UPC2025: The second international workshop on the physics of Ultra Peripheral Collisions

Monday 9 June 2025 - Friday 13 June 2025

Saariselkä, Finland

Book of Abstracts

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Negative flow as a signature of microscopic collective flow

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It is not understood how collective flow can occur in low-multiplicity systems such as minimum-bias proton-proton collisions. The problem is that these system appears to be too short lived to form equilibrated matter. To understand flow in these systems and the flow observed by ATLAS for UPC events, one typically need a flow mechanism that is not equilibrated.

In this talk, I discuss low-multiplicity flow mechanisms from two distinct microscopic models: one based on repulsion between string-like fields and another based on effective kinetic theory. The main goal is to demonstrate that both flow mechanisms can for low-multiplicity systems produce anisotropies where the elliptic flow is negative –this is opposite to hydrodynamic flow, where the elliptic flow is positive. We therefore think that this is a unique fingerprint of these mechanisms and propose to search for this signature.

If the microscopic origin of the collective flow can be determined, then we foresee that one can use this to perform in-situ studies of the strong nuclear interactions in any high-energy collision system that exhibits collective flow, i.e., to map out these collisions.

The talk will be based on the preprint: https://arxiv.org/abs/2409.16093.

Exclusive processes and small-x physics / **6**

Nuclear suppression in diffractive vector meson production within the color glass condensate framework

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Diffractive vector meson production is a golden channel in the search for gluon saturation. The color glass condensate (CGC) framework has been successfully applied to describe diffractive vector meson production in $e+p$ collisions at HERA. Predictions for $\gamma+Pb$ collisions realized in ultraperipheral collisions at the LHC are however overestimating the experimental data at large center of mass energy, implying that the calculated saturation effects are not strong enough to describe the nuclear suppression. In this work we perform a combined Bayesian analysis of J/ψ production data from both $\gamma+p$ and $\gamma+Pb$ collisions within the CGC framework based on an impact parameter dependent McLerran-Venugopalan model combined with JIMWLK evolution to describe the center of mass energy dependence. The combined fit confirms the challenges of the framework to describe both $\gamma+p$ and $\gamma+Pb$ data simultaneously hinting at shortcomings of the framework. We discuss major sources of uncertainty and suggest possible solutions including model extensions. We further present predictions for intermediate systems such as $\gamma+O$ collisions whose measurement in UPCs could provide further insight into the A dependence of the J/ψ production cross section.

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Collectivity in UPC and p+A collisions

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I will review the status of our understanding of collectivity in ultra peripheral heavy ion and p+A collisions.

New directions in UPCs, connection to heavy-ion physics, and synergies with EIC and other facilities / **9**

Probing QCD Collectivity over the Widest Rapidity Gap in Photonuclear Collisions at CMS

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Understanding collectivity in small systems like proton-proton and proton-ion collisions remains a key challenge in heavy-ion physics. Recent LHC studies show signs of collectivity in high-multiplicity photonuclear collisions, where a quasi-real photon from one nucleus interacts with the other nucleus. In this talk, we present CMS measurements of two- and multi-particle correlations from photonuclear collisions using PbPb data at $\sqrt{s_{NN}} = 5.36$ TeV collected during the LHC Run 3. By leveraging the full detector acceptance, we explore wide pseudorapidity gaps up to 7–8 units, correlating particles in the central tracker with the Hadron Forward (HF) detector, which significantly reduces non-collective contributions and enhances the search for long-range near-side ridge effects.

Elliptic and triangular azimuthal anisotropies are extracted as functions of particle transverse momentum and event multiplicity. Furthermore, the first measurements of four-particle azimuthal correlations in high-multiplicity events are presented, offering a direct probe of collective effects. These results provide key insights into collectivity in photonuclear collisions and shed light on the potential conditions for QGP formation in small systems.

Overview / **10**

Experimental overview on UPC results at STAR

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Experimental overview on UPC results at STAR.

Exclusive processes and small-x physics / **11**

Probing nuclear gluon distributions via coherent J/Ψ and $\Psi(2S)$ photoproduction in ultraperipheral PbPb collisions at CMS

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Ultraperipheral collisions (UPCs) of relativistic heavy ions provide a unique laboratory for studying photon-induced reactions due to their intense photon flux. Vector mesons, such as J/Ψ and $\Psi(2S)$, can be produced via γ + A interactions, offering a powerful tool for probing the gluonic properties of the target nucleus. The J/Ψ and $\Psi(2S)$ mesons introduce distinct hard scales, providing unique capabilities for exploring QCD phenomena at different energy scales. In this talk, we present new results of coherent charmonium photoproduction spanning over a wide rapidity coverage in PbPb UPCs with $\sqrt{s_{\rm NN}} = 5.36$ TeV data taken with the CMS experiment during the LHC Run 3. This measurement represents a significant increase in statistics and improved $\Psi(2S)$ detection. The $\Psi(2S)$ are reconstructed from both the J/Ψ + dipion channel, and the dilepton channel, and the J/Ψ are reconstructed from the dilepton decay channel. These results include precise measurements of the coherent photoproduction cross sections for both J/Ψ and $\Psi(2S)$ over the full 0 < |y| < 2.4 region, and exploit the forward neutron tagging technique to resolve the photon-emitter and target ambiguity. The expanded pseudorapidity coverage enables a more comprehensive exploration of the nuclear gluonic structure over a broad range of Bjorken-x values.

Exclusive processes and small-x physics / **12**

Gluon saturation effects in exclusive heavy vector meson and in $c\bar{c}$, $b\bar{b}$ photoproduction

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We study exclusive J/Ψ, Υ, $b\bar{b}$ and $c\bar{c}$ photoproduction for proton and Pb targets in the high-energy limit, with the energy dependence computed using the linear Balitsky-Fadin-Kuraev-Lipatov and the nonlinear Balitsky-Kovchegov evolution equations. The difference between these two evolution equations can be directly attributed to gluon saturation physics. We find that for proton targets there is no difference between the two approaches at the energies of the currently available data, while for Pb targets data shows a clear preference for the evolution with gluon saturation.

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Partonic structure of nuclei from UPCs

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We will present an overview of theoretical and phenomenological studies on the partonic structure of nuclei and small-x dynamics of QCD using photon-nucleus scattering in UPCs. In particular, we review implications of exclusive charmonium and inclusive dijet production in Pb-Pb UPCs at the LHC as well as discuss the potential of new measurements of diffractive dijet and inclusive heavy quark production.

Exclusive processes and small-x physics / **16**

Finite-size effects in color-glass condensate and implications for exclusive vector meson production in ultra-peripheral collisions

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The gluon density in protons and nuclei has been observed to increase very rapidly with energy. At high energies, however, nonlinear effects of QCD start to become important, slowing down the evolution of the gluon density and hence giving rise to gluon saturation. This gluon saturation can be naturally described using the color-glass condensate (CGC) effective field theory.

In practice, descriptions using CGC often employ the so-called infinite-target limit which neglects the dependence on the impact parameter in the collision. In this talk, I will discuss the effects of including a finite size for the target and focus especially on exclusive vector meson production in ultra-peripheral collisions [1]. I will show that neglecting the impact parameter can lead to misleading predictions for protons, while for large nuclei the effect is much smaller.

[1] Heikki Mäntysaari, Jani Penttala, Farid Salazar, Björn Schenke, arXiv:2411.13533 [hep-ph]

Photon-photon physics, precision tests of SM and BSM / 18

Probing the photon Wigner distribution with dilepton production in UPCs

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In recent years, the description of lepton-pair production in ultra-peripheral collisions (UPCs) of heavy nuclei has attracted significant attention, particularly with the release of new RHIC data. The description of this process can be achieved by introducing the so-called Wigner distribution of the photons. They are related via Fourier transform to the generalised transverse momentum dependent distributions (GTMDs), which depend on two internal transverse momenta: k_T and Δ_T. The former is the usual intrinsic transverse momentum also found in the transverse momentum-dependent distributions, whereas the latter corresponds to the (transverse) momentum transfer.
Note that if one is interested in exploring the gluonic content of nuclear matter (e.g., by considering heavy quarkonium production), the QED channel corresponds to the background of the process. Therefore, understanding the *photon* GTMDs is crucial to single out the QCD channel and probe the *gluon* GTMDs.
In this talk I will present the theoretical framework that describes UPCs of heavy ions in terms of photon GTMDs. In particular, I will address the counter-intuitive features that the presence of the two aforementioned transverse momenta generates. I will also discuss how the mass of the produced system modifies both the cross section and some of the various asymmetries that can be measured in this process, based on RHIC and LHC kinematics.

New directions in UPCs, connection to heavy-ion physics, and synergies with EIC and other facilities / 19

Measurements of Coherent J/ψ Azimuthal Asymmetry in Peripheral Pb+Pb Collisions with the CMS Experiment

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The Lorentz-boosted electromagnetic field surrounding relativistic heavy ions can be treated as a large flux of linearly polarized, quasi-real photons. The coherently photoproduced J/ψ mesons inherit the linear polarization of these photons, leading to an azimuthal asymmetry in their decay products relative to the impact parameter. This asymmetry can be estimated using the second-order event plane in peripheral heavy-ion collisions. This novel polarization-dependent observable provides new insights into the transverse spatial distribution of gluons inside large nuclei.

In this talk, we present the centrality and rapidity dependence of the $\cos 2\phi$ angular modulation of decayed muons from coherent J/ψ, measured relative to the second-order event plane in Pb+Pb collisions at $\sqrt{s_{\rm NN}} = 5.36$ TeV. We also discuss the physics implications of these findings and the opportunities offered by future LHC heavy-ion runs.

Photon-photon physics, precision tests of SM and BSM / 20

Progress in NLO calculations for gamma-gamma physics

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I will discuss the recent NLO calculations for gamma-gamma physics.

Overview / **21**

Monte Carlo event generators for UPCs and photon-mediated processes

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I will present an overview on the topic of Monte Carlo event generators for UPCs and photon-mediated processes

Monte Carlo event generators for UPCs and photon-mediated processes / **23**

Recent development on gamma gamma collisions at hadron colliders

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The LHC is not only the energy-frontier collider for parton-parton collisions, but it has proven to work as a powerful photon collider providing photon-photon collisions at center-of-mass energies never reached before. I will present results of the gamma-UPC Monte Carlo event generator [1] that can calculate any arbitrary exclusive final states produced via photon fusion in ultraperipheral collisions of protons and/or nuclei at the LHC, of relevance for novel SM measurements. The latest gamma-UPC developments and comparisons to LHC and RHIC data will be presented [2].

[1] H.-S. Shao and D. d'Enterria, JHEP 09 (2022) 248
[2] Nicolas Crepet, David d'Enterria, Hua-Sheng Shao, in preparation

Exclusive processes and small-x physics / **24**

Recent advances on the solution of the LO and NLO BK equation

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We present our recent results regarding the numerical solution of the BK equation. We discuss the solution of the NLO BK equation including the dependence on the impact parameter. We present the obtained solutions and discuss their properties.

We also discuss solutions to the BK equation formulated in the target rapidity and including the full impact parameter dependence.We utilise the solutions to predict the energy and Mandelstam-t dependence of charmonium and bottonomium production at the LHC, including a discussion of the contribution of the non-linear terms and of the possibility of using cross section ratios of excited to ground states as a signature of saturation

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Probing New Physics in UPCs: Recent results and prospects

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Over the last years, several authors have demonstrated that the study of exclusive processes in hadronic collisions provides new possibilities for the investigation of the Quantum Electrodynamics and Quantum Chromodynamics at high energies, as well as to searching for Beyond the Standard Model (BSM) Physics. In this talk, I will review the recent predictions for the production of new particles (e.g. axionlike, dark photons, charged Higgs, ...) in ultra - peripheral collisions (UPCs) and the constraints derived from current data. Finally, prospects for the next LHC runs will be discussed.

Monte Carlo event generators for UPCs and photon-mediated processes / 26

LbLatNLO: light-by-light at NLO

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In this talk I plan to discuss the next to leading order corrections to light by light scattering process in QCD+QED. Recent experimental observation of this fundamental process in ultra peripheral collision at LHC has revived the interest to precisely predict its cross-section. We discuss two radically different computational approaches, both exact in the fermion mass dependence, thus

offering a strong cross-check of our results. Our two calculations agree with each other and conclude
that including the exact fermion mass contribution typically increases the size of the NLO corrections. We also discuss the
comparison of our results with ATLAS and CMS measurements in ultra-peripheral lead-lead collisions.

Exclusive processes and small-x physics / **27**

Beyond leading-power effects in DVMP at small-x

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Deeply Virtual Meson Production (DVMP) represents a key channel for investigating BFKL dynamics and gluon saturation within nucleons and nuclei. Describing many DVMP observables requires a treatment beyond leading power. We present a systematic framework to address next-to-leading power corrections at small-x, including the saturation regime, and apply it to calculate the $\gamma^* \to M(\rho, \phi, \omega)$ impact factor, with both the incoming photon and outgoing meson carrying arbitrary polarizations. This is particularly relevant since the saturation scale at modern colliders, while entering a perturbative regime, is not large enough to prevent higher-twist effects from being sizable.

Inclusive and diffractive processes and photon, proton and nuclear structure / **29**

Coulomb Dissociation Measurement in Isobaric Collisions at $\sqrt{s_{NN}} = 200$ GeV with the STAR Experiment

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The STAR experiment collected large-statistics datasets from isobar collisions of $^{96}_{44}$Ru $+^{96}_{44}$ Ru and $^{96}_{40}$Zr $+^{96}_{40}$ Zr ions in 2018, offering a valuable opportunity to study Coulomb dissociation via Ultra-Peripheral Collisions (UPCs). Despite having identical mass numbers, these isobars exhibit distinct proton and neutron distributions, leading to variations in their charge and neutron density profiles. These differences are expected to manifest in distinct Coulomb dissociation processes, particularly in the neutron emission spectra which can be measured by the STAR Zero-Degree Calorimeters.

In this talk, we present new measurements on neutron emission from $^{96}_{44}$Ru $+^{96}_{44}$ Ru and $^{96}_{40}$Zr $+^{96}_{40}$ Zr collisions at $\sqrt{s_{NN}} = 200$ GeV. By analyzing these results, we aim to gain deeper insights into the nuclear structure properties of isobaric nuclei, including their implications for neutron skin. These findings contribute to a better understanding of the electromagnetic fields generated in heavy-ion collisions.

Exclusive processes and small-x physics / 30

Exclusive vector-quarkonium photoproduction at NLO in collinear factorisation with evolution of the generalised parton distributions and high-energy resummation

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I will report on our recent complete one-loop study of exclusive photoproduction of vector quarkonia off protons in Collinear Factorisation (CF) including the scale evolution of the Generalised Parton Distributions (GPDs). We have confirmed the perturbative instability of the cross section at high photon-proton-collision energies (W) at Next-to-Leading Order (NLO) in α_s and solved this issue by resumming higher-order QCD corrections, which are enhanced by a logarithm of the parton energies, using High-Energy Factorisation (HEF) in the Doubly-Logarithmic Approximation (DLA) matched to CF. Our NLO CF + DLA HEF results are in agreement with the latest HERA data and show a smaller sensitivity to the factorisation and renormalisation scales compared to Born-order results. Quark-induced channels via interference with gluon ones are found to contribute at most 20% of the cross section for $W_{\gamma p} > 100$ GeV. I will discuss implications for the interpretation of present and future experimental data collected at HERA, the EIC, the LHC via UPCs and future experiments and present an outlook toward extension of our study.

Monte Carlo event generators for UPCs and photon-mediated processes / 31

MC@NLO for UPCs in Sherpa

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We discuss recent developments in the Sherpa event generator with regard to UPCs. Different form factors for the photon flux for both protons and heavy nuclei are compared and finite size effects of the emitters are taken into account. We present preliminary results for jet prodcution at NLO matched to the parton shower using MC@NLO, as well as NLO QED calculations for exclusive muon-pair production at the LHC, comparing to measurements by ATLAS and CMS.

Photon-photon physics, precision tests of SM and BSM / 32

Tau-lepton pair production via di-photon fusion in ultra-peripheral heavy-ion collisions at the ATLAS detector

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In ultra-relativistic heavy-ion collisions, high rates of $\gamma\gamma$ processes occur through the interaction of the large electromagnetic fields of the heavy nuclei. For large impact parameters between the nuclei, i.e. interaction distances larger than the nuclei's radii, the di-photon interaction can be the only one taking place, leading to very clean signatures in the detector. One of the possible signatures in these ultra-peripheral collisions (UPCs) is the production of a τ-lepton pair. The outgoing τ-leptons are back-to-back in the transverse plane, which allows a precise and efficient identification. Processes beyond the Standard Model (BSM) can influence the production cross sections for this process, allowing to probe for and constrain their existence. This talk presents the most recent measurement of di-τ production in UPC-events at a centre-of-mass energy of 5.02 TeV, performed using data from the second running period (Run 2) of the Large Hadron Collider (LHC) and recorded with the ATLAS detector. Using final states where one of the τ-leptons decays involving a muon, fiducial differential cross sections for $\gamma\gamma \to \tau\tau$ production are measured for the first time and compared to currently most advanced theory predictions. Constraints on the electromagnetic moments of the τ-lepton which influence the $\gamma\tau\tau$ vertex contained in $\gamma\gamma \to \tau\tau$ production are extracted and the implications on BSM contributions discussed.

Photon-photon physics, precision tests of SM and BSM / **33**

ATLAS measurements of coincident photon induced processes in ultra-peripheral Pb+Pb collisions

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In ultra-relativistic heavy-ion collisions, the Lorentz-contracted electromagnetic fields of the ions generate intense quasi-real photon fluxes. These lead to photon-induced interactions that have been observed in ultra-peripheral collisions (UPCs), such as vector meson and lepton-pair production. The high photon flux also enables the occurrence of multiple photon-induced processes in a single collision. This talk presents the first measurement of coincident production of $\gamma\gamma \to \mu^+\mu^-$ and a ρ meson in UPC Pb+Pb collisions at 5.02 TeV and 5.36 TeV with ATLAS. Correlations between the di-muon system's properties, such as its mass, and the coincident ρ meson production rate, are also presented. These results can provide tighter constraints on photon fluxes and nuclear charge form factors, as well as insights into nuclear gluon PDFs, beyond those from inclusive ρ meson photoproduction.

Exclusive processes and small-x physics / **34**

Measurements of J/ψ in ultraperipheral Pb+Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.36$ TeV with the ATLAS detector

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The fully stripped ions used in heavy ion collisions at the LHC are an excellent source of high-energy quasi-real photons. These can interact with photons emitted by the oncoming nucleus, or with the nucleus itself, either directly in inelastic processes or diffractively via pomeron exchange. Diffractive photonuclear processes can produce exclusive vector mesons that are uniquely sensitive to the spatial and momentum structure of the nuclear parton distribution functions, as well as spatial fluctuations (hotspots). In Run 3, the ATLAS experiment utilized a low-multiplicity track trigger in heavy ions for the first time, allowing the collection of a large sample of events with a few tracks. A substantial fraction of these are sensitive to dilepton decays of vector mesons, including the J/ψ. First results on J/ψ yields, in association with various topologies of forward neutron emission will be presented using the widest continuous rapidity range available at the LHC. Discussion of important backgrounds from dissociative and multiple-UPC processes will also be provided.

Photon-photon physics, precision tests of SM and BSM / **35**

New Constraints on the Existence of Massive Monopoles in Ultra-Peripheral Heavy Ion Collisions with ATLAS

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In ultraperipheral Pb+Pb collisions, intense electromagnetic fields enable the generation of magnetic monopole pairs via the Schwinger mechanism. Due to their high ionization and unique trajectories in a solenoidal magnetic field, monopoles are expected to leave a large number of clusters in the innermost ATLAS pixel detector without associated reconstructed charged-particle tracks or calorimeter activity. This talk presents a search for monopole-pair production in ultraperipheral Pb+Pb collisions in the monopole mass range of 20–150 GeV, based on 5.36 TeV data recorded in 2023. The results are compared with a recently developed semiclassical model that includes non-perturbative cross section calculations – as well as with a recent search limits obtained by the MoEDAL Collaboration using complementary techniques.

Inclusive and diffractive processes and photon, proton and nuclear structure / **37**

Inclusive and diffractive dijet production with the ATLAS experiment

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In ultra-peripheral collisions (UPCs), emitted photons may participate in a hard-scattering process with partons within the struck nucleus, providing a clean, energetic probe of its parton distributions. This talk presents measurements of jet production in UPCs performed with the ATLAS detector using high-statistics 2018 Pb+Pb data. Events are selected using requirements on jet production and

forward neutron emission, and rapidity gaps are then used to statistically separate inclusive photo-nuclear, photo-diffractive, and two-photon hard-scattering processes. The measured photo-nuclear cross-sections are compared to theoretical models in phase-space regions where significant nuclear PDF modifications are expected but not well constrained by world data, demonstrating the potential of these data to provide a strong new constraint on nPDF effects. Additionally, measurements are performed of jet production in UPCs where neither nucleus emits forward neutrons, which may provide a novel method for probing the radial dependence of nuclear modifications within the target. Studies of jet production without forward neutron emission will also make possible the first measurement of diffractive jet photoproduction in nuclear collisions, which will provide direct input for constraining existing models.

Monte Carlo event generators for UPCs and photon-mediated processes / **38**

The STARlight Monte Carlo Event Generator

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The STARlight Monte Carlo event generator was developed more than 20 years ago and has been used extensively for the study of ultra-peripheral relativistic heavy ion collisions ever since.
STARlight can calculate cross sections for the two-photon production of dilepton pairs and single mesons and for both coherent and incoherent photonuclear production of vector mesons. The photon spectrum is calculated in impact parameter space, and the photonuclear vector meson cross section is calculated with a Glauber model. The effect of quantum-mechanical interference can be included. STARlight also generates Monte Carlo events. Most short-lived mesons are decayed within STARlight, but an interface with Pythia is used for complex decays, such as mesons with multiple final states. General photonuclear interactions can be simulated through an interface with DPM-JET. STARlight has been shown to reproduce many features of ultra-peripheral collisions quite well across a range of energies and colliding species.
An overview of the main features of STARlight will be presented, and recent updates will be discussed. Some comparison to other models will also be presented.

Photon-photon physics, precision tests of SM and BSM / **40**

Measurement of the tau anomalous magnetic moment using Ultra-peripheral collisions with the ALICE detector in Run 3 Pb—Pb data

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The anomalous magnetic moment of the tau lepton (a_τ) is a sensitive probe for the search for deviations from the Standard Model predictions and thus for new physics. This study investigates the feasibility of measuring a_τ using ultra-peripheral collisions (UPCs) at the LHC, where photon-photon interactions ($\gamma\gamma \rightarrow \tau^+\tau^-$) produce tau lepton pairs. We focus on events recorded by the ALICE detector during Run˜3 Pb—Pb data-taking. Events are selected in the decay channel where one tau decays into an electron and neutrinos, and the other decays into a charged pion, or three charged pions, and neutrinos. These samples are enhanced with decays into muons, which are inseparable in the ALICE detector. The clean environment of UPCs minimizes hadronic background, while the advanced particle identification capabilities of the ALICE Time Projection Chamber (TPC) and Time-of-Flight (TOF) systems allow for efficient separation of electrons, pions, and background

particles.
In this talk, prospects for measuring this process by ALICE in Run 3, which benefits from high statistics and improved systematics uncertainties, will be discussed. Results will provide tighter constraints on a_τ, contributing to the broader effort to test the Standard Model's robustness and explore physics beyond it.

Exclusive processes and small-x physics / **42**

Momentum transfer dependence in electronuclear production of heavy quarkonia revisited: Green function formalism

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Momentum transfer distributions $d\sigma/dt$ in diffractive electroproduction of heavy quarkonia on nuclear targets are studied within a rigorous quantum-mechanical approach based on the light-front Green function formalism [1]. Such a formalism allows to include naturally the higher-twist and leading-twist shadowing corrections, as well as
the color transparency effects. Model calculations of $d\sigma/dt$, containing also the correlation between impact parameter of a collision and dipole orientation, are tested by the recent data on charmonium production in ultra-peripheral nuclear collisions. We present also predictions for the reduced quantum coherence effects in $d\sigma/dt$ that can be verified in kinematic regions scanned by experiments at the prepared electron-ion collider.

References:
[1] J. Nemchik, J. Obertova, Phys. Rev. D 110, 054015 (2024)

Exclusive processes and small-x physics / **43**

Centrality dependence in J/Ψ Photoproduction in pp. pA and AA Collisions

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The photoproduction of J/Ψ is investigated in the coherent collisions at LHC energy (√s = 5.02 TeV), for distinct transverse momentum and centrality classes: ultra-peripheral collisions (UPC) and peripheral collisions across different event geometries. An application of the convolution between the photon flux and the photonuclear cross section is explored for UPCs. In the the peripheral regime, different centrality classes were tested (30%-50%, 50%-70%, and 70%-90%) considering an effective photon flux constraining the geometrical region of the nuclei-target . Consistently, an effective photonuclear cross section was applied. The low-x formulation for the distinct geometries, allows the compairison of three dipole models, suited for saturation. Results for both rapidity and transverse momentum distributions are presented and compared to ALICE data showing good agreement.

Exclusive processes and small-x physics / 44

Onset of gluon saturation through incoherent J/psi production at large |t|

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We predict the possibility of detecting signatures of the long-sought saturation in ultraperipheral heavy-ion collisions at currently accessible energies of the LHC. Saturation, as predicted by QCD at high energies, occurs when gluon densities in hadrons become so large that gluons begin to recombine with each other, stabilizing their population. To probe these effects, we study incoherent vector meson production, which is sensitive to fluctuations in the partonic structure of the target.
The energy-dependent Hotspot model, based on the color dipole approach, incorporates subnucleonic degrees of freedom known as hot spots. These hot spots represent regions of high gluonic density, and their positions fluctuate event by event.
Using the energy-dependent Hotspot model, we propose studying the energy dependence of incoherent photoproduction of vector mesons in diffractive processes at various values of the Mandelstam-t variable. Since t is related to the transverse distribution of color charges, analyzing its energy dependence within specific t ranges allows us to isolate fluctuations across different size scales, highlighting the hot spot contributions where saturation is expected.

Exclusive processes and small-x physics / 45

First Study of Exclusive Production of Multi-Hadron Final States in Ultraperipheral Collisions

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The exclusive photoproduction of multi-hadron final states in ultraperipheral
collisions (UPCs) provides a unique avenue to explore quantum chromodynamics (QCD) and the nature of resonances emerging from gluonic interactions.
The ALICE Collaboration has recently performed measurements of exclusive
four-pion photoproduction, revealing data that suggest the presence of two resonances. However, the underlying nature of these resonances remains poorly
understood, necessitating further investigation.
The enhanced capabilities of the ALICE detector during Run 3 open new
opportunities for the study of multi-pion final states, including six- and eight-pion systems, and processes involving charmonium decays into four-hadron final states. These studies provide an invaluable means to probe the dynamics
of highly dense gluonic matter and the interplay between resonant and nonresonant contributions in hadronic systems.
In this talk, we will outline the ALICE program focused on these analyses,
presenting initial results that leverage angular correlation studies to disentangle
the properties of the observed resonances.

Exclusive processes and small-x physics / 46

Prospects for probing generalised parton distributions in 2 to 3 exclusive processes

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In this talk, I will discuss a class of 2 to 3 exclusive processes which can be used to probe generalised parton distributions (GPDs). One of the main advantages of such exclusive processes is that they have an enhanced sensitivity to the x-dependence of GPDs, compared to standard 2 to 2 exclusive processes such as Deeply Virtual Compton Scattering (DVCS), which only give moment-type information. I will focus on the exclusive photon-meson photoproduction process, where the outgoing meson is either a ρ-meson (any charge) or a π-meson (charged only). In fact, if the outgoing meson is chosen to be a transversely polarised rho meson, then the process is directly sensitive to transversity GPDs. This case represents one of the few processes which can probe chiral-odd GPDs at the leading twist. I will discuss the results of calculations that we performed at leading order in the strong coupling constant α_s, and show that such processes deserve experimental studies. In particular, our results indicate that the process can be measured at JLab, COMPASS, LHC in UPCs and at the upcoming EIC. Due to higher energies available in collider mode, one can also focus on the study of GPDs at small skewness parameter ξ.

Inclusive and diffractive processes and photon, proton and nuclear structure / **47**

Updated Measurement of Dijet Production in Ultraperipheral PbPb Collisions with 2018 CMS Data

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Abstract: Exclusive dijet production in ultraperipheral lead-lead (PbPb) collisions has been proposed as a probe to constrain the elliptically polarized gluon distributions of heavy ions. Specifically, the second Fourier harmonic (v_2) of the angle ($\Delta\phi$) between the three-momentum vector sum ($\vec{Q}_T = \vec{p}_{T,1} + \vec{p}_{T,2}$) and vector difference ($\vec{q}_T = \vec{p}_{T,1} - \vec{p}_{T,2}$) of the two highest-$p_T$ jets has been suggested as a sensitive observable for such constraints. This analysis presents an update of the measurement using the larger 2018 PbPb dataset, improving upon the earlier study performed with the 2015 PbPb data. The updated results include a scan of the anti-k_T jet distance parameter R at values of $R = 0.2$, 0.4, and 0.6, as well as a detailed analysis as a function of the dijet transverse momentum sum (Q_T) and dijet rapidity (y_{dijet}), which are sensitive to final-state, out-of-cone gluon radiation effects. The measurement is compared to predictions from the PYTHIA8 event generator for photonuclear jets, which does not incorporate elliptically polarized gluon distributions, and the predictions are found to be in good agreement with the data.

Exclusive processes and small-x physics / **48**

Incoherent J/psi photoproduction in UPC as a probe of the sub-nucleonic structure of nuclei

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template

Inclusive and diffractive processes and photon, proton and nuclear structure / **49**

Production of π, K, p in inclusive UPC events in ALICE

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High-multiplicity proton–proton and proton–lead collisions at LHC energies feature signatures similar to those observed in Pb–Pb collisions, such as e.g. strangeness enhancement and collective expansion effects, which are traditionally attributed to the formation of the quark–gluon plasma. One way to study them is through the measurement of p_T-spectra for identified hadrons such as charged π, K and p, and the ratios of these spectra.

To date, analyses in ultra-peripheral collisions have mostly focused on exclusive photonuclear vector meson production and on two-photon interactions. However, photonuclear interactions, in which the target nucleus breaks up, also occur, and provide novel tests of collective phenomena in small systems. The p_T-spectra of identified pions, kaons and protons in these events have been measured by the ALICE experiment and compared to those obtained in other collision systems.

Monte Carlo event generators for UPCs and photon-mediated processes / **50**

Photo-nuclear collisions in Pythia 8

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We present the recent developments in simulations of ultra-peripheral collisions with the Pythia 8 Monte Carlo event generator. We first review the status of recent comparisons and tuning efforts to HERA photoproduction data which provide the baseline of photon-nucleon interactions. Then we present the vector-meson-dominance (VMD) based approach to model interactions between a real photon and a nucleus target applying the Angantyr model which provides a framework for simulate heavy-ion collisions in Pythia. We compare the simulations to recent UPC data from LHC experiments, including dijets, charged-particles and heavy-flavour mesons. In addition, we present predictions for multiplicity distributions in photo-nuclear collisions at the EIC accounting for the constraints form the UPCs.

Inclusive and diffractive processes and photon, proton and nuclear structure / 51

Inclusive D^0 photoproduction in ultra-peripheral collisions

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We compute the differential cross section for inclusive D^0 production in ultra-peripheral collisions within the Color Glass Condensate framework. Our predictions are found to be in good agreement with preliminary CMS data. Furthermore, we parametrize saturation effects by a nuclear modification ratio for photoproduction R_{pA} and examine the collinear factorization limit of the D^0 differential cross section.

Monte Carlo event generators for UPCs and photon-mediated processes / 52

Dijet Photoproduction in POWHEG-Box

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Photoproduction processes have gained a renewed interest following the approval of the EIC, making their implementation in Monte Carlo event generators highly desirable. I will present recent efforts to develop a POWHEG-BOX extension simulating dijet production from direct and resolved photons at NLO, leveraging the Weizsäcker-Williams Approximation. Its wide-ranging applicability will enable event generation for collisions involving leptons, protons and heavy ions. Thus, it will be particularly useful for the study of ultra-peripheral collisions (UPCs) and for making predictions relevant to the EIC.

Photon-photon physics, precision tests of SM and BSM / 57

azimuthal modulation in photon-induced processes

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Photon-induced processes in ultra-peripheral collisions have attracted considerable attention in recent years due to their potential to probe various aspects of nuclear and particle physics. A key feature of these processes is the azimuthal modulation of particle production, which provides critical insights into the underlying dynamics of interactions involving quasi-real photons. In this talk we will explore the mechanisms behind azimuthal asymmetries observed in photon-induced processes, with a particular focus on their dependence on kinematic variables such as transverse momentum and rapidity. Based on a series of our recent studies, we analyze the origins of azimuthal

modulations in photon-induced reactions, present a unified framework for understanding how these asymmetries emerge from the linearly polarized photon, the final-state soft photon radiation, and the Fermi-scale double-slit interference effect. By examining a range of observables, including di-lepton production, di-jet production, vector meson production, and di-photon production, we either provide predictions for future experiments, or provide theoretical calculations consistent with current experimental measurements.

Photon-photon physics, precision tests of SM and BSM / 60

From photons to dikaon - Theoretical Insights into K^+K^- Production in Nuclear Collisions

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Kaon pairs can be produced via photoproduction (γ-Pomeron) or photon-photon fusion ($\gamma\gamma$). A significant contribution to kaon pair production comes from the decay of scalar, tensor, and vector mesons. The study will provide a comprehensive description of dikaon production at both the elementary ($\gamma\gamma \to m \to K^+K^-$) and nuclear ($PbPb \to PbPbK^+K^-$) levels. The cross section for $\gamma\gamma$ fusion describes results from Belle, TPC/Two-Gamma and ARGUS experiments.

The latest ALICE data [1], which presents measurements of dikaon at midrapidity, unfortunately, does not provide experimental data for the dominant contribution, i.e. contribution from the decay of the $\phi(1020)$ meson. However, a Breit-Wigner distribution incorporating the decay of this resonance has been applied to describe the continuum component. This study aims to provide results across a broader range of kinematic variables and extend the analysis to additional decay channels.

The presentation will include a comparison of theoretical predictions with existing experimental data [1] (in midrapidity region), and provide predictions for the so-called forward range.

[1] ALICE Collaboration, S. Acharya et al., Phys.Rev.Lett. 132 (2024) 22, 222303

Exclusive processes and small-x physics / 61

Exclusive photoproduction of a photon-pion pair in a saturation framework

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The Large Hadron Collider (LHC) has paved the way for an increasingly deeper understanding of hadronic structure. Particularly exciting is the potential to exploit the high center-of-mass energies to investigate gluon saturation in nuclei and nucleons through Ultra Peripheral Collisions (UPC).

We consider the exclusive photoproduction of a photon-pion pair, $\gamma+P \to \gamma+\pi^0+P$, as a promising channel to study gluon saturation. Furthermore, it has recently been demonstrated that this process does not admit a collinear factorization in terms of generalised parton distributions (GPDs) at the leading twist. In such a situation, a (generalized) k_T-dependent factorization, reliable at small-x, is a valid option, since the end-point singularities are naturally regularized by the transverse momenta of the t-channel gluons. The numerics from our analysis indicate that this process could be measured in UPCs at the LHC.

Photon-photon physics, precision tests of SM and BSM / 62

Observation of π+π−π+π− and π+π− final state photoproduction in ultraperipheral heavy-ion collisions at √sNN = 200 GeV at the STAR detector

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One of the most pressing questions in both hot and cold QCD communities is what the physics mechanism responsible for modified parton densities in heavy nuclei is. One promising channel to address this question is the photoproduction of vector mesons, which is considered a clean probe to the nuclear parton structures.
We present a measurement of $\pi^+\pi^-\pi^+\pi^-$ and $\pi^+\pi^-$ photonuclear production in ultraperipheral Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The data were collected in 2014 by the STAR experiment. The $\pi^+\pi^-\pi^+\pi^-$ and $\pi^+\pi^-$ final states, accompanied by mutual excitation of projectile and target, are observed to be greatly enhanced at low transverse momentum, which is consistent with coherent photoproduction. The $\pi^+\pi^-\pi^+\pi^-$ invariant mass spectrum in coherent events exhibits a two-resonance structure around ~ 1.5 and ~ 1.7 GeV/c^2 with widths of around 0.50 and 0.45 GeV/c^2, likely corresponding to $\rho(1450)$ and $\rho(1700)$. Furthermore, a peak corresponding to $\rho(2150)$ is observed. We also observe peaks corresponding to $\rho(1450)$ and $\rho(1700)$ in the $\pi^+\pi^-$ final state and report the ratio of the branching fractions of the $\rho(1450)$, $\rho(1700)$ to $\pi^+\pi^-$ and $\pi^+\pi^-\pi^+\pi^-$. We also present the ratios of $\rho(1450)$, $\rho(1700)$, and $\rho(2150)$ to $\rho_0(770)$ coherent production cross sections. Further, we present the status on the analysis of $\pi^+\pi^-\pi^+\pi^-$ polarization.

Exclusive processes and small-x physics / 63

Probing generalised parton distributions in exclusive meson-meson production

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In this talk, I will focus on an interesting subclass of 2 to 3 exclusive processes, in which a pair of light mesons of large invariant mass is produced through photoproduction. These processes provide access, at leading power, to both chiral-even and chiral-odd quark generalised parton distributions (GPDs), depending on the nature and on the polarisation of the mesons. For the final-state mesons,

all combinations of ρ (both longitudinal and transverse polarisations) and π mesons are considered; however, those processes (e.g. exclusive $\pi^+\pi^-$ photoproduction) that are sensitive to two-gluon exchanges in the t-channel are excluded from our analysis since they have been shown to be inconsistent with a collinear factorisation approach due to the presence of pinched Glauber exchanges. Nevertheless, even after this restriction, a wide range of different channels remain available for study. Detailed results will be presented in the kinematics of JLab, COMPASS, LHC in UPCs, as well as at the upcoming EIC.

New directions in UPCs, connection to heavy-ion physics, and synergies with EIC and other facilities / 65

Photonuclear production of strange particles in ultra-peripheral Pb–Pb collisions with ALICE

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In this study, the production of strange particles is investigated in ultra-peripheral Pbndash;Pb collisions (UPCs) at $\sqrt{s_{\mathrm{NN}}}$ = 5.36 TeV, using data from the ALICE experiment at the LHC. The analysis focuses on selecting photo-nuclear reactions, where a quasi-real photon emitted by the fully ionized nucleus either acts as a point-like particle interacting with a parton in the target nucleus or fluctuates into a vector meson that interacts with the nucleus or parton through the strong interaction. These collisions are characterized by a rapidity boost of the center-of-mass frame in the direction of the target nucleus, creating a rapidity gap on the opposite side, referred to as single-gap topology.

Due to the large impact parameter in such collisions, hadronic interactions are suppressed, allowing charged hadron yields, particularly those of strange particles, to serve as sensitive probes for studying the interplay between hadronic and electromagnetic interactions. By examining the baryon-to-meson ratio, specifically the $\Lambda/\mathrm{K}^0_\mathrm{S}$ yield ratio as a function of transverse momentum (p_T), this analysis aims to distinguish between cold nuclear matter effects and those associated with the formation of quark-gluon plasma (QGP) droplets.

The recent upgrades of the ALICE detector for Run 3, including continuous readout and enhanced tracking systems, significantly improve strange particle identification, especially at low transverse momentum. With a substantially higher interaction rate, ALICE has already collected approximately 40 times more minimum bias events in Run 3 than in Runs 1 and 2 combined. This large dataset provides new opportunities to advance our understanding of UPC physics, strangeness production, and the potential emergence of collective behavior in photo-nuclear interactions.

Monte Carlo event generators for UPCs and photon-mediated processes / 66

Describing UPC data with the Sartre event generator

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We present a comprehensive comparison with the Sartre event generator and available exclusive diffraction data from UPC of heavy ions. Sartre now takes all phenomena unique to UPC into account, i.e. interference effects, neutron emissions due to secondary and tertiary photon interactions, as well as a photon pt, paired with a reliable saturated small-x QCD model (IPSat). This enables us to

use UPC data to constrain parameters of the initial state, such as the Woods-Saxon parameters and the nucleon thickness function, including nucleon substructure. We also use an interpolation to a large-x parametrisation in order to describe final states at the largest and smallest rapidities, which are mixed states of small and large x phenomena, enabling us to describe the entire rapidity and W spectra.

Photon-photon physics, precision tests of SM and BSM / **67**

Investigating Entanglement Enabled Spin Interference in photonuclear $\rho^0 \rightarrow \pi^+\pi^-$ and $\gamma\gamma \rightarrow \pi^+\pi^-$ in Au+Au collisions at STAR

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In ultraperipheral collisions, the invariant mass spectrum of $\pi^+\pi^-$ pairs is very complex due to the numerous production channels and intermediate states. The quantum ambiguity between production channels, referred to as the Entanglement Enabled Spin Interference (EESI) effect, leads to angular anisotropy in the final state. The most dominant contribution to the invariant mass spectrum of $\pi^+\pi^-$ is $\gamma A \rightarrow \rho^0(770) \rightarrow \pi^+\pi^-$, but other photonuclear (γA) and light-by-light ($\gamma\gamma$) channels also must be considered. EESI between the $\gamma\gamma$ and γA channels is expected to produce $A_{1\Delta\phi}$ and $A_{3\Delta\phi}$ signals. This new window into hadronic light-by-light production may provide new theoretical constraints on the anomalous magnetic moment of the muon, where the hadronic light-by-light contribution is one of the largest uncertainties.

In this talk, the first measurement of EESI between photonuclear and light-by-light production of $\pi^+\pi^-$ pairs, including the strong EESI signal associated with the $f_2(1270)$ resonance, will be presented. The EESI observables are then used to isolate $\gamma\gamma \rightarrow \pi^+\pi^-$ in ultraperipheral $Au + Au$ collisions at $\sqrt{s_{NN}} = 200$ GeV.

Exclusive processes and small-x physics / **69**

Phi(1020) production in Ultra-peripheral Collision events measured at LHCb.

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So far, UPC measurements have been restricted to hard processes like quarkonia and jets. LHCb is capable of measuring low-mass vector mesons like rho and phi(1020), which access low Qˆ2 and Bjorken-x gluons in gamma-pomeron processes. These processes provide a better probe into the expected gluon-saturation regime in the nucleus. This talk will present the status of the phi(1020) analysis at LHCb, and perspective on probing the existence of gluon saturation.

Exclusive processes and small-x physics / **70**

Probing the Nuclear and Electromagnetic Structure of Heavy Nuclei at STAR

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Diffractive vector meson photoproduction has long been recognized as an unparalleled probe of the gluon distribution within nuclei, potentially key to elucidating non-linear QCD effects that lead to universal states of dense gluonic matter. ϕ meson photoproduction is particularly useful for studying small-x dynamics, especially gluon saturation, due to its sensitivity to larger dipole sizes compared to, for example, J/ψ and other heavy vector mesons. Compared to the ρ^0 meson, the ϕ meson has a longer lifetime and a larger mass, making it more amenable to theoretical investigation. For these reasons, the measurement of ϕ meson photonuclear production in A+A collisions has been long anticipated. In this talk, we present the measurement of exclusive diffractive photonuclear production of the ϕ meson via the K^+K^- decay channel from Au+Au collisions. We utilize this newly obtained measurement to compare theoretical calculations incorporating gluon saturation effects across orders of magnitude in dipole size, thereby illuminating the small-x gluon distribution within nuclei.

Just as diffractive vector meson production has been employed in high-energy collisions to probe the spatial distribution of gluons within the nucleus, it has recently been demonstrated that photon-photon interactions enable mapping of the photon Wigner distribution within heavy nuclei—a multidimensional image of the electromagnetic fields of high-energy nuclei. To this end, we present the measurement of $\gamma + \gamma \to e^+e^-$ from U+U collisions at $\sqrt{s_{NN}} = 193$ GeV and investigate various approaches for constraining the nuclear (electromagnetic) structure of uranium.

Exclusive processes and small-x physics / **71**

Transverse momentum dependent factorization in the target fragmentation region at small-x

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We consider the differential cross-section for single-inclusive jet production with transverse momentum P⊥ in Deep Inelastic Scattering (DIS) at small Bjorken xBj, mediated by a virtual photon with virtuality Q2. We focus on the kinematic regime where the jet is produced in the target fragmentation hemisphere of the Breit frame, and with P⊥ ≪ Q. For a longitudinally polarised photon, we demonstrate that this cross section is not power of P⊥/Q suppressed and we derive a factorized expression in terms of transverse momentum dependent (TMD) quark and gluon fracture functions. Our formula, valid at next-to-leading order in αs at small x, is akin to the Altarelli-Martinelli identity for the longitudinal DIS structure-function. Numerical estimates show that the quark TMD fracture function is the most sensitive to saturation effects in large nuclei.

Overview / **72**

Experimental overview on UPC results from ALICE

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The ALICE Collaboration has extensively studied coherent and incoherent J/ψ photoproduction, as well as coherent ψ' in ultra-peripheral Pb-Pb collisions using the Run 2 data set, including results from exclusive and dissociative J/ψ mesons in ultra-peripheral p-Pb interactions, together also with the $|t|$-dependence of (in)coherent J/ψ. These measurements, which studied exclusive charmonia photoproduction as a function of e.g. energy, Bjorken-x, rapidity, and neutron emission, provide unique insights into the initial state of protons and ions, with great sensitivity for both gluon saturation and shadowing. The ALICE Collaboration has also carried out various measurements of different final state systems, such as exclusive four pion photoproduction as well as photoproduction of KK pairs, measured for the first time in ultra-peripheral collisions, and even the measurement of the impact-parameter dependence of coherent ρ^0 production. Finally, we will discuss the prospects for these and new measurements using the Run 3 and Run 4 data.

Exclusive processes and small-x physics / **73**

First measurement on the energy and Mandelstam-t dependence of both coherent and incoherent J/Ψ photonuclear production

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A new phenomenon, gluon saturation, is expected to appear at high energies in QCD, where the splitting and production of gluons achieve a dynamic balance. Gluon saturation is expected to appear at lower energies in large nuclei. Due to its high sensitivity to the gluon distribution, the diffractive photoproduction of J/Ψ is an ideal tool to search for the onset of gluon saturation.

ALICE has a unique coverage of the photon-nucleon centre of mass energy, ranging from 20 GeV to 800 GeV, to study the energy dependence of this process with a single detector over three orders of magnitude of Bjorken-x from around 10-2 to 10-5.

In this talk, we will review the latest ALICE result on the energy dependence of coherent J/Ψ production, which samples the average gluon distribution in Pb, and present the new results on the energy dependence of incoherent J/Ψ production at different Mandelstam-t, which samples the variance of the gluon distribution at different size scales as Bjorken-x decreases. These results test the current models of the high-energy limit of QCD in an unprecedented way.

Inclusive and diffractive processes and photon, proton and nuclear structure / **74**

Inclusive UPC charm photoproduction in ALICE

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Inelastic photoproduction of charm has been used previously to constrain the proton gluon distribution at low-x, using e-p collisions. Ultra-peripheral heavy-ion collisions provide an opportunity

to use the same mechanism to study the less known nuclear gluon distribution. In these collisions, a photon emitted from one nucleus interacts with a gluon in the target nucleus, producing a pair of charm anti-charm quarks. These fragment to open- or hidden-charm hadrons, which are reconstructed. The cross sections and transverse momentum distributions for D mesons and J/psi will be presented, and the results compared to model calculations.

Inclusive and diffractive processes and photon, proton and nuclear structure / **75**

Inclusive quarkonium photoproduction at the LHC

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We demonstrate that hadron-hadron collisions at the LHC can be used to extract inclusive photoproduction cross sections. We focus on quarkonium cross sections in proton-lead collisions. We illustrate this by constructing a Monte Carlo for both the signal and background and show that, despite the background having a significantly larger cross section, the signal can be experimentally disentangled by characterising the hadronic activity in the (i) central, (ii) forward, and (iii) far-forward detectors. We find that the resulting cross sections are large enough to be measured at all four of the main LHC experiments. We estimate the background-to-signal ratio after isolation to be of the order of 0.001 and 0.1 in the low and large transverse-momentum regions, respectively. The range of accessible photon-nucleon centre-of-mass energies, $W_{\gamma p}$, at the LHC largely exceeds what has and will be studied at lepton-hadron colliders, HERA and the EIC. As a result, the available kinematics in inclusive photoproduction measurements are broader: the J/ψ P_T spectrum can be extended from 10 GeV (HERA data) to 20 GeV. In addition, we propose and assess the Jacquet-Blondel method to reconstruct the photon-nucleon centre-of-mass energy and the fractional energy of the quarkonium with respect to the photon.

Photon-photon physics, precision tests of SM and BSM / **76**

Impact of inelastic corrections on $\gamma\gamma \to \gamma\gamma$ scattering from UPC at the LHC

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The current state of art estimations lead to cross sections
for $AA \to \gamma\gamma AA$ which are somewhat
smaller than the measured ones by the ATLAS and CMS Collaborations.
We calculate inelastic contribution to $\gamma\gamma \to \gamma\gamma$
scattering process in $AA \to \gamma\gamma XY$ where $X, Y = A, A'$.
We include processes of coupling of photons to individual nucleons
(protons and neutrons) in addition to coherent coupling to the
whole nuclei (call standard approach here).
Both elastic (nucleon in the ground state) and inelastic
(nucleon in an excited state) in the couplings of photons to nucleons
are taken into account. The inelastic nucleon fluxes are calculated
using CT18qed photon PDFs. The inelastic photon fluxes are
shown and compared to standard photon fluxes in the nucleus.
These new mechanisms are related to extra emissions that are rather

difficult to identify at the LHC.
The considered here new contributions can be mistakenly interpreted
as enhanced $\gamma\gamma \to \gamma\gamma$ scattering
compared to the Standard Model result.
We find corrections to the traditional (no nuclear excitation)
contribution $AA \to AA\gamma\gamma$. We find the inelastic
contributions to be 10-15 \% of the standard one.
In addition, we show the ratio of the inelastic corrections to
the standard contribution as a function of diphoton invariant mass
and photon rapidity difference. We find the maximal effect of the inelastic
corrections at $M_{\gamma\gamma} \sim 14$ GeV for the ATLAS
rapidity and transverse momentum acceptance.
Furthermore, the inelastic contribution increases gradually with photon
rapidity difference.

Overview / **77**

Overview of different approaches to exclusive production at small x

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Exclusive processes in high energy collisions can be described in terms of either a collinear factorization or a dipole approach. While these approaches have a common limit, they also differ in many ways. For example one can consider it more important to resum large logarithms of either transverse or longitudinal momenta. There can also be different views about whether the dominant transverse size of the interacting partonic configuration is in the strong or weak coupling regime, and whether its interaction with the target involves interactions with more than two gluons. In the latter case one has an interpretation of the scattering process in terms of gluon saturation. In addition to these aspects, this talk will also discuss using exclusive processes to understand the transverse geometry of gluons in the target.

Exclusive processes and small-x physics / **78**

Coherent J/psi photoproduction in AA collisions with nuclear overlap

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This talk will discuss the experimental results of ALICE, LHCb and STAR collaborations.

New directions in UPCs, connection to heavy-ion physics, and synergies with EIC and other facilities / **79**

Nucleon energy correlator for the odderon

Authors: Heikki Mäntysaari[1]; Yossathorn Tawabutr[1]; Xuanbo Tong[1]

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In this talk, I will present our investigation of the T-odd nucleon energy correlator at small-x and elucidate its connection with spin-dependent odderons. The probe of this nucleon energy correlator involves measuring a single transverse spin asymmetry for the energy pattern in the deep inelastic scattering. We demonstrate that this asymmetry can be served as a clean and sensitive observable for unveiling odderon dynamics at the future electron-ion collider.

Exclusive processes and small-x physics / **80**

Coherent J/psi photoproduction in AA collisions with nuclear overlap from RHIC to LHC energies: theory perspective

Author: Wangmei Zha[1]

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Coherent J/ψ photoproduction in heavy-ion collisions has emerged as a sensitive probe of both the initial-state gluonic structure of nuclei and the dynamical electromagnetic fields generated by relativistic ions. While traditionally studied in ultra-peripheral collisions (UPCs), recent experimental observations by ALICE and STAR collaborations reveal surprising enhancements in low-p_T J/ψ yields in AA collisions with significant nuclear overlap—challenging the assumption that coherent photonuclear processes vanish in hadronic collision regimes. This talk presents a comprehensive theoretical framework to address the survival of coherent J/ψ photoproduction in overlapping AA systems across RHIC and LHC energies. Furthermore, we will delve into an in-depth discussion and critical review of the implications and applications stemming from the linear polarization effects intrinsic to this photoproduction mechanism.

Discussion sessions / **81**

Discussion session: UPCs at the start of EIC running

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The EIC is set to start running around the same time as LHC Run 5. What could be the synergies between EIC and LHC UPC measurements at this time. The EIC is a wonderful machine for studying multidimensional correlations between partons. At the same time the LHC will have greatly expanded detector capabilities that should allow a new era of UPC measurements. I will attempt to sketch these twin capabilities in the hope of starting fruitful discussions on the complementarity of the two machines.

New directions in UPCs, connection to heavy-ion physics, and synergies with EIC and other facilities / **82**

Search for Collectivity in Photo-nuclear Processes at RHIC using STAR Detector

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Investigating collective behavior due to the formation of a fluid-like medium in small collision systems has been a significant focus in the field. A tell-tale signature of this would be the medium's response to the initial state in small collision systems, as predicted by fluid-dynamic models.

Recent RHIC studies of small systems have shown a hierarchy of elliptic anisotropy coefficients (v_2 ^{3}He+Au) $\sim$ v_2(d+Au) $>$ v_2(p+Au)) suggesting fluid-dynamic behavior even in the smallest systems. This raises the question: could a photo-nuclear collision, such as γ+Au also exhibit signatures of collectivity? Notably, signatures of collectivity have been investigated in high-multiplicity, high energy γ+p/Pb collisions at the LHC.

In this work, we explore anisotropic flow in γ+Au processes at RHIC by triggering ultra-peripheral Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. At this collision energy, the maximum photon-nucleon center of mass energy $W_{\gamma N}^{\max} \approx 34.7$ GeV [1], an energy between d+Au collisions at $\sqrt{s_{NN}}$ = 19 GeV and $\sqrt{s_{NN}}$ = 39 GeV, previously performed at RHIC. For both γ+Au and d+Au collisions, a similar multiplicity range is accessible at STAR, making d+Au a suitable baseline system for comparison. Furthermore, the STAR detector's extended rapidity coverage, with mid and forward rapidity upgrades ($|\eta| < 1.5$ and $2.1 < |\eta| < 5.1$) enables the triggering and analysis of photo-nuclear processes. Preliminary measurements of v_2 and v_3 in γ+Au collisions have been conducted at multiplicities and energy levels comparable to those observed in d+Au collisions, where collective behavior has already been established. These results will provide new insights into collectivity in small collision systems, emphasizing the role of initial-state effects and collective behavior in understanding the evolution of the fluid-like medium created in various collision systems at RHIC.

References:
[1] A.J. Baltz et al, The physics of ultraperipheral collisions at the LHC, *Physics Reports*, 458(1):1–171, 2008.

New directions in UPCs, connection to heavy-ion physics, and synergies with EIC and other facilities / **84**

FoCal in ALICE

Authors: ALICE Collaboration[None]; Sami Sakari Rasanen[1]

[1] *University of Jyvaskyla (FI)*

The new forward calorimeter, FoCal, extends the ALICE physics programme with the capability, unique at the LHC, of investigating gluon parton distribution functions (PDFs) down to Bjorken-x of˜10ˆ-6. In this kinematic range, the gluon distributions are expected to behave non-linearly.

FoCal is a high-granularity forward calorimeter to be installed as an ALICE upgrade subsystem during the LHC Long Shutdown 3 and take data during the LHC Run 4. It consists of a compact silicon-tungsten sampling electromagnetic calorimeter (FoCal-E) with pad and pixel readout layers to achieve high spatial and energy resolutions and a hadron calorimeter based on copper capillary tubes read out using scintillator fibres (FoCal-H).

FoCal is optimized for reconstructing direct photons, however, other measurements are foreseen as well. Focal will be able to measure the photo-production cross sections of vector mesons in a wide energy range in photon-proton and photon-lead collisions.

In this presentation we will discuss projected detector performance studies for the main physics observables foreseen to be made with the data expected to be recorded during Run-4 with a focus on the photo-production measurements in p-Pb and Pb-Pb ultra-peripheral collisions.

Photon-photon physics, precision tests of SM and BSM / 85

Measurements of proton-antiproton pairs from QED vacuum excitation in Au+Au ultra-peripheral collisions at $\sqrt{s_{\rm NN}} = 200$ GeV from STAR

Authors: Xin Wu[1]; Xinbai Li[1]

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Relativistic heavy-ion collisions generate extremely strong electromagnetic (EM) fields, providing an ideal environment to study the EM excitation of the vacuum. The Breit-Wheeler process, which involves the electron-position pair production via photon-photon interactions, represents the lowest-order decay mode of the QED vacuum excitation. This process was first observed by the STAR experiment in 2021, and has stimulated further exploration into higher-order decay modes, including hadron-antihadron pair production.

In this presentation, we will report the first measurement of proton-antiproton pairs resulting from QED vacuum excitation in Au+Au ultra-peripheral collisions at $\sqrt{s_{\rm NN}} = 200$ GeV by the STAR experiment. The pairs' invariant mass distributions (from $M_{p\bar{p}}$ = 2.1 to 2.4 $\mathrm{GeV/c^2}$), transverse momentum $p_{\rm T}$ spectra, and the azimuthal angular modulation caused by the polarized EM field will be presented. The measured results will be compared with theoretical calculations. These measurements will shed new light on the understanding of the QED vacuum.

New directions in UPCs, connection to heavy-ion physics, and synergies with EIC and other facilities / 86

UPC Collectivity measurements

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Ultraperipheral collisions (UPCs) of relativistic heavy ion beams lead to a diverse set of photon-nucleus (photonuclear) interactions. Measurements of particles produced in photonuclear reactions can shed light on the QCD dynamics of these novel, extremely asymmetric colliding systems, with energies between those available at RHIC and the LHC. Previous studies by ATLAS have characterized γ+Pb photonuclear collisions through inclusive charged hadron measurements [1], and have observed elliptic and triangular flow coefficients in these events [2]. Previous studies by CMS have also explored the possibility of the collectivity signals in γ+p interactions [3].

This talk will present the potential formation of collective behavior in photonuclear collisions with a particular emphasis on observables sensitive to radial flow, enhanced baryon-to-meson ratios, and strangeness enhancement. The yields of charged hadrons and, for the first time, identified strange hadrons (K^0_S, Λ, and Ξ) are studied differentially in rapidity, transverse momentum, and event multiplicity. These results utilize high-multiplicity photonuclear collisions using 5.02 TeV Pb+Pb data collected by ATLAS in 2018 and are compared to 5.02 TeV p+Pb ATLAS data from 2016, at the same event multiplicities. Additionally, the findings are compared with calculations from DPMJET and hydrodynamic-based models predicting flow even in these ultraperipheral collisions.

[1] ATLAS Collaboration, "Charged-hadron yield measurements in photo-nuclear collisions using 5.02 TeV Pb+Pb data with ATLAS", https://cds.cern.ch/record/2871729
[2] ATLAS Collaboration, "Two-particle azimuthal correlations in photonuclear ultraperipheral Pb+Pb collisions at 5.02 TeV with ATLAS", Phys. Rev. C 104, 014903 (2021)

[3] CMS Collaboration, "Two-particle azimuthal correlations in γ+p interactions using pPb collisions at 8.16 TeV", Phys. Lett. B 844, 137905 (2023)

Overview / **87**

Experimental overview on UPC results from CMS

Authors: CMS Collaboration[None]; Zaochen Ye[1]

[1] *South China Normal University*

An invited overview talk

Overview / **88**

Experimental overview on UPC results from LHCb

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Invited overview talk

Inclusive and diffractive processes and photon, proton and nuclear structure / **89**

Di-hadron spectroscopy in PbPb UPC events measured in LHCb

Author: Cesar Luiz Da Silva[1]

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Vector, scalars and tensor mesons are accessible in the mass spectrum of di-hadrons measured in UPC events. The LHCb experiment is able to identify pions, kaons, proton, electrons, muons and photons at a very low transverse momentum, enabling the observation of a broad spectrum of mesons produced from different kinds of photon and pomeron interactions. This presentation will discuss the potential physics implications of the measured KK mass spectrum obtained in UPC events taken in PbPb crossings, the challenges and perspectives for other di-hadron measurements.

Inclusive and diffractive processes and photon, proton and nuclear structure / **91**

Small-x physics using ZDC at the LHC in UPCs and beyond

Author: Mark Strikman[1]

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We consider production of very forward neutrons in photon-nucleus and proton-nucleus inelastic collisions, which are detected in the LHC detectors by zero degree calorimeters (ZDC) with efficiency close to one. We argue that such measurements would provide a new probe of nuclear shadowing in soft and hard regimes of QCD. In particular, we calculate the distribution over the number of evaporation neutrons produced in photon-nucleus collisions in the kinematics of heavy ion UPCs at the LHC and show that it is correlated with the number of wounded nucleons (inelastic collisions) and, hence, can constrain the mechanism of nuclear shadowing and its x and impact parameter dependence. We also present an extension of these ideas to dijet production in pA scattering, which allows us to semi-quantitatively
explain the recent ATLAS data. Possible strategies for observing an onset of the black disk regime are also described.

Inclusive and diffractive processes and photon, proton and nuclear structure / **92**

Measurement of inclusive D0 production in UPCs with CMS

Author: Jordan Lang[1]

[1] *Massachusetts Inst. of Technology (US)*

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To be included

Photon-photon physics, precision tests of SM and BSM / **93**

Recent results on exclusive ditau production in proton-proton and lead-lead from CMS

Author: Michael Murray[1]

[1] *The University of Kansas (US)*

To be included

Monte Carlo event generators for UPCs and photon-mediated processes / **94**

Upcgen: An event generator for dilepton pair production in UPCs

Author: Paul Alois Buhler[1]

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We present Upcgen, a Monte Carlo event generator designed for simulating dilepton pair production in ultra-peripheral collisions (UPCs) [1]. In Upcgen the dilepton pair production cross section A+A

-> A+A + ll is calculated by folding the elementary gamma gamma -> ll cross section with the two-photon luminosity produced by the colliding nuclei. The calculation of the two-photon luminosity is based on realistic nuclear form factors and the elementary cross section is calculated with the generalized vertex approach. The generator offers a possibility to set the photon polarization and hence study related effects. In addition the value of the lepton anomalous magnetic moment can be set to an arbitrary value which is especially interesting for studies of the tau g-2 via ditau production measurements in UPCs.

[1] Computer Physics Communications 277 (2022) 108388

Overview / **95**

Welcome

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Welcome drink

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Dinner

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Dinner

99

IPC meeting

100

Conference dinner

Inclusive and diffractive processes and photon, proton and nuclear structure / **103**

Predictions for Inclusive Charm Photoproduction in Ultraperipheral Collisions at the LHC Using FONLL

Authors: Anna Maria Stasto[1]; Gian Michele Innocenti[2]

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[2] *Massachusetts Inst. of Technology (US)*

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Abstract: We present theoretical predictions for the inclusive D0 production cross section in ultraperipheral Pb–Pb collisions at the LHC, as a function of transverse momentum and rapidity. The calculations are performed within the Fixed-Order Next-to-Leading Logarithm (FONLL) framework, which is validated using Dˆ* photoproduction cross sections measured in electron–proton collisions at HERA. The pQCD predictions are folded with the latest estimates of the flux of quasi-real photons, including an electromagnetic dissociation factor to describe nuclear breakup. We investigate the sensitivity of these predictions to various nuclear parton distribution functions, fragmentation functions, and to variations of the renormalization and factorization scales. Finally, the results are compared with the first CMS measurements of Dˆ0production in ultraperipheral Pb–Pb collis! ions at LHC energies.

Overview / **104**

Experimental overview on UPC results from ATLAS

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Invited overview talk

Overview / **105**

Connections of UPC to future experiment

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Dinner

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Dinner (bus to Ivalo airport 20.05 TBC)