Exotic hybrid mesons in QCD

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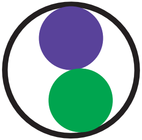
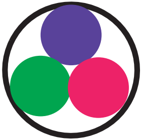
Outline

1. Background of the exotic hadron states
2. Mass spectra for the heavy quarkonium hybrid mesons
   - For the $\bar{c}Gc$ charmonium hybrid states
   - For the $\bar{b}Gb$ bottomonium hybrid states
   - For the $\bar{b}Gc$ open-flavor hybrid states
3. Decay behaviors of hybrid mesons
4. Study for the vector $\bar{s}gs$ hybrids
5. Summary

Quark model

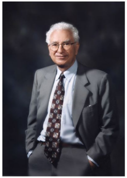


meson($q\bar{q}$)



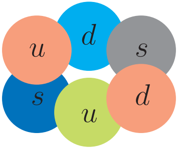
baryon(qqq)

Gell-Mann and Zweig

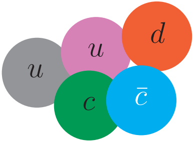


- **Quark model** is established to classify hadrons: mesons ($q\bar{q}$) and baryons (qqq).
- Hadrons with exotic quantum numbers are exotic hadron states.
- **QCD** may allow for hadrons which lie outside the naive quark model. Hadron structures are more complicated in **QCD**: $\mathrm{N}_{\mathrm{quarks}} \neq 2, 3$.
- $SU(3)_c$ **gauge symmetry**: $(N_q - N_{\bar{q}})$ is divisible by 3, plus any number N_g of valence gluons can form a color singlet.

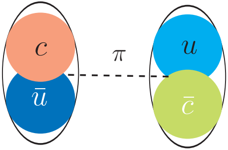
Exotic hadrons in QCD



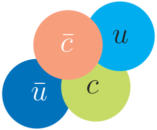
dibaryon



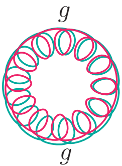
pentaquark



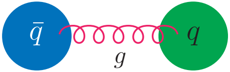
molecule



tetraquark



glueball



hybrid

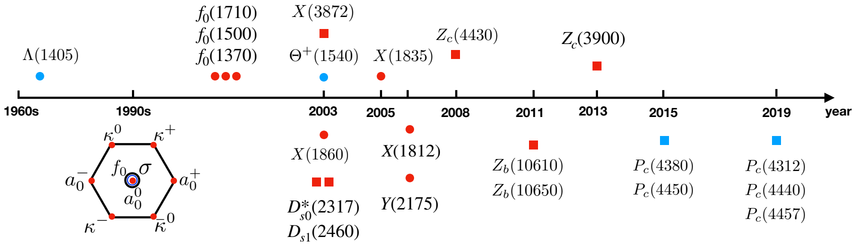
Searching for exotica

Light hadron sector:

- **Dibaryon**: Deuteron, H states, $d^*(2380)$.
- **Hybrid** candidates: $\pi_1(1400)$, $\pi_1(1600)$ and $\pi_1(2015)$ (dispute).
- **Glueball** candidates: $a_0(980)$ and $f_0(980)$.
- **Tetraquark** candidates: light scalar mesons.
- **Pentaquark**: $\Theta^+(1540)$ ($S = 1$, long story of appeared and disappeared)

Heavy hadron sector: breakthough in multiquarks!

- $P_c(4380), P_c(4312), P_c(4440), P_c(4457)$: hidden-charm pentaquark states.
- Plenty of **XYZ states**: candidates of molecules, tetraquarks, hybrids...

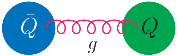


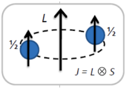
Searching for exotica

These XYZ and P_c states have inspired vigorous theoretical activity:

- Y. R. Liu, H. X. Chen, W. Chen, X. Liu, S. L. Zhu, Prog. Part. Nucl. Phys. 107 (2019) 237-320.
- H. X. Chen, W. Chen, X. Liu, S. L. Zhu, Phys. Rep. 639 (2016) 1-121.
- F.-K. Guo, C. Hanhart, U.-G. Meissner, Q. Wang, Q. Zhao, B.-S. Zou, Rev. Modern Phys. 90(2018) 015004.
- A. Esposito, A. Pilloni, A.D. Polosa, Phys. Rep. 668 (2016) 1-97.
- S.L. Olsen, T. Skwarnicki, D. Zieminska, Rev. Modern Phys. 90 (1) (2018) 015003.
- **Multiquark (tetraquark, pentaquark, hadron molecule) configurations** were extensively investigated to understand the structures of the XYZ and P_c states.
- **Hybrid meson configuration** was much less studied comparing to multiquarks.

Hybrid meson: $[q\bar{q}]_{\mathbf{8_c}}$ + one excited gluonic field





$$\mathbf{8} \otimes \mathbf{8} = \mathbf{1} \oplus \mathbf{8} \oplus \mathbf{8} \oplus \mathbf{10} \oplus \mathbf{10}^{*} \oplus \mathbf{27}$$

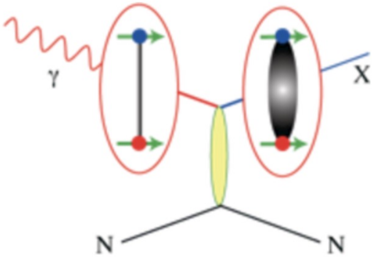
Model	$J^{PC}_{q\bar{q}'}$	J^{PC}_{g}	J^{PC}	Mass (GeV/c^2)
Bag [2, 3]	0^{-+}	1^{+-} (TE)	1^{--}	~ 1.7
	1^{--}	1^{+-} (TE)	$(0,\mathbf{1},2)^{-+}$	$\sim 1.3, 1.5, 1.9$
	0^{-+}	1^{--} (TM)	1^{+-}	heavier
	1^{--}	1^{--} (TM)	$(0,1,2)^{++}$	heavier
Flux tube [4, 5]	0^{-+}	1^{+-}	1^{--}	1.7-1.9
	1^{--}	1^{+-}	$(0,\mathbf{1},2)^{-+}$	1.7-1.9
	0^{-+}	1^{-+}	1^{++}	1.7-1.9
	1^{--}	1^{-+}	$(\mathbf{0},1,\mathbf{2})^{+-}$	1.7-1.9
Constituent gluon [6]/[7]	0^{-+}	1^{--}	1^{+-}	1.3-1.8 / 2.1
	1^{--}	1^{--}	$(0,1,2)^{++}$	1.3-1.8 / 2.2
	1^{+-}	1^{--}	$(0,\mathbf{1},2)^{-+}$	1.8-2.2 / 2.2
	$(0,1,2)^{++}$	1^{--}	$1^{--}, (\mathbf{0},1,2)^{--}, (1,2,3)^{--}$	1.8-2.2 / 2.3
Constituent gluon / LQCD [8, 9]	0^{-+}	1^{+-}	1^{--}	(2.3)
	1^{--}	1^{+-}	$(0,\mathbf{1},2)^{-+}$	(2.1, 2.0, 2.4)
	1^{+-}	1^{+-}	$(0,1,2)^{++}$	($>$ 2.4)
	$(0,1,2)^{++}$	1^{+-}	$1^{+-}, (\mathbf{0},1,\mathbf{2})^{+-}, (1,\mathbf{2},3)^{+-}$	($>$ 2.4)

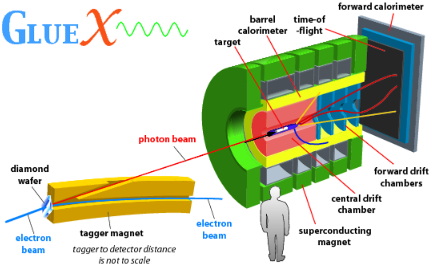
Lightest hybrid supermultiplet: $1^{--}, (0, 1, 2)^{-+}$ (arXiv:1208.5125)

GlueX experiment: searching for Gluonic Excitations

GlueX Physics

Hybrid mesons, and in particular exotic hybrid mesons, provide the ideal laboratory for testing QCD in the confinement regime since these mesons explicitly manifest the gluonic degrees of freedom. Photoproduction is expected to be particularly effective in producing exotic hybrids. This is due to the fact that the quantum numbers of the lowest predicted excited modes of the flux tube, when combined with that of a virtual photon, yield exotic J^{PC}. However, there is little data on the photoproduction of light mesons.





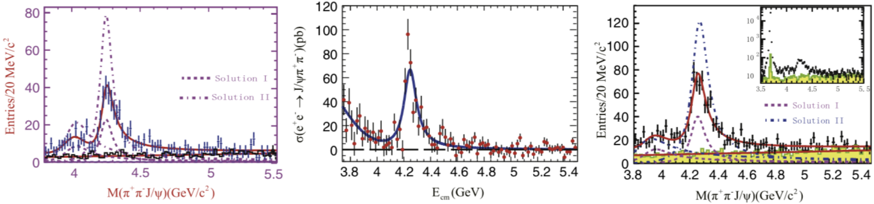
light sector

Heavy sector: $Y(4260)$ in ISR process

In 2005, Babar first announced a structure in $J/\psi\pi^+\pi^-$ mass spectrum:

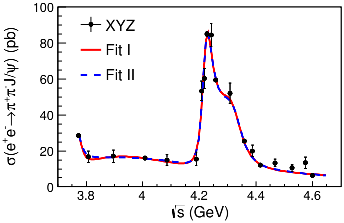
The resonance parameters for the $Y(4260)$ and the observed decay channels.

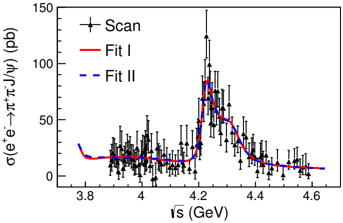
Experiment	Mass (MeV)	Width (MeV)	Decay mode
BaBar [62]	$4259 \pm 8^{+2}_{-6}$	$88 \pm 23^{+6}_{-4}$	$J/\psi\pi^+\pi^-$
CLEO [60]	$4284^{+17}_{-16} \pm 4$	$73^{+39}_{-25} \pm 5$	$J/\psi\pi^+\pi^-$
Belle [142]	$4295 \pm 10^{+10}_{-3}$	$133 \pm 26^{+13}_{-6}$	$J/\psi\pi^+\pi^-$
Belle [119]	$4247 \pm 12^{+17}_{-32}$	$108 \pm 19 \pm 10$	$J/\psi\pi^+\pi^-$
BaBar [143]	$4252 \pm 6^{+2}_{-3}$	$105 \pm 18^{+4}_{-6}$	$J/\psi\pi^+\pi^-$
BaBar [123]	$4244 \pm 5 \pm 4$	$114^{+16}_{-15} \pm 7$	$J/\psi f_0(980)(\to \pi^+\pi^-)$,
Belle [124]	$4258.6 \pm 8.3 \pm 12.1$	$134.1 \pm 16.4 \pm 5.5$	$\pi^\mp Z_c(3900)^\pm(\to J/\psi\pi^\pm)$

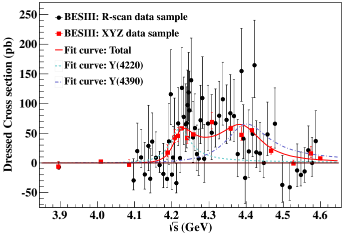


$$J^{PC} = 1^{--}$$

In 2017, BESIII Collaboration presented more precise measurements of $e^+e^- \to \pi^+\pi^- J/\psi$ and $e^+e^- \to \pi^+\pi^- h_c$ cross sections:



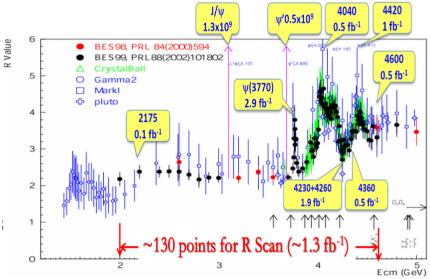


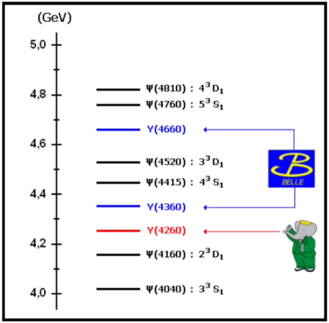


$Y(4260)$: a candidate for charmonium hybrid

Various possibilities of $Y(4260)$:

- Its mass and decays are not consistent with any 1^{--} radially excited S-wave or D-wave $c\bar{c}$ charmonium state. It is nearly impossible to accommodate $Y(4260)$ as a $c\bar{c}$ state.





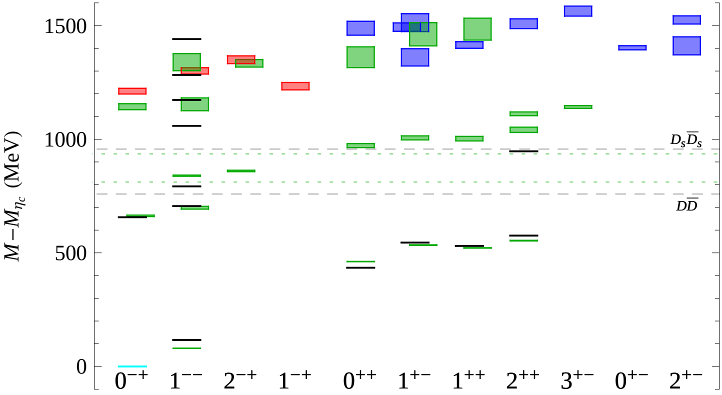
- The discoveries of Y states represents an overpopulation of the charmonium states!

$Y(4260)$: a candidate for charmonium hybrid

Various possibilities of $Y(4260)$:

- Its mass and decays are not consistent with any 1^{--} radially excited S-wave or D-wave $c\bar{c}$ charmonium state. It is nearly impossible to accommodate $Y(4260)$ as a $c\bar{c}$ state.
- The couple-channel effects cannot shift the mass of $\psi(3D)$ from above 4.6 GeV down to 4.26 GeV.
- The $Y(4260)$ seems not a hadronic molecule. Its decay width disfavors the assignments of $\bar{D}D_1$, $\bar{D}D_1'$, $\bar{D}_0D^*$ and $\bar{D}^*D_1'$.
- The 1^{--} glueball is disfavored by its distinct decay patterns.
- The tetraquark hypothesis is also not favored by the not-so-large total width and the absence of the open-charm $D\bar{D}$ decay mode.
- The **charmonium hybrid** interpretation is **strongly favored** by the experimental data, in which the open-charm $D\bar{D}$ decay mode is suppressed.

Charmonium hybrids in LQCD



L. Liu et al., JHEP 07 (2012) 126

Charmonium hybrids in QSR

J. Govaerts et al., Nucl. Phys. B284, 674 (1987)

J^{PC}	2-pt fct	m_R	$\sqrt{s_0}$	J^{PC}	2-pt fct	m_R	$\sqrt{s_0}$
0^{++}	(3,3)	5 5	5 9	0^{-+}	$(\tilde{3},\tilde{3})$	$\underline{5\ 2}$	$\underline{5\ 9}$
	(5,5)(SS)	5 5	5 9		$(\tilde{5},\tilde{5})$(SS)	$\underline{5\ 2}$	$\underline{5\ 9}$
	(5,5)(ST)	5 7	6 2		$(\tilde{5},\tilde{5})$(ST)	$\underline{5\ 3}$	$\underline{6\ 2}$
	(5,5)(TT)	4 8	5 2		$(\tilde{5},\tilde{5})$(TT)	$\underline{4\ 5}$	$\underline{5\ 2}$
	(3,5)(S)	5 8	6 3		$(\tilde{3},\tilde{5})$(S)	$\underline{5\ 4}$	$\underline{6\ 3}$
	(3,5)(T)	5 3	5 8		$(\tilde{3},\tilde{5})$(T)	$\underline{5\ 0}$	$\underline{5\ 8}$
0^{+-}	$(\tilde{4},\tilde{4})$	$\underline{5\ 6}$	$\underline{6\ 3}$	0^{--}	(4,4)	5 9	6 3
1^{++}	$(\tilde{3},\tilde{3})$	5 1	5 5	1^{-+}	(3,3)	$\underline{4\ 9}$	$\underline{5\ 5}$
	$(\tilde{5},\tilde{5})$(SS)	5 3	5 7		(5,5)(SS)	$\underline{5\ 0}$	$\underline{5\ 7}$
	$(\tilde{5},\tilde{5})$(AS)	5 7	6 2		(5,5)(AS)	$\underline{5\ 3}$	$\underline{6\ 2}$
	(5,5)(AA)	4 9	5 2		(5,5)(AA)	$\underline{4\ 7}$	$\underline{5\ 2}$
	$(\tilde{3},\tilde{5})$(S)	5 5	5 9		(3,5)(S)	$\underline{5\ 1}$	$\underline{5\ 9}$
	$(\tilde{3},\tilde{5})$(A)	5 3	5 7		(3,5)(A)	$\underline{5\ 0}$	$\underline{5\ 7}$
1^{--}	(1,1)	5 8	6 2	1^{+-}	(1,1)	$\underline{5\ 5}$	$\underline{6\ 2}$
	(2,2)	$\underline{5\ 2}$	$\underline{5\ 9}$		(2,2)	5 5	5 9
	$(\tilde{4},\tilde{4})$	$\underline{4\ 3}$	$\underline{4\ 7}$		(4,4)	4 4	4 7
	$(\tilde{2},\tilde{4})$	$\underline{5\ 0}$	$\underline{5\ 7}$		(2,4)	5 3	5 7
2^{++}	(5,5)(SS)	4 9	5 2	2^{-+}	$(\tilde{5},\tilde{5})$(SS)	$\underline{4\ 7}$	$\underline{5\ 2}$

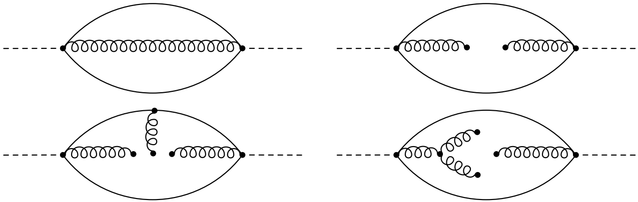
The underlined numbers correspond to unstable sum rules

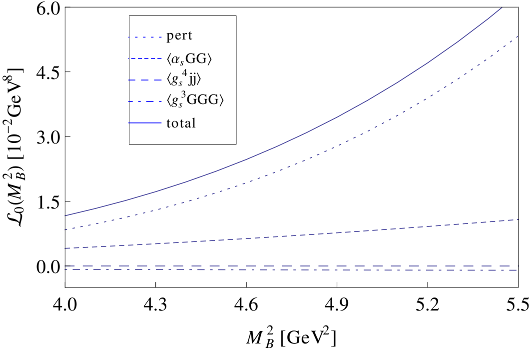
The Lightest hybrid supermultiplet states $1^{--}, (0,1,2)^{-+}$ are unstable!
Only perturbative and two-gluon condensate terms were calculated in OPE.

Hybrid Sum Rules

The quarkonium hybrid interpolating currents:

$$
\begin{aligned}
J_\mu &= g_s \bar{Q} \frac{\lambda^a}{2} \gamma^\nu G^a_{\mu\nu} Q, & J^{PC} &= 1^{-+}, 0^{++}, \\
J_\mu &= g_s \bar{Q} \frac{\lambda^a}{2} \gamma^\nu \gamma_5 G^a_{\mu\nu} Q, & J^{PC} &= 1^{+-}, 0^{--}, \\
J_{\mu\nu} &= g_s \bar{Q} \frac{\lambda^a}{2} \sigma^\alpha_\mu \gamma_5 G^a_{\alpha\nu} Q, & J^{PC} &= 2^{-+}, 1^{++}, 1^{-+}, 0^{-+}, \\
\tilde{J}_\mu &= g_s \bar{Q} \frac{\lambda^a}{2} \gamma^\nu \tilde{G}^a_{\mu\nu} Q, & J^{PC} &= 1^{++}, 0^{-+}, \\
\tilde{J}_\mu &= g_s \bar{Q} \frac{\lambda^a}{2} \gamma^\nu \gamma_5 \tilde{G}^a_{\mu\nu} Q, & J^{PC} &= 1^{--}, 0^{+-}, \\
\tilde{J}_{\mu\nu} &= g_s \bar{Q} \frac{\lambda^a}{2} \sigma^\alpha_\mu \gamma_5 \tilde{G}^a_{\alpha\nu} Q, & J^{PC} &= 2^{++}, 1^{-+}, 1^{++}, 0^{++}.
\end{aligned}
$$



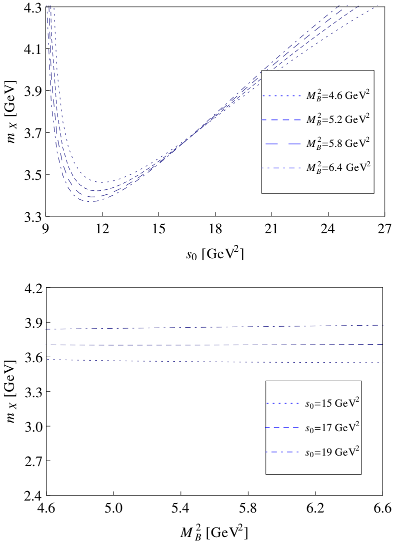


$$\alpha_s(\mu) = \frac{\alpha_s(M_\tau)}{1+\frac{25\alpha_s(M_\tau)}{12\pi}\log(\frac{\mu^2}{M_\tau^2})}, \quad \alpha_s(M_\tau)=0.33;$$

$$\alpha_s(\mu) = \frac{\alpha_s(M_Z)}{1+\frac{23\alpha_s(M_Z)}{12\pi}\log(\frac{\mu^2}{M_Z^2})}, \quad \alpha_s(M_Z)=0.118.$$

Borel curves: hadron mass vs. s_0 and M_B^2

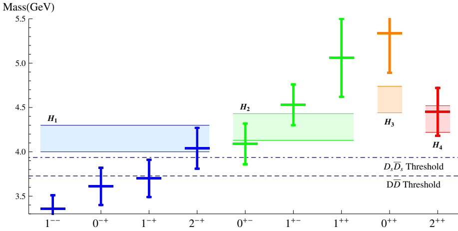
In the 1^{-+} charmonium hybrid channel:



Mass spectra for $\bar{c}Gc$ charmonium hybrids

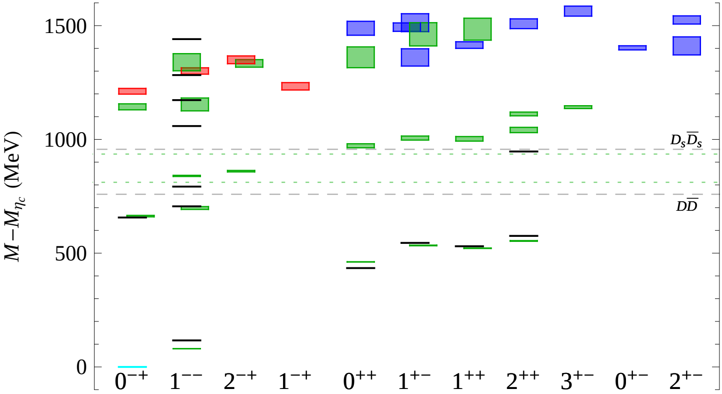
JHEP09(2013)019

J^{PC}	$s_0(\text{GeV}^2)$	$[M^2_{min}, M^2_{max}](\text{GeV}^2)$	$m_X(\text{GeV})$	PC(%)
1^{--}	15	$2.5 \sim 4.8$	3.36 ± 0.15	18.3
0^{-+}	16	$5.6 \sim 7.0$	3.61 ± 0.21	15.4
1^{-+}	17	$4.6 \sim 6.5$	3.70 ± 0.21	18.8
2^{-+}	18	$3.9 \sim 7.2$	4.04 ± 0.23	26.0
0^{+-}	20	$6.0 \sim 7.4$	4.09 ± 0.23	15.5
2^{++}	23	$3.9 \sim 7.5$	4.45 ± 0.27	21.5
1^{+-}	24	$2.5 \sim 8.4$	4.53 ± 0.23	33.2
1^{++}	30	$4.6 \sim 11.4$	5.06 ± 0.44	30.4
0^{++}	34	$5.6 \sim 14.6$	5.34 ± 0.45	36.3
0^{--}	35	$6.0 \sim 12.3$	5.51 ± 0.50	31.0



- Unstable channels are stabilized and the mass predictions are reliable!
- 1^{--} hybrid is lighter than $Y(4260)$, which seem to preclude a pure hybrid interpretation for this state.

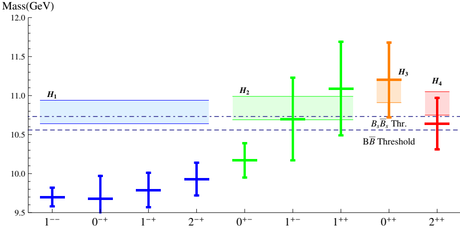
Charmonium hybrids in LQCD



L. Liu et al., JHEP 07 (2012) 126

JHEP09(2013)019

J^{PC}	$s_0(\text{GeV}^2)$	$[M^2_{\text{min}}, M^2_{\text{max}}](\text{GeV}^2)$	$m_X(\text{GeV})$	PC(%)
1^{--}	105	$11 \sim 17$	9.70 ± 0.12	17.2
0^{-+}	104	$14 \sim 16$	9.68 ± 0.29	17.3
1^{-+}	107	$13 \sim 19$	9.79 ± 0.22	20.4
2^{-+}	105	$12 \sim 19$	9.93 ± 0.21	21.7
0^{+-}	114	$14 \sim 19$	10.17 ± 0.22	17.6
2^{++}	120	$12 \sim 20$	10.64 ± 0.33	19.7
1^{+-}	123	$10 \sim 21$	10.70 ± 0.53	28.5
1^{++}	134	$13 \sim 27$	11.09 ± 0.60	27.7
0^{++}	137	$13 \sim 31$	11.20 ± 0.48	30.0
0^{--}	142	$14 \sim 25$	11.48 ± 0.75	24.1



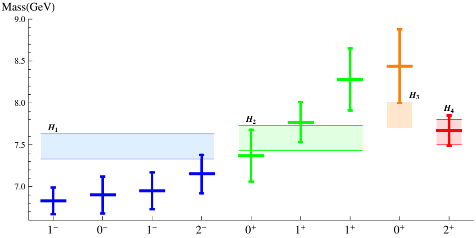
We have confirmed the hybrid supermultiplet structure:

- Lightest hybrid supermultiplet: negative-parity states with $J^{PC} = 1^{--}, (0,1,2)^{-+}$;
- Heavier hybrid supermultiplet: positive-parity states with $J^{PC} = (0,1)^{+-}, (0,1,2)^{++}$;
- Heaviest 0^{--} hybrid may suggest a highly excited gluonic structure.

Mass spectra for $\bar{b}Gc$ open-flavor hybrids

J.Phys. G41 (2014) 025003

Operator	J^P	$s_0(\text{GeV}^2)$	$[M^2_{\text{min}}, M^2_{\text{max}}](\text{GeV}^2)$	$m_X(\text{GeV})$
$\tilde{J}^{(2)}_\mu$	1^-	48	$5.90 \sim 8.80$	6.69 ± 0.13
$\tilde{J}^{(1)}_\mu$	0^-	61	$10.4 \sim 11.5$	6.90 ± 0.17
$J^{(1)}_\mu$	1^-	62	$9.00 \sim 10.7$	6.95 ± 0.16
$J^{(3)}_{\mu\nu}$	2^-	59	$8.00 \sim 10.5$	7.15 ± 0.28
$\tilde{J}^{(2)}_\mu$	0^+	69	$10.9 \sim 12.0$	7.37 ± 0.19
$\tilde{J}^{(3)}_{\mu\nu}$	2^+	66	$8.00 \sim 11.2$	7.67 ± 0.12
$J^{(2)}_\mu$	1^+	70	$5.90 \sim 12.2$	7.78 ± 0.18
$\tilde{J}^{(1)}_\mu$	1^+	74	$9.00 \sim 15.0$	8.21 ± 0.33
$J^{(1)}_\mu$	0^+	79	$10.4 \sim 17.8$	8.43 ± 0.39
$J^{(2)}_\mu$	0^-	76	$10.9 \sim 14.2$	8.48 ± 0.45



The two hybrids with the same J^P have different spin of heavy quarks.

Hybrid decay properties

Selection Rules:

- Kinematically allowed.
- Conversation of $I^G J^{PC}$.
- Heavy quark spin symmetry: the spin of heavy quarks must be the same in process $\bar{Q}GQ \to Q\bar{Q}$+light meson.
- S+P-wave selection rule: hybrids cannot decay into two identical mesons (S+S-wave, P+P-wave).

These typical decay properties can be used to distinguish hybrid states from $c\bar{c}$ and $qc\bar{q}\bar{c}$.

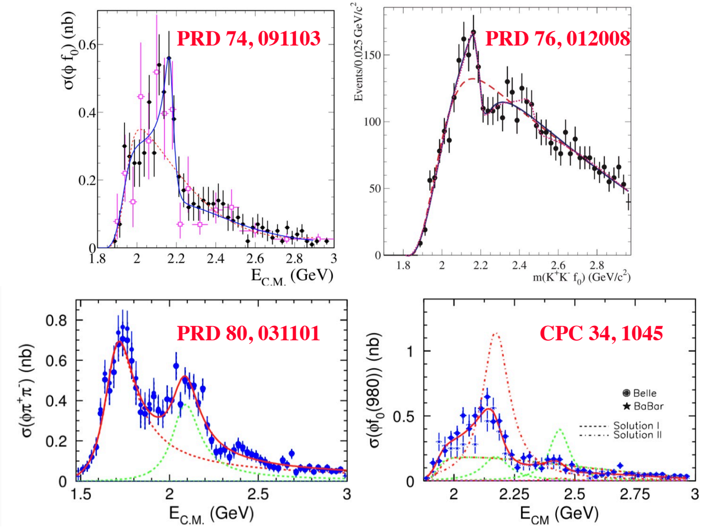
Possible Decay Patterns: $\bar{c}Gc$ charmonium hybrids

$I^G J^{PC}$	$S_{\bar{Q}Q}$	S-wave	P-wave
0^-1^{--}	0	–	–
0^+0^{-+}	1	–	–
0^+1^{-+}	1	–	$J/\psi\omega(782)$
0^+2^{-+}	1	–	$D\bar{D}^*, J/\psi\omega(782)$
0^-0^{+-}	1	–	$J/\psi f_0(600)$
0^+2^{++}	0	–	$D\bar{D}_1, D\bar{D}_2^*, D^*\bar{D}_0^*, D^*\bar{D}_1, D^*\bar{D}_0^*,$
		–	$\eta_c(1S)f_1(1285), \eta_c(1S)f_2(1270)$
0^-1^{+-}	1	$D\bar{D}^*, J/\psi\eta, \psi(2S)\eta, \chi_{c0}(1P)h_1(1170)$	$D\bar{D}_0^*, D\bar{D}_1, D\bar{D}_2^*, D^*\bar{D}_0^*, D^*\bar{D}_2^*, D^*\bar{D}_1$
0^+1^{++}	0	$D\bar{D}^*, D_0^*\bar{D}_1, D_1\bar{D}_2^*,$	$D\bar{D}_0^*, D\bar{D}_1, D\bar{D}_2^*, D^*\bar{D}_0^*, D^*\bar{D}_2^*, D^*\bar{D}_1,$
		–	$\eta_c(1S,2S)f_0(600), \eta_c(1S,2S)f_0(980),$
		–	$\eta_c(1S)f_1(1285), \eta_c(1S)f_2(1270)$
0^+0^{++}	0	$\eta_c(1S,2S)\eta,$	$D\bar{D}_1, D^*\bar{D}_0^*, D^*\bar{D}_1, D^*\bar{D}_2^*, \eta_c(1S,2S)f_1(1285),$
0^-0^{--}		$D\bar{D}_0^*, D^*\bar{D}_1, J/\psi f_1(1285),$	$D\bar{D}^*, D_0^*\bar{D}_1, D_1\bar{D}_2^*, J/\psi\eta, \psi(2S)\eta,$
		$\psi(2S)f_1(1285), \chi_{c1}(1P)\omega(782)$	$\eta_c(1S)\omega(782), \eta_c(2S)\omega(782), \chi_{c(0,1,2)}(1P)h_1(1170)$

- $D^{(*)}\bar{D}_0^*$ and $D^{(*)}\bar{D}_1$ are dominant decay modes!
- Such features are very different from the conventional $c\bar{c}$ states, charmonium-like tetraquarks $qc\bar{q}\bar{c}$ and molecules.
- Such anomalous branching ratios could be understood as a strong hybrid signature!

$\phi(2170)/Y(2175)$

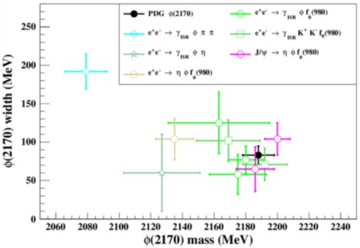
Observed by BaBar in 2006 in the ISR process $e^+e^- \to \phi f_0(980)\gamma$:



$\phi(2170)$

PDG $\phi(2170)$ DECAY MODES

	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	$K^+K^- f_0(980) \to K^+K^-\pi^+\pi^-$	seen
Γ_7	$K^+K^-\pi^0\pi^0$	
Γ_8	$K^+K^- f_0(980) \to K^+K^-\pi^0\pi^0$	seen
Γ_9	$K^{*0}K^{\pm}\pi^{\mp}$	not seen
Γ_{10}	$K^*(892)^0\overline{K}^*(892)^0$	not seen



- **Published experimental information**
  - ✓ **Limited decay modes**
  - ✓ **Inconsistence on mass & width**
- **Theorists explain $\phi(2170)$ as**
  - ✓ **$s\bar{s}g$ hybrid**
  - ✓ **2^3D_1 or 3^3S_1 $s\bar{s}$**
  - ✓ **tetraquark**
  - ✓ **Molecular state $\Lambda\bar{\Lambda}$**
  - ✓ **$\phi f_0(980)$ resonance with FSI**
  - ✓ **Three body system ϕKK**
  - ✓ **Estimated or ruled out: not yet**
- **aspects of $\phi(2170)$ are still not fully understood.**

3

Taken from Yan Wenbiao's talk in 2018

QCD Gaussian sum-rules for the vector $\bar{s}gs$ hybrid

QCD Gaussian sum-rules:

$$G^{\mathrm{QCD}}(\hat{s},\,\tau,\,s_0)\equiv\frac{1}{\sqrt{4\pi\tau}}\int_0^{s_0}e^{-\frac{(\hat{s}-t)^2}{4\tau}}\frac{1}{\pi}\mathrm{Im}\Pi^{\mathrm{QCD}}(t)dt$$

In a double-narrow resonance model

$$\rho^{\mathrm{had}}(t)=f_1^2\delta\left(t-m_1^2\right)+f_2^2\delta\left(t-m_2^2\right)\,.$$

The normalized GSRs

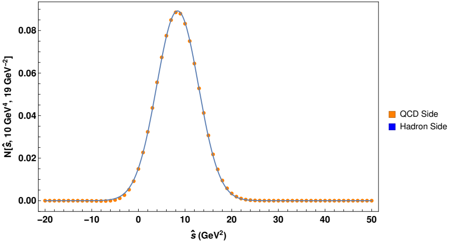
$$N^{\mathrm{had}}\left(\hat{s},\,\tau\right)=\frac{1}{\sqrt{4\pi\tau}}\left(re^{-\frac{(\hat{s}-m_1^2)^2}{4\tau}}+(1-r)e^{-\frac{(\hat{s}-m_2^2)^2}{4\tau}}\right),$$

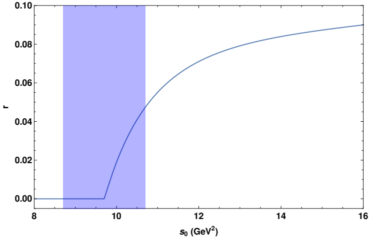
where the normalized couplings are defined as

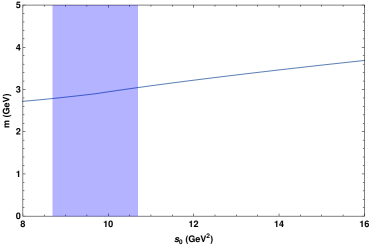
$$r=\frac{f_1^2}{f_1^2+f_2^2}\,,1-r=\frac{f_2^2}{f_1^2+f_2^2}\,,0\leq r\leq 1.$$

QCD Gaussian sum-rules for the vector $\bar{s}gs$ hybrid

arXiv:1905.12779



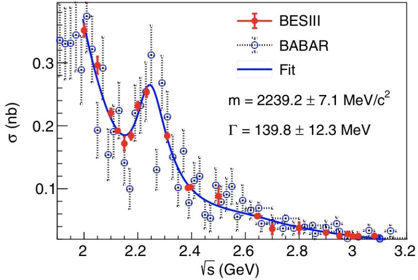


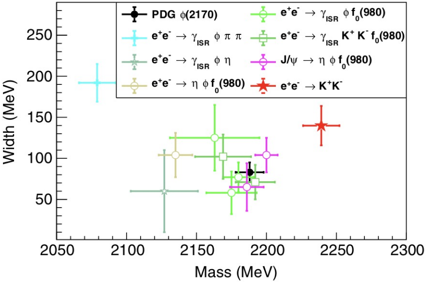


No evidence for a significant strangeonium hybrid component of the $\phi(2170)/Y(2175)$!

BESIII's new measurment in $e^+e^- \to K^+K^-$

Phys.Rev. D99 (2019) no.3, 032001





- **If this structure can be identified with the $\phi(2170)$**, the observed KK decay mode would **disfavour** the $3\,^3S_1$ $s\bar{s}$ meson, strangeonium hybrid, and $ss\bar{s}\bar{s}$ tetraquark interpretations.
- **If this structure can not be identified with the $\phi(2170)$**, the lack of KK decay mode would **disfavour** the $2\,^3D_1$ strangeonium meson and $\Lambda\bar{\Lambda}$ interpretations.
- Further experimental and theoretical studies are needed.

Summary

- We have calculated the mass spectra for the $\bar{c}Gc$, $\bar{b}Gb$ and $\bar{b}Gc$ hybrid states.
- We confirm the supermultiplet structure of the hybrid spectrum.
- Pure hybrid interpretation of $Y(4260)$ seems to be precluded.
- $D^{(*)}\bar{D}_0^*$, $D^{(*)}\bar{D}_1$ and $D_s^{(*)}\bar{D}_{s0}^*$, $D_s^{(*)}\bar{D}_{s1}$ are dominant decay modes for $\bar{c}Gc$ hybrids. $B^{(*)}\bar{B}_1$ are dominant decay modes for $\bar{b}Gb$ hybrids. $B^{(*)}D^{(*)}$ are preferred decay modes for the $\bar{b}Gc$ hybrids.
- Such anomalous branching ratios in these different channels could be understood as a strong hybrid signature!
- The strangeonium hybrid interpretation for $\phi(2170)/Y(2175)$ is not supported in our QSR calculation.

Thank you for your attention!