Innovations in accelerator science and its applications

Accelerators have been the basis of major discoveries in physics and have applications in many scientific, medical or industrial areas. P2IO laboratories have always been major actors in this area and are at the forefront of new technologies. They are operating a few accelerators on site for fundamental research and devote great efforts to R & D and construction of innovative accelerators for both physical and medical applications. Lately, their expertise in linear accelerators based on superconducting cavities has allowed them to participate in major international construction projects, such as SPIRAL2 construction in Caen, XFEL in Hamburg, the future European neutron source in Sweden, and an accelerator-based nuclear waste transmutation project in Belgium. To achieve this program, they are equipped with modern technology platforms, enabling the development of the next generation accelerator techniques that will be required for projects such as ILC or CLIC, successors of CERN LHC.

For medical applications, collaborations are conducted in partnership with Orsay's ProtonTherapy Center and with SOLEIL, for the ThomX innovative project, a X-ray compact source for imaging and therapy.

New ideas are needed to exceed the boundaries of current technologies. Laser/plasma accelerators are a future way that will increase the accelerating gradient by several orders of magnitude. P2IO laboratories are major actors in this area and are partners in the 10PW Apollon laser program.

New generation sensors and signal processing

Development of innovative detectors is crucial for P2IO programs. The Labex structure and leverage allow to strengthen upstream R & D, in order to define strong instrumental programs that can be collectively brought in front of the national and European technological research support actions.

For detectors, the following strong programs can be identified as follows:

- Cryogenic detectors: massive absorber bolometers for dark matter research. Micro-bolometers matrices for X space imagers and infrared, associated cryogenic microelectronics.
- Semiconductor detectors: CdTe detector matrices for spectrometric high resolution spatial gamma cameras, segmented Ge gamma detectors, Si detectors, pixilated CMOS monolithic sensors for fine trajectography.
- Gaseous detectors: multi-layer trackers, temporal projection chambers, neutron and beam detectors based upon microstructured devices, in connection with CERN RD51 program. Development of Micromegas detectors, with full construction technology control, high flux readout and spatial resolution optimization as well as integrated pixilated readout electronics.
- High granularity calorimeters for future electron colliders.
- Cryogenic noble liquid detectors: measurement of scintillation and ionization in temporal projection chambers filled with liquid argon and double phase xenon.
- Scintillators: new crystals and devices for nuclear spectroscopy and medical imaging.

- Photodetectors: characterization of photosensitive devices, development of silicon photomultipliers for applications in physics, astrophysics and medical imaging.
- Detectors with very high temporal resolution: micro channels plates and associated electronics.

Front-end microelectronics is a significant asset of P2IO's laboratories: spatialized low noise circuits for X-gamma spectrometry, front-end circuits for semiconductor and gaseous detectors, circuits for segmented photodetectors readout, ultra-fast analogical samplers allowing a very precise time measurement.

The most advanced circuits integrate an increasing number of system functions, numerical analogical conversion and event buffer management. R&D effort focuses on technological evolutions for space-qualified and radiation hard circuits and on connection to the detector (integrated monolithic sensors, complex hybridization, 3D microelectronic interconnection techniques).

P2IO laboratories are strongly involved in system architecture and signal real time processing. Acquisition, transport, data reduction and embarked calculation rely on mixed hardware and software structures provided by FPGA advanced programmable circuits, on very high bandwidth serial communication links and on optical communications.

Data processing and simulation

Research lead by P2IO various actors rely upon the capacity to treat increasing data volumes generated by experiments (detectors, satellite ...) and upon numerical simulations necessary for the design of experimental tools and data interpretation. For several decades, these volumes increase by a factor of 10 every 10 years. For example, the 4 LHC experiments produce 15 petabytes of data per year. Forthcoming experiments in nuclear physics or astrophysics during the current decade will produce comparable data volumes.
Analysis and data storage, as well as simulated data production, is no longer possible in a single computing center as in the past. One must imagine innovative solutions allowing data distribution on the scale of a continent or on a worldwide basis, while freeing the user of the necessity of knowing their location to treat them. These challenges of large data amounts distributed treatment and storage gave rise to grid computing infrastructures, particularly EGI in Europe and OSG in United States, upon which LHC data processing means exclusively rely.

At the same time, new practices and other types of applications have given rise to new needs:

- An increased flexibility in resources access and allocation which is at the basis of "cloud" technologies development. Such versatile and generic environments will be an essential component of future "virtual observatories" for selecting data based on specific scientific problems and for their intelligent visualization.
- Specific performance problems based on the need to take advantage of highly integrated parallelism, by developing new algorithmic approaches and by controlling new architectures usage, including GPUs.

Thanks to the richness and diversity of computer skills present in P2IO, in terms of application development, resources implementation and R&D on new architectures of parallel and distributed computing, our laboratories are particularly well placed to collectively contribute to future computing platforms for experiments and theoretical research.

Nuclear Energy

Nuclear energy will most probably play an important role in the future in a context where fossil fuels are limited resources and CO_2 emissions must be reduced. Moreover, highly populated and emergent regions ask for more and more energy. Fukushima's accident reminds us that fission nuclear energy is a particular technology: a substantial and continuous improvement of its safety is necessary for its social acceptability. Moreover, optimization of uranium resources consumption and current and future waste management remain major challenges.

Paris region teams participate in the national research effort to ensure the viability of energy policy on the long term both in the nuclear energy production cycle itself and in the management of the various wastes. The law of June 28, 2006 which superseded Bataille's law (1991) has defined, for the period of 2006-2015, a global working framework for research. Research axes developed by P2IO's teams are neutronic simulation of innovative systems and the study of related scenarios, nuclear data needed for future reactors, safety aspects of the core (thermal hydraulic coupling/neutronics), waste transmutation either to burn them in a reactor or to use them as fuel to generate electricity, fuels chemical reprocessing, materials for nuclear and geological storage of long-lived waste.

Health

Among its scientific and technical missions, P2IO's Labex puts forward an interdisciplinary research axis with Biology and Health stakes. For this, it gathers strong assets, combining a unique concentration of instrumentation know-how, structures familiar with medicine-physics interface (IMNC laboratory, IRFU teams, LAL, LLR, IPN) and a rich environment in biomedical platforms.

In order to meet this ambitious interdisciplinary challenge, P2IO's Health pole is organized on the basis of a network associating skills in physics (detectors, accelerators, modeling and methodologies) and biomedical goals focused on cancer treatment and fundamental questions in neurosciences.

More specifically and within this biomedical framework, P2IO concentrates its activities on two areas:

- Multi-modalities clinical and preclinical imaging: this theme includes an upstream instrumental R&D, especially dedicated to photodetection, which irrigates development of innovative detectors for small animal in vivo imaging or clinical imaging (diagnosis, assistance by radioguidance in surgical treatment of cancer, TEP for neurology or therapeutic follow-up in cancer research). This research is extended downstream by a methodological part (reconstruction, signal processing) based on modeling and simulation (GATE platform) that allows a quantitative interconnection between the image and expression of metabolic parameters.
- Radiotherapy: major actor of accelerator physics, P2IO mobilizes its know-how to new radiotherapy methods for cancer treatment. On top of its flagship projects, comes the ThomX machine, a recent EquipEx winner, which aims at developing a new compact source delivering a very intense X-ray flow. This axis also includes research dedicated to hadrontherapy for which P2IO plays both an upstream role (characterization of target

beam interaction, physics deposit dose calculation) and a downstream role (beam profilers design, online dosimetry monitoring, planimetry techniques improvement).