ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-MOPML031

HIGHLIGHTS OF ACCELERATOR ACTIVITIES IN FRANCE ON BEHALF OF THE ACCELERATORS DIVISION OF THE FRENCH PHYSICAL SOCIETY

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Abstract

The French Physical Society is a non-profit organization working to advance and diffuse the knowledge of physics. Its Accelerators division contributes to the promotion of accelerator activities in France. This paper presents the missions and actions of the division, highlighting those concerning young scientists. A brief presentation of the laboratories, institutes, and facilities that are the main actors in the field is given. Significant ongoing and planned projects in France are described, including medical applications. Main French contributions in international projects are then listed. Finally, cultural and technical relationships between industry and laboratories are discussed.

THE FRENCH PHYSICAL SOCIETY

The French Physical Society (SFP) is a non-profit state-approved membership organization working to advance and diffuse the knowledge of physics through publications, scientific meetings, education, outreach, and international activities. It was founded in 1873 to develop and promote Physics in France [1]. It brings together researchers, engineers, students, and teachers working in the field of physics by encouraging their interactions. The SFP is the leading voice for physics in France and an authoritative source of information for advancement and teaching. It aims to increase awareness, access, and understanding of the value that physics holds for the greatest number. Another mission of the SFP is to represent the French Physicists' community in contact with policymakers and other scientist authorities or learned societies. The SFP is structured in 21 geographic sections, 11 thematic divisions, and 9 working commissions. Each year, 19 prizes are awarded to physicists in honor of specific works or actions towards the promotion of physics outside the community. Besides many events, the General Congress of Physics is held biyearly. More recently the SFP has paid special attention to questions related to young physicists, the place of women in physics and strengthening the links with the industries.

ACCELERATORS DIVISION

The Accelerators division strives to promote accelerator activities and gather its community every two years during a national workshop, reviewing accelerator activities and progress in the associated technologies.

The "Jean-Louis Laclare" SFP division prize is awarded to a young scientist who has made a remarkable contribution to the field. In 2017 the meeting brought together 111 participants from public institutes and industry in Roscoff (Brittany, French West coast). Attracting and educating a young public are of major concerns for the division in order to maintain the dynamics of accelerator activities in France. SFP will participate in the organization of IPAC 2020 in Caen.

MAIN ACTORS AND LABORATORIES

France has a long history of applied sciences and technological challenges. The expertise accumulated through national projects and international collaborations is spread over various laboratories covering most requirements for accelerator developments. This paper reflecting the contributions to the latest Roscoff conference [2] should not be considered as an exhaustive review.

Accelerator activities are mostly performed or coordinated by two national scientific research organizations through their specific institutes: **CNRS** (Centre National de la Recherche Scientifique) through IN2P3 (Institut de Physique Nucléaire et de Physique des Particules) and **CEA** (Commissariat à l'Energie Atomique et aux Energies Alternatives) through IRFU (Institut de Recherche sur les lois Fondamentales de l'Univers). Their involvement is distributed among a large number of laboratories dealing with fundamental physics or technological research. Most of these laboratories participate in national, European, or international projects (AMICI, APOLLON, Brightness, CLIC, ELI-NP, ESS, EuPRAXIA, EuroCircol, FAIR, FCC, FuSUmatech, GUINEVERE, HL-LHC, IFMIF, ILC, IPHI, MYRRHA, SPIRAL2, XFE).

The scientific community benefits from four large accelerator-based facilities in operation in France:

- National Large Heavy Ion Accelerator (GANIL, Caen)
- Synchrotron SOLEIL (Gif-Sur-Yvette)
- European Synchrotron Radiation Facility (ESRF, Grenoble)
- European Nuclear Research Centre (CERN, Geneva partially located in France)

The four facilities are at the technology forefront, and maintain a development programme for improving the accelerators performance for the requirements of science.

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Accelerators dedicated to medical applications have become a growing field of activity. The performance of the facilities dedicated to research or to the most demanding clinical applications requires the participation of experts from laboratories and industry. ARRONAX (Nantes), a high intensity 70 MeV cyclotron, is producing innovative radio nuclides for research in nuclear medicine and radiochemistry. CAL (Nice), a 65 MeV cyclotron, has been in operation since 1991 for cancer proton therapy. CPO (Orsay), the proton therapy center of Institut Curie was upgraded with a new 230 MeV cyclotron equipped with an isocentric gantry, completing the existing beamlines. Regarding hadron therapy, ARCHADE (Caen), designed and built by industry, shall start operation in 2018.

Smaller accelerators are also dedicated to research. Under the Louvre Museum (Paris), New AGLAE, a proton electrostatic accelerator of a few MeV is used to investigate manufacturing techniques of fine art. In Orsay, ELYSE, a picosecond short pulse electron accelerator and CLIO, a 45 MeV linac based Free Electron Laser, are operated as user facilities for physics-chemistry research. A 50 MeV electron linac called ALTO (Orsay) and Van de Graff accelerators (Orsay) with light ions are used for nuclear physics. A dedicated Photo-injector test stand, PHIL (Orsay), is used for R&D on photo-injectors. The commissioning of ThomX (Orsay), a 50 MeV Compact Light Source based on Compton Scattering should start toward the end of 2018 or early 2019. Another Compton source is under development in Bruyères-le-Châtel on ELSA, a 30 MeV photo-injector based electron linac operated by CEA-DAM for the study and characterization of detectors and optical materials in the frameworks of Laser Mégajoule and AIRIX, a 20 MeV induction linac.

Several French laboratories (LULI, LOA, LPGP, LLR, LIDYL, DACM) affiliated to CNRS and CEA are currently actively involved in laser-driven wakefield acceleration studies, strongly supported by innovative laser development in academic and industrial environments. The APOLLON laser, designed and built (French academic consortium), will deliver laser pulses with a peak power of up to 10 PW, and will play a key role in testing accelerating concepts for electron acceleration in the multi-GeV range. Pushing these acceleration concepts in plasma, from the demonstration of large accelerating gradients, in the 1 to 100 GV/m, to the achievement of a reliable accelerator usable for applications is the next challenge. This French expertise largely contributes to the EuPRAXIA design study, bringing together a large European consortium to prepare a conceptual design for a multi-GeV plasma based accelerator with industrial beam quality and dedicated user areas.

HIGHLIGHTS OF THE LARGEST INSTALLATIONS LOCATED IN FRANCE

GANIL is one of the four largest laboratories in the world dedicated to research using ion beams. The fields of experimentation range from material irradiation to high energy nuclear physics. Five cyclotrons allow the acceleration of ion beams at various energy ranges from a few keV to 100 MeV per nucleon. Up to 5000 hours of beam per year can be scheduled but 9000 hours of beam time are available to physics in multi-beam mode. In addition to a permanent staff of 250 (physicists, engineers, technicians, administrators…), GANIL is used by 700 visiting scientists from all over the world. Since 2012, the GANIL staff has been largely involved in the construction and installation of the SPIRAL2 facility, including a linear superconducting accelerator for protons, deuterons, and heavy ions, and two experimental rooms. The injector, the RFQ and the linac has been built by CEA and CNRS laboratories, supported by European industry. The first beams have been accelerated in the RFQ in 2015. The linac is waiting for safety authorities' authorization to start the commissioning.

SOLEIL high technology facility is both an electromagnetic radiation source and a research laboratory at the cutting edge of experimental techniques dedicated to matter analysis down to the atomic scale, as well as a service platform open to all scientific and industrial communities. Today, this French third generation synchrotron light source provides photons to 29 beamlines complementary to ESRF. The accelerator complex consists of a 100 MeV Linac, a 3 Hz full energy Booster synchrotron and a 2.75 GeV and 354 m circumference storage ring. Designed as a low emittance (4 nm.rad) source, it delivers 5000 hours of beam per year of high average brilliance radiation over 10 orders of magnitude from the IR–UV–VUV up to hard X-ray. Commissioned in 2006, SOLEIL operates in top-up injection mode for all five diverse filling patterns with a maximum current of 500 mA (beam availability 98-99%). The laboratory has a strong expertise in various accelerator fields (undulators, power supplies, solid state amplifiers, stability to cite just a few of them) and contributes to other projects such as (COXINEL - lasing in an LWFA, SESAME, ThomX, MAX-IV) and develops collaborations with industrials. An active work is being currently performed to define an ultra-low emittance (72 pm.rad) lattice for a major upgrade of SOLEIL in 2024-2026.

ESRF is a European facility supported and shared by 22 partner nations. This third generation light source, in routine operation since 1994, delivers 5500 hours of beam per year to 42 beamlines with availability close to 99 %. The accelerator complex consists of a 200 MeV linac, a 4 Hz full energy Booster synchrotron and a 6 GeV Storage Ring (SR) of 844 m circumference. The 32 cell Double Bend Achromat lattice of the SR provides 4 nm.rad horizontal emittance electron beam. After correction, the vertical emittance is routinely maintained to less than 7 pm.rad. A large variety of insertion devices (in-air undulators, wigglers, in-vacuum undulators, cryogenic in-vacuum undulators) are installed in the 28 available straight sections. Bending magnet radiation is used by 12 beamlines. Since 2009, ESRF has embarked on an ambitious upgrade programme of the machine and beamline infrastructure. Part of it, a new storage ring based on a hybrid 7 bend achromat will replace the existing one in 2019. Reducing the horizontal emittance to less than 140 pm.rad will allow a drastic increase in brilliance and coherence. The facility should be back in operation in August 2020.

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CERN generates a lot of theoretical and experimental work in the French laboratories especially for the development of detectors or accelerator components. In recent years, the CEA and CNRS have contributed to the Large Hadron Collider (LHC) accelerator and detector construction at CERN. French institutes have largely contributed to the design and construction of superconducting quadrupole magnets and part of the cryogenic system of the accelerator. Both laboratories contributed to the design, assembly and tests of the ATLAS and CMS giant magnets. CEA and CNRS are now participating in the Future Circular Collider (FCC) design study (European project Eurocircol).

INTERNATIONAL COLLABORATIONS

In addition to projects in France, CNRS and CEA laboratories contribute to European programmes dedicated to accelerator R&D (MYRTE, EURISOL, Eurocircol, Eupraxia, ARIES...) and provide technological support to European, and international projects.

ESS, the European Spallation Source project at Lund in Sweden will be a major user facility where researchers from academia and industry will investigate scientific questions using neutron beams. CEA and CNRS are largely engaged in the project with the construction of various sections and systems of the linac.

XFEL, the European X-ray Laser at DESY (Hamburg) has received in-kind contribution from France. The 101 cryomodules of the superconducting linear accelerator host 808 cavities (1.3 GHz, 23.6 MV/m). The CEA, largely involved in the development of the superconducting cavities, was responsible for the assembly of the cryomodules, which took place in a dedicated clean room at Saclay. The CNRS was in charge of the production and conditioning of the 808 RF-couplers (1.3 GHz, repetition rate 10 Hz, peak power 150 kW). The RF-conditioning took place in Orsay.

IFMIF-EVEDA will be a 9 MeV, 125 mA CW deuteron accelerator installed in Japan, identical to the low-energy section of the future International Fusion Materials Irradiation Facility accelerators. This demonstrator is intended to test and validate the accelerator design. CEA, in association with Spain, Italy and Belgium is in charge of the accelerator system. It consists of an ion source, a Radiofrequency Quadrupole cavity (RFQ) and the first module of a superconducting linac based on half-wave resonator cavities, the beam dump and the local control system. Installation is progressing, and a first beam at 5 MeV is expected to be extracted from the RFQ in April 2018.

IPHI, a High Intensity Proton Injector (100 mA, 3 MeV) realized in collaboration between CEA, CNRS and CERN for research and development purposes, is under commissioning in Saclay (France). First beams were accelerated in 2016 at low duty cycle. The accelerator is now being commissioned for a duty cycle up to 4%, before going to CW in 2019. IPHI is open to transnational access within the European project ARIES [3] and is used for R&D in view of a possible future compact neutron source.

MYRRHA (Multipurpose hYbrid Research Reactor for High-tech Applications) will be a large research infrastructure designed to demonstrate the physics and technology of a high-power accelerator driven system. A 2.4 MW 600 MeV linac will be coupled with a target whose spallation will drive a subcritical liquid metal cooled nuclear reactor. The system shall demonstrate the feasibility of industrial transmutation of nuclear wastes. For the accelerator part, the main challenge is the extremely high reliability required for the operation (less than 10 beam trips longer than 3 seconds per 3 months). To reach this goal, a redundant injector is added and a fast recovery system can cope with a linac RF-cavity failure by automatically changing the other RF-cavity and the optics tunings. An intermediate stage of the proton accelerator at 100 MeV will be constructed in order to prove the possibility to reach this level of reliability. Academic and French industrial partners are engaged and lead various work packages of the project.

RELATIONS WITH INDUSTRY

The benefits of accelerator research for industry and society consist of spin-offs of new technologies or methods, in accelerator applications and their major subsystems. From a technological point of view, the French industry has demonstrated its ability to support accelerator development for national, European or international projects. A large range of companies, from small and medium-sized enterprises to larger groups, are offering innovative solutions and services in the major technological domains related to accelerators: assembly techniques (brazing, welding…), complex system integration, cryogenics, engineering, high voltage, magnetism, mechanics, optics, RF, vacuum… Links between funding agencies, laboratories, and industry being not as clear as in some other European countries, a dedicated industrial network, called PIGES [4] has been created to promote the French industry know-how and activities, enhance links and initiate common R&D programmes with laboratories. The Accelerators division plays a key role in facilitating relationships between industry/research partners.

EDUCATION

There are two main Universities offering high-level accelerator studies in France: in University Paris-Saclay [5] and University Grenoble Alpes [6]. Most of the students from these two masters join the Joint Universities Accelerator School [7]. CNRS is also coordinating a Massive Online Open Course (MOOC) on particle accelerator as part of the European project ARIES [3].

OUTLOOK

Accelerator research and development has a rich historical background in France, enabling French accelerator teams to remain central skilled partners for all main collaborative projects involving several countries. Maintaining this high level of skills requires to recruit high-quality students. Much effort is being invested into the training of young people as accelerator physicists and engineers. The SFP is taking an active part in promoting this field to the general public, to younger students, to public institutions and to industry.

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