French-Polish Co-operation in Nuclear and Particle Physics

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ABSTRACT

Co-operation in nuclear and particle physics between Poland and France has been lasting as officially signed agreement for 37 years. It continuously grows and involves more and more scientific exchange. The article gives an overview, with historical aspects, of main achievements and the future. The documents and publications are in the web page http://copin.ifj.edu.pl.

1. Introduction with historical aspects

The co-operation between Poland and France in the domain of nuclear physics, one can consider to begin with Maria Sklodowska-Curie and her work on "radioactivity" - the term she was the first to use - including her discovery of Polonium and Radium in 1898. She was also the first to say that:

"...the ability to radiate does not depend on the arrangement of the atoms in a molecule but it is related instead to the interior of the atom ..."

That 'interior' of the atom was then, in 1911, discovered by Ernst Rutherford as the nucleus.

One may consider then that Maria Sklodowska-Curie was the first to suspect existence of the nucleus. So, it is rather eligible to state that the French-Polish co-operation has begun at the end of XIX century. Later on, Maria Sklodowska-Curie engaged herself rather into radiochemistry. Consequently, co-operation in nuclear physics became rather scarce till the Second World War. After the War, it was begun by personal contacts. In the late 50th, Jerzy Jastrzebski went to France as a student and later on continued to work at Orsay Laboratory. Being employed, he acted as a French representative in ISOLDE Facility at CERN in 1967-68. Early in

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the 60th, Eugeniusz Bożek^{††} cooperated with French physicists at *Centre* Recherches Nucleaires Strasbourg de in (present Institut Pluridisciplinaire Hubert Curien). In the same institution continued from the very beginning of 1971 the author of the present contribution. At the same time, in the field of particle physics the French-Polish contacts were represented by Tomasz Hofmokl^{††} who was engaged at LAL in Orsay. Tomasz's activity was preceded by Ryszard Sosnowski - starting in 1968 he spent 2 years in Ecole Polytechnique, Laboratoire de Physique, Paris. Certainly I might have not traced all nuclear and/or particle physicist from Poland who pioneered the forthcoming co-operation.

Those early 'missions' with excellent contribution to research profited in promotion of a regular Polish-French exchange. An official cooperation was established in 1974 with *Institut National de Physique Nucléaires et Physique des Particules* (IN2P3) right after it had been created in 1971. A Convention was signed (see Fig. 1) by the director of IN2P3 – Jean Teillac, representing the French party, and Jerzy Pniewski, the director of the Institute of Experimental Physics of the University of Warsaw, representing the Polish institutions.



Fig. 1 Copies of the first and last pages of the Convention on Polish-French co-operation signed in 1974.

The Convention was a tremendous step forward as it enabled Polish physicists to co-operate very actively with French colleagues, and gave access to French experimental modern facilities to perform joint research at a very high level. It facilitated greatly exchange between both countries in the severe times of the Iron Curtin (also in getting passports and visas). Later, the Convention opened possibilities to create other forms of collaboration programs like PICS - *Programme International de Cooperation Scientifique*, GDRE (*Groupement de Recherches Européen*) or JUMELAGE, and more recently LEA (*Laboratoire Européen Associée*) (see below). The latter forms of the co-operation were proposed to perform specific studies at selected large facilities in France, mostly experimental. Several programs have been run, which are summarized in Table 1.

For the XXth Anniversary of the Convention, in 1994, JUMELAGE was signed between IN2P3 and the Institute of Nuclear Physics in Krakow. The scientific program was coordinated by dr. Jean-Pierre Vivien^{††} from the *Institut de Recherches Subatomiques* (former: *Centre de Recherches Nucléaires*) in Strasbourg and the author. An important goal of the program was to perform studies - both experimental and theoretical - at the powerful accelerator *VIVITRON* with the use of the multidetector γ -array *EUROGAM* (replaced later by *EUROBALL*) and a specific detector RFD – *Recoil Filter Detector* - of recoiled nuclei created in the target in a nuclear reaction (see page 10). The detector RFD was built in *IFJ PAN* in Krakow. Convention de *JUMELAGE* allowed physicists from Poland – not only scientists from IFJ PAN in Krakow - to enlarge the area of their researche due to increased funding by CNRS on that new form of co-operation. After three consecutive renewals that form of cooperation was ended and later was replaced by LEA (see later).

A longe-range coordination of the exchange has been very well established. The mixed French-Polish Committee meets regularly each December and judges the year's reports of each collaboration, the results and the scientist exchanges. At the same time, it makes the attribution of researcher-days to each collaboration for the forthcoming year considering the suggested demands by the collaboration leaders out of the total amount of about 700 researcher-days foreseen for a year exchange.

PIC5					
PICS n°	Country	Responsible person in France	Responsible person in Poland	Subjects	
83	Poland	Jean-Eudes AUGUSTIN	Tomasz HOFMOKL	Analyse des résultats de l'expérience	
1990-1992		LAL Orsay	Inst. of Experimental Physics, Warsaw Univ.(Poland)	DELPHI	
84		Daniel GUERREAU	Eryk PIASECKI	ORION - Etude de la matière nucléaire chaude	
1990-1992	Poland	GANIL	Inst. of Experimental Physics, Warsaw Univ. (Poland)		
		IPN Orsay, CRN Strasbg, LPC Caen	HMI - Berlin (Germany)		
143		F. BECK	J. STYCZEN	Détecteur de noyaux de recul et expérience de	
1992-1994	Poland	CRN Strasbourg	Institute of Nuclear Physics PAN, Cracow(Poland)	faible activité auprès d'EUROGAM	
258	Poland	G. AUGER	J. ZYLICZ	Towards 100Sn	
1994-1996		GANIL	Inst. of Experimental Physics, Warsaw Univ.(Poland)		
463	Czech Rep.	B. ERAZMUS	R. LEDNICKY	Development and application of particle	
1997-1999	and	Subatech Nantes	Institute of Physics - Prague (Czech Rep.)	interferometry methods in experiments with	
	Poland		J. PLUTA	heavy ions	
			Inst. of Physics - Techn. Univ., Warsaw (Poland)		
1110	Poland	JP. COFFIN	J. PLUTA	Silicon Detector Ensemble for Ultra-Relativistiv	
2001-2003		IReS Strasbourg and Subatech	Inst. of Physics - Techn. Univ., Warsaw (Poland)	Heavy-Ion Experiments	
3291	Poland	V. RAUCH	E. PIASECKI	Silicon Detector Ensemble for Ultra-Relativistic	
2005-2007		IReS Strasbourg	Inst. Phys. Exp. Warsaw Univ.	Heavy-Ion Experiments	
			(SLCJ Warsaw and IFJ PAN Cracow, Poland)		

TABLE 1. List of PICS, GDRE, JUMELAGE and LEA accomplished in the frame of IN2P3 - POLOGNE collab	oration
DICC	

JUMELAGE - GDRE - LEA

Coll. n°	Country	Responsible person in France	Responsible person in Poland	Subjects	
Jumelage	Poland	JP. VIVIEN	J. STYCZEN	EUROGAM	
n° 15		IReS Strasbourg	Institute of Nuclear Physics, Cracow (Poland)	Etude de structure nucléaire	
1995-2003					
GDRE	Poland	B. ERAZMUS	J. PLUTA	EUREA	
n° 141	(Russia)	Subatech	Inst. of Physics - Techn. Univ., Warsaw (Poland)	Heavy lons at RHIC and LHC	
2005-2012	(Ukraine)	and G. MARTINEZ	BTL JINR Dubna (Russia)		
			ITEP and FRRF (Russia)		
			BITP Kiev (Ukraine)		
LEA n° 566	Poland	M. LEWITOWICZ	B. FORNAL	COPIGAL	
2008-2011		GANIL	Institute of Nuclear Physics, Cracow (Poland)	The Collaboration COPIN-GANIL on physics of	
				exotic nuclei	

2. Present status of the co-operation

Within the Convention signed in 1974, the co-operation continued till 2006 very successfully. The exchange, has been relatively well equilibrated as shown in Fig.2 with exception of PICS's, GDRE's and JUMELAGE shown in green bars. The latter forms of the co-operation were devoted mostly to experiments at large scale facilities in France, which demanded longer stays of experimentalists and engineers in France.



Fig. 2. Histogram of scientific exchange in nuclear and particle physics Polish-French co-operation since 1974.

The financial needs for the stays of Polish scientists in France have been always guaranteed by the French party. The financial equivalent in Poland was satisfactorily accomplished, although sometimes with difficulties due to variation of the political, organizational, and other changes and often a lack of proper financial instruments. Therefore, in 2006, a consortium COPIN – *Consortium Polonaise des Institutes Nucléaires* was created which actually groups 9 institutes:

IFJ PAN - *The Henryk Niewodniczanski Institute of Nuclear Physics PAN* – coordinator;

UW - University of Warsaw - SLCJ - Heavy Ion Laboratory, - IFD - Institute of Experimental Physics; UJ – Jagiellonian University - IF – Institute of Physics; UMCS – University of Maria Sklodowska-Curie; IPJ – The Andrzej Soltan Institute for Nuclear Studies; PW – Warsaw University of Technology; ITME – Institute of Electronic Materials Technology; US – University of Silesia – IF – Institute of Physics; UWr – University of Wroclaw.

COPIN has a Consortium Council to which representatives from the member institutions are nominated by the directors/rectors. In September 2006, the renewed Agreement of Cooperation was signed between two parties: CNRS/IN2P3 and COPIN (see Fig.3) for four years with an automatic prolongation for another four years' period of cooperation.



Fig. 3 Copies of the first and last pages of the agreement signed between IN2P3/CNRS and COPIN Consortium in 2006, which continued the Convention signed previously in 1974.

The agreement gave authorization to apply to the Polish Ministry for a special funding of the agreement for 4 years and, consecutively, for another 4 years. That has guaranteed the regular exchange.

New needs for intensifying the co-operation due to the forthcoming unique facility SPIRAL 2 being constructed at GANIL, Caen, generated a call for creating *Laboratoire Européen Associé (LEA)*. Consequently, an additional agreement of co-operation has been signed under the name *COPIGAL* (see Fig. 4). *LEA* is a form of co-operation which is similar to the above mentioned *JUMELAGE* or *GDRE* but of higher rank. In fact, of the highest rank of the French international cooperation. *LEA* has significantly enlarged the exchange and co-operation on exotic nuclei with GANIL. These new possibilities of co-operation, on the other hand, have opened more room for exchange in particle physics and applied studies especially concerned with research in nuclear energy.

Strong engagement of Polish physicists has generated Polish involvement into an FP7 EU project called *SPIRAL 2 Preparatory Phase*, co-signed by COPIN. The Polish responsibility (Adam Maj, IFJ PAN) for the *Work Package* 5 is concerned with preparation of new generation detectors for SPIRAL 2 and especially *PARIS* (see page 14) for detection of high energy gamma-rays.



Fig. 4 Establishing of the European Associated Laboratory (LEA) and press release.

3. Some achievements and highlights

The co-operation has been concerned with rather broad range of themes during the past 37 years. Consequently, the number of achievements and highlights is rather rich and hardly to be presented in total, therefore, only some selected topics will be reported.

An important aspect of the co-operation is the availability of very expensive, not accessible in Poland, and highly sophisticated experimental facilities in France for performing research. Those are either particle and heavy-ion accelerators or detector systems and computer facilities: in early days, Strasbourg – Van de Graaff accelerators, later on heavy-ion tandem accelerators offered by CRN (later IReS) in Strasbourg, GANIL in Caen, and accelerators at IPN and LAL in Orsay. A few experiments were also performed with two facilities in Poland – IFJ PAN Krakow (cyclotron, ⁴He) and SLCJ UW Warszawa (cyclotron, heavy-ions).

In parallel, in particle physics all experimental work has been carried out at CERN with LEP (recently - LHC - *Large Hadron Collider*) and at HERA in Hamburg. Of great value to be mentioned has been common studies in theory of both nuclear and particle physics.

The co-operation is characterized by a great mutual trust and an increasing involvement in up-to-date research, which is mostly due to the excellence of the research groups both Polish and French, involved in experimental and theoretical studies.

Altogether, the co-operation furnished close to 1000 common publications in journals and conference proceedings. Based also on that work, accomplished have been several PhD's both in France and Poland, and to be underlined – 7 PhD theses of the type "*co-tutelle*" which means with the two, French and Polish, universities involved and two supervisors.

Nuclear structure

Certainly, this domain has been mobilizing the most of researchers in variety of themes:

- In-beam spectroscopy of nuclei in the fp shell and discovery of a strong, prolate deformation in the neighborhood of 40 Ca,
- Investigation of superdeformation in the A~60 region,
- studies of the role of hyperfine interactions and investigations of magnetic properties of excited states first measurement of *g*-factor for an *yrast trap* in 152 Dy,
- discovery of the second *beck-bending* in 176 Yb,
- discovery of the superdeformed band in ¹⁴⁷Dy,
- forking of superdeformed bands in ¹⁴⁹Dy and its theoretical explanation,
- studies of hyperfine deformation in Ba nuclei.

Hot nuclei

- Jacobi shape transition in light *fp* nuclei,
- Lublin-Strasbourg-Drop (LSD) model; theoretical description of the Jacobi shape transition,
- nuclear reaction mechanism in heavy-ion collisions,

- high-energy photons produced in heavy-ion collisions,
- limit of nuclear excitation energy by neutron calorimetry.

Exotic nuclei

- studies of nuclei far-off stability line by ISOCELE techniques on-line separation,
- production of very neutron deficient nuclei
 o first observation of ¹⁰⁰Sn,
- co-discovery of the 2-proton decay in ⁴⁵Fe,
- studies of quadrupole deformation in ⁴⁴Ar, ^{74,76}Kr, and ⁷⁸Se with Coulomb excitation
 - first direct measurement of the quadrupole moment in an unstable nucleus.
- search of alpha-decaying isomers in trans-lead nuclei using the WIGISOLdevice at SLCJ UW, e.g. identification of an isomer 9in ²¹⁶Fr,
- development of the target-ion source system for ALTO and SPIRAL devices to deliver the radioactive beams of exotic nuclei.

Collisions of ultrarelativistic heavy-ions

- strange particle production and search of quark-gluon plasma in NA36 and NA50 experiments at CERN.

Physics of hadrons

- pion-nucleus interaction studied with OMEGA spectrometer,
- Delta-resonance in nuclear matter.

Particle physics

- proton and antiproton interaction with light nuclei studied with bubble chamber,
- charm particle production in hadron collisions and physics of Jets,
- interactions e-p at H1, DESY,
- DELPHI experiment and simulation of Barrel-Rich,
- radiative corrections for ALEPH,
- R&D for LHC.

Theory

- studies on nucleon-nucleon potential and the field theory,
- the symmetries of nuclei, exotic symmetries like tetrahedral point groups and their investigations,
- formulation of the LSD model (*Lublin-Strasbourg-Drop*),

- formulation of the Shell Model embedded in the continuum and studies of its application to nuclei at the proton drip line, e.g. ⁴⁵Fe two-proton decay,
- mass calculations for whole nuclear chart and comparison with experiment,
- phenomenology of particle production in high-energy processes,
- interactions of mesons.

Applied physics

- studies of various properties of materials by Mössbauer technique,
- investigations of radiation defects accumulation in materials for applications in nuclear plants,
 - first observation of lowering defect accumulation in ZrO₂ with ion dose increase.

4. Present and future physics aspects

4.1 Nuclear Physics

Since 2004, most of the experimental work has been and will be performed at GANIL (Grand Accélérateur National d'Ions Lourds), Caen, and ALTO at IPN, Orsay. GANIL is one of the foremost sites in the World with a heavy-ion accelerator complex which delivers beams both of stable isotopes in the range from ${}^{12}C$ up to ${}^{238}U$ and beams of radioactive species produced with the ISOL technique at SPIRALsystem. Thus, it allows exploring the structure of exotic nuclei and dynamics of nuclear collisions even at extreme conditions. The complex consists of two injector cyclotrons preceded with two ECR ion sources which can either operate in parallel or with one being the first acceleration stage to the other. The separated sector cyclotrons deliver beams of low energy 5-15 MeV/A to the so called low-energy-area SME and full energy -30-100 MeV/A to all experimental areas. Very intensive beams are delivered to "a hot area" where they impinge on a thick production target and produce radioactive isotopes which are extracted by ISOL technique and accelerated in CIME cyclotron to an energy 2-25 MeV/A (that is aforementioned SPIRAL).

The Polish experimentalists are involved in several ongoing studies at GANIL in which they use the state-of-the-art equipment. They also strongly contribute to the development of detector systems.

A variety of detectors is used for investigations of exotic and hot (highly excited) nuclei. Large volume and high efficiency germanium array EXOGAM is mostly employed for gamma radiation detection in experiments with radioactive beams. It is often coupled with one of the spectrometers. Verv selective above mentioned devices. like MUST2/TIARA – a modular charged-particle detector, or the Neutron Wall, are used in studies of direct reactions induced by radioactive beams. The Neutron Wall was constructed and is presently run by an international collaboration with strong contribution of groups from IPJ-Swierk and University of Warsaw. Using a combination of EXOGAM, Neutron Wall and charged particle detectors, several important results were obtained on the properties of very neutron deficient nuclei, with Polish co-authorship. One example of such work is the first observation of isoscalar spin aligned paring phase in ⁹²Pd, recently published in Nature.

INDRA, a 4π multi-detector for charged particles, or NEUTRON WALL are often cited in publications with Polish co-authors. Very high quality experiments have been performed and nice and important results have been obtained. As is illustrated in the attached Table 2. at the end of the paper-, the research program which is pursued in frame the IN2P3-COPIN co-operation consists of the frontier-line topics.

The experimental studies involve research of nuclear structure of exotic nuclei with the use of various tools such as gamma radiation, neutrons, conversion electrons, coulomb excitation, and direct reactions, exploiting both stable and radioactive beams.

Investigations of the nuclear reaction mechanisms in deepinelastic collisions of very heavy nuclei, spectroscopy of di-electron pairs in the energy range 1-2 GeV and measurements of neutron electric dipole moment as well as ultrarelativistic heavy ion collisions studies in the ALICE experiment at LHC constitute a link between experimental nuclear physics and particle physics.

Of great significance are also joint projects in theoretical studies they encompass a broad range of subjects: symmetries in nuclear physics that are of fundamental importance, symmetry breakings and their nuclear structure implications that stimulate searches for experimental finger prints in single particle and collective excitations or discrete symmetries which can imply exotic shapes of nuclei such as e.g., tetra- or octahedral shapes. These undertakings involve several theorists from UMCS, Lublin and IPHC (*Institut Pluridisciplinaire Hubert Curien*), Strasbourg. The research activity that was mentioned above is bound with the works on exotic shapes such as Jacobi and Poincare shapes of hot, fast-rotating nuclei. The studies involve statistical model based on the Liquid Drop model of the nucleus. One of the very recent projects aims at developing methods for assessing predictive power of the mean-filed nuclear Hamiltonians.

For microscopic description of nuclei far-off stability line and weakly bound nuclei, the Shell Model embedded in the continuum seems to work well as it treats simultaneously configuration mixing and the coupling to decay.

4.1.1 Instrumentation

Appreciable achievements in the experimental nuclear physics research have often been generated by construction of sophisticated detector systems by Polish physicists.

RFD - Recoil Filter Detector

In-beam nuclear spectroscopy based on fusion evaporation reactions with both light and heavy ions has been one of the major tools in nuclear structure research for more then 30 years and one of the most rich resource of various data. At bombarding energies not too high above the Coulomb barrier, the fusion evaporation reactions are usually dominant, with a cross section of about 0.1 barn to 1 barn. Often happens that of several reaction channels, one dominates and leads to a particular nucleus of interest. In such cases the coincidence gamma-ray measurements, without any auxiliary detectors, are sufficient to obtain high quality data. This is not the case, however, in studies of heavy nuclei, even slightly beyond Pb - the compound nuclei mostly undergo fission and particle evaporation channels, which leads to nuclei of interest, become weak. This appears drastically worse when going to very heavy nuclei with Z~100. Therefore, to perform spectroscopic studies in that region, it is necessary to make an identification and selection of γ - rays from the desired, rarely occurring evaporation residues.

For that purpose and to overcome aforementioned difficulties, a Recoil Filter Detector (RFD) was built in IFJ PAN. It was intended to be used only in coincidence with γ -spectrometers (multidetector arrays) – like EUROBALL (see Fig. 5).



Fig.5 Recoil Filter Detector (front view) assembled with EUROBALL γ -array (rear view).

The RFD measures evaporation residues in coincidence with γ rays detected in a Ge-array. The recoil selection by time-of-flight technique discriminates against other reaction channels. Therefore, the background is significantly reduced (see Fig. 6) and spectroscopic studies in reactions with low cross section become feasible. This is particularly important for radioactive beam spectroscopy since the beam-associated background radioactivity may well be the dominant contribution to a γ ray spectrum.



Fig.6 The singles γ -spectrum and the singles γ -recoil coincidence spectrum (not normalized) measured with one Ge-detector and the Recoil Filter Detector at VIVITRON.

Moreover, the granularity of the RFD allows for 'tracking' evaporation residues thus providing their velocity vector determination. As a consequence, correction of the gamma-lines Doppler broadening can be performed. This is especially important for light, or medium-light nuclei (Fig. 7) for which the recoil velocity can be high when they are produced in fusion-evaporation reactions with energetic, heavy projectiles.



Fig. 7 Gamma spectra of a single cristal of a cluster detector of EUROBALL: upper – uncorrected; lower – corrected for the true recoil velocity vector measured with RFD for A = 45 with $\langle\beta\rangle = 2.8$ %.

The EUROBALL–RFD combination has heavily been used in various studies at VIVITRON. Among those were investigations of deformed and highly deformed (superdeformed) states in light $f_{7/2}$ shell nuclei, high-spin states in A=60 mass region, spectroscopy in heavy nuclei (¹⁹⁹At, ^{200,201}Po), an attempt for spectroscopy of very heavy ²⁵²Fm, and search for *Jacobi* shape transitions.

ICARE

It is a charged particle and heavy ion (up to A~30) detecting system (array) consisting of Si+CsI telescopes and ionizing chambers placed in 'wings' (see Fig. 8) within a vacuum chamber. The system was built for studies of reaction mechanisms at VIVITRON in IReS in Strasbourg. An important part of the construction was carried out in IFJ PAN.



Fig. 8. Interior view of the ICARE chamber.

ICARE was very successfully exploited in common experiments IReS-IFJ PAN in studies of A=19 and 20 nuclei produced in alphaparticle decay channels after fusion reactions with heavy ions. The measured alpha spectra strongly indicated highly deformed – super- and hyper-deformed shapes in those nuclei, respectively.

After the decision of closing the VIVITRON operation in Strasbourg, we undertook intensive approaches to bring and isntall ICARE in a beam line at the heavy-ion cyclotron in SLCJ at the University of Warsaw (Fig. 9).

Strong engagement of the SLCJ UW staff and some physicists (ICARE project leaders) from IReS was successful and several experiments concerning fusion barrier distributions and angular product distributions in transfers and quasielastic scattering have already been performed with participation of French specialists, as well as other physicists from many countries. Recently, the French partners have gifted ICARE to SLCJ UW.



Fig. 9 ICARE on line of the heavy ion cyclotron at SLCJ UW.

AGATA and EXOGAM2

Gamma spectroscopy is an essential tool in studies of nuclear structure. A very rich, and broad experimental program has been carried out in this domain which has evoked an extensive development of γ -radiation detectors, detector systems and highly sophisticated arrays, mostly based on Germanium crystals. Among those are the EXOGAM and AGATA arrays. The former one is a large solid angle, high efficiency γ -detector, specially designed for Radioactive Beams but also exploited with high intensity stable beams. It is permanently used at GANIL.

AGATA array is a very modern, highly advanced detecting system with segmented germanium crystals (up to 6780 segments!) to allow a novel γ -tracking technique and thus, when fully completed, is designed to be orders of magnitude more powerful than any previous and current γ ray spectrometer. It is considered as a 'travelling detector' to be used in various European laboratories, among those at SPIRAL and SPIRAL2 for the future physics programs.

The modular design allows the array to be constructed in phases and also that separate modules can be used to carry out specific experimental campaigns at different laboratories. The first module – AGATA Demonstrator – has been successfully used in a Coulomb excitation experiment in 42 Ca, proposed by Polish-French co-operation.

Both EXOGAM and AGATA systems incorporate a new signal acquisition method: the charge produced by a γ -ray in a Ge crystal segment is detected with the charge preamplifier from each and digitized right after the first stage. Thus, the signals as 'digits' can be treated numerically with very fast and powerful computing systems. A synchronization of the signals that origin from different detectors is based on a time stamp generated by a common clock.

The Polish contribution to both arrays is designing, construction and implementation of a, so called, AGAVA Interface which is a VME/VXI slave module. The main task of the AGAVA interface is to merge the AGATA time stamp based system with conventional readout and acquisition system using trigger, based on VME or VXI, e.g. in the EXOGAM or other environment. Moreover, a Polish duty was evaluating properties of the AGATA array in connection with ancillary devices, by means of computer simulations.

PARIS

PARIS (Photon Array for the studies of Radioactive and Ion Stable *beams*) is a detector system presently at the design and prototyping stage. The array intends for future radioactive beam facility SPIRAL2 where it will serve as a calorimeter for medium and high-energy gamma-ray spectroscopy. It should have high both energy and time resolutions through the exploitation of the novel scintillator LaBr₃(Ce) which has an energy resolution of ~2.8% at 662 keV, and excellent time response. A wide range of physics cases are envisaged for PARIS, ranging from studies of giant resonances, to nuclear reaction dynamics. PARIS will also be highly modular, allowing greater flexibility and synergies with other detector arrays such as the charged particle detector GASPARD, and the AGATA array of high-purity germanium tracking detectors. However, due to the presently high cost of LaBr₃(Ce), an appropriate trade-off between performance and cost of the array needs to be achieved. The initial concept for this was to employ a calorimeter comprising of two shells of scintillators: an inner array of LaBr₃(Ce), and an outer layer of CsI(Na) or NaI(Tl) scintillators. During the research and development phase of the project, further options emerged employing "phoswich" detector arrangements, where LaBr₃(Ce) is directly coupled to another scintillator, such as NaI(Tl). Detailed simulations of these different for the design of PARIS have been performed with the Monte Carlo simulation package GEANT4. A schematic layout of such a solution for PARIS array is presented in Figure 10. Poland is coordinating the international effort to design and build PARIS array, which apart from being used at SPIRAL2, will also be employed in Polish laboratories (Krakow and Warszawa). For more information see *http://paris.ifj.edu.pl/*.



Fig. 10. Layout of the PARIS array consisting of 220 $LaBr_3(Ce)$ (blue) + NaI (red) phoswich detectors.

SPIRAL2

In the coming years, the nuclear physics co-operation with France will be mostly concerned with SPIRAL2 (*Système de Production d'Ions Radioactives an Ligne* 2^{eme} generation), works on which are concentrated at GANIL (Fig. 11). SPIRAL 2 is a new European nuclear facility (selected for *ESFRI* roadmap) and will be operational from 2014. It aims at providing stable and rare isotope beams with intensities not available as yet with present accelerators. The driver of SPIRAL2 is a high power, CW, superconducting LINAC which is to deliver high intensity beam of deuterons – up to 5 mA – to be directed on a Carbon converter+Uranium target. Production of the radioactive beams is based essentially on the fast neutron induced fission of Uranium. The expected radioactive beam intensities for some nuclei in the mass region A=60-140 will be reaching up to 10^{10} particles per sec, unique in the World.



Fig. 11 Schematic view of the SPIRAL2 facility.

The radioactive beams will have energies ranging from a few keV/A – at the DESIR facility up to 20 MeV/A at the GANIL experimental areas, where available will be variety of next generation detectors among those discussed above - AGATA, PARIS and EXOGAM2 γ arrays, and FAZIA, GASPRD particle detector/arrays, also NEDA – neutron detector, in all of which Polish physicists are heavily involved.

The SPIRAL2 LINAC will also accelerate heavy ions up to energy 14.5 MeV/A and high intensity, up to 1mA. This will provide much broader range of exotic nuclei beyond those produced by ISOL method towards neutron-deficient nuclei and very heavy nuclei produced in fusion-evaporation reactions, or light neutron-rich nuclei via transfer reactions. The heavy-ion beams will also be used to produce exotic nuclei with the use of the Super Separator Spectrometer (S3). The very high neutron flux at the Neutron for Science facility (NFS) produced with high intensity deuterons will open a new field of research and applications at GANIL.

The main goal of SPIRAL2 is extension of knowledge to unexplored and thus unknown regions of the nuclear chart, particularly, the medium and heavy mass regions. The rich scientific program prepared by about 600 world specialists aims at answering many physics and astrophysical questions and at better and deeper understanding the nature of matter. It also addresses to various types of applications of nuclear physics to the society, e.g. nuclear energy and medicine, radiobiology and material science.

The Polish physics community is very much engaged in SPIRAL2 developments via *COPIGAL* agreement within LEA and *SPIRAL2PP* as I said in the introduction. SPIRAL2 has been selected for the Polish roadmap in science.

In the SPIRAL2 project, many countries worldwide are involved (25 institutions from 13 countries): up to now, 15 *Memorandums of Understanding* (MoU), European Associated Laboratories (LEA) - including our *COPIGAL*, and International Associated Laboratories (LIA) agreements have been signed. Ongoing discussions and preparations are directed towards transformation of GANIL with SPIRAL2 facility into a **fully international legal entity and with Poland as the formal Partner**.

4.2 Low Energy and Relativistic Heavy Ion Physics

Relatively long-lasting co-operation in the Relativistic Heavy Ion physics started with participation of physicists from the Faculty of Physics, Warsaw University of Technology (WUT) and the SUBATECH laboratory in Nantes in the low energy heavy ion experiments: E183, E193 and E286 performed at GANIL. The subject of research - influence

of geometrical and dynamical factors on the space-time development of particle emission in the reactions of heavy ions, studied by the analysis of two-particle correlations - has found later his renaissance in the relativistic heavy-ion physics.

Common participation in the NA44 experiment at the CERN/SPS, the STAR experiment at the Relativistic Heavy Ion Collider RHIC (USA), and the recent ALICE experiment at the CERN/LHC resulted in the



creation of GDRE project - EUREA - "*Relativistic Heavy Ions at RHIC and LHC*". It joins experimentalists and theorists from several European countries..

The start of LHC and a broad scientific program of the ALICE experiment have created a new impact for further development of common efforts to understand the properties of matter created in heavy ion collisions.

A search for medium effects in dense baryonic matter has been realized in relativistic heavy-ion collisions in energy range 1-2 AGeV with common experiments using HADES facility at GSI. The cooperation involves 17 institutions while among those two strongly cooperating French and Polish from IPN Orsay and IF UJ Krakow, respectively. In dense baryonic matter studies HADES uses dielectrons as penetrating probes to characterize medium properties. It concentrates also on strangeness production, which at such low energy is confined to high density phase (subthreshold production) and is sensitive to K^+ and $K^$ properties in nuclear matter. From 2016, the experiments will be continued with energy range 8-10 AGeV at FAIR with new SIS100 machine.

4.3 Particle Physics

Co-operation in particle physics is mostly based on experiments carried out at LHC (*Large Hadron Collider*) which has been operating since the end of 2009 at CERN. LHC has opened new perspectives for discoveries of yet unknown particles and interactions. Most of the experimental work is carried out in two experiments ATLAS and CMS, with the main initial aim of verifying the Standard Model in the new energy range not accessible till now.

2010 was a remarkable year for LHC. The machine succeeded in accelerating proton beams up to the energy of 7 TeV in the proton-proton center of mass system, the highest energy ever achieved in laboratory conditions. The luminosity reached the assumed ambitious objective of 10^{32} per square centimeter per second. The ATLAS and CMS experiments collected about 45 pb⁻¹ of the integrated luminosity and published many interesting results confirming the validity of the Standard Model in this new energy regime. Here, we briefly report on some of the studies performed in close cooperation between the IFJ PAN and French institutions: LAPP (Annecy), LPNHE (Paris) and CPPM (Marseille) within the ATLAS experiment at LHC.

First measurements of W and Z bosons production cross-section in p-p collisions at 7 TeV were performed by the ATLAS collaboration for leptonic channels and found to be in agreement with Standard Model predictions based on next-to-next-to-leading order QCD (Quantum Chromo Dynamics) calculations (see Fig.12). In addition, the first observation of the $Z \rightarrow \tau \tau$ channel was reported. Numerous other studies have been carried out, concentrating especially on the reconstruction of low-energy electrons, tagging of the heavy b quarks, and the alignment of the ATLAS detector sub-systems. All of these initial studies provided a good understanding of the detector response as well as improved tuning of Monte Carlo models. Thus, they are indispensable for future highstatistics studies of physics beyond the Standard Model and future potential discoveries. It has to be noted, that on the basis of currently available data the ATLAS collaboration has already provided several limits on new physics phenomena exceeding those derived from lower energy experiments.



Fig.12 The measured W, W^+ and W^- production cross-sections in p-p collisions at 7 TeV for leptonic channels (electrons and muons). Comparison with the theoretical predictions based on next-to-next-to-leading order QCD calculations and with results obtained at lower energies is also shown [JHEP 12 (2010) 060.

The achievements of LHC machine and experiments in 2010 give very promising prospects for studies in 2011 and beyond. They also offer good prospects for future cooperation between Poland and France. Thus, it is foreseen to continue this cooperation in the field of elementary particle physics at the experimental level and within the framework of theoretical and phenomenological studies. The experiments are looking forward to prosperous data collection in 2011-2012. The target of a few fb⁻¹ of integrated luminosity seems to be well within reach. As early as in 2011, it is envisaged to collect the data of two orders of magnitude more than in the previous year. With this high-statistics data ATLAS and CMS would be able to exclude the Standard Model Higgs boson with any mass, and to obtain a three standard deviation observation of Higgs with a mass from 115 GeV/c² to about 500 GeV/c². It would be possible to set a lower limit on the mass of supper symmetric particles at 1 TeV/c². There is also great potential for other searches of new physics phenomena. It is clear that in the next year or two, the landscape of elementary particle physics will change. An important contribution to this change will result from the cooperation between Polish and French physicists.

Collaborations in theory have been concentrated around physics tasks being performed by experiments. Studies and their Monte Carlo implementations have been performed particularly in domain of signatures involving Z and W production as well as luminosity measurements. Essential value for performance of experiments poses work on components of physics signatures such as detector response to soft electrons or tau leptons. Important, not only for establishing signatures of Higgs to gamma above the background, are effects of bremsstrahlung in other decays. Reason for their significance stems from the fact that they affect separation between channels and thus sensitivity of many observables to physics signatures.

The construction of precision Monte Carlo generators for Drell-Yan processes at the LHC, i.e. single W and Z boson production with leptonic decays and development of novel methods for measurement of the Standard Model parameters at the LHC, in particular the W-boson mass and width, the weak-mixing angle are other subjects of the cooperation. So far, the new strategies for high-precision measurements of the W-boson mass and the mass difference between the opposite charged W-bosons at the LHC have been proposed. The crucial role in their development played extensive Monte Carlo simulations with the use of the event generators WINHAC and ZINHAC, constructed within this collaboration. These generators use spin amplitudes for computing the respective matrix elements, for both polarized and unpolarized processes, and include important QCD and electroweak effects for Drell-Yan processes. They are being now extended to incorporate higher-order QCD and electroweak radiative corrections as well as effects of new physics in terms of extra resonances and anomalous bosonic couplings. The current work and plans for the future include also developing efficient methods

for high-precision measurements of the W-boson width and the weakmixing angle at the LHC as well as the use of polarized W-bosons to investigate the mechanism of the electroweak symmetry breaking.

Precise measurements of observables in the accelerator environment are impossible without a precise measurement of the machine luminosity. This problem was a of the scientific collaboration between LPNHE and IFJ PAN, Krakow. The aim was to select a method and prove that with help of a dedicated apparatus the measurement precision of the order of 1% can be reached. It was proposed to base such measurement on the observation of the production rate of the coplanar lepton pairs produced in two-photon interactions at the LHC, which allows for the luminosity determination on the run-by-run basis. The first phase of the project was devoted to the study of the theoretical aspects of these process and it was shown that the various theoretical aspects of the lepton pair production can be controlled at the level of about 1% systematic precision. Present studies concentrate on the development of the detector model and of the measurement method. In future the feasibility studies of the application of the proposed method to the protonion and ion-ion interactions will be performed.

Such works were being conducted within Polish-French groups with strong involvement of theorists from IFJ PAN, IF UJ (*Institute of Physics of the Jagiellonian University*), Krakow and LAPP (Annecy), LPNHE (Paris). Multitude of publications and citations to the articles can be found in the literature. What must be emphasized - not only the mentioned projects will be continued but also challenges related to improving experimental precision will stimulate new projects and will request refinements of the already started ones.

4.3 Nuclear energy aspects

The decision of Polish Government to build the first nuclear power plant in 2020 implies technological demands for nuclear physics applications. The contradictive decision to stop building of nuclear power plant in Żarnowiec about 20 years ago caused a harmful break in investigations and education in the nuclear energy aspects - there is a serious shortage of specialists in that domain. In France, about 80% of electricity comes from nuclear energy. There are under operation several very modern nuclear plants. Great effort has been undertaken on nuclear plants of Generation III+ and IV. Therefore, in France the nuclear technology developments and education are on a very high level. It is then obvious that a long tradition of Polish-French co-operation in the filed of nuclear physics should facilitate its extension to nuclear energy aspects such as investigations of irradiation effects in materials used in preparation of nuclear fuels and for immobilizers of nuclear wastes, as well as in materials applied in construction of various elements of the nuclear plant. Of great importance is education on the university level.

As mentioned earlier, some irradiated materials' studies have already been carried out by Polish scientists and French colleagues. For example, recent studies of the damage accumulation in SiO_2 irradiated with 4 MeV Au ions revealed strong correlation between elastic strain and kinetics of defect accumulation. For the first time, a decrease of defect accumulation with the increase of Au has also been shown.

5. The list of present collaborations

The Table 2. below summarizes the actual collaborations approved by the mixed French-Polish Committee for 2011. It comprises themes of the scientific exchange, responsible persons and their institutions.

Collab.		Subject	Responsible person (France)	Responsible person (Poland)
04-111	Orsay (IPN)	Leptons in pion-induced reactions with HADES	RAMSTEIN	SALABURA
	Cracow (IF UJ)			
04-113	Strasbourg (IPHC)	High-Symmetry point groups in nuclear structure and their	DUDEK	GOZDZ
	Lublin (IPMCSU)	experimental manifestations		
05-115	Paris (LPNHE)	Effets électromagnétiques et mésiques dans les atomes	DEDONDER	WYCECH
	Warsaw (IPJ)	hadroniques		
05-116	Paris (LPNHE)	Développement de programmes Monte-Carlo pour utiliser les	KRASNY	PLACZEK
	Cracow (IFUJ)	faisceaux du LHC comme des faisceaux de bosons électrofaibles		
05-117	Paris (LPNHE)	Etude du mécanisme de brisure de symétrie	KRASNY	CHWASTOWSKI
	Cracow (IFJ PAN)	électrofaible avec le détecteur ATLAS au LHC		
05-118	Orsay (CSNSM)	Simulation du comportement du combustible nucléaire	GARRIDO	TUROS
	Warsaw (IPJ)	usé à l'aide des techniques de faisceaux d'ions		
05-119	Strasbourg (IPHC)	Statistical effects in nuclei and nuclear Jacobi shape transitions	DUDEK	MAJ
	Cracow (IFJ PAN)			
05-120	Grenoble (LPSC)	Recherche sur le moment électrique dipolaire du neutron (nEDM)	REBREYEND	ZEJMA
	Cracow (IF UJ)			
06-121	GANIL	Studies of electromagnetic structure of exotic nuclei with	CLEMENT	NAPIORKOWSKI
	Warsaw (ŚLCJ)	GANIL facilities		

 Table 2. Collaboration Agreement - IN2P3 (France) - COPIN (Poland)

Scientific exchange in 2011

06-122	GANIL Warsaw (ŚLCJ)	Spectroscopie gamma de noyaux N-Z à l'aide d'Exogam	de France	PALACZ
06-126	Orsay (IPN) Cracow (IFJ PAN)	Exotic shapes of nuclei studied with stable and radioactive beams	AZAIEZ	KMIECIK
08-127	Paris (LPNHE) Cracovie (IFJ PAN)	Violation de CP et interactions fortes dans les désintégrations hadroniques des mésons B et D	DEDONDER	LESNIAK
08-128	GANIL Cracow (IF UJ)	New GANIL detection setup for SHE identification	STODEL	WIELOCH
08-130	Palaiseau (LLR) Warsaw (IPJ/UW)	Etude coordonnée des électrons et des muons dans CMS	MINE	ZALEWSKI
08-131	Strasbourg (IPHC) Lublin (UMCS)	Broken symmetries, nuclear structure and collective motion	BARTEL	POMORSKI
09-132	GANIL Cracow (IFJ PAN)	High-energy gamma-rays as a probe of hot nuclei and reactions mechanisms	WIELECZKO	MAJ
09-133	Orsay (CSNSM) Warsaw (ITME)	Transformations structurales induites par l'irradiation dans des oxides pour les applications nucléaires	THOME	JAGIELSKI
09-134	Caen (LPC) Cracow (IFJ PAN)	Analyse des données des campagnes récentes de la collaboration INDRA	BOUGAULT	LUKASIK
09-135	Paris (APC) Lodz (IFJ)	Monte-Carlo generators for p-A and A-A at energies above 10^{17} eV, simulation of extensive air shower development for the highest energy cosmic rays	PARIZOT / CAPDEVIELLE	SZABELSKI
09-136	GANIL Cracow (IEL PAN)	Influence of the neutron excess on binary decays from	BONNET	MAZUREK
10-137	GANIL Cracow (IFJ PAN)	Isospin symmetry breaking exceptional points and effective symmetries from a perspective of the shell model embedded in the continuum	PLOSZAJCZAK	OKOLOWICZ
10-138	Annecy (LAPP) Cracow (IFJ PAN)	Phénoménologie des désintégrations des bons W et Z et de nouveaux états à haute masse au LHC et à l'ILC	HRYN' OVA	WAS
10-139	Marseille (CPPM) Cracow (IFJ PAN)	Towards first physics results: commissioning b-tagging and tau identification using the tracking and calorimeter systems in Atlas	COADOU	WOSIEK
10-140	Paris (LPNHE) Cracow (IFJ PAN)	ATLAS-LPNHEIFJ-ELECINJET: Use of electrons in jets with first Atlas data	DERUE	KACZMARSKA
10-141	Montpellier (LPTA) Cracow (IFJ PAN)	Mesons Scalaires	NARISON	KAMINSKI
CSI-15	Bordeaux (CENB-G) Warsaw (IFD UW/IPJ)	Dissipative collisions of very heavy nuclear systems	CARJAN	SIWEK- WILCZYNSKA
New 11-A cf 08- 129	Annecy (LAPP) Cracow (IFUJ)	Precision measurements with W and Z events in the first phase of the LHC	DI CIACCIO	RICHTER-WAS
New 11-B	Lyon (IPN) Warsaw (IFT UW)	QRPA code for triaxial nuclei	BENNACEUR	DOBACZEWSKI

6. Conclusions

The French-Polish cooperation and scientists exchange in nuclear physics, initiated by Maria Sklodowska-Curie, greatly enlarged in the years 1970th including also particle physics and applications. It furnished important physics results and stimulated discoveries in experimental nuclear and particle physics – it had also a considerable impact on the theory.

Lots of common publications have been released, participation in conferences organized by the partners has been facilitated, several *co-tutelle* PhD's and many PhD's and habilitations in both countries have been completed

The participation in common conferences is a rather important aspect of the co-operation. Among those to be mentioned are periodical Zakopane Conferences – "Zakopane Schools on Nuclear Physics", "Workshops in Kazimierz Dolny", "Mazurian Schools on Physics", "Workshops on Relativistic Heavy Ions" at SUBATECH in Nantes, and several topical conferences and workshops. All provide opportunities for exchange of students, PhD students and staff members from the cooperating institutions.

Of great importance to be underlined is the excellent partner relationships in co-operation that has generated many friendships and good human relations.

I would like to express my thanks to all Responsible Persons from Poland (Table 2.) who made important contributions to this presentation and Bogdan Fornal and Jerzy Jastrzebski for the critical reading.

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