The Study on Electromagnetic Form Factors of $e^+e^- \to$ Four Hadrons at $\sqrt{s}$ from 2.0GeV to J/ψ

WANG Jun
IHEP, CAS, Beijing, 100039, China
E-mail: wangj@hpws2.ihep.ac.cn
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Abstract

The cross sections of $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$ are measured at Ecm=2.0, 2.2, 2.4, 2.6GeV, then the form factors are calculated. The results seem to deviate from Achasov's model including only ρ_1' and ρ_2', while support the assumption including ρ_3'. And the branching ratios of $J/\psi \to \pi^+\pi^-\pi^+\pi^-$, $\pi^+\pi^-K^+K^-$, $\pi^+\pi^-p\bar{p}$ and $K^+K^-K^+K^-$ are measured, which are consistent with the values in PDG.

I. Introduction

VMD (Vector Meson Dominance) has been developed in two main directions: One improvement consists in introducing SU(3)-breaking effects; the other consists in extending the sum of cross section not only to lowest-lying V-mesons but also to their high-mass recurrencies or radial excitations.

Investigations of the electromagnetic form factors of hadrons in e^+e^- annihilation provide important information. Since 1988, $\rho(1600)$ was replaced by two new resonances: $\rho(1450)$, and $\rho(1700)$ in PDG, Erkal[1] had pointed out this possibility with a theoretical analysis on the consistency of 2π and 4π electromagnetic form factors.

Detail experiment data on the pion form factor in timelike region permit highly accurate determinations of the parameters of the ρ-meson and its radial recurrencies such as $\rho(1450)$, $\rho(1700)$. There are intentions to study the electromagnetic form factor in e^+e^- annihilation in the interval of the center-of-mass energy from $\sqrt{s} = 1.5$ GeV up to 5 GeV.

However, there are still no results of the cross section at the energy range between 2.0 and 3.0GeV, whereas the cross section at the energy point above 2.0GeV may be very important to test whether there is other resonances of ρ. For example, the results from $e^+e^- \to \pi^+\pi^-$ reveal there may be the third excitation ρ_3' at about 2.0GeV(see fig. 1).

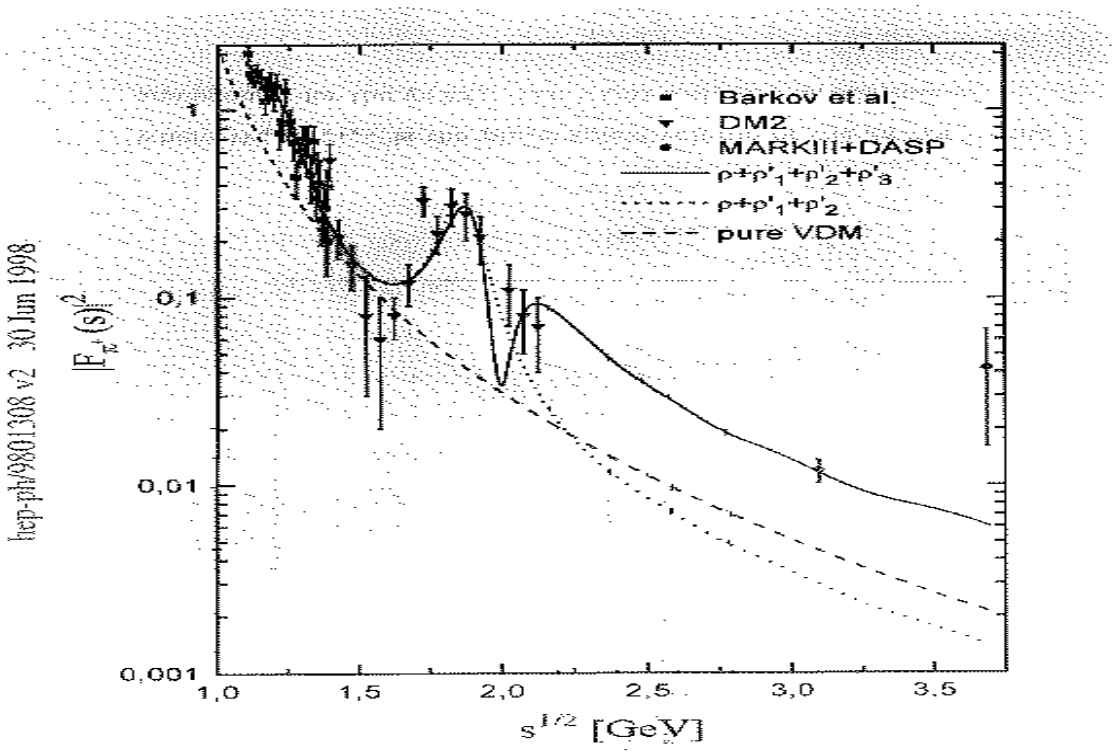

Figure 1: The form factor of $e^+e^- \to \pi^+\pi^-$

II.Expressions for cross sections and form factors

Of the following final states, the cross sections are expressed through form factors as below[2]:

1). If $f = \pi$ or K, then

$$\sigma(e^+e^- \to f^+f^-) = \frac{8\pi\alpha^2}{3s^{5/2}}|F_f(s)|^2 P_f, \tag{1}$$

The form factor of $e^+e^- \to \pi^+\pi^-$ including ρ' model is shown in Fig. 1.

2) If the final states are $2\pi^+2\pi^-$, then

$$\sigma(e^+e^- \to 2\pi^+2\pi^-) = \frac{4\pi\alpha^2}{s^{3/2}}|F_{\rho^0\pi^+\pi^-}(s)|^2 W_{\pi^+\pi^-\pi^+\pi^-}(s), \tag{2}$$

The cross section and form factor including ρ' model are shown in Fig. 2 and 3.

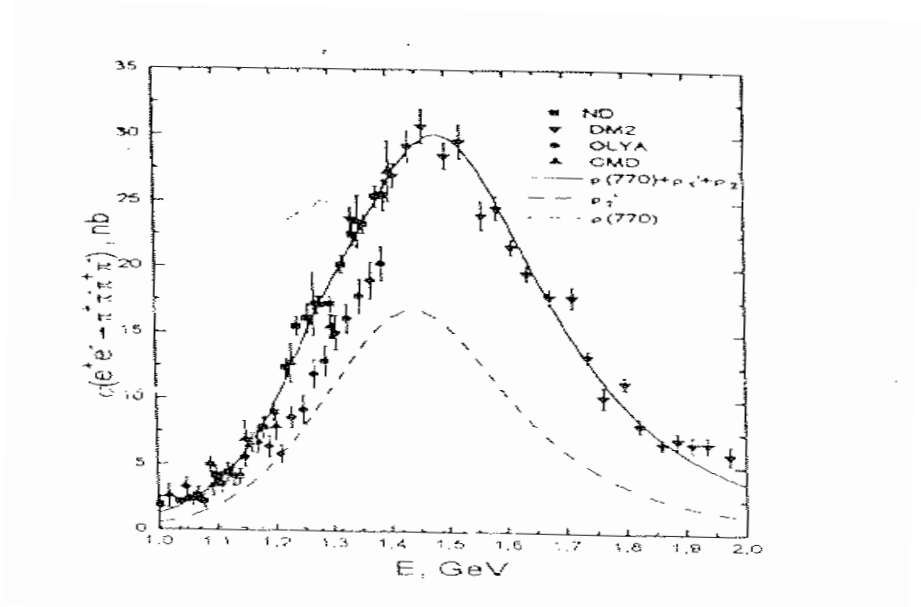

Figure 2: The cross section of $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$

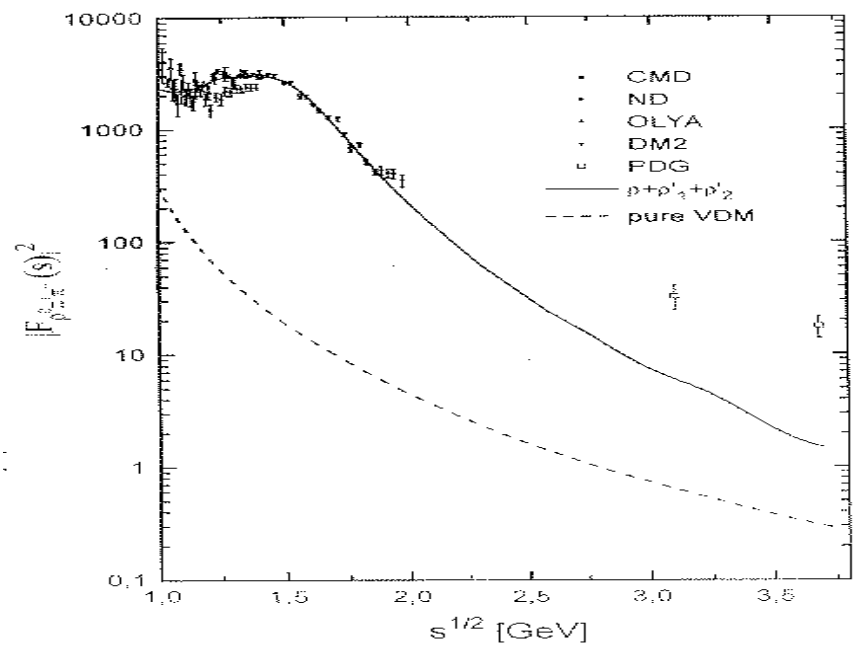

Figure 3: The form factor of $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$

III.The data analysis results of $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$ cross section at Ecm=2.0, 2.2, 2.4, 2.6GeV

$\pi^+\pi^-\pi^+\pi^-$ events selection.(see Fig. 5,6,7,8)

1. NCHRG=4. NTOTCH=0. NNEU$\leq$6.
2. For charged tracks:

- mfit=2 or -19
- $|cos\theta| \leq 0.8$
- Vertex: $|x| \leq 1.5cm$, $|y| \leq 1.5cm$, $|z| \leq 15cm$
- Particle identification by the weight information in TOF, we need the number of tracks identified as π is greater than or equal to 2 and the number of tracks identified as K is less than or equal to 1.

  $N_\pi \geq 2$, $N_K \leq 1$

  To identify a track as π, we need $W_{tof}(\pi) \geq 0.011$,

  and $W_{tof}(\pi)$>W_{tof}(K), $W_{tof}(\pi)$>W_{tof}(p)
- The total momentum of four tracks, $P_{miss} \leq 0.15$
- The invariant mass of four tracks,

  $|M_{\pi\pi\pi\pi} - Ecm(2.0, 2.2, 2.4, 2.6)| \leq 0.2$

3. For neutral tracks, cuts for good photons are:

- $E_{sc} \geq 70MeV$
- The angular relation between the direction of γ cluster after reconstruction and the direction of line from the collision point to the first fired point in SC

  $\Delta \leq 0.4$
- $cos\theta_{\gamma q} \leq 0.98$
- $N_{layer} \geq 2$

we need the number of good photon N_γ=0.

After above selection, from BESII R scan data, 69,51,38,92 $\pi^+\pi^-\pi^+\pi^-$ events have been got at $\sqrt{S}$=2.0,2.2,2.4,2.6GeV respectively.

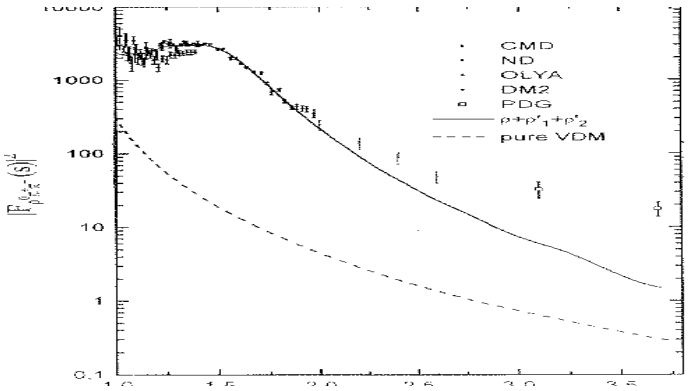

Figure 4: The form factor of $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$

The acceptance is determined from MC simulation using phase space generator.

The integrated luminosity of each energy point, the events passing all cuts and the efficiency determined from MC phase space, 2 background channels $e^+e^- \to \pi^+\pi^-K^+K^-$ and $\gamma\pi^+\pi^-\pi^+\pi^-$ are listed in table 1.

The systematic error are preliminarily estimated as below: the luminosity error is small, the event selection error is about 10%, and the MC error is about 10%, then the total systematic error is about 15%.

Table 1: The cross section of $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$ from BESII

Ecm(GeV)	2.0	2.2	2.4	2.6
Int. Lum.(nb^{-1})	48.2	60.5	63.3	292.9
Evts.	69	51	38	92
Eff. (%)	35.7	36.2	36.2	34.1
σ**(nb)**	**4.01** $\pm$ 0.48 $\pm$ 0.60	**2.33** $\pm$ 0.33 $\pm$ 0.35	**1.76** $\pm$ 0.29 $\pm$ 0.26	**0.92** $\pm$ 0.10 $\pm$ 0.14
$\lvert F\rvert^2$	**212.4**	**118.1**	**87.7**	**45.7**
Background*				
$\pi^+\pi^-K^+K^-$	0	0	0	0
$\gamma\pi^+\pi^-\pi^+\pi^-$	5	3	2	5

* The number are got from MC, the cross section of each BG channel are regarded as same as the $\pi^+\pi^-\pi^+\pi^-$ channel.

The form factors of this 4 points are plotted on fig. 4.

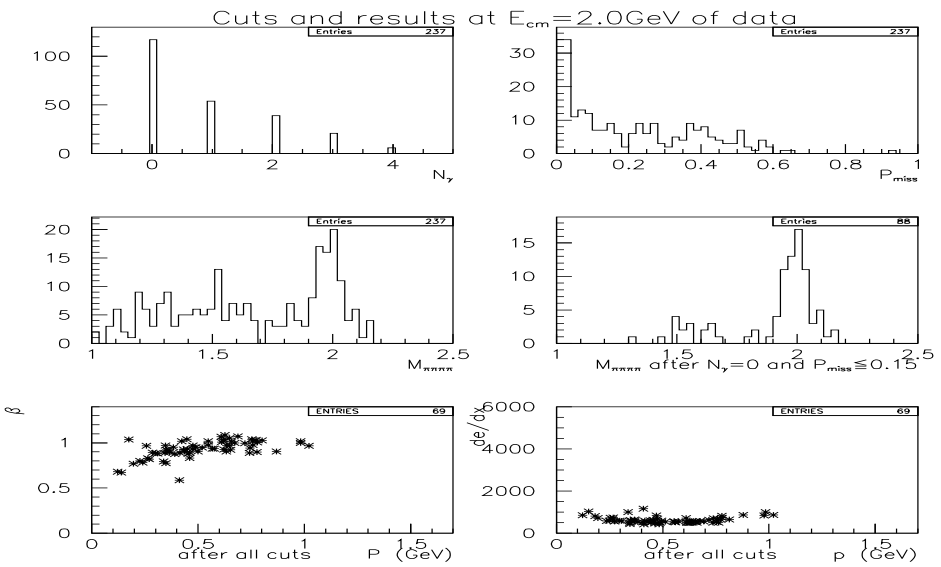

Figure 5: The cuts and results of $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$ at $\sqrt{S} = 2.0GeV$

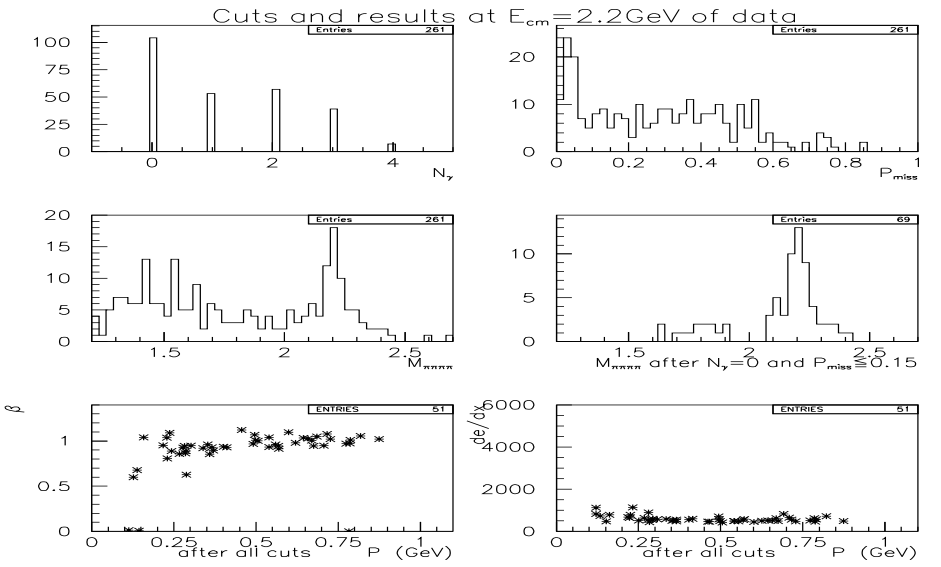

Figure 6: The cuts and results of $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$ at $\sqrt{S} = 2.2GeV$

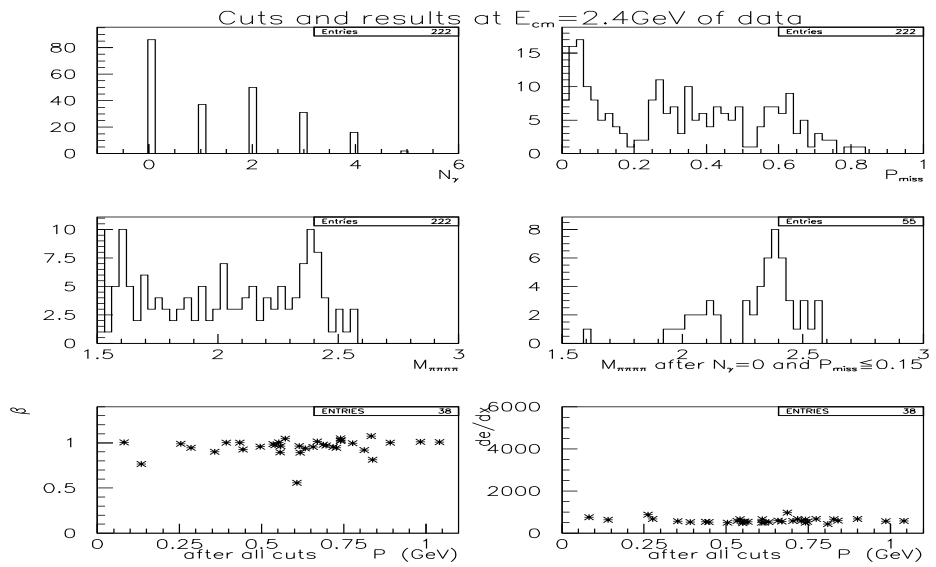

Figure 7: The cuts and results of $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$ at $\sqrt{S} = 2.4GeV$

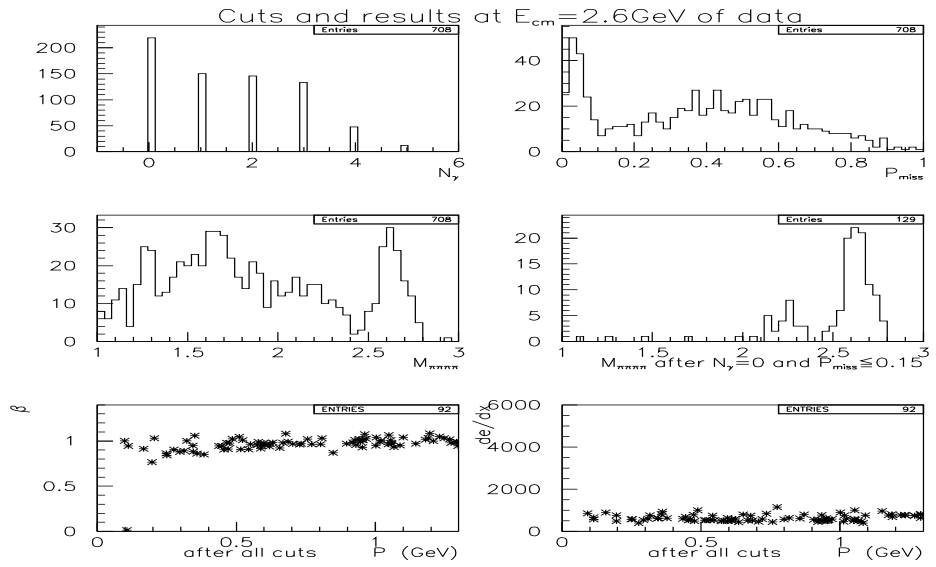

Figure 8: The cuts and results of $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$ at $\sqrt{S} = 2.6GeV$

IV. The data analysis results of $J/\psi \to \pi^+\pi^-\pi^+\pi^-$, $\pi^+\pi^-K^+K^-$, $\pi^+\pi^-p\bar{p}$ and $K^+K^-K^+K^-$.

In order to test the cuts and results at above energy points, we also analyzed the branching ratios of J/ψ decays.

The results in PDG are listed in Table 2.

The cuts are similar to the above analysis, but here the total momentum P_{miss} and invariant mass $M_{\pi\pi\pi\pi}$ cuts are removed, and the Telesis 4c-fit is added, we need $\chi^2 \leq 25$.

After above cuts, the results from BESI data(see Fig.9,10,11) are listed in table 2.

The systematical error is estimated as below: the error of J/ψ total number is about 20%; the error of events selection is about 10%; and the error of MC simulation about 10%. Then the total systematical error is about 25%.

Table 2 : The branching ratio of J/ψ decay

	$\pi^+\pi^-\pi^+\pi^-$	$\pi^+\pi^-K^+K^-$	$\pi^+\pi^-p\overline{p}$	$K^+K^-K^+K^-$
Results on PDG				
Evts	76 (MARK1)	205(MARK1)	1435(MARK2)	19(MARK1)
Br.($*10^{-3}$)	4.0 ± 1.0	7.2 ± 2.3	6.0 ± 0.5	0.7 ± 0.3
Results from BESI				
Evts	3782	4571	4649	287
Acceptance	15.5%	11.6%	9.43%	5.69%
Br.(*10^{-3})	**3.13** $\pm 0.05 \pm 0.78$	**5.29** $\pm 0.08 \pm 1.32$	**6.32** $\pm 0.09 \pm 1.58$	**0.65** $\pm 0.04 \pm 0.16$
Background				
$\pi^+\pi^-\pi^+\pi^-$		0	0	0
$\pi^+\pi^-K^+K^-$	0		0	0
$\pi^+\pi^-p\overline{p}$	0	0		0
$K^+K^-K^+K^-$	0	0	0	
$\gamma\pi^+\pi^-\pi^+\pi^-$	14			
$*\gamma\pi^+\pi^-K^+K^-$		6		
$\gamma\pi^+\pi^-p\overline{p}$			3	
$*\gamma K^+K^-K^+K^-$				1
$\pi^+\pi^-\pi^+\pi^-\pi^0$	2			
$\pi^+\pi^-K^+K^-\pi^0$		0		
$\pi^+\pi^-p\overline{p}\pi^0$			0	
$*K^+K^-K^+K^-\pi^0$				0
$\pi^+\pi^-\pi^0 \to \pi^+\pi^-e^+e^-\gamma$	11			

* No Br in PDG, the number is got by generating 10000 events.

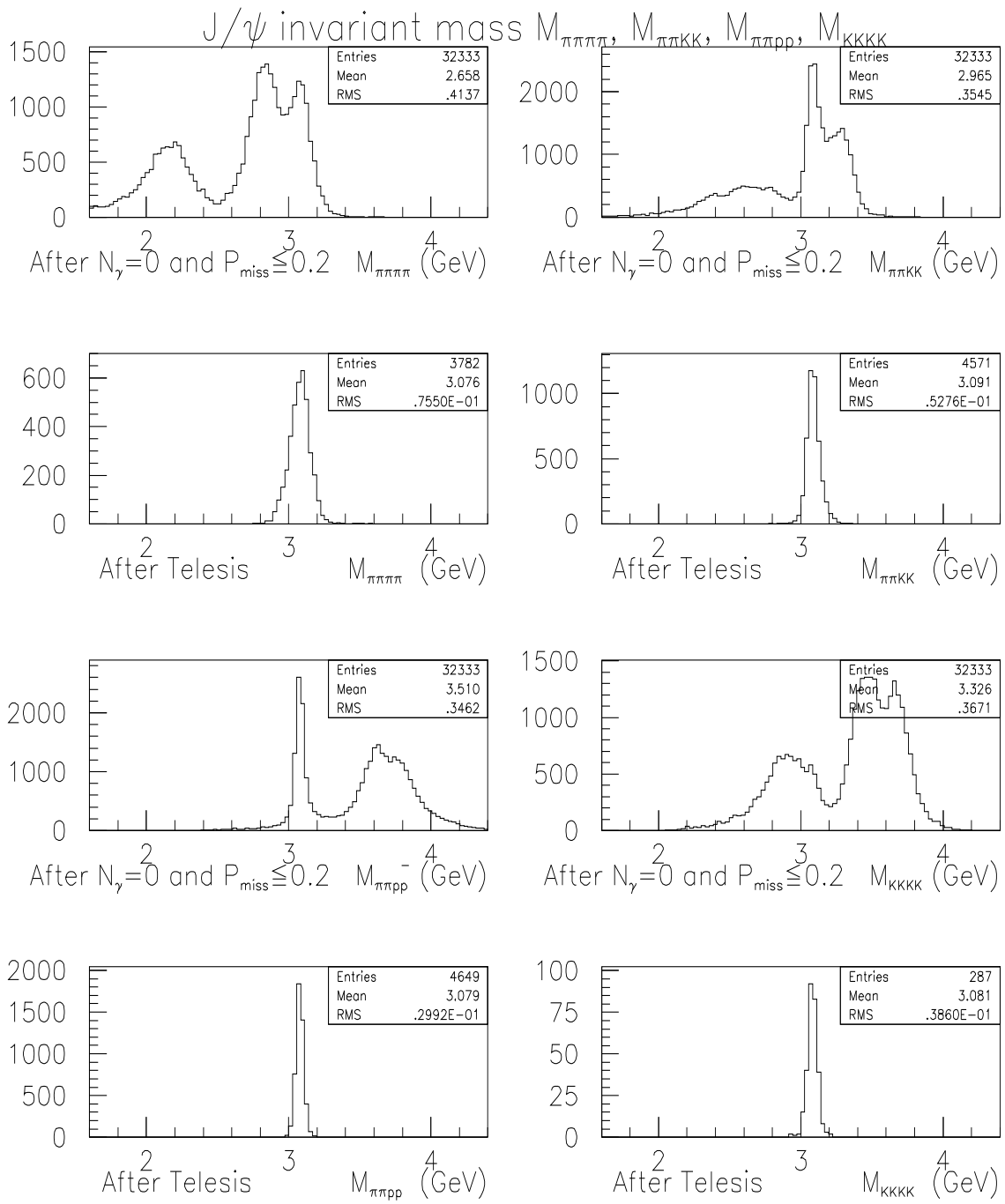

Figure 9: Invariant mass of $\pi^+\pi^-\pi^+\pi^-$,$\pi^+\pi^-K^+K^-$,$\pi^+\pi^-p\bar{p}$ and $K^+K^-K^+K^-$

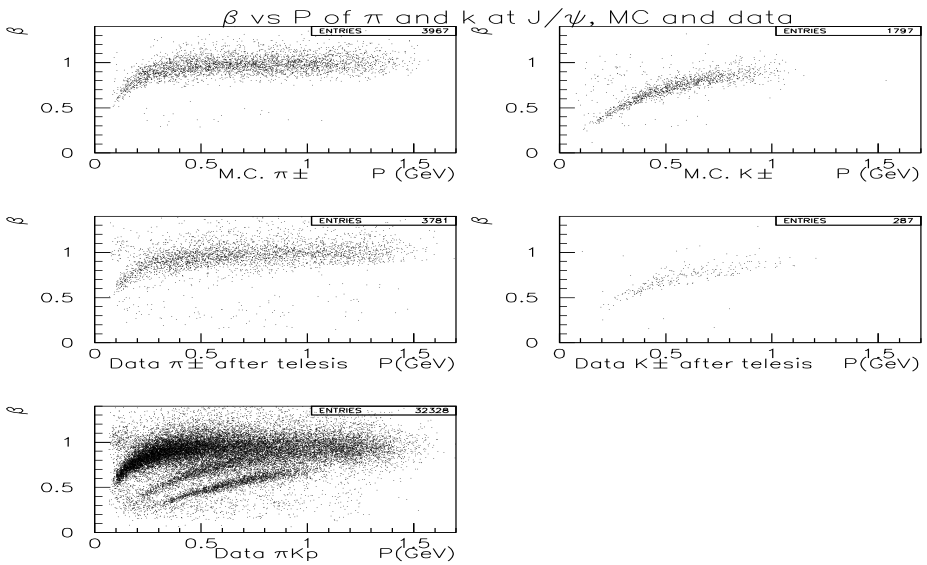

Figure 10: β vs P of π and K at J/ψ

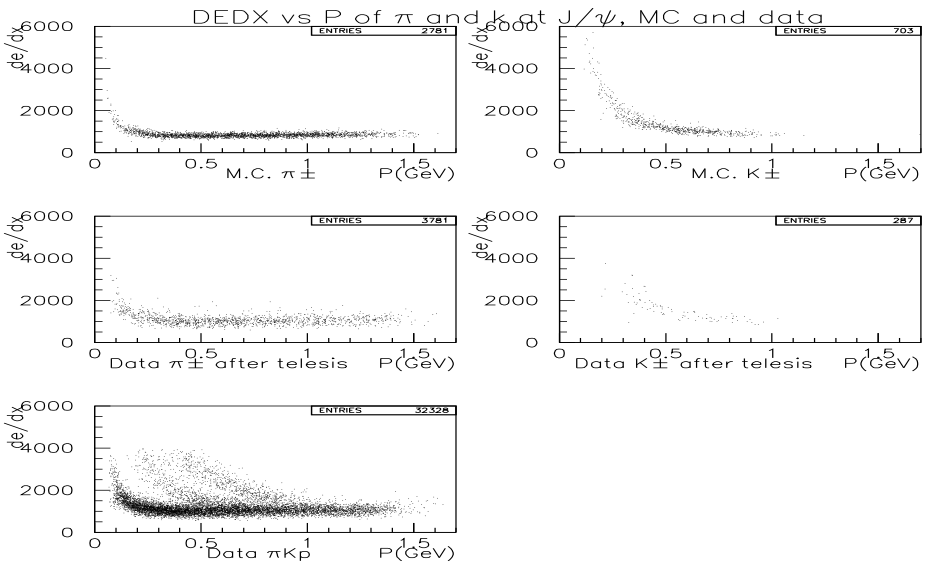

Figure 11: DEDX vs P of π and K at J/ψ

V. Discussion

- The results of $J/\psi \to \pi^+\pi^-\pi^+\pi^-$,$\pi^+\pi^-K^+K^-$, $\pi^+\pi^-p\bar{p}$ and $K^+K^-K^+K^-$ branching ratio are consistent with the value in PDG
- It is the first time to measure the cross section of $e^+e^- \to \pi^+\pi^-\pi^+\pi^-$ at $\sqrt{S}$ from 2.0 to 3.0GeV
- The form factors at the above four energy points seem to deviate from Achasov's model including only ρ_1' and ρ_2', while support the assumption adding ρ_3'

References

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

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