Measurement of the $e^+e^- \to \pi^+\pi^-$ cross-section with the CMD-2 detector

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The general purpose detector CMD-2 at the VEPP-2M electron-positron collider at Novosibirsk has collected about 11 pb^{-1} of integrated luminosity in the center-of-mass energy range from 0.36 up to 1.38 GeV. First part of data taken in the center-of-mass energy range from 0.61 to 0.96 GeV (around the ρ-meson) during 1994 and 1995 runs have been analysed and preliminary results on the $e^+e^- \to \pi^+\pi^-$ cross-section in this energy range are presented.

1. Introduction

The cross-section of the process $e^+e^- \to \pi^+\pi^-$ is given by

$$\sigma = \frac{\pi\alpha^2}{3s}\beta_\pi^3 \left|F_\pi(s)\right|^2,$$

where $F_\pi(s)$ is the pion form factor at the center-of-mass energy squared s and β_π is the pion velocity.

The pion form factor measurement is important for a number of physics problems. Detailed experimental data in the time-like region allows measurement of the parameters of the $\rho(770)$ meson and its radial excitations. Extrapolation of the energy dependence of the pion form factor to the point $s = 0$ gives the value of the pion electromagnetic radius. Exact data on the pion form factor is necessary for precise determination of the ratio

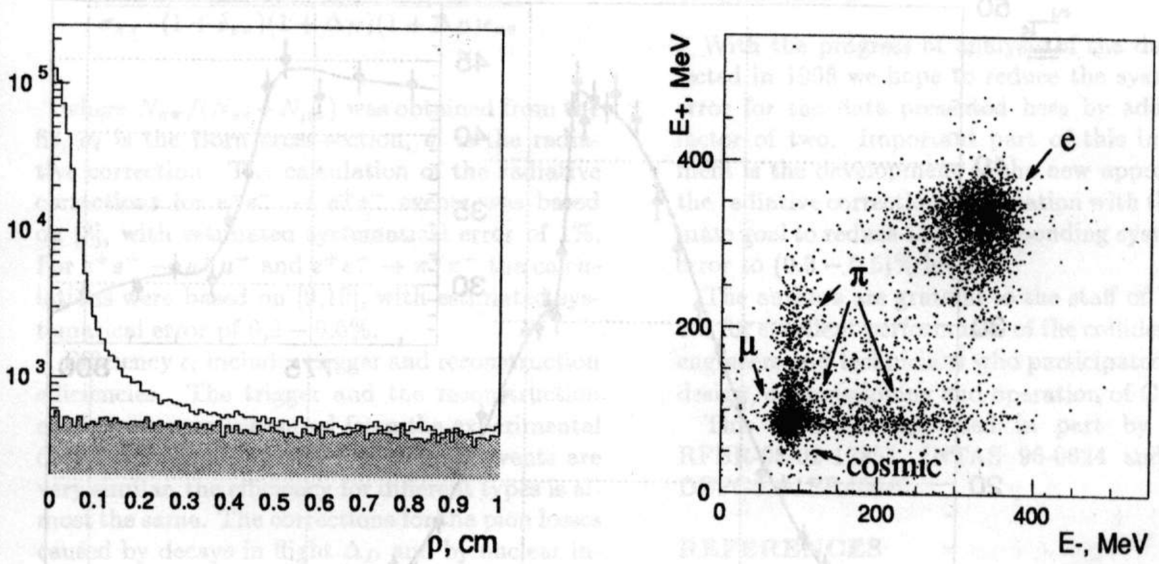
$$R = \sigma(e^+e^- \to hadrons)/\sigma(e^+e^- \to \mu^+\mu^-).$$

Knowledge of R with high accuracy is required to evaluate the hadronic contribution a_μ^{had} to the anomalous magnetic moment of the muon $(g-2)_\mu$ [1], which is important in relation to the E821 experiment in BNL [4]. The ultimate goal of the experiment is to measure the $(g-2)_\mu$ with 0.35 ppm precision while the current precision of the theoretical evaluation of the hadronic contribution is in the $0.6-1.4$ ppm range [2,3]. The most part of the uncertaincy comes in this case from VEPP-2M energy range ($s < 2$ GeV^2/c^2) and from $e^+e^- \to \pi^+\pi^-$ channel.

The CMD-2 detector started its data taking in 1992. During 1994-1995 years three data taking runs were performed dedicated to R measurement. The data were taken at 43 energy points with the center-of-mass energy from 0.61 GeV up to 0.96 GeV with a 0.01 GeV energy step. The small energy step allows calculation of hadronic contributions in model-independent way. In the narrow energy region near the ω-meson the energy steps were $0.002 \div 0.006$ GeV in order to study the ω-meson parameters and the $\rho-\omega$ interference. Since the form factor is changing relatively fast in this energy region, it was important that the beam energy was measured with the help of the resonance depolarization technique at almost all energy points. That allowed a significant decrease of the systematic error coming from the energy uncertainty.

2. Data analysis

From more than $4 \cdot 10^7$ triggers about $4 \cdot 10^5$ events were selected as *collinear* events. The basic selection criteria were as follows:



a) ρ-distribution. Empty histogram correspond to all events, filled histogram correspond to background events only.

b) E^+ versus E^- distribution.

Figure 1. ρ - and energy distributions for background and collinear events.

1. the event was triggered by the charged trigger;
2. one vertex with two oppositely charged tracks was found in the drift chamber; the distance from vertex to the beam axis is less than 0.3 cm;
3. two track in the drift chamber are collinear so that $|\Delta\varphi| < 0.15$ and $|\Delta\Theta| < 0.25$, where φ and Θ are the azimuthal and the polar angles correspondigly;
4. the average momentum of two tracks is between 200 and 600 MeV/c;
5. the average polar angle of two tracks $[\Theta_1 + (\pi - \Theta_2)]/2$ is between 1.1 and $(\pi - 1.1)$ radians.

The selected set of collinear events consists of $e^+e^- \to e^+e^-$, $e^+e^- \to \pi^+\pi^-$, $e^+e^- \to \mu^+\mu^-$ events and the cosmic background. The separation of the cosmic background events was based on the vertex position distribution. Both the longitudinal coordinate (Z) and the distance from the beam axis (ρ) distributions are peaked around the zero for the beam produced events and very broad, almost flat for the cosmic background events. Example of ρ-distribution is shown in figure 1(a).

The energy deposition in the barrel CsI calorimeter by negatively (E^-) and positively (E^+) charged particles were used for the beam produced events separation. The distribution of E^+ versus E^- is shown in figure 1(b). Electrons and positrons usually have large energy deposition since they produce electromagnetic showers. Muons usually have small energy deposition since they are minimum ionising particles. Pions can interact as minimum ionising particles producing small energy deposition or have nuclear interactions inside the calorimeter, resulting in long tails to a higher value of the energy deposition.

The separation was based on the minimization of the following unbinned likelihood function:

$$L = -\sum_{events} \ln\left(\sum_a N_a \cdot f_a(E^+, E^-)\right) + \sum_a N_a, \quad (1)$$

where a is the event type ($a = ee$, $\mu\mu$, $\pi\pi$, *cosmic*), N_a is the number of events of the type a and $f_a(E^+, E^-)$ is the probability density for a type a event to have energy depositions E^+ and E^-. It was assumed that E^+ is uncorrelated with E^- for events of the same type, so we can factorize the probability density:

$f_a(E^+, E^-) = f_a^+(E^+) \cdot f_a^-(E^-)$.

For e^+e^-, $\mu^+\mu^-$ pairs and cosmic events the energy deposition distribution is the same for neg-

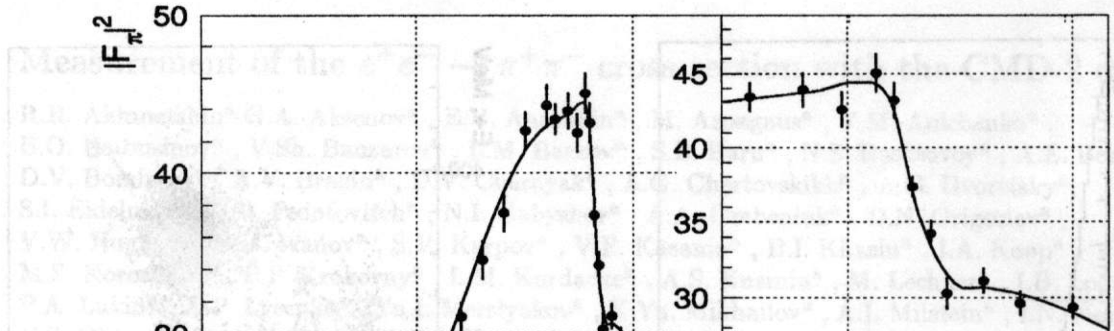


Figure 2. Fit of the CMD-2 (94, 95) pion form factor data

atively and positively charged particles, while these distributions are significantly different for π^+ and π^-. Therefore $f_a^+ \equiv f_a^-$ for $a = ee$, $\mu\mu$ and *cosmic*, but for pions these functions are different.

The energy deposition distribution for electrons and cosmic events were obtained from the same collinear events. Energy deposition of muon was obtained from the simulation and corrected for the additional experimental resolutions like uncertainy of the CsI calorimeter calibration. The energy deposition of pions was obtained from the simulation (for the pions that interact with calorimeter as the minimum ionizing particles), and from the experimental data of $\varphi \to \pi^+\pi^-\pi^0$ decay. This decay gives the source of the clean sample of pions both charges within whole interesting energy range. Also the CMD-2 detector has collected the large statistics of these decays at the φ-meson energy range. Detailes about the energy deposition of the different types of collinear events could be found in [7].

In minimization the ratio $N_{\mu\mu}/N_{ee}$ was fixed according to the QED calculation

$$\frac{N_{\mu\mu}}{N_{ee}} = \frac{\sigma_{\mu\mu}\cdot(1+\delta_{\mu\mu})\varepsilon_{\mu\mu}}{\sigma_{ee}\cdot(1+\delta_{ee})\varepsilon_{ee}},$$

where σ is the Born cross-section, δ is a radiative correction and ε is the reconstruction efficiency. The likelihood function (1) was rewritten to have the following global fit parameters:

$$(N_{ee}+N_{\mu\mu}), \quad \frac{N_{\pi\pi}}{N_{ee}+N_{\mu\mu}}, \quad N_{cosmic}$$

instead of N_{ee}, $N_{\mu\mu}$, $N_{\pi\pi}$ and N_{cosmic}. The number of cosmic events N_{cosmic} was determined before the fit and was fixed during the fit, while its fluctuation was added to the fluctuation of $N_{\pi\pi}$.. The total number of free parameters is about 20, most of which are the energy deposition parameters for different types of particles.

The pion formfactor was calculated as:

$$|F_\pi|^2 = \frac{N_{\pi\pi}}{N_{ee}+N_{\mu\mu}}.$$

$$\frac{\sigma_{ee}\cdot(1+\delta_{ee})\epsilon_{ee}+\sigma_{\mu\mu}\cdot(1+\delta_{\mu\mu})\epsilon_{\mu\mu}}{\sigma_{\pi\pi}\cdot(1+\delta_{\pi\pi})(1+\Delta_N)(1+\Delta_D)\epsilon_{\pi\pi}},$$

where $N_{\pi\pi}/(N_{ee}+N_{\mu\mu})$ was obtained from the fit, σ_i is the Born cross-section, δ_i is the radiative correction. The calculation of the radiative corrections for $e^+e^-\to e^+e^-$ events was based on [8], with estimated systematical error of 1%. For $e^+e^-\to\mu^+\mu^-$ and $e^+e^-\to\pi^+\pi^-$ the calculations were based on [9,10], with estimated systematical error of $0.2-0.5\%$.

Efficiency ϵ_i includes trigger and reconstruction efficiencies. The trigger and the reconstruction efficiencies were measured from the experimental data itself. Since all types of colinear events are very similar, the efficiency for different types is almost the same. The corrections for the pion losses caused by decays in flight Δ_D and by nuclear interactions inside the drift chamber Δ_N were obtained from simulation.

The main sources of systematic error are the radiative corrections calculation (about 1%) and the events separation (about 0.6%). The overall systematic error is estimated to be about 1.4%.

3. Preliminary results

The preliminary results of the pion formfactor merasurement in the 0.61-0.96 GeV center-of-mass energy range are presented in figure 2. To describe the pion formfactor the higher resonances $\rho(1450)$ and $\rho(1700)$ should be taken into account in addition to leading contribution from $\rho(770)$ and $\omega(782)$ [5,11]. At the same time it was shown [12] that the experimental data below 1 GeV is well described by the model based on the hidden local symmetry. We use both approaches to fit the data [7]. Since we fit the pion form factor in the relatively narrow energy region 0.61-0.96 GeV, only one higher resonance $\rho(1450)$ is taken into account. Both fits produce about the same results. For the final value we prefer the Gounaris-Sakurai parametrization as it was traditionally used for the determination of the ρ-meson parameters (see [5] and [11]). The following ρ-meson parameters were obtained from the fit, where the first error is statistical and the second one is systematic:

$$\begin{cases} M_\rho\,(\text{MeV}) & = 775.28\pm0.61\pm0.20, \\ \Gamma_\rho\,(\text{MeV}) & = 147.70\pm1.29\pm0.40, \\ \Gamma(\rho\to e^+e^-)\,(\text{keV}) & = 6.93\pm0.11\pm0.10, \\ Br(\omega\to\pi^+\pi^-) & = (1.31\pm0.23)\%. \end{cases}$$

4. Conclusion

With the progress of analysis of the data collected in 1998 we hope to reduce the systematic error for the data presented here by additional factor of two. Important part of this improvement is the development of the new approach to the radiative corrections calculation with the ultimate goal to reduce the corresponding systematic error to $(0.3-0.5)\%$ level.

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