QUARKS-2018

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Axion search and neutron dipole moment in cryogenic experiments with quantum data receiver

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Outline

- Interaction of the Axion Wind with a magnetized sample
- Search for Solar Axion emitted in M1 transitions of the Sun
- Search for Axions emitted in M1 transitions from the radioactive source
- The detection scheme for two entangled photons comming from axion decay based on quantum SQUID`s logalal gates is presented

QUAX experiment

The QUAX (QUaerere AXion) program explores the feasibility of an apparatus to detect axions as a dark matter component by exploiting its interaction with the spin of electrons.

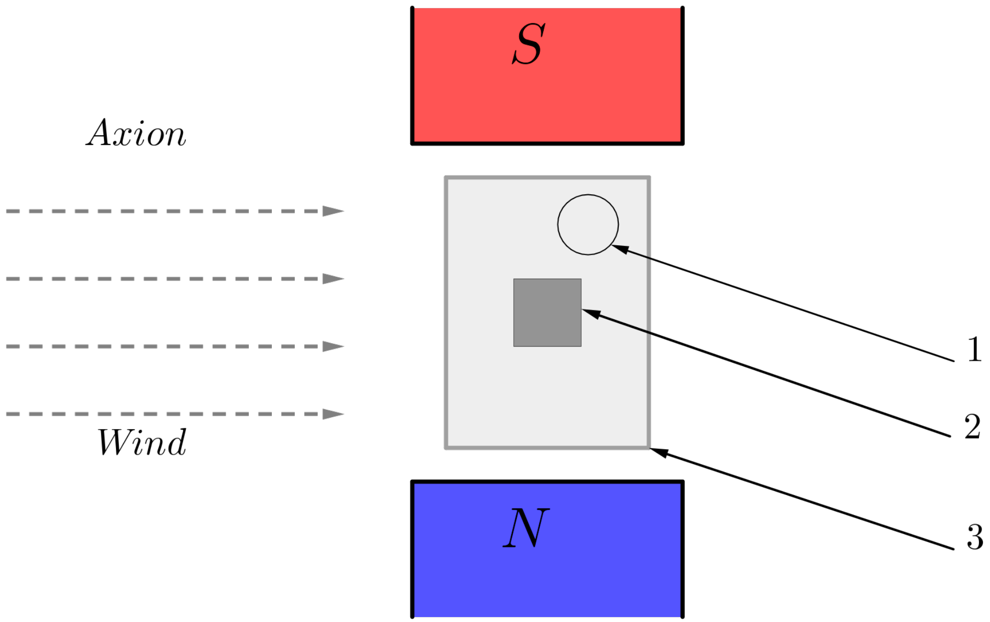
It is useful to write the expected output power by referring to relevant experimental design parameters. For a magnetic sample of volume and spin density they have:

axion mass is determined by a magnetizing field $B_0 = 1.7\,T$

by an ultra low noise superconducting quantum interference device (SQUID) amplifier

arXiv:1802.05552

Interaction of the axion field with a magnetized sample



The magnetized sample behaves as an RF receiver(1) tuned at the Larmor frequency

The sample (2) is placed inside a microwave resonant cavity (3) which is used to reduce the effect of radiation damping and to optimize power collection

- *L. M. Krauss, J. Moody, F. Wilczek, D.E. Morris, Spin coupled axion detections (1985);*
- *A.I. Kakhizde, I.V. Kolokolov, Sov. Phys, JETP 72 598 (1991)*

Axion interaction with electron spin

Electrons interaction with axions and EM fields

$$L=\bar{\psi}(x)\left(i\,\gamma^{\mu}(\partial_{\mu}+ieA_{\mu})-m\right)\psi(x)-ig\,\bar{\psi}(x)\,\gamma^{5}\,\psi(x)\,a(x)$$

Nonreletivistic limits (Pauli equation)

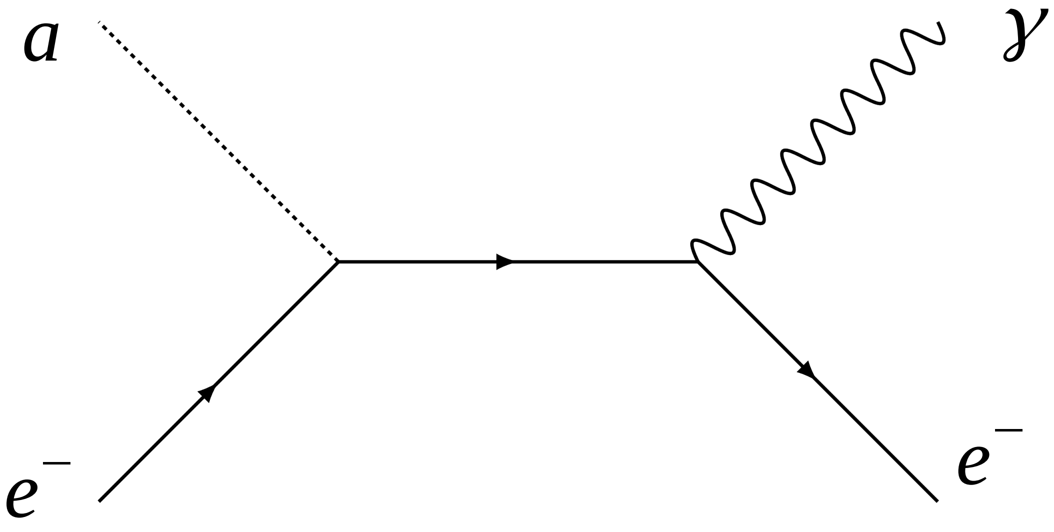
$$\psi=\exp[-i\ m\ t]\begin{pmatrix}\phi\\ \chi\end{pmatrix}$$

$$i\,\partial_{t}\,\varphi=\frac{1}{2m}\left(\boldsymbol{\sigma}(\boldsymbol{p}-e\,\boldsymbol{A})\right)^{2}\phi-\frac{g}{2m}\left(\boldsymbol{\sigma}\cdot\nabla a\right)\varphi$$

“Magnetic field“ of axion wind

$$V=-\boldsymbol{\mu}\,\boldsymbol{H_{a}}\qquad\qquad \boldsymbol{H_{a}}=\frac{g}{2e}\nabla a$$

Non elastic amplitude for axion — photon conversion



$$T_{fi}^{(2)} = \sum_l \int_{t_0}^{t_1} \int_{t_0}^{t_2} \langle f \,|V_{\text{int}}(t_2)|\, l \rangle \langle l \,| V_{\text{int}}(t_1)|\, i \rangle \, dt_1 \, dt_2$$

$$M_{fi} = \sum_l \frac{\langle F \,|V_{eR}|\, l \rangle \langle l \,| V_{ea} |\, i \rangle}{E_1 + \omega_a - E_l + i\dfrac{\Gamma}{2}}$$

$$V_{eR} = \frac{e\,\boldsymbol{A}}{m} \begin{pmatrix} (\boldsymbol{\sigma}\,\boldsymbol{p}) & 0 \\ 0 & (\boldsymbol{\sigma}\,\boldsymbol{p}) \end{pmatrix}$$

The particular chose of parameters

$$m_a = 0.6 \times 10^{-5} F_1 (eV) = 9.1 F_1 (GHz)$$

$$F_1 = \frac{F}{10^{12} GeV} \approx 0.1 - 1$$

$$\rho_a = 0.3 \frac{GeV}{cm^3}$$

$$n_a = \frac{\rho_a}{m_a}$$

The emitted power

$$H_a(\omega)=\frac{1}{T}\int_{\frac{-T}{2}}^{\frac{T}{2}} H_a(t)\exp(i\,\omega t)\,dt$$

$$\frac{d\boldsymbol{m}}{dt}=[\,\gamma\boldsymbol{H}(t)\times\boldsymbol{m}]-\Gamma\,\boldsymbol{m}$$

$$\Gamma=\frac{1}{T}=\frac{\omega_0}{Q_f}$$

$$P=\frac{1}{T_0}\int_{\frac{-T_0}{2}}^{\frac{T_0}{2}} dt\left\langle\boldsymbol{H}\,\frac{d\boldsymbol{m}}{dt}\right\rangle=\frac{P_0\,\frac{\Gamma_f^2}{4}}{\left[(m_a-\omega_0)^2+\frac{\Gamma_f^2}{4}\right]}$$

$$P_0=\left(\frac{4\,m_a}{q^2}\right)\rho_a V\left(\frac{m_a\;g_a}{F}\right)^2 Q_f\,\chi_0\,\upsilon_\perp^2$$

$$P_{out}=3.8\times10^{-26}\left(\frac{m_a}{200\,\mu eV}\right)^3\left(\frac{V_s}{100\,cm^3}\right)\left(\frac{n_S}{2\cdot10^{28}/m^3}\right)\left(\frac{\tau}{2\,\mu s}\right)W$$

The Bloch equation

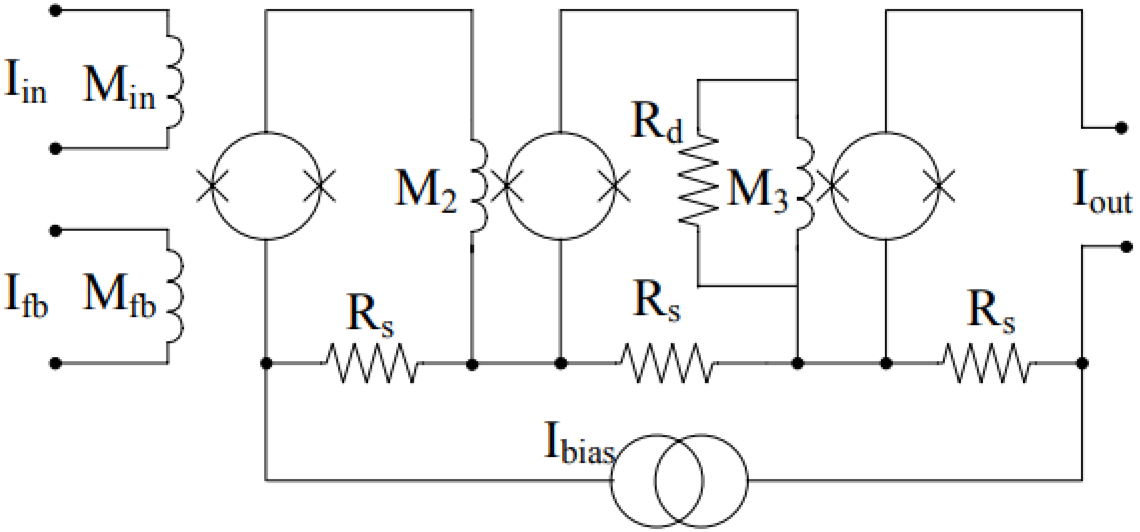
$$\frac{dM_x}{dt} = \gamma\left(\boldsymbol{M}\times\boldsymbol{B}\right)_x - \Gamma_1 M_x - \frac{M_x M_z}{M_0\,\tau_r}$$

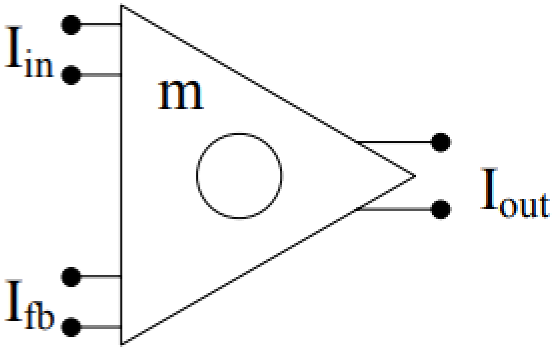
$$\frac{dM_y}{dt} = \gamma\left(\boldsymbol{M}\times\boldsymbol{B}\right)_y - \Gamma_2 M_y - \frac{M_y M_z}{M_0\,\tau_r}$$

$$\frac{dM_z}{dt} = \gamma\left(\boldsymbol{M}\times\boldsymbol{B}\right)_z - \Gamma_1\left(M_0 - M_z\right) - \frac{M_x^2 + M_y^2}{M_0\,\tau_r}$$

Radio friquency SQUID amplifier

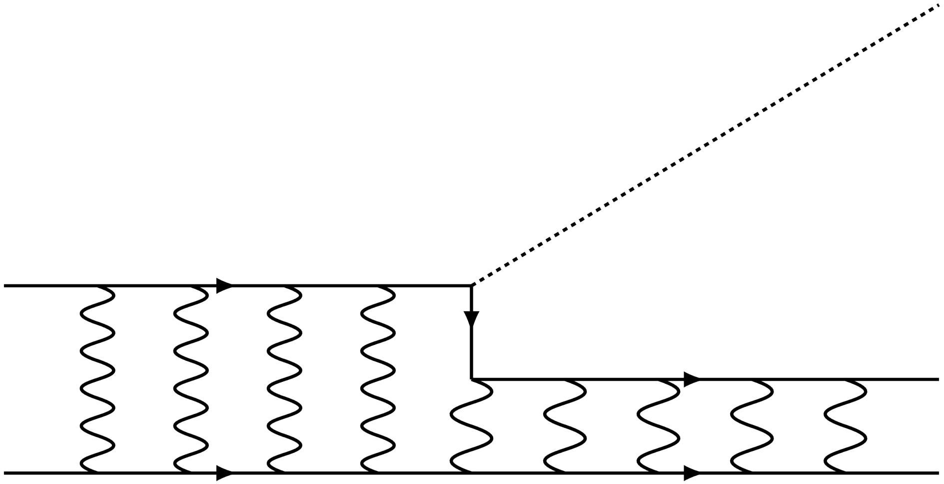
Three-stage SQUID operational ampifier circuit



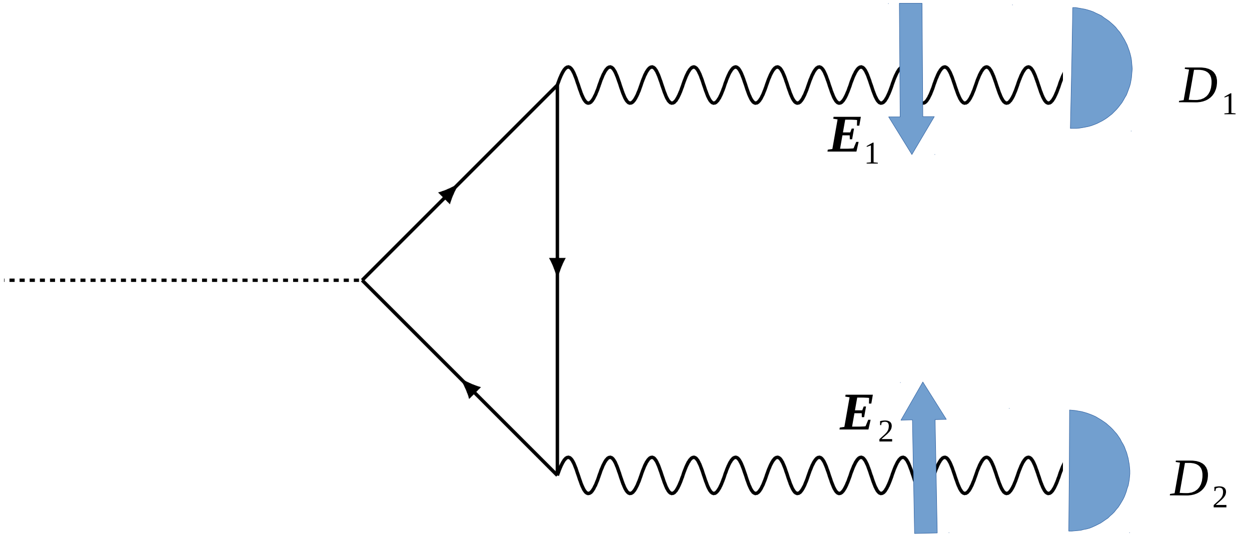


SQUID operational ampifier sumbol

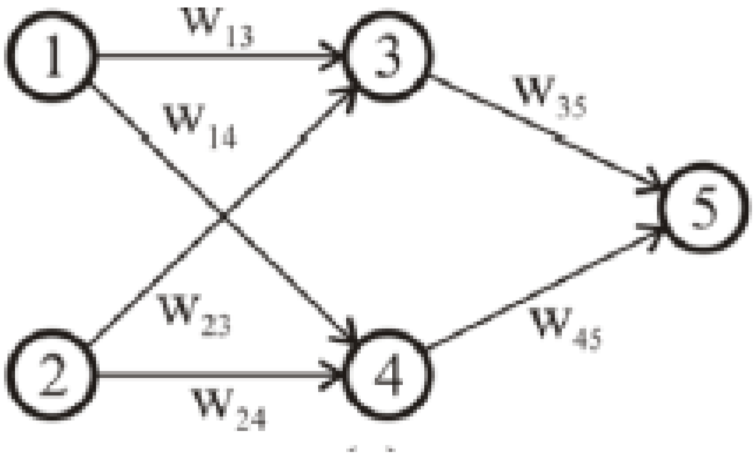
Two entanglament photons detection by neutral network with quantum SQUID gates

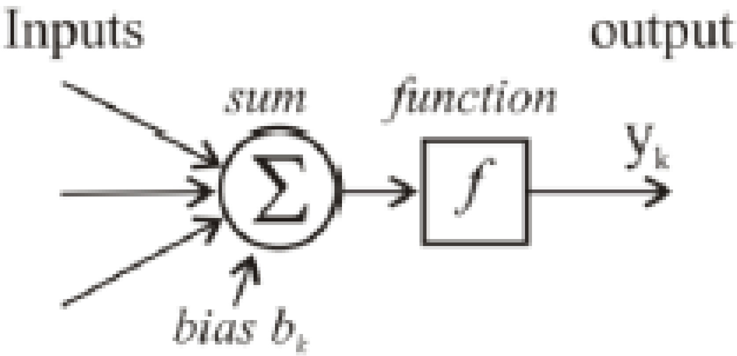


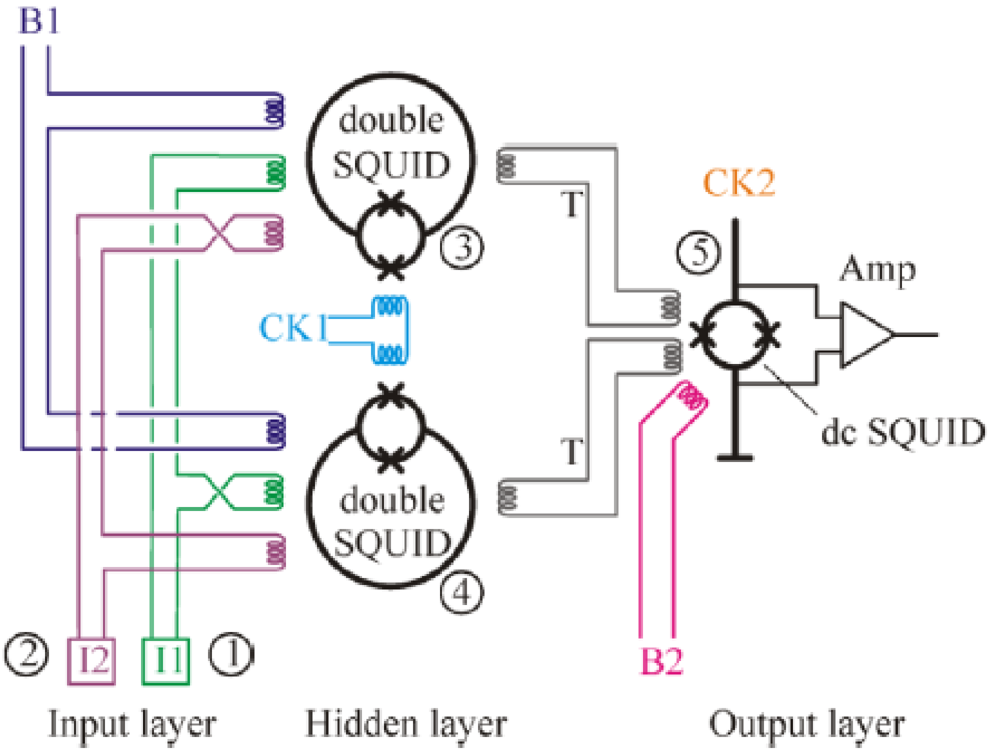
process of the de-excitation in plasma



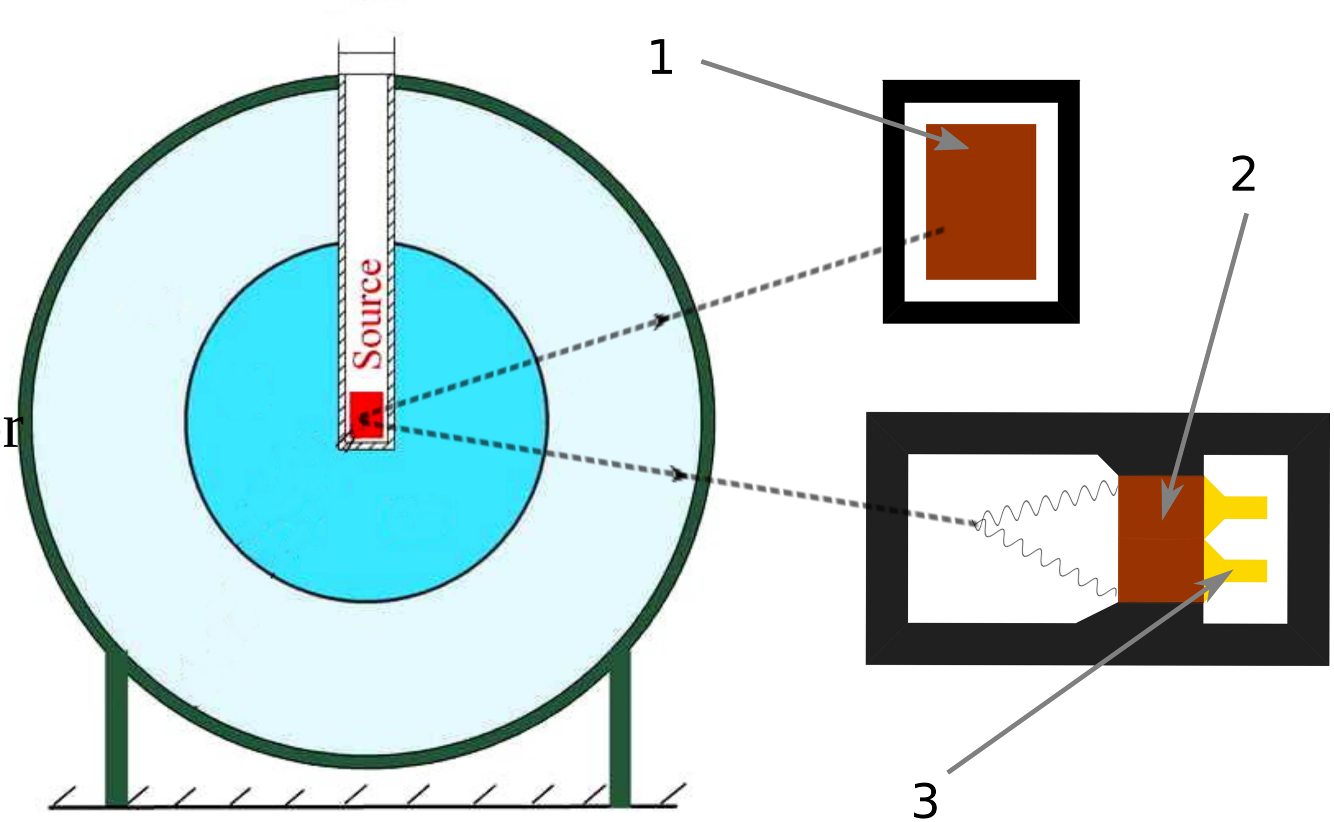
Quantum logical gates XOR







Search for axions emitted in M1 transitions from a source process of the de-excitation



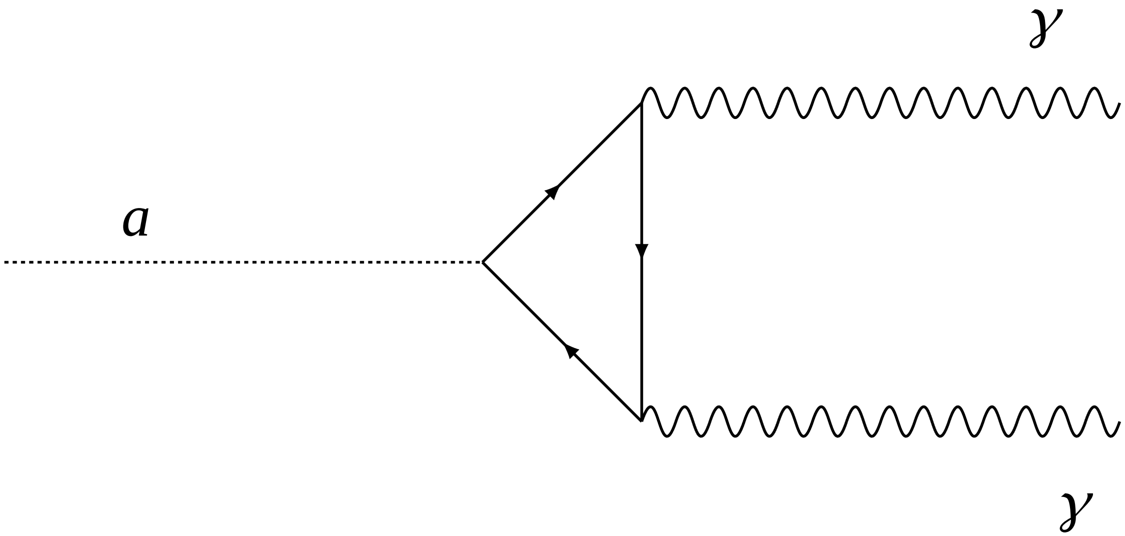
1 — simiconductor detector

2 — scintillator

3 — PMT

Principle of the detection

$$a \rightarrow \gamma\ \gamma$$



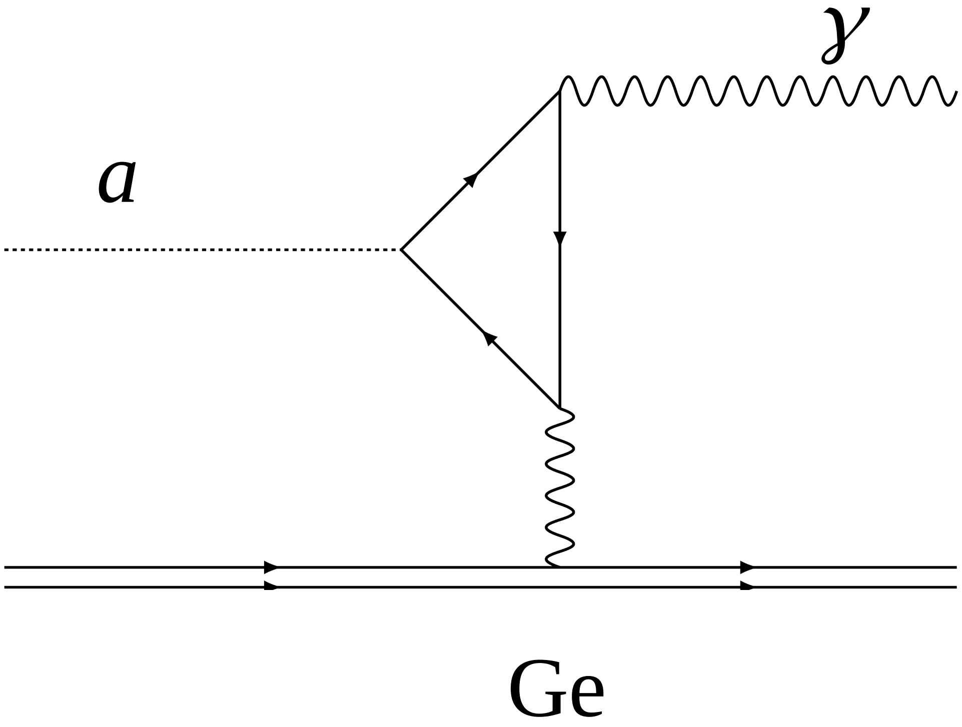
The one-loop diagram yields an effective amplitude governing the decay of the form

$$M_{a\gamma}=\frac{\alpha}{\pi}\frac{1}{f_{a\gamma\gamma}}\epsilon^{\mu\nu\sigma\rho}\epsilon_{\mu}\left(K_{1}\right)\epsilon_{\nu}\left(K_{2}\right)K_{1_{\sigma}}K_{2_{\rho}}$$

F. T. AVIGNONE et al.

Principle of the detection

Primakoff cnovertion in the Ge detector



Expirements basis on this principle

PHYSICAL REVIEW D VOLUME 37, NUMBER 3 1 FEBRUARY 1988

Search for axions from the 1115-keV transition of ^{65}Cu

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(Received 16 July 1987)

Two independent axion searches have been carried out near a well-shielded radioactive ^{65}Zn source ($\sim$15 kCi). One experiment used four NaI(Tl) scintillators to detect coincident photons generated in the decay $a \rightarrow \gamma\gamma$. The second used a shielded 145-cm^3 low-background intrinsic-Ge detector to detect single photons produced by axion "Compton" interactions with detector electrons and by Primakoff conversion off Ge nuclei and off Pb nuclei in the detector shield. We determine general constraints imposed by these experiments on axions that couple to nucleons and to either the electron or two photons. In the case of light axions, the limits obtained in the second experiment are new. For the standard axion, we determine the ranges of f_ϕ and X that are ruled out by our measurements.

I. INTRODUCTION

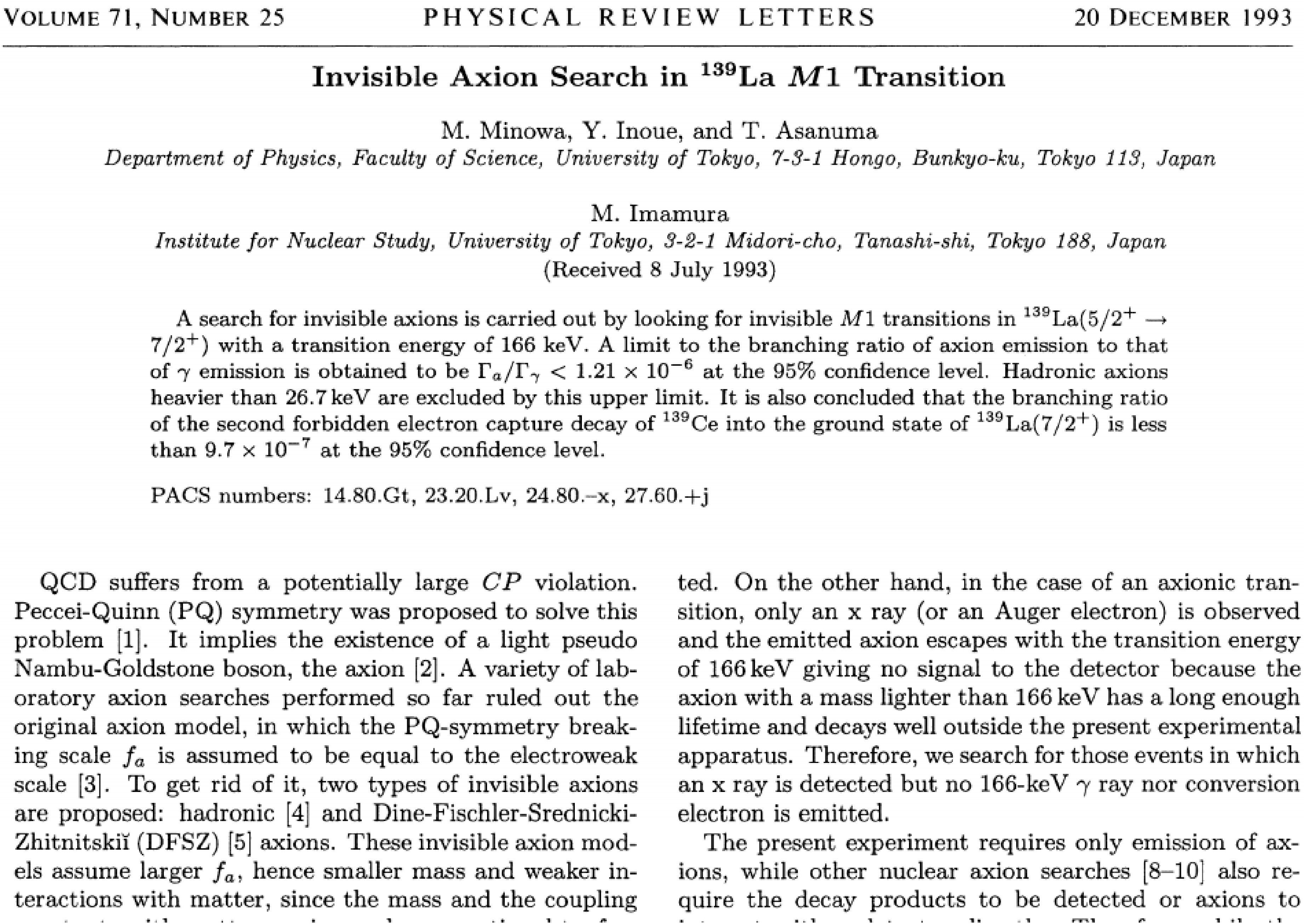
One elegant solution to the strong *CP* problem, the apparent weakness of the *P*- and *CP*-violating term in the QCD Lagrangian, was proposed some time ago by Peccei and Quinn[1] (PQ). Their solution, the imposition of a global chiral U(1) symmetry on the world Lagrangian, implies the existence of a light neutral pseudoscalar, the axion.[2] However, despite many careful searches for axions in beam-dump, reactor, and nuclear-decay experiments, this particle has so far eluded discovery.

Although the original axion, associated with PQ symmetry breaking at the weak scale, is ruled out by experi-

corporating the PQ symmetry. In the present paper we present some new constraints on the couplings of light axions to nucleons.

We have undertaken two independent searches for axions emitted from a well-shielded $\sim$15-kCi ^{65}Zn source. This source feeds the $\frac{5}{2}^-$ excited state in ^{65}Cu that may decay to the ground state by emitting an axion with a total energy of 1115 keV (see Fig. 1). In the first experiment we attempted to detect the photons from the in-flight decay $a \rightarrow \gamma\gamma$ of the emitted axion. The signal was a coincidence between any two of the four NaI(Tl) detectors. We note that this experiment is very similar to the earlier ^{65}Cu experiment performed by Lehmann *et al.*[7]

Expirements basis on this principle



VOLUME 71, NUMBER 25 PHYSICAL REVIEW LETTERS 20 DECEMBER 1993

Invisible Axion Search in ^{139}La $M1$ Transition

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(Received 8 July 1993)

A search for invisible axions is carried out by looking for invisible $M1$ transitions in $^{139}\mathrm{La}(5/2^+ \to 7/2^+)$ with a transition energy of 166 keV. A limit to the branching ratio of axion emission to that of γ emission is obtained to be $\Gamma_a/\Gamma_\gamma < 1.21 \times 10^{-6}$ at the 95% confidence level. Hadronic axions heavier than 26.7 keV are excluded by this upper limit. It is also concluded that the branching ratio of the second forbidden electron capture decay of ^{139}Ce into the ground state of $^{139}\mathrm{La}(7/2^+)$ is less than 9.7×10^{-7} at the 95% confidence level.

PACS numbers: 14.80.Gt, 23.20.Lv, 24.80.–x, 27.60.+j

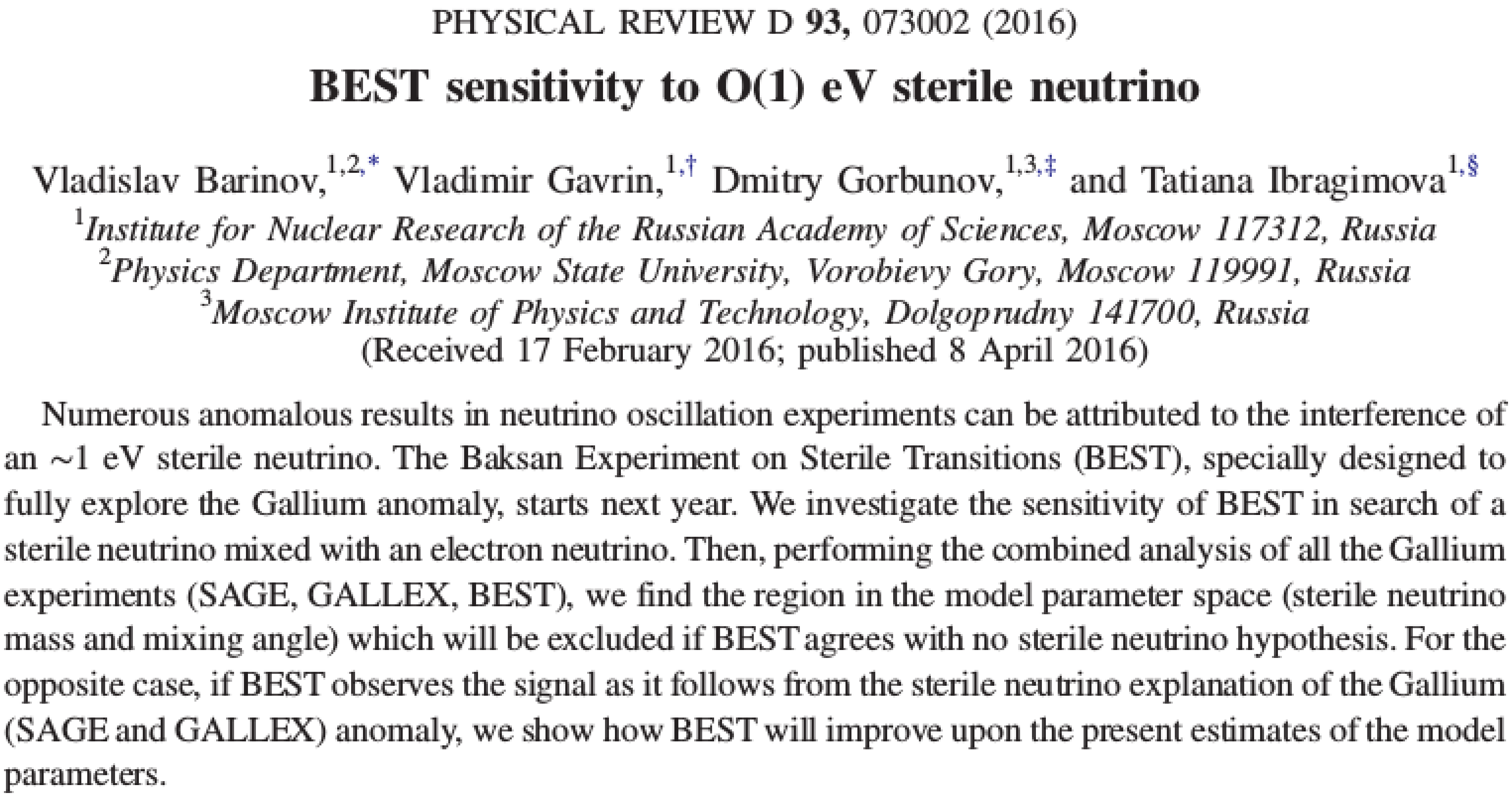
QCD suffers from a potentially large CP violation. Peccei-Quinn (PQ) symmetry was proposed to solve this problem [1]. It implies the existence of a light pseudo Nambu-Goldstone boson, the axion [2]. A variety of laboratory axion searches performed so far ruled out the original axion model, in which the PQ-symmetry breaking scale f_a is assumed to be equal to the electroweak scale [3]. To get rid of it, two types of invisible axions are proposed: hadronic [4] and Dine-Fischler-Srednicki-Zhitnitskiĭ (DFSZ) [5] axions. These invisible axion models assume larger f_a, hence smaller mass and weaker interactions with matter, since the mass and the coupling

ted. On the other hand, in the case of an axionic transition, only an x ray (or an Auger electron) is observed and the emitted axion escapes with the transition energy of 166 keV giving no signal to the detector because the axion with a mass lighter than 166 keV has a long enough lifetime and decays well outside the present experimental apparatus. Therefore, we search for those events in which an x ray is detected but no 166-keV γ ray nor conversion electron is emitted.

The present experiment requires only emission of axions, while other nuclear axion searches [8–10] also require the decay products to be detected or axions to

BEST experiment

In the Baksan Neutrino Observatory



PHYSICAL REVIEW D **93,** 073002 (2016)

BEST sensitivity to O(1) eV sterile neutrino

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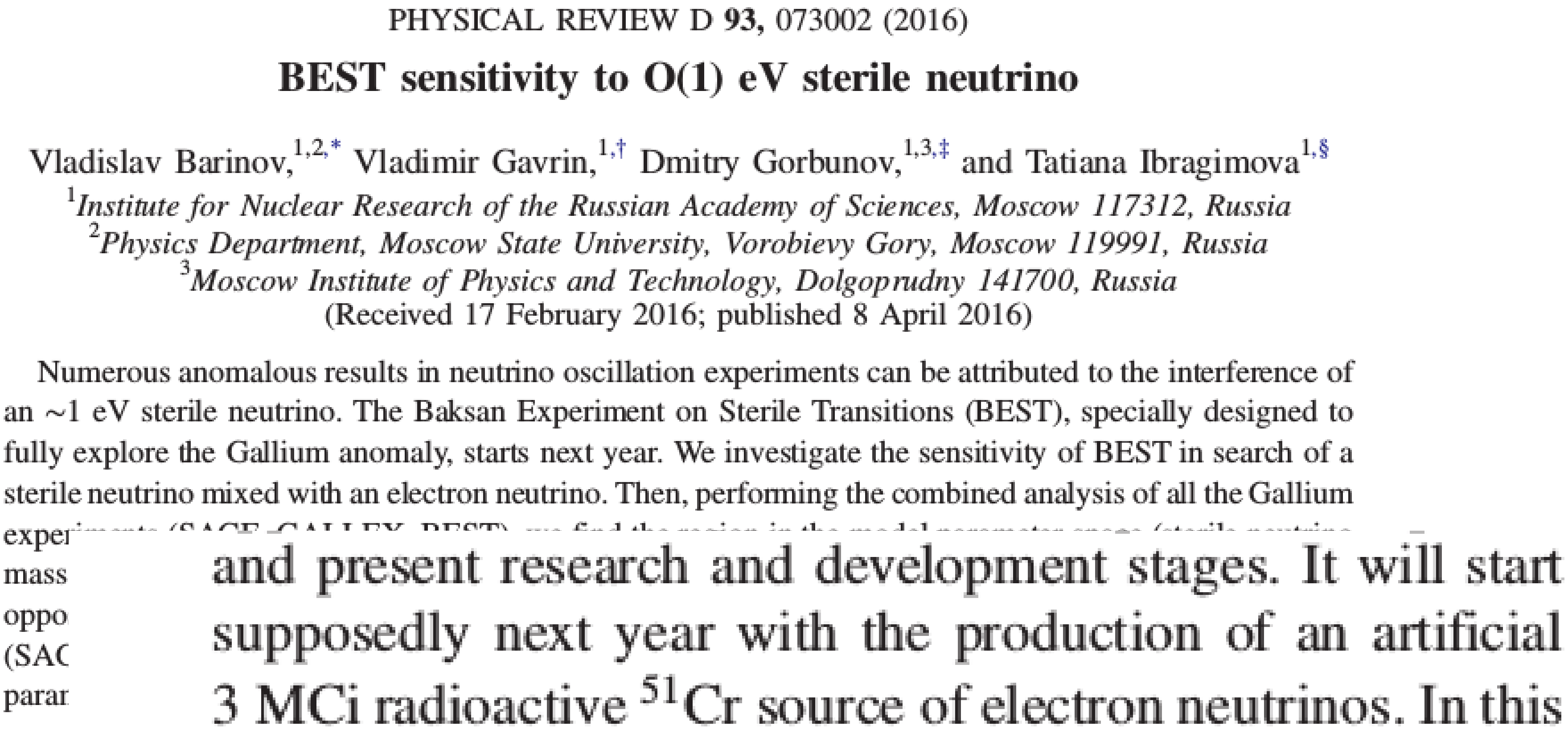
(Received 17 February 2016; published 8 April 2016)

Numerous anomalous results in neutrino oscillation experiments can be attributed to the interference of an ∼1 eV sterile neutrino. The Baksan Experiment on Sterile Transitions (BEST), specially designed to fully explore the Gallium anomaly, starts next year. We investigate the sensitivity of BEST in search of a sterile neutrino mixed with an electron neutrino. Then, performing the combined analysis of all the Gallium experiments (SAGE, GALLEX, BEST), we find the region in the model parameter space (sterile neutrino mass and mixing angle) which will be excluded if BEST agrees with no sterile neutrino hypothesis. For the opposite case, if BEST observes the signal as it follows from the sterile neutrino explanation of the Gallium (SAGE and GALLEX) anomaly, we show how BEST will improve upon the present estimates of the model parameters.

BEST experiment

In the Baksan Neutrino Observatory



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and present research and development stages. It will start supposedly next year with the production of an artificial 3 MCi radioactive ^{51}Cr source of electron neutrinos. In this

Axion — two photon convertion in medium

Axion sources	ω_a	Medium
Electron — ion plasms	$1 - 10^2\ eV$	BBO - crystal
^{51}Cr	$320\ keV$	Vanadium Oxide VO_3
^{57}Co	$14.4\ keV$	Fe-57 inriched FeS2 (pyrite) crystal or Fe intercalated graphite

Searching for Solar axion in the BNO

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Original Russian Text © Yu.M. Gavrilyuk, A.N. Gangapshev, A.V. Derbin, I.S. Drachnev, V.V. Kazalov, V.V. Kobychev, V.V. Kuz'minov, V.N. Muratova, S.I. Panasenko, S.S. Ratkevich, D.A. Semenov, D.A. Tekueva, E.V. Unzhakov, S.P. Yakimenko, 2015, published in Pis'ma v Zhurnal Eksperimental'noi i Teoreticheskoi Fiziki, 2015, Vol. 101, No. 10, pp. 739–745.

New Experiment on Search for the Resonance Absorption of Solar Axion Emitted in the *M*1 Transition of ^{83}Kr Nuclei

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Axions with an energy of 9.4 keV emitted in the *M*1 transition of ^{83}Kr nuclei in the Sun have been sought in the resonance absorption reaction $A + {}^{83}\mathrm{Kr} \to {}^{83}\mathrm{Kr}^* \to {}^{83}\mathrm{Kr} + \gamma, e$ (9.4 keV). A proportional gas chamber filled with krypton and placed in a low-background setup at the underground laboratory of the Baksan neutrino observatory was used to detect γ-ray photons and electrons appearing after the decay of a nuclear level. As a result, a new constraint has been determined on the isoscalar and isovector coupling constants of the axion with nucleons: $|g^3_{AN} - g^0_{AN}| \le 1.29 \times 10^{-6}$. This constraint results in the following new bound on the mass of the axion in the hadronic axion model: $m_A \le 100$ eV (95% C.L.).

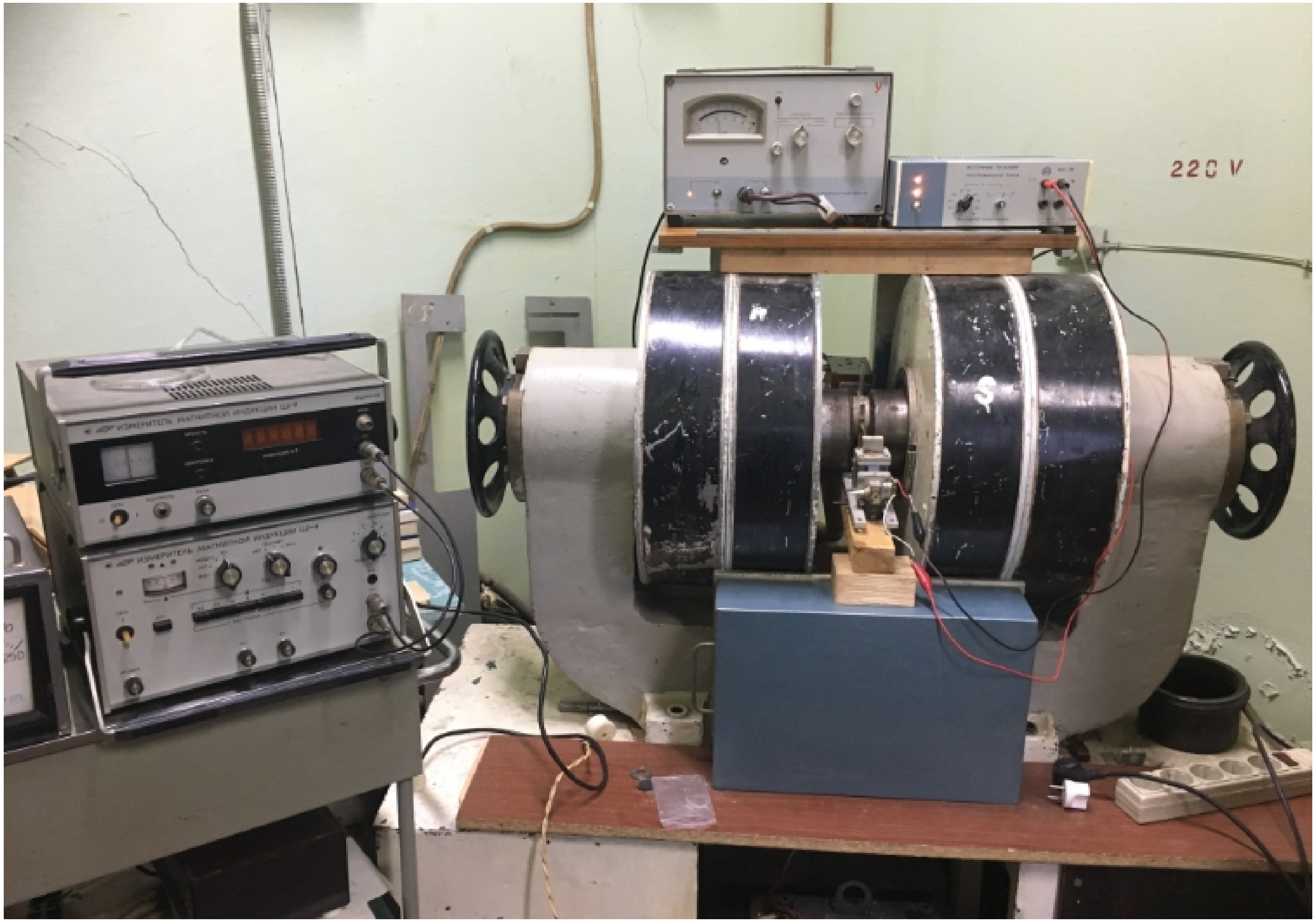
DOI: 10.1134/S0021364015100069

1. INTRODUCTION

The most natural solution to the *CP* problem of strong interactions was obtained by introducing new chiral symmetry [1], spontaneous breaking of which at the energy f_A completely compensates the *CP*-breaking term in the Lagrangian of quantum chromodynamics and is responsible for the appearance of the axion with photons ($g_{A\gamma}$), electrons (g_{Ae}), and nucleons (g_{AN}), which are in turn model-dependent quantities. Consequently, it is possible to consider a wider class of axion-like particles for which the coupling constants and masses of particles are independent parameters. Possible examples of such particles are light *CP*-odd Higgs bosons or light particles with

Possible experiments in the KBSU

The setup realizing the methods of electron ferromagnetic and paramagnetic resonances with NMR



Possible experiments in the KBSU

Possible experiments in the KBSU

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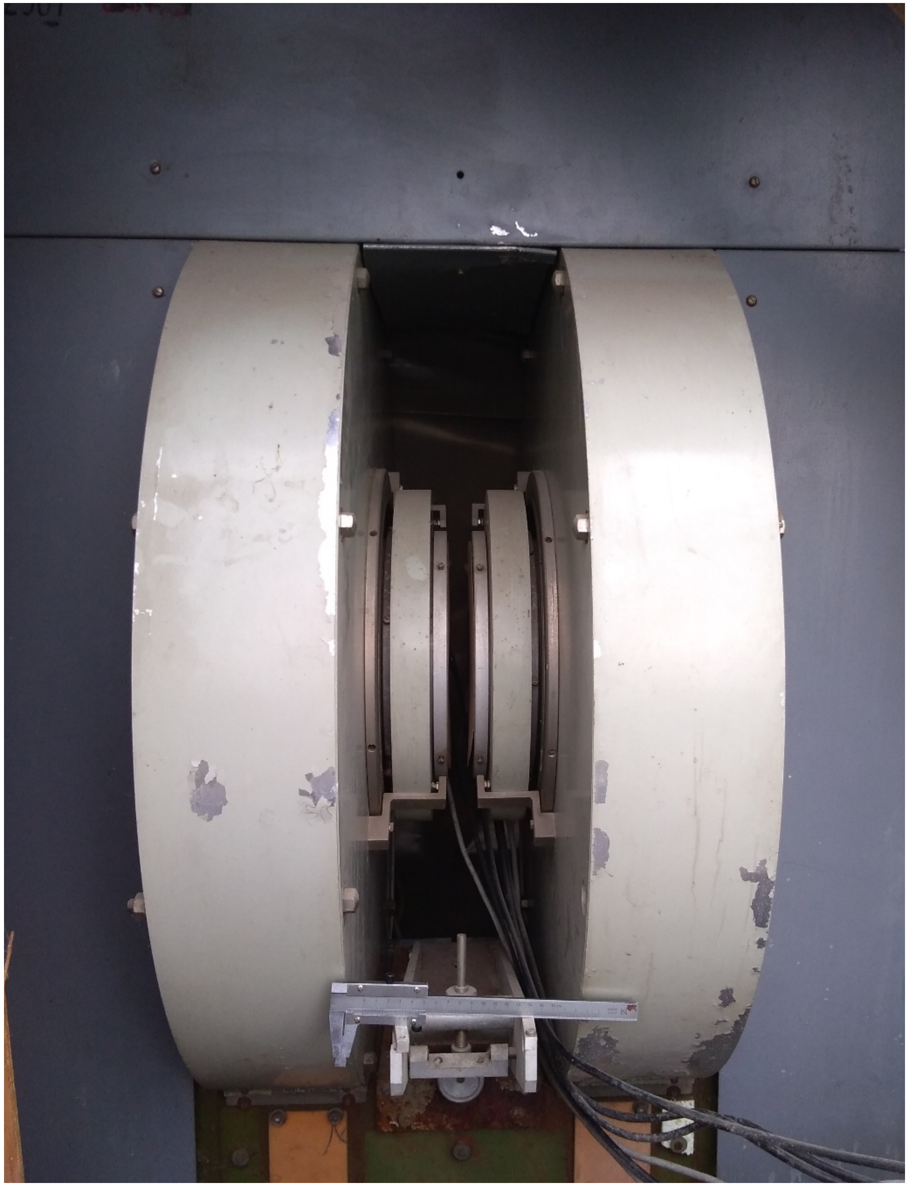

Conclusions

1. The possibilities of Axion search based on the «axion-spin» interaction in magnetized medium could be improved by use of the time modulation external magnetic field and modified SQUID amplifies

2. The use of isotopic source Cr-51 and Co-57 are proposed in frame of Mossbauer techniks in low bacground laborotories such as BNO

3. The technik for two entanglent photons coming from axion decay in medium of optical BBS crystal is proposed. The scheme looks like nural net based on SQUID quantum logical gates

$$H_z = H_0 + H_1 \cos(\omega_1 t)$$

$$H_x = H_1 e^{i\omega t}$$

$$\boldsymbol{m} = \frac{\gamma H_1 \Gamma_2 J_n^2(\lambda) \boldsymbol{M}_0}{(n\omega_1 - \delta\omega)^2 + \Gamma^2}$$

$$H_1 = H_a$$

$$\Gamma^2 = \Gamma_2^2 + \frac{\Gamma_2}{\Gamma_1} \omega_1^2 f_n^2(\lambda)$$

$$S_a = \int_\Omega d\omega\, k\, m(\omega) = \frac{\left(\frac{4\pi}{q^2}\right) \upsilon_\perp^2 \rho_a \left(\frac{m_e\, g_c}{F}\right)^2 (\chi_0 \omega_0 V)^2}{(m_a - \omega)^2 + \frac{\Gamma_f^2}{4}}$$