Forward Physics and QCD at the LHC and EIC

798. WE-Heraeus-Seminar

23 – 27 October 2023

at the Physikzentrum Bad Honnef, Germany

WILHELM UND ELSE HERAEUS-STIFTUNG

Introduction

The Wilhelm und Else Heraeus-Stiftung is a private foundation that supports research and education in science with an emphasis on physics. It is recognized as Germany's most important private institution funding physics. Some of the activities of the foundation are carried out in close cooperation with the German Physical Society (Deutsche Physikalische Gesellschaft). For detailed information see https://www.we-heraeus-stiftung.de

Aims and scope of the 798. WE-Heraeus-Seminar:

Hadron production at very forward rapidities is studied in high-energy proton-proton/ion scattering, lepton-proton/ion scattering, and cosmic ray physics and represents a topic of common interest to these fields. The forward region offers unique opportunities for exploring QCD in small-x and diffractive processes and to search for physics beyond the Standard Model, but it also presents specific experimental challenges in forward hadron detection. Important topics to be discussed within QCD include double-parton scattering, diffraction, BFKL dynamics, saturation, and the color glass condensate. Experimental signatures that will lead to a better understanding of these phenomena are elastic and exclusive processes, forward jet and particle production as well as vector meson, dilepton and photon production. Relevant topics in the search for physics beyond the Standard Model are anomalous couplings, axions and axion-like particles, neutrino properties and the nature of dark matter. The improvement of theoretical predictions and optimization of experimental observables will be central topics of discussion at this seminar. Its purpose is therefore to bring together theorists and experimentalists in high-energy collider experiments and cosmic ray physics, to review the status of forward physics, discuss the opportunities and challenges, and realize synergies between the different fields. Discussions will focus on theoretical predictions and their precision on the one hand and on present experiments at the LHC and RHIC, the forward physics program with the future EIC and FPF, and the connections with cosmic ray physics on the other hand.

Scientific Organizers:

Prof. Dr. Michael Klasen — Universität Münster, Germany
E-mail: michael.klasen@uni-muenster.de

Prof. Dr. Paul Newman — University of Birmingham, UK
E-mail: p.r.newman@bham.ac.uk

Prof. Dr. Christophe Royon — University of Kansas, USA
Email : christophe.royon@ku.edu

Introduction

Administrative Organization:

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Registration:

Elisabeth Nowotka (WE Heraeus Foundation)
at the Physikzentrum, reception office
Monday, 10:00 – 15:00 h

Program

Program

Monday, 23 October 2023

11:00 – 14:00	Registration	
12:30	*LUNCH*	
14:00 – 14:10	Scientific organizers	**Welcome, introductions**
14:10 – 14:50	Raju Venugopalan	**What's big about small x**
14:50 – 15:30	Peter Jacobs	**Overview of forward physics at the LHC**
15:30 – 16:10	Silvia dalla Torre	**The EIC project and the ePIC experiment**
16:10 – 16:35	*COFFEE BREAK*	

PROTON/NUCLEAR TOMOGRAPHY, DPS, GPDS, TMDS

16:35 – 17:10	Emanuele Nocera	**The collinear parton distributions of the proton: Achievements and open issues**
17:10 – 17:45	Tomas Jezo	**Nuclear PDF updates from nCTEQ**
17:45 – 18:20	Katarzyna Wichmann	**Proton structure and HERA data**
18:20 – 18:55	Amanda Cooper-Sarkar	**PDFs from LHC data**
19:00	*DINNER*	

Program

Tuesday, 24 October 2023

08:00	*BREAKFAST*	

PROTON/NUCLEAR TOMOGRAPHY, DPS, GPDS, TMDS

09:00 – 09:35	Jonathan Gaunt	**Information on double-parton scattering from forward physics measurements**
09:35 – 10:10	Valerio Bertone	**3D proton structure in momentum space from current and future forward-physics measurements**
10:10 – 10:45	Daria Sokhan	**GPDs and TMDs at the electron-ion collider**
10:45 – 11:15	*COFFEE BREAK*	
11:15 – 11:50	Charlotte van Hulse	**Proton structure and tomography in fixed-target DIS experiments**
11:50 – 12:15	**Discussion**	
12:15 – 12:25	**Conference photo** (in the front of the lecture hall)	
12:30	*LUNCH*	

Program

Tuesday, 24 October 2023

LOW X, SATURATION

14:00 – 14:35	Edmond Iancu	**Probing gluon saturation via photon-hadron interactions at high energies**
14:35 – 15:10	Agustín Sabio Vera	**The fine print of BFKL dynamics**
15:10 – 15:45	Nestor Armesto	**The color glass condensate and forward physics at the LHC and EIC**
15:45 – 16:10	*COFFEE BREAK*	
16:10 – 16:45	Paul Newman	**Low x physics at ep and pp Colliders**
16:45 – 17:20	Orlando Villalobos Baillie	**Low-x structure functions and nuclear shadowing in heavy ion collisions**

Poster flash talks I

17:20 – 17.30	Thomas Cridge	**MSHT parton distribution function review and recent updates**
17:30 – 17:40	Pit Duwentäster	**Global fits of proton PDFs with non-linear corrections**
17:40 – 17:50	Stephen Maple	**Kinematic fitting for inclusive physics with ePIC at the Electron Ion Collider**
17:50 – 18:00	Zuhal Seyma Demiroglu	**Extraction of the strong coupling with HERA and EIC inclusive data**
18:00 – 18:10	Francesco Giuli	**Impact of inclusive Electron Ion Collider data on collinear parton distributions**

Program

Tuesday, 24 October 2023

Poster flash talks I

18:10 – 18.20	Alexander Neuwirth	**Prompt photon production with up to three jets in POWHEG**
18:20 – 18:30	Florian Jonas	**Measuring prompt photon production with the ALICE Forward Calorimeter (FoCal) upgrade**
18:30 – 18:40	Yair Mulin	**Next-to-leading order photon+jet production**
18:40 – 18:50	Yossathorn Tawabutr	**Complete NLO calculation of forward single-inclusive hadron production in pA collisions**
18:50 – 19:00	Oscar Garcia-Montero	**The McDIPPER: A novel saturation-based 3D initial state model for heavy-ion collisions**
19:00	*DINNER*	

Program

Wednesday, 25 October 2023

08:00	*BREAKFAST*	

TOTAL CROSS SECTIONS, ODDERONS, DIFFRACTION

09:00 – 09:35	Antoni Szczurek	**Diffractive single and double bremsstrahlung at the LHC within tensor pomeron model**
09:35 – 10:10	Vadim Guzey	**Exclusive quarkonium photoproduction**
10 :10 – 10:45	Alexander Jentsch	**Exclusive and diffractive physics at the electron-ion collider**
10:45 – 11:10	*COFFEE BREAK*	
11:10 – 11:45	Kenneth Österberg	**TOTEM experiment: Pomeron and odderon exchange at LHC energies**
11:45 – 12:20	Lydia Beresford	**Diffractive, elastic and total cross section physics at ATLAS**
12:20 – 12:55	Andrea Bellora	**The CMS precision proton spectrometer: Recent results and status**
12:55	*LUNCH*	
14:00 – 14:35	Daniel Tapia Takaki	**tba**
14:35 – 15:10	Ronan McNulty	**Diffractive physics at LHCb**
15:10 – 15:40	**Discussion**	
15:40 – 16:10	*COFFEE BREAK*	

Program

Wednesday, 25 October 2023

Poster flash talks II

16:10 – 16:20	Parker Gardner	**Observation of enhanced long-range elliptic anisotropies inside high-multiplicity jets in pp collisions at the LHC**
16:20 – 16:30	Saray Arteaga Escatel	**Forward jets measurements in proton-lead collisions at CMS**
16:30 – 16:40	Sergio Javier Arbiol Val	**Studies of the LHC optics at point 1 and hard diffractive programme**
16:40 – 16:50	Josh Lomas	**Designing silicon tracking detectors for high radiation environments**
16:50 – 17:00	Maciej Trzebinski	**Overview of ATLAS Roman Pot Detectors: Current status and future perspectives**
17:00 – 17:10	Maciej Lewicki	**Feasibility and discovery potential of diffractive charm production measurement with the ATLAS Forward Proton Detectors**
17:10 – 17:20	Savannah Clawson	**Performance of the ATLAS forward proton detector**
17:20 – 17:30	Kate Lynch	**Inclusive quarkonium photoproduction at the LHC via ultra-peripheral collisions**
17:30 – 17:40	Luis Fernando Alcerro Alcerro	**Probing the gluonic structure of nuclei in ultraperipheral PbPb collisions via vector meson photoproduction with the CMS experiment**

Program

Wednesday, 25 October 2023

Poster flash talks II

17:40 – 17:50	Simone Ragoni	**Studying photonuclear cross sections with UPCs in ALICE**
17:50 – 18:00	Anisa Khatun	**Physics prospects and data preparation for UPC studies with ALICE in Run 3**
18:00 – 18:10	Rainer Schicker	**Summary EMMI workshop on "Forward Physics in ALICE 3"**
18:10 – 18:20	Maura Barros	**Search for new physics at the LHC using the missing mass method**
18:30 – 19:30	**Poster session**	
19:30	*DINNER*	

Program

Thursday, 26 October 2023

08:00	*BREAKFAST*	

BSM, EXCLUSIVE, PHOTON-PHOTON, LONG-LIVED

09:00 – 09:35	Lucien Harland-Lang	**Theory overview of photon-initiated production at the LHC**
09:35 – 10:10	Christophe Royon	**Photon-photon physics at the LHC in pp collisions**
10:10 – 10:45	Brian Cole	**Probing nuclear parton distributions with jet measurements in ultra-peripheral Pb+Pb collisions**
10:45 – 11:20	*COFFEE BREAK*	
11:20 – 11:55	Florian Bernlochner	**tba**
11:55 – 12:30	Tao Han	**BSM physics at the EIC**
12:30 – 13:00	**Discussion**	
13:00	*LUNCH*	
14:30 – 19:00	**Excursion**	
19:00	*HERAEUS DINNER* *(social event with cold & warm buffet with complimentary drinks)*	

Program

Friday, 27 October 2023

08:00	*BREAKFAST*	
COSMIC RAYS		
09:00 – 09:35	Maria-Vittoria Garzelli	**LHC/EIC impact on cosmic ray physics**
09:35 – 10:10	Tanguy Pierog	**QCD challenges in air shower measurements**
SUMMARY		
10:10 – 10:45	Michael Klasen	**Summary**
10:45 – 11:15	*COFFEE BREAK*	
11:15 – 11:45	**Dicussion**	
11:45– 12:00	Scientific organizers	**Poster prizes & closing words**
12:00	*LUNCH*	

End of the seminar and departure

NO DINNER for participants leaving on Saturday; however, a self-service breakfast will be provided on Saturday morning

Posters

Posters

Luis Fernando Alcerro Alcerro	**Probing the gluonic structure of nuclei in ultraperipheral PbPb collisions via vector meson photoproduction with the CMS experiment**
Sergio Javier Arbiol Val	**Studies of the LHC optics at point 1 and hard diffractive programme**
Saray Arteaga Escatel	**Forward jets measurements in proton-lead collisions at CMS**
Maura Barros	**Search for new physics at the LHC using the missing mass method**
Savannah Clawson	**Performance of the ATLAS forward proton detector**
Thomas Cridge	**MSHT parton distribution function review and recent updates**
Zuhal Seyma Demiroglu	**Extraction of the strong coupling with HERA and EIC inclusive data**
Pit Duwentäster	**Global fits of proton PDFs with non-linear corrections**
Oscar Garcia-Montero	**The McDIPPER: A novel saturation-based 3D initial state model for heavy-ion collisions**
Parker Gardner	**Observation of enhanced long-range elliptic anisotropies inside high-multiplicity jets in pp collisions at the LHC**
Francesco Giuli	**Impact of inclusive electron ion collider data on collinear parton distributions**
Florian Jonas	**Measuring prompt photon production with the ALICE Forward Calorimeter (FoCal) upgrade**
Anisa Khatun	**Physics prospects and data preparation for UPC studies with ALICE in Run 3**

Posters

Maciej Lewicki	**Feasibility and discovery potential of diffractive charm production measurement with the ATLAS Forward Proton Detectors**
Josh Lomas	**Designing silicon tracking detectors for high radiation environments**
Kate Lynch	**Inclusive quarkonium photoproduction at the LHC via ultra-peripheral collisions**
Stephen Maple	**Kinematic fitting for inclusive physics with ePIC at the electron ion collider**
Yair Mulin	**Next-to-leading order photon+jet production**
Alexander Neuwirth	**Prompt photon production with up to three jets in POWHEG**
Simone Ragoni	**Studying photonuclear cross sections with UPCs in ALICE**
Rainer Schicker	**Summary EMMI workshop on "Forward Physics in ALICE 3"**
Yossathorn Tawabutr	**Complete NLO calculation of forward single-inclusive hadron production in pA collisions**
Maciej Trzebinski	**Overview of ATLAS roman pot detectors: current status and future perspectives**

Abstracts of Talks

(in alphabetical order)

The Color Glass Condensate and forward physics at the LHC and EIC

N. Armesto[1]

[1] *Instituto Galego de Física de Altas Enerxías IGFAE, Universidade de Santiago de Compostela, 15782 Santiago de Compostela, Galicia-Spain*

The Color Glass Condensate (CGC) is a weak coupling but non-perturbative effective field theory which aims to describe the small x wave function of hadrons and nuclei and their scattering processes at high energies in QCD. It encompasses both the dilute regime where standard linear evolution equations are applicable and the dense regime where non-linear dynamics dominate. At present, it is the best candidate to describe such dense regime from first principles, and constitute the basis of phenomenology in proton-nucleus collisions at the LHC in the forward region and at the future EIC or other lepton-proton/nucleus colliders. In this talk I will review the status of the CGC, particularly in view of the recent NLO calculations both for evolution equations applied to HERA data, and for particle production applied to the LHC and DIS. I will also comment on the relation with the TMD framework.

The CMS Precision Proton Spectrometer: recent results and status

A. Bellora[1], on behalf of the CMS and TOTEM Collaborations

[1]*Università degli Studi di Torino and INFN Torino, Torino, Italy*

The Precision Proton Spectrometer (PPS), formerly known as CMS-TOTEM PPS, is a subdetector of the CMS experiment at CERN, introduced in the LHC Run 2 and designed for measuring protons that escape along the LHC beam line after the interaction in CMS. It provides a powerful tool for advancing BSM searches and studying diffractive processes.
The talk will discuss the key features of proton reconstruction (PPS alignment and optics calibrations), validation chain with physics data (using exclusive dilepton events), and detector performance during the LHC Run 2 [1].
An overview of the physics results using the Run 2 datasets will be presented, covering multiple exclusive production processes as diphoton, top quark pair, Z+X, and vector boson pairs, explored with the aid of the PPS proton tagging [2-5].
The PPS is now taking part to the LHC Run 3 data-taking with a new detector layout and innovative technologies: the new apparatus will be presented, and preliminary results on the Run 3 performance will be shown. Finally, prospects of the PPS upgrade for High Luminosity LHC will be presented [6].

References

[1] CMS and TOTEM Collaborations, Proton reconstruction with the CMS Precision Proton Spectrometer in Run 2, arXiv:2210.05854 (2022), accepted by JINST

[2] CMS and TOTEM Collaborations, Search for exclusive diphoton production with intact protons in PPS, CMS-PAS-EXO-21-007; TOTEM-NOTE-2022-005

[3] CMS and TOTEM Collaborations, Search for central exclusive production of top quark pairs in proton-proton collisions at $\sqrt{s}$ = 13TeV with tagged protons, CMS-PAS-TOP-21-007; TOTEM-NOTE-2022-002

[4] CMS and TOTEM Collaborations, A search for new physics in central exclusive production using the missing mass technique with the CMS detector and the CMS-TOTEM precision proton spectrometer, arXiv:2303.04596 (2023), accepted by EPJC

[5] CMS and TOTEM Collaborations, Search for exclusive $\gamma\gamma \rightarrow$ WW and $\gamma\gamma \rightarrow$ ZZ production in final states with jets and forward protons, JHEP 07 (2023) 229

[6] CMS Collaboration, The CMS Precision Proton Spectrometer at the HL-LHC - Expression of Interest, arXiv:2103.02752 (2021)

Diffractive, Elastic and Total Cross Section Physics at ATLAS

L. Beresford[1] on behalf of the ATLAS Collaboration

[1]*Deutsches Elektronen-Synchrotron DESY, Notkestr. 85, 22607 Hamburg, Germany*

Diffractive and elastic phenomena make up a large fraction of interactions occurring in LHC proton-proton collisions. Due to their non-perturbative nature, measurements of such processes are crucial to improve our understanding of these fundamental processes. Elastic scattering measurements enable determination of important strong interaction quantities, for instance the total cross section. In this talk the most precise high-energy determination of the total cross section and the rho-parameter, the ratio of the real to imaginary parts of the forward elastic scattering amplitude, will be presented. Recent measurements of diffractive processes will also be discussed, as well as the key technique of forward proton tagging which is used in the study of both elastic and diffractive processes.

References

[1] ATLAS Collaboration, European Physical Journal C **83** 441 (2023)

[2] ATLAS Collaboration, Journal of High Energy Physics **02** 042 (2020)

3D proton structure in momentum space from current and future forward-physics measurements

V. Bertone[1]

[1]IRFU, CEA, Université Paris-Saclay, F-91191, Gif-sur-Yvette, France

In this contribution, I will present a recent extraction of unpolarized transverse-momentum-dependent (TMD) distributions from experimental data [1]. I will discuss the theoretical accuracy and the experimental data set considered in this analysis, with particular emphasis on the role of existing forward measurements. I will conclude with some considerations regarding the expected impact on TMDs of the measurements that will be performed at the future Electron-Ion Collider (EIC).

References

[1] MAP Collaboration, *JHEP* 10 (2022) 127

Probing nuclear parton distributions with jet measurements in ultra-peripheral Pb+Pb collisionsF.

Brian Cole[1,2], **Benjamin Gilbert**[1], **and Aaron Angerami**[3]

[1] *Columbia University, New York, NY, USA*
[2] *CERN, Meyrin, Switzerland*
[3] *Lawrence Livermore National Laboratory, Livermore, CA, USA*

It was proposed two decades ago that nuclear parton distributions could be probed in ultra-peripheral heavy ion collisions (UPCs). ATLAS has undertaken a program to carry out such measurements using dijet and multijet final states from which the partonic kinematics can, in principle, be directly measured. In ATLAS, the UPC jet measurements can probe an x and Q^2 range not accessible in DIS or hadronic collisions. In 2017, ATLAS presented preliminary results that established the feasibility of the method, but also demonstrated a number of technical difficulties associated with the measurements driven in part by the lack — at the time — of event generators that incorporate nuclear photon fluxes. A more recent ATLAS measurement has provided preliminary results and ATLAS is near completion of a dedicated low-μ jet calibration which will allow final results from Run 2. New measurements being carried out during the ongoing 2023 Pb+Pb run will improve the statistical precision of the UPC jet measurements and allow the use of the forward neutron topology to probe the impact-parameter dependence of the PDFs. Prospects for measurements of diffractive jet photo-production will also be discussed.

PDFs at the LHC

A.M. Cooper-Sarkar[1]

[1]*University of Oxford, Denys Wilkinson Building, Keble Road, Oxford, OX1 3RH. UK*

Precise knowledge of proton parton distribution functions (PDFs) is a crucial element of accurate predictions of both Standard Model and Beyond Standard Model physics at hadron colliders. This talk presents some of the recent developments, illustrating the impact of LHC measurements on precision PDFs, as determined both by the ATLAS and CMS collaborations, as well as global fitters (CT, MSHT, NNPDF). Comparisons between various global fits are presented, as well as the PDF4LHC combination, and various methodological and theoretical considerations are highlighted.

The EIC project and the ePIC experiment

S. Dalla Torre

INFN, Sezione di Trieste, Trieste, Italy

The Electron-Ion Collider (EIC) will be the only new high-energy collider world-wide in the next twenty-thirty years. Electrons and ions, from p up to U, will collide at high luminosity to explore hadronic physics and making the ultimate understanding of QCD possible. Electron and light nucleus beams will be polarized to address fundamental questions as the origin of the nucleon spin. Other key questions addressed by the project are the origin of the hadron masses and the exploration of high-density gluonic matter. The approved project is successfully progressing at Brookhaven National Laboratory (BNL) in USA. The project includes the ePIC experiment designed to cover the whole physics case at EIC.

The main characteristics of the EIC project and of its accelerator process as well as of the design of the ePIC experiment are discussed. The status of the project is also presented.

LHC/EIC impact on Cosmic Ray physics (theory)

Maria Vittoria Garzelli[1]

[1] *II Institut fuer Theoretische Physik, Universitaet Hamburg, Hamburg, Germany*

I will enlighten the connections of accelerator physics at the Large Hadron Collider (LHC) and the Electron Ion Collider (EIC) with Cosmic Ray (CR) physics, in terms of overlaps and complementarities. I will discuss the similarities and differences in the probed kinematics and collision environments. I will focus in particular on the description of the hadronic interactions, crucial in both cases, and on the utility of the information extracted from colliders for better undestanding the undelying physics of CR interactions in the atmosphere. These considerations might help suggesting new measurements at the LHC and EIC.

Exclusive quarkonium photoproduction

V. Guzey[1,2]

[1] *University of Jyväskyla, P.O. Box 35, 40014 University of Jyväskylä, Finland*
[2] *Helsinki Institute of Physics, P.O. Box 64, 00014 University of Helsinki, Finland*

Exclusive quarkonium photoproduction in ultraperipheral collisions (UPCs) at the LHC provides new information on the partonic structure of nuclei and an important testing ground of small-x dynamics in QCD. We review the status of phenomenological applications of the collinear factorization at next-to-leading order (NLO) of perturbative QCD to coherent J/ψ and Y photoproduction in Pb-Pb UPCs at the LHC with an emphasis of the strong small-x nuclear shadowing of nuclear parton distribution functions (nPDFs) and the residual scale uncertainty. We also discuss outstanding theoretical challenges of the description of these processes in QCD focusing on small-x resummation.

References

[1] K.J. Eskola, C.A. Flett, V. Guzey, T. Löytäinen, H. Paukkunen, Phys. Rev. C **106**, 3, 035202 (2022)
[2] K.J. Eskola, C.A. Flett, V. Guzey, T. Löytäinen, H. Paukkunen, Phys. Rev. C **107**, 4 044912 (2023)
[3] K.J. Eskola, C.A. Flett, V. Guzey, T. Löytäinen, H. Paukkunen, arXiv: 2303.03007 [hep-ph]

BSM Physics at the EIC

Tao Han
Department of Physics and Astronomy
University of Pittsburgh,
Pittsburgh, Pennsylvania 15260, USA

After a brief introduction to the Electron Ion Collider (EIC), I discuss the physics potential of the EIC in searching for new physics beyond the Standard Model (BSM). Examples include the search for charged lepton-flavor violation, a heavy neutral lepton, axion-like particles, testing the effective field theory, and precision measurements of neutral current interactions. Complementarity to the LHC physics will be discussed.

Theory overview of photon-initiated production at the LHC

Lucian Harland-Lang[1]

[1]Department of Physics and Astronomy, University College London, London, WC1E 6BT, UK

In this talk I will summarise the current status and open questions in the theoretical modelling of photon-initiated production at the LHC.

Probing gluon saturation via photon-hadron interactions at high energies

E. Iancu

Institute de Physique Théorique de Saclay
Université Paris-Saclay, F-91191 Gif-sur-Yvette, France

We argue that diffractive jet production in photon-nucleus interactions at high energy is a golden channel to study gluon saturation in the wavefunction of a heavy nucleus, like lead or gold. Photon-nucleus interactions lie at the heart of the future experiments at the EIC and also of the nucleus-nucleus ultraperipheral collisions that are currently investigated at the LHC. Using the color dipole picture and the Color Glass Condensate effective theory, we compute the production of jets via coherent diffraction, that is, via elastic collisions in which the nucleus remains unbroken. We focus on hard processes, where the photon virtuality and/or the jet transverse momenta are much larger than the saturation momentum of the nuclear target. We show that, despite their hardness, these processes are controlled by multiple scattering in the black disk limit and thus are strongly sensitive to gluon saturation. We demonstrate that the associated cross-sections admit transverse-momentum dependent (TMD) factorization, in terms of the unintegrated parton distributions of the Pomeron. This allows us to uncover an interesting duality between multiple scattering in the dipole picture and parton saturation in the Pomeron wavefunction.

References

[1] E. Iancu et al., Phys.Rev.Lett. 128 (2022) 20, 202001
[2] E. Iancu et al., e-Print: 2304.12401 [hep-ph]

Exclusive and Diffractive Physics at the Electron-Ion Collider

A. Jentsch[1]

[1]*Brookhaven National Laboratory, Upton, NY, USA*

The Electron-Ion Collider (EIC) will afford the opportunity to drastically advance our understanding of QCD and the multidimensional structure of both protons and nuclei. An essential component of the EIC physics program is the measurement and study of exclusive and diffractive final states, which yield insight into topics including partonic imaging, structure functions, proton spin, and saturation. The EIC Yellow Report [1] provides a comprehensive look at the exclusive physics program, and several studies have been published since the Yellow Report detailing the experimental needs for these measurements [2,5].

The primary challenge for these final states is measuring the particles they produce, which are generally near-collinear with the outgoing hadron beam and often cannot be seen by the central detectors of the EIC project detector, ePIC. It is therefore important to use subsystems integrated with the outgoing hadron beam-line, the so-called “far-forward” detectors. The ePIC experiment includes a suite of far-forward detectors designed to deliver the necessary geometric coverage and resolution required to achieve the full exclusive physics program envisioned at the EIC. In this presentation, the ePIC far-forward detectors will be briefly introduced, progress on technology selection/evaluation and accelerator integration will be discussed, and a few relevant physics topics will be addressed, in detail.

References

[1] R. Abdul Khalek et al., Nuclear Physics A Volume 1026, October 2022, 122447
[2] A. Jentsch, Z. Tu, and C. Weiss, Phys. Rev. C **104,** 065205, (2021) (Editor’s Suggestion)
[3] W. Chang, E.C. Aschenauer, M. D. Baker, A. Jentsch, J.H. Lee, Z. Tu, Z. Yin, and L.Zheng, Phys. Rev. D **104**, 114030 (2021)
[4] Z. Tu, A. Jentsch, et al., Physics Letters B, (2020)
[5] I. Friscic, D. Nguyen, J. R. Pybus, A. Jentsch, *et al.,* Phys. Lett. B, **Volume 823**, 136726 (2021)

Nuclear PDF updates from nCTEQ

P. Duwentäster[1,2], T. Ježo[3], C. Keppel[4], M. Klasen[3], K. Kovařík[3], A. Kusina[5], C. Léger[6], J.G. Morfín[7], F.I. Olness[8], R. Ruiz[5], P. Risse[3], I. Schienbein[6] and J.Y. Yu[6]

[1]University of Jyväskylä, Department of Physics, Jyväskylä, Finland
[2]Helsinki Institute of Physics, University of Helsinki, Finland
[3]Institut für Theoretische Physik, Universität Münster, Münster, Germany
[4]Jefferson Lab, Newport News, U.S.A.
[5]Institute of Nuclear Physics, Polish Academy of Sciences, Krakow, Poland
[6]LPSC, Université Grenoble-Alpes, Grenoble, France
[7]Fermi National Accelerator Laboratory, Batavia, USA
[8]Department of Physics, Southern Methodist University, Dallas, U.S.A.

We discuss recent updates to the nCTEQ nuclear PDF framework, including vector boson, single inclusive hadron, and heavy quark production data. In particular, this vast body of data provides new constraints on the gluon nPDFs, especially towards the small x values, which is of interest to EIC studies. Not only do these data sets significantly reduce the gluon uncertainty, but they also influence the strange quark density. Moreover, the strange nPDF is further constrained by neutrino deep-inelastic scattering and charm dimuon production data, whose consistency with neutral-current experiments is also re-evaluated. In addition to new data sets, we have implemented an expanded set of computational tools to speed up and enhance the nPDF analysis. These components will form the foundation of a new nCTEQ nuclear PDF reference set.

Diffractive physics at LHCb

R. McNulty[1]

[1]*University College Dublin, Dublin 4, Ireland*

The LHCb detector is fully instrumented between pseudorapidities of 2 and 5 and its forward reach makes it ideally suited to studying diffractive physics, and in particular, central exclusive production. The presence of scintillators at distances of up to 100 m from the interaction point gives the ability to distinguish between processes in which the projectiles remain intact and when they dissociate. I will present measurements of vector meson production and processes mediated by double pomeron exchange. The potential for the observation of glueballs and odderons will be discussed.

Low x physics at ep and pp Colliders

P. Newman

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An experimental perspective is given on the status of low x non-linear dynamics and saturation physics, as studied at electron-proton and proton-proton colliders. The evidence from HERA inclusive and diffractive cross section measurements is reviewed, before moving on to studies of diffractive channels and other low-x-sensitive observables (e.g. forward W and Z production and Drell-Yan) at the LHC. Finally, prospects for more detailed studies at future electron-proton facilities are surveyed.

The Collinear Parton Distributions of the Proton: Achievements and Open Issues

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I review the current knowledge of the collinear parton distribution functions (PDF) of the proton. I discuss how experimental data, theoretical predictions, and statistical techniques are combined to build up this knowledge. I present the main achievements in the determination of PDF precision and accuracy that may contribute to precision and discovery physics at current and future colliders. In particular, I focus on the effects of a variety of theoretical corrections, namely N3LO, photon-induced, and electroweak corrections. I critically examine the limitations of current PDF determinations and the theoretical and computational progress required to overcome some of them.

TOTEM experiment: Pomeron and Odderon exchange at LHC energies

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The TOTEM experiment [1] at CERNs Large Hadron Collider (LHC) is the leading forward physics experiment at the LHC. TOTEM has studied proton-proton (pp) elastic scattering over a wide range of four-momentum transfer t, measured the pp total cross section and investigated diffractive processes in pp collision in detail together with the CMS experiment. One of the key physics motivations is to study processes with Pomeron and Odderon exchange, i.e. exchange of charge parity (C) even and odd colourless gluonic compounds, at LHC energies.

In addition to presenting the physics of elastic and diffractive processes, the presentation will include an account of the physics achievements of the TOTEM experiment, since the start of the LHC. A significant fraction will be devoted to two recent highlights: the observation of Odderon exchange in elastic scattering [2] and the precision study of Pomeron exchange in central exclusive processes [3]. Odderon exchange was observed by combining a study of the difference between differential elastic pp and proton-antiproton $(p\bar{p})$ cross section as function of t in the region of the diffractive minimum and secondary maximum, and a comparison of the pp ρ, the ratio of the real and imaginary hadronic elastic amplitude, and total cross section measurements at LHC with model predictions [4]. Pomeron exchange was studied in detail using central exclusive pion pair production leading to the first observation of the parabolic minimum in the azimuthal angle difference between the two outgoing protons. A probable explanation for this minimum is the interference between the tree diagram and diagrams with additional Pomerons exchanged between the protons.

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QCD Challenges in Air Shower Measurements

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The Pierre Auger Observatory is the world's largest extensive air shower detector. Based on two detection techniques, namely fluorescence telescopes for the observation of the longitudinal development and water Cherenkov detectors for particles at ground, this experiment can be used not only as a cosmic ray observatory, but also to study the basic properties of hadronic interactions leading the development of air showers initiated by these primary cosmic rays. Taking advantage of both detection techniques we will demonstrate that it is possible to test QCD based models using correlations between different air shower observables, like shower maximum and muons at ground, to reduce the uncertainty due to the unknown beam of cosmic rays.

Other cosmic ray experiments like the IceCube detector can measure different energy of muons simultaneously, sensitive to different type of hadrons. Furthermore meta-analysis can be done to test the consistency of the hadronic interaction models used for air shower simulations and the measured data. All-in-all, there is evidences that the current description of forward physics and QCD in the models do not allow for an accurate description of the observed air shower at high energy.

Photon-photon physics at the LHC in pp collisions

C. Royon

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Considering the LHC as a photon photon collider, we will discuss the reach on quartic 4 photon, photon photon WW, 3 photon Z, photon photon t t anomalous couplings at the LHC by tagging the intact protons in the final state. We gain two to three orders of magnitude on sensitivity compared to more standard methods at the LHC. We will also discuss the sensitivities to axion like particles.

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GPDs and TMDs at the Electron-Ion Collider

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The Electron-Ion Collider (EIC), to be constructed at Brookhaven National for a start of operations in the early 2030s, will provide high-precision access to the gluon and sea-quark dominated region of the nucleon [1]. With luminosities of $10^{33\text{-}34}$ $cm^{-2}s^{-1}$, centre of mass energies of 20-140 GeV, highly polarised electron and proton / light-ion beams and almost fully hermetic detectors with excellent forward coverage, the collider will enable measurements of a wide range of processes in a very large, previously-unchartered region of the nucleon phase space. Measurements of exclusive and semi-inclusive processes will enable the high-precision study of the nucleon in 3D through the extraction of, respectively, Generalised Parton Distributions (GPDs), which correlate transverse position and longitudinal momentum of partons, and Transverse Momentum-dependent Distributions (TMDs), which correlate the parton transverse and longitudinal momenta [2].

Processes with sensitivity to GPDs can be accessed in exclusive measurements with minimal four-momentum transfer to the nucleon, which requires high-precision instrumentation in the forward region -- a key design feature of the EIC's ePIC detector. TMD-sensitive measurements typically rely on the detection of produced mesons in the central region, where ePIC has excellent hermeticity and detection sensitivity for a wide momentum-range of charged and neutral species. This talk reviews the prospects of accessing GPDs and TMDs at the EIC.

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Antoni Szczurek

Diffractive single and double bremsstrahlung at the LHC within tensor pomeron model

We evaluate the cross section for diffractive bremsstrahlung of a single photon in the $pp \to pp\gamma$ reaction at high energies and at forward photon rapidities. Several differential distributions, for instance, in y, $k_\perp$ and ω, the rapidity, the absolute value of the transverse momentum, and the energy of the photon, respectively, are presented. We compare the results for our standard approach, based on QFT and the tensor-pomeron model, with two versions of soft-photon-approximations, SPA1 and SPA2, where the radiative amplitudes contain only the leading terms proportional to ω^{-1}. The SPA1, which does not have the correct energy-momentum relations, performs surprisingly well in the kinematic range considered. We discuss also azimuthal correlations between outgoing particles. The azimuthal distributions are not isotropic and are different for our standard model and SPAs. We discuss also the possibility of a measurement of two-photon-bremsstrahlung in the $pp \to pp\gamma\gamma$ reaction. In our calculations we impose a cut on the relative energy loss ($0.02 < \xi_i < 0.1$, $i = 1, 2$) of the protons where measurements by the ATLAS Forward Proton (AFP) detectors are possible. The AFP requirement for both diffractively scattered protons and one forward photon (measured at LHCf) reduces the cross section for $pp \to pp\gamma$ almost to zero. On the other hand, much less cross-section reduction occurs for $pp \to pp\gamma\gamma$ when photons are emitted in opposite sides of the ATLAS interaction point and can be measured by two different arms of LHCf. For the SPA1 ansatz we find $\sigma(pp \to pp\gamma\gamma) \simeq 0.03$ nb at $\sqrt{s} = 13$ TeV and with the cuts $0.02 < \xi_i < 0.1$, $8.5 < \mathrm{y}_3 < 9$, $-9 < \mathrm{y}_4 < -8.5$. Our predictions can be verified by ATLAS and LHCf combined experiments. We discuss also the role of the $pp \to pp\pi^0$ background for single photon production.

Proton structure and tomography in fixed-target DIS experiments

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Deep-inelastic scattering allows the study of the one- and three-dimensional structure of the nucleon in momentum space and in mixed momentum and position space. Various experiments at Jefferson Lab, CERN and DESY have performed measurements, by colliding a lepton beam with a fixed target, of semi-inclusive deep-inelastic scattering interactions and of hard exclusive processes. The former type of processes gives access to the (spin-dependent) three-dimensional parton distributions in momentum space, while the latter provides information on the (spin-dependent) three-dimensional distributions of partons in momentum and position space as well as on the internal distribution of pressure and shear forces inside the nucleon. An overview of the performed measurements and their interpretation, when applicable, will be presented and discussed.

What’s big about small x

Raju Venugopalan

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We outline some of the powerful interdisciplinary connections of QCD at small x in the framework of the Color Glass Condensate Effective Field Theory. These include

a) The problem of thermalization in heavy-ion collisions and some of its universal features
b) The enhancement and possible first measurements of topological sphaleron transitions in a polarized proton at small x
c) A quantitative double copy to gravity and the insights gained from this correspondence

Low-x structure functions and nuclear shadowing in Heavy Ion collisions

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The very intense flux of photons produced by the passage of heavy ions at ultrarelativistic energies has provided a new tool for studying gluon distributions in protons and nuclei. The measurements are made in ultra-peripheral collisions (UPCs)[1,2], where two ultrarelativistic nuclei pass each other at a small impact parameter (of the order of a few fermi), but not close enough for the projectiles to overlap. Under these circumstances strong interaction processes, which give rise to very large multiplicities, are suppressed, and photonuclear and electromagnetic processes dominate.

In this talk a brief introduction to UPCs will be given, in particular describing the principal experimental signatures and the challenges they present The exclusive production of vector mesons, in particular, has been found to give valuable insights into both proton and nuclear pdfs. An overview of what has been found so far, in both pA and A-A interactions, will be given, along with some prospects for the (near) future[3].

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Proton structure and HERA data

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Abstract

The HERA inclusive data are a backbone of every parton density functions (PDF) extraction. Additional information is coming from jet and heavy flavor physics and allows testing QCD and determining some of its parameters, like strong coupling $\alpha_S(M_Z^2)$. A short reminder of so-called HERAPDF philosophy, where PDFs are extracted from HERA data alone, is presented and newest results on HERAPDF parton distributions are reviewed. Additionally some prospects of improving PDFs precision using future EIC data are discussed.

Abstracts of Posters

(in alphabetical order)

Probing the gluonic structure of nuclei in ultraperipheral PbPb collisions via vector meson photoproduction with the CMS experiment

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Intense electromagnetic fields surround nuclei when traveling at relativistic energies. At such high energies, when two nuclei pass each other at an impact parameter greater than the sum of nuclear radii, the strong interaction is suppressed. Instead, nuclei interact electromagnetically via photon exchanges. These photons give rise to a plethora of photo-induced phenomena, sensitive to the gluonic structure of nuclei. In particular, vector meson photoproduction represent very clean processes thar are being explored at LHC.
In this contribution, we discuss the recent result of the CMS Collaboration on photoproduction of J/psi in lead-lead collisions [1] and its impact in our understanding of the nuclear structure.

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Studies of the LHC Optics at Point 1 and Hard Diffractive Programme

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ATLAS detector is equipped with a system dedicated to the measurement of protons scattered at low-angle during the proton-proton interaction. These detectors are named ATLAS Forward Proton (AFP) and are installed ~200 meters from the interaction point in the so-called Roman Pots allowing them to take data very close to the proton beam.
High-momentum protons, scattered into the LHC beam pipe are characteristic signatures of the so-called hard diffractive events - a very interesting, but relatively poorly explored so far at the LHC energies, class of processes. One of the key factors of the diffractive measurement capability is the visibility of scattered protons in the AFP detector acceptance.

The AFP acceptance is due to the influence of the LHC magnets installed between the collision point and the detectors. Therefore, the settings of these magnets, called optics, are central to the analysis of data collected by the Roman pots. During Run 3 data-taking various optics were used. Their impact on the acceptance of the forward proton detectors is discussed. In addition, the studies of future, considered beam optics like “inverted inner triplet polarity” and “HL-LHC” are shown.

Finally, a brief discussion of the possible hard diffractive programme considering AFP acceptance will be held. This includes the processes with single and double-scattered protons associated with high transverse momentum objects (jets, photons, etc.) visible in ATLAS.

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Forward jets measurements in proton-lead collisions at CMS

S. Arteaga Escatel[1,2]

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An excelent tool for constraining the small-x gluon parton distribution functions (PDFs) is exploring the forward rapidity region of jets production. In particular, forward jets with low p_T offer insights into the parton densities and their evolution at small x because at lowest order in α_S , the η and p_T dependence of jets are related to the momentum fraction x carried by the incoming parton. The nominal acceptance for jet reconstruction in CMS extends over the range $|\eta| < 5.2$, limited by the acceptance of the HF calorimeters. However, the acceptance for forward particle production has been extended to $-6.6 < \eta < -5.2$ using the CASTOR calorimeter during special runs[1]. This detector allows for the detection and reconstruction of jets with a minimum p_T of approximately 3 GeV. Therefore, the study of jets using CASTOR provides an opportunity to explore the low-x regime and examine perturbative nonlinear parton evolution effects. CMS measurement of forward inclusive jet cross section for proton-lead collisions at 5.02TeV will be discussed as well as the comparison with Monte Carlo generator models in the context of saturation of gluon densities at low fractional parton momenta.

References

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Search for new physics at the LHC using the missing mass method

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There is an extensive Forward Physics program at the LHC in which forward proton detectors play an indispensable role. They can tag the forward protons and also measure their momenta. These two protons can emit two photons that annihilate, leading to a final state that is detected in the central detector. Combining the information from the forward proton detectors and the central detector, one can use the missing mass method to search for new particles. These new particles can be candidates for dark matter or axion-like particles. The final state would be characterised by a visible signal plus missing energy in the central detector in association with two protons in the forward detector. Studying the balance between the forward proton information and the visible particles in the central detector, the properties of the new particle can be inferred in addition to reducing the combinatorial background, usually overwhelming signal production. Different possible signals will be discussed as a starting point for a future sensitivity study.

Performance of the ATLAS Forward Proton detector

Savannah Clawson[1], **on behalf of ATLAS**

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Since 2016, the ATLAS detector has been equipped with ATLAS Forward Proton (AFP) detectors. AFP aims to measure protons scattered at very small angles, which are a natural signature of so-called diffractive events and photon-fusion processes. The AFP detector consists of four stations which are positioned roughly 200 m along the beamline on either side of the central ATLAS detector. Each station is equipped with four planes of edgeless 3D silicon-tracking sensors and the outer two stations also contain Cherenkov time-of-flight detectors.

AFP detectors took data in various LHC conditions, recording around 72 1/fb of data. This includes special data-taking campaign taken at lowered pile-up (number of proton-proton interactions during single bunch crossing, μ) conditions: 150 1/pb with μ = 2, 0.8 1/pb with μ = 1, 200 1/nb with μ ~0.05 and 0.46 1/nb with μ = 0.005. Already these data sets promise interesting physics analyses, and even more are expected to be collected.

However, for meaningful, precise measurements the performance of ATLAS sub-detectors, especially AFP, has to be understood. Various aspects of the performance of both the tracking and time-of-flight systems will be discussed. This includes trigger and readout efficiency, alignment, etc. Finally, the expectations for the rest of LHC Run 3 will be stated.

MSHT Parton Distribution Function Review and Recent Updates

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I will first review the MSHT20 parton distribution functions (PDFs) [1], the post Run 1 PDF set developed for precision LHC physics and wider applications. I will then focus on subsequent developments and recent progress. This will cover notable experimental, methodological and theoretical advances. I will therefore describe several further studies including amongst others: (1) The study of the strong coupling constant and heavy quark masses in our PDFs [2], resulting in a competitive determination of the $\alpha_S(M_Z)$. (2) QED evolved PDFs and the photon, and impacts on cross-sections. (3) Approximate N3LO PDFs [3] and the inclusion of theoretical uncertainties into PDFs for the first time. (4) Constraining the top quark mass in the PDF fit [4]. (5) Inclusion of a variety of new data sets, from dijet data to seaquest drell-yan data to EIC pseudodata. Of particular relevance for this workshop are the aN3LO PDFs needed for precision calculations and their effects on uncertainties, including the incorporation of missing higher order uncertainties. There are also connections with small x resummation in this work. Meanwhile, separately our studies of the impacts of EIC pseudodata on PDF uncertainties will also be of particular interest.

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Extraction of the strong coupling with HERA and EIC inclusive data

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The sensitivity to the strong coupling $\alpha_S(M_Z^2)$ is investigated using existing Deep Inelastic Scattering data from HERA in combination with projected future measurements from the Electron Ion Collider (EIC) in a next-to-next-to-leading order QCD analysis. A potentially world-leading level of precision is achievable when combining simulated inclusive neutral current EIC data with inclusive charged and neutral current measurements from HERA, with or without the addition of HERA inclusive jet and dijet data. The result can be obtained with significantly less than one year of projected EIC data at the lower end of the EIC centre-of-mass energy range. Some questions remain over the magnitude of uncertainties due to missing higher orders in the theoretical framework.

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Global fits of proton PDFs with non-linear corrections

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We perform numerical studies of non-linear corrections to the DGLAP evolution equations of proton parton distribution function (PDFs), which originate from the gluon recombination in the leading $\log(Q^2)$ approximation. Adding a new non-linear evolution module to the HOPPET toolkit, we find that the non-linear corrections suppress the gluon and quark singlet distributions for $x < 10^{-4}$ by as much as 25% and 20%, respectively. While around the input scale the non-linear corrections affect the gluon and quark distributions dramatically differently with the suppression being largest at $Q < 10$ GeV in the gluon case, they become similar in the large Q limit. Implementing it in the xFitter framework, we carried out a new global fit of proton PDFs with non-linear corrections using the BCDMS, NMC and HERA data on lepton-proton deep inelastic scattering (DIS). We found that these data are not sensitive to the non-linear corrections, but strongly disfavor the small values of the parameter $R < 0.5 GeV^{-1}$ characterizing the gluon spatial overlap. Extending our predictions for the longitudinal structure function $F_L(x, Q^2)$ to the case of EIC and LHeC, we argue that the expected statistics and kinematic reach should allow one to probe the gluon recombination effects in the proton.

The McDIPPER: A novel saturation-based 3D initial state model for Heavy-Ion Collisions

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We present a new 3+1D resolved model for the initial state of ultrarelativistic Heavy-Ion collisions, based on the -factorized Color Glass Condensate hybrid approach [1-4]. This new model responds to the need for a rapidity-resolved initial-state Monte Carlo event generator which can deposit the relevant conserved charges (energy, charge and baryon densities) both in the midrapidity and forward/backward regions of the collision. This event-by-event generator computes the gluon and (anti-) quark phase-space densities using the IP-Sat model, from where the relevant conserved charges can be computed directly. In the present work we have included the leading order contributions to the light flavor parton densities. As a feature, the model can be systematically improved in the future by adding next-to-leading order calculations (in the CGC hybrid framework), and extended to lower energies by including sub-eikonal corrections the channels included. We present relevant observables, such as the eccentricities and flow decorrelation, as tests of this new approach.

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Observation of enhanced long-range elliptic anisotropies inside high-multiplicity jets in pp collisions at the LHC

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A search for QCD collective effects is performed with the CMS experiment via correlation measurements of charged constituents inside jets produced in proton-proton collisions at the LHC. The analysis uses data collected at a center-of-mass energy of $\sqrt{s} = 13$ TeV and an integrated luminosity of 138 fb^{-1}. For charged constituents within a reconstructed jet of cone radius 0.8, two-particle correlations as functions of relative azimuthal angle ($\Delta\phi^*$) and pseudorapidity ($\Delta\eta^*$) are performed in a novel "jet frame," where constituent η, ϕ variables are redefined relative to the direction of the jet. The correlation functions are studied in classes of in-jet charged-particle multiplicity up to nearly 100. Anisotropic Fourier harmonics are extracted from long-range azimuthal correlation functions for $|\Delta\eta^*| > 2$. For low-multiplicity jets, the long-range elliptic anisotropic harmonic, v_2^j, is observed to decrease with multiplicity. This trend is well described by Monte Carlo (MC) event generators. However, a rising trend of v_2^j emerges at an in-jet charged-particle multiplicity above ≈ 80. This trend is not reproduced by MC models. This observation yields new insights into the dynamics of parton fragmentation processes in the vacuum.

Impact of Inclusive Electron Ion Collider Data on Collinear Parton Distributions

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This poster presents the impact of simulated inclusive Electron Ion Collider Deep Inelastic Scattering data on the determination of the proton and nuclear parton distribution functions (PDFs) at next-to-next-to-leading order in QCD.
The influence on the proton PDFs is evaluated relative to the HERAPDF set, which uses inclusive HERA data only, and also relative to the global fitting approach of the MSHT PDFs. The impact on nuclear PDFs is assessed relative to the EPPS16 global fits and is presented in terms of the nuclear modification ratios. For all cases studied, significant improvements in the PDF uncertainties are observed for several parton species.
The most striking impact occurs for the nuclear PDFs in general and for the region of high Bjorken x in the proton PDFs, particularly for the valence quark distributions.

Measuring prompt photon production with the ALICE Forward Calorimeter (FoCal) upgrade

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FoCal is a high-granularity forward calorimeter, which is planned to be installed as an ALICE upgrade subsystem during LHC Long Shutdown 3, and to take data during LHC Run 4. The FoCal acceptance will cover a pseudorapidity interval of $3.2 < \eta < 5.8$, enabling the exploration of QCD at unprecedentedly low Bjorken-x of down to about 10^{-6} — a regime where effects due to non-linear QCD dynamics are expected to be sizable.

The FoCal electomagnetic calorimeter is a compact silicon-tungsten sampling electromagnetic calorimeter (FoCal-E), with pad and pixel longitudinal and transverse segmented readout layers to achieve high spatial resolution for discriminating between isolated photons and decay photon pairs. The FoCal hadronic component (FoCal-H) is constructed from copper capillary tubes filled with scintillator fibers and used for isolation energy measurement and jets.

This contribution presents the capabilities of the FoCal detector to perform measurements of isolated prompt photons, which are produced directly in a hard scattering of two partons. Prompt photons are a particularly robust probe for (nuclear) Parton Distribution Functions (PDFs), because they do not interact strongly with the hadronic medium.This allows the photon propagate through the evolution of the collision unaffected by potential final state effects, carrying information from its production until its detection in the FoCal detector.

Detailed FoCal performance studies will be presented, using simulations of signal and background processes that are propagated through a realistic detector model.
This allows quantification of the FoCal photon reconstruction efficiency, purity and isolation capabilities. In addition, next-to-leading order calculations of prompt photon production are used to estimate the potential impact of prompt photon measurements on the future determinations of nuclear PDFs.

References

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[2] ALICE Collaboration, ALICE-PUBLIC-2023-001
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Physics prospects and data preparation for UPC studies with ALICE in Run 3

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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.

Partonic structure of nuclei

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We analyze the longitudinal structure of nuclei as described in the context of nuclear parton distribution functions (nPDFs). Such a description uses the language of factorization theorems, in analogy to the parton distributions (PDFs) of free protons. We focus on recent results of the nCTEQ collaboration related to the high-x structure of nuclei data a novel phenomenological nPDF parametrization inspired by short-range correlation (SRC) models. The analysis of the above components leads to intriguing results.

References

[1] A.W. Denniston, et al., https://inspirehep.net/literature/2660149

Feasibility and discovery potential of diffractive charm production measurement with the ATLAS Forward Proton Detectors

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In this talk, the feasibility of single-diffractive production of charmed mesons will be dscussed, in particular, the measurement of production cross sections of mesons containing the open charm ($D^\pm$, $D^{*\pm}$, $D_s^\pm$) in diffractive collisions at $\sqrt{s}$ = 13.6 TeV with the ATLAS detector.

The D mesons are identified through the reconstruction of charged particle tracks and associated vertices in the central ATLAS detector, while the diffractive nature of collisions is determined by the forward proton scattering detected by the ATLAS Forward Proton Detectors (AFP). It is planned to study the events with a proton tag on a single side and on both sides of the interaction point.

I will summarize the widely range of theoretical predictions and general feasibility studies for the measurement in ATLAS.

Designing Silicon Tracking Detectors for High Radiation Environments

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Forward physics detectors rely largely on silicon tracking detectors to measure the positions and trajectories of high rapidity particles such as the deflected protons measured by the AFP spectrometer for ATLAS. A significant challenge is the development of silicon detectors which can withstand the high level of radiation present at close proximity to the beam, as is required for forward physics detectors [1, 2]. This poster will cover the damaging effects of radiation on silicon detectors, and how they can be designed to mitigate these effects, including recent advancements made for the ITk project for ATLAS at HL-LHC [3].

References

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[2] CMS Collaboration “CMS-TOTEM Precision Proton Spectrometer” CERN-LHCC-2014-021 ; TOTEM-TDR-003 ; CMS-TDR-013 (2014)

[3] ATLAS Collaboration “Technical Design Report for the ATLAS Inner Tracker Strip Detector” CERN-LHCC-2017-005, ATLAS-TDR-025 (2017)

Inclusive quarkonium photoproduction at the LHC via ultra-peripheral collisions

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Quarkonia offer a unique laboratory to study the interplay between long- and short-distance hadronic physics. Despite being discovered almost 50 years ago, there is no single description of quarkonium production that can reproduce all of the data. In particular, no description can reconcile the hadro- and photoproduction data. Owing to the limited available photoproduction data, we explore the possibility to use ultra-peripheral proton-lead collisions at the LHC to study inclusive J/psi photoproduction, namely when a quasi-real photon emitted by the fully stripped lead ion breaks a proton to produce a J/psi. Owing to the extremely large energies of the colliding hadrons circulating in the LHC, the range of accessible energies largely exceed what has been and will be studied at lepton-hadron colliders like HERA and the LHC. We obtain a leading-order inclusive-photoproduction cross section of 50 microbarns, we find that inclusive-photoproduction can be isolated from possible hadroproduction processes by imposing the absence of significant activity in the lead-going direction, and may be further isolated by imposing rapidity-gap based cuts on detector activity. We estimate the background-to-signal ratio to be of order 0.001 and 0.01 at CMS and LHCb. In addition, we propose a method to reconstruct the collision energy of the photon-nucleon system as well as the elasticity, z. This reconstruction will allow kinematic regions to be defined that minimize theoretical uncertainty as well as offering a lever-arm to understand the quarkonium production mechanism. We find that z can be reconstructed with a resolution of 0.3 and 0.1 in the lowest and largest z regions, respectively.

Kinematic Fitting for Inclusive Physics with ePIC at the Electron Ion Collider

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An accurate reconstruction of the kinematic variables x, y, Q^2 is essential for the inclusive physics program at the future EIC. Conventional reconstruction methods usually rely on two of the four measured quantities (energy and angle of the scattered electron and hadronic final state) with the resolution of such methods depending on the kinematic regime under study, detector acceptance and resolution effects, and the size of radiative processes. A kinematic fit using all measured quantities simultaneously allows one to obtain an estimate of the kinematic variables, as well as the energy of possible initial state radiation. A technique was developed to perform fitting in a Bayesian framework using informative priors for the relevant quantities. Detailed simulation studies were performed using the ePIC detector for neutral current e-p scattering samples (including initial state radiation), and kinematic resolutions studied for several conventional methods and the kinematic fit based method. The ability of the ePIC detector to accurately reconstruct inclusive kinematics at the EIC is demonstrated, and an improved resolution achieved using the kinematic fitting approach

Next-to-leading order photon+jet production

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Using the CGC effective theory together with the hybrid factorisation, we study forward photon+jet production in proton-nucleus collisions beyond leading order. We first compute the "real" next-to-leading order (NLO) corrections, i.e. the radiative corrections associated with a three-parton final state, out of which only two are being measured. Then we move to the "virtual" NLO corrections to dijet production, in which a gluon loop is included as a part of the amplitude, before or after the measurement. Each of these loop diagrams diverges, and we explain our treatment in order to obtain finite expression for the cross section.

We explicitly work out the interesting limits where the unmeasured gluon is either a soft, or the product of a collinear splitting. We find the expected results in both limits: the B-JIMWLK evolution of the leading-order dijet cross-section in the first case (soft gluon) and, respectively, the DGLAP evolution of the initial and final states in the second case (collinear splitting).

References

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Prompt photon production with up to three jets in POWHEG

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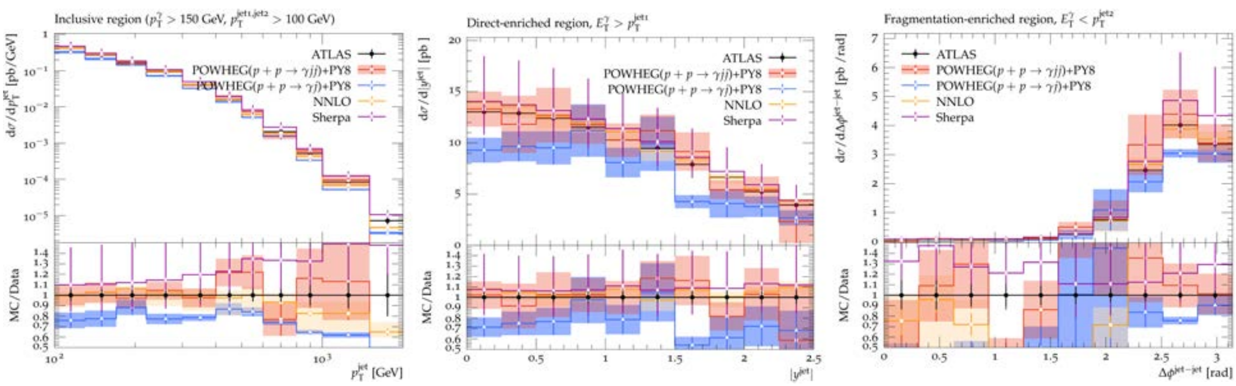
The production of prompt photons in association with jets is a very sensitive probe of the gluon distribution in light and heavy nuclei as well as of the properties of the quark-gluon plasma. We present a new calculation of prompt photon production with up to three jets at next-to-leading order of (NLO) QCD matched to parton showers with the POWHEG method. As applications, we examine correlations between the photon and the produced up to three jets as well as different approaches to photon fragmentation. The POWHEG approach does not require relying on photon fragmentation functions, instead a parton shower is matched to the generated event.
The following figures show preliminary results of the new calculation for an isolated photon plus two-jet analysis performed by ATLAS in pp collisions at 13 TeV [1]. The analysis examines several observables in different regimes, namely inclusive, direct-enriched and fragmentation-enriched contributions, based on the particle with the largest transverse momentum. In addition to the experimental data, predictions from Sherpa [1], our previous calculation of direct photons in POWHEG with PYTHIA8 [2] as well as recent NNLO corrections [3] are given. Although the data is higher than predicted by the leading order calculation, all higher order calculations agree reasonably well with the data.



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[2] Jezo, T. et al. JHEP 11, 033 arXiv: 1610.02275 [hep-ph] (2016)
[3] Badger, S. et al., arXiv: 2304.06682 [hep-ph] (Apr. 2023)

Studying photonuclear cross sections with UPCs in ALICE

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Ultra-peripheral collisions (UPC) are events characterised by large impact parameters between the two projectiles, larger than the sum of their radii. In UPCs, the protons and ions accelerated by the LHC do not interact via the strong interaction and can be regarded as sources of quasireal photons.
The study of vector meson photoproduction in UPCs is of great interest since it is sensitive to low-x gluons. Using the Run 2 data, the ALICE Collaboration has carried out various measurements on coherent J/ψ photoproduction, including the rapidity-differential cross section, and the cross section for the coherent J/ψ photoproduction accompanied by emission of forward neutrons. The data have been compared to models incorporating nuclear shadowing effects and gluon saturation.
In this contribution, the new results of the ALICE Collaboration are presented which extend the study of the photonuclear cross sections by covering the range in Bjorken-x $1.1 \cdot 10^{-5} < x < 3.3 \cdot 10^{-2}$.

Summary EMMI workshop on "Forward Physics in ALICE 3"

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The goal of the EMMI workshop “Forward Physics in ALICE 3”, scheduled in Heidelberg, oct 18-20, is to review and discuss the physics programme which becomes accessible in pp, pA and AA-collisions if very forward tracks can be measured in the ALICE 3 detector under discussion[2]. The addressed physics topics in pp-collisions are, among others, elastic and inelastic scattering, single and double diffractive dissociation, and exclusive production of dileptons, W^+W^- and $t\bar{t}$-pairs.
Exclusive production of dileptons and $c\bar{c}$-pairs are among the discussed topics in pA-collisions, whereas in AA-collisions the prospects for measuring signatures of gluon-saturation are of highest interest. I will give an overview of this workshop, and will present some of the experimental constraints to carry out such measurements in the future.

References

[1] R.Schicker, Phys. Inst., University Heidelberg
[2] Letter of intent for ALICE 3, arXiv:2211.0249

Complete NLO Calculation of Forward Single-Inclusive Hadron Production in pA Collisions

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We study the single-inclusive particle production from proton-nucleus collisions in the dilute-dense framework of the color glass condensate (CGC) at next-to-leading order (NLO) accuracy. In this regime, the cross section factorizes into hard impact factors and dipole-target scattering amplitude describing the eikonal interaction of the partons in the target color field. For the first time, we combine the NLO impact factors with the dipole amplitude evolved consistently using the NLO Balitsky-Kovchegov (BK) equation. The resulting π^0 cross section with all parton channels included are consistent with the recent LHCb measurements [1]. In particular, this demonstrates that it is crucial to consistently include all the ingredients at NLO accuracy, as the NLO evolution coupled to the leading order impact factor is shown to produce a large Cronin peak that is not visible in the data. The dependence of the results on rapidity will also be discussed.

References

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Overview of ATLAS Roman Pot Detectors: Current Status and Future Perspectives

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[2] on behalf of the ATLAS Forward Detector group

The ATLAS detector is equipped with two systems dedicated for the measurement of so-called diffractive protons. Absolute Luminosity For ATLAS (ALFA [1]), installed during Run 1, is designed to operate in a dedicated, very special settings of the LHC accelerator - so-called high-beta* optics. These settings allow to measure protons scattered elastically. The second system, ATLAS Forward Proton (AFP [2]), was installed during Run 2. Its goal is to take data during “regular” LHC campaigns. The aim is to study hard diffraction and “photon physics” as well as search for Beyond Standard Model processes.

Since their installation, several significant developments were done to improve the performance of ATLAS forward detectors. The most recent refurbishments and improvements done during LHC Long Shutdown 2 will be reported. This includes developments on the silicon tracking and time-of-flight (ToF) detectors as well as services like detector cooling.

Finally, the summary of data taken so far and plans for further Run 3 data-taking campaigns, considering various LHC scenarios, will be discussed.

References

[1] ATLAS Collaboration, ATLAS-TDR-18, CERN-LHCC-2008-004
[2] ATLAS Collaboration, ATLAS-TDR-024, CERN-LHCC-2015-009