

# **UPC 2023: International workshop on the physics of Ultra Peripheral Collisions**

Sunday, 10 December 2023 - Friday, 15 December 2023

Playa del Carmen

## **Book of Abstracts**



# Contents

Probing gluon saturation via diffractive jets in nucleus-nucleus UPCs . . . . .	1
Lepton pair photo-production in peripheral, ultra-peripheral and isobaric heavy-ion collisions . . . . .	1
Photon photon physics at the LHC . . . . .	1
Saturation effects in exclusive heavy vector meson photoproduction at the LHC . . . . .	2
Inclusive and diffractive dijet photoproduction in ultraperipheral Pb-Pb collisions at the LHC . . . . .	2
A generator of forward neutrons for ultra-peripheral collisions: nOOn . . . . .	3
Single and double inclusive hadron production in Ultra-Peripheral Collisions: Next to Leading Order Corrections . . . . .	3
Vector meson production as a tool to search for gluon saturation from pA to eA to UPC . . . . .	3
Double Parton Scattering in Ultraperipheral Collisions . . . . .	4
Latest LHCb UPC results . . . . .	4
Collision geometry in UPC dijet production . . . . .	5
Initial electromagnetic field dependence of photon-induced production in isobaric collisions at STAR . . . . .	5
Angular modulation of photon-induced $J/\psi$ and lepton pair production in heavy ion collisions at STAR . . . . .	6
The ratio of $\Psi(2s)$ and $J/\Psi$ exclusive photoproduction cross-sections as a tool to detect non-linear QCD evolution . . . . .	6
Photoproduction measurements in UPC at STAR . . . . .	6
Di-Hadron Photoproduction in Au+Au 200 GeV Ultra Peripheral Collisions . . . . .	7
Photo-nuclear collisions in Pythia 8 . . . . .	7
Lepton pair production in UPCs . . . . .	8
'Rapidity gaps in UPC: status and perspectives' . . . . .	8
A Forward Calorimeter in ALICE . . . . .	8

Measurements of the properties of photonuclear events in UPC with the ATLAS detector	9
Measurement of dijet production in UPC with the ATLAS detector . . . . .	9
Measurement of dilepton production from photon fusion processes in UPC in Pb+Pb collisions with the ATLAS detector . . . . .	10
Recent results from ultra-peripheral lead-lead collisions with ATLAS . . . . .	10
Dimuon production at low transverse momentum in peripheral Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV at STAR . . . . .	10
Vector meson production using Balitsky-Kovchegov equation including the dipole orientation . . . . .	11
Quantum mechanics in coherent photoproduction: the limits of coherence, and multiple vector mesons . . . . .	11
Theory overview of vector meson photo production . . . . .	12
Energy dependence of $J/\psi$ in UPCs at the LHC . . . . .	12
Resummation at small x and implications for virtual photon scattering . . . . .	12
Photon-photon collisions with the gamma-UPC MC generator . . . . .	12
Exclusive $J/\psi$ Photoproduction and Entanglement-Enabled Spin Interference in Ultra-Peripheral Collisions at STAR . . . . .	13
Azimuthal angle distributions of leptons in the Wigner function approach . . . . .	13
Light-by-light scattering in ultraperipheral collisions of heavy ions with future FoCal and ALICE 3 detectors . . . . .	14
Novel aspects of particle production in UPCs . . . . .	14
The role of $J/\psi$ meson in peripheral heavy-ion collisions . . . . .	15
Four-pion state in UPC . . . . .	15
Exclusive $\eta_c$ production by $\gamma\gamma^*$ interactions in electron-ion collisions . . . . .	16
Proton and neutron evaporation from excited ions in the light-by-light scattering process	16
Open charm/beauty photoproduction in ultraperipheral heavy-ion collisions . . . . .	17
Two-boson interactions in the color dipole approach at LHC ultraperipheral collisions .	17
Coherent photoproduction of light vector meson off nuclear targets using the color dipole approach . . . . .	18
Exclusive photoproduction of excited quarkonia in ultraperipheral collisions . . . . .	18
Axion Physics in UPC and LbyL Scattering . . . . .	18
BSM searches in UPCs: recent results and prospects . . . . .	19
Latest UPC Results at STAR . . . . .	19

Observation of the $\gamma\gamma \rightarrow \tau\tau$ production in PbPb collisions with the CMS experiment . . .	20
UPC dijets at small-x: interplay of Color Glass Condensate and Sudakov resummation . . .	20
Single and double ratio of elastic vector meson production to inclusive hadron production cross section as a possible signal of saturation in UPCs . . . . .	20
The STARlight Monte Carlo . . . . .	21
Photoproduction of $J/\psi$ and dileptons in events with nuclear overlap with ALICE . . . .	21
Overview of latest UPC results from CMS . . . . .	22
Photoproduction of $J/\psi$ in UPC accompanied by neutron emission . . . . .	22
Exclusive Vector Meson Physics at the EIC . . . . .	23
Historical introduction to ultra peripheral collisions . . . . .	23
Recent results on ultra-peripheral collisions with the ALICE experiment . . . . .	23
UPC physics with ALICE in Run 3 . . . . .	23
Measurement of the impact-parameter dependent azimuthal anisotropy in coherent rho0 photoproduction with ALICE . . . . .	24
K+K- photoproduction in ultra-peripheral Pb-Pb collisions with ALICE . . . . .	24
Lepton Pair Production via Two-Photon Process in UPC at STAR . . . . .	25
Introduction . . . . .	25
Welcome to the student day at UPC 2023 . . . . .	25
Review of HERA results from an experimental point of view . . . . .	25
Review of main QCD ideas . . . . .	25
Review of UPC from an experimental point of view . . . . .	25
Overview of the EIC . . . . .	26
Welcome and introductions . . . . .	26
IPC meeting . . . . .	26
IPC breakfast . . . . .	26
Time for networking . . . . .	26
Discussion session . . . . .	26
Discussion session . . . . .	26
The Correlated Spatial Structure of the Proton: Two-body densities as a framework for dynamical imaging . . . . .	27
Collecting conference badges . . . . .	27

Student registration . . . . .	27
Registration . . . . .	27
I.ANN QCD: The Inter-American Network of Networks of QCD . . . . .	27
Event advertising . . . . .	27
UPC 2025 presentation . . . . .	28
Closing remarks . . . . .	28

**UPC and saturation / 1****Probing gluon saturation via diffractive jets in nucleus-nucleus UPCs****Authors:** Edmond Iancu<sup>1</sup>; Alfred Mueller<sup>2</sup>; Dionysios Triantafyllopoulos<sup>3</sup>; Shu-yi Wei<sup>4</sup><sup>1</sup> *Université Paris-Saclay (FR)*<sup>2</sup> *Columbia University*<sup>3</sup> *ECT\*/FBK*<sup>4</sup> *Shandong University***Corresponding Authors:** shu-yi.wei@polytechnique.edu, ahm4@columbia.edu, edmond.iancu@cea.fr, trianta@ectstar.eu

We argue that diffractive photo-production of jets in coherent nucleus-nucleus ultra-peripheral collisions (UPCs) at high energy is a golden channel to study gluon saturation. By “coherent” we mean elastic processes in which both nuclei emerge unbroken after the collision and the final state exhibits large rapidity gaps. We study such processes within the colour glass condensate effective theory, where the elastic photon-nucleus interactions are described as a colourless, multi-gluon, exchange, a.k.a. the Pomeron. We show that the dominant channel is the diffractive production of three jets in an asymmetric configuration. Two of the jets are hard and propagate at nearby pseudo-rapidities. The third jet is semi-hard, with transverse momentum comparable to the nuclear saturation momentum, and is well separated in pseudo-rapidity from the hard dijets. Such configurations allow for strong scattering and probe the unintegrated parton distributions of the Pomeron in the high gluon density regime. We show that gluon saturation controls the cross-section and leave its imprints on the structure of the final state, notably on the rapidity distribution of the three jets.

2

**Lepton pair photo-production in peripheral, ultra-peripheral and isobaric heavy-ion collisions****Author:** Shi Pu<sup>1</sup><sup>1</sup> *University of Science and Technology of China***Corresponding Author:** sldvmforever@gmail.com

We study the lepton pair photoproduction in peripheral heavy-ion collisions based on the formalism in our previous work [Phys. Rev. D 104, 056011 (2021)]. We present the numerical results for the distributions of the transverse momentum, azimuthal angle and invariant mass for  $e+e-$  and  $\mu+\mu-$  pairs as functions of the impact parameter and other kinematic variables in Au+Au collisions. Our calculation incorporates the information on the transverse momentum and polarization of photons which is essential to describe the experimental data. We observe a broadening effect in the transverse momentum for lepton pairs with and without smear effects. We also observe a significant enhancement in the distribution of  $\cos(2\varphi)$  for  $\mu+\mu-$  pairs. Our results provide a baseline for future studies of other higher order corrections beyond Born approximation and medium effects in the lepton pair production. We also studied the photo-production in the isobaric collisions.

**Two-photon interactions / 3****Photon photon physics at the LHC****Author:** Christophe Royon<sup>1</sup>

<sup>1</sup> *The University of Kansas (US)*

**Corresponding Author:** christophe.royon@cern.ch

We will discuss photon photon physics at the LHC when protons are intact in the final state and can be detected in PPS (CMS) or AFP (ATLAS). We will review the sensitivities to quartic anomalous couplings and the search for axion-like particles in pp collisions. In addition, we will present the complementary gamma gamma physics at lower masses in heavy ion collisions.

**UPC and saturation / 4**

## **Saturation effects in exclusive heavy vector meson photoproduction at the LHC**

**Authors:** Christophe Royon<sup>1</sup>; Jani Penttala<sup>2</sup>

<sup>1</sup> *The University of Kansas (US)*

<sup>2</sup> *UCLA*

**Corresponding Authors:** jani.penttala@gmail.com, christophe.royon@cern.ch

The gluon density has been observed to increase rapidly with energy, which would eventually violate unitarity. At high energies, however, nonlinear effects start to become important, slowing down the evolution of the gluon density and hence giving rise to gluon saturation. While there have already been strong hints of saturation in the currently available data, a definite measurement of saturation is still lacking. As exclusive vector meson production is expected to be sensitive to saturation, it offers one possible channel for measuring saturation.

The purpose of this talk is to study the magnitude of saturation effects in exclusive heavy vector meson photoproduction at the LHC. This is done by comparing predictions from linear and nonlinear models for the evolution of the gluon density. The difference in these models is the high-energy evolution of the dipole amplitude, which is done according to the BFKL and BK equations respectively. This allows us to quantify the effects of saturation in this process and determine whether saturation can be measured at the LHC.

**Inclusive photonuclear interactions / 5**

## **Inclusive and diffractive dijet photoproduction in ultraperipheral Pb-Pb collisions at the LHC**

**Author:** Vadim Guzey<sup>1</sup>

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

**Corresponding Author:** vadim.a.guzey@jyu.fi

Photoproduction of dijets is an important complementary probe of the partonic structure of protons, nuclei and real photons in QCD. We will review applications of the next-to-leading order (NLO) perturbative QCD in the framework of collinear factorization to inclusive and diffractive dijet photoproduction in heavy-ion ultraperipheral collisions (UPCs) in the kinematics of the Large Hadron Collider (LHC). We will demonstrate that this approach provides a good description of the preliminary ATLAS data in the inclusive case and has the potential to improve the determination of small-x nuclear parton distribution functions (nPDFs) by a factor of 2. In the diffractive case, we will focus on the effect of the strong nuclear shadowing and the sensitivity to mechanisms of QCD factorization breaking in diffraction.



**Monte Carlo models / 6****A generator of forward neutrons for ultra-peripheral collisions: nOOn****Author:** Michal Broz<sup>1</sup><sup>1</sup> *Czech Technical University in Prague (CZ)***Corresponding Author:** michal.broz@cern.ch

The study of photon-induced reactions in collisions of heavy nuclei at RHIC and the LHC has become an important direction of the research program of these facilities in recent years. In particular, the production of vector mesons in ultra-peripheral collisions (UPC) has been intensively studied. Owing to the intense photon fluxes, the two nuclei participating in such processes undergo electromagnetic dissociation producing neutrons at beam rapidities. Here, we introduce the nOOn (pronounced noon) Monte Carlo program, which generates events containing such neutrons. nOOn is a ROOT based program that can be interfaced with existing generators of vector meson production in UPC or with theoretical calculations of such photonuclear processes.

In this talk we will present latest developments on the program, particularly the extension to new nuclei (gold, oxygen or uranium). Framework developed to deal with datasets for various nuclei opened a possibility to study variations of the output coming from usage of different photo-neutron ( $\gamma+A \rightarrow A'+Xn$ ) cross sections. This is of particular interest because in UPC events the two fold ambiguity on the photon energy can be disentangled via the measurement of the forward neutron multiplicity. In the past several experimental groups performed a measurement of the photo-neutron cross section, but no agreement on a 'PDG-like' mean value exist in the field. Using nOOn we studied the uncertainty of the modified photon flux coming from usage of various datasets of the photo-neutron cross section. The variation of the fluxes due to this effect has to be taken into account when they are used in future experiments.

**UPC and saturation / 7****Single and double inclusive hadron production in Ultra-Peripheral Collisions: Next to Leading Order Corrections****Author:** Jamal Jalilian-Marian<sup>1</sup><sup>1</sup> *Baruch College, CUNY***Corresponding Author:** jamal.jalilian-marian@baruch.cuny.edu

We calculate the Next to Leading Corrections to single and double inclusive hadron production in Deep Inelastic Scattering (DIS) and in Ultra-Peripheral Collisions (UPC) using the Color Glass Condensate effective theory of QCD at small  $x$ . We argue that single inclusive hadron production where momentum of the produced hadron is of the order of Saturation scale provides a sensitive probe of saturation dynamics. We discuss applications to UPC events in the LHC.

**Vector meson photoproduction / 8****Vector meson production as a tool to search for gluon saturation from pA to eA to UPC****Authors:** Bjoern Schenke<sup>1</sup>; Farid Salazar<sup>2</sup>; Heikki Mäntysaari<sup>3</sup>; Ramona Vogt<sup>None</sup>; Vincent Cheung<sup>4</sup>; Zhongbo Kang<sup>None</sup>

<sup>1</sup> *Brookhaven National Lab*<sup>2</sup> *UCLA/UCB/LBNL*<sup>3</sup> *University of Jyväskylä*<sup>4</sup> *LLNL*

**Corresponding Authors:** faridsalazar03@gmail.com, bschenke@quark.phy.bnl.gov, heikki.mantysaari@jyu.fi, zkang@g.ucla.edu, hscheung@ucdavis.edu, rlvogt@lbl.gov

Vector meson production in high-energy UPCs is an excellent tool to study the dynamics of small- $x$  gluons inside nuclei. Employing the Color Glass Condensate (CGC) effective field theory, I will describe the impact that gluon saturation has in exclusive and semi-inclusive  $J/\psi$  production in UPC reactions.

In the first part of the talk, I will focus on exclusive  $J/\psi$  production and show how non-linear saturation effects change the density profile of a heavy nucleus, and that such modifications are necessary to obtain a good description of ALICE and LHCb data on Pb+Pb UPCs [1]. We employ a joint impact parameter and transverse momentum-dependent cross-section framework in order to incorporate the finite photon transverse momentum and the interference between the cases for which the role of photon emitter and target are interchanged between the nuclei. We show that these effects are comparable to the experimental precision for  $p_T$  differential cross sections and must be included when comparing to LHC data.

In the second half of the talk, I will present our results for direct  $J/\psi$  production in a joint CGC + Non-relativistic QCD framework [2]. We establish the correspondence between our results with those obtained within the transverse momentum dependent (TMD) framework and its “Improved” version ITMD. We show quantitative results for the size of  $k_T$  factorization-breaking contributions in the CGC at realistic kinematics attained in UPCs at RHIC and the LHC.

[1] Heikki Mäntysaari, Farid Salazar and Björn Schenke. *Phys.Rev.D* 106 (2022) 7, 074019. e-Print: 2207.03712 [hep-ph]

[2] Vincent Cheung, Zhongbo Kang, Farid Salazar, and Ramona Vogt. [in progress]

## Vector meson photoproduction / 10

# Double Parton Scattering in Ultraperipheral Collisions

**Author:** Bruna Stahlhöfer<sup>1</sup>

<sup>1</sup> *UFSC*

**Corresponding Author:** stahlhofer.bruna@posgrad.ufsc.br

Double Parton Scattering (DPS) is an important way for which we can investigate the parton distributions of the proton and the nucleus. Although, we know that such scatterings should occur in high energy collisions, the formalism to describe it lack of answers to questions like — is there a universal effective cross section? In direction to explore such questions, we investigate DPS in ultraperipheral collision (UPC) where the effective cross section is not a constant as usually is in the central collisions, as we point in our results. Furthermore, once we allow the nucleus to break in an ultraperipheral proton–nucleus collision, we provide insights concerning the photon distribution of the nucleus. Also, as the effective cross section have a complex dependence with the longitudinal fraction energy carrying by the photon in the initial state, we evaluate cross sections with photon and gluons in the initial state producing quark–antiquark pairs or dilepton and quark–antiquark in the final state.

## Reports from the RHIC and LHC experiments / 11

## Latest LHCb UPC results

**Author:** Cesar Luiz Da Silva<sup>1</sup>

<sup>1</sup> *Los Alamos National Laboratory (US)*

**Corresponding Author:** cesar.luiz.da.silva@cern.ch

Ultra peripheral collisions has a large range of observables which are kinematically hard to be measured. These includes light vector mesons from coherent effects and other probes requiring soft particle tracking. The LHCb experiment has unique capabilities to study multiple UPC observables, thanks to its low transverse momentum tracking and particle identification. This presentation will report on the recent results on quarkonia states and the exploration of other vector mesons produced in coherent and incoherent processes in PbPb collisions. Future detector upgrades will increase even further the access to soft tracks using the Magnet Station tracker. Projections and new physics achievables will be discussed.

### Inclusive photonuclear interactions / 12

## Collision geometry in UPC dijet production

**Author:** Petja Paakkinen<sup>None</sup>

**Corresponding Author:** petja.k.m.paakkinen@jyu.fi

Inclusive dijet photoproduction in ultraperipheral nucleus-nucleus collisions (UPCs) has been promoted as a probe of nuclear parton distribution functions (nPDFs). However, due to the requirement of no nuclear overlap in such events, the impact parameter space is restricted. This becomes important in dijet production, where the requirement of having high- $p_T$  jets means that one has to have energetic enough photon in the initial state, more likely to originate from close the source nucleus. We show that a significant portion of the measured dijets at large measurable  $z_\gamma$  (correspondingly small  $x_A$ ) in UPC PbPb collisions at 5.02 TeV come from events with relatively small impact parameters of the order of few nuclear radii, and the cross section predictions therefore become sensitive to the modelling of the nuclear geometry and photon flux close to the source nucleus. We comment on the implications of these geometrical effects for the use of UPC dijets as a constraint of nPDFs.

### Two-photon interactions / 13

## Initial electromagnetic field dependence of photon-induced production in isobaric collisions at STAR

**Author:** Kaifeng Shen<sup>None</sup>

**Corresponding Author:** kshen@rcf.rhic.bnl.gov

The Lorentz-boosted electromagnetic field, arising from colliding nuclei, can be treated as a flux of quasi-real photons. Consequent photonuclear ( $\propto Z^2$ ) and photon-photon ( $\propto Z^4$ ) processes could reasonably explain the observed enhancements of  $J/\psi$  and  $e^+e^-$  pair production at very low transverse momenta ( $p_T$ ) in peripheral heavy-ion collisions. The STAR experiment collected datasets of  $^{96}_{44}\text{Ru}+^{96}_{44}\text{Ru}$  and  $^{96}_{40}\text{Zr}+^{96}_{40}\text{Zr}$  collisions at  $\sqrt{s_{NN}} = 200$  GeV in 2018, which provide a unique opportunity to study the field strength dependence of photon-induced processes.

In this presentation, we will present measurements of  $J/\psi$  and  $e^+e^-$  pair production at very low  $p_T$  in peripheral and ultra-peripheral isobaric collisions, and study the electromagnetic field dependence of photon-induced production by comparing measurements between isobaric and Au+Au collisions. Physics implications of these results will be discussed together with model comparisons.

**Vector meson photoproduction / 14****Angular modulation of photon-induced  $J/\psi$  and lepton pair production in heavy ion collisions at STAR****Author:** Kaiyang Wang<sup>1</sup><sup>1</sup> *University of Science and Technology of China***Corresponding Author:** czswky@mail.ustc.edu.cn

Ultra-strong electromagnetic field in relativistic heavy-ion collisions can generate a large flux of linearly polarized quasi-real photons. Photons emitted by one nucleus can interact with the other whole nucleus or individual nucleons to produce vector meson ( $\gamma + A \rightarrow V + A$ ). On the other hand, interactions between photons emitted by two nuclei can produce lepton pairs ( $\gamma + \gamma \rightarrow l^+ + l^-$ ). Notably, azimuthal asymmetries between the pair momentum and the daughter momentum could arise from the linear polarization of incident photons. The photon-induced vector mesons and lepton pairs carry information about the original electromagnetic field, which provides a sensitive probe to study the polarization dependent effects predicted by spin interference and QED vacuum birefringence.

In this presentation, we will report the angular modulation measurements of the photon-induced  $J/\psi$  and  $e^+e^-$  pair production in Ru+Ru, Zr+Zr and Au+Au peripheral and ultra-peripheral collisions at  $\sqrt{s_{NN}} = 200$  GeV. The angular modulation of  $\mu^+\mu^-$  pairs in Au+Au peripheral collisions will also be presented. Physics implications of these results will be discussed together with model comparisons.

**UPC and saturation / 15****The ratio of Psi(2s) and J/Psi exclusive photoproduction cross-sections as a tool to detect non-linear QCD evolution****Authors:** Marco Antonio Alcazar Peredo<sup>1</sup>; Martin Hentschinski<sup>2</sup><sup>1</sup> *Universidad de las Américas Puebla*<sup>2</sup> *Universidad de las Americas, Puebla***Corresponding Authors:** martin.hentschinski@gmail.com, marco.alcazarpo@udlap.mx

We study the proposal that the ratio of Psi(2s) and J/Psi exclusive photoproduction cross-sections might serve as an indicator of the presence of non-linear QCD evolution, related to the presence of high and potentially saturated gluon densities in both the proton and a lead nucleus. Our study employs recent fits of the GBW and BGK dipole model and provides predictions for both exclusive photoproduction on a proton and on a lead nucleus. While the cross-sections for photoproduction on a proton depend only weakly on non-linear low x corrections, we find an increased sensitivity for the cross-section ratio, which is directly related to the node in the Psi(2s) wave function. We further give a description of recent ALICE data for exclusive J/Psi photoproduction on a lead nucleus and provide predictions for Psi(2s) photoproduction on a lead nucleus as well as for the corresponding cross-section ratio.

**Vector meson photoproduction / 16****Photoproduction measurements in UPC at STAR****Author:** Jaroslav Adam<sup>1</sup>

<sup>1</sup> *Czech Technical University in Prague (CZ)*

**Corresponding Author:** jaroslav.adam@cern.ch

Exclusive vector meson photoproduction in ultra-peripheral collisions (UPC) is a unique tool to study quantum chromodynamics in nucleus-nucleus collisions. In a UPC, photon induced interaction takes place on one of the nuclei, while the other is the source of virtual photon. Neutrons may be emitted from the target nucleus and eventually detected in a very forward calorimeter. Here we report on cross section measurements of  $J/\psi$  and  $\psi(2S)$  photoproduction in UPC at STAR experiment in Au-Au collisions at  $\sqrt{s_{NN}} = 200$  GeV. The cross sections are evaluated as a function of meson rapidity, square of its transverse momentum and photon-nucleus center-of-mass energy for the case of very forward neutron detection.

**Two-photon interactions / 17**

## Di-Hadron Photoproduction in Au+Au 200 GeV Ultra Peripheral Collisions

**Author:** Xin Wu<sup>1</sup>

<sup>1</sup> *University of Science and Technology of China*

**Corresponding Author:** wuxinust@mail.ustc.edu.cn

Relativistic heavy-ion collisions generate extremely strong electromagnetic fields, providing an ideal environment to study the electromagnetic excitation of the vacuum. The Breit-Wheeler process, the lowest-order decay mode of the QED vacuum excitation into electron-positron pairs, has been experimentally verified by the STAR collaboration, stimulating further investigations of higher-order decay modes, such as baryon-antibaryon and meson-antimeson pairs.

This presentation reports the first measurements of baryon-antibaryon and meson-antimeson pairs from QED vacuum excitation in Au+Au ultra-peripheral collisions at  $\sqrt{s_{NN}} = 200$  GeV by the STAR experiment. The invariant mass and pair  $p_T$  distributions are shown. These measurements will shed new light on the understanding of the QED vacuum.

**Monte Carlo models / 18**

## Photo-nuclear collisions in Pythia 8

**Authors:** Ilkka Helenius<sup>1</sup>; Marius Utheim<sup>None</sup>

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

**Corresponding Authors:** ilkka.m.helenius@jyu.fi, marius.m.uthheim@jyu.fi

Ultraperipheral heavy-ion collisions provide the first opportunity to study collisions between photons and heavy ions in high-energy colliders. The quasi-real photons emitted by the nuclei may fluctuate into a hadronic state and in fact this hadronic contribution will provide the bulk of the photon-hadron cross section. In case of a heavy-ion target the partonic structure of these resolved photons give rise to additional interactions between the photon remnants and the target nucleons increasing the multiplicity of such events compared to a collision with a proton target.

In this talk I will present our current framework to simulate photon-ion interactions with Pythia 8 general-purpose Monte Carlo event generator. As a first step we have applied vector-meson dominance to model the resolved photon and the Angantyr model in Pythia to sample number and type

of collisions between a heavy ion and the different vector-meson states. We compare our setup with the full photoproduction model and with the existing HERA data in case of proton target. Then we present comparisons of our approach to the recent ATLAS UPC data with heavy-ion target including multiplicity and rapidity distributions of charged particles. Furthermore we study whether the observed two-particle correlations could be reproduced within the model that does not contain any collectivity from hydrodynamics. In addition, we compare against fixed-target NA61/Shine data for pion-nucleus collisions where we can apply the developed framework in a different environment.

**Monte Carlo models / 19**

## Lepton pair production in UPCs

**Author:** Yajin Zhou<sup>1</sup>

<sup>1</sup> *Shandong University, China*

**Corresponding Author:** jinyazhou@gmail.com

The coherent photons induced by relativistic heavy ions are highly linearly polarized, in close analogy to the linear polarization of gluons in a large nucleus. We proposed to measure the photon polarization through azimuthal asymmetries in dilepton production in ultraperipheral collisions. Our prediction for the asymmetries were soon confirmed by the STAR experiment with high precision. We refined our analysis recently by including the final state soft photon radiation effect beyond the double leading logarithm approximation. The azimuthal asymmetries and acoplanarity at relatively high transverse momentum provide unique opportunities to test the resummation formalism thanks to the extremely high photon flux in UPCs. Our results clearly show the feasibility to access the sub-leading resummation effects in UPCs at the RHIC and LHC.

**Inclusive photonuclear interactions / 20**

## 'Rapidity gaps in UPC: status and perspectives'

**Author:** Mark Strikman<sup>1</sup>

<sup>1</sup> *Pennsylvania State University (US)*

**Corresponding Author:** mark.strikman@cern.ch

We consider processes with production of a leading heavy vector meson, dijet followed by rapidity gap in UPC. We argue that the knock out mechanism of the elastic scattering of hard Pomeron off constituents of nucleon/nucleus dominates in a wide range of momentum transfer due to the structure of the resummed Pomeron. The suit of rapidity gap processes in which neutrons are detected in the zero degree calorimeter is described which would allow to probe in a great detail the small  $x$  dynamics both in hard and soft regimes reaching in the hard regime  $x \sim 10^{-5}$ . In particular, it would be possible to probe impact parameter dependence of the gluon nuclear shadowing.

**Future RHIC and experiments, and the EIC / 22**

## A Forward Calorimeter in ALICE

**Author:** Ionut Cristian Arsene<sup>1</sup>

<sup>1</sup> *University of Oslo (NO)*

**Corresponding Author:** ionut.cristian.arsene@cern.ch

The Forward Calorimeter (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 fibers (FoCal-H).

The FoCAL detector extends the ALICE physics programme with the capability, unique at the LHC, of investigating gluon Parton Distribution Functions (PDFs) down to Bjorken- $x$  of  $\sim 10^{-6}$ . In this kinematic range, the gluon distributions are expected to behave non-linearly. FoCal is optimized for reconstructing direct photons, however, other measurements are foreseen as well. In particular, 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, going to Bjorken- $x$  values as low as a few  $10^{-6}$ .

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.

**Photoproduction in peripheral collisions / 23**

## Measurements of the properties of photonuclear events in UPC with the ATLAS detector

**Corresponding Author:** sruthy.jyothi.das@cern.ch

Ultraperipheral collisions of relativistic heavy ion beams lead to a diverse set of photon-nucleus (photonuclear) interactions. The measurements of particle production in photonuclear reactions can shed light on the QCD dynamics of the novel, extremely asymmetric colliding systems, with energies between those available at RHIC and the LHC. Previous studies by ATLAS indicate significant elliptic and triangular flow coefficients in these events. Thus, it is imperative to check these events for other potential QGP signatures including radial flow, strangeness enhancement, and enhanced baryon/meson production. This talk presents the measurement of charged hadron and identified particle yields ( $K_S^0$ ,  $\Lambda$ , and  $\Xi$ ) in photonuclear collisions using 5.02 TeV Pb+Pb data collected in 2018 by ATLAS. The charged hadron and identified particle yields are presented as a function of pseudorapidity and transverse momentum in different categories of event multiplicity. The results are compared with 5.02 TeV p+Pb data collected in 2016 by ATLAS at the same event multiplicities. The results are also compared with calculations from DPMJET and hydrodynamic-based models. These comparisons enable detailed characterizations of photonuclear collision properties, including the photon energy distribution and whether small QGP droplets may be formed.

**Inclusive photonuclear interactions / 24**

## Measurement of dijet production in UPC with the ATLAS detector

**Corresponding Author:** blair.daniel.seidlitz@cern.ch

In relativistic heavy ion collisions, the charged ions produce an intense flux of equivalent photons. Thus, photon-induced processes are the dominant interaction mechanism when the colliding nuclei have a transverse separation larger than the nuclear diameter. In these ultra-peripheral collisions

(UPCs), the photon provides a clean, energetic probe of the partonic structure of the nucleus, analogous to deep inelastic scattering. This talk presents a measurement 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, rapidity gaps, and forward neutron emission to identify photo-nuclear hard-scattering processes. The precision of these measurements is augmented by studies of nuclear break-up effects, allowing for detailed comparisons with theoretical models in phase-space regions where significant nuclear PDF modifications are expected but not strongly constrained by existing data.

#### Two-photon interactions / 25

### Measurement of dilepton production from photon fusion processes in UPC in Pb+Pb collisions with the ATLAS detector

**Corresponding Author:** iwona.grabowskabold@gmail.com

Relativistic heavy-ion beams at the LHC are accompanied by a large flux of equivalent photons, leading to multiple photon-induced processes. This talk presents a series of measurements of dilepton production from photon fusion performed by the ATLAS Collaboration. Recent measurements of exclusive dielectron production in ultra-peripheral collisions (UPC) are presented. These processes provide strong constraints on the nuclear photon flux and its dependence on the impact parameter and photon energy. Comparisons of the measured cross-sections to QED predictions from the Starlight and SuperChic models are also presented. Tau-pair production measurements can constrain the tau lepton's anomalous magnetic dipole moment ( $g-2$ ), and a recent ATLAS measurement using muonic decays of tau leptons in association with electrons and tracks provides one of the most stringent limits available to date.

#### Reports from the RHIC and LHC experiments / 26

### Recent results from ultra-peripheral lead-lead collisions with ATLAS

**Corresponding Author:** klaudia.burka@cern.ch

Relativistic heavy-ion beams at the LHC are accompanied by a large flux of equivalent photons, leading to multiple photon-induced processes. This talk presents a series of measurements of such processes performed by the ATLAS Collaboration. Measurements of exclusive dilepton production (electron, muon, and tau pairs) are discussed. These processes provide strong constraints on the nuclear photon flux and its dependence on the impact parameter and photon energy. In particular, measurements of the cross-sections in the presence of forward neutrons provide an additional experimental handle on the impact parameter range sampled in the observed events. Furthermore, the tau-pair production measurements can constrain the tau lepton's anomalous magnetic dipole moment. High statistics measurements of light-by-light scattering shown in this talk provide a precise and unique opportunity to investigate extensions of the Standard Model, such as the presence of axion-like particles. Presented measurements of muon pairs produced via two-photon scattering processes in hadronic Pb+Pb collisions provide a novel test of strong-field QED and can be a potentially sensitive electromagnetic probe of the quark-gluon plasma. These include the dependence of the cross-section and angular correlation on the mean- $p_T$  of the dimuon pair, the rapidity separation between the muons, and the angle that the pair makes with the second-order event-plane.



**Photoproduction in peripheral collisions / 27****Dimuon production at low transverse momentum in peripheral Au+Au collisions at  $\sqrt{s_{NN}} = 200$  GeV at STAR****Author:** Ziyang Li<sup>None</sup>**Corresponding Author:** lzy9404@mail.ustc.edu.cn

The strong electromagnetic field generated by the colliding nuclei in heavy-ion collisions can be represented by a spectrum of photons leading to photon-induced interactions. While such interactions are traditionally studied in ultra-peripheral collisions (UPC) without any nuclear overlap, significant enhancements of dilepton pairs and  $J/\psi$  production at very low transverse momentum ( $p_T < 0.2$  GeV/c) above the expected hadronic interaction yields have been observed experimentally in non-UPC events via the  $e^+e^-$  channel. The observed excess yields exhibit a much weaker centrality dependence compared to the hadronic production and are consistent with photon-induced interactions. The measurements of very low  $p_T$  vector meson and dilepton production in peripheral heavy-ion collisions provide a unique opportunity to study photoproduction in collisions with well-defined and smaller impact parameters compared to that of UPC.

In 2014 and 2016, the STAR experiment recorded large samples of Au+Au collisions at  $\sqrt{s_{NN}} = 200$  GeV. In this presentation, we will present new measurements of very low  $p_T$  dilepton and  $J/\psi$  production in peripheral Au+Au collisions via the  $\mu^+\mu^-$  channel using these datasets. These measurements are complementary to the previous dielectron results. Distributions of invariant mass,  $p_T^2$ , and nuclear modification factor will be shown. Physics implications will also be discussed together with model comparisons.

**Vector meson photoproduction / 28****Vector meson production using Balitsky-Kovchegov equation including the dipole orientation****Author:** Jan Cepila<sup>1</sup><sup>1</sup> *Czech Technical University in Prague (CZ)***Corresponding Author:** jan.cepila@fjfi.cvut.cz

In this talk a solution of the target-rapidity Balitsky-Kovchegov (BK) equation will be presented considering the complete impact-parameter dependence, including the orientation of the dipole with respect to the impact-parameter vector. The target-rapidity formulation of the BK equation introduces non-locality in rapidity. Three different prescriptions are considered to take into account the rapidities preceding the initial condition. The solutions are used to compute the structure functions of the proton and the diffractive photo- and electro-production of  $J/\psi$  off protons and nuclei. The predictions agree well with HERA data, confirming that the target-rapidity Balitsky-Kovchegov equation with the full impact-parameter dependence is a viable tool to study the small Bjorken- $x$  limit of perturbative QCD at current facilities like RHIC and LHC as well as in future colliders like the EIC.

**Vector meson photoproduction / 29****Quantum mechanics in coherent photoproduction: the limits of coherence, and multiple vector mesons****Author:** Spencer Robert Klein<sup>1</sup>

<sup>1</sup> *Lawrence Berkeley National Lab. (US)*

**Corresponding Author:** srklein@lbl.gov

Coherent photoproduction has long been studied in UPCs. Although interference between the two nuclear targets has been studied, other quantum mechanical problems have received much less attention. In this talk, I will discuss some open problems, including studying the limits of coherence, and quantum mechanical aspects of multiple vector meson production in a single UPC.

**Vector meson photoproduction / 30**

## **Theory overview of vector meson photo production**

**Author:** Bjoern Schenke<sup>1</sup>

<sup>1</sup> *Brookhaven National Lab*

**Corresponding Author:** bschenke@quark.phy.bnl.gov

I will review calculations of vector meson production in ultra peripheral collisions. I will focus on exclusive J/Psi and rho production at RHIC and LHC and address their potential to elucidate nuclear effects including gluon saturation, as well as nuclear structure, sub-nucleonic fluctuations, and entanglement driven interference effects. I will focus on dipole models and compare to calculations in other frameworks.

**Vector meson photoproduction / 31**

## **Energy dependence of J/ψ in UPCs at the LHC**

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

<sup>1</sup> *Université Paris-Saclay (FR)*

**Corresponding Author:** michael.winn@cern.ch

**Inclusive photonuclear interactions / 32**

## **Resummation at small x and implications for virtual photon scattering**

**Author:** Anna Maria Stasto<sup>1</sup>

<sup>1</sup> *Pennsylvania State University (US)*

**Corresponding Author:** ams52@psu.edu

**Monte Carlo models / 33**

## **Photon-photon collisions with the gamma-UPC MC generator**

**Author:** David d'Enterria<sup>1</sup>**Co-author:** Huasheng Shao<sup>2</sup><sup>1</sup> CERN<sup>2</sup> Centre National de la Recherche Scientifique (FR)**Corresponding Authors:** huasheng.shao@cern.ch, david.d'enterria@cern.ch

The automated generation of arbitrary exclusive final states produced via photon fusion in ultra-peripheral high-energy collisions of protons and/or nuclei,  $A+B \rightarrow A+X+B$ , is implemented in the MadGraph5\_aMC@NLO and HELAC-Onia Monte Carlo codes. Cross sections are calculated in the equivalent photon approximation using  $\gamma$  fluxes derived from electric dipole and charge form factors, and incorporating hadronic survival probabilities. In the case of exclusive dilepton productions, QED corrections at next-to-leading-order accuracy are included. Multiple examples of  $\gamma\gamma$  cross sections computed with this setup, named gamma-UPC, are presented for proton-proton, proton-nucleus, and nucleus-nucleus ultraperipheral collisions (UPCs) at the Large Hadron Collider and Future Circular Collider. Total photon-fusion cross sections for the exclusive production of spin-0, 2 resonances (quarkonia, ditauonium, and Higgs boson; as well as axions and gravitons), and for pairs of particles ( $J/\psi$ ,  $J/\psi$ ,  $WW$ ,  $ZZ$ ,  $Z\gamma$ ,  $t\bar{t}$ ,  $HH$ ) are presented. Differential cross sections for exclusive dileptons and light-by-light scattering are compared to LHC data.

**Vector meson photoproduction / 34**

## Exclusive $J/\psi$ Photoproduction and Entanglement-Enabled Spin Interference in Ultra-Peripheral Collisions at STAR

**Author:** ASHIK IKBAL<sup>None</sup>**Corresponding Author:** ashikhep@gmail.com

In ultra-peripheral collisions (UPCs), exclusive vector meson photoproduction, e.g.,  $\rho^0$  and  $J/\psi$ , has been considered one of the most sensitive probes to the gluon structure in heavy nuclei. Recently, it was discovered that the linear polarization of the photons involved in these processes can enable measurements of the nuclear geometry through the so-called entanglement-enabled spin interference with the  $\rho^0$  meson. However, the possibility that the interference can happen at the level of vector mesons cannot be falsified using  $\rho^0$  data. The longer lifetime and non-localized wave function of  $J/\psi$  at the time of its decay would not result in an interference pattern similar to the  $\rho^0$  unless the entanglement occurs between the photon and the Pomeron phases emitted from each nucleus, providing an opportunity to study the source of the entanglement.

In this talk, we will report first measurements of the differential cross sections of photoproduced  $J/\psi$  as functions of rapidity  $y$  and  $p_T^2 \approx -t$  (up to  $2.25 \text{ (GeV}/c)^2$ ) in Au+Au UPCs at  $\sqrt{s_{NN}} = 200 \text{ GeV}$  recorded by STAR. The results will be presented for different combinations of neutron emission detected in zero degree calorimeters, which can be used to resolve the photon energy ambiguity. These data provide important constraints for nuclear parton distribution functions and sub-nucleonic shape fluctuations in heavy nuclei in the kinematic range  $x_{\text{parton}} \sim 0.015 - 0.03$ .

We also present the first measurement of the interference pattern for those photoproduced  $J/\psi$ . The observation of a positive  $\cos(2\Delta\phi)$  modulation in the angular separation between the  $J/\psi$  and one of its decay daughters is predicted to be a signature of entanglement between the photon and Pomeron phases. Finally, we will provide an outlook for significantly improved measurements anticipated during the final RHIC runs in 2023-2025.

**Vector meson photoproduction / 35**

## Azimuthal angle distributions of leptons in the Wigner function approach

**Author:** Wolfgang Schaefer<sup>None</sup>

**Corresponding Author:** wolfgang.schafer@ifj.edu.pl

We revisit the Wigner function approach to the impact parameter dependent dilepton pair production developed in [M. Klusek-Gawenda, WS, A. Szczurek Phys.Lett.B 814 (2021) 136114]. We study the distribution of the angle between difference and sum of lepton transverse momenta, and show how it relates to the orbital angular momentum of leptons. The dependence on impact parameter is discussed, and we also present the different components of the Wigner function in the  $t$ -channel. A brief comparison to similar angular distributions in diffractive quark pair production will be presented.

**Future RHIC and experiments, and the EIC / 36**

## Light-by-light scattering in ultraperipheral collisions of heavy ions with future FoCal and ALICE 3 detectors

**Author:** Antoni Szczurek<sup>None</sup>

**Corresponding Author:** antoni.szczurek@ifj.edu.pl

We discuss possible future studies of photon-photon (light-by-light) scattering using planned FoCal and ALICE 3 detectors. We include different mechanisms of  $\gamma\gamma \rightarrow \gamma\gamma$  scattering such as double-hadronic photon fluctuations,  $t/u$ -channel neutral pion exchange or resonance excitations ( $\gamma\gamma \rightarrow R$ ) and deexcitation ( $R \rightarrow \gamma\gamma$ ). The broad range of (pseudo)rapidities and lower cuts on transverse momenta open a necessity to consider not only dominant box contributions but also other subleading contributions. Here we include low mass resonant  $R = \pi^0, \eta, \eta'$  contributions. The resonance contributions give intermediate photon transverse momenta. However, these contributions can be eliminated by imposing windows on di-photon invariant mass. We study and quantify individual box contributions (leptonic, quarkish). The electron/positron boxes dominate at low  $M_{\gamma\gamma} < \sim 1 \text{ GeV}$  di-photon invariant masses. The  $\text{PbPb} \rightarrow \text{PbPb} \gamma\gamma$  cross section is calculated within equivalent photon approximation in the impact parameter space. Several differential distributions are presented and discussed. We consider four different kinematic regions. We predict cross section in the (mb-b) range for typical ALICE 3 cuts, a few orders of magnitude larger than for the current ATLAS or CMS experiments. We also consider the two- $\pi^0$  background which can, in principle, be eliminated at the new kinematical range of the ALICE 3 measurements by imposing dedicated cuts on di-photon transverse momentum and *slash* or so-called vector asymmetry.

**Monte Carlo models / 37**

## Novel aspects of particle production in UPCs

**Author:** Fernando Navarra<sup>1</sup>

<sup>1</sup> University of São Paulo, Brazil

**Corresponding Author:** navarra@if.usp.br

In this talk I will address two topics. First I will discuss the production of pions at very large rapidities ( $y > 7$ ) in p-Pb and Pb-Pb collisions at the LHC. These pions are produced through the magnetic excitation of nucleons in the target due to the strong magnetic field generated by the projectile, i.e.,  $N \rightarrow \Delta \rightarrow N' \pi$ . This process has a very large cross section and can be used to measure the magnetic field produced by the projectile. The details of the calculations were published in Phys.Lett.B 805 (2020) 135463 (arXiv:1910.00711) and Phys.Rev.C 103 (2021) 2, 024902 (arXiv:2011.00726). I plan to report on new developments and improvements. Second, I will briefly review the works (especially arXiv: 2307.12387) on the production of exotic charmonium in UPCs and then present the calculation of the production cross section of a D-Dbar molecular state in photon-photon collisions in UPCs. This calculation involves the use of an effective Lagrangian to produce the pair of charm mesons and a prescription to bind them together forming the bound state. This is work in progress and will be concluded by the end of this year.

38

## The role of $J/\psi$ meson in peripheral heavy-ion collisions

**Author:** Mariola Klusek-Gawenda<sup>1</sup>

**Co-author:** Antoni Szczurek

<sup>1</sup> *Institute of Nuclear Physics Polish Academy of Sciences*

**Corresponding Authors:** mariola.jadwiga.klusek-gawenda@cern.ch, antoni.szczurek@ifj.edu.pl

We study the  $J/\psi$  photoproduction in ultrarelativistic lead-lead collisions at the LHC energy. In the present approach, as an example, we use a simple model based on a vector dominance picture and multiple scattering of the hadronic ( $c\bar{c}$ ) state in a cold nucleus. Equivalent photon approximation in the impact parameter space, which successfully describes data for ultraperipheral processes, is used for more central heavy-ion collision. For semi-central collisions ( $b < R_{Pb} + R_{Pb}$ ), a modification of the photon flux seems necessary. We discuss different physics-motivated approximations. We try to estimate the cross sections for different centrality bins and  $J/\psi$  mesons emitted in the forward rapidity range ( $2.5 < y < 4$ ) corresponding to ALICE experimental results. Reasonable results will be presented but open questions will also be discussed.

*Photoproduction of  $J/\psi$  mesons in peripheral and semicentral heavy ion collisions,*  
Mariola Klusek-Gawenda and Antoni Szczurek,  
Published in: Phys.Rev. **C93** (2016) 4, 044912.

**Two-photon interactions / 39**

## Four-pion state in UPC

**Author:** Mariola Klusek-Gawenda<sup>1</sup>

<sup>1</sup> *Institute of Nuclear Physics Polish Academy of Sciences*

**Corresponding Author:** mariola.jadwiga.klusek-gawenda@cern.ch

We study the production of  $2\pi^+2\pi^-$  in ultraperipheral heavy-ion collisions at RHIC and LHC energies. The recent H1 preliminary data [1] are utilized to improve the description of the poorly known

$\gamma p \rightarrow 4\pi^\pm p$  process. Predictions for photon-nucleus interactions were calculated for various excited states of  $\rho$  meson. We will present an agreement of theory with the available STAR data at RHIC [2]. The comparison of  $2\pi^+2\pi^-$  invariant mass spectrum and nuclear total cross section shows that  $\rho(1570)$  plays a crucial role [3] in correctly describing existing experimental data. STAR data for the four-pion state were interpreted as the decay of  $\rho(1700)$  resonance. New H1 data allows us to verify this reasoning. Nuclear predictions will also be given for LHC energy at the central and forward regions of rapidities.

[1] H1 Collaboration, S. Schmitt, 26th International Workshop on Deep Inelastic Scattering and Related Subjects (DIS 2018): Port Island, Kobe, Japan, April 16-20, 2018,

[2] STAR Collaboration, B.I. Abelev et al., Phys. Rev. C81 (2010) 044901,

[3] M. Klusek-Gawenda and J. Daniel Tapia Takaki, Acta Phys. Polon. B51 (2020) 6, 1393.

## Future RHIC and experiments, and the EIC / 40

### Exclusive $\eta_c$ production by $\gamma\gamma^*$ interactions in electron-ion collisions

**Authors:** Antoni Szczurek<sup>None</sup>; Izabela Babiarz<sup>1</sup>; Victor Goncalves<sup>2</sup>; Wolfgang Schaefer<sup>None</sup>

<sup>1</sup> *Institute of Nuclear Physics Polish Academy of Sciences*

<sup>2</sup> *Universidade Federal de Pelotas*

**Corresponding Authors:** wolfgang.schafer@ifj.edu.pl, antoni.szczurek@ifj.edu.pl, barros@ufpel.edu.br, izabela.babiarz@ifj.edu.pl

One of the main goals of future electron-ion colliders is to improve our understanding of the structure of hadrons. We study the exclusive  $\eta_c$  production by  $\gamma^*\gamma$  interactions in eA collisions and demonstrate that future experimental analysis of this process can be used to improve the description of the  $\eta_c$  transition form factor. The rapidity, transverse momentum and photon virtuality distributions are estimated considering the energy and target configurations expected to be present at the EIC, EicC and LHeC and assuming different predictions for the light-front wave function of the  $\eta_c$  meson. Our results indicate that the electron-ion colliders can be considered an alternative to providing supplementary data to those obtained in  $e^-e^+$  colliders.

## Two-photon interactions / 41

### Proton and neutron evaporation from excited ions in the light-by-light scattering process

**Authors:** Mariola Klusek-Gawenda<sup>1</sup>; Pawel Jucha<sup>1</sup>

<sup>1</sup> *Institute of Nuclear Physics Polish Academy of Sciences*

**Corresponding Authors:** mariola.jadwiga.klusek-gawenda@cern.ch, pawel.jucha@ifj.edu.pl

In 2017, the ATLAS collaboration published an article that confirmed the experimental phenomenon of light-by-light scattering [1]. This process entails the creation of photon pairs as a consequence of the interaction between strong electromagnetic fields. The effect was successfully recorded through the intense photon flux generated during ultra-peripheral collisions of heavy ions. Two additional experimental results of light-by-light scattering were reported in the following years: one by the CMS collaboration [2] in 2018, and another by the ATLAS experiment [3] in 2019.

Light-by-light scattering is accompanied by the excitation of nuclei, which can result in the emission of nucleons from the nucleus. A similar effect is observed in processes such as  $\rho_0$  meson photoproduction [4] or dimuon production [5]. Utilizing the formalism described in [6], the cross-section for light-by-light scattering accompanied by neutron emission was calculated. Furthermore, predictions prepared for the cross-section associated with proton emission, up to date unexplored for any other process, will be discussed. The developed results serve as a guiding framework for future experiments related to heavy-ion collisions, aimed at investigating light-by-light scattering.

**Bibliography:**

- [1] M. Aaboud et al. (ATLAS Collaboration), *Nature Phys.* 13852 (2017)
- [2] CMS Collaboration, *Phys. Lett. B* 797 (2019) 134826
- [3] G. Aad et al. (ATLAS Collaboration), *Phys. Rev. Lett.* 123 (2019) 052001
- [4] J. Adam and others (ALICE Collaboration), *JHEP* 09 (2015) 095
- [5] G. Aad and others (ATLAS Collaboration), *Phys. Rev. C* 104, 024906 (2021)
- [6] M. Klusek-Gawenda, M. Ciemala, W. Schafer, and A. Szczurek, *Phys. Rev. C* 89, 054907 (2014)

**Inclusive photonuclear interactions / 42**

## Open charm/beauty photoproduction in ultraperipheral heavy-ion collisions

**Authors:** Anna Maria Stasto<sup>1</sup>; Gian Michele Innocenti<sup>2</sup>; Mark Strikman<sup>1</sup>; Sohyun Park<sup>3</sup>

<sup>1</sup> *The Pennsylvania State University*

<sup>2</sup> *CERN*

<sup>3</sup> *Boston University*

**Corresponding Authors:** gian.michele.innocenti@cern.ch, spark1@bu.edu, mxs43@psu.edu, ams52@psu.edu

In ultraperipheral heavy-ion collisions, a photon emitted by one nucleus can interact with the other nucleus via photon-gluon fusion and lead to heavy quark production. The resulting yields of open charm or beauty depend on the photon flux and the gluon distribution within nuclei, enabling this process to probe the nuclear gluon distribution function. We extend the previous calculations for the heavy quark photoproduction cross section using updated parton distribution functions and including higher order corrections to the partonic cross section.

43

## Two-boson interactions in the color dipole approach at LHC ultraperipheral collisions

**Author:** Gabriel Zardo Becker<sup>1</sup>

**Co-author:** Emmanuel de Oliveira<sup>2</sup>

<sup>1</sup> *Federal University of Santa Catarina - UFSC*

<sup>2</sup> *UFSC, Brazil*

**Corresponding Authors:** emmanuel.de.oliveira@ufsc.br, zardobecker@gmail.com

In the high energy limit, a boson has enough energy to fluctuate into a quark-antiquark pair, i.e., a color dipole, before interacting with the target. Therefore, the interaction between two bosons, such as  $\gamma$ ,  $W^\pm$ ,  $Z$  or  $g$ , can be studied through the dipole-dipole interaction. In this work, we investigate these interactions in ultraperipheral collisions and estimate the double vector meson production that can be measured at the LHC.

**Vector meson photoproduction / 44****Coherent photoproduction of light vector meson off nuclear targets using the color dipole approach**

**Authors:** Cheryl Henkels<sup>None</sup>; Emmanuel Grève de Oliveira<sup>1</sup>; Haimon Otto Melchior Trebien<sup>2</sup>; Roman Pasechnik<sup>3</sup>

<sup>1</sup> UFSC, Brazil

<sup>2</sup> Universidade Federal de Santa Catarina

<sup>3</sup> Lund university

**Corresponding Authors:** cherylhenkels@hotmail.com, roman.pasechnik@thep.lu.se, haimontrebien@yahoo.com.br, emmanuel.de.oliveira@ufsc.br

We study the coherent photoproduction of light vector mesons in  $AA$  collisions using the color dipole approach. We use the Glauber–Gribov formalism, however, it has to be supplemented by the gluon shadowing, since the coherence length of higher dipole Fock states is smaller than the nucleus radius. We fit this gluon shadowing to the deep inelastic structure function  $F_2$  (E665) and  $\rho$  meson photoproduction (ALICE) data, obtaining the value  $R_G(Q^2 = 0.15 \text{ GeV}^2) = 0.85$  with an excellent description of the five datapoints. We have also made predictions for the coherent photoproduction of  $\rho(2S)$ ,  $\omega(1S, 2S)$  and  $\phi(1S, 2S)$  using the holographic vector meson wave functions.

**Vector meson photoproduction / 45****Exclusive photoproduction of excited quarkonia in ultraperipheral collisions**

**Author:** Haimon Trebien<sup>1</sup>

<sup>1</sup> Universidade Federal de Santa Catarina

**Corresponding Author:** broadcast4815@gmail.com

In this talk, we discuss the exclusive photoproduction of ground and excited states of  $\psi(1S, 2S)$  and  $\Upsilon(1S, 2S)$  in ultraperipheral collisions (UPCs). Using the potential approach in order to obtain the vector meson wave function, we find a good agreement of our calculations with data from the LHC and HERA colliders for  $J/\psi(1S, 2S)$  and  $\Upsilon(1S)$  in  $\gamma p$  collisions. We extend the calculations, via Glauber–Gribov model, to the nuclear case applying them to  $AA$  UPCs. Our results, compared to the LHC data, show the necessity of the inclusion of two main nuclear effects, called gluon shadowing and finite coherence length.

**Inclusive photonuclear interactions / 46****Axion Physics in UPC and LbyL Scattering**

**Author:** César Omar Ramírez Álvarez<sup>1</sup>

**Co-authors:** Arturo Fernández Téllez<sup>1</sup>; Alan Ignacio Hernández Juárez<sup>2</sup>

<sup>1</sup> Benemérita Universidad Autónoma de Puebla

<sup>2</sup> FES-Cuautitlán UNAM



**Corresponding Authors:** arturo.fernandez.tellez@cern.ch, alaban7\_3@hotmail.com, cesaromarramirezalvarez@gmail.com

The light-by-light scattering (LbyL),  $\gamma\gamma \rightarrow \gamma\gamma$ , is a rare process in the Standard Model (SM) in which two photons interact and produce another pair of photons in the final state. The first direct evidence of this process at the LHC was established by the ATLAS experiment in 2017 [1] and subsequently confirmed by the CMS experiment in 2019 [2], both using data collected in 2015. ALICE is one of the LHC experiments where no evidence of LbyL scattering has been found. However, it is estimated that after its upgrade (ALICE3), evidence of LbyL scattering may be discovered, allowing for a comparison of the obtained data with Monte Carlo generator studies.

LbyL scattering occurs at the lowest order in Quantum Electrodynamics (QED) through virtual box diagrams and is prohibited in classical electrodynamics. Since strong interaction is sought to be minimized, this process is studied in ultra-peripheral collisions (UPC) of heavy ions at high energies. Furthermore, it has been proposed as a channel for exploring physics beyond the SM.

In this work, the phenomenological and experimental implications associated with SM or extension models (for example, an Axion-Like Particles (ALP) model), are analyzed under the context of ALICE physics. Monte Carlo studies are presented with the gamma-UPC+MadGraph5\_aMC@NLO generators through diphoton invariant mass distributions for the LbyL scattering process and different scenarios for ALP-photon coupling at different values of ALP masses.

[1] ATLAS Collaboration. Evidence for light-by-light scattering in heavy-ion collisions with the ATLAS detector at the LHC. *Nature Phys* 13, 852–858, 2017.

[2] CMS Collaboration. Evidence for light-by-light scattering and searches for axion-like particles in ultraperipheral PbPb collisions at  $\sqrt{s_{NN}} = 5.02$  TeV. *Physics Letters B*, 797, 2019.

48

## BSM searches in UPCs: recent results and prospects

**Author:** Victor Gonçalves<sup>1</sup>

<sup>1</sup> *Universidade Federal de Pelotas*

**Corresponding Author:** barros@ufpel.edu.br

The experimental study of photon –induced interactions in hadronic collisions became a reality in the last years, motivated by the possibility of improving our understanding of the Standard Model as well as by the opportunity to use these processes as an alternative tool to search for New Physics. Recent results provided the first observation of the light –by –light (LbL) scattering, which is one of the most important predictions of Quantum Electrodynamics (QED), and demonstrated that the experimental analysis of the dilepton production by two - photon interactions is feasible. Moreover, such results also allow us to search for signals of Beyond the Standard Model (BSM) Physics in these final states. In this contribution I will discuss the searching of new particles (Axion - like and Dark photons) and anomalous electromagnetic moments of  $\tau$  lepton in ultra peripheral collisions (UPCs) and present some prospects.

**Reports from the RHIC and LHC experiments / 51**

## Latest UPC Results at STAR

**Author:** David Tlusty<sup>1</sup>

<sup>1</sup> *Creighton University*

**Corresponding Author:** tlusty@gmail.com

Relativistic heavy ions are sources of strong electromagnetic fields which produce photon-induced interactions. These interactions are usually studied in ultra-peripheral collisions (UPCs) of the relativistic heavy ions. The UPCs can produce di-lepton or di-hadron pairs via the  $\gamma\text{-}\gamma$  interactions or produce vector mesons via the  $\gamma\text{-nuclear}$  interactions. Both the photo-produced vector mesons and the lepton/hadron pairs carry the original electromagnetic field. In addition, the photo-produced vector mesons are sensitive to the gluon parton distribution of the entire target nucleus (coherent production) or the individual nucleons (incoherent production).

In this talk, recent STAR results on vector mesons, di-lepton pairs, and di-hadron photo-production will be discussed. The measurements will be compared with available models to discuss the relevant implications.

## Two-photon interactions / 52

### Observation of the $\gamma\gamma \rightarrow \tau\tau$ production in PbPb collisions with the CMS experiment

**Author:** Matthew Nickel<sup>1</sup>

<sup>1</sup> *The University of Kansas (US)*

**Corresponding Author:** matthew.thomas.nickel@cern.ch

Ultrapерipheral nucleus-nucleus collisions produce very large photon fluxes such that fundamental quantum-mechanical processes can be observed and studied in a novel way. In this presentation, an observation of the  $\tau$  lepton photoproduction at LHC is reported, using ultraperipheral lead-lead collision data collected by CMS. This measurement paves the way for a precise determination of the lepton anomalous magnetic moment which, contrary to the electron and muon counterparts, is poorly constrained.

## UPC and saturation / 54

### UPC dijets at small-x: interplay of Color Glass Condensate and Sudakov resummation

**Author:** Cyrille Marquet<sup>1</sup>

<sup>1</sup> *CPHT - Ecole Polytechnique*

**Corresponding Author:** cyrille.marquet@cern.ch

We compute the cross section for the inclusive photo-production of a pair of jets at next-to-leading order accuracy in the Color Glass Condensate framework. We study the emergence of the large Sudakov logarithms in the back-to-back limit, and show that they cannot appear consistently unless the low-x resummation is kinematically constrained.

## Photoproduction in peripheral collisions / 55

### Single and double ratio of elastic vector meson production to inclusive hadron production cross section as a possible signal of saturation in UPCs

**Author:** Huachen Sun<sup>1</sup>

**Co-authors:** Yuri Kovchegov ; Zhoudunming Tu<sup>2</sup>

<sup>1</sup> *Ohio State University*

<sup>2</sup> *BNL*

**Corresponding Authors:** zhoudunming.tu@cern.ch, kovchegov.1@osu.edu, sun.2885@osu.edu

We explore a new ratio of observables in ultra-peripheral  $A + A$  and  $A + p$  collisions as a potential signal of saturation physics. We consider the ratio  $R_1$  of elastic vector meson photo-production cross section to the inclusive hadron or jet photo-production cross section. The ratio can be measured in the  $\gamma + A$  and  $\gamma + p$  collisions taking place in the UPCs. We label the ratios  $R_1(A)$  and  $R_1(p)$ , respectively, with  $A$  the atomic number of the nucleus. Constructing the double ratio  $R_2(A) = R_1(A)/R_1(p)$ , and performing a small- $x$  calculation both in the quasi-classical approximation and by including small- $x$  evolution, we observe that  $R_2(A)$  exhibits a markedly different  $A$  dependence inside and outside the saturation region. Whether we are probing the physics inside or outside the saturation region is determined by the transverse momentum  $p_T$  of the hadron or jet: for  $p_T \lesssim Q_s$  the inclusive production cross section in the denominator of  $R_1$  is largely probing the physics inside the saturation region, while for  $p_T \gg Q_s$  it is probing the physics outside the saturation region, with  $Q_s$  the saturation scale. The size of the produced meson in the elastic cross section also affects whether saturation region is probed or not in the elastic cross section in the numerator of  $R_1$ . In the case of a relatively compact meson production, for instance, for  $J/\psi$ , the double ratio  $R_2(A)$  grows faster with  $A$  inside the saturation region ( $p_T \lesssim Q_s$ ) than outside ( $p_T > Q_s$ ). For a larger meson, like  $\rho$ , the double ratio  $R_2(A)$  decreases with  $A$  outside the saturation region ( $p_T > Q_s$ ), and remains relatively flat inside the saturation region ( $p_T \lesssim Q_s$ ).

**Monte Carlo models / 56**

## The STARlight Monte Carlo

**Author:** Joakim Nystrand<sup>1</sup>

<sup>1</sup> *University of Bergen (NO)*

**Corresponding Author:** joakim.nystrand@cern.ch

The STARlight Monte Carlo calculates cross sections and generates events for a variety of ultra-peripheral collisions. In particular two-photon production of dilepton pairs and single mesons, and photonuclear production of vector mesons. The collision geometry plays a major role in these interactions, and the photon spectrum is thus calculated in impact parameter space. The photonuclear vector meson cross section is calculated from a Glauber model. STARlight is also interfaced to DP-MJET, through which general photonuclear interactions,  $\gamma + A \rightarrow X$ , can be simulated.

The major development of STARlight was performed some time ago, and it has since remained relatively stable. It has sometimes been referred to as an “industry standard” for ultra-peripheral collisions. Some new features have, however, been added recently, for example the decay mode  $J/\psi \rightarrow p + \bar{p}$ , updated branching ratios have been implemented, and the modelling of light-nuclei has been improved. This talk will present the main ingredients of STARlight and compare it to some other models for ultra-peripheral collisions which have recently come on the market.

**Photoproduction in peripheral collisions / 57**

## Photoproduction of $J/\psi$ and dileptons in events with nuclear overlap with ALICE

**Author:** Nicolas Bizé<sup>1</sup>

<sup>1</sup> *Subatech - Nantes Université*

**Corresponding Author:** nicolas.bize@subatech.in2p3.fr

Photon-photon reactions and the production of the  $J/\psi$  meson through photonuclear reactions have been extensively studied in ultra-peripheral heavy-ion collisions, in which the impact parameter is larger than twice the nuclear radius. In recent years, coherently photoproduced  $J/\psi$  and dilepton production via photon-photon interactions have also been observed in nucleus-nucleus ( $A-A$ ) collisions with nuclear overlap. Such quarkonium measurements can help to constrain the nuclear gluon distributions at low Bjorken- $x$  and high energy, while the continuum dilepton production could be used to further map the electromagnetic fields produced in heavy-ion collisions. In addition, these measurements can shed light on the theory behind photon-induced reactions in  $A-A$  collisions with nuclear overlap, including possible interactions of the measured probes with the formed and fast expanding quark-gluon plasma. Furthermore, the produced quarkonium is expected to keep the polarization of the incoming photon due to  $s$ -channel helicity conservation. Thus, in order to confirm the photoproduction origin of the very low- $p_T$   $J/\psi$  yield excess, polarization measurement is an important observable. The ALICE detector can perform quarkonium production measurements at both mid ( $|y| < 0.9$ ) and forward ( $2.5 < y < 4$ ) rapidities down to  $p_T = 0$ . In this presentation, the new ALICE measurements of the  $J/\psi$   $y$ -differential cross section and the first polarization results of coherently photoproduced  $J/\psi$  via the dimuon decay channel at forward rapidity in Pb-Pb collisions at  $\sqrt{s_{NN}} = 5.02$  TeV are reported. Additionally, the measurement of an excess with respect to expectations from hadronic production in the dielectron yield, at low mass and  $p_T$ , at midrapidity in Pb-Pb collisions at  $\sqrt{s_{NN}} = 5.02$  TeV is presented. The results are compared with available theoretical models.

**Reports from the RHIC and LHC experiments / 58**

## Overview of latest UPC results from CMS

**Corresponding Author:** georgios.krintiras@cern.ch

Overview of latest UPC results from CMS.

**Vector meson photoproduction / 59**

## Photoproduction of $J/\psi$ in UPC accompanied by neutron emission

**Corresponding Author:** l.alcerro@cern.ch

Gluons are found to become increasingly dominant constituents of nuclear matter when being probed at higher energies or smaller Bjorken- $x$  values. This has led to the question of the ultimate fate of nuclear gluonic structure at extreme density. In ultraperipheral collisions (UPCs) of relativistic heavy ions, the coherent heavy flavor vector meson production via photon-nuclear interactions is of particular interest, since its cross section is sensitive to the nuclear gluon density. However, in symmetric UPCs, a two-way ambiguity in determining the photon-emitter and the target prevents the extraction of contributions involving high- and low-energy photon-nucleus interactions. This limitation, therefore, had so far reduced our capability to probe the extremely small- $x$  regime. In this talk, we will present the first measurement of coherent charmonium photoproduction, where the two-way ambiguity is solved by implementing a forward neutron tagging technique using UPC lead-lead collisions recorded by the CMS experiment at 5.02 TeV. Results of coherent  $J/\psi$  production will be presented. We will discuss the physics implications of these results, as well as exciting opportunities in future LHC heavy ion runs.

## Future RHIC and experiments, and the EIC / 64

### Exclusive Vector Meson Physics at the EIC

**Author:** Nathaly Santiesteban<sup>1</sup>

<sup>1</sup> *University of New Hampshire*

**Corresponding Author:** nathaly.santiesteban@unh.edu

Abstract to be provided

## First plenary / 65

### Historical introduction to ultra peripheral collisions

**Author:** Carlos Bertulani<sup>1</sup>

<sup>1</sup> *Texas A&M University-Commece*

**Corresponding Author:** carlos.bertulani@tamuc.edu

In this talk, there will be a historical introduction to the physics of UPCs from both theory and experimental perspectives.

## Reports from the RHIC and LHC experiments / 66

### Recent results on ultra-peripheral collisions with the ALICE experiment

**Author:** David Grund<sup>1</sup>

<sup>1</sup> *Czech Technical University in Prague (CZ)*

**Corresponding Author:** david.grund@cern.ch

In this talk, we will present the recent experimental results on the physics of ultra-peripheral heavy ion collisions using the ALICE detector, including the measurements of both heavy and light vector mesons in both ultra-peripheral p-Pb and Pb-Pb collisions.

## Future RHIC and experiments, and the EIC / 67

### UPC physics with ALICE in Run 3

**Author:** Anisa Khatun<sup>1</sup>

<sup>1</sup> *The University of Kansas (US)*

**Corresponding Author:** anisa.khatun@cern.ch

The ALICE experiment has undergone a major detector upgrade for Run 3, expanding its detection capabilities for a wide variety of studies. The new continuous readout, “trigger-less mode”, will

significantly enhance the physics potential for ultra-peripheral collision analyses. In this talk, we will discuss some of the physics analyses that can be carried out in ultra-peripheral collisions using the Run 3 data, and will present some of the first physics performance plots in both proton-proton and heavy-ion collisions.

**Vector meson photoproduction / 68**

## Measurement of the impact-parameter dependent azimuthal anisotropy in coherent $\rho^0$ photoproduction with ALICE

**Author:** Andrea Giovanni Riffero<sup>1</sup>

<sup>1</sup> *University and INFN Torino (IT)*

**Corresponding Author:** andrea.giovanni.riffero@cern.ch

Exclusive vector meson photoproduction in ultraperipheral heavy-ion collisions is a well-established tool to probe the gluon structure of the colliding nuclei. This talk will focus on the observation of entanglement-enabled spin interference in the  $\rho^0$  meson photoproduction, in the form of angular anisotropy. Such an anisotropy appears due to two different factors: the first is that the photons involved in the process are linearly polarized along the impact parameter and the second is the quantum interference between the two entangled amplitudes that contribute to the  $\rho^0$  photoproduction cross section. Furthermore, the interference effect strongly depends on the impact parameter of the collision, which acts as the distance between the openings of a two-slit interferometer.

In this talk, we present the first measurement of this anisotropy in coherent  $\rho^0$  photoproduction from ultraperipheral Pb–Pb collisions at a center-of-mass energy of  $\sqrt{s_{NN}}=5.02$  TeV per nucleon pair, as a function of the impact parameter of the collision, estimated classifying the events in nuclear-breakup classes defined by neutron emission. The  $\rho^0$  mesons are detected by the ALICE experiment through their decay into a pion pair. The anisotropy occurs as a function of  $\phi$ , defined as the azimuth angle between the two vectors formed by the sum, and the difference, of the four-momentum of the pions, respectively. It results in a  $\cos(2\phi)$  modulation of the photoproduced  $\rho^0$ ; the amplitude of the modulation is found to increase by about one order of magnitude from large to small impact parameters. This trend has found to be compatible with the available theoretical predictions.

**Vector meson photoproduction / 69**

## K+K- photoproduction in ultra-peripheral Pb-Pb collisions with ALICE

**Author:** Minjung Kim<sup>1</sup>

<sup>1</sup> *University of California Berkeley (US)*

**Corresponding Author:** minjung.kim@cern.ch

In ultra-peripheral collisions (UPCs), the photon fluctuates to a quark-antiquark dipole which then elastically scatters off the nucleus, emerging as vector meson and opposite-charge pseudoscalar meson pair. The excellent particle identification capabilities of ALICE enable the study of photoproduced  $\pi^+\pi^-$  and  $K^+K^-$  pairs at midrapidity in Pb–Pb collisions at  $\sqrt{s_{NN}} = 5.02$  TeV. We will present the exclusive  $K^+K^-$  photoproduction cross section in ALICE, measured for the first time in UPCs. We will discuss about the interference between resonance contribution of  $\phi(1020) \rightarrow K^+K^-$  and direct pair production, obtained from a fit to the invariant mass spectrum of  $K^+K^-$  pairs, with comparison to the  $\pi^+\pi^-$  system.

**Two-photon interactions / 70****Lepton Pair Production via Two-Photon Process in UPC at STAR****Corresponding Author:** wangmei.zha@cern.ch

Relativistic ultra-peripheral heavy-ion collisions (UPCs) generate an extremely intense electromagnetic field, offering an ideal setting for investigating the electromagnetic excitation of the vacuum. The lowest-order QED excitation involves the creation of lepton pairs through two-photon fusion, commonly referred to as the Breit-Wheeler (BW). In this presentation, we will report a comprehensive study of BW process in UPCs conducted at STAR for Au+Au collisions at  $\sqrt{s} \text{NN} = 200 \text{ GeV}$ . We will present the total production rate, differential pair mass, and transverse momentum distributions as indicators of the characteristics of lepton pairs from BW process in heavy-ion collisions. Furthermore, we will also discuss the angular modulation of the process which provides insights into the behavior of the interacting photons, elucidating their resemblance to real photons with transverse linear polarization.

71

**Introduction****Corresponding Author:** daniel.tapia.takaki@cern.ch

72

**Welcome to the student day at UPC 2023****Corresponding Author:** daniel.tapia.takaki@cern.ch

73

**Review of HERA results from an experimental point of view****Corresponding Author:** jesus.guillermo.contreras.nuno@cern.ch

74

**Review of main QCD ideas****Corresponding Author:** ams52@psu.edu

75

**Review of UPC from an experimental point of view**

**Corresponding Author:** [jesus.guillermo.contreras.nuno@cern.ch](mailto:jesus.guillermo.contreras.nuno@cern.ch)

76

## **Overview of the EIC**

**Corresponding Author:** [ams52@psu.edu](mailto:ams52@psu.edu)

**First plenary / 77**

## **Welcome and introductions**

**Corresponding Author:** [daniel.tapia.takaki@cern.ch](mailto:daniel.tapia.takaki@cern.ch)

78

## **IPC meeting**

Meeting of the International Program Committee

79

## **IPC breakfast**

Breakfast of the International Program Committee

80

## **Time for networking**

81

## **Discussion session**

**Corresponding Authors:** [tuzhoudunming@gmail.com](mailto:tuzhoudunming@gmail.com), [charlotte.barbara.van.hulse@cern.ch](mailto:charlotte.barbara.van.hulse@cern.ch), [vadim.a.guzey@jyu.fi](mailto:vadim.a.guzey@jyu.fi)

82



## Discussion session

**Corresponding Authors:** michael.winn@cern.ch, mark.strikman@cern.ch, james.daniel.brandenburg@cern.ch

UPC and saturation / 83

### The Correlated Spatial Structure of the Proton: Two-body densities as a framework for dynamical imaging

**Author:** Zaki Panjsheeri<sup>None</sup>

**Co-author:** liuti simonetta

**Corresponding Authors:** zap2nd@virginia.edu, sl4y@virginia.edu

The Fourier transforms of generalized parton distributions (GPDs) give single-particle spatial densities of the quarks and gluons inside the proton. The average radius of each partonic component of the nucleon as well as the charge and matter densities of the nucleons are among physical quantities to which GPDs provide insight. However, to obtain a fuller dynamical picture of the proton's internal structure, information on the relative positions between partons is crucial. Such information is not directly contained in the single-particle densities, but we propose that two-particle densities can capture such correlations between the quarks and gluons in the transverse plane. Connecting the two-body densities to the observables for exclusive experiments, we show that two-particle densities can be defined in QCD with generalized double parton distributions (GDPDs).

84

## Collecting conference badges

85

## Student registration

86

## Registration

Monte Carlo models / 87

### LANN QCD: The Inter-American Network of Networks of QCD

**Corresponding Author:** daniel.tapia.takaki@cern.ch

Monte Carlo models / 88

## **Event advertising**

89

## **UPC 2025 presentation**

**Corresponding Authors:** [ilkka.helenius@cern.ch](mailto:ilkka.helenius@cern.ch), [heikki.mantysaari@jyu.fi](mailto:heikki.mantysaari@jyu.fi)

90

## **Closing remarks**

**Corresponding Author:** [daniel.tapia.takaki@cern.ch](mailto:daniel.tapia.takaki@cern.ch)