Light flavor vector mesons between 2 and 3 GeV at BESIII

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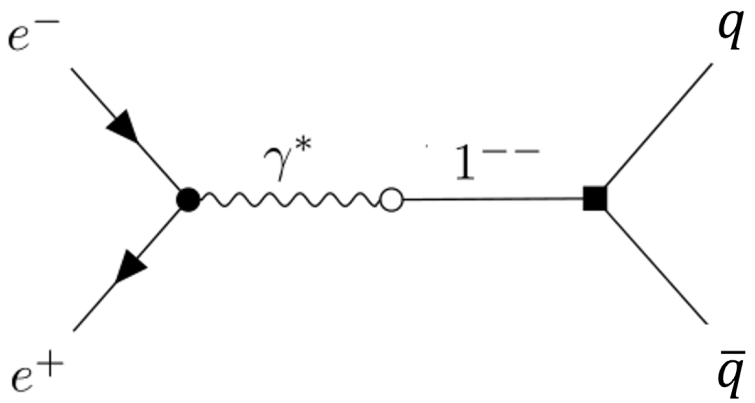
Outline

- Motivation
- BESIII experiment
- Data sets
- Results
  - ρ^*, ω^*, ϕ^* related analyses
- Summary

Motivation

- Light flavor vector mesons
  - Tools to investigate property of non-perturbative QCD
    - mass, width, decay pattern, production rate …
  - Contribution to hadron spectroscopy
  - Analogy to heavy flavor vector meson, exotic hadron
    - Charmonium, bottomonium, strangeonium?
  - Directly produced in electron-positron annihilation
  - Possible states:
    - ρ^*: $\rho(2000)$, $\rho(2150)$, $\rho(2270)$
    - ω^*: $\omega(2205)$, $\omega(2290)$, $\omega(2330)$
    - ϕ^*: $\phi(2170)$



ρ^*, ω^* and ϕ^* states

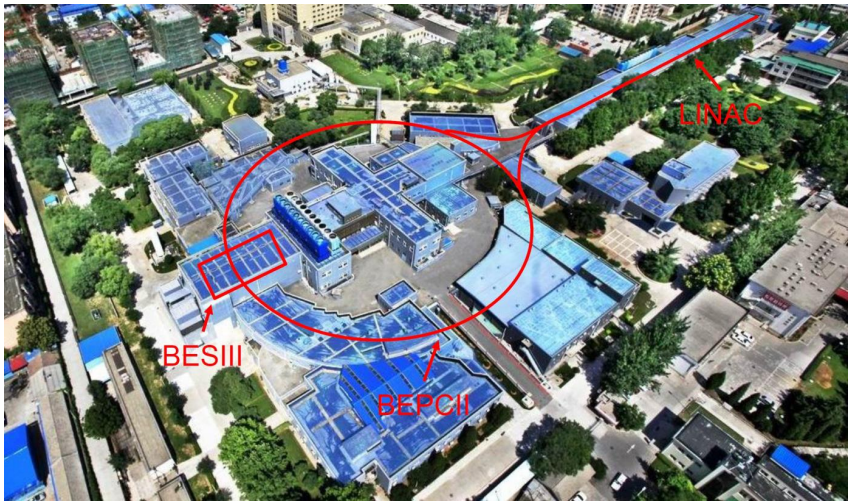
- Many vector states between $\sqrt{s}$ = [2.0, 3.0] GeV
  - ρ^*, ω^*, ϕ^*, exotic states, mixture?
- Couplings to different channels help to reveal their nature
- Common decay patterns: $\rho^* - \omega^* - \phi^*$ mixing?
- Identification of exotic particle with nonexotic quantum numbers
- Well-established experimental meson spectrum is required to
  - Eliminate conventional quarkonia
  - Study the possibility of a complicated pattern of mixing between exotica and conventional mesons

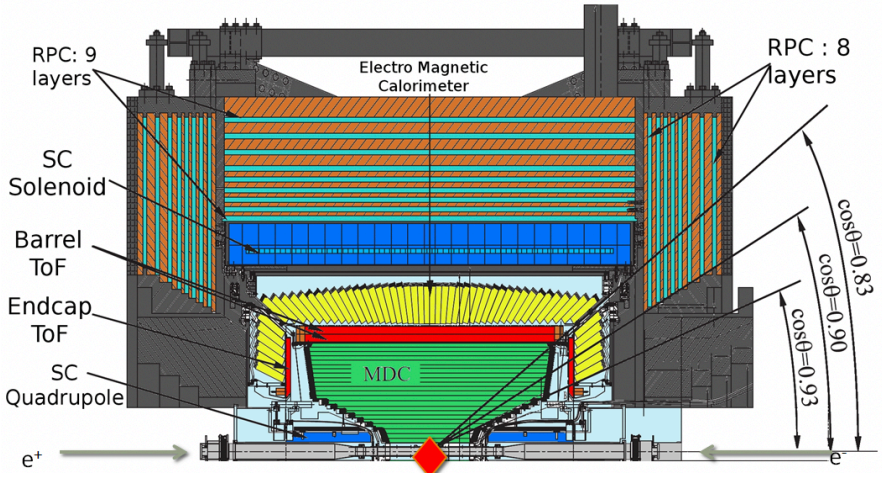
TABLE XII. Decay amplitudes squared (excluding the decay strength constants).

Decay	Products	Squared amplitude
$\rho^* \to PP$	$K\bar{K}$	**PRD79, 014036** $^{4}_{8}$
	$\pi\pi$	
$\rho^* \to VP$	$\bar{K}^*K$	2
	$\rho\eta$	$2\cos^2\phi_P$
	$\rho\eta'$	$2\sin^2\phi_P$
	$\omega\pi$	$2\sin^2\phi_V$
	$\phi\pi$	$2\cos^2\phi_V$
$\omega^* \to PP$	$K\bar{K}$	$12\sin^2\theta_V^*$
$\omega^* \to VP$	$\phi\eta$	$2(\sqrt{2}\cos\phi_V^*\sin\phi_V\sin\phi_P + \sin\phi_V^*\cos\phi_V\cos\phi_P)^2$
	$\phi\eta'$	$2(\sqrt{2}\cos\phi_V^*\sin\phi_V\cos\phi_P - \sin\phi_V^*\cos\phi_V\sin\phi_P)^2$
	$\omega\eta$	$2(\sqrt{2}\cos\phi_V^*\cos\phi_V\sin\phi_P - \sin\phi_V^*\sin\phi_V\cos\phi_P)^2$
	$\omega\eta'$	$2(\sqrt{2}\cos\phi_V^*\cos\phi_V\cos\phi_P + \sin\phi_V^*\sin\phi_V\sin\phi_P)^2$
	$\rho\pi$	$6\sin^2\phi_V^*$
	$K^*\bar{K}$	$2(\sin\phi_V^* + \sqrt{2}\cos\phi_V^*)^2$
$\phi^* \to PP$	$K\bar{K}$	$12\cos^2\theta_V^*$
$\phi^* \to VP$	$\phi\eta$	$2(-\sqrt{2}\sin\phi_V^*\sin\phi_V\sin\phi_P + \cos\phi_V^*\cos\phi_V\cos\phi_P)^2$
	$\phi\eta'$	$2(\sqrt{2}\sin\phi_V^*\sin\phi_V\cos\phi_P + \cos\phi_V^*\cos\phi_V\sin\phi_P)^2$
	$\omega\eta$	$2(\sqrt{2}\sin\phi_V^*\cos\phi_V\sin\phi_P + \cos\phi_V^*\sin\phi_V\cos\phi_P)^2$
	$\omega\eta^*$	$2(-\sqrt{2}\sin\phi_V^*\cos\phi_V\cos\phi_P + \cos\phi_V^*\sin\phi_V\sin\phi_P)^2$
	$\rho\pi$	$6\cos^2\phi_V^*$
	$K^*\bar{K}$	$2(\cos\phi_V^* - \sqrt{2}\sin\phi_V^*)^2$

BESIII experiment

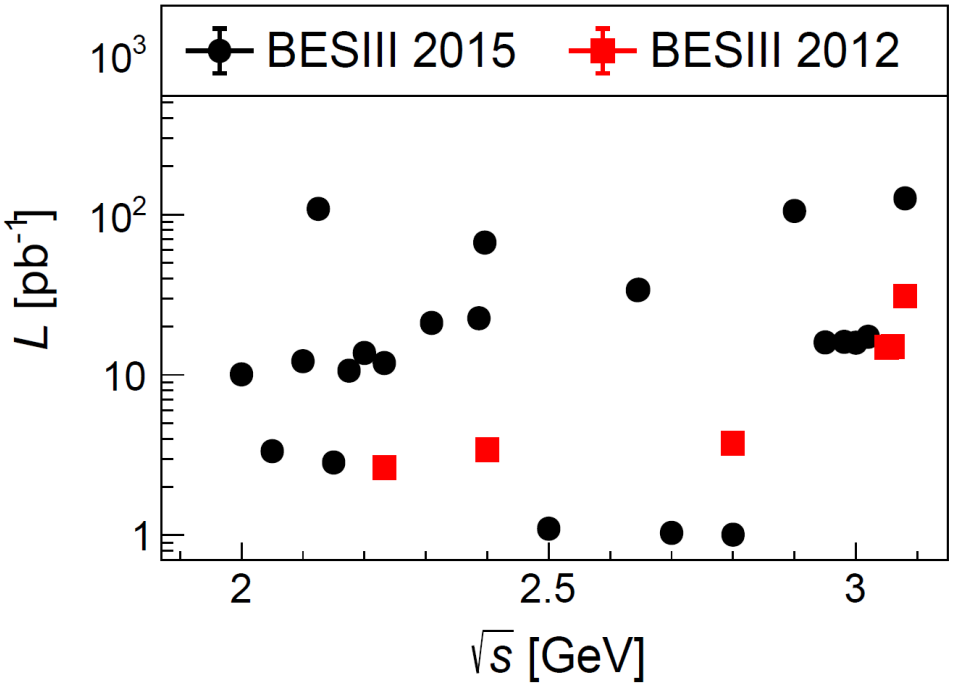
- electron-position collision
- $\sqrt{s}$: 2 - 4.95 GeV
- $\mathcal{L}$: 1x10^{33} cm^{-2}s^{-1} at 3.77 GeV
- Sub-detectors
  - MDC:
    multilayer drift chamber
    σ_p/p=0.5% @1 GeV, $\sigma_{dE/dx}$=6%
  - TOF: Time-of-Flight
    barrel: σ_T=68 ps P.S.; endcaps:
    MRPC, 60 ps
  - EMC: Electromagnetic calorimeter,
    $\Delta E/E$ = 2.5% @1 GeV, σ_x ~ 6mm @1GeV
  - MG: superconductor magnet
  - MUC: Muon Counter, efficiency 96%





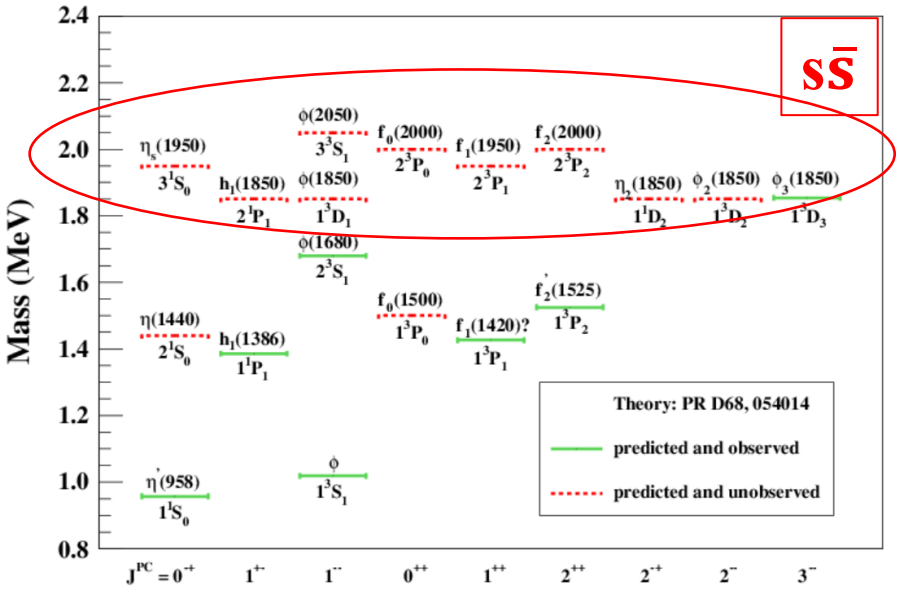
Data sets

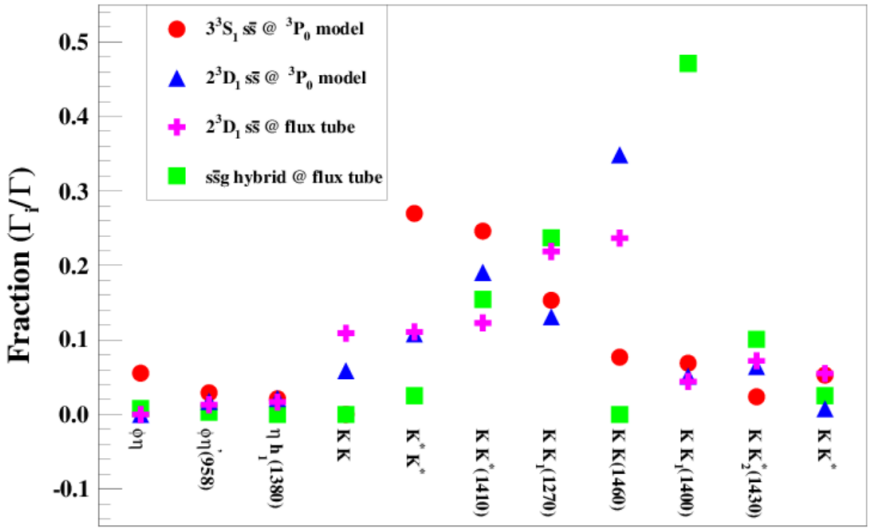
- Data below J/ψ
- $\sqrt{s}$: 2.0 – 3.08 GeV
- $\mathcal{L}$: ~650 pb^{-1}
- ρ^*, ω^*, ϕ^*: Excited Light flavor vector meson directly produced
- Line shape scan to study properties of light flavor vector mesons



$\phi(2170)$

- Strangeonium spectrum
  - Based on potential model
  - Many unobserved
  - Hard to distinguish from others
- Strangeonium-like state
  - Analogy to charmonium-like
  - $\phi(2170)$: possible one
  - Strength of coupling to different final states

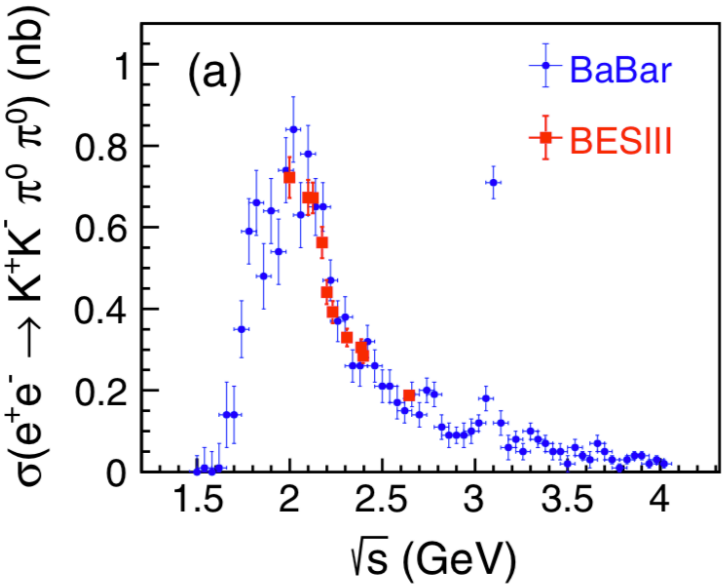


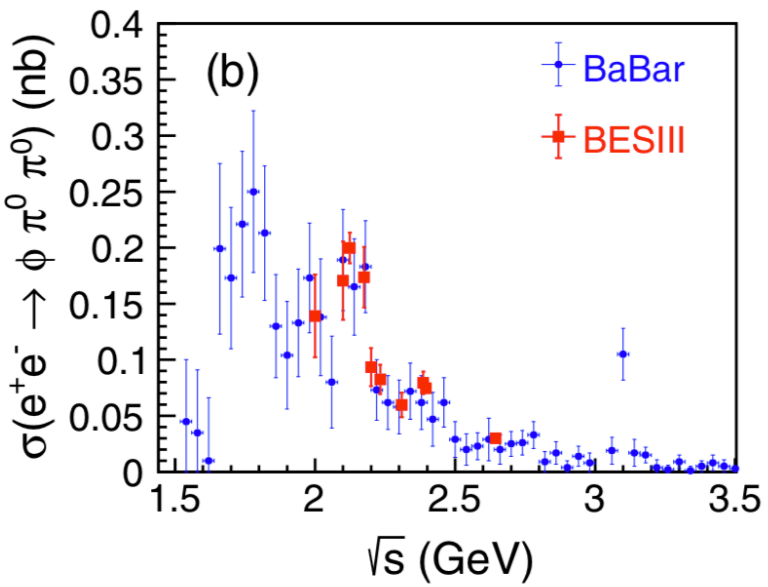


$\phi(2170)$ in $K^+K^-\pi^0\pi^0$

- $K^+K^-(\phi)\pi^0\pi^0$
  - Improved precision of cross section
  - Partial wave analysis (PWA) to extract internal processes

[PRL124, 112001(2020)]

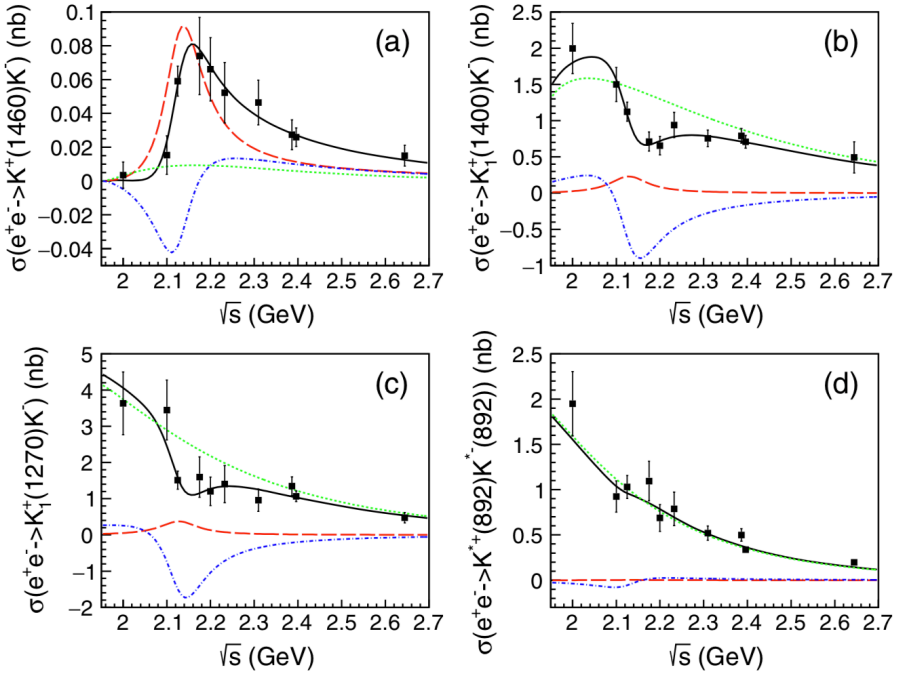




$\phi(2170)$ in $K^+K^-\pi^0\pi^0$

- $K^+K^-(\phi)\pi^0\pi^0$
  - Resonance in internal processes: 6.3σ
    - $M = 2126.5 \pm 16.8 \pm 12.4\ \mathrm{MeV}/c^2$
    - $\Gamma = 106.9 \pm 32.1 \pm 28.1\ \mathrm{MeV}$
  - Internal processes in PWA
    - $K^+(1460)K^-$: 4.4σ
    - $K_1^+(1400)K^-$: 4.8σ
    - $K_1^+(1270)K^-$: 1.4σ
    - $K^{*+}(892)K^{*-}(892)$: 1.2σ

[PRL124, 112001(2020)]



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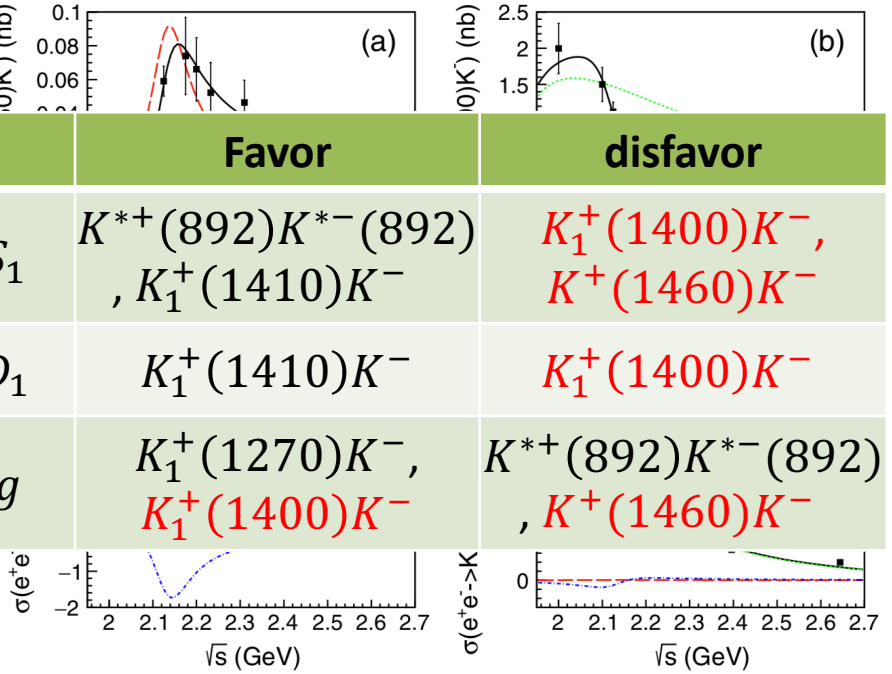


	Favor	disfavor
3^3S_1	$K^{*+}(892)K^{*-}(892)$, $K_1^+(1410)K^-$	$K_1^+(1400)K^-$, $K^+(1460)K^-$
2^3D_1	$K_1^+(1410)K^-$	$K_1^+(1400)K^-$
$s\bar{s}g$	$K_1^+(1270)K^-$, $K_1^+(1400)K^-$	$K^{*+}(892)K^{*-}(892)$, $K^+(1460)K^-$

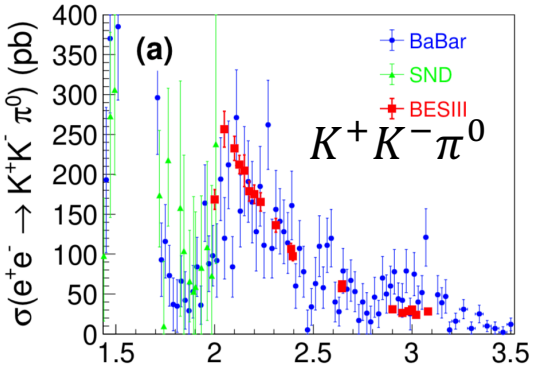
None of 3^3S_1, 2^3D_1 $s\bar{s}$ states and $s\bar{s}g$ state agree well with the result

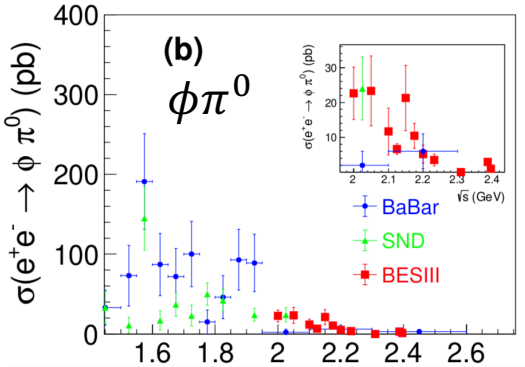
$\phi(2170)$ in $K^+K^-\pi^0$

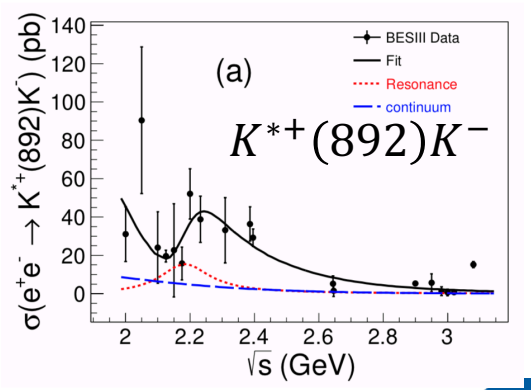
- $K^+K^-(\phi)\pi^0$
  - PWA to extract internal processes
  - Resonance in internal processes: 7.1σ
    - $M = 2190 \pm 19 \pm 37\ \mathrm{MeV}/c^2$
    - $\Gamma = 191 \pm 28 \pm 60\ \mathrm{MeV}$
  - $K^+K^-\pi^0$
    - $\phi\pi^0$
    - $K^{*+}(892)K^-$: 3.7σ
    - $K_2^{*+}(1430)K^-$: 6.1σ

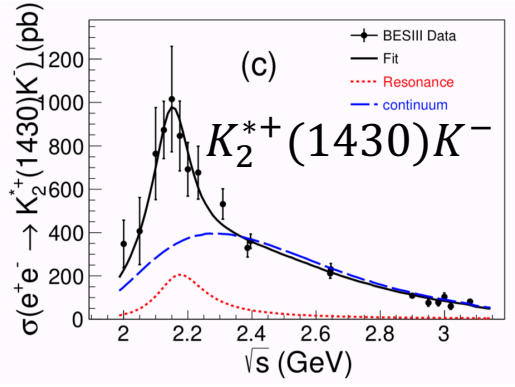
[JHEP07(2022)045]

$$\frac{Br(\phi(2170) \to K_2^{*+}(1430)K^-)}{Br(\phi(2170) \to K^{*+}(892)K^-)} = 12.6 \pm 4.5 \quad (22.7 \pm 4.1)$$





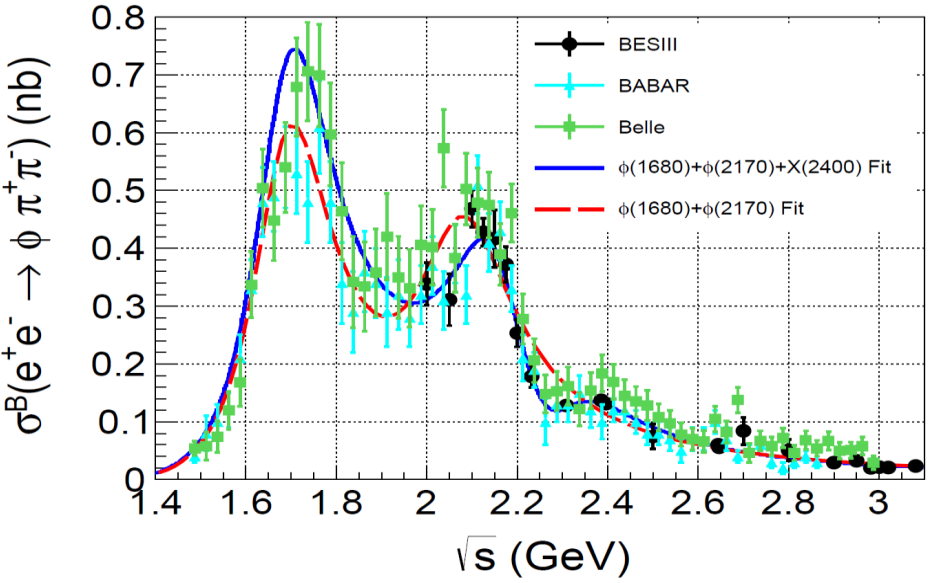




$\phi(2170)$ in $\phi\pi^+\pi^-$

- $\phi\pi^+\pi^-$
  - Resonances at 2.1, 2.4 GeV
  - Possible contribution from $\phi(2170)$

[arXiv:2112.13219]

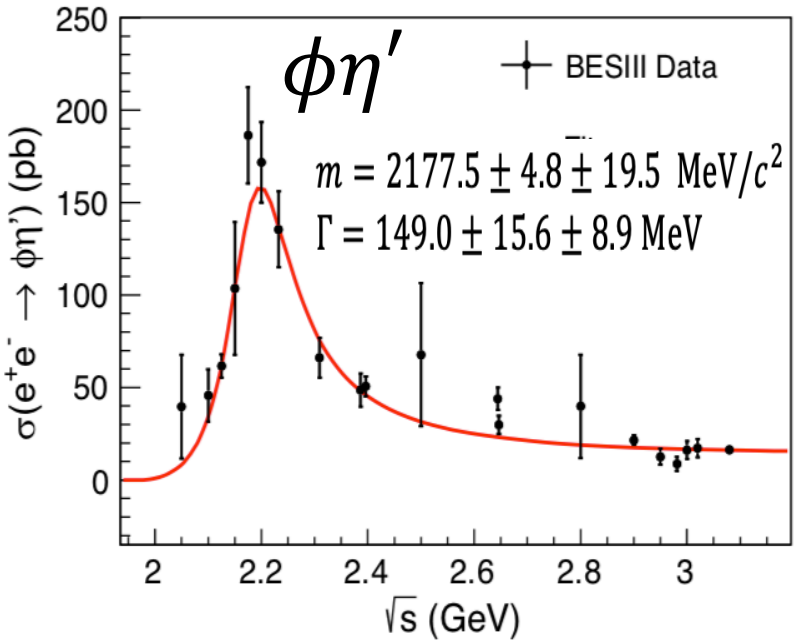


Parameters	Solution I	Solution II	Solution III	Solution IV
$M_r(\phi(1680))$		1675 ± 7		
$\Gamma_r(\phi(1680))$		238 ± 29		
$Br\Gamma_{ee}(\phi(1680))$	35.3 ± 1.5	39.0 ± 1.3	20.7 ± 1.3	18.8 ± 0.9
$M_r(\phi(2170))$		2174 ± 23		
$\Gamma_r(\phi(2170))$		207 ± 49		
$Br\Gamma_{ee}(\phi(2170))$	60.2 ± 34.5	329 ± 211	123 ± 83	22.9 ± 12.6
$\phi_P(\phi(2170)/\phi(1680))$	0.75 ± 0.14	-0.99 ± 0.60	2.90 ± 0.87	2.46 ± 0.68
$M_r(\mathrm{R}(2400))$		2276 ± 42		
$\Gamma_r(\mathrm{R}(2400))$		320 ± 112		
$Br\Gamma_{ee}(\mathrm{R}(2400))$	50.7 ± 35.7	350 ± 247	112 ± 82	15.6 ± 9.0
$\phi_P(\mathrm{R}(2400)/\phi(1680))$	-2.92 ± 0.65	2.91 ± 0.52	0.03 ± 0.27	0.56 ± 0.84

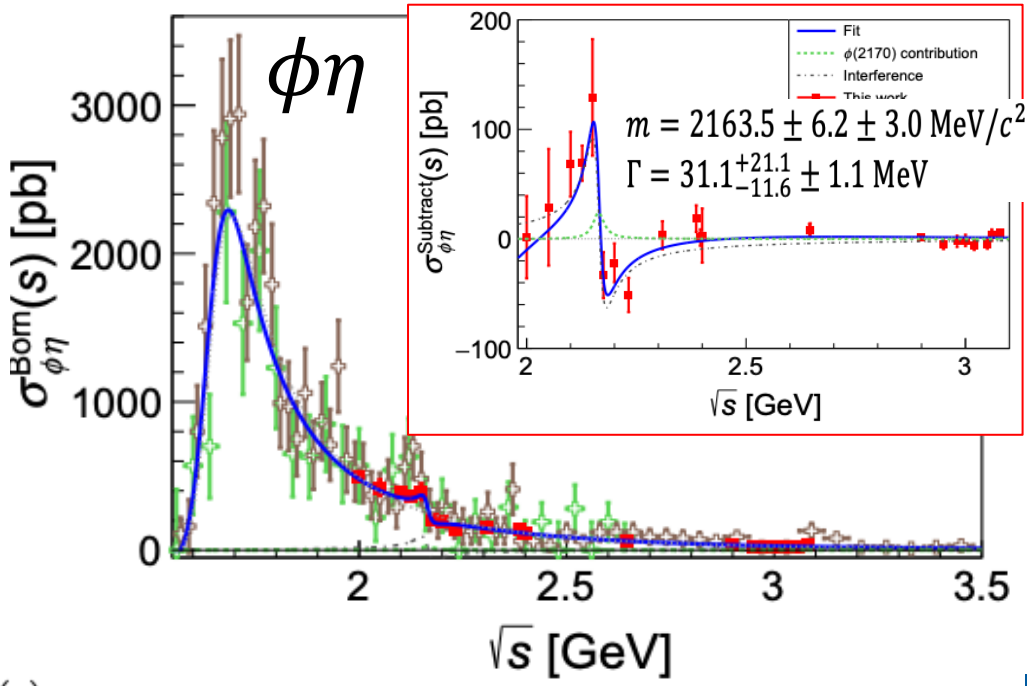
$\phi(2170)$ in $\phi\eta/\phi\eta'$

- $\phi\eta$ and $\phi\eta'$
  - Resonance around 2.2 GeV
  - Br($\phi\eta$)/Br($\phi\eta'$)=$0.03^{+0.02}_{-0.01}$, $(1.42^{+0.56}_{-0.46})$, disfavor $s\bar{s}g$ interpretation [PRD59, 034016; PLB650, 390]

[PRD102, 012008(2020)]



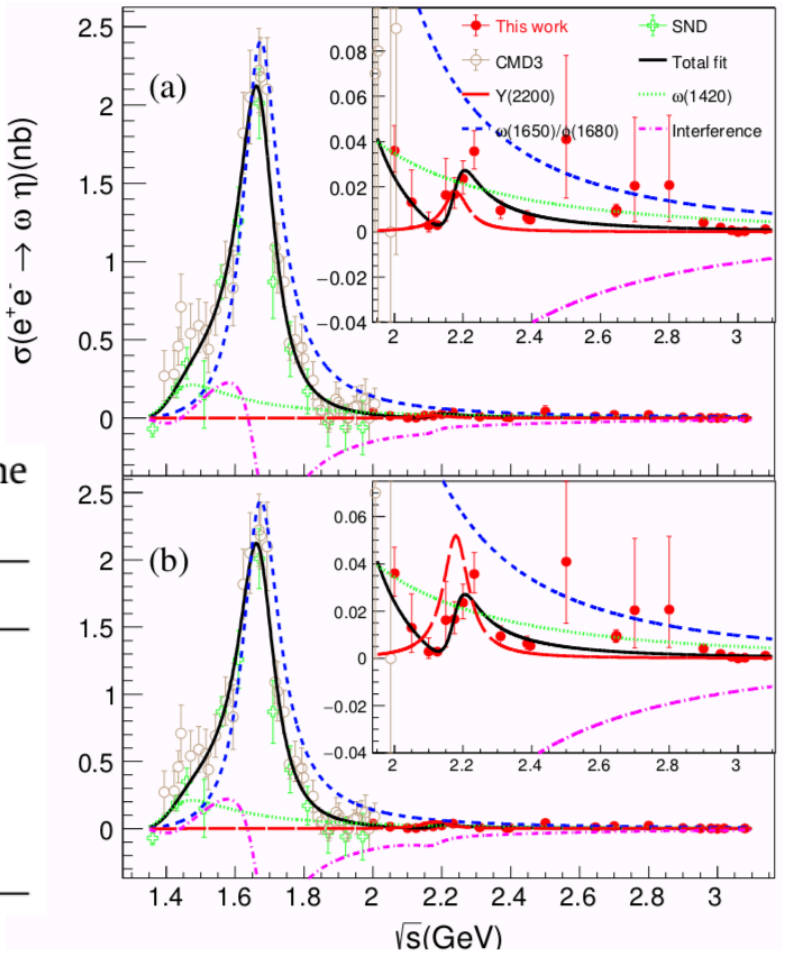
[PRD104.032007(2021)]



$\phi(2170)$ in $\omega\eta$

- $\omega\eta$
  - Resonance around 2.2 GeV
  - $\omega\eta$ is consistent with $\phi(2170)$
    - also can be a ω^*

[PLB 813 (2021) 136059]



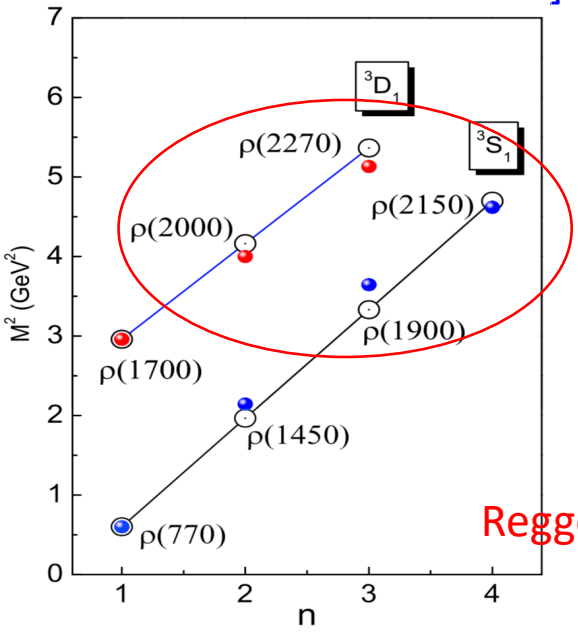
Resonance parameters of the $Y(2180)$ as obtained in the fit to the $e^+e^- \to \omega\eta$ dressed cross section.

Parameters	Solution I	Solution II
$m_{Y(2180)}$ (MeV/c^2)	2176 ± 24	
$\Gamma_{Y(2180)}$ (MeV)	89 ± 50	
$\Gamma^{ee} \cdot B^{\omega\eta}$ (eV)	0.43 ± 0.15	1.25 ± 0.48
φ	2.6 ± 0.3	1.9 ± 0.2
significance	6.2σ	

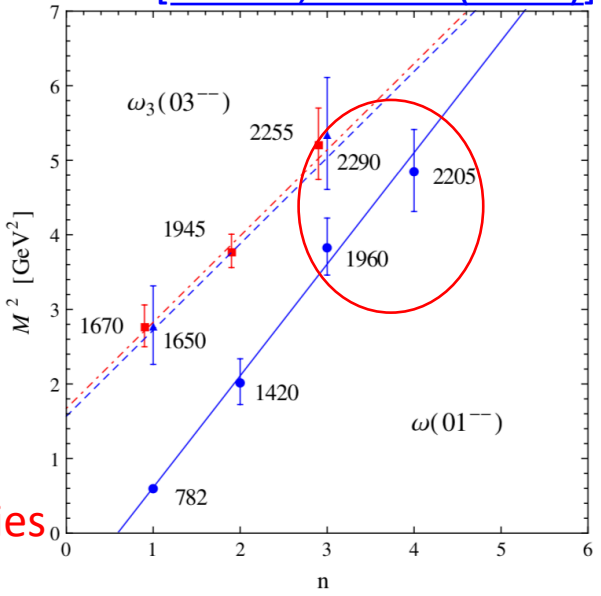
Other vector mesons

- ρ^* and ω^*
  - Members above 2 GeV, controversies about their nature
    - Pure state or mixture?
    - Decay patterns can be used to identify them

[PRD88,034008(2013)]



[PRD85,094006(2012)]

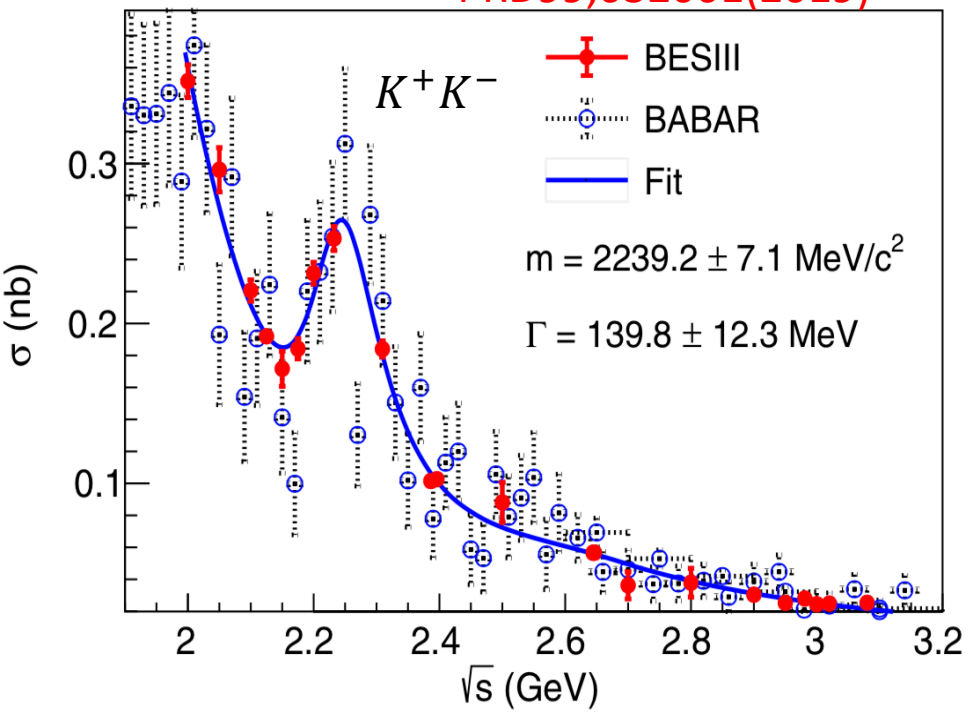


Regge trajectories

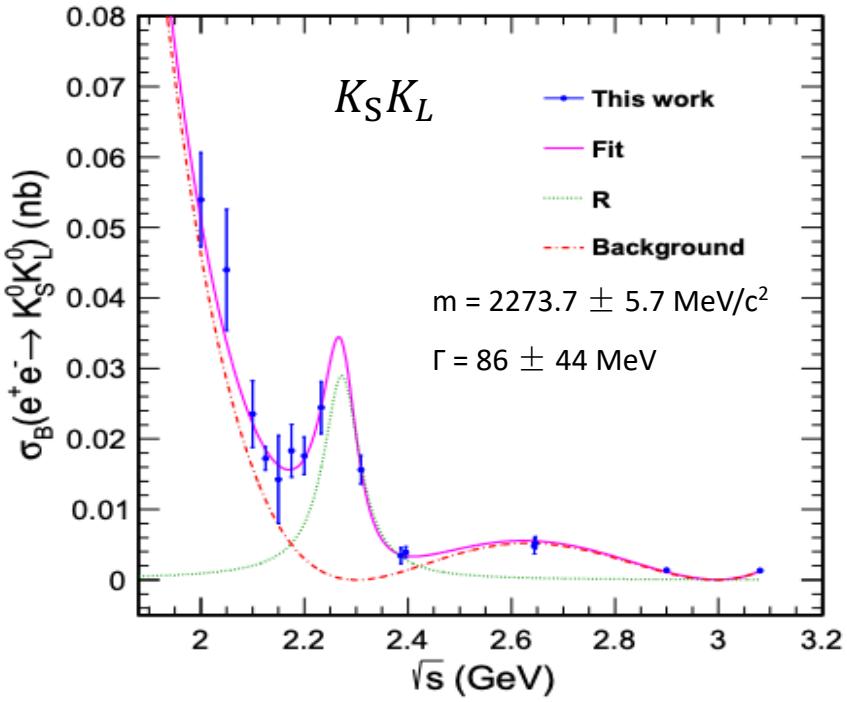
KK

- K^+K^-, K_SK_L

PRD99,032001(2019)



PRD104,092014(2021)

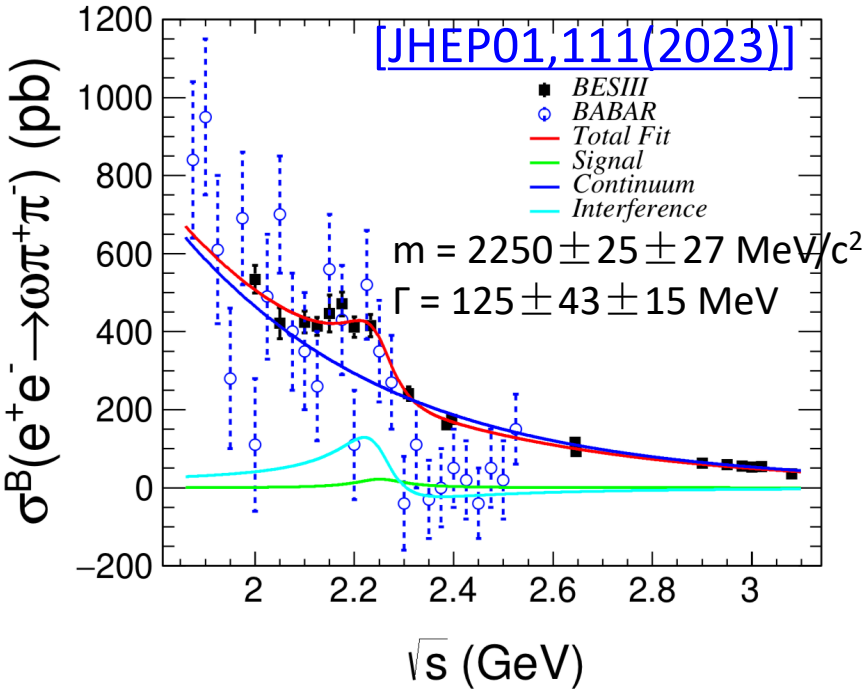


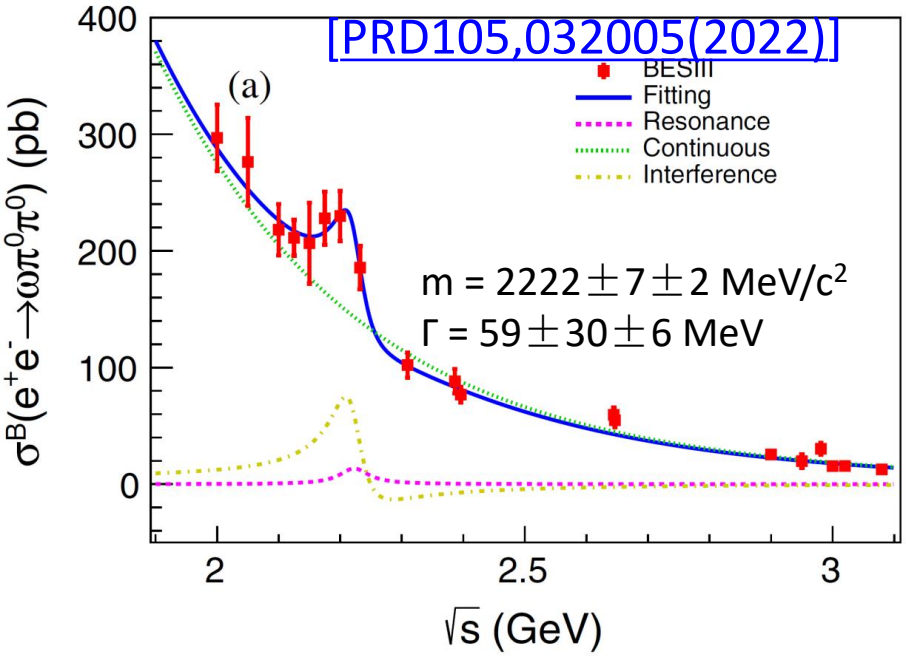
Discrepancy: mass higher, width much larger than $\phi(2170)$

Resonance also exist in $\pi^+\pi^-$ process, maybe ρ(2150), $\phi(2170)$, or mixture?

$\omega\pi\pi$

- $\omega\pi^+\pi^-$ and $\omega\pi^0\pi^0$
  - Clear structure around 2.2 GeV in both channels
  - Combined $\omega\pi\pi$: m = 2232±19±27 MeV/c², Γ = 93±53±20 MeV
  - Structure also in subprocesses $\omega f_0(500)$, $\omega f_0(800)$, $\omega f_0(1370)$, $\omega f_2(1270)$, $b_1(1235)\pi$ → ω^*

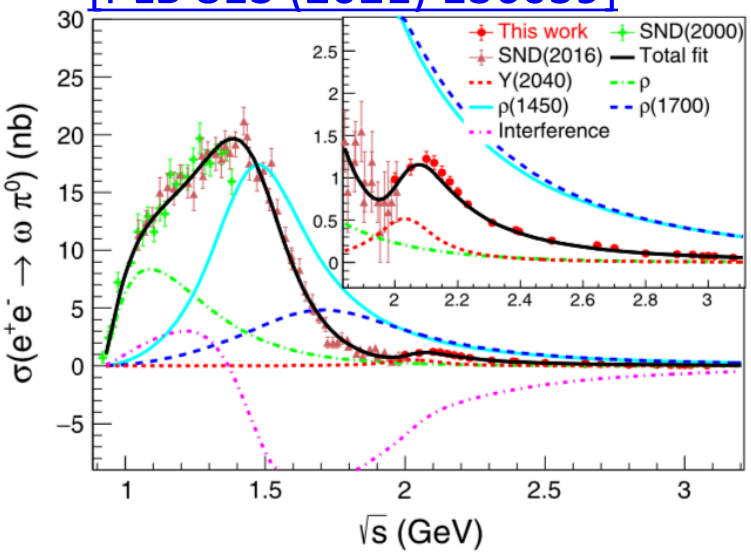


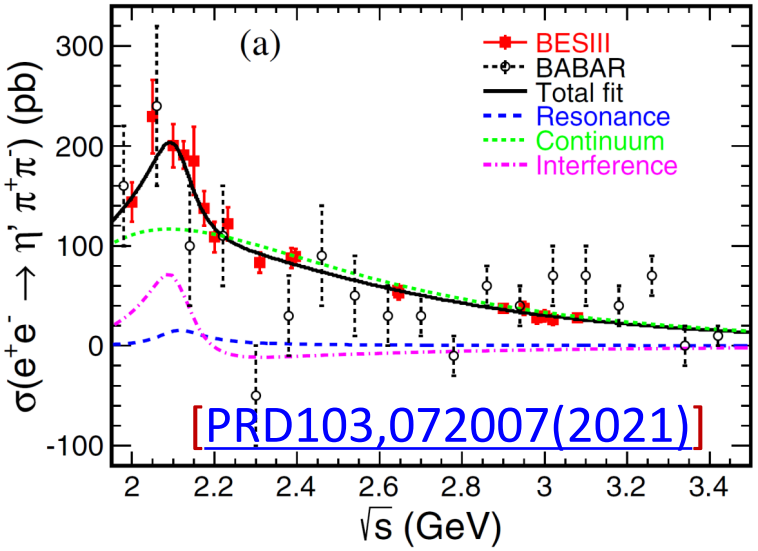


Other channels

- $\omega\pi^0$
  - Resonance around 2.1 GeV
    - m = 2034 ± 13 ± 9 MeV/c²
    - Γ = 234 ± 30 ± 25 MeV
    - Isospin 1, ρ^*,ρ(2000) or ρ(2150)?
- $\eta'\pi^+\pi^-$
  - Resonance around 2.1 GeV
    - m = 2111±43±25 MeV/c²
    - Γ = 135±34±30 MeV
    - ρ^*?

[PLB 813 (2021) 136059]





Summary

- Many results on light flavor vector mesons from BESIII between 2 to 3 GeV
  - Exclusive channels
  - Partial wave analyses: $K^+K^-\pi^0\pi^0$, $K^+K^-\pi^0$ and $\omega\pi\pi$
- $\phi(2170)$
  - Its nature is still controversial
  - Efforts from theoretical and experimental sides are desirable
- The nature of ρ^*, ω^*, ϕ^* call for further studies, like couple-channel analysis or partial wave analysis.