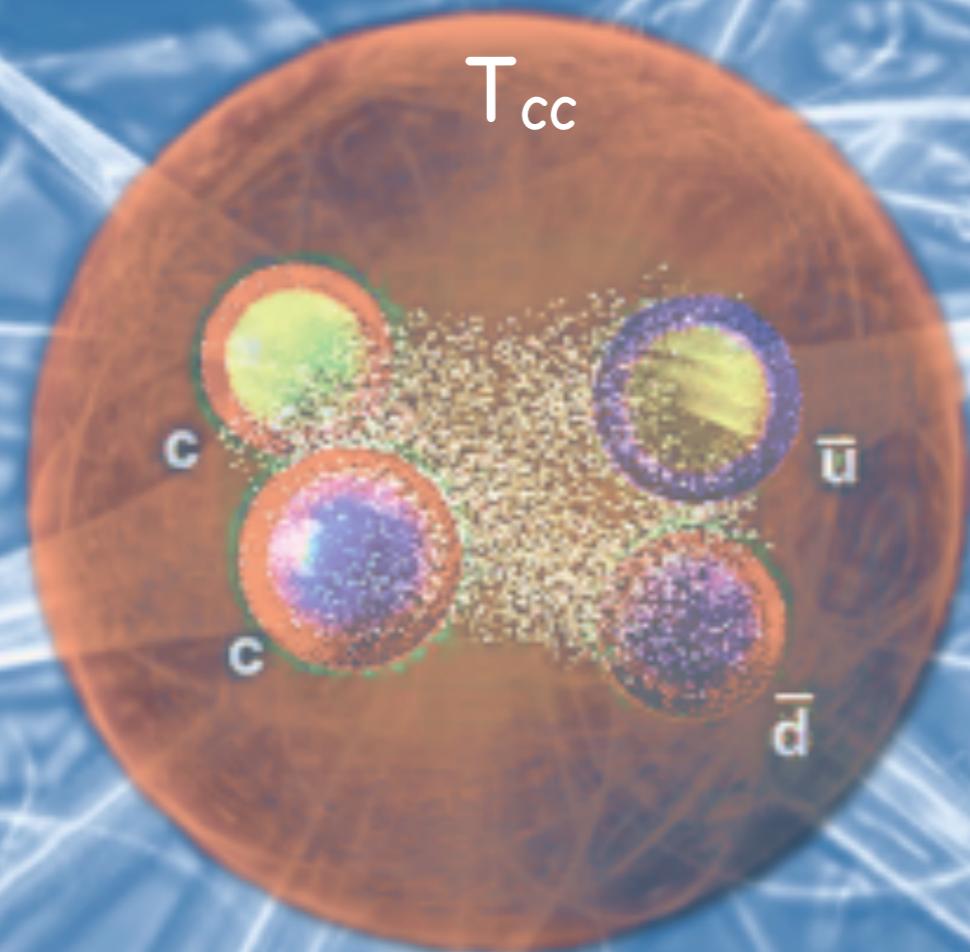


Double charm tetraquark and other exotics

22 – 23 de nov. de 2021
IP2I, Lyon

Exotics in QCD Sum Rules



Marina Nielsen
Universidade de São Paulo

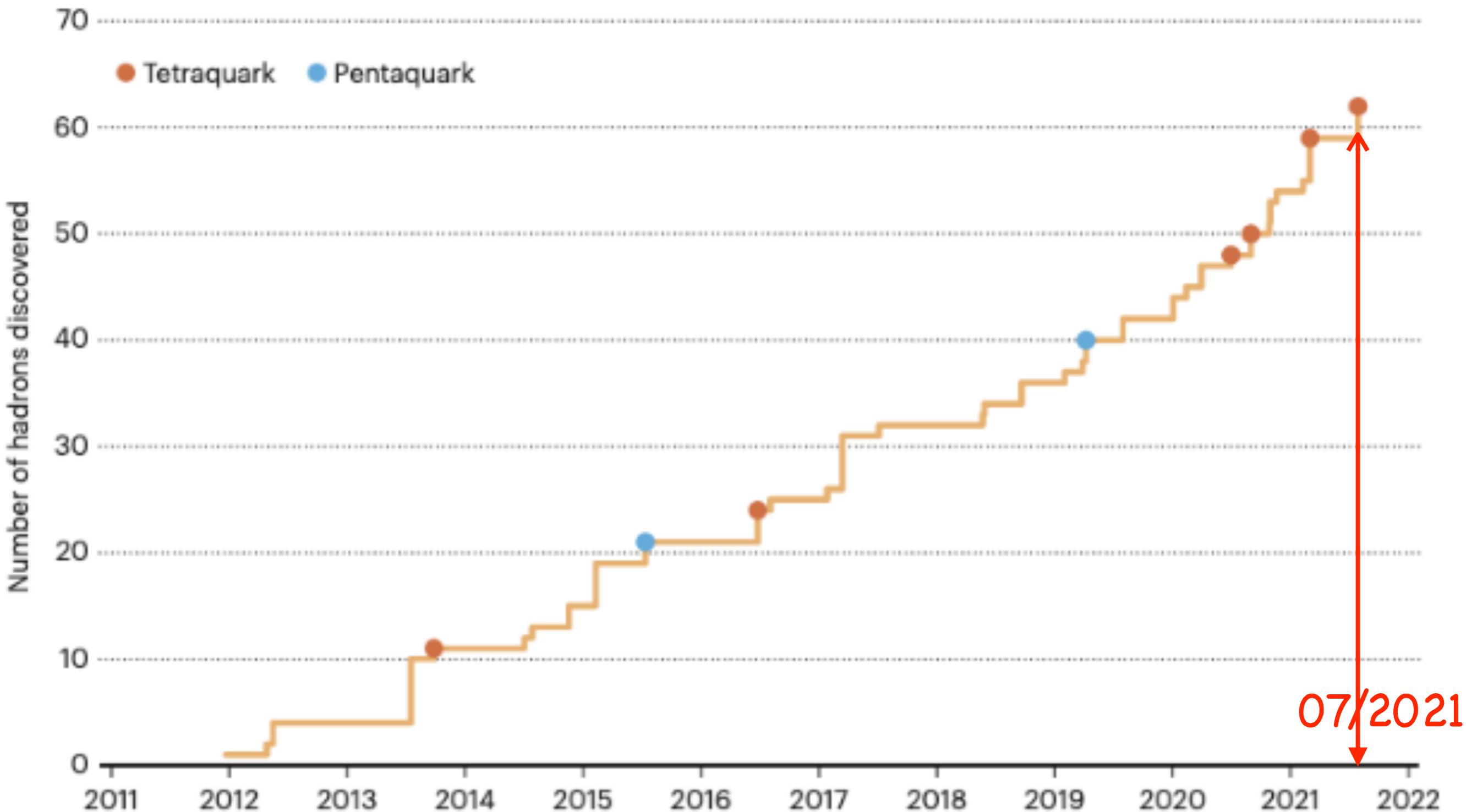
Candidates to Exotic Charmonium States

State	m (MeV)	Γ (MeV)	J^{PC}	Process (mode)	experiment	Year
$X(3872)$	3871.69 ± 0.17	< 1.2	1^{++}	$B \rightarrow K(\pi^+ \pi^- J/\psi)$ $p\bar{p} \rightarrow (\pi^+ \pi^- J/\psi) \dots$ $B \rightarrow K(\omega J/\psi)$ $B \rightarrow K(D^0 \bar{D}^0)$ $B \rightarrow K(\gamma J/\psi)$ $B \rightarrow K(\gamma \psi(2S))$ $e^+ e^- \rightarrow \pi^+ \pi^- J/\psi$ $p\bar{p} \rightarrow (\pi^+ \pi^- J/\psi) \dots$	Belle [22–24], BaBar [25] CDF [26–28], DØ [29] Belle [30], BaBar [31] Belle [32, 33], BaBar [34] Belle [30], BaBar [35, 36] BaBar [36], LHCb [37] BESIII [38] LHCb [39, 40], CMS [41]	2003
$Z_c^+(3900)$	3886.6 ± 2.4	28.2 ± 2.6	1^{+-}	$Y(4260) \rightarrow (J/\psi \pi^+) \pi^-$ $Y(4260) \rightarrow (D\bar{D}^*)^+ \pi^-$	BESIII [42], Belle [43], CLEO-c [44]] BESIII [45]	2013
$Y(3940)$	3918.4 ± 1.9	20 ± 5	$0/2^{++}$	$B \rightarrow K(J/\psi \omega)$ $e^+ e^- \rightarrow e^+ e^-(\omega J/\psi)$	Belle [46], BaBar [31, 47] Belle [48], BaBar [49]	2004
$X(3940)$	3942_{-8}^{+9}	37_{-17}^{+27}	$?^{?+}$	$e^+ e^- \rightarrow J/\psi \dots$ $e^+ e^- \rightarrow J/\psi (DD^*)$	Belle [50] Belle [51]	2005
$Y(4008)$	3891 ± 42	255 ± 42	1^{--}	$e^+ e^- \rightarrow \pi^+ \pi^- J/\psi$	Belle [43, 52], BESIII [53]	2007
$Z_c^+(4020)$	4024.1 ± 1.9	13 ± 5	$?^{?-}$	$e^+ e^- \rightarrow \pi^-(\pi^+ h_c)$ $Y(4260) \rightarrow \pi^-(D^* \bar{D}^*)^+$	BESIII [54] BESIII [55]	2013
$Z_1^+(4050)$	4051_{-43}^{+24}	82_{-55}^{+51}	$?^{?-}$	$B \rightarrow K(\pi^+ \chi_{c1}(1P))$	Belle [56], BaBar [57]	2008
$Z_c^+(4055)$	4054 ± 3	45	$(?^{?-})$	$e^+ e^- \rightarrow \pi^-(\pi^+ \psi(2S))$	Belle [58]	2014
$Z_c^-(4100)$	$(4096 \pm 28)_{-32}^{+28}$	152_{-45}^{+70}	$0^{++}/1^{+-}$	$B^0 \rightarrow K^+(\pi^- \eta_c(1S))$	LHCb [59]	2018
$Y(4140)$	4146.8 ± 2.4	22_{-7}^{+8}	1^{++}	$B \rightarrow K(\phi J/\psi)$	CDF [60, 61], DØ [62], LHCb [63], BESIII [64, 65]	2009
$X(4160)$	4156_{-25}^{+29}	139_{-65}^{+113}	$?^{?+}$	$e^+ e^- \rightarrow J/\psi(D^* \bar{D}^*)$	Belle [51]	2007
$Z_c^+(4200)$	4196_{-30}^{+35}	370_{-110}^{+99}	1^{+-}	$B \rightarrow K(\pi^+ J/\psi)$	Belle [66]	2014
$Y(4220)$	4218_{-4}^{+5}	59_{-10}^{+12}	1^{--}	$e^+ e^- \rightarrow \chi_{c0} \omega$ $e^+ e^- \rightarrow \omega \omega$	BESIII [67] DESY-16-091	2014
$Z_2^+(4250)$	4248_{-45}^{+185}	177_{-72}^{+321}	$?^{?+}$	$B \rightarrow K(\pi^+ \chi_{c1}(1P))$	Belle [56], BaBar [57]	2008
$Y(4260)$	4230 ± 8	55 ± 19	1^{--}	$e^+ e^- \rightarrow \pi^+ \pi^- J/\psi$ $e^+ e^- \rightarrow K^+ K^- J/\psi$ $e^+ e^- \rightarrow \pi^0 \pi^0 J/\psi$ $e^+ e^- \rightarrow Z_c(3900)^{\pm} \pi^{\mp}$	BaBar [71, 72], CLEO-c [73], Belle [43, 52], BESIII [53] CLEO-c [74], BESIII [45] CLEO-c [74] Belle [43], BESIII [42]	2005
$X(4350)$	$4350.6_{-5.1}^{+4.6}$	$13.3_{-10.0}^{+18.4}$	$?^{?+}$	$e^+ e^- \rightarrow \phi J/\psi$	Belle [75]	2009
$Y(4360)$	4368 ± 13	96 ± 7	1^{--}	$e^+ e^- \rightarrow \pi^+ \pi^- \psi(2S)$ $e^+ e^- \rightarrow \pi^+ \pi^- J/\psi$	BaBar [76, 77], Belle [58, 78], BESIII [69] BESIII [53]	2007
$Y(4390)$	$4391.5_{-7.8}^{+7.3}$	$139.5_{-20.7}^{+16.3}$	1^{--}	$e^+ e^- \rightarrow h_c \pi^+ \pi^-$	BESIII [68]	2016
$Z^+(4430)$	4478_{-18}^{+15}	181 ± 31	1^{+-}	$B \rightarrow K^-(\pi^+ \psi(2S))$ $B \rightarrow K^-(\pi^+ J/\psi)$	Belle [79–81], BaBar [82], LHCb [83] Belle [66], BaBar [82]	2007
$X(4630)$	4634_{-11}^{+9}	92_{-32}^{+41}	1^{--}	$e^+ e^- \rightarrow \Lambda_c^+ \Lambda_c^-$	Belle [84]	2008
$Y(4660)$	4643 ± 9	72 ± 11	1^{--}	$e^+ e^- \rightarrow \pi^+ \pi^- \psi(2S)$ $e^+ e^- \rightarrow \Lambda_c^+ \Lambda_c^-$	Belle [58, 78], BaBar [77] BESIII [64]	2007

and more ...

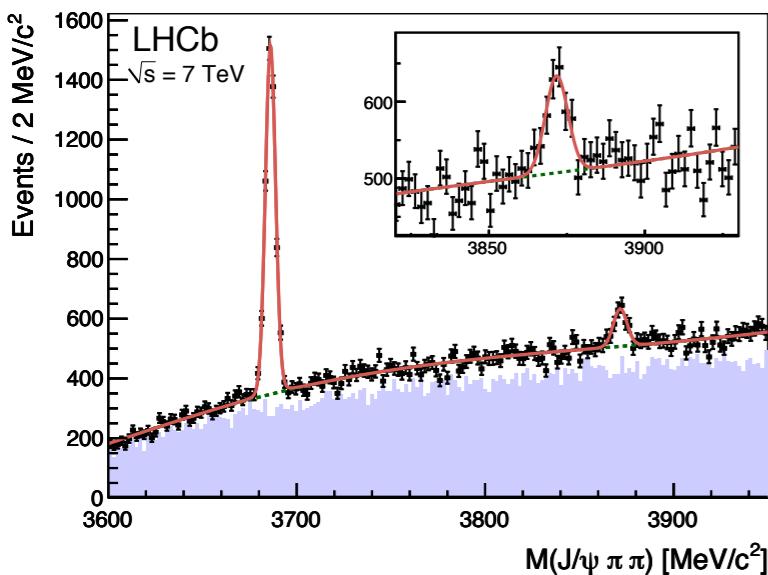
Hadrons discovered at LHC:

62 new hadrons were discovered at LHC, including many exotic states



Exotic Spectroscopy: "my" overview

- 2003: Discovery of $X(3872)$ by Belle started a new era in exotic spectroscopy.



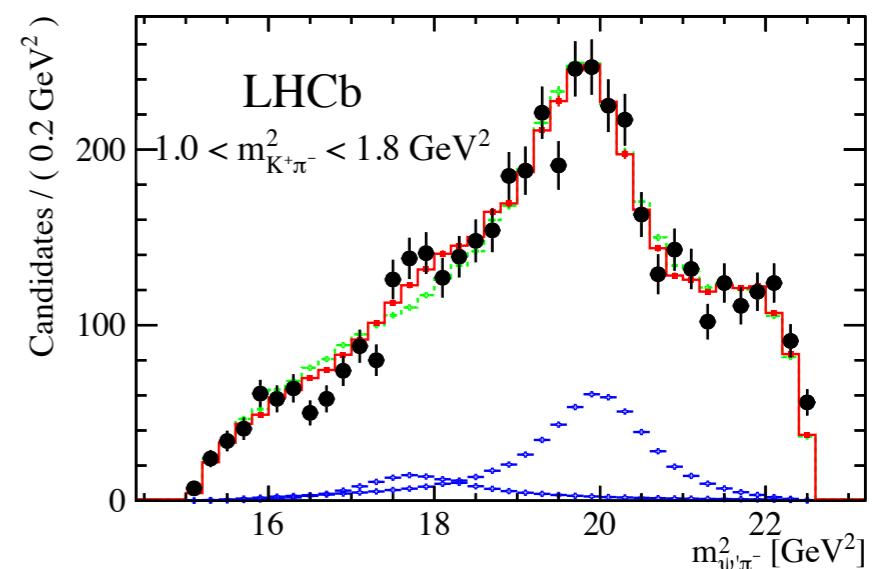
$$M_x = (3871.65 \pm 0.06) \text{ MeV}$$
$$\Gamma = (1.19 \pm 0.21) \text{ MeV}$$
$$J^{PC} = 1^{++}$$

$\chi_{c1}(3872)$

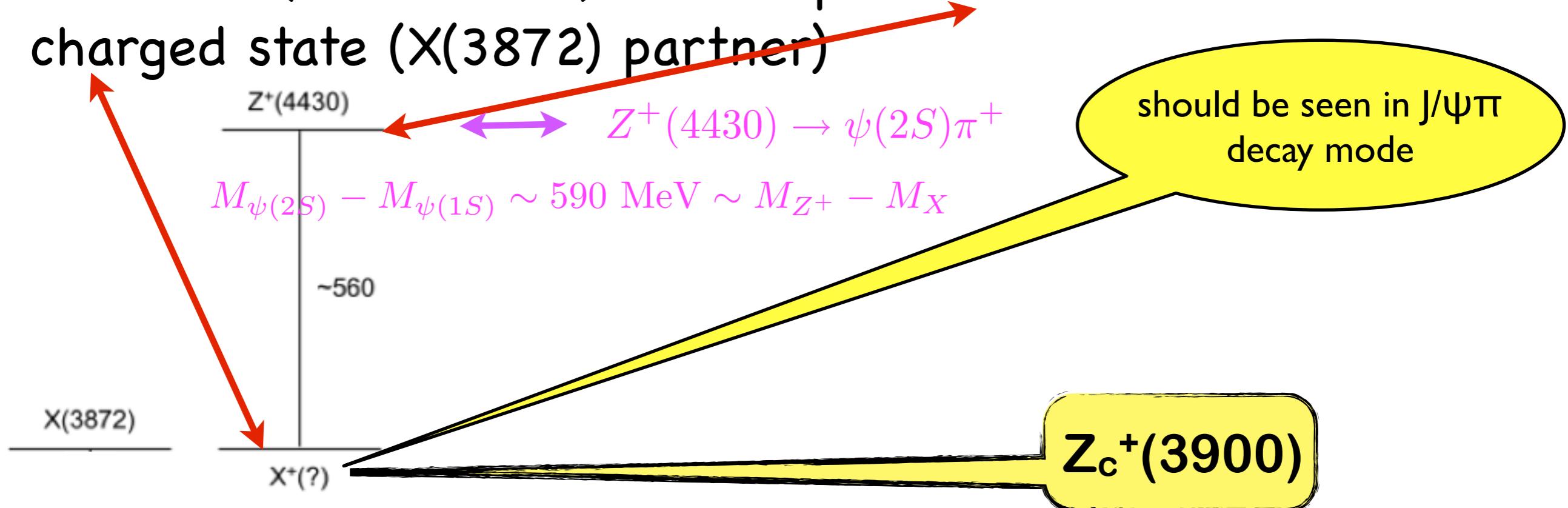
also known as $X(3872)$

- 2007: Observation of $Z^+(4430)$ by Belle: the first charged tetraquark state. Not confirmed by BaBar in 2009. Confirmed by LHCb in 2014

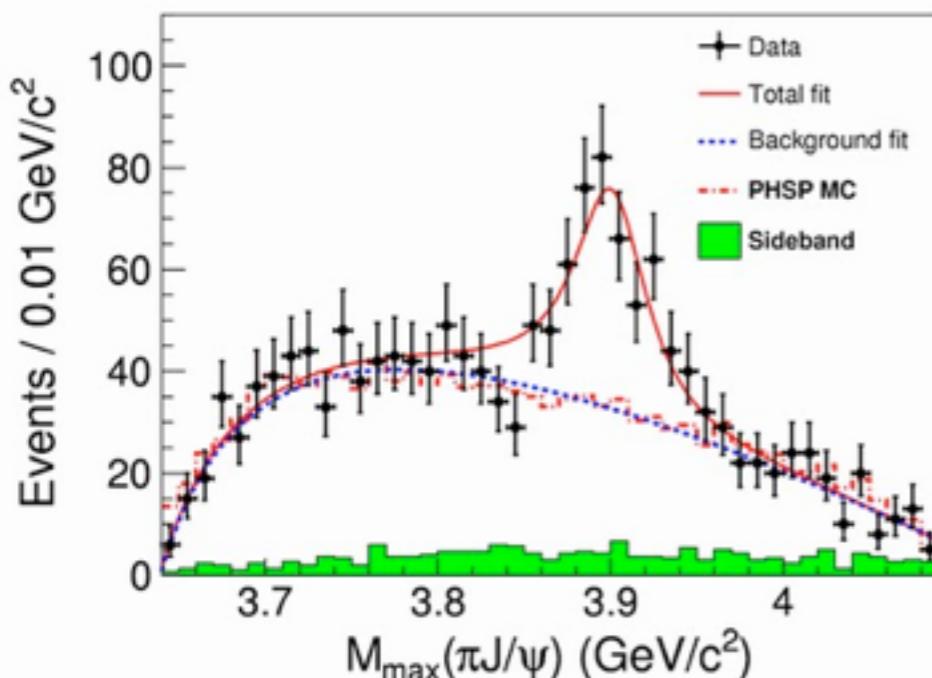
$$M = (4478 \pm 16) \text{ MeV}$$
$$\Gamma = (181 \pm 31) \text{ MeV}$$
$$J^P = 1^+$$



Maiani et al. (arXiv:0708.3997) : four-quark radial excitation of the 1^+ charged state ($X(3872)$ partner)



- 2013: Observation of $Z_c^+(3900)$ by Belle and BESIII



$Z_c^+(3900)$

B E S III



arXiv:1303.5949

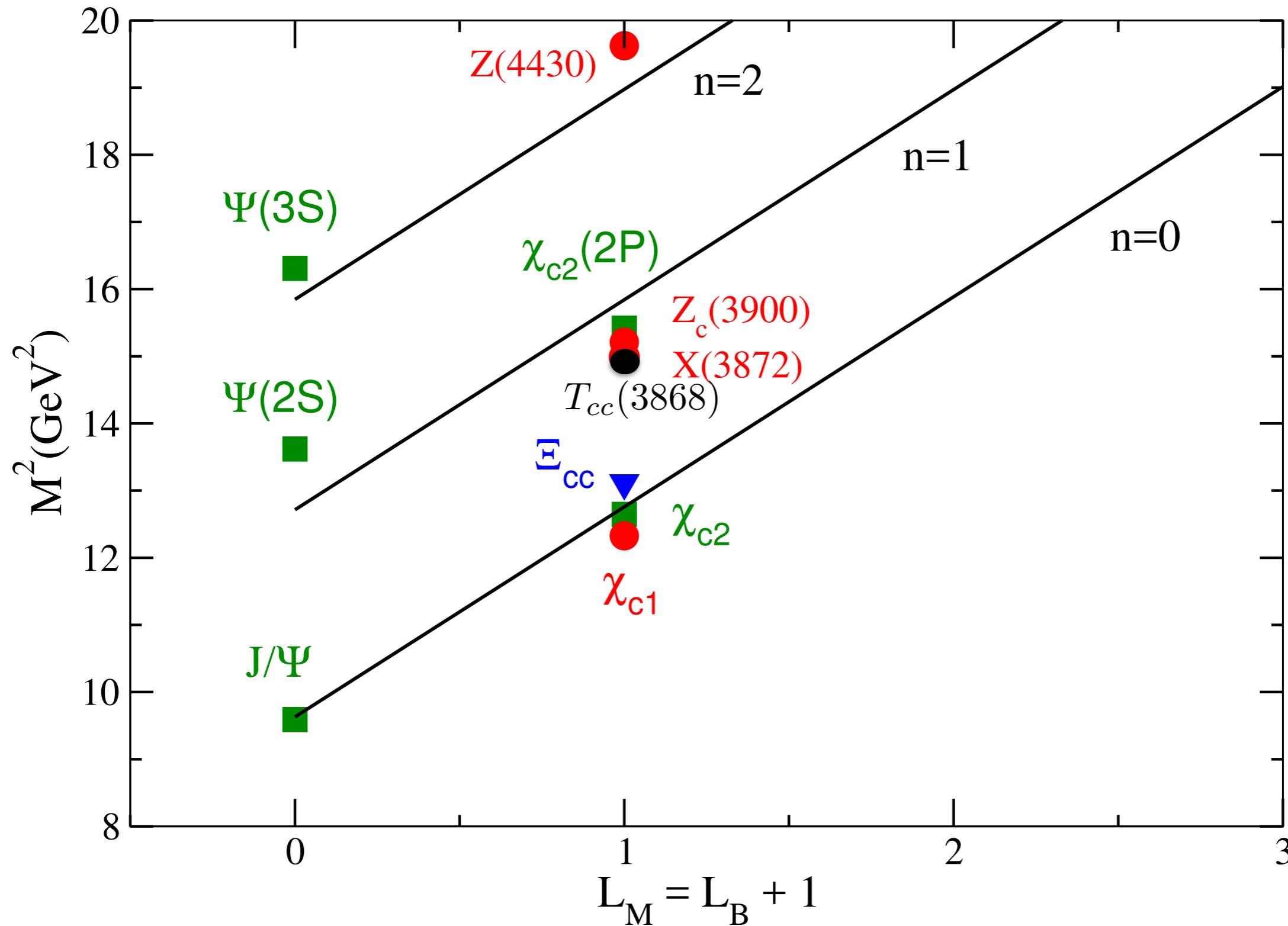
arXiv:1304.0121

$Y(4260) \rightarrow (J/\psi\pi^+)\pi^-$

$M = (3887.1 \pm 2.6)$ MeV
 $\Gamma = (28.4 \pm 2.6)$ MeV
 $J^P = 1^+$

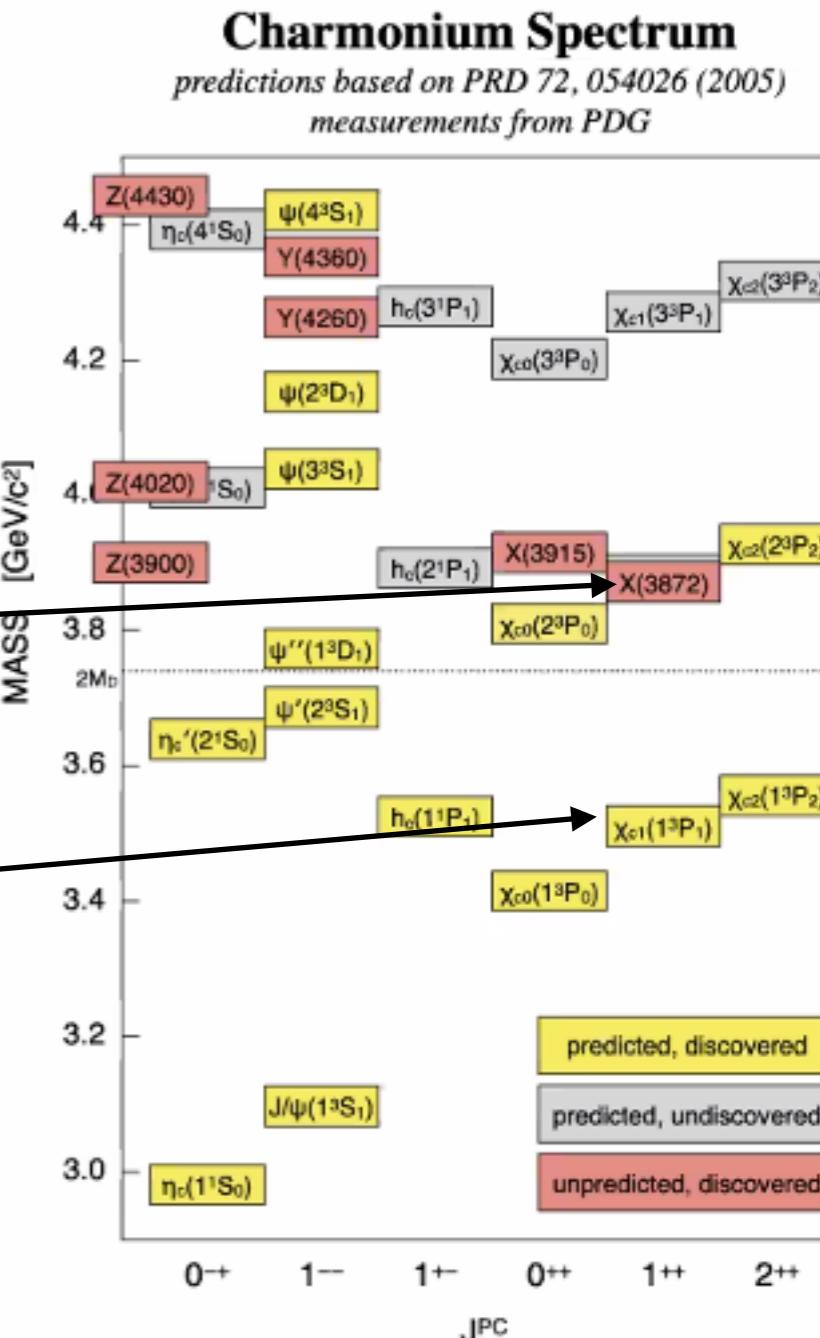
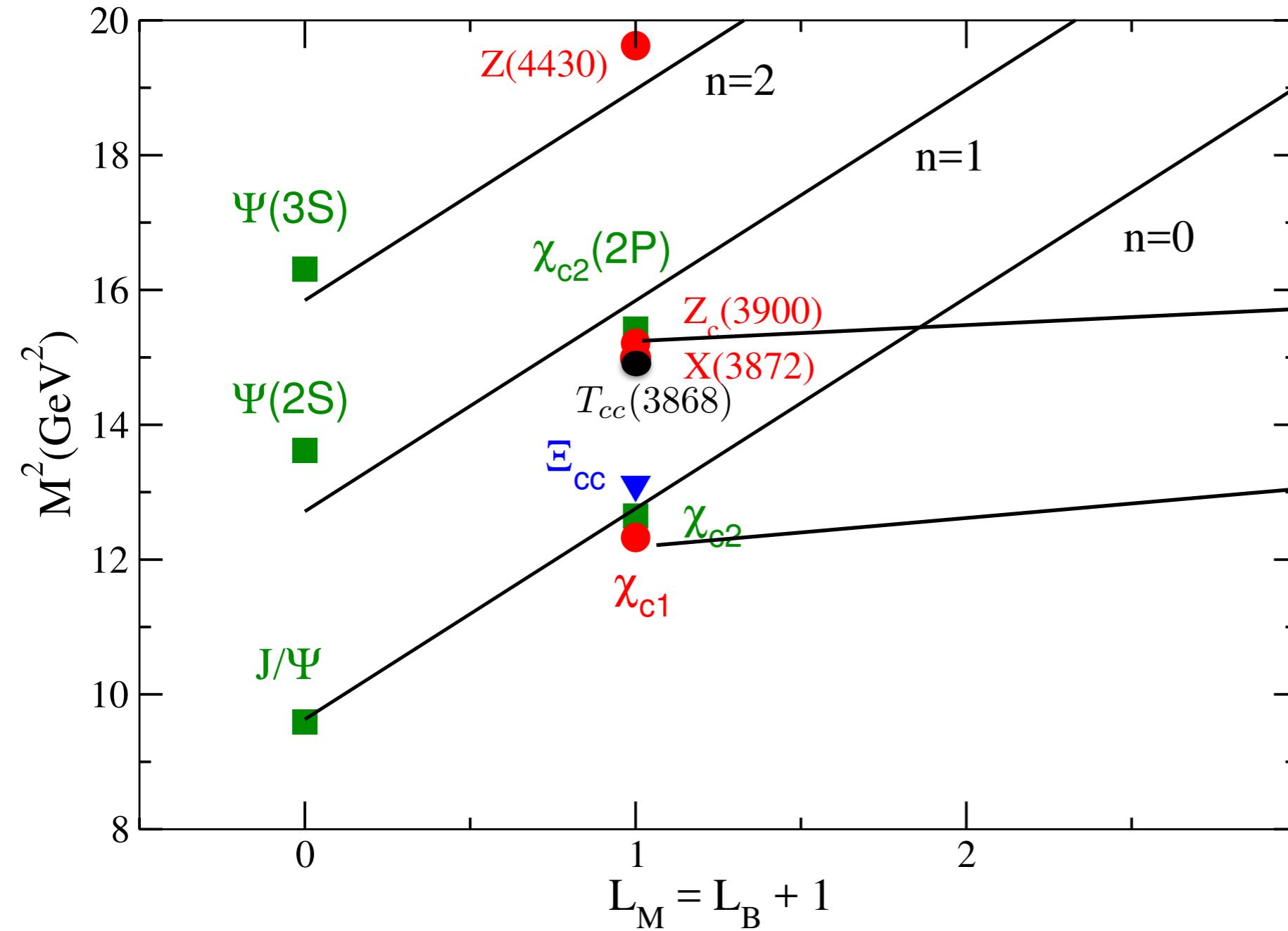
SuSyLFHQCD

MN, Brodsky, Téramond, Dosch, Navarra, Zou (arXiv:1805.11567)



SuSyLFHQCD

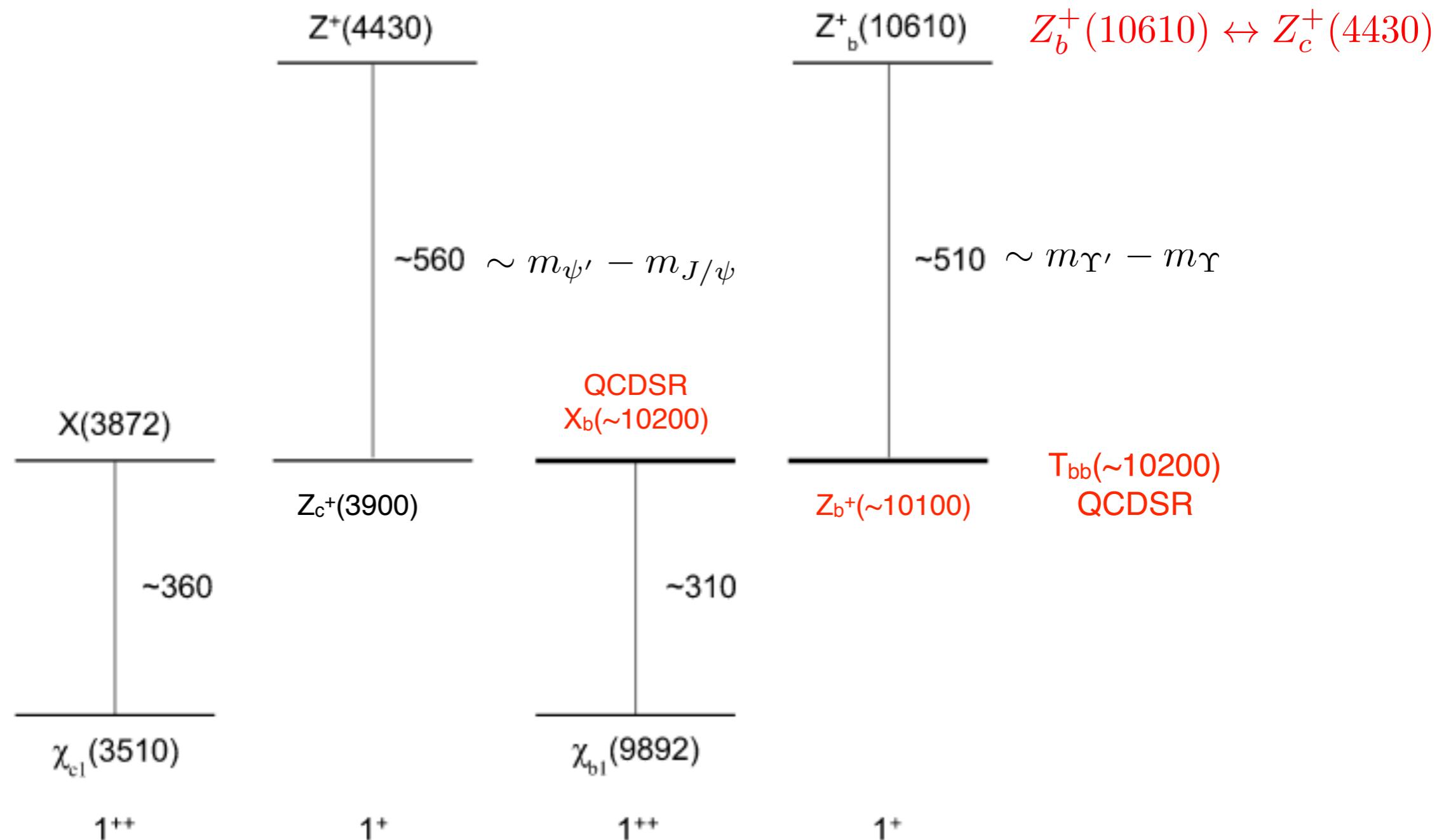
MN, Brodsky, Téramond, Dosch, Navarra, Zou (arXiv:1805.11567)



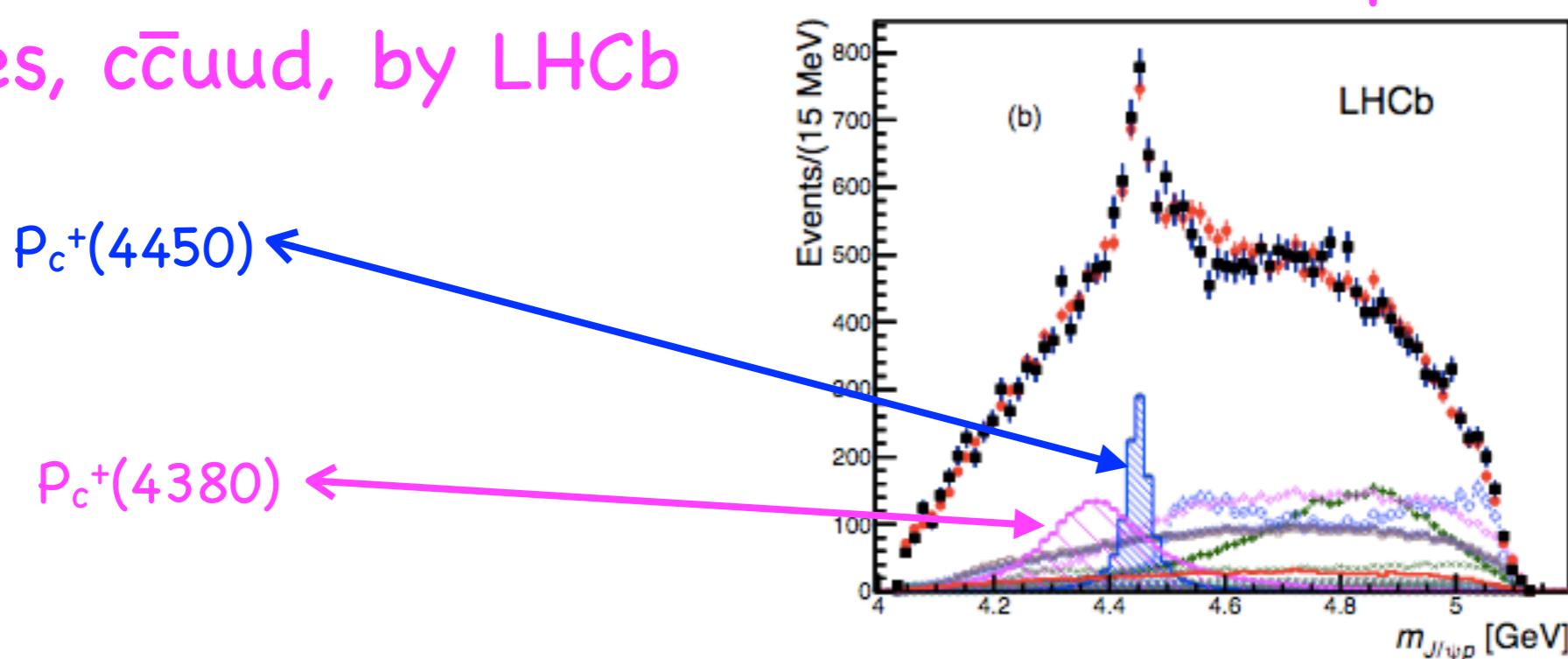
- 2011: Observation of $Z_b^+(10610)$ by Belle: the first beauty charged tetraquark state: $J^P=1^+$, $M=(10,607 \pm 2)$ MeV, $\Gamma=(18.4 \pm 2.4)$ MeV

$$M_{B^*} + M_B = 10,605 \text{ MeV} \Rightarrow Z_b^+(10610) \leftrightarrow Z_c^+(3900)$$

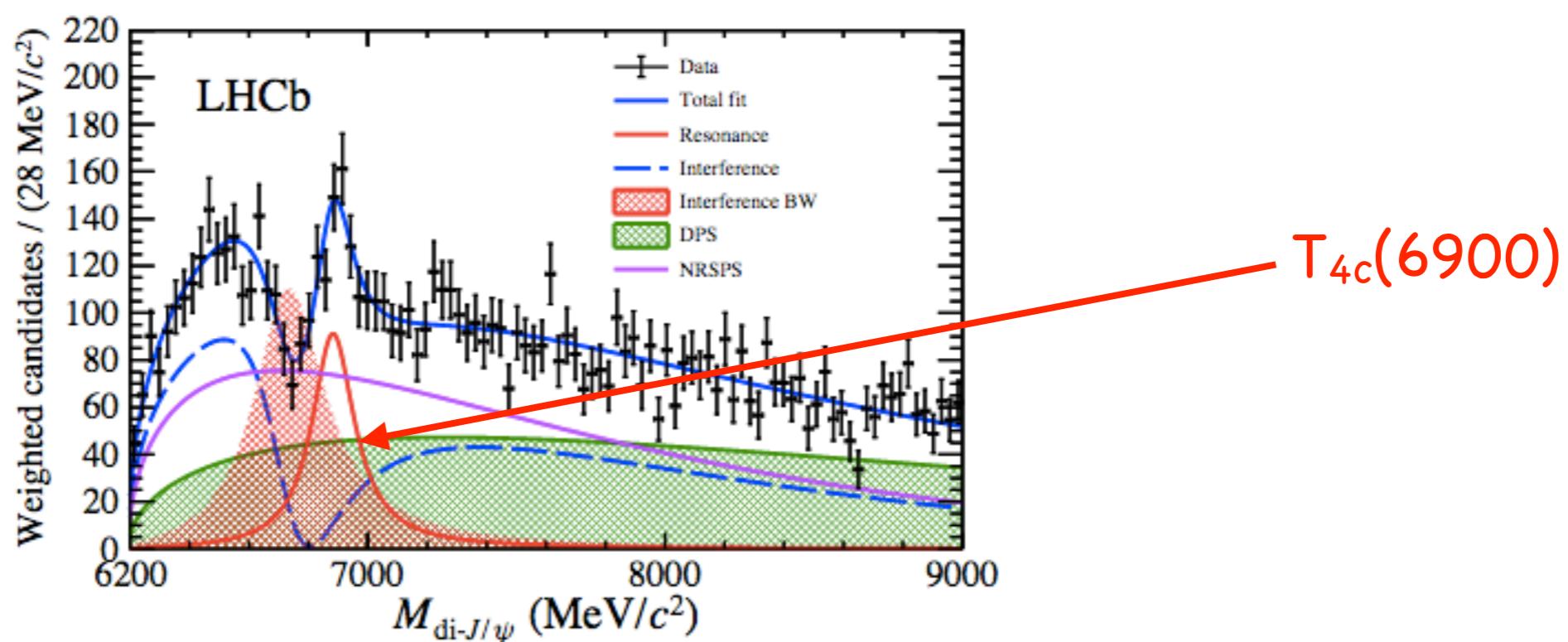
2b or not to be, Navarra, MN, Richard (arXiv:1108.1230)



- 2015: Observation of the first charmed pentaquark states, $c\bar{c}uud$, by LHCb



- 2020: Observation of the $X(c\bar{c}\bar{c}\bar{c})$ by LHCb.

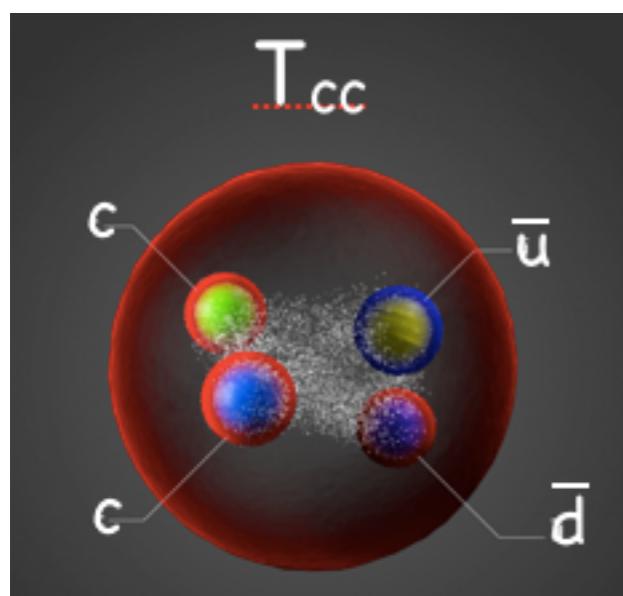


- 2020: Observation of $Z_{cs}^-(3985) \rightarrow D_s^{*-} D^0$ by BESIII.
The first strange charged tetraquark state.



- 07/2021: Observation of T_{cc} : a double charmed tetraquark

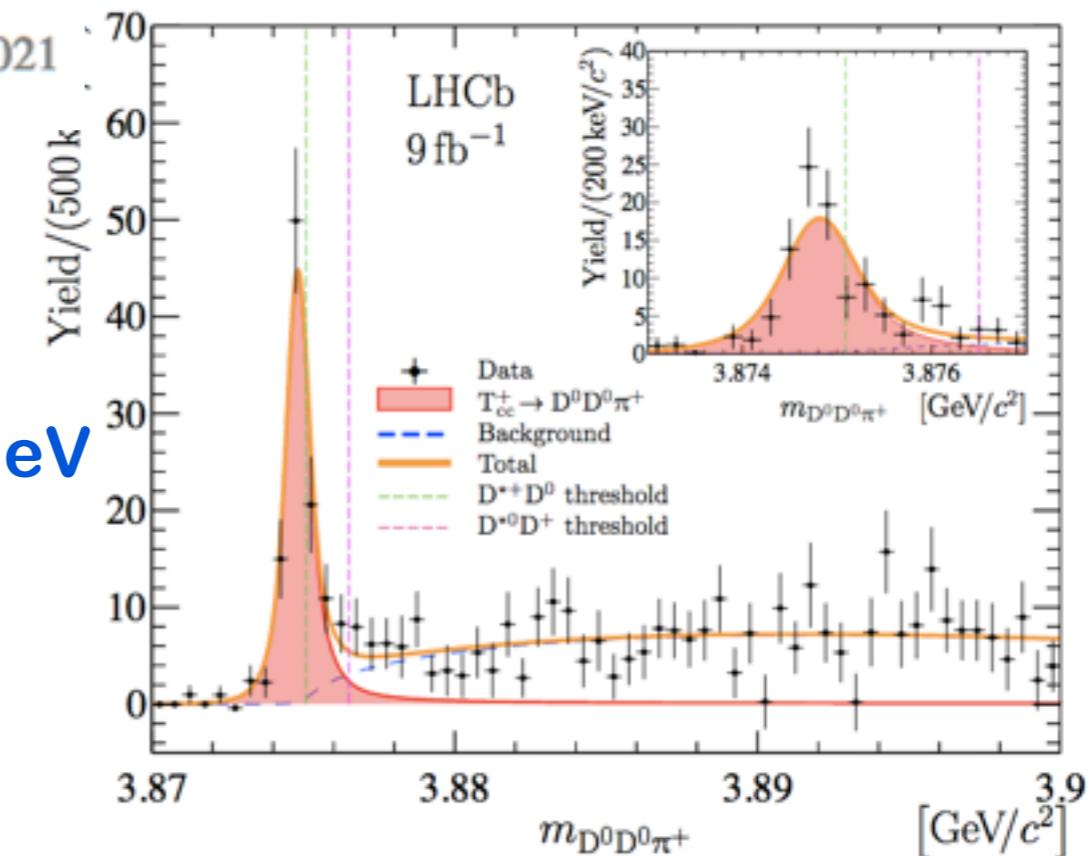
arXiv:2109.01038v2 [hep-ex] 3 Sep 2021



$$M = (3874.817 \pm 0.061) \text{ MeV}$$

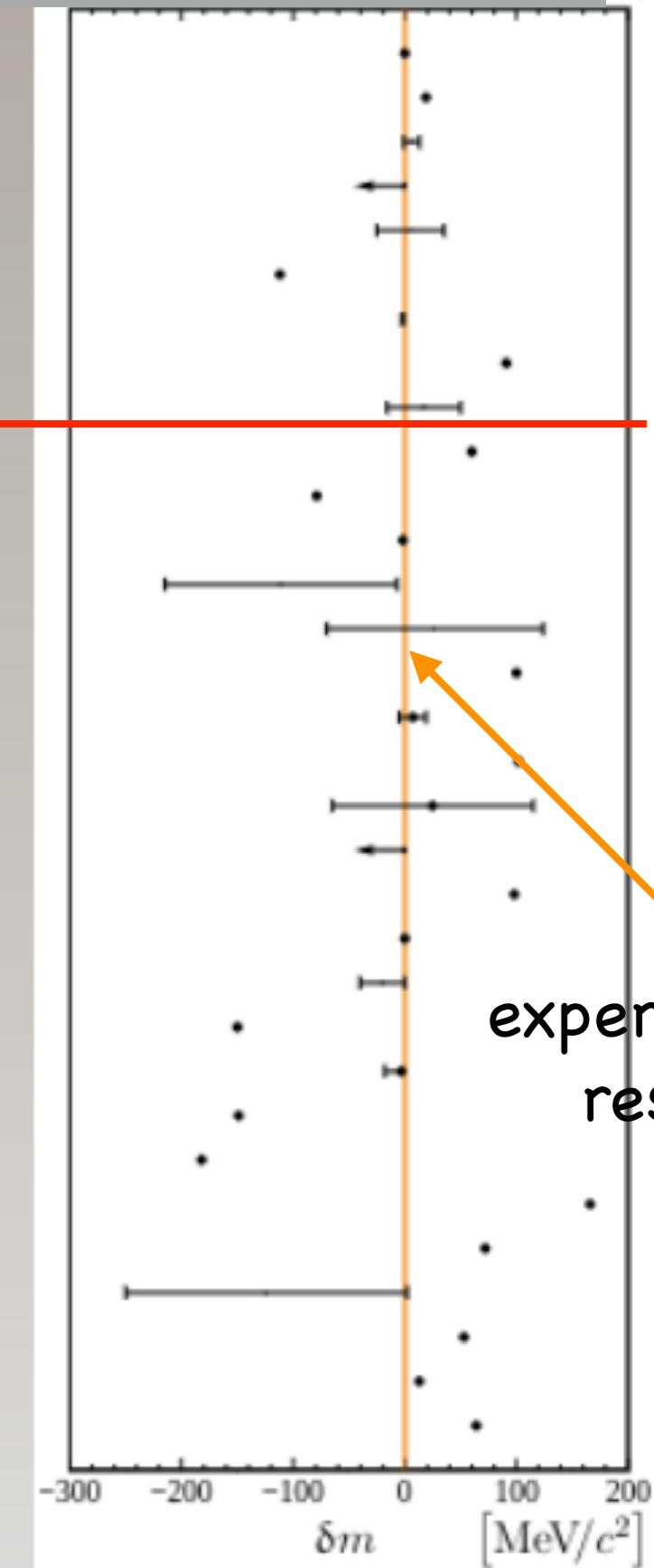
$$\Gamma = (0.410 \pm 0.170) \text{ MeV}$$

$$J^P = 1^+$$



Theoretical Predictions for T_{cc}

Reference		Year	$\delta'm$ [MeV/c ²]
J. Carlson, L. Heller and J. A. Tjon	36	1987	~ 0
B. Silvestre-Brac and C. Semay	37	1993	+19
C. Semay and B. Silvestre-Brac	38	1994	[-1, +13]
S. Pepin, F. Stancu, M. Genovese and J. M. Richard	39	1996	< 0
B. A. Gelman and S. Nussinov	40	2002	[-25, +35]
J. Vijande, F. Fernandez, A. Valcarce, A. and B. Silvestre-Brac	41	2003	-112
D. Janc and M. Rosina	42	2004	[-3, -1]
F. Navarra, M. Nielsen and S. H. Lee	43	2007	+91
J. Vijande, E. Weissman, A. Valcarce	44	2007	[-16, +50]
D. Ebert, R. N. Faustov, V. O. Galkin and W. Lucha	45	2007	+60
S. H. Lee and S. Yasui	46	2009	-79
Y. Yang, C. Deng, J. Ping and T. Goldman	47	2009	-1.8
G.-Q. Feng, X.-H. Guo and B.-S. Zou	48	2013	-215
Y. Ikeda, B. Charron, S. Aoki, T. Doi, T. Hatsuda, T. Inoue, N. Ishii, K. Murano, H. Nemura and K. Sasaki	49	2013	[-70, +124]
S.-Q. Luo, K. Chen, X. Liu, Y.-R. Liu and S.-L. Zhu	50	2017	+100
M. Karliner and J. Rosner	51	2017	$7 \pm 12 \rightarrow 1$
E. J. Eichten and C. Quigg	52	2017	+102
Z. G. Wang	53	2017	$+25 \pm 90$
G. K. C. Cheung, C. E. Thomas, J. J. Dudek and R. G. Edwards	54	2017	$\lesssim 0$
W. Park, S. Noh and S. H. Lee	55	2018	+98
A. Francis, R. J. Hudspith, R. Lewis and K. Maltman	56	2018	~ 0
P. Junnarkar, N. Mathur and M. Padmanath	57	2018	[-40, 0]
C. Deng, H. Chen and J. Ping	58	2018	-150
M.-Z. Liu, T.-W. Wu, V. Pavon Valderrama, J.-J. Xie and L.-S. Geng	59	2019	-3^{+4}_{-15}
G. Yang, J. Ping and J. Segovia	60	2019	-149
Y. Tan, W. Lu and J. Ping	61	2020	-182
Q. F. Li, D.-Y. Chen and Y.-B. Dong	62	2020	+166
E. Braaten, L. P. He and A. Mohapatra	63	2020	+72
D. Gao, D. Jia, Y.-J. Sun, Z. Zhang, W.-N. Liu and Q. Mei	64	2020	[-250, +2]
J.-B. Cheng, S.-Y. Li, Y.-R. Liu, Z.-G. Si, T. Yao	65	2020	+53
S. Noh, W. Park and S. H. Lee	66	2021	+13
R. N. Faustov, V. O. Galkin and E. M. Savchenko	67	2021	+64



experimental
result

1987

2007

2021

QCD Sum Rule

Fundamental Assumption: Principle of Duality

$$\Pi(q) = i \int d^4x e^{iq \cdot x} \langle 0 | T[j(x)j^\dagger(0)] | 0 \rangle$$

Theoretical side

quark level
quark and gluon
degrees of freedom

Wilson OPE

Phenomenological side

hadron level
hadron parameters
(masses, couplings,
form-factors,...)

dispersion relation

$$\Pi_i^{phen} \leftrightarrow \Pi_i^{OPE}$$

$$\Pi^{phen} = -\lambda^2 \frac{1}{m^2 - q^2} + \text{continuum}$$

$\lambda \Rightarrow$ coupling current-state

$$\Pi^{OPE}(q^2) = \int_{s_{min}}^{\infty} ds \frac{\rho^{OPE}(s)}{s - q^2}, \quad \rho^{OPE}(s) = \frac{1}{\pi} \text{Im}[\Pi^{OPE}]$$

Continuum

s_0 : continuum parameter

$$\Pi^{phen}(Q^2) \leftrightarrow \Pi^{OPE}(Q^2)$$

valid at small Q^2

valid at large Q^2

To improve the matching \Rightarrow Borel transform

Borel Transform {

- eliminates subtraction terms
- suppresses higher order condensates
- increases importance pole contribution

$$\lambda^2 e^{-m^2/M^2} = \int_{s_{min}}^{s_0} ds e^{-s/M^2} \rho^{OPE}(s)$$

$$m^2 = \frac{\int_{s_{min}}^{s_0} ds s \rho_i^{OPE}(s) e^{-s/M^2}}{\int_{s_{min}}^{s_0} ds \rho_i^{OPE}(s) e^{-s/M^2}}$$

Good Sum Rule \rightarrow Borel window such that:

- pole contribution > continuum contribution
- good OPE convergence
- good Borel stability

OPE side: condensates

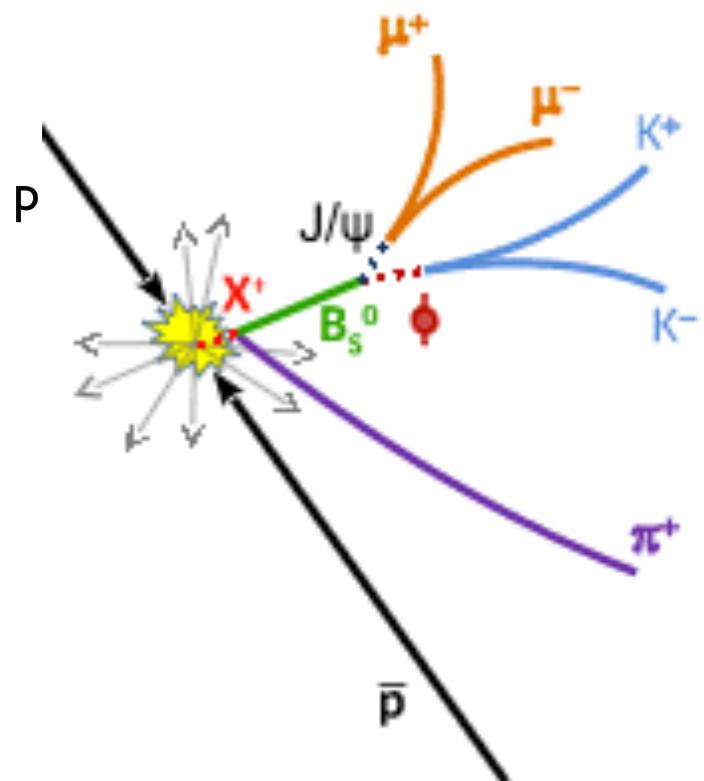
{

- quark condensate
- gluon condensate
- mixed condensates
- four-quark condensate

With QCDSR one can get anything

not true!

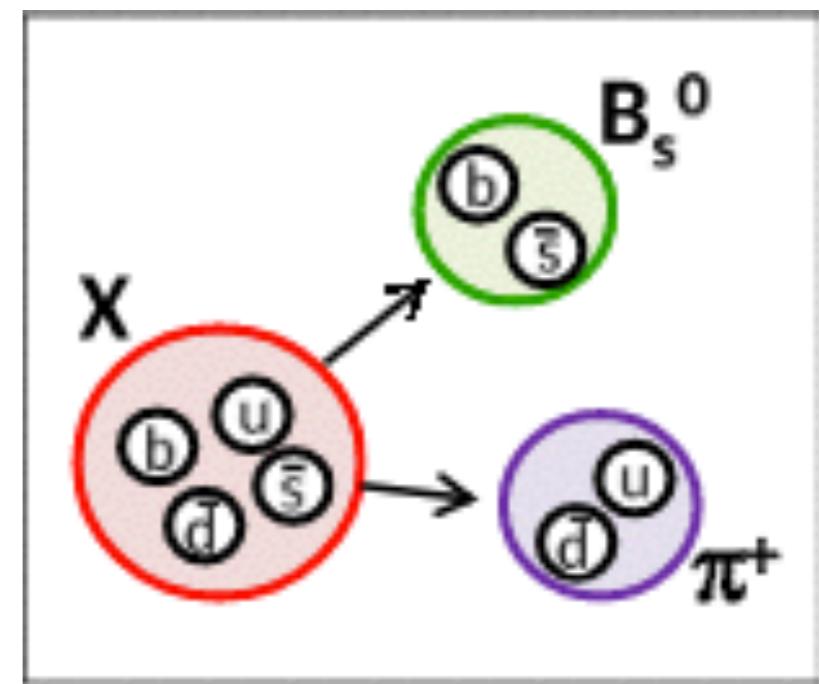
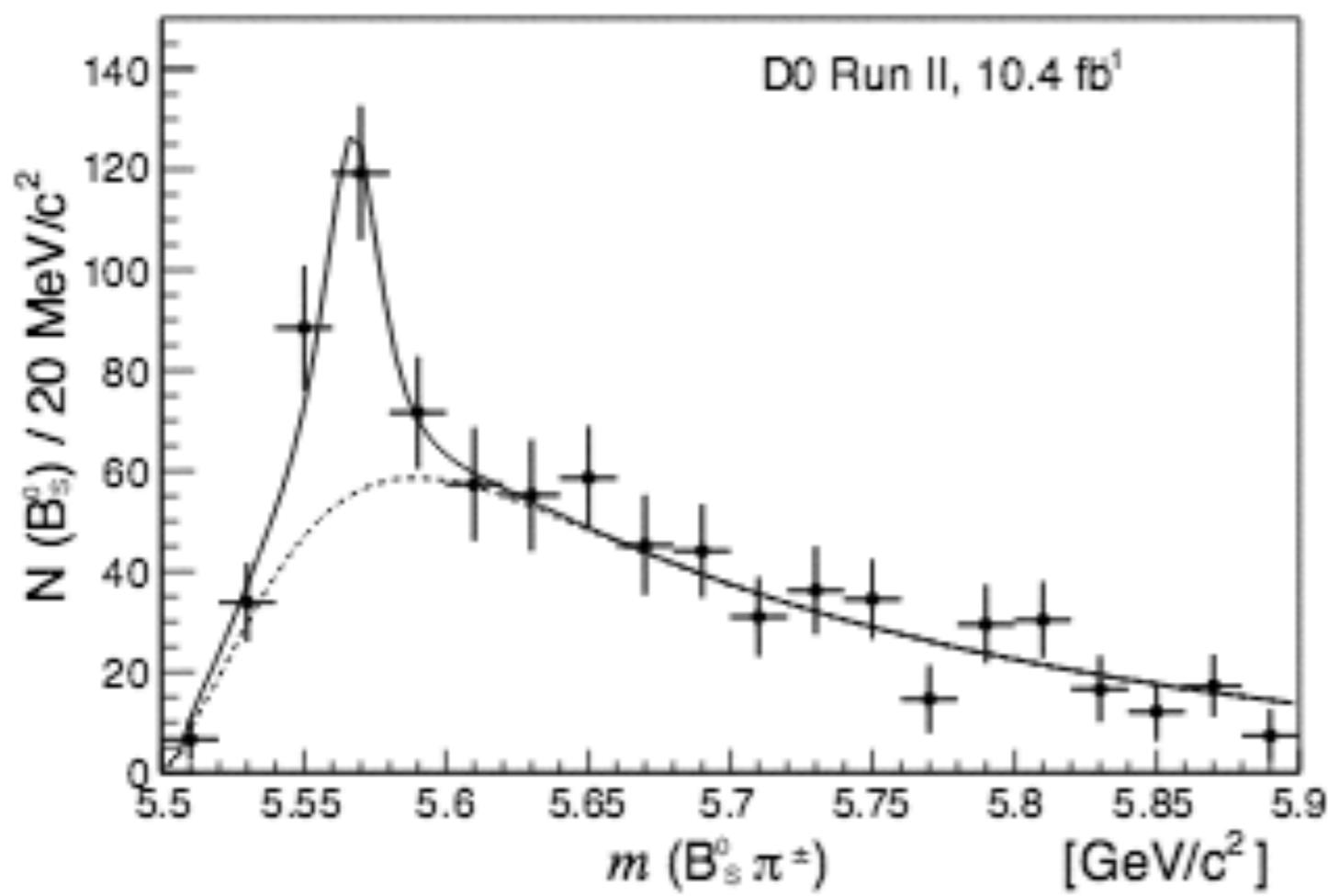




$X^\pm(5568)$

Phys. Rev. Lett. 117, 022003 (2016).

$$X^\pm(5568) \rightarrow B_s^0 \pi^\pm$$



$M = (5567.8 \pm 2.9 \pm 1.2) \text{ MeV}$
 $\Gamma = (21.9 \pm 6.4 \pm 3.5) \text{ MeV}$
 stat. significance 5.1σ

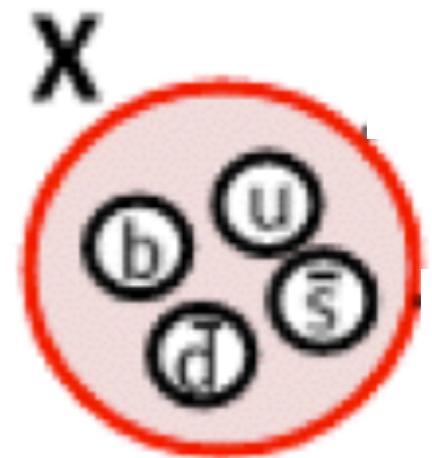
QCDSR calculation for $X^+(5568)$ mass

Khemchandani, MN, Zanetti: arXiv:1602.09041

tetraquark current
with $J^P = 0^+$

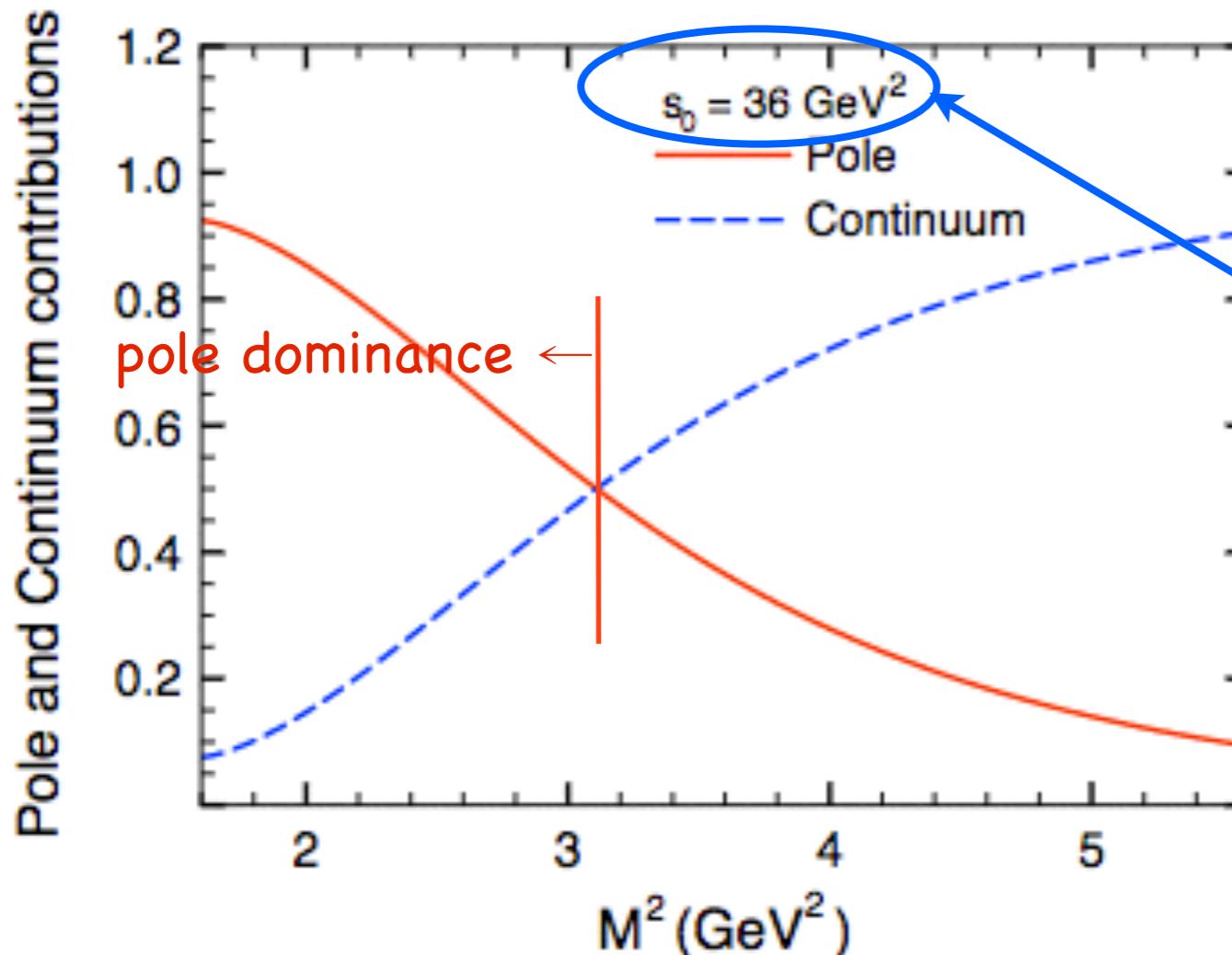
$$j_X = \epsilon_{abc} \epsilon_{dec} (u_a^T C \gamma_5 b_b) (\bar{d}_d \gamma_5 C \bar{s}_e^T)$$

$$\Pi(q) = i \int d^4x e^{iq \cdot x} \langle 0 | j_X(x) j_X^\dagger(0) | 0 \rangle$$



$$\Pi(x) = f (S^u(x) S^d(-x) S^s(x) S^b(-x))$$

OPE for the quark propagator

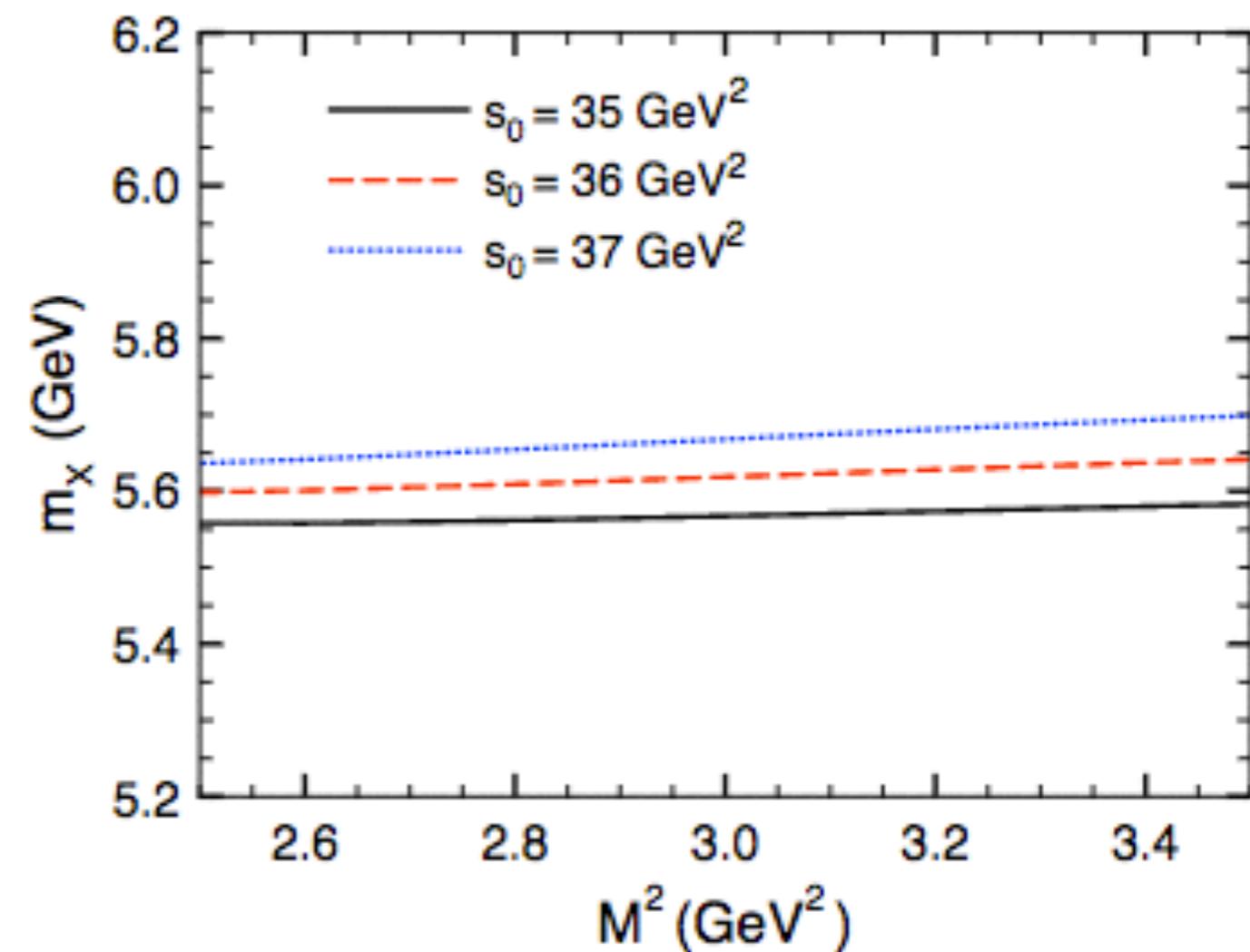


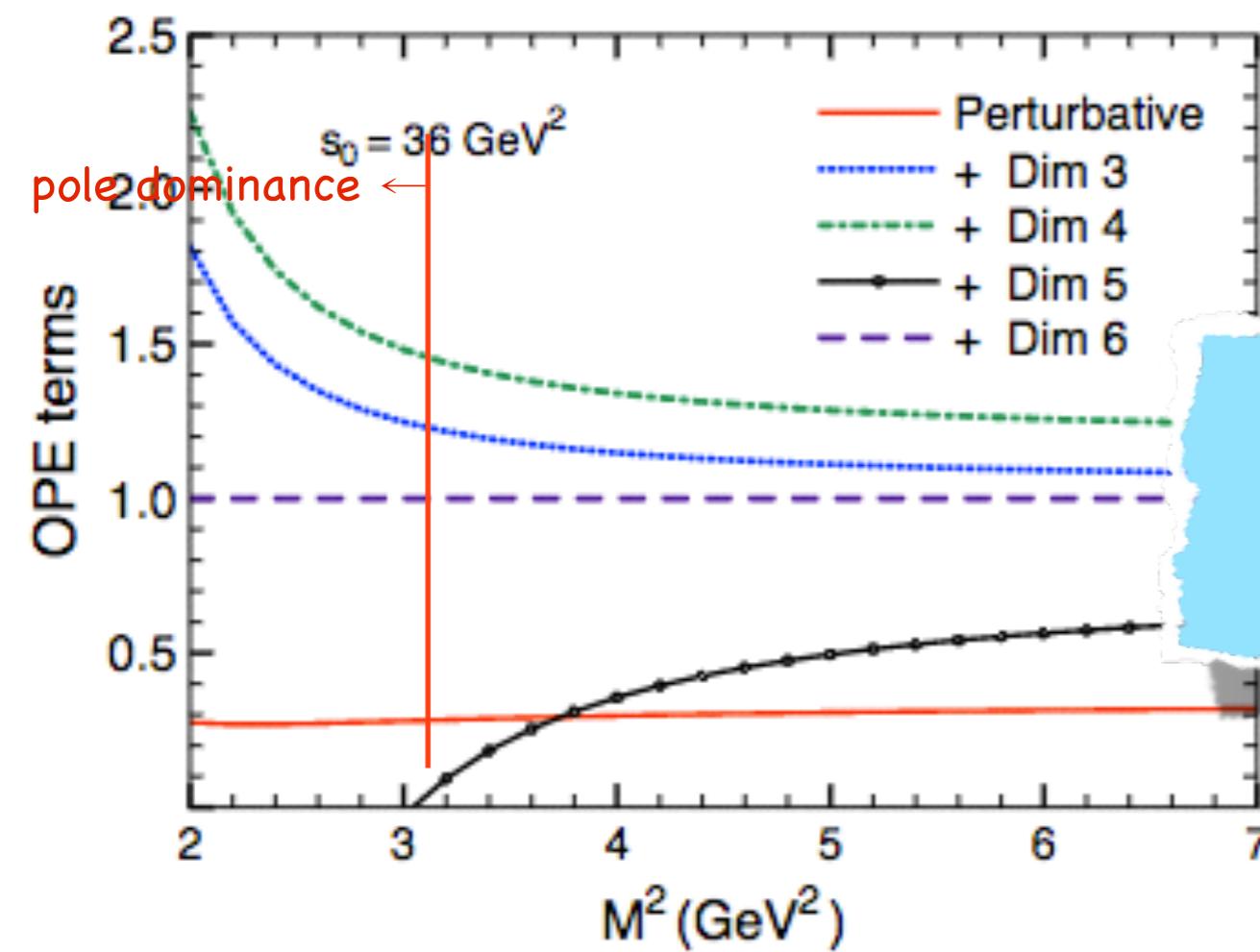
Khemchandani, MN, Zanetti:
arXiv:1602.09041

$s_0?$ In general
 $s_0 = (m_x + 0.5 \text{ GeV})^2$

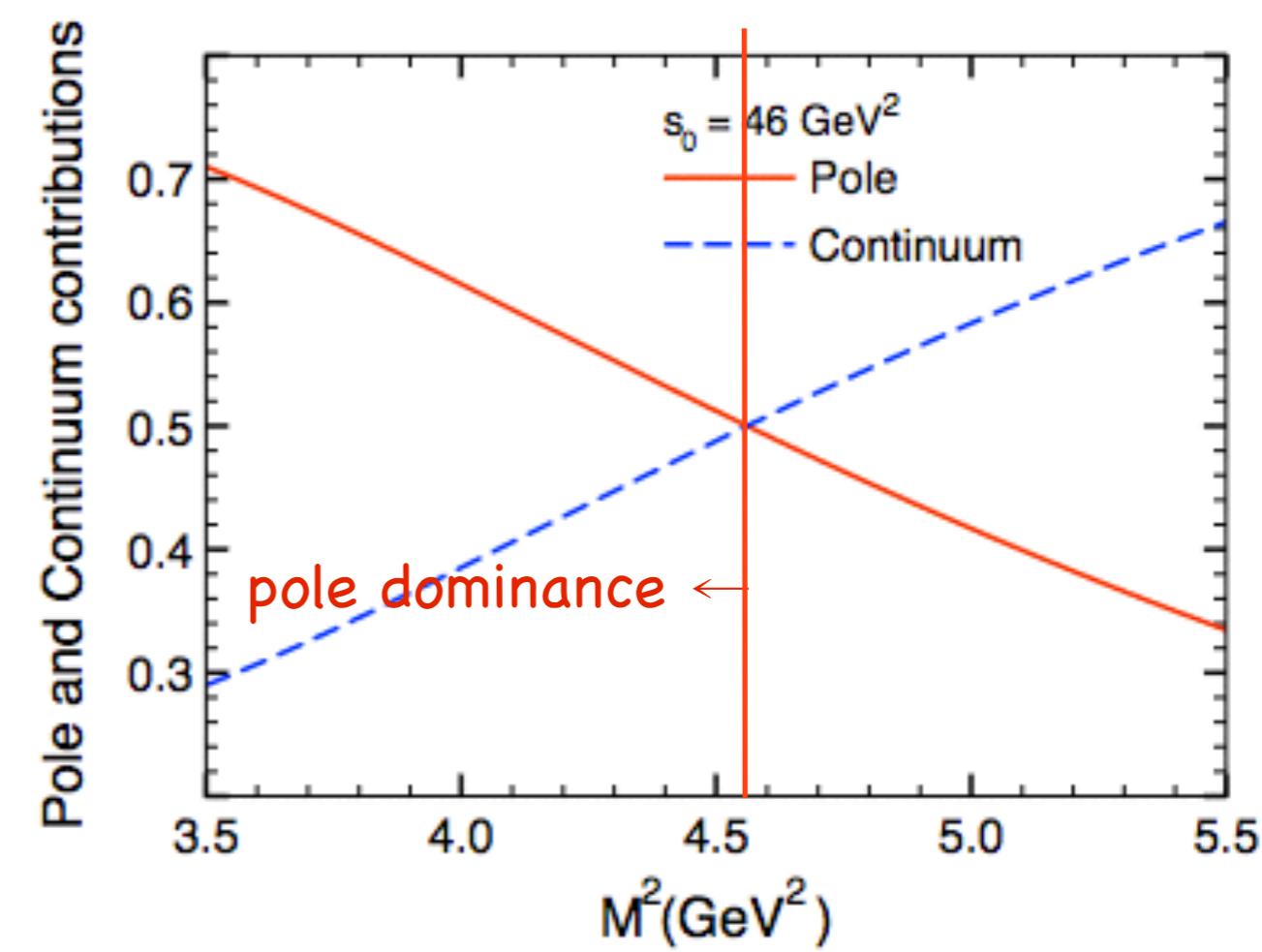
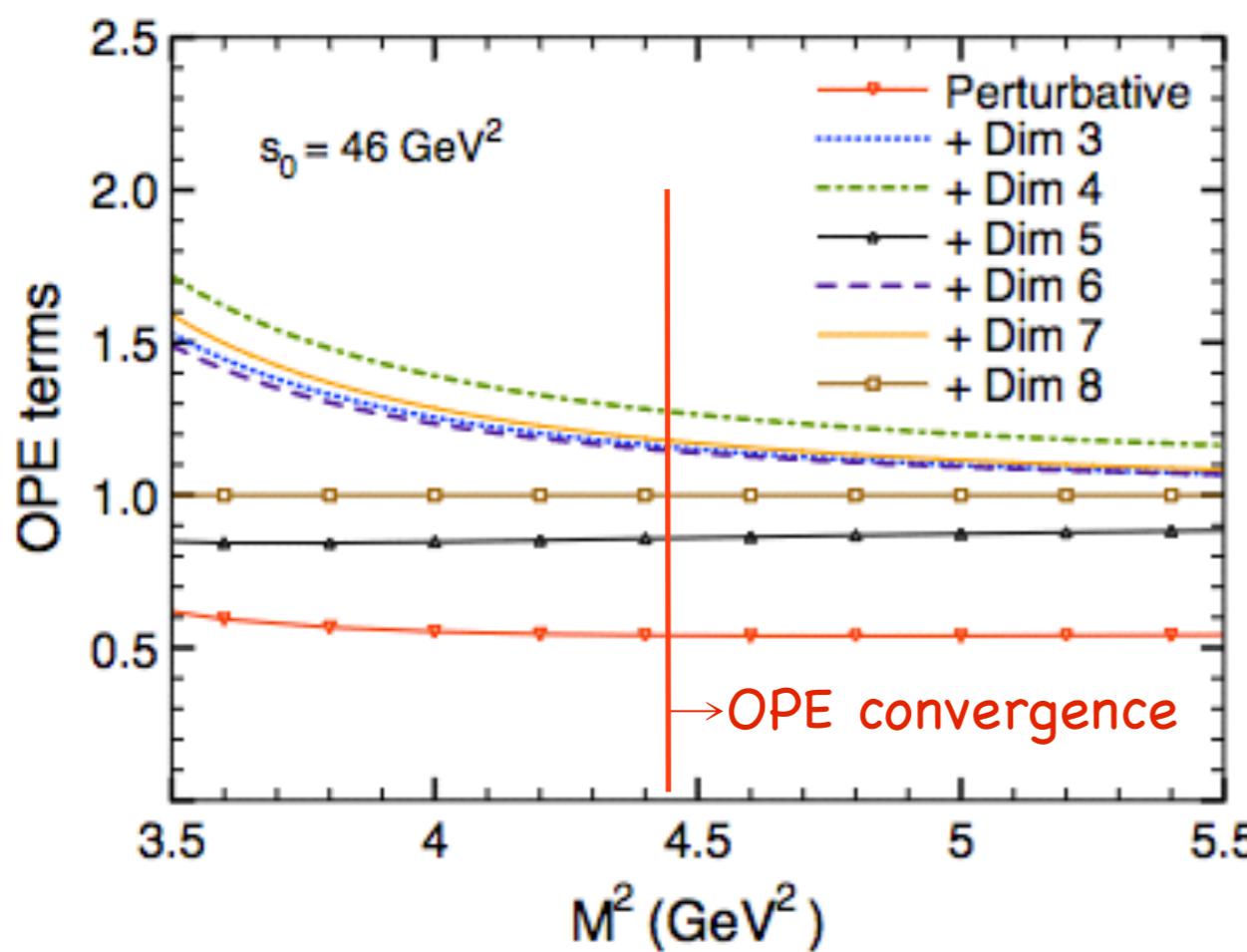
$m_x = (5.58 \pm 0.17) \text{ GeV}$

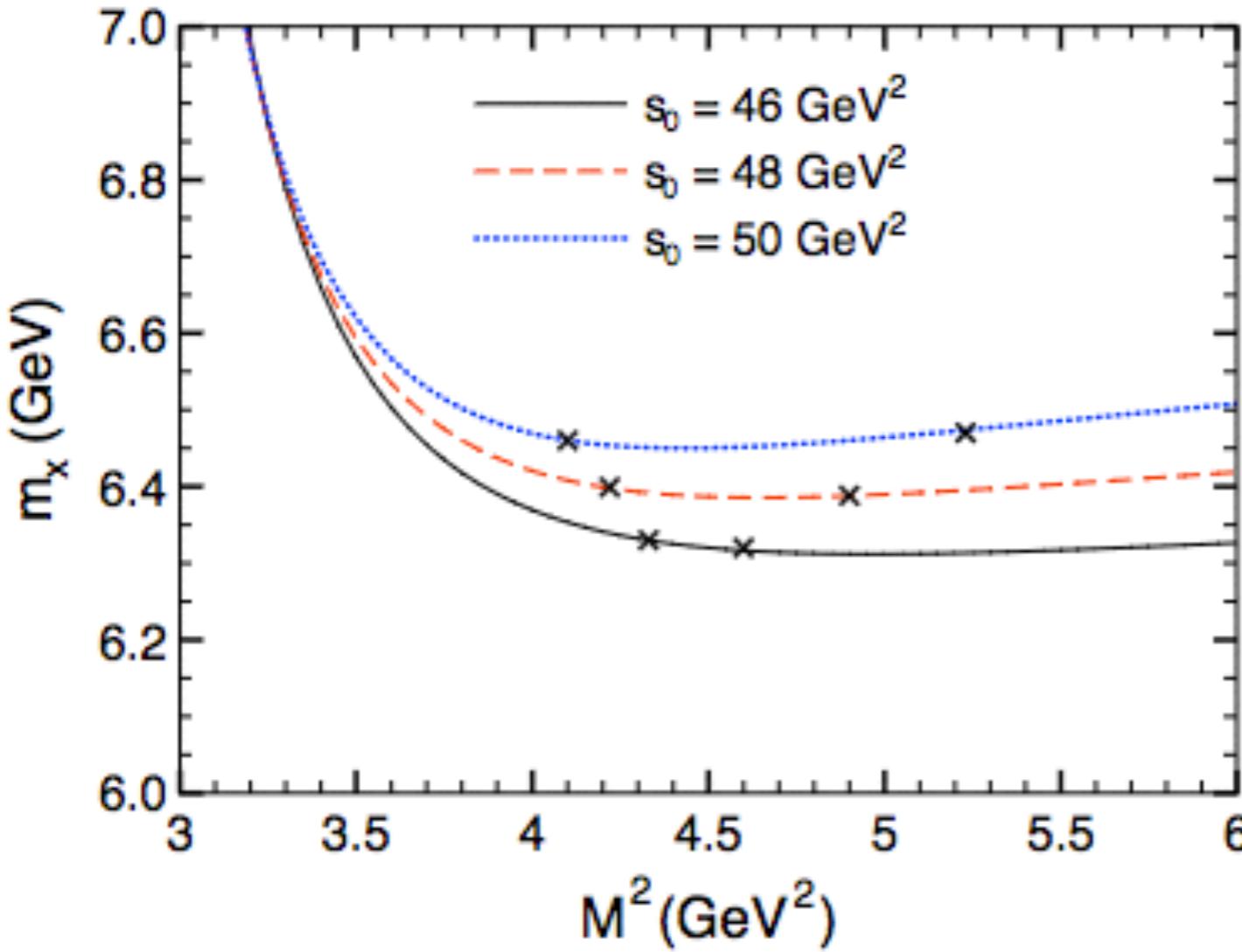
OPE convergence?





No OPE convergence for
 $s_0 < 46 \text{ GeV}^2$





Khemchandani, MN, Zanetti
Phys. Rev. D 93, 096011 (2016)

$m_x = (6.39 \pm 0.10) \text{ GeV}$

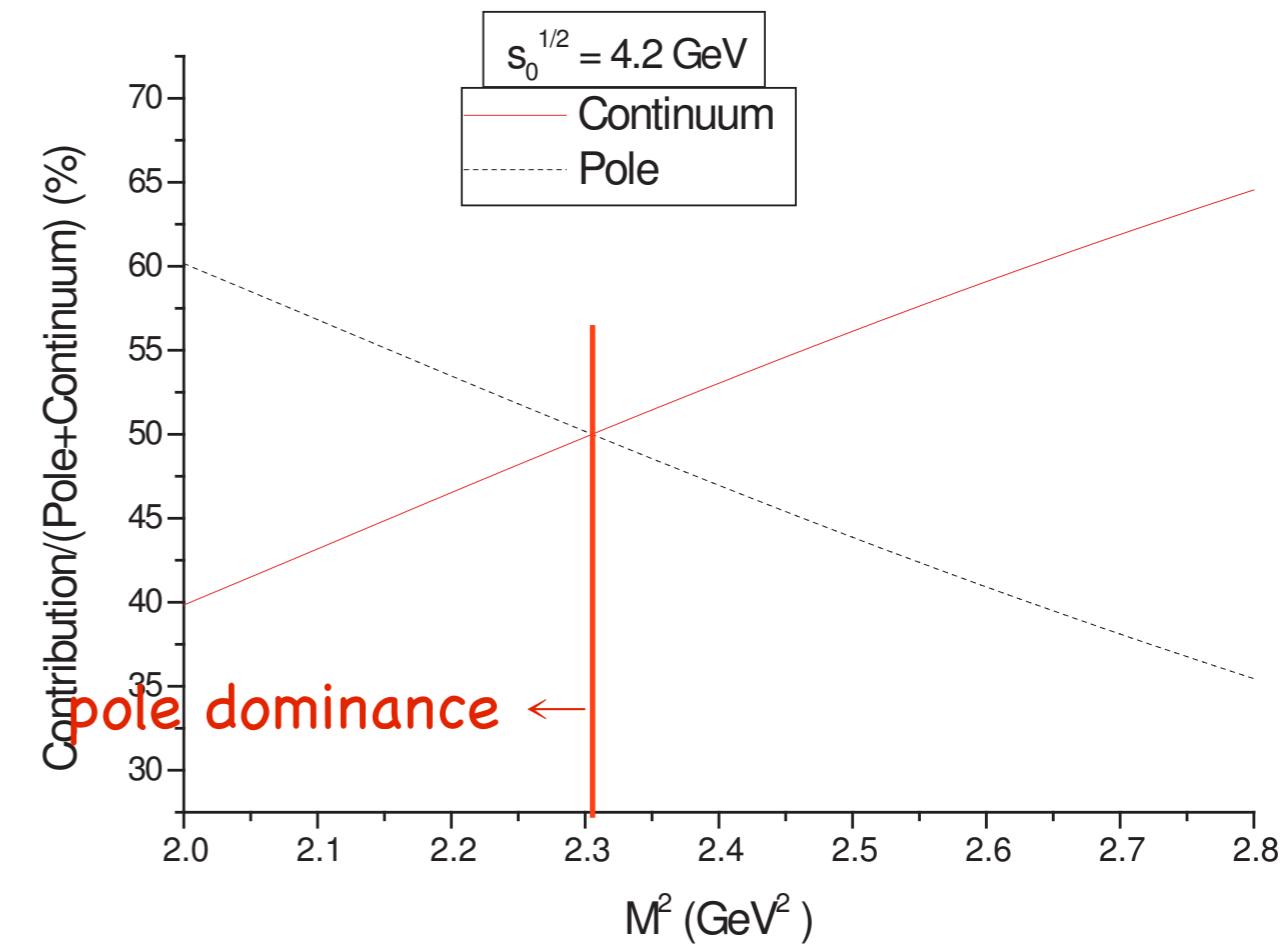
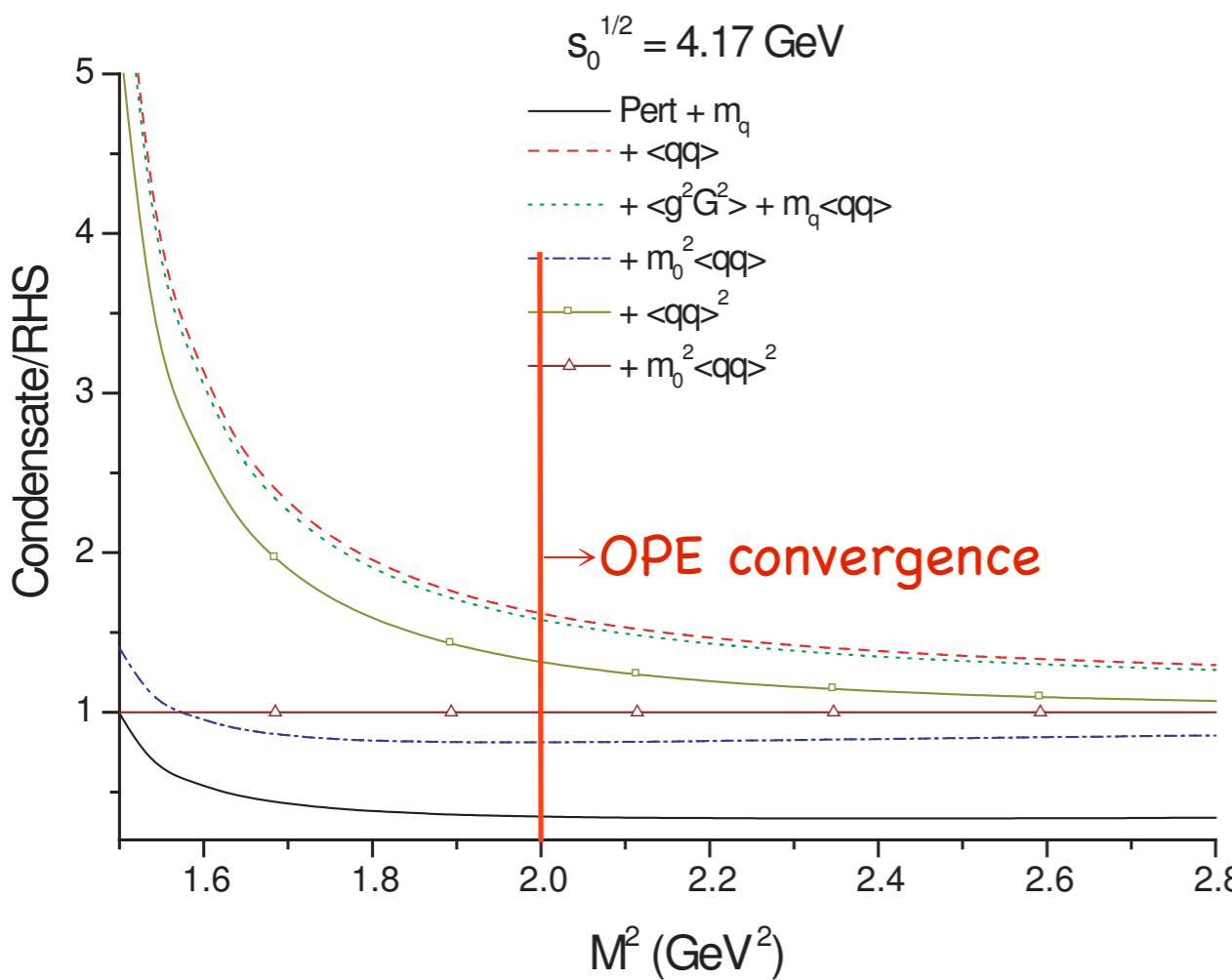
not compatible with
 $X(5568)$ mass!

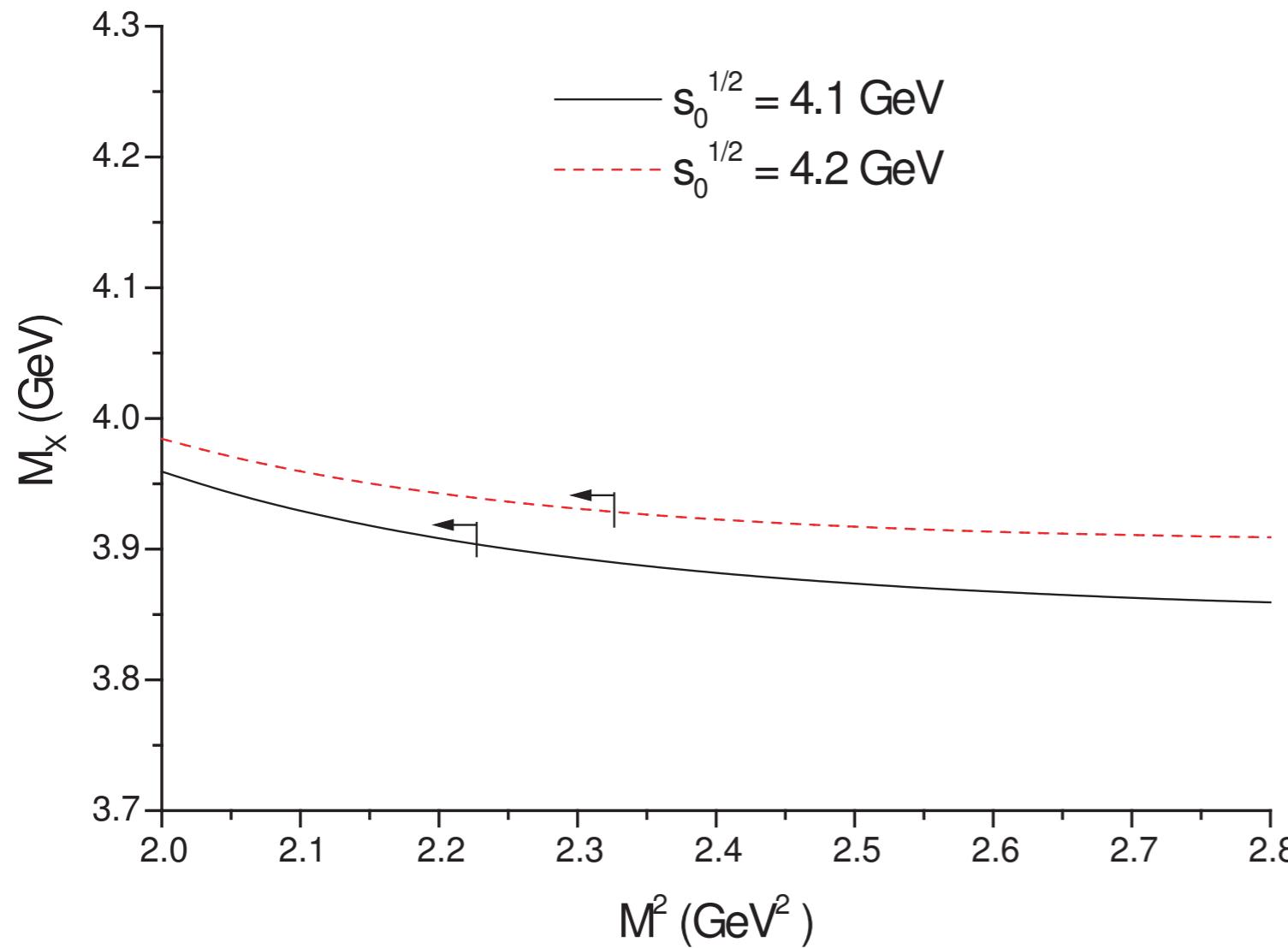
LHCb (Phys. Rev. Lett. 118, 109904 (2017)), CDF (Phys. Rev. Lett. 120, 202006 (2018)) and ATLAS (Phys. Rev. Lett. 120, 202007(2018)): no structure is found from $B_s^0 \pi^+$ from threshold up to 6000 MeV

First QCD Sum Rule Calculation for X(3872)

Matheus, Narison, MN, Richard: tetraquark current (PRD75(07)014005)

$$j_\mu = \frac{i\epsilon_{abc}\epsilon_{dec}}{\sqrt{2}} [(q_a^T C \gamma_5 c_b)(\bar{q}_d \gamma_\mu C \bar{c}_e^T) + (q_a^T C \gamma_\mu c_b)(\bar{q}_d \gamma_5 C \bar{c}_e^T)]$$





$$m_X = (3.92 \pm 0.13) \text{ GeV}$$

Prediction for X_b :

$$m_{X_b} = (10.26 \pm 0.30) \text{ GeV}$$

Lee, MN, Wiedner: $D^0 \bar{D}^{*0}$ molecular current (arXiv:0803.1168)

$$j_\mu^{(q,mol)}(x) = \frac{1}{\sqrt{2}} \left[(\bar{q}_a(x) \gamma_5 c_a(x) \bar{c}_b(x) \gamma_\mu q_b(x)) - (\bar{q}_a(x) \gamma_\mu c_a(x) \bar{c}_b(x) \gamma_5 q_b(x)) \right]$$

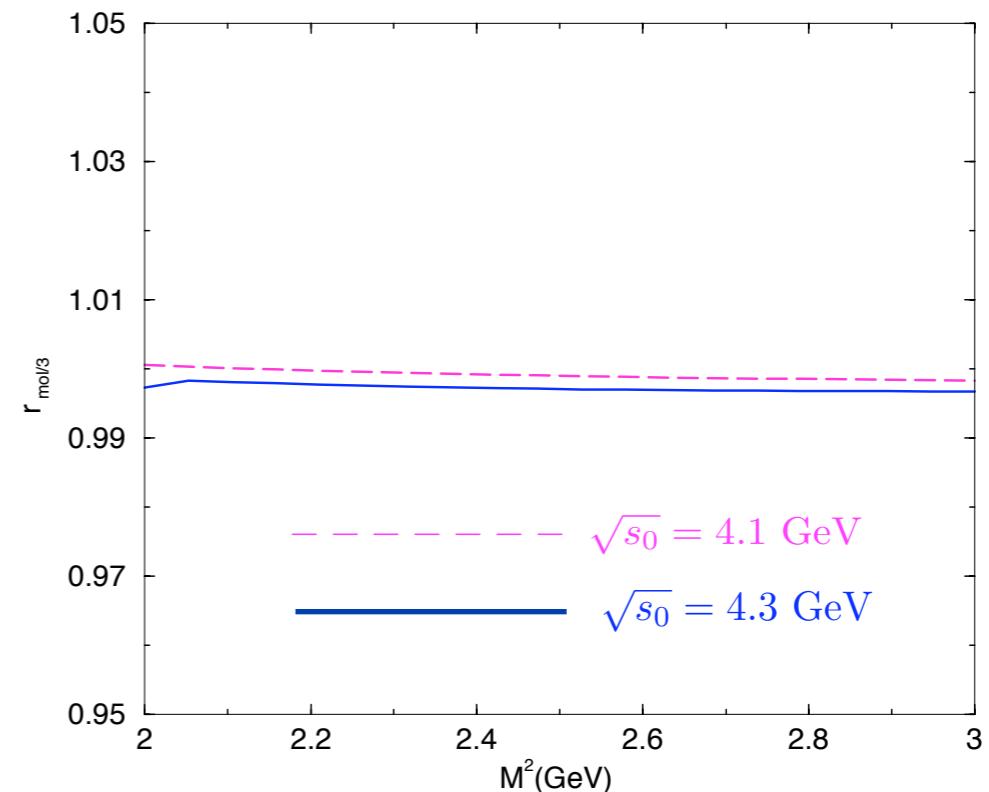
$$m_X = (3.87 \pm 0.07) \text{ GeV}$$

double-ratio sum rules:

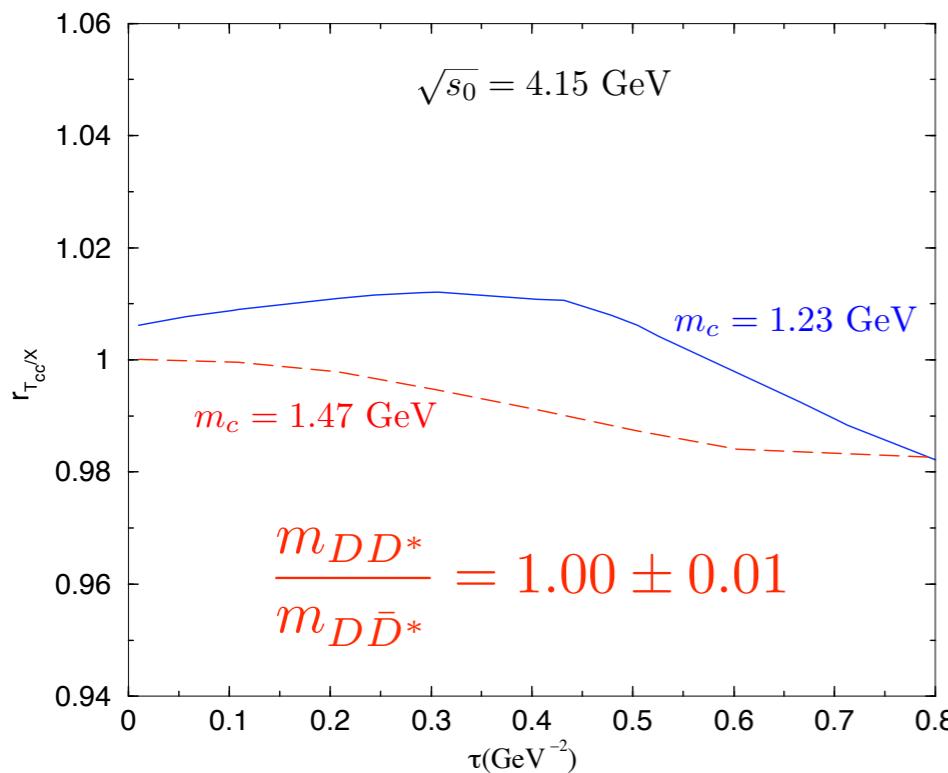
$$r_{mol/3} = \frac{M_{mol}}{M_3}$$

Narison, Navarra, MN, PRD83(11)016004

differences smaller than 0.01%



Since T_{cc} ($cc\bar{q}\bar{q}$) can be described by a DD^* current and $X(3872)$ ($c\bar{c}q\bar{q}$) by a $\bar{D}D^*$ current, similar comparison can also be made for X and T_{cc} states.



Dias, Narison, Navarra, MN, Richard
(arXiv:1105.5630)

Using the $X(3872)$ experimental mass our prediction for the T_{cc} mass is:

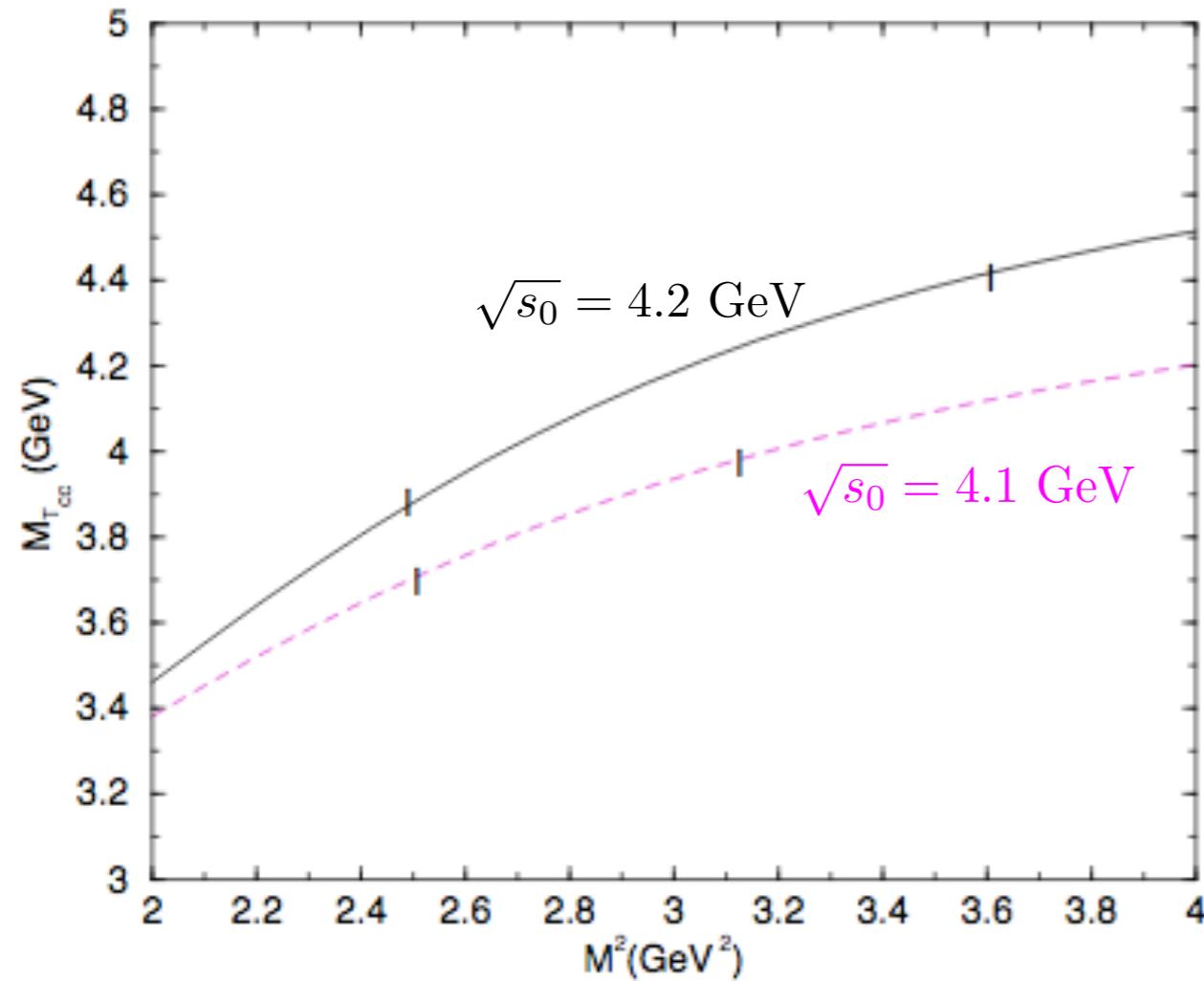
$$M_{T_{cc}} = (3872.2 \pm 39.5) \text{ MeV}$$

First QCD Sum Rule Prediction for T_{cc}

Navarra, MN, Lee, hep-ph/0703071

$$T_{cc}^+([cc][\bar{u}\bar{d}]) \ J^P = 1^+$$

Tetraquark current with $J^P = 1^+$



light antiquark: $\epsilon_{abc}[\bar{u}_b \gamma_5 C \bar{d}_c^T]$

heavy diquark: $\epsilon_{aef}[c_e^T C \gamma_\mu c_f]$

$$m_{T_{cc}} = (4.0 \pm 0.2) \text{ GeV}$$

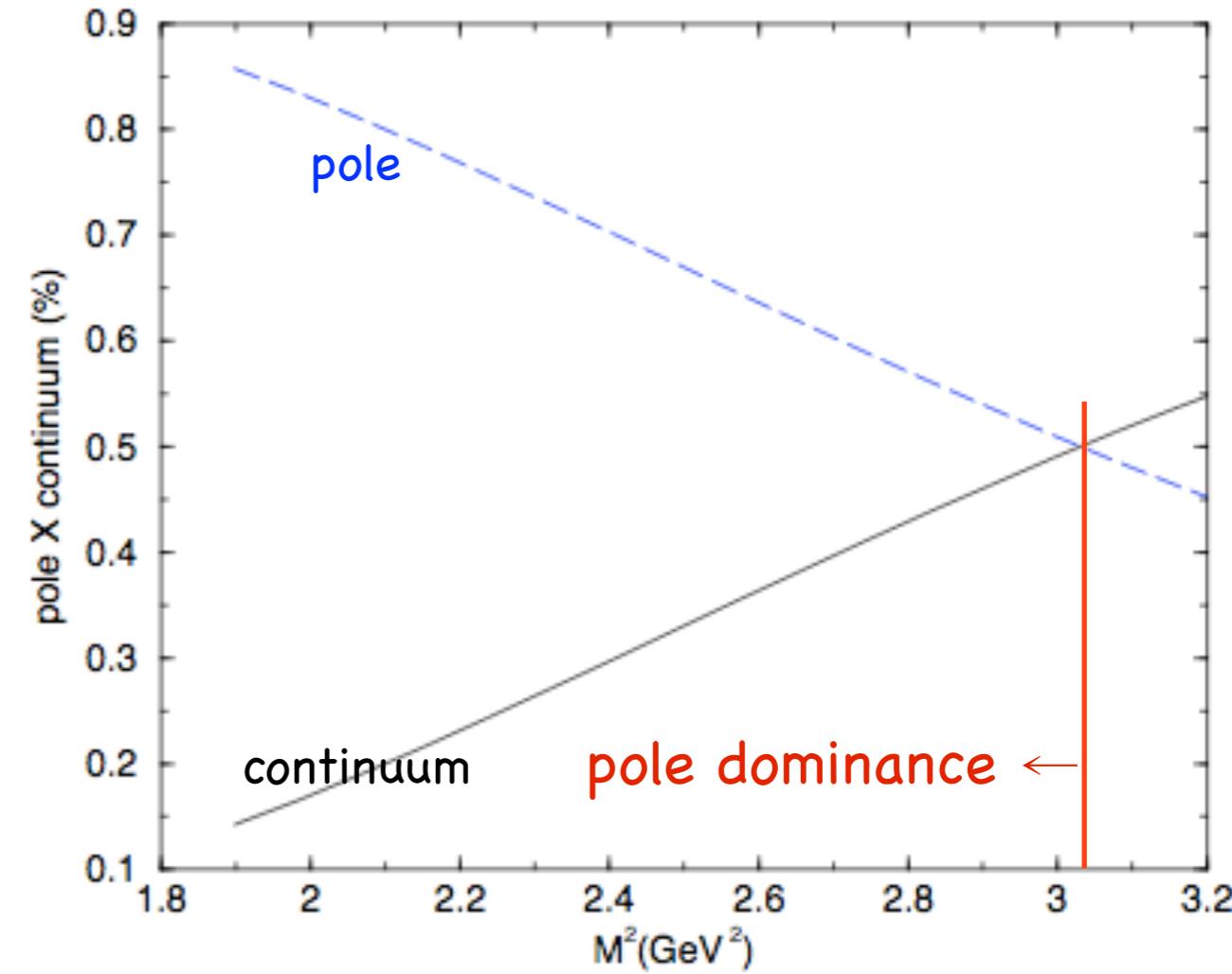
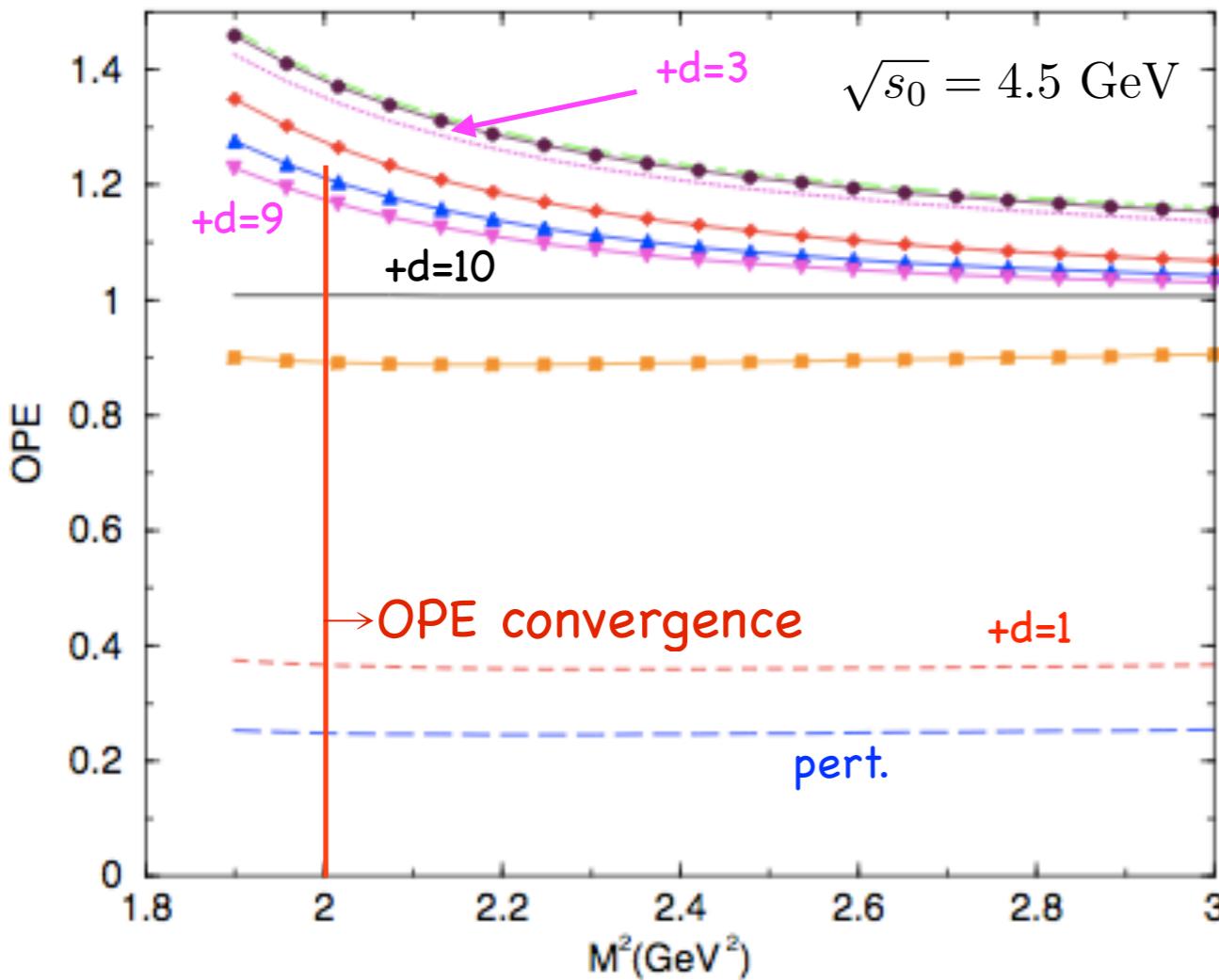
Prediction for T_{bb} :

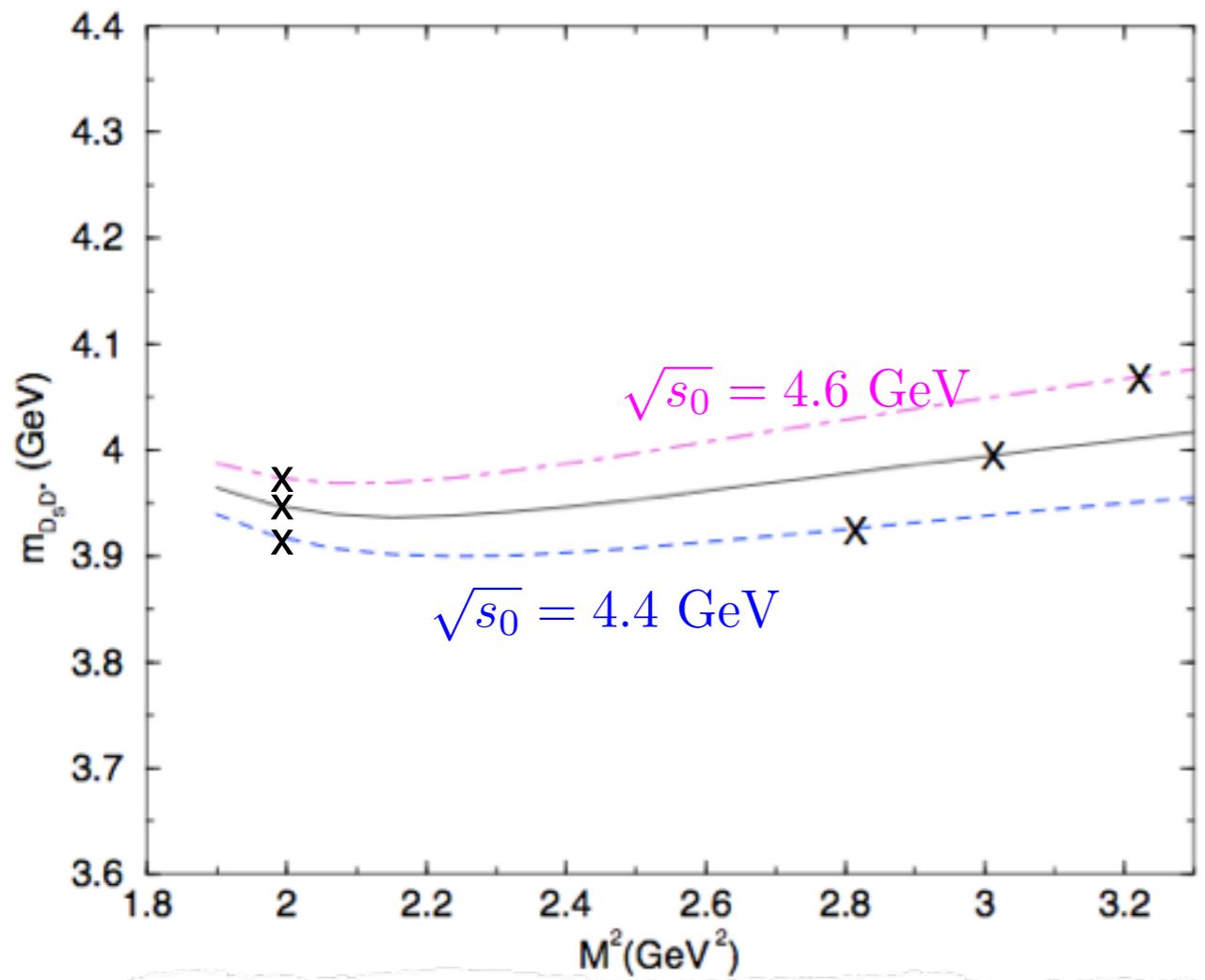
$$m_{T_{bb}} = (10.2 \pm 0.3) \text{ GeV}$$

Prediction for a Z_{cs}^+ state from QCD Sum Rule

Lee, MN, Wiedner, arXiv:0803.1168, $D_s^+ \bar{D}^*$ molecular current

$$j_\mu = \frac{i}{\sqrt{2}} [(\bar{s}_a \gamma_5 c_a)(\bar{c}_b \gamma_\mu d_b) - (\bar{s}_a \gamma_\mu c_a)(\bar{c}_b \gamma_5 d_b)] \quad (J^P = 1^+)$$





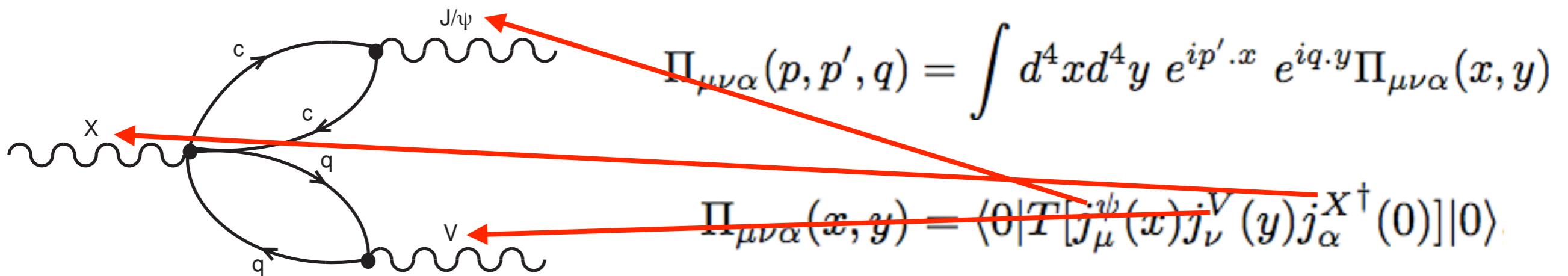
$$m_{Z_{cs}} = (3.97 \pm 0.08) \text{ GeV}$$

Lee, MN, Wiedner, arXiv:0803.1168

$$m_{Z_{cs}}^{exp} = (3.983 \pm 0.002) \text{ GeV}$$

arXiv:2011.07855

Decay width from QCD Sum Rule

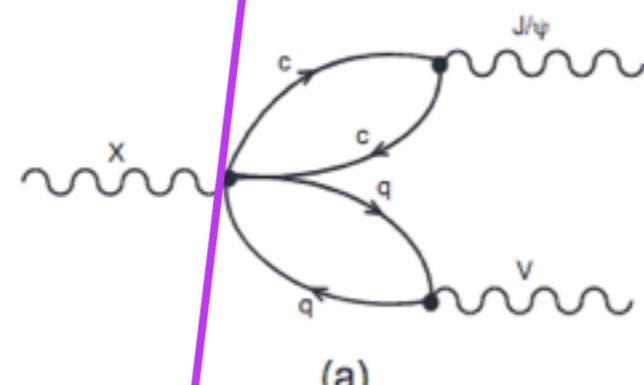


Decay width $X(3872) \rightarrow J/\psi \pi\pi$

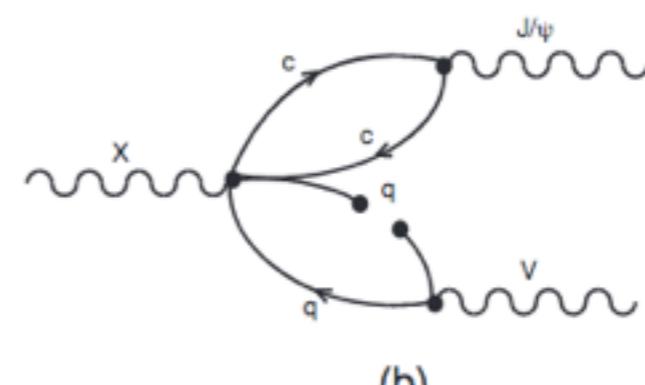
(Navarra, MN, PLB639 (06)272)

coupling constant

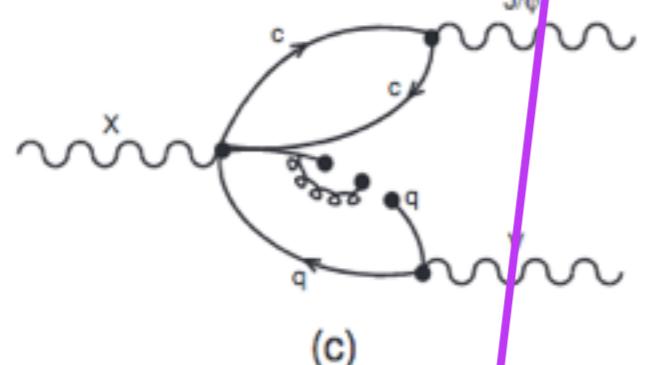
$$\Pi_i^{q(phen)} \frac{A_i g_{X\psi V}(q^2)}{(q^2 - m_V^2)(p^2 - m_X^2)(p'^2 - m_\psi^2)} + \int_{4m_c^2}^{\infty} \frac{\rho_i^{cont}(p^2, q^2, u)}{u - p'^2} du.$$



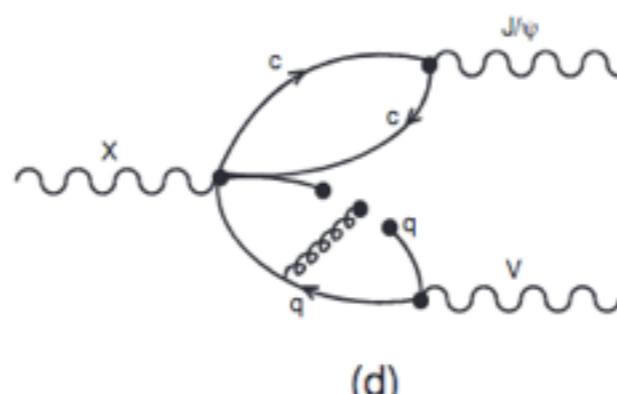
(a)



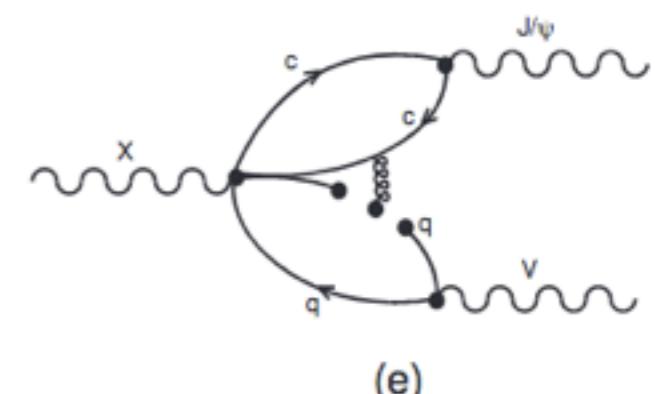
(b)



(c)



(d)

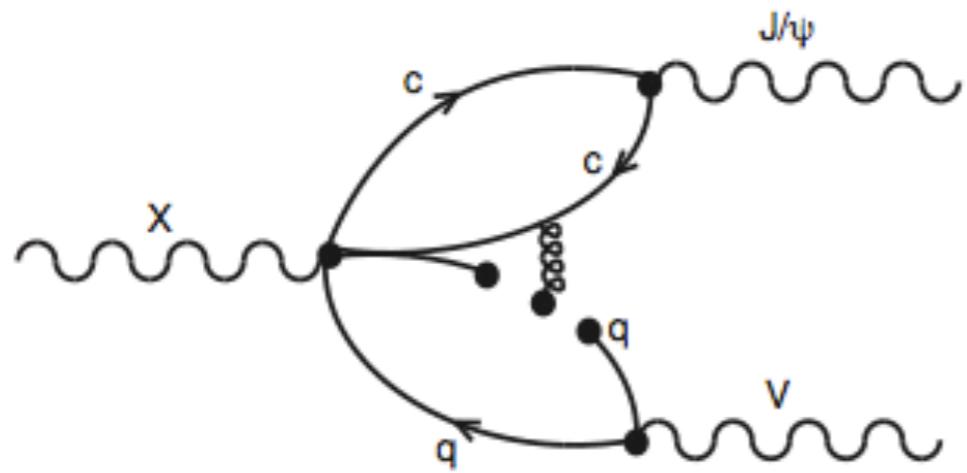


(e)

$$\Gamma(X \rightarrow J/\psi(n\pi)) \longrightarrow g_{X\psi V}$$

Problem: decay width $X \rightarrow J/\psi \pi\pi$
 $\sim 50 \text{ MeV}$

How to solve this problem?



If $X(3872)$ is a genuine tetraquark state, only color-connected diagrams will contribute

$$\Gamma_{CC}(X \rightarrow J/\psi (n\pi)) = (0.7 \pm 0.2) \text{ MeV}.$$

Navarra, MN, (PLB639(06)272)

Compatible with the experimental $X(3872)$
width: $\Gamma < 1.2 \text{ MeV}$

QCDSR Results for decay widths of the $Z_c^+(3900)$

Dias, Navarra, MN, Zanetti
arXiv:1304.6433

OPE side: only color-connected diagrams

Vertex	coupling constant (GeV)	decay width (MeV)
$Z_c^+(3900)J/\psi\pi^+$	3.89 ± 0.56	29.1 ± 8.2
$Z_c^+(3900)\eta_c\rho^+$	4.85 ± 0.81	27.5 ± 8.5
$Z_c^+(3900)D^+\bar{D}^{*0}$	2.5 ± 0.3	3.2 ± 0.7
$Z_c^+(3900)\bar{D}^0D^{*+}$	2.5 ± 0.3	3.2 ± 0.7

$$\Gamma_{Z_c^+} = (63 \pm 18) \text{ MeV}$$

$$\Gamma_{Z_c^+}^{BES} = (46 \pm 22) \text{ MeV}$$

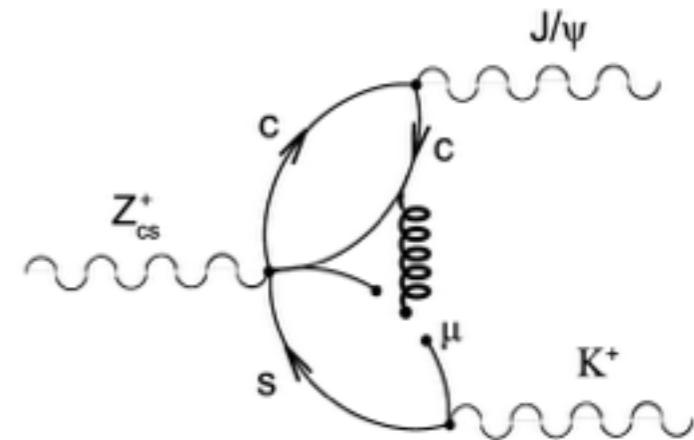
$$\Gamma_{Z_c^+}^{BELLE} = (63 \pm 35) \text{ MeV}$$

Very good agreement

QCDSR Prediction for the decay width of Z_{cs}^+

Dias, Liu, MN, arXiv:1307.7100

Again only color-connected diagrams were considered



Vertex	coupling constant (GeV)	decay width (MeV)
$Z_{cs}^+ J/\psi K^+$	2.58 ± 0.30	11.2 ± 3.5
$Z_{cs}^+ \eta_c K^{*+}$	3.4 ± 0.3	10.8 ± 6.2
$Z_{cs}^+ D_s^+ \bar{D}^{*0}$	1.4 ± 0.3	1.5 ± 1.5
$Z_{cs}^+ \bar{D}^0 D_s^{*+}$	1.4 ± 0.4	1.4 ± 1.4

$$\Gamma_{Z_{cs}} = (24.9 \pm 12.6) \text{ MeV}$$

$\Gamma \text{ BES} = (12.8 \pm 4.7) \text{ MeV}$
arXiv:2011.07855

Very good agreement

Conclusions

Exotic states are real, and QCDSR calculations can be trusted!

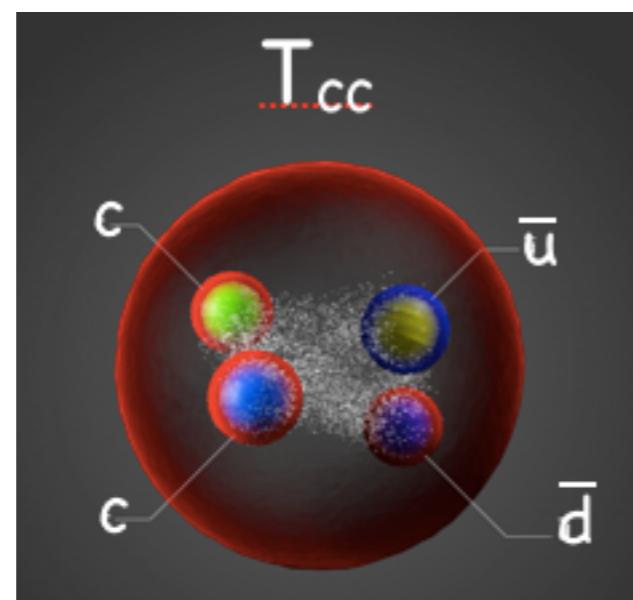
$X(3872) \rightarrow$ The first and best studied charmonium tetraquark candidate. Its mass and decay width can be well described in QCDSR.

$Z_c^+(3900) \rightarrow$ For sure a tetraquark state. Its mass and decay width can be well described in QCDSR.

$Z_c^+(4430) \rightarrow$ First observed charged tetraquark state. Possible first radial excitation of $Z_c^+(3900)$

$Z_{cs}^+(3985) \rightarrow$ first [c \bar{c} u \bar{s}] observed $J^P=1^+$ tetraquark state. Predictions by QCDSR are consistent with its mass and decay width.

$T_{cc}^+(3875) \rightarrow$ The star of this conference, and the most expected tetraquark state. First prediction in 1987. First QCDSR prediction in 2007. Finally observed by LHCb in 2021.



Thank you!