Summary of the context and overall objectives of the project

The AIDA-2020 project brought together the leading European infrastructures and academic institutions in detector development for particle physics, regrouping more than 10,000 scientists. 19 countries and CERN were involved in this programme aligned with the European Strategy for Particle Physics. With the upgrade of the Large Hadron Collider (LHC) and its experiments, the community had to overcome unprecedented challenges, which AIDA-2020 addressed.

AIDA-2020 advanced detector technologies beyond previous limits by offering well-equipped test beam and irradiation facilities for testing detector systems under its Transnational Access (TA) programme. Common software tools, microelectronics chips and data acquisition systems were also provided. These shared high-quality infrastructures and standards ensured a coherent development by collegially involving experts across Europe. The enhanced coordination within the European detector community leveraged EU and national resources and contributed to maintaining Europe's leadership in the field.

Work performed from the beginning to the end of the project and main results

WP1 (Project management and coordination) monitored the progress through bi-monthly meetings of the Steering Committee and was ensuring the contractual and administrative implementation of the project. Four Annual Meetings, held at Hamburg, Paris, Bologna and Oxford, plus an online Final Meeting were organised and each was attended by around 120 participants, who praised the role of AIDA-2020 as a forum for exchange across projects and collaborations.

Activities in **WP2 (Innovation and Outreach)** included the website, quarterly publication of the newsletter, and production of videos on facilities open for Transnational Access. A so-called Proof of Concept fund supported three projects targeted at applications of AIDA-2020 technologies outside of particle physics, e.g. in medicine. Important steps towards commercialisation of results have been made, in the form of license agreements and the founding of a spin-off company.

WP3 (Advanced software) has delivered software tools, which are being integrated into and routinely used in experiments running today, e.g. a new geometry package suitable for vectorised computing. Further developments include packages for alignment corrections and the sophisticated Pandora particle flow algorithms.

In **WP4 (Micro-electronics and interconnections)** the two main deliverables consisted in complex and highly integrated CMOS readout chips for new instrumentation: a 65 nm chip for the pixel detectors developed in WP6 and WP7 for the LHC upgrade and a 130 nm chip for the gaseous detectors and calorimeters supported in WP13 and WP14.

In **WP5 (Data acquisition system for beam tests)**, the Trigger-Timing Logic Unit for detector tests in high-energy particle beams has been developed and can be used to synchronise detectors, which have different timing and triggering structures. Data acquisition and quality monitoring software have undergone significant development. The DAQ system has already been used for detector prototypes for a future Linear Collider, as well as for detectors for the LHC upgrade.

The activities of **WP6 (Novel high voltage and resistive CMOS sensors)** focused on hybrid detectors and monolithic CMOS devices. The excellent performance of the monolithic prototypes before and after irradiation, and the cost effectiveness of their fabrication cycle, have consolidated this approach. Industrialization and system issues, related to detector assembly and deployment, have also been addressed.

WP7 (Advanced hybrid pixel detectors) optimised the sensors for the silicon-based vertexing and tracking systems, using planar and 3D diodes or low gain avalanche detector technologies. The focus moved towards the characterization of hybrid pixel sensors, for which radiation-tolerance were successfully assessed.

The activities of **WP8 (Large cryogenic liquid detectors)** were embedded in the Neutrino Platform at CERN. Key technologies for purity monitoring, photo-detection, very high voltage supply, charge readout, associated cryogenic front-end electronics and DAQ were developed and tested. Many of these developments have been integrated and conducted in large prototype detector recording cosmic ray data in 2017.

In **WP9 (New support structures and micro-channel cooling)** standard miniaturized hydraulic connection technologies have been defined to allow for rapid prototyping, extreme minimization, and long-term reliability under high pressure and radiation doses. A state-of-the-art testing facility for boiling flows of CO_2 in mini- and micro-channels is now ready for exploitation at CERN, and precision test stands for ventilation and vibration tests were set up at Oxford.

The **TA programme** was organised in **WP10, WP11 and WP12** for test beams, irradiation and characterization facilities, respectively. All facilities provided support to users, in some cases exceeding the target access units, thus demonstrating the demand from the community.

In **WP13 (Innovative gas detectors)** tools to produce and characterise resistive plate chambers and micro-pattern gas detectors were developed. Novel architectures and technological tools, in particular in the field of dedicated readout electronics were steadily developed. Environmentally friendly gas mixtures have been explored to minimise the global warming impact of these detectors.

WP14 (Infrastructure for advanced calorimeters) developed calorimeter systems based on silicon or scintillator, and test infrastructures for advanced optical materials have been commissioned and used. Common beam tests of CMS and CALICE calorimeter prototypes highlight the fruitful exchange between LHC and Liner Collider targeted developments. The demonstration of an assembly chain for silicon-based calorimeter elements was achieved.

As part of **WP15 (Upgrade of beam and irradiation test infrastructure)**, a new version of EUDET-type pixel telescopes has been constructed and installed at CERN, and a high-resolution silicon strip telescope was commissioned at DESY. A new gas system and a new dose monitoring system have been installed at CERN's Gamma Ray Irradiation Facility GIF++, and the upgrades foreseen for irradiation facilities at CERN, Birmingham and

Ljubljana have been completed. A new beam line was installed at Frascati, and a photon tagging system was prepared.

Results from all these activities have not only been documented in Milestone and Deliverable reports, but also found their way into numerous conference presentations and publications in refereed journals with world-wide audiences, to an extent exceeding by far the original targets of the project.

Objectives	AIDA-2020 Targets	AIDA-2020 Results
Scientific dissemination	**180** publications including: **60** journal publications **50** conference contributions	**361** publications including: **106** journal publications **69** conference contributions
General communication and news	**10** articles in newsletters and other communication channels	**14** issues with **86** articles in newsletters and other communication channels
Cross-border cooperation	**38** beneficiaries from **19** countries	**38** beneficiaries from **19** countries
Knowledge sharing in the community	**450** project members in **15** work packages	**450** project members in **15** work packages
Enhanced Transnational Access	Up to **300** TA user projects with **940** users and **30504** access units	**281** TA user projects with **1082** users and **34599** access units
Pre-industrialisation of novel detector technologies	**3-4** projects supported by the Proof-of-Concept fund	**3** projects supported by the Proof-of-Concept fund
Training of PhD scientists and engineers	**60** PhD students	**76** PhD students

Progress beyond the state of the art, results and potential impacts (including the socio-economic impact and the wider societal implications of the project)

Recently the upgrades of the LHC experiments, conceived to cope with unprecedented demands of data rates, radiation hardness and timing precision, have taken shape. They not only maintain the performances under much harsher conditions, but even improve them and thus open up new potential for physics discoveries. This becomes possible through visionary concepts and novel technologies, for which AIDA-2020 activities have been crucial, for example for establishing radiation-hard sensor technologies and readout electronics, for preparing the first implementation of highly granular calorimeter concepts, and by providing test infrastructures and software tools that keep pace with the ever more ambitious demands.

AIDA-2020 was a unique framework at European level to unfold such synergies and coordinate the research on common needs of the field as a whole. The impact on the competitiveness of European detector science is evidenced by the leading roles of European representatives in many global projects.

The socio-economic impact of AIDA-2020 rests on two pillars. Particle physics, like accelerator science, is particularly strong in pre-procurement R&D for series production, as required for big accelerator projects. Industrial partners then capitalise on the acquired know-how for applications targeting other markets. With dedicated Academia meets Industry events, AIDA-2020 proactively reached out to open up further fields, for example in non-destructive testing, for a fruitful transfer of particle detector technologies to meet the growing demands of industry for the faster and more detailed characterization of complex products and installations. In addition, AIDA-2020 has launched a dedicated funding for projects developing applications beyond particle physics together with industrial partners. The supported projects realised the knowledge transfer to applications via license agreements and spin-offs, with two of the three projects in the public health sector.