Recent Results on Light hadron Spectroscopy from BESII

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Outline

- **Introduction**

- **Recent results from BESII**
  - **Observation of Y(2175) in $J/\psi \to \eta \phi f_0(980)$**
  - **PWA of $J/\psi \to \gamma \phi \phi$**
  - **Measurement of $J/\psi \to \omega / \phi K \bar{K} \pi$**
  - **Observation of J/ψ and $\psi(2S) \to n K^0_S \bar{\Lambda}$ +c.c**

- **Summary**

Introduction

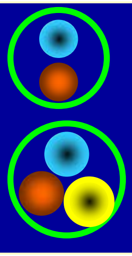
Multi-quark State, Glueball and Hybrid

- **Hadrons consist of 2 or 3 quarks：**

  Naive Quark Model：

  Meson（ q $\bar{q}$ ）

  Baryon（q q q）

- **New forms of hadrons:**
  - **Multi-quark states： Number of quarks >= 4**
  - **Hybrids： $q\bar{q}g$， qqqg …**
  - **Glueballs： gg， ggg …**

Introduction

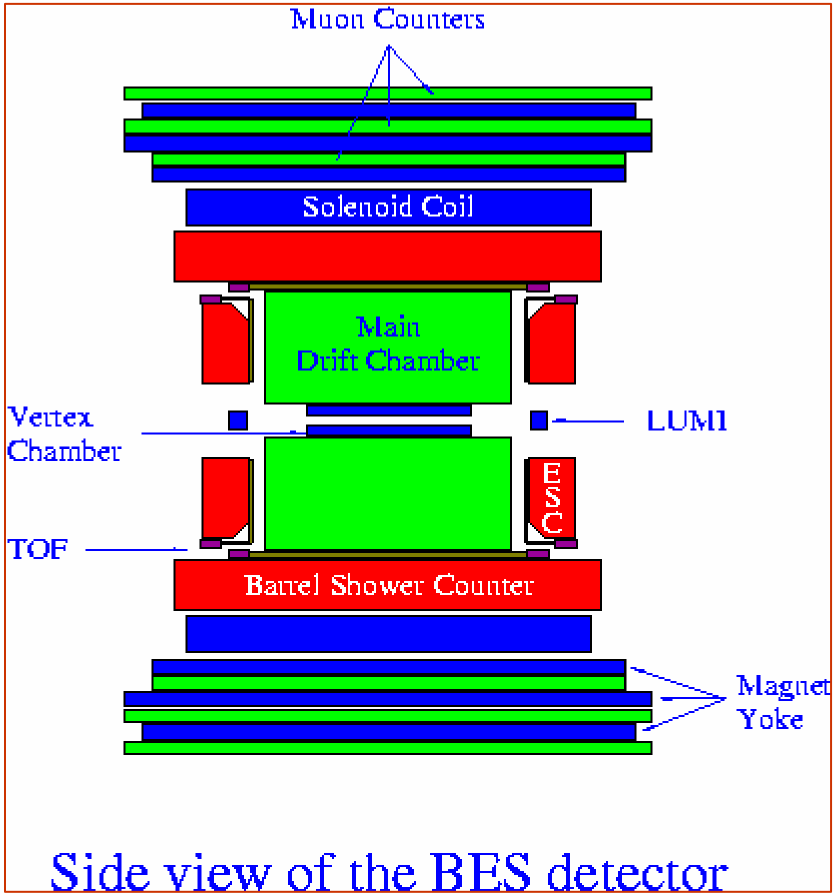
Multi-quark states, glueballs and hybrids have been searched for experimentally for a very long time, but none is established.

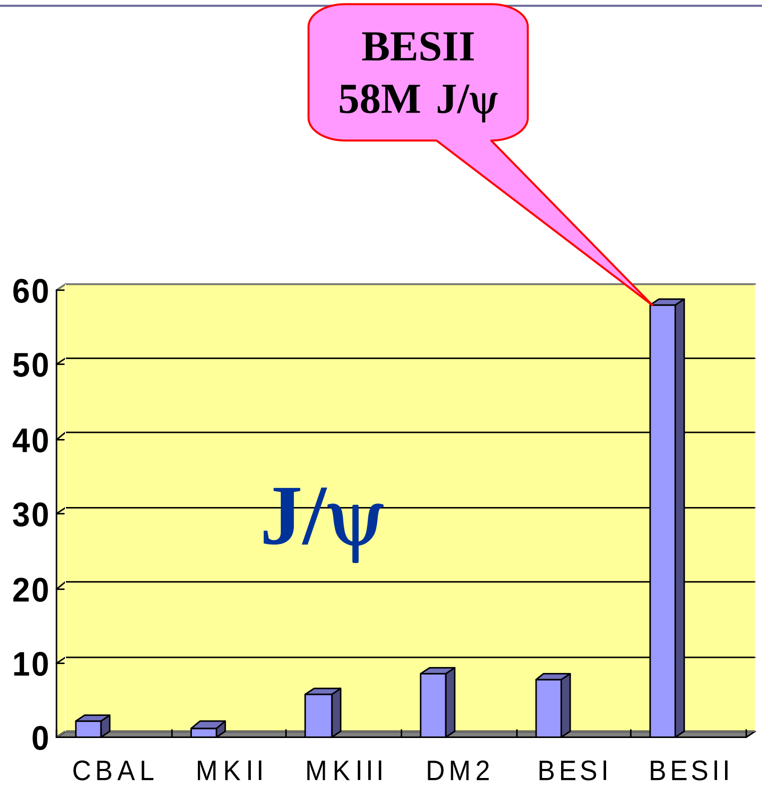
However, the effort has never been stopped, especially, during the past couple of years, a lot of surprising experimental evidences showed the existence of hadrons that cannot (easily) be explained in the conventional quark model.

J/ψ decays provide ideal Lab for searchs for new forms of hadrons and study of the light hadron spectroscopy.

Introduction

BESII





Observation of Y(2175) in $J/\psi \to \eta \phi f_0(980)$

Observation of Y(2175) at BaBar

A structure at 2175MeV was observed in

$e^+e^- \to \gamma_{ISR}\, \phi f_0(980)$,

$e^+e^- \to \gamma_{ISR}\, K^+K^- f_0(980)$

initial state radiation processes

BABAR Collaboration Home Page

$$M = 2175 \pm 10 \pm 15\ \text{MeV}$$

$$\Gamma = 58 \pm 16 \pm 20\ \text{MeV}$$

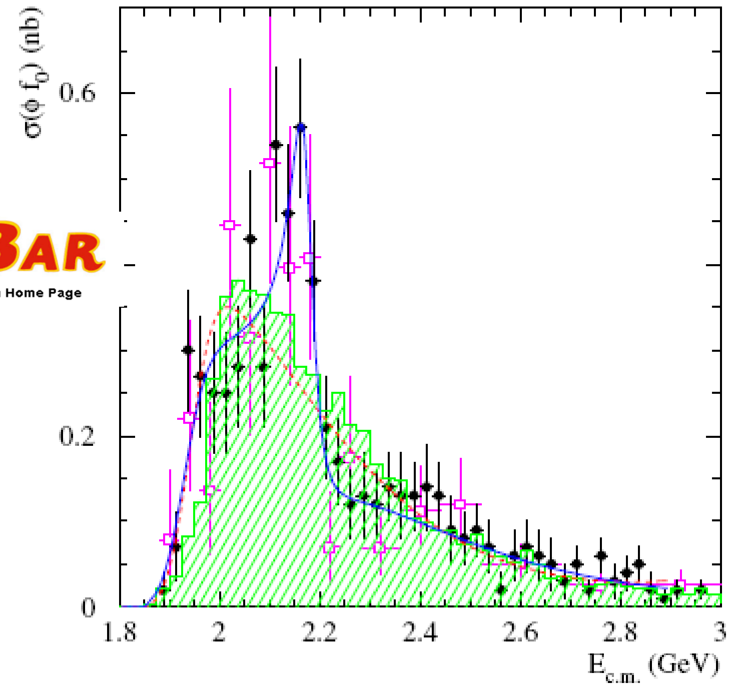


FIG. 27 (color online). The $e^+e^- \to \phi(1020) f_0(980)$ cross section measured in the $K^+K^-\pi^+\pi^-$ (circles) and $K^+K^-\pi^0\pi^0$ (squares) final states. The hatched histogram shows the simulated cross section, assuming no resonant structure. The solid (dashed) line represents the result of the one-resonance (no-resonance) fit described in the text.

Phys. Rev. D 74 (2006) 091103(R)

Y(2175) in $J/\psi \to \eta\,\phi\,f_0(980)$

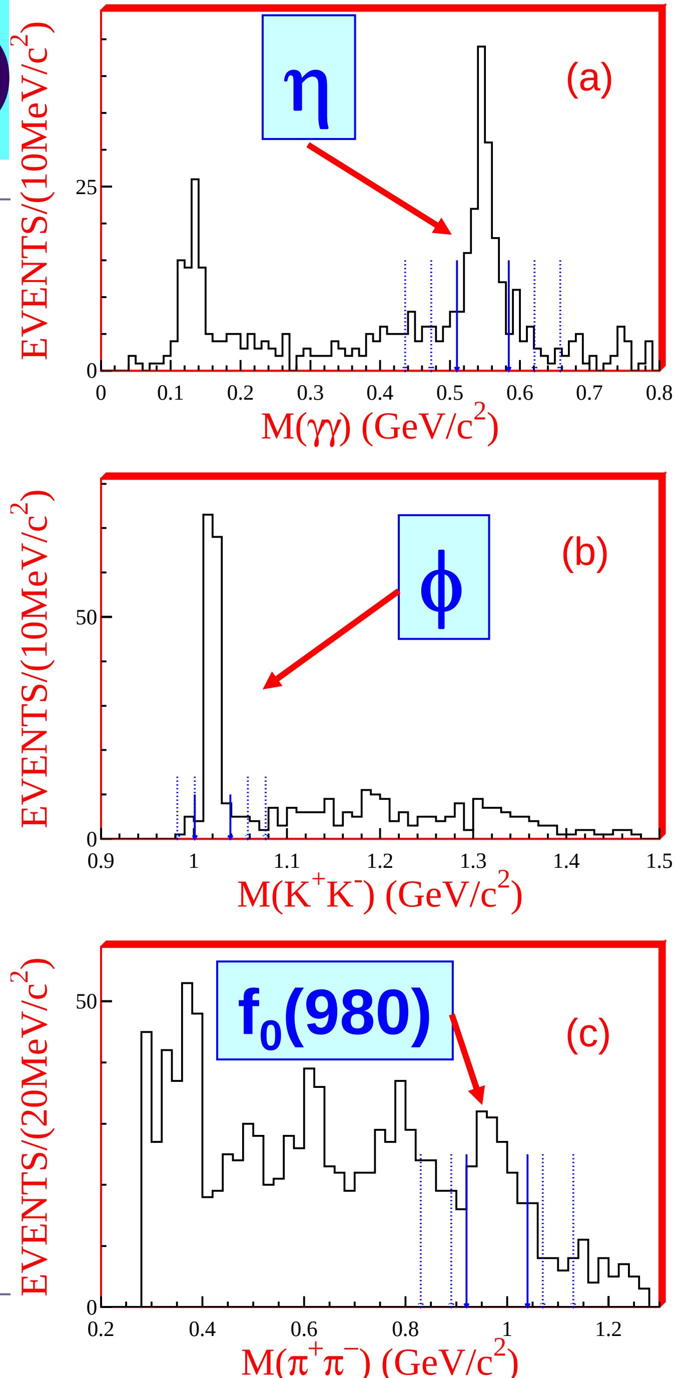
Final states:

$\eta \to \gamma\gamma$

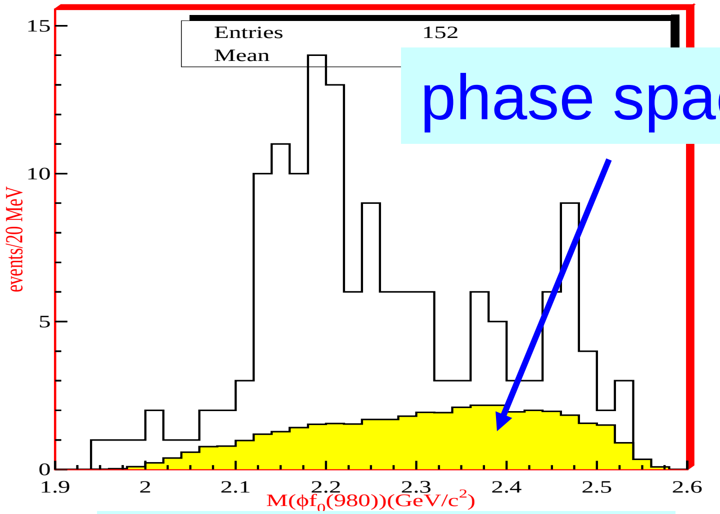
$\phi \to K^+K^-$

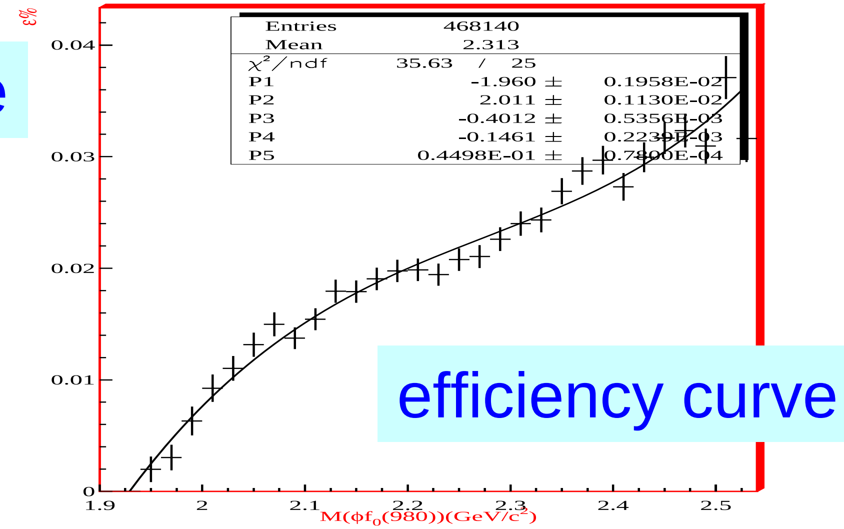
$f_0(980) \to \pi^+\pi^-$

signal and sideband regions

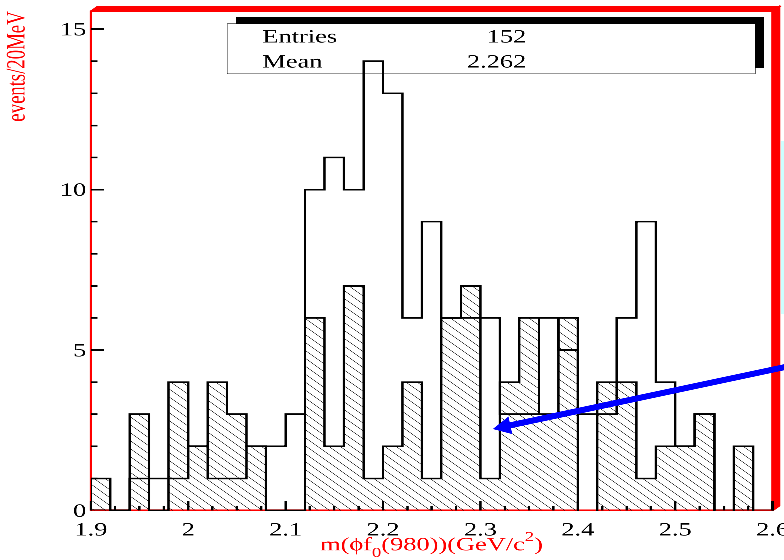


A peak around 2175 MeV/c² is observed in $J/\psi \to \eta\phi f_0(980)$



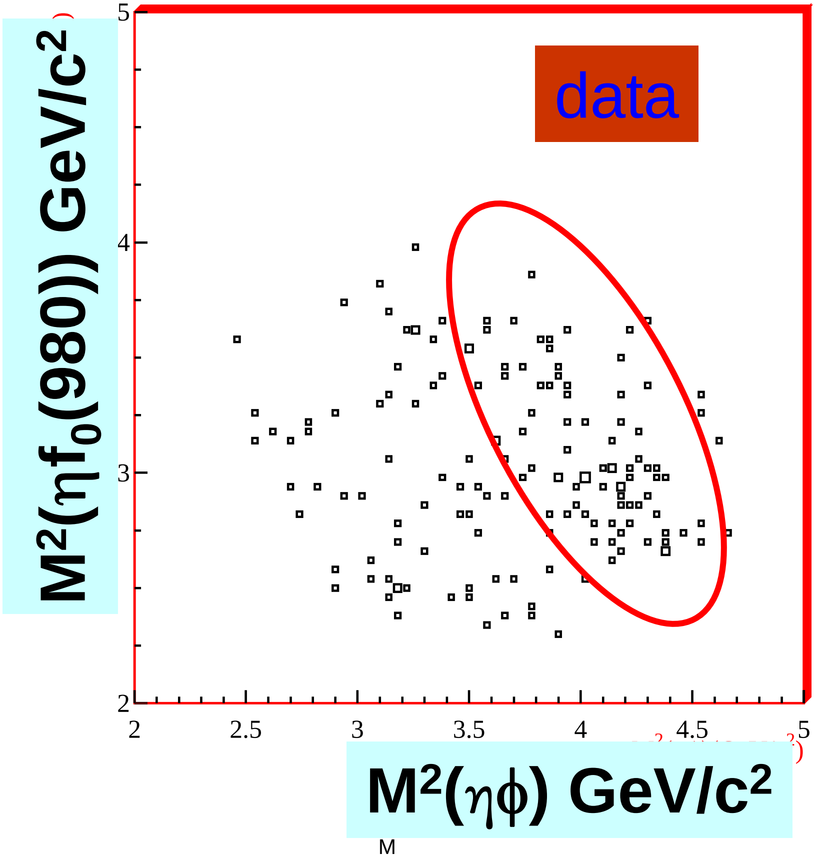


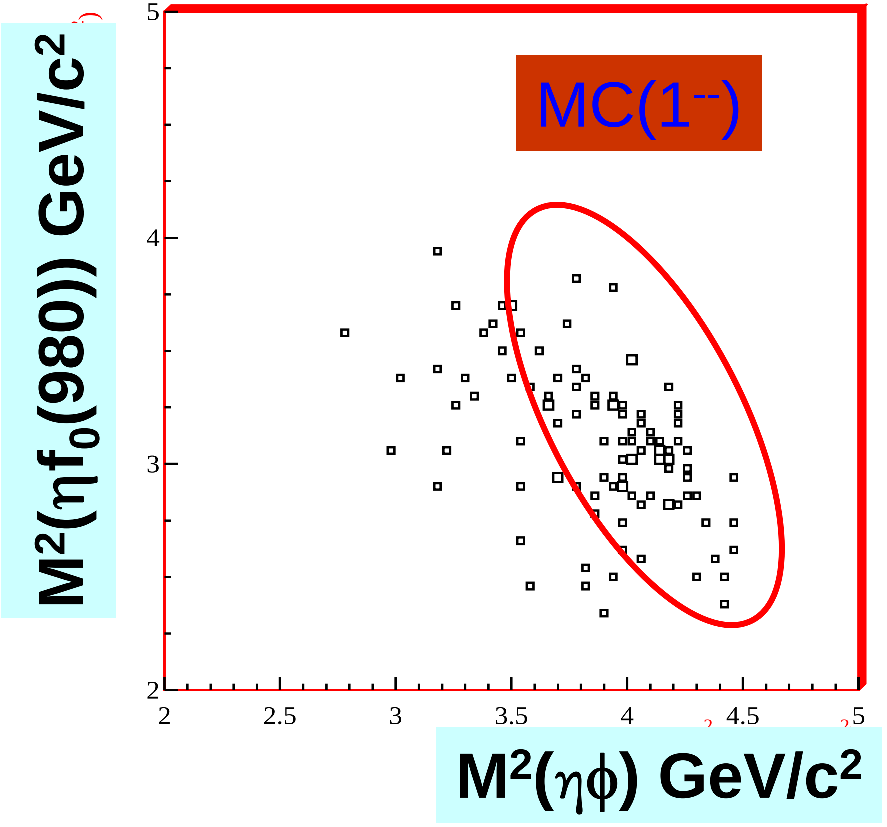
$M(\phi f_0(980))$ GeV/c²



Backgrounds from sideband estimation

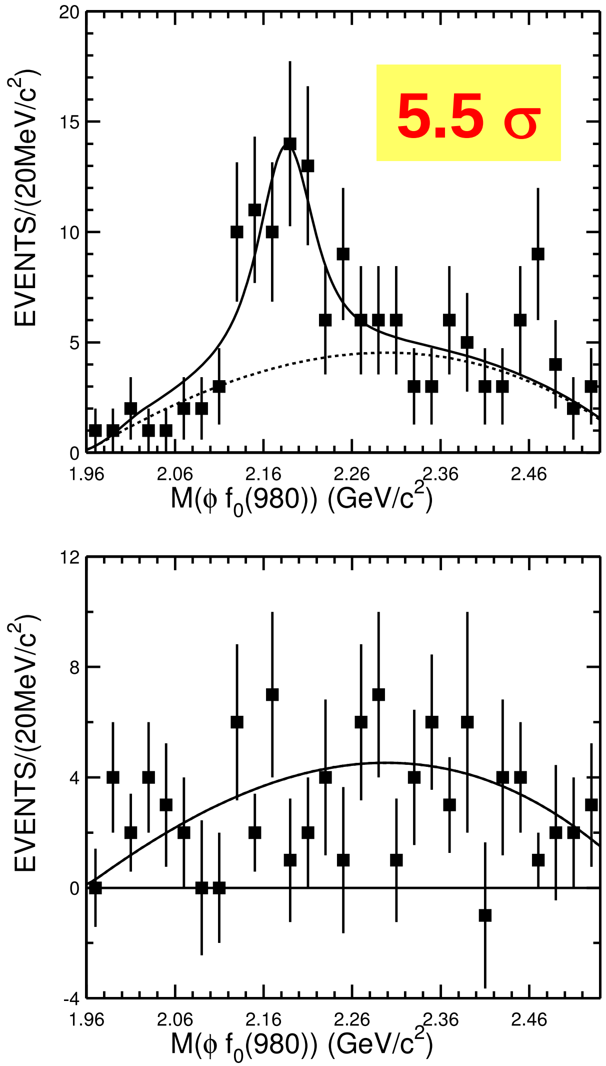
$M^2(\eta f_0(980))$ vs. $M^2(\eta\phi)$ (Dalitz plot)





Y(2175) in $J/\psi \to \eta \phi f_0(980)$

Phys.Rev.Lett. 100, 102003 (2008).



Simultaneous fit to signal and sideband events with:

Breit-Wigner ⊗ Gaussian

and

third-order polynomial

$M = 2.186 \pm 0.010 \pm 0.006$ GeV/c^2

$\Gamma = 0.065 \pm 0.023 \pm 0.017$ GeV/c^2

$N_{events} = 52 \pm 12$

$$B(J/\psi \to \eta Y(2175)) \times B(Y(2175) \to \phi f_0(980)) \times B(f_0(980) \to \pi^+\pi^-) = (3.23 \pm 0.75(stat) \pm 0.73(syst)) \times 10^{-4}$$

What's Y(2175)?

Some theoretical interpretations:

- A conventional $s\bar{s}$ state?
- An $s\bar{s}$ analog of Y(4260) ($s\bar{s}g$)?
- An $s\bar{s}s\bar{s}$ 4-quark state?

More experimental information needed.

Partial Wave Analysis of $J/\psi \to \gamma\phi\phi$

PWA of $J/\psi \rightarrow \gamma\phi\phi$

- LQCD studies give the result that the masses of the lowest-lying glueballs range from 1 to 3 GeV/c^2. Radiative J/ψ decays provide an excellent laboratory for testing these predictions.

- Systems of two vector particles have been intensively examined for signatures of gluonic bound states. Pseudoscalar enhancements in $\rho\rho$ and $\omega\omega$ final states have been seen in radiative J/ψ decays.

- Recently a scalar signal near threshold X(1810) is observed in the $\omega\phi$ invariant mass spectrum from the doubly OZI suppressed decays of $J/\psi \rightarrow \gamma\omega\phi$,which add a new puzzle to the low-lying scalar mesons. Looking for analog scalar mesons in $J/\psi \rightarrow \gamma\phi\phi$ will help to understand the nature of X(1810).

$\eta(2225)$ in $J/\psi \to \gamma\phi\phi$

MARKIII collaboration and DM2 collaboration studied $J/\psi \to \gamma\, \phi\phi$ decays.

A pseudoscalar signal near threshold is observed in the $\phi\phi$ invariant mass spectrum,

known as $\eta(2225)$ in PDG with

a mass of $M = 2220 \pm 18$ MeV/c^2 and

a width of $\Gamma = 150^{+300}_{-60} \pm 60$ MeV/c^2.

- **PRL 65 1309 MRK3 $J/\psi \to \gamma K^+K^-K^+K^-$**
  168 events
  $J/\psi \to \gamma K^+K^-K^0_S K^0_L$
  119 events
- **PL B179 294 DM2 $J/\psi \to \gamma K^+K^-K^+K^-$**
  92 events
- **PL B241 617 DM2 $J/\psi \to \gamma K^+K^-K_S^0K_L^0$**
  33 events

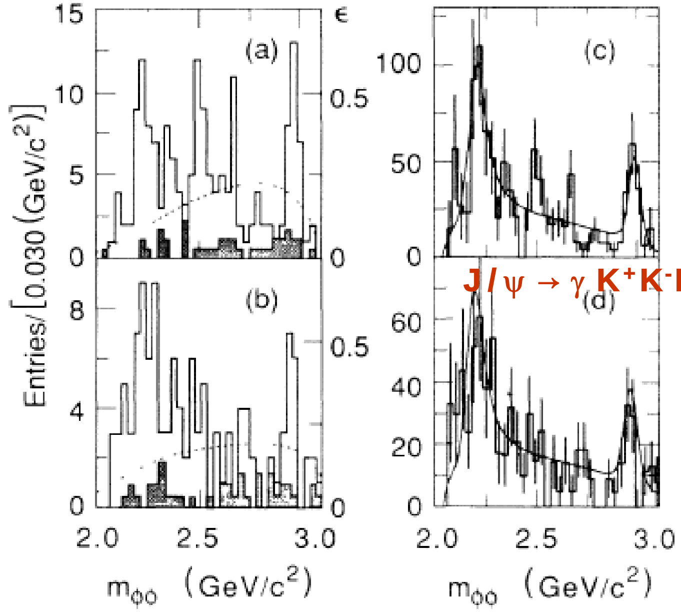
Structures are observed in

$\pi^- p \to \phi\phi + n$, $\pi\pi \to \phi\phi$ reactions

- **PL B201 568 etc.**

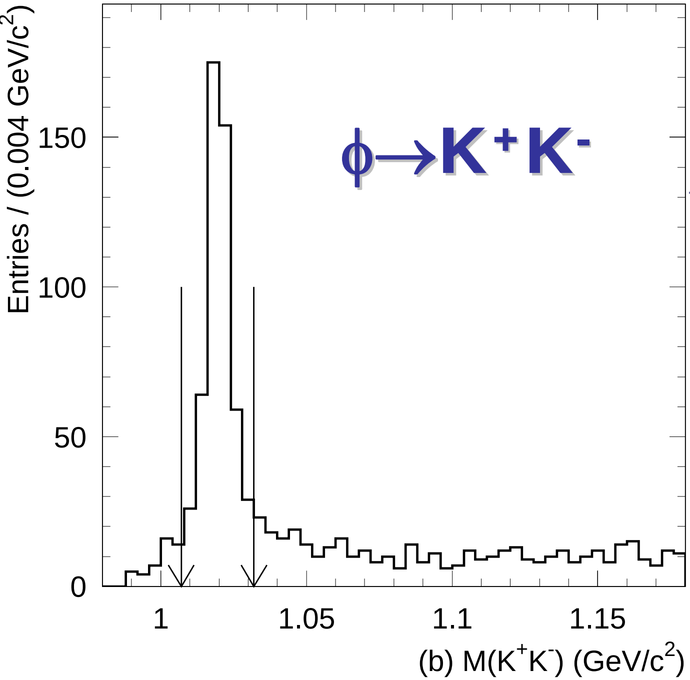
MARKIII

$J/\psi \to \gamma K^+K^-K^+K^-$



$J/\psi \to \gamma K^+K^-K^0_S K^0_L$

FIG. 2. The observed $\phi\phi$ invariant-mass spectra from (a) $J/\psi \to \gamma K^+K^-K^+K^-$ and (b) $J/\psi \to \gamma K^+K^-K^0_S K^0_L$; (c),(d) the corresponding $\phi\phi$ invariant-mass spectra after efficiency correction. Shaded histograms show background estimates; dashed curves show detection efficiencies denoted by ϵ; solid curves show fits described in the text.



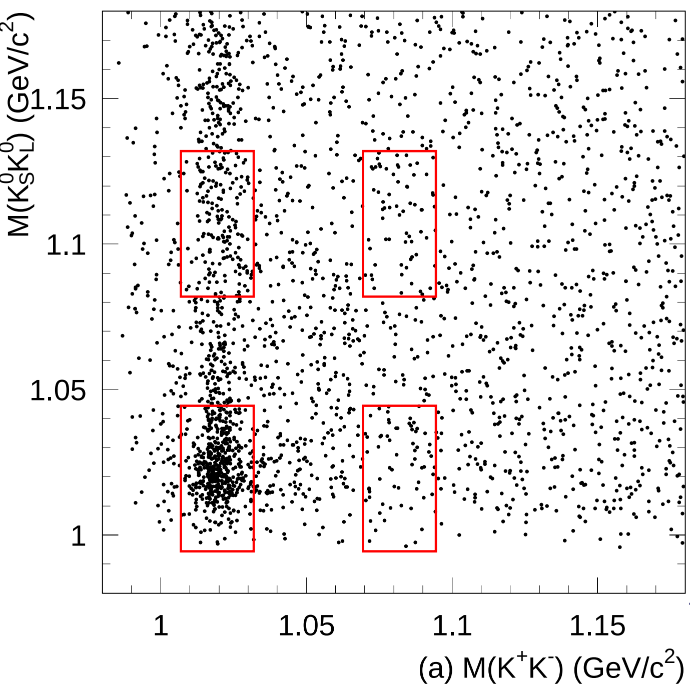
PWA of $J/\psi \rightarrow \gamma \phi \phi$ at BESII

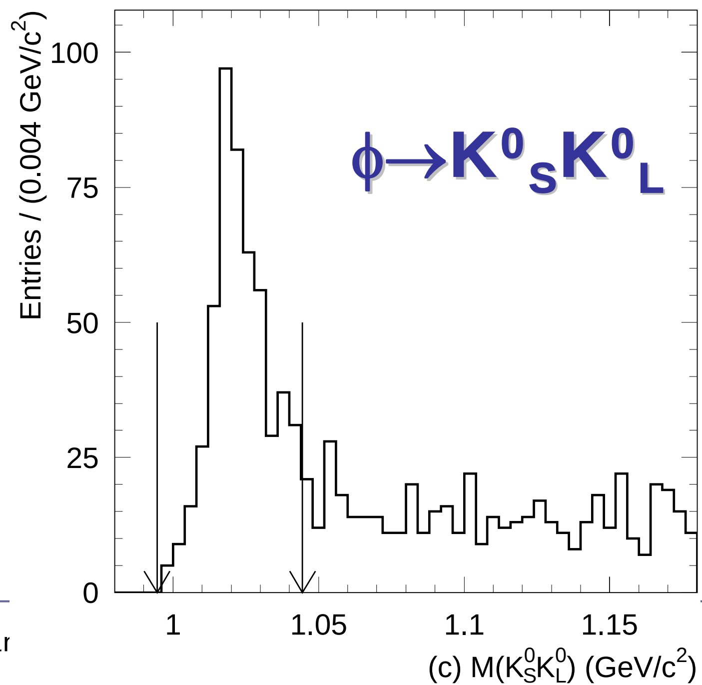
Final states:

$\phi \rightarrow K^+K^-$,

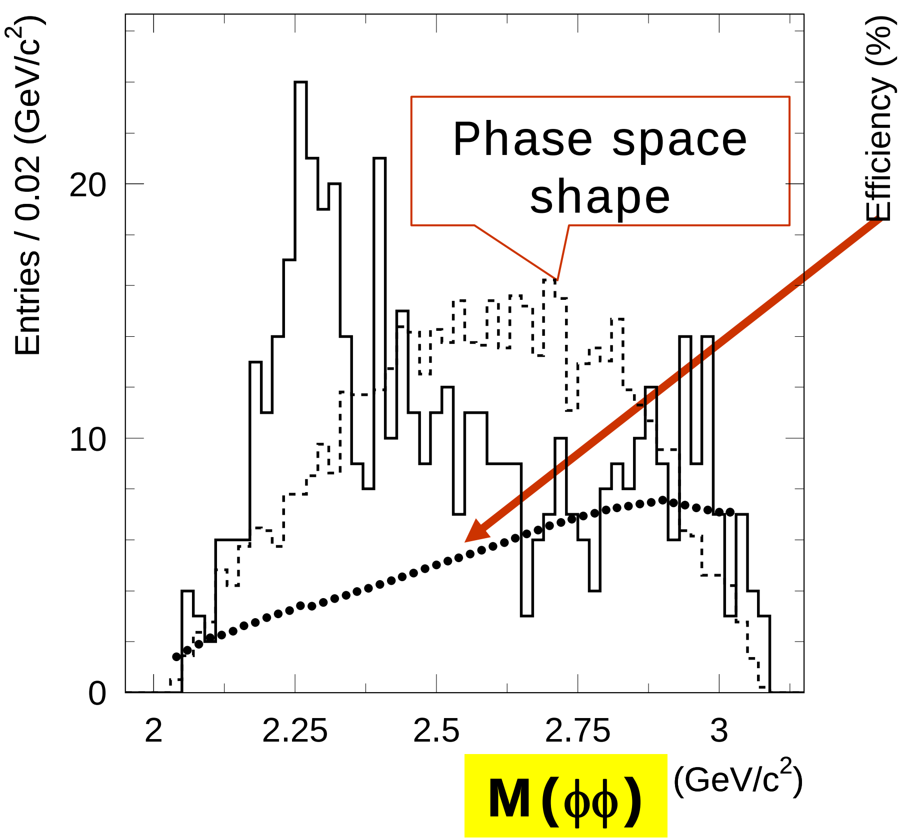
$\phi \rightarrow K_S^0 K_L^0$ ($K_S^0 \rightarrow \pi^+\pi^-$, K_L^0 is missing)

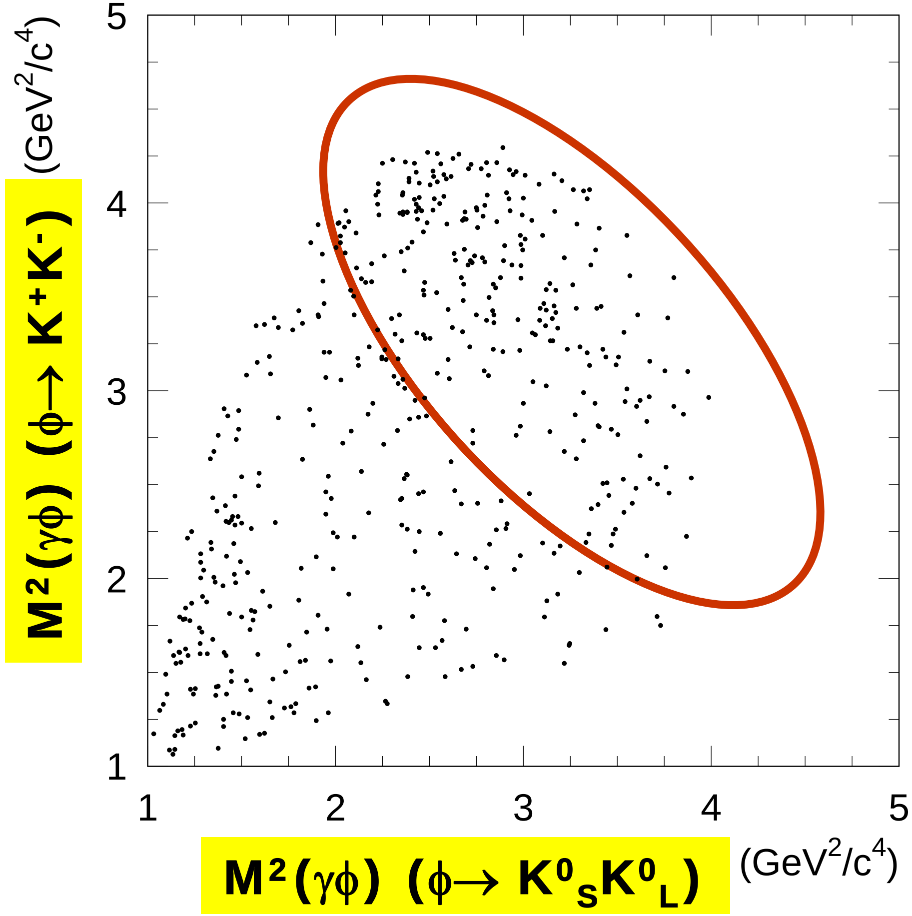
a 2C-kinematic fit is performed





An enhancement close to threshold is observed





Partial wave analysis results

1. PWA shows the structure is dominated by 0^{-+} state: $\eta(2225)$ (>10 σ).

   if fitting with 0^{++}, -ln L is worse by 95
   if fitting with 2^{++}, -ln L is worse by 27

2. $M=2.24^{+0.03}_{-0.02}{}^{+0.03}_{-0.02}$ GeV/c^2,
   $\Gamma= 0.19^{+0.03}_{-0.03}{}^{+0.06}_{-0.04}$ GeV/c^2

   The branching fraction is:
   $Br(J/\psi \rightarrow \gamma\, \eta(2225))$
   $*Br(\eta(2225) \rightarrow \phi\phi) = (4.4^{+0.4}_{-0.4}{}^{+0.8}_{-0.8})\times 10^{-4}$

Phys.Letts. B662, 330 (2008)

PDG value
$M=2.220 \pm 0.018$ GeV/c^2;
$\Gamma= 0.150\ ^{+0.300}_{-0.060} \pm 0.060$ GeV/c^2;
Br: $(2.9 \pm 0.6) \times 10^{-4}$

Partial wave analysis results

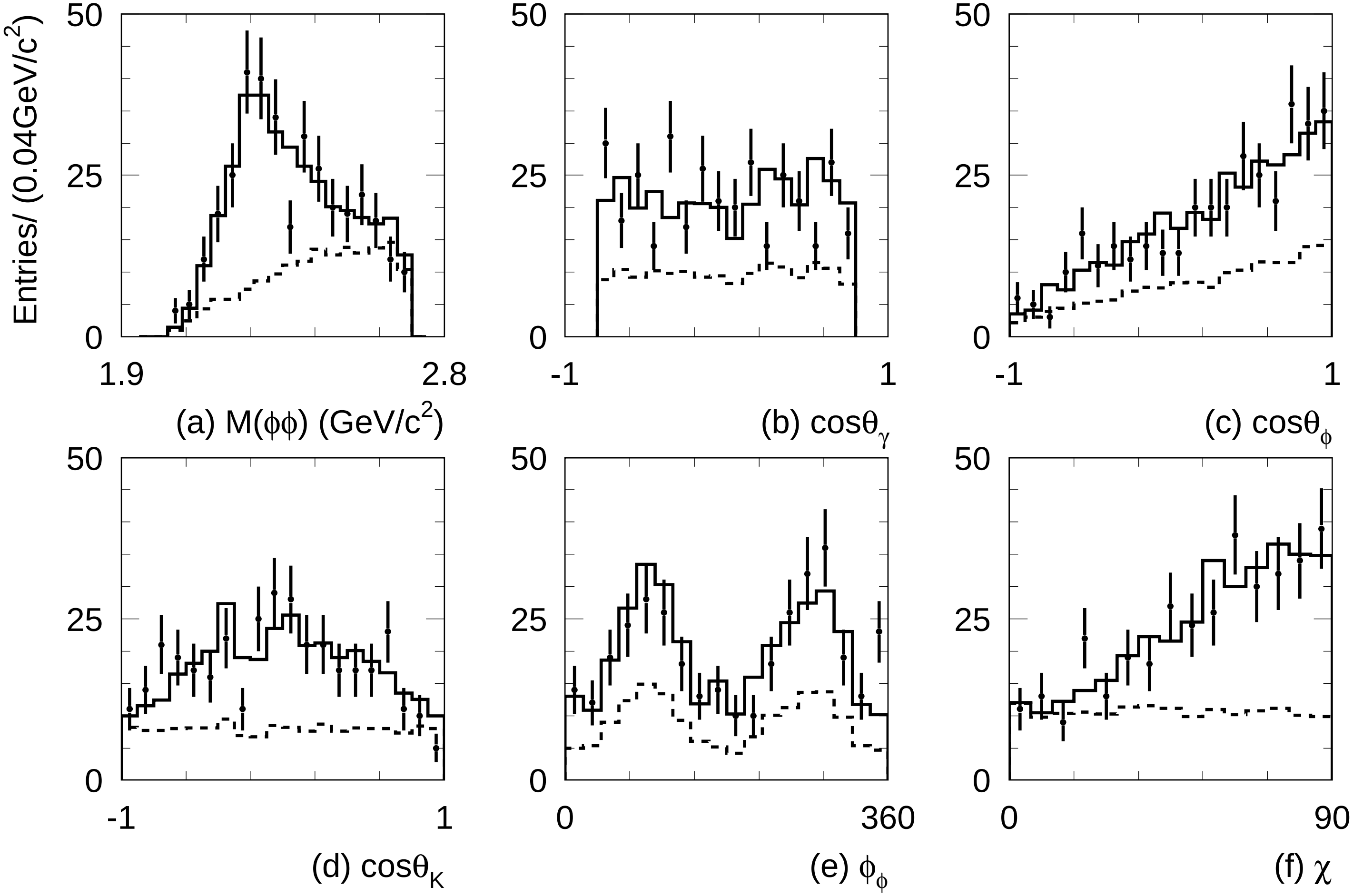
If fitting with a 0^- resonance and an interfering 0^- phase space,

the –ln L improves by 0.4

=> 0^- phase space is negligible

	Resonance	Mass (GeV/c^2)	Width (GeV/c^2)	Num. of events	Sign.
0^-+0^-	$\eta(2225)$	$2.28^{+0.02}_{-0.02}$	$0.18^{+0.04}_{-0.04}$	$323.3^{+21.9}_{-22.9}$	>10 σ
	extra 0^-	$2.36^{+0.02}_{-0.03}$	$0.07^{+0.11}_{-0.05}$	$31.2^{+13.1}_{-12.5}$	0.8 σ
0^-+0^+	$\eta(2225)$	$2.25^{+0.01}_{-0.01}$	$0.19^{+0.04}_{-0.02}$	$199.6^{+18.4}_{-18.5}$	>10 σ
	extra 0^+	$2.01^{+0.08}_{-0.11}$	$0.14^{+0.17}_{-0.10}$	$23.8^{+10.4}_{-9.1}$	2.1 σ
0^-+2^+	$\eta(2225)$	$2.24^{+0.01}_{-0.02}$	$0.23^{+0.04}_{-0.02}$	$204.2^{+20.9}_{-18.6}$	>10 σ
	extra 2^+	$2.25^{+0.02}_{-0.01}$	$0.05^{+0.04}_{-0.02}$	$47.0^{+9.8}_{-11.3}$	3.3 σ

Partial wave analysis results



Measurement of $J/\psi \to \omega / \phi K \bar{K} \pi$

Measurement of $J/\psi \to \omega\ /\ \phi\ K \bar{K} \pi$

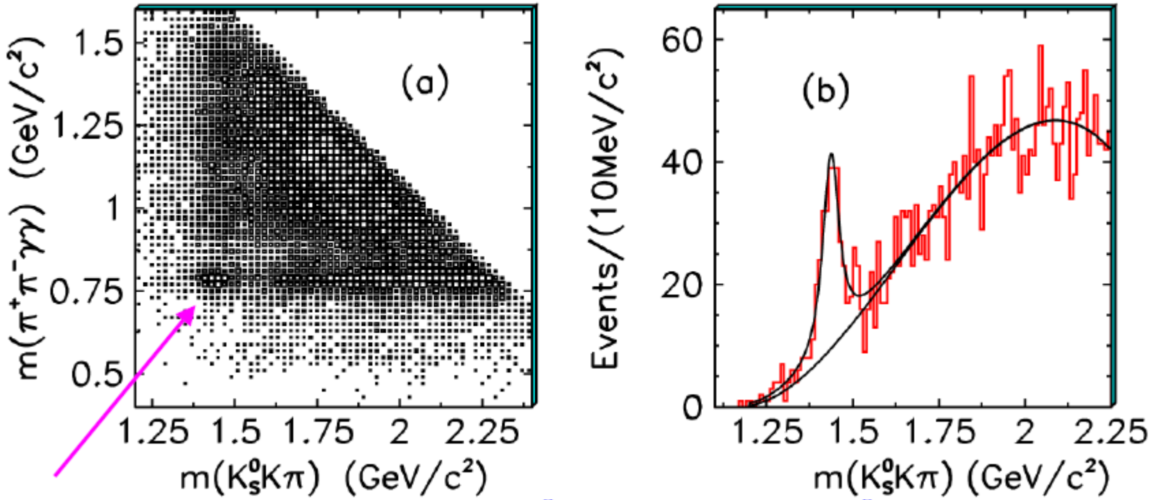
- One structure (E/ι(1440))near 1.44 GeV, may due to two states(η(1405),η(1475)), one couples to $a_0(980)\pi$ and KK π, the other couples to K*K.

- Mass and width are not well measured.

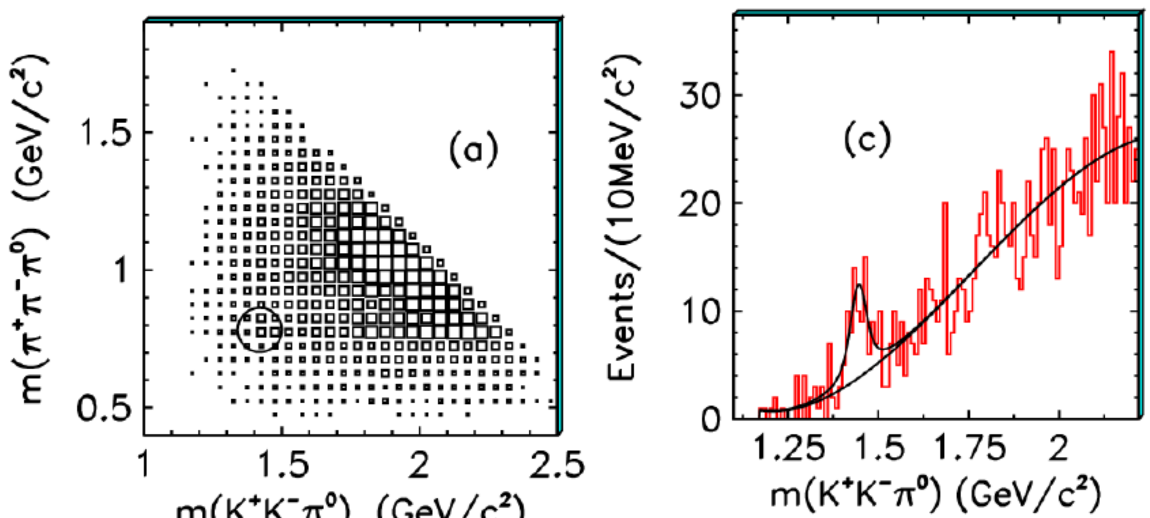
- Measurements of $J/\psi \to \omega\ /\ \phi\ X$ is very helpful to understand the nature of the structure

X(1440) in $J/\psi \to \omega K \bar{K} \pi$

- Final states: $\omega \rightarrow \pi^+\pi^-\pi^0$, $KK\pi = K_S K\pi$

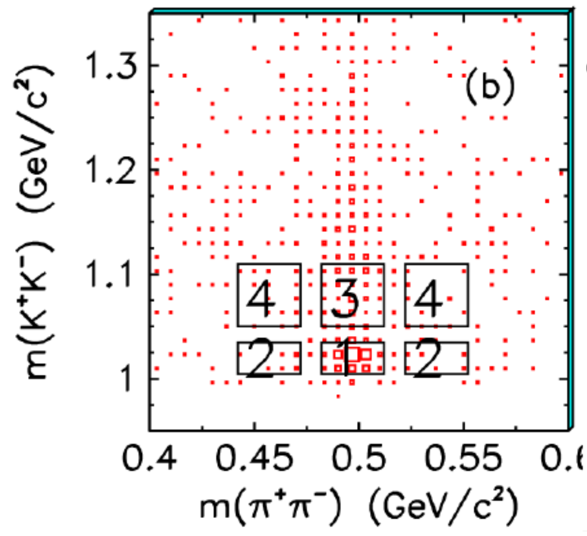


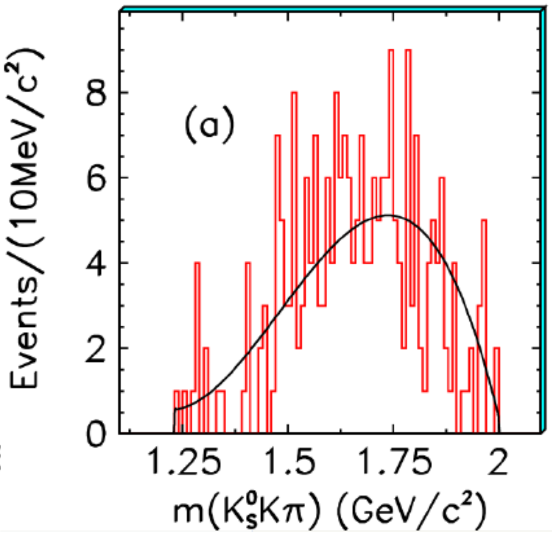
- Final states: $\omega \rightarrow \pi^+\pi^-\pi^0$, $KK\pi = K^+K^-\pi^0$



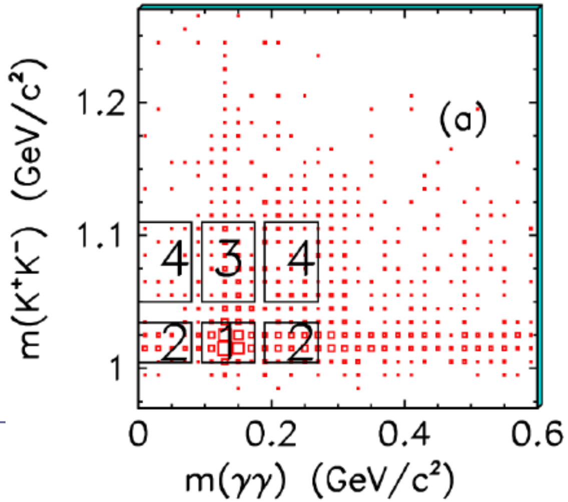
X(1440) in $J/\psi \to \phi \ K \ \bar{K} \ \pi$

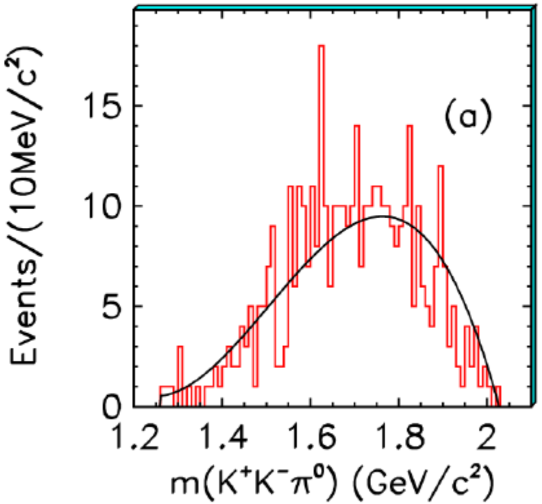
- Final states: $\phi \to K^+K^-$, $KK\pi = K_S K\pi$





- Final states: $\phi \to K^+K^-$, $KK\pi = K^+K^-\pi^0$





X(1440) in $J/\psi \to \omega$ / $\phi K \bar{K} \pi$

TABLE V. The mass, width, and branching fractions of J/ψ decays into $\{\omega, \phi\}X(1440)$.

$J/\psi \to \omega X(1440)$	$J/\psi \to \omega X(1440)$
$(X \to K_S^0 K^+ \pi^- + \text{c.c.})$	$(X \to K^+ K^- \pi^0)$
$M = 1437.6 \pm 3.2$ MeV$/c^2$	$M = 1445.9 \pm 5.7$ MeV$/c^2$
$\Gamma = 48.9 \pm 9.0$ MeV$/c^2$	$\Gamma = 34.2 \pm 18.5$ MeV$/c^2$
$B(J/\psi \to \omega X(1440) \to \omega K_S^0 K^+ \pi^- + \text{c.c.}) = (4.86 \pm 0.69 \pm 0.81) \times 10^{-4}$	
$B(J/\psi \to \omega X(1440) \to \omega K^+ K^- \pi^0) = (1.92 \pm 0.57 \pm 0.38) \times 10^{-4}$	
$B(J/\psi \to \phi X(1440) \to \phi K_S^0 K^+ \pi^- + \text{c.c.}) < 1.93 \times 10^{-5}$ (90% C.L.)	
$B(J/\psi \to \phi X(1440) \to \phi K^+ K^- \pi^0) < 1.71 \times 10^{-5}$ (90% C.L.)	

$B(J/\psi \to \omega X)/B(J/\psi \to \phi X) > 20$

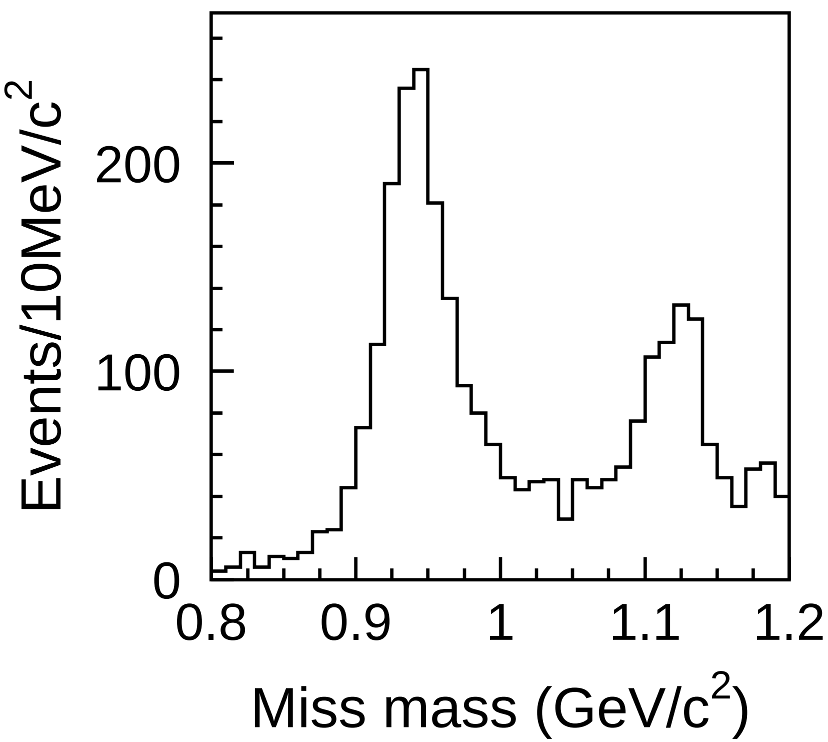
=>X(1440) couples to ω stronger than to ϕ

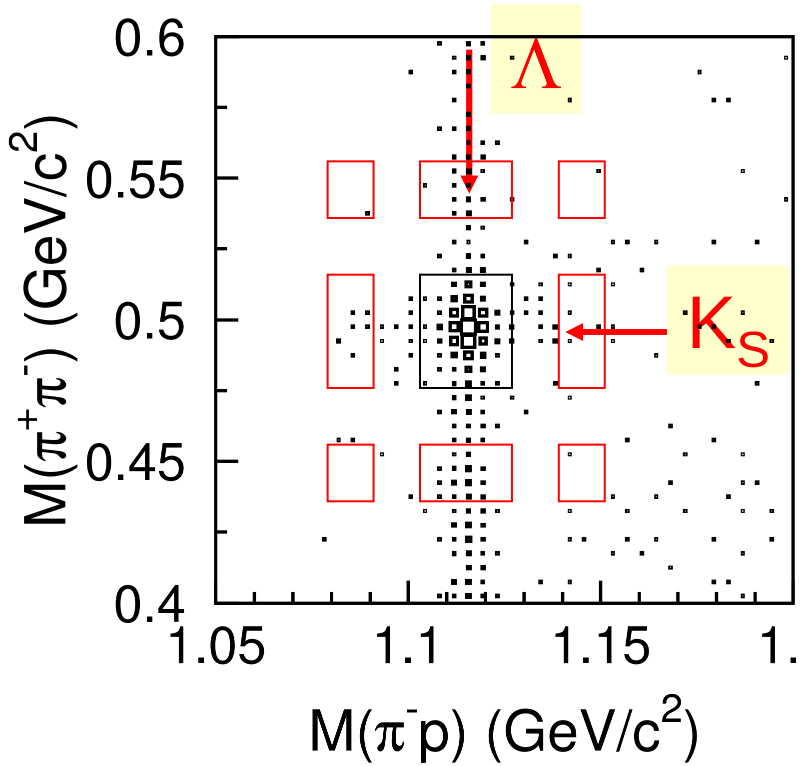
=> large $n\bar{n}$ component

Phys.Rev. D77, 032005(2008)

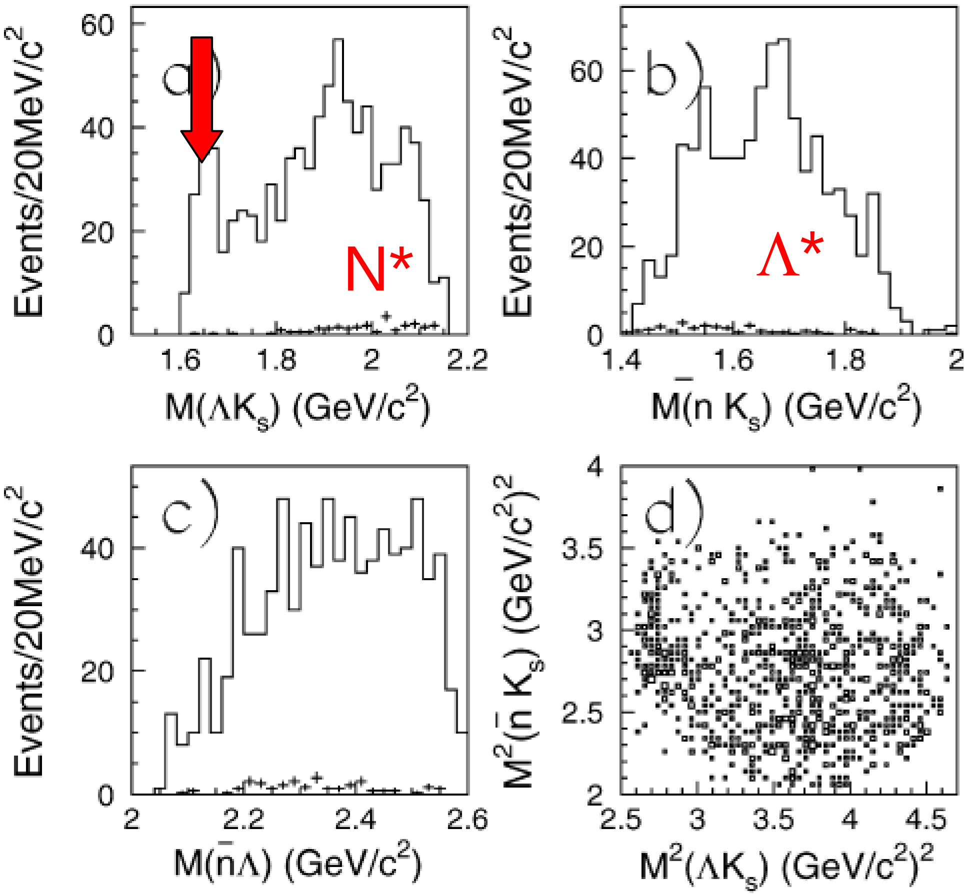
Observation of J/ψ and $\psi(2S) \to n K^0_S \bar{\Lambda}$ +c.c

J/ψ and $\psi(2S) \rightarrow n\ K^0_S\ \bar{\Lambda}$ +c.c





Phys.Letts. B659, 789 (2008).



- **There is no obvious enhancement near n $\bar{\Lambda}$ threshold.**

  (X(2075) was observed in J/$\psi \to$ p K^- $\bar{\Lambda}$)

- **An enhancement near ΛK_s threshold is evident**
- **N* and Λ* found in the ΛK_s and nK_s spectrum**

More statistics and PWA are needed for the detail information

Summary

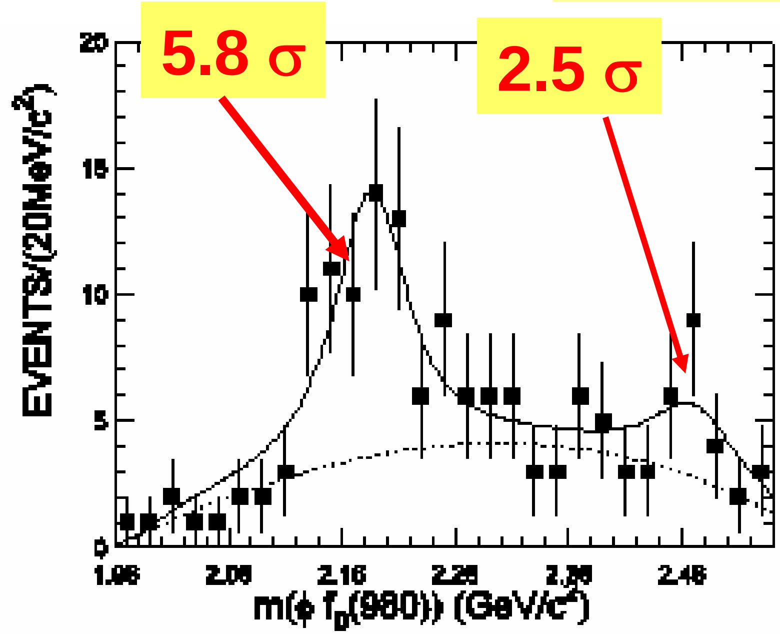
- Observation of Y(2175) at BESII.
- Partial wave analysis of $J/\psi \to \gamma \phi \phi$.
- X(1440) production with an ω or a ϕ.
- Observation of J/ψ and $\psi(2S) \to n K^0_S \bar{\Lambda}$ +c.c.
- We are expecting more new results on hadron spectroscopy at BESIII.

THANKS

Backup

Fit with two resonances

- **BG shape is fixed to sideband BG**
- **the mass and width of the second peak are fixed to those of from BaBar.**



M =2.186 ± 0.010GeV/c²

Γ= 0.065 ± 0.022GeV/c²

N1 events= 47±14

N2 events= 22±11

$$B(J/\psi \to \eta Y(2175)B(Y(2175) \to \varphi f_0(980))B(f_0(980) \to \pi^+\pi^-) = (2.92 \pm 0.87(stat)) \times 10^{-4}$$

Backup

	Mass(%)	Width(%)	Branching ratio(%)
Mass and width of $\eta(2225)$	$\sim$	$\sim$	± 6.6
Extra components	$^{+0.4}_{-0.0}$	$^{+21.1}_{-0.0}$	$^{+2.6}_{-0.0}$
Breit-Wigner parameterization	± 0.9	± 5.3	± 1.1
Background treatment	± 0.4	± 20.1	± 10.2
Fitting bias	$+0.2$	$+11.4$	-6.0
Particle ID	$\sim$	$\sim$	± 4
Photon efficiency	$\sim$	$\sim$	± 1
Wire resolution	± 0.4	± 5.3	± 10.7
Intermediate decays	$\sim$	$\sim$	± 1.9
Total J/ψ events	$\sim$	$\sim$	± 4.7
Total systematic error	$^{+1.2}_{-1.1}$	$^{+32.2}_{-21.5}$	$^{+17.7}_{-18.5}$

5. BW

Using BW with momentum dependency (Kühn-Santamaria parameterization)

$(2.26^{+0.02}_{-0.01}, 0.18^{+0.04}_{-0.03})$ 193.3+15.6-15.5 0.0329

$$BW(R) = \frac{1}{s - M_R^2 + i\sqrt{s}\Gamma_R(s)}, \Gamma_R(s) = \Gamma_R(\frac{M_R^2}{s})(\frac{p(s)}{p(M_R^2)})^{2l+1}$$

Pole position is

$M - i/2\Gamma = (2.25^{+0.03}_{-0.02}) - i/2(0.18^{+0.03}_{-0.04})$ (GeV/c^2)

w.r.t.

The pole position with the naive Breit-Wigner parameterization

$M - i/2\Gamma = (2.24^{+0.03}_{-0.02}) - i/2(0.19^{+0.03}_{-0.03})$ (GeV/c^2)

M:0.9%; W:5.3%; Br:1.1%

Systematic errors

6. Fitting bias

Generating 35 sizable samples of signal and background (**according to the results**) to perform the MC I/O check.

The **averaged offsets** between the output values of mass, width and number of signal events and their input values are taken as one source of systematic uncertainties.

Fitting bias

M: +0.2%; W:+11.4% Br: -0.6%

In addition, the **RMSD** (Root mean square deviation) of the output values are taken as their expected statistical errors, which can be compared with the fitting results.

Expected statistical errors are consist with the fitting results

M: 0.5%; W:16.6%; Br: 10%

Backup

3, The contributions of some known resonances from PDG

Extra resonances	Mass of 0^- (GeV/c^2)	Width of 0^- (GeV/c^2)	Significance
$f_0(2100)$	2.25	0.20	1.8 σ
$f_0(2330)$	2.24	0.19	0.3 σ
$f_2(2010)$	2.24	0.22	1.4 σ
$f_2(2150)$	2.25	0.20	2.2 σ
$f_J(2220)$	2.24	0.23	2.0 σ
$f_2(2300)$	2.23	0.25	2.6 σ