Summary of Spin Physics Parallel Sessions

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Abstract. We summarize the activities in the spin physics parallel sessions of the 8th conference on intersections between particle and nuclear physics.

Introduction

For spin physics in this conference, we had five parallel sessions and over 500 minutes of presentations. We had twenty-six scheduled talks with twenty-four of them presented at the conference (fourteen in experiment, two in machine and instrumentation, and eight in theory). The talks reported the activities at almost all major high energy spin experiments around the world and covered a wide range of recent theoretical developments in this field. The spin physics parallel sessions had overwhelming participation and were full of exciting discussions.

Polarized parton distributions

The determination of polarized quark distributions, $\Delta q(x, \mu)$, and the gluon distribution, $\Delta g(x, \mu)$, is essential for testing QCD perturbation theory in its spin sector as well as for searching answers to the question on how the nucleon’s spin is distributed among its constituents.

In the framework of QCD, the spin of a nucleon can be expressed as an expectation value of the QCD angular momentum operator in the nucleon state [1],

$$\frac{1}{2} = \frac{1}{2} \Delta \Sigma(\mu) + \Delta g(\mu) + L_q(\mu) + L_g(\mu),$$

where $\Delta \Sigma(\mu) \equiv \sum_q \int_0^1 dx [\Delta q(x, \mu) + \Delta \bar{q}(x, \mu)]$ and $\Delta g(\mu) = \int_0^1 dx \Delta g(x, \mu)$ are the total quark and gluon helicity, respectively; and $L_q(\mu)$ and $L_g(\mu)$ are quark and gluon orbital angular momentum (OAM), respectively. The scale $\mu$ indicates the momentum scale at which these quantities are measured. Combining all polarized deep inelastic scattering (DIS) measurements, the quark helicity contribution to the proton spin is found to be about $\Delta \Sigma \sim 0.2$ [1], which is much smaller than the unity expected from the naive quark model. In order to test the sum rule in Eq. (1), we need to measure the individual pieces on the right-hand-side.

The polarized parton distributions (pPDFs), $\Delta q(x, \mu)$ and $\Delta g(x, \mu)$ are nonperturbative but universal quantities, and are not direct physical observables. It is the QCD factorization theorem that connects them to polarized hadronic cross sections via perturbatively calculated partonic hard scattering processes. The pPDFs can be extracted from measurements of polarized cross sections with longitudinally polarized protons.
Until the advent of the RHIC spin program, high energy collisions with longitudinally polarized protons only took place in lepton-hadron DIS. By measuring the double longitudinal spin asymmetry of inclusive DIS cross sections, $A_{LL}$, one can extract the structure function, $g_1(x, Q^2)$, of the polarized proton,

$$g_1^p(x, Q^2) = \frac{1}{2} \left[ \sum_{q, \bar{q}} \Delta C_q(x, \alpha_s) \otimes \Delta q(x, Q^2) + \Delta C_g(x, \alpha_s) \otimes \Delta g(x, Q^2) \right]$$

(2)

where the symbol $\otimes$ represents the convolution over the parton's momentum fraction and the coefficient functions, $\Delta C_i$ with $i = q, \bar{q}, g$, are perturbatively calculable. By fitting all available data on the $g_1$ structure function for proton and neutron at different values of Bjorken $x$ and scale $Q$ and using the DGLAP evolution equation to control the $Q$-dependence of pPDFs, good constraints on polarized valence quark distributions have been obtained [2, 3]. It was also found that the magnitude of polarized sea distributions are much smaller than that of polarized valence quark distributions and uncertainties on sea distributions are much larger.

The HERMES collaboration improved the separation of quark flavors and extracted the sea and strange quark distributions by the measurement of semi-inclusive DIS (SIDIS) production of $\pi^\pm$ and $K^\pm$. With the help of existing quark-to-hadron fragmentation functions, they reported the first determination of leading order (LO) $\Delta \bar{u}$, $\Delta \bar{d}$, and $\Delta \bar{s}$ with the assumption of $[\Delta s/s](x) = [\Delta \bar{s}/\bar{s}](x)$ [2]. The HERMES collaboration found no significant breaking of the flavor symmetry in the light sea and no indication of a negative strange sea contribution in fits to DIS data [2]. Kretzer in his talk emphasized the importance of good knowledge of the relevant fragmentation functions for the interpretation of these SIDIS measurements [4]. The HERMES collaboration also reports the effort to explore the use of SIDIS $\Lambda$ production for improved sensitivity on $\Delta s$ [5].

With the high luminosity at the Jefferson Laboratory (JLab), the double spin asymmetry $A_{LL}$ in inclusive DIS was measured for the first time in and near the resonance region, from which spin structure functions were measured near $x = 1$ [6].

With a very successful 2002 run, the COMPASS collaboration recorded 1.2 fb$^{-1}$ DIS data with a longitudinally polarized target and 0.3 fb$^{-1}$ DIS data with a transversely polarized target. Reconstruction of events and data analysis are underway. The COMPASS collaboration expects to have first physics results soon [7].

The gluon helicity distribution, $\Delta g$, is a key quantity in our understanding of the proton spin. Unfortunately, because gluon contributions only enter the $g_1$ structure function at next-to-leading-order (NLO) order and indirectly via the DGLAP evolution, only limited information on $\Delta g$ has been obtained from inclusive DIS measurements. The Asymmetry Analysis Collaboration (AAC) reports that global fits to all existing inclusive DIS data do not provide good constraints on $\Delta g(x, \mu)$ and do not even determine the sign [3]. With the fact that most hard processes at hadron colliders are dominated by gluon initiated subprocesses, the RHIC spin program will provide promising new information on $\Delta g$.

With the proton spin transversely polarized with respect to the collision axis, a novel helicity flip chiral-odd twist-2 quark distribution – known as transversity distribution, $\delta q(x, \mu)$, is theoretically allowed [8]. However, there is no leading twist gluon transversity because it would require two units of helicity flip. Since perturbative hard processes...
conserve helicity, chiral-odd distributions must appear in pairs. That is, transversity can never be measured in polarized inclusive DIS cross sections.

Although transversity can be in principle extracted from the measurement of double transverse spin asymmetries, \( A_{TT} \propto \delta q(x) \otimes \delta q(x') \), in jet- or inclusive hadron production in polarized hadronic collisions, the asymmetries are often too small to be extracted experimentally because of the dominance (or lack) of gluonic contribution to the unpolarized (or polarized) cross sections [9].

Therefore, \( \delta q(x, \mu) \), is better determined from observables dominated by quark-initiated partonic subprocesses, like \( A_{TT} \) of Drell-Yan, which unfortunately suffers from the low rate at the luminosities presently available at RHIC. The single transverse spin asymmetry \( A_{UT} \) in SIDIS between a unpolarized lepton beam and a transversely polarized target is proportional to a combination of \( \delta q(x) \otimes \Delta D(z, k_T) \) with the Collins’ \( k_T \)-dependent fragmentation function \( \Delta D(z, k_T) \) [10]. Transversity distributions could also be accessed by measuring \( A_{UT} \) in SIDIS in combination with interference fragmentation functions [11].

**Single spin asymmetries in SIDIS**

Single spin asymmetries (SSA) in SIDIS between a unpolarized lepton beam and a polarized target can be achieved via the Collins [10] and Sivers [12] mechanisms at leading twist or the Qiu-Sterman mechanism [13] at twist-3. Because of Lorentz invariance of QCD, we need at least four vectors including the spin vector to construct a physically observed SSA. For example, SSAs in SIDIS should be proportional to \( \epsilon_{\mu\nu\alpha\beta} q^\mu P^\nu S^\alpha p^\beta \) where \( q \) is momentum of the virtual photon, \( P \) (\( S \)) are momentum (spin) of the polarized target, and \( p \) is the momentum of the observed final-state hadron. Consequently, SSAs have a unique \( \sin(\phi) \) dependence with \( \phi \) being the angle between the plane of the three four-vectors \((q, P, S)\) and the plane of the four-vectors \((q, P, p)\).

Let \( q \) and \( P \) define the collision \( z \)-axis and \( p_T \) be the transverse momentum of the observed hadron in this frame, then the SSA should be roughly proportional to the dimensionless coefficient: \( p_T M/(p_T^2 + M^2) \) with the typical hadronic mass \( M \ll Q \) [10]. Therefore, SSAs in general have two distinct regions of phase space: leading twist SSA when \( p_T \ll M \) and twist-3 SSA when \( p_T \gg M \). When \( p_T \) is small, while \( Q \) in SIDIS provides the hard scale required for the validity of the leading twist approximation, SSAs should be proportional to \( p_T/M \); and the Collins and Sivers mechanisms lead to non-vanishing SSAs: \( A_{UT} \propto \delta q(x) \otimes \Delta D(z, k_T) + \Delta f(x, k_T) \otimes D(z) \). The size and sign of the asymmetry are controlled by the nonperturbative \( k_T \)-dependent Collins’ fragmentation function \( \Delta D(z, k_T) \) and the \( k_T \)-dependent Sivers’ distribution function \( \Delta f(x, k_T) \). When \( p_T \) is of order of the hard scale \( Q \), SSAs should be proportional to \( M/p_T \), a typical twist-3 behavior; and Qiu and Sterman show that the SSA is proportional to new twist-3 tri-parton correlation functions and the corresponding partonic hard scattering pieces can be systematically calculated in pQCD [13]. In terms of final-state interaction between outgoing quark and target spectator, Brodsky et al. [14] explicitly demonstrated that the Sivers contribution to SSAs in SIDIS does not vanish.

Both the HERMES collaboration [15] and the CLAS collaboration [16] observed SSAs in \( e + P(S) \rightarrow e' + \pi(p) + X \) when the target proton spins are oriented either along or perpendicular to the direction of incoming lepton, and verified that both \( A_{UL} \) and \( A_{UT} \) are proportional to \( \sin(\phi) \). \( A_{UL} \) is mainly sensitive to the Collins effect while \( A_{UT} \) should include contributions from both the Collins and Sivers effects.
On the theory side, Gamberg [17] reported explicit model calculation of SSAs for both $A_{UL}$ and $A_{UT}$. Afanasev [18] reported a calculation of a beam SSA. Instead of the target spin vector, the beam SSA is due to a polarized virtual photon on an unpolarized target in SIDIS. The beam SSA is suppressed by an extra power of $1/Q$ compared to the SSA from target spin.

Hasuko [19] reported the status of a program to measure spin dependent fragmentation functions at the Belle experiment in Japan. By measuring the final-state hadron azimuthal asymmetry and correlation, it will be possible to extract the Collins function and possibly other chiral-odd fragmentation functions.

** Orbital angular momentum and generalized parton distributions **

Asymptotically, the quarks, including both helicity and OAM, carry about 52% of total proton spin while the gluons carry the rest [20]. Since quark helicity contributes about 20% of the proton’s spin, a significant quark contribution to the proton’s spin must come from its OAM [1]. Therefore, knowing the OAM contribution of partons is crucial for understanding the decomposition of the nucleon’s spin in Eq. (1).

Generalized parton distributions (GPDs) share the same operators as normal parton distributions, but are evaluated with a pair of nucleon states of different momenta. GPDs carry much more information than what parton distributions can provide. Belitsky [21] emphasized that parton orbital angular momentum is directly related to GPDs. He also pointed out that deep virtual Compton scattering (DVCS), recently measured at HERMES, H1 and CLAS, is the cleanest hadronic reaction that gives access to GPDs. The HERMES collaboration reported a measurement of GPDs from SIDIS meson production [22].

Ji et al. [23] introduced a phase-space distribution in terms of the GPDs to describe the probability to find a quark at a given momentum and position. Parton OAM plays an important role in determining the phase-space distribution because of its connection to GPDs. The phase-space distribution provides the possibility to study spatial distributions of partons inside a nucleon.

** RHIC spin program **

The RHIC spin program had its first polarized proton-proton collision two years ago. Two brief polarized proton runs in 2002 and 2003 have resulted in first physics results on transverse spin asymmetries and many important advances in accelerating high current polarized proton beams to high energies as well as proton beam polarimetry at high energies. The main goal of the program is to measure polarized parton distributions, in particular the polarized gluon distribution. However, the combination of available spin orientations and a broad range of experimental processes will also allow to probe the physics beyond the leading twist QCD dynamics as well as beyond the Standard Model.

The STAR Collaboration [24] has measured the single transverse spin asymmetry $A_N$ for pion production both for positive and negative rapidity $y$. In the 2003 run, spin rotators were commissioned and for the first time, double spin asymmetries $A_{LL}$ were measured in a hadron collider. The data analysis for $A_{LL}$ in jet production is in progress and will provide first new information on the gluon helicity distribution [24]. With similar physics motivation, the PHENIX collaboration is carrying out analysis of double spin asymmetries in inclusive hadron production [25].
In order to improve the figure of merit for the asymmetry measurements, MacKay [26] argued that it will be possible for RHIC to raise the beam polarization from 35-40% to 70%. He discussed possible methods and plans to improve the luminosity of the polarized beam, which is now about a factor 30 below the design value. Bravar [27] showed that elastic $p^\uparrow C \rightarrow p^\uparrow C$ has been used successfully as a fast polarimeter at RHIC.

With three DIS machines (HERMES, Compass, JLab) running at different energies and RHIC spin program in a full swing, we will soon have more precise data to cover a wide spectrum of spin physics. A new experiment to test the factorization of SIDIS was just proposed to JLab [28]. Spin physics is getting more and more exciting now!

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