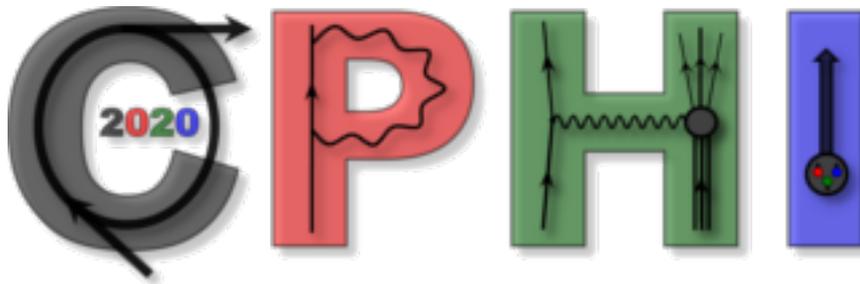


# Correlations in Partonic and Hadronic Interactions - 2020 (CPHI-2020)

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## Book of Abstracts



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**Morning / 34**

## **Welcome**

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**Morning / 12**

## **Extraction of unpolarized TMDs: successes and problems**

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I present the results of the extraction of unpolarized TMDs by the Pavia group. I describe the Pavia 2017 extraction, which included data from SIDIS and DY and performed the analysis at NLL, and the recent Pavia 2019 extraction, which included data from DY and reached N3LL accuracy. I will discuss the problems we encounter in the description of SIDIS data at higher accuracy.

**Morning / 27**

## **The transverse spin structure of the nucleon: overview and perspectives of COMPASS SIDIS measurements**

**Author:** Anna Martin<sup>1</sup>

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The SIDIS data collected from 2002 to 2010 in COMPASS using a high energy muon beam and transversely polarised proton and deuteron targets, have allowed to performed many unique measurements. In this talk the main results and their interpretation, as well as the new expected measurements, will be reviewed. The need of the more deuteron data and the perspectives from the future COMPASS data taking will also be summarised.

**Morning / 51**

## **The Jefferson Lab TMD Studies at 12 GeV**

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In an effort to understand the internal structure of the nucleon, parton distributions describing longitudinal momentum, helicity and transversity distributions of quarks and gluons, have been generalized to account also for the transverse momentum of partons, providing important information on the spin-orbit correlations of partons in the nucleon. Transverse Momentum Dependent parton distributions (TMDs) yields a 3D picture of the nucleon in momentum space and can be accessed in semi-inclusive processes.

The recently upgraded Continuous Electron Beam Accelerator Facility (CEBAF) at Jefferson Lab (JLab) provides a unique opportunity to study the quark TMDs, particularly in the valence quark region, and a coherent and comprehensive TMD program using SIDIS measurements is underway. The program takes advantages of the complementary capabilities of different detectors in the experimental Halls A, B and C.

In this talk we present an overview of the latest developments in studies of TMDs at JLab and discuss newly released results, ongoing activities, as well as planned near term and future measurements.

**Morning / 17**

## Recent Results from RHIC: Cold QCD & Spin

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The partonic structure of the proton has been established in deep inelastic scattering and a detailed picture of the nucleon has emerged from a wide range of experiments and global analyses. Proton-proton collisions at RHIC allow direct access to the gluon content in the nucleon and polarized beams introduce an additional degree of freedom, spin, which is naturally connected to parton kinematics. Transverse spin phenomena are enabling studies of transverse momentum dependent distribution functions and spin-orbit correlations beyond a one-dimensional picture. At the same time, they are closely linked to questions about universality of the process dependence of color exchanges, factorization, and possibly saturation effects a very small partonic momenta.

**Morning / 16**

## Helicity Distributions and OAM at Small x

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We derive and solve small-x evolution equations determining the small-x asymptotics of quark and gluon helicity PDFs and TMDs and orbital angular momentum (OAM) distributions. Our evolution equations resum powers of  $\alpha_s \ln^2(1/x)$ . At large  $N_c$ , solving our equations, we obtain the following small-x asymptotics for helicity PDFs and OAM:

$$\Delta\Sigma(x, Q^2) = -L_{q+\bar{q}}(x, Q^2) \sim \left(\frac{1}{x}\right)^{\frac{4}{\sqrt{3}}} \sqrt{\frac{\alpha_s N_c}{2\pi}},$$

$$\Delta G(x, Q^2) \sim L_G(x, Q^2) \sim \left(\frac{1}{x}\right)^{\frac{13}{4\sqrt{3}}} \sqrt{\frac{\alpha_s N_c}{2\pi}}.$$

Morning / 22

## The origin of single transverse-spin asymmetries in high-energy collisions

**Authors:** Justin Cammarota<sup>1</sup>; Leonard Gamberg<sup>2</sup>; Zhongbo Kang<sup>3</sup>; Joshua Miller<sup>4</sup>; Daniel Pitonyak<sup>5</sup>; Alexey Prokudin<sup>None</sup>; nobuo sato<sup>6</sup>

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We present, for the first time, a phenomenological analysis that demonstrates all single transverse-spin asymmetries (SSAs) in high-energy collisions have a common origin. Namely, they are due to the intrinsic quantum-mechanical interference between single- and multi-parton states. We perform the first global fit of data from Semi-Inclusive Deep Inelastic Scattering, Drell-Yan,  $e^+e^-$  annihilation into hadron pairs, and proton-proton collisions. Consequently, we are able to identify a unique set of functions that describes all observed SSAs. Furthermore, we achieve the first phenomenological agreement with lattice on the tensor charge of the nucleon.

Morning / 66

## Recent HERMES results on polarized semi-inclusive deep-inelastic scattering

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After fifty years of investigations, the nucleon structure is still far from being understood and continues to represent a unique test bench for QCD. Despite the enormous progresses achieved in five decades of deep-inelastic scattering (DIS) experiments, a number of crucial open questions are still on the carpet and subject of intense theoretical and experimental studies. In the last two decades, semi-inclusive DIS was established as a unique tool for the study of the non-collinear structure of nucleons, involving the parton transverse momentum  $p_T$  as an additional degree of freedom. Requiring the detection of at least one final state hadron in coincidence with the scattered lepton, it opened the way not only to the measure of the chiral-odd transversity distribution, the last missing leading-twist collinear parton distribution function, but also to a variety of new  $p_T$ -dependent PDFs, known as TMDs. Describing correlations between the quark transverse momentum and the quark or the nucleon spin (spin-orbit correlations), TMDs account for a number of intriguing effects observed in polarized and unpolarized reactions, and allow for a 3-dimensional description of the nucleon in momentum space (nucleon tomography). Furthermore, they could provide insights into the yet unmeasured quark orbital angular momentum. At leading-twist eight TMDs enter the SIDIS cross section in conjunction with a fragmentation function. In addition, going to the twist-3 level allows us to probe novel quark-gluon correlations. At HERMES, these distribution functions are probed through specific azimuthal modulations in the distribution of hadrons produced in semi-inclusive DIS of unpolarized or longitudinally polarized electrons and positrons off unpolarized and polarized nucleons. Amplitudes of some of these modulations sensitive to the beam polarization, recently extracted also in a three-dimensional kinematic space, will be presented in more detail.

Afternoon / 41

## Extraction of Sivers and Transversity: access to the exotics of polarized parton densities

**Author:** Marco Radici<sup>1</sup>

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The Sivers and Transversity distributions represent the prototype of naive T-odd and chiral-odd parton densities, respectively. Having a good knowledge of the former allows to test the QCD prediction of specific non-universality, while the first Mellin moment of the latter, the so-called tensor charge, might represent a possible portal to new physics beyond the Standard Model. I will present the latest extraction of the Sivers function, for the first time starting from the extracted unpolarized TMD distribution in a consistent TMD framework. I will also discuss the latest results for Transversity from a global analysis of pion-pair production in deep-inelastic scattering and in proton-proton collisions, with particular emphasis on the comparison with recent lattice calculations of the valence and isovector components of the tensor charge.

Afternoon / 3

## Description of unpolarized DY and SIDIS data within TMD factorization

**Author:** Alexey Vladimirov<sup>None</sup>

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I present the analysis of the semi-inclusive deep inelastic scattering (SIDIS) and Drell-Yan events within transverse momentum dependent (TMD) factorization. The high quality of the fit confirms a complete universality of TMD non-perturbative distributions and demonstrates good agreement between the theory and the data. Also, I provide the discussion on phenomenological analyses of various parts of the TMD factorization, such as sensitivity to non-perturbative parameterizations, perturbative orders, collinear distributions, correlations between parameters, and others.

Afternoon / 67

## Accessing TMDs with an unpolarised target at HERMES

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The HERMES experiment collected from 1995 to 2007 a wealth of deep-inelastic scattering data using 27.6 GeV longitudinally polarised electrons and positrons and various unpolarised as well as longitudinally and transversely polarised gas targets. This allowed for a series of diverse measurements. Among them are measurements in semi-inclusive deep-inelastic scattering that provide information on various transverse-momentum-dependent parton distribution functions and fragmentation

functions. Related results from HERMES using an unpolarised nucleon and a longitudinally and effectively unpolarised lepton beam are presented and discussed.

**Afternoon / 50**

## TMD observables in unpolarised SIDIS at COMPASS

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In 2016 and 2017 the COMPASS Collaboration at CERN collected a large sample of DIS events with a longitudinally polarized 160 GeV/c muon beam scattering off a liquid hydrogen target. A small subsample of the collected data has been analysed to extract preliminary results for the transverse momentum dependent charged hadron multiplicities and the amplitudes of the azimuthal modulations  $A_{UU}^{\cos \phi_h}$ ,  $A_{UU}^{\cos 2\phi_h}$  and  $A_{LU}^{\sin \phi_h}$ . Both multiplicities and azimuthal asymmetries can be related to the intrinsic transverse momentum  $k_T$  of the quarks, while  $A_{UU}^{\cos \phi_h}$  and  $A_{UU}^{\cos 2\phi_h}$  are also related to the still unknown Boer-Mulders TMD PDF  $h_1^\perp$ . In this talk, preliminary results from the 2016 data will be shown for both observables. It is found that the unpolarised azimuthal asymmetries exhibit strong kinematic dependences, which are similar to the published COMPASS deuteron results. Recently, it has been demonstrated that particles coming from the decay of diffractively produced vector mesons contribute considerably to these observables. The planned strategy for the 2016/17 data analysis will be discussed.

**Afternoon / 14**

## COMPASS results on pion and kaon multiplicities in DIS and ratios of K-/K+ and pbar/p multiplicities.

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We present preliminary COMPASS results on pion and kaon multiplicities produced in semi-inclusive deep inelastic scattering of 160 GeV muons off a pure proton (LH2) target. The results constitute a data set of more than 600 points for pions and 600 for kaons, covering a large  $x$ ,  $Q^2$  and  $z$  domain in a fine binning with  $W > 5$  GeV<sup>2</sup>. The results from the sum of the  $z$ -integrated multiplicities  $M(\pi^+) + M(\pi^-)$  and  $M(K^+) + M(K^-)$  are presented versus  $x$  and compared to earlier COMPASS results on a deuteron target and to other experiments.

In addition, we show the K-/K+ as well as pbar/p multiplicity ratios measured for hadrons carrying a large fraction  $z$  of the virtual-photon energy,  $0.5 < z < 1$ , using an isoscalar 6LiD target. The ratios can be obtained with lower systematic errors. For values of  $z$  larger than 0.8, the results contradict expectations obtained using the formalism of (next-to-) leading order perturbative quantum chromodynamics. In particular the data show a strong dependence upon the missing mass  $M_x$ , not expected from the calculations. The results suggest that additional corrections to the formalism may be required to take into account the phase space available for hadronization.

**Afternoon / 56**

## unpolarized fragmentation related measurements at Belle

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The fragmentation process can be cleanly studied at electron-positron colliders where no hadrons exist in the initial state. The Belle experiment at the KEK-B collider has accumulated more than one inverse ab of data. This large amount of data has been used to measure various fragmentation related quantities such as single and di-hadron cross sections for several hadron types. In this presentation the unpolarized measurements will be discussed, in particular the transverse momentum dependent single hadron cross sections as well as updates to fractional momentum dependent single and di-hadron cross sections.

**Afternoon / 47**

## Hadronization with polarization degrees of freedom

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Considering polarization degrees of freedom in the final state of hard, semi-inclusive interactions allows a more focused access to the partonic structure of the nucleon. The respective fragmentation functions can be used to study QCD in the non-perturbative regime complementary to polarized (TMD) PDFs. This talk will discuss recent and anticipated results on polarized fragmentation functions in  $e+e-$  and SIDIS.

**Afternoon / 8**

## Universality-breaking effects in $e+e-$ hadroproduction

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Recent BELLE measurements provide the cross section for single hadron production in  $e+e-$  annihilations, differential in the hadron transverse momentum with respect to the thrust axis. Universality breaking effects due to process-dependent soft factors make it very difficult to relate this cross section to that corresponding to hadron-pair production in  $e+e-$  annihilations, where TMD fragmentation functions are defined through the so-called “square-root definition”. I will examine this correspondence in the framework of CSS factorization and provide the sketch of a scheme that might allow to relate 1-jet to 2-jet  $e+e-$  cross sections, neatly separating soft and collinear non-perturbative effects from the terms which can be calculated using a perturbative approach.

Morning / 10

## Transverse momentum weighted transverse spin asymmetries at COMPASS

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The hadron structure is commonly described by transverse momentum dependent (TMD) parton distribution functions (PDFs), which encode all possible correlations between the hadron spin, the parton spin and the transverse component of the parton momentum  $k_T$ . They have been studied by COMPASS in semi-inclusive deep inelastic scattering (SIDIS) and Drell–Yan (DY) reactions with transversely polarised proton targets by measuring the transverse spin asymmetries (TSAs). The TSAs in SIDIS contain convolutions over the transverse momentum of TMD PDFs and TMD fragmentation functions (FFs). Similarly, the TSAs in DY are interpreted as convolutions of the TMD PDFs of the target and beam hadrons. To extract the TMD PDFs, an ansatz for their dependence on  $k_T^2$  is needed. Different observables –the transverse momentum weighted TSAs –were proposed a long time ago. Instead of convolutions, they contain products of various  $k_T^2$ -moments of the TMD PDFs and FFs. To measure the weighted TSAs, one needs to weight the events with correct powers of the transverse momentum of the final state hadron in SIDIS or of the dimuon in DY. COMPASS has recently measured the weighted TSAs in both SIDIS and DY to complement its results on the standard TSAs. Thanks to their straightforward interpretation, the Sivers functions measured in SIDIS and DY can be directly compared. Additionally, COMPASS also obtains information on the pion valence Boer–Mulders function, the correlation of the parton transverse spin and its  $k_T$ .

Morning / 15

## Dihadron beam-spin asymmetries at CLAS12

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Azimuthal correlations in the production of hadron pairs in semi-inclusive deep-inelastic scattering provide rich information on nucleon structure. The additional degree of freedom present in the two hadron final state allows for studies of correlations in the hadronization process, which can access novel fragmentation functions not accessible in single hadron production. Consequently, several PDFs such as the higher-twist collinear PDF  $e(x)$  or the as yet unmeasured dihadron fragmentation function  $G_1^\perp$  can be extracted. We present preliminary charged pion beam-spin asymmetries from a subset of the data taken in 2018 with the CLAS12 detector at Jefferson Lab. The data were taken with a 10.6 GeV polarized electron beam and an unpolarized liquid-hydrogen target. The large kinematic acceptance and sample size allows for a multidimensional analysis in Bjorken  $x$ ,  $z$  and the invariant mass of the hadron pair.

Morning / 35

## SIDIS Single Pion Beam Spin Asymmetry measurements with CLAS12

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The CLAS12 detector at Jefferson Laboratory (JLab) started data taking with a polarized 10.6 GeV electron beam, interacting with an unpolarized liquid hydrogen target in February 2018. The collected statistics enables a high precision study of the moment  $A_{LU}^{sin(\phi)}$  corresponding to the polarized electron beam spin asymmetry in semi-inclusive deep inelastic scattering.  $A_{LU}^{sin(\phi)}$  is a twist-3 quantity which provides information about the quark gluon correlations in the nucleon. The contribution will present a simultaneous study of all three pion channels ( $\pi^+$ ,  $\pi^0$  and  $\pi^-$ ) over a large kinematic range of  $z$ ,  $x_B$ ,  $P_T$  and  $Q^2$  with virtualities  $Q^2$  ranging from 1 GeV<sup>2</sup> up to 8 GeV<sup>2</sup>. Based on the available statistics, a multidimensional analysis becomes possible.

Morning / 54

## Transverse Single Spin Asymmetries in the $pp \rightarrow p\pi^0 X$ Process at STAR

**Author:** Christopher Dilks<sup>1</sup><sup>1</sup> *Duke University***Corresponding Author:** christopher.dilks@duke.edu

A significant sample of  $pp \rightarrow p\pi^0 X$  events has been observed at STAR in  $\sqrt{s} = 200$  GeV transversely polarized  $pp$  collisions, with an isolated  $\pi^0$  detected in the forward pseudorapidity range  $2.65 < \eta < 3.9$ , along with the forward-going proton  $p$ , which scatters near the beamline into Roman Pot detectors. The sum of the  $\pi^0$  and the scattered proton energies is consistent with the incident proton energy of 100 GeV, indicating that no further particles are produced in this direction. It is postulated that the forward incident proton may have fluctuated into a  $p + \pi^0$  system, with the  $\pi^0$  angular momentum correlated with the initial proton spin. The  $p + \pi^0$  system scatters off the other beam proton and separates such that the  $\pi^0$  has a transverse momentum of  $\sim 2$  GeV/ $c$  and the proton has a transverse momentum of  $\sim 0.2$  GeV/ $c$ . The other beam proton shatters into the remnant particles  $X$ , all in the backward direction. Correlations between the  $\pi^0$  and scattered proton will be presented, along with single spin asymmetries which depend on the azimuthal angles of both the pion and the proton. This is the first time that spin asymmetries have been explored for this process, and a model to explain their azimuthal dependence is needed.

Morning / 49

## Inclusion of vector meson production in the Monte Carlo simulation of polarized quark fragmentation

**Authors:** Albi Kerbizi<sup>1</sup>; Xavier Artru<sup>2</sup>; Anna Martin<sup>3</sup><sup>1</sup> *Universita e INFN Trieste (IT)*<sup>2</sup> *Univ. Lyon, UCBL, CNRS, IP2I*<sup>3</sup> *Trieste University and INFN (IT)***Corresponding Author:** albi.kerbizi@cern.ch

A very recent extension of a stand alone Monte Carlo simulation program of polarized quark fragmentation is presented. The initial program, implementing the recursive string+3P0 model, was restricted to the production of pseudoscalar mesons. The extension incorporates vector mesons, for the first time in accordance with quantum rules for spin.

The effects on observables like Collins and di-hadron transverse spin asymmetries are shown.

**Morning / 63**

## Two-Photon-Exchange Corrections to SIDIS

**Author:** Andrei Afanasev<sup>1</sup>

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We are developing a unified approach that will include QED corrections to all of the structure functions of polarized SIDIS. In this talk, key features of SIDIS in one-photon approximation will be reviewed, and approaches to a consistent data analysis beyond the leading order in the electromagnetic interaction will be presented.

**Morning / 44**

## Radiative corrections in polarized SIDIS

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The important sources of the systematical uncertainties in polarized SIDIS experiments are the QED radiative corrections (RC). Here the model-independent RC that include the effects of real photon radiation and loop diagrams (leptonic vertex correction, and vacuum polarization) are presented. The effects were analytically computed within the Bardin-Shumeiko approach resulting in explicit equations in leading and next-to-leading orders. The numeric estimation of the correction due to the real photon radiation requires the integration over wide kinematical region of the unobservable real photon emission from the lepton leg withing SIDIS and exclusive final state and therefore requires knowledge of all 5 spin-averaged and 13 spin-dependent structure functions (SFs) in these region. In our illustrations for JLAB kinematics we used the WW-SIDIS model and a simple approach for exclusive SFs. The ways to address limitations of our calculations due to limited knowledge of all exclusive SFs are discussed.

**Afternoon / 5**

## Probing nucleon's structures using Drell-Yan process with unpolarized/polarized targets at Fermilab

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The mysterious asymmetry of the anti-quarks inside nucleon remains to be investigated. The experiment SeaQuest, with unpolarized targets, aims to do so. The experiment finished data collection

in 2017. A preliminary result will be given in this presentation. The spin structure of the nucleon remains a mystery. Recent studies suggest that the orbital angular momentum of sea quarks could significantly contribute to the proton's spin. The SpinQuest will access the anti-quark Sivers functions using polarized NH<sub>3</sub> and ND<sub>3</sub> targets. A non-zero asymmetry, observed in SpinQuest, would be a strong indication of non-zero sea-quark orbital angular momentum. The SpinQuest can also probe the sea quark's transversity as well as the tensor charge of polarized ND<sub>3</sub>. The status of the SpinQuest preparation will be presented.

**Afternoon / 31**

## Drell-Yan measurements at COMPASS

**Author:** Riccardo Longo<sup>1</sup>

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COMPASS is a fixed-target experiment in operation at the CERN North Area (SPS, M2 beam-line) since 2002. An important part of the broad physics programme of the experiment is dedicated to the exploration of the transverse spin-structure of the nucleon, studying target transverse spin (in)dependent azimuthal asymmetries arising in the Drell-Yan cross-section.

In 2015 and 2018, COMPASS performed two years of Drell-Yan data taking, using a 190 GeV/c  $\pi^-$  beam impinging on a transversely polarized NH<sub>3</sub> target. In this talk, recent Drell-Yan results from COMPASS will be presented along with prospects for ongoing studies.

**Afternoon / 29**

## Power corrections at moderate $q_T$ from Reggeized Partons

**Authors:** Maxim Nefedov<sup>1</sup>; Vladimir Saleev<sup>2</sup>

<sup>1</sup> *Uni. Hamburg, Uni. Samara*

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Power-suppressed  $O(q_T^2/Q^2)$  corrections to the Drell-Yan TMD cross-sections and structure functions, which restore QED gauge-invariance of the hadronic tensor in TMD factorization will be discussed in a framework of Parton Reggeization Approach [1,2]. These corrections are important in the region of moderate  $q_T \sim Q$  for the description of  $q_T$ -spectrum and Helicity Structure Functions, and are not taken into account in the standard (Collinear Factorization based) construction of a  $Y$ -term. Therefore these corrections could potentially contribute to the resolution of  $q_T$ -puzzle in Drell-Yan and SDIS.

[1] M. Nefedov and V. Saleev,  
“Off-shell initial state effects, gauge invariance and angular distributions in the Drell-Yan process,”  
Phys. Lett. B 790, 551 (2019)  
doi:10.1016/j.physletb.2018.12.071  
[arXiv:1810.04061 [hep-ph]].

[2] M. Nefedov and V. Saleev,  
“Off-shell initial state effects and gauge invariance in the Drell-Yan process,”  
PoS DIS 2019, 193 (2019)

doi:10.22323/1.352.0193  
[arXiv:1906.08681 [hep-ph]].

Afternoon / 37

## Measurement of pion induced Drell-Yan at AMBER experiment

**Author:** Marcia Quaresma<sup>1</sup>

<sup>1</sup> *LIP Laboratorio de Instrumentacao e Fisica Experimental de Part*

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AMBER is a newly proposed experiment at CERN with the aim of contributing in the field of QCD. Among several ideas, the measurement of the pion induced Drell-Yan with the two pion charges is one of the proposed measurements. The combination of the two pion charges together with a carbon target gives access to observables sensitive to the separation between sea and valence in the pion. In addition, with the inclusion of a W target, studies on the nuclear effects are also possible with the particularity of studying their flavour dependence. The scientific proposal for this measurement is currently being evaluated by SPS Committee and should be soon presented to the CERN Council. In a later stage, the plan is to measure the kaon induced Drell-Yan. A precise knowledge of the pion and kaon structures, together with the proton, lead us to the possibility of better understanding the origin of the hadrons masses. In this talk the proposed measurement will be introduced and some projections will be showed.

AKM-70 / 69

## Aram's no-nonsense TMD's

**Corresponding Author:** p.j.g.mulders@vu.nl

AKM-70 / 60

## SSAs in Electroproduction

**Author:** Harut Avakian<sup>None</sup>

**Corresponding Author:** avakian@jlab.org

The quark-gluon dynamics manifests itself in a set of non-perturbative functions describing various spin-spin and spin-orbit correlations. Single and Dihadron semi-inclusive production, both in current and target fragmentation regions, provide a variety of spin and azimuthal angle dependent observables. In this talk, we present several measurements of Spin-Azimuthal Asymmetries sensitive to the orbital structure, and in particular, the Kotzinian-Mulders asymmetry.

AKM-70 / 46

## Physics at the back of an envelope

**Author:** Alexey Prokudin<sup>None</sup>

**Corresponding Author:** prokudin@jlab.org

I will tell a few (pseudo)scientific anecdotes of my 15+ year old friendship and scientific collaboration with Aram Kotzinian dedicated to his 70th Birthday.

**AKM-70 / 55**

## Exploring the spin effects in dihadrons with Aram

**Author:** Hrayr Matevosyan<sup>1</sup>

<sup>1</sup> *University of Adelaide*

**Corresponding Author:** hrayr.matevosyan@adelaide.edu.au

In this talk I will present some highlights from the work we have done in collaboration with Aram Kotzinian on exploring spin-induced dihadron correlations in quark hadronization process, and the measurements we proposed for accessing the quark-polarization-dependent dihadron fragmentation functions in  $e^+e^-$  and SIDIS experiments.

**AKM-70 / 45**

## Nucleon-spin-dependent azimuthal asymmetries and beyond: AKM 55-70

**Author:** Bakur Parsamyan<sup>1</sup>

<sup>1</sup> *CERN, University of Turin and INFN*

**Corresponding Author:** bakur.parsamyan@cern.ch

Measurements of the nucleon spin (in)dependent azimuthal asymmetries in semi-inclusive DIS are one of the most important sources of information about transverse momentum dependent parton distribution and fragmentation functions. Aram Kotzinian is one of the pioneers of this field.

**Morning / 30**

## Mechanical properties of particles

**Author:** Maxim V. Polyakov<sup>None</sup>

**Corresponding Author:** maxim.polyakov@rub.de

Selected topics related to the physics of the energy-momentum tensor (EMT) form factors are discussed.

**Morning / 58**

## overview of the COMPASS GPD program

**Author:** Nicole d'Hose<sup>1</sup>

<sup>1</sup> CEA - Université Paris-Saclay

**Corresponding Author:** nicole.dhose@cea.fr

In 2016 and 2017 exclusive reaction measurements were performed at the M2 beamline of the CERN SPS using 160 GeV positively and negatively charged muon beams scattering of a liquid hydrogen target. The Deeply Virtual Compton Scattering (DVCS) is the golden exclusive reaction to study Generalized Parton Distributions (GPDs). For this reaction, the scattered muons and the produced real photons were detected by the COMPASS spectrometer, which was supplemented by an additional electromagnetic calorimeter for the detection of large-angle photons. To insure the exclusivity of the reaction, the recoil protons were detected by the CAMERA detector, which measures the time of flight between two barrels of scintillators surrounding the 2.5 m long target. We will summarize the status of the analysis of the data and present results from the one-month 2012 pilot run which represents about one tenth of the total statistics collected in 2016-17.

By summing up the DVCS cross sections when using either a positive or a negative muon beam the total DVCS cross section and its  $|t|$ -dependence can be extracted. From this measurement mainly related to the GPD  $H$ , a first estimate of the transverse extension of partons in the proton probed in the sea-quark domain is determined. We will also report on the cross section for exclusive  $\pi^0$  production and its  $|t|$  and azimuthal dependence as well as on the spin density matrix elements for exclusive omega meson production. These measurements are aiming to constrain GPDs, in particular the chiral-odd (transversity) GPDs  $H_T$  and  $\tilde{E}_T$ .

**Morning / 70**

## Challenges in Nuclear Femtography

**Corresponding Author:** latifa@jlab.org

**Morning / 32**

## Study of GPDs at HERMES

**Author:** Hrachya Marukyan<sup>1</sup>

<sup>1</sup> A.Alikhanyan National Science Laboratory (Yerevan Physics Institute)

**Corresponding Author:** marukyan@mail.desy.de

The HERMES experiment has collected a wealth of deep-inelastic scattering data using the 27.6 GeV polarized electron or positron beams at HERA and various pure gas targets, both unpolarized and polarized. This allowed for a series of unique measurements. Among them are measurements in hard exclusive processes, such as deeply virtual Compton scattering process or exclusive meson production processes. They provide information on the three-dimensional structure of the nucleon both in momentum space and in mixed momentum and position space. Results on various cross-section asymmetries, sensitive to generalized parton distributions and thus to the three-dimensional nucleon structure in mixed momentum and position space, are shown. The operation of a recoil detector during the last two years of HERMES running enabled for the full kinematic reconstruction of the events of exclusively produced real photons and a clean (with a background well below the 1%) measurement of the beam-helicity asymmetry. Also, first measurement of the beam helicity asymmetry related to the associated deeply virtual Compton scattering process, where the proton is excited to a  $\Delta$ -resonance state, was possible using the recoil detector information. Spin density matrix elements and transverse-target spin asymmetries in exclusive meson production on unpolarized protons and deuterons and on transversely polarized protons, respectively, as well as helicity

amplitude ratios from exclusive rho production on transversely polarized protons are presented as well.

**Morning / 28**

## Chiral Odd GPDs

**Author:** Gary Goldstein<sup>1</sup>

<sup>1</sup> *Tufts University*

**Corresponding Author:** gary.goldstein@tufts.edu

The 3-dimensional structure of the nucleon in QCD involves the specification of quark and gluon momenta and spin distributions. Generalized parton distributions (GPDs) encode the distributions in terms of fractional longitudinal and transverse momenta, spin helicity and transversity. The transversity transfer from the nucleon to its constituents in electroproduction is measured via chiral odd interactions between the beam and the partons, the transversity GPDs. These are most directly determined in cross sections and asymmetries for exclusive electroproduction of pseudoscalar mesons, particularly pions and eta mesons. Predictions from a successful “Flexible Model” for these GPDs will be presented and compared with some of the extensive data on meson electroproduction.

**Morning / 2**

## Studies of Transversity GPDs

**Author:** Valery Kubarovsky<sup>None</sup>

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A longstanding goal in nuclear and particle physics has been to describe the three-dimensional structure of the nucleon in terms of the quarks and gluon fields. In this regard, exclusive electron scattering experiments, in which all final state particles are measured, are important contributors. Examples are electron elastic scattering, deeply virtual Compton scattering (DVCS), and deeply virtual meson electroproduction (DVMP). The latter includes pseudoscalar mesons with intrinsic spin and parity  $J^P = 0^-$ , such as  $\pi^0$ ,  $\pi^-$ ,  $\pi^+$  and  $\eta$ , and vector mesons, which have the same spin and parity as the photon,  $J^P = 1^-$ , such as  $\rho^-$ ,  $\rho^+$ ,  $\rho^0$ ,  $\omega$  and  $\phi$ . Exclusive electron scattering reactions at high momentum transfers directly related to Generalized Parton Distributions (GPDs) of quarks and gluons. Most reactions studied, such as DVCS or vector meson electroproduction, are primarily sensitive to the chiral-even GPDs. Very little is known about the chiral-odd GPDs, which are difficult to access since hard subprocesses with the quark spin-flip are suppressed. It turns out that pseudoscalar meson electroproduction, and especially  $\pi^0$  and  $\eta$  production, were identified as especially sensitive to the parton helicity-flip subprocesses.

Dedicated experiments to study Deeply Virtual Meson Production out of proton and neutron have been carried out at Jefferson Lab. The cross sections and asymmetries of the exclusive pseudoscalar meson electroproduction processes in a very wide kinematic range of  $Q^2$ ,  $x_B$  and  $t$  have been measured with CLAS. The comparison of these data with the theoretical models will be presented. The extraction of the transversity GPDs parameters using global fit of the available data will be discussed in the report.

**Morning / 20**

## The proton charge radius from the PRad experiment

**Author:** Haiyan Gao<sup>1</sup>

<sup>1</sup> *Duke University*

**Corresponding Author:** gao@phy.duke.edu

Despite decades of efforts in studying the internal structure of the nucleon, there are still a number of puzzles surrounding the proton such as its spin, mass, and the charge radius. The proton charge radius puzzle developed about ten years ago refers to a 5-7  $\sigma$  discrepancy between the ultrahigh precise values of the proton charge radius determined from muonic hydrogen Lamb shift measurements and the CODATA values compiled from electron-proton scattering experiments and hydrogen spectroscopy measurements. In this talk, I will introduce the proton charge radius puzzle and then focus on the PRad experiment at Jefferson Lab and its result.

**Morning / 26**

## Proton radius with COMPASS++/AMBER

**Authors:** Jan Friedrich<sup>1</sup>; COMPASS++/AMBER<sup>None</sup>

<sup>1</sup> *Technische Universitaet Muenchen (DE)*

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With many attempts to experimentally constrain the leading-order term describing the non-pointlike nature of the proton, i.e. its mean-square charge radius, the overall situation is still ambiguous and is a quest for new precision data. COMPASS++/AMBER aims at contributing with a high-statistics measurement of high-energy muon-proton elastic scattering, complementing the respective campaign with low-energy muons at MUSE/PSI. Data taking is proposed from 2022 on.

**Afternoon / 9**

## Prompt photon production in the $k_T$ -factorization: parton Reggeization approach

**Author:** Vladimir Saleev<sup>1</sup>

**Co-authors:** Maxim Nefedov<sup>2</sup>; Alexandera Shipilova<sup>2</sup>; Anton Karpishkov<sup>1</sup>

<sup>1</sup> *Samara National Research University*

<sup>2</sup> *Samara State University*

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Parton Reggeization approach (PRA) is based on  $k_T$ -factorization of hard processes at multi-Regge kinematics. In PRA, initial state partons are treated as Reggeized gluons and Reggeized quarks, which are quantum fields of Lipatov's Effective Theory [1]. This one guarantees gauge invariance for off-shell hard amplitudes. As it was shown in [2], unintegrated (transverse momentum dependent) parton distribution functions (uPDFs) of off-shell partons  $\Phi(x, \mathbf{q}_T^2, \mu^2)$  is naturally described by the Kimber-Martin-Ryskin (KMR) model [3].

Inclusive production of isolated photon is described in the leading order (LO) of PRA via  $2 \rightarrow 1$  parton subprocess  $Q\bar{Q} \rightarrow \gamma$ . The gauge invariant amplitude of this process is proportional to Fadin-Sherman effective vertex  $\Gamma_{Q\bar{Q}\gamma}^\mu$  [4].

At first, we study single photon production in LO PRA in  $pp(p\bar{p})$  collisions at the energies of LHC and Tevatron Colliders using original KMR model for uPDFs. To study processes at sufficiently low energies (from  $\sqrt{S} = 20$  to  $\sqrt{S} = 200$  GeV), we suggest modified multi-Regge approximation in which modified KMR model can be used at arbitrary  $x$ . We describe old data from SPS, RHIC and predict photon spectra for future SPD NICA experiment.

We have studied photon production in LO and NLO PRA in Refs. [5]-[8].

[1] L.N. Lipatov L.N. Gauge invariant effective action for high energy processes in QCD. Nucl. Phys. **{\bf B452}** (1995) 369;  
L.N. Lipatov, M.I. Vyazovsky. Quasi-multi-Regge processes with a quark exchange in the t-channel, Nucl. Phys. **{\bf B597}** (2001) 399.

[2] A.V. Karpishkov, M.A. Nefedov and V.A. Saleev,  $B\bar{B}$  angular correlations at the LHC in parton Reggeization approach merged with higher-order matrix elements, Phys. Rev. D 96 (2017) no.9, 096019.

[3] M. A. Kimber, A. D. Martin, and M. G. Ryskin, Unintegrated parton distributions and prompt photon hadroproduction, Eur. Phys. J. C12 (2000) 655.

[4] V. Fadin V and V. Sherman, Fermion reggeization in nonabelian calibration theories, JETP Lett. 23 (1976) 599.

[5] M. Nefedov and V. Saleev, Diphoton production at the Tevatron and the LHC in the NLO approximation of the parton Reggeization approach, Phys. Rev. D92 (2015) no.9, 094033

[6] B.A. Kniehl, M.A. Nefedov and V.A. Saleev, Prompt-photon plus jet associated photoproduction at HERA in the parton Reggeization approach Phys. Rev. D89 (2014) no.11, 114016

[7] B.A. Kniehl, V.A. Saleev, A.V. Shipilova and E.V. Yatsenko, Single jet and prompt-photon inclusive production with multi-Regge kinematics: From Tevatron to LHC, Phys. Rev. D **{\bf 84}** (2011) 074017

[8] V.A. Saleev, Prompt photon photoproduction at HERA within the framework of the quark Reggeization hypothesis, Phys. Rev. D78 (2008) 114031.

**Afternoon / 18**

## **Gluon structure of hadrons with prompt photons at COMPASS-AMBER and NICA-SPD.**

**Author:** Alexey Guskov<sup>1</sup>

<sup>1</sup> *Joint Institute for Nuclear Research (RU)*

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Prompt photon production in hadronic collisions is a proven way to access unpolarised and polarised gluon structure of hadrons. Possible physics with prompt photons at the COMPASS-AMBER experiment at CERN and at the SPD experiment at the NICA collider at JINR (Dubna, Russia) will be presented.

**Afternoon / 25**

## **The transverse single spin asymmetry in photon SIDIS**

**Author:** Marc Schlegel<sup>1</sup>

**Co-authors:** Weeam Albaltan <sup>1</sup>; Alexey Prokudin

<sup>1</sup> *New Mexico State University*

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The transverse single spin asymmetry of a nucleon is discussed for the semi-inclusive production of photons in lepton-nucleon collisions. Arguments are given that this particular observable is very suitable to study quark-gluon correlation functions in the nucleon. Experimental data, for example taken at a future Electron-Ion Collider, on this observable may help to constrain these correlation functions. In this way one can gain more insight into the origin of transverse single spin asymmetries.

**Afternoon / 4**

## Has vector meson polarization the impact on its interaction with matter?

**Author:** Sergey Gevorkyan<sup>1</sup>

<sup>1</sup> *JINR*

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Light vector mesons  $V = \rho, \omega, \varphi, K^*$  etc. can be transversely (helicity  $\lambda = \pm 1$ ) or longitudinally ( $\lambda = 0$ ) polarized.

Has their polarization impact on their interaction with nucleons and nuclei?

The unstable meson total cross section with nucleon can be extracted by measuring the absorption of mesons in the production off nuclei as

the nuclear absorption depends on the meson-nucleon total cross section and consequently on the vector meson polarization.

Whereas the meson coherent photoproduction off nuclei allows to determine the transverse total cross section  $\sigma_T(VN)$  the incoherent production can be a good tool

to extract the information on the value of the total cross section of longitudinally polarized vector meson with nucleon  $\sigma_L(VN)$ . In the talk we discuss the importance of a knowledge

of this cross sections and possibility to determine these quantities from  $\omega$  mesons photoproduction at JLAB and charge exchange reaction on a set of nuclei  $\pi^- A \rightarrow V A'$  using the

COMPASS++/AMBER facility at SPS,CERN.

**Afternoon / 23**

## New Results on PDFs in Nucleons and Nuclei

**Author:** Misak Sargsian<sup>1</sup>

<sup>1</sup> *Florida International University*

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We report an observation of new properties of valence quark partonic distribution that allows to derive new relations that can be used to constrain phenomenological parameterizations of PDFs. These relations allow to formulate a “mean field theorem” according to which no fixed number constituent exchanges can be responsible for the valence quark distributions in  $0.1 < x < 0.3$  region. This in turn explains why no nuclear medium modification is observed for partonic distribution in this regio

Afternoon / 52

## Present and Future Studies of Color Transparency and Hadronization in Hall B

**Author:** Michael Wood<sup>1</sup>

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For a complete description of the strong interaction, Quantum Chromodynamics (QCD) must be able to predict the dynamics of the free quarks in the nuclear medium. Put another way, the nucleus is a good laboratory to study the propagation of free quarks and the formation of color-neutral objects. This talk will describe a program at Hall B at the Thomas Jefferson National Accelerator Facility (JLab) to study Color Transparency and Hadronization. Color Transparency is the process of the cancellation of QCD color fields for small singlet system of quarks and gluons and predicts a vanishing of the final state interactions of hadrons with the nuclear medium in exclusive processes at high momentum transfers. Hadronization is the process of forming hadrons out of quarks and gluons, and using various nuclei allows for studies of the propagation time and the formation time. Existing data from CLAS6 and future experiments with CLAS12 will be presented.

Afternoon / 11

## Baryon-to-meson Transition Distribution Amplitudes: basic properties, physical interpretation and experimental perspectives

**Author:** Kirill Semenov-Tian-Shansky<sup>1</sup>

**Co-authors:** Bernard Pire<sup>2</sup>; Lech Szymanowski<sup>3</sup>

<sup>1</sup> *PNPI*

<sup>2</sup> *CPHT Ecole Polytechnique*

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Baryon-to-meson Transition Distribution Amplitudes (TDAs) appear as building blocks within the collinear factorized description of amplitudes for a class of hard exclusive reactions such as hard exclusive meson electroproduction off a baryon in the near-backward region and baryon-antibaryon annihilation into a meson and a lepton pair.

In this talk we present a general overview of the fundamental properties of baryon-to-meson TDAs and address their physical contents with the special emphasize on the interpretation in the impact parameter space.

We also discuss the observable quantities sensitive to the onset of the collinear factorization regime for the corresponding hard exclusive reactions and consider experimental perspectives for accessing baryon-to-meson TDAs at JLab and at future facilities such as PANDA@GSI and EIC.

Afternoon / 68

## Bound and Free Nucleon Structure

**Author:** Eli Piassetzky<sup>1</sup>

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Atomic nuclei are made of protons and neutrons, themselves composed of quarks and gluons. Understanding how the nuclear environment impacts the quark-gluon structure of bound nucleons is an outstanding challenge. While the first evidence for such impact, known as the 'EMC effect', was observed over 35 years ago, a generally accepted explanation of the dynamics driving it is still lacking. I will present new high-energy electron-scattering data, that, combined with existing data, indicate that the underlying cause and dynamics of the EMC effect is the structure modification of close-proximity nucleons. A global analysis of deep inelastic scattering (DIS) data on the proton and on nuclei from  $A = 2$  (deuterium) to 208 (lead) presented here, quantify the modification of the structure function of nucleons bound in atomic nuclei (the EMC effect) within the framework of a universal modification of nucleons in short-range correlated (SRC) pairs. It also allow to extracted neutron-to-proton structure function ratio ( $F_n/F_p$ ) with smaller uncertainties than previous extractions.

**Morning / 33**

## Large Transverse Momentum

**Author:** Ted Rogers<sup>1</sup>

<sup>1</sup> *Old Dominion University/Jefferson Lab*

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I will discuss issues related to transverse momentum dependent cross sections in the limit that the transverse momentum is comparable to hard scales.

**Morning / 42**

## TMDs and collinear twist-3 functions in the CSS formalism

**Authors:** Leonard Gamberg<sup>1</sup>; Andreas Metz<sup>2</sup>; Daniel Pitonyak<sup>3</sup>; Alexey Prokudin<sup>None</sup>

<sup>1</sup> *Penn State University Berks*

<sup>2</sup> *Temple University, Philadelphia*

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I will report on the application of the improved Collins-Soper-Sterman (iCSS) factorization formalism for the case of polarized observables, such as the Sivers effect in semi-inclusive deep-inelastic scattering. I will discuss how this study is being extended beyond leading order; this has direct impact on issues of relating/matching TMDs onto collinear twist-3 functions. I will briefly discuss the validity of the well-known relations, such as between the weighted TMD Sivers function and the collinear twist-3 Qiu-Sterman function, and their use in phenomenological studies of the 3-D structure of hadrons.

**Morning / 61**

## Comparing single spin asymmetries in hadronic and heavy-ion collisions

**Authors:** Oleg Teryaev<sup>1</sup>; Valentin Zakharov<sup>2</sup>

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The basic ingredients of generation of single spin asymmetries are the formation of pseudovector, interference of amplitudes and emergence of imaginary phase. The latter, provided by final (initial) state interactions due to twist 3 effects or Sivers function in hadronic collisions, is suggested to correspond to the dissipation effects in heavy-ion collisions. Manifestation of the latter due to the appearance of baryonic cores in the quantized vortices in pionic superfluid is addressed. The experimental studies of the transition between hadronic and heavy-ion collisions is discussed.

**Morning / 19**

## Hadron structure and dynamics in Minkowski space

**Author:** Tobias Frederico<sup>1</sup>

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The solution of the Bethe-Salpeter equation in Minkowski space resorting to an integral representation will be discussed for different systems composed by fermions and bosons. This framework provides results for the momentum distributions and electromagnetic form factor of a dynamical pion model [1] with constituent quarks exchanging an effective gluon inspired by lattice calculations of the gluon dressing function, and a phenomenological quark-gluon vertex [2], which will be also discussed. A recent application to a fermion-boson system, resembling a quark-diquark model of the nucleon [3], is also reported and the associate momentum distributions will be shown. In particular for this model the issue of scale invariance is addressed. In addition, we discuss some future directions of this Minkowski space framework to describe the hadron structure.

[1] W. de Paula, T. Frederico, G. Salmè, M. Viviani, R. Pimentel, Eur. Phys. Jour. C 77, 764 (2017).

[2] O. Oliveira, W. de Paula, T. Frederico, J. P. B. C. de Melo, Eur. Phys. Jour. C 79, 116 (2019).

[3] J. H. A. Nogueira, V. Gherardi, T. Frederico, G. Salmè, D. Colasante, E. Pace, Phys. Rev. D 100, 016021 (2019).

**Morning / 39**

## QCD factorization and hadron production near threshold

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All observed hadrons are color neutral, while they are all emerged from colored quarks and gluons (or partons) in high energy collisions. The COMPASS collaboration published precise data on production cross section of charged hadrons in lepton-hadron semi-inclusive deep inelastic scattering, showing almost an order of magnitude larger than next-to-leading order QCD calculations when hadrons were produced near the threshold. In this talk, I will discuss QCD factorization that is necessary for connecting the produced hadrons to colored partons, explore the transition between the inclusive and exclusive production when hadrons are produced with a low multiplicity, and quantify our capability to measure the three-dimensional hadron structure at the newly upgraded CEBAF at JLab and the future Electron-Ion Collider.

**Morning / 24**

## The spin content of the nucleon sea

**Author:** Bo-Qiang Ma<sup>1</sup>

<sup>1</sup> *Peking University*

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From recent observations of  $W^{\pm}$  asymmetries and spin transfer to Lambda production in polarized proton and proton collisions at RHIC, we can obtain constraints on the polarization of  $u$ bar,  $d$ bar,  $s$  and  $s$ bar inside the proton. Theoretical predictions and perspectives are confronted with these experimental observations.

**Morning / 6**

## The Strong Conjecture for Confinement

**Author:** Dennis Sivers<sup>1</sup>

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This talk provides an introduction to the conjecture *The confinement mechanism for QCD involves a domain wall of topological (CP-odd) charge separating the interior volume of hadrons from an exterior volume*. The description is formulated in terms of the chiral structure of Yang-Mills-Maxwell equations for confined sources carrying color charge in the adjoint representation of SU(2) with spherical symmetry.

**SJB-80 / 72**

## Nuclei as Laboratories for QCD

**Author:** Liuti Simonetta<sup>None</sup>

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Recent experimental and theoretical developments are bringing once more to the forefront how nuclear medium effects on the partonic structure of the nucleon are key for probing the fundamental properties of QCD. I will review the new progress and advancements in this field.

**SJB-80 / 36**

## **Stan Brodsky and the 1974 November Revolution**

**Author:** Dennis Sivers<sup>1</sup>

<sup>1</sup> *Portland Physics Institute*

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A discussion of Stan Brodsky's work shortly before and after the discovery of the J/psi particle.

**SJB-80 / 53**

## **From Light-Cone Wave Functions to Generalized Parton Distributions**

**Author:** Markus Diehl<sup>1</sup>

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Like many other quantities, Generalized Parton Distributions can be represented in terms of Light-Cone Wave Functions. This connection has several important physics aspects, which I review with a historical perspective, from early work at the turn of the millenium to recent developments.

**SJB-80 / 43**

## **The ultimate free lunch: the light-front vacuum**

**Author:** Matthias Burkardt<sup>1</sup>

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I will discuss the tremendous simplifications arising from a 'trivial' vacuum in the light-front formulation of field theory and how that can be reconciled with non-zero vacuum condensates and dynamical symmetry breaking.

**SJB-80 / 38**

## **Fock expansion of Bound States**

**Author:** Paul Hoyer<sup>1</sup>

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Bound states may be approximated by their valence Fock states  $|val\rangle$ , with higher Fock components perturbatively generated by the Hamiltonian,  $H^n|val\rangle$ . In temporal ( $A^0 = 0$ ) gauge Gauss' law appears as a constraint on physical states, fixing the instantaneous potential energies of all Fock components. A dimensionful parameter arises in QCD through the boundary condition on the solution of Gauss' law. This determines the confinement scale. The quantum numbers of atoms and hadrons are given by their valence states since the Hamiltonian conserves  $J^{PC}$ . Such approximate QCD states may serve as a model for studying TMD's and other parton distributions.

**SJB-80 / 57**

## Light-Front Holographic QCD: From counting rules to a unified description of parton distributions

**Author:** Guy de Teramond<sup>1</sup>

<sup>1</sup> UCR

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In this talk I will present an overview of the work with Stan Brodsky on nonperturbative QCD based on the gauge / gravity correspondence and light-front quantization. I will recount how our earlier incursions into this new area have gradually evolved into an active field of research. Our endeavor has been instrumental in bringing together a wonderful team of collaborators which has contributed to unveil unsuspected connections and analytic insights into hadron structure and dynamics.

**SJB-80 / 64**

## A Fixed-Target Program at the LHC: the genesis

**Author:** Jean-Philippe Lansberg<sup>1</sup>

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I will review the evolution of the AFTER@LHC project.

**SJB-80 / 74**

## A Gauge Principle in Financial Markets

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**Morning / 73**

## EIC: the science program and machine designs

**Corresponding Author:** bmck@jlab.org

**Morning / 13**

## The LHCspin project

**Author:** Pasquale Di Nezza<sup>1</sup><sup>1</sup> *INFN e Laboratori Nazionali di Frascati (IT)***Corresponding Author:** pasquale.di.nezza@cern.ch

The LHCspin project aims to bring both polarized and unpolarized physics at the LHC through the installation of a gaseous fixed target at the upstream end of the LHCb detector. The forward geometry of the LHCb spectrometer ( $2 < \eta < 5$ ) is perfectly suited for the reconstruction of particles produced in fixed-target collisions. The fixed-target configuration, with center-of-mass energies ranging from  $\sqrt{s}=115$  GeV in pp interactions to  $\sqrt{s_{NN}}=72$  GeV in collisions with nuclear beams, allows to cover a wide backward rapidity region, including the poorly explored high x-Bjorken and high x-Feynman regimes. The project has several ambitious goals regarding new-era quantitative searches in QCD through the study of the nucleon's internal dynamics in terms of both quarks and gluons degrees of freedom. The first fundamental step of installing the unpolarized target has been already reached in LHCb with the SMOG2 system.

The status of the project is presented along with a selection of physics opportunities.

**Morning / 40**

## Physics with charmonia at the SPD and AMBER experiments

**Author:** Igor Denisenko<sup>1</sup><sup>1</sup> *Joint Institute for Nuclear Research (RU)***Corresponding Author:** igor.denisenko@cern.ch

The inclusive  $J/\psi$  production is a powerful probe of the hadron structure. The process is sensitive to gluon and quark PDFs, has a large cross-section and clean experimental signal. At the same time, the interpretation of the experimental results is complicated due to the uncertainty of the  $J/\psi$  production mechanism and by the presence of so-called feed-down contributions, i.e. decays of the heavier charmonia states. The talk will cover unpolarized and polarized physics with charmonia at the SPD and AMBER experiments.

**Morning / 21**

## Probing Gluon Sivers Function in J/Psi Production at EIC

**Author:** Asmita Mukherjee<sup>None</sup>

We discuss  $J/\psi$  and  $J/\psi + jet$  production in electron-proton collision at the future EIC that can probe the poorly known gluon Sivers function.

**Morning / 48**

## Advancing hadronization: From inclusive production to multi-particle correlations

**Author:** Christine Aidala<sup>1</sup>

<sup>1</sup> *University of Michigan (US)*

**Corresponding Author:** christine.angela.aidala@cern.ch

Hadron structure and hadronization are flip sides of the “confinement coin,” yet hadronization has received much less attention in previous decades than hadron structure, in part due to its inherently dynamical nature. As we start to increase our focus on hadronization, new theoretical developments and experimental capabilities provide fertile territory for advances in our understanding. Recent results from the LHCb experiment on the hadronization of light quark jets will be shown, and prospects for future measurements at LHCb as well as the Electron-Ion Collider will be discussed.

**Morning / 62**

## Concluding remarks

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**Morning / 65**

## From the QCD Lagrangian to Hadron Structure and Interactions: A 55-Year Experience

**Author:** Stanley J. Brodsky<sup>1</sup>

<sup>1</sup> *SLAC National Accelerator Laboratory, Stanford University*

**Corresponding Author:** sjbth@slac.stanford.edu

I will discuss three central problems in QCD: (a) hadron dynamics and spectroscopy from light-front holography and superconformal algebra; (b) the behavior of the QCD running coupling in both the nonperturbative and perturbative domains; and (c) the elimination of perturbative QCD renormalization scale ambiguities. I will also review some highlights of my research in hadron physics over the last 55 years.

**SJB-80 / 59**

## QED Insights for Precision Tests of QCD and Beyond

**Author:** Susan Gardner<sup>1</sup>

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Stan Brodsky’s earliest papers were on precision tests of QED, and his focus on the “QED analog” has provided a powerful reductionist framework with which to compare and understand QCD phenomena. I will review examples, and consider the implications for precision tests of and searches for physics beyond the Standard Model.

**Afternoon / 71**

## **Medium Effects Across Scales: Bound Nucleon Structure & Short-Range Correlations**

**Corresponding Author:** hen@mit.edu

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## **Introduction**

**Afternoon / 7**

## **Stan Brodsky and the 1974 November Revolution**

**Author:** Dennis Sivers<sup>1</sup>

<sup>1</sup> *Portland Physics Institute*

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A discussion of Stan Brodsky's work shortly before and after the discovery of the J/psi particle.