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1. Search for sterile neutrinos

The BEST (Baksan Experiment on Sterile Transitions) experiment carried out at the Baksan neutrino observatory of INR RAS has provided new data confirming the presence of the so-called 'gallium anomaly' (lack of electron neutrinos), which may testify to the existence of sterile neutrino ν_s [1]. The gallium anomaly was discovered in SAGE and GALLEX experiments on solar neutrino detection on the basis of the reaction $^{71}\mathrm{Ga}(\nu_e, e^-)\ ^{71}\mathrm{Ge}$. During detector calibration by radioactive sources, the count rate turned out to be lower than expected. A possible explanation may be a transformation (oscillations) of some electron neutrinos into sterile neutrinos $\nu_e \to \nu_s$ that do not participate directly in weak interactions. Hypothetical ν_s have not yet been reliably detected, but some indications of their existence have been obtained in oscillation experiments. Rather massive ν_s could also constitute 'warm' dark matter in the Universe. In the new BEST gallium experiment, V N Gavrin (Institute for Nuclear Research, RAS) and his colleagues registered neutrinos from the radioactive source $^{51}\mathrm{Cr}$ with well-known activity, prepared in the Dmitrovgrad reactor. In the BEST detector, two gallium volumes were applied at different average distances to the source. The existence of two oscillation lengths decreased theoretical uncertainties. In interpreting the results, an improved reaction cross section was used, which provides a higher confidence that all the nuclear-physical processes are taken into account correctly. In the new measurements, the deficit of ν_s amounted to 20–24%, and the general fidelity of the existence of gallium anomaly increased from $2-3\sigma$ to over 5σ [2]. Thereby, the probability of the existence of ν_s is heightened, provided that no other reason for the divergence is found. The most probable values of the mass parameter and the angle of mixing ν_s are $\Delta m^2 \approx 1.25$ eV and $\sin^2\theta \approx 0.34$ (considering the SAGE and GALLEX data). Another BeEST (Beryllium Electron capture in Superconducting Tunnel junctions) experiment gave the first constraint on $^7\mathrm{Be} \to {}^7\mathrm{Li}$ obtained using beta decays β [3]. ^{7}Be nuclei were implanted into a superconducting tunnel junction quantum sensor. Decays with the capture of one of the electrons from the electron shell into the atomic nucleus were observed. Then, a neutrino (not registered in the experiment) will escape and the nucleus will get a recoil. The recoil energy excites electrons and thus causes tunnel current steps. In the recoil energy spectrum, four peaks were observed, corresponding to the ground and excited states of ^{7}Li nuclei. In the presence of ν_s, the spectrum must have been distorted. This effect has not been revealed with present-day accuracy. The obtained constraint on the matrix element of ν_e and ν_s mixing in the mass interval between 100 and 850 keV is better by an order of magnitude than those obtained in other experiments. ν_s is also being searched for in NOvA experiment conducted with the participation of scientists from Institute for Nuclear Research of the Russian Academy of Science (RAS), Joint institute for Nuclear Research (JINR), and Lebedev Physical Institute of RAS [4]. Measurements are being taken at Fermilab by two detectors at distances of 1 and 810 km from the antineutrino acceleration source, but no oscillations into ν_s have yet been found. The absence of a notable ν_s contribution allowed obtaining additional constraints on the mixing angles and mass parameters. For reliable conclusions concerning the existence of ν_s, further studies are needed.

2. ϕ-meson-proton interaction

A shift of the hadron mass in a nuclear medium through a partial restoration of chiral symmetry is predicted in the framework of quantum chromodynamics. Some evidence of this effect was obtained in experiments with ϕ mesons. It is, however, difficult to interpret the obtained data because of theoretical and experimental uncertainties in the mechanism of ϕ-meson-nucleon interactions. Investigated in the ALICE experiment at the Large Hadron Collider were pp collisions with an energy of 13 TeV in the center-of-mass system, and interactions between produced ϕ-mesons and protons were observed [5]. The ϕp interaction was established to have the character of attraction with the main contribution to it made by elastic processes, while inelastic ones only amount to $< 0.17\%$. The interaction constant $g_{N-\phi} = 0.14 \pm 0.03$ (stat.) ± 0.02 (syst.) was found from the measurements of two-particle correlation functions. These new data may clarify different effects related to ϕ-meson-nucleon interactions. Russian researchers from Budker Institute of Nuclear Physics of Siberian Branch of the Russian Academy of Science (BINP SB RAS), Institute for Nuclear Research (INR) RAS, Joint Institute for Nuclear Research (JINR), Moscow Institute of Physics and Technology (MIPT), Nuclear research center Kurchatov Institute (including Institute for Theoretical and Experimental Physics (ITEP), State research center Institute for High Energy Physics (SRC IHEP), and Konstantinov Petersburg Nuclear Physics Institute (PINP), National Research Nuclear University Moscow Engineering Physics Institute (MEPhI),

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Russian Federal Nuclear Center All-Russian Research Institute of Experimental Physics (RFNC–VNIIEF), and Saint Petersburg University (SPbU) are taking part in the ALICE experiment.

3. Photonuclear reaction $\gamma n \to K^0\Sigma^0$

The cross section of the reaction $\gamma n \to K^0\Sigma^0$ near the threshold K^* has been measured in the BGOOD experiment being performed at the University of Bonn with the participation of Russian scientists from PINP and INR RAS [6]. A peak was revealed at an energy of $\sim$ 2050 MeV, which may correspond to the multiquark vector meson-baryon resonance. This model was proposed by A Ramos and E Oset in 2013 for the uds-quark sector. An analogous model in the form of a pentaquark configuration in the sector of charmed heavy quarks was applied earlier to explain P_C states observed in the LHCb experiment at the Large Hadron Collider. In the BGOOD experiment, liquid-hydrogen and deuterium targets were exposed to gamma-ray quanta of bremsstrahlung generated by an electron beam. The reaction products were observed using magnetic spectrometers and track and plastic scintillation detectors. Candidate particles K^0 were selected by recording photon pairs from decays $K^0_S \to \pi^0\pi^0 \to (\gamma\gamma)(\gamma\gamma)$. Other criteria of selection were also employed. In the framework of statistical uncertainties, the peak at 2050 MeV corresponds to the model of A Ramos and E Oset. Thus, the multiquark state in the light-quark sector was revealed, perhaps, for the first time. However, since alternative interpretations have not been ruled out, additional statistical data and new experiments are needed. For nuclear photonics, see [7, 8].

4. Diffraction method of measuring the Casimir–Polder force

The Casimir–Polder force appears between a separate atom and a polarized surface owing to quantum fluctuations of an electromagnetic field. Measuring this force is of interest from the fundamental viewpoint in the search for new interactions on nanometer scales and may appear to be important for microelectromechanical systems. C Garcion (Sorbonne Paris North University, France) and his co-authors demonstrated in their experiment a new technique for measuring the Casimir–Polder force on scales of $\approx$15–51 nm in the course of interference of an atomic beam on a flat diffraction grating [9]. The idea of their method implies that, when the atom approaches the grating, it is affected by the Casimir–Polder force, which results in a decrease in the grating gap effective width, which affects, in turn, the interference pattern. The grating was made by the electron lithography method in a 100-nm Si_3N_4 plate on a 1×1-mm^2 plate. A beam of metastable argon atoms was sent to the grating at a velocity of ~ 20 m s^{-2}. The interference pattern recorded by the detector behind the plate corresponded to the main contribution from the Casimir–Polder potential with nearly 15% deviations associated with the contribution of the van der Waals potential being noticed. Thus, the experiment demonstrated a high sensitivity of the new diffraction method.

5. Low-energy excitations in $Cu_3Zn(OH)_6FBr$

Y Wei (Beijing National Laboratory for Condensed Matter Physics and the Institute of Physics, Chinese Academy of Sciences) and their co-authors have investigated specific heat conductivity of a low-temperature compound $Cu_3Zn(OH)_6FBr$ [10]. The state of a quantum spin liquid is assumed to take place in this polycrystal, but more detailed studies are needed for a reliable conclusion. In particular, the picture can be clarified through an analysis of elementary excitations in low-temperature $Cu_3Zn(OH)_6FBr$. The researchers have found that, as the temperature lowers, the graph of thermal conductivity shows an arm at $\sim$ 4 K, while with further cooling the thermal conductivity takes on a power-law form $\propto T^{1.7}$. This behavior is best of all explained by the interaction of vortex excitations — visons with magnetic impurities. Such an effect resembles a coherence length variation in the Pippard model for superconductors and may testify to a distant quantum entanglement of excitations.

6. Möbius strip microlaser

Y Song (Paris-Saclay University, France and Lanzhou University, China) and their co-authors have examined a microlaser whose resonator was a polymer ring in the form of a Möbius strip nearly $\sim 50\,\mu$m in radius fabricated of a photoresist IP-G780 by the method of direct lithography [11]. The photoresist was doped over the volume by dye particles (active medium), and pumping was realized transversely by an additional laser. The set of lasing generation modes measured by spectrometer and an SSD camera differed from the set of circular modes in conventional ring microlasers ('whispering gallery' modes) and corresponded to periodic geodesics (the shortest trajectories) of light on a one-sided Möbius strip.

7. Proton therapy

At INR RAS, as at some other Russian research centers, nuclear physics medicine has been developed for many years already. One of the avenues is proton beam therapy — the use of proton beams to treat oncological diseases. By varying the accelerator energy, proton beams allow finding the place where protons with a maximum absorbed dose stop and minimizing irradiation of the surrounding nonmalignant tissues. A group of authors from INR RAS worked out a conception of compact linear accelerators for proton therapy. The aim is to obtain a pulsed proton beam with a maximum energy up to 230 MeV and a cross section of the order of mm. They performed numerical simulations, using Geant4, of the effect of a monoenergetic proton beam on tissues [12]. These calculations estimated the characteristics of irradiation dose distribution. The optimal version for dose field formation in the region of a tumor is a magnetic scanning system. For nuclear medicine, see [13–18].

8. Lunar neutrinos

Charged particle (cosmic ray) fluxes incident on Earth's atmosphere cause the birth of 'atmospheric' neutrinos. Similarly, the collision of cosmic rays with lunar soil leads to hadron cascades and 'lunar' ν generation. The birth of ν with energies over 10 GeV in this process has already been considered, in particular, by researchers from INR RAS G T Zatsepin and L V Volkova, who showed that the flux of such ν from the Moon is smaller by 2–4 orders of magnitude than the flux of atmospheric ν. Researchers from INR RAS and MIPT, S V Demidov and D S Gorbunov, have calculated theoretically the ν flux from the Moon in the region of lower energies of 10 MeV–10 GeV [19]. Pions and kaons produced in hadron cascades decelerate in the lunar regolith. As a result, in the decay of these particles, a noticeable monochromatic component appears in the low-energy spectrum of lunar ν. It turns out that at an energy of < 53 MeV a flux of lunar ν may exceed that of atmospheric ν by an order of magnitude, but only in the direction towards the Moon. It may be the next generation of neutrino telescopes that will be able to register ν from the Moon's. The direction of ν arrival, 12% flux variations during the Moon motion along an elliptic orbit around Earth, as well as the shape of the spectrum may help distinguish lunar ν above the background.

9. Horizons of black hole merger

In recent years, the LIGO/VIRGO gravitational-wave detectors have found events of black hole (BH) mergers. Researchers from Germany and Canada, D Pook-Kolb, R A Hennigar, and I Booth, developed a new method of identifying trapped surfaces of light in numerical calculations and, using it, traced the behavior of horizons in merging BHs with different masses [20]. It turns out that, after collisions of BHs, their apparent horizons interpenetrate and their common outer apparent horizon appears, tending with time to an event horizon, while the inner apparent horizon moves towards the center until it is annihilated by trapped surfaces. In a sense, the smaller BH continues its existence inside the larger one. In nonstationary geometry, a large number of such intersecting trapped surfaces appear, and their number tends to infinity. The authors investigated trapped surface stability to discover that only three of them, coinciding with horizons, remain stable.

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