ИФВЭ
IHEP

STATE RESEARCH CENTER OF RUSSIA

INSTITUTE FOR HIGH ENERGY PHYSICS

IHEP 97-75

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DEBUT OF SPIN PHYSICS AT DUBNA

Invited talk presented at the 7-th International Seminar on High Energy Spin Physics, SPIN-97, July 7-12, 1997, JINR, Dubna

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Protvino 1997

UDK 681.3.06.069 M–24

Abstract

Nurushev S.B. Debut of Spin Physics at Dubna: IHEP Preprint 97-75. – Protvino, 1997. – p. 14.

Dubna was one (and only one in the former USSR) of the Scientific Centers that started to develop the High Energy Spin Physics in the early 1950s. Many experimental and theoretical inventions originated in Dubna were later distributed over the world but these facts were not widely publicized. I attempt in this brief review to outline the Debut of Spin Physics at Dubna and describe the main activities related to this event.

Аннотация

Нурушев С.Б. Начало спиновой физики в Дубне: Препринт ИФВЭ 97-75. – Протвино, 1997. – 14 с.

Дубна была одним (и единственным в бывшем СССР) из научных центров, начавших развивать спиновую физику высоких энергий в начале 1950-х годов. Многие экспериментальные и теоретические разработки, выполненные в Дубне, были позже распространены по всему миру, но эти факты широко не афишировались. В этом кратком обзоре я делаю попытку очертить начальные этапы спиновой физики в Дубне и описать основные работы, имеющие к ней отношение.

The goals of this talk

It is obvious at the moment that the Spin Phenomena survived an enormous increase of the energy in defiance of the strong theoretical statements that it should die with the growth of energy (examples are the Regge pole model, PQCD). This fact is not yet well understood and Spin Phenomena continue to be the very interesting subject for further study. Recently several recollections were presented in different Spin Physics Gatherings outlining the role of some well known laboratories in polarization study and no one of those speakers mentioned the earlier stage of this physics either and therefore Dubna seems to become an outsider. This is unfair and I, as one of eyewitnesses and a direct participant of the experimental spin studies at Dubna, attempt to emphasize the important role played by Dubna in Spin Physics Developments.

The Spin Physics at Dubna was really the International Affair in which a lot of physicists from the JINR member countries have participated. After leaving Dubna several of those physicists continued their activities on polarization physics at different High Energy Physics Laboratories. They brought to the new places their knowledge and experience gained at Dubna and strongly stimulated the development of High Energy Spin Physics.

Some of the spin physicists who stayed at Dubna quitted this field of research but another part of spin society continued its activity on polarization study till 1970s. They attempted to produce and accelerate the polarized proton beam at the synchrocyclotron, but such attempt was not successful. Another venture was more successful: Dubna physicists built first polarized target and used it in the experiment. In the mid-70s a strong Dubna team went to the 70 GeV IHEP accelerator and pushed ahead the Spin Program there together with their colleagues from IHEP, ITEP and Saclay. After finishing the polarization measurements in elastic hadron scattering (still unique experiment at high energy due to the complete inclusion of particle and antiparticle polarizations) successfully, the Dubna physicists built a new type of very efficient polarized target, so called "frozen spin" target. This target was very intensively used for study of the polarization phenomena in the exclusive charged exchange reactions induced by negative pions of 40 GeV/c and later in inclusive reactions. It continues to be at present a backbone of Polarization Program at Protvino. At the beginning of 80s the physicists from Laboratory of High Energy Physics successfully accelerated the polarized deuteron beam in the synchrophasotron giving new incentives to the progress of High Energy Spin Physics. Therefore this branch of research becomes a stable and attractive feature of modern High Energy Physics Program at Dubna.

The main theoretical achievements in Spin Physics reached at Dubna during 1955-1970 can be briefly listed as follows:

- formulation of the programme of the complete set of experiments;
- spin transformation to different Lorentz systems;
- predictions of the asymptotic behaviours of spin observables in hadron interactions;
- Chou Kuan-chao-Lapidus-Gerasimov-Drell-Hearn-sum rule;
- hypothesis of γ_5 invariance of strong interactions;
- invention of odderon type pole in hadronic interactions;
- numerical calculations of the polarization effects in the region of the Coulomb-Nuclear Interference(CNI);
- completion of the phase shift analysis just above the pion production threshold;
- test of isobar production mechanism suggested by Mandelstam;
- wide application of the one pion exchange model (OPEM) to the phase shift analysis and to the interpretation of the inclusive pion asymmetry;

The experimental study of the polarization effects lead to the following main results:

- practical realization of the complete set of experiments for pp-scattering; good progress was also made in the pn scattering;
- unique phase shift analysis for the pp scattering;
- first asymmetry measurement of inclusively produced pions;
- first measurement of polarization of inclusively produced protons;
- study of nuclear effects in the polarized proton scattering;
- polarization measurements in the region of Coulomb-nuclear interference (in pp- and pC-elastic scattering).

The spin physics technology was marked by several achievements as follows:

- production of the proton beams with different orientation of polarizations;
- inventions of different type polarimeters (diffractive scattering on nuclei, elastic proton double scattering, reduction of energy to the one, where the analyzing power is known);
- invention of the large aperture detector (spark chambers, hodoscopical systems) to study double and triple scattering parameters;
- first use of the internal target for the proton polarization measurement by the double scattering technique.

This Seminar gives us one more chance to meet together and discuss all our problems, in particular, where we are and in which direction we must and can push the Spin Physics.

In order to avoid a question: what does the High Energy Spin Physics mean? Let me refer to two papers written by the famous physicists:

"With a successful start-up of synchrocyclotron in our country in 1949, a new branch of scientific research came into existence — Physics of High Energy and Particles" (an extract from the booklet devoted to the 70's Anniversary of Prof. M.G.Meshcheryakov's birth and written by Bogolubov N.N., Frank I.M. and Azhgirey L.S., 1982, Dubna, USSR).

"I was very much pleased by the fact, that this Symposium is held here, at Dubna, since in the Soviet Union a wide-footing experimental study of Polarization Phenomena has began in 1956-1958 in our Laboratory, Laboratory of Nuclear Problems" (excerpt from Foreword written by Prof. Dzhelepov for Proc. of the International Symposium on Polarization Phenomena in High Energy Spin Physics, November 17-20, 1981, Dubna, USSR).

After such Introduction I am going into the details of above listed items.

The Major Experimental Results

1953. Prof. M.G.Meshcheryakov, at that time Director of the Institute of Nuclear Problems, set-up a team consisting of two physicists, namely, Stoletov G.D. and Zaplatin N.L. with the task to extract a proton beam diffractively scattered on the internal target of 660 MeV Synchrocyclotron, the biggest in the world accelerator at that time. Soon I arrived from MEPHI as an ungraduated student and joined this group. Prof. M.G.Meshcheryakov was my scientific supervisor and guided my scientific activity.

1954. Production of 565 MeV polarized proton beam.

We got a first polarized proton beam and wrote our first Internal Scientific Report: G.D.Stoletov and S.B.Nurushev S.B. RINP, 1954. I am very proud of this work, since it was my first successful step in science and this science was the Spin Physics. The following parameters of the polarized proton beam were measured: polarization, $P_B = 33 \pm 2\%$, intensity $I_B = 10^4/cm^2 \cdot sec$. The research program realized on this beam included: a) the angular dependence of proton polarization, b) the polarization dependence on atomic number, c) polarization in elastic and quasi-elastic pp-scattering, d) polarization in inelastic scattering. The main conclusions were:

- the polarization angular dependence at 660 MeV (kinetic energy) has a peak around scattering angle $\theta = 7^o$. Having a large scattering angle at the first attempt (15^o), we did not reach an optimum position of the internal target in getting the polarized proton beam;
- the elastic polarization at the scattering on nuclei is higher than the inelastic one;
- the pp-elastic scattering polarization is higher than the one for quasi pp-scattering;
- polarization weakly depends on the atomic number.

It is worthwhile outlining several technological approaches applied at this stage:

- use of the current carrying wire (proposed by M.Kozodaev and A.Tyapkin) for tracing the beams;
- polarimeters: 1) double scattering method, 2) use of process with known analyzing power; 3) photo-emulsion (Grigoriev E.L., Detection of polarization of beams of fast particles by means of photo-emulsions, *Sov.J. JETP* **28** 761 (1955));
- separation of polarizations for different mechanism of reactions applying the methods of magnetic analysis, energy range measurements and the elastic scattering kinematics.

1955. Production of 635 MeV polarized proton beam.

The quality of the beam was much higher than that of the previous one (as expected), though it was not an optimum, since we couldn't reach 7^o and only 9^o scattering angle due to the hardware limitations. The following parameters of the polarized proton beam of 635 ± 15 MeV were measured: polarization $P_B = 58 \pm 3\%$ and intensity $I_B = 10^5$ pp/cm^2·sec (G.D.Stoletov and S.B.Nurushev Internal Report RINP, 1955). This beam was widely used in fulfilling the complete set of experiments. The physics program realized by using this beam is described below.

1956. The polarization of 660 MeV protons in nuclear scattering. (M.G.Meshcheryakov, S.B.Nurushev, and G.D.Stoletov. *JETP* , **31** 361(1956))).

This paper gave a first public description of the productions details of the two polarized proton beams with kinetic energies of 565 and 635 MeV. The thorough study of mechanisms of creation of the polarization in nuclear scattering revealed the interesting features: the biggest polarization comes from the diffractive scattering on the nuclei, while in the elastic proton-proton scattering it is smaller. The polarization of the inelastically scattered protons decreases with the loss of energy. Comparing our data with the data at 300 MeV, one can conclude that the nuclear polarization weakly depends on the energy, while in the elastic pp-scattering it continues growing.

1957. Polarization in pp-scattering at 635 MeV (M.G.Meshcheryakov, S.B.Nurushev and G.D.Stoletov, *JETP* **33** 37 (1957)).

After the measurement of the differential cross-section this experiment was second in the list of the complete set of experiments and it was made for the first time at 635 MeV. It started a long way toward a Phase Shift Analysis (PSA) and a direct reconstruction of the pp-elastic scattering amplitudes. The angular dependence of the polarization parameter already indicated the necessity of inclusion of ^3F-waves into analysis.

1958. The triple scattering of protons at 660 MeV. 1: The measurement of triple scattering parameter D(90^0) (Yu.P.Kumekin, M.G.Meshcheryakov, S.B.Nurushev, and G.D.Stoletov, *JETP* **35** 1398 (1958)). Following the suggestion made by L.Wolfenstein for the first time we started a realization of the triple scattering program at 660 MeV. The magnitudes of the spin-transfer parameter showed that most of beam polarization is transferred to the final protons at 90^o in *c.m.s*. The direct reconstruction of the amplitudes was made showing that the leading force at this energy is a spin-orbital interaction.

1959.

- Method of production of longitudinally polarized proton beam (Yu.P. Kumekin, K.S. Marish, S.B. Nurushev, and G.D. Stoletov. JINR Preprint P-278, Dubna, 1959).
  It became obvious that the realization of the triple scattering program requires a longitudinally polarized proton beam. The standard technique of applying a solenoid in order to rotate the normal component of polarization to the transverse one (and then a further rotating of polarization by dipole magnet) was not realistic for us. I suggested instead of making a first scattering in the horizontal plane to do it in a vertical plane: the polarization appears naturally in a horizontal plane. In order to bend a beam up or down I proposed the very simple magnetic shims installed in the special geometry to create a horizontal field. It worked successfully.
- On possible sets of experiments for a simultaneous analysis of data on nucleon-nucleon scattering and polarization in p-n-collisions at 635 MeV (B.M.Golovin, V.P.Djelepov, V.S.Nadezhdin, V.I.Satarov. *JETP* **36** 433 (1959)).
  In this paper it is suggested that analysis of data on n-p- and p-p-scattering be carried out simultaneously, as this should reduce the number of experiments required to reconstruct the scattering amplitude. Sets of experiments are presented which should yield sufficient information if the aforementioned analysis is performed. The angular dependence of the polarization in p-n-collisions at 635 MeV has been measured. A difference has been detected in the energy and angular dependence of the polarization for the states of a nucleon-nucleon system possessing different isotopic spins (T = 0 and T = 1).

1960. The triple scattering of protons at 660 MeV. 2: The angular dependence of depolarization (Yu.P.Kumekin, M.G.Meshcheryakov, S.B.Nurushev, and G.D.Stoletov. *JETP* **38** 1451 (1960)).

In the whole measured range the spin-transfer tensor D (later called D_{NN}) was significant revealing the important contribution of the spin-transfer mechanism to the elastic scattering process. 32 years later the measurement of the same parameter at the inclusive Λ-production by the polarized proton beam quantitatively proved that the spin transfer mechanism exists also at such high energy as 200 GeV (see, for example, S.B.Nurushev, *Int.J. of Mod. Phys. A* **12** 3433 (1997)).

1962. The triple scattering of protons at 660 MeV. 3: The angular dependence of parameter R (Yu.P.Kumekin, M.G.Meshcheryakov, S.B.Nurushev and G.D.Stoletov, *JETP* **43** 1665 (1962)).

This tensor measures a rotation of the polarization vector after scattering. It shows a portion of the initial beam polarization rotated around the beam axis. Its value varied between 0.28 and 0.49 at the angular interval (cms) $54^o - 126^o$. As it was later indicated by Chou and Yang, this parameter should survive at asymptotic energies, indicating the rotating hadronic matter inside the nucleons.

1963.

- Polarization in p-p-scattering at the proton energy of 8.5 GeV (V.P.Kanavetz, L.I.Levintov, and B.V.Morozov. *Phys. Lett.* **7** 165 (1963)).
  This experiment was featured by two things: 1) a first use of the internal target for polarization measurement by double scattering technique, and 2) the highest in energy. This novel technique was later applied to the higher energy accelerators, but no one made a reference to this pioneering work. Though the polarization was zero in the frame of error bar, for the first time it was shown that the internal target might be used for the double scattering experiment with the goal to measure the polarization of the scattered particles. Indeed, it was done at Fermilab much later and, there is a suggestion to use the same technique at RHIC.
- The longitudinally polarized proton beam of 6-m synchrocyclotron (Yu.P.Kumekin, M.G.Meshcheryakov, S.B.Nurushev and G.D.Stoletov, *Atomic Energy* **14** 38 (1963)).
  The idea suggested in 1959 was finally realized and the proton beam not only longitudinally polarized, but also with a possibility to get other components of polarization, was built. And also as a byproduct the polarized neutron beam was produced. This universal polarized beam was finally an optimum beam, as mentioned above. Its parameters: $P_B = 60 \pm 5\%, I_B = 10^6$ pol.prot./cm^2·sec permitted to measure many observables by different groups. Much later such a technique was realized too at Gatchina accelerator, but the authors of publication did not mention the pioneering work done at Dubna either.
- Triple proton scattering at 660 MeV, 4 : Angular dependence of A parameter (Yu.P. Kumekin, M.G. Meshcheryakov, S.B. Nurushev, and G.D. Stoletov, *JETP* **46** 50 (1963)).
  As theorists predicted, the measurement of the A parameter was essential for the improvement of PSA. After inclusion the experimental data on A parameter into PSA, the number of solutions decreased to two.
- Small angle elastic scattering of 660 MeV protons on carbon nuclei (L.S.Azhgirei, Yu.P.Kumekin, M.G.Meshcheryakov, S.B.Nurushev, G.D.Stoletov and Huang Tieh-ch'iang. *JETP* **17** 123 (1963)).
  The differential cross section and polarization for elastic scattering of 660 MeV protons by carbon nuclei were measured in the range $1.8^o \leq \theta_L \leq 9^o$. This angular range corresponds to the region of invariant momentum transfer $5 \cdot 10^{-4} \leq \mid t \mid \leq 10^{-2}$ (GeV/c)^2, which just presents the Coulomb-Nuclear Interference(CNI) region. Such measurements allowed one to make the following conclusions:
  – the slope parameters of spin flip and nonflip amplitudes are different;
  – the slope parameters are different for real and imaginary parts of both amplitudes;
  – the spin-orbital potential for nucleon-nucleous interaction is complex.
- Application of small size photomultiplier FEU-35 to the experiments with relativistic particles (A.S.Kuznetsov, S.B.Nurushev and Khan-Ve-Tsyuan'. JINR Preprint P-1315, Dubna, 1963).

Very soon it became obvious for the spin physicists (I mean experimentalists) that double, moreover the triple scattering measurements require a huge increase in the detector acceptance. Therefore, the several directions in detector developments were pursued. Here we decided to build the hodoscopical system with a good space resolution by developing a small-size photomultiplier. We found that FEU-35 was suitable for our goal. We used this technique in inclusive pion asymmetry measurement. Later, being already at IHEP, Serpukhov, we continued this line and made a good progress.

1964. Set-up for polarization study at high energy proton scattering (S.Kh.Biktimirov, Yu.P.Kumekin, S.B.Nurushev, G.D. Stoletov. *PTE* **1** 25 (1964)).

The universal apparatus was designed and built, which permitted to measure the triple scattering parameters like D, A and R. The same apparatus is able to measure the spin correlation parameters like C_{NN}, C_{SS}, C_{NS}.

1965. Double pp-scattering at 667 MeV (A.S.Azhgirey, Yu.P.Kumekin, M.G.Meshcheryakov, S.B.Nurushev and G.D.Stoletov. *Phys.Lett.* **18** 203 (1965)).

The net double elastic pp-scattering scheme was realized at 667 MeV. The first elastic scattering protons were selected by the magnetic spectrometer, while the selection of the elastic scattering on the second target was realized by detecting the protons with the conjugated telescopes. First of all, such technique permitted to calibrate the polarization of the protons from the elastic pp-scattering. Second for the first time the polarization was measured in the region of the CNI scattering (the range of -t was: $1.8 \cdot 10^{-3} \leq -t \leq 0.17$ (GeV/c)^2). At -t= 2.2·10^{-3}(GeV/c)^2 the polarization equals $5 \pm 2.4\%$ just as in the E704 experiment at 200 GeV. These data together with the previous CNI data from Carbon target are waiting for a detailed analysis aimed a possible extraction of the spin flip hadron amplitude.

1966.

- Measurement of the parameter R in the elastic pn-scattering at 605 MeV and the nucleon-nucleon phase shift analysis (Yu.M.Kazarinov, F.Lehar, A.F.Pisarev, Yu.N.Simonov, Z.Janout. *J. of Nucl. Phys.* **4** 567 (1966)).
  The triple scattering parameter R_{pn} and polarization P_{pn} in pn-scattering at 90^o and $125^o(c.m.s.)$ have been measured at 605 MeV. The measurements were performed using spark chambers. The analyzing power and “instrumental parameters” have been determined experimentally. The values were found to be: $R_{pp}(90^o) = 0.50 \pm 0.11, P_{pp}(90^o) = -0.07 \pm 0.06, R_{pn}(125^o) = -0.06 \pm 0.28, P_{pn}(125^o) = -0.44 \pm 0.16$. It is shown that one out of 3 previous PSA sets can be excluded on the basis of the new data.
- Hodoscopical set-up for the study of polarization effects in nucleon-nucleon collisions (A.S.Kuznetsov, S.B.Nurushev and Khan-Ve-Tsyuan’. JINR Preprint P-2486, Dubna, 1966).

The first implementation of the scintillating on-line hodoscopes to study spin started at Dubna. Such hodoscopes were used for the first measurement of the analyzing power of the inclusively produced pions.

<u>1967</u>

- Spin correlation in the elastic scattering of polarized 605 MeV protons on protons (B.M.Golovin, R.Ya.Zulkarneev, V.S.Kiselev, S.V.Medved, V.G.Nikanorov, A.F.Pisarev, G.L.Semashko. *J. of Nucl. Phys.* **5** 146 (1967)).
  The spin correlation coefficients in the elastic pp-scattering were measured at $90^o c.m.s.$, using a polarized 605 MeV proton beam. Spark chambers controlled by scintillation counters were used in the measurements. The following values of the coefficients were determined: $C_{nn} = 0.56 \pm 0.18, C_{KP} = 0.27 \pm 0.18, C_{qKn} = 0.92 \pm 0.38$.
- Asymmetry in the emission of π^+-mesons in 612 MeV pp-collisions with a polarized proton beam (A.A.Borisov, A.S.Kuznetsov, V.E.Lukashov, S.B.Nurushev V.L.Solovyanov. Yad.Fiz. **5** 348 (1967)). Experiments are described determining the azimuthal asymmetry in the inclusive production of π^+ mesons in proton-proton collisions using a 612 MeV polarized proton beam. The measurements were performed in the region of l.s. angles $85^o - 125^0$ using a scintillating hodoscopical device. For fixed angles the asymmetry was determined for three values of the π^+-meson emission energy. The experimental results are compared with the predictions of the OPE and isobar models.

<u>1970</u>. Double N-N scattering on polarized proton target (J.Bystricky, J.$\breve{C}$ech, Z.Janout, Yu.M.Kazarinov and F.Lehar. *Czech.J. of Phys.* **20** 381 (1970)).

The triple scattering depolarization transfer parameter D_t in elastic p-p-scattering was measured at an energy of 660 MeV using a polarized target. All measurements have been carried out with the help of an optical spark chamber. The following results have been obtained: $D_t(90^o) = D(90^o) = 0.54 \pm 0.10, D_t(130^o) = D(580) = 0.72 \pm 0.11$.

<u>1971.</u> Polarization of secondary protons in reactions $pp \to \pi^+ pn$ and $pp \to \pi^0 pp$ at 669 MeV (L.S.Azhgirey, I.K.Vzorov, V.N.Zhmyrov, A.S.Kuznetsov, M.G.Mescheryakov, G.D.Stoletov, A.F.Filozov, V.I.Chizhikov. *J. of Nucl. Phys.* **13** 581 (1971)).

Polarization of secondary protons emitted with the energy of $\simeq$370 MeV in reactions $pp \to \pi^+ pn, pp \to \pi^o pp$ is measured at angles $8.3^o, 14.5^o$ and 18.0^o at the incident proton energy of 663 MeV. Along the direction of a normal to the plane containing the vectors of momenta of incident and registered protons, the polarization values are found to be: P(8.3^o) = 0.20±0.05, P(14.5^o)= 0.21±0.05, and $P(18.0^o) = 0.15 \pm 0.05$. The results obtained can be described by the one-pion exchange model which takes into account the one-pion formfactor of nucleons and the singularity of the amplitude behaviour of S_{11} state of πN system off the mass shell.

This was the first measurement of the inclusive proton polarization.

Theoretical Spin Physics

Part A: General Approach

1957.

- Reconstruction of the scattering matrix of a two-nucleon system (L.Puzikov, R.Ryndin, Ya.Smorodinsky. *Nucl. Phys.* **3** 436 (1957)). The problem of the number of experiments which are necessary for the determination of the elements of the elastic scattering matrix is discussed. It is shown that in virtue of the unitary condition the required number of experiments equals the number of complex functions entering the scattering matrix. In the case of nucleon-nucleon scattering the elastic scattering matrix can be determined on the basis of 5 experiments: measurement of the cross section, polarization, normal components of the polarization correlation tensor and the normal components of the triple scattering tensors (for both particles). It is shown that experiments with rotation of polarization by the external magnetic field are not necessary for phase-shift analysis.
- About the unitary relations for elastic scattering of particles with arbitrary spin (R. Ryndin, Ya. Smorodinsky. *JETP* **32** 1584 (1957)). It is shown that the optical theorem can be extended in order to include a spin of particles. In general the number of unitary relations equals the number of nonzero amplitudes at zero degree. It is proven that this number is 3 for pp-elastic scattering.

1958.

- Phenomenological analysis of reactions of the $a + a' \to b + b'$ type.
  S.M.Bilenky, L.I.Lapidus, L.D.Puzikov and R.M.Ryndin. *Nucl. Phys.* **7** 646 (1958)).
  Conditions for the construction of the matrix from the experimental data for reactions of the $a + a' \to b + b'$ type are considered on the basis of general principles of quantum mechanics. The reaction matrix M is expanded in a complete set of the irreducible tensor operators $T^{JM}(j_b, j_a)$, and the number of complex scalar functions which define it, is computed for the case when invariance under space rotations and reflections is taken into account. Time reversal invariance of the interaction leads to relations between polarization effects in the direct and inverse reactions. The number of experiments required for complete construction of the reaction matrix in the presence of several channels can be determined on the basis of unitarity of the S matrix.
- Relativistic theory of reactions involving polarized particles (Chou Kuang-chao, M.I. Shirokov. *JETP* **34** 1230 (1958)).
  It is shown that the relativistic formulas for the angular distributions, polarization vectors and tensors of reactions of the $a + b \to c + d$ type in the rest system are essentially the same as the nonrelativistic formulas if the particle spin is defined as the internal angular momentum of the particle with respect to its center of mass. The square of this intrinsic angular momentum is the Lorentz invariant. The particle spins are arbitrary, their rest masses are not equal to zero.

1961-1965 Chou Kuang-chao-Lapidus-Gerasimov-Drell-Hearn Sum Rule.

(L.I.Lapidus, Chou Kuang-chao, *JETP* **41** 1547 (1961). S.B.Gerasimov, *J. of Nucl. Phys.* **2** 598 (1965)). Abstract from latter paper: "The damping of the nucleon magnetic momentum in a nucleous is estimated on the basis of a sum rule for magnetic momenta, which follows from the subtractionless dispersion relations and the low-energy theorem for the Compton-effect amplitude. It is shown that the Pauli principle, in the approximation of the Fermi gas model, decreases the anomalous magnetic moment of a bound nucleon by 7-8% in comparison with a free nucleon". The sum rule was written in the following way:

$$2\pi^2 e^2 g^2/M^2 = \int_{\omega_{thr}}^{\infty} \frac{\sigma_R(\omega) - \sigma_L(\omega)}{\omega} d\omega. \quad (1)$$

Here e is a charge, g is the anomalous magnetic moment, M is the nucleon mass; σ_R and σ_L mean the cross-section for the right and left-handed virtual photons. At present this sum rule becomes a crucial tool for solving the "spin crisis" problem.

1963.

- On the total cross sections for reactions with polarized beams and polarized targets (S.M. Bilenky and R.M. Ryndin. *Phys.Lett.* **6** 217 (1963)).
  The measurement of the total cross section for all the processes for various orientations of the beam and target polarizations allows one to determine the imaginary parts of all three amplitudes for the forward elastic pp-scattering.
- On asymptotical relations between polarizations in the crossing reactions (S.M.Bilenky, Nguen Van Hieu and R.M.Ryndin. JINR Preprint P-1404, 1963, Dubna).
  Assuming that the asymptotical regime is reached, several predictions were made for the relations between polarizations. Some of them are as follows:
  – polarizations of protons in the reactions $\pi^{\pm}+p \to \pi^{\pm}+p$ must be mirror symmetric. This statement was proved to be correct by experiments;
  – the same statement for the p+p→ p+p and $\bar{p}+p \to \bar{p}+p$ is not correct as shown by experiments at Serpukhov;
  – the polarization of the neutron in reaction $\pi^- + p \to \pi^0 + n$ should be zero. This is not true at 40 GeV, as it was measured at Serpukhov.
  Many other predictions of this paper are waiting for further experimental verification.

1966. Relativistic reconstruction of N-N scattering matrix (S.M.Bilenky, L.I.Lapidus, R.M.Ryndin. *JETP* **9** 891 (1966)).

It is shown how the nucleon-nucleon scattering matrix can be reconstructed from the experimental data at fixed values of the angle and energy in the relativistic case. Different reconstruction procedures are considered. Relativistic formulae have been obtained for reconstructing nucleon-nucleon scattering matrix in the state with net total isospin from the np and pp-scattering data.

1967. Ideas on New Experiments on Polarized Target (L.I.Lapidus *Rev.of Mod. Phys.* **39** 689 (1967)).

A possible application of polarized proton targets and polarized proton and antiproton beams to a direct testing of T, P, C invariance and the CPT theorem is considered. Procedure for a direct determination of the T-violated amplitude T from experimental data is given. Deviations from symmetry properties for polarization tensors in elastic scattering due to the bremsstrahlung effect are considered. The P invariance can be tested both in the up-down asymmetry measurement and in the total cross-section measurements using the polarized beam and polarized target. The measurement of the total polarization cross section σ_{p1p2} is of interest for testing higher isotopic symmetries.

Part B: Phenomenological Approach

1. Direct reconstruction of amplitudes.

1958.

- Possible experiments for investigation of inelastic scattering of nucleons (L.M.Soroka. *JETP* **34** 87 (1958)).
  Some nontrivial experiments on the angular correlations of π-mesons and nucleons based on the existence of azimuthal asymmetry in the emission of these particles in reaction N+N $\rightarrow$ π +N+N at 650 MeV are suggested. Analoguos effects in a polarized nucleon beam are also considered.
- About the pp-scattering in state $^1D_2$ at 616 Mev (L.M. Soroka. *JETP* **35** 276 (1958)).

  Using the unitarity condition and some simplifying assumptions the contribution of singlet D-state to the pp-absorption coefficient was estimated. This result is useful in making PSA.

1959. Reconstruction of the pp matrix at 90^o (S.B.Nurushev, *JETP* **37** 301 (1959)).
At 90^o and an energy range $140-635$ MeV, the amplitudes of the elastic pp-scattering matrix were reconstructed. It was shown that in this range the triplet interaction becomes important. In an energy interval of 315 - 635 the spin-orbital amplitude prevails over others.

2. Phase shift analysis.

1963.

- Phase shift analysis at 657 MeV (R.Ya.Zul'karneev and I.N.Silin, *Phys.Lett.* **3**265(1963)).

  Phase shift analysis was made with inclusion of states up to l=3, Coulomb phases. No meson production at ^3F states. Several sets of solutions were obtained.
- Phenomenological analysis of pp-interaction at 657 MeV, 1 (A.S.Azhgirey, N.P.Klepikov, Yu.P.Kumekin, M.G.Meshcheryakov, S.B.Nurushev and G.D.Stoletov. *JETP* **45** 1174 (1963)).

A PSA is made of experimental data on pp-elastic scattering at 660 MeV. It is assumed that the peripheral phases may also contribute to the pion production and that partial waves with $l \geq 5$ are calculable through the OPE model. One preferable solution was found.

- A further investigation of pp-phase shifts at 657 MeV (A.S. Azhgirey, N.P.Klepikov, Yu.P.Kumekin, M.G.Meshcheryakov, S.B.Nurushev, and G.D.Stoletov. *JETP* **46** 1074 (1963)).
  The results of a phase shift analysis of pp-elastic scattering at 657 MeV are refined by inclusion of the new data on the angular dependence of the triple scattering parameter A. Arguments are presented indicating that the phase shift set obtained is unique.

3. Models.

1962. On the approximate γ_5 invariance of strong interaction theory (A.A.Logunov, V.A.Meshcheryakov, A.N.Tavkhelidze. Proc. of the Int. Conf. on H.E.Ph., July 4-11, Geneva, 1962, p.151).

Assuming that at the asymptotic energies the strong interaction is γ_5 invariant it is shown that, for example, polarizations of nucleons vanish in elastic πN- and NN-scatterings. These statements were checked in experiments up to 300 GeV and do not seem fulfilled yet. The oncoming polarization experiments at colliders may furnish a precise test of this hypothesis.

1965. Production of the π-mesons on polarized protons in reaction $NN \to NN\pi$ in one pion exchange model (S.B.Nurushev, V.L.Solovyanov, JINR P-2382, Dubna, 1965.). The main conclusions are:

1. It is shown by numerical calculations that the OPE model gives a good description of the experimental data on π^+ production in reaction $pp \to p+n+\pi^+$ at 660 MeV, if the normalization is made to the total cross section of this reaction.
2. It is established that in the OPE approximation the polarization effects in reaction $NN \to NN\pi$ are completely determined by the excited state of nucleons with T=J=1/2.
3. It is proposed to realize a set of polarization experiments in order to clarify the mechanism of pion productions at the energy of interest. In particular, the expected left-right asymmetry in pion production on the polarized proton beams was calculated.

1972. Spin effects at very high energies and $X^0(960)$ meson (A.Bujak, A.Filippov, V.Ogievetsky, A.Zaslavsky. JINR Preprint E2-6847, Dubna, 1972).

The assumption was made that the meson $X^0(960)$ has the same quantum numbers as a pomeron but negative parity. Then the following relations were obtained for the spin dependent total cross-sections:

$$\sigma_S = [1 - 2 \cdot \frac{r_X(0)}{r_P(0)}] \cdot \sigma_0, \sigma_{t,0} = [1 + 2 \cdot \frac{r_X(0)}{r_P(0)}] \cdot \sigma_0, \sigma_{t,+1} = \sigma_{t,-1} = \sigma_0.$$

If one puts the ratio of residues $r_X(0)/r_P(0) = 0.3$, as it was done in this paper, then we get the asymptotic estimates: for singlet $\sigma_S = 0.4\sigma_0$, for triplets $\sigma_{t,o} = 1.6\sigma_0, \sigma_{t,+1} = \sigma_{t,-1} = \sigma_0$. The recent result from E704 does not seem to support such big spin contributions at 200 GeV. One needs more experimental data on this subject in asymptotic region.

Impact of Dubna's Spin Activity on the International Spin Physics Development

There are several aspects of such advent:

- experimental data obtained at Dubna were widely used by spin community (Hoshizaki is an example);
- the experimentalists gaining nice experience on Spin Physics at Dubna have made the crucial contributions to its developments in other scientific centers like IHEP, ITEP, SPINP, etc.;
- the ideas developed by theorists at Dubna were and continue to be widely used by scientists over the world (a complete set of experiments, direct reconstruction of amplitudes, phase shifts results, sum rule, CNI results, etc.)
- Dubna physicists, staying at JINR, made substantial contributions to the Spin Physics Developments in IHEP(examples of HERA, PROZA), Gatchina, Prague, Tbilisi, etc.
- International Collaborations. At the moment Dubna is a member of several big Collaborations on Spin Physics at CERN, Hamburg, BNL, UNK, etc.
- last in the list but not least: a new Generation, let me say a 2-d Generation of spin physicists has grown in Dubna. The open-minded, talented people are pushing ahead many interesting ideas and bring the important new results on Spin Physics.

Obviously these facts stem mostly from the advent of Spin Physics at Dubna in the early 1950's.

Future of Spin Physics at Dubna

According to the publications the Spin activity at Laboratory of Nuclear Problems, which played a leading role at that time had dropped down and almost stopped around 1970s. It was a regrettable event, since Laboratory would have a chance to develop a polarized target, accelerate a polarized proton beam, invent many other ideas and keep Spin Physics in Laboratory at high level. But life is tough and this science interrupted there. But very soon, in 1975, the good news appeared: a team headed by Yu.K.Pilipenko announced the development of an efficient source of polarized hydrogen and deuterium at Laboratory of High Energy Physics. A little bit later at the Dubna 1981 Spin Symposium, Academician A.M. Baldin announced on the successful acceleration of the polarized deuterons in the 10 GeV synchrophasotron. Therefore, the center of Experimental Spin Research moved to the Laboratory of High Energy Physics and it continues to be a topical item in the whole Physics Program at JINR.

Summary

Dubna made the tremendous efforts in the developments of High Energy Spin Physics in the period of 1953-1970. The high quality polarized proton beam of variable polarization orientation, the different polarimeters, the large aperture detectors with high space and energy resolutions, the detectors for spin correlation measurements were developed. A lot of experimental data were accumulated and the first phase shift analyses above the pion production threshold were made. The dependences of polarization effects on free and bound nucleons, nuclei, on isotopic and usual spin were measured. The first ever data on the analyzing power and polarization of inclusively produced pions and protons were obtained. The tests of Mandelstam isobar model, the OPE model using the experimental spin information were made. The general approaches, like the complete set of experiments, the sum rule, the relativistic rotation of spin, etc. were applied to the study of spin effects. Later, a significant progress was made in construction of the polarized target with the "frozen" spin, polarized sources and acceleration of polarized deuterons. At present the Experimental and Theoretical Laboratories are making the essential contributions to the International Spin Study. The influence of Dubna on the International Spin Community is indisputable.

Acknowledgments

Let me express my appreciation to the Organizing Committee of VII High Energy Spin Physics Seminar, Spin-97, especially to A.M.Baldin, V.V. Burov and A.V.Efremov, for personal invitation, invaluable support and tremendous efforts in gathering so much enthusiastic Audience for discussions of the Spin Physics.

Received November 14, 1997

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Начало спиновой физики в Дубне.

Оригинал-макет подготовлен с помощью системы LaTeX.
Редактор Е.Н.Горина.

Подписано к печати 18.11.97. Формат 60 × 84/8.
Офсетная печать. Печ.л. 1.75. Уч.-изд.л. 1.34. Тираж 150. Заказ 13.
Индекс 3649. ЛР №020498 17.04.97.

ГНЦ РФ Институт физики высоких энергий
142284, Протвино Московской обл.

Индекс 3649

П Р Е П Р И Н Т 97-75, И Ф В Э, 1997