Title: Development of Monolithic CMOS Tracking Detectors for Future Higgs Factory Experiments
Proposal initial contact (PI TBD): Harald Fox and Yanyan Gao
Institutes involved and their contact:

- Edinburgh - Yanyan Gao
- Lancaster - Harald Fox
- Queen Mary - Adrian Bevan, Seth Zenz
- STFC RAL PPD - Jens Dopke
- STFC Daresbury - Roy Lemmon, Marcello Borri
- University of Liverpool - Tim Jones

Overview: a brief (less than 300 words) overview of the project, including high level aims and objectives

The European Strategy for Particle Physics has identified an electron-positron "Higgs factory" as the highest-priority next collider. Several major international projects have been proposed, with a possibility of data-taking as early as 2035. *This proposal aims to identify and address key instrumentation challenges in vertexing, tracking, and machine detector interface (MDI) for the upcoming Higgs factory*. It is fully aligned with the international detector R&D (DRD) roadmap process set forth by the European Committee for Future Accelerators (ECFA) in 2020.

Tracking detectors for Higgs factory experiments typically have large active areas in the O(100) square-metres, and require high granularity, low power consumption and minimal material budget. Different sensor technologies are often used to optimise the overall performance in vertexing and tracking, also with respect to beam induced background in the MDI region. Fully commercial monolithic silicon sensor technology, such as HV-CMOS, emerge as some of the most promising options overall. Given the intrinsic complexity and long lead time expected for future Higgs factory experiments, a system level prototyping must be carried out as early as possible together with innovative sensor developments.

This proposal has two main objectives: 1) to develop a tracking detector demonstrator, using state-of-the-art CMOS sensors, that has scalability for large area production as a core element of its design and includes a low-mass mechanical support and efficient cooling strategy, and 2) to explore innovative CMOS sensor technologies, particularly those with smaller feature sizes (e.g., 55nm), open-source process design kits (OpenPDKs), and ultra thin and curved designs.

The proposed research has a strong synergy with several on-going R&D projects, such as the LHCb Upgrade II (MightyTracker) and Mu3e, but also benefits the ALICE3 SVT upgrade, Belle2 vertex detector upgrade, and the EIC tracking detector R&D. However, the physics requirements and expected beam conditions of future Higgs factory experiments are significantly different, which requires a dedicated R&D programme. It has extended impact in areas such as medical physics and muon tomography.

Further information and initial considerations for the proposal:

External partners:

- Karlsruhe Institute of Technology (KIT) - Ivan Peric
- Hochschule RheinMain - Daniel Muenstermann
- INFN Milano - Attilio Andreazza (FCC-ee IDEA tracker R&D, sensor and system)
- INFN Pisa - Fabrizio Palla (FCC-ee IDEA tracker R&D mechanics)
- IHEP - Joao Guimaraes de Costa and Yiming Li (CEPC vertex and tracker R&D)

Sensor characterisation and system prototyping based on 180nm technology: Edinburgh, Lancaster, and Liverpool have been closely involved with the Higgs factory tracking detector R&D community since 2019, focusing on the overall system level design and prototyping. Built upon our expertise from the ITk project, progress has been made on multi-module structure construction and readout using the ATLASPix3 chips. Quad-modules - consisting of four single chips - with Shunt LDO power regulators allowing for Serial Powering are in the current pipeline in 2024. Initial tests with multi-module setups, including telescope and quad-module, have been carried out in both the lab and beam tests. Liverpool provided design concepts and inputs on mechanical support. Pisa is working on carbon-fibre based staves supporting these modules.

In parallel we have been collaborating with KIT on several new designs using 180nm technology, with new features such as on-sensor data aggregation (`daisy chaining') and single command line communication with the chip. Some preliminary smaller sensors have been available. This funding would allow us to take a leading role in the characterisation of these chips and strengthen our connections with KIT.

This funding will allow us to maintain our current strong position and build up to a much more prominent and leading role and a sizable share in the production.

Smaller feature development (55nm): KIT led the initial design and production of a low capacitance small fill factor pixel design at the 55nm node with the SMIC foundry. Some first proof-of-principle sensors were produced and are available for testing early 2024. With this proposal, we can take an early lead in characterising those chips. Further development will be supported using our TPA-TCT setup, which will allow us to contribute to the design for the next submissions and strengthen our links with CMOS foundries.

Open-source process design kits (OpenPDKs): One general issue of chip development for long-term projects is the short life cycle time of most process nodes. This is illustrated by the fact that several nodes that have been used for LHC experiments are not available any more. Constantly porting chip designs is resource intensive and some features might actually deteriorate in smaller feature size nodes. A possible way out is the usage of open-source process design kits (OpenPDKs) for HV-CMOS sensors. PDKs translate the electrical circuit into the pn-junctions and transistors in the silicon and metal traces contacting them. Whilst usually safeguarded by non-disclosure agreements and considered trade secrets by the foundries, the OpenPDK approach promotes the usage of a library/process description that is completely public. This allows any fab/foundry to offer this process and would enable UK fabs to commercialise HV-CMOS sensors based on the chip designs explored within DRD3.

Ulta-thin and curved CMOS sensors: RAL and QMUL have started working on thinned and curved silicon sensors for Higgs factory MDI design, in synergy with the ALICE3 R&D and Belle2 iVTX upgrade.

DRD task cross-reference: DRD-3 task 3.1 (High granularity, rad-hard CMOS sensors) and 3.5 (Simulation).