Light flavour vector mesons between 2 and 3 GeV at BESIII

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On behalf of BESIII collaboration

ICHEP 2024 | PRAGUE

17–24 lug 2024
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Why?

– Tool to investigate properties in non-perturbative QCD
- mass, width, decay pattern, production rate …

– Contribution to hadron spectroscopy

– Many vector states between 2.0 and 3.0 GeV
– $\rho*$, $\omega*$, $\phi*$, exotic states, mixture?
- ρ^*: $\rho(2000)$, $\rho(2150)$, $\rho(2270)$
- ω^*: $\omega(2220)$, $\omega(2290)$, $\omega(2330)$
- ϕ^*: $\phi(2170)$

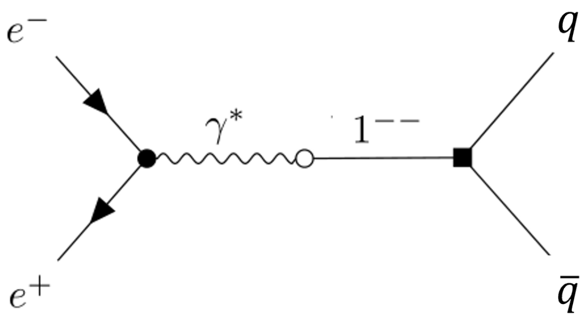
Need to be confirmed

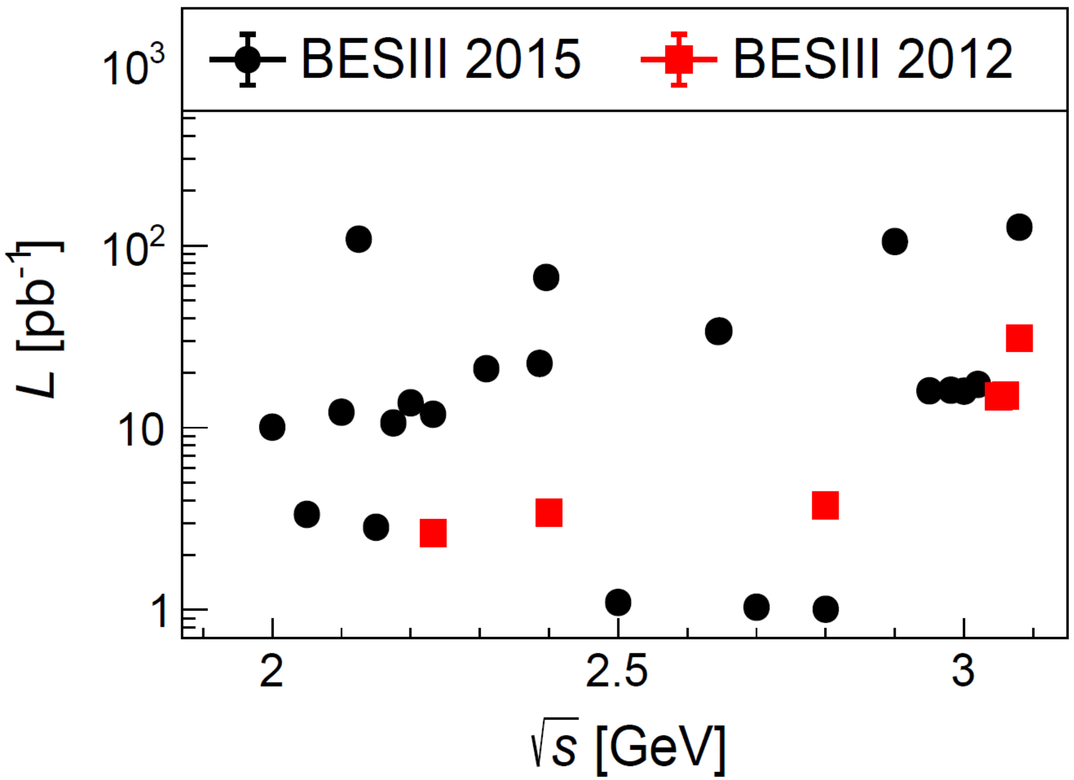
– Analogy to heavy flavour vector meson, exotic hadron
- Charmonium, bottomonium, strangeonium?
- Exotics states with strange quark
✓ intermediate mass, bridge between light and heavy quark

- Couplings to different channels may help to reveal their nature
- Common decay patterns: is there $\rho^* - \omega^* - \phi^*$ mixing?
- Identification of exotic particle with non exotic quantum numbers

Data samples (for these studies)

1) Data below J/ψ
- ecm: 2.0 – 3.08 GeV
- $\mathcal{L}$: ~650 pb-1
- Excited Light flavour vector meson directly produced in electron-positron annihilation ($\rho*$, $\omega*$, $\phi*$)





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Line shape scan to study properties of light flavour vector mesons

2) PWA using charmonia world largest data samples
10 Billions J/ψ
2.7Billions ψ(3686)

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Recent (2024) results from BESIII

- Study of $e^+e^- \to K_S^0 K_L^0 \pi^0$ JHEP01(2024)180
- Study of $e^+e^- \to \pi^+\pi^-\pi^0$ https://arxiv.org/abs/2401.14711 Accepted by PRD
- Study of $e^+e^- \to \omega\eta'$ https://arxiv.org/abs/2401.14711 Accepted by JHEP
- Study of $e^+e^- \to \eta\pi^+\pi^-$ PHYSICAL REVIEW D 108, L111101
- Study of $J/\psi \to \phi\pi^0\eta$ *Ask me in QT!!* https://arxiv.org/abs/2311.07043

On-going analyses: $J/\psi \to K^+K^-\eta'$ $\psi(3686) \to \phi\eta\eta'$

ϕ(2170) aka Y(2175)

First observed by BaBar in 2006 in ISR process
$e^+ e^- \rightarrow \phi f_0(980) \gamma$
Then investigated by Belle, BES, BESIII

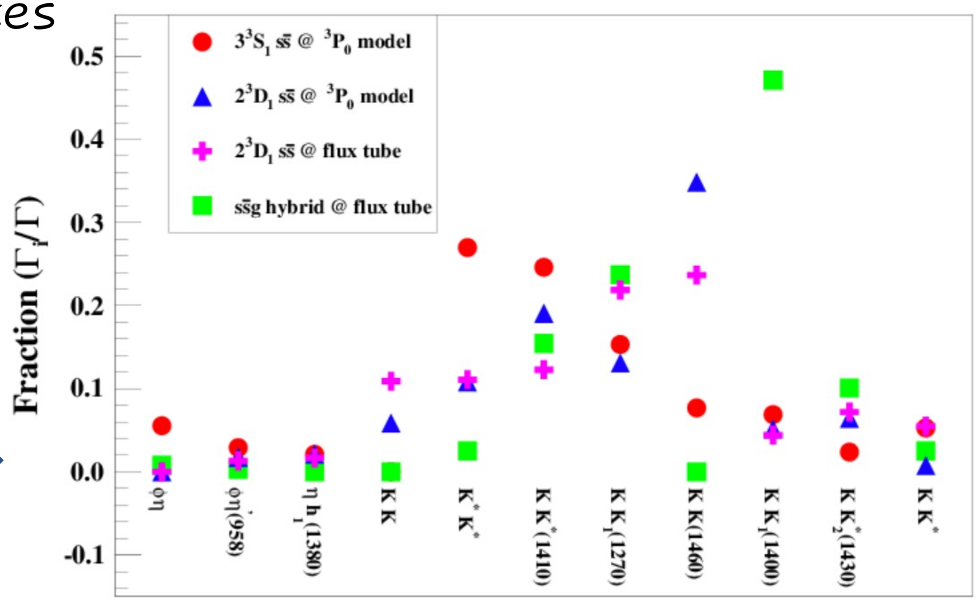
Studied in many exclusive channels:

$\phi\eta, \phi\eta', \phi f_0(980), K^+K^-, K_S^0 K_L^0, K^*(892)^+K^-, K_2^*(1430)^+K^-, K^*(892)^+K^*(892)^-$ +other excited $K\bar{K}$ states

None is dominant

Confirmed by BESIII in the
$K(1400)^+K^-$, $K_1(1400)^+K^-$, $K_1(1270)^+K^-$, and $\phi\eta'$ final states

Its nature still controversial:
a traditional $s\bar{s}$ state (3^3S_1, 2^3D_1), a $s\bar{s}g$ hybrid, a tetraquark state, a $\Lambda\bar{\Lambda}$ bound state, or a $\phi K\bar{K}$ resonance, strangeonium-like state.
The predicted decay width varies depending on the assumed nature



$\Gamma(\phi\eta) < \Gamma(\phi\eta')$

Disfavour hybrid hypothesis
Favours strangeonium-like state
With η −η ′ mixing

$e^+e^- \to K_S^0 K_L^0 \pi^0$ study

JHEP01(2024)180

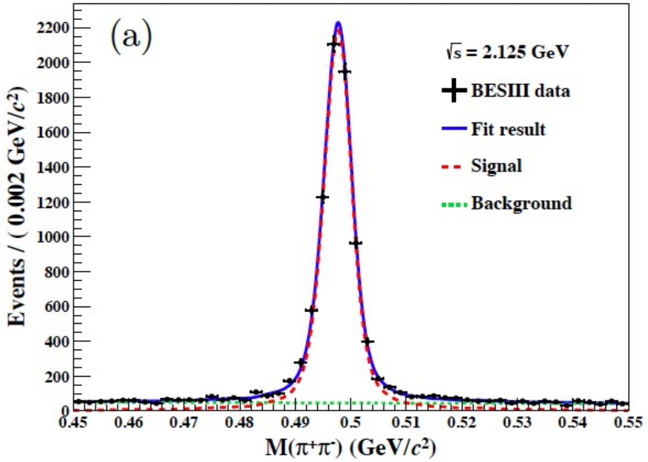
$\sqrt{s}$ =[2.00-3.08]GeV

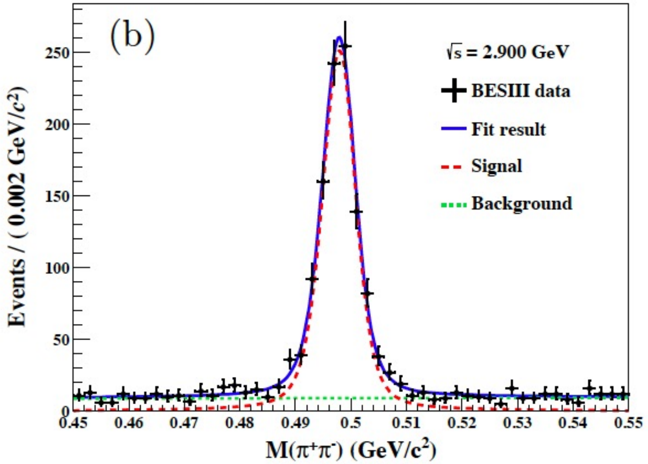
Previously investigated by ISR process by BaBar
And by SND (in lower energy region)

$$e^+e^- \to K_S^0 K_L^0 \pi^0$$

$$K_S^0 \to \pi^+\pi^-$$

$$\pi^0 \to \gamma\gamma$$





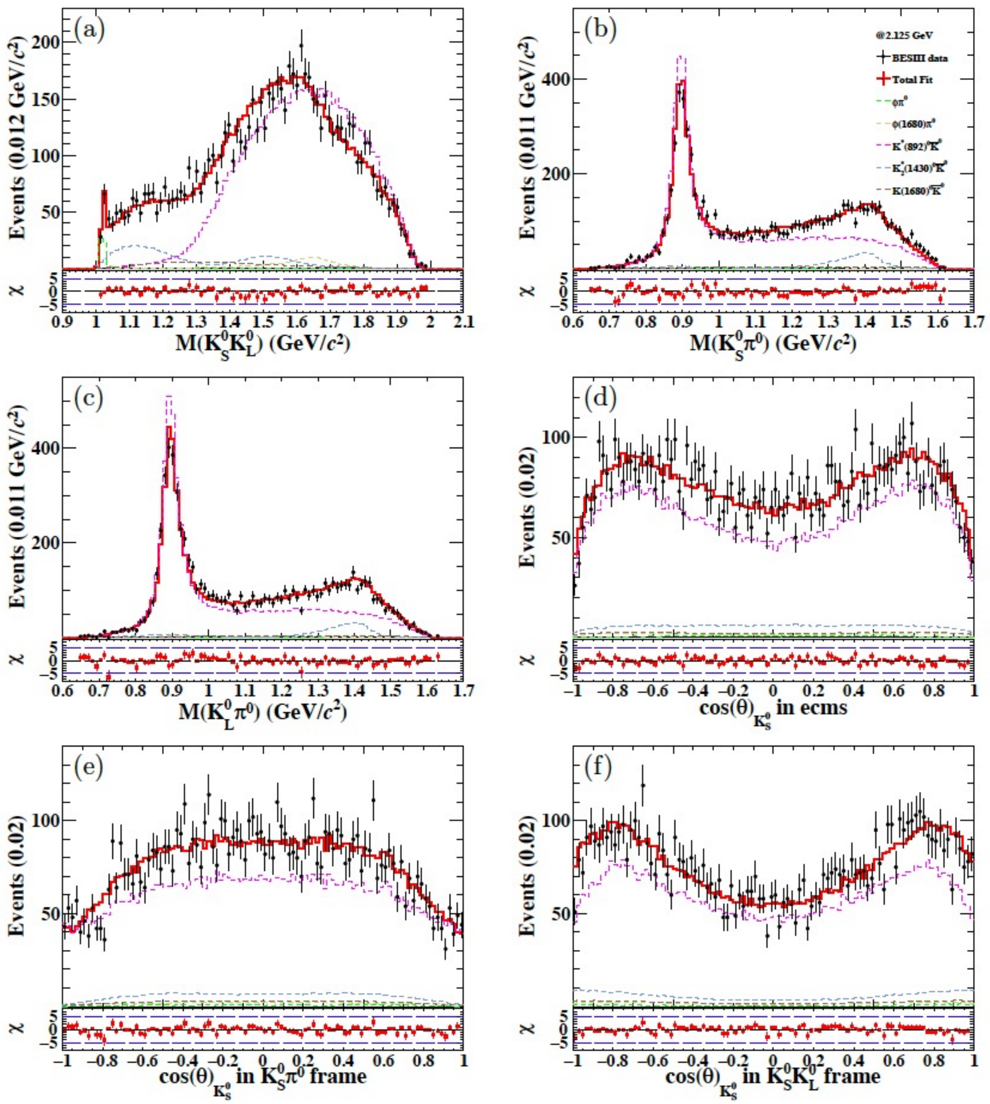
$e^+e^- \to K_S^0 K_L^0 \pi^0$ study

arXiv:2309.13883v2

$\sqrt{s}$ =[2.00-3.08]GeV

Previously investigated by ISR process by BaBar
And by SND (in lower energy region)

$\sqrt{s} = 2.125$ GeV



PWA (in GPUPWA framework),
Masses and widths of intermediate resonances fixed to PDG (quasi two-body decay amp and covariant tensor amp formalism)
BASELINE: $K^*(892)^0\bar{K}^0, K_2^*(1430)^0\bar{K}^0$

Intermediate states (decaying. $K_S^0K_L^0$ or $K_S^0(K_L^0)\pi^0$) are included in the solution if the statistical significance is greater than 5σ,

Process	Significance		
	2.125 GeV	2.396 GeV	2.900 GeV
$\phi\pi^0$	13.1σ	8.6σ	9.7σ
$\phi(1680)\pi^0$	11.1σ	12.2σ	8.3σ
$K^*(892)^0\bar{K}^0$	>30σ	>30σ	>30σ
$K_2^*(1430)^0\bar{K}^0$	29.2σ	5.7σ	5.1σ
$K(1680)^0\bar{K}^0$	9.8σ	8.4σ	7.6σ

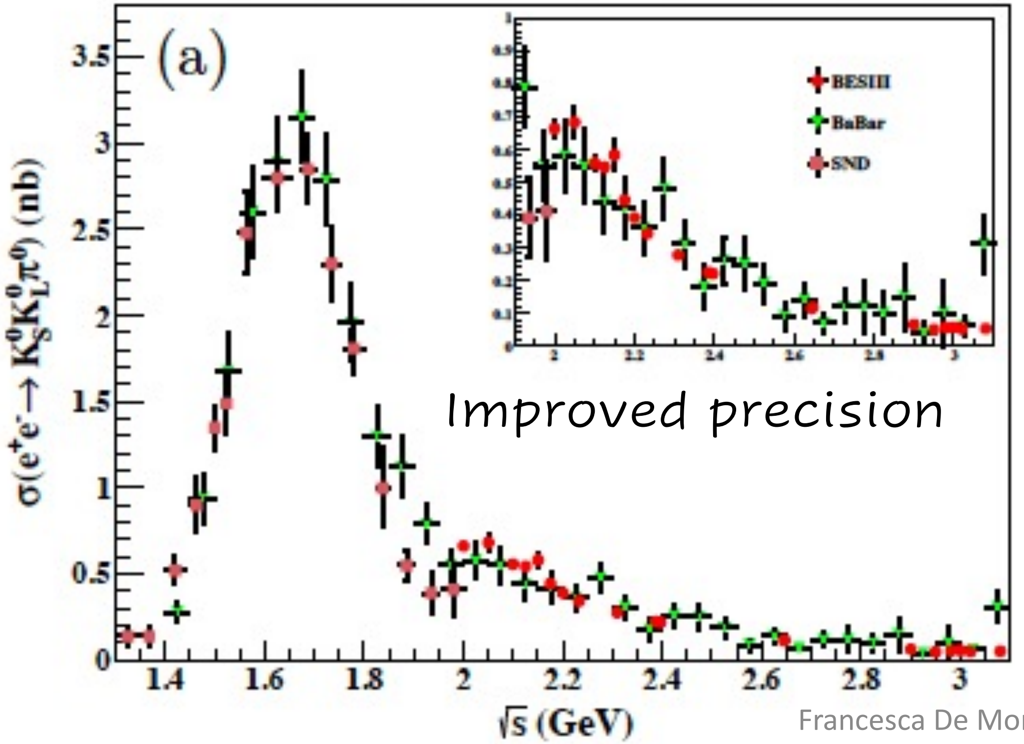
Process	Fraction (%)		
	2.125 GeV	2.396 GeV	2.900 GeV
$\phi\pi^0$	0.78±0.56	0.87±0.61	1.82±1.11
$\phi(1680)\pi^0$	2.39±1.23	5.96±2.10	5.22±1.50
$K^*(892)^0\bar{K}^0$	79.89±1.12	86.01±1.38	72.65±2.11
$K_2^*(1430)^0\bar{K}^0$	7.42±0.83	1.93±0.57	1.85±0.82
$K(1680)^0\bar{K}^0$	3.00±1.11	6.73±1.91	5.82±1.96

$K^*(892)^0\bar{K}^0$ dominates over $K_2^*(1430)^0\bar{K}^0$

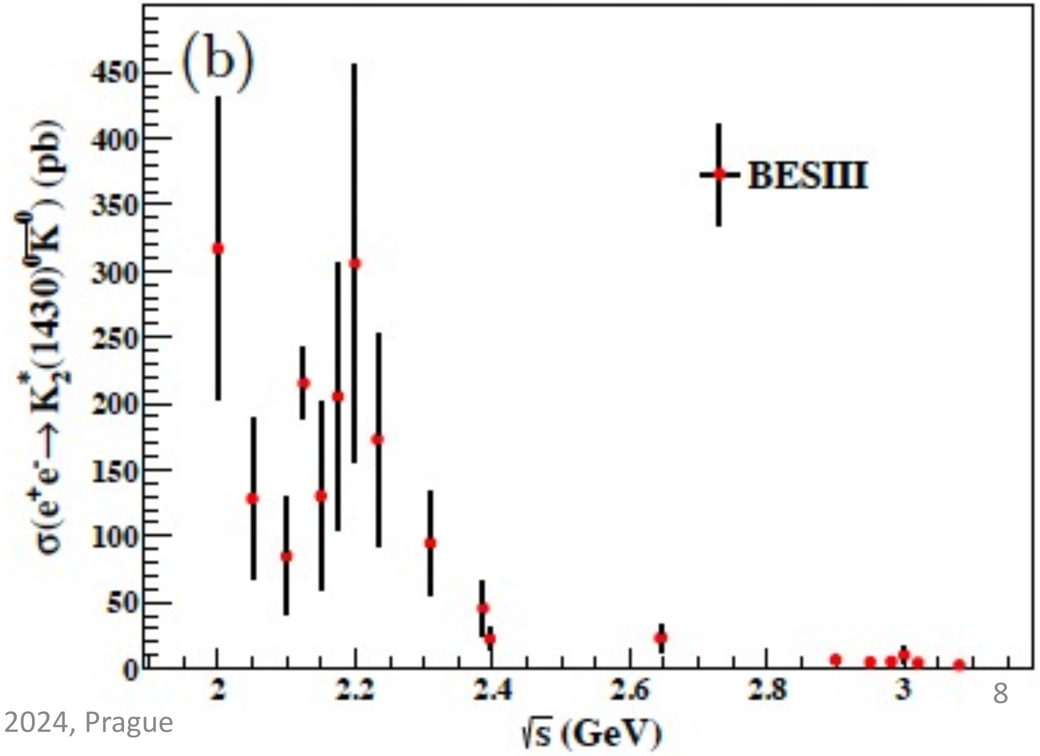
Opposite with respect to the charged channel $e^+e^- \rightarrow K^+K^-\pi^0$ JHEP 07 (2022) 04

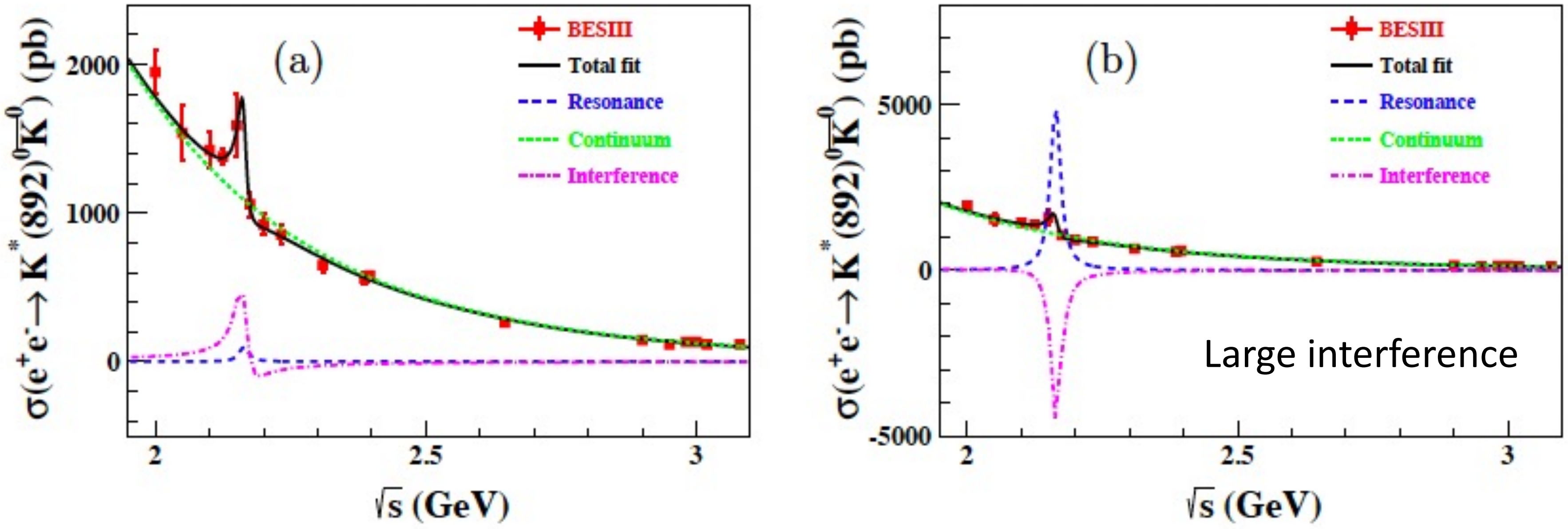
As found from BaBar previously for analogous channels

Lineshape of subprocesses can be measured using relative fraction obtained in PWA



Improved precision





Two solutions with same mass and width for the resonance

Fit with coherent sum of continuum and resonant (BW) component as PDF

$$\sigma = \left| \frac{\sqrt{12\pi\Gamma_Y \Gamma_Y^{e^+e^-}\mathcal{B}}}{M_Y^2 - s - iM_Y\Gamma(\sqrt{s})} \sqrt{\frac{P(\sqrt{s})}{P(M_Y)}} e^{i\phi_Y} + c_1 \frac{\sqrt{P(\sqrt{s})}}{s^{c_2}} \right|^2,$$

$$M_Y = (2164.7 \pm 9.1 \pm 3.1)\mathrm{MeV/c^2}$$
$$\Gamma_Y = (32.4 \pm 21.0 \pm 1.8)\mathrm{MeV}$$

Hint of a vector meson state around 2.2 GeV with a significance of 3.2σ.

The resonance parameters (very narrow width especially) very close to the BESIII results measured through the φη channel [1] of the φ(2170) meson.

[1] Phys. Rev. D 104 (2021) 032007

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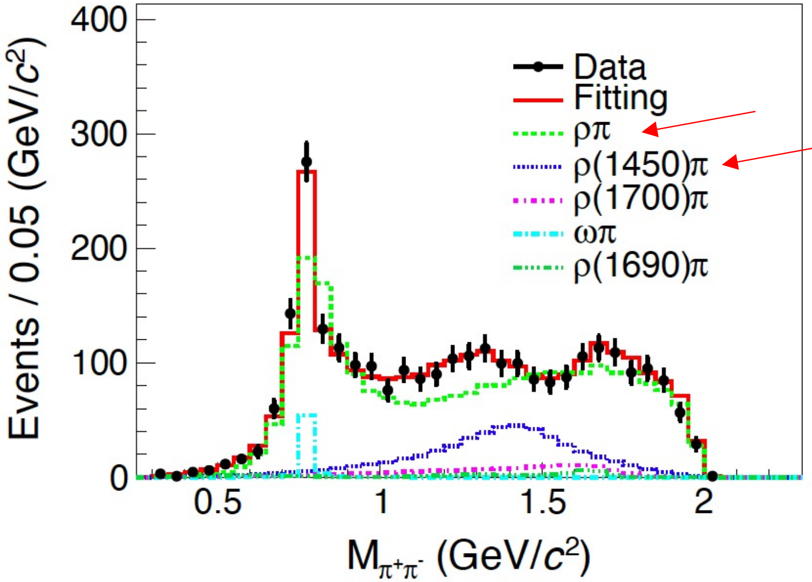
$e^+e^- \to \pi^+\pi^-\pi^0$

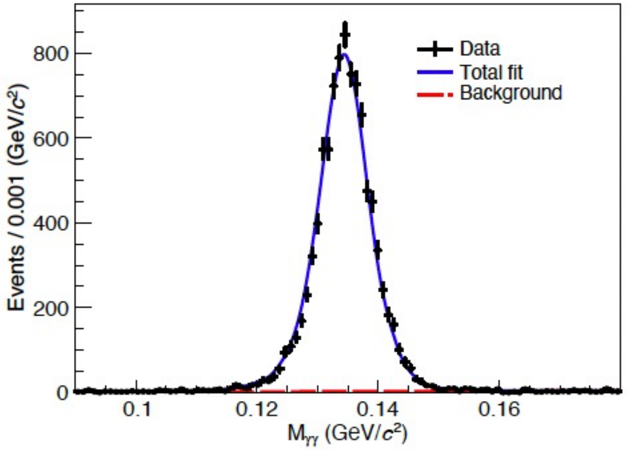
https://arxiv.org/abs/2401.14711

$\sqrt{s}$ =[2.00-3.08]GeV

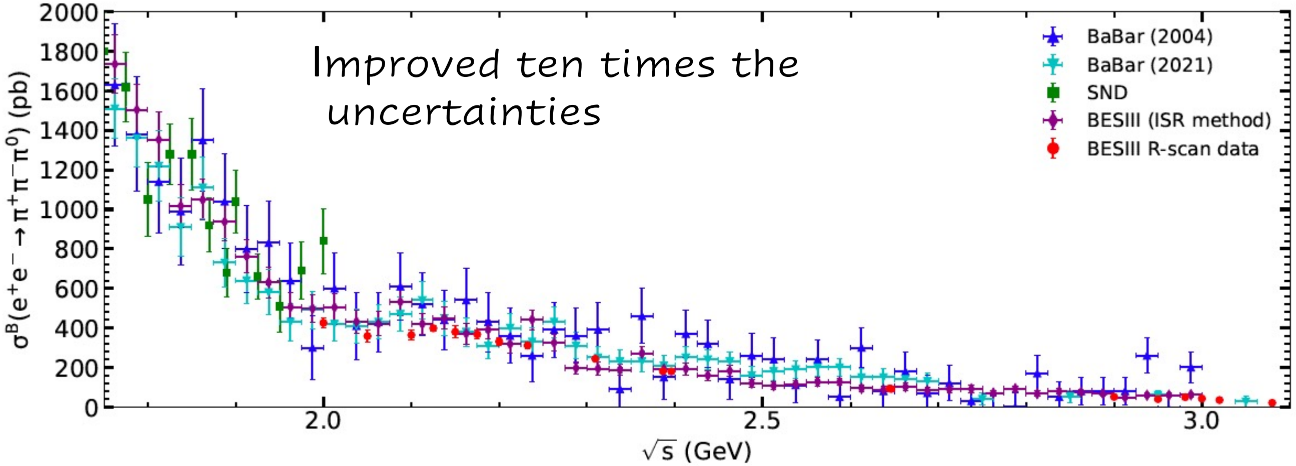
PWA performed



$\sqrt{s}$(GeV)	2.1250	2.3960	2.9000
$\rho\pi$	$> 50\sigma$	$> 50\sigma$	27σ
$\rho(1450)\pi$	18σ	10σ	13σ
$\rho(1700)\pi$	6.5σ	6.4σ	6.6σ
$\rho_3(1690)\pi$	14σ	9.2σ	6.8σ
$\rho(1570)\pi$	1.3σ	1.1σ	0.13σ
$\omega\pi$	31σ	11σ	9.7σ
$\omega(1420)\pi$	2.8σ	0.21σ	1.8σ
$\omega(1650)\pi$	3.5σ	0.29σ	0.53σ
$\omega_3(1670)\pi$	3.4σ	1.6σ	0.56σ



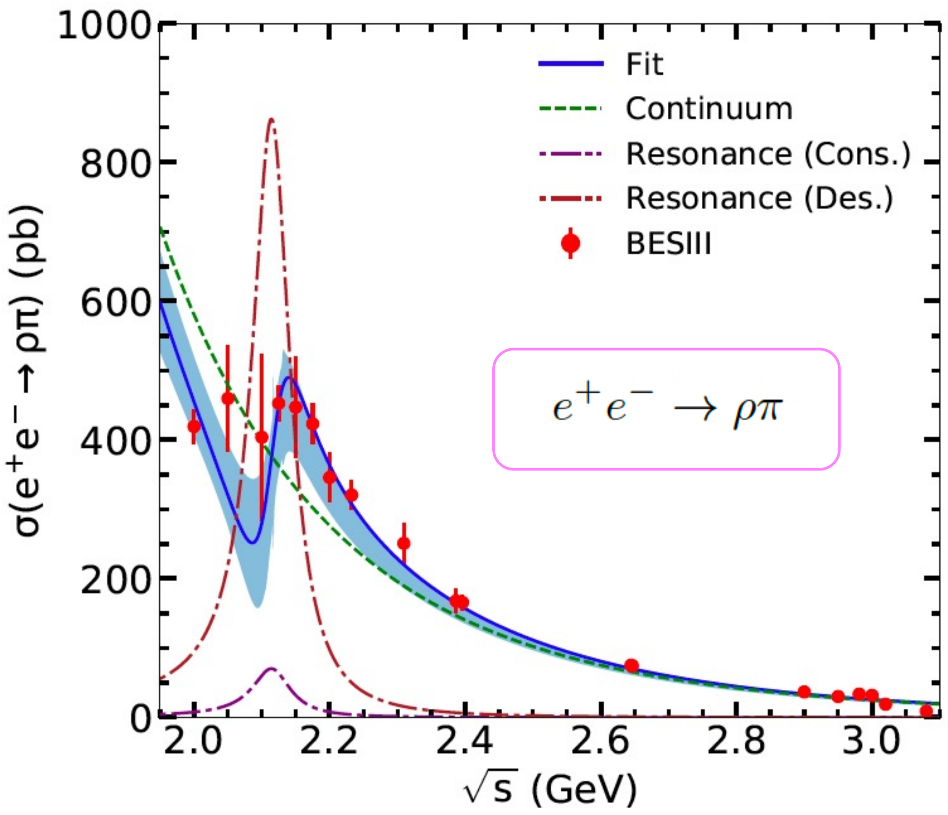
UML fit
For signal yield

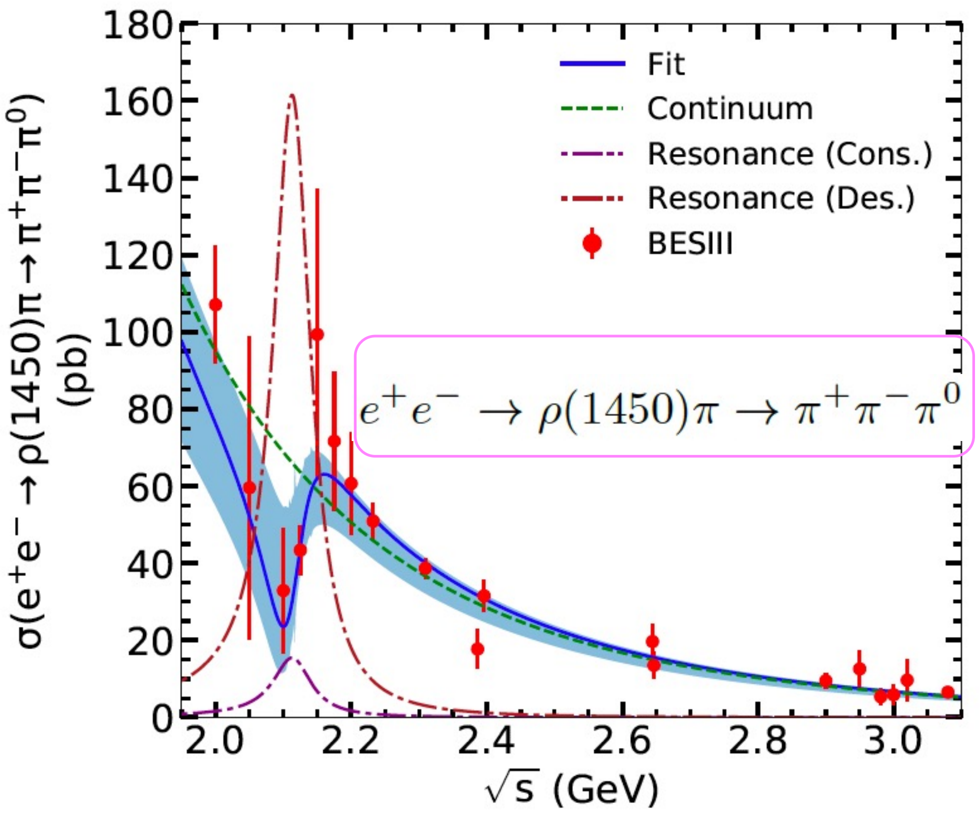


Improved ten times the uncertainties

Born cross section also for major intermediate states(for $\omega\pi^0$ more precise BESIII result (Phys. Lett. B 813, 136059 (2021) already available)

Simultaneous fit, assuming the same resonant structure (ω^*)



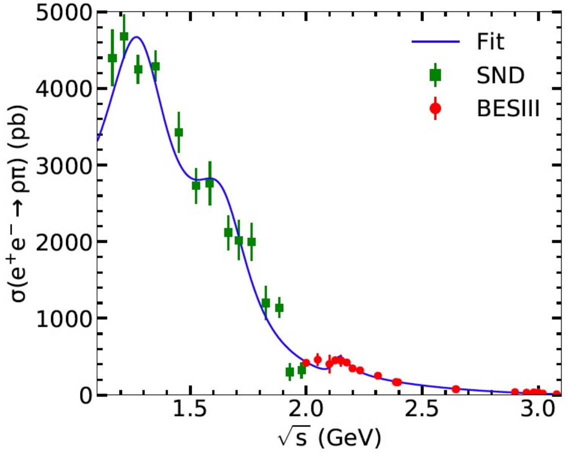


PDF: $|f_r(s)e^{i\phi_r} + f_c(s)|^2$

$$f_r(s) = \frac{M_r}{\sqrt{s}} \frac{\sqrt{12\pi(\hbar c)^2 \Gamma^r_{ee} Br \Gamma_r}}{s - M_r^2 + iM_r\Gamma_r} \sqrt{\frac{\Phi(\sqrt{s})}{\Phi(M_r)}}, \qquad f_c(s) = a\frac{\sqrt{\Phi(\sqrt{s})}}{(\sqrt{s})^b}.$$

Multiple solution: same M and width but different phase and $\Gamma^R_{ee}Br$

https://arxiv.org/abs/2401.14711



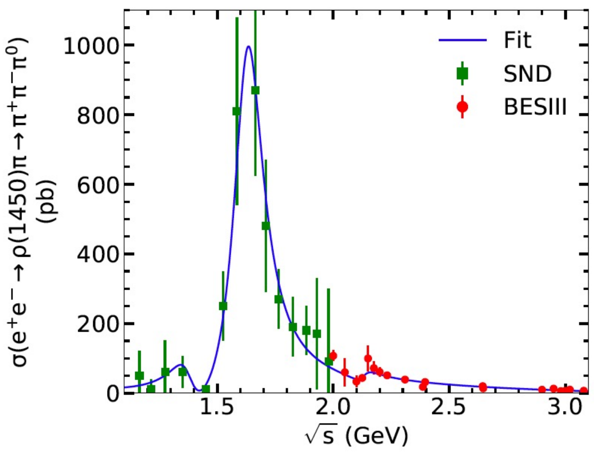


TABLE V. Fit results of the $e^+e^- \to \rho\pi$ and $e^+e^- \to \rho(1450)\pi \to \pi^+\pi^-\pi^0$ processes, where the uncertainties are statistical only.

	Nominal fit	Alternative fit
Mass	2119 ± 11 MeV/c^2	2134 ± 14 MeV/c^2
Width	69 ± 30 MeV	74 ± 31 MeV
χ^2	41.9	73.3
Number of free parameters	10	18
Degrees of freedom (ndf)	28	48
χ^2/ndf	1.50	1.53
Significance	5.9σ	5.2σ

Alternative fit with SND data @ low energies
SND-helps to constraint the continuum

To evaluate systematics

$M = 2119 \pm 11 \pm 15\ \mathrm{MeV}/c^2$ $\Gamma = 69 \pm 30 \pm 5\ \mathrm{MeV}$ **> 5 σ significance**

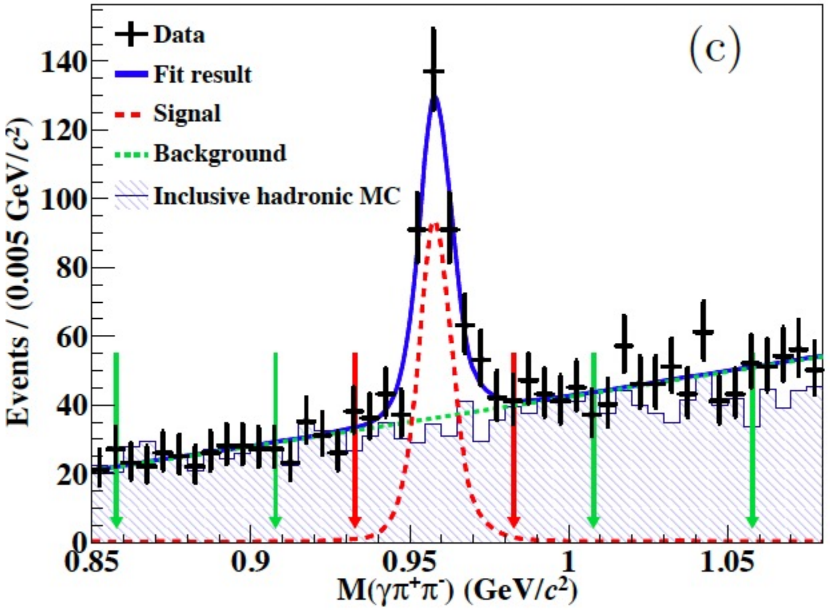
For G-parity conservation it should be an exited ω or ϕ state.
ϕ State ruled out by OZI suppression in this final state channel.

ω* candidate

Further studies needed to clarify the situation.

$e^+e^- \to \omega\eta'$

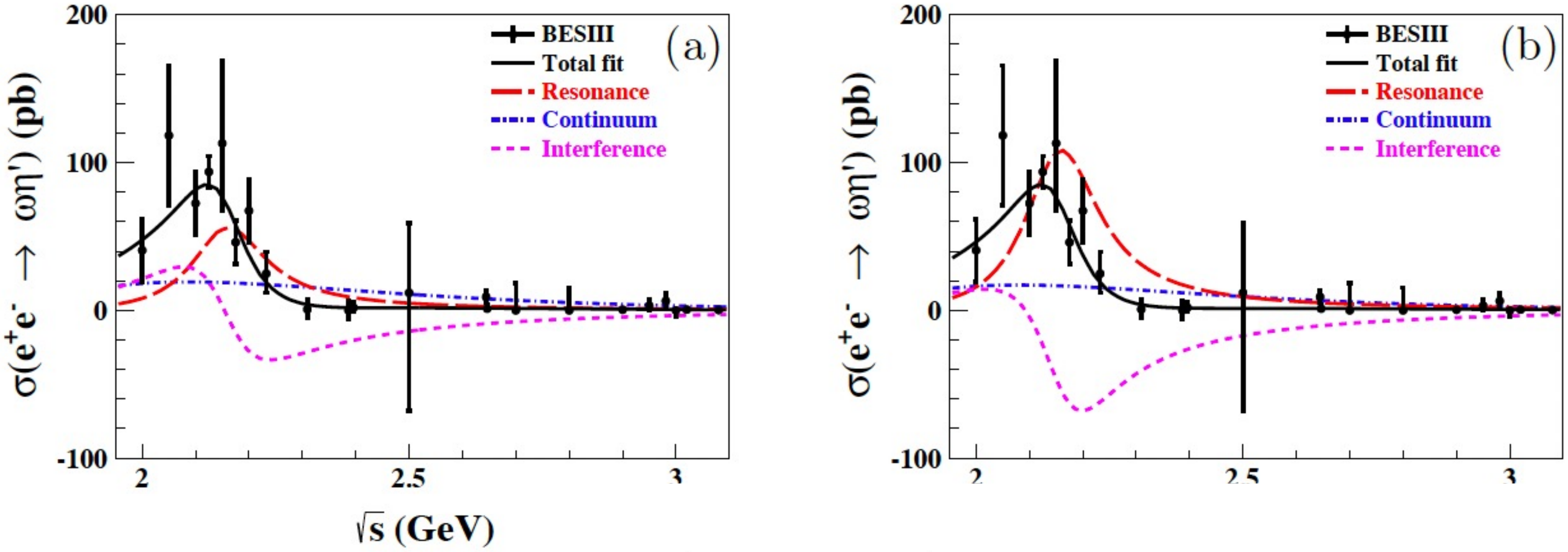
arXiv:2404.07436v1



$\sqrt{s}$ =[2.00-3.08]GeV

$e^+e^- \to \omega\eta'$ $\eta' \to \gamma\pi^+\pi^-$

$\omega \to \pi^+\pi^-\pi^0$



Parameter	Solution 1	Solution 2
M_R (MeV/c^2)	$2153 \pm 30(\text{stat.}) \pm 31(\text{syst.})$	
Γ_R (MeV)	$167 \pm 77(\text{stat.}) \pm 7(\text{syst.})$	
ϕ (rad)	$3.78 \pm 0.24(\text{stat.}) \pm 0.12(\text{syst.})$	$3.16 \pm 0.4(\text{stat.}) \pm 0.2(\text{syst.})$
$\Gamma_R^{e^+e^-}\mathcal{B}_R^{\omega\eta'}$ (eV)	$5.72 \pm 1.68(\text{stat.}) \pm 1.5(\text{syst.})$	$2.99 \pm 1.68(\text{stat.}) \pm 1.2(\text{syst.})$
Significance	9.6σ	

$$\sigma = \frac{12\pi}{s^{3/2}}|f_1 + e^{i\phi}f_2|^2 PS(\sqrt{s}),$$

$$f_2 = \sqrt{\frac{\Gamma_R^{e^+e^-} \cdot B_R^{\omega\eta'}}{PS(m_R)}} \frac{m_R^{3/2}\sqrt{\Gamma_R}}{s - m_R^2 + i\sqrt{s}\Gamma_R},$$

$$f_1 = C_0 \cdot e^{-p_0(\sqrt{s}-M_{\text{th}})},$$

three possible ω excited state candidates around 2.2 GeV, $\omega(2220)$, $\omega(2290)$ and $\omega(2330)$

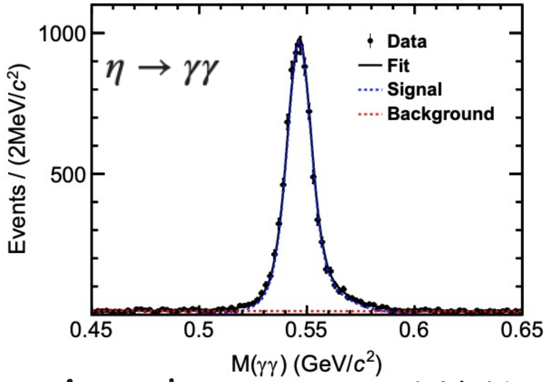
Mass and width in agreement within 3 σ with structures around 2.2 GeV by BESIII in

$$\omega\eta,\ \omega\pi^0\pi^0,\ \omega\pi^+\pi^-$$

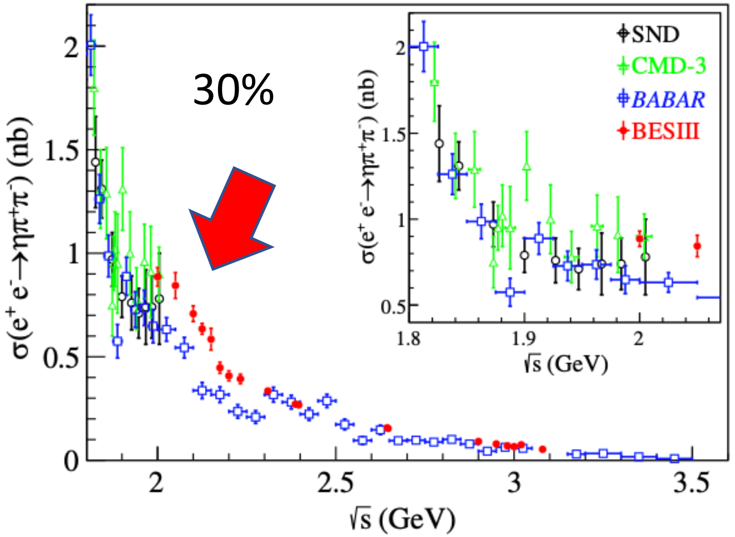
$e^+e^- \to \eta\pi^+\pi^-$

[PHYSICAL REVIEW D 108, L111101]

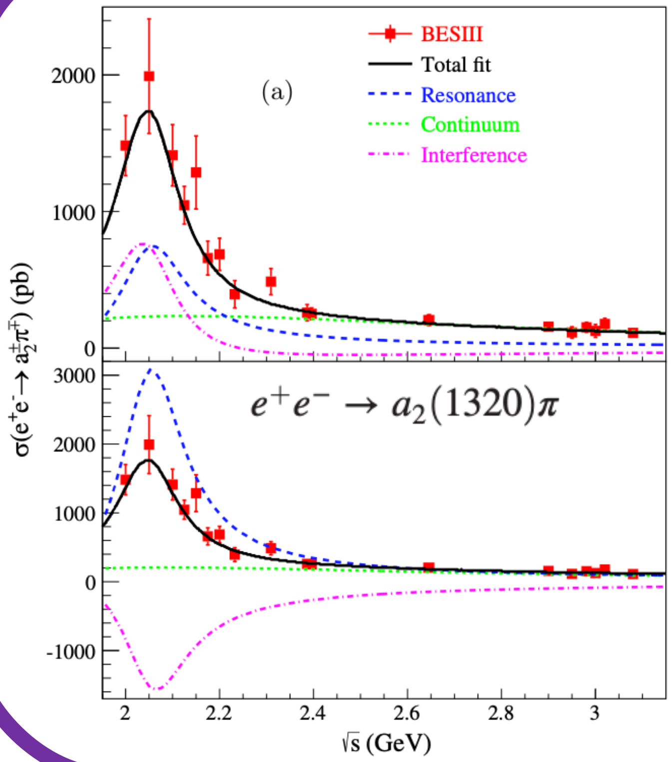
$\sqrt{s}$ =[2.00-3.08]GeV



simultaneous UML fit



PWA based on the GPUPWA framework



$$\sigma(s) = |f_1 + e^{i\phi} f_2|^2,$$

BW
$$f_2 = \frac{\sqrt{12\pi\Gamma_R^{ee} \cdot \mathcal{B}_R \Gamma_R^{\mathrm{tot}}}}{s - M_R^2 + iM_R \cdot \Gamma_R^{\mathrm{tot}}} \sqrt{\frac{\Phi(\sqrt{s})}{\Phi(M_R)}},$$

$$f_1 = C_0 \cdot s^{-n} \sqrt{\Phi(\sqrt{s})},$$

Parameter	Solution 1	Solution 2
M_R (MeV/c^2)	$2044 \pm 31 \pm 4$	
Γ_{tot}^R (MeV)	$163 \pm 69 \pm 24$	
$\mathcal{B}_\mathcal{R}\Gamma_{e^+e^-}^R$ (eV)	$34.6 \pm 17.1 \pm 6.0$	$137.1 \pm 73.3 \pm 2.1$
ϕ (rad)	$1.95 \pm 0.97 \pm 0.06$	$4.35 \pm 0.48 \pm 0.43$

5.5 σ

TABLE I. Statistical significances and fit fractions of possible intermediate processes at $\sqrt{s} = 2.125$, 2.396, and 2.900 GeV.

$\sqrt{s} = 2.125$ GeV			$\sqrt{s} = 2.396$ GeV			$\sqrt{s} = 2.900$ GeV		
Process	Significance (σ)	Fraction (%)	Process	Significance (σ)	Fraction (%)	Process	Significance (σ)	Fraction (%)
$\rho(770)\eta$	>20	58.0 ± 1.0	$\rho(770)\eta$	>20	69.5 ± 2.5	$\rho(770)\eta$	>20	66.8 ± 2.2
$a_2(1320)\pi$	>20	24.1 ± 0.8	$a_2(1320)\pi$	>20	13.0 ± 1.1	$a_2(1320)\pi$	>10	21.7 ± 2.1
$\rho(1450)\eta$	>10	1.8 ± 0.3	$\rho(1450)\eta$	5.1	1.0 ± 0.4	$\rho(1450)\eta$	>10	16.5 ± 0.4
$a_2(1700)\pi$	>10	2.0 ± 0.3	$\rho_3(1690)\eta$	9.7	2.5 ± 0.5	$\rho(1700)\eta$	6.5	2.1 ± 0.1
…	…	…	$a_2(1700)\pi$	6.8	2.7 ± 0.4	…	…	…
…	…	…	$\rho(1700)\eta$	5.8	1.9 ± 0.9	…	…	…

Same properties of $\rho(2000)$ found by BESIII in $e^+e^- \to \omega\pi^0$ [Phys. Lett. B 813, 136059 (2021)]

First Observation of $\rho(2000) \to a_2(1320)\pi$.

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Summary

- Relevant contribution of BESIII in the spectroscopy of vector mesons between 2 and 3 GeV
- Recent results presented:

$$e^+e^- \to K_S^0 K_L^0 \pi^0$$
$$e^+e^- \to \pi^+\pi^-\pi^0$$
$$e^+e^- \to \omega\eta'$$
$$e^+e^- \to \eta\pi^+\pi^-$$

- Many others are coming (Stay Tuned!!)

Thank you
For your attention

謝謝

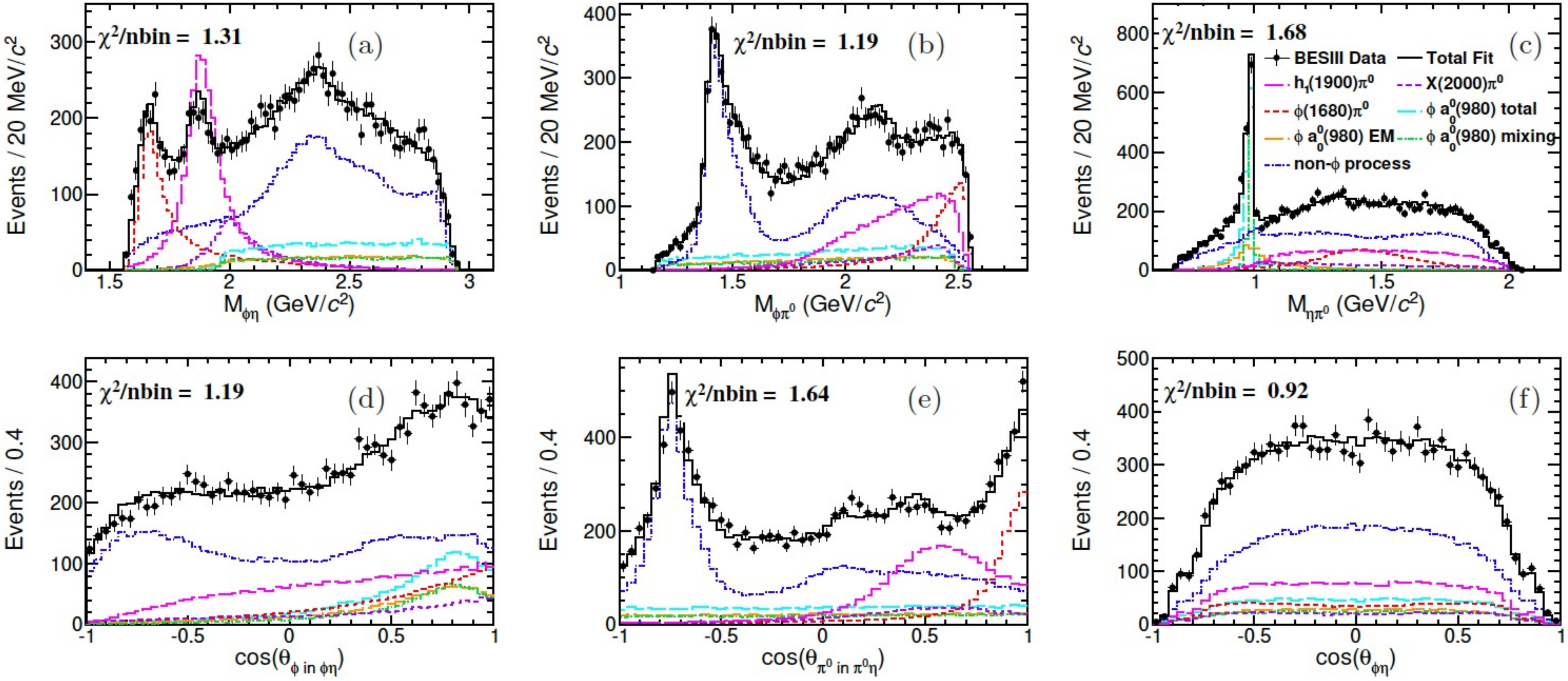
Spares

https://arxiv.org/abs/2311.07043

$J/\psi \to \phi\pi^0\eta$

6

PWA covariant tensor amplitude method.



the structure at 1.9 GeV/c² on the $M(\phi\eta)$ distribution can not be described only by a new axial-vector state (h1(1900)), but requires an additional vector state (X(2000)).

First observation of two new structures

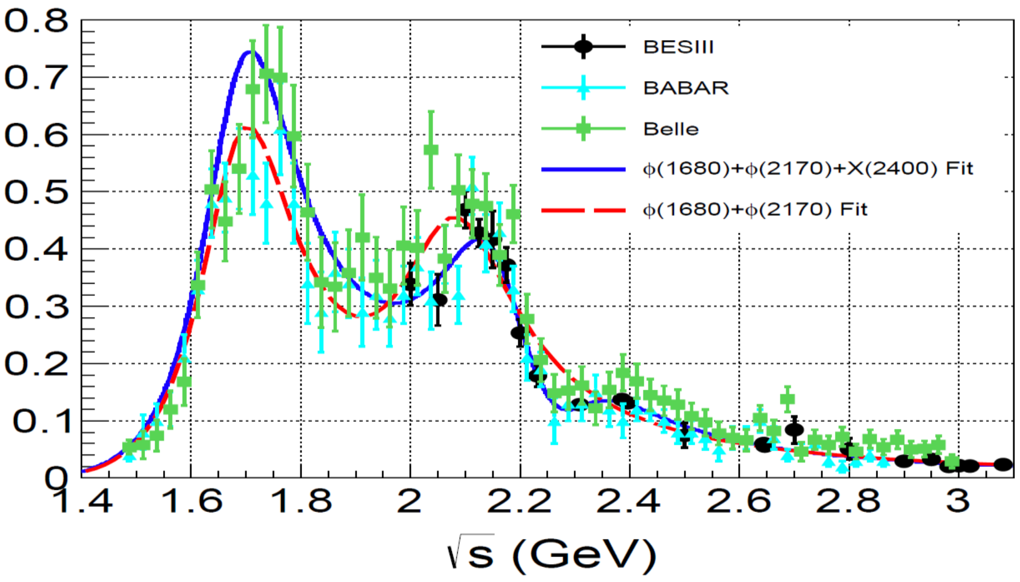
https://arxiv.org/abs/2311.07043

Process	M (MeV/c^2)	Γ (MeV)	$\mathcal{B}$ (10^{-6})	σ
$\phi(1680)\pi^0$	$1668 \pm 7 \pm 25$	$147 \pm 14 \pm 35$	$5.34 \pm 0.25 \pm 0.88$	36
$X(2000)\pi^0$	$1996 \pm 11 \pm 30$	$148 \pm 16 \pm 66$	$2.76 \pm 0.22 \pm 0.67$	17
$h_1(1900)\pi^0$	$1911 \pm 6 \pm 14$	$149 \pm 12 \pm 23$	$9.29 \pm 0.33 \pm 0.72$	24
$\phi a_0(980)_{\mathrm{EM}}$	–	–	$2.81 \pm 0.24 \pm 0.55$	19
$\phi a_0(980)_{\mathrm{mix}}$	–	–	$2.73 \pm 0.14 \pm 0.19$	32

The h_1(1900) axial vector meson can be assigned as the h_1(2P) strangeonium state→ mass and width agree well with the theoretical predictions
The X(2000) state can be associated to the ϕ(3S) or ϕ(2D) states, but its mass and width have large discrepancies with the theoretical predictions

Important input to establish the strangeonium spectrum

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

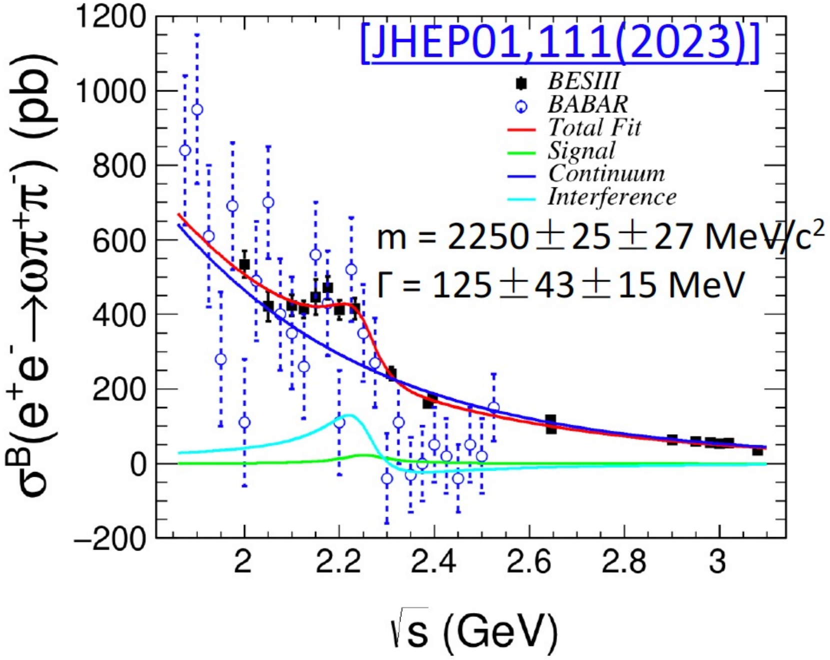


Parameters	Solution I	Solution II	Solution III	Solution IV
$M_r(\phi(1680))$		1675 ± 7		
$\Gamma_r(\phi(1680))$		238 ± 29		
$Br\Gamma_{ee}(\phi(1680))$	35.3 ± 1.5	39.0 ± 1.3	20.7 ± 1.3	18.8 ± 0.9
$M_r(\phi(2170))$		2174 ± 23		
$\Gamma_r(\phi(2170))$		207 ± 49		
$Br\Gamma_{ee}(\phi(2170))$	60.2 ± 34.5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

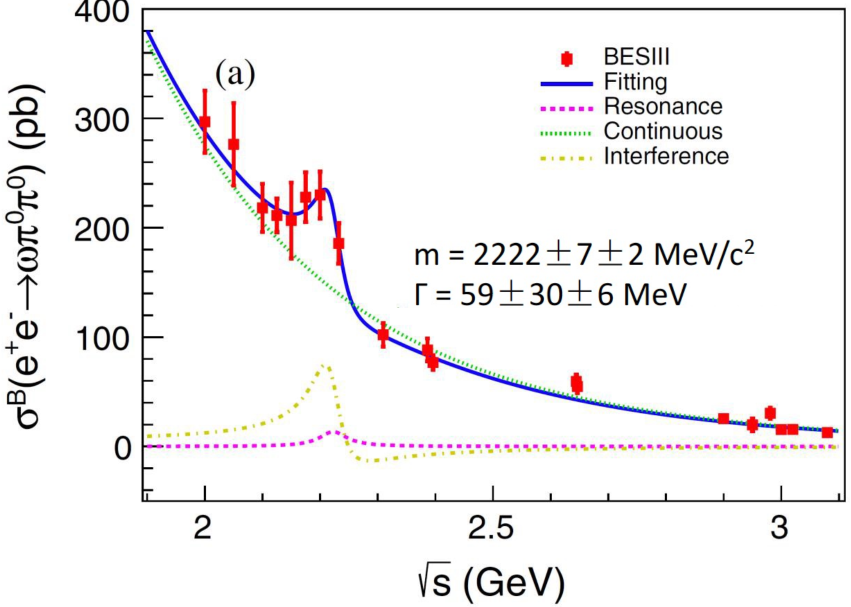
arXiv:2112.13219

ωππ

- $\omega\pi^+\pi^-$ 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^*



[PRD105,032005(2022)]



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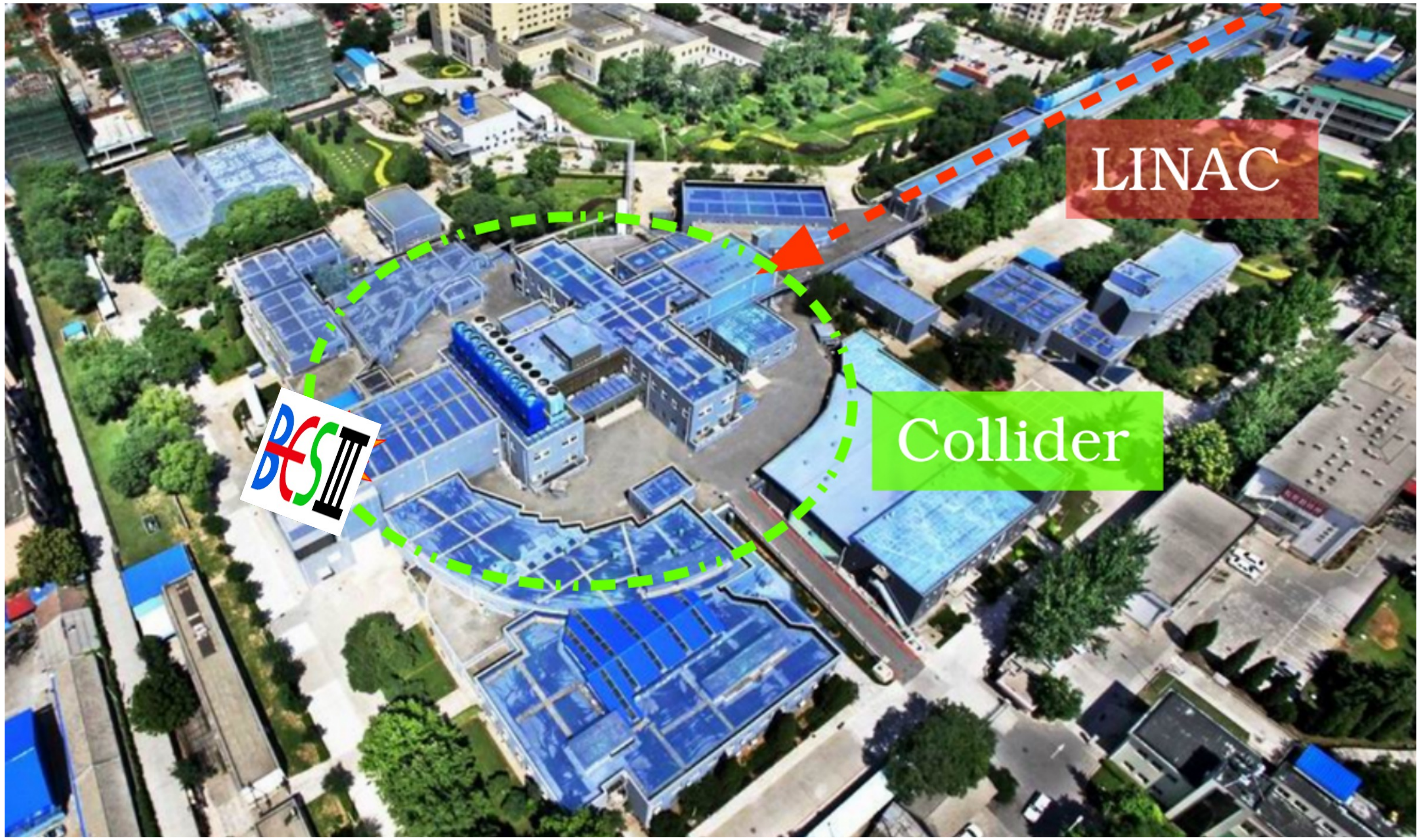
Institute of High Energy Physics
Chinese Academy of Sciences



Electron-positron collider

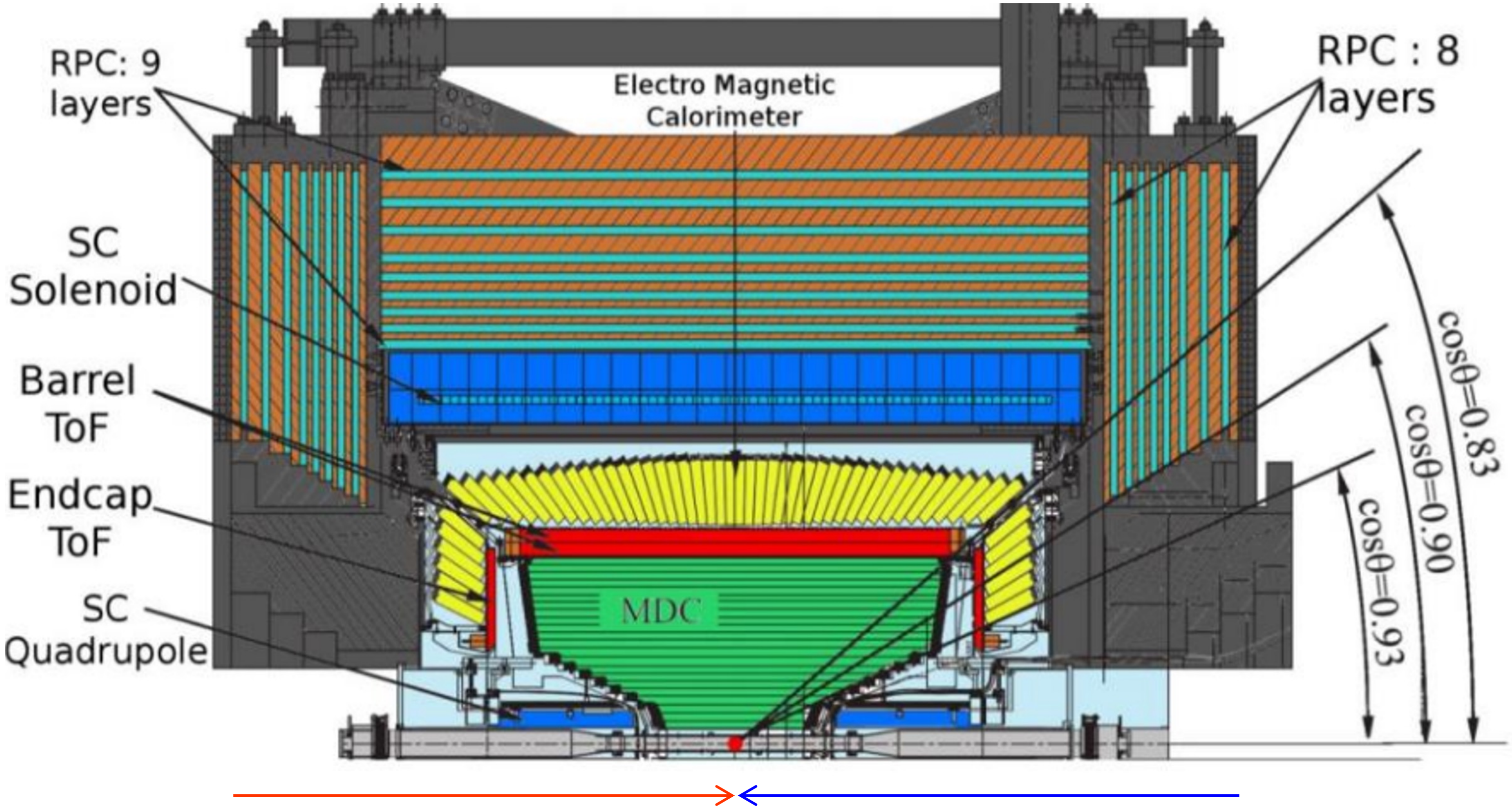
$E_{cm} = 2 - 4.95$ GeV

Luminosity = 10^{33} $cm^{-2}s^{-1}$

Being upgraded to increase luminosity at high energy and extend the cme energy range

BESIII @ BEPCII

1 Tesla Magnetic field



Muon counters:
$\delta_{r\varphi}$ = 1.4 cm – 1.7 cm

Electromagnetic Calorimeter:
$dE/\sqrt{E}$ (1 GeV) = 2.5 %

Time Of Flight:
σ_t (barrel) = 70 ps
σ_t (endcap) = 60 ps

Main Drift Chamber:
σ_x (1 GeV/c) ~ 130 μm
dp/p (1 GeV/c) = 0.5 %

Mass and width of the structure are in agreement within 3 σ $e^+e^- \to \omega\eta'$ structures around 2.2 GeV by BESIII in $\omega\eta,\ \omega\pi^0\pi^0,\ \omega\pi^+\pi^-$

three possible ω excited state candidates around 2.2 GeV, ω(2220), ω(2290) and ω(2330)

Assuming same R for BESIII result in ωη[Phys. Lett. B 813 (2021) 136059]
:

$$R = \frac{B_R^{\omega\eta'}}{B_R^{\omega\eta}} = \left|\frac{\cos(\Theta_0 - \Theta)}{\sin(\Theta_0 - \Theta)}\right|^2 \frac{\Omega_{\eta'}}{\Omega_\eta} = 0.34 \pm 0.07$$

By lattice QCD, based on the η − η′ mixing angle

ideal mixing angle between pure $s\bar{s}$ and $u\bar{u} - d\bar{d}$,

$$R = 13.30 \pm 6.06 \pm 3.61,\ 2.39 \pm 1.63 \pm 1.01,\ 4.58 \pm 2.21 \pm 1.34,\ 6.95 \pm 4.60 \pm 2.83$$

Combining previous BESIII result with the multiple solutions for the resonance parameters

Many vector states between s = [2.0, 3.0] GeV
– $\rho*$, $\omega*$, $\phi*$, exotic states, mixture?

• Couplings to different channels may help to reveal their nature

• Common decay patterns:
is there $\rho^* - \omega^* - \phi^*$ mixing?

• Identification of exotic particle
with non exotic quantum numbers

From the experimental POV
→established meson spectrum required

– to rule out conventional quarkonia
– to study mixing between exotica
and conventional mesons

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

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

PRD79, 014036

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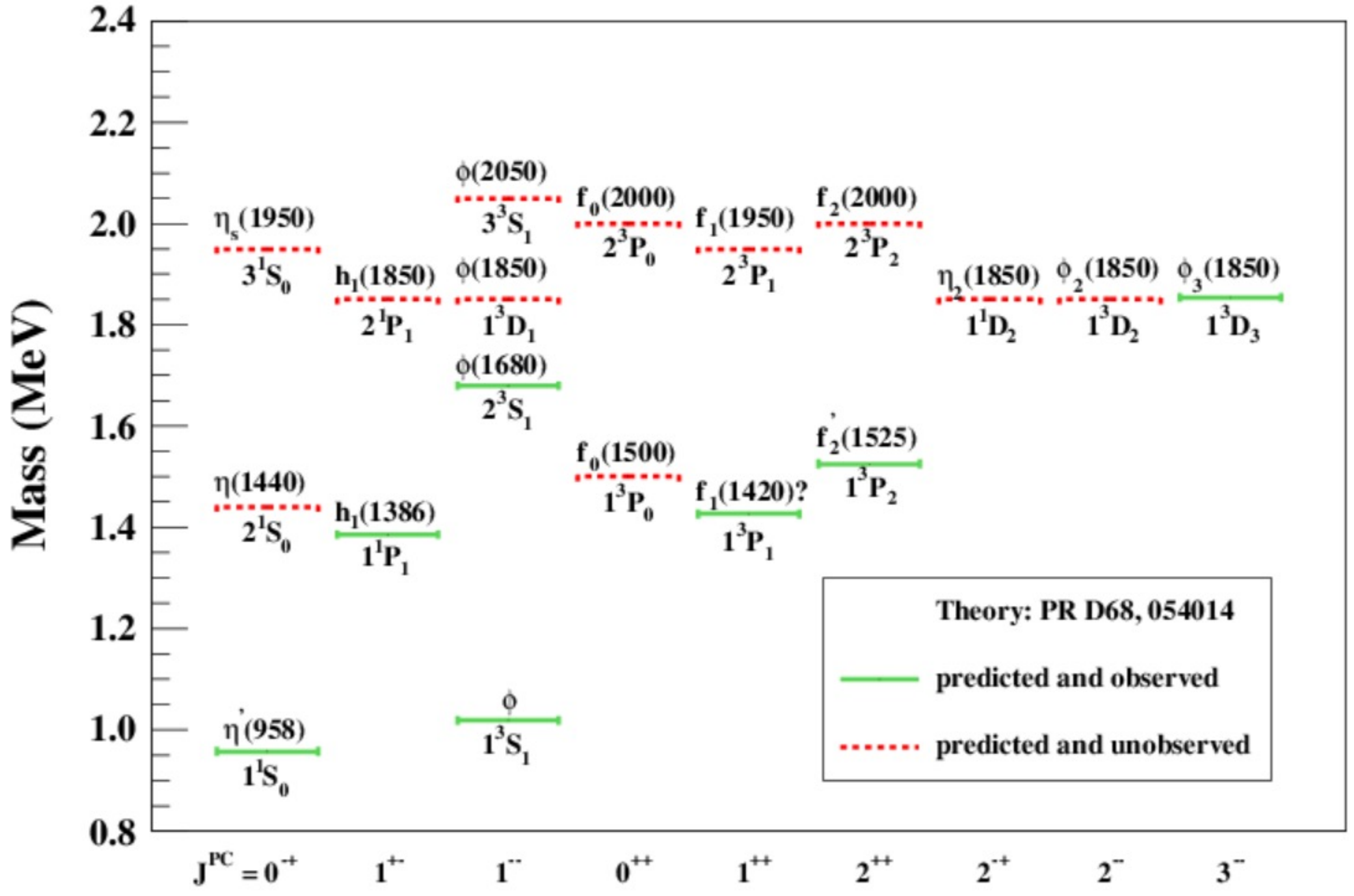
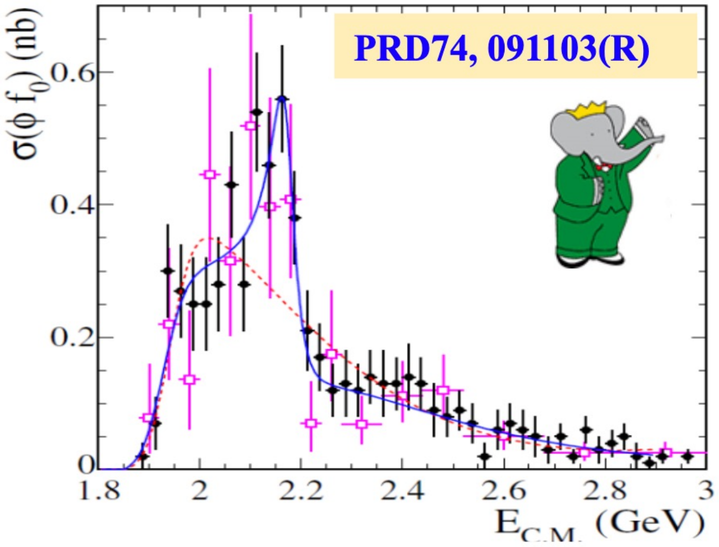
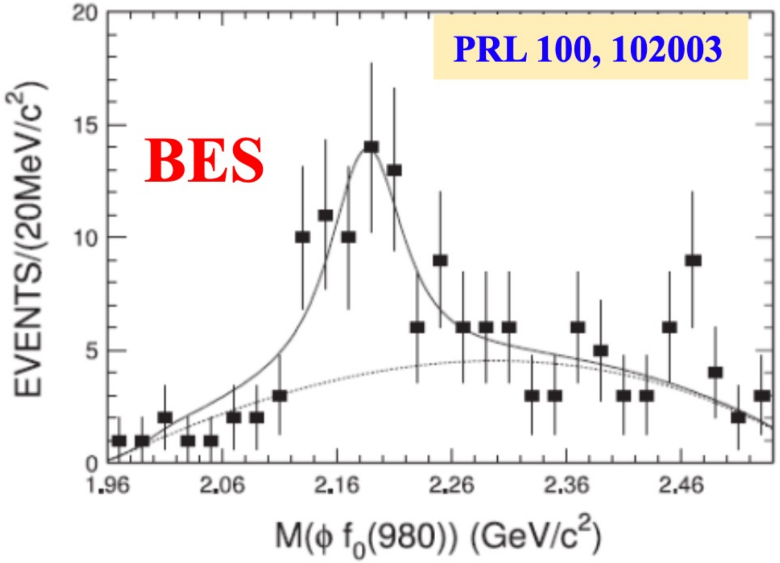
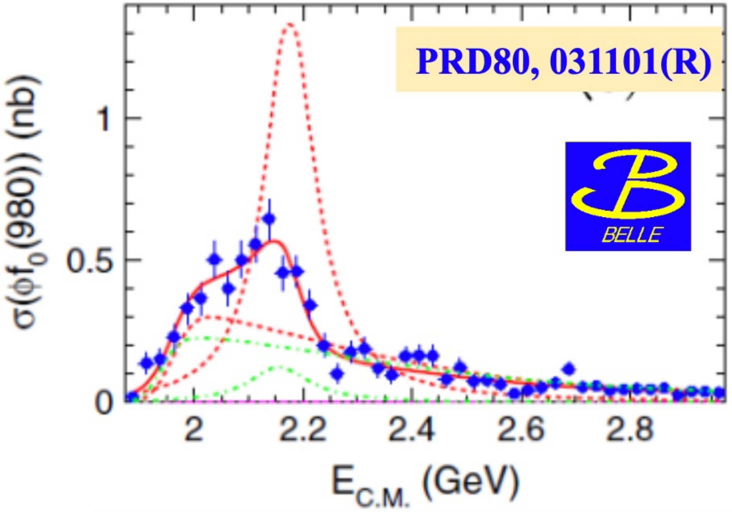








$$e^+e^- \Rightarrow \begin{cases} Y(2175) \to \phi(1020)\pi^+\pi^- & \text{strange,} \\ Y(4260) \to J/\psi\pi^+\pi^- & \text{charm,} \\ \Upsilon(10860) \to \Upsilon(1S,2S)\pi^+\pi^- & \text{bottom,} \end{cases}$$

ϕ(2170) as strange analogue of Y(4220)

2

ρ* and ω* vector mesons

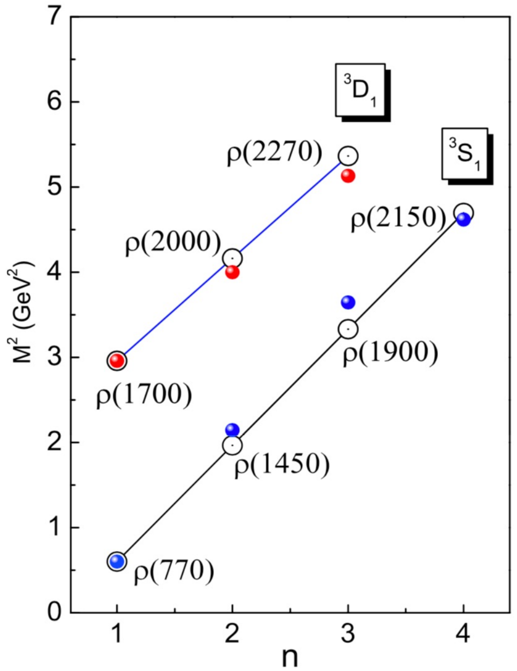
– Members above 2 GeV, their nature controversial

- Pure state or mixture?
- Decay patterns can be used to identify them

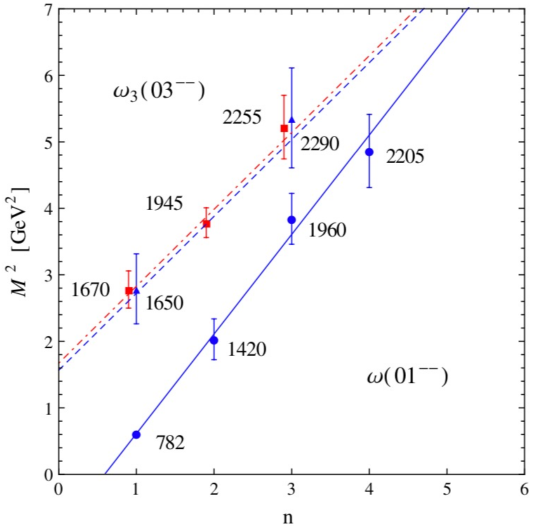
Recentely we investigated

ω*:

$$e^+e^- \to \pi^+\pi^-\pi^0$$
$$e^+e^- \to \omega\eta$$
$$e^+e^- \to \eta\pi^+\pi^-$$



PRD88,034008(2013)



PRD85,094006(2012)

In comparison with $e^+e^- \to K^+K^-\pi^0$ [JHEP 07 (2022) 045]

- $\frac{\sigma(e^+e^- \to K^*(892)^+K^-)}{\sigma(e^+e^- \to K^*(892)^0K^0)} < 0.2$
- $\frac{\sigma(e^+e^- \to K_2^*(1430)^+K^-)}{\sigma(e^+e^- \to K_2^*(1430)^0K^0)} \sim 0 - 40$