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Foreword

This year, for the 9th time, students, graduates, and teachers from the field of Experimental Nuclear and Particle Physics at FNSPE CTU met at the annual winter workshop. The meeting was held during the week of 17.–24. 01. 2015 at *Penzion Krakonoš* in the Jizera Mountains in the Czech Republic. The main goal of the workshop is to follow the progress of students, discuss problems and experiences and also to get to know each other better. Each participant gave a talk about their work or progress during the previous year. Extended abstracts of these talks are published in the proceedings you are holding now.

Editors

Optical readout of electromagnetic calorimeter FoCal

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ALICE (A Large Ion Collider Experiment) is Cern's heavy-ion detector built to detect a phase of matter (quark-qluon plasma) which governs at extreme energy densities and have formed after the big bang. Overtime the components become outdated and new technologies provide solution in the form of upgrades. FoCal (Forward Calorimeter) should replace PMD detector (Photon Multiplicity Detector) which measures the multiplicity and spatial distribution of photons produced in the collisions.

The Forward Calorimeter was designed to measure high-energy photons of transverse momentum between 1 GeV and 100 GeV. Pseudo rapidity is assumed to be in an interval $\mu \in (2.5, 5)$ surrounding the whole beam. The next step refers to an ability the FoCal can distinguish between the direct incoming and secondary formed photons. What is more, there is possibility to differ photons and neutral pi-mesons in the area of big momenta. The Calorimeter offers measurements of isolated speed photons what should get better our perception of correlation between rapidity and transverse momentum. This fact could expend studies of nucleons in the field of small Bjorken's x and transferred momentum Q^2.

There are two possibilities how can be the detector installed. The detector is possible to place 3.5 m away from the centre of collision. The second proposal is more convenient because moves the detector to distance of eight metres out of the magnet which allows us to take some extra space for hardware. Yet have been considered two concepts of FoCal design. The first possibility admits tungsten towers and silicon detectors. The second encloses scintillation detectors.

Very important for the detector's hardware is its radiation immunity. Characteristic of the cascade is determined by Moliere radius and radiation length in the medium. Interacting particle inside the detectors absorber makes electromagnetic cascade that produces energetic photos. These energetic particles should damage an equipment therefore was optical readout system moved to safe zone. The method uses scintillators which detects flash, when the atom was excited by gamma ray. Photomultiplier and detector are linked by optical fibres (3900). Geometry of the fibres was upgraded by glass balls. The balls are fixed in the end of fibre and enlarge the whole absorbent surface.

Signal from the photomultiplier is read out by camera called "Fastcamera 13". The camera uses CMOS (Complementary Metal Oxide Semiconductor) technology. System CMOS offers much higher speed of scanning than CCD (charge-coupled device). Due to CMOS high light sensitivity the camera has very good resolution. CMOS is cheaper technology than CCD and provides reading each the pixel particularly. Moreover, this technology allows to build small devices, e.g. camera dimensions are (74x79x132) mm. With 1.3 Megapixels resolution (1280 x 1024) and by the maximal resolution ($5x10^5$ FPS) has the camera relatively small energy consumption. Its small dimensions predicts weigh only something about ¡600 g.

FPGA (Field Programmable Gate Array) has closely relation to CMOS technology. It is "new generation" of logic integrated circuit (IC). In the contrary with CPU it has its own symmetric structure of logic cells. The IC has no destined operation (like CPU) - own programming of the each cell, even if the system runs. The operating cells is possible to link one to another without using central matrix or they should be reprogrammed by a code when there were a few cells damaged - without PCB change. FPGA silicon chips contents up few thousands of logical cells and more then 8 million logic gates (NAND). Speed of processing HD data by FPGA fields is therefore very high. Combination of these technologies may contributes to develop cheap, radiation safe and rely quick detector.

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On the amount of saturation coming from HERA data

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One of the most interesting problems nowadays in QCD is to understand the behaviour of the gluon structure of the proton. Large amount of inclusive data mainly from deep inelastic scattering at HERA at small Bjorken x allows to test the high-energy limit of QCD. It is known that hadron structure function $F_2(x, Q^2)$ shows large increase of the number of gluons at fixed values of the virtuality, Q^2, of the photon in this limit. The growth of the gluon density was understood to be due to gluon-branching processes described by the BFKL evolution equation. However, data suggest less gluons in a hadron than there should be according to the solution of BFKL equation. The unitarity of the cross section implies that the gluon density should stop growing at some point and a recombination of gluons occurs. This is known as saturation. The presence of recombination generates a scale, the so called saturation scale, $Q_s(x)$, which separates regions with linear rise of the gluon density from non-linear saturated regime.

A usual framework to study saturation phenomena is the Color Glass Condansate (CGC); an effective theory, which describes the high energy limit of QCD [1, 2]. The CGC generates a set of equations known as the JIMWLK equations. These equations are equivalent to a hierarchy of equations found by Balitsky[3]. In the limit of a large number of colours, the hierarchy reduces to one equation, which was independently derived by Kovchegov [4] within the colour dipole model. This equation, called the Balitsky-Kovchegov (BK) equation, describes the evolution in rapidity Y of the dipole scattering amplitude $N(r, Y)$ for the scattering of a colour dipole of transverse size r with a target

$$\frac{\partial N(r,Y)}{\partial \ln Y} = \int d\vec{r}_1 K(\vec{r},\vec{r}_1,\vec{r}_2)\Bigg(N(r_1,Y)+N(r_2,Y)-N(r,Y)-N(r_1,Y)N(r_2,Y)\Bigg),$$

where $\vec{r}_2 = \vec{r} - \vec{r}_1$. The kernel incorporating the running of the coupling is given by

$$K(\vec{r},\vec{r}_1,\vec{r}_2) = \frac{\alpha_s(r^2)N_C}{2\pi}\left(\frac{r^2}{r_1^2 r_2^2} + \frac{1}{r_1^2}\left(\frac{\alpha_s(r_1^2)}{\alpha_s(r_2^2)} - 1\right) + \frac{1}{r_2^2}\left(\frac{\alpha_s(r_2^2)}{\alpha_s(r_1^2)} - 1\right)\right),$$

with

$$\alpha_s(r^2) = \frac{12\pi}{(11 - \frac{2}{3}N_C)\ln\left(\frac{4C^2}{r^2\Lambda_{QCD}^2}\right)},$$

where N_C is the number of colours and C is a parameter to be fixed by comparing to data. The solutions of the rcBK equation have been used to describe a variety of HERA data: inclusive, diffractive and exclusive production of vector mesons using

$$F_2(x,Q^2) = \frac{Q^2}{4\pi^2\alpha_{em}}\sigma_0 \int d\vec{r} \int_0^1 dz \left|\Psi^{\gamma^* \to q\bar{q}}(z,r,Q^2)\right|^2 N(r,x),$$

where Ψ denotes the wave function of a dipole and σ_0 is fixed by the initial conditions.

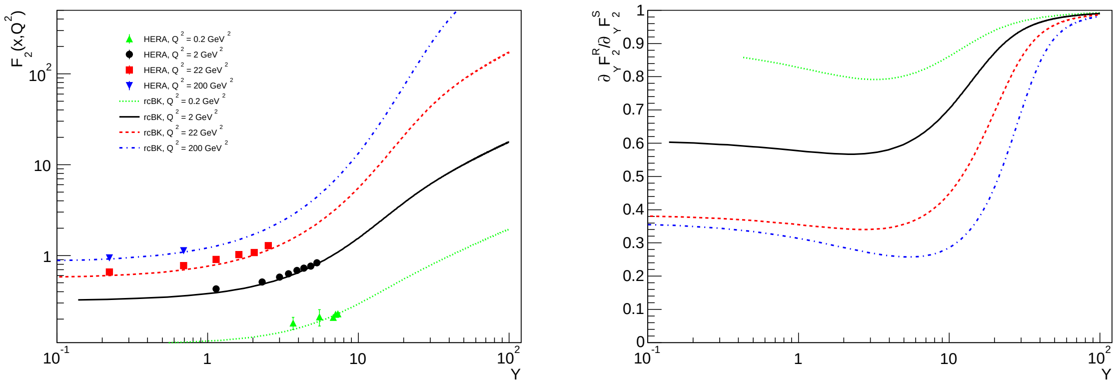

Figure 1: Left: description of HERA data from [5] using the colour dipole formalism and the solution of the rcBK equation for $Y = \ln(0.01/x)$. Right: relative contribution of the recombination to the splitting term of the rcBK equation to the evolution with rapidity of F_2 for four different values of the photon virtuality, Q^2.

Nevertheless, the results coming from the BK equation are particularly important in heavy-ion physics, where the onset of saturation can describe some of observed cold nuclear matter effects. Since the initial conditions (e.g. [6]) used for the solution of BK equation for recent collider (RHIC,LHC) experiments are extracted from HERA data, it is very important to critically analyse the amount of saturation predicted at HERA kinematic range. Upper figure shows that the onset of saturation is quite strong at large Bjorken $x \sim 0.01$ even at low energies corresponding to HERA experiments, which is unexpected and have not been studied so far. Possible discussion has to be made leading to modification of the definition of the saturation scale, that leads to the smaller contribution of saturation effects at HERA kinematics and yet the agreement between the calculation and the data remains intact. It will allow to extract new set of initial conditions with realistic contribution of saturation effects.

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Triangular flow in heavy-ion collisions within the HYDJET++

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The pressure gradients inside the system created in a collisions of relativistic heavy-ion cause a collective outward motion of particles which can be measured. The collective flow can yield information about bulk properties of the matter created in the collision. In peripheral collisions, the spatial asymmetry of the initial overlap zone and its subsequent symmetry restoration give rise to anisotropy in momenta of outcoming particles, thus creating the so-called anisotropic flow. The azimuthal distribution of produced particles can be expanded into a Fourier series w. r. t. reaction plane Ψ_R as

$$E\frac{\mathrm{d}^3N}{\mathrm{d}^3p} = \frac{1}{2\pi}\frac{\mathrm{d}^2N}{p_T\mathrm{d}p_T\mathrm{d}y}\left\{1+\sum_{n=1}^{\infty}2v_n\cos\left[n(\phi-\Psi_R)\right]\right\} \tag{1}$$

with flow harmonics $v_n = \langle\cos\left(n(\phi-\Psi_R)\right)\rangle$ figuring as Fourier coefficients. The elliptic flow v_2 is the main component of the anisotropic flow at RHIC energies. It is caused by the asymmetry of the initial overlap region, which has also given it its name. A very interesting feature of elliptic flow at RHIC is the number-of-constituent-quarks scaling (NCQ) [?]. However, v_2 have been found to be broken at LHC.

The triangular flow v_3 arises on the other hand from the event-by event fluctuations of the overlap zone. Hints of scaling behaviour of triangular flow have been reported by both RHIC and LHC [1, 2].

We performed a study of triangular flow in Pb+Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV and in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV using HYDJET++ Monte Carlo heavy-ion generator [3]. HYDJET++ combines a parametrized hydrodynamics for soft part of spectra with a microscopic jet quenching generator for hard and semi-hard collisions, giving a realistic shape to the flow distributions for different hadron species. The model also enables study of influence of final-state interactions on flow of created hadrons. Motivated by the preliminary NCQ results for v_3, the NCQ for RHIC and LHC were studied. In both cases the distribution have been found to be affected by the decays of the resonances as they drive the flow towards scaling behaviour.

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Coherent production of $J/\Psi \to p\bar{p}$ bar in Pb-Pb Ultra-Peripheral Collisions

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The photonuclear reactions are reactions of a photon and a nucleus. In ultra-peripheral Pb-Pb collisions exclusive J/Ψ production may occur. There are two mechanisms of this production. In coherent production photon couples coherently to almost all the nucleons, in incoherent production photon couples to a single nucleon. The coherent production is characterized by low transverse momentum of the produced J/Ψ particle ($p_T \simeq 60MeV/c$) where the nucleus does not usually break up. The exchange of aditional photons may cause the break-up of nucleus. It occurs in about 30% of the events. The Pb-Pb exclusive J/Ψ production is accompanied by the QED (quantum electrodynamics) process of two photon interaction producing a $l\bar{l}$ lepton pair in J/Ψ decays.

The ultra-peripheral collisions are collisions in which two nuclei are seperated by the impact parameter. The impact parameter is larger than the sum of radii of these nuclei. Although the hadronic interaction is suppressed, the cross section for the photonuclear interaction stays large because of the strong electromagnetic field. The intensity of electomagnetic field is propotional to the square to the electric charge of the nucleus.

Exclusive J/Ψ photoproduction was measured in Au-Au collisions at RHIC, exclusive photoproduction of J/Ψ and $\Psi(2S)$ in γp (photon-proton) interaction at HERA has been modelled in perturbative QCD (quantum chromodynamics). The ALICE Collaboration published the first results on the coherent photoproduction of J/Ψ in ultra-peripheral Pb-Pb collisions at the LHC. The J/Ψ particle has been measured in e^+e^- and $\mu^+\mu^-$ decay channel.

My work is to assess the posibilities of measuring coherent production of J/Ψ deacaying into a $p\bar{p}$ pair in ultra-peripheral Pb-Pb collisions using the capabilities of the central detectors in ALICE. For the assessment I use Monte Carlo data generated with STARLIGHT. The STARLIGHT Monte Carlo models 2-photon interactions in peripheral heavy ion collisions. This study has not ever been done before. We expect to get better resulution for the J/Ψ than in case of J/Ψ decaying into a $l\bar{l}$ pair. It is expected to get better resolution because the proton radiates less photons, when traversing the detector, than the electrons or muons. It allows a better measurement of its momentum.

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J/ψ production in central U-U collisions at STAR

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The theory of strong interaction predicts that under conditions of high temperature and high energy density the nuclear matter may undergo a phase transition into a novel state of matter called quark-gluon plasma (QGP). We expect that this state of matter was present in the earliest stages of the universe shortly after the Big Bang and also that it can be experimentally recreated in high energy heavy-ion collisions.

An important probe in the study of the medium created in collisions of heavy ions are heavy quarks (c and b). We discuss physics of heavy quarks and heavy quarkonia - bound states of heavy quarks and their antiquarks (e.g. J/ψ). Heavy quarkonia have been predicted to dissociate inside the QGP due to Debye color screening of quark and antiquark potential [1]. Since different quarkonia states have different binding energies and the Debye screening length depends on the temperature attained by the QGP medium the individual states are expected to break up at different temperatures of the medium [2]. Therefore, measuring the quarkonia states that survived in hot and dense phase can serve as a "thermometer" of the QGP.

The STAR detector at the Relativistic Heavy-Ion Collider (RHIC) in Brookhaven National Laboratory in USA is one of the foremost experiments in the study of quark-gluon plasma. It was designed to investigate the strongly interacting matter by detecting and identifying charged particles at midrapidity. We describe the main subdetectors of the STAR detector used for particle identification: Time Projection Chamber (TPC), Time of Flight (TOF) detector and Barrel Electromagnetic Calorimeter (BEMC). The TPC is the main tracking device of the STAR detector and provides particle identification by measuring ionization energy loss. The TOF measures the time of flight of particles and improves particle identification capabilities of the TPC. The BEMC measures energy of high p_T particles (e^+, e^-, γ).

We present recent results on heavy quarkonia production measurements and our current results on analysis of J/ψ production in the sample of 1-5% central U-U collisions at the center-of-mass energy per nucleon-nucleon pair $\sqrt{s_{NN}}$ =193 GeV at STAR. We also present our work with data from subdetectors, methods of data selection and the other steps we need to take to achieve our goal, i.e. to reconstruct the signal of J/ψ meson in the decay channel J/$\psi \rightarrow e^+e^-$.

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Non-photonic electrons at the STAR experiment

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A hot and dense form of matter called quark-gluon plasma (QGP) is being studied at the STAR experiment at ultrarelativistic heavy-ion collisions. Unfortunately, it is not possible to study QGP directly. Therefore, one has to rely on the final spectra of particles that are coming out of the interaction point and which are detected by e.g. the STAR experiment.

One of the experimental probes that help us to study the properties of quark-gluon plasma are heavy quarks, such as c and b. These quarks are created during the early stages of heavy-ion collisions before the creation of QGP, thus their production is not influenced by this medium. However, the final production of particles which contain these quarks can be affected by the strongly interacting medium. Therefore, these particles are good probes for the study of QGP.

D and B mesons are composed of one heavy quark and one light quark. Measurements of these particles are commonly denoted as open heavy flavor measurements, which can be performed via hadronic or semileptonic decay channels. In the case of a semileptonic decay channel the open heavy flavor mesons decay into one hadron, electron and antineutrino. Such a measurement is called analysis of non-photonic electrons and it can be helpful in the study of how do heavy quarks lose energy while traversing the hot and dense medium.

A sensitive variable which can reveal us the effects of the QGP on particle spectra is nuclear modification factor R_{AA} 1. In case the R_{AA} is below 1, it is called suppression and it means that the particle have lost energy by the means of interaction with the medium while traversing it.

$$R_{AA} = \frac{d^2N_{AA}/dydp_T}{\langle N_{bin}\rangle d^2N_{pp}/dydp_T} \tag{1}$$

The preliminary results in Au+Au 0-10% central collisions at $\sqrt{s_{NN}} = 200$ GeV the STAR experiment observed a strong suppression of non-photonic electrons which indicates that heavy quarks strongly interact with the QGP. In the year 2012 U+U collisions at the energy $\sqrt{s_{NN}} = 193$ GeV were taken. At the very central collisions there is 20% more energy density in U+U collisions than in Au+Au collisions which could conclude into more suppression [1]. It would be interesting to see the nuclear modification factor of non-photonic electrons in 0-5% central U+U collisions and compare it to the Au+Au collisions.

The above mentioned analysis is being performed at the STAR experiment. The first preliminary results are obtained, such as invariant yield of non-photonic electrons. In the close future also the nuclear modification factor will be showed and compared to the central Au+Au collisions.

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Quarkonia and Quark-Gluon Plasma

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The potential of two quarks has the form $V_s = -\frac{4}{3}\frac{\alpha_s}{r} + kr$, where r is distance between quarks, k constant and α_s running coupling constant. The second term causes very strong attractive force for higher values of r. The confinement of quarks follows from this term. The first one is called coulombic, because of similarity to electromagnetic potential of two particles with different charge. However, an important difference occurs. α_s is running constant. It depends on four momentum transfer Q^2. For lower values of distances r or higher values of energies the Q^2 increases. Consequently, α_s tends to zero, the mentioned phenomenon is called the asymptotic freedom. Under this condition quarks and gluons are not bounded in hadrons anymore [1]. Deconfined stage of matter is called Quark-Gluon Plasma (QGP).

This stage of matter appeared at the beginning of the universe. Presently we are probably able to approach it in heavy ion collisions for example in STAR at BNL. There are many possibilities of probing QGP. One of them are quarkonia, bound states of quarks and its antiquarks. Two important kinds of them should be enumerated, charmonium $c\bar{c}$ and bottomonium $b\bar{b}$ families. J/ψ and Υ are ground charmonium and bottomonium states, respectively. Especially, J/ψ appears in an abundant amount in heavy ion collisions.

Qurkonia are expected to be melted in QGP due to Debye-like screening. Quarks and gluons are not bounded in QGP and are allowed to move freely. Debye radius depends on temperature T of QGP. It decreases with increasing temperature. If the Debye radius fall below quarkonium radius, potential of the quarks begins to be screened and the quarkonium is melted. The phenomenon resembles an electrical screening in plasmas and electrolites [2]. Temperatures of melting are different for each quarkonium state. Thus, the suppressed states of quarkonia differentiate for different temperatures.

However, it is not so simple. There are another effects which can modify observed quarkonium yield. The quarkonia can be suppressed also in cold matter. Furthermore, quarkonium yield is enhanced by recombination in hot and dense medium. It is important to take into account all those effects and compare analysed data with theoretical predictions.

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Exclusive production of ρ^0 in p-Pb Ultra-Peripheral Collisions

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A collision of particles is characterized by an impact parameter b, which is defined as the perpendicular distance between the path of two particles with a radius R_1 and R_2. When two highly accelerated particles collide with an impact parameter larger than the sum of nuclear radii, the strong interaction is suppressed due to the short range and only electromagnetic interaction may occur. This we called an ultra-peripheral collision. The electromagnetic field of relativistic nuclei is contracted and its intensity (and the number of virtual photons surroundings the nucleus) is proportional to Z^2. [1]

In ultra-peripheral collisions the ρ^0 meson is produced by a process called photoproduction. It is a type of the electromagnetic process where photon-photon or photon-nuclei collisions happen. In proton-lead collisions, the lead is the source of photon and the proton is the target. Photon-photon and photon-lead interactions are suppressed. The photoproduction of ρ^0 can be elastic or dissociative. In the former, proton remain in its ground state, in the latter case it breaks up. The ρ^0 meson decays dominantly in $\pi^+\pi^-$ pair.

The ALICE experiment at LHC provides a great oportunity to the ultra-peripheral collisions thanks to the good resolution in low p_T. A typical UPC event is characterized by a small number of tracks. In my case there are two good reconstructed tracs. I am analyzing 6 runs in LHC13b period using the CINT1 trigger. This trigger record data if there is some activity in pixel detectors.

Because of low number of tracs, there is lot of beam-gas background events. It can be cutted by the V0 detectors, which should by empty when the ρ^0 is produced. Then pions are identified by means of ionization losses in a time projection chamber (TPC). Also these events should have opposite charge. If not, it means that there are lost tracks and those ones can be used to determine the number of lost good tracks. An important role play zero degree calorimeters, which show signal if the proton breaks up. Therefore they can be used to determine the number od non-exclusive candidates. The TPC also reconstruct the position of a primary vertex. It may be located far from the bunch crossing, which means that it is a secondary vertex of another particle, for example K^0_S. Its lifetime is $10^{-10}s$ and also decays in $\pi^+\pi^-$. The mean lifetime of ρ^0 is $10^{-24}s$ thus it decays immediately.

The exclusive production of ρ^0 meson was never measured in p-Pb ultra-peripheral collision, so it is an attractive topic. Also the results can be compared with Pb-Pb collisions in ALICE and with photoproduction of ρ^0 in HERA experiment.

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History of Antimatter

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The history of antiparticle and later antimatter started in 1932. The first theoretical mention about positron was in Dirac´s paper. Dirac equation produced in this paper, a unification of quantum mechanics and special relativity. The solution of the equation was positron. Finaly it was discoverd by C.Anderson in 1933 in cosmic ray. Bevatron, new synchrotron with acceleration protons energy to 1 GeV, was built at Lawrence Berkeley National Laboratory In 1954. The next year (1955) was discovered antiproton, and year after(1956) antineutrino was discovered. Antiproton decelator was built in CERN In 1997. The Antiproton Decelerator (AD) creates low-energy of antiprotons for antimatter´s studies. In 2002 the AD produced a lot of antiatoms for the first time. Six experiments are runing on AD until oday. The first two CERN´s experiments, ATHENA and ATRAP (Antihydrogen Trap), created thousands of atoms of "cold" antimatter. Especially ATRAP has helped to provide the first glimpse inside antihydrogen atoms after researchers successfully created and measured a large number of them. The next one experiment ATHEN, followed success of experiment ALPHA, captures and studies atoms of antihydrogen. ALPHA uses another trapping method to hold the antihydrogen atoms and keep it them for longer before they anihilated. In June 2011 ALPAH was trapped antimatter atoms for 16 minutes.

Another CERN´s experiment on AD is ASACUSA (Atomic Spectroscopy And Collisions Using Slow Antiprotons). ASACUSA studies the interactions between matter and antimatter for help colliding beams of antiprotons on various kinds of normal atoms and molecules.

The last experiment is AEGIS (Antihydrogen Experiment: Gravity, Interferometry, Spectroscopy), it is the direct measurement of the Earth's gravitational acceleration on antihydrogen. The main system of measure by system of grattings in the deflectometer splits the antihydrogen beam into parallel rays. This grattings form makes a periodic pattern. Than physicists can measure, how much the antihydrogen drops deflected during horizontal flight. The AEGIS experiment represents the first direct measurement of a gravitational effect on antimatter.

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Analysis of the decay $B_s^0 \to J/\psi\phi$

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The $B_s^0 \to J/\psi\phi$ decay channel is expected to be sensitive to new physics contributions in CP violation field of study. In this channel, CP violation occurs due to interference between direct decays and decays occurring through $B_s^0 - \overline{B_s^0}$ mixing. The frequency of this mixing is characterized by the mass difference ΔM_s between light (B_L) and heavy (B_H) mass eigenstates. Difference between decay widths can be described using a CP-violating phase ϕ_s

$$\Delta\Gamma_s = \Gamma_L^s - \Gamma_H^s = 2\,|\Gamma_{12}^s|\,\cos\phi_s. \tag{1}$$

ϕ_s is small in the concept of the Standard Model and can be related to CKM quark mixing matrix via the relation

$$\phi_s \simeq -2\,\arg\left(-\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}\right). \tag{2}$$

Predicted value is $\phi_s = -0.0368 \pm 0.0018$ rad. Many new physics models predict large ϕ_s values whilst satisfying all existing constraints, including the precisely measured value of ΔM_s.

Our analysis is based on 4.9 fb^{-1} of $\sqrt{s} = 7$ TeV data from proton-proton collisions collected with the ATLAS detector in the year 2011. After various track quality and trigger cuts applied (details can be found in [2]) we have used 131,000 B_s^0 candidates within a mass range of $5.15 < m(B_s^0) < 5.65$ GeV. An unbinned maximum likelihood fit have been then performed on these candidates to extract the parameters characterising the decay.

Update to the previous measurement [1] with the addition of flavour tagging is presented here. Generally, flavour tagging significantly improve any CP violation measurement. Initial flavour of (neutral) B_s can be inferred using the other B-meson, typically produced in the event (so called "Opposite-Side Tagging" method). To study and calibrate the these methods, events containing the decays of "self-calibrated" channel $B^\pm \to J/\psi K^\pm$ can be used (flavour of the B-meson at production is provided by the kaon charge).

Detector effect have been studied using Monte Carlo (MC) samples. So-called "acceptance maps" (relying on three angles and p_T) have been created and applied to the data. Also an observed time dependence of the muon trigger have been corrected by weighting function (derived using real data and MC).

The full unbinned maximum likelihood fit contains 25 free parameters. Below the important parameters are summarized: mean B_s^0 lifetime, the decay width difference $\Delta\Gamma_s$, the transversity amplitudes $|A_0(0)|$ and $|A_\parallel(0)|$ and the CP-violating week phase ϕ_s. All of them are consistent with the world average values. Comparison between untagged and tagged analysis is shown in Figure 1. The overall uncertainty of the weak phase ϕ_s has been significantly improved by using flavour tagging (untagged value was $\phi_s = 0.22 \pm 0.41$ (stat.) ± 0.10 (syst.) rad).

$$\begin{aligned} \phi_s &= 0.12 \pm 0.25 \text{ (stat.)} \pm 0.05 \text{ (syst.) rad} \\ \Delta\Gamma_s &= 0.053 \pm 0.021 \text{ (stat.)} \pm 0.010 \text{ (syst.) ps}^{-1} \\ \Gamma_s &= 0.677 \pm 0.007 \text{ (stat.)} \pm 0.004 \text{ (syst.) ps}^{-1} \\ |A_\parallel(0)|^2 &= 0.220 \pm 0.008 \text{ (stat.)} \pm 0.009 \text{ (syst.)} \\ |A_0(0)|^2 &= 0.529 \pm 0.006 \text{ (stat.)} \pm 0.012 \text{ (syst.)} \end{aligned}$$

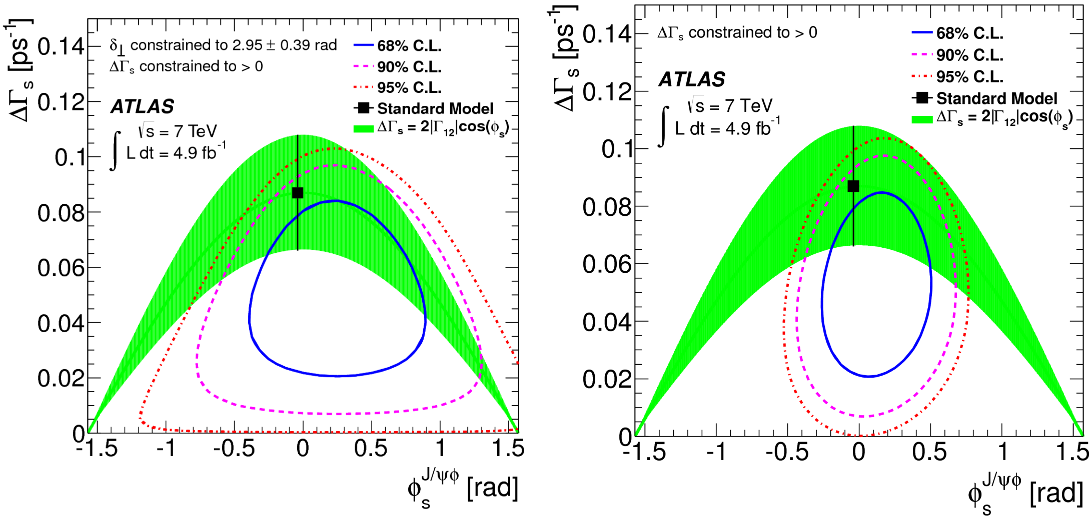

Figure 1: Likelihood contours in the $\phi_s - \Delta\Gamma_s$ plane for untagged (left) and tagged (right) analysis. The blue line shows the 68% likelihood contour, the dashed pink line shows the 90% likelihood contour and the red dotted line shows the 95% likelihood contour (statistical errors only). The green band is the theoretical prediction of mixing- induced CP violation.

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Sampling electromagnetic calorimeter FOCAL

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FoCal is forward sampling electromagnetic calorimeter, which is planned as upgrade for ALICE experiment at CERN LHC. It should measure high energies photons in the pseudorapidity range $2,5 < \eta < 4,5$ for energies E $\approx$ 500GeV/c. It should differ photons from neutral pions in various momentum and good energy measurement. It will replace currently PMD detector at a distance of 3,5m from interaction point.

Calorimeters are devices for measuring particle energy, which is transformed into measurable quantity. Calorimeters are divided into electromagnetic calorimeters and hadronic calorimeters. Electromagnetic calorimeters are used for measure electrons and photons through their electromagnetic interactions. Hadronic calorimeters measure hadrons through their strong and electromagnetic interactions. Calorimeters can be also divided into sampling and homogeneous calorimeters. Sampling calorimeters consist of absorber, produces particle shower, and active medium, where is energy deposited. Homogeneous calorimeters are built of one type of material, which can decrease energy and also generate signal.

Electromagnetic shower starts, when particle (photon, electron or positron) incident on block of material produces secondary particles. If electron or positron has energy higher than critical energy, lose their energy mainly by bremsstrahlung. Bremsstrahlung is phenomenon, when charged particle going through the nuclei curve his trajectory and emit photon. If this photon has energy higher than critical energy make electron-positron pair, and so on.

The conceptual design of FoCal is a sampling silicon-tungsten calorimeter, consist of 21-24 layers. Between 3,5mm tungsten layers is silicon pad for readout. Silicon pads will be in two types, low granularity and high granularity, which will be placed every fifth layer. Our faculty is thinking different. Design of FoCal is 32layers of 1,5mm thick tungsten and 0,5mm thick plastic scintillator. The light will be transported by optical fibres and readout by high-speed camera. Advantage of this design is better radiation hardness, very fast readout and absence of cooling system.

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Study of jet production at RHIC

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In the present particle physics, many experiments are focused on the research of quark-gluon plasma, which is a state of hot and dense nuclear matter consisting of free partons (quarks and gluons) and exists at extremely high temperature and density. QGP is created in ultra-relativistic heavy-ion collisions. Immediately after the collision partons undergo fragmentation and hadronization, which results in jets, collimated sprays of particles. Jets are studied in order to determine the properties of QGP. They can be quenched in heavy-ion collisions and this phenomenon also helps in the research of QGP. Jets are reconstructed from particles which energy and momentum are measured in detectors. Jet-finding algorithms are used for jet reconstruction and their main goal is to cluster a set of charged tracks and neutral energy measured by detectors into jets. The algorithm selects a set of particles, which are typically emitted close to each other in angle, and combines their momenta to form the momentum of a jet. The selection process is called the "jet algorithm" and the momentum addition rule is called the "recombination scheme". Jet resembles kinematic properties of the original parton therefore allows to access early stages of the collision. Jet reconstruction is successful in the p+p collisions, while in the heavy-ion collision environment is more complicated due to the large background.
Ideal jet algorithm has to fulfil several attributes. It should be fully specified by constituent-particle selection process, the constituent-particle kinematic variables, the various corrections, specifications for clustering, energy and angle definition, and all details of jet splitting and merging should be clearly and completely defined. Further requirements are order independence (algorithms behaves equally at the parton, particle and detector level) and detector independence. Ideal algorithm is also collinear and infrared safe - adding of an infrared or collinear particle into an event will not influence existence or shape of measured jets. Finally, due to the enormous number of analysed data, jet algorithm should be stable and provide jet identification with a minimum of computer time.
Jet algorithms can be divided into two groups: cone and clustering. Moreover, according to the selection of a starting particle, jet algorithms can be divided into seedless and seeded algorithms that start from the most energetic particle. Cone algorithm draws a virtual cone around the highest p_T particle and everything inside the cone is defined as a jet. The most important cone algorithms are the Cone, which is seed and infrared unsafe, and SISCone, which is in contrast to Cone seedless, infrared and collinear safe. The next category of algorithms is clustering algorithms. They are based on selecting a starting particle and then sequentially add other particles that are close enough to the arising jet. The most commonly used clustering algorithms are the k_T and the anti-k_T. All are infrared safe and differ from each other in calculation of the distance between particles. The k_t recombines the closest first, but the anti-k_T recombines primarily the most p_T particles.

This work gives a brief introduction to jet algorithms and serves as a preparation for the further analysis of jets in nucleus-nucleus collisions at RHIC.

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Event shape analysis in ultrarelativistic nuclear collisions

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Quark-gluon plasma (QGP) is very dense state of matter expected to be present few microseconds after the Big Bang. Nowadays, it is present in the first fm/c during high-energy heavy-ion collisions. Small drop of QGP, called fireball, can be created. However, it is not possible to study this state of matter directly, we are able to study hadronic gas that originates from the fireball. We focus on studying the QGP properties via azimuthal angle distribution and mainly via its anisotropies. These anisotropies are generated mainly in the early stage of the collision. Therefore, they are a good probe for initial conditions.

One way of studying the event shape was introduced in [1]. This approach is called *event-shape engineering*. The main idea is to compare all kinds of collisions and separate those with similar initial conditions. It compares events using their *flow vector* $\vec{Q}_n \stackrel{def}{=} \left(\sum_{i=1}^{M} \cos(n\phi_i)\,, \sum_{i=1}^{M} \sin(n\phi_i)\right)$, where M denotes multiplicity, ϕ is azimuthal angle. The measure is the flow vector's magnitude $q_n = Q_n/\sqrt{M}$. This vector gives us the idea of where in which azimuthal direction most of the particle are emitted. Assuming negligible nonflow, q_n distribution provides information about flow fluctuations.

Our work studies this approach via the algorithm, proposed in [2] and [3]. This algorithm was initially used for distinguishing good scientific authors from bad authors using their citation record. In this case, we sort events according to their angular record. The algorithm compares and sorts different azimuthal angle histograms according to their similarity. It uses the Bayesian concept of probability. The algorithm allows us to determine a good measure of events. It's simplicity allows many different ways of event analysis. Moreover, it provides a multiplicity-independent insight. From an experimental point of view, this is a huge advantage, because it is assumed that higher multiplicity implies more head-on collisions. This is not necessarily true. Furthermore, impact centrality is not the only fluctuating initial condition.

We study several different measures of events. We also present several simulation results of this approach and discuss the advantages and disadvantages of this approach.

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Study of b-jet tagging at ALICE

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Quark-gluon plasma (QGP) is a state of hot and dense nuclear matter, which probably existed right after Big Bang and which could be created by colliding heavy nuclei. These collisions are studied in colliders at BNL and at CERN. ALICE (A Large Ion Collider Experiment) is one of experiments at CERN, which is dedicated to study QGP in PbPb collisions. Reference studies for results from PbPb collisions are made in pp collisions.

Quark-gluon plasma can be studied by many different ways, one of them is observation of partons, which were passing this matter. These partons cannot be observed directly, but after their hadronization into jets, which are collimated showers of hadrons in final state.

Jets in collisions can be reconstructed by different ways, one of them, most frequently used is anti-k_T algorithm. Our goal is then to find a parton, which induced these jets. This parton is called a mother particle, and after hadronisation, it can be a part of some hadron. If mother parton is b quark, after hadronisation it is a part of B-meson, which cannot be observed directly in detector. It decays into other, lighter hadrons and leptons, which can be observed in detectors. These jets are called b-jets. Motivation for b-jet reconstruction is to study energy loss of b quark in QGP (it is expected to be smaller like for lighter quarks and gluons), redistribution of this lost energy and fragmentation of b quark in medium.

In first half of presentation, different b-tagging algorithms and their results will be described [1] [2]. These algorithms use large invariant mass of secondary vertices from B-mesons decays and large impact parameter of tracks going from these vertices. This algorithms are Simply Secondary Vertex and Track Counting. At ALICE, we are trying to create new algorithm, using leptons with high energy and impact parameter (these this kind of leptons is expected to be created in decays of heavy flavor particles).

The final part of presentation contains interesting results from studies of simulations of collisions. Different properties of b-jets, B-mesons and algorithms to search for true b-jets in simulations are included.

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STAR Heavy Flavor Tracker

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Experiments over the last decades suggest that a hot and dense matter, Quark-Gluon Plasma (QGP), has been formed in central Au+Au collisions. Due to their mass heavy quarks are produced by hard processes only. This property makes heavy quarks a good probe for studying the initial state of QGP. Due to limited yield of heavy flavor particles, short lifetimes and a large combinatorial background a precise vertex detector is needed.

A new micro vertex detector called Heavy Flavor Tracker (HFT) was installed in STAR for the 2014 heavy ion run. The HFT was build to extend STAR heavy flavor measurements by improving its vertex resolution. The HFT consists of three silicon detectors arranged in four layers around STAR interaction point. The outermost layer, Silicon Strip Detector (SSD), is located at the radius of 22 cm in a form of double-sided silicon strips. Second layer, Intermediate Silicon Tracker (IST), is located at radius of 14 cm as single-sided silicon strips. The two innermost layers located at 8 and 2.8 cm are parts of PXL detector, which is based on CMOS Monolithic Active Pixel Sensor (MAPS) technology used for the first time in an accelerator experiment. A mechanical support enables an installation of the PXL detector within a 12 hour shift during the ongoing run.

HFT can be used to study heavy flavor production by the measurement of displaced vertices. Total charm yield can be used for Charmonium suppression, R_{AA} of charm and bottom for energy loss in QGP and (D_0) Charm flow for thermalization.

During the 14.5 GeV Au+Au collisions run radiation related sensor damage occurred. The observed damage took many different forms: increased current consumption, full or partial loss subarrays, etc. The damage accumulate into first two weeks of 200 GeV Au+Au run until precaution were aplied. Most damage occurred in the inner layer, 14 % of total active surface was damaged. The current threshold was reduced from 400 mA to 120 mA, PXL detector was turned on when the collision rate was low enough and all sensors were power-cycled every 15 minutes. After this modification 2 more sensors were damaged in remaining 3 months of the run.

PXL demonstrates that MAPS technology is suitable for vertex detectors used in collider experiments.

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t-Dependence of the cross section for the coherent production of J/Psi in Pb-Pb UPC

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Here, I present my research project, which is the analysis of coherent J/Psi production in ultra-peripheral collisions (UPC) of lead-lead beams at LHC.

UPC occur when two projectiles interact at an impact parameter larger than the sum of their radii. What happens is, that projectiles don't interact strongly, but only via their clouds of virtual photons. Number of virtual photons is proportional to Z^2. This fact brings an idea to use heavy-ion collisions to study electromagnetic interaction. Pb-Pb collisions programme at LHC offers an interesting data, which can be analyse in many ways.

ALICE was built to study heavy-ion collisions at the LHC. It consists. It consists of many different detectors with large acceptance in pseudorapidity with almost full azimuthal angle coverage. In my analysis I use the following detectors ITS, TPC, ZDC a V0. ZDC a V0 are used to veto activity at large rapidities. ITS detector will be described by my college. In this presentation I will present in more detail the TPC.

The Time Projection Chamber (TPC) is a main particle tracking device in ALICE. It is a large volume filled with a gas mixture of Ne and CO_2. It is divided in 36 sectors comprising 557,568 readout channels. The TPC is immersed in an homogenous magnetic field of 0.5 T. When a charge particle ionizes the gas when traversing the TPC, the released electrons drift to the end-caps of the TPC where they are detected. The position where they impinge on the end-caps and the time where they do it, are enough to reconstruct the point where the gas was ionised. The succession of points where the gas is ionised allows to reconstruct the trajectory of the particle. The TPC can be used to identify particles, because the energy loss by ionisation at a given momentum depends on the mass of the particle. It allows to identify the muon tracks from the decay of the J/Psi requiring that the measurement of their energy loss is within four standard deviation from the expectation of a Bethe-Bloch parameterisation of the gas in the TPC.

In general, I'm comparing p_t resolution of real data and Monte-Carlo simulations. The real data was measured at LHC at midrapidity in 2011 during ultraperipheral Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. Applying cuts for J/Psi particle I can obtain 170 J/Psi candidates, which is slightly less, than ALICE colaboration achieved in [3]. So far, I have computed the effect of the acceptance and efficiency of the detector using MC simulations. These results are needed to correct the measure data. MC simulations will also be used to study the resolution of the kinematics of J/Psi. From the first results this ratio looks flat, which are good news for the analysis.

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Non-identical kaon femtoscopy at STAR experiment

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High energy heavy ion collisions provide means to study properties of nuclear matter under the extreme conditions. It is expected that a new state of matter called quark-gluon plasma is created during these collisions. However this system exists only for a brief period of time with typical space and time extents on the order of 10^{-14}m. To form the quark-gluon plasma, it is necessary to have high temperature and density. In nature these extreme conditions existed few microseconds after the Big bang, which created our universe 13.7 billion years ago. Therefore it is assumed, that the quark-gluon plasma existed in that time and this is one of the motivation to study the quark-gluon plasma.

One of the possible way, how to study the quark-gluon plasma is by using two-particles correlation femtoscopy[1]. It is the most widely used experimental tool for measuring characteristic sizes and life-time of the created systems. By correlation femtoscopy, the source during emission of particles is measured. The correlation function is consisted of the relative source function and the wave function describing interaction between two emitting particles. This source function depends on the relative distances of two emitted particles. Thus the correlation function measured the size of the region, from which this pair of particles can be emitted. This region is called "the homogeneity region". To obtain full information about the time and the space structure of the source is necessary comparison of the measured parameters with models. One of the most most commonly used hydrodynamics model is called blast wave model, which was developed by Retiere and Lisa[2].

In the past, the correlation femtoscopy was done with two identical particle. But the correlation function can be deal with non-identical particles. Non-identical correlation femtoscopy can provide a new information about the source - the emission asymmetries, which are results of the dynamic evolution of the source.

Due to the high luminosity, which was achieved at the RHIC non-identical femtoscopy is also possible. It is assumed, that non-identical kaon femtoscopy should be more sensitive to the source size[3]. This higher sensitive is given by the resonance ϕ (1020), which we would observed. The resonance ϕ (1020) is the result of the Coulomb and strong final state interaction. Up to now, there are only results from Pb+Pb collisions at SPS(NA49)[4].

In my presentation, the newest results from Au+Au collisions at energy $\sqrt{(s_{NN})}$=200GeV from the STAR experiment will be introduced. The correlation function for the unlike-sign kaon will be presented. It will be shown correlation functions for various sized sources. Also the comparison of sensitive correlation function for unlike-sign and like-sign kaon will be presented.

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Study of saturation effects in hadrons using Balitsky-Kovchegov evolution equation

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Large amount of experimental data mainly from deep inelastic scattering experiments at small Bjorken x allows to test the high energy limit of QCD. It is known that hadron structure functions show large increase of the number of gluons in this limit. This gluon evolution is described by the BFKL evolution equation. However, experimental data suggests that there are less gluons in a hadron then there should be according to the solution of the BFKL equation. This deviation can be due to parton saturation. According to this phenomenon the number of gluons in a hadron is given by the difference by the radiaton and recombination processes which leads to dynamically generated balance in the number of gluons driven by the saturation scale. These non-linear effects in hadrons are described by the Balitsky-Kovchegov evolution equation (BK). This process of saturation starts to occur for particles at high rapidities. Solution of the BK is particularly important in the heavy-ion physics. However finding a solution of the BK evolution equation is not very straightforward. These solutions depend on the choice of a initial condition which is obtained from measured data from first years of the HERA accelerator measurements. These initial condition functions need yet to be verified and compared with the new data acquired at HERA or at the LHC. Once fitting initial condition is found, it will be possible to obtain from the BK evolution equation the DIS structure functions and estimate the contribution of the saturation effect when compared to the older BFKL evolution equation. It is also possible to compute cross sections from the structure functions. Numerical methods are used to find the solution of the BF evolution equation, especially the Runge-Kutta method of fourth order and others for evaluating the integral inside BK equation. Stability of these methods is also discussed and an optimal way of solving this complex equation is yet being developed.

$$\frac{\partial N(r,y)}{\partial y} = \int d^2 r_1 k(r, r_1, r_2)(N(r_1, y) + N(r_2, y) - N(r, y) - N(r_1, y)N(r_2, y)) \qquad (1)$$

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Exclusive dilepton production

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There are two main interesting processes considered in this work: WW production and dilepton production. The former contains quartic gauge coupling vertex, where, by adding new terms to the corresponding lagrangian, physics beyond the standard model is being searched. Dilepton production is currently being measured at 7 TeV data at ATLAS, WW production has been measured at 7 TeV only at CMS [1]. By now, there is no such measurement at 8 TeV.

The measurement of exclusive dilepton production at 8 TeV is important for many reasons. We will reach not only higher energy, but also four times more data than at 7 TeV. The pile-up will also be higher, nearly simmilar as at the next run at 13 TeV. As a consequence, we will gain experience, how to prepare the measurement after the next run.

In February 2014, a task force was set up to explore possible extensions beyond the phase 2 ATLAS uprade. The taskforce has focused in particular on additional or improved instrumentation of ITk covering beyond pseudorapidity of 2.5. The goal was to determine the impact of such upgrade on some Standard Model analyses. One of the discussed analyses was analysis of exclusive dilepton production.

The aim of the study is to investigate the impact of larger acceptance of the forward tracker in pseudorapidity solely on the isolation of exclusive events - exclusivity requirement of exactly two charged particles. The study is carried out for exclusive dilepton production and it is expected that simmilar conclusions would be found for a different final state, such as WW.

It has been found, that a significant improvement in exclusive requirement can be achieved, if forward tracks can be reconstructed at low pT (larger than 400 MeV). Tracking with 1 or 2 GeV does not seem to bring large improvements for the isolation of exclusive signal, but might help to control and separate quasi exclusive contributions in the data.

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Measurement of charged particle spectra at the LHC at 13TeV

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Since detector ATLAS is not able to detect all particles or reconstruct them precisely, it is required to determine efficiencies of the detector in order to tune Monte Carlo generators. Those are found by measuring the charged particle spectra. Data used are from Minimum Bias events, meaning almost all events are considered. Only basic selections are implemented, e.g. on transverse momentum, pseudorapidity or number of charged particles. Data are analysed with a minimal model dependence. Aside from determining efficiencies, this measurement is also used to simulate pile-up, where pile-up verticies are simulated as Minimum bias events. At last, this measurement is also used in determining biases on high p_T due to underlying event/pile up.

Aside from a new centre-of-mass energy $\sqrt{s} = 13$ TeV, another significant change in comparison with the last run on LHC will be the new insertable BLayer added to ATLAS Inner Detector. This will lead to one more hit per track on average, resulting in better track reconstruction.

Distributions measured are $\frac{1}{N_{ev}}\frac{\mathrm{d}N_{ch}}{\mathrm{d}\eta}$, $\frac{1}{N_{ev}}\frac{1}{2\pi p_T}\frac{\mathrm{d}^2N_{ch}}{\mathrm{d}\eta\mathrm{d}p_T}$, $\frac{1}{N_{ev}}\frac{\mathrm{d}N_{ev}}{\mathrm{d}n_{ch}}$ and $< p_T > vs.n_{ch}$. The first two are basicaly normalised densities of particles in (p_T, η) phase-space. The third shows multiplicity of charged particle per event.

This measurement is a replication of older article [1]. Framework is based on older analysis, but had to be rewriten in order to work with the ATLAS new data format xAOD. Currently, basic framework for analysis is almost completed and main focus is on plotting and correction macros.

Framework was tested on non-pile-up MC sample with following selections (based on older analysis):

- $p_T > 500$ MeV, $|\eta| < 2.5$, $n_{ch} >= 1$
- requirements on Primary vertex and Pileup: Veto if another vertex with 4+ tracks
- $|d_0| < 1.5$ mm, $|z_0.sin(\theta)| < 1.5$ mm (impact parameters), χ^2 prob > 0.01
- requirements on hits (for example 3+ hits in Pixel detector)

Another selections are planned designed for extrapolation to $p_T = 0$ or to reduce contribution from diffractive events.

Corrections used are from data for 8 TeV, but since they are dependent only on p_T and η, they produce good results with difference between particle level and corrected tracks smaller that 5 % in both the lower regions of p_T and whole η region. As expected, there is a greater number of average hits in pixel detector due to the new layer.

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Studium kvarkonií na urychlovači LHC pomocí detektoru ATLAS

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The quarkonium is bound state of a heavy quark and antiquark of the same flavour. It is the simplest system bound by a combination of strong and electromagnetic interactions. Since the binding energies of the quarkonia systems are at the edge of perturbative QCD energy scale, study of the $Q\bar{Q}$ system properties serves to improvement the understanding of the strong force. The most widely known state of charmonium is the J/ψ resonance, which can decay via electromagnetic interaction into a $\mu^+\mu^-$ or e^+e^- pair, easily observed in detector. This presentation is devoted to the measurement of the double-differential inclusive fiducial $J/\psi \to \mu^+\mu^-$ production cross section in proton-proton collisions at $\sqrt{s} = 8$ TeV measured by the ATLAS detector at the Large Hadron Collider (LHC). Furthermore, the measurement of fraction of J/ψ produced indirectly from the decay of B mesons is presented.

In the beginning of this presentation, the Standard Model of particles and interactions is briefly introduced. This is followed by basic description of the quarkonia properties focusing on the elementary properties of the J/ψ resonance, and the ATLAS detector as a tool used to study of the charmonia resonances.

The main part is devoted to description of the performed steps in the analysis process. The J/ψ production cross-section is determined in four slices of J/ψ rapidity and in eleven slices of J/ψ particle transverse momentum starting at 7 GeV. To obtain the real number of produced J/ψ particles in each bin, the measured yield is corrected by the detector and reconstruction efficiencies. Furthermore, the yield can be affected by the different production mechanisms modifying the kinematic acceptance. All of this together gave us the the double-differential inclusive fiducial $J/\psi \to \mu^+\mu^-$ production cross section and all of the discrepancies arising from the different models are counted as a systematic uncertainties. The measurement of indirect J/ψ particles, divided with the same step size as for inclusive fiducial differential production cross-section is based on the long B mesons lifetime. The vertex of J/ψ particle from the B mesons decay is displaced out of primary vertex. Thus, as a discrimination variable, pseudo-proper lifetime is used.

The acquired results of indirectly produced J/ψ mesons fractions are compared to the results of the ATLAS 2010 data analysis at $\sqrt{s} = 7$ TeV [1], while the acquired inclusive fiducial cross sections are compared to the Monte Carlo data samples. Both results are in good agreement, especially in low transverse momenta regions.

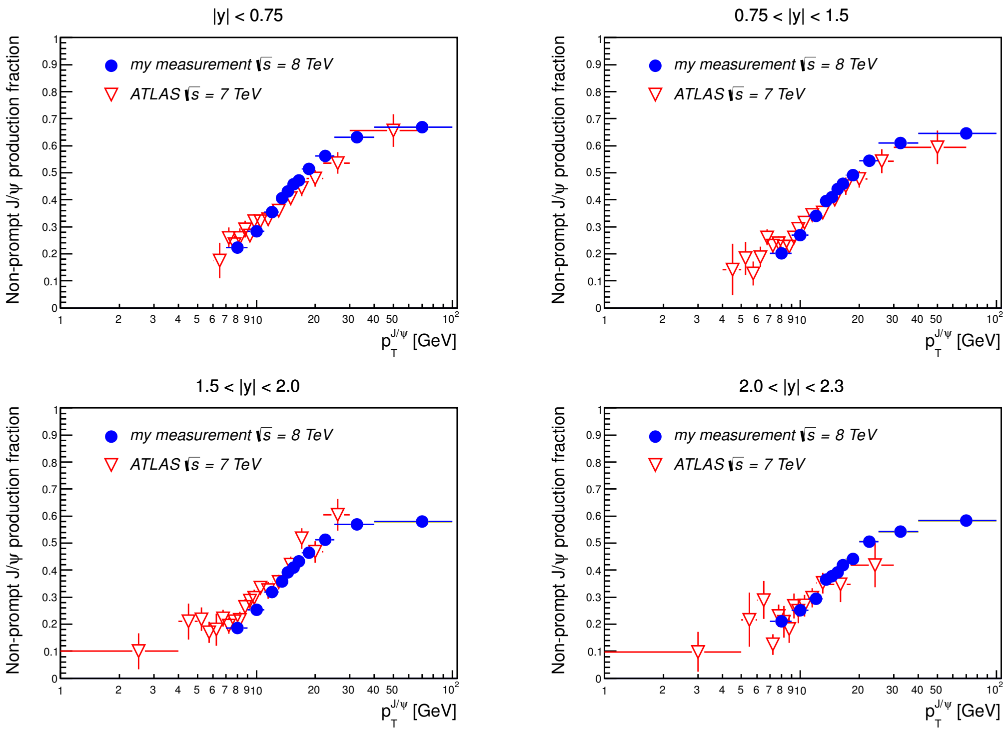

Figure 1: The fraction of J/ψ produced indirectly from the decay of B meson to all J/ψ in pp collision. The data are compared with an equivalent result from ATLAS at $\sqrt{s} = 7$ TeV.[1]

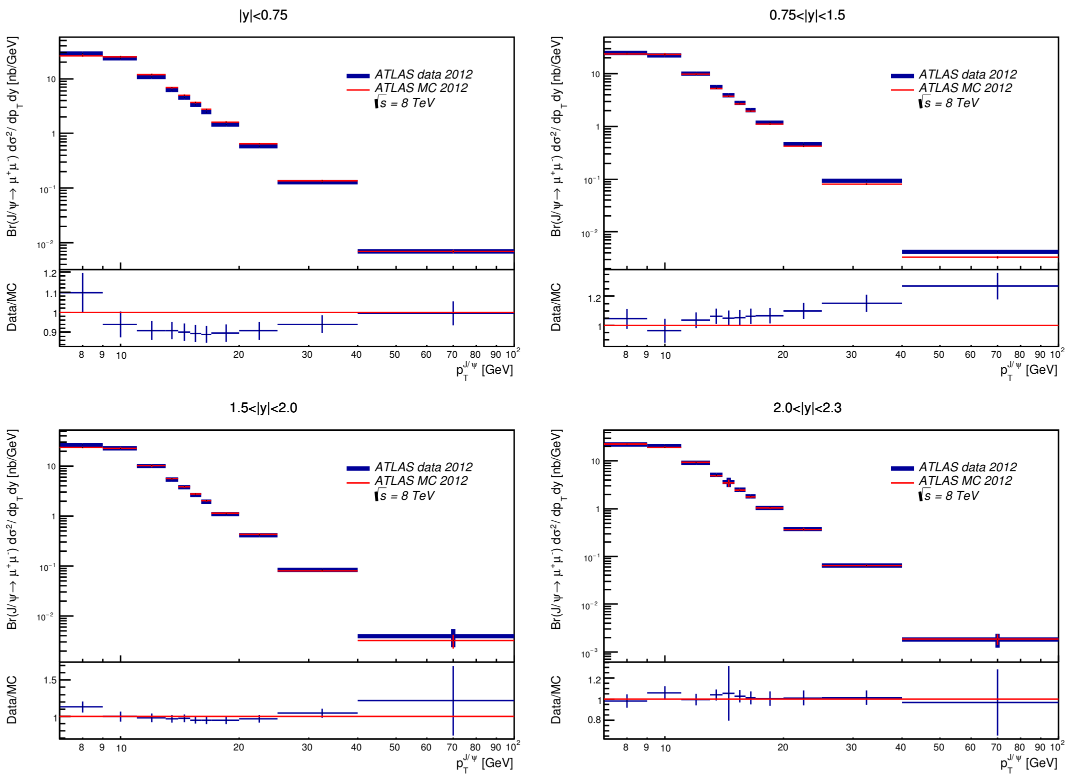

Figure 2: The measured cross sections compared to the cross sections obtained from the MC with the data to MC ratios. The MC has been reweighted on the same workspace as the cross section determined from the data.

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B–physics at ATLAS

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B–physics is a common name for the field of study concerning b quarks, so called B mesons. They are particularly interesting for a variety of reasons, namely the quark mixing and its role in CP violation and measurement of production cross-sections of heavy-flavor quarkonia. Some massive particles decay into b quarks, e.g. top quarks and the Higgs.

The B mesons have sufficient lifetime and high invariant masses. Moreover, due to the b quark being more massive than anything it decays into, the corresponding b–jets have high multiplicities and contain particles with high transverse momentum.

The CP violation has been observed in the spontaneous oscillation of $B_s = (\bar{b}s)$ into its antiparticle and in B_s decays. The Standard Model yields precise predictions for both phenomena. If a precise measurement deviates from the theoretical predictions, a process not described by Standard Model can be involved.

The ATLAS at the LHC is one of the two experiments studying B meson decays, the other one being the LHCb. The production cross section of the B mesons at the LHC energy is estimated to be 500 μb, i.e. far larger than at any other machines.

Aim of this thesis is to measure properties of the B_s meson, namely its mass and proper decay time, from the $J/\psi\phi$ decay channel. Preliminary analysis of the B_s mass has been performed, using 2012 data from pp collisions at ATLAS at $\sqrt{s} = 8$ TeV and integrated luminosity 14.3 fb^{-1}.

Fitting is performed in RooFit using an unbinned likelihood fit with a gaussian signal and an exponential background. Mass of the B_s meson extracted from the fit is $m_B = (5366.8 \pm 0.3)$ MeV. For comparison, the current table value [3] is $m_B = (5366.77 \pm 0.24)$ MeV, and the value from the 2011 analysis [1] is $m_B = (5364.0 \pm 1.4)$ MeV. All errors are considered to be statistical. So far, no significant deviation from the table value has been observed.

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Neutral strange particles production at ALICE

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Theory of Quantum Chromodynamics (QCD) predicts a phase transition of hadronic matter at high temperatures and high energy densities. Under these conditions quarks and gluons are no longer confined inside hardons (as in normal conditions) and form a state called "quark-gluon plasma" (QGP). It is believed that this form of matter existed in the early stage of evolution of the Universe. According to experimental results, it seems that this state can be recreated in ultra-relativistic heavy-ions collisions. Study of QGP properties may improve our knowledge of QCD.

Spectra of hadrons measured at the Large Hadron Collider (LHC) manifest strong enhancement of baryon-to-meson ratio in heavy-ions collisions. This behaviour has been observed at the Relativistic Heavy-Ion Collider (RHIC) and also at LHC [1]. This phenomenon is observed not only for light hadrons (containing lightest u and d quarks) but also for heavier strange particles, namely K^0_S and Λ, and cannot be explained by fragmentation.

Strange neutral particles, K^0_S and Λ, decay into two daughter particles, one with positive and one with negative electric charge. Due to its typical "V-shaped" topology, these strange mother particles are called V0 particles and provide a suitable tool for investigation of the anomalous baryon/meson production. A detailed investigation of the origin of this phenomenon is currently ongoing at A Large Ion Collider Experiment (ALICE), one of the four main experiments at LHC.

High p_T partons are produced in the early stage of the collision. These hard partons radiate softer ones, which leads to a cascade of partons. These sets of partons are called jets. Since partons cannot be observed, jets are experimentally detected as a collimated sprays of high-p_T hadrons.

Study of V0 particle production inside of jets can bring insights into physics origin of this anomaly and quantify the interplay of fragmentation at high p_T and parton recombination mechanism dominating at low p_T.

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Charged Jet Reconstruction in Au+Au Collisions at $\sqrt{s_{NN}} = 200$ GeV at STAR

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1 Introduction

Jets - collimated sprays of hadrons created by fragmentation of hard scattered partons - represent an important tool to explore the properties of the hot and dense nuclear matter created in heavy-ion collisions. However, full jet reconstruction in such events is a challenging task due to extremely large and fluctuating background, which generates a large population of combinatorial jets that overwhelm the true hard jet population.

2 Methodology

Jets are reconstructed using infra-red safe and collineary safe clustering anti-k_T algorithm implemented in the FASTJET software package [1]. Their momentum is then corrected by subtracting the median energy density multiplied by the jet area.

We reduce the combinatorial background arising in the heavy ion collisions by imposing a momentum cut on the jet's leading hadron $p_T^{leading}$ [2]. This however induces a bias on the measured jet momentum distribution and breaks the collinear safety of the jet reconstruction procedure (insensitivity of the jet reconstruction algorithm to the splitting of one track into two tracks with the same total momentum, e.g. due to the imperfection of the detector).

As a part of our analysis we try to estimate the effect of this bias on the obtained jet momentum spectrum.

Further step is the correction for the background fluctuations and detector effects, namely track reconstruction efficiency and tracking momentum resolution, by means of unfolding. We use both singular value decomposition (SVD) and Bayesian unfolding [3], [4]. We use several different assumptions as prior distributions for the unfolding. Ideally, the output of the unfolding should not depend on this initial assumption.

3 Data Sample

This analysis uses minimally biased data from Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV recorded by the STAR experiment during the RHIC Run11. We use only charged tracks reconstructed by the time projection chamber (TPC) detector which satisfy cut on minimal momentum $p_T^{min} > 0.2$ GeV/c.

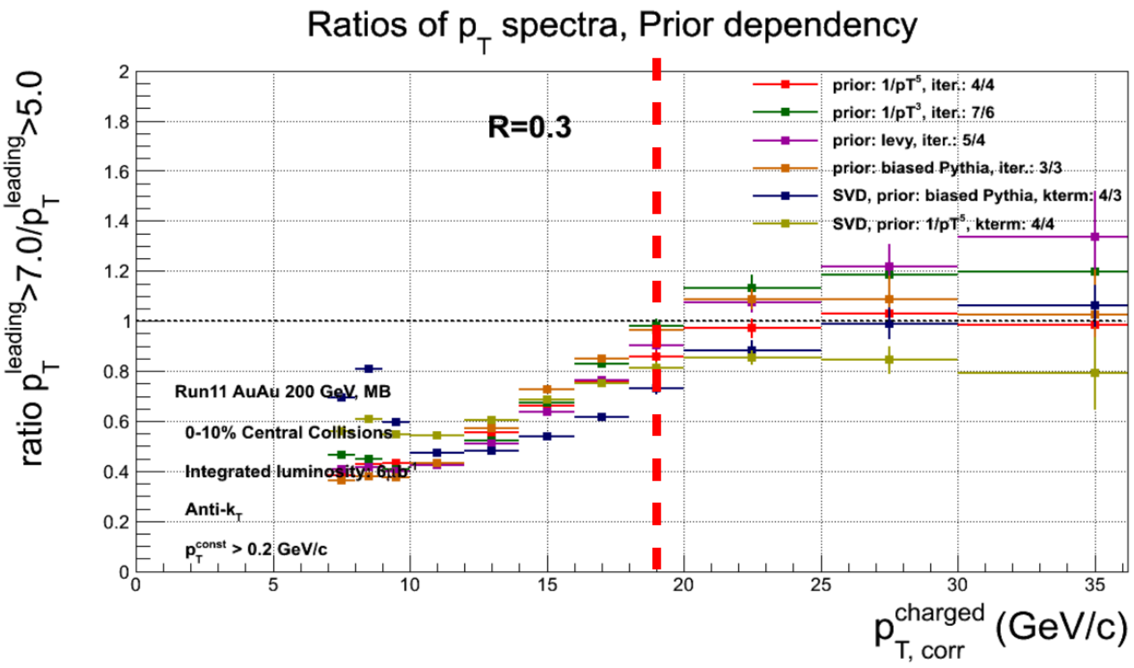

Figure 1: Ratio of jet transverse momentum spectra for two different values of $p_T^{leading}$ cut. Several different priors and two types of unfolding are compared.

4 Results

Fig. 1 shows the ratio of inclusive charged jet transverse momentum spectra for two different values of $p_T^{leading}$ cut. Both Bayesian and SVD unfolding and different prior assumptions are compared. These ratios are consistent within $\pm 20\%$ up to $p_T \simeq 30$ GeV/c. The bias of the $p_T^{leading}$ cut manifests up to $p_T \simeq 20$ GeV/c.

The unfolded inclusive charged jet p_T spectra are therefore nearly unbiased and possessing a reasonably small systematic error from the unfolding within the range of 20-30 GeV/c.

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Hard probes production in heavy ion collisions

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One of the main goals of relativistic heavy ion physics at large collider experiments such as Large Hadron Collider (LHC) at CERN is a study of quantum chromodynamics (QCD) matter at extreme temperatures and densities. Matter under these conditions is generally known as quark gluon plasma (QGP). In this state quarks and gluons are not anymore strongly bounded in hadrons but they are in deconfinement state. QGP is formed very early after collision and it is assumed that this hot and dense state of matter existed in the early stages of the Universe.

QGP has been studied by so-called hard probes, such as high transverse momentum charged particles, jet, Z and W bosons and isolated photons. Hard probes fall into two categories: strongly interacting probes, such as hadrons and jets, and not strongly interacting probes (e.g. weak bosons and direct photons). One of key observables in studies of jet quenching is the nuclear modification factor R_{aa}, defined as the ratio of particle yields in nucleus-nucleus compared to nucleon-nucleon collisions, normalized by numbers of binary collisions. Compact Muon Solenoid (CMS) detector has obtained R_{aa} for various particles as jets. Results clearly indicate suppression of charged particles in nucleus-nucleus (Pb-Pb and Au-Au) collisions and no changes for non-strongly interacting particles.

Besides of collisions of collimated flows of particles, another opportunity to study heavy ion physics presents experiment using fixed target. One of them is proposed A Fixed-Target ExpeRiment at LHC (AFTER). AFTER is designed to use the proton and lead-ion beams of the LHC extracted by bent crystal. Such an extraction mode does not alter the performance of the collider experiments at the LHC. Main advantages of AFTER is possibility to access gluon and heavy quark distributions of proton and neutron at large x and large negative Feynman x domain. For study of QGP there is an opportunity to study nuclear matter versus the features of the hot and dense matter formed in heavy-ion collision, including the formation of the QGP, which can be studied in Pb-A collisions over the full range of target-rapidity domain with a large variety of nuclei.

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Heavy Flavor Tracker at the STAR Experiment

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The Heavy Flavor Tracker (HFT) is a new state-of-the-art detector installed at the STAR experiment in January 2014. It is placed inside the Time Projection Chamber field cage and consists of four layers of silicon detectors divided into three subsystems: A double sided strip detector SSD (Silicon Strip Detector), a silicon pad detector, called IST (Intermediate Silicon Tracker), and finally two innermost layers of pixel detectors, based on the state-of-the-art MAPS technology. The Pixel detector provides pointing resolution of up to 25 μm for high p_{T} particles and the purpose of the two outermost layers (IST and SSD) is to lead the tracks from TPC to the pixels.

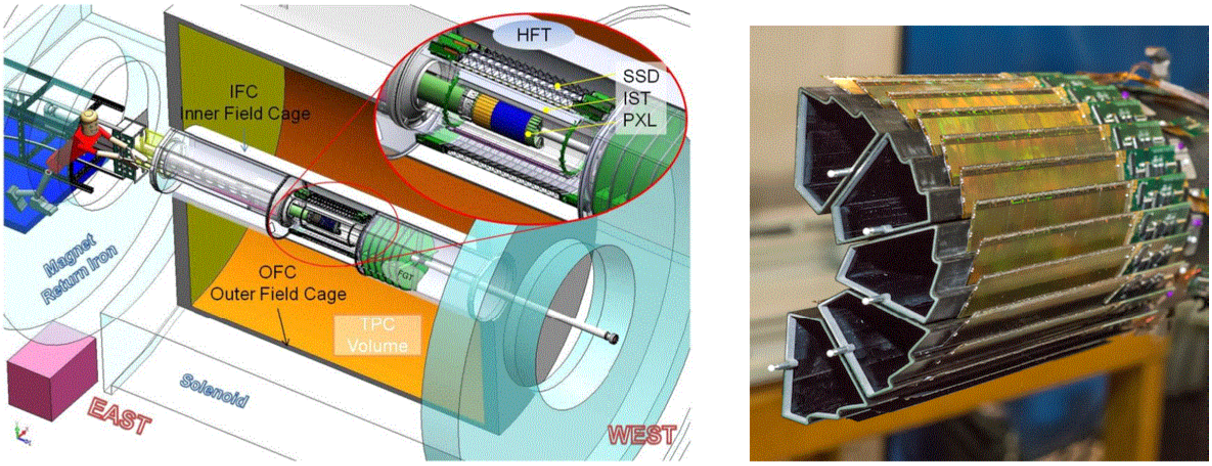

Figure 1: Left: Illustration of the STAR HFT upgrade SSD, IST and PXL at 22, 14 and 8, 2.8 cm radii, respectively. RIGHT: Picture of one half of the PXL detector, consisting of five sectors.

The HFT provides excellent primary and secondary vertex position measurement capability. This allows for precision measurements of the displaced vertices of hadrons containing heavy flavor, such as D^0 and Λ_c, over a broad momentum region. This will allow for better measurements of the yields of these hadrons. Moreover, the combined analysis of the identified charm hadrons and the non-photonic electrons will allow for the measurement of bottom production and azimuthal anisotropy at RHIC top energy. These measurements will bring us new insights into the properties of the strongly coupled QGP matter created at RHIC, such as parton energy loss mechanisms, medium thermalization, and heavy quark diffusion constant.

The MAPS technology provides excellent resolution with extremely low amount of material introduced into the volume the detector, however its biggest challenge is its relatively low radiation hardness. For this reason, a spare has been built witch can be exchanged with the irradiated Pixel layers. The damaged part can be refurbished and used as a spare again. Moreover, the Pixel features an innovative insertion mechanism that allows for an exchange of the whole subdetector within 48 hours.

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Study of nuclear matter at the LHC

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The LHC (Large Hadron Collider) the largest and most powerful particle collider in the world, which is located in CERN laboratory nearby Geneva on the border between France and Switzerland. It is a storage ring collider, i.e. two synchrotrons in which particles are accelerated in opposite directions. Thanks to this layout the centre of mass of two colliding particles is stationary in laboratory system, which makes detection of the products of the collision much easier. Furthermore higher energies can be reached this way compared to beam-target setup. In case of the LHC it is $\sqrt{s} = 7$ TeV for proton-proton (pp) collisions and $\sqrt{s_{NN}} = 2,76$ TeV for Pb+Pb collisions (energies in centre of mass system per nucleon pair, before upgrade).

The properties of strongly interacting nuclear matter, the quark-gluon plasma (QGP), is these days studied mainly through heavy-ion collisions. There are three experiments taking part in Pb+Pb measurements at the LHC. The main one is ALICE (A Large Ion Collider Experiment), which operates well with high particle (product) densities and takes part in Pb+Pb collisions only. The other two, ATLAS (A Toroidal LHC Apparatus) and CMS (Compact Muon Spectrometer), are good at measuring particles with high transverse momenta p_T and participate on both Pb+Pb and pp runs. There is one more experiment at the LHC, the LHCb, but it never participated in Pb+Pb measurements.

There are two main motivations for the heavy-ion collision experiments. The first one is study of early stages of the universe because it is thought that the QGP was present approximately 10^{-5} s after the big bang [1] and that is why the heavy-ion coll. are sometimes called "little bang". Second one is improving knowledge in field of particle physics, e.g. behaviour of particles at high energies or time evolution of the QGP.

Problem is that the QGP can not be measured directly. Only particles created during the collision are detected and complex reconstruction of each event is needed and for this purpose many variables are measured. There are a few, which are worth mentioning as an example.

One of those is nuclear modification factor R_{AA}, which is defined as [2]

$$R_{AA} = \frac{\mathrm{d}N_{ch}^{AA}(p_T)/\mathrm{d}p_T}{\langle N_{coll}\rangle \mathrm{d}N_{ch}^{pp}(p_T)/\mathrm{d}p_T} \tag{1}$$

where $\mathrm{d}N_{ch}^{AA}(p_T)/\mathrm{d}p_T$ and $\mathrm{d}N_{ch}^{pp}(p_T)/\mathrm{d}p_T$ are transverse momentum densities of charged particles in heavy-ion and pp collisions, $\langle N_{coll}\rangle$ is number of binary collisions. If heavy-ion coll. behaved as simple superposition of nucleon-nucleon coll., the nuclear modification factor would be equal to unity. This principal seems logical, but measurements show suppression for heavy-ion coll. at high p_T.

Another interesting variable is elliptic flow v_2, which shows asymmetry in p_T spectra. Dominantly in semicentral heavy-ion coll. there are preferred directions in such spectra relative to the reaction plane due to collective behavior of the medium. This is caused by shape asymmetry of the "active zone" of the collision, frequently referred as an "almond shape". This phenomenon is strongest in semicentral coll. because the "active zone" is large enough to create QGP (in contrast to peripheral one) and the shape asymmetry is much bigger than in central collision.

The list of interesting variables could go on for several more pages, but there is unfortunately not space to discuss them all.

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Measurements of charged particle distributions sensitive to the underlying event

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An underlying event in a proton-proton collisions represents everything except the process of interest (e.g. $q\bar{q} \to Z$). It is sometimes also reffered as remnants of QCD interactions, which cannot be described by perturbative theory, but is better simply parametrized.

It is well known today that protons have an inner structure, therefore it is not an elementary particle like electron. Proton consists of gluons and quarks, in general both reffered as partons. The Underlying event can be contributed by several phenomen. One of them are multiparton interactions (MPI). When a collision between two protons occurs, it is possible that more then one parton of the proton is interacting, hence multiparton interaction. The most part of the Underlying event is represented by these so called Multiparton interactions. The prove or the manifestation of MPI is that the cross section of hard scattering exceeds the total cross section. Several MPI models for Monte Carlo generators have been developed. One example of them is Sjöstrand-Zijl MPI model which uses an asumption that the average number of interactions between partons $\langle n \rangle$ is $\langle n \rangle = \frac{\sigma_{2\to 2}}{\sigma_{ND}}$ where the $\sigma_{2\to 2}$ is the cross section of all $2 \to 2$ processes ($gg \to gg$, $qq \to qq$, ...)derived from theory and σ_{ND} is the cross section of non difracting processes measured in experiments. The reason why only non difracting processes are taken is because it is hard to express difracting processes but possible to arrange experiments in a way that their contribution can be neglected thus $\sigma_{tot} \approx \sigma_{ND}$. Another accountable contributions to the Underlying event are due to initial and a final state radiations. These radiations take a place before (initial) and even after (final) partons interact. The Particles which go in a way with a smaller angle between them and the interacting partons are radiated more likely then the particles with a bigger angle.
Charged particle distributions are measured in order to obtain a knowledge about an ambient activity (Underlying event). An example of these distributions is $\langle d^2\Sigma p_T/d\eta d\phi\rangle$ mean sum of transverse momentum p_T of stable charged particles per unit $\eta - \phi$. All distributions are measured in three different regions -Toward, Transverse, Away which are defined by ϕ towards a particle with the highest p_T reffered as a leading particle.

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Low proton flux measurements at the U-120M cyclotron for tests of radiation hardness

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The ALICE experiment [1] at the CERN LHC accelerator is going to upgrade its inner silicone tracker detector (ITS). Besides precise tracking this detector has a role to determine location of primary and secondary vertices of particles leaving the interaction point and to provide fast triggering signal. Region close to the beam pipe is, however, exposed to large radiation load. Consequently, there might be non-negligible radiation damage induced on the used electronics and other parts of the detector. Therefore, it is important to test the radiation hardness of all detector parts and to search for radiation tolerant technologies and materials.

Field-programmable gate arrays (FPGA), wires, and other parts which are intended to be used for the new ITS detector are being tested for radiation hardness in low proton flux provided by the U-120M cyclotron at the Nuclear Physics Institute of AS CR in Řež [2]. The main purpose is to determine what is the maximum dose, that individual components can accept without a negative effect on their function. To determine this dose, it is necessary to know relatively accurately what proton flux is delivered by the cyclotron at given proton beam energy.

The energy range of proton beam at the Rez cyclotron reaches form approx. 10 MeV up to 34 MeV. In order to provide well defined, reproducible beam conditions for our tests and to allow fast changes of beam parameters, the end of cyclotron beam pipe was supplemented by an energy degrader. The Degrader consists of five aluminum plates with different thicknesses (8, 4, 2, 1, 0.5 mm), which can be moved into the beam or stay out of it. It is possible to operate them remotely from a control room and to change their configuration. This system thus allows to control the exact dose that was delivered to the device under test.

The tests of radiation hardness require very low proton fluxes which are far below what can be measured by the standard tools available to the cyclotron operators. Hence, it was necessary to develop other methods to determine the instantaneous proton flux with sufficient accuracy. For this purpose we use a commercial ionization chamber from PTW Freiburg [3]. Since the manufacturer of does not provide conversion factor between the proton flux and the current measured by the chamber we had to cross-calibrate the response of the chamber using the Timepix detector [4]. In the talk we will discuss evolution of lateral beam profiles when varying configuration of degrader plates.

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Jets physics

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Head-on high energy scattering allows to study objects consisting of heavy particles which are very close to each other. Evolution of partons, in these objects is described mainly by two fragmentation models - string and cluster.

Studied objects called jets are collimated clusters of roughly conical shape with high enough transverse momentum. The analysis of physical situation is simplified because jets reduce number of studied objects to only several clusters. Jets are very useful for studying the structure of protons and heavy particles such as heavy quarks, for example top and bottom.

There were suggested several methods, how to distribute partons to jets, called jet algorithms. These algorithms are basically divided into two groups: Cone algorithms and Clustering algorithms. Different procedures for finding jets, can provide different results, which can occur even for one algorithm if the input parameters are changed. Therefore it is not often easy to answer unambiguously which algorithm is suitable for the concrete situation. Typical parameters of a jet algorithm are: radius of cone R in the plane of pseudorapidity and azimuth angle (η, Φ) and minimum valuefor the transversal energy E_T or another variable determining a jet seed (potential particle for the generation of jet).

In order to make jet algorithms reliable it is necessary to impose a few conditions on their properties, such as for example infrared safety, in other words insensibility for soft radiation or collinear safety, which provide identical results (a number of jets) if one heavy particle is replaced by two particles with a total sum of energy equal to the energy of the original particle. Other required properties are universality and independence of the experiment.

In summary, for each physical analysis, it is ideal to study several jets algorithms ant to choose one which is theoritically safest. Nowadays it turns out that for most of analyses, the safest jet algorithm is the so called anti-k_t algorithm [2].

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