The all-charm tetraquark and its contribution to two photon processes

Author: Panagiotis Kalamidas

Supervisor: Prof. Dr. Marc Vanderhaeghen

Institut für Kernphysik
Johannes Gutenberg-Universität

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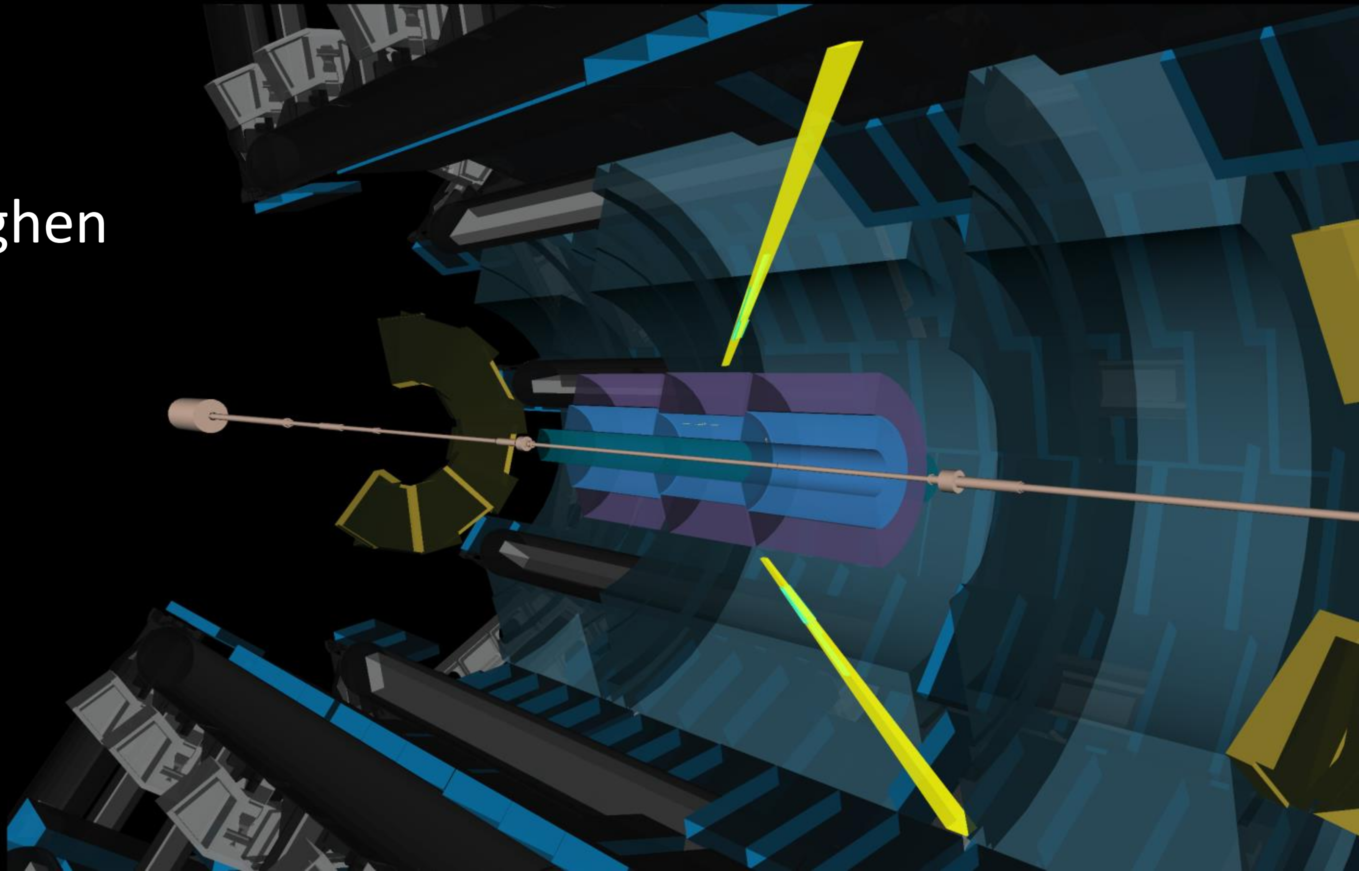
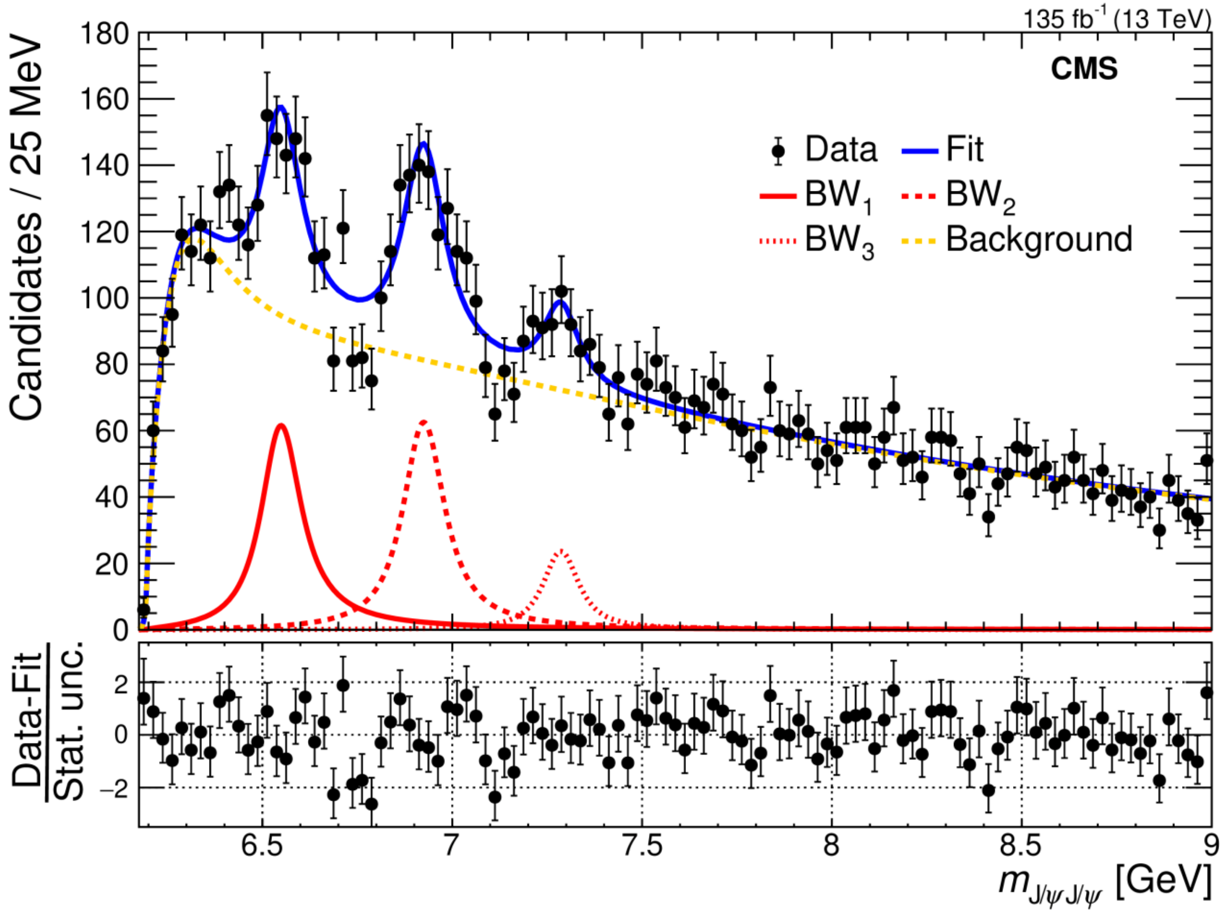


Illustration can be found in [1].

Motivation

- Discovery of new exotic states in di-J/ψ, J/ψ, Ψ(2S) spectra.
- X (6900) in di-J/ψ spectrum.
- Considered a $cc\bar{c}\bar{c}$ state.
- Light by light scattering excess compared to SM in the region 5-10 GeV.



Di-J/ψ invariant mass spectrum. [2]

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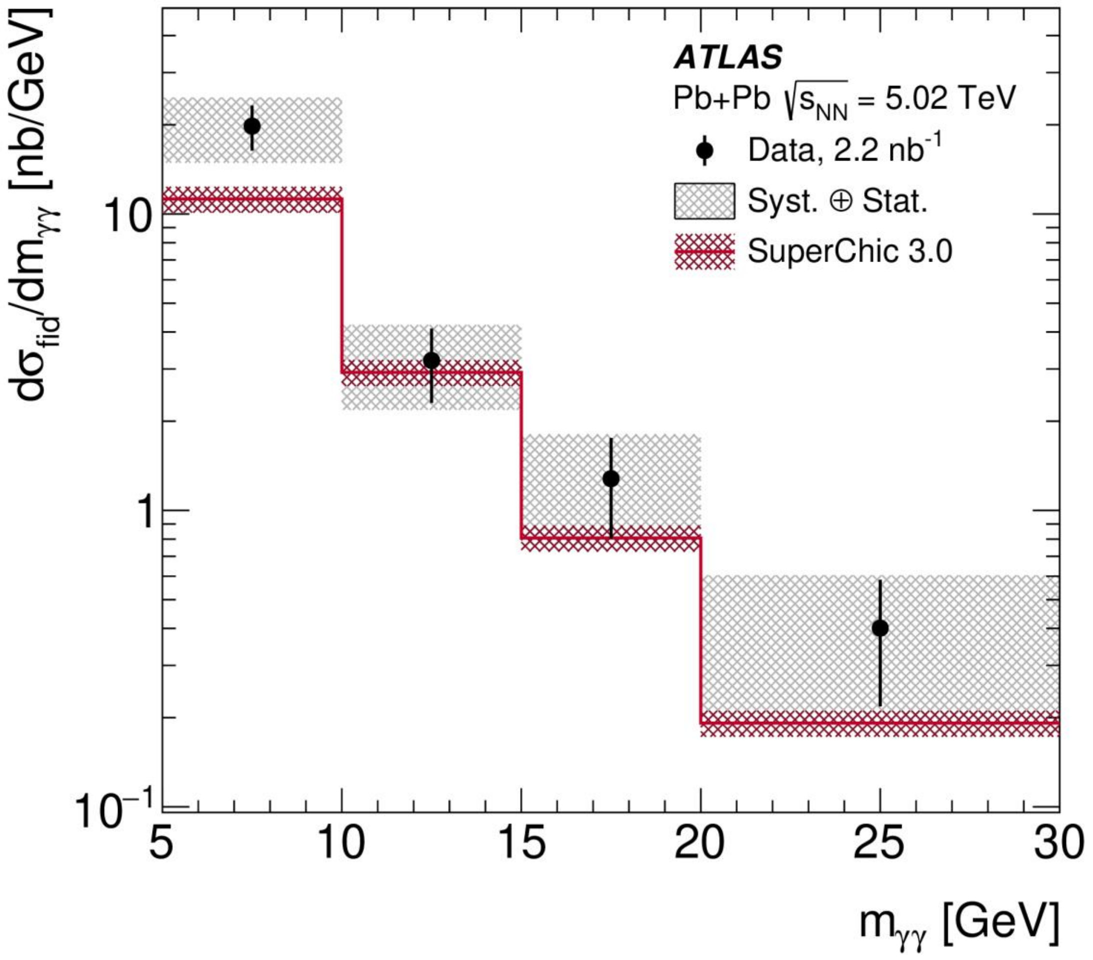
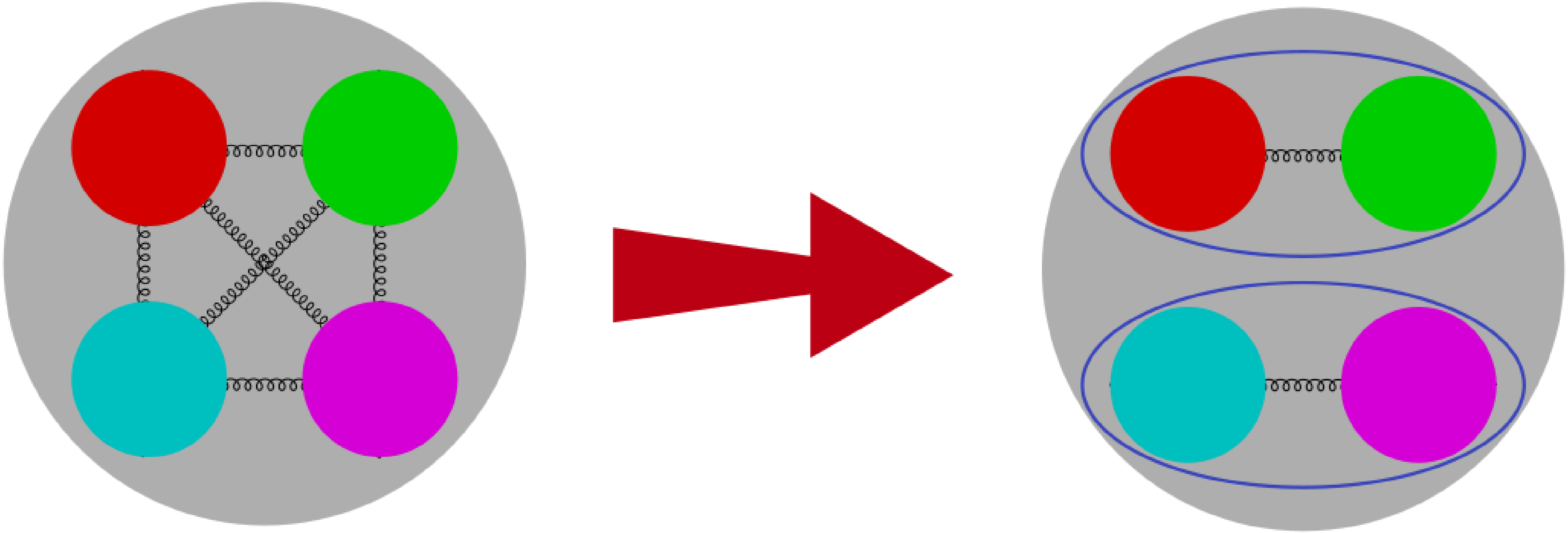
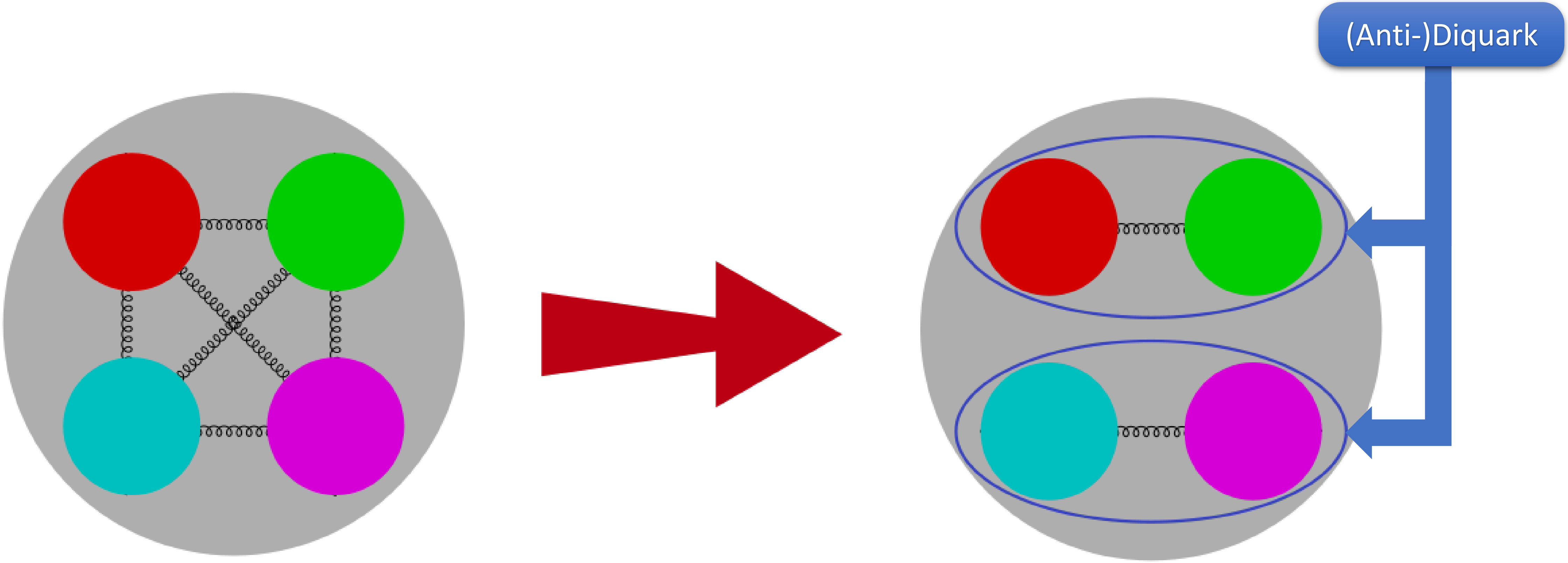


Differential fiducial cross section of γγ→γγ for diphoton invariant mass. [3]



Complicated four body problem

Three two body problems



Complicated four body problem

Three two body problems

Model Parameters

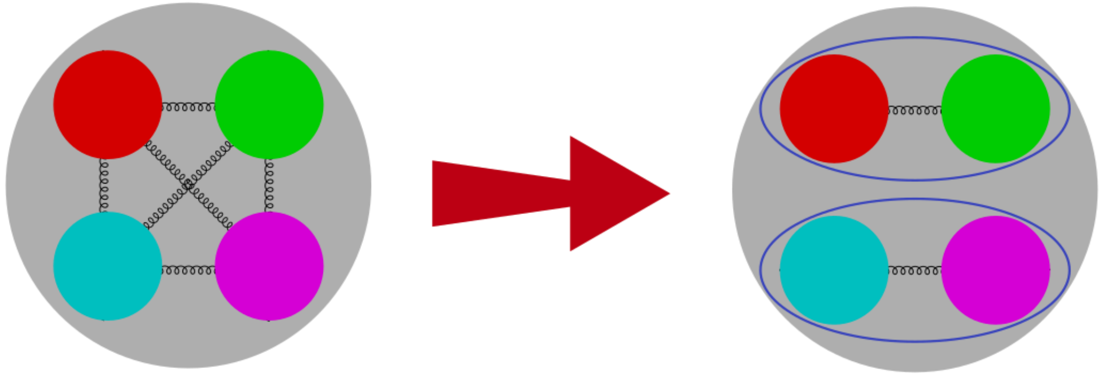
- SU(3) colour symmetry

$$3 \otimes 3 = \overline{3} \oplus 6\,,\ \overline{3} \otimes 3 = 8 \oplus 1$$

- Cornell Potential [4]

$$\mathcal{V} = \kappa_s \frac{\alpha_s}{r} + br + V_{SS} + V_{LS} + V_T$$

- Surprisingly accurate for $c\bar{c}$ spectrum.
- Extend to all charm tetraquark.



Diquark Picture

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More attractive one gluon exchange

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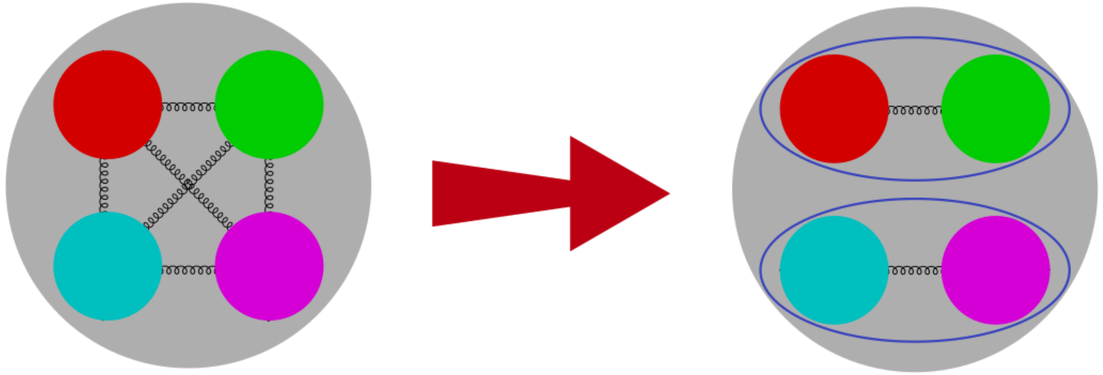


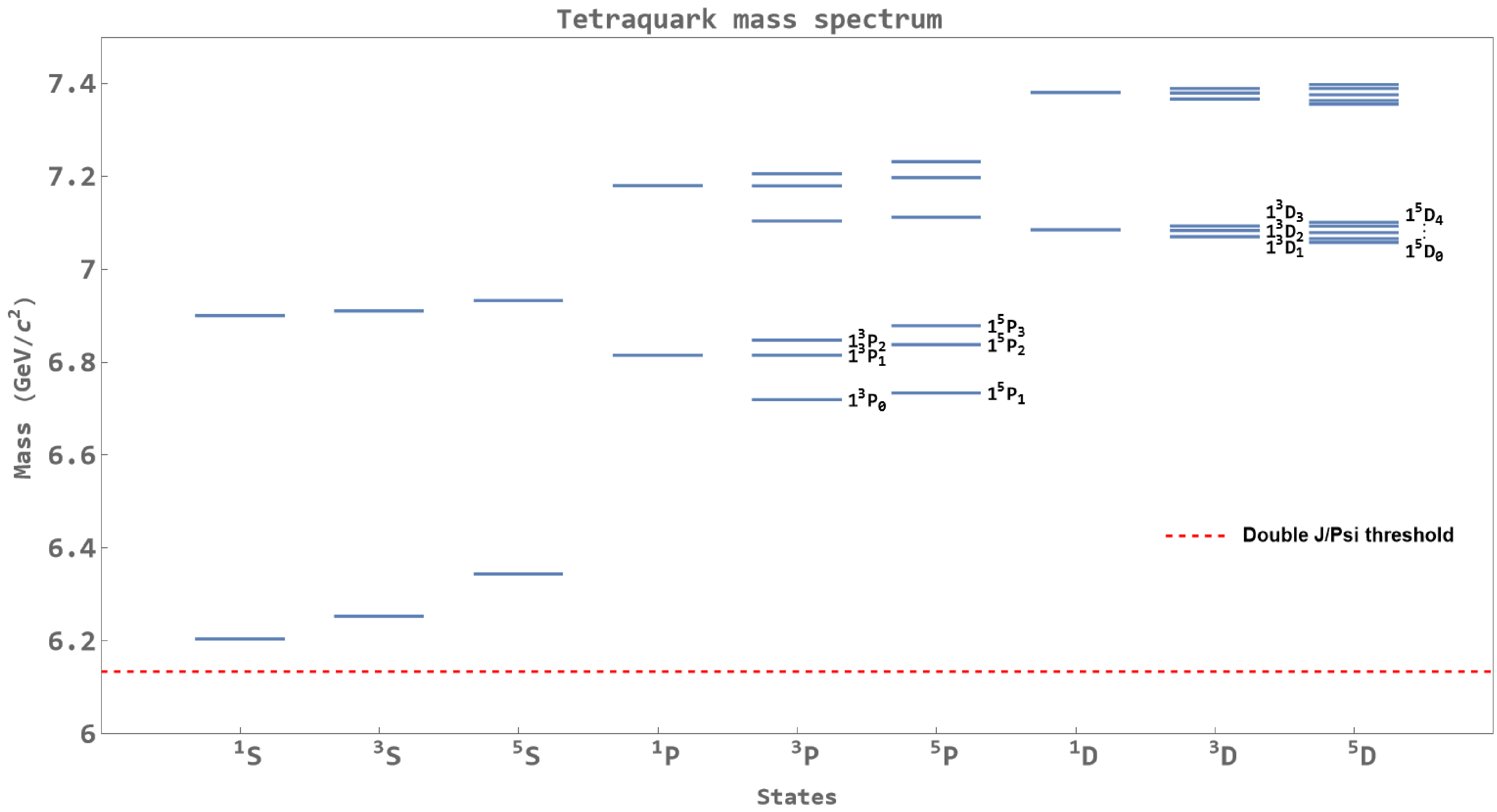
Diquark Picture

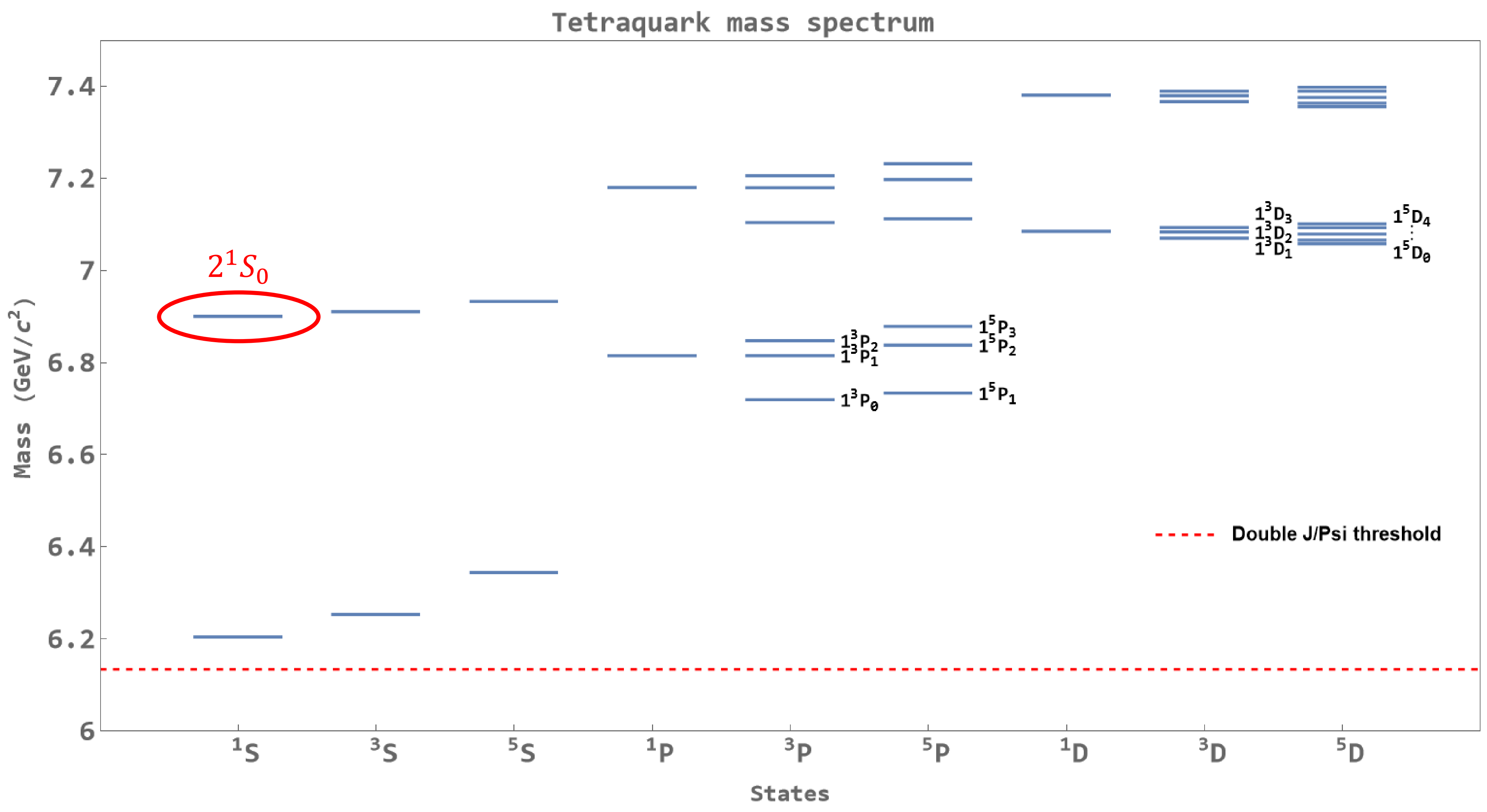
Fitting of states

- Find parameters from c$\bar{c}$ fit to experiment.
- Use ground state diquarks.
- Possible identifications of X (6900) are 0^{++}, 2^{++}, 0^{-+} etc.
- Free parameter is $M_{diquark}$.

We use the 2^1S_0 state in this case.

- In this case $M_{diquark} = 3.2590$ GeV.
- Solve Schroedinger equation and get $M_{tetraquark}$ and numeric evaluation of $R_{n(ls)j}(r)$.


Tetraquark mass spectrum
Mass (GeV/c^2)
7.4
7.2
7
6.8
6.6
6.4
6.2
6
States
1S
3S
5S
1P
3P
5P
1D
3D
5D
1^3D_3
1^3D_2
1^3D_1
1^5D_4
1^5D_0
1^3P_2
1^3P_1
1^3P_0
1^5P_3
1^5P_2
1^5P_1
Double J/Psi threshold



Tetraquark mass spectrum
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2^1S_0
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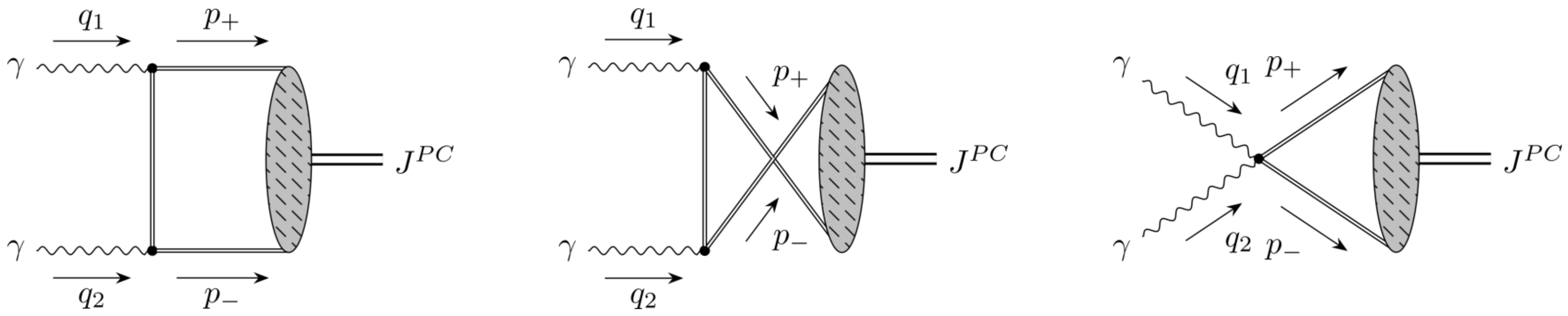
1^3D_1
1^5D_4
1^5D_0
Double J/Psi threshold
^1S
^3S
^5S
^1P
^3P
^5P
^1D
^3D
^5D
States

Two Photon Decay

- Diquarks are spin 1, coupling like SM W boson.



- Helicity amplitudes $\mathcal{M}^{++}_{\lambda_1\lambda_2}$ and $\mathcal{M}^{+-}_{\lambda_1\lambda_2}$ (due to symmetries)

  $\Longrightarrow \sigma_{\Lambda=0}$ and $\sigma_{\Lambda=2}$ calculated

- Convolution integral

$$\langle n(ls)jm_j|\mathcal{M}^{++}_{\lambda_+\lambda_-}|\overrightarrow{q}\rangle = \int \frac{d^3\overrightarrow{p}}{(2\pi)^3}\tilde{\Psi}_{n(ls)jm_j}(\overrightarrow{p})\left[\frac{2M_t}{2E(\overrightarrow{p})2E(\overrightarrow{p})}\right]^{1/2}\langle\overrightarrow{p}|\mathcal{M}^{++}_{\lambda_+\lambda_-}|\overrightarrow{q}\rangle$$

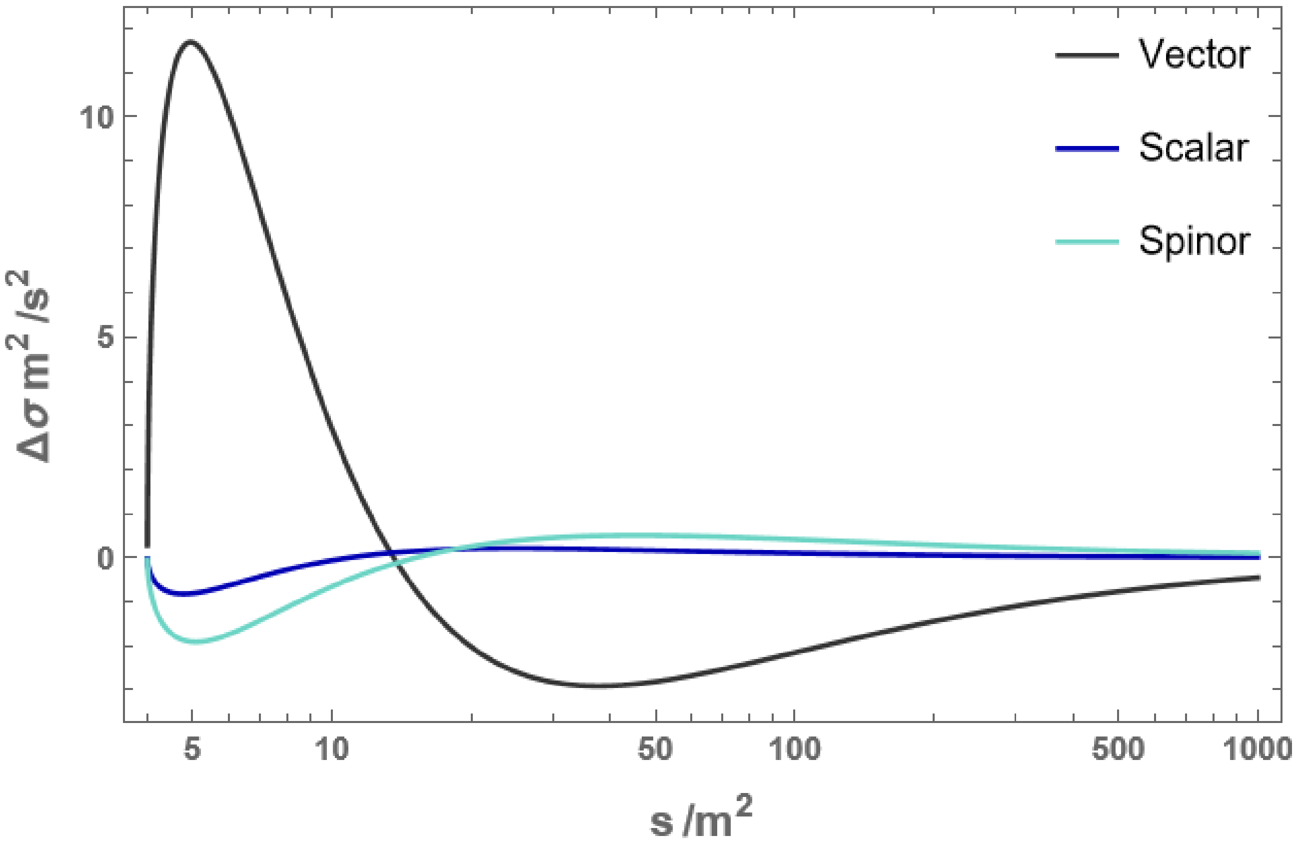
Decay Widths

- $\Delta\sigma = \sigma_2 - \sigma_0$.
- Different spins, different behaviour.
- Sum rule,

$$\int_{s_0}^{\infty} \frac{ds}{s} \left(\sigma_{\Lambda=2} - \sigma_{\Lambda=0}\right) = 0$$

- Decay Rate (Preliminary):

$$\Gamma\left(0^{++} \to 2\gamma\right) = 1.32 \text{ keV}$$



Two photon cross section difference for scalar, spinor and vector particles.

What is next?

- Repeat for possible contributions between 5-10 GeV.
- Calculate interferences.
- Review different identifications.
- Promising results.
- New data expected for LbL scattering.
- Smaller bins $\Rightarrow$ more accurate comparison.

References

[1] Collaboration, A. (2017). ATLAS Event Display: Light-by-Light Scattering. https://cds.cern.ch/record/2278547

[2] Collaboration, C. (2023). Observation of new structure in the J/ψJ/ψ mass spectrum in proton-proton collisions at $\sqrt{s}$ = 13 TeV.

[3] Collaboration, A. (2021). Measurement of light-by-light scattering and search for axion-like particles with 2.2 nb^{-1} of Pb+Pb data with the ATLAS detector. JHEP, 3, 243. https://doi.org/10.1007/JHEP11(2021)050

[4] Debastiani, V. R., & Navarra, F. S. (2019). A non-relativistic model for the $[cc][\bar{c}\bar{c}]$ tetraquark. Chin. Phys. C, 43(1), 013105. https://doi.org/10.1088/1674-1137/43/1/013105

Thank you for your time.

Back up slides

Potential Contributions

- Notation same as in [4],

$$V_{SS} = -\frac{8\pi\kappa_s\alpha_s}{3m^2}\left(\frac{\sigma}{\sqrt{\pi}}\right)^3 e^{-\sigma^2 r^2}\overrightarrow{S}_1\cdot\overrightarrow{S}_2$$

$$V_{LS} = -\left(\frac{3\kappa_s\alpha_s}{2m^2r^3}+\frac{b}{2m^2r}\right)\overrightarrow{L}\cdot\overrightarrow{S}$$

$$V_{T} = -\frac{12\kappa_s\alpha_s}{4m^2r^3}\left(\frac{\left(\overrightarrow{S}_1\cdot\overrightarrow{r}\right)\left(\overrightarrow{S}_2\cdot\overrightarrow{r}\right)}{r^2}-\frac{1}{3}\left(\overrightarrow{S}_1\cdot\overrightarrow{S}_2\right)\right)$$