Decay Spectroscopy of Exotic Nuclei at FAIR

Part I – Track Record

The members of our collaboration have played world leading roles in developing the burgeoning field of decay spectroscopy studies of highly exotic nuclei. Our collaboration is ideally placed to develop, and scientifically exploit, a new advanced technology implantation detector system for decay spectroscopy studies on the new Facility for Anti-proton and Ion Research (FAIR) at Darmstadt, Germany. This detector system will be instrumented with Application Specific Integrated Circuit (ASIC) technology. Research profiles of the individual participating institutions and the senior team members are given below.

The **Edinburgh Nuclear Physics Group** developed the world's first spectroscopy performance Double-sided Silicon Strip Detector (DSSD) system for implantation decay experiments on exotic nuclei. The high density micro-electronic instrumentation system was designed by Edinburgh (**Dr. Davinson**) jointly with the CCLRC Rutherford Appleton Laboratory (RAL) microelectronics group. The Edinburgh group led the development of the Recoil Decay Tagging (RDT) technique for use with large Ge gamma-detector arrays in collaboration with the Liverpool and CCLRC Daresbury groups. The Edinburgh group have used this instrumentation, and techniques to study the structure and decays of exotic proton drip-line nuclei. In both recent EPSRC IGR (Internal Grant Review) reports, the referees described the Edinburgh group's work in this field as "world leading". **Professor Woods** was elected the first spokesperson of the Decay Spectroscopy Group (DESPEC) for the FAIR project, and prepared and presented the original scientific Letter of Intent for this project. The science case was graded excellent (A) by the International Review Panel and DESPEC is now integrated within the overall FAIR project. Professor Woods is currently convener of the DESPEC DSSD group charged with producing a new generation DSSD system for the study of exotic nuclei using the new Super-FRS (Fragment Separator) facility at FAIR.

The **Liverpool Nuclear Physics Group** played the lead role in the development of the advanced GREAT (Gamma Recoil Electron Alpha Tagging) implantation detector system at the Jyvaskyla facility, Finland. In collaboration with CCLRC Daresbury, a new concept of triggerless data read-out (TDR) system was successfully developed for RDT studies. These systems have been used by members of the Liverpool and Daresbury groups to make internationally leading contributions to the structure and decays of heavy proton drip-line nuclei. **Dr. Page** and **Professor Nolan** have played prominent roles in campaigns of decay spectroscopy experiments at the GSI and GANIL fragmentation facilities, including beta decay studies of proton-rich nuclei, first half-life measurements of superallowed Fermi decays of odd-odd $N = Z$ nuclei, and studies of nuclei at the neutron drip line where both neutron and gamma-ray coincidences were analysed. Dr Page is a member of the DESPEC DSSD and gamma-ray detector groups, and is playing a key role in the forthcoming active stopper campaign at GSI.

The **CCLRC Daresbury Nuclear Physics Group**, led by **Professor Simpson**, has pioneered the development of large spectrometer arrays and is internationally recognised as a world leading nuclear spectroscopist. Professor Simpson is currently the Project Manager for AGATA (Advanced GAmma Tracking Array), chairperson of the RISING (Rare Isotope Spectroscopic Investigation at GSI) detector and infrastructure working group, and a member of the FAIR STI (Science and Technical Issues) working group, Daresbury has world class expertise in innovative nuclear physics instrumentation, in particular, high speed data acquisition and processing, systems control and analysis software. This expertise will be linked with the internationally recognised ASIC expertise of the microelectronics group at RAL. This will enable the collaboration to fully exploit the state-of-the-art DSSDs designed by Edinburgh and Liverpool. Senior team members at Daresbury include **I.Lazarus** and **P.J. Coleman-Smith** who were principally responsible for the successful development of the TDR system for the GREAT detector system. Lazarus is joint co-coordinator for ASIC developments for the NUSTAR (NUclear STructure and Astrophysics and Reactions) community at FAIR, and a key member of the NUSTAR data acquisition group. **V.Pucknell** is the UK's leading Nuclear Physics software engineer, responsible for many of the data acquisition systems used in many large experimental projects throughout the world.

The **CCLRC RAL Microelectronics Design Group** delivers typically 10 ASIC designs per year for research systems. It has 10 staff with over 100 years combined experience and is expert in very low noise applications for extreme environments. It maintains access to the software tools and mixed signal design flows for several leading-edge CMOS foundries. The group is responsible for the design of custom ASICs and interface electronics, and for subcontracting their manufacture. Currently their work includes high energy physics and scientific space applications. It has also developed a full set of radiation-hard high-resolution ADC and DAC devices for synchrotron instrumentation at CCLRC Daresbury. Medical applications include ASICs for the instrumentation of large area, thin film transistor arrays for semiconductor X-ray systems, and gamma cameras for real-time heart visualisation systems. Senior team members at RAL include **M.French** who is head of the microelectronics group, and has 15 years' experience in designing ASICs for scientific instrumentation. **S.Thomas** has over 15 years' experience of analogue IC design and is currently directing the design of low noise analogue systems for angiography systems, and is leading the development of new ASIC readout architectures for CCD applications in particle physics. He was the principal engineer who in collaboration with the Edinburgh group delivered the previous generation of world leading microelectronics instrumentation system for nuclear decay spectroscopy studies.

Key Scientific and Technical Publications by the Collaboration

Production cross sections of protactinium and thorium isotopes produced in fragmentation of ^{238}U at 1A.GeV
J. Kurcewicz, Z.Liu, M.Pfützner, P.J.Woods, T.Davinson *et al.*,
Nuclear Physics A (2006) in press.

Ground state proton radioactivity from ^{121}Pr: When was this exotic nuclear decay mode first discovered ?
A.P. Robinson, P.J. Woods *et al.*,
Physical Review Letters 95 (2005) 032502.

Decay spectroscopy of suburanium isotopes following projectile fragmentation of ^{238}U at 1 GeV/u
Z. Liu, J. Kurcewicz, P.J. Woods, T.Davinson *et al.*,
Nuclear Instruments and Methods in Physics Research A 543 (2005) 591.

Multi-strip silicon detectors for studies with low energy radioactive nuclear beams
T. Davinson, Nuclear Physics A 746 (2004) 188.

The GREAT Spectrometer
R.D. Page, J. Simpson, *et al.*,
Nuclear Instruments and Methods in Physics Research B 204 (2003) 634.

Rotational bands in the proton emitter ^{141}Ho
D. Seweryniak, P.J. Woods *et al.*,
Physical Review Letters 86 (2001) 1458.

Radioactivity - Are protons leaving in pairs?
P.J. Woods, Science 291 (2001) 995.

The GREAT Triggerless Total Data Readout Method.
I.Lazarus, P.J.Coleman-Smith, J.R.Cresswell, S.C.Letts, R.D.Page, V.F.E. Pucknell, J.Sampson, J.Simpson, J.Thornhill *et al.*,
IEEE Transactions on Nuclear Science 48 (2001) 567.

Louvain-Edinburgh Detector Array (LEDA): a silicon detector array for use with radioactive nuclear beams
T. Davinson *et al.*,
Nuclear Instruments and Methods in Physics Research A 454 (2000) 350.

Fine structure in the decay of the highly deformed proton emitter ^{131}Eu
A.A. Sonzogni, C.N. Davids. P.J. Woods *et al.*,
Physical Review Letters 83 (1999) 1116.

Observation of Fermi Superallowed β^+ Decays in Heavy Odd-Odd, $N = Z$ Nuclei: Evidence for 0+ Ground States in ^{78}Y, ^{82}Nb and ^{86}Tc
C. Longour, R.D. Page, *et al.*,
Physical Review Letters 81 (1998) 3337.

Proton radioactivity from highly deformed nuclei
C.N. Davids, P.J. Woods *et al.*,
Physical Review Letters 80 (1998) 1849.

Nuclei beyond the proton drip-line
P.J. Woods and C.N Davids,
Annual Review of Nuclear and Particle Science, 47 (1997) 541.

Nuclear Physics - proton decay at the drip-line
P.J. Woods, Nature 381 (1996) 25.

In-beam gamma-ray spectroscopy above ^{100}Sn using the new technique of recoil decay tagging (RDT)
E.S. Paul, P.J. Woods, T. Davinson, R.D. Page, I Lazarus, J. Simpson *et al.*,
Physical Review C 195 (1995) 51.

A Double-sided silicon strip detector system for proton radioactivity studies
P.J. Sellin, P.J. Woods, T. Davinson, R.D. Page, S. Thomas *et al.*,
Nuclear Instruments and Methods in Physics Research A 311 (1992) 217.

Decay Spectroscopy of Exotic Nuclei at FAIR

Part 2 – Case for Support

Background

Research in exotic nuclei is the key driving force in the development of modern nuclear physics, with several major new international exotic beam facilities being planned. This research is revealing new phenomena in nuclei far from stability, and is beginning to re-shape our understanding of explosive astrophysical events. Exciting new insights into nuclear structure, and nuclear astrophysical processes, will be revealed by exploring the properties of exotic nuclei at the next generation of exotic beam facilities, most notably at the new FAIR (Facility for Anti-proton and Ion Research) accelerator complex at Darmstadt, Germany.

The development of FAIR has been given the highest priority by the Nuclear Physics European Collaboration Committee (NuPECC), one of four Expert Committees of the European Science Foundation (ESF). The facility will have high energy (up to 1.5 GeV/u) heavy ion primary beams with 100 times the current intensities at the world leading GSI laboratory, Darmstadt. Exotic nuclei will be produced either by heavy ion fragmentation or fast fission of ^{238}U. Such Uranium beams are unique internationally, and have been described as "the Gold of GSI". These reaction products will be separated from the intense primary beams using the new, high acceptance, Super-FRS (Fragment Separator) device, leading to increases in the yields of exotic nuclei up to a factor of 10,000. This separation is efficient, fast ($\leq$ 100ns), and chemically non-selective. It allows the event-by-event identification of isotopes, and can be operated in "cocktail" mode, in which a number of exotic nuclei are simultaneously produced, or, a single isotope can be studied in isolation.

Decay studies lie at the very frontier of the field of exotic nuclei. Ultra-high sensitivity decay experiments - gleaning key physical information from a very small number of events - can be performed by implanting very short-lived isotopes into Double-sided Silicon Strip Detectors (DSSDs). In the present proposal we aim to design, construct and test a new Advanced Implantation Detector Array (AIDA) with ASIC-based instrumentation for charged particle decay spectroscopy measurements at the focal plane of the Super-FRS at FAIR. The timing of this proposal is driven by the need to deliver a fully operational implantation decay system for the scheduled advent of exotic beams in 2010. Such a system lies at the core of the highly rated DESPEC science programme for FAIR. The very recent international Review Panel assessment of Technical Proposals has reaffirmed that "DESPEC is a natural exploitation of the rare exotic beams that emanate from FAIR", and that "Decay Spectroscopy of new nuclei is one of the key elements of exotic nucleus research". Other European groups within the DESPEC (Decay Spectroscopy) and HISPEC (High-resolution in-flight spectroscopy) collaborations will take responsibility for development of the γ and neutron detector systems. Key aspects of the science programme are described below.

Science Programme

Accessing r-process Nuclei

The most spectacular astronomical events in the Galaxy are supernovae. There are two distinct categories: accretion driven events and core collapse. The former are currently understood as a carbon deflagration/detonation in a CO white dwarf that reaches the Chandrasekhar mass through accretion from a binary companion. The CO mass increases as hydrogen falls onto the star's surface and is converted via the hot CNO cycles. This mechanism naturally leads to reproducible light curves and the consequent usefulness of type Ia supernovae as standard candles for cosmology studies.

Core collapse supernovae occur in more massive stars. The out-going shock wave following core collapse is energised by a tremendous neutrino outburst which results in the large scale dissociation of nuclear material. Such a scenario is a likely site for the r-process, a succession of (n,γ) reactions on a timescale shorter than competing β-decays. An alternate site for the r-process may be the merging of two neutron stars, and recent observational data of non-solar abundances of medium-heavy elements ($Z \leq 50$) in very old (metal-poor) stars suggest there may even be a third possible r-process site.

The r-process is of fundamental importance for the synthesis of the heavy elements. An understanding of the r-process, and its astrophysical origins, has been identified as one of the 11 most outstanding issues in astrophysics by the recent U.S. National Research Council Committee on the Physics of the Universe. The path of the r-process is influenced by the lifetimes, β-delayed neutron branches, and neutron separation energies (S_{n}) of very neutron-rich nuclei (see figure 1). Decay studies using the proposed DSSD system will be required to measure lifetimes, and β-n branches, while precision mass measurements performed with an ion trap system will be used to derive S_{n} values. Only very limited pioneering studies of the properties of r-process nuclei have been performed so far, including measurements on the present FRS at GSI (involving the Edinburgh group), and at CERN on the ISOLDE facility. The high energy

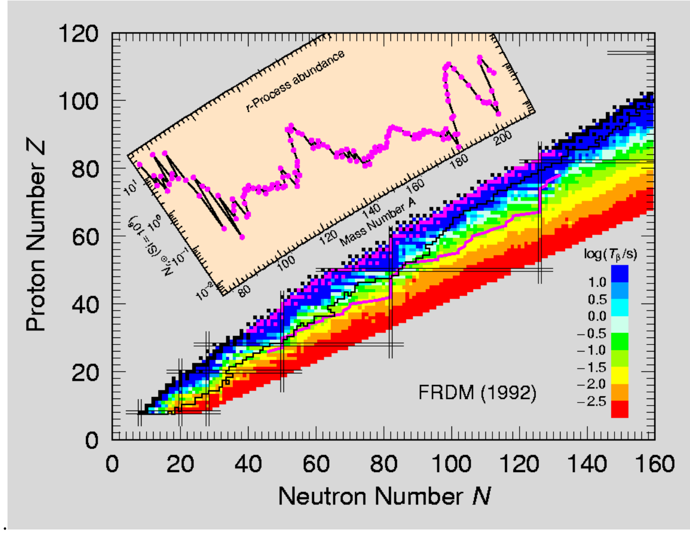

Figure 1: Beta decay half lives calculated in the framework of the finite-range droplet model (FRDM), and the most likely pathway of r-process nucleosynthesis (purple line). The inset shows the measured solar abundances of nuclei produced in the r-process; their maxima correspond to the neutron shell closures $N = 50, 82$ and 126.

fission of extremely intense beams of ^{238}U will allow the population of whole new swathes of nuclei lying along the r-process path. Detailed decay spectroscopic studies (β-γ and β-n) of very neutron-rich nuclei will provide valuable information on the development of nuclear structure between β-stability and the r-process path, as well as the first insights into the evolution of shell structure towards the neutron drip-line. This is of particular importance for the mass regions before and after the classical magic neutron numbers 50, 82 and 126 where phase transitions may occur associated with new magic numbers. Detailed simulation studies of elemental abundances are indicative of a possible quenching of shell structure in very neutron-rich nuclei. This is therefore a crucial issue for both nuclear structure and astrophysics. Measuring the β-decay of $Z = 40$, $N = 70$ ^{110}Zr, possibly replacing ^{122}Zr ($N = 82$) as the neutron-magic waiting point isotope, would be a key test of $N = 82$ shell quenching and the predicted development of new shell gaps very far from stability.

Nuclei Near the $N = Z$ Symmetry Line

Many of the salient themes of modern nuclear physics research come into play along the $N = Z$ line. These nuclei provide an ideal terrain for probing the charge independence of the strong force, and to study symmetry breaking effects which increase with nuclear charge, Z. In $N = Z$ nuclei, protons and neutrons occupy orbitals of identical quantum numbers. The resulting large spatial overlap of the neutron and proton wave functions may give rise to a new pairing phase in nuclei mediated by proton-neutron (p-n) Cooper pairs. In contrast to n-n or p-p pairs which couple only to isospin $T = 1$ and spin $S = 0$, p-n pairs couple to $T = 0$ and $S = 1$. β-decay studies of pairs of mirror nuclei will provide an ideal tool for exploring the strength of $T = 0$ and $T = 1$ pairing effects in nuclei, and can be used to explore isospin symmetry breaking.

Studies of superallowed Fermi β-decays from $N = Z$ and $N = Z - 2$ nuclei can be used to make precision tests of the Conserved Vector Current (CVC) hypothesis (the independence of the weak interaction strength from the hadronic environment), and unitarity of the quark flavour mixing (CKM) matrix, in the electroweak sector of the Standard Model. There is great current interest in these areas driven by new measurements of the V_{us} CKM matrix element, and ultra high precision mass measurements using ion traps. In the latter case, the precision of tests of the CVC hypothesis is becoming limited by a knowledge of the charge dependent correction factor, δ_C which increases in strength with increasing Z. High precision studies of Fermi decays from high Z nuclei (up to ^{98}In) are therefore extremely important to test and constrain theoretical calculations of δ_C. For such studies, it is essential to make precise measurements of the half-life, and decay branch to the 0^+ mirror analogue state. These experiments will exploit the production of intense, high Z, exotic beams produced by ultra high energy heavy ion fragmentation at the FAIR facility, and the separation and collection of essentially pure samples of these rare isotopes using the Super-FRS. Combined, lifetime and branching ratio measurements will be performed using the proposed DSSD system, and a modular Ge gamma-array in close geometry. Precision values of the masses, and derived β-decay Q-values, can be made in separate experiments using the Ion Trap system on the low energy branch of the Super-FRS.

The Limits of Particle Stability

In astrophysical X-ray burster scenarios, densities and temperatures are speculated to be so extreme that nuclear reactions can be driven along the proton drip-line as high as Te isotopes, where alpha photo-disintegration terminates the rp(rapid proton)-process. These bursts of energy are characterised by light curves persisting typically around ∼100s. Very little is known about the properties of nuclei in the upper reaches of the rp-process. In several instances, it is expected that waiting points will be created at $N = Z$ nuclei where proton photo-disintegration creates an equilibrium with proton capture, that is eventually broken by β-decay. Precise β-decay half-life, and β-delayed proton branch measurements will enable important constraints to be made on the path of nucleosynthesis, and rate of energy generation in X-ray bursters.

Very recently, two examples of ground-state two proton radioactivity, ^{45}Fe and ^{54}Zn, have been reported using the fragmentation of intense beams of heavy ions, and evidence has also been found for ^{48}Ni. It is undoubtedly the case that many heavier even Z nuclei will exhibit this important phenomenon if they can be accessed. The lifetimes can be very short, and are expected to be sensitive to the two proton decay energy, and the shape and shell structure, of the nuclei involved. Such studies will be enhanced at FAIR by the provision of extremely intense beams of high Z nuclei. A particularly important test case will be that of ^{103}Te. It is stabilised against alpha decay by the $N = 50$ shell closure, and two proton decay is expected to be the dominant decay branch. Decaying into the $Z = 50$ closed shell nucleus ^{101}Sn, a measurement of the decay rate will form an important benchmark in understanding this phenomenon, as a high two proton spectroscopic factor would be expected, and the dominant participating proton orbitals ($d_{5/2}$) are known.

The phenomenon of one proton radioactivity has already revealed a rich source of information on the structure of nuclei beyond the proton drip-line as high as $Z = 83$ (^{185}Bi). Dominant fission branches of the fused compound nucleus have thus far prevented the extension of these measurements to higher Z nuclei. This is potentially a rich region for such studies, as shape co-existence effects are expected to strongly influence the proton decay rate, and provide a unique insight into the effect of oblate nuclear shapes on this process. The Edinburgh group led an exploratory study on the current GSI FRS, to look at production of sub-Uranium proton-rich nuclei using the fragmentation of ^{238}U beams. We concluded that with beams in excess of 10^9 pps we would be able to access proton emitting sub-Uranic isotopes such as ^{195}Fr and ^{201}Ac. This compares with projected ^{238}U intensities of 10^{12} pps at the FAIR facility. Such implantation decay studies will therefore be performed using the new DSSD system.

Methodology – The Advanced Implantation Detector Array (AIDA)

The proposed decay experiments for the FAIR facility require a fast recovery, high efficiency, high energy resolution implantation detector system for ultra-sensitive studies of the charged particle decays of implanted exotic nuclei. Exotic nuclei of ∼50—150MeV/u will be transmitted by the Super-FRS, passing through an array of beamline detectors to provide particle identification, energy and tracking information. They will then be implanted into AIDA where their decay properties can be studied using AIDA, and the surrounding γ and neutron detector arrays.

In general, the selected exotic nuclei will be distributed across an image plane of ∼24cm×8cm with an expected total implantation rate ∼10kHz. Their range in silicon will be up to ∼5mm and their implantation profile will have transverse widths of $\sigma_x = \sigma_y$ ∼2cm and a longitudinal width of σ_z ∼mm. The segmentation of AIDA enables the correlation of the implanted exotic nuclei with their subsequent radioactive decays – each quasi-pixel of a DSSD operating as a functionally independent implantation-decay detector. The degree of segmentation required to minimise random implantation-decay correlations is determined by the implantation profile and rate, and the longest half-lives to be observed. For the applications considered here, this could be of the order of seconds (β-decay). This implies that the segmentation should provide a quasi-pixel size of ∼0.5mm×0.5mm.

The AIDA system consists of multiple planes of DSSDs (see figure 2). Each plane would have an area of ∼24cm×8cm, a thickness of ∼1mm and a strip pitch of 625μm. The first and final planes would act as a ΔE and veto detector, respectively. The ΔE plane would measure the energy and position of the exotic nuclei as they enter AIDA, and would unambiguously associate implantation events with the corresponding data from the upstream beamline detectors. The veto plane would be used to identify those events which did not stop within AIDA. The exotic nuclei of interest would be implanted into intermediate planes – typically 2–6. The number of intermediate planes will vary with the particular requirements of individual experiments.

AIDA will require 512 channels of instrumentation per DSSD plane, giving a maximum of 4096 channels for the complete system. For the ΔE plane, the instrumentation will operate over a ∼GeV dynamic range, while the intermediate implantation planes will require decay spectroscopy performance within a dynamic range of 20MeV. For the most short-lived exotic nuclei, decaying by one or two proton emission, this spectroscopic performance needs to be maintained within $\sim \mu$s of the deposition of multi-GeVs of kinetic energy from the implanted ion. High energy resolution is essential both to identify a small number of these decays as a peak in the presence of background, and to obtain high energy precision for theoretical comparisons of half-lives with quantum tunnelling decay rate calculations.

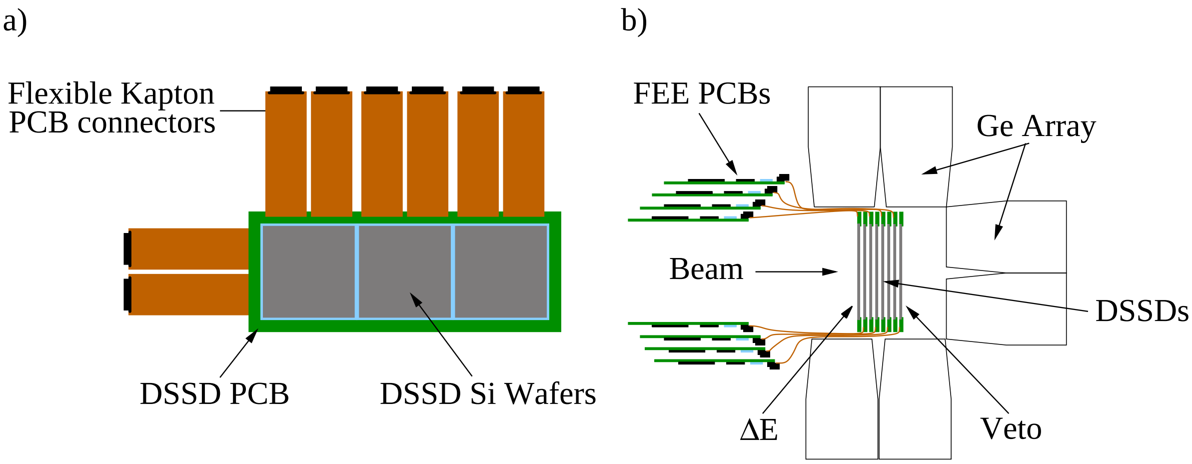

Figure 2: Schematic diagram of AIDA showing, a) the 24cm×8cm DSSD plane, and b) a cross sectional view of AIDA with a surrounding γ detector array illustrating the position of the front-end electronics (FEE).

The high degree of segmentation of the AIDA DSSDs reduces the capacitative and leakage current contributions from the DSSDs to the noise levels of the readout instrumentation ($\sim$ 5 keV r.m.s.). Crucially, this also allows the operation of a low threshold for the efficient detection of low energy β-particles.

The very high number of instrumented channels needs to be achieved while maximising the efficiency, and minimising the size, of the surrounding γ and neutron detector arrays (not shown in figure 2). The AIDA readout instrumentation must therefore be close-packed around the sides and back of the DSSD array with a minimum of material between AIDA and the γ, and neutron detectors. The requirement for multi-channel spectroscopy performance, with high channel density in a confined space, makes ASIC technology essential for the instrumentation of AIDA. The AIDA ASIC will contain the complete analogue front end for 16 channels from preamplifier through shaping amplifier to analogue to digital converter. It will be designed to provide the necessary overload recovery performance following implantation, by using an a.c. coupled, bipolar transistor reset feedback loop structure (Landis *et al.*, IEEE NS45 (1998) 805). The preamplifiers will reset themselves within $\sim\mu$s as they detect their output exceeding a preset threshold of 20MeV (implanted energy is not measured as it is not needed for particle identification). A key point of the proposed ASIC is that very fast ($\sim\mu$s) overload recovery is achieved by resetting the preamplifier whilst still within its linear range; the bipolar reset allows a.c. coupling to the detector thereby avoiding ASIC offset problems.

A spectroscopy grade ADC will be integrated with the ASIC. The instrumentation will be be modularised by mounting multiple ASICs on 128-channel Front End Electronics (FEE) PCBs. The FEE PCBs would also have a Field Programmable Gate Array to manage digital data from the ASICs, and timestamp data provided by a common NUSTAR system. This will synchronise event data generated by the AIDA, γ, and neutron detector systems. Digital event data will be transmitted via fibre optic Gbit Ethernet connections to a network switch and PC, which will merge all data and forward it to another PC (emulating the NUSTAR DAQ) for online analysis and data storage. All AIDA data will use the common NUSTAR data format. This architecture provides the capability for AIDA to operate either standalone, or fully integrated with other detector systems. As a member of the NUSTAR data acquisition working group, Ian Lazarus is ideally placed to ensure that the AIDA data acquisition will integrate seamlessly with other detector systems, and will conform to appropriate standards.

The largest silicon strip detectors currently manufactured are produced from 6″ diameter wafers. In order to produce AIDA DSSD planes of the required size, the individual DSSD silicon wafers will be ~8cm×8cm. Three silicon wafers will be packaged together on a custom PCB to provide mechanical support, with flexible Kapton PCBs to provide the electrical connections. The horizontal strips will be connected in series to simplify readout. In order to minimise the size of the ASIC and FEE PCB, passive polysilicon bias resistors and a.c. coupling capacitors will be integrated onto the detector wafer. DSSDs of this type and with a thickness of 1mm are an established technology. For some applications, it is envisaged that multiple planes of single ~8cm×8cm area DSSDs (of the same design) will be used in a reduced form of AIDA to observe the decays of one particular isotope with the surrounding γ and neutron detector arrays in a compact, high efficiency geometry.

Exotic beams from the Super-FRS at FAIR are scheduled for delivery to the DESPEC area in 2010. The funding of this proposal will enable the collaboration to develop the AIDA system and associated ASIC instrumentation, and conduct extensive bench, and in-beam system tests (see appended Gantt chart). This will ensure that AIDA will be on time, and immediately available to contribute to the core DESPEC science programme at FAIR.

Project Management

Dr Davinson will be overall technical manager of the project. He will consult with other members of the FAIR DESPEC collaboration on the detailed scientific requirements for the design of AIDA. He has strong ties with all groups in the current proposal, and with the wider European DESPEC collaboration. The project will be coordinated by regular telephone conferences, monthly project design meetings and more extended quarterly project review meetings (with PIs) held alternately at Daresbury and RAL. Project information will be shared via a public project website (`http://www.ph.ed.ac.uk/~td/AIDA`).

Dissemination

The scientists involved have a very strong track record of giving many invited talks at high profile international meetings (including opening keynote talks) and have written invited review articles, and papers, for high impact journals such as Science, Nature, and Physical Review Letters. As stated above, we will provide a public access website giving extensive information about project progress, meeting minutes, presentations, test results, application notes etc. This will form the core of the documentation infrastructure to support detector and ASIC applications by other parties.

Relevance to Beneficiaries

The science programme outlined in this proposal will address key issues relating to the astrophysical r-process, nuclear structure at the limits of stability, and the physics of the Standard Model. As such, the results will be of great interest to a wide international community of nuclear physicists, particle physicists and astrophysicists. The ASIC instrumentation is a key technology for the future nuclear physics programme with many opportunities for wider exploitation at future international radioactive beam facilities such as the EURISOL project. Both CCLRC RAL and Daresbury have proven records in providing open access to advanced instrumentation and software technology. ASIC technology is becoming pervasive in advanced radiation detection and imaging technologies. Projects of this type enhance core CCLRC skills and capabilities to the benefit of the wider UK science base.

Justification of resources

Staff The staff resources requested for this project are detailed in the individual JeSRP1 forms. Some of the staff (Davinson, Cresswell, Fayz, Seddon, Thornhill, Wells, Coleman-Smith, Lazarus, Letts and Pucknell) are partly or fully funded by the EPSRC Nuclear Physics Platform Grant which commenced July 15, 2005 for a period of 48 months. This proposal would finish after the end of the platform grant and we therefore request limited support for these staff which reflects the percentage of their time committed to this project during its last 12.5 months. Note: the Investigator times quoted are consistent with pre-fEC levels.

Edinburgh [1] Dr Davinson will be the Project Manager responsible for the ongoing coordination of the production of AIDA. He has initiated, and is already leading the DESPEC collaboration discussions of AIDA design concepts with particular reference to other DESPEC detector systems (he gave the opening presentation at the recent HISPEC/DESPEC collaboration meeting in Valencia). He is internationally recognised for his development and delivery of charged particle detector and instrumentation systems for wide ranging research programmes at international accelerator facilities. His expertise will be critical to the design and specification studies, AIDA prototype evaluation and AIDA commissioning. The platform grant provides 16 man-months of support for Dr. Davinson, of which 13 would be allocated to AIDA - the remainder would be allocated to the support of other UK programmes. An additional 14 man-months equivalent support for Dr. Davinson is requested, for crucial commissioning tests of AIDA during the remaining period of the present grant proposal (ending July 31, 2010) not already covered by the platform grant.

The AR1A post will support the design and development of the DSSD. This includes device physics to understand the behaviour of the DSSD with very high energy implants, packaging design concepts, prototype testing and evaluation, calibration and data analysis software, design and implementation of bench and in-beam tests. This scientist would also support ongoing implantation-decay experiments on the present FRS at GSI (and other related facilities). This includes the recently proposed study of β, proton, alpha and γ-decay branches in the region of the doubly-magic nucleus ^{100}Sn in collaboration with Munich (T.Faestermann), and an extension of earlier β-delayed neutron measurements of near r-process nuclei performed in collaboration with Mainz (K-L.Kratz). Technical support (4 man months) from the Edinburgh electronics workshop is also requested for the design and simulation of the electrical characteristics of the flexible Kapton PCBs.

Liverpool The primary role of the Liverpool RA will be to drive the beta decay experimental programmes. This will necessitate a strong involvement in the ongoing spectroscopy experiments on the FRS and other related spectrometers. The RA will also play a vital role in testing and evaluation of the DSSD system and instrumentation, both in the UK and at GSI, and in the installation of the spectrometer in GSI.

[1] These salaries have been calculated using pay scales currently available to the University of Edinburgh. New pay structures will be introduced during the request period and, as agreed with RCUK, reimbursement of any net costs will be expected at reconciliation stage.

Staff at Liverpool will be responsible for aspects of the mechanical, electrical and software work. A total of 28.5 months of effort is required for the necessary 3D design, high precision fabrication and assembly for the DSSD and instrumentation housings, support stands and rails, EMI/RFI screening and radiation shielding (Seddon, McCormick, Cooke, Norman, Burns). Effort totalling 18 months is also required for the ASIC wire bonding jig design, the ASIC wire bonding, and the low voltage power supply design and construction (Thornhill, Wells, Lockwood, Daniels). The design and testing of software tools for the high voltage control system (Sampson) and part of the data acquisition software (Cresswell) also require 8 months of staff effort. Part of this effort is already funded under the EPSRC Nuclear Physics Platform Grant up to July 15, 2009. The request for these personnel on the RP form covers the period from July 16, 2009 to the end of this grant request July 31, 2010. The remaining cost of this pooled staff effort (totalling 35.4 months) is entered as General Technical Services under Other Directly Allocated Costs. This heading also includes £24.7k to cover departmental running costs, e.g. administration and laboratory costs.

CCLRC Daresbury The staff requested will be responsible for the design, simulation, layout, production and integration of the FEE PCB, data acquisition and its integration with other DESPEC detector systems. Daresbury will also be responsible for software development for ASIC control and data acquisition, and the FPGA firmware for FEE data management and processing. A total of 14.4 months of electronics engineering (Lazarus, Coleman-Smith) and 19.2 months of software engineering (Pucknell, Letts) is required over the whole period of the grant. This effort is already funded under the EPSRC Nuclear Physics Platform Grant up to July 15, 2009. The request for these personnel on the RP form covers the period from July 16, 2009 to the end of this grant request July 31, 2010. An electronics technician (6 months) is required for electronics testing and commissioning. Mechanical engineering effort of 6 months throughout the period is also required from Daresbury (Fayz). Of this, 4.5 months is already funded under the EPSRC Nuclear Physics Platform Grant. The remaining 1.5 months is requested to support the installation of AIDA during the period between the end of the platform grant and the end of the grant request period.

CCLRC RAL French and Thomas are leaders of the microelectronics group at RAL and will manage Crooks, Murray and the ASIC Library Support Engineer. Their expertise and experience in supervising a project such as this is absolutely essential. French and Thomas are supported by CCLRC. The staff requested (Crooks, Murray and ASIC Library Support Engineer) will be responsible for the design, simulation and layout of the prototype and production ASICs, manage the multi-project wafer (MPW) submissions and wafer runs, and perform initial wafer acceptance tests to identify operational dies. The requested level of staff support at CCLRC Daresbury and RAL is based upon their extensive project experience in the production of such devices. Payroll costs reflect the outstanding experience and capabilities of the CCLRC staff and the necessity to retain staff and maintain the skills base.

Travel & Subsistence Travel and subsistence requests are based upon regular project meetings at CCLRC Daresbury and RAL, and DESPEC and NUSTAR collaboration meetings in Europe. Support is required for in-beam commissioning and testing of equipment, and the related ongoing scientific programme of exotic decay studies, primarily on the FRS at GSI. Support is also requested to present proposals at PAC meetings and for presentations at international conferences. Travel and subsistence funds for those persons on the EPSRC Nuclear Physics Platform Grant are not included in this request.

Consumables CAD and FPGA design software for CCLRC DL and Liverpool will be provided by the EPSRC Nuclear Physics Platform Grant.

Equipment Details of the capital costs of the project are given in the individual JeSRP1 forms. The DSSD non-recurrent engineering (NRE) charges for the photomasks, packaging and electrical connectors, prototype and production costs are based upon a representative quotation from Micron Semiconductor Ltd (quotation appended). We assume the purchase of prototype 24cm$\times$8cm and 8cm$\times$8cm DSSDs and nine production detectors (ΔE, Veto and the intermediate planes). The number of requested detectors reflects typical AIDA configurations and the inevitable degradation and loss of detectors due to radiation damage during the course of the experimental programme. The capital costs of the ASIC development are based upon the standard costs of multi-project submissions and wafer production costs using the Austria Micro Systems AG 0.35μm CMOS process. The prototype ASIC costs are based on an estimated size of 75mm^2 and the current Europractice cost of £400 per mm^2. Costs for the production ASIC are higher than the prototype ASIC to allow for the larger number of ASICs required of the production run. Additional costs include the design and procurement of a dedicated wafer test rig to identify operational dies. The capital costs of the prototype and production FEE PCBs are based upon standard PCB production and probable component costs. DAQ costs include the necessary fibre optic Gbit Ethernet infrastructure, PCs for data merging and online analysis and a PC with appropriate interfaces for slow control. In addition to these costs it will be necessary to purchase low-voltage power supplies for the instrumentation and a high-voltage mainframe to bias the DSSDs. Materials for the construction of the instrumentation, support stands, radiation shielding etc. are required. The support assembly will be mounted on a commercially available rail system so that AIDA (and the γ and neutron detectors arrays) can be quickly and safely removed from the beam position to make way for other HISPEC/DESPEC experiments.