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Searching for a new force at VEPP–3

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We propose an experiment to search for a new gauge boson, A′, in e^+e^- annihilation by means of a positron beam incident on a gas hydrogen target internal to the VEPP–3 storage ring. The search method is based on a missing mass spectra in the reaction $e^+e^- \to \gamma \mathrm{A}'$. It allows observation of the A′ signal independently of its decay modes and life time. The projected result of this experiment corresponds to an upper limit on the square of coupling constant $|f_{e\mathrm{A}'}|^2 = 1\cdot 10^{-8}$ with a signal-to-noise ratio of five to one at an A′ mass of 15 MeV.

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I. INTRODUCTION

The search for an experimental signature of physics beyond the Standard Model is a major effort of modern particle physics, see e.g.[1]. 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[2,3], there could be extra U(1) symmetry, which requires a new gauge boson, U, also called the A′-boson. The boson could be light and weakly interacting with known particles. Most constraints for the light A′-boson parameters were obtained from electron and muon anomalous magnetic moments $(g-2)$ and particle decay modes[4–7].

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[4,6,8,9]. The possible connection between the A′-boson and dark matter in view of the observed slow positron abundance has been investigated for several years and is often referred to as MeV dark matter (MDM)[10–13]. The theory of dark matter proposed by N. Arkani-Hamed and collaborators[8], which provided an interpretation of a number of key astrophysical observations, sparked additional interest in a A′-boson search in the mass range below 1 GeV.

Several methods were used in the search for the A′-boson signal, considering "invisible" decay modes of the A′-boson. Therefore, they result in an upper limit for $f_{qA'} \times B_{[A' \to invisible]}$. 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 A′-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 A′-boson. A recent experiment[14] using statistics of $1.2 \cdot 10^8$ $\Upsilon(3S)$ events provided the best data for $\Upsilon(3S)$ decay to $A^0 + \gamma$ and a limit on the coupling of the A′-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 $3 \cdot 10^{-6}$, here the A^0 notation used as in paper[14], from which the limit $f_{bA^0} < 4 \cdot 10^{-7} m_{A^0}\,[\text{MeV}]$ was obtained[5]. An additional hypothesis of coupling constants universality is required to get a bound on f_{eA^0}, 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 $f_{\mathrm{eA'}} < 1.0 \cdot 10^{-4} \cdot m_{\mathrm{A'}}$ [MeV][6,7].

A direct measurement of $f_{eA'}$ and $\mathbf{m}_{\mathbf{A'}}$ could be made by detecting the decay of the A′-boson to an electron-positron pair and reconstructing the e^+e^- invariant mass. It requires a significant branching of A′-boson decay to the e^+e^- pair. A complication of this method is the high level of electromagnetic background in the mass spectrum of e^+e^-, so such a measurement requires large statistics. Recently the data sets accumulated in collider experiments have been used for such an analysis[13,15,16].

Electron 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[17–20]. 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[21,22]. The APEX experiment in JLab Hall A[23] 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 fixed-target experiments are planned: at Jefferson Lab, including the Heavy Photon Search (HPS)[24] and DarkLight[25]; at MAMI[21].

A sensitive A′-boson search could be performed with a low energy e^+e^- collider[9], 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 A′-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^+)–beam 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[26,27]. The VEPP–3 electron/positron storage ring at the Budker Institute at Novosibirsk[28], 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 A′-boson in a mass range $\mathbf{m}_{\mathbf{A'}} = \mathbf{5 - 20}$ 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 $\mathbf{e^+e^- \to \gamma A'}$ in an energy range $\mathbf{E_\gamma = 50 - 400}$ MeV and angular range $\theta_\gamma^{\mathbf{CM}} = \mathbf{90^\circ \pm 30^\circ}$ ($\theta_\gamma^{\mathbf{Lab}} = \mathbf{1.5^\circ - 4.5^\circ}$).