Pursuit of Spin Physics Program at RHIC

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Throughout 1990s, the Radiation Laboratory directed by M. Ishihara was engaged in two major programs: firstly the RIB Physics Program using RIPS at RARF, RIKEN and secondly the Spin Physics Program using the Relativistic Heavy-ion Collider (RHIC) at Brookhaven National Laboratory (BNL), USA. This article describes the latter engagement by emphasizing the aspects of historical evolution of the program.

Our engagement in the international collaboration program on spin physics was started in 1995, aiming at clarification of the anomalous phenomenon of proton spin crisis,[1)] which casted a fundamental question about the origin of nucleon spin. As a matter of fact, our intensive commitment served to implement this program as a flagship objective of the RHIC project, being alternate with the Heavy Ion Physics Program as originally founded. The RIKEN BNL Research Center (RBRC) was created in 1997 to support our activities on this program. The spin program has been successful in revealing the important roles of gluons and parton orbital angular momenta, and further extension of the program has motivated the proposal of the US next-generation project of Electron Ion Collider (EIC).

The Spin Physics Program is one of the two principal programs at RHIC, BNL, aiming at the determination of the polarized parton distribution function of nucleons. Our initiative to commit to this program followed a recommendation of the headquarters of RIKEN, which strongly encouraged us to set up any cutting-edge program on nuclear physics to be conducted in international collaboration. The RHIC Spin Physics Program turned to reality when the Radiation Laboratory gave its commitment to this program by bringing a sizable grant from the Science and Technology Agency (STA) to build a full set of Siberian snakes and spin rotators. Indeed, these devices were essential to facilitate the acceleration and manipulation of spin-polarized protons through the rings of RHIC. A grant was also obtained to build a single unit of muon arm for the PHENIX detector assembly. Moreover, RBRC was created in the BNL campus to support our research activities at the site of the RHIC facility.

Since we were quite new to the field of relativistic QCD physics, our major efforts in the initial stage were devoted to call for relevant international collaborators. The Japanese spin physics team was soon formed, consisting of groups from Kyoto University and Tokyo Institute of Technology as well as the RIKEN Radiation Laboratory. We also managed to establish a strong tie with the powerful spin physics group around BNL led by G. Bunce and T. Roser. Thus, these two groups from US and Japan were destined to take the leading role in promoting the RHIC Spin Physics Program. To help such practice G. Bunce was invited to serve as the Deputy Leader of the Experimental Group of RBRC while I served as the Leader. As was always the case for the RHIC project, this program was conducted under a framework of international collaboration. Between the two major collaborations formed for the RHIC project, we have chosen the PHENIX Collaboration, rather than the STAR Collaboration, since we anticipated close cooperation with a large number of Japanese researchers who had been already registered in the former Collaboration. The Radiation Laboratory group in the early stage consisted of N. Saito, Y. Goto, N. Hayashi, K. Kurita, M. Okamura, S. Yokkaichi, T. Ichihara, Y. Watanabe, A. Taketani, and J. Murata besides myself. The group was further reinforced by acquiring several fellows at RBRC, including M. G. Perdekamp, A. Deshpande, and A. Bazilevsky. They soon manifested themselves to become leading figures in the Spin Physics Program.

Throughout the 1990s, our research activities were mainly devoted to the construction of the PHENIX detector assembly and of accelerator devices required for polarized protons. Specifically, the RIKEN group was committed to the construction of one unit of muon arm, where the magnet assembly was manufactured by Mitsubishi Electric Co. under the direction of T. Ichihara while A. Taketani and K. Kurita took major roles in completing detector arrays for muon ID and J. Murata for muon tracker. The development of a laser-driven ion source was an important R&D issue to realize an intense polarized proton beam, and M. Okamura made a central contribution to its accomplishment. Another important agenda was to develop the polarimeter, which is crucial to determine the degree of spin polarization of the accelerated protons. The RIKEN group led by N. Saito and K. Kurita was successful in establishing the relevant methodology.[2)] Meanwhile, Y. Goto worked on the EM calorimeter in the central arm of the PHENIX assembly to make it useful for the Spin Physics Program. M. G. Perdekamp and A. Bazilevsky also joined in this activity. In fact the π^0 detection as described later was facilitated with this device.

At Wako a computer facility called the Computing Center in Japan for RHIC physics (CC-J) was built[3)] under the leadership of T. Ichihara. Y. Watanabe and S. Yokkaichi also made great contributions to the development and operation of the CC-J. With a computation speed equivalent to 160 high-performance CPUs and a disk capacity of about 135 TB supplemented by

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tape storage capacity of 1400 TB, the CC-J immediately gained the status of the primary center for data analysis for the Spin Physics Program. It also served as a principal Asian local center for the PHENIX Collaboration by allowing Japanese and Asian colleagues to analyze the data from the Heavy-Ion Program as well. The CC-J has been in sound operation since its commissioning in 2001, being reinforced by a series of successive upgrades. It has thus far contributed to the publication of 42 papers and awarding of 42 Ph.D. degrees.

The Spin Physics Program at RHIC was originally inspired by the so-called spin puzzle that the quark contribution alone is not sufficient to account for the nucleon spin of 1/2. Hence, the extent of gluon contribution was inquired to pin down the anomalous phenomenon. In this respect, spin-polarized proton beams at RHIC were indispensable since collisions with protons well reveal various gluon-induced processes, which in turn may exhibit the polarized gluon distribution of the nucleon. Many simulation works were then performed to identify the observables most sensitive to the spin-polarized gluons. Thus, the measurement of the double-helicity asymmetry of π^0 at $\sqrt{s} = 200$ GeV was chosen to be the first experiment to be performed.

RHIC was commissioned in the year 2000, while the leadership of this program has been taken over since 2001 by H. En'yo, the newly assigned Chief Scientist of the Radiation Laboratory. The experiment on the double-helicity asymmetry of π^0 was realized in 2003[4] and several succeeding years.[5] In later years the measurement of double-helicity asymmetry was extended to other cases, such as at different energies of $\sqrt{s} = 62.4$[6] and 510 GeV[7] and with different probes like the mid-rapidity jet.[8] These data were combined to be subjected to global QCD analysis, revealing the behavior of the polarized gluon distribution over the range of Bjorken x, $0.05 < x < 0.2$. The gluon spin polarization integrated over the observed x region is reduced to 0.15 ± 0.06[9] or $0.10 + 0.06/-0.07$ in the unit of Planck constant,[10] depending on the method of global analysis. These values are roughly comparable with the known quark contribution of 20–30% of the total spin of 1/2. Consequently the combined contributions of gluons and quarks so far observed is still insufficient to account for the total spin.

Thus, missing polarized spin should be sought for over the gluons in the domain of very small x and/or in another degree of freedom, i.e., the orbital angular momenta carried by partons. In fact, several experiments performed at RHIC revealed a non-vanishing analyzing power,[11] indicating the significant roles of parton orbital angular momenta. The study of transverse components of parton spins is called for. As a matter of fact, the EIC project for the next-generation parton physics aims at the investigation of generalized (3-dimensional) parton distributions as well as of the gluon behaviors in the small x region. A. Deshpande at the Experimental Group of RBRC has been a central force to work out this proposal.

Meanwhile, the Theory Group of RBRC has developed in its own way. Since T. D. Lee took the Directorship of RBRC, he extended the center objective to serve as a world center for nursing brilliant young scientists in theoretical physics related to QCD. To enhance this activity, a novel system of joint appointment between any of the US universities and RBRC was introduced. This initiative, strongly pursued by the Director himself, resulted in great success, producing many leading nuclear theorists worldwide, such as D. E. Kharzeev, who now directs the Theory Group of RBRC.

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