NEDENSAA Project

Neutron Detector
Developments
for Nuclear Structure,
Astrophysics and Applications

Detailed project information

1. Background, rationale and review of the state of the art

Neutron detectors are commonly used in research centres all over the world for both basic science as well as for applications. However, the improvements over the last few decades in neutron detection techniques have been modest in comparison to other fields of nuclear instrumentation. The materials, detection techniques and the associated electronics developed 40 years ago are still the main stay of present day detection systems. Most of the neutron detectors used nowadays are:
- Gaseous detectors. These are mainly based on the 3He(n,p), 10B (n,alpha), 1H(n,p) and (n,fission) reactions. Owing to their gaseous nature, they have low intrinsic efficiencies, limited time resolution and require especial safety measures in their use (due to toxicity, flammability or other aspects). Furthermore, the recent price increase of 3He by a factor of about 10 supports the need to develop neutron detectors covering a range from thermal energies up to several hundreds of keV with reasonable efficiencies and cost.
- Liquid organic scintillators. They are based on the 1H(n,p) scattering and are still one of the preferred options for building large scale neutron spectrometers when neutron-gamma discrimination is required. They are however difficult to handle (due to their toxicity and flammability) and depending on the size, the lowest neutron energy that can be detected is ~100 keV.
- Solid organic scintillators. They are also based on the 1H(n,p) scattering and are one of the preferred options for building large neutron spectrometers when neutron-gamma discrimination is not required, i.e. for favorable neutron signal to γ-ray background ratios. The energy detection threshold is ~100 keV.
- Organic scintillators loaded with neutron converters. They rely on 1H(n,p) scattering which moderates the neutron energy after a few collisions and trigger a different (n, charged particle) or (n,γ) reaction in the dopant.
- Solid inorganic scintillators. Some solid inorganic scintillators doped with neutron converters are being used in neutron spectroscopy. However, due to the limited presence of dopant and the neutron reaction cross sections involved (typically charged particle production), their efficiency drops rapidly at energies above a few tens of keV.

The readout of most of these scintillators is made via a traditional photomultiplier and analog electronics chain. This presents a significant limitations in terms of neutron-gamma discrimination and the associated neutron detection threshold. For some applications it is essential to perform neutron-gamma discrimination, which is obtained by pulse shape analysis (PSA) of the signal. Different pulse-shape analysis methods are then used to disentangle the neutrons from the gamma rays. This process has been performed until recently using analog electronics. The advent of commercial digitizers with frequencies from 100 MHz up to 1GHz should provide for a more refined PSA and, more prosaically, the use of such digital processing obviates the need to split the signal when using analog electronics, thus providing for a substantial decrease in the detection threshold. For example it has recently been demonstrated that the Neural Network algorithm has around one order of magnitude better performances than traditional algorithms. In addition, an alternative to the traditional Photo Multipliers could be the silicon photomultipliers (SiPMs) which are currently undergoing very rapid improvements in size (3mm x 3mm is now offered by several suppliers) and in dark count rate. It is therefore conceivable that with some adjustments as e.g. light concentrators, SiPMs may become competitive also for large areas with limited solid angle. Neutron detector arrays could be coupled for in-beam and beta-delayed neutron studies to gamma-ray arrays that allow to select the weakly populated channels or study the states populated above the neutron separation energy. The coupling of these two kinds of detectors should be studied in detail in order to optimize their performances. Of particular interest is the possible use of germanium gamma detectors and new scintillator materials that provide medium energy resolution with excellent timing properties.

As outlined above, the presently available methods and technologies need to be substantially improved. In particular, new materials with higher light output and better neutron-gamma discrimination, better characterization of scintillator materials, new detector concepts, new readout systems based on SiPM, digital electronics, and the optimization of the coupling of neutron and gamma-ray arrays should be explored.

2. Objectives of the project and expected results:

The present project has been designed to address the most important aspects relating to neutron detection that need to be improved in order to permit new neutron detector arrays for experiments at FAIR, SPIRAL2, SPES and Jyväskylä to be constructed. In the following, the different facets of the project will be discussed.

One of the first needs is to synthesize and characterize new solid scintillators, which could be used in any situation including under vacuum and which do not present the drawbacks of existing liquid scintillators. The synthesized scintillators have to be fast (rise time of the order of a nanosecond) and present a high quantum efficiency. The emitted light should be preferentially in the blue region and the material (matrix) transparent to this light. The new materials will need to present performances at least as good as those of the existing liquid scintillators (in terms of neutron-gamma discrimination, intrinsic efficiency, energy (time) resolution, etc.

To succeed, a collaboration between physicists and chemists is essential. The physicists will define the properties required of the new materials and the chemists have the difficult job to synthesize them. The scintillation properties of each of the samples produced will be characterised in detail by the physics groups (WP2) using dedicated digital electronics and optical techniques, which are available and under development (WP4 and WP5).

For the characterisation of the new materials as well as existing scintillator materials it is essential to determine the response under well-controlled radiation conditions. Both experiments and accurate Monte Carlo simulations have to be used for this purpose. The important measures are light output (detector efficiency and energy resolution) and signal shape (detector time resolution and particle discrimination). This will be done over a very broad range of energies (from few to ~100 MeV). Therefore, it is necessary to accurately determine the properties of detector materials to be able to judge their applicability to different neutron detection applications, as well as generate a reference standard to which the properties of new materials can be compared. Identifying the best available facilities for the different tests is one of the important early objectives of the project (WP2).

A further objective is the investigation of the limits and new uses of existing materials, as well the optimisation of the geometries, assembly and detector response for specific applications. These studies will include the characterisation of the detector time/energy resolution, efficiency and detection threshold. The investigation of the applicability of new materials, only available in small sizes at present but expected to be grown in larger volumes in the future will be investigated. For this purpose, two different reference cases will be considered:

- A neutron spectrometer for decay studies, where special emphasis will be made in extending the detection limit below 100 keV, if possible down to thermal energies. As a result, the optimal configuration for a neutron time of flight spectrometer sensitive to neutron energies up to 100 keV will be obtained.

- A neutron spectrometer to be used as an ancillary detector for a γ-ray spectrometer. As a result, the optimal size, shape and material selection for a high-energy neutron multiplicity filter will be determined.

The materials to be investigated and characterised are:
- LaBr3/LaCl3/CeBr3 crystals coupled to appropriate neutron converters which generate ionising particles that can be detected in the scintillators.
- Inorganic scintillators doped with 6Li, like LiI with and without 6Li enrichment.
- Organic scintillators doped with 10B and 6Li: BC523A, BC454A among others.
- Elpasolites like CLLB, CLLC and CLYC.

These objectives will be first investigated by Monte Carlo simulations and the most promising solutions will be tested in the laboratory. Such activities will proceed as part of work packages WP2, WP4, WP5 and WP6.

Another objective is to study the possibility to replace the traditional Photo Multipliers by new silicon photon sensitive devices built from avalanche photodiodes (SiPM) which are of great interest for certain applications due to the independence of the signal parameters from external magnetic fields, its extremely compact mechanical design, and the availability of several competing suppliers. However, there are still some major challenges to overcome:
- the demonstration that some of the inevitable loss of geometric efficiency due to the much smaller SiPM size, when compared to the typical scintillator used for neutron detection, can be recovered e.g. using light concentrators, based on the limited solid angle in the very long scintillator bar that is optically separated from its neighbour,
- the study of the time resolution when several SiPMs are connected in parallel.

It is expected that the dark rate can be kept under control by applying a relatively high threshold for this application, where relatively high light yields are expected.

Currently, contacts exist e.g. by the Dresden group with the KETEK, with whom, ideally, in collaboration one could build a large-area SiPM prototype for readout. The first step here is the technical feasibility, to advance the SiPM fabrication techniques to large areas. A second step to be determined later in collaboration with industrial partners will be whether this solution will be an economically viable alternative to classical PMTs.

The digitalization of the signals and their processing is another important objective of the project. The advent of commercial digitizers that allow to sample the signals with frequencies from 100 MHz up to 1GHz provides a large variety of new possibilities to improve the PSA algorithms, lower detection thresholds and decrease the deadtime of the acquisition system. Two main aspects will be considering the present project. The first is related to the optimum frequency and dynamic range for the digitalization of the signals. The second is related to the synchronization of the neutron detector with other detectors, such as gamma arrays, to provide the trigger with essentially no deadtime and only latencies for the further validation or rejection of a trigger event. Commercial digitizers as well as digitizers under development within partners will be tested and their performances investigated. The synchronization between the neutron detectors and the germanium arrays could be done, for example, via a Global Trigger System (GTS) already developed, which needs modifications (extra leaves) to allow each neutron detector to be part of the trigger.

Another important objective is the optimization of neutron detector geometries and the coupling with existing and new gamma detector arrays. This development requires the implementation and study of the various possible neutron detector geometries coupled with the gamma detector configurations, the use of existing and the development of new event generators, as well as the development of analysis tools to characterize the results of the simulations. The ultimate goal is to optimize the individual efficiency of the different arrays as well as the efficiency and performance of the combined detector systems.

The final objectives, of crucial importance for the future of the community, are to develop the training and networking in the field of the neutron detectors. Indeed, all future projects for detectors at FAIR, SPIRAL2, SPES, Jyväskylä or ISOLDE for example, will require collaboration at a European level. As such the project will develop and maintain the contacts between the different groups, by organizing meetings and by collating and documenting the results from the different partners and Work Packages. Moreover, the training of early stage researchers and doctoral students involved in the project will be an important component of the project. Indeed, the detection of neutrons is of importance in many fields beyond the nuclear physics (eg., medicine, nuclear energy, detection of explosives etc) and the training of young researchers in the field is clearly beneficially both to these fields and the future of basic research.