

Charmoniumlike States at BESII

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On Behalf of BESIII Collaboration

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• Quark Model [1964 by Gell-Mann and Zweig]



• Exotic hadrons:







A SCHEMATIC MODEL OF BARYONS AND MESONS *

M. GELL-MANN

Lowest Configuration!



Received 4 January 1964

California Institute of Technology, Pasadena, California

anti-triplet as anti-quarks q. Baryons can now be constructed from quarks by using the combinations (qqq), $(qqqq\bar{q})$, etc., while mesons are made out of $(q\bar{q})$, $(qq\bar{q}\bar{q})$, etc. It is assuming that the lowest baryon configuration (qqq) gives just the representations 1, 8, and 10 that have been observed, while the lowest meson configuration $(q \bar{q})$ similarly gives just 1 and 8.





Glueball







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Beijing Electron Positron Collider II and BESIII







Solenoid Magnet: 0.9/1.0 T

MUC $\sigma_{R\Phi}$: 2 cm



TOF

σ_T:80 ps 110 ps (60 ps)

MDC

dE/dx: 6% σ_p /p: 0.5% at 1GeV/c_

EMC

 $\Delta E/E$: at 1GeV 2.5% 5.0% σ_{z} : 0.6 cm/ \sqrt{E}

BESIII Data Samples



Can measure $\sigma[e^+e^- \rightarrow h_i]$ (CS) with high precision using direct e^+e^- annihilation data at BESIII \Rightarrow Y states



BESIII Data Samples



Can measure $\sigma[e^+e^- \rightarrow h_i]$ (CS) with high precision using direct e^+e^- annihilation data at BESIII \Rightarrow Y states



Discovery of Y States

- - Confirmed by CLEO and Belle
 - \blacksquare Mass > 4 GeV, above $D\overline{D}$ threshold
 - Solution Served in inclusive hadron cross section
 - Not observed in open charm pair cross section



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Y(4230) in Open Charm Process



| | | | | \downarrow | | | | | |
|-----------------------------|---------------------|-----------------|-------------------|----------------------|---------------|----------------|---------------------|-------------------------------|---------------------------------|
| $\Gamma_{ee}B(\mathrm{eV})$ | $\pi^+\pi^- J/\psi$ | $\pi^+\pi^-h_c$ | $\omega\chi_{c0}$ | $\pi^+\pi^-\psi(2S)$ | $\eta J/\psi$ | K^+K^-J/ψ | $\pi^+\pi^- J/\psi$ | $\pi^{\pm}(D\bar{D}^*)^{\mp}$ | $\pi^{\pm}(D^*\bar{D}^*)^{\mp}$ |
| Min | 1.7[0.2] | 4.6[2.9] | 2.5[0.2] | 0.02[0.01] | 4.0[0.5] | 0.29[0.10] | 0.22[0.25] | 8.6[1.6] | 4.8[0.9] |
| Max | 14.6[1.2] | | | 1.64[0.83] | 11.9[1.1] | 0.42[0.15] | 0.53[0.15] | 77.4[10.1] | 22.4[9.0] |

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Mass and width from different process



determined with BW parameterization consider possible interference



Measurement of $\sigma [e^+e^-]$

- The first evidence of $e^+e^- \rightarrow \eta h_c$ was found by
- The process $e^+e^- \rightarrow \eta h_c$ was observed for the resonance around 4.2 GeV was observed PR
- New data (15 fb⁻¹) between \sqrt{s} =4.13 to 4.6 GeV has been collected by BESIII



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$$\rightarrow \eta h_c$$
]



y CLEO at
$$\sqrt{s}$$
=4.17 GeV [3 σ] PRL 107, 041803 (2011)
e first time at \sqrt{s} =4.226 GeV by BESIII, a hint of a



Measurement of $\sigma[e^+e^-$



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4.85

Measurement of $\sigma[e^+e^-$



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$$\rightarrow \eta h_{C}$$

$$\Rightarrow \eta h_{C}$$

$$\Rightarrow \sigma^{dressed} = |BW_{1} + BW_{3}e^{i\phi}|^{2} + |BW_{3}|^{2}$$

$$\Rightarrow \sigma^{dressed} = |BW_{1} + |BW_{3} +$$



Observation of Y(4500)



 $M = 4484.7 \pm 13.3 \pm 24.1 \text{ MeV}/c^2$ $\Gamma = 111.1 \pm 30.1 \pm 15.2 \text{ MeV}$

- A 5S-4D mixing state (J. Z. Wang et al. PRD99, 114003 (2019) [Width 2σ larger]
- A heavy-antiheavy hadronic molecule (X. K. Dong et al. Prog. Phys. 41, 65 (2021))







 $M = 4469.1 \pm 26.2 \pm 3.6 \text{ MeV}/c^2$, $\Gamma = 246.3 \pm 36.7 \pm 9.4 \text{ MeV}$

- A $cs\bar{c}\bar{s}$ state from LQCD (T. W. Chiu et al. PRD73, 094510) (2006))
- Solution \cong Assuming structures in *KKJ*/ ψ and πD^*D^* are the same, $B[Y \rightarrow \pi D^* \overline{D}^*]/B[Y \rightarrow K \overline{K} J/\psi] \sim 10^2$, inconsistent with hidden-strangeness tetraquark nature (F. Z. Peng et al. PRD107, 016001 (2023))

New Information from $\sigma[e^+e^- \rightarrow \omega\chi_{c1,2}]$

- New data (11.0 fb⁻¹) between \sqrt{s} =4.3 to 4.95 GeV has been collected by BESIII





• The process $e^+e^- \rightarrow \omega \chi_{c1,2}$ was observed for the first time at $\sqrt{s}=4.6$ GeV or 4.42 GeV by BESIII PRD 93, 011102(R) (2016)



- $M = 4413.6 \pm 9.0 \pm 0.8 \text{ MeV}/c^2$ $\Gamma = 110.5 \pm 15.0 \pm 2.9 \text{ MeV}$
- Significance over PHSP: 10.7σ
- Parameters consistent with $\psi(4415)$, implying the existence of $\psi(4415) \rightarrow \omega \chi_{c2}$





a(Ca)/

 $\alpha(C \alpha)/\lambda$







Production Properties of $D_{s1}(2536)$ **and** $D_{s2}^*(2573)$







• 15 data samples corresponding to a total integrated lum. of 6.6 fb⁻¹ from \sqrt{s} =4.53 to 4.95 GeV



• Fit with $\sigma = |BW_0(\sqrt{s}) + BW_1(\sqrt{s})e^{i\phi_1}|^2$

- In both processes, the first resonance is around 4.6 GeV, with a width of 50 MeV
- Second strucutre is around 4.75 GeV with a width of 25 MeV in $D_s^+ D_{s1}(2536)^-$, around 4.72 GeV with a width of 50 MeV in $D_{s}^{+}D_{s2}^{*}(2573)^{-}$

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Precise Measurement of Open Cham Cross Section





Precise Measurement of $\sigma[e^+e^- \rightarrow D_s^+D_s^-]$



- (E. Eichten, K. Gottfried, T. Kinoshita, K. D. Lane, T. M. Yan, PRD21, 203 (1980))
- Maximum cross section around 4.02 GeV higher than previous studies using ISR method
- A narrow dip around 4.23 GeV, close to $D_s^{*+}D_s^{*-}$ threshold
- Constant ratio to $D_s^{*+}D_s^{*-}$, where a structure around 4.78 GeV is observed

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• 138 data samples corresponding to a total integrated lum. of 22.9 fb⁻¹ from \sqrt{s} =3.94 to 4.95 GeV

Cross section peaks above the threshold, implies the presence of a strong coupled channel effect



Precise Measurement of $\sigma[e^+e^- \rightarrow D_s^+D_s^-]$



- Constant ratio to $D_s^{*+}D_s^{*-}$, where a structure around 4.78 GeV is observed

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• 138 data samples corresponding to a total integrated lum. of 22.9 fb⁻¹ from \sqrt{s} =3.94 to 4.95 GeV



Precise Measurement of $\sigma[e^+e^- \rightarrow DD]$

Partial reconstruction



PRL133, 081901 (2024)





• 150 data samples corresponding to a total integrated lum. of 20 fb⁻¹ from \sqrt{s} =3.8 to 4.95 GeV

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PRL133, 081901 (2024)





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Four-Quark Matter: Z_c



Seen in both charged and neutral modes



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Strange Partner of Z_c States: Z_{cs}



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C-even States

- Small production rate in radiative transition process
- Radiative and hadronic transitions to X(3872) are observed at BESIII
- Several decay modes of X(3872) have been searched: $\pi^0 \chi_{c1}$ [observed], $\pi\pi\chi_{c0,1,2}, \pi\chi_{c0}, \pi\pi\eta, \gamma\psi_2(3823)$
- Found evidence of X(3915)/X(3960) [$\omega J/\psi$ mode], no obvious signal for X(4140), X(4274), X(4500) [$\phi J/\psi$ mode], no evidence of X₂(4013) $[D\bar{D} \text{ mode}]$









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Line Shape of X(3872)



- * Effects of the couple-channels and the off-shell D^{*0} are included in the parameterization
- * Line shape mass: $M_X = (3871.63 \pm 0.13^{+0.06}_{-0.05}) \text{ MeV}$
- Weinberg's compositeness: Z=1 pure elemental state; Z=0 -pure bound state

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| | | | | Bas |
|----------------------|-----------------------------------|----------------------------------|----------------------------------|----------------|
| Pa | rameters | BESIII | LHCb | 19.8 |
| | g | $0.16 \pm 0.010^{+1.12}_{-0.11}$ | $0.108 \pm 0.003^{+0}_{-0}$ |).005).006 |
| Re | [EI] (MeV) | $7.04 \pm 0.15^{+0.07}_{-0.08}$ | 7.10 | |
| Im | [EI] (MeV) | $-0.19 \pm 0.08^{+0.14}_{-0.19}$ | -0.13 | |
| $\Gamma[\pi^+\pi^-]$ | $J/\psi]/\Gamma[D^0\bar{D}^{*0}]$ | $0.05 \pm 0.01^{+0.01}_{-0.02}$ | 0.11 ± 0.03 | |
| FW | HM (MeV) | $0.44_{-0.35-0.25}^{+0.13+0.38}$ | $0.22^{+0.06+0.25}_{-0.08-0.17}$ | 5 7 |
| | Z | 0.18 | 0.15 (0.33) | |



- Dedicated scan sample around the resonance



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Summary

- Benefit from the fine scan data samples collected between $\sqrt{s}=3.8$ to 4.95 GeV, good performance of BEPCII and BESIII, the properties of charmonium and charmoniumlike states have been studied
 - Y(4260) has fine structure, the lower one Y(4230) is observed in more than 10 decay modes, including open charm modes Solution Discovered new charmonium-like states Y(4500) and Y(4710)/Y(4790)

 - In the cross-section line shapes are very complicated, more sophisticate d analysis may determine the pole positions of these states better and help to understand their nature
 - \bigcirc Observed four-quark matter Z_c and Z_{cs} states, need to search for partners to establish the spectroscopy
 - Decay and production properties of C-even states have been investigated using clean samples
 - New production mechanism of C-even state has been found, opens a new avenue for study of hadrons
- BEPCII is upgrading, increase the luminosity at \sqrt{s} =4.7 GeV by a factor of 3, and extend the \sqrt{s} up to 5.6 GeV starting from 2028, more exciting results are expected!



Thank You!





60 復旦大學 20 BESIII (2022). $_{18}$ + This work — Fit result $D_{s}^{*} D_{s}^{*-}$ 600 ····· Y(4500) ····· Y(4710) Y(4500) K^+K^-J/ψ (qd) $> 6\sigma$ *Y*(4710)

60

80

200

4.2

4.4

4.6

4.8

s(GeV)

^₄.8

^{1.6}4.6 5

√s(GeV)

• Y(4626) observed in $e^+e^{40} \rightarrow \gamma_{\text{ISR}}D_s^+D_{s1}(2536)^-$, and evidence of Y(4620) in $e^+e^- \rightarrow \gamma_{\text{ISR}}D_s^+D_{s2}^*(2573)^-$ (qd)₀ 20 (qd) 20 26 10 10

X(3872) Decay Property





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| Ratio | 90% C.L Upper Limit |
|--|---------------------|
| $\frac{\mathcal{B}(X(3872) \rightarrow \pi^0 \chi_{c0})}{\mathcal{B}(X(3872) \rightarrow \pi^+ \pi^- J/\psi)}$ | 3.6 |
| $\frac{\mathcal{B}(X(3872) \rightarrow \pi^0 \chi_{c0})}{\mathcal{B}(X(3872) \rightarrow \pi^0 \chi_{c1})}$ | 4.5 |
| $\frac{\mathcal{B}(X(3872) \rightarrow \pi^+ \pi^- \chi_{c0})}{\mathcal{B}(X(3872) \rightarrow \pi^+ \pi^- J/\psi)}$ | 0.56 |
| $\left \frac{\mathcal{B}(X(3872)\to\pi^0\pi^0\chi_{c0})}{\mathcal{B}(X(3872)\to\pi^+\pi^-J/\psi)}\right $ | 1.7 |

PRD 105, 072009 (2022)

 $Z_{cs}' in K^+ D^{*0} D_s^{*-}$



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Update of $\eta\psi(3686)$ and Search for X(3872)

* 8.9 fb⁻¹ data sample from 4.288 to 4.951 GeV



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Future Data Samples

Table 7.1. List of data samples collected by BESIII/BEPCII up to 2019, and the proposed samples most column shows the number of required data taking days with the current (T_C) and upgraded (\int_{C} implementation and beam current increase.

| Energy | Physics motivations | = |
|--------------------|--|------|
| 1.8 - 2.0 GeV | R values Nucleon cross-sections | |
| 2.0 - 3.1 GeV | R values Cross-sections | Fine |
| J/ψ peak | Light hadron & Glueball J/ψ decays | |
| ψ (3686) peak | Light hadron & Glueball Charmonium decays | 0 |
| $\psi(3770)$ peak | D^0/D^{\pm} decays | |
| 3.8 - 4.6 GeV | R values XYZ/Open charm | Fine |
| 4.180 GeV | D_s decay XYZ /Open charm | |
| 4.0 - 4.6 GeV | XYZ/Open charm Higher charmonia cross-sections | 16 |
| 4.6 - 4.9 GeV | Charmed baryon/XYZ cross-sections | |
| 4.74 GeV | $\Sigma_c^+ \bar{\Lambda}_c^-$ cross-section | |
| 4.91 GeV | $\Sigma_c \overline{\Sigma}_c$ cross-section | |
| 4.95 GeV | Ξ_c decays | |



