THE UK NuStAR PROJECT*

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The UK NuStAR project is the largest nuclear physics project presently funded by the Science Technology Facilities Council (STFC) in UK. The aim of the project is to design, construct and deliver detectors and subdetector systems for FAIR. The main project deliverables are a DESPEC multidetector array for fast timing measurements, a HISPEC ToF detector for mass measurements after the secondary target, and the Si tracker for precise vertex determination in R^3B experiments with liquid hydrogen target.

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1. Introduction

The UK NuStAR project [1] aims at the design, construction and delivery of equipment for FAIR (Fcility for Antiproton and Ion Research) [2], one of the biggest international accelerator facilities which presently is under construction.

FAIR will deliver beams for APPA (Atomic, Plasma Physics and Applications), CBM (Compressed Barionic Matter), NuStAR (Nuclear Structure, Astrophysics and Reactions), and PANDA (anti-Proton ANnihilation at DArmstadt) collaborations, representing the four pillars of FAIR. This facility will be built by a consortium of institutions from twelve member countries, one of which is UK.

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The NuStAR Collaboration comprises nine experiments with more than 700 scientists from more than 170 institutions worldwide. These experiments are: HISPEC (HIgh-resolution SPECtroscopy), DESPEC (DEcay SPECtroscopy), R^3B (Reactions with Relativistic Radioactive Beams), MATS (precision Measurements of very short-lived nuclei with Advanced Trapping System), LaSpec (Laser Spectroscopy), ILIMA (Isomeric beams, LIfetimes and MAsses), ELISe (ELectron-Ion Scattering in a Storage Ring), EXL (EXotic nuclei studied in Light-ion induced reactions at the NESR storage ring), SuperFRS Experiments, SHE (Super-Heavy Element Research).

UK has the responsibility for building of a fast-timing detector array for DESPEC, Time-of-Flight (ToF) detector for HISPEC and the Si tracker for R^3B. These three detectors, built within the UK NuStAR project, together with the implantation and decay detector AIDA, constitute the UK contribution to FAIR. An overview of the UK NuStAR project and its deliverable will be given in the present manuscript.

2. Overall organization

The UK NuStAR project is the largest nuclear physics project presently funded by the Science and Technology Facilities Council (STFC) in UK. The project involves eight UK universities (University of Birmingham, University of Brighton, University of Edinburgh, University of Liverpool, University of Manchester, University of Surrey, University of West of Scotland, University of York) and the STFC Daresbury Laboratory.

The UK project had started on the 1^{st} of April 2010 and will be closed on the 31^{st} of March 2016. It disposes with a budget of over 8M British pounds, 7.4M of which are provided by the UK Science Technology Facilities Council (STFC). For the duration of the project a total manpower of ≈ 80 FTE was allocated.

The UK NuStAR project management uses a tailored PRINCE2 environment. The project has four levels of management. These are the Oversight Committee (OsC), UK NuStAR Project Management Board, Project Manager and Work Package (Team) Leaders. The OsC is appointed by the STFC and is external to the project. It oversights the project, monitors the project progress through reports due twice a year, and advises STFC. The UK NuStAR Management board manages the project by exception and gives *ad hoc* directions. The board 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 Team Leaders are responsible for the delivery of the project products.

The work on the project is organized in three work packages (WP) focused on the construction of DESPEC, HISPEC and R^3B equipment. The Team Leaders liaise with all identified national and international share holders, regarding the respective work package, and with the Project Manager (PM) and the Project Principal Investigator (PPI). The Team Leaders, PM, PPI and the Institutions' PIs constitute the UK NuStAR Management Board.

The WPs control is exercised via quarterly finance reports delivered by each of the institutions involved in the project, and via monitoring of the WP progress against the plans approved by the UK NuStAR Management Board. The UK NuStAR project progress is monitored by the Management Board and reported to the OsC twice a year.

In-process and appraisal methods are used to control the quality of the UK NuStAR products. The in-process methods were used to test the equipment *versus* pre-defined criteria at different construction stages. Appraisal of some of the final products was performed with sources and in-beam.

A risk management strategy was set in order to identify, assess and control the risks associated with the delivery of the three work packages. The UK NuStAR working allowance budget amounts to 0.7M British pounds.

3. Project work packages

3.1. UK DESPEC

The UK DESPEC (DEcay SPECtroscopy) [3, 4] work package (WP) aims at the design, construction and delivery of detectors, electronics and mechanics for the FAst-TIMing Array (FATIMA), as part of the international FATIMA Collaboration [5]. FATIMA is a γ-ray array which will be used for sub-nanosecond lifetime measurements in DESPEC experiments. The equipment, built within the present project, comprises 36 $LaBr_3$:Ce detectors and associated Electronics and Data Acquisition (EDAQ) system, as well as mechanical support structure and integration to the LEB infrastructure, shown in Fig. 1.

The $LaBr_3$:Ce detectors are built of cylindrical crystals doped with 5% of Ce and having sizes of 2 in in length and 1.5 in in diameter. The crystals are optically coupled to fast 8-stage photomultiplier tubes and mounted inside aluminium alloy cans.

The scintillator detectors issue two signals — dynode and anode for energy and timing measurements, respectively. The energy signals are processed by 1 GHz VME digitizers, model V1751C procured from CAEN. The time signals are processed by three 16-channel Constant Fraction Discriminators, model V812B, and two 32-channel Time-to-Digital Converter (TDC) with a resolution of 25 ps, model V1290A, commercially available from CAEN. This approach, which is rather unconventional for the international FATIMA Collaboration where Ortec-based NIM front-end electronics (FEE) is used, allows for a more compact FATIMA FEE configuration. The

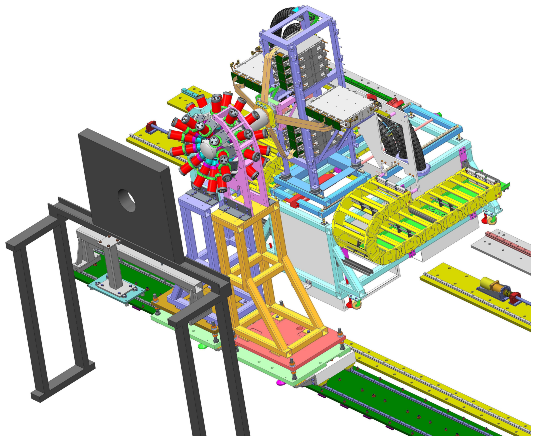

Fig. 1. DESPEC layout.

electronics, needed for all 72 energy and time channels, is fitted within one 21-slot VME crate. Optical fibre connects the V2718KITB crate controller with a A3818 VME-PCI bridge, mounted on the EDAQ computer PCI bus. A logic module V1495, with programmable FPGA, allows for synchronization of the 1 GHz digitizers with the TDC.

Given that FATIMA has a fast timing response but a poor energy resolution, the system will operate in a stand alone mode only in experiments where only few, well-separated, γ rays are emitted. In all other cases, FATIMA has to be in conjunction with other detectors. In particular at FAIR, it will be used with the SuperFRS particle detectors and in coincidence with AIDA (Advanced Implantation Detector Array) [6]. The SuperFRS detectors provide particle identification after fragmentation and fission of relativistic beams. The AIDA detector, placed in FATIMA geometric centre, provides high resolution measurement of the heavy ion implantation position. This information is crucial for FATIMA, given that the change in the implantation position along the x-axis, perpendicular to the beam axis, can lead to a γ-ray flight time difference of up to several hundreds of picoseconds, which is comparable to the $LaBr_3$:Ce time resolution.

The FATIMA EDAQ integration into DESPEC EDAQ will be achieved via a V1495 logic module, which is also used for the TDCs synchronization with the digitizers. This module hosts mezzanine cards, series A1535, capable of receiving and issuing VME and NIM signals. The module can receive and deliver clock signals from and to external devices, but also trigger signals and word numbers. This allows for the system to be highly integrable to other external devices. In July 2015, the EDAQ was successfully tested at GANIL where time stamps, data word numbers and trigger signals were received by a GANIL Centrum card.

At FAIR, the 36 $LaBr_3$:Ce detectors will be arranged around AIDA in three rings. The geometrical structure was designed by STFC Daresbury after Monte Carlo simulations [7] and extensive tests of the $LaBr_3$:Ce detectors with sources at the Environmental Lab at the University of Surrey, and with stable and radioactive beams at the University of Birmingham (UK), IFIN-HH (Romania), ILL (Grenoble), JYFL (Jyväskylä), and RIKEN (Japan).

The FATIMA array will be operational in the sub-nanosecond time range, *i.e.* much faster than the existing HPGe detector arrays, but also will be more efficient for low energy X and γ rays.

3.2. UK HISPEC

UK HISPEC (HIgh-resolution in-flight SPECtroscopy) work package aims at the design, construction and delivery of a Time-of-Flight (ToF) detector for the Lund-Y-Cologne CAlorimeter (LYCCA) [8]. LYCCA will be mounted at one of the SuperFRS focal planes, where the LEB building will host HISPEC and DESPEC equipment, and will work in coincidence with the high resolution gamma spectrometer AGATA [9]. Indeed, LYCCA was recently used in conjunction with AGATA during the PreSPEC campaign [10, 11]. The PreSPEC campaign at GSI is the predecessor of HISPEC. The UK, and Daresbury in particular, has a leading role in the AGATA–LYCCA coupling design.

LYCCA will be used to deduce proton numbers Z and mass numbers A from energy loss, total energy and Time-of-Flight (ToF) measurements for recoils obtained after the secondary target. LYCCA, equipped with the Large Stop detector, will provide mass identification with a resolution of $M = 0.5\,u$ due to the fast response of the scintillator detector used. Its time resolution is 43 ps.

The large stop detector design is based on extensive studies with large area polycrystalline diamond detectors [12] and plastic scintillators [13]. In-beam tests were performed with the two detector types [8]. As a result, the plastic scintillator was chosen as material to be used for the construction of the large stop ToF detector, now built by UK.

The large stop detector, mounted inside the LYCCA chamber shown in Fig. 2, consists of a scintillator membrane with a diameter of 40 cm. The readout of the light signal is through 56 fast photomultiplier tubes. The PMTs are mounted on a ring around the membrane and fixed by using a silicon rubber. The detector is mounted on a mounting flange and fixed by clamping rings. Blackout material, placed in front and behind the LYCCA stop detector, shields it from background photons. The entire detector is then mounted on a horseshoe, which accommodates also the LYCCA DSSD front-end electronics (FEE) arranged in a ring at 90° with respect to the beam axis. The FEE of the LYCCA DSSD wall consists of AIDA-type Application-Specific Integration Circuit (ASIC) microchips.

In 2016/17 LYCCA will be used at the University of Cologne in anticipation of the beams at GSI and FAIR.

Fig. 2. LYCCA chamber with the large stop detector and the FEE cards wired and mounted on the horseshoe structure at Daresbury.

3.3. UK R^3B

The UK R^3B is the largest of all three UK NuStAR WPs. The WP disposes with a budget of 5.1M pounds. The manpower committed to the WP is 45.5 FTE from the University of Birmingham, STFC Daresbury Lab., University of Edinburgh, University of Liverpool, and University of Surrey. The aim of the work package is to design and construct the Si tracker for the R^3B NuStAR Collaboration, which comprises the construction of the Si tracker detector, mechanics support structure, target chamber and the R^3B target mechanism, front-end electronics and data acquisition. The Si tracker will be used for precise position measurements with the liquid hydrogen target.

The tracker will be made of Double Side Silicon Strip (DSSSD) sensors. The Si sensors have a thickness of 300 μm and a strip width of 20 μm. The Si sensors, delivered by Micron, are tested in Liverpool and only those sensors passing the tests are accepted.

The tracker consists of two layers — one inner and one outer layer. The outer layer comprises 12 detectors, each of which consists of three 300 μm tick Si sensors. The inner layer comprises 6 detectors, each of which is built of two 300 μm tick Si sensors.

Because the ladders will be mounted in a close packed geometry, the readout will be performed from the back-end of each of the units. Therefore, the neighbouring sensors in one detector unit have to be electrically coupled on both sides and strip-by-strip, after they are being glued on a carbon fibre frame.

The readout from the Si detectors will be performed via custom made ASIC microchips. 16 chips will be used for the readout of each side of one Si detector unit, *i.e.* 32 per detector unit or 576 ASICs for the entire tracker. The chips are mounted on a buffer card and cooled by using copper blocks. Such assemblies are electrically coupled to each of the Si detector units. Assembling procedures and custom-made jigging for bonding of the Si sensors and the ASIC microchips to the Si ladders are shown in Fig. 3.

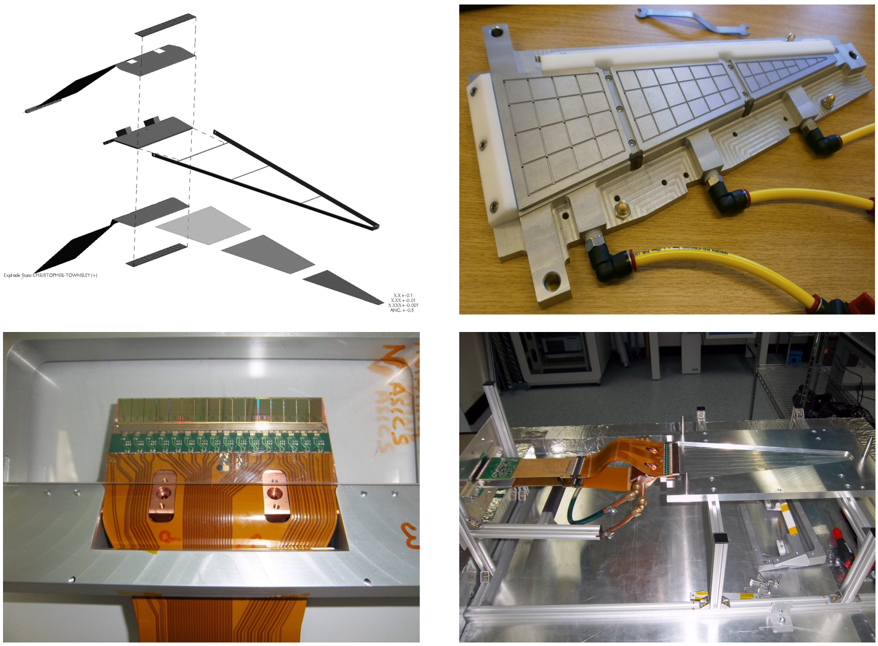

Fig. 3. Si sensor production procedure (upper left); Alignment jigging (upper right); Board with 16 ASIC microchips (lower left) and Jigging for coupling of the ASICs to the Si detector (lower right).

The Si tracker layers will be arranged in a conical geometry and will be placed inside CALIFA calorimeter [14], beam upstream before the superconducting GLAD magnet as shown in Fig. 4 (left). To validate the construction procedures, a test experiment was successfully performed at GSI in September 2014. Figure 4 (right) shows the Si tracker prototype tested in this experiment.

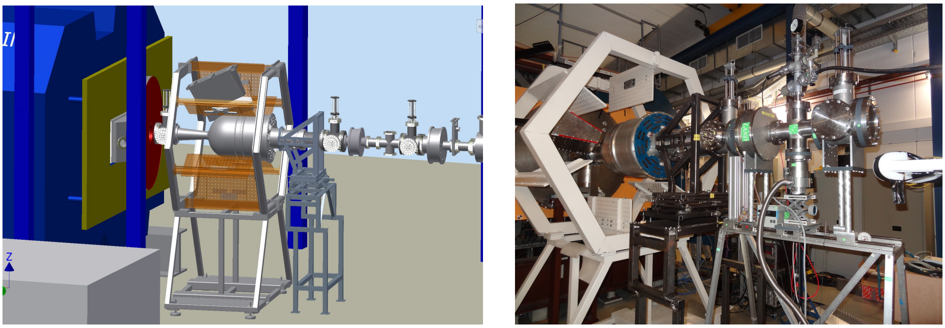

Fig. 4. Si tracker design (left). Si tracker support structure and vacuum chamber at GSI (Sept 2014) (right).

4. Conclusions

Three detector systems have been built in the UK for NuStAR at FAIR. A fast-timing array for sub nanosecond measurements for DESPEC, a ToF detector for HISPEC and the Si Tracker for precise vertex measurements in R^3B. In the next few years, different parts of these devices will be tested and used worldwide in anticipation of beams at GSI and FAIR.

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