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ARIES – Development of Accelerator Technology in Europe 2017-2020: Global and Local Consequences

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Abstract—**The article describes chosen, yet key parts of newly established European, infrastructural research and development project ARIES (2017-2020) - Accelerator Research and Innovation for European Science and Society, to be realized inside the framework of the H2020 programme. Two institutions from Poland participate in ARIES – these are Warsaw University of Technology and Institute of Nuclear Chemistry and Technology. ARIES is a topical continuation of the previous infrastructural accelerator projects realized uninterruptedly since 2003 – FP6 CARE – Coordinated Accelerator Research in Europe and FP7 TIARA – Test Infrastructure and Accelerator Research Area, EuCARD – European Coordination for Accelerator Research and Development, and EuCARD2. The article is simultaneously a part of a series of papers concerning the participation of Polish doctoral students and young researchers, especially from the Warsaw University of Technology, in large European and world experiments of the discovery class, including building large research infrastructures like: FLASH and EXFEL, ESS, ITER and DEMO, IFMIF, but also satellites built by the ESA, etc. ARIES embraces, among others, the following subjects: energy efficiency and management, cost lowering, miniaturization and ultra-high field gradients, promotion innovation, industrial applications, societal implications, new materials and components, new methods of particles acceleration including laser-plasma-particles interaction, and building new generations of systems.**

Keywords—**renewing and maintenance of large research infrastructures, research efforts in Europe, accelerator science and technology, large research infrastructures, research experiments of discovery class, research and technical innovations in Europe, technology transfer issues to industry, social implications**

I. INTRODUCTION

EUROPEAN infrastructural projects, funded inside the framework programmes, now by H2020, and after 2020 by the planned FP9, are very important to the research communities due to several fundamental reasons. These large projects, through the focused and considerable funding, build the future in key areas of research and development for the next decades. They are quite precisely targeted to these areas (physics, chemistry, biomedicine, engineering sciences, environmental protection) which first maintain the competitiveness of Europe as a leader in scientific and technical areas, and second will improve in the near time scale the quality of life of the Europeans. Thus, the impact of such projects is equally global and local. Participation in such projects is a honour, proof of aspiration to belong to the first league, and at least for smaller participants a recognition by the leaders. The active participation in such project realization is a strong help in the development of one's own staff, also research and technical infrastructure, so as to enable the participant to become an active force adding up efficiently to a joint development effort. The possibility to add to the common creative effort is a powerful development force for the local scientific community and the entire local society. Lack of such a possibility is a misfortune of the local research and technical communities and degradation of the local society.

Infrastructure projects have a particularly advantageous feature - they integrate additionally topical research projects. This is what happens with the discussed here ARIES project, and so was with the EuCARD project. It is estimated that around the recently realized accelerator infrastructure projects in Europe there were gathered experiments expanding our horizons of knowledge but also applications worth more than one billion Euro. Similar effects are observed in other sectors, eg. in photonics, which is also actively seeking to infrastructure projects through a well-organized and influential European Technology Platform Photonics 21. Very active in the field of self-organization and acquisition of research projects is also the European research community of material engineering. Interesting issue of ARIES project realisation is to show, on the background of the project technical and research contents, its European impact, as well as a local one, particularly in Poland. Even if the participation of research teams from Poland are small, the impact seems to be disproportionate big. We risk to try to answer this question.

II. HOW TO ESTABLISH A LARGE INFRASTRUCTURAL EUROPEAN RESEARCH PROJECT AND WHAT COMES OUT OF THIS?

The European community of accelerator research and technology, gathered around the biggest European laboratories like CERN, DESY, GSI, PSI, INFN, CNRS, CEA, etc., coordinated by such bodies as ECFA, ESGARD-TIARA, etc., has developed research infrastructure project to be financed within the H2020 concerning the impact of innovation in this area on the European science and technology and wider on the society. The infrastructural project ARIES - Accelerator Research and Innovation for the European Science and Society, coordinated by CERN, will be implemented in the years 2017-2020. The project with a budget of approx. 30 million Euro, includes more than 40 partners, which are mainly the

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institutions with own accelerator infrastructure. The project is a continuation of previous joint efforts by the European communities as TIARA - Test Infrastructure and Accelerator Research Area, also CARE and EuCARD. Preparation of such a large initiative is coordinated by the European Steering Group for Accelerator Research and Development ESGARD/TIARA. ARIES focuses on a limited number of key accelerator technologies, putting the emphasis on the role and impact of research and technical innovations on the society.

Such an approach to the construction of massive European research projects, submitted and currently realised in the H2020 framework programme, is observed in significant parts of scientific communities, including not only accelerator but also for example laser, photonic, and material engineering organized around the European technology platform Photonics21. The technologies selected for development within the ARIES and similar projects have a degree of technological readiness from 1 to 4, and it is expected that as a result of the project will be promoted to levels above 5. The priority possess technologies that have a potential of interacting directly with the industry and leading to practical applications or creating spin-off businesses. The research areas with a lower level of technical readiness are encompassed in the project by networking activities, so as to allow their experimental verification. Institute of Nuclear Chemistry and Technology and Warsaw University of Technology participate from Poland in ARIES. The main participants of ARIES are institutions from Germany, France, Italy, England, also Switzerland, Spain and Scandinavia.

Establishment of such large, multi-million European research infrastructure projects is closely managed by a multi-level scientific and economic policy developed by the EU and member states. Strong and relevant pan-European collaborations are built by the topical groups of interests to be sure to achieve a success in the tough submission process. The structure of such consortia is generally as follows. The initiators are the owners of major European infrastructure. The core group invites a number of key research and technical centres fulfilling certain criteria. These criteria aim at two main targets: strengthen the core team, filling properly the gaps in the expertise front, and increase considerably the chances of project submission acceptance. Some of the choice criteria for additional beneficiaries are: have relevant, confirmed, i.e. known widely enough expertise, fit to the particular subject details of the project, supplement properly geographic distribution of the submission, are university based cooperating with larger research laboratory, offer attractive transnational access to the well-equipped laboratory, etc. Having in one's own country a major institutionalized research infrastructure facilitates, and sometimes even makes it possible at all to participate in a large prestigious project. A very positive and successful example is the large Scandinavian MAX-IV infrastructure which participates obligatory in all major European and global initiatives, that well takes care of the interests of smaller Scandinavian laboratories and in particular numerable small and scattered groups from universities operating in the adequate field of accelerator science and technology. Without a strong support of the active key national institution, such university groups would be much less likely to participate in the mainstream of the biggest European projects.

This can be applied to Poland - a great and one of the main European accelerator infrastructure projects, just excellent in terms of the planned technological progress – and there are participating only two institutions from Poland? Well, it is great that generally we are here. We do not have in the country a strong promoter, the tractive force of a sufficiently high potential and authority in Europe to take care of our interests. Such a promoter of the European scale (like DESY, CEA, INFN, PSI, etc.) must be built on the best national existing infrastructures and R&D institutions like NCBJ, IFJ PAN, the largest universities. But this may be done only with appropriately strong support of relevant political forces. So far, the local political will seems to be not ripe enough. First, build ripe infrastructure of class in Poland, establish a strong active community around, gain experience by diligent and hard work i.e. by blood, sweat and tears, and second, try to join the league of top owners. There is no other way. We catch up with such large projects as beneficiaries only through our diligence, but mostly with a lot of luck. Of course, one can immediately add to this a noble ideology that we are so outstanding that without us anything can be done. Unfortunately it is not the truth. This is the state who with its abilities and authority determines the presence and position of their sectors in Europe. We scientists can only gain research footholds, defend them fiercely, and we are just doing this. Polish sector of science and technology at the European level does not meet the expectations of its many national representatives, particularly these very active internationally. This is the situation prevailing not only in the physical and engineering research sectors but also in others. ARIES is one of numerable and similar projects now run by the H2020 program.

Using effectively the participation in such a prestigious project as ARIES, and other similar ones, we are trying to involve the cooperation of national students, graduate students and young scientists. Operating in an environment of discovery experiments, knowing the heads of the research groups and the details of run research, enables efficient promotion of our students of engineering sciences and physics. Today, even without such a support of mentors they take care of themselves increasingly efficiently, going where the science is created, where is the research front, in many areas where it is not present in the country. Such a unidirectional flow of young talent will be smaller or disappear if the situation is more symmetrical. If we have in the country places where also we will be able to invite European youth to work with us, together with our youth. Currently talents depart. In this work we describe the ARIES project and our relatively small participation in it, as well as the participation of our youth, which generally carries out their research in major beneficiaries of the project. In several similar articles published in the last few years in the Electronica Journal by Association of Polish Electrical Engineers we described the participation of our youth in many other projects, of discovery class, conducted mainly in Europe but also in the US and Japan like: CARE, TIARA, EuCARD, EuCARD2, MAX-IV, ESS, TESLA, FLASH, EXFEL, CEBAF, LCLS, ITER and others.

ARIES project tries, according to the H2020 program guidelines, to reconcile several fundamental threads promoted in scientific research by the European Union, as the emphasis on research in the field of missing links between disciplines in such a way as to maximize the passage of scientific and technological progress to potential test pilot applications and then practical ones, also strong promotion of innovation, as well as the initial works preceding the future great experiments potentially revealing significant knowledge advances. For defined 18 project tasks in ARIES, 7 applies to network activities, 5 to international access to unique research infrastructures and 5 to joint research activities, including promotion of innovation. Led by CERN, the task of project coordination includes supervision of the continuity of accelerator research in Europe, disseminating the results of research, technical support and supervision of the publications of the project's work results in the dedicated series of monographs on accelerator science and technology, supporting the exchange of doctoral students and young scientists between laboratories, help in training of personnel specialized in the accelerator technology including current e-learning methods, support co-operation with industry, help in public meetings of topical task forces and workshops, dynamic reconfiguration of financing for emerging needs and support solutions to new problems of technological development and the strategic studies and scenarios resulting from the research update, all for the purpose of the development of accelerator technology in Europe.

The proportions of technical and research layers in ARIES are completely different compared to previous framework programs of the EU in favour of intensive financing of scientific networks, a significant increase in the mobility of professionals and a wider opening of access between institutional research infrastructures, as well as significantly increased interaction with the public. ARIES (and infrastructure projects of a similar type) is required to generate, develop and maintain the so-called "societal contacts" and intensely "promote innovation". CERN, the main coordinator of the ARIES project, almost from its beginning was in favour to these values, so it is rather the EU to begin to more strongly emphasize the research exchange in its development framework programs implemented recently. Open repositories of scientific data, open database software and hardware, substantial help in the implementation, application notes, available to the public lectures on different levels, access to laboratories for professionals and the general public, etc., make up around the science and technology, a new, very positive atmosphere additionally favouring its development, encourage capable young people to build their careers with science. Polish youth science in the field of electronics, IT and physics is no different, as they would like to tie its career to the fascinating world of research, and they often do this. These are often large leading European laboratories, where they work and stay for longer, from where the professional return to the mother country is very difficult.

III. Topical Area of the Infrastructural Accelerator Project ARIES

In terms of specific technological solutions ARIES is focused on: the development of the production of radioisotopes (eg. PET isotopes and therapeutic ones) using compact and relatively cheap commercial accelerators, development of new low-cost design of compact electron accelerators for wide industrial applications, miniaturization of accelerators, new klystrons of high energy efficiency , ultra-low-loss accelerator resonant cavities, efficient production of neutrons from targets bombarded with protons, energy efficient methods of particle beam transport, new methods of multi-stage acceleration of the particles using laser-photonics and laser-plasma techniques, use for particles acceleration of intense beams of light with orbital non-polarization momentum that is, with a helical wave front (as opposed to the spin angular momentum), betterment of laser-plasma acceleration by increasing electron bunch charge and energy, construction of low-emittance accumulating rings by developments in technology, injectors, and beam dynamics, ultra-precise control of beam quality in accelerators, increased reliability and availability of accelerators, new materials and in particular high temperature superconductors and ultimately heat and radiation resistant materials, new thin-film technologies, reliable network synchronization of distributed equipment of research and industrial grade, distributed atomic clock, new solutions for optics and modulated electron guns, and new generation of accelerator electronics.

IV. Application of Low- and Medium Energy Accelerators in Medicine and Industry

The project undertook the task to document existing applications of electron beams in Europe. Work has begun on new solutions for these applications with the use of technologies resulting from recent research. It uses devices of greater energy efficiency, greater gradient of accelerating fields, thus having smaller footprint, new materials for the cathode and the window for the radiation beam, energy recovery, and superconducting technologies. Innovative solutions in the design of miniature and energy efficient electron accelerators are offered directly to producers. There are developed standardized modular solutions, significantly lowering the cost of production, including new ways of radiation shielding, equipment servicing, etc. New solutions are specifically aimed at small and medium-sized enterprises, new companies entering this market sector, university laboratories and research-development institutions. The task includes exploration of possible new uses of compact electron linacs with energy in the range of 30 - 140 MeV, especially in biomedical areas. Potential applications include, for example: direct cancer treatment using an electron beam having higher energy values than the currently used, radioisotopes production directly by using electron beam or indirectly using gamma rays in a converter. There is built a prototype accelerator of this kind, which can open up a whole new production lines of this class of devices. Documentation of this prototype will be available for further development by the industry. One can tell it is an extraordinary generosity, but in the hot interest of the European society.

V. Production of Medical Radioisotopes – PET, Diagnostics, Imaging and Short-lived Therapeutic

The aim is to improve the availability of certain types of radioisotopes and generally significant reduction in their production costs. There is optimized a design of miniature prototype of isotopes manufacturing cyclotrons, measuring just tens of centimetres. Such devices may be purchased and be in place in the larger therapy centres, avoiding complicated and expensive transport logistics. Such tiny cyclotrons produce single dose PET isotopes for the current individual therapy in a hospital. Development of cheaper methods of radioisotopes production on site concerns especially these with a very short half life time as ^{11}C and ^{15}O. There are also examined accelerator based production technologies of most commonly used imaging isotope ^{99m}Tc, directly or through ^{99}Mo, and therapeutic isotopes to which the access is difficult due to insufficient supply. Such production usually requires more energy, higher beam currents, and in some cases other beams than the beam used to produce PET isotopes. At this stage, there are researched alternatively several solutions for accelerators: short RF linacs with compact quadrupole magnets, FFAG accelerators - fixed field alternating gradient and laser - plasma accelerators. These new accelerators allow the study of new therapeutic isotopes optimized for particular use and of low-cost production, using a variety of laser-accelerated ion beams.

VI. Energy Saving in Large Energy-consuming Research Infrastructures

Large accelerator infrastructures are extensive consumers of electricity, and of relatively low conversion efficiency. Efficient RF MW power sources are the basis for improving the efficacy of large infrastructures. New large-scale projects such as the FCC-ee accelerator and the ESS will work with lower acceleration field frequencies. There are needed new klystron sources, kladistrons and other ones efficiently bunching electrons, with the target efficiency of at least 80%, and perhaps even in the vicinity of 90%. Energy efficiency of accelerator infrastructures is also increased through optimization of energy converter targets and particle types, like protons into neutrons. There are examined new configurations of spallation moderators for neutron sources. Generally, the overall efficiency of the whole accelerator infrastructure is considered, i.e. from the power grid to the energy of generated particle beam. An important issue is the passive and active magnetic shielding using several different techniques, like cold, hot, compensating coils of magnetic flux passing the openings of the shield. The energy can be recovered from the high-current pulsed quadrupole magnets powering pulsed beam transfer lines. Optimizing of the energy management in large research infrastructures can lead to significant savings, event to an estimated level of GWh.

VII. Innovative Technologies: Ultra-durable Materials for Temperature and Radiation, New Beams, Thin Films

Accelerator technology requires usage of ultra-strong materials for beam collimation and other purposes like construction of high-power targets and beam windows, beam absorbers, composite materials with special characteristics as resistance to high-energy deposits, resistance to large energy densities, mechanical impacts and thermal radiation, ionizing radiation by proton, ion and laser beams. The materials are tested theoretically and in the laboratory. They are optimized for significant exposure to radiation and cyclic heavy duty thermo-mechanical interaction. The new materials are researched for mechanisms of degradation, such as embrittlement, transmutation, and gas emissions. The preventive means are looked for decreasing or preventing the degradation. Materials with large thermal and mechanical resistance and of a significant thermal conductivity, are used in the aerospace industries, automotive, and electronics. A separate direction of research is about creating defect colour centres in diamond in order to build luminescent screens, as well as spin qubits in diamond for quantum computing.

Electron beams of great intensity and modulated electron guns are subject to investigation. In particular the research is on an integrated electron gun with power modulator and electron lens, embracing beam diagnostics, beam dynamics and profile, and beam transport in the lens. The aim is to build a prototype model of the electron RF gun with integrated lens for use in low-energy synchrotron hadron colliders and high energy machines. Such electron guns may be needed in the future by hundreds.

Thin film technology for superconducting RF cavities is a key research subject. The research is associated with decreased production costs of superconducting accelerator cavities. Potential source of lower costs is to replace the very expensive volume material by a thin superconducting layer. The main focus of work includes: preparation of the substrate, applying thin layers, testing and interface between layers, evaluation of superconductivity and long-term stability. The substrate requires precise cleaning and polishing to obtain steady-state chemical surface topography and proper mechanical properties to minimize the impact of surface characteristics of the final thin film. The layer after application requires annealing, removing defects and increasing size of crystallite domains. Improving of the layer parameters is performed by methods of laser technology.

VIII. Innovative and New Accelerators

The group of new researched accelerators embrace – plasma, laser, dielectric, photonic and semiconductor ones. The European research network for new accelerators, coordinated by DESY, is composed of over 50 members. The research priorities of the network relate to multi-section particle accelerators, based on plasma pumped by lasers or by particle beams, but also dielectric electron accelerators. The research is primarily on dynamic generation of accelerating sections in plasma, as well as acceleration technologies using photonic components and semiconductor devices. The area of new accelerator technology attracts research youth for whom scientific - technical schools are organized. An important goal of the ARIES project is to attract the interest of young people by fascinating scientific topics emerging from brand new subjects in the field of accelerator science and technology. Coordination of research efforts in the new rapidly developing and interdisciplinary field on the border between material engineering, photonics, electronics, mechatronics and accelerator technology at the European level is a non-trivial task, but worth the effort. There is observed intensification of the pace of work and generation of valuable research results. Wide front of the basic work on new accelerator techniques at the European level is negotiated between the key laboratories and optimized in terms of human effort, time and cost, and yield the necessary results to achieve the assumed developmental stages.

In such a system of tight global cooperation, single and isolated labs are much less likely to get major results. In addition to the coordination of current and planned works, the new accelerator technology network manager creates adequate strategic groups, intensely developing further research directions. This method of common work organization builds a kind of almost formal large and efficient plant of science, involving many people, generally well-chosen experts in the field. The European network of new accelerators initiates, promotes, supports and coordinates its activities with similar, strongly thematically related, projects and initiatives like EuPRAXIA and AWAKE. Such efficient plant of new science is EuPRAXIA, defining itself as a big distributed research infrastructure of the capabilities many times in excess of a single laboratory. The aim of the EuPRAXIA project is to build a compact European plasma accelerator with a good beam quality. The EuPRAXIA project, based on several key technology active demonstrators of plasma, has to create effective prototypes of ultra-compact accelerators for scientific use, industrial, medical and energy. In turn, the AWAKE project, located at CERN, is testing the use of 400 GeV proton beam from the SPS accelerator to accelerate the electron beam of TeV energy in a single plasma section of very big field gradient.

Acceleration techniques using large field gradients are subject to intense research. In the laser - plasma accelerators of LWFA type, bigger length of the acceleration path causes de-phasing effect between the pumping pulse and accelerated bunch. After some time the pumping pulse energy is depleted. This implies the need to make multiple serial plasma acceleration stages to obtain the electron beam with energy above 10 GeV. The first stage of acceleration from the low-energy side of the electron beam has the task of coupling the whole accelerator with the injection stage. Next accelerator stages are separated from the injection, allowing them to dynamically and precisely structure the plasma medium. Initially there are tested two-stage structures using a powerful sub-EW laser. The electrons are transported from the fully optical injector to a single-stage booster. The booster is developed into a multi-stage scheme with compact inter-stage transport. Compact transport line has to be achromatic, isochronous and astigmatic, which is a major technical requirement for energy of 200 MeV. Current tests focus on the optimization of the injector construction.

In recent times, the technology of laser-plasma acceleration has made a considerable progress. Many laboratories have demonstrators of laser - plasma injectors generating electron beams with energy in the range of GeV. A typical injector uses Gaussian laser pulses with high intensity to produce the wave excited in the plasma. The development goes towards the use of non-Gaussian pulses, of orbital angular momentum for generating a non-linear wave induced in the plasma to allow the acceleration of electrons and positrons to higher energy. The use of optimized laser pulses and compact betatron radiation sources is a completely new research subject, requiring a novel theoretical and experimental approach. Optimized optical pumping pulses of plasma with vortex beams of the orbital angular momentum give relativistic electron/positron beams and X-rays with a wide range of parameters, including exotic and polarized beams.

Laser-induced dielectric accelerators manufactured by nano-technologies are the subject of research towards the construction of a single, large-gradient and effective stage of compact sources of radiation. Work on the compact, attosecond X-ray source of radiation, excited by THz wave, based on the inverse Compton scattering, made on the free electron crystal are carried out inside the AXSIS project [axsis.desy.de]. The object of research is to optimize the dielectric structures for laser plasma excitation, materials testing to obtain maximum acceleration gradient, the design and performance of the beam test stand-up. The aim is to provide an electron beam acceleration energy of 100 MeV with a single dielectric structure.

Laser-plasma accelerators, in the current tests, operate on very small charges of bunches in the electron beam (1 - 10 pC bunch charge for a few hundred MeV beam). This is approximately three orders of magnitude smaller than in conventional accelerators. The test methods are increasing the bunch charge while maintaining high beam quality. So small charge prevents many work applications. Work is continuing on laser ionization injection such as cold and transverse optical and volume shaping the plasma density.

IX. Future of Accelerators: Diagnostics and Ultra-Low Emittance

Particle beam quality determines the progress in accelerator technology and its future. Only high quality beam provides experimental progress. There are tested and classified the degradation mechanisms of beams in accelerators in terms of their particular effect on the beam. There are developed methods of preventing, reducing or avoiding the beam degradation, including new technologies with a significant impact on the beam parameters as ultra-precision electron optics, thin RF films in accelerating cavities which reduce accelerator impedance. Standards are being developed to substantially increase the reliability and availability of accelerator infrastructures. Such optimized standards, in the system of open infrastructure data, will be introduced for use by other laboratories. Methods are developed to improve the stabilization of the beam, based on more accurate models of the accelerator electrical circuit impedance, resulting in impedance reduction, and prevention of harmful electron cloud in the future accelerators, also development of new concepts and precision multi-level, multi-parameter and high-speed systems and stable feedback loop for the beam. Charged particle beam may exhibit instability associated with electro-magnetic beam interaction with the accelerator resistance and discontinuities of the vacuum chamber, as well as detrimental interactions with the electron cloud which forms in the vacuum chamber. There is no possibility of full accelerator impedance compensation and forming of the electron cloud. This awakes the need to apply for a beam an advanced stabilizing feedback with advanced electronic measurement and diagnostic systems.

The researched issues also include the recovery of energy from electron linacs, for example by beam recirculation. Today, such solutions of working multi-pass linacs do not exist, but there are advanced plans to build them, and for some solutions, the constructions have just began. There is created a database for linacs, their energy and the possibility of its recovery by applying FFAG magnetic arcs. There are studied innovative and alternative methods of energy recovery. The electron and proton linacs designers cooperate with electrons sources designers on the interaction optimization in terms of injection efficiency and pulsed beam quality.

The research is carried out on the development of some of the concepts of the present technology accelerators which are currently working on the energy front, also energy system accelerators and hadron therapy ones, as opposed to separate new solution of discussed laser-plasma, laser-plasma-particle, photonic and dielectric-semiconductor accelerators. Intermetallic crystals, including Tungsten and others, show significant potential for application in accelerator systems for curving the charged beam paths. There are investigated several far-reaching fundamental directions of development of accelerators and colliders, including photon colliders of gamma-gamma type, photon-nucleon, muon colliders, new concepts of colliders without ionization cooling. There are considered concepts using large accumulation rings of the LHC class for detection of gravitational waves, as alternative technologies for LIGO interferometry.

Ultra-low emittance of the beam is related to the use of damping rings, high quality innovative magnets, two-beam instability in colliders near to the interaction point, beam dynamics, theoretical model of the machine, vacuum system, fundamental frequency RF system and harmonics, bunch structure, high intensity beam current, new work modes of accumulation rings, etc. Ultra-low emittance rings are necessary for the construction of high-quality accumulation rings for future accelerators, ring based Higgs factories, B-factories, emittance damping rings for linear colliders, and for test and research infrastructures. Issues related to the topic of ultra-low emittance rings are: efficient and fast injection, quality of the transfer lines, non-linear dynamics of beams and technology of innovative magnets with longitudinal gradients curving the beam, superconducting inserts, fields quality and adjustment tolerances for inserts, collective phenomena and vacuum quality, superconducting SCRF system, LLRF system, impedance degradation leading to the heating, control and manipulation of bunch length, and ion instabilities.

With the construction of large and complex research infrastructures there is related the development of measurement and diagnostic methods. Modern proton and ion linacs working with very large field gradients are operating on the border of the critical parameters of the beams dynamics. The obvious goal is to build high-current, low-emittance and low-loss machines. The basis is a very precise control of beam parameters and high quality diagnostics. Beam position monitors serve as the main tool for determining the local position of the beam in the accelerator vacuum pipe and allow bunch phase measurement by time of flight method. There are used digital processing methods of the measurement signals in the frequency domain to increase the accuracy. Very high intensity beam enforce the use of non-invasive measurements. Invasive methods were employed to measure the profiles of transverse and longitudinal beams of low intensity. Precise and rapid, non-invasive methods use a number of innovative ways like electro-optical, photonic, synchrotron radiation analysis, and various gas monitors, such as the measurement of the shape of the individual electron bunches passing through the ultrasonic gas flow propagated transverse to the direction of the beam in a vacuum tube accelerator. Optimal adjustment of beam position in the accelerator vacuum tube and the bending focusing and correction magnets apertures is performed automatically by the operating feedback loops. For the feedback loop there are developed optimal algorithms for beam orbit corrections, maintain stability, locate and reduce losses, prevent too close beam approach to the pipe wall, avoid resonances and other instabilities. Many tasks of the feedback loop requires its very fast reaction. The achievable accelerator beam intensity, in some cases, is limited by the instability caused by the wake fields. Wake fields change the beam parameters via transverse and longitudinal emittance growth, excitation of coupled modes, or inter-bunch modes. These changes have to be measured and properly evaluated, before the control system will intervene with any correction. The rate of the adjustment loop is determined by the system clock of the infrastructure accelerator, the dimensions of the whole machine, and transmission delays.

Monitoring the position of the beam is used not only to determine the local trajectory and the shape of the closed orbit, but also to obtain the overall properties and performance of the magnets and various types of instability. Position monitoring provides, after processing, the control signals for the fast feedback loop. There are monitored many operating parameters of the accelerator infrastructure providing large amounts of information that must be stored, analysed on-line and some off-line. New sources of synchrotron radiation reduce their emittance even a hundred times in comparison with large currently working sources of the third generation. The requirements on the stability of the beam grow from 10% in relation to the beam diameter to less than 1%, which demands the accuracy determination of the closed orbit of the beam less than 100 nm, and the required bandwidth of fast feedback regulation over 1 kHz. The feedback system is implemented in hardware on the level of electron beam and also the level of photon beam. Innovative methods for measuring the bundle cross profile are required for the development of new FEL sources. We operate in the area femto-physics and femto-technologies – the synchronization method must ensure femtosecond accuracy, and the adjustment methods must ensure sub-nanometre precision.

X. Promotion of Innovation in ARIES Project

European infrastructure projects under the framework program H2020 include almost obligatory a task force on the promotion of innovation. The ARIES project has a small but dedicated innovation fund, initially not assigned to a specific task, but designed for the implementation of emerging ad-hoc issues requiring urgent and quick check of the concept. Innovation fund is to strengthen and promote the application potential of the project and develop the interfaces to work with industry. Framework criteria have been developed for the allocation of resources from this fund for the teams participating in the project. The criteria include, among others, market research and feasibility proof. There were scheduled several meetings with industry during the four-year duration of the ARIES project. There was appointed an industrial advisory council of the project, with set management principles of intellectual properties and licensing of the project results. There were identified several areas in which the project can provide industry with highly innovative products, including: high temperature, mechanical and radiation resistant materials, high temperature superconductors and high-power superconducting cables, and a precise, distributed clock and synchronization system for industrial and medical applications, adapted from proven and innovative technological solutions for accelerators.

There are examined composite carbon-graphite materials with high resistance to significant energy deposits, of high thermal and electrical conductivity, which withstand significant radiation dose. The materials are produced from powders using laser based additive production methods. There are also formed MgB_2 layers on the surface of metal substrate. In the area of high temperature superconductors, the basic issue related to their wider use is necessary breakthrough for the cost of materials and their industrial production. The materials have to be able to work in very strong magnetic fields. It is necessary to master a cheaper industrial mass production of wide strip of YBCO/REBCO for magnetic fields exceeding the value of 20 T, and the critical current density approximately 1 kA/mm^2 and for temperatures around 4 K. The tapes have a multilayer structure. The mechanical carrier is Cu overlaid with thin buffer layers and HTS, and covered with silver. Manufacturing methods are electroplating or laser – powder additive manufacturing. High power electrical cables are made from the tapes, of considerable lengths 100 m, and good mechanical properties. Some cables are impregnated. Such cables must permit winding of coils of complex shapes. There are examined characteristics of the cable as magnetization, power loss as a function of frequency, currents, fields and critical temperatures. Critical parameters are measured as function of cable tension (tensile, compressive and torsion) and the angle of the magnetic field relative to the surface of the HTS tape. HTS cables are used in prototype, accelerator class dipole magnets. If we manage to do such a large dipole of the high quality and field uniformity of the order of 10 T and 4 K, the magnets could in the future replace the current massive LHC dipoles 8 T running at 2 K. This means substantial energy savings in system power magnets, because 2 K helium is superfluid and requires much more energy to maintain this state.

Distribution network of events in real time is a kind of a nervous systems for research experiments and large industrial equipment and medical devices. The system consists of a main clock, fibre-optic distribution network, receivers, hardware and software, interfaces to the supported infrastructure, operator and user interfaces, interfaces to industry standards like SCADA. The characteristics of the practical utility of the system are: scalability to hundreds or even thousands of nodes, nanosecond signal precision, high reliability, and ease of use. CERN, as the ARIES project coordinator, provides the key intellectual values of such innovative solutions in open repositories of hardware and software to initiate correlated development processes and industrial products in Europe and globally. The aim is to produce, on the basis of studies made in ARIES, more widely available product, and dissemination of other innovative solutions beyond the pilot site testing carried out under the project.

XI. Access to Accelerator Research Infrastructures via the ARIES Project

If Europe is to be competitive not only in terms of the development of science and technology, but it aims to be a leader, it is necessary to gradually change the scientific policy of individual countries in the direction of openness, especially for leading scientists and European young researchers. In principle, the method is simple, the largest and most interesting scientific experiments of discovery class must attract the most talented young people from different countries and of different backgrounds. Project ARIES participates actively in the process of opening and globalization of science by supporting the fellowships of interested researchers, especially young people, in key and currently intensively developed laboratories of the beneficiaries of the project. ARIES project offers access grants for interested research teams to selected laboratories of the project participants.

Typical logistics of such access is as follows. The project covers the expenses of some of the experimental team for a period of time for the measurement campaign approximately 2-3 weeks, which corresponds to several tens of hours of access to the beams. Experimental conditions are determined and prepared a few months earlier by a qualified scientific and technical local staff, so that the use of beams was then optimized. Access grants typically take no more than 10% of the effective time of the shared research infrastructure. Access grants are allocated by competitions and usually to teams known and experienced in offered technology (plus young scientists), but also are encouraged to cooperate with interdisciplinary teams that can bring a new quality to the area of research. The idea of a broad sharing of large research infrastructures in the field of accelerator technology, and related areas as FEL lasers succeed, if after the ARIES project the stable and uninterrupted access mechanism will be continued. In short, if it is not a one-time action, implemented just because it is available external financing in Europe. Such a solution would be a failure, the more that so far the access to such infrastructures within Europe was not easy. The access demanded, among other things, considerable finances. Let's look below, at the selected access offers of the ARIES project. An important reflection in the review of this offer may be asking, what do we have in Poland to make available internationally in this one or related area of research and technology.

Lund University has created a laser acceleration laboratory as a complementary part to a large laser centre infrastructure, the largest in Scandinavia, and has made it available via the ARIES project. The centre conducts its own studies using several pulsed, high intensity lasers, which are closely related to the 3 GeV synchrotron MAX IV infrastructure. The laboratory specializes in laser-accelerated particle beams and ion beams, and generation of X-ray with high energy electron beams. The laboratory offers access to acceleration class laser pulses, of 60 TW peak power, 30 fs duration, temporal contrast 10^9, and 10 Hz repetition rate. The laser set has a diffraction limited focusing adaptive optics, acousto-optic modulators for pulse shaping and piezo-electrically driven mirror to actively stabilize the beam. The laboratory is equipped with a set of targets and chambers for plasma generation, laser acceleration, diagnostic instrumentation for particle detection and X-rays. The electron bunched beam generated in the process of laser acceleration is synchronized with the sampling 30 fs laser pulse and has the following parameters: bunch charge 1 - 10 pC, energy 100-200 MeV, duration 2-5 fs, and emittance several mm mrad. The laboratory has, for various innovative research, a unique combination of highly synchronized laser and particle beams.

Uppsala University provides HNOSS infrastructure working in the laboratory FREIA for the project ARIES users. The laboratory is testing a pulsed multi-source CW RF (352 and 400 MHz) station, and high power horizontal cryostat (1.8 - 4.5 K) designed for simultaneous testing of two superconducting resonant microwave accelerator cavities. It is aimed at testing cavities designed for large, just under construction, infrastructure of the European spallation neutron source ESS, as well as for the development of the LHC - HiLumi infrastructure and future FEL projects. The laboratory is equipped with a full set of power units, control, measurement and diagnostics and characterization of cavities, including the self-oscillating loop.

Access to research infrastructure for laser acceleration as well as chemical and physical interaction of laser radiation with matter is offered within ARIES by a very strong French national centre CNRS, CEA Saclay, near Paris. Multi-beam laser infrastructure 200 TW, beam intensity on target 10^{19} W/cm^2, several kJ of energy, is available in LULI laboratory, also via the LASERLAB-Europe. In order to increase the temporal contrast, the laser beam passes through a double plasma mirror located between the compressor and the experimental chamber. The lab has an electron beam with energy of 50 - 200 MeV, which can interact synchronously with the laser beam. Currently there are preferred multi-stage electron acceleration experiments with plasma – laser set up. There is also partly accessible, just under construction, multi-PW APOLLON laser infrastructure (consortium CILEX), with energy density 10^{22} W/cm^2. Full availability of the infrastructure is planned for the years 2018-2020.

Access to the 3 MeV proton IPHI injector with high beam currents of 100 mA is offered by the CEA Saclay. The infrastructure consists of an ion source, MW klystron RF system, accelerator and diagnostic lines. The infrastructure is flexible and allows for proton beam diagnostics, testing RF components, conversion to a neutron beam, research focused on the properties of constructed ESS/Lund infrastructure, proton and neutron research on different targets with neutron intensity up to 10^{13}/s. There are encouraged new users to cooperate by joining experiments in their own national laboratories, with the possibilities offered by IPHI infrastructure.

Karlsruhe Institute of Technology KIT offers via ARIES access to the infrastructure of the two accelerators ANKA and FLUTE. The aim is to try to significantly expand the front of research in Europe in the field of nano and micro-technology using electron and photon beams. Attracting more experiments in the hot field of nanotechnology is assessed as very beneficial to the well-known research centre KIT and especially for young scientists. ANKA is a typical universal electron accumulation ring with dedicated experimental lines. ANKA infrastructure is equipped with a full measurement instrumentation, diagnostic and research, and encourages the creative extension by external teams of experimentalists. All data from the infrastructure are available in an extensive, public website. FLUTE is a research infrastructure in the field of THz radiation. The source is an electron linac and FIR FEL. There are also available for experiments three synchronized pulsed beams of high intensity - optical, electron and THz in frequency range of 0.1-100 THz. FLUTE is also equipped with full instrumentation measurement and diagnostics.

DESY is a great, world-leading, photon research centre, perfectly oriented for international cooperation. Inside ARIES, it offers access to a completely new, just built infrastructures such as SINBAD. The laboratory has 100 MeV electron linac with fs bunches, charge 0.1-20 pC, even nC, and several beamlines. Electron bunches are optimized for plasma wake field acceleration, but also for using dielectric and semiconductor structures. Heterogeneous acceleration processes of particles are synchronized with fs accuracy. Quality parameters of the beam are measured. Full beam diagnostics is developed. Beam jitter is minimized, etc. DESY has a highly developed universal laboratory infrastructure, including mechanical, electronic, IT, etc., and offers it generously to external users.

STFC Daresbury laboratory offers within ARIES access to VELA infrastructure, which is a universal linear electron accelerator combined with a configurable test laboratories. Accelerator and testing laboratories are optimized for testing medical and industrial applications such as: health care - imaging, radiotherapy, sterilization; security - scanning of goods; energy - building energy accelerators, sub-critical power reactors; Industrial - processing of polymers, rheology modification; Environment - water sterilization, environment associated material processing with cleaning treatment; and research and development towards the construction of high-tech commercial markets for new applications of accelerators. VELA is equipped with full parameters monitoring system of the beam before and after the experiment and the associated parameters. VELA is a leading development lab for industrial scanning systems. There is active demonstrator of three-dimensional imaging system with Compton scattering and time of flight measurement, dedicated to freight containers. There are also developed methods for imaging using electron diffraction. The laboratory encourages new collaborators to joint research activities, in order to expand the front of potential work applications.

CERN offers within ARIES several test stands and development, like Xbox equipped with high-power klystrons operating in X-band 12 GHz. Laboratory set ups are dedicated to test the RF accelerator structures with a very high gradient in excess of 100 MV/m and high peak power of 100 MW. Unique set ups are associated with the CLIC accelerator infrastructure test line and are dedicated to the development of the accelerator RF structures for this future linac and the collider, but also for new structures for XFEL sources, Compton/Thomson sources, etc. The test line allows for experimental accelerator structures to be practically checked, like deflecting cavities, pulse compressors, specialized acoustic sensors, X-ray, photonic instrumentation and diagnostic equipment, fibre optic signal transmission lines.

XII. ARIES Project Realization – What are the Gains?

Undertaking the ARIES project provides the research community with a reliable and well-targeted continuation of the development works on accelerator technology, which started at the European level in the beginning of 2000. These years of the joint implementation of a number of large infrastructure projects led to the renewal and strengthening of the European scientific and technical research area. There has been a positive consolidation of the, now much more frequently meeting, European accelerator community. The community is centralized around the strongest centres - owners of critical infrastructure. There is also observed a significant development of smaller academic centres, which were invited to take an active part in the reconstruction of the infrastructures. This community has strengthened and rebuilt itself, adapting to the current requirements of economic and political decision-making, regarding their representation to external forces including global co-ordination bodies of science, and above all the EU bodies. European co-ordination committee, previously ESGARD and now TIARA represents very effectively this science and technology sector, taking care of its appropriate place among the development priorities of Europe.

What does this mean for Poland? We are represented in the activities of TIARA by efficient national accelerator technology consortium leader, which is the IFJ PAN in Kraków. Our voice is, however, limited by the lack of our own large accelerator infrastructure. In the previous accelerator infrastructure projects - CARE and EuCARD, there participated more national centres. Worrying is the reduction in the participant number and smaller share of only two centres from the country in the ARIES project. Positive is the decision of the European consortium TIARA to organize a plenary meeting of the Collaboration Council in the summer of 2017 in Warsaw. Worrying are leaves, very likely permanent, of young scholars from Poland to work in experiments developed dynamically by such projects as EuCARD and ARIES. Positive are widely reported success of these young people in the difficult conditions of open science and competition.

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