Mass And Possible Quantum Numbers of $X(6900)$

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Various faces of QCD

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Basic Information

- Mass of a charm quark ≈ 1.27 GeV
- $J/\Psi = 3.0969$ GeV
- $\eta_c = 2.9839$ GeV

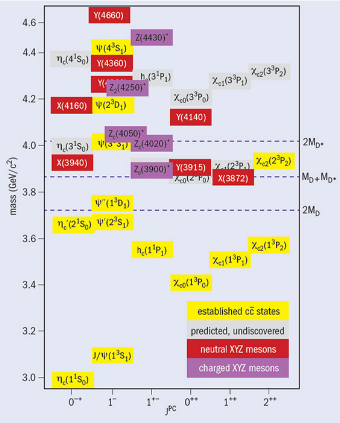


Figure: Charmonium spectrum. Source: Front. Phys. 10 101401.

- Introduction of the problem
- Method of solving the problem
- Discussion of the results

The discovery of X(6900)

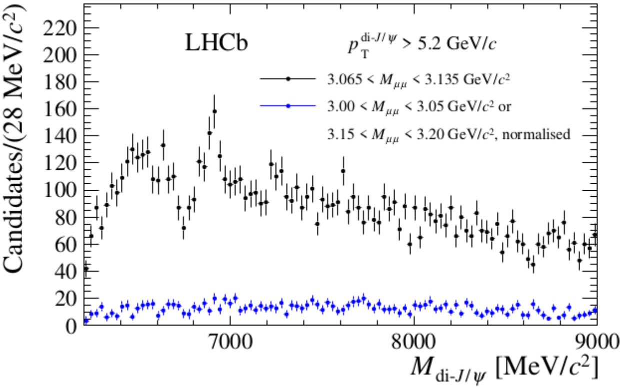
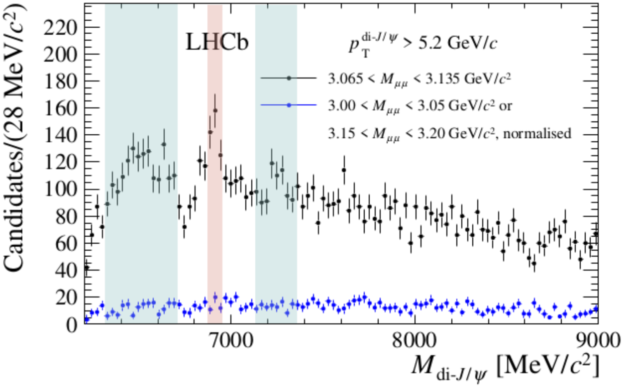


Figure: Invariant mass spectrum of J/ψ-pair candidates.
Source: LHCb-PAPER-2020-011

The discovery of X(6900)



Exotic Hadrons

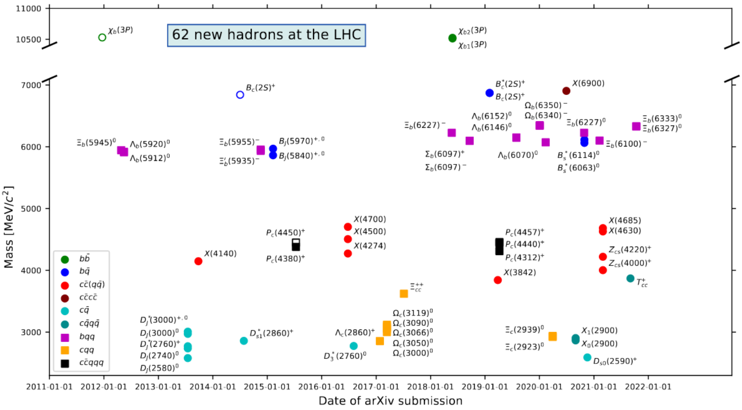


Figure: New hadrons by the date of their discovery. Source: LHCb-PUB-2022-013

All-charm Tetraquark

- Quark content: $cc\bar{c}\bar{c}$
- Fully heavy
- Exotic meson
- Known mass $\approx$ 6.87 GeV

Quantum numbers for mesons:

$$J^{PC}$$

- $J = L + S$
- $P = (-1)^{L+1}$
- $C = (-1)^{L+S}$

The Problem

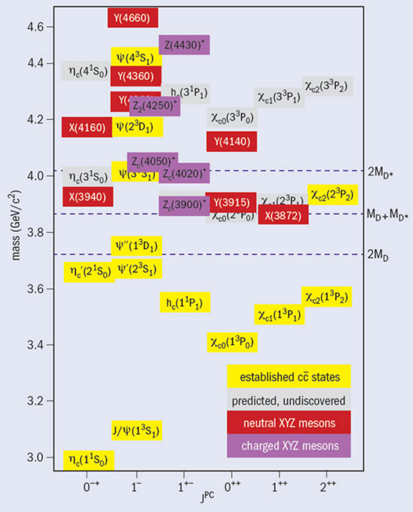
- What are the quantum numbers of $X(6900)$?
- Why the most prominent resonance has such a high mass?
- What are the other visible structures?

My attempt:

arXiv:2309.04794, "All-charm tetraquark mass and possible quantum numbers of X(6900)"

The Solution

- Solutions of Schrödinger Equation for charmonium spectrum
- Construction of all-charm tetraquark structures and the tetraquark spectrum
- Discussion of the results

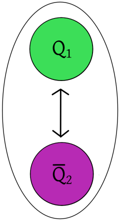


Solving Schrödinger Equation

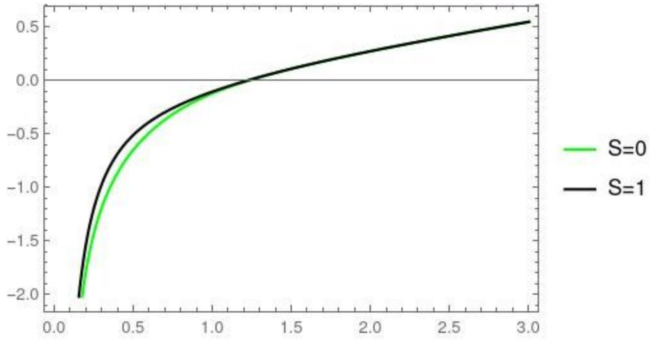
- We are using the Runge-Kutta method: Int. J. Mod. Phys. C 10, 607–620 (1999)
- The Hamiltonian is meant to describe bound states: Source: Phys. Rept. 200, 127–240 (1991)

The Hamiltonian:

$$H = m_1 + m_2 + \frac{1}{2\mu_{12}}\Big(-\frac{d^2}{dr^2} + \frac{l(l+1)}{r^2}\Big) + V_{12}^{G} + V_{12}^{SS} + V_{12}^{LS} + V_{12}^{T}$$



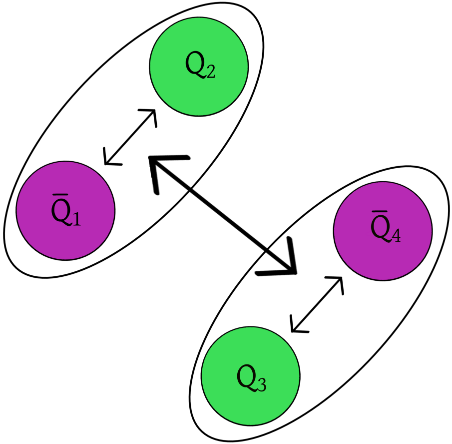
The Strong Interaction



One gluon-exchange:

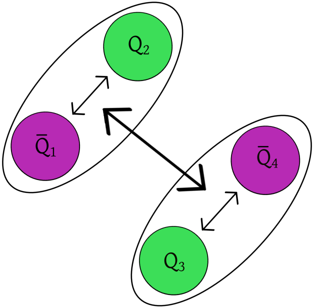
$$V_{ij}^{G}(r_{ij}) = \kappa_s \frac{\alpha_s}{r_{12}} + \sigma r_{12}$$

The Tetraquark Structure



- Quark-antiquark: $3 \otimes \bar{3} = 1 \oplus 8$
- Quark-quark: $3 \otimes 3 = \bar{3} \oplus 6$

The Tetraquark Structure



- Meson-meson: $8 \otimes 8 = 1 \oplus 8 \oplus 8 \oplus 10 \oplus \overline{10} \oplus 27$
- Diquark-antidiquark:
  - $6 \otimes \bar{6} = 1 \oplus 8 \oplus 27$
  - $3 \otimes \bar{3} = 1 \oplus 8$

Reference:

- R. Jaffe: Phys. Rev. D 15, 267 (1977)

Results

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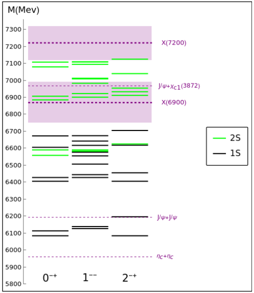
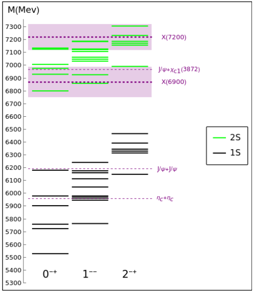
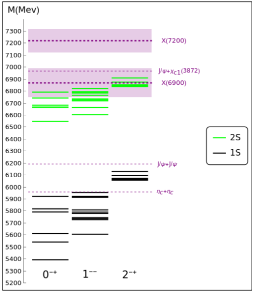
Triplet-antitriplet:



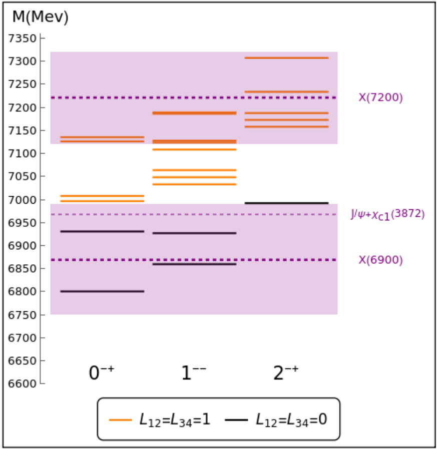
Sextet-antisextet:



Octet-octet:



Results



All 2S states for the sextet-antisextet structure.

Wave function

$$|D_6(1^3S_1)\rangle = |Y_0^0 \times X_\sigma^{1,1} \times \; X_c^6 \times X_f\rangle$$

- Y_0^0 - symmetric
- X_c^6 - colour wave function - symmetric
- $|X_{1,1}^\sigma\rangle = |\uparrow\uparrow\rangle$
- $|X_f\rangle = |cc\rangle$

Possible answers

- The most prominent resonances: sextet-antisextet
- Possible quantum numbers: 0^{-+} or 1^{--}
- Lack of prominent ground state: effect of the Pauli exclusion principle

Thank you for your attention.
Special thanks to my supervisor, prof. David Blaschke.

Recommended literature:

- A. Ali, L. Maiani, A.D. Polosa, "Multiquark Hadrons"
- D. Blaschke, K. Redlich, C. Sasaki and L. Turko, Understanding the Origin of Matter: Perspectives in Quantum Chromodynamics"

Backup: Spin Dependent Terms

$$V_{ij}^{SS}(r_{ij}) = -\frac{8\kappa_s\alpha_s\pi}{3m^2}\left(\frac{\sigma_{ss}}{\sqrt{\pi}}\right)^3 e^{-\sigma_{ss}^2 r_{ij}^2} S_i S_j$$

$$V_{ij}^{LS}(r_{ij}) = \left[-\frac{3\kappa_s\alpha_s}{2m^2}\frac{1}{r_{ij}^3} - \frac{b}{2m^2}\frac{1}{r_{ij}}\right] LS$$

$$V_{ij}^{T}(r_{ij}) = -\frac{12\kappa_s\alpha_s}{4m^2}\frac{1}{r_{ij}^3}\left(\frac{(S_i r_{ij})(S_j r_{ij})}{r_{ij}^2} - \frac{S_i S_j}{3}\right)$$

Backup: Exotic Hadron Types

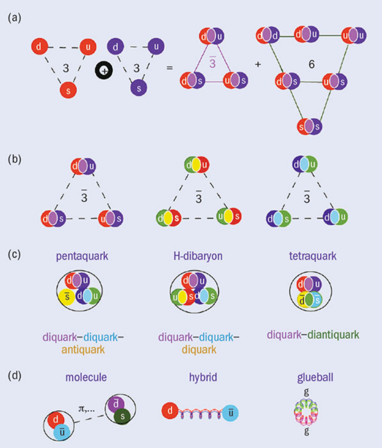


Figure: Diquarks and possible exotic hadrons. Source: Front. Phys. 10 101401

Backup: Atlas results

Figure: Fitted mass spectra in the di-$J\Psi$ (left) and $J/\Psi + \Psi(2S)$ (right) channel. Gathering and fitting was performed by the Atlas collaboration. Source: ATLAS Notes:ATLAS-CONF-2022-040