New resonance X(1835) and Enhanced structures at BESII

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- Introduction
- Strong enhancement in $J/\psi \to \gamma p\bar{p}$
- New resonance X(1835) in $J/\psi \to \gamma\pi^+\pi^-\eta'$
- Enhanced structure in $J/\psi \to \gamma\omega\phi$

J/ψ radiative decays

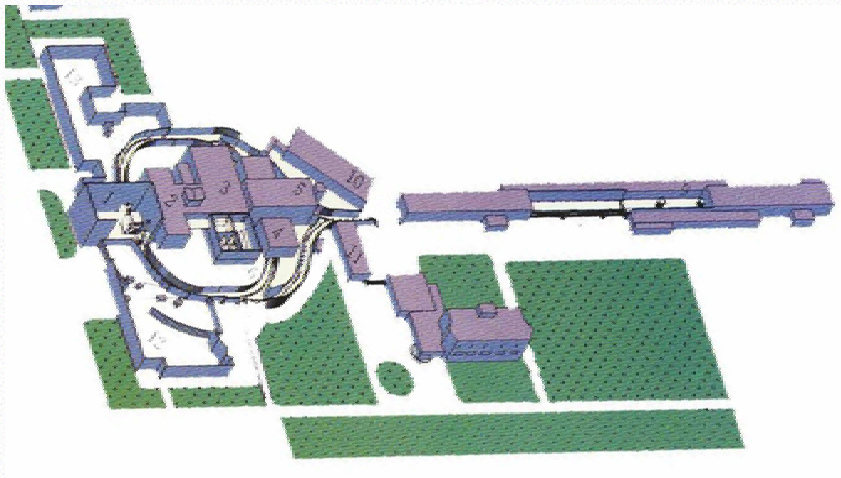
- New observation of broad 1^{--} resonance in $J/\psi \to K^+K^-\pi^0$
- Other structures in $J/\psi \to pK^-\bar{\Lambda}$
- σ meson from $J/\psi \to \omega\pi^+\pi^-$
- κ meson from $J/\psi \to \bar{K}^*(892)^0 K^+\pi^-$

J/ψ hadronic decays

- Summary

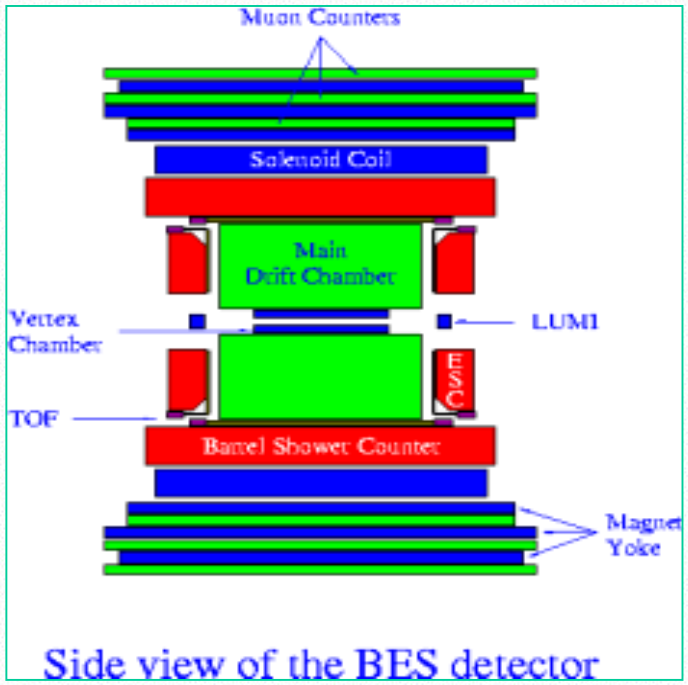
The Beijing Electron Positron Collider (BEPC)

A unique e^+e^- machine operating in 2-5 GeV since 1989

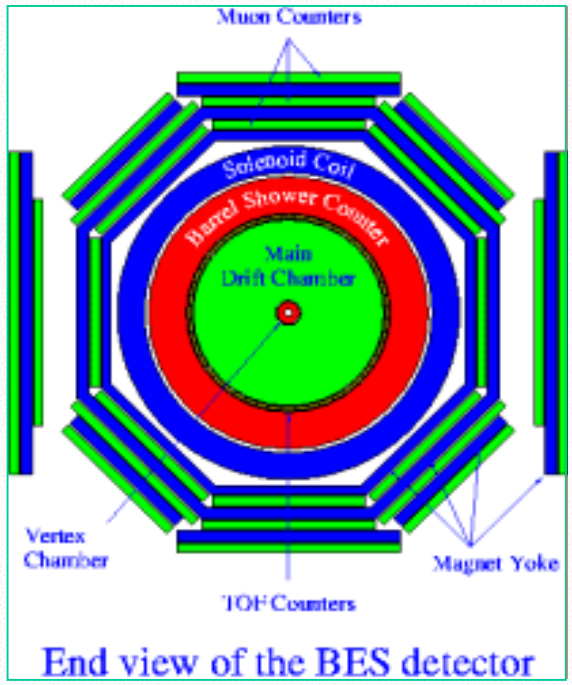


- **Single bunch, E_{cm}~2-5 GeV,L ~ 1x10^{31} /cm^2·s at 3.68 GeV**
- **5-6 months/year for HEP**
- **140mA @ 2.2 GeV, 3 month/year for synchrotron radiation run**

BESII Detector



Side view of the BES detector



End view of the BES detector

VC: σ_{xy} = 100 μm

MDC: σ_{xy} = 220 μm

$\sigma_{dE/dx}$ = 8.5 %

$\Delta p/p = 1.7\%\sqrt{(1+p^2)}$

TOF: σ_T = 180 ps

BSC: $\Delta E/\sqrt{E}$ = 22 %

σ_ϕ = 7.9 mr

σ_z = 2.3 cm

μ counter: $\sigma_{r\phi}$ = 3 cm

σ_z = 5.5 cm

B field: 0.4 T

Introduction

- Established picture by QCD and Quark model
  - Strong interaction among quarks mediated by gluon
  - Color confinement : hadrons as color singlets
  - Hadrons consist of constituent quarks : $q\bar{q}$ or qqq
  - Most hadrons are consistent with predicted spectroscopy

$q\bar{q}$ assignments (PDG)

Light mesons

Heavy mesons

$n\,^{2s+1}\ell_J$	J^{PC}	$I=1$ $u\bar{d},\ \bar{u}d,\ \frac{1}{\sqrt{2}}(d\bar{d}-u\bar{u})$	$I=\frac{1}{2}$ $u\bar{s},\ d\bar{s};\ \bar{d}s,\ -\bar{u}s$	$I=0$ f'	$I=0$ f
$1\,^1S_0$	0^{-+}	π	K	η	$\eta'(958)$
$1\,^3S_1$	1^{--}	$\rho(770)$	$K^*(892)$	$\phi(1020)$	$\omega(782)$
$1\,^1P_1$	1^{+-}	$b_1(1235)$	K_{1B}[†]	$h_1(1380)$	
$1\,^3P_0$	0^{++}	$a_0(1450)$	$K_0^*(1430)$	$f_0(1710)$	
$1\,^3P_1$	1^{++}	$a_1(1260)$	K_{1A}[†]	$f_1(1420)$	
$1\,^3P_2$	2^{++}	$a_2(1320)$	$K_2^*(1430)$	$f_2'(1525)$	
$1\,^1D_2$	2^{-+}	$\pi_2(1670)$	$K_2(1770)$[†]	$\eta_2(1870)$	
$1\,^3D_1$	1^{--}	$\rho(1700)$	$K^*(1680)$[‡]		
$1\,^3D_2$	2^{--}		$K_2(1820)$[‡]		
$1\,^3D_3$	3^{--}	$\rho_3(1690)$	$K_3^*(1780)$	$\phi_3(1850)$	
$1\,^3F_4$	4^{++}	$a_4(2040)$	$K_4^*(2045)$		
$1\,^3G_5$	5^{--}	$\rho_5(2350)$			
$1\,^3H_6$	6^{++}	$a_6(2450)$			
$2\,^1S_0$	0^{-+}	$\pi(1300)$	$K(1460)$	$\eta(1475)$	
$2\,^3S_1$	1^{--}	$\rho(1450)$	$K^*(1410)$[‡]	$\phi(1680)$	

$n\,^{2s+1}\ell_J$	J^{PC}	$I=0$ $c\bar{c}$	$I=0$ $b\bar{b}$	$I=\frac{1}{2}$ $c\bar{q},\ \bar{c}q;\ b\bar{q},\ \bar{b}q$	$I=0$ $c\bar{c};\ b\bar{c}$	$I=\frac{1}{2}$ $b\bar{q},\ \bar{b}q;\ b\bar{q},\ \bar{b}q$	$I=0$ $b\bar{s};\ \bar{b}s$	$I=0$ $b\bar{c};\ \bar{b}c$
$1\,^1S_0$	0^{-+}	$\eta_c(1S)$	$\eta_b(1S)$	D	$D_s^{\pm}$	B	B_s	$B_c^{\pm}$
$1\,^3S_1$	1^{--}	$J/\psi(1S)$	$\Upsilon(1S)$	D^*	$D_s^{*\pm}$	B^*	$B_s^{*\pm}$	
$1\,^1P_1$	1^{+-}	$h_c(1P)$		$D_1(2420)$	$D_{s1}(2536)^{\pm}$			
$1\,^3P_0$	0^{++}	$\chi_{c0}(1P)$	$\chi_{b0}(1P)$		$D_{sJ}^*(2317)^{\pm}$[†]			
$1\,^3P_1$	1^{++}	$\chi_{c1}(1P)$	$\chi_{b1}(1P)$		$D_{sJ}(2460)^{\pm}$[†]			
$1\,^3P_2$	2^{++}	$\chi_{c2}(1P)$	$\chi_{b2}(1P)$	$D_2(2460)$	$D_{s2}^*(2573)^{\pm}$			
$1\,^3D_1$	1^{--}	$\psi(3770)$						
$2\,^1S_0$	0^{-+}	$\eta_c(2S)$						
$2\,^3S_1$	1^{--}	$\psi(2S)$	$\Upsilon(2S)$					
$2\,^3P_{0,1,2}$	$0^{++},1^{++},2^{++}$		$\chi_{b0,1,2}(2P)$					

Introduction

- Unestablished predictions by QCD & QCD-inspired models
  - Multi-quark states : $q\bar{q}q\bar{q}$, $q\bar{q}qqq$
  - Self-coupling of gluons
  - New forms of matter : glueball (gg) and hybrid ($q\bar{q}g$)
  - Exotic states (molecule of meson-meson, baryon-baryon)

Updated LQCD Predictions

Y. Chen et al., Phys. Rev. D 73, 014516(2006)

First excited state (2^{++})

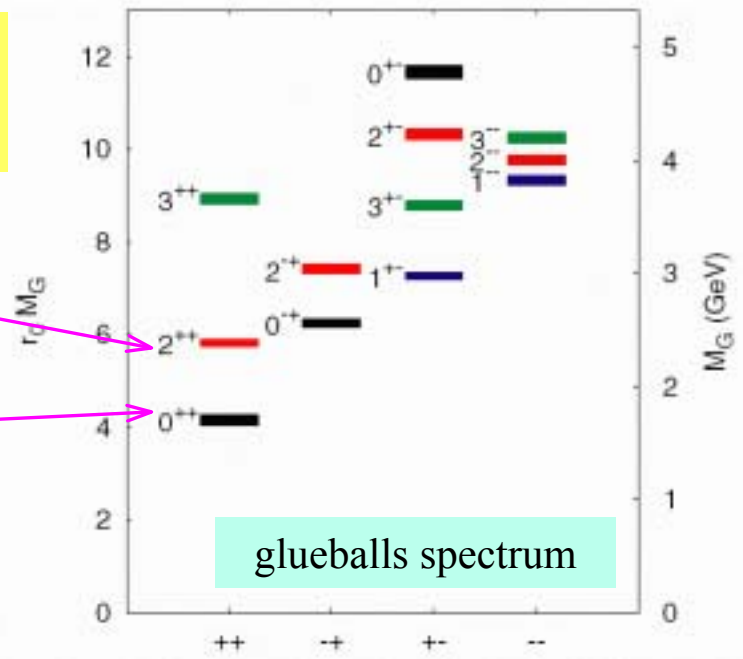
2390 ±124 MeV

Lightest state (0^{++})

1711±94 MeV

Lightest hybrid ($J^{PC} = 1^{-+}$) : 1.9 GeV

C.Michael, hep-ph/0101287 (2001)



Introduction

- Mixing effect between glueball and $q\bar{q}$ state
  - 0^{++} meson may mix with lightest glueball
  - Mass of physical state could be altered by mixing

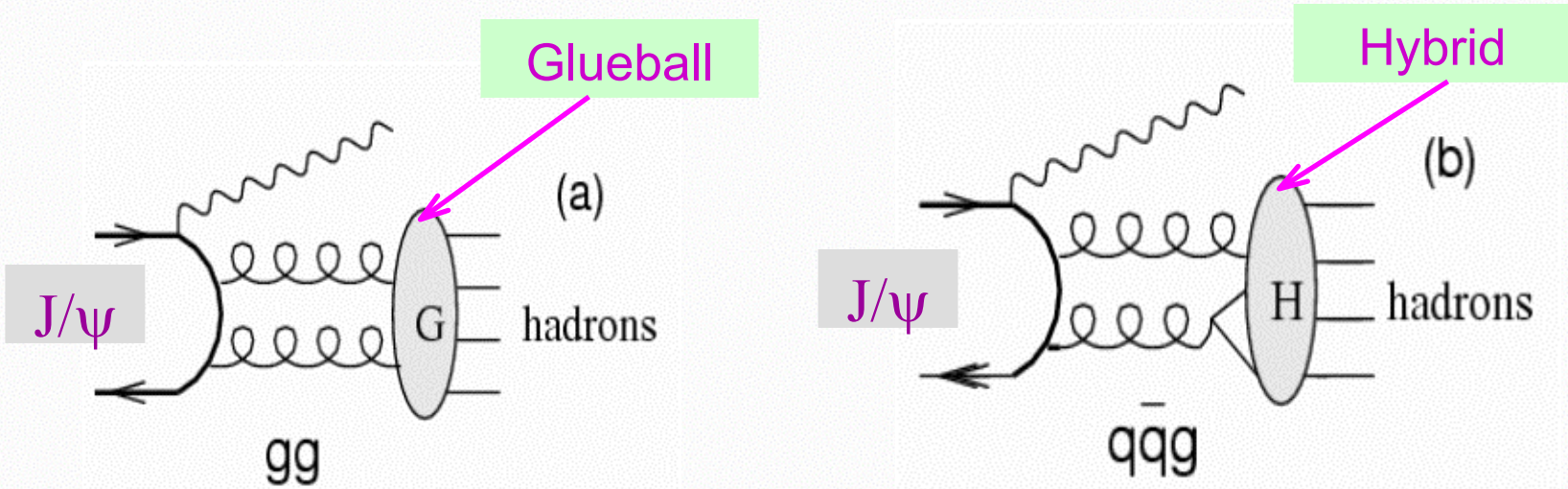
C.Amsler and F.E. Close, Phys. Rev. D53, 295(1996);

F.E. Close and A. Kirk, Eur. Phys. J. C21, 531 (2001).

- Search for hybrid meson with exotic J^{PC}
  - Exotic $J^{PC} = 2^{+-},\ 1^{-+},\ 0^{+-}\ and\ 0^{--}$ (absent in $q\bar{q}$ meson list).
  - Predictions on hybrid mass
    - Around 1.9 GeV from gluon flux tube model
    - Lightest hybrid (1^{-+}) is 1.9 GeV by LQCD but 1.4 GeV by Bag model

Introduction

- Good hunting ground for glueball and hybrid
  - J/ψ decays may provide gluon-enriched sample
  - Particularly, J/ψ radiative decays

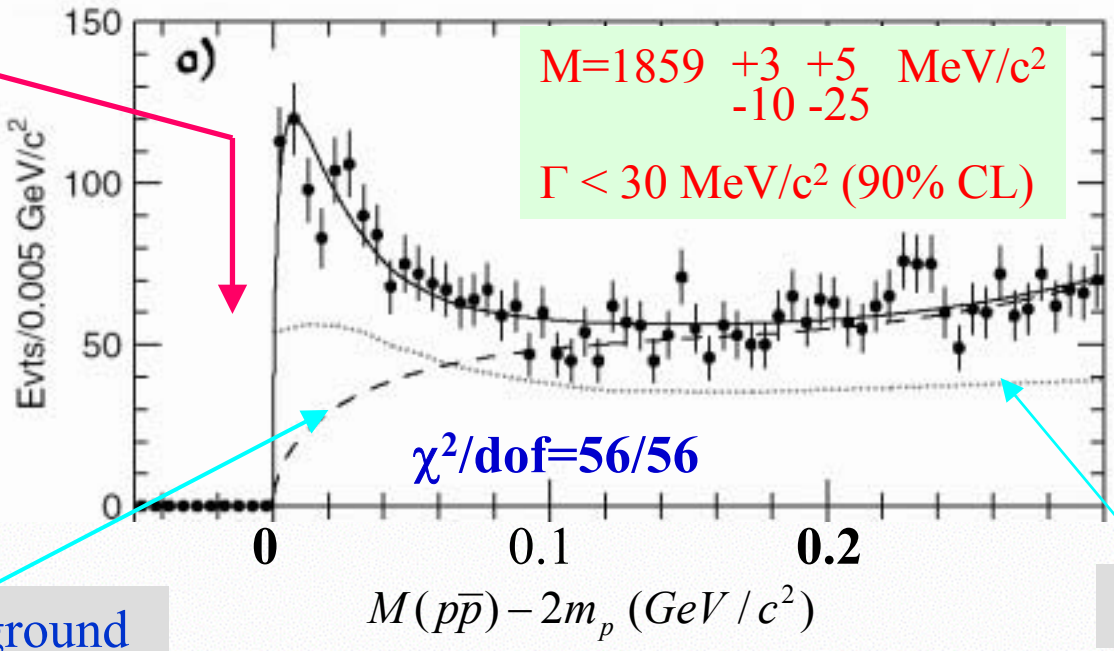


- as well as for exotics
  - Molecule of meson-meson and baryon-baryon
  - including h-h bound state

Strong enhancement in $J/\psi \to \gamma p\bar{p}$

Fit to $J/\psi \to \gamma p\bar{p}$ without FSI

- Fit to $p\bar{p}$ enhancement
  - Signal : acceptance-weighted S-wave BW function
  - Background : fixed shape from $J/\psi \to \pi^0 p\bar{p}$ phase-space MC



fitted peak position

Fitted background

acceptance

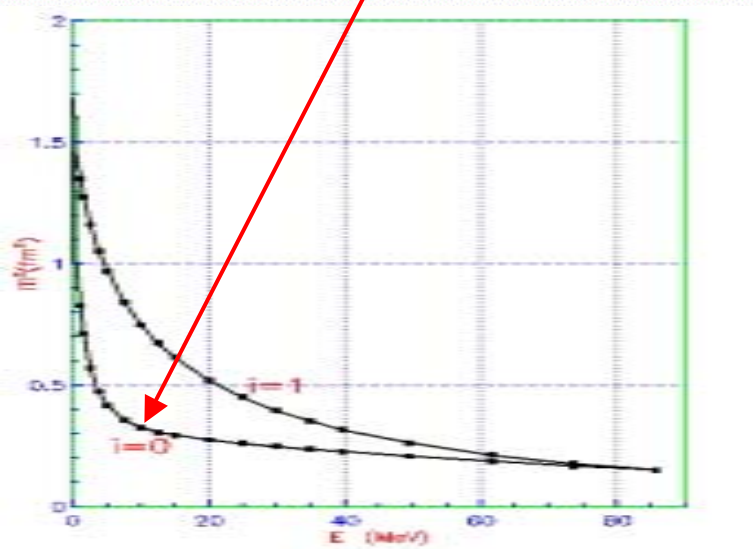
BES Collab., Phys. Rev. Lett., 91, 022001 (2003)

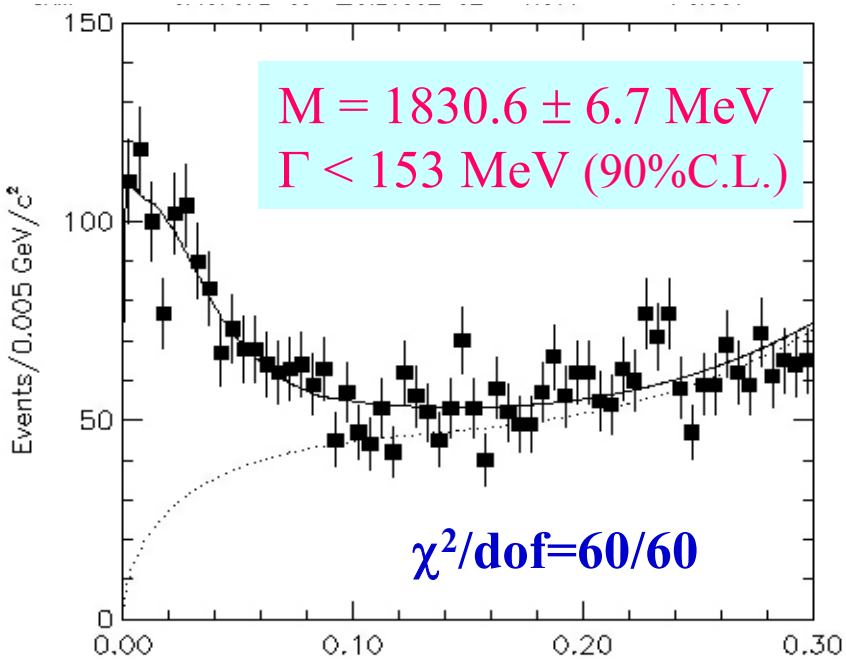
Strong enhancement in $J/\psi \to \gamma p\bar{p}$

S-wave BW fit to $p\bar{p}$ with FSI

Include FSI curve (I=0) from

A.Sirbirtsev et al. Phys Rev D71: 054010(2005)





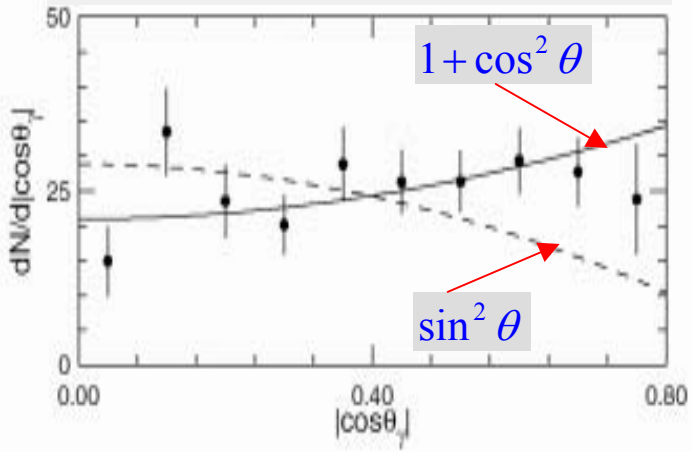
$M_{p\bar{p}} - 2m_p\ (GeV/c^2)$

Strong enhancement in $J/\psi \to \gamma p\bar{p}$

Fits to P-wave BW and known resonances

- S-wave $p\bar{p}$ with even C parity :
  0^{-+} pseudoscalar
- Fit with P-wave BW function (0^{++})
  but without FSI : χ^2/dof=59/56
- Both scalar and pseudoscalar have same photon angular distribution of $1+\cos^2\theta$.

|cosθ| distribution for photons
- background-subtracted
- acceptance-corrected



Two known spin-zero resonances can be ruled out.

$J^{PC} = 0^{-+}$

$\eta(1760)$: $\chi^2/\text{dof} = 323/58$

$\pi(1800)$: χ^2/dof is even worse

Strong enhancement in $J/\psi \to \gamma p\bar{p}$

X(1860) strongly coupled to $p\bar{p}$

- BES measured:

$$Br(\mathrm{J}/\psi \to \gamma\, \mathrm{X}(1860)) \cdot Br(\mathrm{X}(1860) \to \mathrm{p\bar{p}}) = (7.0 \pm 0.4^{+1.9}_{-0.8}) \times 10^{-5}$$

- From Crystal Ball result, we estimate:

$$Br(J/\psi \to \gamma X(1860)) < 2 \times 10^{-3}$$

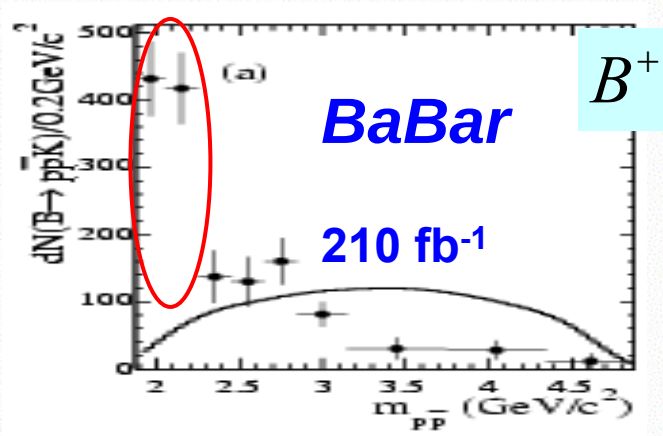
- We would have:

$$Br(X(1860) \to p\bar{p}) > 4\%$$

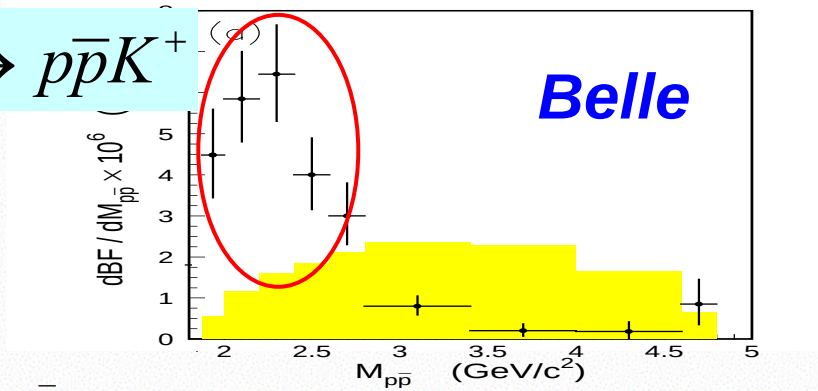
- It indicates that X(1860) has large coupling to $p\bar{p}$
- Interesting that it is observed in J/ψ radiative decay

Strong enhancement in $J/\psi \to \gamma p\bar{p}$

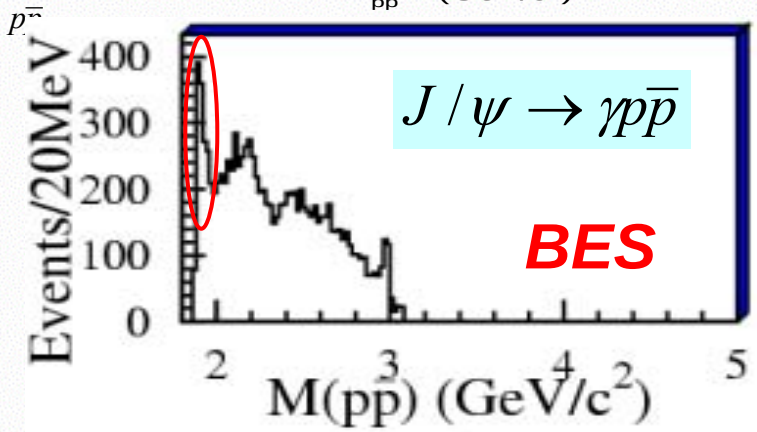
$p\bar{p}$ structure in B decay



$B^+ \to p\bar{p}K^+$



Broad $p\bar{p}$ structure in B decay while enhancement in J/psi decay is much narrower.



- Broad $p\bar{p}$ structure in B decay is attributed to quark fragmentation effect.

Strong enhancement in $J/\psi \to \gamma p\bar{p}$

No $p\bar{p}$ structure in $\Upsilon(1S) \to \gamma\, p\bar{p}$

- Search for $X \to p\bar{p}$ at $\Upsilon(1S)$ by CLEO (PRD73, 032001 (2006))
  - QCD prediction for light meson production :
    $$r = Br(\Upsilon(1S) \to \gamma X) / Br(J/\psi \to \gamma X) \cong 4\%$$
  - measured upper limit : $r < 0.7\%$ $(90\% C.L.)$
    using BES's $Br(J/\psi \to \gamma X, X \to p\bar{p}) = 7 \times 10^{-5}$ as input.

No enhancement near $p\bar{p}$ threshold

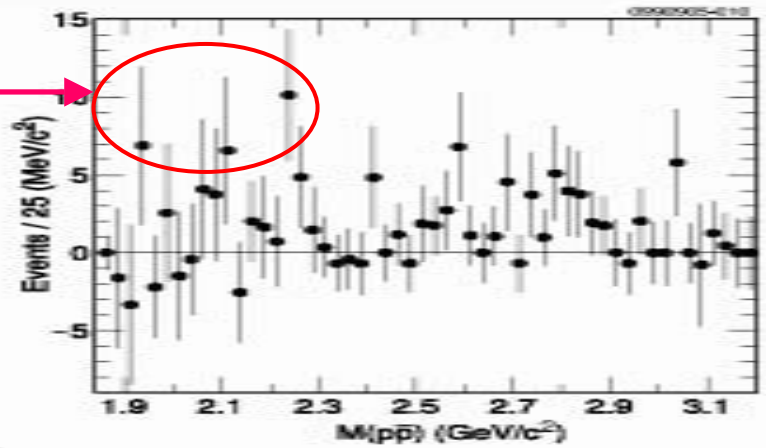


FIG. 7: Invariant mass of $p\bar{p}$ from $\Upsilon(1S) \to \gamma p\bar{p}$.

Discussion

- Broad $p\bar{p}$ in B decays at Babar and Belle
  - can be interpreted by quark fragmentation.
- No $p\bar{p}$ structure in $\Upsilon(1S) \to \gamma\, p\bar{p}$ at CLEO
  - PDG gives
    - $Br(J/\psi \to \gamma\eta') = 4.3\times10^{-3}$ and $Br(\Upsilon(1S) \to \gamma\eta') < 1.6\times10^{-5}$
  - $J/\psi \to \gamma X(1860)$ from BES could have similar decay mechanism as $J/\psi \to \gamma\eta'$.
- X(1860) is a possible candidate for $p\bar{p}$ bound state
  - deuteron is a molecule of proton-neutron
  - $p\bar{p}$ can be weakly bound as baryonium

Observation of New X(1835) in

$$J/\psi \to \gamma \pi^+ \pi^- \eta'$$

where $\eta' \to \pi^+ \pi^- \eta \to \pi^+ \pi^- \gamma\gamma$ *and* $\eta' \to \gamma\rho \to \gamma\pi^+ \pi^-$

- Baryonium interpretation of $p\bar{p}$ structure requires
  - a new resonance around 1.86 GeV, and
  - observation via other decay mode
  - containing gluon component or η' in final state

New resonance X(1835)

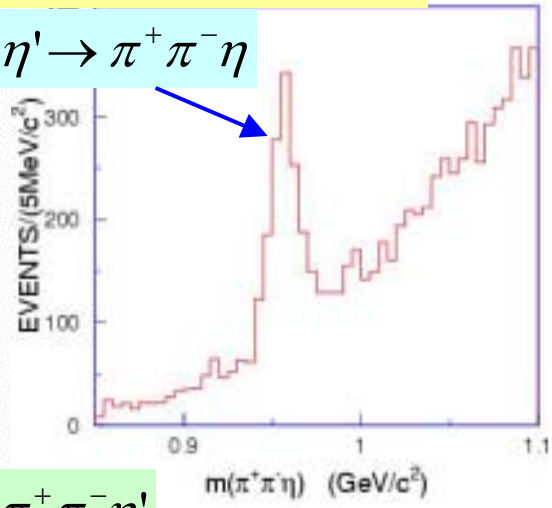
Analysis of $J/\psi \to \gamma \pi^+\pi^-\eta'(\eta' \to \pi^+\pi^-\eta)$

Event selection

- Charged track with good helix fit
- C.L. for π/K/p hypothesis
  - TOF and dE/dx combined
  - at least three pions identified
- 4-c kinematic fit
  - $\chi^2(\pi\pi\pi\pi\gamma\gamma) < 8$
  - $\chi^2(\pi\pi\pi\pi\gamma\gamma) < \chi^2(KK\pi\pi\gamma\gamma)$

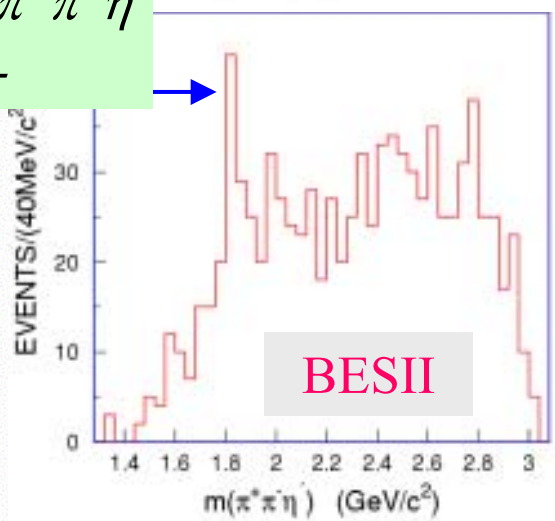
- η mass cut
- 5-c kinematic fit with η mass constrained
  - to improve $M_{\pi^+\pi^-\eta}$ resolution

$\eta' \to \pi^+\pi^-\eta$



$X(1835) \to \pi^+\pi^-\eta'$

5.1σ



New resonance X(1835)

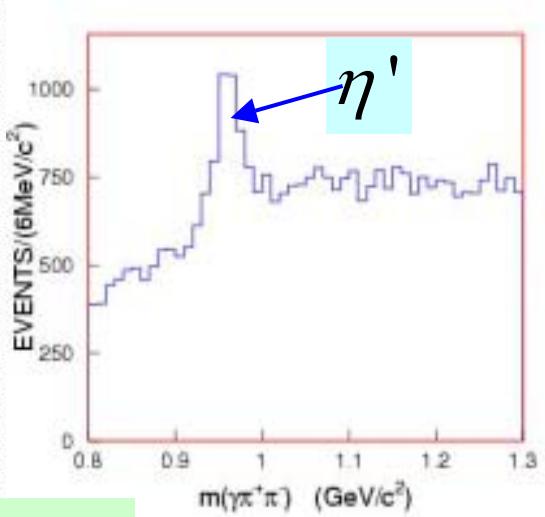
Analysis of $J/\psi \to \gamma\pi^+\pi^-\eta' \quad (\eta' \to \gamma\rho)$

Event selection

- Charged track
- π/K/p separation
- 4-c kinematic fit

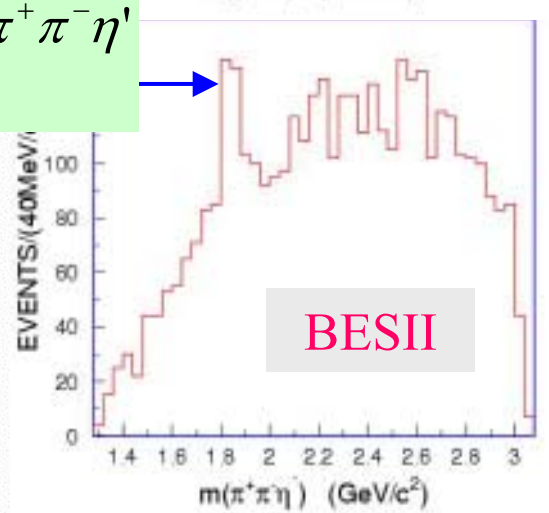
same as $\eta' \to \pi^+\pi^-\eta$

- π / η / $\omega \to \gamma\pi^0$ mass cut to suppress backgrounds from
  - $J/\psi \to \pi^+\pi^-\pi^+\pi^-\pi^0$
  - $J/\psi \to \pi^+\pi^-\pi^+\pi^-\eta$
  - $J/\psi \to \pi^+\pi^-\pi^+\pi^-\omega$
- η' *and* ρ mass cut
- Combination with minimum of $|M_{\gamma\pi^+\pi^-} - m_{\eta'}|$ is selected



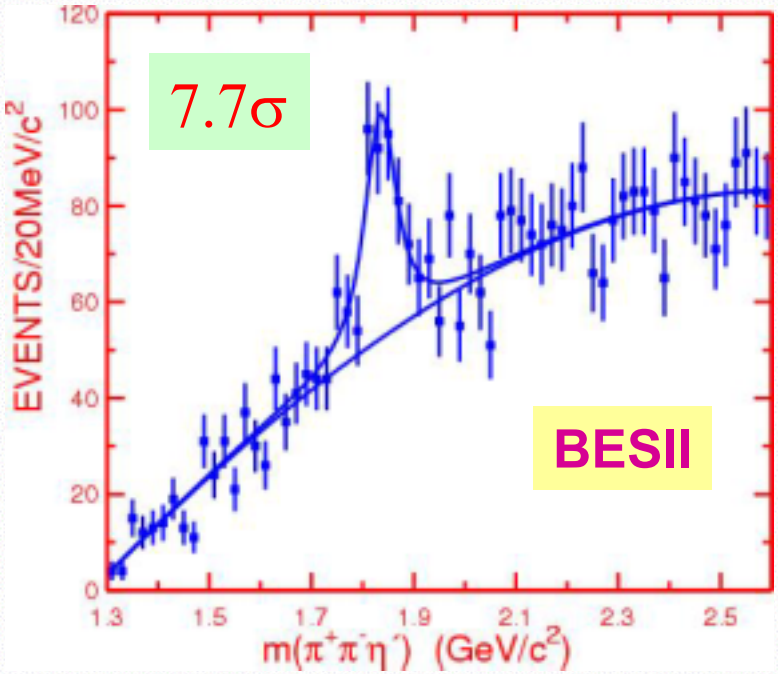
$X(1835) \to \pi^+\pi^-\eta'$

6.0σ



New resonance X(1835)

Fitting to $\pi^+\pi^-\eta'$ mass spectrum



The $\pi^+\pi^-\eta'$ mass spectrum for η' decaying into $\eta'\to\pi^+\pi^-\eta$ and $\eta'\to\gamma\rho$

$$N_{obs} = 264 \pm 54$$

$$M = 1833.7 \pm 6.1 \pm 2.7 MeV$$

$$\Gamma = 67.7 \pm 20.3 \pm 7.7 MeV$$

$$B(J/\psi \to \gamma X)B(X \to \pi^+\pi^-\eta') = (2.2 \pm 0.4 \pm 0.4) \times 10^{-4}$$

BES Collab., Phys. Rev. Lett., 95, 262001 (2005)

$$c.f.: \quad B(J/\psi \to \gamma X)B(X \to p\bar{p}) = (7.0 \pm 0.4^{+1.9}_{-0.8}) \times 10^{-5}$$

New resonance X(1835)

X(1835) and X(1860) could be same state

- S-wave BW fit to $p\bar{p}$ mass spectrum is modified to include
  - effect of FSI (zero Isospin S-wave)
  - yields $M = 1830.6 \pm 6.7\ MeV/c^2$, $\Gamma < 153\ MeV/c^2$ (90% C.L.)
- $\pi^+\pi^-\eta'$ is a favored decay mode for $p\bar{p}$ bound state according to "G.J. Ding and M.L. Yan, Phys. Rev. C 72, 015208 (2005)".
- Both favor 0^{-+}, but needs to be measured as an important test.
- Other interpretations of X(1835) are not excluded.

Observation of ωϕ threshold enhancement

- We studied doubly OZI suppressed process:

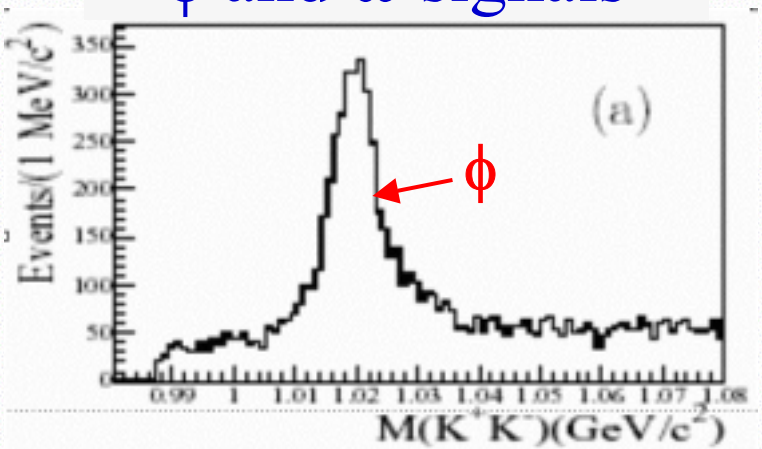
$$J/\psi \to \gamma + \omega + \phi$$

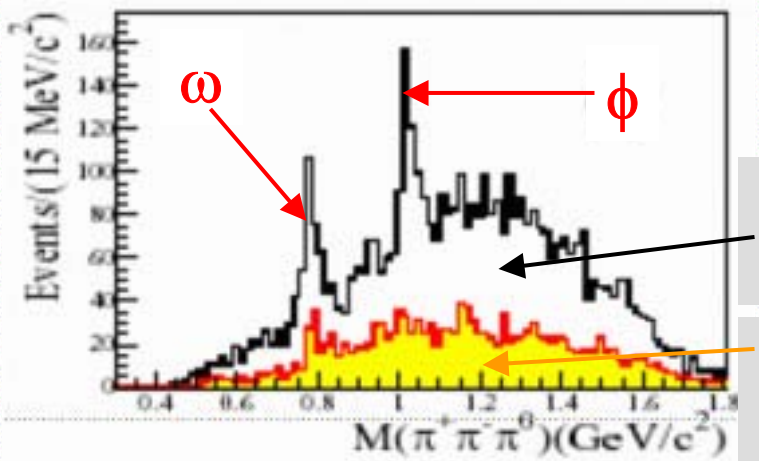
$$\omega \to \pi^+\pi^-\pi^0 \qquad \phi \to K^+K^-$$

Enhanced structure in $J/\psi \to \gamma\omega\phi$

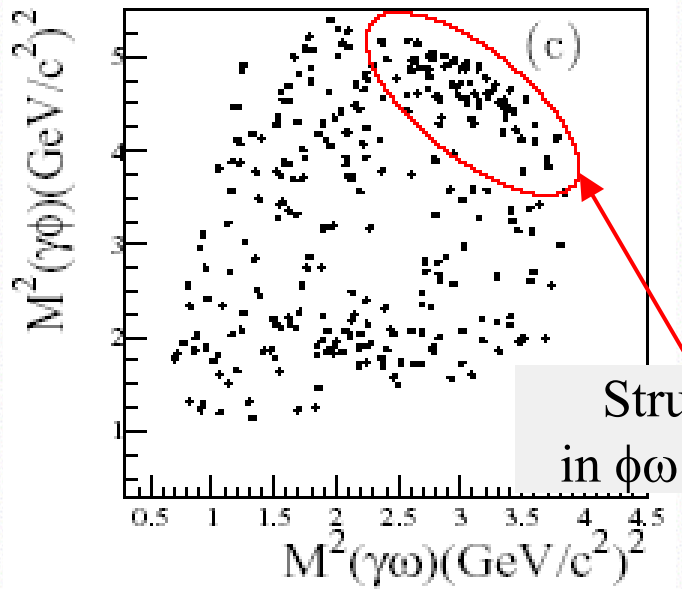
Selected candidate events at BESII

ϕ and ω signals





Dalitz Plot



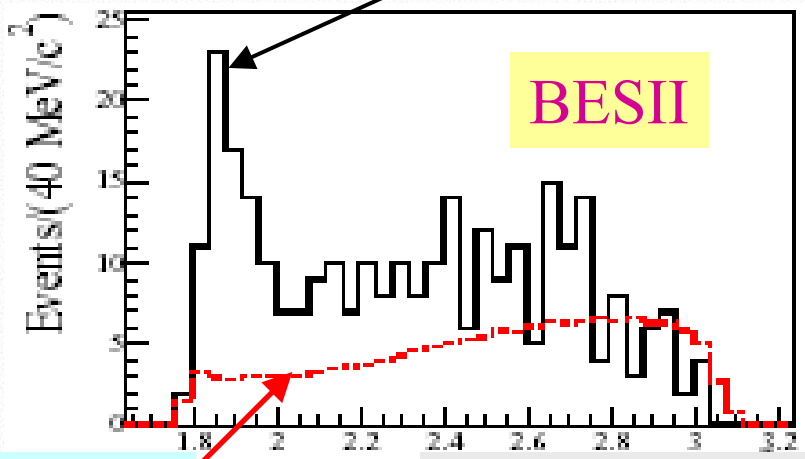
Structure in $\phi\omega$ system

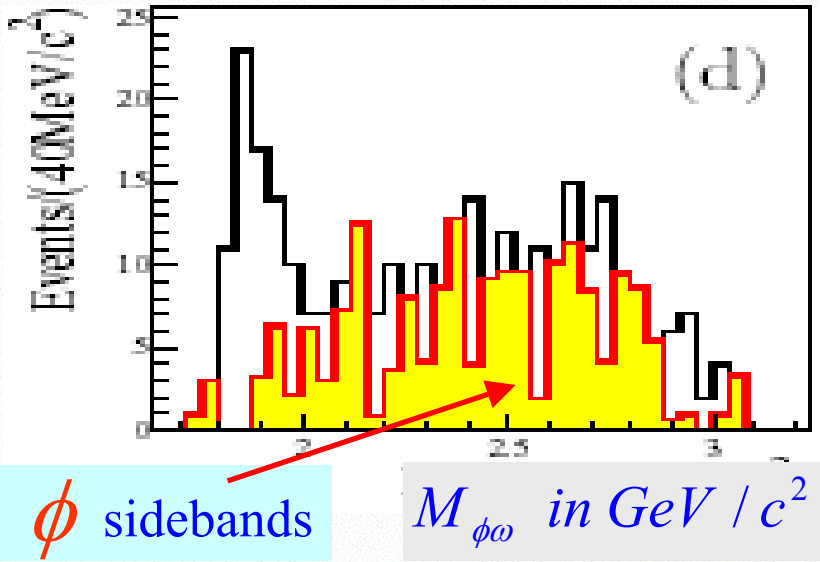
Events with $m_{K^+K^-}$ in ϕ region at recoil side

Events with $m_{K^+K^-}$ in ϕ sideband region

Enhanced structure in $J/\psi \to \gamma\omega\phi$

Clear $\phi\omega$ threshold enhancement





No enhanced structure near $\phi\omega$ threshold from sideband

Enhanced structure in $J/\psi \to \gamma\omega\phi$

Results

- The double OZI decay of J/ψ→γωϕ are observed.
- Significant ωϕ structure (> 10σ) is found near mass threshold.
- PWA : Covariant helicity coupling amplitude method

  N. Wu and T.N. Ruan, commun. Theor. Phys.(Beijing) 35, 547(2001) and 37, 309(2002)
- Best fit with a S-wave BW function gives
  - mass $1812^{+19}_{-26} \pm 18 MeV/c^2$, width 105±20±28 MeV/c^2
  - product branching fraction

$$B(J/\psi \to \gamma X)B(X \to \omega\phi) = (2.61 \pm 0.27 \pm 0.65) \times 10^{-4}$$

- Fits with S, P, D-waves for γX and ωϕ systems are studied.
- The enhancement X(1810) favors 0^{++} and S-wave for ωϕ
- Its mass and width does not fit to any known scalars in PDG.

BES Collab., Phys.Rev.Lett.96:162002,2006.

Enhanced structures in J/ψ hadronic decays

Broad structure in $J/\psi \to K^+K^-\pi^0$

New observation of a broad 1^{--} resonant structure of K^+K^- near 1.5 GeV/c^2

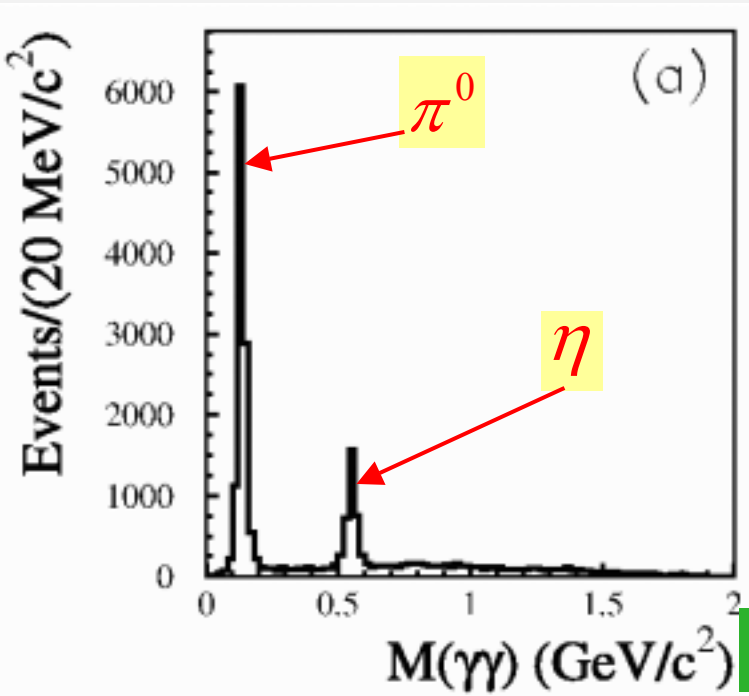
Preliminary

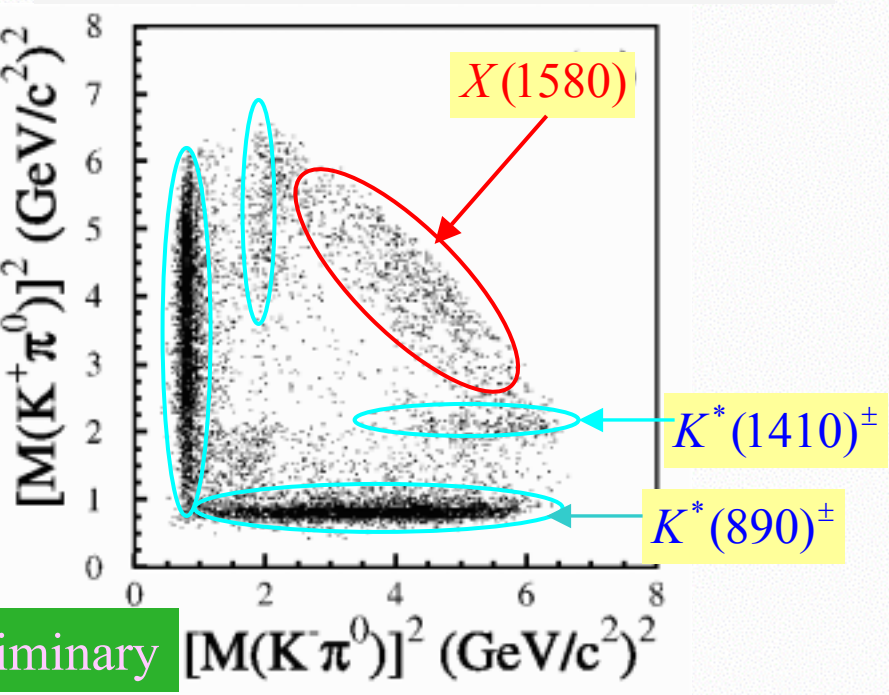
Broad structure in $J/\psi \to K^+K^-\pi^0$

Dalitz plot in data

Event selection

- C.L. for π/K/p hypothesis
  - TOF and dE/dx combined
  - both Kaons identified
- π^0 mass cut
- 4-c kinematic fit
  - $\chi^2(K^+K^-\gamma\gamma) < 10$
  - best χ^2 is chosen if more photons





Preliminary

Broad structure in $J/\psi \to K^+K^-\pi^0$

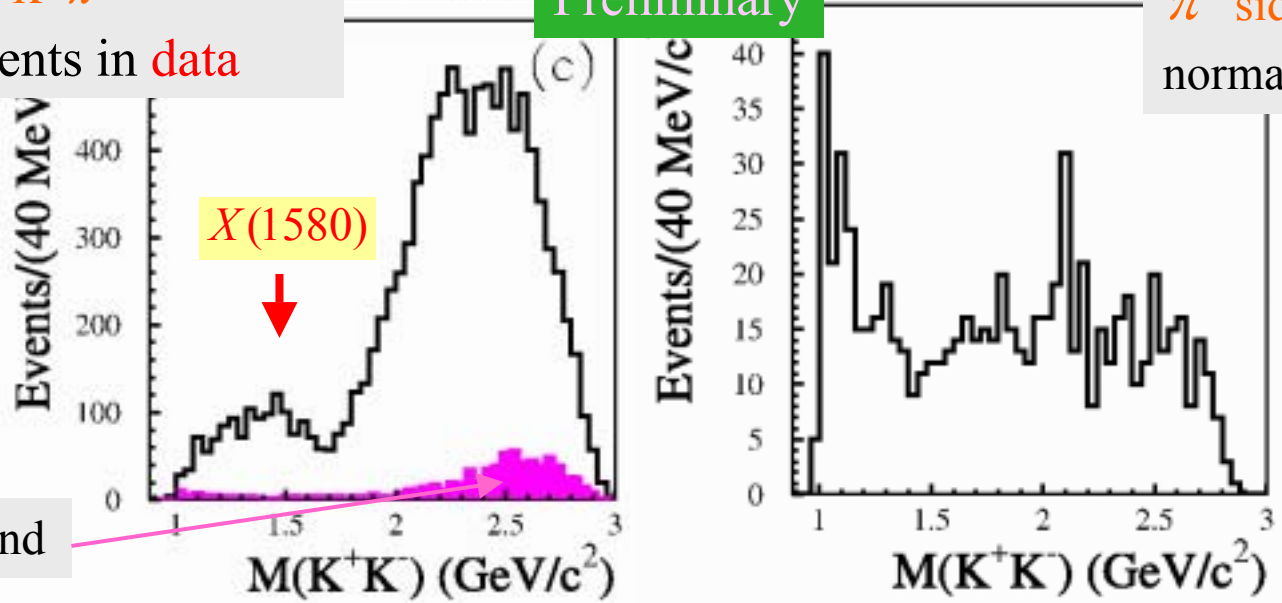
Observed invariant mass of K^+K^- system from $K^+K^-\pi^0$ final states

- Background study
  - π^0 sideband (2%)
  - dominant (6%) from $\rho\pi$
- negligible from $J/\psi \to \omega\pi^+\pi^-$ and $J/\psi \to \gamma\eta_C \to \gamma K^+K^-\pi^0$

$K^+K^-\pi^0$ candidate events in data

Preliminary

Background from π^0 sideband (un-normalized) in data



Broad structure in $J/\psi \to K^+K^-\pi^0$

Partial Wave Analysis of $K^+K^-\pi^0$ events

Preliminary

- Five decay modes are included :

  $J/\psi \to (X, \rho(1700))\pi_0,\ (X,\rho) \to K^+K^-;$

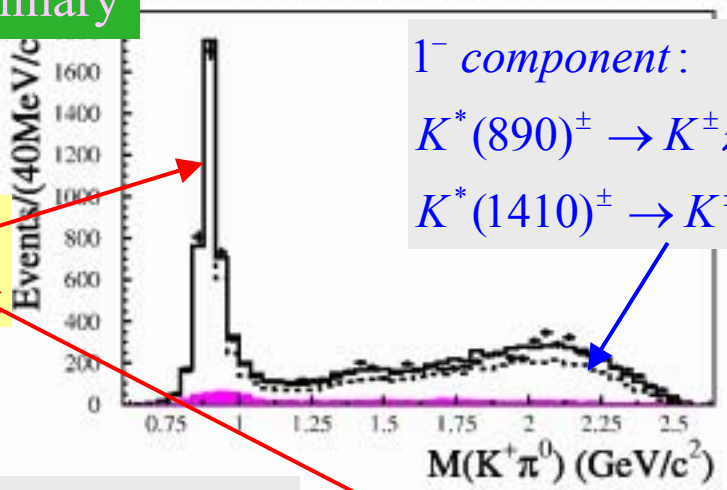
  $J/\psi \to (K^*)^{\pm}K^{\mp}, (K^*)^{\pm} \to K^{\pm}\pi^0,$

  where $K^* = K^*(890), K^*(1410);$

  Phase space.

points : data

hist : PWA fit



1^- *component* :

$K^*(890)^{\pm} \to K^{\pm}\pi^0$

$K^*(1410)^{\pm} \to K^{\pm}\pi^0$

- Amplitudes are defined by

  Covariant tensor formalism

B.S. Zhou and D.V. Bugg, Eur. Phys. J. A16, 537(2003)

- BW with energy-dependent width

$$BW(s) = \frac{1}{s - M_R^2 + i\sqrt{s}\Gamma_R(s)};$$

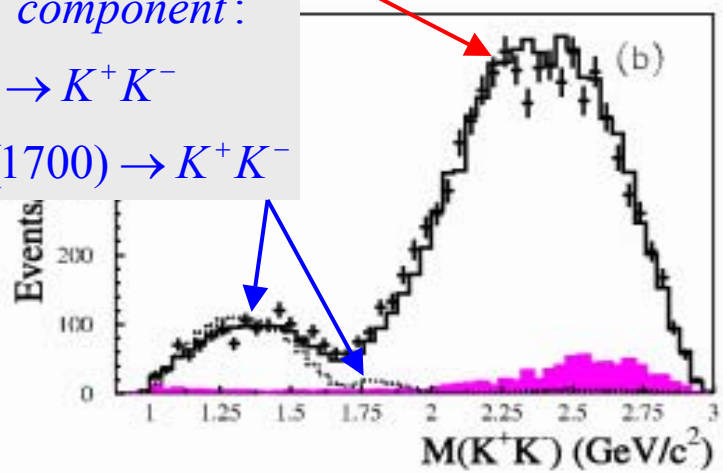
$$\Gamma_R(s) = \Gamma_R(M_R^2)\frac{M_R^2}{s}\left(\frac{p(s)}{p(M_R^2)}\right)^{2l+1}$$

J.H. Kuhn, A. Satamaria, Z. Phys. C48, 445 (1990).

1^{--} *component* :

$X \to K^+K^-$

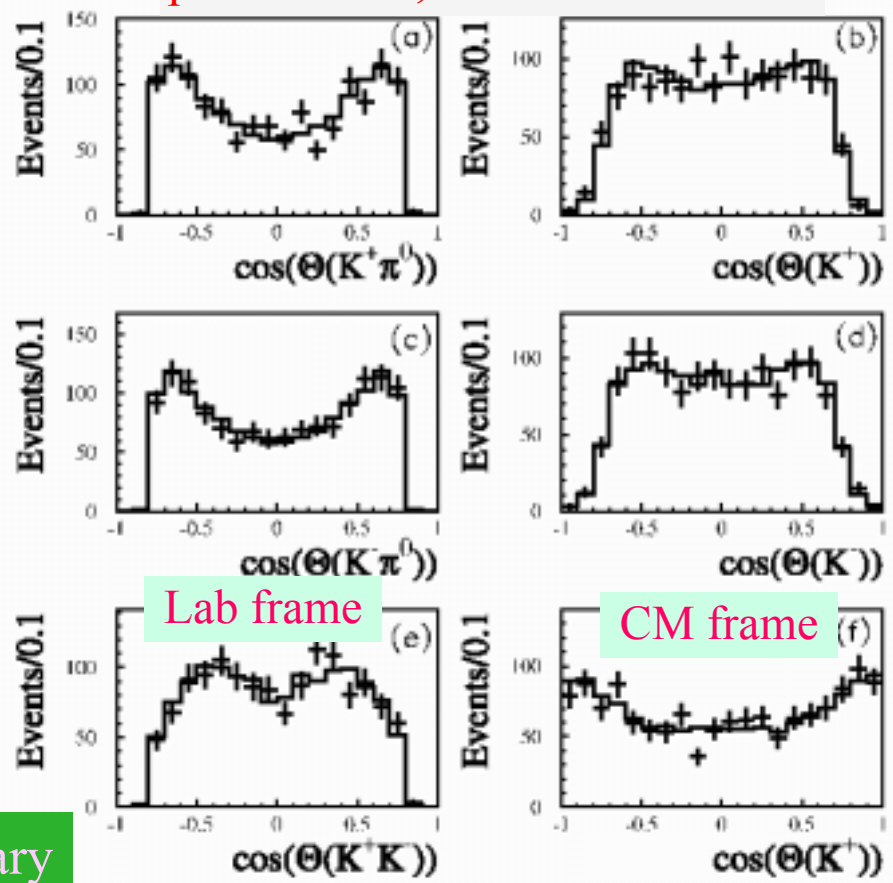
$\rho(1700) \to K^+K^-$



Broad structure in $J/\psi \to K^+K^-\pi^0$

Angular distributions for events with $M_{K^+K^-} < 1.7\,GeV/c^2$ from PWA fit

points : data, hist : PWA fit



- Successful fit seen in angular distributions:
  - (a),(c),(e) are polar angles in lab. reference frame
  - (b),(d),(f) are polar angles in CM frames of $K^{\pm}\pi^0$ and K^+K^- respectively.

Broad structure in $J/\psi \to K^+K^-\pi^0$

Significance study of X resonance

Preliminary

States included in PWA fit	Difference in Log-likelihood	comment
$X + K^*(890) + K^*(1410) + \rho(1700) + PS$	0	Best fit
$K^*(890) + K^*(1410) + \rho(1700) + PS$	533	Remove one of states used in best fit
$X + K^*(1410) + \rho(1700) + PS$	11438	
$X + K^*(890) + \rho(1700) + PS$	465	
$X + K^*(890) + K^*(1410) + PS$	28	
$X + K^*(890) + K^*(1410) + \rho(1700)$	138	
$\rho(770) + \rho(1900) + \rho(2150) + (K^*(890) + K^*(1410) + \rho(1700) + PS)$	85	Known states
$\rho(1450) + (K^*(890) + K^*(1410) + \rho(1700) + PS)$	36	

- $\rho(1450)$ can be ruled out also due to its small branching fraction

$$Br(\rho(1450) \to K^+K^-) < 1.6\times10^{-3} \quad (95\%C.L.)$$

Broad structure in $J/\psi \to K^+K^-\pi^0$

Systematic errors

Preliminary

Uncertainty from inclusion of other possible states

Sources	ΔS	ΔM(MeV)(pole)	$\Delta\Gamma$ (MeV)(pole)	B.R. (%)
adding $K^*(1680)$	-14	52.4	9.2	-2.1
adding $K^*(2075)$	-1.6	-26.6	-52.2	0.9
adding $K_2^*(1430)$	-0.1	-8	-17.6	-1.4
adding $\rho(1900)$	-0.1	-7	40.4	2.8
adding $\rho(2150)$	-2.3	51.4	9.4	26.8
adding $\rho(770)$	-13	-58	-111.6	-29.9
Total		$^{+73.4}_{-64.7}$	$^{+42.5}_{-124.5}$	$^{+27.0}_{-30.0}$

- Dominant uncertainty from inclusion of other possible states
- Here, possible K*(2075) found in $J/\psi \to pK\bar{\Lambda}$ by BES
- Uncertainties in parameters of known resonances, MDC wire resolution, PID and total number of J/ψ events are considered.

Broad structure in $J/\psi \to K^+K^-\pi^0$

Results

Preliminary

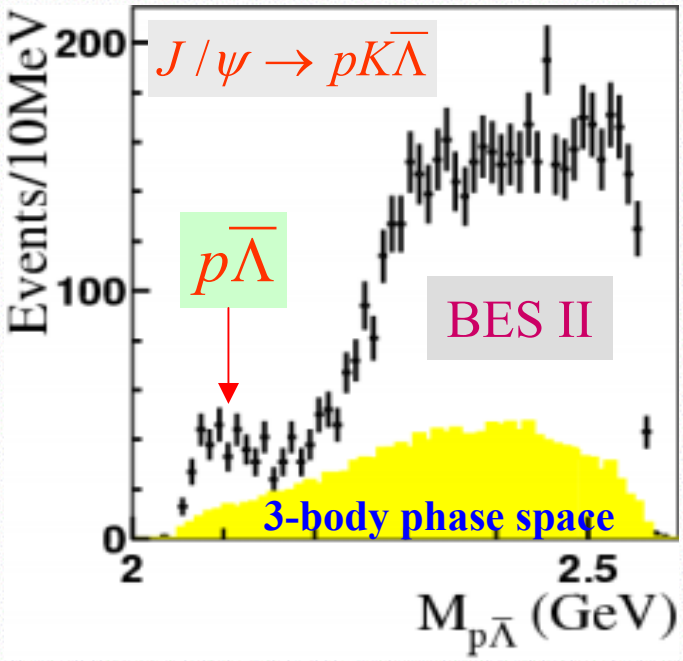
- PWA fit with $X, \rho(1700), K^*(890), K^*(1410)$ and nonresonant (PS) gives :
  - $J^{PC} = 1^{--}$ (3^{--} is ruled out by worse likelihood)
  - The pole position for X : $(1576^{+49+98}_{-55-91}) - i(409^{+11+32}_{-12-67})\ MeV/c^2$
  - $Br(J/\psi \to X\pi^0) \cdot Br(X \to K^+K^-) = (8.5 \pm 0.6^{+2.7}_{-3.6}) \times 10^{-4}$
  - big destructive interference among $X, \rho(1700)$ and PS
- Broad 1^{--} structure is not compatible with any known mesons

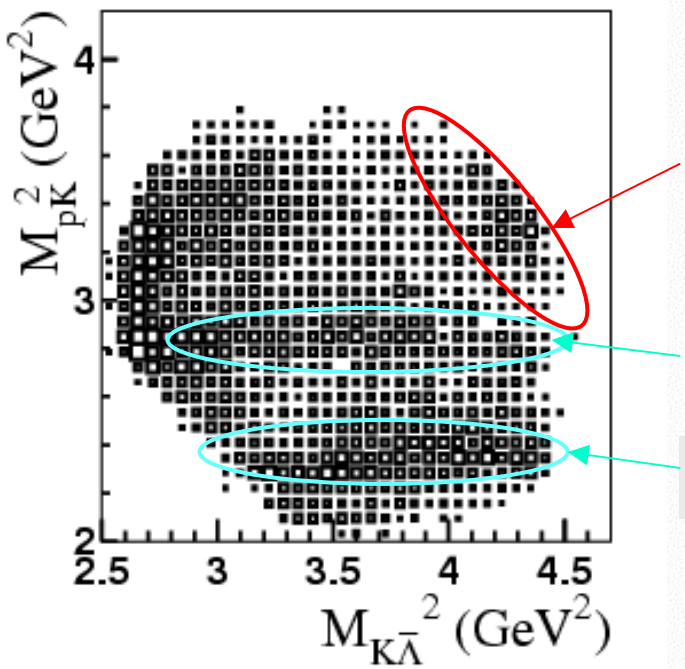
Observations of $p\bar{\Lambda}$ and $K^-\bar{\Lambda}$ threshold enhancement in

$$J/\psi \to pK^-\bar{\Lambda}$$

Enhanced structures in $J/\psi \to pK^-\bar{\Lambda}$

Anomalous enhancement near $p\bar{\Lambda}$ threshold





S-wave BW fit: $M = 2075 \pm 12 \pm 5$ MeV

$\Gamma = 90 \pm 35 \pm 9$ MeV

$$B(J/\psi \to K^- X)B(X \to p\bar{\Lambda}) = (5.9 \pm 1.4 \pm 2.0) \times 10^{-5}$$

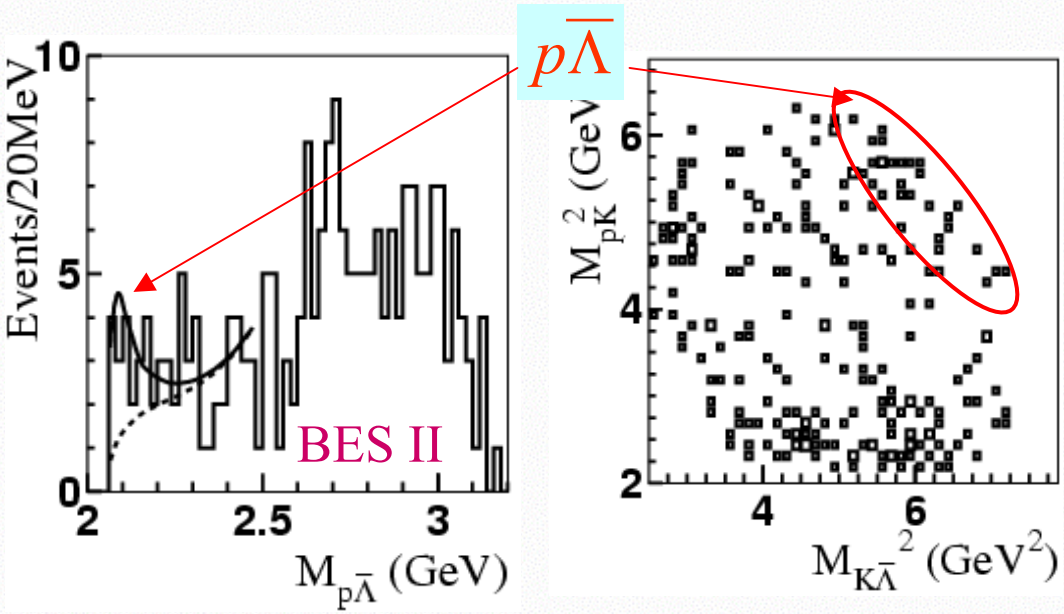
BES Collab., Phys. Rev. Lett. 93, 112002 (2004)

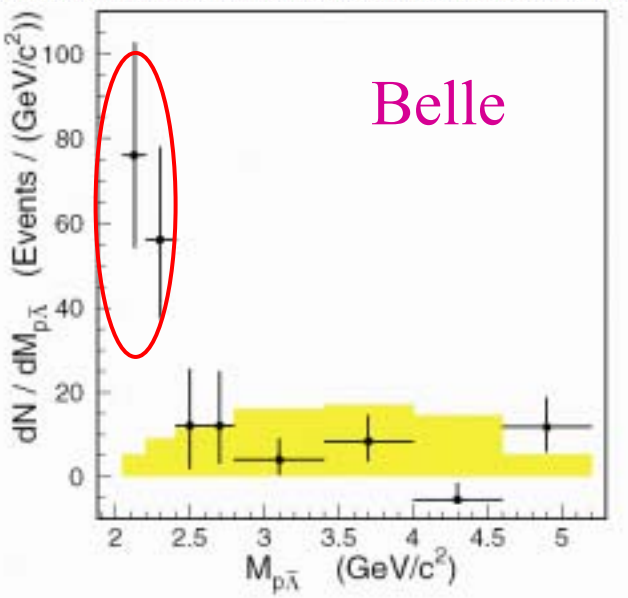
Enhanced structures in $J/\psi \to pK^-\bar{\Lambda}$

Similar $p\bar{\Lambda}$ enhancements

❖ from $\psi' \to pK\bar{\Lambda}$ at BESII

❖ $B \to p\bar{\Lambda}\pi$ at Belle





4σ away from phase space

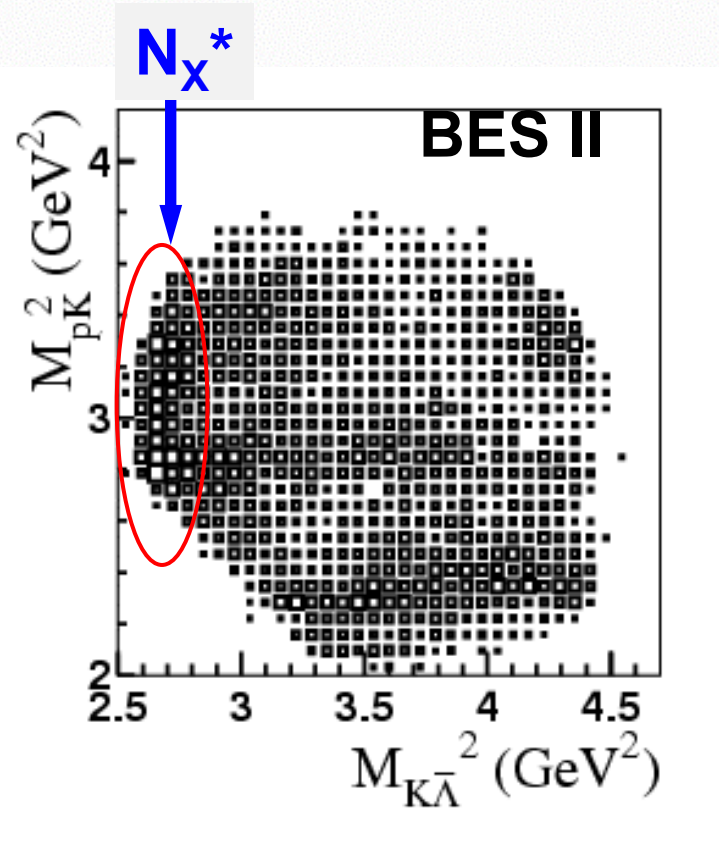
Enhanced structures in $J/\psi \to pK^{-}\overline{\Lambda}$

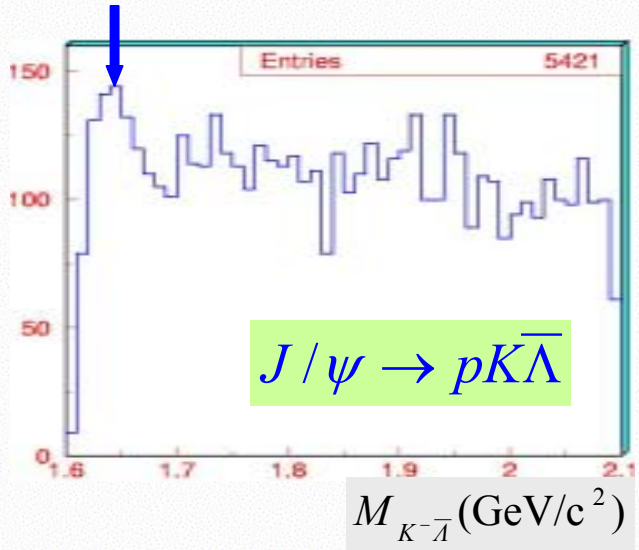
Discussions

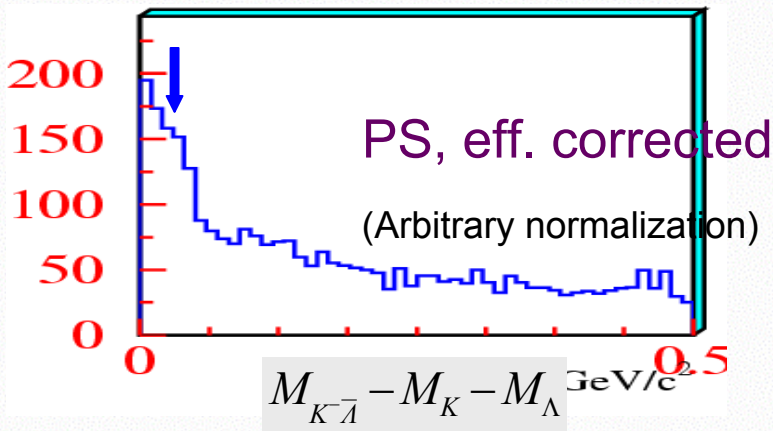
- It can also be fit with P-wave BW resonance.
- PWA with interference between N^{*} and Λ^{*} show :
  - large Br of J/ψ decays to N^{*} and Λ^{*} are required.
- Theoretical calculations for FSI are needed.
- Unlikely as conventional K*
  - No evidence for X(2075) from J/ψ → $K^{+}K^{-}\pi^{0}$
  - Search for its Kπ 、 Kππ decay modes would help to understand its nature.

Enhanced structures in $J/\psi \to pK^-\bar{\Lambda}$

Strong enhancement near $K^-\bar{\Lambda}$ threshold





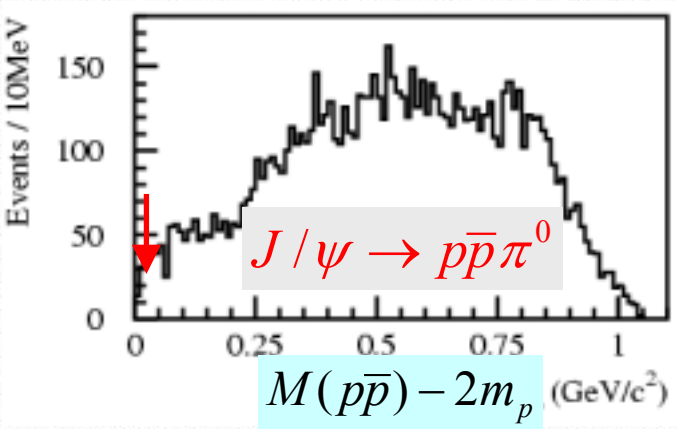


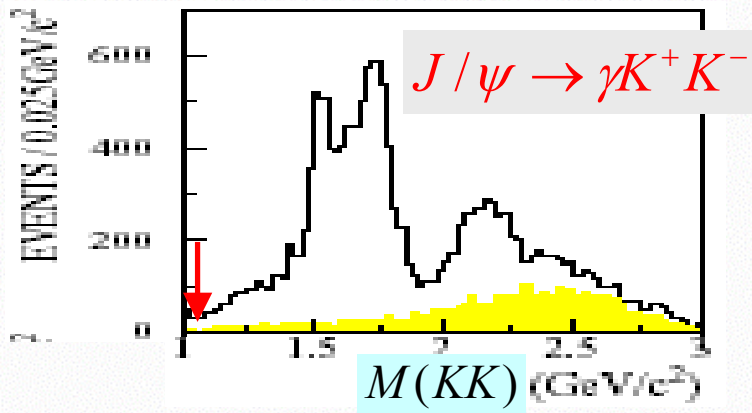
Enhanced structures in $J/\psi \to pK^-\overline{\Lambda}$

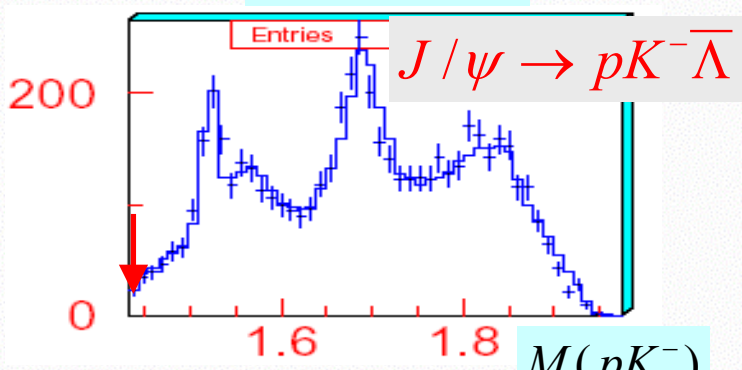
- A strong enhancement is observed near $M_{K\Lambda}$ mass threshold.
- Preliminary PWA with various combinations of possible N^* and Λ^* in the fits. The structure N^*_X has :
  - Mass 1500~1650MeV ⇨ $N^*_X(1610)$
  - Width 70~110MeV
  - J^P favors $\frac{1}{2}^-$
- It has large $B(J/\psi \to pN^*_X)\cdot B(N^*_X \to K^-\overline{\Lambda}) \approx 2\times 10^{-4}$; suggesting N_X^* has strong coupling to $K\Lambda$.

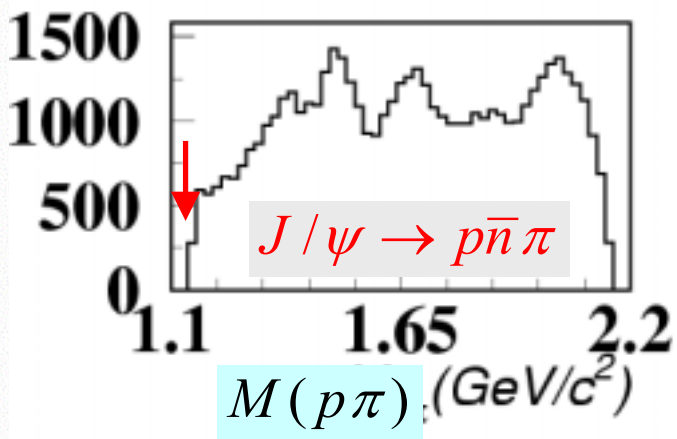
Threshold enhancement is not universal

- No threshold enhancement is seen in many other J/ψ decays.
- For example, in following J/ψ radiative or hadronic decays









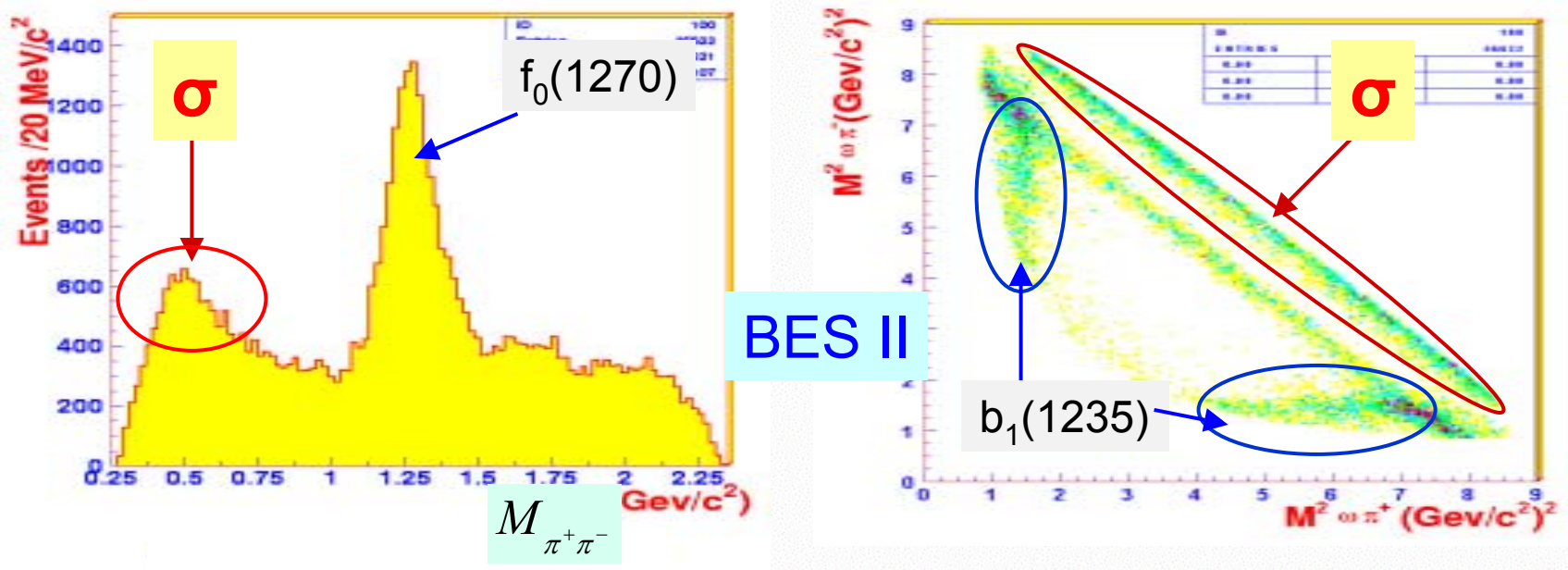
Observation of two Scalar Mesons : σ, κ

- Light scalar meson spectrum is important to understand PQCD.
- **σ** and **κ** (or $K_0^*(800)$), together with $f_0(980)$ and $a_0(980)$, are possible cadidates as four-quark states.
- Long-standing puzzle on the existence of **κ.**
- Determination of **σ, κ** provides information to understand chiral symmetry in QCD.
- Note that **σ, κ** are close to their threshold.

σ meson from $J/\psi \to \omega\pi^+\pi^-$

BES Collab., Phys. Lett. B633, 681 (2006)

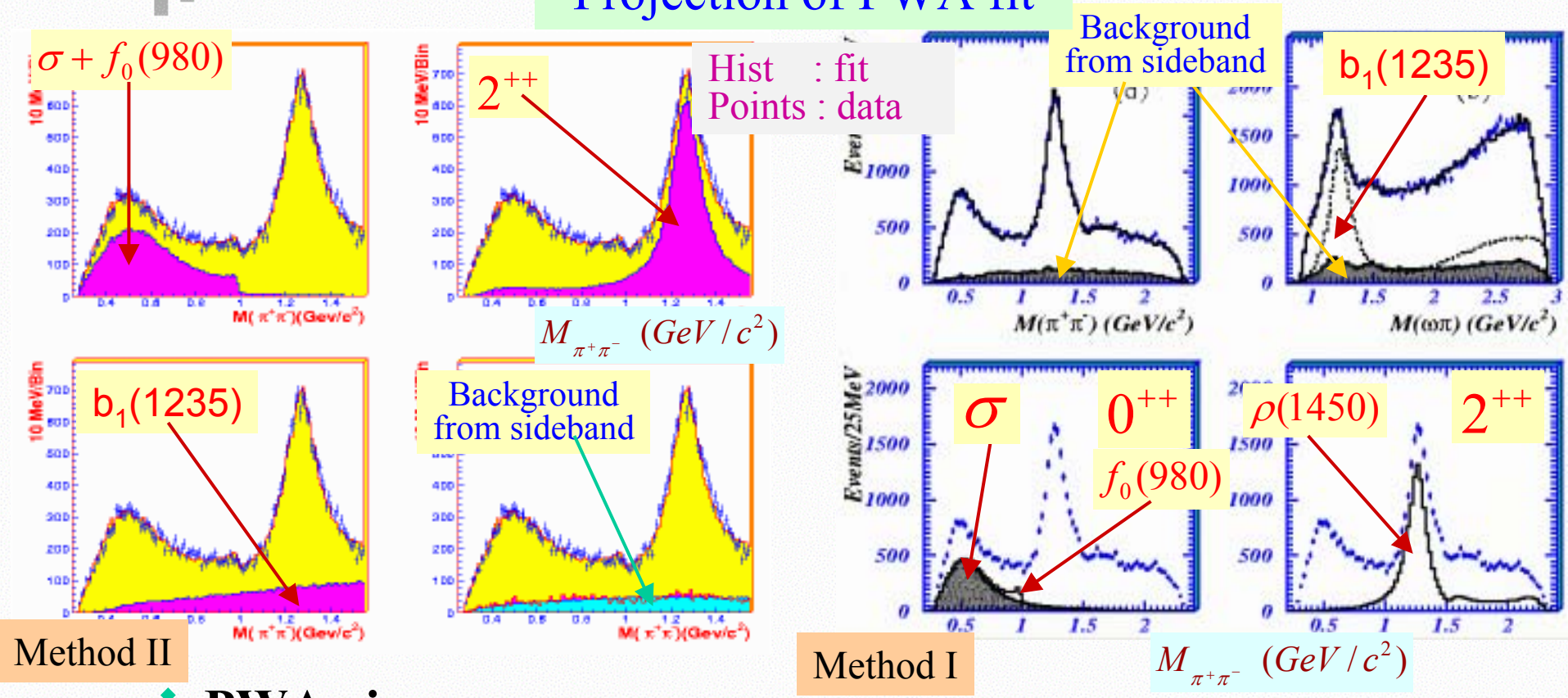
- BES II observed broad σ resonance in $J/\psi \to \omega\pi^+\pi^-$.



- Decay channels included in PWA fit :
  - $J/\psi \to \omega\sigma$, $J/\psi \to b_1(1235)\pi$, $J/\psi \to \omega f_2(1565)$
  - $\to \omega f_2(1270)$, $\to \rho(1450)\pi$, $\to \omega f_2(2240)$
  - $\to \omega f_0(980)$,

σ meson from $J/\psi \to \omega\pi^+\pi^-$

Projection of PWA fit



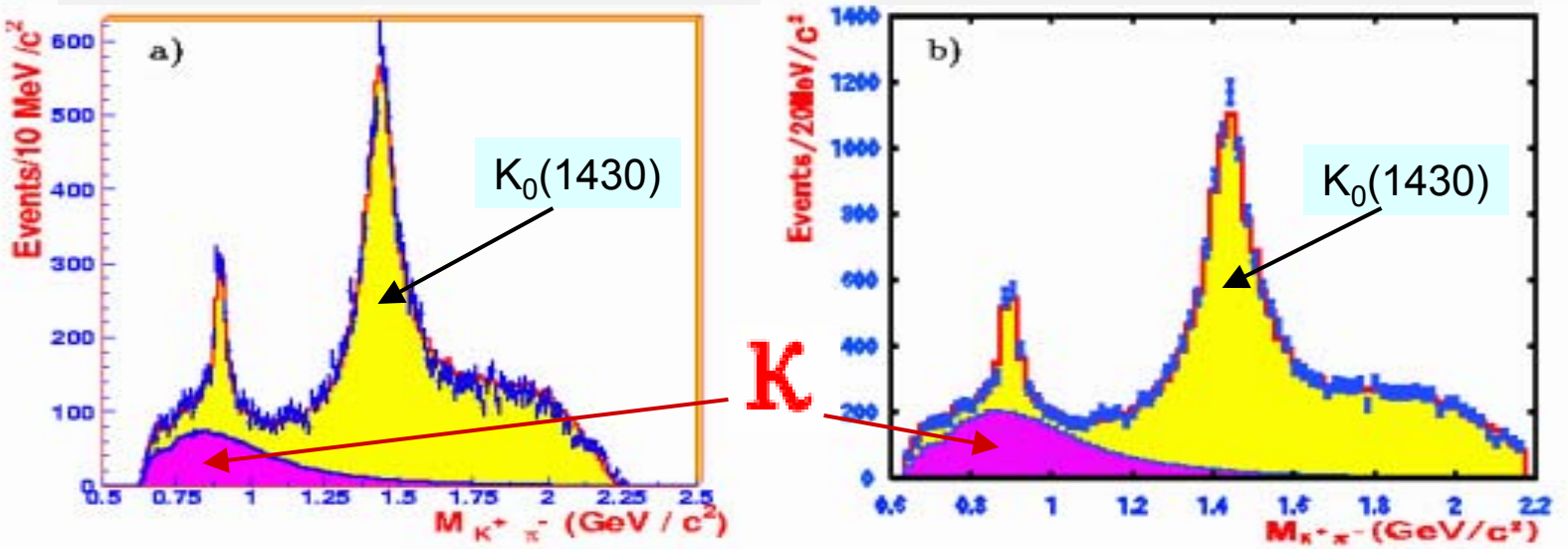
- **PWA gives :**
  - spin-parity $J^{PC} = 0^{++}$
  - Averaged pole : $(541 \pm 39) - i(252 \pm 42)$ MeV

(Phys. Lett. B 598, 149 (2004))

Evidence for κ in $J/\psi \to K^*(890)^0 K^-\pi^+$

Method A : covariant helicity amplitude analysis

Method B : Covariant field Theoretical approach



- PWA for $K^*(892)^0K^-\pi^+$ in $J/\psi \to K^+ K^- \pi^+\pi^-$ is performed
- Averaged mass and width of κ from two methods

$$M = (878 \pm 23^{+64}_{-55})\ MeV/c \quad , \quad \Gamma = (499 \pm 52^{+55}_{-87})\ MeV/c$$

corresponding to a pole at $(841 \pm 30^{+81}_{-73}) - i(309 \pm 45^{+48}_{-72})\ MeV/c$

BES Collab., Phys. Lett. B633, 681 (2006)

Summary

- Strong enhancement X(1860) in $p\bar{p}$ system is observed
  - from J/ψ radiative decay.
  - It could be a baryonium candidate.
- New resonance X(1835) via $X \to \pi^+\pi^-\eta'$ mode is also observed from J/ψ radiative decay.
  - X(1835) and X(1860) could be same state
  - Further test with their J^{PC} determination is required.
  - Other interpretation of X(1835) is not excluded yet.
- Enhanced $\omega\phi$ structure, X(1810), is observed
  - from doubly OZI suppressed J/ψ radiative decay
  - X(1810) favors 0^{++} and S-wave for $\omega\phi$ system

Summary

- A couple of resonant structures are observed from J/ψ hadronic decays, including
  - New broad 1^{--} structure X(1580) of K^+K^- system from $J/\psi \to K^+K^-\pi^0$
  - Structures for $p\bar{\Lambda}$ near 2075 MeV/c^2 and for $K^-\bar{\Lambda}$ near 1610 MeV/c^2 from $J/\psi \to pK^-\bar{\Lambda}$.
  - broad σ meson from $J/\psi \to \omega\pi^+\pi^-$ and clear evidence of κ meson from $J/\psi \to \overline{K^*}(890)^0 K^+\pi^-$

Summary

- J/ψ decays is an ideal hunting ground to search for exotics.
- To understand those states, more works in both experiments and theoretical calculations are needed.

Thanks

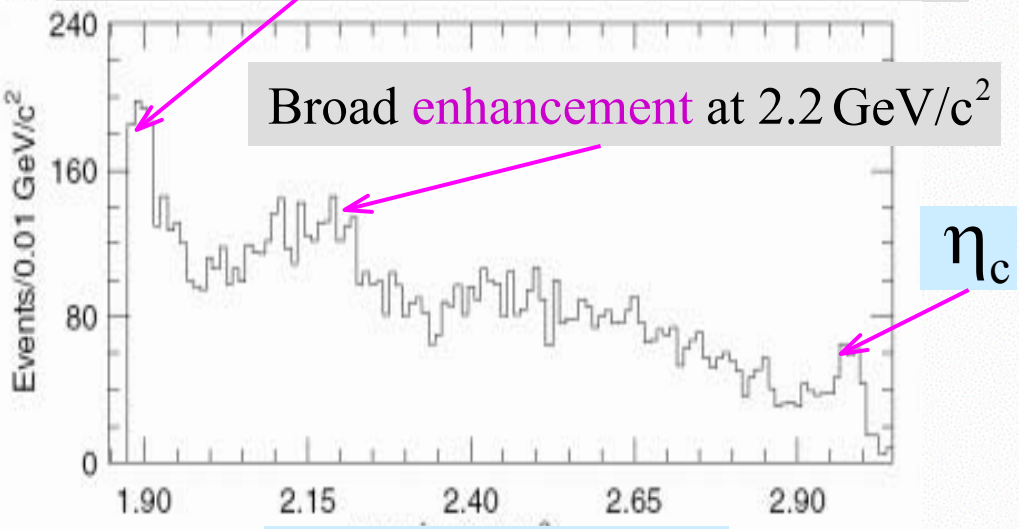
Strong enhancement in $J/\psi \to \gamma p\bar{p}$

❖ Low-mass $p\bar{p}$ pairs produced vi radiative decays from 58 million J/ψ events

❖ Event selection

- Charged track with good helix fit
- K/p separation : dE/dx
  K contamination < 1%/track
- 4-c kinematic fit
  C.L.$_{\gamma p\bar{p}}$ > 0.05, C.L$_{\gamma p\bar{p}}$ > C.L$_{\gamma K^+K^-}$
- Highest C.L. taken if more than one photon in event

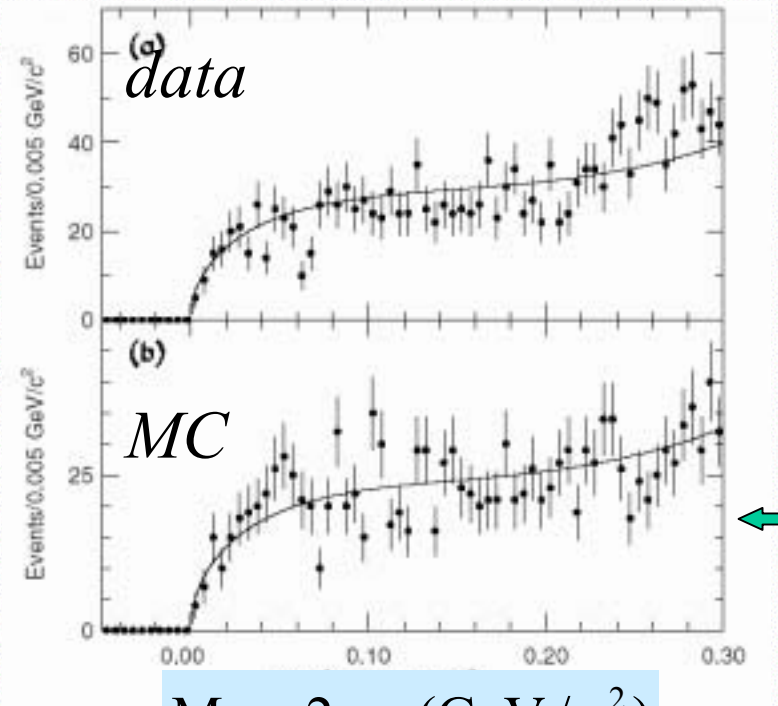
Observation of a narrow enhancement near $p\bar{p}$ threshold in $J/\psi \to \gamma p\bar{p}$



Strong enhancement in $J/\psi \to \gamma p\bar{p}$

Background

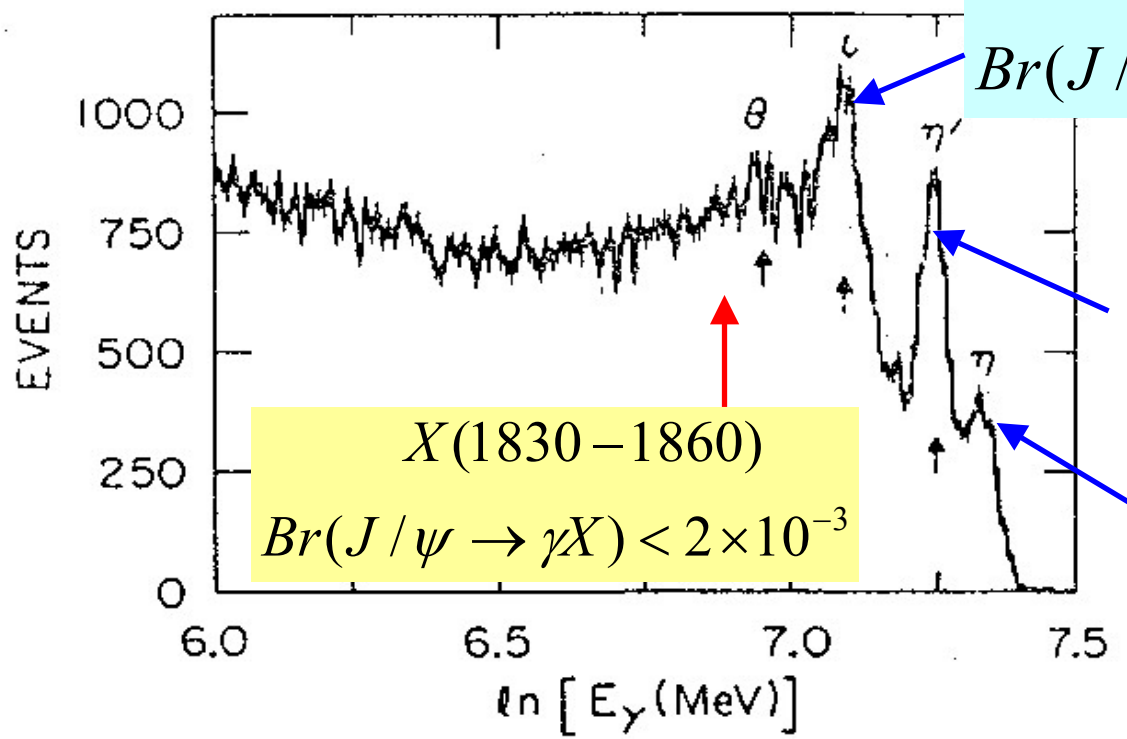
- Dominant background from $J/\psi \to \pi^0 p\bar{p}$
  - with $\pi^0 \to \gamma\gamma$ decay and one missing photon



$J/\psi \to \pi^0 p\bar{p}$ events survived from $J/\psi \to \gamma p\bar{p}$ selection

No enhancement near threshold

Crystal Ball results on inclusive photon spectrum of J/ψ decays



$\Gamma \approx 50\ MeV$

$Br(J/\psi \to \gamma\iota(1440)) \sim 3\times10^{-3}$

$BR(J/\psi \to \gamma\eta') \sim 4.3\times10^{-3}$

$BR(J/\psi \to \gamma\eta) \sim 0.9\times10^{-3}$

$X(1830-1860)$

$Br(J/\psi \to \gamma X) < 2\times10^{-3}$

ppbar bound state in NNbar potential

- Paris NNbar potential: (Paris 93, B. Loiseau et al., hep-ph/0411218, 0501112)
  - For $^{11}S_0$, there is a bound state:

    E = - 4.8 - i 26.3 MeV

    quite close to the BES observation.
- However, Julich NNbar model:(A. Sibirtsev et al., hep-ph/0411386)
  - For $^{11}S_0$: E = - 104 - i 413 MeV

    seems quite far away from BES observation.

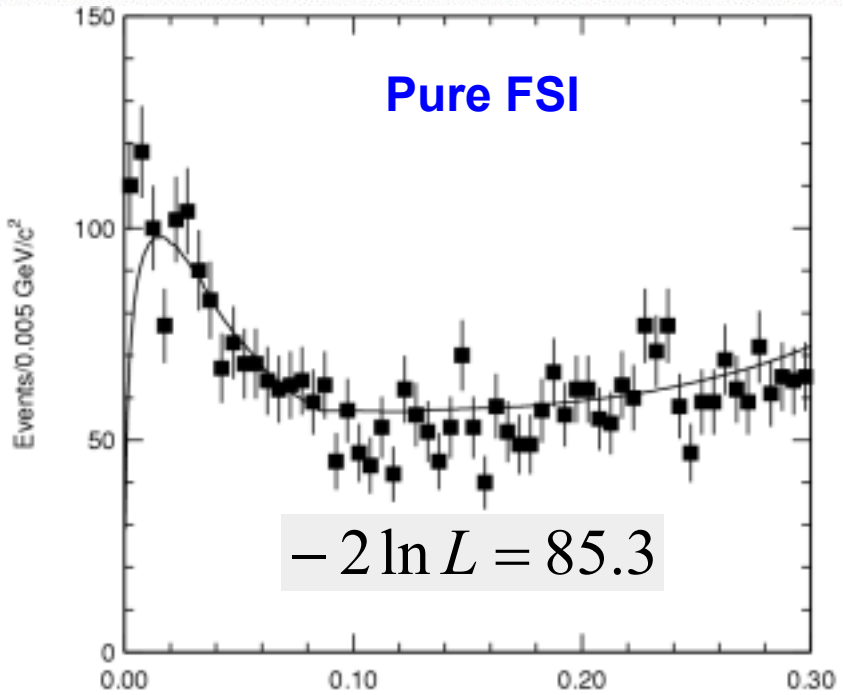
They both predict an $^{11}S_0$ ppbar bound state, although they are quantitatively different.

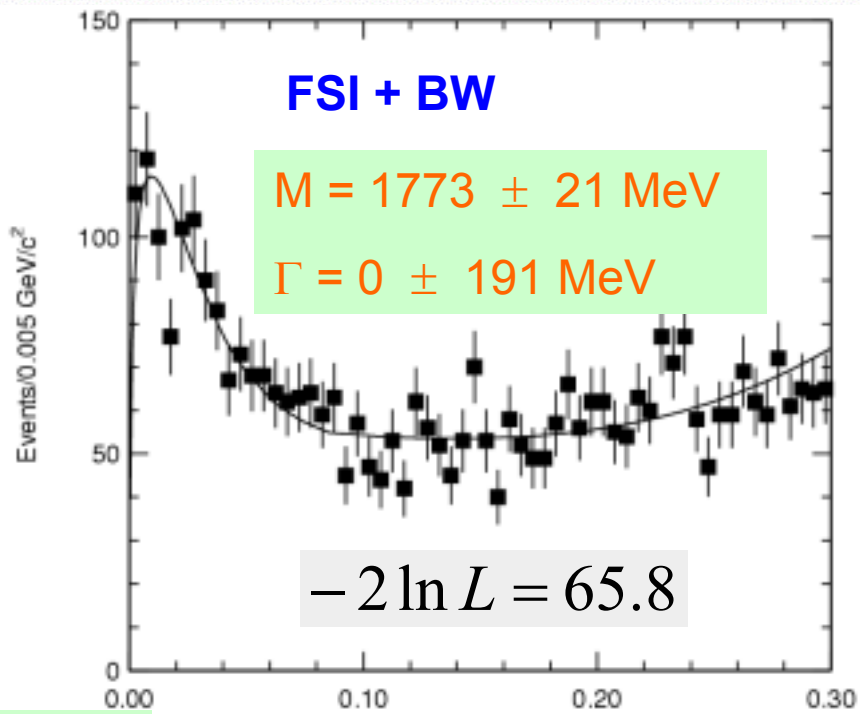
Discussion on I=1 S-wave FSI

Strong enhancement in $J/\psi \to \gamma p\bar{p}$

Pure FSI disfavored (III) — I = 1

Pure I=1 S-wave FSI is disfavored by more than 3 σ.





$M_{p\bar{p}} - 2m_p$

Strong enhancement in $J/\psi \to \gamma p\bar{p}$

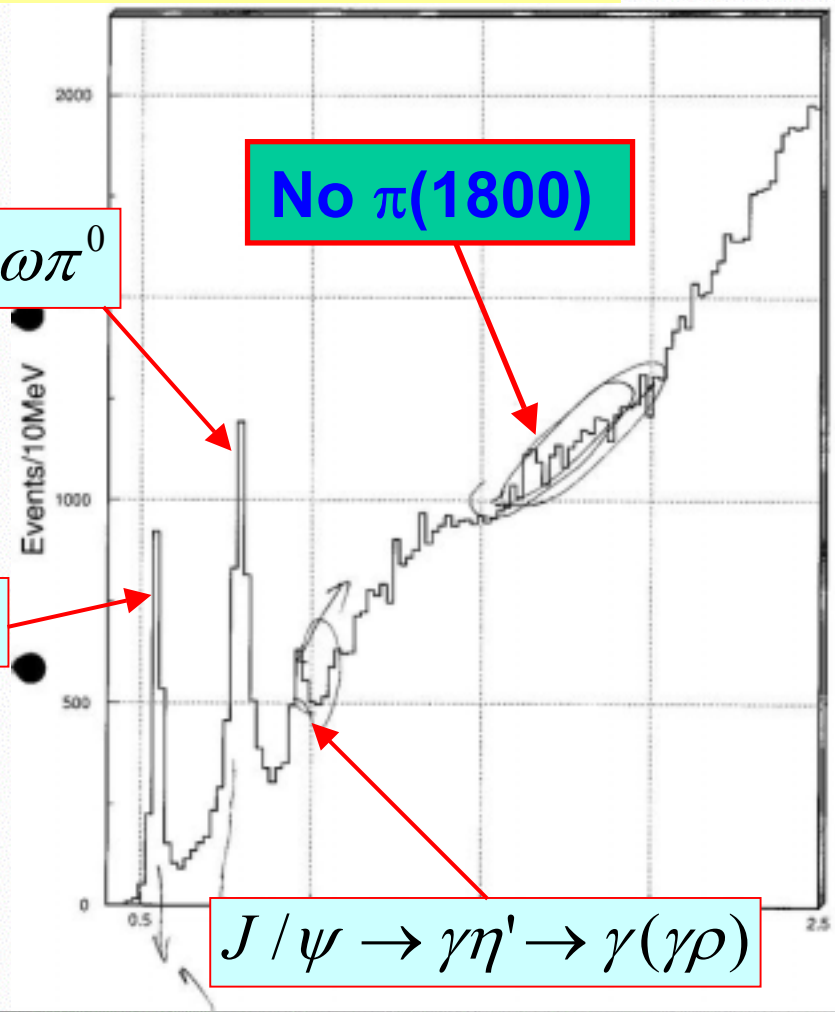
I=0 dominant in J/ ψ radiative decays

- **Most I = 0 states have been observed in J/ ψ radiative decays with big production rate (especially for 0^{-+} mesons) such as η, η', η(1440), η(1760), $f_2(1270)$, $f_2(1525)$, $f_0(1500)$, $f_0(1710)$.**

- **The only observed I=1 meson in J/ ψ radiative decays is π^0 with low production rate $4*10^{-5}$, e.g., no evidence for π(1800) in J/ψ → γ 3 π process.**
- **It is unlikely to be from π(1800) .**
- **I=1 S-wave FSI seems unlikely.**

$$J/\psi \to \gamma\pi^+\pi^-\pi^0$$

BES II Preliminary



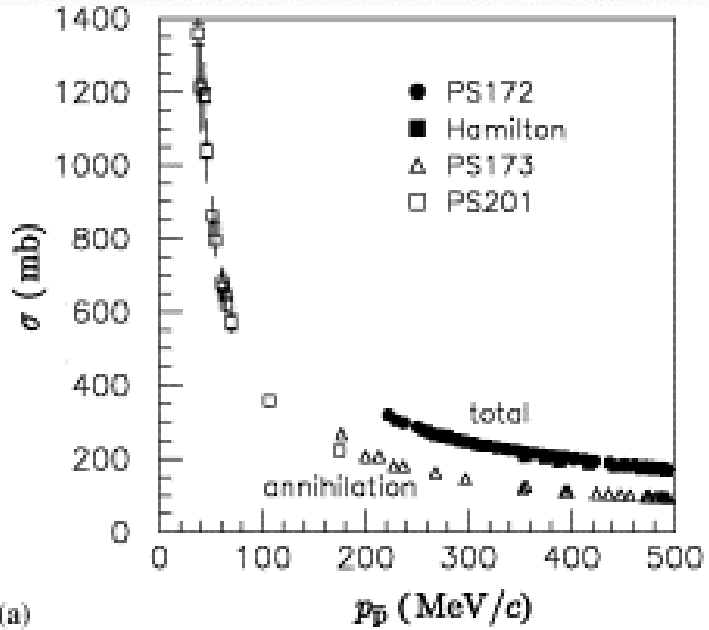
Signature of a pp_bar Bound State

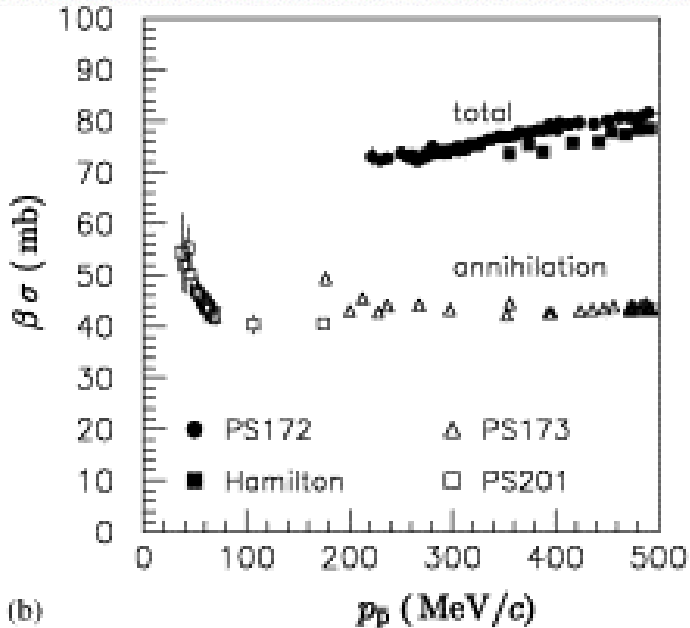
- **$\eta'\pi\pi$ mode is expected to be the a favorable decay mode for a ppbar bound state below ppbar mass threshold (** G.J. Ding and M.L. Yan, hep-ph/0502127 **).**
  - **There are gluon contents in proton and anti-proton.**
  - **η' has strong coupling to gluons.**

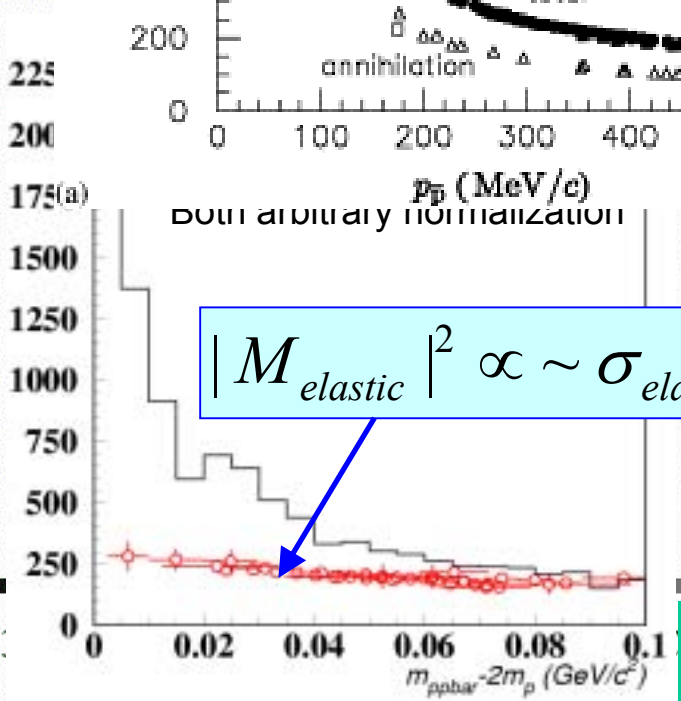
NO strong dynamical threshold enhancement in $p\bar{p}$ cross sections (at LEAR)

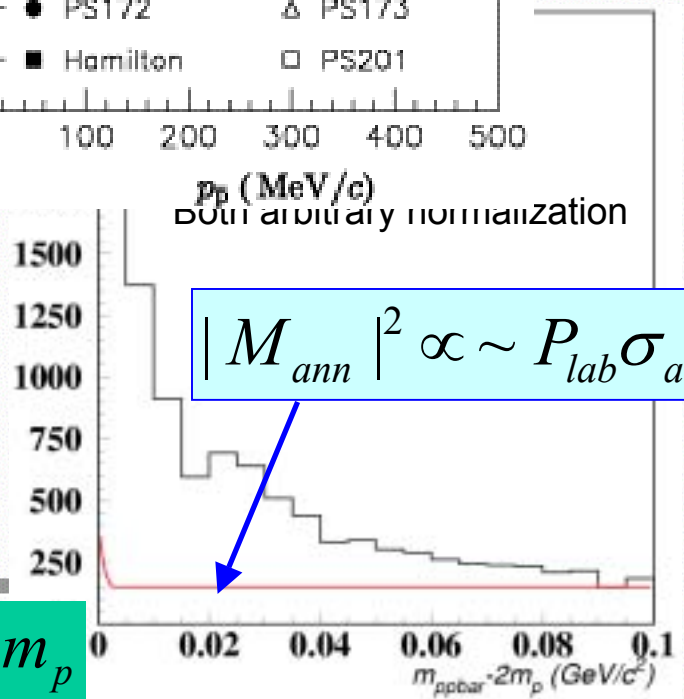
- **Wi** … are
  ver… …
  ele… …x
  ele…
- → **m**

$|M|^2$









$M(p\bar{p}) - 2m_p$

Discussion

Theoretical works and recent reviews on $p\bar{p}$ bound state (baryonium)

- Earlier models
  - E. Fermi, C.N. Yang, Phys. Rev. 76, 1739 (1949)
  - Y. Nambu and G. Jona-Lasinio, Phys. Rev. 122, 345 (1961).
- Later models
  - I.S. Sharpiro, Phys. Rept. 35, 129 (1978)
  - C.B. Dover, M. Goldhaber, PRD 15, 1997 (1977)
  - A. Datta, P.J. O'Donnell, PLB 567, 273 (2003)
  - M.L. Yan et al., hep-ph/0405087
  - B. Loiseau et al., hep-ph/0411218
- Recent reviews
  - E. Klempt et al., Phys. Rep. 368, 119 (2002)
  - J.M. Richard, Nucl. Phys. B (proc. Suppl.) 86, 361 (2000).

New resonance X(1835)

Comparison of two decay modes

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

  m=1827.4±8.1MeV/c^2 , Γ=54.2±34.5MeV/c^2

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

  m=1836.3±7.9MeV/c^2 , Γ=70.3±23.1MeV/c^2

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

  $B(J/\psi \to \gamma X)B(X \to \pi^+\pi^-\eta') = (1.8 \pm 0.7) \times 10^{-4}$

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

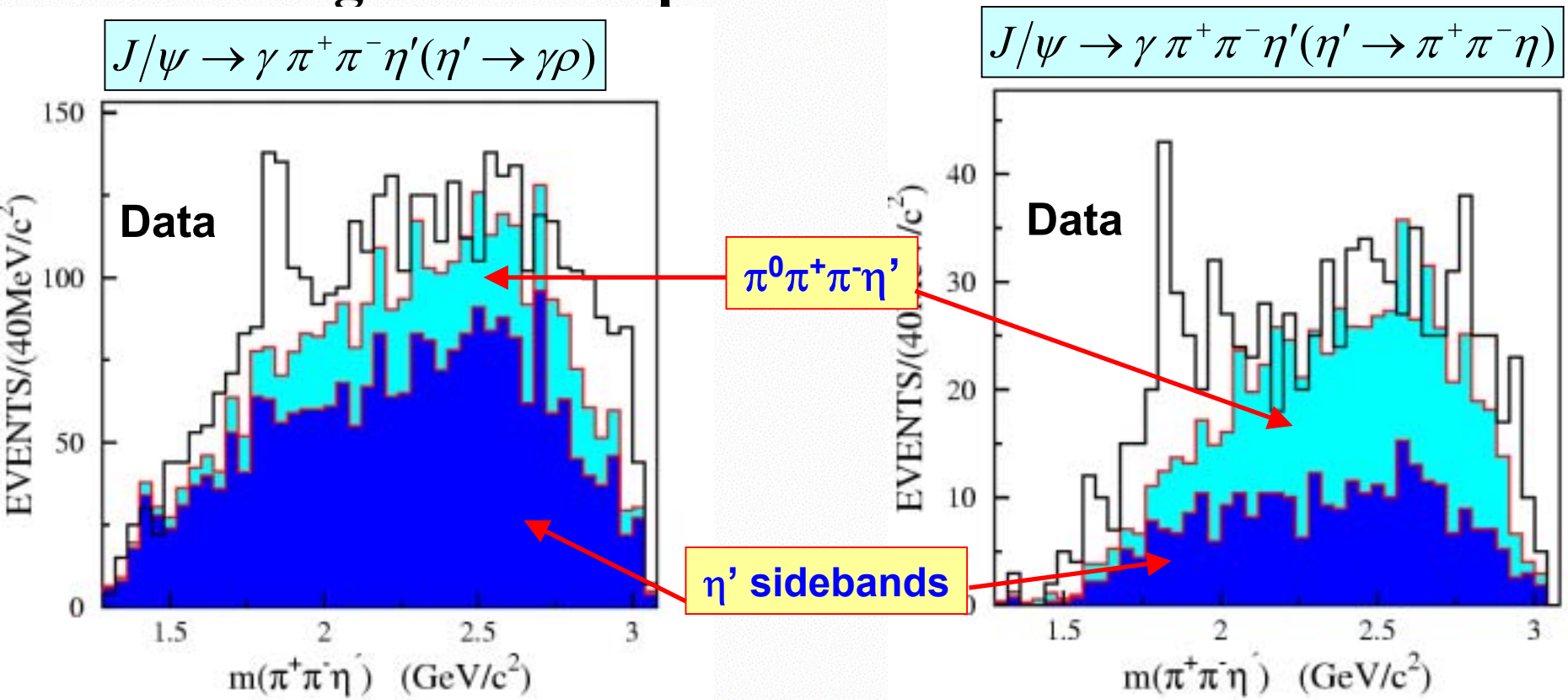
  $B(J/\psi \to \gamma X)B(X \to \pi^+\pi^-\eta') = (2.3 \pm 0.5) \times 10^{-4}$

- The mass, width and branching fractions obtained from two different decay modes are consistent with each other.

New resonance X(1835)

Mass plots with backgrounds

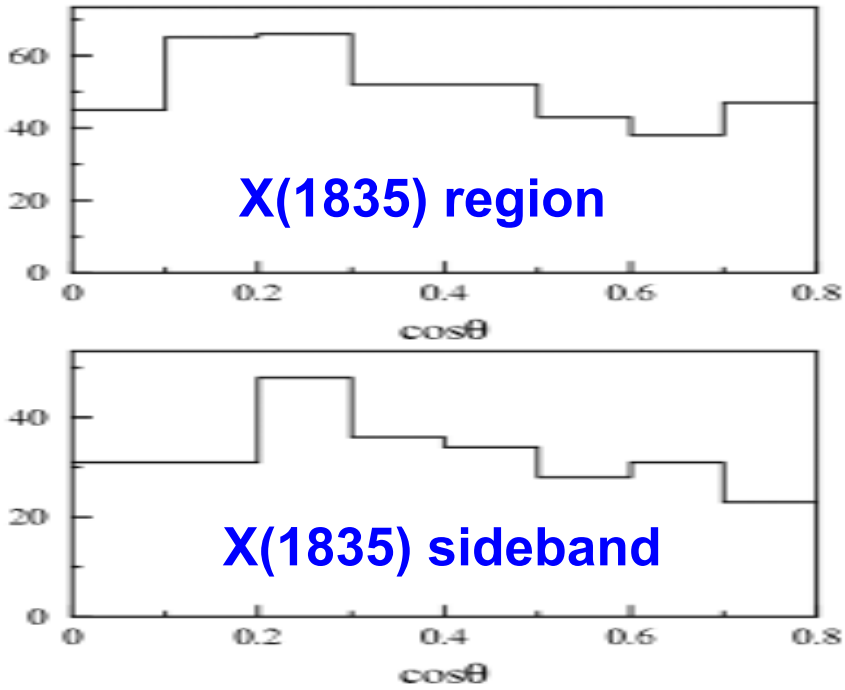
- **Background components are different.**

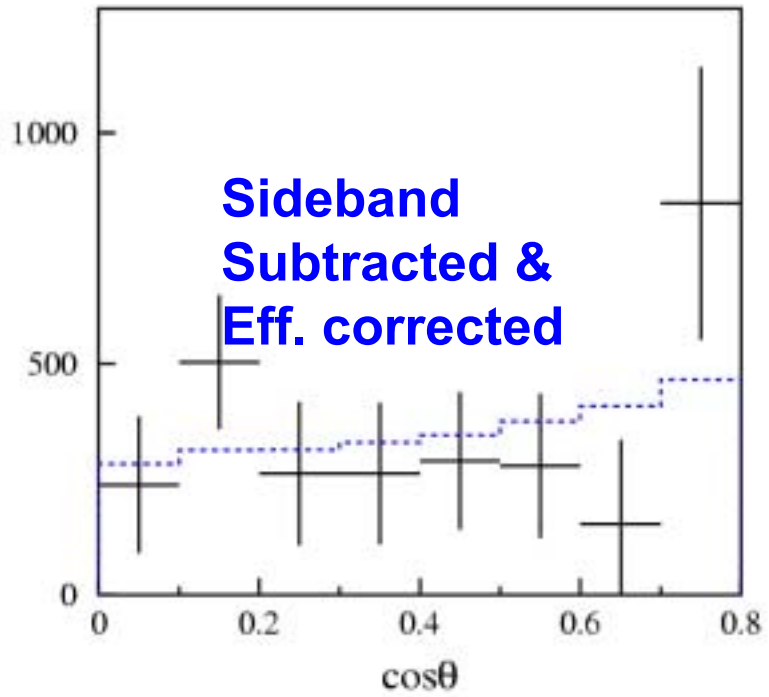


New resonance X(1835)

Photon angular distributions in $J/\psi \to \gamma \pi^+\pi^-\eta'(\eta' \to \gamma\rho)$

- For Data – it is not inconsistent with 0^{-+} -- statistics is too low.

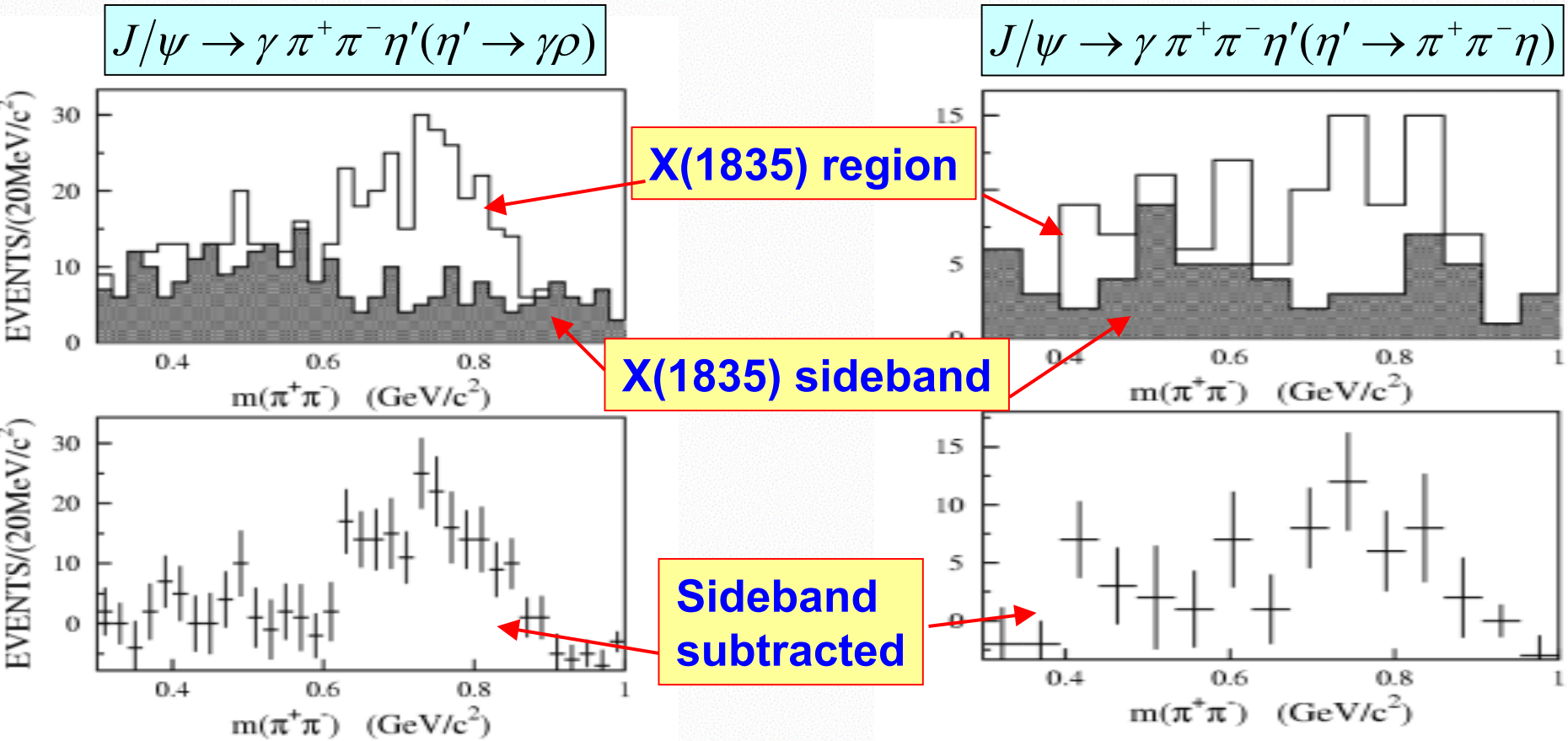




New resonance X(1835)

$M_{\pi\pi}$ distributions

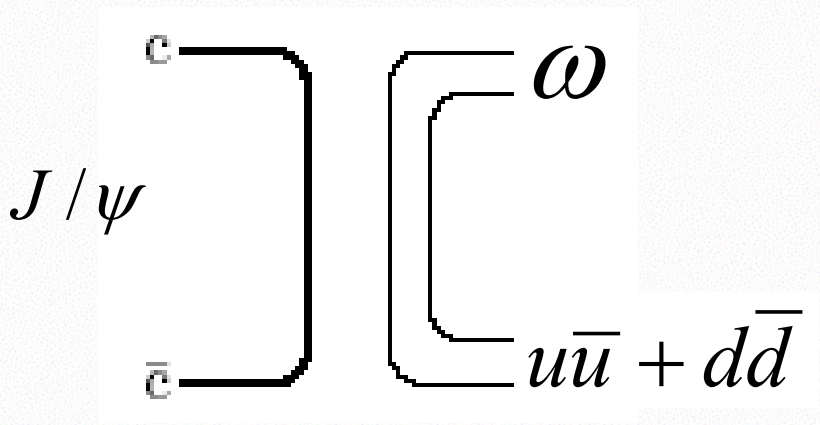
- **Data – It peaks at high mass, but not at threshold.**

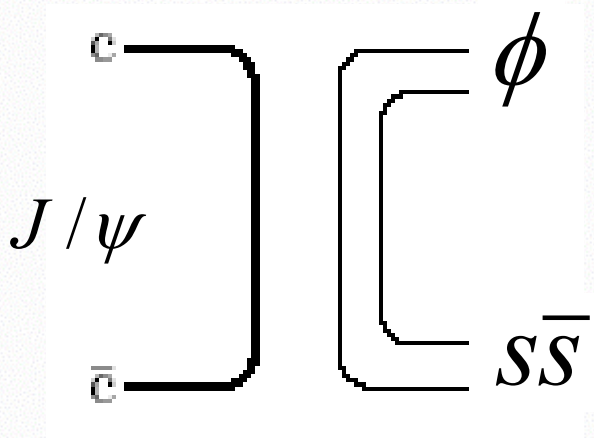


Enhanced structure in $J/\psi \to \gamma\omega\phi$

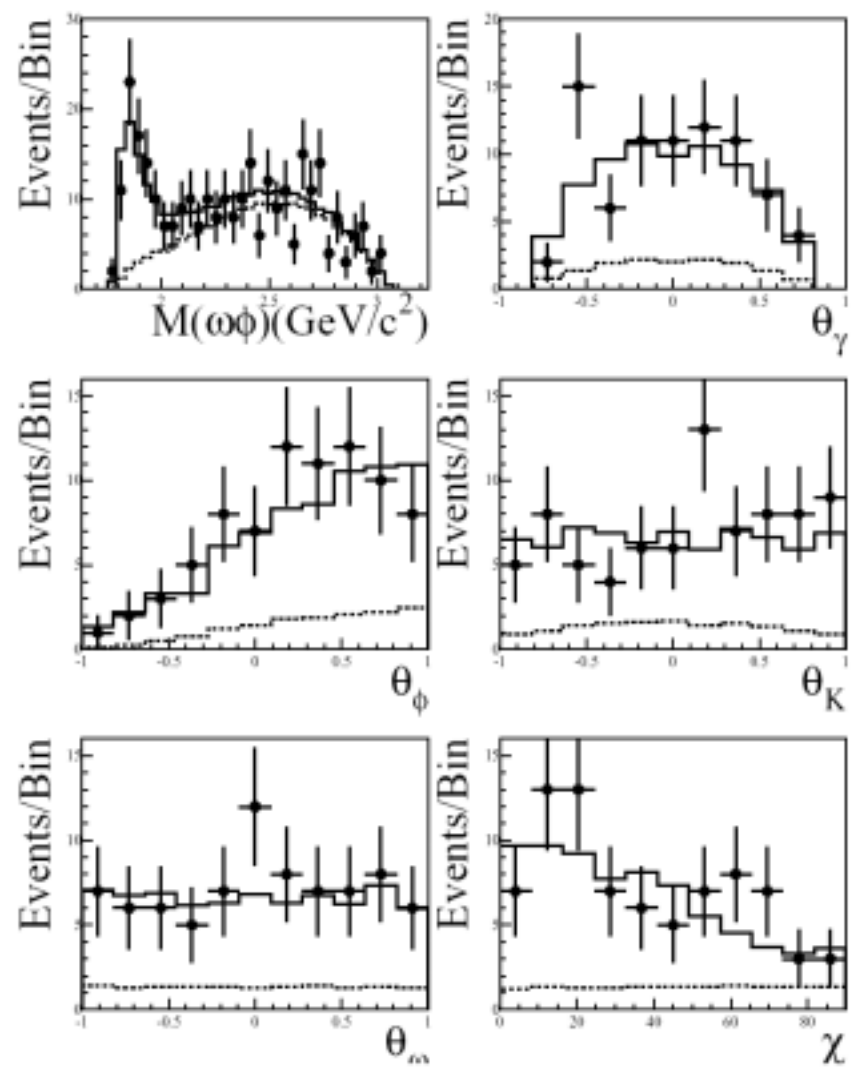
Single OZI suppressed process

- OZI rule : an ω (or **Φ**) signal determines the $u\bar{u}+d\bar{d}$ (or $s\bar{s}$) component at recoil side in J/ψ hadronic decays.





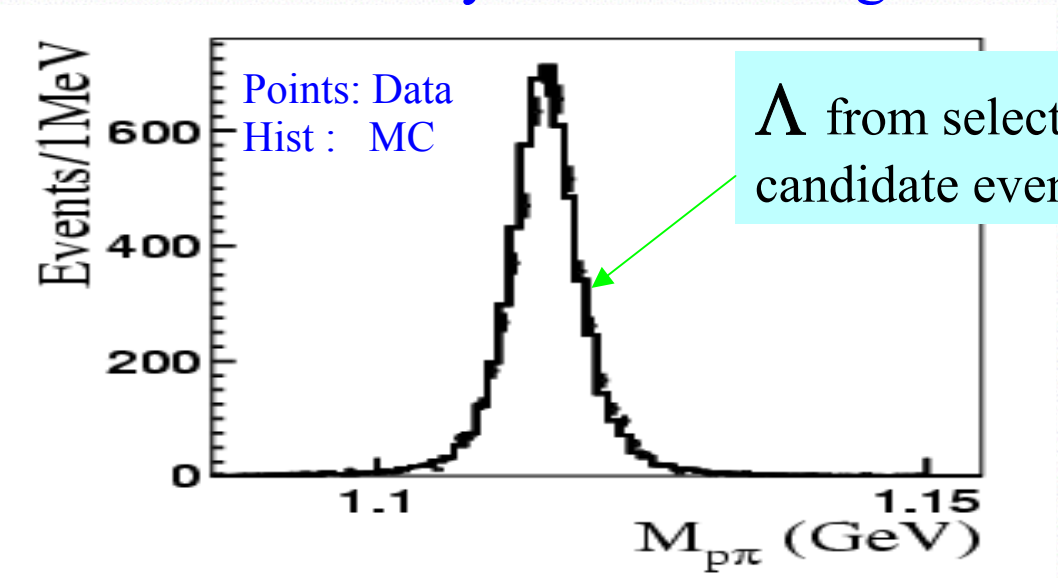
Enhanced structure in $J/\psi \to \gamma\omega\phi$



Enhanced structures in $J/\psi \to pK^-\overline{\Lambda}$

High Purity of Signal after Selection

- It can be shown by the clean Λ signal

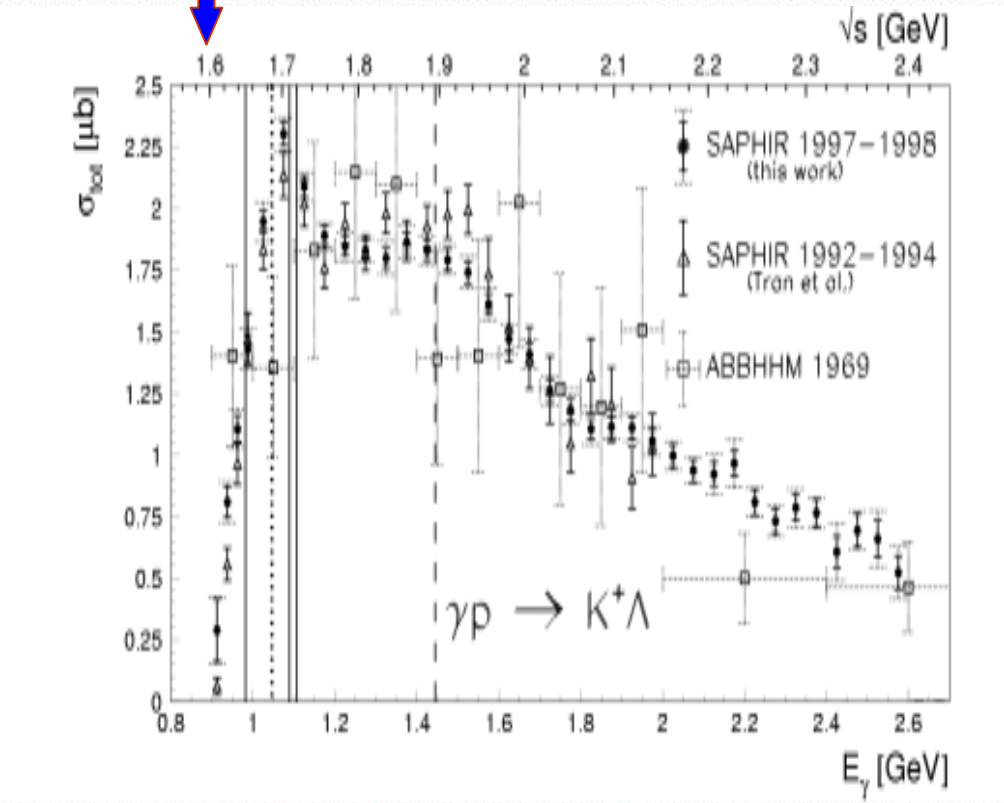


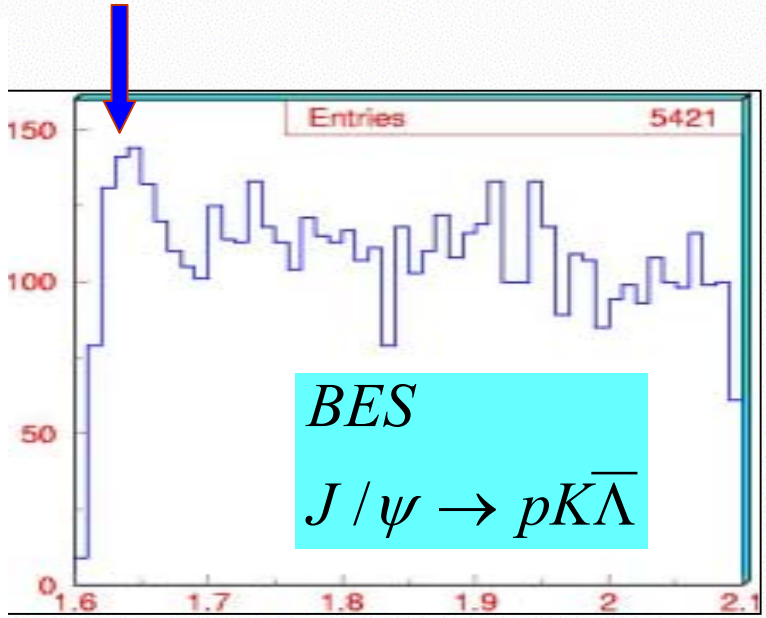
- MC background study: only 1~2%

  Dominantly from $pK\overline{\Sigma} + c.c.$

Enhanced structures in $J/\psi \to pK^-\overline{\Lambda}$

This enhancement is not seen in $\gamma p \to K\Lambda$ process at SAPHIR

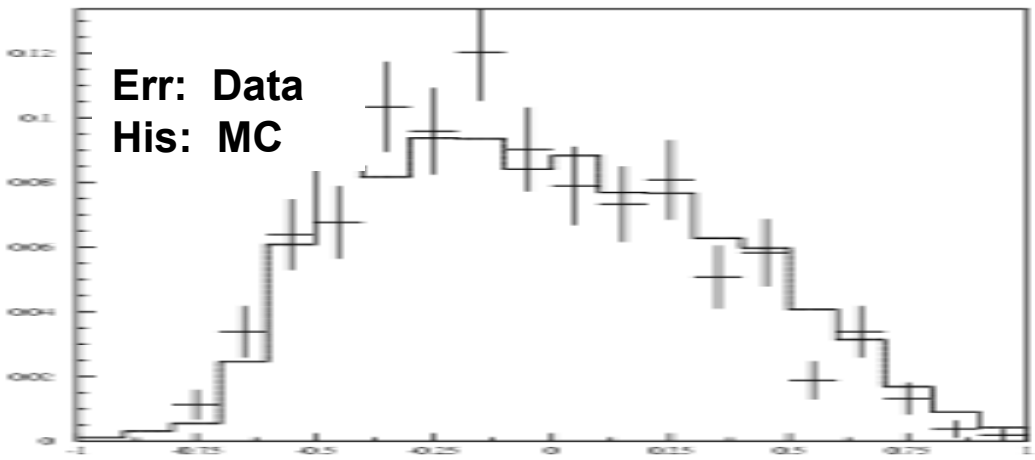




Enhanced structures in $J/\psi \to pK^{-}\overline{\Lambda}$

$\cos\theta_p$ distribution is consistent with S-Wave

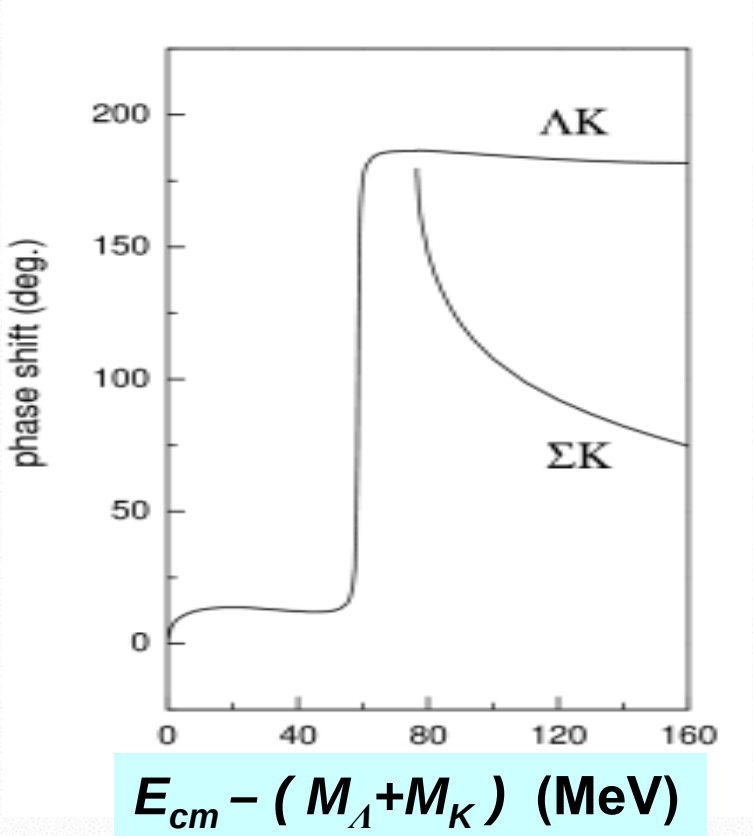
- MC also show non-uniform and asymmetric distribution of $\cos\theta_p$. $(M_{p\bar{\Lambda}+c.c.} < 2.15GeV)$



$\cos\theta_p$

- The enhancement is consistent with S wave.

ΛK resonance in chiral SU(3) quark model



- Using chiral SU(3) quark model
- Based on a coupled-channel study of ΛK and ΣK states
- The phase shift shows the existence of a ΛK resonance between ΛK and ΣK mass threshold.

(F. Huang, Z.Y. Zhang et al. Hep-ph/0501102)

The KΛ threshold enhancement $N^*_X(1610)$ observed by BESII could be a KΛ bound state.