

Recent BES Results on $\Psi(2S)$ Decay

Xiaohu Mo

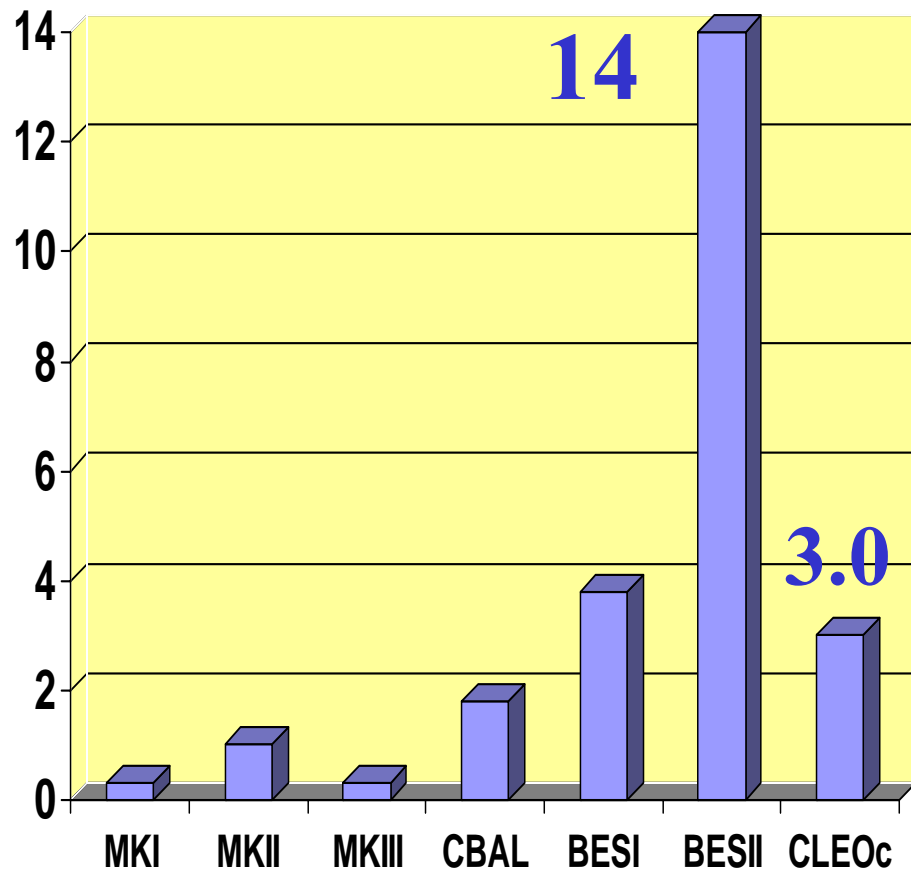
IHEP, Beijing

for the BES Collaboration

DAΦNE 2004: Physics at meson factories

7-11 June 2004 - Laboratori Nazionali di Frascati - Italy

14 M ψ' events



01.11-02.3

6.4 pb⁻¹ ψ' con. data

@ 3.65 GeV

58M J/ψ events

@ 3.10 GeV

27 pb⁻¹ ψ'' data

@ 3.773 GeV

• $\psi' \rightarrow VP$

• $\psi' \rightarrow VT$

• $\psi' \rightarrow PP$

($\psi', J/\psi \rightarrow K_S^0 K_L^0$)

• $\psi' \rightarrow J/\psi -$

contained

12% rule and “ $\rho\pi$ puzzle”

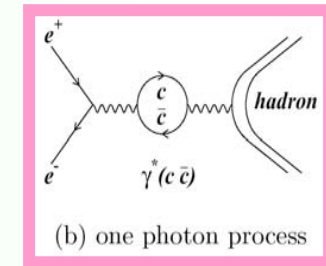
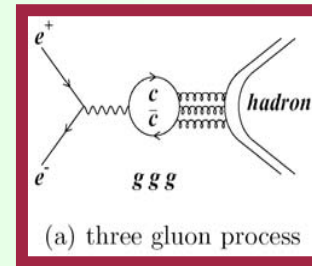
• 12% rule

[the relation between J/ψ and ψ']

$$Q_h = \frac{B_{\psi' \rightarrow X}}{B_{J/\psi \rightarrow X}} = \frac{B_{\psi' \rightarrow e^+e^-}}{B_{J/\psi \rightarrow e^+e^-}} = 12\%$$

- Violation was revealed by MARK-II, confirmed by BES at higher sensitivity;
- Provide new clues concerning the dynamics of charmonium decay .

The Relative Phase



J/ψ Decays:

- | | |
|--|---------------------------------------|
| 1. AP : <u>90°</u> | M. Suzuki, PRD63, 054021 (2001) |
| 2. VP : <u>(106 ± 10)°</u> | J. Jousset et al., PRD41, 1389 (1990) |
| | D. Coffman et al., PRD38, 2695 (1988) |
| | N. N. Achasov, talk at Hadron2001 |
| 3. PP : <u>(90 ± 10)°</u> | M. Suzuki, PRD60, 051501 (1999) |
| 4. VV : <u>(138 ± 37)°</u> | L. Köpke and N. Wermes, |
| | Phys. Rep. 74, 67 (1989) |
| 5. \overline{NN} : <u>(89 ± 15)°</u> | R. Baldini et al., PLB444, 111 (1998) |

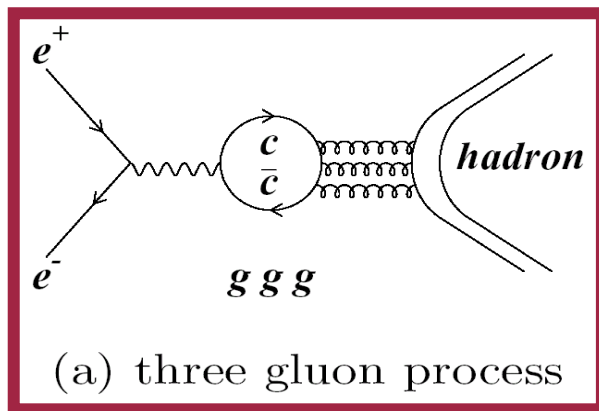
} Large phase |
~ 90°

ψ' Decays:

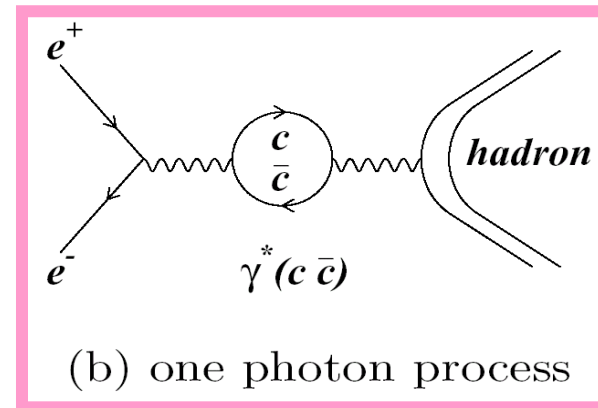
- | | |
|---|---|
| 1. VP : φ = <u>- 90°</u>
or 180° | P. Wang et al. , PRD69, 057502 (2004) |
| 2. PP : φ = <u>(- 82 ± 29)°</u>
or (+121 ± 27)° | J. Z. Bai et al. , PRL92, 052001 (2004) |

} Large phase
~ - 90°

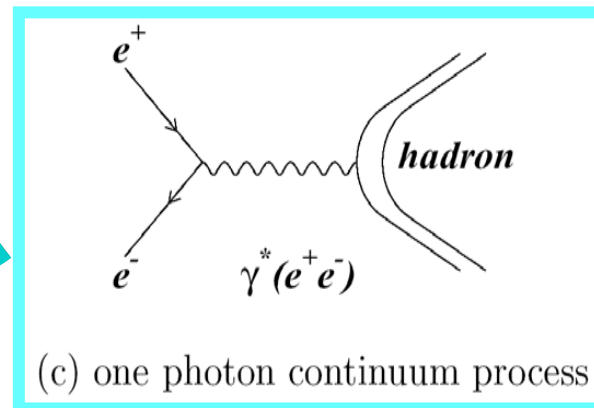
The phase study in e^+e^- experiment



$\pm \phi$
Phase



interference

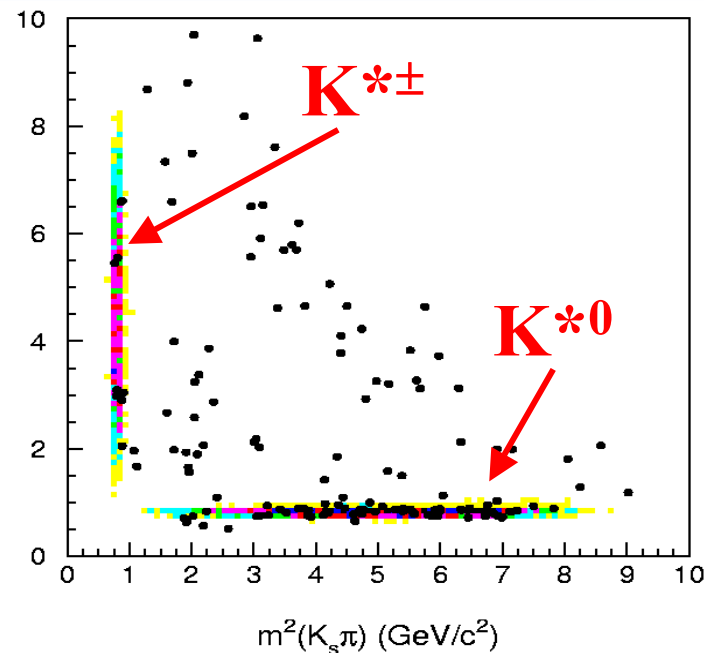
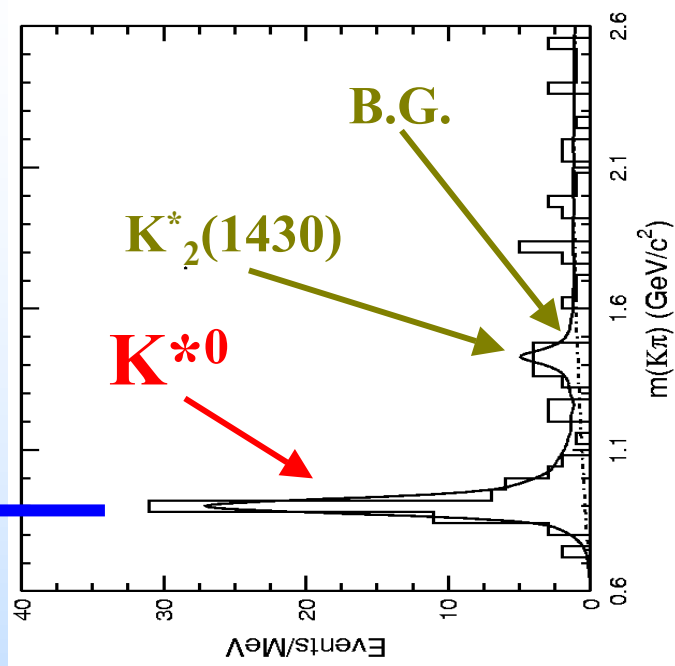


interference

Take the continuum contribution and its interference effect into consideration, we could determine not only the magnitude but also the sign of the phase. Furthermore, the cont. contr. and its int. effect will exert obvious influence on BR. measurement.

$\psi' \rightarrow VP$

$K^*(892)K + c.c.$



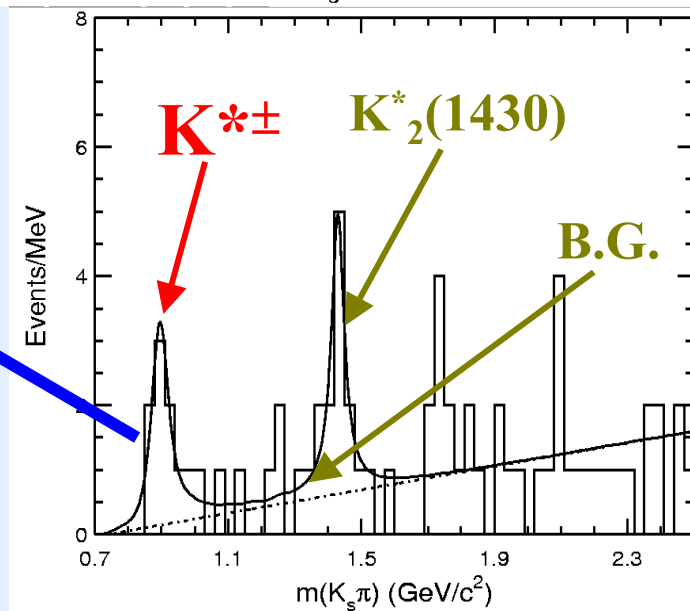
65.6 ± 9.0
Evt. 11σ

$\text{Br}_0(15.0 \pm 2.1 \pm 1.7) \times 10^{-5}$

$\text{Br}_{\pm}(2.9 \pm 1.3 \pm 0.4) \times 10^{-5}$

9.6 ± 4.2
Evt. 3.5σ

WITHOUT CONSIDERATION OF
CONTINUUM CONTRIBUTION !



$\psi' \rightarrow VP$

$$\begin{aligned} K^{*0} K^0 &: g(1-s_g) + e && \text{Phys. Rep.} \\ K^{*\pm} K^\mp &: g(1-s_g) - 2e && 174(1989) 67 \end{aligned}$$

$$\sigma(K^{*+} K^- + \text{c.c.}) : (20.9 \pm 9.1 \pm 2.3) \text{ pb}$$

$$\sigma(K^{*0} K^0 + \text{c.c.}) : (107 \pm 15 \pm 12) \text{ pb}$$

$$\text{@} 3.686 \text{ GeV} \ \& \ \mathcal{L} = (19.72 \pm 0.86) \text{ pb}^{-1}$$

$$\sigma(K^{*+} K^- + \text{c.c.}) : < 19 \text{ (90\% C.L.)}$$

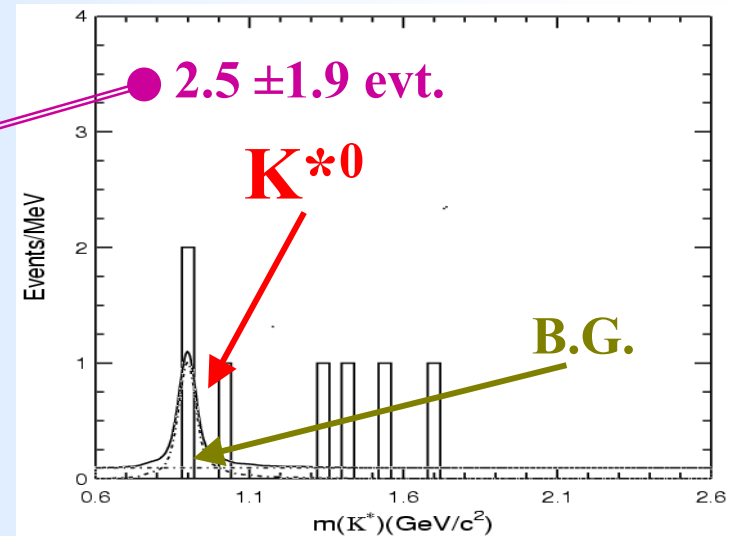
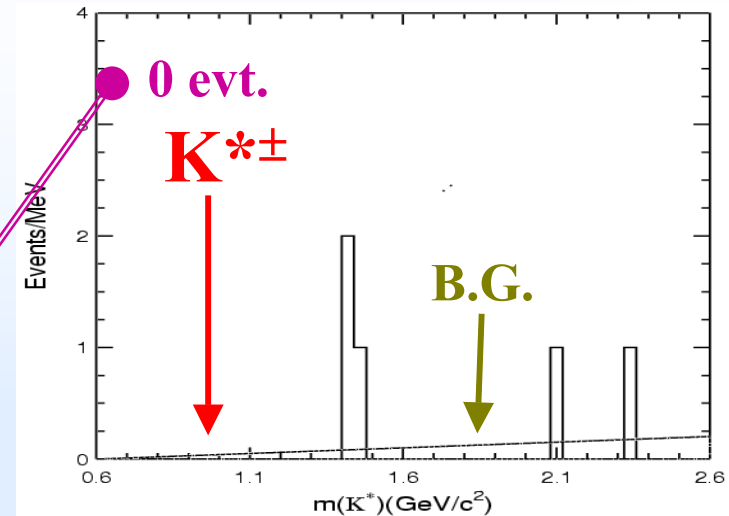
$$\sigma(K^{*0} K^0 + \text{c.c.}) : < 30 \text{ (90\% C.L.)}$$

$$\text{or : } (16 \pm 12 \pm 2) \text{ pb}$$

$$\text{@} 3.650 \text{ GeV} \ \& \ \mathcal{L} = (6.42 \pm 0.24) \text{ pb}^{-1}$$

From simple estimation, we can see the continuum contribution can be more **10 %**

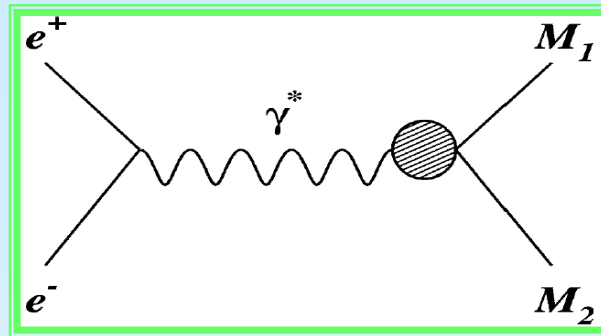
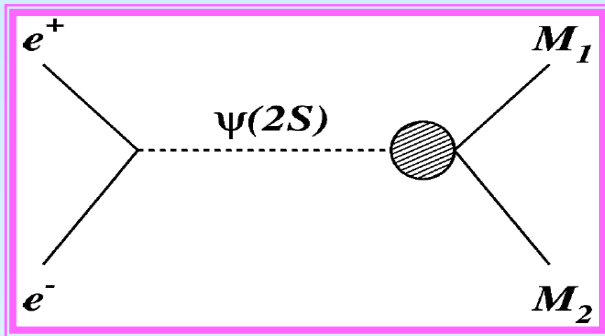
$K^*(892)K + \text{c.c.}$



$6.4 \text{ pb}^{-1} \ \psi' \text{ con. Data @ } 3.65 \text{ GeV}$

$\Psi' \rightarrow VP$

$\omega\pi^0$



Wang, Mo, Yuan
PLB557, 192(2003)

$$\sigma_{Born}^{Res}(s) = \frac{12\pi\Gamma_e\Gamma_f}{(s - M^2)^2 + \Gamma_t^2 M^2}$$

$$\sigma_{Born}^{Con}(s) = \frac{4\pi\alpha^3}{s^{3/2}} |\mathcal{F}_f|^2 \mathcal{P}_f(s)$$

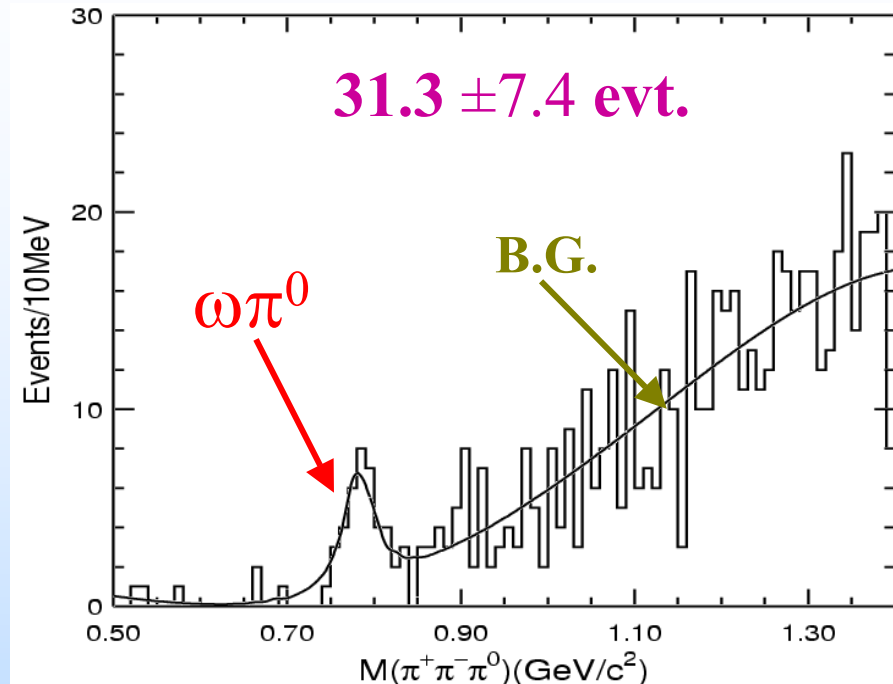
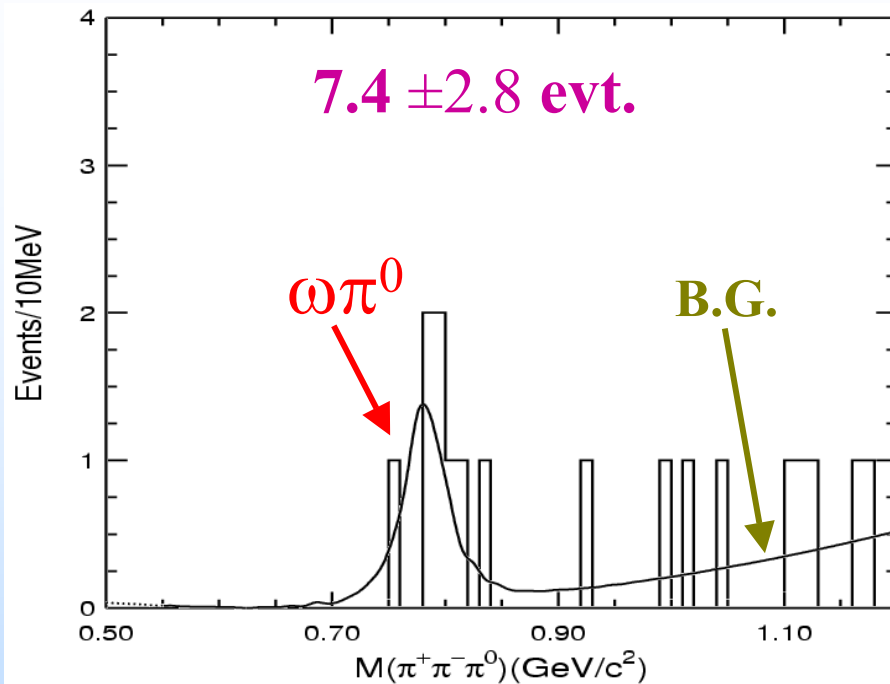
$$\sigma_{Born}(s) = \frac{4\pi\alpha^3}{s^{3/2}} \left[1 + 2\Re B(s) + |B(s)|^2 \right] |\mathcal{F}_f|^2 \mathcal{P}_f(s)$$

$$B(s) \equiv \frac{3\sqrt{s}\Gamma_e/\alpha}{s - M^2 + i\Gamma_t M} e^{i\phi}$$

$$\sigma_{r.c.}(s) = \int_0^{x_m} dx F(x, s) \frac{\sigma_{Born}(s(1-x))}{|1 - \Pi(s(1-x))|^2}$$

$$\sigma_{exp}(W) = \int_0^\infty dW' \sigma_{r.c.}(W') G(W', W).$$

Form factor evaluation shows the contribution from continuum can come up to 60% in total observed section at BES

$\psi' \rightarrow VP$ $\omega\pi^0$ 

@3.650GeV & $\mathcal{L} = (6.42 \pm 0.24) \text{ pb}^{-1}$

@3.686GeV & $\mathcal{L} = (19.72 \pm 0.86) \text{ pb}^{-1}$

$7.4 \times (19.72/6.42) \sim 23, \Rightarrow \text{Con. / Tot.} = 23/31 \sim 70\%$
consistent with theoretical expectation 60%

Studies of $\text{Br}(\psi' \rightarrow \omega\pi^0)$ and $\mathcal{F}_{\omega\pi^0}(s)$ are in progress

$$\psi' \rightarrow VP$$

❖ **BES-II results (Preliminary)**

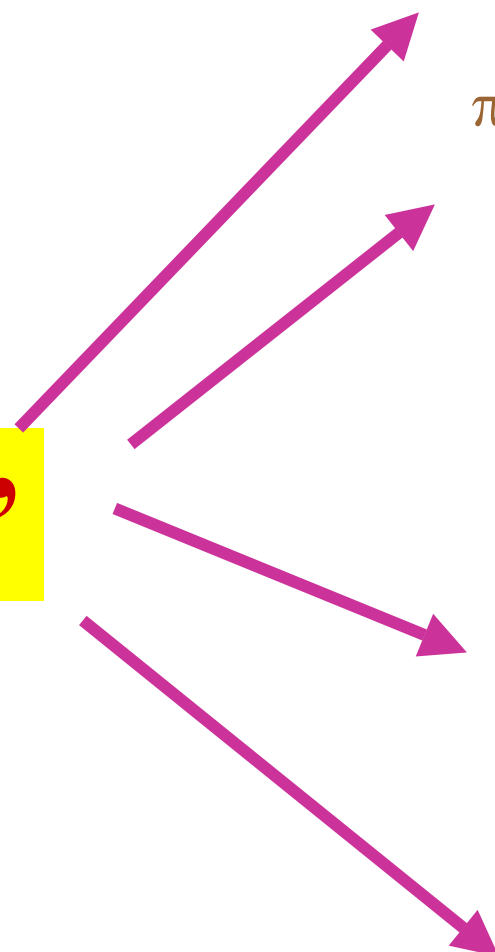
VP Mode	Final states	N^{fit} (@3.686GeV)	N^{fit} (@3.65GeV)
$\omega\pi^0$	$\pi^+\pi^-\gamma\gamma\gamma$	31.3 ± 7.4	7.4 ± 2.8
$K^{*0}K^0 + \text{c.c.}$	$K\pi K_S(\pi^+\pi^-)$	65.6 ± 9.0	2.5 ± 1.9
$K^{*+}K^- + \text{c.c.}$	$K\pi K_S(\pi^+\pi^-)$	9.6 ± 4.2	0

VP Mode	$B(\psi' \rightarrow X)(10^{-5})$	$B(J/\psi \rightarrow X)(10^{-4})$ (PDG2002)	$Q_h(\%)$
$\omega\pi^0$	< 3.27	4.2 ± 0.6	< 7.8
$K^{*0}K^0 + \text{c.c.}$	15.0 ± 2.7	42 ± 4	3.6 ± 0.7
$K^{*+}K^- + \text{c.c.}$	2.9 ± 1.9	50 ± 4	0.58 ± 0.29

Suppressed w.r.t. 12% rule !!

$\psi' \rightarrow VT$

ψ'



ω
 \downarrow
 $\pi^+ \pi^- \pi^0$
 ρ
 \downarrow
 \downarrow
 $\pi \pi$

f_2
 \downarrow
 $\pi^+ \pi^-$
 a_2
 \downarrow
 $\rho \pi$
 \downarrow
 $\pi \pi$

$\Rightarrow \pi^+ \pi^- \pi^+ \pi^- \pi^0$
 \downarrow
 $\gamma \gamma$

$\Rightarrow \pi^+ \pi^- \pi^+ \pi^- \pi^0$
 \downarrow
 $\gamma \gamma$

K^*
 \downarrow
 $K \pi$

K^*_2
 \downarrow
 $K \pi$

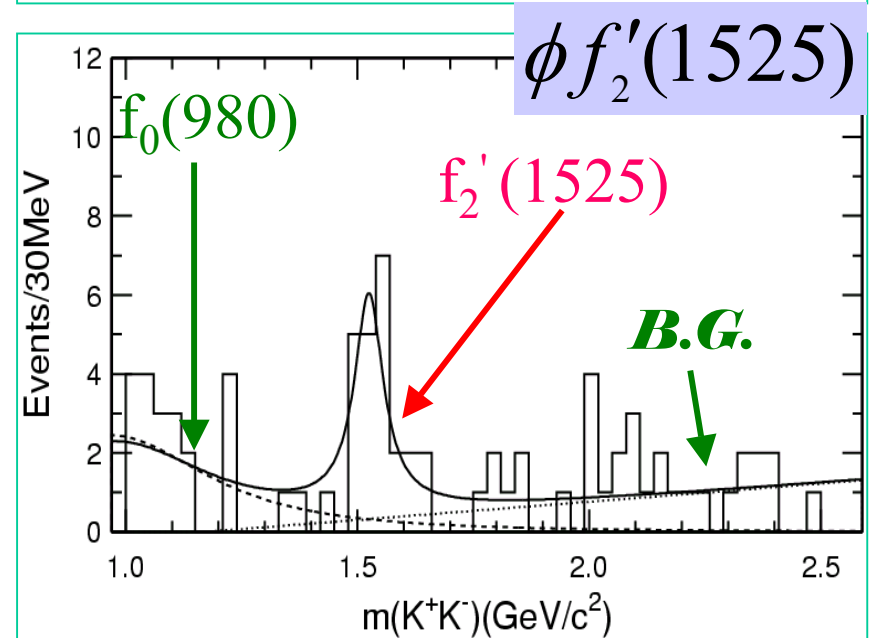
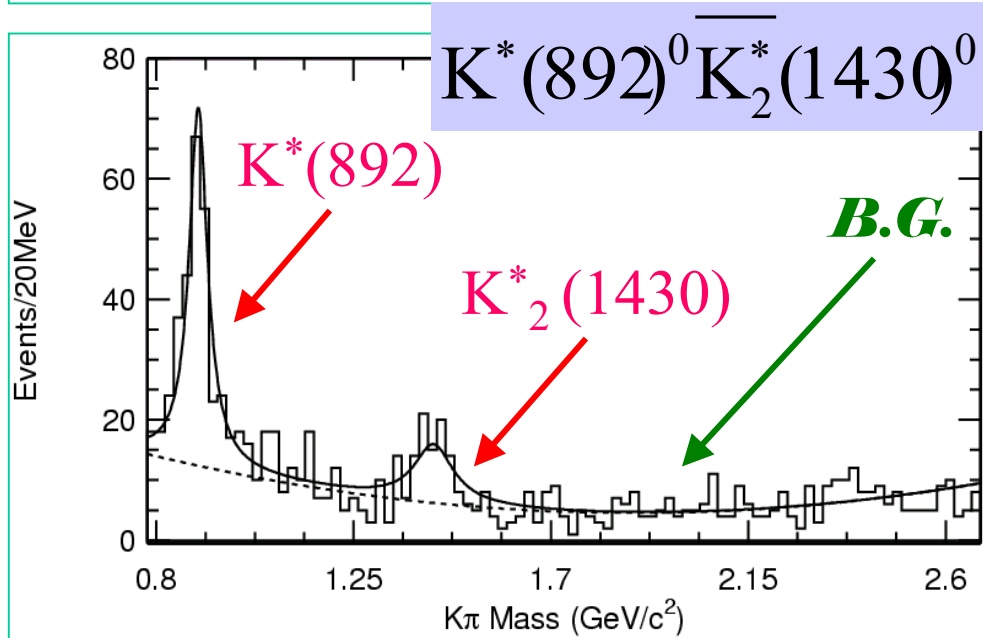
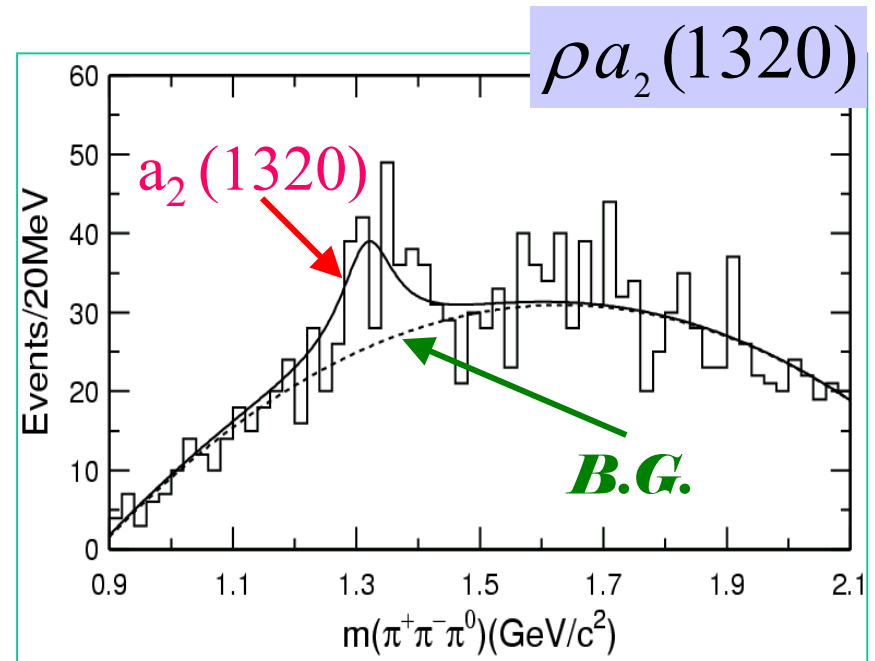
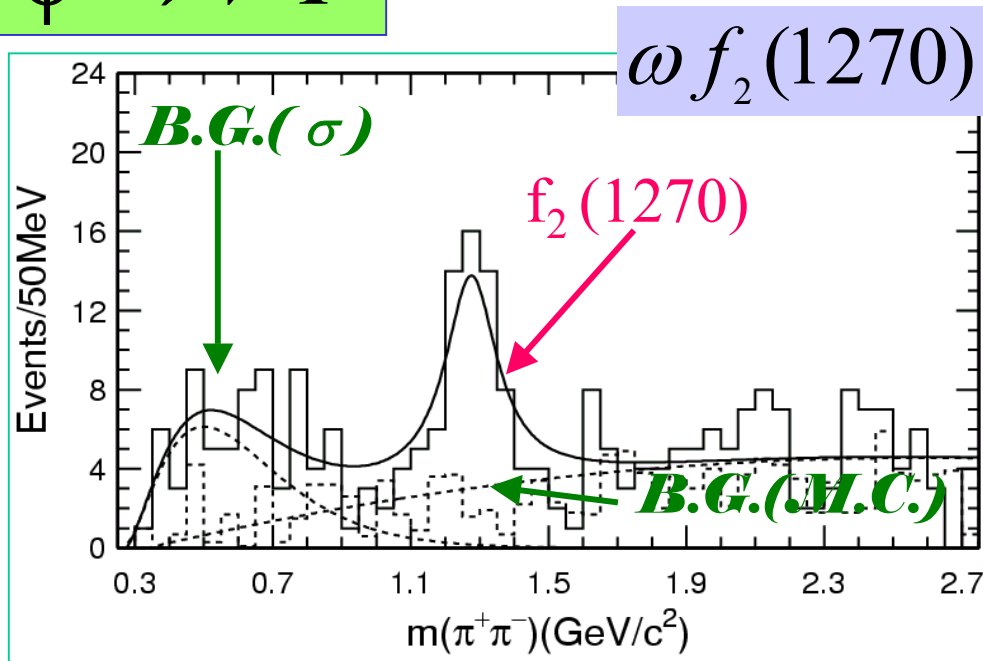
$\Rightarrow K^+ K^- \pi^+ \pi^-$

ϕ
 \downarrow
 $K K$

f'_2
 \downarrow
 $K K$

$\Rightarrow K^+ K^- K^+ K^-$

$\psi' \rightarrow VT$



$\psi' \rightarrow VT$

$$B_{\psi' \rightarrow X} = \frac{n_{\psi' \rightarrow X \rightarrow Y}^{\text{obs}}}{N_{\psi'} \cdot B_{X \rightarrow Y} \cdot \epsilon^{\text{MC}}}$$

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

† This value from DM2 only

Accepted by PRD

Suppressed!!

12 % rule

Parameterization and phase study

VT -Parameterization

$$\omega f_2 : g + e$$

$$\rho a_2 : g + e$$

$$K^* \overline{K}_2^* : g(1-s_g) - e(2-s_e)$$

$$\phi f_2' : g(1-2s_g) - 2e(1-s_e)$$

A.Seiden, H.F.-W. Sadrozinski and E.Haber : Phys.Rev.D38, 824 (1988)

PP -Parameterization

$$\pi^+ \pi^- : E$$

$$K^+ K^- : (\sqrt{3}/2) M + E$$

$$K_S K_L : (\sqrt{3}/2) M$$

E.Haber and J.Perrier :
Phys.Rev.D32, 2961 (1985)

PP -Parameterization

$$\pi^+ \pi^- : (E + E_C)$$

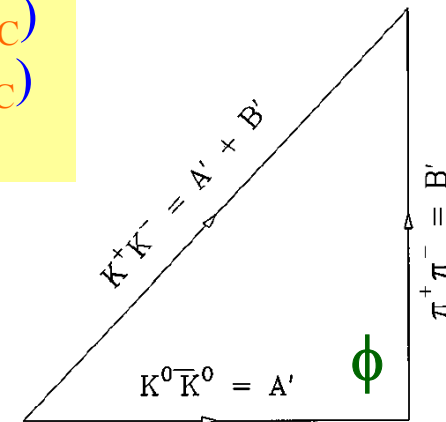
$$K^+ K^- : (\sqrt{3}/2) M + (E + E_C)$$

$$K_S K_L : (\sqrt{3}/2) M$$

Continuum Contribution

Too many parameters;
Few channels measured;
Limited data sample .

Phase undetermined



C.Z.Yuan, P.Wang and X.H.Mo:
PLB567, 74 (2003)

Parameterization and phase study

$$\sigma_{\pi^+\pi^-}^{\text{Born}}(s) = \frac{4\pi\alpha^2}{s^{3/2}} [1 + 2\Re B(s) + |B(s)|^2] \\ \times |\mathcal{F}_\pi(s)|^2 \mathcal{P}_{\pi^+\pi^-}(s),$$

$$\sigma_{K^+K^-}^{\text{Born}}(s) = \frac{4\pi\alpha^2}{s^{3/2}} [1 + 2\Re(\mathcal{C}_\phi B(s)) + |\mathcal{C}_\phi B(s)|^2] \\ \times |\mathcal{F}_\pi(s)|^2 \mathcal{P}_{K^+K^-}(s),$$

$$\sigma_{K_S^0 K_L^0}^{\text{Born}}(s) = \frac{4\pi\alpha^2}{s^{3/2}} \mathcal{C}^2 |B(s)|^2 |\mathcal{F}_\pi(s)|^2 \\ \times \mathcal{P}_{K_S^0 K_L^0}(s),$$

$$B(s) = \frac{3\sqrt{s} \Gamma_{ee}/\alpha}{s - M_{\psi(2S)}^2 + i M_{\psi(2S)} \Gamma_t}$$

$$\mathcal{C}_\phi \equiv 1 + \mathcal{C}e^{i\phi}$$

C.Z.Yuan, P.Wang and X.H.Mo:
PLB567, 74 (2003)

DASP:

$$\mathcal{B}(\psi(2S) \rightarrow \pi^+\pi^-) = (8 \pm 5) \times 10^{-5},$$

$$\mathcal{B}(\psi(2S) \rightarrow K^+K^-) = (10 \pm 7) \times 10^{-5},$$

BES-I:

$$\mathcal{B}(\psi(2S) \rightarrow \pi^+\pi^-) = (0.84 \pm 0.55_{-0.35}^{+0.16}) \times 10^{-5},$$

$$\mathcal{B}(\psi(2S) \rightarrow K^+K^-) = (6.1 \pm 1.4_{-1.3}^{+1.5}) \times 10^{-5}.$$

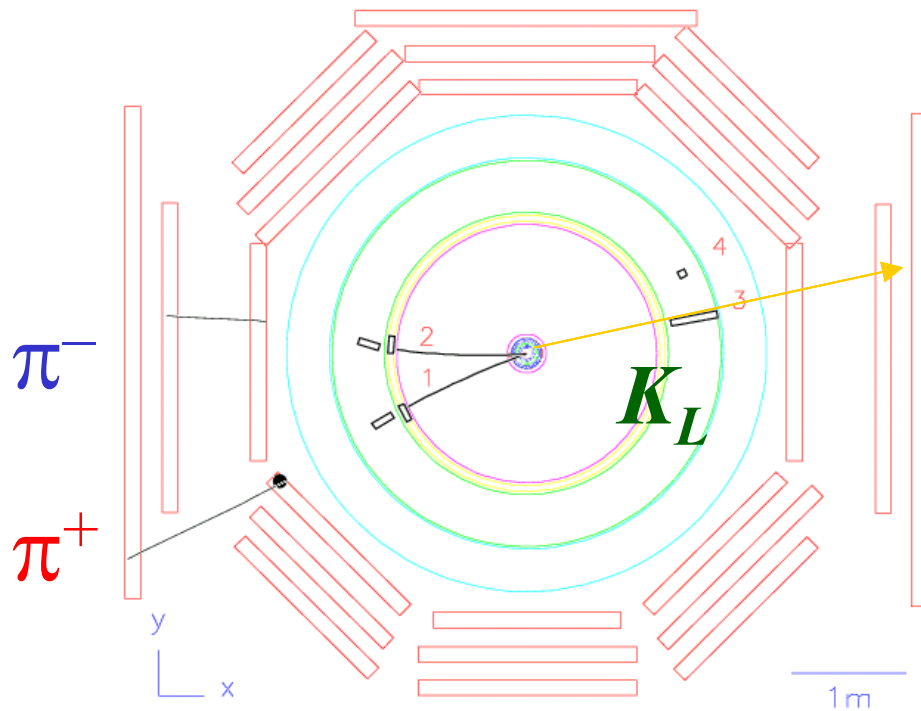
BES Collaboration: PRL 92, 052001 (2004)

$$\mathcal{B}_{\psi' \rightarrow K_S K_L} = (5.24 \pm 0.47 \pm 0.48) \times 10^{-5}$$

$$\phi = (-82 \pm 29)^\circ, \text{ or } (+121 \pm 27)^\circ$$

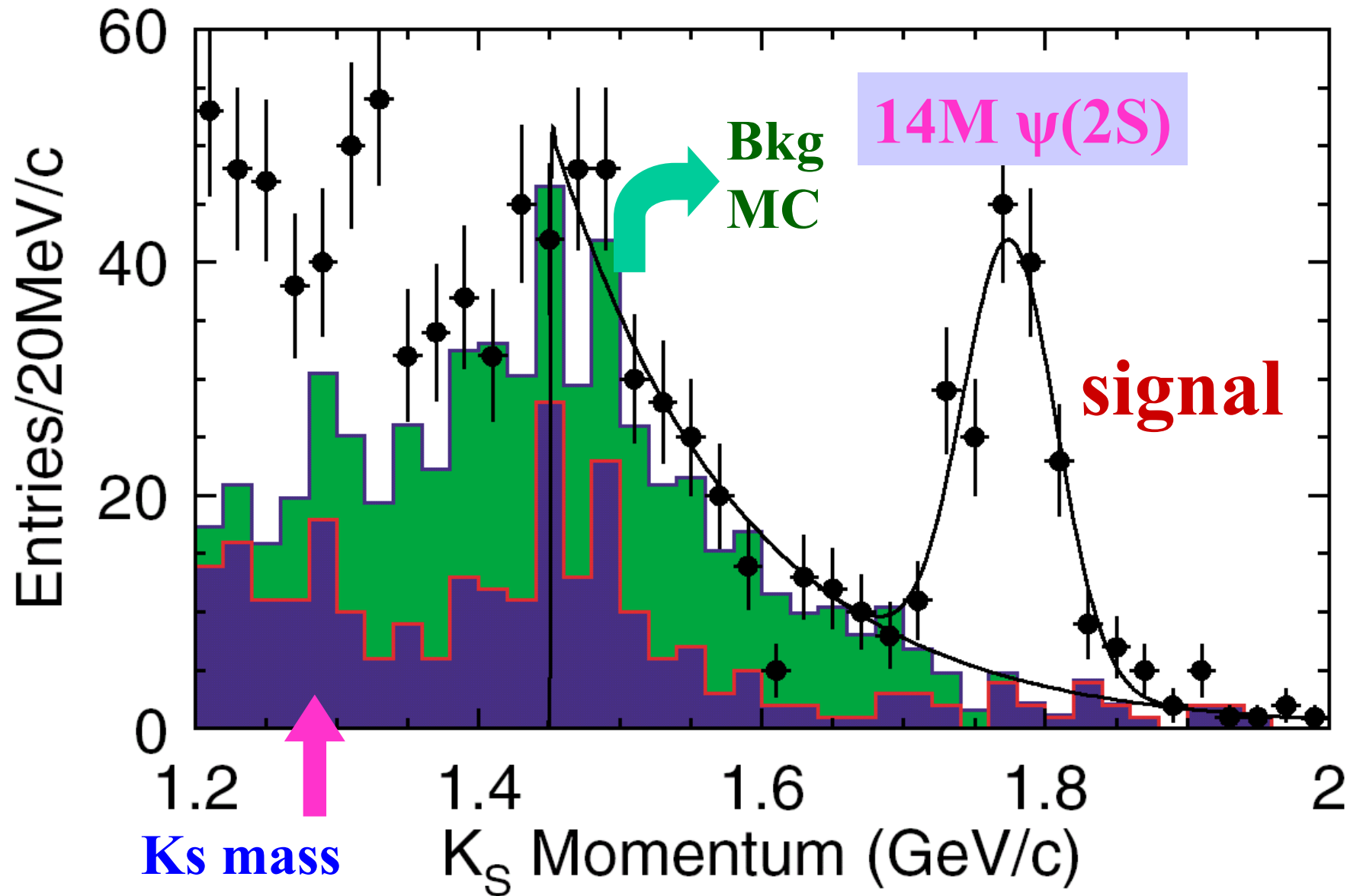
$$\psi' \rightarrow K_S K_L$$

Event Selection



1. *Two Good charged tracks with net charge zero ;*
2. *Decay length in transverse plane greater than 1.0 cm for K_S ID;*
3. *Total Energy of photon candidates less than 1 GeV.*

$\psi' \rightarrow K_S K_L$



PRL 92, 052001 (2004)

$$\psi' \rightarrow K_S K_L$$

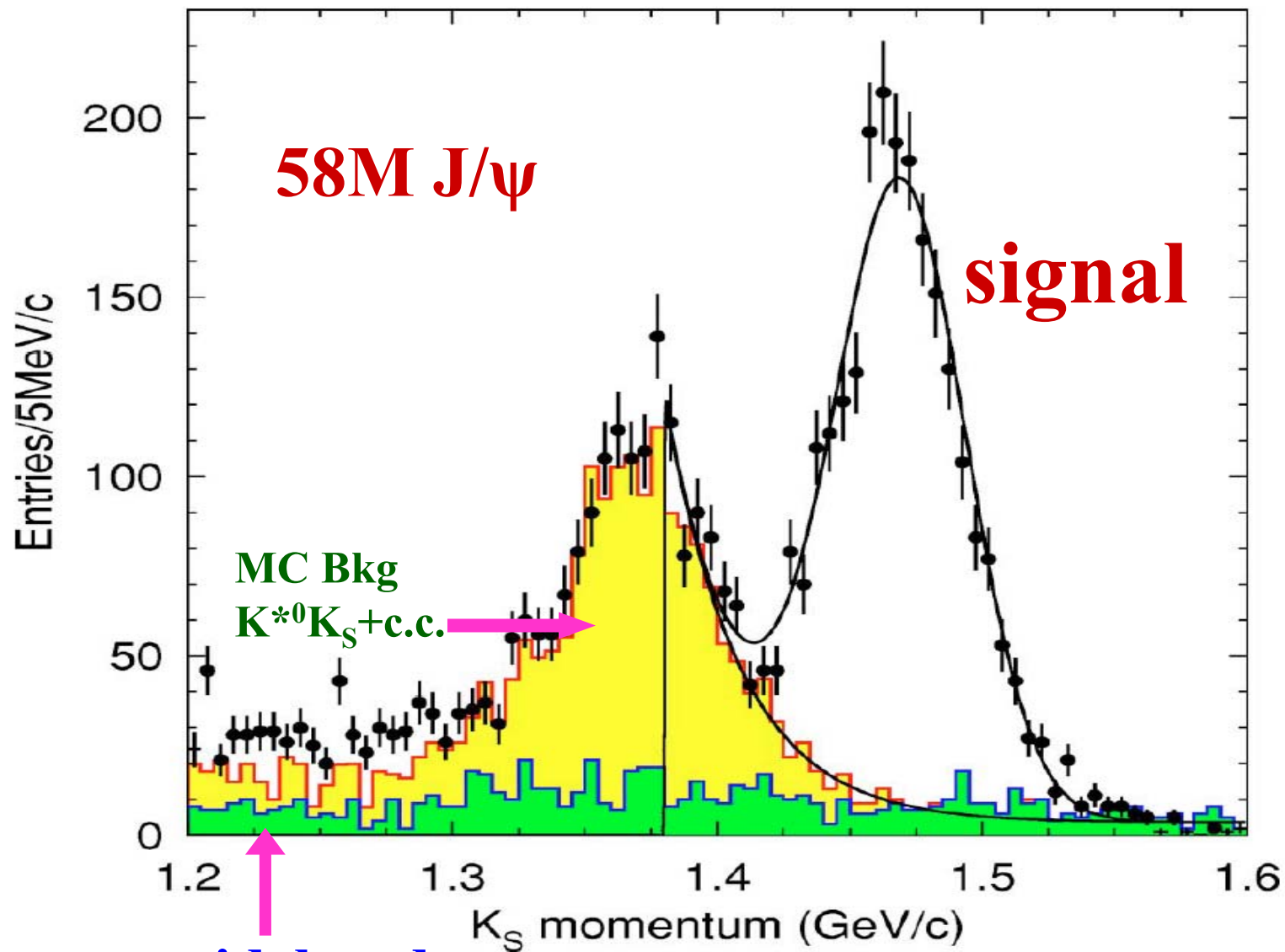
BESII: first measurement for $B(\psi' \rightarrow K_S K_L)$

$$B_{\psi' \rightarrow K_S K_L} = \frac{n^{\text{obs}} / (\varepsilon \cdot f)}{N_{\psi'} \cdot B_{K_S \rightarrow \pi^+ \pi^-}}$$

<i>Quantity</i>	<i>Value</i>
n^{obs}	156 ± 14
$\varepsilon_{MC} (\%)$	41.59 ± 0.48
$f (\%)$	74.6 ± 3.5
$N_{\psi'} (10^6)$	14.0 ± 0.7
$B_{K_S \rightarrow \pi^+ \pi^-}$	0.6860 ± 0.0027
$B_{\psi' \rightarrow K_S K_L} (10^{-5})$	$5.24 \pm 0.47 \pm 0.48$

PRL 92, 052001 (2004)

$J/\psi \rightarrow K_S K_L$



Ks mass sidebands

PRD 69, 012003 (2004)

$J/\psi \rightarrow K_S K_L$

BESII: Higher precision for B ($J/\psi \rightarrow K_S K_L$)

$$B_{J/\psi \rightarrow K_S K_L} = \frac{n^{\text{obs}} / (\varepsilon \cdot f)}{N_{J/\psi} \cdot B_{K_S \rightarrow \pi^+ \pi^-}}$$

<i>Quantity</i>	<i>Value</i>
n^{obs}	2155 ± 45
$\varepsilon_{MC}(\%)$	38.69 ± 0.23
$f(\%)$	77.2 ± 3.4
$N_{\psi'} (10^6)$	57.7 ± 2.7
$B_{K_S \rightarrow \pi^+ \pi^-}$	0.6860 ± 0.0027
$B_{J/\psi \rightarrow K_S K_L} (10^{-4})$	$1.82 \pm 0.04 \pm 0.13$

PDG2002: $\mathcal{B}_{J/\psi \rightarrow K_S K_L} = (1.08 \pm 0.14) \times 10^{-4}$

$\sim 4\sigma$ diff.

PRD 69, 012003 (2004)

$J/\psi, \psi' \rightarrow K_S K_L$

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

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

$$\frac{B_{\psi' \rightarrow K_S K_L}}{B_{J/\psi \rightarrow K_S K_L}} = (28.8 \pm 3.7) \%$$

$$Q_h = \frac{B_{\psi' \rightarrow X}}{B_{J/\psi \rightarrow X}} = 12\%$$

$> 4\sigma$

$B(\psi')$ enhanced!

“12%” rule and mixing model

Wang, Yuan and Mo:
PLB574,41(2004); &
hep-ph/0402227;

👁 $\psi' \rightarrow P P$ **enhanced**

👁 $\psi' \rightarrow V T$ **suppressed**

👁 $\psi' \rightarrow V P$ **some**

greatly suppressed

(such as $\rho \pi$ & $K^{*0} K^0$)

J.L.Rosner : PRD64,094002(2001)

$J/\psi = |1^3S_1\rangle,$

$\psi' \& \psi'' = |2^3S_1\rangle \& |1^3D_1\rangle :$

$\langle f | \psi' \rangle = \langle f | 2^3S_1 \rangle \cos\theta - \langle f | 1^3D_1 \rangle \sin\theta ,$

$\langle f | \psi'' \rangle = \langle f | 2^3S_1 \rangle \sin\theta + \langle f | 1^3D_1 \rangle \cos\theta .$

($\theta=12^\circ$)

Some recent studies indicate the S- and D-wave mixing model is a **natural, calculable** model ! It probably gives a unified explanation for all 12% rule violated decays

“12%” rule:

$$|\langle f | J/\psi \rangle / \langle f | 2^3S_1 \rangle|^2 = \Gamma_{ee}(J/\psi) / \Gamma_{ee}(2^3S_1) \\ \Rightarrow \langle f | 2^3S_1 \rangle$$

Mixing :

$$1. \langle f | \psi' \rangle = \langle f | 2^3S_1 \rangle \cos\theta - \langle f | 1^3D_1 \rangle \sin\theta$$

$$\langle f | \psi' \rangle \& \langle f | 2^3S_1 \rangle \Rightarrow \langle f | 1^3D_1 \rangle$$

$$2. \langle f | \psi'' \rangle = \langle f | 2^3S_1 \rangle \sin\theta + \langle f | 1^3D_1 \rangle \cos\theta$$

$$\Rightarrow \langle f | \psi'' \rangle \Rightarrow \text{Br}(f)$$

The measurement at ψ'' can be used to **test the mixing model !**

$J/\psi, \psi' \rightarrow K_S K_L$

A solution of ψ' enhancement
Wang, Mo and Yuan, hep-ph/0402227

$$\begin{aligned} |\psi'\rangle &= |2^3S_1\rangle \cos\theta - |1^3D_1\rangle \sin\theta, \\ |\psi''\rangle &= |2^3S_1\rangle \sin\theta + |1^3D_1\rangle \cos\theta, \end{aligned}$$

$$\Gamma(\psi'' \rightarrow f) = \frac{C_f}{M_{\psi''}^2} |\sin\theta R_{2S}(0) + \eta \cos\theta|^2,$$

$$\Gamma(\psi' \rightarrow f) = \frac{C_f}{M_{\psi'}^2} |\cos\theta R_{2S}(0) - \eta \sin\theta|^2,$$

$$\Gamma(J/\psi \rightarrow f) = \frac{C_f}{M_{J/\psi}^2} |R_{1S}(0)|^2,$$

$$\begin{aligned} \frac{\Gamma(\psi' \rightarrow f)}{\Gamma(J/\psi \rightarrow f)} &= \frac{\Gamma(\psi' \rightarrow e^+e^-)}{\Gamma(J/\psi \rightarrow e^+e^-)} \\ &\times \left| \frac{\cos\theta R_{2S}(0) - \eta \sin\theta}{\cos\theta R_{2S}(0) - \frac{5}{2\sqrt{2}m_c^2} \sin\theta R_{1D}''(0)} \right|^2, \end{aligned}$$

$$\frac{\Gamma(\psi'' \rightarrow f)}{\Gamma(\psi' \rightarrow f)} = \frac{M_{\psi'}^2}{M_{\psi''}^2} \left| \frac{\sin\theta R_{2S}(0) + \eta \cos\theta}{\cos\theta R_{2S}(0) - \eta \sin\theta} \right|^2.$$

Searching for
 $\psi'' \rightarrow K_S K_L$
to test the model!

Prediction on ψ'' branching fraction:

$$0.12 \pm 0.07 \leq 10^5 \times \mathcal{B}(\psi'' \rightarrow K_S^0 K_L^0) \leq 3.8 \pm 1.1$$

Wait for CLEOc/BESIII for the answer!

$\psi' \rightarrow J/\psi$ -Contained

Motivation: Improve Exp. Precision and Test The. Calculation

$$\begin{aligned} & B(\psi(2S) \rightarrow \text{hadrons})/B(J/\psi \rightarrow \text{hadrons}) = \\ & B(\psi(2S) \rightarrow ggg + gg\gamma)/B(J/\psi \rightarrow ggg + gg\gamma) \\ & = 0.23 \pm 0.07 : \text{Disagrees with "12 \% Rule"} \end{aligned}$$

Important to measure $\psi' \rightarrow X J/\psi$ and components.

Theoretical prediction for charmonium hadronic transition amplitude can be tested by the high statistics measurements

M. Suzuki: PRD63, 054021, (2001).

Y. F. Gu & X. H. Li: PRD63, 114019 (2001).

G. A. Miller : Phys. Rep. 194,1(1990).

Y. P. Kuang : PRD24, 2874(1981);D37, 1210 (1988)

Inclusive Method [BES-I]

$$XJ/\psi, J/\psi \rightarrow \mu^+ \mu^-$$

Anything J/ψ

$\pi^0 \pi^0 J/\psi$

$\eta J/\psi$

$\gamma \chi_{c1}, \chi_{c1} \rightarrow \gamma J/\psi$

$\gamma \chi_{c2}, \chi_{c2} \rightarrow \gamma J/\psi$

Both accepted by

PRD;

hep-ex/0403023;

hep-ex/0404020.

Exclusive Method [BES-II]

$$\gamma\gamma J/\psi, J/\psi \rightarrow l^+ l^-$$

$\pi^0 J/\psi$

$\eta J/\psi$

$\gamma \chi_{c1}, \chi_{c1} \rightarrow \gamma J/\psi$

$\gamma \chi_{c2}, \chi_{c2} \rightarrow \gamma J/\psi$

$\psi' \rightarrow X J/\psi$

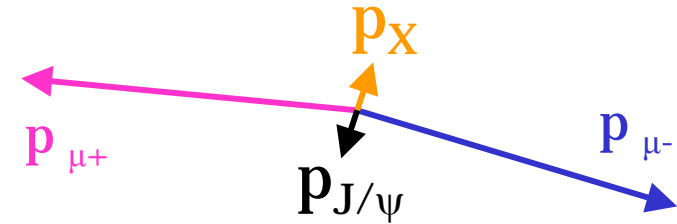
Inclusive Method

Method – identify $J/\psi \rightarrow \mu^+ \mu^-$

Select muons ; I C fit to $m_{J/\psi}$; determine m_X

$$\vec{p}_X = -\vec{p}_{J/\psi}$$

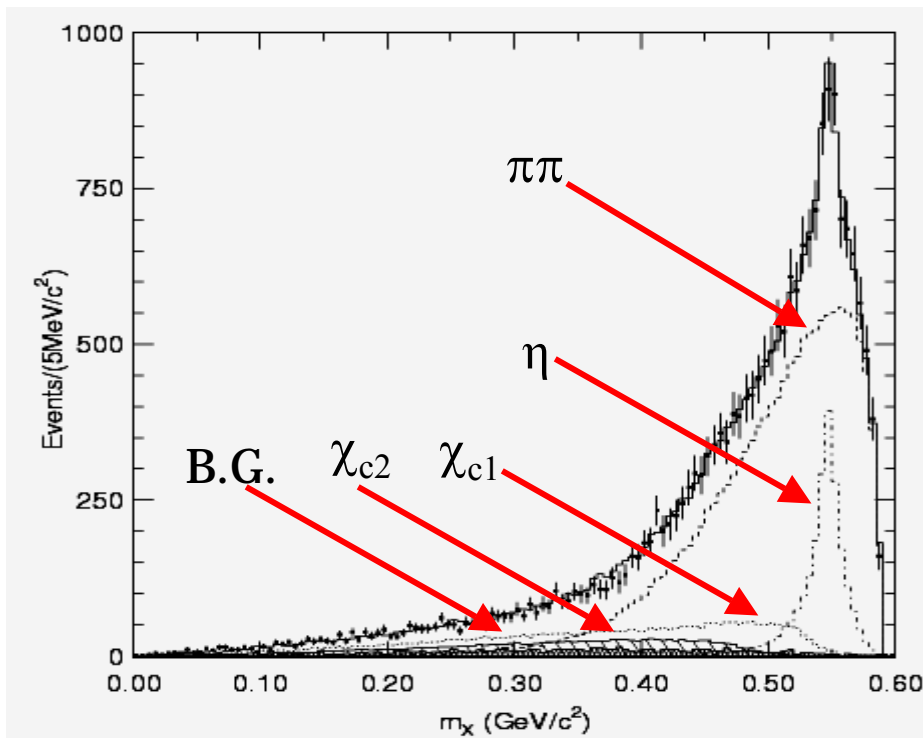
$$E_X = m_{\psi(2S)} - E_{J/\psi}$$



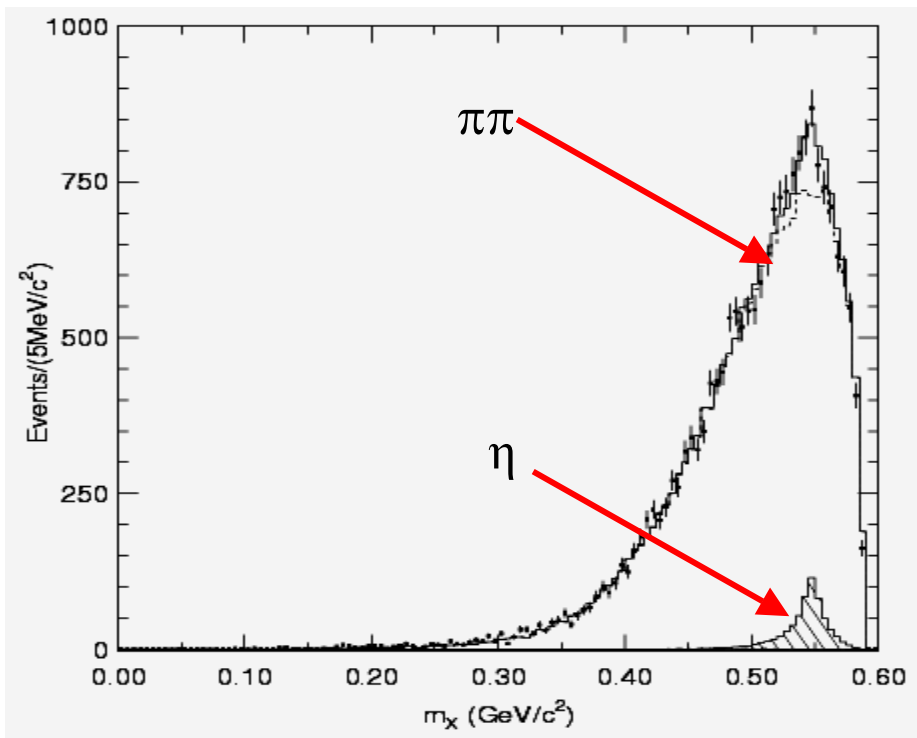
m_X is plotted for with and without extra charged-track cases. Fit two plots simultaneously with component shapes.

$$\chi^2 < 7$$

no extra

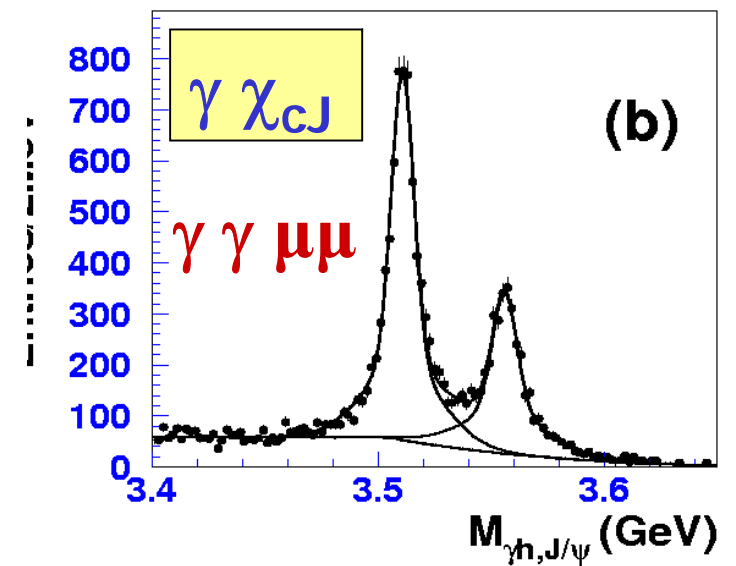
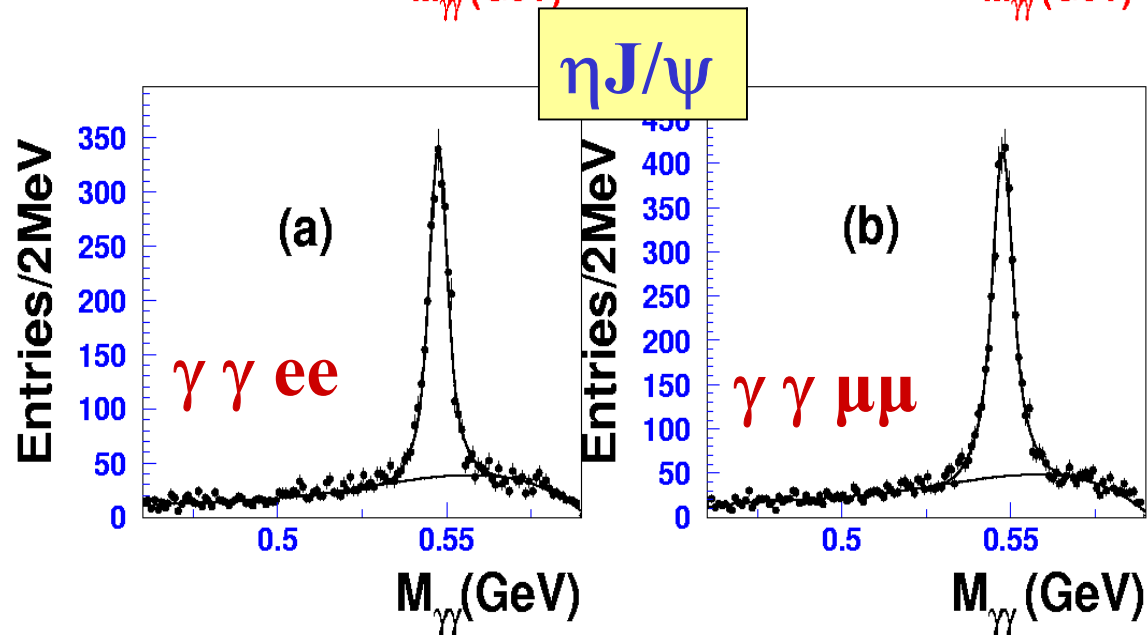
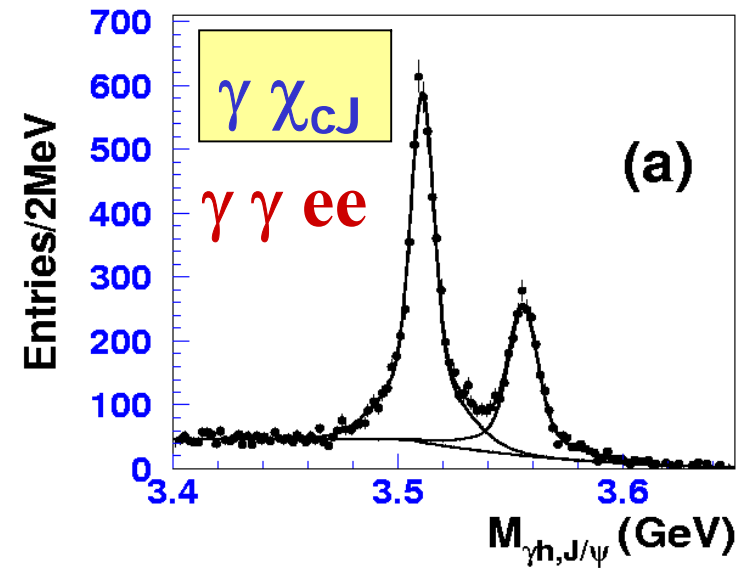
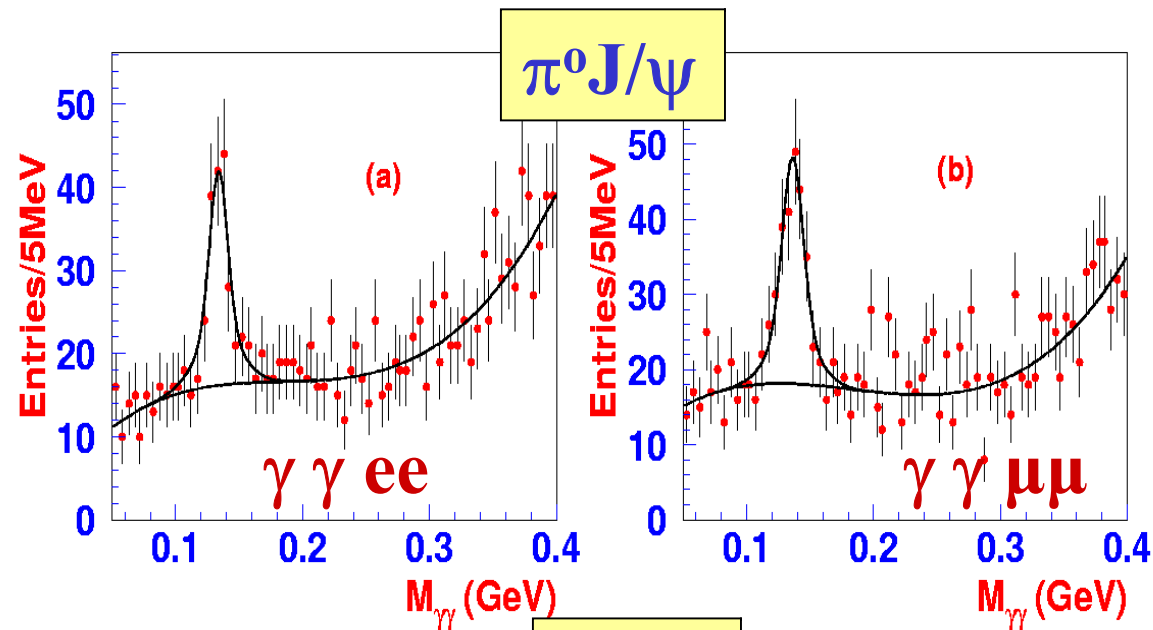


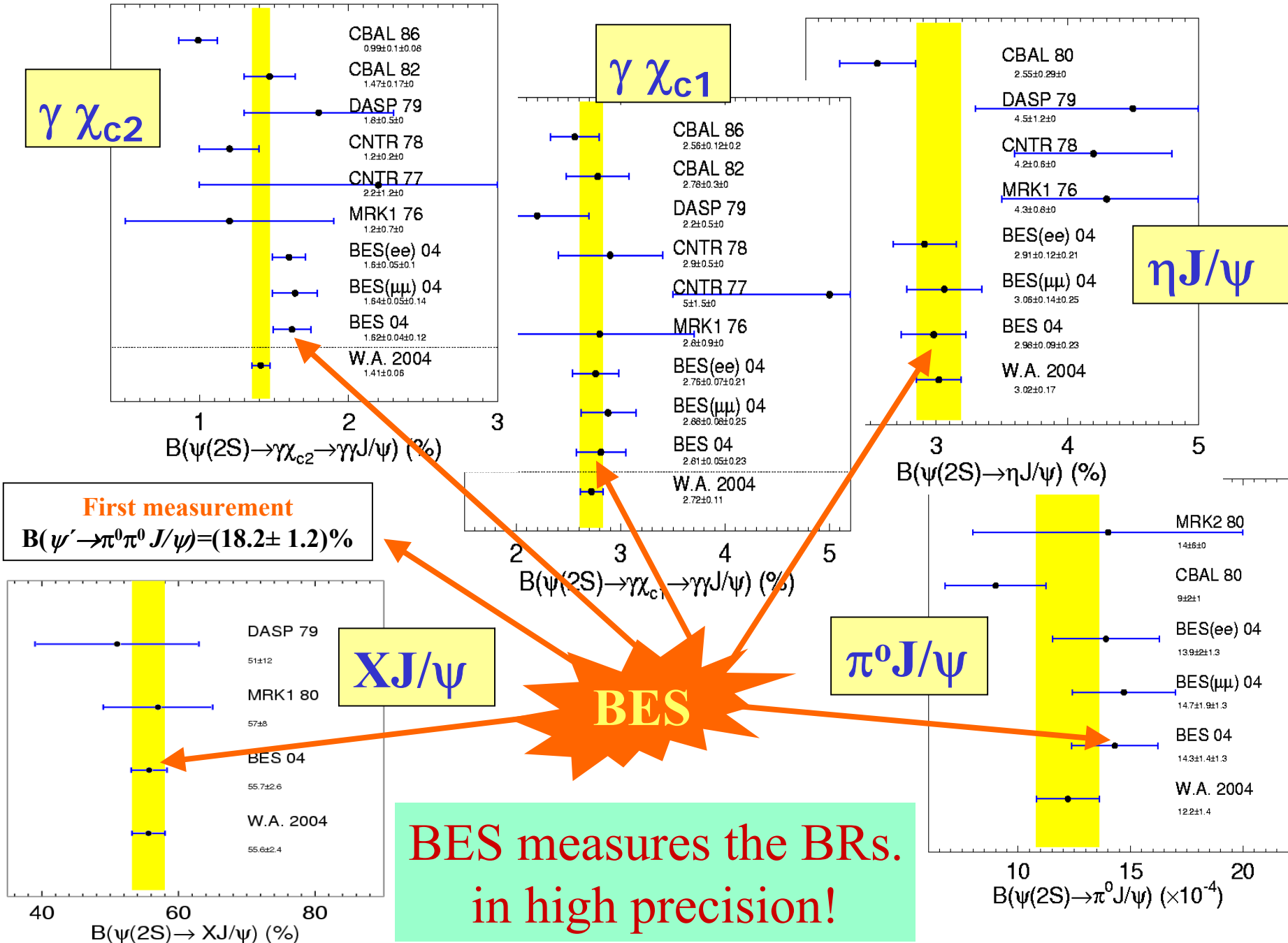
extra



$$\psi' \rightarrow \gamma \gamma J/\psi$$

Exclusive Method





$\psi' \rightarrow \gamma \gamma J/\psi$

Discussions

BES (+PDG for Υ):

$$\mathbf{R=0.048\pm0.007}$$

$$\mathbf{R' < 0.0098}$$

$$\mathbf{R'' < 0.0065}$$

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

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

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

- PCAC [G. A. Miller, Phys. Rep. 194,1(1990)]: **R=0.0162** (too small!)

$$R = \frac{27}{16} \left(\frac{p_\pi}{p_\eta} \right)^3 r^2, \quad r = (m_d - m_u) / (m_s - 0.5 \cdot (m_d + m_u))$$

- QCD Multipole Expansion & BTG potential model
[Y. P. Kuang, PRD24, 2874(1981), *ibid.* 37, 1210(1988)]

$$\mathbf{\underline{R' = 0.0025}}$$

$$\mathbf{\underline{R'' = 0.0013}}$$

$$R' \approx \left(\frac{m_c}{m_b} \right)^2 \cdot \left(\frac{p_\eta(\Upsilon')}{p_\eta(\psi(2S))} \right)^3 \cdot \left(\frac{f(\Upsilon')}{f(\psi(2S))} \right)^2$$

$$R'' \approx \left(\frac{m_c}{m_b} \right)^2 \cdot \left(\frac{p_\eta(\Upsilon'')}{p_\eta(\psi(2S))} \right)^3 \cdot \left(\frac{f(\Upsilon'')}{f(\psi(2S))} \right)^2$$

Summary

- 🧠 Studies are made for $K^* \bar{K}$ and $\omega \pi$ channels, about which the cont. contr. and its interference are taken into account.
- 🧠 For VT channel, ωf_2 , ρa_2 , $K^* K_2^*$ and $\phi f_2'$ are measured.
- 🧠 For PP channel, $K_S^0 K_L^0$ is first observed in ψ' decay; and the precision is improved for $J/\psi \rightarrow K_S^0 K_L^0$.
- 🧠 $\psi' \rightarrow J/\psi$ -contained final states are studied to improve experimental precision and test theoretical predications.

- 👁 Test of 12% rule ;
- 👁 Study of phase between strong and EM amplitudes ;
- 👁 Prediction & Evaluation involving mixing model.

Thanks a lot !

谢谢！

Search for ψ' , $J/\psi \rightarrow K_S K_S$

- CP violating process
- Test EPR paradox
(Einstein-Podolsky-Rosen)
- MarkIII: 2.7M J/ψ
 $\mathbf{B(J/\psi \rightarrow K_S K_S) < 5.2 \times 10^{-6}}$
(@90% C.L.)
- BESII: 58M J/ψ
14M ψ'

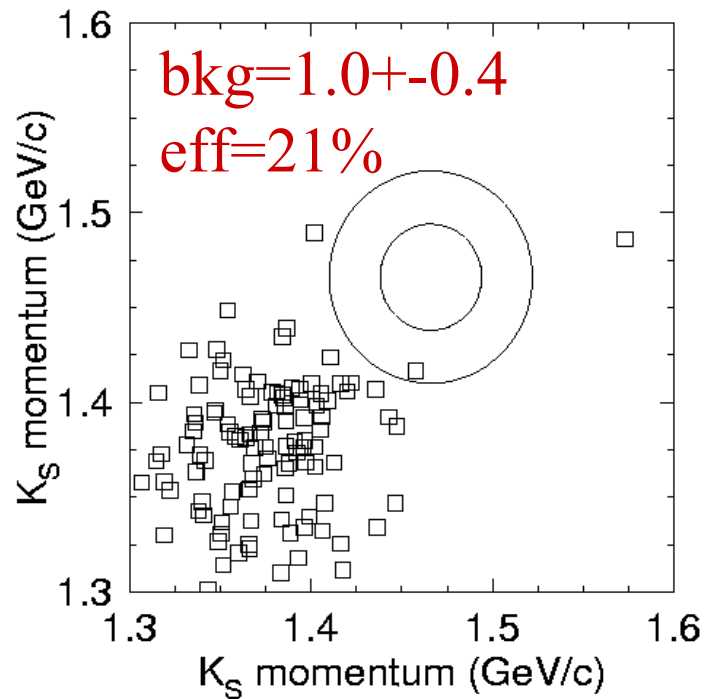
Events selection

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

$\psi', J/\psi \rightarrow K_S K_S$

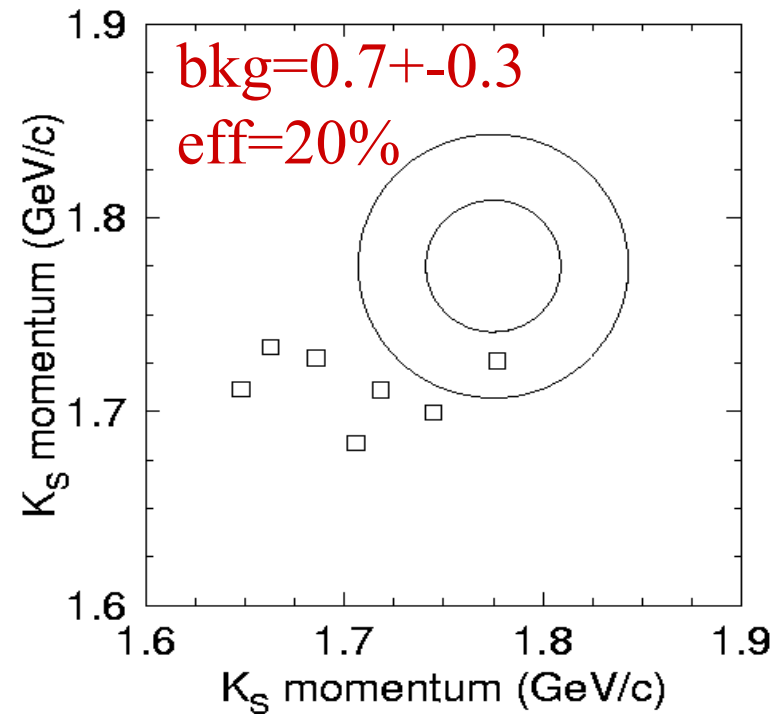
2 circles – 1 σ & 2 σ regions from MC

1 evt in 2 σ region



$J/\psi \rightarrow K_S K_S$ candidate

1 evt in 2 σ region



$\psi' \rightarrow K_S K_S$ candidate

$$\psi', J/\psi \rightarrow K_S K_S$$

Upper Limits (@95% C.L.)

R	J/ψ	$\psi(2S)$
n^{obs}	1	1
n_{UL}^{obs}	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
$B(K_S^0 \rightarrow \pi^+ \pi^-)$	0.6860 ± 0.0027	
$B(R \rightarrow K_S^0 K_S^0) <$	1.0×10^{-6}	4.6×10^{-6}

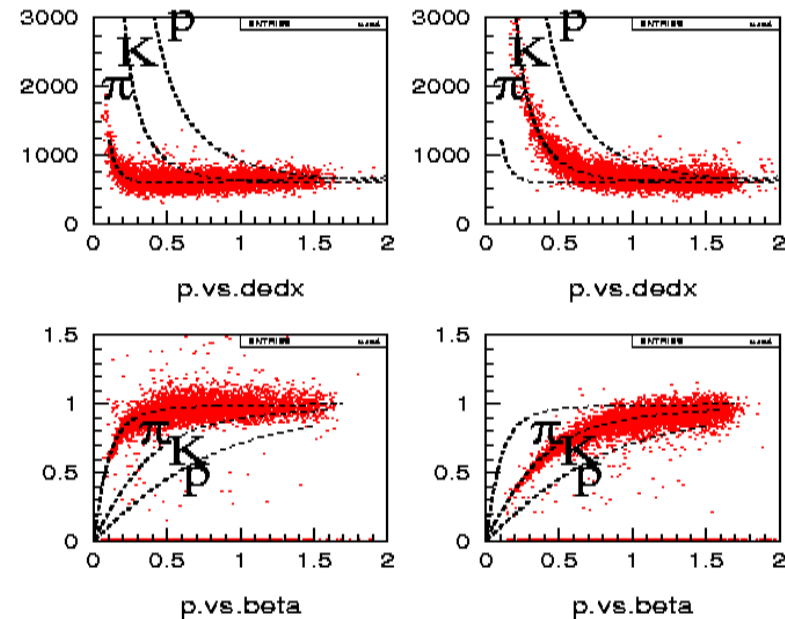
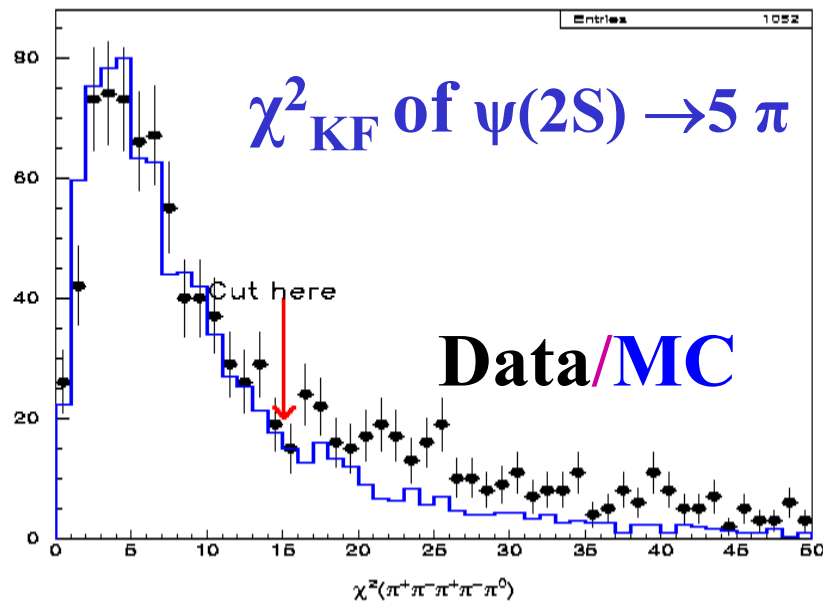
- 1st upper limit for $B(\psi' \rightarrow K_S K_S)$.
- Higher sensitivity for $B(J/\psi \rightarrow K_S K_S)$ upper limit.
- Sensitivity insufficient for testing EPR paradox and CP violation.

PLB (in press)

$$\psi' \rightarrow VT$$

Event Selection

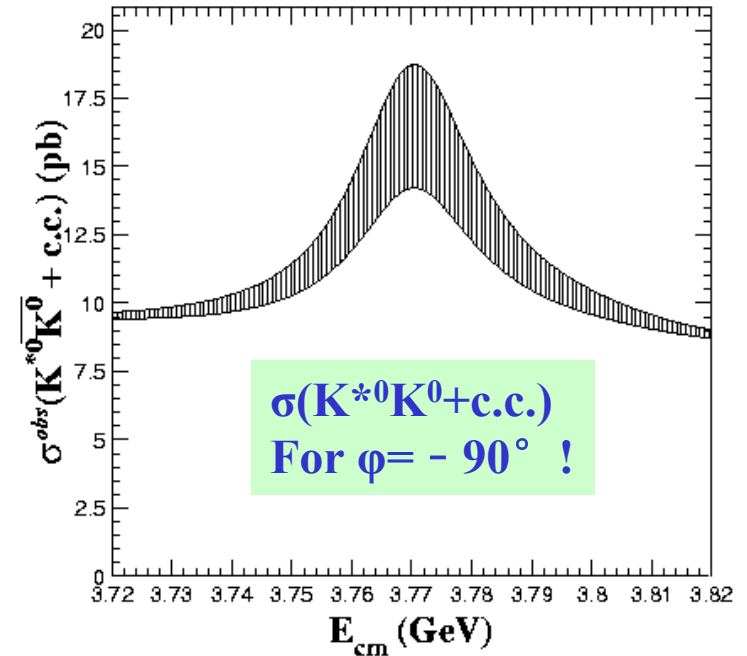
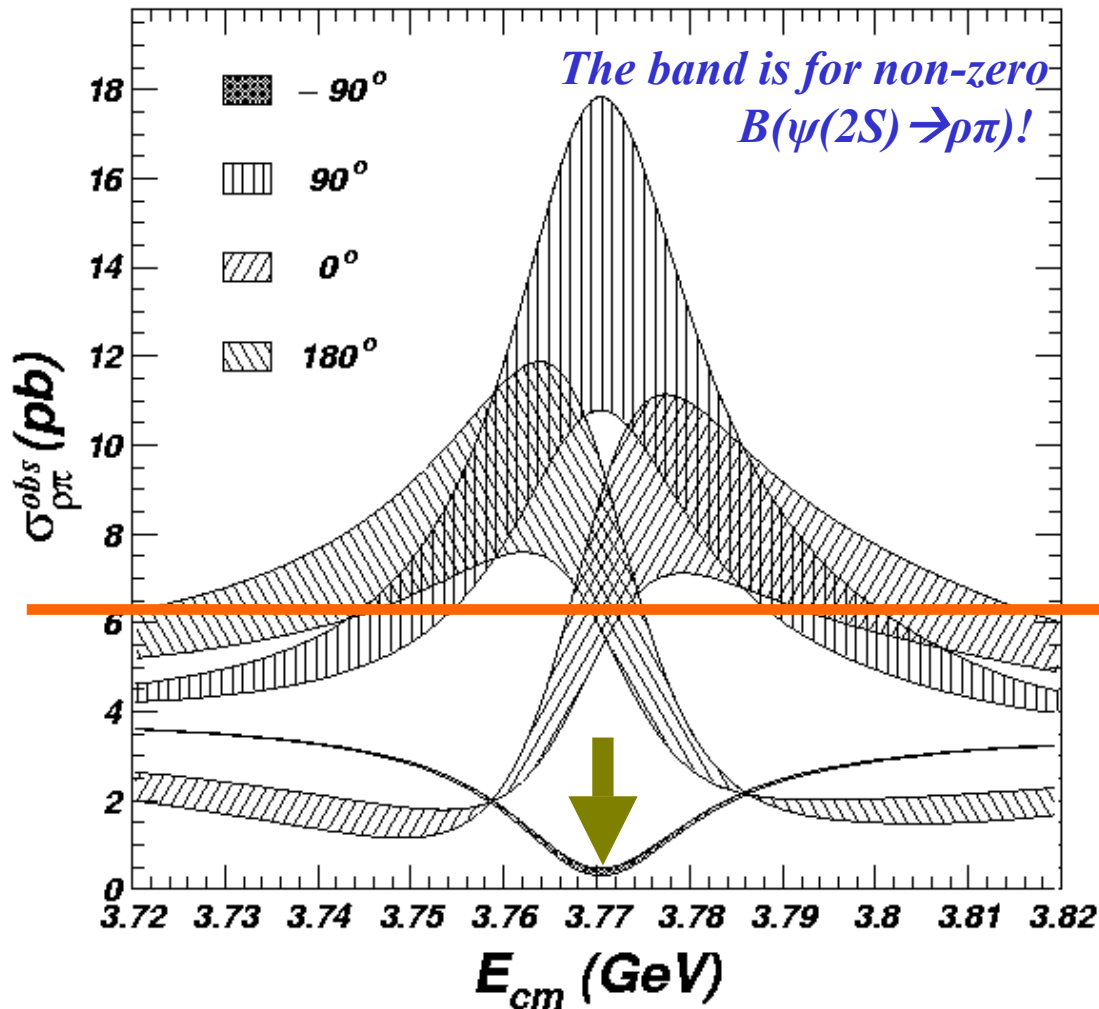
1. **Four** charged tracks with net charge zero;
2. $|\cos\theta| < 0.80$ for all tracks;
3. **PartID** using TOF+dE/dx
4. At least 2 photon candidates for π^0 channels;
5. Remove $\psi(2S) \rightarrow \pi^+ \pi^- J/\psi$ background;
6. **Kinematic fit** (4C/5C), Prob > 0.01.



$J/\psi, \psi' \rightarrow \rho\pi$

A solution of ψ' suppress
Wang, Yuan and Mo: PLB574,41(2003)

To measure $B(\psi'' \rightarrow \rho\pi)$, the best way is to do the energy scan!



MK3 UL (<6.3pb)
Favors $\phi = -90^\circ$!

*Missing $\rho\pi$ signal and/or enhanced $K^{*0}K^0$ signal indicate BRs at 10^{-4} level.*

$\psi' \rightarrow J/\psi$ -Contained

Both Accepted by PRD

J/ ψ -contained final state ($XJ/\psi, J/\psi \rightarrow \mu^+ \mu^-$) Inclusive Method [BES-I]		
Channel	$B_{XJ/\psi} / B_{\pi\pi J/\psi}$ (%)	$B_{XJ/\psi}$ (%) [$B_{\pi\pi J/\psi} = (30.5 \pm 1.6)\%$]
<i>Anything</i> J/ ψ	$1.867 \pm 0.026 \pm 0.055$	$56.9 \pm 0.8 \pm 3.4$
$\pi^0 \pi^0 J/\psi$	$0.570 \pm 0.009 \pm 0.026$	$17.4 \pm 0.3 \pm 1.2$
$\eta J/\psi$	$0.098 \pm 0.005 \pm 0.010$	$3.00 \pm 0.16 \pm 0.33$
$\gamma \chi_{c1}, \chi_{c1} \rightarrow \gamma J/\psi$	$0.126 \pm 0.003 \pm 0.038$	$3.9 \pm 0.16 \pm 1.2$
$\gamma \chi_{c2}, \chi_{c2} \rightarrow \gamma J/\psi$	$0.060 \pm 0.000 \pm 0.028$	$1.84 \pm 0.01 \pm 0.86$

J/ ψ -contained final state ($\gamma\gamma J/\psi, J/\psi \rightarrow l^+ l^-$) Exclusive Method [BES-II]			
Channel	$B_{\gamma\gamma J/\psi, J/\psi \rightarrow \mu^+ \mu^-}$ (%)	$B_{\gamma\gamma J/\psi, J/\psi \rightarrow e^+ e^-}$ (%)	Combine $B_{\gamma\gamma J/\psi}$ (%)
$\pi^0 J/\psi$	$0.147 \pm 0.019 \pm 0.013$	$0.139 \pm 0.020 \pm 0.013$	$0.143 \pm 0.014 \pm 0.013$
$\eta J/\psi$	$3.06 \pm 0.14 \pm 0.25$	$2.91 \pm 0.12 \pm 0.21$	$2.98 \pm 0.09 \pm 0.23$
$\gamma \chi_{c1}, \chi_{c1} \rightarrow \gamma J/\psi$	$9.11 \pm 0.24 \pm 1.12$	$8.73 \pm 0.21 \pm 1.00$	$8.90 \pm 0.16 \pm 1.05$
$\gamma \chi_{c2}, \chi_{c2} \rightarrow \gamma J/\psi$	$8.12 \pm 0.23 \pm 0.99$	$7.90 \pm 0.26 \pm 0.88$	$8.02 \pm 0.17 \pm 0.94$