Fully-heavy tetraquark spectra and production at hadron colliders

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Based on RLZ 2010.09082

第五届“强子谱和强子结构研讨会” **Online**

Outline

- **Fully heavy tetraquark**
- **Bethe-Salpeter equation**
- **Speactra and Regge Projectories**
- **Production of fully heavy tetraquarks**
- **Summary**

Lots of references… I apologize if I miss the references in this talk

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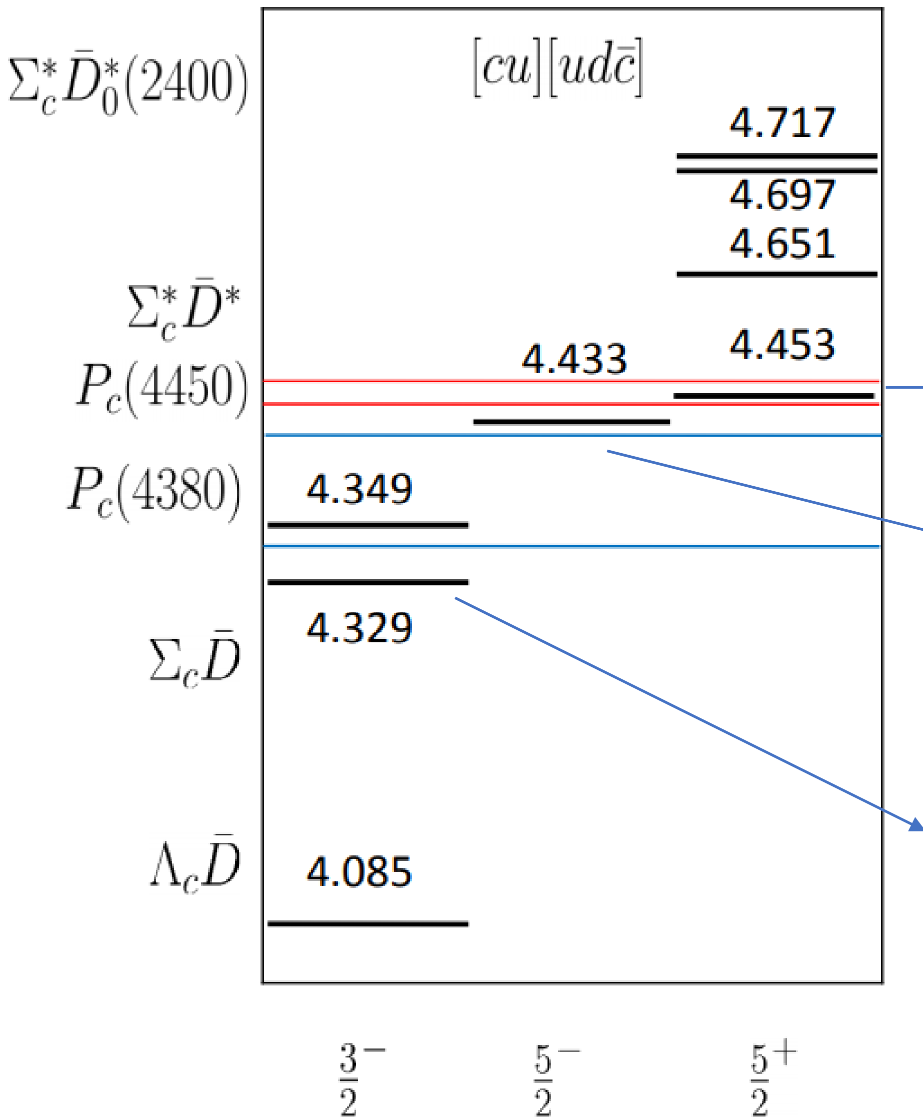
Diquark-triquark model



RLZ, C.F. Qiao, Phys.Lett.B 756 ,259(2016)
1510.08693
The predictions can also explain the new data

$$M_{P_c(4457)^+} = 4457.3 \pm 0.6^{+4.1}_{-1.7} MeV,$$
$$\Gamma_{P_c(4457)^+} = 6.4 \pm 2.0^{+5.7}_{-1.9} MeV.$$

$$M_{P_c(4440)^+} = 4440.3 \pm 1.3^{+4.1}_{-4.7} MeV,$$
$$\Gamma_{P_c(4440)^+} = 20.6 \pm 4.9^{+8.7}_{-10.1} MeV;$$

$$M_{P_c(4312)^+} = 4311.9 \pm 0.7^{+6.8}_{-0.6} MeV,$$
$$\Gamma_{P_c(4312)^+} = 9.8 \pm 2.7^{+3.7}_{-4.5} MeV;$$

LHCb *Phys.Rev.Lett.* 122 , 22, 222001(2019)

Diquark-antidiquark model

$$E^i_j = \begin{pmatrix} \frac{Z_c^0}{\sqrt{2}} + \frac{X}{\sqrt{6}} & Z_c^+ & Z_{cs}^+ \\ Z_c^- & -\frac{Z_c^0}{\sqrt{2}} + \frac{X}{\sqrt{6}} & Z_{cs}^0 \\ Z_{cs}^- & \bar{Z}_{cs}^0 & -2\frac{X}{\sqrt{6}} \end{pmatrix},$$

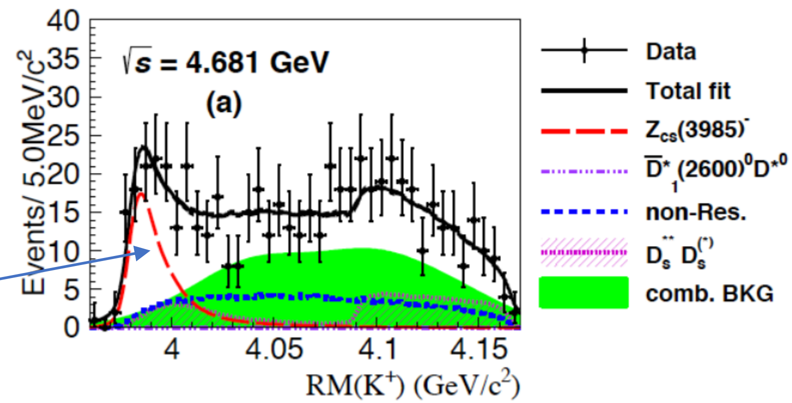
RLZ, Phys.Rev.D 94 (2016) 5, 054009
1607.02799
The predictions can also explain Zcs(3985)

$$Z_c^0 = \frac{1}{\sqrt{2}}(u\bar{u} - d\bar{d})c\bar{c}, \qquad X = \frac{1}{\sqrt{6}}(u\bar{u} + d\bar{d} - 2s\bar{s})c\bar{c}$$

$$Z_c^+ = u\bar{d}c\bar{c}, \qquad Z_c^- = d\bar{u}c\bar{c}, \qquad Z_{cs}^+ = u\bar{s}c\bar{c},$$

$$Z_{cs}^- = s\bar{u}c\bar{c}, \qquad Z_{cs}^0 = d\bar{s}c\bar{c}, \qquad \bar{Z}_{cs}^0 = s\bar{d}c\bar{c},$$

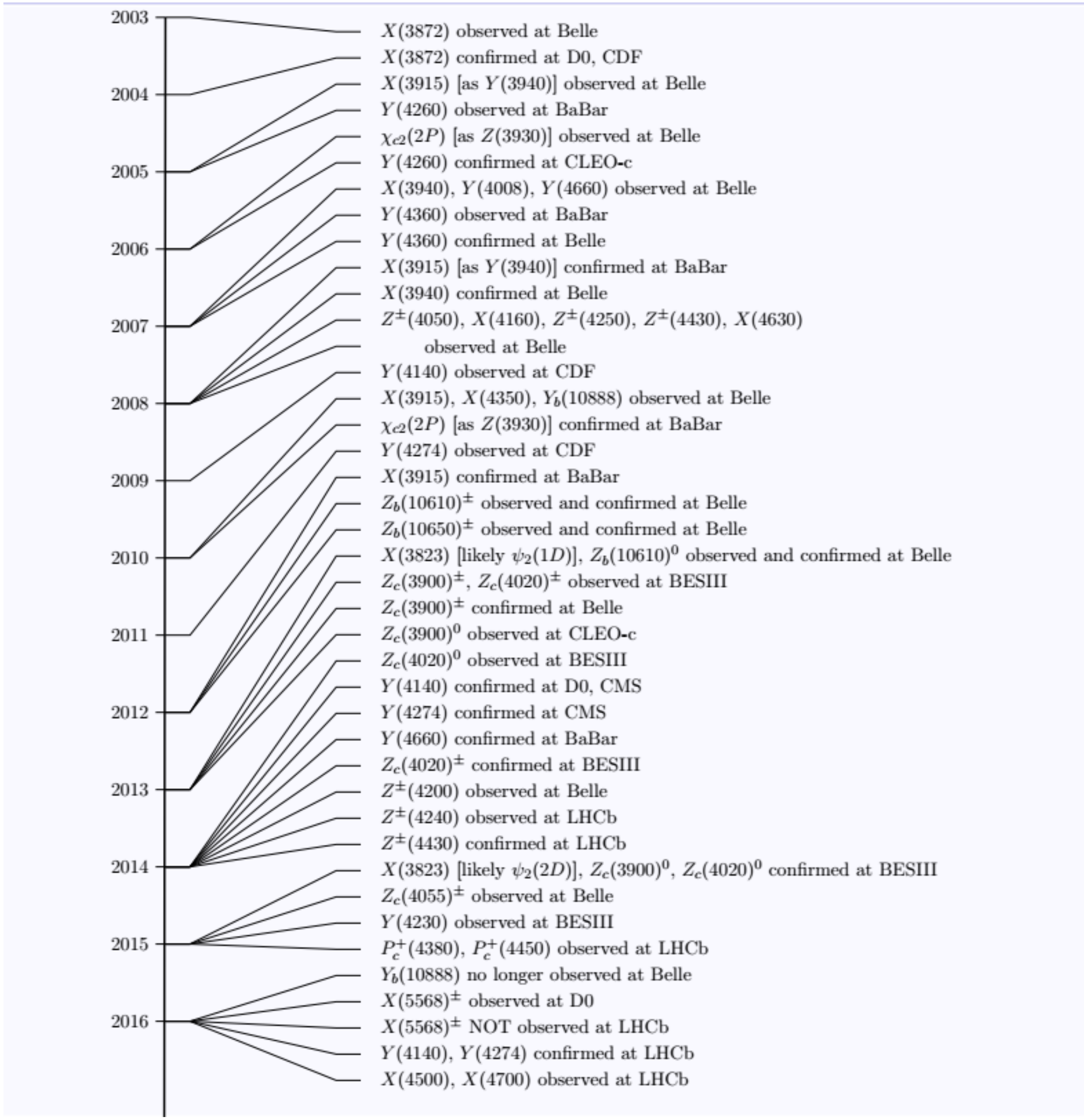
$$X' = \frac{1}{\sqrt{3}}(u\bar{u} + d\bar{d} + s\bar{s})c\bar{c}. \qquad (4$$



$$m(Z_{cs}) = \begin{cases} 4.00\ \text{GeV}, 4.04\ \text{GeV}, & J^P = 0^+, \\ 4.03\ \text{GeV}, 4.08\ \text{GeV}, 4.09\ \text{GeV}, & J^P = 1^+, \\ 4.17\ \text{GeV}, & J^P = 2^+, \end{cases}$$

BESIII 2011.07855

Exotic states(XYZ、Pc)



Exotic states(XYZ、 Pc)

2017 — Y(4140) is confirmed by CDF

2018 — Zc(4100) is observed (3 sigma) by LHCb

2019 — Pc(4312)、 Pc(4440)、Pc(4457) are observed (or confirmed) by LHCb
Y(10752) is observed by Belle

2020 — X(6900) is observed by LHCb
Pcs(4459) is observed by LHCb
X0(2900)、X1(2900) are observed by LHCb
Zcs(3985) is observed by BESIII
Y(2040) is observed by BESIII

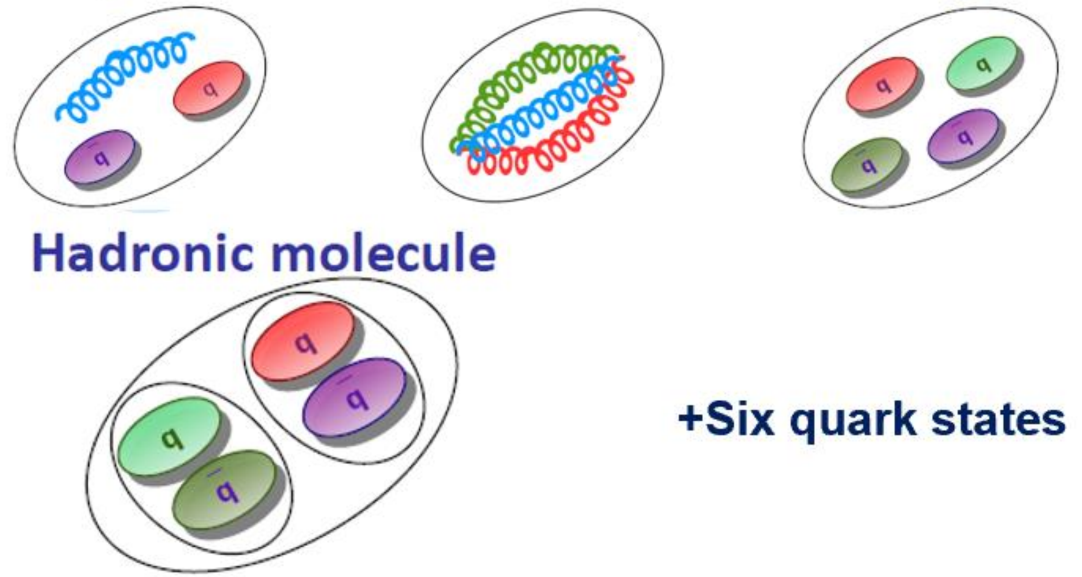
Lots of discoveries in multi-quark states in the past 17 years

QCD Color Confining

Exotic mesons:

Hybrid　　Glueball　　Tetraquark

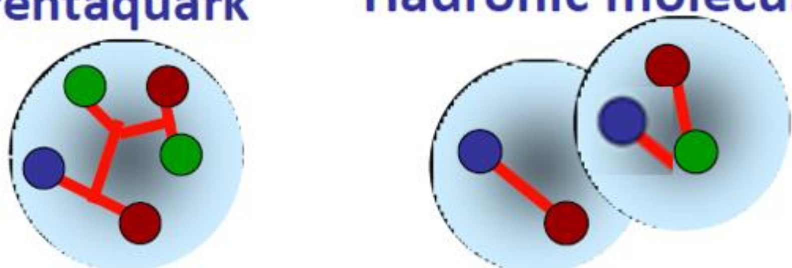
Hadronic molecule



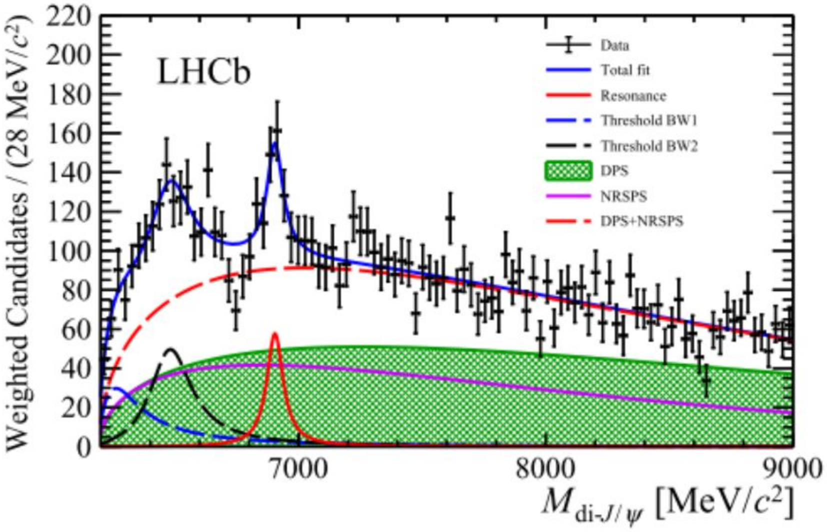
+Six quark states

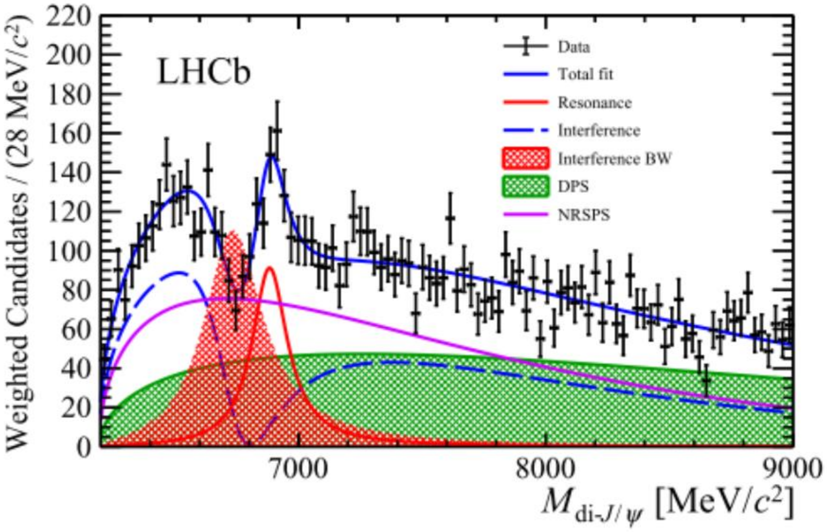
Pentaquark　　Hadronic molecule

Exotic baryons:



X(6900)





$$m_{X(6900)} = 6905 \pm 11 \pm 7\text{MeV},$$
$$\Gamma_{X(6900)} = 80 \pm 19 \pm 33\text{MeV},$$

$$m_{X(6900)} = 6886 \pm 11 \pm 11\text{MeV},$$
$$\Gamma_{X(6900)} = 168 \pm 33 \pm 69\text{MeV},$$

LHCb *2006 .16957*

Can directly strong decay to double J/psi
Candidate of fully charm tetraquark [C C Cbar Cbar] for the first time

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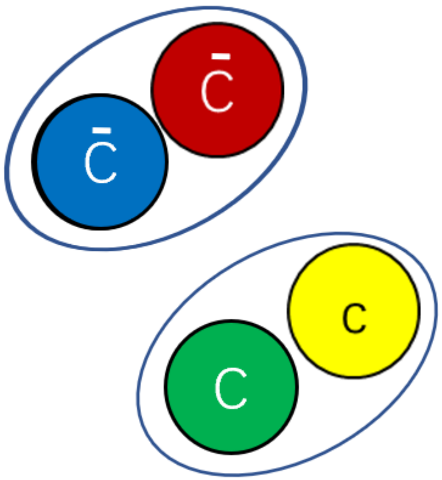
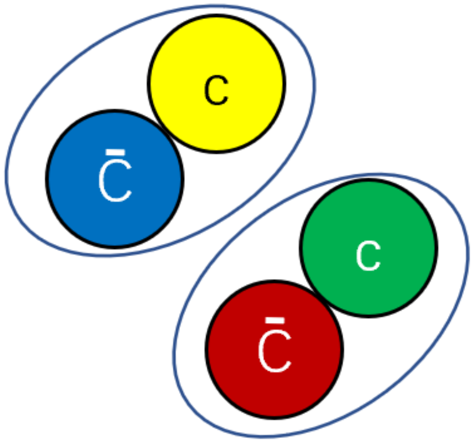
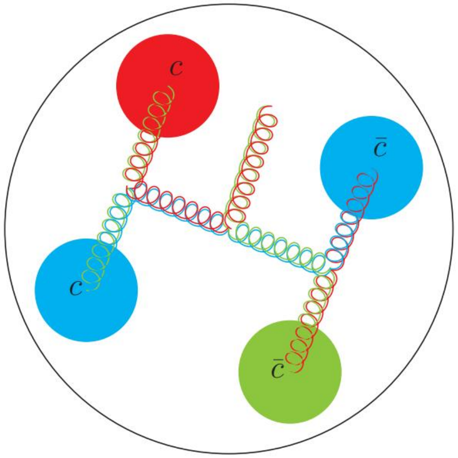
X（6900） models



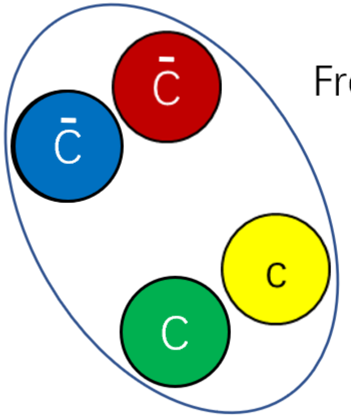
Diquark-antidiquark



J/psi-J/psi (psi(2s))
Molecule



Gluonic Tetracharm
Hybrid



Free tetraquark

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Fully heavy tetraquark Refs

K. T. Chao, Z. Phys. C 7, 317 (1981)

J. P. Ader, J. M. Richard and P. Taxil, Phys. Rev. D 25, 2370 (1982)

A. M. Badalian, B. L. Ioffe and A. V. Smilga, Nucl. Phys. B 281, 85 (1987)

……

J. Wu, Y. R. Liu, K. Chen, X. Liu and S. L. Zhu, Phys. Rev. D 97, no.9, 094015 (2018)

W. Chen, H. X. Chen, X. Liu, T. G. Steele and S. L. Zhu, Phys. Lett. B 773, 247-251 (2017)

Z. G. Wang, Eur. Phys. J. C 77, no.7, 432 (2017)

M. Karliner, S. Nussinov and J. L. Rosner, Phys. Rev. D 95, no.3, 034011 (2017)

J. M. Richard, A. Valcarce and J. Vijande, Phys. Rev. D 95, no.5, 054019 (2017)

M. N. Anwar, J. Ferretti, F. K. Guo, E. Santopinto and B. S. Zou, Eur. Phys. J. C 78, no.8, 647 (2018)

M. S. Liu, Q. F. L¨u, X. H. Zhong and Q. Zhao, Phys. Rev. D 100, no.1, 016006 (2019)

C. Deng, H. Chen and J. Ping, [arXiv:2003.05154]

…….

Bethe-Salpeter(BS) WF

Bethe-Salpeter,Phys. Rev. 84,1232 (1951)

- **Consider the diquark-antidiquark model**
- **First consider 0^++, 2^++ states**
- **The Bethe Salpeter wave function(WF) can be defined as**

$$\chi\left(x_1, x_2, p\right) = \left\langle 0\left|T\left[\mathcal{D}_0\left(x_1\right)\mathcal{D}_0\left(x_2\right)\right]\right| T_{4Q}(p)\right\rangle ,$$

$$\chi'\left(x_1, x_2, p\right) = \mathcal{P}_{\mu\nu}\left\langle 0\left|T\left[\mathcal{D}_1^{\mu}\left(x_1\right)\mathcal{D}_1^{\nu}\left(x_2\right)\right]\right| T_{4Q}(p)\right\rangle ,$$

$$\chi^{\mu\nu}\left(x_1, x_2, p\right) = \left\langle 0\left|T\left[\mathcal{D}_1^{\mu}\left(x_1\right)\mathcal{D}_1^{\nu}\left(x_2\right)\right]\right| T_{4Q}(p)\right\rangle .$$

$$p_1 = \alpha_1 p + q, \qquad p_2 = \alpha_2 p - q,$$

$$p = p_1 + p_2$$

$\alpha_1 = m_1/(m_1 + m_2)$ and $\alpha_2 = m_2/(m_1 + m_2)$

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BS Equation

Bethe-Salpeter,Phys. Rev. 84,1232 (1951)

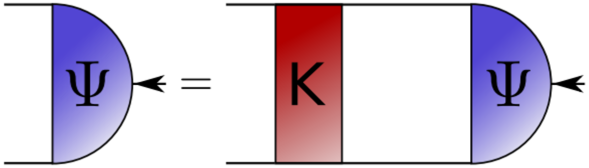
- **BS WF in momentum space**

$$\chi\left(x_1, x_2, p\right) = e^{-ip\cdot X} \int \frac{d^4 q}{(2\pi)^4} e^{-iq\cdot x} \chi_p(q),$$

$X = \alpha_1 x_1 + \alpha_2 x_2$ and $x = x_1 - x_2$.

- **BS equation**

$$\chi_p(q) = S_{\mathcal{D}_0}\left(p_1\right) \int \frac{d^4 k}{(2\pi)^4} K(p, q, k) \chi_p(k) S_{\mathcal{D}_0}\left(p_2\right),$$



Instantaneous approximation

$$\chi_p(q) = S_{\mathcal{D}_0}(p_1)\int \frac{d^4k}{(2\pi)^4} K(p,q,k)\chi_p(k) S_{\mathcal{D}_0}(p_2),$$

- **Diquark propagator**

$$S_{\mathcal{D}_0}(p_i) = \frac{i}{p_i^2 - m_i^2 + i\epsilon} = \frac{i}{\left(\alpha_i p - (-1)^i q_{\parallel}\right)^2 - \omega_i^2 + i\epsilon},$$

$$q_{\parallel}^{\mu} = \frac{(p\cdot q)p^{\mu}}{M^2} \text{ and } q_{\perp}^{\mu} = q^{\mu} - q_{\parallel}^{\mu} \qquad \omega_i = \sqrt{m_i^2 + |\mathbf{q}|^2}.$$

- **Instantaneous approx.**

$$K(p,q,k)|_{\mathbf{p}=0} \simeq M^2 V(\mathbf{q},\mathbf{k}) = M^2 V(\mathbf{q}-\mathbf{k}),$$

C.-H. Chang, J.-K. Chen, X.-Q. Li, G.-L. Wang,CTP43,113(2005)

BS Equation in 3-dimension

- **Integrate** $q_{||}^{\mu}$ **, for two identical diquarks**

$$(M - 2\omega)\chi_p(q_\perp) = \tau(M,\omega)\eta(q_\perp),$$

where $\tau(M,\omega) = \frac{M^2}{\omega(M+2\omega)}$ $\omega_1 = \omega_2 = \omega.$

$$\chi_p(q_\perp) = \int \frac{dq_{||}}{2\pi}\chi_p(q) = \int \frac{dq_{||}}{2\pi}\chi_p(q_{||}, q_\perp),$$

$$\eta_p(q_\perp) = \int \frac{d^3k_\perp}{(2\pi)^3}V(q_\perp - k_\perp)\chi_p(k_\perp).$$

Potential

- **In nonrelativistic limit，** $\tau(M,\omega) = \frac{M^2}{\omega(M+2\omega)} \to 1$

  BS equation turns to Schrodinger Equation

- **One can assume a long-ranged linear confining potential, a short-ranged one gluon exchange potential**

$$V(r) = -\frac{4}{3}\frac{\alpha_s(r)}{r} + \lambda r + V_S\delta(r).$$

$$V_s = \frac{32\pi\alpha_s}{9m_{\mathcal{D}}^2}\mathbf{S}_{\mathcal{D}}\cdot\mathbf{S}_{\bar{\mathcal{D}}}$$

L. Cao, Y.C. Yang, H. Chen, Few-Body Syst.53,327-342(2012)

$$m_{cc} = 3.0GeV, \quad m_{bc} = 6.2GeV, \quad m_{bb} = 9.4GeV, \quad \lambda = 0.147GeV^2$$

Spectra

X(6900) ?

Tetraquark (GeV)	$T_{4Q}(0^{++})$	$T'_{4Q}(0^{++})$	$T_{4Q}(2^{++})$
$T_{cc\bar{c}\bar{c}}(1S)$	5.96	5.91	5.98
$T_{cc\bar{c}\bar{c}}(2S)$	6.48	6.46	6.49
$T_{cc\bar{c}\bar{c}}(3S)$	6.87	6.86	6.88
$T_{cc\bar{c}\bar{c}}(4S)$	7.18	7.17	7.19
$T_{bc\bar{b}\bar{c}}(1S)$	12.37	12.36	12.38
$T_{bc\bar{b}\bar{c}}(2S)$	12.98	12.97	12.98
$T_{bc\bar{b}\bar{c}}(3S)$	13.40	13.39	13.40
$T_{bc\bar{b}\bar{c}}(4S)$	13.62	13.62	13.62
$T_{bb\bar{b}\bar{b}}(1S)$	18.93	18.92	18.93
$T_{bb\bar{b}\bar{b}}(2S)$	19.54	19.54	19.54
$T_{bb\bar{b}\bar{b}}(3S)$	19.96	19.96	19.96
$T_{bb\bar{b}\bar{b}}(4S)$	20.11	20.11	20.12

Regge Projectories

- **Different Regge poles move in the complex angular momentum J-plane in Regge theory**

Phys.Rev.Lett. 8, 41 (1962)

- **Linear Regge projectories**

$$J = \alpha M^2 + \alpha_0, \quad (J, M^2) \text{ plane}$$

$$n_r = \beta M^2 + \beta_0, \quad (n_r, M^2) \text{ plane}$$

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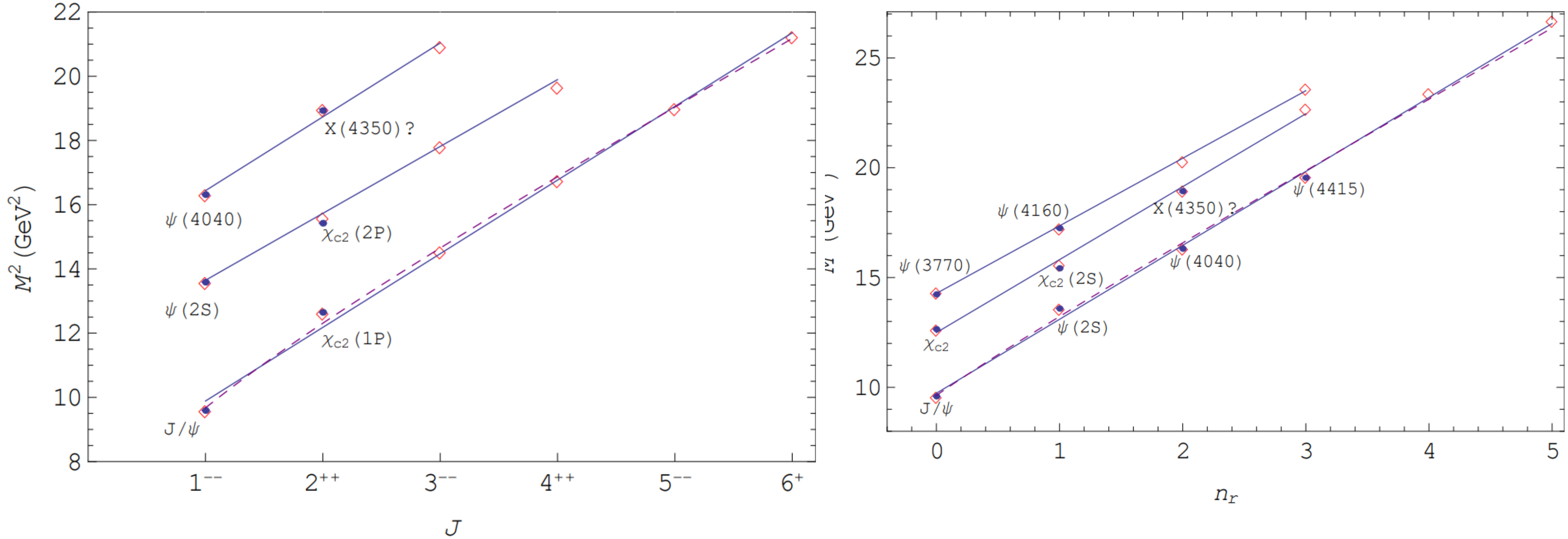
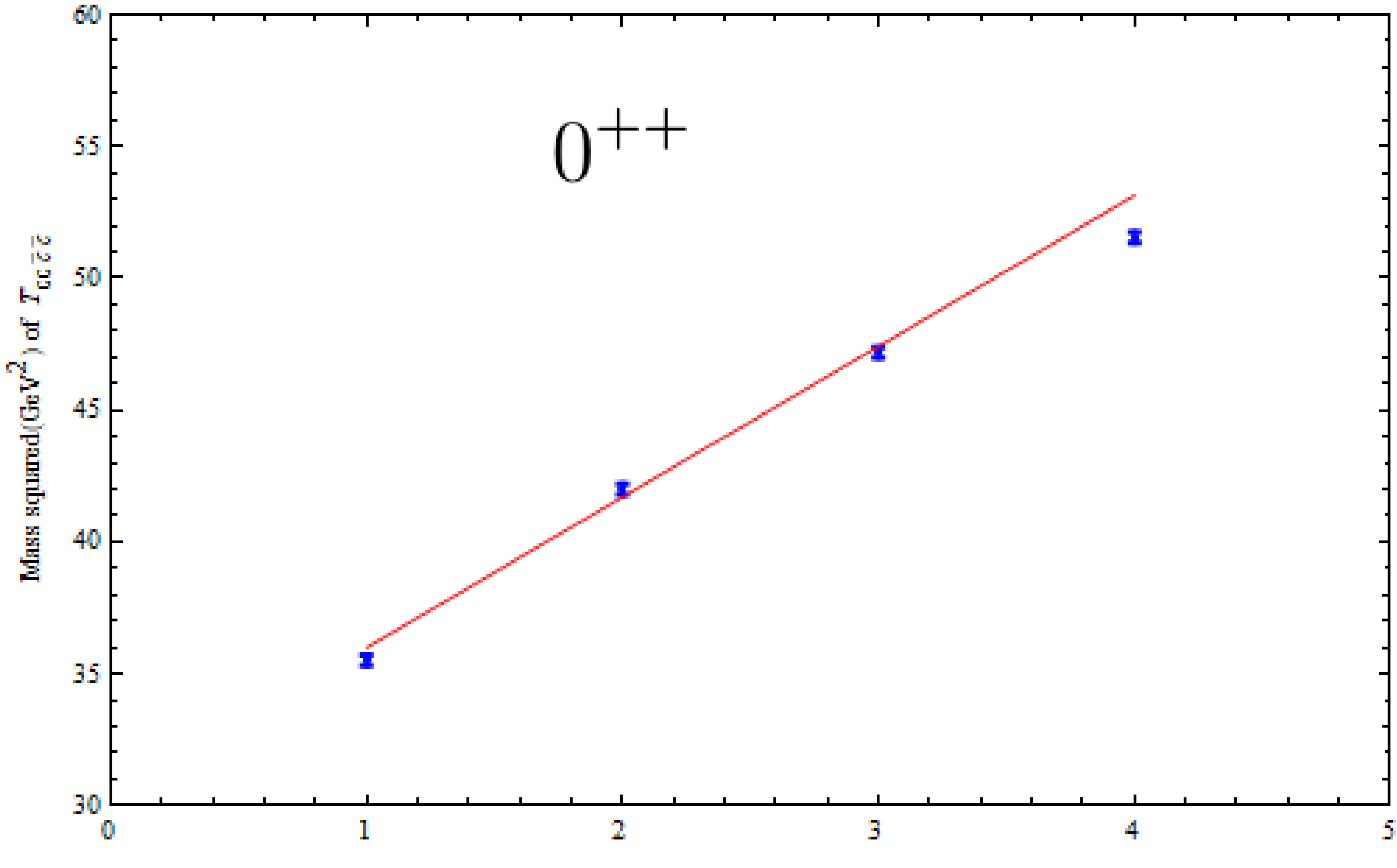
Regge Projectories



$$\chi^2 = \sum_{i=1}^{N} \left[\frac{M_i(\alpha,\alpha_0;\beta,\beta_0) - M_i}{M_i} \right]^2 .$$

$$\alpha(\eta_c) = 0.35 \pm 0.04 GeV^{-2}, \quad \alpha_0(\eta_c) = -3.17 \pm 0.43, \quad \chi^2 = 0.002,$$
$$\alpha(J/\psi) = 0.39 \pm 0.04 GeV^{-2}, \quad \alpha_0(J/\psi) = -2.86 \pm 0.50, \quad \chi^2 = 0.001,$$
$$\beta(\eta_c) = 0.29 \pm 0.03 GeV^{-2}, \quad \beta_0(\eta_c) = -2.67 \pm 0.38, \quad \chi^2 = 0.004,$$
$$\beta(J/\psi) = 0.31 \pm 0.02 GeV^{-2}, \quad \beta_0(J/\psi) = -3.07 \pm 0.29, \quad \chi^2 = 0.002.$$

Regge Projectories



$$\beta(T_{cc\bar{c}\bar{c}}) = 0.175 GeV^{-2}, \quad \beta_0(T_{cc\bar{c}\bar{c}}) = -6.3.$$

Production

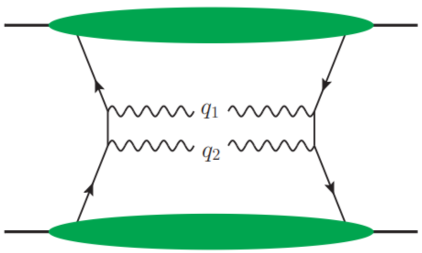
- **The production of fully heavy tetraquark is important**

To study:
Tetraquark structure

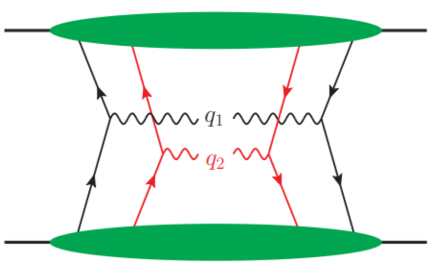
Single parton scattering
Double parton scattering
Multi parton scattering

Factorization formulae

Pt distribution



single scattering:

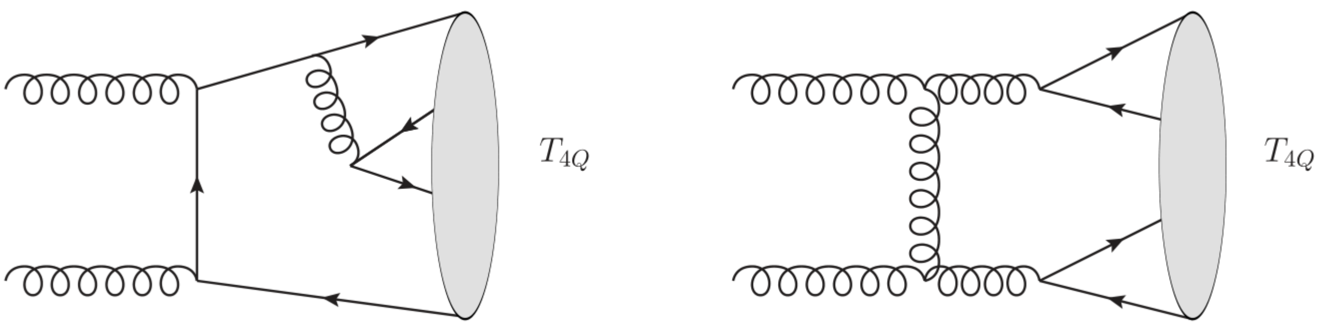


double scattering:

Factorization Formula

$$\sigma\left(p+p\to T_{4Q}+X\right)=\sum_{i,j=q,g}\int_0^1 dx_1 dx_2 f_{i/p}\left(x_1,\mu\right)f_{j/p}\left(x_2,\mu\right)\int_0^1 dz\hat{\sigma}_{ij}^{(0)}$$
$$\times H_{ij}\left(z;\mu\right)\delta\left(z-\frac{m_{T_{4Q}}^2}{x_1 x_2 s}\right),$$

$$p+p\to g+g\to T_{4Q},\quad p+p\to g+g\to T_{4Q}+g.$$



Typical Feynman Diagrams for the production of Fully heavy tetraquark

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Amplitude Calculation

$$\mathcal{M}[g(\epsilon_1(p_1)) + g(\epsilon_2(p_2)) \to T_{4Q}(0^{++}, p_H)] = \left[a g_{\mu\nu} + b\frac{p_{H\mu} p_{H\nu}}{p_H^2} \right] \epsilon_1^\mu \epsilon_2^\nu,$$

$$\mathcal{M}[g(\epsilon_1(p_1)) + g(\epsilon_2(p_2)) \to T_{4Q}(2^{++}, \epsilon^*(p_H))] = \left[c\epsilon^*_{\mu\nu} + d\frac{p_{H\mu} p_{H\nu} p_{1\alpha} p_{1\beta} \epsilon^*_{\alpha\beta}}{p_H^4} + f\frac{g_{\mu\nu} p_{1\alpha} p_{1\beta} \epsilon^*_{\alpha\beta}}{p_H^2} \right.$$
$$\left. + g\frac{p_{H\nu} p_{1\alpha} \epsilon^*_{\mu\alpha}}{p_H^2} + h\frac{p_{H\mu} p_{1\alpha} \epsilon^*_{\nu\alpha}}{p_H^2} \right] \epsilon_1^\mu \epsilon_2^\nu.$$

Long-distance matrix elements of tetraquark:
series of two-body LDMEs

$$\langle 0|\mathcal{O}^{T_{4Q}}|0\rangle = \sum_i c_{\mathbf{1}i} \frac{\langle 0|\mathcal{O}^{Q\bar{Q}[^{2S+1}L_J]^{[\mathbf{1}i]}}|0\rangle \langle 0|\mathcal{O}^{Q\bar{Q}[^{2S+1}L_J]^{[\mathbf{1}i]}}|0\rangle}{m_{T_{4Q}}^2}$$
$$+ \sum_j c_{\mathbf{8}j} \frac{\langle 0|\mathcal{O}^{Q\bar{Q}[^{2S+1}L_J]^{[\mathbf{8}i]}}|0\rangle \langle 0|\mathcal{O}^{Q\bar{Q}[^{2S+1}L_J]^{[\mathbf{8}i]}}|0\rangle}{m_{T_{4Q}}^2},$$

LDMEs discussed also in Y. Q. Ma and H. F. Zhang, 2009.08376;
F. Feng, Y. Huang, Y. Jia, W. L. Sang, X. Xiong and J. Y. Zhang, 2009.08450

Cross Section

$$\hat{\sigma}_{gg}^{(0)}(T_{bc\bar{b}\bar{c}}(0^{++})) = \frac{4\pi^5(r+1)^8\alpha_s^4\,(C_A-2C_F)^2}{27 s_J^2 r^4 m_{T_{bc\bar{b}\bar{c}}}^8} c_{\mathbf{11}} \left[\langle 0|\mathcal{O}^{b\bar{c}}({}^3S_1^{[1]}))|0\rangle\right]^2,$$

$$\hat{\sigma}_{gg}^{(0)}(T'_{bc\bar{b}\bar{c}}(0^{++})) = \frac{4\pi^5(r+1)^8\alpha_s^4\,(C_A-10C_F)^2}{81 r^4 m_{T_{bc\bar{b}\bar{c}}}^8} c_{\mathbf{10}} \left[\langle 0|\mathcal{O}^{b\bar{c}}({}^1S_1^{[0]}))|0\rangle\right]^2,$$

$$\hat{\sigma}_{gg}^{(0)}(T_{bc\bar{b}\bar{c}}(2^{++})) = \frac{64\pi^5(r+1)^8\alpha_s^4\,(C_A-4C_F)^2}{81 s_J^2 r^4 m_{T_{bc\bar{b}\bar{c}}}^8} c_{\mathbf{11}} \left[\langle 0|\mathcal{O}^{b\bar{c}}({}^3S_1^{[1]}))|0\rangle\right]^2,$$

r=mc/mb, for fully charm or fully bottom, by the replacement

$$\hat{\sigma}_{gg}^{(0)}(T_{cc\bar{c}\bar{c}}(0^{++},2^{++}))$$

$$m_{T_{bc\bar{b}\bar{c}}} \to m_{T_{cc\bar{c}\bar{c}}},\ \langle 0|\mathcal{O}^{b\bar{c}}({}^3S_1^{[1]}))|0\rangle \to \langle 0|\mathcal{O}^{c\bar{c}}({}^3S_1^{[1]}))|0\rangle\ (\text{ or } \langle 0|\mathcal{O}^{c\bar{c}}({}^1S_0^{[1]}))|0\rangle),\ \text{and } r \to 1.$$

$$\hat{\sigma}_{gg}^{(0)}(T_{bb\bar{b}\bar{b}}(0^{++},2^{++}))$$

$$m_{T_{bc\bar{b}\bar{c}}} \to m_{T_{bb\bar{b}\bar{b}}},\ \langle 0|\mathcal{O}^{b\bar{c}}({}^3S_1^{[1]}))|0\rangle \to \langle 0|\mathcal{O}^{b\bar{b}}({}^3S_1^{[1]}))|0\rangle\ (\text{ or } \langle 0|\mathcal{O}^{b\bar{b}}({}^1S_0^{[1]}))|0\rangle),\ \text{and } r \to 1.$$

Estimation

Consider:

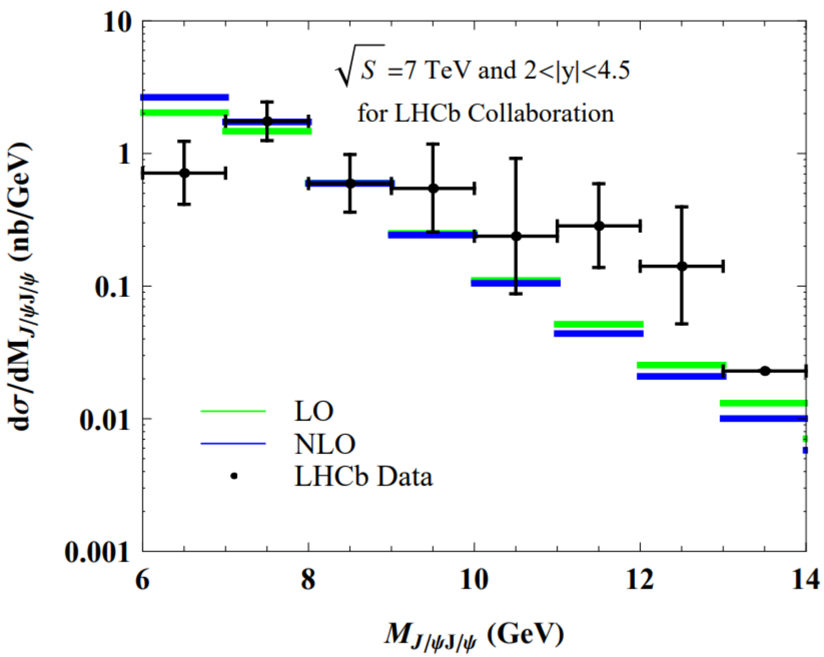
- X(3872) cross section

$$\sigma^{\text{prompt}}(pp \to X(3872) + \text{anything}) \cdot \mathcal{B}(X(3872) \to J/\psi\pi^+\pi^-) = 1.06 \pm 0.11\,(\text{stat.}) \pm 0.15\,(\text{syst.})\,\text{nb.}$$

CMS 2013 7TeV

- Double J/psi cross section

$$\sigma_{Exp.} = 1.49 \pm 0.07 \pm 0.14\ \text{nb},$$ CMS 2013 7TeV



- Fully charm tetraquark prediction

$$\sigma_{T_{4c}}(\sqrt{s} = 14\,\text{TeV}) \simeq (7.0 \pm 4.8)\,\text{nb}$$

Carvalho et al, 1511.05209

- Extract the coupling constant

$$c_{11} \sim 10^{-3} \text{ and } c_{10} \sim 10^{-3} - 10^{-4}.$$

Results

$$\frac{\sigma(T_{cc\bar{c}\bar{c}}(2^{++}))}{\sigma(T_{cc\bar{c}\bar{c}}(0^{++}))} \sim 260$$

$$\frac{\sigma(T'_{cc\bar{c}\bar{c}}(0^{++}))}{\sigma(T_{cc\bar{c}\bar{c}}(0^{++}))} \sim 320$$

$$\frac{\sigma(T_{cc\bar{c}\bar{c}}(0^{++}(2S)))}{\sigma(T_{cc\bar{c}\bar{c}}(0^{++}(1S)))} \sim 0.4$$

$$\frac{\sigma(T_{cc\bar{c}\bar{c}}(0^{++}(3S)))}{\sigma(T_{cc\bar{c}\bar{c}}(0^{++}(1S)))} \sim 0.1$$

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Low Pt behavior

Sudakov Large Double Logarithms

- Differential cross section depends on Q_1(Pt), where $Q^2 \gg Q_1^2$

$$\frac{d\sigma}{dQ_1^2} = \frac{1}{Q_1^2} f_1 \otimes f_2 \otimes \sum_i \alpha_s^i \ln^{2i-1} \frac{Q^2}{Q_1^2} + \cdots$$

- We have to resum these large logs to make reliable predictions

  CSS resummation: Collins, Soper, Sterman, 1985

CSS resummation

$$\left.\frac{d\sigma}{dyd^2p_\perp}\right|_{p_\perp\ll m_{T_{4Q}}} = \hat{\sigma}_{gg}^{(0)}\frac{\alpha_s C_A}{2\pi^2}\int dx_1 dx_2 f(x_1,\mu) f\left(x_2,\mu\right)\frac{1}{p_\perp^2}\left[\frac{2\left(1-\xi_1+\xi_1^2\right)^2}{\left(1-\xi_1\right)_+}\delta\left(1-\xi_2\right)\right.$$
$$\left.+\frac{2\left(1-\xi_2+\xi_2^2\right)^2}{\left(1-\xi_2\right)_+}\delta\left(1-\xi_1\right)+2\ln\frac{m_{T_{4Q}}^2}{p_\perp^2}\delta\left(1-\xi_2\right)\delta\left(1-\xi_1\right)\right],$$

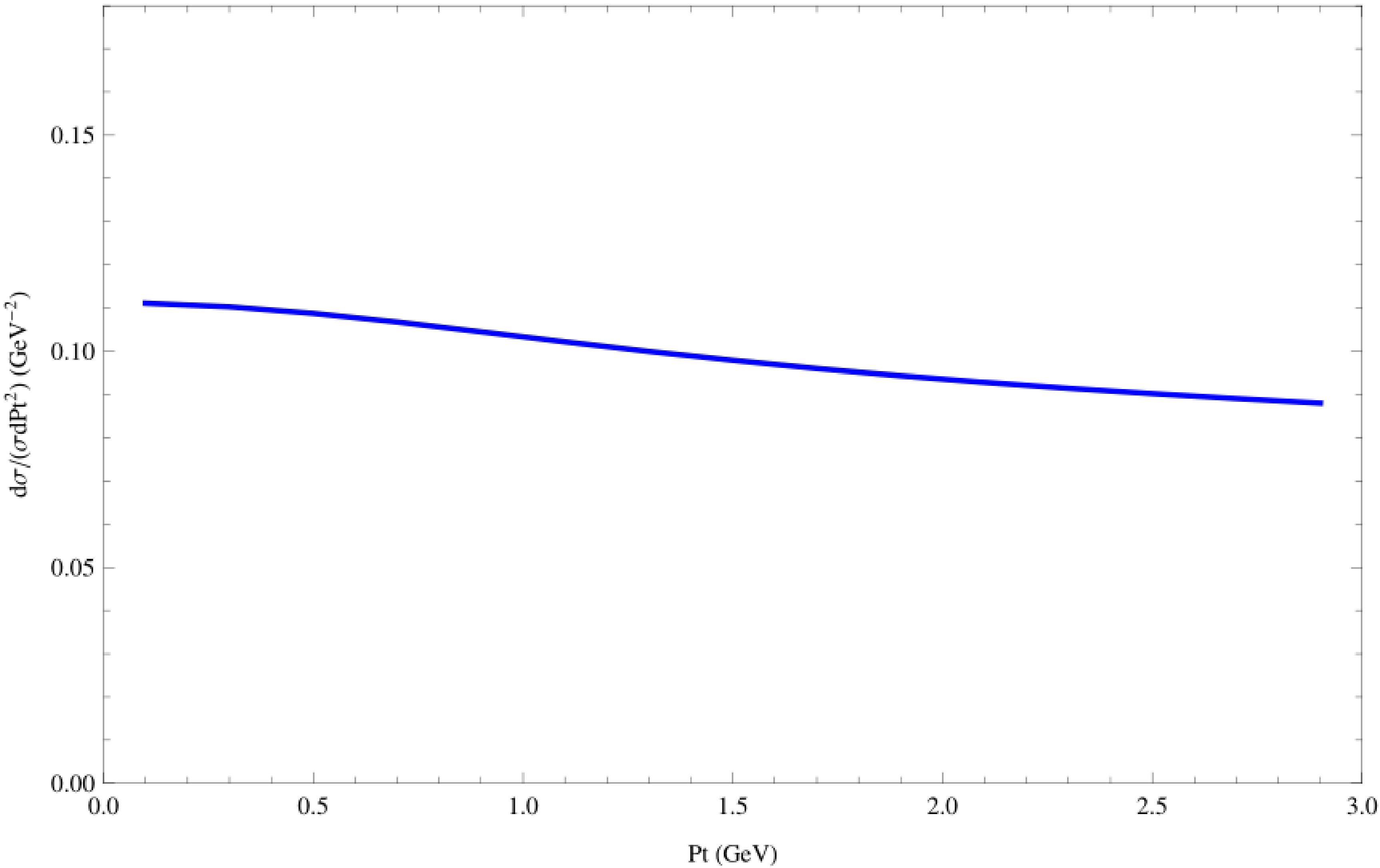
After resummation

$$\left.\frac{d\sigma}{dyd^2p_\perp}\right|_{p_\perp\ll m_{T_{4Q}}} = \frac{1}{(2\pi)^2}\int d^2b e^{i\vec{p}_\perp\cdot\vec{b}} e^{-\mathcal{S}_{sud}(b,m_{T_{4Q}},C_1,C_2)} W\left(b, m_{T_{4Q}}, \xi_1, \xi_2\right),$$

$$\mathcal{S}_{sud}(b, m_{T_{4Q}}, C_1, C_2) = \int_{C_1^2/b^2}^{C_2^2 m_{T_{4Q}}^2}\frac{d\mu^2}{\mu^2}\left[A\log\frac{C_2^2 m_{T_{4Q}}^2}{\mu^2}+B\right],$$

$$W^{NP}(b) = \exp\left[-g_1-g_2\ln\left(\frac{Q}{2Q_0}\right)-g_1 g_3\ln\left(100x_1x_2\right)\right]b^2,$$

Distribution at low Pt



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Summary

- Spectra of fully heavy tetraquarks can be studied using Bethe-Salpeter equation and Regge projectories
- Production of fully heavy tetraquarks is important to uncover the nature of X(6900)

For the spectra and the production, talks also by C.R. Deng, H.F. Zhang, C. Gong, Z.Y. Yang, Y.S. Yang this afternoon.

Thank you so much!