Recent Results on Charmonium Physics at BES

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Results and perspective of particle physics
19th Rencontre de Physique de la Vallee d`Aoste

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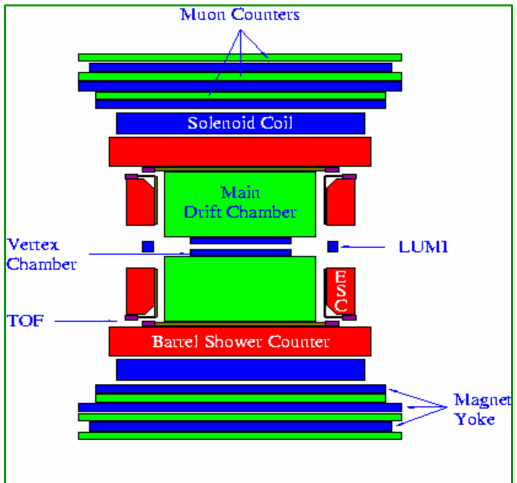
Outline

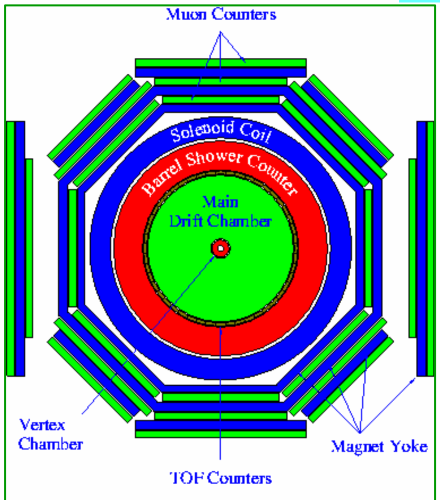
- BESII Detector and Data
- κ and σ study at BES
- Test of pQCD 12% rule at BES

BESII Detector and Data

BESII Detector



Side view of the BES detector

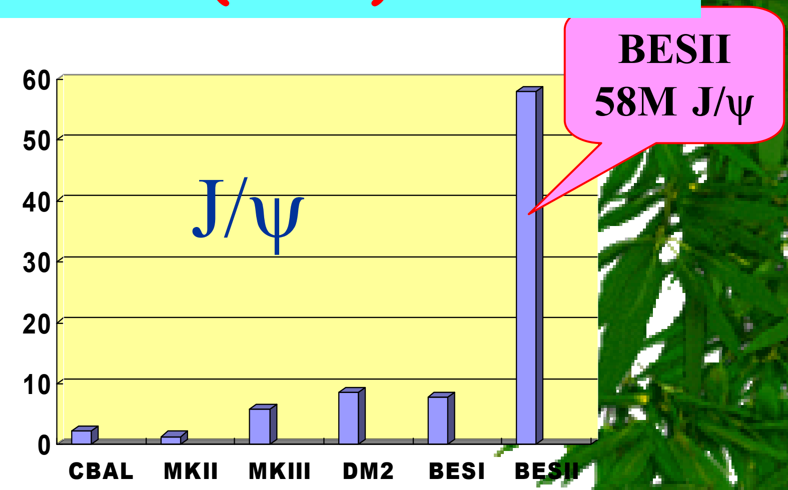


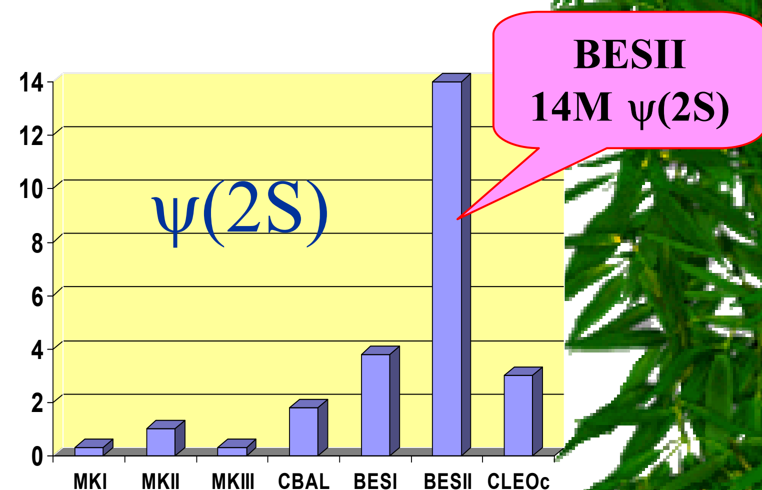
End view of the BES detector

VC: $\sigma_{xy} = 100\ \mu m$
MDC: $\sigma_{xy} = 220\ \mu m$
$\sigma_{dE/dx} = 8.5\ \%$
$\Delta p/p = 1.78\sqrt{(1+p^2)}$
μ counter: $\sigma_{r\phi} = 3$ cm
$\sigma_z = 5.5$ cm

TOF: $\sigma_T = 180$ ps
BSC: $\Delta E/\sqrt{E} = 21\ \%$
$\sigma_\phi = 7.9$ mr
$\sigma_z = 2.3$ cm
B field: 0.4 T

World J/ψ and ψ(2S) Samples ($\times 10^6$)





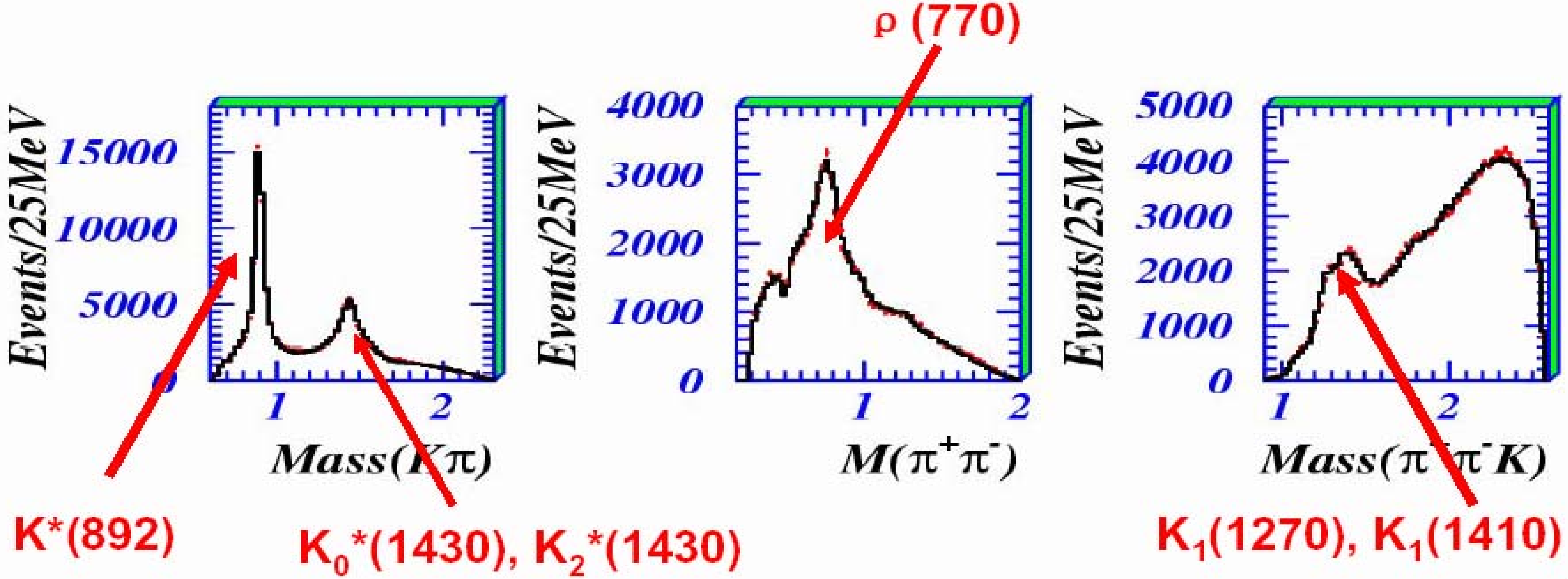
κ and σ study at BES

- There has been much argument whether σ and κ exist, experimental knowledge on the light scalars is very important to the understanding of QCD in the non-perturbative region.
- The BESII data have much higher statistics, and lead to a much more decisive partial wave analysis.

κ in $J/\Psi \rightarrow K^+ \pi^- K^- \pi^+$

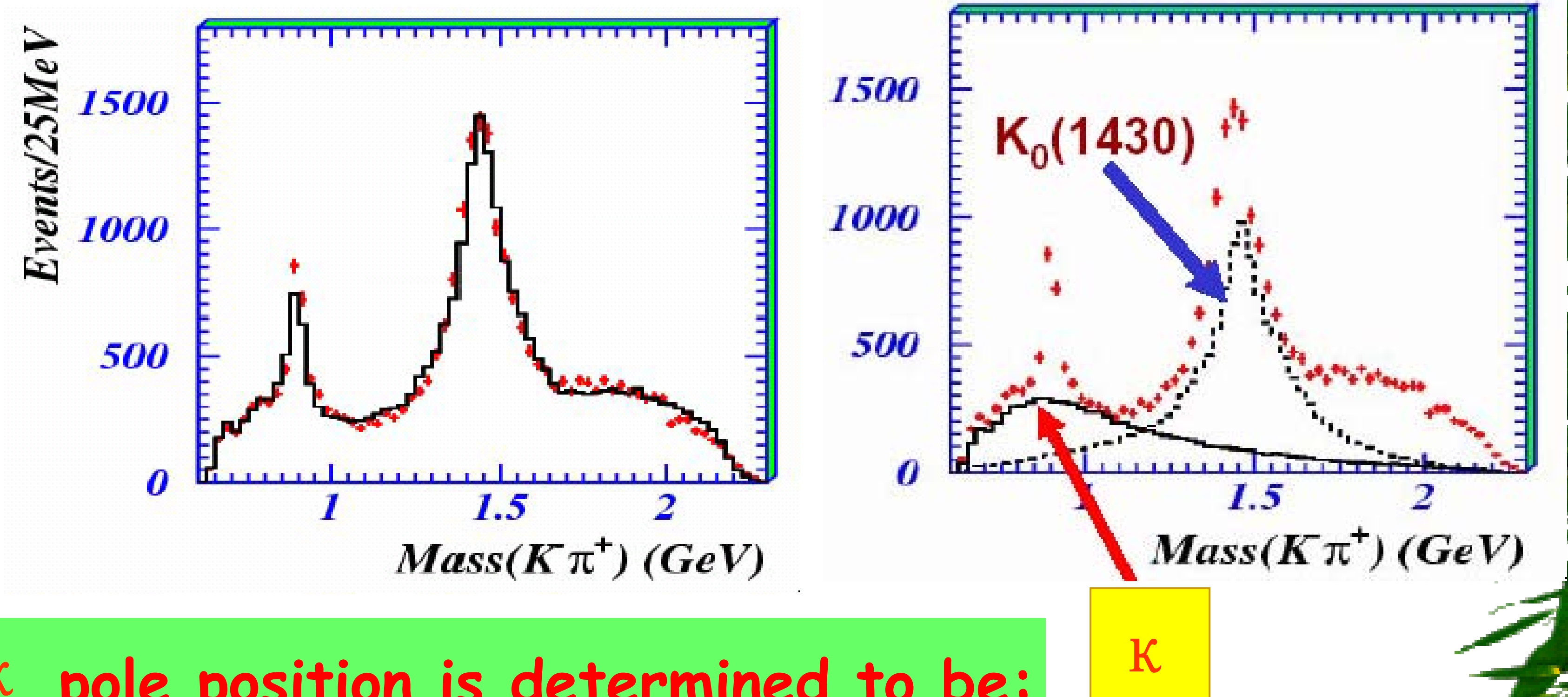
- Events over all of 4-body phase space have been fitted to the following channels:

- $J/\psi \to K^*(892)K_0^*(1430)$, $K^*\kappa$, $K^*K_2^*(1430)$, $K^*K_0^*(1950)$;
- $J/\psi \to K_1(1400)K$, $K_1(1270)K$;
- $J/\psi \to K_0^*(1430)\kappa$, $K_0^*(1430)K_0^*(1430)$, $K_2^*(1430)K_0^*(1430)$;
- $J/\psi \to \rho a_0(980)$, $\rho a_2(1320)$, $\rho a_2(1700)$, $\rho a_2(1990)$, $\rho a_2(2270)$.



κ in J/Ψ→K⁺ π⁻ K⁻ π⁺ (Con't)

The κ and $K^*_0(1430)$ contributions:



κ pole position is determined to be:

$$(760 \pm 20(sta) \pm 40(sys)) - i(420 \pm 45(sta) \pm 60(sys))\ \mathrm{MeV}.$$

κ in J/Ψ→K*(892)⁰ K⁻ π⁺

- Two independent PWA by Method A and B have been performed :
- Decay channels used in the fit:

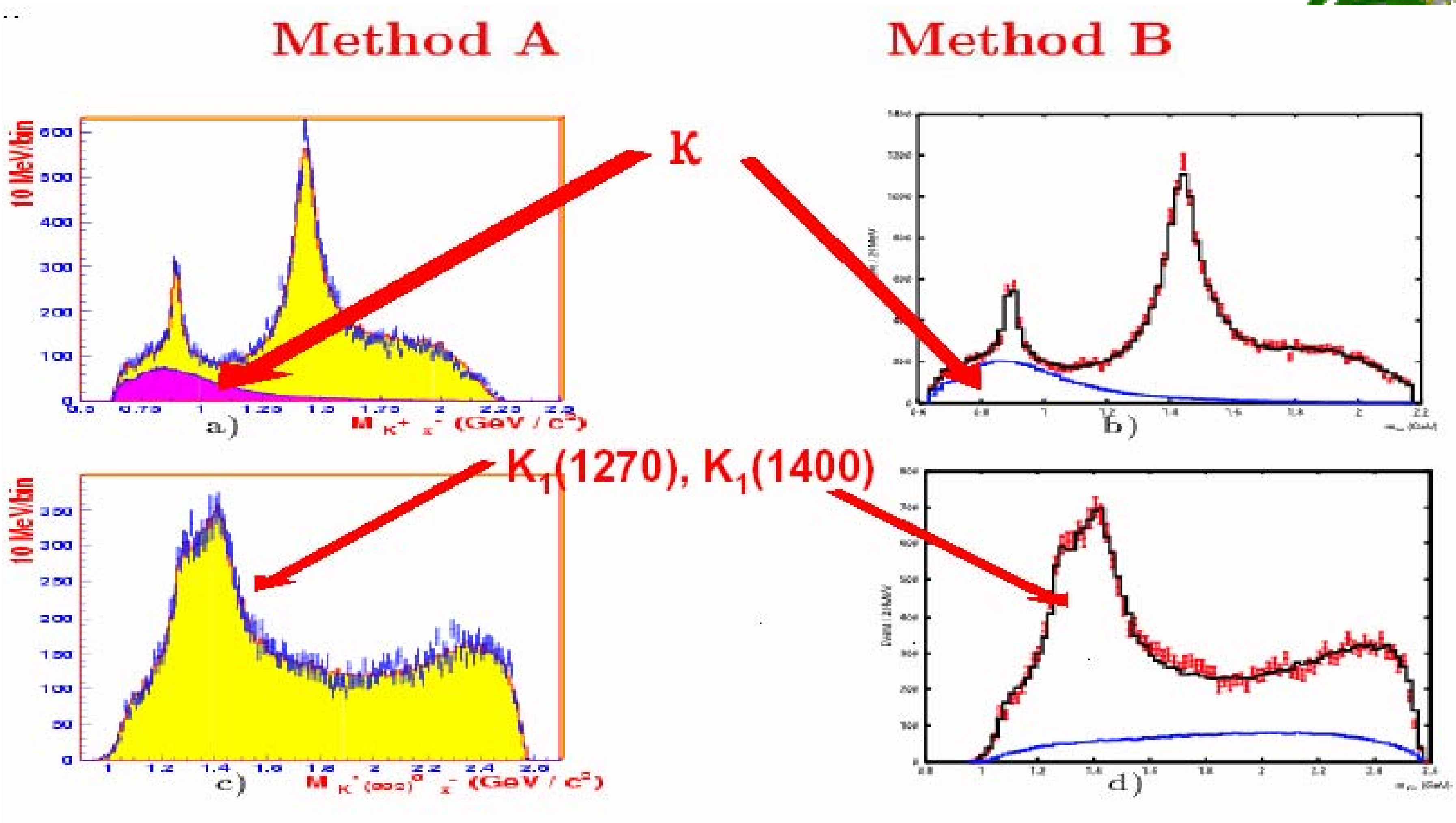
⊙ $J/\psi \rightarrow K^*(892)K_0^*(1430)$, $K^*\kappa$, $K^*K_2^*(1430)$, $K^*K_2^*(1922)$;
⊙ $J/\psi \rightarrow K_1(1400)K$, $K_1(1270)K$.

- Two methods produce similar results: κ is needed.

The averaged value for κ pole position is:

$$(841 \pm 78^{+81}_{-73}) - I(309 \pm 91^{+48}_{-72})MeV$$

κ in J/Ψ→$K^*(892)^0 K^- \pi^+$(Con't)



σ B-W parameterizations

- (a). from PDG

$$BW_\sigma(s, m, \Gamma) = \frac{1}{m^2 - s - im\Gamma_{const.}}$$

- (b). B. Hyams et al., Nucl. Phys. B64(1973),134

$$BW_\sigma(s, m, \Gamma) = \frac{G_\sigma}{m^2 - s - im\Gamma_{tot}(s)} , \qquad \Gamma_{tot}(s) = g_1 \frac{\rho_{\pi\pi}(s)}{\rho_{\pi\pi(m^2)}} + g_2 \frac{\rho_{4\pi}(s)}{\rho_{4\pi}(m^2)} , \ldots$$

- (c). E.M Aitala et al., Phys. Rev. Lett. 86(2001)770

$$BW_\sigma(S, m, \Gamma) = \frac{1}{m^2 - s - im\Gamma_\sigma(s)} , \qquad \Gamma_\sigma(s) = \frac{g_\sigma^2 \sqrt{\frac{s}{4} - m_\pi^s}}{8\pi s}$$

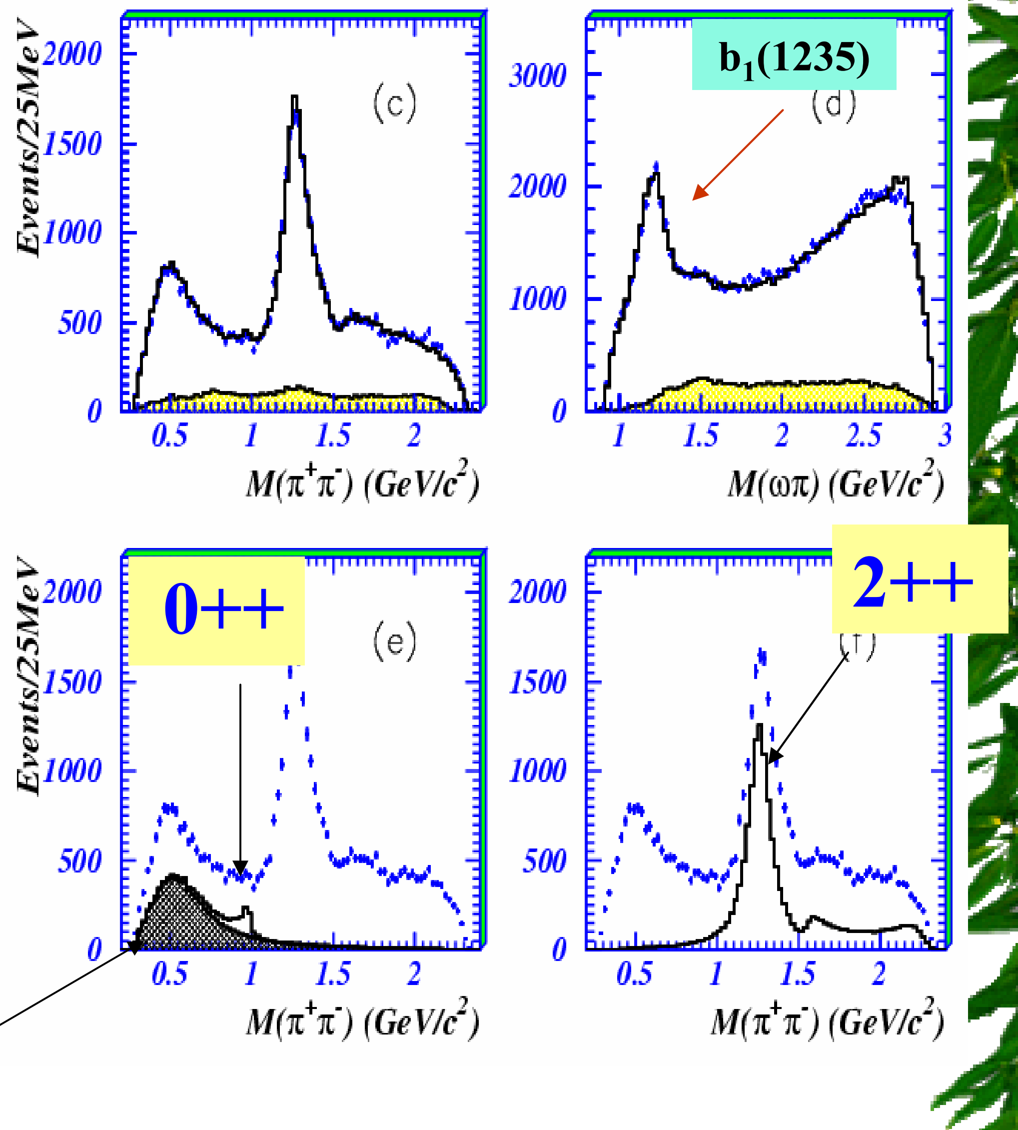
- (d). H.Q. Zheng et al., Nucl. Phys. A733(2004)235

$$BW_\sigma(S, m, \Gamma) = \frac{1}{m^2 - s - im\Gamma_\sigma(s)} , \qquad \Gamma_\sigma(s) = \alpha \sqrt{\frac{s}{4} - m_\pi^s}$$

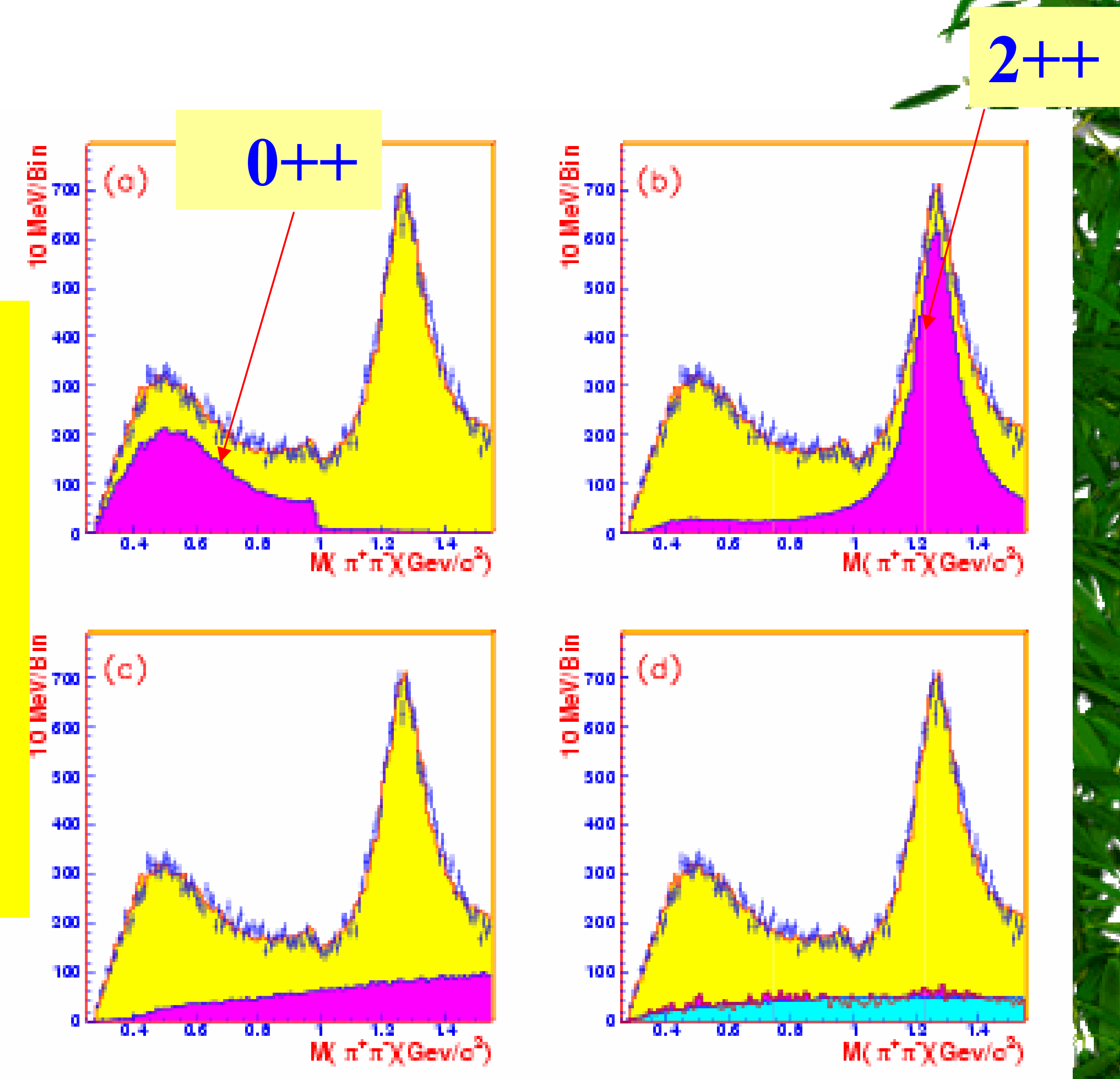
σ in J/Ψ→ ω π⁺ π⁻ (Method I)

Channels fitted to the data:

J/ψ→ωf$_2$(1270)
ωσ
ωf$_0$(980)
b$_1$(1235)π
ρ'(1450)π
f$_2$(1565)ω
f$_2$(2240)ω



σ in $J/\Psi \rightarrow \omega \pi^+ \pi^-$ (Method II)



Channels fitted to the data:

$J/\psi \rightarrow \omega f2(1270)$
$\omega\sigma$
$\omega f0(980)$
$b1(1235)\pi$
phase-space

Fit results:

Method I

B-W parameterization	Pole Position (MeV)
(a)	$(542 \pm 7 \pm 20) - i(269 \pm 15 \pm 25)$
(b)	$(542 \pm 7 \pm 15 \pm 30(extrap)) - i(249 \pm 15 \pm 20 \pm 30(extrap))$
(c)	$(570 \pm 7 \pm 19) - i(274 \pm 14 \pm 22)$

Method II

B-W parameterization	Pole Position (MeV)
(a)	$(512^{+16+36}_{-13-31}) - i(252^{+14+40}_{-9-33})$
(c)	$(558^{+14+42}_{-17-46}) - i(231^{+12+58}_{-14-45})$
(d)	$(521^{+19+44}_{-18-49}) - i(237^{+6+33}_{-7-36})$

Averaged pole position:

$$(541 \pm 39) - i(252 \pm 42) \ \textbf{MeV}$$

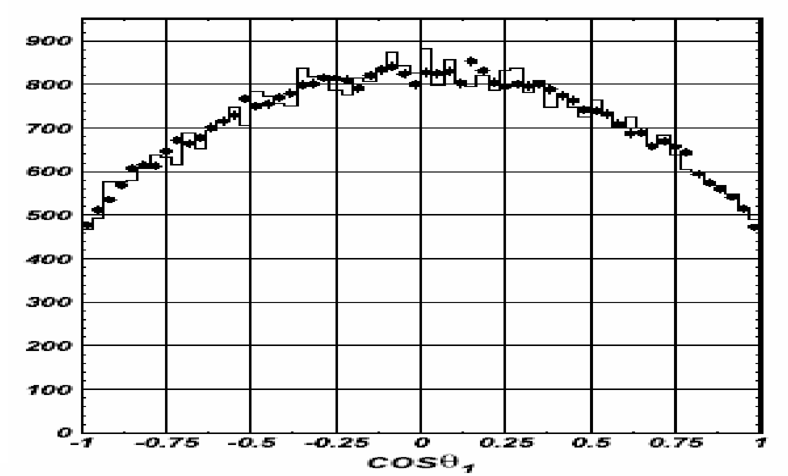
σ in Ψ(2S)→ $\pi^+\pi^-$ J/Ψ

Components fitted in the data:

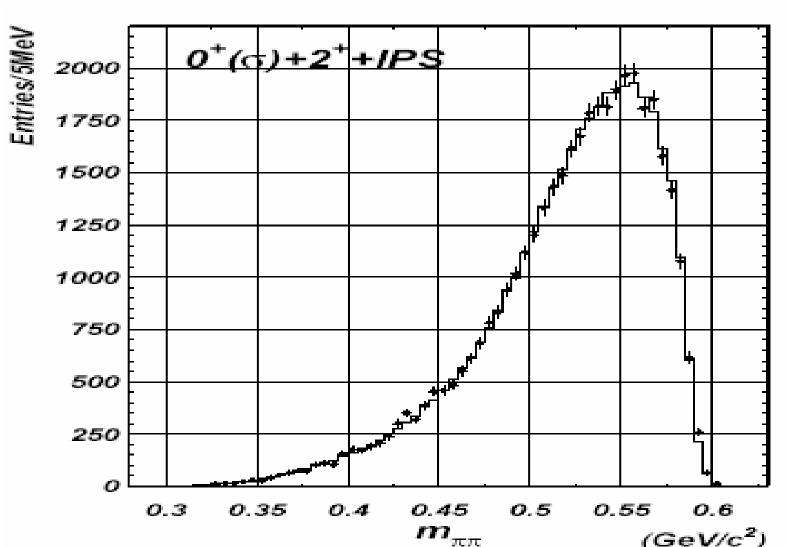
Ψ(2S)→ σ + J/Ψ

B.G (0^+) + J/Ψ

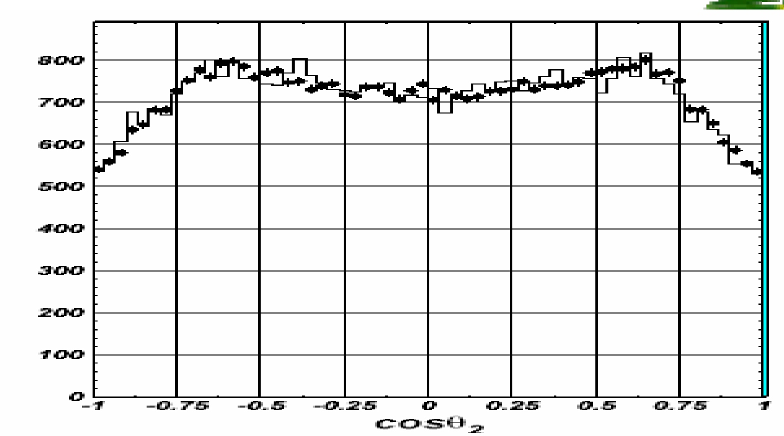
2^+ + J/Ψ



Cos θ of σ



dipion invariant mass



Cos θ of π +

σ in Ψ(2S)→ $\pi^+\pi^-$ J/Ψ (cont.)

Fit results show:

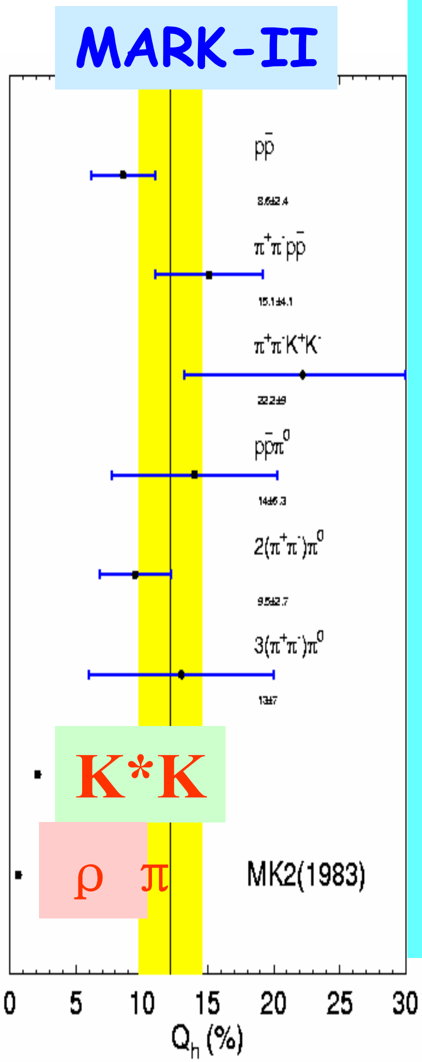
- A strong destructive interference between σ and B.G.,
- 2^+ contribution is small.

pole position is consistent with J/Ψ

$(541 \pm 39) - i(252 \pm 42)$ **MeV** (J/Ψ)

BW parameteration	pole position(MeV)
(a)	$(553 \pm 15 \pm 47) - i(254 \pm 23 \pm 54)$
(c)	$(559 \pm 6 \pm 26) - i(179 \pm 7 \pm 17)$
(d)	$(554 \pm 13 \pm 66) - i(240 \pm 4 \pm 20)$

Test of pQCD 12% Rule at BES



- pQCD rule (12% rule)

  [the relation between J/ψ and ψ']

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

- Violation was revealed by MARK-II, confirmed by BES at higher sensitivity.
- Provide information for under-standing the charmonium decay dynamics.

Test of pQCD 12% Rule(con't)

Theoretical explanations:

- Brodsky, Lepage, Tuan: { PRL 59 (1987) 621 }
  Intermediate vector glueball
- Chaichian & Torngvist : { NP B323 (1989) 75 }
  Hadronic form factor
- Pinsky : { PL B236 (1990) 479 }
  Generalized hindered M1 transition
- Li-Bugg-Zou { PR D55 (1997) 1421 }
  Final-state interaction
- Brodsky-Karliner { PRL 78 (1997) 4682 }
  Intrinsic charm $|q\bar{q}c\bar{c}\rangle$ Fock components of the light vector mesons

… … … …

Test of pQCD 12% Rule (con't)

Measure the BRs of $\psi(2S)$ & corresponding Q values

for 10 VP channels,

1 PP channel,

to test pQCD 12% rule.

VP Mode

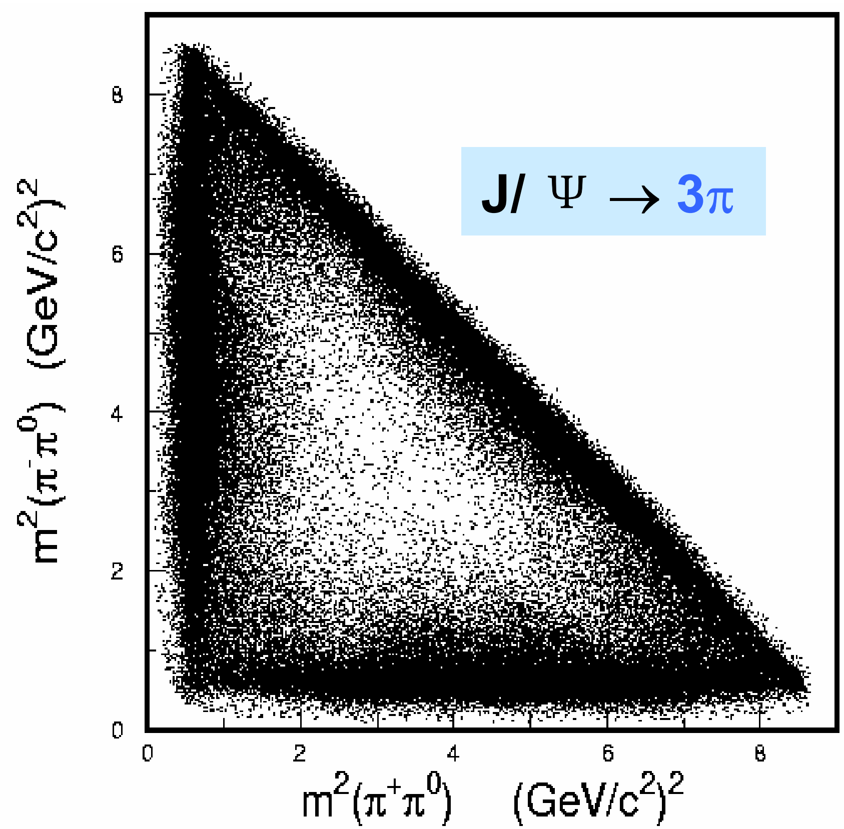
- PWA for $\psi(2S)\to\pi^+ \pi^- \pi^0$
- BRs for $\psi(2S)\to K^*K$
- BRs for $\psi(2S)\to(\rho,\omega,\varphi)(\pi,\eta,\eta')$
  measured
- Background from continuum considered
  using Ecm=3.65 GeV data sample

VP Mode (Con't)

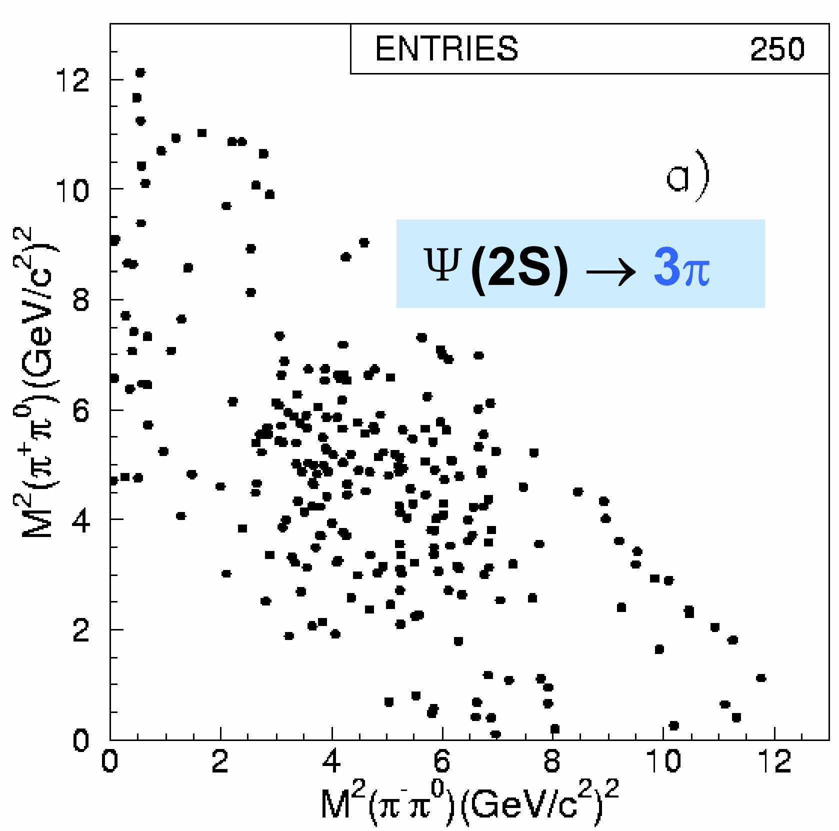
ρ π

hep-ex/0408047 submitted to PLB

Dalitz plot for J/ Ψ and Ψ(2S) → 3π are very different



PRD70 (2004) 012005



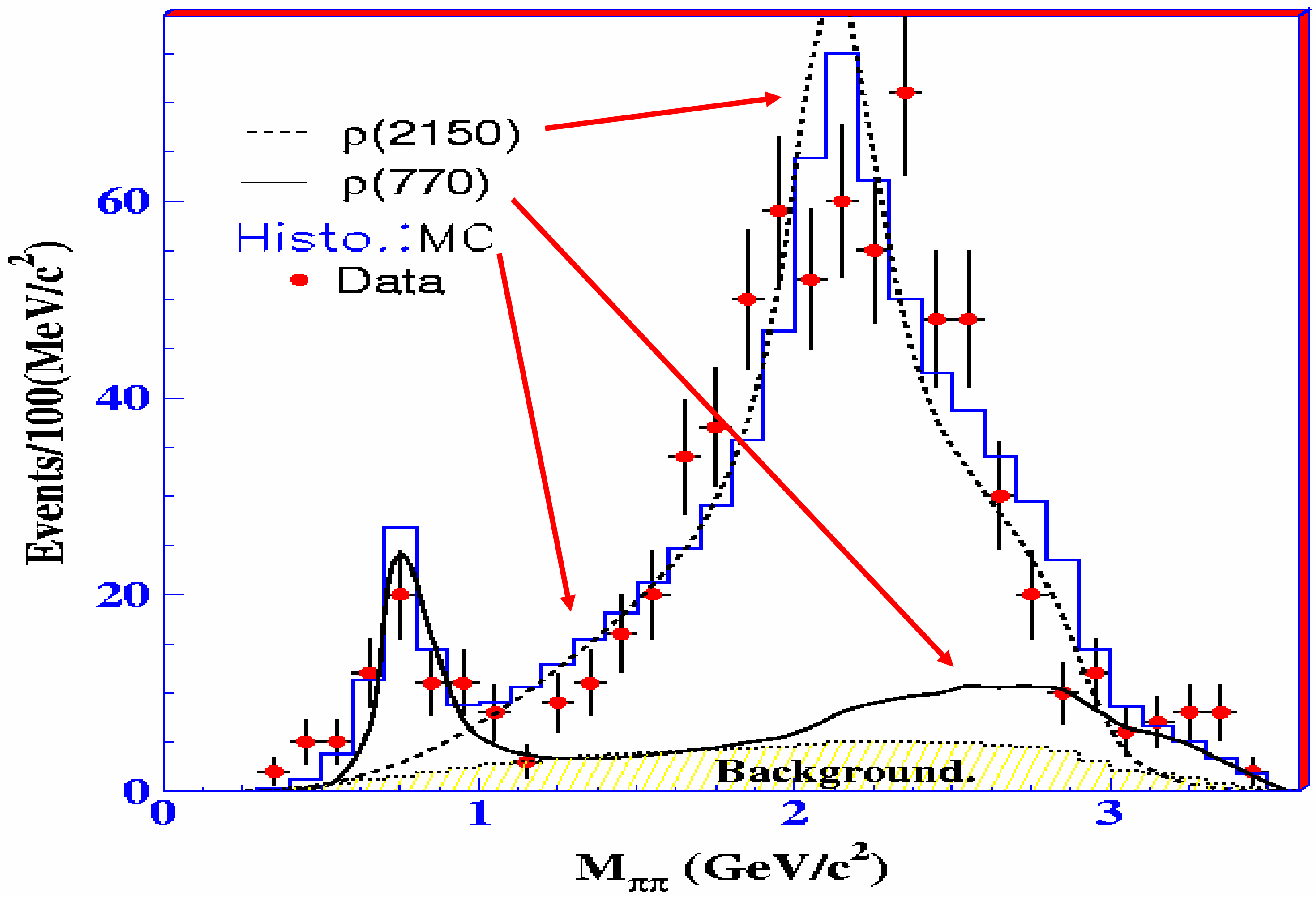
BESII

VP Mode (Con't)

ρ π Mode

BESII (PWA)

ρ(770), ρ(2150) -- dominant



VP Mode (Con't)

$\rho\ \pi$ (Con't)

Results on BRs

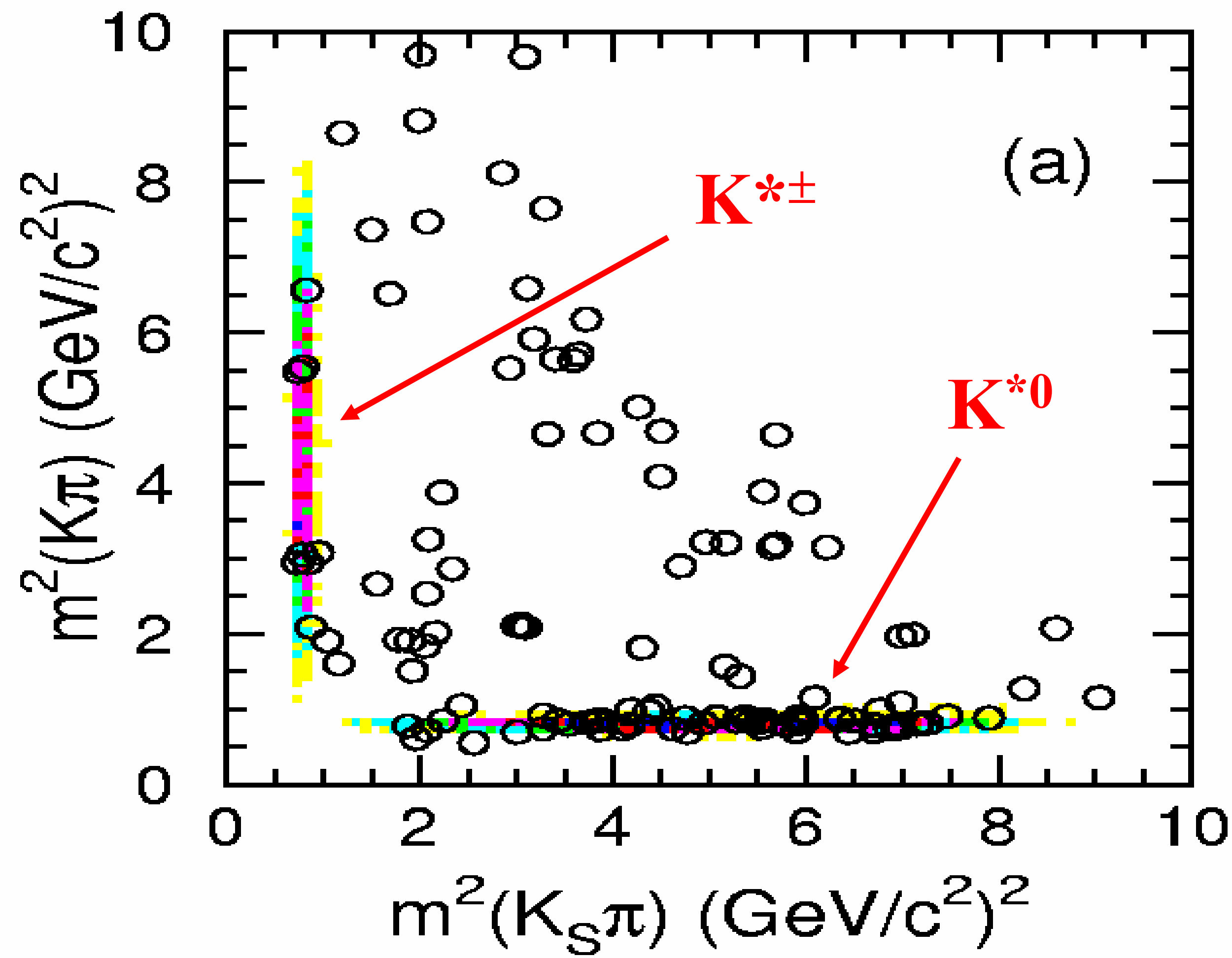
$BR(\Psi(2S) \to\ )$	BESII (10^{-5})	PDG04 (10^{-5})
$\pi^+ \pi^- \pi^0$	$18.1 \pm 1.8 \pm 1.9$	8 ± 5
$\rho\ \pi$	$5.1 \pm 0.7 \pm 0.8$	< 8.3
$\rho(2150)\ \pi \to \pi^+ \pi^- \pi^0$	$19.4 \pm 2.5\ ^{+11.2}_{-2.1}$	

Interference taken into account

VP Mode (Con't)

K*(892)K

Dalits plot in
ψ (2S) →K*(892)K→ $K_S K\pi$



hep-ex/0407037 , submitted to PLB

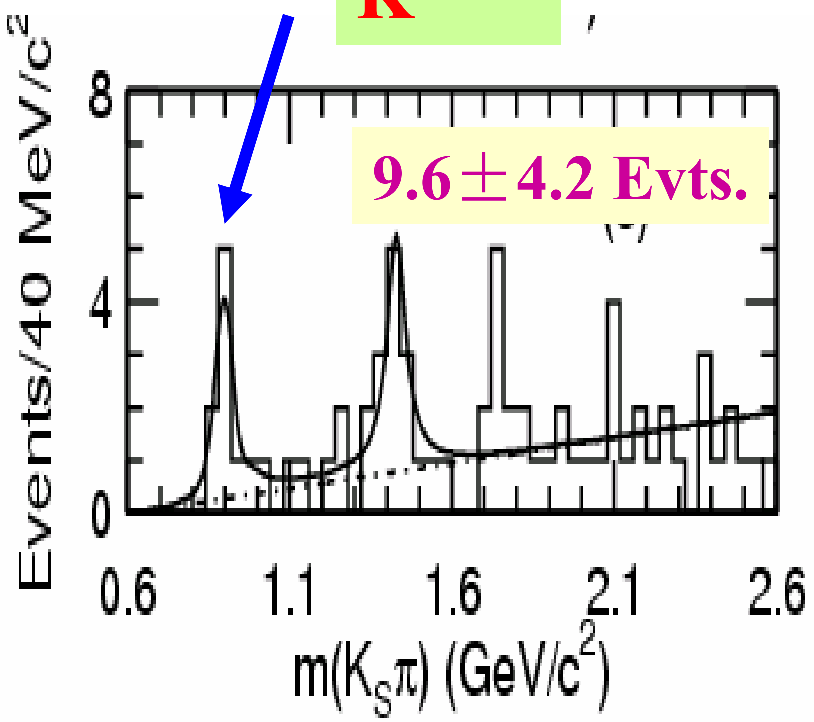
VP Mode (Con't)

K*(892)K (Con't)

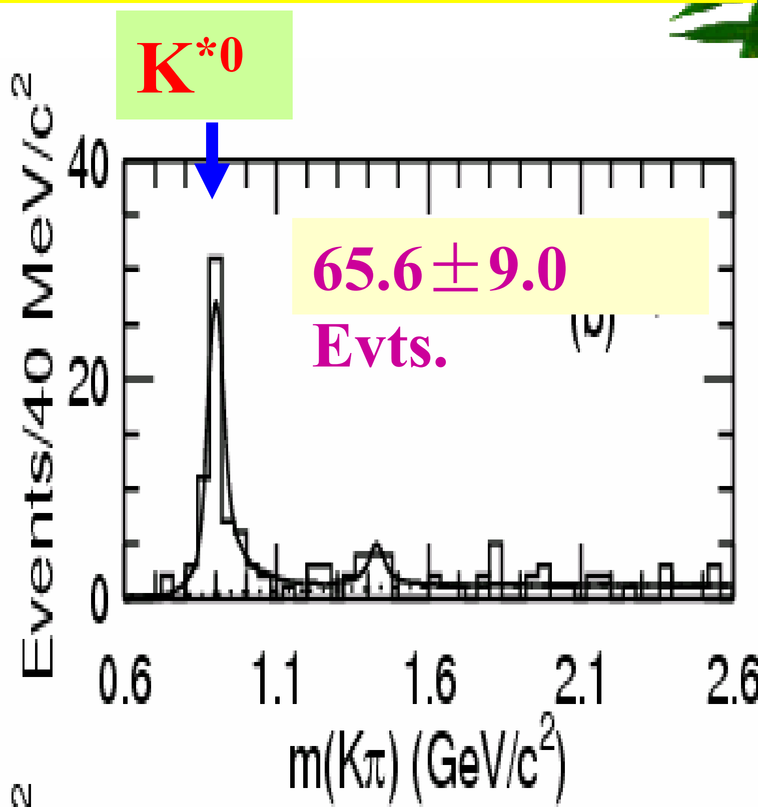
$Br_0(13.3^{+2.4}_{-2.7} \pm 1.7) \times 10^{-5}$

$Br_\pm(2.9^{+1.3}_{-1.7} \pm 0.4) \times 10^{-5}$

$\Psi(2S) \to K^+ K^*(892)^- + c.c.$



$\Psi(2S) \to \bar{K}^0 K^*(892)^0 + c.c.$

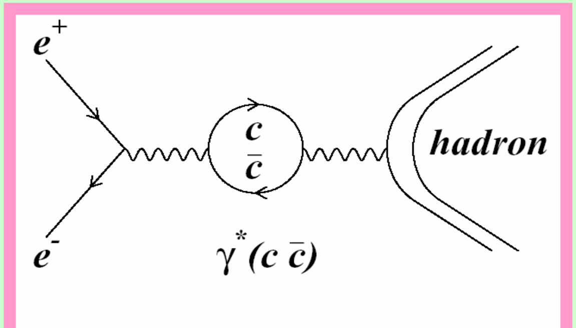


$$\frac{\mathcal{B}(K^*(892)^0\bar{K}^0 + c.c.)}{\mathcal{B}(K^*(892)^\pm \bar{K}^\mp + c.c.)} = 4.6^{+2.9}_{-2.2}$$

isospin-violation

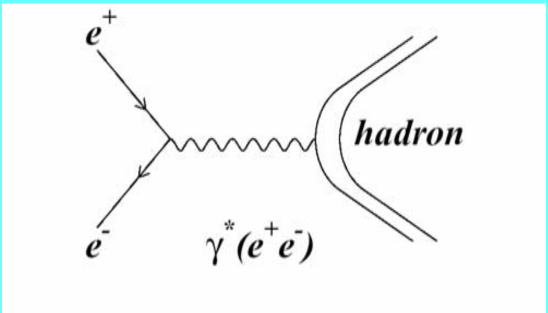
VP Mode (Con't)

EM Process: $\omega\pi^0, \rho\eta, \rho\eta'$ at Ecm=3650,3686,3773 MeV



(b) one photon process

interference



(c) one photon continuum process

For **EM** processes at continuum **e+e- → (VP)** $\omega\pi^0$, $\rho\eta$, $\rho\eta'$

$$\sigma_{\mathrm{Born}}(s) = \frac{4\pi\alpha^2}{s^{3/2}} \cdot |\mathcal{F}_{VP}(s)|^2 \cdot \mathcal{P}_{VP}(s),$$

$P_{vp}(S)=q^3_{vp}/3$; q^3_{vp} - momentum of V or P ;

$F_{vp}(s)$ – form factor ;

For **EM** processes at Ψ**(2S) → (VP)** $\omega\pi^0$, $\rho\eta$, $\rho\eta'$

$\sigma=\sigma^R+\sigma^{cont}$ ($\sigma^{INT} \approx 0$, P.Wang et al, PL B593 (2004) 89)

VP Mode (Con't)

EM Process: $\omega\pi^0, \rho\eta, \rho\eta'$ **at Ecm=3650,3686,3773 MeV**

PRD70 (2004) 112007

Ecm=3650 MeV

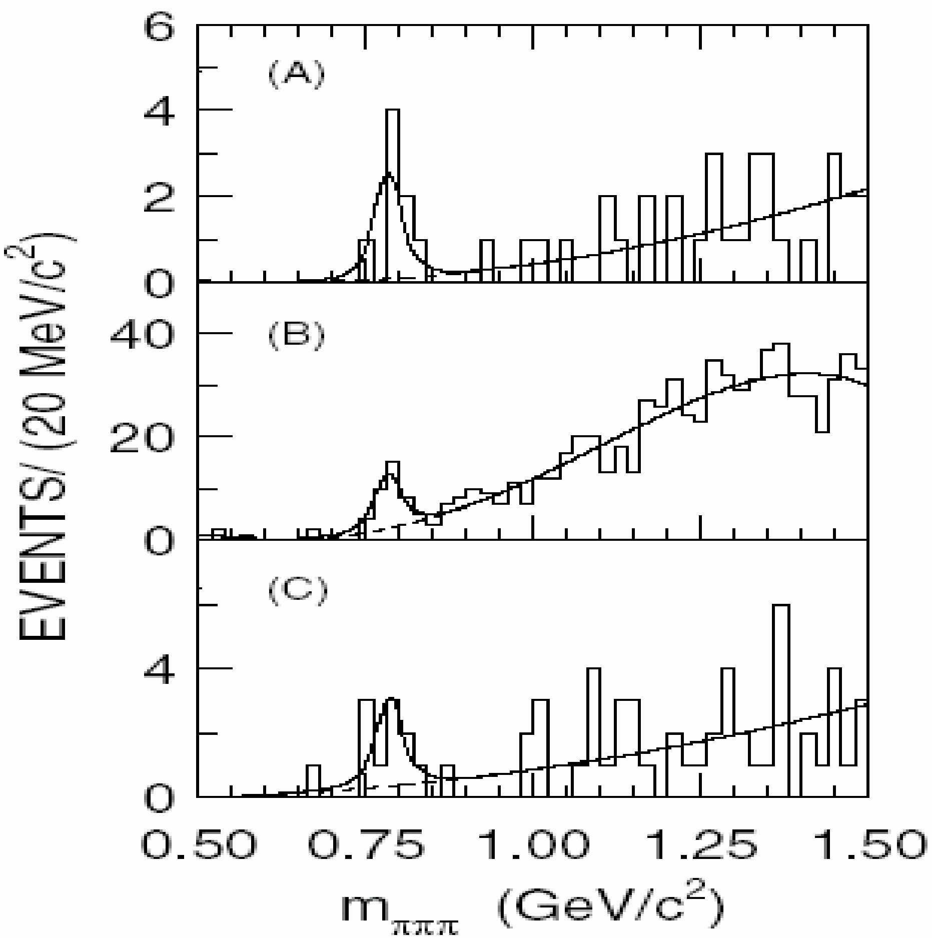
$L = 6.42\ pb^{-1}$

Ecm=3686 MeV

$N_{\psi(2S)} = 19.8 pb^{-1}$

Ecm=3773 MeV

$L = 17.3\ pb^{-1}$



EM Process: $\omega\pi^0, \rho\eta, \rho\eta'$ at Ecm=3650,3686,3773 MeV

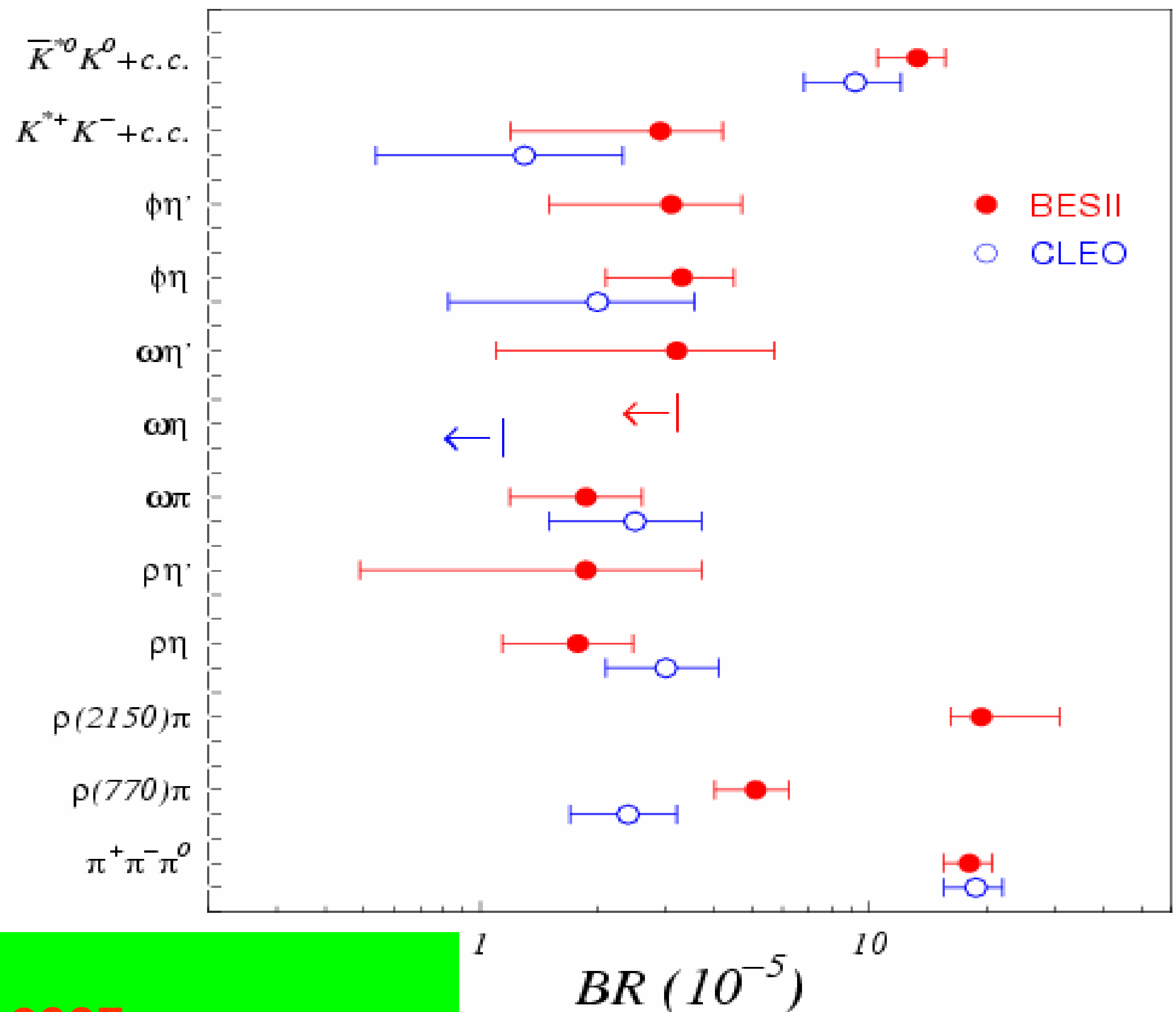
$F_{VP}(S)$ and $B(\Psi(2S) \to VP)$ for $\omega\pi^0, \rho\eta, \rho\eta'$

PRD70 (2004) 112007

State	Ecm(GeV)	σ_{Born}(pb)	$\|F_{vp}\|$(GeV^{-1})	$B_{\psi(2S)\to VP}(\times 10^{-5})$
$\omega\pi^0$	3.650	$24.3^{+11.0}_{-9.0} \pm 4.3$	$0.051^{+0.12}_{-0.10}$	$1.87^{+0.68}_{-0.62} \pm 0.28$
	3.686	$19.2^{+6.3}_{-5.7} \pm 2.9$	$0.045^{+0.008}_{-0.007}$	
	3.773	$10.7^{+5.0}_{-4.1} \pm 1.7$	$0.034^{+0.008}_{-0.007}$	
$\rho\eta$	3.650	$8.1^{+7.4}_{-4.9} \pm 1.1$	$0.030^{+0.014}_{-0.009}$	$1.78^{+0.67}_{-0.62} \pm 0.17$
	3.686	$18.4^{+8.6}_{-7.8} \pm 1.9$	$0.046^{+0.011}_{-0.010}$	
	3.773	$7.8^{+4.4}_{-3.5} \pm 0.08$	$0.030^{+0.009}_{-0.007}$	
$\rho\eta'$	3.650	< 89	< 0.192	$1.87^{+1.64}_{-1.11} \pm 0.33$
	3.686	$18.6^{+15.4}_{-10.3} \pm 3.6$	$0.050^{+0.021}_{-0.015}$	
	3.773	< 28	< 0.106	

BESII vs.CLEO (ψ' BRs Results)

Upper limit @90% C.L.



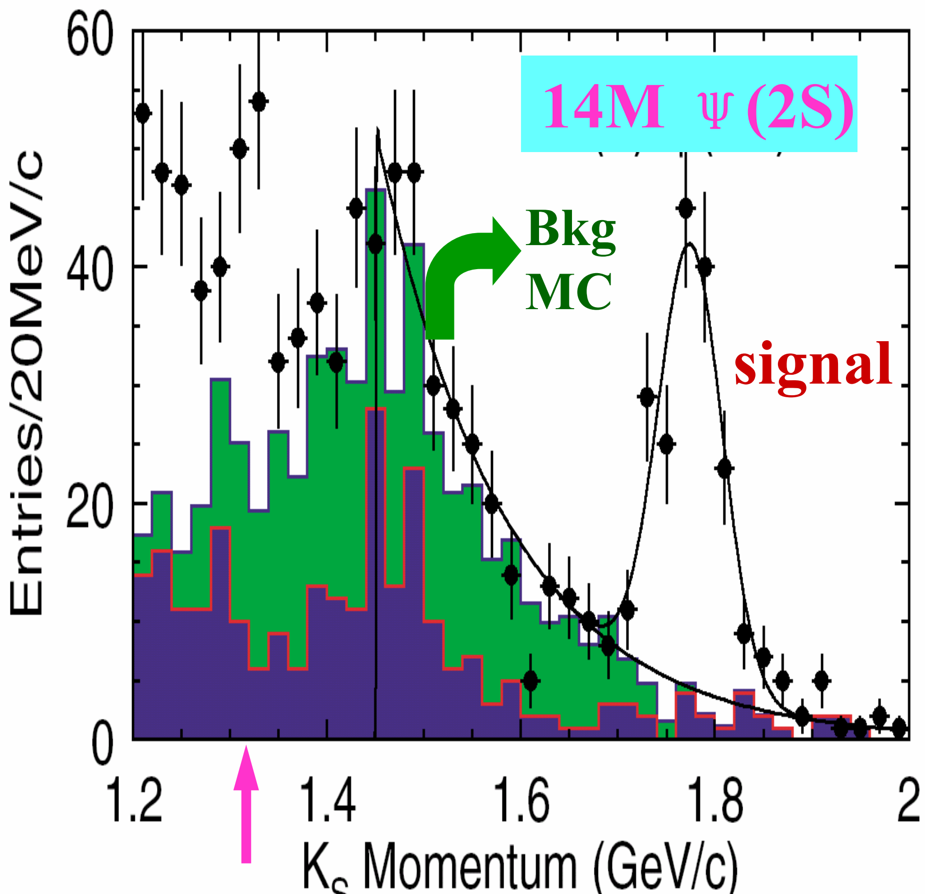
- Most channels BRs are consistent.
- BES BR($\rho\pi$) > CLEO , because PWA takes into account the interference.

CLEO BRs from P.R.L.94:012005,2005

PP Mode

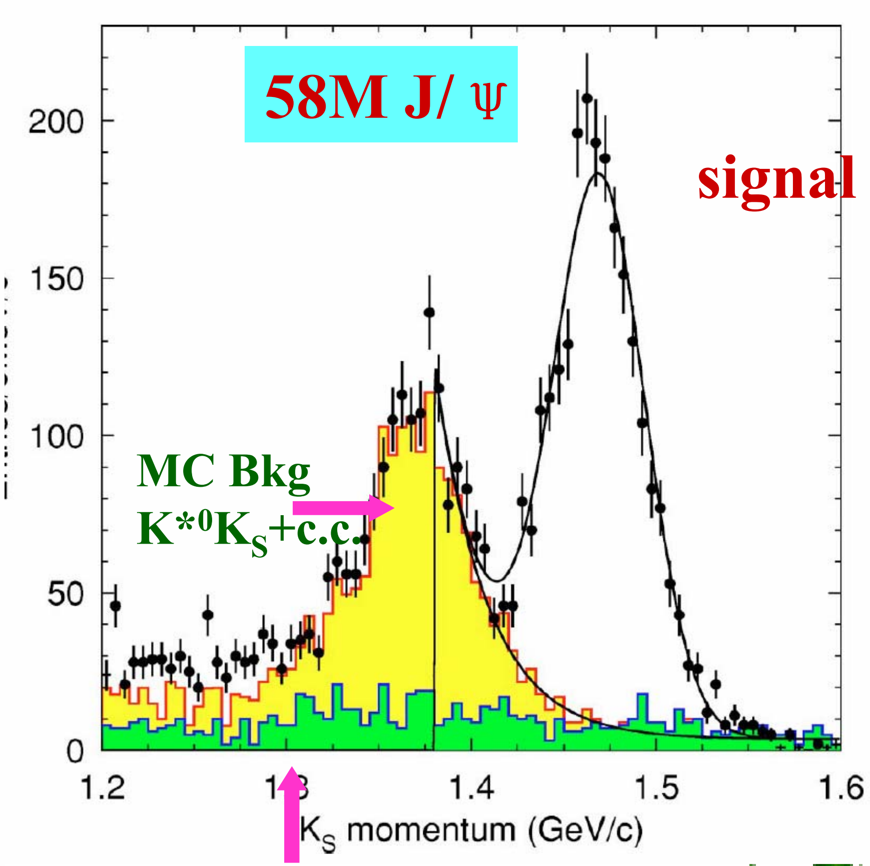
PRL92 (2004) 052001

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



PRD69 (2004) 012003

$J/\Psi \to K_S K_L$



PP Mode (Con't)

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

1st measurement

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

Improved Accuracy

$$\frac{B_{\psi(2S)\to K_S K_L}}{B_{J/\psi \to K_S K_L}} = (28.8 \pm 4.3)\%$$

$$\mathcal{Q}_h = \frac{\mathcal{B}_{\psi(2S)\to X}}{\mathcal{B}_{J/\psi \to X}} = 12\%$$

4σ

B(Ψ(2S)) enhanced!

SUMMARY

σ and κ have been carefully studied with PWA method.

Evidence for the κ as a peak close to the threshold. The pole position was determined.

The σ peak is clearly seen in $J/\Psi \to \omega \pi^+ \pi^-$

we can get the same pole parameters from $\Psi' \to \pi^+ \pi^- J/\Psi$ process even though there is no obvious σ peak.

SUMMARY (Con't)

\# Measurements for BRs or upper limits of VP channels:
$\psi' \to (\rho, \omega, \varphi)(\pi, \eta, \eta')$, $K^*\bar{K}$

\# In $\psi' \to 3\pi$, $\rho(770)$ & $\rho(2150)$ dominant.

\# Large isospin-violation in $\psi' \to K^* \bar{K}$ channel.

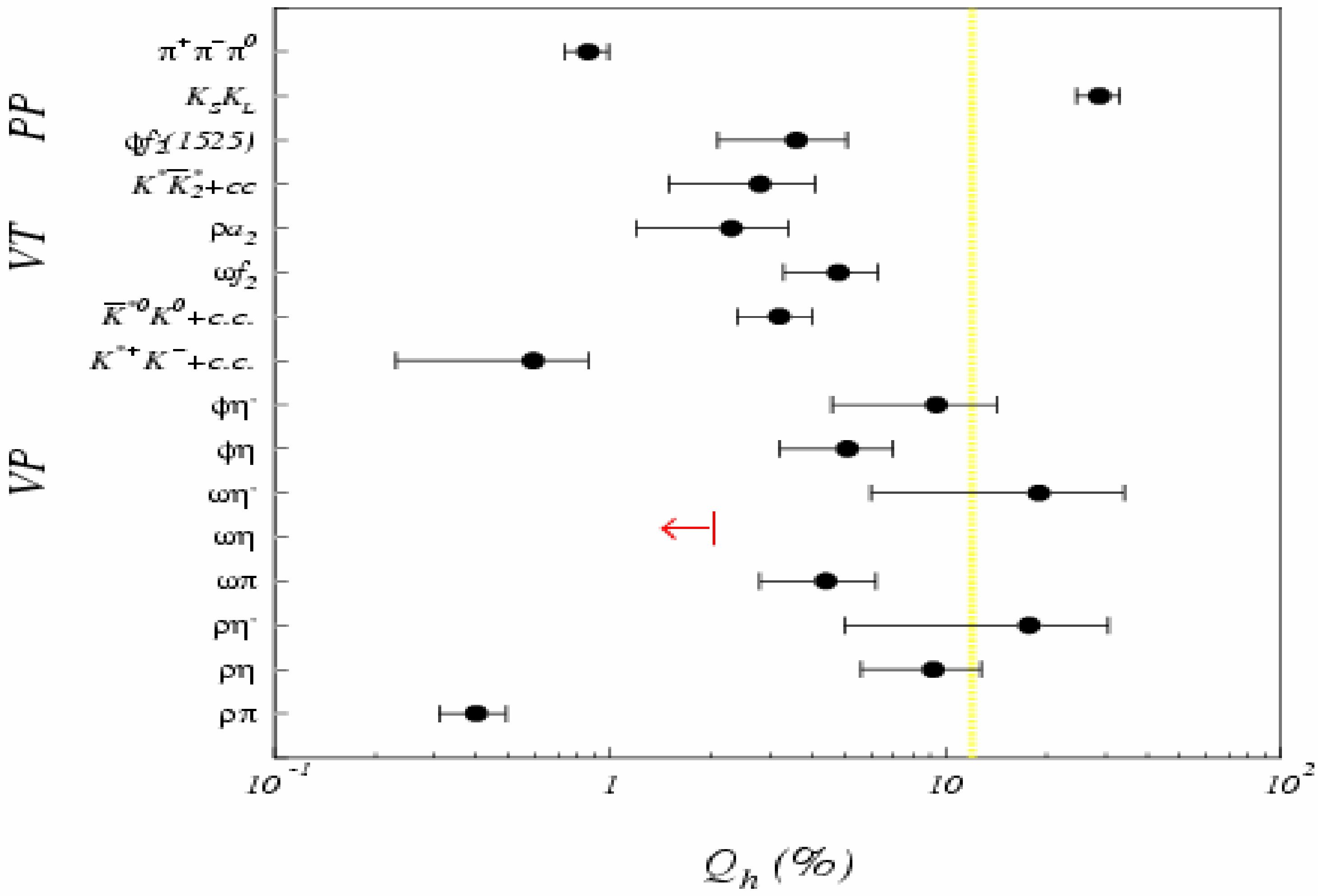
\# First measurement for BR of $\Psi(2S) \to K_S K_L$;

\# 12% rule tested for all these decay modes.
some suppressed, some enhanced, some consistent.

\# 12% rule seems to be too simplistic.

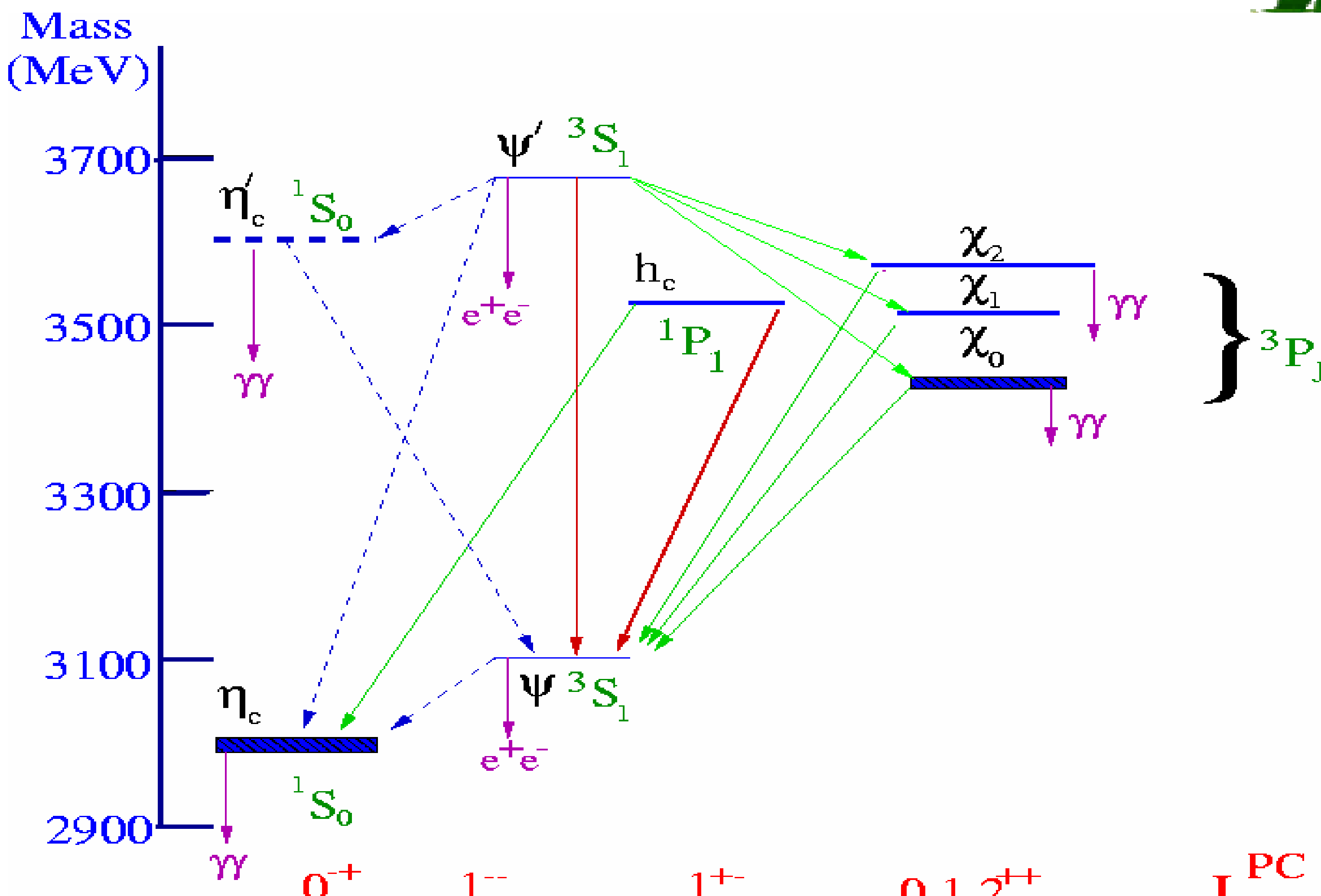
Test of pQCD 12% Rule

SUMMARY (Con't)



Thanks a lot!

INTRODUCTION



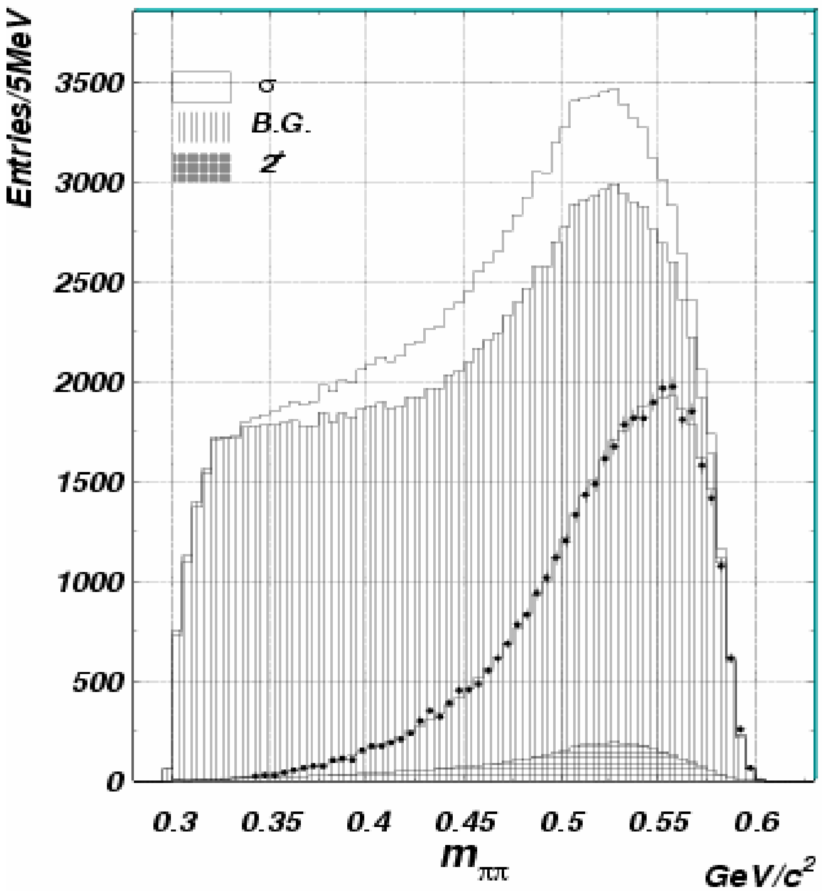
σ in Ψ(2S)→ $\pi^+\pi^-$ J/Ψ(cont.)

Large cancellation: example

chiral symmetry and so called Alder Zero require the amplitude to be vanish near the threshold, then there must be such a cancellation.

Details in :

hep-ph/0308308



VP Mode (Con't)

K*(892)K (Con't)

BRs of $\rho\,\pi$ & $\overline{K^+}K^{*-}$ +cc

Comparison with previous results

(Upper limit @90% C.L.)

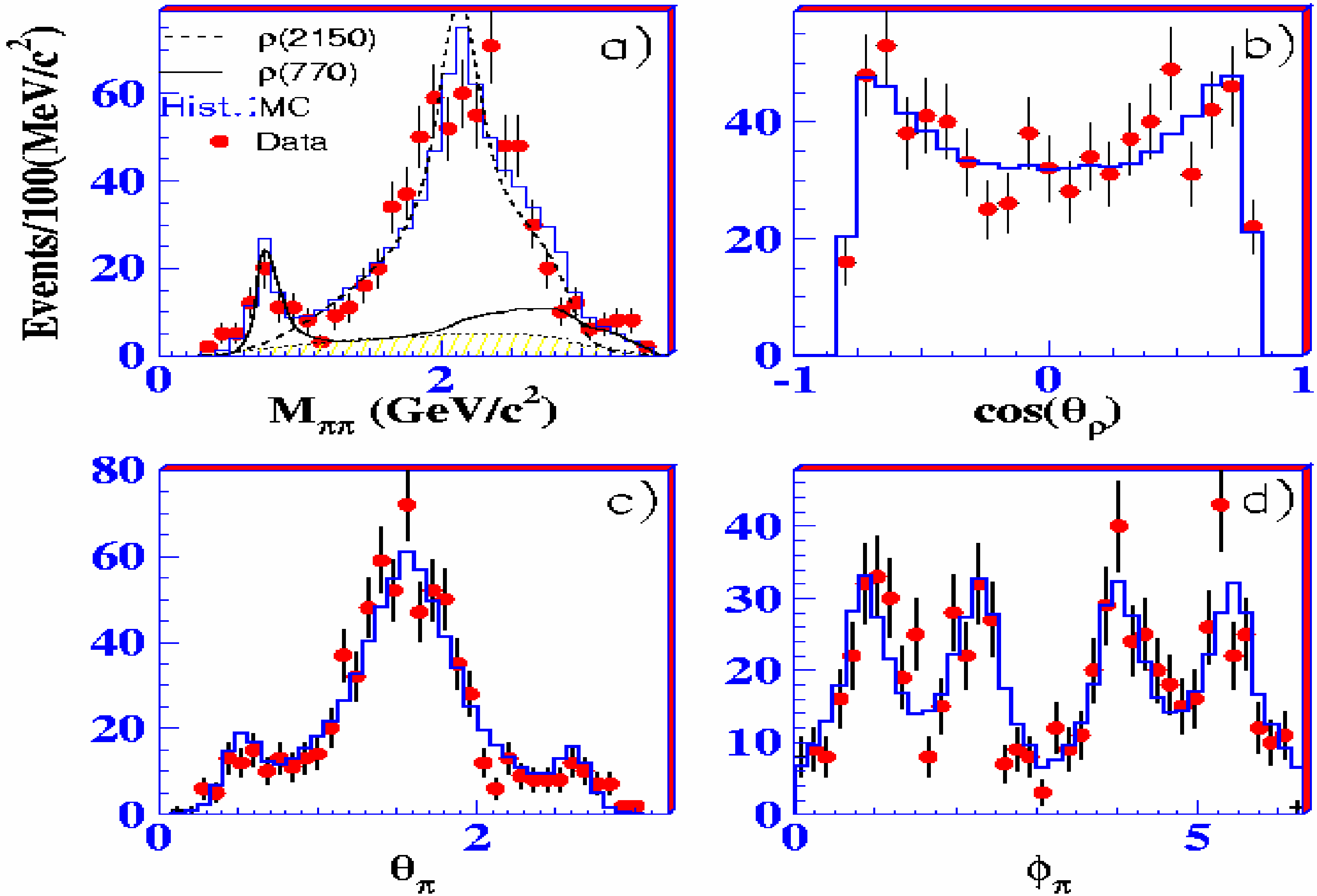
EXP	$B(\psi' \to \rho\,\pi)$ $(\times 10^{-5})$	Q ($\rho\,\pi$) (%)	$B(\psi' \to K^+K^{*-}$ +cc) $(\times 10^{-5})$	Q (K^+K^{*-}) (%)
MK II	< 8.3	< 0.65	< 5.4	< 1.1
BES I *	< 2.9	< 0.23	< 3.2	< 0.64
BES II	**5.1 ±0.6 ± 0.7****	**0.40 ±0.08****	**2.9 ± 1.4 ± 0.4**	**0.58 ±0.29**

* Y.S.Zhu, Proc. Ichep 96, p.507

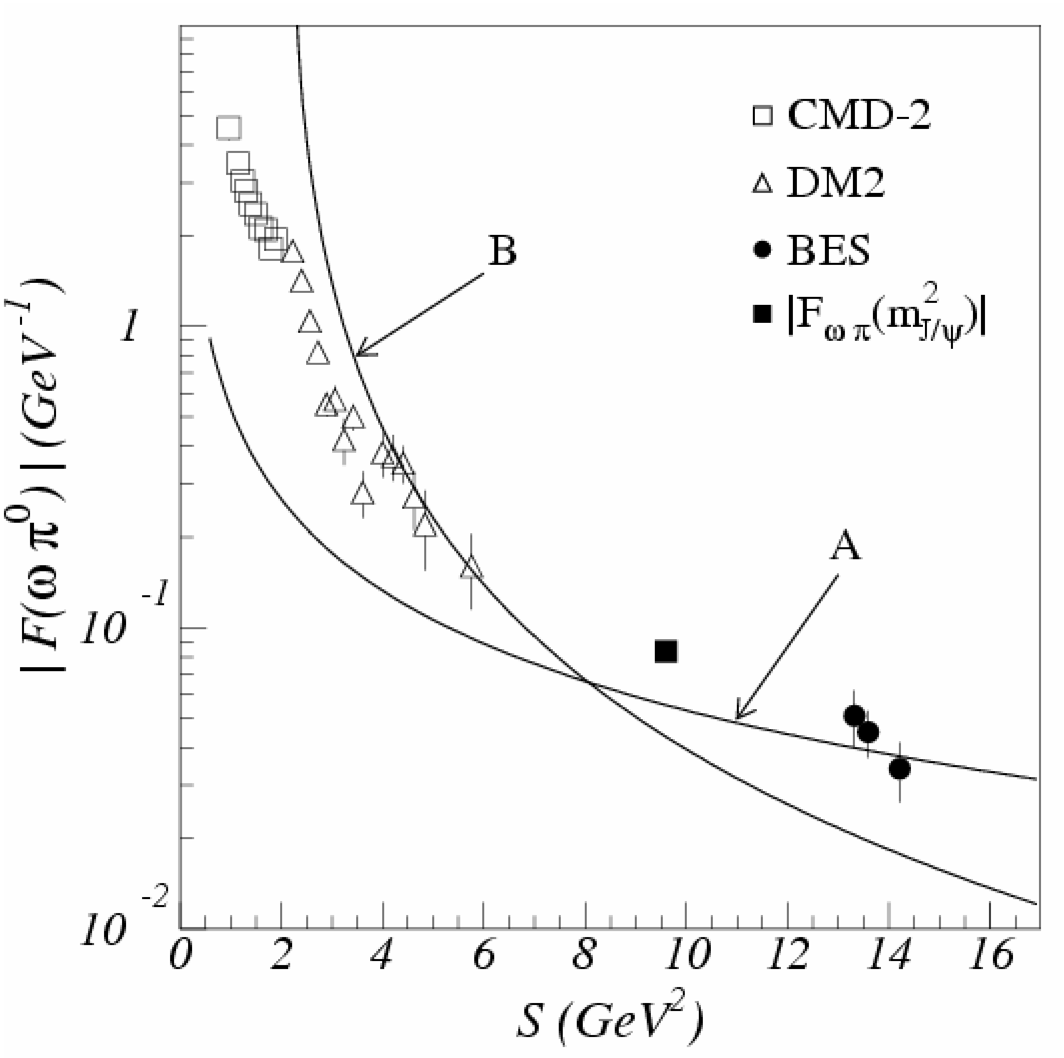
** BES II . PWA takes into account $\rho(770)$, excited ρ states & their interferencies.

VP Mode (Con't)

ρ π (Con't)



EM Process: $\omega\pi^0, \rho\eta, \rho\eta'$ at Ecm=3650,3686,3773 MeV



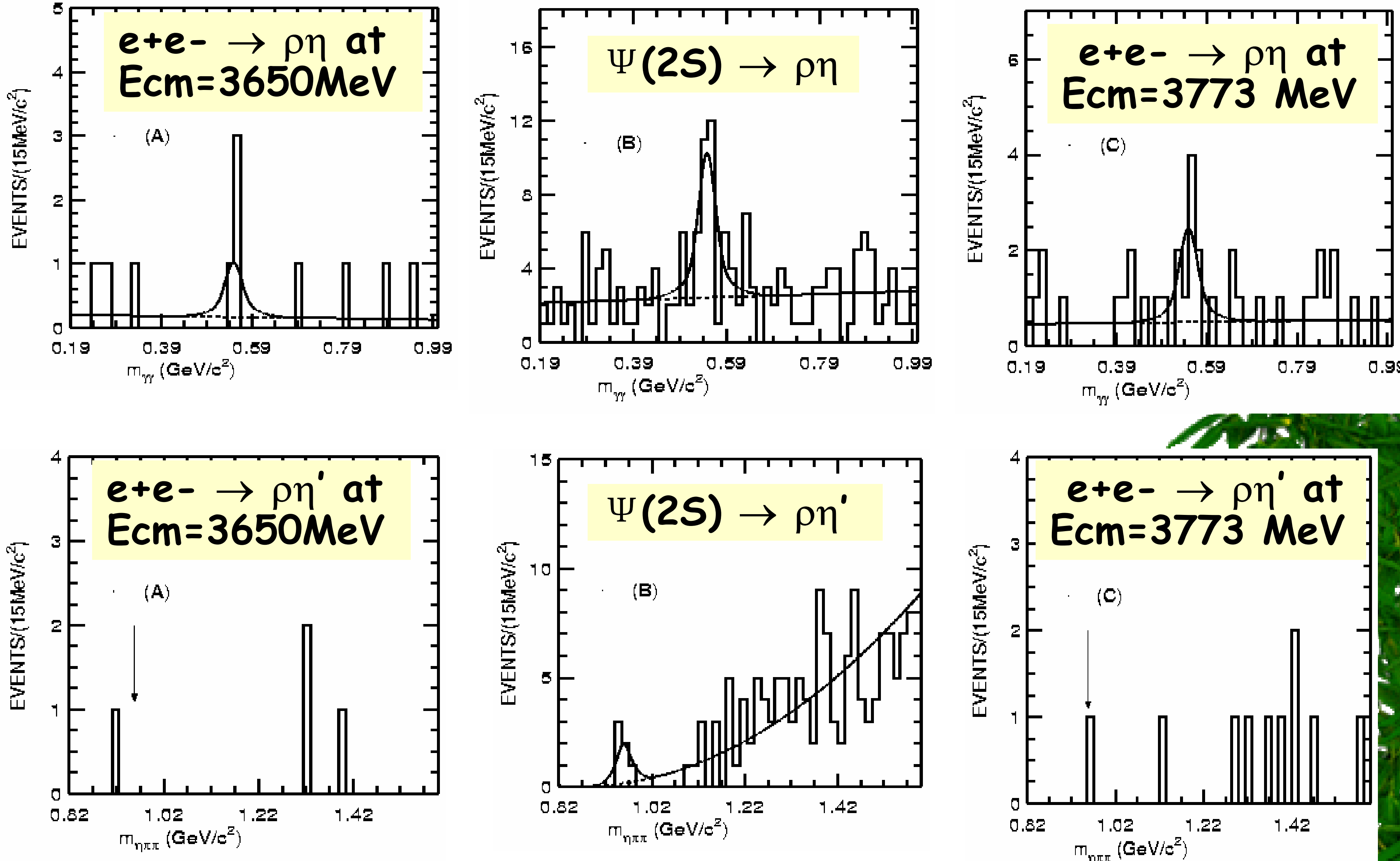
Form factor for $\Psi(2S) \rightarrow \omega\pi^0$

Curve A -- J.Gerard, PLB425(1998)365
$F(\omega\pi^0) \sim 1/S$

Curve B –V.Chernyak, hep-ph/9906387
$F(\omega\pi^0) \sim 1/S^2$

EM Process: $\omega\pi^0, \rho\eta, \rho\eta'$

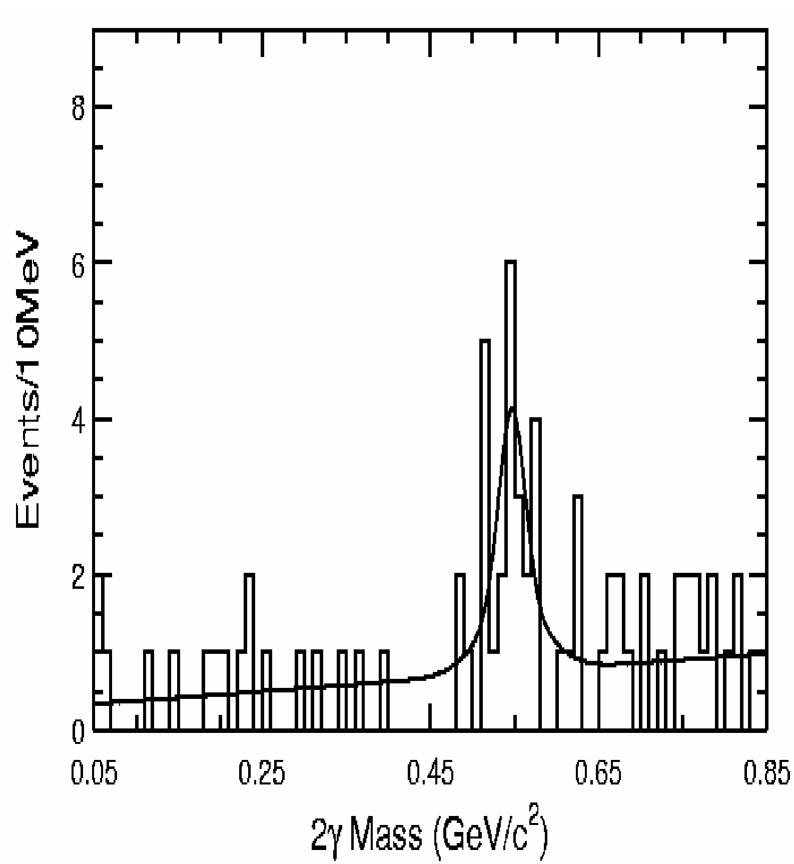
at Ecm=3650,3686,3773 MeV



Other VP Channels

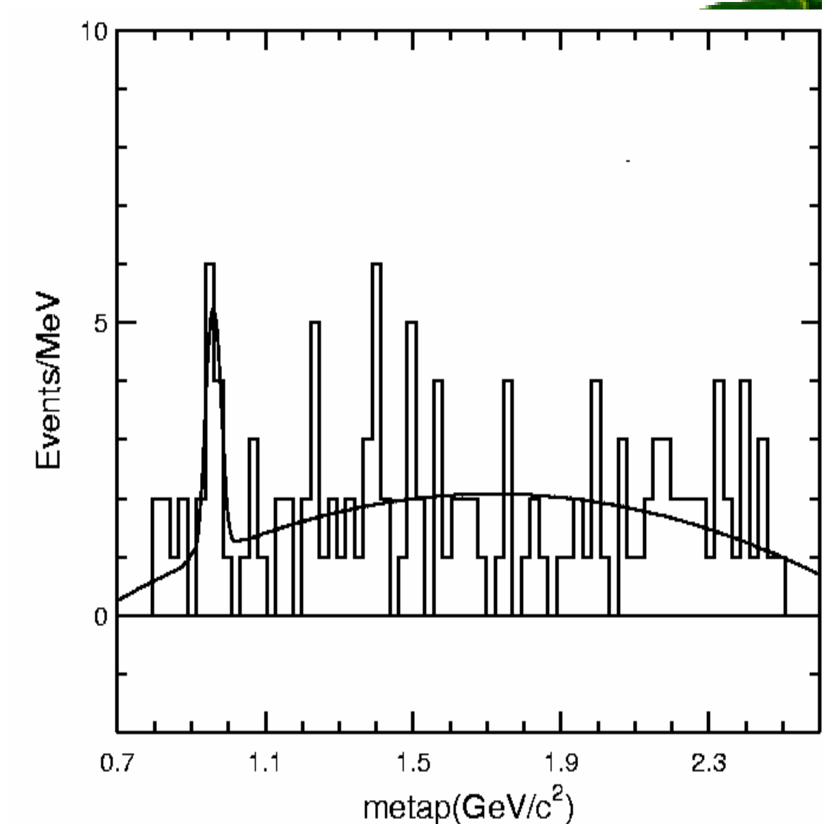
$\Psi(2S) \rightarrow \varphi\eta$

{ $\Psi(2S) \rightarrow \varphi\, \pi^0$ not seen }



$\Psi(2S) \rightarrow \varphi\eta'$

($\eta' \rightarrow \pi^+\pi^-\eta,\ \pi^+\pi^-\gamma$)

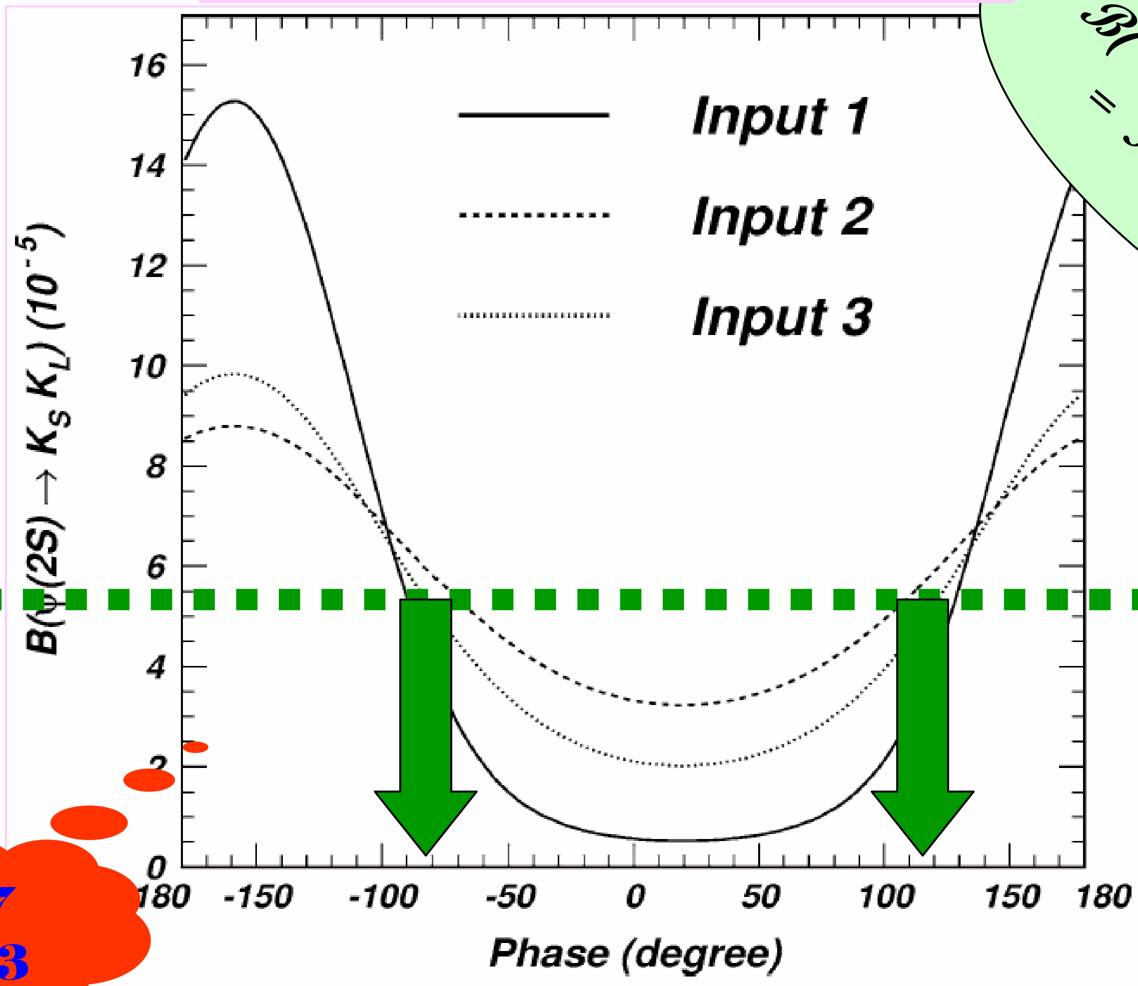


PP Mode (Con't)

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

Phase between strong and EM amplitude

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



$\mathcal{B}(\psi(2S) \to K_S K_L) = 5.24 \times 10^{-5}$

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$-(82 \pm 29)^\circ$ $(121 \pm 27)^\circ$

VT Mode

BES-II

$$B_{\psi' \to X} = \frac{n^{obs}_{\psi' \to X \to Y}}{N_{\psi'} \cdot B_{X \to Y} \cdot \varepsilon^{MC}}$$

VT mode	$B_{\psi' \to X}$ (10^{-4}) (BES-II)	$B_{J/\psi \to X}$ (10^{-3}) (PDG2004)	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

Suppressed!!

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