent need to measure and understand the relative yields for both very asymmetric and symmetric fission in uranium isotopes.

Using high-energy neutrons, one expects also to explore a new area of light excited fission-fragments produced through (n,xn) or spallation reactions before fission, and to study in particular isomeric levels on the scale of milliseconds.

In these experiments the de-excitation of the fission fragments will be detected with GEANIE : an array of 11 planar X-ray detectors and 20 coaxial Ge γ-ray detectors. The setup placed inside the target chamber will consists of "BYG MAC" : a stack of thin fissile target sandwiched by two photovoltaic cells : see figure 3.

Lifetime measurements in fission fragments [11]

Over the last few years, there has been a dramatic increase in available information on the low-energy structure of very neutron-rich nuclei [2,3]. Despite the obvious physical interest of these nuclei, there remains a dearth of information regarding the lifetime of their excited states; a quantity which is very sensitive to nuclear structure, such as the deformations.

The proposed setup shown in figure 3 should be installed inside EUROBALL IV and will consist of a ^{252}Cf source mounted on a Au backing. Fission fragments emitted to the right will first pass through a Au degrader, before being detected in a 64-element array of photovoltaic cells which will give both the angle and energy of the fragments.

By moving the distance between the source and the degrader, lifetime in the range of 1ps to 1ns can be measured.

Superdeformation in $Z > 82$ nuclei

The population of high-spin states in heavy nuclei by heavy-ion reactions is severely impaired by the high fission probability. In fact, the total cross section is dominated by fission, and the channels of interests represent at most a few % of the total cross section. In this case events not associated with fission can be selected (fission veto) if almost all fission fragments are detected in a quasi 4π detector. With a near 4π geometry, we have also the possibility to stop recoil products in the target chamber, in order to search for shape isomers.

A possible geometry for such a fission veto is shown in figure 3 and could be used at EUROBALL IV for superdeformation and fission isomer studies, for example in Po isotopes.

REFERENCES

1. *Ancillary detectors and devices for Euroball.* Edited by H. Grawe and the Euroball ancillary detectors group, 1998.
2. I. Ahmad and W.R. Phillips, *Rep. Prog. Phys.* **58**, 1415 (1995).
3. J.H. Hamilton *et al.*, *Prog. Part. Nucl. Phys.* **Vol 35**, 635 (1995).
4. G. Siegert, *Nucl. Instr. and Meth.* **164**, 437 (1979).
5. E. Liatard *et al.*, *Nucl. Instr. and Meth.* **A267**, 231 (1988).
6. N.N Ajitanand *et al.*, *Nucl. Instr. and Meth.* **A300**, 354 (1991).
7. F.B. McLean and T.R. Oldham, *IEEE Trans. on Nucl. Sci.* **NS-29, No 6**, 2018 (1982).
8. H.W. Schmitt, W.E. Kiker and C.W. Williams, *Phys. Rev.* **137**, B837 (1965).
9. G.F. Knoll, *Radiation detection and Measurement*, Willey and Sons, Inc, 1989.
10. C. Gautherin et al., *Eur. Phys. J.* **A1**, 391 (1998).
11. G. Smith, private communication.