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Experiment Study of $f_0(975)$ in J/ψ Decays

BES Collaboration*

(Institute of High Energy Physics, the Chinese Academy Sciences, Beijing, China)

Based on 7.8 × 10^6 J/ψ events collected by the BES at BEPC, the hadronic decays $J/\psi \to \phi\pi^+\pi^-$ and $J/\psi \to \omega\pi^+\pi^-$ are studied, and the branching ratios of these process and the mass and width of f_0 are obtained. The angular distribution of $J/\psi \to \phi f_0$, $f_0 \to \pi^+\pi^-$ is fitted and the helicity amplitude ratios of this process are given for the first time.

Key words: scalar meson, threshold effect, spin-parity, helicity.

1. INTRODUCTION

The behaviors and properties of 0^{++} scalar mesons are the topic people have been interested in. $f_0(975)$ is one of these scalar mesons.

The f_0 was observed for the first time by $\pi^- p \to n\pi^+\pi^-$ reaction in 1973 [1], and the clear f_0 signal was also found in later e^+e^- collider experiments. Mark II [2] studied the inclusive J/ψ decay ($J/\psi \to \pi^+\pi^- + X$) in 1981 and gave the f_0 parameters as:

$$m = (974 \pm 4) - i(14 \pm 5)\text{MeV}.$$

In 1988 and 1989, DM2 [3] and Mark III [4] reported the results of exclusive channels $J/\psi \to \phi f_0$, $f_0 \to \pi^+\pi^-$, respectively. The obvious f_0 signal was observed and the branching ratio was given:

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* A listing of the BES collaborators can be found in the appendix of this article. Unless otherwise noted, most researchers are affiliated with the address above.

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$$(Br(J/\psi \to \phi f_0) \times Br(f_0 \to \pi^+\pi^-))_{DM2} = (2.4 \pm 0.2 \pm 0.4) \times 10^{-4};$$
$$(Br(J/\psi \to \phi f_0) \times Br(f_0 \to \pi^+\pi^-))_{MARKIII} = (4.2 \pm 0.3 \pm 0.6) \times 10^{-4}.$$

For decay channel $J/\psi \to \omega\pi^+\pi^-$, a small signal near 1 GeV was seen in the invariant mass spectrum of the $\pi^+\pi^-$ system recoiling against the ω by DM2 collaboration. They fit this spectrum in 900-1400 MeV range using an incoherent sum of two Breit-Wigner functions over a polynomial background, setting the f_0 width to 35 MeV, and obtained

$$m = 959.4 \pm 6.5\text{MeV},$$
$$Br(J/\psi \to \omega f_0) \times Br(f_0 \to \pi^+\pi^-) = (1.10 \pm 0.21 \pm 0.16) \times 10^{-4}.$$

Mark III found only a small enhancement near f_0 mass in channel $J/\psi \to \omega\pi^+\pi^-$ and didn't give out the mass and width.

According to these experimental results, many theorists have made efforts to understand the scalar "meson" f_0. However, after about 20 years' controversy, the nature of f_0 is still not settled. Is f_0 just the $s\bar{s}$ meson [5], the multiquark state [6], or the $K\bar{K}$ molecular bound state? [7] Therefore, further experimental studies for the f_0 are of great meaning in understanding the nature of f_0.

Based on 7.8×10^6 J/ψ events collected by BES detector at BEPC, we studied the channels $J/\psi \to \phi\pi^+\pi^-$ and $J/\psi \to \omega\pi^+\pi^-$ systematically. The branching ratios of these two processes and the mass and width of f_0 were given. After fitting the angular distribution of $J/\psi \to \phi f_0$, $f_0 \to \pi^+\pi^-$, the helicity amplitude ratio of this process was obtained for the first time. These experimental results will no doubt provide information in understanding f_0.

2. $J/\psi \to \phi f_0$, $f_0 \to \pi^+\pi^-$

2.1. Event Selection

In the four-prong events, obtained after general offline processing, the net charge of four charged tracks $\sum_{i=1}^{4} Q_i$ is required to be zero. The vector sum of four charged tracks is required to be less than 0.3 GeV. The vertex cuts are: $|x| < 6$ mm, $|y| < 6$ mm, and $|z| < 80$ mm.

At least one charged track is determined to be a kaon within 3σ by time of Flight Counter (TOF) or DEDX (dE/dx of main drift chamber) measurement. Four-constraint kinematic fits are performed for all possible $K^+K^-\pi^+\pi^-$ combinations, and the combination with least χ^2 is assumed to be the correct one. If only one charged track is determined to be a koan within 3σ by TOF or DEDX measurement, $\chi^2 < 7$ is required, and if at least two charged tracks are determined to be kaons within 3σ by TOF or DEDX measurement, $\chi^2 < 25$ is required. We analyzed about 7.8×10^6 J/ψ events from run 462-961, run 1248-1616, run 1750-1940, and run 3579-3739, according to the preceding event selection criteria.

2.2. The Fitting of $\pi^+\pi^-$ Invariant Mass Spectrum Recoiling Against ϕ

Figure 1 shows the invariant mass spectrum of $\pi^+\pi^-$ system in $J/\psi \to \phi\pi^+\pi^-$. An obvious f_0 signal near 1 GeV with a steep fall on the high mass side can be observed. To consider the asymmetry of spectrum due to $K\bar{K}$ threshold effect, the coupled-channel fitting formula [8] is adopted to fit the signal f_0 by using the Maximum Likelihood method:

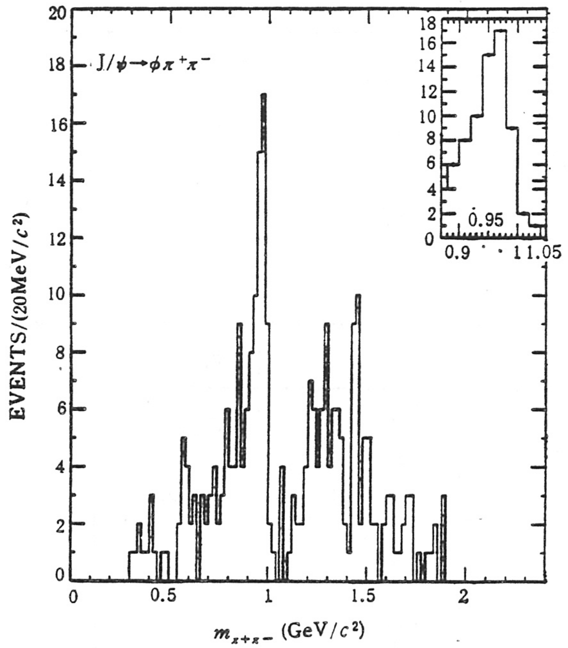

Fig. 1
$\pi^+\pi^-$ invariant mass spectrum recoiling against ϕ.

$$\frac{d\sigma}{dm} \sim \frac{\Gamma_\pi}{|m_R^2 - m^2 - i m_R(\Gamma_\pi + \Gamma_K)|^2},$$

where m_R is the resonance mass,

$$\Gamma_\pi = g_\pi \sqrt{\frac{m^2}{4} - m_\pi^2}, \qquad \Gamma_K = \begin{cases} g_K \sqrt{\frac{m^2}{4} - m_K^2} & \text{above threshold} \\ i g_K \sqrt{\frac{m^2}{4} - m_K^2} & \text{below threshold} \end{cases},$$

g_π and g_K are the coupling constants for $f_0 \to \pi^+\pi^-$ and $f_0 \to K^+K^-$, respectively.

From the results of Monte Carlo simulation, the acceptance in f_0 mass range is almost uniform, and the mass resolution $\sigma_m = 10$ MeV.

The fitted results for the mass and width of f_0 are: $m = 969 \pm 4$ MeV, $\Gamma = 43 \pm 8$ MeV.

2.3. Branching Ratio of $J/\psi \to \phi f_0$

From the fitting of $\pi^+\pi^-$ invariant mass spectrum, 59 f_0 events are obtained. The efficiency given by Monte Carlo simulation is about 10%, and the total J/ψ events are 7.8×10^6. Therefore, the branching ratio of this process is: $Br(J/\psi \to \phi f_0) = (2.9 \pm 0.4 \pm 0.5) \times 10^{-4}$.

2.4. Angular Distribution of $J/\psi \to \phi f_0$

For the strong decay process $J/\psi \to V + X$, $V \to P_1^+ P_2^-$, $X \to P_3^+ P_4^-$, the helicity of the angular distribution is [9]:

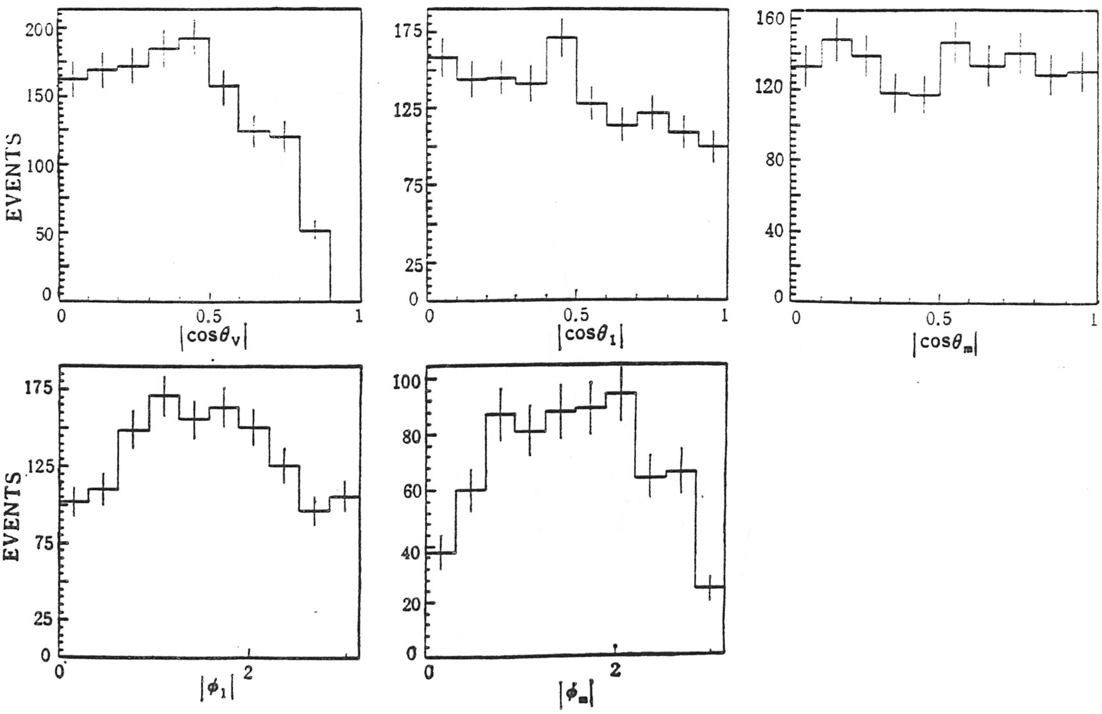

Fig. 2
The detection efficiency for the decay $J/\psi \to \phi f_0$, $f_0 \to \pi^+\pi^-$ versus different angles. The meanings of θ_V, θ_1, θ_m, ϕ_1, and ϕ_m refer to the text.

$$W(\theta_V,\theta_1\varphi_1,\theta_m\varphi_m) \sim \sum I_{\lambda_J,\lambda'_J}(\theta_V)\cdot A_{\lambda_V\lambda_X}\cdot A^*_{\lambda'_V\lambda'_X}\cdot D^{1*}_{\lambda_V,0}(\theta_1,\varphi_1,0)$$
$$\cdot\, D^{1}_{\lambda'_V,0}(\theta_1,\varphi_1,0)\cdot D^{S*}_{-\lambda_X,0}(\theta_m,\varphi_m,0)\cdot D^{S}_{-\lambda'_X,0}(\theta_m,\varphi_m,0),$$

in which S is the spin of X, $A_{\lambda_V\lambda_X}$ is the helicity amplitude of $e^+e^- \to J/\psi \to V + X$, θ_V is the angle between directions of meson V and e^+ beam in J/ψ static frame, and (θ_1,φ_1) and (θ_m,φ_m) are the polar and azimuthal angles of P_1^+ and P_3^+ in meson V and X centers of mass systems, respectively. The ratios of helicity amplitudes are defined as:

$$x = \frac{A_{11}}{A_{10}},\quad y = \frac{A_{12}}{A_{10}},\quad z_1 = \frac{A_{00}}{A_{10}},\quad z_2 = \frac{A_{01}}{A_{10}},$$

If X is a scalar meson, we have

$$W \sim (1+\cos^2\theta_V)\sin^2\theta_1 - \sin^2\theta_V\sin^2\theta_1\cos(2\varphi_1)$$
$$+\, 2\sin^2\theta_V\cos^2\theta_1 z_1^2 - 2\sin 2\theta_V\sin\theta_1\cos\theta_1\cos\varphi_1 z_1,$$

By using the method of helicity analysis [10], we fit the angular distribution of decay $J/\psi \to \phi f_0$,

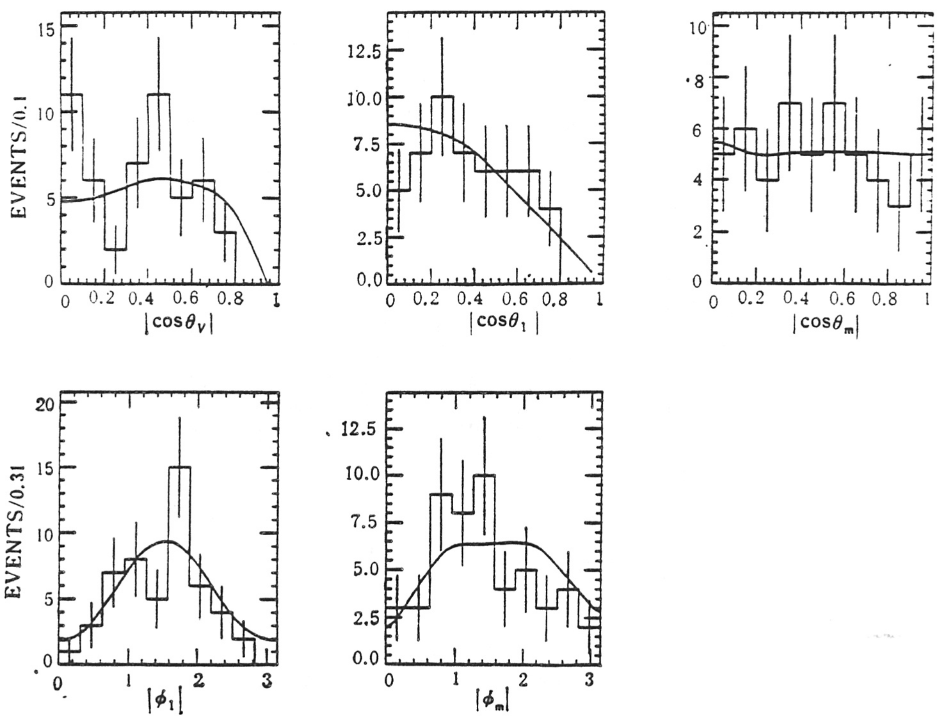

Fig. 3
The angular distribution of the decay $J/\psi \to \phi f_0$, $f_0 \to \pi^+\pi^-$. The data are represented by histograms and the fit results by curves.

$f_0 \to \pi^+\pi^-$. The angular resolution function can be treated as a δ function because of the good position resolution of the main drift chamber of BES. The efficiency curves from Monte Carlo simulations are shown in Fig. 2 and the angular distributions of data and the results of fitting are shown in Fig. 3. From the uniform distribution of $\cos\theta_m$, we get the conclusion of f_0 being a 0^{++} scalar meson. The maximum likelihood fitting results in the parameter value of $z_1 = 0.09 \pm 0.18$.

3. $J/\psi \to \omega f_0$, $f_0 \to \pi^+\pi^-$

3.1. Event Selection

In the four-prong events, the net charge of four charged tracks $\sum_{i=1}^{4} Q_i$ is required to be zero. We also require the number of neutral tracks to be two to six. TOF and DEDX measurements are used to identify particles. The maximum weight of charged π's must satisfy $W_\pi^{max} > 0.95$. In the kinematic fitting, we assume any two of the neutral tracks and four charged tracks to be $\gamma\gamma$ and $2(\pi^+\pi^-)$, respectively, and then perform 4C-fit $\chi^2 < 50$, select the combination with the least χ^2 as the needed combination $2(\pi^+\pi^-)\gamma\gamma$. The π^0 is selected by the cut $|m_{\gamma\gamma} - 0.135| < 0.06$ GeV and then the ω is selected by the cut:

$$|m_{\pi^+\pi^-\pi^0} - 0.783| < 0.06 \text{ GeV}.$$

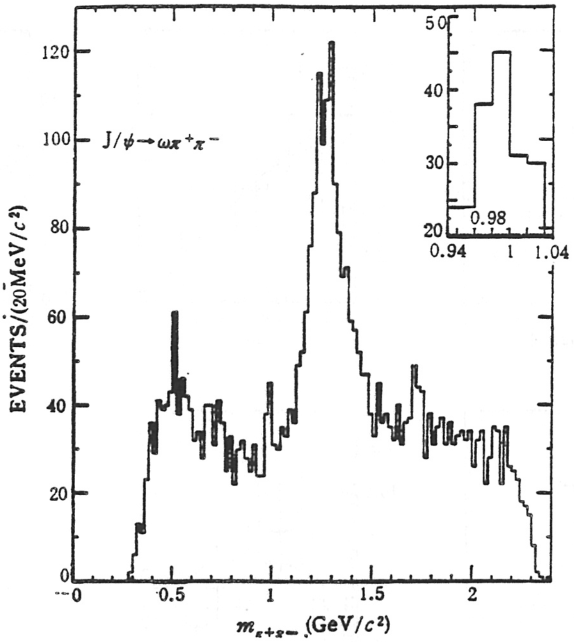

Fig. 4

$\pi^+\pi^-$ invariant mass spectrum recoiling against ω.

Based on the preceding event selection criteria, we analyzed 7.8×10^6 J/ψ events from run 462-961, run 1248-1616, run 1750-1940, and run 3579-3739.

3.2. $\pi^+\pi^-$ Invariant Mass Spectrum Recoiling Against ω

From the $\pi^+\pi^-$ invariant mass spectrum recoiling against ω, shown in Fig. 4, we can see that there is a clear accumulation of events at the mass near 1 GeV. By taking into account the mass resolution near 1 GeV $\sigma_m = 10$ MeV, obtained from Monte Carlo simulation, and fitting the whole mass range using five incoherent B-W functions over a polynomial background, the parameters of f_0 are given as: $m_{f_0} = 985 \pm 9$ MeV, $\Gamma_{f_0} = 11 \pm 6$ MeV.

Because the efficiency in f_0 range by Monte Carlo is about 7.1% and the total f_0 events is 32, the branching ratio can be calculated as: $Br(J/\psi \to \omega f_0) = (1.3 \pm 0.8 \pm 0.2) \times 10^{-4}$.

4. CONCLUSIONS

We have investigated the $\pi^+\pi^-$ invariant mass spectrum from $J/\psi \to \phi\pi^+\pi^-$ and $J/\psi \to \omega\pi^+\pi^-$. The f_0 signals were observed in both channels. The fitting results show that the position of f_0 recoiling against ϕ is lower than its position of recoiling against ω, whereas the width is larger. Are these two f_0s the same state? From the theoretical point of view, if these two f_0s are considered as the same state, the assumption of f_0 as a $s\bar{s}$ state cannot explain the appearance of f_0 in $J/\psi \to \omega\pi^+\pi^-$, although it explains the f_0 in $J/\psi \to \phi f_0$ well. On the other hand, we can consider the same problem for f_0's partner a_0. In $J/\psi \to \gamma K^+K^-\pi^0$ channel, there is an obvious $\iota(1440)$ pear in $K\bar{K}\pi^0$ mass spectrum and a clear $a_0(980)$ in $K\bar{K}$ mass spectrum. It can be deduced that this $a_0(980)$ comes from the decay of $\iota(1440)$. However, in channel $J/\psi \to \gamma\eta\pi^+\pi^-$, there exists a clear a_0 in the $\eta\pi$ spectrum, but no $\iota(1440)$ in the

$\eta\pi\pi$ mass spectrum. Therefore, this a_0 does not come from $\iota(1440)$ decay, and we have the same question, that is, are these a_0s the same state? Our results are still preliminary. More channels and more statistics are needed to study f_0 carefully.

REFERENCES

[1] S. D. Protopopescu *et al.*, *Phys. Rev.*, **D7**(1979): p. 1279.
[2] G. Gidal *et al.*, *Phys. Lett.*, **107B**(1981): p. 153.
[3] A. Falvard *et al.*, *Phys. Rev.*, **D38**(1988): p. 2706.
[4] L. William *et al.*, *Proceedings of Hadron '89*, (1989): p. 109.
[5] D. Morgan, *Phys. Lett.*, **51B**(1974): p. 71.
[6] R. J. Jaff, *Phys. Rev.*, **D15**(1977): p. 267.
[7] J. Weistein *et al.*, *Phys. Rev.*, **D27**(1983): p. 588; *Phys. Rev.*, **D41**(1990): p. 2236.
[8] S. M. Flatte, *Phys. Lett.*, **63B**(1976): p. 224.
[9] Yu Hong and Shen Qixin, *High-energy Phys. and Nucl. Phys.* (Chinese Edition), **14**(1990): p. 504.
[10] Bai Jingzhi *et al.*, *High-energy Phys. and Nucl. Phys.* (Chinese Edition) **17**(1993): p. 97.
[11] G. Eigen, *CALT-68-1483*, (1987), pp. 78, 81.

APPENDIX

This BES Collaboration consists of the following researchers:
Bai Jingzhi, Chen Guangpei, Chen Hongfang[1], Chen Shaomin, Chen Shenjian, Chen Yaqing, Chen Yu, Chen Yuanbo, Cheng Zhengdong, Cheng Baoshen, Cui Huachuan, Cui Xiangzong, Ding Huiliang, Ding Weiyan, Du Zhizhen, Fan Xiaoling, Fang Jian, Gao Cuishan, Gao Meili, Gao Shuqi, Gao Wenxiu, Gu Jianhui, Gu Shudi, Gu Weixin, Gu Yifan, Guo Yanan, Guo Yuyi, Han Ying, Han Shiwen, He Ju, He Mao[2], He Keren, Hu Guiyun, Hu Hongbo, Hu Tao, Hu Xiaoqing, Huang Deqiang, Huang Yinzhi, Jiang Chunhua, Jin Shan, Jin Yan, Ke Zunjian, Kang Shuhui, Lai Yuanfen, Lang Pengfei, Lan Huibin, Li Fang, Li Jin, Li Qun[2], Li Peiqin, Li Qiming, Li Rubo, Li Wei, Li Weidong, Li Weiguo, Li Xiaonan, Lin Shuzi, Liu Huaimin, Liu Qi, Liu Rongguang, Liu Yan, Liu Jinghua, Liu Zhenan, Lü Junguang, Luo Shuanqun, Ma Aimin, Ma Encheng, Ma Jimao, Mao Huishun, Mao Zepu, Meng Xiangcheng, Ni Huiling, Nie Jing, Pan Lingjun, Qi Nading, Que Youkun, Rong Gang, Shao Yuying, Shen Benwei, Shen Dingli, Shen Hong, Shen Xiaoyan, Sheng Huayi, Song Xiaofei, Shi Huanzhang, Sun Fang, Sun Hansheng, Tan Yiping, Tong Guoliang, Tang Shuqiu, Wang Linzhou, Wang Man, Wang Lingshu, Wang Peiliang, Wang Ping, Wang Shaomin, Wang Taijie, Wang Yunyong, Wei Chenglin, Xi Deming, Xia Xiaomi, Xie Peipei, Xie Xiaoxi, Xie Yigang, Xu Rongsheng, Xu Dezhi, Xu Zhijing, Xue Shengtian, Yan Jie, Yan Wuguang, Yang Chanyou, Yang Chunmin, Yang Wei, Ye Minghan, Ye Shizhang, Yu Chunxu, Yu Zhongqiang, Yu Chuansong, Yuan Changzheng, Zhang Bingyun, Zhang Changchun, Zhang Dahua, Zhang Huiling, Zhang Jian, Zhang Jiawen, Zhang Shaoqiang, Zhang Liangsheng, Zhang Xueyao[2], Zhang Yu, Zhang Yueyuan, Zhuang Baoan, Zhao Dixin, Zhao Meng, Zhao Jingwei, Zhao Pingde, Zhao Weiren, Zhao Wenheng, Zheng Jianping, Zheng Linsheng, Zheng Zhipeng, Zhou Baoqing, Zhou Guangpu, Zhou Huashi, Zhou Li, Zhou Yuehua, Zhou Xiaofan, Zhu Qiming, Zhu Yucan, and Zhu Yongsheng

Most researchers may be contacted at the Institute of High Energy Physics, the Chinese Academy Sciences, Beijing, China. A few other researchers, distinguished numerically, are affiliated with the following institutions:

1 — Department of Physics, Shandong University, Jinan, Shandong, China;

2 — Department of Modern Physics, University of Science and Technology of China, Hefei, Anhui, China.