

$\phi(2170)$ production in the $\gamma p \rightarrow \eta \phi p$ reaction

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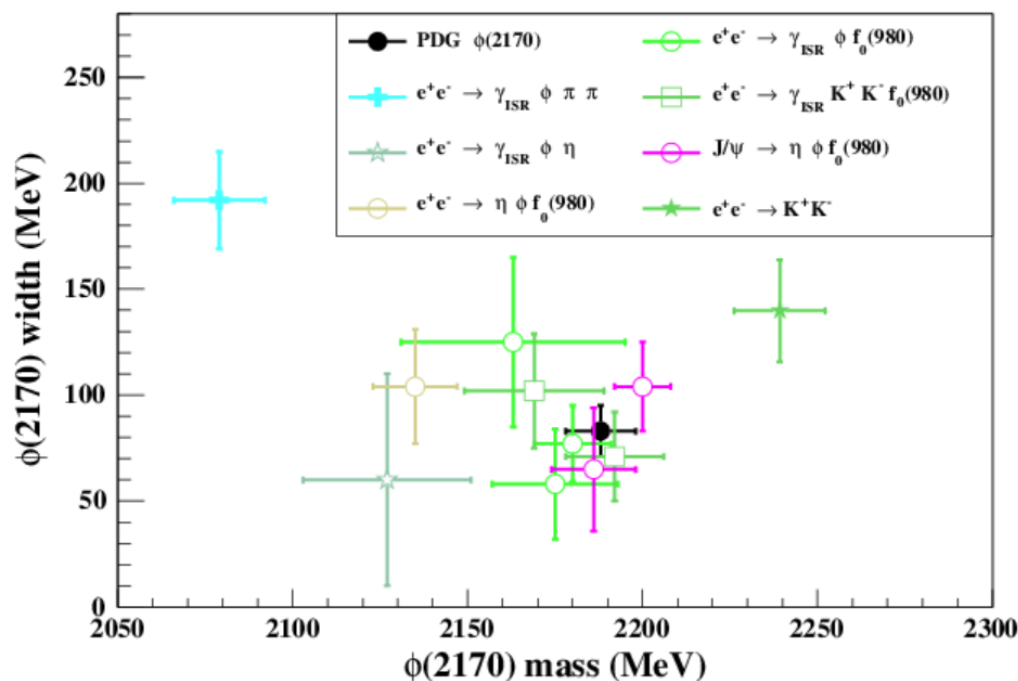
$\phi(2170)$ mass from PDG

<u>VALUE (MeV)</u>	<u>EVTs</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
2135 $\pm 8 \pm 9$	95	ABLIKIM	19I BES3	$e^+e^- \rightarrow \eta\phi f_0(980)$
2239.2 $\pm 7.1 \pm 11.3$		¹ ABLIKIM	19L BES3	$e^+e^- \rightarrow K^+K^-$
2200 $\pm 6 \pm 5$	471	ABLIKIM	15H BES3	$J/\psi \rightarrow \eta\phi\pi^+\pi^-$
2180 $\pm 8 \pm 8$		^{2,3} LEES	12F BABR	10.6 $e^+e^- \rightarrow \phi\pi^+\pi^-\gamma$
2079 $\pm 13 \begin{smallmatrix} +79 \\ -28 \end{smallmatrix}$	4.8k	⁴ SHEN	09 BELL	10.6 $e^+e^- \rightarrow K^+K^-\pi^+\pi^-\gamma$
2186 $\pm 10 \pm 6$	52	ABLIKIM	08F BES	$J/\psi \rightarrow \eta\phi f_0(980)$
2125 $\pm 22 \pm 10$	483	AUBERT	08S BABR	10.6 $e^+e^- \rightarrow \phi\eta\gamma$
2192 ± 14	116	⁵ AUBERT	07AK BABR	10.6 $e^+e^- \rightarrow K^+K^-\pi^+\pi^-\gamma$
2169 ± 20	149	⁵ AUBERT	07AK BABR	10.6 $e^+e^- \rightarrow K^+K^-\pi^0\pi^0\gamma$
2175 $\pm 10 \pm 15$	201	^{3,6} AUBERT,BE	06D BABR	10.6 $e^+e^- \rightarrow K^+K^-\pi\pi\gamma$

All the information was obtained from the e^+e^- collision EXPs.

$\phi(2170)$ decays from PDG

	Mode	Fraction (Γ_i/Γ)
Γ_1	$e^+ e^-$	seen
Γ_2	$\phi \eta$	Limited decay modes
Γ_3	$\phi \pi \pi$	
Γ_4	$\phi f_0(980)$	
Γ_5	$K^+ K^- \pi^+ \pi^-$	seen
Γ_6	$K^+ K^- f_0(980) \rightarrow K^+ K^- \pi^+ \pi^-$	seen
Γ_7	$K^+ K^- \pi^0 \pi^0$	seen
Γ_8	$K^+ K^- f_0(980) \rightarrow K^+ K^- \pi^0 \pi^0$	
Γ_9	$K^{*0} K^\pm \pi^\mp$	not seen
Γ_{10}	$K^*(892)^0 \bar{K}^*(892)^0$	not seen



- Take from **W.B. Yan** talk. 第五届XYZ会议, 2018年@郑州。
- **Inconsistence** on mass and width



Theoretical explanations

- Hybrid $s\bar{s}g$ PLB650,390,PRD59, 034016
- 2^3D_1 or 3^3S_1 $s\bar{s}$ PLB657,49, PRD85, 074024, PRD99,074015
- Tetraquark PRD98, 014011,NPA791,106, PRD78,034012, PRD99,036014
- Molecular state $\Lambda\bar{\Lambda}$ PRD96,074027, PRD87,054034
- $\phi f_0(980)$ resonance PRD80,054011
- ϕKK three body system PRD78, 074031, PRD83, 116002

The available experimental information is not enough to confirm or refute the above interpretations.
It is essential to confirm a resonance in at least two different reactions.



Photo-production

- To learn about the hadron spectrum
- The intense photon beam can be used to study the strangeonium-like state, because of the strong affinity of the photon for $s\bar{s}$, for instance: ϕ , $\phi(1680)$
- $\phi f_0(980)$ mode $\rightarrow \phi(2170)$ has the $s\bar{s}$ component

$\Gamma(\phi\eta) \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$					$\Gamma_2\Gamma_1/\Gamma$
VALUE (eV)	EVTS	DOCUMENT ID	TECN	COMMENT	

• • • We do not use the following data for averages, fits, limits, etc. • • •

1.7±0.7±1.3	483	AUBERT	08S	BABR	10.6 $e^+e^- \rightarrow \phi\eta\gamma$
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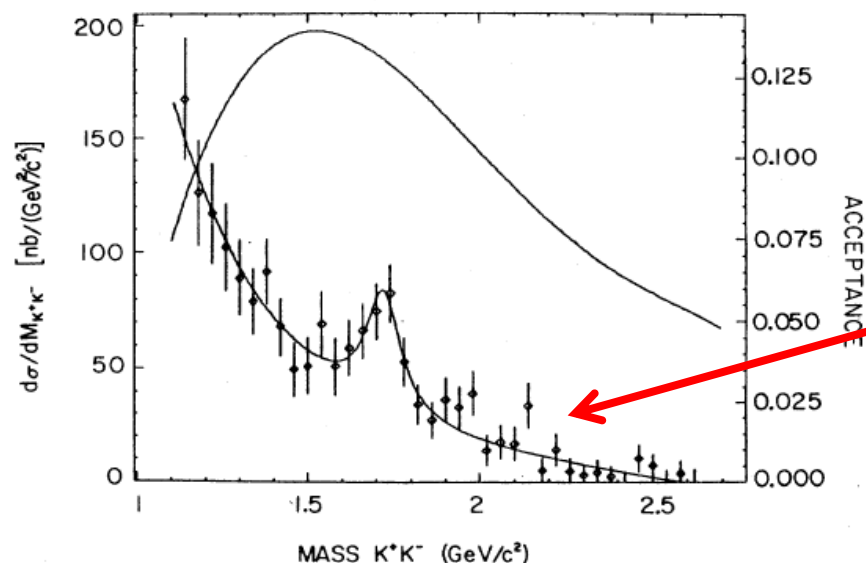
$\Gamma(\phi f_0(980)) \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$					$\Gamma_4\Gamma_1/\Gamma$
VALUE (eV)	EVTS	DOCUMENT ID	TECN	COMMENT	

2.3±0.3±0.3	13,14	LEES	12F	BABR	10.6 $e^+e^- \rightarrow \phi\pi^+\pi^-\gamma$
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photo-production

High-energy photoproduction of $\pi^+\pi^-\pi^0$, K^+K^- , and $p\bar{p}$ states

J. Busenitz, C. Olszewski, P. Callahan, G. Gladding, A. Wattenberg, M. Binkley, J. Butler, J. Cumalat, I. Gaines, M. Gormley, D. Harding, R. L. Loveless, and J. Peoples
Phys. Rev. D **40**, 1 – Published 1 July 1989



Fermilab broad-band
photon beam by
Experiment 401

Enhancement structure

FIG. 25. $(d\sigma/dM_{KK})(\gamma N \rightarrow K^+K^-N)$ under assumptions stated in the text. The solid acceptance curve on top uses the scale on the right.

$\gamma p \rightarrow \eta \phi p$

• Threshold

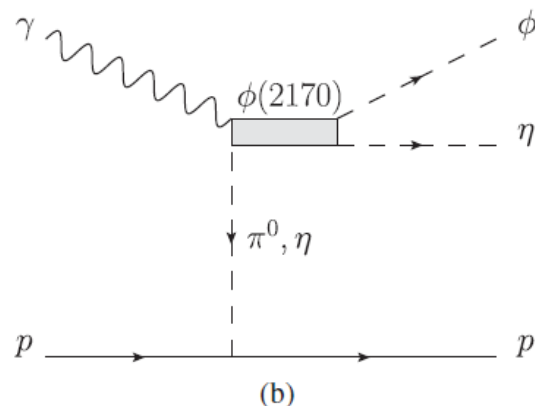
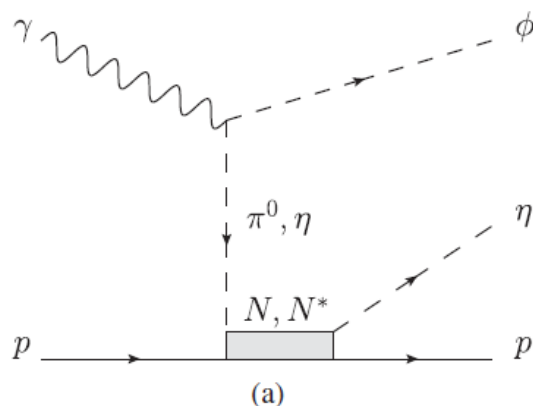
✓ $\phi f_0(980) \sim 2.0 \text{ GeV}$

✓ $\eta \phi \sim 1.6 \text{ GeV}$

$\Gamma(\phi\eta) \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$					$\Gamma_2\Gamma_1/\Gamma$
VALUE (eV)	EVTS	DOCUMENT ID	TECN	COMMENT	
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$1.7 \pm 0.7 \pm 1.3$	483	AUBERT	08S	BABR	$10.6 \text{ e}^+ \text{e}^- \rightarrow \phi \eta \gamma$
$\Gamma(\phi f_0(980)) \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$					$\Gamma_4\Gamma_1/\Gamma$
VALUE (eV)	EVTS	DOCUMENT ID	TECN	COMMENT	
$2.3 \pm 0.3 \pm 0.3$	13,14	LEES	12F	BABR	$10.6 \text{ e}^+ \text{e}^- \rightarrow \phi \pi^+ \pi^- \gamma$

- **GlueX**: search for $\phi(2170)$ in photo production
[1305.1523](#).
- **CLAS12**: $\gamma p \rightarrow \eta \phi p$ strangeonium-like state
[EPJ Web Conf. 96, 49201013 \(2015\)](#).

Mechanisms of $\gamma p \rightarrow \eta \phi p$



$$\mathcal{L}_{\pi NN} = -\frac{g_{\pi NN}}{2m_N} \bar{N} \gamma_5 \gamma_\mu \vec{\tau} \cdot \partial^\mu \vec{\pi} N,$$

$$\mathcal{L}_{\pi NN^*} = ig_{\pi NN^*} \bar{N}^* \vec{\tau} \cdot \vec{\pi} N + \text{H.c.},$$

$$\mathcal{L}_{\eta NN} = -\frac{g_{\eta NN}}{2m_N} \bar{N} \gamma_5 \gamma_\mu \partial^\mu \eta N,$$

$$\mathcal{L}_{\eta NN^*} = ig_{\eta NN^*} \bar{N}^* \eta N + \text{H.c.}$$

$$\mathcal{L}_{\gamma\phi\pi} = \frac{e}{m_\phi} g_{\gamma\phi\pi} \epsilon^{\mu\nu\alpha\beta} \partial_\mu \phi_\nu \partial_\alpha A_\beta \pi,$$

$$\mathcal{L}_{\phi^*\gamma\eta} = \frac{e}{m_{\phi^*}} g_{\phi^*\gamma\eta} \epsilon^{\mu\nu\alpha\beta} \partial_\alpha \phi_\beta^* \partial_\mu A_\nu \eta,$$

$$\mathcal{L}_{\gamma\phi\eta} = \frac{e}{m_\phi} g_{\gamma\phi\eta} \epsilon^{\mu\nu\alpha\beta} \partial_\mu \phi_\nu \partial_\alpha A_\beta \eta,$$

$$\mathcal{L}_{\phi^*\phi\eta} = \frac{g_{\phi^*\phi\eta}}{m_{\phi^*}} \epsilon^{\mu\nu\alpha\beta} \partial_\alpha \phi_\beta^* \partial_\mu \phi_\nu \eta.$$

Parameters

• 1-20 MeV for $\eta\phi$ mode

- PRD85,074024 (2012), PRD99,360 074015 (2019),
- PLB650, 390 (2007), PRD68, 054014 (2003)

$$\Gamma[\phi^* \rightarrow \phi\eta] = \frac{g_{\phi^*\phi\eta}^2}{12\pi} \frac{|\vec{p}_{\eta\phi}|^3}{m_{\phi^*}^2},$$

$$\Gamma[\phi^* \rightarrow \eta\gamma] = \frac{e^2 g_{\phi^*\eta\gamma}^2}{12\pi} \frac{|\vec{p}_{\eta\gamma}|^3}{m_{\phi^*}^2},$$

TABLE I. Model parameters used in the present work, the masses, widths, and branching ratios are taken from the Particle Data Group [39].

State	Mass (MeV)	Width (MeV)	Decay channel	Adopted branching ratio	$g^2/4\pi$
ϕ	1019	4.25	$\gamma\pi$	1.3×10^{-3}	1.60×10^{-3}
			$\gamma\eta$	1.3×10^{-2}	3.97×10^{-2}
$N(1535)$	1535	150	$N\pi$	0.42	3.43×10^{-2}
			$N\eta$	0.42	0.28
$\phi(2170)$	2188	83	$\gamma\eta$	...	2.41×10^{-2}
			$\phi\eta$	...	3.59×10^{-2}

• $\gamma\eta$ mode (M1+G1 wavefunctions)

$$\frac{\Gamma(\phi(1680) \rightarrow \gamma\eta)}{\Gamma(\phi \rightarrow \gamma\eta)} \simeq 1.1,$$

$$\frac{\Gamma(\phi(2170) \rightarrow \gamma\eta)}{\Gamma(\phi \rightarrow \gamma\eta)} \simeq 3,$$

$$\Gamma(\phi(1680) \rightarrow \gamma\eta) \simeq 0.06 \text{ MeV}$$

$$0.09 \text{ MeV PRD65,092003}$$

$$0.14 \pm 0.09 \text{ MeV PRC77,045204}$$

$$\Gamma(\phi(2170) \rightarrow \gamma\eta) \simeq 0.17 \text{ MeV}$$

Results

$$d\sigma(\gamma p \rightarrow \eta \phi p) = \frac{1}{8E_\gamma} \sum |\mathcal{M}_{\text{total}}|^2 \times \frac{d^3 p_3}{2E_3} \frac{d^3 p_4}{2E_4} \frac{m_p d^3 p_5}{E_5} \times \delta^4(p_1 + p_2 - p_3 - p_4 - p_5), \quad (28)$$

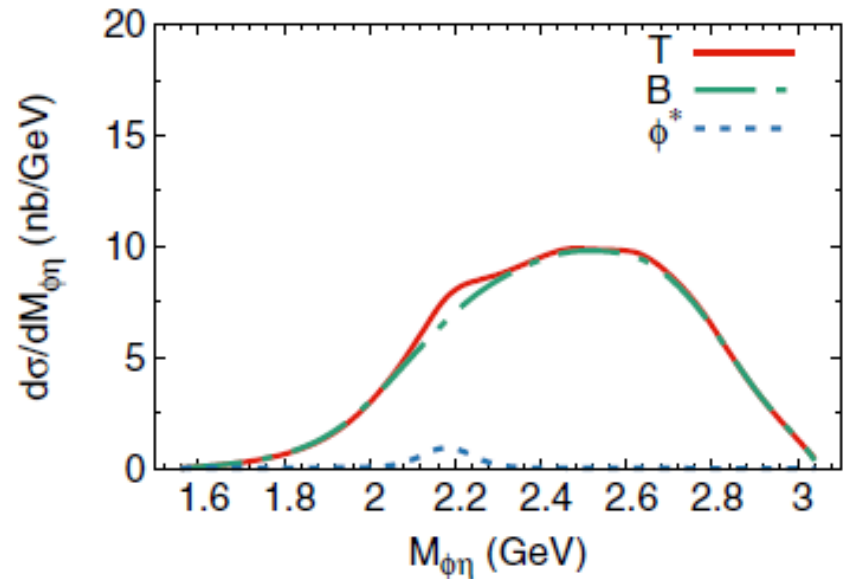
$$\mathcal{M}_{\text{total}} = \mathcal{M}_N^\pi + \mathcal{M}_{N^*}^\pi + \mathcal{M}_N^\eta + \mathcal{M}_{N^*}^\eta + \mathcal{M}_{\phi^*},$$

$$\begin{aligned} \mathcal{M}_N^\pi &= \frac{ie g_{\pi NN} g_{\eta NN} g_{\gamma \phi \pi}}{(2M_N)^2 m_\phi} \mathcal{F}(q_\pi^2, M_\pi^2) \mathcal{F}(q_N^2, M_N^2) \\ &\times \bar{u}(p_5, s_5) \gamma_5 \not{p}_4 G_N(q_N) \gamma_5 \not{q}_\pi u(p_2, s_2) G_\pi(q_\pi) \\ &\times \epsilon^{\mu\nu\alpha\beta} p_{3\mu} \epsilon_\nu^*(p_3, s_3) p_{1\alpha} \epsilon_\beta(p_1, s_1), \end{aligned}$$

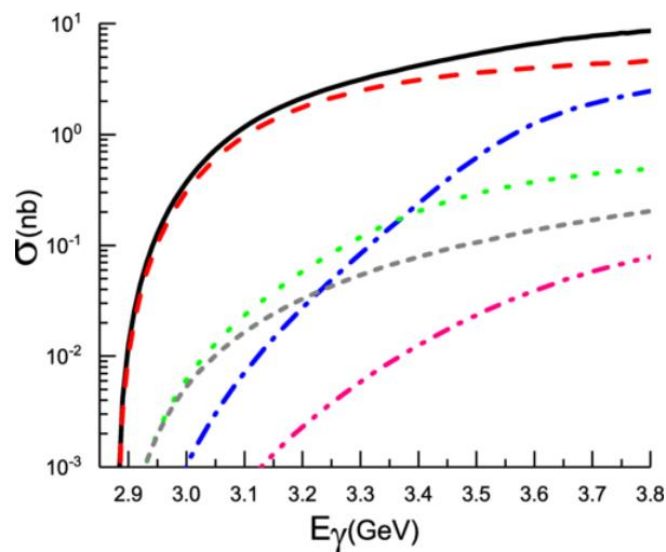
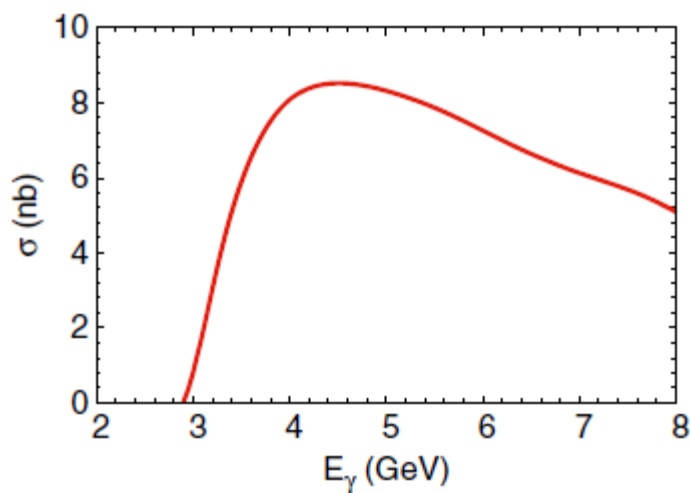
$$\begin{aligned} \mathcal{M}_{N^*}^\pi &= -\frac{ie g_{\pi NN^*} g_{\eta NN^*} g_{\gamma \phi \pi}}{m_\phi} \mathcal{F}(q_\pi^2, M_\pi^2) \mathcal{F}(q_{N^*}^2, M_{N^*}^2) \\ &\times \bar{u}(p_5, s_5) G_{N^*}(q_{N^*}) u(p_2, s_2) G_\pi(q_\pi) \\ &\times \epsilon^{\mu\nu\alpha\beta} p_{3\mu} \epsilon_\nu^*(p_3, s_3) p_{1\alpha} \epsilon_\beta(p_1, s_1), \end{aligned}$$

$$\begin{aligned} \mathcal{M}_{\phi^*} &= -\frac{ie g_{\eta NN} g_{\phi^* \eta} g_{\phi^* \gamma \eta}}{2M_N m_\phi^2} \mathcal{F}(q_\eta^2, M_\eta^2) \mathcal{F}(q_{\phi^*}^2, M_{\phi^*}^2) \\ &\times \bar{u}(p_5, s_5) \gamma_5 \not{q}_\eta u(p_2, s_2) G_\eta(q_\eta) \\ &\times \epsilon^{\mu\nu\alpha\beta} p_{3\mu} \epsilon_\nu^*(p_3, s_3) p_{\phi^* \alpha} G_{\phi^*}(\beta\rho)(q_{\phi^*}) \\ &\times \epsilon^{\rho\sigma\delta\lambda} p_{\phi^* \sigma} p_{1\delta} \epsilon_\lambda(p_1, s_1). \end{aligned}$$

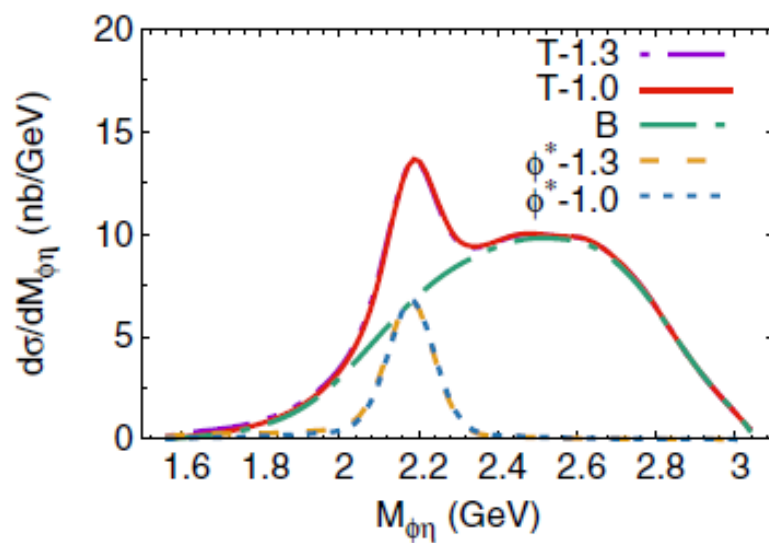
$$G_{\phi^*}^{\mu\nu}(q) = i \frac{g^{\mu\nu} - q^\mu q^\nu / M^2}{q^2 - M^2 + iM\Gamma},$$



Total cross section



J. Q. Fan, S. F. Chen, and B. C. Liu, Nucleon resonance production in the $\gamma p \rightarrow p\eta\phi$ reaction, Phys. Rev. C 99, 450 025203 (2019).



$$\mathcal{F}_M = \left(\frac{\Lambda_M^2 - M^2}{\Lambda_M^2 - q^2} \right)^2,$$

$$\Gamma(\phi(2170) \rightarrow \eta\phi) \simeq 6.6 \text{ MeV}$$

C. Q. Pang, PRD99,360 074015 (2019).

$$\Lambda_{\phi^*} = 1.0 \text{ GeV}$$

$$\Lambda_{\phi^*} = 1.3 \text{ GeV}$$



Summary

- Motivated by the small enhancement around 2150MeV in the KK mass distribution of $\gamma p \rightarrow KKp$, and the $\text{Br}(\phi(2170) \rightarrow \phi\eta)$ is of same order as the one of $\phi f_0(980)$, we propose to search for $\phi(2170)$ in the reaction $\gamma p \rightarrow \eta\phi p$.
- Reggeon exchange is important at large energy and forward angle, but should not change too much the shape of the $\eta\phi$ mass distribution, which is relevant to the signal of $\phi(2170)$
- The couplings of $\phi(2170)$ to $\eta\phi$ and $\gamma\eta$ are important, and can be derived from the experimental data in future.



-
- Our calculations show that there will be a **peak**, at least **a bump structure** around 2180 MeV in the $\phi\eta$ mass distribution, and the magnitude of the total cross section from our model is consistent with other works.
 - GlueX and **CLAS12** have the plans, and we suggest to search for $\phi(2170)$ in the reaction of $\gamma p \rightarrow \eta\phi p$



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