



燕山大学
YANSHAN UNIVERSITY

Exploring the role of higher ω meson states in the
 $e^+e^- \rightarrow b_1(1235)\pi$ process

第五届强子与重味物理理论与实验联合研讨会

Presenter: Zhao-Yang Wu (吴翌洋)

Collaborators: Zi-Yue Bai(白紫跃) and Li-Ming Wang(王利明)

arXiv:[2511.06664]—under review at PRD.

2026.03.30

Outline

I . Background & Motivation

II . The cross section of $e^+e^- \rightarrow b_1(1235)\pi$
around 2 GeV

III. Numerical result

IV. Summary

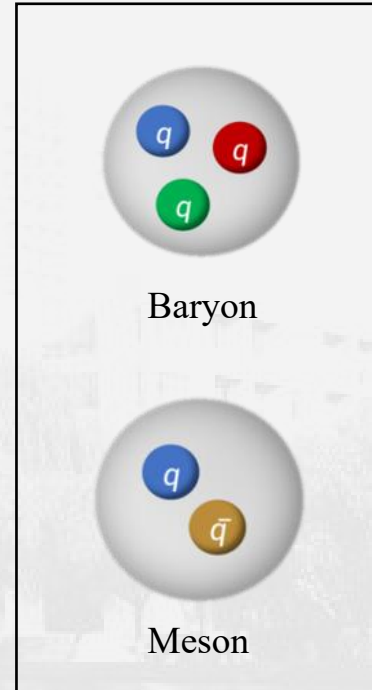
I .Background & Motivation



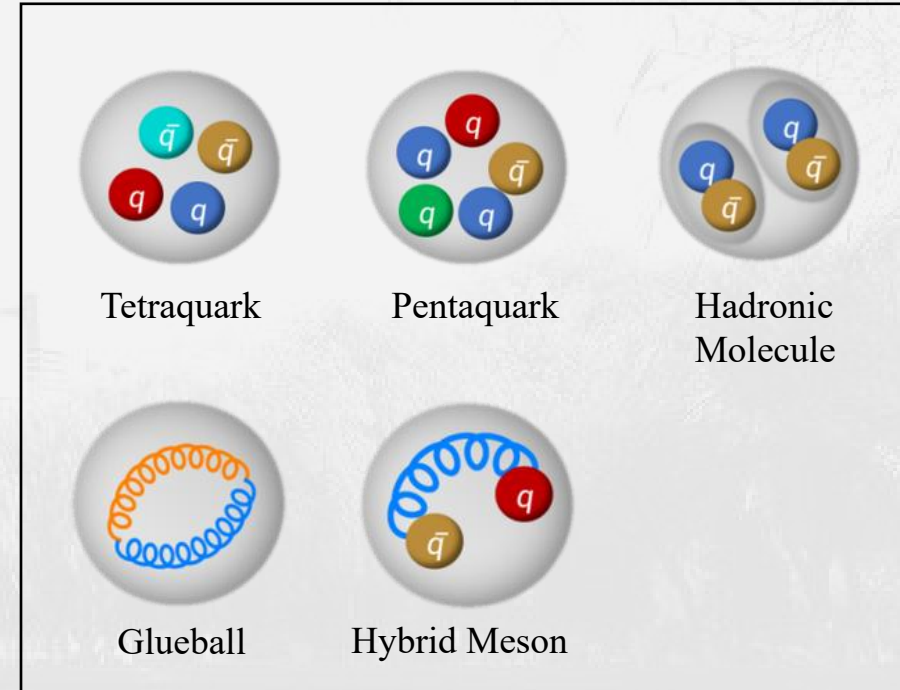
Standard Model of Elementary Particles

	three generations of matter (fermions)			interactions / force carriers (bosons)	
	I	II	III		
mass	$\approx 2.16 \text{ MeV}/c^2$	$\approx 1.273 \text{ GeV}/c^2$	$\approx 172.57 \text{ GeV}/c^2$	0	$\approx 125.2 \text{ GeV}/c^2$
charge	$\frac{2}{3}$	$\frac{2}{3}$	$\frac{2}{3}$	0	0
spin	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	0
QUARKS	u up	c charm	t top	g gluon	H higgs
	d down	s strange	b bottom	γ photon	SCALAR BOSONS
	e electron	μ muon	τ tau	Z Z boson	
ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	W W boson		
LEPTONS	$< 0.8 \text{ eV}/c^2$	$< 0.17 \text{ MeV}/c^2$	$< 18.2 \text{ MeV}/c^2$	$\approx 80.3692 \text{ GeV}/c^2$	
	0	0	0	± 1	
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	
					GAUGE BOSONS VECTOR BOSONS

Conventional Hadrons



Exotic Hadron

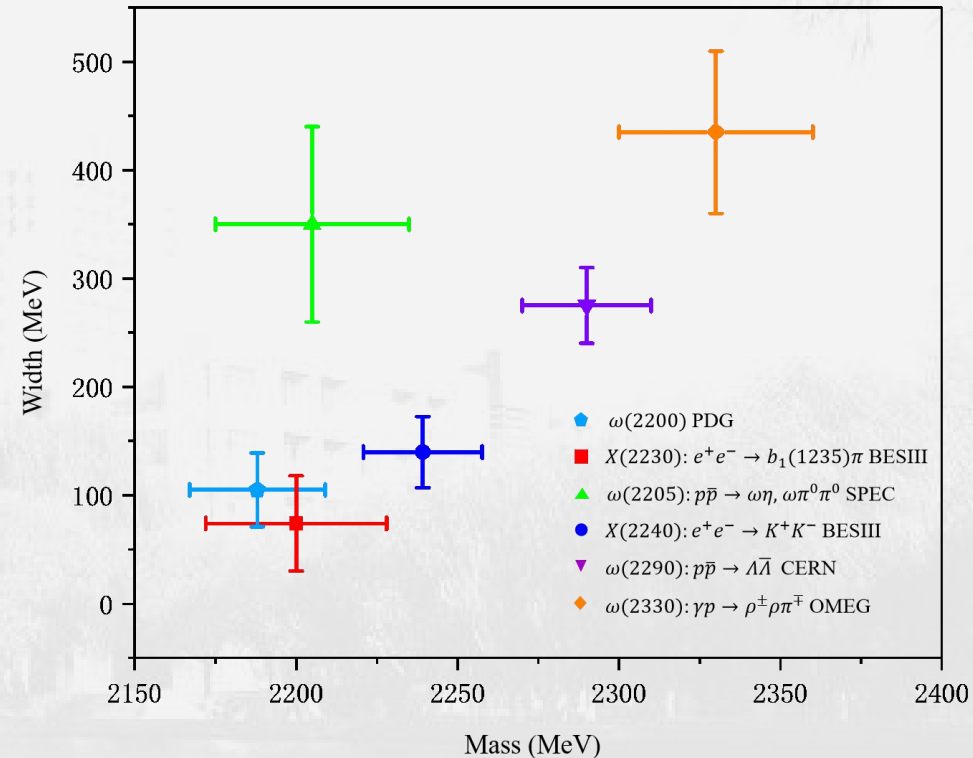
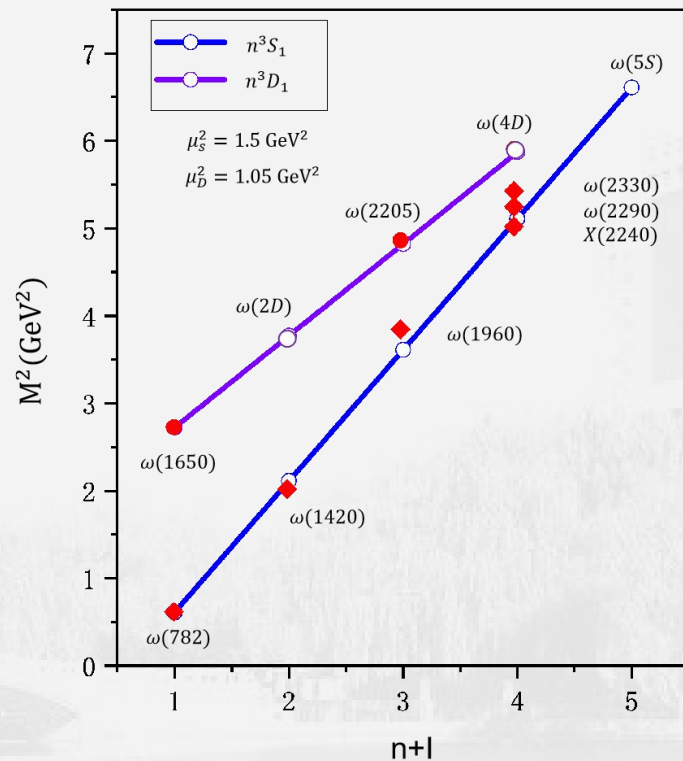


- LIGHT UNFLAVORED MESONS:

For $I=1$ (π, ρ, a): $u\bar{d}$, $(u\bar{u} - d\bar{d})/\sqrt{2}$, $d\bar{u}$;

for $I=0$ ($\eta, \eta', h, h', \omega, \phi, f, f'$): $c_1(u\bar{u} + d\bar{d}) + c_2(s\bar{s})$

• A brief review of the ω meson



- $\omega(782)$ as the S-wave ground state, $\omega(1420)$ and $\omega(1960)$ as candidate 2S and 3S radial excitations. $\omega(1650)$ as the D-wave ground state. [Phys. Rev. D 110, 030001 \(2024\)](#).
- The situation above 2 GeV becomes considerably more complex in the 2.0-2.3 GeV region, where several ω -like states have been reported, which need further research.

[Phys. Lett. B 542, 19 \(2002\)](#), [Eur. Phys. J. C 36, 161 \(2004\)](#), [10.1016/05503213\(84\)90304-3 \(1983\)](#),

[Phys. Rev. D 99, 032001 \(2019\)](#).

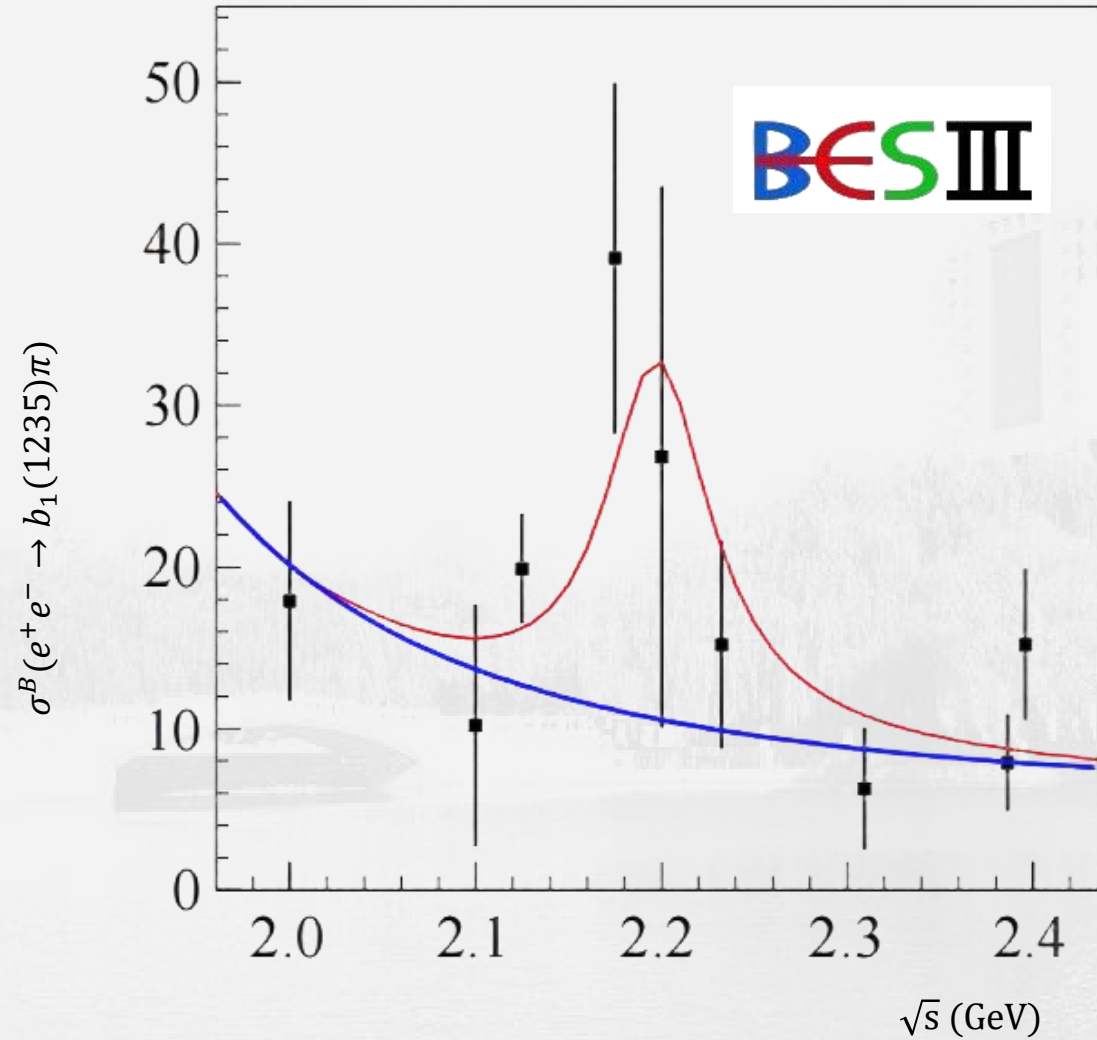
State	M_{theo} (GeV)	Candidate
$\omega(1S)$	0.775	$\omega(782)$
$\omega(2S)$	1.413	$\omega(1420)$
$\omega(3S)$	1.862	$\omega(1960)$
$\omega(4S)$	2.180	$X(2240), \omega(2290), \omega(2330)$
$\omega(1D)$	1.633	$\omega(1650)$
$\omega(2D)$	2.003	
$\omega(3D)$	2.283	$\omega(2205)$

□ Theoretical masses of ω states by the MGI model and their experimental candidates.

[*@Phys. Rev. D 101, 074022 \(2020\)*](#)

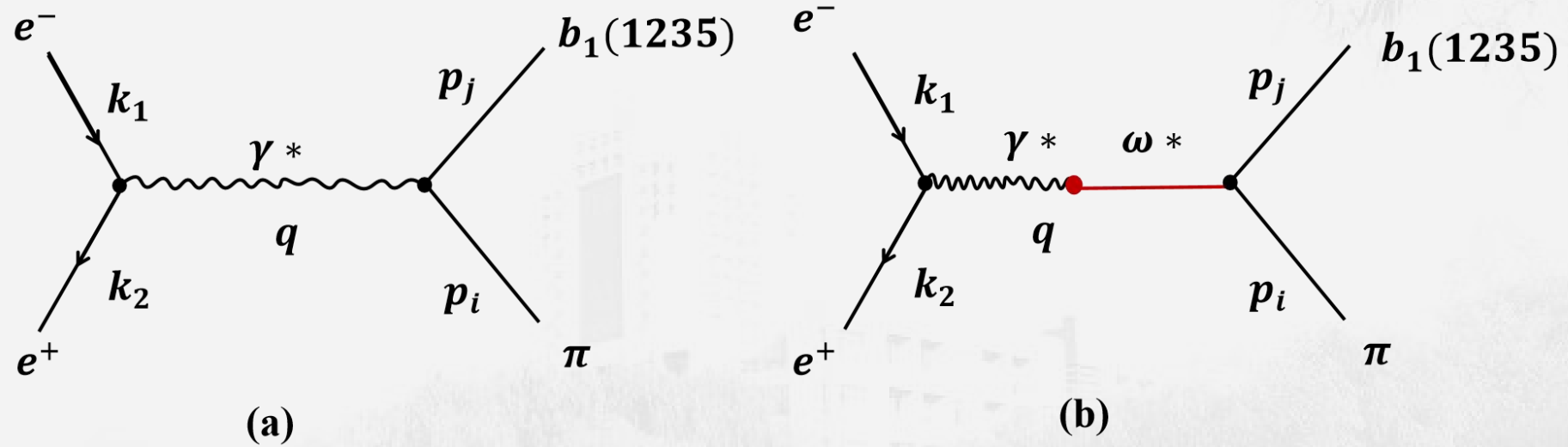


□ The mass, total width, and the branching ratios of the OZI-allowed strong decays of the $\omega(4S)$ and $\omega(3D)$ states.



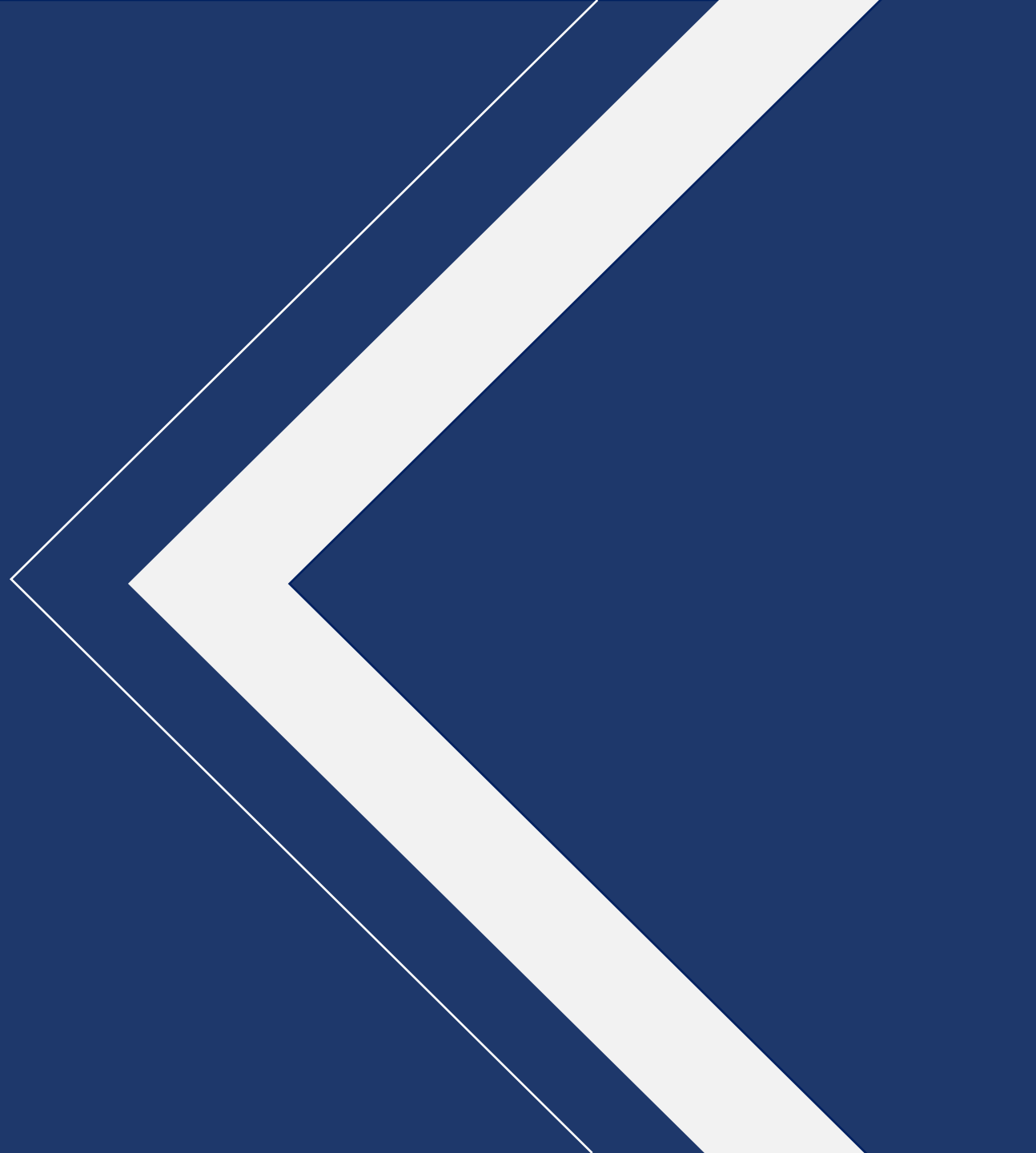
There exists an explicit enhancement structure near 2.2 GeV.

JHEP 03, 093 (2023)



- For the enhancement structure in $e^+e^- \rightarrow b_1(1235)\pi$ process around 2.2 GeV, the conservation of G-parity in this reaction suggests that the intermediate resonant state is likely an excited ω meson.

II. The cross section of
 $e^+e^- \rightarrow b_1(1235)\pi$
around 2 GeV



The effective Lagrangian

$$\mathcal{L}_{\gamma\nu} = \frac{-em_{\nu}^2}{f_{\nu}} \mathcal{V}_{\mu} A_{\mu}$$

$$\mathcal{L}_{\gamma b_1 \mathcal{P}} = ig_{\gamma b_1 \mathcal{P}} A_{\mu} \mathcal{P} b_1^{\mu}$$

$$\mathcal{L}_{\nu b_1 \mathcal{P}} = ig_{\gamma b_1 \mathcal{P}} \mathcal{V}_{\mu} \mathcal{P} b_1^{\mu}$$



The amplitudes

$$\mathcal{M}_{Dir} = \bar{v}(k_1)(ie\gamma_{\mu})u(k_2)\left(-\frac{g^{\mu\nu}}{s}\right)\varepsilon^{*\nu}(p_j)\mathcal{F}(s)$$

$$\mathcal{M}_{\omega^*} = g_{\omega^*(b_1(1235))}\bar{v}(k_1)(ie\gamma_{\mu})u(k_2)\left(-\frac{g^{\mu\nu}}{s}\right)\left(-\frac{em_{\omega^*}^2}{f_{\omega^*}}\right) \times \frac{\tilde{g}_{\mu\nu}}{s-m_{\omega^*}^2+im_{\omega^*}\Gamma_{\omega^*}}\varepsilon^{*\beta}(p_j)$$

$$\bar{v}(\mathbf{k}_1, \lambda_1) = (\lambda_1\omega_{\lambda_1}(\mathbf{k}_1)\xi_{-\lambda_1}^{\dagger}(\mathbf{k}_1), -\lambda_1\omega_{-\lambda_1}(\mathbf{k}_1)\xi_{-\lambda_1}^{\dagger}(\mathbf{k}_1))$$

$$u(\mathbf{k}_2, \lambda_2) = \begin{pmatrix} \omega_{-\lambda_2}(\mathbf{k}_2)\xi_{\lambda_2}(\mathbf{k}_2) \\ \omega_{\lambda_2}(\mathbf{k}_2)\xi_{\lambda_2}(\mathbf{k}_2) \end{pmatrix} \quad \lambda_1, \lambda_2 = \pm$$

$$\omega_{\lambda}(\mathbf{k}) = \sqrt{E_p + \lambda|\mathbf{k}|}$$

$$\xi_{+}(\mathbf{k}) = \frac{1}{\sqrt{2|\mathbf{k}|(|\mathbf{k}| + k^3)}} \begin{pmatrix} |\mathbf{k}| + k^3 \\ k^1 + ik^2 \end{pmatrix} \quad \xi_{-}(\mathbf{k}) = \frac{1}{\sqrt{2|\mathbf{k}|(|\mathbf{k}| + k^3)}} \begin{pmatrix} -k^1 + ik^2 \\ |\mathbf{k}| + k^3 \end{pmatrix}$$

$$\lambda_3 = 0, \pm$$

$$\varepsilon^{*\beta}(\mathbf{p}, 0) = \frac{1}{m|\mathbf{p}|} \begin{pmatrix} |\mathbf{p}|^2 \\ p^0 p^1 \\ p^0 p^2 \\ p^0 p^3 \end{pmatrix}$$

$$\varepsilon^{*\beta}(\mathbf{p}, +) = \frac{1}{-\sqrt{2}|\mathbf{p}||\mathbf{p}_T|} \begin{pmatrix} 0 \\ p^1 p^3 - ip^2 |\mathbf{p}| \\ p^2 p^3 + ip^1 |\mathbf{p}| \\ -|\mathbf{p}_T|^2 \end{pmatrix}$$

$$\varepsilon^{*\beta}(\mathbf{p}, -) = \frac{1}{-\sqrt{2}|\mathbf{p}||\mathbf{p}_T|} \begin{pmatrix} 0 \\ p^1 p^3 + ip^2 |\mathbf{p}| \\ p^2 p^3 - ip^1 |\mathbf{p}| \\ -|\mathbf{p}_T|^2 \end{pmatrix}$$

$$|\mathbf{p}_T| = \sqrt{(p^1)^2 + (p^2)^2}$$

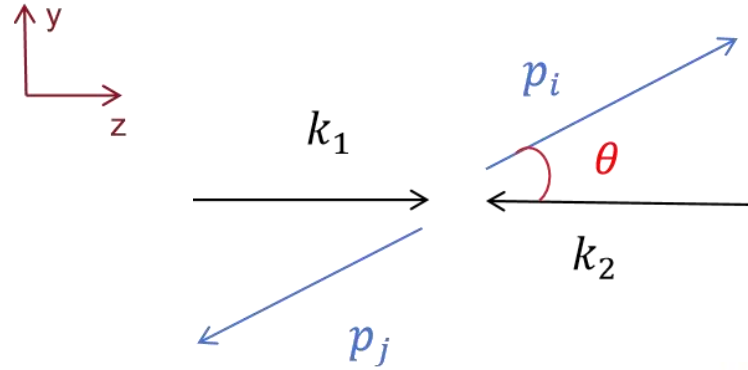
Total amplitude

$$\mathcal{M}_{Total} = \mathcal{M}_{Dir} + \sum_R \mathcal{M}_R e^{i\phi_R}$$



Differential cross section

$$d\sigma = \frac{1}{32 \pi s} \frac{|\vec{p}_{j,cm}|}{|\vec{k}_{1,cm}|} |\overline{\mathcal{M}_{Total}}|^2 d \cos\theta$$



$$k_1 = \{E_1, 0, 0, |\mathbf{k}_1|\} \quad E_1 = \frac{s + m_1^2 - m_2^2}{2\sqrt{s}}$$

$$k_2 = \{E_2, 0, 0, -|\mathbf{k}_2|\} \quad E_2 = \frac{s + m_2^2 - m_1^2}{2\sqrt{s}}$$

$$|k_1| = |k_2| = \sqrt{E_1^2 - m_1^2} = \sqrt{E_2^2 - m_2^2}$$

$$p_i = \{E_i, |\mathbf{p}_i| \sin \theta_i, 0, |\mathbf{k}_1| \cos \theta_i\} \quad E_i = \frac{s + m_i^2 - m_j^2}{2\sqrt{s}}$$

$$p_j = \{E_j, -|\mathbf{p}_j| \sin \theta_i, 0, -|\mathbf{k}_1| \cos \theta_i\} \quad E_j = \frac{s + m_j^2 - m_i^2}{2\sqrt{s}}$$

$$|p_i| = |p_j| = \sqrt{E_i^2 - m_i^2} = \sqrt{E_j^2 - m_j^2}$$

□ The dilepton width of these intermediate ω meson state.

$$\Gamma_{(\omega^* \rightarrow e^+e^-)} = \frac{4\pi}{3} \alpha^2 m_{\omega^*} f_{\omega_{S/D}}^2$$

where

$$f_{\omega_S} = \sqrt{2/3} V_{\omega^*}, f_{\omega_D} = \sqrt{4/27} V'_{\omega^*}$$

The factors V_{ω^*} and V'_{ω^*} are given by :

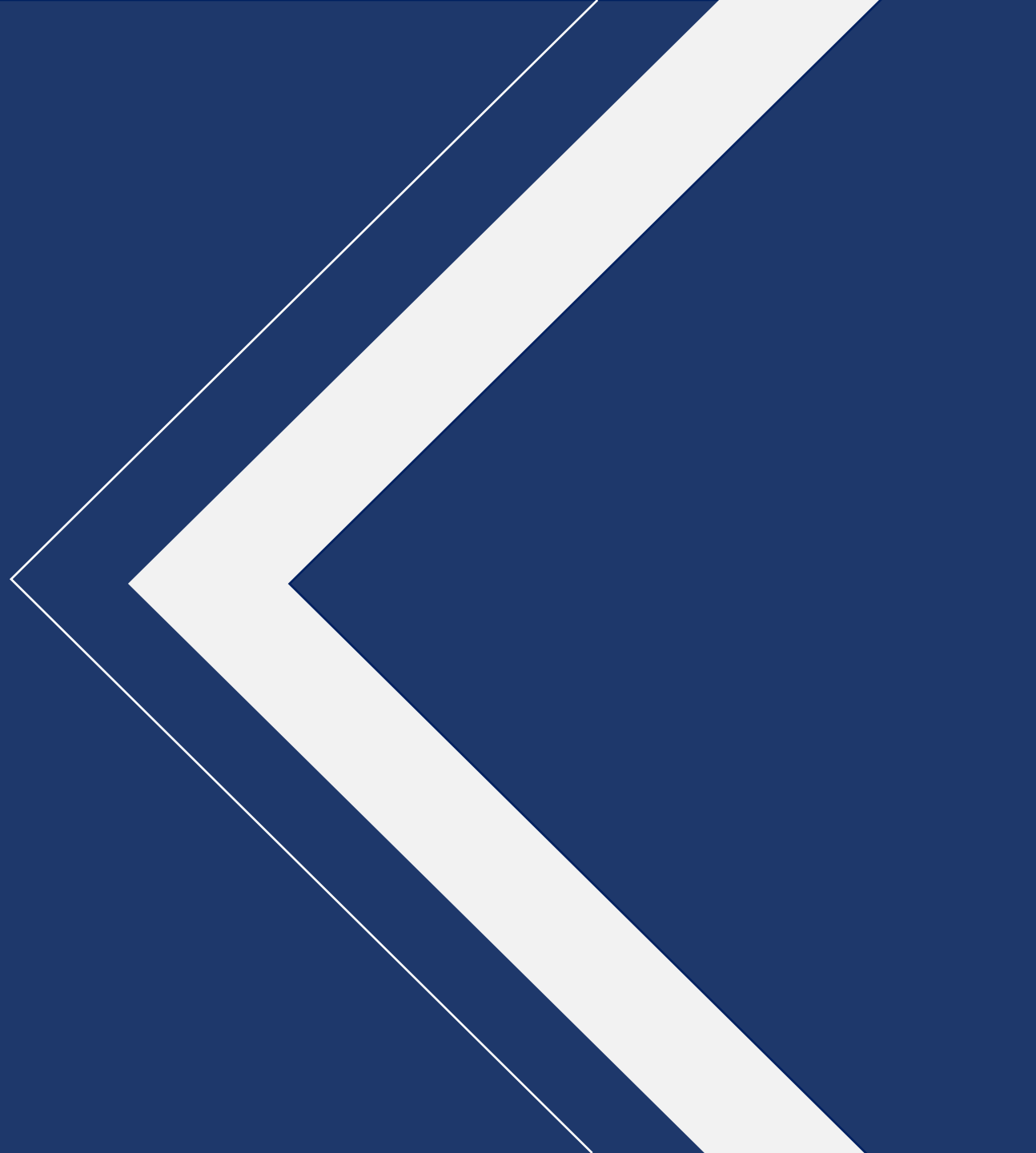
$$V_{\omega^*} = m_{\omega^*}^{-2} \tilde{m}_{\omega^*}^{1/2} (2\pi)^{-3/2} \int d^3 p (4\pi)^{-1/2} \phi_{\omega^*}(p) \\ \times p^2 \left(\frac{m_1 m_2}{E_1 E_2} \right)^{1/2}$$

$$V'_{\omega^*} = m_{\omega^*}^{-2} \tilde{m}_{\omega^*}^{1/2} (2\pi)^{-3/2} \int d^3 p (4\pi)^{-1/2} \phi_{\omega^*}(p) \\ \times p^2 \left(\frac{m_1 m_2}{E_1 E_2} \right)^{1/2} \left(\frac{p}{E_1} \right)^2$$



$$\Gamma_{\omega^* \rightarrow e^+e^-} = \frac{e^4 m_{\omega^*}}{12\pi f_{\omega^*}^2}$$

III. Numerical result

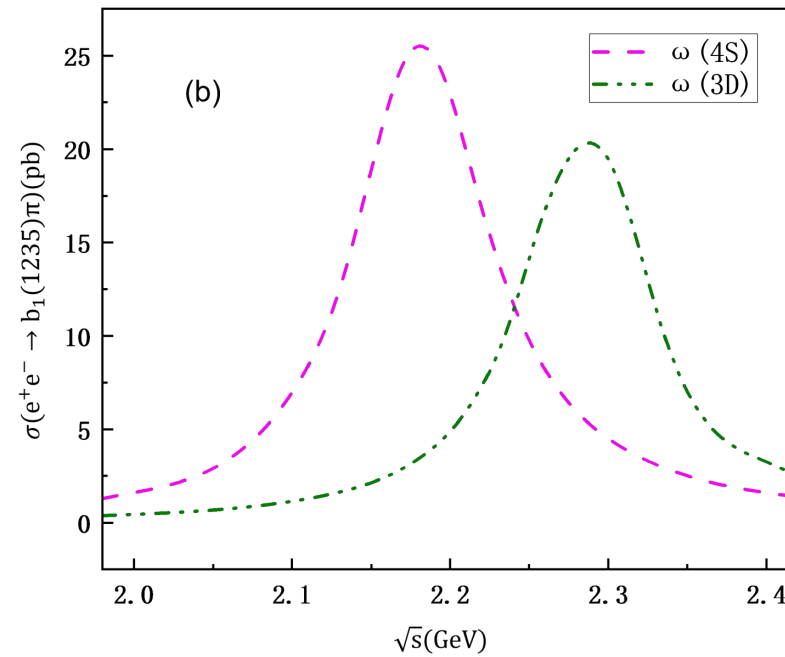
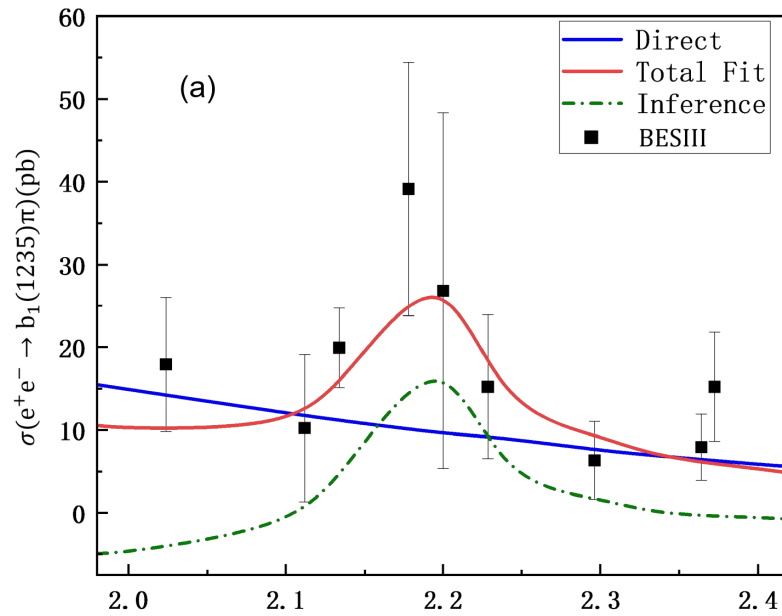


Parameters	Values
$a(\text{GeV}^3)$	2.35 ± 0.07
$b(\text{GeV}^{-1})$	0.47 ± 0.02
$\phi_{\omega(3D)} (\text{rad})$	1.617 ± 0.003
$\phi_{\omega(4S)} (\text{rad})$	1.581 ± 0.002
$g_{\omega(4S)b_1(1235)\pi} (\text{GeV})_{\text{Fit}}$	0.78 ± 0.09
$g_{\omega(3D)b_1(1235)\pi} (\text{GeV})_{\text{Fit}}$	1.15 ± 0.08
$g_{\omega(4S)b_1(1235)\pi} (\text{GeV})_{\text{Theo}}$	0.82
$g_{\omega(3D)b_1(1235)\pi} (\text{GeV})_{\text{Theo}}$	1.22
$\chi^2/n.d.f$	1.37

$$\mathcal{L}_{\text{int}} = g_{\omega^*b_1\pi} \omega^{*\mu} b_{1\mu} \pi$$

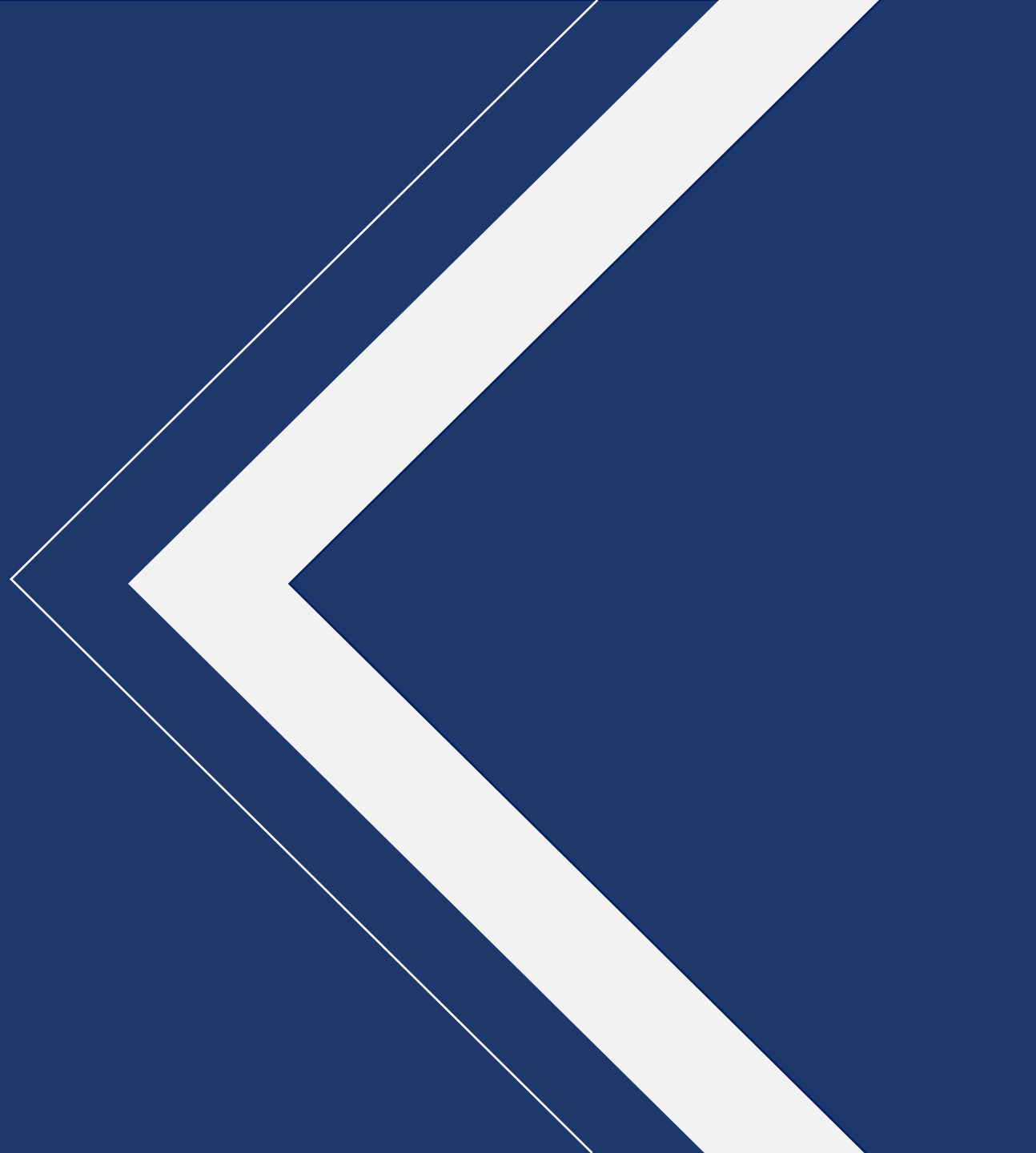
$$\mathcal{M} = g_{\omega^*b_1\pi} \epsilon^\mu(p) \epsilon_\mu^*(p_1)$$

$$\Gamma_{\omega^* \rightarrow b_1\pi} = \frac{1}{3} \times \frac{|\vec{p}_1|}{8\pi m_{\omega^*}^2} \sum |\mathcal{M}|^2$$



- ❑ We choose $\omega(4S)$ and $\omega(3D)$ as intermediate resonances.
- ❑ Both the $\omega(4S)$ and $\omega(3D)$ states contribute significantly and with comparable magnitude to the observed cross section.
- ❑ Specifically, the $\omega(4S)$ resonance produces a prominent peak around 2.2 GeV, while the $\omega(3D)$ generates a broader enhancement centered near 2.3 GeV.

IV. Summary



- When reproducing the experimental data $e^+e^- \rightarrow b_1(1235)\pi$ around 2.2 GeV. It is predominantly generated by the significant constructive interference between the $\omega(4S)$ and $\omega(3D)$ states, and with comparable magnitude to the observed cross section.
- This interpretation, supported by the fitted resonance parameters and phase angles, successfully resolves previous experimental discrepancies and aligns with theoretical expectations.
- e^+e^- annihilation into light mesons is helpful to better understand the ρ , ω and ϕ higher excitations around 2 GeV.