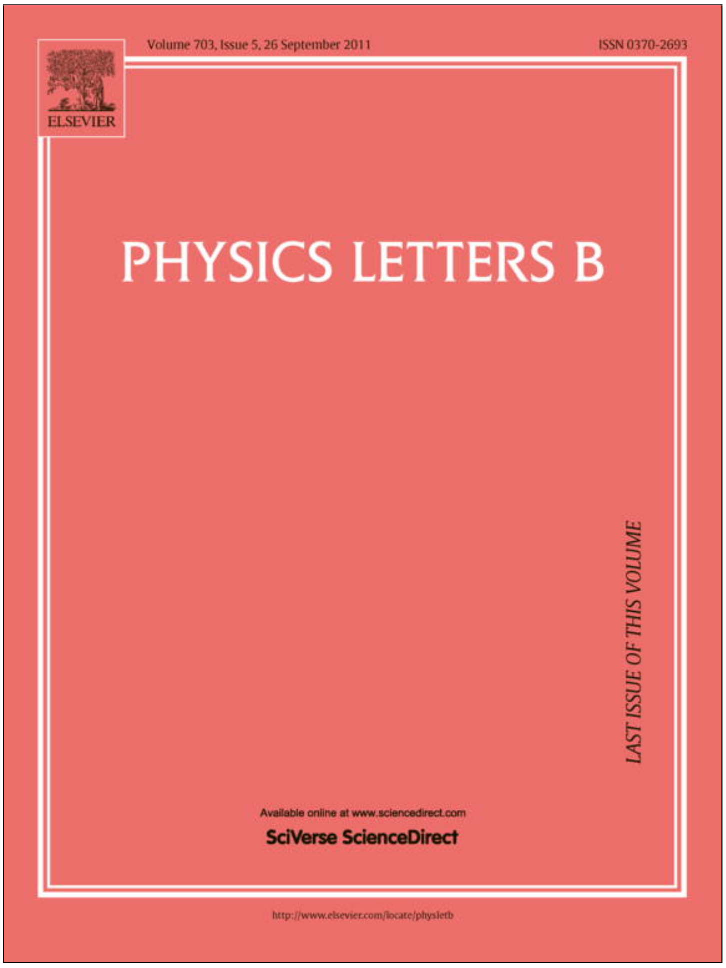
Volume 703, Issue 5, 26 September 2011
ISSN 0370-2693
ELSEVIER
PHYSICS LETTERS B
LAST ISSUE OF THIS VOLUME
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Physics Letters B 703 (2011) 543–546

Contents lists available at SciVerse ScienceDirect

Physics Letters B

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Search for narrow resonances in e^+e^- annihilation between 1.85 and 3.1 GeV with the KEDR detector

V.V. Anashin [a], V.M. Aulchenko [a,b], E.M. Baldin [a,b], A.K. Barladyan [a], A.Yu. Barnyakov [a], M.Yu. Barnyakov [a], S.E. Baru [a,b], I.Yu. Basok [a], O.L. Beloborodova [a,b], A.E. Blinov [a,*], V.E. Blinov [a,c], A.V. Bobrov [a], V.S. Bobrovnikov [a], A.V. Bogomyagkov [a,b], A.E. Bondar [a,b], A.R. Buzykaev [a], S.I. Eidelman [a,b], D.N. Grigoriev [a], Yu.M. Glukhovchenko [a], V.V. Gulevich [a], D.V. Gusev [a], S.E. Karnaev [a], G.V. Karpov [a], S.V. Karpov [a], T.A. Kharlamova [a,b], V.A. Kiselev [a], V.V. Kolmogorov [a], S.A. Kononov [a,b], K.Yu. Kotov [a], E.A. Kravchenko [a,b], V.N. Kudryavtsev [a], V.F. Kulikov [a,b], G.Ya. Kurkin [a,c], E.A. Kuper [a,b], E.B. Levichev [a,c], D.A. Maksimov [a], V.M. Malyshev [a], A.L. Maslennikov [a], A.S. Medvedko [a,b], O.I. Meshkov [a,b], S.I. Mishnev [a], I.I. Morozov [a,b], N.Yu. Muchnoi [a,b], V.V. Neufeld [a], S.A. Nikitin [a], I.B. Nikolaev [a,b], I.N. Okunev [a], A.P. Onuchin [a,c], S.B. Oreshkin [a], I.O. Orlov [a,b], A.A. Osipov [a], S.V. Peleganchuk [a], S.G. Pivovarov [a,c], P.A. Piminov [a], V.V. Petrov [a], A.O. Poluektov [a], V.G. Prisekin [a], A.A. Ruban [a], V.K. Sandyrev [a], G.A. Savinov [a], A.G. Shamov [a], D.N. Shatilov [a], B.A. Shwartz [a,b], E.A. Simonov [a], S.V. Sinyatkin [a], A.N. Skrinsky [a], V.V. Smaluk [a,b], A.V. Sokolov [a], A.M. Sukharev [a], E.V. Starostina [a,b], A.A. Talyshev [a,b], V.A. Tayursky [a], V.I. Telnov [a,b], Yu.A. Tikhonov [a,b], K.Yu. Todyshev [a,b], G.M. Tumaikin [a], Yu.V. Usov [a], A.I. Vorobiov [a], A.N. Yushkov [a], V.N. Zhilich [a], V.V. Zhulanov [a,b], A.N. Zhuravlev [a,b]

[a] *Budker Institute of Nuclear Physics SB RAS, Novosibirsk 630090, Russia*
[b] *Novosibirsk State University, Novosibirsk 630090, Russia*
[c] *Novosibirsk State Technical University, Novosibirsk 630092, Russia*

ARTICLE INFO

Article history:
Received 13 July 2011
Received in revised form 7 August 2011
Accepted 8 August 2011
Available online 24 August 2011
Editor: M. Doser

Keywords:
Narrow resonances

ABSTRACT

We report results of a search for narrow resonances in e^+e^- annihilation at center-of-mass energies between 1.85 and 3.1 GeV performed with the KEDR detector at the VEPP-4M e^+e^- collider. The upper limit on the leptonic width of a narrow resonance $\Gamma^R_{ee} \cdot \mathrm{Br}(R \to hadr) < 120$ eV has been obtained (at 90% C.L.).

1. Introduction

After the J/ψ discovery, a search for other narrow resonances was performed in several experiments. The energy range between J/ψ and Υ mesons was explored with MARK-1 at SPEAR [1], LENA at DORIS [2], and MD-1 at VEPP-4 [3]. The upper limit on the leptonic width of narrow resonances obtained in these analyses varied between 15 and 970 eV depending on energy. Searches in the energy range below J/ψ mass and down to 1.42 GeV were performed only in experiments at ADONE [4–10] with upper limits of about 500 eV. Recently the latter energy region was revisited by the KEDR Collaboration [11] in view of a discovery of unexpected exotic states above the charm threshold, including the narrow $X(3872)$ state, which proved that surprises are still possible even at low energies [12]. This Letter reports results of a search for narrow resonances in e^+e^- annihilation in the center-of-mass (c.m.) energy range 1.85–3.1 GeV. The experiment was performed at the VEPP-4M e^+e^- collider in Novosibirsk in 2009 and 2010.

The outline of this Letter is as follows. In Section 2 we describe our apparatus and trigger conditions. Section 3 describes the experiment. Section 4 deals with hadronic event selection. Section 5

* Corresponding author.
E-mail address: A.E.Blinov@inp.nsk.su (A.E. Blinov).

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doi:10.1016/j.physletb.2011.08.016

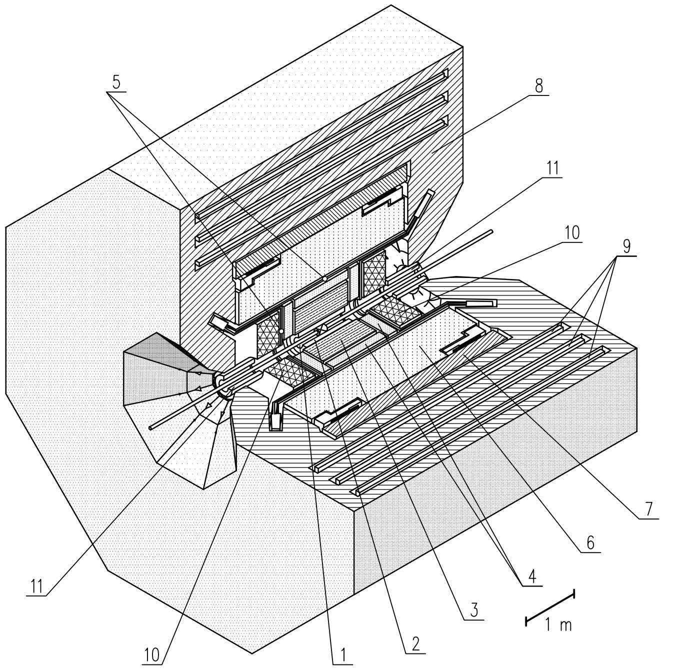

Fig. 1. KEDR detector. 1 — vacuum chamber, 2 — vertex detector, 3 — drift chamber, 4 — threshold aerogel counters, 5 — ToF-counters, 6 — liquid krypton calorimeter, 7 — superconducting coil (0.6 T), 8 — magnet yoke, 9 — muon tubes, 10 — CsI-calorimeter, 11 — compensation solenoid.

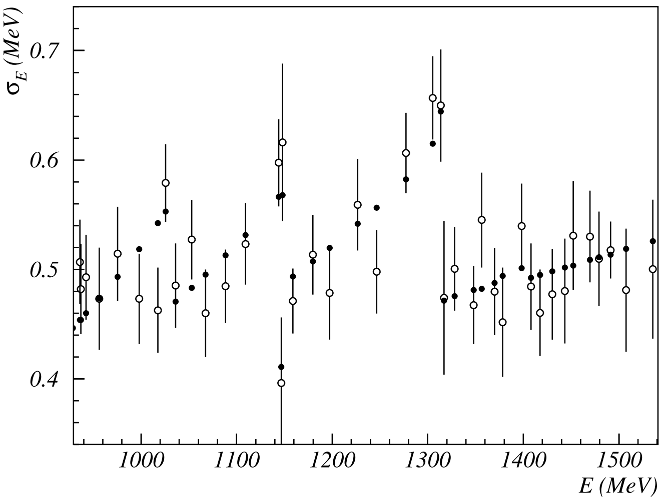

Fig. 2. The beam energy spread $\sigma_E(E_{beam})$ dependence on the beam energy. Open circles — values of σ_E, obtained from σ_z of the interaction region. Black points — fit of $\sigma_E(E_{beam})$ based on the currents in major magnetic elements.

covers a fit procedure and results while Section 6 is reserved for conclusions.

2. VEPP-4M collider and KEDR detector

The electron–positron accelerator complex VEPP-4M [13] is designed for high-energy physics experiments in the c.m. energy range (W) from 2 to 12 GeV. The collider consists of two half-rings, an experimental section where the KEDR detector is installed, and a straight section, which includes an RF cavity and injection system. The luminosity at the J/ψ in an operation mode with 2 by 2 bunches reaches 1.5×10^{30} cm^{-2}s^{-1}.

One of the main features of the VEPP-4M is its capability to precisely measure beam energy using two techniques [14]: resonant depolarization and infrared light Compton backscattering. The accuracy of VEPP-4M energy determination with resonant depolarization reaches $\simeq 10$ keV in the J/ψ region [15]. However, such measurement is time-consuming and requires dedicated calibration runs without data taking. A new technique developed at the BESSY-I and BESSY-II synchrotron radiation sources [16,17] was adopted for VEPP-4M in 2005. It employs the infrared light Compton backscattering and has worse precision compared to the resonant depolarization (50–70 keV in the J/ψ region), but unlike the latter can be used during data taking [14].

The KEDR detector (Fig. 1) is described in detail elsewhere [18]. It includes a tracking system consisting of a vertex detector and a drift chamber, a particle identification system of aerogel Cherenkov counters and scintillation time-of-flight counters, and an electromagnetic calorimeter based on liquid krypton in the barrel and CsI crystals in the endcap. The superconducting solenoid provides a longitudinal magnetic field of 0.6 T. A muon system is installed inside the magnet yoke. The detector also includes a high-resolution tagging system for studies of two-photon processes. The online luminosity measurement is performed with two sampling calorimeters which detect photons from the process of single bremsstrahlung.

A trigger of the KEDR detector consists of two levels: primary and secondary. Both operate at the hardware level and are designed to provide high efficiency for events with two charged tracks. A primary trigger uses signals from the time-of-flight counters and calorimeters as inputs, and the typical rate is 5–10 kHz. It can be fired by one of the following conditions: two separated time-of-flight counters or one time-of-flight counter and one cluster in the endcap calorimeter or two clusters in the opposite endcap calorimeters or one cluster in the barrel calorimeter. A secondary trigger uses signals from the vertex detector, drift chamber, and muon system in addition to the systems listed above, and the rate is 50–150 Hz.

3. Experiment description

The experiment was performed in 2009 and 2010. The energy scan started just above the J/ψ and finished at $W = 1.85$ GeV. The beam energy E_{beam} was measured by the Compton backscattering technique described in Section 2. In order to maximize luminosity, parameters of the magnetic structure of VEPP-4M were readjusted periodically with decreases of the beam energy. This caused non-trivial dependence of the beam energy spread σ_E on E_{beam}. The spread σ_E was measured using its relation with the longitudinal size of the interaction region σ_z. The values of $\sigma_E(E_{beam})$ and their fit, based on the currents in major magnetic elements, are shown in Fig. 2.

A search for narrow resonances was conducted by automatic decrease of the c.m. energy by about $2\sigma_W$ (1.4–1.9 MeV) steps after collection of required integrated luminosity at each point. In order to get energy-independent sensitivity in terms of Γ^R_{ee}, an integrated luminosity per energy point varied from 0.3 nb^{-1} in the upper part of the energy range to 0.12 nb^{-1} in the lower one. The data taken at each energy were analyzed on line. In order to improve sensitivity, an integrated luminosity was doubled at the energy points with significant excess of candidate events.

Luminosity was monitored using the process of single bremsstrahlung, while the analysis uses the offline measurement based on elastic e^+e^- scattering in the endcap calorimeter. A total integrated luminosity $\int L\,dt \simeq 300$ nb^{-1} was collected.

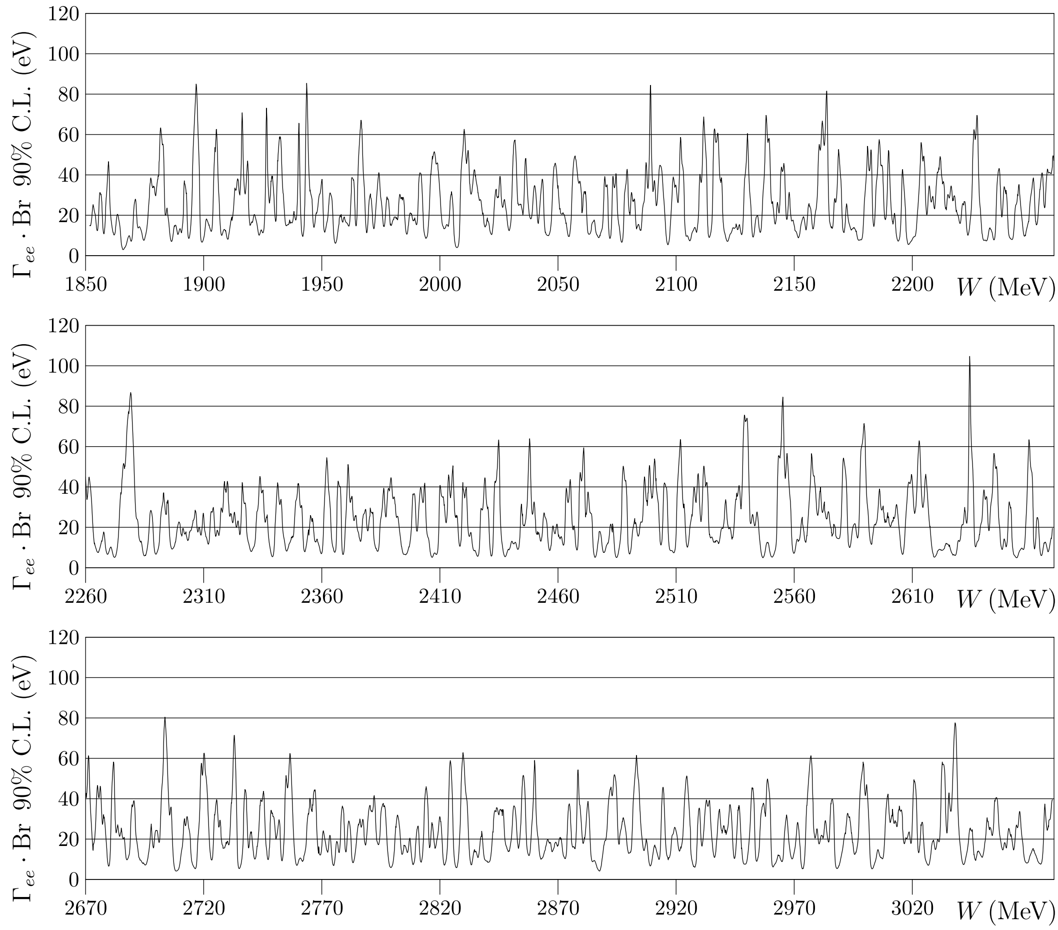

Fig. 3. W-dependence of 90% C.L. upper limit on $\Gamma^R_{ee} \cdot \mathrm{Br}(R \to hadr)$.

4. Event selection

The event selection has two stages. At the first stage we define the following track-level criteria for charged tracks:

1. The distance of the track's closest approach to the beam in the transverse plane and along the beam axis should be less than 0.5 and 10 cm, respectively;
2. The energy deposited by the track in the barrel liquid krypton calorimeter is above 20 MeV.

At the second stage the following event-selection criteria, which take into account both tracking and calorimetric information, were applied:

1. The total energy deposited in the calorimeter is above 400 MeV;
2. At least two charged tracks in the event satisfy the first of the track-level criteria;
3. At least one "good" charged track satisfies both track-level criteria;
4. There is a charged track acoplanar to the "good" one: $|\Delta\phi - \pi| > 0.15$ rad;
5. Aplanarity of event (a sum of momenta transverse to the "event plane") is above $0.1E_{beam}$;
6. There are less than 4 hits in the muon chambers;
7. $|\Sigma p_z/\Sigma E| < 0.5$, where Σp_z and ΣE are the total longitudinal momentum and energy of all particles, respectively.

Condition 4 rejects cosmic rays, Bhabha, and dimuon events. Condition 5 rejects radiative Bhabha events and dimuons. Condition 6 rejects cosmic ray showers. Condition 7 rejects two-photon processes and events with hard initial state radiation.

5. Fit procedure and results

The observed number of hadronic events in data taking runs (N_i^{obs}) was fitted using the maximum likelihood method [19]:

$$-2\ln\mathcal{L} = 2\sum_i \left[N_i^{\mathrm{obs}} \ln\left(\frac{N_i^{\mathrm{obs}}}{N_i^{\mathrm{exp}}}\right) + N_i^{\mathrm{exp}} - N_i^{\mathrm{obs}} \right]. \tag{1}$$

The expected number of hadronic events in data taking runs (N_i^{exp}) is obtained as

$$N_i^{\mathrm{exp}} = \sigma(W_i) \cdot L_i, \tag{2}$$

where $\sigma(W_i)$ and L_i are the hadronic cross section at the c.m. energy of the run and the run integrated luminosity, respectively.

The hadronic cross section $\sigma(W)$ is parameterized with a function that assumes the existence of a resonance with mass M_R, and the leptonic width Γ^R_{ee} on top of the flat non-resonant background:

$$\sigma(W) = \sigma_0 + \varepsilon_h(M_R) \int dW'\,dx \cdot \sigma_{e^+e^- \to R \to hadr}(W') \cdot \mathcal{F}(x, W') G\left(\frac{W - W'}{\sigma_W(M_R)}\right), \tag{3}$$

where

$$\sigma_{e^+e^-\to R\to hadr}(W) = \frac{6\pi^2}{M_R^2}\Gamma_{ee}^R \cdot \mathrm{Br}(R\to hadr)\cdot\delta(W-M_R),$$

σ_0 is the non-resonant background cross section at $W = M_R$, ε_h is the event selection efficiency for the resonance hadronic decays, $\mathcal{F}(x, W)$ is the radiative correction function [20], and $G(x)$ is the Gaussian function. The value of $\sigma_W(M_R)$ is obtained from the fit plotted in Fig. 2 as $\sigma_W = \sqrt{2}\sigma_E$.

In order to have enough background events for a σ_0 measurement, the fits use the energy range $M_R \pm 13$ MeV. The fits were performed with M_R varied by 0.1 MeV steps taking only σ_0 and $\varepsilon_h\Gamma_{ee}^R \cdot \mathrm{Br}(R \to hadr)$ as free parameters. The fits did not reveal statistically significant narrow resonances other than J/Ψ.

In order to set an upper limit on Γ_{ee}^R, the event selection efficiency ε_h should be estimated. It has been obtained as follows:

1. Since $\Gamma_{ee}^{J/\Psi} \cdot \mathrm{Br}(J/\Psi \to hadr)$ is known from the other measurements [21], $\varepsilon_h(J/\Psi)$ of about 62% was obtained at the very beginning of the scan in the J/Ψ energy range.
2. The hadronic decays of a hypothetical resonance might differ from those of the J/Ψ. The relative uncertainty of ε_h due to this factor was estimated as 10% from comparison of two Monte Carlo simulations: $J/\Psi \to hadrons$ and $e^+e^- \to hadrons$ in continuum.
3. Variation of ε_h with energy was estimated from the drop of the visible cross section of $e^+e^- \to$ hadrons after it was corrected for the W^{-2} dependence. Taking into account R measurements in this energy region [22], the relative decrease of ε_h in the experimental energy range was estimated as (22 ± 7)%.
4. Taking all the factors conservatively, $\varepsilon_h(W)$ has been obtained by the linear interpolation between 56% at $W = 3.1$ GeV and 40% at $W = 1.85$ GeV.

The energy-dependent 90% C.L. upper limits on $\Gamma_{ee}^R \cdot \mathrm{Br}(R \to hadr)$ with the highest value of about 105 eV, obtained from such a fit, are shown in Fig. 3.[1] Variation of σ_W within its 10% systematic uncertainty could increase the limit to 120 eV.

6. Conclusions

A detailed study of the energy range 1.85–3.1 GeV at the VEPP-4M collider with the KEDR detector revealed no new narrow resonances in the reaction $e^+e^- \to hadrons$. An upper limit obtained for the leptonic width of possible resonances

$$\Gamma_{ee}^R \cdot \mathrm{Br}(R \to hadr) < 120 \text{ eV} \quad (90\% \text{ C.L.})$$

is four to five times more stringent than that obtained in this energy range in earlier experiments at ADONE [4–10].

Acknowledgements

This work was partially supported by the Russian Foundation for Basic Research, Grants 07-02-00816-a, 10-02-00695-a, 11-02-00112-a, 11-02-00558-a and RF Presidential Grant for Sc. Sch. NSh-5655.2008.2.

Appendix A. Supplementary material

Supplementary material related to this article can be found online at doi:10.1016/j.physletb.2011.08.016.

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[1] Detailed information on the results of our analysis can be found in two tables in the electronic supplement to this Letter.