Phoswich scintillator assemblies: Application to the Simultaneous detection of Particle and Gamma radiation

Proposal Acronym: ***PASPAG***

Activity number: ***WP9 - JRA1***

Descriptive title of the activity: ***Phoswich scintillator assemblies: Application to the Simultaneous detection of Particle and Gamma radiation***

Webpage: http://www.iem.cfmac.csic.es/departamentos/nuclear/WEB-PASPAG/webstyle1/

OBJECTIVES

The PASPAG JRA aims to improve infrastructure for European Large Scale Facilities such as FAIR, ISOLDE, SPIRAL2 & ELI-NP to make best use of the high investment in delivering radioactive ion beams. Efficient gamma-ray and charged-particle detection are key tools for experimental nuclear physics. Future nuclear physics facilities will make strong demands on the capability and performance of such detector systems. For example, the optimum gamma-ray spectrometer would combine a maximum of solid angle with good rate capability and energy resolution. New scintillator materials and photon detector technologies in combination with high granularity will help to tackle the challenges associated with extreme Doppler shift at relativistic energies.

DESCRIPTION OF WORK

PASPAG exploits novel scintillator materials and explores new techniques and concepts such as phoswich detectors and segmented or hybrid scintillators. We focus on developing the capability to simultaneously detect high-energy gamma rays, neutrons and charged particles. We also take this technology out of basic science to be exploited for societal applications within, for example, the areas of nuclear medicine and homeland security. Depending on the applications, features like energy resolution, position sensitivity, high rate capability, and insensitivity to magnetic fields or radiation hardness are of importance.

TASK1 Novel Scintillator Materials: (INFN – CNRS – CSIC – IFJ PAN - USC)

The performances of new scintillator materials, and their possible use as detectors, are not well known and thus require specific characterisation. The results of such studies are of particular interest not only for the researchers but especially for the producers of these materials in order to be able to make and sell detectors that can be commonly used in applications and not only for use by specialists of the field. We have identified a number of new promising scintillator materials that have become commercially available, i.e. materials that we are planning to further investigate in more detail during the PASPAG project. See milestone M3.0 and deliverable D9.1 for details. Below follows a short summary of the work performed.
The collaboration has and is continuously performing a survey of the commercial availability of new scintillator materials. In the first half of 2016, it was possible to order $CeBr_3$ (maximum size 3”x3”) and CLYC (maximum size 2”x2”) while in the second half of 2016 CLLB (1” diameter – 1” height), CLLBC (1” diameter - 1” height) and larger volume ^{7}Li-enriched CLYC scintillator (3” diameter - 3” height) became available. In the beginning of 2017, also Co-Doped $LaBr_3$:Ce (1” diameter - 1” height) have become commercially available and we are presently testing this material.

The activity has therefore focused on:

a) The measurements of the CLLB (1” diameter - 1” height) performances. Two crystals, of different size, have been acquired by the CNRS unit (with ENSAR2 funds). The smaller volume crystals were delivered in January 2017 and it is now under test.

b) The analysis of the data focused on the measurement of the fast-neutron detection efficiency of two 1” diameter - 1” height CLYC crystals (one enriched with ^{6}Li and one enriched with ^{7}Li).

c) The analysis of the data relative to the measurement of the position sensitivity of a 3” x 3” $LaBr_3:Ce$ crystal with the aim of correcting for the Doppler broadening.

d) The measurement of the response of large-volume (3.5” diameter - 8” height) $LaBr_3:Ce$ detector to almost monochromatic gamma rays from 5 to 38 MeV.

Further, the construction of scintillator detectors for nuclear physics applications needs also a careful survey of the production process, including a quality assurance of the different elements. In order to guarantee that the final detector complies with the specifications, the acceptance tests corresponding to certain components are of highest importance. The group at USC and the group at CSIC have dedicated part of their time to this subject. The milestone 3.1 describes in details the work to construct a scintillator readout test-bench for crystal quality, energy resolution and non-uniformity response for large CsI(Tl) crystals and performance properties of the avalanche photo diodes (APDs) used for readout of these crystals.

TASK2 Phoswich detectors: (IFJ PAN – U Warsaw – USC – CSIC – U York – TUM - CTH)

Phoswich detectors are where two different scintillators are optically coupled. Typically, the scintillators are chosen so that the light output of the two materials has very different timing properties so that the energy deposited in the two parts of the phoswich can be extracted.
As the peak wavelength of emission from novel scintillators can vary strongly, we explore the optimum coupling to high-performing photo-sensors including metal package PMTs and solid-state replacements such as silicon drift detectors (SDD) and silicon photomultipliers (SiPM).

At CSIC and CTH a Phoswich array (CEPA4) consisting of a package of 4x (LaBr3:Ce + LaCl3:Ce) crystals has been tested using different sensors. This is a prototype unit for the future CALIFA calorimeter for the R3B experiment at FAIR and should be able to determine the energy of high-energy gamma rays (1-30 MeV) as well as high-energy protons (100 -700 MeV) at a very high rate. This means first that it needs very fast crystals, and second sensors of high dynamic range. We are testing both SiPM and especially Mu-metal packaged PM tubes both being relatively insensitive to magnetic field. At CTH a special test bench was built, which sandwiched the CEPA4 in between four thick Plastic scintillators in order to detect cosmic muons that as minimum ionising particles simulate the high energy proton response, see Fig. 1. An outcome of the first test was that the sensor saturates (too much light) and it cannot measure simultaneously gamma rays and protons over the full range. Thus, we obtained in collaboration with Hamamatsu, a new voltage divider where we can take the signal out also from the last dynode with less amplification and can have two parallel readouts to increase the dynamic range.
This new system will be tested at IFJ PAN in 2018 when we expect the first (out of 8) complete module for the CALIFA front-cap to be delivered.

The IFJ PAN researchers are investigating alternatives for the PARIS detector and have obtained a CeBr3+NaI:Tl phoswich for making comparison with the original LaBr3+NaI:Tl combination. Presently, one has 4xLaBr/NaI and 5xCeBr/NaI Phoswiches under test. In collaboration with the University of York group, a SiPM array (SENSL J-series) is under test for the readout of these detectors. Furthermore, one has at the ATOMKI van de Graaf facility used several (p,gamma) reactions in order to have well-defined high-energy gamma rays up to 17.6 MeV.

At TUM, one is developing a new vey fast readout electronics: a GHz sampling add-on-board to be used to enhance the existing FEBEX3 50 MHz board. This development is important to be able to have an efficient *pulse-shape-analysis* readout of fast Phoswich detectors at a reasonable price. One has also developed the iPHOS technique that makes possible the gamma-ion identification in single crystals.

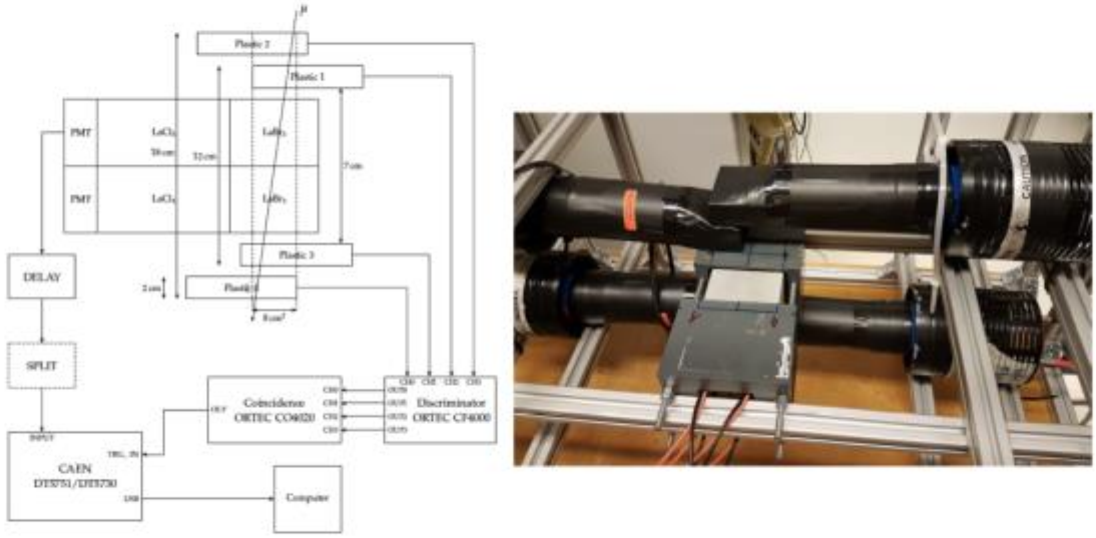

Figure 1: Setup used for measuring signals generated by muons. The fours plastic scintillators makes up the trigger. Once a coincidence of all four detectors occurs triggers the digitizer, allowing to record the pulses caused by the muon in the LaBr3 crystals. To left is shown the electronic scheme, and to the right a photo of the setup. (From Master thesis by Giovanni Bruni: *Development of Front-End Readout for the CALIFA Detector,* Subatomic Physics CTH 2017.

TASK3 Hybrid arrays and their applications: (U York – USC – IFJ PAN)

A third task of this project will be to investigate hybrid detector arrays. By hybrid arrays, we mean highly-segmented assemblies of different scintillator materials, and also the combined use of photosensors on the same detector package; for example, position sensitivity achieved with SiPMs on one side and a PMT on the other to obtain the best energy or timing resolution. This task will also address societal applications outside fundamental research. Such applications span a broad range from medical imaging to homeland security.

Research and development have been carried out into hybrid scintillator detectors for nuclear physics and societal applications. The focus is on the potential for the application of SiPMs for light collection. Their excellent performance has been demonstrated in terms of energy resolutions comparable to the best obtained with regular PMTs – close to 3% at 662-keV when coupled to $LaBr_3$. Moreover, specific technical issues in their deployment have been overcome through development of a bespoke temperature-stabilising bias circuit. SiPMs facilitate innovative solutions for light collection unachievable with PMTs and show excellent promise for realising the determination of point of interaction within large scintillator crystals. Hybrid prototype designs are advanced on this basis. They will be the subject of Monte-Carlo simulations. Data will be obtained with a bespoke collimated-beam scanning system, which will allow to evaluate the prototype detector performance in the next phase of the project. The progress of this work is detailed in the Deliverable D9.2.

We have considered two choices for the SiPMs to be used in this project. The first are from Hamamatsu - a major international company based in Japan - which manufactures all kinds of photosensors including PMTs. The second option are SiPMs produced by SensL, a smaller spin-off company from University College Cork and based in Ireland. The York group has collaborated with SensL for the last ten years both directly and through their industrial partners, Kromek PLC. With Kromek, the York group developed a hand-held radiation detector based on a SiPM coupled to a CsI(Tl) crystal [1]. This product has transformed into the D3S [2] wearable radiation detection system. This company has recently received a $6M order for 12000 units from the US government. The strong experience of working with SensL both directly and indirectly dictated the choice of sensor.

[1] http://kromek.com/index.php/products/all-nuclear-products/sigma
[2] http://kromek.com/index.php/link-3/oem-solutions/ubiquitous-radiation-network-solution

SUBTASK 3.3 Secondary Electron Emission: (GSI – U Cologne – U Rzeszow)

This part of the collaboration is investigating basic properties of secondary electron emission (SEE) from selected nanomaterials. It is still unknown what properties of material influence the enhancement of SEE under influence of ionising radiation. There has been a vast amount of new materials developed around the globe. Most of them have never been tested for SEE properties and as potential candidates for development of new class of radiation detectors. These detectors are of great interest for both, analytical industry and scientific community. There is a constant demand in the scientific community and industry for highly efficient and high-speed detectors systems. We are developing a new class of detector(s) based on these nanomaterials. A detailed report on the activity can be found on the PASPAG webpage http://www.iem.cfmac.csic.es/departamentos/nuclear/WEB-PASPAG/webstyle1/ .