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**

OBJECTIVES

The PASPAG JRA aims to improve infrastructure for European Large Scale Facilities such as FAIR, 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

In this JRA, we will exploit novel scintillator materials and explore new techniques and concepts such as phoswich detectors and segmented or hybrid scintillators. We will focus on developing the capability to simultaneously detect high-energy gamma rays, neutrons and charged particles. The emphasis will be on a modular approach both in the scintillator crystals and photosensors as well as in the electronics where improved throughput and effective data processing will allow for compact scalable devices. This JRA will also look to taking this technology out of basic science so that it can 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 differing importance.

The work of this JRA serves to broaden the physics cases which can be addressed by gamma-ray spectroscopy. There are important synergies with other work packages within this overall project, e.g.: NA NUSPIN, JRAs AGATA and ECOS2 (particularly in connection with detection under high intensity conditions) and TNA as NLC for detector tests.

The JRA is organised into different tasks, strongly connected with each other that range from the identification and characterisation of new materials (TASK 1) to the construction of small-size phoswich prototypes (TASK 2) and hybrid detectors (TASK 3), to be used in applications.

TASK1 Novel Scintillator Materials:

A wide range of promising new scintillators are becoming commercially available, such as CeBr₃, CLYC [1] and GAGG; others such as GYGAG:Ce, CLLB, CLLC, will be available in the near future. It has also recently been discovered that co-doping inorganic scintillators might increase the crystal proportionality and significantly improve the energy resolution [2]. It is not clear, however, how these developments in scintillator performance might translate into practical applications for nuclear physics and the new materials need to be characterised in this regard.

SUB-TASK 1.1: Basic R&D on developing new scintillators is outside the scope of this project. Instead, we will obtain commercially-available scintillators and work closely with industry, using our contacts to obtain small samples of new materials not yet on the market. The project will focus on characterizing such materials and exploring their combination with different photosensors in order to identify their usefulness in basic research and societal applications. Key parameters to be explored

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are energy resolution, timing resolution, particle pulse-shape discrimination, radiation hardness and efficiency.

SUB-TASK 1.2: Thin crystals of high light-yield scintillators such as LaBr₃:Ce could potentially provide position sensitivity due to the effective localisation of the scintillation light. This feature could be used to tackle the challenge of Doppler Broadening in nuclear physics but would also be extremely useful in several societal applications, for example, homeland security, medical imaging or radiotherapy. We will construct an 'imager' using scintillators with one or two transparent windows. The system will be optimised in terms of choice of photosensor and geometry. Algorithms will be designed and tested to reconstruct the position resolution.

The output of this Task (Deliverable) will be two-fold: firstly, a report on the performance of various novel scintillators for nuclear physics applications in terms of response to gamma rays, thermal and fast neutrons; the second deliverable will be the prototype 'imager'.

TASK2 Phoswich detectors:

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. Phoswich solutions are attractive for discriminating high-energy charged particles and gamma rays. They can also be a good solution for making economic use of novel scintillators to make detectors which have high energy resolution for low-energy gamma rays and high efficiency at the expense of resolution for high-energy gamma rays.

SUB-TASK 2.1: As the peak wavelength of emission from novel scintillators can vary strongly, it will be necessary to explore the optimum coupling to high-performing photo-sensors including ultra-bright PMTs and solid-state replacements such as silicon drift detectors (SDD) and silicon photomultipliers (SiPM).

SUB-TASK 2.2: To separate the different components in the light emission, digital systems based on flash ADCs may be the most flexible solution. The amount of data has to be reduced by digital preprocessing in the frontend. Optimized algorithms have to be developed to deliver sufficient performance and throughput. Dedicated in-beam tests are foreseen at the proton beam facility in Krakow and heavy ion facilities in Orsay and Warsaw.

The output of Task2 will be the construction and evaluation of various prototype phoswich designs.

TASK3 Hybrid arrays and their applications:

A third strand 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 strand will also address societal applications outside fundamental research. Such applications span a broad range from medical imaging to homeland security.

SUB-TASK 3.1: Novel scintillators with improved energy resolution, coupled to silicon photomultipliers or APDs in combination with digital pulse processing will provide a route forward for various applications requiring good timing properties or high-rate capability. Timing resolutions of

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100s of ps for some silicon photomultipliers [3] mean that this technology is very relevant to applications like PET imaging. We will construct hybrid detector systems (phoswich) with layers of different scintillators and semiconductors of high timing- and energy- resolution in order to improve SPECT imaging by removing physical collimation. This will exploit the Compton camera technique.

SUB-TASK 3.2: Applications in the area of homeland security, where illicit movement of fissile material and dirty bombs are of particular concern. The radioactive material should be localized and identified from drones or other mobile vehicles. Advances in signal processing and digital electronics offer considerable scope for development and improvements for these applications. Greater sensitivity can be envisaged in radionuclide identification and characterisation. We will, by using the phoswich technique in combination with digital pulse identification, build segmented detectors that can be carried by drones, and thus be able to determine the direction (localize) and identify hidden radioactivity.

SUB-TASK 3.3: New scintillator materials are of particular interest in nuclear structure applications with radioactive beams. Excellent timing and energy resolution is needed in order to discriminate rare events of interest from dominant background. A test setup, combining particle-tracking detectors with high-resolution scintillators will be realised and employed at GSI.

The output of Task3 will be a report summarising the achievements .

- [1] http://rmdinc.com/clyc
- [2] F.G.A. Quarati et al., Nucl. Intrum. Meth. A 735, 655 (2014).
- [3] http://sensl.com/products/silicon-photomultipliers/bseries/

DELIVERABLES

Deliverable (number)	Deliverable name	Work package number	Short name of lead participant	Туре	Dissemination level	Delivery date
WP1.1	Scintillator Materials	TASK1	INFN	Report and imager	PU	36
WP1.2	Phoswich Assemblies	TASK 2	CSIC	Prototypes	PU	42
WP1.3	Hybrid arrays	TASK 3	U.YORK	Report	PU	52

Table 3.1c: List of Deliverables