Searching for a new force at VEPP–3

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We propose an experiment to search for a new gauge boson in e^+e^- annihilation by means of a positron beam incident on a gas hydrogen target internal to the VEPP–3 storage ring. The projected result of this experiment corresponds to an upper limit on the square of coupling constant $|f_{eU}|^2 = 1 \cdot 10^{-8}$ with a signal-to-noise ratio of five to one.

I. INTRODUCTION

The search for an experimental signature of super symmetry, proposed in the mid 1970s, see e.g. [1], is a major effort of modern particle physics, see review [2]. Most of the search activity is focused on possible heavy particles with a mass scale of 1 TeV and above. At the same time, as was suggested by P. Fayet, there could be another interesting $U(1)$ symmetry, which requires a new gauge boson [3, 4]. The boson could be light and weakly interacting with known particles. Most constraints for the light U-boson parameters were obtained from electron/muon $g-2$ and particle decay modes [5–8].

Renewed interest in a search for the new gauge boson has been seen recently, as such a boson may provide an explanation for various astrophysics phenomena, accumulated during the last decade, which are related to dark matter [9, 10]. The possible connection between the U-boson and dark matter in view of the observed positron abundance has been investigated for several years and is often referred to as light dark matter (LDM)[11–14].

Several methods, which were used in the search for the U-boson signal, were considering "invisible" decay modes of the U-boson. Therefore, they result in an upper limit for $\mathbf{f_{qU}} \times \mathbf{B_{[U \to invisible]}}$. The first method uses precise experimental data on exotic decay modes of elementary particles, e.g. $\pi^\circ \to invisible + \gamma$, for the calculation of the upper limit of the U-boson coupling constant to the specific flavor. These upper limits for decay of the J/Ψ and Υ to a photon plus invisible particles were obtained experimentally by means of the "missing particle" approach, where a missing particle in the event type $e^+e^- \to \gamma X$ leads to a yield of events with a large energy photon detected at a large angle with respect to the direction of positron and electron beams. From the yield of such events the coupling constant could be determined for a wide range of mass of the hypothetical U-boson. A recent experiment [15] using statistics of $1.2 \cdot 10^8$ $\Upsilon(3S)$ events provided the best data for $\Upsilon(3S)$ decay to $U + \gamma$ and a limit on the coupling of the U-boson to the b-quark. In the mass region below 100 MeV, the limit for $B(\Upsilon(3S) \to \gamma A^0) \times B(A^0 \to \text{invisible})$ is $3 \cdot 10^{-6}$, from which the limit $\mathbf{f_{bA} < 4 \cdot 10^{-7} m_U}$ [MeV] was obtained [6]. An additional hypothesis of coupling constants universality is required to get a bound on $\mathbf{f_{eU}}$, so direct measurement of the coupling to an electron is of large interest. Currently, the upper limit on the vector coupling obtained from the discrepancy between the calculated electron anomalous magnetic moment and the measured one is $\mathbf{f_{eU} < 1.0 \cdot 10^{-4} \cdot m_U}$ [MeV] [7, 8], and the limit from the measured/calculated muon anomalous moment is $\mathbf{f_{\mu U}} < 1.0 \cdot 10^{-3}$ for the mass region $m_U = 10 - 100$ MeV [8].

A direct measurement of f_{eU} and $\mathbf{m_U}$ could be done by detecting the decay of the U-boson to an electron-positron pair and reconstructing the e^+e^- invariant mass. A complication of this method is the high level of electromagnetic background in the mass spectrum of e^+e^-, so such a measurement requires very large statistics. Recently the data sets accumulated in collider experiments have been used for such an analysis [14, 16, 17].

Electron beam fixed-target experiments, where a new boson can be produced from radiation off an electron beam incident on an external target, are now widely discussed [18–21]. The first significant experimental results on upper limits for a new boson coupling to an electron in the sub-GeV mass range have been reported [22, 23]. The APEX experiment in JLab Hall A [24] will probe couplings $\alpha'/\alpha > 10^{-7}$ and masses $\sim 50 - 550$ MeV. The result of the test run, with only 1/200 of the data of the full APEX experiment, has already demonstrated the feasibility of such an approach [22]. Other electron beam fixed-target experiments are planned: at Jefferson Lab, including the Heavy Photon Search (HPS) [25] and DarkLight [26]; at MAMI [23]; and at DESY (the HIdden Photon Search, HIPS) [27].

A sensitive U-boson search could be performed with a low energy e^+e^- collider [10], where several search techniques could be used:

- The invisible particle method
- Invariant mass of the final e^+e^- pair
- Missing mass with single-arm photon detection.

To search for the U-boson with a mass of 10-20 MeV, the center-of-mass energy of e^+e^-, E_{cm}, should be low. The production cross section is proportional to $1/E_{cm}^2$, so for low E_{cm}, even a modest luminosity would be sufficient for a precision measurement.

However, no colliding e^-e^+ facility in this energy region exists or is planned to be constructed. Still, a similar operation can be achieved if an available positron beam of a few hundred MeV energy is incident on a fixed target [28, 29]. The VEPP–3 electron/positron storage ring at the Budker Institute at Novosibirsk [30], with its internal target facility and high-intensity positron beam injection complex, are uniquely suited for such measurements.

We propose to perform a search for the U-boson in a mass range $\mathbf{m_U = 5 - 20}$ MeV using a 500 MeV positron beam incident on an internal hydrogen target, providing a luminosity of $\mathbf{10^{32}}$ $\mathbf{cm^{-2}s^{-1}}$, by detecting γ-quanta from the process $\mathbf{e^+e^- \rightarrow \gamma U}$ in an energy range $\mathbf{E_\gamma = 50 - 400}$ MeV and angular range $\theta_\gamma^{\mathbf{CM}} = \mathbf{90^\circ \pm 30^\circ}$ ($\theta_\gamma^{\mathbf{Lab}} = \mathbf{1.5^\circ - 4.5^\circ}$).

II. THE CONCEPT

In the proposed experiment we would like to explore the technique of the missing mass measurement approach with single-arm photon detection. The concept of the method is partly described in [29]. A positron beam in a storage ring with an energy E_+ of a few hundred MeV and an internal hydrogen gas target make up an "e^+e^- collider". In such a collider it is possible to search for a light U-boson with a mass of up to $m_U[MeV] \sim \sqrt{E_+[MeV]}$. Unlike all other experiments with a fixed target, which are based on the detecting of e^-e^+ pairs from U-boson decay, ***in the proposed experiment no special assumptions about decay modes of the U-boson are required.*** In this proposal we consider a low luminosity ($\sim 10^{32}$ cm^{-2}s^{-1}) measurement and a combination of on-line and off-line veto on the bremsstrahlung and multi-photon background processes.

In the process $e^+e^- \rightarrow U\gamma$ a measurement of the photon energy and its angle allows a reconstruction of the missing mass spectrum and a search for a peak corresponding to the U-boson. In such a spectrum the dominant signal corresponds to the annihilation reaction $e^+e^- \rightarrow \gamma\gamma$. The signal for the U-boson will be shifted to the area of the continuum (see the illustration in Fig. 1). The continuum part of the event distribution is dominated by photons emitted in a process of positron scattering from an electron or a proton in the target (bremsstrahlung) and by photons from the

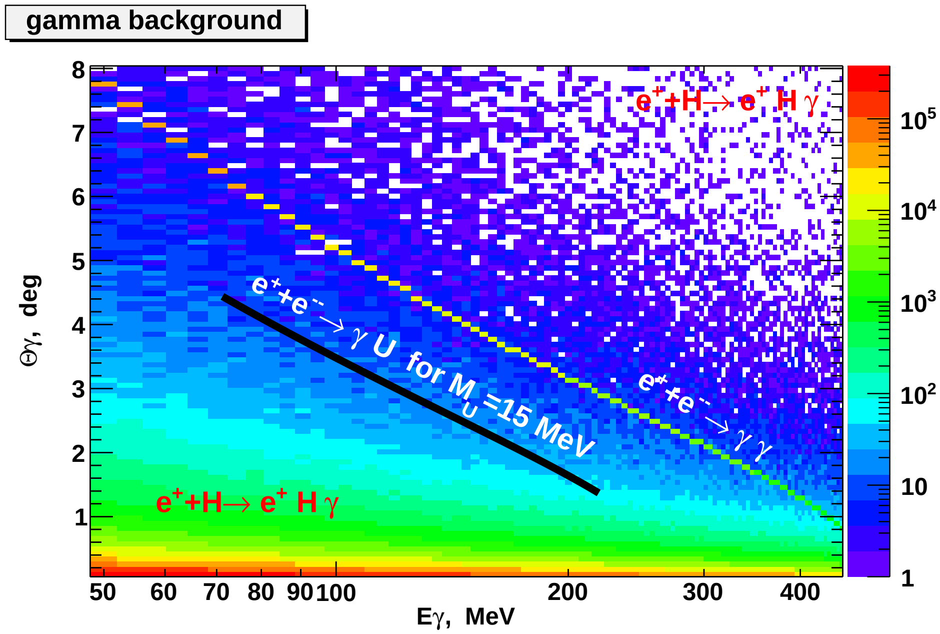

FIG. 1. Two-dimensional distribution of the photon events in the scattering angle and the photon energy for a 500 MeV positron beam incident on a hydrogen gas target. The black band shows the location of U-boson events of 15 MeV mass.

three-photon annihilation process. Contributions of other reactions, e.g. $\gamma^\star p \to p\pi^0 \to p\gamma\gamma$, are at least 3 orders of magnitude smaller than that of positron bremsstrahlung.

A key property of the proposed experimental setup is the ability to suppress the QED background significantly, both on-line and off-line, thus greatly improving the sensitivity of the search.

III. THE KINEMATICS AND CROSS SECTION

Two-photon annihilation is a dominant process of high-energy photon production in e^+e^- collisions at a cms energy of a few tens of MeV. Two reactions, depicted in the left panel of Fig. 2, are two-photon annihilation and the production of an exotic U-boson. The kinematics for the two-

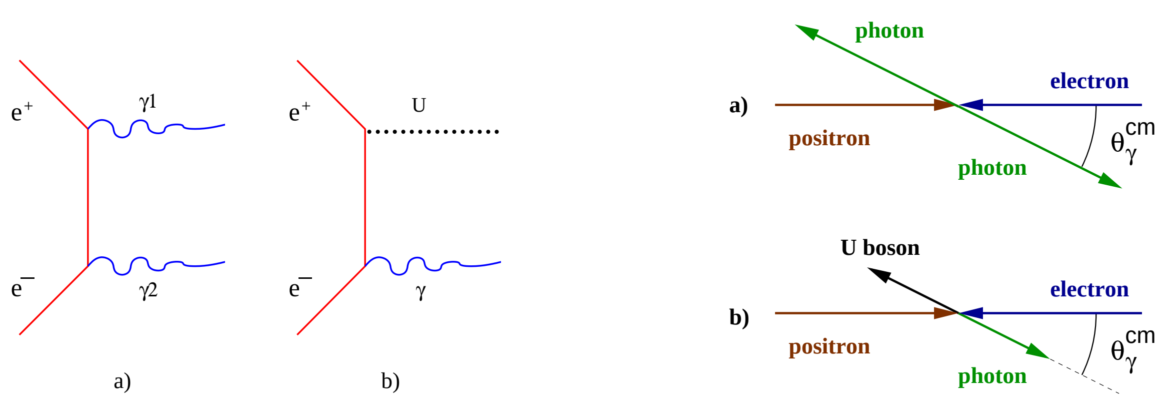

FIG. 2. The diagrams: a) two-photon annihilation, b) the U-boson$-\gamma$ production. The kinematics of $e^+e^- \to \gamma + \gamma$ and $e^+e^- \to U + \gamma$ reactions.

body final state is shown in the right panel of Fig. 2. The energy in the center of mass system $\sqrt{s} = \sqrt{2m^2 + 2E_+ m}$, where m is the electron mass and E_+ the positron energy, and the emission angle of the final photon θ_γ with respect to the direction of the positron beam, defines the value of the photon energy E_γ. In the case of two-photon production: $E^{lab}_{\gamma(\gamma\gamma)} \approx E_+(1 - \cos\theta^{cm}_\gamma)/2$. In the case of U-boson production: $E^{lab}_{\gamma(U\gamma)} = E^{lab}_{\gamma(\gamma\gamma)} \cdot (1 - M^2_U/s)$. The kinematic boost from the cm system to the lab leads to a larger photon energy in the forward direction, which helps the measurement of the photon energy. The large variation of the photon energy with the photon angle in the lab system provides an important handle on the systematics.

Figure 3 shows some correlations between kinematic variables for the proposed setup at VEPP–3.

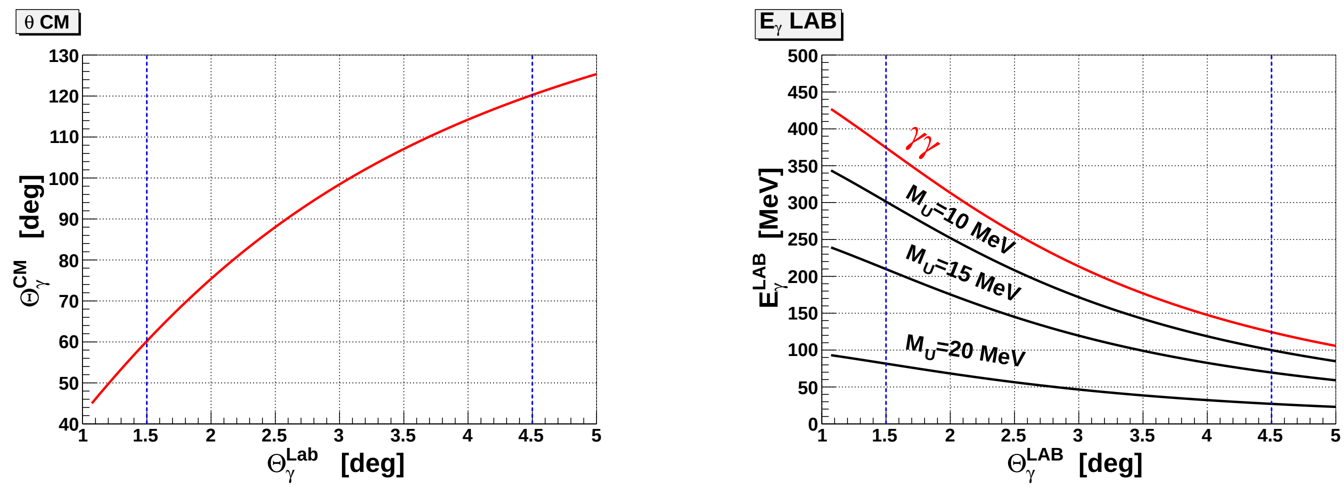

FIG. 3. Kinematic correlations for positron-electron annihilation at $E_+ = 500$ MeV. Left panel: photon polar angle in Lab frame vs. that in CM for two–photon annihilation. Right panel: photon energy vs. its polar angle for $e^+e^- \to \gamma\gamma$ and for $e^+e^- \to \gamma$U. Dotted vertical lines indicate the range covered in the proposed measurements.

The energy spectrum of the photons from the annihilation process in the lab frame is expressed by [31]:

$$\frac{d\sigma}{d\epsilon} = \frac{\pi r_e^2}{\gamma_+}\frac{1}{\epsilon}\left[1 + \frac{2}{\gamma_+} - \epsilon - \frac{1}{\epsilon\gamma_+^2}\right] \tag{1}$$

where $\epsilon = E^{lab}_\gamma/(E_+ + m)$, with $\epsilon_{min} = 1/2\left[1 - \sqrt{(\gamma_+ - 1)/(\gamma_+ + 1)}\right]$ and $\epsilon_{max} = 1 - \epsilon_{min}$.

The main physical background process producing a single photon, hitting the photon detector, is the positron bremsstrahlung. The differential cross section of this reaction in the case of a thin hydrogen target is given by the following expression [32]:

$$\frac{d\sigma_\gamma}{dE_\gamma d\Omega_\gamma} = \frac{4\alpha r_e^2}{\pi}\frac{1}{E_\gamma}\left\{\frac{2y-2}{(1+l)^2} + \frac{12l(1-y)}{(1+l)^4} + \left[\frac{2-2y+y^2}{(1+l)^2} - \frac{4l(1-y)}{(1+l)^4}\right]\right.$$
$$\left.\times\left[1 + 2\ln\frac{2\gamma_+(1-y)}{y} - \left(1 + \frac{2}{B^2}\right)\ln\left(1+B^2\right)\right]\right\}, \tag{2}$$

where $y = E_\gamma/E_+$, $l = \gamma_+^2\theta_\gamma^2$, $B = 4\alpha\gamma_+(1-y)/y(1+l)$.

The expected rate of photons from these processes is shown in Fig. 4

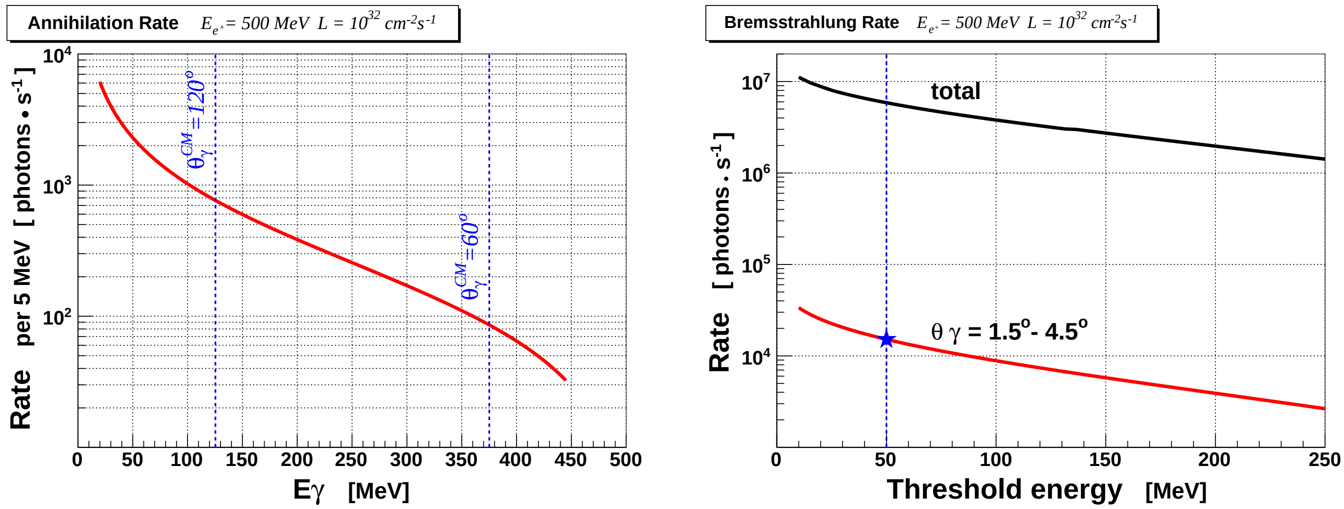

FIG. 4. Expected background photon rates at beam energy $E_+ = 500$ MeV and luminosity $L = 10^{32}cm^{-2}s^{-1}$. Left panel: from positron-electron annihilation. Dotted vertical lines indicate the range covered in the proposed measurements. Right panel: from positron bremsstrahlung on hydrogen. At a 50 MeV threshold, the expected rate for the proposed detector configuration is $1.5 \cdot 10^4\ s^{-1}$.

IV. THE PROPOSED EXPERIMENTAL SETUP

VEPP–3 is an acummulator ring, operating as an intermediate accelerator/storage ring of electrons and positrons for the VEPP-4 collider. The internal target is located in one of the two 12-meter-long straight sections of the VEPP–3 ring. In the same straight section there are also two RF cavities, four quadrupoles and one sextupole lenses, elements of beam injection and ejection. The space available for the internal target equipment is 217 cm long.

The physics program of the VEPP–3 internal target facility is concentrated on measurements of tensor target asymmetries in electro- and photo-reactions on a tensor polarized deuteron [33]. Recently, a measurement of cross-section ratio for the elastic scattering of the positron and electron on the proton was carried out [34]. That measurement demonstrated a reliable operation with the positron beam and the internal hydrogen target during a 4-month run at a luminosity of $\sim 10^{32}$ cm^{-2}s^{-1}. Further improvement of the VEPP–3 performance is anticipated after the commissioning of the VEPP-5 electron/positron injection complex is completed [35]. Besides an increase of the positron injection rate, this new injection scheme will allow up to 18 bunches in VEPP–3, which is essential for the reduction of the probability of accidental veto.

The layout of the proposed experiment at VEPP–3 is presented in Fig. 5. The particle detectors to be used in the proposed experiment and the arrangement of components in the internal target area differ substantially from those used in the previous internal target experiments at VEPP–3.

A. Beam optics

In order to allow the photons of the positron-electron annihilation to pass to the detector without obstruction, a set of dipole magnets will be installed in the beam line.

Dipoles D1, D2 and D3 (see Fig. 5) make up a chicane. The first dipole bends the positron beam by an angle of 10° toward the ring center. The target is placed behind the D1 magnet. The second dipole D2 bends the beam outward from the ring center by 20° and sweeps scattered positrons and other charged particles produced in the target away from the photon detector, while photons are flying to the detector and passing only through a thin beryllium window. Finally, the third dipole, D3, is used to rotate the positron beam back to the VEPP–3 beam line.

A similar structure with 3 dipole and 2 quadrupole magnets is now under construction to be used for the tagging of almost-real photons in measurements of tensor target asymmetries in photodeuteron reactions with a polarized deuterium target [33]. The D1, D3, Q1 and Q2 magnets from the Tagger can be directly used in the proposed experiment. However, the D2 magnet has to be modified substantially, or even constructed from scratch, because its aperture must be significantly larger than is required for the Tagger. Furthermore, some sections of vacuum chamber have to be replaced with new ones specially designed and manufactured for the proposed experiment.

B. Internal target

A thin-walled open-ended storage cell cooled to 25°K and filled with hydrogen gas will be used as an internal target. Two additional quadrupoles Q1 and Q2 serve to compress the transverse size of the positron beam inside the storage cell, thus allowing the use of a small–opening cell. Together with cell cooling, this permits us to obtain the required target thickness with a smaller amount of hydrogen gas injected into the target. The gas leaks out of the cell ends into the ring vacuum chamber and must be pumped out promptly. Four powerful pumps will be installed, two in the target chamber, one upstream and one downstream from the target chamber.

C. Photon detector

The photon detector can be placed at a distance of between 4 m and 8 m from the target. The requirements for the detector are:

- Energy resolution on the level of $\sigma_E/E = 5\%$ for photons with energy $E_\gamma = 100 - 450$ MeV.
- Angular resolution on a level of $0.1°$.
- Angular acceptance as defined by a requirement to detect both photons from two-photon annihilation:
  - in ϕ : either total 2π, or two symmetrical sectors, e.g. (ϕ_1, ϕ_2) and $(\phi_1 + \pi, \phi_2 + \pi)$;
  - in θ : symmetrical range in θ_γ^{CM} around 90°, e.g. $\theta_\gamma^{CM} = 60° - 120°$, which corresponds to $\theta_\gamma^{LAB} = 1.5° - 4.5°$.
- The detector should be able to sustain a modest photon rate of several hundred kHz over its whole area.

We are considering two examples for the calorimeter:

1. The electromagnetic calorimeter of the PRIMEX experiment at JLab [36] consists of 1152 lead–tungstate ($PbWO_4$) scintillating crystals of $2.05\times2.05\times18$ cm^3 size ($20.2X_0$), surrounded with 576 lead glass blocks of $3.8 \times 3.8 \times 45$ cm^3 size ($10.3X_0$). In the PRIMEX experiment γ-quanta with an energy of a few GeV were detected with resolutions $\delta E/E = 2\%$ and $\delta x = 1.2$ mm at $E_\gamma = 2$ GeV for PbWO crystals and $\delta E/E = 4.5\%$ and $\delta x = 3.7$ mm for Lead Glass blocks.

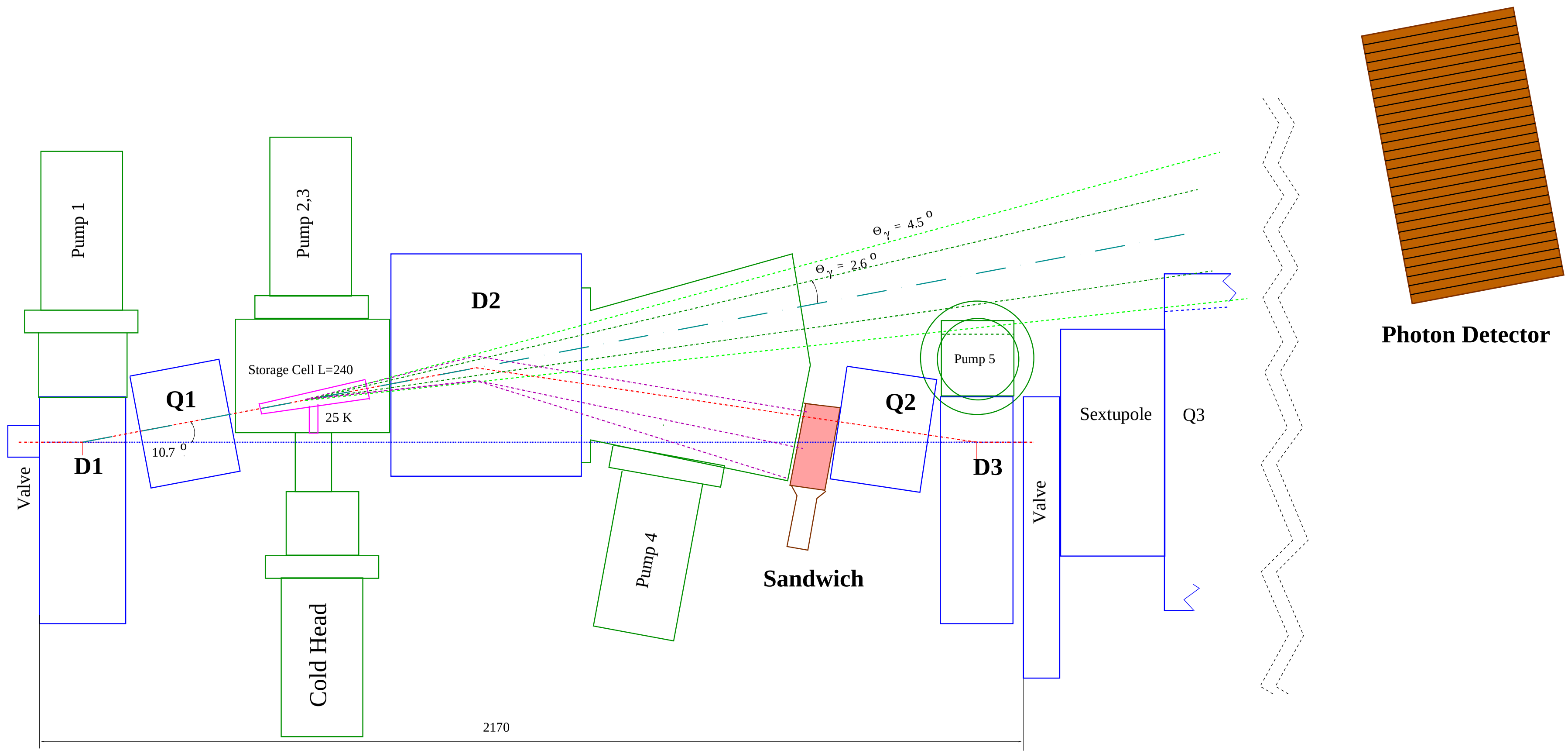

FIG. 5. The layout of the proposed experiment at VEPP–3

There is no direct measurement of PRIMEX calorimeter energy and angular accuracy at photon energy below 1 GeV, but this can be estimated by extrapolating the energy dependence measured for 1–5 GeV. Thus, for $E_\gamma = 200$ MeV one obtains :
– $\delta E/E = 5.7\%$ and $\delta x = 2.5$ mm for $PbWO_4$ crystals
– $\delta E/E = 13\%$ and $\delta x = 11$ mm for Lead Glass blocks.

Although the accuracy of such an estimation is questionable, there is still a clear indication that the performance of Lead Glass blocks is not adequate for the proposed experiment, and one should plan to use the inner part of the PRIMEX calorimeter, containing the lead–tungstate crystals only. That defines the usable area of the photon detector based on the PRIMEX calorimeter as 70×70 cm^2. Therefore, the calorimeter must be installed not farther than 4 m from the target in order to cover the polar angular range of 4.5°.

As the $PbWO_4$ crystal light yield is highly temperature dependent ($\sim 2\%/^o$C at room temperature), temperature stabilization of the calorimeter is mandatory. Throughout the PRIMEX experiment, the calorimeter was operated at a temperature of 14 ± 0.1^oC, which was maintained by the circulation of a cool liquid around the outer body of the calorimeter assembly.

2. The electromagnetic calorimeter of the CLEO-II detector [37] consists of 8000 CsI(Tl) crystals of $5 \times 5 \times 30$ cm^3 size ($16.2X_0$). It is used to measure electron and photon energy in a wide range; therefore, a direct measurement of its performance at a photon energy of interest for the proposed experiment is available:

$$\delta E/E = 3.8\% \;\text{ and }\; \delta x = 12 \text{ mm} \quad \text{for } E_\gamma = 180 \text{ MeV}$$

One can see that in the energy range of the proposed experiment, a CsI(Tl)–based calorimeter provides better energy resolution but worse spatial resolution than that based on PWO_4–crystals. Therefore, the CsI(Tl)–calorimeter must be placed as far as possible from the target, i.e. about 8 m. In this case it would take about 800 crystals to cover the required angular range. A few notes on this detector option should be mentioned:
– The CLEO-II calorimeter assembly is clearly inappropriate for the proposed experiment, so a mechanical support must be designed and constructed;
– CsI(Tl) crystal has a long light emitting time. Therefore, its ability to work at high background rate is limited. However, due to the relatively small luminosity of the proposed experiment as well as the high segmentation of the calorimeter, a long output pulse seems not to be a problem. Even for crystals covering the lowest polar angle, the expected rate of background photons is estimated to be at a few kHz level for the luminosity of 10^{32}cm^{-2}s^{-1}. However, it is supposed that the performance of these crystals will slowly deteriorate as the experiment luminosity is increased.

Both calorimeters are equipped with front-end electronics and FastBus–based DAQ suitable for use in the proposed experiment.

In Fig. 6 a top view of the VEPP–3 hall in the vicinity of the internal target equipment and possible locations of the photon detector are shown.

It seems that the best detector performance would probably be achieved by using a combination of PRIMEX and CLEO-II calorimeters, placed at an 8 m distance from the target. In such a calorimeter the $PbWO_4$ crystals should be installed at a very small polar angle, where photons have the highest energy, thus providing better angular accuracy, sufficient energy resolution and high rate capability, while the CsI(Tl) crystals should cover larger polar angles, where photon rates are much lower, providing better resolution at smaller photon energy.

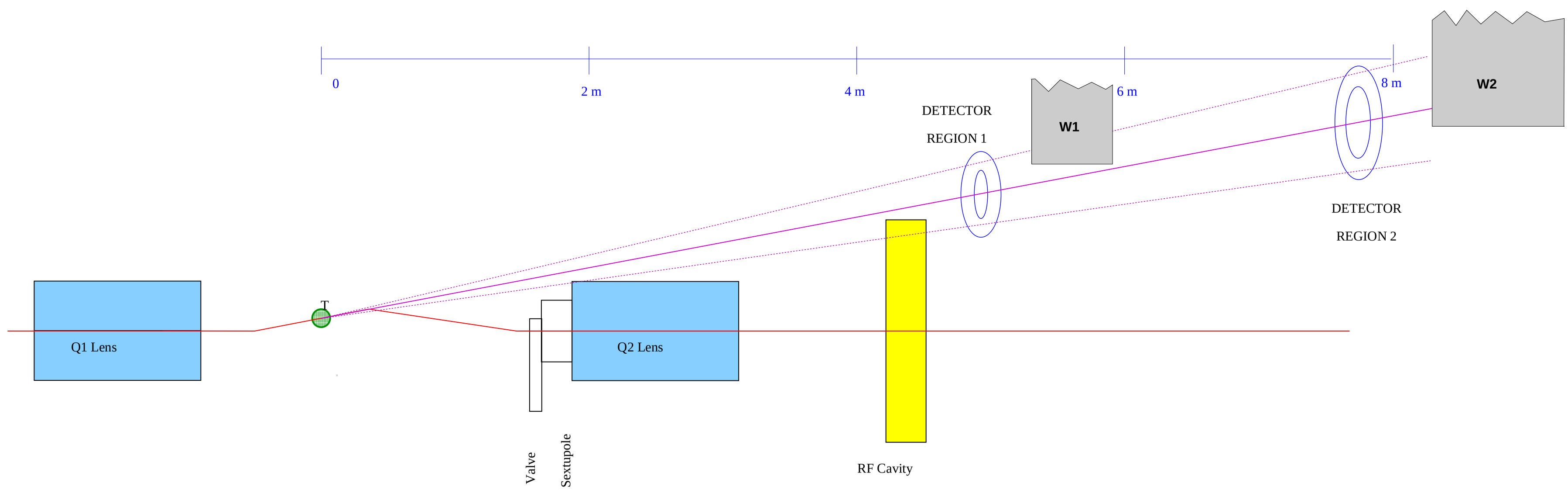

FIG. 6. Top view at the VEPP–3 area close to the internal target equipment. Two possible locations of the photon detector are indicated. The RF cavity will be removed; it is not needed for VEPP–3 when the injection complex is operating. W1 (concrete wall) and Q2 (quadrupole lens) will be machined around the VEPP–3 median plane to provide a free path for photons to the detector.

The experiment will require a careful account of the detector responses. The energy response will be calibrated by using $\gamma-\gamma$ coincidence events produced with the hydrogen target. These data will also provide a detector line shape determination. The use of the electron beam instead of the positron beam provides a way to obtain the "white" photon spectra without the U-boson signal and the two-photon line.

The left panel of Fig. 7 shows the result of a calculation of the photon spectra for the case of an internal hydrogen gas target of $6.5 \cdot 10^{14}$ at/cm^2 thickness ($3 \cdot 10^{-11} X_0$), positron beam current of 25 mA (i.e. a luminosity of 10^{32}cm^{-2}s^{-1}) and a 500 MeV positron beam energy. The intensity of the background process in the proposed type of search is about 30-100 times below the annihilation process, $e^+e^- \rightarrow \gamma\gamma$, whose peak is moving with the scattering angle. In the case of an electron beam (Fig. 7, right panel), the energy spectrum is smooth; this will be used for the calibration of the detector response.

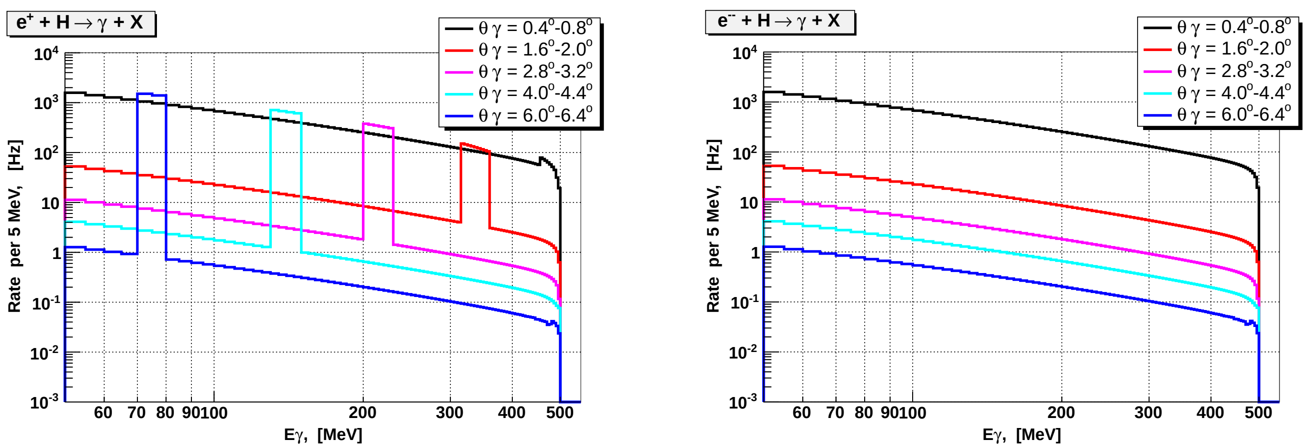

FIG. 7. The photon spectra in the case of a positron beam (left panel) and an electron beam (right panel) incident on an internal hydrogen target with a $6.5 \cdot 10^{14}$ at/cm^2 thickness. Beam energy is 500 MeV and beam current is 25 mA in both cases. Bumps on the left panel, whose positions are moving with the scattering angle, are due to positron-electron annihilation process.

D. Positron veto counter

The main single–photon QED background comes from positron bremsstrahlung on hydrogen. Since in this process the positron is losing energy and is swept out by the D2 dipole magnet, such background events can be vetoed by detecting the scattered positron. For this purpose, compact sandwich counters will be installed downstream from the D2 magnet. To be able to detect as many scattered positrons as possible, the veto detector will be placed at the largest possible distance from the target–110 cm, right before the Q2 quadrupole lens, see Fig. 5. The layout of the sandwich counters is shown in Fig. 8.

The total rate of positrons emitting a photon with energy above the $E_\gamma = 50$ MeV threshold can be estimated by integrating Eq. 2. For the luminosity of $L = 10^{32}$ the rate is 6 MHz, see Fig. 4. If VEPP–3 is operating in a single-bunch regime, this would mean that a bremsstrahlung photon with $E_\gamma > 50$ MeV is emitted every time the beam passes through the target. The veto counter would be useless at this luminosity if it detected all positrons including those which emit photons outside the photon detector acceptance.

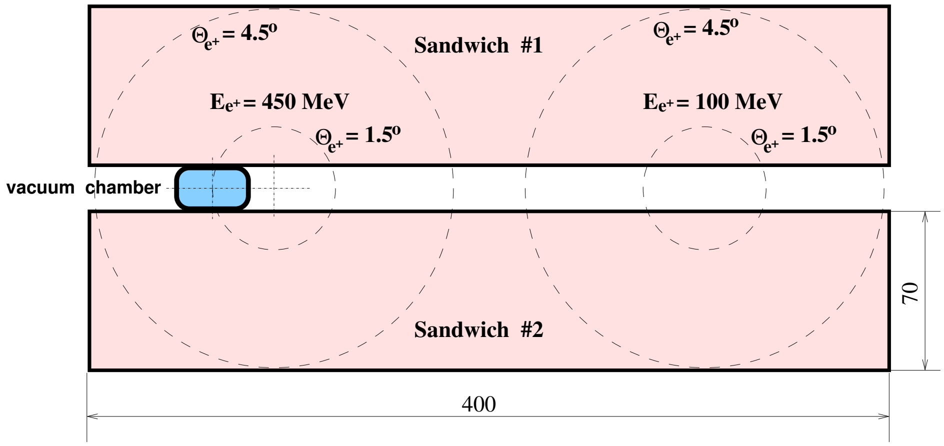

FIG. 8. The layout of the sandwich detectors

This is why the veto counter consists of two identical parts placed above and below the VEPP–3 vacuum chamber. The vertical gap between the two parts is equal to the height of the vacuum chamber ~ 2 cm and corresponds to the polar angle of 9 mr $= 9 \cdot \gamma_+^{-1}$ for positrons scattered in the vertical plane. Due to this gap, positrons which scatter at a very small angle will not be detected. This reduces dramatically the counting rate of the veto counter and makes the anticoincidence with the photon detector feasible. However, a part of the positrons which scatter at the angles of interest ($\theta = 1.5° - 4.5°$) close to the VEPP–3 median plane will also miss the veto counter, and the emitted photons will not be discarded. To avoid this, a similar horizontal "band" in the photon detector will be excluded from the trigger and analysis. A loss in the ϕ–acceptance due to the gap is only about 20%; it can be compensated for by increasing the experimental luminosity, which is now not limited by the rate of the veto counter.

The sandwich detector will be composed of 15 layers of 3 mm thick Tungsten + a 2 mm thick plastic scintillator, for a total thickness of $15X_0$. The expected efficiency for detecting a positron in an energy range 100–450 MeV is above 98%. Therefore, the events from the bremsstrahlung process will be suppressed by a factor of 50.

E. Online trigger and data rate

The operation of the main on-line trigger will be based on the following logic:

- threshold on minimum energy deposition in calorimeter, $E_{\rm cal} > 50$ MeV;
- veto on positron with energy above 100 MeV detected in the veto counter;
- veto on maximum energy deposition in the calorimeter, $E_{\rm cal} < 450$ MeV.

The expected rate of the photon trigger is about 50 kHz. Assuming a conservative value for the on-line suppression factor of 10 for combined veto-channels, one obtains a 5 kHz final trigger rate, which is reasonably low for the FastBus-based data acquisition system, giving a dead time loss below 5%. With an expected maximum channel occupancy of 20% the data rate will be 4 Mb/s, well below the FastBus specifications. Therefore, the readout will not contribute to the dead time, provided that the event buffering is enabled.

V. RUN TIME AND THE PROJECTED SENSITIVITY

The internal hydrogen target and positron beam at VEPP–3 allows a routine operation at a luminosity of at least 10^{32} cm^{-2}s^{-1} with the possibility of increasing by a factor of 5-10. Considering positron beam energy of 500 MeV, scattering angles $\theta^{CM} = 90^\circ \pm 30^\circ$ and a luminosity of 10^{32} cm^{-2}s^{-1}, the photon rate from the annihilation process will be 30 kHz. In a **six-month** run the total accumulated statistics will be $3.5 \cdot 10^{11}$ events, assuming 75% efficiency of time utilization.

The continuum background is mainly due to positron bremsstrahlung on hydrogen which is suppressed by at least a factor of 50 using the veto on detected scattered positrons and discarding all events with more than one photon in the photon detector. Assuming the relative energy resolution of the photon detector to be about 5%, we will use a 15%-wide energy bin for the search window. The background rate in a 15% photon energy interval after the off-line suppression is estimated to be 0.08% of the annihilation photon rate. Therefore, the statistical uncertainty in the number of background events will be $1.7 \cdot 10^4$. The U-boson signal with the number of events equal to background statistical fluctuation corresponds to $4.8 \cdot 10^{-8}$ of the annihilation events, giving a square of coupling constant $\mathbf{|f_{eU}|^2 = 2.2 \cdot 10^{-9}}$. Such sensitivity will present up to **a three orders** improvement for the limit on the $\mathbf{|f_{eU}|^2}$ compared to the one obtained from the measurement of the electron anomalous magnetic momentum g_e–2, assuming the vector coupling to electron and the mass $m_U \approx 15$ MeV.

Figure 9 shows a plot of the coupling constant ratio α'/α versus the mass of the new boson m_U. A region which will be accessible for the search in the proposed experiment is outlined, together with some other completed and proposed measurements. (Note that $\alpha'/\alpha = |f_{eU}|^2/4\pi\alpha$).

VI. SUMMARY

We propose a sensitive search of an exotic U-boson using a missing mass reconstruction in a positron-electron annihilation, utilizing the VEPP–3 internal target facility and the VEPP-5 positron/electron injection complex at the Budker Institute of Nuclear Physics, Novosibirsk, Russia.

The key features of the proposed measurement are:

- the missing mass method, in which no assumptions about decay modes of the U-boson are required;
- the mass range for the proposed search is 5-20 MeV, which is not accessible in most other proposed fixed-target or colliding-beam approaches;
- relatively low experimental luminosity ($\sim 10^{32}$cm^{-2}s^{-1}) allows the use of available detectors and conventional data acquisition;
- the use of a veto-detector for scattered positrons and a symmetric (in ϕ_γ and $\theta_\gamma^{\rm CM}$) photon detector permits a suppression of the QED background by a factor of 50-100, resulting in the increase of the search sensitivity by one order of magnitude.

The projected sensitivity for the square of the coupling constant of the U-boson to electron is $|f_{eU}|^2 = 1.1 \cdot 10^{-8}$ at $m_U = 15$ MeV with a signal-to-noise ratio of five to one.

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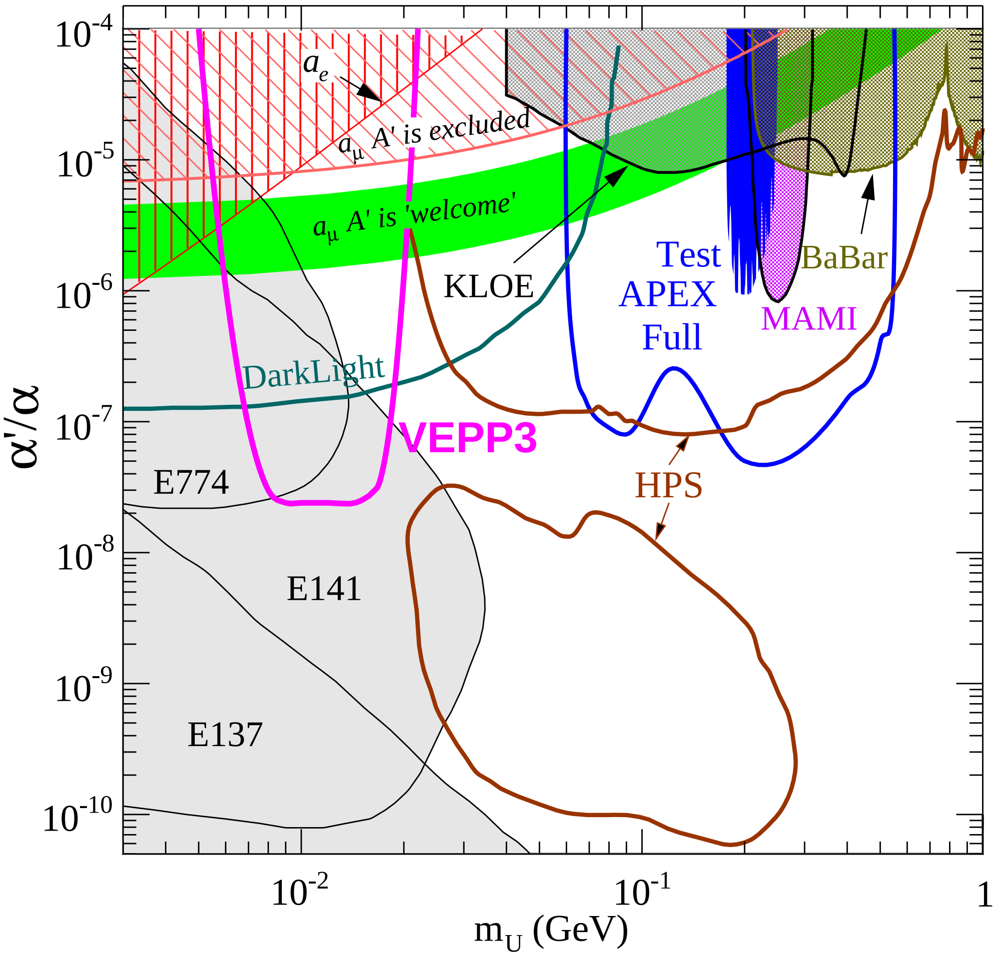

FIG. 9. Existing and projected upper limits of a coupling constant of a new boson to lepton vs. its mass. The shaded areas are the results of the completed direct searches: beam dump experiments at SLAC: E137, E141, E774 [38, 39]; e^+e^- colliding beam experiments: BaBar [16], KLOE [17]; fixed–target experiments: MAMI [23], APEX Test run [22]. The hatched areas are regions excluded by the results of the measurements of anomalous magnetic moments of electron and muon [8]. The green band indicates a "welcome" area, where the consistency of theoretical and experimental values would improve to 2σ or less [8]. Curves show areas of search of other proposed experiments: Full APEX [24], HPS [25], DarkLight [26] and the proposed experiment (VEPP3). Note that the beam dump experiments have sensitivity only for the processes with the visible decays of the U-boson. Therefore, they don't guarantee a total exclusion of a new boson, and the projected VEPP–3 results will provide explicitly new data even in the regions already checked by those measurements.

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