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1. A search for effects beyond the Standard Model

The CMS (Compact Muon Solenoid) collaboration at the Large Hadron Collider in CERN performed a search for a new physics beyond the Standard Model of elementary particles in observations of angular distribution of dijets — pair high-energy jets of particles produced in pp collisions with center-of-mass energy of 13 TeV [1]. New effects might affect the statistical distributions or change reaction cross sections compared to the predictions of the Standard model [2–4]. It was for the first time that the experimental data were compared to the second (next-to-next-to) leading order QCD correction with allowance for the first correction to electroweak processes. The obtained constraints on the parameters of the theories are sometimes much stronger than the previous ones. In particular, up to energies of 13.4 TeV the exchange of virtual gravitons is excluded, and the formation of quantum black holes is excluded for their masses of < 6.3 TeV and < 8.5 TeV depending on the scenario. Constraints are obtained on the contact interaction of quarks and on their possible internal structure — ‘subquarks.’ Vector and axial-vector mediators of interaction between quarks and dark matter particles are excluded in the mass interval from 4 to 6.2 TeV. The anomalous triple gluon coupling in the effective field theory and the value of the coupling between axion-like particles and gluons is also constrained from above.

2. A new approach to explanation of the arrow of time

One of the most fundamental problems in physics is the origin of the ‘arrow of time,’ that is, the direction of physical system evolution [5]. A new approach is presented in the paper by S.G. Rubin (NRNU MEPhI) [6] in the framework of multidimensional paradigm [7]. S.G. Rubin proposed to associate the direction of the time run with the monotonous increase in the volume of the additional space. As distinct from the conventional approaches associating time direction with the increase in the entropy of matter, the new model identifies the direction of time with the growth of the geometric entropy of the additional space, expressed through the number of the causally disconnected regions contained in

it. It is important that in the presence of additional dimensions this number and, accordingly, the total entropy grow exponentially faster than in the case of ordinary three-dimensional space. Due to this, the global entropy gradient dominates over local fluctuations and sets an irreversible direction of time at each 3-dimensional point in our space. S.G. Rubin’s theory is based on the fundamental postulate of causality, implicitly used in the discussion of the well-known cosmological arrow of time, according to which there is a chain of transitions between states with ever-increasing entropy. A modification of the described model with the use of G. Perelman’s entropy method was proposed in paper [8]. Specifically, the arrow of time is associated with a change in the shape of additional space, while maintaining its volume, which allows the model to be consistent with the known experimental constraints on the variability of the universal gravitational constant G .

3. Low-energy nuclear reactions

Nuclear reactions with energy below 1 MeV per nucleon are of great interest for understanding processes in stars, but they are hardly reproducible in laboratory conditions because of a low probability of nuclear interactions. Good possibilities for studying low-energy reactions are provided by storage rings of heavy metals. At the storage ring CRYRING@ESR in GSI (Helmholtz Center for Heavy Ion Research in Darmstadt, Germany), nitrogen ions were slowed down to required energy and were directed with high accuracy to the target — a cryogen-temperature hydrogen beam [9]. The reaction products were registered using silicon band detectors. The $^{15}\text{N}(p,p)^{15}\text{N}$ reaction cross section at an energy below 1 MeV per nucleon followed the Rutherford formula for elastic scattering, and at >1 MeV/u a more complex dependence appeared, which is explained by resonance states of ^{15}O nuclei. Also investigated was the reaction $^{15}\text{N}(p,\alpha_0)^{12}$ at 426 keV/u, which corresponds to a record low center-of-mass energy of 403 keV. The obtained reaction cross section 62.3 ± 7.0 mbn is consistent with the results of other measurements. The developed experimental methods offer new prospects for investigation of low-energy nuclear reactions.

4. Transdimensional anomalous Hall effect

As distinct from the usual Hall effect, the anomalous Hall effect occurs even in the absence of an external magnetic field [10, 11]. The electron free pathlength l_z is, as a rule, much less than the system thickness and a two-dimensional Hall effect with thickness averaging effectively takes place. In their experiment, Q. Li (Nanking University, China) and their co-

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authors realized an opposite case, where the sample thickness was much larger than the atomic layer thickness, but smaller than or comparable with l_z , and demonstrated for the first time an essentially new type of the anomalous Hall effect [12]. The heterostructure with 9-layer rhombohedral graphene encapsulated between two layers of hexagonal boron nitride (hBN) and thin graphite plates was examined. The existence of magnetic hysteresis of Hall resistance with magnetization both in-plane and in perpendicular direction was revealed. This hybrid state is due to a special metallic phase, which violates the time reversal symmetry. The authors called the new intermediate regime between 2D and 3D cases a transdimensional anomalous Hall effect.

5. High-energy gamma-ray emission from the supernova remnant IC 433

The morphology and the spectrum of the supernova remnant IC 433, which is located at a distance of 1.5 kpc, were observed at the high-altitude gamma-ray observatory LHAASO (Large High Altitude Air Shower Observatory) [13, 14]. Registered in the vicinity of IC 443 were both the point gamma-ray source, observed earlier by several gamma-ray telescopes at lower energies, and the extended gamma-ray emission detected by E. Fermi observatory. According to the LHAASO data, the spectrum of the point source continues according to the power law with an exponent of $\simeq 3.0$ up to the maximum measured energy of ~ 30 TeV without a visible dip and has a singularity corresponding to π^0 -meson decays. This may indicate that gamma-ray photons were produced by the hadronic mechanism in the interaction between cosmic rays and gas, the cosmic ray energy reaching ~ 300 TeV. Thus, as has long been suspected, the supernova remnants may be sources of cosmic rays with energies in the sub-PeV region (pevatrons). Russian scientists from the INR RAS and MIPT are participants in the LHAASO collaboration.

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