

粲偶素衰变中强-电磁干涉的研究

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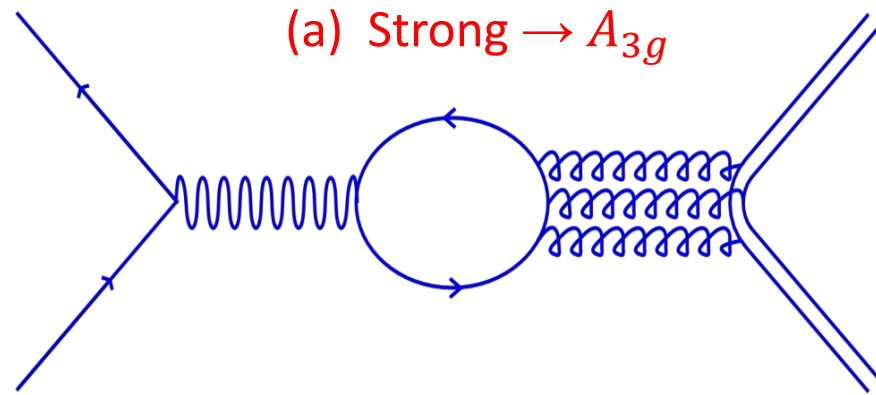
华北电力大学

第五届强子与重味物理理论与实验联合研讨会

河北师范大学

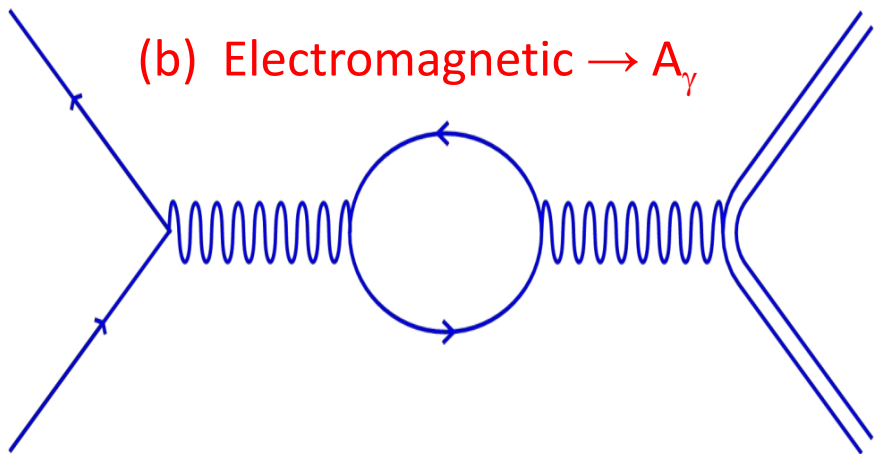
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Theory for the phase between strong and EM



(a) $e^+e^- \rightarrow R(q\bar{q}) \rightarrow$ hadrons via strong mechanism;

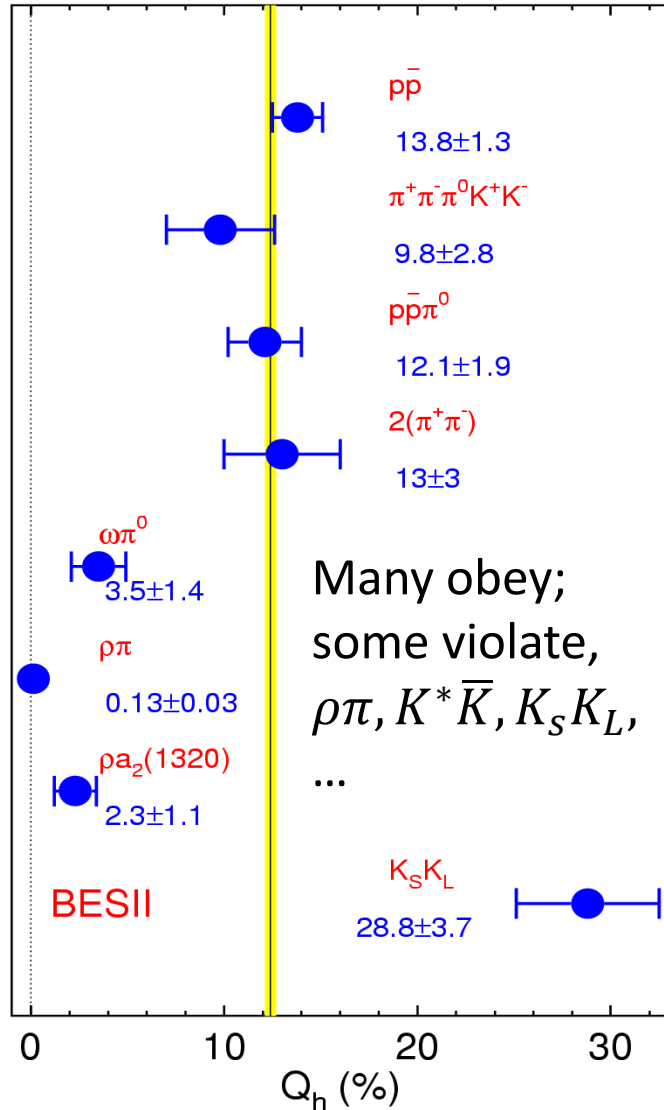
(b) $e^+e^- \rightarrow R(q\bar{q}) \rightarrow$ hadrons via EM mechanism;



pQCD regime: all are Real, phase between A_{3g} and A_γ should be 0° or 180°

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

$\rho\pi$ -puzzle and $\psi(3770) \rightarrow \text{non-}D\bar{D}$ puzzle



$$Q_h = \frac{Br_{\psi' \rightarrow X}}{Br_{J/\psi \rightarrow X}} = \frac{Br_{\psi' \rightarrow e^+e^-}}{Br_{J/\psi \rightarrow e^+e^-}} \sim 13\%$$

- Some argue that the phase differs in J/ψ and $\psi(2S)$ decays that cause different interferences and measured Br.

$$Br(\psi(3770) \rightarrow D^0\bar{D}^0) = (49.7 \pm 0.2 \pm 2.4)\%$$

$$Br(\psi(3770) \rightarrow D^+D^-) = (36.4 \pm 0.2 \pm 2.0)\%$$

$$Br(\psi(3770) \rightarrow D\bar{D}) = (86.1 \pm 0.2 \pm 4.1)\%$$

BESII results

$$Br(\psi(3770) \rightarrow \text{non-}D\bar{D}) = (13.9 \pm 0.2 \pm 4.1)\%$$

- Very few channels are observed!
- Strong interference between $A_{\psi(3770)}$ and A_{cont} ?

Γ_{10}	$b_1(1235)\pi$	$< 1.4 \times 10^{-5}$
Γ_{11}	$\phi\eta'$	$< 2.3 \times 10^{-5}$
Γ_{12}	$\omega\eta'$	$< 4 \times 10^{-4}$
Γ_{13}	$\rho^0\eta'$	$< 6 \times 10^{-4}$
Γ_{14}	$\phi\eta$	$(3.1 \pm 0.7) \times 10^{-4}$
Γ_{15}	$\omega\eta$	$< 1.4 \times 10^{-5}$
Γ_{16}	$\rho^0\eta$	$< 5 \times 10^{-4}$

Phase in J/ψ decay

SU3 in 1^-0^- ^[1,2,3,4], 0^-0^- ^[1,2,3], 1^-1^- ^[1], 1^+0^- ^[5], $B\bar{B}$ ^[2,6,7] decays show the phase in J/ψ decays between A_g and A_γ is $|\Phi| \sim 90^\circ$.

- $PP(0^-0^-)(\pi^+\pi^-, K^+K^-, K_S K_L)$ ^[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]
- $VP(1^+0^-)(K_1^\pm(1400)K^\mp, K_1^\pm(1270)K^\mp)$ ^[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]

- [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).

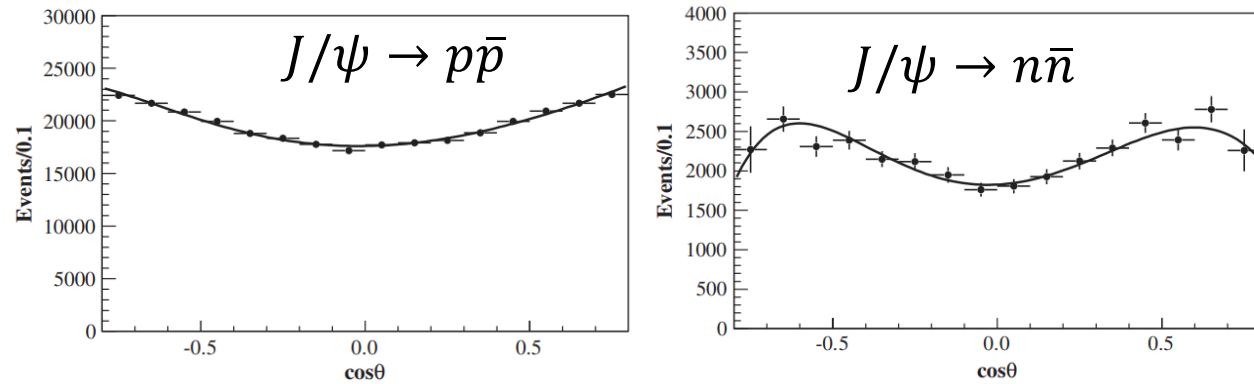
Decay	Amplitude	PDGx10 ⁴	Fitx10 ⁴	$\Delta\chi^2$
$\rho^0 \pi^0$	$g e^{i\phi} + e$	169.0 ± 15.0	133.00	1.13
$K^{*+} K^-$	$g (1-s) e^{i\phi} + e$	51.2 ± 3.0	51.5	0.01
$K^{*0} K^0$	$g (1-s)e^{i\phi} - 2e$	43.9 ± 3.1	48.5	0.48
$\omega \eta$	$(g X+d)e^{i\phi} + eX$	17.4 ± 2.0	18.5	0.06
$\phi \eta$	$(g (1-2s)Y+d)e^{i\phi} - 2eY$	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

Phase in $J/\psi \rightarrow N\bar{N}$

BESIII, PRD 86, 032014 (2012)



- $E_p(E_n)$ and S are EM and strong amplitudes of $J/\psi \rightarrow p\bar{p}$ ($n\bar{n}$), ϕ is the phase angle between $E_p(E_n)$ and S .
- Assumption:
 - $E_n = -E_p$ and $S_p = S_n = S$

$$Br(J/\psi \rightarrow p\bar{p}) = (2.112 \pm 0.004 \pm 0.031) \times 10^{-3}$$

$$\alpha = 0.595 \pm 0.012 \pm 0.015$$

$$Br(J/\psi \rightarrow n\bar{n}) = (2.07 \pm 0.01 \pm 0.17) \times 10^{-3}$$

$$\alpha = 0.50 \pm 0.04 \pm 0.21$$

$$\begin{aligned} \phi &= \cos^{-1}[(\mathcal{B}(J/\psi \rightarrow p\bar{p}) - S^2 - E_p^2)/(2SE_p)] \\ &= (88.7 \pm 8.1)^\circ. \end{aligned}$$

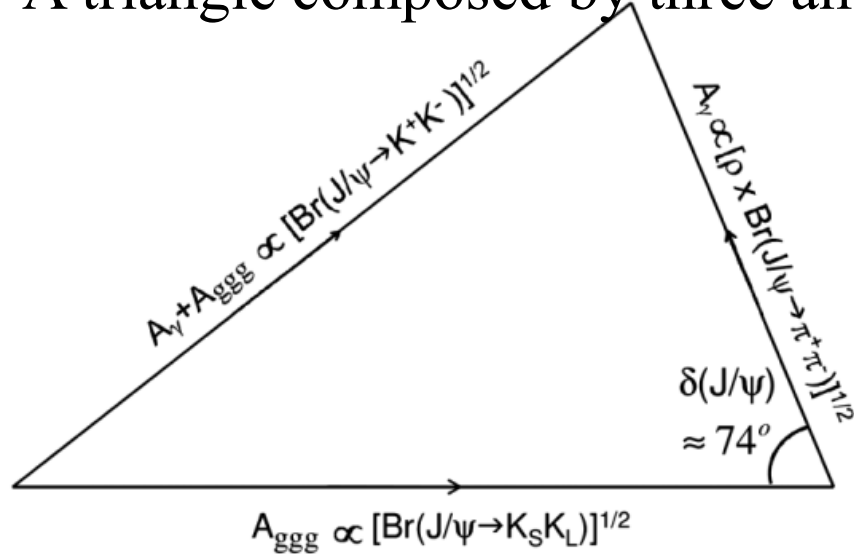
➤ The strong interaction is dominant.

➤ $\Phi = (-85.9 \pm 1.7)^\circ$ or $(+90.8 \pm 1.6)^\circ$ combined with other baryon decays from BES, MarkII, DMII, BESII, BESIII experiments. *K. Zhu, X. H. Mo, C. Z. Yuan, Inter. J. Mod. Phys. A, 30, 1550148 (2015)*

Phase in J/ψ and $\psi(2S) \rightarrow P\bar{P}$

A triangle composed by three amplitudes

Z. Metreveli, PRD 85, 092007 (2012)



$$\delta(\psi)_{\text{PP}} = \cos^{-1} \left(\frac{\mathcal{B}(K_S K_L) + \rho \mathcal{B}(\pi^+ \pi^-) - \mathcal{B}(K^+ K^-)}{|2\sqrt{\mathcal{B}(K_S K_L) \times \rho \times \mathcal{B}(\pi^+ \pi^-)}|} \right)$$

Φ in J/ψ

	Mark III [10]	BES [16]	This analysis
$\mathcal{B}(J/\psi \rightarrow \pi^+ \pi^-) \times 10^4$	1.58 ± 0.25	...	1.47 ± 0.18
$\mathcal{B}(J/\psi \rightarrow K^+ K^-) \times 10^4$	2.39 ± 0.33	...	2.86 ± 0.21
$\mathcal{B}(J/\psi \rightarrow K_S K_L) \times 10^4$	1.01 ± 0.18	1.82 ± 0.13	2.62 ± 0.21
$\delta(J/\psi)$	$(88 \pm 11)^\circ$	...	$(73.6 \pm 5.6)^\circ$

Φ in $\psi(2S)$

	DASP [13] 1979	BES [6,7] 2004	CLEO [8] 2005	This analysis
$\mathcal{B}(\psi(2S) \rightarrow \pi^+ \pi^-) \times 10^6$	80 ± 50	8.4 ± 6.5	8 ± 8	7.6 ± 2.6
$\mathcal{B}(\psi(2S) \rightarrow K^+ K^-) \times 10^6$	100 ± 70	61 ± 21	63 ± 7	74.8 ± 4.5
$\mathcal{B}(\psi(2S) \rightarrow K_S K_L) \times 10^6$	...	52.4 ± 6.7	58.0 ± 9.0	52.8 ± 4.2
$\delta(\psi(2S))$	...	$(91 \pm 35)^\circ$	$(87 \pm 20)^\circ$	$(113.4 \pm 11.5)^\circ$

Phase in J/ψ and $\psi(2S) \rightarrow P\bar{P}$

With only two $K\bar{K}$ amplitudes

BABAR, PRD 92, 072008 (2015)

$$\mathcal{B}(\psi \rightarrow K^+K^-) = |A_\gamma^{K^+K^-} + A_s e^{i\varphi}|^2,$$

$$\mathcal{B}(\psi \rightarrow K_S K_L) = |\kappa A_\gamma^{K^+K^-} + A_s e^{i\varphi}|^2,$$

$$\delta\mathcal{B} = 2\sqrt{\frac{\sigma_0}{\sigma_\psi}} A_s \sin\varphi.$$

Φ in J/ψ	$J/\psi \rightarrow K_S K_L$	φ	$\varphi(\kappa=0)$
	BES [35]		$(97 \pm 5)^\circ$	$(98 \pm 4)^\circ$
		$-(97 \pm 5)^\circ$	$-(96 \pm 4)^\circ$
Seth <i>et al.</i> [18]		$(111 \pm 5)^\circ$	$(108 \pm 4)^\circ$
		$-(109 \pm 5)^\circ$	$-(107 \pm 4)^\circ$

Φ in $\psi(2S)$	φ	$\varphi(\kappa=0)$
		$(82 \pm 12)^\circ$	$(92 \pm 9)^\circ$
	$-(58 \pm 14)^\circ$	$-(57 \pm 12)^\circ$

$\mathcal{B}(\psi \rightarrow K^+K^-) \times 10^4$

Measured value

Corrected with $\sin\varphi > 0$

Corrected with $\sin\varphi < 0$

$e^+e^- \rightarrow K^+K^-$ average

$\psi(2S) \rightarrow J/\psi\pi^+\pi^-$, $J/\psi \rightarrow K^+K^-$ [18]

J/ψ

$\psi(2S)$

$3.36 \pm 0.20 \pm 0.12$

$3.22 \pm 0.20 \pm 0.12$

$3.50 \pm 0.20 \pm 0.12$

2.43 ± 0.26 [3,31,32]

2.86 ± 0.21

5%
in $\Delta\mathcal{B}$

$0.73 \pm 0.15 \pm 0.02$

$0.62 \pm 0.15 \pm 0.02$

$0.83 \pm 0.15 \pm 0.02$

0.71 ± 0.05 [11]

15%
in $\Delta\mathcal{B}$

$\psi(2S) \rightarrow J/\psi\pi^+\pi^-$, $J/\psi \rightarrow K^+K^-$

$(3.072 \pm 0.023 \pm 0.050)$

BESIII recent result
PRD 110, 032006 (2024)

Phase in $\psi(2S)$

From the analysis of BESIII data made by R. Baldini^[1]:

- $\psi(2S) \rightarrow VP (1^- 0^-)$: $\Phi = (159 \pm 12)^\circ$
- $\psi(2S) \rightarrow K^* K$ only: $\Phi = (159 \pm 24)^\circ$
- $\psi(2S) \rightarrow PP (0^- 0^-)$: $\Phi = (95 \pm 11)^\circ$

Analysis by Mahiko Suzuki^[2] with Babar data:

- $\psi(2S) \rightarrow 1^- 0^-$: tends to have large phase,
- $\psi(2S) \rightarrow 1^+ 0^-$: $\Phi \sim 0^\circ$
- Difference could be caused by lower statistics of Babar data than that of BESIII.

PP($0^- 0^-$) mode from BES result^[3]:

- $\psi(2S) \rightarrow K_S K_L, K^+ K^-, \pi^+ \pi^-$:
 $\Phi = (-82 \pm 29)^\circ$ or $(121 \pm 27)^\circ$

Analysis^[4] of $\psi(2S)$ decaying to baryon pairs from CLEO and BESII:

- **baryon pairs:**
 $\Phi = (-98 \pm 25)^\circ$ or $(+134 \pm 25)^\circ$

The Φ change between J/ψ and $\psi(2S)$ is a puzzle, very likely related to $\rho\pi$ puzzle

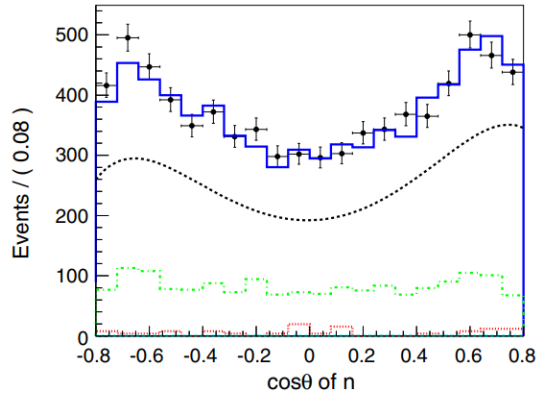
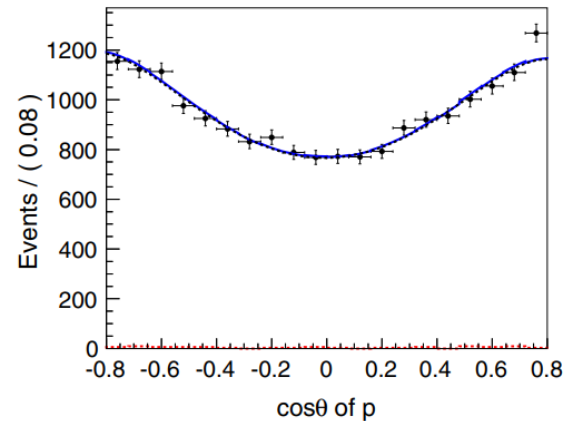
[1] Rinaldo Baldini Ferroli, Orsay (France), 2014

[2] Mahiko Suzuki, Phys. Rev. D 63, 054021 (2000)

[3] BES Collaboration, Phys. Rev. Lett. 92, 052001 (2004)

[4] K. Zhu, X. H. Mo, C. Z. Yuan, Inter. J. Mod. Phys. A, 30, 1550148 (2015)

Phase in $\psi(2S) \rightarrow N\bar{N}$ BESIII, PRD 98, 032006 (2018)



- $Br(\psi(3686) \rightarrow n\bar{n}) = (3.06 \pm 0.06 \pm 0.14) \times 10^{-4}$
- $\alpha_{n\bar{n}} = 0.68 \pm 0.12 \pm 0.11$
- $Br(\psi(3686) \rightarrow p\bar{p}) = (3.05 \pm 0.20 \pm 0.12) \times 10^{-4}$
- $\alpha_{p\bar{p}} = 1.03 \pm 0.06 \pm 0.03$

- The α values are similar in $J/\psi \rightarrow N\bar{N}$, $\Phi \sim 90^\circ$.
- In $\psi(3686) \rightarrow N\bar{N}$, α values are different.
- A more complex mechanism in $\psi(3686) \rightarrow N\bar{N}$?
- It makes a similar and straight forward extraction of the phase angle impossible in the decay of $\psi(3686) \rightarrow N\bar{N}$, and further studies are deserved.

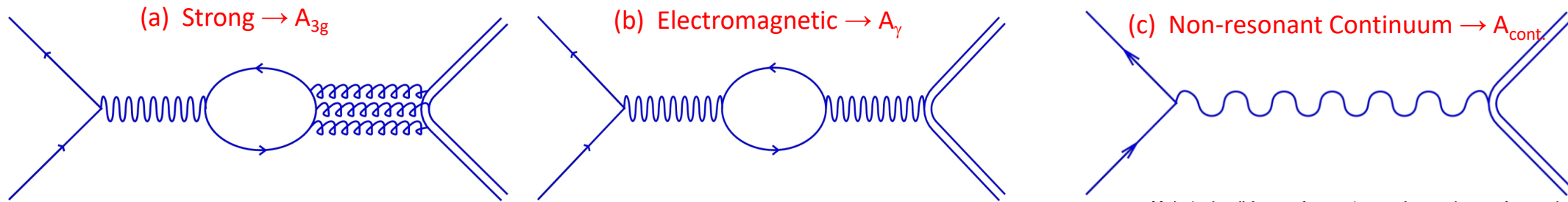
Phase in $\psi(3770)$

- From R. Baldini (Orsay (France), (2014)), $|\Phi| \sim 90^\circ$

decay	continuum	$\Psi''(3770)$	sign	
$\rho\pi$	13.1 ± 2.8	7.4 ± 1.3	-	CLEOc, PRD 73(2006)012002
$\phi\eta$	2.1 ± 1.6	4.5 ± 0.7	+	CLEOc, PRD 73(2006)012002
$\rho\rho$	0.74 ± 0.08	0.4 ± 0.02	-	BESIII Y.Liang, Nov (2012)

- From P. Wang (arxiv:hep/0410028v2 (2004)),
 - Φ holds -90° in OZI suppressed decays of $\psi(3770)$.
 - From the $\rho\pi$ cross section measurement at $\psi(3770)$ and 3.67 GeV, $\rho\pi$ production is suppressed possibly by interference.

SU(3) independent--Scan method

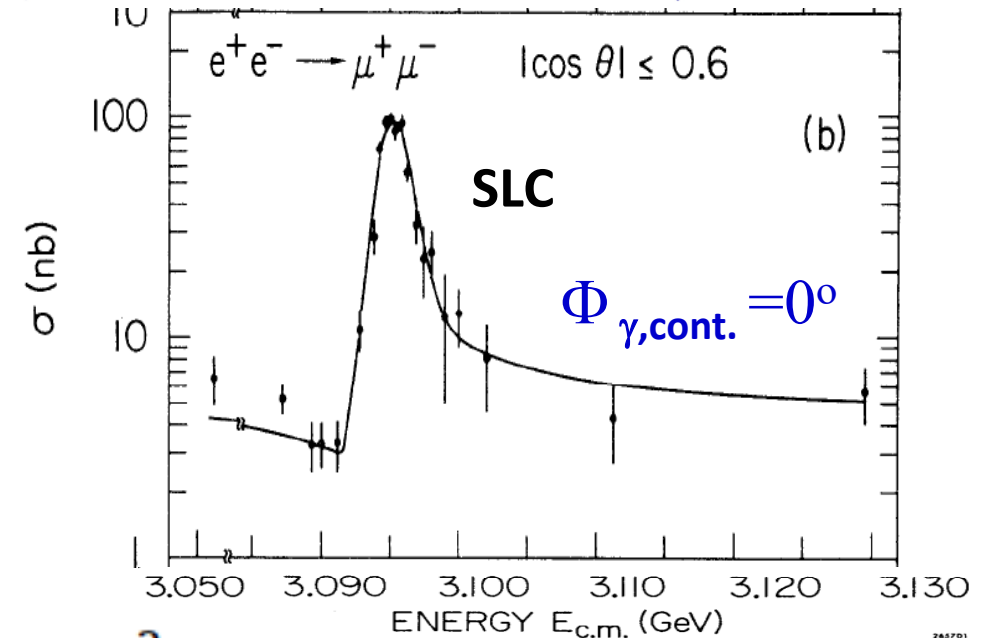


$$\sigma_{born} = |A_{3g} e^{i\Phi_{g,cont.}} + A_{\gamma} e^{i\Phi_{\gamma,cont.}} + A_{cont.}|^2$$

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

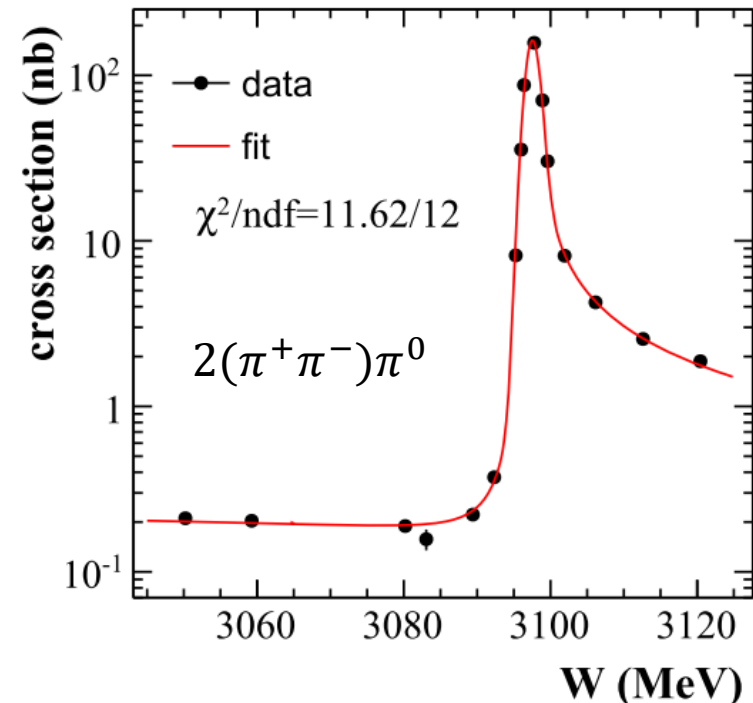
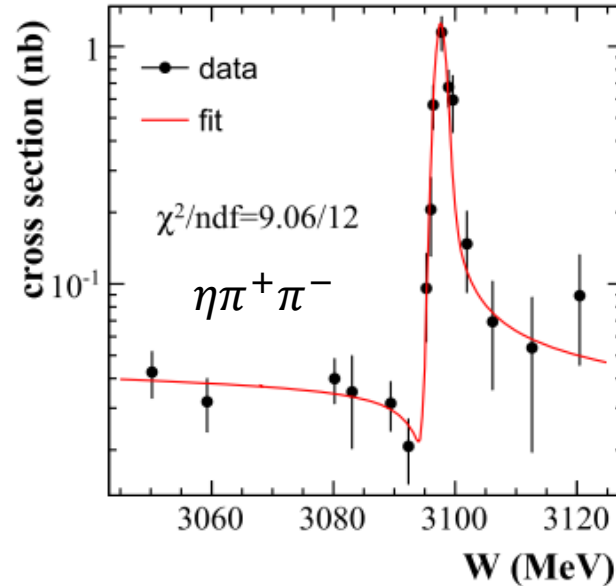
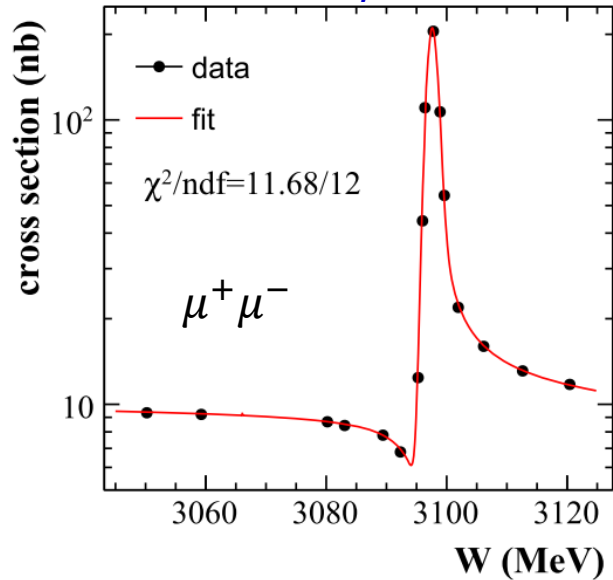
$$\sigma_{born} = |A_{3g} e^{i\Phi_{g,EM}} + A_{\gamma} + A_{cont.}|^2$$

$$\sigma^0(W) = \left(\frac{\mathcal{A}}{W^2}\right)^2 \frac{4\pi\alpha^2}{W^2} \left| 1 + \frac{3W^2 \sqrt{\Gamma_{ee}\Gamma_{\mu\mu}} (1 + C e^{i\Phi_{g,EM}})}{\alpha M(W^2 - M^2 + iM\Gamma)} \right|^2$$



Scan measurement of $e^+e^- \rightarrow J/\psi \rightarrow 2(\pi^+\pi^-)\pi^0$

BESIII, Phys. Lett. B 791, 375 (2019)



- $\Phi_{\gamma,cont.}^{\mu\mu} = (3.0 \pm 10.0)^\circ$
- $\Phi_{\gamma,cont.}^{\eta\pi^+\pi^-} = (-2 \pm 36)^\circ$ or $(-22 \pm 36)^\circ$
- $S_E = (0.90 \pm 0.03) \text{ MeV}$

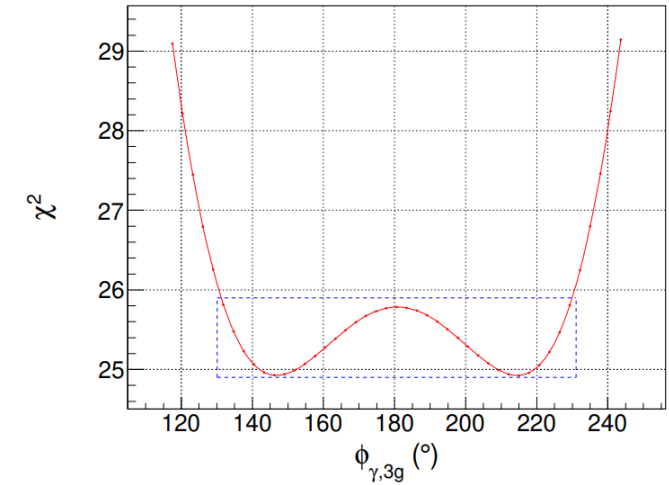
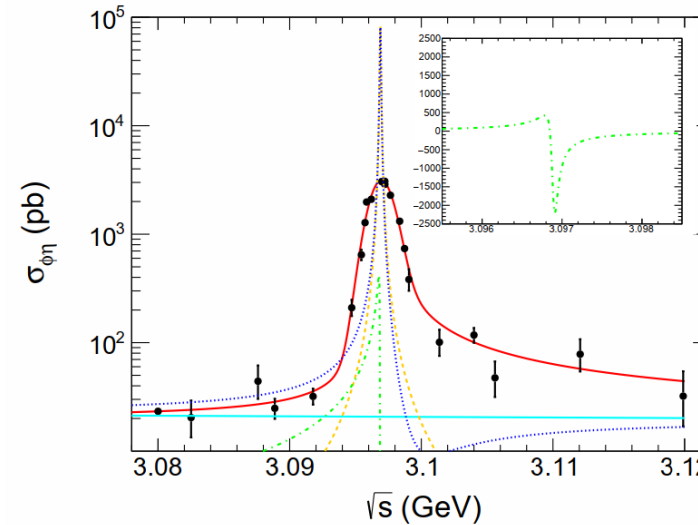
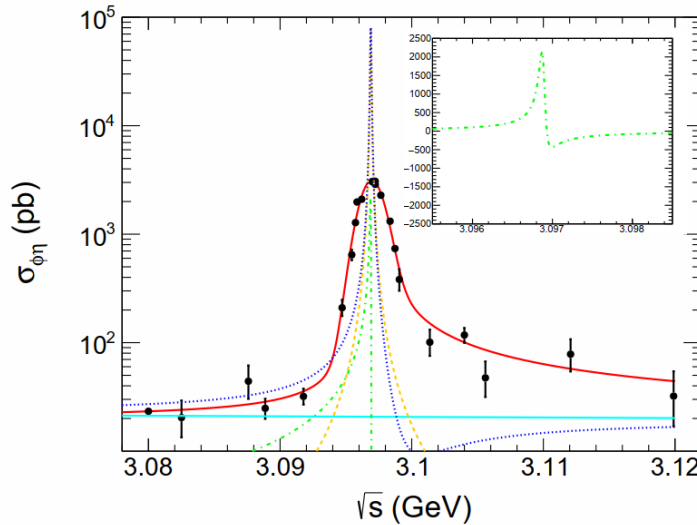
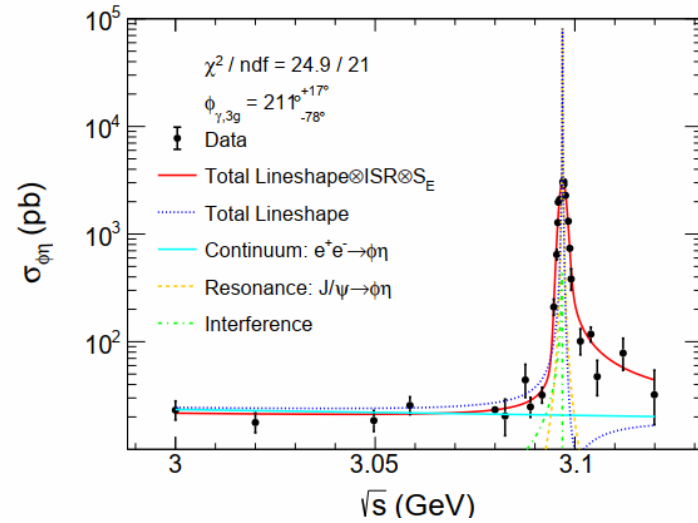
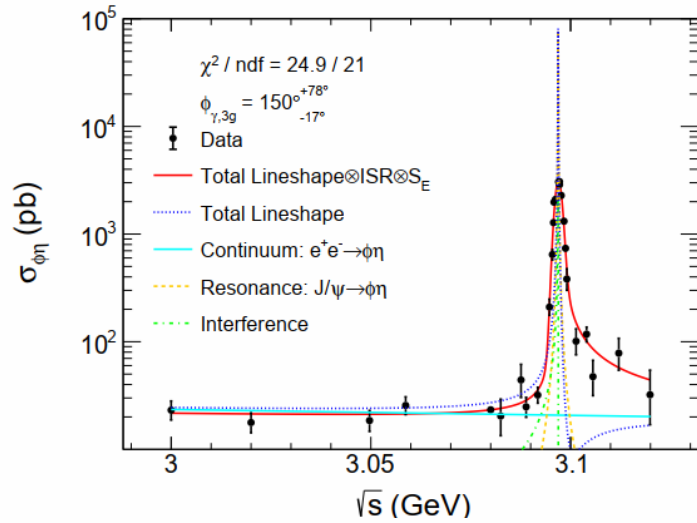
	$\Phi_{g,EM}$	$\mathcal{B}_{5\pi}$ (%)
Solution I	$(84.9 \pm 3.6)^\circ$	4.73 ± 0.44
Solution II	$(-84.7 \pm 3.1)^\circ$	4.85 ± 0.45

$$\mathcal{B}_{PDG} = (4.1 \pm 0.5)\%$$

The phase between A_γ and A_{3g} is found being consistent with 90° .

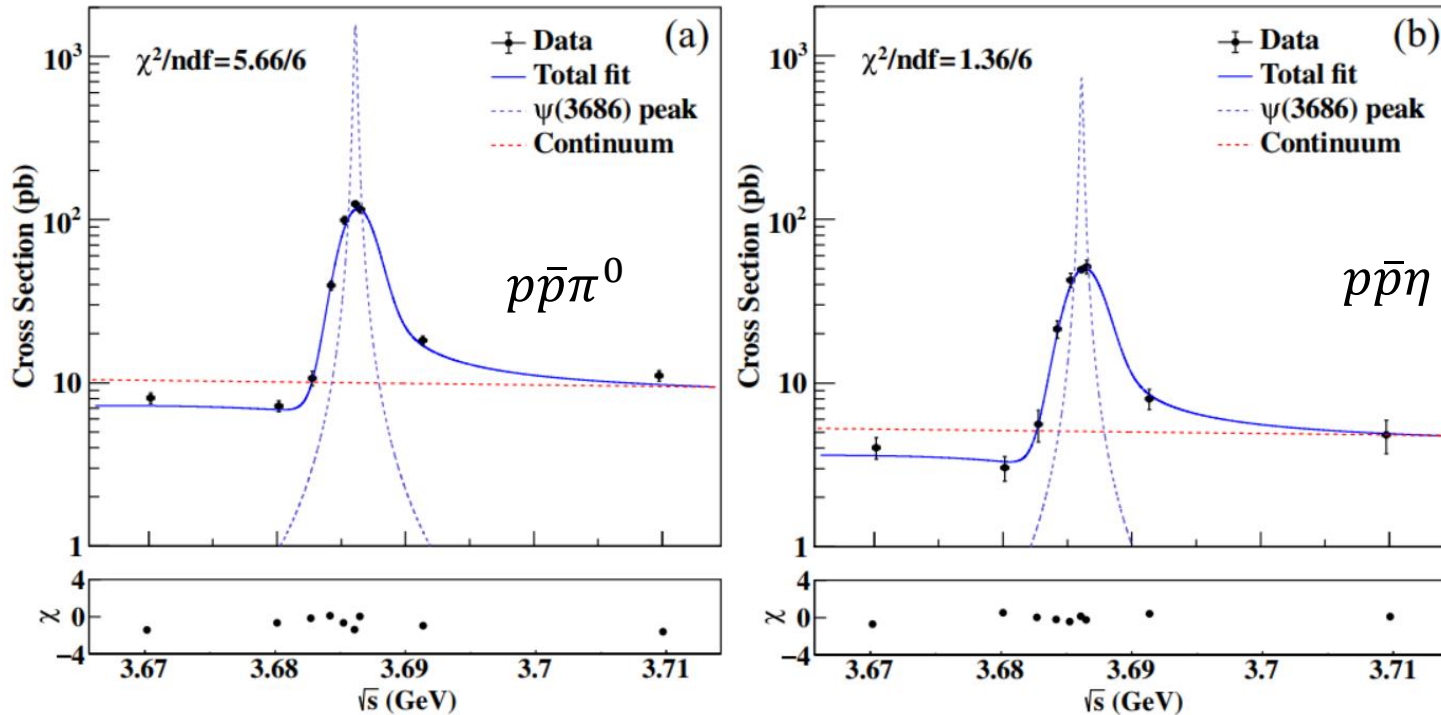
Scan measurement of $e^+e^- \rightarrow J/\psi \rightarrow \phi\eta$

BESIII, submitted to JHEP, arXiv: 2505.05888



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

Scan measurement of $e^+e^- \rightarrow \psi(2S) \rightarrow p\bar{p}\pi^0(\eta)$



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

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

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

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

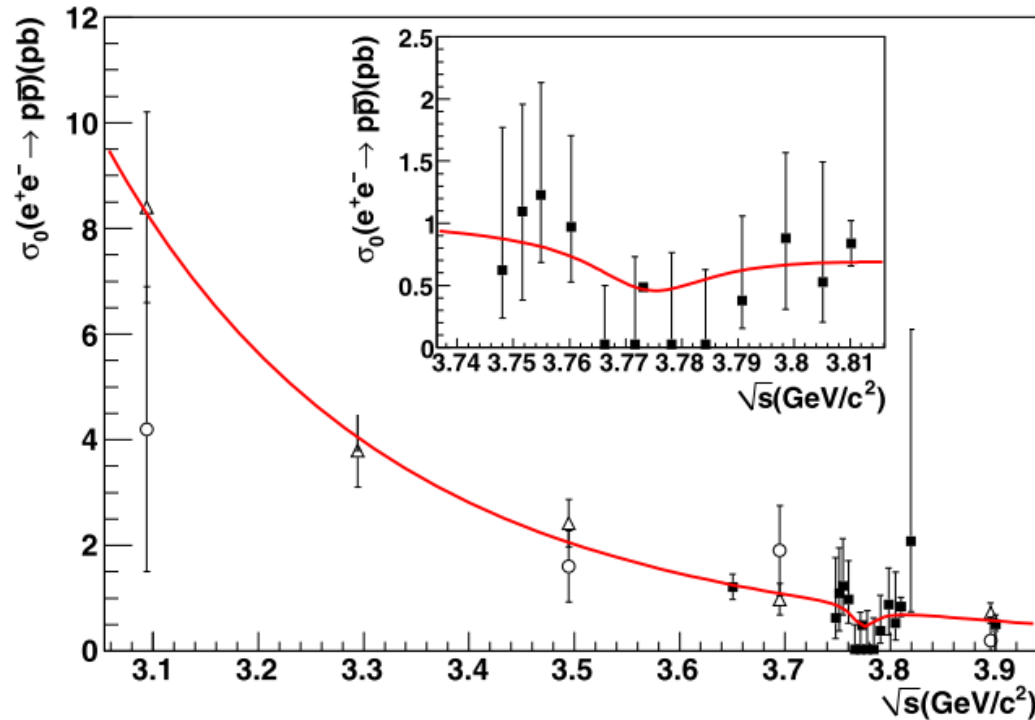
➤ Phase is consistent with $\pm 90^\circ$ after converting.

channel	Solution	ϕ ($^\circ$)	Br ($\times 10^{-6}$)	Φ ($^\circ$)	Br_{PDG} ($\times 10^{-6}$)
$\psi(2S) \rightarrow p\bar{p}\pi^0$	Constructive	65.0 ± 6.7	$133.9 \pm 11.2 \pm 2.3$	75.0 ± 8.9	153 ± 7
	Destructive	-68.9 ± 5.7	$183.7 \pm 13.7 \pm 3.2$	-77.9 ± 7.1	
$\psi(2S) \rightarrow p\bar{p}\eta$	Constructive	58.9 ± 14.1	$61.5 \pm 6.5 \pm 1.1$	69.8 ± 22.1	60 ± 4
	Destructive	-63.8 ± 12.1	$84.4 \pm 6.9 \pm 1.4$	-73.6 ± 17.5	

➤ The interference brings change in branching fraction results.

Scan measurement of $e^+e^- \rightarrow \psi(3770) \rightarrow p\bar{p}$

BESIII, Phys. Lett. B 735, 101 (2014)



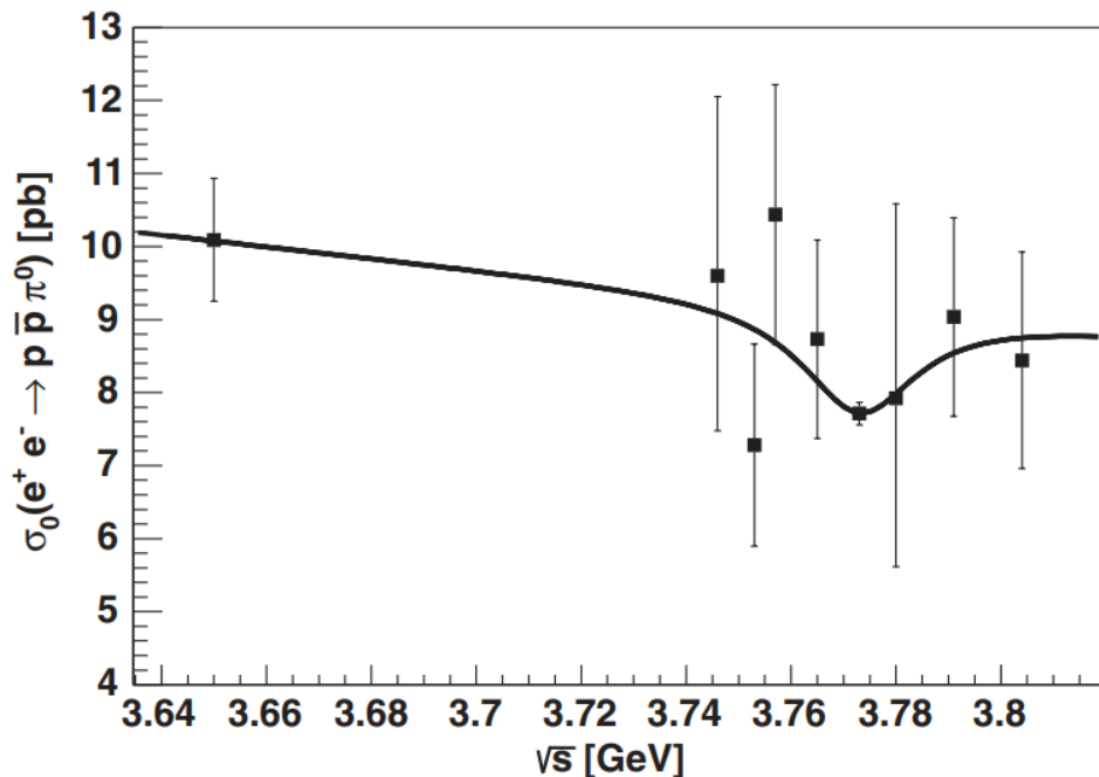
$$\begin{aligned}\sigma(s) &= |A_{con} + A_{\psi}e^{i\phi}|^2 \\ &= \left| \sqrt{\sigma_{con}(s)} + \sqrt{\sigma_{\psi}} \frac{m_{\psi}\Gamma_{\psi}}{s - m_{\psi}^2 + im_{\psi}\Gamma_{\psi}} e^{i\phi} \right|^2\end{aligned}$$

$\sigma_{(\psi(3770) \rightarrow p\bar{p})}^{dressed}$ (pb)	ϕ ($^{\circ}$)
$0.059^{+0.070}_{-0.020} \pm 0.012$ (< 0.166 at 90% C.L.)	$255.8^{+39.0}_{-26.6} \pm 4.8$
$2.57^{+0.12}_{-0.13} \pm 0.12$	$266.9^{+6.1}_{-6.3} \pm 0.9$

Even the interference is between A_{con} and A_{ψ} , the phase $\Phi_{3g,\gamma}$ is still close to -90° since A_g is much larger than A_{γ}

Scan measurement of $e^+e^- \rightarrow \psi(3770) \rightarrow p\bar{p}\pi^0$

BESIII, Phys. Rev. D 90, 032007 (2014)



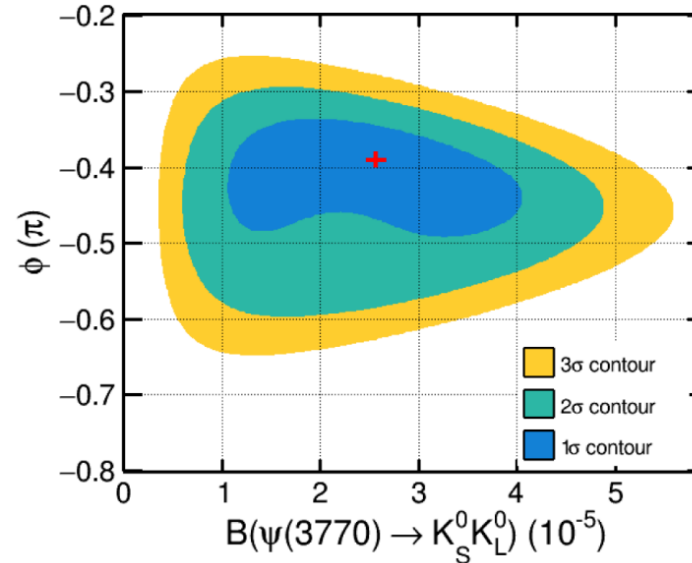
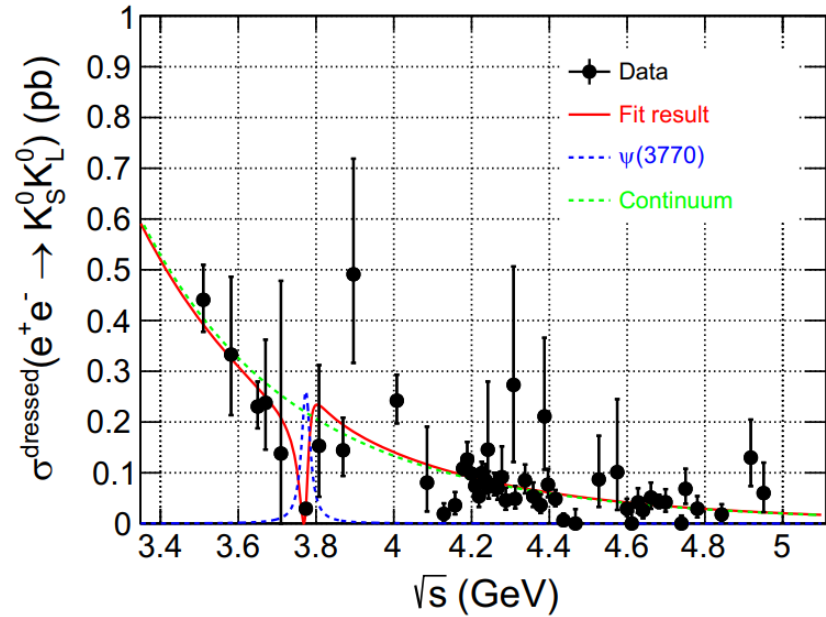
$$\sigma(s) = \left| \sqrt{\sigma_{\text{con}}} + \sqrt{\sigma_{\psi}} \frac{m\Gamma}{s - m^2 + im\Gamma} \exp(i\phi) \right|^2$$

Solution	$\sigma_0^{\psi(3770) \rightarrow p\bar{p}\pi^0}$ [pb]	ϕ_{Fit} [°]	$\sigma_0^{p\bar{p} \rightarrow \psi(3770)\pi^0}$ at 5.26 GeV [nb]
1	< 0.22	$269.8_{-48.0}^{+52.4} \pm 11.0$	< 0.79
2	$33.8 \pm 1.8 \pm 2.1$	$269.7 \pm 2.3 \pm 0.3$	122 ± 10

- The phase $\Phi_{3g,\gamma}$ is still close to -90° assuming A_g is much larger than A_γ
- **Significance for $\psi(3770)$ resonance $\sim 1.5 \sigma$**

Scan measurement of $e^+e^- \rightarrow \psi(3770) \rightarrow K_S K_L$

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



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

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

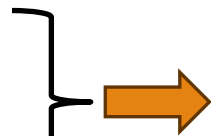
- $B = (2.63_{-1.59}^{+1.40}) \times 10^{-5}$ and $\phi = (-0.39_{-0.10}^{+0.05})\pi$ within 1σ likelihood contour.
- Significance of $\psi(3770)$ resonance contribution determined to be 10σ .
- First observe the **charmless decay** $\psi(3770) \rightarrow K_S K_L$.

Summary

- The phase between strong and EM can be measured with SU(3) dependent method and scan method.
- Critical problems about the phase is a mystery:
 - Is the phase universal? Independent of initial or final state?
 - What is the sign of the phase?
- Input from theorists is highly welcome!

Inter. between A_{EM} and A_g

Inter. between A_{cont} and A_{res}



Measurements (Br) deviate from its true value (heavily).

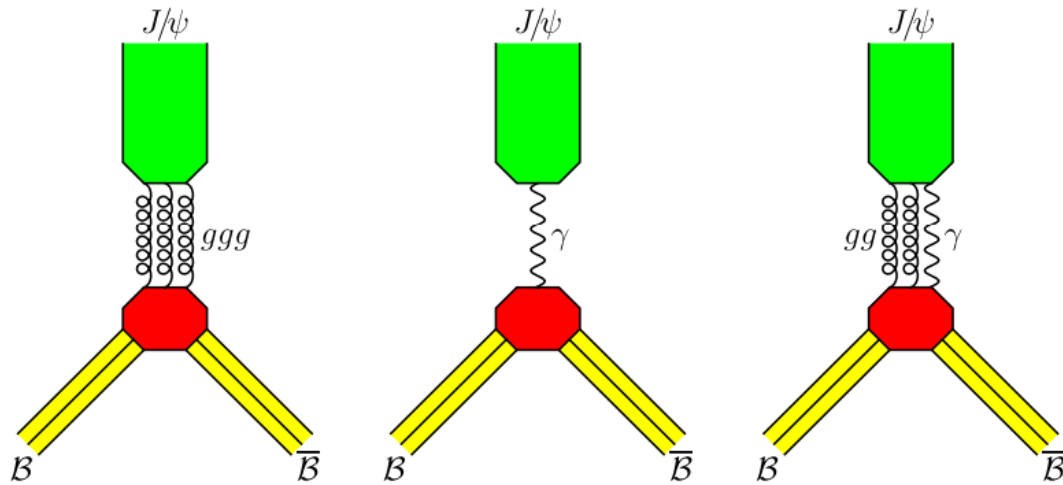
Must be considered in all measurements!

Thanks for your attention!

Model dependent experimental evidences

from J/ψ decays

R. Baldini, A. Mangoni, S. Pacetti, K. Zhu;
Phy. Lett. B 799, 135041 (2019)



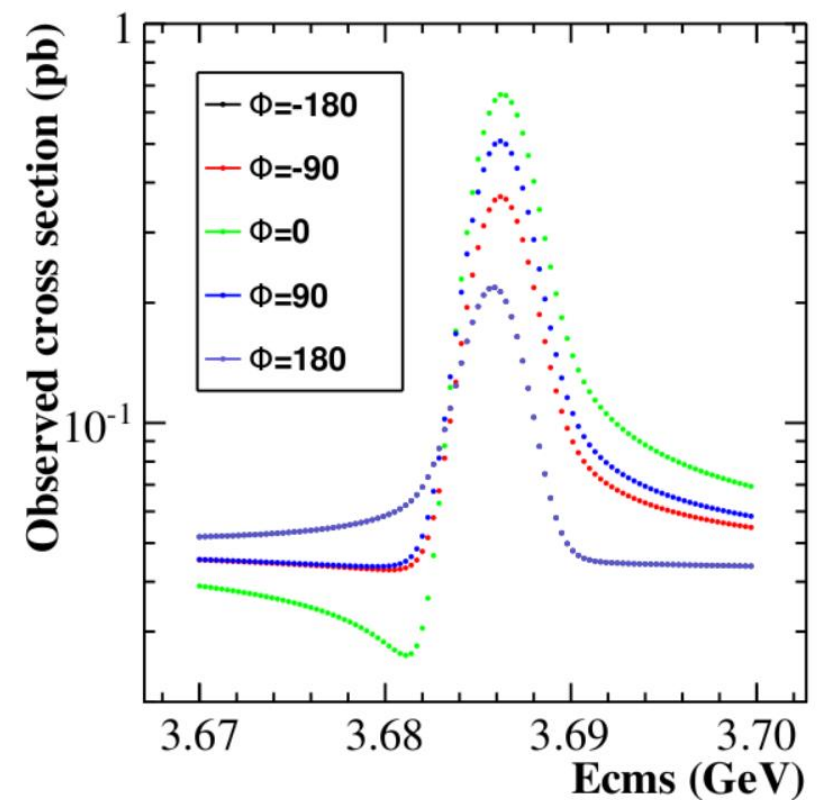
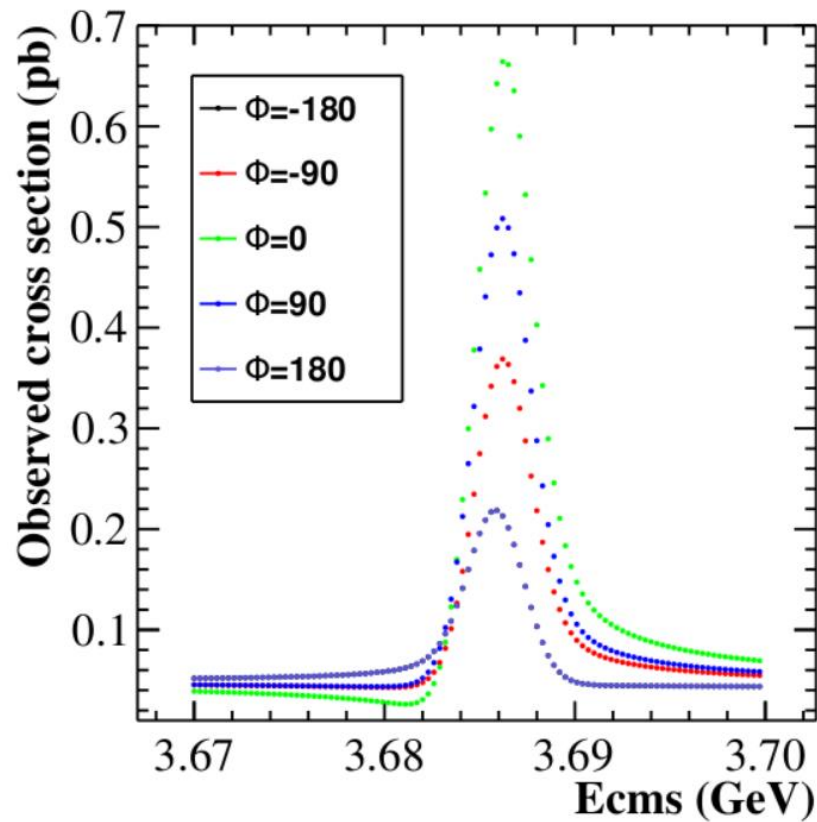
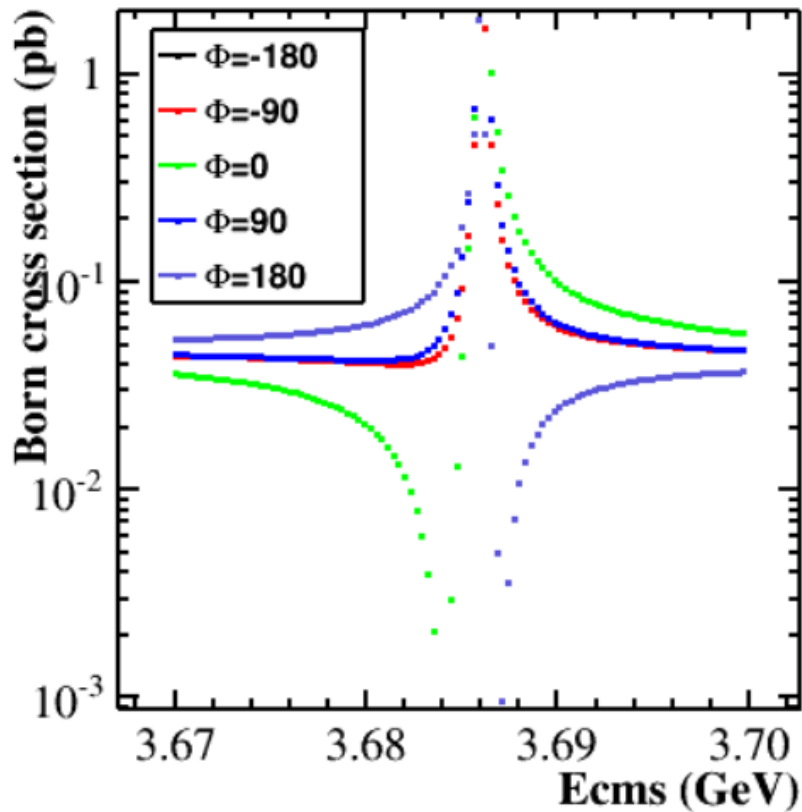
$B\bar{B}$	$BR_{B\bar{B}}^{\text{exp}} \times 10^3$	$BR_{B\bar{B}} \times 10^3$
$\Sigma^0 \bar{\Sigma}^0$	1.164 ± 0.004	1.160 ± 0.041
$\Lambda \bar{\Lambda}$	1.943 ± 0.003	1.940 ± 0.055
$\Lambda \bar{\Sigma}^0 + \text{c.c.}$	0.0283 ± 0.0023	0.0280 ± 0.0024
$p \bar{p}$	2.121 ± 0.029	2.10 ± 0.16
$n \bar{n}$	2.09 ± 0.16	2.10 ± 0.12
$\Sigma^+ \bar{\Sigma}^-$	1.50 ± 0.24	1.110 ± 0.086
$\Sigma^- \bar{\Sigma}^+$	/	0.857 ± 0.051
$\Xi^0 \bar{\Xi}^0$	1.17 ± 0.04	1.180 ± 0.072
$\Xi^- \bar{\Xi}^+$	0.97 ± 0.08	0.979 ± 0.065

- Consider the small contribution from $A_{gg\gamma}$
- Assume $A_{gg\gamma}$ has the same phase as A_{3g} to A_γ
- Perform SU(3) analysis based on experimental branching ratios of J/ψ decaying to baryons

$$\Phi = (73 \pm 8)^\circ$$

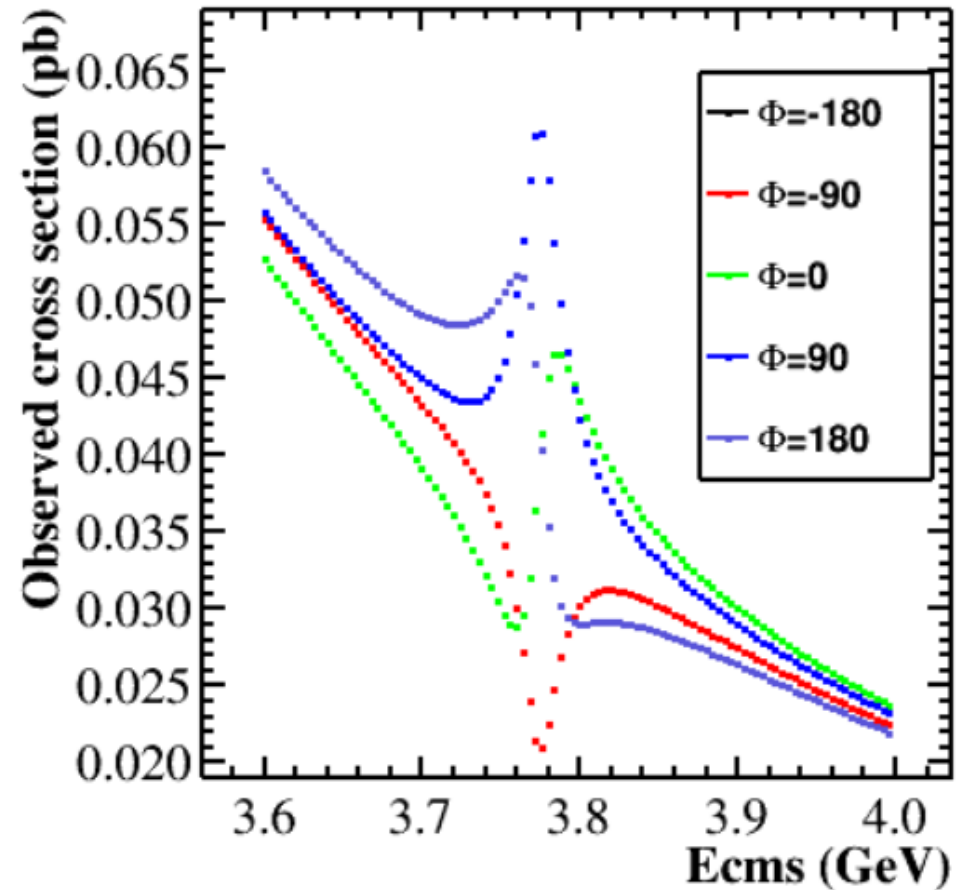
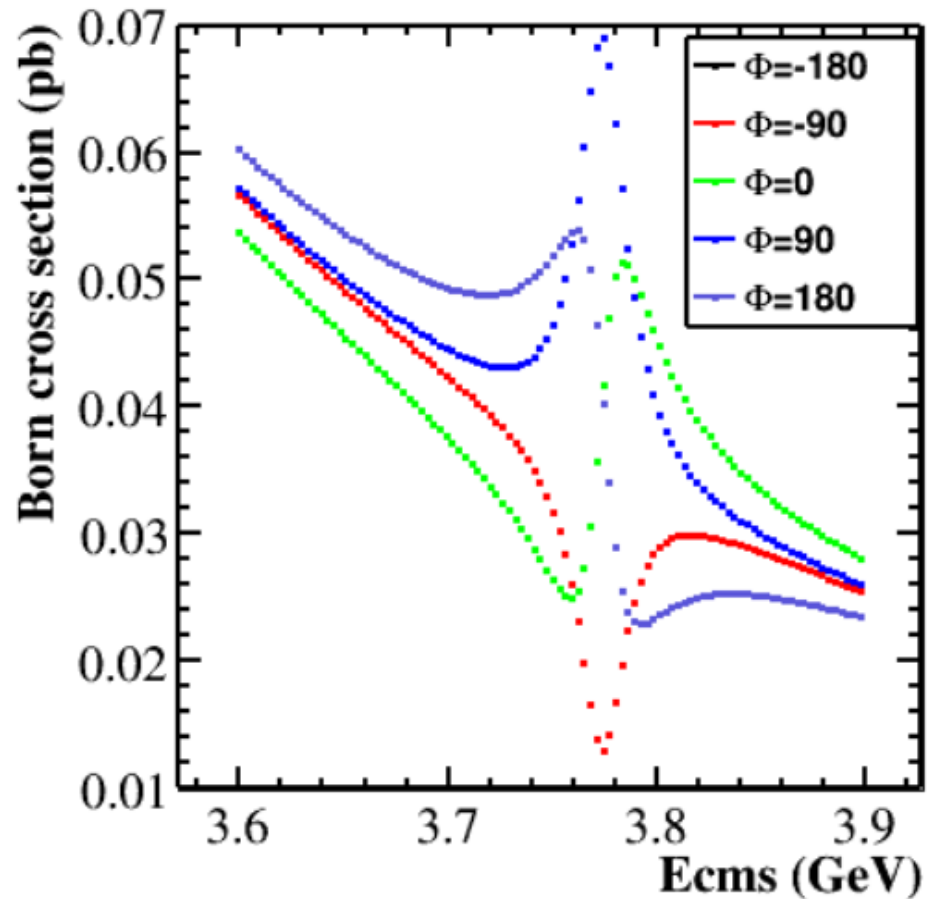
Br result from SU(3)
very close to PDG

Prediction for line-shapes of $\psi(3686)$



- For narrow resonances, the beam energy spread is much larger than the natural width.
- The observed cross section and Born cross section are very different.

Prediction for line-shapes of $\psi(3770)$



- For wide resonances, the beam energy spread is smaller than the natural width.
- The observed cross section and Born cross section are very similar.

四种相互作用

Properties of the Interactions

The strengths of the interactions (forces) are shown relative to the strength of the electromagnetic force for two u quarks separated by the specified distances.

Property	Gravitational Interaction	Weak Interaction (Electroweak)	Electromagnetic Interaction	Strong Interaction
Acts on:	Mass – Energy	Flavor	Electric Charge	Color Charge
Particles experiencing:	All	Quarks, Leptons	Electrically Charged	Quarks, Gluons
Particles mediating:	Graviton (not yet observed)	W^+ W^- Z^0	γ	Gluons
Strength at $\begin{cases} 10^{-18} \text{ m} \\ 3 \times 10^{-17} \text{ m} \end{cases}$	10^{-41} 10^{-41}	0.8 10^{-4}	1 1	25 60

- 四种作用荷：引力只有吸引/弱力只有衰变/电磁力同斥异吸/强力如何吸引、排斥？
- 强力：跑动耦合常数！（尺度越小越小：渐进自由）
- 弱力：跑动耦合常数！（尺度越小越大）
- 电磁力：跑动耦合常数！（尺度越小越大）
- 引力：耦合常数？跑动否？怎么跑？

How are they entangled in the certain decay?

Theory for the phase between strong and EM

$$A_g^H = \sum_h \langle h|3g\rangle \langle 3g|\psi\rangle$$

$$A_\gamma^H = \sum_h \langle h|\gamma\rangle \langle \gamma|\psi\rangle$$

Clearly,

$$A_g^{*H} A_\gamma^H = \langle \psi|3g\rangle \langle 3g|(\sum_h |h\rangle \langle h|)|\gamma\rangle \langle \gamma|\psi\rangle = 0$$

is equivalent to

$$\langle 3g|\gamma\rangle = 0$$

Since $\sum_h |h\rangle \langle h| = 1$

Universality independent of final states or intermediate resonances.

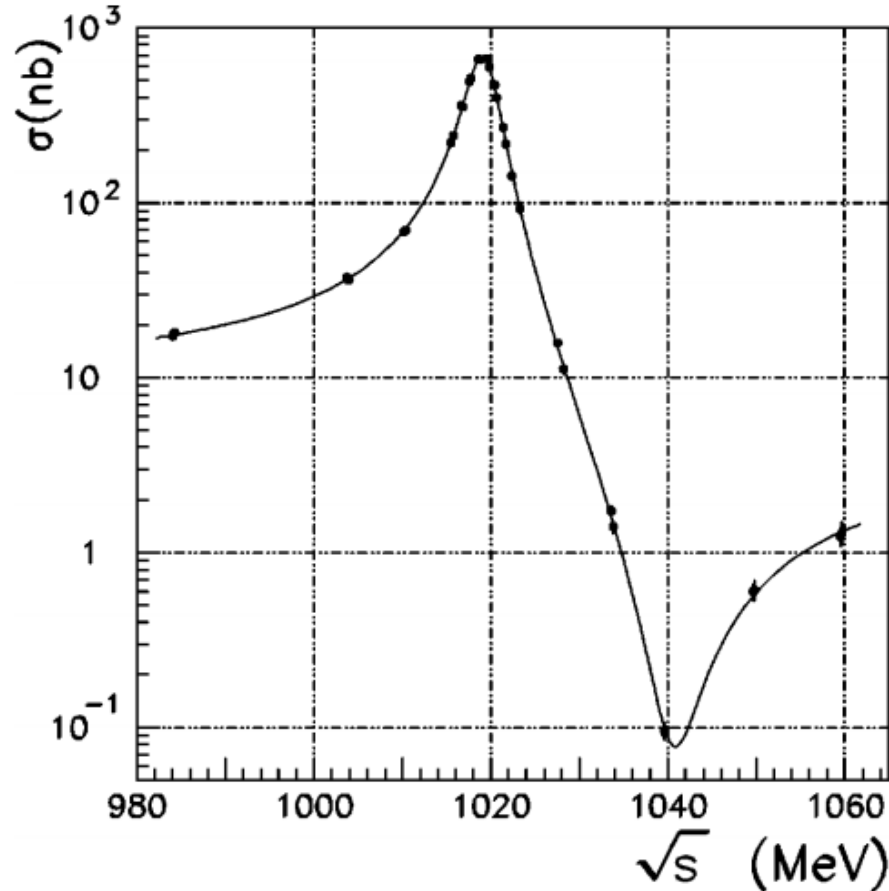
For exclusive channels common to J/ψ and $\psi(2S)$, there cannot be significant differences in relative abundances if the three-gluon intermediate state makes any physical sense.

J.-M. Gerard, J. Weyers, Phys. Lett. B 462, 324 (1999);
P. Wang, C.Z. Yuan, X.H. Mo, Phys. Rev. D 69, 057502 (2004);
M. Suzuki, Phys. Rev. D 58, 111504 (1998); etc.

Model dependent experimental evidences

from ϕ decays

The interference between ϕ and $\omega(\omega')$ was observed at SND.



➤ $e^+e^- \rightarrow \phi \rightarrow \pi^+\pi^-\pi^0$:

A_γ is dominate

➤ $e^+e^- \rightarrow \omega(\omega') \rightarrow \pi^+\pi^-\pi^0$:

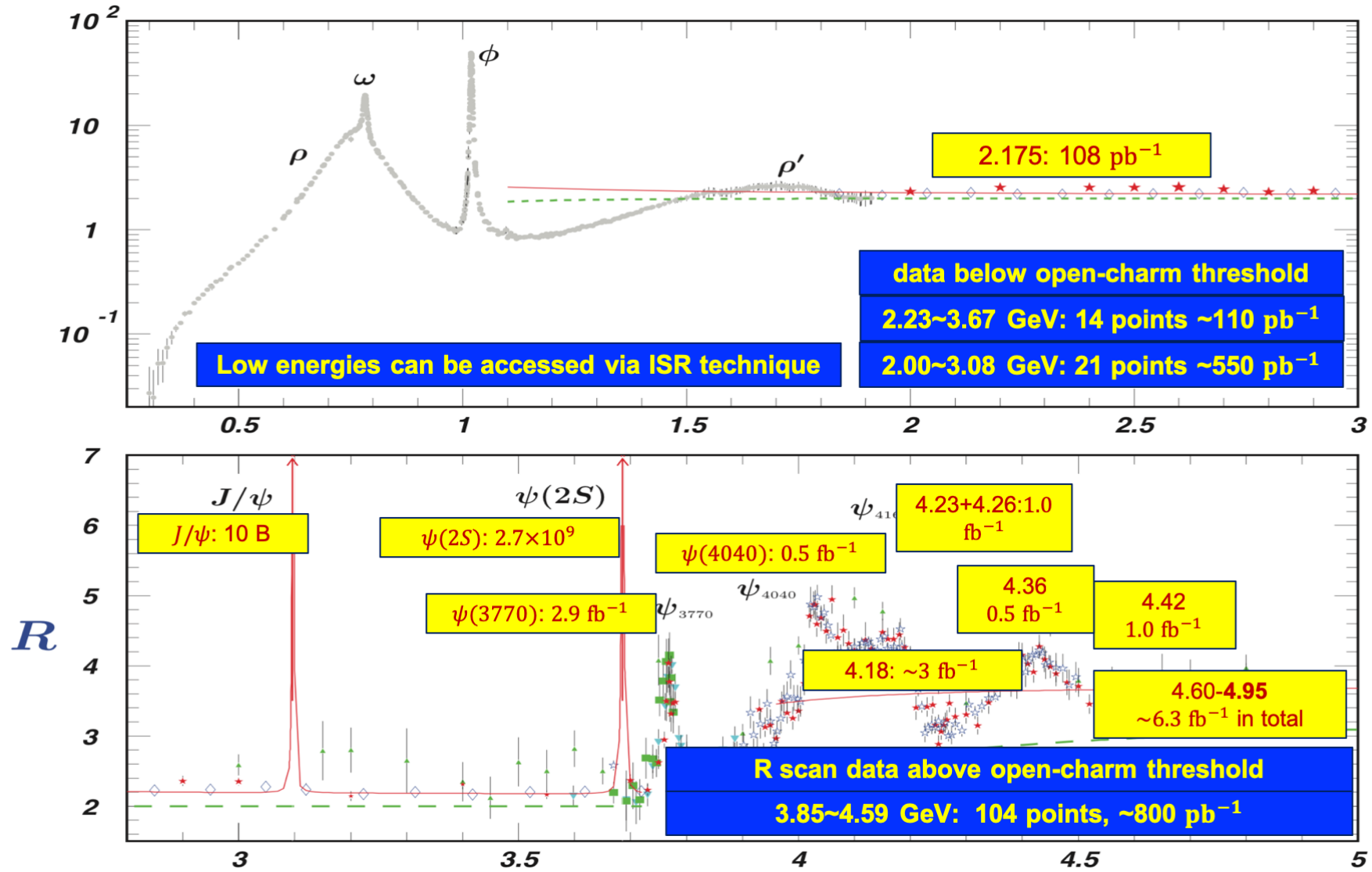
A_{3g} is dominate

➤ $\Phi_{\phi-\omega(\omega')} \sim \Phi_{g,\gamma}$

• $\Phi_{\phi-\omega(\omega')} \sim \mathbf{180^\circ}$ ^[1]

[1] SND coll., Phys. Rev. D 63, 072002 (2001)

BESIII datasets



Scan method and measurement

- The born cross section:
- The observed cross section:

$$\sigma^{\text{theory}}(W) = \int_{W-nS_E}^{W+nS_E} GS(W - W'') dW'' \int_0^{x_f} dx F(x, s) \sigma^0(s(1-x))$$

- Minimization method:
$$\chi^2 = \sum_{i=1}^{16} \frac{[\sigma_i^{\text{obs}} - f\sigma''(W_i)]^2}{(\Delta\sigma_i^{\text{obs}})^2 + \left[\Delta W_i \cdot \frac{d\sigma''(W)}{dW}\right]^2} + \left(\frac{1-f}{\Delta f}\right)^2$$

- Analytical formula was developed to reduce two integrations to one,
hep-hp 14:7,585-595(1990); CPC 41:083001(2017); CPC 48:113104 (2024); PRD 110:053010(2024);

Scan measurement -- upcoming

channel	J/ψ	$\psi(3686)$	$\psi(3770)$
K^+K^-	Francesca De Mori(Turino), report	Yadi Wang(NCEPU),draft	
$K_S K_L$		Jie Yuan(NCEPU),report	Bolun Zhang(IHEP), PRL132, 131901 (2024)
$\pi^+\pi^-$	Yipeng Zhao(NCEPU), under study	Yipeng Zhao(NCEPU), under study	Yipeng Zhao(NCEPU), under study
$\pi^+\pi^-\pi^0(\rho\pi)$	Tengjiao Wang (IHEP), report	Yijia Zeng(NKU)+Tengjiao Wang(IHEP)+Chen Xie(NJU), report	Yijia Zeng(NKU)+Tengjiao Wang(IHEP)+Chen Xie(NJU), report
$\pi^+\pi^-\eta(\rho\eta)$		Junhua Li+Caiying Pang(GXNU), BAM-889	Zhiqing Liu (SDU)
$\pi^+\pi^-\eta'(\rho\eta')$			
$K^+K^-\pi^0(K^{*\pm}K^\mp)$	Tianyou Li (NKU), BAM-968	Tianyou Li(NKU)+Chen Xie(NJU), report	Chen Xie(NJU)+Tianyou Li(NKU), report
$K_S K^\pm \pi^\mp (K^{*0} \bar{K}^0)$	Chen Xie (NJU), BAM-996	Chen Xie(NJU), report	Chen Xie(NJU), report
$\omega\eta$	Zhikun Xi (WHU), memo in tau-QCD	Yiqi Du (WHU), memo in charmonium	Jiaojiao Song(HNNU)+ Yateng Zhang(ZZU), report
$\omega\eta'$	Hailing Song (USTC)+Yanning Wang (WHU), BAM-00991	Zhefei Tian (WHU), BAM-00977	Jiaojiao Song(HNNU)+ Yateng Zhang(ZZU), report
$\omega\pi^0$	Wenhao Ya (WHU), memo in Tau-QCD	Baoxin+Yiqi (WHU), memo in charmonium	
$\phi\pi$	Yan Zhang (NCEPU)		
$\phi\eta$	Zequn Sun(IHEP)+Nefedov Yury(JINR)		Junhao Yin(NKU), report
$\phi\eta'$	Yanwen Luo+Jianxin Wang(WHU), report		
$\mu^+\mu^-$	Published		Gang Rong (BAM-)

channel	J/ψ	$\psi(3686)$	$\psi(3770)$
$p\bar{p}$	Marco Destifanis(Turino), BAM-106	Yanan Wang(NCEPU), BAM-822, draft	
$\Sigma^+\bar{\Sigma}^-$	Jiajun Liu(SCU), BAM-729, draft		JHEP05(2024)022
$\Sigma^0\bar{\Sigma}^0$	Muzaffar Irshad+Hao Zhang(USTC), BAM-612		LZU
$\Lambda/\bar{\Lambda} + X$	Zihao Qu(SCU), BAM-702, draft, CWR		
$\Xi^-\bar{\Xi}^+$			JHEP11(2023)228
$\Xi^0\bar{\Xi}^0$			JHEP11(2024)062
$\Lambda\bar{\Lambda}$	Jianyong Zhang (IHEP), report		PRD 104, L091104 (2021)
$K^-\bar{\Xi}^+\Lambda, K^-\bar{\Xi}^+\Sigma^0$			JHEP07(2024)258
$\phi\pi^+\pi^-/\phi\pi^0\pi^0$		Frederik (Munster)	Tianyou Li (NKU)
$K^*\bar{K}$		Chen Xie	Jiaojiao Song (HNU)
$\pi^+\pi^-\pi^0$	Tingjiao Wang(IHEP)		Yijia Zeng, Yaoyu Duan (IHEP)
$\eta\pi^+\pi^-(\eta\rho, \eta\omega, a_2\pi)$		Caiying Pang ()	
在此处键入公式。			

Hopefully, there will be 3-5 papers will be published in 2025!

Require more efforts from our referees.