Search for the process $e^+e^- \to D^*(2007)$ with the CMD-3 detector

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Abstract. A search for the process $e^+e^- \to D^{*0}(2007)$ has been performed with the CMD-3 detector at the VEPP-2000 e^+e^--collider. Two main decay modes of the $D^{*0}(2007)$ decay, $D^0\pi^0$ and $D^0\gamma$, followed by $D^0 \to K^+\pi^-\pi^+\pi^-$ are used in this analysis. With an integrated luminosity of 3.7 pb^{-1} collected at the center-of-mass energy $E_{c.m.}$=2006.62 MeV our preliminary upper limit is $\mathcal{B}_{D^{*0}\to e^+e^-}<1.6\times 10^{-6}$ at 90%C.L.

1 Introduction

The process $e^+e^- \to D^*$ is a good probe for New Physics. Estimation of the lower limit on the branching fraction in Standard Model $\mathcal{B}(D^* \to e^+e^-) \sim (0.1 - 5) \times 10^{-19}$ gives a much smaller value than in some other models. For example, in model with Z – mediated gauge interaction the branching fraction is $\mathcal{B}(e^+e^- \to D^*) < 2.5\times 10^{-11}$ [1]. The process $e^+e^- \to D^*$ has clear advantages with respect to the $D^0 \to e^+e^-$ decay: the helicity suppression is absent, and a richer set of effective operators can be probed.

In this paper we report a search for the process $e^+e^- \to D^*$, then $D^{*0} \to D^0\pi^0(\mathcal{B}_{D^{*0}\to D^0\pi^0}$=64.7±0.9%) and $D^{*0} \to D^0\gamma(\mathcal{B}_{D^{*0}\to D^0\gamma}$=35.3±0.9%) decay chains [2]. We reconstructed D^0 in the mode $D^0 \to K^+\pi^-\pi^+\pi^-(\mathcal{B}_{D^0\to K^+\pi^-\pi^+\pi^-}$=8.11±0.15%). Four particles with only one kaon in final state lead to low physical background.

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2 CMD-3 detector and data set

The Cryogenic Magnetic Detector (CMD-3) described elsewhere [3] is installed in one of the two interaction regions of the VEPP-2000 e^+e^- collider [4]. The detector tracking system consists of the cylindrical drift chamber (DC) and double-layer cylindrical multiwire proportional Z-chamber, both installed inside a thin (0.085 X_0) superconducting solenoid with 1.3 T magnetic field. DC contains 1218 hexagonal cells and provides a measurement of charged particle momentum and of the polar (θ) and azimuthal (ϕ) angles. An amplitude information from the DC wires is used to measure the ionization losses dE/dx of charged particles with $\sigma_{dE/dx} \approx$ 11-14% accuracy for minimum ionizing particles. A barrel electromagnetic calorimeter placed outside the solenoid consists of two subsystems: an inner liquid xenon (LXe) calorimeter (5.4 X_0 thick) surrounded by a scintillation CsI crystal calorimeter (8.1 X_0 thick). BGO crystals with 13.4 X_0 are used as an endcap calorimeter. The detector has two triggers: neutral and charged. A signal for neutral one is generated by the information from calorimeters, while the charged trigger comes from the tracking system. The return yoke of the detector is surrounded by scintillation counters which serve as a veto for cosmic events.

To obtain a detection efficiency, Monte Carlo (MC) simulation of the detector based on the GEANT4 [5] package has been developed. Simulated events are subject to the same reconstruction and selection procedures as the data. MC simulation includes photon jet radiation by initial electrons calculated according to Refs. [6]. Background was estimated using the multihadronic Monte Carlo generator MHG2000 [7].

The search is based on the 3.7 pb^{-1} of an integrated luminosity collected with the CMD-3 detector at the center-of-mass (c.m.) energy close to the nominal D^{*0}(2007) mass: $m_{D^{*0}} = 2006.85 \pm 0.05$ MeV/c^2 [2]. During the whole period of data taking the collider beam energy was continuously monitored using the Back-Scattering-Laser-Light system[8, 9]. The average value of the c.m. energy is $\mathrm{E}^{\mathrm{av.}}_{\mathrm{c.m.}}$ = 2006.632±0.008 MeV and the beam energy spread of the VEPP-2000 collider is $\sigma_{\mathrm{E_{c.m.}}}$ = 0.954 ± 0.053 MeV.

3 K/π separation

To perform kaon/pion separation, we use the probability density functions (PDF) $f_{K/\pi}(p, dE/dx_{\mathrm{DC}})$ for charged K/π with the momentum p to produce the energy losses dE/dx in the DC. The parameters of PDF are determined by approximating the dE/dx_{DC} versus momentum distribution. First we use a sample of $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$ events to determine $f_\pi(p, dE/dx_{\mathrm{DC}})$, then the function $f_K(p, dE/dx_{\mathrm{DC}})$ is determined using $e^+e^- \to K^+K^-\pi^+\pi^-$ events. This procedure is performed separately for simulation and experiment.

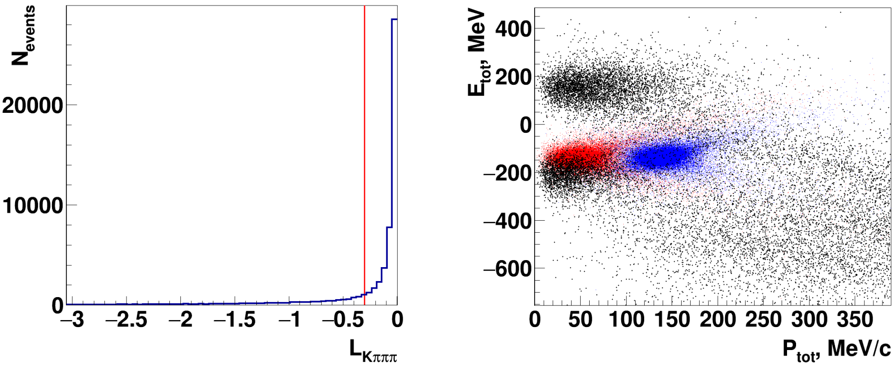
The log-likelihood function (LLF) for the hypothesis that for i=(1,2,..,N$_{tracks}$) the particle with the momentum p$_i$ and energy losses (dE/dx)$_i$ is the particle of α_i type (α_i=K or π) is defined as:

$$L_{K\pi\pi\pi} = \log\left(\frac{\prod f^i_\alpha(p, dE/dx_{\mathrm{DC}})}{\prod[f^i_\pi(p, dE/dx_{\mathrm{DC}}) + f^i_K(p, dE/dx_{\mathrm{DC}})]}\right).$$

We search for the combination of $(\alpha_1, \alpha_2, \alpha_3, \alpha_4)$, for which LLF is maximum and assume that there are one kaon and three pions in an event (L$_{K\pi\pi\pi}$). Figure 1(a) shows the L$_{K\pi\pi\pi}$ value for four-track events from simulation of $D^{*0} \to D^0\pi^0$.

4 Event Selection

Candidates for the process under study are required to have four good charged-particle tracks. We assign pion or kaon mass to each track and calculate the total energy E_{tot} =



a. b.

Figure 1. a.) E_{tot} vs P_{tot}. Black points correspond to experimental data, red points – $D^{*0} \to D^0\pi^0$ simulation, blue points – $D^{*0} \to D^0\gamma$ simulation. b.) $L_{K\pi\pi\pi}$ value for $D^{*0} \to D^0\pi^0$ simulation.

$\sum_{i=1}^{4} \sqrt{p_i^2 + m_\pi^2} - 2E_{beam}$. The distribution of E_{tot} vs P_{tot} (total momentum of four particles) is presented in Fig. 1(b). Black points correspond to experimental data, red points – simulation of the process $D^{*0} \to D^0\pi^0$, blue points – simulation of the process $D^{*0} \to D^0\gamma$. Selection criteria are:

$D^{*0} \to D^0\pi^0$

- $|E_{tot}$-141.6$|<$ 40 MeV
- $|P_{tot}$-46$|<$ 50 MeV/c

$D^{*0} \to D^0\gamma$

- $|E_{tot}$-136.6$|<$ 40 MeV
- $|P_{tot}$-138.6$|<$ 50 MeV/c

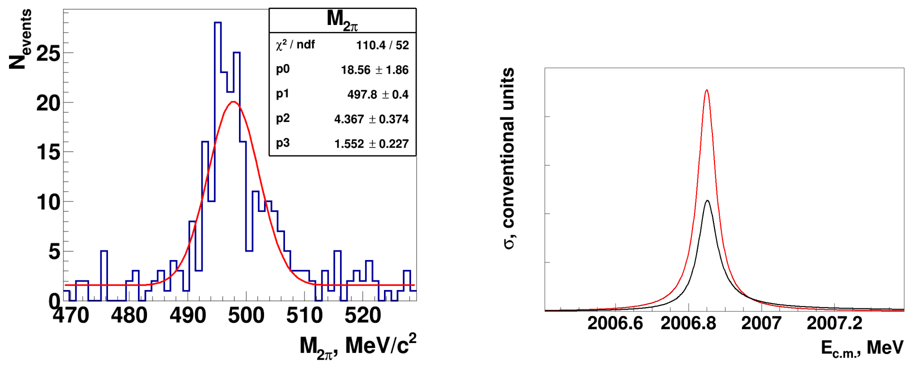
The detector efficiency after imposing conditions on energy and momentum is about 25% and is mainly determined by the acceptance of the drift chamber.

According to simulation with the multihadronic generator MHG2000 [7], the main background processes are $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$, $K^+K^-\pi^+\pi^-$, $\pi^+\pi^-\pi^+\pi^-\pi^0$, $\pi^+\pi^-\pi^+\pi^-\pi^0\pi^0$, $\pi^+\pi^-\pi^+\pi^-\pi^+\pi^-$, $K_S^0 K^\pm\pi^\mp$, $K_S^0 K^\pm\pi^\mp\pi^0$. To suppress physical background with K_S we use a condition on the invariant mass of two pions: $|M_{\pi^+\pi^-} - 498| > 15$ MeV/c^2. The distribution of $M_{\pi^+\pi^-}$ for $K_S^0 K^\pm\pi^\mp$ and $K_S^0 K^\pm\pi^\mp\pi^0$ events is presented in Fig. 2(a). The last condition reduces the efficiency by $\sim$ 3%.

We also use a condition on LLF for physical background suppression:

- $L_{K\pi\pi\pi}$>-0.3 (all background events, this condition is presented in Fig. 1(a) as a red line.)
- $L_{KK\pi\pi}$<-3 ($K^+K^-\pi^+\pi^-$ events)
- $L_{\pi\pi\pi\pi}$<-3 ($\pi^+\pi^-\pi^+\pi^-$ events)

These conditions reduce the efficiency by $\sim$ 10%.



a. b.

Figure 2. a.) $M_{\pi^+\pi^-}$ for $K_S^0 K^\pm \pi^\mp$ and $K_S^0 K^\pm \pi^\mp \pi^0$ events b.) The red line — cross section of $e^+e^- \to D^{*0} \to D^0\pi^0$ in a standard resonance form, the black line — cross section convolved with the radiator function.

5 Upper limit calculation

The cross section of $e^+e^- \to D^{*0} \to D^0\pi^0$can be written in a standard resonance form:

$$\sigma(E) = \frac{12\pi}{m_{D^*}^2} \mathcal{B}_{D^* \to e^+e^-} \mathcal{B}_{D^{*0} \to D^0\pi^0} \frac{m_{D^*}^2 \Gamma_{D^*}^2}{(m_{D^*}^2 - E^2)^2 + E^2\Gamma_{D^*}^2}, \tag{1}$$

One can calculate the actual value of the D^{*0} width from the measured total width of the charged D^{*+} meson: $\Gamma_{D^{*0}} = 60$ keV [1].

The integrated production cross section is calculated using the energy spread $\sigma_{\mathrm{E_{c.m.}}}$ and the radiator function F(x,E) [6, 10]:

$$\sigma_{\mathrm{int}} = \int_0^{E_{\mathrm{beam}}} dE \int_0^1 \frac{1}{\sqrt{2\pi}\sigma_{\mathrm{E_{c.m.}}}} e^{-\frac{(\mathrm{E_{c.m.}^{av.}} - \mathrm{E})^2}{2\sigma^2_{\mathrm{E_{c.m.}}}}} \cdot F(x, E) \cdot \sigma(E(1-x))dx\,, \tag{2}$$

The comparison of cross section of the process $e^+e^- \to D^{*0} \to D^0\pi^0$in a standard resonance form (red line) and the cross section convolved with the radiator function (black line) is presented on figure 2(b). These radiative corrections decrease the number of signal events by approximately 40% and the ratio of the energy spread to the Γ_{D^0} decreases the number of signal events by approximately a factor of 30.

The final formula for the branching fraction is:

$$\mathcal{B} = \frac{N}{L_{int} \cdot \epsilon_{D^{*0} \to f} \cdot \mathcal{B}_{D^{*0} \to f} \cdot \mathcal{B}_{D^0 \to K^+\pi^-\pi^+\pi^-} \cdot C}. \tag{3}$$

where L=3701 nbn^{-1} – integrated luminosity collected at the c.m. energy $E_{c.m.}$=2006.6 MeV, $\epsilon_{D^* \to D^0\pi^0}$=13.4% and $\epsilon_{D^* \to D^0\gamma}$ =13.2% – efficiencies, C = 62769 – calculated constant.

For evaluating the number of background events the event selection procedure was performed for low energy points $E_{c.m.}$=1900-2000 MeV.

We got two candidates for $D^0\gamma$ events with the estimated background = 1.2±0.5 and one $D^0\pi^0$ event with the background = 1.5±0.7. As a result, we can estimate the upper limit as $\mathcal{B}(D^* \to e^+e^-) < 1.6 \times 10^{-6}$ at 90% C.L. using the Bayesian Approach.

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