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ABSTRACT BOOK

PARALLEL SESSION

A

The Proton Form Factor Ratio Results from Jefferson Lab

Vina Punjabi

Norfolk State University, Norfolk, Virginia 23504, USA

The ratio of the proton form factors, G_{Ep}/G_{Mp}, has been measured extensively, from Q^2 of 0.5 GeV^2 to 8.5 GeV^2, at the Jefferson Laboratory, using the polarization transfer method. This ratio is extracted directly from the measured ratio of the transverse and longitudinal polarization components of the recoiling proton in elastic electron-proton scattering. The polarization transfer results are of unprecedented high precision and accuracy, due in large part to the small systematic uncertainties associated with the experimental technique. There is an approved experiment at JLab, **GEP(V)**, to continue the ratio measurements to 12 GeV^2. A dedicated experimental setup, the Super Bigbite Spectrometer (SBS), will be built for this purpose. It will be equipped with a focal plane polarimeter to measure the polarization of the recoil protons. The scattered electrons will be detected in an electromagnetic calorimeter. In this presentation, I will review the status of the proton elastic electromagnetic form factors and discuss a number of theoretical approaches to describe nucleon form factors.

Experimental Search for Two-Hard-Photon Exchange in Elastic *ep*

C.F. Perdrisat

The College of William and Mary, Williamsburg, VA 23187, USA

A remarkable change of paradigm was precipitated by the results, obtained 12 years ago, of new measurements of the proton form factor ratio; the two form factors, G_{Ep} and G_{Mp}, are not in a constant ratio, as had been concluded from previous cross section experiments, and would be the case if charge and magnetization spatial distributions were the same. Rather, as the series of polarization measurements at JLab shows, the ratio $\mu_p G_{Ep}/G_{Mp}$ decreases smoothly from 1 at Q^2=0, to about 0.15 at Q^2=8.5 GeV^2 [1], with Q^2 the four momentum transfer. The interesting question is then: how can the results using two methods both related through the Born approximation, be found to lead to a different form factor ratio? The short answer is cross sections require radiative corrections, which tend to mask G_{Ep} for increasing Q^2, whereas recoil polarization experiments measure the ratio of two components of the recoil polarization, which tends to cancel the effect of radiative corrections. Radiative corrections to the cross section of ep scattering have a long history. They may just not be accurate enough when the ratio $G_{Ep}/G_{Mp} \approx 0.05$ and $\tau = Q^2/4{m_p}^2 \approx$2.5. For this Q^2 and with the Born cross section given by $d\sigma \approx G_{Ep}^2 + (\tau/\epsilon)G_{Mp}^2$, with ϵ the kinematic factor, the contribution to the cross section of G_{Ep} becomes smaller than 0.1%, i.e. non-measurable in cross section experiments. The other hypothesis, is that the radiative corrections are incomplete, and that the exchange of two hard photon is the source of the discrepancy [2]; the idea has been pursued in numerous works, but to this day there is no direct evidence that two hard photons exchange is the major source of the discrepancy.

A recent experiment at Jefferson Lab has searched for a kinematical dependence of the G_{Ep}/G_{Mp} ratio [3]. Such a dependence is predicted in models including exchange of two hard photons, and is small. No effect has been observed on the ratio at Q^2=2.5 GeV^2, with uncertainty of 0.01 on a ratio value $\mu_p G_{Ep}/G_{Mp}$=0.69, over a large range of ϵ -values; these results put severe constrains on the behavior of the three corrections terms ΔG_{Ep}, ΔG_{Mp} and $Y_{2\gamma}$ generated by the two-photon contribution [4].

A continuation of the measurement of the ratio by polarization transfer to larger Q^2 would provide different constrains on the two-photon terms than the e+/e-cross section ratio; it would also provide one more definite proof that double polarization experiments determine the actual Born form factors. Kinematical dependence will be measurable with JLab at 12 GeV, for Q^2 up to 4.5 GeV^2, with accuracy comparable to the recent JLab Hall C experiment.

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Accessing the time-like proton form factors in the unphysical region

J. Boucher, A. Dbeyssi, M. Gumberidze, T. Hennino, R. Kunne, B. Ma, D. Marchand, S. Ong, B. Ramstein, E. Tomasi-Gustafsson and J. Van de Wiele

Institut de Physique Nucléaire, CNRS-IN2P3, Université Paris-Sud, 91406 Orsay Cedex, France

With the PANDA detector and the antiproton beams which will be built at the FAIR accelerator complex, it will be possible to get new insight in the proton structure by performing new form factor determination. Indeed, the proton elastic form factor moduli $|G_E|$ and $|G_M|$ will be extracted separately up to $q^2 = 14\,(GeV/c^2)^2$ using the angular distribution of the $\overline{p}p \to e^+e^-$ reaction, while an effective form factor will be determined up to $22\,(GeV/c^2)^2$ by measuring the corresponding integrated cross-section [1]. However, only the kinematical domain $q^2 > 4M_p^2$, where M_p is the proton mass, is available. To access the unphysical region, which is totally unexplored, one may use the $\overline{p}p \to \pi^\circ e^+e^-$ reaction where the neutral pion takes away a part of the system energy allowing to explore a wide q^2 range continuously between q^2_{max}, quite close to s, and almost zero. The first Lagrangian-based calculation [2] of the reaction $\overline{p}p \to \pi^\circ e^+e^-$ has been extended [3] to derive the 5-fold differential cross section and relate it to linear combinations of hadronic tensors. Under the assumption of one nucleon exchange, the hadronic tensors are then expressed in terms of the 2 complex proton electromagnetic form factors. An extraction method which provides an access to the proton electromagnetic form factor ratio $R = |G_E|/|G_M|$ and to the cosine of the phase difference $(\varphi_E - \varphi_M)$ is developed. The determination of the form factor phase difference will be completely new and accessible without measuring any polarization observables. Extended simulations, taking into account the detector acceptance and efficiency, were performed to show how the ratio R and the cosine of the phase difference can be extracted from the e^+ angular distribution in the virtual photon rest frame. The precision on the determination of these quantities is determined using the expected counting rates via Monte Carlo method. Furthermore, a model was developed to calculate the background reaction $\overline{p}p \to \pi^\circ\pi^+\pi^-$, which is kinematically the most serious one. The background to signal ratio was estimated under different cut combinations on the particle identification likelihoods provided by the different detectors and on the kinematical fit confidence levels. As a result [4], the background contribution can be reduced to the percent level or even less, while keeping the corresponding signal efficiency from a few % in the ω vector meson resonance region to 30% for $q^2 = 2\,(GeV/c^2)^2$.

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Exclusive limits of Drell-Yan processes

O.V. Teryaev

141980, JINR, Dubna, Russia

We discuss the Drell–Yan (DY) process and what one can extract from the experimental data at planned PANDA, COMPASS and NICA experiments about the Generalized Parton Distributions and pion Distribution Amplitude. It is stressed that DY data may provide the important complementary information on the shape of the latter. The special role is payed to the virtual boson tensor polarizations and the relevant positivity bounds. The transitions to various exclusive limits are analyzed. The possible relations between various non-perturbative ingredients are discussed.

The Drell-Yan processes admit various exclusive limit. In the first one, for large x_F, the pion is described [1, 2, 3] by its distribution amplitude rather than parton distribution, while the nucleon is still described by (inclusive) parton distributions. The angular distribution of the pair is sensitive to the shape of pion DA which is especially interesting in view of still unresolved [4] BaBar puzzle.

Another step to exclusivity, appearing for small invariant mass of the produced hadronic system, is provided by the description of nucleon by GPDs [5]. this process can be realized at COMPASS even without detecting the final nucleon.

Yet another mechanism (requiring the detection of both final hadrons) is provided by the description of both colliding hadrons by GPDs when the collinear factorization is violated but analytic continuation may be explored [6].

In all the cases the angular distributions for dileptons and positivity bounds [7] for them play the crucial role.

The transition to exclusive limit may represent the duality [8] between the different factorization mechanisms.

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Correlations in Multiple-Parton Interactions

Markus Diehl [a], Tomas Kasemets [a]

[a] DESY, Notketraße 85, 22607 Hamburg, Germany

In double parton interactions the two hard scatterings are correlated via double parton densities. We examine the double Drell-Yan process and the impact of the correlations on the differential cross section. In particular the spin of the interacting quarks correlate the decay planes of the vector bosons, and we investigate upper limits on spin correlations following from positivity of the double parton densities.

Extraction of Sivers functions with TMD evolution

M. Anselmino [a,b], M. Boglione [a,b], S. Melis [c]

[a] Dipartimento di Fisica Teorica, Università di Torino, Via P. Giuria 1, I-10125 Torino, Italy
[b] INFN, Sezione di Torino, Via P. Giuria 1, I-10125 Torino, Italy
[c] European Centre for Theoretical Studies in Nuclear Physics and Related Areas (ECT*), Villa Tambosi, Strada delle Tabarelle 286, I-38123 Villazzano, Trento, Italy

The QCD evolution of unpolarized Transverse Momentum Dependent(TMD) distribution functions and of the Sivers function have been discussed in recent papers [1, 2, 3, 4]. Following these results we reconsider previous extractions of the Sivers function from SIDIS data and propose a simple strategy which allows to take into account the Q^2 dependence of the TMDs. Clear evidence of the TMD evolution can be seen in available data, mostly in the newest COMPASS results off a transversely polarized proton target.

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Bessel-Weighted asymmetries and the Sivers Eect

Leonard Gamberg

Penn State University-Berks, Reading, PA 19610, USA

We revisit the concept of weighted asymmetries [1, 2] in semi-inclusive deep inelastic scattering (SIDIS) and Drell Yan processes. For example in SIDIS, considering the cross section in Fourier space, conjugate to the outgoing hadron's transverse momentum, convolutions of transverse momentum dependent parton distribution functions and fragmentation functions become simple products. Individual asymmetric terms in the cross section can be projected [3] out by means of a generalized set of weights involving Bessel functions. Advantages of employing these Bessel weights are that they suppress (divergent) contributions from high transverse momentum and that soft factors cancel in (Bessel-) weighted asymmetries. Also, the resulting compact expressions immediately connect to previous work on evolution equations for transverse momentum dependent parton distribution and fragmentation functions and to quantities accessible in lattice QCD. Bessel-weighted asymmetries are thus model independent observables that augment the description and our understanding of correlations of spin and momentum in nucleon structure [3]. We will consider the Sivers transverse single spin asymmetry within this framework.

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Sivers Effect and Transverse Single Spin Asymmetry in $e + p^{\uparrow} \rightarrow e + J/\psi + X$

Rohini M. Godbole [a], Anuradha Misra [b], Asmita Mukherjee [c], Vaibhav Rawoot [b].

[a] Centre for High Energy Physics, Indian Institute of Science, Bangalore, India.
[b] Department of Physics, University of Mumbai, Mumbai, India.
[c] Department of Physics, Indian Institute of Technology Bombay, Mumbai, India.

We discuss the possibility of using electroproduction of J/ψ as a probe of gluon Sivers function by measuring single spin asymmetry (SSA) in experiments with transversely polarized protons and electron beams. We estimate SSA for JLab, HERMES, COMPASS and eRHIC energies using color evaporation model of charmonium production and find asymmetry up to 25 % for certain choices of model parameters which have been used earlier for estimating SSA in SIDIS and Drell Yan process.

Quark angular momentum and the Sivers asymmetry

M. Radici [a)], A. Bacchetta[b)]

[a)] Istituto Nazionale Fisica Nucleare, sezione Pavia, via Bassi 6 I-27100 Pavia (Italy)
[b)] Dipartimento Fisica, Università di Pavia, and
Istituto Nazionale Fisica Nucleare, sezione Pavia, via Bassi 6 I-27100 Pavia (Italy)

According to the definition of Ref. [1], the total longitudinal angular momentum of a parton a (with $a = q, \bar{q}$) at some scale Q^2 can be computed as a specific moment of generalized parton distribution functions (GPD):

$$J^a(Q^2) = \frac{1}{2} \int_0^1 dx\, x \Big(H^a(x,0,0;Q^2) + E^a(x,0,0;Q^2) \Big). \tag{1}$$

The GPD $H^a(x,0,0;Q^2)$ corresponds to the familiar collinear unpolarized parton distribution function (PDF) $f_1^a(x;Q^2)$. The forward limit of the GPD E^a does not correspond to any collinear PDF. The only "experimental" information we have is via the nucleon anomalous magnetic moments:

$$\kappa^{p(n)} = \int_0^1 \frac{dx}{3} \Big[2E^{u_v(d_v)}(x,0,0) - E^{d_v(u_v)}(x,0,0) - E^{s_v}(x,0,0) \Big], \tag{2}$$

where u_v, d_v, s_v, indicate the valence contributions.

Inspired by results of the spectator model (see, *e.g.*, Ref. [2]) and theoretical considerations [3], at a specific scale Q_L and for all flavors a we assume

$$f_{1T}^{\perp(0)a}(x;Q_L^2) = -L(x)\, E^a(x,0,0;Q_L^2), \tag{3}$$

where we define the n-th moment of the Sivers function $f_{1T}^{\perp a}$ with respect to its transverse momentum $k_\perp$ as

$$f_{1T}^{\perp(n)a}(x;Q^2) = \int d^2k_\perp \left(\frac{k_\perp^2}{2M^2} \right)^n f_{1T}^{\perp a}(x,k_\perp^2;Q^2), \tag{4}$$

with M the nucleon mass. In Eq. (3), the flavor-independent function $L(x)$ is usually named "lensing function" [4].

The collinear $k_\perp$ moment of the Sivers function can be extracted by fitting data on single-spin asymmetries in semi-inclusive deep-inelastic scattering (SIDIS) on transversely polarized proton targets [5]. In principle, the assumption (3) allows one to constrain both the shape of the GPD E^a, using the SIDIS data, and its integral, using the values of $\kappa^{p(n)}$. We show that it is possible to successfully perform such fit [6].

The outcome of our fit is threefold: *i*) we get a new, more constrained, parametrization of the Sivers function $f_{1T}^{\perp a}(x,k_\perp^2)$; *ii*) we get a new parametrization for the collinear limit of the GPD $E^a(x,0,0)$; *iii*) we can plausibly quantify the quark angular momentum, including the contribution of sea quarks.

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Status on the Transversity parton distribution: the dihadron fragmentation functions way

A. Courtoy [a)], A. Bacchetta [b,c)], M. Radici [b)]

[a)] IFPA, AGO Department, Université de Liège, Belgium
[b)] INFN Sezione di Pavia, via Bassi 6, I-2710 Pavia, Italy
[c)] Dipartimento di Fisica Nucleare e Teorica, Università di Pavia

We present the first observations of the transversity parton distribution based on an analysis of pion-pair production in deep inelastic scattering off transversely polarized targets [1]. This is the first attempt to determine the transversity distribution in the framework of collinear factorization. This extraction relies on the knowledge of dihadron fragmentation functions, which are obtained from electron-positron annihilation measurements. Consequently, we also report on the first extraction of interference fragmentation functions from the semi-inclusive production of hadron pairs in back-to-back jets in e^+e^- annihilation [2]. A nonzero asymmetry in the correlation of azimuthal orientations of opposite $\pi^+\pi^-$ pairs is related to the transverse polarization of fragmenting quarks, inducing a significant polarized dihadron fragmentation function.

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Transverse spin and transverse momentum distributions from COMPASS

Giulio Sbrizzai

Trieste University and INFN

COMPASS is a fixed target experiment at the CERN SPS taking data since 2002. One of the main topics of its broad physics program is the study of the spin structure of nucleons by measuring semi-inclusive deep inelastic scattering (SIDIS) of a high energy muon beam off polarized deuteron and proton targets. In particular the measurements of transverse spin and intrinsic transverse momentum effects are important to understand the nucleon transverse structure. This talk addresses the recent COMPASS preliminary results on this topic. The recent measurement of the Collins and Sivers asymmetries extracted from the data collected in 2010 using a transversely polarized NH3 (polarized proton) target is presented. The interesting results on the spin averaged azimuthal distributions and transverse momentum dependent distributions extracted from the data collected in 2004 on the 6LiD polarized target are also discussed. See also Refs. [1, 2, 3].

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Exclusive ρ^0 muoproduction on transversely polarised protons and deuterons

Katharina Schmidt

Universität Freiburg, Physikalisches Institut, Hermann-Herder-Str. 3, 79104 Freiburg, Germany

The theoretical framework of Generalized Parton Distributions (GPDs) provides a dynamical and geometrical picture of the nucleon. Additional to the longitudinal momentum information of partons they contain information on the transverse localisation of the constituents. The exclusive production of ρ^0 mesons off a transversely polarised target allow to constrain the GPD E which is connected, according to Ji's sum rule, with the total angular momentum of quarks and gluons.
At the COMPASS experiment at CERN measurements were performed scattering a 160 GeV/c muon beam off a transversely polarised ^{6}LiD (2003-2004) and NH_3 (2007, 2010) target. The final state particles are detected with the two-stage spectrometer with high resolution tracking and calorimetry.
This talk gives an introduction to the analysis of exclusively produced ρ^0 mesons in high energy muon scattering off transversely polarised protons and deuterons. Results for the transverse target single spin asymmetry $A_{UT}^{sin(\phi-\phi_s)}$ are presented.

Transversity in exclusive electroproduction of pseudoscalar mesons

P. Kroll

Fachbereich Physik, Universität Wuppertal, D-42097 Wuppertal, Germany

It will be argued that recent measurements on pion electroproduction performed by the HERMES and CLAS collaborations provide clear and almost model-independent indications for strong contributions from transversely polarized virtual photons. Within the handbag approach such contributions are modelled by transversity GPDs accompanied by twist-3 meson wave functions. On the basis of generalized parton distributions constructed from a double distribution ansatz and constrained by lattice QCD, predictions will be presented for various pseudoscalar meson channels and compared with experiment. The talk is based on Refs. [1, 2].

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Diffractive gauge bosons production beyond QCD factorisation

Roman Pasechnik [a] and Boris Kopeliovich [b]

[a] Theoretical High Energy Physics, Department of Astronomy and Theoretical Physics, Lund University, SE 223-62 Lund, Sweden
[b] Departamento de Física, Universidad Técnica Federico Santa María, Casilla 110-V, Valparaíso, Chile

The diffractive radiation of abelian fields expose unusual features, which make it very different from diffraction in DIS, and lead to a dramatic breakdown of QCD factorisation in diffraction.

The first, rather obvious source for violation of factorisation is related to absorptive corrections (called sometimes survival probability of large rapidity gaps), which are absent in diffractive DIS, but strongly suppress the off-diagonal diffractive processes, like those which are under consideration in this paper.

The second, more sophisticated reason to contradict factorisation is specific for abelian radiation, namely, a quark cannot radiate in the forward direction (zero momentum transfer), where diffractive cross sections usually have a maximum [1].

Third, the mechanism of abelian radiation in the forward direction in *pp* collisions is related to participation of the spectator partons in the proton. Namely, the perturbative QCD interaction of a projectile quark is responsible for the hard process of a heavy boson radiation, while a soft interaction with the projectile spectator partons provides color neutralization, which is required for a diffractive (Pomeron exchange) process [2]. Such an interplay of hard and soft dynamics is also specific for the process under consideration, which makes it different from the diffractive DIS, dominated by soft interactions, and which also results in breakdown of factorisation [3, 4].

We discuss the single diffractive gauge bosons (γ^*, $W^\pm$, Z) production in proton-proton collisions at different (LHC and RHIC II) energies in the color dipole approach (for results on the diffractive Drell-Yan case, see Refs. [3, 4]). The calculations are performed at forward rapidities of the lepton pair. The predictions for the diffractive cross sections, differential in momentum fraction and invariant mass of the lepton pair, are presented. We study the physical implications of the QCD factorisation breaking for this class of processes, and point out its effect on the energy and scale dependence of the corresponding cross sections.

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High precision measurements of the neutron spin structure in HallA at JLab

G. Cates [a)], E. Cisbani [b)], G.B. Franklin [c)], N. Liyanage [a)], Z.-E. Meziani [d)], A. Puckett [e)], G. Rosner [f)], B. Wojtsekhowski [g)], X. Zheng [h)]

[a)] University of Virginia, Charlottesville, VA 22904, USA
[b)] INFN Rome - Sanità group, 00161 Rome, Italy
[c)] Cornegie Mellon University, Pittsburgh, PA 15213, USA
[d)] Temple University, Philadelphia, PA 19122, USA
[e)] Los Alamos National Laboratory, Los Alamos, NM 87545, USA
[f)] University of Glasgow, Glasgow G12 8QQ, Scotland, UK
[g)] Jefferson Lab, Newport News, VA 23606, USA
[h)] Massachusetts Institute of Technology, Cambridge, MA 02139, USA

The long standing quest for the origin of the spin of the nucleon is going to take a remarkable leap at the Thomas Jefferson National Laboratory in the coming years.

JLab is undergoing an important upgrade which will double the maximum energy of its high intensity longitudinally polarized electron beam by the beginning of 2014. The beam will be delivered simultaneously on the 3 existing experimental halls (adequately upgraded) and a new hall dedicated to real photon physics.

An intense physics program will exploit the advantages offered by the new JLab experimental equipment to investigate the nucleon spin structure, in terms of high accuracy and extended phase space.

In this respect, high luminosity experiments will be carried on in the Hall A on a polarized 3He target (effective neutron target) in the Deep Inelastic Scattering limit. An inclusive measurement with unprecedented precision [1] will be devoted to the determination of the photon asymmetry A1n at large $x_{Bjorken} \sim 0.71$ in the valence region, where perturbative QCD calculations exist and are sensitive to the quark Orbital Angular Momentum (OAM) contributions to the nucleon wave function. Moreover, combination of these new data with measurements on the proton will permit a flavor decomposition of the polarization of the parton distribution functions. This will be likely one of the early experiments at JLab after the energy upgrade.

In addition, the first high statistics determination of the neutron single spin asymmetry in semi inclusive scattering of pion and kaon off transversely polarized 3He target [2] is also expected to run in Hall A, using the newly developed high luminosity, large acceptance Super BigBite Spectrometer (SBS) [3]. The neutron single spin asymmetry, at leading twist, is related to the Transversity and Sivers quark distribution functions which are sensitive to the relativistic effects inside the nucleon and the quark OAM contribution respectively.

Both experiments will benefit of new GEM (Gas Electron Multiplier) tracking detectors able to operate in the high background flux expected in high luminosity experiments.

In the talk, theoretical and experimental details of the above two precise measurements will be presented.

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QWEAK at Jefferson Lab: precision measurement of the parity-violating e-P asymmetry

P.M. King [a] for the QWEAK collaboration [b]

[a] Ohio University, Athens, Ohio, USA
[b] Jefferson Laboratory, Newport News, VA, USA

The QWEAK experiment is a precision measurement of the parity-violating asymmetry in elastic scattering of longitudinally polarized electrons from the proton at $Q^2 = 0.03$ (GeV/c)^2, with a beam energy of 1.16 GeV. In these kinematics, the leading term of the asymmetry is proportional to the weak charge of the proton, allowing the QWEAK experiment to determine the weak charge of the proton with an expected 4% combined statistical and systematic error. In combination with measurements from atomic parity violation, this will impose a strong constraint on the values of the vector weak charges of the u and d quarks, C_{1u} and C_{1d}; inclusion of the QWEAK data is expected to reduce the allowed phase space of the couplings by about a factor of five[1] compared to the 2010 PDG analyses[2]. This determination of the proton's weak charge may be used to determine the weak mixing angle, $\sin^2\theta_W$, with a relative error of 0.3%, providing a competitive measurement of the running of $\sin^2\theta_W$ to low Q^2. To reach the desired precision, various supplemental measurements must be made to correct the asymmetry or constrain the systematic errors. These include measurements of parity-violation in the N-Δ transition quasielastic scattering from aluminum, and the beam-normal single spin asymmetry arising from two-photon exchange. The QWEAK data collection began in the summer of 2010 and will conclude in May 2012. The status of the data collection and analysis will be discussed.

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Prospective for A Fixed-Target ExpeRiment at the LHC: AFTER @ LHC

J.P. Lansberg [a], R. Arnaldi [b], S.J. Brodsky [c], V. Chambert [a], J.P. Didelez [a], B. Genolini [a], E.G. Ferreiro [d], F. Fleuret [e], C. Hadjidakis [a], A. Rakotozafindrabe [f], P. Rosier [a], E. Scomparin [b] and U.I. Uggerhøj [g]

[a] IPNO, Université Paris-Sud, CNRS/IN2P3, F-91406, Orsay, France
[b] INFN Sez. Torino, Via P. Giuria 1, I-10125, Torino, Italy
[c] SLAC National Accelerator Laboratory, Theoretical Physics, Stanford University, Menlo Park, CA 94025, USA
[d] Departamento de Física de Partículas, Universidade de Santiago de Compostela, 15782 Santiago de Compostela, Spain
[e] Laboratoire Leprince Ringuet, École Polytechnique, CNRS/IN2P3, 91128 Palaiseau, France
[f] IRFU/SPhN, CEA Saclay, 91191 Gif-sur-Yvette Cedex, France
[g] Department of Physics and Astronomy, University of Aarhus, Denmark

We discuss the possibility of the conception of a multi-purpose fixed-target experiment with the proton or lead ion LHC beams extracted by bent crystals. As simple as it seems, the multi-TeV LHC beams will allow for the most energetic fixed-target experiments ever performed. Such an experiment, tentatively named AFTER for A Fixed-Target ExperRiment, gives access to new domains of particle and nuclear physics complementing that of collider experiments, in particular that of Brookhaven's Relativistic Heavy Ion Collider (RHIC) and the projects of Electron-ion colliders (EIC). We have already evaluated that the instantaneous luminosity achievable with AFTER using typical targets would surpass that of RHIC by more than 3 orders of magnitude. Beam extraction by bent crystals offers an ideal way to obtain a clean and very collimated high-energy beam, without decreasing the performance of the LHC. This technique is now becoming mature with successful tests at SPS (450 GeV) and at the Tevatron (900 GeV) and with future tests at the LHC (3.5 or 7 TeV). The fixed-target mode also has the advantage to allow for spin measurements with polarized target and for an access over the full backward rapidity domain up to $x_F \simeq -1$.

The aim of such an experiment is to perform novel studies of rare configurations of the proton wave function which contain gluon or heavy-quarks with high momentum fraction; the gluon content in the deuteron and neutron in a wide momentum-fraction range; the correlation between the proton spin and the gluon angular momentum through the Sivers effect and novel spin correlations; the production of W and Z bosons in their threshold domain; the deconfinement dynamics in the target-rest frame in heavy-ion collisions and the melting of excited heavy-quark bound states in the deconfined QCD phase; the nucleus structure function for momentum fractions close to and above unity; and ultra-peripheral collisions in a fixed-target mode.

Quark phase-space distributions and orbital angular momentum

Cédric Lorcé [a], Barbara Pasquini [b]

[a] IPNO, Université Paris-Sud, CNRS/IN2P3, 91406 Orsay, France
and LPT, Université Paris-Sud, CNRS, 91406 Orsay, France
[b] Dipartimento di Fisica Nucleare e Teorica, Università degli Studi di Pavia, Pavia, Italy,
and Istituto Nazionale di Fisica Nucleare, Sezione di Pavia, Pavia, Italy

We discuss the Wigner functions of the nucleon which provide multi-dimensional images of the quark distributions in phase space. They combine in a single picture all the information contained in the generalized parton distributions (GPDs) and the transverse-momentum dependent parton distributions (TMDs) [1]. In particular, we present results for the distribution of unpolarized/longitudinally polarized quarks in an unpolarized/longitudinally polarized nucleon obtained in a light-cone constituent quark model [2]. We show how quark orbital angular momentum can be extracted from these distributions and compare it with alternative definitions given in terms of the GPDs and the TMDs [2, 3].

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GPD's at HERMES

Aram Movsisyan
(on behalf of the HEMRES collaboration)

Yerevan Physics Institute

The formalism of Generalized Parton Distributions (GPD) is currently considered to be one of the most promising frameworks to provide a three dimensional description of the nucleon structure. An interest to GPDs is also governed by their relation to the quark angular momentum in the nucleon. Experimentally the GPDs can be accessed through measurement of hard exclusive processes such as hard leptoproduction of real photons or mesons. The HERMES experiment at DESY Hamburg studies hard exclusive processes using polarized electron or positron beams from HERA and an internal gas target. Information about GPDs is gained from the measurements of asymmetries that appear in the azimuthal distributions of produced mesons and photons.

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Measurement of Deeply Virtual Compton Scattering (DVCS) cross sections with CLAS

H.S. Jo
For the CLAS Collaboration

IPN Orsay, 91406 Orsay, France

The Generalized Parton Distributions (GPDs) provide a new description of the complex internal structure of the nucleon in terms of its elementary constituents, the quarks and the gluons. The GPDs describe the correlation between the transverse position and the longitudinal momentum fraction of the partons in the nucleon, extending the information obtained from the measurements of the Form Factors and the Parton Distribution Functions. Deeply Virtual Compton Scattering (DVCS), the electroproduction of a real photon on a single quark of the nucleon $eN \to eN\gamma$, is the most straightforward exclusive process allowing access to the GPDs. The DVCS process interferes with the Bethe-Heitler (BH) process, in which the real photon is emitted by either the incoming or the scattered electron instead of the nucleon. A dedicated experiment to study DVCS with the CLAS detector of Jefferson Lab has been carried out using a 5.776 GeV polarized electron beam and an unpolarized hydrogen target, allowing to collect DVCS events in the widest kinematic range ever explored in the valence region : $1 < Q^2 < 4.6$ GeV^2, $0.1 < x_B < 0.58$, $0.09 < -t < 3$ GeV^2. We will present preliminary results on the extraction of the unpolarized DVCS/BH $ep \to ep\gamma$ cross sections and of the difference of the polarized cross sections, this latter being linearly proportional to the imaginary part of the DVCS amplitude, and therefore to the GPDs. We will show the constraints on the GPDs which can be extracted from these results, using some of the latest fitting codes.

Deeply virtual Compton scattering on longitudinally polarized protons and neutrons at CLAS

S. Niccolai, for the CLAS Collaboration

Institut de Physique Nucléaire d'Orsay, Orsay, France

The Generalized Parton Distributions (GPDs), first introduced nearly two decades ago, have emerged as a universal tool to describe hadrons, and nucleons in particular, in terms of their elementary constituents, the quarks and the gluons. Deeply Virtual Compton scattering (DVCS) ($eN \to e'N'\gamma$) is the simplest process to access GPDs of the nucleon (N). The DVCS amplitude interferes with the amplitude for Bethe-Heitler (BH), the process where the real photon is emitted either by the incoming or the scattered electron. The DVCS-BH interference gives rise to spin asymmetries, which can be connected to combinations of GPDs. Depending on the target nucleon (proton or neutron) and on the polarization observable extracted, different sensitivity to the four leading-order twist-2 GPDs (H, E, $\tilde{H}$, $\tilde{E}$) for each quark flavor (u, d) can be exploited.

This talk focuses on results obtained at Jefferson Lab using a nearly-6-GeV polarized electron beam, two longitudinally polarized (via DNP) solid targets of protons (NH_3) and neutrons (ND_3) and the CEBAF Large Acceptance Spectrometer. DVCS/BH events have been selected over the following kinematic range: $1 < Q^2 < 4.5$ GeV^2, $0.1 < x_B < 0.58$, $0.09 < -t < 1.8$ GeV^2. Preliminary results for target-spin asymmetries — mostly sensitive to the u-quark contribution to the imaginary parts of H and $\tilde{H}$ ($Im(H_u)$, $Im(\tilde{H}_u)$) — and double (beam-target) asymmetries ($Re(H_u)$ and $Re(\tilde{H}_u)$) for proton-DVCS, as well as very preliminary extractions for beam- ($Im(E_d)$) and target-spin asymmetries ($Im(H_d)$) for neutron-DVCS will be presented.

Timelike Compton Scattering at JLAB, RHIC and LHC

Jakub Wagner

National Center for Nuclear Research, ul. Hoza 69, 00-681 Warsaw

Generalized Parton Distributions (GPDs) offer a new way to access the quark and gluon nucleon structure. We advocate the need to supplement the experimental study of deeply virtual Compton scattering by its crossed version, timelike Compton scattering (TCS) i.e. the exclusive photoproduction of a lepton pair with large invariant mass [1]. We review recent progress in this domain, emphasizing the need to include NLO corrections [2, 3, 4] to any phenomenological program to extract GPDs from experimental data. We also stress that data on TCS at high energy should be available soon thanks to the proposed experimental program at JLab at 12 GeV, and study of ultraperipheral collisions at the RHIC and LHC which opens a window on quark and gluon GPDs at very small skewness [5].

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The DVCS program in Hall A at Jefferson Lab

Julie Roche

Ohio University, Athens OH 45701, USA.

The DVCS in Hall A/JLab experiments aim at providing data relevant to the *"3-D structure of the nucleon"* exploration by measuring precise absolute cross-sections in the Deep Exclusive domain. Deeply Virtual Compton Scattering off the nucleon ($\gamma^* N \to \gamma N$) is the simplest process which is sensitive to the Generalized Parton Distribution functions. Currently, the DVCS in Hall A program is articulated in three steps. The first generation of experiments [1, 2] showed the importance of precise measurement of absolute cross-section. The second generation of experiments (data under analysis) will provide a complete separation of all terms making up the total cross-section. And the third generation of experiments (data to be taken with the 12 GeV beam at JLab) will provide measurements over an extended kinematic range. In this talk, I will review the status of the DVCS in Hall A program.

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Theory and phenomenology of helicity amplitudes for high energy exclusive leptoproduction of the $\rho-$meson

A. Besse [a)], S.Wallon [a) c)], L. Szymanowski [b)]

[a)] LPT Orsay, Universite Paris-Sud, CNRS, 91405, Orsay, France
[b)] National Center for Nuclear Research (NCBJ), Warsaw, Poland
[c)] UPMC Univ. Paris 06, faculte de physique, 4 place Jussieu, 75252 Paris Cedex 05, France

Exclusive leptoproduction of vector mesons has been the subject of recent significant progress, both theoretically and experimentally. In particular, the hard regime with a highly virtual photon exchange allows to separate a short distance dominated amplitude of hard subprocess from suitably defined hadronic objects. However, a consistent picture is still missing, in particular for contributions to the scattering amplitude beyond the leading power in the photon virtuality.

We recently described the hard production of transversally polarized rho-meson, up to twist 3 accuracy, including 2- and 3- particles Fock-states, in the HERA kinematics of high center-of-mass energy. Futhermore, we here show how saturation effects could be included in our model. This is based on the dipole representation of the scattering amplitude in coordinate space, which we extend up to twist 3, based on our previous studies of the scattering amplitude in momentum space. We compare our model with H1 and ZEUS data for the ratios of helicity amplitudes $T(\gamma_T^* \to \rho_T)/T(\gamma_L^* \to \rho_L)$ and $T(\gamma_T^* \to \rho_L)/T(\gamma_L^* \to \rho_L)$ and get a good description of the data.

πN transition distribution amplitudes and backward electroproduction of pions

K. Semenov-Tian-Shansky

IFPA, département AGO, Université de Liège, 4000 Liège, Belgium

The extension of the concept of generalized parton distributions (GPDs) leads to the introduction of baryon to meson transition distribution amplitudes (TDAs), non-diagonal matrix elements of the nonlocal three quark operator between a nucleon and a meson state. These non-perturbative objects appear as a building block in the collinear factorized description of amplitudes for a class of hard exclusive reactions prominent examples being hard exclusive pion electroproduction off a nucleon in the backward region and baryon-antibaryon annihilation into a pion and a lepton pair.

We discuss general symmetry properties of baryon to meson TDAs following from the underlying symmetries of QCD. We generalize the notion of double distributions introduced in the context of GPDs and construct the spectral representation for baryon to meson TDAs in terms of quadruple distributions. Using chiral symmetry together with the crossing relation between πN TDAs and πN generalized distribution amplitudes we establish the threshold soft pion theorem for πN TDAs which determines the magnitude of πN TDAs at a low normalization point. We propose a factorized Ansatz for the corresponding quadruple distributions with input from the soft pion theorem. The spectral representation is complemented with a D-term like contribution from the nucleon exchange in the cross channel.

We study backward pion electroproduction in the QCD collinear factorization approach and present estimates of the cross section and of the transverse target single spin asymmetry. Finally we discuss perspectives of experimental measurements.

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Measurement of Collins Asymmetries in inclusive production of pion pairs in e^+e^- collisions at *BaBar*

Fabio Anulli (for the *BaBar* Collaboration)

Istituto Nzionale di Fisica Nucleare, Sezione di Roma, I-00185 Rome, Italy

The transversity distribution function, which describes the quark transverse polarization inside a transversely polarized nucleon, is the least known leading-twist component of the QCD description of the partonic structure of the nucleon. Transversity can be extracted from semi-inclusive deep inelastic scattering (SIDIS) data, where, however, it couples to a new fragmentation function, called Collins function [1]. Indipendent information on the Collins function can be obtained from inclusive studies of e^+e^- annilihation processes. We present a preliminary measurement of the azimuthal asymmetries in the process $e^+e^- \to q\bar{q} \to \pi\pi X$, where the two pions are produced in opposite hemispheres, based on a data sample collected by the *BABAR* experiment at a center-of-mass energy of about 10 GeV. The Collins function is then extracted from the measured asymmetries; the obtained results can be compared to previous measurements performed by the Belle experiment [2, 3], and can be used for global analyses combining e^+e^- and SIDIS data, as done in Ref [4].

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Finite-t and target mass corrections in off-forward hard reactions

V. M. Braun [a)], A. N. Manashov [a,b)]

[a)] Institut für Theoretische Physik, Universität Regensburg, D-93040 Regensburg, Germany
[b)] Department of Theoretical Physics, St.-Petersburg University, 199034, St.-Petersburg, Russia

We develop a general approach to the calculation of target mass and finite $t = (p' - p)^2$ corrections in hard processes which can be studied in the framework of the operator product expansion and involve momentum transfer from the initial to the final hadron state. Such corrections, which are usually referred to as kinematic, can be defined as contributions of operators of all twists that can be reduced to total derivatives of the leading twist operators. As the principal result, we provide a set of projection operators that pick up the "kinematic" part of an arbitrary twist-four operator in QCD [1, 2]. A complete expression is derived for the time-ordered product of two electromagnetic currents that includes all kinematic corrections to twist-four accuracy. The results are immediately applicable to the studies of deeply-virtual Compton scattering [3, 4, 5], transition $\gamma^* \to M\gamma$ form factors and related processes.

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