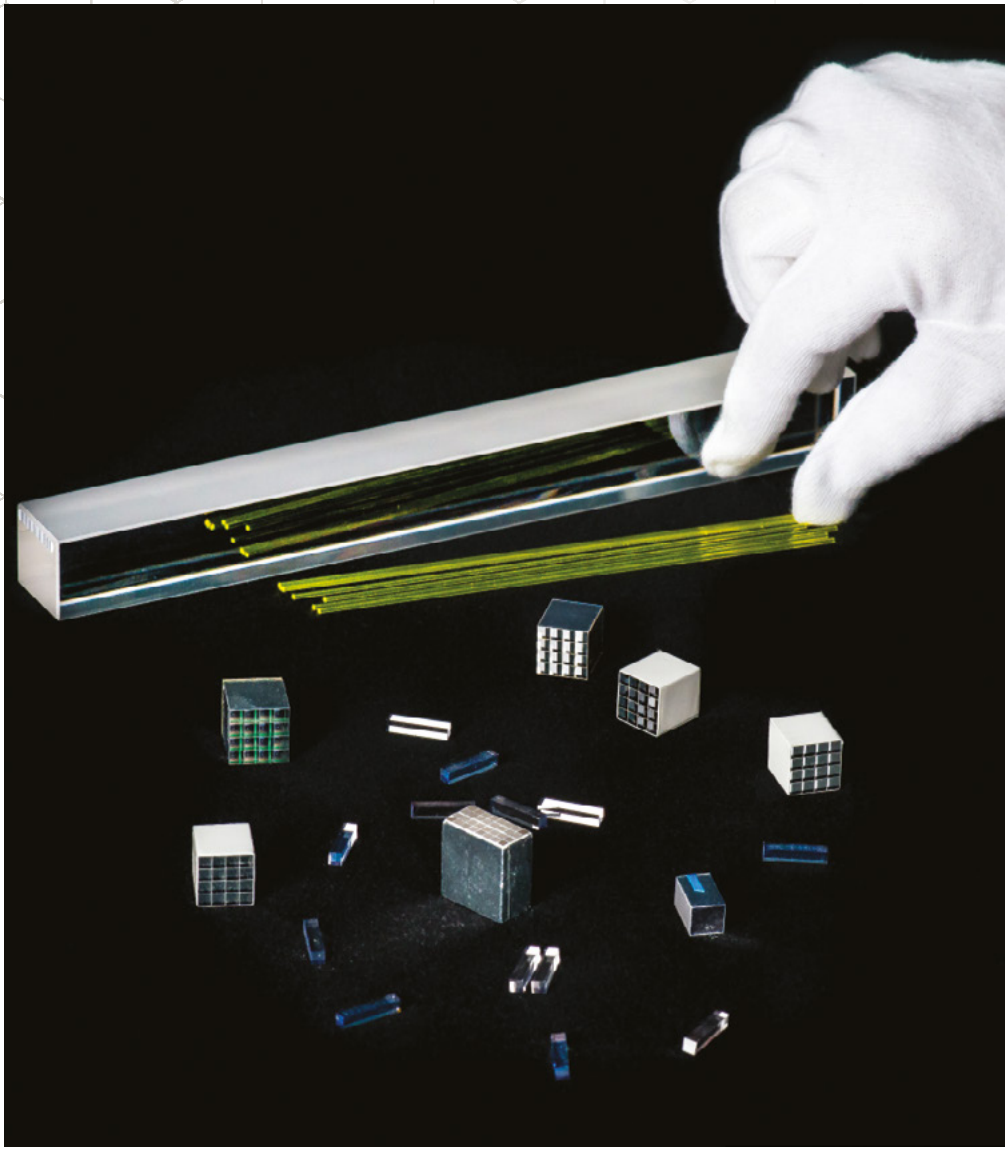
PUSHING THE FRONTIERS OF TECHNOLOGY

To conduct research at the frontiers of knowledge, CERN scientists develop, and sometimes invent, cutting-edge technologies and processes. These new technologies often find applications beyond their immediate field. CERN keeps in close contact with innovation partners in industry to allow them to benefit from the Laboratory's most recent innovations. Knowledge transfer – the transfer of technologies and know-how to society – is an important mission for the Laboratory.



These scintillating crystals were developed for high energy physics (top) and for medical imaging (small crystals and matrices in the foreground), in the framework of the Crystal Clear collaboration and the European FP7 project EndoTOFPET-US.
Crystal Clear, which celebrated its 25th birthday in 2016, was initiated to develop new scintillating crystals for the LHC experiments. The collaboration's work has benefited not only particle physics but also medical imaging and other industrial applications.
Today, Crystal Clear is developing new prototype detectors based on scintillating crystals for use in both high-energy physics and medical imaging, with particular emphasis on positron emission tomography (PET). (OPEN-PHO-TECH-2017-005-4)

DIVERSE APPLICATION FIELDS: FROM MEDICAL TO AEROSPACE AND MORE

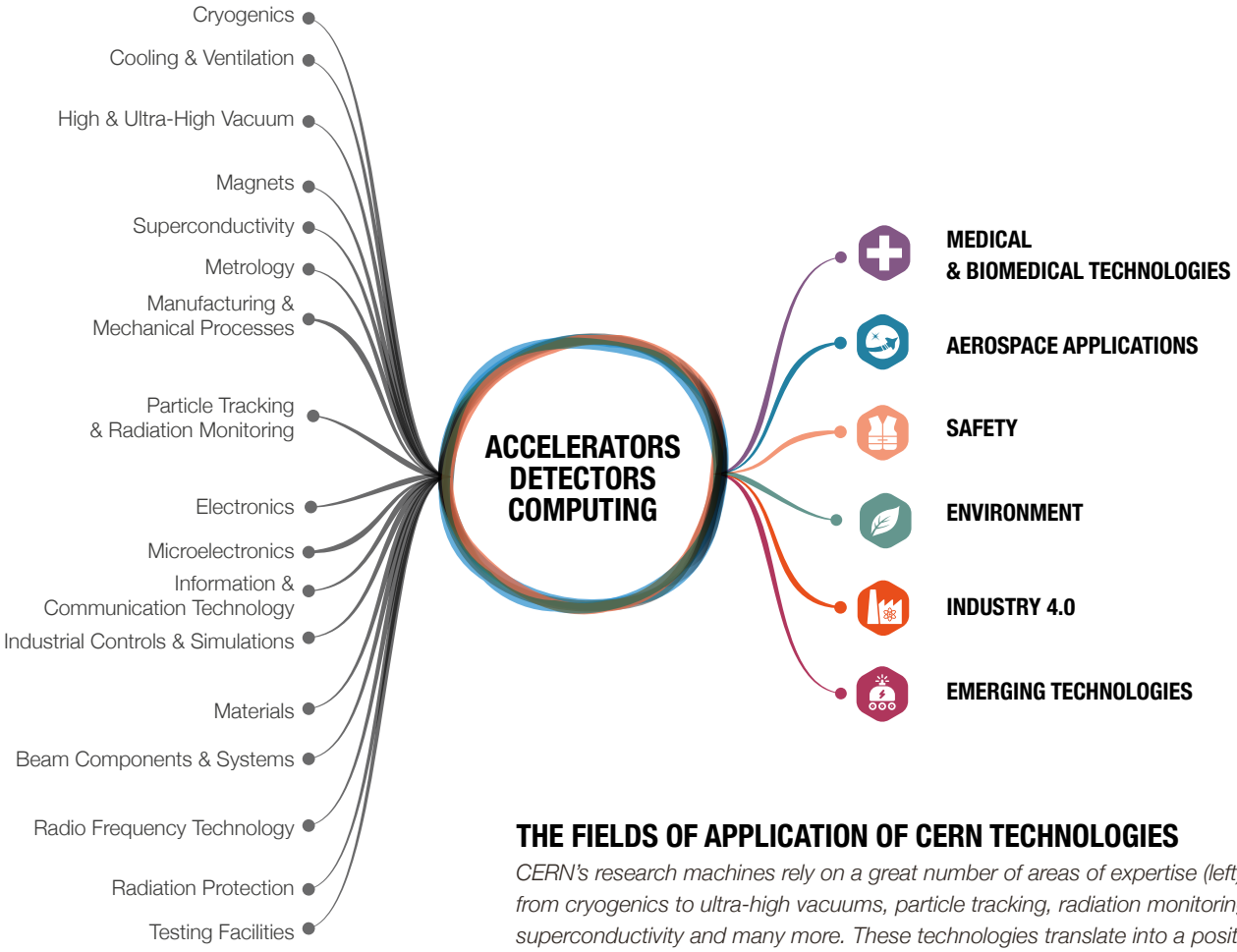
CERN's expertise builds broadly on three technical fields: accelerators, detectors and computing. Behind these three pillars of technology lie a great number of areas of expertise, ranging from cryogenics to ultra-high vacuums, particle tracking, radiation monitoring, superconductivity and many more. In 2016, these technologies, and the human expertise associated with them, translated into a positive impact on society in many different fields: medical and biomedical technologies, aerospace applications, safety, the environment and industry 4.0 (including robotics and the "Industrial Internet of Things").

In 2016, CERN's contribution to **medical and biomedical technologies** was significantly strengthened by identifying strategic avenues and implementing a new organisational set-up. By working closely with medical communities and Member and Associate Member States, CERN can ensure that it provides solutions to the end-users' needs.

The year 2016 was busy and exciting for MedAustron – a facility located in Wiener Neustadt, Austria, which uses an accelerator to generate ion beams for cancer therapy and research. The accelerator has been operating 24/7 since January, and in September the facility was legally certified to operate as an outpatient clinic, with the first medical treatment performed on 14 December. By 2020, full operation will have been reached, with about one thousand patients being treated per year. CERN contributed considerably to the development and construction of the centre's accelerator system.

In 2016, CERN and the University of Bath released new open-source software for medical imaging. This shareware toolbox provides fast, accurate 3D X-ray image reconstruction, with applications in medical imaging for cancer diagnosis and treatment. It offers a simple and accessible way to improve imaging and potentially reduce radiation doses for patients. The software is based on cone-beam computed tomography, a scanning process that takes 2D X-ray pictures and processes them into a 3D image. The toolbox is called the Tomographic Iterative GPU-based Reconstruction (TIGRE) toolbox, and is available on an open-source basis on GitHub. The collaboration hopes that its open-source approach will bring together academics and clinicians.

To support its **aerospace applications**, CERN is establishing a network of institutional partnerships with space agencies, industry, universities and international organisations, and 2016 was fruitful in this respect. In June, CERN signed an agreement with the Swiss Space Center (SSC). The agreement ensures that CERN can benefit from the SSC's



THE FIELDS OF APPLICATION OF CERN TECHNOLOGIES

CERN's research machines rely on a great number of areas of expertise (left), ranging from cryogenics to ultra-high vacuums, particle tracking, radiation monitoring, superconductivity and many more. These technologies translate into a positive impact on society in many different fields (right).

In 2016, MedAustron, a new ion therapy centre in Austria, began operation. The synchrotron of this medical research and treatment centre was developed in collaboration with CERN.

expertise in space activities and its extended network in Switzerland, supporting the transfer of CERN's technologies and expertise to the aerospace field.

In September, a memorandum of understanding was signed between CERN and the Euclid Consortium, giving the Euclid space mission the status of "recognised experiment" at CERN. Euclid – a European space mission that aims to study the nature of dark matter and dark energy – has now officially chosen the CERN Virtual Machine File System for its nine data centres. This system, called CernVM-FS, was developed by researchers at CERN as a means of sharing software and codes efficiently in big-data environments. As well as its use by Euclid, it is currently also used in high-energy physics experiments to distribute about 350 million files.

Since 2016, CERN has been participating in the Fibre Optic Sensor Systems for Irrigation (FOSS4I) research project, which has **environmental applications**. It aims to design a system for optimised irrigation based on technologies developed for high-energy physics. The irrigation system will use fibre-optic sensors designed to measure parameters such as temperature, humidity and fertilisers present in the soil of cultivated fields. The system will help to build more sustainable agriculture by enabling water savings, increasing crop yields and reducing the use of pesticides and fertilisers. The fibre humidity sensors are based on those developed for the CMS experiment. A key aspect of this project is its open approach: all hardware will be released under CERN's Open Hardware Licence, and the software will be released under an open-source licence. The research programme was launched by the UK Lebanon Tech Hub (UKLTH). CERN, as part of its knowledge transfer efforts, will lead the project and provide continued knowledge transfer support after its initiation.

Industry 4.0 is the new trend of increased automation in industry, often associated with connected sensors, autonomous robots and big-data technology. The start-up Terabee uses CERN sensor technology and has begun to provide aerial inspections and imaging services by deploying drones. After fruitful collaboration with CERN, where sensors were used to ensure the safety of operations in the complex environments of the LHC, the business has expanded to include sensor development. In 2016, the start-up won the first place in the automation category of the prestigious Startup World awards at the Automatica trade fair.

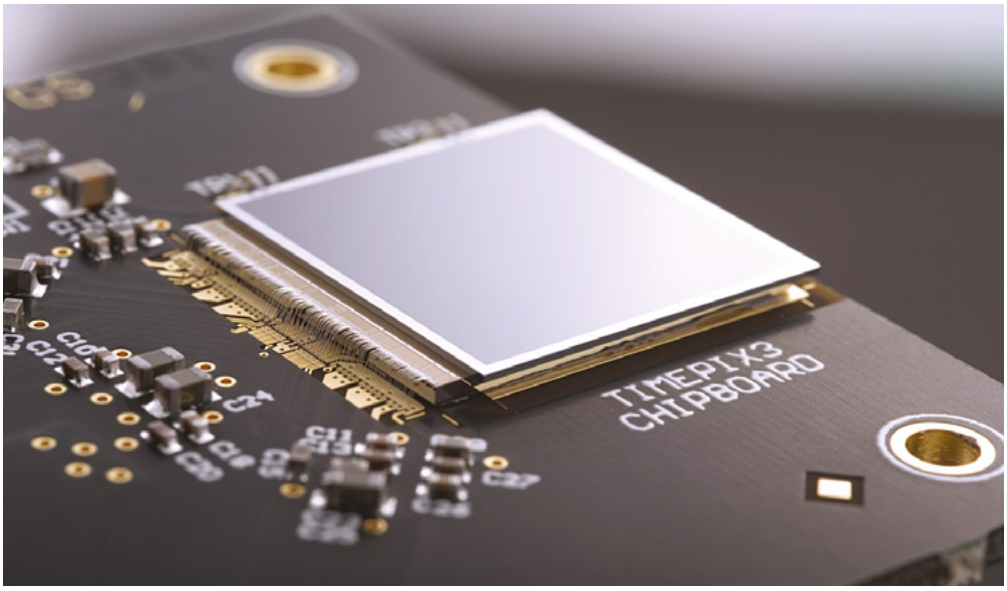
ACCELERATING INNOVATION

Innovation can happen organically, in the sense that new ideas and technologies eventually develop into new products or adapt to market needs. Actively investing in innovation can accelerate the process. To this end, CERN invests in many activities through its Knowledge Transfer group, which provides advice, support, training, networks, seminars and infrastructure to facilitate the transfer of CERN's know-how to industry and eventually to society.

In 2016, CERN was highlighted as an example of a successful regional innovation initiative in the Global Innovation Index (GII) published by the World Intellectual Property Organisation (WIPO), Cornell University and INSEAD. In 2016, a series of Knowledge Transfer seminars, which can be viewed free of charge via webcast, highlighted the impact of CERN on society.

The **CERN Knowledge Transfer Fund** selects innovative CERN projects with high potential for a positive impact on society. Over the last six years, it has become a pivotal tool for creating links between research and industry. To date, 38 projects have been funded and 21 completed in a wide range of fields. They have so far led to 17 knowledge transfer agreements with industry and research institutes.

Beyond its mission to champion innovation, the CERN Knowledge Transfer Fund has also contributed to developing



The Timepix3 chip is a multipurpose hybrid pixel detector developed in the framework of the Medipix collaborations, having applications in medical imaging, education, space dosimetry and material analysis. Originally developed for use in the LHC experiments, Medipix technologies are an outstanding example of how technology devised at CERN can create societal impact. (CERN-PHOTO-201702-048-4)

human capital. Students and young professionals have gained valuable industry-oriented experience. Today, they continue their careers in fundamental or applied research or in industry. Another milestone was reached in 2016: two projects co-funded by the European Commission, AIDA-2020 and ARIES, incorporated a Proof-of-Concept fund modelled on CERN's Knowledge Transfer Fund.

In 2016, CERN funded six new projects covering new applications for CERN technology in fields ranging from cancer diagnostics and aerospace applications to next-generation cloud computing, radiation protection and digital preservation.

After successfully concluding its first phase, **SCOAP3**, the open access initiative for particle physics has been extended for another three years. This initiative, managed by CERN, makes scientific articles available free of charge to everyone, at no direct cost to authors and readers. Since its launch in 2014, it has made 13 500 articles by some 20 000 scientists from 100 countries accessible to anyone. This success is made possible by 3000 libraries in 43 countries contributing funds previously used to subscribe to the journals, with the additional support of eight funding agencies. Participating publishers have observed a doubling of the number of article downloads since the start of the initiative.

During its second year of operation, **IdeaSquare** continued to make important progress in connecting detector-related R&D activities with cross-disciplinary Masters-level student teams working on societal challenges. IdeaSquare organised or hosted more than 80 events in 2016, including knowledge transfer workshops, challenge-based innovation courses and weekend hackathons. An online journal was created to record the education- and innovation-related processes at IdeaSquare in order to measure its longer-term societal impact.

BUILDING A CULTURE OF ENTREPRENEURSHIP

In 2016, CERN continued to work towards creating a culture of entrepreneurship within the Organization. The many avenues explored include the network of business incubation centres, entrepreneurship meet-ups and mixers and seminars, where budding entrepreneurs can share ideas and experience with experts.
CERN has established a network of business incubation centres (BICs) throughout its Member States to assist entrepreneurs and small technology businesses in taking CERN technologies and expertise to the market.
CERN signed its ninth business incubation centre agreement with the Italian National Institute of Nuclear Physics (INFN) in June 2016. Currently, 18 start-ups and spin-offs are using CERN technologies in their business. In 2016, 23 start-up companies submitted expressions of interest in entering six of the BICs.

COLLABORATIONS

CERN engages with international organisations, is establishing a network of partnerships, and participates in the knowledge transfer activities of several projects co-funded by the European Commission. The Organization is involved in several knowledge transfer networks, such as EIROforum, an umbrella organisation of eight international research organisations.

CERN continues its collaborative activities in projects co-funded by the EC. Of the 12 new projects selected for funding in 2016, two are coordinated by CERN: ARIES, a large integrating activity involving accelerator science and technology, including industrial and societal applications, and RADSAGA, a Marie Skłodowska-Curie Innovative Training Network relating to electronics used in space, for aviation, on the ground and in accelerators.