ARIES

Accelerator Research and Innovation for European Science and Society

Horizon 2020 Research Infrastructures GA n° 730871

DELIVERABLE REPORT

Final EuroNNAc and EAAC Report

DELIVERABLE: D5.2

Document identifier:	ARIES-D5.2
Due date of deliverable:	End of Month 46 (February 2021)
Justification for delay:	Required adaption to new Expert Panel as outcome of European Strategy for Particle Physics
Report release date:	08/04/2021
Work package:	WP5: European Network for Novel Accelerators
Lead beneficiary:	DESY
Document status:	Final

ABSTRACT

This report presents a short summary of the outcome of work progress in the tasks of the European Network for Novel Accelerators (EuroNNAc) and the status of European strategies for plasma accelerators and dielectric accelerators. The European Advanced Accelerator Concepts workshops were held in 2017 and 2019, they serve as a growing forum for discussions and coordination of activities and are reported on. The WP5 work led, amongst others, to the advance of a new European research Infrastructure EuPRAXIA, coordinated input to the European Strategy for Particle Physics and finally to the recent formation of a European Expert Panel for the contribution of this field of science to Particle Physics.

For more information on ARIES, its partners and contributors please see http://aries.web.cern.ch

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement No 730871. ARIES began in May 2017 and will run for 4 years.

Delivery Slip

	Name	Partner	Date
Authored by	R. Assmann	DESY	16/12/2021
Edited by	R. Assmann	DESY	30/03/2021
Reviewed by	R. Assmann	DESY	30/03/2021
Approved by	Steering Committee		08/04/2021

TABLE OF CONTENTS

Executive summary

The European Network for Novel Accelerators (EuroNNAc), as WP5 in the ARIES project, has expanded its coordinating role for advanced accelerators in Europe.

It organized the European Advanced Accelerator Concepts workshops that were held in 2017 and 2019. Those workshops serve as a growing forum for discussions and coordination of activities. The attendance reached record levels, saturating the capacity of the workshop venue.

Efforts to promote the work of young scientists were further strengthened and the Simon van-der-Meer Prize for a young scientist was awarded for the first time. A specialized course of the CERN accelerator school for plasma accelerators was successfully pioneered.

The work led, amongst others, to the advance and support of a new European research Infrastructure EuPRAXIA, that successfully completed its Conceptual Design Report in October 2019 and has been proposed by European governments for the ESFRI roadmap update in 2021.

Coordinated input for the European Strategy for Particle Physics from advanced accelerators was provided. This finally led to the recent formation of a European Expert Panel for the contribution of this field of science to Particle Physics.

1. Introduction

RF accelerator technology has been a major success story over the past 90 years, enabling the development of complex large-scale machines and applications in a variety of fields from high-energy physics and photon science to medical technologies and industrial tools.

With more than 300,000 machines in use, accelerator-based technologies have been established as essential instruments all over the world today and will continue to play important roles in the future, as several of the scientific roadmaps of European and international communities demonstrate.

Plasma accelerators generate accelerating fields that are up to 1,000 times higher than fundamentally possible in RF accelerators. They therefore offer a promising alternative path to the high-energy frontier, promoting a new generation of highly compact accelerators. Similarly, dielectric accelerators offer attractive features and benefits. The required research and development on those innovative technologies is performed at universities and large national and international laboratories. The European Network for Novel Accelerators (EuroNNAC), as WP5 in ARIES, provides a common discussion forum and self-coordination for the large number of experiments and groups involved in Europe and world-wide.

ARIES and WP5 therefore fulfill crucial roles for linking the established excellence of RF accelerators with novel technologies, including high power lasers, for coordinating efforts and for the discussion of coherent plans and roadmaps.

Fig 1: The European Network for Novel Accelerators (EuroNNAc) includes representatives from more than 60 research institutes as indicated in the network map.

2. The European Advanced Accelerator Concepts Workshop Series

The European Advanced Accelerator Concepts Workshop (EAAC) has been organized by WP5 in 2019 the fourth time, reaching over 370 applications for participation with 83 student grant applications. This illustrates the dynamism of the European novel accelerator community, attracting many young scientists. Unfortunately, not all applicants could be accepted due to space limits. The total number of participants was 276, there were 16% female and 84% male participants. Participation included representatives of conventional and advanced accelerator technology, from 17 countries, mainly from Europe but also from Asia, the US and Russia. After a selection process, 47 student grants were given to young scientist to allow their participation. A special student meeting was organized to foster discussion and networking.

The European Advanced Accelerator Concepts Workshop has the mission to discuss and foster methods of beam acceleration with gradients beyond state of the art in operational facilities. The most cost effective and compact methods for generating high energy particle beams were reviewed and assessed. This includes diagnostics methods, timing technology, special needs for injectors, beam matching, beam dynamics with advanced accelerators and development of adequate simulations.

Fig. 2 Participants of the EAAC2019 conference on Elba in September 2019

This workshop was organized in the context and with sponsoring of the EU/ARIES funded European Network for Novel Accelerators (EuroNNAc3), a network of more than 60 institutes and universities. Additional sponsors for EAAC2019 included CERN, DESY, INFN, ICFA, VACUUM FAB, Radia Beam, THALES and Radiasoft.

The Website for the EAAC was created as an indico website, the agenda was set up and published on the website: https://agenda.infn.it/e/EAAC2019. The proceedings have been published after peer review as Volume 1596 (2020) of the IOP conference proceedings [1].

3. The Advanced Accelerator School and the Simon van-der-Meer Prize

1.1 THE CERN ACCELERATOR SCHOOL ON ADVANCED ACCELERATORS

In accordance with the ARIES Work Program and WP5, an international school on "High Gradient Wakefield Acceleration" has been organised in spring 2019, in order to disseminate the impressive know-how accumulated in the field over the past few years, summarise the state of the art, and provide a platform to train new students joining this field. Following suggestions of the EuroNNac3 Network of ARIES (WP 5) and of an international program committee to oversee the preparation, the school was organised under the umbrella of the CERN Accelerator School, CAS. In this way, the school was not only profiting from the CAS and CERN's administrative experience but could become a way to strengthen the collaboration between traditional accelerator physics and the new wake-based systems in an attempt to close the gap between the classical and the novel acceleration techniques.

The school was planned from the beginning as a truly European and even international event. The school welcomed 70 students from 25 different nationalities, among them, beyond Europe, China, United States and Japan. 26 lecturers from 11 countries were giving courses, seminar talks or acting as tutors for the more practical work, the so-called case studies, where the students are asked to apply what they had learned and thus to do actual design work under the leadership of experienced colleagues.

Fig. 3 Participants of the lecture series on "High Gradient Wakefield Acceleration" that was organised in spring 2019 with the IST in Lisbon, institute in Portugal.

1.2 THE EAAC STUDENT PRIZES AND THE SIMON VAN-DER-MEER PRIZE

In accordance with the work programme of Task 5.5, "Young Scientist Networking and Academic Standards", a special meeting has been organised during the biannual EAAC workshop, to complement the official workshop program. Within 2 hours of an open and fruitful discussion session, the particular needs for the young scientists have been addressed in order to facilitate the exchange of information and expertise among the young colleagues.

The main topics discussed were related to the training of young scientists on the topic of high gradient acceleration techniques, the issue of information exchange and, related to that, the idea to create a web-platform, optimised for and focused on the needs of students. Special attention has been put on the possibilities of students and colleagues in their early career, to gain visibility among the fast-growing community in a large and rapidly developing new field of physics.

Along with this item, two poster sessions were organised in the frame of the EAAC workshop and - following good tradition - three poster prizes were nominated by a selection committee for outstanding work. A Prize Award Selection Committee with R. Walczak in the chair, unanimously decided to award the first Simon van der Meer Early Career Award in Novel Accelerators to Spencer Gessner. The award consisted of a stipend of € 3000, financed by sponsors, and a certificate that was presented to the laureate at the EAAC conference. The laureate was invited to present a dedicated presentation.

Fig. 4 Students of the EAAC2019 conference on Elba in September 2019

4. The EuPRAXIA Project

1.3 EuPRAXIA, the Advanced Accelerator Project inside the EuroNNAc Network

The European Network for Novel Accelerator has brought together a large number of institutes from Europe and world-wide. In 2014 sixteen of the network members proposed together a European Design Study on an advanced accelerator project, supported by fourteen associate partners. The common initiative was grown out of network discussions and continued to use EuroNNAc and the EAAC as a discussion forum.

The consortium grew by 2021 to 40 partners and 10 observers, bringing together most of the major actors in this field. The network of facilities formed from the EuroNNAc network and around EuPRAXIA is shown in Figures 3 and 4.

Fig. 5: The research facilities that are being constructed or operated by European members of the European Network for Novel Accelerators (EuroNNAc) and that are part of the EuPRAXIA Consortium. From (REF).

Fig. 6: The research facilities that are being constructed or operated by International members of the European Network for Novel Accelerators (EuroNNAc) and that are part of the EuPRAXIA Consortium..From (REF)..

1.4 RESULT AND OUTLOOK OF THE EUPRAXIA DESIGN STUDY

The EuPRAXIA ("European Plasma Research Accelerator with Excellence in Applications") project focuses on high-gradient accelerating technologies that have been highlighted in European Strategy for Particle Physics update for 2020. It comes at an excellent time to fulfil some of the challenges addressed by this strategy update. Through combining plasma wakefield acceleration with compact X-band RF accelerators, this technology proposal not only foresees a large potential for accelerator R&D over the next ten years, but also promises to drive forward a possible next generation of ultra-compact accelerators with their own varied range of applications.

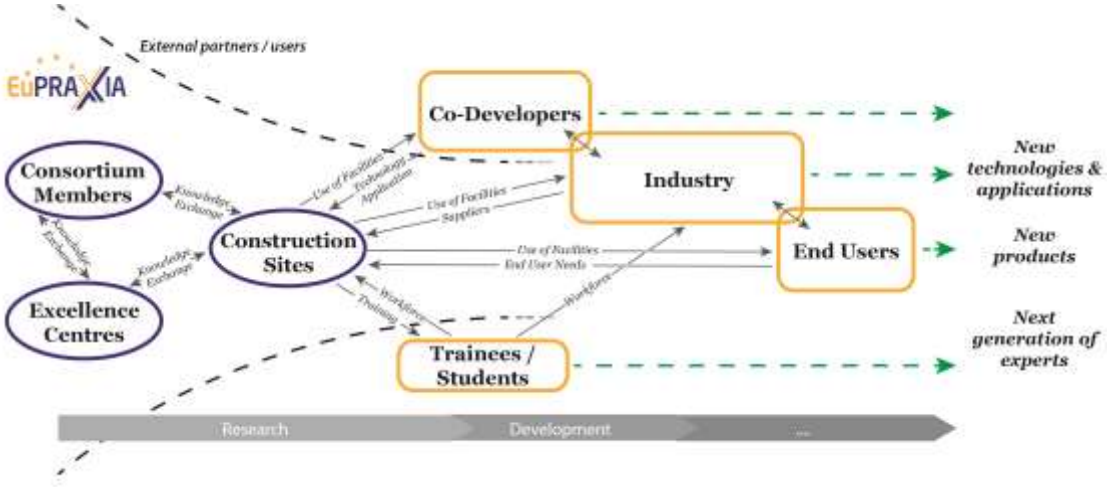

Fig 7: Concept of EuPRAXIA as an Open Innovation Research Infrastructure in Europe, advancing compact accelerator technologies, including plasma accelerators, from the research phase into the development and exploitation phases (reprinted from [2]).

EuPRAXIA started as a conceptual design study for a novel research infrastructure based on plasma accelerator technologies in 2015 and concluded last year with the Journal publication of a Conceptual Design Report [3]. With contributions from 243 researchers and more than 40 partner institutions, it proposes the construction of a distributed accelerator facility that offers:

1) improved performance compared to current state-of-the-art plasma wakefield accelerators with electron energies of 1 to 5 GeV and a beam quality approaching purely RF-based machines,

2) a significant reduction in size and possible savings in cost over state-of-the-art RF-based accelerators, and

3) varied applications for existing and emerging accelerator user communities in Europe.

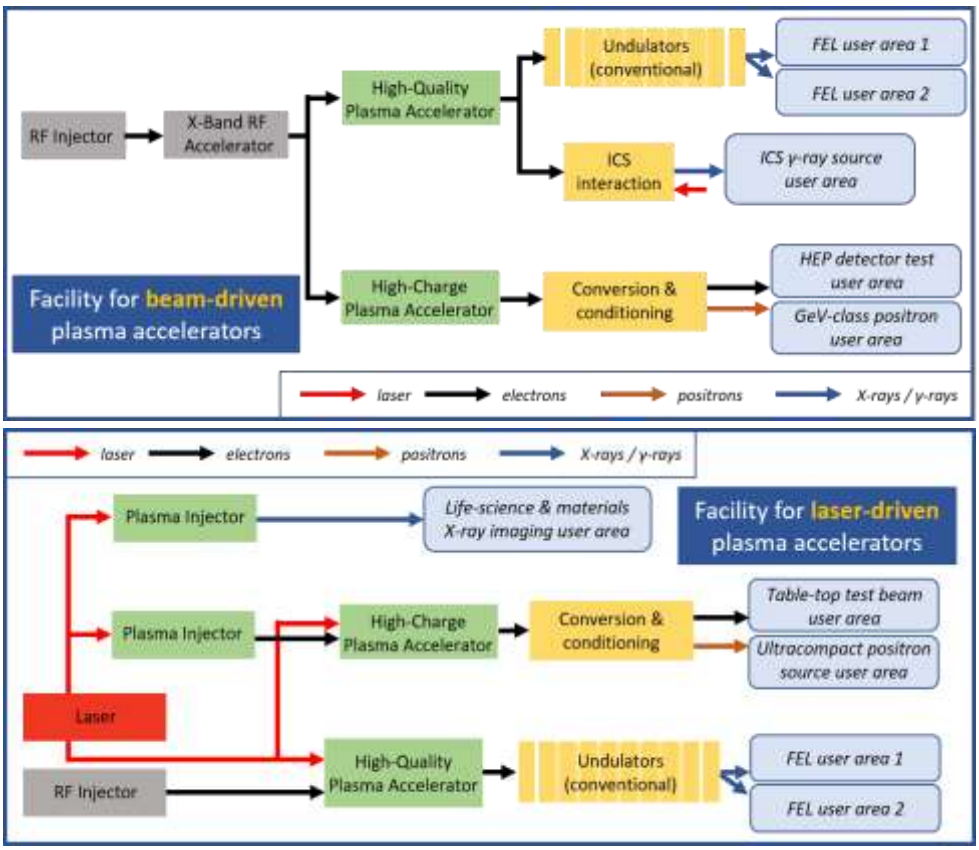

Fig 8: Schematic machine layouts of the two EuPRAXIA construction sites (reprinted from the EuPRAXIA Conceptual Design Report, 2019, accepted for publication in EPJ-ST).

To realise these goals, the design combines well-established solutions, such as in beam transport, diagnostics and undulator technology, with improved methods and novel concepts developed during the study, many of which have been peer-reviewed and published in high-impact journals, for example [4] and [5]. For the acceleration stages themselves, six different

technical options have been selected and are foreseen to be prototyped as part of the technical design, ranging from a very compact single-stage, all-plasma beamline to larger setups using one or several plasma targets as energy boosters to an RF-accelerated electron beam.

The EuPRAXIA concept proposes two main facilities to be constructed. The first site will be based at the INFN Laboratori Nazionali di Frascati in Italy and will be focused on beam-driven plasma acceleration. Housing an X-band accelerator up to 1 GeV combined with plasma accelerator stages to boost energies up to 5 GeV, the facility will be capable of running an X-ray free-electron laser, while also offering applications, such as a GeV-scale positron source, a compact inverse Compton scattering-based photon source as well as a "table-top" test beam station for particle physics detectors. The second major EuPRAXIA site, on the other hand, will be based on laser-plasma acceleration and its final location will be decided by 2025 from among a set of several outstanding facilities in Europe. Although also combining RF and plasma technology to develop a robust machine design, the centrepieces of this site will be a laser system with up to 1 Petawatt peak power and a 20 to 100 Hz repetition rate, designed in collaboration with laser institutes and industry with the potential to upgrade to kHz operation in the future. The laser-driven EuPRAXIA construction site will be focused in particular on making use of the short acceleration distances in laser wakefield acceleration and provide a compact betatron-based photon source together with positron and electron beams for material and diagnostics studies. A free-electron laser is also foreseen as a larger-scale application.

With the implementation of these two facilities envisaged to be completed only around 2027 to 2031, they are complemented by a set of excellence centres and clusters of expert institutions across Europe. The former in particular are foreseen as key R&D facilities that are based on existing technical infrastructures. As these centres contribute significantly to the development, testing, and prototyping of new technologies to be integrated in the construction sites, but in parallel also gain from the knowledge and lessons learned across the entire infrastructure, this model thus allows to integrate national investments in the field of compact accelerator R&D very synergistically into the wider European concept.

Since the completion of the funded design study at end of 2019, the EuPRAXIA collaboration has prepared the next phases of the project. An important milestone in this context has been the negotiation of a new consortium agreement, organising the preparatory phase and technical design. This agreement has been signed by 50 organisations from fifteen countries as Members and Observers, a significant increase over the previous membership. A second major endeavour is EuPRAXIA's application to the ESFRI Roadmap Update 2021. This proposal has been submitted in September 2020 and sees Italy as the lead country with additional political support at government level from Czech Republic, Hungary, Portugal and United Kingdom, as well as contributions from several other EU member states.

Fig 9: 3D-rendering of the EuPRAXIA construction site at INFN-LNF. The design process of the building has recently started, it will have dimensions of 134m x 35m with a potential extension added at a later point (image credits: Simona Incremona, General Services and Technical Division).

In summary, the European research infrastructure EuPRAXIA with its large-scale consortium brings together most of the members of the EuroNNAc network for an advanced accelerator project. It will allow advancing critical accelerator R&D on highly compact accelerators, as demanded in the 2020 Update of the European Strategy for Particle Physics, it will continue to bring together existing European infrastructures in this domain, it will establish first pilot applications for plasma accelerators, it will strengthen the links to the important European laser industry, and it will build two scientific flagship projects. One construction site will be in the metropolitan area of Rome in Italy and will deliver critical and much needed photon science capabilities for research into materials, bacteria, viruses and health for this area. The high-tech EuPRAXIA innovation project can thus drive scientific advance in Europe with medium electron beam energies and can contribute to a sustainable economic development with highly qualified jobs and possible spin-off companies, while being a critical stepping stone to future particle physics colliders based on plasma acceleration.

5. Strategic Input and Coordination

1.5 Input to 2020 Update of the European Strategy for Particle Physics

In 2012 the European Strategy Preparatory Group received for the first time detailed input about the prospects and promise of plasma accelerators [6], a 15 page report provided by the EU-funded European Network for Novel Accelerators (EuroNNAc). The 2017 EuroNNAC report

on a European strategy (31 pages) is available at [7]. In December 2018 the network provided a short update and input to the 2020 update of European Strategy for Particle Physics.

EuroNNAc Summary on Promise of Plasma Accelerators:

Plasma accelerators generate accelerating fields that are up to 1,000 times higher than fundamentally possible in RF accelerators. Plasma accelerators therefore offer a promising alternative path to the high-energy frontier. Laser pulses, electron or proton bunches (drivers) can excite these ultra-high fields in plasma devices. The three driver technologies are explored in theoretical and experimental programs in- and outside of Europe. Since 2012 laser-driven plasma accelerators have demonstrated beam energies above 8 GeV and bunch charges up to 0.5 nC. Electron-driven plasma accelerators have demonstrated high-efficiency and multi-GeV acceleration of electrons and positrons. Proton-driven plasma accelerators have shown acceleration of electrons by 2 GeV. The progress is rapid, also in supporting technologies like lasers with high peak power (CPA awarded with the 2018 Nobel Prize of Physics) and high average power, plasma sources and plasma lenses.

While there are many tasks still to be handled there is no proven show-stopper in the new plasma technology for reaching high beam energies. Beam quality is now the focus and this can be demonstrated at a few GeV of beam energy with scientific applications like free-electron lasers, fixed target experiments or X ray imaging devices. Ongoing activities towards producing high quality beams with the various driver technologies will serve as a required stepping stone to a plasma linear collider.

New Major Plasma Acceleration Projects since the last European Strategy Update:

Important new projects were funded since the last strategy update in Europe and beyond. These include the Horizon2020 EU Design Study for a “European Research Plasma Accelerator with eXcellence In Applications” EuPRAXIA involving 41 institutes [3, 8], the international AWAKE experiment [9] at CERN involving 18 institutes and the international ALEGRO study [10] on a possible future plasma linear collider. New national activities in Europe since 2012 are the Plasma Wakefield Accelerator Steering Committee (PWASC) in the UK [11], the multi-institutional laser plasma acceleration project ATHENA [12] in the Helmholtz Association in Germany, the ELBE center at HZDR, CILEX in France, CLARA and SCAPA in the UK, EuPRAXIA@SPARC_LAB at INFN-LNF in Italy [13], Lund in Sweden, JuSPARC at FZJ [14] and FLASHForward, KALDERA and SINBAD at DESY. There are strong activities with new funding on plasma acceleration in Japan (ImPACT), in China (Synergetic Extreme Condition User Facility SECUF) and in the US (FACET-II, BELLA).

EuroNNAc Proposal for the 2020 Strategy Update:

The next European strategy for particle physics should explicitly list ultra-high gradient plasma acceleration and, if possible, its supporting international projects (see above) as essential R&D towards a compact alternative for future colliders.

1.6 EUROPEAN STRATEGY FOR PARTICLE PHYSICS UPDATE 2020 ON ADVANCED ACCELERATORS

The published 2020 Update for the European Strategy for Particle Physics by the European Strategy Group [15] proposes clear challenges and development goals for the near- and long-term future of accelerators in particle physics. It emphasizes in particular the importance of innovation in accelerator technology, listing it as "a powerful driver for many accelerator-based fields of science and industry" with "technologies under consideration includ[ing] high-field magnets, high-temperature superconductors, plasma wakefield acceleration and other high-gradient accelerating structures" and emphasizing the need to define "deliverables for this decade […] in a timely fashion".

1.7 FORMATION OF EXPERT PANEL FOR "HIGH GRADIENT ACCELERATORS – PLASMA AND LASER"

The explicit mentioning of "plasma wakefield acceleration and other high-gradient accelerating structures" in the high priority section of the strategy document marked a success for the field of advanced accelerators and WP5 of ARIES. In follow-up to the strategy document five expert panels for critical accelerator R&D have been formed by the Laboratory Director's Group (LDG) in Europe in January 2021:

1) High Field Magnets - Low Temperature & HTS.
2) High Gradient Acceleration - Plasma, Laser.
3) Muon Collider.
4) ERL.
5) High Gradient Accelerating Structures - RF (n.c. and s.c.).

The panels are charged to develop a roadmap proposal for their domains. The expert panel report to the LDG which will discuss the proposed accelerator R&D roadmap with the CERN council.

The formation of the expert panel "High gradient acceleration: Plasma and Laser" is a further success for the field of advanced accelerators, a recognition of the scientific results achieved and the efforts spent to disseminate those results into the accelerator field. EuroNNAc and EAAC played an important role in this process since we started them in 2012 and 2013.

The leadership and the membership of the expert panel "High gradient acceleration: Plasma and Laser" exhibits large overlap with EuroNNAc such that full synergy is ensured. Panel members include: Ralph Assmann (DESY/INFN, chair), Edda Gschwendtner (CERN, deputy chair), Kevin Cassou (IN2P3/IJCLab), Sebastian Corde (IP Paris), Laura Corner (Liverpool), Brigitte Cros (LPGP-CNRS-U Paris Saclay), Massimo Ferrario (INFN), Simon Hooker

(Oxford), Rasmus Ischebeck (PSI), Andrea Latina (CERN), Olle Lundh (Lund), Patric Muggli (MPI Munich), Phi Nghiem (CEA/IRFU), Jens Osterhoff (DESY), Tor Raubenheimer (SLAC), Arnd Specka (IN2P3/LLR), Jorge Viera (IST), Matthew Wing (UCL).

The expert panel is charged with the following mandate in the field of beam-driven and laser-driven plasma accelerators as well as dielectric accelerators:

- Develop a long-term roadmap for the next 30 years towards a HEP collider or other HEP applications.
- Develop milestones for the next 10 years taking explicitly into account the plans and needs in related scientific fields as well as the capabilities and interests of the stakeholders.
- Establish key R&D needs matched to the existing and planned R&D facilities.
- Give options and scenarios for European activity level and investment.
- Define deliverables and required resources for achieving those until the next European strategy process in 2026, in order to enable as best as possible critical decisions for R&D lines for HEP.

A 30-40 page document with the proposed roadmap will be prepared during 2021 and will be provided to the LDG in November of this year. The EuroNNAc network in WP5 of ARIES is already used extensively to interact with the full community of advanced accelerators and to gather the community input in a series of townhall meetings. It is foreseen to use the EAAC in 2021 for discussing and iterating a draft R&D roadmap in our field.

6. Conclusions: towards a European R&D Roadmap for Novel Accelerators

The European Network for Novel Accelerators (EuroNNAc), WP5 in ARIES, has continued its efforts on self-coordination of the novel accelerator field with its many groups and institutes involved. More than 60 institutes have joined the network and have made the European Advanced Accelerator Concepts (EAAC) workshop into one of the largest and most successful in this domain. The EAAC provides a forum for discussion and coordination of activities. The EuroNNAc/WP5 work led, amongst others, to the advance of a new European research Infrastructure EuPRAXIA (focused at photon science and lower energy applications), coordinated input to the European Strategy for Particle Physics and finally to the recent formation of a European Expert Panel in the field of novel accelerators by Particle Physics.

The new expert panel will in 2021 further develop a European R&D roadmap for plasma accelerators and dielectric accelerators. Members of the EuroNNAc network were charged to drive the expert panel. Thus, full synergy will be ensured. The EuroNNAc network is used heavily to collect input from the full community and to iterate the developed strategy within the field. The EAAC will be used to present and to discuss the roadmap before submission to the LDG and the CERN council.

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Annex: Glossary

Acronym	Definition
ARIES	Accelerator Research and Innovation for European Science and Society
EuroNNAc	European Network for Novel Accelerators (WP5 in ARIES), founded in 2012 at CERN
EAAC	European Advanced Accelerator Concepts workshop, a bi-yearly series of large workshops founded by EuroNNAc in 2013
EuPRAXIA	European Plasma Research Accelerator with Excellence in Applications, a EU-funded Design Study from 2015-2019, presently proposed for the ESFRI roadmap update 2021
AWAKE	Advanced Proton Driven Plasma Wakefield Acceleration Experiment
ALEGRO	Advanced LinEar collider study GROup
CAS	CERN Accelerator School
LDG	Group of European Lab Directors, representing large particle physics laboratories in Europe