Gluonia Search at BES

Results from J/ψ Decays

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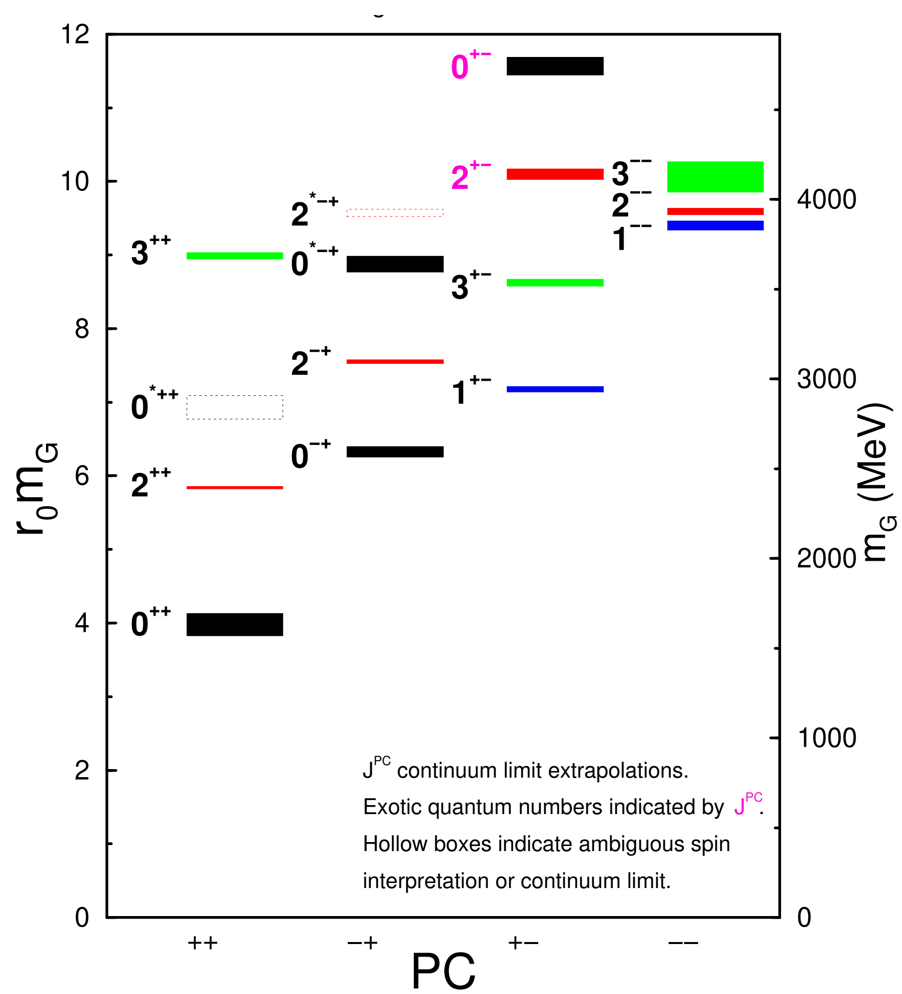
- Glueball, J/ψ and BES
  - Glueball
  - J/ψ
  - BES
- Glueball Search at BES using J/ψ data
  - Channels analysed and Methods used
  - $f_0(1500)$
  - $f_J(1710)$
  - $\xi(2230)$
- Summary

Glueball

Existence of Glueball is a strong prediction of QCD!

Observation of glueballs is a direct test of QCD!

Gluonia masses from LQCD



QCD Spectral Sum Rules give masses at the same level.

What we learn from Theories:

$$
\begin{array}{lcl}
0^{++} & \sim & 1.5 - 1.7 \text{ GeV} \\
2^{++} & \sim & 2.2 \text{ GeV} \\
0^{-+} & \sim & 2.0 \text{ GeV}
\end{array}
$$

Glueball search and difficulties

Many experiments tried to search for them, and some glueball candidates were found, but no one is definitely identified as glueball!

Difficulties:

- Complexity in $1.0 \sim 3.0$ GeV
- Mixing between glueball and $q\bar{q}$ mesons

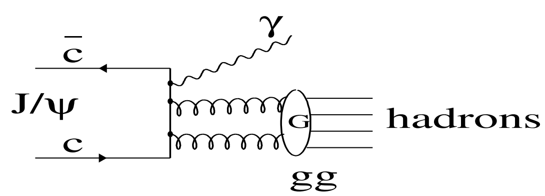
J/ψ

- Found in 1974 at BNL and SLAC
- $c\bar{c}$ bound state
- $I^G(J^{PC}) = 0^-(1^{--})$
- mass: 3096.88 $\pm$ 0.04 MeV
- width: 87 $\pm$ 5 keV

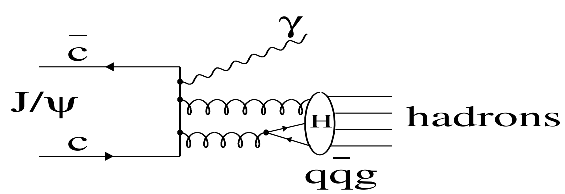
It was studied by MARK-I, MARK-II, MARK-III, Crystal Ball, DM2, ..., and BES.

$\boxed{\text{BES is the only live experiment study } J/\psi \text{ decays!}}$

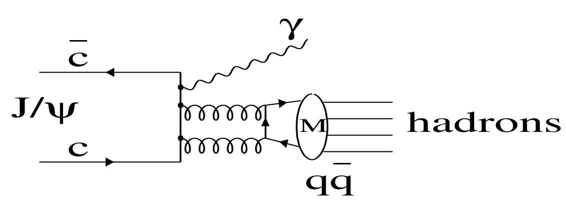
Gluonia production in J/ψ decays



$\Gamma(\gamma G) \sim \mathcal{O}(\alpha\alpha_s^2)$



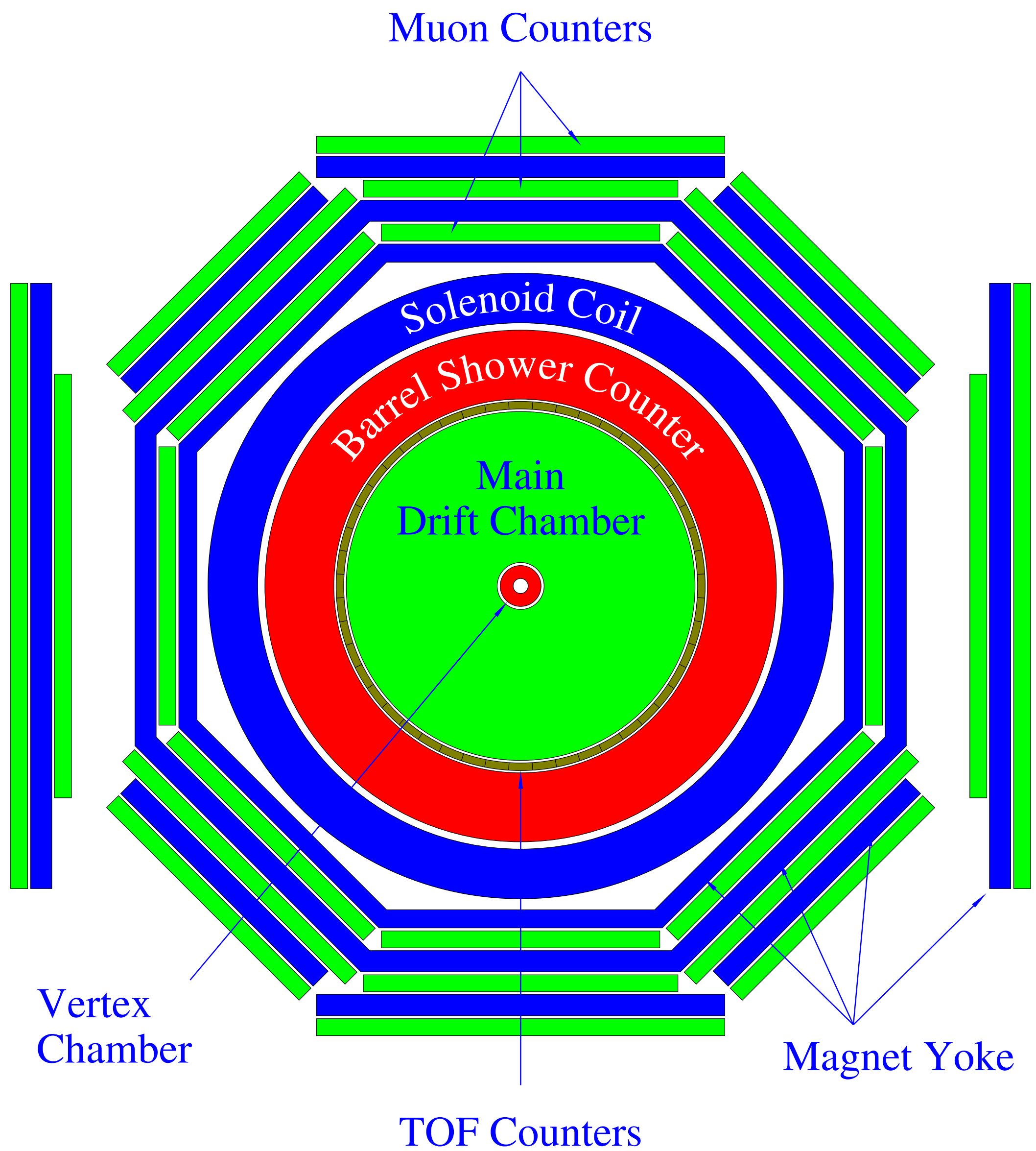
$\Gamma(\gamma H) \sim \mathcal{O}(\alpha\alpha_s^3)$



$\Gamma(\gamma M) \sim \mathcal{O}(\alpha\alpha_s^4)$

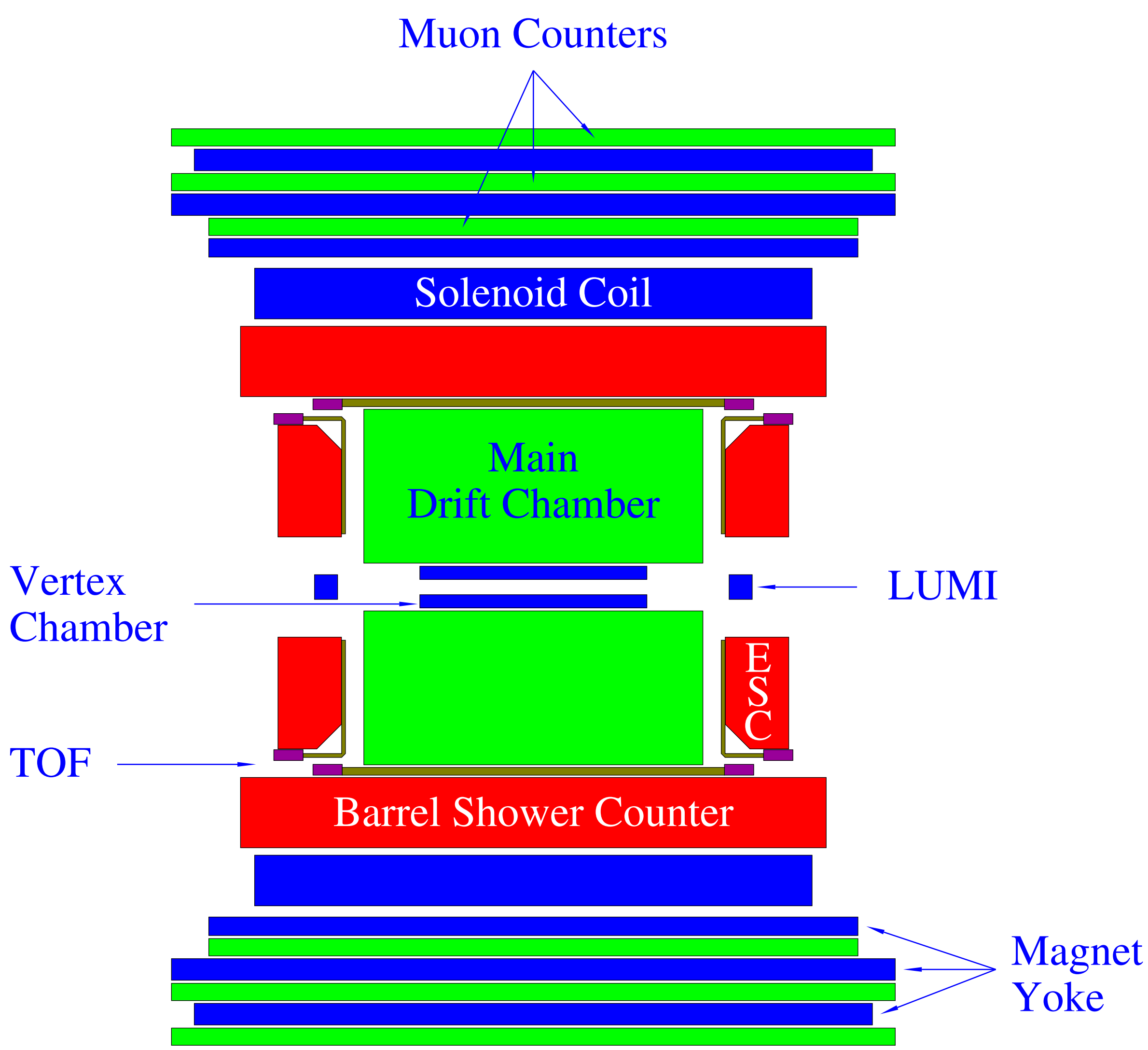
Glueball-rich production in radiative J/ψ decays!

BES detector



End view of the BES detector

BES detector



Side view of the BES detector

BES detector performance

- Drift Chamber (DC):

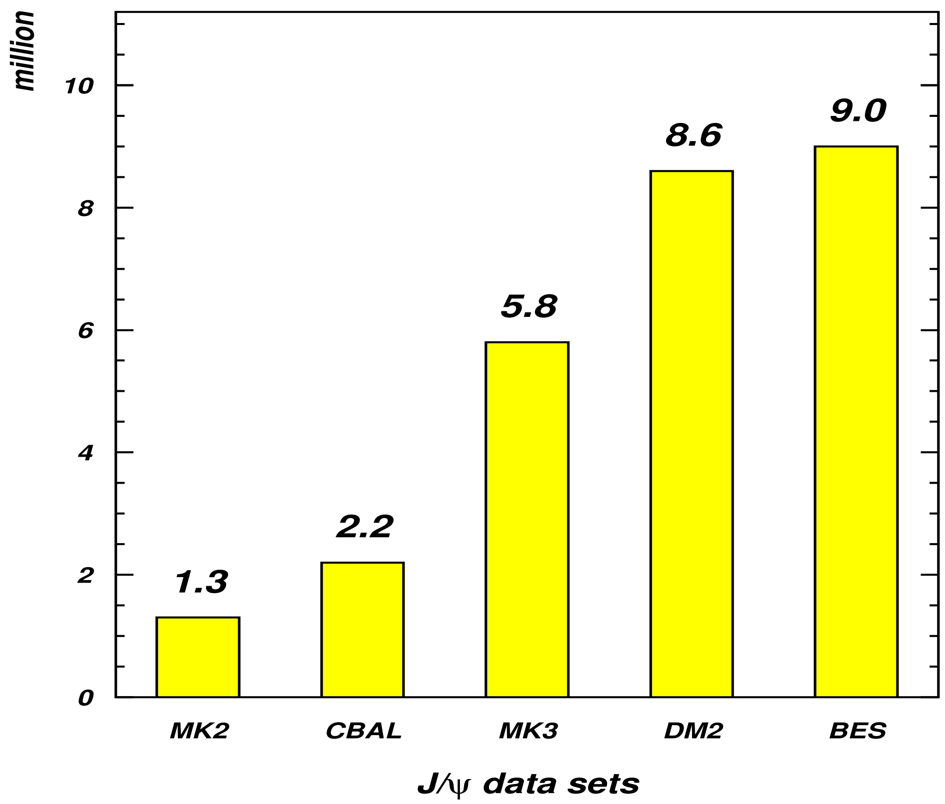
σ_p/p(p in GeV)	$\sim 1.8\%\sqrt{1+p^2}$
$\sigma_{xy}(\mu$m)	~ 200
$\sigma_{dE/dx}$	$\sim$ 9%
p^{π}_{min}(MeV/c)	$\sim$ 80

- Time of Flight (TOF): ~ 180 ps
- Shower Counter (SC):

σ_E/E(GeV)	$\sim 21\%/\sqrt{E}$
σ_ϕ(mr)	$\sim$ 7
σ_Z(cm)	$\sim$ 5
E^{γ}_{min}(MeV)	$\sim$ 100 ($\varepsilon \sim 80\%$)

- Vertex Chamber (VC)
- Muon Chamber (MUC)

J/ψ data, Channels Analyzed and Methods Used



Channels Analyzed:
$J/\psi \to \gamma\pi^+\pi^-$, γK^+K^-, $\gamma K_s^0 K_s^0$, $\gamma p\bar{p}$, $\gamma 2(\pi^+\pi^-)$, $\gamma\pi^0\pi^0$, ...

Methods used in analysis:
Mass spectra analysis, moment analysis and partial wave analysis (PWA).

Results on $f_0(1500)$, $f_J(1710)$ and $\xi(2230)$ will be presented.

$f_0(1500)$

History:

- MK3 found a broad 0^- in $J/\psi \to \gamma 2(\pi^+\pi^-)$ via $\rho\rho$ intermediate state at 1.55 GeV. (86)
- DM2 observed the same structure. (89)
- E760: peak at $m_{\eta\eta} = 1.5$, 0^- forbidden! (93)
- Reanalysis of MK3 data, including $\sigma\sigma$ contribution, yields: 0^{++} at 1.5 GeV. (95)

NEW results:

CBAR	$p\bar{p}$ annihilation at rest	$K_L^0 K_L^0$, $\eta\eta$, $\pi^0\pi^0$, $\eta\eta'$, $4\pi^0$
OMEGA	pp central production	$2(\pi^+\pi^-)$
OBELIX	$\bar{n}p$, $p\bar{p}$	$\pi^+\pi^-$

World Average:

$$m_{f_0(1500)} = 1500 \pm 10\,\text{MeV}$$

$$\Gamma_{f_0(1500)} = 112 \pm 10\,\text{MeV}$$

$f_0(1500)$: PWA of $J/\psi \to \gamma 2(\pi^+\pi^-)$ at BES

$$
\begin{array}{llll}
J/\psi \to \gamma\ X & & & \\
\quad\quad \hookrightarrow & Y & + & Z \\
 & \hookrightarrow \pi^+\pi^- & & \hookrightarrow \pi^+\pi^-
\end{array}
$$

$$
\begin{array}{lll}
X \to \rho & + & \rho \\
\quad\ \hookrightarrow \pi^+\pi^- & & \hookrightarrow \pi^+\pi^-
\end{array}
$$

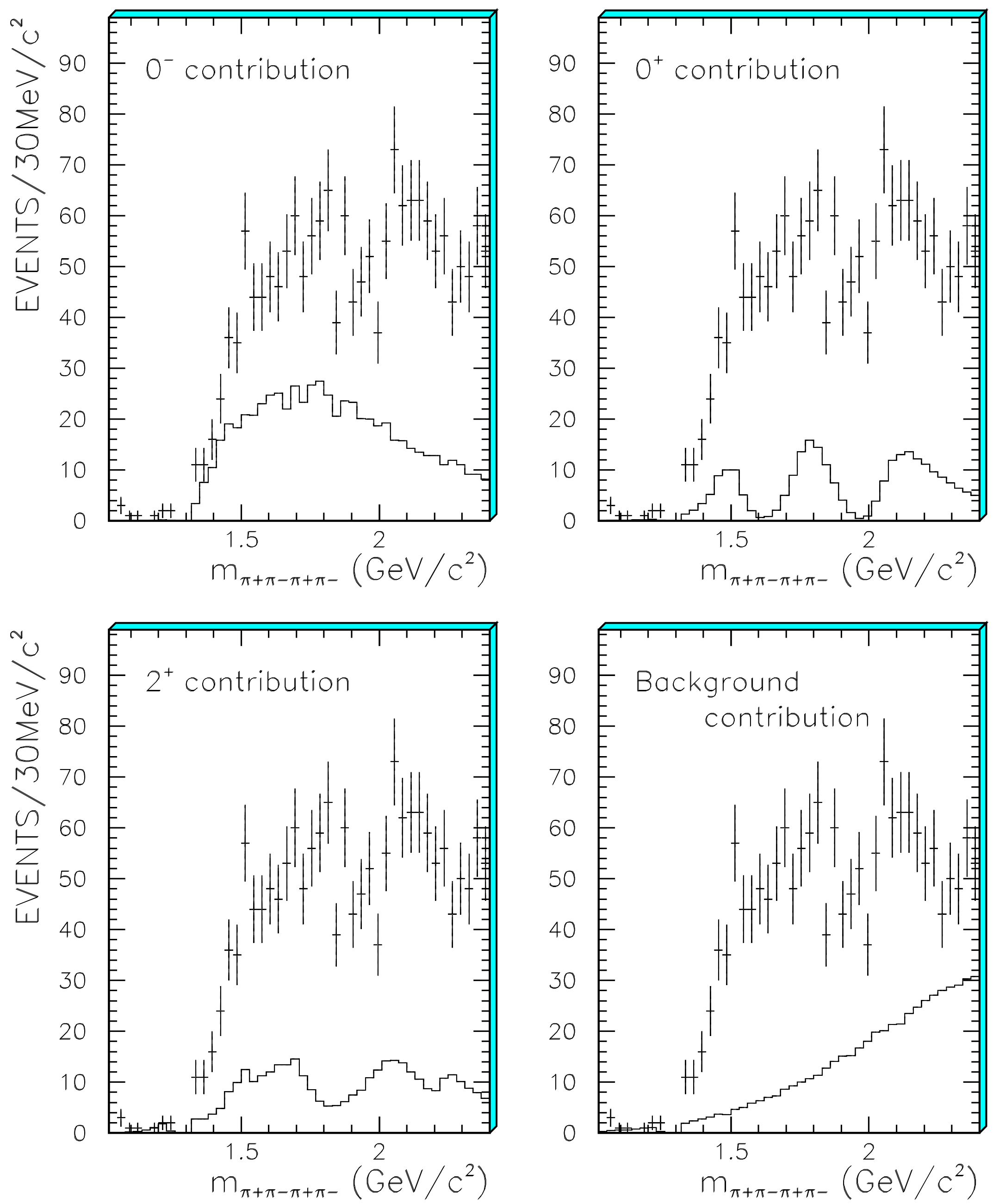
$$
\begin{array}{lll}
X \to \sigma & + & \sigma \\
\quad\ \hookrightarrow \pi^+\pi^- & & \hookrightarrow \pi^+\pi^-
\end{array}
$$

$$
\begin{array}{lll}
X \to f_2(1270) & + & \sigma \\
\quad\ \hookrightarrow \pi^+\pi^- & & \hookrightarrow \pi^+\pi^-
\end{array}
$$

$$
\begin{array}{l}
X \to \pi + \pi(1300) \\
\quad\quad\quad\quad \hookrightarrow \pi + \quad \sigma \\
\quad\quad\quad\quad\quad\quad\quad\quad \hookrightarrow \pi^+\pi^-
\end{array}
$$

$$
\begin{array}{l}
X \to \pi + \pi(1300) \\
\quad\quad\quad\quad \hookrightarrow \pi + \quad \rho \\
\quad\quad\quad\quad\quad\quad\quad\quad \hookrightarrow \pi^+\pi^-
\end{array}
$$

$f_0(1500)$: *PWA of* $J/\psi \to \gamma 2(\pi^+\pi^-)$ *at BES*



PWA of $J/\psi \to \gamma 2(\pi^+\pi^-)$

		Measured		Final Fit			
J^P	state	Mass (MeV)	Γ (MeV)	Mass (MeV)	Γ (MeV)	Decay	L or $^{2S+1}L_J$
2^+	$f_2(1270)$	1305^{+95}_{-35}	410^{+290}_{-160}	1275	185	$\rho\rho$	$^1D_2$ $^3D_2$
0^-	$\eta(1420)$	1395^{+16}_{-13}	200^{+9}_{-6}	1395	200	$\rho\rho$	$L=1$
0^+	$f_0(1500)$	1500^{+16}_{-18}	95^{+30}_{-20}	1500	120	$\sigma\sigma$	$L=0$
2^+	$f_2(1560)$	1470^{+20}_{-20}	175^{+65}_{-60}	1565	150	$\rho\rho$	$^5S_2$ $^1D_2$ $^3D_2$
2^+	$f_2(1690)$	1710^{+35}_{-35}	410^{+220}_{-160}	1710	175	$\rho\rho$	$^5S_2$
0^+	$f_0(1780)$	1770^{+30}_{-20}	100^{+60}_{-40}	1770	190	$\sigma\sigma$	$L=0$
2^+	$f_2(1950)$	2015^{+70}_{-70}	350^{+150}_{-70}	2015	350	$f_2\sigma$	$^5S_2$
						$\sigma\sigma$	$^1D_2$ $^3D_2$
						$\rho\rho$	$^1D_2$ $^3D_2$
0^+	$f_0(2100)$	2040^{+30}_{-30}	200^{+140}_{-65}	2100	200	$\sigma\sigma$	$L=0$
2^+	$\xi(2230)$	2215^{+20}_{-20}	115^{+85}_{-55}	2220	115	$f_2\sigma$	$^5S_2$
						$\sigma\sigma$	$^5S_2$ $^3D_2$
						$\rho\rho$	$^5S_2$ $^3D_2$

$f_0(1500)$: *the signal in* $J/\psi \to \gamma 2(\pi^+\pi^-)$

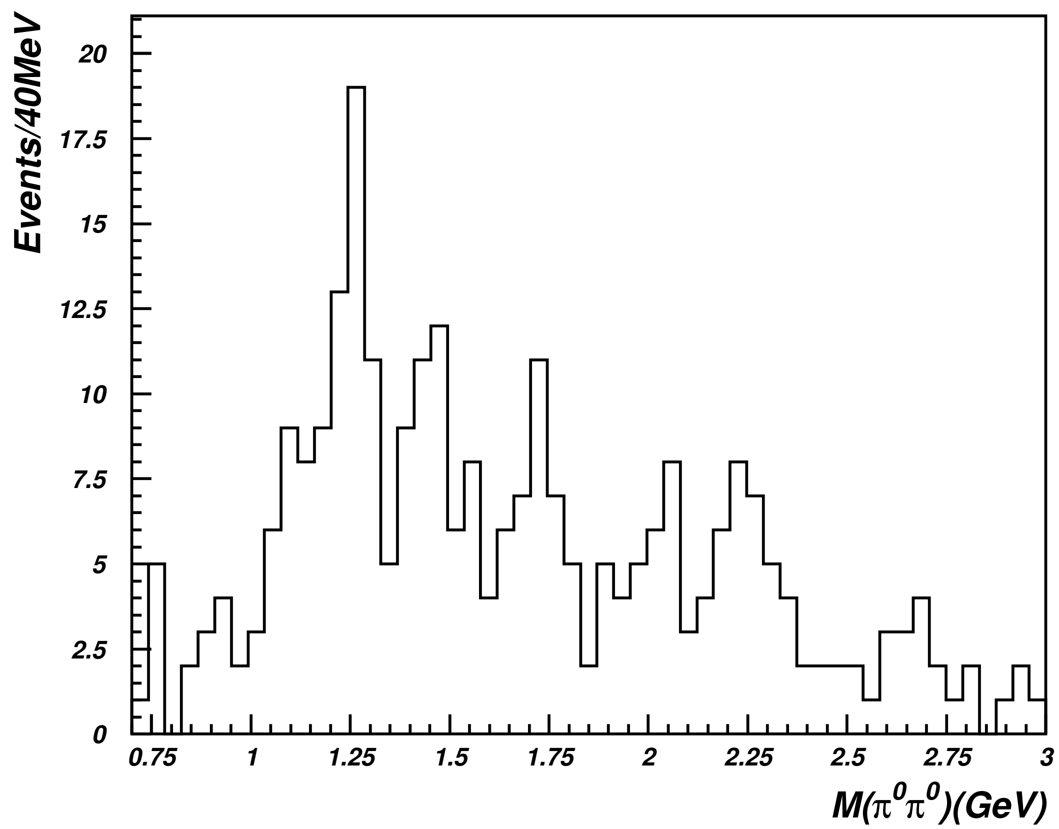
In 0^+ partial wave, at 1.5 GeV, clear signal with statistical significance : 4.3 σ !

$$m = 1500^{+16}_{-18}\text{MeV}$$
$$\Gamma = 95^{+30}_{-20}\text{MeV}$$

$$\mathcal{B}(J/\psi \to \gamma f_0 \to \gamma 2(\pi^+\pi^-)) = (2.1 \pm 0.3 \pm 0.3) \times 10^{-4}$$

Decay Mode: $\sigma\sigma$ $(L = 0)$ dominated.

$f_0(1500)$: *signal in* $J/\psi \to \gamma\pi^0\pi^0$



- Peak at $\sim$ 1500 MeV
- about 18 events
- Statistical significance: $3 \sim 4\sigma$
- Spin-parity not determined

$f_0(1500)$: *conclusions from BES*

1. mass and width of $f_0(1500)$ consistent with other experiments;

2. dominant $\sigma\sigma$ decay mode in 4π channel supports its glueball interpretation.

$f_J(1710)$

History:

- first observed by CBAL in $J/\psi \to \gamma\eta\eta$ in 1982
- other radiative J/ψ decays: $\gamma\pi^+\pi^-$, γK^+K^-, $\gamma K_s^0 K_s^0$ and hadronic J/ψ decays: ϕK^+K^-, ωK^+K^-, $\phi K_s^0 K_s^0$ etc.
- pp central production:
  $pp \to pp(\pi^+\pi^-, K^+K^-, K_s^0K_s^0, 2(\pi^+\pi^-))$
- $\pi^- N \to (K_s^0 K_s^0)X,\ \eta\eta N^*$

Large discrepancies in mass, width and spin-parity!

M (MeV)	Γ (MeV)	J^P	TECN	Exps.
1713 ± 10 1706 ± 10	181 ± 30 104 ± 30	2^+ 2^+	OMEGA OMEGA	$pp \to ppK^+K^-$ $pp \to ppK_s^0K_s^0$
1720 ± 14	130 ± 20	2^+	MARK3	$J/\psi \to \gamma K^+K^-$
1670 ± 50	160 ± 80	2^+	CBAL	$J/\psi \to \gamma\eta\eta$
1748 ± 10	264 ± 25	$even^+$	E760	$p\bar{p} \to \pi^0\eta\eta$
1707 ± 10 1698 ± 15	166 ± 33 136 ± 28	? ?	DM2 DM2	$J/\psi \to \gamma K\bar{K}$ $J/\psi \to \gamma\pi^+\pi^-$
...	...			

$f_J(1710)$: *Recent results*

- Reanalysis of MK3 J/ψ data

Mass (MeV)	Width (MeV)	J^P	Exps.
1704^{+16}_{-23}	124^{+52}_{-44}	0^+	$\gamma\pi^+\pi^-, \gamma K\bar{K}$
1750 ± 15	160 ± 40	0^+	$\gamma 2(\pi^+\pi^-)$
1620 ± 16	160^{+60}_{-20}	2^+	$\gamma 2(\pi^+\pi^-)$

- L3: $\gamma\gamma \to K_s^0 K_s^0$

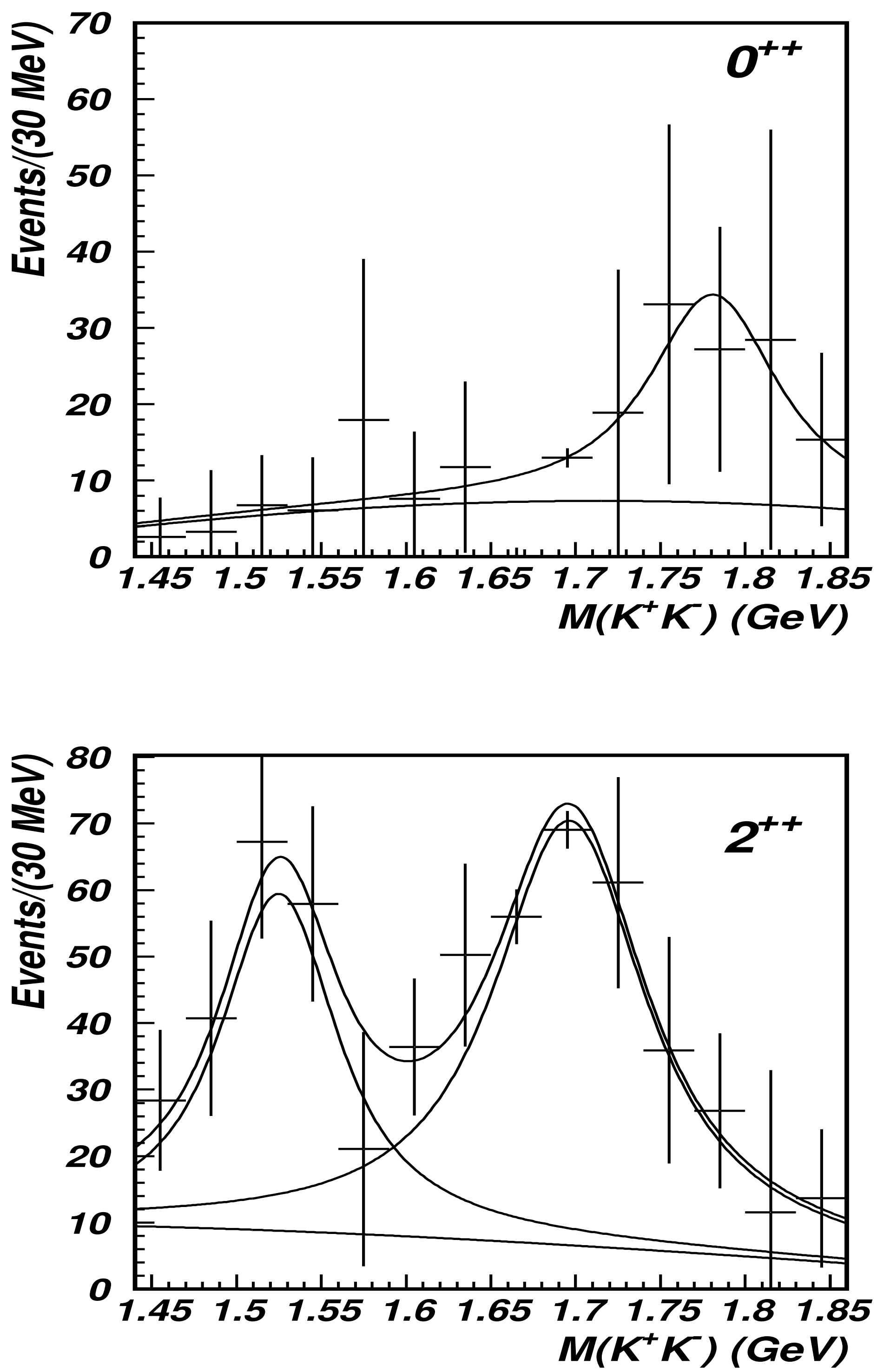
  - mass: 1770 ± 20 MeV
  - width:200 ± 50 MeV
  - significance: 5σ
  - $J^P = 0^+$ preferred

$f_J(1710)$: *BES results:* $J/\psi \to \gamma K^+K^-$

The Moment analysis showed that both 0^{++} and 2^{++} exist in $f_J(1710)$ region.

J^P	Mass (MeV)	Width (MeV)	$\mathcal{B}(J/\psi \to \gamma X \to \gamma K^+K^-)$ $(\times 10^{-4})$
0^+	$1781 \pm 8^{+10}_{-31}$	$85 \pm 24^{+22}_{-19}$	$0.8 \pm 0.1^{+0.3}_{-0.1}$
2^+	$1696 \pm 5^{+9}_{-34}$	$103 \pm 18^{+30}_{-11}$	$2.5 \pm 0.4^{+0.9}_{-0.4}$
$f_2'(1525)$	$1516 \pm 5^{+9}_{-15}$	$60 \pm 23^{+13}_{-20}$	$1.6 \pm 0.2^{+0.6}_{-0.2}$

$f_J(1710)$: BES results: $J/\psi \to \gamma K^+K^-$

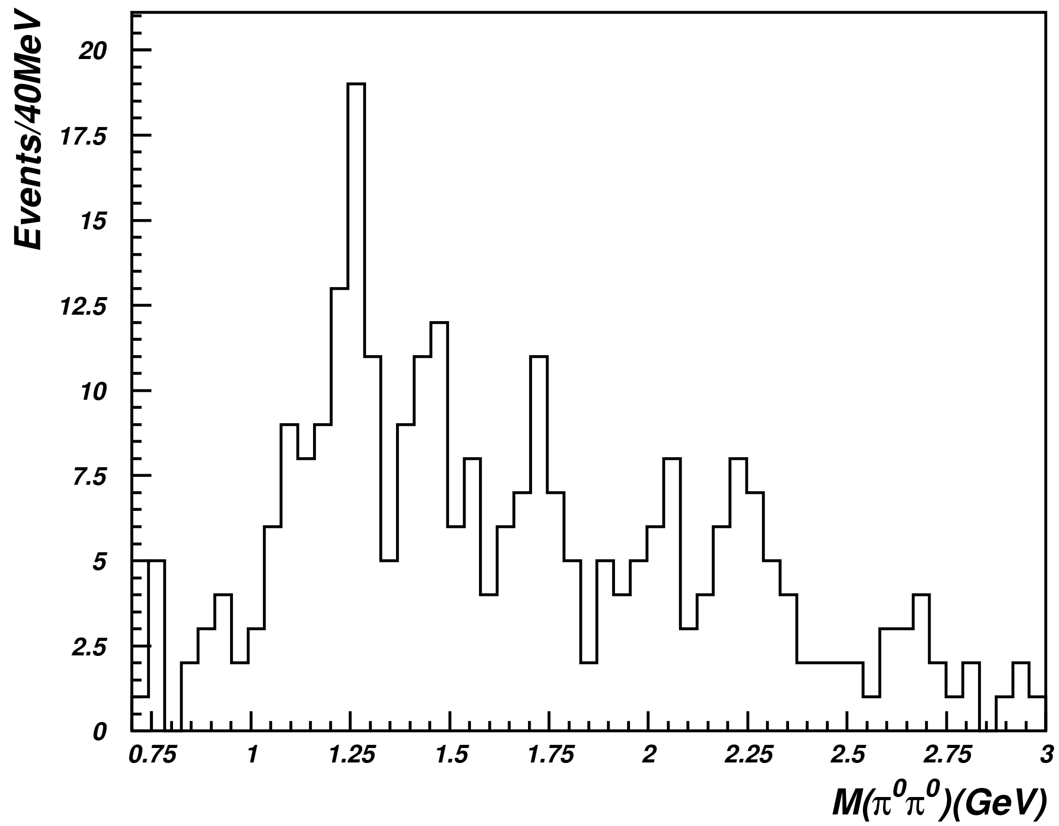


$f_J(1710)$: BES result: $J/\psi \to \gamma 2(\pi^+\pi^-)$

The PWA analysis showed that both 0^{++} and 2^{++} exist in $f_J(1710)$ region.

J^P	Mass (MeV)	Width (MeV)	decay	L or $^{2S+1}L_J$	Signif.	$\mathcal{B}(J/\psi \to \gamma X \to \gamma 4\pi^\pm)$ $(\times 10^{-4})$
0^+	1770^{+30}_{-20}	100^{+60}_{-40}	$\sigma\sigma$	$L=0$	3.3σ	$2.6 \pm 0.4 \pm 0.4$
2^+	1710^{+35}_{-35}	410^{+220}_{-160}	$\rho\rho$	$^5S_2$	3.4σ	$2.1 \pm 0.3 \pm 0.3$

$f_J(1710)$: *signal in* $J/\psi \to \gamma\pi^0\pi^0$



- 3.6σ (18 events) signal in $f_J(1710)$ region
- BW fit (fix width to 100 MeV) gives

$$m = (1720 \pm 39)\,\text{MeV}$$

$$\mathcal{B}(J/\psi \to \gamma f_J(1710) \to \gamma\pi^0\pi^0) = (8.3 \pm 5.3 \pm 2.8) \times 10^{-5}$$

- Spin-parity not determined

$f_J(1710)$: *conclusions from BES*

1. $f_J(1710)$ is not a single state, it contains 0^+ in high mass side and 2^+ in low mass side;

2. in $2(\pi^+\pi^-)$ decays of $f_J(1710)$, 0^+ component dominated by $\sigma\sigma$;

3. $\mathcal{B}(f_J(1710) \to K\bar{K}) > \mathcal{B}(f_J(1710) \to \pi\pi)$;

4. Moment analyses to $J/\psi \to \gamma K\bar{K}$ of MK3 in contradiction to that at BES, indicates the importance of how to deal with the multi-solution problem in this analysis.

5. To take into account $f_2'(1525)$ and $f_J(1710)$ interference and avoid multi-solution problem encountered in moment analysis, PWA analysis to $J/\psi \to \gamma K\bar{K}$ is expected.

PWA analysis of $J/\psi \to \gamma K^+K^-$ is in processing ...

$\xi(2230)$

History:

- first observed by MK3 in $J/\psi \to \gamma K^+K^-$ and $\gamma K_s^0 K_s^0$, No evidence in DM2 analysis, No signal in CBAL inclusive photon spectrum;
- observed by GAMS in $\pi^- p \to \eta\eta' n$;
- observed in by LASS in $K^- p \to K^+K^-\Lambda$ and $K_s^0 K_s^0 \Lambda$.

Exps.	Mass (MeV)	Width (MeV)
$\pi^- p \to \eta\eta' n$ (GAMS(86))	2220 ± 10	<resl. (100)
$J/\psi \to \gamma K^+K^-$ (MK3(86))	2230 ± 15	$26^{+20}_{-16} \pm 17$
$J/\psi \to \gamma K_s^0 K_s^0$ (MK3(86))	2232 ± 10	$18^{+23}_{-15} \pm 10$
$K^- p \to K^+K^-\Lambda$ (LASS(88))	2209 ± 17	60^{+107}_{-57}
$\pi^- p \to K_s^0 K_s^0 n$ (E147(88))	2230 ± 20	80 ± 30

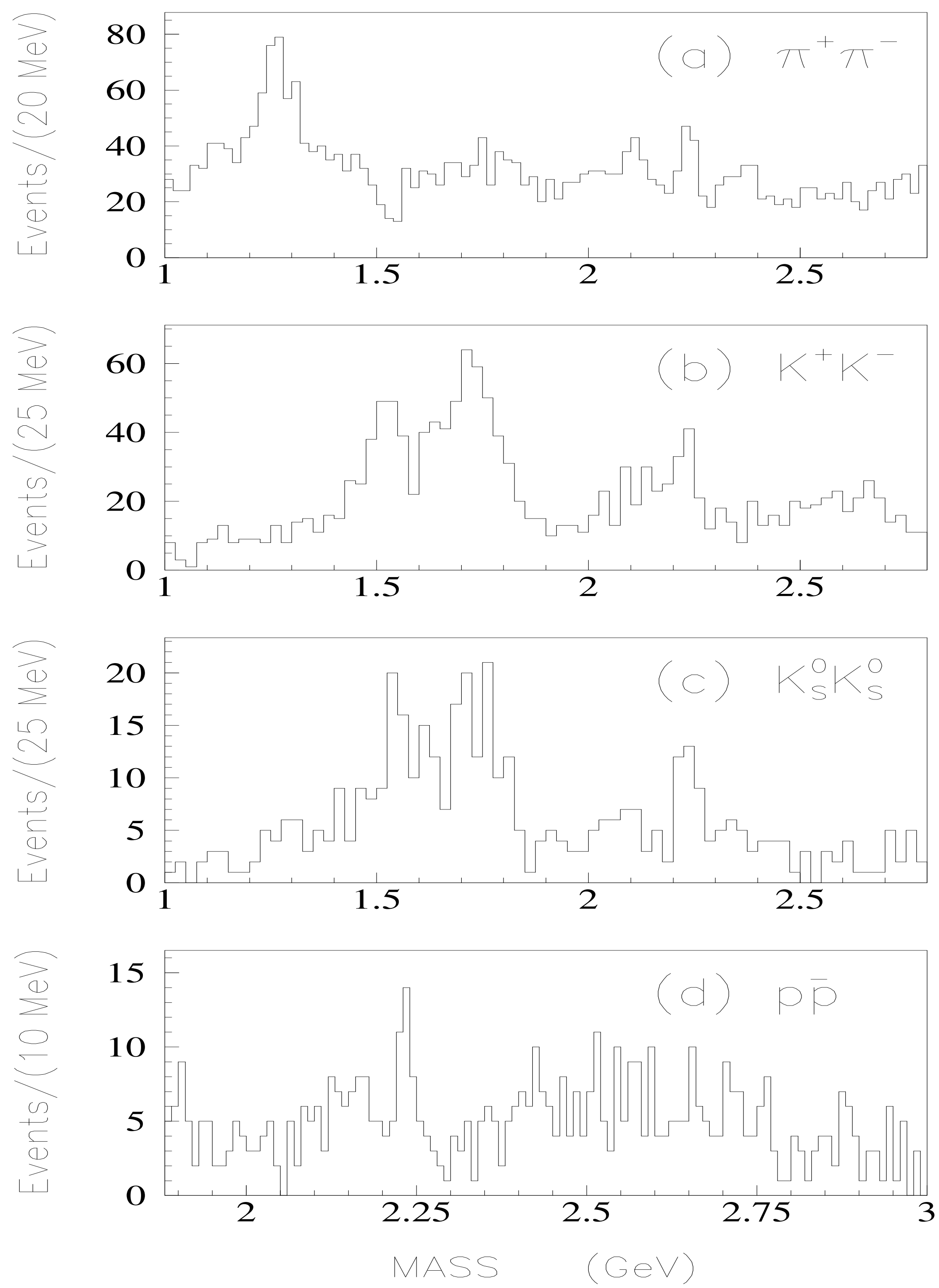
Recent results:

- $p\bar{p}$ annihilations see no signal in $\xi(2230)$ mass region PS202 obtained:

$$\mathcal{B}(\xi \to \bar{p}p) \cdot \mathcal{B}(\xi \to K_s^0 K_s^0) \leq 7.5 \times 10^{-5}$$

- no signal in $\gamma\gamma \to K_s^0 K_s^0$, $\pi^+\pi^-$ (CLEO, L3)

$\xi(2230)$: *BES results*



$\xi(2230)$: *BES results*

Channel	Mass (MeV)	Width (MeV)	$\mathcal{B}(J/\psi \to \gamma\xi \to \gamma X\bar{X})$	signif.
K^+K^-	$2230^{+6}_{-7} \pm 16$	$20^{+20}_{-15} \pm 17$	$(3.3^{+1.6}_{-1.3} \pm 1.2) \times 10^{-5}$	4.1σ
$K^0_s K^0_s$	$2232^{+8}_{-7} \pm 15$	$20^{+25}_{-16} \pm 14$	$(2.7^{+1.1}_{-0.9} \pm 0.8) \times 10^{-5}$	4.0σ
$\pi^+\pi^-$	$2235 \pm 4 \pm 6$	$19^{+13}_{-11} \pm 12$	$(5.6^{+1.8}_{-1.6} \pm 2.0) \times 10^{-5}$	4.6σ
$p\bar{p}$	$2235 \pm 4 \pm 5$	$15^{+12}_{-9} \pm 9$	$(1.5^{+0.6}_{-0.5} \pm 0.5) \times 10^{-5}$	3.8σ
$\pi^0\pi^0$	2246 ± 36	$20(Fixed)$	$(4.5 \pm 2.6 \pm 1.3) \times 10^{-5}$	4.1σ

$J/\psi \to \gamma 2(\pi^+\pi^-)$

2^+ structure at 2215 ± 20 MeV and width 115^{+85}_{-55} observed with statistical significance 2.5σ, decay modes including $f_2(1270)\sigma$, $\sigma\sigma$ and $\rho\rho$.

$$\mathcal{B}(J/\psi \to \gamma f_2 \to \gamma 2(\pi^+\pi^-)) = (1.3 \pm 0.2 \pm 0.2) \times 10^{-4}$$

Due to the large width, hard to be $\xi(2230)$!

$\xi(2230)$: *conclusions from BES*

1. $\xi(2230)$ does exist;
2. $\xi(2230)$ has small width;
3. $\xi(2230)$ decays show flavour symmetry;
4. $2(\pi^+\pi^-)$ result indicates maybe there are more than one 2^+ states in 2230 MeV mass region;
5. combine with JETSET result

   $\mathcal{B}(J/\psi \to \gamma\xi(2230)) \geq (2.3 \pm 0.6) \times 10^{-3}$,

   rich produced in J/ψ radiative decays (even too rich!).
6. large branching ratio decay mode not detected.
7. spin-parity hard to determine currently due to low statistics.

SUMMARY

- Based on 9 million J/ψ events recorded by BES, the gluonia candidates $f_0(1500)$, $f_J(1710)$ and $\xi(2230)$ are studied in their many decay modes using different methods, some interesting results about these states are got, and they will be helpful for the interpretation of the nature of these states and the final recognition of the glueball. Many more works are going on and more information about the light meson spectroscopy is expected in the near future.

- After upgrading, BES has performed the R_{had} measurement at $\sqrt{s} = 2 \sim 5$ GeV successfully, and it will take more J/ψ data from this autumn on. With higher statistics ($\sim 5 \times 10^7$) and better detector performance, more contributions will be made to the test and development of QCD at low energy.