Test of pQCD 12% Rule at BES

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OUTLINE

- Introduction
- $\psi(2S) \rightarrow VP$
- $\psi(2S) \rightarrow VT$
- $J/\psi, \psi(2S) \rightarrow PP$
- Summary

INTRODUCTION

pQCD 12% rule:

T. Appelquist & H.D. Politzer, PRL 34 (1975) 43

A. De Rujula & S.L. Glashow, PRL 34 (1975) 46

☛ **For J/ψ and ψ(2S) inclusive decays to hadrons via 3 gluons, the ratio of ψ(2S) and J/ψ BRs is**

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

ρπ puzzle:

- **Suppression in VP mode (ρπ & $K^*\bar{K}$ + c.c.) revealed by MARK-II** M.E.B. Franklin et al, PRL 51 (1983) 963

$$Q_{\rho\pi} < 0.6\%,\ Q_{K^*(892)\bar{K}} < 2\%$$

- **Suppression confirmed by BESI with higher sensetivity**

Y.S. Zhu, Proc. of ichep '96, p.507

$$Q_{\rho\pi} < 0.23\%, Q_{K^*(892)\bar{K}} < 0.64\%$$

- **Suppression in VT mode found by BESI**

J.Z. Bai et al, PRL 81 (1998) 5080

$Q(\omega f_2) < 4.0\%$, $Q(\rho a_2) < 2.1\%$, $Q(K^*K^*_2) < 1.8\%$, $Q(\phi f_2') < 3.7\%$

Observation of VP final states from ψ(2S) decays by CLEO-c N.E. Adam et al, hep-ex/0407027

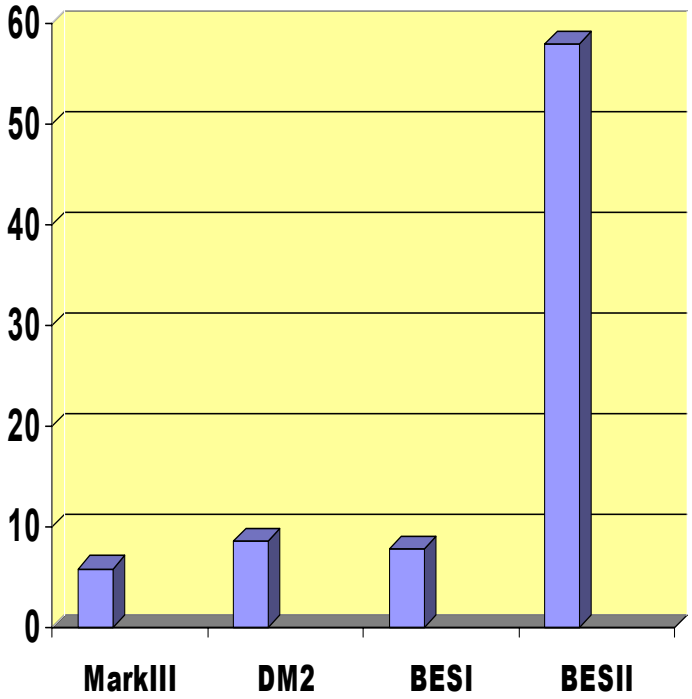
Theoretical explanations:

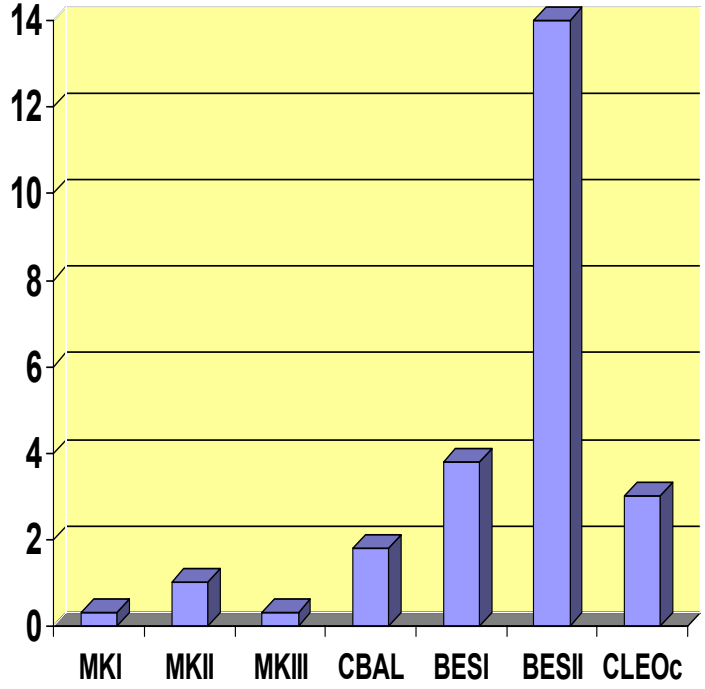
- **Brodsky, Lepage, Tuan** PRL 59 (1987) 621 **Intermediate vector glueball**
- **Chaichian & Tornqvist** NP B323 (1989) 75 **Hadronic form factor**
- **Pinsky** PL B236 (1990) 479 **Generalized hindered M1 transition**
- **Li-Bugg-Zou** PR D55 (1997) 1421 **Final-state interaction**
- **Brodsky-Karliner** PRL 78 (1997) 4682

  Intrinsic charm |qqcc> Fock components of the light vector mesons
- **Chen-Braaten** PRL 80 (1998) 5060 **Fock state with $c\bar{c}$ pair in a color-octet**
- **Gerard-Weyers** PL B462 (1999) 324 **cc annihilation into 5g via 2 steps**
- **Feldmann-Kroll** PR D62 (2000) 074006

  Decays thru light-quark Fock component by a soft mechanism
- **Suzuki** PR D63 (2001) 054021 **ψ(2S) - vector glueball mixing**
- **Rosner** PR D64 (2001) 094002 **ψ(2S) - ψ(1D) mixing**
- **J. P. Ma** PR D65 (2002) 097506 **Relativistic Correction**

World J/ψ and ψ(2S) Samples (×10⁶)





Measure the BRs of ψ(2S) & corresponding Q_h values

for 10 VP channels, 4 VT channels, 1 PP channel,

to test pQCD 12% rule.

1. VP Mode

- **BRs for $\psi(2S) \to (\rho,\omega,\varphi)\,(\pi,\eta,\eta')$, $K^*\bar{K}$ + c.c.**

  measured

- **PWA for $\psi(2S) \to \pi^+\pi^-\pi^0$**

- **Background from continuum considered**

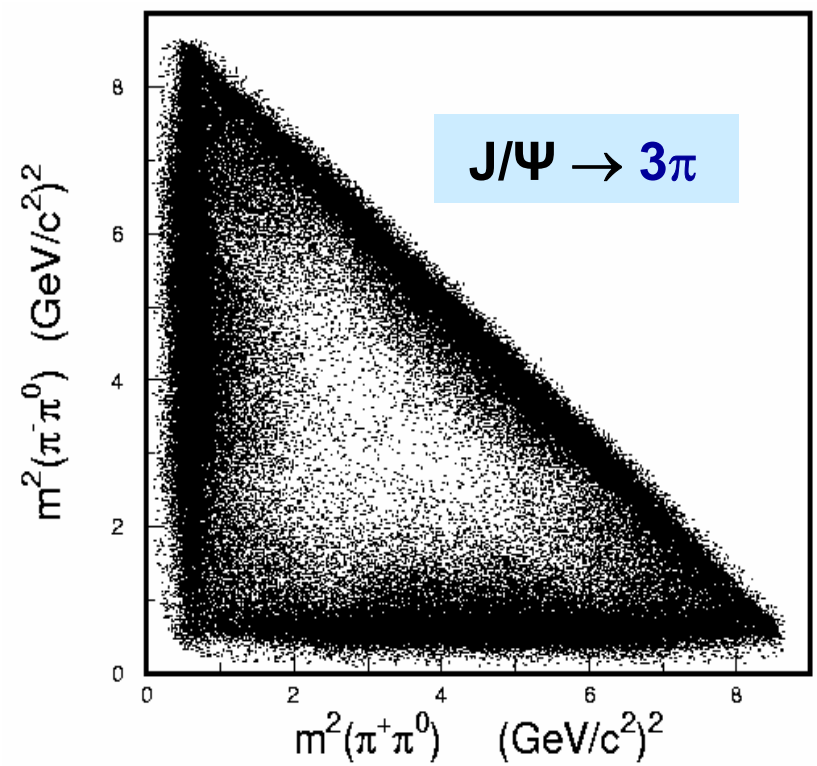
  using Ecm = 3.65 GeV data sample

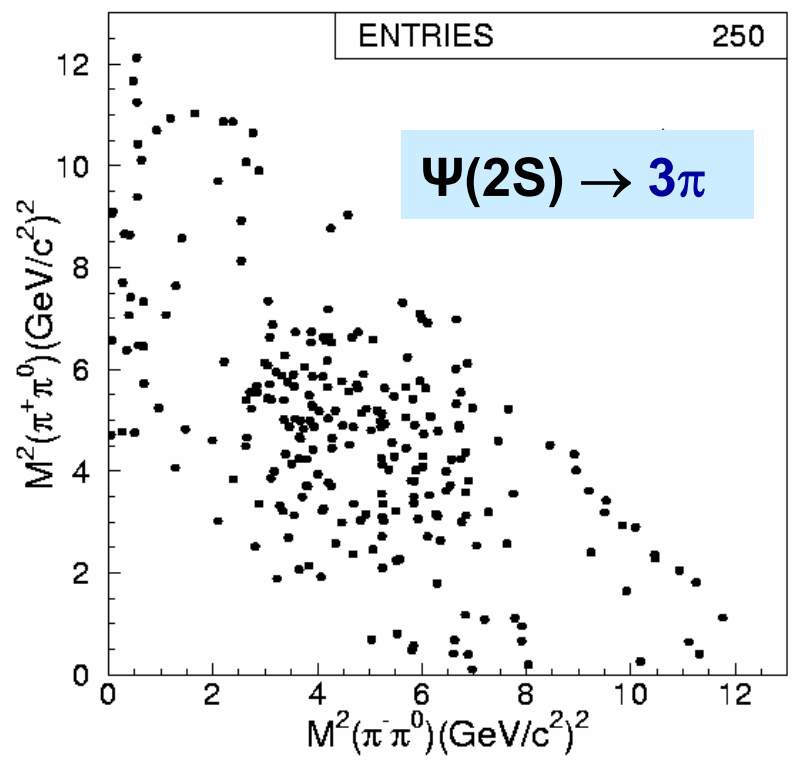
  (luminosity ~ 1/3 of $\psi(2S)$ sample)

1.1 ρπ

hep-ex/0408047 submitted to PRL

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





PRD70 (2004) 012005

BESII Preliminary

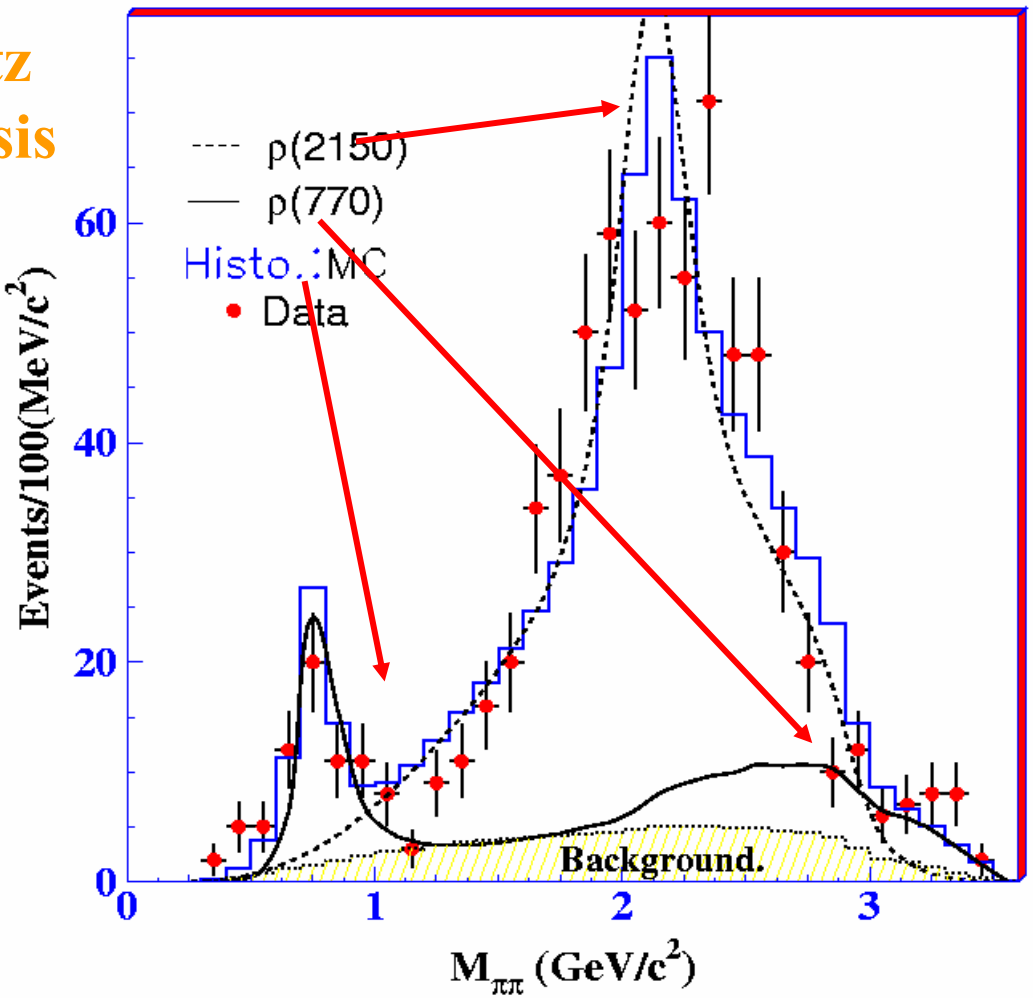
BESII Preliminary
(PWA)

Mππ in ψ(2S) → 3π

ρ(770), ρ(2150) — dominant

from Dalitz plot analysis

⇒



BESII Preliminary
(PWA)

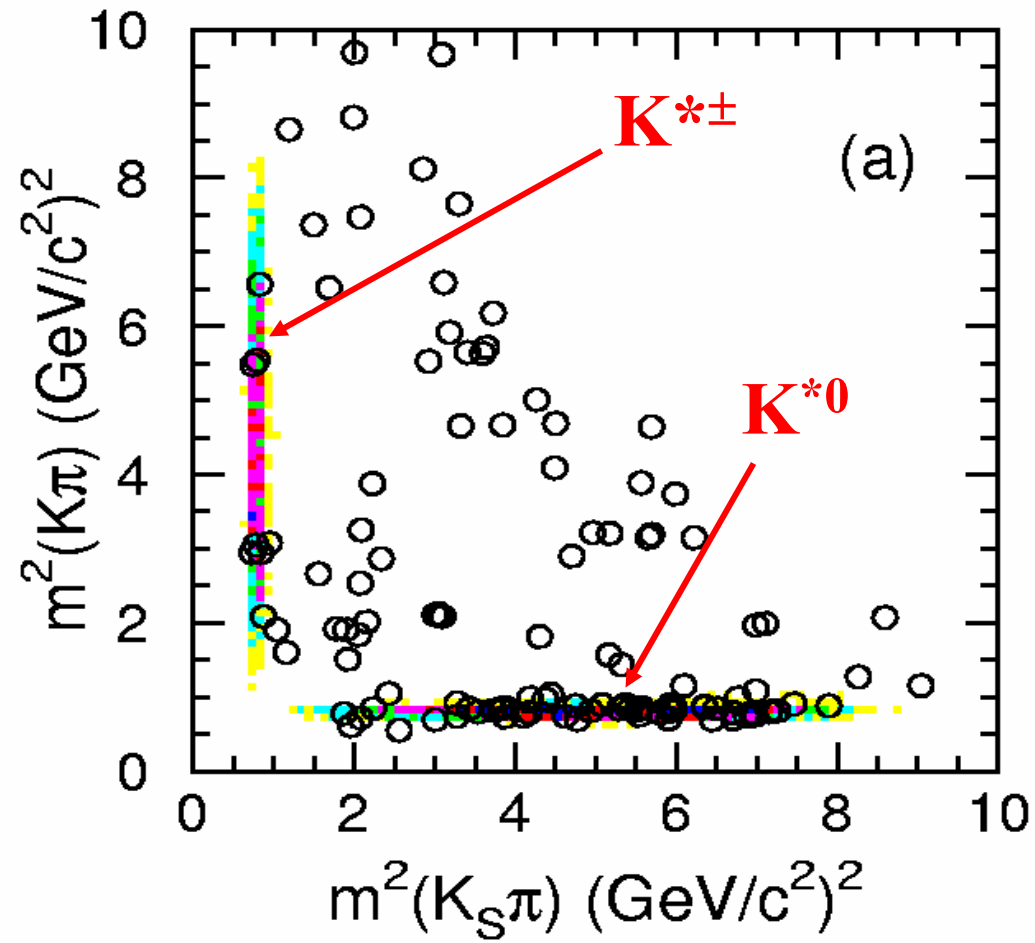
Results on BRs

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

- **1st measurement or precision much improved**
- **Interference taken into account between the two peaks**

1.2 K*(892)K

Dalitz plot in
$\psi(2S) \rightarrow K_S K\pi \rightarrow K^*(892)K$



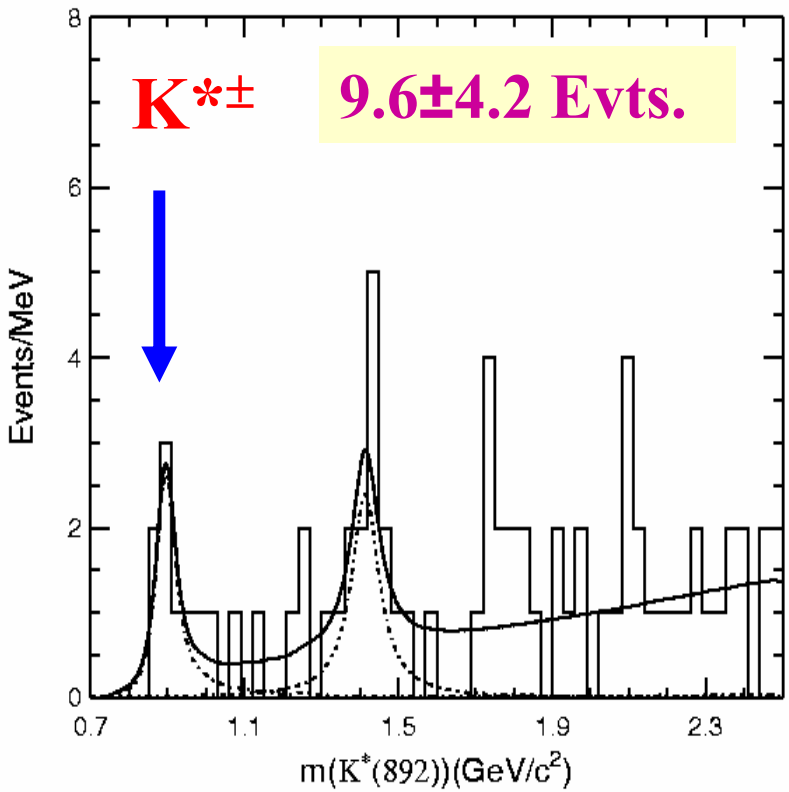
hep-ex/0407037 submitted to PRL

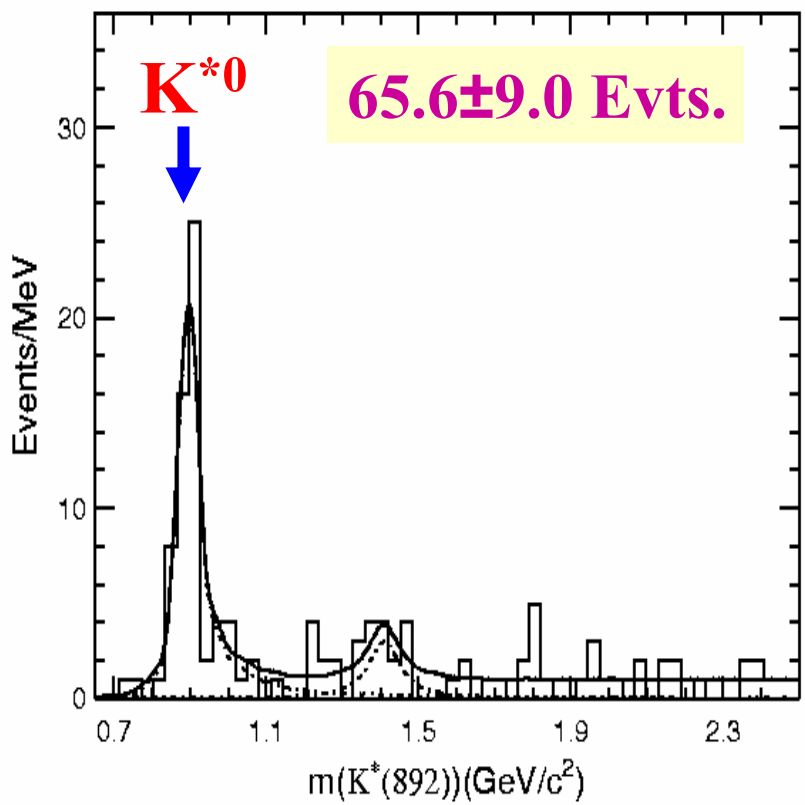
$Br_0(15.0\pm2.1\pm1.9)\times10^{-5}$

$Br_{\pm}(2.9\pm1.3\pm0.4)\times10^{-5}$

$\psi(2S) \to K^{\mp}K^*(892)^{\pm}$

$\psi(2S) \to \bar{K}^0 K^*(892)^0$



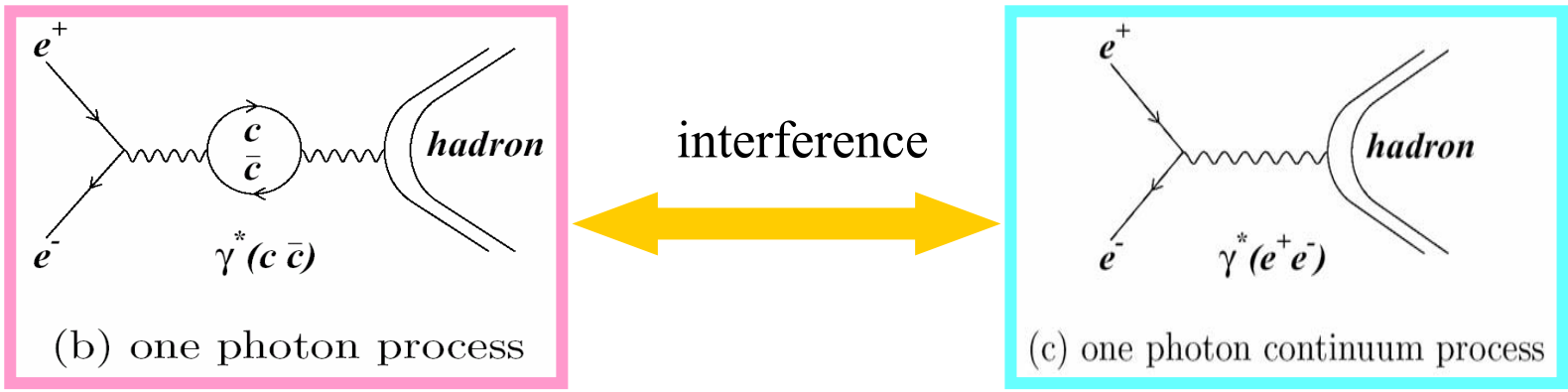


$$\frac{\mathcal{B}(K^*(892)^0\bar{K}^0+c.c.)}{\mathcal{B}(K^*(892)^{\pm}\bar{K}^{\mp}+c.c.)} = 5.2\pm2.7$$

isospin-violation

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

at Ecm=3650,3686,3773 MeV



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

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

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

$F_{vp}(s)$ – form factor ; ξ=1, 0.672, 0.325 for $\omega\pi^0$, $\rho\eta$, $\rho\eta'$.

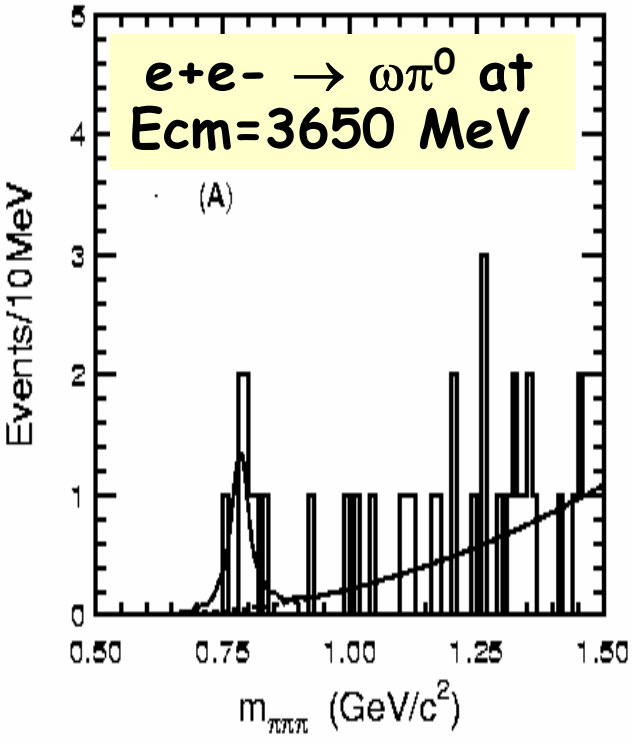
- **For EM processes at $\Psi(2S) \to$ (VP) $\omega\pi^0$, $\rho\eta$, $\rho\eta'$**

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

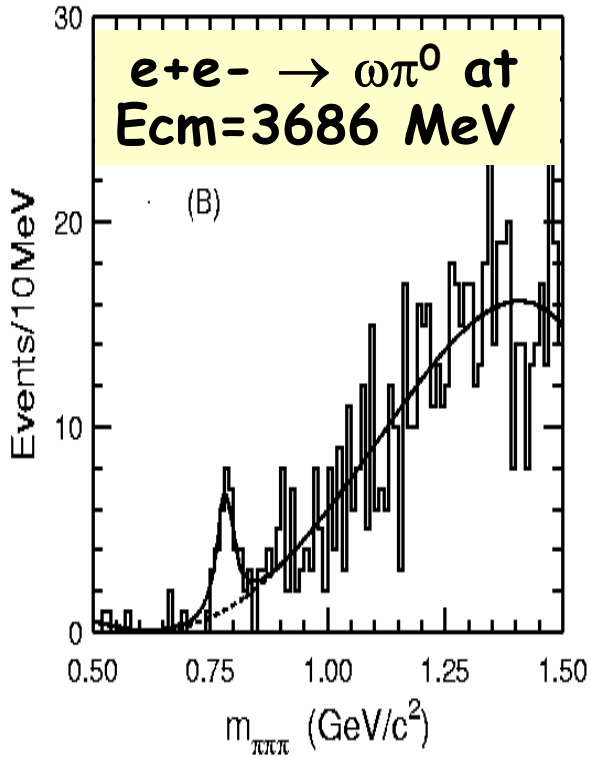
- **BRs & $F_{vp}(M_{\psi(2S)})$ obtained simultaneously**

BESII Preliminary

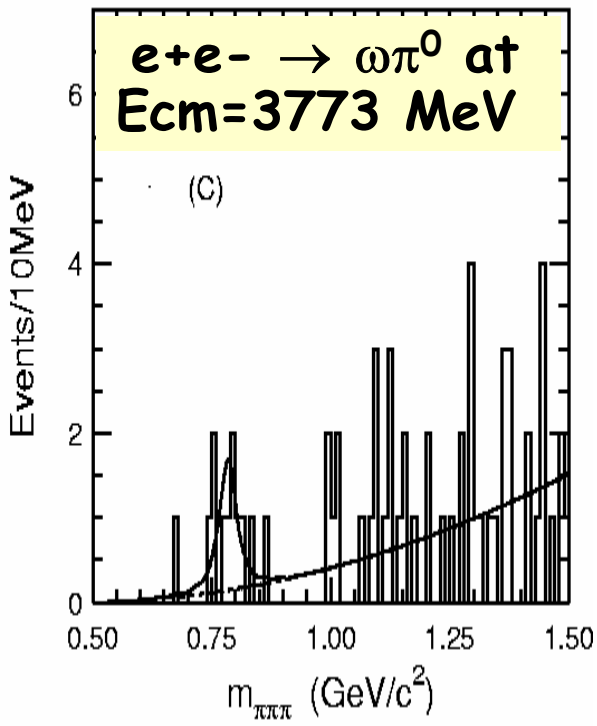
continuum



ψ'



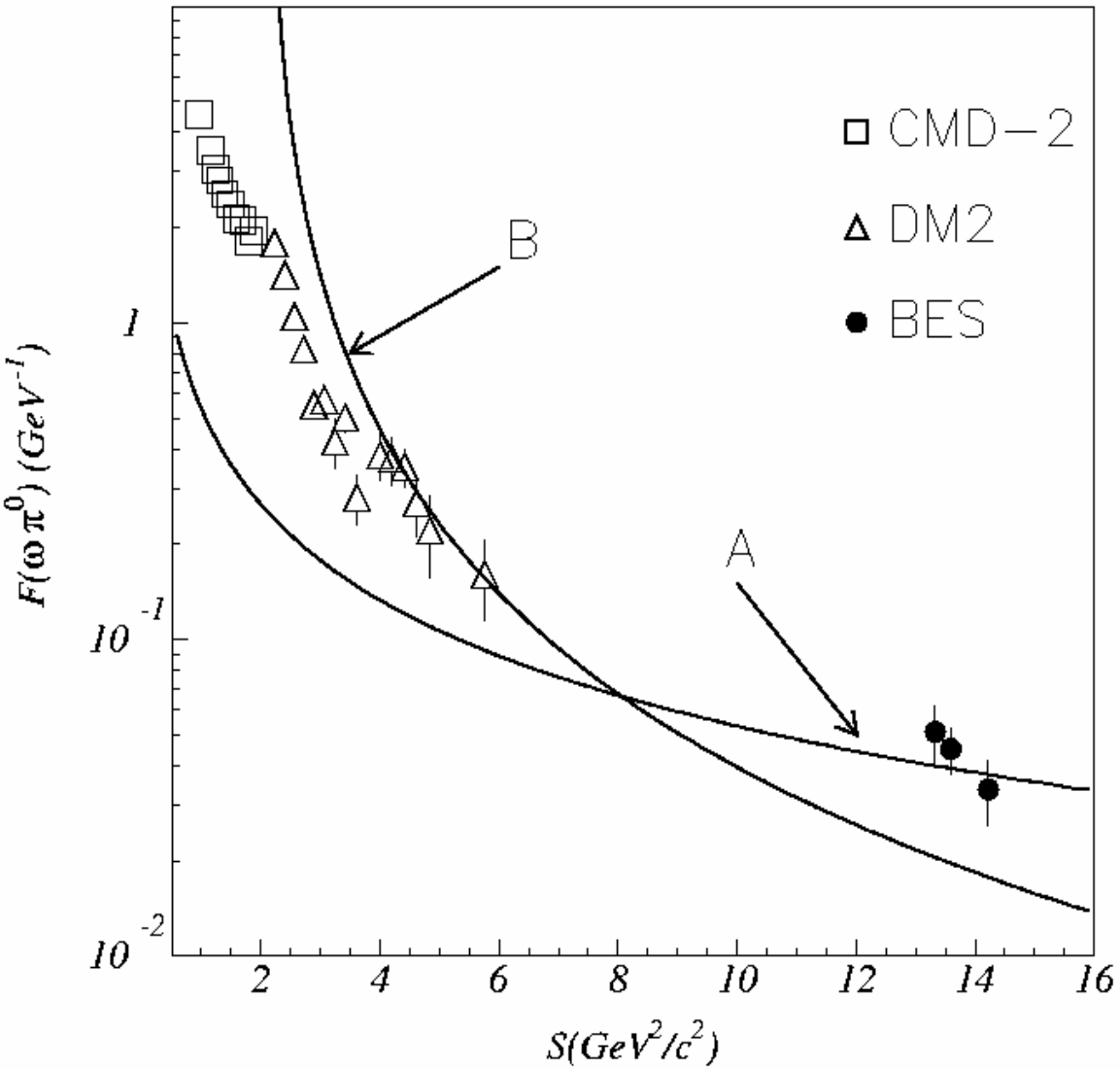
ψ''



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

BESII Preliminary

State	Ecm(GeV)	σ_{Born}(pb)	$\lvert F_{vp}\rvert$(GeV^{-1})	$B_{\psi(2S)\rightarrow VP}(\times 10^{-5})$
$\omega\pi^0$	3.650	$24.3 \pm 9.3 \pm 4.7$	0.051±0.011	1.88±0.64±0.32
	3.686	$19.1 \pm 5.9 \pm 3.2$	0.045±0.008	
	3.773	$10.7 \pm 4.6 \pm 1.9$	0.034±0.008	
$\rho\eta$	3.650	$8.1 \pm 6.3 \pm 1.2$	0.036±0.014	1.78±0.65±0.22
	3.686	$18.4 \pm 6.1 \pm 2.3$	0.054±0.010	
	3.773	$7.8 \pm 3.9 \pm 1.0$	0.035±0.009	
$\rho\eta'$	3.650	< 110	< 0.19	1.87±1.27±0.36
	3.686	$19 \pm 12 \pm 4$	0.078±0.025	
	3.773	< 39	< 0.11	



BESII Preliminary

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

$F(\omega\pi^0) \sim 1/S^2$

1.4 Results of VP mode

Upper limit @90% C.L. * Preliminary

$\psi(2S) \to$	Nevt	$B(\psi(2S))$ $(\times 10^{-5})$	$B(J/\psi)$ $(\times 10^{-4})$ PDG04	Q_h (%)
$\rho(770)\pi$		**$5.1 \pm 0.7 \pm 0.8$**	127 ± 9	**0.40 ± 0.08**
$\rho(2150)\pi$		$.4 \pm 2.5^{+11.2}_{-2.1}$		
$\rho\eta$	13.2 ± 4.8	**$1.78 \pm 0.65 \pm 0.22$**	1.93 ± 0.23	**9.2 ± 3.7**
$\rho\eta'$	2.5 ± 1.7	**$1.87 \pm 1.27 \pm 0.36$**	1.05 ± 0.18	**17.8 ± 12.9**
$\omega\pi$	14.0 ± 4.8	**$1.88 \pm 0.64 \pm 0.32$**	4.2 ± 0.6	**4.5 ± 1.8**
$\omega\eta$	< 3.3	**< 1.1**	15.8 ± 1.6	**< 0.7**
$\omega\eta'$	4.2 ± 3.3	**$3.1 \pm 2.4 \pm 0.7$**	1.67 ± 0.25	**19 ± 16**
$\varphi\pi$	< 3.0	**< 0.3**	< 0.068	
$\varphi\eta$	17.8 ± 5.3	**$3.5 \pm 1.0 \pm 0.6$**	6.5 ± 0.7	**5.4 ± 1.9**
$\varphi\eta'$	9.1 ± 3.6	**$3.3 \pm 1.3 \pm 0.7$**	3.3 ± 0.4	**10.0 ± 4.6**
$K^+K^{*-}+c.c.$	9.6 ± 4.2	**$2.9 \pm 1.3 \pm 0.4$**	50 ± 4	**0.58 ± 0.25**
$K^0K^{*0}+c.c.$	65.6 ± 9.0	**$15.0 \pm 2.1 \pm 1.9$**	42 ± 4	**3.6 ± 0.8**

2. 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 ± 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

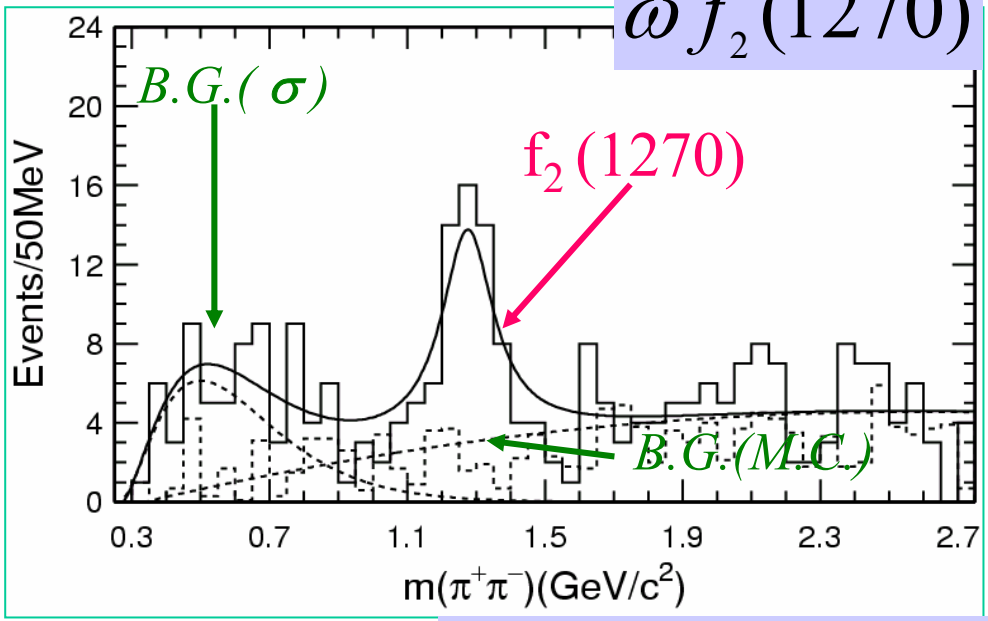
† This value from DM2 only

PR D69 (2004) 072001

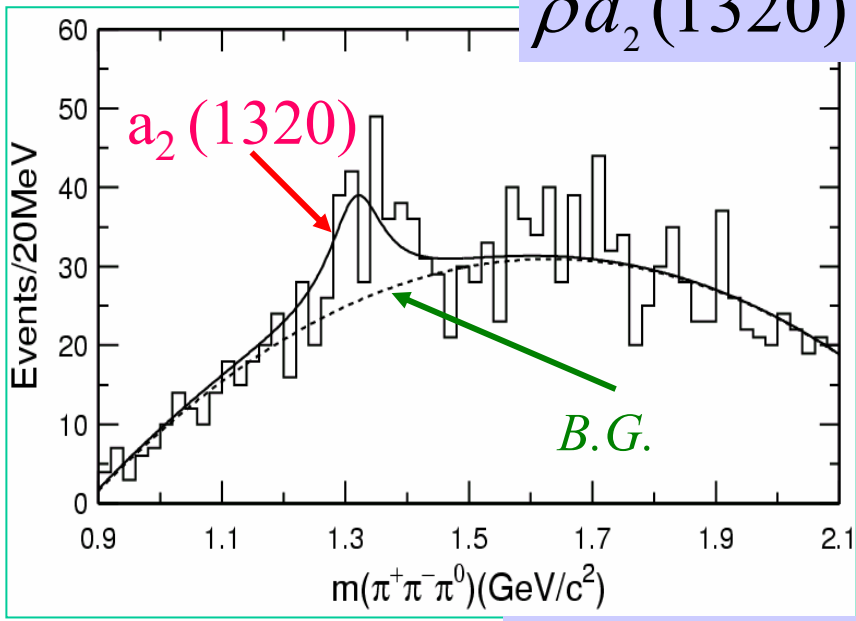
Suppressed!!

BES-II

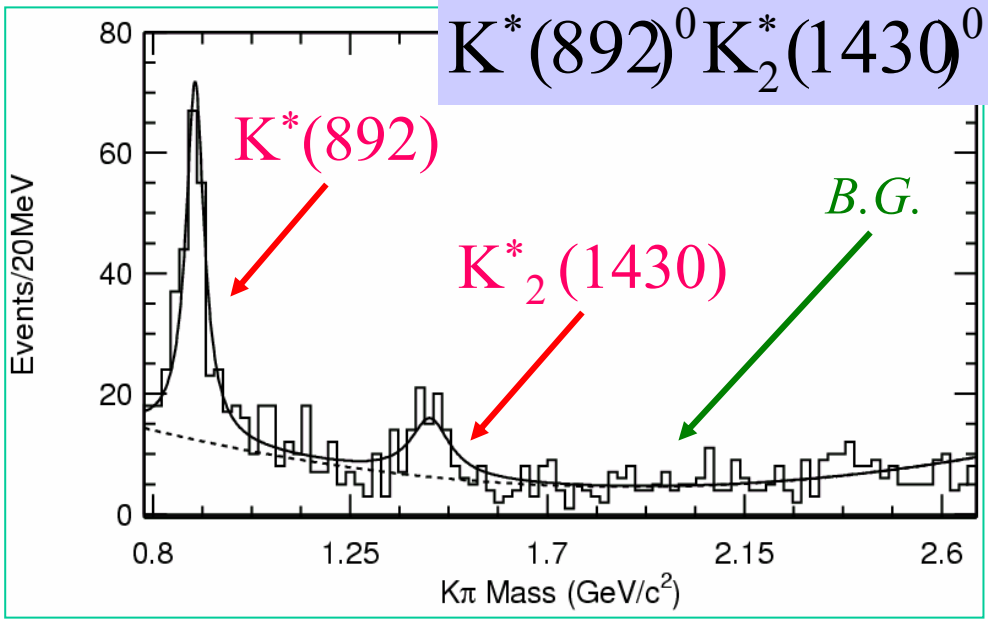
$\omega f_2(1270)$

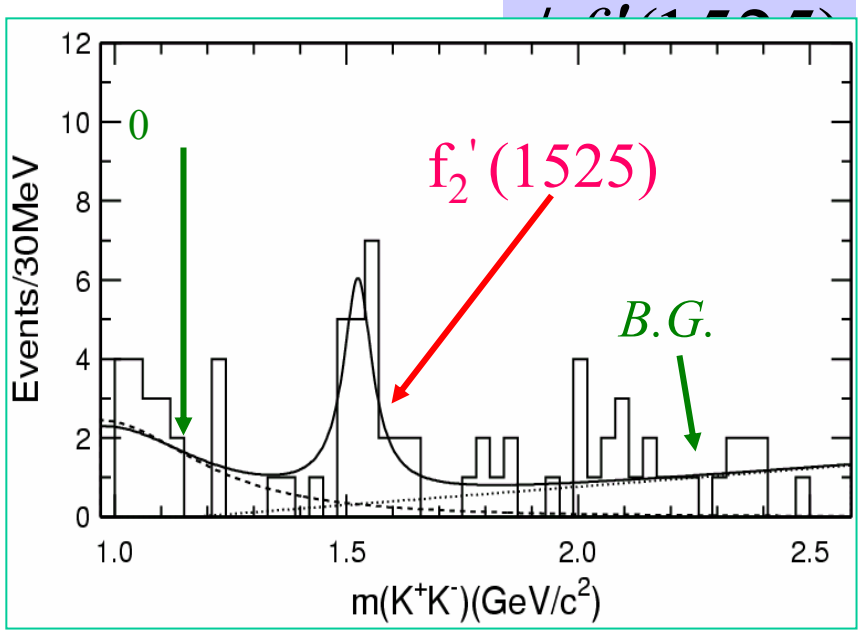


$\rho a_2(1320)$



$K^*(892)^0\overline{K}_2^*(1430)^0$

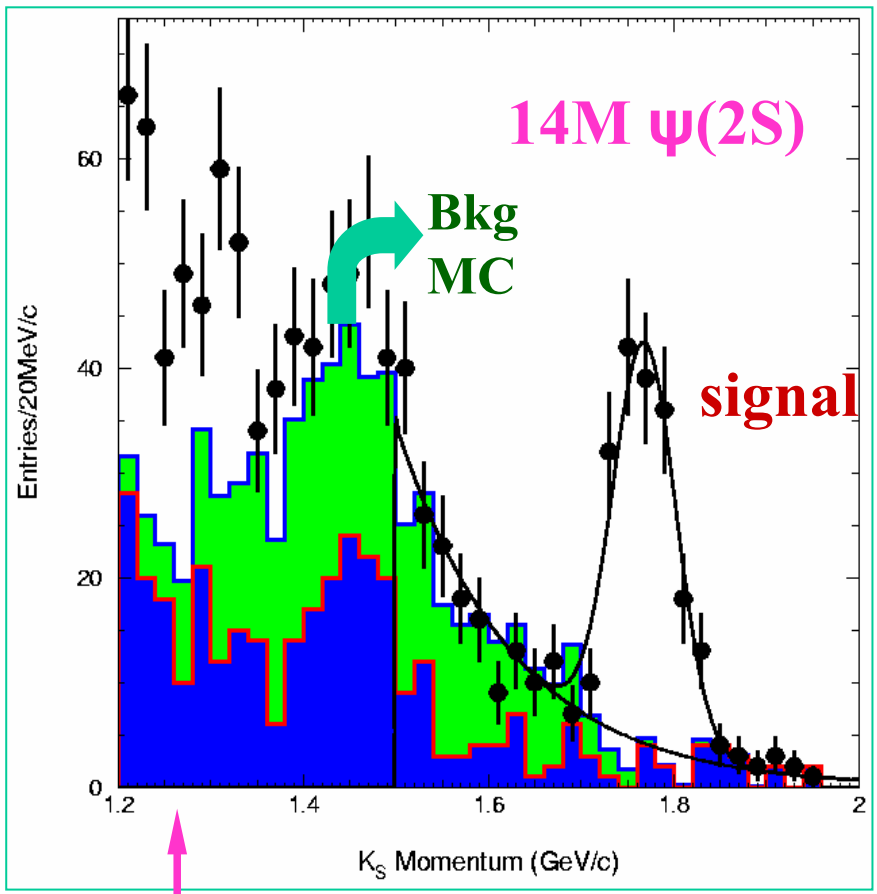


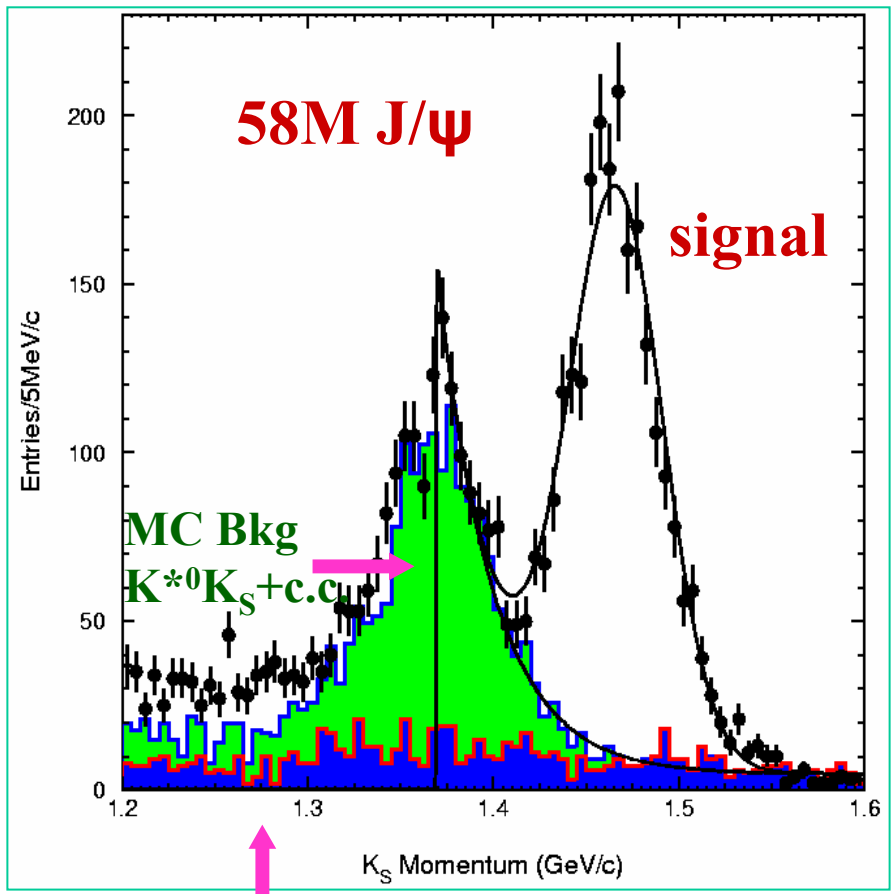


3. PP Mode

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

$J/\Psi \rightarrow K_S K_L$





Ks mass sidebands

Ks mass sidebands

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

1st measurement

PRL92 (2004) 052001

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

Improved Accuracy

PRD69 (2004) 012003

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

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

4σ

B(ψ(2S)) enhanced!

SUMMARY

- **Measurements** for BRs or upper limits of VP channels:

$$\psi(2S) \rightarrow (\rho,\omega,\varphi)(\pi,\eta,\eta'),\ K^*K$$

- Improved measurement for BRs of VT channels:

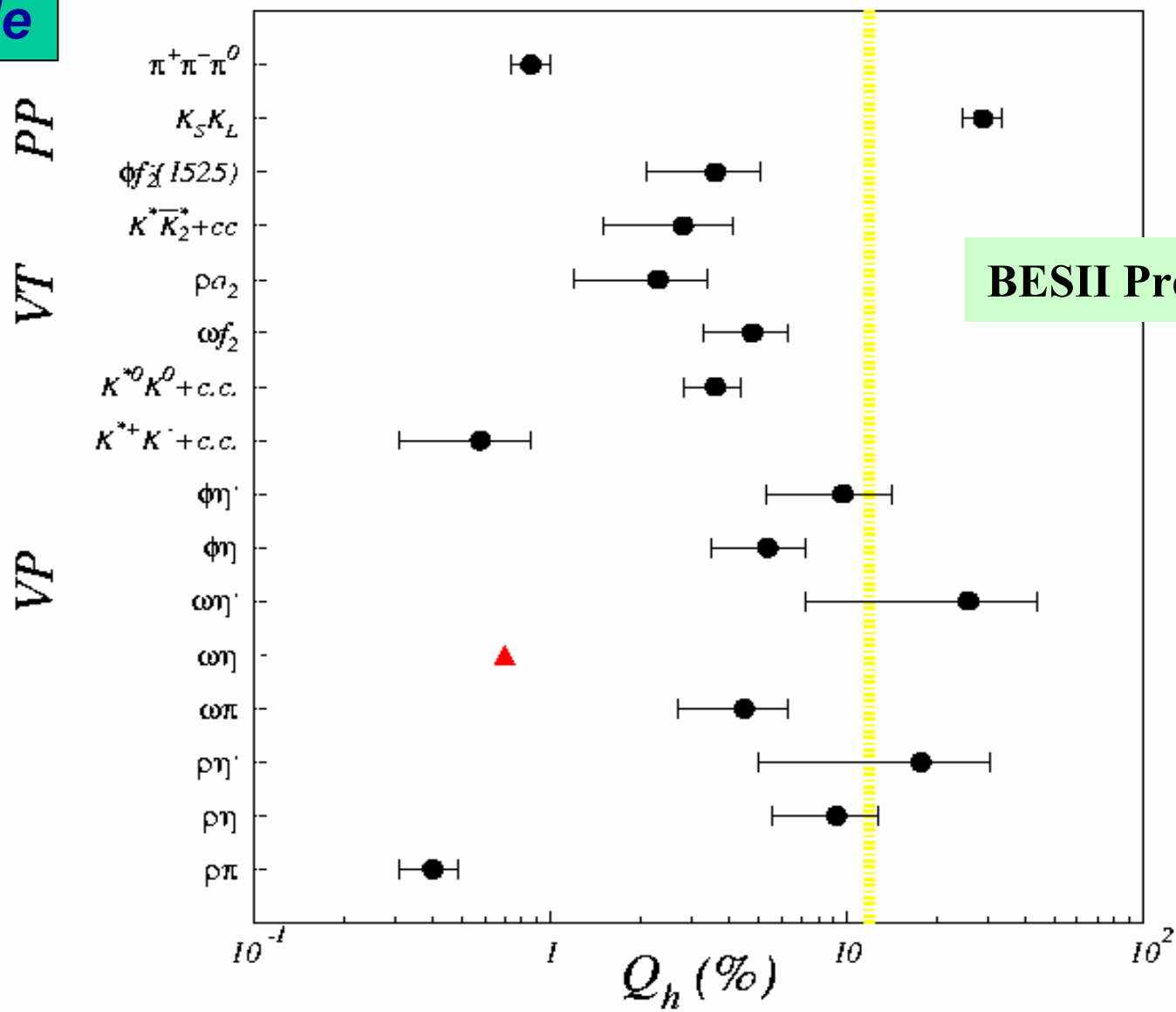
$$\psi(2S) \rightarrow \omega f_2,\ \rho a_2,\ K^*\,K^*_2,\ \varphi f_2'$$

- **First measurement** for BR of $\psi(2S) \rightarrow K_S K_L$.

12% rule tested for all these decay modes.

Test of pQCD 12% Rule

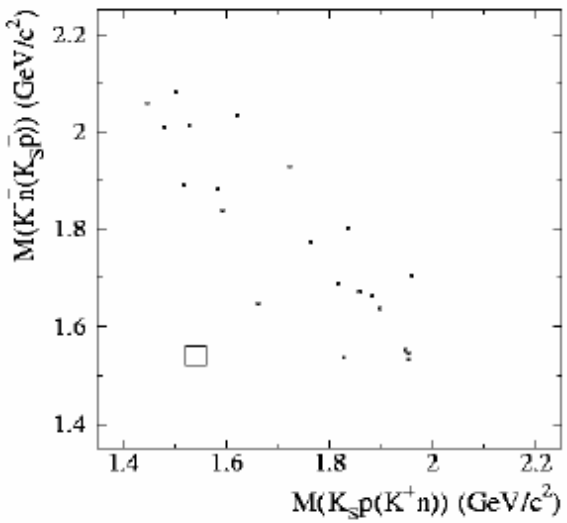
SUMMARY

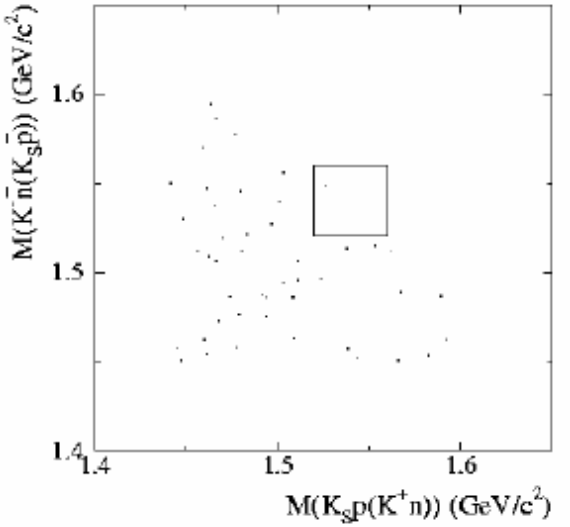


BESII Preliminary

Pentaquark searches at BES

$\Theta^+(1540)$





$\psi(2S)$ J/ψ

No clear pentaquark state $\Theta(1540)$ (or $\overline{\Theta}$) is observed.

Upper limits @ 90% C.L.

PRD 70 (2004) 012004

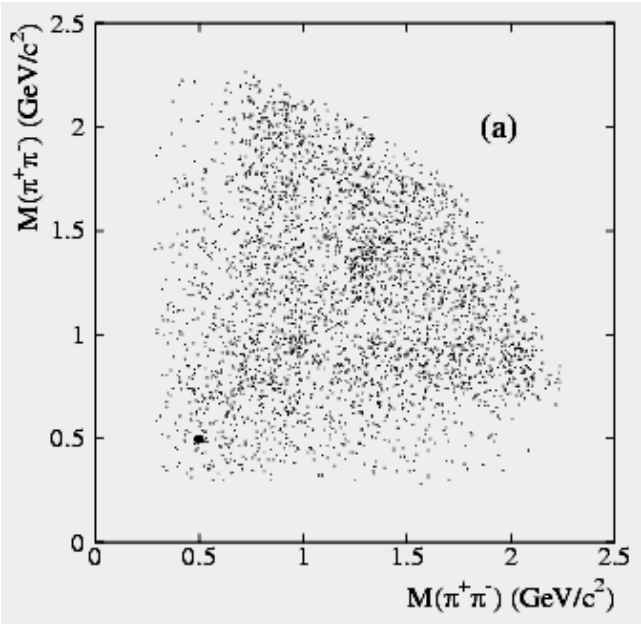
$$\mathcal{B}(\psi(2S) \to \Theta\bar{\Theta} \to K^0_S p K^- \bar{n} + K^0_S \bar{p} K^+ n) < 0.84 \times 10^{-5}$$

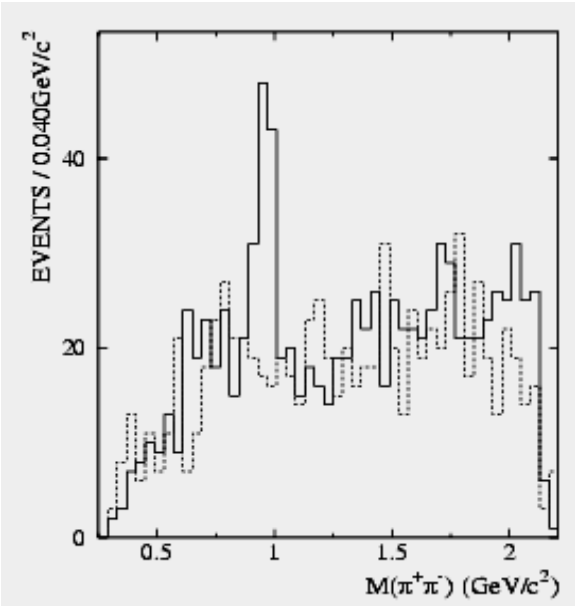
$$\mathcal{B}(J/\psi \to \Theta\bar{\Theta} \to K^0_S p K^- \bar{n} + K^0_S \bar{p} K^+ n) < 1.1 \times 10^{-5}$$

$\chi_{c0} \to f_0(980)f_0(980)$

Study $\psi(2S) \to \gamma\chi_{c0}$ **$f_0(980)$: controversial**

$\to \gamma f_0 f_0 \to \gamma\pi^+\pi^-\pi^+\pi^-$





Plot mass recoiling from f_0

$B(\chi_{c0} \to f_0 f_0 \to \pi^+\pi^-\pi^+\pi^-) = (7.6 \pm 1.9 \pm 1.6) \times 10^{-4}$

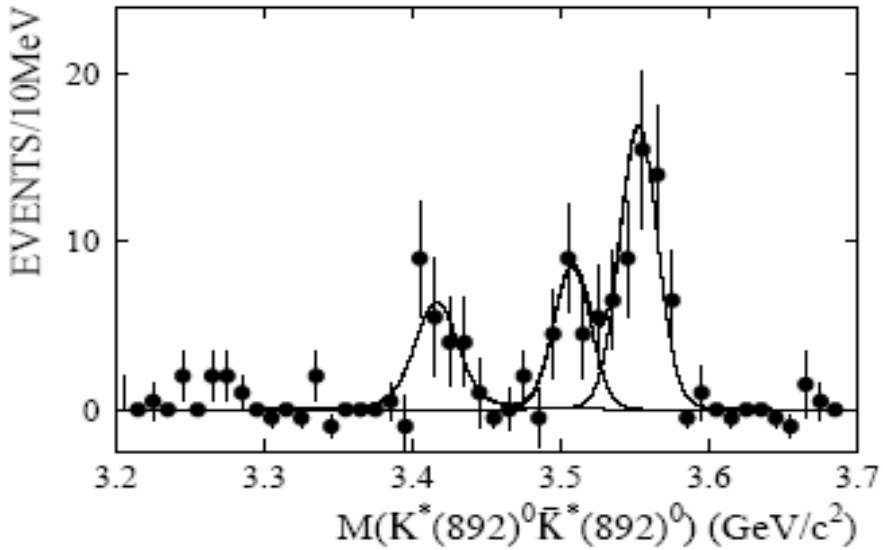
Accepted by PRD, hep-ex/0406079

$\chi_{c0,1,2} \to K^*(892)\bar{K}^*(892)$

Measure more decays to better understand P-wave χ_{cJ} decays.

Study $\psi(2S) \to \gamma\chi_{c0,1,2}$

$\to \gamma K^*\bar{K}^* \to \gamma\pi^+\pi^-K^+K^-$



$$\mathcal{B}(\chi_{c0} \to K^*(892)^0\bar{K}^*(892)^0) = (1.55 \pm 0.35 \pm 0.30) \times 10^{-3},$$

$$\mathcal{B}(\chi_{c1} \to K^*(892)^0\bar{K}^*(892)^0) = (1.58 \pm 0.32 \pm 0.29) \times 10^{-3},$$

$$\mathcal{B}(\chi_{c2} \to K^*(892)^0\bar{K}^*(892)^0) = (4.67 \pm 0.55 \pm 0.85) \times 10^{-3},$$

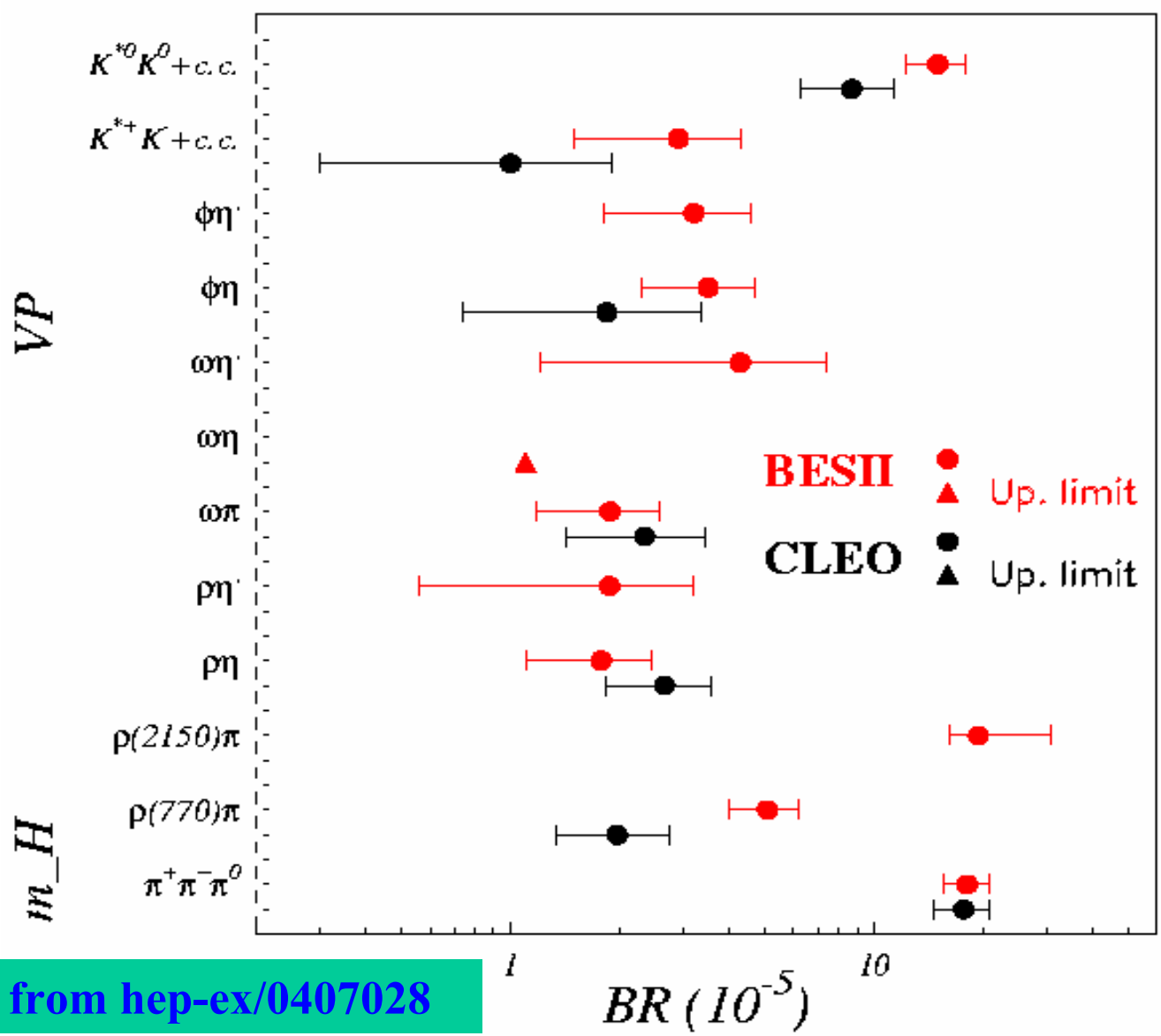
Submitted by PRD, hep-ex/0408012

BESII vs. CLEO (ψ(2S) BRs Results)

BESII Preliminary

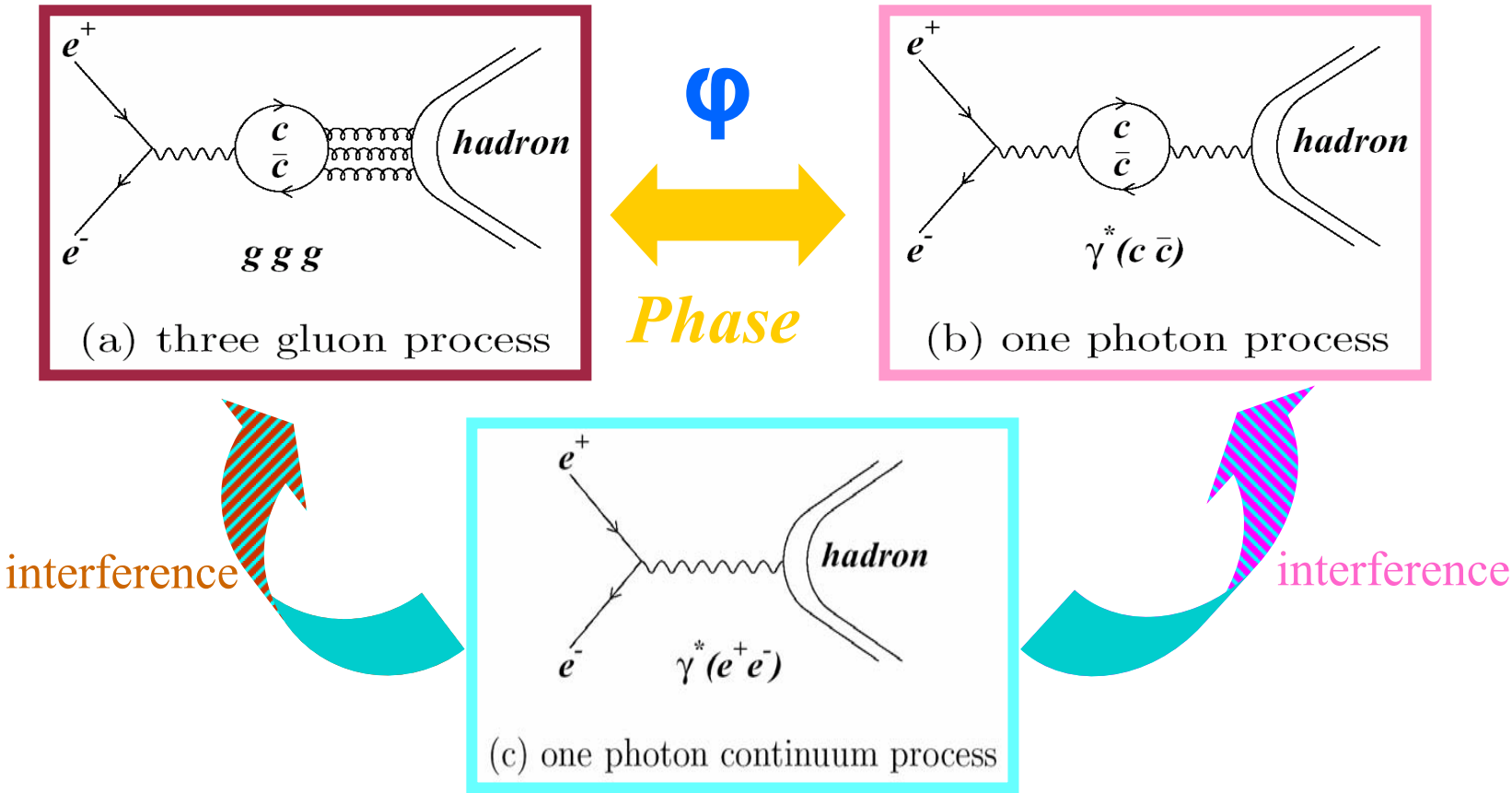
Upper limit @90% C.L.

- **Most channels BRs are consistent.**
- **The data agree well; the treatments of continuum are different.**



CLEO BRs calculated from hep-ex/0407028

The phase and interference in e^+e^- experiment



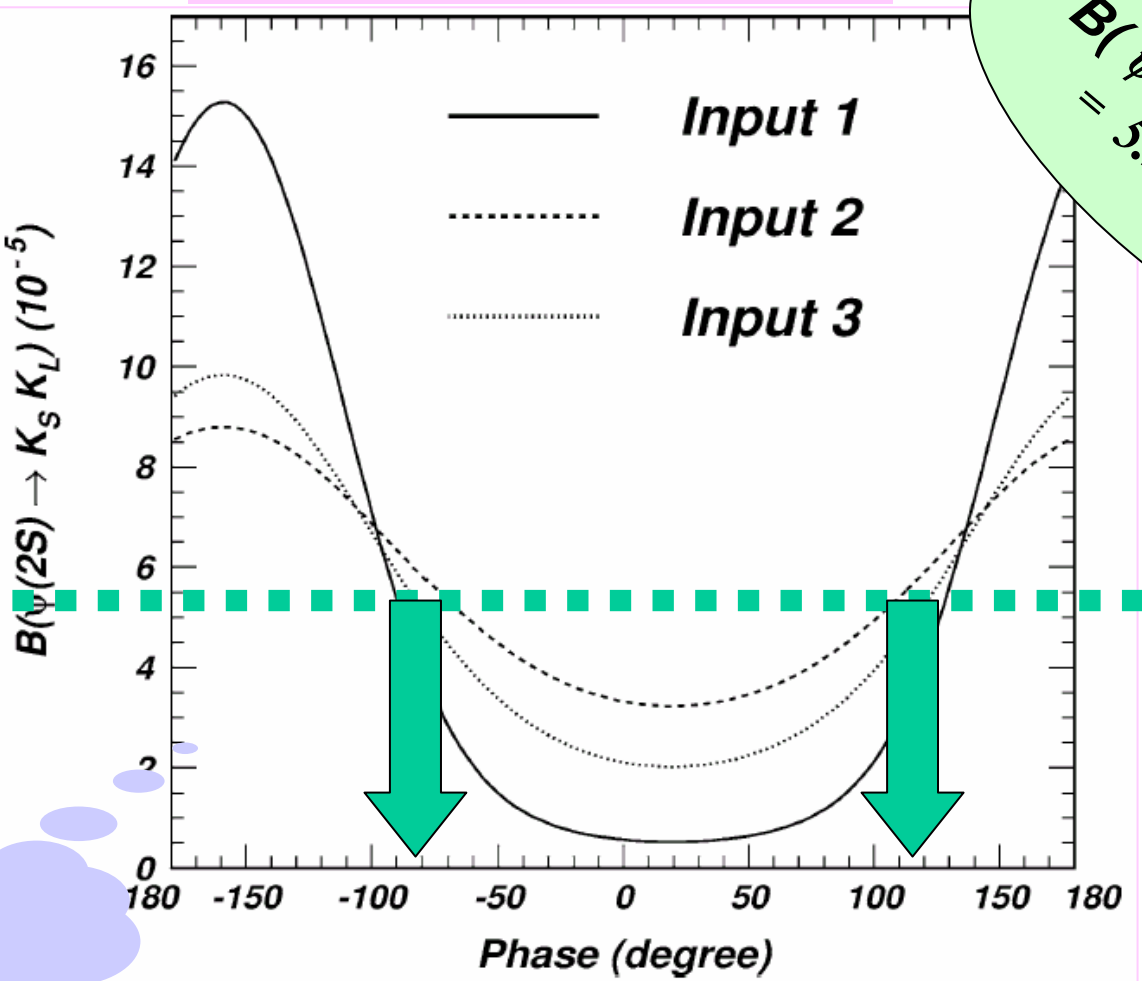
- For decays via strong and EM amplitudes,
  the phase and continuum contribution must be considered.
- For EM decays,
  the continuum contribution must be considered.

3. 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.



$B(\psi(2S) \to K_S K_L) = 5.24\times10^{-5}$

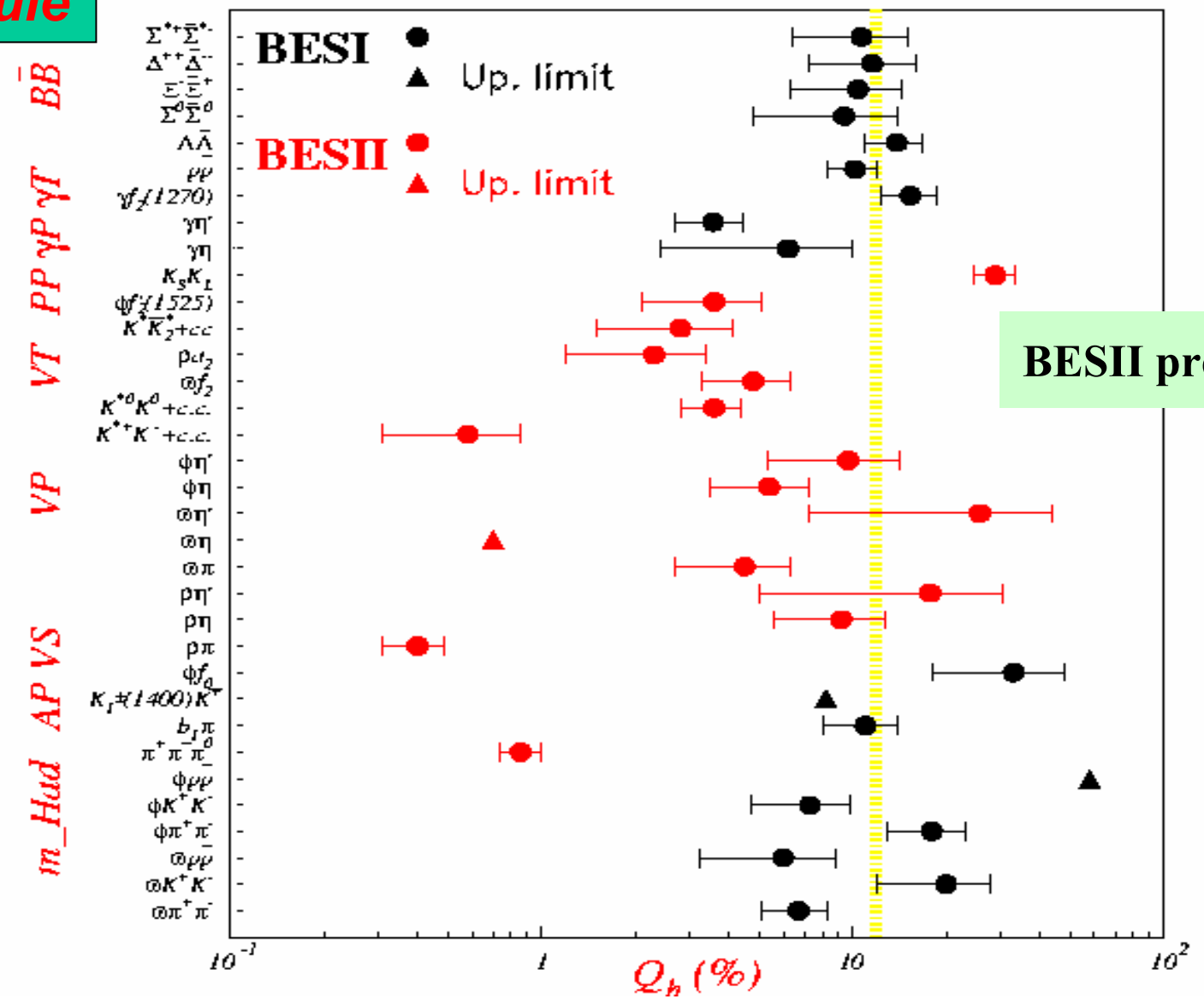
PLB567 (2003)73

$-(82\pm29)°$

$(121\pm27)°$

Test of pQCD 12% Rule

SUMMARY



Comments

 # 12% rule seems to be too simplistic.

 # A theory which can quantitatively describing these data is desired.

 # More and accurate data on J/ψ and ψ(2S) are helpful to elucidate the J/ψ and ψ(2S) properties, as well as properties of strong interaction.