# Čvrtý miniworkshop difrakce a ultraperiferálních srážek

Anotace prezentovaných příspěvků

## 1 Session 1

### 1.1 Introduction to our group activities
*Guillermo Contreras*

A brief overview of the spirit of the meeting and the motivation of our different activities is presented. In particular, it is stressed that all activities—detector construction, analyses of experimental data, and computation of theoretical predictions as well as development of phenomenological models—are united by our quest to understand QCD in the high-energy limit.

### 1.2 News from Wien
*Roman Lavička*

Moving electric charge is source of magnetic field. Standard Model charged particles with spin have rotating charge and hence a magnetic field. The strength of this magnetic field depends on particle structure and properties. Therefore, measurement of this field allows us to test Standard Model.

The anomalous magnetic moment represents $a_\tau$ a deviation from the expected magnetic moment of the simplest object, point-like fermion, and is often measured in the experiments. This presentation refers about the previous measurements of $a_\tau$ of leptons and the feasibility of such measurement of $\tau$ lepton at the experiment ALICE with Run 3 data.

### 1.3 News from Zurich
*Marek Matas*

Dark matter is one of the long-standing mysteries of modern-day physics. Its gravitational effects have been well known for several decades, yet any other type of interaction with ordinary matter has yet escaped conclusive detection. This talk focused on summarizing the crucial findings that brought the scientific community to believe that there is such a thing as dark matter and then on what are the main ideas on how to capture its elusive dark matter-standard model interaction. As an example for the future of this hunt, a graphene-based direct detection experiment has been sketched out since this can utilize directionality as a strong suppressor of the potential statistical backgrounds.

# 2 Session 2

## 2.1 Construction and installation of the FDD
*Vojtěch Zabloudil*

The ALICE (A Large Ion Collider Experiment) detector is undergoing a major upgrade of its setup throughout the Long Shutdown 2. The main difference for the upcoming Run 3 is the increase of the interaction rate to 50 kHz in Pb-Pb collisions and to 1 MHz in pp collisions, which is two orders of magnitude larger compared to Run 2. This demands improvements in data acquisition and computing infrastructure. The majority of the detectors switches to continuous readout, yet some of the older systems need an external trigger. In order to provide this task, while fulfilling the upgrade expectations, the new Fast Interaction Trigger (FIT) is added to the system.

The FDD is a scintillation detector covering the forward pseudorapidity. It is divided into two stations: FDD-A and FDD-C which are located at a distance of 17 m and 19.5 m from the interaction point, respectively. The pseudorapidity coverage is from 4.8 to 6.3 for the FDD-A and from $-7.0$ to $-4.9$ for the FDD-C. Each station is made of two layers of plastic scintillators further subdivided into four quadrants. For each quadrant, there is a plastic scintillator connected to a pair of wavelength-shifting (WLS) bars that collect the light produced by the scintillator. The light is further transferred via optical fibres to a photomultiplier tube (PMT), where it is converted into the corresponding electrical signal.

The construction of the FDD is divided into several steps. Firstly, the WLS bars are glued to the scintillator, which together form a pad. The pad is then covered into aluminium foil in order to avoid external light coming into the pad. After two reflective layers, a layer for protective purposes is used. This consists of aluminium plates which provide protection against damage.

To complete the FDD module, the pads need to be connected to the PMTs by optical fibres. These are bunches of 96 optical fibres. The endings of the fibre bunches are glued together to properly fit the corresponding areas. A circular ending is on the PMT side, since the photocathode of the PMT is circular. The WLS bars are rectangular, so the fibres are shaped into a rectangle on this side.

The FDD funcionality heavily relies on the properties and quality of the used PMTs. For this purpose, twenty Hamamatsu H8409-70 fine-mesh PMTs were tested to choose the sixteen best-performing PMTs for the installation. This was done by irradiation of the PMTs with a low-intensity laser to get the single photon calibration. Two PMTs were used in one run, one whose voltage was set at different values to perform the calibration and the other operated at a constant voltage for reference purposes. The selection was done according to the relative amplitude and charge gain.

## 2.2 Film of the installation of FDD-A by Macej Slupecki

*Guillermo Contreras*

One of our colleagues in ALICE, Macej Slupecki, produced a nice film following the installation of the FDD-C in the tunnel of the LHC. It lasts 7 min and shows the restricted working conditions, the final position of the detector and how the fibre bundles were passed through a hole in the wall separating the cavern, where the PMTs are installed from the tunnel where the detector is placed.

## 2.3 What comes next for FDD and our lab

*Solangel Rojas*

The forward Diffractive Detector (FDD) is a sub-detector of the Fast Interaction Trigger (FIT), the lower latency trigger system of the ALICE experiment in the LHC. In this talk was presented a brief overview of the actual status of the FDD and the related systems being commissioned in preparation for the Pilot-beam test and the RUN-3 of the LHC planned to start at the beginning of February of 2022. Additionally, the intended plan was presented to research the ageing of plastic scintillator materials. To investigate the performance of the materials used for the FDD detector when exposed to high radiation conditions.

## 2.4 Cosmic rays: hands on!

*Solangel Rojas and Vojtěch Zabloudil*

The cosmic rays are high energy particles constantly coming from outer space and create a shower of many particles when such cosmic rays impact the atmosphere molecules on Eart. Some particles from the shower have a long enough lifetime to reach the surface of the Eart (e.g. muons) and can be detected using scintillator detectors. With the aim to make a brief introduction to the world of particle detector physics, a simple experiment was prepared using two pallets of plastic scintillators, each of them attached to a photomultiplier to see the light generated by the muons crossing the scintillator. The students were able to manipulate the detectors, see the signals from the detectors in the oscilloscope, set up coincidences and count the muon flux at different angles with respect to the zenith-angle.
Reference:
Special relativity in the school laboratory: a simple apparatus for cosmic-ray muon detection. P. Singh and H. Hedgeland 2015 Phys. Educ. 50 317

# 3 Session 3

## 3.1 Construction and status of the MFT

*Diana Krupová*

The operation of the Large Hadron Collider (LHC) is divided into several years of running, which are followed by periods called Long Shutdown dedicated to maintenance and upgrade. During the Long Shutdown 2 (LS2), which is happening now, the ALICE experiment will undergo significant changes in both hardware and software section. One of the affected detector subsystems of ALICE is the Muon spectrometer. Its performance will be greatly enhanced by a new detector, the Muon Forward Tracker (MFT), which will start its operation after the LS2.

The main motivation for building the MFT lies in the heavy flavor sector. In particular, it will improve the determination of the production vertex and tracking. We will be able to measure muon offset at primary vertex, which will allow us to separate muons from open charm or open beauty decays. Furthermore, thanks to the MFT we will be able to measure secondary vertices of decaying particles, which will help us to discriminate prompt $J/\Psi$ and $J/\Psi$ coming from $B$ decays.

The MFT has full azimuthal coverage, and spans -3.6 $< \eta <$ -2.45 in pseudorapidity. It consists of 5 disks, each with 2 faces. On each face there are ladders with 2-5 sensors, the ALPIDE silicon pixels of 0.4 $m^2$ size. The whole MFT will contain 936 sensors.

The Muon Forward Tracker (MFT) was designed to add precise vertexing capabilities to muon tracking at forward rapidities. The MFT detector incorporates ALPIDE silicon chips assembled in ladders. After the assembly, the ladders are tested and qualified according to a specific procedure. One of the goals is to obtain a uniform threshold: to find the suitable operating point for each chip, a process called threshold tuning is used. Another crucial tool in ladder qualification process is the eye measurement, performed in order to test signal strength and stability. After gluing the ladders to the half-disks, the qualification procedure is repeated.

The MFT is now installed at CERN and participating in global commissioning

## 3.2 Film of the installation of MFT and FT0C by Macej Slupecki

*Guillermo Contreras*

One of our colleagues in ALICE, Macej Slupecki, produced a nice film following the test installation of the MFT and FIT detectors assembled together in a prototype of the mechanical structure used for the final installation.

The teams, using this prototype, work out the best way to install the detector and carry out the signal cables from the very inside of ALICE towards the exterior of the L3 magnet.

### 3.3 QC for the MFT

*Tomáš Herman*

To ensure that the data recorded by the ALICE detector at the LHC, more precisely by its Muon Forward Tracker (MFT), are not corrupted and can be used for physics analysis, it is necessary to control the quality of the data. To this goal, ALICE developed a new framework for Quality Control (QC) within the new O2 system. This system can sample any data stream in the ALICE workflow and process and check the quality of the recorded data. The checks are partially automatic and partially done by a dedicated QC shifter. The QC software can also examine the evolution of the data with time and the correlation of different monitored variables.

During the ongoing commissioning of the ALICE detector in preparation for the LHC Run 3, the MFT QC monitors the status of the readout (RU) lanes, the pixel hit maps and chip occupancy for MFT Digits and the topology type ID and the occupancy per chip and per layer for the MFT Clusters. The efforts on the QC development, including QC data analysis and preparation of instruction for the shifters, are now escalating as the incoming Pilot beam test will collide beams in the LHC for the first since LHC Run 2.

### 3.4 What is next for MFT

*Tomáš Herman*

To ensure a smooth operation of the MFT detector it is necessary to organize it well. To this goal, there is a complex operational structure in the organization of the MFT project. The Institutional Board is composed of team leaders from all the institutes contributing to the project. This body is voting on all important decisions regarding the project. The daily operation of the project is managed by the Coordination Board composed of the project leader and the deputy project leader. They interact with the ALICE Collaboration and Management Boards. In addition, there is the Technical Coordinator and Data Run coordinator. The Technical Coordinator is responsible for all the hardware components of the detector, while the Data Run Coordinator is responsible for the Physics and Software side of the project. They both interact with the System Run Coordinator, who is responsible for the smooth running of the MFT detector during operation. This is achieved in cooperation with the coordinators and experts for the different subsystems of the detector.

The MFT detector is in a phase of active commissioning with activities escalating in the view of the fast-approaching Pilot beam test in which nominal beam collisions will be executed for the first time in the LHC since the end of Run 2. This test will be very beneficial for the detector preparation which will continue up until February of 2022 when the LHC will start to operate again. In March and April, there is a commissioning period to make sure that the detector works flawlessly before the first proton data taking will start in March of 2022. This will continue until the December of that year when there will be ion collision measurement for the first time since 2018.

### 3.5 Further upgrades: ITS2 and ALICE 3

*Katarína Křížková Gajdošová*

The future of the Large Hadron Collider (LHC) and its experiments is planned for several years in advance. Its operation is divided into several years of running, which are followed by periods called Long Shutdown dedicated to maintenance and upgrade. In Run 3, starting from 2022, ALICE experiment will take data with significant upgrades and new detector systems. The Inner Tracking System (ITS2) and Time Projection Chamber (TPC) are upgraded to cope with higher interaction rates and to improve the tracking precision especially at low $p_T$. New Muon Forward Tracker (MFT) will significantly improve the physics analysis in the forward region, and the Fast Interaction Trigger (FIT) system contains new trigger detectors and will improve the analyses in diffraction physics or luminosity monitoring. All the data redout, reconstruction, and also final user analysis will be performed with a new computing software called Online&Offline ($O^2$).

During Run 4, ALICE will operate with another two major upgrades. The Inner Tracking System (ITS3) will have bendable silicon layers with unprecedently low material budget, further improving the physics results at low $p_T$ and reconstruction of decay vertices of heavy-flavor particles. The Forward Calorimeter (FoCal) will be new addition to the ALICE detector, focusing on the physics at low Bjorken $x$ and photon physics.

Finally, plans for Run 5 are already ongoing. A Letter of Intent for a completely new experiment called ALICE3 is in preparation. The detector will be compact and mainly based on silicon, with a peculiar feature of having few layers of the detector inside of the beam pipe to bring the material budget to the lowest level possible, and to be as close to the interaction vertex as possible. This detector would be mainly focused on studies of (multiple)-heavy-flavor particles and low-$p_T$ photons, to explore a new area of QGP physics, not yet addressed by the current measurements nor by the preceding upgrades.

## 4 Session 4

### 4.1 LO b-BK studies

*Matěj Vaculčiak*

The talk about the leading order Balitsky-Kovchegov (BK) equation was given as part of the 4th Miniworkshop on Diffraction and UPC.

Firstly a brief introduction of the role of the BK equation as a theoretical tool to study quantum chromodynamics at high energies. Next the electron–proton deep inelastic scattering was discussed as an important experimental setup of such studies. Within this context various observable quantities, such as the structure functions, were presented. These then serve as on output of the theory that can be confronted with the experimentally measured data, thus putting the theory to the test.

The second part of the talk was dedicated to discussion of the BK equation as such. Its particular terms were discussed, putting stress on the significance of the non-linear term. The resulting effect of the parton saturation was explained briefly. Finally, several results of the so-called 2-dimensional BK equation were presented together with an outline of future research direction.

### 4.2 Balitsky-Kovchegov equation at next-to-leading order
*Dagmar Bendová*

This contribution summarizes the theoretical development of the leading order Balitsky-Kovchegov equation towards the next-to-leading order precision and the current status of its numerical solutions. Balitsky-Kovchegov (BK) equation is one of the evolution equations of quantum chromodynamics (QCD) which describe the evolution of the partonic structure of hadrons. Specifically, it describes dressing of a color dipole with decreasing Bjorken-$x$ – therefore, it tells us the change of the dipole scattering amplitude with the increasing energy. This serves as an input into phenomenological calculations of various QCD processes, e.g. deep inelastic scattering (DIS) or vector meson (VM) production. In the color-dipole approach to these processes, one of the interaction particles – electron in case of DIS, or proton/nucleus in case of VM production in ultraperipheral collisions – emits a virtual photon. This photon can be seen as fluctuating into the $q\bar{q}$ pair which can interact strongly with the target particle – proton or a nucleus – via exchange of gluons. Since the dipole and the target hadron are connected by a boost of the system, the BK equation describes both the evolution of the color dipole structure and the gluon structure of the hadron. At leading order (LO), the equation describes the situation where one of the dipole constituents emits a gluon. In an appropriate limit, this gluon can be seen as a new $q\bar{q}$ pair. Therefore, the original dipole splits into two new daughter dipoles, which can interact with the target hadron. Since the equation is non-linear, it also describes a possibility of recombination of these dipoles back into the original dipole. The LO BK equation has been successfully used in description of above mentioned processes. The equation has also been solved with an explicit impact-parameter dependence. With the advance in theoretical description of QCD processes to higher orders of the perturbation theory, and the need of more precise description of experimental data and subsequent predictions for new measurements, comes also the need to solve the BK equation beyond leading-order. The full next-to-leading order (NLO) BK equation was proposed by Balitsky and Chirilli in Phys.Rev., D77 (2018) 014019. The subsequent works (Iancu et al.) have incorporated some of the NLO corrections into the LO version of BK equation and successfully used this equation in fitting the DIS data from HERA. The full NLO BK equation has been solved numerically by Lappi and Mantysaari in Phys. Rev., D91 (2015) 074016, however some instabilities of the numerical results have been reported. Using an appropriate resummation, the authors managed to obtain a stable numerical solution in their following work and used this progress to perform a first fit to DIS at the NLO precision. In subsequent works, Iancu et. al. argue that the evolution should be performed in the target rapidity frame, not the dipole one as was done so far. The arguments are that this frame allows for a proper resummation of the NLO contributions, improves the instability problem, and provides a proper connection with the rest of the ingredients in phenomenological applications. Although there has been an huge development in QCD phenomenology at NLO, the numerical solutions of the NLO BK equation, its extension to the impact-parameter plane, and its use in phenomenological calculations are still open topics, which are of high interest of QCD phenomenology today.

## 4.3 Vector meson production with hot spot model
*Radim Dvořak*

The structure of hadron can be studied using quantum chromodynamics. This theory describes interactions between quarks and gluons. These effects can be studied in several processes one of them is deep inelastic scattering in which interact proton with the electron by exchange of virtual photon. For a description of this process was introduced several variables. First is virtuality Q2 of a virtual photon which describes its wavelength (higher virtuality leads to smaller wavelength). Another variable Bjorken x which is energy in the collision (smaller Bjorken x leads to higher energies). Based on this experiment was developed Parton model of hadrons in which hadrons are described as a group of partons and virtual photon interact only with one of them. When we increase the virtuality of the virtual photon its wavelength will be smaller which will cause observation of the finer structure of hadrons. With decreasing Bjorken x (higher energies) hadron can be described as more same "size" partons. The number of same size partons can not be divergent so in one moment they start saturation. These processes can be described using evolution equations.

Vector meson production is another process that is sensitive to hadron structure. Vector mesons are particles composed from pair quark-antiquark with parity $-1$ and angular momentum $+1$. For example, meson J/Psi is composed of $c\bar{c}$. The process of production vector mesons can be described in the colour dipole approach. Same as in deep inelastic scattering there is the collision of an electron with a proton. Virtual photon is produced and this virtual photon produces pair quark-antiquark which strongly interact with a proton. Nextly the pair produce vector meson. In exclusive production, the proton will not decay. On the contrary in dissociative production proton decay into a hadronic system. The amplitude of this process can be divided into three parts - dipole cross-section, an overlap of virtual photon and vector meson and corrections. Overlap can be get from two models - gaussian and boosted gaussian. Dipole amplitudes N can be found from the GBW model. GBW model has no dependence on impact parameter b so this dependence has to be added in the structure-function of a proton. In the first part is the proton model as Gaussian distribution in the second part is used hot spot model. In this model is proton taken as a group of hot spots which are randomly distributed. The hot spot model is used as follows. Firstly is generated middle value of a number of hot spots, then for each event is generated a real number of hot spots from modified

Poisson distribution. Nextly are generated random positions of hot spots. Final amplitude is given as the middle value (or variance) of these amplitudes for exclusive (dissociative) production. The main advantage of the hot spot model is the possibility to compute the dissociative production of vector mesons. From amplitude is possible to compute a differential cross-section of production and then a total cross-section.

# 5 Session 6

## 5.1 Introduction to percolation

*Guillermo Contreras*

Percolation is related to the field of phase transitions, where in this case the phenomena are governed by geometrical effects. In this talk, a brief review of the motivation for percolation based on the original paper is presented. Then the basic steps for an analysis on percolation are exemplified with lattice percolation in 2 dimensions. The algorithms to perform the required computations, and their extensions to the continuum case are presented.

Finally, a series of papers where ideas of percolations are used to describe processes in different fields are discussed. These papers include forest fires, segmentation of ecological environments, social preferences, network resilience and, of interest for this workshop, applications to QCD.

## 5.2 Percolation and QCD

*Dagmar Bendová*

Percolation is a process which can be described as a random, gradual filtration of a fluid through a porous medium. Therefore, opposite to a diffusion process, it ascribes the random mechanism not to the fluid which is going through the medium, but to the penetrated medium itself. This process can be applied in various fields, e.g. in solid state physics, biology, IT, and many others. Interestingly, the percolation theory can find its application also in our area of interest – particle physics. It is well known observation that quarks and gluons, which form hadrons, can't be find isolated – they are always bound inside the hadron. The gluon field between the quarks forms a narrow flux tube (string) of color charge which stretches with the increasing separation between the quarks. However, the field does not weaken and at large separation when a string should "break". A new $q\bar{q}$ pair is created at some point, thus maintaining quarks and gluons bound into colorless hadrons. This analogy with strings can be applied to multiparticle production in nuclear collisions at high energies, where color strings are stretched between the projectile and the target and observed hadrons are formed from hadronization of these strings. In this picture, color strings can be seen as small discs filled with color field in the transverse space. The number of strings grows with increasing energy and number of participants, and at a sufficiently high density, the strings may overlap. As a result, a cluster of color charge is formed from overlapping strings which, at some critical density of the strings, appears as a macroscopic cluster spanning over the most of the interaction area. The mergence of the macroscopic cluster marks the outset of the percolation phase transition. The quark gluon string model, developed by Pajares et al. (see e.g. Phys.Rev.Lett 77 3736, 1996), has been successful in describing one of the first experimental signatures of formation of quark-gluon plasma (QGP) – a suppression of the $J/\psi$ meson production in central Pb-Pb collisions – and provided predictions for (at that time) future measurements at RHIC and LHC, where the formation of QGP in high-energy heavy-ion collisions was later confirmed. The observation from the model and its comparison to data was following: a QGP domain is formed when the density of the string rises above some critical threshold and the medium enters a percolation phase, in which it behaves as a color conductor. In the subsequent works by the authors, the color string percolation model has been successfully used to predict many other observables related to the QGP formation like temperature and energy density, equation-of-state, or particle correlations.

# 6 Session 6

## 6.1 Coherent J/Psi production with forward neutrons

*Michal Broz*

Relativistic heavy ions are accompanied by high photon fluxes due to their large electric charge. At large impact parameters the photonuclear interactions can be seen in the Ultra-Peripheral Collisions (UPCs). Because of the high photon flux, the UPC events have a high probability to be accompanied by additional photon exchanges that excite one or both of the ions. Neutron-differential studies are considered as a promising tool to decouple low-x and high-x contributions in vector meson photo-production. In this talk we describe an analysis of the coherent J/psi photoproduction with forward neutrons measured by ALICE. Coherent J/psi photoproduction cross section evaluated differentially in —y— and neutron emission classes. Forward neutrons from electromagnetic dissociation measured in neutron ZDCs, events selected using timing measurements in the calorimeter. Ingredients for x-section evaluated as function of —y— or neutron class, as needed. Cross section corrected for event loss due to veto by charged particles from EMD.

## 6.2 Forward neutrons for incoherent J/Psi production

*Vendulka Fílová*

Measured cross section of J/$\psi$photoproduction consists of two contributions. One contribution corresponds to a high-energetic photon interacting with a nucleus and the second term corresponds to a low-energetic photon probing low-$x$ gluons. An interaction of high-energetic photon is sensitive to lower-$x$ gluons than the low-energetic photon. Measuring the cross section of incoherent

J/$\psi$photoproduction with emission of forward neutrons measured in the Zero Degree Calorimeters (ZDC) gives us a tool to disentangle these two contributions and reach the full range of $x \in (10^{-5}; 10^{-2})$.

In an incoherent J/$\psi$photoproduction a photon couples to a single nucleon inside a target nucleus. The recoiled nucleon re-scatters and causes a break-up of the target nucleus with one or more neutrons emission in the forward rapidity. The process is characterized by the J/$\psi$transverse momentum larger than $p_T > 300$ MeV/$c$.

The probability of the neutron emission in incoherent process is close to one and there is a correlation between the direction of the produced J/$\psi$and the direction of emitted neutrons because neutrons always follow the direction of the target nucleus movement. Studying such processes provides an opportunity to investigate gluon behavior at values of very small $x$.

In my talk I presented a very first look on the Run 2 data, selecting incoherent J/$\psi$candidates. I showed the differences in the transverse momentum spectra for different ZDC classes (0n0n), (0nXn), (Xn0n) and (XnXn), meaning no neutrons in either side of the ZDC, one or more neutrons in the C-side, at least one neutron in the A-side and one or more neutrons in the both sides of the detector, respectively. I showed energy distributions of the Zero Degree Calorimeter and also the fact that there is more events in the (0nXn) class, corresponding to the fact that a vector meson J/$\psi$is mostly produced by a low-energetic photon. It is due to the small flux of photons with high energy.

This quick look on the data showed that it is meaningful to do a full analysis of incoherent J/$\psi$photoproduction with neutron emission expecting some relevant results.

## 6.3 Asymmetries in coherent vector meson production
*Guillermo Contreras*

Recently, a new observable has been proposed to study more in depth the structure of hadrons using photon induced processes. The idea is to use the fact that the photons from a fast moving particle are quasi real, which makes them transverse polarised and in addition they are linearly polarised. This last fact defines a direction in space.

If the process happens in a system of equal colliding particles, then there is an interference effect, which, due to the different directions of the incoming polarised photons, produces a $\cos(2\phi)$ modulation, where $\phi$ is an azimuthal angle suitably defined. These studies go beyond the standard polarisation analysis because they involve an interference effect which introduces an extra dependence in kinematic variables. All this is briefly discussed in this talk.

## 6.4 Asymmetries in coherent J/Psi production
*Sára Haidlová*

The gluon structure of hadrons and its behaviour according to the measuring conditions is a problem of great interest in quantum chromodynamics and particle physics in general. The structure is studied via deep-inelastic scattering, which proved to be a good instrument for probing the hadron structure. For the study of hadron structure and the hadron photoproduction, the ultra-peripheral collisions (UPCs) with high energy are commonly used.

UPCs occur for impact parameters larger than the sum of radii of colliding nuclei. Thanks to this large impact parameter, particles interact only through their electromagnetic fields and due to the acceleration of the particles, their electromagnetic fields are contracted and can be considered as a source of quasi-real linearly polarized photons. Occurring processes of interest are interactions of two photons from the field of each nuclei and interaction of the photon that fluctuates into quark-antiquark pair that subsequently scatters of the second nucleon most likely resulting in the creation of vector meson.

The experiment to study these processes are conducted with high energy, which allows to study hadron structure for low Bjorken-$x$ and allows for the use od pQCD. By measureing the scattering angle of the J/$\psi$ allow for further studies of the evolution in Bjorken-x of the structure of hadrons.

The measurements of the coherent photoproduction have been previously conducted by ALICE at $\sqrt{s_{NN}} = 2.76$ TeV in 2011 and the data recieved from these measurements have been analyzed. The azimuthal asymmetry has been studied by STAR Collaboration at $\sqrt{s_{NN}} = 200$ GeV showing the theoretically predicted azimuthal asymmetry in central and ultra-peripheral collisions and their sensitivity to the nucleon structure.

## 6.5 UPC plans in Run 3
*Michal Broz*

The higher LHC luminosity and experimental upgrades leads to an improved samples of UPC events. ALICE will use continuous readout, that means no trigger-based constraints and high-efficiency collection of large samples. Thus the increases in sample sizes larger than by scaling the luminosity. Using the Run3 sample we will be able to extend substantially the x range for coherent J/psi photoproduction on nuclei using the impact parameter distribution in peripheral and ultra-peripheral collisions and via forward neutron production. We will measure high statistics coherent Upsilon(1S) production in gamma-p and gamma-A where we can probe the gluon shadowing at a factor of 10 higher Q2 than in J/psi production. Beyond precise cross section measurements for J/psi, psi prime and upsilon(1S) will llow tomographic measurements that can be used to infer information on the nuclear wave function.

# 7 Session 7

## 7.1 Flow fluctuations

*Katarína Křížková Gajdošová*

Measurements of anisotropic flow $v_n$ are one of the best probes to characterize the properties of the quark-gluon plasma (QGP). Models of a heavy-ion collision, which include hydrodynamics to describe the QGP phase, can be constrainted by these measurements. They helped to determine that the QGP behaves as a strongly interacting liquid with very low shear viscosity over entropy density ratio $\eta$/s. However, the initial conditions in the models are still poorly known. In this talk, we will focus on constraining the initial eccentricity distributions $P(\epsilon_n)$ of the overlap region of the colliding nuclei.

Thanks to a linear relation between the eccentricity $\epsilon_n$ and anisotropic flow $v_n$ for $n < 4$, one can determine the shape of $\epsilon_n$ distribution via measurements of $v_n$ distribution, $P(v_n)$. One of the methods to address this is to measure the higher moments of the distribution, in particular its cumulants. If the $P(v_n)$ is of a Bessel-Gaussian shape, the ratios of higher order cumulants $v_n\{m\}/v_n\{k\}$ should be equal to unity, while in case of an Elliptic Power distribution, they will deviate from unity. The later was indeed confirmed by ALICE, ATLAS and CMS experiments. New results on $p_T$-differential measurements of ratios of higher order cumulants bring additional detailed information into our understanding of the initial conditions. It was found, that Elliptic Power distribution is only valid at low $p_T < 3$ GeV/$c$, while Bessel-Gaussian is more appropriate description at higher $p_T$. In addition, a hint for a $p_T$-dependence was found in the results, which would suggest influence from hydrodynamic fluctuations. These results could add new constraints to the models of heavy-ion collisions.

## 7.2 Previous multiplicity measurements

*Helena Hesounová*

Multiplicity measurements of pp collisions done by ALICE during Run 2 were processed using KNO scaling and fitted with NBD. Results were published in a study 'ALICE Collaboration: Charged-particle multiplicities in proton-proton collisions at $\sqrt{s} = 0.9$ to 8 TeV, Eur. Phys. J. C, 77:33 (2017)'. This study focused on inelastic and non-single difractive events, for which it showed that multiplicity distributions and pseudorapidity densities both follow a smooth evolution from $\sqrt{(s)} = 0.9$ to 8 TeV. It also showed that KNO scaling is violated for both inelastic and NSD events and the discrepancies grow with higher energies and wider pseudorapidity ranges. Single NBD fit holded up only for NSD events with low energy and low multiplicity, whereas double NBD fits all the data with a satisfying precision. Based on the measured data current simulation generators fail to produce accurate data for any studied events with high multiplicity. Data from pp collisions were used to study quantum entanglement. According to 'Zhoudunming Tu, Dmitri E. Kharzeev, Thomas Ullrich: Einstein-Podolsky-Rosen Paradox and Quantum Entanglement at Subnucleonic Scales, Physical

Review Letters 124, 062001 (2020)' these experimental data were in agreement with quantum entanglement theory, which gives us a strong indication of the presence of quantum entanglement at subnucleoninc scales.