Spin Physics Summary

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Abstract.
We present a brief summary of recent results presented at the Spin Physics Working Group at DIS 2005. The Spin Physics parallel sessions hosted a total of 33 talks equally distributed between experimental and theoretical aspects. An improved theoretical understanding in several recent topics of interest in this field is now evident, especially in the emerging area of transversity distributions.

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Precise results on the spin-dependent structure functions $g_1^p(x,Q^2)$ and $g_1^d(x,Q^2)$ were presented by the HERMES Collaboration while a new measurement of A_1^d and $g_1^d(x,Q^2)$ from the COMPASS experiment extends this measurement to lower values of x_{Bj} and higher Q^2. HERMES showed the comprehensive dataset on g_1 including results from proton, deuterium and neutron targets. The latter comes both from the ^{3}He measurement and from the difference of the proton data from the deuterium data. These results adopt a multidimensional unfolding to take into account both radiative background and intra-bin migration. The technique implies the elimination of the systematic correlation between different kinematic bins [1]. COMPASS combined the 2002 and 2003 data taking for an integrated luminosity of $\sim$1500 pb^{-1} covering a Q^2 range up to 100 GeV^2. Data significantly improved statistical accuracy in the low x region (down to 10^{-3}, with good agreement with previous experiments [2].

HERMES all showed the final results of the first measurement of the tensor asymmetry A_{zz} and the tensor structure function $b_1^d(x,Q^2)$ [3]. These results show that. as a nuclear-polarized deuteron target always carries a large tensor polarization, it is a priori not justified to neglect the effect of the tensor asymmetry while analyzing g_1^d measurements. In practice, b_1 represents the difference in the quark distribution between the helicity-0 and the averaged non-zero helicity states of the deuteron.

Our understanding of the high x region has significantly improved with new data of unprecedented precision from experiemnts at Jefferson Laboratory. This facilitates access not only to the valence quark region, but also the more elusive spin structure function g_2 in order to study the higher twist effects. Results on A_1^n [4] show, for the first time, a significant positive value for for high x, as would be expected with $SU(6)$ breaking. In particular, the results are in significant disagreement with the predictions from leading-order perturbative QCD models that assume hadron helicity conservation. This suggests that effects beyond leading-order perturbative QCD, such as the quark orbital angular momentum, may play an important role in this particular kinematic region. In summary, although the statistical accuracy is definitely good enough to allow a detailed analysis of the overall behavior of the helicity structure functions, there still remain regions at high and low x where our present knowledge is insufficient to distinguish between various models.

The resonance region for both proton and neutron have been investigated by precision data on spin structure provided by several experiments in all three experimental Halls A, B and C in JLab[5]. These results indicate that for Q^2 less than $\sim$1.5 GeV^2, quark-hadron duality is violated for g_1, mostly due to the strong negative contribution of $\Delta(1232)$.

The transversity distribution $h_1(x)$ completes the mapping of the spin structure of the nucleon at leading twist. Several features (i.e. the chiral-odd nature) makes transversity an attractive subject for detailed experimental investigation. As is well known, two main mechanisms affect azimuthal single-spin asymmetries on transversely polarized targets. The so-called Collins effect is probably the most representative of the different observables involving trasversity. Here a chiral-odd fragmentation function allows the observation of chiral-odd $h_1(x)$, which is otherwise impossible to access directly in a DIS process. On the other hand, a correlation between the intrinsic transverse momentum of an unpolarized quark and the direction of the transverse spin of its parent nucleon can exist and is described by the (naive) t-odd Sivers distribution function $f_{1T}^{\perp}(x)$. Probably the most interesting qualitative feature is that transversity distributions require a non-zero orbital angular momentum of the unpolarized quark.

HERMES, after the publication [6] of the first evidence for azimuthal single spin asymmetries in the semi-inclusive production of charged pions on transversely polarized target, has shown even more significant signals for both Collins and Sivers mechanisms analyzing the data collected during the period 2002-2004 with a pure hydrogen target. Asymmetries have been shown as a function of x, the hadron momentum fraction z and the hadron transverse momentum $P_{h\perp}$. The average Collins moment is positive for π^+ and negative for π^-. Significantly, the magnitude of the π^- moment appears to be similar in magnitude to that for π^+. The average Sivers moment is significantly positive for π^+, showing for the first time that a non-vanishing orbital angular momentum of quarks inside the nucleon is required. For the π^- the averaged Sivers moment is consistent with zero. The COMPASS has devoted 20% of the running time to transversely polarized ^6LiD (deuteron) target and has shown the data collected during the year 2002 corresponding to an integrated luminosity of about 200 pb^{-1}. Results have been shown for positive and negative charged hadrons selecting all hadrons or the leading one only [7]. Within the accuracy of the measurement, both the Collins and Sivers asymmetries turned out to be small and compatible with zero, with a marginal indication of a Collins effect at large z for both positive and negative charges. Concerning the Sivers asymmetry, the work presented by A.Prokudin [8] has demonstrated that HERMES results for protons and COMPASS results do not contradict each other. In 2006 the COMPASS collaboration plans to take data on a transversely polarized proton target (NH_3).

As previously explained, due to the chiral-odd nature, both the transversity and the Collins fragmentation function cannot be measured directly in conventional DIS processes. The results from HERMES and COMPASS are a convolution of these two objects. However, in order to measure transversity one needs that particular fragmentation function (FF) to be precisely known. BELLE, using hadron production from e^+e^- interactions, has shown the first signature of the Collins fragmentation function using a combined measurement of a quark and an anti-quark distribution. In fact, the number density for producing two unpolarized hadrons from transversely polarized quarks contains two times the chiral-odd FF, resulting in a chiral-even object accessible in electromagnetic interaction directly. A clear signature is visible, with the data also showing an increase with rising fractional energy z. This result can be consider a milestone in the study of the chiral-odd objects connected to the transversity measurement.

In case of $\vec{p}p$ scattering the situation shows some complication because, together with the Collins and Sivers mechanism, there is the contribution of the higher twist initial-state or final state interactions. However, in the hadron-hadron scattering, the first non zero single spin asymmetries were observed in pion production by E704 [9]. They have generated much interest since leading-twist collinear factorized pQCD predicts these asymmetries should be small. Much of the rising interest now is at RHIC with the idea that a full QCD description of the proton requires the inclusion of transverse momentum. In general, the performance of the polarized RHIC collider has been steadily improving. Transverse polarization data sets from 2003 and 2004 were both obtained with less than half Picobarn^{-1} of beam. The average proton beam polarization in 2003 was less than 20%. In the current year (2005), online polarization values in excess of 50% have been seen. Moreover a luminosity about one order of magnitude greater than the one used to extract the presented results have been collected. A much higher statistics measurement of these transverse asymmetries can be expected in the near future. STAR has shown the first measurements at $\sqrt{s}$=200 GeV indicating that the π^0 production exhibits a large single spin asymmetry which increases rapidly for x_F above about 0.3 [10]. These results are similar to those observed at lower energy by the aforementioned E704 experiment. Furthermore, for backward production, relative to the polarized beam, no significant asymmetry is observed. This result for this k_T measurement is exactly what the Sivers model predicts. If events are selected with a pair of π^0's separated by approximately 180^o in azimuthal angle and produced within the very forward kinematic region, the momentum of an observed π^0 represents a very large fraction of the jet energy. The typical fragmentation fraction for these events is about 90%. The STAR collaboration has established, for the first time, that these dramatic transverse spin asymmetries persist at the higher energies of the RHIC collider. It is worth mentioning that, while the asymmetries are similar, the cross sections at lower energy did not agree with perturbative calculations. With improving forward calorimetry working in the rapidity range -1$< \eta <$4, used in conjunction with the existing more central STAR detector system, this experiment will be able to distinguish the signatures of the Collins and Sivers effects. PHENIX, with a limited dataset of 0.15 pb^{-1} had calculated the transverse single spin asymmetry for π^0 in the central arm of the spectrometer ($|\eta|<$0.35 and non-identified charged hadrons at x_F=0 and transverse hadron momentum up to $p_\perp$= 5 GeV. In the results there is an overall scale uncertainty of $\pm$35% from uncertainty in the absolute polarization, and an absolute uncertainty of 0.2% on all points. The asymmetry at mid-rapidity is consistent with zero, to the few percent level, for all $p_\perp$ for both the π^0 and charged hadrons. In a near future PHENIX will access the measurement of back-to-back di-hadron azimuthal correlation to decouple contributions to SSA from the Sivers function. The BRAHMS experiment is well suited to study single spin asymmetries for identified pions at moderate x_F because of the PID coverage up to momenta of 40 GeV and the option to measure at $\eta \simeq 4$. The π^+ measured asymmetries are positive while the π^- are negative i.e. the same sign dependence as seen in the E704 data at lower energy. In addition the protons are found to have an asymmetry consistent with zero. BRAHMS has also compared the data vs. extrapolations of twist 3 (initial state) calculations [11]. The pQCD is apriori not valid at the lower values of $p_\perp$ covered in the presented measurement. Nevertheless it gives a good estimate how kinematic cuts may effect predictions as to give rise to a near constant asymmetry in a limited range of x_F. Both the magnitude and the x_F dependence is in reasonable agreement with the data. All the RHIC data show the clear potential to provide an independent means of determining the transversity distribution, provided that the Collins mechanism proves to be dominant.

A complete different way to approach transversity has been show by HERMES and COMPASS concerning the single spin asymmetries in two-hadron production in semi inclusive DIS. Although this method comes at the expense of a large statistical uncertainty, it has the advantage to relate, at leading twist, directly to the product of h_1 and the fragmentation function, whereas the single-hadron method show a a convolution of that product with the transverse momentum of the hadron. Moreover the two-hadron measurement involves a completely different fragmentation function as compared to the single-hadron one providing an independent method of measuring transversity. Specifically the fragmentation functions involved describe the interference between different production channels of the pion pair. HERMES has measured this asymmetry on transversely polarized hydrogen target in the invariant mass region $0.51 < M_{\pi+\pi-} < 0.97$ GeV, showing significant non zero results. The asymmetry is clearly positive over the mentioned entire invariant mass range and largest in the region of the ρ^0 mass. At the end of 2005 HERMES expects to collect a full data sample to lead to a decrease of the uncertainty on the asymmetry with approximately a factor $\sqrt{2}$ allowing a multi-dimensional analysis studying the x and z dependence. COMPASS has investigated the same asymmetry choosing hadron pairs selecting all combinations of positive and negative hadrons. The measurements has been performed as a function of M_{hh}, x and z showing a very small or no significant signal. Especially the asymmetry vs M_{hh} does not at all show any strong dependence. COMPASS expects new results including hadron identification using RICH information resulting in a cleaner hadron sample and a complementary measurement on a proton target from the planned run in 2006.

Besides the transversity distribution h_1 itself, there are other objects describing the transverse polarization of quarks but this time in longitudinally polarized targets. Hall B at Jefferson Lab has shown single-spin and double-spin asymmetries in semi-inclusive electroproduction of pions with a polarized NH_3 target using the CEBAF 6 GeV polarized electron beam [12]. In particular for such kind of process the only azimuthal asymmetry arising in leading order is the $sin2\phi$ moment involving the transverse momentum dependent Collins fragmentation function and the Mulders distribution function $h_{1L}^{\perp}$. One of the key results shown was a factorization test coming from examining the z-dependence of the double spin asymmetry for π^+, π^- and π^0. If factorization holds, the asymmetries should be approximately independent of z, broken by the different weights given to the polarized u and d quarks by the favored and unfavored fragmentation functions. These studies suggested that factorization works at CEBAF 5.7 GeV for $W > 2$ GeV, $Q^2 > 1.1$ GeV^2, $0.15 < x < 0.5$ and $0.3 < z < 0.7$. The data for π^+ show a clear $sin\phi$ and $sin2\phi$ modulations and the x-dependence is consistent with the expectation. No sign of a large unfavoured Collins function is seen. The π^+ asymmetry is dominated by u-quarks, therefore with some assumption about the ratio of unfavoured and favoured Collins functions, it can provide a first glimpse of the twist-2 function $h_{1L}^{\perp}$. This extraction, however, still suffers from low statistics and significant systematics coming from the theoretical assumptions.

Another important topic addressed in the Spin Physics sessions was the measurement of the gluon polarization, with new results shown by PHENIX and COMPASS. The PHENIX experiment has started making measurement of double spin asymmetries that would eventually lead to the polarised gluon distribution. The measurements were done for π^0 production in longitudinally polarised proton-proton collisions. Moreover, PHENIX has reported the unpolarised cross section for π^0 production at mid-rapidity which is described extremely well by the next-to-leading-order pQCD calculations over eight orders of magnitude. This becomes the basis on which the measured asymmetries will be interpretable in terms of polarised gluon distribution in the pQCD formalism directly sensitive to the polarised gluon distribution function in the proton through gluon-gluon and gluon-quark scattering subprocesses. The data to date are consistent with $\Delta G/G$=0, albeit with large errors. Due to the uncertainties of theoretical nature, it is still not possible to rule out large values of gluon polarization. Significant results will be be available soon, with improved statistics and the beam polarization. In particular after the installation of a superconducting "Siberian Snake" system, the beam polarization is expected to be above 60%.

A more direct way to measure the gluon polarization has been presented by COMPASS based on the helicity asymmetry of the photon-gluon fusion cross-section. The analysed data are still unsufficient to access the gluon contribution directly (i.e. by D^0 or D^* production) so what has been measured was the spin asymmetry of quasi-real photopruduction events for which a pair of large trasverse momentum hadrons is produced. However the asymmetry has many competitive processed that must be subtracted by using a Monte Carlo. In this case the PYTHIA generator has been used. This introduces large systematic uncertainties which substancially decrease the significance of the results. Analysing both the kinematical regions for $Q^2 < 1$ and $Q^2 > 1$ GeV^2 data show no significant gluon polarization for an avarage x_g=0.095. An agreement in that specific x_g, at the level of 1.5 σ, has been shown with the models [13, 14]. It is worth mentioning that a large positive gluon polarization has been shown previously by HERMES [15] using the same method. However this result is not in contradiction with the COMPASS one because of the different kinematical region where this result was extracted and because it suffers from the same large uncertainties from theoretical modelling.

Finally, a special session was devoted to new proposals for future projects, with topics ranging from improvements in electron and proton polarimetry to ideas for new experiments. The PAX collaboration has presented a rich and innovative physics program to be realised in the upcoming FAIR hadron facility at the GSI laboratory. The storage of polarised antiprotons at HESR will open unique possibilities to test QCD in an unexplored kinematic domain. The idea is to have polarised antiprotons produced by spin-filtering with an internal polarised gas target providing access to a wealth of single- and double-spin observables. This includes a first measurement of the transversity distribution of the valence quarks in the proton as well as a first measurement of the moduli and the relative phase of the time-like electric and magnetic form factors of the proton.

In conclusion, the physics goals in the field of spin physics related to deep inelastic scattering were clearly outlined in the parallel sessions. The evolution of a new topic and the steady improvements to topics that have been studied previously show the ability of this subfield to explore missing elements and address new theoretical concepts. Our understanding of the spin structure of hadronic matter continues to improve and we are looking forward to an exciting future.

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