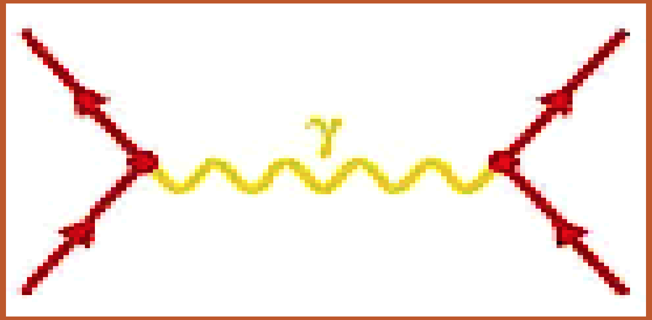
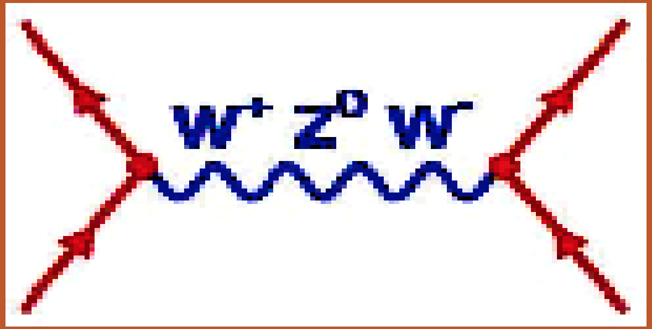
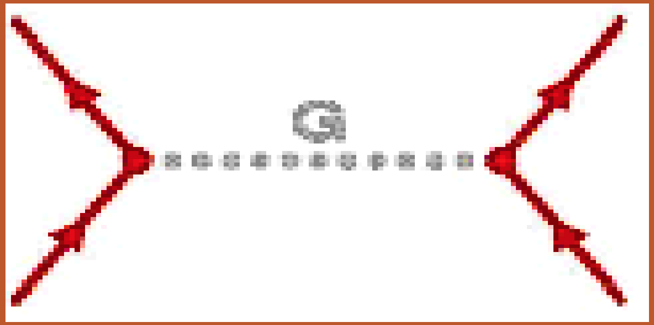






粲偶素衰变中强-电磁作用之间的相位差

王雅迪

华北电力大学

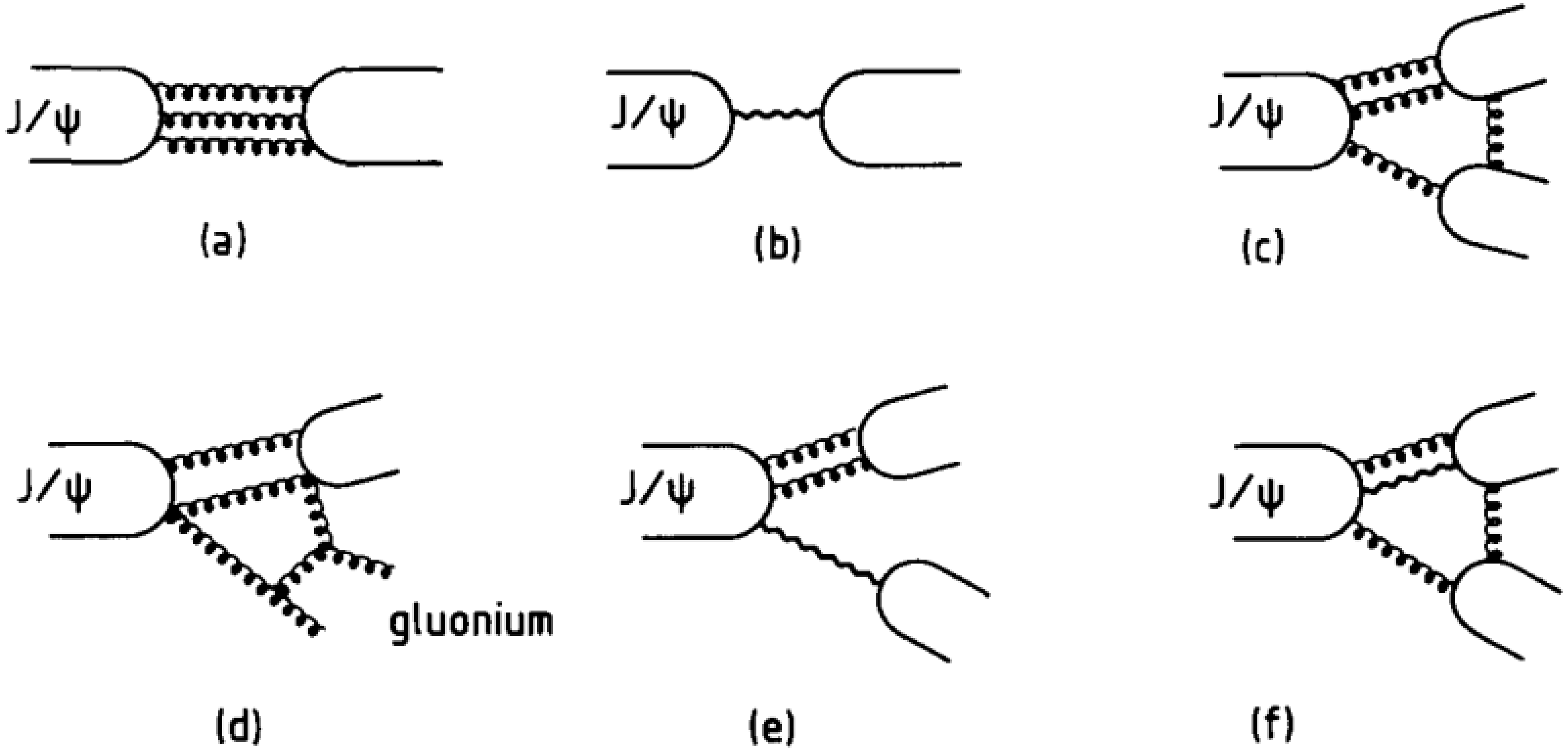
中国物理学会高能物理分会第十二届全国会员代表大会暨学术年会

2026年7月13日-19日

广东 ▪ 广州

WANGYADI@NCEPU.EDU.CN

粲偶素衰变中最重要的两种基本相互作用



(a) SOZI -- g

(b) EM – e

(c) DOZI -- $r \times g$

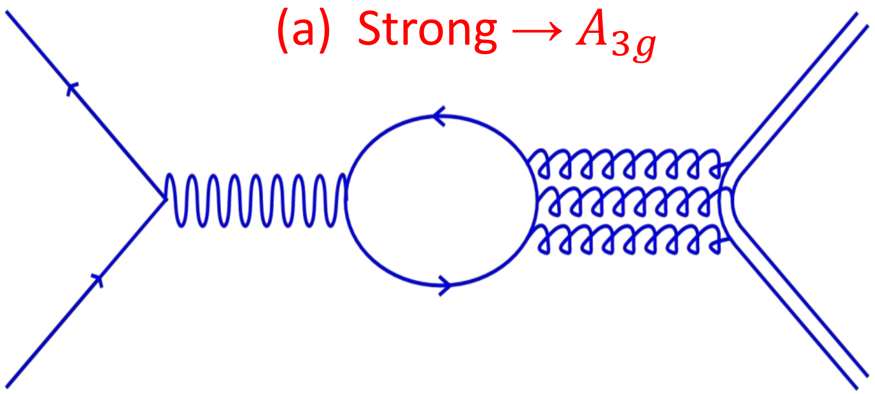
DOZI-s – $s \times g$

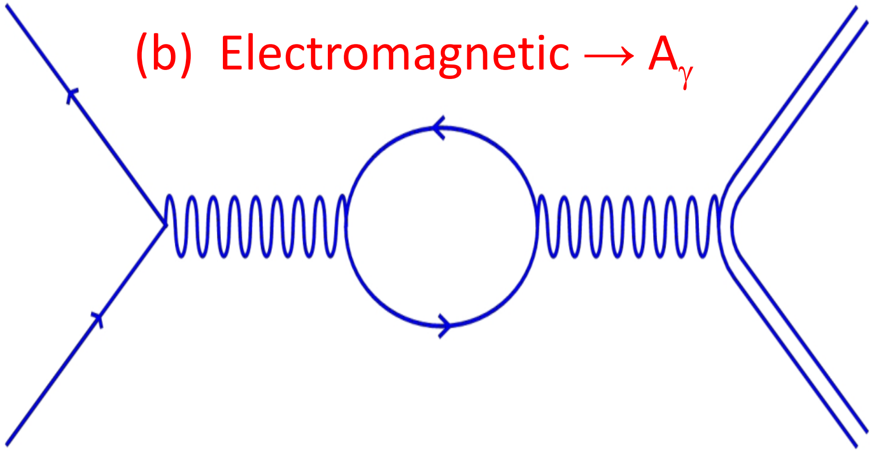
(e) $\sim 0.3 \times e$

(f) $\sim 0.2 \times e$

From *L. Kopke and N. Wermes, J/ψ decays*

粲偶素衰变中最重要的两种基本相互作用





(a) 强相互作用: $e^+e^- \to R(q\bar{q}) \to$ hadrons;

(b) 弱相互作用: $e^+e^- \to R(q\bar{q}) \to$ hadrons;

近乎所有理论文章中默认:

- **微扰QCD(pQCD)能区，两种基本相互作用的耦合常数均为实数。**
- **推论:二者导致的振幅之间的相位为0° 或 180°**
- **对于所有 $q\bar{q}\,(1^{--})$，相位差是否统一数字(普适性)？**

V.L. Chernyak and I.R. Zhinitsky, Nuclear Physics B 246, 52 (1998)

报告提纲

- 基于SU(3)对称性的**间接**实验结果（“SU(3)方法”）
  - $\mathrm{J}/\psi, \psi(2S), \psi(3770)$
- 基于BESIII实验的直接**实验**结果（“扫描实验方法”）
  - $e^+e^- \to J/\psi \to \Sigma^+\bar{\Sigma}^-$
  - $\mathrm{e}^+\mathrm{e}^- \to \mathrm{J}/\psi \to K_S^0 K^+\pi^-$
  - $\mathrm{e}^+\mathrm{e}^- \to \mathrm{J}/\psi \to \phi\eta$
  - $e^+e^- \to \psi(2S) \to K^+K^-$
  - $e^+e^- \to \psi(2S) \to p\bar{p}\pi^0(\eta)$
  - $e^+e^- \to \psi(3770) \to K_S K_L$
  - $e^+e^- \to \psi(3770) \to \Sigma$
- 总结与展望

J/ψ 衰变中相角的测量—SU(3)方法

基于SU(3)， 1^-0^-[1,2,3,4], 0^-0^-[1,2,3], 1^-1^-[1], 1^+0^-[5], $B\bar{B}$[2,6,7] 等衰变模式中均呈现约 **90°** 相位差.

- $PP(0^-0^-)(\pi^+\pi^-, K^+K^-, K_SK_L)$ [1,2,3]
- $VP(1^-0^-)(\rho\pi, \omega\pi^0, \phi\pi^0, \rho\eta, \omega\eta, \phi\eta, \rho\eta', \omega\eta', \phi\eta', \bar{K}^*K)$ [1,2,3,4]
- $VP(1^+0^-)\left(K_1^\pm(1400)K^\mp, K_1^\pm(1270)K^\mp\right)$[5]
- $VV\ (1^-1^-)(\rho^+\rho^-, K^{*+}K^{*-}, K^{*0}\bar{K}^{*0})$ [1]
- $B\bar{B}(p\bar{p}, n\bar{n}, \Lambda\bar{\Lambda}, \Sigma^0\bar{\Sigma}^0, \Sigma^+\bar{\Sigma}^-, \Xi^0\bar{\Xi}^0, \Xi^+\bar{\Xi}^-, \Sigma^0\bar{\Lambda}+\bar{\Sigma}^0\Lambda)$ [2,6,7]

Decay	Amplitude	PDGx10^4	Fitx10^4	$\Delta\chi^2$
$\rho^0\pi^0$	$g\,e^{i\phi}+e$	169.0 ±15.0	133.00	1.13
$K^{*+}K^-$	$g\,(1-s)\,e^{i\phi}+e$	51.2 ± 3.0	51.5	0.01
$K^{*0}K^0$	$g\,(1-s)e^{i\phi}-2e$	43.9 ± 3.1	48.5	0.48
$\omega\eta$	$(g\,X+d)e^{i\phi}+eX$	17.4 ± 2.0	18.5	0.06
$\phi\eta$	$(g\,(1-2s)Y+d)e^{i\phi}-2eY$	7.5 ± 0.8	3.9	4.02
$\rho\eta$	$3eX$	1.9 ± 0.2	2.2	0.30
$\omega\pi$	$3e$	4.5 ± 0.5	4.1	0.11
$\omega\eta'$	$(g\,X'+d')\,e^{i\phi}+eX'$	7.0 ± 7.0	11.9	0.10
$\phi\eta'$	$(g\,(1-2s)Y'+d')\,e^{i\phi}-2eY'$	4.0 ± 0.7	6.1	1.87
$\rho\eta'$	$3eX'$	1.1 ± 0.2	1.1	0.04

Parameter		Fit
SU_3 strong Amplitude	g	7.22 ± 0.38
SU_3 breaking strange	s	0.18 ± 0.04
SU_3 breaking DOZI	r	-0.04 ± 0.02
e.m. Amplitude	e	0.75 ± 0.04
Phase	ϕ	**81.51± 6.75**

-- from Rinaldo Baldini

[1] L. Köpke and N. Wermes, Phys. Rep. 174, 67 (1989)
[2] G. Lopez Castro, J. L. Lucio M. and J. Pestieau, hep-ph/9902300v1 (1999)
[3] Mahiko Suzuki, Physical Review D 57, 5717 (1998)
[4] P. Wang, C.Z. Yuan, X.H. Mo, Phys. Rev. D 69, 057502 (2004)
[5] Mahiko Suzuki, Physical Review D 63, 054021 (2001)
[6] R. Baldini et al, Physics Letters B 444, 111-118 (1998)
[7] K. Zhu et al., Int. J Mod. Phys. A30, 1550148 (2015).

$\psi(3686)$ 与 $\psi(3770)$衰变—SU(3)方法

$\psi(3686)$

- $VP\ (1^-0^-)$: $\boldsymbol{\Phi = (159 \pm 12)^\circ}$ 基于BESIII结果 [1,2]
- $B\bar{B}$: $\Phi = (-98 \pm 25)^\circ$ or $(+134 \pm 25)^\circ$ 基于CLEO和BES结果 [5]
- PP($K_S K_L, K^+K^-, \pi^+\pi^-$) :
  - $\Phi = (-82 \pm 29)^\circ$ or $(121 \pm 27)^\circ$ 基于 BES 结果[3]
  - $\Phi = \left(110.5^{+16.0}_{-9.5}\right)^\circ$ 基于CLEO数据[4]
  - $\Phi = (95 \pm\ 11)^\circ$ 基于BESIII 结果 [1]

$\psi(3770)$

- ✓ $\Phi \sim -90^\circ$ 对近乎所有 OZI 压低过程成立[6]
- ✓ $|\Phi| \sim 90^\circ$ from R. Baldini[1]

decay	continuum	Ψ''(3770)	sign	
ρ π	13.1±2.8	7.4±1.3	-	CLEOc, PRD 73(2006)012002
φ η	2.1±1.6	4.5±0.7	+	CLEOc, PRD 73(2006)012002
p p̄	0.74±0.08	0.4±0.02	-	BESIII Y.Liang, Nov (2012)

[1] Rinaldo Baldini Ferroli, Orsay (France), 2014
[2] Mahiko Suzuki, Phys. Rev. D 63, 054021 (2000)
[3] BES Collaboration, Phys. Rev. Lett. 92, 052001 (2004)
[4] Z. Metreveli, Phys. Rev. D 85, 092007 (2012)
[5] K. Zhu, X. H. Mo, C. Z. Yuan, IJMPA30, 1550148 (2015)
[6] P. Wang, arxiv:hep/0410028v2 (2004)

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干涉相位不同，是否$\rho\pi$疑难的主要原因?

$$R = \frac{Br(J/\psi \to VP)}{Br(\psi(3686) \to VP)} \neq 12\%$$

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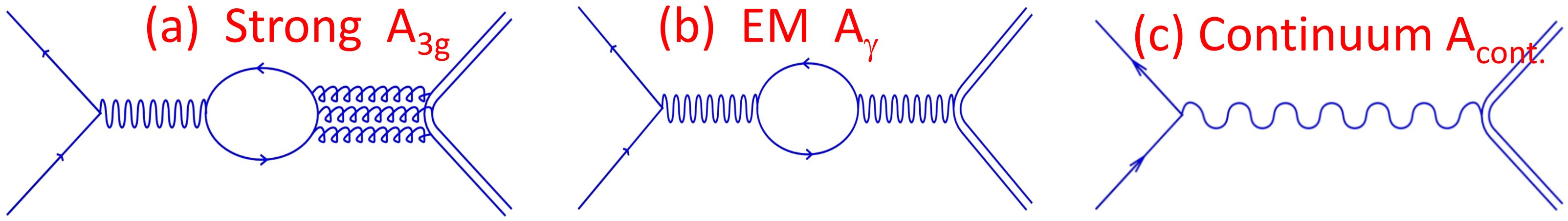
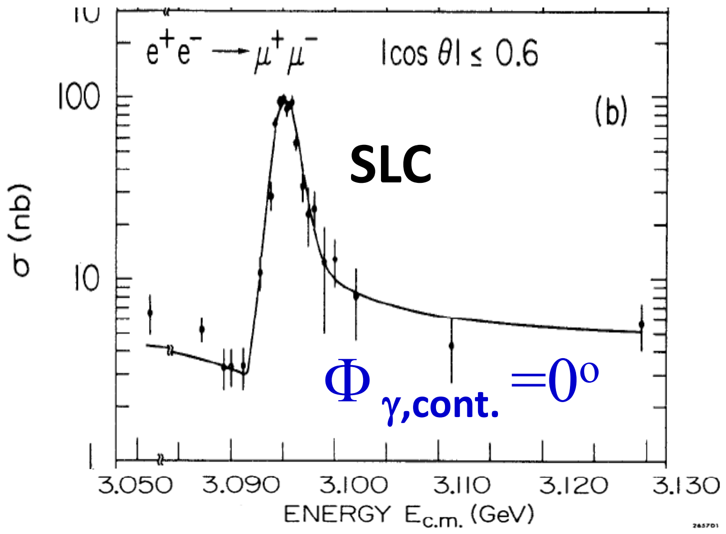
$\Phi = -90^\circ$ 导致负干涉行为，$\psi(3770) \to \mathrm{non}-D\bar{D}$ 疑难的主要原因?

[1] Rinaldo Baldini Ferroli, Orsay (France), 2014
[2] Mahiko Suzuki, Phys. Rev. D 63, 054021 (2000)
[3] BES Collaboration, Phys. Rev. Lett. 92, 052001 (2004)
[4] Z. Metreveli, Phys. Rev. D 85, 092007 (2012)
[5] K. Zhu, X. H. Mo, C. Z. Yuan, IJMPA30, 1550148 (2015)
[6] P. Wang, arxiv:hep/0410028v2 (2004)

独立于SU(3)实验 — 扫描方法



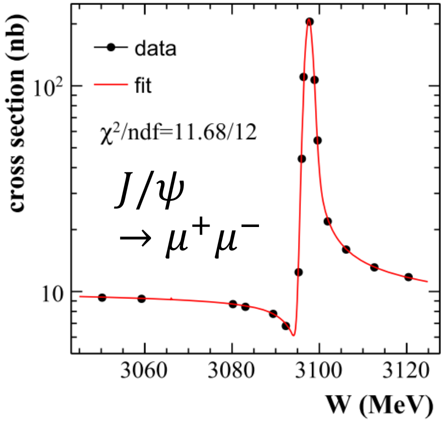


$\Phi_{\gamma,cont.} = 0^o$

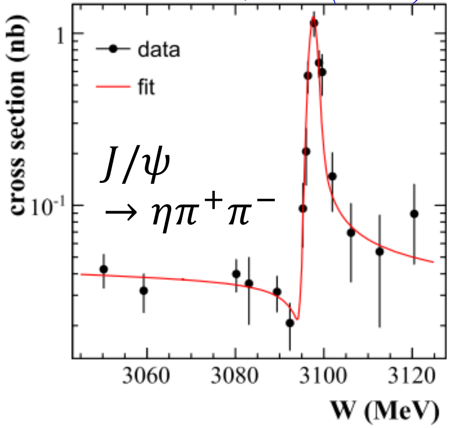
$$\sigma_{born} = \left|A_{3g}e^{i\Phi_{g,cont.}} + A_{\gamma}e^{i\Phi_{\gamma,cont.}} + A_{cont.}\right|^2$$

With $\Phi_{\gamma,cont.} = 0$, $\sigma_{born} = |A_{3g}e^{i\Phi_{g,cont.}} + A_{\gamma} + A_{cont.}|^2$

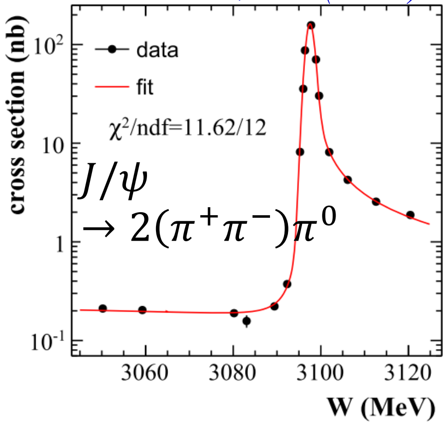
PLB 791, 375 (2019)



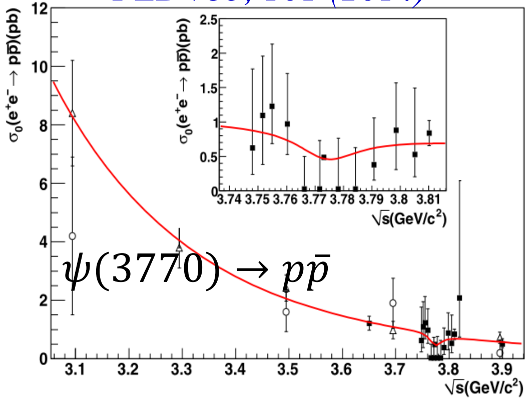
PLB 791, 375 (2019)



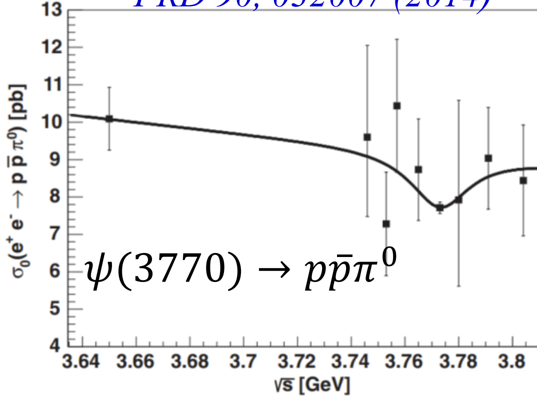
PLB 791, 375 (2019)



PLB 735, 101 (2014)



PRD 90, 032007 (2014)

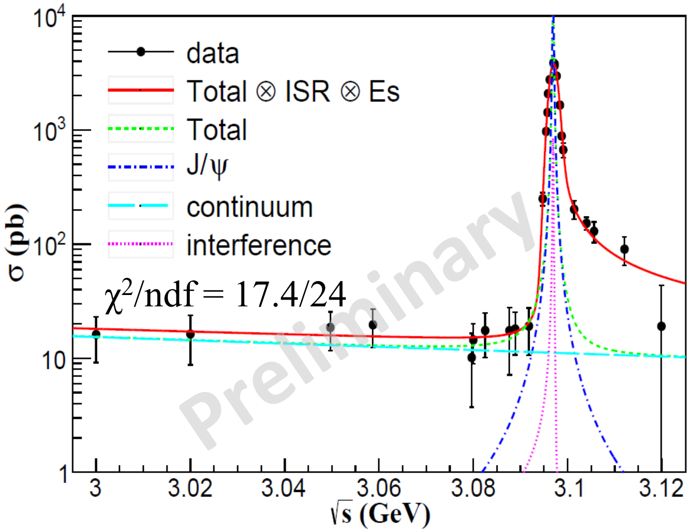


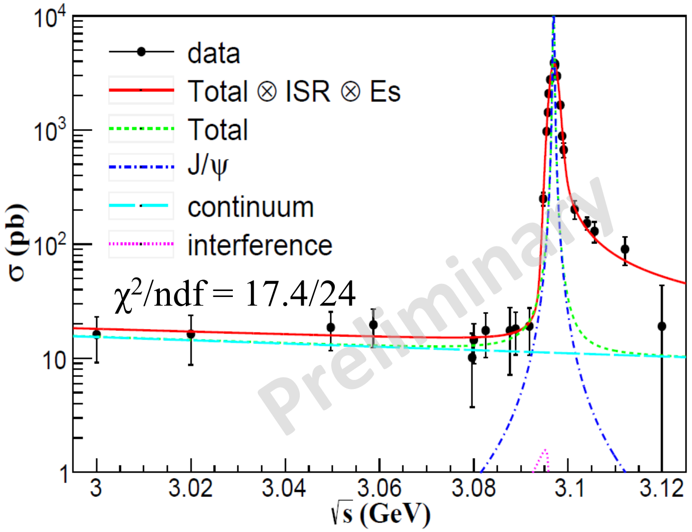
$\Phi_{\gamma,cont.} \sim 0°$

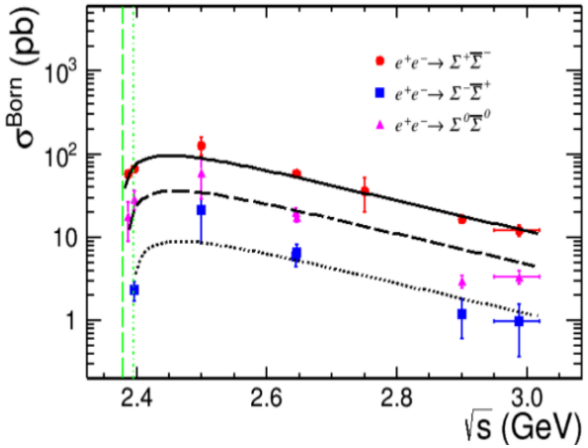
$|\Phi_{\gamma,cont.}^{J/\psi\to5\pi}| \sim 90°$

$\Phi_{res,cont.}^{\psi(3770)\to p\bar{p},p\bar{p}\pi^0} \sim -90°$

$e^+e^- \to J/\psi \to \Sigma^+\bar{\Sigma}^-$







"Σ production puzzle"

$\sigma(\Sigma^+\bar{\Sigma}^-):\sigma(\Sigma^0\bar{\Sigma}^0):\sigma(\Sigma^-\bar{\Sigma}^+)$

$= 9.7 \pm 1.3 : 3.3 \pm 0.7 : 1$

正解：

$\Phi_{3g,\gamma} = (107.9 \pm 24.9)^\circ$

$\mathcal{B} = (1.14 \pm 0.04) \times 10^{-3}$

负解：

$\Phi_{3g,\gamma} = (-107.6 \pm 24.3)^\circ$

$\mathcal{B} = (1.19 \pm 0.04) \times 10^{-3}$

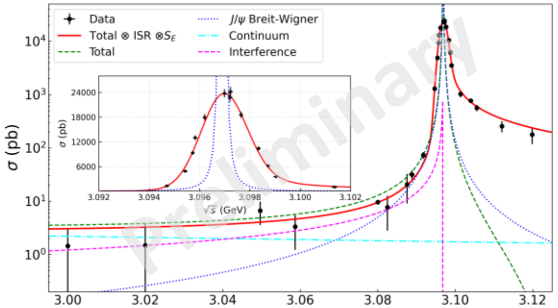
Process	Branching fraction	$\alpha_{J/\psi}$
$J/\psi \to \Sigma^+\bar{\Sigma}^-$	$(1.027 \pm 0.005) \times 10^{-3}$	-0.508 ± 0.006
$J/\psi \to \Sigma^0\bar{\Sigma}^0$	$(1.17 \pm 0.03) \times 10^{-3}$	-0.45 ± 0.02
$J/\psi \to \Sigma^-\bar{\Sigma}^+$		

- ❑ 目前结果~ 90°，与SU(3)方法得到的结果在1σ范围保持一致.
- ❑ 分支比结果比PDG值: $(1.07 \pm 0.04) \times 10^{-3}$均高出 2 σ . 干涉影响 ?

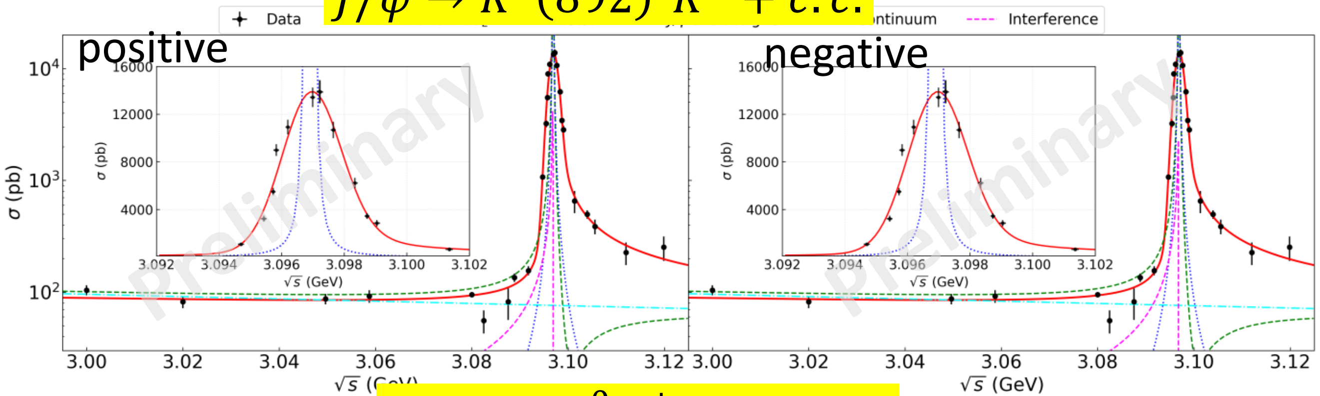
$e^+e^- \to J/\psi \to K_S^0 K^+\pi^-$

分波分析“拆解”各成分

$J/\psi \to K^*(892)^+ K^- + c.c.$



$J/\psi \to K^*(892)^0\bar{K}^0 + c.c.$



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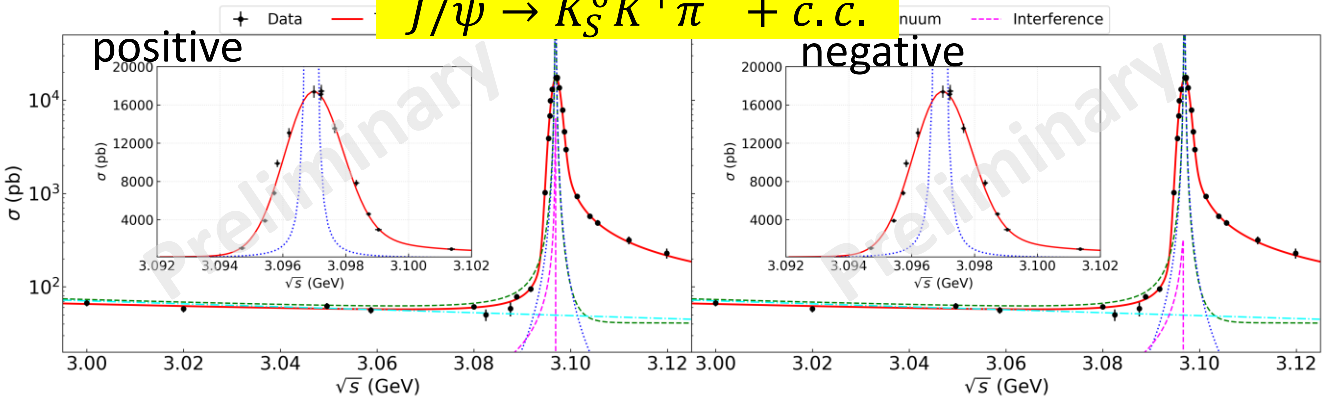
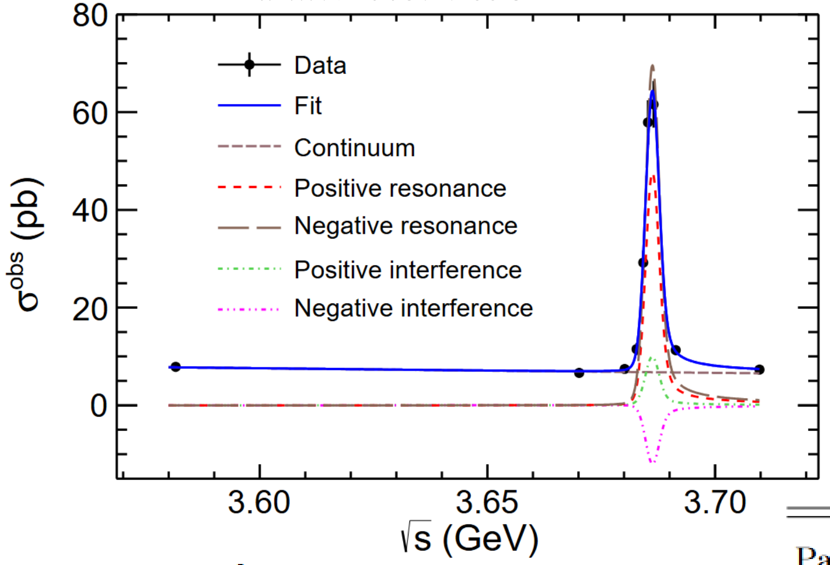


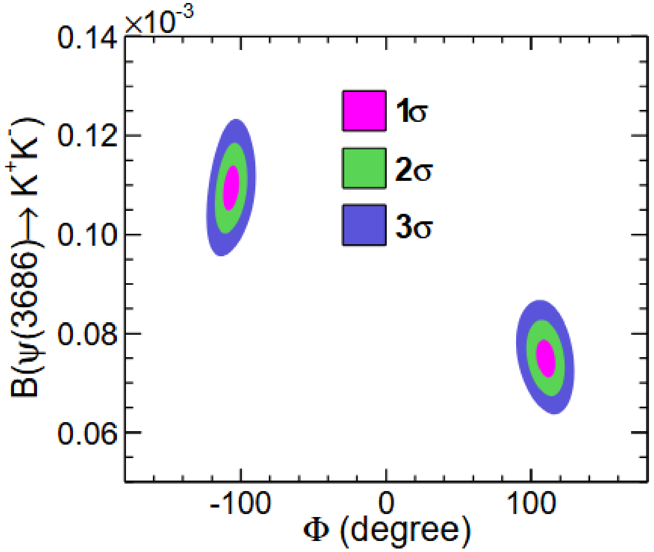
Channels	$\phi_{\gamma,3g}$ sign	$\mathcal{C}$	$\mathcal{B}$ $(\times 10^{-3})$	$\phi_{\gamma,3g}$ $(^\circ)$	S_E (MeV)	χ^2/ndf
$J/\psi \to K_S^0 K^+\pi^-$	Positive	4.31 ± 0.22	5.17 ± 0.20	123.7 ± 5.3	0.90 ± 0.02	16.0/22
	Negative	4.38 ± 0.22	5.36 ± 0.20	-123.1 ± 5.2	0.90 ± 0.02	16.0/22
$J/\psi \to \bar{K}^0 K^*(892)^0$	Positive	3.67 ± 0.27	4.18 ± 0.18	155.2 ± 15.5	0.92 ± 0.03	30.1/22
	Negative	3.71 ± 0.25	4.31 ± 0.19	-154.1 ± 15.5	0.92 ± 0.03	30.1/22
$J/\psi \to K^+ K^*(892)^-$	...	25.06 ± 2.51	7.09 ± 0.28	180.1 ± 31.8	0.88 ± 0.02	21.2/22

- 不同于90°的干涉角，*强烈的末态相互作用（FSI）？*
- $R_{3g} = \left|\dfrac{A_{3g}^{K^*(892)^0}}{A_{3g}^{K^*(892)-}}\right|^2 = 0.884 \pm 0.050$ or 0.909 ± 0.050, *强作用振幅遵循同位旋守恒*
- $R_\gamma = \left|\dfrac{A_\gamma^{K^*(892)^0}}{A_\gamma^{K^*(892)-}}\right|^2 = 44.7 \pm 9.4$, *电磁作用振幅同位旋严重破缺*

$e^+e^- \to \psi(2S) \to K^+K^-$

arxiv:2603.29854





$$\delta B = 2\sqrt{\frac{\sigma_0}{\sigma_\psi}} A_{3g} sin\phi_{g,\gamma}$$

BaBar, PRD 92, 072008 (2015)

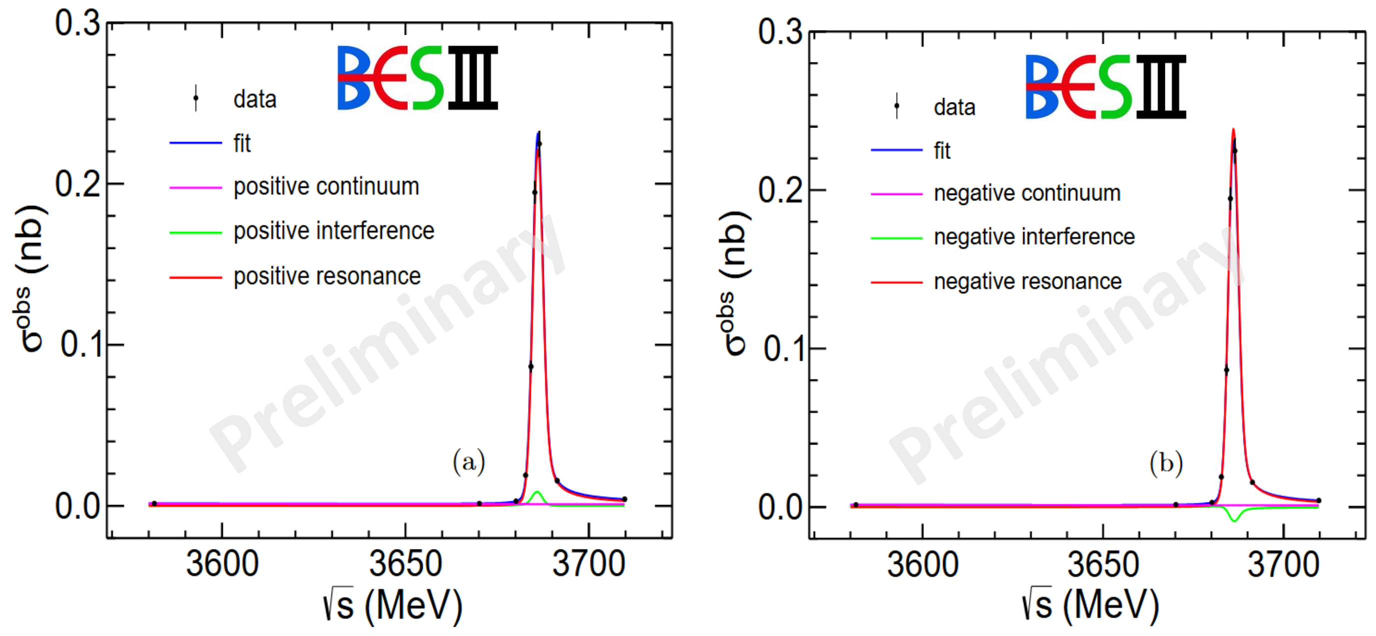
$\mathcal{B}(\psi \to K^+K^-) \times 10^4$	J/ψ		$\psi(2S)$	
Measured value	$3.36 \pm 0.20 \pm 0.12$	5% in ΔB	$0.73 \pm 0.15 \pm 0.02$	15% in ΔB
Corrected with $\sin\varphi > 0$	$3.22 \pm 0.20 \pm 0.12$		$0.62 \pm 0.15 \pm 0.02$	
Corrected with $\sin\varphi < 0$	$3.50 \pm 0.20 \pm 0.12$		$0.83 \pm 0.15 \pm 0.02$	
$e^+e^- \to K^+K^-$ average	2.43 ± 0.26 [3,31,32]		0.71 ± 0.05 [11]	

arxiv:2603.29854

Parameter	This work Positive	This work Negative	BES	CLEO	Seth *et al.*
Φ (°)	110.1 ± 6.7	-106.8 ± 5.7	$(89 \pm 35)^\circ$	$(93 \pm 20)^\circ$	$(66.6 \pm 11.5)^\circ$
$\mathcal{C}$	3.18 ± 0.16	3.77 ± 0.15	$2.6^{+0.9}_{-1.4}$	$2.8^{+1.2}_{-2.8}$	–
$\mathcal{F}$ (GeV^2)	0.467 ± 0.009	0.467 ± 0.009	–	–	
$\mathcal{B}$ (10^{-5})	7.49 ± 0.41	10.94 ± 0.49	6.1 ± 2.1	6.3 ± 0.7	7.48 ± 0.45

- 两个解首次分离（差别超3σ）→分支比精确测量.
- 相角 Φ 与分支比 $\mathcal{B}$ 存在强关联.
- 干涉导致分支比差别 ~30%，负解对应的分支比与PDG一致.

$e^+e^- \to \psi(2S) \to p\bar{p}$



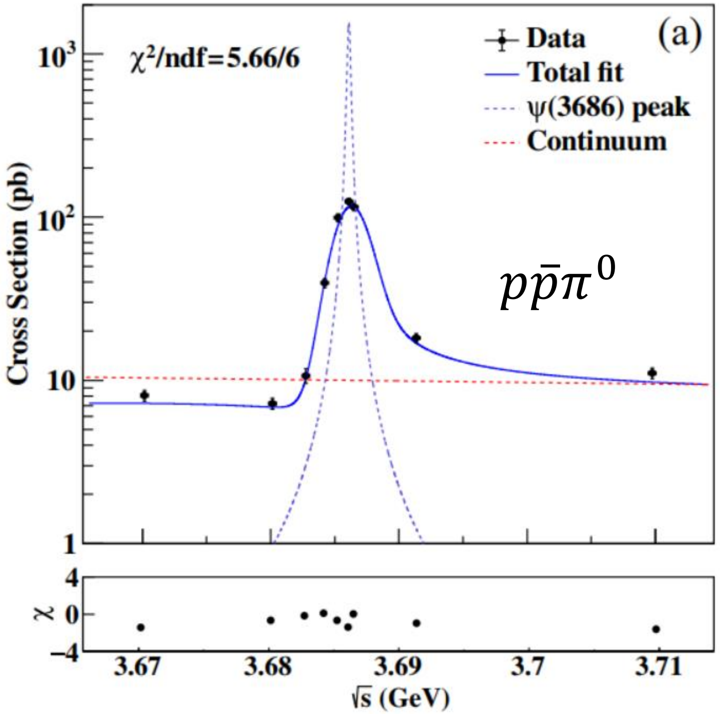
$$\sigma(s) = \frac{4\pi\alpha^2\beta C}{3s}\left(\frac{G_0}{s^2}\right)^2\left(1+\frac{1}{2\tau}\right)\left|1+\left(1+\mathcal{C}e^{i\Phi_{g,EM}}\right)\frac{s}{M}\frac{3\Gamma_{ee}/\alpha}{s-M_\psi^2+i\Gamma_\psi M_\psi}\right|^2$$

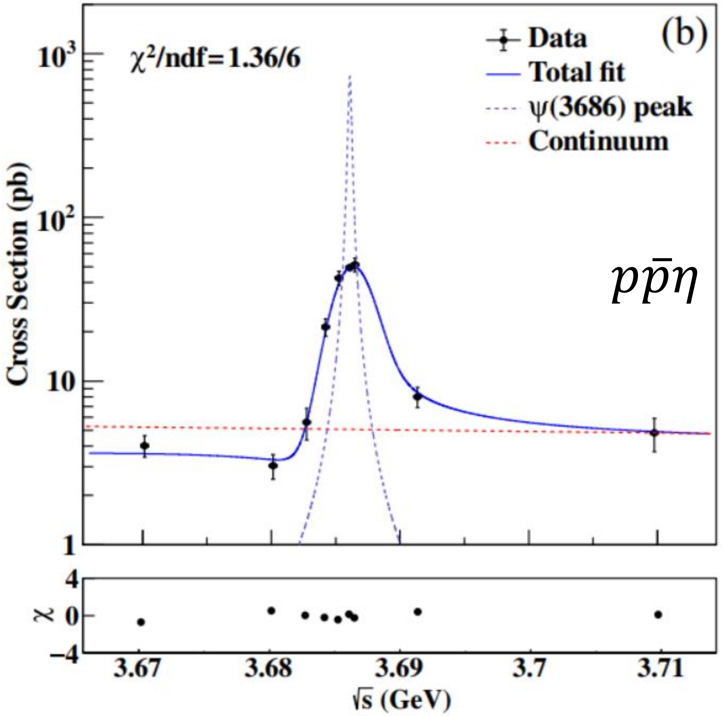
Parameter	Positive	Negative
$\Phi_{g,EM}(^\circ)$	105.9 ± 9.4	-105.3 ± 9.1
M_ψ (MeV/c^2)	3685.99 ± 0.08	3685.99 ± 0.08
$\mathcal{C}$	16.02 ± 1.25	16.63 ± 1.23
G_0 (GeV^4)	2.38 ± 0.15	2.38 ± 0.15
$\mathcal{B}$ (10^{-4})	3.21 ± 0.13	3.47 ± 0.19

VALUE (10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
2.94 ± 0.08 OUR FIT					
3.02 ± 0.08 OUR AVERAGE					
$3.05 \pm 0.02 \pm 0.12$	19k	ABLIKIM	2018T	BES3	$e^+e^- \to \psi(2S) \to p\bar{p}$
$3.08 \pm 0.05 \pm 0.18$	4.5k	[1] DOBBS	2014		$e^+e^- \to \psi(2S) \to p\bar{p}$
$3.36 \pm 0.09 \pm 0.25$	1.6k	ABLIKIM	2007C	BES	$e^+e^- \to \psi(2S) \to p\bar{p}$
$2.87 \pm 0.12 \pm 0.15$	557	PEDLAR	2005	CLEO	$e^+e^- \to \psi(2S) \to p\bar{p}$
1.4 ± 0.8	4	BRANDELIK	1979C	DASP	$e^+e^- \to \psi(2S) \to p\bar{p}$
2.3 ± 0.7		FELDMAN	1977	MRK1	$e^+e^- \to \psi(2S) \to p\bar{p}$

- $|\Phi| \sim 90^\circ$
- $\mathcal{B}$ is consistent with the previous BESIII and PDG.

$e^+e^- \to \psi(2S) \to p\bar{p}\pi^0(\eta)$





BESIII, Phys. Rev. D 111, 032011 (2025)

$$\sigma_{\rm Born} = |A_{\rm con} + A_{\rm res} \times e^{i\phi}|^2$$

$$A_{\rm con}(s) = a/s^n$$

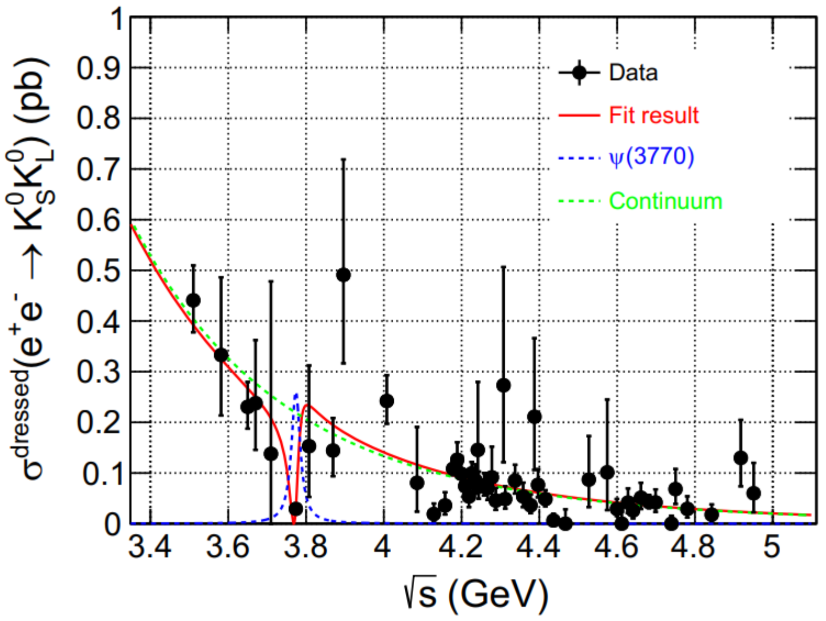
$$A_{\rm res}(s) = \frac{\sqrt{12\pi\Gamma_{ee}\Gamma_{\rm tot}\mathcal{B}_f}}{s - M^2 + iM\Gamma_{\rm tot}}$$

- 截面公式稍微有不同
- 相角在误差范围内与 $\pm 90°$ 一致.

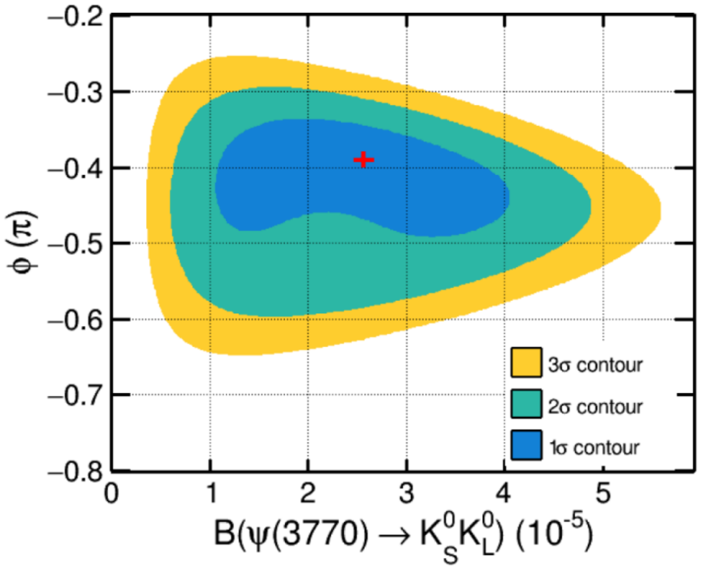
channel	Solution	ϕ (°)	Br ($\times 10^{-6}$)	Φ (°)	Br_{PDG}($\times 10^{-6}$)
$\psi(2S) \to p\bar{p}\pi^0$	Constructive	65.0 ± 6.7	$133.9 \pm 11.2 \pm 2.3$	82.5 ± 8.9	153 ± 7
	Destructive	-68.9 ± 5.7	$183.7 \pm 13.7 \pm 3.2$	-83.8 ± 7.1	
$\psi(2S) \to p\bar{p}\eta$	Constructive	58.9 ± 14.1	$61.5 \pm 6.5 \pm 1.1$	77.3 ± 22.1	60 ± 4
	Destructive	-63.8 ± 12.1	$84.4 \pm 6.9 \pm 1.4$	-79.5 ± 17.5	

- 干涉对分支比的影响是肉眼可见的！

$e^+e^- \to \psi(3770) \to K_S K_L$



BESIII, Phys. Rev. Lett. 132, 131901 (2024)



$$\sigma^{\text{dressed}} = \left| BW \cdot e^{i\phi} + \frac{a}{(\sqrt{s})^n} \cdot \sqrt{\Phi(\sqrt{s})} \right|^2$$

$$BW = \frac{\sqrt{12\pi\Gamma_{ee}\Gamma B}}{s - M^2 + iM\Gamma} \sqrt{\frac{\Phi(s)}{\Phi(M)}},\ \Phi(s) = \frac{q^3}{s}$$

- 两个解在1σ 范围内区分不开，$\mathcal{B} = (2.63^{+1.40}_{-1.59}) \times 10^{-5}$and $\phi = \left(-0.39^{+0.05}_{-0.10}\right)\pi$.
- $\psi(3770)$ 显著性超过 10σ.
- 首次观测到不含粲强子末态衰变 $\psi(3770) \to K_S K_L$.

总结与展望

channel	positive		negative	
	Φ	Br or σ	Φ	Br or σ
$J/\psi \to 2(\pi^+\pi^-)\pi^0$	$(84.9 \pm 3.6)^\circ$	$(4.73 \pm 0.44)\%$	$(-84.7 \pm 3.1)^\circ$	$(4.85 \pm 0.45)\%$
$J/\psi \to \phi\eta$	$[133^\circ, 228^\circ]$			
$J/\psi \to \Sigma^+\bar{\Sigma}^-$	$(107.9 \pm 24.9)^\circ$	$(1.14 \pm 0.04) \times 10^{-3}$	$(-107.6 \pm 24.3\ )^\circ$	$(1.19 \pm 0.04) \times 10^{-3}$
$J/\psi \to K^*(892)^+ K^-$	$(180.1 \pm 31.8)^\circ$		$(7.09 \pm 0.28) \times 10^{-3}$	
$J/\psi \to K^*(892)^0\bar{K}^0$	$(155.2 \pm 15.5)^\circ$	$(4.18 \pm 0.18) \times 10^{-3}$	$(-154.1 \pm 15.5)^\circ$	$(4.31 \pm 0.19) \times 10^{-3}$
$J/\psi \to K_S^0 K^+\pi^-$	$(123.7 \pm 5.3)^\circ$	$(5.17 \pm 0.20) \times 10^{-3}$	$(-123.1 \pm 5.2)^\circ$	$(5.36 \pm 0.20) \times 10^{-3}$
$\psi(3686) \to K^+K^-$	$(110.1 \pm 6.7)^\circ$	$(7.49 \pm 0.41) \times 10^{-3}$	$(-106.8 \pm 5.7)^\circ$	$(10.94 \pm 0.48) \times 10^{-5}$
$\psi(3686) \to p\bar{p}$	$(105.9 \pm 9.4)^\circ$	$(3.21 \pm 0.13) \times 10^{-4}$	$(-105.3 \pm 9.1)^\circ$	$(3.47 \pm 0.19) \times 10^{-4}$
$\psi(3686) \to p\bar{p}\eta$	$(77.3 \pm 22.1)^\circ$	$(61.5 \pm 6.5 \pm 1.1) \times 10^{-6}$	$(-79.5 \pm 17.5)^\circ$	$(84.4 \pm 6.9 \pm 1.4) \times 10^{-6}$
$\psi(3686) \to p\bar{p}\pi^0$	$(82.5 \pm 8.9)^\circ$	$(133.9 \pm 11.2 \pm 2.3) \times 10^{-6}$	$(-83.8 \pm 7.1)^\circ$	$(183.7 \pm 13.7 \pm 3.2) \times 10^{-6}$
$\psi(3770) \to K_S K_L$	$(-0.39^{+0.05}_{-0.10})\pi$		$(2.63^{+1.40}_{-1.59}) \times 10^{-5}$	
$\psi(3770) \to p\bar{p}$	$(255.8^{+39.0}_{-26.6} \pm 4.8)^\circ$	$(0.059^{+0.070}_{-0.020} \pm 0.012)$ pb	$(266.9^{+6.1}_{-6.3} \pm 0.9)^\circ$	$(2.57^{+0.12}_{-0.13} \pm 0.12)$ pb
$\psi(3770) \to p\bar{p}\pi^0$	$(269.8^{+52.4}_{-48.0})^\circ$	$(0.06^{+0.10}_{-0.04})$ pb	$(269.7 \pm 2.3)^\circ$	(33.8 ± 1.8) pb
…	…	…	…	…

总结与展望

- 强-电磁作用之间的相位差可以用更精确的扫描实验方法直接测量.
- 目前实验数据对三个粲偶素呈现了不同的表现：
  - J/ψ衰变中，除VP末态表现出较大角度，其余$|\Phi|\sim 90^{\circ}$
  - $\psi(3686)$衰变中，$|\Phi|\sim 90^{\circ}$，多解问题导致分支比测量结果差别很大
  - $\psi(3770)$衰变中，$\Phi\sim -90^{\circ}$，呈现负干涉

  ⇒ 分支比测量需考虑干涉!!!
- 但与此相关的几个关键问题仍未解决：
  - Φ是否普适量？与初态、末态相关？
  - Φ值为多少？
  - Φ的物理本源是什么?
- “参会”有益，热忱欢迎理论及实验学家对此问题的讨论！

Thanks for your attention!

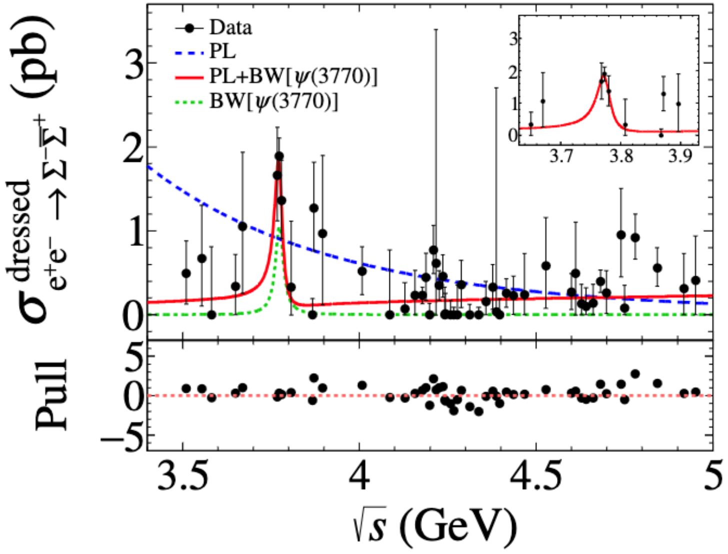
$e^+e^- \to \psi(3773) \to \Sigma^+\bar{\Sigma}^-$

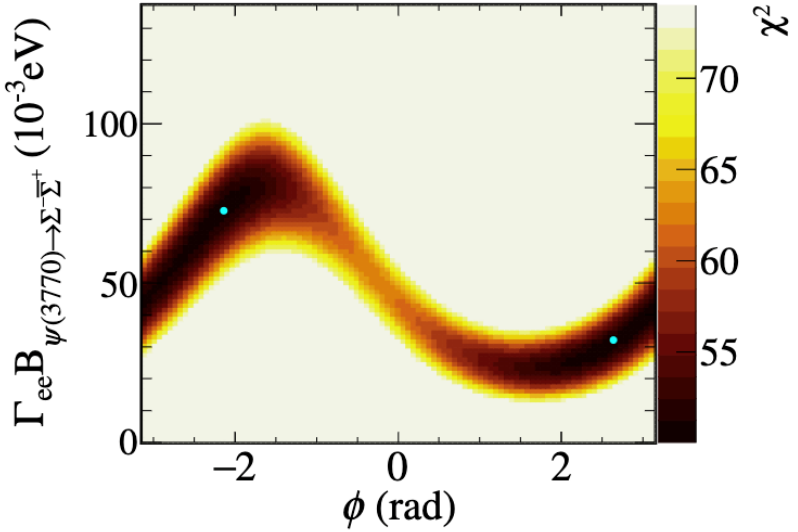
arxiv:2602.23835

$$\sigma^{\text{dressed}}(\sqrt{s}) = \left| c_0 \frac{\sqrt{P(\sqrt{s})}}{\sqrt{s}^{\,n}} + e^{i\phi}\text{BW}(\sqrt{s})\sqrt{\frac{P(\sqrt{s})}{P(M)}} \right|^2$$

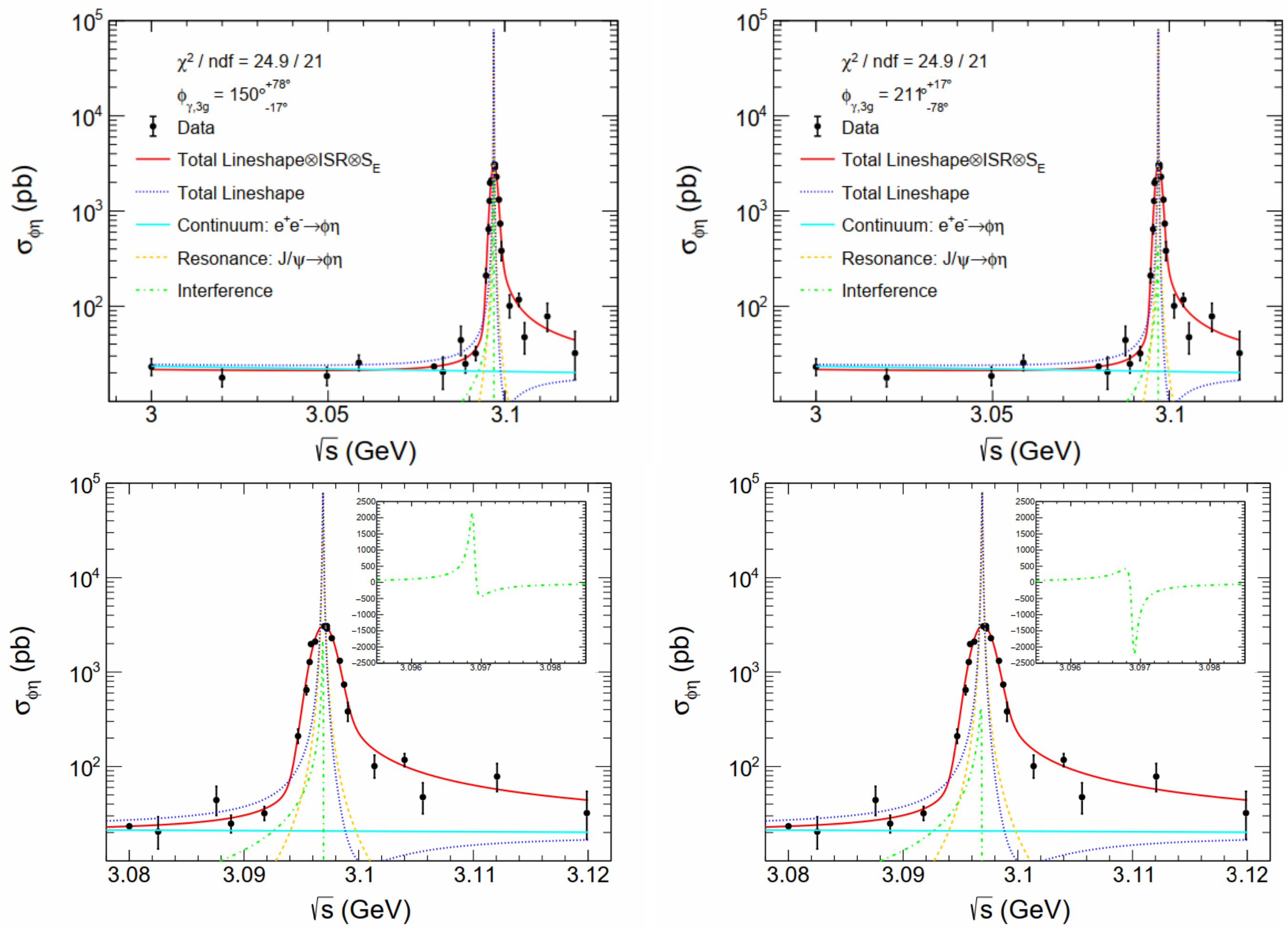
Parameter	Solution I	Solution II	χ^2/n.d.f
$\phi_{\psi(3770)}$	-2.0 ± 0.2	2.3 ± 0.2	$50.2/(52-4)$
$\Gamma_{ee}\mathcal{B}_{\psi(3770)}$	75.3 ± 4.5	27.7 ± 2.8	

- Relative phase compatible with 90°
- The decay $\psi(3770) \to \Sigma^-\bar{\Sigma}^+$ is observed for the first time with a significance of 5.5σ.



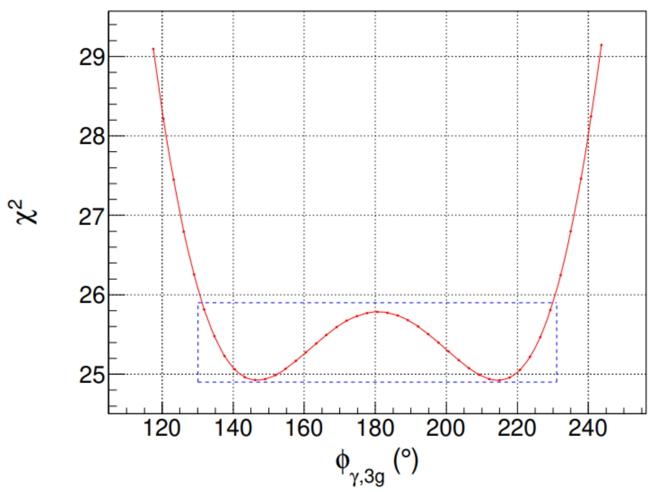


Scan measurement of $e^+e^- \to J/\psi \to \phi\eta$



2012 scan+2015/2018/2019 additional data points at 26 c.m. energies, total 452 pb^{-1}

BESIII, JHEP11(2025)077



- Two solutions
- Indistinguishable within 1σ confidence
- $\boldsymbol{\Phi_{3g,\gamma} \in [133^\circ, 228^\circ]}$