郑州大学
ZHENGZHOU UNIVERSITY

第十届XYZ研讨会

arXiv:2503.00437

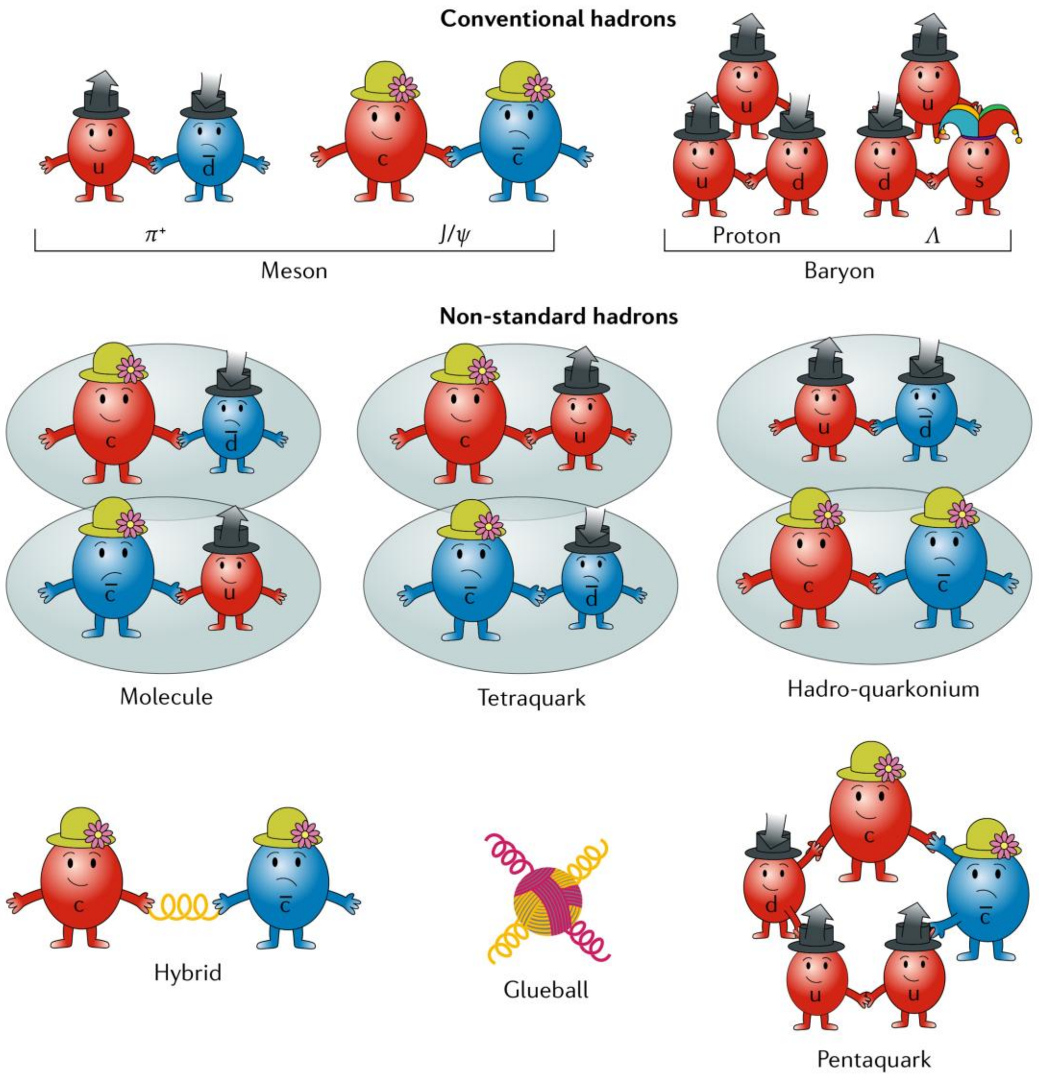
The $B^- \to J/\psi\eta' K^-$ reaction and the Y(4710) and $K_0^*(1430)$ contributions

吕文韬 郑州大学

合作者：段漫玉，李德民，王兵，陈殿勇，王恩

2025年4月13日

Background



➢Conventional hadrons:

Meson

Baryon

➢Non-standard hadrons:

Molecule

Tetraquark

Pentaquark

Hybrid

Glueball

Nature Rev. Phys. 1 , 480 (2019)

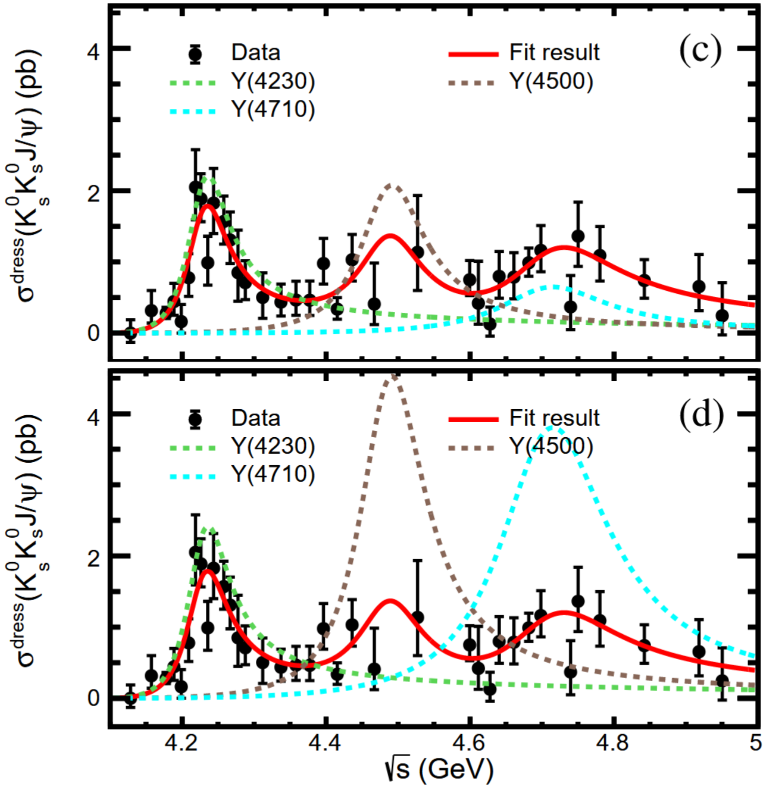
Background

ZHENGZHOU UNIVERSITY 郑州大学

- In 2023, BESIII Collaboration have reported a new vector charmonium-like state Y(4710) and measured its mass and width.

[Phys. Rev. D 107 (2023) 092005]

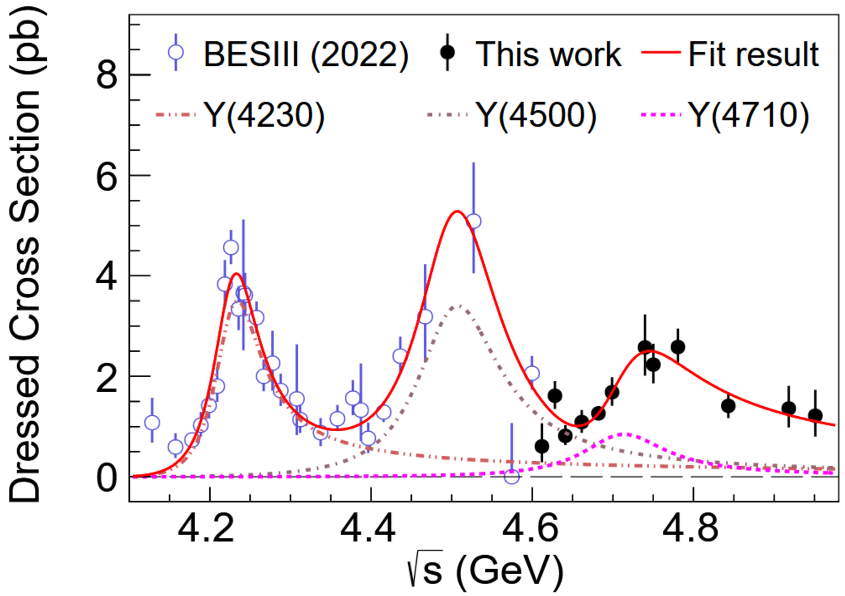
[Phys. Rev. Lett. 131 (2023) 211902]



$4.2\,\sigma$

$M = 4704.0 \pm 52.3 \pm 69.5$ MeV

$\Gamma = 183.2 \pm 114.0 \pm 96.1$ MeV



$M = 4708^{+17}_{-15} \pm 21$MeV

$\Gamma = 126^{+27}_{-23} \pm 30$ MeV

Over $5.0\,\sigma$

Background

ZHENGZHOU UNIVERSITY

◻ PART of theoretical explanations of the $Y(4710)$

- **Conventional charmonium:**

  Phys. Rev. D 77 (2008) 014033: $\psi(5S)$ (linear potential quark model)

  Phys. Rev. D 95 (2017) 034026: $\psi(5S)$ (linear potential quark model)

  Phys. Rev. D 98 (2018) 016010: $\psi(5S)$ (linear potential quark model)

  Phys. Rev. D110 (2024) 056034: $\psi(4D)$ (unquenched quark model)

- **Compact tetraquark :**

  Nucl. Phys. B 1002 (2024) 116514: $[sc]_{\tilde{V}}[\overline{sc}]_A - [sc]_A[\overline{sc}]_{\tilde{V}}$ (QCD Sum rule)

  arXiv:2502.11351: $[sc]_{\tilde{V}}[\overline{sc}]_A - [sc]_A[\overline{sc}]_{\tilde{V}}$ (QCD Sum rule)

- **Hybrid :**

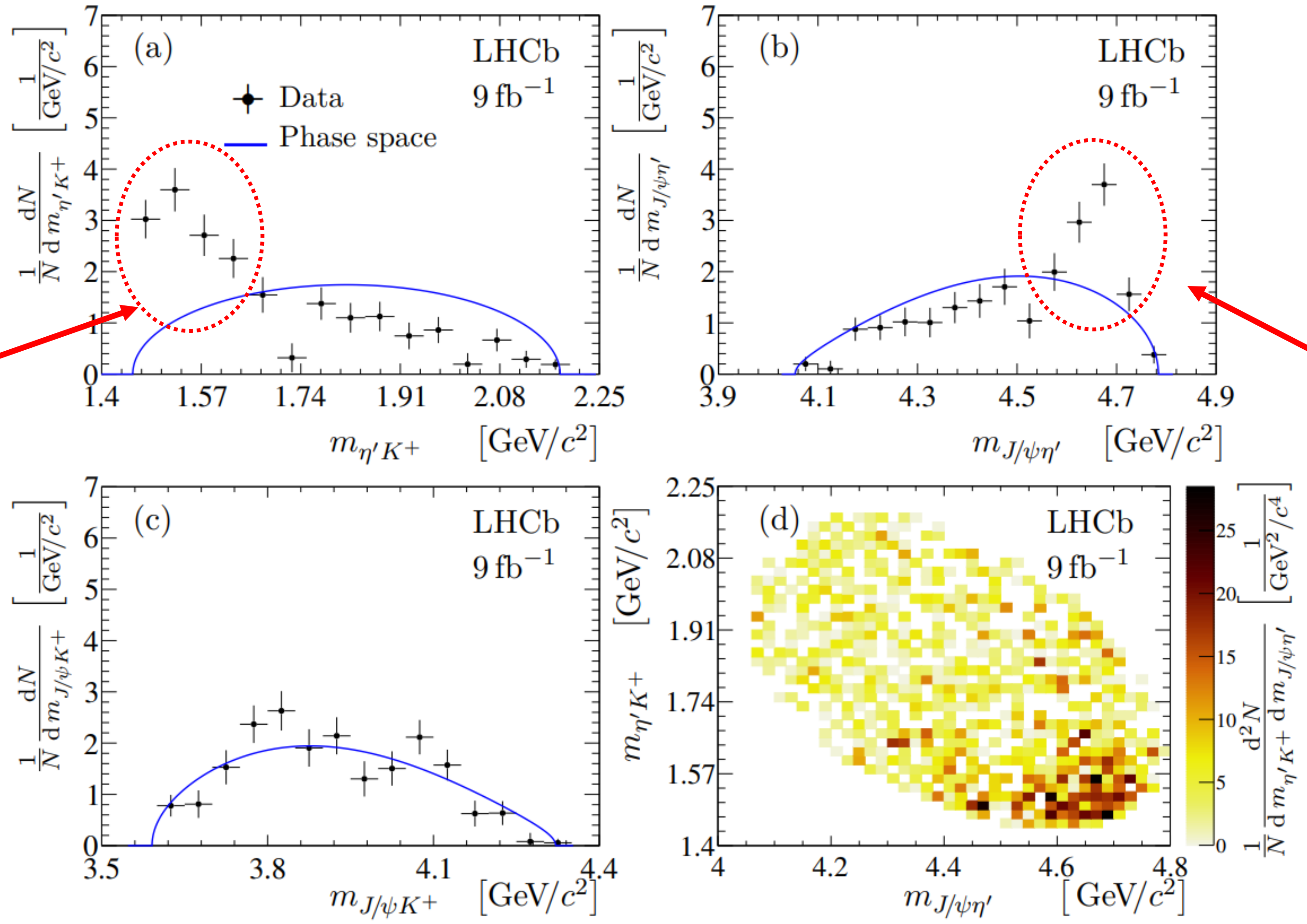
  Phys. Rev. D 110 (2024) 094040: $H_1(4507)$

  Phys. Rev. D 107 (2023) 054034: $H_1[1^{--}](4812)$

Background

- In 2023, LHCb Collaboration have measured the process $B^+ \to J/\psi\eta' K^+$

[JHEP 08 (2023) 174]



Signal of K^*

Possible signal of Y(4710)

$$\mathcal{B}(B^+ \to J/\psi\eta' K^+) = (3.06 \pm 0.29 \pm 0.18 \pm 0.04) \times 10^{-5}$$

Background

The possible excited kaon states around $\eta' K^-$ threshold

State	Spin-parity	Mass/MeV	Width/MeV
$K_1(1400)$	1^+	1403	174
$K^*(1410)$	1^-	1414	232
$K_0^*(1430)$	0^+	1425	270
$K_2^*(1430)$	2^+	1432.4	109
$K(1460)$	0^-	1482.40	335.60

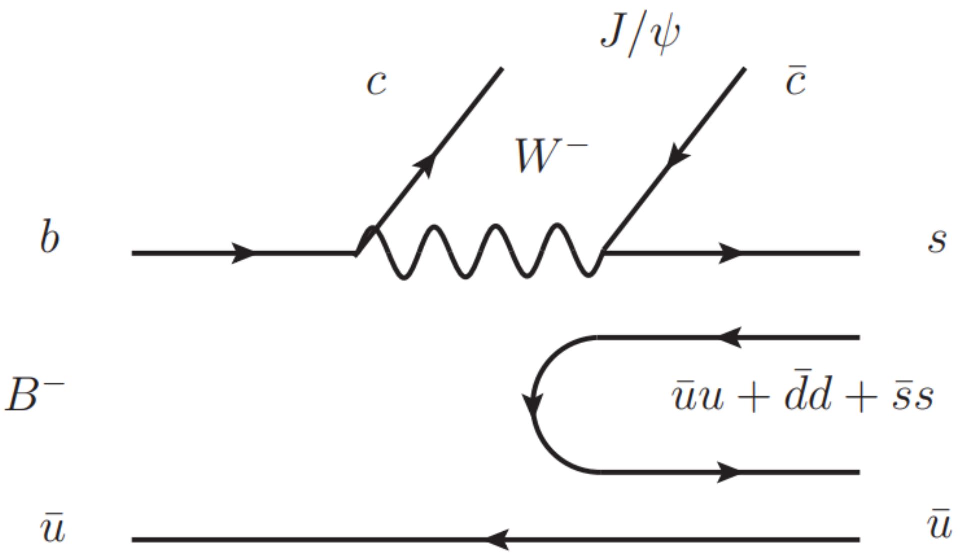
We have only considered the contribution from $K_0^*(1430)$

- $K_1(1400)$ and $K(1460)$ cannot couple to $\eta' K^-$ because of the parity
- $K^*(1410) \to \eta' K^-$ and $K_2^*(1430) \to \eta' K^-$ are not observed in experiment
- $K_0^*(1430) \to \eta' K^-$ is observed in $\chi_{cJ} \to \eta' K^+ K^-$ (BESIII) and $\eta_c \to \eta' K^+ K^-$ ($BABAR$)

[Phys. Rev. D 89 (2014) 074030] [Phys. Rev. D 104 (2021) 072002]

Formalism

□ Quark level diagram



$$V=\begin{pmatrix} \frac{\omega+\rho^0}{\sqrt{2}} & \rho^+ & K^{*+} \\ \rho^- & \frac{\omega-\rho^0}{\sqrt{2}} & K^{*0} \\ K^{*-} & \bar{K}^{*0} & \phi \end{pmatrix}.$$

□ Hadronization

$$\sum_i s(\bar{u}u+\bar{d}d+\bar{s}s)\bar{u}=\sum_{i=1}^{3} V_{3i}V_{i1},$$

$$\begin{aligned} H &= J/\psi\left\{K^{*-}\left(\frac{\rho^0}{\sqrt{2}}+\frac{\omega}{\sqrt{2}}\right)+\bar{K}^{*0}\rho^-+K^{*-}\phi\right\} \\ &= J/\psi\left\{\frac{1}{\sqrt{2}}K^{*-}\rho^0+\frac{1}{\sqrt{2}}K^{*-}\omega+\bar{K}^{*0}\rho^-+K^{*-}\phi\right\}. \end{aligned}$$

Formalism

In the isospin basis

$$
\begin{aligned}
|K^{*-}\rho^0\rangle &= -\left|\frac{1}{2},-\frac{1}{2}\right\rangle|1,0\rangle \\
&= -\left[\sqrt{\frac{2}{3}}\left|\bar{K}^*\rho,\frac{3}{2},-\frac{1}{2}\right\rangle - \sqrt{\frac{1}{3}}\left|\bar{K}^*\rho,\frac{1}{2},-\frac{1}{2}\right\rangle\right] \\
&= -\sqrt{\frac{2}{3}}\left|\bar{K}^*\rho,\frac{3}{2},-\frac{1}{2}\right\rangle + \sqrt{\frac{1}{3}}\left|\bar{K}^*\rho,\frac{1}{2},-\frac{1}{2}\right\rangle
\end{aligned}
$$

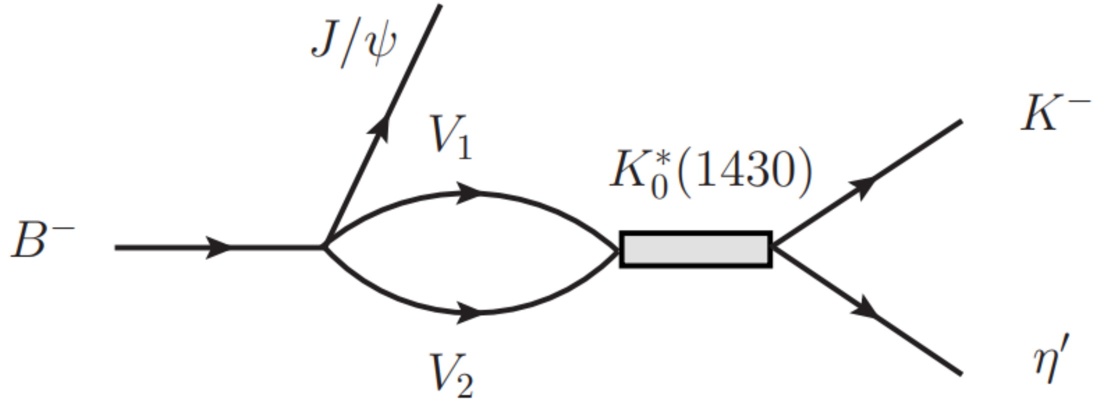
$$
\begin{aligned}
|\bar{K}^{*0}\rho^-\rangle &= \left|\frac{1}{2},\frac{1}{2}\right\rangle|1,-1\rangle \\
&= \sqrt{\frac{1}{3}}\left|\bar{K}^*\rho,\frac{3}{2},-\frac{1}{2}\right\rangle + \sqrt{\frac{2}{3}}\left|\bar{K}^*\rho,\frac{1}{2},-\frac{1}{2}\right\rangle
\end{aligned}
$$

$$
\begin{aligned}
\frac{1}{\sqrt{2}}|K^{*-}\rho^0\rangle + |\bar{K}^{*0}\rho^-\rangle &= \left(\sqrt{\frac{1}{6}}+\sqrt{\frac{2}{3}}\right)\left|\bar{K}^*\rho,\frac{1}{2},-\frac{1}{2}\right\rangle \\
&= \frac{3}{\sqrt{6}}\left|\bar{K}^*\rho,\frac{1}{2},-\frac{1}{2}\right\rangle .
\end{aligned}
$$

Hadronization

$$
H = J/\psi\left\{\frac{3}{\sqrt{6}}\bar{K}^*\rho + \frac{1}{\sqrt{2}}\bar{K}^*\omega + \bar{K}^*\phi\right\}.
$$

The mechanisms from the intermediate $K_0^*(1430)$



Formalism

郑州大学 ZHENGZHOU UNIVERSITY

□ The decay amplitude

$$\mathcal{T}^{K_0^*(1430)} = p_{J/\psi} \sum_i h_i \tilde{G}_i \frac{g_i g_{\eta' K^-}}{M^2_{\eta' K^-} - M^2_{K_0^*} + i M_{K_0^*} \Gamma_{K_0^*}},$$

$$h_{\bar{K}^*\rho} = \frac{3}{\sqrt{6}}, h_{\bar{K}^*\omega} = \frac{1}{\sqrt{2}}, h_{\bar{K}^*\phi} = 1.$$

$$\begin{aligned}\tilde{G}(s) = & \frac{1}{N^2} \int_{(M_1-2\Gamma_1)^2}^{(M_1+2\Gamma_1)^2} d\tilde{m}_1^2 \left(-\frac{1}{\pi}\right) \mathrm{Im} \frac{1}{\tilde{m}_1^2 - M_1^2 + i\tilde{\Gamma}_1 \tilde{m}_1} \\ & \times \int_{(M_2-2\Gamma_2)^2}^{(M_2+2\Gamma_2)^2} d\tilde{m}_2^2 \left(-\frac{1}{\pi}\right) \mathrm{Im} \frac{1}{\tilde{m}_2^2 - M_2^2 + i\tilde{\Gamma}_2 \tilde{m}_2} \\ & \times G(s, \tilde{m}_1^2, \tilde{m}_2^2)\end{aligned}$$

□ The couplings

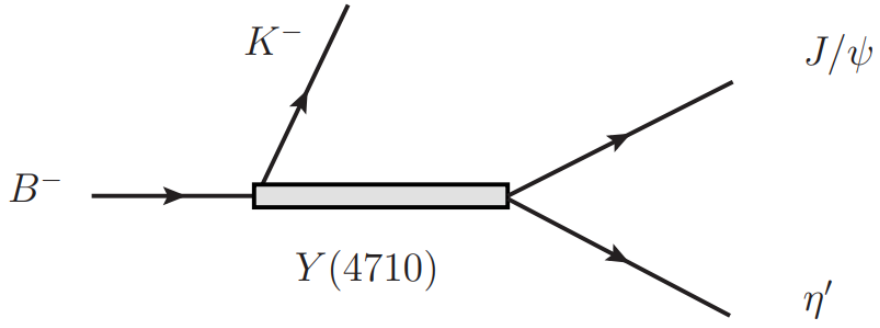
	ρK^*	$K^*\omega$	$K^*\phi$
g	$(8102, -i959)$	$(1370, -i146)$	$(-1518, i209)$

Phys.Rev.D 79 (2009) 074009

$$\begin{aligned}N^2 = & \int_{(M_1-2\Gamma_1)^2}^{(M_1+2\Gamma_1)^2} d\tilde{m}_1^2 \left(-\frac{1}{\pi}\right) \mathrm{Im} \frac{1}{\tilde{m}_1^2 - M_1^2 + i\tilde{\Gamma}_1 \tilde{m}_1} \\ & \times \int_{(M_2-2\Gamma_2)^2}^{(M_2+2\Gamma_2)^2} d\tilde{m}_2^2 \left(-\frac{1}{\pi}\right) \mathrm{Im} \frac{1}{\tilde{m}_2^2 - M_2^2 + i\tilde{\Gamma}_2 \tilde{m}_2},\end{aligned}$$

Formalism

□ The mechanisms from the intermediate Y(4710)



□ The total amplitude

$$\mathcal{T} = V_P \left\{ \mathcal{T}^{K_0^*(1430)} + \mathcal{T}^{BG} e^{i\phi} + \mathcal{T}^{Y(4710)} e^{i\phi'} \right\},$$

$$\mathcal{T}^{BG} = C p_{J/\psi},$$

□ The decay amplitude

$$\mathcal{T}^{Y(4710)} = \frac{V_Y \tilde{k}_K \tilde{k}_{\eta'} \cos\tilde{\theta}}{M^2_{J/\psi\eta'} - M^2_{Y(4710)} + i M_{Y(4710)} \Gamma_{Y(4710)}},$$

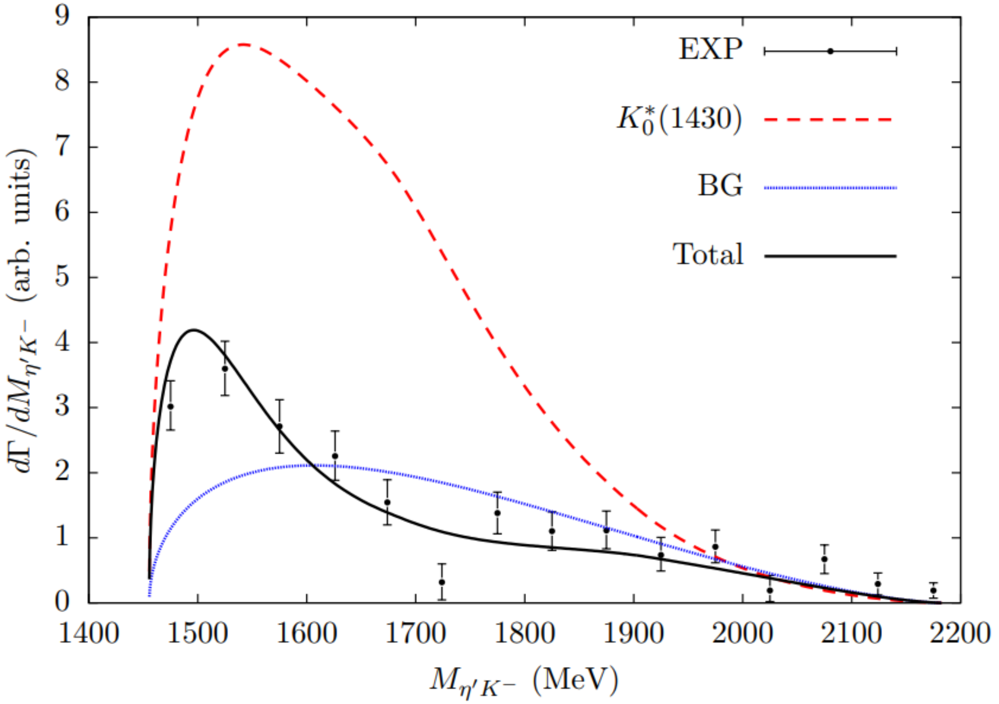
$$\cos\tilde{\theta} = \frac{M^2_{J/\psi K^-} - M^2_B - M^2_{\eta'} + 2P^0_B P^0_{\eta'}}{2|\tilde{k}_{\eta'}||\tilde{k}_K|},$$

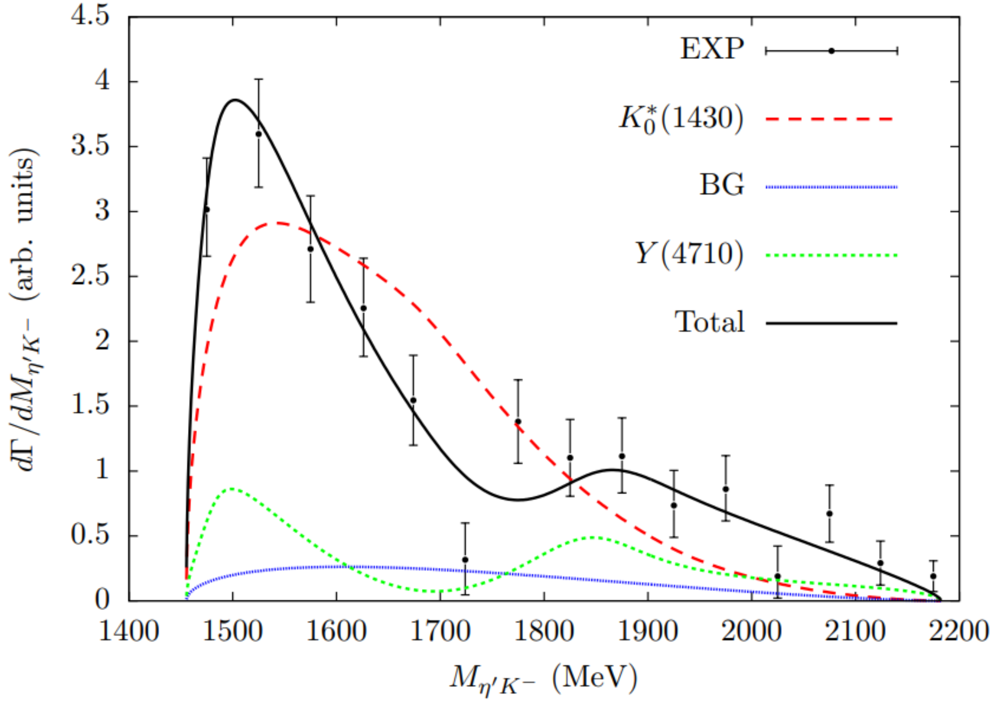
$$|\tilde{k}_K| = \frac{\lambda^{1/2}(M^2_{J/\psi\eta'}, M^2_B, m^2_{K^-})}{2M_{J/\psi\eta'}},$$

$$|\tilde{k}_{\eta'}| = \frac{\lambda^{1/2}(M^2_{J/\psi\eta'}, m^2_{\eta'}, m^2_{J/\psi})}{2M_{J/\psi\eta'}},$$

The results without/with Y(4710)

□ The $\eta' K^-$ invariant mass distributions

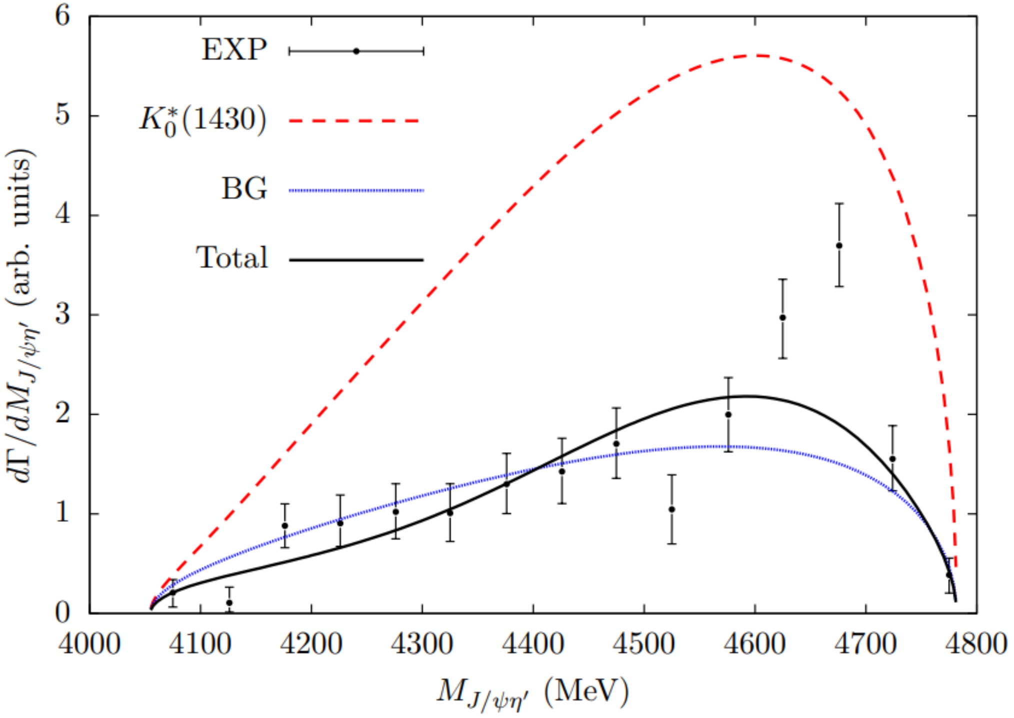


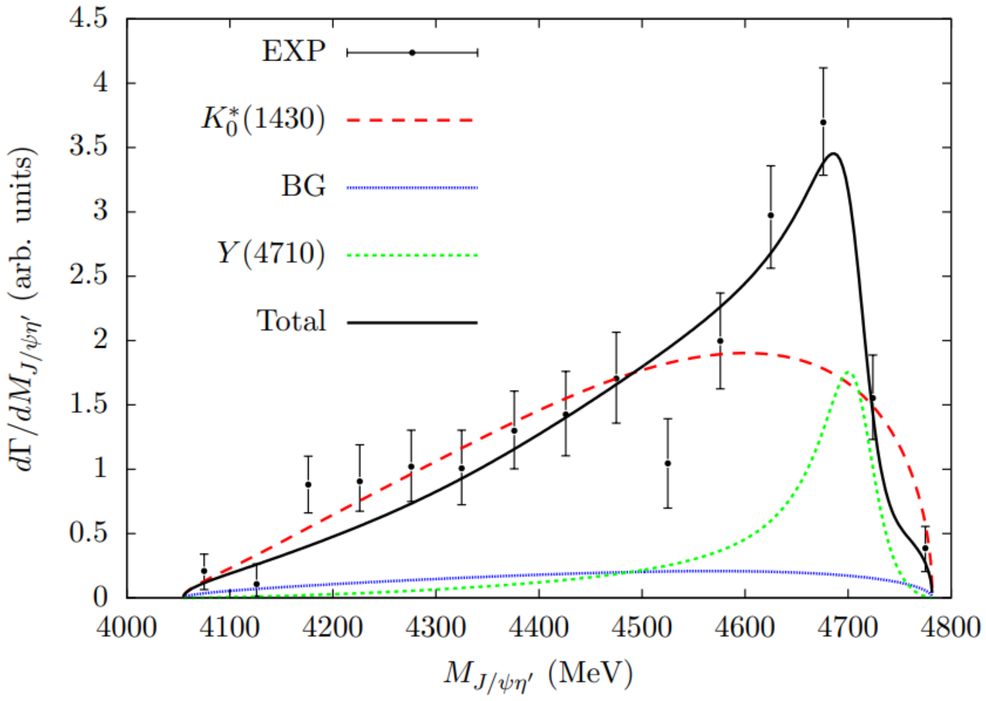


	V_P	C	V_Y	ϕ	ϕ'	M_Y / MeV	Γ_Y / MeV	χ^2 / d.o.f
Without Y(4710)	1493.6	6.99×10^{-5}		-0.13π				2.65
With Y(4710)	870.12	4.23×10^{-5}	0.782	-0.26π	1.51π	4710.7	65.17	1.59

The results without/with Y(4710)

□ The $J/\psi\eta'$ invariant mass distributions



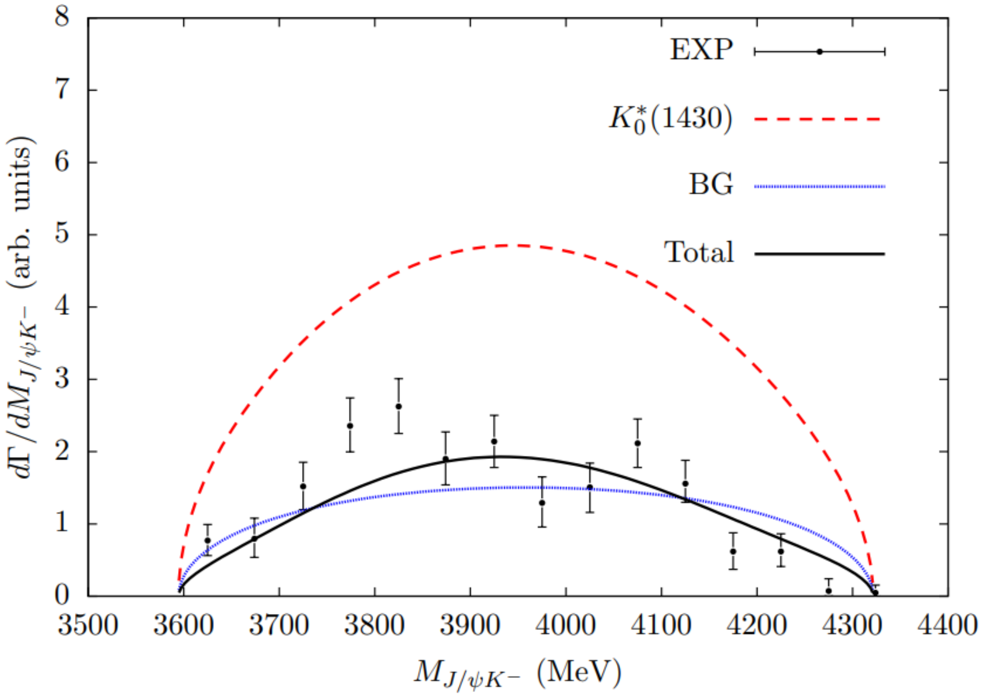


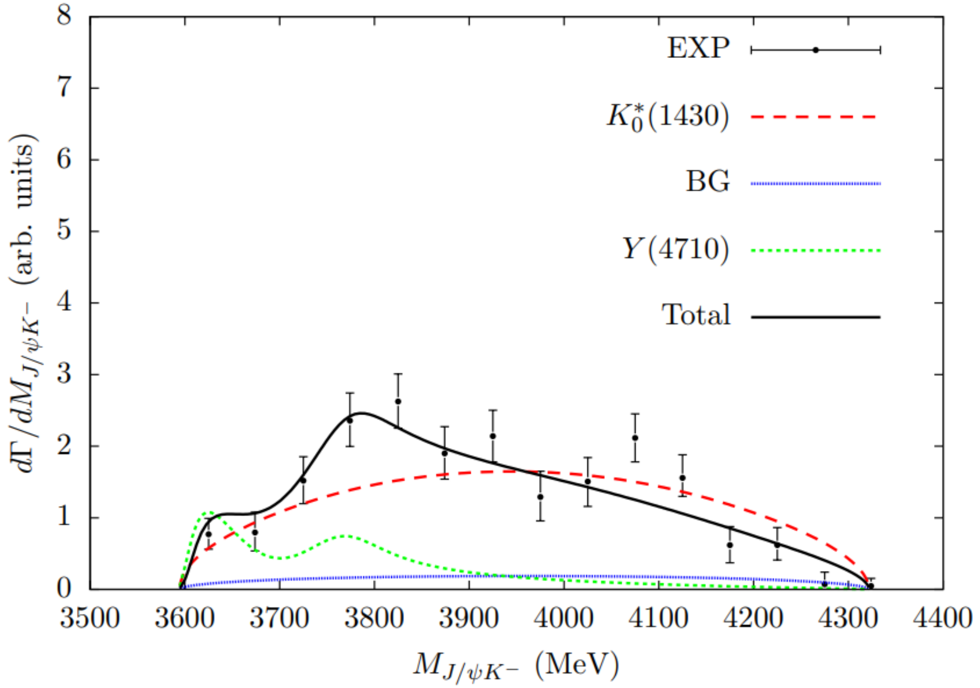
	V_P	C	V_Y	ϕ	ϕ'	M_Y / MeV	Γ_Y / MeV	χ^2 / d.o.f
Without Y(4710)	1493.6	6.99×10^{-5}		-0.13π				2.65
With Y(4710)	870.12	4.23×10^{-5}	0.782	-0.26π	1.51π	4710.7	65.17	1.59

The results without/with Y(4710)

郑州大学 ZHENGZHOU UNIVERSITY

□ The $J/\psi K^-$ invariant mass distributions

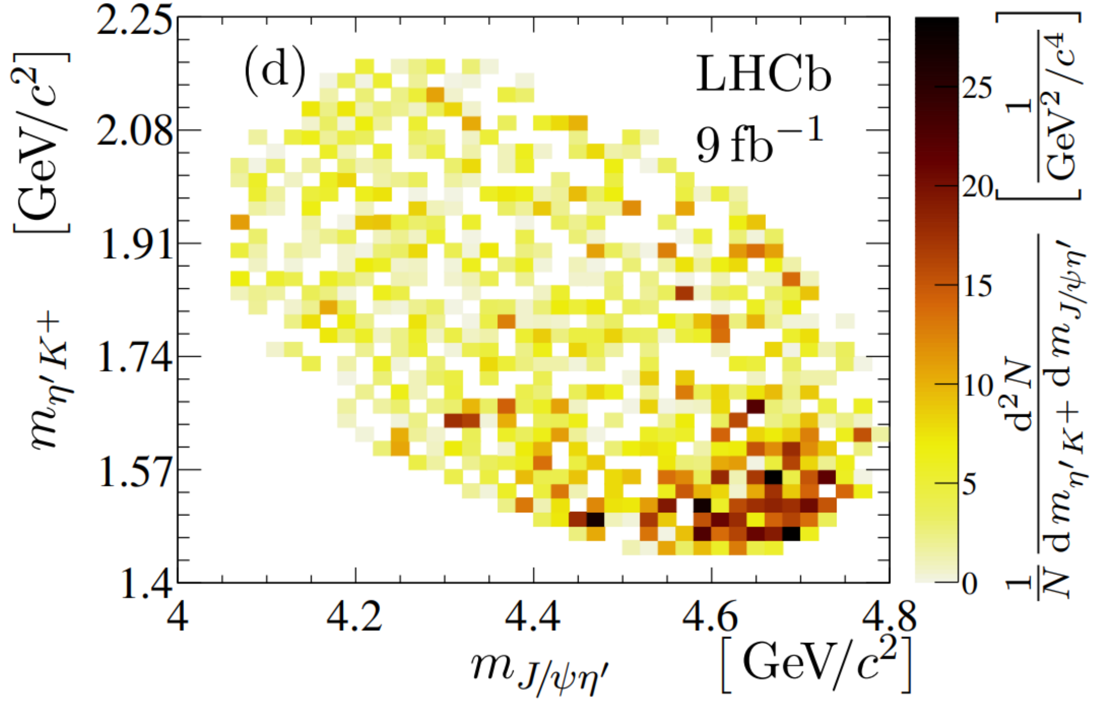




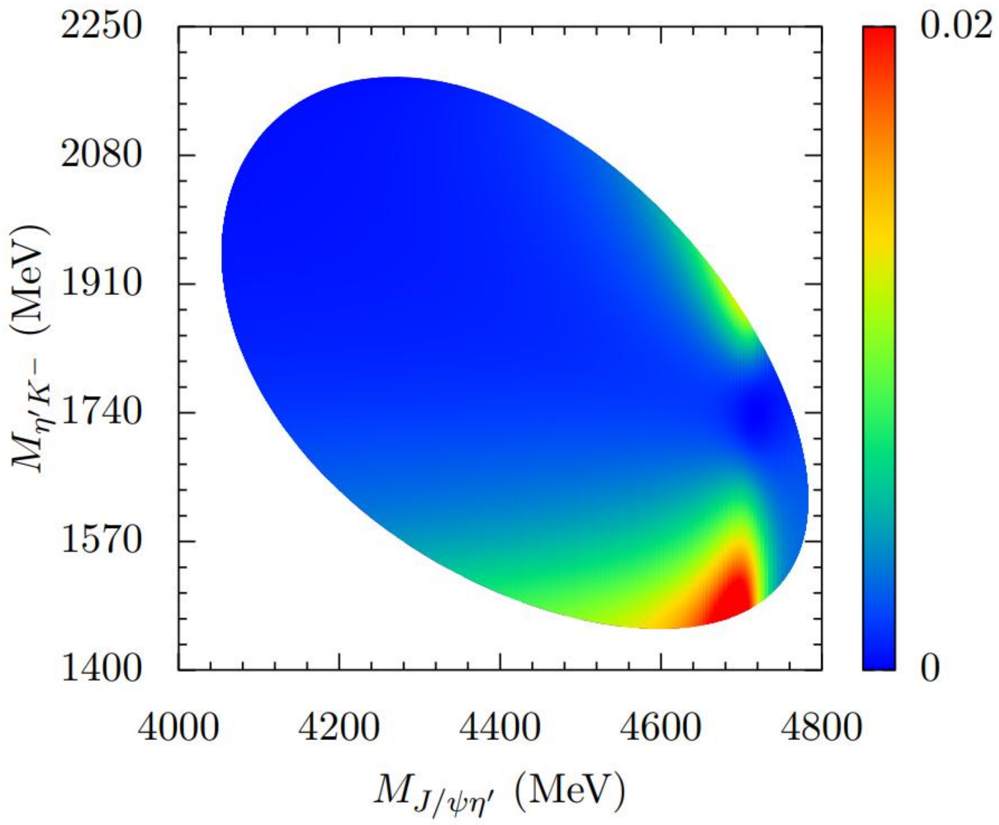
	V_P	C	V_Y	ϕ	ϕ'	M_Y / MeV	Γ_Y / MeV	χ^2 / d.o.f
Without Y(4710)	1493.6	6.99×10^{-5}		-0.13π				2.65
With Y(4710)	870.12	4.23×10^{-5}	0.782	-0.26π	1.51π	4710.7	65.17	1.59

The results with Y(4710)

□ The Dalitz plots of $J/\psi\eta'$ vs. $\eta' K^-$ for the $B^- \to J/\psi\eta' K^-$



[JHEP 08 (2023) 174]



Summary

ZHENGZHOU UNIVERSITY

- The threshold enhancement structure in the $\eta' K^-$ invariant mass distribution of $B^- \to J/\psi\eta' K^-$ should be due to $K_0^*(1430)$.
- The peak structure around 4.7 GeV in the $J/\psi\eta'$ invariant mass distribution should be due to $\mathrm{Y}(4710)$.
- The decay mode of $\mathrm{Y}(4710) \to J/\psi\eta'$ is Okubo-Zweig-Iizuka (OZI) suppressed for the charmonium state.
- The more precise measurements could be used to test the existence of the $\mathrm{Y}(4710)$ state and to explore its nature.

Thank you very much!