SUMMARY OF THE SPIN PHYSICS WORKING GROUP AT DIS2002*

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We summarize in this report the experimental and theory talks which were presented in the Working Group 3 "Spin Physics" at the DIS2002 workshop. Recent progress achieved in several interesting topics will be underlined and also what to expect in the future.

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1. Introduction

The spin structure of the nucleon is an important and very active research field. Many new experimental results were reported at the workshop. The precision on the measurement of the inclusive observables is higher and also more exclusive measurements are being performed with studies of correlations. The first *pp* collisions with polarized beams at high energy have been obtained and new theoretical developments have been discussed.

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For an overview of the situation in this field and the definition of the basic quantities, the reader is also referred to the plenary talk by U. Stösslein, Status and Perspectives of the Spin Physics.

2. New results on polarized parton distributions and near future DIS experiments

In this section we discuss new measurements reported at the workshop concerning spin dependent structure functions, plans of measurements with fixed targets, new analyses of polarized parton distributions and some new determination of the quark polarizations from semi-inclusive data.

2.1. New spin asymmetry and polarized structure function measurements

Several results from experiments currently running or recently finished were presented. Here we first summarize the inclusive spin asymmetry measurements by Hermes at DESY, E99–117 and E97–103 at Jefferson Lab and E155/E155X at SLAC.

New results presented by Hermes concern the g_1 structure function with a deuterium target. During year 2000 very stable running conditions of HERA and the target density being twice as high as in 1998/1999, have allowed to collect about ten million events, five times the statistics of any earlier year. Target polarization was 85%. Very precise data on g_1/F_1 were obtained (see presentation by M. Contalbrigo) extending down to $x \approx 5 \times 10^{-3}$ at low Q^2. These data improved our knowledge about spin effects in deuteron in a wide kinematical range. In future, the extraction of the tensor polarization function b_1 for deuterium is foreseen. These high statistics data allow also significant improvement on semi-inclusive asymmetries with single hadron, single pion and even some first data for single kaon production. Such data together with previously available asymmetries on proton target allow the quark polarization determination (see talk by M.C. Simani). The QCD analysis at Leading Order (LO), was performed by the Hermes Collaboration including their new deuterium data. It uses as important input, the fragmentation functions, which correlate the flavor of the struck quark and the type of hadron produced in the final state. The following observations were made: There is no evidence for negative polarization of the strange sea, no significant flavor symmetry breaking in the light sea is detected. Systematic uncertainty is dominated by the uncertainty of the fragmentation model. This will be improved by dedicated measurements of these functions at Hermes.

At Jefferson Lab, measurements of spin asymmetries are performed with a high intensity polarized electron beam of $12 \mu A$ on a polarized He^3 target (see presentation by P. Żołnierczuk). The beam energy of 5.7 GeV restricts the measurements to the high x region of 0.3–0.6 (E99–117). Three data points were presented for the A_1^n spin asymmetry with a precision one order of magnitude better than previously achieved. The accuracy of this measurement is still statistically dominated. These data should give important constraints on the valence quark polarization at high x. The other measurement (E97–103) is done on a transversely polarized target for almost constant x at different Q^2, by means of a variable beam energy. A precise determination of A_2^n will allow studies of higher twist contributions to g_2. With an accurately measured A_1^n, one can determine the expectation for the Wandzura–Wilczek contribution ($g_2^{\rm WW}$) to g_2^n, as well as its Q^2 dependence. From these informations, it is possible to separate the contributions to g_2^n of twist-3 and higher. The data are already collected and statistical errors (estimated from on-line analysis) are of the order of 0.01, which is five-seven times smaller than the expected $g_2^{\rm WW}$ contribution.

From SLAC a set of inclusive measurements is extended by precise measurements of the A_2 asymmetries on transversely polarized targets and the determination of g_2 (see presentation by S. Rock). The extracted g_2 structure function is than compared with the Wandzura–Wilczek predictions in the simple twist-2 model $g_2^{\rm WW}(x,Q^2) = -g_1(x,Q^2) + \int_x^1 dy/y g_1(y,Q^2)$. The twist-3 d_2 matrix element was derived from the integral of the difference of the measured g_2 and the expected twist-2 contribution $g_2^{\rm WW}$. The values obtained for proton and neutron are positive and different from zero at two standard deviation level.

2.2. Near future fixed target experiments

A broad fixed target program exists at SLAC (see presentation by S. Rock) including a polarized Møller scattering experiment running this year and next year, for a precise determination of $\sin^2\Theta_W$, and three photoproduction experiments. From the photoproduction experiments one will look at the gluon polarization from open charm production and this is planned for 2006. After this, a measurement of total hadronic cross section asymmetry in the energy range 10–45 GeV for testing the GDH sum rule, is also foreseen (2007).

At CERN with the muon beam, the COMPASS experiment (see presentation by M. Leberig) took some first test data last year. This experiment is going to measure $\Delta G/G$ with open charm production and events with high transverse momentum pairs of hadrons and identified kaons. All elements of the initial layout were successfully commissioned, various novel detector principles were proven to work, the large polarized target filled with ^{6}LiD was successfully polarized to 55%. This year 100 days of data taking are foreseen.

2.3. New analyses of polarized parton distributions

More precise data from inclusive measurements (g_1 and g_2) allow to improve the determination of the polarized parton distributions. At the workshop three papers related to this subject were presented. Each of them touches different aspects for a refined use of the data.

All the analyses are done in QCD at the Next-to-Leading Order (NLO) and the parton distributions selected for the parametrization are always gluons and valence and sea quarks (and antiquarks) of different flavors. Two methods to parametrize them are used in general: one way is to parametrize the polarized parton distributions directly and the other one is to use the unpolarized distributions as a basis and to converte them to polarized parton distributions, by means of simple multiplicative functions of x.

In the analysis presented by H. Böttcher, polarized parton distributions are parametrized directly and special care is taken to determine the fully corrolated errors on these distributions. This particular aspect of QCD fits was already considered before, but here it is done in a very systematic way. Fully correlated 1σ error bands were derived and are available in the form of FORTRAN code for the wide ranges $1 < Q^2 < 10^6$ GeV^2 and $10^{-9} < x < 1$. The extracted value of α_S is consistent with the world average. Also very interesting attempt to the scheme invariant QCD evolution was performed for the structure function $g_1(x, Q^2)$ and its derivative in $\log Q^2$. Such approach is promissing and can be even more usefull for higher statistics data. In this analysis the factorization scale uncertainties do not occur.

In the work presented by A.V. Sidorov, the second choice for parametrization of the polarized parton distributions was taken with $\Delta f_i(x, Q^2) = A_i x^{\alpha_i} f_i^{\rm MRST}(x, Q^2)$, where $f_i^{\rm MRST}(x, Q^2)$ stands for the Martin–Roberts–Stirling–Thore parametrization for the unpolarized data. In this way the number of free parameters is reduced. The A_1 data were used in the fit and studies of the size of possible higher twist contributions to this quantity are presented. No sign of signifficant higher twist contribution was observed. The parametrization is avaliable from the Durham data base.

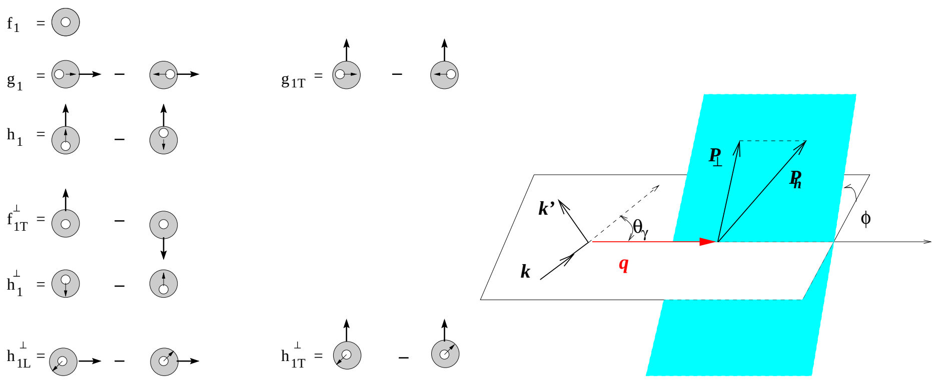
An attempt to obtain polarized parton distributions with a completely different and new method was presented by J. Soffer. In a global NLO-QCD analysis polarized and unpolarized PDF are determined using a statistical approach for the description of the nucleon structure. The building blocks are quark (antiquark) distributions of a given flavor and helicity. The polarized parton densities at initial energy scale are described for quarks (antiquarks) by Fermi–Dirac distributions and for gluons by Bose–Einstein distributions. Free parameters are *four* chemical potentials and *one* universal temperature. The potentials for quark and antiquark of opposite helicity have opposite signs and the potential of the gluon is zero. A rather good description of a big set of unpolarized and polarized data is obtained in the wide kinematical range available. Some predictions can be made in the framework of this approach and their tests will soon be possible, for example for the high x data from Jefferson Lab, or light sea quarks flavor symmetry breaking with parity violating helicity asymmetries in $W^{\pm}$ and Z^0 production in polarized pp collisions at RHIC.

In the determination of polarized parton densities the role of semi-inclusive data was studied (see presentation by E. Leader). To complete the experimental information which could help to achieve the flavor separation one should add semi-inclusive data. Such analysis were already performed in LO by experimental groups. Here an attempt to extract PDF in a model independent way is discussed. The extraction of ratios of fragmentation functions needed in the PDF determination from semi-inclusive data in LO and NLO is possible from DIS and e^+e^- data. Fragmentation functions $D_u^{\pi^+}$, $D_d^{\pi^+}$ and $D_s^{\pi^+}$ can be obtained and the influence of their uncertainty on the $\bar{d}$ and s polarizations is significant, considering the low precision of the data at this point. Strong need for hadron multiplicity measurements with good identification was stressed.

3. Novel structure and fragmentation functions

Several generations of deep-inelastic scattering (DIS) experiments have provided us with a precise map of the unpolarized parton distribution functions in the proton. These PDF's are denoted $q(x)$ or $f_1^q(x)$, where the label q indicates quark flavor. As described in the previous section, new data are now extending our knowledge into the sector of the helicity-dependent quark distributions, denoted $\Delta q(x)$ or $g_1^q(x)$. But a full understanding of the spin-structure of the nucleon requires more information. In this section, we provide an overview of some of the novel distribution and fragmentation functions that are being explored for the first time by present experiments.

In 1996, Mulders and Tangerman performed a complete tree-level analysis of the semi-inclusive deep-inelastic scattering (SIDIS) cross-section, taking into consideration all measurable spin-degrees of freedom in the initial and final state [1]. Their work identified a series of 8 structure functions of the proton at leading twist, along with an analogous set of 8 fragmentation functions. These functions are illustrated graphically in Fig. 1(a). In each picture, the virtual photon probe is assumed to be incident from the left, the large and small circles represent hadrons and quarks respectively, and the arrows indicate their spin directions. The notation for the fragmentation functions is obtained by replacing the letters f, g, and h with D, G, and H respectively.



(a) (b)

Fig. 1. (a) Summary of the classification scheme of [1] for leading-twist distribution functions. (b) Diagram of SIDIS kinematics.

Each of these functions describes qualitatively different information about hadronic structure and formation. The Mulders decomposition of the cross-section reveals that experiments may access them by measuring *azimuthal moments* in spin-dependent SIDIS. Fig. 1(b) illustrates the definition of ϕ, the azimuthal angle of a final-state hadron relative to the lepton scattering plane, measured around the virtual photon direction. New data are providing first glimpses of several new distribution and fragmentation functions, and much more can be expected in the near future.

An even more recent avenue of theoretical research is the development of Generalized Parton Distributions (GPD's). The GPD formalism provides a unified description of a wide range of observables, such as electromagnetic form factors, conventional parton distributions, and hard exclusive cross sections. GPD's also offer the tantalizing prospect of a complete map of the proton wavefunction, including partonic correlations. Perhaps most exciting of all is the chance to access the unknown orbital angular momentum of quarks and gluons via GPD's [2]. First data on hard exclusive processes, sensitive to these new functions, have begun to appear in recent years.

3.1. Transversity

Of the eight structure functions shown in Fig. 1(a), $f_1(x)$, $g_1(x)$, and $h_1(x)$ have a special property: they are the only ones which survive on integration over transverse momentum k_{T}. (The other functions are all implicitly dependent on intrinsic quark transverse motion, which is necessarily related to the unknown orbital angular momentum of quarks in the nucleon.) The third of these distributions (denoted $h_1^q(x)$ or $\delta q(x)$) is termed *transversity*, and represents the degree to which the quarks are polarized along the proton's spin direction when the proton is polarized *transversely* to the virtual photon. Transversity has several interesting properties. In a non-relativistic picture of the nucleon, the longitudinal and transverse spin distributions are the same: $h_1^q(x) = g_1^q(x)$. However in a relativistic setting where the nucleon is observed by a high-energy beam, boosts and rotations do not commute and these functions need not be the same. Also, unlike in the case of g_1, the gluon polarization does not mix with quark polarization in h_1, leading to a different evolution with Q^2. Further, the tensor charge of the nucleon can be determined from the first moment of $h_1^q(x) - h_1^{\bar{q}}(x)$. This quantity is purely sensitive to valence quarks, and offers a promising point of comparison with lattice QCD calculations.

Three years ago, the HERMES experiment presented first results on the single-spin azimuthal asymmetry $A_{\rm UL}(\phi)$ for semi-inclusive charged pion production from a longitudinally polarized hydrogen target. The asymmetry for π^+ production displayed a pronounced $\sin\phi$ dependence and was rapidly interpreted as first evidence for a non-zero transversity distribution. M. Dueren at this workshop presented further results of this type from HERMES. The asymmetry $A_{\rm UL}(\phi)$ for π^0 production from hydrogen has now been analyzed, and agrees with the earlier measurement for π^+. Preliminary results from the deuterium-target data of the years 1998-2000 were also shown. The $\sin\phi$ moments of the deuterium asymmetries (termed analyzing powers) are displayed in Fig. 2. The analyzing power is of similar magnitude for π^+ and π^- production, and about half as large as that for π^+ production from hydrogen. These qualitative features of the measurements, as well as their kinematic dependences, are in agreement with simple expectations based on transversity.

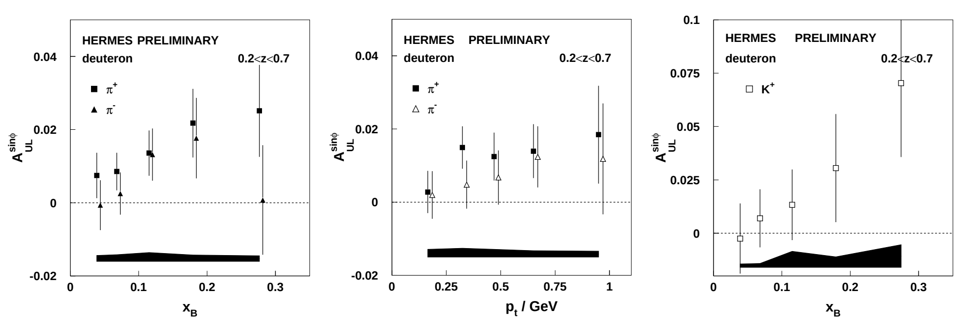


Fig. 2. HERMES preliminary results on the analyzing power $A_{\rm UL}^{\sin\phi}$ for semi-inclusive charged pion and kaon production from a deuterium target.

A variety of theoretical calculations have been performed to confront the HERMES results. These calculations involve other unknown quantities, such as the Collins fragmentation function $H_1^{\perp}(z)$ and the unknown leading-twist distribution function $h_{1L}^{\perp}(x)$ (see Fig. 1). They also reveal that the data are likely dominated by higher-twist effects. Nevertheless, using model-based estimates for $h_1(x)$ (*e.g.* from the Chiral Quark Soliton Model) and reasonable ansätze for the unknown functions, reasonable agreement with the data is readily obtained. An important development was presented at this workshop by A. Efremov, who uncovered a pair of sign errors in earlier calculations. A larger estimate for the size of the Collins function is now obtained, which is promising for future SIDIS measurements.

With this baseline understanding of the data in hand, clear guidance is available on which measurements to perform next. The most direct access to transversity in SIDIS lies in measurements with transversely polarized targets. HERMES has already changed to a transverse-target configuration, and a precise measurement of $A_{\rm UT}(\phi)$, sensitive at leading twist to the product of transversity and the Collins function, will form a cornerstone of HERMES Run 2. The RHIC-Spin and COMPASS experiments also have plans for future measurements sensitive to transversity, and a forthcoming analysis of high-statistics data from BELLE will yield much more precise information on the Collins fragmentation function.

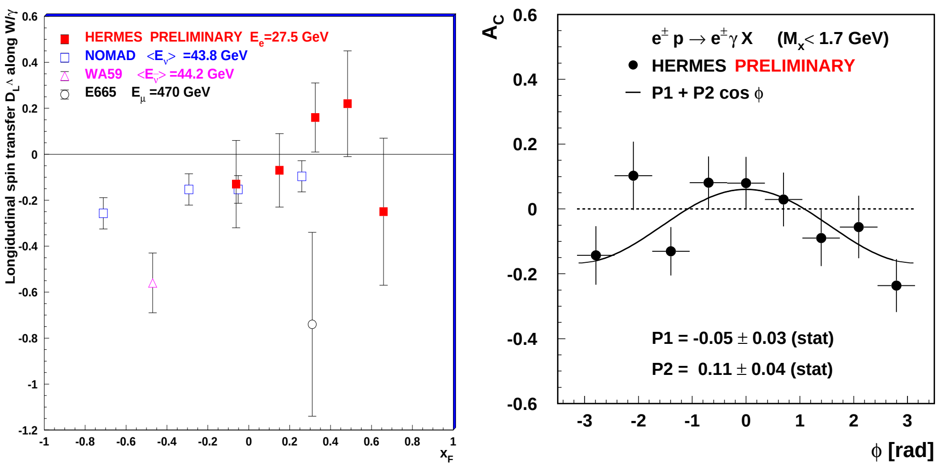
3.2. Spin-dependent fragmentation functions and Λ polarization

The HERMES measurement of a non-zero analyzing power $A_{\rm UL}^{\sin\phi}$ provides first evidence for not only the transversity structure function, but also for the existence of the Collins fragmentation function $H_1^{\perp}(z)$. This function acts as a "polarimeter" for initial-state quark polarization: it correlates the transverse spin of the struck quark with the angular distribution of hadrons in the jet it generates. But apart from its utility in measuring transversity, the existence the Collins function is deeply interesting in its own right. As $H_1^{\perp}$ is odd under the application of naive time reversal, and both the electromagnetic and strong interactions are T-even, it must arise from some interference mechanism. This teaches us that the fragmentation process possesses a large degree of *phase coherence*. It is rather surprising that such interference effects persist at high energies, given the large number of amplitudes that must be involved in semi-inclusive hadron production.

Another powerful window on spin effects in the fragmentation process comes from measurements of Λ polarization. The parity-violating weak decay $\Lambda \to p\pi^-$ allows the hyperon's spin to be determined from the angular distribution of its decay products, providing unique access to spin degrees of freedom in the final state. Talks at this conference by D. Naumov,

Y. Naryshkine, and O. Grebenyuk presented new data on Λ polarization in deep-inelastic scattering with positron and neutrino beams.

One question addressed by Λ polarization measurements is the following: do hadrons from the fragmentation process preserve any memory of the spin of the struck quark? The HERMES experiment uses a longitudinally polarized positron beam of 27.6 GeV, while the NOMAD experiment uses fixed-helicity neutrino beams of 43.8 GeV. In both cases, the polarized virtual photon may only be absorbed by quarks of a certain helicity, thereby effectively producing a polarized quark beam in the forward direction. Both experiments presented data on the correlation $D_{\mathrm{LL}'}$ between this struck quark polarization and the longitudinal polarization of Λ's in the final state. These results are sensitive to the spin-transfer fragmentation function $G_1(z)$. Fig. 3(a) displays the most recent measurements from both experiments.



(a) (b)

Fig. 3. (a) Measurements from NOMAD and HERMES of the longitudinal spin transfer $D_{\mathrm{LL}'}$ from the virtual boson to the final state Λ in DIS with neutrino (NOMAD) and positron (HERMES) beams. (b) HERMES measurement of the beam charge asymmetry $A_{\mathrm{C}}(\phi)$ in the exclusive single-photon production region.

The HERMES data is concentrated in the current-fragmentation region ($x_{\mathrm{F}} > 0$) and is consistent with zero spin transfer. This is at first sight surprising, in light of the significant longitudinal spin transfer measured by the OPAL and ALEPH e^+e^- annihilation experiments [4]. Those experiments were able to explain their results using a Monte Carlo simulation based on the Lund string model and a few simple hypotheses [1]. They postulated that

[1] It is important to note that these data have large errors and are compatible with alternative theoretical ideas (for a recent review see Ref. [5])

the struck quark retained its helicity perfectly through the fragmentation process, but that the quarks from string breaking had random spin orientations. Thus the key ingredient for observing a non-zero spin transfer in this model is the fraction of Λ's which *contain* the struck quark. In contrast to the LEP findings, Monte Carlo studies performed at HERMES kinematics reveal that very few of the Λ's contain the struck quark, even at rather large values of $x_{\rm F}$. More detailed studies were presented by NOMAD. These studies revealed that even in the forward production region, the hyperons frequently contain the target remnant. The message of these investigations is that Λ production in intermediate-energy DIS is closely connected with the complex and poorly-understood dynamics of the target fragmentation region.

However Λ's produced in close proximity to the target fragment may prove interesting as well. As proposed in Ref. [6], Λ polarization in the target fragmentation region may be sensitive to the strange quark polarization in the target nucleon. The NOMAD data at $x_{\rm F} < 0$ show an onset of negative polarization as one moves from the forward to the backward region of Λ production. In particular, the data also display a pronounced dependence on W, the invariant mass of the final-state hadronic system: the polarization increases at lower W, where the Λ is more likely to contain a strange quark from the sea of the target. The NOMAD data were successfully fit with a phenomenological model based on negatively-polarized instrinsic strangeness in the proton, the constituent-quark model of hyperon spin structure, and an adjustable spin-transfer coefficient.

Finally, both NOMAD and HERMES presented data on transverse Λ polarization, as produced by unpolarized beams and targets. This "self-polarization" of hyperons has been observed and studied for many years in hadronic beam experiments, and is associated with the polarizing fragmentation function $D_{1\rm T}^{\perp}(z)$. Like the Collins function, this fragmentation function is odd under naive time reversal and therefore also indicative of strong phase coherence in the fragmentation process. No model has yet been able to explain the full body of data that has been amassed from hadron beam experiments.

By comparison, data on the effect in photo- and lepto-production is scant, and new results from NOMAD (in the neutrino-DIS regime) and HERMES (in the photo-production regime of $Q^2 \approx 0$) provide valuable new pieces to the long-standing puzzle of transverse hyperon polarization. Discussions at the workshop revealed a difference in sign convention between the two experiments. Along the traditional transverse axis $\hat{n} = \hat{p}_{\rm beam} \times \hat{p}_{\Lambda}$, both experiments measure positive Λ polarization, in contrast to the negative values consistently observed in proton beam experiments.

3.3. Generalized Parton Distributions

As described above, Generalized Parton Distributions provide a powerful new framework with which to describe nucleon structure. Unlike the familiar PDF's, which represent forward matrix elements of the proton, the GPD's are sensitive to *off-forward* matrix elements, with different initial and final states. This off-forwardness introduces the tantalizing prospect of access to the unknown orbital angular momentum of partons in the proton.

To measure the GPD's, one must turn to hard-exclusive processes: measurements at large scales where all particles are detected in the final state. The cleanest of these reactions is Deeply Virtual Compton Scattering (DVCS), where a single real photon of high energy is produced from the scattering of a hard virtual photon from a nucleon target. First exploratory measurements of this type have just begun to appear in the last two years. R. Stamen presented measurements of the DVCS yield from the H1 and ZEUS experiments, sensitive to the square of the DVCS amplitude. New data from HERMES were presented by R. Shanidze, sensitive instead to the inteference of the DVCS and Bethe–Heitler (BH) processes. These reactions have indistinguishable final states, but their interference may be isolated by measurements of the beam-spin and beam-charge dependence the cross-section for single-photon production. The HERMES data, taken with an unpolarized hydrogen target, reveal a pronounced $\sin\phi$ moment in the beam-spin asymmetry $A_{\rm LU}(\phi)$. Here ϕ is the azimuthal angle of the real photon relative to the lepton-scattering plane, as shown in Fig. 1(b). The data are sensitive to the imaginary part of the DVCS-BH intereference term, and agree well with calculations performed in the GPD framework. Combining electron-beam data from 1998 and positron-beam data from 2000, the beam charge asymmetry $A_{\rm C}(\phi) = (N^{e+}(\phi) - N^{e-}(\phi))/(N^{e+}(\phi) + N^{e-}(\phi))$ was also investigated. This asymmetry is sensitive to the real part of the interference term. As shown in Fig. 3(b), a clear $\cos\phi$ dependence was found for events in the exclusive region, also in agreement with theoretical expectations.

The near future looks promising for further measurements of hard-exclusive photon and meson production. At the HERMES experiment, only the scattered beam lepton and the real photon from the DVCS process are detected by the spectrometer, and the exclusivity of the events must be determined using a missing mass technique. Unfortunately, the missing mass resolution at the kinematics of these measurements is around 800 MeV, making it impossible to conclusively determine the exclusivity of the events. The HERMES experiment has begun construction of a recoil detector, with anticipated installation in 2004. N. d'Hose also presented plans for construction of a similar device at the COMPASS experiment, where exclusive measurements at higher scales can be performed. Finally, spin-dependent measurements at the highest scales of all will soon be possible at the H1 and ZEUS experiments, thanks to the installation of new spin rotators and the upgrade of several detector components.

4. First polarized *pp* collisions at RHIC-BNL

The Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL), had a first five weeks run, as a polarized proton collider ending at the beginning of 2002. In this run, at the center of mass energy $\sqrt{s} = 200$ GeV, a luminosity $L = 1.5 \times 10^{30}\mathrm{cm}^{-2}\mathrm{sec}^{-1}$ and a beam polarization $P = 25\%$ were achieved, at maximum. We should stress that this was the first-ever run of a polarized proton collider, whose highest energy is expected to be $\sqrt{s} = 500$ GeV, with $L = 2 \times 10^{32}\mathrm{cm}^{-2}\mathrm{sec}^{-1}$ and $P = 70\%$. How RHIC makes polarized protons, how to measure the beam polarization, why it was so small in this run, all these important issues have been briefly explained in the presentations by L.C. Bland for the STAR Collaboration and Y. Goto for the PHENIX Collaboration. We have heard about Siberian Snake and Coulomb Nuclear Interference (CNI) polarimeter at RHIC. They gave us a rapid description of the detectors and their kinematic range. We were also told the long-term goals of the spin program for both experiments. Clearly one of the main goal is to provide a better answer to the long-standing question: where is the proton spin? Direct photon production, which is sensitive to quark-gluon Compton scattering, will allow a direct precise measure of the gluon polarization $\Delta G(x)$, so far poorly known from scaling violations in polarized DIS, spanning a small Q^2 range. The flavor decomposition of the quark (antiquark) polarization will be achieved accurately by the copious $W^{\pm}$ production at RHIC and, as mentioned above, there are serious hopes to probe the transversity quark distributions. Although results were not yet available, the first run has measured single transverse-spin asymmetries A_N in the production of π^0, γ and charged hadrons in the mid-rapidity region ($x_{\mathrm{F}} = 0$, $p_{\mathrm{T}} \leq 8$ GeV/c) and in the very forward region (large x_{F}, $p_{\mathrm{T}} \leq 0.2$ GeV/c).

5. Special features of polarized structure functions

The concept of duality, first introduced more than thirty years ago by Bloom and Gilman, allows us to relate the scattering amplitude in the low energy region, dominated by resonances contributions, to the high energy region described by Regge exchanges. In inclusive electron scattering, quark-hadron duality provides a relationship between resonances physics and DIS at high Q^2. The smooth scaling data measured in DIS at high Q^2 is, in average, equal to the data measured in the resonance region at lower Q^2, for a fixed range of the Bjorken scaling variable x. In her presentation, A. Fantoni noticed that duality has been observed in unpolarized structure function, since the integrated ratio $F_2^{\rm Res}/F_2^{\rm DIS}$, plotted *versus* Q^2, remains close to 1, except for $Q^2 < 1.5$ GeV^2, where it drops below 1. It is therefore legitimate to ask if duality occurs also for the polarized structure function $g_1^p(x,Q^2)$. The HERMES preliminary results are in the range $1.2 \leq Q^2 \leq 12$ GeV^2 and the ratio of the first moments $\Gamma_1^{\rm Res}/\Gamma_1^{\rm DIS}$ is close to 1 and independent of Q^2 in this range. This is the first test of duality in polarized DIS. Note that, as in unpolarized DIS, this ratio drops below 1 for the lower Q^2 values measured at SLAC by E143. Further studies of duality for the neutron structure function $g_1^n(x,Q^2)$ will be made.

To understand the behavior of the polarized structure functions, in the low Q^2 region, dominated by nonperturbative mechanisms, is indeed very important. This issue was considered, in a particular framework, in the contribution of B. Badełek. To predict the low Q^2 behavior of $g_1^p(x,Q^2)$ one uses a method based on the Generalized Vector Meson Dominance (GVMD) model, which was successfully applied to the low Q^2 behavior of the unpolarized structure function $F_2(x,Q^2)$. One takes into account the contribution of both light and heavy vector mesons which couple to a virtual photon. The heavy meson component is directly related to the structure function, in the scaling region, and the light meson component is normalized by using the Drell–Hearn–Gerasimov–Hosoda–Yamamoto (DHGHY) sum rule, for the first moment of g_1, in the photoproduction limit $Q^2 = 0$. The prediction for $I(Q^2)$, the DHGHY moment for the proton, which is in good agreement with recent preliminary data from Jefferson Laboratory, is also compared with other theoretical estimates.

6. New theoretical developments and related issues

The concept of Collins fragmentation function has been mentioned earlier as well as some comments about its existence and its relevance, in particular, to probe the quark transversity distribution $h_1(x)$. In his contribution, A. Bacchetta presented a calculation of the Collins fragmentation function for pions in the framework of a chiral invariant approach at a low energy scale. It uses the model of Manohar and Georgi, where massive constituent quarks and Goldstone bosons are the effective degrees of freedom, in the nonperturbative regime of QCD. The model depends on some parameters, in particular on μ^2, the virtuality of the fragmenting quark. To test the approach, they first calculated the unpolarized fragmentation function, $D_1(z)$, and the transverse momentum distribution of a produced hadron, $\langle |k_{\rm T}| \rangle$. The results are reasonably well described, although they depend on μ^2. Next they turn to the prediction of the Collins function, which is found to grow as z increases, in agreement with the trend of present data. It is also consistent with the extraction performed recently by A. Efremov *et al.* On the basis of this approach, they have estimated several spin asymmetries for semi-inclusive DIS, which will be very soon accessible at HERMES, COMPASS and CLAS and also an azimuthal cos2ϕ asymmetry for e^+e^- annihilation into two hadrons, which should be measurable at BABAR and BELLE.

Single Spin Asymmetries (SSA) are known to be difficult to treat in perturbative QCD and an overview of different concepts related to them was presented in the contribution of O. Teryaev. In order to describe the parton-hadron and hadron-parton transitions, there are essentially a few nonperturbative objects, whose list is given below with increasing complexity. First, the usual parton distribution describing the fragmentation of a hadron into a parton, which does have a T-odd component, so no imaginary phase to produce a SSA. Next, the fragmentation function describing the fragmentation of a parton into a hadron, which can give rise to a T-odd effect, *e.g.* jet handedness, the Collins function *etc.*, needed to produce a nonzero SSA. Finally, the FRACTURE function, combining the properties of FRAgmentation and struCTURE functions, which can also generate T-odd effects. The possible experimental manifestations of these effects in connection with HERMES and NOMAD, have been discussed and also their relation with recent theoretical suggestions

Deep inelastic *diffractive ep* scattering at high energy is an important process. It is characterized by the existence of a rapidity gap, namely, the fact that the outgoing proton is well separated in rapidity from the diffractively produced hadrons. In the unpolarized case one finds from experiment that the scaling violations for the diffractive structure function $F_2^{\rm D}$ are similar to those of the usual structure function F_2. Moerover the ratio $F_2^{\rm D}/F_2$ remains almost constant and of the order of $1/8$ to $1/10$, in the whole kinematic region. These special features have been investigated successfully using the light-cone expansion in the generalized Bjorken region. New results in the case of polarized deep inelastic diffractive *ep* scattering have been presented by J. Blümlein. It is described in the same framework and the evolution equations are given. It is also shown that the twist-2 contribution to the diffractive structure function $g_2^{\rm D}$ is obtained from $g_1^{\rm D}$, by a Wandzura–Wilczek relation similar to the usual one. Future polarized experiments might be able to check these predictions.

Finally let us mention a presentation by H. Kawamura on the first calculation of universal QED corrections to polarized electron scattering in higher orders. These corrections turn out to be very large in some kinematic regions and have therefore to be known precisely. Both singlet and nonsinglet cases have been studied.

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