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Abstract

Collisions of ultrarelativistic heavy ions provide a mean to study a variety of strong, weak and electromagnetic interactions. Measurements described in this thesis include photon-induced processes in ultraperipheral collisions of heavy ions. The analysed data from collisions of lead nuclei at the energy of 5.02 TeV per nucleon pair were recorded by the ATLAS detector at the LHC in CERN. The ions travelling at relativistic velocities are accompanied by the electromagnetic field, which can also be interpreted as a flux of photons. Due to this fact, apart from nucleon-nucleon interactions, one can also observe photon-nucleon and photon-photon interactions. The latter become dominant in ultraperipheral collisions, when the distance between interacting nuclei is greater than the sum of their radii. Photon-photon interactions occur also in proton-proton collisions, between electromagnetic fields of ultrarelativistic protons. However, each photon flux scales quadratically with the ion atomic number, Z, what in case of photon-photon beams leads to a Z^4 enhancement of the cross-sections for the given process. Therefore, ultraperipheral heavy-ion collisions enable measurements of rare processes, and also searches for new phenomena and new particles, being signals of so-called New Physics.

This thesis discusses measurements of ultraperipheral lead-lead collisions, with a significant contribution of the author of this thesis, during her doctoral studies. The thesis is focused on two processes: photon-photon scattering or light-by-light scattering, $\gamma\gamma \to \gamma\gamma$, and the main background for this process, exclusive production of electron-positron pairs, $\gamma\gamma \to e^+e^-$. In the Standard Model, the $\gamma\gamma \to \gamma\gamma$ reaction is allowed through loops involving virtual charged fermions or $W^\pm$ bosons. This process can also be considered as background for the New Physics, for example for decays of axion-like particles. Precision measurements of the process would enable setting the new limits for several processes beyond the Standard Model.

The exclusive production of electron-positron pairs, which is one of the fundamental processes of quantum electrodynamics, is a benchmark process for other analyses of ultraperipheral collision data. Precision measurements of this process would help improve the Monte Carlo simulations for photon-photon interactions, in particular modelling of the photon fluxes, associated to charged nuclear beams. Production of lepton-antilepton pairs originating from photon-photon interactions is also possible in events with simultaneous hadronic interactions. Measurement of photon-induced processes in such events provides a new probe of Quark-Gluon Plasma.

The cross-sections for photon-induced processes in ultraperipheral collisions are decreasing with the centre-of-mass energy of the photon-photon system. The transverse energy of photons/electrons in the final state reaches out to tens of GeV, but the spectrum is dominated by particles with the energy of a few GeV. Its efficient detection poses a challenge for the ATLAS detector, which was designed and optimised for high-energy particles, with transverse momenta above 20 GeV. A characteristic feature of the considered processes is also low acoplanarity of the photon-photon or electron-positron final states Acoplanarity quantifies a difference in the azimuthal angles between final-state particles. Its value close to zero means that they have opposite directions in the azimuthal angle.

The important aspect of successful measurements with low transverse momentum photons and electrons was preparation of the efficient trigger, i.e. a set of algorithms that enables the online selection during the data taking in the ATLAS experiment, done by the author of this thesis. This step required development of the dedicated strategy, implementing online selection and its optimisation both at the first, hardware level, and at the second, software level. Trigger

selection is tightly related to the studied processes: events with low activity in the central detector, minor activity in the tracking system and very low activity in the forward direction were recorded. A great challenge was the low energy of the final state particles in the studied processes, which was close to the noise threshold of the detector electronics. Thanks to the selection optimisation, the trigger efficiency was significantly improved in the 2018 Pb+Pb data taking with respect to the trigger used in the 2015 Pb+Pb run.

In this thesis, the results of the integrated and differential fiducial cross-sections are presented for light-by-light scattering and exclusive production of electron-positron pairs. The second process is measured with high precision. In particular the statistical uncertainty on the integrated fiducial cross-section is at the level of 0.6%, while the systematic uncertainty is dominated by the electron reconstruction and identification component and it amounts to 10%. The differential cross-sections are measured in several kinematic variables or both processes. The presented results are compared with theoretical predictions from Starlight and SuperChic for the measured processes. The measurements become important input to further improvement of the modelling of photon-induced processes in ultraperipheral collisions of relativistic nucleus-nucleus beams.

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