J/ψ Radiative Decays

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Outline

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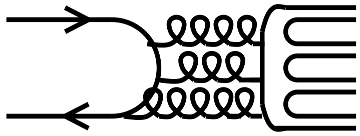
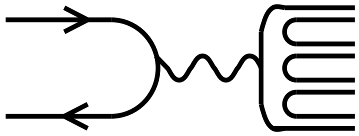
- **Previous results on J/ψ radiative decays**
- **Preliminary results from BESII**
  - **Partial Wave Analyses results**
  - **measurement of η_c**
  - **search for interesting states**
- **Summary**

Introduction

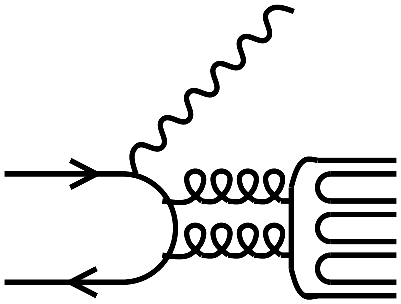
1. J/ψ Radiative Decays



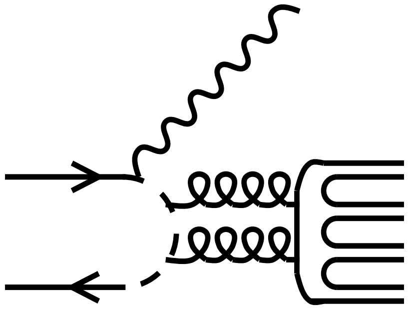
(a) Hadronic decay.



(b) Electromagnetic decay.



(c) Radiative decay.

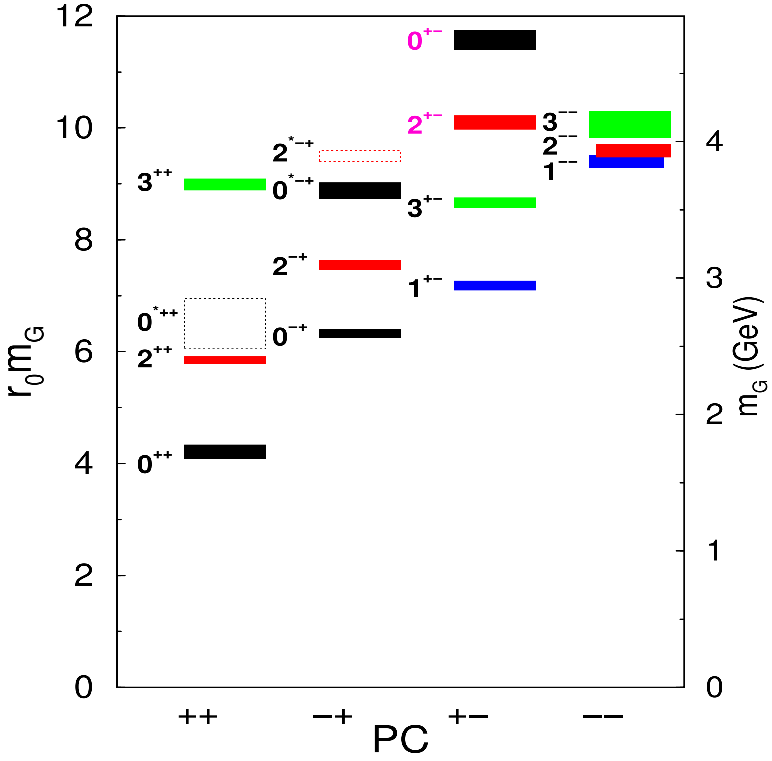


(d) Via η_c

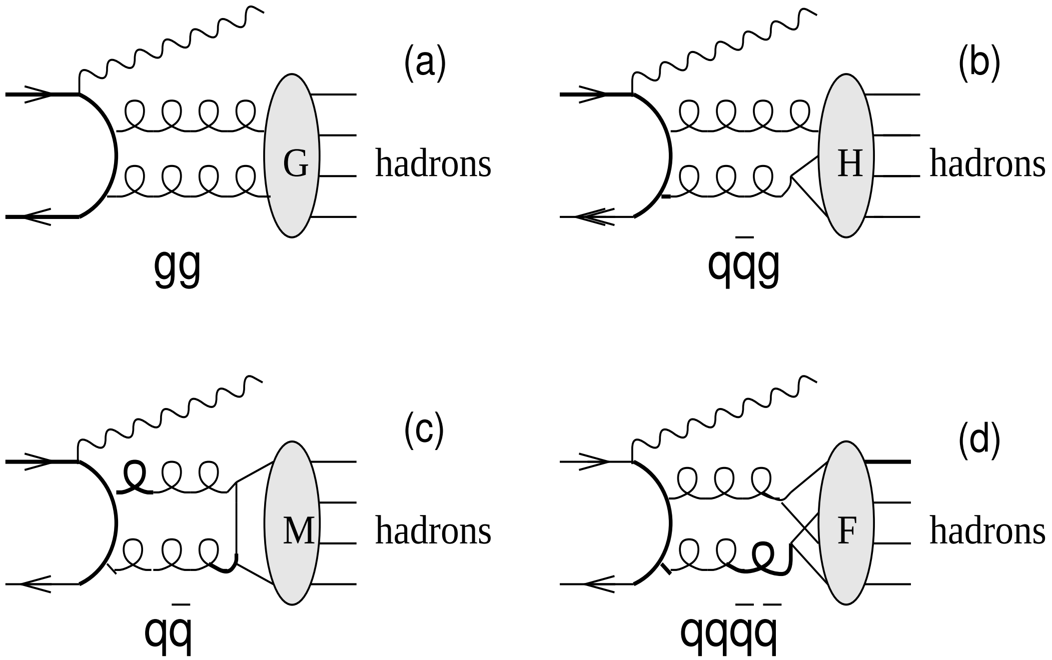
$$Br(J/\psi \to \gamma gg) = (6 \pm 2)\%$$

- **Based on non-Abelian gauge field theory, QCD is considered as a theory to describe the strong interaction.**
- **QCD predicts the existence of new types of hadrons – glueball, hybrid.**
- **Lattice QCD: the ground scalar glueball in 1.5-1.7 GeV; the 2^{++} around 2.3 GeV**
- **J/ψ decay is a good lab. for the study of hadronic spectroscopy, glueball and hybrid search.**

Glueball spectrum from LQCD:



C.Morningstar and M.Peardon, PR D60(1999)



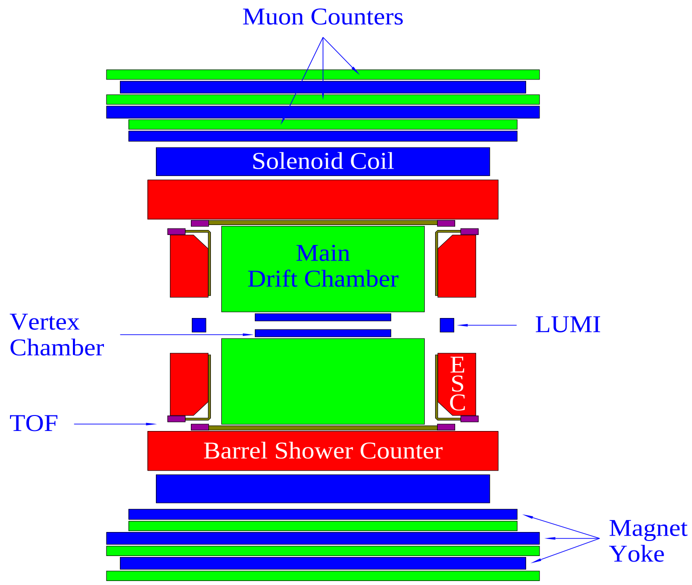
$$\Gamma(J/\psi \to \gamma G) \sim O(\alpha\alpha_s^2), \quad \Gamma(J/\psi \to \gamma H) \sim O(\alpha\alpha_s^3)$$

$$\Gamma(J/\psi \to \gamma M) \sim O(\alpha\alpha_s^4), \quad \Gamma(J/\psi \to \gamma F) \sim O(\alpha\alpha_s^4)$$

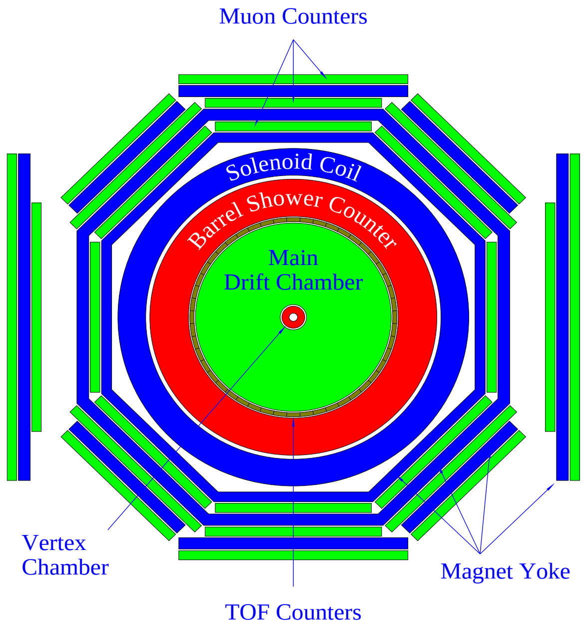
Glueballs have enhanced production in J/ψ radiative decays.

2. about BES

- **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** $5 \times 10^{30} cm^{-2} s^{-1}$



Side view of the BES detector



End view of the BES detector

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

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

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

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

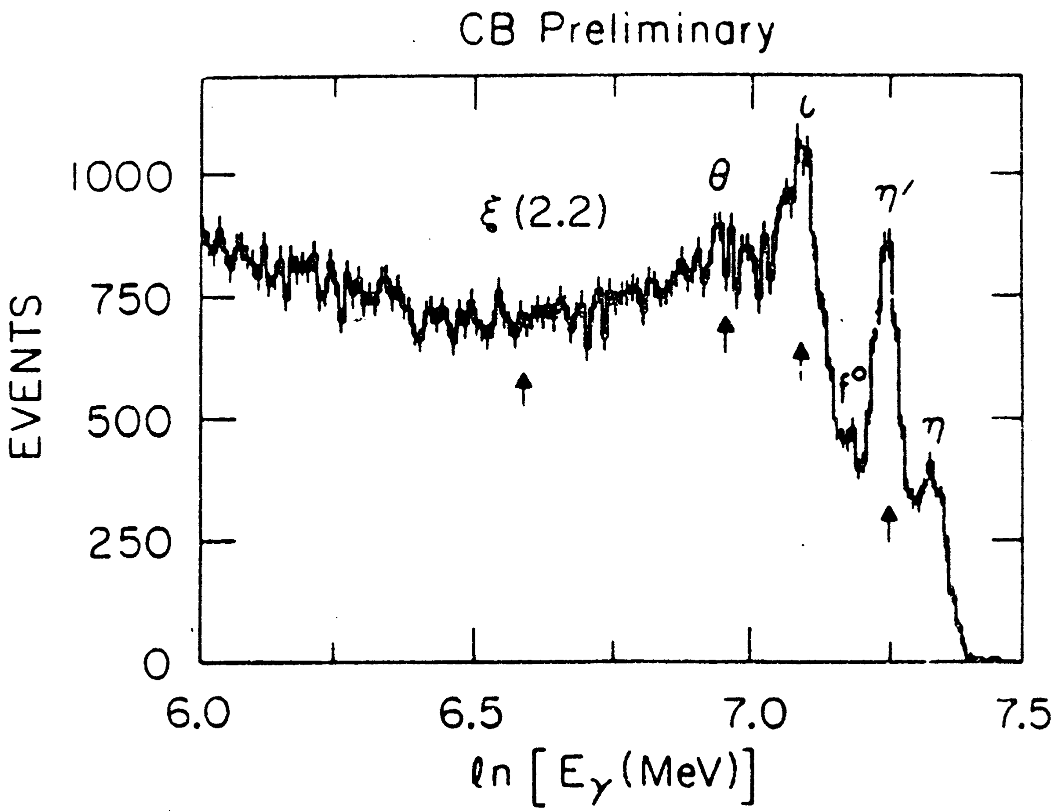
Data Collected with BES I and BES II

Detector	E_{CM}(GeV)	Physics	Data Sample
BES I	3.097 3.686 4.03 3.55, m_τ scan	J/ψ $\psi(2S)$ D_S, D m_τ	7.8×10^6 3.96×10^6 $22.3pb^{-1}$ $5pb^{-1}$
BES II	2-5 GeV R scan $\psi(2S)$ scan 3.097 ψ'' scan 3.686	R, α_{QED}, g-2 res. para. J/ψ res. para. $\psi(2S)$	6+85 points 24 points 57×10^6 $\sim 2.2pb^{-1}$ $\sim 14 \times 10^6$

Previous Results on J/ψ Radiative Decays

- the inclusive photon spectrum
- the M1 - transition $J/\psi \to \gamma\eta_c$
- radiative production of $q\bar{q}$ mesons
- search for glueballs and new resonances

1. Inclusive photon spectrum from Crystal Ball

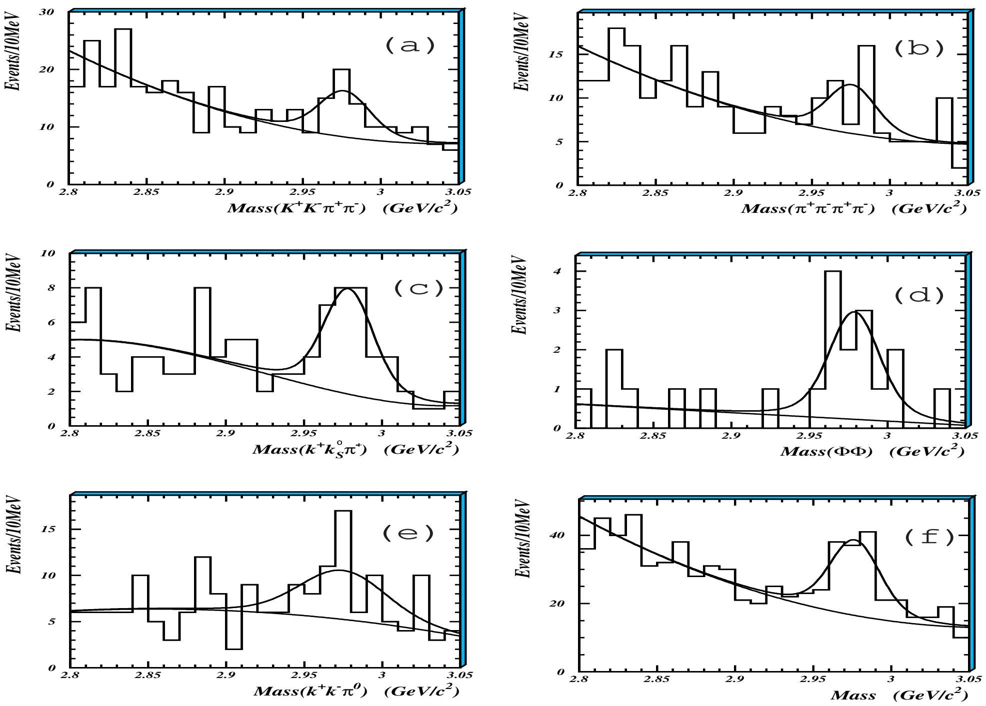


2. M1 - transition $J/\psi \to \gamma\eta_c$

Process	Exp.	Mass (MeV)	Width (MeV)
e^+e^-	**MRK2(80)**	2982 ± 8	
$J/\psi, \psi' \to \gamma X$	**CBAL(86)**	$2984 \pm 2 \pm 4$	11.5 ± 4.5
$J/\psi \to \gamma\eta_c$	**MRK3(86)**	2980.2 ± 1.6	
$J/\psi \to \gamma p\bar{p}$	**MRK3(86)**		$10.1^{+37.0}_{-8.2}$
$p\bar{p} \to \gamma\gamma$	**SPEC(87)**	$2982.6^{+2.7}_{-2.3}$	$7.0^{+7.5}_{-7.0}$
$J/\psi \to \gamma 4K$	**MRK3(90)**	$2969 \pm 4 \pm 4$	
$J/\psi \to \gamma\eta_c$	**DM2(91)**	2974.4 ± 1.9	
$p\bar{p} \to \gamma\gamma$	**E760(92)**	$2988.3^{+3.3}_{-3.1}$	$23.9^{+12.6}_{-7.1}$
e^+e^-	**DLPH(98)**	2999 ± 8	
$\psi' \to \gamma\eta_c$	**BES(99)**	$2975.8 \pm 3.9 \pm 1.2$	
PDG2000		2979.8 ± 1.8	$13.2^{+3.8}_{-3.2}$

BES I(2000) $J/\psi \to \gamma\eta_c$

$\eta_c \to K^+K^-\pi^+\pi^-$, 4π, $K\overline{K}\pi$ **and** $\phi\phi$.



$$M = 2976.3 \pm 2.3 \pm 1.2 \text{ MeV}$$

$$\Gamma = 11.0 \pm 8.1 \pm 4.1 \text{ MeV}$$

3. Radiative production of $q\bar{q}$ mesons

- $J/\psi \to \gamma$ + **Pseudoscalar** (π^0, η **and** η')

$$\eta(547) = \eta_8 \cos\theta_P - \eta_1 \sin\theta_P$$

$$\eta'(958) = \eta_8 \sin\theta_P + \eta_1 \cos\theta_P$$

A study of $\eta - \eta'$ system is important in:

– **understanding the large production of η' in J/ψ radiative decays**

– **not ideally mixing of $\eta - \eta'$**

The decays $J/\psi \to \gamma\eta$ and $\gamma\eta'$ have been measured by DASP, MARKII, MARKIII, Crystal Ball, DM2 and BESI.

- $J/\psi \to \gamma$ + **Tensor**
  $f_2(1270)$, $f_2'(1525)$ ... in $\pi\pi$, $K\overline{K}$....
- $J/\psi \to \gamma$ + **Scalar**
  $f_0(980)$, $f_0(1370)$ ...
- $J/\psi \to \gamma$ + **Axialvector**
  $f_1(1285)$, $f_1(1530)$ in $\eta\pi\pi$, $K\overline{K}\pi$ ...

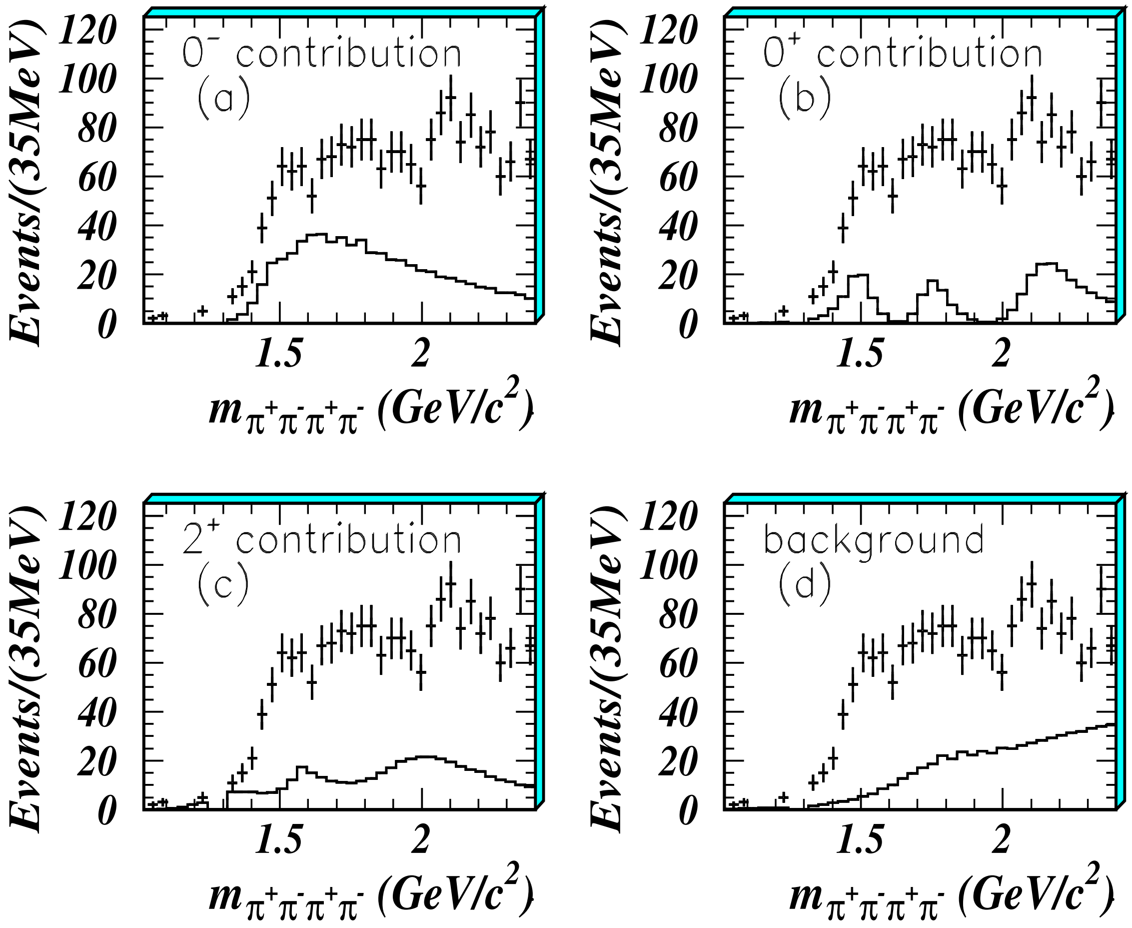
The resonance parameters, decay branching ratios and polarization parameters were measured.

4. Search for glueballs and new resonances

$f_0(1500)$

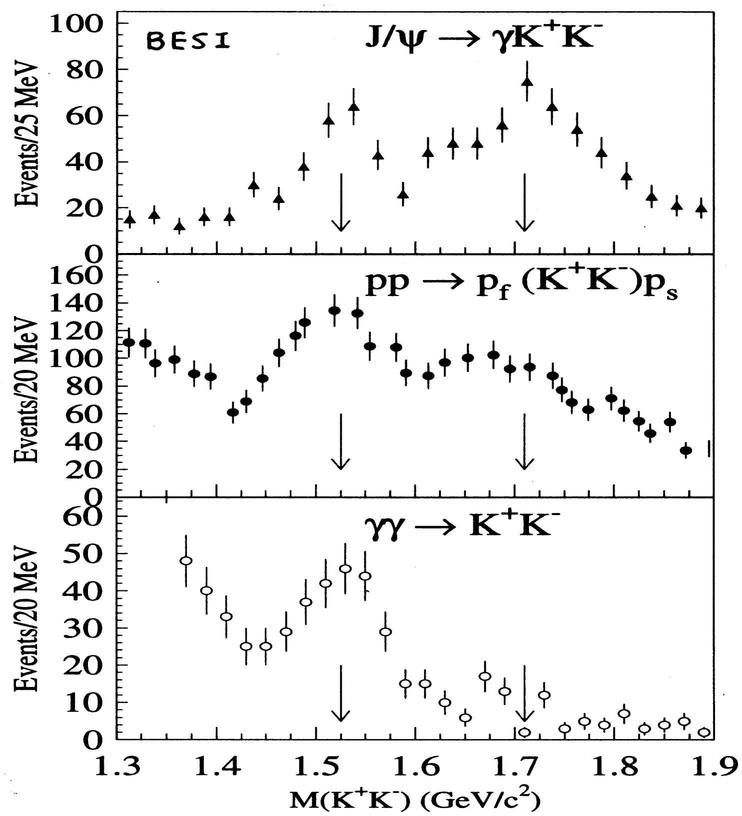
- **Most of the $f_0(1500)$ data is from Crystal Barrel $p\bar{p}$ annihilation at rest experiment.**
- **OBELIX observed $f_0(1500)$ in $\bar{n}p \to \pi^+\pi^+\pi^-$.**
- **WA91 and WA102 observed $f_0(1500)$ in $pp \to p_f(\pi^+\pi^-)p_s$ and $pp \to p_f(\pi^+\pi^-\pi^+\pi^-)p_s$.**
- **Re-analysis of MARKIII $J/\psi \to \gamma\pi^+\pi^-\pi^+\pi^-$ data by D. Bugg gave the 0^{++} at the mass of 1.5 GeV (95).**
- **BESI data on $J/\psi \to \gamma 4\pi$ confirmed the 0^{++} at the mass of 1.5 GeV (2000).**

$J/\psi \to \gamma\pi^+\pi^-\pi^+\pi^-$ from BESI 7.8×10^6 events



$f_0(1710)$

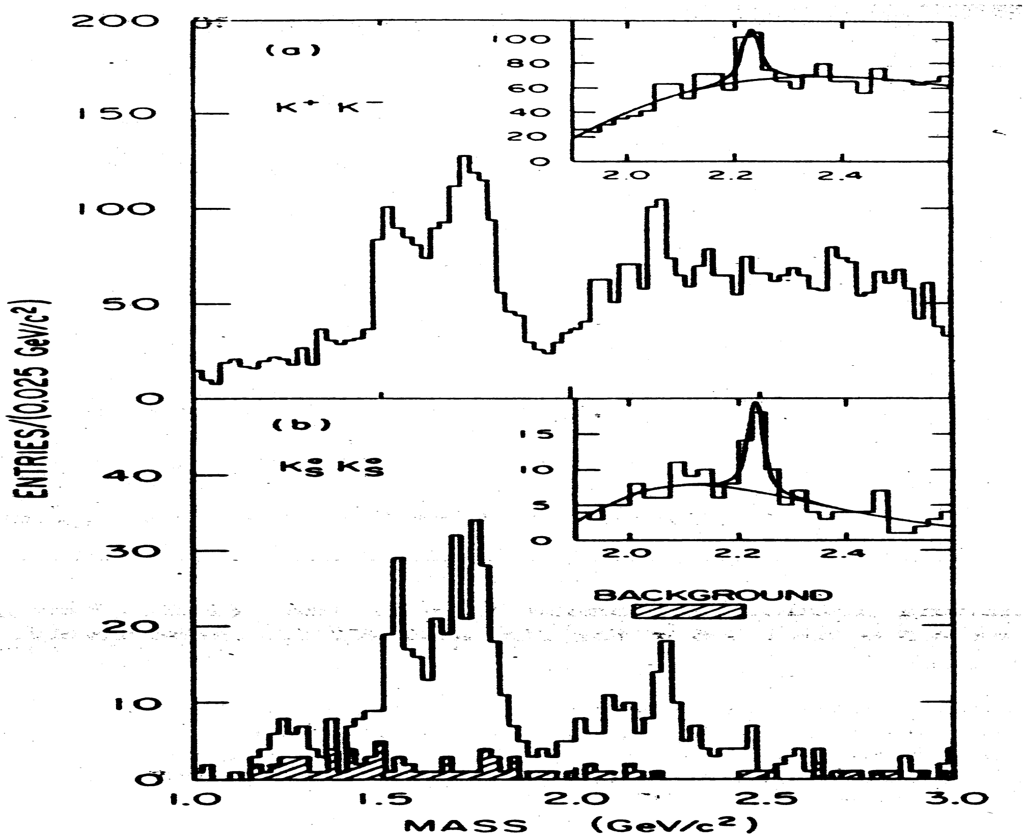
long history of uncertainty on $f_0(1710)$



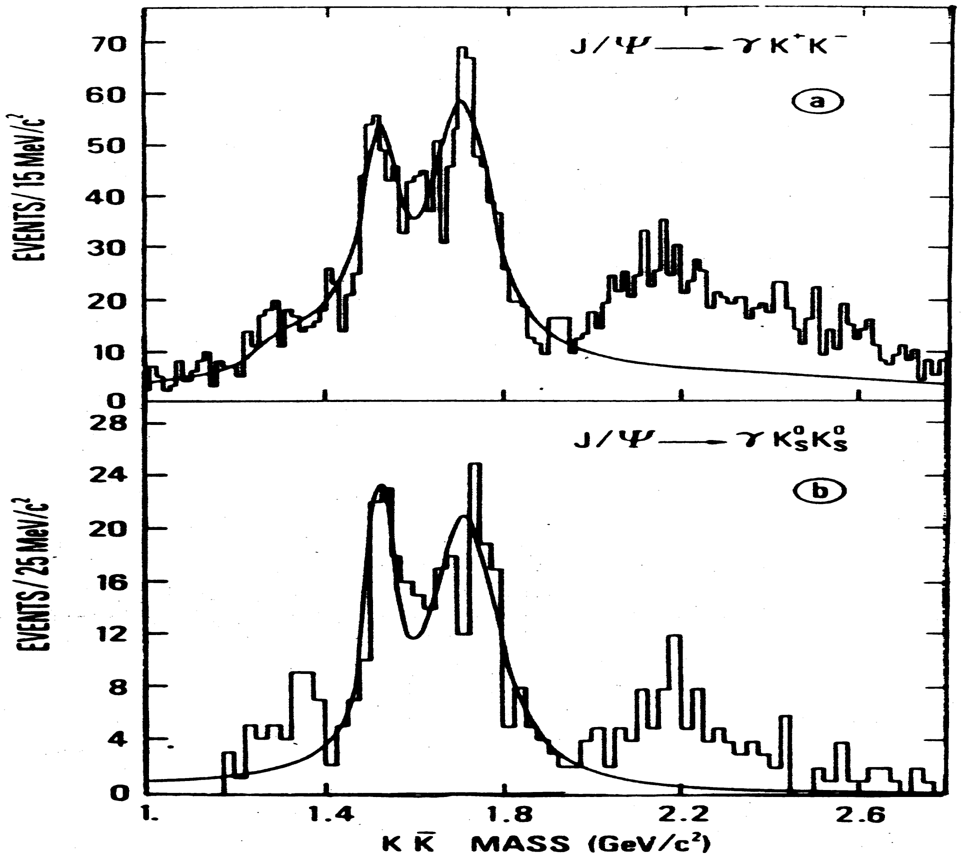
Process	Collaboration	M(MeV)	Γ(MeV)	J^{PC}
$J/\psi\to\gamma\eta\eta$	CBAL(82)	1640 ± 50	220^{+100}_{-70}	2^{++}
$\pi^-p\to K^0_sK^0_sn$	BNL(82)	1771^{+77}_{-53}	200^{+156}_{-9}	0^{++}
$\pi^-N\to K^0_sK^0_sn$	FNAL(84)	1742 ± 15	57 ± 38	—–
$\pi^-p\to\eta\eta N$	GAMS(86)	1755 ± 8	<50	0^{++}
$J/\psi\to\gamma K^+K^-$	MARKIII(87)	1720 ± 14	130 ± 20	2^{++}
$J/\psi\to\gamma K\bar{K}$ $\gamma\pi^+\pi^-$	DM2(88)	1707 ± 10 1698 ± 15	166 ± 33 136 ± 28	—–
$pp\to ppK^+K^-$ $ppK^0_SK^0_S$	WA76(89)	1713 ± 10 1706 ± 10	181 ± 30 104 ± 30	2^{++}
$J/\psi\to\gamma K\bar{K}$	MARKIII(91)	1710 ± 20	186 ± 30	0^{++}
$p\bar{p}\to\pi^0\eta\eta$	E760(93)	1748 ± 10	264 ± 25	$(even)^{++}$
$J/\psi\to\gamma4\pi$	MARKIII data D. Bugg *et al.*(95)	1750 ± 15	160 ± 40	0^{++}
$J/\psi\to\gamma K^+K^-$	BES(96)	$1696\pm5^{+9}_{-34}$ $1781\pm8^{+10}_{-31}$	$103\pm18^{+30}_{-11}$ $85\pm24^{+22}_{-19}$	2^{++} 0^{++}
$J/\psi\to\gamma K\bar{K}$	MARKIII data W. Dunwoodie(97)	1704^{+16}_{-23}	124^{+52}_{-44}	0^{++}
$pp\to p_f(K^+K^-)p_s$	WA102(99)	1730 ± 15	100 ± 25	0^{++}
$pp\to p_f(\pi^+\pi^-)p_s$	WA102(99)	1750 ± 25	105 ± 34	0^{++}
$pp\to K^+K^-\pi^+\pi^-$	WA102(99)	1710 ± 16	126 ± 24	0^{++}
$pp\to p_f(K^+K^-)p_s$	WA76(99)	1710 ± 25	105 ± 34	0^{++}
$pp\to p_f\eta\eta p_s$	WA102(00)	1698 ± 18	120 ± 26	0^{++}
$J/\psi\to\gamma4\pi$	BES(00)	1740^{+20}_{-25}	135^{+40}_{-25}	0^{++}

$\xi(2230)$

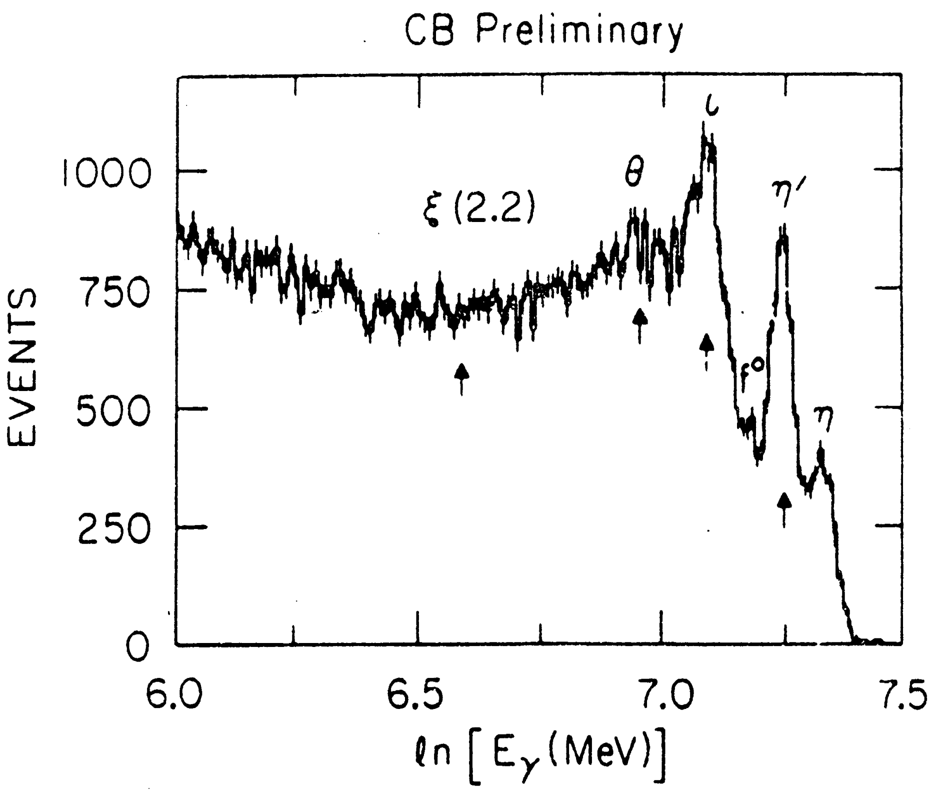
- **MARKIII(1986) observed $\xi(2230)$ in $J/\psi \to \gamma K\overline{K}$ for the first time.**



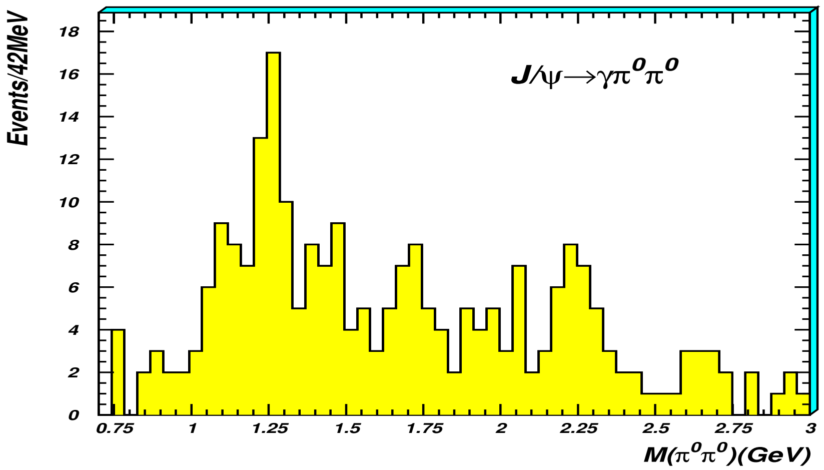
- **DM2 didn't find a narrow signal in 2230 MeV mass region.**

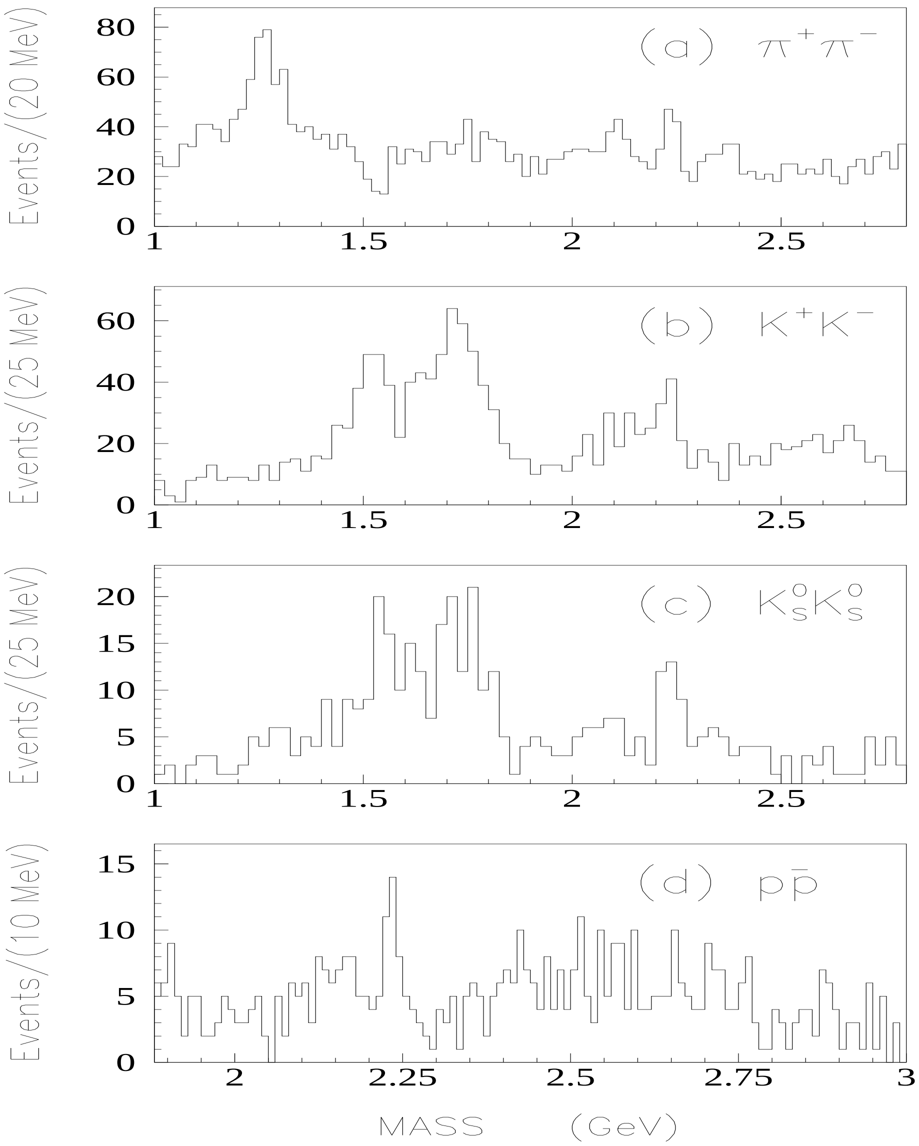


- **No evidence of $\xi(2230)$ in Crystal Ball inclusive photon spectrum.**



- **BESI results(1996) confirmed the existence of $\xi(2230)$ in $J/\psi \to \gamma K\overline{K}$, based on 7.8×10^6 J/ψ data.**
- **BESI(1996,1998) observed the non-strange decay modes of $\xi(2230)$ to $\pi\pi$ and $p\bar{p}$.**
- **No $\xi(2230)$ in CLEO and L3 two-photon collision experiments.**



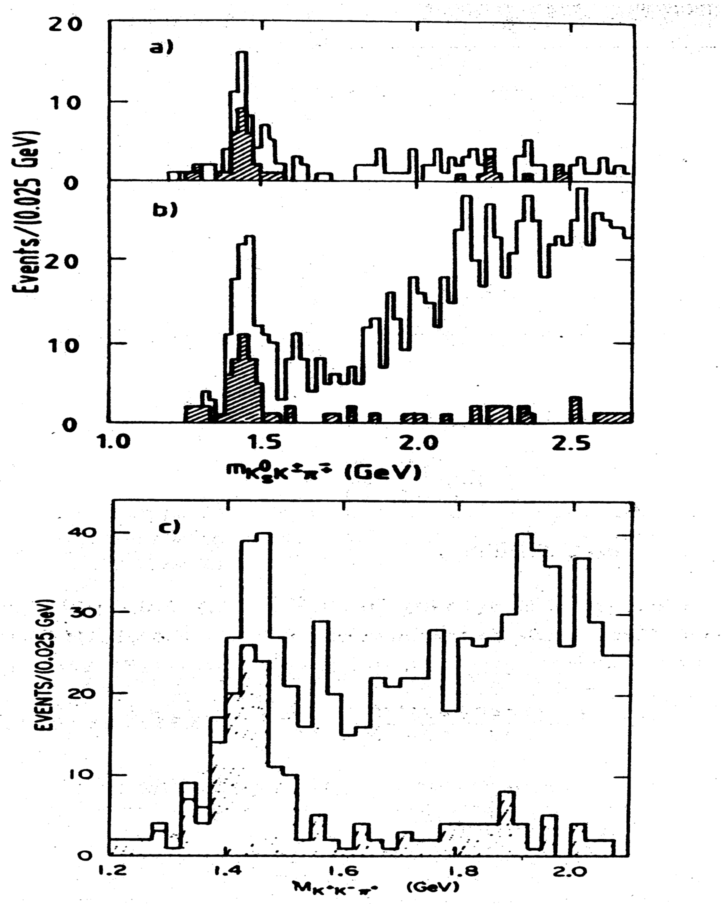


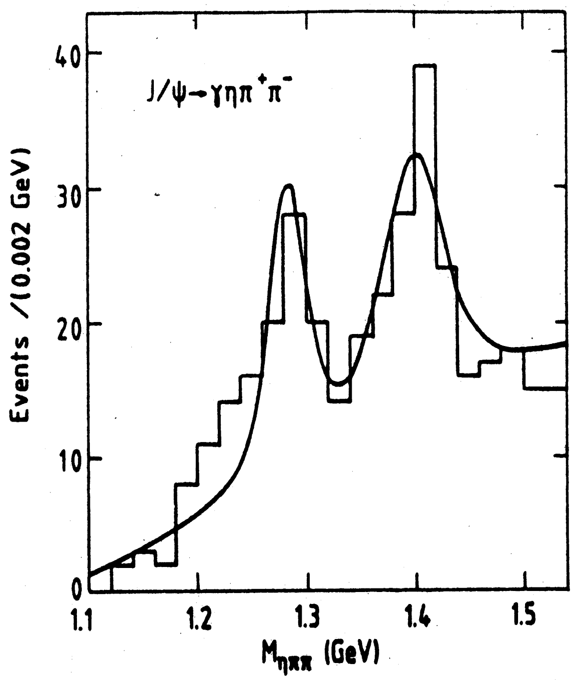
(a) $\pi^+\pi^-$
Events/(20 MeV)
(b) K^+K^-
Events/(25 MeV)
(c) $K^0_SK^0_S$
Events/(25 MeV)
(d) $p\bar{p}$
Events/(10 MeV)
MASS (GeV)

$\iota/\eta(1440)$

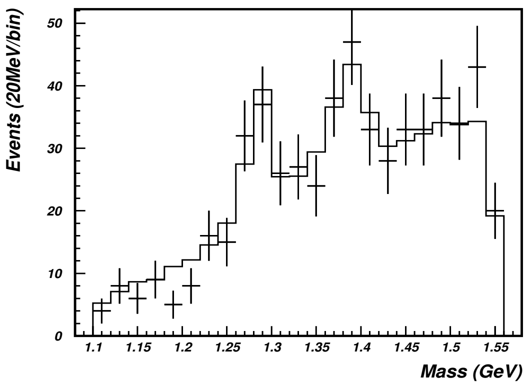
- **First observed in** $J/\psi \to \gamma K_s K^{\pm}\pi^{\mp}$ **channel by the MarkII in 1980**
- **Crystal Ball (1983) from** $K\overline{K}\pi$
- **MarkIII (1990) from** $J/\psi \to \gamma K\overline{K}\pi$ **and** $\gamma\eta\pi\pi$
- **DM2 (1992) from** $J/\psi \to \gamma K\overline{K}\pi$ **and** $\gamma\eta\pi\pi$
- **BESI data (1998) on** $J/\psi \to \gamma K^+K^-\pi^0$ **and** $\gamma\eta\pi^+\pi^-$
- **BESI data (2000) on** $J/\psi \to \gamma K_s^0 K^{\pm}\pi^{\mp}$

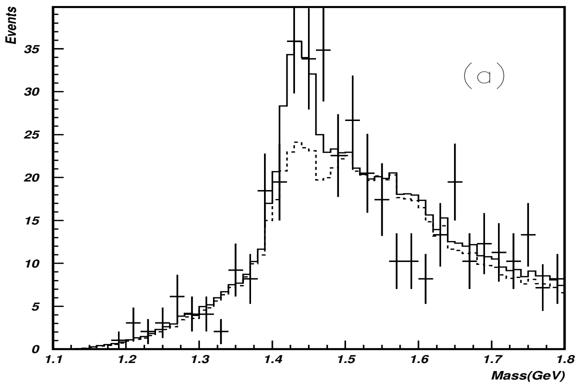
MARKII and MARKIII results:

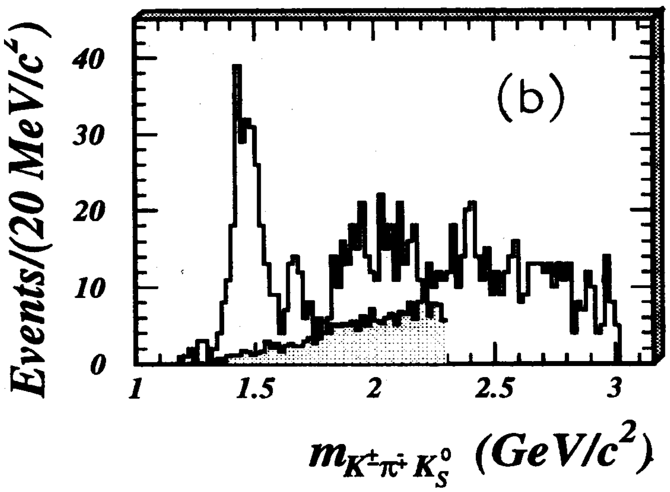




BESI $J/\psi \to \gamma\eta\pi^+\pi^-$, $\gamma K^+K^-\pi^0$ and $\gamma K_s K\pi$:



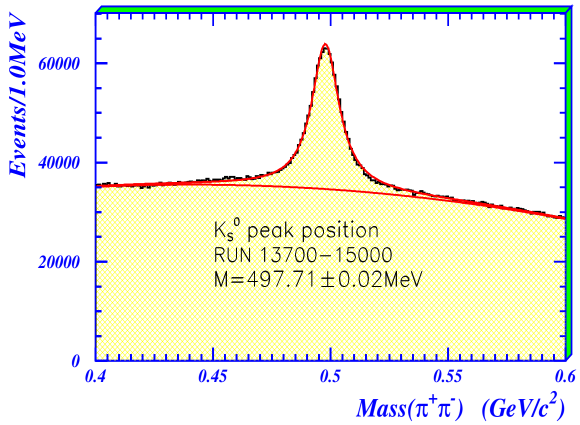


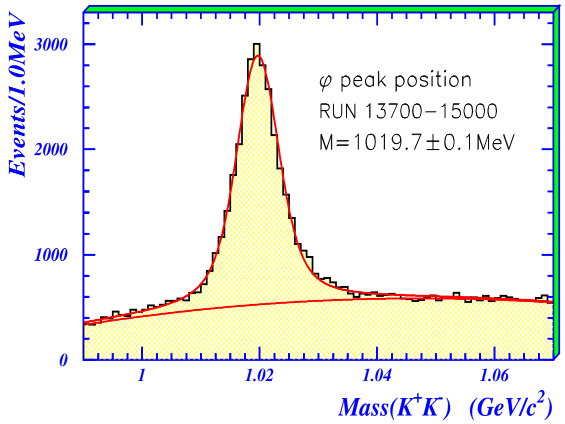


Preliminary Results from BESII

1. data set and data quality

around 5.8×10^7 J/ψ **events**

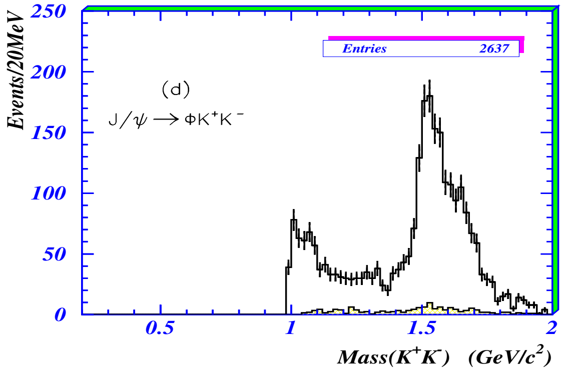




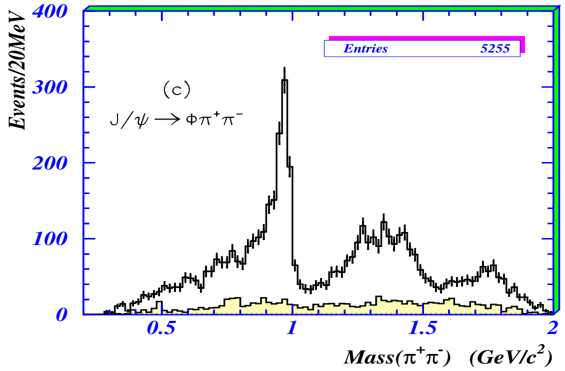
inclusive $\pi^+\pi^-$ **inclusive** K^+K^-

58M J/ψ preliminary!

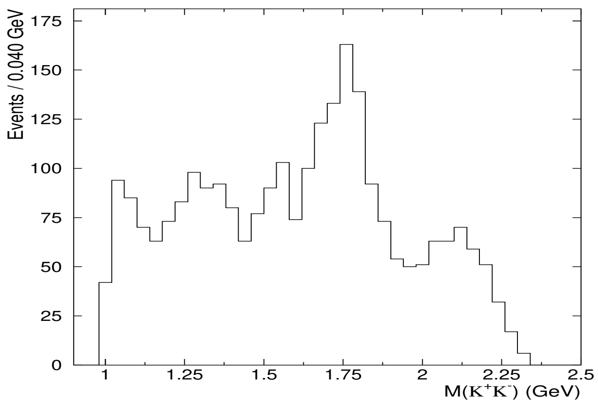
$J/\psi \to \phi K^+ K^-$



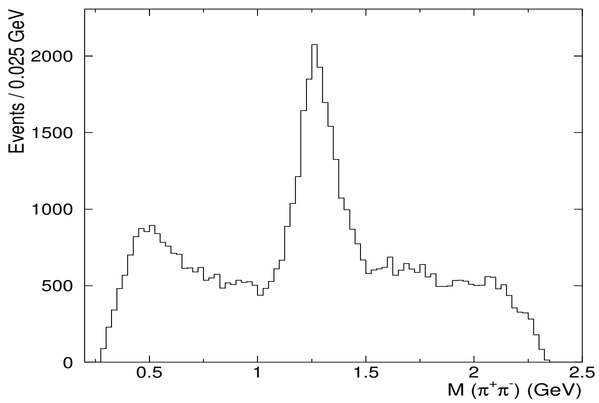
$J/\psi \to \phi \pi^+ \pi^-$



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

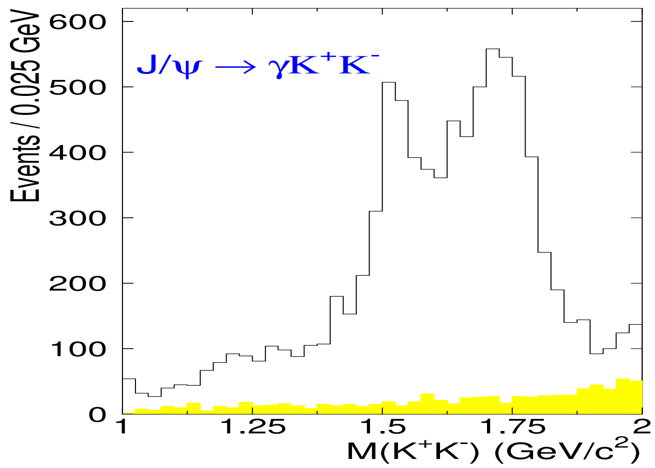


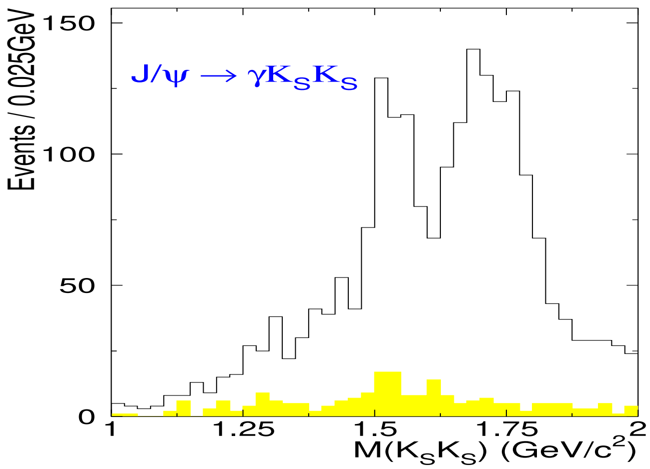
$J/\psi \to \omega \pi^+ \pi^-$

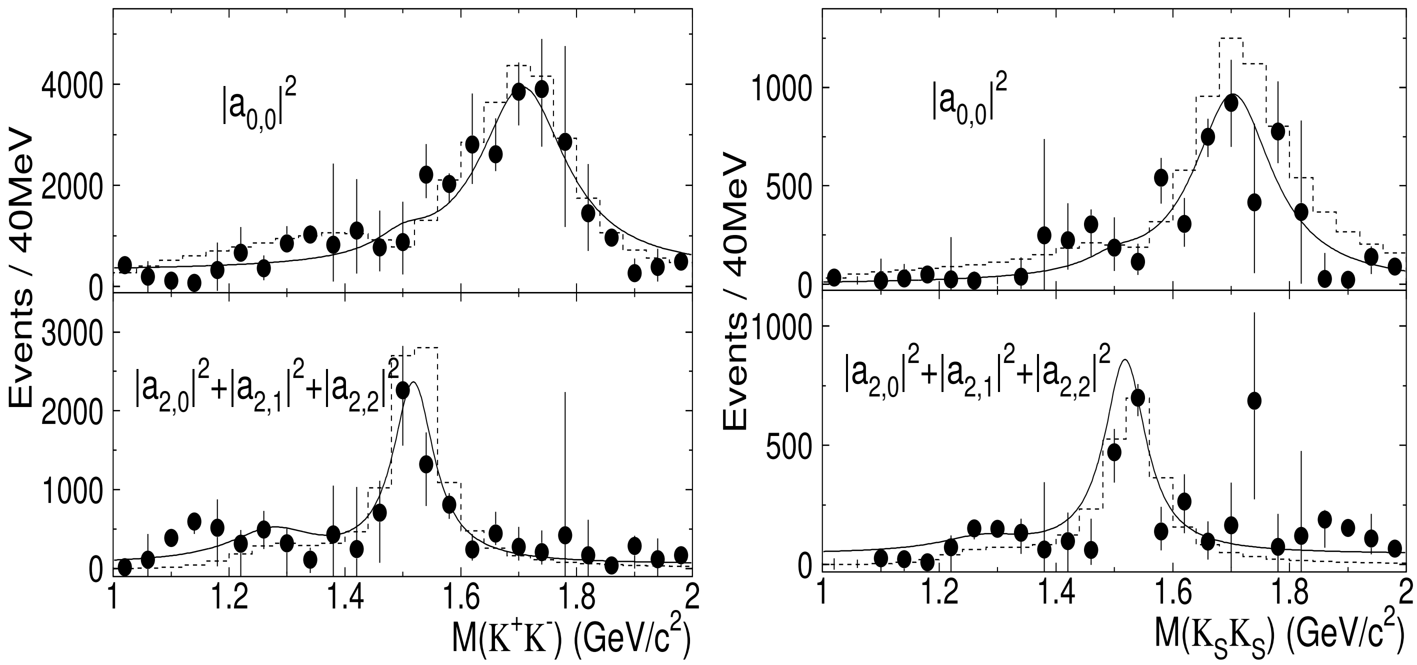


2. PWA of $J/\psi \to \gamma K\overline{K}$ (preliminary)

- amplitudes are fitted to the relativistic covariant tensor expressions
- global and bin-by-bin fits are performed in 1-2 GeV mass region
- the maximum likelihood method is applied in the fit







- **dots with error bar — efficiency corrected data points**
- **solid curves — coherent superposition of the individual Breit-Wigner resonance fit**
- **dash histogram — global fit**

Results from PWA of $J/\psi \to \gamma K\overline{K}$:

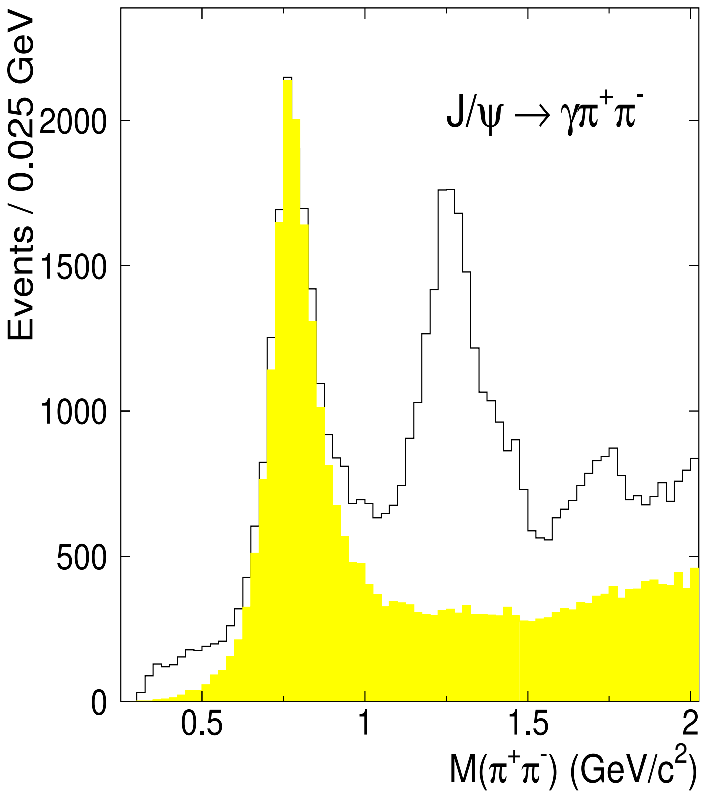
(Preliminary!)

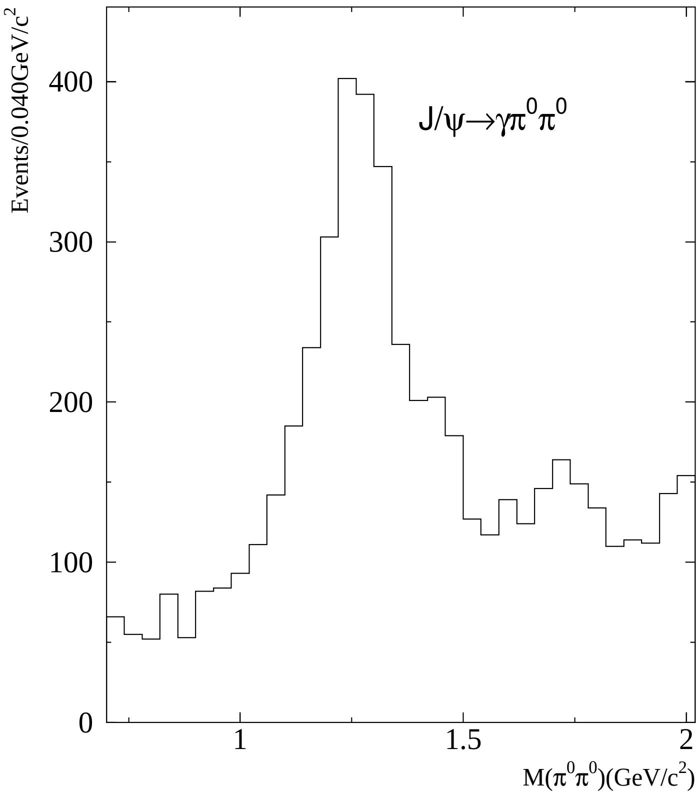
- **clear** $f_2'(1525)$

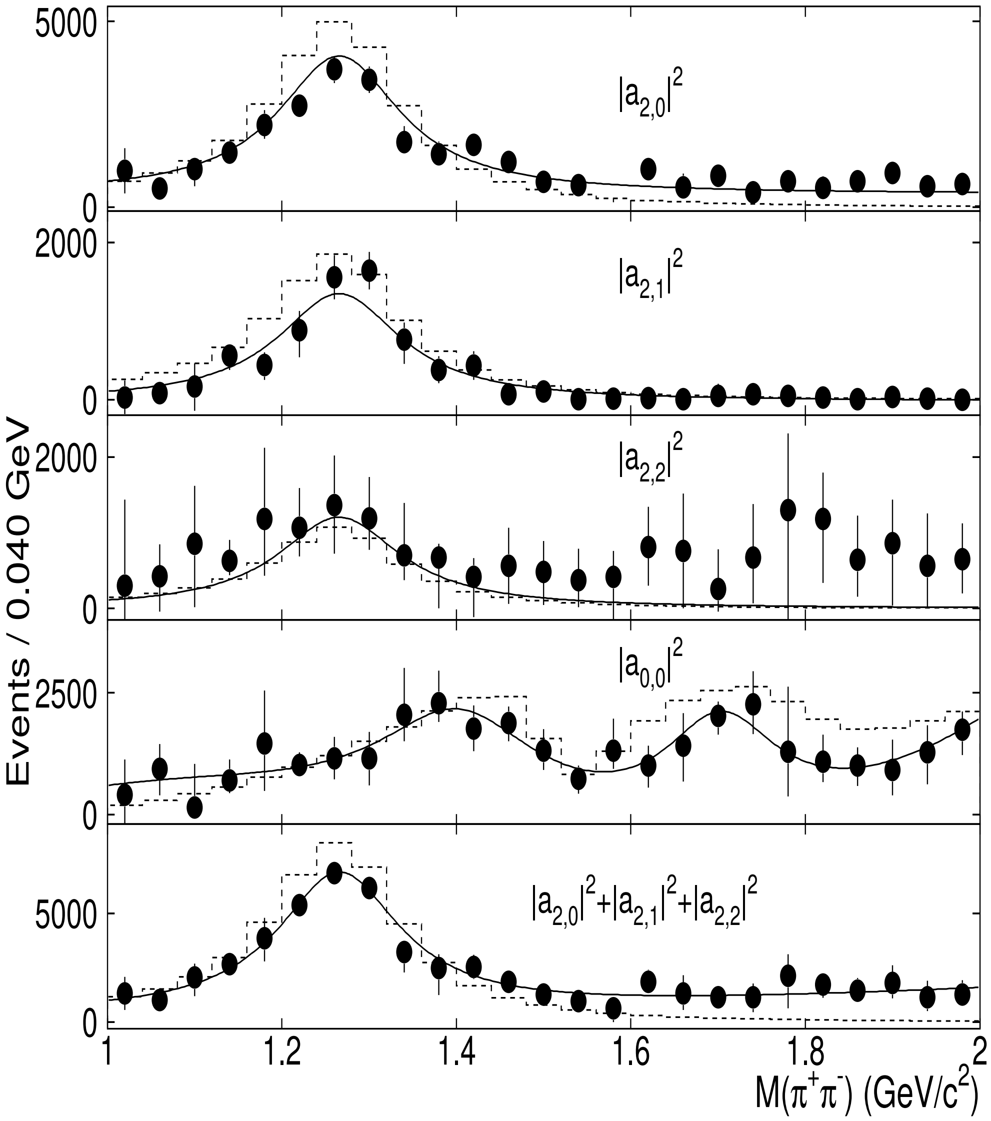
  $M = 1518 \pm 6$ **MeV** $\quad \Gamma = 84^{+28}_{-24}$ **MeV**
- **evidence of** $f_2(1270)$
- 0^{++} **is dominant in 1.7 GeV mass region**

  $M = 1703^{+8}_{-10}$ **MeV** $\quad \Gamma = 163^{+27}_{-22}$ **MeV**
- **weak** 2^{++} **in 1.7 GeV mass region**

3. PWA of $J/\psi \to \gamma\pi^+\pi^-$ (preliminary)







Events / 0.040 GeV
$|a_{2,0}|^2$
$|a_{2,1}|^2$
$|a_{2,2}|^2$
$|a_{0,0}|^2$
$|a_{2,0}|^2+|a_{2,1}|^2+|a_{2,2}|^2$
$M(\pi^+\pi^-)$ (GeV/c^2)

Results from PWA of $J/\psi \to \gamma\pi^+\pi^-$:

(Preliminary!)

- **well known** $f_2(1270)$

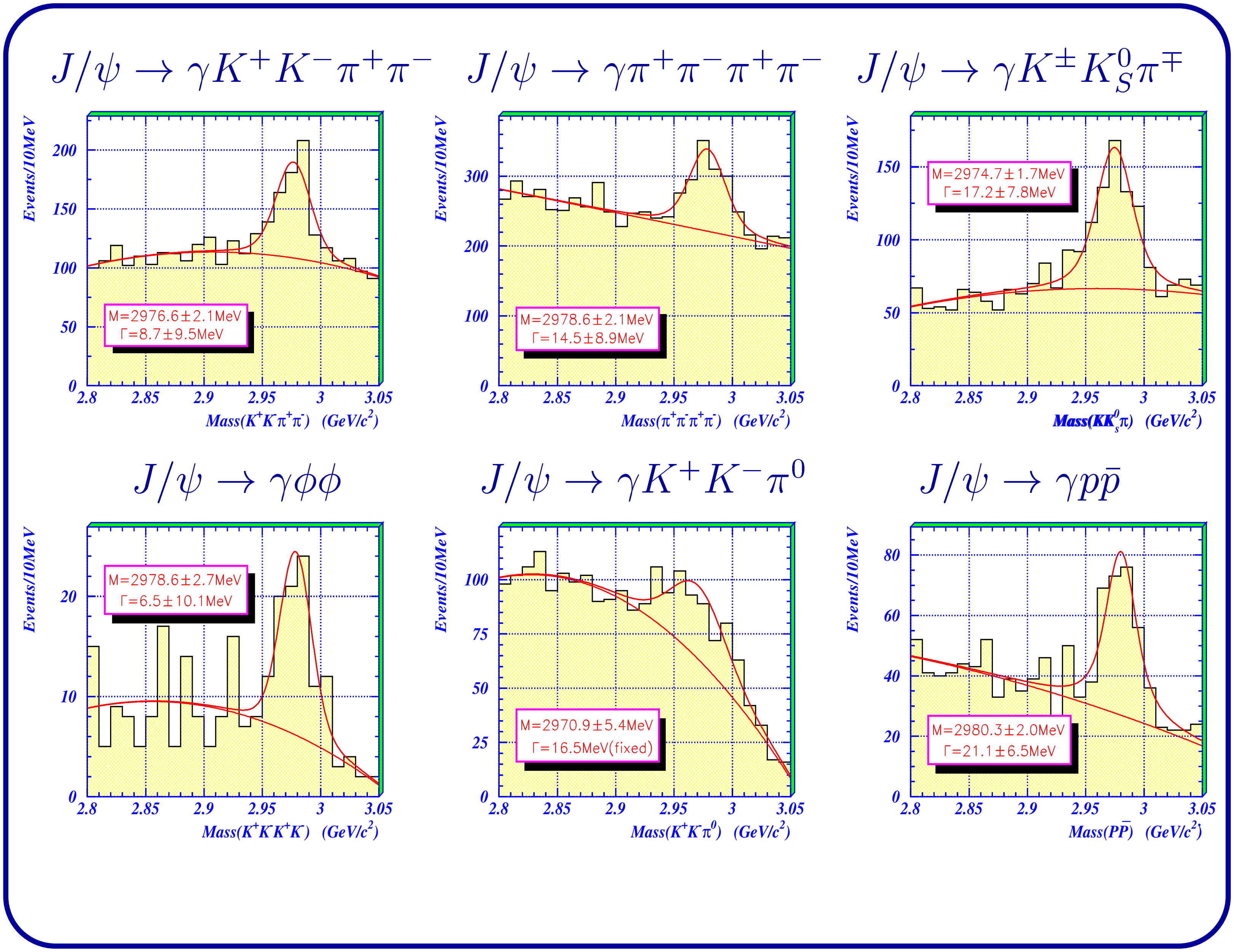
  $M = 1518 \pm 6$ **MeV** $\quad \Gamma = 84^{+28}_{-24}$ **MeV**
- **evidence of** $f_2(1270)$
- **two** 0^{++} **in 1.4 and 1.7 GeV mass regions**

  $M = 1703^{+8}_{-10}$ **MeV** $\quad \Gamma = 163^{+27}_{-22}$ **MeV**

  $M = 1703^{+8}_{-10}$ **MeV** $\quad \Gamma = 163^{+27}_{-22}$ **MeV**

4. Measurement of η_c using BESII data (Preliminary!)

$$
\begin{aligned}
J/\psi &\rightarrow \gamma\eta_c \\
\eta_c &\rightarrow K^+K^-\pi^+\pi^- \\
&\quad\ \pi^+\pi^-\pi^+\pi^- \\
&\quad\ K^\pm K^0_S\pi^\mp \rightarrow K^\pm\pi^\mp\pi^+\pi^- \\
&\quad\ \phi\phi \rightarrow K^+K^-K^+K^- \\
&\quad\ K^+K^-\pi^0 \\
&\quad\ p\bar{p}
\end{aligned}
$$


$J/\psi \to \gamma K^+K^-\pi^+\pi^-$
M=2976.6±2.1MeV
Γ=8.7±9.5MeV
Mass($K^+K^-\pi^+\pi^-$) (GeV/c^2)
$J/\psi \to \gamma \pi^+\pi^-\pi^+\pi^-$
M=2978.6±2.1MeV
Γ=14.5±8.9MeV
Mass($\pi^+\pi^-\pi^+\pi^-$) (GeV/c^2)
$J/\psi \to \gamma K^\pm K^0_S \pi^\mp$
M=2974.7±1.7MeV
Γ=17.2±7.8MeV
Mass($KK^0_s\pi$) (GeV/c^2)
$J/\psi \to \gamma \phi\phi$
M=2978.6±2.7MeV
Γ=6.5±10.1MeV
Mass($K^+K^-K^+K^-$) (GeV/c^2)
$J/\psi \to \gamma K^+K^-\pi^0$
M=2970.9±5.4MeV
Γ=16.5MeV(fixed)
Mass($K^+K^-\pi^0$) (GeV/c^2)
$J/\psi \to \gamma p\bar{p}$
M=2980.3±2.0MeV
Γ=21.1±6.5MeV
Mass($P\bar{P}$) (GeV/c^2)
Events/10MeV

The fitted values (errors are statistical only).

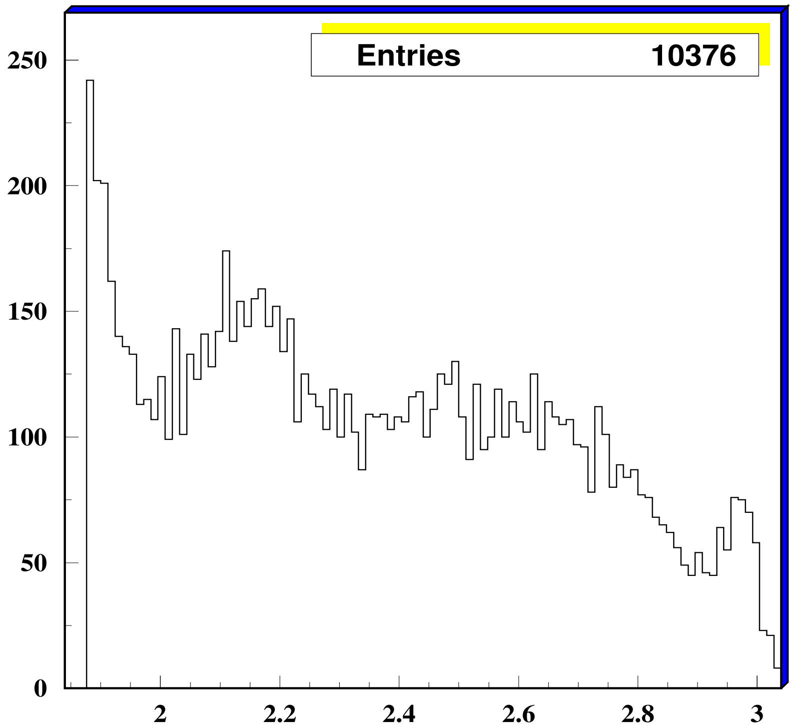
Channel	No. of events	mass(MeV)
$K^+K^-\pi^+\pi^-$	330.5 ± 78.9	2976.6 ± 2.1
$\pi^+\pi^-\pi^+\pi^-$	521.1 ± 115.4	2978.6 ± 2.1
$K^\pm K^0_S\pi^\mp$	440.1 ± 79.1	2974.7 ± 1.7
$\phi\phi$	66.9 ± 18.1	2978.6 ± 2.7
$p\bar{p}$	221.2 ± 40.2	2980.3 ± 2.0

Combining the weighted average with the results for the five decay channels, we have:

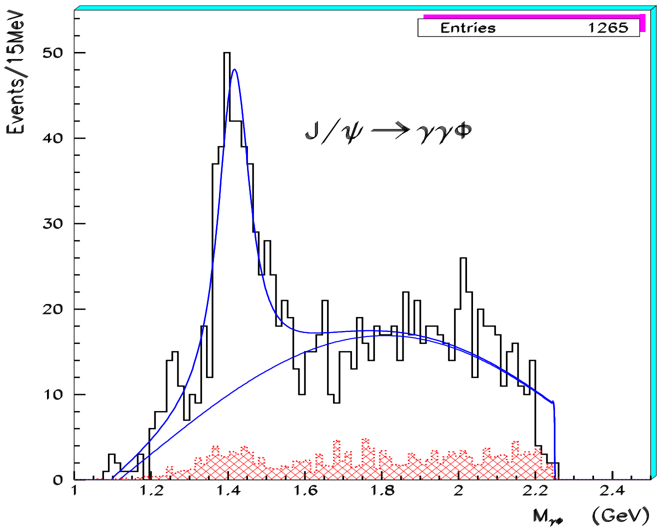
$M_{\eta_c} = 2977.4 \pm 0.9(stat)$ **MeV** $(\chi^2/\mathbf{dof} = 5.3/4)$

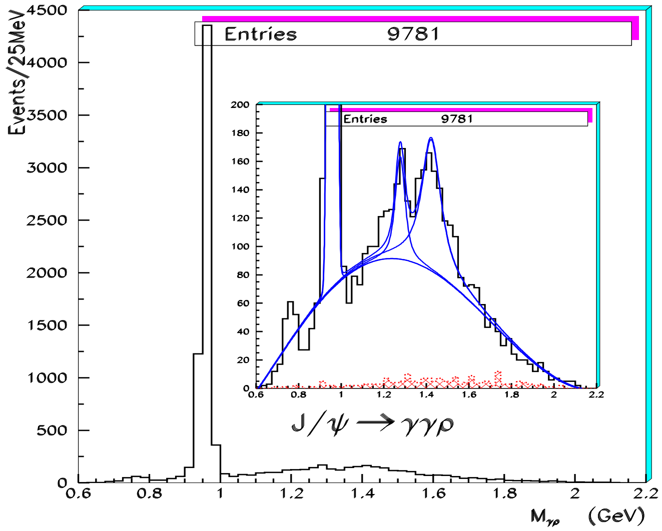
$\Gamma_{\eta_c} = 15.3 \pm 3.7(stat)$ **MeV** $(\chi^2/\mathbf{dof} = 2.1/4)$

5. Near threshold structure in $J/\psi \to \gamma p\bar{p}$



6. $J/\psi \to \gamma\gamma V$ results





Decay Mode	Mass (MeV)	Width (MeV)	Sign.	Exp.
$J/\psi \to \gamma X(1420)$	**1431 ± 17**	**88 ± 28**	**4.4σ**	**BESI**
$\to \gamma\gamma\rho^0$	**1422.5 ± 6.3**	100.0 ± 3.5	13.9σ	**BESII**
$J/\psi \to \gamma X(1420)$	**1424 ± 15**	**73 ± 58**	4.6σ	**BESI**
$\to \gamma\gamma\phi$	1415.9 ± 4.8	91.1 ± 14.4	14.6σ	**BESII**

Summary

- J/ψ **radiative decays – a good lab.**
- **PWA results of** $J/\psi \to \gamma K\bar{K}$ **and** $\gamma\pi^+\pi^-$
- **the measurement of** η_c
- **the analyses of** $J/\psi \to \gamma p\bar{p}$ **and** $\gamma\gamma V$