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GEM-based detectors for direct detection of low-mass WIMP, solar axions and narrow resonances (quarks).

B.M.Ovchinnikov, V.V.Parusov*

Institute of Nuclear Research of RAS, Moscow, Russia.

*Corresponding author: parusov@inr.ru

Abstract.

Gas electron multipliers (GEMs) with wire (WGEMs) or metal electrodes (MGEMs), which don't use any plastic insulators between electrodes are created. The chambers containing MGEMs (WGEMs) with pin-anodes are proposed as detectors for searching of spin-dependent interactions between Dark Matter (DM) particles and gases with nonzero-spin nuclei (H_2, D_2, ^3He, ^{21}Ne, CF_4, CH_4, etc.). In this paper, we present a review of such chambers.

For investigation of the gas mixtures Ne+10%H_2, H_2 (D_2) +3ppmTMAE, the chamber containing WGEM with pin-anode detection system was constructed. In this paper we present the results of an experimental study of these gaseous mixtures exited by an α - source. Mixture of Ar + 40 ppm C_2H_4 and mixture 50% Xe + 50%CF_4 have been investigated. The spatial distributions of photoelectron clouds produced by primary scintillations on α- and β-particle tracks, as well as the distributions of photoelectron clouds due to photons from avalanches at the pin-anode, have been measured for the first time.

In our experiments as another filling of the chambers for search of low-mas WIMP (<10 GeV/c^2), solar neutrino and solar axions with spin-dependent interaction we propose to use the mixtures: D_2 + 3ppmTMAE, ^3He + 3%CH_4, ^{21}Ne + 10%H_2, at pressure 10-17 bar. And in our experiment with liquid gases is used the mixtures with ^{19}F (LAr + CF_4, LXe + CF_4) and mixture LCH_4 + 40ppm TMAE.

The time projection chamber (TPC) with the mixture D_2 + 3ppmTMAE filling allow to search of spin-dependent interactions of solar axions and deuterium. As well as we present the detecting systems for search of narrow pp-resonances (quarks) in accelerators experiments.

Keywords: MGEM, pin-anodes, Low-Mass WIMP, Axions, Quarks, TPC, SD-interactions, H_2, CF_4, CH_4, TMAE.

1. Introduction

More than forty years ago G. Charpak and F. Sauli have introduced their Multi-Step Chambers to overcome limitations of gain in Parallel-Plate and Multi-Wire Proportional Chambers (MWPC) [1, 2]. Currently there are different types of detectors for fast detection and localization of charged particles exist. One of them is a Gas Electron Multiplier (GEM) [2-4]. More coarse macro-patterned detectors are thick-GEMs (THGEM) [5-7] or patterned resistive thick GEM devices (RETGEM) [8].

However, the most essential disadvantage of GEMs consists in their low reliability and stability. The matter is that in a process of dispersion of the GEM's cathode electrodes by positive ions of proportional avalanches in GEM with metal or high-resistive electrodes (RETGEM), a sedimentation of the sprayed carrying-out material on the walls of holes with subsequent leaks and breakdowns between

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electrodes takes place. Micro-pattern gaseous detectors (MPGD), due to their tiny electrode structure and small avalanche gaps, are very fragile and can be easily damaged by sparks appearing at high operational gains (typically at gains of 10^4 or slightly more) [7].

Therefore, we were concentrated on development of more robust designs of GEM detectors with wire (WGEM) [9-12] or metal electrodes (MGEM) [13, 14]. In our next works [15-18, 21, 25, 37] it was suggested that the search for spin-dependent WIMP-nucleon interactions with help of detecting system GEM + pin-anodes can be performed.

2. Gas electron multipliers with metal electrodes.

The idea of GEM without plastic insulators was first mentioned in our works [9-13]. In the paper [14] we have described a novel concept of MGEMs with etching holes. In Fig.1 we present the designs of metal GEMs.

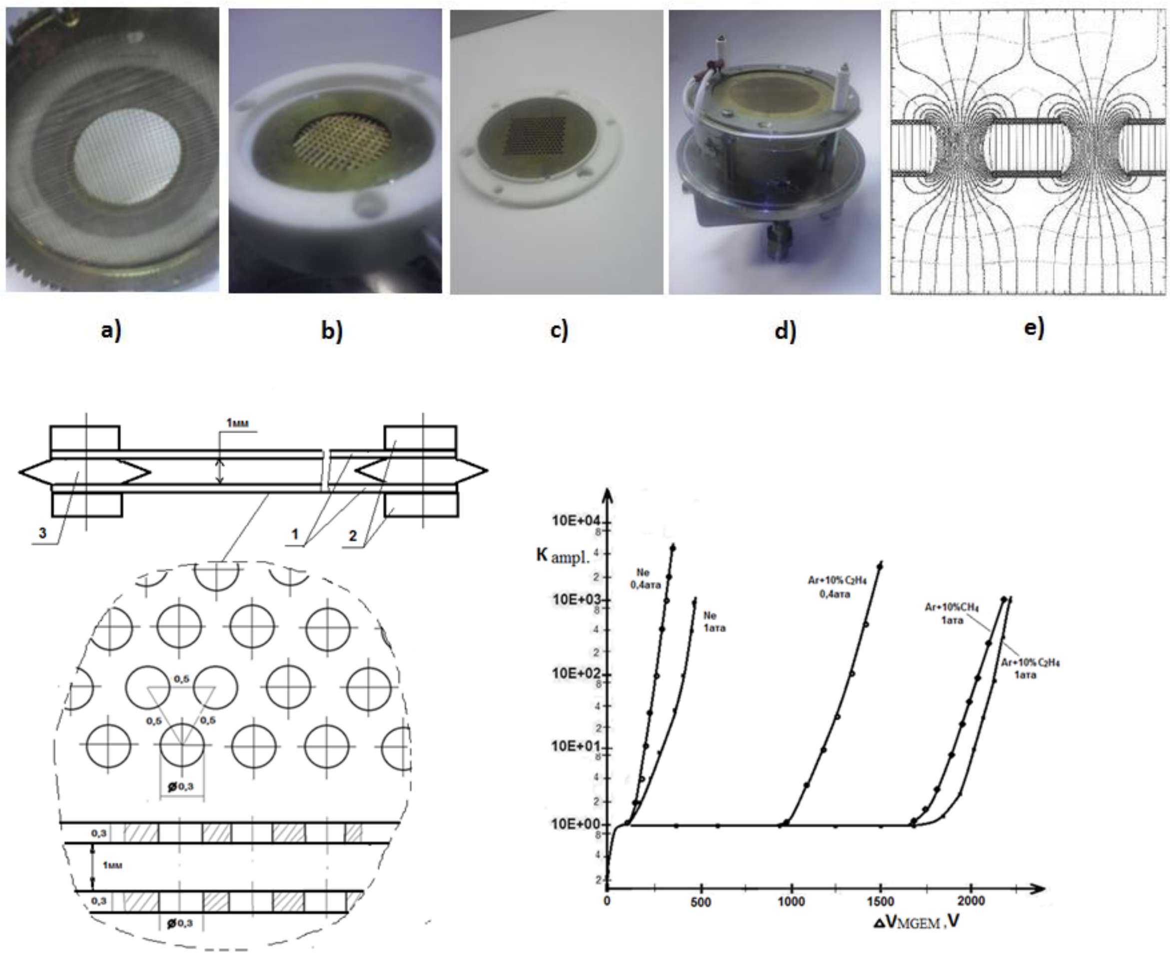


Fig.1. Designs of metal GEMs [9-13]: a,b) GEMs with wire electrodes; c) GEM with metal electrodes; d) GEM with the etching of holes and result of test [14]; e) electric field structure in the GEM.

3. Chamber with system WGEM + pin-anodes.

In Fig. 2 we present the wire gas electron multiplier (WGEM) in combination with pin-anode and results of test (Fig.3). In this section we discuss the operation principle of MWPC, GEM and system GEM + pin-anode (Fig.4).

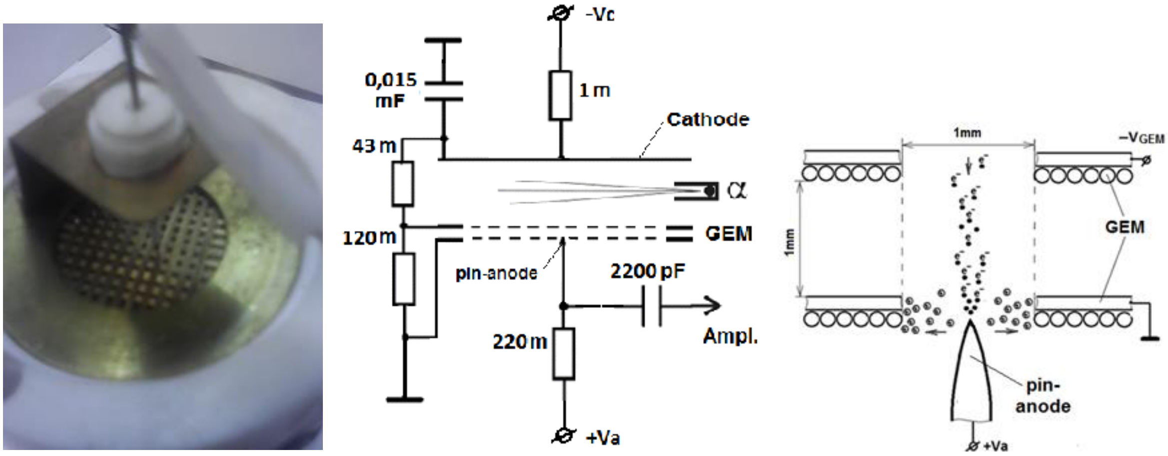


Fig.2. Detection system for testing of WGEM + pin-anode with diagram of the travel of positive ions from avalanches developed at the pin and electrons being collected at the pin [16, 17, 21, 25].

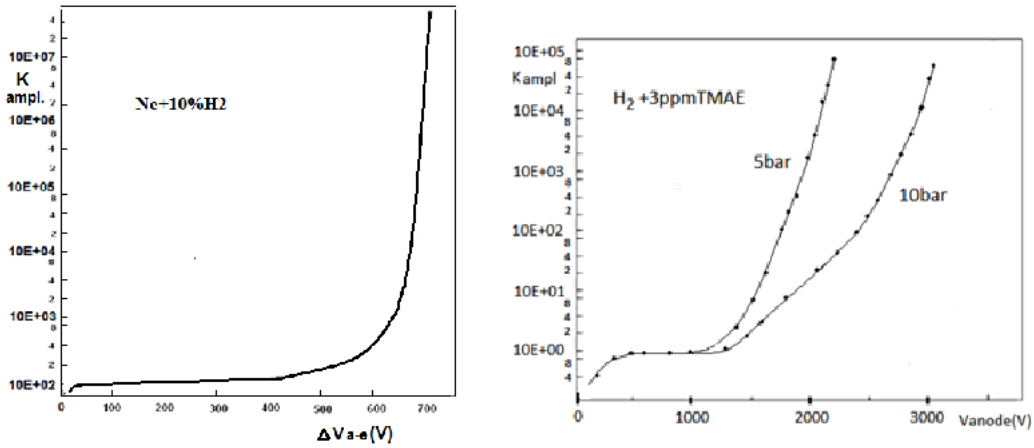


Fig.3. Measured amplification factor of a system WGEM + pin-anode with mixtures: Ne + 10%H_2 (1 bar) [21] and H_2 + 3ppm TMAE (5, 10 bar) [25].

The operation principle of Multi-Wire Proportional Chambers (a), GEM (b) and system GEM + pin-anode (c) is illustrated in Fig.4. The factors which have allowed us to obtain high electron multiplication factors in the GEM + pin-anode system are as follows:

(1) High electric field strength in the system GEM + pin-anode makes it possible to obtain a big length of electron avalanche and high value of the electron multiplication factor (10^6-10^7);

(2) Positive ions from the avalanche at the pin are transferred by the electric field, mainly, to the walls of the hole in which the pin is located and, in smaller quantities, towards the ionization electrons being collected at the pin, which rules out the possibility of streamers being developed at the interface

(3) For GEM (see technology b) extraction efficiency decrease at low transfer fields values due to a worst electron extraction capability from the lower side of the GEM [32];

(4) Absence of a plastic insulation excludes the emergence of leakage current and spark breakdown between electrodes. Accidental spark events in such system don't lead to their failure as positive ions quickly move away from breakdown by a strong electric gap field.

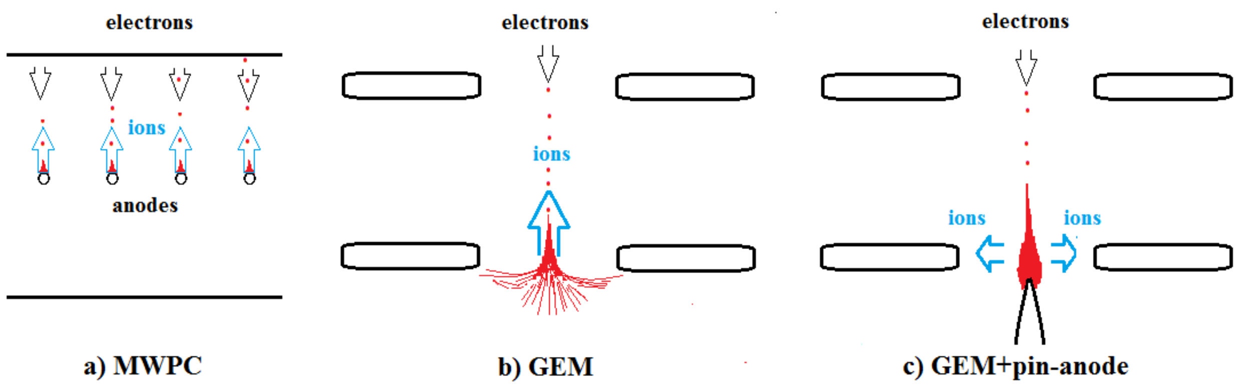


Fig.4. Operation principle of Multi-Wire Proportional Chambers (a), GEM (b) and GEM+pin-anode (c). Electron avalanches are shown for three technologies (a, b, c); red paths are electron trajectories, also the drift of ions is indicated (blue paths).

4. A short review of chambers with system GEM + pin-anodes for direct detection of WIMP.

In work [15] the idea of focusing screen with holes + system pin-anodes already was shown. The wire gas electron multipliers in combination with pin-anodes are proposed for detection of events:

(1) In the gas phase of a double-phase argon (xenon) chamber [16, 17]. Hydrogen with a concentration of 10 % is added to argon to eliminate feedbacks via photons emitted by excited argon molecules in avalanche development processes during detection of events in the gaseous argon.

(2) In chamber gas mixture Ne + 10%H_2 for direct detection of WIMP with mass ≤ 0.5 GeV/c^2 [21]. Based on the work [22], where in a spherical proportional detector the energy threshold is about 100eV, while the amplification factor of the detecting system is about 10^4, we estimate the threshold of our experiment to be about ~100 eV·10^4/5·10^7 < 1eV. As another filling of the chamber is used the mixture ^{21}Ne+10%H_2 for search of spin-dependent interaction [23, 35, 36].

(3) In chamber with gas mixture H_2 + 3ppm TMAE for direct detection of WIMP with mass ⩽ 10 GeV/c^2 and solar axions [25]. As another filling of the chamber is used the mixture deuterium (D_2) + 3ppm TMAE. Because the energy of axion is equal to ~1 keV [26], is transfers the energy to recoil deuterium. The H_2(D_2)-filling provides the electron background suppression, because the recoil protons in H_2-medium have the short track [30], as distinguished from background electrons.

(4) In double-phase chambers with LXe + CF_4 and LCH_4 + TMAE filling (section 7). In our experiments [15-18] with liquid gases mixtures is used the mixtures for search of spin-dependent WIMP-nucleon interacting.
(5) In scintillation and ionization fast chambers with mixture Xe + CF_4 for accelerators experiments (section 9).

In the time projection chamber (TPC) with the mixture D_2 + 3ppmTMAE filling we use of two-step system GEM + MWPC (section 8).

5. A method for background reduction in experiments for direct detection of WIMPs.

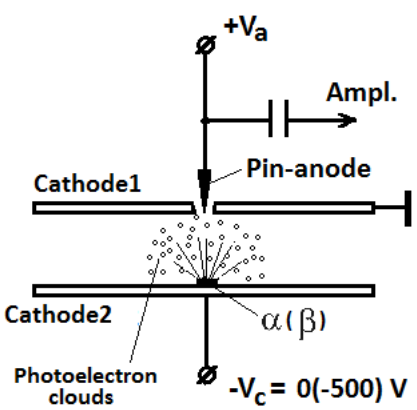
To suppress the β, γ and n0 backgrounds, we proposed [18] a addition in liquid argon of photosensitive dopants and a comparison of scintillation (S1) and ionization signals (S2) for every event is suggested. The addition in liquid Ar of photosensitive TMA, TMG or C_2H_4 [19] and suppression of triplet component of scintillation signals ensures the detection of scintillation signals with high efficiency and provides a complete suppression of the electron background.

In work [20] we investigated of scintillation (S1) and ionization signals (S2) on a mixture of Ar + 40ppm C_2H_4 at a pressure of 5 bar.

The measurements were taken inside the chamber similar a chamber with pin-anode (see Fig. 5 left). The mixture was irradiated with α (239Pu) and β (63Ni) particles. The chamber was used with potentials of pin-anode Va = 1300 V, Kamp ~10^4 (β) and Va = 520V, Kamp = 30 (α).

Peak S1 (Fig. 5 right) is associated with the cloud of photoelectrons from the chamber volume due to scintillation photons with λ = 128 nm, which are emitted upon excitation of argon atoms with α(β) particles: hν + C_2H_4 → C_2H_4* + e–. Peak S2 is due to ionization electrons from α(β) particles. Peak S2 fluctuates in the amplitude for different events, since the β-particle spectrum lies in the range of E^{min} - E^{max} (17 - 67 KeV). Peak S3 can be attributed to the cloud of photoelectrons from the chamber volume produced by photons from avalanches at the pin-anode.

The results obtained in our study suggest that it is possible to develop large volume detectors capable of detecting scintillations with a 100% geometrical efficiency, by contrast to the well known detection techniques based on photomultipliers having efficiency of only a few percent [27].



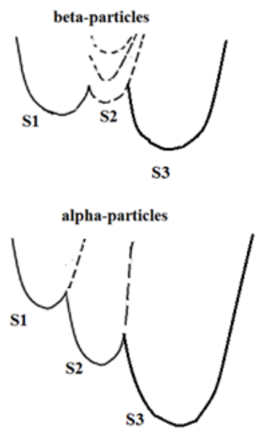


Fig. 5. The chamber filled with the mixture of Ar + 40ppm C_2H_4 at a pressure of 5 bar. The mixture was irradiated with α (239Pu) and β (63Ni) particles. The chamber was used in potentials of pin-anode Va = 1300 V, Kamp ~10^4(β-particles) and Va = 520V, Kamp = 30 (α-particles). –Vc = 0V.

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6. Chambers with $Xe+CF_4$ (1:1) gas mixture.

6.1 The ratio S1/S2 for β and α-particles. Nanosecond timing scintillation chamber with mixture $Xe+CF_4$ filling.

Recently we have investigated a scintillation signal (S1) and a ratio scintillation to ionization signal (S1/S2) for β and α-particles on prototype of fast chamber (Fig.6) with mixture $Xe+CF_4$ (1:1) filling at a pressure of 10 bar. This chamber was irradiated with α (239Pu) and β (63Ni) particles. The scintillations signals (S1) were measured separately of photomultiplier (PMT-85) with fast shifter (OB-205). The ionizations signals (S2) were measured on anode of chamber. The addition in Xe of CF_4 and suppression of long triplet component of signals (27 ns) ensures the detection of scintillation signals with high speed (1ns).

A shifter OB-205 has a maximum sensitivity range of 185 nm and converts with high efficiency of UV-light in visible light (420 nm). And also he have fast luminescence lifetime (~ 1ns) and high photoluminescence quantum yield (99%). The measurements S1 signal used a fast amplifier and an oscilloscope Le Croy-232. Electronegative impurities O_2, C_2F_4 and C_3F_8 were removed from the gases an a purification system to a level of 10^{-8} O_2 equivalent (0,01 ppm). The entire system (chamber+ gas system) was checked by the "ISTOK" gas analyzer [32] for the presence of known electronegative impurities, which were not detected as a result.

For alpha particles, the ratio A=S1/S2 was 0.63 and B=S1/S2 for beta particles 25.The ratio beta to alpha was B/A=25/0,63=40.

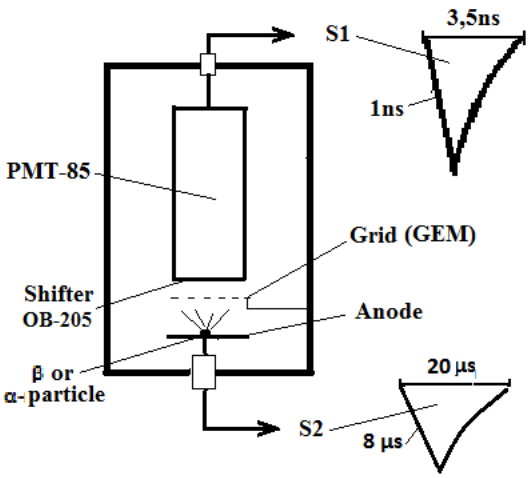

Table 2.

U(V)	1000	1100	1200	1300	1400	T(ns)
Xe+CF4	200	500	900	1300	1800	1ns
CF4	56	120	200	400	800	2ns
Ar+CF4	15	25	70	120	290	3ns
Ne+CF4	20	70	180	275	620	6ns
Xe	600	1000	2200	4500	7000	27ns

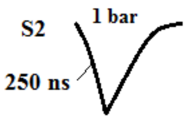

Fig.6. Left: prototype of fast chamber with mixture $Xe+CF_4$ (1:1) filling. Right: amplitude of scintillations signals (mV), which measured of photomultiplier for α-particles on different gases at pressure 10 bar. U (V) - voltage of PMT-85 (1000V – 1400V). The potential applied to anode is Va = +400V, the gap of anode – grid is 8mm.

For mixture $Ar+CF_4$ (1:1) at a pressure 10 bar, the speed is 3 ns. For mixture $Ne+CF_4$ (1:1) at a pressure 10 bar, the speed is 6 ns(see Table 2). To get a electron multiplication factor (10^3) and large electroluminescence signals, the chamber instead of a grid is set to WGEM [9]. And to get a large electron multiplication factor (10^4- 10^5) and large ionization anode signals, the chamber instead of a anode is set to system GEM+pin-anodes [16, 17, 21, 25].

6.2 The chamber with hole + pin-anode with Xe + CF_4 filling. The measurements photoelectron signals for α and β- particles.

The measurements were taken in the pin-anode chamber (Fig.7 left) [20]. The chamber was used in two operating modes at cathode potentials Vc = 0 and –500 V. In both cases, cathode C2 was grounded. The results obtained thereby are presented in Fig.7 right. The wide peaks observed when α and β events were detected at Vc = 0 can be attributed to clouds of photoelectrons due to primary scintillations on particle tracks and to photoelectrons produced by photons from avalanches at the pin anode, as well as to ionization electrons from tracks of α and β particles (Fig.8). Since the concentration of photosensitive dopant CF_4 was high, all three peaks merged into a single wide peak, by contrast to the spectrum from the mixture of Ar + 40 ppm C_2H_4 in which these three peaks are recorded separately (see section 5.3).

Apparently, CF_4 photoionization takes place in the mixture of Xe + CF_4: hν (Xe_2*)→ CF_4 → e^+ + F + CF_3^-. When a negative potential of –500 V is applied to chamber cathode C1, all photoelectrons gather on chamber cathode C2, and only ionization electrons from α and β particles are detected at the pin anode. Figure 7 (right) present the multiplication factor of ionization electron at the pin-anode in the chamber from α and β particles tracks as a function of the anode potential in the mixture Xe+CF_4 (1:1) at pressures of 1 and 10 bar. In these measurements, voltage Vc = –500 V was applied to cathode C1, and cathode C2 was grounded. For 1 bar, the maximum electron multiplication factor equal to 3×10^4 was obtained for β particles and Kmax = was obtained for α-particles.

The use of CF_4 dopant in noble gas with the aim of increasing the electron drift velocity was described in numerous papers [20]. Our results have demonstrated that CF_4 is a photosensitive dopant for Xe. As a result, it is possible to detect scintillations in a chamber filled with a mixture of Xe+CF_4 with a 100% geometrical efficiency, with is required in the experiment of the search for DM in the Universe for development of detectors with a high mass and complete suppression of background due to Kr^{85} and external **γ**-rays. As well fluorine-19 has a large spin-dependent WIMP-proton cross-section [35, 36, 37].

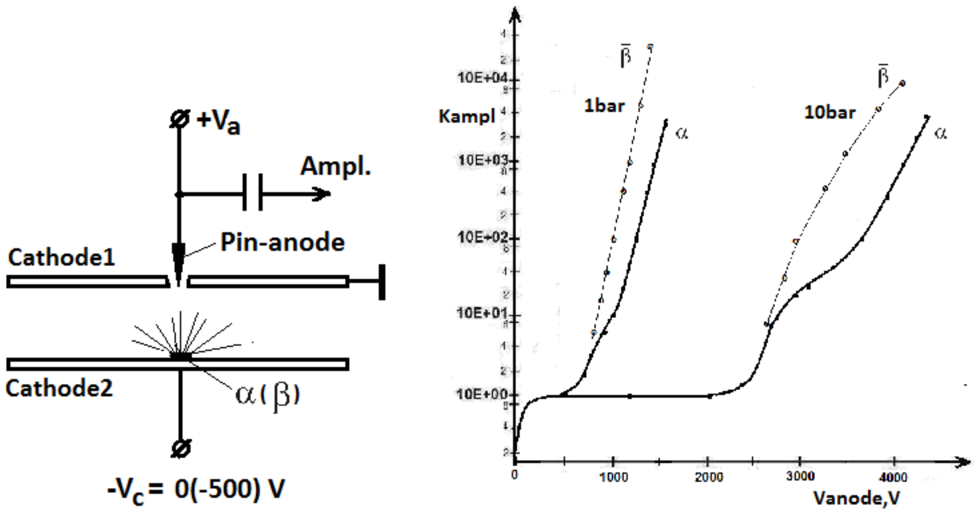

Fig.7 Left: the chamber with Xe+CF_4 (1:1) filling [20]. Right: the multiplication factor of ionization electron at the pin-anode in the chamber from α (239Pu) and β (63Ni) particles tracks as a function of the anode potential (0 - 4500V).

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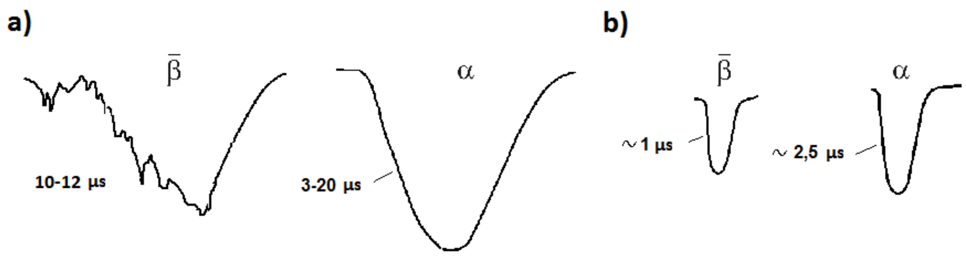

Fig.8.The signals of chamber with the mixture of Xe + CF_4 (1:1) filling at a pressure of 10 bar after irradiation with α and β particles at Va = 3000-4000 V and (a) Vc = 0 V, (b) Vc = -500 V.

7. Search for spin-dependent WIMP-nucleon interactions.

7.1 Double-phase xenon chamber with a system GEM +pin-anodes.

In particle physics, the lightest supersymmetric particle (LSP) is the generic name given to the lightest of the additional hypothetical particles found in supersymmetric models. In models with R-parity conservation, the LSP is stable; in other words, it cannot decay into any Standard Model particle, since all SM particles have the opposite R-parity. There is extensive observational evidence for an additional component of the matter density in the universe, which goes under the name dark matter. The LSP of supersymmetric models is a dark matter candidate and is a weakly interacting massive particle (WIMP).

From the elementary particle physics in the framework of the standard Bing Bang nucleosynthesis model one infers that DM consists manly of WIMPs: massive neutrinos, axions and particles predicted by SUSY.

The most probable candidates for the WIMP are the neutralino, predicted by supersymmetric theories (SUSY) [35].

The direct method for WIMP search consists in detection for their elastic scattering on detector nuclei. The WIMP interaction probability in detector can be represented in a form:

$$R = a_p W_p^2 + a_n W_n^2 + a_0 V^2,$$

where the first two terms determine the spin-dependent (sd) scattering and the last one is the spin-independent (si) scattering [35]. The ratio of the number of spin-dependent WIMP scattering Rsd to the number of spin-independent scattering Rsi can be represent in a form:

$$Rsd / Rsi = \eta_A \cdot \eta_{SUSY},$$

where η_A is determined by nuclear structure, and η_{SUSY} – by neutralino-quark interaction in SYSY model.

The dependence of η_A from atomic number A for nuclei (^1H, D_2, ^3He, ^{73}Ge, ^{127}I and others) with nonzero spins is shown in Fig. 9 (Left) [35]. The dependence $R_{sd}(A)/R_{sd}(Ge^{73})$ on neutralino mass are shown in Fig. 9 (Right) for nuclei ^{19}F and NaI [36]. One can see that more strong restrictions on spin-dependent part of WIMP interactions can be obtained in experiment with ^{19}F (Ar+CF_4, Xe+CF_4) as compared with other nuclei [20, 37]. The measurements are especially attractive in region of WIMP mass 8 GeV ≤ m_x ≤ 14 GeV, where R_{sd} > R_{si}.

At present time a great experiments [24, 26-28] are carried out for WIMP search with detector containing nuclei LAr, LXe, NaJ, Ge, the spin-independent (coherent) scattering for which is large [28,29]. One can see, that sensitivity of these experiments for spin-dependent scattering is 10-100 times less of expected effect as distinguished from coherent scattering experiments (see. Fig.9 right).The proposed in this work experiments increases the sensitivity of spin-dependent measurements to the point of the expected effect.

In this context, in our experiments [21, 25, 39] as another filling of the chambers for search of low-mas WIMP (<10 GeV/c^2) and solar axions with spin-dependent interaction with deuterium (D_2), ^3He, ^{19}F and ^{20}Ne we propose to use the mixtures: ^{20}Ne + 10%H_2, D_2 + 3ppmTMAE, ^3He + 3%CH_4 at pressure 10-17 bar. And in our experiments [16-18] with liquid gases mixtures is used the mixtures with ^{19}F: LAr + CF_4 and LXe + CF_4. The relative scintillation light outputs for investigated gases evaluated by an distribution area is shown in Fig 10.

In this section, we describe a double-phase xenon chamber with a system GEM +pin-anodes and system of photomultipliers. Fig. 11 shows a design of the chamber.

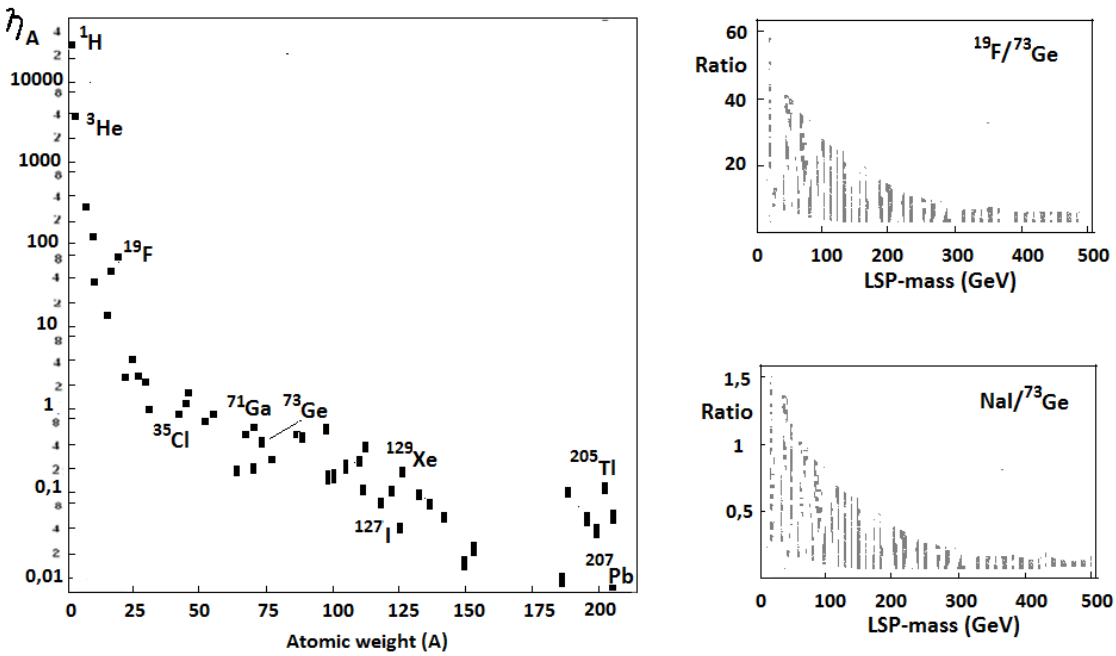

Fig. 9. Left: The dependence of nuclear factor η_A from atomic number A for the nuclei with nonzero spins [35]. The high of symbols presents the change of η_A in a WIMP mass interval 10 GeV ≤ m_x ≤ 500 GeV. Right: The dependence of Rsd (A)/ Rsd (^{73}Ge) from WIMP mass for ^{19}F and NaI [36].

Gas	Xe gas	LXe	Xe+CF_4	LXe+CF_4	LCF_4/CF_4	LAr+CF_4/Ar+CF_4
Scintil. output	1	1	0,3	0,16	0,5	0,5

Fig. 10. The ratio of relative scintillation light outputs for different gases mixtures [44].

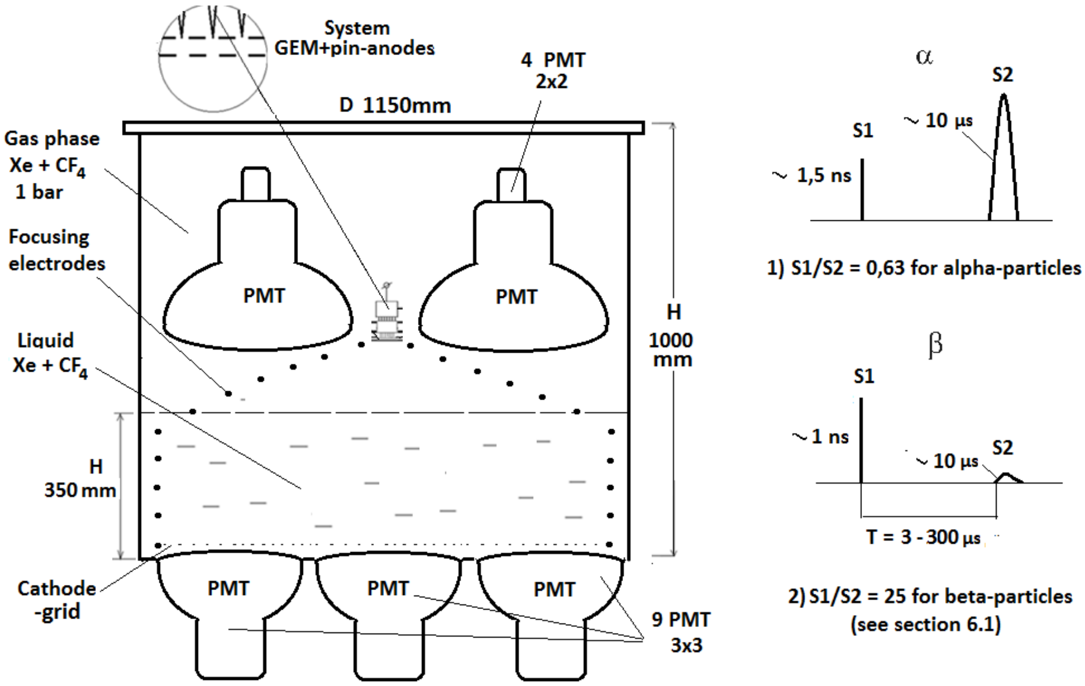

Fig. 11. Double-phase xenon chamber with a system GEM +pin-anodes and photomultipliers.

To suppress the β background, we proposed a comparison of scintillation singlet signal (S1) and ionization signal (S2) for every event is suggested. The addition in Xe of CF_4 and suppression of long triplet component of signals (27 ns). For alpha particles, the ratio A=S1/S2 was 0.63 and scintillation (S1) and B=S1/S2 for beta particles 25.The ratio beta to alpha was B/A=25/0,63=40 for 50%Xe + 50%CF_4 gases mixture (see section 6.1 and 6.2). The delay time between S1 and S2 is T = 3-300 µs, because: the drift time of electrons is T = 0-300 µs in LXe + CF_4, and the drift time electrons is T = 1-3 µs in gases phase 50%Xe + 50%CF_4 [44].

7.2 The double-phase chamber with LCH_4 + TMAE mixture for search of spin-dependent WIMP-nucleon interactions.

In work [46] it is shown that the absolute lower bound for the rate of direct DM detection is due to the spin-dependent WIMP-nucleon interaction, and a new-generation experiment aimed at detecting DM with sensitivity higher than 10^{-5} event/(kg · day) should have a nonzero-spin target to avoid missing of the DM signal. In work is claimed that for targets with spin- nonzero nuclei it might be the spin-dependent interaction that determines the lower bound for the direct detection rate when the cross section of the scalar interaction, which is usually assumed to be the dominant part, drops below 10^{12-13} pb particular, from this work one can see that all fluorine-containing targets (LiF, CF_4, C_2F_6, and CaF_2, etc.) have almost the same sensitivity to both the SD and SI WIMP-nucleus interactions.

Among all materials considered a detector with a ^{73}Ge, ^{129}Xe, or NaI target has better prospects to confirm or to reject the DAMA result [29] due to the largest values of the lower bounds for the total rate R(10, 50) > 0.06 -0.08 events/(kg day). If, for example, one ignores the SI WIMP interaction, then all materials have almost the same prospects to detect DM particles with the only exception of CH_4 (see Fig. 12. The results obtained are based on previous evaluations of the neutralino-proton (neutron) spin and scalar cross sections for the neutralino masses $m_\chi < 200$ GeV/c^2.

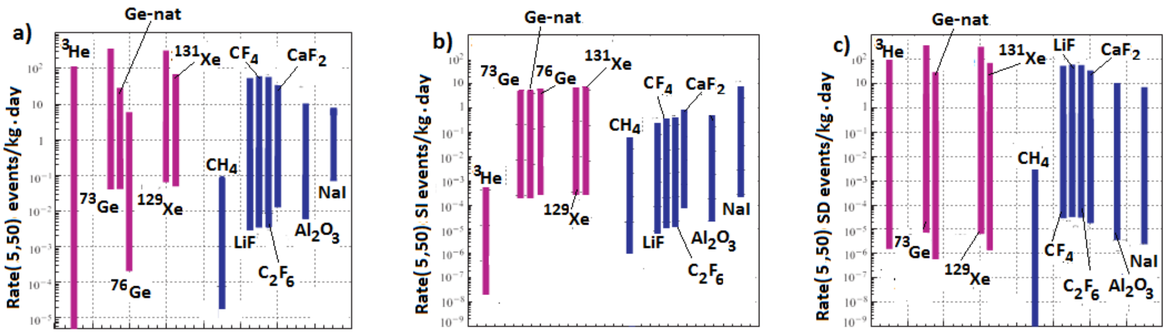

Fig. 12: a) variations of expected event rates, *R* (5, 50), for a number of targets followed from the DAMA-allowed cross sections σ_{SD} and σ_{SI}. Targets with nonzero-spin nuclei from the odd-neutron (odd-proton) group model are given in the left (right) part of the figure; b) variations of expected spin-independent contributions to the event rate, R (5, 50)SI, in a number of targets followed from the DAMA-allowed cross sections σSD and σSI; c) the same as in b, but for the spin-dependent contributions *R* (5, 50)SD [46].

In this context, in our experiment [15] with liquid CH_4 as another filling of the chamber for search of low-mas WIMP (<10 GeV/c^2) we propose to use the mixture LCH_4 + 40ppmTMAE (see Fig. 13).

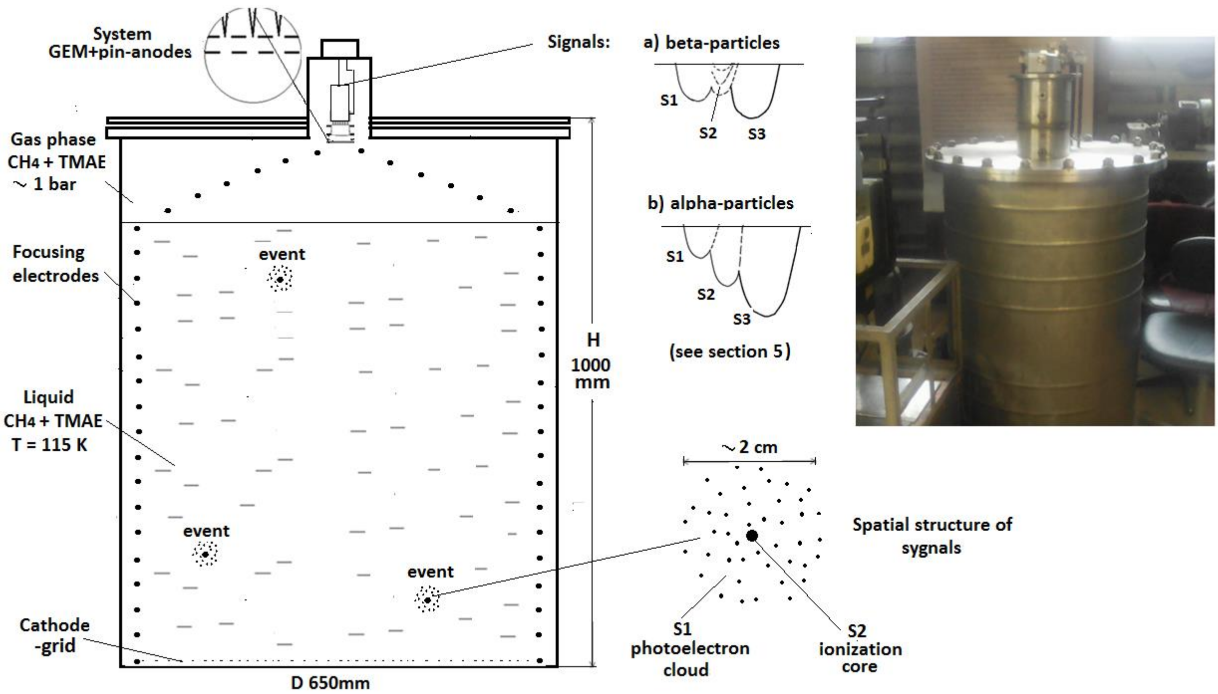

Fig. 13. A liquid-methane ionization chamber with a system GEM + pin-anodes for search of spin-dependent WIMP-nucleon interactions.

The body of the chamber is made of titanium. The cathode-grid of the chamber is immersed in liquid methane. The layer of liquid methane above the cathode is equal to 800 mm. The temperature of liquid methane is equal to 115 K and the pressure of gaseous methane over the liquid methane is equal to 1,3 bar for this temperature. The system GEM + pin-anodes is placed in gaseous methane. The addition in liquid CH_4 of photosensitive TMAE [19] and suppression of triplet component of scintillation signals ensures the detection of scintillation signals with high efficiency and provides a complete suppression of the electron background (see section 5). As well as, in our experiments we use a system GEM + pin-anodes to more efficiently remove the background from the chamber electrodes and walls using positional veto of background signals.

8. Time-projection chamber with high dE/dz and energy resolutions.

It is known that multi-wire proportional chambers (MWPC) used in time-projection chambers (TPC) fail to provide good energy resolution [34]. This is mainly due to the fact that multiplication of ionization electrons occurs in chamber regions with different electric field intensities resulting in variation of the multiplication factor. Additionally, the MWPC features a low dEl/dz resolution in the drift direction of the ionization electrons due to slow motion of positive ion clouds from anode wires.

In our paper [38], we describe a TPC with both high energy and dE/dz resolutions. Fig. 14 shows a design of the chamber. The chamber contains the cathode 1 with a 4-mm-diameter collimating opening, behind which a 239Pu source with a 10^5 flow rate is installed at a distance of 10 mm. The rings 3 provide a uniform drift field. The MWPC 5 used for electron multiplication contains the cathode MWPC wound with a 2-mm pitch of a beryllium bronze 100-µm-diameter wire. The anode is winded of a 20 µm diameter W + Au wire with a 2 mm pitch. The MWPC gap is 2 mm. In projection, the anode wires are exactly in the middle between the cathode wires. The chamber contains cathode 6 and anode 7 of the measurement gap. The maximum electron multiplication factor for α-particles is $\sim 10^3$. To get the total electron multiplication factor (10^5), the chamber is set to MGEM 4 with the etching of holes [14].

Due to the photon mechanism, when the avalanche evolves in the anode MWPC wire, an electron charge proportional to the initial ionization charge appears in the transfer gap between the electrodes 5 and 6. This charge drifts towards the measurement gap between the electrodes 6 and 7. Electrodes 6 and 7 are winded of a 100 µm diameter wire with a 1 mm pitch. The width of the gap 5-6 is 4 mm. The electric field intensity in this gap is insufficient for evolving avalanches and the gap records the electrons without multiplication, i.e., in the induction operation mode of the ionization chamber.

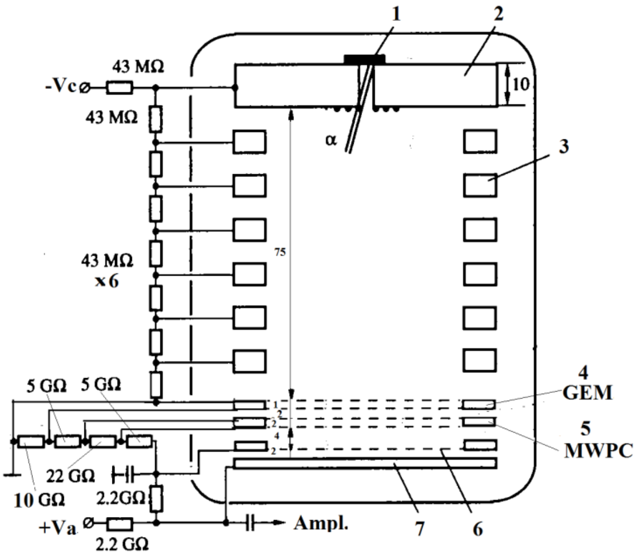

Fig. 14. Time projection chamber with MWPC and GEM.

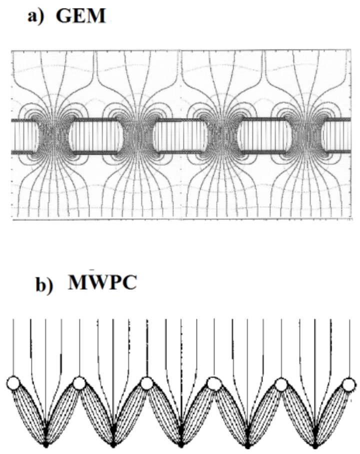

Fig. 15. Electric field structure in the GEM(a) and MWPC(b).

Fig. 15 shows the electric field structure in the MWPC and GEM gaps. Since the electric field intensity in the MWPC gap is much higher than in the drift gap and due to the symmetric location of the cathode relative to the anode wires, the electric field lines, when passing from the drift gap to the MWPC gap, concentrate into a narrow beam, which is orthogonal on the average to the anode plane and sufficiently uniform. As a result, the electron multiplication occurs in a more homogeneous electric field than in usual MWPCs, in which the electric field lines meet the anode wires at different angles in different MWPC regions and have different average densities.

In the process of its evolution, the avalanche discharge involves about 180° of the anode wire in the azimuth. In our case, conditions for the evolving discharge are the same for all ionization electrons within the drift gap, because the field distributions on all wires are identical, and the fields are more homogeneous.

Since, for usually utilized mixtures, the electron drift speed in the measurement and drift gaps is $\sim n\cdot 10^6$ and $\sim n\cdot 10^5$ cm/s, respectively, and the measurement gap is small, the calculated dE/dz resolution referred to the TPC drift gap appears to be sufficiently high: the chamber resolves the track regions or separate tracks spaced by ~ 0.2 mm.

In order to determine the energy resolution, the chamber was filled with an Ar + 0.5% C_2H_2 + 10%CH_4 mixture at a total pressure of 3,5 bar. When recording a-particles from a 239Pu source, the energy resolution was 8.1% (half-intensity half-width).

Three anode grids with 0,2mm pitch and 0,2mm gaps may be placed in the ionization chamber for detection of x, y and 45° x-coordinates. The electrons are moving after multiplication through three anode grids inducting on them the signals. The errors for x, y-coordinates will be equal to 0,2mm and error for z-coordinate will be 0,2mm (not including diffusion errors).

The method allows you to measure the direction of movement of particles. In our work [45] we have study of TPC with the Penning mixture He+3%CH_4 filling at a pressure 17 bar for direct detection of solar neutrinos. As another filling is use the mixture ^{3}He + 3%CH_4 for search of SD-interactions. As well time projection chamber with the mixture D_2 + 3ppmTMAE filling at a pressure 10 bar allow to search of spin-dependent interactions of solar axions and deuterium [21, 23, 25].

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Finally, we compare this chamber with existing multistage avalanche chambers, which also provide high energy and dE/dz resolutions and with the MICROMEGAS chambers [7]. The MWPC used in our chamber in place of the avalanche chamber allows it to operate under an increased pressure of the filling gas (up to 10 - 20 bar), whereas other chambers are intended for operation mostly at pressures lower than the atmospheric pressure. The high resolution (dE/dx, dE/y, dE/z) of the TPC allows you to measure the direction of the flow of solar neutrinos and axions. Directionality allows to use only electrons recoiling away from the sun, effectively eliminating most background events.

9. Detecting chambers for search of narrow pp-resonances (quarks) in the energy region 150 – 300 MeV.

The existence of narrow peculiarities in a two-proton system was observed by JINR scientists in nucleon reactions with π-mesons production [40]. Over time the statistics has substantially been enlarged by this group and narrow pp-peaks at the level 3-5 standard errors have proved to be present in various reactions within a wide energy range [41]. Analyzing the effective mass distributions in the system of particles np, $\pi^-\pi^-$, $\pi^+\pi^-$ from inelastic reactions with π-mesons production this group also found the narrow peculiarities, excitation energies of which were just the same as those for pp-system. This group has observed narrow π^- p-resonances which excitation energies coincide well with those of pp-systems. In work [42] Y.A.Troyan group has observed the existence of narrow pp-resonances in elastic pp-scattering differential cross-section within 116-199 MeV.

The results are compared with the data of various experiments of elastic scattering at the energy region 0,2 - 10 GeV/c^2 (Fig. 16).

The experiment with MPWC which detectors the recoil protons with mixture Xe + izo-C_4H_{10} (1:1) under a pressure 15 torr we proposed in year 1993 to search for narrow pp-resonances (quarks) in the energy region 150 – 300 MeV at the MMF accelerator [43]. In the experiment the external proton beam of the accelerator is used with the energy changed from 160 MeV to 300 MeV, intensity 2×10^{11} protons per second and energy spread 0,5 MeV (FWHM). The formed proton beam goes through the tube filled with hydrogen under a pressure of 5 bar (see Fig.13).

Recoil protons from the elastic pp-scattering are detected at angles 70° laboratory system for coincidence with gas proportional and scintillation detectors. Detectors adsorb the recoil protons with the energies up to 35 MeV. This experiment requires high speed of ionization electrons collection time and respectively, the detector resolution time is about 10^{-8} sec.

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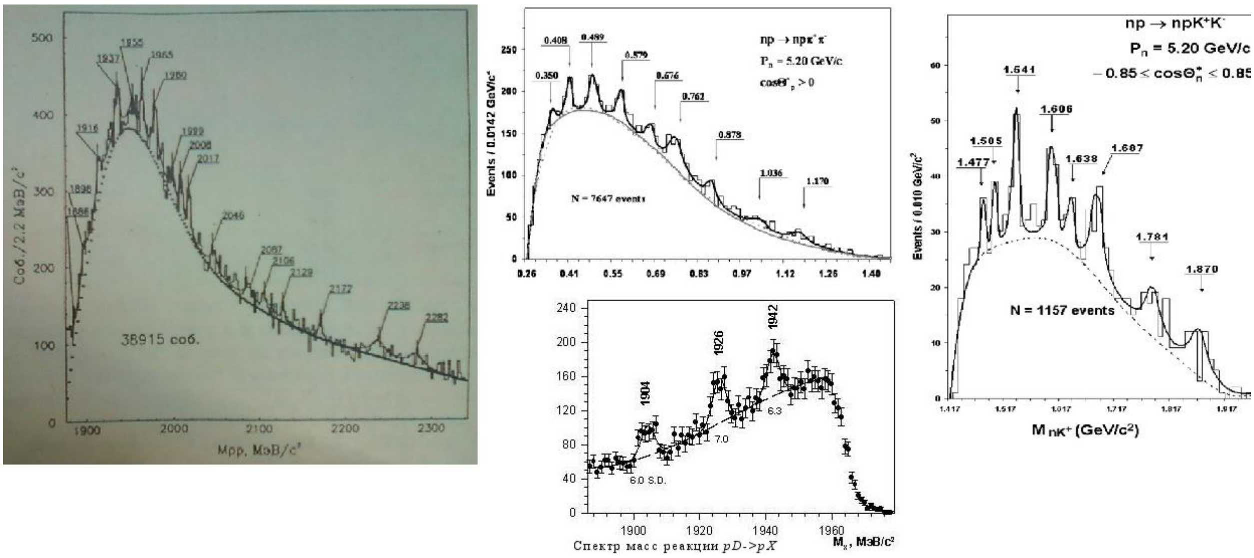

Fig. 16.The results of experiments JINR (Dubna) and MMF (INR, Moscow).

We propose detect the recoil protons with the energies up to 35 MeV on scintillation chamber (see section 6.1) with Xe+CF_4 (1:1) filling under a pressure 50 torr and ionization chamber with system GEM+pin-anodes under a pressure 15 torr(see Fig.17). Signals are picked up from the scintillation and ionization chamber by fast amplifier and then are transferred to coincidence and anticoincidence circuits with a resolving time 10^{-8} sec. When the signal from the scintillation chamber coincides with that from the ionization chamber the signal amplitude of the latter is registered by the amplitude analyzer. Its readings determine the total number of the events at a certain energy and detection angle (N_{events} + N_{backgr}). The ratio N_{events}/N_{backgr} is determined an elastic peak against the background.

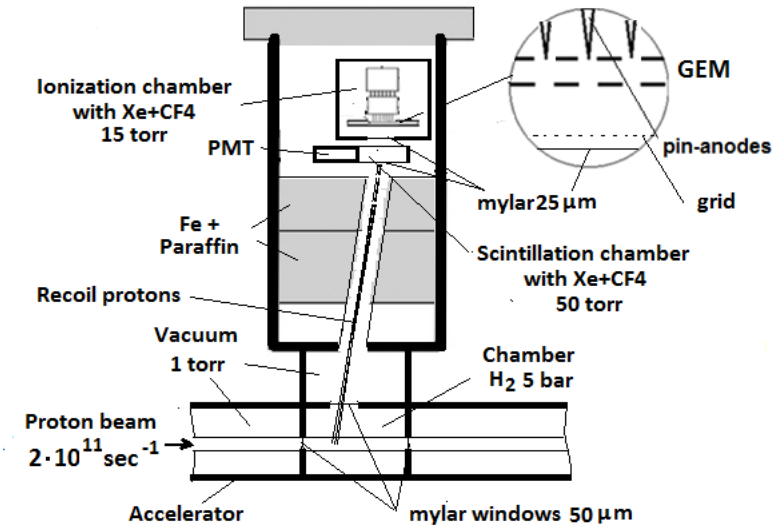

Fig.17. Experimental setup with scintillation and ionization chambers.

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We would like to mention that chambers with systems MGEM+pin-anodes, can have many applications for detecting events in accelerator experiments. As well as, the authors are currently studying the possibility of using spin-dependent reactions of light gases with nonzero-spin nuclei in high energy physic.

10. Discussion

In our works we have study the Penning mixtures: He + 3% CH_4, Ne + 30%H_2, Ar + 10%Xe, Ar + 10%H_2, 50%He + 50%Ne [45] and Ar(Xe) + 20%CF_4, LAr(LXe) + 20%CF_4 [44].

In this work we propose as another filling of the chambers for search of low-mas WIMP (<10 GeV/c^2) and solar axions on spin-dependent interaction with deuterium (D_2), ^{3}He, ^{19}F and ^{21}Ne is used the mixtures: ^{21}Ne + 10%H_2 [21], D_2 + 3ppmTMAE [25], ^{3}He + 3%CH_4 [39] at pressure 10-17 bar. And in our experiment with liquid mixtures [16-18, 37, 44] is used the mixtures LAr + CF_4 (^{19}F) and LXe + CF_4 (^{19}F).

The time projection chamber [38] with the mixture D_2 + 3ppmTMAE filling at a pressure 10 bar allow to search of spin-dependent interactions of solar axions and deuterium (section 8).

In work [46] is claimed that for targets with spin- nonzero nuclei it might be the spin-dependent interaction that determines the lower bound for the direct detection rate when the cross section of the scalar interaction, which is usually assumed to be the dominant part, drops below 10^{-12}- 10^{-13} pb. In particular, from this work one can see that all fluorine-containing targets (LiF, CF_4, C_2F_6, and CaF_2, etc.) have almost the same sensitivity to both the SD and SI WIMP-nucleus interactions. Among all materials considered a detector with a ^{73}Ge, ^{129}Xe, or NaI target has better prospects to confirm or to reject the DAMA result [29] due to the largest values of the lower bounds for the total rate R(10, 50) > 0.06 -0.08 events/(kg day). If, for example, one ignores the SI WIMP interaction, then all materials have almost the same prospects to detect DM particles with the only exception of CH_4.

In this context, in our experiments [15] with liquid CH_4 as another filling of the chamber for search of low-mas WIMP (<10 GeV/c^2) we propose to use the mixtures LCH_4 + 40ppmTMAE (section 7.2).

The results obtained in our works [15-18] suggest that it is possible to develop large volume detectors capable of detecting scintillations with a 100% geometrical efficiency, by contrast to the well known detection techniques based on photomultipliers having efficiency of only a few percent. [27]

11. Summary & Outlook

In our works [9-14] GEMs with wire (WGEM) or metal electrodes (MGEM) and gas gap between metal electrodes without plastic were realized. An absence of a plastic insulation between electrodes of these GEMs excludes leakage currents and spark breakdowns between the electrodes.

In our works [16, 17, 21, 25] it was suggested to search low mass WIMPs and solar axions with help of chambers with GEMs and systems WGEM (MGEM) + pin-anodes. In work [18] we proposed a addition in liquid Xe (Ar) of photosensitive dopants and a comparison of scintillation (S1) and ionization signals (S2) for every event is suggested. In our works [15, 25, 37] it was suggested that the search for spin-dependent WIMP-nucleon interactions with help of detecting system GEM + pin-anodes can be performed.

In that respect we would like to add the next important comments:

1. As far as WIMPs with large masses (> 10 GeV) experimentally were not found so far [24, 27, 29, 31], it is necessary to search the WIMP with small masses (≤ 10 GeV/c^2).

2. The data of the new DAMA/LIBRA–phase2 confirm a peculiar annual modulation of the single-hit scintillation events in the (2–6) keV energy range (WIMP mass < 10 GeV/c^2) satisfying all of the multiple requirements of the Dark Matter [29]. J.Va'vra have supposed [31] that this effect is explained by low mass WIMP (~1 GeV/c^2) scattering on protons in H_2O molecules (H^+).

3. As well as, it is necessary to search of WIMP with small masses (≤ 10 GeV/c^2) in spin-dependent interactions between DM particles and gases with nonzero-spin nuclei (H_2, D_2, ^3He, CF_4 ,CH_4, etc.) [46].

Finally, we would like to mention that MGEMs can have various applications in medicine. Such MGEMs can be used in different medical instruments for their use in X-ray surgery or Positron Emission Tomography (PET), where a high operation stability and reliability of the whole complex of instrument is required. Recently we have proposed a PET system, based on these MGEMs and BaF_2-crystals [47].

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