

Further Properties of Extra Light-Vector Mesons $\omega'(1300)$ and $\rho'(1300)$

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1. Introduction

(1) Masses and widths of the $\omega(1420)$ and $\rho(1450)$ disperse dependent upon their observed processes. (PDG2006)

$\omega(1420)$		$I^G(J^{PC}) = 0^-(1^{--})$				$\rho(1450)$		$I^G(J^{PC}) = 1^+(1^{--})$			
		$\omega(1420)$ MASS						$\rho(1450)$ MASS			
VALUE (MeV)	EVTS	DOCUMENT ID	TECN	COMMENT		VALUE (MeV)	DOCUMENT ID	TECN	COMMENT		
(1400-1450) OUR ESTIMATE											
• • • We do not use the following data for averages, fits, limits, etc. • • •											
1350 ± 20 ± 20		AUBERT,B	04N	BABR	$10.6 e^+ e^- \rightarrow \pi^+ \pi^- \pi^0 \gamma$	1582 ± 17 ± 25	2382	CMD2	$e^+ e^- \rightarrow \pi^0 \pi^0 \gamma$		
1400 ± 50 ± 130	1.2M	¹ ACHASOV	03D	RVUE	$0.44-2.00 e^+ e^- \rightarrow \pi^+ \pi^- \pi^0$	1349 ± 25 ± 5	341	⁴ ALEXANDER	01B	CLE2	$B \rightarrow D(*) \omega \pi^-$
1450 ± 10		² HENNER	02	RVUE	$1.2-2.0 e^+ e^- \rightarrow \rho \pi$	1523 ± 10		⁵ EDWARDS	00A	CLE2	$\tau^- \rightarrow \omega \pi^- \nu_\tau$
1373 ± 70	177	³ AKHMETSHIN 00D	CMD2	1.2-1.38	$e^+ e^- \rightarrow \omega \pi^+ \pi^-$	1463 ± 25		⁶ CLEGG	94	RVUE	
1370 ± 25	5095	ANISOVICH	00H	SPEC	$0.0 p\bar{p} \rightarrow \omega \pi^0 \pi^0 \pi^0$	1250		⁷ ASTON	80C	OMEG	$20-70 \gamma p \rightarrow \omega \pi^0 p$
1400 ± 100 ~ 1400		⁴ ACHASOV	98H	RVUE	$e^+ e^- \rightarrow \pi^+ \pi^- \pi^0$	1290 ± 40		⁷ BARBER	80C	SPEC	$3-5 \gamma p \rightarrow \omega \pi^0 p$
~ 1460		⁵ ACHASOV	98H	RVUE	$e^+ e^- \rightarrow \omega \pi^+ \pi^-$	-					
1440 ± 70		⁶ ACHASOV	98H	RVUE	$e^+ e^- \rightarrow K^+ K^-$						
1419 ± 31	315	⁷ CLEGG	94	RVUE							
		⁸ ANTONELLI	92	DM2	$1.34-2.4 e^+ e^- \rightarrow \rho \pi$						
$\omega(1420)$ WIDTH										$\rho(1450)$ WIDTH	
VALUE (MeV)	EVTS	DOCUMENT ID	TECN	COMMENT		VALUE (MeV)	DOCUMENT ID	TECN	COMMENT		
(180-250) OUR ESTIMATE											
• • • We do not use the following data for averages, fits, limits, etc. • • •											
450 ± 70 ± 70		AUBERT,B	04N	BABR	$10.6 e^+ e^- \rightarrow \pi^+ \pi^- \pi^0 \gamma$	429 ± 42 ± 10	2382	²⁰ AKHMETSHIN 03B	CMD2	$e^+ e^- \rightarrow \pi^0 \pi^0 \gamma$	
870 ± 500 - 300 ± 450	1.2M	⁹ ACHASOV	03D	RVUE	$0.44-2.00 e^+ e^- \rightarrow \pi^+ \pi^- \pi^0$	547 ± 86 ± 46	341	²¹ ALEXANDER	01B	CLE2	$B \rightarrow D(*) \omega \pi^-$
199 ± 15		¹⁰ HENNER	02	RVUE	$1.2-2.0 e^+ e^- \rightarrow \rho \pi$	400 ± 35		²² EDWARDS	00A	CLE2	$\tau^- \rightarrow \omega \pi^- \nu_\tau$
188 ± 45	177	¹¹ AKHMETSHIN 00D	CMD2	1.2-1.38	$e^+ e^- \rightarrow \omega \pi^+ \pi^-$	311 ± 62		²³ CLEGG	94	RVUE	
360 ± 100 - 60	5095	ANISOVICH	00H	SPEC	$0.0 p\bar{p} \rightarrow \omega \pi^0 \pi^0 \pi^0$	300		²⁴ ASTON	80C	OMEG	$20-70 \gamma p \rightarrow \omega \pi^0 p$
240 ± 70		¹² CLEGG	94	RVUE		320 ± 100		²⁴ BARBER	80C	SPEC	$3-5 \gamma p \rightarrow \omega \pi^0 p$
174 ± 59	315	¹³ ANTONELLI	92	DM2	$1.34-2.4 e^+ e^- \rightarrow \rho \pi$						

(2) In the $\tilde{U}(12)$ level-classification scheme of hadrons, the extra vector mesons are predicted in the ground S-wave state of $(q\bar{q})$ system.

(S. Ishida, M. Ishida and T. Maeda, Prog. Theor. Phys. 104(2000)785; S. Ishida, M. Y. Ishida, Phys. Lett.B539(2002)249-256; K. Yamada, KEK Proc. 2006-8,P23)

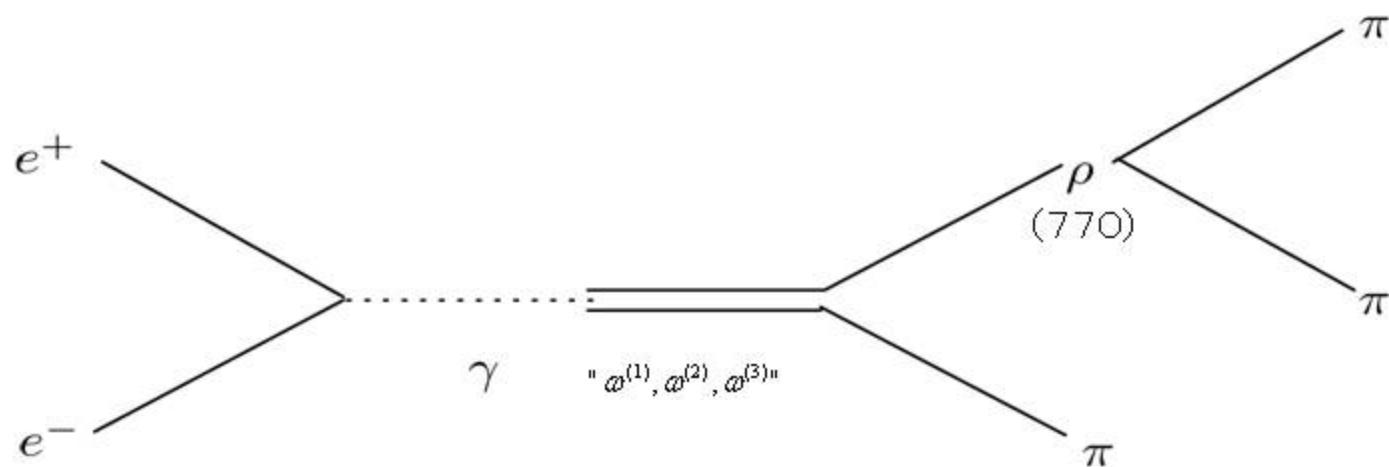
(3) The studies in hadroproduction and others have shown indication of low mass extra states.

(A. Donnachie and Yu. S. Karashnikova, Proc. 9th Hadron Conf.2001.AIP Conf. Proc.619(2005)5; Phys.Rept.403-404(2004)281-301; C. Amsler, et. Al. , Nucl. Phys. A740(2004)130)

- We re-analyze the $e^+e^- \rightarrow \pi^+\pi^-\pi^0$ data by SND/BABAR and $e^+e^- \rightarrow \omega \pi^0$ data by SND/CMD2/DM2 .

2. Analysis of the $e^+e^- \rightarrow \pi^+\pi^-\pi^0$ and indication of $\omega(1300)$

Method of analysis of $e^+e^- \rightarrow \pi^+\pi^-\pi^0$



Possible combination of the " ω " $\rightarrow\rho\pi\pi \rightarrow \pi\pi\pi$

$$\text{"}\omega\text"} \rightarrow \rho^0 \pi^0 \rightarrow \pi^+ \pi^- \pi^0$$

$$\text{"}\omega\text"} \rightarrow \rho^- \pi^+ \rightarrow \pi^- \pi^0 \pi^+$$

$$\text{"}\omega\text"} \rightarrow \rho^+ \pi^- \rightarrow \pi^+ \pi^0 \pi^-$$

Experimental data

Extra Vector Meson
 $\omega(1300)$

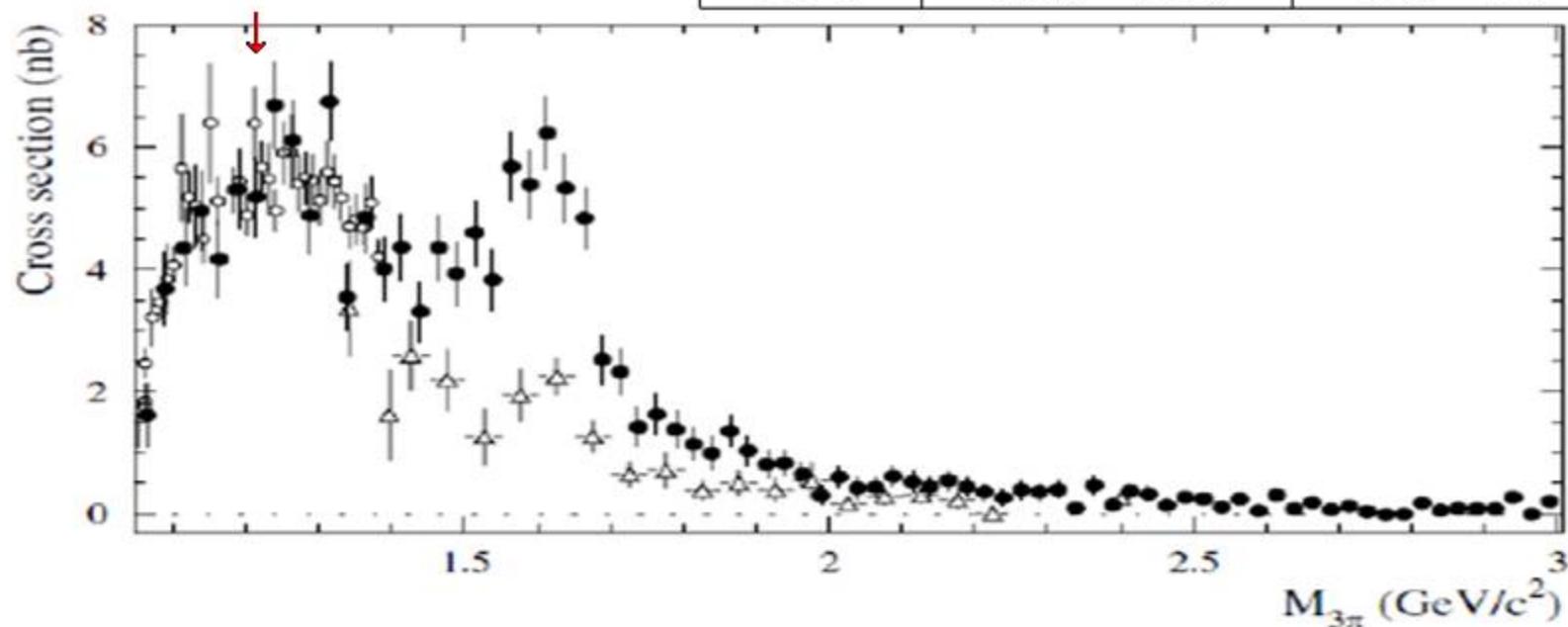
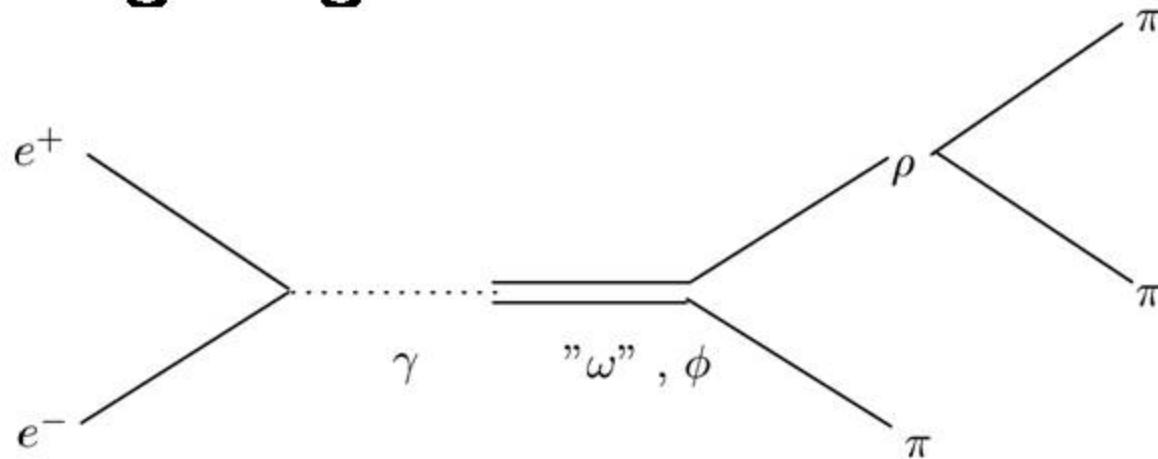


FIG. 18. The $e^+e^- \rightarrow \pi^+\pi^-\pi^0$ cross section measured in this work (filled circles), by SND (open circles), and DM2 (open triangles).

Effective Lagrangian of $e^+e^- \rightarrow \gamma \rightarrow " \omega ", \phi \rightarrow \rho \pi \rightarrow 3\pi$



$$\mathcal{L}_{e^+e^-\gamma} = ie\bar{\psi}_e\gamma_\mu\psi_e \mathbf{A}_\mu$$

$$\mathcal{L}_{V\gamma} = \left(\frac{em_\rho^2}{f_\rho} \rho_\mu^0 + \frac{em_\omega^2}{3f_\omega} \omega_\mu - \frac{\sqrt{2}em_\phi^2}{3f_\phi} \phi_\mu \right) A_\mu + \dots$$

$$\mathcal{L}_{\omega\rho\pi} = g_{\omega\rho\pi} \epsilon_{\mu\nu\lambda\kappa} \partial_\mu \omega_\nu \partial_\lambda \rho_\kappa \cdot \boldsymbol{\pi} + \dots$$

$$\mathcal{L}_{\phi\rho\pi} = g_{\phi\rho\pi} \epsilon_{\mu\nu\lambda\kappa} \partial_\mu \phi_\nu \partial_\lambda \rho_\kappa \cdot \boldsymbol{\pi}$$

$$\mathcal{L}_{\rho\pi\pi} = -f_{\rho\pi\pi} \rho_\mu (\boldsymbol{\pi} \times \partial_\mu \boldsymbol{\pi})$$

Cross Section

$$\sigma(s) = \frac{4\pi\alpha^2}{s^{\frac{3}{2}}} \left(\frac{g_{\omega\rho\pi}}{3f_\omega} \right)^2 \left| A_0 \frac{m_\omega^2 \sqrt{F_\omega(s)}}{m_\omega^2 - s - im_\omega\Gamma_\omega} + A_1 \frac{m_\phi^2 \sqrt{F_\phi(s)}}{m_\phi^2 - s - im_\phi\Gamma_\phi} + A_2 \frac{m_{\omega_2}^2 \sqrt{F_{\omega_2}(s)}}{m_{\omega_2}^2 - s - im_{\omega_2}\Gamma_{\omega_2}} \right. \right. \\ \left. \left. + A_3 \frac{m_{\omega_3}^2 \sqrt{F_{\omega_3}(s)}}{m_{\omega_3}^2 - s - im_{\omega_3}\Gamma_{\omega_3}} + A_4 \frac{m_{\omega_4}^2 \sqrt{F_{\omega_4}(s)}}{m_{\omega_4}^2 - s - im_{\omega_4}\Gamma_{\omega_4}} \right|^2 \frac{4\pi\Gamma_p(s)}{s^{\frac{1}{2}}} \right.$$

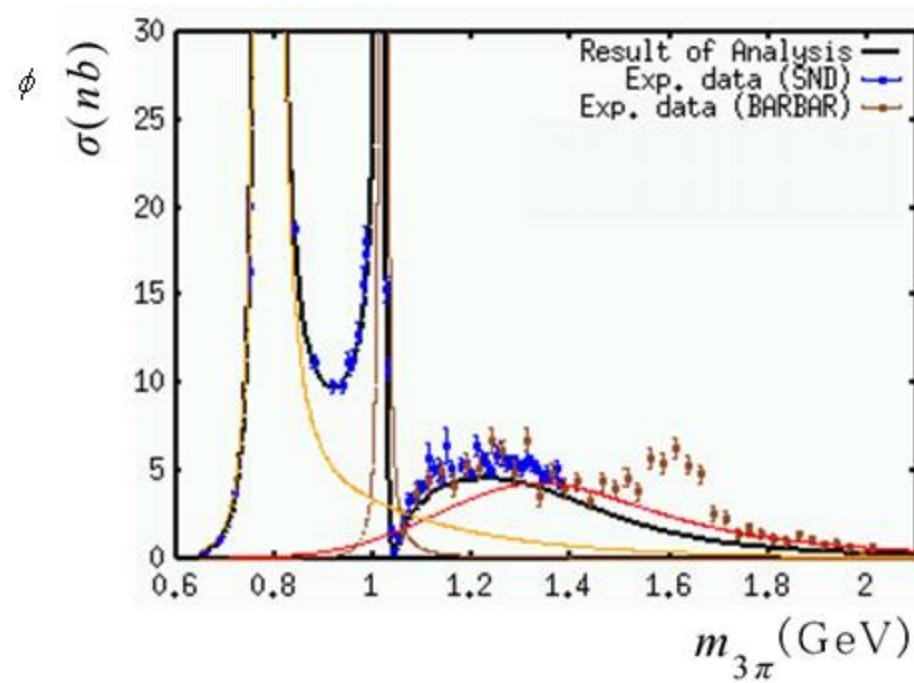
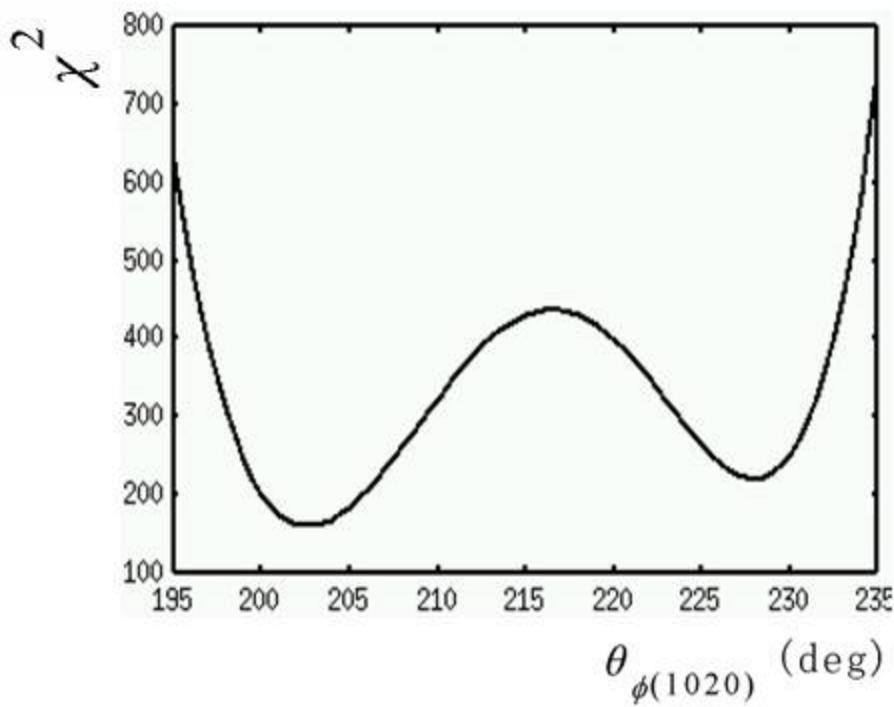
$$F_R = \frac{2m_R^2}{m_R^2 + s}$$

$$A_1 = \frac{\left(\frac{-\sqrt{2}g_{\phi\rho\pi}}{3f_\phi}\right)}{\left(\frac{g_{\omega\rho\pi}}{3f_\omega}\right)} = \frac{f_\omega}{f_\phi} \frac{g_{\phi\rho\pi}}{g_{\omega\rho\pi}}$$

$$A_i = \frac{\left(\frac{g_{\omega_i\rho\pi}}{3f_{\omega_i}}\right)}{\left(\frac{g_{\omega\rho\pi}}{3f_\omega}\right)} = \frac{f_\omega}{f_{\omega_i}} \frac{g_{\omega_i\rho\pi}}{g_{\omega\rho\pi}}, i = 2, 3, 4$$

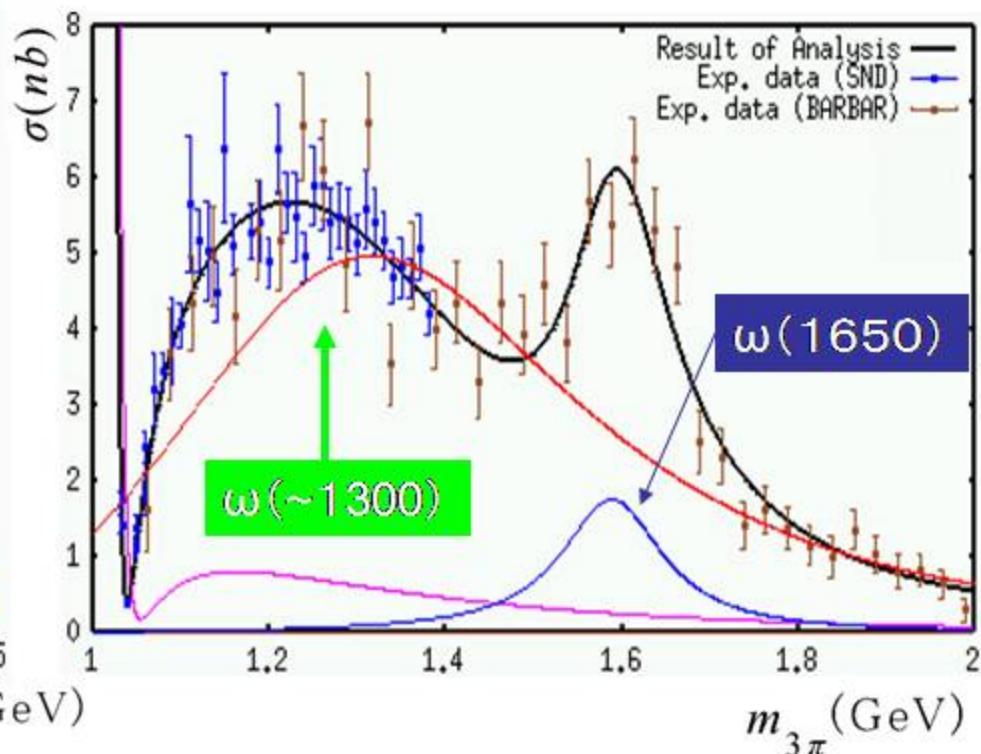
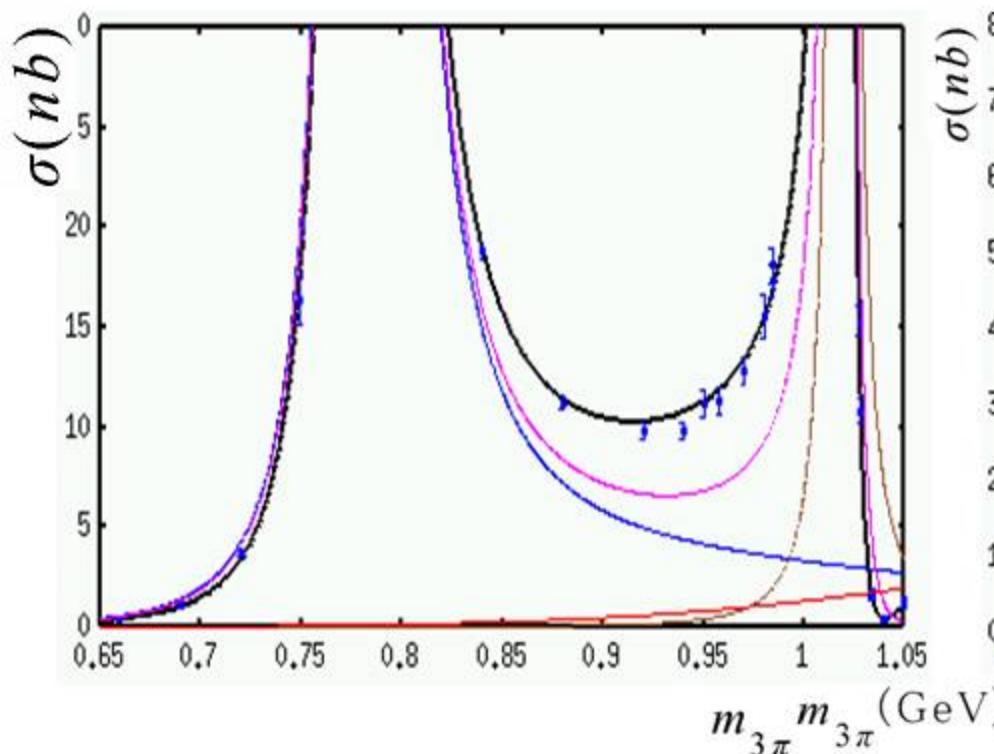
Relative phase θ between $\omega(782)$ and $\phi(1020)$

Using data(below 1GeV/c²), we fit phase θ
(we take into account $\omega(1300)$)



Result of Analysis (1)

With $\omega(782)$, $\phi(1020)$; PDG data
 $\omega(1300)$, $\omega(1650)$; Fitted

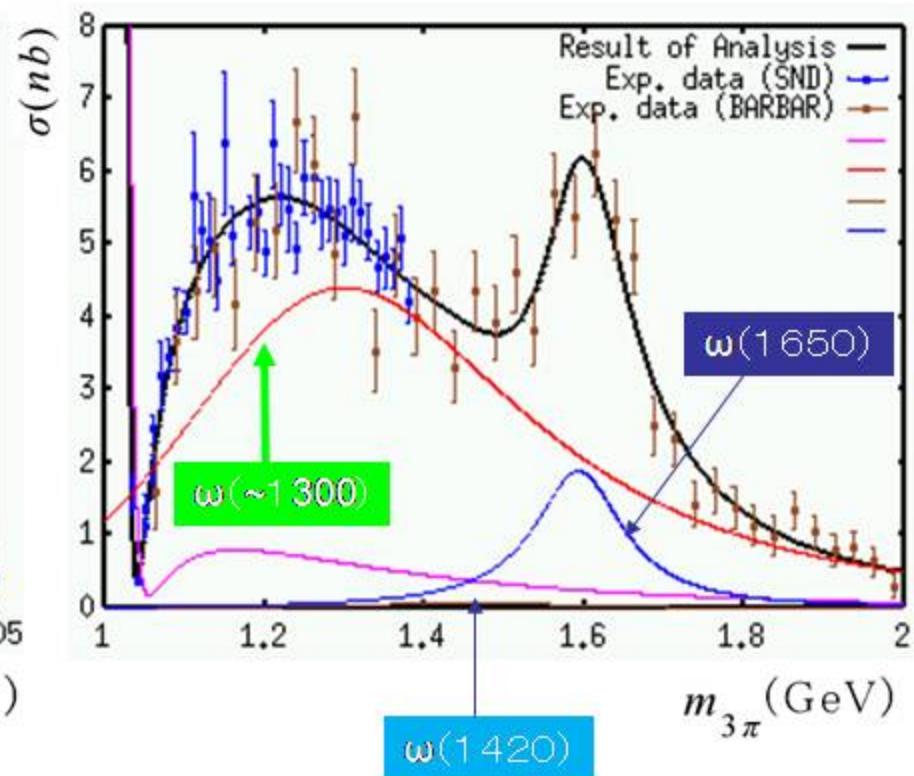
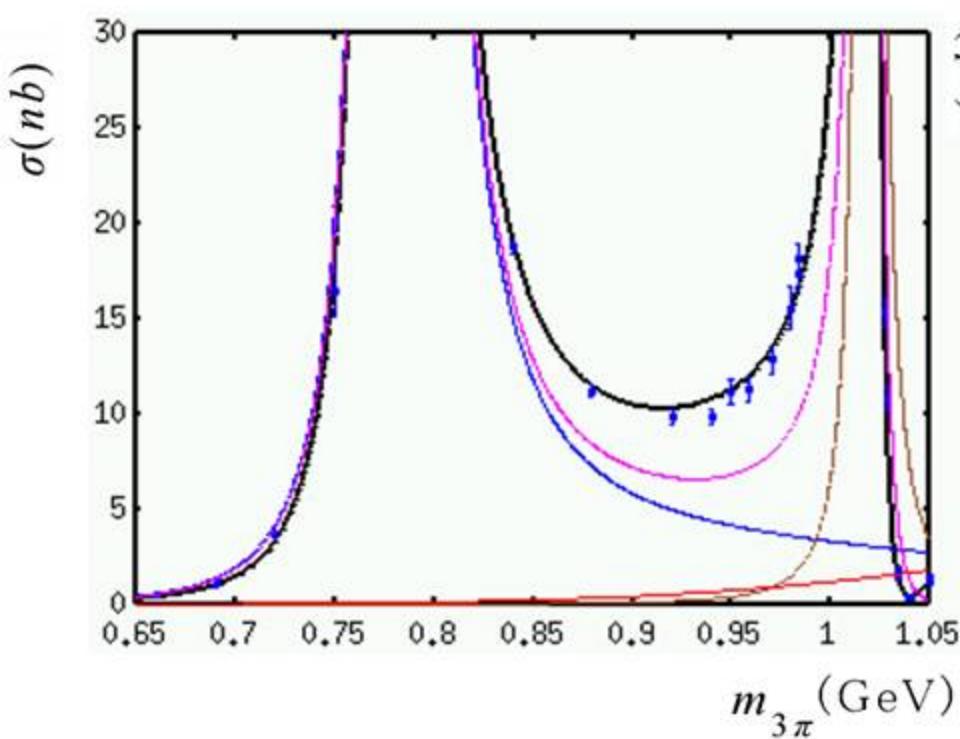


Result of Analysis (1)

	$\omega(1300)$	$\omega(1420)$	$\omega(1650)$
χ^2		170	
$N_D - N_P$		$(155 - 14) = 141$	
$\tilde{\chi}^2$		1.21	
$m[MeV]$	1243 ± 2	—	1588 ± 5
$\Gamma[MeV]$	672 ± 5	—	139 ± 8
A	-0.530 ± 0.003	—	-0.039 ± 0.001

Result of Analysis (2)

With $\omega(782), \phi(1020)$; PDG data
 $\omega(1300)$; Fitted
 $\omega(1420), \omega(1650)$; Fitted (With constraint to mass and width by PDG values)



Result of Analysis (2)

	$\omega(1300)$	$\omega(1420)$	$\omega(1650)$ † Upper bound
χ^2		168	
$N_D - N_P$		$(155 - 17) = 138$	
$\tilde{\chi}^2$		1.22	
$m[MeV]$	1229 ± 14	1450^\dagger	1592 ± 6
$\Gamma[MeV]$	635 ± 55	250^\dagger	135 ± 19
A	-0.486 ± 0.076	-0.019 ± 0.012	-0.039 ± 0.007

Summary of Analyses of $e^+e^- \rightarrow \pi^+\pi^-\pi^0$

- Using data(below 1GeV/c²), we fit phase θ between $\omega(782)$ and $\phi(1020)$
 $\theta = 205 \pm 2(\text{deg.})$ (we take into account $\omega(1300)$)

- Result of Analysis (1)**

Fitted to exp. Data with $\omega(782)$, $\phi(1020)$ $\omega(1300)$ and $\omega(1650)$

$$\bar{\chi}^2 = 170/(155-14) = 1.21$$

- Result of Analysis (2) (With $\omega(1300)$)**

Fitted to exp. Data with $\omega(782)$, $\phi(1020)$, $\omega(1300)$, $\omega(1420)$ and $\omega(1650)$.

$$\bar{\chi}^2 = 168/(155-17) = 1.22$$



Results strongly indicate the Existence of Extra Light-Vector Meson $\omega(1300)$

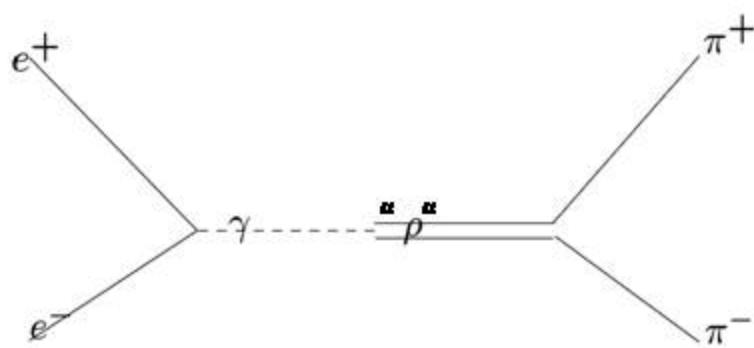
$$m_{\omega(1300)} = 1243 \pm 2 \text{ [MeV]}$$

$$\Gamma_{\omega(1300)} = 643 \pm 5 \text{ [MeV]}$$

3. Analysis of the $e^+e^- \rightarrow \omega\pi^0$ and indication of $\rho(1300)$

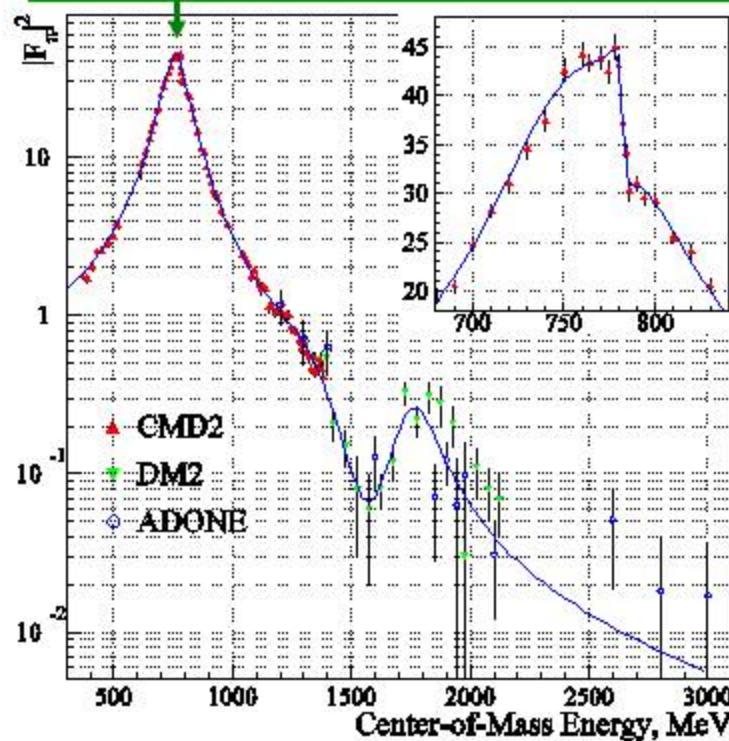
[Method of Analysis of the $e^+e^- \rightarrow \omega\pi^0$]

This process is inconvenient for
study of $\rho(1300)$



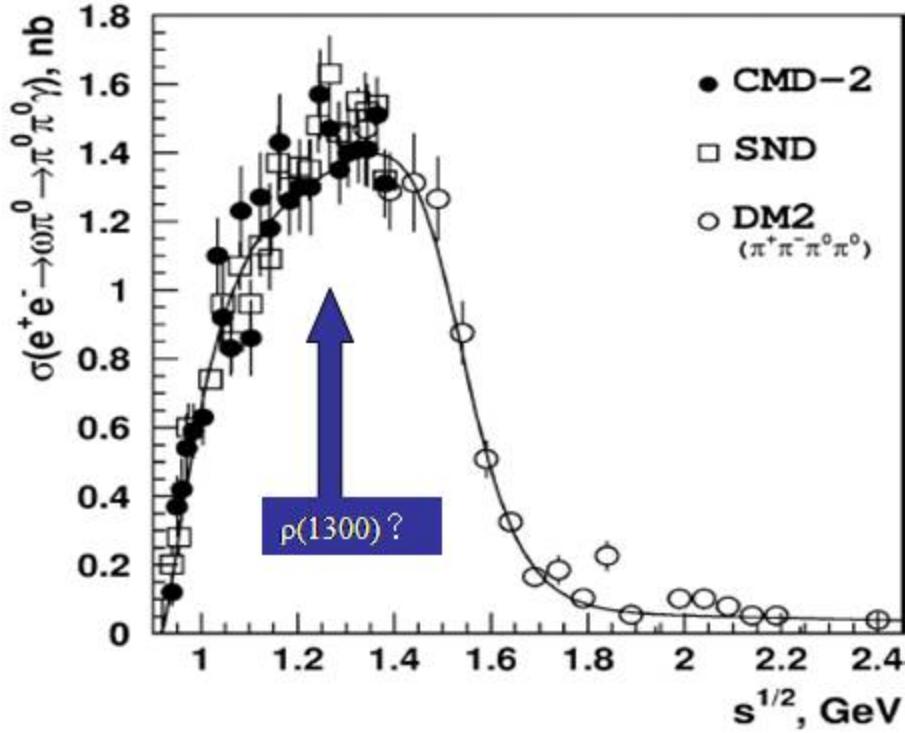
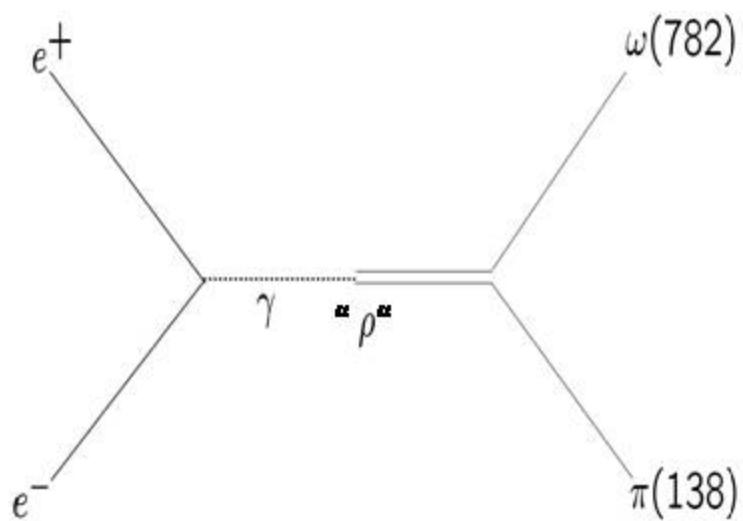
The diagram for the $e^+e^- \rightarrow \pi^+\pi^-$

There is a huge event concentration
around $\rho(770)$ mass region



[Experimental data of $e^+e^- \rightarrow \pi^+\pi^-$]

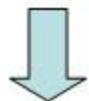
[Experimental data of $e^+e^- \rightarrow \omega\pi^0$]



Threshold of $\omega\pi^0$ channel

PLB562 (2003)173,(CMD-2)

$$(m_{\omega\pi^0} > m_\omega + m_{\pi^0} = 782 + 138 [MeV] = 920 [MeV])$$



Contribution from $\rho(770)$ can be almost excluded in this channel.

Cross Section of $e^+e^- \rightarrow \omega\pi^0$

Free Parameters Related to Production Coupling Constant

$$\sigma_0(s) = \frac{4\pi\alpha^2}{s^{\frac{3}{2}}} \left(\frac{g_{\rho\omega\pi}}{f_\rho} \right)^2 \left[\frac{m_\rho^2 \sqrt{F_\rho(s)}}{D_\rho(s)} + A_1 \frac{m_{\rho_1}^2 \sqrt{F_{\rho_1}(s)}}{D_{\rho_1}(s)} + A_2 \frac{m_{\rho_2}^2 \sqrt{F_{\rho_2}(s)}}{D_{\rho_2}(s)} + A_3 \frac{m_{\rho_3}^2 \sqrt{F_{\rho_3}(s)}}{D_{\rho_3}(s)} \right]^2 P_f(s)$$

$$P_f(s) = \frac{1}{3} p_\omega(s)^3 \cdot B_{\omega \rightarrow \pi^0\gamma}$$

; Phase Space of $\omega\pi^0$

$$p_\omega(s) = \frac{\sqrt{(s - m_\omega^2 - m_{\pi^0}^2)^2 - 4m_\omega^2 m_{\pi^0}^2}}{2\sqrt{s}}$$

; Momentum of ω
at ρ CMS

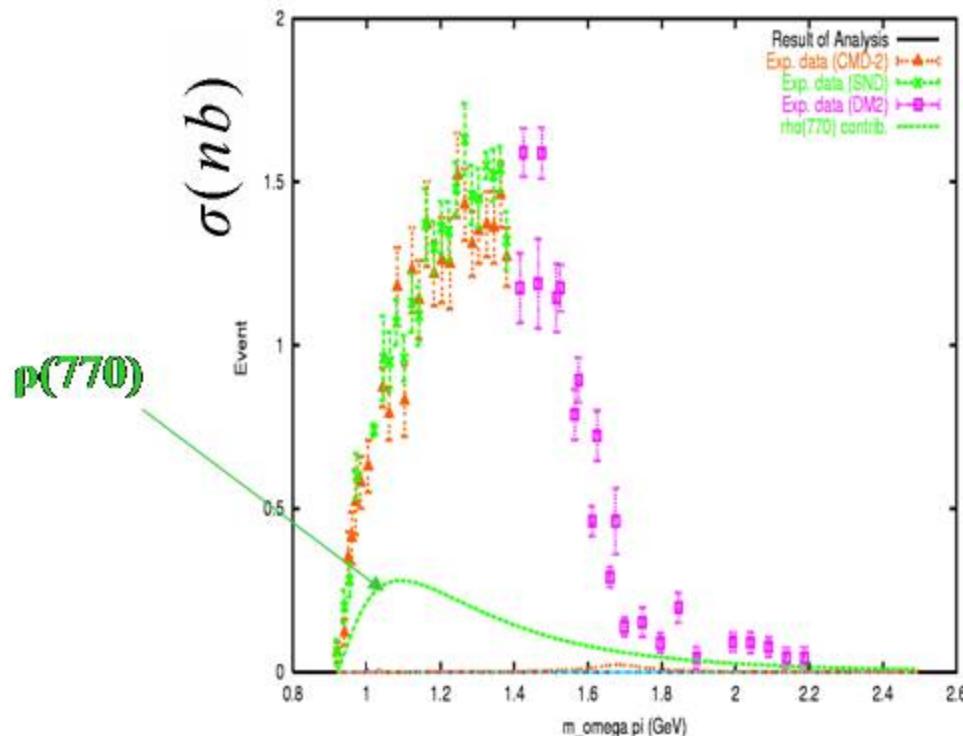
$$B_{\omega \rightarrow \pi^0\gamma} = 0.085 \pm 0.005$$

; BR of $\omega \rightarrow \pi^0\gamma$

$$\frac{1}{D_R(s)} = \frac{1}{m_R^2 - s - im_R\Gamma_R}$$

$$F_R(s) \equiv \frac{2m_R^2}{m_R^2 + s}$$

Estimation of the Contribution from $\rho(770)$



$$\Gamma_{\rho^0 \rightarrow e^+ e^-}^{\text{exp}} = 6.75 [\text{keV}] \rightarrow f_\rho = 5.04$$

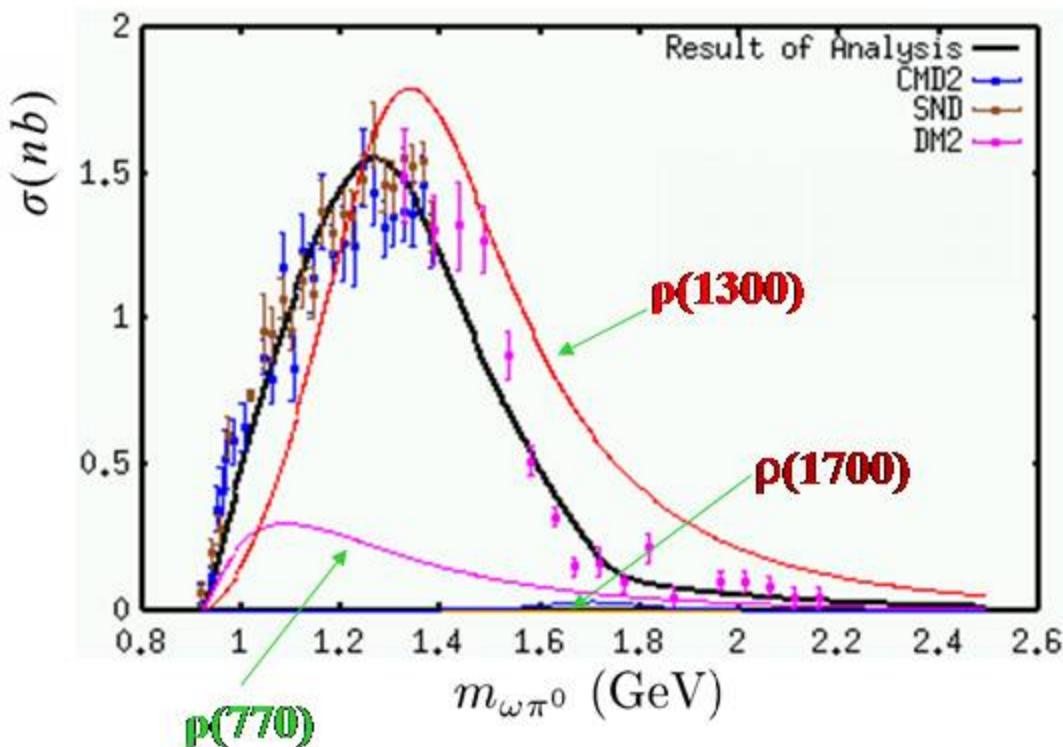
$$\Gamma_{\omega \rightarrow \rho\pi \rightarrow 3\pi}^{\text{exp}} = 8.44 [\text{MeV}] \times 0.888 \rightarrow g_{\omega\rho\pi} = 12.47 [\text{GeV}^{-1}]$$



Contribution from $\rho(770)$ is expected
by input of experimental values

• Result of Analysis

- With $\rho(770)$; Fixed to PDG
 - $\rho(1300)$; Fitted with free parameters
 - $\rho(1700)$; Fitted (With constraint to mass and width by PDG values)
-



Result	$\rho(1300)$	$\rho(1450)$	$\rho(1700)$
Analysis3	$\frac{\chi^2}{N_D - N_P} = \frac{214}{65 - 7} = 3.69$		
$m[MeV]$	1264 ± 2	—	1700
$\Gamma[MeV]$	560 ± 4	—	267
A	-0.524 ± 0.003	—	0.017 ± 0.003

Summary of Analyses of $e^+e^- \rightarrow \omega\pi^0$

- Result of Analysis (with $\rho(1300)$)
Fitted to exp. data by introducing $\rho(1300)$.

$$\tilde{\chi}^2 = \frac{214}{65-7} = 3.69$$



**Results strongly indicate the Existence of
Extra Light-Vector Meson $\rho(1300)$**

$$m_{\rho(\sim 1250)} = 1247 \pm 2 \text{ [MeV]}$$
$$\Gamma_{\rho(\sim 1250)} = 506 \pm 4 \text{ [MeV]}$$

4. Interpretations of the analysis results ($\omega(1300)$, $\rho(1300)$)

	Analysis result A	Nonrelativistic Q.M. (PDG)	$\tilde{U}(12)$ -Scheme
$\omega(770)$	Large	1^3S_1	1^3S_1
$\omega(1300)$	-0.53	_____	$1^3S_1^1$
$\omega(1450)$	_____	2^3S_1	1^1P_1
$\omega(1700)$	-0.039	1^3D_1	2^3S_1

$$\left| \psi_p(0) \right|^2 \sim 0$$

	Analysis result A	Nonrelativistic Q.M. (PDG)	$\tilde{U}(12)$ -Scheme
$\rho(770)$	Large	1^3S_1	1^3S_1
$\rho(1300)$	-0.52	_____	$1^3S_1^1$
$\rho(1450)$	_____	2^3S_1	1^1P_1
$\rho(1700)$	0.017	1^3D_1	2^3S_1

$$\left| \psi_p(0) \right|^2 \sim 0$$

5. Conclusions

(1) We re-analyze the $e^+e^- \rightarrow \pi^+\pi^-\pi^0$ data by SND/BABAR and $e^+e^- \rightarrow \omega\pi^0$ data by SND/CMD2/DM2 .

- Indication of $\omega(1300)$ is shown in analysis of $e^+e^- \rightarrow \pi^+\pi^-\pi^0$

$$m_{\omega(\sim 1300)} = 1243 \pm 2 \text{ [MeV]}$$

$$\Gamma_{\omega(\sim 1300)} = 672 \pm 5 \text{ [MeV]}$$

- Indication of $\rho(1300)$ is shown in analysis of $e^+e^- \rightarrow \omega\pi^0$

$$m_{\rho(\sim 1300)} = 1264 \pm 2 \text{ [MeV]}$$

$$\Gamma_{\rho(\sim 1300)} = 560 \pm 4 \text{ [MeV]}$$

(2) We don't included $\omega(1420)$ and $\rho(1450)$, (χ seems no difference between $\omega(1300)$, $\omega(1650)$ case and $\omega(1300)$, $\omega(1420)$, $\omega(1650)$.)

(3) Relative phases $\omega(1300)$ and $\omega(1650)$ against $\omega(782)$, are both negative in our results. Relative phases $\rho(1300)$ and $\rho(1700)$ against $\rho(770)$ are - and + in our results.

(4) $\Gamma_{\omega(1300)} / \Gamma_{\rho(1300)} \sim 1.2$ in our results.

$$\Gamma_{\omega(1300)} \sim \Gamma_{\omega(1300) \rightarrow \rho\pi}, \quad \Gamma_{\rho(1300)} = \Gamma_{\rho(1300) \rightarrow \omega\pi} + \Gamma_{\rho(1300) \rightarrow \pi\pi} + \Gamma_{\rho(1300) \rightarrow \pi\pi\pi}$$

(5) Such low-mass vector mesons $\omega(1300)$, $\rho(1300)$ have places in the $\tilde{U}(12)$ - level-classification scheme of hadrons .