# 7th Workshop of the APS Topical Group on Hadronic Physics
# – program and abstracts –

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## Recent developments in Heavy-Ion Theory

Soeren Schlichting (University of Washington)

Over the past decades relativistic heavy-ion collision experiments have revealed exciting properties of nuclear matter under extreme conditions. While a first principle theoretical description of the space-time dynamics of a heavy-ion collision remains an outstanding challenge, significant progress has been achieved and I will discuss recent theoretical developments in this direction. Specifically, I will focus on recent progress in understanding the early-time pre-equilibrium dynamics and theoretical challenges in describing collective phenomena in p+p/A collisions.

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## Anomalous Chiral Transport in High-Energy Nuclear Collisions

Jinfeng Liao (Indiana University Bloomington)

Anomalous chiral transport processes, with the notable example of Chiral Magnetic Effect (CME) and Chiral Magnetic Wave (CMW), are remarkable phenomena that manifest microscopic quantum anomaly of chiral fermions in a macroscopic many-body setting. Significant progress has been achieved both in their theoretical understanding and in their experimental search. In this talk, an elementary introduction will be given for the CME as well as other anomalous chiral effects such as the Chiral Magnetic Wave (CMW) and the vorticity-driven effects. The theoretical foundation for describing them is rapidly emerging, in particular the anomalous fluid dynamics framework. We combine this new framework with the state-of-the-art, data-validated viscous hydro simulations of heavy ion collisions to describe the anomalous chiral transport of various charges in the quark-gluon plasma. Such a simulation tool has allowed us to systematically examine and contrast the transport of conserved charges with and without anomaly effects, as well as to quantitatively compare modeling predictions with experimental data. We will present these results and discuss their implications for the search of anomalous chiral transport effects. Finally the currently pressing issues and anticipated future developments, in the context of recently formed Beam Energy Scan Theory (BEST) Collaboration, will be envisioned.

## The Proton Radius: Are We Still Puzzled?

Evangeline Downie (George Washington University)

The proton radius puzzle is the difference between the radius of the proton as measured with electron scattering and atomic hydrogen spectroscopy, and that measured in muonic hydrogen. In 2010, the CREMA Collaboration published their measurement of the proton radius $R_p = 0.8409(4)$ fm, which was made by studying the Lamb shift in muonic hydrogen. Although ten times more precise than the 2010 PDG value of $R_p = (0.877 \pm 0.007)$ fm, the CREMA result is completely incompatible with it. Until that point, The PDG value had been in good agreement with both scattering and spectroscopy results. Since 2010, there have been many theoretical and experimental efforts to try to resolve the puzzle: the CREMA collaboration have made a series of measurements in light nuclei, the PRad experiment at JLab and Intial State Radiation experiment in Mainz have sought to measure the radius at lower momentum transfer, there have been efforts at the Max Planck Institute for Quantum Optics in Munich to re-measure the hydrogen spectroscopy lines, and meanwhile many theorists have been trying to analyze the issue from multiple perspectives. A future experiment on Muon Scattering has also recently been funded by NSF (the MUon proton Scattering Experiment, MUSE). We will review the current status of the Proton Radius Puzzle, and look at future efforts which aim to make the puzzle less puzzling.

## Resonances and QCD

Raul Briceno (Jefferson Lab)

The non-perturbative nature of quantum chromodynamics (QCD) has historically left a gap in our understanding of the connection between the fundamental theory of the strong interactions and the rich structure of experimentally observed phenomena. For the simplest properties of stable hadrons, this is now circumvented with the use of lattice QCD (LQCD). In this talk I discuss a path towards a rigorous determination of few-hadron observables from LQCD. I illustrate the power of the methodology by presenting recently determined scattering amplitudes and their resonance content.

## Investigation of the Hadronic Decay $\eta \to \pi^+\pi^-\pi^0$ with CLAS

Daniel Lersch (Forschungszentrum Jülich)

The amplitude of the isospin violating decay $\eta \to \pi^+\pi^-\pi^0$ is sensitive to the ratio Q of the light quark masses. This decay amplitude is accessible via a Dalitz Plot analysis, resulting in a set of parameters which can be compared to theoretical predictions. The latest measurements on those parameters have been performed by the KLOE and the WASA-at-COSY experiment. The results of both experiments are consistent with each other, but show discrepancies to recent theoretical calculations. A different approach is given by a partial wave analysis which has been performed on the WASA-at-COSY data set and lead to a direct determination of Q. The goal of this analysis is to determine the Dalitz Plot parameters for the decay $\eta \to \pi^+\pi^-\pi^0$ and compare them to existing results. Additionally, a partial wave analysis shall be performed. The decay mode $\eta \to \pi^+\pi^-\pi^0$ has been measured with the large acceptance spectrometer CLAS at the Jefferson Laboratory. The $\eta$-mesons are produced via the photoproduction reaction $\gamma p/top\eta$. This talk will give an overview about the current status of the analysis of the CLAS g12 data set with respect to the decay $\eta \to \pi^+\pi^-\pi^0$.

## Test Fundamental Symmetries via Precision Measurements of $\pi^0$, $\eta$ and $\eta'$ Decays

Liping Gan (University of North Carolina Wilmington)

Light neutral meson decays provide a unique laboratory to test fundamental symmetries in physics. A comprehensive Primakoff experimental program at Jefferson Laboratory (JLab) is aimed at gathering high precision measurements on the two-photon decay widths and the transition form factors at low four-momentum transfer squares for $\pi^0$, $\eta$ and $\eta'$ via the Primakoff effect. The results of these measurements will offer stringent tests on the chiral anomaly and provide sensitive probe for the origin and dynamics of chiral symmetry breaking in the confinement QCD. In addition, the JLab Eta Factory (JEF) experiment has been recently developed to measure various $\eta$ decays with emphasis on rare neutral modes. It will have a factor of two orders of magnitude reduction in backgrounds compared to all other existing or planned experiments in the world. Such low background data will serve as important hadronic probes for weakly-coupled new forces, such as a dark force via a leptophobic dark $V_B$-boson or a new C-violating, P-conserving force. The status of these experimental activities and their physics impacts will be discussed.

## Strong interaction with strangeness in the low energy regime: strange atoms, resonances, nuclei

Johann Marton (Stefan Meyer Institute, Austrian Academy of Sciences)

There is substantial progress in the understanding of the strong interaction involving strange quarks. However, many aspects of the interactions of antikaons with nucleons and nuclei are still open which are also related to the open question about the role of strangeness in neutron stars. The K- nucleon interaction is strongly attractive at low energies in agreement to theory. This attraction is observed in kaonic hydrogen, which was studied in experiments at the DAΦNE electron-positron collider of LNF-INFN (Frascati/Italy). Resonances like the elusive $\Lambda(1405)$ in the s-wave impose questions about its nature. In recent theoretical studies it is described as a dynamically generated resonance with two poles. This topic is included in the AMADEUS project at LNF-INFN, which is focused on the study of the nuclear interaction with strangeness at low energy. On the other hand the SIDDHARTA2 project also at LNF-INFN will study kaonic deuterium to extend our knowledge with the antikaon-neutron interaction. Together with our result on kaonic hydrogen we will be able to deduce the scattering lengths in both isospin channels. The results of the antikaon interaction experimental studies and an outlook to the future studies will be presented.

## First attempts at a global fit of unpolarized Transverse Momentum Distributions

Alessandro Bacchetta (University of Pavia and INFN Pavia)

I will describe recent efforts to extract Transverse Momentum Distributions (TMDs) from measurements in semi-inclusive DIS, Drell-Yan processes, and Z boson production. These efforts can be considered as the first attempt at a global fit of unpolarized TMDs. The results are encouraging, but several open challenges remain to be addressed and more experimental information is needed to improve the extractions.

## Generalized TMDs

Andreas Metz (Temple University)

We give a brief overview of the field of Generalized TMDs. In particular, we address the question if/how Generalized TMDs could be measured.

# Mapping the hadronization description in Pythia to the correlation functions of TMD factorization

Markus Diefenthaler (Jefferson Lab)

In a collaboration between Jefferson Lab and the Pythia collaboration, we aim to map the non-perturbative description of hadronization in the Pythia Monte Carlo Event Generator (MCEG) to the correlation functions of TMD factorization. In a LDRD project, we investigate the connection between the description of hadronization phenomena in nuclear and high-energy physics, work towards a MCEG for TMDs, and by doing so make fundamental contributions to the theoretical framework for TMDs.

## Pion in jet asymmetries at RHIC: test of evolution

Alexei Prokudin (Jefferson Lab)

Recent measurements of spin asymmetry for pion in jet by STAR Collaboration show little sensitivity to QCD evolution. In this talk I will apply TMD factorization to this process and give a detailed explanation of observed asymmetries.

## Initial conditions for hydrodynamics from weakly coupled pre-equilibrium evolution

Derek Teaney (Stony Brook)

We use effective kinetic theory, accurate at weak coupling, to simulate the preequilibrium evolution of transverse energy and flow perturbations in heavy-ion collisions. We provide a Green function which propagates the initial perturbations to the energymomentum tensor at a time when hydrodynamics becomes applicable. With this map, the complete pre-thermal evolution from saturated nuclei to hydrodynamics can be modelled in a perturbatively controlled way.

## QCD equation of state at high temperatures

Alexei Bazavov (Michigan State University)

The equation of state (EoS) in 2+1 flavor QCD has recently been established in the continuum limit at the physical quark masses. The HotQCD collaboration result provides the EoS in the temperature range from 130 to 400 MeV. We extend the HotQCD equation of state to higher temperatures. We utilize the Highly Improved Staggered Quarks (HISQ) action. We perform computations at the pion mass of about 300 MeV since the effects of heavier than physical light quark masses are negligible above 400 MeV. To control the cutoff effects and approach to the continuum limit, computations are done on the lattices with temporal extent Nt=8, 10 and 12.

## Heavy Flavor Production at RHIC

Lijuan Ruan (Brookhaven National Laboratory)

I will review the most recent open heavy flavor and quarkonium results at RHIC and present how we use the heavy flavor probes to study the properties of the medium created at RHIC.

## Heavy intrinsic quarks in hadrons: theory, constraints, and consequences

Susan Gardner (University of Kentucky)

I review the manner in which heavy intrinsic quarks in hadrons appear in QCD, offering an overview of theoretical predictions and existing experimental constraints. I also discuss possible future probes and phenomenological consequences.

## Hadron structure studies with a fixed-target experiment at the LHC - AFTER@LHC

Andrea Signori (Jefferson Lab)

I will illustrate some of the opportunities for hadron structure studies at a future multi-purpose fixed-target experiment at the LHC. The proton beams at the LHC allow for the most energetic fixed-target experiments ever performed, opening new kinematic windows on hadron and nuclear physics which integrate the knowledge available from collider experiments (in particular RHIC and EIC). I will discuss how AFTER@LHC will shed light on the proton-spin puzzle by investigating Transverse-Momentum Dependent parton distribution functions (TMDs). Unpolarized proton-proton collisions allow to access unpolarized quark and gluon TMDs, the Boer-Mulders quark TMD and the distribution of linearly polarized gluons in unpolarized protons. Looking at polarized targets, single-transverse-spin asymmetries (STSAs) for processes such as Drell-Yan lepton-pair and quarkonium production will allow measurements of polarized TMDs for quarks and gluons, such as the Sivers functions. Moreover, I will show how, thanks to the boost of the fixed target mode, the acceptance of detectors like LHCb and ALICE in the fixed-target mode allows to analyze processes which are sensitive to the intrinsic charm content of the proton. In particular, I will address some aspects of D meson, charm + photon as well as J/psi-pair production.

## Intrinsic Charm at LHCb

Philip Ilten (MIT)

The unique design of the LHCb detector allows for novel methods of probing intrinsic charm (IC). Its forward coverage and excellent c-tagging capabilities provide sensitivity to valence-like IC from Z + charm-jet events in pp collisions. The System for Measuring the Overlap with Gas (SMOG), initially designed for precision luminosity measurements, can also be used as a fixed target experiment sensitive to IC. Details of the SMOG program to-date, will be given.

## Hadron structure from lattice QCD

Jeremy Green (DESY Zeuthen)

Recent progress in lattice QCD calculations of hadron structure will be reviewed, with an emphasis on nucleon structure. A wide range of nucleon observables are being studied in modern lattice calculations. The axial charge and electromagnetic form factors are well known from experiment, and serve as benchmarks for lattice calculations. Sigma terms and tensor and scalar charges are relevant for interpreting results of searches for dark matter and physics beyond the Standard Model. Other observables give insight into the quark and gluon substructure of the nucleon. Challenges in controlling systematic uncertainties will be discussed.

## Recent results on QCD thermodynamics from Lattice

Sayantan Sharma (BNL)

Fluctuations of conserved charges like baryon number and strangeness are important observables to understand the nature and interactions between the degrees of freedom in different phases of QCD. The higher order fluctuations are particularly important to get information on the location of possible QCD critical end-point and to understand the interplay between fluctuations and non-trivial topological properties in QCD. In this talk I will highlight the recent theoretical and algorithmic developments made in lattice gauge theory in calculating the higher moments of conserved charges. I will also discuss how the lattice data on fluctuations and correlations of different conserved charges could be used for determining the QCD equation of state at finite density, to constraint the possible location of critical end-point in the QCD phase diagram and understand the nature and interactions among quasi-particles across the chiral crossover transition in QCD.

## Lattice QCD determination of quark masses and $\alpha_s$

Christine Davies (University of Glasgow)

The quark mass and strong coupling constant parameters of the QCD Lagrangian are free parameters in the Standard Model and can only be determined by comparison of theory and experiment. Lattice QCD gives us direct access to the QCD Lagrangian and so is well-suited to the determination of these parameters. I will review the methods used to date, the results obtained and prospects for future improvement.

## Impact of New Results from CLAS on Baryonic Resonances

Michael Döring (George Washington U and Jefferson Lab)

Photoproduction experiments provide a key to finding new baryonic resonances. New precise measurements of polarization observables emerge from FROST at JLab and from other facilities around the world like ELSA and MAMI, allowing to determine the multipoles and baryonic resonance parameters to much increased precision. The impact from FROST data is discussed and improvements for future analyses are outlined. Those comprise improved input from elastic $\pi N$ scattering in multi-reaction analyses, more general interpretation of uncertainties in helicity couplings by including correlations, and extensions to electroproduction as planned at JLab.

## Minimal Models for Partial-Wave Analysis

Justin Landay (George Washington University)

Partial-wave analysis of experimental data provides the point of comparison between many theoretical approaches and Nature. The parametrization of partial waves is guided by theoretical principles of scattering theory and effective approaches to QCD; however, data themselves can be used to find the simplest model from a large class of possible ones, to deliver a minimally parametrized yet accurate description of the data. The workflow includes the combination of the Least Absolute Shrinkage and Selection Operator (LASSO) with criteria from information theory and cross validation. This model selection process is illustrated in the example of low-energy pion photoproduction.

## Hadron spectroscopy at JPAC

Alessandro Pilloni (Jefferson Lab)

We review some of the recent achievements of the Joint Physics Analysis Center, a theoretical collaboration with ties to experimental collaborations, which aims at providing amplitudes suitable for the analysis of the experimental data on hadron physics. Since its foundation in 2013, the group is focused on hadron spectroscopy in preparation for the present and forthcoming high statistics experiments, as Belle II, BESIII, CLAS12, GlueX, COMPASS and LHCb.

## A Search for the LHCb Pentaquark using Photoproduction of $J/\psi$ near Threshold in Hall C at Jefferson Lab

Burcu Duran (Temple University)

We will present on the recently approved Jefferson Lab experiment E12-16-007 which aims at measuring the $J/\psi$ photoproduction cross section as a function of proton momentum transfer variable $t$ and photon energy $E\gamma$ in the region of the recently discovered LHCb charmed pentaquark $P_c(4380)$ and $P_c(4450)$ resonances. The experiment will be performed using the Hall C HMS and SHMS spectrometers in coincidence to detect $e^+e^-$ di-lepton $J/\psi$ decay pair. The spectrometer settings were optimized to allow for the kinematics where the s-channel pentaquark signal, if it exists, is maximized compared to the $t$-channel background $J/\psi$ production. This measurement has the potential to confirm the existence of the s-channel charmed pentaquark with $5\sigma$ confidence down to 1.3% coupling to the $J/\psi$ - p decay.

## Recent results on exclusive hadronic cross section measurements with the BABAR detector

Claudia Patrignani (for INFN Genova)

The BABAR Collaboration has an intensive program studying hadronic cross sections in low-energy $e^+e^-$ annihilations, accessible via initial-state radiation. Our measurements allow significant improvements in the precision of the predicted value of the myon anomalous magnetic moment. These improvements are necessary for shedding light on the current $3\sigma$ difference between the predicted and the experimental values. We have published results on a number of processes with two to six hadrons in the final state, and other final state are currently under investigation. We report here on the most recent results obtained by analysing the entire BABAR dataset, in particular the measurement of the $e^+e^- \to \pi^+\pi^-\pi^0\pi^0$, which is one of the least known contribution to the cross section in the energy region between 1 and 2 GeV. We also present the measurement of the $\pi^+\pi^-\eta$, and of the full set of final states with two kaons and two pions.

## Nucleon-Nucleon Correlations and the Quarks Within

Gerald Miller (UW, Seattle)

This talk reviews our current understanding of how the internal quark structure of a nucleon bound in nuclei differs from that of a free nucleon. We focus on the interpretation of measurements of the EMC effect for valence quarks, a reduction in the Deep Inelastic Scattering (DIS) cross-section ratios for nuclei relative to deuterium, and its possible connection to nucleon-nucleon Short-Range Correlations (SRC) in nuclei. Our review of the available experimental and theoretical evidence shows that there is a phenomenological relation between between the EMC effect and the effects of SRC that is not an accident. There is an underlying cause of both effects: the influence of strongly correlated neutron-proton pairs is largely responsible. This conclusion needs to be solidified by the future experiments and improved theoretical analyses.

## Short-range NN interactions: Experimental Past and Future

Nadia Fomin (University of Tennessee)

High momentum components of the nuclear wave-function are believed to arise as a result of short-range NN correlations in the ground state. The 6 GeV era at Jefferson Lab has yielded a wealth of information about these high momentum nucleons across many nuclei, and revealed a tantalizing connection to the EMC effect, possibly linking very different kinematic regimes. Existing measurements will be reviewed and future measurement plans will be discussed.

## Properties of light nuclei from lattice QCD

William Detmold (MIT)

Fundamentally, nuclear physics arises from the Standard Model. The calculation of key nuclear physics quantities from this underlying theory is extremely challenging because of the multiple scales of physics that are involved and the severe computational complexity. The availability of petascale (and the prospect of exascale) high performance computing is changing this situation by enabling the extension of the numerical techniques of lattice Quantum Chromodynamics (LQCD), applied successfully in particle physics, to the more intricate dynamics of light nuclei. In this talk, I will discuss this new frontier and the emerging understanding of hadrons and nuclei directly from the Standard Model. In particular, I will discuss recent LQCD calculations of their electroweak interactions and structure and prospects for calculations of nuclear modification of parton distributions.

## Nucleon Parton Structure from the DSEs

Kyle Bednar (Kent State University)

The parton structure of the nucleon is investigated using QCD's Dyson-Schwinger equations (DSEs). The formalism used here builds in numerous features of a QCD approach, for example, the dressing of parton propagators and dynamical formation of non-pointlike di-quark correlations. All needed elements, including the nucleon wave function solution from a Poincaré covariant Faddeev equation, are encoded in spectral-type representations in the Nakanishi style. This greatly facilitates calculations and allows insight into how the essential features of the parton distributions arise from key underlying mechanisms. As a first step, results for the nucleon quark distribution functions will be presented. A major aim is the extension to the transverse momentum-dependent parton distributions (TMDs) and initial results for this will be discussed if possible.

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# Recent Breakthrough in LQCD Structure Calculations

Yibo Yang (University of Kentucky)

Higgs boson provides the source of the fundamental particle mass. But how it is related to the proton mass and then the mass of the observable matters, is an interesting, important, and yet unanswered question. The total masses of the three valence quark in the proton are less than 10 MeV which is directly related to the Higgs boson, while the total proton mass is 938 MeV. It is clear that the question can only be answered by solving QCD nonperturbatively, and/or with information from the experiment. I will report the progress on the proton mass decomposition based on the energy momentum tensor of QCD. We made the calculations with the chiral fermion on several 2+1 flavor domain wall fermion sea configurations which have different lattice spacing, volume and several values of the sea quark masses including the physical value. The results are matched to that on the MS-bar scheme at 2GeV with 1-loop perturbative calculation.

# Gluonic Transversity from Lattice QCD

Phiala Shanahan (Massachusetts Institute of Technology)

We present an exploratory study of the gluonic structure of the $\phi$ meson using lattice QCD (LQCD). This includes the first investigation of gluonic transversity via the leading moment of the twist-two double-helicity-flip gluonic structure function $\Delta(x, Q^2)$. This structure function only exists for targets of spin $J \geq 1$ and does not mix with quark distributions at leading twist, thereby providing a particularly clean probe of gluonic degrees of freedom. We also explore the gluonic analogue of the Soffer bound which relates the helicity flip and non-flip gluonic distributions, finding it to be saturated at the level of 80%. This work sets the stage for more complex LQCD studies of gluonic structure in the nucleon and in light nuclei where $\Delta(x, Q^2)$ is an 'exotic glue' observable probing gluons in a nucleus not associated with individual nucleons.

## The hadronic light-by-light contribution to muon $g-2$ from lattice QCD

Luchang Jin (BNL)

The current measurement of muonic $g-2$ disagrees with the theoretical calculation by about 3 standard deviations. Hadronic vacuum polarization (HVP) and hadronic light by light (HLbL) are the two types of processes that contribute most to the theoretical uncertainty. The current value for HLbL is still given by models. We report our latest lattice calculation of hadronic light-by-light contribution to muon $g-2$ using our recent developed moment method. The connected diagrams and the leading disconnected diagrams are included. The calculation is performed on a $48^3 \times 96$ lattice with physical pion mass and 5.5 fm box size. We expect sizable finite volume and finite lattice spacing corrections to the results of these calculations which will be estimated in calculations to be carried out over the next 1-2 years.

# Nucleon matrix elements from Moments of Correlation Functions and the Proton Charge Radius

David Richards (Jefferson Lab)

We show how momentum-space derivatives of hadron form factors can be related to their coordinate space moments computed in lattice QCD through a Fourier Transform. The method provides a priori information about the $Q^2$ dependence of form factors. As a specific application of the method, we obtain the slope of the isovector form factor of the nucleon at the various $Q^2$ accessible on the lattice, and hence derive the isovector charge radius. The method has potential application to the calculation of other form factors, including those relevant to hadronic weak decays.

## Quarkonium production at LHC from pp to AA

Enrico Scomparin (INFN Torino, Italy)

The study of the production of quarkonia in heavy-ion collisions represents one of the most important tools for the characterization of the Quark-Gluon Plasma. In particular, the screening of the color force in a deconfined medium is predicted to lead to a suppression of the production of charmonium and bottomonium states with respect to the yields observed in pp collisions. At the same time, re-generation mechanisms between deconfined heavy quarks, during the QGP phase or when the system hadronizes, may lead to an increased production. Extended studies on quarkonium have been carried out at the LHC in Pb-Pb collisions, up to a center-of-mass energy per nucleon-nucleon collision $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV. Results on several charmonium (J/$\psi$, $\psi(2S)$) and bottomonium ($\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$) states are available. In this talk I will review the main achievements of the LHC program and discuss their implications for QGP studies.

## Heavy quarkonium at finite temperature from lattice effective field theories

Alexander Rothkopf (Heidelberg University)

Heavy quarkonium presents a unique probe of the quark-gluon plasma produced in relativistic heavy-ion collisions. While Bottomonium is expected to act as a test particle traversing the medium in the collision center, recent measurements of finite $J/\Psi$ flow by the ALICE collaboration hint at the participation of the charm quarks in the collectivity of the bulk. Here we present our recent results on the in-medium properties of kinetically thermalized heavy quarkonium using effective field theories in combination with lattice QCD. We contrast the computation of spectral functions from a direct lattice effective field theory approach, called NRQCD [1] with an indirect one via the complex real-time potential extracted from Wilson line correlators on the lattice [2]. Consequences for phenomenology, e.g. for the $J/\Psi$ / $\Psi'$ ratio [3], as well as $\chi c(nP)$ feed-down [4] are discussed.

[1] see e.g. S.Kim, P.Petreczky, A.R. (in preparation), 1512.05289 and Phys.Rev. D91 (2015) 054511

[2] Y. Burnier, O.Kaczmarek, A.R. PRL 114 (2015) 082001

[3] Y. Burnier, O.Kaczmarek, A.R. JHEP 1512 (2015) 101

[4] Y. Burnier, O.Kaczmarek, A.R. JHEP 1610 (2016) 032

## Polyakov loop and Polyakov loop correlators in lattice QCD

Johannes Heinrich Weber (Technische Universität München)

I discuss lattice calculations of the Polyakov loop and of Polyakov loop correlators for QCD with 2+1 flavors and almost physical quark masses using the highly improved staggered quark action (HISQ). I elucidate how the Polyakov loop and related observables behave in the crossover region and how these observables probe the deconfinement aspects of the crossover. I examine the short- and long-distance regimes of Polyakov loop correlators and discuss the color-screening in the thermal medium. I also discuss the onset of weak-coupling behavior at high temperatures and short distances.

## Issues in relating small and large transverse momentum dynamics in transverse-momentum-dependent processes

Bowen Wang (Old Dominion University)

The transverse-momentum-dependent (TMD) factorization has been applied to make theoretical predictions for many TMD processes with a large enough momentum scale. In this framework, transverse momenta of both perturbative and nonperturbative origin are incorporated. It is very non-trivial to make the transition between these two types of dynamics, especially when the hard momentum scale is small. In this talk I discuss issues with TMD factorization at low momentum transfer and report our progress in treating these issues.

## SIDIS and Drell-Yan transverse spin physics programmes at COMPASS experiment

Bakur Parsamyan (University of Turin and INFN)

The COMPASS experiment (SPS, CERN) covers a broad range of physics aspects in the field of hadron structure and spectroscopy. Particular focus is given to the exploration of the transverse spin structure of the nucleon via the study of spin (in)dependent azimuthal asymmetries measured in semi-inclusive deep inelastic scattering (SIDIS) and Drell-Yan (DY). Within QCD parton model approach, these phenomena give access to the set of transverse momentum dependent (TMD) parton distribution functions (PDFs) parametrizing the spin structure of the nucleon. Between 2002 and 2010 COMPASS performed series of SIDIS measurements, using a longitudinally polarized muon beam of 160 GeV/c momentum and transversely polarized $^6LiD$ and $NH_3$ targets. First COMPASS Drell-Yan measurements with a 190 GeV/c pion beam and transversely polarized $NH_3$ target have been taken in 2015 and will be continued in 2018. The measurement of the Sivers and all other azimuthal asymmetries in polarized SIDIS and Drell-Yan at COMPASS provides a unique possibility to test predicted in QCD universal and process-dependent features of TMD PDFs using essentially the same experimental setup and exploring a comparable kinematic domain. In this talk recent COMPASS SIDIS results and important aspects of Drell-Yan measurements will be reviewed together with the results from relevant theoretical calculations.

# Exotic Hadrons at LHC

Claudia Patrignani (Universita' di Bologna and INFN Bologna)

A number of states containing heavy quarks have been observed in recent years by many experiments. Their properties are, at best, difficult to reconcile with a conventional meson interpretation; some of them are manifestly exotic. I will present recent results from LHC aimed at understanding the nature of these puzzling states

# Results from the OLYMPUS Experiment at DESY

Michael Kohl (Hampton University)

Hard two-photon exchange has been favored theoretically to explain the previously observed discrepancy in measurements of the elastic proton electric-to-magnetic form factor ratio with polarized and unpolarized methods. Several experiments have been carried out to investigate the effects of two-photon exchange. The OLYMPUS experiment at DESY has been one of three dedicated experiments to use comparisons of positron-proton and electron-proton scattering to unequivocally determine the effects of two-photon exchange. Results from the OLYMPUS experiment will be presented. This work has been supported by the U.S. National Science Foundation and Department of Energy.

# The Proton Size and Muon Experimental Anomalies Are Explained by a New Interaction Proportional to Charge

John Ralston (University of Kansas)

The "proton size puzzle" and the "muon anomalous moment problem" are incomplete descriptions of significant discrepancies between experiments and standard model calculations. Actually the field has confronted a new regime of ultra-precise physics where traditional piece-meal analysis methods are no longer self-consistent. Determining the proton size $r_p$, the Rydberg constant $R_\infty$, the fine structure constant $\alpha$ and electron mass $m_e/h$ is an inextricably coupled problem at current levels of precision. In being based on assumptions about the fundamental constants, the "muon-physics" discrepancies have not actually been shown to come from the muon sector. We have conducted a new global fit to the entire body of precision experimental data and electroweak theory. Least-squares fits to all the fundamental constants are made with and without a generic "no-name" boson, of undetermined spin, that interacts universally with leptons and hadrons proportional to electric charge. The analysis discovers a new local minimum of best fit statistic, where all of $r_p$, $R_\infty$, $\alpha$, $m_e/h$ have new values compared to previous work. The study is the first to consistently accommodate all the high-precision data. A new particle, similar to the "dark photon" but differing in detail, is predicted to be observed in electron- and muon-based experiments.

## The two-photon exchange experiment at VEPP-3

Alexander Gramolin (Budker Institute of Nuclear Physics)

The ratio of the elastic $e^+p$ to $e^-p$ scattering cross sections has been measured precisely at the VEPP-3 storage ring (Novosibirsk, Russia). This allows us to determine the hard two-photon exchange contribution to elastic electron-proton scattering, which is believed to be the cause of the apparent discrepancy between the Rosenbluth and polarization transfer methods of measuring the proton electromagnetic form factors. Our data obtained at $Q^2$ values from 0.3 to 1.5 $GeV^2$ show evidence of the hard two-photon exchange effect, thus supporting the proposed explanation. The VEPP-3 results are compared with several predictions and with the data from similar measurements reported recently by the CLAS and OLYMPUS collaborations.

# Spin Dependent Quark GPDs in a Flexible Spectator Model and Deeply Virtual Lepton Scattering

Gary Goldstein (Tufts University)

Chiral Even and Odd Generalized Parton Distributions (GPDs) for Valence Quarks are obtained in a "flexible" spectator model. The parametrization is constrained by nucleon form factors, PDFs and some earlier Deeply Virtual Compton Scattering data. The model has been extended to cover the full range of experimentally attainable kinematics. A broad range of measured and measurable deeply virtual processes - cross sections and polarization asymmetries - is compared with existing data and predicted for future data.

# Twist three distribution functions and the role of intrinsic partonic transverse momentum in orbital angular momentum in QCD

Abha Rajan (University of Virginia)

It is well known that the valence quark spins do not add up to the proton spin. We probe the partonic orbital angular momentum (OAM) contribution to the spin sum rules using the Generalized Parton Distributions(GPDs) and Generalized Transverse Momentum Distributions (GTMDs). These functions are obtained by parameterizing the QCD quark quark correlator function in different scenarios. By looking at the parametrization of the completely unintegrated correlator and finding the underlying substructure of these functions, we find the so called Lorentz Invariance Relations between collinear objects, the GPDs, and ones that depend on the partonic intrinsic transverse momentum, the GTMDs. The GTMD $F_{14}$ which describes OAM connects through these relations to the twist three GPD $\tilde{E}_{2T}$ thus allowing us to study the role of quark gluon interactions for different choices of gauge links. Other helicity combinations give rise to more LIRs which, in general, are significant for understanding the non-perturbative origin of the spin structure of the proton.

## First Measurements of Timelike Form Factors of Lambda, Sigma, Cascade, and Omega Hyperons at —Q2— = 14 GeV2, and Evidence for Diquark Correlations

Kamal Seth (Northwestern University)

The results of the first measurements of the electromagnetic form factors of hyperons, $\Lambda^0$, $\Sigma^0$, $\Sigma^+$, $\Xi^0$, $\Xi^-$, and $\Omega^-$ for the large timelike momentum transfer of $|Q2|$ = 14.2 GeV$^2$ are presented by analyzing data taken with the CLEO detector for 805 pb$^{-1}$ of $e^+e^-$ annihilations at $\Psi(3770)$, $\sqrt{s}$ = 3.77 GeV, and 586 pb$^{-1}$ at $\sqrt{s}$ = 4.17 GeV at the CESR collider. Updated results for inclusive production of hyperons, $B$ or $\bar{B}$, at $\Psi(2S)$, $\sqrt{s}$ = 3.69 GeV, are also presented. In both inclusive production and in $B\bar{B}$ pair production it is found that although both 0 and 0 have the same —u, d, s quark content, 0 production is significantly larger than that of 0. It is proposed that this arises because of the different "diquark correlations" between 0 and 0, which Wilczek and colleagues have labeled as "good" and "bad" diquarks.

## Studying time-like electromagnetic baryonic transitions with HADES

Beatrice Ramstein (Institut de Physique Nucleaire)

Originally designed to study medium effects in $e^+e^-$ production in heavy-ion reactions in the SIS-18 energy range (1-3 GeV/nucleon) [1] installed at GSI is a versatile detector. Its excellent particle identification capabilities allowed for a systematic investigations of dielectron, strange particles and pion production in proton, deuteron or heavy-ion induced reactions on proton or nucleus. The obtained dilepton spectra measured at various beam energies show important contributions from baryon resonances decays ($R \rightarrow Ne^+e^-$) and a strong influence of the intermediate vector mesons ($\rho/\omega/\phi$) in the corresponding time-like electromagnetic form factors. In order to directly access such transitions, HADES has started a dedicated pion-nucleon programme [2]. For the first time, combined measurements of hadronic and dielectron final states have been performed in $\pi$-N reactions, using polyethylene and carbon targets. Differential cross-sections of the exclusive channels with two pions in the final state ($\pi^-\pi^+n$, $\pi^0\pi^-p$) were obtained in the second resonance region with an unprecedented statistics. These new data were included in the partial wave analysis (PWA) of the Bonn-Gatchina group [3] together with the world data on pion and photon production. The obtained solution provides the excitation function of the two-pion production in photo- and pion- induced reactions around the pole of the N(1520)$D_{13}$ resonance and of its decomposition into the different resonant, non-resonant and $\rho$ contributions. Results for the exclusive $ne^+e^-$ production will be compared to various model calculations. In addition, the results about the $\rho$ contribution in the two-pion production channels are used to investigate the validity of the Vector Dominance Model for baryon transitions. The angular distributions of the leptons, which contain additional information on the electromagnetic structure of the different transitions, will be discussed. Finally, the prospects for HADES measurements at SIS-18 in the near future and later at SIS-100 (FAIR) will be presented.

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[2] P. Salabura, J. Stroth, L. Fabbietti (HADES), Nucl. Phys. News 25 (2015) 22.
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## Observation of Transverse Lambda Polarization in $e^+e^-$ Annihilation at Belle

Anselm Vossen (Indiana University)

Measurements the transverse polarization of lambda hyperons with respect to their production plane are sensitive to the polarizing fragmentation function $D_{1T}^{\perp\Lambda/q}$. This fragmentation function might be part of the explanation of the significant transverse polarization of Lambda in p+p scattering. It can also seen as the hadronization analogue to the Sivers function, since it describes the transverse momentum dependent transverse polarization of the hyperon. As a chiral-even, naive time-reversal-odd function it also allows to test universality, in particular the sign, of these functions between different processes. We present the first observation of the transverse polarization of Lambda hyperons in e+e- annihilation using the Belle detector using a dataset of about 800fb-1 collected at or near 10.58 GeV.

## Unitarized amplitudes for diffractive production of three pion resonances

Andrew Jackura (Indiana University)

We present some results on the analysis of $3\pi$ resonances from peripheral scattering of pions off of nuclear targets. The light meson sector is rich with states that can be accessed through three pions. In the modern search for exotic mesons, it is important to understand how to extract resonances in these channels. The analysis is motivated by the recent release of the largest data set on diffractively produced three pions by the COMPASS collaboration. The model emphasizes the $3\pi$ production process and their final state interactions which satisfy $S$-matrix principles. We apply our model to the recent results from the COMPASS experiment. We develop the model for partial waves, and focus on the $J^{PC} = 2^{-+}$ sector and search for resonances.

## Multiplicities in pp Collisions at $\sqrt{s} = 13$ TeV with Different MC Models

Khadeejah ALGhadeer (Louisiana Tech University)

Modeling of the charged-particle multiplicity dependence on transverse momentum, pseudorapidity and the relationship between the mean transverse momentum and charged-particle multiplicity are presented for pp collisions at center of mass energy $\sqrt{s} = 13$ TeV with two different Monte Carlo event generators, Pythia 8 and Herwig++ 2.7.1, including studies of light quarks and heavy quarks, $t\bar{t}$ production. The results are achieved with charged particles with transverse momentum larger than 500 MeV and absolute pseudorapidity less than 3, in events with at least one charged particle, and in events with at least six charged particles filling these kinematic requirements.

## Recent results on quasi parton distributions

Jianhui Zhang (University of Regensburg)

In recent years impressive progress has been made on directly calculating the full x-dependence of parton quantities from the quasi ones that are defined as spatial correlators. In this talk, I will discuss the quasi parton distribution and some recent results on its application to calculating parton distributions.

## Renormalization Issues on Long-Link Operators

Martha Constantinou (Temple University)

Parton distribution functions (PDFs) provide important information on the quark and gluon structure of hadrons which, at leading twist, they give the probability of finding a specific parton in the hadron carrying certain momentum and spin, in the infinite momentum frame. Due to the fact that PDFs are light-cone correlation functions, they cannot be computed directly on a Euclidean lattice. Recently, a novel direct approach has been proposed by X. Ji suggesting that one can compute quasi-distribution functions, which are accessible in Lattice QCD. This formalism provides a promising means of studying quark distribution functions in nucleons, as for large momenta, one can establish connection with the physical PDFs through a matching procedure. In this talk we will discuss aspect of this direct approach, with main focus on the renormalization. In particular, we study gauge invariant "Wilson line" operators of the type: $\bar{\psi}(x)\Gamma U(x,y)\Psi(y)$, where $\bar{\Psi}$ and $\Psi$ are quark fields, $U(x,y)$ is a path-ordered exponential of the gluon field and $\Gamma$ is a product of Dirac gamma matrices. The extended nature of these "Long-Link" operators results in a nontrivial renormalization, including a finite factor, as well as, contributions which diverge linearly and logarithmically with the lattice spacing. We will discuss possible mixing of such operators in the Lattice Regularization, as well as, alternative prescriptions to extract the linear divergence.

## Gradient flow renormalization of Quasi parton distributions

Kostas Orginos (William and Mary / JLab)

Gradient flow, is a method that allows us to construct lattice quasi PDFs that are finite in the continuum limit. In the small flow time limit, the moments of the smeared quasi PDFs are proportional to those of the light-front PDFs. These proportionality coefficient obey a renormalization group equation that allows us to derive renormalization scale evolution equations for the matching kernel that relates the smeared quasi PDF and the renormalized light-front PDFs. Based on these results we propose a new methodology for obtaining light-front PDFs from lattice QCD.

## Quark orbital dynamics in the nucleon from Lattice QCD – from Ji to Jaffe-Manohar orbital angular momentum

Michael Engelhardt (New Mexico State University)

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 used to define transverse momentum dependent parton distributions (TMDs). By supplementing these matrix elements with a nonzero momentum transfer, mixed transverse position and momentum (GTMD) 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.

## Quarkonium production in proton-nucleus collisions at collider energies

Kazuhiro Watanabe (ODU/JLab)

Heavy quark pair production in high energy proton-nucleus (pA) collisions provides valuable information of the gluon saturation dynamics in a heavy nucleus at small value of Bjorken x. Nowadays, large amounts of data accumulated by RHIC and LHC enable us to examine calculations in small-x saturation formalism or Color Glass Condensate (CGC). Essentially, heavy quark pair production has been studied in the saturation/CGC framework at leading order (LO) with use of the running coupling Balitsky-Kovchegov equation (rcBK) which includes a subset of next-to-leading order (NLO) corrections. Although there are model dependence concerning a description of bound state formation at long distance, the recent comparisons of theoretical computations with data have clarified significant issues of the previous saturation/CGC framework. Some of the important topics are listed below. The previous saturation/CGC framework can roughly describe $J/\psi$ production in pp/pA collisions, whereas $\Upsilon$ production cannot be described by the previous saturation/CGC framework. In fact, the mean transverse momentum of produced $\Upsilon$ is much larger than the typical saturation scale of target hadron. We found that Sudakov effect on top of the saturation effect provides strong $p_\perp$-broadening for $\Upsilon$ production. This fact indicates higher order calculations must be important to understand further quarkonium production in the saturation/CGC framework. In addition to $\Upsilon$ production, $\psi(2S)$ production in pA collisions is also important. RHIC and LHC experiments reported that $\psi(2S)$ suppression in pA collision compared to pp collision is stronger than that of $J/\psi$. The previous saturation/CGC framework can not describe the data because the initial state interaction should not interfere with bound state formation in later stage. Currently, the description of bound state formation is being improved in the saturation/CGC framework. The data can be naturally interpreted by taking into account final state interaction in pA collision. In this talk, I will firstly present a brief review of the saturation/CGC framework and then illustrate the above topical issues.

## Diffractive vector meson production and initial state fluctuations in DIS

Heikki Mäntysaari (Brookhaven National Laboratory)

Exclusive vector meson production can be used to directly probe the gluon density of a hadron. Measuring the cross section differentially in transverse momentum transfer makes it possible to determine the transverse density profile (via coherent diffraction) and density fluctuations (incoherent diffraction) of the target hadron. This knowledge about the geometric fluctuations of the proton is particularly important for understanding collective phenomena observed in proton-nucleus collisions. We calculate coherent and incoherent diffractive vector meson production in photon-proton scattering at high energy. We demonstrate that incoherent gamma-p scattering is sensitive to sub-nucleon scale fluctuations, and show that the effect of geometric fluctuations can be disentangled from saturation scale fluctuations. The Bjorken-x (or energy) evolution of the fluctuations is studied by solving the JIMWLK evolution equation. In particular, we study the energy evolution of the diffractive cross section. This is particularly interesting, as the ALICE collaboration has recently observed the disappearance of the incoherent contribution to the diffractive cross section in ultraperipheral p+A collisions at high energies, which suggests that the proton gets smoother at small x. The fluctuating proton, constrained by the HERA data, is then used as input for hydrodynamic calculations of azimuthal anisotropy coefficients in proton-nucleus collisions, which we show to be sensitive to initial state geometric fluctuations.

References:
H. Mäntysaari, B. Schenke, Phys. Rev. D94 (2016) no.3, 034042 , arXiv:1607.01711
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## Polarized Heavy Quarkonia Production in the Color Evaporation Model

Vincent Cheung (University of California, Davis)

Even more than 40 years after the discovery of $J/\psi$, the production mechanism of quarkonia is still not well understood. Non-Relativistic Quantum Chromodynamics (NRQCD), perhaps the best known approach for studying quarkonia production can reproduce the $J/\psi$ $p_T$ distribution. However, the long distance matrix elements (LDMEs) fitted from the $p_T$ distributions fail to correctly describe the polarization. In this talk, I will outline the recent challenges to NRQCD and present the first leading order prediction of the polarization using the Color Evaporation Model, which integrates over all color states.

## Heavy-quarkonium theory in the LHC era

Bernd Kniehl (II. Inst. f. Theor. Phys., Univ. Hamburg)

We review the present landscape of heavy-quarkonium theory, its tests by worldwide collider and fixed-target experiments, and the future perspectives offered by the LHC. Special emphasis is placed on the effective quantum field theory of nonrelativistic QCD (NRQCD), endowed with the factorization theorem conjectured by Bodwin, Braaten, and Lepage, which arguably constitutes the most probable candidate theory at the present time. Being impressively consolidated at the next-to-leading order by the world's data on unpolarized $J/\psi$ production, NRQCD factorization has now reached the crossroads because the predicted universality of the long-distance matrix elements is challenged by recent measurements of $J/\psi$ polarization and $\eta_c$ yield.

## Experimental investigations in QCD in the next decade: from JLab12, sPHENIX to the EIC

Abhay Deshpande (Stonybrook)

The recently completed NSAC Long Range Plan has recommended an exciting 10+ years of physics program to be conducted in campaigns of critical detector and machine upgrades of the CEBAF and RHIC. Both communities of scientists involved in RHIC and JLab12 programs are expected to combine forces to exploit the exciting opportunities provided by a future Election Ion Collider (EIC) to be built at one of the above locations. I will give an overview of the physics highlights with each of these stages going through he 12 GeV upgrade of the CEBAF, sPHENIX detector expected to come online early next decade at RHIC, followed by the EIC, in the second half of the decade.

## Quark Polarization at Small x

Matthew Sievert (Los Alamos National Laboratory)

Parton distribution functions in the small-x limit have long been known to be dominated by gluon bremsstrahlung produced in the BFKL and BK / JIMWLK evolution mechanisms. This small-x gluon cascade generates high color-charge densities, leading to the effective semi-classical theory known as the color-glass condensate (CGC). While this unpolarized small-x evolution has been thoroughly studied, the evolution of the polarized parton distributions is much less understood. Using modern CGC techniques, we calculate the small-x evolution equations for the helicity distribution of polarized quarks. This polarized small-x evolution is quite different from the unpolarized evolution, bringing in much more complicated dynamics which transfer spin to small x. Although the quark polarization at small x is initially suppressed, strong evolution corrections substantially enhance the amount of spin at small x. By solving our equations (numerically, in the large-Nc limit), we compute the asymptotic behavior of the quark helicity at small x, and we discuss the implications of this result for the outstanding Proton Spin Puzzle.

# Precision Prediction for Higgs Production at Small Transverse Momentum

HuaXing Zhu (MIT)

In this talk I will discuss a precision calculation for transverse-momentum distribution of the Higgs boson at the LHC, in the framework of Soft-Collinear Effective Theory. Thanks to the recently calculated three-loop anomalous dimension for rapidity divergence, the large logarithms of $Q_T$ can be resummed to approximate $N^3$LL accuracy, including the full tower of logarithms at $N^3$LO. With the large amount of data from the LHC, this will allow a precision test of our understanding of (mostly perturbative) gluon TMD.

## Inclusive jets and their substructure within SCET

Felix Ringer (Los Alamos National Laboratory)

We review the treatment of inclusive jets and their substructure within Soft Collinear Effective Theory (SCET). The cross section for these observables can be written in a factorized form in terms of hard functions and so-called semi-inclusive jet functions. The semi-inclusive jet functions satisfy renormalization group (RG) equations which take the form of standard timelike DGLAP evolution equations, analogous to collinear fragmentation functions. By solving these RG equations, the resummation of potentially large single logarithms $(\alpha_s \ln R)^n$ can be achieved. An important example of jet substructure observables are the distributions of hadrons inside a reconstructed jet. In particular, we focus on the fragmentation of heavy quark flavors inside jets. We present numerical results at NLO+NLL$_R$ accuracy and compare to existing data from the LHC.

## Transverse Momentum Dependent Fragmenting Jet Functions with Applications to Quarkonium Production

Thomas Mehen (Duke University)

We introduce the transverse momentum dependent fragmenting jet function (TMDFJF), which appears in factorization theorems for cross sections for jets with an identified hadron. These are functions of $z$, the hadron's longitudinal momentum fraction, and transverse momentum, $p_T$, relative to the jet axis. In the framework of Soft-Collinear Effective Theory (SCET) we derive the TMDFJF from both a factorized SCET cross section and the TMD fragmentation function defined in the literature. The TMDFJFs are factorized into distinct collinear and soft-collinear modes by matching onto $\mathrm{SCET}_+$. As TMD calculations contain rapidity divergences, both the renormalization group (RG) and rapidity renormalization group (RRG) must be used to provide resummed calculations with next-to-leading-logarithm prime (NLL') accuracy. We apply our formalism to the production of $J/\Psi$ within jets initiated by gluons. In this case the TMDFJF can be calculated in terms of NRQCD (Non-relativistic quantum chromodynamics) fragmentation functions. We find that when the $J/\Psi$ carries a significant fraction of the jet energy, the $p_T$ and $z$ distributions differ for different NRQCD production mechanisms. Another observable with discriminating power is the average angle that the $J/\Psi$ makes with the jet axis.

## Transverse momentum spectra at the LHC

Varun Vaidya (LANL)

Transverse momentum spectra of gauge bosons are the primary observables that involve a new class of generalized PDF's called TMDPDF's( Transverse momentum dependent pPDF's) that probe the 3 -dimensional structure of hadrons. Two of the most important of these observables are the Higgs and Drell-Yan transverse momentum spectra. I will talk about the precision calculation of these cross-sections in the low transverse momentum regime using the formalism of Soft Collinear Effective Theory (SCET). I ll present results at NNLL accuracy using different resummation schemes and discuss possible sources or errors in this theoretical computation.

## Photon production in the bottom-up thermalization of heavy-ion collisions

Naoto Tanji (Heidelberg University)

Recent classical-statistical numerical simulations have established the "bottom-up" thermalization scenario of Baier et al. as the correct weak coupling effective theory for thermalization in ultrarelativistic heavy-ion collisions. I will talk on a parametric study of photon production in the various stages of this bottom-up framework and compare the contribution of the off-equilibrium "Glasma" and that of a thermalized Quark-Gluon Plasma. I argue that such Glasma contributions are important and may dominate photon production in peripheral and even semi-central heavy-ion collisions. Furthermore, I will report on first kinetic simulations of photon production in the expanding Glasma that will quantify our estimates and determine how brightly the Glasma shines relative to the Quark-Gluon Plasma.

## Thermal Photon Emission in Heavy Ion Collisions

Axel Drees (Stony Brook University)

Over the past years PHENIX has published numerous results on direct photon production from Au+Au collisions at 200 GeV. The results show a large direct photon excess at low momentum, which increases with centrality, while the inverse slope of ∼240 MeV remains independent of centrality within errors. The direct photons are emitted with a large anisotropy with respect to the reaction plan, both second and third order anisotropy coefficients have been observed. The data are qualitative consistent with thermal radiation emitted from the hot matter created in the collisions. Quantitative model comparisons are challenged by the tension between high yield, which one expects to build up early in the collision, and large anisotropy, which one expects from the later stages in the collision. Several analyses of data sets with higher statistics, with different collision systems, and different beam energies are underway to provide more constraints. In this talk I will review the latest PHENIX results, including new results from lower beam energy.

## Photon Puzzle at RHIC: a theory perspective

Chun Shen (Brookhaven National Lab)

Electromagnetic probes are considered as clean messengers from the hot dense medium created in the Relativistic Heavy-Ion Collider (RHIC) and the Large Hadron Collider (LHC). In this talk, I will review the theoretical developments in the study of electromagnetic radiation in relativistic heavy-ion collisions. The recent progress in the rates for photon and lepton pair production is discussed. Together with the improvements in the hydrodynamic descriptions of the bulk medium, I will emphasize the combined efforts to resolve the "direct photon flow puzzle" in the RHIC experiments. Further prediction of the direct photon production in small collision systems at the top RHIC and BES relevant energies can elucidate the properties of quark gluon plasma.

## Classical-statistical simulations and the Chiral Magnetic Effect

Niklas Mueller (Institute for Theoretical Physics, Heidelberg University)

We present how the dynamics of the Chiral Magnetic Effect (CME) and Chiral Density Waves can be described during the pre-equilibrium stage of a heavy-ion collision, using classical-statistical real-time lattice simulations [1-3]. To this end we present results in a simplified set-up with dynamical (Wilson and Overlap) fermions simultaneously coupled to color and electromagnetic fields. We demonstrate that our simulations enable us to test CME related effects quantitatively, including its proposed robustness as being 'topological protected', and we find that for realistic magnetic fields and quark masses important differences to previous idealized descriptions arise. We give an overview on how our microscopic approach ties into a larger picture, comprising anomalous dynamics at all stages of a heavy ion collision – from kinetic descriptions to hydrodynamic evolution.

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## Perspective on meson and baryon form factors

Craig Roberts (Argonne)

Modern facilities are poised to tackle fundamental questions within the Standard Model, aiming to reveal the nature of confinement, its relationship to dynamical chiral symmetry breaking (DCSB) - the origin of visible mass - and the connection between these two, key emergent phenomena. There is strong evidence to suggest that they are intimately connected with the appearance of momentum-dependent masses for gluons and quarks in QCD, which are large in the infrared: $m_g \sim$500MeV and $M_q \sim$350MeV. They are also expressed with particular force in the partonic structure of hadrons, e.g. in valence-quark parton distribution amplitudes and functions, and, consequently, in hadron elastic and transition form factors. This presentation will explain that we are now in a position to exhibit the consequences of confinement and DCSB in such observables, opening the way to empirical verification of their expression in the Standard Model.

## Perspective on experiments with meson form factors and exclusive meson production

Tanja Horn (Catholic University of America)

Meson electroproduction data play an important role in our understanding of hadron structure and the dynamics that bind the basic elements of nuclear physics. Pion and kaon form factors are of particular interest as they are connected to the Goldstone modes of chiral dynamical symmetry breaking. The last decade saw a dramatic improvement in precision of charged pion form factor data and new results have become available on the pion transition form factor. Increasing the virtual photon mass in electron scattering experiments allows one to reach smaller distance scales. In this regime one becomes more and more sensitive to the partonic picture where hard and soft physics have been shown to factorize and Generalized Parton Distributions (GPDs) provide the most complete description of the non-perturbative physics. Recent data and prospects for deep exclusive pion electroproduction are presented. Experimental tests of our theoretical understanding of the reaction mechanism are shown including longitudinal-transverse separated charged-pion cross section data and ratios. The prospects to use projected charged- and neutral pion data to further determine the spin, charge-parity and flavor of GPDs, including the helicity-flip GPDs, are discussed.

## Precision measurement of the proton elastic cross section at high $Q^2$

Longwu OU (MIT)

The electromagnetic form factors (FF) are of fundamental importance in the investigation of nucleon structure and can be measured in high energy electron scattering experiments and interpreted in the framework of the one-photon exchange approximation. Current data on the proton form factors have significant statistical and systematic uncertainties at large $Q^2$, which limits the precision of the extracted physics information. The GMp experiment in Hall A at Jefferson Lab performed measurements of elastic *ep* scattering cross sections to a statistical precision of better than 2% over a $Q^2$ range of 7-16 $(\mathrm{GeV/c})^2$ . These measurements are useful inputs for many nuclear experiments at similar kinematics and represent a great complement to the world's cross section data set. Taken at relatively large scattering angles and hence with suppressed contributions from the electric form factor, these data will provide important information on the proton magnetic form factor at high $Q^2$. In this talk, the instrumentation and techniques used in the experiment will be described, and the current status of the analysis will be presented.

# Pion form factor at high momentum transfer from lattice QCD

Bipasha Chakraborty (Jefferson Lab)

The pion electromagnetic form factor, $F_\pi$, is a fundamentally important topic for our understanding of the hadron structure and the transition from perturbative to nonperturbative QCD. JLAB's experiment E12-06-101 proposes to extend the high quality $F_\pi$ data to $Q^2 = 6.0$ GeV$^2$ as a part of JLAB's 12 GeV upgrade. Being motivated by this, we present our ongoing lattice calculation of $F_\pi$ using the method of distillation and the variational approach which significantly reduce the excited state contamination. We are studying the shape of the vector form factor in the $Q^2$ range from zero to a few GeV$^2$ using Wilson quark formalism and our $20^3 3 \times 28$ anisotropic lattice configuration with light (up/down) and strange quarks in the sea and 400 MeV pion mass.

## Intrinsic Charm from CTEQ/TEA PDF fits

Sayipjamal Dulat (Michigan State)

The CTEQ/TEA machinery for measuring Parton Distribution Functions is used to obtain estimates and limits on non-perturabative (”intrinsic”) charm quark contributions to the proton wave function.

## Constraints and implications for the nucleon's intrinsic charm from QCD global analysis

Timothy Hobbs (University of Washington)

The array of collider and fixed-target experiments either presently taking data or planned for the near future has renewed a focus on precise determinations of the proton's quark substructure as quantified by its parton distribution functions (PDFs). In this context, special focus has attached to the PDF of the charm quark, given its special relevance to, e.g., collider backgrounds and potential role in dark matter searches. At the same time, the charm PDF possesses a unique phenomenology in that it is generated mainly perturbatively, but also has the possibility for a nonperturbative (or intrinsic) component. In this talk I will describe the details of a recent QCD global analysis which found that existing data strongly constrain the total magnitude of the intrinsic charm PDFs predicted in various modeling scenarios. I will discuss the implications of this finding for ongoing theoretical work as well as for future experimental measurements.

## IC at IC: IceCube can constrain the intrinsic charm of the proton

Ranjan Laha (KIPAC, Stanford University and SLAC)

The discovery of extraterrestrial neutrinos in the $\sim 30$ TeV – PeV energy range by IceCube provides new constraints on high energy astrophysics. An important background to the signal are the prompt neutrinos which originate from the decay of charm hadrons produced by high energy cosmic-ray particles interacting in the Earth's atmosphere. It is conventional to use pQCD calculations of charm hadroproduction based on gluon splitting $g \to c\bar{c}$ alone. However, QCD predicts an additional "intrinsic" component of the heavy quark distribution which arises from diagrams where heavy quarks are multiply connected to the proton's valence quarks. We estimate the prompt neutrino spectrum due to intrinsic charm. We find that the atmospheric prompt neutrino flux from intrinsic charm is comparable to the pQCD contribution once we normalize the intrinsic charm differential cross sections to the ISR and the LEBC-MPS collaboration data. In future, IceCube will constrain the intrinsic charm content of the proton and will contribute to one of the major uncertainties in high energy physics phenomenology.

## Towards combined QCD global analysis of polarized and unpolarized PDFs and fragmentation functions

Nobuo Sato (Jefferson Lab)

We present a new global QCD analysis of spin-dependent PDFs (SPDF) and fragmentation functions (FF) performed by the JAM (Jefferson Lab Angular Momentum) Collaboration, based on all available data on inclusive spin structure functions from CERN, SLAC, DESY and JLab, and all semi-inclusive hadron production data from electron-positron annihilation experiments, including the most recent measurements from Belle and BaBar. Preliminary results on combined SPDFs and FFs using polarized semi-inclusive data from COMPASS and HERMES will be presented.

## Phenomenological constraints on transverse single-spin asymmetries from Lorentz invariance relations

Daniel Pitonyak (Penn State Berks)

We review the status of transverse single-spin asymmetries (SSAs) $\mathrm{A}_N$ in proton-proton collisions within the collinear twist-3 framework. We use newly derived constraints from Lorentz invariance relations, along with previously known equation of motion relations, to rewrite $\mathrm{A}_N$ in terms of a maximum number of so-called kinematical functions, which are weighted integrals of TMD functions. From this, we are able to give an estimate for the SSA using known TMD inputs and provide constraints on the lesser known so-called dynamical (multi-parton) correlators.

## Scale evolution equations for transverse momentum weighted TMD functions

Shinsuke Yoshida (Los Alamos)

We discuss the next-leading-order(NLO) transverse-momentum weighted single-transverse spin asymmetry in semi inclusive deep inelastic scattering based on the collinear factorization approach. The leading-order cross section can be expressed in terms of twist-3 functions associated with transverse momentum weighted TMD functions and therefore the NLO contribution provides scale evolution equations for them. We present our results of the evolution equations for Sivers type, Collins type and Sivers-fragmentation type contributions.

## Parton Orbital Angular Momentum: Experimental Leads

Simonetta Liuti (University of Virginia)

We will present and discuss how parton orbital angular momentum can be accessed by measuring the correlation of the parton intrinsic transverse momentum and the proton momentum transfer encoded in both twist three Generalized Parton Distributions (GPDs) and in matrix elements that depend on the parton transverse momentum (Generalized TMDs).

## Universal Transverse Momentum Dependent Fragmentation in Jets

Duff Neill (LANL)

Fragmentation is a fundamental probe of the transition between the perturbative description of QCD and the non-perturbative regime. One would like to understand how the partonic quantum numbers, flavor, spin, charge, and momentum, are transported to the hadronic final state. Of utmost importance is simply the conversion of the momentum of a parton into the momentum carried by the observed hadron, in particular its three dimensional distribution inside a jet. Traditional definitions of jet axes, such as the thrust axis in $e^+e^-$ collisions, introduce a soft sensitivity such that the transverse momentum of the hadron receives an non-negligible contribution from the soft underyling event, making comparisons between fragmentation with transverse momentum measured in hadron-hadron, hadron-electron, or $e^+e^-$ fraught with uncontrolled contributions from factorization breaking effects and/or non-global logarithms. I will show how by a simple change in the definition of the jet axis, one can eliminate these complications, giving a transverse momentum spectrum purely determined by collinear splittings. I will also briefly consider applications of this new observable.

## Physics Driving the Design of the EIC Detectors modify Content

Yulia Furletova (JLAB)

A high luminosity polarized electron-ion collider (EIC) has been proposed as a future nuclear science program. It is envisioned as a next-generation US facility, as recommended by US Nuclear Science Advisory Committee in its 2015 Long Range Plan, for investigating of fundamental aspects of QCD, for exploring the quark-gluon structure and dynamic of hadrons and nuclei. This talk will cover key physics topics, motivating the design for the EIC detectors.

## $K_L$ facility at JLab

Moskov Amaryan (Old Dominion University)

In this talk we discuss the possibility of creating a secondary beam of neutral kaons at JLab. This will allow us to unravel more than a hundred missing“ hyperon states predicted by the Quark Model and recent lattice QCD calculations, which will have a great impact not only on hadron spectroscopy, but also on fundamental features of thermodynamics of the early universe and heavy-ion interactions at freeze-out during the first microsecond after the Big Bang.

## Overview of the Jefferson Lab 12 GeV Experimental Program in Halls A,B, and C

David Gaskell (Jefferson Lab)

The 11 GeV beam energy available in experimental Halls A, B, and C as part of the Jefferson Lab 12 GeV Upgrade, combined with the new equipment in those halls will provide a rich and diverse physics program. This program includes inclusive measurements used to constrain polarized and unpolarized quark distributions in nucleons, exclusive reactions to access nucleon and meson form factors and GPDs, semi-inclusive measurements aimed at constraining TMDs, as well as measurements from nuclei to provide further insight into the origins of Short Range Correlations and the EMC Effect. The experimental equipment was designed with the above program in mind and the three halls provide complementary capabilities. Magnetic focusing spectrometers in Hall C (the new SHMS and existing HMS) will provide precision separated and unseparated cross section measurements and ratios. The new large acceptance CLAS12 spectrometer in Hall B enables measurements over broad regions of phase space. In Hall A, the new SBS spectrometer, used in conjunction with the existing HRS or Big Bite spectrometers will provide access to very large $Q^2$ and allow for measurements requiring both high luminosity and large acceptance. This talk will give an overview of the upcoming experimental program in Halls A,B, and C, in particular highlighting synergies between the hall programs, which will allow Jefferson Lab to maximize the science output its 12 GeV program.

## The Super Bigbite Program for Hall A at Jefferson Lab

Seamus Riordan (Stony Brook University)

The Super Bigbite project encompasses a set of experiments which utilize the principles of large acceptance, highly reconfigurable magnetic spectrometers that aim to measure fundmental structure of nucleons at high momentum-transfer in experimental Hall A at the Thomas Jefferson National Accelerator Facility in Newport News, Virginia. These experiments push the bounds of what has been previously experimentally accessible with newly developed, state of the art equipment and the newly upgraded 12 GeV CEBAF polarized electron beam, focusing on measuring three of the four elastic nucleon form factors to high precision at large $Q^2$. Additionally utilizing this equipment, measurements of transverse momentum distributions of the neutron through semi-inclusive deep-inelastic scattering in the channels $\vec{n}(e, e'\pi^{\pm}(K^{\pm}))$ have also been approved as well as a measurement of tagged deep inelastic scattering. An overview of the apparatus, experimental program, and impact on the understanding of nucleon structure will be presented.

## Dark Sectors

Philip Tanedo (UC Riverside)

As the weakly-interacting massive particle paradigm for dark matter continues to be suffocated by the current generation of experimental searches, many theorists have turned to the proposal that dark matter may be associated with additional new states that mediate dark forces. This modest generalization turns out to offer surprisingly rich phenomenology and new experimental handles to understand the properties of dark matter.

## Using the SeaQuest Spectrometer to Search for Dark Photons

Michelle Mesquita de Medeiros (Argonne National Laboratory)

SeaQuest/E906 is a fixed target experiment at Fermilab that uses the 120 GeV proton beam from the Main Injector to induce Drell-Yan interactions and study anti-quark distributions in the nucleon. The resulting dimuons from the Drell-Yan interactions between the beam and the targets travel through an iron magnet, which also serves as a beam dump, before reaching the spectrometer. In the absorption process in the dump many particles are produced, including, possibly, dark photons through processes such as proton bremsstrahlung and eta decay. The dark photons could decay into a dimuon that could be detected by the SeaQuest spectrometer further downstream. The distance between the creation of a dark photon and its decay is determined by its coupling to the EM sector. The decay vertex is therefore significantly displaced, allowing for a very low background search. By selecting these displaced vertex dimuons and analyzing the invariant mass distribution, we can search for a dark photon signature. We will be presenting the latest status of the dark photon search in the SeaQuest experiment.

This work was supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics, under Contract No. DE-AC02-06CH11357.

## Dark Sector Searches at Jefferson Lab

Ross Corliss (MIT)

Despite compelling astrophysical evidence for the existence of dark matter in the universe, we have yet to positively identify it in any terrestrial experiment. Several experiments have recently begun at Jefferson Lab to add to this effort. With varying and complementary approaches, APEX, BDX, DarkLight, and HPS will probe the range of light Dark Matter, searching for new particles in the mass range of 10 MeV/$c^2$ to 1 GeV/$c^2$. I will briefly introduce the motivations for such searches, and describe the status of each of these experiments.

## Supersymmetric Meson-Baryon Properties of QCD from Light-Front Holography and Superconformal Algebra

Stanley Brodsky (SLAC National Accelerator Laboratory, Stanford Univsersity)

A remarkable feature of QCD is that the mass scale which controls color confinement and hadron mass scales does not appear explicitly in the QCD Lagrangian. However, de Alfaro, Fubini, and Furlan have shown that a mass scale can appear in the equations of motion without affecting the conformal invariance of the action if one adds a term to the Hamiltonian proportional to the dilatation operator or the special conformal operator. Applying the same procedure to the light-front Hamiltonian leads to a unique confinement potential $\kappa^4\zeta^2$ for mesons, where  is the LF radial variable conjugate to the invariant mass. The same result, including spin terms, is obtained using light-front holography, the duality between the front form and $AdS_5$, if one modifies the action by the dilaton $e^{\kappa^2\zeta^2}$ in the fifth dimension z. Generalizing this procedure using superconformal algebra, leads to a unified Regge spectroscopy of meson, baryon, and tetraquarks, including remarkable supersymmetric relations between the masses of mesons and baryons of the same parity. One also predicts observables such as hadron structure functions, transverse momentum distributions, and the distribution amplitudes defined from the hadronic light-front wavefunctions. The mass scale underlying confinement and hadron masses can be connected to the mass parameter in the QCD running coupling by matching the nonperturbative dynamics to the perturbative QCD regime. The result is an effective coupling defined at all momenta and the determination of a momentum scale which sets the interface between perturbative and nonperturbative hadron dynamics.

## Jets in Heavy Ion Collisions

Dennis Perepelitsa (University of Colorado Boulder)

Fully reconstructed jets have become a sophisticated and widely-used tool through which to probe the properties of the quark-gluon plasma created in nucleus-nucleus collisions at RHIC and the LHC. In this talk, I will give an experimental overview of some of the the latest developments in these measurements, including recent results from the LHC Run 2 Pb+Pb data-taking on high-statistics photon-jet correlations, heavy flavor-tagged jet production, and modification of jet substructure.

## Photon at NLO as a CGC probe in p+A collisions

Sanjin Benic (University of Zagreb)

We report on a first NLO computation of photon production in p+A collisions at collider energies within the Color Glass Condensate framework, significantly extending previous LO results. At central rapidites, our result is the dominant contribution and probes multi-gluon correlators in nuclei. At high photon momenta, the result is directly sensitive to the nuclear gluon distribution. We work within the dilute-dense approximaton where the NLO result contains two processes, the annihilation process and the process with quark-antiquark pair and a photon in the final state. We provide a full analytical result as well as a numerical evaluation for the NLO inclusive cross section. These results are partially contained in `http://arxiv.org/abs/1602.01989` and `https://arxiv.org/abs/1609.09424`

## From small to moderate-x: beyond the eikonal approximation

Andrey Tarasov (BNL)

In recent years significant progress has been made in our understanding of the small-x physics beyond the eikonal approximation. Rigorous analysis of the dependence on the transverse momentum helps us better understand not only physics of the Regge limit, but to connect it to the kinematic limit of the moderate-x as well. I'll describe the technique we used in calculation of TMD evolution observed in the Drell-Yan process and present some recent results.

## An Effective Theory for small-R jets

Christopher Lee (Los Alamos National Laboratory)

Logarithms of jet radii R become large in jet cross sections when R is small. In exclusive jet cross sections with jets of energy Q and a veto on additional jets of energy E, we find that logs of R come from ratios of not one but two hierarchies of scales, QR over Q and ER over E. We construct an effective field theory with modes for both hard-collinear and soft-collinear scales QR and ER, allowing the factorization of dependences on all scales, and resummation of logarithms of R to arbitrarily high accuracy in resummed perturbation theory.

## Dissertation Award talk - Strangeness and Charge Symmetry Violation in the Nucleon

Phiala Shanahan (Massachusetts Institute of Technology)

Experimental tests of QCD through its predictions for the strange quark content of the proton have been drastically restricted by our lack of knowledge of the violation of charge symmetry (CSV). We find unexpectedly tiny CSV in the proton's electromagnetic form factors by performing the first extraction of these quantities based on an analysis of lattice QCD data. The resulting values are an order of magnitude smaller than current bounds on proton strangeness from parity violating electron-proton scattering experiments. This result paves the way for a new generation of experimental measurements of the proton's strange form factors to challenge the predictions of QCD.

# APS Fellow talk - Parity Violation in Electron Deep Inelastic Scattering

Xiaochao Zheng (University of Virginia)

I will focus on the physics of the PVDIS (parity violation in deep inelastic scattering) measurements at Jefferson Lab, both from 6 GeV and for the future 12 GeV program.

## APS Fellow talk - The Heavy-Quark Exotics: A Snapshot from February 2017

Richard Lebed (Arizona State University)

Hadronic physics has been immensely enriched in the past 14 years, with the addition of dozens of presumptive tetraquark and pentaquark states that have been discovered primarily in the charmonium and bottomonium sectors. Every year since 2003 has brought fresh discoveries, so this talk will start with a short tour of the new states and how the field stands at this moment. Then we will tour the various theoretical interpretations of the states (Spoiler alert: None of them are entirely satisfactory!). Finally, I will present my own contribution, the "dynamical diquark picture" of states bound not as molecules, but rather through a competition between large energy releases and the constraints of color confinement.

## Generalized Parton Distributions: an overview

Carlos Munoz Camacho (IPN-Orsay)

Deeply Virtual Compton Scattering (DVCS) is the easiest reaction that accesses the Generalized Parton Distributions (GPDs) of the nucleon. GPDs offer the exciting possibility of mapping the 3-D internal structure of protons and neutrons by providing a transverse image of the constituents as a function of their longitudinal momentum. A vigorous experimental program is currently pursued at Jefferson Lab (JLab) to study GPDs through DVCS. New results recently released will be shown and discussed. We will conclude with an outlook on the Upgrade of JLab to 12 GeV, which will allow the full exploration of the valence quark structure of nucleons and the extraction of full tomographic images.

## GPDs and the PARTON software project

Cédric Mezrag (Argonne National Laboratory)

Generalised Parton Distributions (GPDs) has been introduced in the 1990's and have been studied both experimentally and theoretically since then. If the general framework of the field is now well established, the GPDs themselves are still hardly known, since they are hard to extract from experimental data. On the other hand several phenomenological models have been developed, and QCD-connected computations in the continuum are planned for the forthcoming years. After a presentation of the status of the GPDs field, I will introduced the PARTON software project, dedicated to GPDs, and thought to allow both experimental and theoretical studies of GPDs.

## Impact of Jefferson Lab data on global PDF analysis

Wally Melnitchouk (Jefferson lab)

This talk will review new insights into the quark structure of the nucleon that have been made with recent global QCD analysis of parton distributions, using new analysis techniques to take into account the latest high-precision data from Jefferson Lab.

## Exploring hadron structure in Drell-Yan measurements at SeaQuest

Markus Diefenthaler (Jefferson Lab)

The SeaQuest experiment at Fermilab continues a series of Drell-Yan measurements to explore the antiquark content of the nucleon and to study the modifications to nucleon structure when the nucleon is embedded into a nuclei. To extend existing measurements to larger values of Bjorken-x, a 120 GeV proton beam extracted from Fermilab's Main Injector is used, resulting in 50 times more luminosity than previous experiments and enabling access to values of x up to 0.9. The key physics goals of the SeaQuest collaboration include the investigation of the dramatic dbar(x)/ubar(x) flavor asymmetry in the nucleon sea and its behavior at high x as well as the study of the EMC effect in Drell-Yan scattering and the unexpected absence of any antiquark excess in existing data. After a short introduction to the physics program of the SeaQuest experiment, I will present the status report on the ongoing data taking and analysis and possible updates to the SeaQuest experiment with polarized target and beam.

# Sivers program at STAR

Salvatore Fazio (Brookhaven National Laboratory)

Accessing the Sivers TMD function in proton+proton collisions through the measurement of transverse single spin asymmetries (TSSAs) in weak boson production is an effective path to test the fundamental QCD prediction of the non-universality of the Sivers function. 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. The TSSA amplitude, $A_N$, has been measured at STAR in proton+proton collisions at $\sqrt{s} = 500$ GeV, with a recorded integrated luminosity of 25 $\text{pb}^{-1}$. 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. RHIC plans to run proton+proton collisions of transversely polarized beams at $\sqrt{s} = 510$ GeV in 2017, delivering an integrated luminosity of 400 $\text{pb}^{-1}$. This will allow STAR to perform a precise measurement of TSSAs in both weak boson and Drell-Yan production as well as other observables sensitive to the non-universality of the Sivers function via Twist-3, e.g. the TSSA of direct photons.

## Perturbative vs non-perturbative aspects of TMD phenomenology

Mariaelena Boglione (University of Turin and INFN Torino)

The practical implementation of TMD phenomenology becomes particularly involved when it comes to describing SIDIS cross sections over a wide range of transverse momenta. Even more so in the region of low to moderate $q_T$, where the interplay between perturbative and non-perturbative effects are more prominent. I will discuss a (personal) selection of relevant issues and show their consequences on phenomenological models and global fittings.

## Probing collinear and TMD fragmentation functions through hadron distribution inside the jet

Zhongbo Kang (UCLA)

We consider both the collinear and transverse momentum distribution of hadrons within a fully reconstructed jet. In particular, we demonstrate how such a distribution can be used to probe collinear and TMD fragmentation functions. We show the phenomenological application, for both unpolarized and polarized collisions (e.g., Collins azimuthal asymmetry), which has been measured at both RHIC and/or LHC.

# Study of Unpolarized TMD Functions from HERMES Data

Mason Albright (Pennsylvania State University)

We study unpolarized TMD distributions and fragmentation functions using HERMES data. We perform both Hessian and Monte Carlo analyses of the data and extract the widths of unpolarized TMDs. Critical evaluation of flavor dependence of widths is reported.

# Latest results from GlueX

Elton Smith (JLab)

The GlueX experiment aims to study the gluonic degrees of freedom in QCD by mapping the light meson spectrum with an emphasis on searching for and studying light hybrid mesons. Hybrid mesons, and in particular exotic hybrid mesons, provide the ideal laboratory for testing QCD in the confinement regime since these mesons explicitly manifest the gluonic degrees of freedom. GlueX uses a solenoid-based detector and the new 12-GeV electron beam at Jefferson Lab to produce a 9-GeV beam of linearly polarized photons to study the photoproduction of light mesons. We will present results from our commissioning run, which already represents an order-of-magnitude statistical increase over the very limited existing world data.

# Threshold photoproduction of J/$\psi$ with the GlueX experiment

Lubomir Pentchev (Jefferson Lab)

The GlueX experiment uses a linearly-polarized tagged-photon beam produced by electrons from the 12 GeV CEBAF machine. The detector system is based on a 2 T solenoid and includes e.m. calorimeters and drift chambers providing full acceptance coverage. The experiment allows us, for the first time, to study J/$\psi$ photoproduction from the threshold, at 8.2 GeV, up to a photon energy of 12 GeV. Results from the recent commissioning run, where we took 25 billion triggers, will be presented. The precise knowledge of the beam energy, combined with the recoil proton reconstruction and the identification of the J/$\psi$ decay products, $e^+/e^-$, allows us to achieve a high mass resolution. With the data from the upcoming physics runs, we expect to have enough statistics to be able to distinguish between different production mechanisms.

# Analytical methods in understanding light meson dynamics at GlueX

Emilie Passemar (Indiana University/JLab)

# The QCD Equation of State at $\mu_B > 0$ from Lattice QCD

Hiroshi Ohno (University of Tsukuba)

In this talk I will show our recent lattice studies on the QCD equation of state (EoS) at non-vanishing baryon chemical potential. The QCD EoS has been calculated with Taylor expansions including contributions from up to sixth order in baryon, strangeness and electric charge chemical potentials in a temperature range between 135 and 330 MeV. Using 4 different sets of lattice cut-offs, continuum extrapolations of thermodynamic quantities have been performed. I will discuss truncation effects of Taylor expansions. I will also show results of lines of constant pressure, energy and entropy densities in $T$-$\mu_B$ plane and compare them with the QCD chiral crossover line as well as experimental results on freeze-out parameters in heavy ion collisions. Then, I will discuss the location of a possible critical point.

## Fluctuations of conserved charges from the lattice

Szabolcs Borsanyi (University of Wuppertal)

Fluctuations of electric charge, baryon number and strangeness are well defined observables in the QCD grand canonical ensemble. They can be calculated on the lattice at zero and small chemical potential and can be measured in the RHIC or LHC experiments at chemical freeze-out. We review the recent lattice results for higher moments of these fluctuations and discuss their use in heavy ion phenomenology.

## The RHIC beam energy scan program, the search for the QCD critical point, and reasons to be optimistic

Paul Sorensen (Department of Energy and Brookhaven National Lab)

Before the search for the Quark Gluon Plasma (QGP) commenced at RHIC, it was hoped that the QGP could be discovered through the observation of non-monotonic trends in a variety of observables. These smoking-gun signals were not observed in the data taken at higher beam energies, and the discovery of the perfect liquid QGP relied on careful comparisons between models and data. No non-monotonic trends were observed at RHIC, until data from a beam energy scan were collected and carefully analyzed. In this talk, I'll present and discuss data from several measurements that exhibit trends suggestive of interesting features in the phase diagram of QCD.

## APS Fellow talk - Low-energy effective action for pions and a dilatonic meson

Maarten Golterman (San Francisco State University)

Recent simulations suggest the existence of a very light singlet scalar in QCD-like theories that may be lying just outside the conformal window. Assuming that the lightness of this scalar can be explained by an approximate dilatation symmetry, we develop an effective field theory framework for both the pions and this light scalar, the "dilatonic meson." We argue that a power counting exists that puts this effective field theory on a systematic footing. We contrast the leading-order behavior of masses with that in a theory with only pions, and comment on the behavior of the effective theory breaks down near the sill of the conformal window.

# APS Fellow talk - Another spin puzzle: large beam-target spin asymmetries in exclusive pion electroproduction

Peter Bosted (William and Mary)

Beam-target double spin asymmetries, beam single-spin asymmetries, and target single-spin asymmetries in exclusive $\pi^+$ and $\pi^0$ electroproduction were obtained from scattering of 1.6 to 6 GeV longitudinally polarized electrons from longitudinally polarized protons using the CEBAF Large Acceptance Spectrometer (CLAS) at Jefferson Lab. The kinematic range covered is final state invariant mass $1.1W2.7$ GeV and four-momentum transfer squared $0.05Q^25$ GeV$^2$, with good angular coverage in the forward hemisphere. The asymmetry results were divided into approximately 46,000 (6000) kinematic bins for $\pi^+$ ($\pi^0$). The present results are found to be in reasonable agreement with unitary isobar fits to previous world data for $W < 1.7$ GeV and $Q^2 < 0.5$ GeV$^2$, with discrepancies increasing at higher values of $Q^2$, especially for $W > 1.5$ GeV. A new preliminary unitary isobar fit is able to provide an adequate description of the $\pi^+$ data to $W = 2$ GeV. Very large target-spin asymmetries are observed for $Q^2 > 1$ GeV$^2$ and $W > 2$ GeV and larger values of $t$. In the hadron-nucleon picture, this suggests that nucleon resonances continue to play a significant role for values of $W$ as large as 2.7 GeV. In the quark-parton picture, this suggests that higher-twist contributions cannot be neglected. It is hooped that these experimental results will spark theoretical interest.