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## HIGHLIGHTS OF ACCELERATOR ACTIVITIES IN FRANCE ON BEHALF OF THE ACCELERATOR DIVISION OF THE FRENCH PHYSICS SOCIETY

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### *Abstract*

The French Physics Society is an association with the purpose of promoting physics and physicists. In this context, the accelerator physics and associated technologies 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 which are the main actors in the field will then be given. Significant projects which are underway or planned will be described, including medical applications. The major contribution of France to international projects will then be introduced. Finally the cultural and technical relations between industry and laboratories will be discussed.

### THE FRENCH PHYSICS SOCIETY

The French Physics Society (SFP) is an association created in 1873 in order to participate in the development and promotion of Physics in France [1]. The SFP brings together researchers, engineers, students, and teachers. It coordinates actions for promoting physics to the general public, ministries, public bodies or other science communities. The society also awards 15 prizes, most of them for the achievements of young scientists.

The SFP includes several divisions, among which the accelerator physics and associated technologies division strives to promote accelerator activities. A dedicated conference is organized every two years for a national review of accelerator physics activities and for an update on the associated technologies. On this occasion the “Jean-Louis Laclare” prize is awarded to a young scientist who has made a remarkable contribution to the field. In 2009 the meeting brought together 118 participants from 25 institutes and 11 companies in Roscoff, a town located on the west coast of France (Figure 1). Attracting and educating a young public is of major concern for the division in order to maintain the dynamics of accelerator activities in France.

### 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 is not intended as an exhaustive review of all available

expertise, facilities or laboratories, but more as a general overview and an introduction of what can be found in France. The content of this paper reflects the contributions to the latest Roscoff conference [2].

Accelerator activities are mostly performed or coordinated by the two national organisations 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 issues. Most of these laboratories participate in national, European, or international projects (SPIRAL2, IPHI, LHC, CLIC, XFEL, ILC, IFMIF, GUINEVERE,..).

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

#### *National laboratories:*

- National Large Heavy Ion Accelerator (GANIL, Caen)
- Synchrotron SOLEIL (Saclay)

#### *European facilities:*

- European Synchrotron Radiation Facility (ESRF, Grenoble)
- European Nuclear Research Center (CERN, Geneva), partially located in France

The four facilities are at the forefront of technology, while maintaining the availability and reliability of user facilities at the highest possible level. All of them have a development programme for improving the performance of the accelerators to fulfil the requirements of science.

Accelerators dedicated to medical applications have become a growing field of activity. The performance of the machines dedicated to research or to the most demanding clinical applications requires the participation of experts from laboratories and industry. The main medical projects were presented at the Roscoff conference. A high intensity 70 MeV cyclotron recently built at Nantes, ARRONAX, aims at producing innovative radio nuclides for research in nuclear medicine and to perform research in radiochemistry. A 65 MeV cyclotron, CAL, has been in operation since 1991 in Nice for cancer protontherapy. CPO, the Orsay proton therapy center is upgrading its facility used for patient treatments. A new 230 MeV cyclotron equipped with an isocentric gantry under commissioning will complement the existing beamlines [3]. Regarding hadrontherapy, ETOILE (Lyon)

has been approved for funding [4], and ARCADE (Caen), is under study. Both machines will be designed and built by industry.

Smaller accelerators are also used for research. In Paris, under the Louvre museum, AGLAE, a proton electrostatic accelerator of a few MeV is used to investigate manufacturing techniques of fine art. In Orsay, ELYSE a pico-second short pulse electron accelerator and CLIO a 50 MeV linac based Free Electron Laser are operated as user facilities for physics-chemistry. Also, based in Orsay a 50 MeV electron linac called ALTO and Van de Graff accelerators with light ions are used for nuclear physics. Small accelerators are also used in Orleans for physics-chemistry and in Bordeaux in nuclear physics.

Investigating new acceleration concepts, characterized by large accelerating gradients, is an active field of research in French laboratories. Electron accelerator techniques based on laser-plasma interactions in gas targets have demonstrated accelerating gradients in the range 1 to 270 GV/m [5]. Theoretical and experimental approaches indicate promising results and the potential of such techniques for linear accelerators, even if a lot of work is still needed to build operational facilities.

### 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 per nucleon to 100 MeV per nucleon. 5000 hours of beam per year are scheduled but 9000 hours of beamtime are available to physics in multibeam mode. Since the very beginning (1975), GANIL has actively participated in European projects in cooperation with many laboratories. In addition to a permanent staff of 250 (physicists, engineers, technicians, administrators...), GANIL is used by 700 visiting scientists from all over the world. GANIL is engaged in the construction of the SPIRAL2 facility, (radioactive ion production system accelerated online) with a linear superconducting accelerator based driver. SPIRAL2 will provide France and Europe with technological and scientific leadership, as this facility, which is as large as the existing GANIL complex, will produce the only exotic beams of their kind in the world, starting in 2012. The heart of the future machine features a superconducting linear accelerator, delivering intense beams onto a thick target. The injector, the RFQ and the Linac [6] will be built by CEA and CNRS laboratories, supported by European industry.

**SOLEIL** is a third generation synchrotron light source, aimed at providing photons for the French user community in order to complement the ESRF and replace Super-ACO and DCI [7]. The accelerator complex consists of a 100 MeV Linac, a 3 Hz full energy Booster synchrotron and a 2.75 GeV Storage Ring of 354 m in circumference. Designed as a low emittance (3.7 nm rad)

source with a modified Chassman Green optics, it features a total of 162 m of straight sections (4×12 m, 12×7 m, 8×3.6 m). 26 beamlines will exploit the high average brilliance radiation which extends from the IR–UV–VUV up to hard X-ray (50 keV). The first electrons were stored and accumulated in 2006. SOLEIL is now delivering photons to 20 beamlines with a current of 400 mA in top-up mode and high beam position stability (<1μm). It routinely serves the beamlines with availability above 96 % thanks to the very reliable operation of its original RF system (solid state amplifiers and superconducting cavities). The laboratory has been developing innovative insertion devices, the next one to come being a cryogenic undulator, and is presently implementing canted undulators in straight sections using magnetic chicanes. An electron bunch slicing scheme will soon deliver 100 fs long X-rays pulses to two beamlines. SOLEIL is also involved in a collaboration with LAL (Laboratoire de l'accélérateur linéaire) to study a compact X-ray source (ThomX) based on the Compton Back Scattering process, and contributes to several FEL projects over the world.

**ESRF** is a European facility supported and shared by 19 countries [8]. This third generation light source, in routine operation since 1994, delivers 5500 hours of beam per year to 42 beamlines with an availability that reached 99 % in 2009. The accelerator complex consists of a 200 MeV linac, a 10 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 produces a low emittance electron beam (4 nrad). 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 15 beamlines. ESRF has now embarked on an ambitious 7 year upgrade programme of the machine and beamline infrastructures. The accelerator complex will benefit from the lengthening of several insertion device straight sections from five to six meters, some of them with canted undulator geometry. The RF system will face a major reconstruction with the replacement of klystron based transmitters by high power solid state amplifiers and the development of HOM damped cavities operating at room temperature.

**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 CTF3 (CLIC Test Facility N°3) experimental station for CLIC (CERN Linear Collider), and in the development of accelerating structures for the future SPL (Superconducting Proton Linac) injector, involving some industrial support.

## INTERNATIONAL COLLABORATIONS

In addition to projects in France, the CNRS and CEA laboratories contribute to European programs dedicated to accelerator R&D (EUROTRANS, EURISOL, EuCARD, SLHC-PP, ILC-PP, ...) and provide technological support to European, and international projects.

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

**IFMIF-EVEDA** will be a 9 MeV, 125 mA cw deuteron accelerator installed in Japan, identical to the low energy section of one of the International Fusion Materials Irradiation Facility accelerators [9]. This demonstrator is intended to test and validate the accelerator design and technology. CEA in association with CIEMAT, INFM and SCK-CEN 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.

**IPHI**, (High Intensity Proton Injector) will be the prototype of a driver for future high current proton accelerators. The project realised in collaboration between CEA, CNRS and CERN is under installation in Saclay, (France). IPHI (100 mA, 3 MeV) is composed of a proton source, a low energy beam transport, a RFQ accelerating cavity and a diagnostic beamline.

**GUINEVERE** (Generator of Uninterrupted Intense Neutrons at the lead VENUS REactor) was inaugurated in March 2010 at SCK-CEN in Mol (Belgium) [10]. This installation is a low power mock-up of an Accelerator Driven System built within EUROTRANS, dedicated to nuclear waste treatment. CNRS designed and built the accelerator GENEPI-3C (240 keV electrostatic deuteron generator) operating in DC and pulse mode, to be coupled in a vertical configuration with a sub-critical nuclear core.



Figure 1: The French accelerator meeting 2009, Roscoff, France, 11-14 October, 2009.

**ILC**, the International Linear Collider  $e^+e^-$  project for high energy physics is based on two superconducting linear accelerators. French laboratories are mainly involved in the interaction area (beam optics for the beam delivery system) and design study of the superconducting solenoidal magnet for the International Large Detector.

## RELATIONS WITH INDUSTRY

The benefits of accelerator research for industry and society consist of spin-offs of new technologies or methods, in applications of accelerators 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, even though the links between funding agencies, laboratories and industry are not as clear as in some other European countries. The accelerator division of the SFP aims at facilitating collaborations between laboratories and industry. French SMEs and larger companies are now increasingly involved in the above mentioned projects, through a network called PIGES (Partenaires Industriels pour les Grands Equipements Scientifiques).

## OUTLOOK

Accelerator research and development has a rich historical background in France, as testified by the present diversity found within numerous laboratories. Today, most projects require collaboration between a large number of nations, of which France is an active participant. The main issue to maintain this potential is the recruitment of high quality students. Large efforts should be invested in the training of young people as accelerator physicists. The French Physics Society SFP is taking an active part in promoting this field to the general public, to younger students, and to the French industrial support network PIGES.

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