$\varphi(2170)$ production in the $\gamma p \to \eta\varphi p$ reaction

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φ(2170) mass from PDG

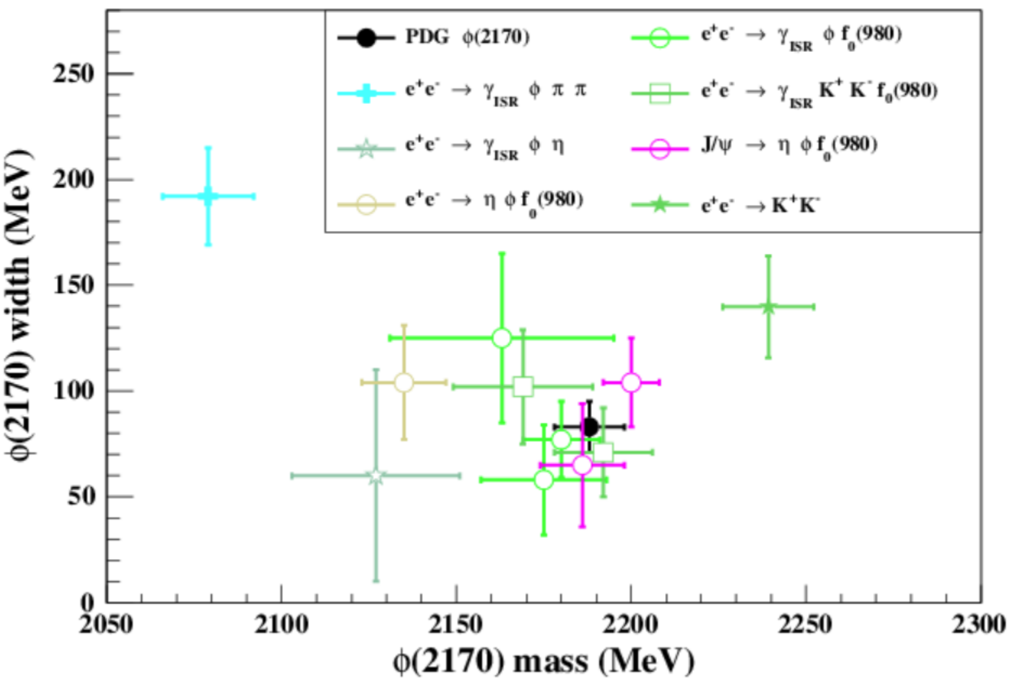
VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$2135 \pm 8 \pm 9$	95	ABLIKIM	19I	BES3	$e^+e^- \rightarrow \eta\phi f_0(980)$
$2239.2 \pm 7.1 \pm 11.3$		[1] ABLIKIM	19L	BES3	$e^+e^- \rightarrow K^+K^-$
$2200 \pm 6 \pm 5$	471	ABLIKIM	15H	BES3	$J/\psi \rightarrow \eta\phi\pi^+\pi^-$
$2180 \pm 8 \pm 8$		[2,3] LEES	12F	BABR	$10.6\ e^+e^- \rightarrow \phi\pi^+\pi^-\gamma$
$2079 \pm 13 ^{+79}_{-28}$	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.

φ(2170) decays from PDG

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

Limited decay modes



- 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, φ(1680)
- $\phi f_0(980)$ mode → φ(2170) has the $s\bar{s}$ component

$\Gamma(\phi\eta) \times \Gamma(e^+e^-)/\Gamma_{total}$ — $\Gamma_2\Gamma_1/\Gamma$

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 $e^+e^- \rightarrow \phi\eta\gamma$

$\Gamma(\phi f_0(980)) \times \Gamma(e^+e^-)/\Gamma_{total}$ — $\Gamma_4\Gamma_1/\Gamma$

VALUE (eV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
2.3±0.3±0.3		13,14 LEES	12F	BABR	10.6 $e^+e^- \rightarrow \phi\pi^+\pi^-\gamma$

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

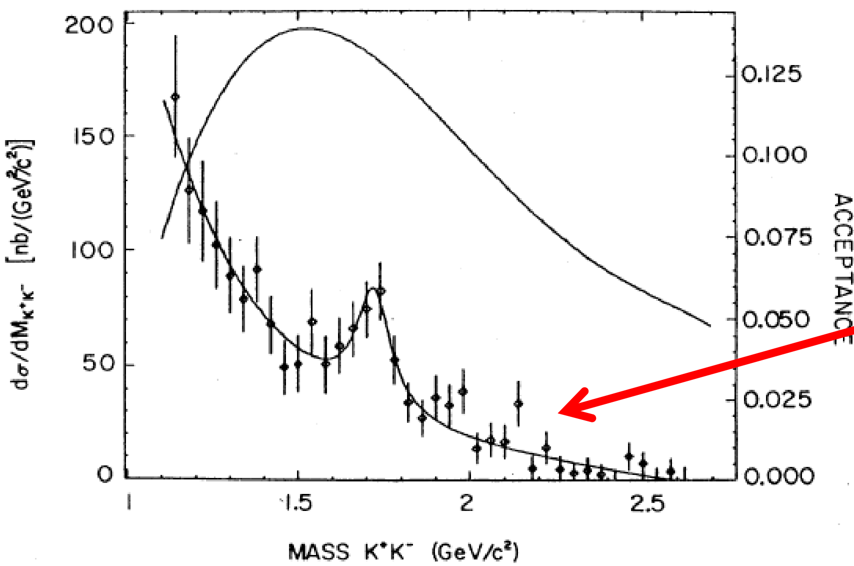


FIG. 25. $(d\sigma/dM_{KK})(\gamma N \to K^+K^-N)$ under assumptions stated in the text. The solid acceptance curve on top uses the scale on the right.

Fermilab broad-band photon beam by Experiment 401

Enhancement structure

$\gamma p \to \eta\phi p$

- **Threshold**

✓ $\phi f_0(980)$ ~2.0 GeV

✓ $\eta\phi$ ~1.6 GeV

$\Gamma(\phi\eta) \times \Gamma(e^+e^-)/\Gamma_{total}$ — $\Gamma_2\Gamma_1/\Gamma$

VALUE (eV)	EVTS	DOCUMENT ID		TECN	COMMENT
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$\Gamma(\phi f_0(980)) \times \Gamma(e^+e^-)/\Gamma_{total}$ — $\Gamma_4\Gamma_1/\Gamma$

VALUE (eV)	EVTS	DOCUMENT ID		TECN	COMMENT
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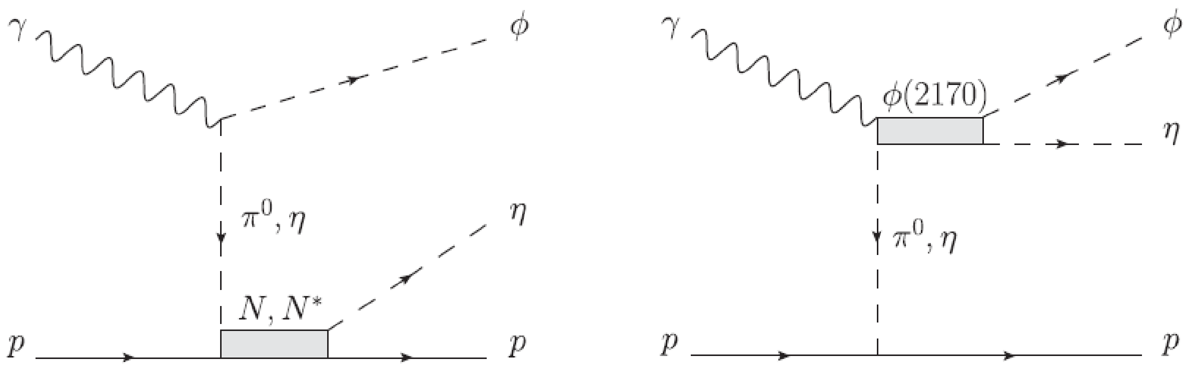
- **GlueX**: search for φ(2170) in photo production
  1305.1523.
- **CLAS12**: $\gamma p \to \eta\phi p$ strangeonium-like state
  EPJ Web Conf. 96, 49201013 (2015).

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



(a) (b)

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

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

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

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

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

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

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

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

Parameters

- **1-20 MeV for ηφ mode**
  - **PRD85,074024 (2012),PRD99,360 074015 (2019),**
  - **PLB650, 390 (2007), PRD68, 054014 (2003)**

$$\Gamma[\phi^* \to \phi\eta] = \frac{g^2_{\phi^*\phi\eta}}{12\pi}\frac{|\vec{p}_{\eta\phi}|^3}{m^2_{\phi^*}},$$

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

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}

- **γη mode（M1+GIwavefunctions）**

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

$$\Gamma(\phi(1680)\to\gamma\eta) \simeq 0.06\ \mathrm{MeV}$$

0.09 MeV PRD65,092003
0.14±0.09 MeV PRC77,045204

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

$$\Gamma(\phi(2170)\to\gamma\eta) \simeq 0.17\ \mathrm{MeV}$$

Results

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

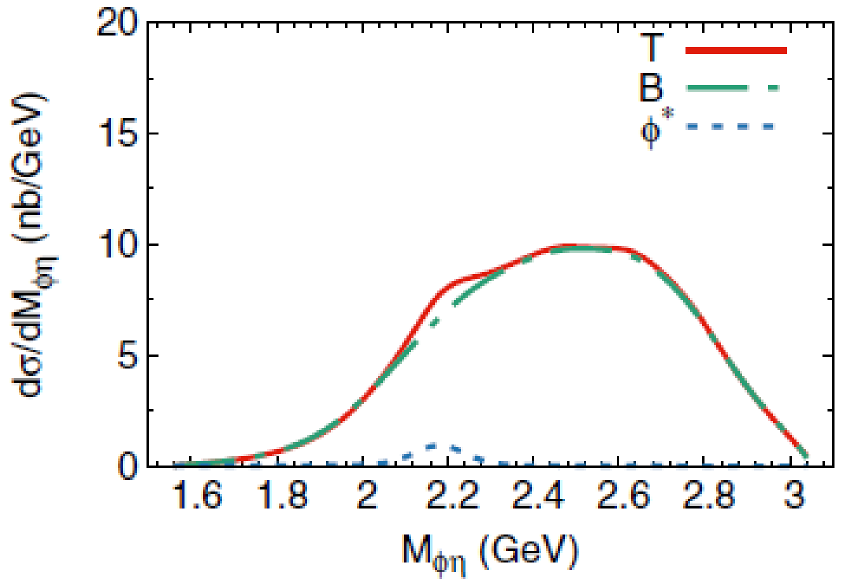
$$\mathcal{M}_{\text{total}} = \mathcal{M}_N^\pi + \mathcal{M}_{N^*}^\pi + \mathcal{M}_N^\eta + \mathcal{M}_{N^*}^\eta + \mathcal{M}_{\phi^*},$$

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

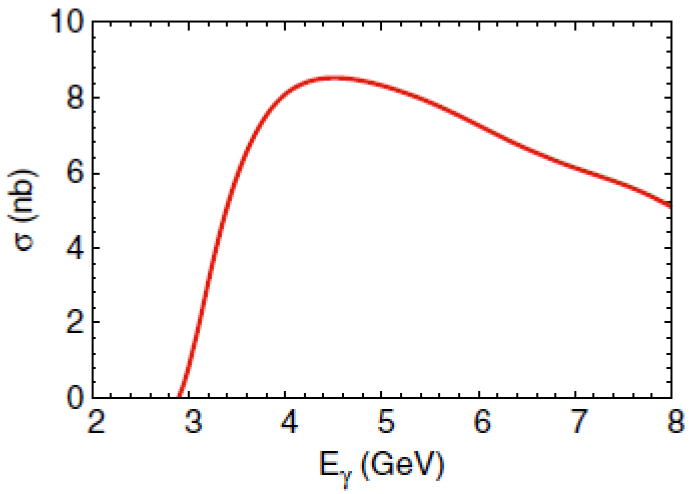
$$\mathcal{M}_N^\pi = \frac{ieg_{\pi NN}g_{\eta NN}g_{\gamma\phi\pi}}{(2M_N)^2 m_\phi}\mathcal{F}(q_\pi^2, M_\pi^2)\mathcal{F}(q_N^2, M_N^2) \times \bar{u}(p_5,s_5)\gamma_5\not{p}_4 G_N(q_N)\gamma_5\not{q}_\pi u(p_2,s_2)G_\pi(q_\pi) \times \epsilon^{\mu\nu\alpha\beta}p_{3\mu}\varepsilon_\nu^*(p_3,s_3)p_{1\alpha}\varepsilon_\beta(p_1,s_1),$$

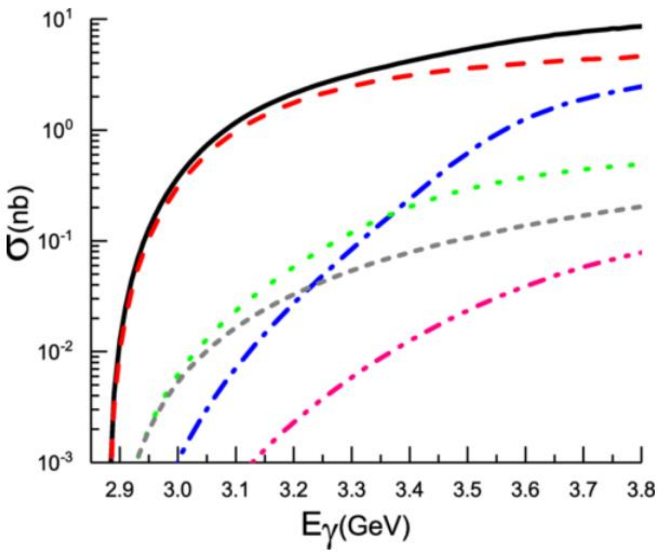
$$\mathcal{M}_{N^*}^\pi = -\frac{ieg_{\pi NN^*}g_{\eta NN^*}g_{\gamma\phi\pi}}{m_\phi}\mathcal{F}(q_\pi^2, M_\pi^2)\mathcal{F}(q_{N^*}^2, M_{N^*}^2) \times \bar{u}(p_5,s_5)G_{N^*}(q_{N^*})u(p_2,s_2)G_\pi(q_\pi) \times \epsilon^{\mu\nu\alpha\beta}p_{3\mu}\varepsilon_\nu^*(p_3,s_3)p_{1\alpha}\varepsilon_\beta(p_1,s_1),$$

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

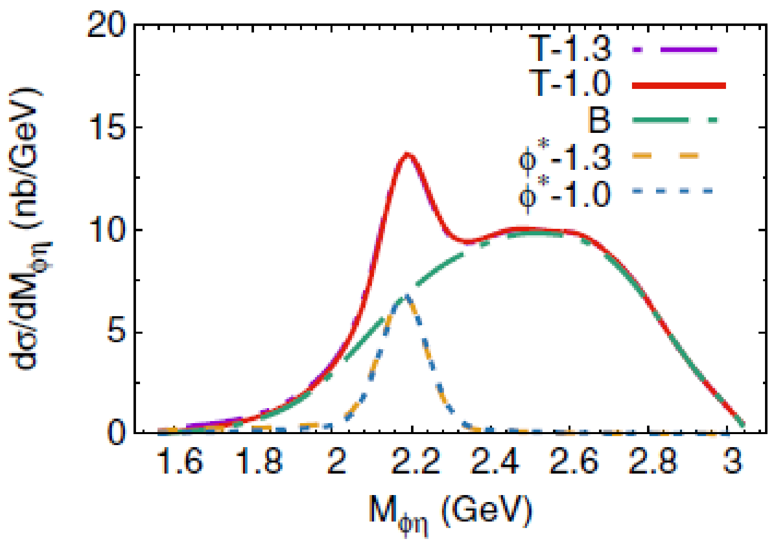


Total cross section





J. Q. Fan, S. F. Chen, and B. C. Liu, Nucleon resonance production in the γp → pηϕ reaction, Phys. Rev. C 99, 450 025203 (2019).



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

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

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 γp → KKp, and the Br(φ(2170)→φη) is of same order as the one of φf_0(980), we propose to search for φ(2170) in the reaction γp → ηφp.
- Reggeon exchange is important at large energy and forward angle, but should not change too much the shape of the ηφ mass distribution, which is relevant to the signal of φ(2170)
- The couplings of φ(2170) to ηφ and γ η 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 φη mass distribution, and the magnitude of the total cross section from our model is consistent with other works.**
- **GlueX and CLAS12 haves the plans, and we suggest to search for φ(2170) in the reaction of γp → ηφp**

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