**Resummation, Evolution, Factorization 2020**

**7-11 December**

**Book of Abstracts**

**Factorization, evolution and resummation for heavy quarkonium production**

***Jianwei Qiu (Jefferson Lab)***

Heavy quarkonium production in high energy collisions offers unique perspectives into the formation of QCD bound states. With the multiple scales involved in the production, it is an ideal observable for exploring and testing our knowledge on QCD factorization, evolution and resummation, and our ability to extract nonperturbative and strongly interacting, but universal physics at the hadronic scale with controllable approximation. In this talk, I will present some new progresses in understanding and evaluating the transverse momentum distribution of heavy quarkonium production in terms of QCD factorization, evolution, resummation and the matching.

**Quasi-Distributions for PDFs and TMDs**

***Iain Stewart (MIT)***

In this talk I discuss recent progress on the use of quasi-distributions for carrying out rigorous calculations of the momentum dependence of parton distributions with lattice QCD. I review results for quasi-PDFs before focussing on quasi-transverse momentum distributions (TMDs). In particular for TMDs, first results are now available that involve direct computation of the non-perturbative contribution to the Collins-Soper evolution kernel (aka rapidity anomalous dimension) for TMDs.

**Large-momentum effective field theory for partons and light-cone physics**

***Xiangdong Ji (University of Maryland)***

Partons are effective degrees of freedom describing the structure of hadrons involved in high-energy collisions. Familiar theories of partons are QCD light-front quantization and soft-collinear effective theory, both of which are intrinsically Minkowskian. A ``new'' form of the parton theory has been formulated in terms of the old-fashioned, Feynman's infinite momentum frame, in which the parton degrees of freedom are filtered through infinite-momentum external states. The partonic structure of hadrons is then related to the matrix elements of static (equal-time) correlators in the state |Pz=∞⟩. This representation lays the foundation of large-momentum effective theory (LaMET) which approximates parton physics through a systematic M/Pz expansion of the lattice QCD matrix elements at a finite but large momentum Pz, and removes the residual logarithmic-Pz dependence by the standard effective-field-theory matching and running.

**Euclidean Observables for PDF Determinations**

***Luigi Del Debbio (University of Edinburgh)***

Monte Carlo simulations of lattice QCD can provide interesting inputs for the determination of Parton Distribution Functions and we have witnessed a momentous growth of dedicated simulations in recent years. Following seminal work by Collins, in this talk I will address some theoretical issues in the context of a scalar field theory toy model.

**Collinear Expansions of Cross Sections**

***Bernhard Mistlberger (SLAC)***

I will discuss a new approach to systematically expand collider cross sections around a kinematic limit where all final state radiation is collinear to one of the scattering protons. In particular, I show how such an expansion can provide an effective tool to derive physical approximations and how it can be used to extract universal quantities of scattering cross sections like transverse momentum dependent parton distribution functions.

**TMD PDFs and FFs: N3LO, Analytic Continuation, and Reciprocity**

***Hua Xing Zhu (Zhejiang University)***

In this talk I will report the recent progress in the calculation for quark and gluon TMD PDFs at N3LO. Using crossing symmetry obeyed by amplitudes in SCET, we obtained the corresponding TMD fragmentation functions at the same order by analytic continuation. As a by-product we determined for the first time the complete time-like Altarelli-Parisi kernel at NNLO, and provided evidence for a mysterious reciprocity relation between space-like and time-like kernel through NNLO in QCD.

**QCD aspects in V+jets measurements at the LHC**

***Vieri Candelise (University of Trieste and INFN Trieste)***

Experimental measurements of the associated production of vector bosons and jets (V+jets) constitutes an excellent framework to test several aspects of perturbative QCD. Total and differential cross sections of vector bosons produced in association with jets and heavy flavours have been extensively studied in LHC proton collisions at 13 TeV with the ATLAS and CMS detectors. Differential cross sections as function of a broad range of kinematical observables are measured and compared with the state-of-art theoretical predictions. Final states with a vector boson and jets can be also used to study electroweak initiated processes, such as the vector boson fusion production of a Z or W boson that are accompanied by a pair of energetic jets with large invariant mass. Selected results from the ATLAS and CMS experiments will be presented for the production of V+jets, V+heavy flavours and in the electroweak production mode.

**resummation benchmarking for DY production at the LHC: current achievements and challenges to come**

***Daniel Froidevaux (CERN/MEPHI)***

Very precise predictions of the differential transverse momentum (qT) spectrum of W and Z bosons and of the ratio of these spectra are needed to improve the systematic uncertainty on the measurement of the W-boson mass at the LHC. For the the first time ever, in the context of the LHC precision electroweak working group, a systematic benchmarking of a wide variety of resummation calculations, performed up to N3LL and using very diverse approaches, has been ongoing since a couple of years. In this talk, I will cover the results achieved to-date by a wide group of theorists and experimentalists. The studies and comparisons are basically completed for the pure resummation part of the calculations and are now reaching their final level of benchmarking with the incorporation of and matching to the fixed-order terms required at high values of qT. The main remaining challenges of this benchmarking will also be discussed, such as the evaluation of the systematic uncertainties, the inclusion of non-perturbative terms, and the impact of heavy flavours.

**Transverse Momentum Resummed Calculations in reSolve and Z’ searches**

***Thomas Cridge (University College London)***

I will discuss a novel application of transverse momentum (qT) resummed calculations to BSM Z’ searches. To do so I first introduce the program reSolve for making predictions of differential spectra including qT resummation, typically this has been applied in the Standard Model such as for Drell-Yan and diphoton signals. Then I will move onto the use of such calculations in BSM scenarios characterised by heavy wide Z’s, which are typically more sensitive to QCD corrections, and how these resummed calculations can be used in searches at future runs of the LHC. I will show that a variety of variables together can enhance sensitivity to these experimentally challenging signals, in particular focusing on the complementarity between differential cross-sections and the forward-backward asymmetry.

**Rapidity anomalous dimension: theory and practice**

***Alexey Vladimirov (Regensburg University)***

Collins-Soper kernel (or rapidity anomalous dimension) is a non-perturbative function that dictates the evolution of transverse momentum dependent (TMD) distributions. I give a review of the latest theory developments regarding CS-kernel and the comparison to the data. The main points of the talk are the non-perturbative definition of rapidity anomalous dimensions and its correspondence to the soft anomalous dimension.

1707.07606, 2003.02288

**Quark and gluon helicity distributions and OAM at small x**

***Yuri Kovchegov (The Ohio State University)***

An integral part of the proton spin puzzle is the contribution to the proton spin coming from quarks and gluons having small very values of the Bjorken x variable. This contribution is mostly beyond the reach of current experiments and is very hard to calculate numerically on the lattice. It appears that theoretical understanding of quark and gluon helicity distributions at small x is needed to assess the amount of proton spin coming from this region. In my talk I will describe the recent theoretical work aimed at finding the small-x asymptotics of the quark and gluon helicity distributions, along with their orbital angular momenta (OAM). I will derive small-x evolution equations for helicity and solve them to find the small-x asymptotics of the parton helicity distributions and OAM. The results of this work can be compared to the data to be collected at the upcoming Electron-Ion Collider (EIC) in order to extrapolate the small-x helicity distributions to be measured at EIC to even smaller values of x, thus completely constraining the proton spin coming from small x and helping to resolve the proton spin puzzle.

1511.06737 [hep-ph], 1808.09010 [hep-ph], 1901.07453 [hep-ph]

**Small-x TMDs: an overview**

***Feng Yuan (Lawrence Berkeley National Laboratory)***

I will present an overview on the TMDs at small-x, focusing on current status and future perspectives, in particular, we can learn from the planned electron-ion collider.

**Resummation of non-global observables**

***Thomas Becher (University of Bern)***

I discuss progress in the resummation of non-global observables. For cross sections in this category the pattern of enhanced logarithms depends on the directions of individual partons in the underlying hard process. Due to this dependence the resummation is driven by a fairly complicated RG evolution equation, which can be solved numerically using parton shower methods. I will present the code ngl-resum (see https://pypi.org/project/ngl-resum/), a flexible implementation of leading-logarithmic resummation and show results for gaps between jets in top production as a sample application of this framework. I will also briefly talk about the prospects for higher-logarithmic resummation.

**Progress on jets in SCET**

***Wouter Waalewijn (University of Amsterdam)***

I will describe recent progress in the descriptions of jets using Soft-Collinear Effective Theory, covering a selection of topics in the areas of higher-order calculations, jet substructure, jet grooming and recoil-free jets.

**Glauber Cancellation in Effective Field Theory**

***Ira Rothstein (Carnegie Mellon University)***

Previous SCET proofs of factorization for various processes implicitly assumed the cancellation of the Glauber mode contributions. This talk will attempt to plug this hole in the proof for the case of Drell-Yan.

**Factorisation in Colour Singlet Production**

***Jonathan Gaunt (University of Manchester)***

Factorisation of observables into hard, collinear, and soft functions is key to making many predictions at colliders. I discuss the validity of this factorisation approach for two observables in the context of the production of a colour singlet V at hadronic colliders - the transverse momentum of V (focussing on spin-dependent observables), and hadronic transverse energy E\_T accompanying V. For both cases I discuss why factorisation does or does not apply. Based on arXiv: 1405.2080 and arXiv:1709.04935.

**Towards precision PDFs**

***Sasha Glazov (DESY)***

**Factorized approach to radiative corrections for lepton-hadron semi-inclusive deep inelastic scatterings**

***Jianwei Qiu (Jefferson Lab)***

One of the great advantages of lepton-hadron deep inelastic scattering is the control of hard probe - the kinematics of exchanged vector boson. However, QED radiation induced by the hard collision makes it difficult to precisely control the kinematics of exchanged vector boson, in particular, for the lepton-hadron semi-inclusive deep inelastic scattering, from which the precision of angular modulation between the leptonic and hadronic scattering planes is necessary for extracting transverse hadron structure encoded in various transverse momentum dependent parton distributions or the TMDs. In this talk, I will present our recently proposed new factorized approach to QED radiative corrections (RCs) to both inclusive and semi-inclusive lepton-hadron deep-inelastic scattering. The new approach provides a uniform treatment of RCs for the extraction of parton distribution functions, transverse momentum dependent distributions, and other partonic correlation functions from lepton-hadron collision data, and a systematic way to resum the logarithmic enhanced RCs. Our unified factorization approach to QCD and QED dynamics will impact the physics analyses at the future Electron-Ion Collider.

**LHeC Physics at the HL-LHC**

***Anna Stasto (Penn State University)***

**Parallel Speakers**

**Monday 7 December**

**Fiducial qT​ resummation of color-singlet processes at N3LL+NNLO**

***Tobias Neumann (Brookhaven National Laboratory)***

We present a framework for qT resummation at N3LL+NNLO accuracy for arbitrary color-singlet processes based on a factorization theorem in SCET. Our implementation CuTe-MCFM is fully differential in the Born kinematics and matches to large-qT​ fixed-order predictions at relative order αs^2​. It provides an efficient way to estimate uncertainties from fixed-order truncation, resummation, and parton distribution functions. In addition to W±, Z and H production, also the diboson processes γγ,Zγ,ZH, and W±H are available, including decays. We discuss and exemplify the framework with several direct comparisons to experimental measurements as well as inclusive benchmark results. In particular, we present novel results for γγ and Zγ at N3LL+NNLO and discuss in detail the power corrections induced by photon isolation requirements.

arXiv:2009.11437

**Resummation of fiducial power corrections in the Drell-Yan transverse momentum distribution**

***Markus Ebert (Max-Planck-Institut für Physik)***

I will discuss the impact of fiducial cuts on transverse momentum factorization and resummation, showing that in general they give rise to linear power corrections, compared to quadratic corrections in inclusive measurements. I will show how these next-to-leading power corrections can be resummed to all orders in the strong coupling. The method is illustrated by resumming the Drell-Yan $q\_T$ spectrum and $\phi^\*$ distribution with fiducial cuts at N$^3$LL$^{(0+1)}$+NNLO$\_0$.

2006.11382

**QCD+QED qT Factorization for Z/W production and decay**

***Georgios Billis (DESY)***

I will discuss the QCD+QED factorization at small qT for the neutral and charged Drell-Yan process including the decay of the heavy vector boson. This involves describing the heavy boson near its resonance using Heavy Vector Effective Theory (HVET) and the initial/final em-charged states using Soft Collinear Effective Theory (SCET). I investigate all the relevant regimes set by the qT measurement, the mass and width of the intermediate heavy boson and identify the relevant factorization at small qT for each. In particular, I show that in a certain scale hierarchy the standard qT factorization is recovered with nontrivial implications for the case of the W boson.

<https://indico.cern.ch/event/911911/contributions/3879733/>

**QCD resummations in the lattice calculation of PDFs**

***Yong Zhao (Brookhaven National Laboratory)***

In modern methods to calculate the PDFs in lattice QCD, they can be extracted from static observables in a boosted hadron state through a factorization formula. The factorization formula matches the observable defined at the parton momentum or lattice scale to the PDF at MSbar scale $\mu$, where the running is determined by the DGLAP equation. Besides, at large-$x$, soft singularities also lead to threshold logarithms that can be resummed using the standard techniques. In this talk, we discuss the QCD resummations in the above factorization formulas, and present their effects on the currently available lattice results of the pion PDF.

**Quark and Gluon quasi-PDFs at low-x**

***Giovanni Antonio Chirilli (University of Regensburg)***

Quasi parton distribution functions (PDFs) are related to the matrix elements of bilocal operators with space-like separation. The possibility to calculate these objects on the lattice has attracted much attention in the QCD community. I will present the behavior of quark and gluon quasi-PDFs at low-x.

**Effective Field Theory for Jet substructure in heavy ion collisions**

***Varun Vaidya (MIT)***

I develop an Effective Field Theory (EFT) framework to compute jet substructure observables for heavy ion collision experiments. I consider dijet events that accompany the formation of a weakly coupled Quark Gluon Plasma(QGP) medium in a heavy ion collision and look at the simultaneous measurement of jet mass along with the transverse momentum imbalance between the jets accounting for both vacuum and medium evolution. The jets are groomed using a suitable grooming algorithm in order to mitigate effects of soft contamination from Multi-parton interactions as well as the QGP medium. This has the great advantage that we do not have to keep track of the evolution of the QGP medium into subsequent soft hadrons since these are groomed away from the final jet. Treating the energetic jet as an open quantum system interacting with a QGP bath, I write down a factorization formula within the SCET(Soft Collinear Effective Theory) framework, in which the forward scattering regime acounts for the interaction of the medium with the jet. This leads me to a Lindblad type master equation for the evolution of the reduced density matrix of the jet in the Markovian approximation. The resulting solution allows a resummation of large logarithms that arise due to the final state measurements imposed while simultaneously summing over multiple interactions of the jet with the medium. I find that the the decoherence between the hard interaction that creates the jet and the subsequent medium interactions leads to $\ physical$ Infra-Red(IR) collinear divergences that are otherwise absent in pure vacuum evolution. I show that these IR divergences are completely regulated by the medium induced gluon mass and highlight the need to develop a multi-scale EFT approach in the future to resum the new logarithms that arise from these divergences.

arXiv:2010.00028

**Z + jet results from CMS and comparison with TMDs**

***Bugra Bilin (Universite Libre de Bruxelles (BE))***

This talk presents CMS measurements of differential Z + jets production cross section using p-p

collision data at 8 and 13 TeV . The results include Z boson production with heavy flavor as well as

forward jets. Obtained differential results have been compared withPB TMD predictions obtained

with Cascade for various kinematic and angular variables.

**Perturbative uncertainties in the Drell-Yan spectrum at low qT**

***Giuseppe Bozzi (University of Pavia)***

We study the interplay between theoretical uncertainties and non-perturbative corrections to the qT spectrum of Drell-Yan production. We consider TMD factorisation and qT resummation and highlight differences and similarities. The final aim is to provide a reliable theoretical-uncertainty estimate that will eventually allow us to faithfully determine non-perturbative effects from fits to data.

**Uncertainties and challenges in TMD extraction**

***Ignazio Scimemi (Universidad Complutense Madrid)***

In this talk I would report on recent developments of TMD extraction from experimental data. I will in particular consider the sensitivity of the extraction PDF and expermental data and how this may drive current and future research.

**Three-Reggeon ladders and four-loop amplitudes in the high-energy limit**

***Giulio Falcioni (The University of Edinburgh)***

Scattering amplitudes in the Regge limit are conveniently described by replacing the highly energetic particles with Wilson lines with the same velocities. The evolution of the Wilson line operators in rapidity, governed by the Balitsky-JIMWLK equation, determines the dominant logarithms in the scattering amplitudes. Using this approach, in the recent paper <https://arxiv.org/abs/2012.00613> we compute four-loop $2\to2$ scattering amplitudes at NNLL accuracy. Focusing on infrared singularities, we derive constraints on the soft anomalous dimension generating the infrared divergences of the amplitudes in every gauge theory, with full colour dependence.

**The Regge limit at NNLL with SCET**

***Gregory Ridgway (MIT)***

The regge limit of QCD and related gauge theories allows us to learn about the all-orders (in \alpha\_s) behavior of interacting QFT. The formulation of Glauber operators in SCET gives us novel information about this limit, providing organizational structures that are different than other formalisms. This allows us to resolve the open puzzle of how to organize the dynamics of three reggeon exchange that first enters at NNLL, including separating contributions from planar and non-planar corrections.

**Multiparton webs beyond three loops**

***Anurag Tripathi (IIT Hyderabad)***

Correlators of Wilson-line operators are fundamental ingredients for the study of the infrared properties of non-abelian gauge theories. In perturbation theory, they are known to exponentiate, and their logarithm can be organised in terms of collections of Feynman diagrams called webs. We study the classification of webs to high perturbative orders, proposing a set of tools to generate them recursively: in particular, we introduce the concept of Cweb, or correlator web, which is a set of skeleton diagrams built with connected gluon correlators, instead of individual Feynman diagrams. As an application, we enumerate all Cwebs entering the soft anomalous dimension matrix for multi-parton scattering amplitudes at four loops, and we compute the mixing matrices for all Cwebs connecting four or five Wilson lines at that loop order, verifying that they obey sum rules that were derived or conjectured in the literature. Our results provide the colour building blocks for the calculation of the soft anomalous dimension matrix at four-loop order.

<https://arxiv.org/abs/2003.09714>

**Tuesday 8 December**

**Multijet merging with PB TMDs**

***Armando Bermudez Martinez (DESY)***

We present an approach to multijet merging using the MLM procedure based on PB TMDs and the corresponding TMD parton shower. We show that multijet merging is possible with PB TMDs and that it leads to smaller uncertainties compared to conventional approaches. We show first applications of the method for Z+j measurements from the LHC.

**Perturbative uncertainties in unitarized NLO merging**

***Leif Gellersen (Lund University)***

Precise background predictions for collider searches require the estimation of perturbative uncertainties of jet observables. Besides uncertainties based on renormalization scale variations in matrix element and parton shower calculations, the definition of next-to-leading order multi-jet merging schemes contributes to the perturbative uncertainty budget. In this talk, I discuss and compare both contributions in the context of unitarized NLO merging within Pythia 8. I will argue that these uncertainties are intertwined, and may both contribute similarly to the error budget, at odds with conventional strategies.

<https://inspirehep.net/literature/1777761>

**Intrinsic kt and low mass DY production**

***Mikel Mendizabal (DESY)***

We present an application of PB TMDs to low mass DY production and show that measurements at low energies are well described with the same mechanism as used to describe the DY q\_t spectrum at the LHC. We also investigate the role of the intrinsic, no-perturbative kt distribution, both for the PB approach at NLO as well as for conventional parton shower approaches.

**The PMC$\_\infty$: Infinite-Order Scale-Setting method using the Principle of Maximum Conformality and preserving the Intrinsic Conformality ({\it iCF})**

***Leonardo Di Giustino (University of Insubria, Italy)***

It has become conventional to simply guess the renormalization scale in pQCD expansions. The resulting predictions for pQCD series have unphysical dependence on the choice of renormalization scheme, diverge as $n !$, and give incorrect predictions in the QED Abelian limit. We introduce a new method, {\it PMC$\_\infty$}, which systematically eliminates the conventional renormalization scale-setting ambiguities in pQCD predictions. The PMC$\_\infty$ method resums infinite sets of $\beta$ terms and preserves a key property underlying the scale invariance of physical observables in renormalizable SU(N)/U(1) gauge theories: {\it Intrinsic Conformality} (iCF). This new method solves the conventional renormalization scale ambiguities at each order in pQCD consistent with the properties of the Principle of Maximum Conformality (PMC). Moreover, the PMC$\_\infty$ method eliminates the factorial renormalon growth $n! \alpha^s \beta^n $, all dependence on the choice of the renormalization scheme, and thus all uncertainties related to renormalization scale and scheme ambiguities up to the order of accuracy. The PMC$\_\infty$ agrees with traditional Gell Mann – Low scale setting method which is used in the Abelian QED limit of QCD. We also introduce a new method to unambiguously identify all the terms in the iCF parametrization, such as the conformal scales, the conformal coefficients, and the $\beta$-terms, which then can be applied to both numerical and analytical calculations. We illustrate the PMC$\_\infty$ for the thrust and C-parameter of jet distributions in electron-positron annihilation and show how to apply this new method to observables in QCD in general. The initial results using this new method and the evaluation of theoretical errors using standard criteria for theory uncertainties show that the PMC$\_\infty$ significantly improves theoretical predictions for virtually all jet shape variables. The elimination of renormalization ambiguities using the PMC$\_\infty$ greatly increases the precision of pQCD predictions and thus the sensitivity of measurements to new physics. It also exposes the remarkable underlying conformal features of pQCD predictions.

Phys.Rev. D 102 (2020) 1, 014015.

**The true unintegrated distribution for inclusive DIS?**

***Renaud Boussarie (LANL)***

It is customary to distinguish two main regimes of perturbative QCD. For an observable with a hard scale Q^2 and the center-of-mass energy s, the Bjorken regime Q^2 ~ s and the Regge (or small x) limit s>>Q^2 have been studied separately intensively. The main question to address the continuity between both regimes, namely the very distinct non-perturbative elements, has been answered when it was proven that the so-called unintegrated distributions which appear in the Regge limit can be written as the strict x=0 limit of the so-called TMD distributions which appear in the Bjorken regime.

I will introduce a new scheme and a new expansion which interpolates between both regimes, and I will address how going beyond the strict x=0 limit modifies the form of the non-perturbative distributions. In particular, I will discuss the unintegrated distribution which appears in one of the simplest observables, namely inclusive Deep Inelastic Scattering, when one restores an actual dependence on x in the distribution.

**Gauge-invariant TMD factorization for Drell-Yan process at small x**

***Ian Balitsky (JLAB/ODU)***

The Drell-Yan hadronic tensor for electromagnetic (EM) current is calculated in the Sudakov region $s\gg Q^2\gg q\_\perp^2$ with ${1\over Q^2}$ accuracy, first at the tree level and then with double-log accuracy. It is demonstrated that in the leading order in $N\_c$ the higher-twist quark-quark-gluon TMDs reduce to leading-twist TMDs due to QCD equation of motion. The resulting hadronic tensor is EM gauge-invariant and depends on two leading-twist TMDs: $f\_1$ responsible for total DY cross section, and Boer-Mulders function $h\_1^\perp$. The naive estimates of four Lorentz structures of hadronic tensor seem to agree with LHC results at corresponding kinematics.

**Heavy-quark hadroproduction in different heavy-quark mass renormalization schemes: phenomenological implications**

***Maria Vittoria Garzelli (Hamburg Universitaet)***

We discuss the phenomenological implications of the use of different renormalization schemes for the heavy-quark masses in heavy-quark hadroproduction at the LHC, with considerations on the convergence of the perturbative expansion of the cross-sections in the strong coupling constant, when adopting different mass renormalization, renormalization and factorization scale options. In particular, we focus on the MSbar and MSR schemes, as alternatives to the most widely adopted on-shell scheme. We also explore the consequences of using heavy-quark short-distance masses, instead of on-shell masses, when performing simultaneous extractions of parton distribution functions, alpha\_S and heavy-quark mass values. Contributing authors: M.V. Garzelli, L. Kemmler, S. Moch, O. Zenaiev

M.V. Garzelli, L. Kemmler, S. Moch, O. Zenaiev, arXiv:2009.07763

**Heavy flavor production in the high energy limit of strong interactions**

***Michael Fucilla (Università della Calabria)***

Heavy flavor physic has long been considered a perfect framework for testing perturbative QCD at colliders, due to the smallness of the running coupling. However, at modern colliders, heavy-flavor production enters a two-scale regime, called semi-hard. In this regime perturbative expansions are afllicted by the precense of large energy-logarithms, which have to be resummed in a closed form in order to make serious predictions. The most general framework for such a resummation is the Balitsky-Fadin-Kuraev-Lipatov (BFKL) approach. In this talk, I will review how to construct such predictions in the case of production of two heavy-quark separated by a large interval in proton-proton or in electron-positron collisions. Then, I will discuss the extension of the analysis to meson final states.

A. D. Bolognino, F. G. Celiberto, M. Fucilla, D. Yu. Ivanov, and A. Papa. "High-energy resummation in heavy-quark pair hadroproduction". Eur. Phys. J. C (2019). arXiv: 1909.03068 [hep-ph].

**B-jet production at the LHC**

***Luis Ignacio Estevez (DESY)***

We apply PB TMDs together with initial state TMD parton shower to the production of Z+b as well as to inclusive b-jet production. We investigate the effect of the VFNS as well as a fixed flavor scheme with newly determined 4-flavor PB TMD densities. We show that both approaches give a consistent and good description of Z+b jet events. We also give prospects for inclusive b-jet production at highest energies.

**Transverse Momentum dependent parton distribution functions**

***Sara Taherimonfared (DESY)***

We present new fits to determine transverse momentum dependent (TMD) parton densities to HERA DIS data. The role of alphas for the TMD distribution is investigated. We present a first determination of fixed flavor PB TMDs. We also present the first TMD density of the photon, covering a wide range in x, kt and mu.

**Transverse momentum dependent cross-section factorization for dijet and heavy-meson pair processes in DIS**

***Rafael del Castillo (Universidad Complutense de Madrid)***

We employ soft collinear effective theory (SCET) to study a dijet production process in deep-inelastic-scattering (DIS) in an electron-proton collider, measuring the imbalance of the two hard probes in the Breit frame. In order to achieve factorization of the transverse momentum dependent (TMD) cross-section, we need to introduce a new soft function that we calculate at one-loop, regulating rapidity divergencies with the delta-regulator. We have also found that the same soft function can be used to achieve factorization of heavy-meson pair production in DIS using boosted-heavy-quark effective theory (bHQET). For both processes, we check anomalous dimension consistency relations and we have used this relation along with a universality argument regarding the heavy-quark jet function to extend our soft function anomalous dimension result up to three loops. The study of these processes could provide new knowledge of the TMD gluon distributions, to which they are sensitive. Dijet processes like the one we study here are expected to be observed in the future EIC.

<https://arxiv.org/abs/2008.07531v2>

**NLP factorization and endpoint divergences in DIS**

***Sebastian Jaskiewicz (Durham University IPPP)***

Endpoint divergences in convolution integrals appear ubiquitously in factorization formulas for various processes at next-to-leading power (NLP). The appearance of divergent convolutions prevents systematic resummation of large logarithms at NLP. Overcoming this complication has recently received increased attention. In the first part of my talk, I will show how refactorization and renormalization group methods inspired by soft-collinear effective field theory are applied to derive the soft-quark Sudakov exponentiation formula. Then, focusing on the off-diagonal DIS near the threshold x → 1 limit, I will discuss how the NLP soft-quark Sudakov formula, combined with d-dimensional consistency relations, allows for the summation of the large double logarithms of (1-x) to all orders in the strong coupling constant.

2008.04943

**Wednesday 9 December**

**Structure functions for the spin-1 deuteron**

***Shunzo Kumano (KEK/J-PARC)***

In the spin-1 deuteron, there are additional polarized structure functions which do not exist in the spin-1/2 nucleons. Especially, the gluon transversity appears as a new distribution in the deuteron. We proposed to investigate the gluon transversity distribution at hadron accelerator facilities [1]. Although there was recent experimental progress on quark transversity distributions, there is no experimental information on the gluon transversity. The gluon transversity does not exist for the spin-1/2 nucleons due to the helicity-conservation constraint. One needs a hadron with spin more than or equal to one, so that the helicity flip of two units is allowed. In our work, we proposed the possibility for finding the gluon transversity at hadron-accelerator facilities, especially in the proton-deuteron Drell-Yan process, by showing theoretical formalism and numerical results. This Drell-Yan experiment is under consideration in the Fermilab-E1039 experiment. The NICA project could also contribute to this topic. Since the internal spin-1/2 nucleons within the deuteron cannot contribute directly to the gluon transversity, it could be a good observable to find a new non-nucleonic component beyond the simple bound system of nucleons in nuclei. I also explain recent progress on the tensor-polarized PDFs [2], future prospects, and our proposal on new TMDs and PDFs in twist 3 and 4 for spin-1 hadrons [3].

[1] S. Kumano and Qin-Tao Song, Phys. Rev. D 101 (2020) 054011 & 094013.

[2] S. Kumano and Qin-Tao Song, Phys. Rev. D 94 (2016) 054022;

W. Cosyn et al., Phys. Rev. D 95 (2017) 074036. [3] S. Kumano and Qin-Tao Song, arXiv: 2011.08583.

**Azimuthal single- and double-spin asymmetries in semi-inclusive deep-inelastic lepton scattering at HERMES**

***Luciano Pappalardo (University of Ferrara)***

A comprehensive set of azimuthal single-spin and double-spin asymmetries in semi-inclusive leptoproduction of pions, charged kaons, protons, and antiprotons from transversely polarized protons is presented. These asymmetries include the previously published HERMES results on Collins and Sivers asymmetries, the analysis of which has been extended to include protons and antiprotons and also to an extraction in a three-dimensional kinematic binning and enlarged phase space. They are complemented by corresponding results for the remaining four single-spin and four double-spin asymmetries allowed in the one-photon-exchange approximation of the semi-inclusive deep-inelastic scattering process for target-polarization orientation perpendicular to the direction of the incoming lepton beam. Depending on the time, those results will be complemented by asymmetries using longitudinally polarized and unpolarized targets.

arXiv:2007.07755 [JHEP (in press)]

**Transverse momentum distributions and their evolution in SIDIS**

***Harut Avakian (JLab)***

Single and Dihadron semi-inclusive and hard exclusive production, both in current and target fragmentation regions, provide a variety of spin and azimuthal angle dependent observables, sensitive to the dynamics of quark-gluon interactions. Studies of the multidimensional partonic distributions are currently driving the upgrades of several existing facilities (JLab, COMPASS and RHIC), and the design and construction of new facilities worldwide (EIC, FAIR). In this talk, we present ongoing and planned measurements of different observables in semi-inclusive DIS, providing access to evolution and transverse momentum dependence of partonic distributions.

**Transverse momentum dependent splitting functions in Parton Branching based evolution equations**

***Lissa Keersmaekers (University of Antwerp)***

The Parton Branching (PB) approach provides evolution equations and a method to solve them, that account for the transverse momentum of partons and hence allows to obtain transverse momentum dependent (TMD) parton densities. However, even though the transverse momentum is known in every branching, the branching probabilities that have been used in these equations assume that the parton has no transverse momentum. In this work we study evolution equations based on the PB evolution equations that take into account transverse momentum in branching probabilities by using the recently calculated TMD splitting functions. We present the evolution equations and their solutions obtained with a Monte Carlo Simulation and show numerically the effects that TMD splitting functions have on the TMD distribution functions.

**Obtaining stable NLO corrections in High-Energy Factorization using Modified Multi-Regge Kinematics approximation**

***Maxim Nefedov (Samara University)***

The perturbatively-stable scheme of Next-to-Leading order (NLO) calculations of cross-sections for multi-scale hard-processes in DIS-like kinematics is developed in the framework of High-Energy Factorization. The evolution equation for unintegrated PDF, which resums log1/z-corrections to the coefficient function in the Leading Logarithmic approximation together with a certain subset of Next-to-Leading Logarithmic and Next-to-Leading Power corrections, necessary for the perturbative stability of the formalism, is formulated and solved in the Doubly-Logarithmic approximation. An example of DIS-like process, induced by the operator tr[GμνGμν], which is sensitive to gluon PDF already in the LO, is studied. Moderate (O(20%)) NLO corrections to the inclusive structure function are found at small xB<10−4, while for the pT-spectrum of a leading jet in the considered process, NLO corrections are small (<O(20%)) and LO of kT-factorization is a good approximation. The approach can be straightforwardly extended to the case of multi-scale hard processes in pp-collisions at high energies.

https://arxiv.org/abs/2003.02194 [JHEP08(2020)055]

**Entanglement, partial set of measurements, and diagonality of the density matrix in the parton model**

***Haowu Duan (North Carolina State University)***

We analyze the entanglement in the context of high energy QCD. First, in order to provide a firm connection to experimental observables, we define the “entropy of ignorance” which quantifies the entropy associated with ability to perform only a partial set of measurement on a quantum system. For the parton model the entropy of ignorance is equal to the Boltzmann entropy of a classical system of partons. We analyze a calculable model used for describing low x gluons in Color Glass Condensate approach, which has similarities with the parton model of QCD. In this model we calculate the entropy of ignorance in the particle number basis as well as the entanglement entropy of the observable degrees of freedom. We find that the two are similar at high momenta, but differ by a factor of order unity at low momenta. We explicitly demonstrate that that the reduced density matrix of the small x gluons is not diagonal in the particle number basis. We then show that the reduced density matrix can be diagonalized in a quasi-particle basis. Moreover, the matrix elements have the form of Boltzmann weights ${\rm diag}(e^{-n\beta\omega)$, $n=0,1…$ , where $n$ is the number of quasi-particles. At small momenta, $\beta \omega$ is proportional to $k/Q\_s$, demonstrating the apparent thermal behavior of small x gluons at low transverse momentum. We discuss the implication of our results in the context of the future EIC.

ArXiv 2001.01726 [hep-ph] (PhysRevD.101.036017)

**Small-x Helicity Phenomenology**

***Daniel Adamiak (Ohio state university)***

One of the key components to solving the proton spin problem is understanding the small-x asymptotics of the helicity parton distribution functions (hPDFs). Several years ago, novel, small-x evolution equations were derived using the shock-wave/Wilson line formalism, designed for calculating the x-dependence of the quark and gluon hPDFs and the proton g1 structure function. These equations can be used to predict the contribution to the spin of the proton coming from the helicities of the small-x quarks and gluons. In this talk we will present the first-ever attempt to describe the world data on the g1 structure function at small x using the evolution equations derived the novel evolution equations within the JAM global analysis framework. Our results serve as a prediction for future measurements at the EIC and can be used to estimate the net amount of quark spin at small-x, ultimately bringing us one step closer to understanding the proton spin. \*This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics under Award Number DE-SC0004286.

**Lensing Mechanism Meets Small-x Physics: Single Transverse Spin Asymmetry in p↑+p and p↑+A Collisions**

***M. Gabriel Santiago (The Ohio State University)***

We calculate the single transverse spin asymmetry in polarized proton-proton and polarized proton-nucleus collisions (AN) generated by a partonic lensing mechanism. The polarized proton is considered in the quark-diquark model while its interaction with the unpolarized target is calculated using the small-x/saturation approach. The phase required for the asymmetry is caused by a final-state gluon exchange between the quark and diquark, as is standard in the lensing mechanism of Brodsky, Hwang and Schmidt. The expression we obtain for the asymmetry AN of the produced quarks has the following properties:(i) The asymmetry is generated by the dominant elastic scattering contribution and 1/N2c suppressed inelastic contribution;(ii) The asymmetry grows or oscillates with the produced quark's transverse momentum pT until the momentum reaches the saturation scale Qs, and then only falls off as 1/pT for larger momenta;(iii) The asymmetry decreases with increasing atomic number A of the target for pT below or near Qs, but is independent of A for pT significantly above Qs. We discuss how these properties may be qualitatively consistent with data published by the PHENIX collaboration and with preliminary data reported by the STAR collaboration.

Yuri V. Kovchegov, M. Gabriel Santiago, Phys.Rev.D 102 (2020) 1, 014022

**Helicity at Small x: Oscillations and LLA Corrections**

***Yossathorn Tawabutr (The Ohio State University)***

Proton spin puzzle is a longstanding problem in high-energy and nuclear physics: how is the proton spin distributed between quarks and gluons in the proton? A missing piece of the puzzle is the amount of spin coming from the quarks inside the proton at small Bjorken-x. Integral equations which predict quark helicity distributions at small x were derived only recently. In this work, we construct a numerical solution of these equations at large-$N\_c\&N\_f$, with the aim to establish the small-x asymptotics of the quark helicity distribution. (Here $N\_c$ and $N\_f$ are the numbers of quark colors and flavors.) Our main result is the following: we find that the quark helicity distribution should oscillate as a function of $\ln(1/x)$. The oscillation period depends on $N\_f$ and spans many units of rapidity. This result may relate to the sign variation of the strange quark helicity distribution with x seen in phenomenology. Our solution provides a better constraint on the quark's helicity distribution at small x, contributing to the resolution of the proton spin puzzle. This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics under Award Number DE-SC0004286.

Kovchegov, Y.V., Tawabutr, Y. Helicity at small x: oscillations generated by bringing back the quarks. J. High Energ. Phys. 2020, 14 (2020). <https://doi.org/10.1007/JHEP08(2020)014>

**Particle production beyond eikonal accuracy in dilute-dense CGC framework**

***Pedro Augusto Agostini (Galician Institute of High Energy Physics (IGFAE))***

Within the Color Glass Condensate effective theory, most observables are computed by adopting the eikonal approximation. At asymptotic energies, this corresponds to treating the dense target as an infinitely thin shockwave. However, finite longitudinal width corrections to the shockwave approximation might be important at realistic energies. In such a case, the propagation of a parton through the medium is defined by a background propagator that follows a Brownian trajectory. In previous works [1,2] we used the two gluon exchange approximation - called glasma graphs -on the propagators to compute particle production and correlations in pp collisions. In order to extend the calculation to dense targets, thus in proton-nucleus collisions, here we propose a new way to compute correlators of two background propagators by discretizing the path integrals and using a localized version of the GBW model at each discretized step. We compare our result with the multiple soft scattering approximation applied in jet quenching calculations and apply them to single inclusive gluon production. [1] P. Agostini, T. Altinoluk and N. Armesto, Eur.Phys.J.C 79 (2019) 7, 600, e-Print: 1902.04483 [hep-ph]. [2] P. Agostini, T. Altinoluk and N. Armesto, Eur.Phys.J.C 79 (2019) 9, 790, e-Print: 1907.03668 [hep-ph].

P. Agostini, T. Altinoluk and N. Armesto, Eur.Phys.J.C 79 (2019) 7, 600, e-Print: 1902.04483 [hep-ph]. and P. Agostini, T. Altinoluk and N. Armesto, Eur.Phys.J.C 79 (2019) 9, 790, e-Print: 1907.03668 [hep-ph].

**Full next-to-eikonal quark propagator in the CGC and applications**

***Alina Czajka (National Centre for Nuclear Research)***

Within the Color Glass Condensate effective theory or other related frameworks, the theoretical description of low-x (or high-energy) QCD processes sensitive to the nonlinear gluon saturation physics relies on two main pillars. The first one is the semiclassical approach: due to the high density of low x gluons in an incoming proton or nucleus target, scattering processes off that target reduce to scattering processes on a semiclassical background gluon field. In particular, dense-dilute scattering processes at low x can then be formulated within perturbation theory in presence of a strong background gluon field. The second main pillar is the eikonal approximation, which amounts to neglecting power-suppressed corrections in the high-energy limit. Within the semiclassical framework, the eikonal approximation is equivalent to an infinite Lorentz boost of the background field, which is then contracted to a gluon shockwave. This approximation is crucial to make possible the systematic resummation of multiple interactions with the target. It is by definition a better and better approximation as the energy of the collision increases. But corrections beyond the eikonal approximation can be large at intermediate energies, in particular at RHIC and EIC, and their study is thus becoming a priority. In this talk, I will present the calculation of the complete next-to-eikonal corrections (first subleading power) to the quark propagator through the target, including both the effects of the finite longitudinal width of the target and of the transverse components of the background field. I will also present the first applications of this next-to-eikonal quark propagator to the calculation of next-to-eikonal corrections to selected observables.

**In-medium transverse momentum broadening effects on di-jet observables**

***Martin Rohrmoser (Institute of Nuclear Physics Polish Academy of Sciences)***

Heavy ion collisions at high energies can be used as an interesting way to recreate and study the medium of the quark-gluon plasma (QGP). We particularly investigate the jets produced in hard binary collisions and their interactions with a tentative medium. These jets were obtained numerically from the Monte-Carlo simulations of hard collisions using the KATIE-framework [1], where parton momenta within the colliding nucleons were describe by means of transverse momentum distributions (TMD). We evolved these jets within a medium that contains both, transverse kicks (yielding a broadening in momentum transvers to the jet-axis) as well as medium induced radiation within the MINCAS-framework [2] following the works of [3,4]. After favorable comparison of our results with experimental LHC-data on jet-quenching we make predictions for the decorrelation of dijets. In particular, we study deviations from a transverse momentum broadening that follows a Gaussian distribution. References: [1] A. van Hameren, Comput.Phys.Commun. 224 (2018) 371-380 [2] K. Kutak, W. Płaczek, R. Straka, Eur.Phys.J. C79 (2019) no.4, 317 [3] J.-P. Blaizot, F. Dominguez, E. Iancu, Y. Mehtar-Tani, JHEP 1301 (2013) 143 [4] J.-P. Blaizot, F. Dominguez, E. Iancu, Y. Mehtar-Tani, JHEP 1406 (2014) 075

arxiv: 1911.05463 [hep-ph] (accepted to be published at Physical Review C)

**Thursday 10 December**

**High energy factorization at NLO: forward Higgs production**

***Martin Hentschinski (Universidad de las Americas Puebla)***

We present the result for forward Higgs production at next-to-leading order in the strong coupling within high energy factorization in the infinite top mass limit. Our result is based on an explicit calculation of real corrections which then have been combined with virtual corrections determined earlier by M.A. Nefedov, including an appropriate subtraction mechanism. Apart from being of relevance for direct phenomenological studies (e.g. BFKL resummation for Higgs + jet), our results are a subset for the determination of the complete high energy resummed Higgs production cross-section at next-to-leading logarithmic accuracy. In addition, it will be of use for the further of study transverse momentum dependent factorization in the high energy limit.

in preparation; in collaboration with K.Kutak and A. van Hameren

**Higgs-plus-jet distributions as stabilizers of the high-energy resummation**

***Francesco Giovanni Celiberto (ECT\*/FBK Trento & INFN-TIFPA)***

We propose the inclusive hadroproduction of a Higgs boson and of a jet, featuring large transverse momenta and separated by a large rapidity distance, as a novel probe channel for the manifestation of the Balitsky–Fadin–Kuraev–Lipatov (BFKL) dynamics. We bring evidence that high-energy resummed distributions in rapidity and transverse momentum exhibit a solid stability under higher-order corrections, thus offering us a faultless chance to gauge the feasibility of precision calculations of these observables at the hand of the BFKL approach. We come out with the message that future, exhaustive studies of the inclusive Higgs-boson production, would benefit from the inclusion of high-energy effects in a unified formalism where distinct resummations are concurrently embodied.

arXiv:2008.00501

**NLO impact factors: Present status and outlook*Mohammed Maher Abdelrahim Mohammed (Università della Calabria & INFN Gruppo collegato di Cosenza)***

The role and the present status of the next-to-leading order impact factors in the Balitsky-Fadin-Kuraev-Lipatov (BFKL) approach for the cross sections at high energy √ s in perturbative QCD is briefly reviewed.

**Extraction of Sivers functions from SIDIS and Drell-Yan data with TMD evolution**

***Marcin Bury (Regensburg University)***

We perform extraction of Sivers functions from the available polarized Semi-Inclusive Deep Inelastic Scattering, Drell-Yan and W±/Z boson production data.

The extraction is performed at N3LO and NNLO perturbative precision within the ζ-prescription for TMDs. The results are compared to the existing extractions.

**Factorization of $e^+e^- \to H \, X$ cross section, differential in z, $P\_T$ and thrust in the quasi $2$-jet limit**

***Andrea Simonelli (University of Turin and INFN)***

Factorizing the cross section for single hadron production in $e^+e^-$ annihilations is a highly non trivial task when the transverse momentum of the outgoing hadron with respect to the thrust axis is taken into account. We work in a scheme that allows to factorize this cross section as a convolution of a calculable hard coefficient and a TMD fragmentation function, computed to next to leading order and next to leading log accuracy. This result, differential in $z$, $P\_T$ and thrust, will then be generalized to any order in perturbation theory. The factorization scheme we propose relates the TMD parton densities defined in 1-hadron and 2-hadron processes, restoring the possibility to perform global phenomenological studies of TMD physics including experimental data from Drell-Yan processes, semi-inclusive deep inelastic scattering, $e^+e^- \to H\_1 H\_2 X$ and $e^+e^- \to HX$ annihilations.

**Lambda Polarizing fragmentation function from Belle e+e- data**

***Marco Zaccheddu (Istituto Nazionale di Fisica Nucleare, Università degli Studi di Cagliari)***

We present a phenomenological analysis of the experimental data from Belle Collaboration for the transverse Lambda polarization both for the case of inclusive (plus a jet) and of associate production, measured in e+e- annihilation processes. Within a transverse momentum dependent (TMD) approach, we extract for the first time the quark polarizing fragmentation function for a Lambda hyperon, a TMD distribution giving the probability that an unpolarized quark fragments into a transversely polarized spin-1/2 hadron.

<https://doi.org/10.1103/PhysRevD.102.054001>

**Estimates for the single-spin asymmetries in $p^{\uparrow}p \to J/\psi X$ process\\ at PHENIX RHIC and SPD NICA**

***Anton Karpishkov (Samara National Research University and JINR)***

We study the transverse single-spin asymmetry (SSA) in $p^{\uparrow}p \to J/\psi X$ within the framework of the generalized parton model (GPM). To predict production cross-section of prompt $J/\psi$ we use two different approaches, the non-relativistic QCD (NRQCD) factorization approach and the Improved Color Evaporation Model (ICEM), and show how the predicted results for SSAs depend on choice of hadronization model. We demonstrate that PHENIX collaboration data on SSA in the process $p^{\uparrow}p \to J/\psi X$ constrain the gluon Sivers function of the proton and rule-out one of existing parametrisations. Estimates for the SSAs in $p^{\uparrow}p \to J/\psi X$ process for the conditions of planned SPD NICA experiment are also presented for the first time.

<https://arxiv.org/abs/2008.07232>

**High-Energy Factorization for Drell-Yan process in hadron collisions with new Unintegrated PDFs**

***Vladimir Saleev (Samara National Research University)***

The formalism for uniform description of Drell-Yan transverse-momentum spectrum is presented in a framework of High-Energy Factorization, which smoothly interpolates between Collins-Soper-Sterman formalism at |qT|≪Q and usual Collinear Parton Model at |qT|∼Q≪sqrt(S.) The new formula for deriving Unintegrated Parton Distribution Functions(UPDFs) from collinear ones is introduced, which leads to excellent description of the shape of Z-boson |qT|-spectrum at high energies up to |qT|/sqrt(S)≃0.02. Description of normalized |qT|-distributions at low energies is achieved via the fit of non-perturbative parameters of quark UPDFs. Reasonable description of angular distributions of leptons in the dilepton center-of-mass frame is also obtained with new UPDFs.

<https://arxiv.org/abs/2009.13188>

**Polarized pion induced Drell-Yan and TMD factorization**

***Alexei Prokudin (PSU Berks and Jefferson Lab)***

The Drell-Yan process provides important information on the internal structure of hadrons including transverse momentum dependent parton distribution functions (TMDs).

In this work we present calculations for all leading twist structure functions describing the pion induced Drell-Yan process. The non-perturbative input for the TMDs is taken from the light-front constituent quark model, the spectator model, and available parametrizations of TMDs extracted from the experimental data. TMD evolution is implemented at Next-to-Leading Logarithmic (NLL) precision for the first time for all asymmetries. Our results are compatible with the first experimental information, help to interpret the data from ongoing experiments, and will allow one to quantitatively assess the models in future when more precise data will become available.

**Pion TMDs**

***Leonard Gamberg (Penn State University Berks)***

We present a study of the transverse momentum dependent distribution of the pion (pion TMD) from pion-induced Drell-Yan (DY) scattering. We describe the DY cross section over the entire range of transverse momentum for moderate Q kinematics, using the state-of-the-art Collins Soper Sterman (CSS) transverse momentum dependent factorization formalism matching onto the fixed order large transverse momentum description of the transverse momentum dependent cross section. Further, using the JLAB Angular Momentum Collaboration (JAM) machinery we extract the pion TMD using Bayesian inference. This setup will allow us to perform a simultaneous self-consistent determination of pion and nucleon TMDs from hard processes and map out the 3-D structure of pions

**Friday 11 December**

**Associated Higgs + jets production at the LHC and CCFM gluon dynamics in proton**

***Maxim Malyshev (SINP MSU)***

We consider the associated production of Higgs boson and hadronic jet(s) in pp collisions at the LHC for the first time using the kt-factorization approach. Our analysis is based on the off-shell gluon-gluon fusion subprocess, where non-zero transverse momenta of initial gluons are taken into account and covers diphoton, WW\* and ZZ\* decay channels. The transverse momentum dependent (TMD) gluon densities in the proton are taken from Catani-Ciafaloni-Fiorani-Marchesini evolution equation. To simulate the kinematics of the produced jets the TMD parton shower implemented into the Monte-Carlo event generator CASCADE is applied. The comparison of our results with the latest experimental data taken by the CMS and ATLAS Collaborations and conventional higher-order perturbative QCD calculations is presented. We highlight observables, which are sensitive to the TMD gluon densities in a proton.

**Forward trijet production at LHC**

***Andreas van Hameren (IFJ PAN)***

A multiparton extension of the so-called small-x Improved Transverse Momentum Dependent factorization (ITMD) is used to calculate azimuthal angle distributions for three jets produced in the forward rapidity region, both for proton-proton and proton-lead collisions at center of mass energy 5.02 TeV. Effects related to both the change from the standard kT-factorization to ITMD factorization as well as changes from p-p collision to p-Pb are presented. Large differences in the distribution between the two factorization approaches allow to both improve the small-x gluon distributions as well as to validate the approaches. An observed significant depletion of the nuclear modification ratio points at the possibility to search for saturation effects using trijet final states.

**All-plus helicity off-shell gauge invariant multigluon amplitudes at one loop**

***Etienne Blanco (IFJ PAN)***

We calculate one loop scattering amplitudes for arbitrary number of positive helicity on-shell gluons and one off-shell gluon treated within the quasi-multi Regge kinematics. The result is fully gauge invariant and possesses the correct on-shell limit. Our method is based on embedding the off-shell process, together with contributions needed to retain gauge invariance, in a bigger fully on-shell process with auxiliary quark or gluon line.

arXiv:2008.07916

**Attempting gluon TMD studies with Jpsi+gamma final state**

***Vato Kartvelishvili (Lancaster University, UK)***

The results of a simulation-based feasibility study for gluon TMD distribution function measurement based on inclusive associated production of a vector quarkonium state and a photon, in proton-proton collisions at LHC energies.

In preparation

**Bottomonia production and polarization in the NRQCD with kT-factorization**

***Nizami Abdulov (Lomonosov Moscow State University)***

The Υ(nS) production and polarization at high energies is studied in the framework of kT-factorization approach. Our consideration is based on the non-relativistic QCD formalism for bound states formation and off-shell production amplitudes for hard partonic subprocesses. The direct production mechanism and feed-down contributions from radiative χb(mP) decays are taken into account. The transverse momentum dependent gluon densities in a proton were derived from the Ciafaloni–Catani–Fiorani–Marchesini evolution equation and Kimber-Martin-Ryskin prescription. Treating the non-perturbative color octet transitions in terms of the mulitpole radiation theory, we extract the corresponding non-perturbative matrix elements for Υ(nS) and χb(mP) mesons from a combined fit to Υ(nS) transverse momenta distributions measured by the CMS and ATLAS Collaborations at the LHC energies √s=7 and 13 TeV and from the relative production rate R(χb(nP)/Υ(nS)) measured by the LHCb Collaboration at √s=7 and 8 TeV. Then we apply the extracted values to investigate the polarization parameters λθ, λφ and λθφ, which determine the Υ(nS) spin density matrix. Our predictions have a good agreement with the currently available data within the theoretical and experimental uncertainties.

**Revisiting the production of J/psi pairs at the LHC**

***Andrei Prokhorov (Lomonosov Moscow State University)***

We consider the prompt double J/ψ production in pp collisions at the LHC in the framework of kT-factorization QCD approach. Using the fragmentation mechanism, we evaluate the color octet contributions to the production cross sections taking into account the combinatorial effects of multiple gluon radiation in the initial state driven by the Ciafaloni–Catani–Fiorani–Marchesini evolution equation. We demonstrate the importance of these contributions in a certain kinematical region covered by the CMS and ATLAS measurements. On the other hand, the experimental data taken by the LHCb Collaboration at forward rapidities and moderate transverse momenta can be described well by O(α4s) color singlet terms and contributions from the double parton scattering mechanism. The extracted value of the effective cross section is compatible with many other estimations based on different final states.