$e^+e^- \to \phi\pi^+\pi^-$过程中$\phi(2170)$的三角奇异性解释

第九届手征有效场论研讨会·长沙

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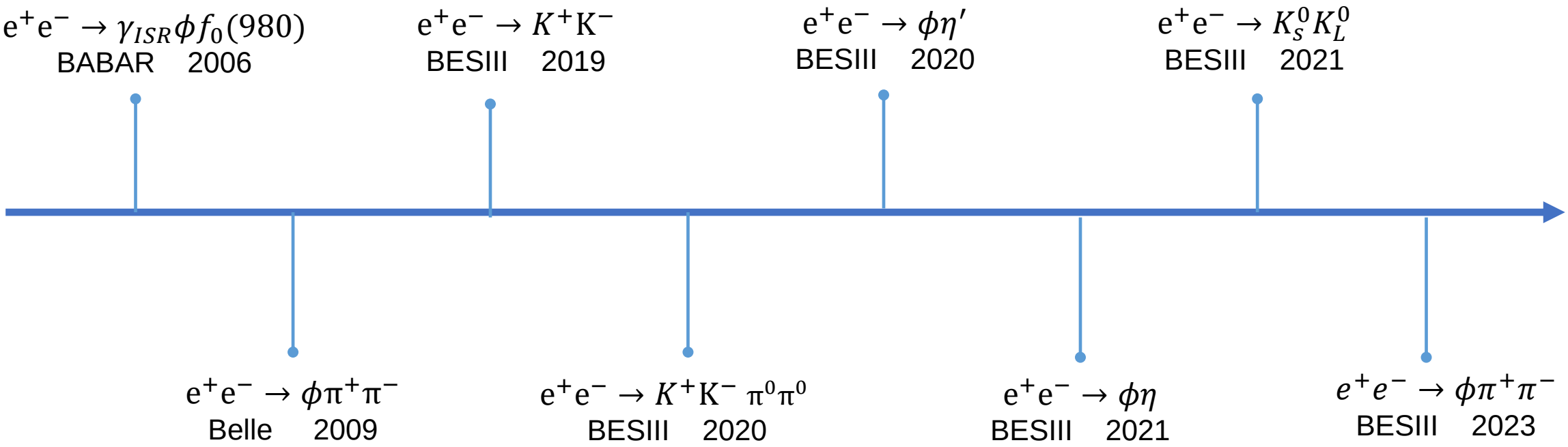
$\phi(2170)$


$e^+e^- \to \gamma_{ISR}\phi f_0(980)$
BABAR 2006
$e^+e^- \to \phi\pi^+\pi^-$
Belle 2009
$e^+e^- \to K^+K^-$
BESIII 2019
$e^+e^- \to K^+K^-\pi^0\pi^0$
BESIII 2020
$e^+e^- \to \phi\eta'$
BESIII 2020
$e^+e^- \to \phi\eta$
BESIII 2021
$e^+e^- \to K_S^0K_L^0$
BESIII 2021
$e^+e^- \to \phi\pi^+\pi^-$
BESIII 2023

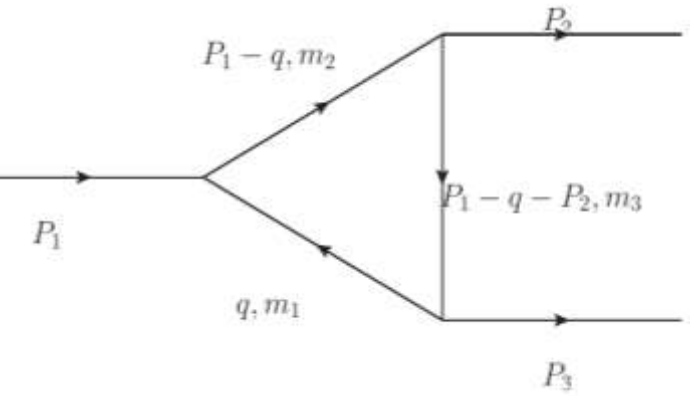
1. 研究背景

	BABAR		BESIII		Belle	
	M(MeV)	Γ(MeV)	M(MeV)	Γ(MeV)	M(MeV)	Γ(MeV)
$e^+e^- \to \gamma_{ISR}\phi f_0(980)$	$2175 \pm 10 \pm 15$	$58 \pm 16 \pm 20$	$2135 \pm 8 \pm 9$	$104 \pm 24 \pm 12$	2163 ± 32	125 ± 40
$e^+e^- \to K^+K^-$	2201 ± 19	70 ± 38	$2239.2 \pm 7.1 \pm 11.3$	$139.8 \pm 12.3 \pm 20.6$		
$e^+e^- \to K^+K^- \pi^0\pi^0$	2169 ± 20	102 ± 27	$2126.5 \pm 16.8 \pm 12.4$	$106.9 \pm 32.1 \pm 28.1$		
$e^+e^- \to \phi\eta'$			$2177.5 \pm 4.8 \pm 19.5$	$149.0 \pm 15.6 \pm 8.9$		
$e^+e^- \to \phi\eta$	$2125 \pm 22 \pm 10$	$61 \pm 50 \pm 13$	$2163.5 \pm 6.2 \pm 3.0$	$31.1^{+21.1}_{-11.6}$		
$e^+e^- \to K_S^0K_L^0$			$2273.7 \pm 5.7 \pm 19.3$	$86 \pm 44 \pm 51$		
$e^+e^- \to \phi\pi^+\pi^-$	$2180 \pm 8 \pm 8$	$77 \pm 15 \pm 10$	$2178 \pm 20 \pm 5$	$140 \pm 36 \pm 16$	2079 ± 13	192 ± 23

$s\bar{s}$介子态?　　$s\bar{s}g$杂化态?　　$ss\bar{s}\bar{s}$四夸克态?　　$\Lambda\bar{\Lambda}$束缚态?

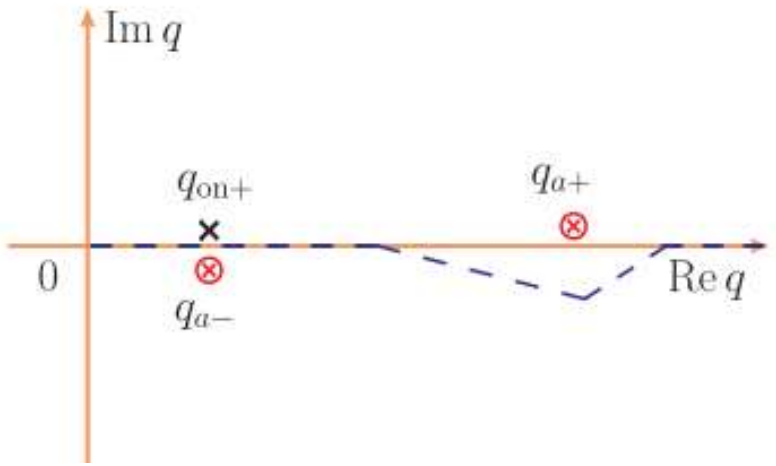
末态粒子相互作用产生的 $\phi K\bar{K}$ or $\phi f_0(980)$ 共振态?

1. 研究背景



$$I = i\int \frac{d^4q}{(2\pi)^4}\frac{1}{(q^2 - m_1^2 + i\varepsilon)[(P_1 - q)^2 - m_2^2 + i\varepsilon][(P_1 - q - P_2)^2 - m_3^2 + i\varepsilon]}$$

$$\Rightarrow 2\pi\int_0^\infty dq\frac{q^2}{[P_1^0 - E_1(\vec{q}) - E_2(\vec{q}) + i\varepsilon]}\int_{-1}^{1} d\cos\theta\frac{1}{[P_1^0 - E_1(\vec{q}) - P_2^0 - \sqrt{m_3 + P_2^2 + q^2 + 2qP_2\cos\theta} + i\varepsilon]}$$



$$q_{on+} = \frac{\lambda^{1/2}(M_1^2, m_1^2, m_2^2)}{2M_1} + i\varepsilon$$

$$q_{a+} = \gamma(vE^* + p_1^*) + i\varepsilon$$

$$q_{a-} = \gamma(vE^* - p_1^*) - i\varepsilon$$

$$q_{b+} = \gamma(-vE^* + p_1^*) + i\varepsilon$$

$$q_{b-} = -\gamma(vE^* + p_1^*) - i\varepsilon$$

·Melahat Bayar, Francesca Aceti, Feng-Kun Guo, and EulogioOset, Phys. Rev. D 94, 074039 (2016)

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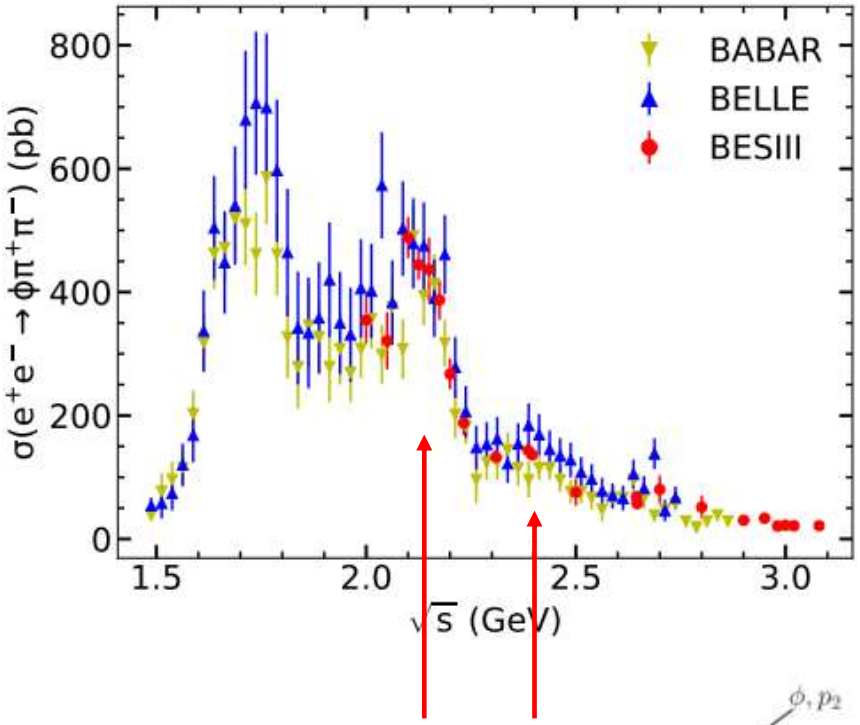
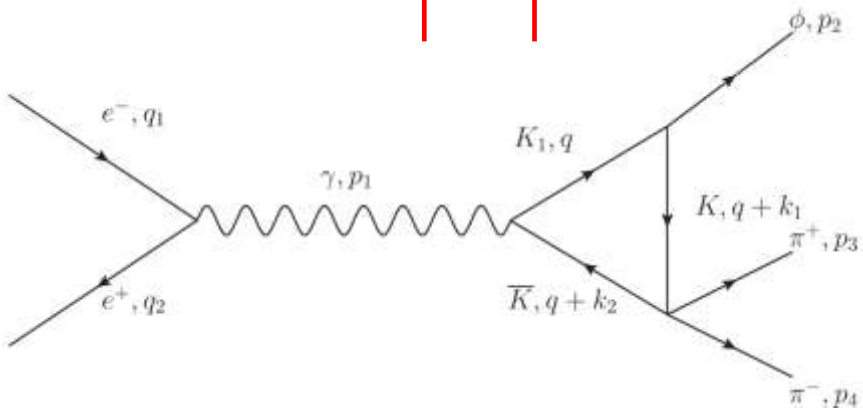
$e^+e^- \to \phi\pi^+\pi^-$过程中$\phi(2170)$的三角奇异性解释

2. $e^+e^- \to \phi\pi^+\pi^-$过程中$\phi(2170)$的三角奇异性解释





·M. Ablikim et al. (BESIII Collaboration), Phys. Rev. D 108, 032011(2023)
·J. P. Lees et al. (BABAR Collaboration), Phys. Rev. D 86,012008 (2012).
·C. P. Shen et al. (Belle Collaboration), Phys. Rev. D 80, 031101 (2009).

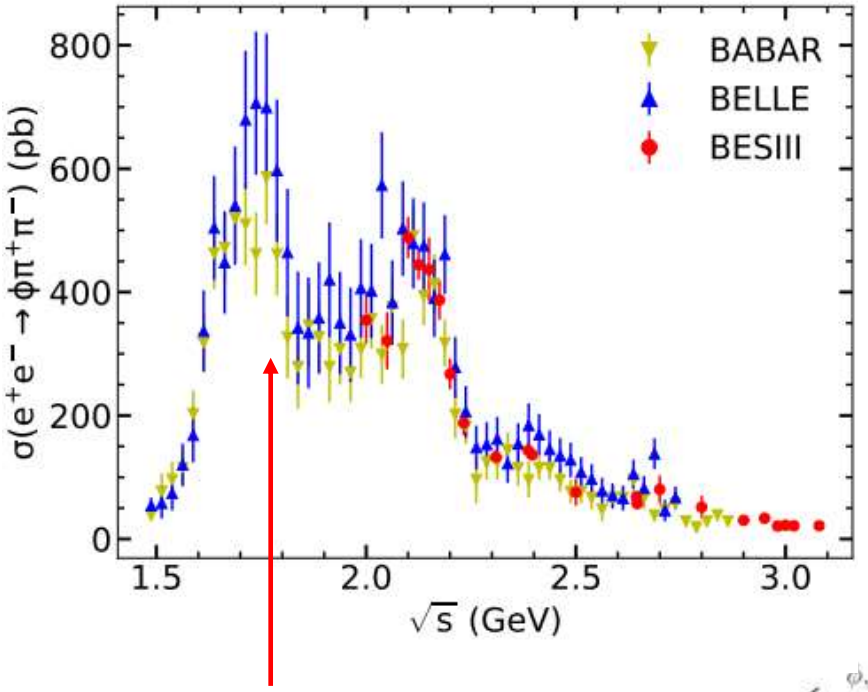
$$M = M_{e^+e^-\to K_1\bar{K}} G_{K_1\bar{K}K}\ t_{K\bar{K}\to\pi^+\pi^-(I=0)}$$

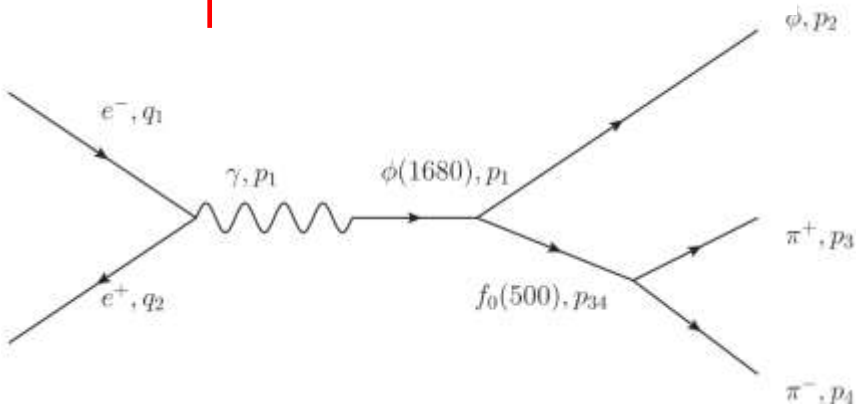
$$M_{e^+e^-\to K_1\bar{K}} = u_e(-i\gamma^\mu)\bar{v}_e \frac{-ig_{\mu\nu}}{p_1^2} g_{\gamma\to K_1\bar{K}} e^{-a(\sqrt{s}-m_\phi-2m_\pi)}$$

$$G_{K_1\bar{K}K} = \int \frac{g_{K_1\to K\phi}\left(g^{\nu\rho} - \frac{q^\nu q^\rho}{m_{K_1}^2}\right)\phi_\rho}{(q^2-m_{K_1}^2)[(q+k_1)^2-m_K^2][(q+k_2)^2-m_K^2]} \frac{d^4q}{(2\pi)^4}$$

$$t_{K\bar{K}\to\pi^+\pi^-(I=0)} = \frac{V}{1-VG}$$

2. $e^+e^- \to \phi\pi^+\pi^-$过程中$\phi(2170)$的三角奇异性解释





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$$M = M_{e^+e^-\to\phi(1680)} M_{\phi(1680)\to\phi f_0(500)} M_{f_0(500)\to\pi^+\pi^-}$$

$$M_{e^+e^-\to\phi(1680)} = u_e(-i\gamma^\mu)\bar{v}_e \frac{-ig_{\mu\nu}}{p_1^2} g_{\gamma\to\phi(1680)}$$

$$M_{\phi(1680)\to\phi f_0(500)} = g_{\phi(1680)\to\phi f_0(500)} \phi(1680)^\mu \phi_\mu$$

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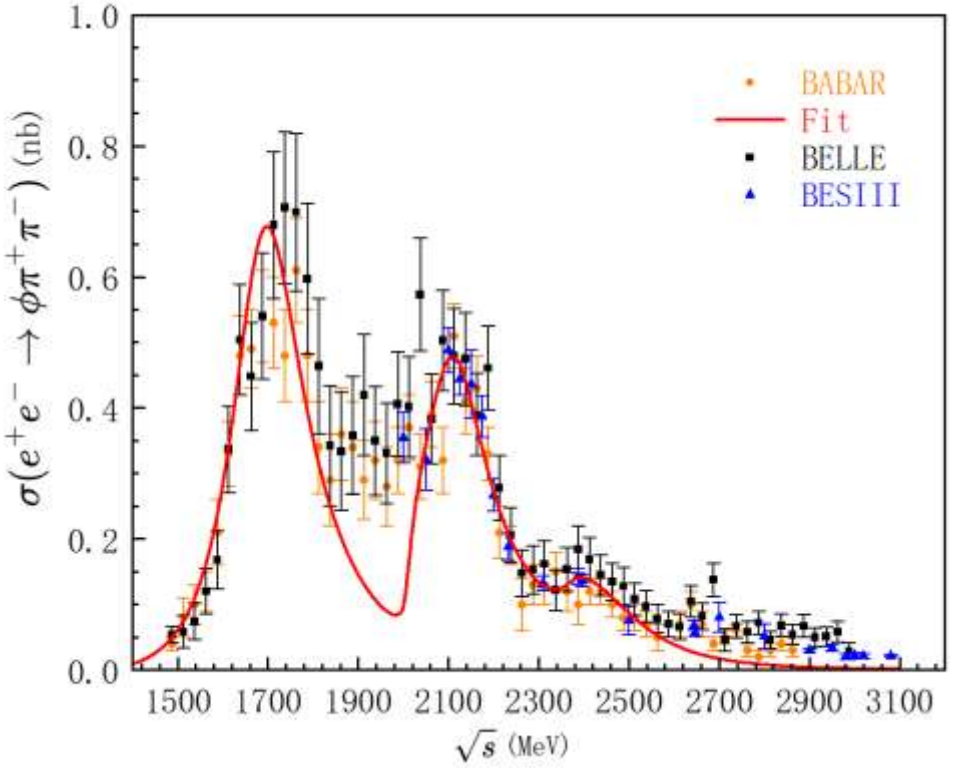


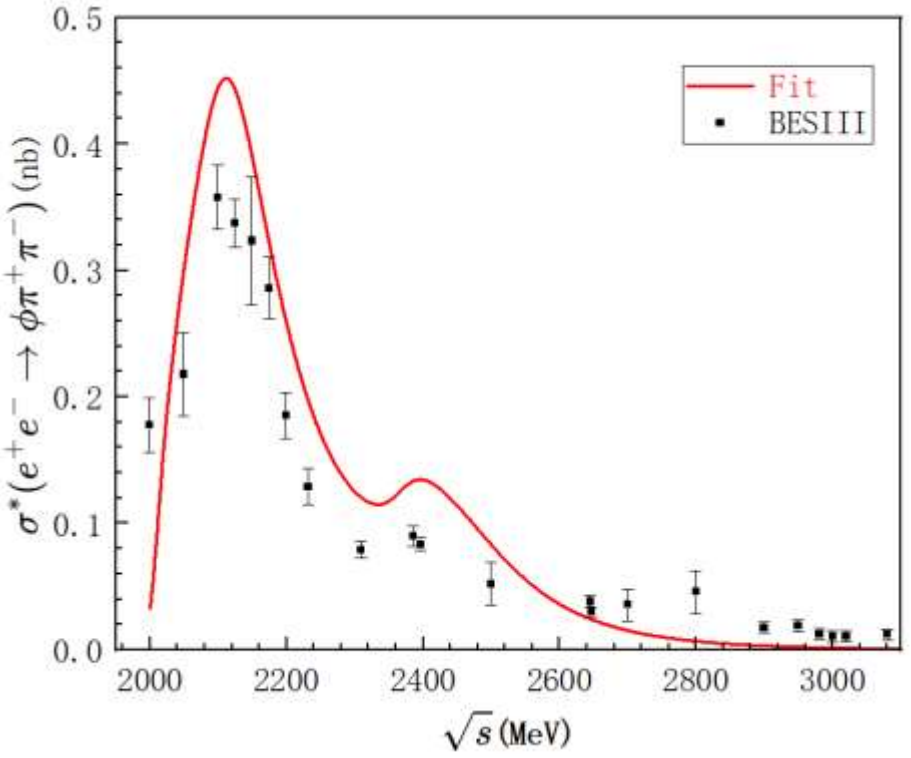
$$\chi^2/dof = 3.126$$

$\sqrt{s}$(MeV)	m_{K_1}(MeV)	Γ_{K_1}(MeV)	$g_{\gamma\to K_1\bar{K}}$
2170	1606.01	95.498	0.740
2400	1871.93	56.506	2.208
$K_1(1650)$	1650 ± 50	150 ± 50	

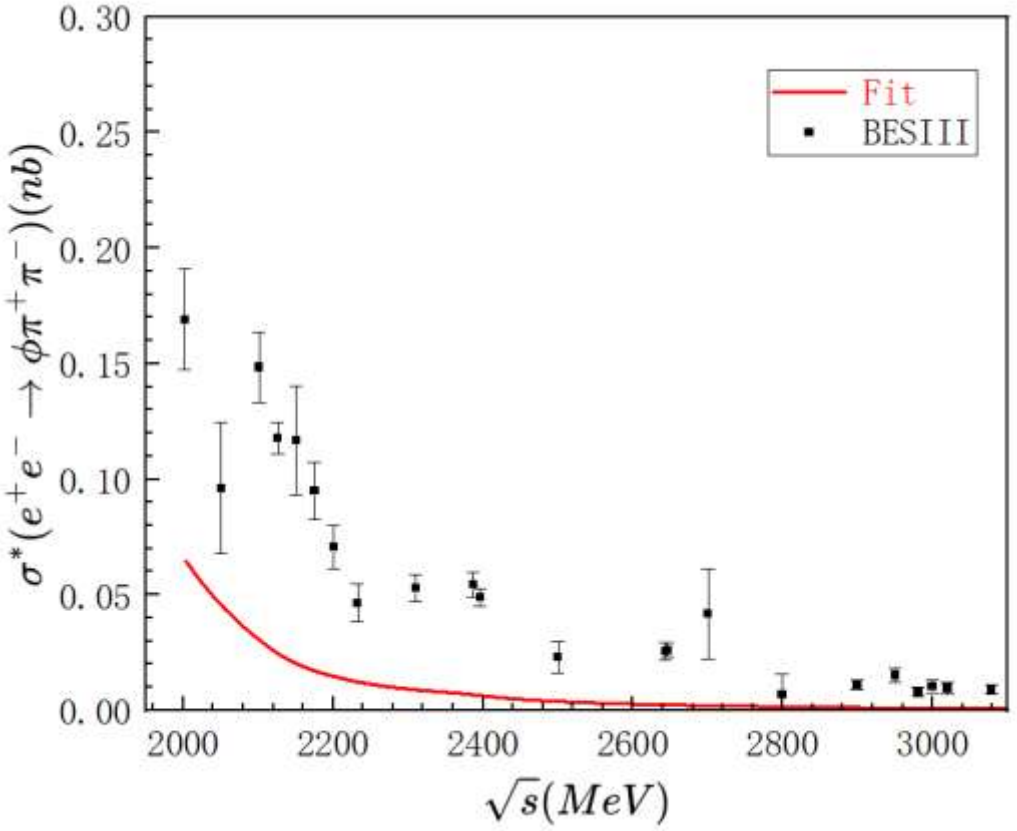
· S. Navas et al. (Particle Data Group), Phys. Rev. D 110, 030001 (2024)

$g_{\gamma\to\phi(1680)}$	$a(\mathrm{MeV})^{-1}$
3.959×10^{-3}	6.056×10^{-3}

2. $e^+e^- \to \phi\pi^+\pi^-$过程中$\phi(2170)$的三角奇异性解释



$M_{\pi^+\pi^-} \in [850,1100]MeV$

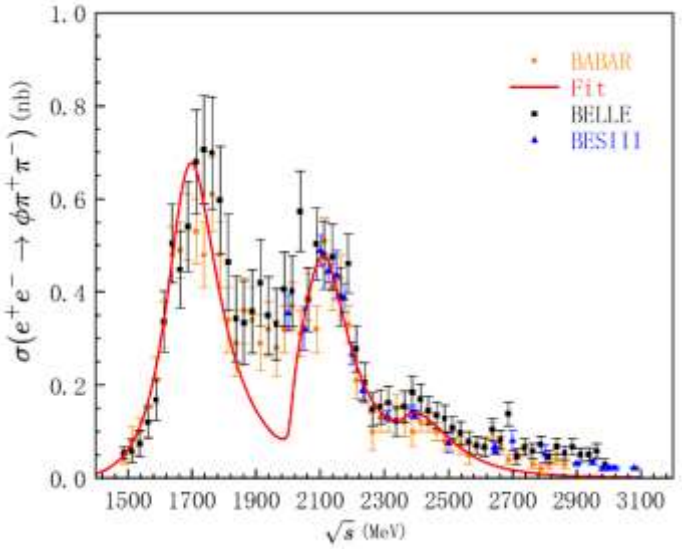


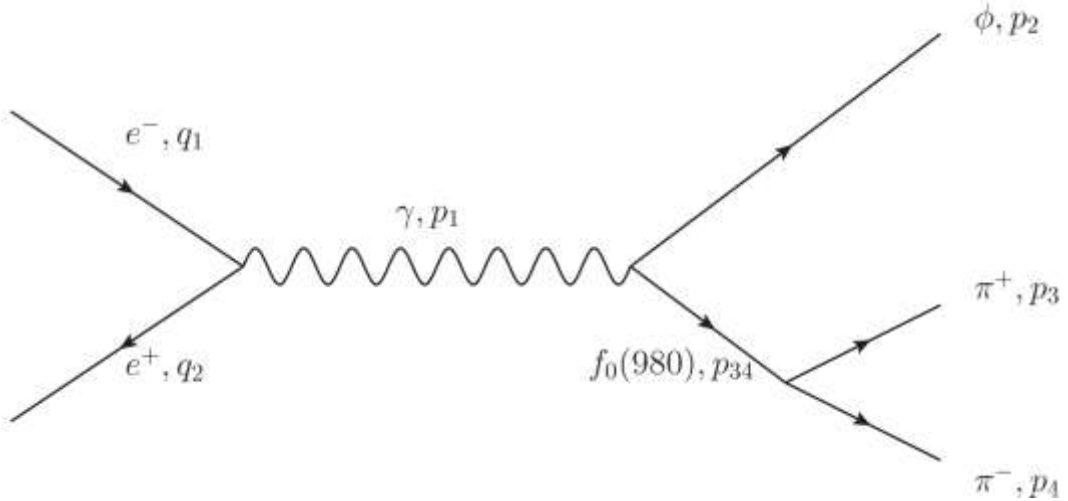
$M_{\pi^+\pi^-} \notin [850,1100]MeV$

3.总结&展望

1. 利用$K_1(1650)$与$K\bar{K}$三角奇异性复现了$e^+e^- \to \phi\pi^+\pi^-$过程中的$\phi(2170)$信号

2. 利用三角奇异性原理与$e^+e^- \to \phi\pi^+\pi^-$过程中的$R(2400)$的信号，预言了$M \approx 1872MeV$，$\Gamma \approx 56.5MeV$的$K_1$粒子





感谢大家！

Q&A