

# **Strong and Electromagnetic $J/\psi$ and $\psi(2S)$ Decays into Pion and Kaon Pairs**

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**in collaboration with J. H. Kühn, based on arXiv:0904.0515**

- ▶ Motivation
- ▶ Description of narrow resonances
- ▶ Present experimental situation
- ▶ BESIII - what one can improve
- ▶ Summary

# Experimental data: PDG09 + ...

	$J/\psi$	$\psi(2S)$
$M$ [MeV]	$3096.916 \pm 0.011$	$3686.09 \pm 0.04$
$\Gamma_{ee}$ [keV]	$5.55 \pm 0.14 \pm 0.02$	$2.38 \pm 0.04$
$\mathcal{B}(e^+e^-)[\%]$	$5.94 \pm 0.06$	$0.752 \pm 0.017$
$\mathcal{B}(K^+K^-)[10^{-5}]$	$23.7 \pm 3.1$	$6.3 \pm 0.7$
$\mathcal{B}(K_S^0 K_L^0)[10^{-5}]$	$14.6 \pm 2.6$	$5.4 \pm 0.5$
$\mathcal{B}(\pi^+\pi^-)[10^{-5}]$	$14.7 \pm 2.3$	$0.9 \pm 0.5$ [w.a. by CLEO]
$\sigma(K^+K^-)[\text{pb}]$	-	$5.7 \pm 0.8$ [CLEO]
$\sigma(K_S^0 K_L^0)[\text{pb}]$	-	$< 0.74$ (90% C.L.) [CLEO]
$\sigma(\pi^+\pi^-)[\text{pb}]$	-	$9.0 \pm 2.2$ [CLEO]
$\Delta\alpha$	$0.02117$ [F.J.+...]	$0.02219$ [F.J.+...]

# Previous analyses

►  $F_\pi(J/\psi)$

J. Milana, S. Nussinov and M. G. Olsson Phys. Rev. Lett. 71, 2533 (1993)

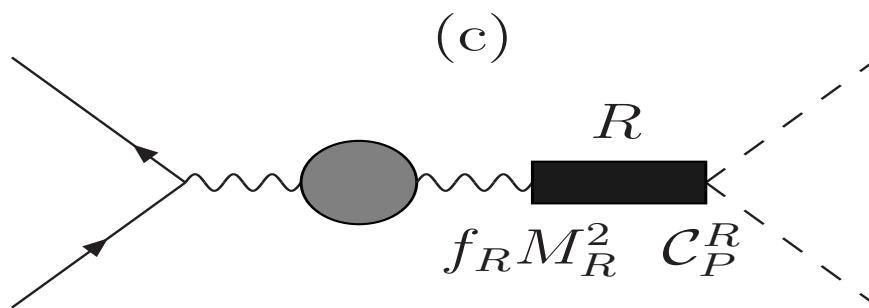
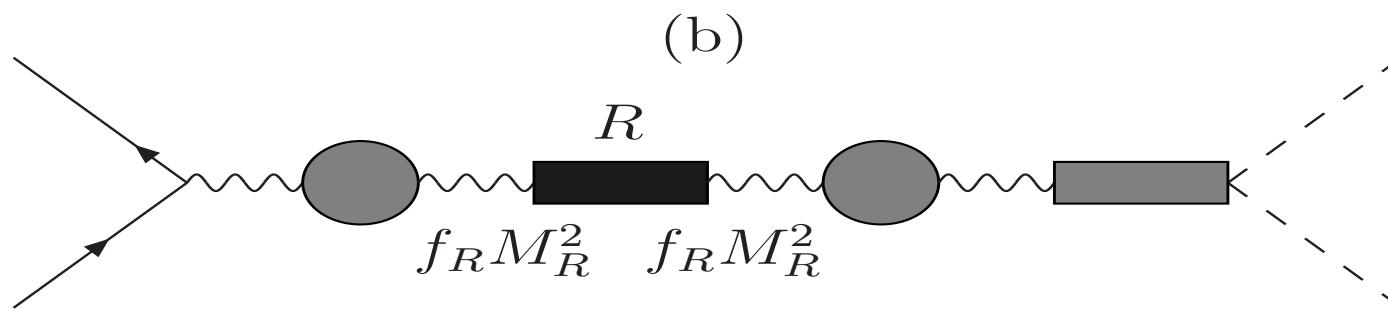
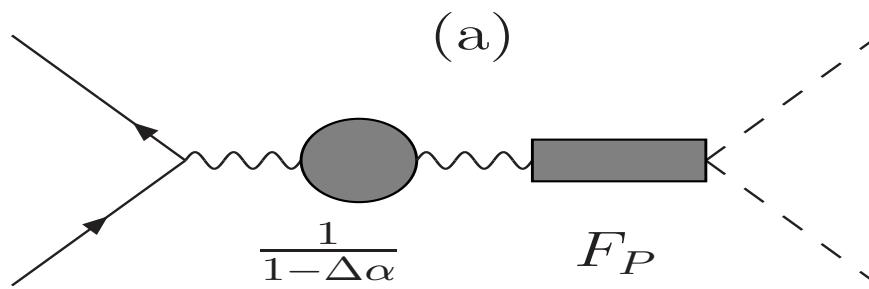
►  $J/\psi \rightarrow \pi^+\pi^-, K^+K^-, K_SK_L$

J. L. Rosner, Phys. Rev. D 60 (1999) 074029

M. Suzuki, Phys. Rev. D 60, 051501(R) (1999)

K. K. Seth, Phys. Rev. D 75 (2007) 017301

# Contributions to $e^+e^- \rightarrow M\bar{M}$



# Contributions to $e^+e^- \rightarrow P\bar{P}$

$$\sigma(e^+e^- \rightarrow P\bar{P}) = \frac{\pi\alpha^2}{3s} |F_P|^2 \beta^3$$

$$\times \left| \frac{1}{1-\Delta\alpha} + \sum_R \frac{3\sqrt{s}}{\alpha} \frac{\Gamma_e^R(1+c_P^R)}{s-M_R^2+i\Gamma_R M_R} \right|^2$$

# Contributions to $e^+e^- \rightarrow P\bar{P}$

$$\sigma(e^+e^- \rightarrow P\bar{P}) = \frac{\pi\alpha^2}{3s} |F_P|^2 \beta^3$$

$$\begin{aligned} & \times \left( \frac{1}{(1-\Delta\alpha)^2} + \sum_R \left\{ \frac{9s}{\alpha^2} \frac{(\Gamma_e^R)^2}{(s-M_R^2)^2 + \Gamma_R^2 M_R^2} \right. \right. \\ & \times \left[ |1 + c_P^R|^2 + \frac{2\alpha M_R}{3\sqrt{s}(1-\Delta\alpha)} \frac{\Gamma_R}{\Gamma_e^R} \text{Im}(c_P^R) \right] \\ & \left. \left. + \frac{6\sqrt{s}\Gamma_e^R}{\alpha(1-\Delta\alpha)} \frac{\left(1 + \text{Re}(c_P^R)\right)(s-M_R^2)}{(s-M_R^2)^2 + \Gamma_R^2 M_R^2} \right\} \right) \end{aligned}$$

# Decay width

One should not use

$$\Gamma(R \rightarrow P\bar{P}) = \Gamma^{QED} \times |1 + c_P^R|^2$$

but

$$\begin{aligned}\Gamma(R \rightarrow P\bar{P}) = \Gamma^{QED} \times & \left[ |1 + c_P^R|^2 \right. \\ & \left. + \frac{2\alpha M_R}{3\sqrt{s}(1-\Delta\alpha)} \frac{\Gamma_R}{\Gamma_e^R} \text{Im}(c_P^R) \right]\end{aligned}$$

# Pion form factor

$$|F_\pi|^2 = \frac{4\mathcal{B}(R \rightarrow \pi^+ \pi^-)}{\beta_\pi^3 \mathcal{B}(R \rightarrow e^+ e^-)}$$

	$J/\psi$	$\psi(2S)$
$ F_\pi ^2 [10^{-3}]$ above Eq.	$10.0 \pm 1.6$	$4.8 \pm 2.73$
$ F_\pi ^2 [10^{-3}]$ off peak	-	$5.92 \pm 1.46$

CLEO:Phys. Rev. Lett. 95,(2005) 261803

$$|F_\pi|^2(\sqrt{s} = 3.671 \text{ GeV}) = (5.63 \pm 1.42) \cdot 10^{-3}$$

$$\psi(2S) \rightarrow K^+K^-$$

$$R_+ \equiv \frac{4\mathcal{B}(K^+K^-)}{\beta_{K^+}^3 \mathcal{B}(e^+e^-)} = |F_{K^+}|^2 [ |1 + c_+|^2 + \textcolor{red}{r} \text{Im}c_+ ]$$

$$\textcolor{red}{r} = \frac{2\alpha}{3(1-\Delta\alpha)\mathcal{B}(e^+e^-)} = 0.663 \pm 0.015$$

$$R_+ = (3.75 \pm 0.43) \cdot 10^{-2}$$

$$\psi(2S) \rightarrow K^+K^-$$

$$S_+ - R_+ \frac{\gamma^2}{4} = |F_{K^+}|^2 [1 + \gamma(1 + \text{Rec}_+)]$$

$$S_+ = \sigma(e^+e^- \rightarrow K^+K^-)(1 - \Delta\alpha)^2 / \left(\frac{\pi\alpha^2}{3s}\beta_{K^+}^3\right)$$

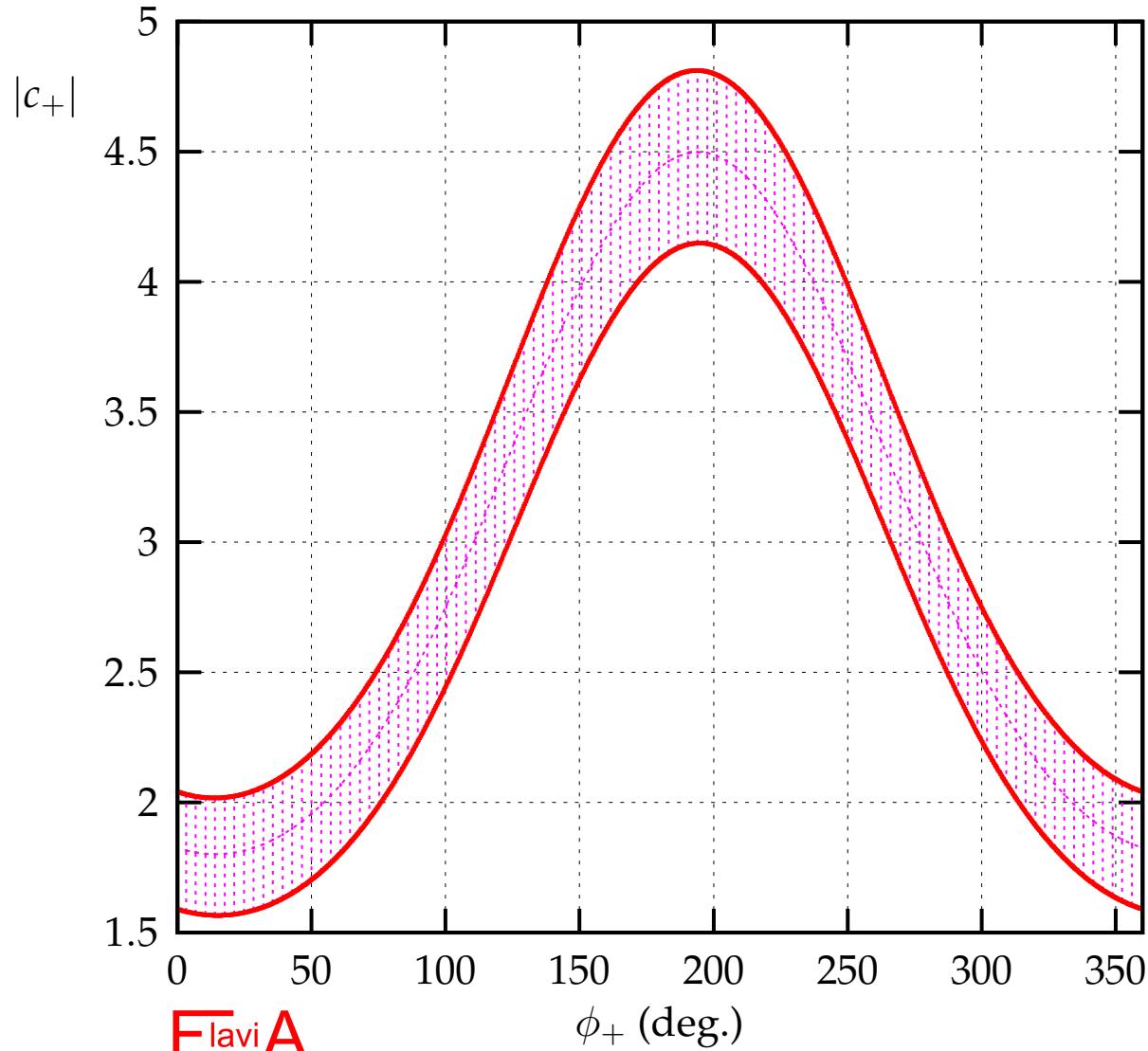
$$\gamma = \frac{\Gamma_e}{E-M_R} \frac{3(1-\Delta\alpha)}{\alpha}$$

CLEO:  $\gamma = -0.063 \pm 0.001$

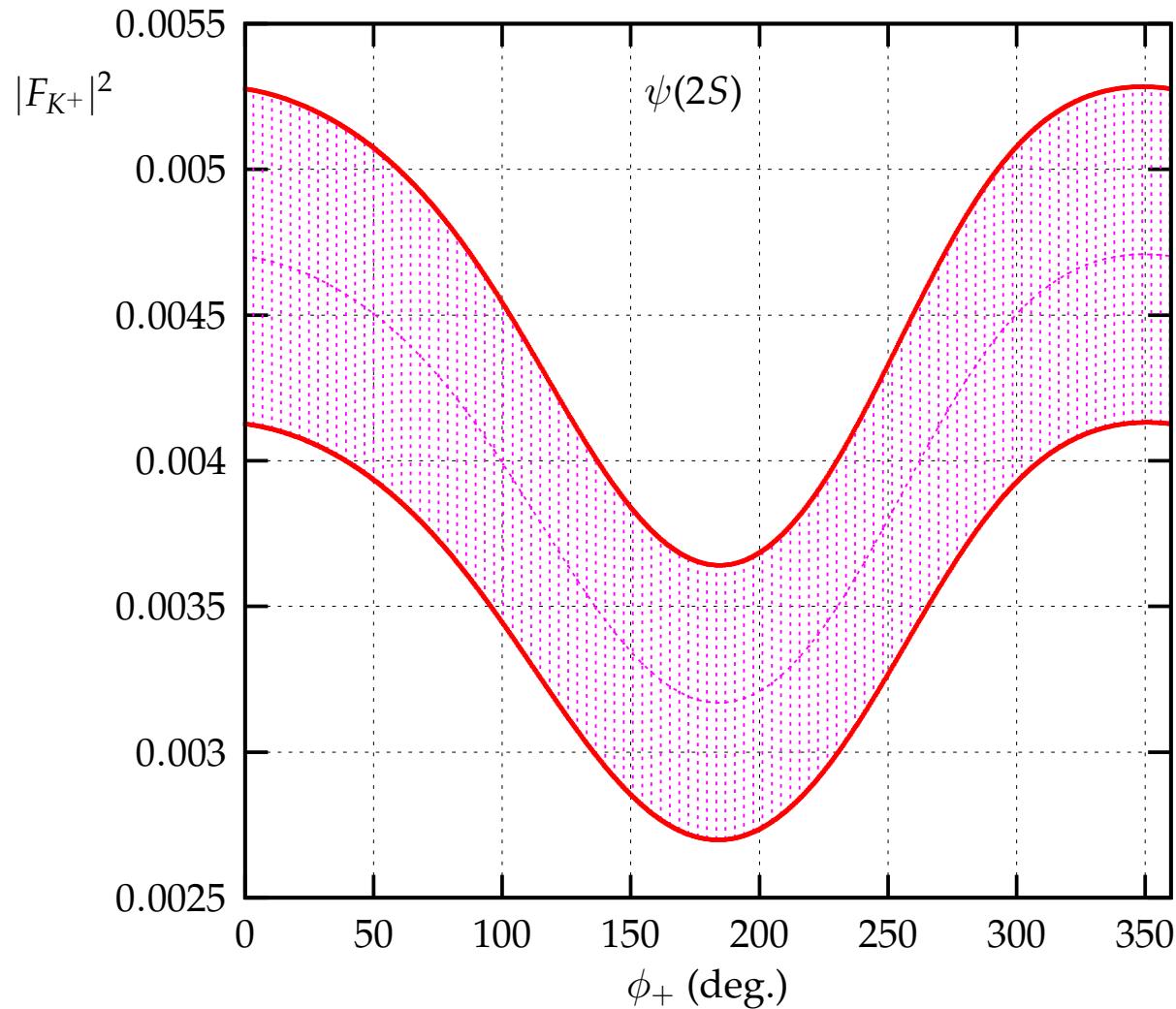
$$\psi(2S) \rightarrow K^+K^-$$

$$\frac{R_+}{S_+ - R_+ \frac{\gamma^2}{4}} = \frac{1 + 2|c_+| \cos(\phi_+) + |c_+|^2 + r|c_+| \sin(\phi_+)}{1 + \gamma(1 + |c_+| \cos(\phi_+))}$$

$$\psi(2S) \rightarrow K^+K^-$$



$\psi(2S) \rightarrow K^+K^-$



$$\psi(2S) \rightarrow K^+ K^-$$

$$0.052 < |F_{K^+}| < 0.073$$

to be compared with CLEO

$$0.059 < |F_{K^+}| < 0.067$$

# Can we improve ?

$$\sigma(e^+e^- \rightarrow K^+K^-, E = M_{\psi(2S)} - 20\text{MeV})$$

$$= (5.55 \pm 0.28)pb$$

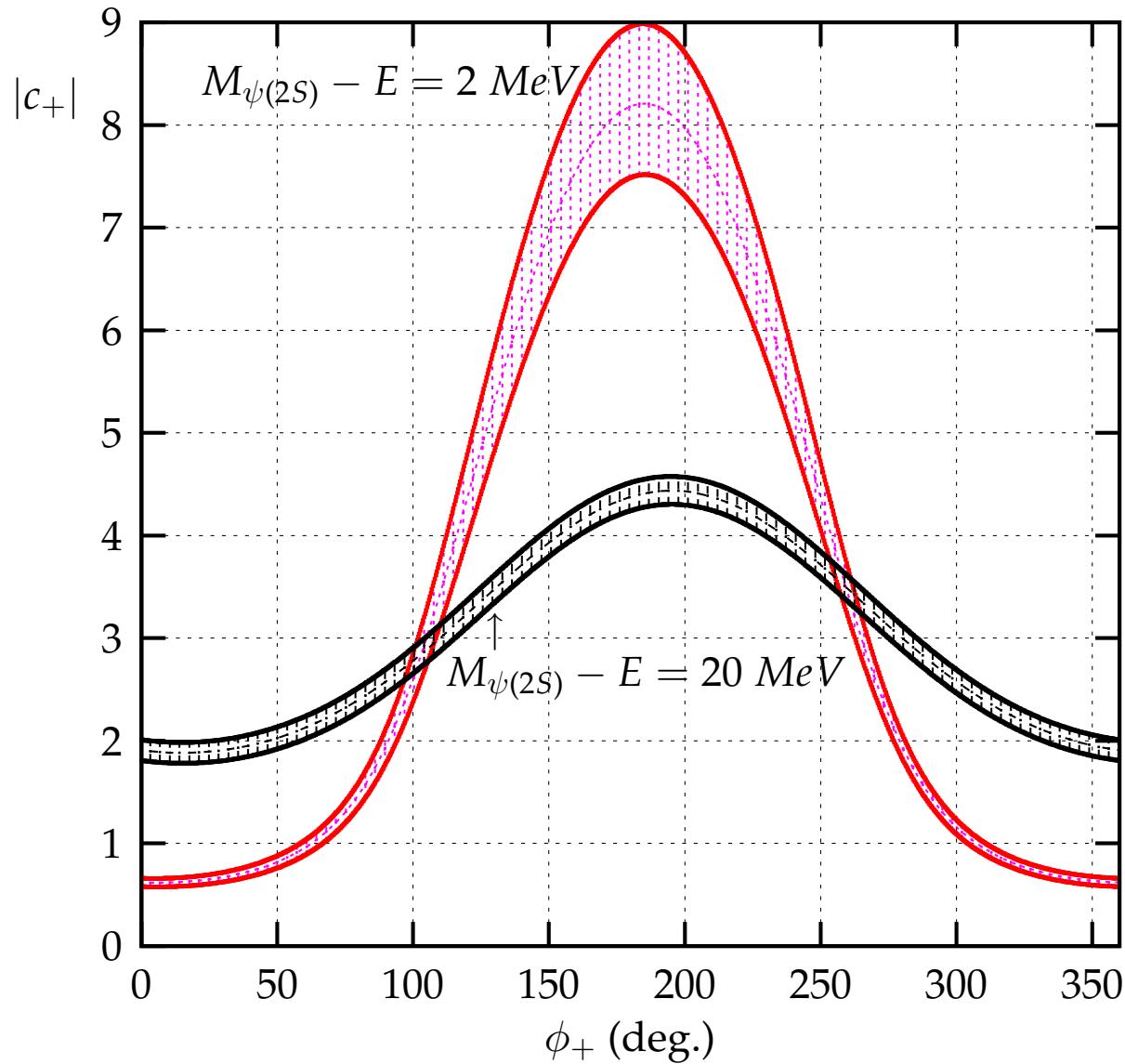
$$\sigma(e^+e^- \rightarrow K^+K^-, E = M_{\psi(2S)} - 2\text{MeV})$$

$$= (7.68 \pm 0.38)pb$$

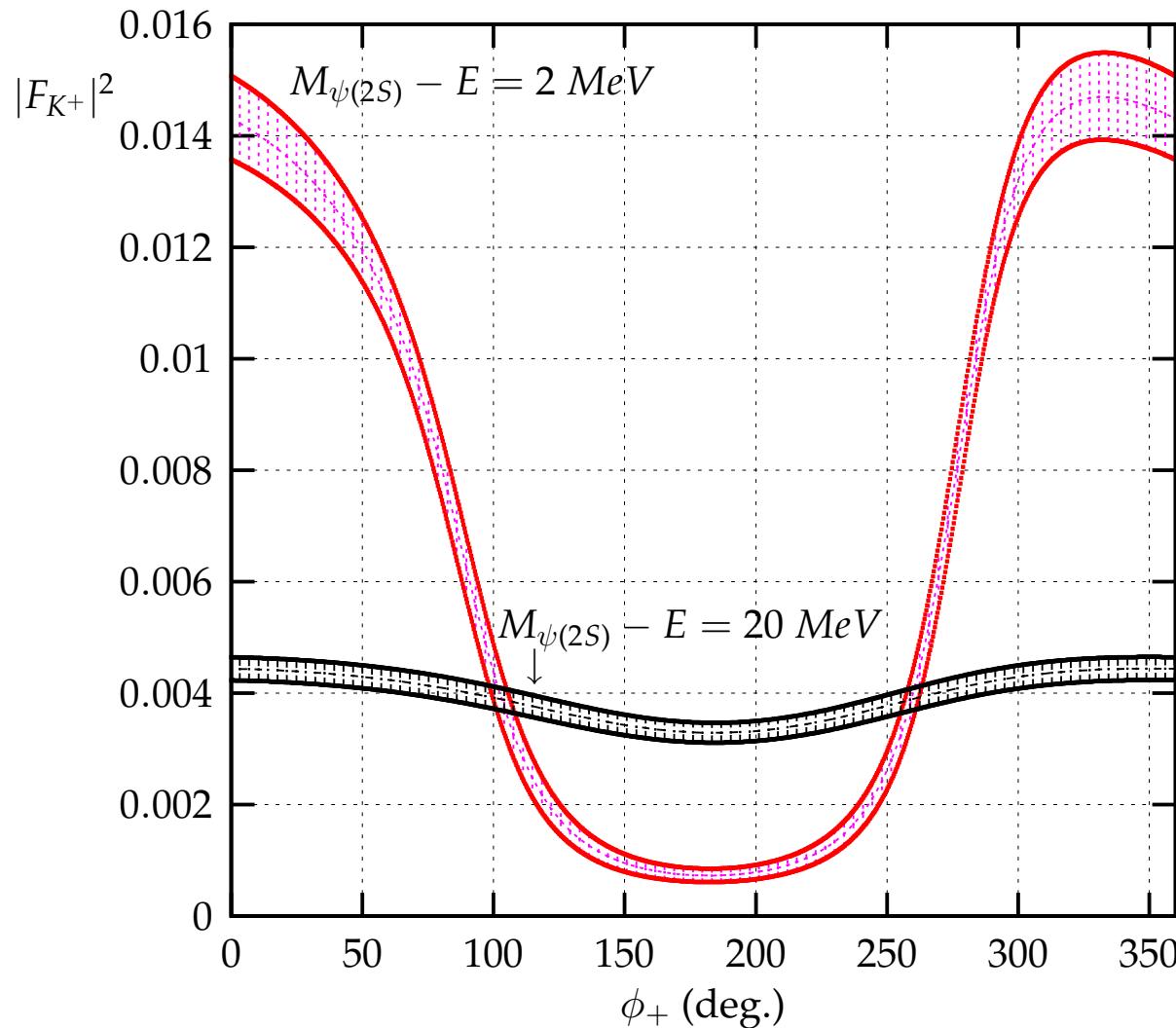
$$\mathcal{B}(\psi(2S) \rightarrow K^+K^-) = (6.3 \pm 0.35) \cdot 10^{-5}$$

With a luminosity of BES III of  $2.6 \cdot 10^3 \text{pb}^{-1}/\text{month}$  one expects about 1000  $K^+K^-$  events in 2 days of running

# The expected improvement



# The expected improvement



$$\psi(2S) \rightarrow K^0 \bar{K}^0$$

$$\sigma(e^+e^- \rightarrow K_S^0 K_L^0) < 0.74 \text{ pb}$$

at 90% C.L., obtained by CLEO 15 MeV below the resonance.

isospin symmetry:

$$A_{QCD}^R(K^+ K^-) = A_{QCD}^R(K^0 \bar{K}^0)$$

$$c_+ F_{K^+} = c_0 F_{K^0}$$

$$\psi(2S) \rightarrow K^0 \bar{K}^0$$

$$|\frac{1}{c_0}| = |\frac{A_{QED}^R}{A_{QCD}^R}| < 0.187 \pm 0.008$$

$$|F_{K^0}| < 0.0282 \pm 0.0003$$

to be compared with the limit obtained by CLEO: interference neglected

$$|F_{K^0}| < 0.023$$

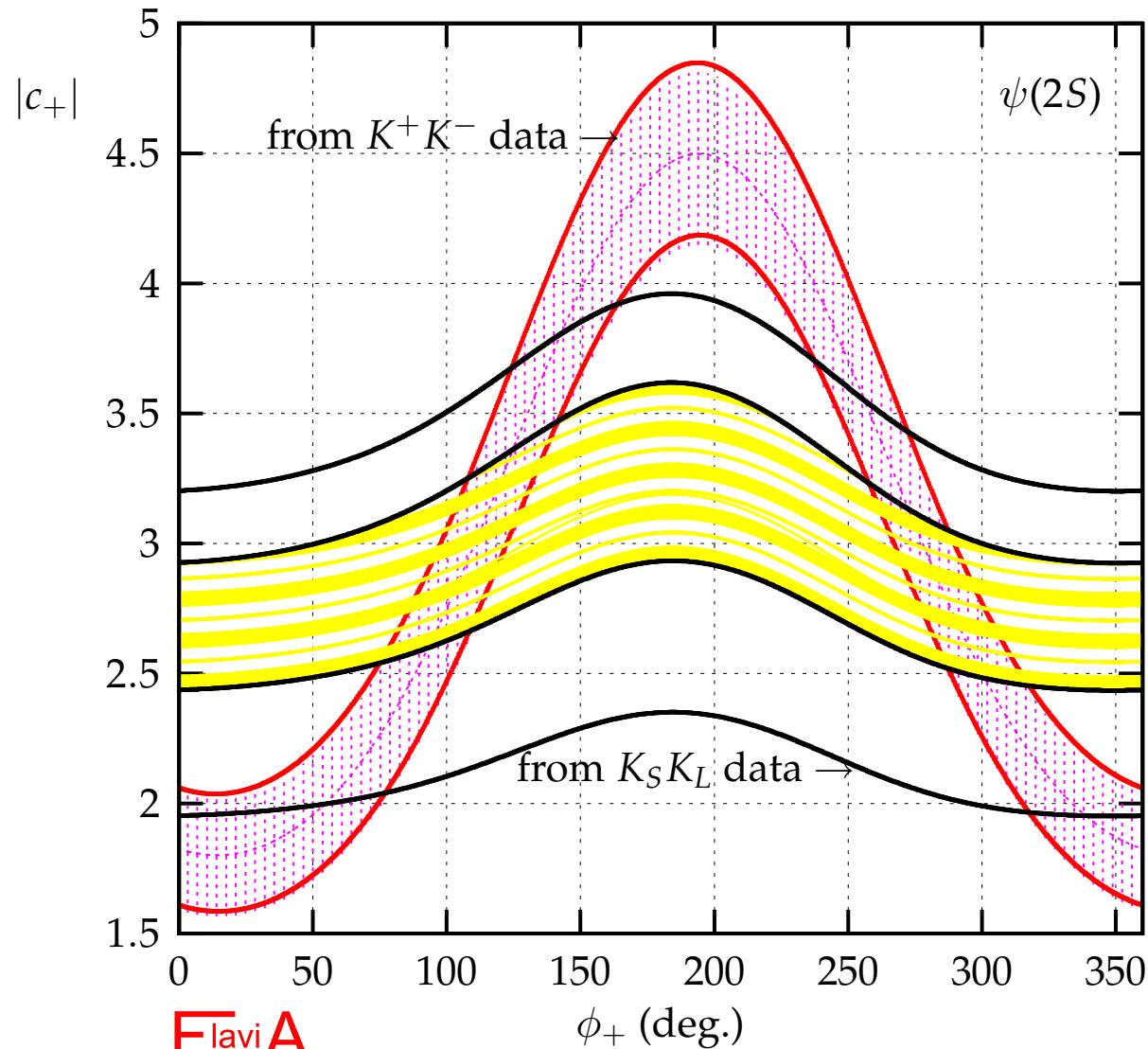
$$\psi(2S) \rightarrow K^0 \bar{K}^0$$

$$|F_{K^0} \cdot c_0| < 0.174 \pm 0.009 \pm 0.024$$

first error is due to the error on  $R_0$  and the second originates from the unknown strength of the interference between  $A_{QED}^R$  and  $A_{QCD}^R$

$$|F_{K^0} \cdot c_0| = |F_{K^+} \cdot c_+|$$

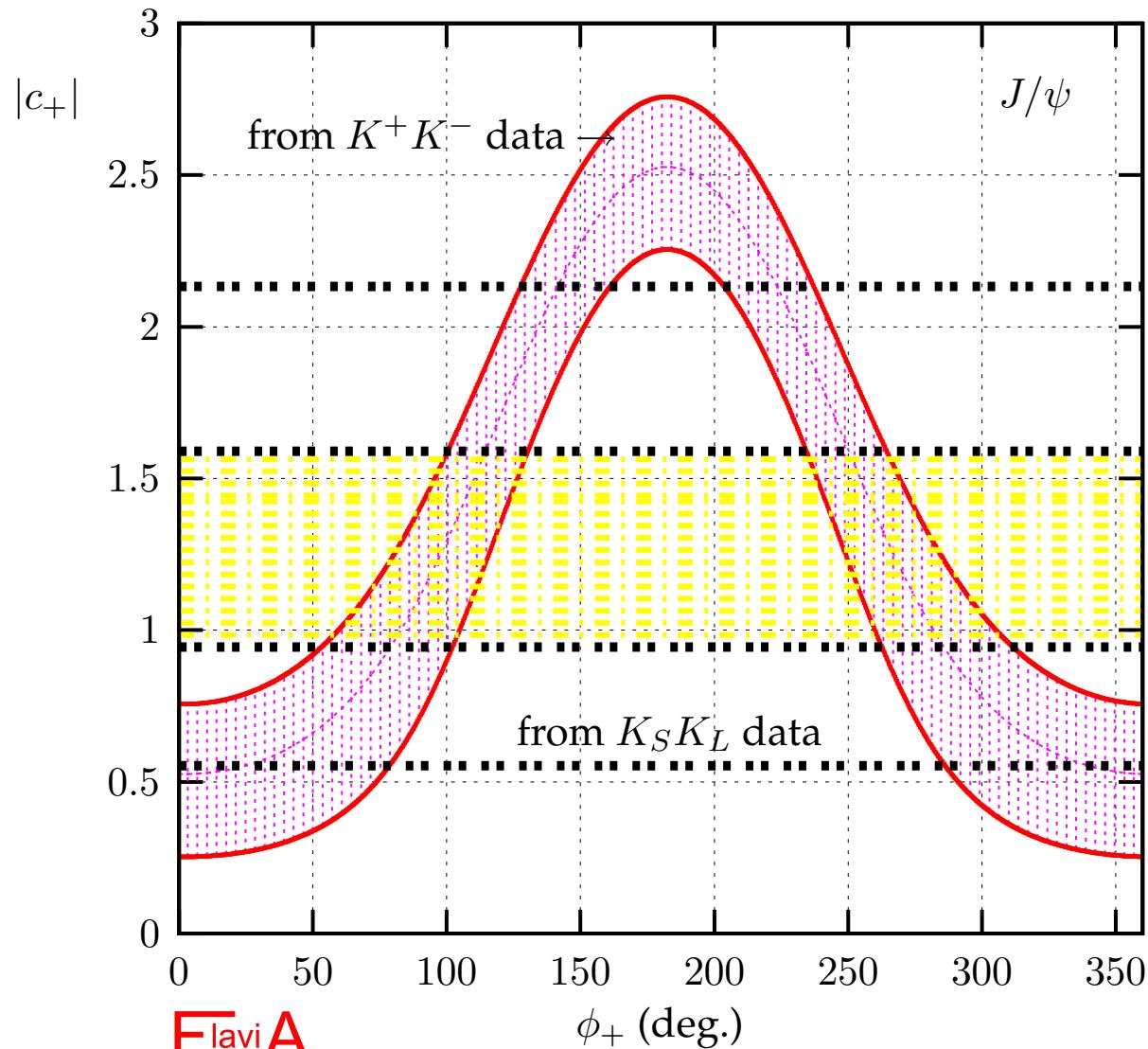
$$\psi(2S) \rightarrow K^+K^-, \psi(2S) \rightarrow K_SK_L$$



$$J/\psi \rightarrow K^+K^-, J/\psi \rightarrow K_SK_L$$

- NO off resonance measurement available
- analysis depends critically on the assumptions on the kaon form factors
- $A_{QED}^{J/\psi}(K_S^0 K_L^0) = 0$  vs.  $\neq 0$
- interference important

# $J/\psi \rightarrow K^+K^-$ , $J/\psi \rightarrow K_SK_L$



# Conclusions

- ▶  $J/\psi$  and  $\psi(2S)$  decays into pairs of ps. mesons reanalysed
- ▶ previously neglected interference terms important
- ▶ assumptions on the neutral kaon form factor relevant
- ▶ the combination of two cross section measurements close to the resonance with the corresponding branching ratio leads to a model independent determination (up to a twofold ambiguity) of strong amplitude, form factors and their relative phase.