The Measurement of Electromagnetic Form Factors of Hadron at $E_{cm} = 2.6GeV$

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I. Motivation

- Investigations of the electromagnetic form factors of hadron provide important information about their structure.
- After the analysis of 2π and 4π electromagnetic form factors, the $\rho(1600)$ was replaced by two new resonances $\rho(1450)$, and $\rho(1700)$ in 1988 PDG.
- VDM (Vector meson Dominance Model) has been developed in two main directions:
  1. Extending the sum from lowest-lying V-mesons to their high-mass recurrencies or radial excitations. Such as Prof. N.N.Achasov's Model.
  2. Improvement consists in introducing SU(3)-breaking effects.
- The pion form factor has been studied serially from $\sqrt{s} = 0.3$ GeV to $\sqrt{s} = 2.1$ GeV, but no more data at the interval of center-of-mass energy from $\sqrt{s} = 2.1$ GeV up to 3.1 GeV.
- Prof. N.N.Achasov predicted the existence of a new ρ radial excitation at about 2.1 GeV. (see Fig. 1)

This is a good opportunity for BEPC to reveal and confirm the hypothesis.

II. Data Analysis at $E_{cm} = 2.6GeV$ and Discussion

0.1 $e^+e^- \to \pi^+\pi^-, K^+K^-$

0.1.1 Background channels

In our object channels , the possible background channels are included:

$$e^+e^- \to e^+e^-$$

$$e^+e^- \to \mu^+\mu^-$$
$$e^+e^- \to p\bar{p}$$
$$e^+e^- \to \rho\pi$$
$$e^+e^- \to n\gamma\pi^+\pi^-, n\gamma K^+K^-$$

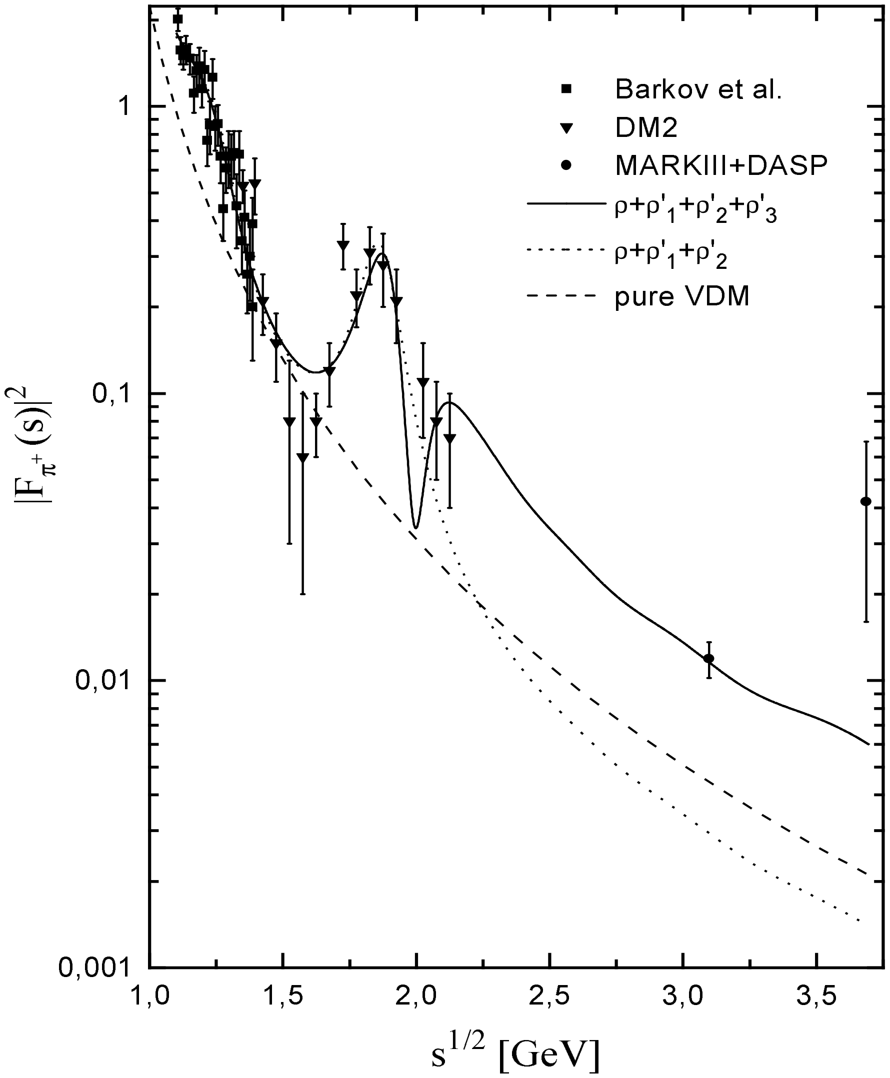

Fig. 1

Figure 1: The π EM Form Factor

0.1.2 Event Selections

- TOF: $N_K \geq 1$, or $N_\pi \geq 1$
- There are two and only two oppositely charged tracks
- The acollinearity of the tracks is less than 5^o (see Fig. 2)

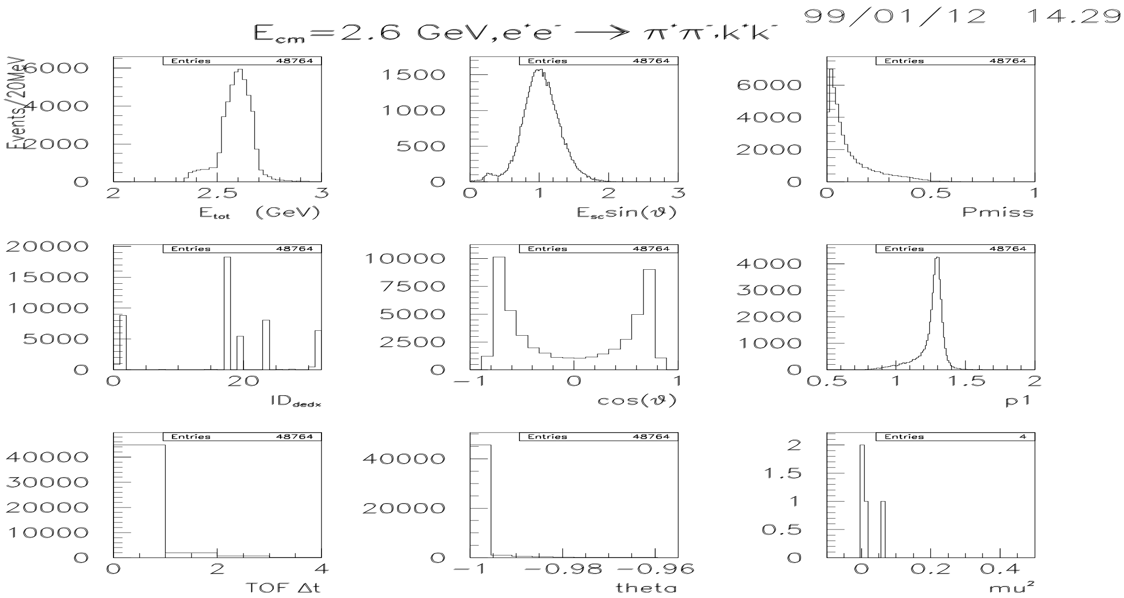

Figure 2: Real Data Plots

- $P_{miss} \equiv \sqrt{(\sum\limits_{N_{chrg}} P_x)^2 + (\sum\limits_{N_{chrg}} P_y)^2 + (\sum\limits_{N_{chrg}} P_z)^2}$
  $\leq 0.2GeV/c$ (see Fig. 2)
- $1.1 > P_{1,2} > 1.32$ GeV/c (see Fig. 2)
- Δ_{TOF} t $\leq$ 4ns (see Fig. 2)
- $E_{sc} \times sin(\theta) \leq 0.35GeV$
  DEDX: $N_e = 0$
- $P_{xy} \leq 0.75GeV$, at least 1 layer μ chamber hitted,
  $0.75 < P_{xy} \leq 0.95GeV$,at least 2 layers μ chamber hitted,
  $P_{xy} > 0.95GeV$, at least 3 layers μ chamber hitted
  If the behavior of the track as mentioned above, it will be rejected as μ.
- $|cos\theta| \leq 0.66$
- The total isolated photon numbers $N_\gamma = 0$:
  $N_{neu} \leq 5$
  $E_{sc} \geq 70MeV$
  $\Delta \leq 0.4$
  $|cos\theta_{\gamma q}| \leq 0.98$
- $|E_{2\pi} - E_{cm}| < |E_{2p} - E_{cm}|$ or
  $|E_{2K} - E_{cm}| < |E_{2p} - E_{cm}|$
  $|E_{2\pi} - E_{cm}| < 0.08GeV$ or $|E_{2K} - E_{cm}| < 0.08GeV$

After above selections, 4 $e^+e^- \rightarrow \pi^+\pi^-, K^+K^-$ candidates have been got at $E_{cm} = 2.6GeV (\pounds = 292.9 \pm 2.2nb^{-1})$.

0.1.3 Results

The detection efficiency (ε) is determined from Monte Carlo simulation. The results are $\varepsilon_\pi \simeq 10.8\%$ for the $\pi^+\pi^-$ final states and $\varepsilon_k \simeq 9.7\%$ for the K^+K^- case.

- After considering the radiative correction $(1+\delta) \simeq 0.91$ which has been calculated according to Ref.[10] , finally we obtain the cross section of $e^+e^- \rightarrow \pi^+\pi^-$ and the π form factor according to VDM as follow:

$$\sigma_\pi^{VDM} = \frac{(\sigma_\pi^{VDM})^{exp}}{1+\delta} = 0.058 \pm 0.046 \pm 0.006nb$$

$$(|F_\pi|^2)^{VDM} = 0.018 \pm 0.015 \pm 0.002$$

- After considering the radiative correction $(1+\delta) \simeq 0.92$ which has been calculated according to Ref.[10] , finally we obtain the cross section of $e^+e^- \rightarrow \pi^+\pi^-$ and the π form factor according to Prof. N.Achasov's "ρ" model as follow:

$$\sigma_\pi^\rho = \frac{(\sigma_\pi^\rho)^{exp}}{1+\delta} = 0.122 \pm 0.065 \pm 0.013nb$$

$$(|F_\pi|^2)^\rho = 0.039 \pm 0.021 \pm 0.004$$

0.1.4 Discussions

The comparison with existing data on the e^+e^- annihilation shows that some new resonance structures may be present in the mass range between 2GeV and 5GeV. Searching them may help in a better understanding of the mass spectrum in both the simple and a more sophisticated quarks models.

From our result, it seems to deviate from the "pure VDM" and "$\rho+\rho_1'+\rho_2'$" models, but prefer to "$\rho+\rho_1'+\rho_2'+\rho_3'$ " model.

0.2 $e^+e^- \rightarrow \pi^+\pi^-\pi^+\pi^-$

0.2.1 Event Selections

- N_{chrg}=4. ΣQ=0. $N_{neu} \leq$6.
- For charged tracks:
  1. $p_{miss} \leq$0.2GeV/c
  2. The invariable mass of the four charged tracks:
     $2.45 \leq M \leq 2.75\text{GeV}/c^2$
  3. Particle identification by the weight information in TOF, we need at least 2 of the four tracks are identified as π:
     $N_\pi \geq 2$, and $N_k \leq 1$.
- For neutral tracks, we require none of the neutral tracks is isolated photon.
  N_γ=0
  The select conditions for isolated photons are as below:
  1. $E_{sc} \geq 70MeV$

2. $\Delta \leq 0.4$
3. $|cos\theta_{\gamma q}| \leq 0.98$

After above selections, 91 $e^+e^- \rightarrow \pi^+\pi^-\pi^+\pi^-$ events have been got at $E_{cm} = 2.6GeV$.

0.2.2 Backgrounds

The following background channels are included:

$$e^+e^- \rightarrow \pi^+\pi^-K^+K^-$$
$$e^+e^- \rightarrow \gamma\pi^+\pi^-\pi^+\pi^-$$

We use HOWL to generate 10000 background events each of the above two background channels, after the above cut, 3 $\pi\pi KK$ events have been left and 132 $\gamma\pi\pi\pi\pi$ events have been left. So the mixation of $\pi\pi KK$ can be ignored.

0.2.3 Results

After considering the radiative correction ($1 + \delta \simeq 0.93$) Finally the cross section has been obtained:

1.13±0.12±0.11nb.

0.3 $e^+e^- \rightarrow \pi^+\pi^-\pi^+\pi^-\pi^0$

0.3.1 Events Selections

- N_{chrg}=4. ΣQ=0. $2 \leq N_{neu} \leq 12$.
- For charged tracks:
  Particle identification by the weight information in TOF, we need at least 2 of the four tracks are all identified as π:
  $N_\pi \geq 2$ and $N_K \leq 1$
- For neutral tracks, we require at least 2 of the neutral tracks is isolated photon.
  $N_\gamma \geq 2$
  The select conditions for isolated photons are as below:
  $E_{sc} \geq 20MeV$
  $\Delta \leq 0.4$
  $|cos\theta_{\gamma q}| \leq 0.98$
- The mass fit of π^0 and the invariance mass of all tracks:
  1. Two isolated photons have been selected to fit the π^0 mass , and the following criterion has been required
     $0.07GeV \leq M_{\pi^0} \leq 0.20GeV$
  2. The cut of the invariance mass of all tracks is as below:
     $2.2GeV \leq M \leq 3.0GeV$

After above selection, 58 $e^+e^- \rightarrow \pi^+\pi^-\pi^+\pi^-\pi^0$ events have been got at $E_{cm} = 2.6GeV$.

0.3.2 Backgrounds

The following background channels are include:

$$e^+e^- \to \pi^+\pi^-K^+K^-\pi^0$$
$$e^+e^- \to \gamma\pi^+\pi^-\pi^+\pi^-$$

We use HOWL to generate 10000 background events each of the above two background channels, after the above cut, 84 $\pi\pi KK\pi^0$ events have been left and 30 $\gamma\pi\pi\pi\pi$ events have been left.

0.3.3 Results

After considering the radiative correction $(1+\delta \simeq 0.99)$, Finally the cross section has been obtained:

2.72± 0.36±0.45nb.

0.4 $e^+e^- \to \pi^+\pi^-\omega$ event

0.4.1 Event Selections

Based on the cut of $e^+e^- \to \pi^+\pi^-\pi^+\pi^-\pi^0$, we add the cut of ω mass as follows:

$$0.70GeV \leq M_\omega \leq 0.85GeV$$

After above selection, 16 $e^+e^- \to \pi^+\pi^-\omega$ events have been got at $E_{cm} = 2.6GeV$.

0.4.2 Backgrounds Check

We have checked the following background channels:

$$e^+e^- \to \pi^+\pi^-K^+K^-\pi^0$$
$$e^+e^- \to \gamma\pi^+\pi^-\pi^+\pi^-$$

We use HOWL to generate 10000 background events each of the above two background channels, after the above cut, 27 $\pi\pi KK\pi^0$ events have been left and 5 $\gamma\pi\pi\pi\pi$ events have been left.

0.4.3 Results

After considering the radiative correction $(1+\delta \simeq 0.99)$ Finally the cross section has been obtained:

1.27± 0.31±0.32nb.

0.5 $e^+e^- \to \pi^+\pi^-\pi^0$

0.5.1 Event Selections

- N_{chrg}=2. ΣQ=0. $2 \leq N_{neu} \leq 6$.
- For charged tracks:
  1. The acollinearity of the tracks is more than 5^o
  2. Δ_{TOF} t $\leq$ 4ns
  3. $|cos\theta| \leq 0.8$
- For neutral tracks, we require at least two neutral tracks are isolated photon.
  $N_\gamma \geq 2$
  The select conditions for isolated photons are as below:

1. $E_{sc} \geq 50MeV$
2. $|cos\theta_a| \geq 0.951$
3. $|cos\theta_{\gamma q}| \leq 0.966$

- After two isolated photons have been selected , we fit the invariable mass of π^0:
$$0.05 \leq M_{\pi^0} \leq 0.2$$
- In order to identify K and π, we fit the invariable mass of K and π from TOF and MDC , and required:
$$(2M)^3 \leq 0.2 \text{ (to select } \pi)$$
$$(2M)^3 \geq 1.0 \text{ (to select K)}$$
Events with at least one track can be indentified as π in $\pi^+\pi^-\pi^0$ or one track can be identified as K in $K^+K^-\pi^0$ are selected , but if one π and one K in the same event , it will be rejected.
- At last,we fit the energy of $e^+e^- \to \pi^+\pi^-\pi^0, K^+K^-\pi^0$
$$2.3 \leq E \leq 2.9GeV \ (e^+e^- \to \pi^+\pi^-\pi^0)$$
$$2.3 \leq E \leq 2.9GeV \ (e^+e^- \to K^+K^-\pi^0)$$

After above selection, 7 $e^+e^- \to \pi^+\pi^-\pi^0$ events.

0.5.2 Background Check

The following background channels are include:

- $e^+e^- \to K^+K^-\pi^0$

0.5.3 Results

The cross section is measured to be:
$$\sigma = N_{obs}/[L * A]$$
After considering the radiative correction $(1+\delta \simeq 0.97)$, we obtain the cross section of $e^+e^- \to \pi^+\pi^-\pi^0$:
$$\sigma = \mathbf{1.84 \pm 0.67 \pm 0.38nb}$$

III. Summary

Channels	Events	Cross Setcion(nb)
$e^+e^- \to \pi^+\pi^-$	4	$0.122 \pm 0.065 \pm 0.013$
$e^+e^- \to 2(\pi^+\pi^-)$	91	$1.13 \pm 0.12 \pm 0.11$
$e^+e^- \to 2(\pi^+\pi^-)\pi^0$	58	$2.72 \pm 0.36 \pm 0.45$
$e^+e^- \to \omega\pi^+\pi^-$	16	$1.27 \pm 0.31 \pm 0.32$
$e^+e^- \to \pi^+\pi^-\pi^0$	7	$1.84 \pm 0.67 \pm 0.38$

In order to test our analysis method , we also analyzed BES J/ψ data, Our results are consist with that from PDG.

Channels	Br(PDG)	BES Preliminary Results
$e^+e^- \to \pi^+\pi^-$	$(1.47 \pm 0.23) \times 10^{-4}$	$\sim 1.48 \times 10^{-4}$
$e^+e^- \to 2(\pi^+\pi^-)$	$(4.1 \pm 1.0) \times 10^{-3}$	$\sim 3.42 \times 10^{-3}$
$e^+e^- \to 2(\pi^+\pi^-)\pi^0$	$(3.37 \pm 0.26)\%$	$\sim 3.44\%$
$e^+e^- \to \omega\pi^+\pi^-$	$(7.21 \pm 1.0) \times 10^{-3}$	$\sim 9.86 \times 10^{-3}$

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References

[1] Erkal and Olsson, Z.Phys. C31(1986)615

[2] N.N.Achasov and A.A.Kozhevnikov, Phys. Rev. D55(1997)2663

[3] N.N.Achasov and A.A.Kozhevnikov, Phys. Rev. D57(1998)4334

[4] R.Hofstadter, Electron scattering and nuclear and nucleon structure, (W. A. Benjamin, 1963)

[5] M.Castellano et al., Nuovo Cimento A41(1973)1. G.Bassompierre et al., Phys. Lett. B64(1976)475. B.Delcourt et al., Phys. Lett. B86(1979)395. D.Bisello et al., Nucl. Phys. B224(1983)379

[6] M.Conversi et al., Nuovo Cimento 40(1965)690. D.L.Hartill et al., Phys. Rev. 184(1969)1415. C.Baglin et al., Phys. Lett. B163(1985)400. G.Bardin et al., Phys. Lett. B255(1991)149; Phys. Lett. B257(1991)514

[7] T.A.Armstrong et al., Phys. Rev. Lett. 70(1992)1212

[8] G.Bardin et al., Nucl. Phys. B411(1994)3

[9] A.Antonelli et al., Phys. Lett. B334(1994)431

[10] E.A.Kuraev and V.S.Fadin Sov. J. Nucl. Phys. 41(1985)466. Hu Haiming Reported to BES Future Physics in July 1998. A.Osterheld SLAC-PUB-4160 Dec. 1986. C.Edwards SLAC-PUB-5160 Jan. 1990. J.D.Jackson Nucl. Inst. Method 128(1975)13. A.D.Bukin et al., Phys. Lett. B73(1978)226

[11] G.Cosme et al., Nucl. Phys. B152(1979)215

[12] G. Cosme et al., Phys. Lett. B63(1976)349

[13] C. Bacci et al et al., Phys. lett. B95(1980)139

[14] A. Cordier et al., Phys. Lett. B81(1979)389

[15] R.C.Jhonson et al., Phys. Lett. B63(1976)95

[16] J.E.Augustin et al., Nucl. Phys. B320(1989)1-19