"Fundamental Interactions of Fields and Particles" 01-3-1135-2019/2023
(Scientific Division of the Theory of Fundamental Interactions)
84 scientists
Leaders: D.I. Kazakov, O.V. Teryaev

5 projects

1. **Quantum Field Theory and Physics beyond the Standard Model**
   (sector **1 of Quantum Field Theory**)
   A.V. Bednyakov
   D.I. Kazakov

2. **QCD and Hadron Structure**
   I.V. Anikin
   (sector 4 of Standard Model) **S.V. Mikhailov**
   O.V. Teryaev

3. **Phenomenology of Strong Interactions and Precision Physics**
   (sector 2 of Strong Coupling Methods)
   M.A. Ivanov
   V.I. Korobov

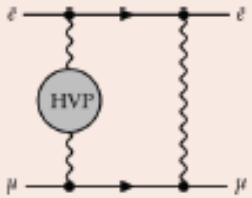
4. **Theory of Hadronic Matter under Extreme Conditions**
   (sector 6 of Hadronic Matter Physics) **V.V. Braguta**
   E.E. Kolomeitsev
   S.N. Nedelko

5. **Theory of Electroweak Interactions and Neutrino Physics**
   (sectors 3 of Neutrino Physics, 5 of Hadron Structure)
   A.B. Arbuzov
   V.A. Naumov

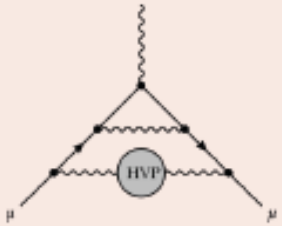
Quantum Field Theory and Physics beyond the Standard Model

Leaders: Kazakov D.I., Bednyakov A.V.

- **Perturbative: Feynman Integrals** Bezuglov, Borlakov, Kotikov, Onishchenko, Vladimirov
  - Methods of calculation/resummation of FI in various space-time dimensions
  - Automatic reduction/evaluation: development of efficient computer codes
  - New high-order computations, e.g,

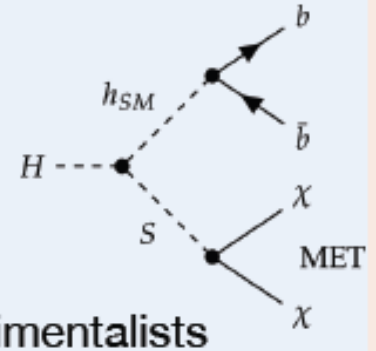


  - Two-loop μe - scattering and quarkonia production
  - Three-loop massive form-factors and polarisation operators in QCD
  - Spectrum of anomalous dimensions in a number of CFTs at 6 loops
- **Non-perturbative:** Nesterenko, Solovtsova ,Kotikov, Onishchenko, Iakhibbaev, Tolkachev



  - Dispersive approach to g-2; (Fractional) Analytical Perturbation Theory
  - Quantum Spectrum Curve: new solutions for N=4 SYM, ABJM
  - Holography: Dual description of fishnets and fishchains
  - Large charge expansions: application to realistic gauge models

- Dark matter in Particle physics and Astrophysics
- Study of experimental prospects of BSM
  - Two-Higgs-Doublet Model(+ portal couplings to dark sector)
  - SUSY extensions with additional non-anomalous U(1)
  - “Simplified” models with reduced number of parameters
- Comprehensive analysis of possible signatures in collab. with experimentalists

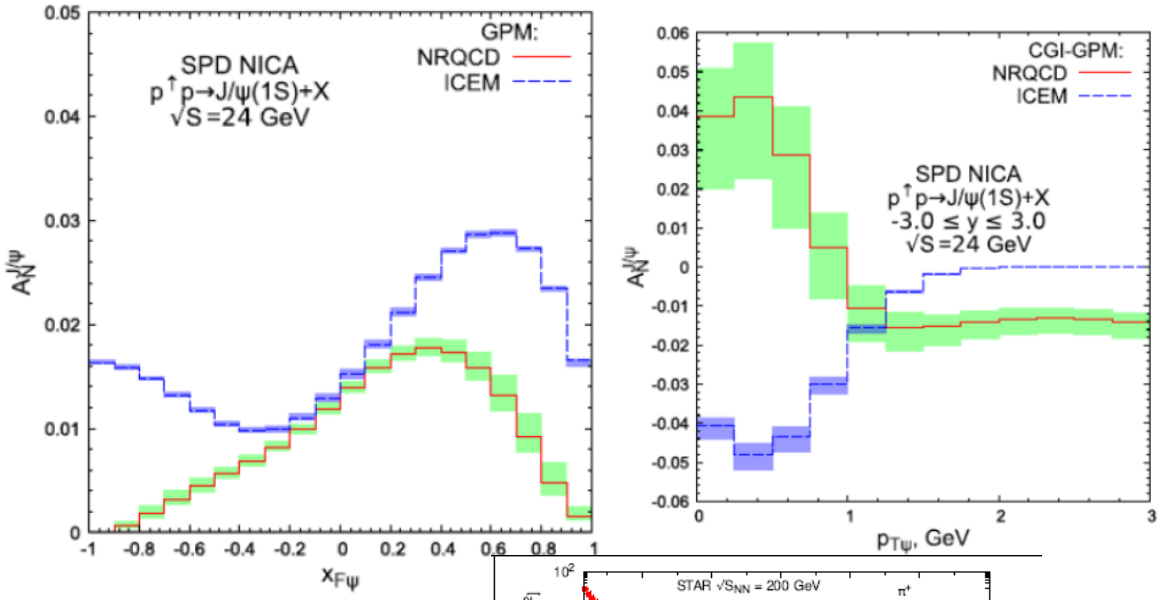


Baushev, Kozlov, Das, Mukhaeva, Savina

Project: QCD and Hadron Structure. Leaders: I.V. Anikin, S.V. Mikhailov, O.V. Teryaev

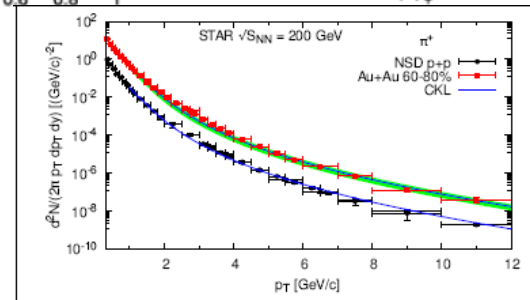
Transverse Momentum Dependent Sivers function of gluons may be studied by SPD@NICA. Calculations of relevant Single Spin Asymmetry in quarkonia production is performed using Non-Relativistic QCD and Improved Color Evaporation Model. V.A. Saleev

The calculations of similar asymmetries for D-mesons and direct photons is planned.



Fragmentation Functions: from tests with current data to predictions for NICA

D. Kotlorz



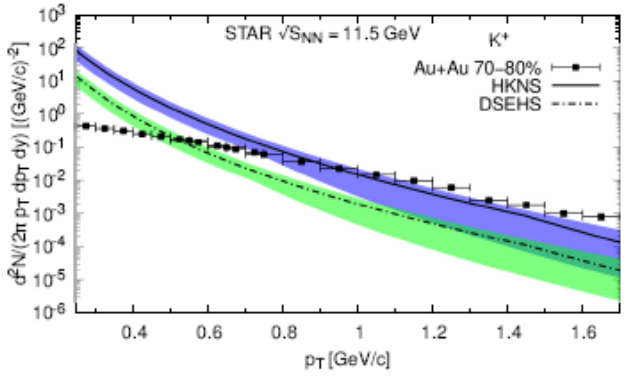
arXiv:2205.02516, *Tests of the parametrizations of Fragmentation Functions using data on inclusive pion and kaon production*

s

The single transverse spin asymmetry

$$A_N = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}}$$

as a function of x_F and p_T. The calculations were done in the Generalized Parton Model and strong dependence on hadronization model (NRQCD or ICEM) was demonstrated.



Will NICA be able to test the various parametrizations of Fragmentation Functions?

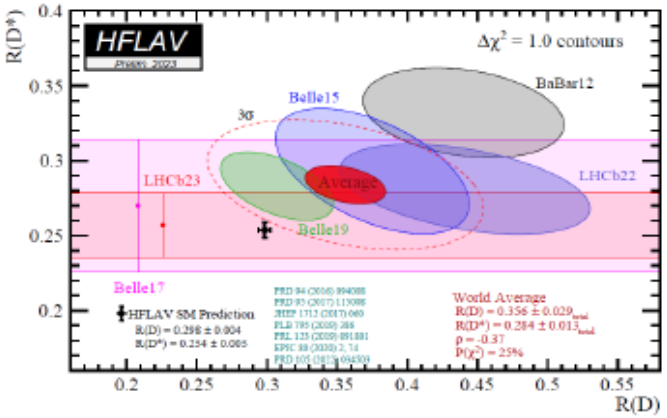
Project: Phenomenology of strong interactions and precision physics

Leaders: V.I. Korobov and M.A. Ivanov

M.A.Ivanov,

A. Issadykov

Lepton Flavor Universality Tests



$$\mathcal{R}(D^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)}\tau\bar{\nu}_\tau)}{\mathcal{B}(B \to D^{(*)}\mu\bar{\nu}_\mu)}$$

$$D^{(*)} = D \quad \text{or} \quad D^*$$

$\Longleftarrow$ The state-of-art related to $R(D)$ and $R(D^*)$ ratios including the latest two LHCb-measurements in 2023

The world average shows a 3.2σ tension with the SM prediction.

New Physics (NP) effects can be contracted into

$SU(3)_C \otimes SU(2)_L \otimes U(1)_Y$ and Lorentz invariant operators:

$\bar{L}L\bar{Q}Q, \quad \bar{\tau}L\bar{c}Q, \quad \bar{\tau}L\bar{Q}b, \quad \bar{L}L\bar{c}c, \quad \bar{L}L\bar{b}b, \quad \bar{\tau}\tau\bar{c}c, \quad \bar{\tau}\tau\bar{b}b, \quad \bar{\tau}\tau\bar{Q}Q$

In addition to $b \to c\tau\nu_\tau$ NP modifies also $b\bar{b} \to \tau^+\tau^-$ and $c\bar{c} \to \tau^+\tau^-$ transitions. These lead to LFU violation in Υ and ψ leptonic decays.

We are planning to analyze the constraints on NP effects in both cases.

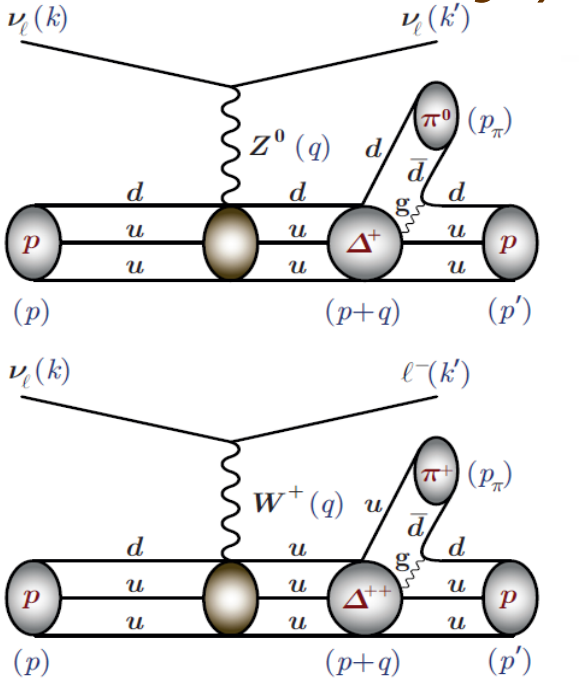
Project : **Theory of Electroweak Interactions and Neutrino Physics. Leaders: A.B. Arbuzov and V.A. Naumov**

Interactions of leptons with nuclei

To analyze the results of modern (e.g. NOvA) and future (Hyper-Kamiokande, DUNE, etc.) neutrino experiments, precise knowledge of the cross sections for neutrino scattering by nuclei is required.

As a part of the work we plan:

- **Further development of the superscaling model with an effective nucleon mass (SuSAM*) and its tuning by electrons-nucles scattering data.**
- **The refined SuSAM* model will be used to describe quasi-elastic (anti)neutrino scattering on nuclei.**
- **Further development of models of single-pion resonant production. This includes a generalization of a new formalism, based on the SU(6) relativistic quark model and taking into account the final pion dynamics.**



The obtained results will be implemented in the GENIE Monte Carlo neutrino event generator and used to modelling the ν-induced events in the DUNE near detectors under construction.

Selected references:

*I.D. Kakorin and K.S. Kuzmin, "Resonance axial-vector mass from experiments on neutrino-hydrogen and neutrino-deuterium scattering," Phys. Rev. D **104**, 9 (2021) 093001.*

*I. Ruiz Simo et al., I.D. Kakorin, V.A. Naumov, K.S. Kuzmin, J.E. Amaro, "Analysis of the kinematic boundaries of the quasielastic neutrino nucleus cross section in the superscaling model with a relativistic effective mass," Phys. Rev. D **105**, 1 (2022) 013001.*

Project: Theory of Hadronic Matter under Extreme Conditions.
Leaders: V.V. Braguta, E.E. Kolomeitsev, S.N. Nedelko

Lattice study of rotating QCD (V.V. Braguta, A. A. Roenko, D.A. Sychev)

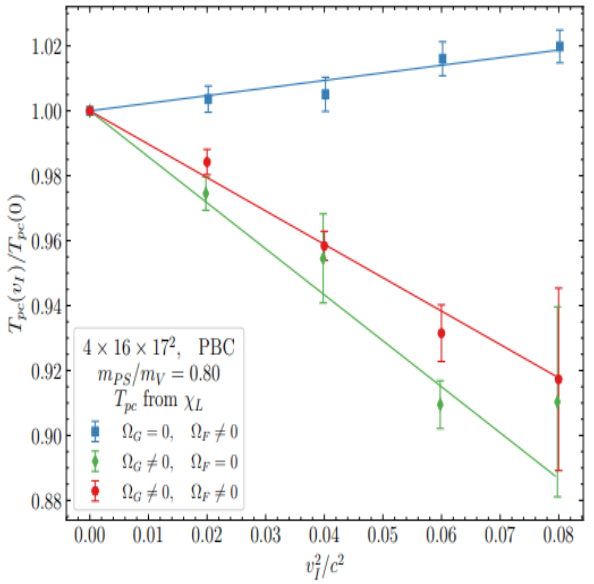
The obtained results

One can rotate gluons and quarks separately

If one rotates only fermions, the critical temperatures of QCD decrease

If one rotates only gluons, the critical temperatures of QCD increase

For rotating QCD (both fermions and gluons), the critical temperatures increase



Questions to be studied

- *Equation of state for rotating gluodynamics and QCD*
- *Space inhomogeneous phase transitions due to the rotation*
- *Static interaction potential and Polyakov line in the rotation frame*
- *Instabilities results from the rotation*
- *Fluctuations and correlation functions of momentum in quark-gluon plasma*

Modern Mathematical Physics: Integrability, Gravity and Supersymmetry

Theme code: 01-3-1138-2019

Leaders: A.P.Isaev, S.O. Krivonos
27 research scientists including 11 Dr.sc, 11 Cand.sc, 3 PhD student, 2 undergrad. stud.

The Theme includes 3 projects:

- **Integrable systems and Symmetries** (Leaders: N.A.Tyurin, A.P.Isaev,S.O.Krivonos)
- **Supersymmetry, Higher Spins, Gravity** (Leaders: E.A.Ivanov, S.A.Fedoruk)
- **Quantum Gravity, Cosmology and Strings** (Leaders: I.G.Pirozhenko, D.V.Fursaev)

Main task of the Theme is ***the development of mathematical methods for solving the most important problems of modern theoretical physics***, namely

- Development of new mathematical methods for studying and describing a wide class of classical and quantum integrable systems and their exact solutions;
- Analyzing and searching for solutions to a wide range of problems of supersymmetric theories, including models of strings and other extended objects;
- Study of nonperturbative regimes in supersymmetric gauge theories;
- Development of cosmological models of the early Universe, gravitational waves and black holes.

Over the past six years, five JINR First Prizes in Theoretical Physics have been received:

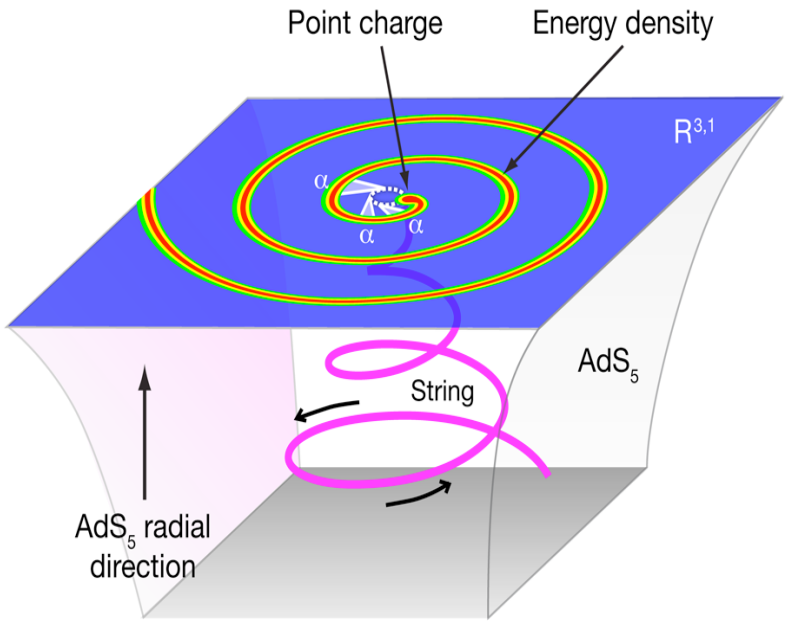
- 2017, N.A.Tyurin
- 2018, S.O.Krivonos, O.Lechtenfeld, A.O.Sutulin
- 2019, A.P.Isaev, V.A.Rubakov
- 2020, J.Kunz, I.Perapechka, J.Shnir
- 2022, E.A. Ivanov, I.L. Buchbinder, B.S. Merzlikin, K.V. Stepanyants

Over the past five years, 175 papers have been published in leading foreign and 23 in Russian journals.

Modern Math. Physics: Integrable systems and symmetries

Leaders: A.P. Isaev, S.O. Krivonos, N.A. Tyurin; 10 research scientists, including 2 Dr.Sc., 5 Cand.Sc., 1 PhD St., 2 Undergrad. St.

The project aims to study various holographic systems and its properties. The holographic duality states that gravity in (d+1)-dimensions is equivalent to a gauge theory in a flat d-dimensional space-time at strong coupling.

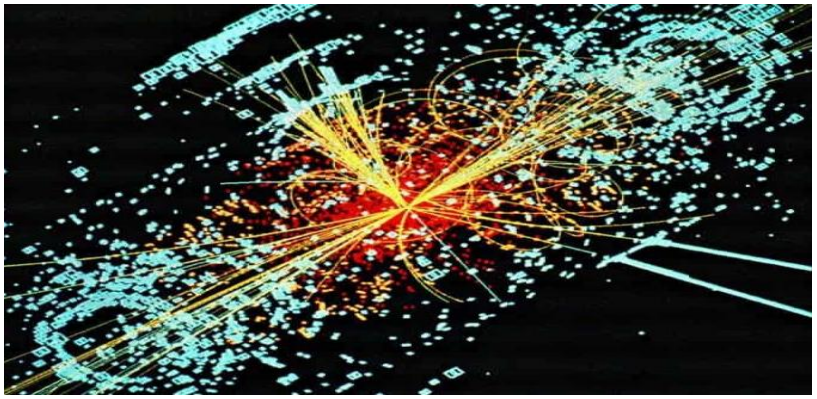


We will focus on the following issues:

- Integrable structures in holographic models with conformal symmetry at zero and finite temperature
- Construction of exactly solvable holographic models and obtaining exact string classes solutions
- Studies of holographic renormalization group flows, which correctly describe deformations of conformal fields theories

Modern Mathematical Physics:

Supersymmetry, Higher Spins, Gravity



Leaders: E.A.Ivanov, S.A.Fedoruk
9 research scientists including 6 Dr.sc, 2 Cand.sc,
1 PhD student

OFF-SHELL SUPERFIELD MODELS IN HARMONIC SUPERSPACE APPROACH:

- Studying the quantum structure of N=(0,1) and N=(1,1), 6D super Yang-Mills theories and calculating all leading and subleading two-loop counterterms by the background superfield method;
- Elaboration of unconstrained superfield description of N=2, 4D supersymmetric higher spin theories in superconformal and anti-de Sitter cases.

SUPERSYMMETRY IN HIGHER SPIN THEORY AND SUPERSYMMETRIC MECHANICS:

- Exploring the so called infinite spin theories and their supersymmetric and quantum extensions;
- Studying various versions of supersymmetric and superconformal quantum mechanical models, including integrable many-particle systems.

TOPOLOGICAL OBJECTS IN COSMOLOGY AND BLACK HOLE PHYSICS:

- Exploring new class of solutions of extended Einstein gravity with Chern-Simons term;
- Investigating several problems in superconformal 2D and 4D field theories using the developed apparatus of rarefied elliptic and hyperbolic gamma functions.

Modern Mathematical Physics:

Quantum gravity,cosmology and strings

Leaders: I.G.Pirozhenko, D.V. Fursaev
8 research scientists including 3 Dr.sc, 5 Cand.sc,
1 PhD student, 2 undergrad. stud.

IN CLASSICAL GRAVITY:

- Studying all kinds of gravitational wave phenomena, including shock waves in General Relativity, various sources of gravitational wave background, such as cosmic strings;

- Elaboration of cosmological models that explain the properties of the observable Universe based on field theory methods and modified gravity.

IN QUANTUM GRAVITY:

- Developing the apparatus of quantum field theory in an external classical gravitational background, new methods for an approximate estimation of the effective gravitational action in various regimes;

- Studying asymptotic symmetries in gravity, relationship between gravity, thermodynamics and quantum entanglement, the holographic properties of gravity and AdS/CFT correspondence.

Bogoliubov Laboratory of Theoretical Physics

DUBNA INTERNATIONAL ADVANCED SCHOOL OF THEORETICAL PHYSICS

Rector of DIAS-Th D.I. Kazakov Theme Leader I.G. Pirozhenko

- *Scientific and educational project successfully developing at BLTP JINR since 2003 comprises: schools of various levels are regularly held for students, postgraduates and young scientists,review lectures on problems of modern physics for JINR staff, digital archive.*

Goals

in-depth training in the field of modern theoretical and mathematical physics; educating senior students, graduate students and young scientists in the areas of advanced research of the BLTP JINR and on JINR priority topics, encouraging young scientists to collaborate with BLTP JINR,

Cooperation with JINR University Center, JINR-based Departments at Dubna State University, Moscow Institute of Physics and Technology, Moscow State University, Yerevan Institute of Physics etc.

Events in 2023:

- *Two schools on theoretical physics:*

«School on Physics of Quark-Gluon Matter» 20.03 - 03.04.2023

«Advanced Methods of Modern Theoretical Physics: Integrable and Stochastic Systems» 23 -28.07.2023

- *Regular review lectures on gravity and cosmology for JINR staff*
- *New web-page of DIAS-Th (work in progress)*

DUBNA INTERNATIONAL ADVANCED SCHOOL OF THEORETICAL PHYSICS

FUTURE

- *to continue organizing regular schools on JINR priority topics and modern scientific areas for students, post-graduate students and young scientists from the JINR Member States and other countries;*
- *to return the number of schools to the pre-pandemic level , to enhance the participation of different countries in them;*
- *to continue preparing review lectures on problems of modern physics for JINR staff;*
- *to participate in the educational activities at the JINR-based departments of MSU, MEPhI, MIPT, Dubna University together with JINR University Center;*
- *to continue/renew cooperation with Russian and foreign scientific organizations, higher educational institutions in educational activities;*
  - *To collaborate*
    -with other projects promoting popular science;
    -with Russian Federation foundations (Russian Federation Science Foundation, Federal Target Programs) and international foundations in organizing and conducting international schools for students, graduate students and young scientists.
- *supporting the DIAS-TH website;*
- *video broadcasting and recording of lectures; supporting the digital archive of DIAS-TH.*