Strategic R&D Programme on Technologies for Future Experiments

Input to the European Strategy Group

CERN

Experimental Physics Department

December 2018

Strategic R&D Programme on Technologies for Future Experiments

Martin Aleksa*, Jakob Blomer*, Benoit Cure*, Michael Campbell*, Carmelo D'Ambrosio*, Dominik Dannheim*, Michael Doser, Federico Faccio*, Philippe Farthouat°, Roger Forty, Corrado Gargiulo*, Patrick Janot°, Christian Joram°, Manfred Krammer°, Lucie Linssen°, Pere Mato°, Paolo Moreira*, Luciano Musa*, Eraldo Oliveri*, Antti Onnela*, Heinz Pernegger*, Petra Riedler*, Christoph Rembser*, Werner Riegler°, Burkhard Schmidt°, Graeme Stewart*, Herman Ten Kate* and Francois Vasey*

* Co-convenor of a working group

° Member of the steering committee

CERN

Experimental Physics Department

Abstract

Instrumentation is a key ingredient for progress in experimental high energy physics. The Experimental Physics Department of CERN has defined a strategic R&D (Research and Development) programme on technologies for future experiments. Provided the required resources can be made available, it will start in 2020 and initially extend over five years. The selection of topics and the established work plans are the result of a transparent and open process, which lasted 14 months and involved several hundred of physicists and engineers at CERN and in the broader HEP community.

This R&D programme is in the tradition of previous similar initiatives, the DRDC projects in the 1990’s and the White Paper R&D programme (2008-2011) that have been instrumental in providing the technologies which are presently in use at the LHC experiments or which will be deployed in the coming LHC upgrades (Phase-I and Phase-II). Examples of the achievements of the White Paper R&D programme are the validation of the CMOS 130 nm technology, the GEM single mask technique, radiation hard optical links, DC-DC converters and the CernVM file system.

The results of this new R&D programme will be building blocks, demonstrators and prototypes, which will form the technological basis for possible new experiments and experiment upgrades beyond the LHC Phase-II upgrades scheduled for the long shutdown LS3. These include in particular detectors at CLIC, FCC-hh and FCC-ee but also further upgrades of the LHC experiments. The main challenges come on the hadron collider side from the very high luminosity operation, leading to extreme pile-up, track density, radiation loads and data throughput, but also from the need for unprecedented precision in vertexing and tracking, combined with very low material budgets and highly granular calorimetry on the lepton collider side.

The new programme targets the primary challenges of the detectors complemented by equally demanding challenges in the domains of electronics, mechanics, cooling, magnets and software. A large part of the required R&D work will be carried out jointly with external groups from universities and research labs exploiting organically grown networks and relations, but also dynamic and efficient structures like the RD50 and RD51 collaborations. For many developments, close cooperation with industrial partners will be crucial.

Contents

1 Introduction

Progress in experimental physics relies often on advances and breakthroughs in instrumentation, leading to substantial gains in measurement accuracy, efficiency and speed, or even opening completely new approaches and methods.

At this moment in time, the landscape of particle physics at the high energy frontier is well defined until the High Luminosity upgrade of the LHC (HL-LHC) scheduled for the long shutdown LS3 (2024-2026), going along with large-scale and fundamental upgrades of the ATLAS and CMS detectors, which concern almost all parts of the experiments. ALICE and LHCb undergo major upgrades already in LS2 (2019-2020). While the detector R&D for the LS2 upgrades is largely complete, the R&D for the LS3 upgrades is in full swing and will still continue for a couple of years.

Given the size and complexity of modern particle physics experiments, their life cycle from conception to full exploitation is measured in decades, and even just the upgrade of an existing detector may require 10 years.

Many of the experimental technologies that are going to be deployed in the upgraded detectors have their roots in the so-called White Paper[1] R&D programme which CERN pursued from 2008 to 2011. Examples are the single mask technique allowing the building of square-metre size GEM detectors, qualification of the 130 nm CMOS technology, the fast and radiation hard Gigabit optical links (GBT, versatile links), the radiation hard DC-DC converters and the CernVM file system that is now a cornerstone of HEP distributed computing. Going back 10 - 15 years further, it is fair to say that the DRDC[2] programme in the 1990s with almost 50 R&D projects laid the foundations for the construction of the LHC detectors as they are currently in operation.

[1] L. Linssen, CERN LHC upgrade R&D projects and irradiation plans, LHCC upgrade session, 1 July 2008. https://indico.cern.ch/event/36149/

[2] http://committees.web.cern.ch/Committees/obsolete/DRDC/Projects.html

Beyond LS3, the experimental options are manifold. While the full exploitation of the potential of the HL-LHC is the clear top priority for the next 15 years, a number of studies for a major post-LHC project at CERN are being pursued: FCC (ee, hh, eh) and CLIC. On a global scale, these efforts complement advanced design studies for an International Linear Collider that can be hosted in Japan and plans for the CEPC in China, for precision studies of the properties of the Higgs boson. In addition, there may be new fixed target and beam dump experiments or upgrades explored under the Physics Beyond Colliders initiative hosted by CERN.

In the past year, by means of a bottom-up process involving several hundreds of colleagues[3] at CERN and from the HEP community, we have worked out an R&D programme that concentrates on advancing the key technologies rather than on developing specialized applications.

Following the above considerations, such an endeavour, which follows the tradition of the previous R&D programmes, is critical and timely for any new detectors and upgrades after LS3.

The programme covers technological R&D activities in the domains of detectors, electronics, software and intimately connected domains like mechanics, cooling and experimental magnets. Experiment-specific developments are in general *not* covered. It is expected that these specific activities, once defined by the experiment collaborations and reviewed by the respective committees, will be financed through their own budget lines.

The R&D programme focuses on areas where the EP department has significant expertise and infrastructure and already plays a leading or unique role. Many of the developments will be carried out jointly with external groups, also exploiting dynamic and efficient structures like the RD50 and RD51 collaborations, and with industrial partners.

Provided the required resources can be found, this R&D programme will start in 2020, ramp up in 2021, and extend until 2024, at least for its initial definition. It is organized in eight work packages, and for each of them detailed work plans were established, including milestones and deliverables, as well as resource estimates. The working group convenors and steering committee members established a detailed report[4] of which the present document gives a concise summary.

2 Technological Requirements

The requirements of potential post-LS3 upgrades of the LHC detectors and the ongoing detector studies for CLIC and FCC (ee, hh, eh) served as main guidelines for the choice of technologies, however even for the detectors at the HL-LHC some additional upgrades are already foreseen and others are at least foreseeable. Each of these high energy frontier projects pushes the requirements in one or several characteristics like tracking precision, timing, material budget, radiation hardness or data rate, to very challenging values—far beyond the reach of currently available technologies. Also non-collider projects were looked at, such as SHiP, KLEVER or antimatter experiments at the Antiproton Decelerator. Their needs in terms of instrumentation are disparate but still has significant overlap with the efforts for instrumentation of collider experiments.

The HL-LHC programme is designed to deliver a total of at least 3 ab^{-1} of integrated luminosity to both ATLAS and CMS by 2035-2040. The detectors will have to cope with instantaneous luminosities of up to

---

[3] A list of the names has been submitted to the ESG as confidential addendum.

[4] Strategic R&D Programme on Technologies for Future Experiments, CERN-OPEN-2018-006 https://cds.cern.ch/record/2649646

7 x 10^{34} $cm^{-2}s^{-1}$, leading to a number of interactions per bunch crossing of up to 200. In LS3 timing layers are foreseen to be added in the endcaps of ATLAS and CMS (and also in the barrel for CMS), which will enable 4D reconstruction of primary vertices with a time resolution of the order of 50 ps, mitigating the pile-up problem. It is conceivable that the regions facing the highest radiation loads will degrade in timing performance and require replacement by sensors of an improved technology.

The LHCb collaboration foresees a second upgrade with preparatory work in LS3 and main installation in LS4 of a detector which can cope with luminosities of up to 2 x 10^{34} $cm^{-2}s^{-1}$, thus 10 times more than the current upgrade under preparation. Key components to be updated are the vertex detector (VELO), the RICH and the electromagnetic calorimeter. Apart from coping with the severe radiation requirements, tracking and calorimetry technologies need to be developed which provide timing in the tens of ps range. A completely new high performance RICH, possibly with SiPM photodetectors, poses a whole range of technological challenges.

ALICE is also in the process of submitting an Expression of Interest for a future upgrade of its Inner Tracking System (ITS). Compared to the one currently under preparation, it will feature an unprecedentedly low material budget of 0.05% X_0 per layer. For its realisation, monolithic silicon pixel technology at wafer-scale needs to be developed that is ultra-thinned such that the sensors can be bent to truly cylindrical layers.

The detector requirements at a future circular hadron collider, FCC-hh (E_{CM} = 100 TeV), bring us to largely uncharted territory. With a peak luminosity of 30 x 10^{34} $cm^{-2}s^{-1}$ and a planned integrated luminosity of 30 ab^{-1}, the detector will face a pile-up of up to 1000 and radiation levels that are again 1-2 orders of magnitude larger than those at the HL-LHC. The resulting data rates lie in the hundreds of TB/s. Timing of tracks with 5-10 ps precision is required for pile-up mitigation. Software to handle the rate and complexity of the data is not available today. The expected radiation levels at the innermost layers call for major improvements in the tracking sensor technology. Progress is also needed in the electromagnetic calorimetry where fine granularity Liquid Argon or silicon-tungsten technology are interesting options. An FCC-hh detector will require a very large and strong solenoid magnet, complemented by smaller magnets in the forward areas.

The requirements at future lepton colliders, namely the linear CLIC (E_{CM} = 350-3000 GeV) and the circular FCC-ee (E_{CM} = 88-365 GeV) are very different. The focus is on high tracking precision (few μm) with very small cell size and very low material budgets (0.2-0.3%), highly granular calorimetry to allow particle-flow reconstruction, and moderate hit time capabilities (1-10 ns). The specific bunch train structure of CLIC allows pulsed powering of the front-end electronics and thus reduced cooling needs. FCC-ee requirements can be largely fulfilled by the CLD detector, a version of the CLIC baseline detector, with dimensions scaled to the smaller energies and half the magnetic field strength (2T). An alternative study, IDEA, puts emphasis on tracker transparency and particle-ID, both in the tracker and the dual readout calorimeter.

3 Work programme

The work programme is structured as eight work packages (WP), addressing well-defined technological challenges. A number of joint activities extend over WP boundaries and lead to clear synergies. Most activities will rely on co-operations with external groups.

3.1 Silicon Detectors (WP1)

Most future experiments will employ silicon technology for tracking and vertexing. To address the main challenges outlined above, four activities are foreseen.

- Development of **hybrid pixel sensors** with advanced features to be combined with high performance readout ASICs. These developments target small pixels, high-resolution timing and high-rate applications and comprise studies of various planar and LGAD sensor designs, as well as an ASIC development for very high speed and fine timing.
- Development of **monolithic CMOS sensors** for the innermost radii for maximum performance, and for the outer-layers as cost effective pixel trackers with high granularity and low material budget. Stitching and thinning of sensors may allow for truly cylindrical sensor shapes of wafer size with very low material budget.
- The **module** activity is closely linked to the hybrid and monolithic pixel detectors and focuses on the development of pixel modules and their integration for future applications. It comprises study of interconnection technologies (2.5D, 3D), integration concepts for 'standard' and ultra-thin silicon pixel detectors, module concepts integrating photonic chips and module integration to overall detector systems (including cooling and powering).
- **Detector simulations** and modelling of radiation damage, as well as the development of dedicated **characterization** setups and flexible data-acquisition systems for testing purposes.

3.2 Gas based detectors (WP2)

Gas based detection will remain a key technology in particle physics experiments. Detectors for the ILC, CLIC or FCC will rely on large area muon systems and, specifically for the ILC, on a large volume central TPC. Muon detectors will cover active areas greater than 1000 m^2 for FCC experiments. A common challenge will be the high rate capabilities. Three main lines of activities are proposed:

- **Large area gaseous detector systems**. Reliable and efficient mass production of all parts of large area gas based detectors is mandatory for any future detector. Recent experience during the upgrade of the LHC experiments shows that problems with mass production of the detectors can jeopardise construction schedules and bring the entire project to risk. New solutions for large area systems shall be addressed, specifications and procedures be developed, tested and documented.
- Foster **tools** required for future detector developments and for prototype design and evaluation. This includes detector gas studies and analyses, also under environmental aspects, further development of simulation and modelling tools as well as electronics and general instrumentation for detector testing and characterisation.
- Future detector developments call for **novel materials** as well as new **fabrication techniques**. Those will be explored on small prototypes. The use of solid converters for fast and precise timing measurements, and 3D-printing of amplifying structures, are two examples. This activity will enlarge CERN expertise in fields such as nanotechnologies and material science, fields that are not exhaustively covered today and which might bring high potential for future applications.

3.3 Calorimetry and light-based detectors (WP3)

Calorimetry and light-based detectors have been combined in a work package, as there are several potential synergies. Three topics for calorimetry and one topic each for Ring Imaging Cherenkov (RICH) counters and scintillating fibre trackers were identified:

- **Liquid Argon technology** remains of interest, mainly for its intrinsic radiation hardness, 3D imaging capability, high granularity and timing resolution. The work plan foresees studies of highly granular electrode designs, timing studies, measurements of the LAr properties in very high ionisation regimes and engineering studies for high-density signal feedthroughs.
- **Scintillator based detectors** are of interest for electromagnetic (e.g. LHCb upgrade) and hadronic domains (e.g. FCC-hh). A main question concerns the radiation hardness of potentially interesting crystals like YAG and GAGG, also at low temperatures, as required by the operation of irradiated

SiPM photodetectors. An ATLAS TileCal-like hadron calorimeter is a promising option for FCC-hh, provided that its granularity can be increased requiring different photodetectors and an improved optical concept.

- **Silicon based calorimetry** is a highly interesting technology for a CLIC/FCC-ee detector. Given that CMS is in the process of developing a new High Granularity Calorimeter (HGCal) in this technology, which is to be installed in the endcaps during LS3, further studies in this domain will be based on results and lessons learned from this project.
- The **RICH detectors** of LHCb play a key role for the experiment's flavour physics. The future upgrade in LS4 foresees a completely new RICH system with highly boosted performance and radiation tolerance. From the numerous developments required, this R&D programme will concentrate on the development of light carbon-fibre based mirrors and a compact vessel for very low-temperature operation of SiPM detectors. Here the developments profits from synergy with the mechanics work package and can rely on specific expertise and infrastructure at CERN.
- The interest in the **scintillating fibre (SciFi) tracking** technology has been greatly boosted by the availability of SiPM arrays that allow for fast and efficient readout. LHCb is currently building the world's largest SciFi tracker and foresees further upgrades in the future. The fibre technology itself has not seen much innovation in the past decades and their modest radiation hardness is a limitation. Studies will therefore concentrate on the development of fibres with higher yield and shorter decay time. Also additive production techniques may overcome the limitations of the labour intensive fibre pull technology.

3.4 Detector mechanics (WP4)

Detector mechanics and infrastructure such as detector cooling systems have often a crucial impact on detector design, operation and ultimately also on physics performance. Mechanics usually has to compete with conflicting requirements like minimum space use, thermal constraints, high precision, low mass and radiation hardness. In this programme, three main R&D lines were identified:

- **Low mass mechanical structures** for future HEP Experiments, in particular thermomechanical components for tracking detectors, which have to ensure precise sensor positioning and efficient heat evacuation at minimum material budget. A further topic is the development of **low mass composite cryostats**, which is inspired by impressive progress in the aerospace industry. Such structures based on CF-reinforced polymers could find applications in cryogenic calorimeters and detector magnets and in both cases reduce the amount of non-active material in front of the electromagnetic calorimeter.
- New **detector interfaces and service architecture** for automated installation and maintainability. Radiation levels in a future hadron collider and radiation-cooling times will severely constrain operational and maintenance scenarios. This calls for detector design and interface adaptations accounting for shielding, remote opening/manipulation and limited (short) human access as well as for a study of the use of automated and robotic solutions.
- In inner tracking systems, **high performance cooling** is required to evacuate the heat dissipated by the front-end electronics and to keep the silicon sensors at low temperature to mitigate radiation related effects. Dual phase CO_2 cooling, the baseline technology for HL-LHC detector upgrades, will fail to satisfy the cooling needs of next generation experiments, which are expected to require operation well below -40°C. The R&D focuses on new and environment friendly coolants (like CO_2/N_2O mixtures) but also on methods and technologies to increase the integration and cost effectiveness of cooling systems.

3.5 Integrated Circuits (WP5)

The High Energy Physics ASIC community is currently designing in 130 nm and 65 nm commercial-grade CMOS technologies. New smaller feature size processes bring potential advantages, like more functionality and higher speed, but also bear risks like the unknown radiation hardness and come at a high cost. Continuing with the current processes is not an option, as they will eventually be discontinued. The R&D will therefore concentrate on:

- Selection and radiation qualification of **future mainstream CMOS technologies**. This will include classic planar 28 nm technologies and the more advanced FinFETs for the 16 nm generation and below. Work with these technologies requires specific infrastructure such as CAD tools, work flows but also enablers like NDAs and training to be established.
- The **Through Silicon Via (TSV) technology** allows data to be accessed in any position of large readout chips, therefore it has the potential to eliminate the bottleneck to high data rates represented by the present need to transfer all data to one side of the chip. The TSV technology has to be developed in the new mainstream technology and made compatible with bump bonding. Additionally, access to industrial wafer stacked CMOS lines will be sought because of the potential to provide low cost high performance hybrid pixel layers.
- **Design and IP activity** in the new technology: aimed at the design of circuit functions that are needed for the development of complex mixed-signal ASICs and SOCs, and of power management blocks. This includes Improvements of existing FEAST2 DC-DC converters to increase voltage rating (25V), their radiation hardness and B-field tolerance.

3.6 High speed links (WP6)

Radiation-hard high speed data links play an ever growing role in modern experiments. The state-of-the-art marked by the lp-GBT under development for the LHC Phase-II upgrades, provides data rates of 10 Gb/s and stands radiation levels of 1 MGy and 10^{15} n_{eq} cm^{-2}. Three lines of R&D activities have been identified to bring the performance of high-speed data links to the levels required by future detectors:

- The **ASICs** activity targets 28 Gb/s to 56 Gb/s link data rates and will be carried out in synergy with WP5 for the selection and characterization of the most suitable and radiation resistant technologies. The ASICs will deal with aggregation, serialization/deserialization and driver/receiver functions necessary at the front-ends of the detectors.
- The performance of high-end state-of-the-art **FPGAs** that form the backend of the links in the counting room is already matching the targeted data rates of the front-end ASICSs and hence no custom hardware developments are foreseen. The efforts will therefore concentrate on the development of code and mastering of the tools associated to high performance FPGAs, in particular for 28 Gb/s and 56 Gb/s transceivers.
- **Optoelectronics** is key to transferring data between front- and back-ends. 28 Gb/s and 56 Gb/s links for future experiments will hit distance and radiation resistance limits which need to be investigated, understood and mitigated. The R&D will cover both legacy VCSEL-based technology and, with a larger reach, the more advanced Silicon Photonics technology.

3.7 Software (WP7)

Software forms a critical part of the HEP programme, in the generation and simulation of physics events, in the data acquisition systems and triggers of the experiments, through to the reconstruction and analysis phases. Software needs to be a first-class citizen in the development of new experiments, studied alongside the detector designs. Relying on hardware improvements alone will not even meet the computing requirements of the HL-LHC so there is a large gap which calls for significant investment in software R&D. We focus on the exploitation of new computing accelerators and on identifying new abstractions that ease the life of physicists. Much of our current software requires complete re-engineering to exploit the parallel capabilities of modern compute and storage devices. The following five R&D areas are critical:

- **Faster Simulation**. The projected computing resources needed to produce the simulated data needed for new experiments would exceed any reasonable computing budget by a large margin. The R&D aims for at least an order of magnitude speed-up by developing fast parametrisations that exploit machine learning.
- **Reconstruction for High Particle Multiplicity Environments.** Event reconstruction in pp collisions at high-luminosity or in a high-multiplicity heavy ion environment suffers substantially from a combinatorial explosion in track reconstruction and particle flow. This R&D makes advances in algorithms that scale better with pile-up, that exploit modern parallel hardware, and are designed for new detector concepts such as timing detectors and high-granularity calorimeters
- **Efficient Analysis Facilities.** The drastically increased data rates at future colliders pose a serious challenge for HEP physics analysis where the turn-around time must remain short. R&D will be undertaken in three specific areas: increasing the data reading rate; developing programming models that boost scientists' productivity; helping to design distributed Analysis Facilities specifically targeting this workflow.
- **Frameworks for Heterogeneous Computing.** To achieve the expected processing throughput within an acceptable budget, it will become mandatory to take a "heterogeneous computing" approach, coupling general processing CPUs with more efficient devices (GPUs, FPGAs and others) running dedicated workflows. A toolkit for heterogeneous computing will be developed that allows existing HEP experiment frameworks to integrate accelerated compute devices and will also address key questions of efficiency and robustness.
- **Data management across experiments**. Data management will need to adapt to a shared storage and network infrastructure serving many more HEP and astrophysics communities in the future. To achieve efficient data management we will undertake R&D in dynamic resource sharing models that can schedule concurrent requests from multiple experiments in an optimal way.

A sixth supporting activity will develop a common turnkey software stack for future experiments needed for detector R&D. Feedback to the detector design from physics studies requires a full software suite, from simulation to analysis. Unlike the software of a running experiment, detector studies tools must be lightweight and able to adapt rapidly to detector design changes and proposed accelerator scenarios. The existing software stacks used by the CLIC and FCC study groups will be streamlined and merged and then prepared for reuse by new detector study groups.

3.8 Detector magnets (WP8)

Detector magnets and magnet systems are key components of future experiments. In order to cope with in some cases tremendously increased requirements, challenges in different domains need to be addressed. We see deeper experimental caverns in the range of 300 to 400 m underground, specific garage positions for detector maintenance, much larger dimensions, much larger stored energies and magnet operating currents up to 40 kA.

- **Advanced Magnet Powering** for high stored energy detector magnets. These comprises developments, such as a Free Wheel System (FWS), a Persistent Current Switch (PCS), compact, high performance Quench Protection Dump Units (QPDU) that will improve the stability and efficiency of the operation of such magnet systems while minimizing energy consumption in an effort to be more economical and ecologically sound.

- **Reinforced Super Conductors and Cold Masses.** The next generation detector magnets will require very high yield strength Al stabilized and reinforced NbTi/Cu conductors. This need is not only expressed for large bore high field detector magnets but also for detectors with the design goal of a 2-4 T solenoid cold mass with a radiation length less than 1 X_0 (an option for a FCC-ee detector), allowing a few centimetres of Al alloy in cold mass and conductor only. This activity is foreseen at a later stage of the R&D program, possibly for the second 5-year phase.
- **Ultra-Light Cryostat studies.** As described above, studies of next-generation cryostats for detector magnets and calorimeter cryostats will be performed to meet the design goal for minimum radiation length. These studies shall result in a table-top demonstrator of about 1 m^3 size.
- New **4 T General Purpose Magnet Facility** for Detector Testing. Many of the future detectors will have to work in a 4 T magnetic field. For testing detector units and performing calibration with magnetic field, a general purpose 4 T test facility is required that will replace or complement the outdated systems available at the CERN North Area providing maximum fields of 1.9 and 3 T, respectively. The efforts in this R&D programme are restricted to a conceptual design study of such a facility while its implementation will require funding from other sources.
- **Innovation in magnet controls, safety & instrumentation**. The current LHC and the next generation detector magnets will operate over several decades. We have therefore defined a R&D programme targeting the upgrade of existing instrumentation and new technologies, concentrated on three domains: quench detection, magnet control systems, and magnetic measurements. The 4 T general-purpose test facility will serve as a use case for these developments.

4 Conclusions

We have defined a strategic R&D programme focused on technologies that we consider crucial for future experiments at the high energy frontier. The initiative follows the tradition of previous R&D programmes that made fundamental and vital technological contributions to the current LHC experiments and their upgrades. Given the multitude and complexity of the challenges ahead, the initiative is timely and would ensure continuity following the LHC Phase-II R&D efforts. Support for this initiative from the European Strategy Update process would be crucial.

To be effective and efficient, the implementation of this programme relies on two factors: 1) appropriate funding throughout its lifetime in terms of materials and investments, but also in terms of experienced researchers, postdocs and students, and 2) sustained cooperation with partners from the HEP community. Motivated by the great success of R&D collaborations like RD50 (radiation hard silicon detectors) and RD51 (micro pattern gas detectors), we could see this model also applied to other areas.

The total budget, over the initial 5-years period, was estimated to be 23.5 MCHF for materials and longer term investments (lab equipment), plus about 450 person-years of doctoral students and postdocs (fellows).

Acknowledgements

We would like to thank all colleagues—at CERN and from external institutes—who actively participated to this process by contributing ideas, proposals and critical feedback. Their experience and views were essential for developing the process. We will heavily rely on their cooperation also during the implementation phase. Finally, we express our gratitude to the CERN management for their support and encouragement.