Form No. 24

**Search for dark sectors in missing energy events**

NA-64

CODE OF THEME: 02-1-1096-2010/2022

***Universidad Tecnica Federico Santa Maria (UTFSM),Valparaiso, Chile*** S. Kuleshov, W. K. Brooks, H. Hakobyan, S. Kovalenko, G. Vasquez Arenas, P. Ulloa

***Rheinische Friedrich-Wilhelms-Universität Bonn, Germany*** M. Ball, M. Hösgen, B. Ketzer

***Institute for High Energy Physics, Protvino, Russia*** S.V. Donskov, V.A. Kachanov, Yu.V. Mikhailov, V.A. Poliakov,V.D. Samoylenko, A.P. Filin

***Joint Institute for Nuclear Research (JINR), Dubna, Russia*** LHEP: T.L.Enik, A.A. Feschenko, G.D. Kekelidze, V.Yu. Karjavine, V.А. Kramarenko, V.M. Lysan, D.V. Peshekhonov, A.A. Savenkov,I.A. Zhukov, P.V.Volkov, A.V.Ivanov, V.Е.Burtsev, LNP: V.Frolov, Directorate: V.A. Matveev

***P.N. Lebedev Physical Institute of the RAS (LPI), Moscow, Russia*** V.O. Tikhomirov, K. Zhukov

***Institute for Nuclear Research of the RAS (INR), Moscow, Russia*** A.V. Dermenev, S.N. Gninenko, A.E. Karneyeu, M.M. Kirsanov, N.V. Krasnikov, L.V. Kravchuk, O. Petukhov, I.I. Tkachov, D.A. Tlisov, A.N. Toropin

***Tomsk Polytechnic University (TPU), Tomsk, Russia*** R.R. Dusaev, V.E. Lyubovitsky, A.Yu. Trifonov, B.I. Vasilishin

***ETH Zurich, Institute for Particle Physics, Zurich, Switzerland*** D. Banerjee, D.A. Cooke, P. Crivelli, B. Radics, A. Rubbia

NAMES OF PROJECT LEADER: V.Matveev

NAME OF PROJECT DEPUTY LEADER: D.Peshekhonov

DATE OF SUBMISSION OF PROPOSAL OF PROJECT TO SOD \_\_\_\_\_\_\_\_\_

DATE OF THE LABORATORY STC \_\_\_\_\_\_\_\_\_ DOCUMENT NUMBER \_\_\_\_\_\_\_\_\_

STARTING DATE OF PROJECT \_\_\_\_\_\_\_\_\_

(FOR EXTENSION OF PROJECT –– DATE OF ITS FIRST APPROVAL) \_\_\_\_\_\_\_\_\_

Form No. 25

PROJECT ENDORSEMENT LIST

**Search for dark sectors in missing energy events**

NA-64

02-1-1096-2010/2022

Project leader: Victor Matveev

|  |  |  |
| --- | --- | --- |
| APPROVED BY JINR DIRECTOR | \_\_\_\_\_\_\_\_\_\_\_ | \_\_\_\_\_ |
| ENDORSED BY |  |  |
| JINR VICE-DIRECTOR | \_\_\_\_\_\_\_\_\_\_\_ | \_\_\_\_\_ |
| JINR CHIEF SCIENTIFIC SECRETARY | \_\_\_\_\_\_\_\_\_\_\_ | \_\_\_\_\_ |
| CHIEF ENGINEER | \_\_\_\_\_\_\_\_\_\_\_ | \_\_\_\_\_ |
| HEAD OF SCIENCE ORGANIZATION DEPARTMENT | \_\_\_\_\_\_\_\_\_\_\_ | \_\_\_\_\_ |
| LABORATORY DIRECTOR | \_\_\_\_\_\_\_\_\_\_\_ | \_\_\_\_\_ |
| LABORATORY CHIEF ENGINEER | \_\_\_\_\_\_\_\_\_\_\_ | \_\_\_\_\_ |
| PROJECT LEADER | \_\_\_\_\_\_\_\_\_\_\_ | \_\_\_\_\_ |
| PROJECT DEPUTY LEADERS | \_\_\_\_\_\_\_\_\_\_\_ | \_\_\_\_\_ |
| ENDORSED |  |  |
| RESPECTIVE PAC | \_\_\_\_\_\_\_\_\_\_\_ | \_\_\_\_\_ |

Form №26

Suggested time-table and resources necessary for realization of the Project

**Search for light dark matter at the SPS CERN**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Units of measure | Resource requirements for 2020-2022 | Laboratory resources | | |
| 1st year | 2nd year | 3rd year |
| Basic units and equipment: | Gas system, electronics (FEE), DAQ, detectors |  |  |  |  |
| Required recourses:  а) ООЭП of the Laboratory  б) Design department of the laboratory | standard hour standard hour |  |  |  |  |
| в) Accelerator  г) Reactor  д) Computer | hour  hour  hour |  |  |  |  |
| Operating costs | thousand US$ |  |  |  |  |
| Funding source:  Budget expenditures  Including foreign funds | thousand US$  thousand US$ | 360  105 | 145  50 | 130  45 | 85  10 |
| Contributions of collaborators  Grant contributions (INTAS+МНТЦ)  Contributions of sponsors  Contributions according agreements  Other sources | thousand US$  thousand US$  thousand US$  thousand US$  thousand US$ |  |  |  |  |

PROJECT LEADER

Form № 29

**Estimated expenditures on the Project NA-64 “Search for dark sectors in missing energy events”**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Expenditure items | Full cost | 1st year | 2nd year | 3rd year… |
|  | Direct expenses for the Project |  |  |  |  |
| 6. | Materials | 145k$  common funds | 45  15 | 45  15 | 10  15 |
| 7. | Equipment | 95k$ | 45 | 30 | 30 |
| 8. | Construction/repair of premises | k$ |  |  |  |
| 9. | Payments for agreement-based research | k$ |  |  |  |
| 10. | Travel allowance, including:  a) non-rouble zone countries  b) rouble zone countries  c) protocol-based | 120k$ | 40 | 40 | 40 |
|  | Total direct expenses  \* including Belarus contribution | 360  105\* | 145  50\* | 130  45\* | 85  10\* |

PROJECT LEADER V.A.Matveev

LABORATORY DIRECTOR V.D.Kekelidze

LABORATORY CHIEF ENGINEER-ECONOMIST G.G.Volkova

**Introduction**

One of the biggest puzzles in physics is that 85% of the matter in our universe is “dark”: it does not interact with the photons of the conventional electromagnetic force and is therefore invisible to our eyes and telescopes.

Several models of dark matter suggest the existence of dark sectors consisting of SU(3)C x SU(2)L x U(1)Y singlet fields. These sectors of particles do not interact with the ordinary matter directly but could couple to it via gravity. In addition to gravity, there might be another very weak interaction between the ordinary and dark matter mediated by U'(1) gauge bosons A' (dark photons) mixing with our photons. In a class of models the corresponding dark gauge bosons could be light and have the γ-A' coupling strength laying in the experimentally accessible and theoretically interesting region. If such A' mediators exist, their di-electron decays A' → e+e- could be searched for in a light-shining-through-a-wall experiment looking for an excess of events with the two-shower signature generated by a single high energy electron in the detector. Our experiment aims to probe the still unexplored area of the mixing strength 10-5 < ε < 10-3 and masses MA' < 100 MeV by using 50-150 GeV electron beams from the CERN SPS.

**What project adds to the international scenario**

NA-64 is a fixed-target experiment at the CERN SPS utilizing the active beam dump combined with the  missing energy approach for the searches  of   invisible decays of dark photons  (A') with the mixing strength 10-5 < ε < 10-3 and masses MA' < 100 MeV,  invisible decays of (pseudo)scalar mesons, in particular K\_S ,  K\_L -> invisible, and hadron and muon interactions resulting in invisible final states due to production of new penetrating particles. The experimental signature of this process –has never been experimentally tested before.

The advantage of our approach is that the sensitivity (or number of signal events) of the experiment is roughly proportional to the Z' couplig  squared ε^2,  associated with the Z' production in the primary interaction  in the target. While in a classical beam dump experiment, it is proportional to ε^4, one ε^2 came from the Z' production, and another ε^2 is either from the probability of Z' decays or   their  interactions in a detector located at a large distance from the beam dump.  The  sensitivities  of these  two methods depend  on the region under study in the  (ε^2 ; m\_Z') parameter space, background level for a particular process, available  beam intensity, etc.  In some cases,  much less running time and primary beam intensity are required to observe a signal event with our approach.

**JINR group responsibilities and activities**

The JINR group is responsible for the tracking sub-system: coordinate detectors based on the thin-wall drift tubes (straw tubes).

* Documentation on the manufacturing of double-layer straw tube (2 and 6 mm diameters) chambers

with 20x20 cm2 working area were developed;

* 6 frames for 2mm and 8 frames for 6mm straw tube chambers were manufactured;
* developed documentation on the read-out from both type of chambers (2mm and 6mm, 96 channels and 64 channels);
* manufactured 600 6mm straw tubes and 800 2mm straw tubes;
* all chambers were assembled, equipped and successfully tested with ion sources and with a real beam;
* prepared on-line monitor and visualization for the straw tube chambers, decoding and data acquisition software, chambers included in the NA-64 data-base;
* straw tube chambers described and included in the MC and reconstruction software of NA-64 experiment;
* JINR team participated in 3 NA-64 data taking runs as a responsible for the straw tube chambers.

**Experiment status (report & plans)**

During the runs in years 2016-2018 the NA64 collected data for search of A´ through the invisible decay mode. The data taking was carried out in an electron beam with the intensity of up to 107 particles per spill with the duration of 4.8 seconds and particle energy of 100 GeV.

The data from years 2016 and 2017 have been processed and published, the total statistics is ~1011 events, candidates for the signal corresponding to the signature of the dark photon have not been detected. Part of the year 2017 run was devoted to the search for a new hypothetical X-boson with the mass of 16.7 MeV, the existence of which could explain the result on the anomalous production of e+e - pairs in the decay of the excited state 8Be\* obtained in the ATOMKI experiment. 5.4x1010 events were taken, hypothetical boson was not found, obtained data allowed to significantly increase the limit on the coupling constant of the X-boson with an electron, as well as on the mixing parameter of the A´ with the conventional photon.

During the run in 2018 an amount of 2х1011 events were taken in a search for the invisible mode and 3х1010 - for the visible one, data are being analyzed. The same year a permanent experimental zone at CERN on the H4 channel was allocated for the experiment. Preparatory works on its arrangement started. The facility should be upgraded for more efficient operation with a high beam intensity and be prepared for the 2021 run, during which it is planned to increase significantly the statistics by registering more than 5x1011 events for further searches for A´ and X-boson decays. 7 new 6mm double layers chambers 1200x600 mm2 have to be produced and equipped by the 2021 run.

The NA64 research program is not limited to the data taking with electron beam. Currently, the collaboration is preparing a proposal for the measurements at the muon channel of the SPS accelerator, which could make a significant contribution to the solution of the (g-2) problem of the anomalous magnetic moment of the muon. A test run might be carried out at the end of 2021, or the beginning of 2022.

In frame of the extending program with electron beam and preparation to the data taking with muon beam we plan to start development of new large area straw tube chambers, provide R&D with cosmic and ion-sources aimed on the improvement of the chamber characteristics, tests of electronics and DAQ modernization, take part in data analysis and MC simulation.

**Publications during 2017-2019:**

##### Search for invisible decays of sub-GeV dark photons in missing-energy events at the CERN SPS, NA64, Phys. Rev. Lett. 118 (2017) 011802

##### Search for vector mediator of Dark Matter production in invisible decay mode, NA64 collaboration, Phys.Rev. D 97 (2018) 072002;

**FTE of the JINR group = 5**

G. Kekelidze (0,4), V. Karjavine (0,1), V. Kramarenko (0,4), V. Lysan (0,8), V. Matveev (0,1), D. Peshekhonov (0,3), A. Savenkov (0,3), I. Zhukov (0,8), A.Festchenko (0,1), T.Enik (0,2), P.Volkov (0,5), A.Ivanov(0,3), V.Burtsev(0,5), V.Frolov (0,2).

**SWOT analysis:** no visible risks

**Short project description**

**Search for the decay *A’ → invisible***

The interaction between *γ*'s and *A'*s is given by a kinetic mixing [1, 3, 4]:*Lint= - ½ ε Fμν A'μν,* where *Fμν,A'μν* are the ordinary and the dark photon fields, respectively, and parameter *ε* is their mixing strength. The diagram for production of A' in the reaction *e- Z → e- Z A', A’ → invisible* is shown in Fig. 1.

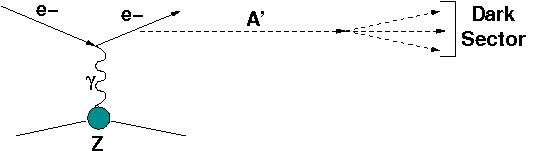


Figure 1. Diagram illustrating production of massive *A'* by electrons scattering off a nuclei *(A,Z),* in the reaction *e- Z → e- Z A',* with subsequent *A'* decay into dark sector states.

Part *f* of the primary energy is carried away by the dark photon, i.e. *EA’ = fE0*. The dark photon, or its invisible decay products, penetrates the detector without interaction. The remaining part of the primary energy *Ee = (1-f) E0* is deposited in the target by the scattered electron. Thus, occurrence of *A’* would appear as an excess of events whose signature is a single electromagnetic (e-m) shower in the target with energy *Ee* accompanied by the significant missing energy *Emiss = E0 – EA’* above those expected from the background [50, 51].

The process of the dark photon production and subsequent invisible decay*, A’ → invisible* is expected to be a very rare event. The total number of *A'*s produced by ne electrons in a target with thickness t >> X0 is [11]:

nA' ~ ne C (ε2 me2)/MA'2,

where the parameter *C ≈ 10* is only logarithmically dependent on the choice of target nucleus, me is the electron mass and *MA'*- the *A'* mass. The spectrum is

*dnA'/dEA' ~ k x (1+x2 / {3 (1-x)}) ,*

where *k* is a constant, and *x=EA'/E0*.

(For recent works on heavy particles production through photon exchange with a nucleus see also [57, 58].)

It is argued in [26], that the parameter C is actually C≈ 5. Nevertheless, one can see that, compared to the bremsstrahlung rate, the A' production is suppressed by a factor ≈*ε2 me2/MA'2*. Therefore, for the parameter region of our interest, it is expected to occur with rate ≤10-13-10-9of the ordinary photon production rate. Hence, its observation presents a challenge for the detector design and performance.

**The setup**

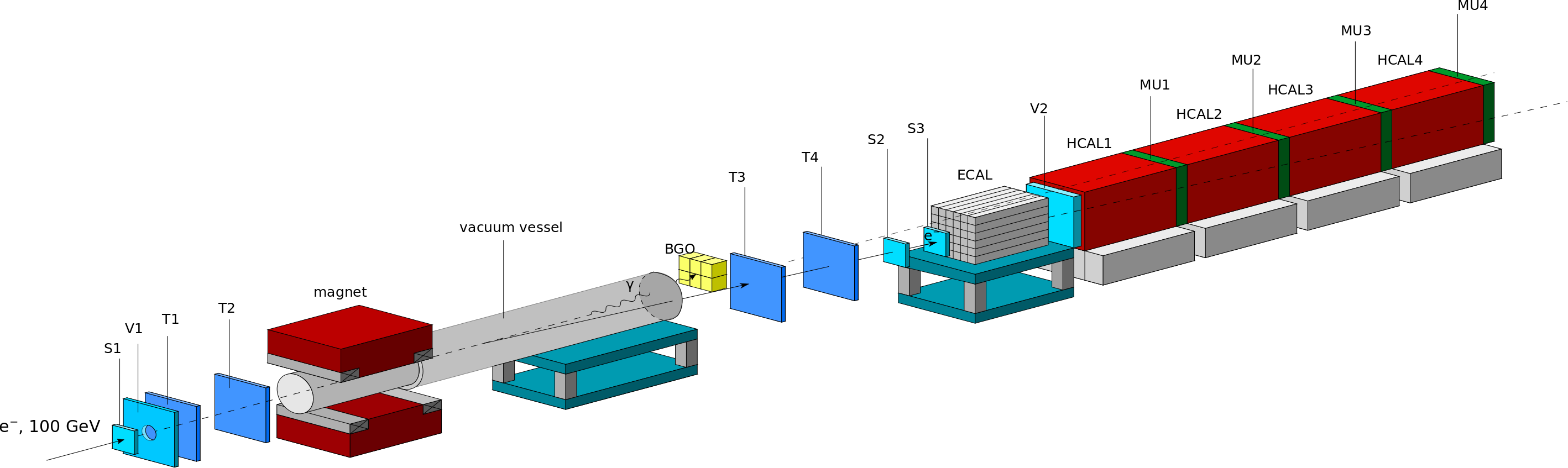
The experimental setup specifically designed to search for the *A' → invisible* decays is schematically shown in Fig. 2.

Figure 2. Schematic illustration of the current version of the NA-64 setup to search for *A’ → invisible* decays of the bremsstrahlung *A’*s produced in the reaction *eZ → eZA’* of 100 GeV e- incident on active ECAL target.

We work with 100 GeV beam energy, where the admixture of other charged particles in the beam (beam purity) is below 10-2.

The detector utilizes beam defining scintillator (Sc) counters S1-S3, and magnetic spectrometer consisting of two successive dipole magnets and a low-material-budget tracker. The tracker includes two upstream Micromega chambers (T1, T2) and two down stream GEM stations (T3, T4) allowing for the measurements of e- momenta with precision *δp/p≈1%* [53]. The magnet also served as an effective filter rejecting low energy component of the beam. *The setup is additionally equipped with up to the 6 (2 X and 2 Y oriented) double layer straw chambers with a sensitive area of 200×200 mm2 each based on Kapton tubes with wall thickness of 70 μm.* To enhance the electron identification the synchrotron radiation (SR) emitted by electrons is used for their efficient tagging. A 15m long vacuum vessel between the magnets and the ECAL minimizeсabsorption of the SR photons before their detection immediately at the downstream end of the vessel by a SR detector (SRD). The latter can be either an array of BGO crystals or Pb-Sc sandwich calorimeter with a very fine segmentation [50]. By using SRD the level of the hadron contamination in the beam, *π/e-≤ 10-2,*can be further suppressed by a factor ~*103*. The detector is also equipped with an active target, which is e-m calorimeter (ECAL) for measurement of the electron energy with an accuracy *δE/E≈10%/√E*. The ECAL is a matrix of 6x6 “shashlyk” type modules assembled from Pb and Sc plates with the wave-shifting read-out fibers inserted in spiral in order to avoid energy leak into the fibers if they would be inserted straight. Downstream the ECAL, the detector is equipped with high-efficiency veto counter V2, and a massive, hermetic hadron calorimeter (HCAL) of length *30λint* (nuclear interaction lengths). The HCAL serves as a dump to absorb completely and measure the energy of hadronic secondaries, produced in the *e-A* interaction in the target. Three muon plane counters, MU1-MU3, located between the HCAL modules are used for final-state muon identification.

The signal candidate events should satisfy the following selection criteria:

* the incoming particle track should have a small angle with the beam axis to reject large angle tracks from possible upstream interaction;
* the energy deposited in the SRD should be within the SR range emitted by *e-*s and intime with the trigger;
* the lateral and longitudinal shape of the shower in the ECAL should be consistent with the one expected for a signal shower [54];
* no signal in the veto counter V2.

**Background**

The search for the *A’ → invisible* decays requires particular attention to the background. There are several sources which may mimic the *A’ → invisible* signal: upstream *e-* interactions, *μ→eνν* and *π, K→eν* decays in-flight, energy leakage from particle punch-through in t*he HCAL,* processes due to pile-up of two or more particles, instrumental effects due to energy loss through cracks in the upstream detector coverage, etc.

Table 1. The expected contributions to the total level of background from different sources estimated for beam energy 100 GeV.

|  |  |
| --- | --- |
| Source | Expected level |
| *Beam contamination:*  - π, *p*, μ reactions and punch-through,…  - e- low energy tail due to bremsstrahlung,  π,μ-decays in flight | < 10-13-10-12  < 10-12 |
| *Detector imperfectness:*  ECAL+HCAL energy resolution, transverse hermeticity, holes, dead material, cracks… | <10-13 |
| *Physical:*  - hadron electro production, e.g.  - e-A→e-A\* + n,π,ρ,J/Ψ  - n punch-through, μ inefficiency  - the weakprocess e- Z→e- Zνν | < 10-13  < 10-13 |
| *Total* | < 10-12 |

The background was estimated by Monte-Carlo simulation (MC) and with real data obtained during the beam tests in 2015-2016 [55]. For details see [55, 51].

**Search for the decay *A’ →e+e-***

The experimental setup designed to search for *A’ →e+e-*decays is schematically shown in Figure 3.

The *A'* is emitted with respect to electron beam axis predominantly at an angle *ΘA’ ≤ Θe+e-*≈*mA’/EA'*, which is typically smaller than the opening angle of the *A’→ e+e-* decay products *Θe+e-*. Thus, the approximation of *A'* emission collinear with the beam axis is justified; the same is done in many calculations [11].

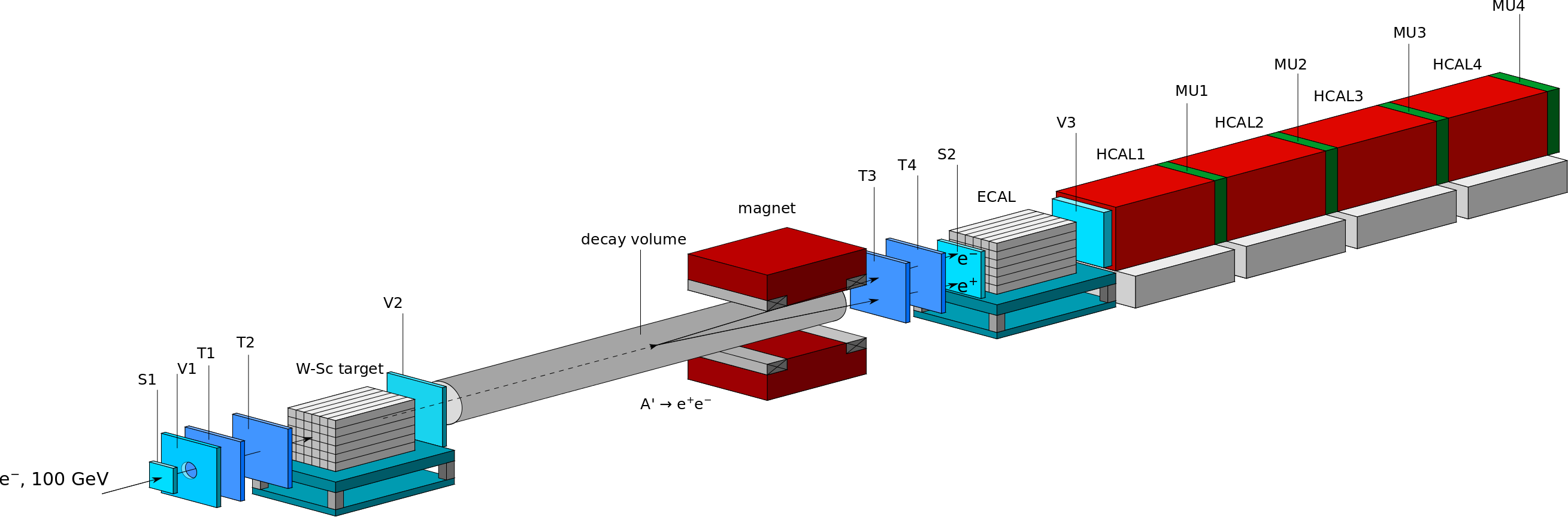


Figure 3. Schematic illustration of the setup proposed to search for dark photons in a light-shining-through-a-wall type experiment.

The corresponding *A’−> e+e-* decay rate is given by:

*Γ(A’−> e+e-) = α/3 ε2 MA' √ {1- 4me2/MA'2 (1+ 2 me2 /MA'2)}* .

It is assumed that this decay mode is dominant and the branching ratio *Γ(A’−> e+e-) / Γtot ≈ 1*.

For this experiment the detector (see Fig. 3) is additionally equipped with a high density, compact e-m calorimeter (ECAL1) to detect *e-* primary interactions. The decay volume (DV) and space after the downstream end of the DV up to the e-m calorimeter ECAL will be additionally equipped with high precision low-material-budget tracking detectors based on the straw tube technology (do not shown in the Fig. 3).

The method of the search is the following [59]. The dark photons *A'* are produced through the mixing with bremsstrahlung photons from the electrons scattering off nuclei in the W-Sc target, an e-m calorimeter with energy resolution *ΔE/E ≃ 0.18/√E*, X,Y resolution ≃ 3 mm, *e/π* rejection ~10−2. This happens typically within the first few radiation lengths (*X0*) of the target. The bremsstrahlung *A'* then penetrates the rest of the target and the veto counter V2 without interaction, and decays in flight into an *e+e-* pair in the decay volume DV with diameter ≃30 cm and15 m length.

A fraction *f* of the primary electron energy, *E1 = f E0,*is deposited in the target calorimeter. Its downstream part serves as a dump to absorb completely the e-m shower tail. For radiation length ≤1 cm, and total thickness of the W-Sc target of≈*30X0* the energy leak into the V2 is negligibly small. The remaining part of the primary electron energy *E2 = (1-f)E0* is transmitted through the “targetwall'' by the dark photon *A'*, and deposited in the downstream calorimeter ECAL via the *A'* decay in flight in the DV, as shown in Fig.4. At high *A'* energies, EA' ≥ 30 GeV, the opening angle Θe+e- ≈ mA’/EA’ of the decay *e+e-* pair is too small to be resolved as two e-m showers in the ECAL, so the pairs are mostly detected as a single electromagnetic shower. Thus, if mA’ ~ 50 MeV and EA’ = 50 GeV, one obtains Θmin ~ 2 mrad, so the *e+e-* pair can be resolved as two separated tracks *in front of the ECAL.*

The occurrence of *A’→e+e-*  decays would appear as an excess of events with two e-m-like showers in the two calorimeters that should satisfy the following selection criteria:

* the starting point of (e-m) showers in the W-Scand ECAL should be localized within a few first *X0*s,
* the lateral and longitudinal shapes of both showers are electromagnetic like. The fraction of the total energy deposition in the W-Sc is *f*≤ 0.1, while in the ECAL it is *(1-f)≥ 0.9*,
* no energy deposition in the V2,
* the signal (number of photoelectrons) in the decay counter S2 is consistent with the one expected from two minimum ionizing particle (mip) tracks. At low beam energies, *E0*≤30 GeV, two isolated tracks in the *straw tube* tracker are required,
* the sum of energies deposited in the W-Sc+ECAL is equal to the primary energy, *E1 +E2 = E0*.

**Background**

The contributions from all background sources are summarized in Table 2 for beam energy 100 GeV. The dependence on the energy is rather weak. The total background level is conservatively estimated to be ≤ 3 10-13, and is dominated by the admixture of hadrons in the electron beam. Thus, a search accumulating ≈10-13 e- events is expected to be essentially background free.

Table 2. Expected contributions from different background sources estimated for beam energy of 100 GeV.

|  |  |
| --- | --- |
| Source of the background | Expected level |
| punch-through *e-*s or *γ*s | ≤ 10-13 |
| hadronic interactions | ≤ 2x10-13 |
| μ interactions and decays | ≤ 10-14 |
| accidentals | ≤ 10-14 |
| Total | ≤ 3x10-13 |

For the background free case *NA'90%(mA')* = 2.3 events, the exclusion regions corresponding to accumulated electrons on the target*109*, *1010, 1011, 1012*are shown in Fig. 5.

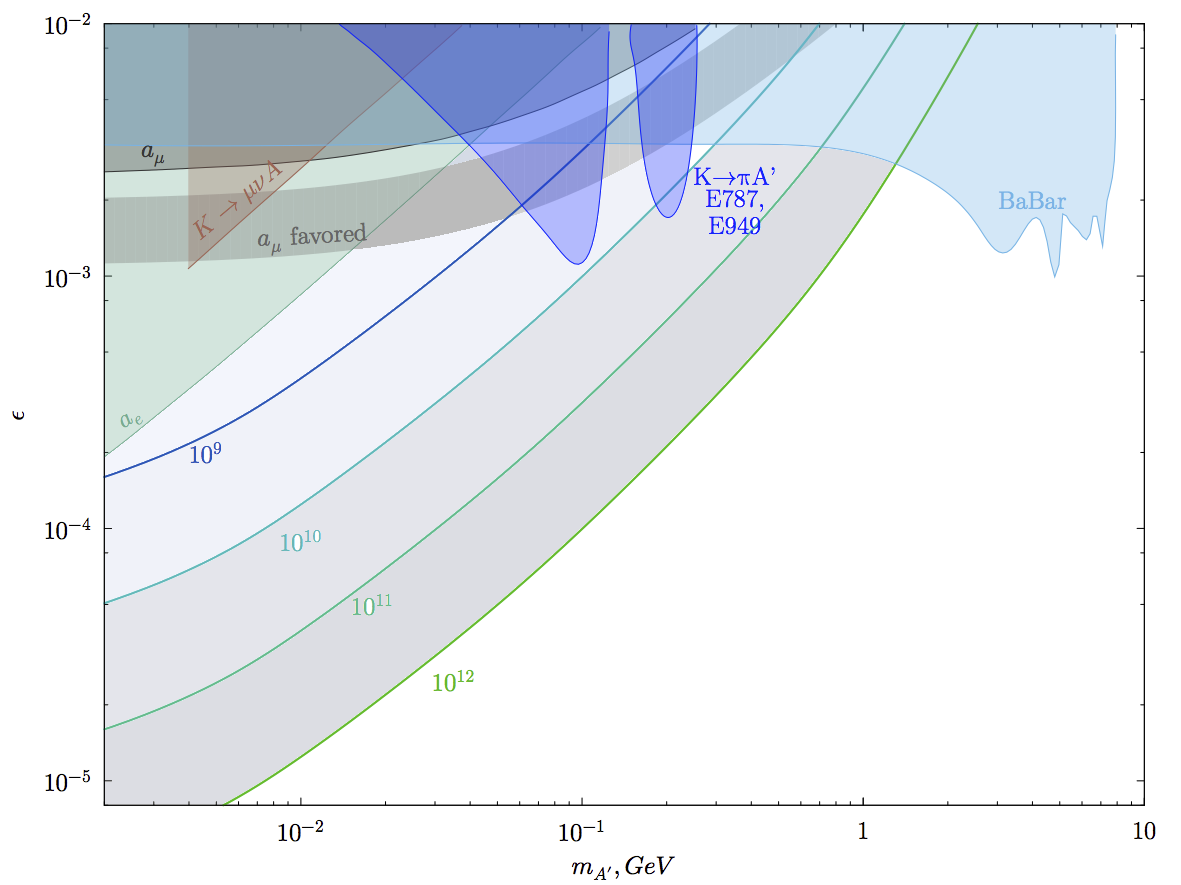


Figure 5. Constraints in the *ε* vs *mA’* plane for invisibly decaying *A'* assuming they can decay invisibly to a pair of dark-sector states *χχ*, provided *mA’ > 2 mχ.* The color lines show the expected 90% C.L. exclusion areas corresponding, respectively, to 109, *1010, 1011, 1012* accumulated electrons at 100 GeV for the background free case. Various other constraints (shaded regions) are also shown [arxiv: 1604.08432]. The constraint from the BaBar mono-photon search is given as blue shaded region. Further limits are shown from the anomalous magnetic moment of the electron ae, and muon aμ, the rare kaon decay K+→π+ A' and leptonic decay K+→ μ+νμ A' searches.

For the background free case (*NA'90%(mA')* = *2.3 events*), the exclusion regions corresponding to accumulated electrons on the target*1011,1012, 1013* are shown in Fig.6.

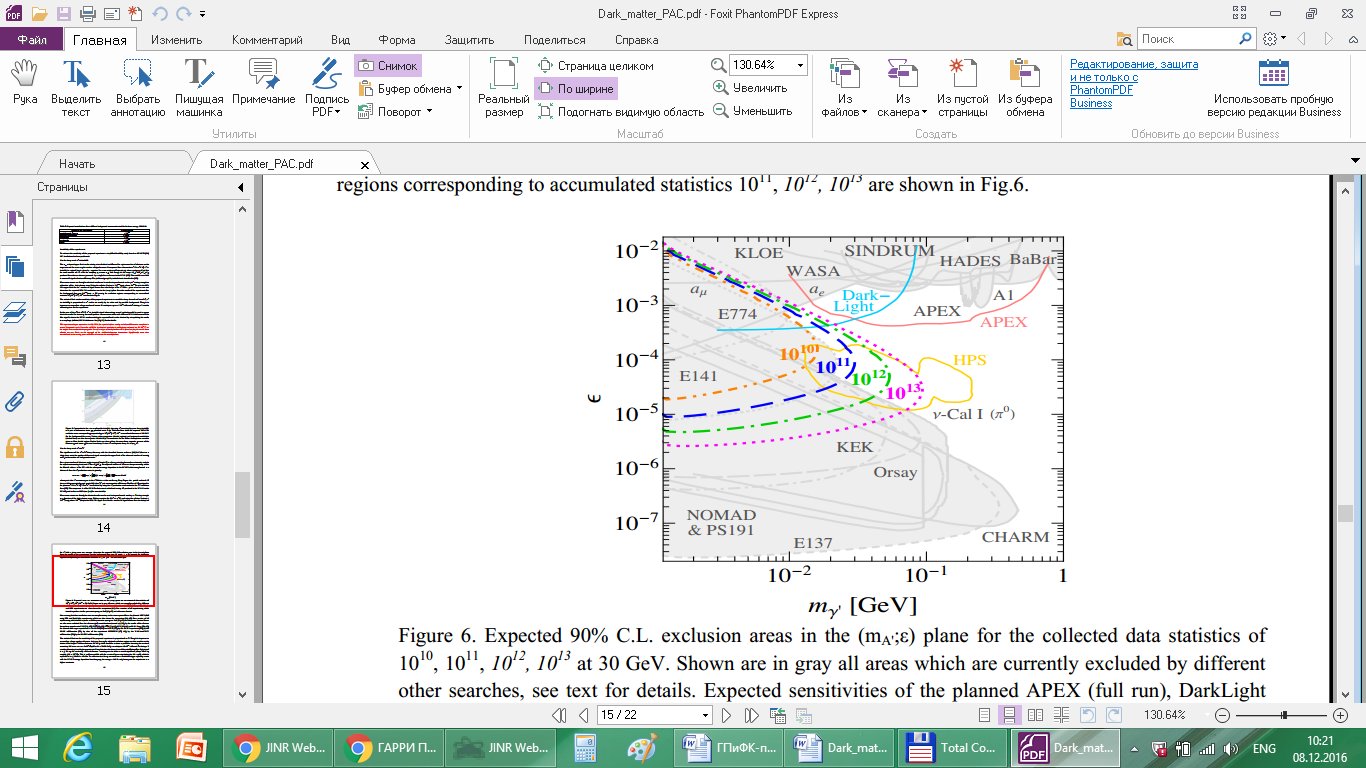


Figure 6. Expected 90% C.L. exclusion areas in the (mA';ε) plane for the accumulated electrons on the target of *1010, 1011,1012, 1013*at 30 GeV. Shown are in gray all areas which are currently excluded by other searches, see text for details. Expected sensitivities of the planned APEX (full run), DarkLight and HPS experiments are also shown for comparison [61]. For a review of all experiments, which intend to probe a similar parameter space, see Ref. [61, 62] and references therein.

The statistical limit on the sensitivity of the proposed experiment is proportional to *ε4*. Thus, it is important to accumulate a large number of events. As it was shown, the size of the exclusion region is also sensitive to the choice of the length *L'* of the calorimetric target that should be as short as possible. Assuming the maximal secondary H4 beam rate *ne* ≈ 5x106 e-/spill at *E0* ≈ 30-50 GeV, we anticipate ≈3x1012 collected *e-*s during ~ 3 months of run time.

**Conclusion**

Due to their specific properties, dark photons are an interesting probe of physics beyond the Standard Model both from theoretical and experimental point of view. We propose to perform a light-shining-through-a-wall experiment dedicated to аsensitive search for dark photons in the still unexplored intervals of the mixing strength 10-5≤ε≤ 10-3 and masses *mA’* ≤ 100 MeV by using available electron beams from the CERN SPS. The experiment has the capability for a sensitive search for *A'*s decaying invisibly to dark-sector particles such as dark matter. Our feasibility study shows that a sensitivity for the search of the *A’ → invisible* decay mode in terms of branching fraction *Br(A’) = σ(e-Z→e-ZA’, A’→ invisible)/σ(e-Z→e-Zγ)* at a level below a few parts in 1012 is within reach. The intrinsic background due to the presence of low energy electrons in the beam can be suppressed by using a tagging system, which is based on the detection of synchrotron radiation of high-energy electrons. The search would allow covering a significant fraction of the yet unexplored parameters space for the *A’ → invisible* decay mode.

If *A'*s exist, also their decays *A’ → e+e-* could be observed by looking for events with two-shower topology of energy deposition in the detector. The key point is an observation of events with almost all beam energy deposition in the downstream ECAL calorimeter, located behind the “W-Sc wall''.

The sensitivity of the search for the *A’ → e+e-* decay in terms of the ratio of the cross sections *σ(e-Z→e-ZA’)/σ(e-Z→e-Zγ)* at a level of ≤ 10-13 – 10-12 could be achieved. In the case of non-observation, the expected exclusion areas are complementary to the ones from the planned APEX (full run), DarkLight, and other experiments intended to probe a similar parameter space [61, 62].

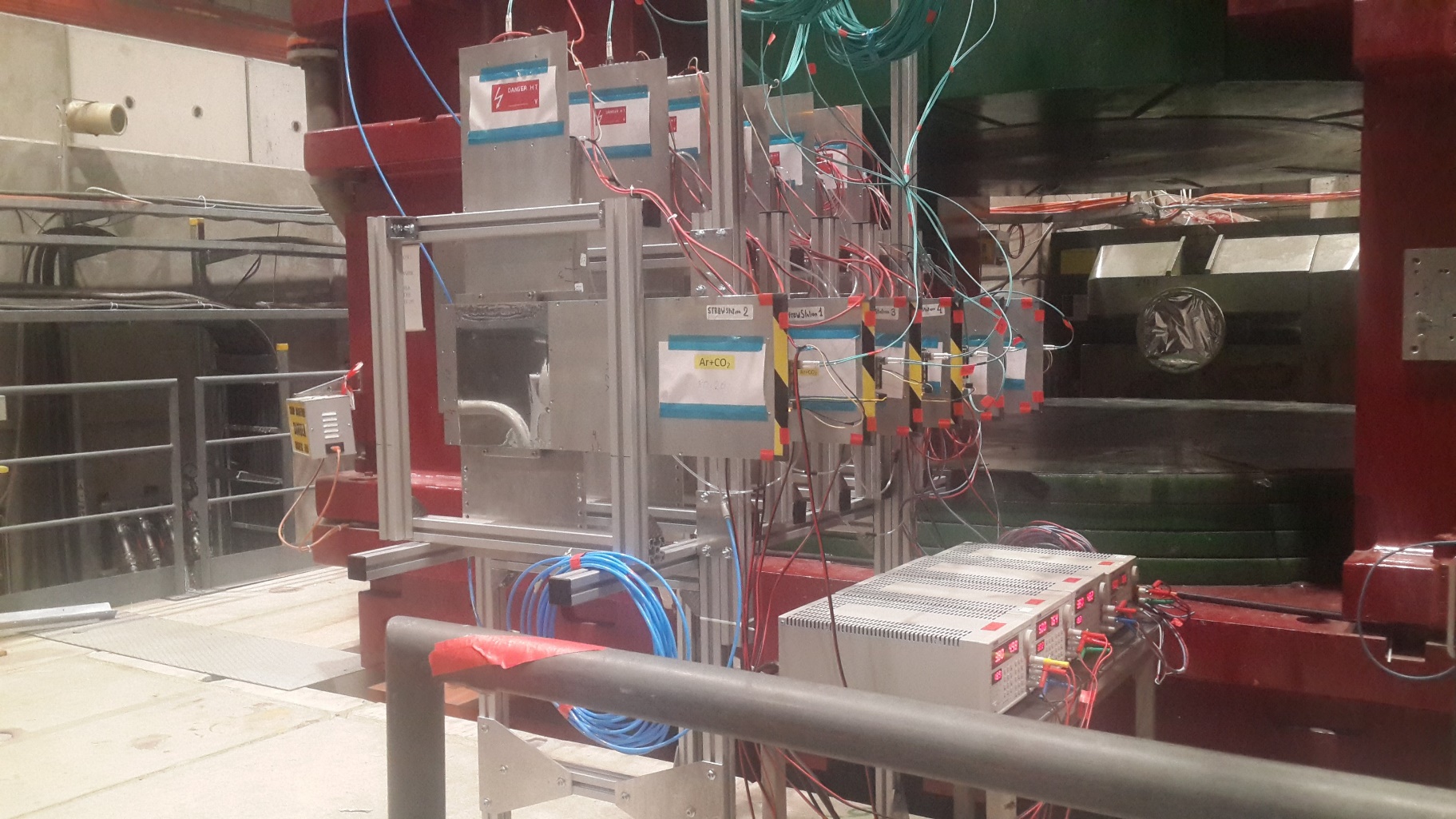
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Figure 7. JINR straw tracker at the experimental hall during 2018 data taking run

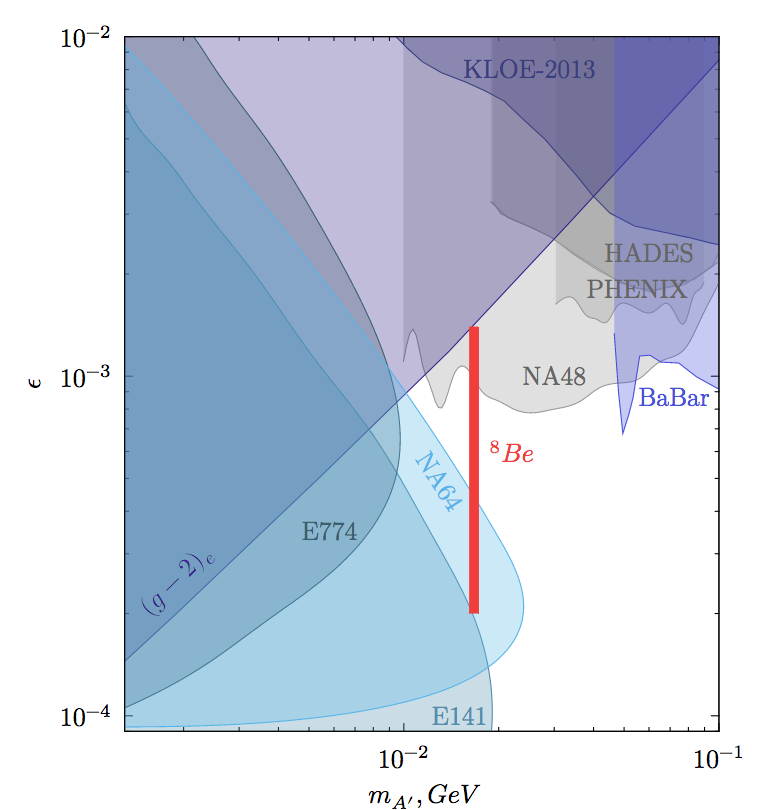
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Figure 8. Part of the year 2017 run was devoted to the search for a new hypothetical X-boson with the mass of 16.7 MeV, the existence of which could explain the result on the anomalous production of e+e - pairs in the decay of the excited state 8Be\* obtained in the ATOMKI experiment. 5.4x1010 events were taken, hypothetical boson was not found, obtained data allowed to significantly increase the limit on the coupling constant of the X-boson with an electron, as well as on the mixing parameter of the A´ with the conventional photon.

**Reference**

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