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WORKSHOP SUMMARY

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Almost eighty talks have been given during the five days of the workshop. A huge concentration of information, which I have tried to squeeze into a few pages. Daring reductionism, with basically no benefit.

На нескольких страницах кратко изложено содержание восьмидесяти докладов, сделанных за пять дней конференции.

INTRODUCTION

An impressive amount of information has been exchanged among the 100 people who attended this workshop, which belongs to an established tradition of biennial meetings dedicated to High-Energy Spin Physics, regularly held in the odd-years since 1981. Five full days, from morning to evening, essentially without any break, and being constantly watched by the black and white pictures of Prof. Bogoliubov and his collaborators...

Given the number of international conferences which take place almost continuously and almost everywhere in the world one might have expected a more relaxed atmosphere. On the contrary, the engagement of all the participants to make the meeting a most fruitful one was remarkable: on average very good and even excellent talks were given, and I cannot remember of a single talk after which no questions were risen up. Undoubtedly this is due to the magic moment spin physics is presently witnessing: JLAB experiments and HERMES have reached their maturity and are producing many and many physics results, RHIC is performing better and better, and PHENIX and STAR have started to produce physics, and at CERN the COMPASS experiment is harvesting billions of semi-inclusive deep inelastic scattering events with the high energy polarized muon beam. On the theoretical side, major advances are also occurring: GPD's are now enjoying a solid framework, the invariance properties of PDF's and of FF's, and in particular of the T-odd ones, are systematically being scrutinized, the extraction of the spin PDF from the data is getting more and more precise.

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In this situation it is not easy to make a summary. I will try to do my best to convey an idea of the great variety of subjects which have been touched, but it is impossible to give credits to everybody in only 10 pages. And I ask the colleagues I do not mention explicitly to forgive me for that.

1. PARTON DISTRIBUTION FUNCTIONS AND FRAGMENTATION FUNCTIONS

Many excellent review talks have been given, as well as several interesting new results. A. Metz has addressed the issue of the universality of the fragmentation functions. He showed how universality could be demonstrated in a simple one-loop calculation for fragmentation in semi-inclusive deep inelastic scattering (DIS) and electron–positron annihilation, but arguments were given why it should hold in general. Universality in semi-inclusive deep inelastic scattering was again a central issue in the talk of O. Teryaev, who also addressed the problems of factorization and of k_T dependence. In discussing the notion of twist, he showed that the Collins fragmentation function is actually of twist-3.

A. Efremov has given a remarkably clear overview of all possible azimuthal asymmetries in hadron–lepton production in deep inelastic scattering off longitudinally and transversely polarized targets. Using the transversity distribution given by the chiral quark-soliton model of the Bochum group and the average Collins analyzing power obtained from the DELPHI data they can well reproduce (without any free parameter) the HERMES 2002 data. A good and rigorous work on the behaviour of the structure function g_1 at small-x, i.e., in a region where the DGLAP equations cannot be used, was presented by B. Ermolaev. Properly accounting for all double-logarithmic contributions and the QCD running coupling effects, he can predict the Regge behaviour of g_1 and numerical values for the intercepts of the singlet and nonsinglet components, liable to be checked experimentally. The small-x behaviour of Parton Distributions has been investigated by A. Illarionov as well, who showed very good fits to the F_2 data from the H1 collaboration.

Checking Lorentz invariance relations between parton distributions was the subject of the talk of M. Schlegel: the Bochum group has found that the derivation of the Lorentz-invariance relations fails if the path-ordered exponential, which ensures gauge invariance, is taken into account in the correlator. D. Stamenov illustrated a NLO analysis to extract the higher twist corrections to the spin-dependent proton and neutron g_1 structure functions from the world data on $g_1(x, Q^2)$. The corrections were found to be not small, their x-dependence depends on the target, and of course a correct extraction of the polarized parton distributions from the data requires taking them into account in the analysis.

A beautiful introduction to the physics of the Generalized Parton Distributions (GPD) was given by M. Burkardt. A topic which usually requires a lot of technicalities has been given a much appreciated pedagogical approach in what probably will be remembered as the best talk of the Workshop. In the second part of his talk, M. Burkardt has suggested a simple interpretation of the Sivers effect, in terms of the angular momentum of the flavour dipole. The specific case of deeply virtual Compton scattering (DVCS) was also addressed in two very good talks, one by L. Mankiewicz, who computed the NLO corrections to the WW contribution to twist-3, $L \to T$ amplitude in DVCS arising from quark operators, and one by J. Marroncle, who described a possible measurement of DVCS using the COMPASS spectrometer.

2. QUARK MODELS

In the framework of a covariant chiral quark model with nonlocal quark–quark interactions A. Dorokhov has reported on the behaviour of the vector and axial-vector Correlators. A very technical talk, with a specific prediction: in the $Q^2 \to 0$ limit, he obtains an interesting prediction ($2.9 \cdot 10^{-4}$ fm^3) for the pion polarizability.

K. I. Kubo illustrated an interesting «quark rearrangement model», a phenomenological model which is capable of reproducing well spin asymmetries in all inclusive and semi-inclusive reactions. He also illustrated examples of exclusive hadronic reactions where the model predictions were at variance with the experimental data, and discussed possible explanations.

B. Ioffe proposes the use of J/Ψ polarization in e^+e^- collisions and in heavy-ion collisions to disentangle various mechanisms of charmonium production and as a probe of quark–gluon plasma. Analogously, V. Saleev has studied the polarization of the J/Ψ produced in hadronic collisions as a test of various k_T factorization schemes.

X. Artru summarized his most recent work with J. M. Richard, devoted to the study, with the density matrix formalism, of the exclusive reaction $\bar{p}p \to \bar{\Lambda}\Lambda$, where one, two and three spin data exist. The emphasis is on positivity constraints, but the main objective is the strangeness content of the nucleon and the relation between low-energy and high-energy phenomena. The strangeness content of the nucleon was also addressed in the work of S. Gerasimov, which focuses on the role of nonvalence degrees of freedom in the baryon magnetic moments. An important result of this analysis is to rule out a possible negative value for Δs.

S. Troshin illustrated a constituent quark model which nicely reproduces the well known hyperon polarization data. Interest arouse when Y. Alexandrov presented new data on the polarization of Λ inclusively produced in Σ-proton scattering at 340 GeV/c momentum: at variance with the other data, the observed

polarization does not plateau at high p_T, but decreases to zero or even negative values for $p_T \sim 1$ GeV/c. A nice review of Λ physics in DIS and of the rich potential of the COMPASS experiment in this field was given by M. Sapozhnikov.

Quite different was the content of the talk by A. Pankov, who studied the possibility to uniquely identify the effect of graviton exchange from other new physics in high energy at e^+e^- linear collider with polarized beams. The proposed tool for this analysis is a centre-edge cross-section asymmetry, which shows a dependence on the angle which separates central from edge collisions which is universal for spin-2 particle exchange, and whose sensitivity increases with the polarization of the colliding beams.

3. SPIN IN NUCLEAR PHYSICS

Three talks were dedicated to the study of the $dd \to {}^3\mathrm{H}p$, ${}^3\mathrm{He}n$ reactions with the polarized deuteron beam at RIKEN (M. Janek, T. Vasiliev, V. Ladygin). The precise vector and tensor analyzing power data obtained in the experiment allow one to probe the high momentum structure of ${}^3\mathrm{H}$ and ${}^3\mathrm{He}$ and to make significant tests with the existing potential models (Paris and Bonn) which cannot presently reproduce the new data. More specifically, neither the triton binding energy, nor the scattering cross sections can be obtained from the models. According to the authors, agreement can be restored by introducing three-nucleon forces. Studies of Deuteron break-up are also ongoing at COSY and at VEPP-3. The reaction $pd \to ppn$ is also studied at COSY, at higher energies (1–2 GeV), where several spin parameters will be measured to better understand the role of rescattering in the initial and final state (Y. N. Uzikov). At the 2 GeV electron storage ring VEPP-3, using an internal polarized deuteron target, all the three tensor analyzing power components in deuteron photodisintegration have been measured. D. M. Nikolenko has shown that the new measurements provide much better accuracy for the tensor analyzing power than the previous ones.

4. SOFT SPIN PHYSICS

An overview of the measurements of neutron–proton spin observables at 0 degrees carried out in Dubna by the DELTA–SIGMA experiment was given by V. I. Sharov. The JINR LHE accelerator provided the highest energy polarized neutron beams (up to 4.5 GeV/c) in the world for these measurements. Using the Dubna movable PT they measured the neutron–proton total cross-section difference for parallel and antiparallel longitudinal spin states, in the range 1.2–3.7 GeV. The behaviour of the data cannot be explained by traditional nuclear models. An interesting historical review of this field of physics was made by

L. Strunov, who also stated that the measurement of a complete data set of np spin observables at 0° is the aim of the collaboration.

V. Kanavets and D. Novinsky on behalf of the PNPI–ITEP Collaboration reported on new measurements of Polarization and Spin Rotation parameter in πp scattering in the region of the cross-section minimum, at 1.78 and 2.07 GeV/c. The measurements are being carried on at ITEP. D. Svirida and V. Sumachev underlined the importance of disposing of spin rotation parameters (and specific reference was made to the measurement the PNPI–ITEP Collaboration had performed at 1.43 GeV/c) to solve the existing ambiguity in PWA's. The more recent analyses do not confirm 4 out of 13 «well-established» resonant states, which means that light-meson spectroscopy essentially needs to be revisited.

An impressive review of the experimental work on the total cross-section measurements of circularly polarized photons with longitudinally polarized protons and neutrons, being done at MAMI and at the Bonn accelerator ELSA, was given by A. Thomas. The aim of this measurements is to check the Gerasimov–Drell–Hearn (GDH) sum rule, which connects the helicity dependent photoabsorption cross section with the anomalous magnetic moment of the nucleon. The measurements, which are shown in Fig. 1 extend over several years, and presently the sum rule is verified to 5%. In the context of extending the measurements to higher and higher energies (CEBAF and SPRING8) an interesting generalization of the GDH sum rule to the case of Parity Violating amplitudes was discussed by K. Kurek.

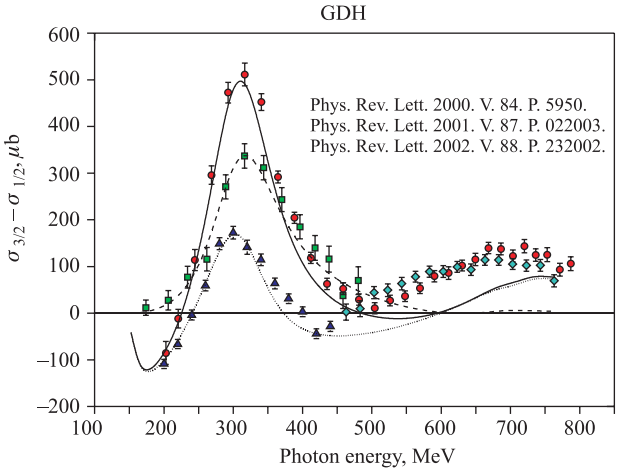


Fig. 1. Overview on the helicity dependent partial photoabsorption cross sections measured at MAMI. ● — total; ■ — $\pi^0 p$; ▲ — $\pi^+ n$; ◆ — $\pi\pi N$

New data on single-spin asymmetry (SSA) in inclusive π^0 production in pp collisions at 70 GeV/c were shown by V. Mochalov, on behalf of the PROZA-M Collaboration in Protvino. Within the errors of the measurements, the asymmetry is zero for p_T between 1 and 3 GeV/c, in strong disagreement with the corresponding CERN data at 24 GeV/c, and in agreement with the FNAL data at 200 GeV/c, as can be seen in Fig. 2.

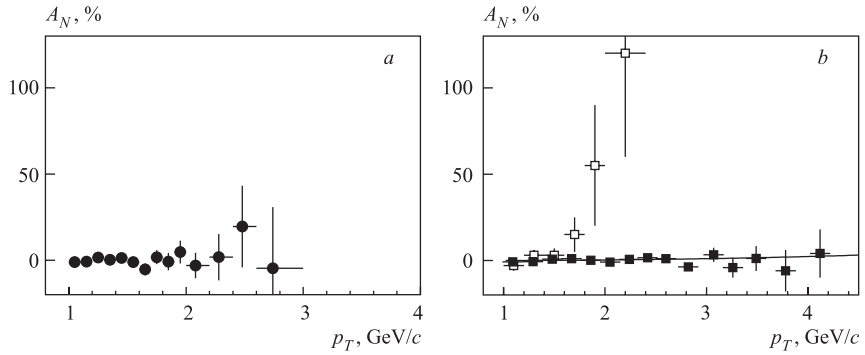


Fig. 2. *a*) Summed A_N for two detectors (● — Protvino experiment). *b*) Asymmetry at 24 GeV (□ — CERN experiment) and at 200 GeV (■ — E704 at FNAL)

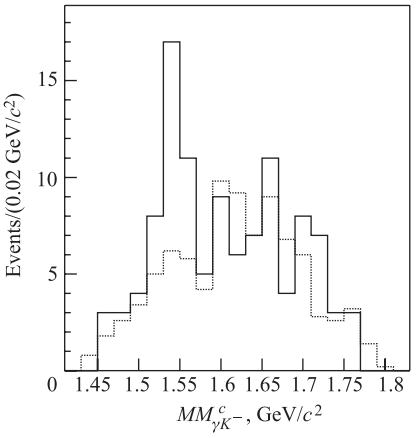
An impressive analysis of the LEP data on the spin alignment of vector mesons produced in the fragmentation of a polarized quark has been shown by Z. Liang. The results of this analysis have been applied to both lepton–nucleon and nucleon–nucleon scattering with polarized beam, and specific predictions for the polarization of the vector mesons produced in these reactions have been worked out.

A related subject was also discussed by A. Chukanov, who presented results of the measurement of the spin alignment of the $K^*(892)$ vector meson in neutrino-muon charged current and neutral current interactions. The data were taken by the NOMAD Collaboration. The results were compared with theoretical predictions based on the analysis of e^+e^--annihilation data at the Z^0 pole by the LEP experiments. A. Chukanov also showed first measurements of Λ and $\bar{\Lambda}$ polarization in neutrino neutral current interactions.

5. SURPRISES

One of the most pleasant surprises at this workshop, at least for me, has been the report by Y. Ohashi on the θ^+, the narrow $S = +1$ Baryon resonance first seen at Spring-8. The state was produced by the polarized photon beam, whose energy

ranged from 1.5 to 2.4 GeV, in the reaction $\gamma N \to k^- k^+ N$, and was identified as a narrow ($\Gamma < 15$ MeV/c^2) $K + n$ resonance at 1540 MeV/c^2. The original data are shown in Fig. 3. Having strangeness $+1$ the state is manifestly exotic. Both the mass and the width of the state coincide remarkably well with the prediction of the chiral soliton model, which was proposed in 1997 by D. Diakonov, V. Petrov and M. Polyakov. According to this model, the masses of the lightest pentaquark $(4q, \bar{q})$ baryon multiplet, an antidecuplet (see Fig. 4) had to be rather small, and the width of the lightest member was expected to be very narrow.



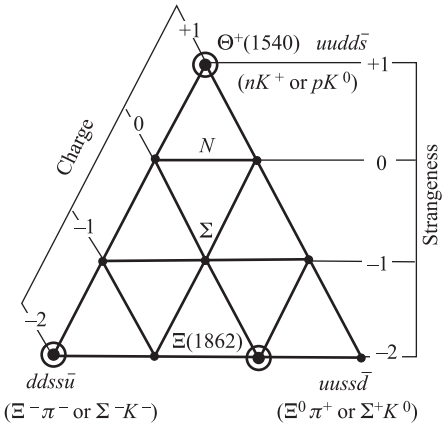


Fig. 3. The corrected missing mass distribution $MM^c_{\gamma K^-}$ for the signal sample (solid line) and for events from the LH_2 (dotted line) normalized in the region above 1.59 GeV/c^2

Fig. 4. A hypothetical antidecuplet of pentaquark baryons. The states at the corners of the triangle are manifestly exotic and cannot be made of three quarks. Experiments now see candidates for the three circled members

Our workshop had the privilege to be the first International Conference in which this state was reported. Y. Ohashi reported also on successive sightings of the same state in other experiments (DIANA at ITEP, CLAS at CEBAF, and SAPHIR at ELSA). At the time of writing this report, two narrow $\Xi\pi$ peaks have been announced by the NA49 Collaboration at CERN, which are good candidates for the isospin quartet of predicted pentaquark states with quark content $(ddss\bar{u})$ and $(dus\bar{sd})$.

The prediction of exotic states is as old as QCD. From this point of view, the problem was the nonobservation of exotic states. Many states have been announced in the past, which could not survive successive investigations. Still, I have the feeling that matters might be different this time.

6. THE LARGE EXPERIMENTAL FACILITIES

CLAS. H. Avakian not having been able to attend the Workshop, P. Bosted gave an overview of the physics being worked out at CLAS. The results basically refer to the data taken in 2000/2001, an impressive total of $23 \cdot 10^9$ events. The resonance structures at low Q^2 of the g_1 data on both proton and deuteron merge smoothly to the high energy DIS limit for $Q^2 > 1$ and $W^2 > 4$. The very high statistics of the data allows one for the first time to guess the high-x behaviour of A_1^p ($A_1^p \to 1$ as $x \to 1$). The data on exclusive channels asymmetries (single pion photoproduction) for longitudinally polarized proton target give a first indication of a nonzero $\sin 2\phi$ moment, as foreseen by A. Kotzinian and P. Mulders. Also, factorization studies performed at 5.7 GeV (see Fig. 5) showed no significant variation in the x-dependence of A_1^p for different z ranges, as expected if factorization holds.

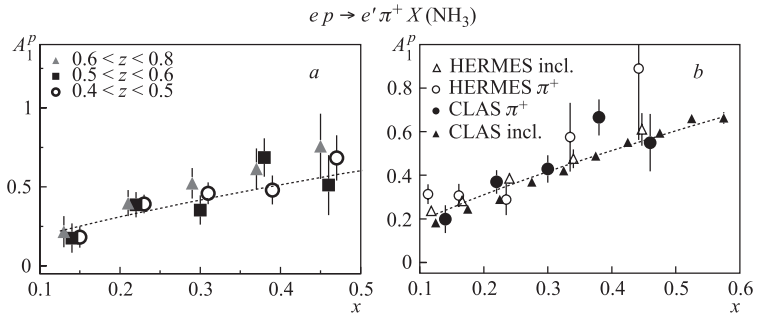


Fig. 5. The double-spin asymmetry as a function of x for different z ranges from CLAS 5.7 GeV polarized target data (*a*) and as a function of x for inclusive and semi-inclusive samples at CLAS and HERMES (*b*)

HERMES. While there was strong expectation for new results from the run with transversely polarized target, no report was given on transversity. After a nice general introduction on the formalism of GPD's, H. Marukyan concentrated on DVCS as being measured by HERMES: a very clear Single-Spin Azimuthal Asymmetry had been measured, which compared well with the result of a GPD calculation. A. Nagaitsev reported on the first measurement ever being performed of the structure function b_1 using the HERMES tensor polarized deuteron target. The spin-1 nature of the deuteron allows for a third structure function, b_1, which correlates in the QPM the partonic momentum distribution with the spin of the nucleon, and which can be derived from the tensor Asymmetry A_T. The preliminary results shown are in agreement with a model by K. Bora and R. Jaffe.

COMPASS. After a long commissioning in the summer of 2001, this new spectrometer has started data taking in 2002, when a total of $6 \cdot 10^9$ good events were put on tape. A similar number of events is being collected this year. After many years of hardware construction and commissioning, a huge effort on the off-line and on the analysis is presently ongoing. Using the CERN polarized muon beam at 160 GeV, SIDIS measurements have been made using a 1.2 m long polarized D6Li target. In the longitudinal target mode the experiment wants to extract the gluon polarization from a measurement of the open charm spin asymmetry: signals of D^0 and D^* were shown by F. B. Alternatively, high-p_T pairs of hadrons are also used to tag the photon–gluon fusion process and access ΔG: estimates of the accuracy which could be reached were also given by F. B. (a similar analysis performed with the SMC data was presented by K. Kowalik, suggesting a small and negative ΔG). In parallel to the ΔG programme, several physics channels are also being investigated, like exclusive production of vector mesons, as reported by J. Marroncle, and the Λ physics, as reviewed by M. Sapoznikov.

By rotating the target spin orthogonal to the beam direction, COMPASS has had in 2002 a first transversity run. The data have been fully analyzed, and their sensitivity to the Collins asymmetry was quoted by F. B.: it should be adequate to test current model predictions, like the one of A. Efremov et al. A similar amount of data has been collected in 2003.

RHIC. Polarized protons at RHIC are by far the most important tool spin physics could dream of disposing of to-day and in the years to come. A huge effort is ongoing on the machine side and on the experimentalists side to have the programme really fly, an effort well summarized by the many talks on the subject, by L. Bland, on the accelerator and the physics at STAR, A. Taketani, on the PHENIX experiment, A. Bazilevsky, on the π^0 cross section and the A_{LL} measurements with PHENIX, I. Alekseev, on the pp2pp experiment G. Bunce, on the overall spin physics programme at RHIC, S. B. Nurushev, on the STAR experiment, A. Bravar, on polarimetry at RHIC, and by A. Deshpande on the possibilities offered by e-RHIC.

Although RHIC is still far from the design operating values (in the 2003 run the luminosity was still a factor of 20 down, and the polarization 0.2–0.3 rather than the design value of 0.7) several physics results are already available. Initially results were obtained with vertical beam polarization, while in the last RHIC run the commissioning of the spin rotator magnets around the PHENIX and STAR interactions regions was completed, and data with longitudinally polarized beam could be collected. For the transverse beam, highlights are the A_N data in inclusive π^0 production from the STAR Collaboration at $\sqrt{s} = 200$ GeV: the cross sections are consistent with pQCD calculations and the asymmetries shown at SPIN 2002 are confirmed. Also, an interesting very forward neutron asymmetry, large and negative (–10%) was discovered for neutron production in pp collisions by PHENIX.

In the longitudinal spin mode PHENIX has measured the longitudinal double-spin asymmetry A_{LL} for π^0 production. Their preliminary measurements are slightly negative in all four p_T bins, possibly hinting at a small value for ΔG. Their measured π^0 cross sections are also in agreement with pQCD calculations, giving confidence that the process is indeed coming from hard scattering of quarks and gluons in the two protons.

CONCLUSIONS

It has been a pleasure to attend this most interesting workshop and an honour to give this summary talk, and I would like to thank the organizers, and in particular the Chairman Anatoli Efremov for their invitation.

This workshop has proven that the progress in the many aspects of spin physics is so rapid that one year is a perfect time interval from one major meeting to the next. One year from now the XVI International Spin Physics Symposium will take place in Trieste, on October 10–16, 2004, and you know that we have already started to work for that event. Extrapolating over year next what we have seen and heard (and also what we have not seen...) at this workshop, I am fairly confident that the Trieste Symposium will be a most interesting one, and I hope to see you all there.