Expressions of Interest for the Development of Detector Concepts and Sub-detector Systems for the Future Circular Collider FCC

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Abstract

This document accompanies a compilation of submissions of Expressions of Interest (EoIs) for the development of detector concepts and sub-detector systems for the Future Circular Collider (FCC). The actual EoIs can be found in a back-up document submitted in parallel; they are also collected in an indico repository and individually linked in a table in this document for quick access. This summary gives background information about the process leading to these EoIs, presents an overview and general observations, and proposes further steps.

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Detector concepts and sub-detector systems

The precision requirements at the FCC-ee, in particular for operation at the Z pole, represent a formidable challenge for the development of detectors beyond the current state of the art. The newly created international detector R&D (DRD) collaborations pursue a vigorous technology programme which is to a large extent motivated by the needs of the FCC and exploits synergies with other future projects prioritised by the European Strategy of Particle Physics (ESPP). Detector concepts, in this framework denoting full collider experiments, informed by engineering considerations and modeled in consistent simulation suites, are indispensable to guide the R&D; they provide realistic integration constraints and feedback on the full-detector performance of individual design choices in the interplay of components. While the combination of technologies in a given concept should remain open where technically reasonable and promising in view of physics performance, sub-detectors must be developed with system aspects in mind from the beginning; tracking detectors for example must be light-weight and calorimeters be compact. The sub-detectors are expected to become focal points of the work in the DRDs, with overarching system aspects and overall performance addressed in the concept study groups in the coming years.

Calls for EoIs

In order to encourage the federation of international efforts, to assist in community building and to enhance the visibility of emerging cooperation, the Physics Experiments and Detector (PED) pillar of the FCC feasibility study launched two calls for EoIs, one for studies at detector concept level and one for sub-detector developments with emphasis on system aspects. The EoIs were requested to be compact documents including

- The scope of planned activities for the next 3-5 years
- The partners (institutes), their expertise and the names of one or two contact persons
- The connection with technological activities in the DRD framework and between sub-detector efforts and concept study groups
- References to relevant more detailed documentation.

Process of EoI collection

The calls were launched in October 2024. As a first step, interested parties were invited to register their intent to prepare an EoI via a web portal on a publicly visible spreadsheet, with contact names, topics and (list of) institutes. In many cases small consortia had already been formed. The spreadsheet was then sorted such that related EoIs, addressing the same sub-detector or technology, appeared next to each other. This facilitated groups to get in contact; as a result some initiatives grew in number of institutes, others were merged. In January, a half-day meeting was held as a satellite event to the FCC Physics Workshop, where all groups preparing EoIs had the opportunity to present their plans. This highlighted further opportunities for groups to join forces, and also new players and technologies appeared which had not been visible in the FCC detector context so far. The submitted set of EoIs for the ESPP update represents a snapshot of a community formation process which has just started and is expected to continue.

Overview of received EoI submissions

The submissions have been arranged in several groups as shown in the Table below, with the number of EoIs:

Topic	Number of EoIs
Detector Concepts	4
Vertex Detector	2
Main Tracker and Envelopes	10
Calorimeters	8
Luminometers	2
Particle ID	1
Coil	1
Muon	5
Trigger/DAQ/Electronics	3
Algorithms, AI	2
Machine Detector Interface	1

General observations

The submitted EoIs present ongoing and proposed detector R&D projects targeted towards concrete FCC-ee detector concepts and subsystems. Most sub-detector initiatives are contained in existing DRD proposals and activities already, while others can find a home in existing or updated proposals in the DRD framework, except the development of large coils and some aspects of the MDI. The collection presented here provides a unique view on the FCC-targeted activities within the broader scope of the DRDs which can help to further focus and structure their work. In general, the projects are not stand-alone activities, but embedded in the ecosystems of the relevant DRDs; they typically reside in one DRD, possibly with links to others. The detector concept study groups overarch the sub-detector projects and pull the studies together at the overall detector level.

The most important fact to note is that almost all submissions propose concrete work plans for the next phase of 3-5 years; the institutes express the intention to get actively engaged in the near-term, preparatory work towards large FCC detectors, rather than just stating a general interest in some future project. The EoIs are not resource-loaded, but the scope of activities is generally reasonable in view of the current stage of the FCC project. Often several phases are foreseen, reflecting realistic expectations towards a gradual ramp-up of efforts. The activities start with studies to better understand performance requirements in detail and include further work on simulation and digitisation software. The hardware activities begin with component evaluation and sensor prototyping, proceed to system demonstrators and later to scalable prototypes which will also help the costing to solidify. Some projects address infrastructure needs, too, for example test beam telescopes.

Conclusions

Altogether, the response to the calls for Expressions of Interest exceeded expectations and attracted new participants to the FCC project. There is a strong interest in addressing the system aspects of sub-detectors and thus to go beyond the development of the underlying sensor technologies; the sub-systems form a focal point of federated R&D within the DRD collaborations and a bridge to link the technological developments to the bigger picture of the detector concepts, without necessarily being specifically tied to a particular concept at the present stage. In this sense, the call was hitting a “sweet spot” between generic R&D and the formation of proto-collaborations.

There are clear ideas about the near-term work to be done, many of which already prepared in the process towards the DRD proposals, but many were also developed in response to the calls discussed here. The detector concept study groups are expanding their simulation and reconstruction tool kits, and will have to tackle new tasks like supporting the development of overall TDAQ architectures or the elaboration of construction and installation scenarios. The overall goal will be to establish the desired physics performance for detectors for the four interaction regions at the FCC-ee with optimised cost, founded in the performance and costing of scalable prototypes and testbeam-verified simulation.

The community has impressively demonstrated the wish and the capability to self-organise and to aggregate in informal consortia, joining forces and expertise towards common goals. It is expected that this will remain a dynamic process as the FCC detector community grows further, integrates new topics and consolidates efforts.

The next steps for the FCC detector activities will include the identification of possibly uncovered areas with the goal to point these out to potential newcomers. For the time being, the *Detector Concepts Work Package* of the FCC PED Pillar is considered to remain the home of sub-detector activities and will provide a general platform for exchange with the different detector concept study groups without duplicating the DRD structures. However, new meeting fora can be established where needs arise, and as resources for intensified progress become available. At the present stage, FCC PED and DRD jointly arranged topical workshops can be an efficient means to support the communities in making the next steps.

Supporting documentation

As stated in the introduction, the actual content of the individual EoIs is bundled in a compilation submitted as a back-up document to the ESPP. The EoIs have also been collected in an indico repository and can be individually accessed via the following Table of Content, by clicking the link.

Title	Link	Institutes
Detector Concepts		
IDEA Detector Concept	Link	INFN (IT), ANL (US), Baylor University (US), BNL (US), Brandeis University (US), Buffalo University (US), Caltech (US), CEA Irfu (FR), CERN, Edinburgh University (UK), FNAL (US), Gangneung-Wonju National University (KO), IJCLAB (F), INFN (IT), INFN LASA (IT), IP2I

		Lyon (F), Kyungpook National University (KO), Lancaster University (UK), MIT (US), Oak Ridge (US), Princeton University (US), Purdue University (US), Rutgers University (US), SLAC (US), Stony Brook University (US), Sussex University (UK), Texas Tech (US), University of Maryland (US), University of Michigan (US), University of Milano-Bicocca, University of Seoul (KO), Chung-Ang University (KO), University of Virginia (US), University of Zurich (CH), Yonsei University (KO)
ALLEGRO Detector Concept	Link	CERN, APC, B. K. C. College, Brookhaven National Laboratory, Charles University, CNRS/IN2P3, Columbia University, Department for Physics and Technology, DSM/IRFU (Institut de Recherches sur les Lois Fondamentales de l'Univers), Ecole Polytechnique Fédérale de Lausanne (EPFL), Haute école du paysage, High Energy Physics Institute, Horia Hulubei National Institute of Physics and Nuclear Engineering, IJCLab, INFN Laboratori Nazionali di Frascati, INFN Sezione di Napoli, INFN Sezione di Pisa, INFN Sezione di Roma, INFN Sezione di Roma Tre, Institut de Physique des 2 Infinis de Lyon - CNRS/IN2P3, Institute for Particle Physics, Institute of Experimental Physics of the Slovak Academy of Sciences, Institute of Physics, Instituto de Física Corpuscular (IFIC), Laboratório de Instrumentação e Física Experimental de Partículas - LIP, LAPP, LPC, LPNHE, Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), National Institute for Research and Development of Isotopic and Molecular Technologies, National University of Science and Technology Politechnica, Niels Bohr Institute, Paul Scherrer Institut, Sapienza Università di Roma, Southern Methodist University, Stony Brook University, Technische Universität Dresden, Università di Napoli 'Federico II', Universität Zürich, Université de Genève, Université de Strasbourg, University of Arizona, University of Bern, University of Michigan, University of Texas at Austin, Weizmann Institute of Science, ZHAW Zurich University of Applied Sciences
ILD Detector Concept	Link	AGH University of Krakow, University of Barcelona, Bergische Universität Wuppertal, University of Birmingham, University of Bonn, Vrije Universiteit Brussel, Department of Physics, CEA/Irfu Universite Paris Saclay, Centro Brasiliero de Pesquisas Fısicas, Centro de Investigaciones Energeticas, Centre de Physique des Particules de Marseille, Deutsches Elektronen-Synchrotron, Dhofar University, Deutsches Elektronen-Synchrotron DESY, Albert-Ludwigs-Universität Freiburg, University of Hamburg, Hiroshima University, MPG Halbleiterlabor, IHEP-Beijing, Indiana University, Institut de Physique des Deux Infinis de Lyon, Institut Pluridisciplinaire Hubert Curien, Institute of Physics of the Czech Academy of Sciences, Instituto de Física de Cantabria (CSIC-Univ.Cantabria), Instituto de Fisica Corpuscular, Instituto de Microelectronica de Barcelona, Instituto Tecnologico de Aragon, University of Tokyo, Laboratoire de physique des 2 infinis - Irène Joliot-Curie, Iwate University, University of Kansas, Karlsruhe Institute of Technology, KEK, Kindai University, Kogakuin University of Technology and Engineering, Kyushu University, IP-Paris/CNRS, Laboratoire de Physique Nucléaire et de Hautes Energies, Lund University, University of

		Mainz, McGill University, Nationaal instituut voor subatomaire fysica, Nippon Dental University, Northern Illinois University, OMEGA, Osaka Metropolitan University, Princeton University, Saga University, Shinshu University, University Siegen, Taras Shevchenko National University of Kyiv, Department of Particle Physics, Tohoku University, Tsinghua University, University College London, University of Science and Technology of China,
CLD Detector Concept	Link	ANL, CERN, KIT, IPHC-DRS
Vertex Detector		
Vertex detector design, integration and simulation	Link	INFN - Genova, Frascati, Milano, Padova, Perugia, Pisa, Torino, Trieste-Udine, ETH Zurich, Paul Scherrer Institute, University of Zurich, Brown University, BNL, FNAL, LBNL, MIT, SLAC, Stony Brook University
FCC Snail-shape vErtEx Detector	Link	IPHC, CPPM, IP2I, LPNHE, APC
Main Tracker and Envelopes		
Straw tracker	Link	Brookhaven National Laboratory, Duke University, Harvard University, Institute of Nuclear Physics, Joint Institute for Nuclear Research, Max-Planck-Institut für Physik, Michigan State University, SLAC National Accelerator Laboratory, Tufts University, University of California, University of Florida, University of Massachusetts, University of Michigan, University of Pennsylvania, University of Texas
Development of an ultra-light drift chamber operating in helium atmosphere with PID capabilities based on cluster counting technique	Link	INFN Bari, INFN Lecce, IJCLAB, BNL, Purdue University
Time of Flight and Tracking for FCC-ee with Monolithic CMOS sensors	Link	Université Paris-Saclay, CNRS/IN2P3
Scintillating fibre tracker (SciFi)	Link	EPFL, BNL
Modules for Vertex detector/Silicon Wrapper with combined tracking and timing capability in LFoundry 110nm technology	Link	INFN - Bologna, Milano, Padova, Pavia, Perugia, Pisa, Torino, TIFPA, FNAL
Particle beam telescope with versatile DMAPS chip	Link	ITA, IGFAE, IFIC, CSIC-UVEG, IFCA, CSIC-UC

Carbon fibre wire chamber	Link	Purdue University
Monolithic Active Strip Sensors	Link	TU Dortmund University, University of Clermont Auvergne
Fast timing layers at FCC-ee	Link	INFN CERN, Paul Scherrer Institute, University of Zurich, Brandeis University Waltham, Brookhaven National Laboratory, SLAC National Accelerator Laboratory, University of California Santa Cruz, University of New Mexico
Large Area Tracking Systems for FCC-ee Detectors	Link	Santa Cruz Institute for Particle Physics
Calorimeter		
SiW-ECAL	Link	Argonne, CERN, DMLab, IFIC - CSIC/UV, IJClab, Imperial College London, LLR, LPNHE, Omega, SLAC, U. Oregon, U. Tokyo,
SiPM-on-Tile HCAL	Link	DESY, Universität Hamburg, Universität Heidelberg, Karlsruhe Institute of Technology, Johannes Gutenberg-Universität Mainz, University of Texas at Arlington, Northern Illinois University, FZU Prague
TileCal HCAL for ALLEGRO	Link	INCDTIM, LIP, IFIC Valencia, University of Bergen, FZU, Charles University, Tbilisi State University, CERN, LPCA, INFN & University di Pisa
ALLEGRO Noble Liquid Ecal	Link	CPPM, CERN, University of Texas at Austin, LAPP, Stony Brook University, Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), Brookhaven National Laboratory, APC, University of Arizona, IJCLab, Southern Methodist University, Omega, Charles University, New York University, Technische Universität Dresden, Horia Hulubei National Institute of Physics and Nuclear Engineering, Institute of Experimental Physics of the Slovak Academy of Sciences, Columbia University, Brown University
GRAiNITA	Link	CNRS/IN2P3, IJCLab Orsay and LPCA Clermont, Institute for Scintillation Materials of the National Academy of Sciences of Ukraine, Kyiv National Taras Shevchenko University
Dual-Readout Fiber Sampling Calorimeter	Link	INFN - Bologna, Catania, Milano, Pavia, Pisa, Roma, Yonsei University, Kyungpook National University, Gangneung-Wonju National University, University of Seoul, Chung-Ang University, University of Sussex, Texas Tech University
T-SDHCAL	Link	P2I-Lyon, CIEMAT-Madrid, Vrije Universiteit Brussel, OMEGA, Universidad de Cordoba, Shanghai Jiao Tong University, Yonsei University, SungKyunKwan University, Universit de Tunis El Manar
MAXICC / CalVision	Link	INFN & University of Milano-Bicocca, INFN & University of Napoli, INFN & University of Perugia, ANL, Baylor University, Brandeis University, University at Buffalo, Caltech, The Catholic University of America, FNAL, University of Maryland, MIT, University of Michigan, Princeton University, Purdue University, ORNL, Rutgers University, SLAC, Stony Brook

		University, Texas Technical University, University of Virginia, CERN, IP2I Lyon, Institute for Scintillation Materials NAS of Ukraine
Lumical		
Luminosity calorimeter - SiW	Link	Niels Bohr Institute (DK), Institute of Space Science (RO), AGH University of Krakow (PL), IFIC (E), CERN (CH), Aarhus University (DK), Tel Aviv University (IL)
Development of SNSPDs (quantum sensors)	Link	University of Zurich, University of Geneva
Particle Identification		
ARC - A compact RICH detector	Link	University of Genova and INFN Genova, CERN, University of Warwick, University of Oxford
Coil		
HTS Solenoid	Link	INFN, University of Milano,CERN
Muons		
Development of micro-RWELL technology for the Muon system	Link	Laboratori Nazionali di Frascati, INFN Sez. Torino, INFN Sez. Bologna
Resistive Micromegas for muon system	Link	INFN sezione di Napoli, Università di Napoli Federico II, INFN sezione di Roma Tre, Università Roma Tre
Detector development and production, MPGDs or MWPC	Link	Weizmann Institute of Science, Technion – Israel Institute of Technology
Timing RPCs for muon system	Link	Istituto Nazionale di Fisica Nucleare Torino, Università degli Studi di Torino, Istituto Nazionale di Fisica Nucleare and Politecnico Bari, Max Planck Institute for Physics, Laboratorio Nazionale di Frascati
A Muon System with Square Drift Tubes and Scintillator Strips	Link	Brookhaven National Laboratory, Fermi National Accelerator Laboratory, SLAC National Accelerator Laboratory, University of California, Harvard University, University of Massachusetts, University of Michigan, Michigan State University, Tufts University, University of Virginia, University of Washington, INFN Sezione di Roma,
Trigger/DAQ/Electronics		
TDAQ Architecture design and R&D	Link	Max-Planck-Institut für Physik, University of Birmingham, University of Geneva, Indiana University, SLAC National Accelerator Laboratory, Brookhaven National Laboratory, Boston University, Argonne National Laboratory, CERN,
Wireless communications within the vertex detector	Link	Ohio State University, University of Zurich, Zurich University of Applied Sciences
Embedded FPGAs for ML-based Readout	Link	SLAC, LBNL, Baylor University, Fermilab, University of Hawaii, University of Michigan
Algorithms (including AI)		

Machine Learning for Particle Flow	Link	University of California, CERN, University of Geneva, Weizmann Institute of Science, Technical University of Munich, SLAC, NICPB
AI Aided Detector Design Optimization	Link	University of Geneva, Technical University of Munich, SLAC
Machine Detector Interface		
Interaction Region Elements and Integration	Link	INFN Laboratori Nazionali di Frascati, Pisa, BNL, FNAL, JLAB, SLAC

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