Statement of Interest in the Development of an STFC Strategic Investment in R&D on Depleted Monolithic Active Pixel Sensor (DMAPS) Technologies

*This SoI follows the document "**R&D on High Granularity HV/HR-CMOS Detectors for Future Experiments**" submitted to the July 2016 meeting of the PPAP and signed by representatives of the Universities of Birmingham, Bristol, Brunel, Glasgow, Lancaster, Liverpool, Manchester, Oxford, Sheffield, Queen Mary University London, The Open University, STFC Particle Physics Department and STFC Technology Department*

This SoI proposes that STFC create a cross-facility, strategic, long-term Research Capacity built around core skills to forge an international network of excellence in the development of the next-generation of silicon sensors. Like the highly successful accelerator R&D and distributed computing programmes, a dedicated sensor R&D strategy benefits all STFC stakeholders, makes the maximum use of investment, and eliminates the deficiencies associated with trying to pursue long-term development with intermittent, short-term funding. The SoI proponents are recommending a new way of working and are not seeking funding through the usual mechanisms. We have used the pro-forma to show the commitment of university partners to work with STFC in achieving this goal.

Silicon sensors, in all their formats, are a strategic and enabling technology. They are used throughout STFC's research areas. They have played a key role in many discoveries in the last 30 years and much of STFC's scientific output has only been possible due to these devices. Areas affected include particle physics (e.g. vertex and tracking detectors), astronomy (photon detection, especially for Earth Observation), laser facilities (Fluorescent Lifetime Measurements), nuclear and neutron science (tracking and mass spectroscopy), photon and x-ray science and space science (photon and low-energy electron detection), Transmission Electron Microscopy (sensors), and health (in-vivo radiation monitoring and hadron therapy), as well as commercialization opportunities (e.g. very high-speed cameras).

There is a growing consensus that the current hybrid silicon sensor technology will be replaced by Depleted Monolithic Active Pixel Sensors (DMAPS) using commercial CMOS technologies. HV-CMOS implementations exploit processing developed for commercial power devices to give deep depletion devices such that a large, fast signal is generated, while HR-CMOS options feature much higher resistivity and thicker epitaxial layers, also from large-scale CMOS imaging vendors. HV/HR-CMOS detectors bring major improvements in the critical areas of: speed, radiation-hardness, sensitivity, noise, timing, response uniformity, cost and large-area formats.

An STFC multi-disciplinary Research Capacity with long-term continuity of funding for HV/HR CMOS sensor R&D can compete with the rapid developments overseas (particularly in France, Germany, Italy, Switzerland and the US) where major strategic and specific project investments are being made now. UK groups are already making tentative international contributions but a more substantial, cohesive, and consistent investment is needed to retain the UK's leading position. The intellectual base exists in the UK university sector, STFC's departments, and allied areas, but resources for sensor design, device evaluation and device submission are currently inadequate to compete with the very high levels of investments elsewhere.

The sensor R&D consortium would coordinate the combined resources of university research groups, STFC national laboratories and external partners to develop and exploit the necessary sensor technology for STFC's future scientific programmes and facilities, resulting in leadership roles at the highest international level. It would provide a focus for excellence that could both work with and lead major international partnerships. It would achieve a world-class R&D provision that the wider STFC community could access to leverage its own research. It would avoid duplication, maximise investment, and provide a forum for the exchange of ideas.

Development of HV/HR-CMOS sensors by the consortium would provide a globally-recognised focus for collaboration with industry, developing commercial products and applications that would stimulate economic growth, create new commercial markets, promote industrial investment, and encourage cutting-edge innovation and the transfer of research skills into real-world applications. The technology developed would enable STFC to access new funds that address global challenges and help build UK industrial capabilities.

The UK desperately needs highly-skilled people, trained in the latest technology. The sensor R&D consortium would provide an international-quality training of the next generation of experts by bringing together a substantial number of summer students, apprentices, doctoral students and early-career engineers and researchers in a vibrant and exciting research environment.

The need for a sensor R&D consortium, which was presented to the PPAP, emerged from a community meeting in March 2016 attended by 55 members of the UK particle, nuclear, and astronomy communities and STFC's Technology Department with presentations outlining the technologies being developed, current plans and opportunities in particle and nuclear physics, astronomy, and health, along with the international context. The importance of DMAPS for future facilities was emphasised along with the huge potential for a broad range of applications, improving or extending far beyond those where current MAPS solutions are being offered by TD and/or physicists in STFC funded university groups. The need to rebuild UK leadership in detector R&D was seen as not only vital to future successes in STFC projects, but also to maximising the competitiveness of UK world-class facilities.

To structure the consortium, 8 work packages are initially proposed to address key areas. WP0 will provide the overall management and coordination of the consortium. Then there will be three generic development areas, common across the consortium: WP1 (system integration, such as powering, including bias blocks and regulators, or common I/O blocks for high bandwidth data transfer, including common front end board development); WP2 (equipping large areas at low cost, including yield improvement, stitching and edge minimization) and WP3 (device simulation with development of a common tool-kit). There will also be full device prototyping work-packages, including all aspects of design, manufacture and evaluation of specific devices toward the following areas: WP4 (position measurement in high rate/dose environments with high granularity and optimised for accurate timing); WP5 (large area position and energy measurement with fixed collection depth for uniformity of response with angle and radiation) and WP6 (ultra-low noise, high dynamic range). Finally, WP7 will cover the hosting of conferences, training and the dissemination of expertise, coordinating a steady stream of industry-ready ASIC designers, detector experts and FPGA programmers. WP7 will also interface with STFC facilities, coordinate international connections and provide industrial link-ups.

The proposed funding model is similar to that used successfully to support UK accelerator and distributed computing R&D, recognizing the need for dedicated support mechanisms for multi-year, strategic technologies. A national DMAPS R&D Consortium, working with national and international partners, would develop applications of the technology that target the needs of STFC-funded facilities, near-term future projects, and the required R&D to meet the most challenging aspects of longer-term future projects. It would ensure UK capabilities remain internationally competitive.

The proposal is to ramp up funding, over a period of 4 years, to a level where it can support at STFC national laboratories and at universities, in a rolling funding model, 5 FTEs of full time designer effort and 5 FTEs of device evaluation effort. It would also need to support: processing (2 engineering runs per year with UK as lead or sole contributor, as well as 4 submissions either to multi-project runs or contributions to collaborative runs), equipment and read-out, training (ideally 2 studentships awarded per year) and travel. By the end of the first 4 year period, funding would be at a level of £0.5M/year for processing; £0.6M/year for designers; £0.5M/year for device evaluation; £0.1M/year for project students; £0.06M/year for read-out and equipment and £0.07M/year for travel and £0.03M/year allowing the UK to organize a regular major international conference on DMAPS detector applications. This implies a steady state of around £1.8M/year. Depending on the profile, this might be expected to cost £5.1M over the first 4 year funding cycle and £7.2M for each subsequent 4 year period. The need for continuity of funding is vital and the 4 year review cycle would help to ensure retention of expert designers.

The need for strategic investment that sustains UK leadership in sensor development for the future is vital and should be expected to pay the same dividends in terms of applications across STFC and beyond as previous investment in silicon sensor and ASIC development. The consensus is that the latest developments in DMAPS technology will be a game-changer across many fields. However, without investment, the UK will not be able to propose and lead future detector projects and over time will lose international standing. A coherent and targeted long-term programme is proposed to establish the UK as a world leader in these exciting new technologies.