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Construction of the UK DESPEC Array for Fast-Timing Measurements

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Abstract. UK NuSTAR is the largest Nuclear Physics project, presently funded by the UK Science and Technology Facilities Council. The project aims at construction and delivery of equipment for the R^3B, HISPEC, and DESPEC experiments at FAIR. In this contribution, the status of the UK DESPEC work package and related activities will be presented.

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1 Introduction

The Nuclear chart contains 294 mass chains with more then 3000 nuclei experimentally studied. Only a small fraction of these nuclei ($\approx$282) are stable, while the majority of them are either naturally radioactive or artificially produced. It is believed that the nuclear landscape can be further extended by more than 3000 nuclei, which presently represents the 'Tera incognita' on the Segre chart. What is more tantalizing, however, is the range that nuclear lifetimes can span. The range of nuclear lifetimes covers more than 50 orders of magnitude from the shortest-living resonances, such as ^{15}F with $T_{1/2} = 380 \times 10^{-24}$ s, for example, to lifetime much longer than the age of the Universe, such as the ground state of ^{116}Cd, for example, which has $T_{1/2} = 3.3 \times 10^{19}$ y. In such a wide range precise lifetime measurements cannot be made with a single instrument and by using one sole method. Therefore, in the last century, a vast variety of methods and instruments were elaborated for lifetime measurements. Among these are the Coulomb excitation, Nuclear Resonance Fluorescence, Doppler Shift Attenuation methods, Recoil Distance Doppler Shift and direct Electronic Timing methods. These are reviewed in [1] and represent only few of the timing methods used for measurements in the 'narrow' range of few femtoseconds to several nanoseconds. While these methods have been deployed for stable nuclei, or for nuclei placed close to the line of β-stability, their application for lifetime measurements in exotic nuclei produced in contemporary Radioactive Ion Beam (RIB) Facilities is far of being straightforward.

This contribution reports on the construction of a device, designed to measure lifetimes in exotic nuclei and sensitive in the range of few tens of picoseconds to a few nanoseconds. The detector system, built in UK within the UK NuSTAR grant is to be used at Facility for Antiproton and Ion Research (FAIR) and represents a core equipment of the international FAst TIMing Array (FATIMA) Collaboration [2].

2 UKNUSTAR Project

2.0.1 FAIR

In the last few decades RIB Facilities have emerged all over the world with leading centres in Europe, Japan, US and China. The largest European RIB project is FAIR [3], which is still under development and is expected to become operational in the year 2022. This successor of GSI will provide exotic nuclei produced in fission and fragmentation reactions with heavy ions at relativistic energies. The cocktail of fragments will be separated in-flight by using the SuperFRS magnetic spectrometer, consisting of six dipole magnets, quadrupole focusing elements and beam tracking particle detectors. In one of the final foci of the SuperFRS, the Low Energy Branch (LEB) building will accommodate the HISPEC (HIgh-Resolution In-flight SPECtroscopy) and DESPEC (DEcay SPECtroscopy) experiments of the NuSTAR[2] project. The HISPEC/DESPEC experiments will aim at high-resolution in-beam and decay γ-ray spectroscopy in exotic nuclei. FATIMA is the core DESPEC device, constructed to operate down to the sub-nanosecond time range.

2.0.2 Project Goals

The UK contribution to FAIR is realized trough the UK NuSTAR grant [4], funded by STFC (Science and Technology Facilities Council). The project commenced on 1st of April 2010 and will be closed on 31st of March 2016. The work on the project is organized in three work packages (WP) aiming at delivering core equipment for R^3B (Reaction with Relativistic Radioactive Beams),

[2]NuSTAR collaboration has 800 members and is one of the four FAIR pillars

HISPEC [5] and DESPEC [6] experiments. The R^3B devices, delivered by the UKNUSTAR project, are the Si Tracker [7], mounting and support mechanical structures, as well as associated Electronics and Data Acquisition (EDAQ). The HISPEC components, delivered by the present project, are the large LYCCA stop detector which is now built and tested, mechanics, and EDAQ. Finally, UK builds a system of fast-timing detectors [8] for DESPEC, which represents a core part of the international Fatima Collaboration. The UK system comprises 36 $LaBr_3$:Ce detectors, mechanics and EDAQ stand alone system. The UK FATIMA project is in its final stage with the in beam commissioning expected at the last quarter of year 2015.

2.0.3 Project Organization and Resources

The UKNUSTAR Project uses a tailored PRINCE2 [9] environment. The project has four levels of Management. These are the Oversight Committee (OsC), UK NuSTAR Project Management board, Project Manager and Work Package Leaders. The OsC is appointed by the STFC and is external to the project. It oversights the project, monitors project progress through reports due twice a year, and advises STFC. The UKNUSTAR Management board gives add hoc directions and manages by exception. It comprises 13 members and meets four times a year. The UK NuSTAR Project manager is responsible for the day-to-day management of the project within defined tolerances. The Work Package leaders are responsible for the delivery of the project products.

Eight UK universities and STFC Daresbury are involved in this project. The resources, with which the UKNUSTAR project disposes, are 8.5M British pounds. For the duration of the project, a total of 75.5 FTE were allocated to all work packages. The DESPEC WP represents the smallest share of the UK NuSTAR project. Its budget is 1.2M and the manpower amounts to 12 FTE, allocated for the duration of the project [10].

3 UK DESPEC

3.1 Product description

The UK FATIMA array has 36 $LaBr_3$:Ce detectors, each of which comprising cylindrical crystals with sizes of 2" in length and 1.5" in diameter. The crystals are optically coupled to fast 8-stage R9779 photomultiplier tubes (PMT) with one dynode and one anode outputs from the PMT base. The PMT has 0.8 mm thick μ-metal shield. The detectors are individually mounted in aluminum alloy cans. The $LaBr_3$:Ce crystals are shielded from scattered γ rays via lead rings, placed on the top of the front cap of the aluminum cans.

The FATIMA array, shown in Figure 1, will be mounted at the final focus of the SuperFRS, around the position sensitive implantation and decay detector

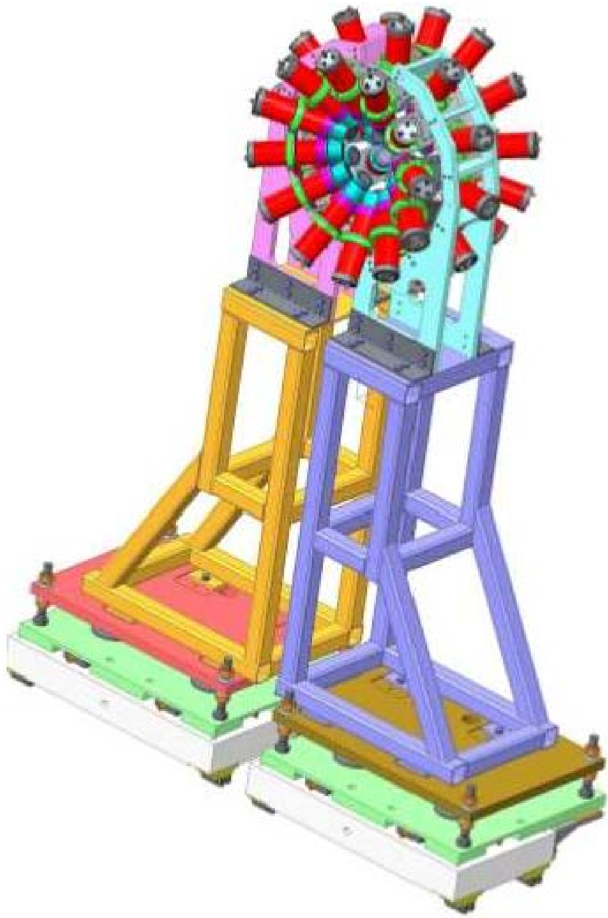

Figure 1. (Color online) A CAD image of the FATIMA array and support structure to be used at FAIR

AIDA [11]. Different mounting geometries were analyzed in order to optimize the performance of the system [12]. The selected design is a ball of detectors, focused in the geometric center of the array. Based on this analysis, a mechanical set up, capable to accommodate three rings of 12 detectors has been built. By using this set up, the detectors in the two outer rings will be placed at $\pm 44^{\circ}$ with respect to the beam axis in GSI/FAIR. The detectors in the inner ring will be mounted at 4° with respect to the beam axis. A fourth ring is envisaged to accommodate $LaBr_3$:Ce from within the international FATIMA collaboration. The weight of the holding structure and the mechanical frame is 378 kg, without the $LaBr_3$:Ce detectors. The beam height is 167 cm.

The signals from the UK FATIMA will be processed by a VME-based Electronics and Data Acquisition system, commercially available from CAEN. This design is rather unconventional for the international FATIMA collaboration, which uses mainly NIM-based front-end electronics, but our solution allows for a high integrity of the system while keeping the cost of the 36-channel EDAQ minimal. This design is based on analogue VME timing, comprising three Constant Fraction Discriminators V812B and two Time-to-Digital Converter, model V1290A. The energy signals are analyzed by five V1751 1-GHz digitizers. The TDC and the digitizers are synchronized with the aid of a V1495 modules. The entire EDAQ is fitted within one crate with 32 slots, leaving enough space for additional equipment to be hosted, if needed. The data readout is trough the V2718KIT controller, connected to a PC via an optical link to A3818 VME-to-PCI bridge. The EDAQ is remotely controlled by MIDAS package, developed in Daresbury laboratory. HV power supplies for the 36-detector system are fitted within another crate. The EDAQ and the HV crates are accommodated within a flight rack.

The UK FATIMA array is modular and flexible to operate with external devices. The system can accept external triggers, time stamps and data word numbers by using a V1495 module, which hosts mezzanine cards allowing to interface the system with other VME- and NIM- based systems.

3.2 Quality tests and commissioning

The UK FATIMA array is now built and its detectors were tested with sources in the Environmental Laboratory at the University of Surrey, and in a number of in-beam experiments worldwide. Experiments with stable beams were performed at NIPNE-Romania [13], Birmingham-UK, and JYFL-Finland. They have been also used in one n-induced fission experiment at ILL-France [14], and recently with radioactive beams in RIKEN-Japan [15].

The energy resolution of the system is about 3% for the 662-keV line of ^{137}Cs. The efficiency of the whole system is estimated to 7%, obtained for a system comprising 36 $LaBr_3$:Ce detectors [12]. The time resolution, obtained with two $LaBr_3$:Ce detectors and a ^{60}Co source, is 272 ps.

The commissioning of the EDAQ system is planned for the last quarter of FY2015/16. The aim of the commissioning is to test the conceptual design of the system in a stand alone mode, but also, given that FATIMA will always be used in conjunction with other devices, to test its integration capabilities. Thus the aim of the commissioning is to prove the system is working, and to test its performance in a more realistic environment at higher background and at higher count rates.

As discussed above, FATIMA will not be operational at FAIR in the near future. Therefore, the full array is planned to be operated in two separate campaigns outlined in the following sections.

3.2.1 GANIL campaign

In this campaign, FATIMA will be operated with VAMOS [16] and AGATA [17] as shown in Figure 2 and will be mounted on the EXOGAM frame [18]. The $LaBr_3$:Ce detectors will be 'packed' in FATIMA triple clusters and mounted at the EXOGAM frame openings, placed at 90° with respect to the beam axis. This allows for the 24 detectors to be placed 11.5 cm to the target position. The $LaBr_3$:Ce will be shielded from the VAMOS fringe field via extended EXOGAM μ-metal shields. The EDAQ integration logic is realized with a V1495 commercial module. Common time stamps, data word numbers and trigger signals will be received from the GANIL Centrum module.

Three experimental proposals, requesting FATIMA, were approved and will be scheduled in 2017.

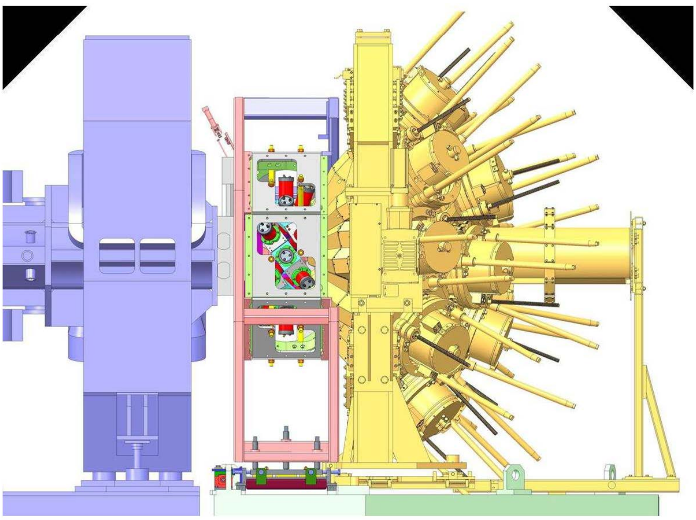

Figure 2. (Color online) Mechanical integration of FATIMA with VAMOS (in blue) and AGATA (in yellow). FATIMA $LaBr_3$:Ce detectors will be mounted on the EXOGAM structure, in between VAMOS and AGATA.

3.2.2 Argonne campaign

The conceptual design of the FATIMA integration to the Gammasphere (GS) [19] is based on previous experience with other hybrid arrays [13, 15], as well as on previous experience with the GS [20]. In this campaign independent mechanical structure shown in Figure 3, 25 $LaBr_3$:Ce detectors will be mounted in an area traditionally designated for one of the Gammasphere hemispheres. The closest distance from the target, at which the $LaBr_3$:Ce detectors will be mounted, is 13 cm. The second half of the GS hemisphere will be covered by 55

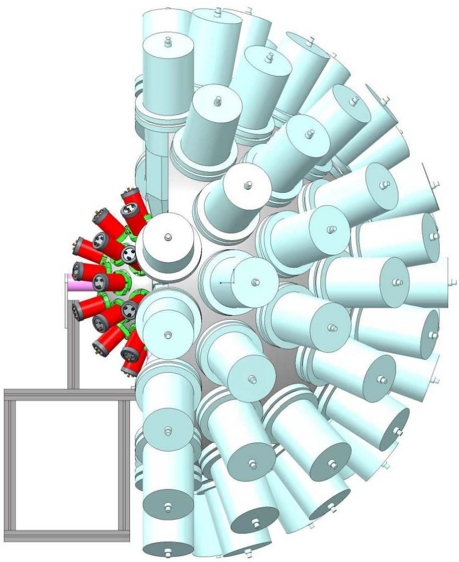

Figure 3. (Color online) Mechanical integration of FATIMA with Gammasphere.

Gammasphere HPGe detectors. As in the GANIL case, FATIMA will be able to receive time stamps and trigger from the digital GS by using the V1495 module set to communicate with the Argonne MyRIAD card [21]. The digital Gammasphere will run in a triggerless mode and will trigger FATIMA whenever any of the HPGe detector is fired. This operational mode will allow to reduce the size of the data while keeping the necessary minimum of information, needed for lifetime measurements.

We have one LoI and one experimental proposal approved by Argonne PAC and a 30-day long run with ^{252}Cf source is scheduled for the Christmas break of year 2015.

3.3 Project Benefits

The FATIMA multidetector array will be sensitive in the nanosecond and sub-nanosecond timing range, which extends the lower time range limit of the existing HPGe arrays by three order of magnitudes. Thus, a combined hybrid array comprising large number of $LaBr_3$:Ce and HPGe detectors, 'a la' RoSphere [13], can cover over six orders of magnitudes, allowing measurements of isomeric states and shorter lived states to be done without changing the experimental set up. Such a device will open new horizons in the study of the evolution of collectivity, evolution of single particle states, internal structural changes etc.. Recently, new results were obtained on the half-life of the 2^+ state in ^{106}Zr [15], for example, which would not be achievable with the conventional HPGe detectors. It is interesting to note also that there are about 4000 states with half-lives measured in the range from few picoseconds to few nanoseconds. One can expect as many states in the nanosecond and sub-nanosecond range in the nuclei placed in the 'Tera incognita', which opens exciting new possibilities for the application of FATIMA in the quest for new nuclear physics phenomena.

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