The Experimental Research on "$\rho\pi$ puzzle"

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Abstract

A data sample of about 3.8 million $\psi(2S)$ events is used to perform a comprehensive analysis of vector-plus-pseudoscalar-meson(VP) decays of $\psi(2S)$ for the first time in the world.The experimental results are as follows:
1.Br($\psi(2S) \to \rho\pi$)$< 2.3 \times 10^{-5}$.
2.Br($\psi(2S) \to \rho\eta$)=$(2.1\pm1.1\pm0.5) \times 10^{-5}$=$(2.1\pm1.2) \times 10^{-5}$.
3.Br($\psi(2S) \to \rho\eta'$)$< 3.0 \times 10^{-5}$.
4.Br($\psi(2S) \to \omega\pi^0$)=$(4.0\pm1.0\pm0.6) \times 10^{-5}$=$(4.0\pm1.1) \times 10^{-5}$.
5.Br($\psi(2S) \to \omega\eta$)$< 2.6 \times 10^{-5}$.
6.Br($\psi(2S) \to \omega\eta'$)=$(7.6\pm4.4^{+2.0}_{-1.5}) \times 10^{-5}$=$(7.6^{+4.8}_{-4.6}) \times 10^{-5}$.
7.Br($\psi(2S) \to \phi\pi^0$)$< 0.66 \times 10^{-5}$.
8.Br($\psi(2S) \to \phi\eta$)=$(3.3\pm1.4\pm0.6) \times 10^{-5}$=$(3.3\pm1.5) \times 10^{-5}$.
9.Br($\psi(2S) \to \phi\eta'$)$< 5.2 \times 10^{-5}$.
Additionally,we also obtain:
10.Br($\psi(2S) \to \pi^+\pi^-\pi^0$)=$(10.5\pm1.2^{+1.7}_{-1.5}) \times 10^{-5}$=$(10.5^{+2.1}_{-1.9}) \times 10^{-5}$.
Where the first error is statistic,and the second one is systematic.Using above results,the rule of "14%" has been checked and it is found that electromagnetic VP decays of $\psi(2S)$ conserve the rule of "14%".The upper limit of branching ratio of $\psi(2S)\to \phi\pi^0$ at 90% CL nearing that of the J/ψ shows that DOZI electromagnetic decays can be neglected in both J/ψ and $\psi(2S)$.A phenomenological theory is used to analyse overall charaters of $\psi(2S)$ VP decays,and reveals that the strong interaction g is suppressed severely in $\psi(2S)$ relative to J/ψ,moreover g's phase angle relative to eletromagetic interation e is close to 180° at $\psi(2S)$; while it is about 72° at J/ψ. A new model of "$\rho\pi$ puzzle" explanation based on color-octet $c\overline{c}$ production is compared with our experimental results and they are in general consistency.Measurements of the R ratios of $e^+e^- \to \rho\eta$,$\omega\pi^0$,$\phi\eta$ at Ecm=4.03GeV are presented.Finally,electromagnetic form factors of pure eletromagetic VP decays $\rho\eta$ and $\omega\pi^0$ are found to be consistent with the predictions of vector dominance model(VDM) at J/ψ and $\psi(2S)$.

I. Introduction

"$\rho\pi$ puzzle" of J/ψ and $\psi(2S)$ decays has been a famous long-standing mystery of charmonium physics since 1983[1] and draws considerable attention continuously.[2][3][4][5][6][7][8]The perturbative QCD theorem predicts ratios of J/ψ and $\psi(2S)$ decays conserve the rule of "14%".Most hadronic decays of $\psi(2S)$ and J/ψ except $\rho\pi$,K^*K conserve the rule of "14%", so these exceptions voilating the rule of "14%" severely are called "$\rho\pi$ puzzle". From a phenomenological theory[9],VP decays of ψ(including J/ψ and $\psi(2S)$) are expected to occure through four processes:1)OZI-suppressed strong decay via three-gluon annihilation whose relative coupling strength is standed by g;2)electromagnetic decay through a virtual photon from $c\overline{c}$ annihilation,standed by e;3) pure double OZI-suppressed(DOZI) strong decay,standed by rg and 4)SU(3)-breaking strong decay,standed by sg. g is a complex,it has a phase angle relative to e. DOZI-suppressed electromagnetic decay is ignored in the model. The reduced braching ratio of ith ψ VP final state $\overline{B}_{VPi}$ is in proportion to square of ith VP decay amplitude M_i,The expressions of M_i for the different ψ VP final states are shown in table 1.

Table 1

ψ VP decay mode	M_i expression
$\rho^+\pi^-,\rho^-\pi^+,\rho^0\pi^0$	g+e
$\rho\eta$	3eX_η
$\rho\eta'$	3e$X_{\eta'}$
$\omega\pi^0$	3e
$\omega\eta$	$(g+e)X_\eta+\sqrt{2}rg(\sqrt{2}X_\eta+Y_\eta)$
$\omega\eta'$	$(g+e)X_{\eta'}+\sqrt{2}rg(\sqrt{2}X_{\eta'}+Y_{\eta'})$
$\phi\pi^0$	0
$\phi\eta$	$[g(1-2s)-2e]Y_\eta+rg(\sqrt{2}X_\eta+Y_\eta)$
$\phi\eta'$	$[g(1-2s)-2e]Y_{\eta'}+rg(\sqrt{2}X_{\eta'}+Y_{\eta'})$
$K^{*+}\overline{K}^-,\overline{K}^{*-}K^+$	g(1-s)+e
$K^{*0}\overline{K}^0,\overline{K}^{*0}K^0$	g(1-s)-2e

The ratio of electromagnetic form factors $f(q^2)$ for a pure electromagnetic VP decays at q^2=S and at q^2=0 is given by[10][11]: $F^2_{VP}=\frac{|f(S)|^2}{|f(0)|^2}=\frac{\alpha}{3}\frac{p^3_\gamma}{p^3_V}\frac{\sqrt{S}}{\Gamma(V\to P\gamma)}R_{VP}$,where R_{VP} is the ratio of the Born-level cross section for $e^+e^-\to VP$ to the lowest level QED cross section for $e^+e^-\to\mu^+\mu^-$.In the vector dominance model(VDM),the form factor is mediated by one or more vector mesons V^*,f(q^2)(F$_{VP}$) is in proportion to 1/S. BES has acquired the largest $\psi(2S)$ data sample in the world, which contains 3.788×10^6 $\psi(2S)$ events.This provides a good chance for BES to make its contributions in study of "$\rho\pi$ puzzle".After convincingly checked reliability of our data analysis method by measuring the decays of $\psi(2S)\to J/\psi$ plus neutrals [12],we have measured above $\psi(2S)$ VP decays. In the following,we present our results.

II. Branching Ratio Measurements

1. Event Common Preselection

We just use two or four-prong good events of $\psi(2S)$ data sample to measure branching ratios or upper limits at 90% CL of $\psi(2S)$ VP decays.Events preselection requires: a good reconstructed(MFIT=2) event has two or four chraged tracks,zero net charge,a good primary vertex and more than one good gammas. for each charged track,$Rxy<0.015m,|z|<0.15m.|cos\theta|<0.8$. A good gamma must satisfy: hitting barrel shower counter (BSC);First hitting layer number less than six;The angle between the hitting and developing directions in BSC less than 36.9°.Additionally,for two prong events,further require: The minimum angle between a good gamma hitting direction at BSC and any charged track momentum direction(THNC) larger than 11.5°.

2. Data Analysis

2.1 $\psi(2S)\to\rho\pi$ Analysis

The final state of the decay is $\pi^+\pi^-\pi^0$,$\pi^0\to\gamma\gamma$.Further preselection requires the events to have two charged tracks and the good gammas must further satisfy:total number of hitting BSC layers ILAYT>1 ; THNC> 15°.The gammas' deposted energy in BSC: E_γ >50 MeV.The events can pass 4-c kinematic fit under the model $\psi(2S)\to\pi^+\pi^-\gamma\gamma$.We determine the two gammas from π^0 by choosing the lowest 4-c fit χ^2 and mass of the π^0 is below 0.3 GeV.In fact,the sample passed above criteria contains three possible final states: one nonresonant state:$\pi^+\pi^-\pi^0$ and two resonant states:$\rho^0\pi^0$ and $\rho^+\pi^-(\rho^-\pi^+)$ .In order to extract these states,we further require:1) χ^2_{4c-fit} <12. 2) Total momentum of two charged pions:$P_{\pi^+\pi^-}$ >0.6 GeV. 3) good gamma number of the event:NTRK=2. 4) EF1×EF2×XLNN>0.04. EF1 and EF2 are the two gammas' energy after 4c-fitting,XLNN is distance between them. 5) Ratio of deposited energy in BSC to momentum for the charged pion with higher momentum:0.0<EPRAT1<0.5,and $M_{\gamma\gamma}$ >0.03 GeV. 6)The $\rho^0\pi^0$ channel is further required that invariant mass of two charged pions:$|M_{\pi^+\pi^-} - 0.7685|$ <0.15 GeV. 7)The $\rho^+\pi^-(\rho^-\pi^+)$ channel is further required that invariant mass of a charged pion and a neutral pion satisfy: $|M_{\pi^+\pi^0} - 0.7685|$ <0.15 GeV or $|M_{\pi^-\pi^0} - 0.7685|$ <0.15 GeV. The numbers of events surviving each requirement for different type events are shown in Table 2.

Table 2

REQUIREMENT	DATA	MC1	MC2	MC3
In	5575465	20000	20000	20000
Preselection	11812	5686	5025	5130
CUT1	5097	5108	4551	4469
CUT2	1054	4699	4551	3805
CUT3	814	4596	4404	3702
CUT4	340	4468	4354	3576
CUT5	147	3871	3595	3243
CUT1-5,6	10	284	2658	15
CUT1-5,7	14	436	34	2368

MC1: $\psi(2S) \to \pi^+\pi^-\pi^0$. MC2: $\psi(2S) \to \rho^0\pi^0$. MC3: $\psi(2S) \to \rho^+\pi^-(\rho^-\pi^+)$.

There is a apparent difference between EPRAT1 distributions of MC and DATA,so it is necessary to correct MC EPRAT1 efficiency by using pion tracks' data sample and MC momentum distribution,EPRAT1 correction parameter is 0.9013 for $\pi^+\pi^-\pi^0$; 0.8618 for $\rho^0\pi^0$ and 0.9413 for $\rho^+\pi^-(\rho^-\pi^+)$.Relative error of EPRAT1 correction parameter is less than 3%.The data in table 2 has already corrected by EPRAT1 correction parameter. Using cut1 to cut5 to select the nonresonant state $\pi^+\pi^-\pi^0$ (background from two resonant states can be well omitted,and MC generator of the nonresonant state is HOWL),after BW-Fit on π^0 distribution of the nonresonant state, there is 75$\pm$8 events in π^0 peak area while selection efficiency is 19.36%.Then We have: $Br(\psi(2S) \to \pi^+\pi^-\pi^0) = (10.5\pm1.2^{+1.7}_{-1.5}) \times 10^{-5}$. Systematic error includes: 1)$N_{\psi(2S)}$: 8.2%. 2)event selection(including uncertainties from all criteria,BSC strengthen rib, EPRAT1 correction parameter and BW-FIT): 12.8%.Using cut1 to cut6 and $|M_{\pi^0} - 0.135|$ <0.05 GeV to select the resonant state $\rho^0\pi^0$,there is 3 candidates while selection MC efficiency is 12.8%($\rho\pi$ MC generator have already considered VP decay 1+cos$^2\theta$ angular distribution,but MC generators of other VP decays are HOWL). On the other hand,from MC study,we know nonresonant state $\pi^+\pi^-\pi^0$ is dominant background of resonant state $\rho^0\pi^0$. We take Br($\psi(2S) \to \pi^+\pi^-\pi^0$)=8.6×10^{-5} to estimate the background and obtain 4 events.After statistical calculation,We get Br($\psi(2S) \to \rho^0\pi^0$)<9.16×10^{-6}(90% CL). Using cut1 to cut5 and cut7 to select resonance state $\rho^+\pi^-(\rho^-\pi^+)$, after BW-FIT fit on the π^0 distribution,there is 6 candidates while MC selection efficiency is 11.8%.From MC study,we know nonresonance state $\pi^+\pi^-\pi^0$ is still dominant background of this resonance state. We take Br($\psi(2S) \to \pi^+\pi^-\pi^0$)=8.6×10^{-5} to estimate the background and obtain 7 events.After statistical calculation,We get Br($\psi(2S) \to \rho^+\pi^-$ or $\rho^-\pi^+$)< 1.4×10^{-5}. Finally we have: Br($\psi(2S) \to \rho\pi$)< 2.3×10^{-5}.

2.2 $\psi(2S) \to \rho\eta$ Analysis

The final state of the decay is also $\pi^+\pi^-\gamma\gamma$. Further preselection requires the events to have two charged tracks and the good gammas' further selections are same as $\psi(2S) \to \rho\pi$.The events can pass 4-c fit under the model $\psi(2S) \to \pi^+\pi^-\gamma\gamma$.We determine the two gammas from η by choosing the lowest 4-c kinematic fit χ^2 and invariant mass of the two gammas $M_{\gamma\gamma}$ is between 0.2 to 0.9 GeV;invariant mass of two charged tracks $M_{\pi+\pi-}$ is between 0.4 to 1.2 GeV and the lower momentum of two charged tracks is less than 1.3

GeV.Then we further require: 1)χ^2 of 4c fit:CHISS<12. 2)THNC both for two best gamma must greater than 100°. 3)NTRK=2. 4)$|M_{\pi^+\pi^-} - 0.7685| < 0.15$ GeV. 5)$M_{\gamma\gamma}(M_\eta)$ is between 0.3 to 0.85 GeV. 6)0.0<EPRAT1<0.5. The numbers of events surviving each requirement for different type events are shown in Table 3.

Table 3

REQUIREMENT	DATA1	MC1	DATA2	MC2	MC3
In	5575465	50000	1575208	20000	20000
Preselection	1576	17320	450	7014	595
CUT1	560	15720	265	6343	108
CUT2	301	12891	124	5542	79
CUT3	64	12448	76	5363	12
CUT4	30	10166	35	4386	10
CUT5	29	10156	27	4385	10
CUT6	23	8431	21	3622	8.7

DATA1: Ecm=3.686 GeV. DATA2: Ecm=4.03 GeV. MC1: $\psi(2S) \to \rho\eta \to \pi^+\pi^-\gamma\gamma$.
MC2: Ecm=4.03 GeV,$e^+e^- \to \rho\eta \to \pi^+\pi^-\gamma\gamma$. MC3: $\psi(2S) \to \gamma\chi_{c1}, \chi_{c1} \to \gamma J\psi, J/\psi \to \rho\eta \to \pi^+\pi^-\gamma\gamma$.

The data in table 3 has already corrected by EPRAT1 correction parameter(=0.8657).Two types of backgrounds have been studied. 1)from $J/\psi \to \rho\eta$. J/ψ comes from $\psi(2S) \to J/\psi$ plus neutrals.There is 1.7 events fall into η peak area($|M_{\gamma\gamma} - 0.54745|$ <0.07GeV, $\sigma_\eta = 0.022GeV$),so the maximum contribution of the background is 0.006 events by considering Br($\psi(2S) \to J/\psi$ plus neutrals)=23.2%. It can be well neglected. 2)For QED continuous background.We estimate its contribution at $\psi(2S)$ by measuring $R_{\rho\eta}$ value at 4.03 GeV[14]:

$$R_{\rho\eta}=\frac{\Gamma(e^+e^-\to\rho\eta)}{\Gamma(e^+e^-\to\mu^+\mu^-)}=\frac{N_{\rho\eta}}{L\times(1+\delta)\epsilon\times B\times\sigma_{QED}(e^+e^-\to\mu^+\mu^-)\times\epsilon_{trig}}$$

where $N_{\rho\eta}$ is measured $\rho\eta$ events at Ecm=4.03 GeV.After BW-FIT on data $\gamma\gamma$ invariant mass distribution at Ecm=4.03 GeV, there is 6.5 ± 2.7 events in η area.L,$(1+\delta)\epsilon$ are accumulated luminosity (=22.3pb^{-1}) and radiative corrected efficiency respectively; ϵ_{trig} is triger efficiency(=99%);B is the branching ratios of $\rho\eta$ decay (=B($\rho \to \pi^+\pi^-$)$\times B(\eta \to \gamma\gamma)$=0.3925); $\sigma_{QED}(e^+e^- \to \mu^+\mu^-)$=5.34nb at Ecm=4.03 GeV. Then let's calculate $(1+\delta)\epsilon$, since existing initial state radiation(ISR), one of the incoming beam electrons radiates a photon that carries off a fraction k of its energy and the subsequent e^+e^- annihilation process occours at a cm energy $\sqrt{S_{eff}}$ that is reduced from its nominal value $\sqrt{S_{nom}}$ by the factor $S_{eff} = (1-k)S_{nom}$. According to the formulation of Bonneau and Martin[14],the observed cross section at S_{nom},is related to $\sigma_B(S_{eff})$,the Born-level cross section at the reduced energy by: $\sigma_{obs}(S_{nom})= \int_0^{K_{MAX}} dk \times f(k,S_{nom})\sigma_B(S_{eff})$, $f(k,S_{nom})=\beta \times [k^{\beta-1}(1+\delta_1)+\frac{k}{2}]$-$\beta$,

$\beta=\frac{2\alpha}{\pi}[\ln(\frac{S_{nom}}{m_e^2})$-1] =0.07876,where $S_{nom} = 4.03^2 GeV^2$, $\delta_1=\frac{3\beta}{4}+ \frac{\alpha}{\pi}[\frac{\pi^2}{3}$-$\frac{1}{2}]$=0.06555.

In order to apply this formalism,it is further assumed that:

$$\sigma_B(S_{eff})=\sigma_B(S_{nom})(\frac{S_{nom}}{S_{eff}})^n$$

radiative efficiency correction is determined by:

$$(1+\delta)\epsilon =\int_0^{K_{MAX}} dk \times f(k,S_{nom})\frac{S_{nom}^n}{S_{eff}^n}\epsilon_{eff},$$

ϵ_{eff} is determined by HOWL MC at Ecm=$\sqrt{S_{eff}}$,such efficiency is higher than real case since MC cann't simulate cm burst effect, we call the efficiency is $\epsilon1$,and define another efficiency: $\epsilon2(\sqrt{S_{eff}})= \epsilon1(\sqrt{S_{eff}})^2/\epsilon1(\sqrt{S_{nom}})$ to estimate error of $(1+\delta)\epsilon$ from ϵ_{eff} determination method.So $\epsilon2$ falls down much quickly than $\epsilon1$.Cut off energy is 3.53 GeV for $\epsilon1$,while it is 3.71 GeV for $\epsilon2$.and n value can be changed from 1 to 4,$(1+\delta)\epsilon$ values under different conditions are as follows:

efficiency	n=1	n=2	n=3	n=4
$\epsilon 1$	18.68%	18.82%	18.96%	19.12%
$\epsilon 2$	15.93%	16.01%	16.09%	16.17%

We take $\rho\eta$'s $(1+\delta)\epsilon$=18.96% under n=3 and $\epsilon_{eff} = \epsilon 1$,while use the values under n=2 and $\epsilon_{eff} = \epsilon 2$ to estimate $(1+\delta)\epsilon$' s systematic errors from n and ϵ_{eff} respectivily.So $R_{\rho\eta} = (8.6^{+4.6}_{-4.3}) \times 10^{-4}$ at Ecm=4.03GeV. After BW-Fit on data $\gamma\gamma$ invariant mass distribution at Ecm= 3.686 Gev,there is 5.2$^+_-$2.8 events in η peak area while selection efficiency is 16.86%.We obtain $R_{\rho\eta} = (2.73^+_-1.73) \times 10^{-3}$ at Ecm=3.686 GeV. So the contribution of QED continuous background will make the braching ratio of $\psi(2S) \to \rho\eta$ lower than the measured braching ratio: $(-31.5^{+26.1}_{-25.4})$%.On the other hand,MC selection efficiency will be lower 18% if using the MC considered VP angular distribution instead of HOWL by $\rho\pi$ MC experience,this will make the real branching ratio of $\psi(2S) \to \rho\eta$ larger than the measured braching ratio: +21%.Therefore these two opposite effects could cancel each other.Then we have: **Br($\psi(2S) \to \rho\eta$)**=(2.1$^+_-$1.1$^+_-$0.5) $\times$ 10^{-5}**.** For systematic error,the following contributions have been considered:1)$N_{\psi(2S)}$: 8.2%.2)event selection(including uncertainties of all criteria,BSC strengthen rib,EPRAT1 correction parameter, BW-FIT): 23%.

2.3 $\psi(2S) \to \rho\eta'$ Analysis

The final state of the decay is $\pi^+\pi^-\pi^+\pi^-\eta$,$\eta \to \gamma\gamma$ .Further preselection requires events to have four charged tracks and good gammas are further required:ILAYT>1.The events can pass 4-c fit under the model $\psi(2S) \to \pi^+\pi^-\pi^+\pi^-\gamma\gamma$. We determine the two gammas from η by choosing the lowest 4-c kinematic fit χ^2, we try every group of invariant mass combinations of four charged pions and two gammas which form $M_\rho(\pi^+\pi^-)$ and $M_{\eta'}(\pi^+\pi^-\gamma\gamma)$ to determine the combinations by requiring the lowest value of χ^2_{mass}: $(M_\rho - 0.7685)^2 + (M_{\eta'} - 0.95777)^2$. The value of $M_{\eta'}$-M_η to be less than 0.7 GeV. Then we further require: 1)χ^2 of 4c fit:CHISS<12. 2)good gamma number of the event:NTRK=2. 3)$|M_\rho - 0.7685| < 0.18$ GeV. 4)$|M_\eta - 0.54745| < 0.035$ GeV. 5)$|M_{\eta'} - M_\eta - 0.4103| < 0.015$ GeV. The numbers of events surviving each requirement for different type events are shown in Table 4.

Table 4

REQUIREMENT	DATA	MC
In	2507071	20000
Preselection	9529	4435
CUT1	3104	3851
CUT2	975	3710
CUT3	394	3027
CUT4	15	2632
CUT5	0	2523

There is less than 2.44 events of $\psi(2S) \to \rho\eta'$ with 90% CL while selection efficiency is 12.62%.Then we have: Br($\psi(2S) \to \rho\eta'$) $< 3.0 \times 10^{-5}$(90% CL).

2.4 $\psi(2S) \to \omega\pi^0$ Analysis

The final state of the decay is $\pi^+\pi^-\gamma\gamma\gamma\gamma$.Further preselection requires events to have two charged tracks and good gamma number is between 4 to 6. Good gammas are further required: ILAYT>1, E_γ >0.05 GeV.The events can pass 4-c kinematic fit under the model $\psi(2S) \to \pi^+\pi^-\gamma\gamma\gamma\gamma$. We determine the four gammas from two π^0 by choosing the lowest 4-c fit χ^2.we try every group of invariant mass combinations of the four gammas which form $M_{\pi^0 1}$($\gamma\gamma$ with higher energy) and $M_{\pi^0 2}$($\gamma\gamma$ with lower energy) to determine the combinations by requiring the lowest value of χ^2_{mass}: $(M_{\pi^0 1)} - 0.135)^2 + (M_{\pi^0 2} - 0.135)^2$ and invariant mass of any π^0 is less than 0.4 GeV.After 4c-fit,Energy of $\pi^0 1$ is more than 1.5 GeV.Recoil mass of $\pi^0 1(M_\omega)$ is less than 1.0 GeV.Then we further require: 1)χ^2 of 4c fit:CHISS<15. 2)Recoil mass of $\pi^+\pi^-$: $|(M_{\pi^+\pi^-})_{recoil} - M_{J/\psi}$ >0.03 GeV. 3)Invariant mass of $\pi^+\pi^-$ is less than 0.65 GeV. 4)Good gamma number of the event:NTRK=4. 5)Neutral track number of the event:NNEU<6. 6)$M_{\pi^0 1}$ satisfies: $|(M_{\pi^0 1})-0.135|$ <0.045 GeV.($\sigma_{\pi^0 1}$=21.7MeV) 7)M_ω <0.89 GeV.

Two types of backgrounds have been studied.1)From $J/\psi \to \omega\pi^0$,and J/ψ comes from $\psi(2S) \to J/\psi$

Table 5

REQUIREMENT	DATA1	MC1	DATA2	MC2	MC3
In	5575465	50000	1575208	20000	10000
Preselection	5273	4850	670	1843	633
CUT1	2139	4485	291	1706	244
CUT2	2035	4444	284	1676	243
CUT3	1005	4423	113	1664	241
CUT4	318	4258	59	1614	90
CUT5	214	4110	47	1549	71
CUT6	117	3783	35	1421	38
CUT7	16	3727	9	1404	8

DATA1: Ecm=3.686 Gev. DATA2: Ecm=4.03 Gev. MC1: $\psi(2S) \to \omega\pi^0 \to \pi^+\pi^-\gamma\gamma\gamma\gamma$.
MC2: Ecm=4.03 Gev,$e^+e^- \to \omega\pi^0 \to \pi^+\pi^-\gamma\gamma\gamma\gamma$. MC3: $\psi(2S) \to \gamma\chi_{c1}, \chi_{c1} \to \gamma J\psi, J/\psi \to \omega\pi^0 \to \pi^+\pi^-\gamma\gamma\gamma\gamma$.

plus neutrals.There are 4 events fall into the peak area of π^0_2, so the maximum contribution of the background is 0.127 events by considering Br($\psi(2S) \to J/\psi$ plus neutrals)=23.2%. It can be neglected.2)For QED continuous background,same as $\psi(2S) \to \rho\eta$, We use the data sample acquired at Ecm=4.03 GeV to estimate its contribution,and find 7.4$\pm$1.8 events in ω peak area(using $|M_{\pi^0}2 - 0.135| < 0.05GeV$ instead of cut7), $(1+\delta) \times \epsilon$=6.76%, $R_{\omega\pi^0}$=$(1.1^{+0.4}_{-0.3}) \times 10^{-3}$ at Ecm=4.03 GeV;and find 9.7$\pm$2.3 events in π^0_2 peak area at $\psi(2S)$ while selection efficiency is 7.45%, $R_{\omega\pi^0}$=$(5.2^{+2.0}_{-1.8}) \times 10^{-3}$ at Ecm=3.686GeV.So QED continuous background will make the branching ratio of $\psi(2S) \to \omega\pi^0$ lower -21 ± 10%,it just can be cancled by the effect of HOWL MC(+21%). The numbers of events surviving each requirement for different type events are shown in Table 5. Then we have: **Br($\psi(2S) \to \omega\pi^0$)=**$(4.0\pm1.0\pm0.6) \times 10^{-5}$**.** For systematic error,the following contributions have been considered: 1)N_ψ: 8.2%.2)event selection(including all criteria and BW-FIT):12%.

2.5 $\psi(2S) \to \omega\eta$ Analysis

The final state of the decay is still $\pi^+\pi^-\gamma\gamma\gamma\gamma$.Further preselection requires events to have two charged tracks and good gamma number is greater than 3.The good gammas are further required:E_γ >0.03 Gev.The events can pass 4-c kinematic fit under model $\psi(2S) \to \pi^+\pi^-\gamma\gamma\gamma\gamma$. We determine the four gammas from π^0 and η by choosing the lowest 4-c fit χ^2.we try every group of invariant mass combinations of the four gammas which form $M_{\pi^0}(\gamma\gamma)$ and $M_\eta(\gamma\gamma)$ to determine the combinations by requiring the lowest value of χ^2_{mass}: $((M_{\pi^0)} - 0.135)/0.02)^2 + ((M_\eta - 0.54745)/0.033)^2$. Recoil mass of the $\eta(M_\omega)$ is less than 1.2 GeV.Then we further require: 1)χ^2 of 4c fit:CHISS<15. 2)Minimum angle between the direction of any good gamma from π^0 and the direction of any charged track must be less than 85°. 3)Minimum angle between the direction of any gamma from η and the direction of any charged track must be greater than 115°. 4)Good gamma number of the event:NTRK=4. 5)$|M_\omega - 0.78194|$ <0.08 GeV. 6)$|M_\eta - 0.54745|$ <0.06 GeV. 7)$|M_{\pi^0} - 0.135|$ <0.058 GeV. The numbers of events surviving each requirement for different type events are shown in Table 6.

Table 6

REQUIREMENT	DATA	MC
In	5575465	20000
Preselection	7406	3800
CUT1	4991	3478
CUT2	4514	3102
CUT3	939	2380
CUT4	141	1830
CUT5	33	1721
CUT6	3	1568
CUT7	0	1460

There is less than 2.44 events of $\psi(2S) \to \omega\eta$ with 90% CL while selection efficiency is 7.3%.Then we have: **Br(**$\psi(2S) \to \omega\eta$) < (2.6 × 10^{-5}(90% **CL).**

2.6 $\psi(2S) \to \omega\eta'$ Analysis

The final state of the decay is $\pi^+\pi^-\pi^+\pi^-\gamma\gamma\gamma\gamma$.Further preselection requires the events to have four charged tracks and more than three good gammas. The events can pass 4-c kinematic fit under the model $\psi(2S) \to \pi^+\pi^-\pi^+\pi^-\gamma\gamma\gamma\gamma$. We determine the four gammas from π^0 and η by choosing the lowest 4-c fit χ^2.we try every group of invariant mass combinations of the four gammas which form $M_{\pi^0}(\gamma\gamma)$ and $M_\eta(\gamma\gamma)$ to determine the combinations by requiring the lowest value of χ^2_{mass}: $((M_{\pi^0} - 0.135)/0.02)^2 + ((M_\eta - 0.5475)/0.028)^2$ and M_{π^0} is less than 0.35 GeV;M_η is between 0.35 to 0.75 GeV.next we try every group of invariant mass combinations of four charged tracks and the

Table 7

REQUIREMENT	DATA1	MC1	DATA2	MC2	MC3
In	2507071	30000	1575208	20000	20000
Preselection	339	3307	23	2312	7
CUT1	268	3155	17	2213	7
CUT2	230	3155	15	2213	7
CUT3	69	2678	3	1850	3
CUT4	21	2372	1	1649	1
CUT5	12	2325	0	1610	1
CUT6	5	2252	0	1559	1
CUT7	3	2090	0	1452	0

DATA1: Ecm=3.686 GeV. DATA2: Ecm=4.03 GeV.

MC1: $\psi(2S) \to \omega\eta' \to \pi^+\pi^-\pi^+\pi^-\gamma\gamma\gamma\gamma$. MC2: Ecm=4.03 Gev,$e^+e^- \to \omega\eta' \to \pi^+\pi^-\pi^+\pi^-\gamma\gamma\gamma\gamma$.

MC3: $\psi(2S) \to \gamma\chi_{c1}, \chi_{c1} \to \gamma J\psi, J/\psi \to \omega\eta' \to \pi^+\pi^-\pi^+\pi^-\gamma\gamma\gamma\gamma$.

four gammas which form $M_\omega(\pi^+\pi^-\pi^0)$ and $M_{\eta'}(\pi^+\pi^-\eta)$ to the combinations by requiring the lowest value of χ^2_{mass}: $((M_\omega - 0.782)/0.026)^2 + ((M_{\eta'} - 0.9578)/0.029)^2$ and M_ω is between 0.55 to 1.0 GeV;$M_{\eta'} - M_\eta$ is between 0.25 to 0.55 GeV.Then we further require: 1)χ^2 of 4c fit:CHISS<20. 2) Deposited energy in BSC of any best gamma(E_γ) must be greater than 0.03 GeV. 3)$|M_\eta$-0.54745$|$ <0.055 GeV. 4)$|M_\omega$-0.78194$|$ <0.06 GeV. 5)$|M_{\eta'}$-0.95777$|$ <0.055 GeV. 6)Good gamma number of the event: NTRK<6. 7)$|M_{\pi^0}$-0.135$|$ <0.05 GeV.The numbers of events surviving each requirement for different type events are shown in Table 7. Two types of backgrounds have been studied.1) From $J/\psi \to \omega\eta'$, and J/ψ comes from $\psi(2S)$ →J/ψ plus neutrals. There is zero events passing the above selection. 2)From QED background.We use the data sample acquired at Ecm=4.03 GeV to estimate its contribution,and find that there is zero events while selection efficiency is 7.26%.There is $3^{+}_{-}1.7$ events passing the above selection with zerobackgrounds (estimated from sidebins) while selection efficiency is 6.97%.Then we have: **Br**($\psi' \to \omega\eta'$)=$(7.6^{+}_{-}4.4^{+2.0}_{-1.5}) \times 10^{-5}$**.** For systematic error,the following contributions have been considered:1)$N_{\psi(2S)}$: 8.2%.2)event selection (including all criteria):18%. 3)uncertainty from HOWL MC:+22%.

2.7 $\psi(2S) \to \phi\pi^0$ Analysis

The final state of the decay is $K^+K^-\gamma\gamma$. Further preselection requires events to have two charged tracks and the good gammas are further required:ILAYT>1. The events can pass 4-c fit under the model of $\psi(2S) \to K^+K^-\gamma\gamma$. We determine the two gammas from π^0 by choosing the lowest 4-c kinematic fit χ^2,The higher momentum of charged tracks is between 0.6 to 1.5 GeV;the lower momentum of charged tracks is between 0.3 to 1.2 GeV and invariant mass of two charged kions(M_ϕ) is less than 1.2 GeV.Then we further require: 1)χ^2 of 4c fit:CHISS<20. 2)good gamma number of the event:NTRK=2. 3)Higher momentum of charged tracks is less than 1.16 GeV. 4)Minimum angle between the direction of any gamma from π^0 and the direction of any charged track must be greater than 140°. 5)$|M_\phi - 1.0194| < 0.013$ GeV. 6)$|M_{\pi^0} - 0.135| < 0.046$ GeV. The numbers of events surviving each requirement for different type events are shown in Table 8.

Table 8

REQUIREMENT	DATA	MC
In	5575465	50000
Preselection	3252	13062
CUT1	1592	12457
CUT2	325	11832
CUT3	217	11740
CUT4	96	11617
CUT5	27	10728
CUT6	0	10095

There is less 2.44 events of $\psi(2S) \to \phi\pi^0$ with 90% CL while selection efficiency is 20.19%.We have: **Br**($\psi(2S) \to \phi\pi^0$) $< 6.6 \times 10^{-6}$**(90% CL).**

2.8 $\psi(2S) \to \phi\eta$ Analysis

The final state of the decay is also $K^+K^-\gamma\gamma$.Further preselection requires the events to have two charged tracks and the good gammas are further required:ILAYT>1 .The events can pass 4-c fit under the model $\psi(2S) \to K^+K^-\gamma\gamma$.We determine the two gammas from η by requiring 4-c fitting invariant mass of the two gammas close to the mass of η mostly and the invariant mass is less than 1.0 GeV;invariant mass of two charged tracks M_{K+K-} is less than 1.5 GeV.Then we further require: 1)χ^2 of 4c fit:CHISS<18. 2)The higher momentum of charged tracks:P_{high} <1.15 GeV. 3)$|M_{\gamma\gamma} - 0.54745| < 0.045$ GeV. 4)M_{K+K^-} is between 0.98 to 1.062 GeV. The numbers of events surviving each requirement for different type events are shown in Table 9.

Table 9

REQUIREMENT	DATA1	MC1	DATA2	MC2	MC3
In	5575465	20000	1575208	20000	20000
Preselection	3629	6026	922	6068	492
CUT1	1940	5749	581	5739	191
CUT2	1109	5721	189	4985	189
CUT3	101	5185	18	4457	14
CUT4	15	5173	6	4448	13

DATA1: Ecm=3.686 GeV. DATA2: Ecm=4.03 GeV. MC1: $\psi(2S) \to \phi\eta \to K^+K^-\gamma\gamma$.
MC2: Ecm=4.03 GeV,$e^+e^- \to \phi\eta \to K^+K^-\gamma\gamma$. MC3: $\psi(2S) \to \gamma\chi_{c1}, \chi_{c1} \to \gamma J\psi, J/\psi \to \phi\eta \to K^+K^-\gamma\gamma$.

Two types of backgrounds have been studied.1)from $J/\psi \to \phi\eta$,and J/ψ comes from $\psi(2S) \to J/\psi$ plus neutrals.There is 12 events fall into ϕ peak area($|M_\phi - 1.0194| < 0.02GeV$), so the maximum contribution of the background is 0.07 events by considering Br($\psi(2S) \to$J/ψ plus neutrals)=23.2%. 2)From QED continuous background.We use the data sample acquired at Ecm=4.03 GeV to estimate its contribution,there is 5$\pm$2.2 events in ϕ peak area($|M_\phi - 1.0194| < 0.01GeV$) while $(1+\delta)\times\epsilon$=19.61%, $R_{\phi\eta} = (1.12\pm0.55)\times10^{-3}$.After BW-Fit on data two charged tracks invariant mass distribution at Ecm=3.686 GeV, there is 6.2$\pm$2.6 events in ϕ peak area while selection efficiency is 25.865% and $R_{\phi\eta} = (4.3\pm2.2)\times10^{-3}$, so QED continuous background will make the branching ratio of $\psi(2S) \to \phi\eta$ lower: (-26 ± 19)%,just can be cancled by the effect of MC HOWL(+21%). Finally,We have: **Br($\psi(2S) \to \phi\eta$)=**(3.3$\pm$1.4$\pm$0.6) $\times10^{-5}$**.** For systematic error,the following contributions have been considered:1)N$_\psi$:8.2%.2) event selection(including all criteria):16%.

2.9 $\psi(2S) \to \phi\eta'$ Analysis

The final state of the decay is $K^+K^-\pi^+\pi^-\eta$,$\eta \to \gamma\gamma$.Further preselection requires the events to have four charged tracks and the good gammas are further required:ILAYT>1.The events can pass 4-c fit under model $\psi(2S) \to K^+K^-\pi^+\pi^-\gamma\gamma$. In 4-c fit we always assign the chraged track with highest momentum as kion and the chraged track with lowest momentum as pion,other two charged tracks' identification and the two gammas from η are determined by χ^2 of 4-c fit,$P_\phi^2 > 2.0GeV^2$. Then we further require:1)χ^2 of 4c fit:CHISS<25. 2)Minimum angle between the direction of any best gamma from η and the direction of any charged kion track must be greater than 65°. 3)$|M_\eta - 0.54745| < 0.08$ GeV. 4)$|M_\phi - 1.0194| < 0.014$ GeV. 5)$|M_{\eta'} - M_\eta - 0.4103| < 0.025$ GeV. The numbers of events surviving each requirement for different type events are shown in Table 10.

Table 10

REQUIREMENT	DATA	MC
In	2507071	30000
Preselection	2519	5524
CUT1	1269	5335
CUT2	1090	5017
CUT3	147	4858
CUT4	17	4527
CUT5	0	4446

There is less 2.44 events of $\psi(2S) \to \phi\eta'$ with 90% CL while selection efficiency is 14.82%.We have: **Br(**$\psi(2S) \to \phi\eta') < 5.2 \times 10^{-5}$(90% **CL).**

III. Discussion

3.1 Check the rule of "14%"

The summary of checking the rule of "14%" for $\psi(2S)$ VP decays is shown in table 11.Our results

Table 11

$\psi(2S)$ decay mode	our results(10^{-5})	$\frac{0.141Br(J/\psi)}{Br(\psi(2S))}$	BES measured(10^{-5})
$\rho\pi$	<2.3	>77	< 2.8[8]
$\rho\eta$	2.1±1.2	1.30±0.76	< 3.2[13]
$\rho\eta'$	<3.0	>0.49	< 6.2[13]
$\omega\pi^0$	4.0±1.1	1.48±0.46	4.2±1.9[13],3.8±2.0[14]
$\omega\eta$	<2.6	>8.5	< 3.3[13],< 4.5[14]
$\omega\eta'$	$7.6^{+4.8}_{-4.6}$	$0.30^{+0.20}_{-0.19}$	7.6±4.7[13]
$\phi\pi^0$	<0.66	———	< 1.5[13]
$\phi\eta$	3.3±1.5	2.78±1.30	3.5±2.0[13]
$\phi\eta'$	<5.2	>0.89	5.5±3.9[13]
$K^+\overline{K}^*(892)^- + c.c.$	———	>22	< 3.2[8]. < 5.2[13]
$K^0\overline{K}^*(892)^0 + c.c.$	———	7.1±2.5	8.4±2.9[8],13.0±5.2[13]

are consistent with other BES members'(S. L. Olsen[13],Ye shuwei[14] and so on). From table 11,we could find: 1)Except $\psi(2S) \to \rho\pi, K^+K^*(892)^- + c.c., K^0K^*(892)^0 + c.c.$ decays, $\psi(2S) \to \omega\eta$ decay violates the rule of "14%" severely. 2)Electromagnetic $\psi(2S)$ VP decays:$\rho\eta$ and $\omega\pi^0$ conserve the rule of "14%". 3)The upper limit of $\psi(2S) \to \phi\pi^0$ at 90% CL nearing that of the J/ψ shows that DOZI eletromagnetic decay can be neglected in both J/ψ and $\psi(2S)$.

3.2 Phenomenological Analysis

Using phenomenological theory,we could directly obtain:
$\sqrt{\overline{B}(\psi(2S) \to \rho\eta)/\overline{B}(\psi(2S) \to \omega\pi^0)}= X_\eta= 0.75\pm0.24, e = (9.05\pm1.24) \times 10^{-4}$(from measured $\psi(2S) \to \omega\pi^0$).X_η is consistent with the value determined by MARKIII at J/ψ:0.814±0.014[10]. We fix $X_\eta, X_{\eta'}, Y_\eta$ and $Y_{\eta'}$ as the values measured by MARKIII. we assume different phase angle θ from 143° to 180° and use measured branching ratios of of $\psi(2S) \to \omega\eta'$,$\phi\eta$ and $K^0\overline{K}^*(892)^0$+c.c. to calculate values of g,r and s at $\psi(2S)$,and found differences of g,r and s are within 10% when phase angle θ changes from 143° to 180°,and our results show that phase angle is close to 180°,so we take phase angle as 180°,then we have: g=-1.297×10^{-3}, r=-1.482, s=0.1334 at $\psi(2S)$.The errors haven't been analysed yet,but they are estimated to be less than 50%.Using above values,we could calculate the branching ratios of $\psi(2S)$ VP decays by phenomenological theory,the result is shown in table 12.

Table 12

$\psi(2S)$ decay mode	experimental result(10^{-5})	$\frac{experimental}{prediction}$	phenomenomenological prediction(10^{-5})	prediction $\frac{0.141Br(J/\psi)}{Br(\psi(2S))}$
$\rho\pi$	<2.3	9.2	0.25	716
$\rho\eta$	2.1±1.2	0.85	2.48	1.1
$\rho\eta'$	<3.0	2.8	1.07	1.38
$\omega\pi^0$	4.0±1.1	1.0	4.0	1.48
$\omega\eta$	<2.6	3.4	0.76	29.4
$\omega\eta'$	7.6±4.6	1.0	7.6	0.3
$\phi\eta$	3.3±1.5	1.0	3.3	2.78
$\phi\eta'$	<5.2	17.3	0.3	15.5
$K^+\overline{K}^*(892)^-$+c.c.	<3.2	68	0.0468	1506
$K^0\overline{K}^*(892)^0$+c.c.	8.4±2.9	1.0	8.4	7.1

All measured upper limits are more larger than the predictions of phenomenological theory spontaneously.and calculated branching ratio of $\psi(2S) \to \rho\eta'$ conserves the rule of "14%".So we can say that all electromagnetic decays of $\psi(2S)$ are not suppressed,the anwser of "$\rho\pi$ puzzle" will come from strong interation.Ratios of OZI suppressed,purely double OZI suppressed, SU(3)-breaking strong decays relative to electromagnetic decay are:g/e=-

1.43, rg/e=2.12, sg/e=-0.19 at $\psi(2S)$. Comparing with the condition at J/ψ measured by MARKIII[18]: $g = 1.10 \pm 0.04(\theta = 72°), e = 0.12 \pm 0.01, r = -0.15 \pm 0.01, s = 0.12 \pm 0.03$ and g/e=9.2$\pm$0.8. rg/e=-1.38 ± 0.16, sg/e=1.1$\pm$0.3 at J/ψ.

so we could understand the mechanism of "$\rho\pi$ puzzle" from an experimental view: 1)electromagnetic interation e conserve the rule of "14%",so $\psi(2S)$ electromagnetic VP decays are not suppressed. 2)The ratio of g/e at $\psi(2S)$ relative to J/ψ is only -0.155, it indicates that OZI-suppressed strong interation is suppressed severely (about one order) at $\psi(2S)$, moreover signs of g and e are opposite at $\psi(2S)$. 3)The ratio of rg/e at $\psi(2S)$ relative to J/ψ is -1.54, considering errors,the value is consistent with -1.0,it indicates that DOZI strong interation at $\psi(2S)$ conserve the rule of "14%" and plays an important role in $\psi(2S)$ VP decays(r=-1.5).4)The ratio of sg/e at $\psi(2S)$ relative to J/ψ is -0.17,mostly close to the ratio of g/e(-0.155),it indicates that suppressed levels of SU(3)-breaking strong interation and OZI-suppressed strong interation are equal.The ratio of s at $\psi(2S)$ relative to J/ψ is 1.11,it indi-

Table 13 $Q_{VP}(\%)$ comparation

VP decay	X=1	X=2	experimental	phenomenological
$\rho\pi$	0.0–0.25	0.0–0.25	<0.18	0.02$\pm$0.01
$\rho\eta$	14–22	14–22	10.9$\pm$6.4	12.8$\pm$6.4
$\rho\eta'$	12–20	13–21	<28.6	10.2$\pm$5.1
$\omega\pi^0$	11–17	11–17	9.5$\pm$2.9	9.5$\pm$4.8
$\omega\eta$	0–1.6	0–1.6	<1.65	0.49$\pm$0.25
$\omega\eta'$	10–51	12–55	45.5$\pm$28.8	46$\pm$23
$\phi\eta$	0.8–3.6	0.4–3.0	5.1$\pm$2.4	5.1$\pm$2.6
$\phi\eta'$	0.7–2.5	0.5–2.2	<15.8	0.91$\pm$0.46
$K^+\overline{K}^*(892)^-$+c.c.	1.2–3.0	1.2–3.0	2.0$\pm$0.7	2.0$\pm$1.0
$K^0\overline{K}^*(892)^0$+c.c.	0–0.36	0–0.52	<0.64	0.01$\pm$0.005

cates that the ratios of SU(3)-breaking strong interation relative to OZI suppressed stong interation are same at $\psi(2S)$ and J/ψ.

3.3 Checking a New Model

The new model[15] of "$\rho\pi$ puzzle" explanation based on color-octet $c\bar{c}$ production has been checked with our measurements,and found they are in general consistency,see table 13.

3.4 Electromagnetic form factors

$\rho\eta$ and $\omega\pi^0$ are pure eletromagnetic decays,their R values are as follows:

VP decay	3.097GeV	3.686GeV	4.03GeV
$\rho\eta$	$(3.23\pm0.41)\times10^{-3}$	$(2.73\pm1.73)\times10^{-3}$	$(8.6^{+4.6}_{-4.3})\times10^{-4}$
$\omega\pi^0$	$(7.04\pm1.05)\times10^{-3}$	$(5.2^{+2.0}_{-1.8})\times10^{-3}$	$(1.1^{+0.4}_{-0.3})\times10^{-3}$

then their eletromagnetic form factors are:

VP decay	3.097GeV	3.686GeV	4.03GeV
$\rho\eta$	$(3.24\pm0.36)\times10^{-2}$	$(2.39\pm0.79)\times10^{-2}$	$(1.20\pm0.33)\times10^{-2}$
$\omega\pi^0$	$(3.65\pm0.29)\times10^{-2}$	$(2.56\pm0.47)\times10^{-2}$	$(1.05\pm0.24)\times10^{-2}$

We use function c/S(c is a constant) to fit above values at different energy points,and found:
For $\rho\eta$:
first two points,c=0.313$\pm$0.033,χ^2=0.014; add Ecm=4.03GeV,c=0.281$\pm$0.028,χ^2/dof=3.48/2.
For $\omega\pi^0$:
first two points,c=0.35$\pm$0.026,χ^2=0.0017; add Ecm=4.03GeV,c=0.265$\pm$0.019,χ^2/dof=22.8/2.

and their c values are as follows:

VP decay	3.097GeV	3.686GeV	4.03GeV
$\rho\eta$	0.311$\pm$0.035	0.327$\pm$0.107	0.195$\pm$0.054
$\omega\pi^0$	0.350$\pm$0.028	0.348$\pm$0.064	0.171$\pm$0.039

So measured electromagnetic factors of $\rho\eta$ and $\omega\pi^0$ are consistent with VDM predictions at J/ψ and $\psi(2S)$,and much lower at Ecm=4.03GeV.S. L. Olsen has got same conclusion from $\psi(2S) \to \omega\pi^0$ decay.

IV. Conclusion

Nine decays of $\psi(2S)$ to VP final states have been carefully studied.The rule of "14%" of J/ψ and $\psi(2S)$ decays have checked and found electromagnetic VP decays such as $\psi(2S) \to \rho\eta$ and $\omega\pi^0$ are not suppressed while $\psi(2S) \to \rho\pi\ \omega\eta$ is suppressed severely.A phenomenological theory is used to analyse our results and found the phenomenological mechanism of "$\rho\pi$ puzzle"is that OZI suppressed strong interation g is suppressed severely(about one order) relative to J/ψ,and g has opposite sign to e at $\psi(2S)$ ($\theta = 180°$).moreover we found that DOZI strong interation rg like electromagnetic interation e conserves the rule of "14%,SU(3)-breaking interation sg is suppressed at same level as g,and s at $\psi(2S)$ is equal to the value at J/ψ.A new model of "$\rho\pi$ puzzle" explanation based on color-octet $c\bar{c}$ production is in general consistentcy with our experimental results.Finally,measured electromagnetic form factors of $\rho\eta$ and $\omega\pi^0$ are found to be consistent with VDM predictions at J/ψ and $\psi(2S)$.

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FIG.1.BW-FIT on invariant mass distribution of the two gammas after using cut1-5 to select $\psi(2S) \to \pi^+\pi^-\pi^0$ nonresonant state. FIG.2.Invariant mass distribution of the two gammas after using cut1-6 to select $\psi(2S) \to \rho^0\pi^0$. FIG.3.BW-FIT on invariant mass distribution of the two gammas after using cut1-5 and cut7 to select $\psi(2S) \to \rho^+\pi^-(\rho^-\pi^+)$. FIG.4.The Dalitz plot of $M^2_{\pi^+\pi^0}$ and $M^2_{\pi^-\pi^0}$ after using cut1-5 and $|M_{\pi^0} - 0.135| < 0.05GeV$ to select $\psi(2S) \to \pi^+\pi^-\pi^0$ final states.

FIG.5.BW-FIT on invariant mass distribution of the two gammas after using all cuts to select $\psi(2S) \to \rho\eta$. FIG.6.The scatter plot of M_ρ and $M_{eta'} - M_\eta - 0.4103$ after using cut1,2,4 to select $\psi(2S) \to \rho\eta'$. FIG.7.BW-FIT on invariant mass distribution of the two gammas of lower-energy π^0 after using all cuts to select $\psi(2S) \to \omega\pi^0$. FIG.8.The scatter plot of M_η and M_ω after using cut1,2,3,4,7 to select $\psi(2S) \to \omega\eta$.

FIG.9.Invariant mass distribution of the two gammas after using cut1-6 to select $\psi(2S) \to \omega\eta'$. FIG.10.The scatter plot of M_ϕ and M_{π^0} after using cut1-4 to select $\psi(2S) \to \phi\pi^0$. FIG.11.BW-FIT on invariant mass distribution of the two kions' candidates after using all cuts to select $\psi(2S) \to \phi\eta$. FIG.12.The scatter plot of M_ϕ and $M_{\eta'} - M_{eta} - 0.4103$ after using cut1-3 to select $\psi(2S) \to \phi\eta'$.

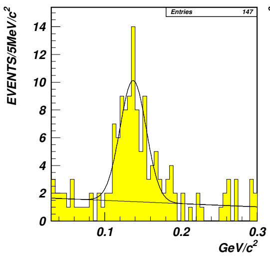

FIG.1.Mpi0

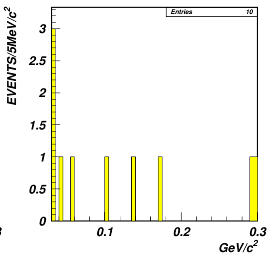

FIG.2.Mpi0

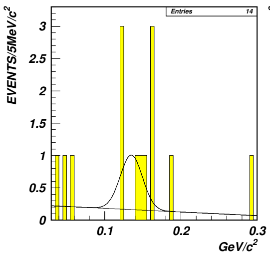

FIG.3.Mpi0

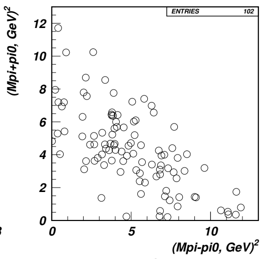

FIG.4.

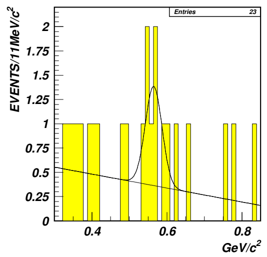

FIG.5.Meta

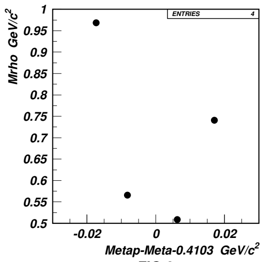

FIG.6.

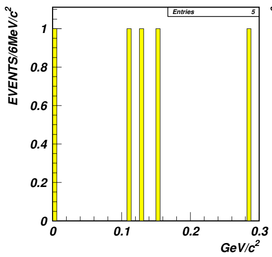

FIG.9.Mpi0

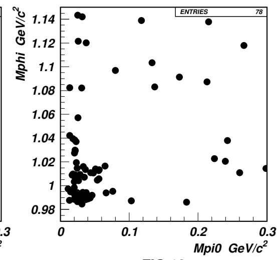

FIG.10.

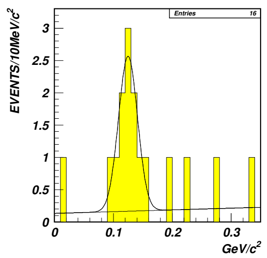

FIG.7.Mpi02

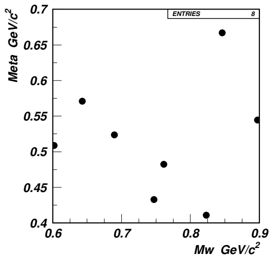

FIG.8.

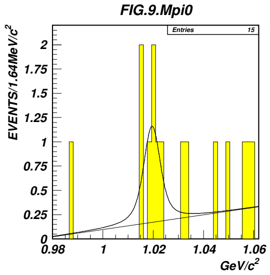

FIG.11.Mphi

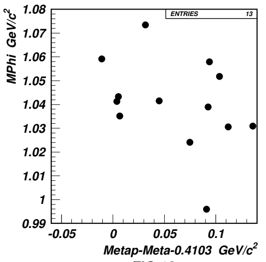

FIG.12.