# XVI Advanced Research Workshop on High Energy Spin Physics

# (DSPIN-15)

September 8–12, 2015, Dubna

*Abstracts*

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*Abstracts*

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The collection of abstracts presented to the XVI Advanced Research Workshop on High Energy Spin Physics (DSPIN-15), (Dubna, September 8–12, 2015) on different theoretical, experimental and technical aspects of this branch of physics.

The contributions are reproduced from the originals
presented by the Organizing Committee.

**XVI Рабочее совещание** по физике спина при высоких энергиях
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Сборник аннотаций представленных на XVI Рабочее совещание по физике спина при высоких энергиях (DSPIN-15) (Дубна, 8–12 сентября 2015 г.) посвященное теоретическим, экспериментальным и техническим аспектам этой области физики.

## 1. The single-spin asymmetry in pp- and pA-collisions

V.V. Abramov [1][†]

(1) *State Research Center Institute for High Energy Physics*
*(NRC "Kurchatov Institute" ), Protvino, Russia*
† E-mail: Victor.Abramov@ihep.ru

Data on single-spin asymmetry $A_N$ in collisions of polarized protons with protons and nuclear targets are analyzed. Existing data are compared with the predictions of the chromomagnetic quark polarization (CPQ) model for the processes of $\pi^{\pm}$, $\pi^0$, $K^{\pm}$, p and antiproton production in inclusive reactions. The results of calculations for single-spin asymmetries in the above processes are presented in the following kinematic region: the c.m. energy $8.77 \leq \sqrt{s} \leq 500$ GeV, $0 \leq p_T \leq 9$ GeV/c, $0 \leq x_F \leq 0.83$. The CPQ model predictions can be used when planning experiments SPASCHARM (IHEP), SPD (JINR), STAR and PHENIX (BNL).

## 2. Run 2015 HJET polarimeter upgrade and performance

Alekseev Igor,
*ITEP, Moscow, Russia*

An absolute polarimeter based on the polarized hydrogen jet is vital for RHIC operations with polarized protons. New silicon detectors of recoiled protons were installed this year. The talk will cover the mew detectors design and performance.

## 3. Gluon poles in semi-inclusive processes

I.V. Anikin
*BLTP, JINR, Dubna, Russia*

†e-mail: anikin@theor.jinr.ru, Igor.Anikin@physik.uni-regensburg.de

## 4. Development of polarized ion source for Dubna high-energy accelerator complex

Belov Aleksandr,
*Institute for Nuclear Research of RAS, Moscow, Russia*

Status and plans for development of the polarized ion source for Dubna high-energy accelerator complex will be presented.

## 5. Absolute polarimeter for the polarized antiproton beam at U70 accelerator of IHEP.

A.A. Bogdanov[1,†], M.A. Chetvertkov[2], V.A. Chetvertkova[2], V.I. Garkusha[3], A.P. Meshchanin[3], V.V. Mochalov[1,3], M.B. Nurusheva[2], S.B. Nurushev[1,2,3], A.V. Ridiger[2], V.L. Rykov[1], P.A. Semenov[1,3], M.N. Strikhanov[1], A.N. Vasiliev[1,3], V.N. Zapolsky[3]

(1) *National Research Nuclear University Moscow Engineering Physics Institute, Moscow, 115409, Russia*
(2) *Federal State Budget Organization State Center Interfizika, Moscow, 115409, Russia*
(3) *State Research Center Institute for High Energy Physics, Protvino, 142284, Russia*
† *E-mail: bogdanov411@mail.ru*

We describe the absolute polarimeter for the beam channel intended to transport the polarized antiproton beam at U70 accelerator. In this case we expect to get the polarize antiproton beams in the momentum range 10-40 GeV/c. It is possible to have all three components of polarization vectors ($P_L$-along the beam line, $P_N$-normal to horizontal plane and $P_S$ lays in horizontal plane). We plan to work with $P_N$ component of polarized beam. To measure the polarization of the antiproton beam we propose to use the absolute polarimeter based on the reaction elastic proton antiproton scattering. In this case we scatter unpolarized antiprotons on polarized proton target and measure polarization $P_N$. On the second stage we scatter the polarized antiproton beam on unpolarized proton target and measure analyzing power $A_N$. The equality $A_N = P_N$ will prove the correctness of our method. The final check will be done by using polarized proton beam with the same momentum as for the antiproton beam. The main aim of this report is to estimate statistical errors end time required to measure directly polarization of the 16 GeV/c antiproton beam. We briefly survey the reactions, which may serve as the base principle for absolute polarimeter.

## 6. A Lepton Bag Model Consistent with Gravity.

Burinskii, Alexander
*Nuclear Safety Institute RAS, Moscow, Russia*

It is known that gravitational and electromagnetic fields of an electron are described by over-rotating Kerr-Newman (KN) black hole solution. Analyzing structure of the source of the KN solution and the consistent Dirac equation, we obtain that this structure has many features of the bag models. As a result,

the consistent with KN gravity dressed electron should represent a rotating bag of the Compton radius, formed by Higgs condensate which gives the mass to the confined inside the bag Dirac field. Peculiarities of the KN bag (presence of a closed relativistic string) give also explanation to the observable point-like structure of the electron. The model may also be extended to other particles of the electroweak sector of the Standard Model.

Reference: A.Burinskii, Gravitating Lepton Bag Model, ZhETP 148(10), (2015) (to appear).

## 7. Dynamic small parameters arising from general principles of symmetry and elementary particle reaction

Chavleishvili Michail
*International University "Dubna", Russia*

We consider general spin particle formalism based on symmetry properties, including requirements of angular momentum conservation in the t-channel. In such "a dynamic amplitude"approach obligatory kinematic factors arise in helicity amplitudes and consequently in expressions of all observable quantities. These spin structures give small parameters in the extremely (low and high) energies. These small parameters suppress contributions of definite helicity amplitudes in observables. There appears "kinematic hierarchy"of contributions of helisity amplitudes in different observable quantities. In such approach we can get many old end several new results for spin-particle reactions.

## 8. Lightlike solitons with spin

Chernitskii, Alexander A.
*University of Engineering and Economic, St. Petersburg, Russia*

New exact solution class of Born − Infeld type nonlinear scalar field model is obtained (see arXiv:1506.09137).

Obtained solutions are solitons propagating with speed of light and having energy, momentum, and angular momentum which can be calculated for explicit conditions.

The appropriate twisted soliton is considered. It is notable that its energy is proportional to its angular momentum in high-frequency approximation.

The ideal gas of such lightlike solitons with minimal twist parameter is considered in a finite volume. Explicit conditions provide that the angular momentum of each soliton in the volume equals Planck constant. The equilibrium energy spectral density for the solitons is obtained. It has the form of Planck distribution in some approximation.

A beam of twisted lightlike solitons is considered. The representation of arbitrary polarization for beam with twisted lightlike solitons is discussed. It is shown that this beam provides the effect of mechanical angular momentum transfer to absorbent by circularly polarized beam. This effect well known for photon beam.

Thus the soliton solution which have explicit likeness with photon is obtained in particular.

## 9. Sivers, Boer-Mulders and transversity distributions in the difference cross sections in SIDIS

Christova Ekaterina

*Institute for Nuclear Research and Nuclear Energy, Sofia, Bulgaria*

A major experimental program is presently underway to determine the Sivers, Böer-Mulders and transversity distributions, vital for understanding the internal structure of the nucleon. To this end we consider the Sivers, Böer-Mulders and transversity azimuthal asymmetries of the difference cross sections of hadrons with opposite charges in SIDIS reactions with unpolarized and transversely polarized target $l + N \to l' + h + X$, $h = \pi^{\pm}, K^{\pm}, h^{\pm}$. We show that on deutron target these asymmetries are particularly simple and determine the sum of the valence-quark $Q_V = u_V + d_V$ transverse momentum dependent distributions without any contributions from the strange or other sea-quark functions.

At present, data on these asymmetries are presented for the integrated asymmetries i.e. the $x_B$- and $z_h$-dependent asymmetries. If data are available in small bins in $Q^2$, so that $Q^2$-dependence of the collinear parton densities and fragmentation functions can be neglected, these expressions simplify dramatically leading to remarkably simple and powerful tests of the implifying assumptions used in extracting these functions from the data.

## 10. Status of the muon $g - 2$

Dorokhov Alexander

*JINR, Dubna, Russia*

We present the current status of the muon g-2 problem. Latest experimental and theoretical news will be reviewed.

## 11. The $Q_{weak}$ Experiment: First Direct Measurement of the Weak Charge of the Proton

Dowd James Franklyn
*The College of William&Mary, Hampton, VA, USA*

The recently completed $Q_{weak}$ experiment at Jefferson Laboratory made the first direct determination of the proton's weak charge, $Q_W^p$, via a measurement of the parity-violating asymmetry in elastic electron-proton scattering at low four-momentum transfer. The Standard Model (SM) makes a precise prediction of $Q_W^p(SM) = 0.0710 \pm 0.0007$. A deviation from this prediction could be an indicator of new physics. A longitudinally polarized electron beam was scattered off a liquid hydrogen target and detected in eight azimuthally symmetric fused silica detectors. The small asymmetry, $A_{ep} = -279 \pm 35(stat) \pm 31(syst)ppb$, was measured by observing the difference in rates seen in the detectors when the helicity of the electron beam was rapidly reversed. The measured asymmetry is the most precise and smallest asymmetry ever measured in an $\vec{e}p$ scattering experiment. Combining this asymmetry with previous parity-violating electron scattering (PVES) data, we obtained a value of $Q_W^p(PVES) = 0.064 \pm 0.012$, which agrees well with the SM value. The results of the experiment's commissioning run, which constitutes about 4% of the total data set, are reported here. Analysis of the remainder of the data set is ongoing and will further reduce the statistical and systematic uncertainties; several aspects of this analysis will be highlighted.

## 12. Extraction of Quark Fragmentation Functions in Leading Order at COMPASS

du Fresne von Hohenesche, Nicolas
*Institut for Kernphysik, Johannes Gutenberg-University, Mainz, Germany*

Quark fragmentation functions (FF) $D_q^h(z, Q^2)$ describe final-state hadronisation of quarks $q$ into hadrons $h$. The FFs can be extracted from hadron multiplicities produced in semi-inclusive deep inelastic scattering using a $\chi^2$ fit. The COMPASS collaboration has recently measured charged hadron multiplicities for identified pions and kaons using a $160\,GeV/c$ muon beam impinging on an iso-scalar target. The data cover a large kinematical range and provide an important input for global QCD analyses of world data at NLO, aiming at the determination of FFs in particular in the strange quark sector. The newest results from COMPASS on pion and kaon multiplicities and LO fragmentation functions will be presented.

## 13. Recent results from the NN-interaction studies with polarized beams and targets at ANKE-COSY

Dymov Sergey

*Forschungszentrum Juelich, Germany,*
*Joint Institute for Nuclear Research Dubna,Russia*

Adding to the nucleon-nucleon scattering database is one of the major priorities of the ANKE collaboration. Such data are necessary ingredients, not only for the understanding of nuclear forces, but also for the description of meson production and other nuclear reactions at intermediate energies.

By measuring the cross section, deuteron analysing powers, and spin-correlation parameters in the $dp \rightarrow \{pp\}_s n$ reaction, where $\{pp\}_s$ represents the $1_{S0}$ state, information has been obtained on small-angle neutron-proton spin-flip charge-exchange amplitudes.

The measurements of $pp$ elastic scattering by the COSY-EDDA have had a major impact on the partial wave analysis of this reaction above 1 GeV. However, these experiments only extended over the central region of c.m. angles, $30° < \theta < 150°$, that has left major ambiguities in the phase shift analysis by the SAID group. In contrast, the small angle region is accessible at ANKE-COSY, that allowed measurement of the differential cross section and the analysing power at $5° < \theta < 30°$ in the 0.8-2.8 GeV energy range.

The data on the $pn$ elastic scattering are much more scarce than those of $pp$, especially in the region above 1.15 GeV. The study of the $dp \rightarrow \{pp\}_s n$ reaction provides the information about the pn elastic scattering at large angles. The small angle scattering was studied with the polarized proton COSY beam and an unpolarised deuterium gas target. The detection the spectator proton in the ANKE vertex silicon detector allowed to use the deuterium target as an effective neutron one. The analysing powers of the process were obtained at six beam energies from 0.8 to 2.4 GeV.

An overview of the experimental program and its recent results will be presented.

## 14. Model for description of parton distribution

Ermolaev Boris

*Ioffe Physico-Technical Institute, St.Petersbyrg, Rusia*

We present a new model to describe non-perturbative contributions to parton distributions in the hadrons. The model is valid for both polarized and non-polarized parton distributions in all kinds of QCD factorization

## 15. Superconducting racetrack booster for the ion complex of MEIC

A.M. Kondratenko, M.A. Kondratenko[1], Filatov, Yury[2], A.D. Kovalenko[2], Ya.S. Derbenev[3], F. Lin[3], V.S. Morozov[3], Y. Zhang[3]

[1]*STL Zaryad, Novosibirsk*
[2]*JINR, Dubna and MIPT, Dolgoprudny, Moscow Region,Russia*
[3]*JLab, Newport News, Virginia, USA*

The current design of the Medium-energy Electron-Ion Collider (MEIC) project at Jefferson lab features a single 9 GeV/c figure-8 booster based on super-ferric magnets. Reducing the circumference of the booster by switching to a racetrack design may improve its performance by limiting the space charge effect and lower its cost. We consider problems of preserving proton and deuteron polarizations in a superconducting racetrack booster. We show that using magnets based on hollow high-current NbTi composite superconducting cable (JINR) allows one to preserve the ion polarization in a racetrack booster up to 9 GeV/c. The booster operation cycle would be a few seconds that would improve the operating efficiency of the MEIC ion complex.

## 16. On the photoabsorption sum rules $\sigma_{-1}$ for selected composite systems (atoms, nuclei and nucleons)

S.B. Gerasimov
*Bogoliubov Laboratory of Theoretical Physics, JINR, Dubna, Russia*

The relativistic dipole moment fluctuation sum rules in the "valence-parton"approximation are considered within the "infinite momentum technique"to trace the effects of the varying coupling constants and correlations of constituent partons in the ground states.

## 17. Overview of Recent Spin Physics Results from STAR

Adam Gibson for the STAR Collaboration
*Valparaiso University, IN 46383; USA*

As the world's only polarized proton collider, the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory plays an important role in understanding the spin structure of the proton. The STAR detector, with its large acceptance for calorimetry and tracking, has been used to study polarized proton collisions for more than a decade with a range of jet, meson, and boson probes. We will discuss jets, neutral pions, and $W$ bosons as probes of the proton's helicity structure. Here STAR measurements have a significant impact on global fits of sea quark polarizations and have provided the first

firm evidence of non-zero gluon polarization within the proton. We will also discuss $W$ and $ZF$ bosons, jets, pions, and pion-jet correlations as probes of the transverse spin structure of the proton, shedding light on such aspects as transverse-momentum-dependent parton distributions and transversity. We will discuss preliminary and recently published results as well as plans for the future.

## 18. About obsevation of Higgs parity at LHC

Ilya Ginzburg

*Sobolev Inst. of Mathematics and Novosibirsk State University, Russia*

CMS and ATLAS announced measering of parity of Higgs boson. In fact, their results are valid for only small class of beyond Standard Model physics. For most of such models such experiments cannot give information about Higgs parity.

## 19. Role of pion pole in hard exclusive meson leptoproduction

S.V. Goloskokov[†]

*JINR, Dubna, Russia*

[†]*goloskkv@theor.jinr.ru*

It is shown that the pion pole contribution is essential in hard $\pi^+$ and the $\omega$ leptoproduction. Our results on spin asymmetries and spin density matrix elements in these reactions were found to be in good agreement with HERMES data. We consider the pion pole effects in the exclusive Drell-Yan $\pi^- p \to l^+ l^- n$ process as well.

We show that transversity effects determined by the GPDs $H_T$ and $\bar{E}_T$ are essential in the description of these reactions.

## 20. Simulation of $^3He(d,p)^4He$ reaction and recent results of the experimental investigation of $dp$ breakup reaction

Janek, Marian

*Zilina University in Zilina, Slovakia*

The feasibility study for the measurements of the polarization observables in the $^3He(d,p)^4He$ reaction for DSS project using a part of the BM@N setup have been performed. Deuteron beam with energy of 1.5 GeV, magnet, 12 stations GEM tracker and TOF wall was used in simulations in order to obtain momentum resolution and to prove the separation of the secondary protons and deuterons. Recent results of the $dp$ breakup reactions with detection of two protons in coincidence for some kinematic configurations at energies from 300 to 500 MeV obtained in Nuclotron will be presented.

## 21. Spin physics and biological membranes

Kiselev, Yury

*JINR, Dubna, Russia*

The formula for calculating the concentration profile of the ions in biological membranes has been obtained. It is assumed that ions are moving in solution under the influence of the electrical field and the gradient of ion concentration. Friction force follows the Stokes' relation assuming the spherical shape of ions. The problem is that ions are covered with unstable hydrated shells that comprising the electric dipoles of water. Such complex electric structures had been considered in the spin physics of the nuclear quadruple moments [1]. We have complicated the Stokes' model by means of simulating shells with prolate or oblate ellipses [2]. It was shown that the effective ion radius definitely depends on the shape of hydrates within a membrane. Calculation of Na+1 and K+1 concentration profiles lead to a conclusion that active and passive transport of ionic species in membrane closely associated with the shape of hydrated shell. The work was performed at the Veksler and Baldin Laboratory of High Energy Physics, JINR, Dubna.
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## 22. The decays of the $X(3872)$–meson in a tetraquark model

Koerner Juergen[†]

*Institut fuer Physik, University of Mainz, Germany*

[†]koerner@thep.physik.uni-mainz.de

We explore the consequences of treating the $X(3872)$-meson as a tetraquark bound state. As a dynamical framework we employ a covariant constituent quark model with built-in confinement. We treat the strong decays $X(3872) \to J/\psi + (\rho, \omega)$ and $X(3872) \to \bar{D}^0 + D^{0*}$, and the electromagnetic decay $X(3872) \to J/\psi + \gamma$.

## 23. Orbital Parameters of Proton and Deuteron Beams in NICA Collider with Solenoid Siberian Snakes

Kondratenko Anatoliy
*Science and Technique Laboratory "Zaryad", Novosibirsk, Russia*

Two solenoid Siberian Snakes are required to obtain ion polarization in spin transparency mode of the NICA collider. The field integrals of the solenoid Snakes for protons and deuterons at maximum momentum of 13.5 GeV/c are equal to 2x50 T×m and 2x160 T×m respectively. The Snakes introduce strong betatron oscillation coupling. The calculations of orbital parameters of proton and deuteron beams in NICA collider with solenoid Snakes are presented.

## 24. Numerical Calculation of Ion Polarization in NICA Collider

Kondratenko Mikhail
*Science and Technique Laboratory "Zaryad", Novosibirsk, Russia*

The NICA Collider with two solenoid Siberian snakes is "transparent" to the spin. The collider transparent to the spin provides a unique capability to control any polarization direction of protons and deuterons using additional weak solenoids without affecting orbital parameters of the beam. The spin tune induced by the control solenoids must significantly exceed the strength of the zero-integer spin resonance, which contains a coherent part associated with errors in the collider's magnetic structure and an incoherent part associated with the beam emittances. We present calculations of the coherent and incoherent parts of the resonance strength in the NICA collider for proton and deuteron beams.

## 25. Recent results on TMDs from the HERMES Experiment

Korotkov Vladislav (for HERMES collaboration)
*IHEP, Protvino, Russia*

HERMES has taken a wealth of deep-inelastic scattering data using the 27.6 GeV polarized lepton beam at HERA and various pure gas targets, both unpolarized and polarized, which opened the door to several unique results. Among them are the first evidences for the naive-T-odd Sivers and Collins effects. An overview of recent HERMES results on measurement of asymmetries $A_{LU}$, $A_{UT}$, and $A_{LT}$ will be presented.

## 26. The last step in the road from QCD to nuclear physics

Boris Kosyakov

*Russian Federal Nucl Center-VNIIEF, Sarov, Russia*

A central problem of QCD is to account for the interaction between quarks in the strong-coupling regime. A direct way for revealing the properties of this regime is to use the Feynman path integral whereby all color degrees of freedom are integrated out except for those of a single quark. Clearly a systematic implementation of this calculation is still a good distance in the future, and yet integrating out the remaining degrees of freedom can be neatly approximated by an effective theory to the low energy QCD. Indeed, plausible assumptions about the mean color field of a given system can be made with a fair degree of confidence, and a semiclassical treatment of the studied single quark is quite possible. A simple but having considerable promise approach to the derivation of an effective theory of this kind was recently proposed in the paper "The bag and the string: Are they opposed?", PLB 744(2015)28-33, by B. P. Kosyakov, E. Yu. Popov, and M. A. Vronskiy. In this presentation we refine this approach and discuss its conceptual and technical aspects as applied to free hadrons, nuclei, and quark-gluon plasmas.

## 27. Electromagnetic interactions of neutrons

Yu.P. Kunashenko

*National Research Tomsk Polytechnic University*
*Tomsk State Pedagogical University Tomsk, Russia*

F magnetic moment can be scattered by electric field of an atom. The physics of this scattering is explained in a following way: in a neutron rest frame the magnetic field appears and the neutron magnetic moment interacts with it. Electromagnetic Schwinger scattering of the fast neutrons was experimentally discovered in 1956 [2]. In the paper [3] dedicated to Semi - Centenary anniversary of discovering of the fast neutrons Schwinger scattering it was done review of theoretical and experimental works on this subject, and also it was described possible new experiments.

Another mechanism of the neutron interaction with electromagnetic field is photon emission. For the first time, the electromagnetic radiation from neutron in an external magnetic field was calculated in [4-6]. The bremsstrahlung and coherent bremsstrahlung from neutrons were studied in [7-9].

It is well known that when the fast charged particle penetrates through aligned crystal, there appears coherent effects (a thin crystal) and channeling. Interaction of the neutrons with crystals were considered in the following papers [10-16]

In a present report we discuss the following questions:

1. Coherent Schwinger scattering of fast neutrons versus coherent elastic nuclear scattering in a crystal.

2. The bremsstrahlung and coherent bremsstrahlung from neutrons.

3. Influence of the elastic nuclear scattering on the neutron bremsstrahlung

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# 28. Reactions $pp \to pp\pi^0$ and $pp \to pn\pi^+$ at 800 MeV

Kurbatov Vladimir

*JINR, Dubna, Russia*

# 29. Gluon Contribution to the Sivers Effect. COMPASS results

Krzysztof Kurek

*National Centre for Nuclear Research, Warsaw, Poland*

I will present the new results on gluon contribution to the Sivers effect, obtained from data collected on transversely polarized proton and deuteron targets at COMPASS.

## 30. Study of polarization effects at Nuclotron
Ladygin, Vladimir
*JINR, Dubna, Russia*

The major goal of the upgraded Nuclotron facility is to obtain the information on the equation-of-state for dense nuclear matter playing a key role in the under standing of the collapse supernovae and neutron stars stability. These studies can be performed either in heavy ion collisions or via the short-range few nucleon correlations. The obtained experimental results and future program with the use of polarized deuteron beam and the internal target station are discussed. The polarization studies for the NN, NA and dA reactions with the extracted deuteron beam at the BM@N setup are proposed. The further extension of the polarization program at BM@N is related with the study of the in-medium modification of the polarization for the strange and multi-strange baryons and the spin alignment for vector mesons decaying in hadronic modes.

## 31. Correlations of internal quantum numbers and entangled states in two-particle systems
Lyuboshitz, Valery V.
*JINR, Dubna, Russia*
*E-mail: Valery.Lyuboshitz@jinr.ru*

The properties of nonfactorizable ( entangled ) two-particle quantum states are discussed. The study of spin correlations of two identical particles with spin $1/2$ at low relative momenta is performed. The angular correlations of decay directions for two unstable particles, connected with the correlations of their spin quantum numbers, are considered. It is shown that, for nonfactorizable two-particle states, the "classical"incoherence inequalities for the correlation tensor components, being analogous to the Bell inequalities, may be violated.

Concretely, the spin correlations and angular correlations for the systems $(\mu^+\mu^-)$, $(\tau^+\tau^-)$, produced in the reactions $e^+e^- \to \mu^+\mu^-$, $e^+e^- \to \tau^+\tau^-$, for the systems of final leptons in the processes $\gamma\gamma \to e^+e^-, \mu^+\mu^-, \tau^+\tau^-$, and also for the $\Lambda\Lambda$ and $\Lambda\bar{\Lambda}$ systems generated in relativistic heavy-ion collisions, have been analyzed. In particular, it is noted that the sharp change of the correlation tensor for the $\Lambda\bar{\Lambda}$ pair with the increase of energy may testify to the passage through the "mixed phase".

Some other correlations of internal quantum numbers, being analogous in structure and having the strongly pronounced quantum character, have been also considered: spin correlations in the $(p, {}^3He)$ system formed in the reaction $\pi^+ + {}^4He \to p + {}^3He$, correlations of linear and circular polarizations of two $\gamma$ quanta, and correlations at the registration of two neutral $K$ mesons generated

in inclusive multiparticle processes with the strangeness conservation ( and also pairs of neutral charmed and beauty mesons $D^0\bar{D}^0, B^0\bar{B}^0, B_s^0\bar{B}_s^0$ ).

## 32. On the angular momentum of the nucleon

Ma Bo-Qiang
*School of Physics, Peking University, Beijing 100871, China*

I will clarify theoretical issues related to the angular momentum of the nucleon and the way to make measurements

## 33. Renormdynamics, Discrete Dynamics and Spin

Makhaldiani, Nugzar
*JINR, Dubna, Russia*

In the Standard Model of Particle Physics (SM), minimal supersymmetric extension of the SM (MSSM), standard pion-nucleon field theory and other models is shown how to define the values of coupling constants and masses. Discrete dynamics, spins and Quanputers considered.

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## 34. Spin density matrix elements in exclusive $\omega$ electroproduction on $^1$H and $^2$H targets at 27.5 beam energy

S.I. Manaenkov (for the HERMES collaboration)
*NRC "Kurchatov Institute"PNPI,Gadchina, Russia*

Exclusive electroproduction of $\omega$-mesons on unpolarized hydrogen and deuterium targets is studied in the HERMES experiment at $Q^2 > 1.0$ GeV$^2$, 3.0 GeV $< W < 6.3$ GeV, and $-t < 0.2$ GeV$^2$. The determination of the longitudinal-to-transverse cross-section ratio reveals that a dominant contribution to the crosssection arises from transversely polarized virtual photons. Violation of $s$-channel helicity conservation is observed for some of spin density matrix elements. A sizable contribution from unnatural-parity-exchange amplitudes to the cross section is found and the phase shift between those amplitudes that

describe transverse $\omega$ production by longitudinal and transverse virtual photons is determined for the first time. A hierarchy of main helicity amplitudes is established. Good agreement is found between the proton data and calculations performed in the Goloskokov-Kroll model that includes pion-pole contribution.

## 35. Overveiw of recent HERMES results
Marukyan Hrachya (for HERMES Collaboration)
*Yerevan Physics Institute, Armenia*

The HERMES experiment at DESY Hamburg collected a wealth of data using the 27.6 GeV polarized electron or positron beams from HERA and various polarized and unpolarized gaseous targets. This unique data set opens the door to various measurements in inclusive and semi-inclusive deep-inelastic scattering. Particularly, the multi-dimensional structure of the nucleon has been studied in semi-inclusive deep-inelastic scattering. Also experimental measurements in hard exclusive electroproduction processes have been carried out from this data.

An overview of more recent and important results from the HERMES will be presented.

## 36. Single hadron transverse spin asymmetries in SIDIS at COMPASS
J. Matousek
*Charles University in Prague, Czech Republic*

The study of the transverse spin structure of nucleons by means of Semi-Inclusive DIS has always been an important part of the broad COMPASS physics program. The COMPASS Collaboration has measured the transverse spin azimuthal asymmetries, Sivers and Collins in particular, in charged hadron production in DIS of 160 GeV/c longitudinally polarized muons off transversely polarized protons and neutrons using $NH_3$ and $^6$LiD targets, respectively. The asymmetries have been investigated by a one-dimensional and, recently, also a multi-dimensional analysis in $x$, $Q^2$, $z$ and $p_T$. Results of these analysis as well as a feasibility study of a new analysis of transverse spin asymmetry in $J/\psi$ production will be presented.

## 37. Polarization transport studies at RHIC

Francois Meot,
*Brookhaven National Laboratory, Upton, NY, USA*

Extensive polarization dynamics studies have been performed at the AGS and RHIC over the past few years, and more recently, further, in the frame of the eRHIC project R&D. An overview of the harvest of spin dynamics and polarization transport outcomes of these studies will be presented, as well as the tracking methods and tools developed and used in this framework.

## 38.Study of single-spin asymmetries with polarized target at the SPASCHARM experimentFF

Mochalov, Vasily (on behalf of the SPASCHARM collaboration)
*IHEP, Protvino, Russia*

A new experiment SPASCHARM for systematic study of polarization phenomena in inclusive and exclusive hadronic reactions is currently under commissioning at IHEP. The universal experimental setup will detect dozens of various resonances and stable particles produced in collisions of unpolarized beams with the polarized target, and at the next stage, using polarized beams. At the first stage with polarized target, the final states composed of light quarks ($u$, $d$, $s$) will be reconstructed. Hyperon polarization and spin density matrix elements of the vector mesons will be measured along with the single-spin asymmetries. The $2\pi$-acceptance in azimuth, which is extremely useful for reduction of systematic errors in measurements of spin observables, will be implemented in the experiment. The solid angle acceptance of the setup, $\Delta\theta \approx$ 250 mrad vertically and 350 mrad horizontally in the beam fragmentation region, covers a wide range of kinematic variables $p_T$ and $x_F$. This provides the opportunity for separating dependences on these two variables which is usually not possible in the setups with a small solid angle acceptance. Unlike some previous polarization experiments, the SPASCHARM will be able to simultaneously accumulate and record data on the both, charged and neutral particle production.

## 39. Study of spin effects with Polarised antiprotons.

V. Mochalov, V. Abramov, V. Rykov, P. Semenov, A. Vasiliev
*IHEP, Protvino, Russia*

Polarization phenomena in strong interactions and spin structure of hadrons still are not fully understood theoretically. In general, any experimental data for proton-antiproton collisions with polarization are of the great interest just

because such data are still very scarce. So far, the only available experimental data with polarized antiproton beam at high energies are the E704 results on single-spin asymmetry in inclusive pion production. In $pp$-collisions at low energies, the $qg$- and $gg$-processes dominate in the production of $cc$-bar and $ss$-bar-pairs. An important feature of antiproton-proton reactions is the direct access to $q\bar{q}$ annihilation interactions via production of $q\bar{q}$ states. In this report we discuss a possible physics program for the future spin experiments on single- and double-spin effects studies with polarized antiprotons.

## 40. Deformed nucleon, quark vorticity, proton spin
Musulmanbekov Genis
*JINR, Dubna, Russia*

In the framework of Strongly Correlated Quark Model (SCQM) the valence quarks in a proton are treated as vortical solitons. SCQM includes chiral symmetry breaking/restoration as interplay between current and constituent quarks, meets local gauge invariance and Lorentz invariance. A proton spin arises from the irrotational vortical field around valence quarks. Namely this field forming the intrinsic spin of quark leads to the "spin crisis".

## 41. The cosmic censorship and stationary bound states of half-spin particles in the field of Reissner-Nordstroem naked singularity
V.P. Neznamov
*Russian Federal Nuclear Center - All-Russian Research Institute of Experimental Physics, Sarov, Russia*

The paper explores quantum mechanics of half-spin particle motion in the field of Reissner-Nordstroem (R-N) naked singularity. The following basic results were obtained:
1. For any quantum-mechanical Dirac particle, irrespective of availability and sign of its electrical charge, the R-N naked singularity is separated by an infinitely large positive potential barrier, that agrees with the hypothesis of cosmic censorship.
2. With similar signs of charges of a particle and the field source of the R-N naked singularity, at some distance from the naked singularity the second completely impenetrable infinitely large potential barrier exists. When the intensity of electromagnetic particle interaction with the R-N field essentially exceeds the gravitational interaction, at the value of particle energy of $E \sim mc^2$ the barrier position is close to half of the classical radius of a charged particle.

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At $E >> mc^2$, the barrier position varies inversely proportional to the particle energy.

3. The analysis of effective potentials and numerical solutions of the Dirac equation have shown that stationary bound states of half-spin particles in the field of R-N naked singularity can exist in case of opposite signs of charges of a particle and the R-N field source as well as in case of an electrically uncharged Dirac particle. In case of the similar signs of the charges, bound states of the Dirac particle can exist in the domain under the second potential barrier.

## 42. JEDI: Towards EDM at COSY

Nikolaev, Nikolai
*L.D.Landau Inst. Theoretical Physics, Chernogolovka, Russia*

A progress report on JEDI efforts towards the first measurement of the proton and deuteron EDM at COSY will be presented, included the record precision determination of the spin tunes and the theoretical and experimental studies of the ring imperfection effects.

## 43. Longitudinally polarized parton distributions with faithful uncertainty estimates

Nocera Emanuele Roberto
*Universita degli Studi di Genova, Italy*

I present recent progress in the determination of longitudinally polarized parton distribution functions from a global analysis of experimental data achieved by the NNPDF collaboration. I review the features of the NNPDF methodology for parton fitting and I illustrate the impact of recent measurements in both fixed-target lepton-nucleon scattering from COMPASS and JLAB and proton-proton collisions from RHIC. I discuss which are the open issues in current determinations of polarized distributions and comment on future improvements from both the theoretical and the experimental sides.

# 44. Polarized antiproton beam at U-70 accelerator of IHEP

S.B. Nurushev [1,2,3†], M.A. Chetvertkov [2], V.A. Chetvertkova [2],
V.I. Garkusha [3], A.P. Meshchanin [3], V.V. Mochalov [1,3], M.B. Nurusheva [1,2,3],
A.V. Ridiger [2], V.L. Rykov [1], P.A. Semenov [1,3], M.N. Strikhanov [1],
A.N. Vasiliev [1,3], V.N. Zapolsky [3]

(1) *National Research Nuclear University Moscow Engineering Physics Institute,
Moscow, 115409, Russia*
(2) *Federal State Budget Organization State Center Interfizika, Moscow, 115409,
Russia*
(3) *State Research Center Institute for High Energy Physics, Protvino, 142284,
Russia*
†E-mail: sbnurushev@mail.ru

The beam channel for polarized protons and antiprotons at U-70 accelerator is currently under development at IHEP, Protvino, Russia. An availability of the both, polarized proton and antiproton beams provides an unique opportunity for comparative studies of spin effects induced by polarized protons and antiprotons in a wide variety of reactions: analyzing powers in inclusive and elastic processes, spin correlation parameters $A_{NN}$, $A_{SS}$, $A_{LL}$, spin dependences in total cross sections: $\Delta\sigma_T$ and $\Delta\sigma_L$. The experimental studies with polarized protons have a long history and, as a result, the quite rich pool of data on observed and measured spin phenomena has been accumulated and is available. However for antiprotons, such a pool is virtually empty. So far, the only experimental study with polarized antiprotons had been carried out by Fermilab experiment E704 on measuring $A_N$ in inclusive production of pions by polarized antiprotons at 200 GeV/c.

While this channel at U-70 of IHEP is designed to operate with the both, polarized antiproton and the high-intensity polarized proton beams, in this report we focus mainly on the feasibility of shaping and transportation of the antiproton beam of a sufficiently high intensity and polarization size. It is shown that the construction of such beam channel will open the first time opportunity for carrying out meaningful experimental studies of spin phenomena in strong interactions induced by polarized antiprotons in the momentum range of $\sim 5$ $-$ 30 GeV/c.

The study of this report addresses technical details of forming the polarized antiproton beam and beam channel equipment, estimates of achievable intensity and polarization as well as some aspects of mentioned above spin-physics.

## 45. Dynamics of fermion with magnetic moment in electromagnetic and gravitational waves

Obukhov, Yuri

*IBRAE RAS, Moscow, Russia*

We study the dynamics of a quantum fermion particle with a nontrivial anomalous magnetic moment in the external classical electromagnetic and gravitational fields. It is described by the covariant Dirac equation modified by the Pauli type terms. Special attention is paid to the case when the external field configurations are waves. The exact solutions of the generalized Dirac-Pauli equation are constructed and the physical meaning of the results obtained is discussed.

## 46. Spin observables in antihyperon-hyperon production at PANDA at FAIR

Papenbrock Michael

*Uppsala University, Sweeden*

E-mail: michael.papenbrock@physics.uu.se perdrisa@jlab.org

The production of antihyperon-hyperon pairs in antiproton-proton annihilations involves the annihilation of at least one light (u, d) quark-antiquark pair and the creation of a heavier (s, c, b) pair. The scale of the production process is given by the mass of the created quark-antiquark pair. Therefore, with the production of strange quarks we are probing the QCD close to its cut-off. By studying hyperon production we learn about the strong interaction in this energy region, i.e. the confinement domain. It is an open question what the relevant degrees of freedom are: constituent quarks and gluons, or hadrons. Spin observables, e.g. the polarisation and spin correlations are excellent tools in order to better understand the physical processes. These are accessible via the weak, parity violating decay of the hyperons which results in an angular asymmetry of the decay products.

The future PANDA experiment at FAIR will provide a unique opportunity to study strange and single-charmed hyperons. Simulation studies done by the Uppsala group show excellent prospects for spin physics with hyperons with the PANDA detector. Results from these simulations, including the feasibility of extracting polarisation parameters from the hyperon decay angular distributions, will be presented in this talk.

## 47. Transverse spin azimuthal asymmetries at COMPASS

Parsamyan Bakur
*University and INFN Turin, Italy*

COMPASS is a high-energy physics experiment operating on the M2 beam line at the SPS at CERN. Using high energy muon and hadron beams experiment covers broad range of physics aspects in the field of the hadron structure and spectroscopy. One of the important objectives of the COMPASS experiment is the exploration of transverse spin structure of nucleon via study of spin (in)dependent azimuthal asymmetries with semi-inclusive deep inelastic scattering (SIDIS) processes and starting from this year also with Drell-Yan (DY) reactions.

Experimental results obtained by COMPASS for azimuthal effects in SIDIS play an important role in the general understanding of the three-dimensional nature of the nucleon. Giving access to the entire ?twsit-2? set of transverse momentum dependent (TMD) parton distribution functions (PDFs) and fragmentation functions (FFs) COMPASS data triggers constant theoretical interest and is being widely used in phenomenological analyses and global data fits. In particular, unique x-Q2-z-pT multidimensional results for transverse spin asymmetries recently obtained by COMPASS will serve as a direct and unprecedented input for TMD Q2-evolution related studies, one of the hottest topics in the field of spin-physics.

In addition, measurement of the Sivers and all other azimuthal effects in polarized Drell-Yan at COMPASS will reveal another side of the spin-puzzle providing a link between SIDIS and Drell-Yan branches. This will be a unique possibility to test universality and key-features of TMD PDFs using essentially same experimental setup and exploring same kinematic domain. In this talk COMPASS results on azimuthal asymmetries, obtained from transversely polarized deuteron and proton data, as well as results of some relevant theoretical calculations will be reviewed. Main focus will be given to the very recent results obtained by the collaboration for multi-dimensional transverse spin asymmetries and to the physics aspects of COMPASS polarized Drell-Yan program.

## 48. Upgraded polarized target for polarized Drell-Yan measurement at COMPASS

Pesek Michael (On behalf of COMPASS collaboration)
*Charles University in Prague, Czech Republic*

In the COMPASS Drell-Yan experiment the pion beam with momentum of 190 GeV/c and intensity up to 108 pions/s interacts with transversely polarized

proton target producing muon pair via Drell-Yan process. The solid $NH_3$ is polarized by dynamic nuclear polarization. Maximum polarization reached during data taking is expected to be up to 85%. The non-interacting beam and other particles produced inside the target is be stopped in the hadron absorber after the target. Two target cells, separated by a 20 cm gap in between, each 55 cm long and 4 cm in diameter give the target material volume about 691 $cm^3$. The target platform has been moved by 2.3 m in upstream direction from the position used in previous experimental setup in order to accommodate the hadron absorber. New target remote control system was devised because of the use of new remote control room which was required due to higher radiation in the experimental hall. The target magnet underwent substantial upgrade. Polarized Drell-Yan data taking has started in May 2015 for period of approximately 140 days. Current status of the target and the modifications which were done will be presented.

## 49. Analysis of half-spin particle motion in static Reissner-Nordstroem and Schwarzschild fields by using effective potentials of the Dirac equation

Popov Eugene
*Russian Federal Nuclear Center, Sarov, Russia*

The paper presents the analysis of effective potentials of Dirac equations in static Schwarzschild and Reissner-Nordstroem fields. It is shown that in all the explored cases, the conditions of the "fall" of particles to appropriate event horizons is implemented. The exception is one of the solutions for the Reissner-Nordstroem extreme field, for which the existence of the stationary bound state of half-spin particles is possible under the event horizon. For quantum-mechanical particles, the Reissner-Nordstroem naked singularity is separated by an infinitely large repulsive potential barrier. The singularities in the center for the Reissner-Nordstroem metric with event horizons (horizon) are also separated for quantum mechanical particles by the similar infinitely large repulsive potential barrier.

## 50. Transition of polarized ions through the system of ring permanent magnets

Prokofichev Yury
*JINR, Dubna, Russia*

The task of the transportation of polarized protons and deuteron beam of an energy 10–20 keV in the given magnetic field is considered. Specifically the

magnetic field is produced by the system of a solenoid and some ring permanent magnets with contrary directed field. The Lorentz equations together with classic equations for vector and tensor polarizations have been solved. The results of numerical simulation for a simple two-ring system are presented, which shows there is no essential depolarization in agreement with theoretical estimation.

## 51. Polarimetry with inclusive pions for the SPASCHARM experiment

Rykov Vladimir

*National Research Nuclear University MEPhI, Moscow Russia*

The new experimental program SPASCHARM for the 70 GeV proton synchrotron is currently under development at the Institute for High Energy Physics, Protvino, Russia. The main physics motivation for the SPASCHARM experiment is the systematic study of spin phenomena for a wide range of inclusive and exclusive reactions in collisions of high-energy polarized hadrons. The experiment will be carried in two stages. At the first stage, the measurements of single-spin asymmetries will be performed, using unpolarized meson and proton beams interacting with the transversely polarized protons of the "frozen" target. At the second stage, polarized proton and antiproton beams in the energy range of $\sim$10-45 GeV will be available along with the polarized target at the new SPASCHARM beam channel 24A.

The polarized protons and antiprotons in the proposed beams are produced by parity-violating decays of $\Lambda$-hyperons: $\Lambda \rightarrow p\pi^-$ and $\overline{\Lambda} \rightarrow \overline{p}\pi^+$. The fast on-line beam tagging is used for assigning the value of transverse polarization to each beam particle trajectory and for selecting the desired polarized beam samples. The beam tagging method is very robust and reliable because it fully relies on the well known characteristics of $\Lambda$-decays and the spin evolution in magnetic field. Nevertheless,the complexity of magnetic field configuration, varying along the beam channel in the chain of magnetic optical elements, makes it necessary to check and confirm the results of tagging with independent beam polarization measurements.

A number of physics processes for measuring absolute beam polarization are to be used at the SPASCHARM experiment. There are two special polarimeters to be built, exploiting the known analyzing power $A_N$ in elastic $pp$-scattering diffractive and Coulomb-Nuclear Interference kinematic regions.

In this report, we discuss the complimentary approach based on using the analyzing power $A_N$ in inclusive pion production. On the course of many years of studying spin phenomena in collisions with polarized protons, it has been found that the single-spin asymmetry $A_N$ at high $x_F$ and moderate $p_T$ is large,

at the level of $\sim 40\%$, and it rather weakly depends on the collision energy in the wide $\sqrt{s}$ -range from 5 to 200 GeV. The cross section of inclusive pion production is large. It represents a significant fraction of the total $pp$ cross section. What is also important to underline that, in the SPASCHARM, it virtually won't be necessary to specially develop and construct some dedicated detectors for such a polarimeter. Inclusive pions will be handled in the main SPASCHARM spectrometer and at the same beam exposition time as the physics processes under the study. The capabilities of the SPASCHARM experiment to carry out the absolute beam polarization measurements, using inclusive pions, are evaluated in this report.

## 52. Studies of systematic limitations in the EDM searches at COSY

Saleev Artem

*Nuclear Physics Institute, Forschungszentrum Juelich, Germany*

Searches of the electric dipole moment (EDM) at a pure magnetic ring, like COSY, encounter strong background coming from magnetic dipole moment (MDM). The most troubling issue is the MDM spin rotation in the so-called imperfection, radial and longitudinal, B-fields. To study the systematic effects of the imperfection fields at COSY we proposed the original method which makes use of the two static solenoids acting as artificial imperfections. Perturbation of the spin tune caused by the spin kicks in the solenoids probes the systematic effect of cumulative spin rotation in the imperfection fields all over the ring. The spin tune is one of the most precise quantities measured presently at COSY at $10^{-10}$ level. The method has been successfully tested in September 2014 run at COSY, unravelling strength of spin kicks in the ring's imperfection fields at the level of $10^{-3} rad$.

## 53. Recent results from COMPASS on exclusive muoproduction

Sandacz, Andrzej (on behalf of COMPASS collaboration)

*National Center for Nuclear Research, Warsaw, Poland*

The high energy polarised muon beam available at CERN, with positive or negative charge, makes COMPASS a unique place for studies of General Parton Distributions (GPDs). The first GPD related COMPASS results were obtained for exclusive vector meson production on transversely polarised protons and deuterons. The data were taken in 2004-2010 with solid-state polarised target, although without recoil detector. Results on various transverse target spin

dependent azimuthal asymmetries will be presented and their relation to GPDs will be discussed.

The dedicated COMPASS GPD program started in 2012 with commissioning of a new long liquid hydrogen target and new detectors, such as the large recoil proton detector CAMERA and the large-angle electromagnetic calorimeter. It was followed by a short pilot "DVCS run". The performance of the setup and first results on DVCS and exclusive $\pi^0$ channels will be demonstrated. The full data taking for the GPD program approved within COMPASS-II proposal is planned in 2016 and 2017. The various observables for this program and expected accuracies will be discussed.

## 54. Azimuthal asymmetries of charged hadrons produced by high-energy muons scattered off longitudinally polarised deuterons

Savin I.A. (on behalf of the COMPASS Collaboration.)
*JINR, Dubna, Russia*

The data of the COMPASS collaboration on asymmetries of charged hadrons produced in the muon SIDIS reactions off the longitudinally polarised deuterons are presented as functions of the hadrons' azimuthal angle it two ways. First, for hadrons integrated over the kinematic variables– integral azimuthal asymmetries. Second, as a function of one of the kinematic variables $x$, $z$ or $p_T^h$. In each case the asymmetries were fitted by the 5-parameter functions which include the azimuthal-angle-independent terms as well as terms modulated with this angle as predicted by the theory. Results of fits are presented and discussed.

## 55. Di-hadron asymmetries and interplay between transversity induced asymmetries in hadron leptoproduction at COMPASS

Sbrizzai Giulio (on behalf of COMPASS collaboration)
*Trieste University, Italy*

New results on the transverse spin azimuthal asymmetries in semi-inclusive DIS reactions extracted by the COMPASS Collaboration from the data collected with a transversely polarised NH3 target are presented. A noticeable similarity between the Collins asymmetry and the dihadron asymmetry, already been observed and reported, inspired a more deep investigation on the angular correlations and the relevant kinematical variables. The resulting phenomenological analysis of the transversity induced asymmetries, presented in this talk, allows to establish quantitative relationships, providing strong indication that they are all driven by a common physical process.

# 56. Momentum transfer dependence of GPDs

Selyugin, Oleg

*JINR, Dubna, Russia*

Momentum transfer dependence of GPDs Abstract: Based on the factorization representation of the General Parton Distributions (GPDs) the momentum transfer dependence was determined by the analysis of the different representation of parton distribution functions (PDFs) and all possible experimental data of the electromagnetic form factors of the proton and neutron. The obtained $t$-dependence of the GPDs check up by analysis of the different hadronic reactions (including exclusive and elastic hadron scattering) in wide energy region with minimum free fitting parameters.

# 57. Possible measurements of spin dependent observables in elastic dN and dd collisions at NICA deuteron beams

Sharov, Vasily

*JINR, Dubna, Russia*

One of the main physical tasks for the $NICA$ collider will be the research in the spin particle physics [1, 2], which continues the $JINR$ research programme in this area. The $NICA$ collider will provide the colliding beams of polarized protons and deuterons with the energy range of $T_{pCM} = 5 \div 12.6\ GeV$ ($\sqrt{s_{pp}} = 12 \div 27\ GeV$) for protons and $T_{dCM} = 2 \div 5.5\ GeV/u$ ($\sqrt{s_{NN}} = 4 \div 13\ GeV$) for deuterons. Obtaining new data on the spin-dependent observables in the elastic $NN$, $dN$ and $dd$ scattering at the $T_{N,d\,Lab}$ energies above 1 $GeV$ can be one of the priority areas of $VBLHEP$ research at the collider.

In our reports on previous conferences [3, 4] we briefly showed the possibilities to measure of the spin-dependent $NN$ observables with colliding beams of polarized protons and deuterons at the $NICA$ collider. The requirements to the parameters of colliding beams, detectors and appropriate infrastructure at $NICA$ have been listed. In this report, we will show the opportunities for research the spin-dependent $dN$ and $dd$ observables using the oncoming bunches deuterons of $NICA$ collider. It will be mentioned some interest within this research from the point of view the theory of fundamental three nucleon interactions and practical use of the results obtained. Some of the existing results of such research will be presented.

Determination of the spin-dependent $dN$ and $dd$ observables in elastic scattering of the spin one particles and the method of their measurement will be presented. A number of advantages of the measurements of the elastic $dN$ ($dd$) observables using colliding hadron beams in comparison with the measurements in the fixed target experiments will be considered from the point of view of

kinematics. We will show that the parameters of the colliding $dd$ beams and characteristics of the $SPD$ detector will be allowed to perform the measurements of a number of the vector and tensor components of analyzing forces for elastic $dN$ ($dd$) collisions. The estimations of the cross sections for elastic $dN$ and $dd$ collisions for a number of energy values of colliding polarized deuterons beams will be presented.

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## 58. Use of the calorimeter to improve analyzing power of the reactions, investigating secondary proton polarization

Sitnik Igor

*JINR, Dubna, Russia*

Traditionally the reaction

$$p + CH_2 \rightarrow forward\ charge\ particle + X\ (1)$$

is used for this aim. Analyzing power of this reaction falls off as $1/p$, where $p$ is the laboratory momentum. At the proton momenta of order $8\ GeV/c$, which are expected at the JLab experiment, the low analyzing power creates problems for off-line analysis of data. On the other hand, it is well known that the reaction

$$p + p \rightarrow p + p$$

has the much more analyzing power in comparison with reaction (1). So, the calorimeter is predestinated for suppression of inelastic events in this reaction. In the report it is shown that the problem is solved quite well.

## 59. The non-singlet $Q^2$-evolution in the inverse Mellin method and the fractional analytic perturbation theory

A.V. Sidorov[1] and <u>O.P. Solovtsova</u>[1,2]

*(1) Joint Institute for Nuclear Research, Russia*
*(2) Gomel State Technical University, Belarus*

We discuss the application of the analytic approach called the fractional analytic perturbation theory (FAPT) to the QCD analysis of the non-singlet combination of unpolarized/polarized inclusive and semi-inclusive DIS data. For the fit of experimental data we use the Jacobi polynomials expansion method as well as the method based on the inverse Mellin transform. We compare results of the fit and estimate the accuracy of the Jacobi polynomial method. The application of variational perturbation theory for description of the $Q^2$-evolution of the $xF_3(x, Q^2)$ structure function is considered.

## 60. Generalized DGLAP evolution

Strózik-Kotlorz, Dorota

*Opole University of Technology, Division of Physics, Opole, Poland,*
*BLTP JINR, Dubna*

We present progress in development of the truncated Mellin moments approach (TMMA). We show our recent results on the generalization of DGLAP evolution equations and discuss some their applications in spin physics.F

## 61. Constituent Quarks in the Standard Model

Sukhoruchkin Sergey

*Petersburg Nuclear Physics Institute 188300 Gatchina*

Tuning effect in particle masses manifests itself in integer relations between masses of leptons, quarks, meson and baryons. It includes also dimensionless relation between well-known masses, for example, the ratio between muon and Z-boson masses $m_\mu/M_Z$=115.9·$10^{-5}$ coinciding with the QED radiative correction $\alpha/2\pi$=115.9·$10^{-5}$. This factor was considered also for the electron rest mass $m_e$ by V. Belokurov and D. Shirkov. Integer presentation of particle masses (n=1,13,16,17,18,115) for values $m_\mu$, $f_\pi$, $m_\pi$, $\Delta M_\Delta$, neutron mass and (n=3x16, n=3x18) for constituent quarks $M_q''$=$m_\rho$, $m_\omega/2$=780 MeV and $M_q$= $3\Delta M_\Delta$=$m_\Xi/3$=441 MeV were found with the period $\delta$=16$m_e$ from the proximity of pion mass splitting to 9$m_e$:
$(m_\mu + m_e)/\delta$=13.00; $f_\pi$=130.7 MeV/$\delta$=16.01; $(m_\pi$-$m_e)/\delta$=17.03.
$\Delta M_\Delta$=147 MeV/$\delta$=18.02: neutron mass $(m_n + m_e)/\delta$=115.007.
From precise ratio between masses of the neutron and the electron $m_n/m_e$=

1838.6836605(11) the shift $\delta m_n$=161.65(6) keV of neutron mass from 115$\delta$-$m_e$ accounts integer ratio $\delta m_N / \delta m_n$=8(1.0001(1)) with the mass splitting of the nucleon $\delta m_N$=1293.3 keV.

Another property of the discussed NRCQM parameters $M_q$=3$\Delta M_\Delta$=$m_\Xi/3$ =441 MeV and $M_q''$=$m_\rho/2$=388.8(2) MeV consists in the empirical observation that their masses and vector boson masses are in the ratios
$M_Z/M_q = 91.19$ GeV/441 MeV $= L^Z$=206.8 and
$M_W/M_q'' = 80.40$ GeV/387.8(2) MeV=$L^W$=207.3
coinciding with the lepton ratio L=$m_\mu/m_e$ with L=13×16-1=207.0 after a small correction $m_e(1 - \alpha/2\pi)$.

# 62. Projections on Double Spin Asymmetry extraction from Hydrogen Jet data at RHIC

Svirida Dmitry
*SSC RF ITEP, Moscow, Russia*

Absolute beam polarization measurements at RHIC are performed using a polarized atomic hydrogen jet target and accumulate enormous amount of statistical material. Regular measurements are based on single spin asymmetries, but transverse double spin asymmetries can also be extracted from the same data with extremely high statistical accuracy. Such an attempt was made at early RHIC times with limited amount of statistics [1].

Recent accurate results on double spin asymmetries from STAR [2] do not correspond to any available theoretical model. At the same time they do not contradict to the observations of [1] at its level of accuracy. Precise determination of transverse double spin asymmetries from hydrogen jet data may confirm or disprove the intriguing result from STAR [2].

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2. D.N. Svirida for the STAR collaboration, Proc. of 21st International Symposium on Spin Physic, 20-24 Oct 2014, Beijing, China.

# 63. Novel effects in twist-3 SSA

Teryaev, Oleg
*JINR, Dubna, Russia*

The novel sources of phases for twist-3 SSA's are considered. The related constraints for Sivers functions are analyzed.

## 64. Self-similarity of Proton Spin and $z$-Scaling

M.V. Tokarev[1]† and I. Zborovský[2]
$^1$*Joint Institute for Nuclear Research, Dubna, Russia*
$^2$*Nuclear Physics Institute, Rež, Czech Republic*
†E-mail: tokarev@jinr.ru

The concept of $z$-scaling previously developed for analysis of inclusive reactions in proton-proton collisions is applied for description of processes with polarized protons. Hypotheses of self-similarity and fractality of the proton spin structure are discussed. The possibility to extract information on spin-dependent fractal dimensions of hadrons and fragmentation process from asymmetries are justified. The double longitudinal spin asymmetry $A_{LL}$ of $\pi^0$ meson and jet production in proton-proton collisions at $\sqrt{s} = 200$ GeV measured at RHIC is analyzed in the framework of $z$-scaling. The spin-dependent fractal dimensions of proton for these processes are estimated.

## 65. Handedness and helicity separation in heavy-ion collisions

Usubov Rahim
*JINR, Dubna, Russia*

The effects of separation of hydrodynamic helicity and handedness in heavy-ion collisions at various energies from NICA to LHC regions are calculated in the framework of (Parton)Hadron String Dynamics model. The handedness correlations between different regions of phase space at the level of 1% are found.

## 66. Double-Polarized pd Scattering and Test of Time-Reversal Invariance

Yu.N. Uzikov
*JINR, Dubna, Russia*

The integrated proton-deuteron cross section $\widetilde{\sigma}$ for the case of the incident proton vector polarization $p_y^p$ and tensor polarization $P_{xz}$ of the deuteron target provides a null test signal for time-reversal invariance violating but P-parity conserving (TVPC) effects. This signal is not affected by the final state interaction and therefore its observation would directly indicate time-invariance violation,like in case of neutron EDM [1]. The corresponding experiment is planned at COSY to search for the TVPC signal [2]. We study the null-test observable $\widetilde{\sigma}$ within the Glauber theory of the double-polarized $pd$ scattering [3,4]. Full spin dependence of the ordinary strong $pN$ scattering amplitudes and different types

of the hypothetical TVPC pN-amplitudes are taken into account. We show that the contribution from the exchange of the lowest-mass meson allowed in the TVPC interaction, i.e. the $\rho$-meson, to the null-test observable $\widetilde{\sigma}$ is zero. The axial $h_1$ meson exchange makes a non-zero contribution. We find that inclusion of the Coulomb interaction does not lead to divergence of the cross section $\widetilde{\sigma}$ and calculate its energy dependence at the proton beam energy 100–1000 MeV.

For comparison, relationships imposed by the T-invariance on differential spin observables $A_y$, $P_y$, $K_x^{z'}$, and $K_z^{x'}$ of elastic pd scattering are considered and the degree to which this relationships are violated is estimated with allowance for the T-odd P-even interaction [5].

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## 67. The physics program of PAX at COSY

Yury Valdau

*HISKP, University Bonn, Germany*

The PAX collaboration has proposed a spin-filtering as a technique to produce the first ever intense beam of polarized antiprotons. As a first step, experiments with protons have been started at the Cooler-SYnchrotron COSY-Juelich. After confirmation of the applicability of the technique with a transverse polarization, the first longitudinal spin filtering experiment is under the preparation at COSY. This experiment requires construction and implementation in to the ring of a "Siberian-snake", which will give access to the longitudinally polarized proton beams at COSY. The new multipurpose silicone detector and an openable storage cell are under the construction for the PAX target place.

It is also planned to use the PAX installation for the test of Time Reversal Invariance experiment at COSY (TRIC). The TRIC experiment is aiming to test a true null observable $A_{y,xz}$ sensitive to the T-odd P-even interaction in a double-polarized $pd$-scattering experiment. The aim of the TRIC experiment is to improve the currently existing upper limit on the T-odd P-even interaction by at least an order of magnitude. The observable of interest will be determined in a transmission experiment studying the beam current decrease in the accelerator as a function of time and polarization of the beam and target. Use of the simplest tensor polarized nucleus, the deuteron, allows one to avoid any corrections connected with target polarization, which are included in the existing upper limit on T-odd P-even interaction. In addition to the PAX detector

and target, the new high precision beam current measurement system will be constructed and implemented in to COSY for the TRIC experiment.

An overview of all the activities carried out by the PAX collaboration at COSY will be presented.

## 68. Measurement of Collins Asymmetry at BESIII

Xiaorui Lyu

*University of Chinese Academy of Sciences, Beijing, China*

There has been increasing interest in understanding the spin phenomena in the nucleon, such as the transverse spin structure (the so-called transversity). The semi-inclusive observables in SIDIS experiments are only connected to the product of quark transversity distribution and the Collins fragmentation function (FF). An independent measurement of the Collins FFs in e+e- annihilation makes it possible to extract the transversity from single transverse spin asymmetries in SIDIS.

The Collins FF connects transverse quark spin with a measurable azimuthal asymmetry (the so-called Collins effect) in the yields of hadronic fragments along the initial quark's momentum. Collins effect has been studied in the Belle and BABAR experiments and non-zero Collins asymmetries have been observed. However, Belle and BABAR run at high Q ( 10GeV) region, and existing SIDIS experiments mostly run at low Q region. Hence, energy evolution from high Q to low Q is not trivial and its theoretical treatment needs to be guaranteed. Direct measurement of Collins function in low Q region will provide important test.

In the BESIII experiment, we explore Double Collins Asymmetries (DCA) by looking at the two back-to-back charged pions. BEIII experiment is an electron-position collider running at 2<Q<4.6 GeV energy region, which has similar energy coverage with the SIDIS experiments. This analysis is carried out based on 65/pb data at Q=3.65 GeV and will provide the first measurement of Collins asymmetry at low Q. This analysis results will be reported in the DSPIN-15 conference.

## 69. Study for a Design of Magnet System for the SPD Detector NICA LHEP JINR

Yudin, Ivan

*JINR, Dubna, Russia*

The choice of magnet system for the Spin Physics Detector of the NICA Collider of LHEP JINR is given. The inverse problem of magnetostatics is solved for a

magnetic field of 0.5 tesla in the aperture a) 3 m x 5 m and b) 3 m x 6 m. We also discuss the design of the magnet with a field of 0.3 T.

The paper presents the results obtained for the "warm"and SC versions of the magnetic system: currents (ampere-turns), the geometry (size) of the coil and the iron yoke, weight (on the whole and the individual elements), the magnet transportation and assembly.

## 70. Gravitational lensing and polarization in astrophysics

*Alexander Zakharov*
*Institute of Theoretical and Experimental Physics, Moscow*

We discuss astrophysical problems connected with gravitational lensing where current and future polarimetric observations are very important to clarify theoretical models. Namely, we consider polarization observations for exoplanet searches with gravitational microlensing, optical polarization for gravitational lens systems, polarization signatures of microlensing in X-ray band like extra features of microlensing for gravitational macrolens.

## 71. Proton spin structure in the covariant approach - new inputs and results

*Zavada, Petr*
*Institute of Physics, Prague, CR*

Proton spin structure generated by the interplay of spins and orbital angular moments of quarks and gluons is analyzed in terms of the covariant quark-parton model. The discussion will touch the still open question of the gluon spin contribution. A preliminary report on the calculation of the QCD evolution of TMD's within covariant approach will be presented.

For details, see: P.Z. Phys.Rev.D 89, 014012 (2014) and P.Z. e-Print: arXiv: 1503.07924 [hep-ph].

# After deadline applications.

## 72. Lattice Studies on Proton Spin Structure

Deka Mridupawan, JINR, Dubna, Russia
*JINR Dubna Russia*

## 73. The gluon masses

Larin Sergey,
*Institute for Nuclear Research, Moscow, Russia*

The QCD Lagrangian can be modified by the adding gluon masses to ensure the agreement of the theory with the fundamental Kaellen-Lehmann spectral representation. On mass-shell renormalizability of the resulting model is discussed.

## 74. Infra-red modified QCD couplings and Bjorken sum rule

V.L. Khandramai[1], O.V. Teryaev[2]
[1]*Gomel State Technical University, Belarus*
[2]*Joint Institute for Nuclear Research, Russia*

We test the recently proposed Simple Modified Perturbation Theory (SiMPT) for the description of the $\Gamma_1^{p-n}$ data at low momentum transfers. The SiMPT constructed on the two grounds:

- the first is pQCD with only one parameter added, an effective "glueball mass" $m_\rho \lesssim M_{gl} \lesssim 1$ GeV, serving as an infra-red regulator,

- the second stems out of the ghost-free Analytic Perturbation Theory comprising non-power perturbative expansion that makes it compatible with linear integral transformations,

is regular in the low-energy region and could serve as a practical means for the analysis of data below 1 GeV up to the infra-red limit. We study non-perturbative Bjorken sum rule higher twists correction by using the SiMPT, the integral representation for infinite sum of higher twists coefficients and the QCD-inspired model for the $Q^2$-dependence of the generalized Gerasimov-Drell-Hearn sum rule.

## 75. Measurement of the charge exchange $dp \to ppn$ reaction using the magnetic spectrometer STRELA at 1.75 A GeV/c

Martinska Gabriela
*University of P.J. Safarik, Kosice, Slovak Republic*

The ratio of the differential cross section of the charge exchange reaction of the deuteron to that of the nucleon, at small transferred momenta, has been discussed in order to estimate the spin-dependent part of the $np \to pn$ charge

exchange amplitude. An estimation of the spin-dependent part of the $np \rightarrow pn$ charge exchange amplitude was made on the basis of $np \rightarrow pn$ data, taken at 1.75 GeV/c per nucleon using the STRELA setup at the Nuclotron accelerator. The $np \rightarrow pn$ amplitude turned out to be predominantly spin-dependent.

## 76. Gauge-invariant gluon TMD and evolution in the coordinate space
Cherednikov Igor
*Universiteit Antwerpen, Belgium*

Fully gauge-invariant maximally path-dependent operator definition of gluon transverse-momentum dependent PDF (gTMD) is proposed and discussed. It is shown that the full set of evolution equations for the gTMD can be obtained from shape-variation integral-differential equations formulated in the coordinate space. Possible applications of the proposed formalism are also addressed.

## 77. np charge exchange polarimetry in GeV region
Piskunov Nikolay
*JINR Dubna Russia*

## 78. Photoproduction of $\omega$-mesons off nuclei and impact of polarization on meson-nucleon interaction
Gevorkyan Sergey
*JINR Dubna Russia*

We propose to study the photoproduction of $\omega$-mesons on complex nuclei with the GlueX detector at Hall D of Jefferson Lab in the photon beam energy range between 5 GeV and 9 GeV. Production of $\omega$'s in coherent photoproduction $\gamma A \rightarrow \omega A$ provides a possibility to measure the total cross section of transversely polarized $\omega$ mesons with nucleon $\sigma_L(\omega N)$. The investigation of incoherent photoproduction $\gamma A \rightarrow \omega A'$ (A' – nuclear excitation or its break-up products) allows one to extract the total cross section of the longitudinally polarized $\omega$ mesons with nucleon $\sigma_L(\omega N)$, which has not yet been measured. We plan to measure the spin density matrix elements of $\omega$ mesons on various nuclei, which also provides an opportunity to estimate the value of $\sigma_L(\omega N)$.