Light Hadrons and New Enhancements in J/ψ Decays at BESII

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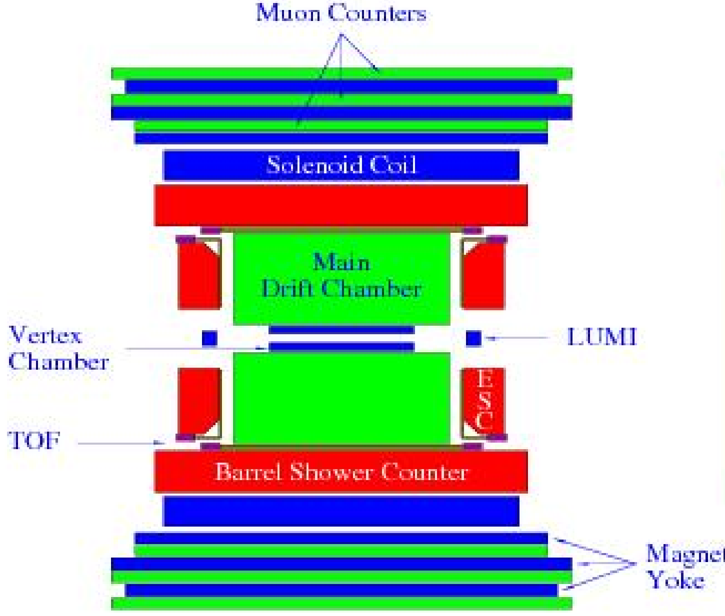
Outline

- Introduction of BEPC/BESII
- 0^{++} Resonances
- 0^{-+} Resonances
- New Enhancements/structures
- Summary

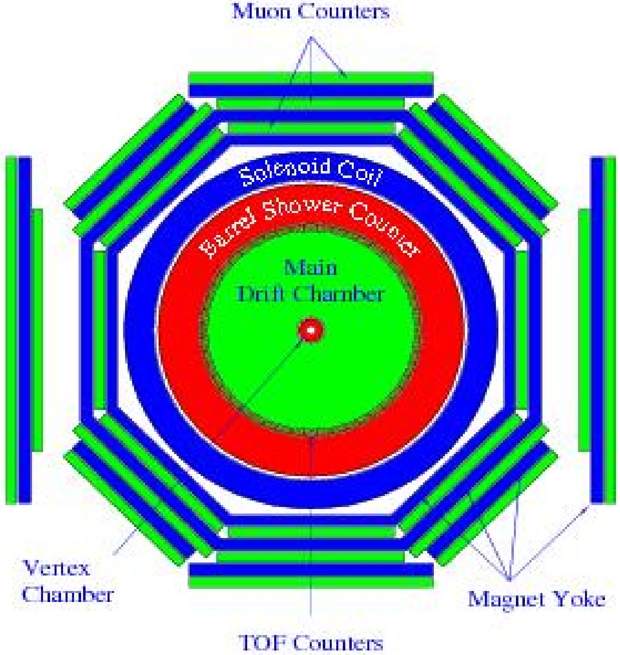
Introduction

- BES (Beijing Spectrometer) is a large general purpose solenoidal detector at Beijing Electron Positron Collider (BEPC).
- Beam energy range from 1.0 to 2.8 GeV
- Luminosity at J/ψ peak $5 \times 10^{30} cm^{-2} s^{-1}$

BESII



Side view of the BES detector



End view of the BES detector

VC: $\sigma_{xy} = 100\mu\mathrm{m}$ **TOF:** $\sigma_T = 180\mathrm{ps}$ μ: $\sigma_{r\phi} = 3\mathrm{cm}$

MDC: $\sigma_{xy} = 100\mu\mathrm{m}$ **BSC:** $\Delta E/\sqrt{E} = 22\%$ $\sigma_z = 5.5\mathrm{cm}$

$\sigma_{dE/dx} = 8.5\%$ $\sigma_\phi = 7.9\mathrm{rm}$

$\Delta p/p = 1.8\%\sqrt{1+p^2}$ $\sigma_z = 2.3\mathrm{cm}$ **B:0.4T**

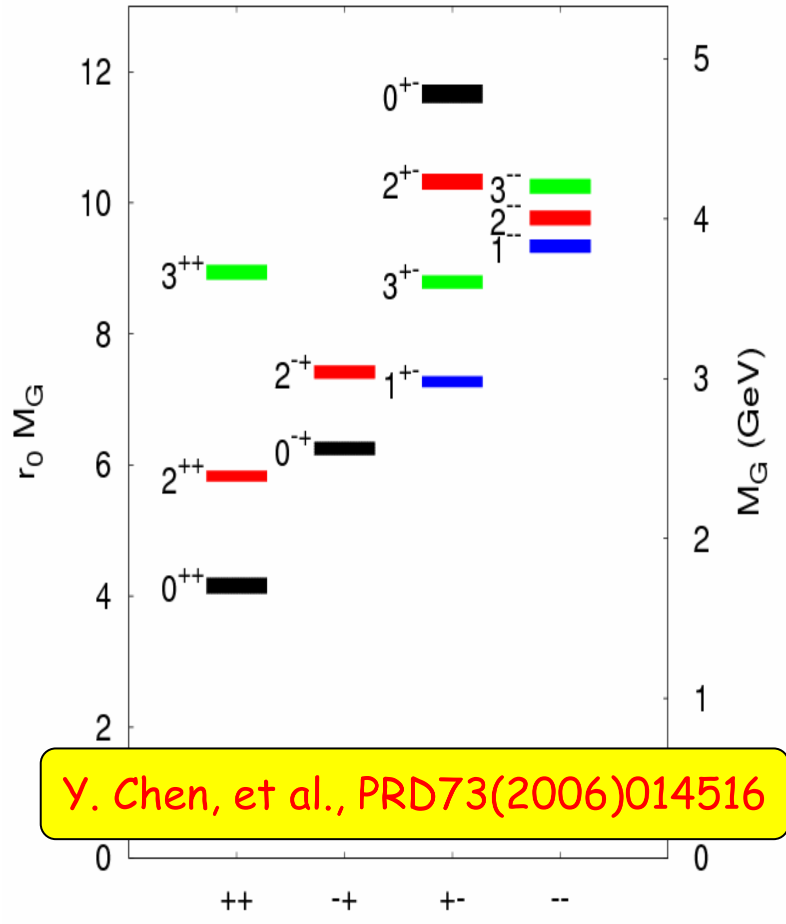
Meson spectrum—Scalars(0^{++})

- **I=0 :** $f_0(600)(\sigma)$, $f_0(980)$, $f_0(1370)$, $f_0(1500)$, $f_0(1700)$, $f_0(1790)$ …
- **I=1/2:** $K^*_0(800)(\kappa)$, $K^*_0(1430)$, $K^*(1950)(?)$,…
- **I=1:** $a_0(980)$, $a_0(1450)$, …

Quark Model: no enough room for all of these scalar particles

Review of Glueball Spectrum

- Some QCD-based theories make predictions to the glueball mass.
- LQCD predicts the lowest glueball state is 0^{++}. The mass is around 1.5 GeV ~ 1.7 GeV.
- LQCD predicts the next lightest glueball is 2^{++}. The mass is around 2.4 GeV.
- The mix of glueball with ordinary $q\bar{q}$ meson makes the situation more difficult.



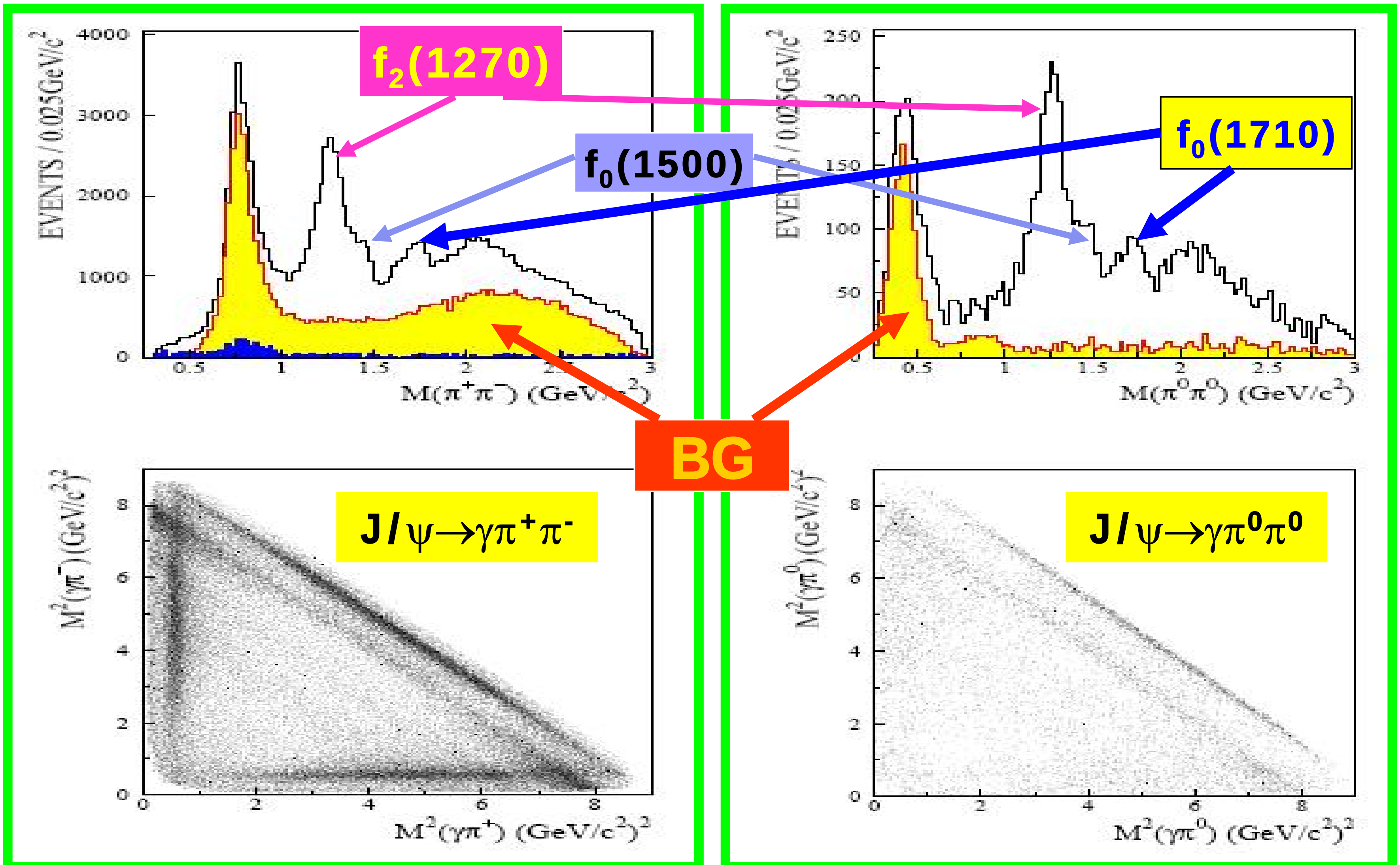
Glueball candidates: $f_0(1500)$, $f_0(1700)$, ...

Meson spectrum—Scalars(0^{++})

$f_0(1370)$, $f_0(1500)$, $f_0(1700)$, $f_0(1790)$

$$J/\psi \to \gamma\pi\pi,\ \gamma KK$$
$$\to \omega KK$$
$$\to \phi\pi\pi,\ \phi KK$$

$J/\psi \to \gamma\pi\pi$



PWA results

- Lower 0^{++} : 0^{++} is strongly preferred over 2^{++}

$$M = (1466 \pm 6 \pm 16)\ \mathrm{MeV}$$

$$\Gamma = (108^{+14}_{-11} \pm 21)\ \mathrm{MeV}$$

- $f_0(1370)$ cannot be excluded.

- Higher 0^{++}: $f_0(1710)$ or $f_0(1790)$ or both?

$$M = (1765^{+4}_{-3} \pm 11)\ \mathrm{MeV}$$

$$\Gamma = (145 \pm 8 \pm 23)\ \mathrm{MeV}$$

$J/\psi \to \gamma\pi\pi$

PWA

$J/\psi \to \gamma X,\ X \to \pi^+\pi^-$			
	Mass (MeV/c^2)	Γ (MeV/c^2)	$\mathcal{B}$ ($\times 10^{-4}$)
$f_2(1270)$	$1262^{+1}_{-2} \pm 8$	$175^{+6}_{-4} \pm 10$	$9.14 \pm 0.07 \pm 1.48$
$f_0(1500)$	$1466 \pm 6 \pm 20$	$108^{+14}_{-11} \pm 25$	$0.67 \pm 0.02 \pm 0.30$
$f_0(1710)$	$1765^{+4}_{-3} \pm 13$	$145 \pm 8 \pm 69$	$2.64 \pm 0.04 \pm 0.75$

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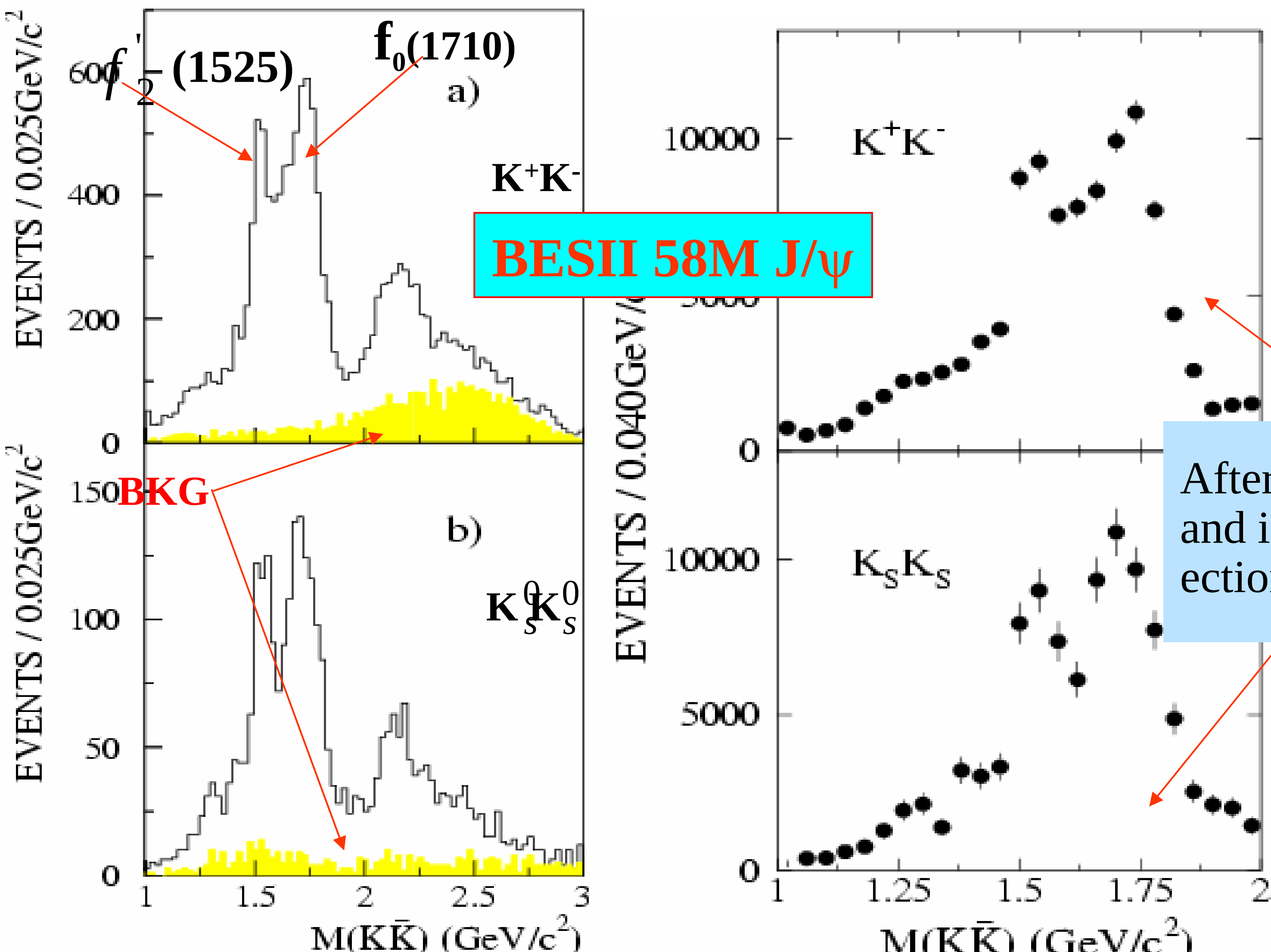
$J/\psi \to \gamma X,\ X \to \pi^0\pi^0$			
	Mass (MeV/c^2)	Γ (MeV/c^2)	$\mathcal{B}$ ($\times 10^{-4}$)
$f_2(1270)$	same as charged channel		$4.00 \pm 0.09 \pm 0.58$
$f_0(1500)$	same as charged channel		$0.34 \pm 0.03 \pm 0.15$
$f_0(1710)$	same as charged channel		$1.33 \pm 0.05 \pm 0.88$

BESII $J/\psi \rightarrow \gamma K^+K^-$ and $\gamma K_S^0K_S^0$



BESII 58M J/ψ

After acceptance and isospin corr-ections

Phys. Rev. D68 (2003) 052003

$J/\psi \to \omega KK$

PWA

- $J/\psi \to \omega\sigma$

  $\to \omega f_0(980)$

  $\to \omega f_0(1710)$

  $\to \omega f_2(1270)$

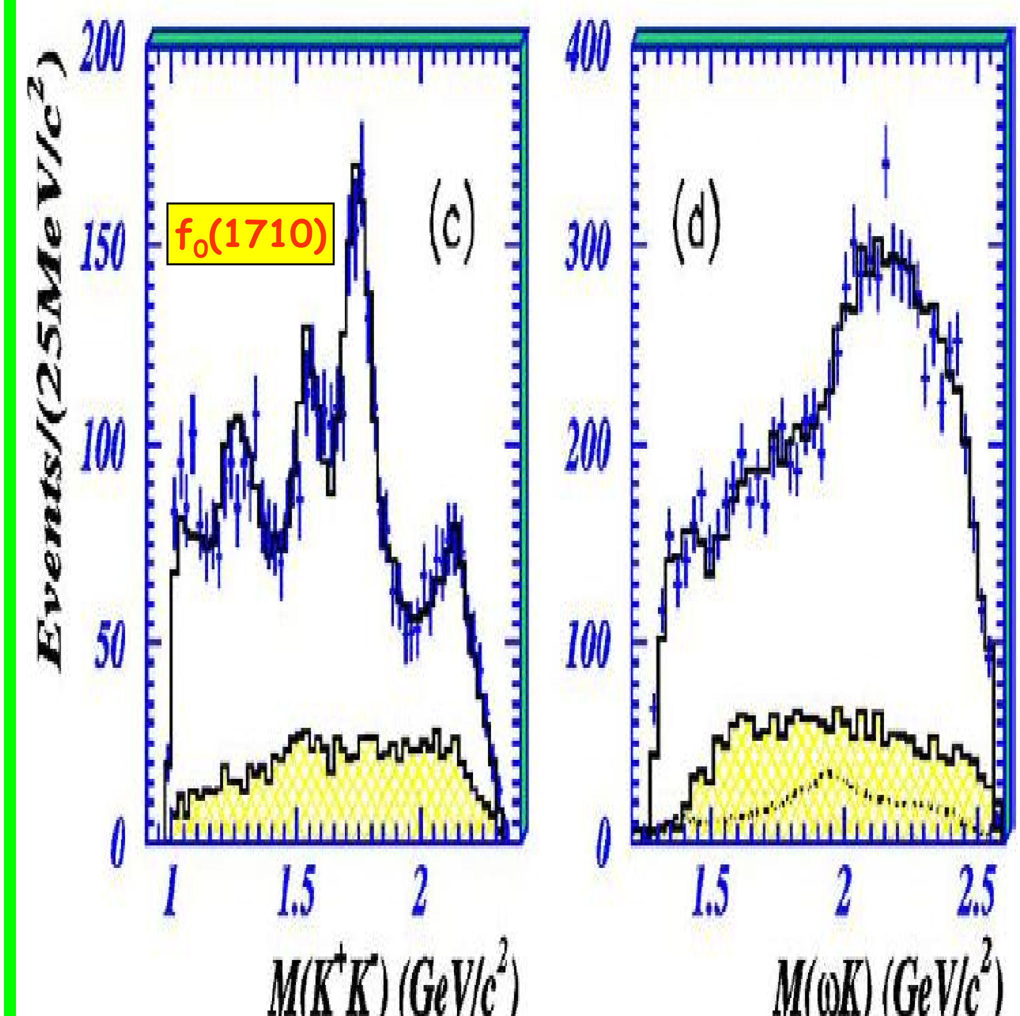
  $\to \omega f_2'(1525)$

  or $\omega f_2(1565)$

  $\to \omega f_2(2150)$

  $\to K_1(1400)K$

  $\to K_1(1950)K$



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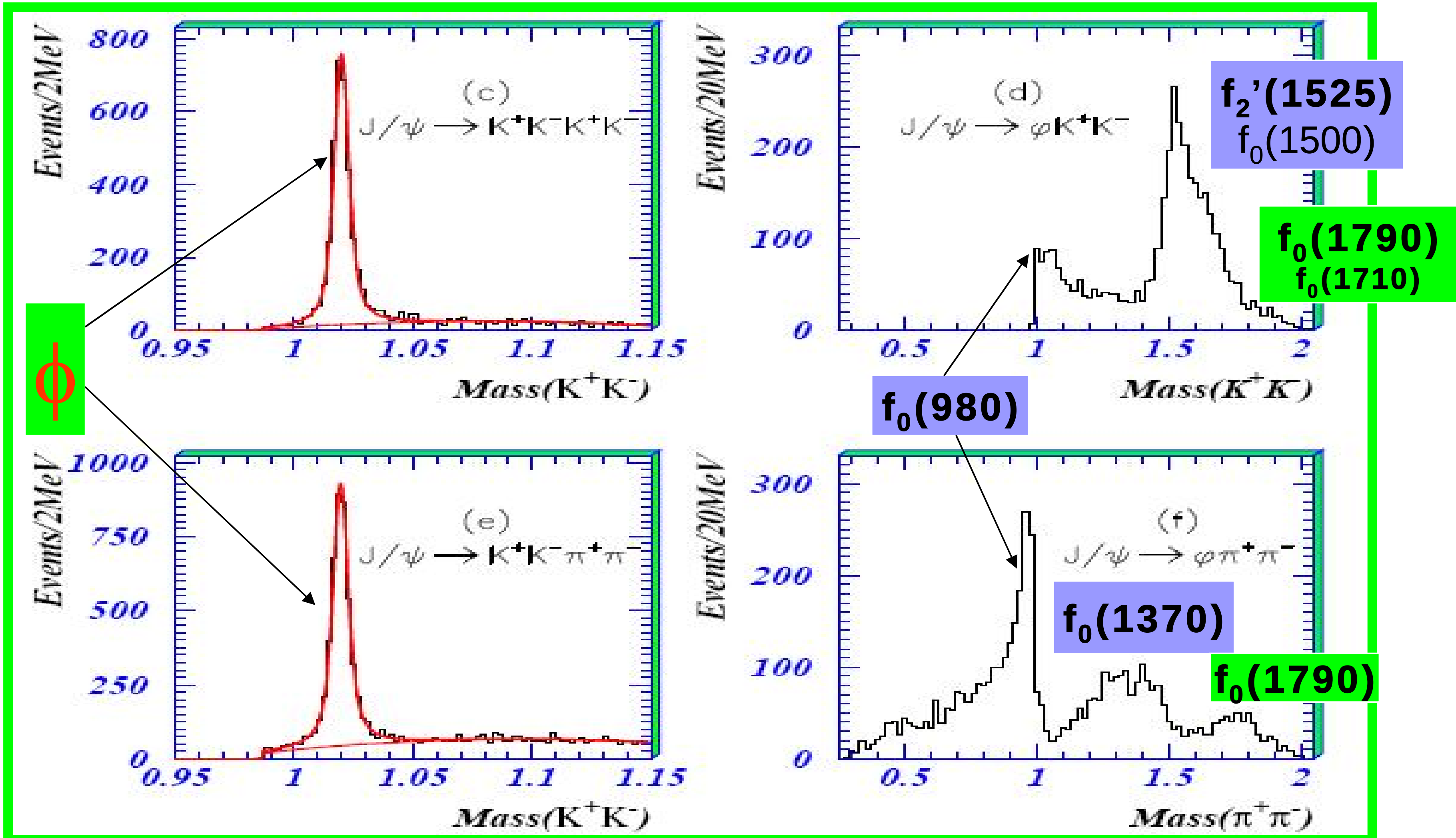
$J/\psi \to \phi\pi\pi, \phi KK$



J/ψ→φππ,φKK

PWA

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Channel	Mass (MeV/c^2)	Width (MeV/c^2)	$B(J/\psi \to \phi X, X \to \pi\pi)$ ($\times 10^{-4}$)	$B(J/\psi \to \phi X, X \to K\bar{K})$ ($\times 10^{-4}$)	ΔS
$f_0(980)$	965 ± 10	see text	5.4 ± 0.9	4.5 ± 0.8	1181
$f_0(1370)$	1350 ± 50	265 ± 40	4.3 ± 1.1	0.3 ± 0.3	83
$f_0(1500)$	PDG	PDG	1.7 ± 0.8	0.8 ± 0.5	51
$f_0(1790)$	1790^{+40}_{-30}	270^{+60}_{-30}	6.2 ± 1.4	1.6 ± 0.8	488
$f_2(1270)$	1275 ± 15	190 ± 20	2.3 ± 0.5	0.1 ± 0.1	241
σ			1.6 ± 0.6	0.2 ± 0.1	120
$f_2'(1525)$	1521 ± 5	77 ± 15	-	7.3 ± 1.1	440
$f_0(1710)$	PDG	PDG	-	2.0 ± 0.7	64

$f_0(1370)$, $f_0(1500)$, $f_0(1710)$, $f_0(1790)$

- $f_0(1370)$ has been seen in $J/\psi \to \phi\pi\pi$, but not in $J/\psi \to \omega\pi\pi$
- No peak of the $f_0(1500)$ directly seen in $J/\psi \to \phi K\bar{K}, \omega K\bar{K}, \phi\pi\pi, \omega\pi\pi$, but in proton-proton scattering is quite clear
- $f_0(1710)$ is observed in both $J/\psi \to \phi K\bar{K}$ and $J/\psi \to \omega K\bar{K}$, but with **$Br(J/\psi \to \omega f_0(1710) \to \omega K\bar{K}) / Br(J/\psi \to \phi f_0(1710) \to \phi K\bar{K}) \sim 6$**, which is against a simple $s\bar{s}$ configuration for this state
- $f_0(1790)$ which is seen in $\pi\pi$ rather than $K\bar{K}$

H. Y. CHENG hep-ph/0609229

- **f_0(1710) is composed primarily of the scalar glueball**
- **f_0(1500) is close to an SU(3) octet**

  The glueball content of f_0(1500) is very tiny because an SU(3) octet does not mix with the scalar glueball.
- **f_0(1370) consists of an approximate SU(3) singlet with some glueball component(~10%)**

Meson spectrum—Pesudoscalars(0^{-+})

- **η(1295), η(1405), η(1475)**
- η(1295): The first radial excitation of η
- η(1405): Decays mainly though $a_0(980)\pi$
  (or direct $K\bar{K}\pi$)
- η(1475): Mainly decay to $K^*(892)\bar{K}$

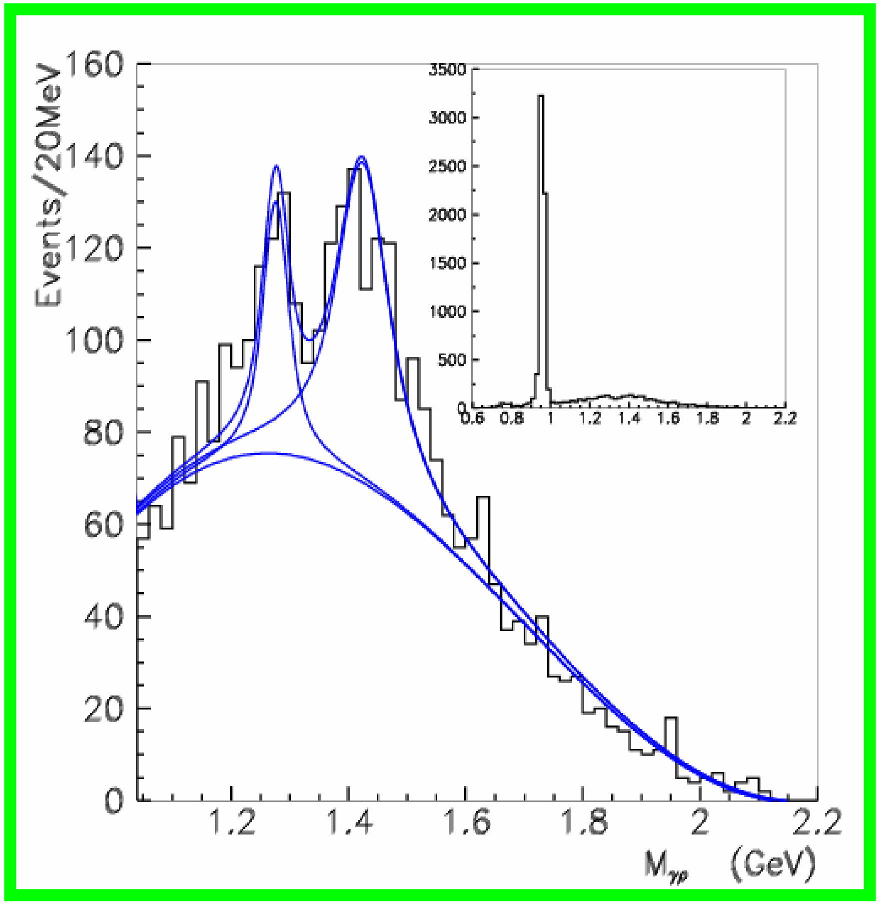
Quark Model: Only two particles needed at here

Which is the first radial excitation of η'(958)?

-- η(1475) or η(1405)?

PWA of $J/\psi \to \gamma\gamma\rho$, $\gamma\gamma\phi$, $\gamma\gamma\omega$, …

$J/\psi \to \gamma\gamma V(\rho,\phi)$



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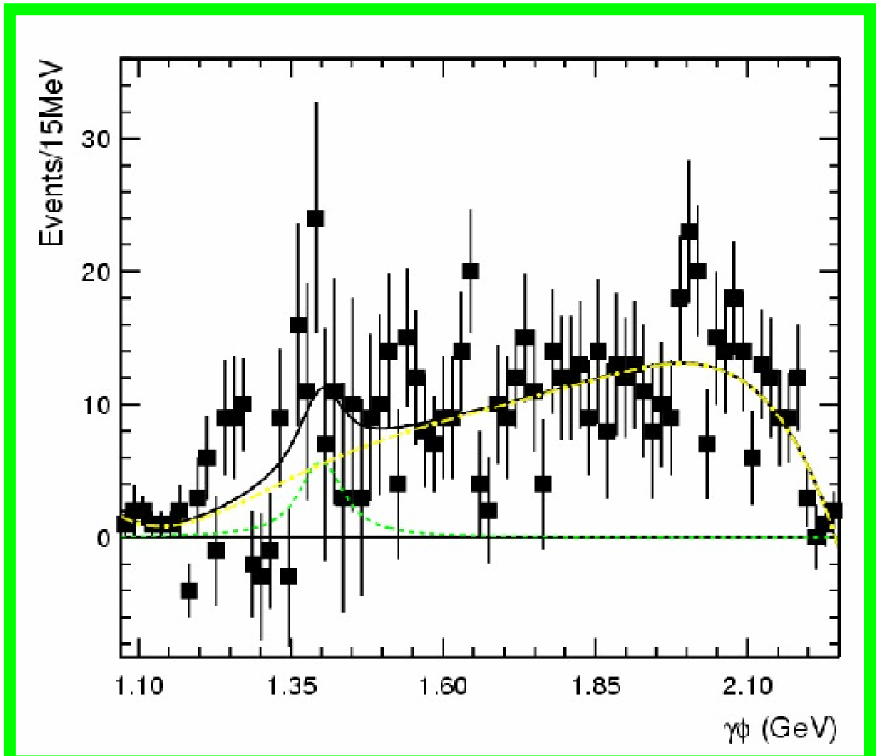
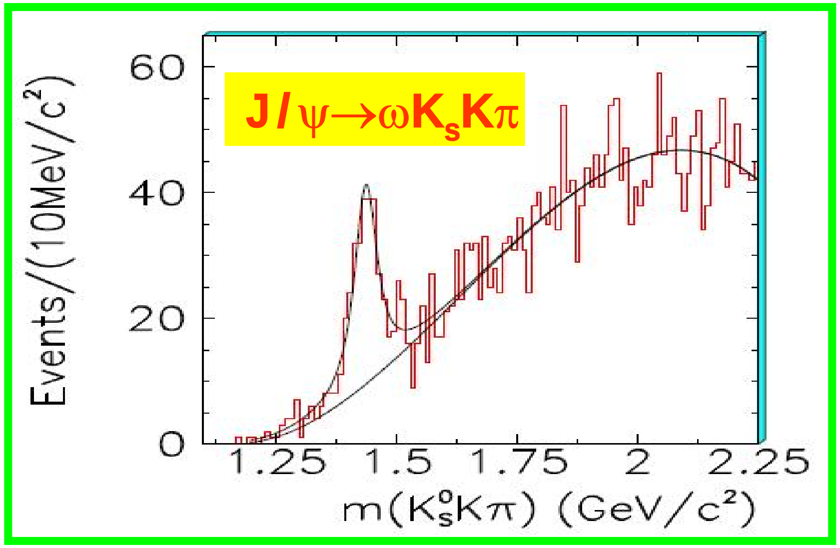


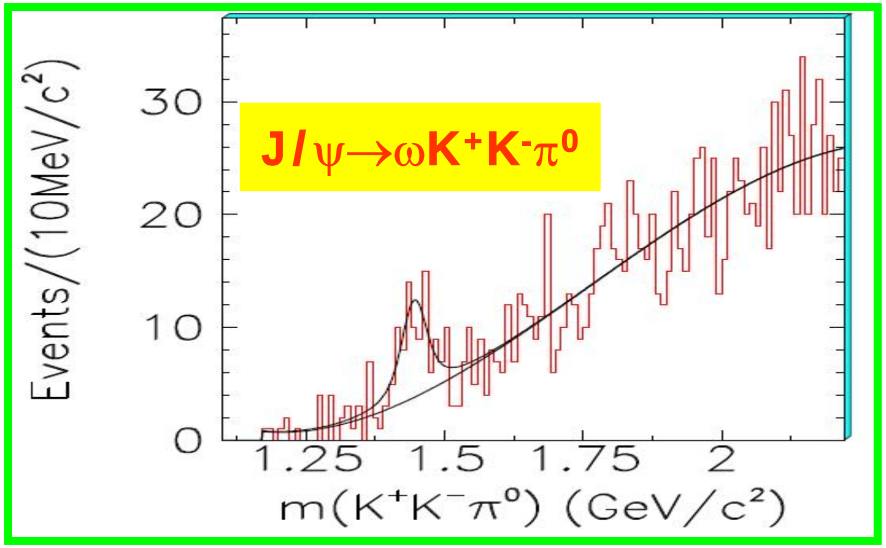
$J/\psi \to \gamma\gamma V(\rho,\phi)$

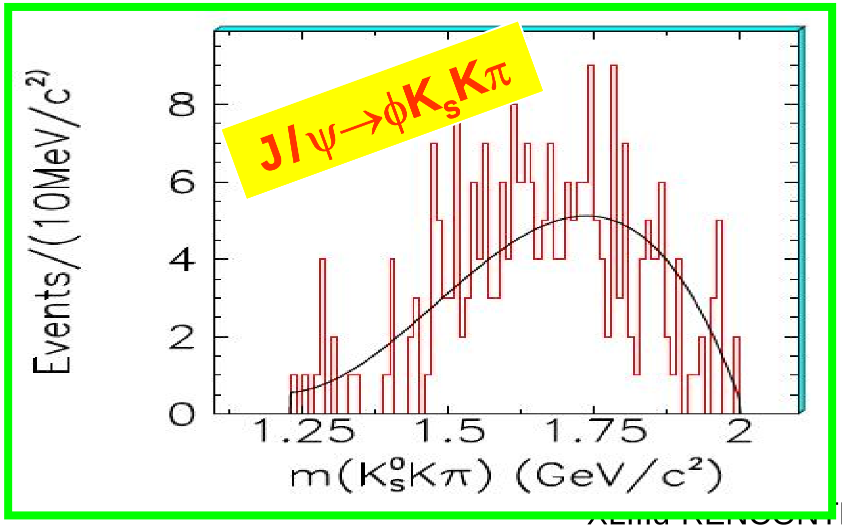
Comparison with other experiments

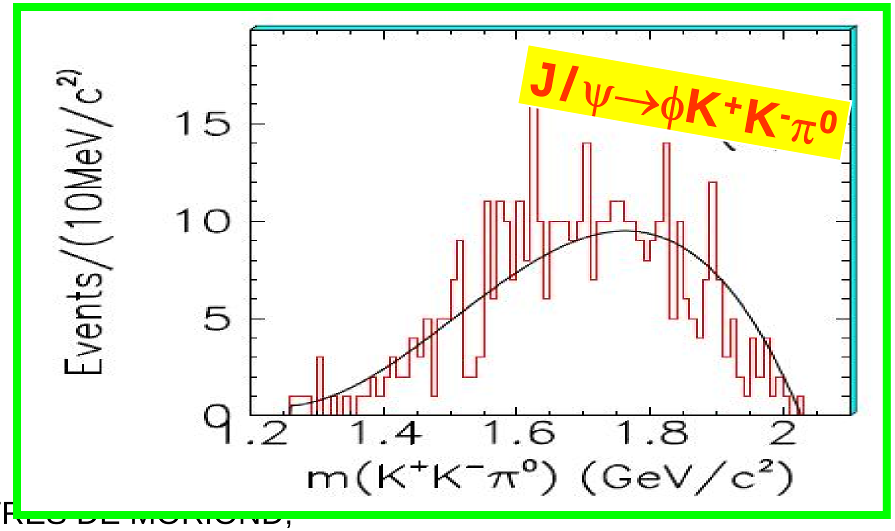
Decay Mode	Mass (MeV/c²)	Width (MeV/c²)	$B(J/\psi \to \gamma X) * B(X \to \gamma V)$ ($\times 10^{-4}$)	Experiment
$f_1(1285) \to \gamma\rho^0$	1281.9 ± 0.6	24.0 ± 1.2	0.34 ± 0.09	PDG [1]
	1271 ± 7	31 ± 14	$0.25 \pm 0.07 \pm 0.03$	MarkIII [7]
	$1276.1 \pm 8.1 \pm 8.0$	$40.0 \pm 8.6 \pm 9.3$	$0.38 \pm 0.09 \pm 0.06$	BESII
$\eta(1440) \to \gamma\rho^0$	1400-1470	50-80	$0.64 \pm 0.12 \pm 0.07$	PDG [1]
	1432 ± 8	90 ± 26	$0.64 \pm 0.12 \pm 0.07$	MarkIII [7]
	$1424 \pm 10 \pm 11$	$101.0 \pm 8.8 \pm 8.8$	$1.07 \pm 0.17 \pm 0.11$	BESII
$\eta(1440) \to \gamma\phi$			< 0.82 (95% C.L)	BESII

arXiv:0712.1411









$J/\psi \to (\omega,\phi)KK\pi$

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

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

$\eta(1440)$ ($\eta(1405)$, $\eta(1475)$)

- $\eta(1440)$ has been seen in $J/\psi \to \gamma\gamma\rho$, $\omega KK\pi$, but not clear structure around 1440 MeV in $J/\psi \to \gamma\gamma\phi$, $\phi KK\pi$

- Octet: **$s\bar{s}$** **(X)**
- Glueball : $\Gamma_{\eta\to\gamma\rho}$ **:** $\Gamma_{\eta\to\gamma\phi}$**=1 : 1** **(X)**
- Singlet-Octet Mixing: $\Gamma_{\eta\to\gamma\rho}$ **:** $\Gamma_{\eta\to\gamma\phi}$**=9 : 2** **(?)**
- Glueball-$q\bar{q}$ meson mixing: **(?)**

New Enhancements/Structures at BESII

- A narrow enhancement is observed in $J/\psi \to \gamma p\bar{p}$. Assuming that the $p\bar{p}$ system is in an S-wave resulted in a resonance with $M=1859^{+3+5}_{-10-25}$ MeV and $\Gamma<30$ MeV. The data not precise enough to determine the angular distribution.

  $Br(J/\psi \to \gamma X)Br(X \to p\bar{p})=(7.0\pm0.4)\times10^{-5}$

- According to the theoretical calculation in hep-ph/0502127(G.J Ding and M.L Yan), the branching fraction of the enhancement(baryonium resonance)decaying to $2(\pi^+\pi^-)\eta$ are much higher than other decay modes, such as $(\pi^+\pi^-)\eta$ and 3η .

- Mass and width from $J/\psi \to \gamma \pi^+\pi^-\eta'$ $(\eta' \to \pi^+\pi^-\eta)$

  $m=1827.4\pm8.1$ MeV/c^2 , $\Gamma=54.2\pm34.5$ MeV/c^2

  Mass and width from $J/\psi \to \gamma \pi^+\pi^-\eta'$ $(\eta' \to \gamma\rho)$

  $m=1836.3\pm7.9$ MeV/c^2 , $\Gamma=70.3\pm23.1$ MeV/c^2

  Combination results

  $m=1833.7\pm6.1$ MeV/c^2 , $\Gamma=67.7\pm20.3$ MeV/c^2

  $Br(J/\psi \to \gamma X)Br(X \to \pi^+\pi^-\eta')=(2.2\pm0.4)\times10^{-4}$

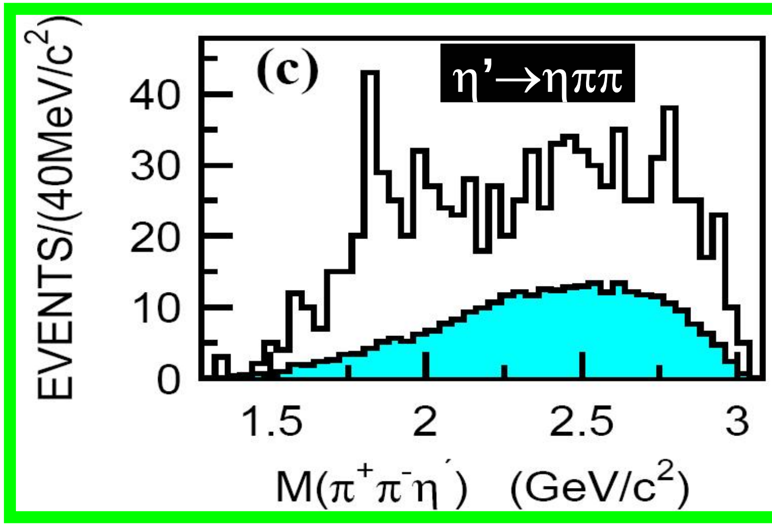
$(J/\psi \to \gamma\eta'(958)\pi\pi)$ X(1835)

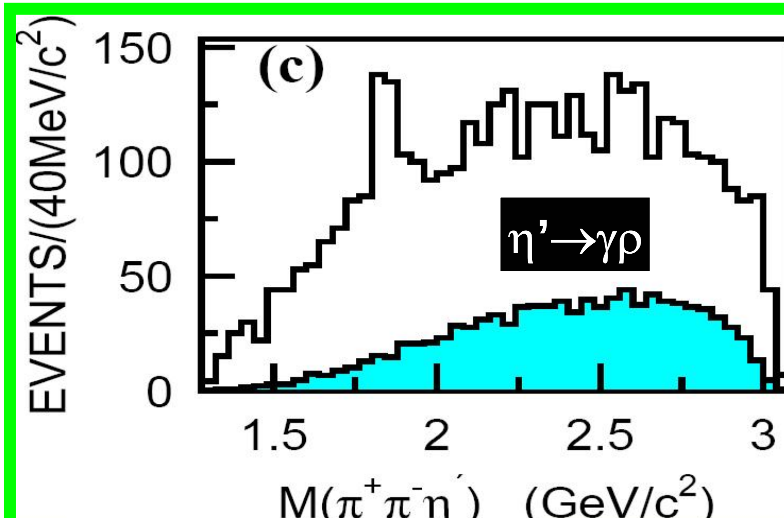
BW-fit

- $M = 1833.7 \pm 6.1 \pm 2.7$ MeV/c^2
- $\Gamma = 67.7 \pm 20.3 \pm 7.7$ MeV/c^2
- $Br(J/\psi \to \gamma X)$
  $* Br(X \to \eta'\pi^+\pi^-)$
  $= (2.2 \pm 0.4 \pm 0.4) * 10^{-4}$

$\sim 7.7\sigma$

Phys. Rev. Lett. 95 (2005) 262001





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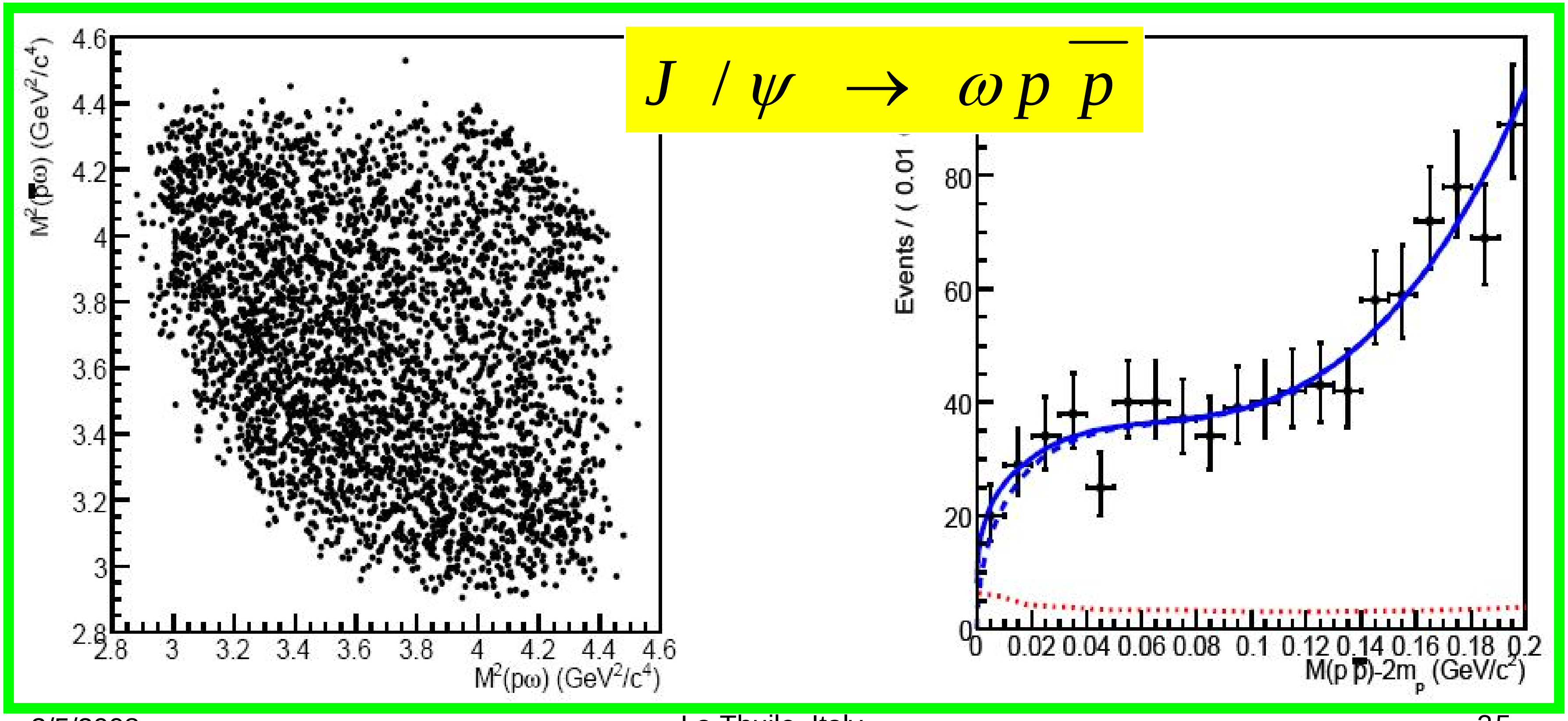
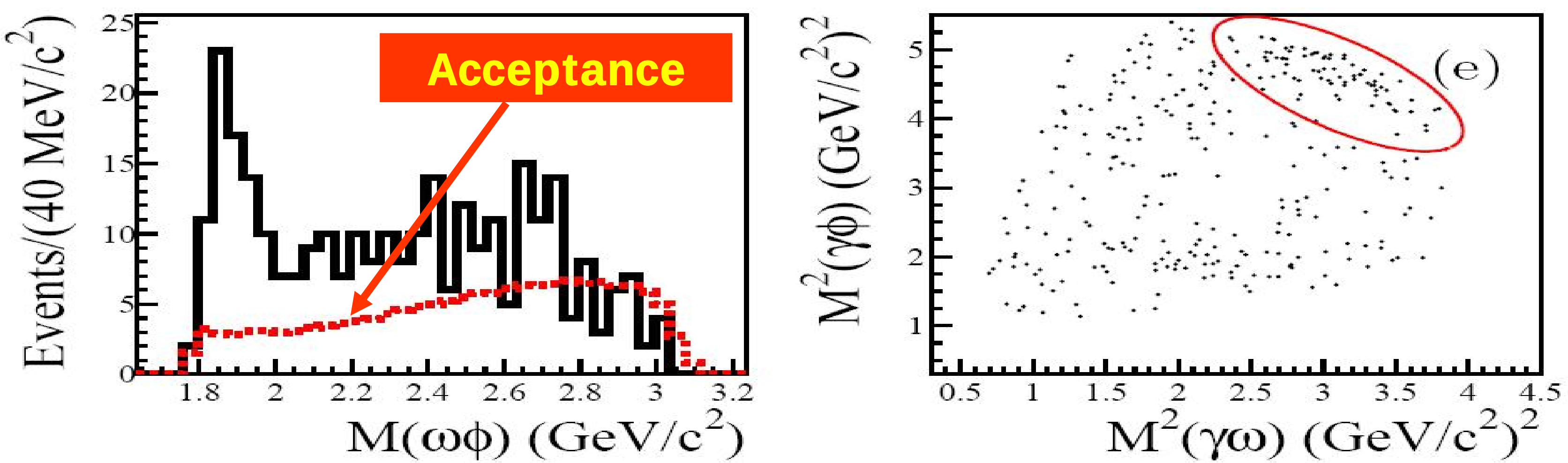
Br(J/ψ→ωX)·Br(X→pp)<1.5∗10⁻⁵ 95% C.L.



$(J/\psi \to \gamma\omega\phi)\ 0^{++}$



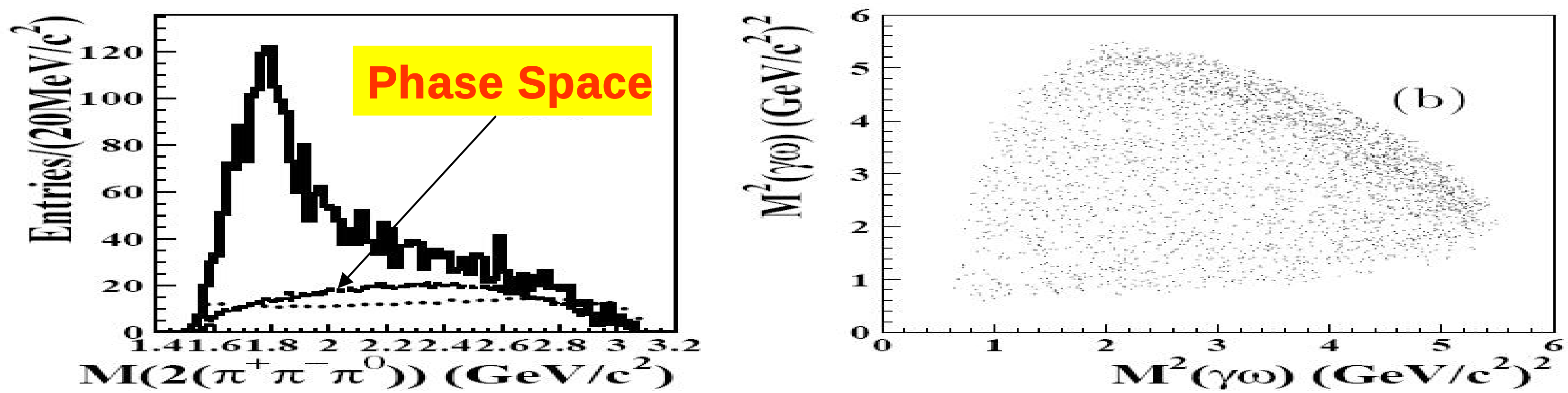
PWA: **0^{++}**

Phys. Rev. Lett. 96 (2006) 162002

- $M = 1812^{+19}_{-26} \pm 18$ MeV/c^2

  $\Gamma = 105 \pm 20 \pm 28$ MeV/c^2
- $Br(J/\psi \to \gamma X) \cdot Br(X \to \omega\phi) = (2.61 \pm 0.27 \pm 0.65) * 10^{-4}$

$(J/\psi \to \gamma\omega\omega)$ 0^{-+}



Phys. Rev. D73 (2006) 112007

PWA

resonance	Events	eff(%)	$Br(\times 10^{-3})$	Sys Err(%)	ΔS	Sig.
$\eta(1760)$	1045 ± 41	1.15	1.98 ± 0.08	16.4	280	$> 10\sigma$
$f_0(1710)$	180 ± 37	1.27	0.31 ± 0.06	25.1	23.5	6.5σ
$f_2(1910)$	151 ± 32	1.68	0.20 ± 0.04	64.9	23.5	5.8σ
$f_2(1640)$	141 ± 26	1.08	0.28 ± 0.05	59.6	21.4	5.5σ

$M = 1744 \pm 10 \pm 15$ MeV/c^2

$\Gamma = 244^{+24}_{-21} \pm 25$ MeV/c^2

Observation of a new 1^{--} resonance 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

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

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

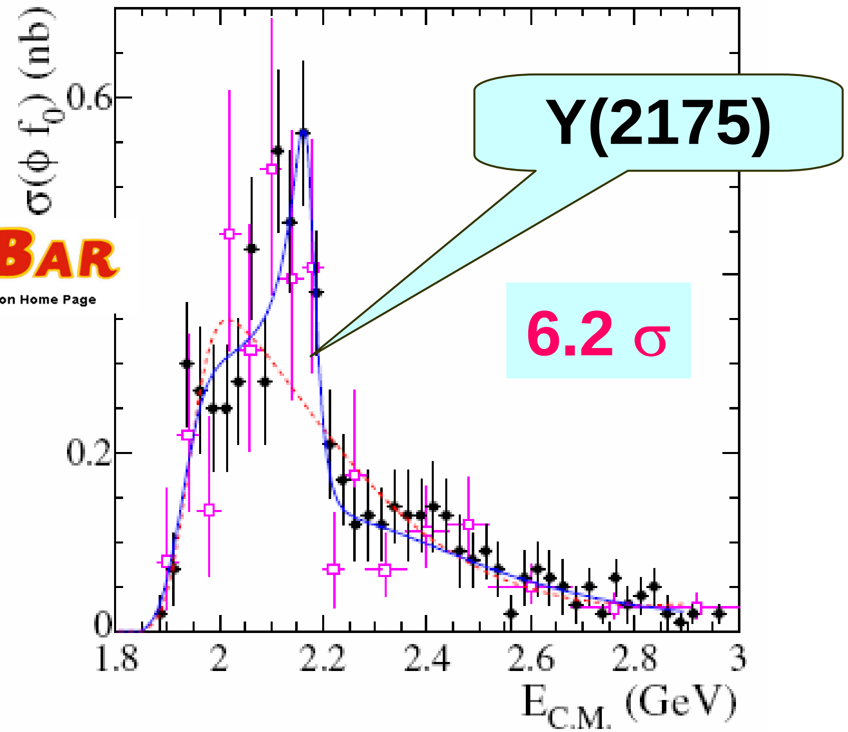
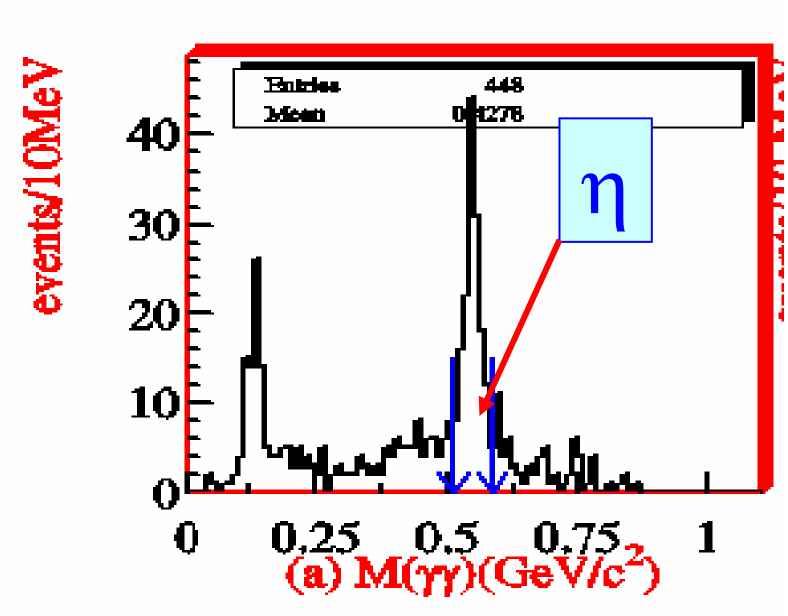
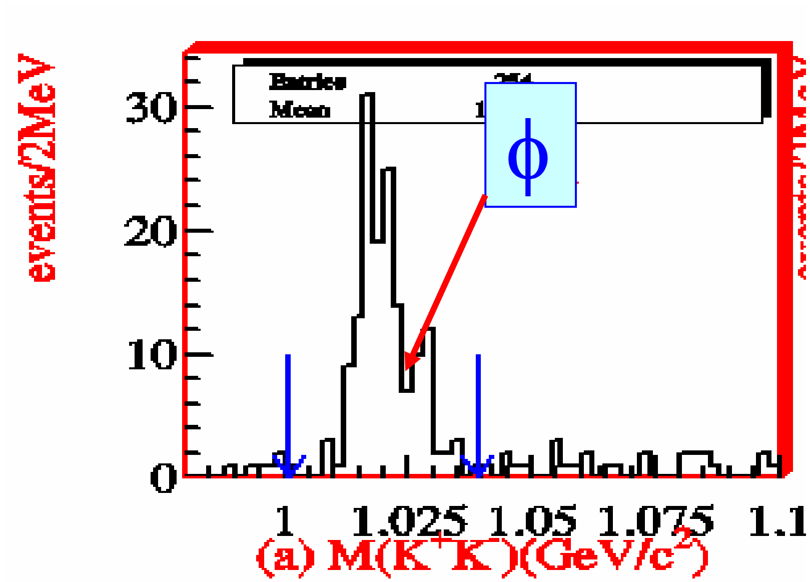


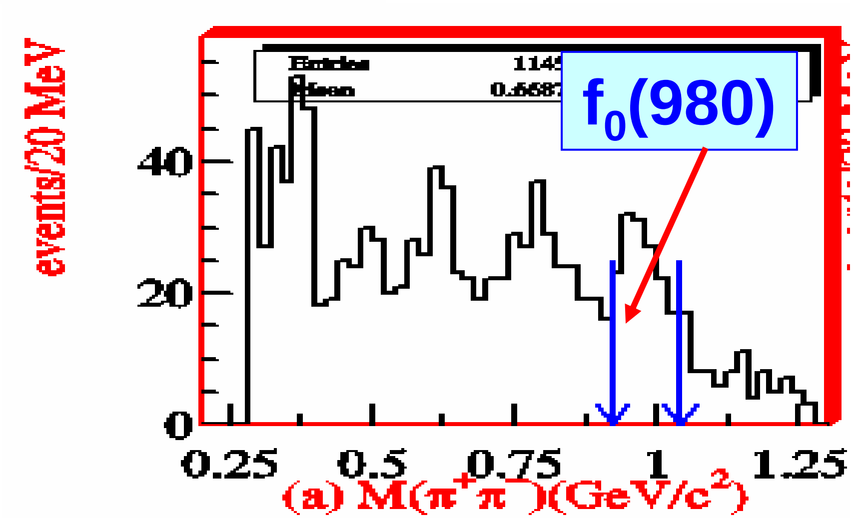
FIG. 6 (color online). The $e^+e^- \to \phi(1020) f_0(980)$ cross section, with about 10% of the $\phi\pi\pi$ contribution, obtained via ISR in the $K^+K^-\pi^+\pi^-$ (circles) and $K^+K^-\pi^0\pi^0$ (squares) final states. The curves represent results of the fits described in the text.

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

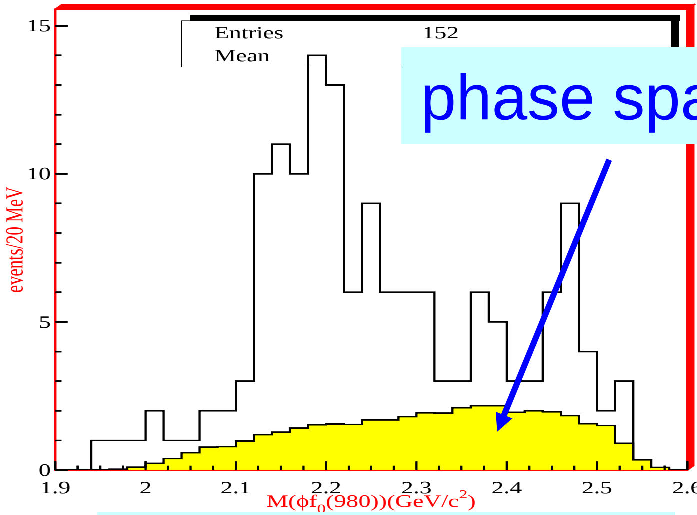
$J/\psi \rightarrow \eta\phi f_0(980)$ (BESII)



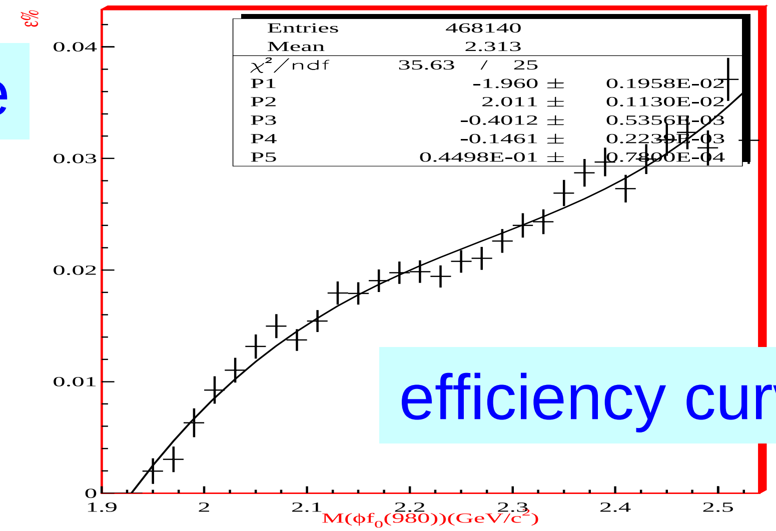


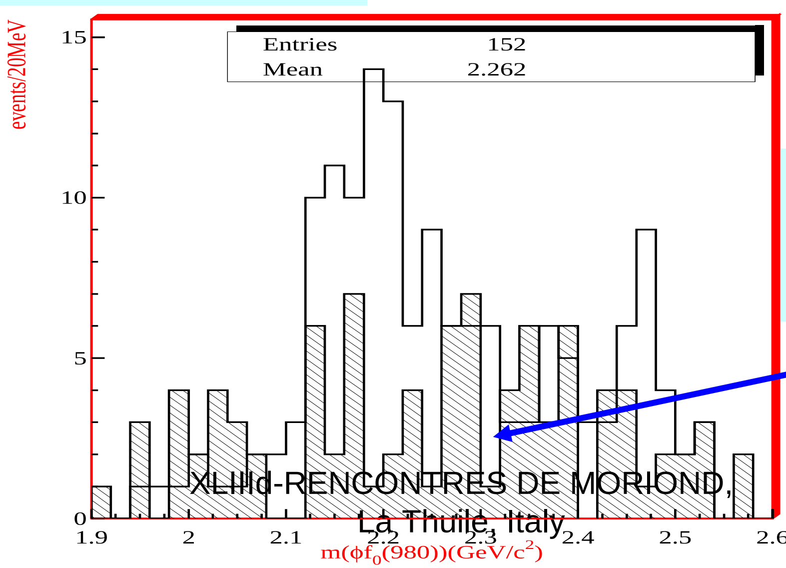


A peak around 2175 MeV/c^2 is observed in $J/\psi \rightarrow \eta\phi f_0(980)$



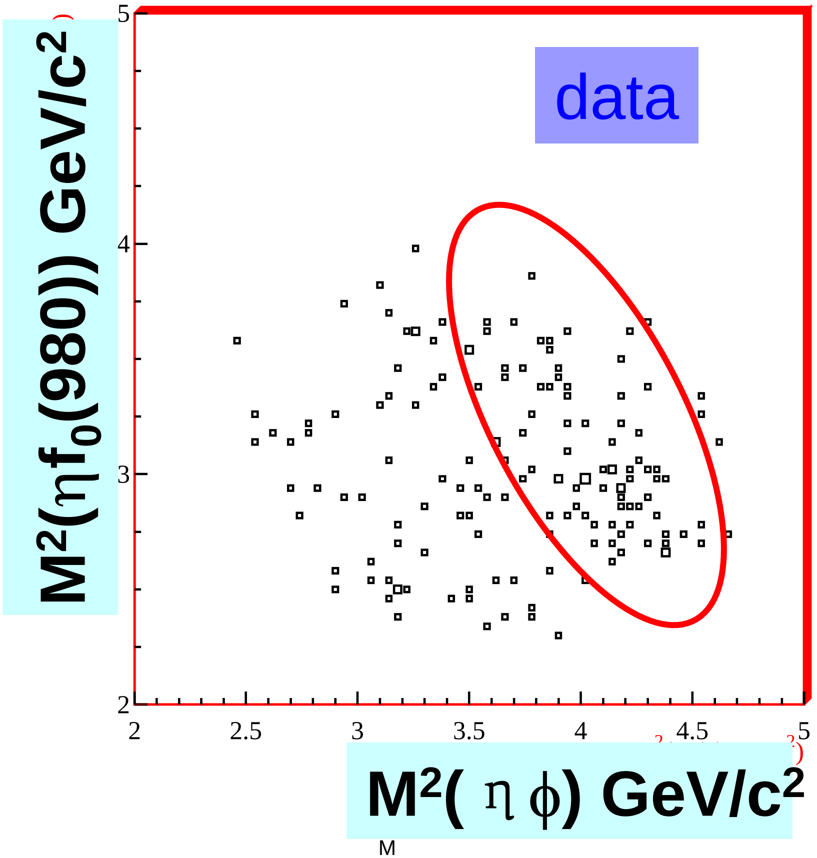
$M(\phi f_0(980))$ GeV/c^2

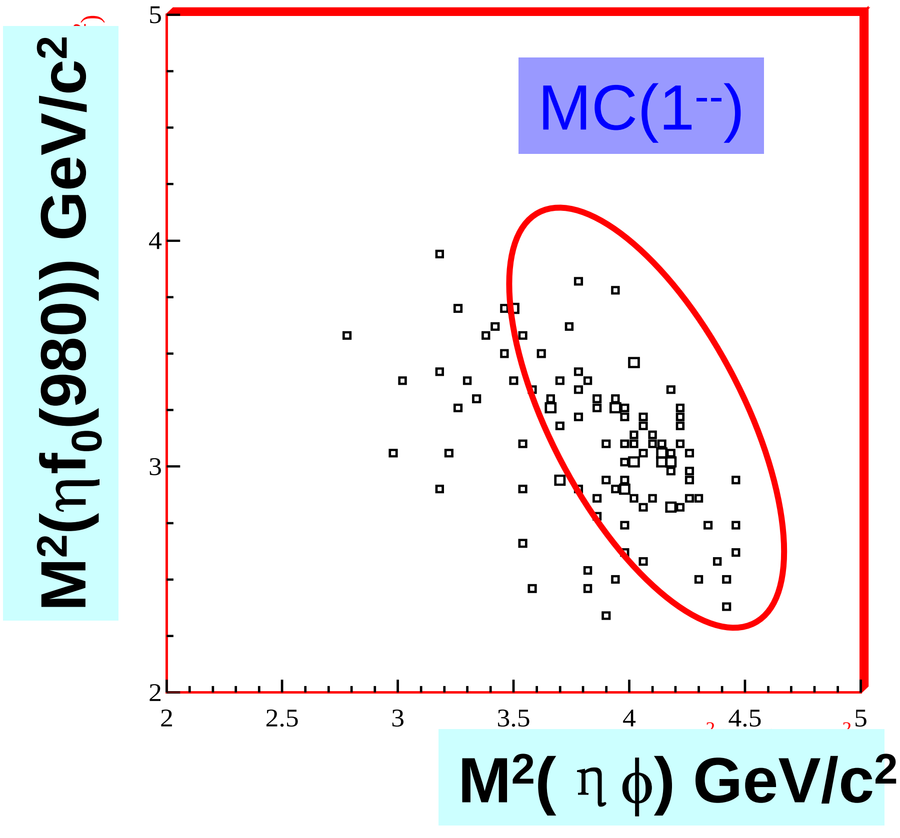




Backgrounds from sideband estimation

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



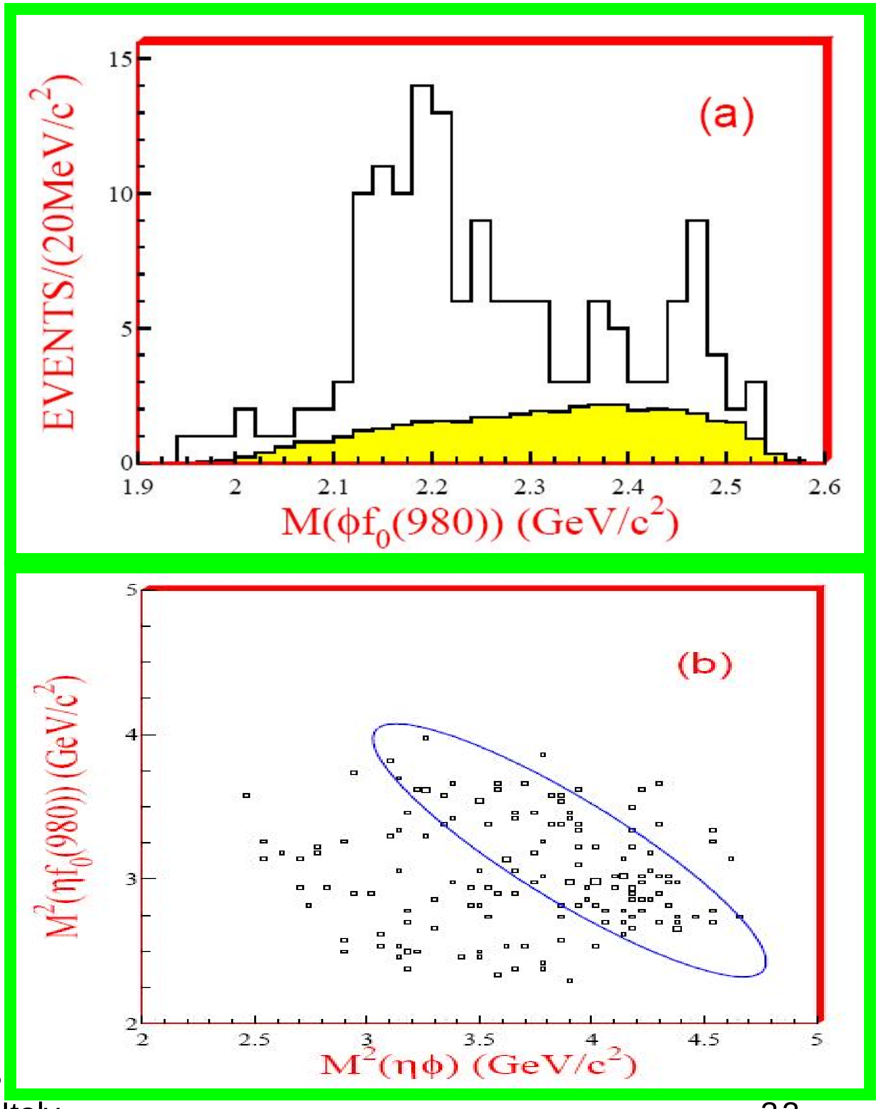


$(J/\psi \to \eta\phi f_0(980))\ 1^{--}$

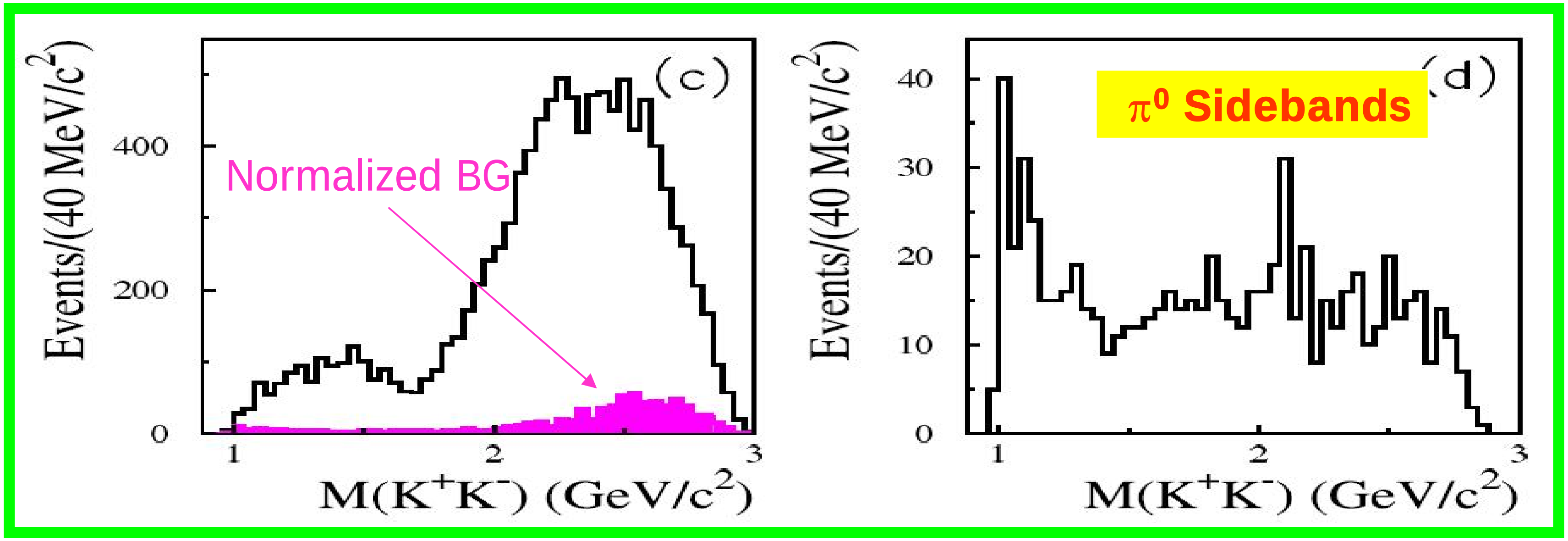
- $M = 2.186 \pm 0.010 \pm 0.006$ **GeV/c²**
  $\Gamma = 0.065 \pm 0.023 \pm 0.017$ **GeV/c²**
- $Br(J/\psi \to \eta Y(2175))$
  $\cdot Br(Y \to \phi f_0(980))$
  $\cdot Br(f_0 \to \pi^+\pi^-)$
  $= (3.23 \pm 0.75 \pm 0.73) * 10^{-4}$

~5σ

arXiv:0712.1143



$(J/\psi \to K^+K^-\pi^0)\ 1^{--}$



PWA: 1^{--}

- **Pole position:** $(1576^{+49+98}_{-55-91})\ \mathrm{MeV}/c^2 - i(409^{+11+32}_{-12-67})\ \mathrm{MeV}/c^2$
- **$Br(J/\psi \to X\pi^0) \cdot Br(X \to K^+K^-) = (8.5 \pm 0.6^{+2.7}_{-3.6}) * 10^{-4}$**

~7.2σ

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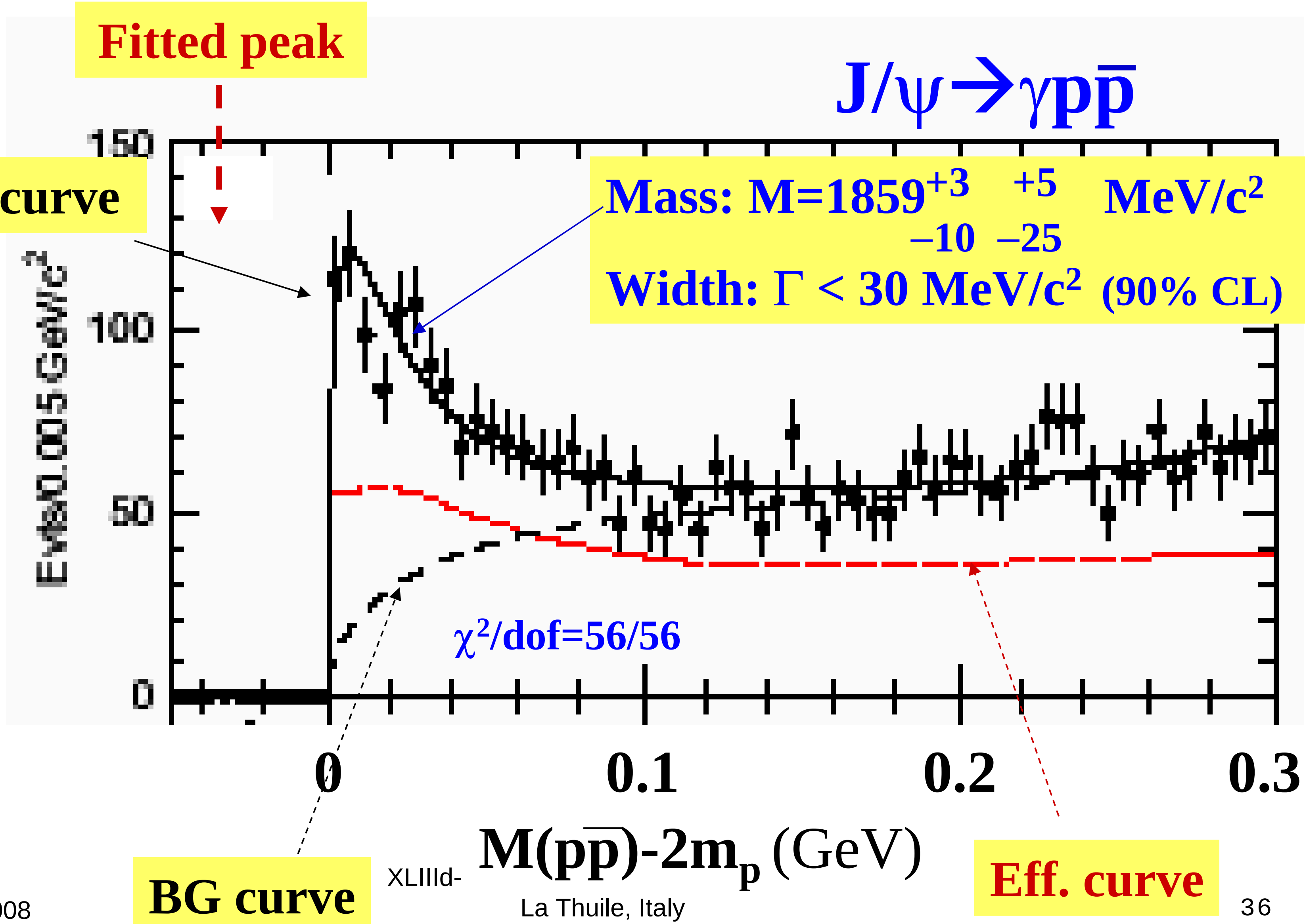
Summary

- Many Hadrons:
  $f_0(1370)$, $f_0(1790)$, $\eta(1440)(\eta(1405),\eta(1475))$, …
- Glueball Candidates
  $f_0(1500)$ in $J/\psi\to\gamma\pi^+\pi^-$, $\gamma\pi^0\pi^0$
  $f_0(1710)$ in $J/\psi\to\gamma K^+K^-$, γK_sK_s, ωK^+K^-
- New enhancements/structures
  $x(1835)(0^{-+})$ in $J/\psi\to\gamma(\pi\pi\eta')$ $(\eta'\to\eta\pi\pi, \gamma\rho)$ 7.7σ
  $x(1859)(0^{-+})$ in $J/\psi\to\gamma(p\bar{p})$
  $x(1760)(0^{-+})$ in $J/\psi\to\gamma(\omega\omega)$ $>10\sigma$
  $x(1810)(0^{++})$ in $J/\psi\to\gamma(\omega\phi)$ $>10\sigma$
  $x(1576)(1^{--})$ in $J/\psi\to\pi^0(K^+K^-)$ 7.2σ
  $y(2175)(1^{--})$ in $J/\psi\to\eta(\phi f_0(980))$ 5.0σ

Thank you!

Fit reults



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BESIII/BEPCII project

BEPCII design goal:

luminosity: 1×10^{33} @ 1.89 GeV

BESIII design goal:

MDC: Momentum resolution: $\frac{\sigma_{P_t}}{P_t} = 0.32\% \oplus 0.37\%$

dE/dX resolution: 6-7%

EMC : CsI(Tl) crystals

Energy resolution: 2.5%@1GeV

Position resolution: 6mm@1GeV

Sub-system	BESIII	BESII
MDC	$\sigma_{xy} = 130\ \mu m$	$250\ \mu m$
	$\Delta P/P = 0.5\%$ @ 1GeV SC magnet	2.4%@1GeV
	$\sigma_{dE/dx} = (6\text{-}7)\ \%$	8.5%
EM Calorimeter	$\Delta E/E = 2.5\%$ @ 1 GeV $\sigma_z = 0.6cm$ @ 1 GeV	20%@1GeV 3cm @ 1 GeV
TOF detector	$\sigma_T(ps)=100$ ps barrel 110 ps endcap	180 ps barrel 350 ps endcap
μ counters	9 layers	3 layers
Magnet	1.0 tesla	0.4 tesla