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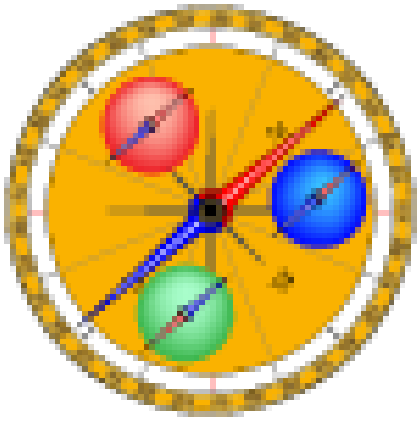

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Session I-a / **1**

Welcome

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Session I-a / **99**

Partonic dynamics and the 3D structure of the nucleon: a global view

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Hadrons emerge as strongly interacting, relativistic bound states of quarks and gluons in Quantum Chromodynamics (QCD), and have complex dynamical internal structure, which are only beginning to be revealed in modern experiments. Since no modern detector can see quarks and gluons in isolation, it is an unprecedented intellectual challenge to "see"and quantify the partonic dynamics and 3D hadron structure. In this talk, I will provide a global view on what have we learned about the hadron structure? how to quantify the hadron structure? and what do we expect to learn in a near future with the existing and future facilities, as well as from lattice QCD?

Session I-a / **63**

TMD theory: factorization, evolution & universality

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I will give an overview of the current state of TMD factorization theory. Focus will be placed on the interface between perturbative and non-perturbative methods. I will end by commenting on prospects for future developments.

Session I-b / **106**

Matching the TMD and collinear factorization framework

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In this talk I will discuss recent work on an improved implementation of the Collins Soper Sterman formalism for combining transverse-momentum-dependent (TMD) factorization and collinear factorization in semi-inclusive DIS (SIDIS). I focus on our extension to the case of polarized observables; in particular the Sivers contribution to the transversely polarized target cross section. We demonstrate how one recovers the expected leading-order collinear twist-3 result from a (weighted) qT -integral of the differential cross section. We are also able to re-derive at leading order the well-known relation between the TMD Sivers function and the (collinear twist-3) Qiu-Sterman function within this framework. This relation allows for the interpretation that the first moment of the Sivers function describes the average transverse momentum of unpolarized quarks in a transversely polarized spin-1/2 target.

Session I-b / **123**

OVERVIEW OF COMPASS RESULTS IN SIDIS AND FUTURE PLANS

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The COMPASS Experiment at CERN is celebrating this year the 20th anniversary of its'activity after the approval in 1997 and in this presentation an overview of the recent results on the Transverse Momentum Dependent (TMD) effects in semi-inclusive DIS reactions will be given. TMD effects have been investigated both in unpolarised SIDIS by measuring the dependence of charged hadrons multiplicities from the transverse momentum PhT and by measuring the azimuthal cosφ and cos2φ modulations related to Cahn and to the Boer-Mulders TMD PDF, in transversely polarised SIDIS by measuring the Collins, the Sivers and all the others transverse spin dependent asymmetries, and recently also in the first ever polarized Drell-Yan experiment, started in 2015. The measurement of the Sivers and all other azimuthal asymmetries at com- parable hard scale in polarized SIDIS and Drell-Yan at COMPASS provides a unique possibility to test predicted universal and process-dependent features of TMD PDFs using essentially similar experimental setup and equipment. The implication of these results will be discussed. Future plans for the investigations of TMDs both in COMPASS and further in the future at the planned EIC will be also briefly presented.

Session I-b / **75**

Weighted Sivers asymmetry in SIDIS at COMPASS

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The Sivers function - one of the most interesting transverse momentum dependent parton distribution functions - can be accessed in the semi-inclusive deep inelastic scattering of leptons off transversely-polarised nucleons by measuring the Sivers asymmetry in hadron production. COMPASS has measured it to be nonzero using a muon beam and a transversely polarised NH3 target. In this talk, the new results of the Sivers asymmetry weighted by powers of the outgoing hadron momentum PT are presented. The weighted asymmetry can be interpreted as a product of the quark Sivers function and fragmentation function, unlike the conventional asymmetry, which is their convolution. The potential of the weighted method is illustrated on a Sivers function first moment

extraction. The result is used to make a straightforward comparison with the weighted asymmetry measured in the Drell-Yan process, recently released by COMPASS.

Session I-b / 83

HERMES results on TMDs and GPDs

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The HERMES experiment collected from 1995 to 2007 a wealth of deep-inelastic scattering data using 27.6 GeV longitudinally polarized electrons and positrons and various unpolarized as well as longitudinally and transversely polarized gas targets. This allowed for a series of diverse measurements. Among them are measurements that provide information on the three-dimensional structure of the nucleon both in momentum space and in mixed momentum and position space. Results from HERMES on semi-inclusive deep-inelastic scattering, providing access to the three-dimensional quark distributions in momentum space, as well as on hard exclusive processes, sensitive to generalized parton distributions and thus to the three-dimensional nucleon structure in mixed momentum and position space, are presented and discussed.

Session I-c / 91

Final state interactions and neutron SSAs from SIDIS by a transversely polarized 3He target

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The time reversal-odd parton transverse momentum distributions (TMDs) in the neutron can be studied through semi-inclusive deep inelastic scattering (SIDIS) experiments off transversely polarized 3He, where a high-energy pion (or kaon) is detected in coincidence with the scattered electron. To disentangle the nuclear and the partonic degrees of freedom, an accurate theoretical description of the process is needed. In a preliminary paper on this subject (S. Scopetta, Phys. Rev. D, 2007), the plane wave impulse approximation (PWIA) was adopted. It was found that the nuclear effects described in PWIA can be taken into account in a simple effective way, and a procedure to safely extract the neutron Collins and Sivers single spin asymmetries (SSAs) was proposed. Later, the spectator SIDIS process off 3He was studied (L.P. Kaptari et al, Phys. Rev. C, 2014), and the final state interaction (FSI) between the hadronizing quark and a recoiling deuteron was taken into account through a distorted spin-dependent spectral function. Very recently (A. Del Dotto et al., Phys. Rev. C 2017, in press), in the same framework, we have completed the analysis of the standard SIDIS process, with the FSI between the observed meson and any possible remnant taken into account. The result, very interesting in particular for the experiments running at the 12 GeV upgrade of Jlab and for the program of the planned electron-ion collider, is that, in the nuclear SSA, the effect of FSI cancels to a large extent and the ususal extraction appears to be safe. An extension of the approach to a relativistic treatment (see A. Del Dotto et al, Phys. Rev. C 2017 for formal developments) will be also addressed.

Session I-c / 111

The SIDIS program at Jefferson Lab

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It goes without saying that transverse momentum dependent distribution functions (TMDs) have emerged as a new and unique window into the dynamics of the nucleons's constituents confined motion as well as offer a platform for continued tests of our understanding of QCD. In this presentation I shall describe a coherent semi-inclusive deep inelastic (SIDIS) experimental program in the valence quark region tailored to support key scientific questions discussed in this workshop. This program was designed and optimized with the use of a variety of polarized and unpolarized targets (protons, deuterons and helium-3s) in tandem with specialized detectors across Halls A, B and C at Jefferson Lab. Today, we are at the dawn of this SIDIS program which promises to provide precision measurements of many important observables relevant to the extraction of the nucleon TMDs as well as advance our understanding of QCD by also investigating the hadronization of struck quarks into mesons, a property close to confinement.

Session I-c / 124

On the extraction of Boer-Mulders functions

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At present, the Boer-Mulders (BM) functions are extracted using the simplifying assumption of their proportionality to the Sivers functions. Here we present 2 independent tests for this assumption using the so-called difference asymmetries i.e. the difference between the cross sections for production of particles and their anti-particles.
Then we apply COMPASS data on SIDIS for the ⟨cos ϕh⟩, ⟨cos 2ϕh⟩ and Sivers asymmetries to these tests. Our analysis shows that it is compatible with the available data if the proportionality is the same for all quark flavours, which, however, does not correspond to the values obtained in existing analysis. This suggests that the published information on the BM functions may be unreliable. The ⟨cos ϕh⟩ and ⟨cos 2ϕh⟩ asymmetries receive contributions also from the, in principle, calculable Cahn effect. We succeed in extracting the Cahn contributions from experiment (we believe for the first time) and compare with their calculated values. Surprisingly, the calculated values agree with the extracted ones only for the old experimental values ⟨k^2_T>=0.18 GeV^2 and ⟨k^2_T>= 0.25 GeV^2 and completely disagree with the much bigger present-day values. The results are based on paper arXiv:1705.10613

Session I-d / 98

Transverse SSAs in pp collisions

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The Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory is the world's only polarized proton collider with center-of-mass energies up to 500 GeV and polarizations of about 60%

for each proton beam and the the worlds most versatile collider, able to collide different species over an extremely wide kinematic range. It provides unique opportunities to study the spin structure in hadronic systems and opens new kinematic regions compared to deep inelastic scattering. The three pillars of the RHIC spin program cover the gluon polarization, sea quark helicity distributions, and transverse spin effects in hadronic systems. The talk will summarize recent results and discuss near term plans and their implications on parton distribution functions in the transverse momentum dependent framework. In addition the new results and unique opportunities to study nuclear effects in the initial and final state will be presented as well.

Session I-d / **88**

Phenomenology of TMDs

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In my talk I will review the current status of studies of 3D structure of the nucleon. I will pay special attention to recent developments in phenomenology of Transverse Momentum Dependent distributions. Current status of phenomenology and prospects for future will be discussed.

Session I-d / **69**

Global fit of unpolarized partonic TMDs

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Transverse momentum dependent (TMD) distributions describe the internal structure of the nucleon in terms of its elementary constituents, including also the dependence on the transverse momentum. TMDs parton distribution (PDF) and fragmentation functions (FF) cannot be easily computed from rst principles, because they require QCD calculations in its nonperturbative regime. We present an extraction of unpolarized TMDs, derived from a simultaneous fit of available data measured in semi-inclusive deep-inelastic scattering, Drell-Yan and Z boson production and taking into account also contributions of TMD evolution at next-to-leading logarithmic accuracy. We discuss the results obtained from this first attempt at a global fit of TMDs and possible future improvements.

Session II-a / **125**

TMDs and spin asymmetries in SIDIS

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In recent years the measurements of single spin asymmetries (SSAs) in final state hadronic distributions in semi-inclusive processes have been widely used to access the underlying Transverse Momentum Dependent (TMD) parton distributions. The detailed understanding of the orbital structure of partonic distributions, encoded in TMD PDFs has been widely recognized as one of the key objectives of the JLab 12 GeV upgrade, and a driving force behind the construction of the Electron Ion

Collider.
Although the interest to TMD PDFs has grown enormously, we are still in need of fresh theoretical and phenomenological ideas. The main challenges still remaining is the extraction of actual TMDs from different spin and azimuthal asymmetries in a reliable and model independent way.
In this talk, we present an overview of the latest developments and future studies of the TMD PDFs from variety of observables accessible in semi-inclusive DIS at different facilities worldwide.

Session II-a / 94

First extraction of transversity from a global fit

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We present the first extraction of the transversity distribution in the frame- work of collinear factorization based on the global analysis of pion–pair pro- duction in deep–inelastic scattering off transversely polarized targets and in proton–proton collisions with one transversely polarized proton. The extrac- tion relies on the knowledge of dihadron fragmentation functions, which are taken from the corresponding electron–positron annihilations. This analysis starts a new phase, deepening our knowledge of the chiral–odd transversity to the same qualitative level as the chiral–even spin averaged and helicity dis- tributions. The improved accuracy of the calculated nucleon tensor charge opens a new way to explore possible effects from new physics in high–precision low–energy nucleon/nuclear cross sections.

Session II-a / 81

Recent analysis of Drell-Yan data

Author: Ignazio Scimemi[1]

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We present a comprehensive analysis and extraction of the unpolarized transverse momentum dependent (TMD) parton distribution functions, which are fundamental constituents of the TMD factorization theorem. We provide a general review of the theory of TMD distributions, and present a new scheme of scale fixation. This scheme, called the ζ-prescription, allows to minimize the impact of perturbative logarithms in a large range of scales and does not generate undesired power corrections. Within ζ-prescription we consistently include the perturbatively calculable parts up to next-to-next-to-leading order (NNLO), and perform the global fit of the Drell-Yan and Z-boson production, which include the data of E288, Tevatron and LHC experiments. The non-perturbative part of the TMDs are explored checking a variety of models. The numerical evaluations are provided by the "arTeMiDe" code, which is introduced in this work and that can be used for current/future TMD phenomenology.

Session II-b / 64

Transversity in inclusive deep inelastic scattering

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A new collinear factorization analysis of inclusive DIS scattering with suitable non-perturbative "jet correlators"shows that a novel, non-perturbative spin-flip term associated with the invariant mass of the produced hadrons couples to the target's transversity distribution function. In inclusive cross sections, this provides a hitherto neglected and large contribution to the twist-3 part of the g2 structure function, which can explain the discrepancy between recent calculations and fits of this quantity. It also provides an extension of the Burkhardt-Cottingham sum rule, now featuring an interplay between the g2 and h1 functions that calls for a re-examination of their small-x behavior, as well as an extension of the Efremov-Teryaev-Leader sum rule, suggesting a novel way to measure the tensor charge of the proton. As part of the calculation leading to these results, novel TMD sum rules are derived.

Session II-b / **70**

JAM extractions of helicity and transversity distributions

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It is well known that polarized semi-inclusive deep-inelastic scattering (SIDIS) observables play an important role in determining the spin structure of the proton. In addition to being used in global QCD analyses to constrain quark helicity distributions, especially for the sea quarks, SIDIS can also give information about the quark structure of a transversely polarized nucleon. In this talk, I will summarize recent efforts by the JAM collaboration to extract quark helicity and transversity distributions from SIDIS asymmetries using Monte Carlo statistical methods.

Session II-b / **117**

Theory status of GPDs

Author: Kresimir Kumericki[1]

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After a brief reminder of the role of GPDs in description of hadron structure, I will review what is known about these functions after a decade and a half of experiments and fits to the data, with emphasis on DVCS. I will show results of global fits, both in traditional and in neural network approach, and discuss the project of public web page serving the resulting GPDs or Compton factors to the community. I will also discuss main challenges for phenomenology in the light of recent and forthcoming experiments.

Session II-b / **110**

Experimental Overview of GPDs

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Generalised Parton Distribution functions (GPDs) have emerged as a very powerful tool to investigate the three-dimensional structure of nucleons, as they encode the correlation between the longitudinal momenta and the transverse positions of their constituents, quarks and gluons. GPDs appear in the non-perturbative description of lepton-induced exclusive reactions, and can be studied in fixed target or collider experiments where a lepton beam interacts with proton or nuclear targets. The mapping of GPDs over the widest possible kinematical domain requires a combined analysis of experimental data collected at different beam energies, and is one of the major physics goals of ongoing and planned experiments at CERN and Jlab. Deeply Virtual Compton Scattering (DVCS), that is the exclusive production of a single real photon in lepton-nucleon interactions, is considered as the "golden" channel for accessing GPDs. However, different combinations of quark and gluon GPDs can be accessed when the photon is replaced by a meson in the final state (Deeply Virtual Meson Production or DVMP). In my talk I will revise the current status of DVCS and DVMP measurements, with particular emphasis on the recent results from Jlab and CERN. In my summary I will also give some perspectives offered by possible future facilities.

Session II-b / **90**

Determination of generalized distribution amplitudes from experimental measurements

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In order to understand the origin of proton spin, it is necessary to probe contributions from partonic orbital angular momenta. Recently, the generalized parton distributions (GPDs) have been investigated to find the partonic orbital-angular-momentum contributions. The GPDs contain information on form factors and parton distribution functions, and they are investigated by the deeply virtual Compton scattering (DVCS). By taking the s-t crossing channel of DVCS, the generalized distribution amplitudes (GDAs) can be studied in the two-photon process $\gamma\gamma \to h$ *hbar which is accessible at KEKB. In 2016, the Belle collaboration reported measurements for the differential cross section on the process* $\gamma\gamma \to \pi^0\pi^0$ in the e^+e^- collision. The pion GDAs should be obtained by analyzing these Belle data. In our analysis, the resonance effects, especially from scalar and tensor mesons f0(500) and f2(1270), are considered to explain the Belle data in addition to the GDA continuum contributions. The GDAs are expressed by a number of parameters, which are determined by a χ^2 analysis. Then, the form factors of the energy-momentum tensor are calculated from the pion GDAs. This is the first finding on gravitational form factors and radii of hadrons from actual experimental measurements: we obtained the mass radius (0.56-0.69 fm) and the mechanical radius (1.45-1.56 fm). In 2018, Belle II will begin to collect data with the upgraded SuperKEKB, so that the errors of the $\gamma^*\gamma \to \pi^0\pi^0$ cross sections should be significantly reduced and that the GDAs of other hadrons can also be investigated. Our studies are valuable in understanding the 3D structure and gravitational properties of hadrons.

Session II-c / **109**

Studies of GPDs (and Time-like Compton Scattering) at Jefferson Lab

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Key properties of the nucleon are encoded in the correlation between their longitudinal momentum and their transverse position, such as the orbital angular momentum. This correlation is expressed through Generalized Parton Distributions (GPDs), which can be understood as spatial densities at different values of the longitudinal momentum of the quark. Validation of our understanding of hard exclusive reactions (pions, kaons, photons) is an essential aspect towards such 3D hadron imaging and potential future flavor decomposition. The key to extracting GPDs from experiment is QCD factorization theorems. Deeply Virtual Compton Scattering (DVCS) is generally thought of as the cleanest tool for accessing the valence quark GPDs. A new and promising opportunity for constraining GPDs is presented by Timelike Compton scattering (TCS) the inverse process to space-like DVCS. TCS offers straightforward access to the real part of the Compton amplitude. Combining space-like and time-like data thus makes it possible to test the universality of GPDs. To potentially extract flavor separated GPDs from experiment, one has to validate the meson factorization theorems, which requires measuring the separated longitudinal and transverse cross sections and their -t and Q2 dependencies. Recent data and prospects for deep exclusive pion, both charged and neutral, and kaon electroproduction are presented, which conceptually would allow for flavor separations. The addition of a neutral particle detection facility and compact photon source would significantly augment these scientific capabilities. We will give an overview of the scientific program enabled by such a facility, and discuss its requirements and plans.

Session II-c / **114**

Exclusive meson production with CLAS/CLAS12 and transverse GPDs

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Generalized Parton Distributions (GPDs) provide a route to spatial tomography of the nucleon, and have revolutionized how we characterize the nucleon structure, by providing a unified description of quark densities in spatial coordinates in relation to their momenta. GPDs can be accessed by measuring hard exclusive processes such as deeply virtual Compton scattering (DVCS) and deeply virtual meson production (DVMP). Studies of the GPDs will be one of the flagship programs of the 12 GeV CEBAF upgrade and a driving force behind the construction of the Electron Ion Collider (EIC). In this talk, I present recent results of the unpolarized differential cross sections and beam/target asymmetries from deeply virtual neutral pion and eta productions in the deep inelastic regime with the CEBAF Large Acceptance Spectrometer (CLAS), and I will also give an overview of the future programs with CLAS12 at Jefferson Lab.

Session II-c / **112**

Exclusive Measurement of DVCS off 4He at 6 GeV and proposal for the 12 GeV

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Inclusive deep inelastic scattering experiments have been instrumental in advancing our understanding of the Quantum Chromodynamics (QCD) structure of nuclei and the effect of nuclear matter on the structure of hadrons. A great example is the observation by the European Muon Collaboration (EMC) of a deviation of the deep inelastic structure function of a nucleus from the sum of the structure functions of the free nucleons, the so-called EMC effect. On the theory side, despite decades of theoretical efforts with increased sophistication, a unifying physical picture of the origin of the EMC effect is still a matter of intense debate. To reach the next level of our understanding of nuclear QCD and unravel the partonic structure of nuclei, experiments need to go beyond the inclusive measurements and focus on exclusive and semi-inclusive reactions. In this talk, results of the first exclusive measurement of deeply virtual Compton scattering off He-4 will be presented. Future measurements at Jefferson Lab 12 GeV using a new CLAS12 Low Energy Recoil Tracker (ALERT) will be discussed.

Session II-c / **108**

On the Dynamical Origin of Proton Angular Momentum

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The quark orbital angular momentum component of the proton spin, Lq, can be defined in QCD both as the integral of a Wigner phase space dis- tribution weighing the cross product of the quark' s transverse position and momentum, and in terms of a twist-three Generalized Parton Distribution (GPD). I will present results on the link between the two definitions, which reflects their dependence on partonic intrinsic transverse momentum. Con- necting the definitions provides the key for correlating direct experimental determinations of Lq in both nucleons and atomic nuclei, with ab-initio QCD calculations.

Session II-d / **65**

PARTONS project: status, features and perspectives

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Generalised Parton Distributions (GPDs) have been introduced 20 years ago and have become one of the main topic of research in Hadron physics both experimentally and theoretically. A significant amount of beam time will be dedicated to their studies after the completion of the JLab upgrade to 12 GeV. However, until now, the GPD community misses the adequate tools to perform systematic studies of GPDs, i.e. allowing people to study the effect of different GPD models, perturbative truncations, twist truncations, evolutions... on different experimental channels. The PARtonic Tomography of Nucleon Software (PARTONS) project is an attempt to answer this need. Capitalising on 4 years of work, the software presents a very flexible architecture allowing the users to implement their own modules without touching the core. The first version is now ready for the public release but awaits the required authorisations and licensing. In this talk, I will presents the different functionalities of PARTONS and highlight how such a software can help us to understand the nucleon structure.

Session II-d / **122**

Transverse spin effects in Drell-Yan processes

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Since long time the Drell-Yan process has been proved to be a very powerful tool to probe the quark and antiquark structure of hadrons. More recently it has been playing a key role in investigating the transverse structure of hadrons thanks to new ongoing and upcoming DY measurements at several facilities in the world. In this talk I will review the current state of studies of transverse structure of hadrons through DY processes, focusing on some open issues which can be addressed in future polarized and unpolarized DY experiments at the existing or forthcoming facilities.

Session III-a / **78**

COMPASS results and program on Drell-Yan measurements

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The COMPASS experiment at CERN (SPS, North area, M2 beamline), as part of its programme addresses the exploration of the spin structure of the nucleon by measuring spin (in)dependent azimuthal asymmetries in semi-inclusive DIS and, recently, also in Drell-Yan processes. Between 2002 and 2011 COMPASS performed a series of SIDIS measurements, using a longitudinally polarized muon beam impinging on longitudinally and transversely polarized 6LiD or NH3 targets. Drell-Yan measurements with a π- beam interacting with a transversely polarized NH3 target started with the 2015 run and will be continued in 2018. The measurement of the Sivers and other azimuthal asymmetries at similar hard scale in polarized SIDIS and Drell-Yan is a complementary and unique possibility to test predicted in QCD (pseudo-)universal features of transvers momentum dependent parton distribution functions. The main focus of this talk will be set on the results of the first ever polarized Drell-Yan measurements performed by COMPASS and related SIDIS results.

Session III-a / **113**

Azimuthal distributions in the Drell-Yan process

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We discuss various aspects of azimuthal asymmetries in the Drell-Yan process, focusing on the role of perturbative-QCD calculations. We address both the fixed-target and the collider regime. Furthermore, we present new pQCD predictions for the Drell-Yan cross section averaged over the azimuthal angle, where we discuss the role of QCD threshold resummation.

Session III-a / **97**

Drell-Yan lepton angular dependencies at the LHC

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The angular distributions of Drell-Yan charged lepton pairs in the vicinity of the Z-boson mass peak probe the underlying QCD dynamics of Z-boson production. This talk presents measurements from ATLAS and CMS collaborations on the set of angular coefficients A0-A7 describing these distributions using pp collisions at √s=8 TeV at the LHC. The measurements are compared to the QCD predictions at leading order, next-to-leading order, and next-to-next-to-leading order in perturbation theory. Drell–Yan charged lepton pairs in addition allow the transverse momentum of Z/γ* bosons, pT(ll) to be measured. The latter requires a precise understanding of the pT calibration and resolution of the final-state leptons. To minimize the impact of systematic uncertainties, the *φ observable derived from the angles subtended by the leptons is introduced. Its resolution is significantly better than that of pT(ll) and therefore it can be used as an alternative probe of pT(ll). Finally, the angular distributions of charged leptons and in particular the angular variable cosθ* between the outgoing lepton and the incoming quark in the Collins–Soper frame is useful for the measurement of the forward-backward asymmetry AFB in the production of Drell–Yan lepton pairs. In turn, measurements of AFB are used to extract the effective weak mixing angle. In this talk, measurements from ATLAS, CMS and LHCb experiments on φ*, cosθ* and AFB are presented at √s = 7,8 and 13 TeV.

Session III-b / **102**

Results on Fragmentation Functions from e+e- facilities

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The precise knowledge of fragmentation functions is necessary for our understanding of hard scattering processes where particles in the final state are detected in terms of factorized pQCD cross-sections.
Studying electron-positron annihilation provides the cleanest access to fragmentation functions. In particular, our knowledge of polarization dependent fragmentation functions have benefited enormously from the data collected at the Belle, BaBar and BES III experiments taking data at the B-factories KEKB and PEP-II as well as the tau-charm factory BEPC-II.
This talk will give an overview of the latest results from these facilities as well as an outlook towards the study of hadronization at the Belle II experiment which will take data at SuperKEKB starting in 2018.

Session III-b / **100**

BELLE: new results on fragmentation and perspectives

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Fragmentation functions, describing the formation of hadrons from partons, are an indispensable tool in the interpretation of hadron-production data, e.g., in the investigation of nucleon structure

via semi-inclusive deep-inelastic scattering. The cleanest process to access fragmentation functions is hadron production in electron-positron annihilation. However, little information can be derived on charge-separated fragmentation functions from single-inclusive hadron production. A better handle on the flavor contributions can be gotten by flavor correlations or tagging: the hadron type in one hemisphere puts constraints on the parton flavor in the other hemisphere and thus on the flavor decomposition of the hadronization process. This can be exploited in inclusive hadron-pair production in electron-positron annihilation. While two hadrons in opposite hemispheres can be used for flavor tagging of single-hadron fragmentation functions, two hadrons in the same hemispheres, e.g., originating from the same parton, open an avenue to a different class of fragmentation functions: dihadron fragmentation functions. They depend not only on the energy fractions of the virtual photon carried by the hadrons but also on the invariant mass of the two hadrons (besides the usual scale dependence). Both scenarios have recently been subject to studies at the Belle experiment. The dependences of the production cross section of pairs of identified light mesons (charged pions and kaons) on the individual z of the mesons or on the combined z and the invariant mass were measured and will be presented as well as discussed in this talk.

Session III-b / 121

Polarized quark TMD fragmentation functions: formalism and MC results

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We present our calculations of the polarization- and transverse momentum dependent single hadron fragmentation functions (FF) and dihadron fragmentation functions (DiFF) using the most recent quark-jet model. In this extension of the model the complete description of a polarized quark state after each step of hadron formation was given, based on a self-consistent treatment of the quark polarization transfer. For the first time all eight leading twist quark-to-quark plus unpolarized hadron splitting functions are taken into account. The resulting integral equations and sum rules shortly discussed for the case of inclusive pion production. Next, we describe the Monte Carlo framework for polarized quark hadronization, and the methods used to extract both single and dihadron FFs from simulated samples. We present the results for these functions, as well as the corresponding analyzing powers. Our model analyzing powers: 1) for a single hadron production are large and have an opposite sign for favored and unfavored channels; 2) for two oppositely charged hadrons production in transversely polarized quark fragmentation are comparable in magnitude with single hadron ones; 3) for two oppositely charged hadrons production in longitudinally polarized quark fragmentation are much smaller in magnitude than those for the transversely. We also note that in general, different combinations of the fully unintegrated transverse polarization-dependent DiFFs enter into the azimuthal asymmetries for the dihadron production in semi-inclusive electron-positron annihilation and lepton nucleon scattering. This might potentially have significant implications for the phenomenological extractions of the transversity via interference fragmentation functions. Our model predicts a factor of two difference between the two definitions.

Session III-b / 103

Collinear polarized PDFs: recent results on helicity and transversity extractions

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I review the current status of the determination of the collinear helicity and transversity parton distribution functions from a global QCD analysis of experimental measurements. I highlight the most recent achievements and outline the open issues to be addressed in the future.

Session III-c / **104**

Overview of lattice QCD results relevant to the study of the 3D structure of the nucleon

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The 3D structure and tomography of the nucleon is among the frontiers of Nuclear Physics, and is under investigation in many experimental facilities worldwide. It also consists a key part of the physics program at a potential next-generation Electron-Ion-Collider. A progress in understanding the nucleons requires a synergy between the experimental and theoretical communities, and Lattice QCD (LQCD) is a powerful non-perturbative tool to provide input from first principle calculations. Progress in the simulation of LQCD has been impressive over the last years and modern simulations are carried out at parameters very close to their physical values. This has allowed to provide reliable estimates for benchmark quantities, but has also led to the exploration of new avenues of hadron structure. In this talk I will present recent developments relevant to the 3D structure of the nucleon. Main focus will be given to the spin of the proton, recent approaches to compute directly the x-dependence of quark PDFs, as well as studies of TMDs on the lattice.

Session III-c / **86**

Pseudo Parton Distributions

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Recently methods for computing the x-dependence of parton distribution functions (PDFs) using lattice QCD were introduced. These methods are an exciting new direction in non-perturbative first principles calculations of hadronic structure. In this talk I am reviewing the basic ideas of this approach. I will introduce the concepts of quasi-PDFs and pseudo PDFs and discuss their relations and properties. Futhermore, I will precent results of recent lattice calculations and discuss prospects for the future and the potential impact in our understanding of hadronic structure.

Session III-c / **82**

Lattice regularization and equal-time correlators for parton distribution functions

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I will present a critical discussion on the problem of lattice computation of structure functions.

Session III-d / **89**

Transverse dynamics of quarks in the proton - from Ji to Jaffe-Manohar orbital angular momentum

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Quark orbital angular momentum (OAM) in the nucleon can be evaluated directly by employing a Wigner function embodying the simultaneous distribution of parton transverse position and momentum. This distribution can be accessed via a generalization of the nucleon matrix elements of quark bilocal operators which have been used previously in the lattice evaluation of transverse momentum dependent parton distributions (TMDs). By supplementing these matrix elements with a nonzero momentum transfer, mixed transverse position and momentum information is generated. In the quark bilocal operators, a gauge connection between the quarks must be specified; a staple-shaped gauge link path, as used in TMD calculations, yields Jaffe-Manohar OAM, whereas a straight path yields Ji OAM. A lattice calculation at a pion mass of 518 MeV is presented which demonstrates that the difference between Ji and Jaffe-Manohar OAM can be clearly resolved. The obtained Ji OAM is confronted with traditional evaluations utilizing Ji's sum rule. Jaffe-Manohar OAM is enhanced in magnitude compared to Ji OAM.

Session IV-a / **105**

EIC in the US: Status of the Project and Outlook of the 3D Nucleon Structure Program

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The interior landscape of nucleons includes a strong-force driven sea of quarks, antiquarks and gluons, with a net surplus of a few ever-present valence quarks. In order to understand how the properties and structure of all forms of nuclear matter emerge from the dynamics of QCD, it is essential to precisely image the gluons and quarks, and to understand the role they and their interactions play in nucleons and nuclei. For this, a new accelerator facility is required, the Electron-Ion Collider, to match the valence quark studies of the upgraded Jefferson Lab. Such a future facility would be the world's first polarized electron-proton collider, and the world's first e-A collider. The science foreseen at and the status of such a future US-based polarized Electron-Ion Collider will be presented.

Session IV-a / **101**

Prospects for measurements of gluon TDMs

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Transverse momentum dependent parton distributions (TMDs) are currently under active investigation, both theoretically and experimentally. For studies of the gluon TMDs higher energy and smaller x values are required, and often processes involving almost back-to-back high-pt particles. These processes can be studied in the required kinematic regime at the high energy hadron colliders RHIC and LHC, and at a future Electron-Ion Collider. In this talk the prospects will be discussed for studies of the distributions of unpolarized and linearly polarized gluons inside unpolarized protons, and of the gluon Sivers effect for transversely polarized protons. Here the emphasis will be on the promising observables, on the inevitable process dependence and its implications, and on the expected dependence on the kinematic variables.

Session IV-a / **77**

A proposal for a polarised target at LHCb

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A polarized fixed-target experiment at LHC will open the way for a broad and unique physics program. The kinematic coverage will also allow to study the negative-rapidity region in the CM, corresponding to the poorly explored high x-Bjorken domain for the target proton. Furthermore, the use of a polarized H or D gas will allow precision measurements of spin-asymmetries in Drell-Yan and in inclusive production of quarkonia, thus opening the way to the measurement of the unknown gluon PDFs, such as the gluon Sivers function. The idea of installing gaseous polarized and unpolarized targets into the LHCb detector (LHCSpin project) is presented along with the status of the project. A selection of relevant physics cases is also discussed.

Session IV-b / **84**

W and Z production at the LHC

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At energy scales typical for electroweak boson production, LHC measurements can provide not only important tests of the Standard Model, but also allow the partonic content of the proton to be constrained by fundamental inputs to parton distribution functions (PDFs). In particular, results from LHCb, a single-arm forward spectrometer instrumented in the pseudorapidity region $2 < \eta < 5$ and optimised for the study of B and D mesons will show the complementarity with those performed at the general purpose detectors, ATLAS and CMS.

Session IV-b / **92**

3D structure of the proton from double parton distribution functions

Author: Matteo Rinaldi[1]

Co-authors: Federico Alberto Ceccopieri [2]; Marco Claudio Traini [3]; Sergio Scopetta [4]; Vicente Vento [1]

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Double parton distribution functions (dPDFs), accessible in high energy proton-proton and proton nucleus collisions, in double parton scattering processes (DPS), represent a new and promising complementary tool, w.r.t. TMDs and GPDs, to explore the 3D partonic structure of the proton. In particular, they encode unknown information on how two partons are correlated in hadrons. To investigate how these partonic correlations affect these distributions, dPDFs have been calculated within the Light-Front approach with constituent quark models (M. Rinaldi et al JHEP 2014). In this scenario, we showed how dynamical correlations, induced by the used model, prevent the factorization of dPDFs in terms of standard PDFs, a common assumption in experimental analyses. Moreover, we have investigated how these correlations affect the so called effective cross section, σ_{eff}, fundamental ingredient for the comprehension of the role of DPS in proton-proton collisions used in experimental studies. To calculate this quantity, dPDFs have been evolved at very high scales through the pQCD evolution procedure. The main evidence of partonic correlations is represented by the x dependence of
ss, being x the longitudinal momentum fraction carried by a parton inside the hadron (M. Rinaldi et al PLB 2016). Due to the importance of partonic correlations, we have addressed the role of perturbative, non perturbative and relativistic correlations, including sea quarks and gluons non perturbatively generated (M. Rinaldi et al JHEP 1610 (2016) 063, Phys.Rev. D 2017). We also calculated the DPS cross section for the same sign W pair production process using, as non perturbative input, dPDFs evaluated within a constituent quark model. We showed that partonic correlations could be observed in next LHC run (F. A. Ceccopieri et al Phys.Rev. D 2017).

Session IV-b / **107**

Higher twists and Lambda polarization

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The (transverse) polarization of Lambda baryons measured in hard reactions may be described in perturbative QCD in terms of polarized twist-3 fragmentation functions. A particularly simple reaction is the production of Lambdas in electron-positron annihilation. Certain aspects of an NLO calculation for transverse spin observables in this process are discussed in this talk.

Session IV-b / **120**

Transverse Momentum Effects in e+e– inclusive single-hadron production

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Transverse momentum dependent fragmentation functions (TMD FFs) contain essential information about hadronization. The non-perturbative ingredients of TMD FFs, should be inferred from phenomenological anal- yses of SIDIS and e+e– annihilation data. For this purpose, it is fun- damental to have at our disposal measurements that allow to decouple different regimes of physics and the effects resulting from different kine- matical variables. One possibility for a clean extraction of the unpolarized fragmentation function, is the of study the single hadron production from e+e– annihilation data. In this talk, I will present the results of a phe- nomenological analysis on existing one-hadron production data, in which we explore which effects may be connected to TMD physics.

Session IV-b / **80**

Transverse momentum distributions of hadrons within jets

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By adopting a generalised parton model approach at leading order in QCD, including spin and intrinsic parton motion effects, we study the Collins azimuthal asymmetries for pions within a large-pT jet produced at mid-rapidity in polarised hadronic collisions. Using available information on the quark transversity distributions and the pion Collins functions, as extracted from semi-inclusive, deeply inelastic scattering and e+e– ⟶ h1h2X processes, we compute estimates for the Collins asymmetries in kinematical configurations presently investigated at RHIC by the STAR Collaboration. Collins-like asymmetries, involving linearly polarised gluons, are also considered. Our predictions, compared against available preliminary data, show a very good agreement, even if some discrepancies, to be further scrutinized both theoretically and experimentally, appear in the transverse momentum dependence of the Collins asymmetry. These results are in favour of the predicted universality of the Collins function and of a mild, if any, evolution with the hard scale of the asymmetries.

Session IV-c / **71**

Transverse single-spin asymmetries in p p ! W(Z0) X at RHIC

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The three-dimensional structure of the proton in momentum space can be described via Transverse Momentum Dependent (TMDs) parton distribution functions. One of these TMDs, known as the Sivers function f⊠1T, describes the correlation of parton transverse momentum with the transverse spin of the nucleon. RHIC is the worlds only facility that can run polarized p+p collisions at a center-of-mass energy large enough to produce weak bosons. Accessing the Sivers function in p+p collisions through the measurement of transverse single-spin asymmetry, AN, in weak boson production is an effective path to test the fundamental QCD prediction of its change of sign (non universality) respectively to e+p processes. Furthermore, it provides data to study the spin-flavor structure of valence and sea quarks inside the proton and to test the evolution of parton distributions. AN has been measured at STAR in p+p collisions at √s = 500 GeV, with a recorded integrated luminosity of 25 pb 1. Within relatively large statistical uncertainties, the current data favor theoretical models that include change of sign for the Sivers function relative to observations in SIDIS measurements, if TMD evolution effects are small. STAR has just collected 350 pb 1 from transversely polarized p+p collisions in run 2017. This will allow us to perform a more precise measurement of AN in both

weak boson and Drell-Yan production as well as other observables sensitive to the non-universality of the Sivers function via the Twist-3 formalism, e.g. AN of direct photons.

Mini symposyum for M. Anselmino's 70th birthday / 126

A TRIBUTE TO MAURO ANSELMINO ON HIS 70TH BIRTHDAY

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A TRIBUTE TO MAURO ANSELMINO ON HIS 70TH BIRTHDAY

Session V-a / 74

New and future transverse spin results at PHENIX

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We would like to present recent results and discuss future opportunities at the PHENIX experiment in transverse spin physics. Several measurements have been performed in p+p collisions using transversely polarized proton beams at the RHIC facility. Recently, p+A collisions with transversely polarized protons have also been performed, and allow the study of nuclear dependences of the transverse spin asymmetries.
Recent results from PHENIX include the transverse spin asymmetries in light meson production (π°, η), where a non-zero asymmetry can be interpreted as an initial state interaction (related to the Sivers effect) or a final state correlation (related to the Collins effect). Also, non-zero charged hadron asymmetries were observed with an interesting nuclear dependence. Transverse spin asymmetries have been measured as well for muons from heavy flavored hadrons and J/Ψ, giving access to higher twist effects related to the gluon Sivers function in p+p and p+A collisions.
Significant non-zero transverse spin asymmetries in very forward neutron production have been observed and interpreted as coming from Reggeon exchange in proton-proton collisions. We will discuss the surprisingly strong nuclear dependence of the asymmetry observed in p+A collisions and its likely origin. Ongoing studies and future results include Drell-Yan transverse spin asymmetries, which will be briefly discussed.

Session V-a / 68

Extraction of the Sivers distribution functions and Sivers sign change: an update

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I will present recent updates on the extraction of the Sivers distribution function using the newest 3D data presently available, and examine their consequences on the long debated issue of the "Sivers sign change".

Session V-a / **53**

New and future transverse spin results at STAR

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Session V-a / **85**

Gluon Sivers function and linearly polarized gluons in J/ψ production in ep collision

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Among the leading twist gluon TMDs, gluon Sivers function (GSF) and Boer-Mulders function (BMF) have been receiving paramount of interest in spin physics, as they provide the spin nature of the hadron. The GSF and BMF describe the density of unpolarized and linearly polarized gluons inside the transversely and unpolarized proton respectively. The non-perturbative GSF and BMF can be extracted by studying the Sivers and $\cos 2\phi$ asymmetries in ep and pp collision. We estimate the Sivers and $\cos 2\phi$ asymmetries in J/ψ production in SIDIS process within TMD factorization framework. The leading order photon-gluon fusion subprocess color octet sates ${}^3S_1$, ${}^1S_0$ and ${}^3P_J$ ($J = 0, 1, 2$) contribution to J/ψ production is considered by employing the NRQCD based color octet model. The estimated negative Sivers asymmetry is in good agreement with COMPASS data at $z = 1$. Sizable $\cos 2\phi$ asymmetry is estimated as a function of Bjorken variable (x_B) and p_T. We also calculate the Sivers asymmetry in photoproduction of J/ψ at Next-Leading-Order in α_s using color octet model.

Session V-b / **87**

Light-cone distributions from the Bethe Salpeter Eq. in Minkowski-space

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The structure of a pseudo-scalar fermion-antifermion bound state is i nvestigated through the solution of the Bethe-Salpeter equation in Minkowski space. The kernel is truncated to the ladder approximation, a form factor is introduced in the vertex, with the exchanged particle being a massive, scalar, pseudo-scalar or a vector boson. The method used for the numerical solution of the four-dimensional integral equation is the Nakanishi integral representation of each component of the Bethe-Salpeter amplitude decomposed in the spinor space, where the weight function is free of singularities that plagues the Bethe-Salpeter equation inMinkowski space. The projection of the normalized Bethe-Salpeter amplitude on the null-plane allows to extract the valence component of the light-front wave function, and from that the valence probability, the transverse and longitudinal momentum distributions. A simple model for the pion is tuned to have a strongly bound quark-antiquark state, with parameters adapted to represent an effective massive gluon in the Feynman gauge, with a form factor for the quark-gluon vertex and constituent quark masses. We briefly discuss how to include physics beyond the valence component in the light-cone distributions, like e.g. the T-odd distribution, and also considering the formulation of observables starting from the Bethe-Salpeter amplitude.

Session V-b / **96**

Transversity and Λ polarization at COMPASS

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Due to their self-analyzing decay, the polarization of Λ hyperons has often been indicated as a possible way to access the transversity function h_1^{q}(x) in SIDIS, where it comes coupled to the chiral-odd H_1^{Λ/q}(z) fragmentation function. Such Λ transversity-transmitted polarization has been measured in COMPASS using the data collected with a transversely polarized proton target and a 160 GeV muon beam. The results on the polarization, extracted as function of Bjorken x, relative energy z and Λ transverse momentum p_t, are presented together with their interpretation.

Session V-b / **72**

SSA in ep↑→hX and contribution of quasi-real photon

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We present an updated phenomenological analysis on transverse Single-Spin Asymmetries (SSAs) for inclusive hadron production in lepton-proton scattering. Adopting a transverse momentum dependent approach, we focus on the role of quasi-real (Weizsacker-Williams) photon exchange, showing its relative contribution to SSAs. Then, using the Sivers and the transversity distributions and the Collins function as extracted from fits to the SSAs for SIDIS and e+e- processes, we show new predictions and comparison with data. The data description shows a general improvement with respect to the previous leading order analysis. Predictions for unpolarized cross sections and SSAs for ongoing and future experiments are also given.

Session V-b / 73

What top quark spin correlations can tell us about gluon transversity

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The production of heavy flavor quark pairs, especially top-anti-top at the LHC, proceed primarily through gluon fusion. Correlations between the gluon spins affects spin correlations between the produced quark and anti-quark. For top-antitop production, their spin asymmetries and double correlations of spins will be manifest in the subsequent hadronization and decay distributions. These asymmetries and correlations are shown to be significant for the dilepton channel, which allows for the extraction of gluon spin information as well as providing a window into possible interactions Beyond the Standard Model. Particular spin related asymmetries will be presented. The implications for experimental determination of gluon transversity will be discussed.

Session V-b / 115

Tensor charge and physics beyond the standard model

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We discuss the impact of the determination of the nucleon tensor charge on searches for physics Beyond the Standard Model. We also comment on the future extraction of the subleading-twist PDF e(x) from Jefferson Lab soon-to-be-released Beam Spin Asymmetry data as well as from the expected data of CLAS12, as the latter is related to the scalar charge. These analyses are possible through the phenomenology of Dihadron Fragmentation Functions related processes, which we briefly report on as well.

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Closeout

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TMDs and spin asymmetries in SIDIS

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In recent years the measurements of single spin asymmetries (SSAs) in final state hadronic distributions in semi-inclusive processes have been widely used to access the underlying Transverse Momentum Dependent (TMD) parton distributions. The detailed understanding of the orbital structure

of partonic distributions, encoded in TMD PDFs has been widely recognized as one of the key objectives of the JLab 12 GeV upgrade, and a driving force behind the construction of the Electron Ion Collider. Although the interest to TMD PDFs has grown enormously, we are still in need of fresh theoretical and phenomenological ideas. The main challenges still remaining is the extraction of actual TMDs from different spin and azimuthal asymmetries in a reliable and model independent way. In this talk, we present an overview of the latest developments and future studies of the TMD PDFs from variety of observables accessible in semi-inclusive DIS at different facilities worldwide.

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The DVCS program in Hall A at Jefferson Lab

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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 ($\gamma^* N \rightarrow \gamma N$) is measured; it is the simplest process which is sensitive to the Generalized Parton Distribution functions. The DVCS in Hall A program is articulated in three steps. The first generation of experiments showed the importance of precise measurement of absolute cross-section. The second generation of experiments, recently published, shows an intriguing sensitivity to gluons. And the third generation of experiments (data to be taken recently with the 12 GeV beam at JLab) will provide measurements over an extended kinematic range. Exclusive neutral pion production is also measured. In this talk, I will review the status of the DVCS in Hall A program.

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Transverse Momentum Dependent Parton Distributions at Small-x

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We will review recent developments in our theoretical understanding of TMDs at small x. We will describe how the small-x asymptotics of various quark and gluon TMDs can be determined by deriving and solving small-x evolution equations. In particular, we will concentrate on the cases of the TMDs for which the small-x asymptotics is known theoretically: unpolarized quark and gluon TMDs, linearly polarized gluon TMD, and the helicity quark and gluon TMDs.

0

Registration

3

Coffee break

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LUNCH

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Latest developments on the Wigner distribution functions

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I will review recent developments on the Wigner distribution functions of the nucleon, which provide multidimensional images of the quark distributions. They depend on both the transverse position and the three-momentum of the quark relative to the nucleon, and therefore combine in a single picture all the information contained in the generalized parton distributions and the transverse-momentum dependent parton distributions. I will consider a few example of Wigner functions, both in the T-even and T-odd sector, and discuss the role of the quark orbital angular momentum in shaping the nucleon and its correlations with the quark and nucleon polarizations. I will discuss the possibility to access information on the quark orbital angular momentum from Wigner functions, in comparison with alternative relations between the orbital angular momentum and the generalized parton distributions. Finally, I will present recent proposals to access the Wigner functions from experimental measurements.