6th Workshop of the APS Topical Group on Hadronic Physics

Abstracts

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Contents

Plenary 1

Heavy Ion physics with the CMS experiment at the LHC

Bolek Wyslough (MIT)

The Large Hadron Collider at CERN collected data with proton-proton, proton-lead ion and lead-lead ion at highest energies available in the laboratory. The physics program of the Compact Muon Solenoid (CMS) experiment includes the studies of heavy ion collisions. The high energies available at the LHC allowed us to conduct high statistics studies of the hot and dense system with hard probes: heavy quarks and quarkonia with an emphasis on the b and Upsilon, high pT jets, photons, as well as W and Z bosons. CMS also conducted extensive studies of bulk particle production by studying azimuthal asymmetry and correlations in particle production at wide range of momenta. In this talk I will present latest results with CMS in proton-Pb and Pb-Pb collisions.

Transverse single-spin asymmetries in single-inclusive hard scattering processes

Daniel Pitonyak (RIKEN BNL Research Center)
Co-authors : KANAZAWA, Koichi (Temple University) ; KOIKE, Yuji (Niigata University) ; METZ, Andreas (Temple University)

Transverse single-spin asymmetries (TSSAs), denoted A_N, in single-inclusive hard scattering processes are fundamental observables to test perturbative QCD that have been around for almost 40 years. However, many open issues remain as to the origin of TSSAs. Currently two theoretical formalisms are widely used: collinear twist-3 (CT3) factorization and the Generalized Parton Model (GPM). We discuss our work in this area using the framework of the former, including recent calculations of pion and direct photon production in proton-proton collisions. We also briefly talk about how lepton-nucleon scattering can offer complementary information to that from proton-proton reactions. Given the progress that has been made so far, continued experimental and theoretical work could finally allow us to understand this longstanding problem.

The Proton Radius - Old Measurements and New Ideas

Guy Ron (Hebrew University of Jerusalem)

The radius of the proton, generally assumed to be a well measured and understood quantity has recently come under scrutiny due to highly precise, yet conflicting,experimental results. These new results have generated a host of interpretations, none of which are completely satisfactory. I will discuss the existing results, focusing on the discrepancy between the various extractions. I will briefly discuss some theoretical attempts at resolution and focus on new scattering measurements, both planned and already underway, that are attempting to resolve the puzzle.

Plenary 2

eRHIC: A QCD microscope to study the glue that binds us all

Elke-Caroline Aschenauer (BNL)

Our understanding of the structure of nucleons is described by the properties and dynamics of quarks and gluons in the theory of quantum chromodynamics. With advancements in theory and the development of phenomenological tools we are preparing for the next step in subnuclear tomographic imaging at a future electron-ion collider (EIC). High center-of-mass energies ($\sqrt{s} \approx 45 - 150$ GeV) in combination with extremely high luminosities (10^{33-34} cm^{-2} s^{-2}) will provide the precision and a kinematic reach well into the gluon dominated regime. This talk will summarize the e+p and e+A physics program, the experimental and technical realization of an EIC at Brookhaven (eRHIC).

Present status of the Phenomenology of Transverse spin

Alexei Prokudin (JLab)

We will discuss the present status of the Phenomenology of Transverse spin. In the recent decades a lot of theoretical and phenomenological attention was given to unraveling the origin of spin asymmetries in polarized hadron and electron scattering. A new concept of 3D (three-dimensional) parton distributions was proposed that allows for a better understanding of the hadron structure. We will review the recent development in the field.In particular we will illustrate the first extraction of the nucleon tensor charge from current experiments by a combined analysis of the Collins asymmetries in two hadron production in e^+e^- annihilations and single inclusive hadron production in deep inelastic scattering processes.

Nucleon imaging with polarized probes and target

Jian-Ping Chen (Jefferson Lab)

Parallel Session: Heavy Quark 1

Hadronic Transitions and Quarkonium-like States Near Threshold

Estia Eichten (Fermilab)

Large hadronic transitions have been observed for some quarkonium states above threshold for strong two-body decays. In particular, these transitions provided a gateway to observing the charged Z states in the charmonium and bottomonium systems. I will explore what can learned from studying the dynamics of these transitions.

Quarkonium-Nucleus Bound States from Lattice QCD

Martin Savage (Univ of Washington)

The spectrum of baryons with charm and bottom quarks

Kostas Orginos (William and Mary / JLab)

In this talk I review recent lattice QCD calculations of the spectrum of baryons containing charm and bottom quarks. Given the recent discoveries of such baryons at LHCb such calculations are timely and provide predictions of the masses of baryons yet to be observed.

Parallel Session: Hadron Structure 1

TMD evolution and the Higgs transverse momentum distribution

Daniel Boer (University of Groningen)

The Higgs transverse momentum distribution turns out to be in principle sensitive to the linear polarization of gluons inside the colliding protons at the LHC. Although the degree of polarization has not yet been determined, linear gluon polarization is especially thought to be relevant at small values of x. The distribution of linearly polarized gluons is given by a transverse momentum dependent parton distribution (TMD). In this talk the description of the Higgs transverse momentum distribution in terms of TMD factorization and the importance of including TMD evolution will be discussed. Estimates of the effect of linear gluon polarization on the Higgs transverse momentum distribution will be given and the extension to Higgs production in association with a jet that is nearly back-to-back in transverse momentum will also be considered.

Overview on phenomenology of TMD evolution and global analysis

Zhongbo Kang (Los Alamos National Laboratory)

I will present an overview talk on the current phenomenology on TMD evolution and global analysis to extract TMDs, and future perspective.

Glue Spin from Lattice QCD

Keh-fei Liu (University of Kentucky)

The theoretical development of the glue spin operator and its relation to the glue helicity observed through hard scattering are summarized. I will present a first lattice calculation of the glue spin content at several nucleon momenta.

Parallel Session: RHIC 1

Quarkonium at T>0 from lattice QCD spectral functions

Alexander Rothkopf (Institute for Theoretical Physics, Heidelberg University)

Heavy quarkonium, the bound states of a heavy quark and antiquark have become precision observables in heavy-ion collisions at RHIC and LHC over the past few years. Understanding their dynamical behavior when immersed in a medium will allow us to extract the properties of the strongly coupled quark-gluon plasma created in the collision center. Lattice QCD is ideally suited for this task, as it can provide non-perturbative insight into the QCD medium in the phenomenologically relevant region around the phase transition. The challenge of extracting real-time information from Euclidean lattice simulations is answered through improved Bayesian reconstructions [1] of spectral functions. For static quark-antiquark pairs, effective field theory methods allow us to derive a Schroedinger equation to describe their time evolution. The real- and imaginary part of the in-medium potential that summarizes the interaction between quarkonium and the surrounding QGP is extracted from spectral functions of lattice QCD Wilson line correlators [2]. Quarkonia of finite mass can also be directly simulated using a lattice discretized version of the effective field theory NRQCD. Evaluated on current generation full QCD ensembles of the HotQCD collaboration, we find from reconstructed meson spectral functions that both the Upsilon as well as the χ_b ground state survive well into the QGP phase up to T=249MeV [3].

[1] Y.Burnier, A.R. Phys.Rev.Lett. 111 (2013) 182003

[2] Y.Burnier, O. Kaczmarek and A.R. arXiv:1410.2546 t.b.p. in PRL

[3] S. Kim, P. Petreczky and A.R. arXiv:1409.3630 t.b.p. in PRD

Dilepton and Quarkonium Measurements in STAR

Frank Geurts (Rice University)

Dilepton measurements play an essential role in the study of hot and dense nuclear matter. Compared to hadrons, leptons have only little interaction with the strongly interacting system. Thus, dileptons provide ideal penetrating probes that allow the study of such a system throughout its space-time evolution. Depending on the dominating contributions in certain invariant mass ranges, these studies include the effects of chiral symmetry restoration, thermal radiation from the quark-gluon plasma, to effects of the medium on the heavy quarks that are created in the primordial processes. Systematic measurements of quarkonium production and elliptic flow may help understand its production mechanism and interactions with nuclear matter.

I will review dilepton and charmonium measurements performed over a range of beam energies by the STAR experiment as well discuss the prospects of recently installed upgrades and future plans.

The physics of sPHENIX with emphasis on bottomonium

Anthony Frawley (Florida State University)

Bottomonium is very attractive for studies of screening in the QGP because there are three states of different radii that can all be observed. The proposed sPHENIX detector will make it possible to compare precise bottomonium production data from heavy ion collisions at RHIC with precise data from the LHC, providing an opportunity to study the properties of the Quark Gluon Plasma at quite different initial temperatures. In addition to initial medium temperature, there are other differences in conditions between the two energies that are helpful in understanding the interplay between competing physics processes. One example of this is the difference in charm and bottom quark production rates, which leads to large differences in the rates of charmonium and bottomonium production via coalescence of heavy quarks. In this talk I will discuss the physics program planned at RHIC with the sPHENIX detector, a state of the art jet and Bottomonium detector, wih emphasis on the insight expected from a comparison of RHIC and LHC bottomonium data with theory.

Parallel Session: Electron Scattering 1

Towards a resolution of the proton form factor problem: new electron and positron scattering data

Dasuni Adikaram (Jefferson Lab)
Co-authors : RIMAL, Dipak (University of Florida) ; WEINSTEIN, Larry (Old Dominion University) ; RAUE, Brian (Florida International University) ; BROOKS, Will (Universidad Tcnica Federico Santa Mara) ; ARRINGTON, John (Argonne National Laboratory)

There is a significant discrepancy between the values of the proton electric form factor, G_E^p, extracted using unpolarized and polarized electron scattering. Calculations predict that small two photon exchange (TPE) contributions can significantly affect the extraction of G_E^p from the un-polarized electron-proton cross sections. We determined the TPE contribution by measuring the ratio of positron-proton to electron-proton elastic scattering cross sections using a , simultaneous, tertiary electron-positron beam incident on a liquid hydrogen target and detecting the scattered particles in the Jefferson Lab CLAS detector. We present the cross section ratios measured at $Q^2 = 1.45$ GeV^2 and at $\epsilon = 0.88$ along with the estimations of systematic uncertainties. A detailed comparison of new results with previous measurements and theoretical calculations will also be presented.

On the reaction mechanism of the Wide Angle Compton Scattering from the proton

Bogdan Wojtsekhowski (Jefferson Lab)

The leading role of the handbag diagram contribution to the WACS process at several GeV photon energy was established by JLab experiment E99-114. At the same time, new data from E07-002 indicates significant corrections which are not possible in the GPD approach. A plan for a new high precision double polarized experiment with 100 times improved data taking productivity will be presented.

Status of the OLYMPUS Experiment

Lauren Ice (Arizona State University)

The OLYMPUS experiment will determine the multiple-photon exchange contribution to elastic lepton-proton scattering, the most likely candidate to resolve the discrepancy between measurements of the proton electric to magnetic form factor ratio, determined using the Rosenbluth separation technique and polarization transfer methods. To this end, the experiment measured the cross section ratio of positron-proton to electron-proton elastic scattering. Data taking took place during 2012 on the DORIS storage ring at the DESY Laboratory in Hamburg, Germany. Electron and positron beams of 2.01 GeV energy were incident on an unpolarized hydrogen target and the elastic scattering cross sections were measured for both beams using a large acceptance spectrometer. This talk will cover the motivation, experiment, and current status of the analysis.

An Independent Spectroscopic Data Analysis of the Proton Size Puzzle

John Ralston (University of Kansas)
Co-authors : MARTENS, John (University of Kansas)

The proton charge radius measured in muonic hydrogen disagrees with other experiments by as much as seven standard deviations. However the "7 measure comes only from electronic hydrogen spectroscopy combined with many other data published by a single group. We perform an independent data analysis of the hydrogen spectrum that finds the charge radius rp = 0.87 ± 0.01. This result revises the discrepancy to 2.5-3.5 standard deviations, while also suggesting that electron scattering data is even more important than previously believed. Previous hydrogen analysis is found to be excessively sensitive to a single transition. The transition has a radically mismatched theoretical uncertainty, which is hundreds to thousands of times larger than its experimental uncertainty. The mismatched transition generates a one-point fit which by itself predicts the main features of previous analysis involving hundreds of free parameters. Rather than devise elaborate methods, we argue that high sensitivity should be avoided altogether in a scientifically conservative approach to resolving the proton size puzzle. We delete the hyper-sensitive transition as an outlier, obtaining the charge radius as well as the Rydberg constant $\mathrm{R}\infty = 1.097373156851 \times 10^7 \pm 8 \times 10^{-5} \mathrm{m}^{-1}$. We recommend the proton size puzzle be confronted by comparing protons to protons with simple, transparent analysis, where the relation between procedural decisions, data, and theory inputs on the final outputs can readily be monitored.

Parallel Session: Hadron Structure 2

Transverse Spin Physics at RHIC - Recent Results and Opportunities

Anselm Vossen (Indiana University)

Polarized proton-proton collisions have opened the door to new transverse spin phenomena that are not accessible in SIDIS. Among them are questions of universality and factorization, which lie at the center of our interpretation of experimental data. This talk will highlight recent results in transverse spin physics in p+p at RHIC and discuss opportunities with polarized proton collisions with data taken in the near future.

Spin Directed Momentum Transfers in transverse momentum factorization and collinear factorization

Dennis Sivers (Portland Physics Institute)

Single Spin Asymmetries in hard collision processes are associated with non-perturbative QCD dynamics leading to spin-directed momentum transfers. These non-perturbative spin-directed momentum transfers can occur either in an initial state or in the fragmentation leading to a final state particle. The dynamical mechanisms leading to single-spin asymmetries are parameterized either as higher-twist corrections in collinear factorization of the hard-scattering or as momentum-dependence in transverse-momentum-dependent distributions and fragmentation functions.

Rapidity evolution of gluon TMDs

Andrey Tarasov (Jefferson Lab)
Co-authors : BALITSKY, Ian (Jefferson Lab)

We study how the rapidity evolution of gluon transverse momentum dependent distribution changes from small x 1 to moderate x ˜ 1.

The Pion Transition Form Factor

Montao Raya (University of Michoacan)

In the framework of Schwinger-Dyson Equations, we calculate the (neutral) Pion-to-two-photons transition form factor. This problem involves quantitatively careful parameterization of the quark propagator and the pion Bethe-Salpeter amplitudes in order to be able to numerically access large space-like momenta of the probing photons. Also, in order to be consistent with the so-called chiral anomaly, G(0)=1/2, and the low momentum experimental data, one must model a consistent quark-photon vertex. Our results are relevant for the experiments carried out at BaBar and Belle, and future experiments of Belle II.

Parallel Session: RHIC 2

Heavy-Flavor Interactions in Medium

Ralf Rapp (Texas A&M University)

We discuss how heavy-flavor particles can be utilized to probe hot and dense QCD matter as produced in high-energy heavy-ion collisions. Toward this end, we introduce a thermodynamic T-matrix formalism to describe the in-medium properties of both open- and hidden-flavor particles. We report on recent progress on extracting a suitable in-medium potential from the in-medium heavy-quark free energy as computed in lattice QCD. We finally highlight some applications of the T-matrix interactions to heavy-ion phenomenology, utilizing a Brownian motion approach for open-heavy flavor transport and a kinetic approach to quarkonium dissociation and regeneration.

Bottomonia production in AA collisions

Michael Strickland (Kent State University)

I will discuss suppression of bottomonia production in relativistic heavy ion collisions due to creation of a short-lived quark gluon plasma (QGP). The suppression of these states is a ”smoking gun” for the creation of the QGP since cold nuclear matter effects on bottomonia production at central rapidities are quite small. I will also highlight the fact that, due to their large masses, these states are virtually immune to contamination from recombination of dissociated states which has plagued the analysis of charmonia suppression in relativistic heavy ion collisions. I will present results of state-of-the-art calculations which incorporate complex-valued heavy quark potentials folded together with non-equilibrium spatiotemporal evolution of the QGP provided by (3+1)-dimensional anisotropic viscous hydrodynamics. The obtained results will be compared to experimental data from both RHIC and LHC experimental collaborations.

The free energy and entropy of a heavy quark pair in the quark-gluon plasma

Dmitri Kharzeev (Stony Brook University and BNL)

Lattice QCD indicates a large amount of entropy associated with the heavy quark-antiquark pair immersed in the quark-gluon plasma. We argue that the increase of this entropy as a function of the inter-quark distance gives rise to an entropic force that can be very effective in dissociating the bound quarkonium states. In addition, the lattice data show a very sharp peak in the heavy quark-antiquark entropy at the deconfinement transition. In the holographic approach, this peak arises because the heavy quark pair acts as an eyewitness to the black hole formation in the bulk the process that describes the deconfinement transition. In terms of the boundary theory, this entropy likely emerges from the entanglement of a long string connecting the quark and antiquark with the rest of the system.

Plenary 3

Extract parton distribution functions from lattice QCD calculations

Jianwei Qiu (Brookhaven National Lab)

Parton distribution functions (PDFs) describe the relation between a hadron and the quarks and gluons (or partons) within it. Without them, we would not be able to understand the hard probes in hadronic collisions, including the Higgs discovery at the LHC. In this talk, I will review a new approach to extract PDFs from the ab initio calculations of single hadron matrix elements using lattice QCD techniques. I argue that the leading power nonperturbative collinear behavior of such matrix elements with a large momentum transfer is the same in both the Euclidean and Minkowski space, and could be systematically factorized into PDFs with infrared safe matching coefficients. PDFs could be extracted from global analysis of the lattice data on these single hadron matrix elements.

Phases of QCD

Larry McLerran (Brookhaven Natl Lab)

Ab-initio determination of the proton-neutron mass splitting

Christian Hoelbling (Wuppertal University)

I present a recent calculation of hadronic isospin splittings in lattice QCD+QED. We work with four non-degenerate flavors of dynamical quarks and perform a combined continuum and infinite volume limit. We reproduce correctly and with a significance of 5 sigma the mass difference between proton and neutron. We compute 4 more isospin splittings, 2 of which are predictions. Finally, we disentangle QED and mass components of the isospin splitting and comment on the relevance of these results for the fine-tuning of the fine structure constant and the mass difference between up and down quarks in the standard model.

Plenary 4

Nucleon Resonances and their Structure

Ralf Gothe (University of South Carolina)
Co-authors : MOKEEV, Viktor (Jefferson Lab)

Meson-photoproduction measurements and their reaction-amplitude analyses can establish more sensitively, and in some cases in an almost model-independent way, the nucleon excitations and non-resonant reaction amplitudes. However, to investigate the strong interaction from explored where meson-cloud degrees of freedom contribute substantially to the baryon structure to still unexplored distance scales where quark degrees of freedom dominate and the transition from dressed to current quarks occurs we depend on experiments that allow us to measure observables that are probing this evolving non-perturbative QCD regime over its full range.

Transition form factors are uniquely suited to trace this evolution by measuring exclusive single-meson and double-pion electroproduction cross sections off the free proton. Recent efforts try to include their isospin dependence by analyzing the cross sections off the quasi-free neutron and proton in Deuterium. In the near future, these exclusive measurements will be extended to higher momentum transfers with the energy-upgraded CEBAF beam and CLAS12 to study the quark degrees of freedom, where their strong interaction is responsible for the ground and excited nucleon state formations. Recent results will demonstrate the status of the analysis and of their theoretical descriptions, and an experimental and theoretical outlook will highlight what shall and may be achieved in the new era of the 12-GeV upgraded transition form factor program.

1) This work is supported in part by the National Science Foundation under Grant PHY1205782.
2) Studies of Nucleon Resonance Structure in Exclusive Meson Electroproduction, Int. J. Mod. Phys. E22 (2013) 1330015.

Excited states and scattering phase shifts from lattice QCD

Colin Morningstar (Carnegie Mellon University)

Progress in computing excited state energies and meson-meson scattering phase shifts in lattice QCD are described. Such calculations are now possible using a stochastic method of treating the low-lying modes of quark propagation that exploits Laplacian Heaviside quark-field smearing. Level identification with a variety of probe interpolating operators is discussed.

Physics Program for Studying GPDs at Jefferson Lab

Stepan Stepanyan (Jefferson Lab)

A broad program for studying the quark and gluon structure of hadrons is underway at Jefferson Lab. The cornerstone of this program is understanding the nucleon structure in the framework of Generalized Parton Distributions (GPDs). The GPDs take the description of the internal structure of the nucleon to a new level by providing access to, among other things, the correlations between the (transverse) position and (longitudinal) momentum distributions of the partons. After the first successful experimental studies of GPDs using Deeply Virtual Compton Scattering (DVCS), a slew of data on spin asymmetries and cross section measurements have been provided by dedicate experiments at Jefferson Lab with 6 GeV CEBAF. These results have been added to the pool of data that are used in global fits to extract GPDs and played important role in constraining theoretical models. Jefferson Lab's electron accelerator, CEBAF, is doubling its energy to 12 GeV and upgrade of experimental equipment is underway in the experimental Halls. The upgrade enables execution of a broader physics program for uncovering the GPDs using exclusive reactions in the new kinematic domain. In this talk, summary of GPD studies with 6 GeV CEBAF and prospects of studies with 12 GeV machine will be discussed.

Parallel Session: RHIC 3

Subleading harmonic flow

Derek Teaney (Stony Brook University)

We perform a Principal Component Analysis (PCA) of $v_3(p_T)$ in event-by-event hydrodynamic simulations of Pb+Pb collisions at the LHC. The PCA procedure identifies two dominant contributions to the two particle correlation function, which together capture 99.9% of the squared variance. We find that the subleading flow (which is the largest source of flow factorization breaking in hydrodynamics) is predominantly a response to the radial excitations of a third-order eccentricity. We present a systematic study of the hydrodynamic response to these radial excitations in 2+1D viscous hydrodynamics. Finally, we construct a good geometrical predictor for the orientation angle and magnitude of the leading and subleading flows using two Fourier modes of the initial geometry.

Ref:

R. Bhalerao, J.Y. Ollitrault, S. Pal, D. Teaney, PRL in press
A. Mazeliauskas, D. Teaney, PRC in press

QCD at nonzero temperature: T_c and the equation of state

Urs M. Heller (American Physical Society)

Recent improvements in methods and algorithms as well as advances in computing resources have enabled ever more precise studies of the QCD finite temeperature transition and of properties of the quark-gluon plasma using lattice gauge theory numerical simulations. In particular, simulations at (almost) physical light quark masses allow for better control of systematic errors. I review the latest results on the QCD transition/crossover temperature T_c and on the equation of state in the temperature range relevant to current heavy ion collision experiments at RHIC and LHC.

Viscous corrections from nonlinear transport

Denes Molnar (Purdue University)
Co-authors : DAMODARAN, Mridula (Purdue University)

Comparison of hydrodynamics calculations to heavy-ion experiments inevitably requires conversion of the fluid to particles ("particlization"). For fluids that are not in perfect local equilibrium, for example because they have nonzero viscosity, one needs a model that describes nonthermal "delta-f" corrections to the phase space density of particle species. In the case of shear viscous fluids, the problem has been customarily ignored and simple additive corrections quadratic in momentum have been applied (so called Grad ansatz). More recently, however, a variety of theoretically better motivated shear corrections have been proposed based on insights from kinetic theory in various approximations (such as linearized kinetic theory, the relaxation time approximation, or near the free streaming limit). The choice of corrections affects observables such as identified particle elliptic flow v2(pT). We present results from accurate numerical simulations of fully nonlinear Boltzmann transport theory, and test the applicability of different shear "delta-f" models.

Parallel Session: Hadron Structure 3

Twist-3 spin asymmetries for inclusive single-hadron production in lepton-nucleon scattering

Andreas Metz (Temple University, Philadelphia)
Co-authors : GAMBERG, Leonard (Penn State Berks) ; KANAZAWA, Koichi (Temple University, Philadelphia) ; KANG, Zhong-bo (Los Alamos National Lab) ; PITONYAK, Daniel (Brookhaven National Lab) ; PROKUDIN, Alexei (Jefferson Lab) ; SCHLEGEL, Marc (Tuebingen University)

In this talk we will address new theoretical work on twist-3 spin asymmetries for the process $l + N \to h + X$, for which nice recent data have been obtained. Specifically, we will discuss the transverse single-spin asymmetry A_N for a polarized nucleon and a polarized final-state hyperon, as well as the longitudinal-transverse double spin asymmetry A_LT. Open questions and future prospects will be mentioned also.

Nucleon structure results from LQCD using Wilson fermions

Sergey Syritsyn 8RIKEN/BNL Research Center)

Aspects of Lattice QCD calculations of transverse momentum-dependent parton distributions (TMDs)

Michael Engelhardt (NMSU)

Transverse momentum-dependent parton distributions (TMDs) can be formally defined in terms of hadronic matrix elements of quark bilocal operators containing staple-shaped gauge connections. A parametrization of the matrix elements in terms of invariant amplitudes serves to cast them in the Lorentz frame preferred for a lattice calculation. An ongoing program of evaluating TMD observables within Lattice QCD is reviewed, summarizing recent progress with respect to several challenges faced by such calculations. Results on the naively T-odd Sivers and Boer-Mulders effects are presented.

Quasi-Classical TMD's of an Unpolarized Spin-1/2 System

Matthew Sievert (Brookhaven National Laboratory)

A dense hadronic system, such as a heavy nucleus or a hadron boosted to high energies, generates strong gluon fields dominated by their classical component. The high density is described by the saturation momentum scale, which provides a dynamical short-distance cutoff and makes these dense systems amenable to perturbative calculations. Building on our previous work, we calculate the transverse-momentum-dependent (TMD) quark parton distribution functions of a dense, unpolarized spin-1/2 system. The possibility of spin-orbit coupling results in nontrivial mixing between the unpolarized and Boer-Mulders TMD's.

Parallel Session: Heavy Quark 2

Perturbative charm production and the prompt atmospheric neutrino flux in light of RHIC and LHC

Ina Sarcevic (University of Arizona)

We re-evaluate the prompt atmospheric neutrino flux, using the measured charm cross sections at RHIC and the Large Hadron Collider to constrain perturbative QCD parameters such as the factorization and renormalization scales, as well as modern parton distribution functions and recent estimates of the cosmic-ray spectra. We find that our result for the prompt neutrino flux is lower than previous perturbative QCD estimates and, consequently, alters the signal-to-background statistics of the recent IceCube measurements at high energies.

Charmonium spectroscopy from Lattice QCD

Daniel Mohler (Fermilab)

I review recent results on charmonium spectroscopy from Lattice QCD. For charmonia well below open charm threshold results from recent determinations controlling all systematic uncertainties will be presented. For states close to and above open charm threshold I review recent exploratory calculations aimed at both conventional and exotic XYZ states.

Leptonic and semi-leptonic decays of heavy mesons from lattice QCD

Paul Mackenzie (Fermilab)

For the last ten years, lattice gauge theory calculations have played a critical role in making possible some of the measurements of the flavor physics program. I describe the role that lattice calculations have played in determining the elements of the CKM quark mixing matrix, and the role that that has played in the search for physics beyond the standard model in the CKM matrix. I also describe the many roles that lattice calculations need to play in the next ten years throughout the programs of high energy and nuclear physics.

Heavy quarkonium production in p+p

Hong Zhang

Parallel Session: RHIC 4

Angular correlations in pA collisions

Vladimir Skokov (Western Michigan University)

From the perspective of the initial state physics, I will discuss large azimuthal asymmetries observed in p+Pb collisions at the LHC. In particular, I will show that individual configurations of the McLerran-Venugopalan model describing a highly boosted hadron/nucleus are azimuthally anisotropic due to fluctuations of color charges. I will also present numerical evidence that impact parameter dependent small-x JIMWLK resummation preserves such anisotropies over several units of rapidity. Based on this, the full BBGKY hierarchy for the n-particle azimuthal cumulant will be discussed.

Two-Gluon Correlations in Heavy-Light Ion Collisions

Yuri Kovchegov (The Ohio State University)
Co-authors : WERTEPNY, Douglas (The Ohio State University)

We present a calculation of the two-gluon production cross section in the saturation framework for a collision of two nuclei. We assume that one of the nuclei is much smaller than the other one: this is the heavy-light ion collision. The gluon correlation function we obtain exhibits both the away-side and near-side 'ridge' structures, giving contributions to the even harmonics (v2, v4, etc) and to the Fourier coefficients extracted from the higher-order cumulants.

Light-Heavy Ion Collisions at RHIC: d+Au and He3+Au

Anne Sickles (University of Illinois)

Analysis of collisions between one small and one large nuclei have suggested that similar hot nuclear matter might be created in these collisions as in heavy ion collisions. In this talk, we will discuss recent results from RHIC from both d+Au and He3+Au collisions and their interpretation.

Parallel Session: Hadron Structure 4

Towards a Direct Measurement of the Quark Orbital Angular Momentum Distribution

Simonetta Liuti (university of virginia)

We discuss the canonical (Ji) and kinetic/mechanical (Jaffe and Manohar) definitions of partonic orbital angular momentum (OAM). It was recently shown by Hatta and Burkardt that the two definitions correspond to the second moment in intrinsic k_T of the same generalized transverse momentum distribution (GTMD), while they differ in their gauge link structure. At the same time, as first observed by Polyakov, canonical orbital angular momentum can be independently described in terms of a twist three generalized parton distribution, which only a straight type of gauge link is allowed for. Here we provide further insight into this problem by showing that the second moment in k_T of the OAM twist two GTMD and twist three GPD, are connected through a Wandzura Wilczeck type relation which generalizes the one originally developed for the polarized twist three distribution, g_T. An important outcome of the picture we provide is that the two different mechanisms for generating partonic OAM can be both tested experimentally and validated by lattice calculations. Additional calculations using the reggeized diquark model are shown that provide an initial guidance for assessing the size of the various contributions.

Nucleon structure results from LQCD using DWF

Taku Izubuchi (Brookhaven National Laboratory)

Nucleon structure from lattice QCD

Giannis Koutsou (The Cyprus Institute)

Recent nucleon structure results from the lattice will be reviewed, from simulations with physical or near physical quark masses. Details on the calculation of quantities such as the nucleon axial charge and the nucleon momentum fraction will be presented. An outlook towards lattice calculations which can impact new physics searches will follow.

Quark Orbital Angular Momentum

Matthias Burkardt (NMSU)

Definitions of orbital angular momentum based on Wigner distributions are used to discuss the connection between the Ji definition of the quark orbital angular momentum and that of Jaffe and Manohar. The difference between these two definitions can be interpreted as the change in the quark orbital angular momentum as it leaves the target in a DIS experiment.The mechanism responsible for that change is similar to the mechanism that causes transverse single-spin asymmetries in semi-inclusive deep-inelastic scattering.

Parallel Session: Electron Scattering 2

Prospects for electron scattering from the triton

Roy Holt (Argonne National Laboratory)

The development of a novel tritium target for Jefferson Lab has led to renewed interest in the mass three system. Very little data exist for electron scattering from the triton. For example, no data exist for deep inelastic scattering from the triton. Deep inelastic scattering measurements for the three-nucleon nuclei provide a powerful means to determine the neutron structure function. The isospin dependence of electron scattering from light nuclei provide information short range correlations in nuclei. An improved determination of the charge radius of the triton should now be possible. The program using the new tritium target as well as some technical aspects of the target will be presented. 1This work was supported by the U. S. Department of Energy, Office of Science, Office of Nuclear Physics, under contract no. DE-AC02-06CH11357.

Nuclear structure and the flavor dependence of the EMC effect

John Arrington (Argonne National Laboratory)
Co-authors : CLOET, Ian (Argonne National Laboratory) ;
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The connection between nuclear cluster structure and modification of the nuclear quark distributions can be seen in the behavior of the EMC effect in light nuclei and in the connection between the EMC effect and the presence of short-range correlations (SRCs) in nuclei. However, it is not yet clear if this related to the high densities associated with these two-nucleon clusters or the high-momenta generated through the short-range part of the N-N interaction. In either case, this connection also suggests that that the difference in proton and neutron distributions in neutron-rich nuclei will generate a difference between the modifications of up- and down-quark distributions in nuclei. I will discuss both interpretations of the connection between SRCs and the EMC effect, their implications on the EMC effect, and plans to better understand the origins of this intriguing connection.

The Qweak Experiment: Early Results and Outlook

Scott MacEwan (University of Manitoba)

The Qweak experiment at Jefferson Lab uses parity-violating electron scattering (PVES) to make a precision measurement of the proton's weak charge QpW. The experiment finished taking data in May 2012 and has reported an initial, low-statistics measurement of the asymmetry in elastic ep scattering at low $Q^2 = 0.0250$ $(\mathrm{GeV/c})^2$ with a beam energy of 1.16 GeV based on approximately 1/25 of the overall data collected in the experiment. Several technical challenges were overcome to successfully measure the small asymmetry including a high power liquid hydrogen target, radiation hard Cerenkov detectors, and precision electron beam polarimetry. The small Q^2 of the measurement has made possible the first determination of the weak charge of the proton, QpW, by incorporating earlier PVES data at higher Q^2 to constrain hadronic effects and the use of state-of-the art theoretical calculations. An overview of the experiment and the initial result will be presented alongside updates to the current status, including polarimetry, kinematics, backgrounds, and data quality analysis.

Deeply Virtual Compton Scattering at JLab 12GeV: First Studies of the Fall 2014 Run at Hall A

Marco Carmignotto (The Catholic University of America)

The Deeply Virtual Compton Scattering (DVCS) collaboration is currently taking the first physics data of the 12 GeV era at Jefferson Lab. With the E12-06-114 experiment running in Hall A, we will extend the extraction of the Generalized Parton Distributions (GPDs) amplitudes through the measurement of the $p(\vec{e}, e'\gamma)p'$ reaction, with scaling tests of the cross section with Q^2 up to 9 GeV^2 at fixed x_{Bj} = 0.36, 0.50, and 0.60. Additionally, separating photons from the decay of neutral pions that are also in the acceptance of our calorimeter will allow us for the extraction of the $p(e, e'\pi^0)p'$ cross section for the same kinematic points. In this talk I will present the first studies of the Fall 2014 data, and discuss preliminary results and projections.

Plenary 5

Old and New Physics with Domain Wall Fermion Lattice QCD

Robert Mawhinney (Columbia University)

During the last two years, simulations with domain wall fermions at physical quark masses have been done at zero and non-zero temperature by the RBC and UKQCD Collaborations and the HotQCD Collaboration. Precision measurements of zero temperature observables, such as the kaon semileptonic form factor and B_K have been done. More challenging observables, such as K to pi pi weak decay amplitudes have been calculated, for $I = 2$ final states, and are being calculated, for $I = 0$ final states. There have also been calculations of the QCD finite temperature phase transition with domain wall fermions, where for the first time the lattice formulation manifests the full symmetries that play a role in the transition. These topics, plus newer calculations, will be discussed.

Exotic spectroscopy in heavy and light flavor

Michael Williams (MIT)

There have been many interesting results in the field of exotic spectroscopy in the past decade, especially in the area of heavy flavor. I will discuss the recent exciting results from the LHCb experiment at CERN with a focus on exotic charm spectroscopy, e.g., the X(3872) and $Z_c(4430)$. Then I will discuss the imminent advance in the field of light-quark spectroscopy expected from the GlueX experiment at JLab and the prospect of finding light-quark exotic states.

Thermodynamic signature of additional strange and charmed baryons

Swagato Mukherjee (Brookhaven National Laboratory)

Signatures of additional strange and charmed baryons obtained from lattice QCD thermodynamics will be presented and their implication of heavy-ion collision experiments will be discussed.

Plenary 6

The Pion and Images of Dynamical Chiral Symmetry Breaking

Ian Cloet (Argonne National Laboratory)

The pion occupies a special place in nuclear physics and encapsulates the myriad complexities of Quantum Chromodynamics (QCD). For example, the pion is both a bound-state of a dressed-quark and a dressed-antiquark in quantum field theory and the Goldstone mode associated with dynamical chiral symmetry breaking (DCSB) in QCD. Using QCDs Dyson-Schwinger equations we will investigate properties of the pion and discuss how they are influenced by DCSB in QCD.

Hadron Spectroscopy: Providing the link between experiment and theory in the intermediate energy region at JLAB

Diane Schott (George Washington University)

The study of hadronic properties and structure is an important part of understanding QCD. Measuring resonances predicted by the Quark Model as well as other complex states such as hybrids or glue balls can lead to insights on quark-confinement and the behavior of gluons. The CEBAF Large Acceptance Spectrometer (CLAS) at Jefferson Lab (JLab) offers a unique set of opportunities in meson and baryon spectroscopy using photon and electron production. This talk will give an update on the experimental results and coordinated efforts from the JLab Physics Analysis Center (JPAC) and George Washington University Data Analysis Center (GWDAC) who's common goals include using observed data to provide insights into the fundamental theory of strong interactions.

Highlights from the RHIC Spin Program

Renee Fatemi (University of Kentucky)

For over a decade the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory has facilitated the development of a rich and diverse spin physics program by consistently providing polarized proton collisions over a wide range of center-of-mass energies. Several pieces of this program, such as the inclusive jet and pion double spin asymmetries that probe the gluon helicity distribution, the W and Z boson observables that are sensitive to the flavor asymmetry of the polarized sea and the large but unexplained transverse single spin asymmetries in the forward direction, have been anticipated and pursued since the inception of the RHIC spin effort. However, the versatility of the collider as well as the STAR and PHENIX detectors, has allowed the spin program to evolve and respond to new and pressing questions in the hadronic spin community. Examples include a burgeoning mid-rapidity transverse spin program that will provide access to the transversity distributions for the first time in hadronic collisions and several critical tests of the predicted Sivers' sign-change in Drell-Yan and direct photon processes. The successes of the flagship measurements, as well as the surprising and novel new directions taken by the RHIC spin program, will be presented and their implications for the future directions of the nuclear physics community will be discussed.

Parallel Session: Heavy Quark 3

New tests of Quarkonium Production Mechanisms using Jet Substructure

Thomas Mehen (Duke University)

Despite decades of study, the underlying mechanism for quarkonium production at high transverse momentum at hadron colliders is not well understood. I describe new observables that involve the measurement of quarkonia within jets that are sensitive to the underlying quarkonium production mechanisms. For example, the distribution for the fraction of energy carried by a quarkonium within a jet is calculable in terms of NRQCD fragmentation functions and the dependence of this distribution on the energy of the jet and the quarkonium energy fraction can be used to perform an independent extraction NRQCD long-distance matrix elements. We derive factorized and resummed cross sections for jets with quarkonia and compare these with Monte Carlo. We also derive a boost invariant soft function that is necessary for jet cross sections at the LHC.

Making Sense of the XYZ Mesons from QCD

Eric Braaten (Ohio State)

The XYZ mesons are unexpected mesons discovered in the last decade that contain a heavy quark and antiquark but have properties that suggest they also have additional constituents. Many of them are surprisingly narrow, and several are definitely tetraquark mesons. Their existence presents a serious challenge to our understanding of the spectrum of QCD. I will explain how the Born-Oppenheimer approximation may provide a framework for understanding the XYZ mesons within QCD.

Cusps and Molecules

Eric Swanson (Univ Pittsburgh)

Possible interpretations of recently discovered exotic mesons are discussed. In particular, it is possible that the Zb and Zc states are kinematical in origin. Tests of this hypothesis are suggested. Molecular and other interpretations of the Z(4475) are also presented.

Parallel Session: RHIC 5

Anisotropic jet quenching in semi-quark-gluon plasmas with magnetic monopoles

Jiechen Xu (Columbia University)
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In ultra-relativistic heavy-ion collisions at RHIC and LHC, high energy jet fragments' nuclear modification factor (R_{AA}) and azimuthal anisotropy (v_2) provide a stringent set of observables in constraining the parton-medium interactions. We present a new jet quenching framework, CUJET3.0, that is shown to simultaneously account for both high p_T single inclusive hadrons R_{AA} and v_2 at both RHIC and LHC energies. CUJET3.0 generalizes our previous perturbative QCD (pQCD) based CUJET2.0 model by incorporating non-perturbative lattice QCD constraints on the suppression of color-electric scatterings and the enhancement of scatterings due to emergent color-magnetic monopoles near the QCD confinement transition temperature. Our analysis provides a novel connection between the jet transport coefficient controlling hard jet quenching observables and the bulk soft "perfect fluidity" of quark-gluon plasmas. We further present predictions of high p_T open heavy flavors R_{AA} and v_2 from CUJET3.0, which can be tested in future RHIC measurements to complement the light quark sector

Photon-nucleus collisions at the LHC

Daniel Tapia Takaki (University of Kansas)

Protons and ions accelerated by the LHC carry an electromagnetic field, which acts as a source of photons. The beam energy at the LHC makes it the most energetic photon source ever built. The interaction of such high-energy photons with nuclei (or protons) can be studied in ultra-peripheral heavy-ion collisions, where the impact parameter is larger than the sum of the nuclear radii and hadronic interactions are therefore strongly suppressed. Both the ALICE and CMS collaborations have studied photonuclear production of vector mesons in ultra-peripheral Pb-Pb and p-Pb collisions. The process effectively corresponds to an interaction between a photon, generated from the electromagnetic field of one of the nuclei with the other (target) nucleus. The study of these photon-nucleus interactions is interesting as a way to probe the nature of the initial state created in high energy nucleus-nucleus collisions.In this talk, the latest results from ALICE and CMS on exclusive production of light and heavy vector mesons in ultra-peripheral Pb-Pb and p-Pb collisions will be reviewed. These studies have demonstrated sensitivities to very low Bjorken-x values in both the proton and the Pb nucleus. The prospects for future analyses on ultra-peripheral collisions at the highest LHC energy will also be discussed.

Forward inclusive π^0/jet and correlation studies in He^3+Au collisions at $\sqrt{s} = 200$ GeV

Xuan Li (Temple University)

The proton gluon distribution function increases rapidly with decreasing x at fixed Q^2, but cannot increase indefinitely as x goes to 0. Gluon saturation is expected at a low x value when gluon recombination balances gluon splitting. The nuclear (with atomic mass number A) gluon distribution is expected to be approximately $A^{1/3}$ larger than the nucleon gluon distribution function at the same x [1]. Forward dijet measurements at RHIC are sensitive to x between 0.001 and 0.02 for the nuclear gluon distribution via forward di-jet measurements in 200 GeV collisions. The rapidity dependent forward di-hadron correlations measured in 2008 RHIC 200 GeV d+Au collisiosn at STAR indicate a smooth transition from dilute parton gas to dense gluon fields inside nuclei [2]. The latest 2014 200 GeV He^3+Au collisions recorded at STAR at RHIC allow us to cross check the consistency of the forward di-hadron correlations between d+Au and He^3+Au collisions. Instead of a forward electromagnetic calorimeter, we installed a lead-scintillator Forward Hadronic Calorimeter (FHC) with the pseudorapidity coverage between 2.8 to 3.4 at STAR for the 2014 RHIC run. The Endcap Electromagnetic Calorimeter (EEMC) at STAR covers pseudo-rapidity between 1.08 and 2, providing the opportunity to probe gluons at intermediate x between 0.003 and 0.02 in 200 GeV collisions. In this talk, we will discuss the methods of forward π^0/jet reconstructed in the FHC, and the FHC jet and EEMC jet-like cluster correlations in the 200 GeV He^3+Au collisions.

[1] H. Kowalski, D. Teaney, Phys. Rev. D (2003) 68, 114005.
[2] X. Li, Nuclear Physics A 904-905 (2013) 823c-826c.

Jet Quenching in Heavy Ion collisions at the CMS detector

Raghav Kunnawalkam Elayavylli (Rutgers University)

The quark gluon plasma is a phase of matter produced during collisions of ultra relativistic heavy ions which the CMS detector is able to study in collisions of lead ions (PbPb). A clear signature of the QGP is the apparent suppression in the inclusive jet transverse momentum when compared with a reference proton-proton (pp) system. Dijet studies in PbPb have confirmed that the reduced yield is a result of a phenomenon called jet quenching where the jets lose energy when traversing the medium. Measurements of the nuclear modification factor and the energy flow of the quenched jets are presented using high statistics pp, pPb(proton lead) and PbPb data taken in 2011-2013 at the LHC. A new data driven method to estimate the fluctuating underlying event density based on the flow modulated forward calorimetric energy distribution is employed.

The LPM Effect in Sequential Bremsstrahlung

Shahin Iqbal (University of Virginia)
Co-authors : ARNOLD, Peter (University of Virginia)

Gluon bremsstrahlung is the dominant process through which high energy particles loose their energy in a Quark Gluon plasma. Calculations of the bremsstrahlung rate are complicated by interference between radiation from multiple collisions, giving rise to the Landau-Pomeranchuk-Migdal (LPM) effect. Previous authors have analysed the case where the coherence lengths of two consecutive emissions overlap, but in limits where at least one of the bremsstrahlung gluons is soft. We have gone beyond this approximation, treating general energies of bremsstrahlung gluons. We also show that the differential rate for double gluon bremsstrahlung can be reduced to a 1-dimensional integral which can be performed numerically.

Parallel Session: Hadron Spectroscopy and Decays

Coupled-channel scattering from lattice QCD

David Wilson (Old Dominion University)

Recently it has become possible to obtain coupled-channel scattering amplitudes using lattice QCD. Using a large basis of operators we are able to obtain a reliable finite volume spectrum describing the $\pi - K$, $\eta - K$ coupled system. Utilising the finite volume formalism proposed by Luescher and extended by several others, we are able to describe the spectra from each lattice symmetry group and this enables constraints to be derived for S, P and D-wave scattering. We find resonant scattering amplitudes and investigate their structure in the complex plane, finding poles that display a pattern similar to the physical $K^\star(892)$, $K_0^\star(1430)$ and $K_2^\star(1435)$ resonances.

Light Meson Decays from Photon-Induced Reactions with CLAS

Michael Kunkel (Forschungszentrum Jülich)

Photo-production experiments with the CEBAF Large Acceptance Spectrometer (CLAS) at the Thomas Jefferson National Laboratory produce data sets with unprecedented statistics of light mesons. With these data sets, measurements of transition form factors for η, ω, and η' via conversion decays can be performed using a line shape analysis on the invariant mass of the final state dileptons. Tests of fundamental symmetries and information on the light quark mass difference can be performed using a Dalitz plot analysis of the meson decay. In addition, the data allows for a search for dark matter, such as the heavy photon via conversion decays of light mesons and physics beyond the Standard Model can be searched for via invisible decays of η mesons. An overview of the first results and future prospects will be given.

Physics Opportunities with Meson Beams

Igor Strakovsky (The George Washington University)
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Over the past two decades, meson photo- and electroproduction data of unprecedented quality and quantity have been measured at electromagnetic facilities worldwide, at investments of many millions of dollars. By contrast, the meson-beam data for the same hadronic final states are mostly outdated and largely of poor quality, or even non-existent, and thus provide inadequate input to help interpret, analyze, and exploit the full potential of the new electromagnetic data. To reap the full benefit of the high-precision electromagnetic data, new high-statistics data from measurements with meson beams, with good angle and energy coverage for a wide range of reactions, are critically needed to advance our knowledge in baryon and meson spectroscopy and other related areas of hadron physics. To address this situation, a state-of-the-art meson-beam facility needs to be constructed. The present paper summarizes unresolved issues in hadron physics and outlines the vast opportunities and advances that only become possible with such a facility.

Excited state energies and scattering phase shifts from lattice QCD with the stochastic LapH method

Andrew Hanlon (University of Pittsburgh) and Jake Fallica (Carnegie Mellon University)
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Recent results in computing excited state energies and meson-meson scattering phase shifts in lattice QCD are presented. A stochastic method of treating the low-lying modes of quark propagation that exploits Laplacian Heaviside quark-field smearing makes such studies possible now. Levels are identified using a variety of probe interpolating operators.

Parallel Session: Theory

Renormalization group approach to calculations in n-particle irreducible field theories

Margaret Carrington (Brandon University)

We use the functional renormalization group to formulate the renormalization of the nPI effective action. The resulting set of coupled integro-differential equations can be solved using a numerical lattice method. The major numerical obstacle is the size of the phase space, which can be reduced by efficiently exploiting the symmetries of the n-point functions. The renormalization group method does not require counter-terms and can be used beyond the level of the 2PI effective action to obtain next-to-leading order contributions to physical observables like viscosity. We present some numerical results for the non-perturbative 2-point and 4-point functions from the 2PI and 4PI effective actions.

A Dynamical Three-Field AdS/QCD Model

Joseph Kapusta (University of Minnesota)

The Anti-de Sitter Space/Conformal Field Theory (AdS/CFT) correspondence may offer new and useful insights into the non-perturbative regime of strongly coupled gauge theories such as Quantum Chromodynamics (QCD). We present an AdS/CFT-inspired model that describes the spectra of light mesons. The conformal symmetry is broken by a background dilaton field, and chiral symmetry breaking and linear confinement are described by a chiral condensate field. These background fields, along with a background glueball condensate field, are derived from a potential. We describe the construction of the potential, and the calculation of the meson spectra, which match experimental data well. We argue that the presence of the third background field is necessary to properly describe the meson spectra.

Practical corollaries of transverse Ward-Green-Takahashi identities

Sixue Qin (Argonne Natl Lab)

The gauge principle is fundamental in formulating the Standard Model. Fermion–gauge-boson couplings are the inescapable consequence and the primary determining factor for observable phenomena. Vertices describing such couplings are simple in perturbation theory and yet the existence of strong-interaction bound-states guarantees that many phenomena within the Model are nonperturbative. It is therefore crucial to understand how dynamics dresses the vertices and thereby fundamentally alters the appearance of fermion–gauge-boson interactions. We consider the coupling of a dressed-fermion to an Abelian gauge boson, and describe a unified treatment and solution of the familiar longitudinal Ward-Green-Takahashi identity and its less well known transverse counterparts. Novel consequences for the dressed-fermion–gauge-boson vertex are exposed.

Nuclear-medium effect on the η decay into 3π: isospin asymmetry v.s. partial restoration of chiral symmetry

Shuntaro Sakai (Kyoto University)
Co-authors : KUNIHIRO, Teiji (Kyoto University)

We explore how the $\eta - \pi^0$ mixing angle and the η meson decay into $\pi^+\pi^-\pi^0$ and $3\pi^0$ are modified in the nuclear medium on the basis of chiral effective field theory. We find that the larger isospin-asymmetry $\delta\rho \equiv \rho_n - \rho_p$ and the smaller total baryon density $\rho \equiv \rho_n + \rho_p$, the more enhanced the mixing angle. It turns out that the effect of the total baryon density on the decay widths overwhelms that coming from the isospin-asymmetry, and the higher theρ, the more enhanced the decay widths; the width for the $\pi^+\pi^-\pi^0$ decay is enhanced with a factor two to three at the normal density ρ_0 with a minor increase due to $\delta\rho$, while that for the $3\pi^0$ decay shows only a small increase of around 10 percent even atρ_0. We find that the ρ dependence of the decay width is caused by the six-body vertex which involves two nucleon lines as well as the four pseudo-scalar bosons and hence only comes into play in the nuclear medium. We show that the ρ dependence is nicely expressed as a renormalization of the pion decay constant $f_\pi^*(\rho)$, which is interpreted to represent the partial restoration of chiral symmetry in the nuclear medium.

A New High-Accuracy Analysis of Compton Scattering in Chiral EFT: Status and Future

Harald W. Grieshammer (Institute for Nuclear Studies, George Washington University)
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Compton scattering from protons and neutrons probes the two-photon response of the nucleon in electric and magnetic fields at fixed photon frequency and multipolarity. As these fields induce radiation multipoles by displacing the target constituents, the angular and energy dependence of the emitted radiation provides detailed tests of the symmetries and strengths which govern the interactions of the constituents with each other and with photons. At low energies, the process is parameterised by six energy-dependent dipole polarisabilities. Their zero-energy limit are the static electric and magnetic scalar dipole polarisabilities α_{E1} and β_{M1}, and the four spin-polarisabilities. Differences between proton and neutron values stem from isospin-breaking interactions, exploring the interplay between chiral symmetry as well as the pattern of its breaking, and short-distance Physics. The information is for convenience often compressed in the static scalar dipole polarisabilities, i.e. the extrapolated values at zero photon energy. In combination with emerging lattice QCD determinations, they provide stringent tests for our theoretical description of hadron structure and are thus fundamental quantities in their own right. Moreover, they are crucial to the neutron-proton mass difference, the proton charge radius puzzle, and the Lamb shift of muonic hydrogen. Recently, a new extraction of the static electric and magnetic scalar dipole polarisabilities of the proton and neutron from all published elastic data below 300 MeV was performed in Chiral Effective Field Theory. ChiEFT is ideal for that purpose since it provides reliable theoretical uncertainties by a model-independent estimate of higher-order corrections and encodes the correct low-energy dynamics of QCD, including, for few-nucleon systems, consistent nuclear currents, rescattering effects and wave functions.

The proton and neutron values turn out to be identical within the accuracy of available data. After reviewing context, ingredients and results of this analysis, this talk discusses the following topics: statistical consistency of the world Compton dataset; status of one- and few-nucleon Compton theory; desirable improvements of the database; elastic and inelastic Compton scattering on deuterons and ^{3}He; and predictions for high-intensity experiments with polarised targets an polarised beams. The goal is to extract not only scalar nucleon polarisabilities, but also the so-far poorly explored spin-polarisabilities, which parametrise the stiffness of the nucleon spin in external electro-magnetic fields (nucleonic bi-refringence/Faraday effect).

Parallel Session: Hadron Structure 5

Nucleon structure from Lattice QCD

Gunnar Bali (University of Regensburg)

I will present results on the structure of the nucleon from lattice simulations of QCD with two mass-degenerate light sea quarks, down to a nearly physical pion mass. We use non-perturbatively improved Wilson fermions. Results will be presented on the distribution of mass and spin among the partons, including isoscalar quantities, the average momentum fraction and some form factors.

An Opportunity for Forward Jet Single Spin Asymmetry Measurements at RHIC

Michael McCumber, (Los Alamos National Laboratory)
Co-authors : JIANG, Xiaodong (LANL)

We explored measurements of transverse single spin asymmetries (SSA) in forward jet productions at RHIC energies, in high energy p+p and 3He+p collisions, prior to the construction of an Electron-Ion Collider (EIC). Forward jets produced at 200 GeV center-of-mass energy carry a non-vanishing SSA, as was shown by the AnDY experiment at RHIC. This left-right bias originates from a correlation between the parton's transverse-momentum and the nucleons transverse spin (Sivers distributions). Gauge invariance predicts that the Sivers distribution is process-dependent, and the Sivers distributions for jet production in hadron-hadron collisions have opposite signs compared to those in semi-inclusive Deep-Inelastic Scattering.

Through simulation studies, we show that valance quarks contributions to jet production can be effectively flavor-ehanced by tagged-jet, with additional requirements imposed on jet properties. For example, up- (down-) quarks contribution can be effectively enhanced by requiring the leading particle in a jet to be positively (negatively) charged. We demonstrate that jet and tagged-jet SSA measurements at RHIC can be used to study quark Sivers distribution at high-x, and its process-dependency. Taking the PHENIX collaborations proposed sPHENIX detector upgrade as an example, we show that with additional instrumentation in the forward direction, an exciting program of forward jet spin-asymmetry measurements can be carried out in conjunction with the sPHENIX's Heavy Ion physics program.

Hadron electric polarizability from lattice QCD

Andrei Alexandru(The George Washington University)

Electromagnetic polarizabilities are important parameters for understanding the interaction between photons and hadrons. For most hadrons these quantities are poorly constrained experimentally since they can only be measured indirectly. New experiments at CERN and Jefferson Lab are planned that will measure the polarizabilities more precisely. Lattice QCD can be used to compute these quantities directly in terms of quark and gluons degrees of freedom, using the background field method. We present results for the electric polarizability for two different quark masses, light enough to connect to chiral perturbation theory. These are currently the lightest quark masses used in polarizability studies. For each pion mass we compute the polarizability at four different volumes and perform an infinite volume extrapolation. For one ensemble, we also discuss the effect of turning on the coupling between the background field and the sea quarks.

The Spin Asymmetries of the Nucleon Experiment - SANE

Oscar Rondon (Institute for Nuclear and Particle Physics - U. of Virginia)
Co-authors : COLLABORATION, Sane (Multiple Institutions)

The Spin Asymmetries of the Nucleon Experiment SANE took data on inelastic and elastic inclusive and coincidence beam-target asymmetries in Hall C at Jefferson Lab. The scattered particles were detected with the large non-magnetic Big Electron Telescope Array BETA and the High Momentum Spectrometer. The Continuous Electron Beam Accelerator Facility - CEBAF delivered polarized electrons that were incident on the U. of Virginia solid polarized proton target. An overview and selected examples of the wealth of collected data, extending from the elastic to the deep inelastic scattering regions, and spanning the four-momentum range from 0.8 to 6 GeV squared, will be presented.

Parallel Session: RHIC 6

A Condensed Matter Approach to QCD - The Beam Energy Scan at RHIC

Michael Lisa (Ohio State University)

Over the past several years, a major component of the experimental program at the Relativistic Heavy Ion Collider (RHIC) has been a systematic study of heavy ion collisions over a large range of energies ($\sqrt{s_{NN}} \sim 5 - 200$ GeV/c). The motivation for this large-scale undertaking is to explore the phase structure of QCD matter for a range of system parameters (temperature and chemical potentials) over which nontrivial structures may emerge. These structures include a first-order phase transition at large net-baryon density and a critical point. The talk will present the current status of the experimental program and intriguing nontrivial trends in several observables that simultaneously suggest a transition in the system. Future directions in the theoretical and experimental program will also be outlined.

Thermal photons and dileptons - puzzles and opportunities

Gabor David (Brookhaven National Laboratory)

Low to moderate p_T photons (<3-4GeV/c) and dileptons produced in heavy ion collisions encode different physics processes, but most models agree that the predominant source is radiation from a thermalized QGP and/or hadronic phase. However, within this paradigm the goal to simultaneously explain the observed high yields and large azimuthal asymmetries remained so far elusive (”direct photon puzzle”). In parallel to constantly improving hydrodynamical and microscopic transport calculations, recently some radical new ideas emerged to explain the ”puzzle”, like magnetic field effects, radiation from the glasma, delayed equilibration and others. Comparing the latest heavy ion results to current calculations we will try to assess what improvements on the experimental side or new what type of measurements would be needed in order to discriminate among competing theoretical scenarios.

Quarkonium production in p+p and p+A collisions

Yan-qing Ma (University of Maryland)

Although the next-to-leading order NRQCD calculation can solve many puzzles of heavy quarkonium production phenomena, it can neither describe data at very high nor very low transverse momentum (pT) region. At very high pT region, a double parton fragmentation formalism was proposed recently, which can systematically reorganize the expansion and resum large logarithms; while at very low pT region, a NRQCD+CGC framework was proposed to take into account the intrinsic transverse momentum and gluon saturation effects.

Nuclear Modification of Quarkonium Production in p+Pb Collisions at the LHC

Ramona Vogt (LLNL/UC Davis) [1]

We make a systematic study of the modifications of quarkonium production in p+Pb collisions at $\sqrt{s_{_{NN}}} = 5$ TeV at the LHC. We compare the uncertainties in the EPS09 shadowing parameterization to the calculated mass and scale uncertainties obtained employng the EPS09 NLO central set. We study the dependence of the results on the proton parton density and the choice of the nuclear modifications. We check whether the results obtained are consistent at leading and next-to-leading order. We determine whether the calculated AA results can be factorized into the convolution of results from pA and Ap collisions. The calculations are compared to the available ALICE and LHCb nuclear modification factors, $R_{pA}(y)$ and $R_{pA}(p_T)$, as well as the forward-backward asymmetries, $R_{FB}(y)$ and $R_{FB}(p_T)$, for both J/ψ and Υ.

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