Recent BES Results on Charmonium Physics

Yongsheng ZHU

IHEP, Beijing 100039, China

for the BES Collaboration

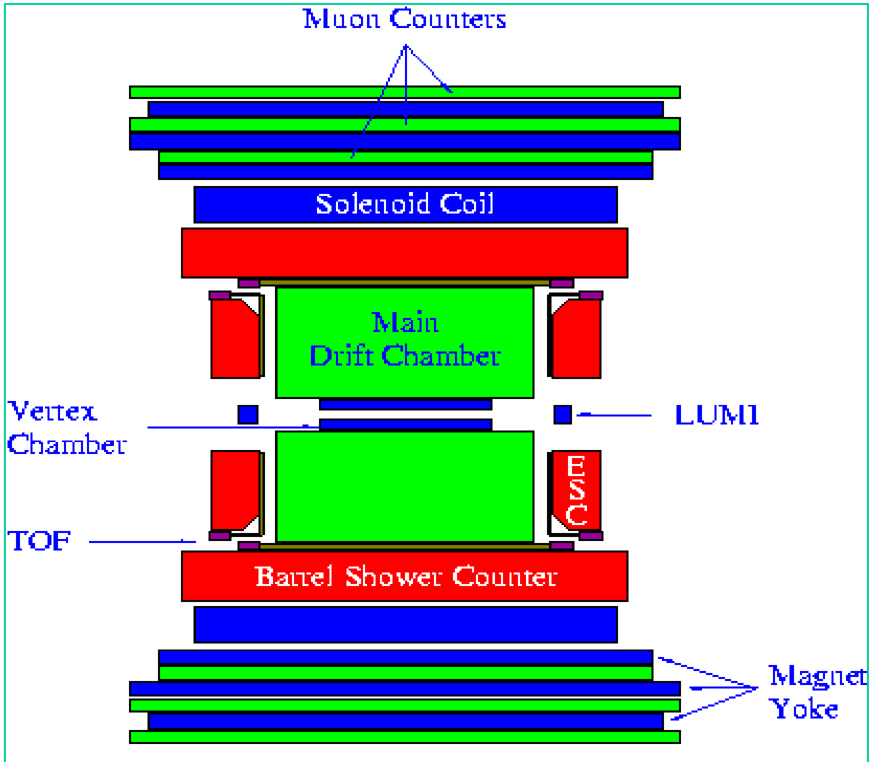
18th Rencontre de Physique de la Vallee d'Aoste

Feb. 29 – Mar. 6, 2004, La Thuile, Aosta Valley, Italy

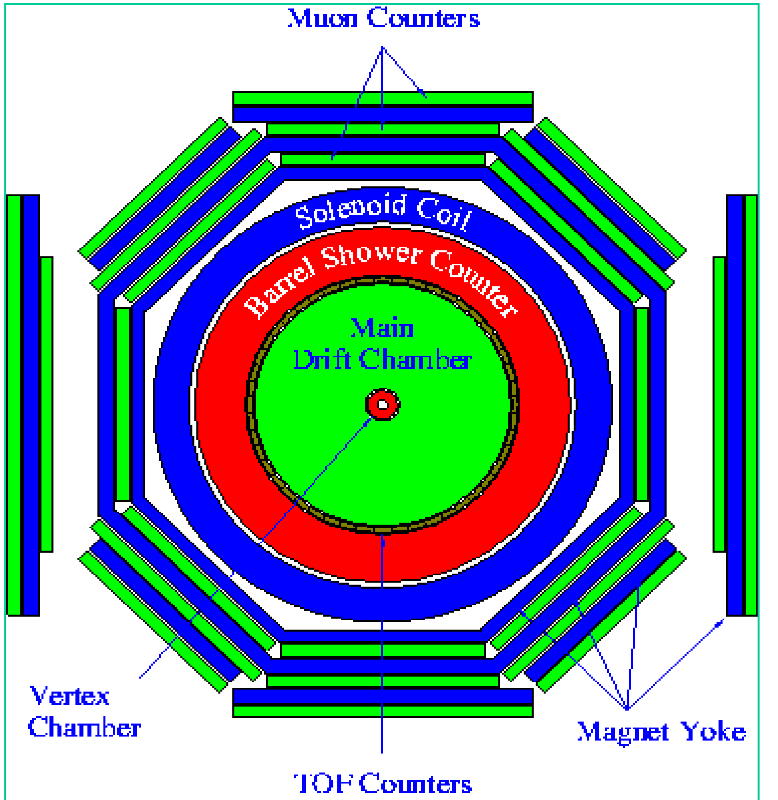
- **Introduction**
- **New states searches and observations**
- **New decay modes observations**
- **Measurements with improved accuracies**
- **Summary**

INTRODUCTION

BESII Detector



Side view of the BES detector



End view of the BES detector

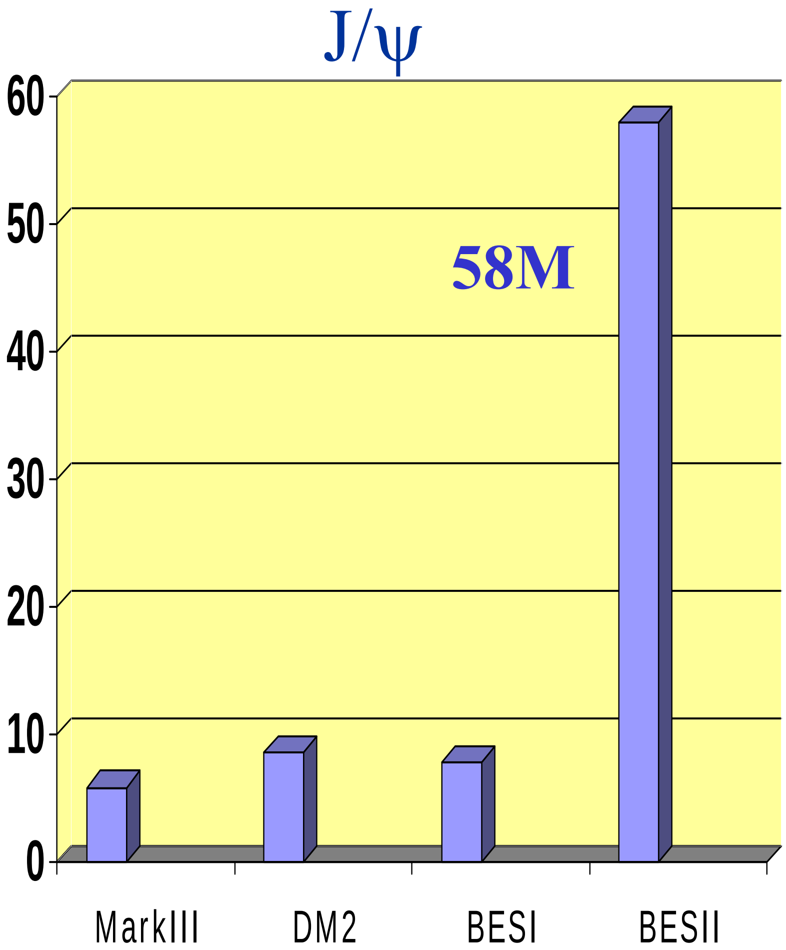
VC: σ_{xy} = 100 μm
MDC: σ_{xy} = 220 μm
$\sigma_{dE/dx}$ = 8.5 %
$\Delta p/p = 1.7\sqrt{(1+p^2)}$

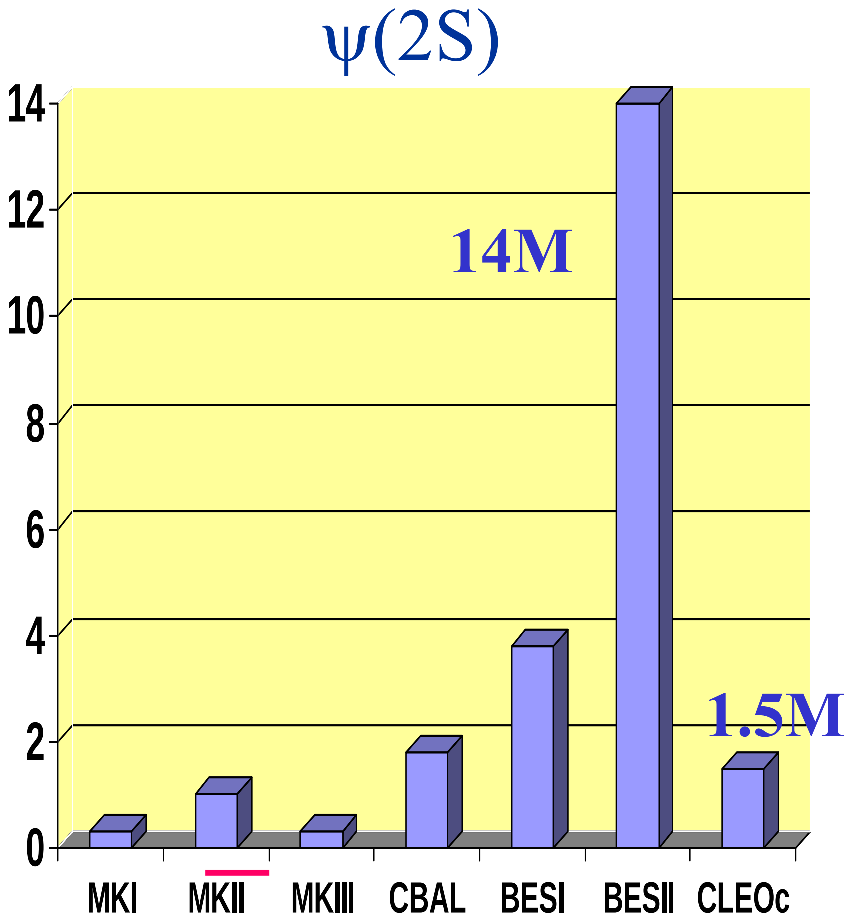
TOF: σ_T = 180 ps
BSC: $\Delta E/\sqrt{E}$ = 22 %
σ_ϕ = 7.9 mr
σ_z = 2.3 cm

μ counter: $\sigma_{r\phi}$ = 3 cm
σ_z = 5.5 cm
B field: 0.4 T

INTRODUCTION

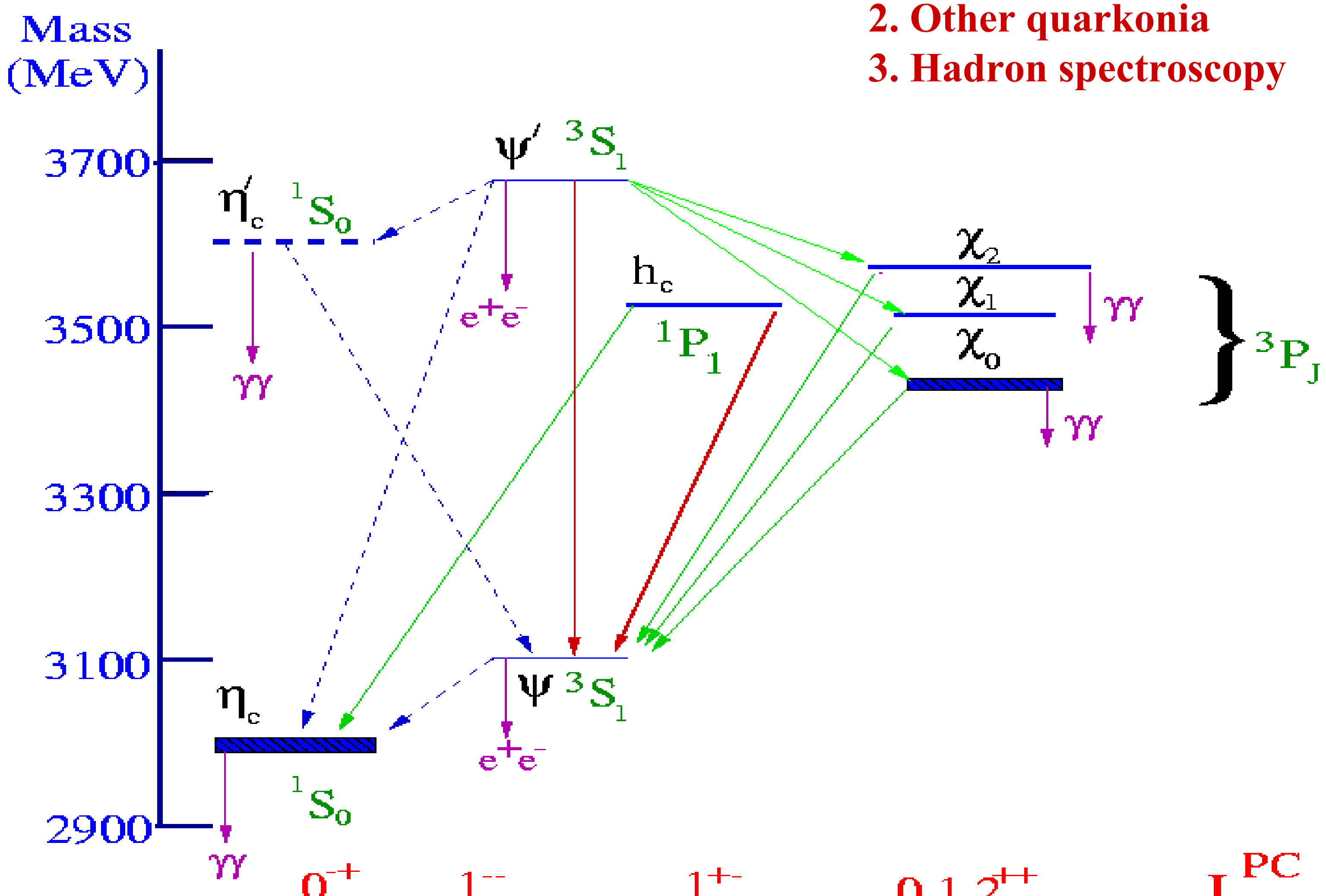
World J/ψ and ψ(2S) Samples (×10⁶)





INTRODUCTION

1. ψ(2S)
2. Other quarkonia
3. Hadron spectroscopy



New States Searches & Observations

1. $J/\psi \rightarrow \gamma p\bar{p}$
2. σ and κ analyses
3. Excited Baryon searches
4. Pentaquark state searches

1. $J/\psi \to \gamma p\bar{p}$

Event Selection of $J/\psi \to \gamma p\bar{p}$

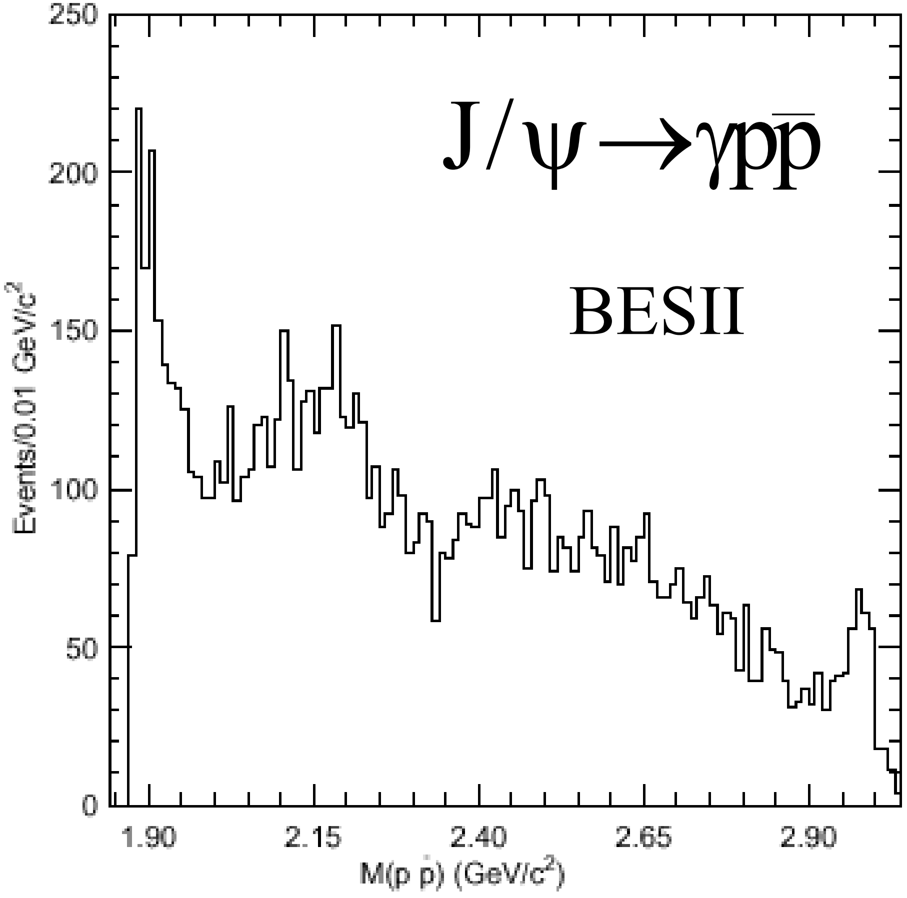
- 2 good charged tracks
- $\geq 1\gamma$ (isolated from charged tracks)
- Particle ID
- 4C-fits

$$-CL(\gamma p\bar{p}) > 0.05$$

$$-CL(\gamma p\bar{p}) > CL(\gamma K^{+}K^{-})$$

1. $J/\psi \to \gamma p\bar{p}$

$p\bar{p}$ masses for selected events



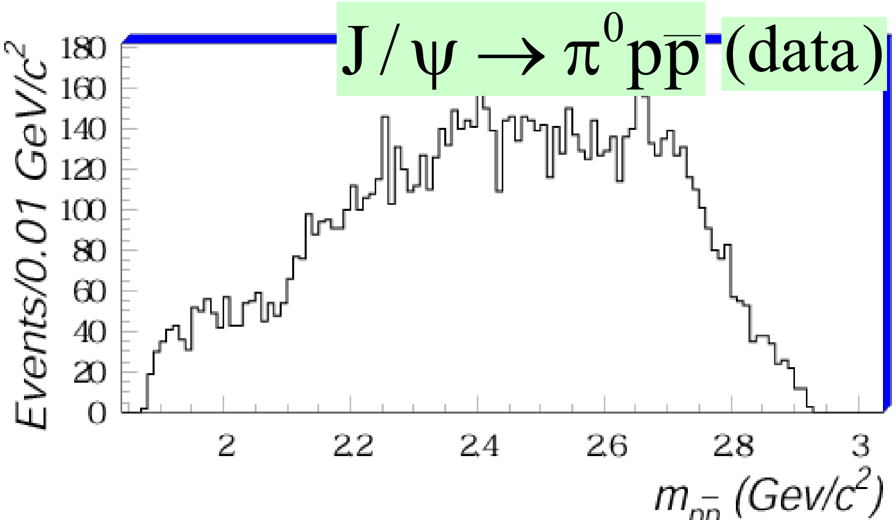
Besides η_c peak, there is a clear enhancement near threshold.

1. $J/\psi \rightarrow \gamma p\bar{p}$

Backgrounds

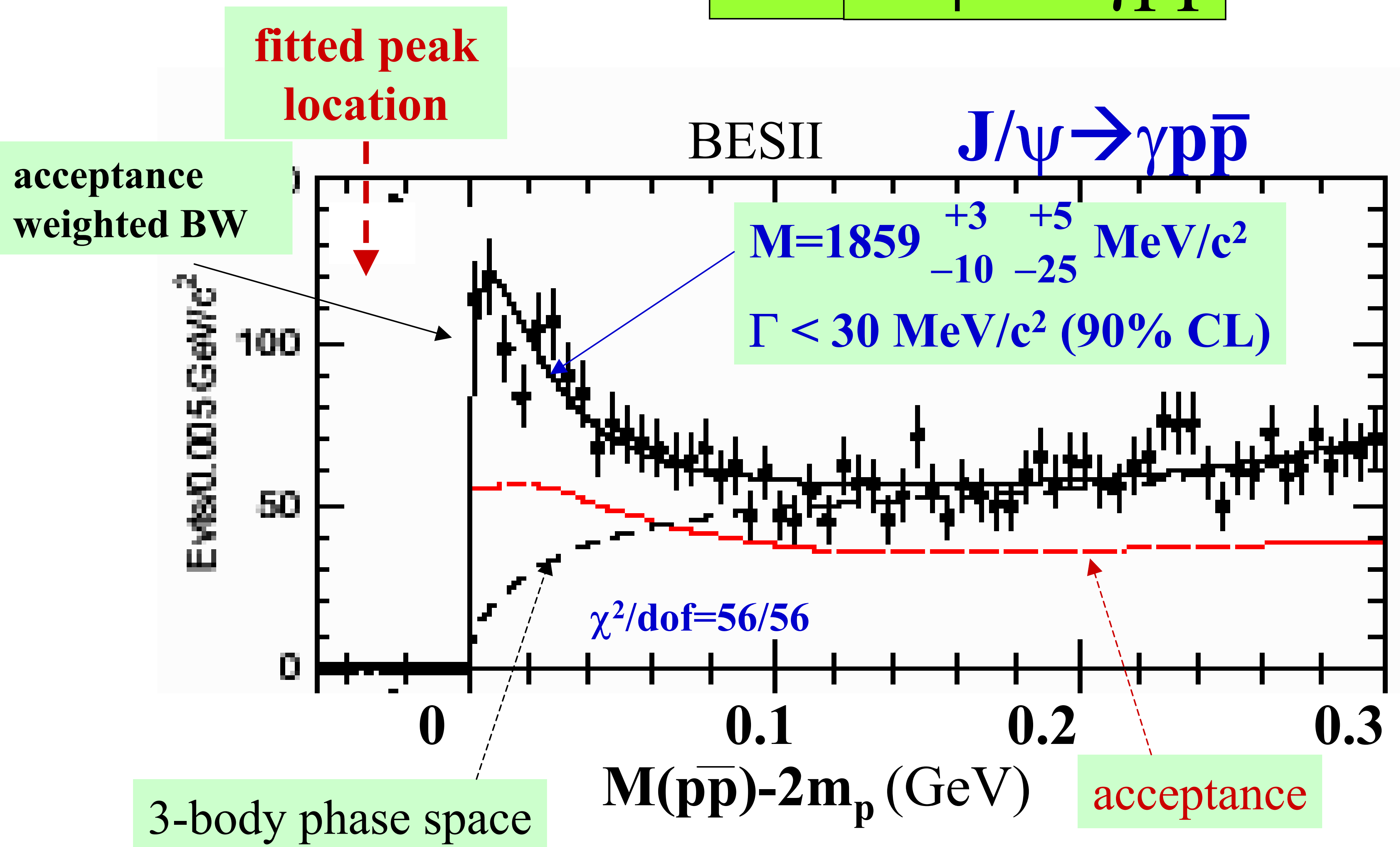
Main backgrounds remained after selection for the mass peak near threshold:

- phase space
- $J/\psi \rightarrow \pi^0 p\bar{p}$ **(almost equal contribution)**



No clear enhancement near threshold

1. $J/\psi \to \gamma p\bar{p}$



It can be fitted as an S-wave resonance

1. $J/\psi \rightarrow \gamma p\bar{p}$

- Any PDG particle can be excluded.
- Its mass and unexpected narrow width suggest a possible interpretation as "deutron like" proton-antiproton bound state (baryonium)

2. σ and κ analyses

σ in $J/\psi \to \omega\pi^+\pi^-$

BES II Preliminary

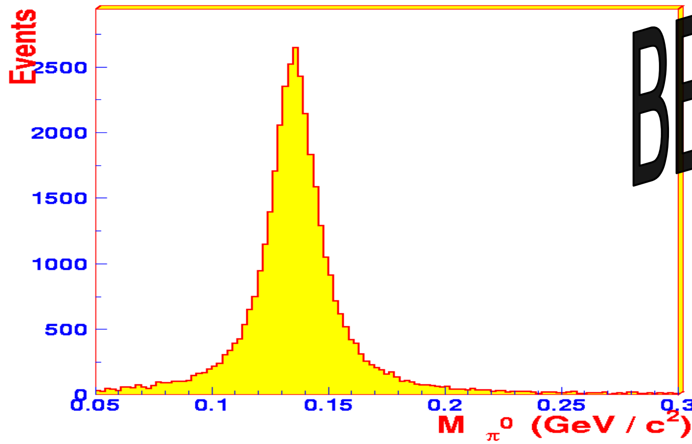


Figure 1: π^0 signal

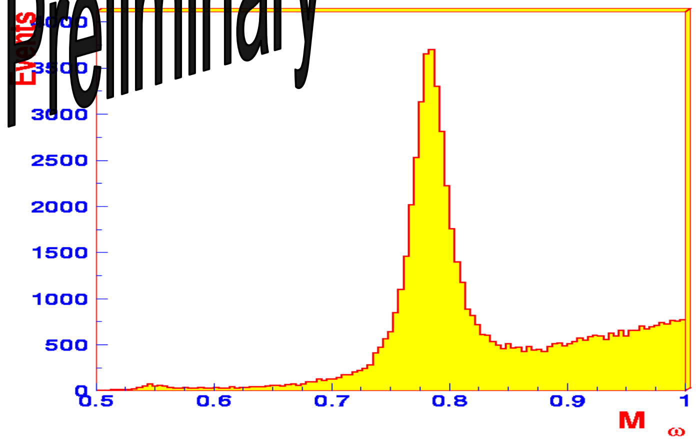


Figure 2: ω signal

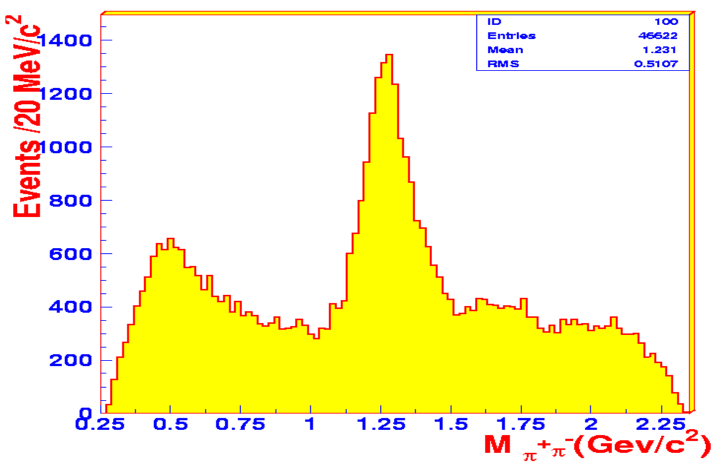
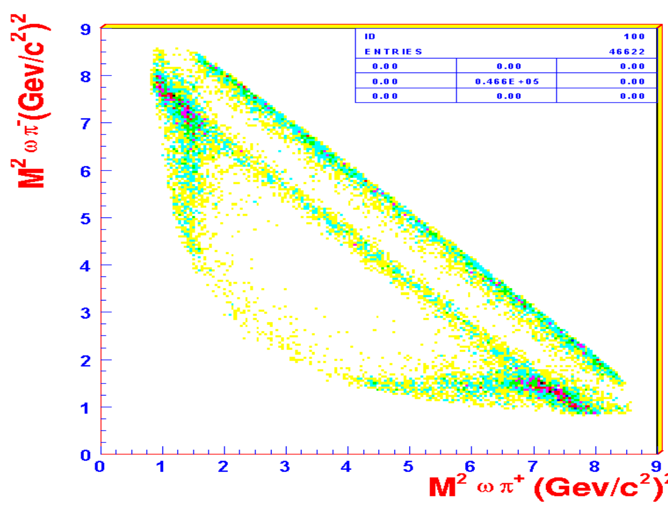


Figure 3: The invariant mass spectrum of $\pi^+\pi^-$



2. σ and κ analyses

σ in $J/\psi \to \omega\pi^+\pi^-$

Method 1	Method 2
<1.55 GeV	whole region
ω decay not used	ω decay used

Channels fitted to the data

$J/\psi \to \omega f_2(1270)$	$J/\psi \to \omega f_2(1270)$
$\omega\sigma$	$\omega\sigma$
$\omega f_0(980)$	$\omega f_0(980)$
$b_1(1235)\pi$	$b_1(1235)\pi$
$\rho\ \pi^+\pi^-\pi^0$	$\rho'(1450)\pi$
phase space	$f_2(2240)\omega$

2. σ and κ analyses

Method 2: Pole position of the σ

If the σ amplitude is written as:

$$f = \frac{G_\sigma}{M^2 - s - iM\Gamma_{tot}(s)},$$

$$\Gamma_{tot}(s) = g_1 \frac{\rho_{\pi\pi}(s)}{\rho_{\pi\pi}(M^2)} + g_2 \frac{\rho_{4\pi}(s)}{\rho_{4\pi}(M^2)},$$

$$g_1 = f(s) \frac{s - m_\pi^2/2}{M^2 - m_\pi^2/2} \exp[-(s - M^2)/a].$$

pole: (542 ±10 ± 40) – i(249 ±25 ±50) MeV

If $\Gamma(s) = \Gamma_0 \rho_{\pi\pi}(s) / \rho_{\pi\pi}(M^2)$

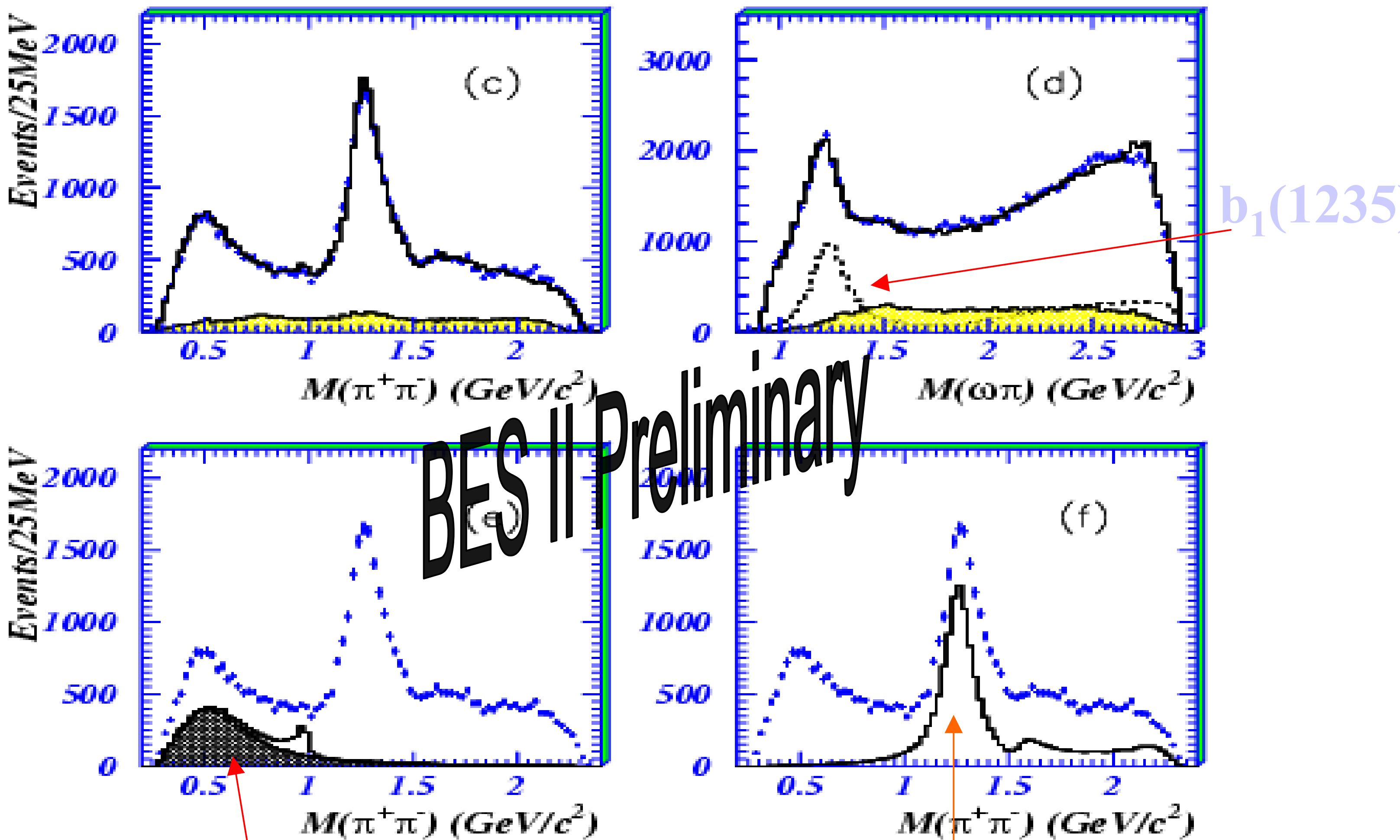
pole: (570 ± 20 ± 45) – i(274±25 ±50) MeV

If Γ = constant

pole: (542 ± 20 ± 40) – i(269 ±30 ±55) MeV

Global fit

2. σ and κ analyses

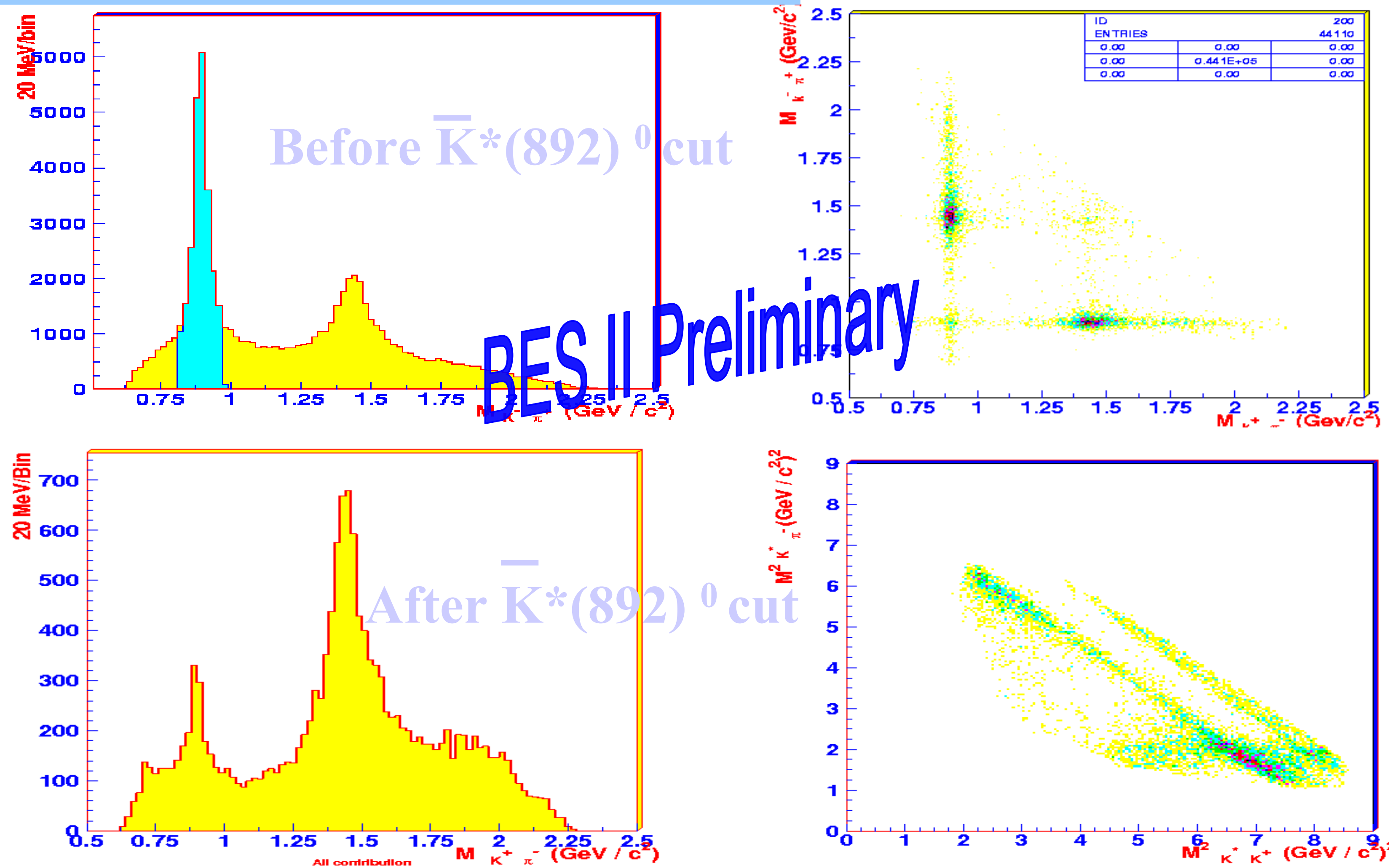


σ contribution

f_2 contribution

2. σ and κ analyses

κ in $J/\psi \to K^+K^-\pi^+\pi^-$ / $K^*K\pi$



3. Excited Baryon searches

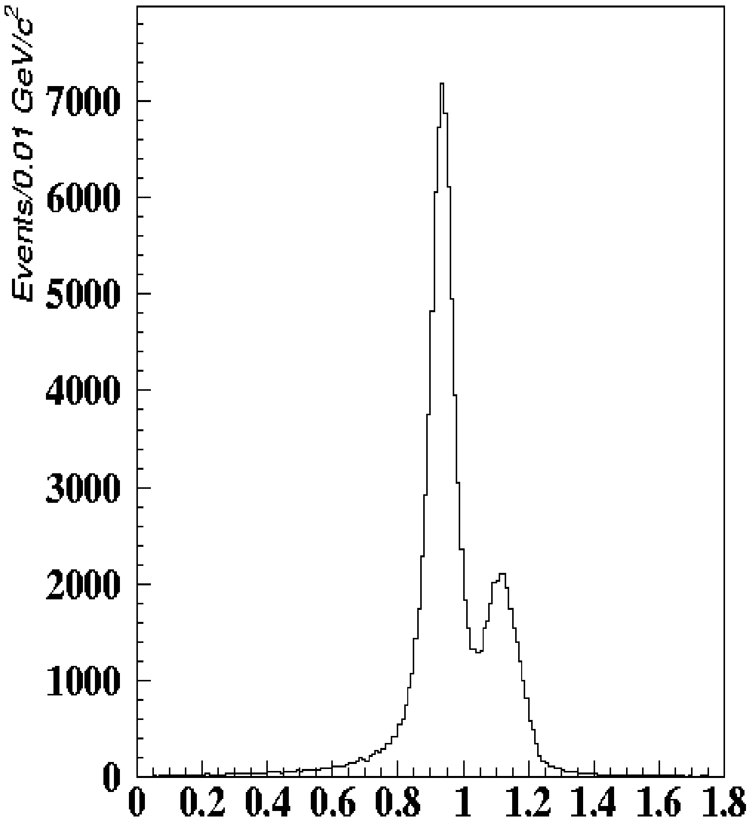
- Probe the internal structure of light quark baryons
- Obtain a better understanding of the strong interaction force in the non-perturbative regime
- $J/\psi \rightarrow p\pi^{-}\overline{n}$

3. Excited Baryon searches

$J/\psi \to p\pi^- \bar{n}$

- Events selection

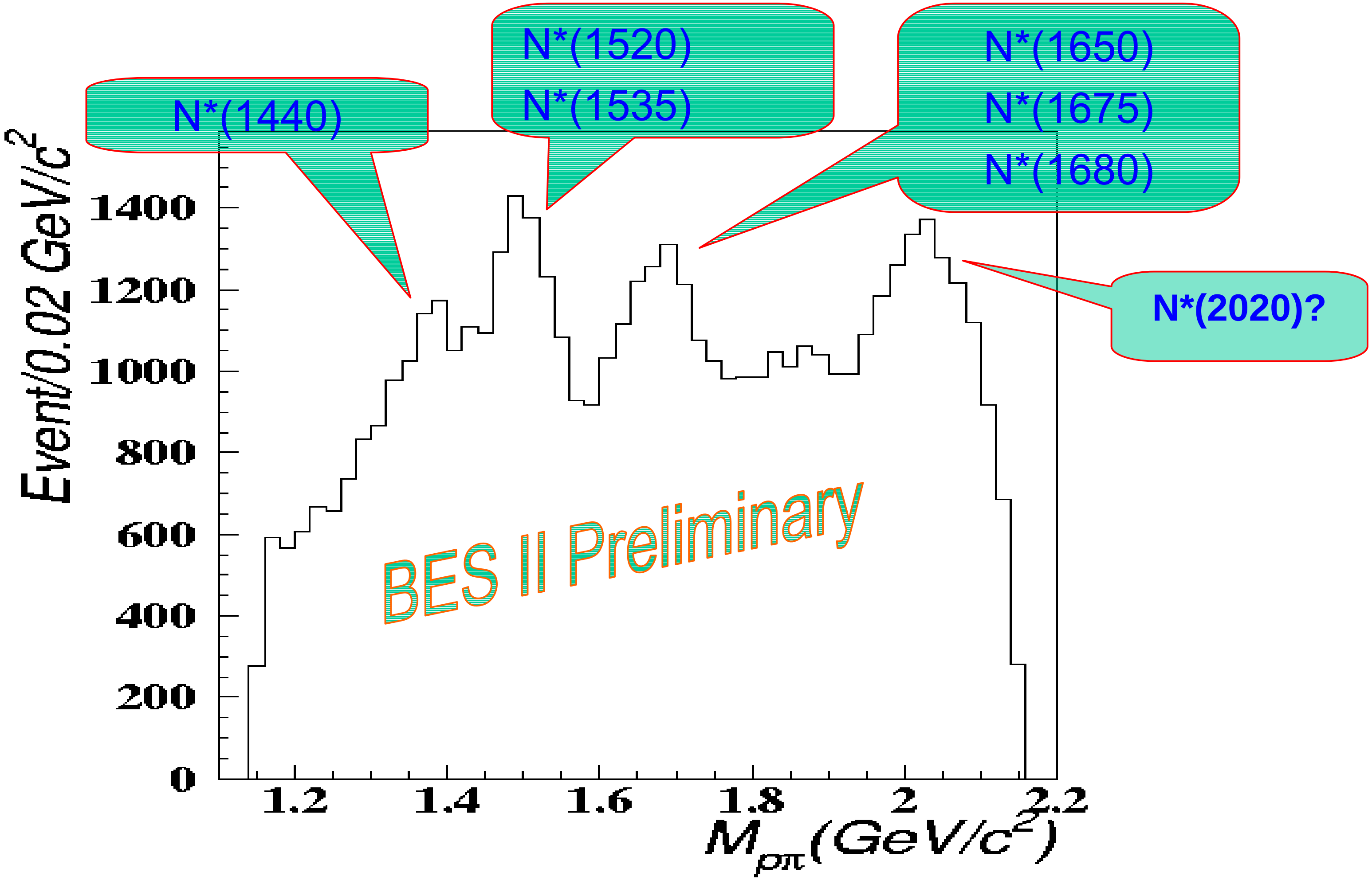
- **2 good charged tracks**
- **Q1+Q2 = 0**
- **|cosθ| < 0.8**
- **PID: TOF and dE/dx**
- ***Prob*(χ^2, 1C) > 0.06**
- **$M_{p\pi}$ > 1.15 GeV**



Missing mass (n)

3. Excited Baryon searches

N* in $J/\psi \to p\pi^-\bar{n}$



4. Pentaquark state search

Pentaquark $qqqq\bar{q}$ searches:
long and interesting history

- **Not forbidden by QCD**
- **Definite evidence of pentaquark states would be an important addition to our understanding of QCD**
- **A baryon S=+1 is a natural candidate**

4. Pentaquark state search

Current experimental results

LEPS @ Spring-8 reported a new resonance Θ,

Close to NK threshold, in $\gamma^{12}C \to K^+K^-X$

$S = +1$, **M = 1540 MeV, Γ < 25 MeV, 4.6 σ**

A 5-quark system ($uudd\bar{s}$) candidate!

DIANA @ ITEP, CLAS @ Jlab, SAPHIR @ ELSA

report similar results subsequently.

HERMES, ZEUS and SVD Collaboration: M ~ 1527 MeV

A strange meson-baryon molecule state or a pentaquark state?

If the latter, it will be the first multi-quark state.

4. Pentaquark state search

Need more experimental facts

(through different processes)

BES investigates the pentaquark state Θ in the hadronic decays of charmonium

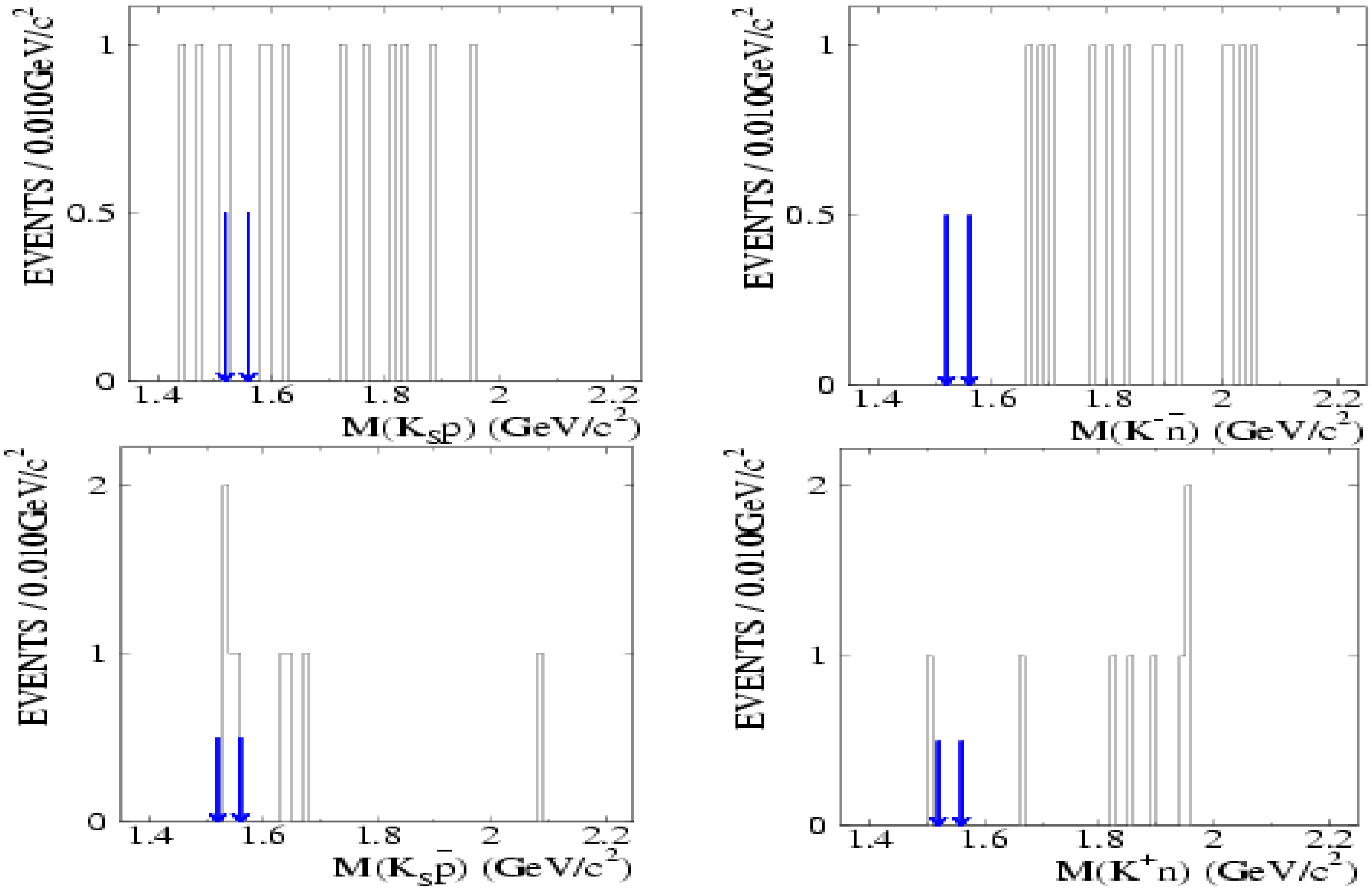
$\psi(2S)$ & $J/\psi \rightarrow \Theta\bar{\Theta} \rightarrow (K_S p)(K^- \bar{n})$ & $(K_S \bar{p})(K^+ n)$

$\Theta \rightarrow K_S p$ or $K^+ n$

$\bar{\Theta} \rightarrow K^- \bar{n}$ or $K_S \bar{p}$

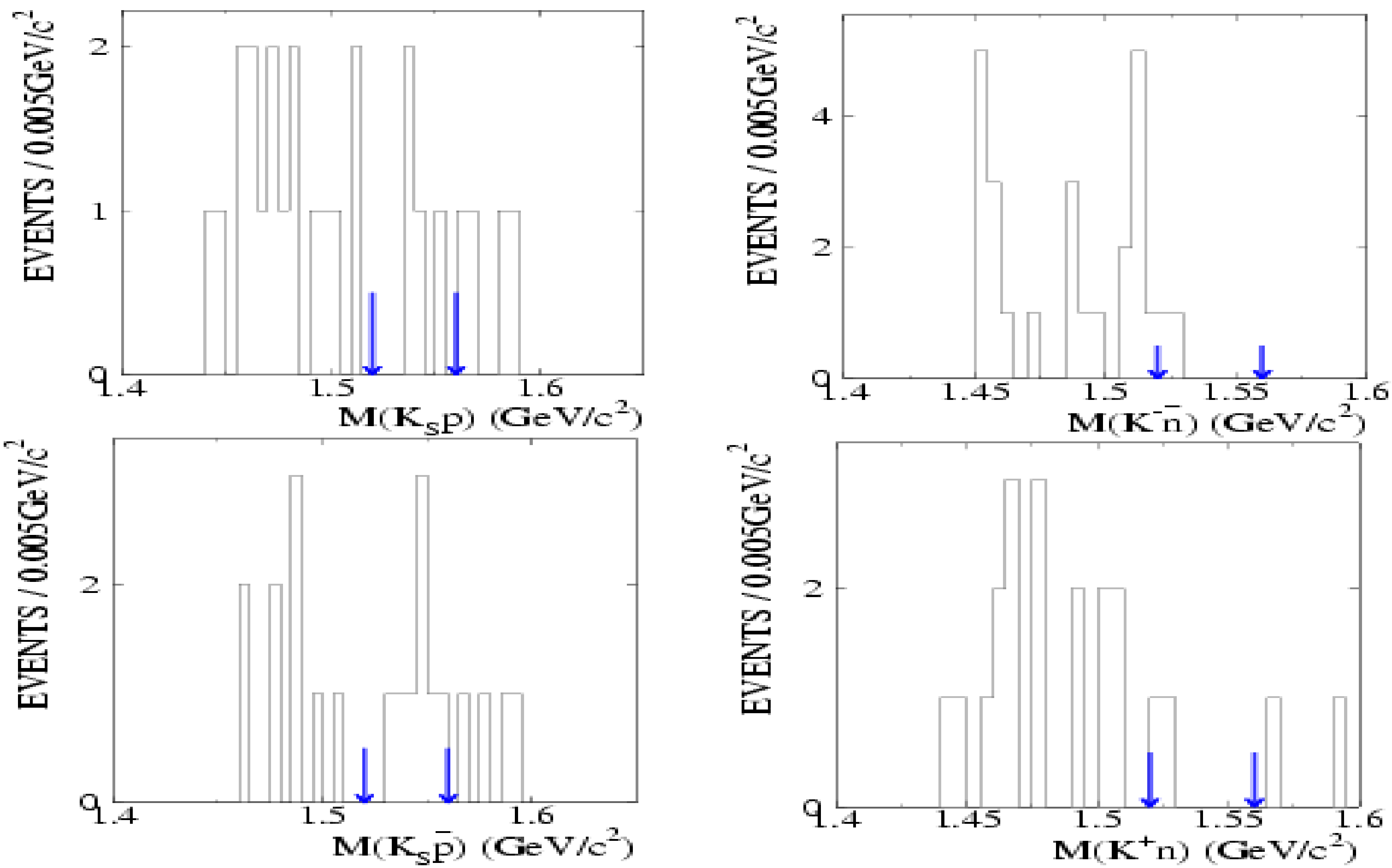
4. Pentaquark state search

Individual Mass Distributions of $\psi(2S) \rightarrow K_S p K^- \bar{n}$ and $K_S \bar{p} K^+ n$ Decays

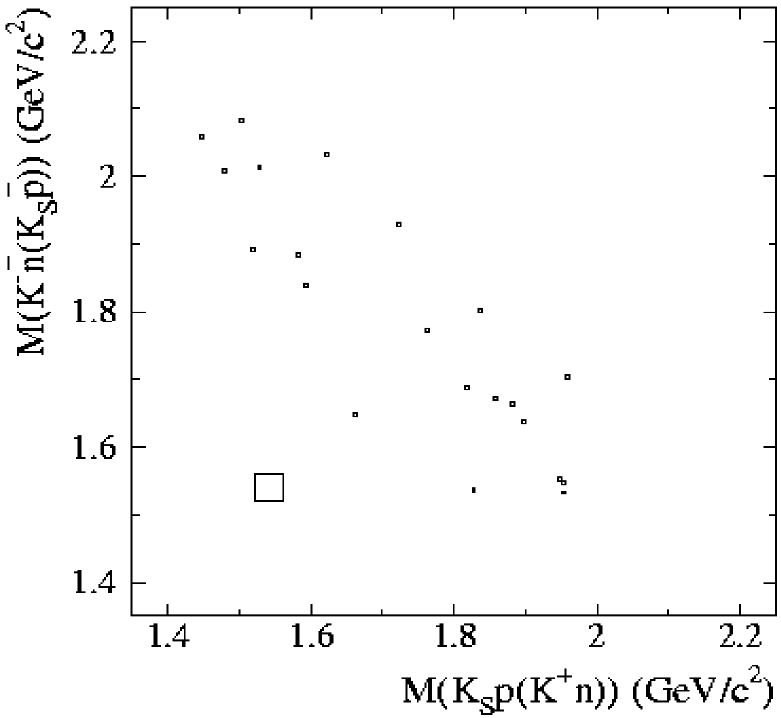


4. Pentaquark state search

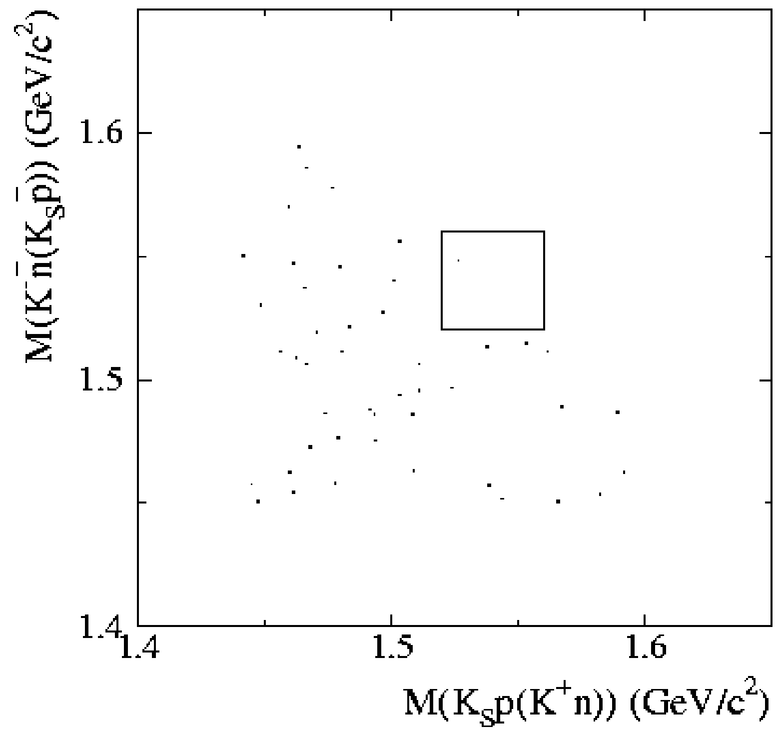
Individual Mass Distributions of $J/\psi \rightarrow K_S p K^- \bar{n}$ and $K_S \bar{p} K^+ n$ Decays



4. Pentaquark state search



$\psi(2S)$



J/ψ

No clear pentaquark state $\Theta(1540)$ (or $\bar{\Theta}$) was observed

4. Pentaquark state search

Upper limits @ 90% C.L.

$$\mathcal{B}(J/\psi \to \Theta\bar{\Theta} \to K_S^0 p K^- \bar{n} + K_S^0 \bar{p} K^+ n) < 1.1 \times 10^{-5}$$

$$\mathcal{B}(J/\psi \to \Theta K^- \bar{n} \to K_S^0 p K^- \bar{n}) < 2.1 \times 10^{-5}$$

$$\mathcal{B}(J/\psi \to \bar{\Theta} K^+ n \to K_S^0 \bar{p} K^+ n) < 5.6 \times 10^{-5}$$

$$\mathcal{B}(J/\psi \to K_S^0 p \bar{\Theta} \to K_S^0 p K^- \bar{n}) < 1.1 \times 10^{-5}$$

4. Pentaquark state search

Upper limits @ 90% C.L.

$$\mathcal{B}(\psi(2S) \to \Theta\bar{\Theta} \to K_S^0 p K^- \bar{n} + K_S^0 \bar{p} K^+ n)$$

$$< \frac{2.30}{0.686 \times (2.85 \pm 0.08)\% \times (14.0 \times 10^6)} = 0.84 \times 10^{-5}$$

$$\mathcal{B}(\psi(2S) \to \Theta K^- \bar{n} \to K_S^0 p K^- \bar{n}) < 1.0 \times 10^{-5}$$

$$\mathcal{B}(\psi(2S) \to \bar{\Theta} K^+ n \to K_S^0 \bar{p} K^+ n) < 2.6 \times 10^{-5}$$

$$\mathcal{B}(\psi(2S) \to K_S^0 p \bar{\Theta} \to K_S^0 p K^- \bar{n}) < 0.60 \times 10^{-5}$$

$$\mathcal{B}(\psi(2S) \to K_S^0 \bar{p} \Theta \to K_S^0 \bar{p} K^+ n) < 0.70 \times 10^{-5}.$$

New Decay Modes Observations

1. $\psi(3770) \rightarrow \pi^+\pi^- J/\psi$

- $\psi(2S) \rightarrow \gamma\chi_c,\ \chi_c \rightarrow \Lambda\bar{\Lambda},\ p\bar{p}$
- $\Psi(2S),\ J/\Psi \rightarrow K_S K_L$
- $\Psi(2S),\ J/\Psi \rightarrow K_S K_S$

1. $\psi(3770) \to \pi^+\pi^- J/\psi$

- $\psi(3770)$ is thought to decay entirely to pure $D\bar{D}$
- Lipkin: It could decay to non-$\overline{DD}$ with a large BR

  Phys. Lett. B 179, 278 (1986)

- Kuang: $\Gamma(\psi(3770) \to \pi^+\pi^- J/\psi) = (25\sim 113)$ keV

  Phys. Rev. D 65, 094024 (2002)

BESII: 27.7 pb^{-1} @~3.773 GeV

1. $\psi(3770) \to \pi^+\pi^- J/\psi$

- Events selection for $\pi^+\pi^- J/\psi \to \pi^+\pi^- l^+l^-$
  - **4 good charged tracks**
  - **Q1+Q2+Q3+Q4 = 0**
  - **$|\cos\theta| < 0.85$**
  - **PID: TOF and dE/dx**

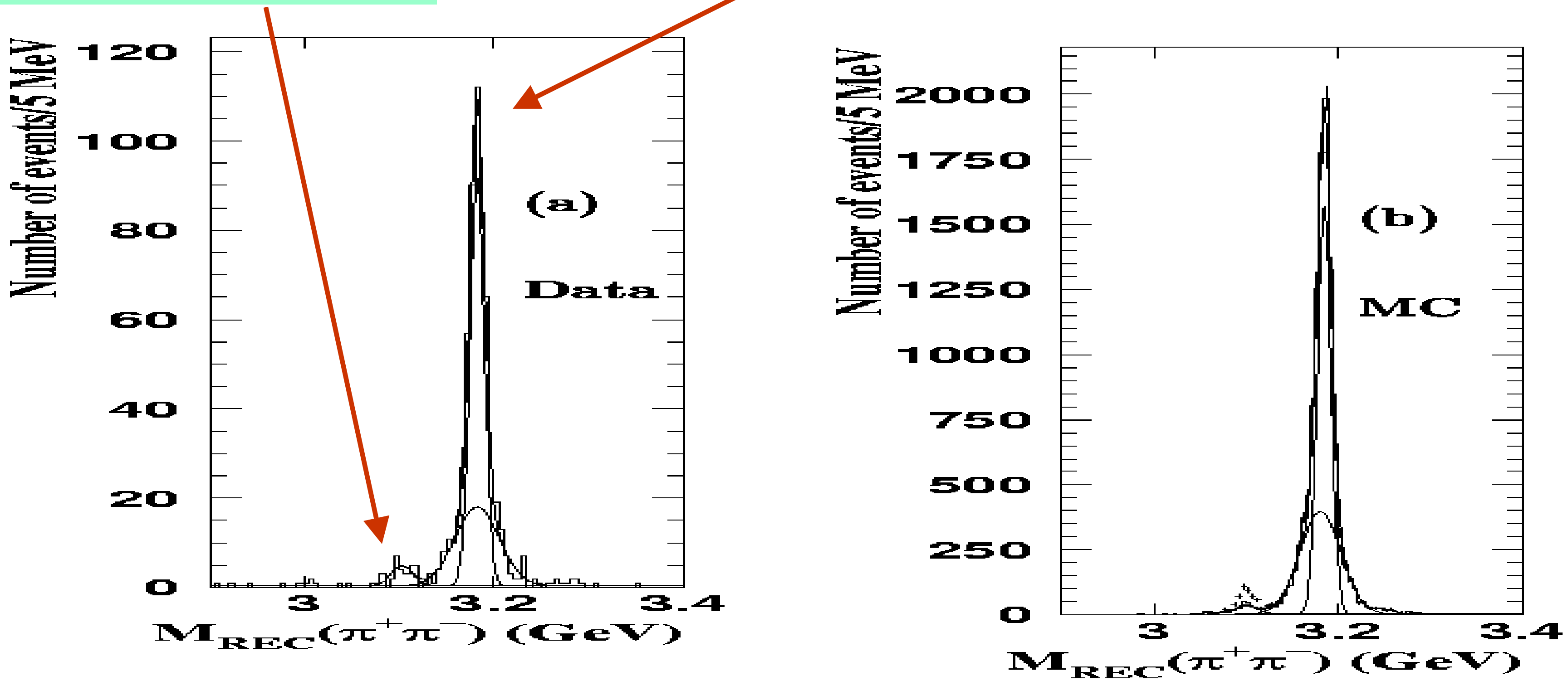
BES Preliminary

1. $\psi(3770) \to \pi^+\pi^- J/\psi$

$M_{REC}(\pi^+\pi^-) = \{(E_{cm} - E_{\pi^+\pi^-})^2 - |P_{\pi^+\pi^-}|^2\}^{1/2}$ **distribution**

$\psi(3770) \to \pi^+\pi^- J/\psi$

ISR return $\psi(2S) \to \pi^+\pi^- J/\psi$



- $| M(J/\psi) - M(l^+l^-) | < 150$ MeV
- $|E(\pi^+\pi^- l^+l^-) - E_{cm}| < 2.5\ \sigma_{E(\pi^+\pi^- l^+l^-)}$

BES Preliminary

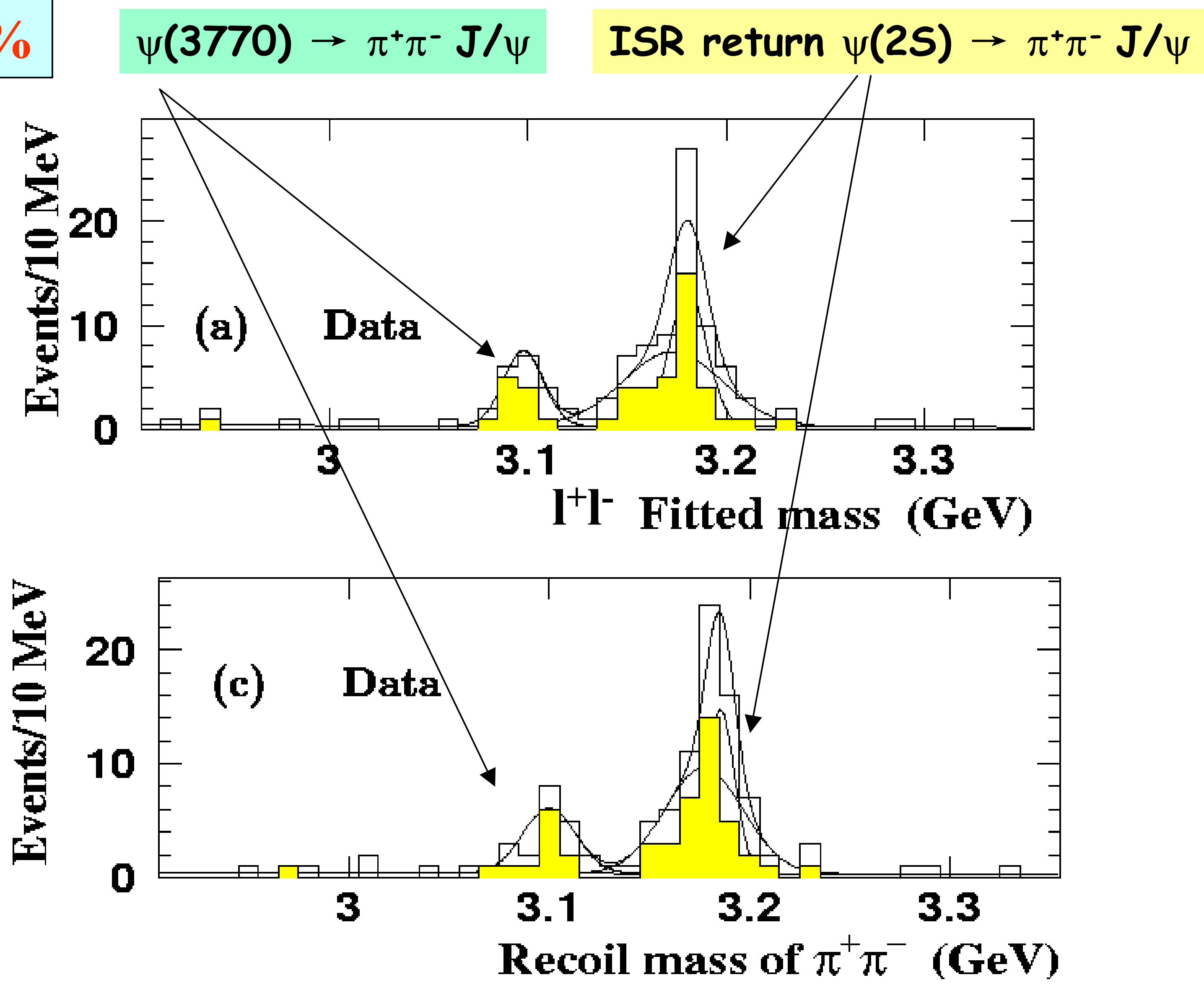
1. ψ(3770) → $\pi^+\pi^-$ J/ψ

Prob(χ^2, 4C) >1%

Open histo:
J/ψ → e^+e^- evt.

Hatched histo:
J/ψ → $\mu^+\mu^-$ evt.

17.8 ± 4.8 evt. fitted



1. $\psi(3770) \to \pi^+\pi^- J/\psi$

BES Preliminary

- **Fitted Total evt.** 17.8 $\pm$4.8

  Bkgd evt. 6.0 $\pm$ 0.5 $\pm$0.6 (MC)

  Signal evt. 11.8 $\pm$4.8

$$B(\psi(3770) \to \pi^+\pi^- J/\psi) = (0.338 \pm 0.137 \pm 0.82)\%$$

$$\Gamma(\psi(3770) \to \pi^+\pi^- J/\psi) = (80 \pm 32 \pm 21) \text{ keV}$$

- **BES has observed the hadronic transition of $\psi(3770) \to \pi^+\pi^- J/\psi$ for the first time**

2. $\chi_c \to \Lambda\bar{\Lambda}$, $p\bar{p}$

- **Color octet mechanism (COM) plays an important role in P-wave quarkonium decay calculation**
  - G. T. Bodwin *et al.*, **PRD 51**, 1125 (1995).
  - H.-W. Huang and K.-T. Cho **PRD 54**, 6850 (1996).
  - J. Bolz *et al.*, **PLB392**, 198 (1997).

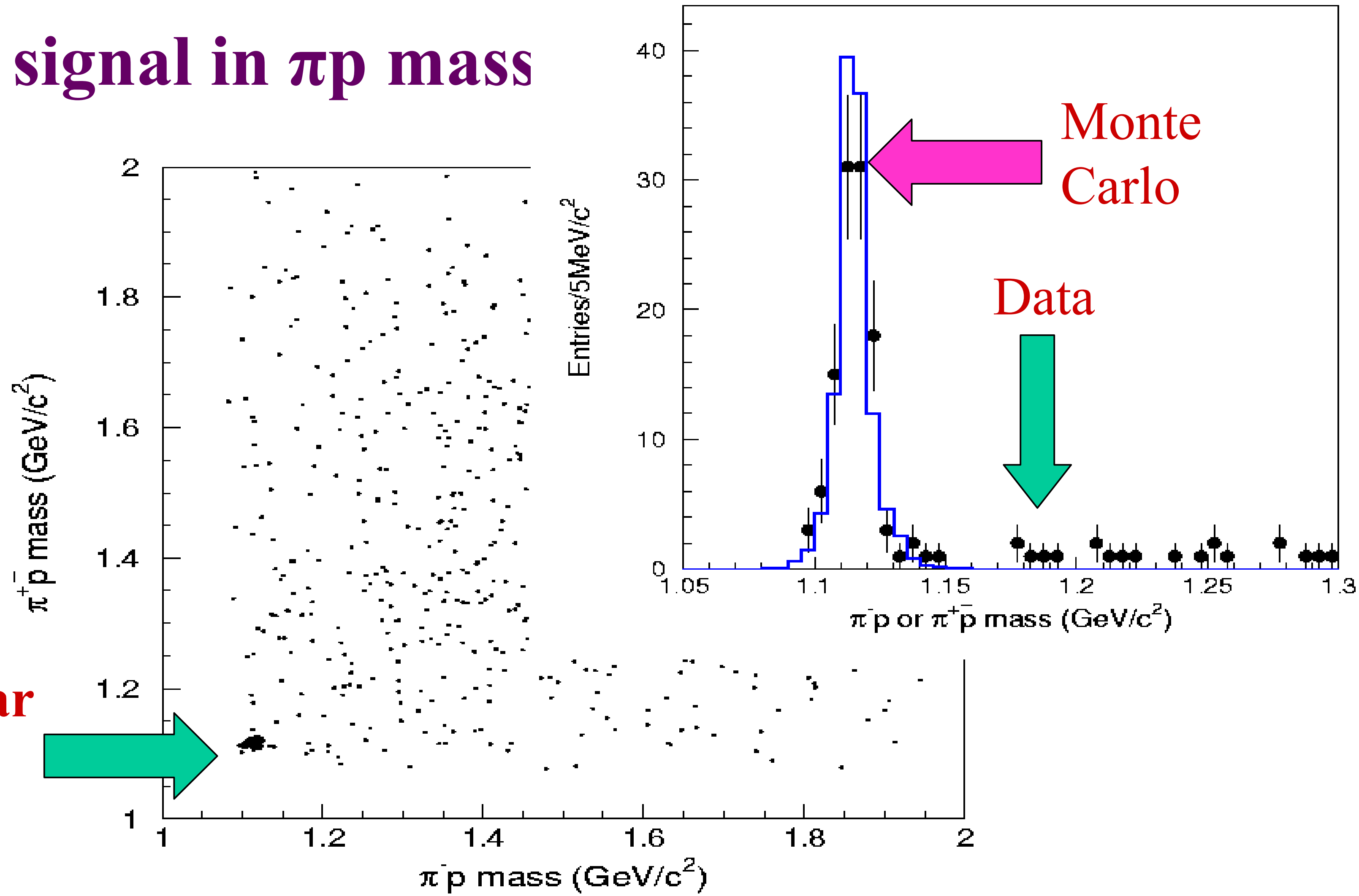
- **BES $\Gamma(\chi_{c0})$ agrees with COM prediction.**
  Phys. Rev. Lett. **81**, 3091 (1998).

- **Using nucleon wave function and Generalizing to other baryons, COM predicts:**
  $\Gamma(\chi_{cJ} \to \Lambda\ \Lambda$**-bar)** $\sim$ **½** $\Gamma(\chi_{cJ} \to$ **p p-bar) for** χ_{c1} **and** χ_{c2}.
  S. M. Wong, Eur. Phys. J. **C14**, 643 (2000).

2. $\chi_c \to \Lambda\bar{\Lambda}$, $p\bar{p}$

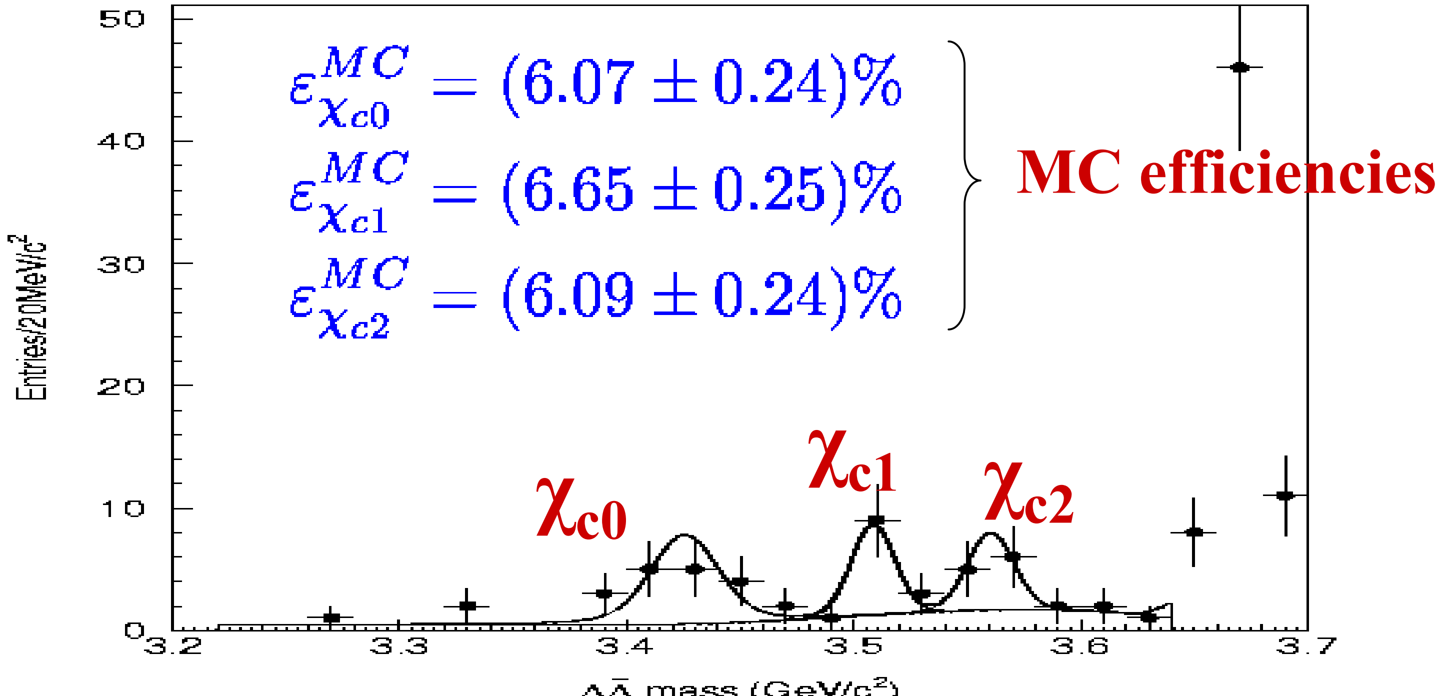
Final states: $\gamma\pi^+\pi^-$pp-bar

Λ signal in πp mass



Clear
Λ Λ-bar
Signal

2. $\chi_c \to \Lambda\bar{\Lambda}$, $p\bar{p}$



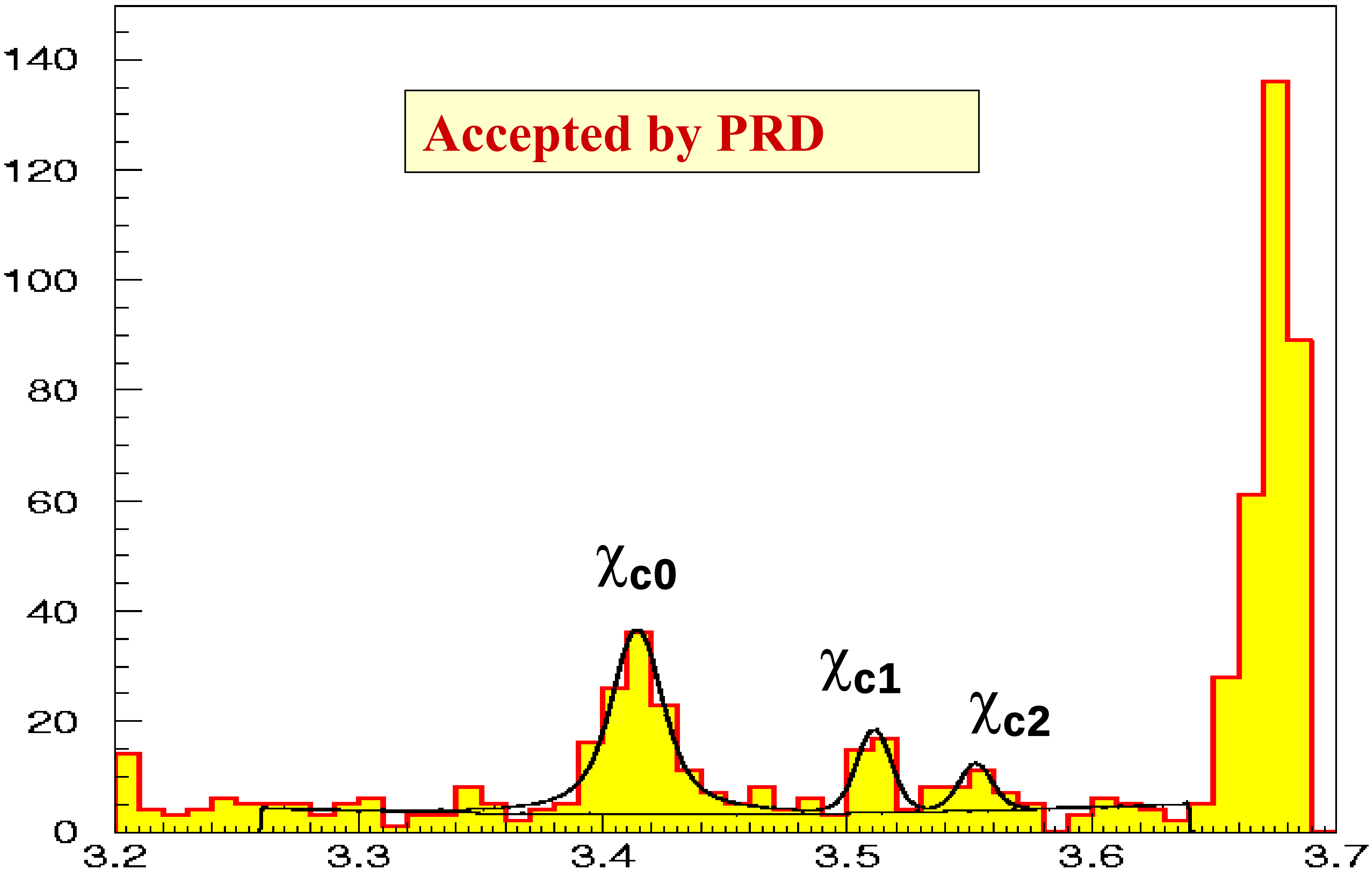
PRD 67, 112001 (2003)

ΛΛ-bar Mass (GeV)

	χ_{c0}	χ_{c1}	χ_{c2}
$B(\chi_{cJ} \to \Lambda\bar{\Lambda})$	$4.7^{+1.3}_{-1.2} \pm 1.0$	$2.6^{+1.0}_{-0.9} \pm 0.6$	$3.3^{+1.5}_{-1.3} \pm 0.7$
$B(\chi_{cJ} \to p\bar{p})$ $(PDG02)$	2.2 ± 0.5	0.72 ± 0.13	0.74 ± 0.10

$\chi_c \to p\bar{p}$

2. $\chi_c \to \Lambda\bar{\Lambda}, \quad p\bar{p}$



$\chi_c \to p\bar{p}$

2. $\chi_c \to \Lambda\bar{\Lambda}$, $p\bar{p}$

$(\times 10^{-4})$	χ_{c0}	χ_{c1}	χ_{c2}
$B(\chi_{cJ} \to \Lambda\bar{\Lambda})$	$4.7^{+1.3}_{-1.2} \pm 1.0$	$2.6^{+1.0}_{-0.9} \pm 0.6$	$3.3^{+1.5}_{-1.3} \pm 0.7$
$B(\chi_{cJ} \to p\bar{p})$ $(PDG02)$	2.2 ± 0.5	0.72 ± 0.13	0.74 ± 0.10
$B(\chi_{cJ} \to p\bar{p})$	$2.71^{+0.43}_{-0.39} \pm 0.47$	$0.57^{+0.17}_{-0.15} \pm 0.09$	$0.65^{+0.24}_{-0.21} \pm 0.10$

- **COM predicts: for χ_{c1} and χ_{c2}.**

  Γ ($\chi_{cJ} \to \Lambda$ Λ-bar) ~½ Γ ($\chi_{cJ} \to$ p p-bar)

- **BES new results for $B(\chi_{cJ} \to \Lambda\bar{\Lambda})$ and $B(\chi_{cJ} \to p\bar{p})$**

  NOT consistent with COM prediction

$\Psi(2S) \rightarrow K_S K_L$

3. $\Psi(2S)$, $J/\Psi \rightarrow K_S K_L$

- **pQCD rule & Phase Study**

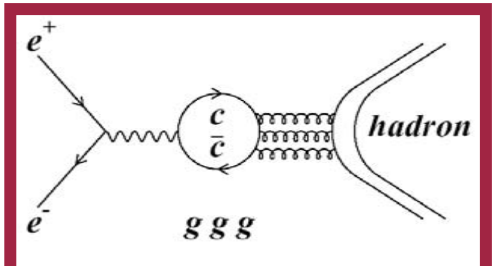
$\psi(2S) \rightarrow Ks\ K_L$: $A_{KsKL} = M$

$\psi(2S) \rightarrow K^+ K^-$: $A_{K+K-} = E+M$

$\psi(2S) \rightarrow \pi^+\pi^-$: $A_{\pi^+\pi^-} = E$

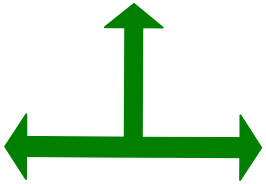
$BR(\psi(2S) \rightarrow Ks\ K_L)$ versus φ

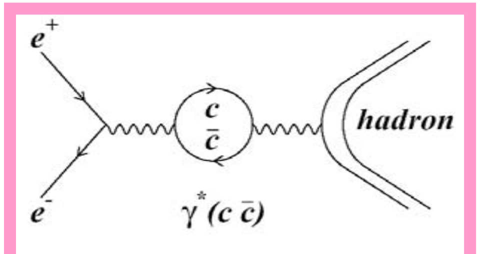
Can be obtained by inputing other two BRs and Including continuum contributions.



(a) three gluon process

Phase

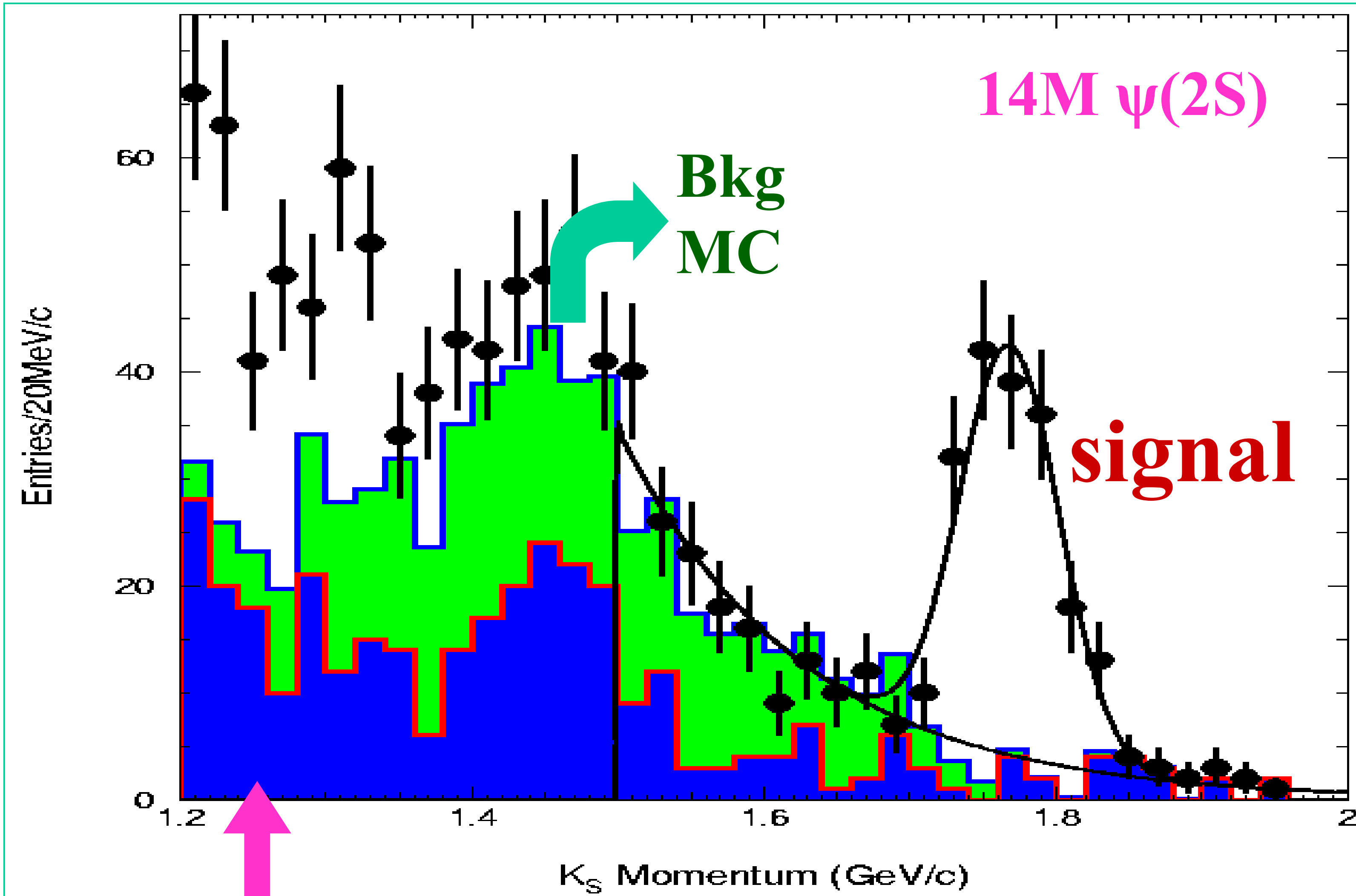




(b) one photon process

$\Psi(2S) \rightarrow K_S K_L$

3. $\Psi(2S)$, $J/\Psi \rightarrow K_S K_L$



Ks mass sidebands

$\Psi(2S) \to K_S K_L$

3. $\Psi(2S)$, $J/\Psi \to K_S K_L$

BESII: First measurement for $B(\psi(2S) \to K_S K_L)$

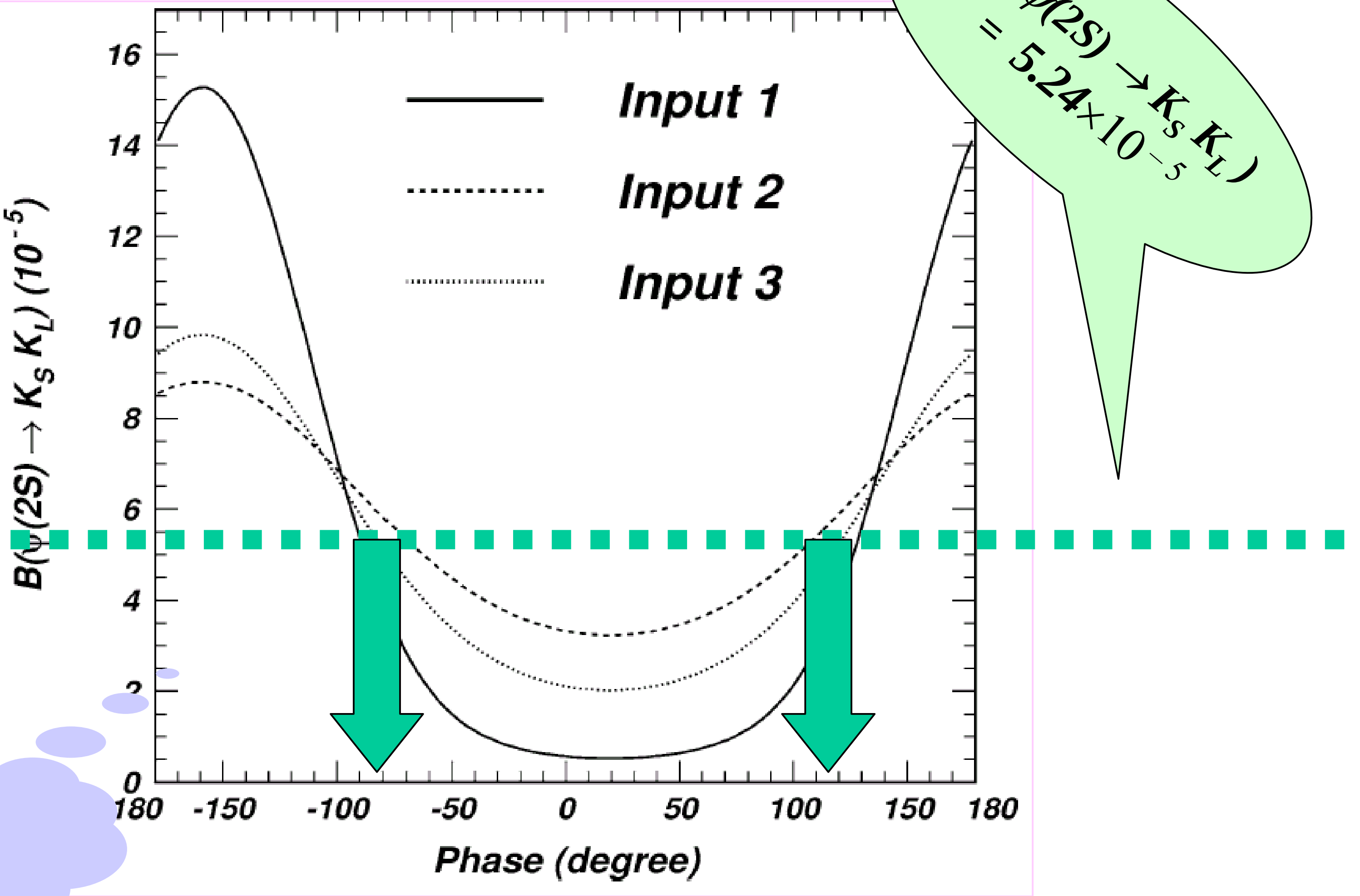
quantity	Value
n^{obs}	156 ± 14
ε_{MC} (%)	41.59 ± 0.48
ε_{trig} (%)	76.0 ± 1.8
ε_{2nd} (%)	98.1 ± 4.0
$N_{\psi(2S)}(10^6)$	14.0 ± 0.7
$B(K_S^0 \to \pi^+\pi^-)$	0.6860 ± 0.0027 [17]
$B(\psi(2S) \to K_S^0 K_L^0)(10^{-5})$	$5.24 \pm 0.47 \pm 0.48$

PRL 92, 052001 (2004)

3. $\Psi(2S)$, $J/\Psi \to K_S K_L$

$\Psi(2S) \to K_S K_L$

K^+K^- & $\pi^+\pi^-$ $\to$ inputs ;
Input 1:DASP;
Input 2:BESI ;
Input 3: K^+K^- from BESI & $\pi^+\pi^-$ by form factor.

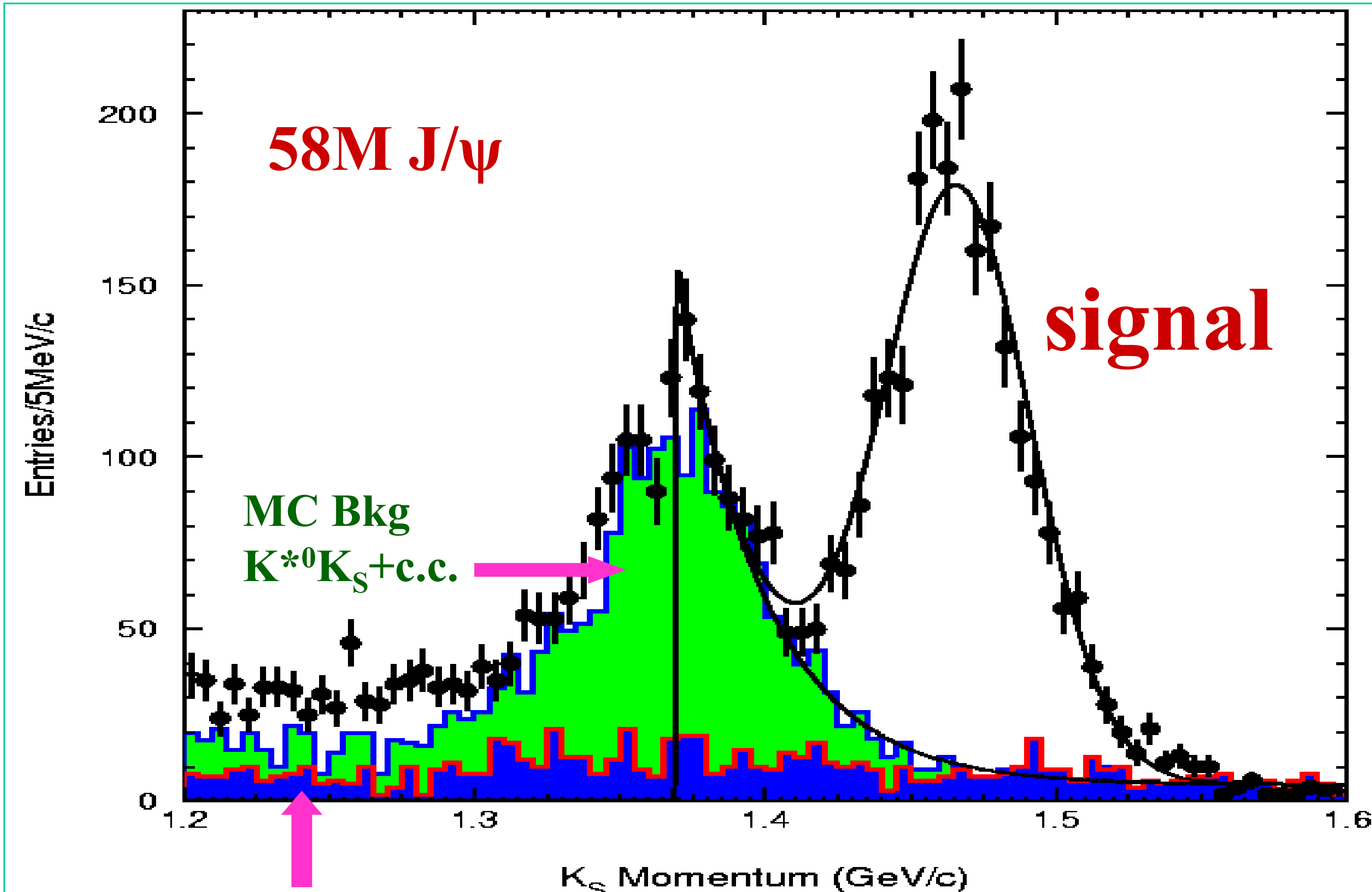


PLB567 (2003)73

$-(80\pm29)°$ $(120\pm27)°$

$J/\Psi \to K_S K_L$

3. $\Psi(2S)$, $J/\Psi \to K_S K_L$



Ks mass sidebands

$J/\Psi \to K_S K_L$

3. $\Psi(2S)$, $J/\Psi \to K_S K_L$

BESII: Higher accuracy for $B(J/\psi \to K_S K_L)$

PRD 69, 012003 (2004)

Quantity	*Value*
n^{obs}	2155 ± 45
ε_{MC} (%)	38.69 ± 0.23
f (%)	77.2 ± 3.4
$N_{\psi(2S)}$ (10^6)	57.7 ± 2.7
$B_{Ks \to \pi^+ \pi^-}$	0.6860 ± 0.0027
$B_{J/\psi \to Ks\,K_L}$ (10^{-4})	$1.82 \pm 0.04 \pm 0.13$

PDG2002: $B_{J/\psi \to Ks\,K_L} = (1.08 \pm 0.14) \times 10^{-4}$

~4σ diff.

3. $\Psi(2S),\ J/\Psi \to K_S K_L$

$$B_{\psi(2S)\to K_S K_L} = (5.24 \pm 0.47 \pm 0.48) \times 10^{-5}$$

$$B_{J/\psi \to K_S K_L} = (1.82 \pm 0.04 \pm 0.13) \times 10^{-4}$$

$$\frac{B_{\psi(2S)\to K_S K_L}}{B_{J/\psi \to K_S K_L}} = (28.8 \pm 3.7)\%$$

$$Q_h = \frac{B_{\psi(2S)\to X}}{B_{J/\psi \to X}} = 12\%$$

$> 4\sigma$

B(Ψ(2S)) enhanced!

4. $\Psi(2S)$, $J/\Psi \rightarrow K_S K_S$

- CP violating process
- Test EPR paradox

(Einstein-Podolsky-Rosen)

versus Quantum theory

- MarkIII: 2.7M J/Ψ

$B(J/\Psi \rightarrow K_S K_S) < \mathbf{5.2 \times 10^{-6}}$

(90% C.L.)

- BESII: 58M J/Ψ

14M $\Psi(2S)$

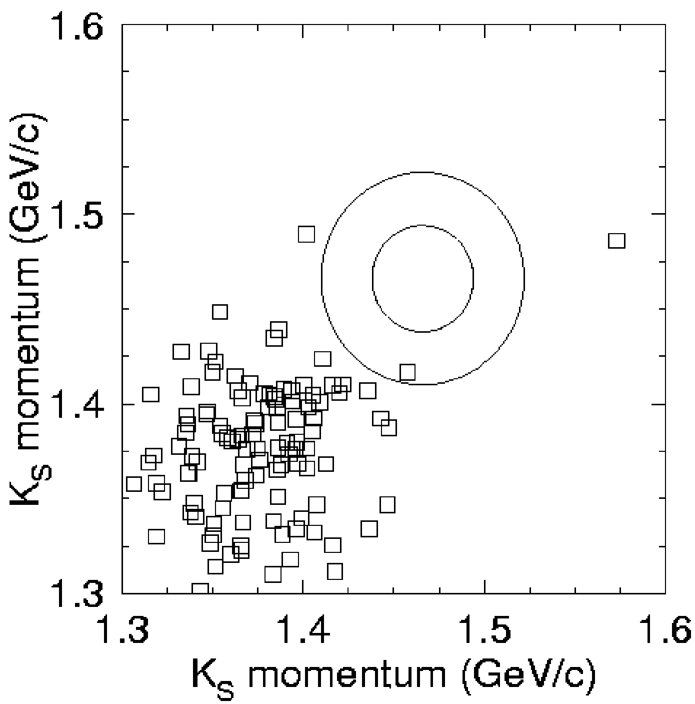
Events selection

- 4 good charged tracks
- Q(sum) = 0
- $|\cos\theta| < 0.8$
- K_S decay length $L_{xy} > 3$ mm
- $|M_{\pi\pi} - M_{K_S}| > 2\,\sigma_M$

4. $\Psi(2S)$, $J/\Psi \rightarrow K_S K_S$

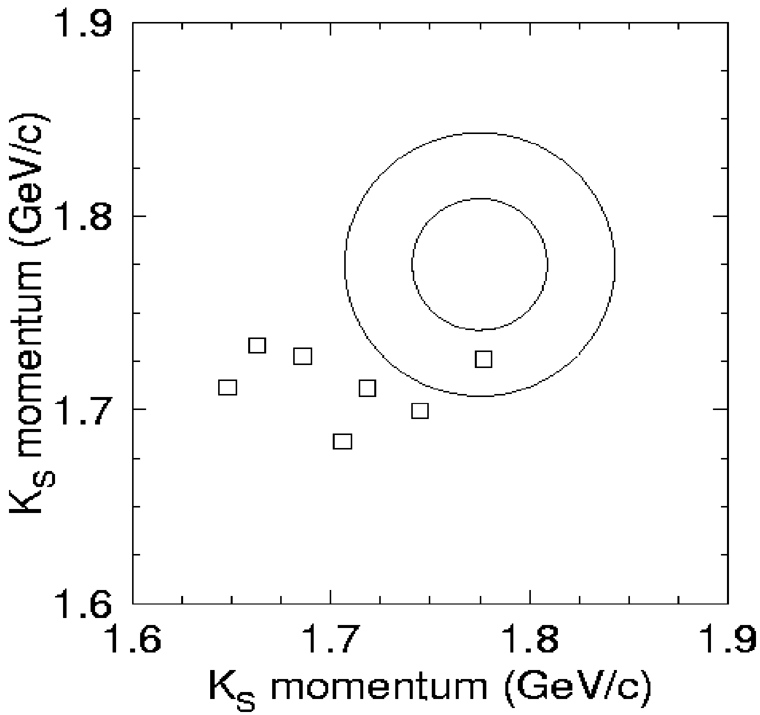
2 circles – 1 σ & 2 σ regions from MC

1 evt in 2 σ region



$J/\Psi \rightarrow K_S K_S$ candidates

1 evt in 2 σ region



$\Psi(2S) \rightarrow K_S K_S$ candidates

4. $\Psi(2S)$, $J/\Psi \rightarrow K_S K_S$

Upper Limits (95% C.L.)

R	J/ψ	$\psi(2S)$
n^{obs}	1	1
n^{obs}_{UL}	4.74	4.74
ε_{MC} (%)	20.74 ± 0.41	19.18 ± 0.39
ε_{trg} (%)	98.2 ± 0.2	96.5 ± 0.7
ε_{2nd} (%)	92.9 ± 4.5	96.2 ± 5.8
$N_{\psi(2S)}(10^6)$	57.7 ± 2.7	14.0 ± 0.7
$\mathcal{B}(K^0_S \to \pi^+\pi^-)$	0.6860 ± 0.0027	
$\mathcal{B}(R \to K^0_S K^0_S) <$	1.0×10^{-6}	4.6×10^{-6}

Submitted to PLB

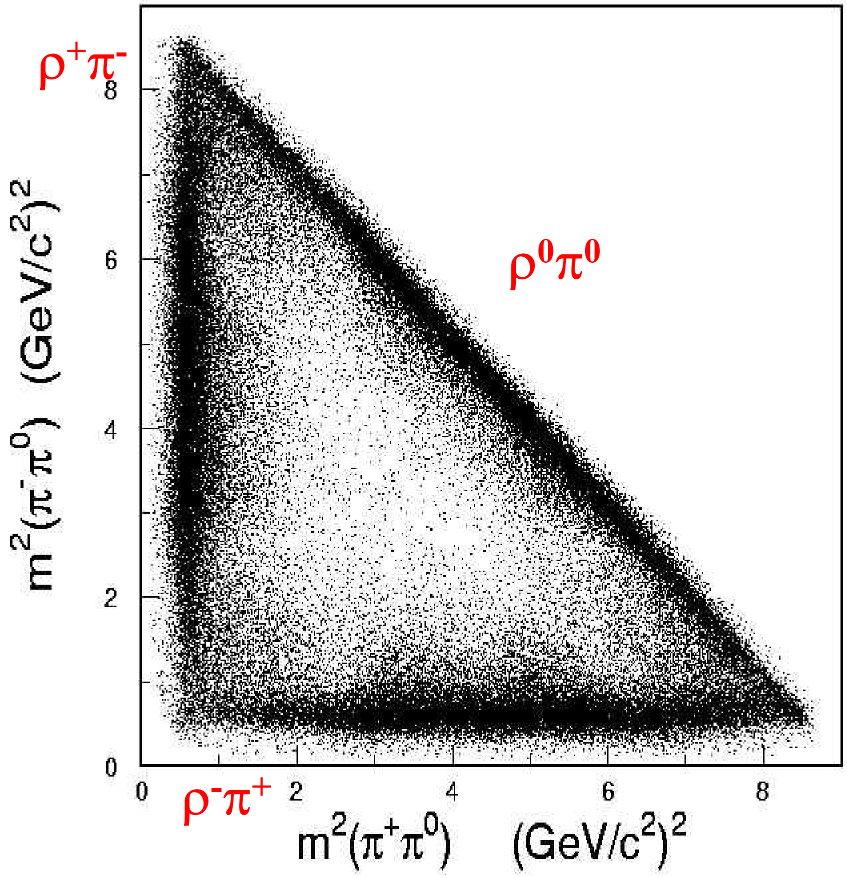
- **1st upper limit for $B(\Psi(2S) \rightarrow K_S K_S)$.**
- **Higher sensitivity for $B(J/\Psi \rightarrow K_S K_S)$ upper limit.**
- **Sensitivity insufficient for testing EPR paradox.**

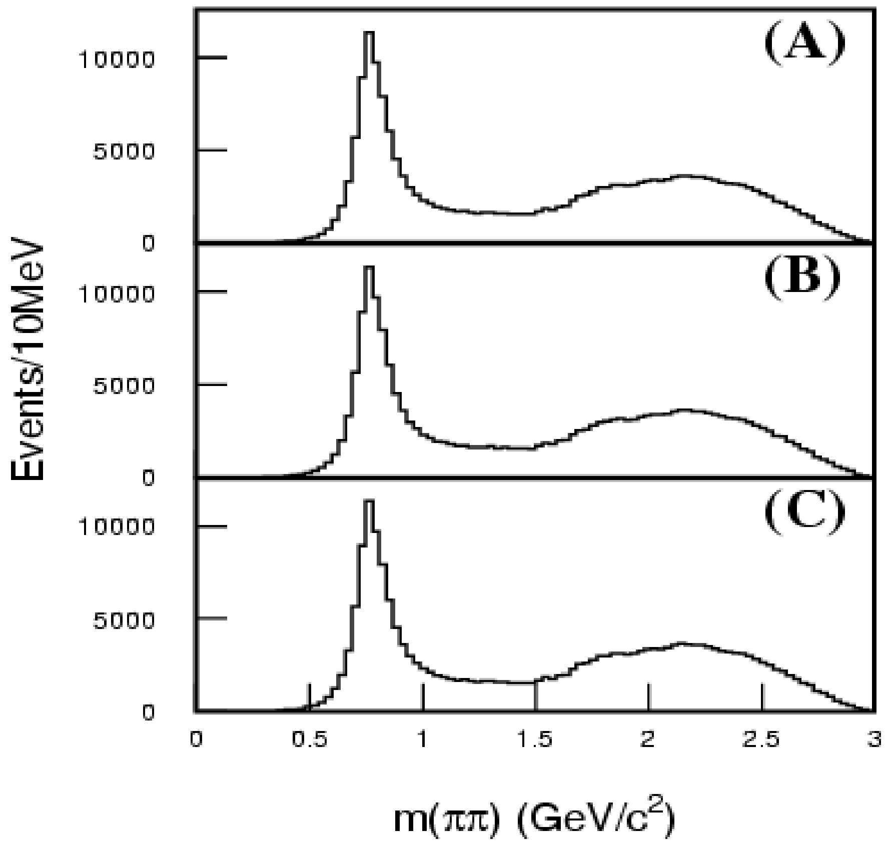
Measurements with Improved Accuracies

1. $B(J/\psi \rightarrow \pi^+\pi^-\pi^0)$
2. $\psi(2S) \rightarrow VT$
3. $\psi(2S) \rightarrow \gamma\ \gamma\ J/\psi$

1. $B(J/\psi \rightarrow \pi^+\pi^-\pi^0)$

Measured from 58M J/Ψ evts.





Measured from 58M J/Ψ evts.

1. $B(J/\psi \to \pi^+\pi^-\pi^0)$

Systematic errors and Branching fraction

Sources	Systematic error (%)
MDC tracking	4
Photon detection efficiency	4
Kinematic fit	4.2
MC model	~ 3
Background uncertainty	< 3
MC statistics	0.39
Number of J/ψ events	4.7
Total	9.5

$$B(J/\psi \to \pi^+\pi^-\pi^0) = (21.35 \pm 0.05 \pm 2.03) \times 10^{-3}$$

Submitted to PRD

1. B(J/ψ → $\pi^+\pi^-\pi^0$)

Measured from 14M Ψ(2S) evts.

Similar cuts used for decay I &II

Many systematic errors cancelled

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

$$\hookrightarrow \; \mu^+\mu^- \qquad (I)$$

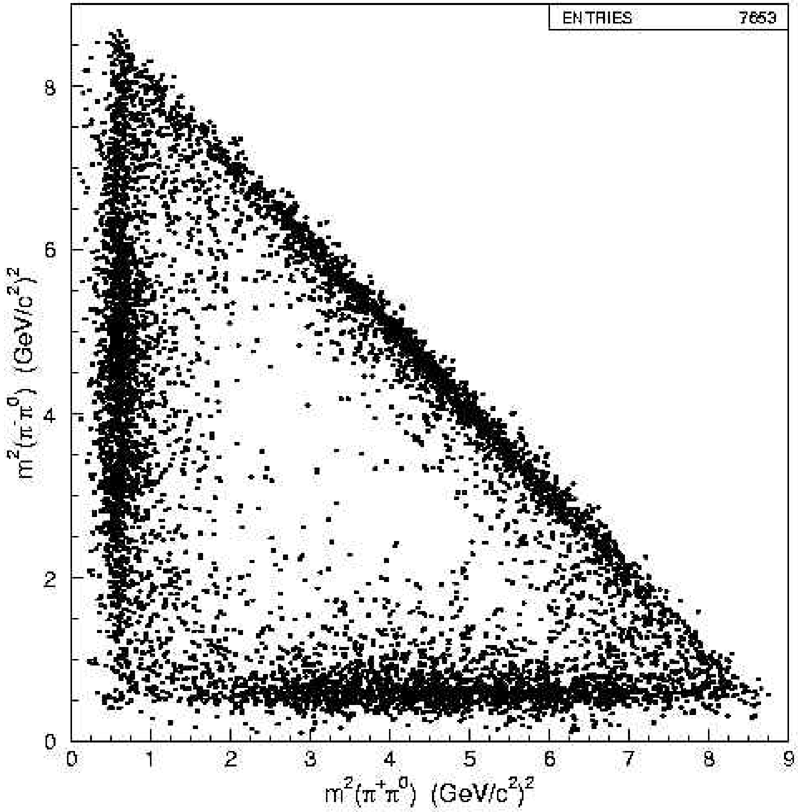
$$\text{and} \; \hookrightarrow \; \pi^+\pi^-\pi^0 \qquad (II)$$

$$B(J/\psi \to \rho\pi) = \frac{N_I^{obs}/\epsilon_I}{N_{II}^{obs}/\epsilon_{II}/B(J/\psi \to \mu^+\mu^-)} \quad (1)$$

$$= \frac{N_I^{obs}}{N_{II}^{obs}} \cdot \frac{\epsilon_{II}}{\epsilon_I} \cdot B(J/\psi \to \mu^+\mu^-), \quad (2)$$

1. B($J/\psi \to \pi^+\pi^-\pi^0$)

Measured from 14M $\Psi(2S)$ evt.



Systematic error

	f_c	Sys. err. (%)
MDC tracking		2.0
Kinematic fit	1.012	1.6
Photon efficiency		4.0
Backgrounds	0.985	1.5
MC model		1.6
$B(J/\psi \to \mu^+\mu^-)$		1.7
$B(\pi^0 \to \gamma\gamma)$		0.03
MC statistics		1.0
Sum	~ 1.0	5.6

$$B(J/\psi \to \pi^+\pi^-\pi^0) = (20.97 \pm 0.21 \pm 1.17) \times 10^{-3}$$

1. $B(J/\psi \rightarrow \pi^+\pi^-\pi^0)$

Discussions of BESII $B(J/\psi\rightarrow\pi^+\pi^-\pi^0)$ results

- 58M J/ψ : $B(J/\psi \rightarrow\pi^+\pi^-\pi^0) = (21.35\pm0.05\pm2.03)\times10^{-3}$

  14M $\psi(2S)$: $B(J/\psi \rightarrow\pi^+\pi^-\pi^0) = (20.97\pm0.21\pm1.17)\times10^{-3}$

- **Combining BESII Result :**

  $$B(J/\psi \rightarrow\pi^+\pi^-\pi^0) = (2.11\pm0.12)\times10^{-2}$$

- **Inconsistent with PDG02 :**

  $$B(J/\psi \rightarrow\pi^+\pi^-\pi^0) = (1.5\pm0.2)\times10^{-2}$$

- **Extensive and careful checks on MC and DATA consistencies had been made, such as**

  MDC reconstruction, kinematic fit, photon detection,

  Barrel Shower Counter performance, etc.

  The agreement between MC and DATA is reasonable.

pQCD rule ***and*** *"$\rho\pi$ puzzle"*

- **pQCD rule :**

the relation between J/Ψ and Ψ(2S) BRs

$$Q_h = \frac{B_{\psi(2S)\to X}}{B_{J/\psi \to X}} = \frac{B_{\psi(2S)\to e^+e^-}}{B_{J/\psi \to e^+e^-}} = 12\ \%$$

- **Violation in VP mode was revealed by MARK-II ,**

confirmed by BES at higher sensitivity

2. $\Psi(2S) \to$ V T

❖ ***BES-I results*** ***PRL81(1998)5080***

PRD67(2003)052002

VT Mode	$\boldsymbol{B}_{\psi(2S)\to X}$ (10^{-4}) (PDG2002 from BES)	$\boldsymbol{B}_{J/\psi\to X}$ (10^{-3}) (PDG1996)	Q_h (%)
ωf_2	< 1.7 (C.L. 90 %) 1.1 ±0.5 ±0.2	4.3±0.6	< 4.0 2.4 ±1.3
ρa_2	< 2.3 (C.L. 90 %)	10.9±2.2	< 2.1
$K^* \overline{K^*}_2$	< 1.2 (C.L. 90 %)	6.7±2.6	< 1.8
$\phi f_2'$	< 0.45 (C.L. 90 %)	1.23±0.21 †	< 3.7

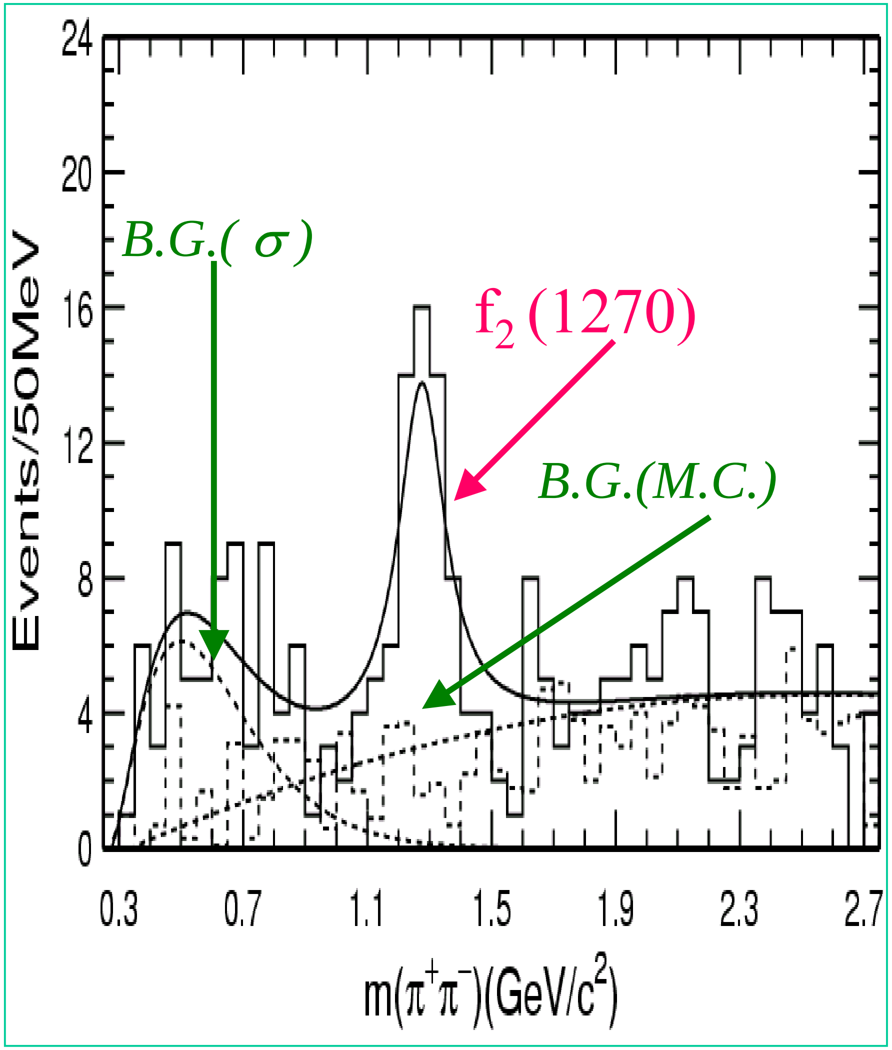
† This value from DM2 only

12 % rule (pQCD rule)

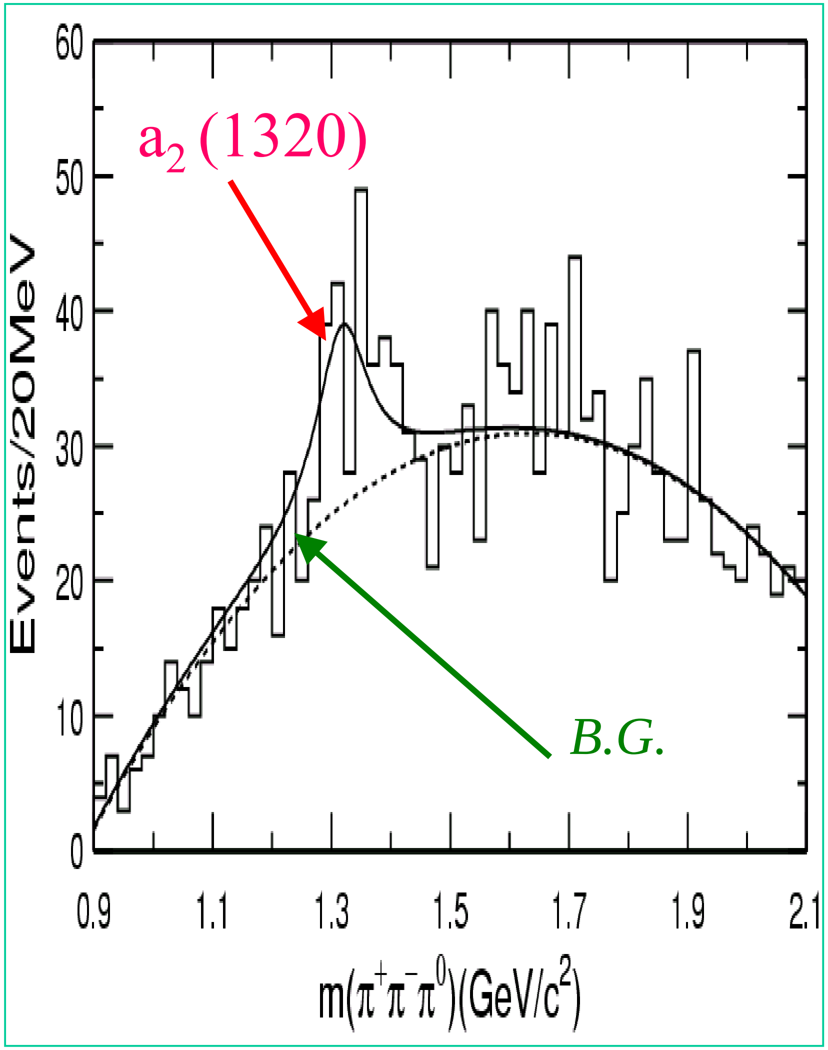
Suppressed!!

BES-II

2. $\Psi(2S) \to$ V T



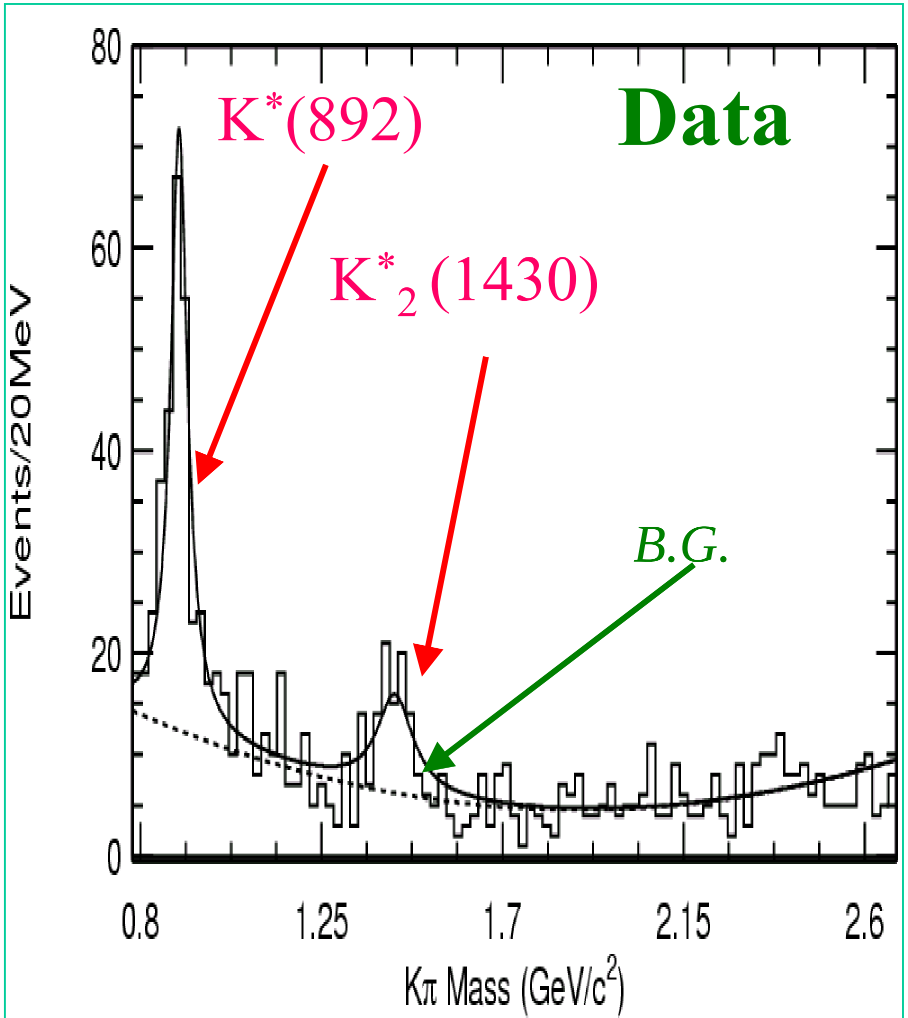
$\omega f_2(1270)$



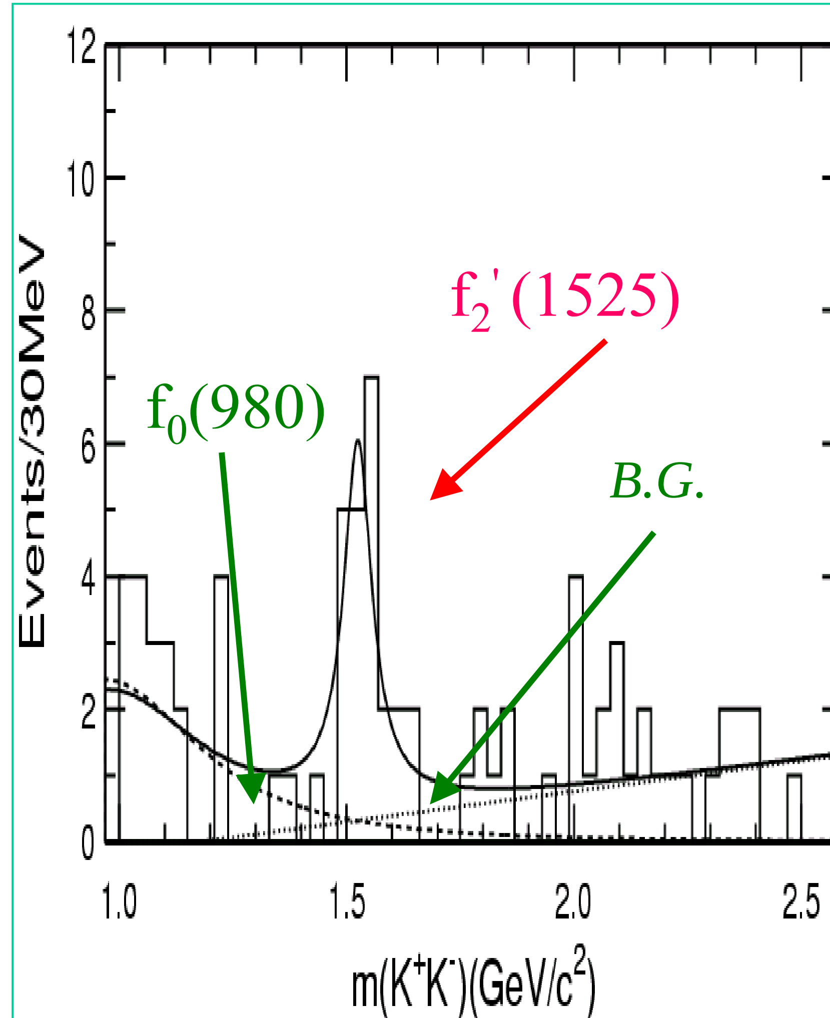
$\rho a_2(1320)$

BES-II

2. $\Psi(2S) \rightarrow$ V T



$$K^*(892)^0\overline{K_2^*}(1430) + c.c.$$



$$\phi f_2'(1525)$$

2. $\Psi(2S) \to V\ T$

$$B_{\psi(2S)\to X} = \frac{n^{obs}_{\psi(2S)\to X\to Y}}{N_{\psi(2S)} \cdot B_{X\to Y} \cdot \varepsilon^{MC}}$$

(pQCD rule)

12 % rule Test

VT mode	$B_{\psi(2S)\to X}$ (10^{-4}) (BES-II)	$B_{J/\psi\to X}$ (10^{-3}) (PDG2002)	$Q_h(\%)$
ωf_2	$2.05 \pm 0.41 \pm 0.38$	4.3 ± 0.6	4.8 ± 1.5
ρa_2	$2.55 \pm 0.73 \pm 0.47$	10.9 ± 2.2	2.3 ± 1.1
$K^* \overline{K^*_2}$	$1.86 \pm 0.32 \pm 0.43$	6.7 ± 2.6	2.8 ± 1.3
$\phi f_2'$	$0.44 \pm 0.12 \pm 0.11$	1.23 ± 0.21 †	3.6 ± 1.5

† This value from DM2 only

Accepted by PRD

Suppressed!!

3. $\Psi(2S) \to \gamma\,\gamma\,J/\psi$

Measure 4 BR:

$\Psi(2S) \to (\pi^o,\eta)J/\psi$; $\Psi(2S) \to \gamma\,\chi_{cJ} \to \gamma\,\gamma\,J/\psi$

- Different measurements deviate each other
- $B(\Psi(2S) \to \pi^o J/\psi)$ very crude
- Theoretical prediction for charmonium hadronic transition amplitude can be tested by our high statistics measurements

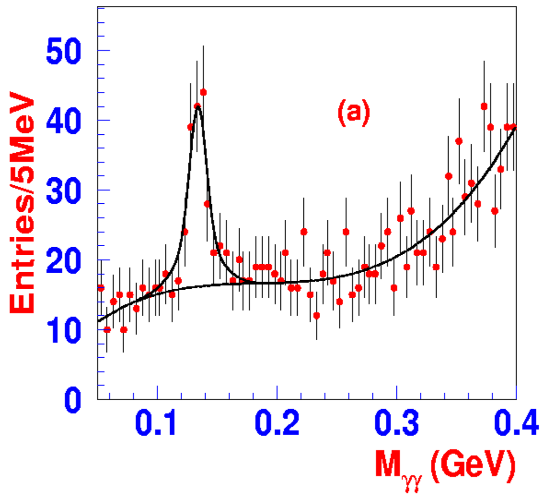
$$R = \frac{\Gamma(\psi(2S)\to\eta J/\psi)}{\Gamma(\psi(2S)\to\pi^0 J/\psi)}$$

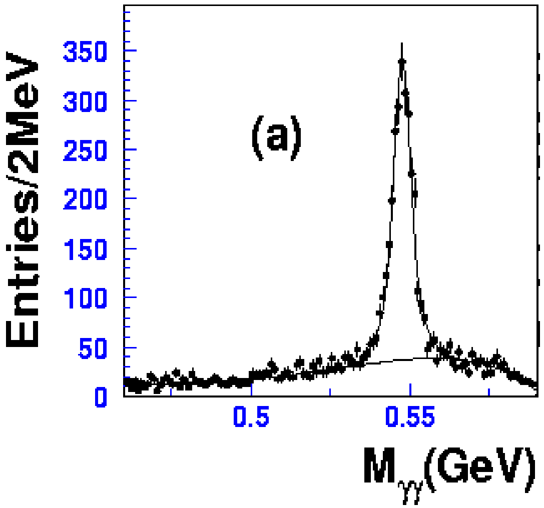
$$R' = \frac{\Gamma(\Upsilon'\to\eta\Upsilon)}{\Gamma(\psi(2S)\to\eta J/\psi)} \qquad R'' = \frac{\Gamma(\Upsilon''\to\eta\Upsilon)}{\Gamma(\psi(2S)\to\eta J/\psi)}$$

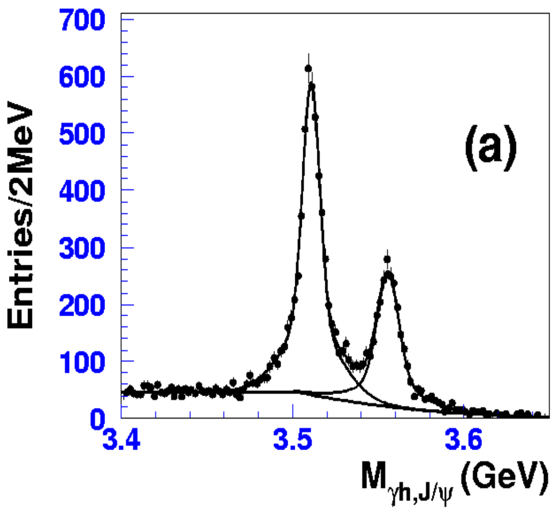
3. $\Psi(2S) \rightarrow \gamma\ \gamma\ J/\psi$

BES Preliminary

$$\gamma\gamma e^+e^-$$







$\Psi(2S) \rightarrow \pi^o J/\psi$

$\Psi(2S) \rightarrow \eta J/\psi$

$\Psi(2S) \rightarrow \gamma\ \chi_{cJ} \rightarrow \gamma\ \gamma\ J/\psi$

BES Preliminary

3. $\Psi(2S) \to \gamma\gamma J/\psi$

Channel	$\pi^0 J/\psi$		$\eta J/\psi$	
Final state	$\gamma\gamma e^+e^-$	$\gamma\gamma\mu^+\mu^-$	$\gamma\gamma e^+e^-$	$\gamma\gamma\mu^+\mu^-$
Event number	123 ± 18	155 ± 20	2465 ± 101	3290 ± 148
Efficiency(%)	11.21	13.34	26.94	34.07
Sys. error(%)	9.68	8.77	8.54	8.40
Correction factor	0.962	0.974	0.962	0.974
BR(%)	$0.139 \pm 0.020 \pm 0.013$	$0.147 \pm 0.019 \pm 0.013$	$2.91 \pm 0.12 \pm 0.21$	$3.06 \pm 0.14 \pm 0.25$
Combine BR(%)	$0.143 \pm 0.014 \pm 0.013$		$2.98 \pm 0.09 \pm 0.23$	
PDG(%)	0.096 ± 0.021		3.13 ± 0.21	

Channel	$\gamma\chi_{c1}$		$\gamma\chi_{c2}$	
Final state	$\gamma\gamma e^+e^-$	$\gamma\gamma\mu^+\mu^-$	$\gamma\gamma e^+e^-$	$\gamma\gamma\mu^+\mu^-$
Event number	5263 ± 124	6752 ± 178	2512 ± 82	3358 ± 96
Efficiency(%)	23.88	29.24	19.70	25.54
Sys. error(%)	12.23	12.45	12.10	12.44
Correction factor	0.962	0.974	0.962	0.974
BR(%)	$8.73 \pm 0.21 \pm 1.00$	$9.11 \pm 0.24 \pm 1.12$	$7.90 \pm 0.26 \pm 0.88$	$8.12 \pm 0.23 \pm 0.99$
Combine BR(%)	$8.90 \pm 0.16 \pm 1.05$		$8.02 \pm 0.17 \pm 0.94$	
PDG(%)	8.4 ± 0.6		6.4 ± 0.6	

$$B(\psi(2S) \to \gamma\chi_{c1}) \cdot B(\chi_{c1} \to \gamma J/\psi) = (2.81 \pm 0.05 \pm 0.23)\%$$

$$B(\psi(2S) \to \gamma\chi_{c2}) \cdot B(\chi_{c2} \to \gamma J/\psi) = (1.62 \pm 0.04 \pm 0.12)\%$$

3. $\Psi(2S) \to \gamma\gamma J/\psi$

Discussion on $\Psi(2S) \to \gamma\gamma J/\psi$ results

- BES $B(\Psi(2S) \to \eta J/\psi)$ is the most accurate value in a single experiment

- BES $B(\Psi(2S) \to \pi^0 J/\psi)$ is the most accurate value and greatly improves the accuracy

- Miller's expectation using PCAC for R (Phys. Rep. 194,1,1990)

$$R = \frac{27}{16}\left(\frac{p_\pi}{p_\eta}\right)^3 r^2,$$

$$r = (m_d - m_u)/(m_s - 0.5 \cdot (m_d + m_u))$$

is equal to 0.0162,

smaller than BES value 0.048+/-0.007 by a factor of 3.

BES Preliminary

3. $\Psi(2S) \to \gamma\gamma J/\psi$

Discussion on $\Psi(2S) \to \gamma\gamma J/\psi$ results

- **QCD Multipole expansion expects:**

  (Y.P.Kuang et al: PRD 24,2874,1981; 37,1210,1988)

  (Using BTG potential model)

$$R'_{BGT} = 0.0025, R''_{BGT} = 0.0013.$$

consistent with

BES results : $R'_{exp} < 0.0098$ $R''_{exp} < 0.0065.$

BES Preliminary

SUMMARY

New States Searches & Observations:

A near $p\bar{p}$ threshold enhancement in $J/\psi \to \gamma p\bar{p}$ found,

$$M = 1859^{+3}_{-10}{}^{+5}_{-25}\ \mathrm{MeV}/c^2$$

$$\Gamma < 30\ \mathrm{MeV}/c^2\ (90\%\ \mathrm{CL})$$

any PDG particle can be excluded.

Clear σ signal shown up in $J/\psi \to \omega\pi^+\pi^-$ decay

unobserved N*(2020)? appeared in $J/\psi \to p\pi^-\bar{n}$

No Pentaquark state seen in

$$J/\psi\ \&\ \psi(2S) \to \Theta\bar{\Theta} \to (K_S p)(K^-\bar{n})\ \&\ (K_S\bar{p})(K^+n)$$

SUMMARY

New Decay Modes Observations:

Evidence of $\psi(3770)$ Non-$D\overline{D}$ decay to

$$\psi(3770) \rightarrow \pi^+\pi^- J/\psi$$

The **first measurements** for BRs or upper limits of

$$\chi_C \rightarrow \Lambda\overline{\Lambda}, \quad \Psi(2S) \rightarrow K_S K_L, \quad \Psi(2S) \rightarrow K_S K_S$$

SUMMARY

- **Measurements with improved accuracies**

 # BESII Results with 58M J/ψ & 14M $\psi(2S)$ evts.

$$B(J/\psi \to \pi^+\pi^-\pi^0) = (2.11 \pm 0.12) \times 10^{-2}$$

much higher than PDG value $(1.5 \pm 0.2) \times 10^{-2}$

 # The first measurements for BRs of (were upper-limits)

$\psi(2S) \to VT$ $(\omega f_2, \rho a_2, K^* K^*_2, \phi f_2')$

 # Improved accuracies for BRs of

$J/\Psi \to K_S K_L$; $\chi_c \to p\bar{p}$

$\Psi(2S) \to (\pi^0, \eta) J/\psi$; $\Psi(2S) \to \gamma \chi_{cJ} \to \gamma \gamma J/\psi$

 # Higher sensetivity for $B(J/\Psi \to K_S K_S)$ upper-limit

Thanks a lot !

谢谢！