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SUMMARY TALK

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To summarize something like 28 plenary talks and about 100 presentations, distributed over 9 parallel sessions, is not a challenge, it is a «mission impossible». Following my personal taste, I will mention only a small sample of all that material, and apologize from the start to all the speakers (the overwhelming majority) whose contributions I will not quote.

A striking feature of this Symposium is the impressive number of contributions to Session 8, «Future Facilities and Experiments». It is a clear sign of the vitality of the field of spin physics. The very first talk [1] of the Symposium was dedicated to NICA (Nuclotron based Ion Collider Facility), an ambitious project being pursued at the Veksler and Baldin Laboratory of High-Energy Physics here at JINR. The main goal of the project is to study the hot and dense strongly interacting baryonic matter in heavy-ion collisions, in an energy range $\sqrt{s_{NN}}$ from 4 to 11 GeV for ^{79}Au. Very much as at RHIC, spin physics is also an important goal of the project, which foresees colliding beams of polarized protons and deuterons, with a programme explained in detail on Thursday [2]. Spin physics is also the main motivation of a new facility (SPASCHARM, for SPin ASymmetries in CHARMonium production) which is being prepared at IHEP [3], and which is devoted to a systematic study of polarization phenomena in hadron–hadron interactions. At CERN, the COMPASS experiment [4] has been approved for an upgrade to execute in 2014 the first ever measurement of polarized Drell–Yan to check the predicted change of sign of the Sivers function when going from SIDIS to Drell–Yan processes, and continue then with measurements of DVCS and SIDIS on a 2.5 m long liquid hydrogen target.

On a different scale, JLab12 is progressing at full speed [5]. The activity which is foreseen at Newport News is impressive: 52 experiments have already been approved and are being prepared to run in four different experimental halls (a new Hall D will complement the three existing ones). The largest effort

(70% of the experiments) is dedicated to the longitudinal, transverse and 3D nucleon structure, and therefore is of great interest to this Symposium. In the same plenary talk, the highlights of the JLab version of a future polarized electron–ion collider were given: a medium energy initial configuration is being pursued (3–11 GeV electrons on 20–100 GeV protons). The corresponding project being pushed by RHIC at BNL [6] foresees a 10–30 GeV electron beam accelerated with a new Energy Recover Linac which will collide with the 250 GeV proton or 100 GeV/n ion beams from RHIC. A considerable amount of work is being devoted to these two projects, presently regarded as the only way for a precision determination of the gluon and sea quark longitudinal polarization and for the 3D scans of the proton in momentum and position space [7], and for which there is a widespread support from the international community. Much international interest goes also to the realization of FAIR at GSI, Darmstadt. The potential of the future PANDA and the PAX experiments to the measurement of the $\bar{p}p$ Drell–Yan reaction was the subject of a plenary talk on Thursday [8], while in a parallel session the most recent results obtained at COSY with the spin filtering technique were reported [9], a prerequisite to polarize an antiproton beam at FAIR. The surprising transverse spin effects observed since several decades in elastic pp scattering were reported in a historical talk [10], which also briefly mentioned a project to polarize at FNAL the protons which are accelerated to 120 GeV by the Main Injector, the intensity of the injector being sufficient to investigate the elastic pp scattering at several GeV^2 transverse momentum.

To conclude this panorama of new facilities, it is mandatory to point at JPARC, the Japanese approach to the intensity frontier, which has a vast and diversified experimental program. This morning we learned [11] with pleasure and a feeling of admiration towards our Japanese colleagues how the laboratory could recover from the tremendous damages caused by the tsunami of last year. While waiting for the approval of the physics program with a polarized proton beam, they have undertaken an extremely ingenious new $g-2$ measurement, which will be a serious competitor to the FNAL experiment.

A central issue of spin physics since 25 years is the spin structure of the proton, and, in particular, the role of the gluons. One of the most important contributions to this Symposium has been given by the STAR Collaboration [12], which presented the first evidence for a nonzero value of ΔG. The analysis of the STAR single jet A_{LL} data collected in Run 9 provides an integrated value for the gluon contribution to the proton spin in the measured x_g range (from 0.05 to 0.2) of 0.13 [13], which is small but definitely not zero. More results are expected from Run 12, and a recent analysis of two-jets events opens the path to constrain the shape of ΔG. New extractions of ΔG from SIDIS data with longitudinally polarized beam and targets, at LO and NLO have been presented by the COMPASS collaboration [14], as well as new A_1 results from the 2011 run with 200 GeV muons and a proton target, which nicely agree with the data collected in 2007. In the nice review talk [15], many contributions of the HERMES experiment were summarized, from the initial DIS and SIDIS measurements with a longitudinally polarized proton target, to the transverse spin measurements, to end up with a recoil detector and the measurements of exclusive reactions, following the increasing interest for a 3D description of the proton. At lower energy, an impressive amount of data is being produced at JLab, where experiments concentrate mainly on exclusive reactions and measurements of transverse momentum-dependent (TMD) PDFs in SIDIS [16].

On the theory side, the proton spin decomposition is attacked mainly along two different approaches, either through generalized parton distributions (GPD) or via lattice calculations. In [17], the relevant GPDs are constructed by means of double distributions, fitting their parameters to the experimental data. The GPDs allow one to study the transverse localization of partons (at least for valence quarks) and to evaluate Ji's sum rule. From the values of the various parton total angular momentum, the conclusion of [17] was that there is no spin crisis any longer. Similar conclusions were drawn by the groups that carry on simulations on the lattice [18]: it is nice to see that the resolving power of these calculations is steadily increasing, also thanks to some recent ideas on how to compute the contributions of disconnected quark lines. The availability of many data has stimulated the submission of many theoretical papers: new NLO QCD analyses of polarized PDFs and FFs, QCD factorization schemes, small x, charm contents, QCD at large distances, GPD parameterization, quark models and magnetic moments. New multiplicities data from HERMES [15] and COMPASS [19] have stimulated new extractions of FF, and it seems that the long standing discrepancy between the negative value of Δs, the polarized strange quark density obtained from all the analysis of inclusive DIS data, and the positive values obtained from combined analysis of inclusive and semi-inclusive DIS data can be solved using the new data [20]. Also, the major controversy on how to split the total angular momentum into separate quark and gluon contribution (Jaffe–Manohar vs. Ji prescriptions) was addressed by several speakers and was the subject of a nice pedagogical talk [21].

All these topics have been further spelled out in Parallel Sessions 1, 2, and 3. A huge number of contributions on experimental results has been presented mainly on SIDIS (21 papers from COMPASS, HERMES and JLab) and from RHIC (13 papers from PHENIX and STAR). The majority of these contributions regard transverse spin and transverse intrinsic momentum phenomena, whose relevance to understand the internal spin structure of the proton is steadily growing in time. Highlights of Session 2 («Spin in Hadronic Reactions») were:

— in forward π^0 production, there is no strong dependence of transverse single-spin asymmetry (SSA) on $\sqrt{s}$ from 19.4 to 200 GeV [22];

— A_n for η meson is consistent with the value for π^0 [22];

— in forward SSA A_n, no sign of $1/p_T$ falloff is seen yet (as expected from pQCD) [7];

— in forward neutron production, the transverse SSA is big and might depend either on $\sqrt{s}$ or on p_T [23].

In Session 3, a full account of all the 8 possible transverse-spin modulations in the SIDIS cross section has been given by COMPASS [24], by HERMES [25] and by the Hall-A experiment at JLab. The most interesting and most studied modulations are associated with the transversity and the Sivers PDF, which by now are pretty well established and on which new data have been shown by COMPASS [26]. New COMPASS data have been presented [27] also on two identified hadron pairs, which data have allowed an independent extraction of the transversity PDF, independent of the one which uses the Collins SSA. Quite interesting are the new COMPASS data on the Sivers asymmetries for positive kaons, which are larger than the corresponding values for positive pions (as already observed by HERMES), but whose values are somewhat smaller than those measured by HERMES, hinting again at the strength of the Q^2 evolution of the TMDs. All the other azimuthal modulations have small amplitudes, all compatible with zero. Still there are indications from the three experiments that the $\cos(\phi_h - \phi_S)$ amplitude, which is related to the so-called worm gear $g_{1T}^{\perp}$, the only LO TMD PDF which is both T-even and chiral-even, could be different from zero and positive. Interesting modulations in the cross section of unpolarized semi-inclusive processes have also been presented by HERMES [28] and COMPASS [29], but I think it is too early to claim for a nonzero Boer–Mulders function.

In Session 5, «Fundamental Symmetries and Spin Physics beyond the Standard Model», a hot topic was the search for pEDM (permanent Electric Dipole Moment). A nonzero pEDM violates both parity P and time-reversal invariance T, thus being a good candidate to solve the mystery of the matter–antimatter asymmetry in the Universe. Several projects are being pursued. In [30], two parallel projects were illustrated, one at BNL and one at Juelich, carrying on the necessary R&D in an international collaboration, and aiming at a sensitivity of 10^{-29} $e\cdot$cm for p, d, and ^{3}He. The search for physics beyond the Standard Model at JPARC mainly looks for lepton flavour violation (the experiment COMET aims at a sensitivity of 10^{-16} for the process $\mu \to e$), while the innovative new muon g-2 experiment will also measure at the same time the μ EDM with a precision of 10^{-21} $e\cdot$cm [11]. The achievements and the potentialities of the Q-weak experiment at JLab were illustrated in the interesting review talk [31]. Apart from measuring Q_W^p, the weak charge of the proton, the experiment is sensitive to new possible parity-violating electron–quark interactions at the TeV scale. The experiment has been completed, and it is a pity that the Collaboration did not take advantage of this Symposium to announce a preliminary result for Q_W^p.

Proposals for signatures for new physics have come also from the high energy frontier: from measurements of the forward–backward asymmetry in the number of Drell–Yan lepton pairs produced at the LHC [32], or from the spectrum of high mass dielectrons or dimuons [33], or from the specific modifications in the angular distribution of the process $e^+e^- \to W^+W^-$ (to be measured at a future ILC) induced by the mixing of the Z with a new heavy boson Z^* [34].

A number of ingenious ideas were illustrated in Session 6, «Acceleration, Storage, and Polarimetry of Polarized Beams». A typical example is the «in-flight flippers» [35], an elegant reply to the request: «We would like to have only spin flipped, but keep the original beam phase space unchanged like in the ideal case for the Siberian snake». Both the SPASCHARM Collaboration at IHEP and the g-2 Collaboration at JPARC are among the future users of the in-flight flippers. The long road map of the PAX Collaboration towards their Holy Grail, a measurement of A_{TT} in $\bar{p}p$ at FAIR, was the subject of the nice review talk [36], which summarized also the most recent results on the spin filtering technique obtained with protons at COSY, where the spin-dependent pp cross section was extracted from the measured beam polarization. The measured cross section was well in agreement with the corresponding quantity computed from the known phase shifts of elastic pp scattering. Twenty years after the original measurement done at the TSR of Heidelberg MPI with 23 MeV protons [37] by the FILTEX Collaboration, the filtering method has been proved to be valid for pp scattering at the second energy value (49 MeV). Needless to say, a spin filtering experiment with antiprotons is necessary in order to validate the method proposed at FAIR by the PAX Collaboration, and the corresponding proposal [38] has been submitted for an experiment at the CERN AD (Antiproton Decelerator).

In Session 7, a great variety of polarized targets were presented, from the new frozen spin target of the A2 Collaboration at the Mainz Microtron (MAMI) [39], whose holding coil had to be as thin as possible to allow low energetic particles to punch through, to the novel HD (Deuterium-Hydride) target operated by the CLAS Collaboration [40] at JLab for the E06-101 experiment in an intense beam of photons (up to 10^8 Hz). Two new high performance polarized sources have been developed at RHIC, a ^{3}He source [41] to collide polarized protons and polarized neutrons and a new high intensity H^- OPPIS source [42]. At JLab an electron gun with a record intensity of 180 μA and 89% polarization has been realized by B. Matthew Poelker and collaborators [43], an achievement which brought him in 2011 the prestigious E. O. Lawrence Award [5].

In the session dedicated to «Spin Physics in Nuclear Reactions and Nuclei» the main issue to me was the quest for the 3-nucleon forces (3NFs), a long standing problem of nuclear physics. A most favourite playground is dp elastic scattering. Thanks to the availability of polarized deuteron beams [44] at the RIKEN Beam Factory (RIBF), a complete set of deuteron analyzing powers for dp elastic scattering is now available at intermediate energies. The precisions of both data and calculations are impressive, and some discrepancies between data and the best 3-body calculations are there. In short, for what concerns cross sections, 3NFs are clearly needed in elastic scattering. Spin observables however are not always well described by adding 2π-exchange 3NFs, and the new data from RIBF at 250 and 300 MeV show serious discrepancies at backward angles. The challenge is still there! In a complementary approach 3NFs will also be studied at COSY, where a «complete experiment» is being planned [45] to study dp break-up at low energies (from 30 to 50 MeV), a region tractable within chiral perturbation theory. The polarized decelerated deuteron beam will be used in conjunction with the PAX set-up (an internal polarized gas target and Si trackers). Chiral perturbation theory is also used to calculate the strong part of the n–p mass difference from the pion production process $pn \to d\pi^0$, a reaction for which the amount of charge symmetry breaking is proposed as a test of QCD [46].

To conclude this overview, I like to quote some contributions to the session on «Medical and Technological Applications of Spin Physics». The possibility to boost fusion reactions of light nuclei by using polarized particles has been the subject of the nice review talk on Wednesday [47]. Work is ongoing in several laboratories, but the number of problems still to be solved is not small. On the medical application side, a promising way for early cancer detection has been presented [48]. It is based on isotopic analysis and the measurement of average values of electric field gradients in the quadrupolar nuclear spins in a blood sample. More specifically, it was shown that

— quadrupolar interactions play an important role in cell active transport;

— active transport in a cell can be disrupted in the case of isotopic substitution which changes the right Q/m (Q is a quadrupole moment, m the atomic mass) ratio for «Sodium–Potassium» pump.

From investigations done using the COMPASS polarized target, the method seems to be a very promising approach to detect an early cancer development.

Cancer diagnostic was also the content of a plenary talk [49] which was given on Friday morning. Apparently, the cancer risk due to the diagnostic ionizing radiation from the today medical imaging procedures is becoming a serious problem in Japan (not to mention Fukushima), so that spin physicists should regard the application of Spin Physics to this important task as a social obligation. A promising approach is the Nuclear Spin Imaging (NSI), a Magnetic Resonance Imaging with the nuclear spins artificially hyperpolarized, i.e., polarized higher than the TE (thermal equilibrium) values. Enhancement factors up to 10^6 can be obtained, opening up a new facet of imaging. This might allow measurements with exceptionally high precision within a time scale shorter than a second. Suitable nuclei are ^{3}He and ^{19}F: handling of ^{3}He is very difficult (and there is a world shortage), ^{19}F however is present in perfluorocarbon (PFC), a chemical compound made mainly of carbon and fluorine atoms, which is used for either artificial blood or liquid ventilation medium. If this activity will be successful, in the future, the angiography which uses radioisotopes or X-rays might be handed over to the hyperpolarized PFC with no use of radiation.

I would like to thank the organizers for asking me to give this summary talk, thus forcing me to look closely at the impressive amount of material which has been presented at this Symposium. I would also like to acknowledge the help I had from some conveners of the parallel session in collecting the most significant material, namely, from A. Belov, M. Garcon, S. Karpuk, K. Kurek, E. Leader, I. Savin, E. Strokovky, O. Teryaev, and A. Vasiliev.

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