PROCEEDINGS OF SCIENCE

Measurement of the $e^+e^- \to \eta\pi^+\pi^-$ Cross Section with SND Detector at VEPP2000 e$^+$e$^-$-collider in the Energy Range 1.08 – 2.00 GeV

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In experiment with SND detector at e^+e^--collider VEPP-2000 a cross-section of the $e^+e^- \to \eta\pi^+\pi^-$ ($\eta \to 2\gamma$) process in energy range $\sqrt{s}$ =1.08–2.00 GeV was measured. It is shown that energy dependence of $e^+e^- \to \eta\pi^+\pi^-$ cross-section can be described by VDM with $\rho(770)$, $\rho(1450)$, $\rho(1700)$ resonances. Invariant mass spectrum of $\pi^+\pi^-$ system and angle distribution of η-meson are compatible with the $\eta\rho$ final state model. Obtained results are compatible with previous experimental results and have lower statistical errors.

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PoS(Hadron 2013)104

1. Introduction

Process $e^+e^- \to \eta\pi^+\pi^-$ was studied in several experiments, e.g. CMD [1], BaBar [2] in $\eta \to \pi^+\pi^-\pi^0$ decay channel, and on VEPP-2M collider with SND detector in $\sqrt{s}$ range 1.04–1.38 GeV in $\eta \to \gamma\gamma$ decay channel [3].

This work continues research, described in [3]. Upgrade of acceleration complex allowed to increase the maximum c.m.s energy up to 2 GeV. Integrated luminosity of the SND at VEPP-2000 data, processed in this work is approximately 4 times greater that on VEPP-2M.

The main diagram of process $e^+e^- \to \eta\pi^+\pi^-$ in vector meson dominance model (VMD) is the diagram shown in fig. 1, where intermediate vector state can be $\rho(770)$, $\rho(1450)$ and $\rho(1700)$. Other diagrams exist, but their contributions are negligible [4].

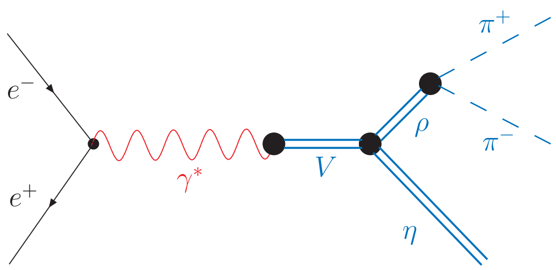

Figure 1: Main diagram of $e^+e^- \to \eta\pi^+\pi^-$ process in VMD.

2. Experiment and event selection

An experiment took place on collider VEPP-2000 in 2011 and 2012 with SND detector in the energy range 1.02–2.00 GeV. Total integrated luminosity of both scans is 33 pb^{-1}.

Preliminary event selection of process $e^+e^- \to \eta\pi^+\pi^-$, $\eta \to \gamma\gamma$ used the following criteria: two charged central tracks and 2 or 3 photons with the cuts on total energy deposition in calorimeter E_{tot}: $0.4 < E_{\text{tot}}/\sqrt{s} < 0.9$.

For selected events a fit of common vertex for both tracks was provided and kinematic reconstruction in hypothesis $e^+e^- \to \pi^+\pi^-\gamma\gamma$ without any assumptions about intermediate states. For events with three photons all photon pairs were processed and then pair with minimum $\chi^2_{\pi^+\pi^-\gamma\gamma}$ was selected. Then events with $\chi^2_{\pi^+\pi^-\gamma\gamma} < 60$ were selected.

The main background processes for the process $e^+e^- \to \eta\pi^+\pi^-$ are: $e^+e^- \to \pi^+\pi^-\pi^0\pi^0$, $e^+e^- \to \pi^+\pi^-\pi^0$, $e^+e^- \to e^+e^-\gamma\gamma$, $e^+e^- \to \eta K^+K^-$, cosmic and beam background.

Background processes, which have no peak in photon pair invariant mass spectrum on η-meson mass were subtracted using this photon invariant mass $m_{\gamma\gamma}^{\text{corr}}$ spectrum kinematic fit. Spectrum was fitted by function $F(x) = F_{\text{peak}}(x) + P_2(x)$, where $F_{\text{peak}}(x)$ describes η-meson peak shape and second degree polynomial — background spectrum.

For the fiting invariant mass spectrum in $e^+e^- \to \eta\pi^+\pi^-$ events a sum of two Gaussian functions was used. Since experimental statistics is inadeqate for measuring all shape parameters, they were measured by MC and fixed on MC values when processing experimental data.

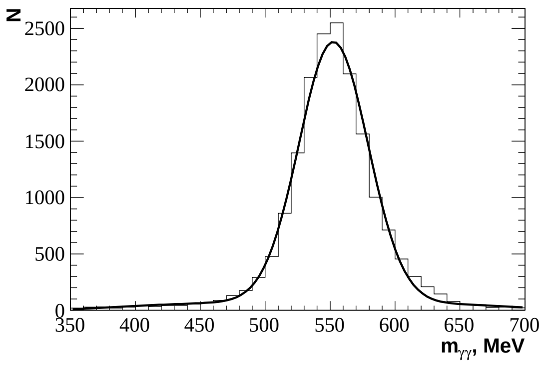

Figure 2: The photon-pair invariant mass spectrum of the $e^+e^- \to \eta\pi^+\pi^-$ MC events, $\sqrt{s} = 1.5$ GeV

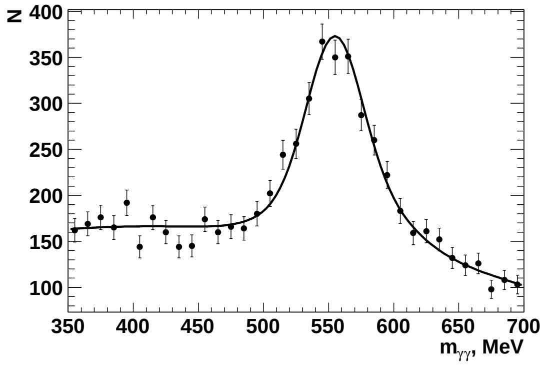

Figure 3: The photon-pair invariant mass spectrum of the selected experimental events, $\sqrt{s} = 1.45 - 1.55$ GeV

Process $e^+e^- \to \eta K^+K^-$ is the only known background having peak on η mass. Its contribution was estimated using BaBar data [5] and was found to be negligible (no more then 0.15%).

Detection efficiency of the $e^+e^- \to \eta\pi^+\pi^-$ process was calculated by MC simulation based on GEANT4 program. During primary events generation radiation corrections for ISR were taken into account. Registration efficiency of $e^+e^- \to \eta\pi^+\pi^-$ process in $\eta \to \gamma\gamma$ decay channel is 27%–37% depending on energy.

3. Luminosity measurement

Integrated luminosity was measured using $e^+e^- \to e^+e^-$ process. For selection of its events the following criteria were used: two charged central collinear tracks are required, $0.65\sqrt{s} < E_1 + E_2 < 1.1\sqrt{s}$, $0.25\sqrt{s} < E_{1,2}$, where E_1 and E_2 — measured energies of particles.

Detection efficiency of the process $e^+e^- \to e^+e^-$ was measure using simulation program, described before. $IL = (N_{exp}/\sigma_{mc}) \cdot (N_{mc}^{tot}/N_{mc})$, where IL — integrated luminosity, N_{mc}^{tot} —total number of simulated events, N_{exp} — number of selected using given criteria experimental events, N_{mc} — number of selected simulated events, σ_{mc} — Bhabha cross-section in simulation.

4. Radiative corrections

Born cross-section $\sigma_{\rm B}(s)$ was calculated using the fit of visible cross-section $\sigma_{\rm vis}(s)$ taking into account ISR radiation corrections.

$$\sigma_{\rm vis}(s) = \frac{N_{exp}}{IL \cdot \varepsilon} = \int_0^{\frac{2E_{max}}{\sqrt{s}}} \sigma_{\rm B}(s(1-z))F(z,s)dz = \sigma_{\rm B}(s) \cdot (1+\delta), \tag{4.1}$$

where N_{exp} is a measured number of experimental events, ε is a detection efficiency, $F(z,s)$ is a photon radiation function, $z\sqrt{s}/2$ — photon energy, δ — radiative correction, $E_{max} = \sqrt{s}/2$ — upper limit of the photon energy.

PoS(Hadron 2013)104

Born cross section of $e^+e^- \to \eta\pi^+\pi^-$ is described by VMD model, including $\rho(770)$, $\rho(1450)$ and $\rho(1700)$ contributions [4].

$$\sigma_{\rm B}(e^+e^- \to \eta\pi^+\pi^-) = \int\limits_{4m_\pi^2}^{(\sqrt{s}-m_\eta)^2} \frac{d\sigma}{dq^2} dq^2,$$
$$\frac{d\sigma}{dq^2} = \frac{4\alpha^2}{3}\frac{1}{s\sqrt{s}}\frac{\sqrt{q^2}\Gamma_\rho(q^2)p_\eta^3(s,q^2)}{(q^2-m_\rho^2)^2+(\sqrt{q^2}\Gamma_\rho(q^2))^2}|F(s)|^2,\;\; P_\eta^2 = \frac{(s-m_\eta^2-q^2)^2-4m_\eta^2 q_2}{4s}. \tag{4.2}$$

Here q — total 4-momentum of $\pi^+\pi^-$-system, $F(s)$ — form factor function.

Dependence of $\rho(770)$ width from 4-momentum was described by formula:

$$\Gamma_\rho(q^2) = \Gamma_\rho(m_\rho^2)\frac{m_\rho^2}{q^2}\left(\frac{p_\pi^2(q^2)}{p_\pi^2(m_\rho^2)}\right)^{\frac{3}{2}},\;\; p_\pi^2(q^2) = \frac{q^2}{4} - m_\pi^2. \tag{4.3}$$

Form factor function $F(s)$ is the following:

$$F(s) = \sum_V \frac{m_V^2}{g_{V\gamma}}\frac{g_{V\rho\eta}}{s - m_V^2 + i\sqrt{s}\Gamma_V(s)},\text{ where } V = \rho(770),\ \rho(1450),\ \rho(1700). \tag{4.4}$$

Here $g_{V\rho\eta}$ and $g_{V\gamma}$ are coupling constants in corresponding vertexes. It is convenient to write the fraction $g_{V\rho\eta}/g_{V\gamma}$ as $g_V e^{i\phi_V}$, where g_V is real positive number.

Values of $|g_{\rho(770)\rho\eta}|$ and $|g_{\rho(770)\gamma}|$ were fixed on values calculated from PDG data [6, 7]. $g_{\rho(1450)}$ and $g_{\rho(1700)}$ were free.

$\phi_{\rho(770)}$ was accepted to be 0, for $\phi_{\rho(1450)}$ and $\phi_{\rho(1700)}$ values 0 and π were allowed.

$\rho(770)$ width was describes by (4.3). For $\rho(1450)$ and $\rho(1700)$ widths were free but tied to table values: $\Gamma_{\rho(1450)} = 400 \pm 60$ MeV and $\Gamma_{\rho(1700)} = 250 \pm 100$ MeV (the special functions, depending on difference between fitted and table values, were added to minimized function). Their masses were fixed to PDG values: $m_{\rho(770)} = 775.49$ MeV, $m_{\rho(1450)} = 1465$ MeV, $m_{\rho(1700)} = 1720$ MeV [6].

5. Results and discussion

The results for Born cross-section are presented on fig. 4. Also results of SND at VEPP2M [3] and BaBar [2] are shown. One can conclude that results of this measurement is compatible with previous experiment results and can be described by VMD with given resonances.

As a test of $\eta\rho$ final state hypothesis a distribution by $\pi^+\pi^-$ system invariant mass and η-meson polar angle distribution were studied. Both distributions are compatible with simulated, based on $\eta\rho$ mechanism (fig. 5,6).

Measured energy dependence of cross-section of $e^+e^- \to \eta\pi^+\pi^-$ process may be used for calculating of $\tau^- \to \eta\pi^-\pi^0\nu_\tau$ decay branching ratio based on CVC hypothesis [9, 10]. Using $Br(\tau^- \to \nu_\tau e^- \nu_e)$=$(17.83 \pm 0.04)\%$ [6] with our data was obtained a value $Br(\tau^- \to \eta\pi^-\pi^0\nu_\tau) = (0.188 \pm 0.058)\%$. PDG value is $0.139\% \pm 0.01\%$ [6]. So value, obtained using our results for $e^+e^- \to \eta\pi^+\pi^-$ cross-section based on CVC hypothesis is compatible with PDG value.

Also branching fraction products for $\rho(1450)$ and $\rho(1700)$ were obtained from measured cross section [8] — $Br(\rho(1450) \to \eta\rho)\cdot Br(\rho(1450) \to e^+e^-)$= $(7.4^{+2.4}_{-2.2}) \times 10^{-7}$ and $Br(\rho(1700) \to \eta\rho)\cdot Br(\rho(1700) \to e^+e^-)$=$(7.2^{+2.5}_{-2.0}) \times 10^{-7}$. According to PDG they are "possibly seen" and "seen" respectively [6].

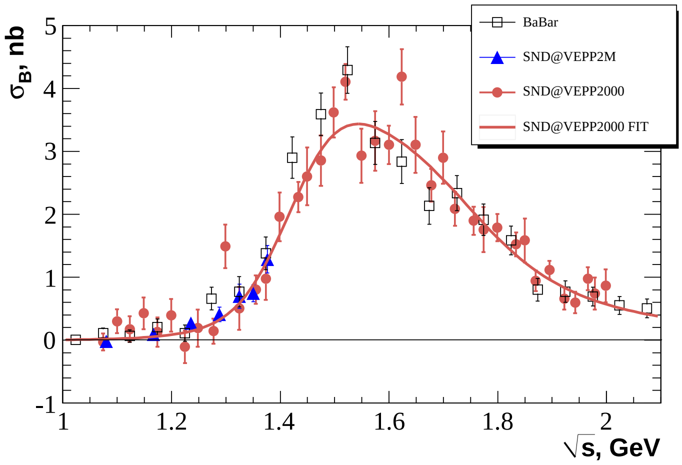

Figure 4: Born cross-section of $e^+e^- \to \eta\pi^+\pi^-$ process, measured in this work and in previous experiments (BaBar, SND@VEPP2M) and a fitting curve described in the text

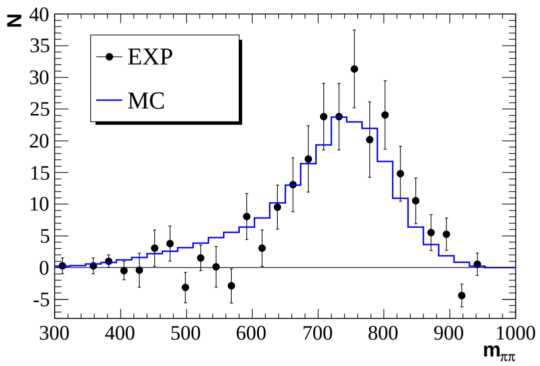

Figure 5: Pion pair invariant mass spectrum, $\sqrt{s}$=1.5 GeV. Points — experimental data, thick line — experimental data fit, thin line — MC

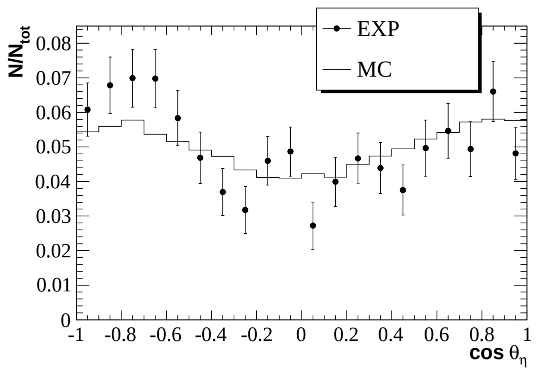

Figure 6: Distribution by polar angle of η-meson. Points - experimental data, solid line - MC

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