LHCb meets Theory

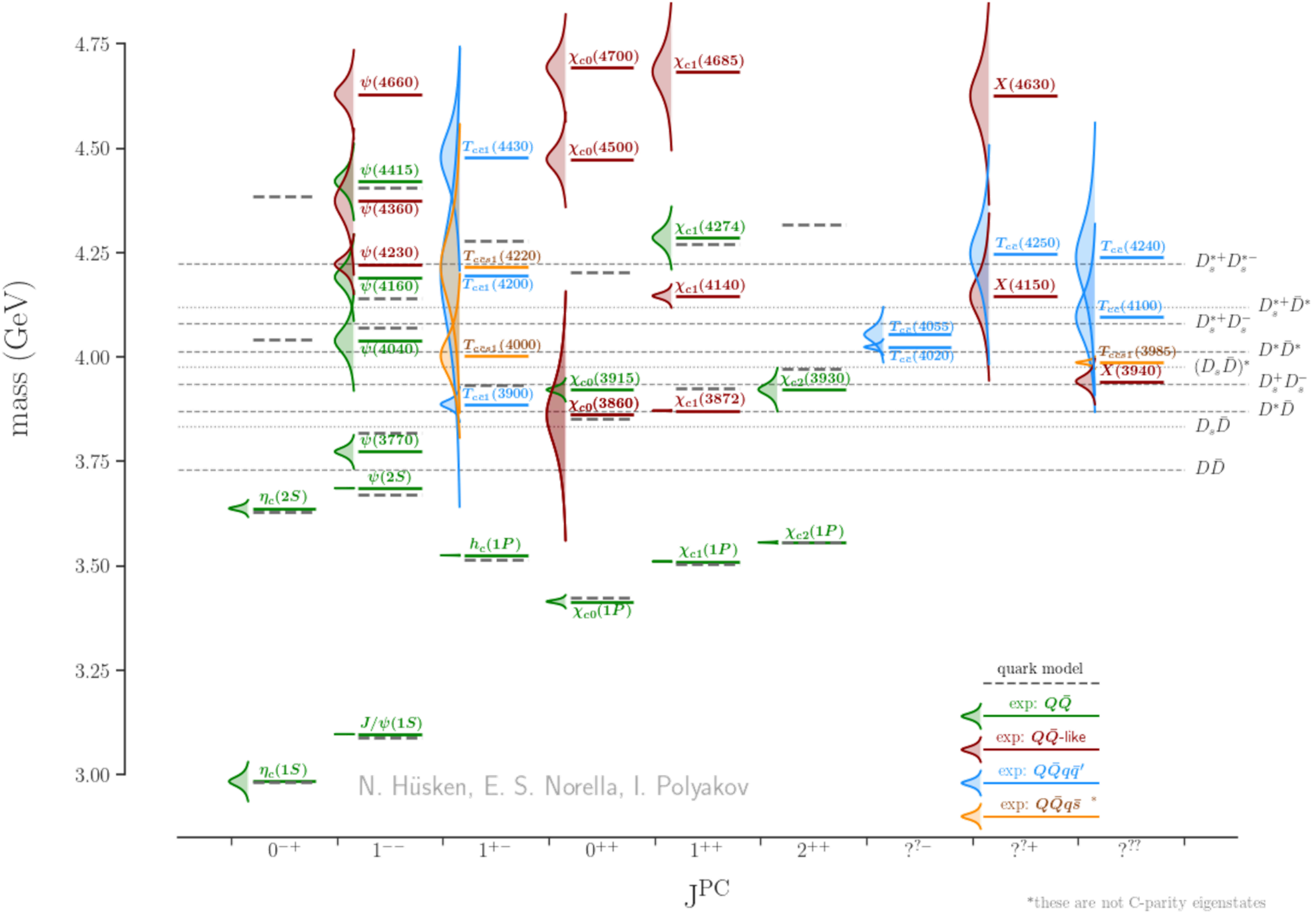
June, 2024

Interpreting the X

Eric Swanson

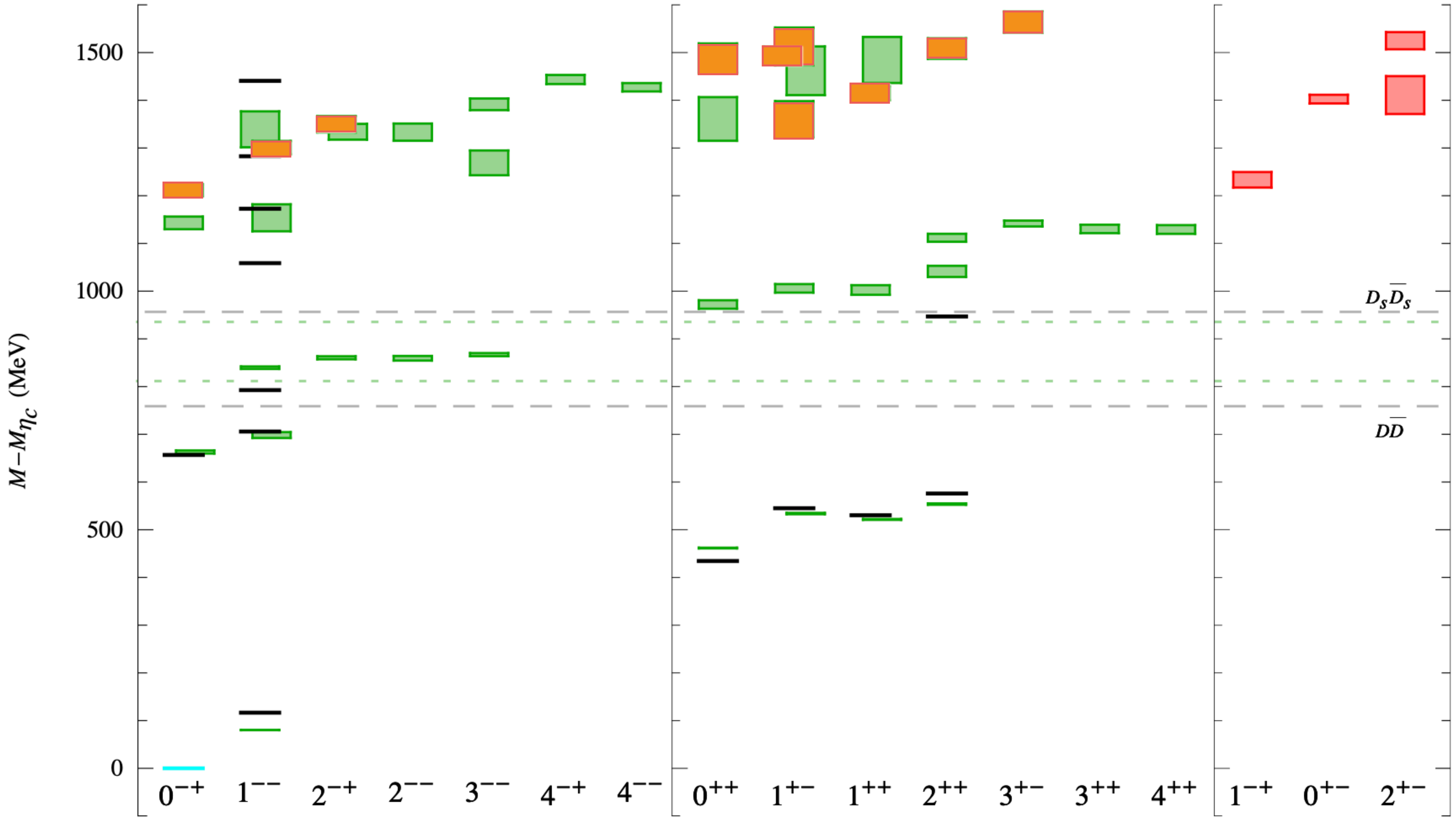
ExoHad
Exotic Hadrons Topical Collaboration

The Landscape



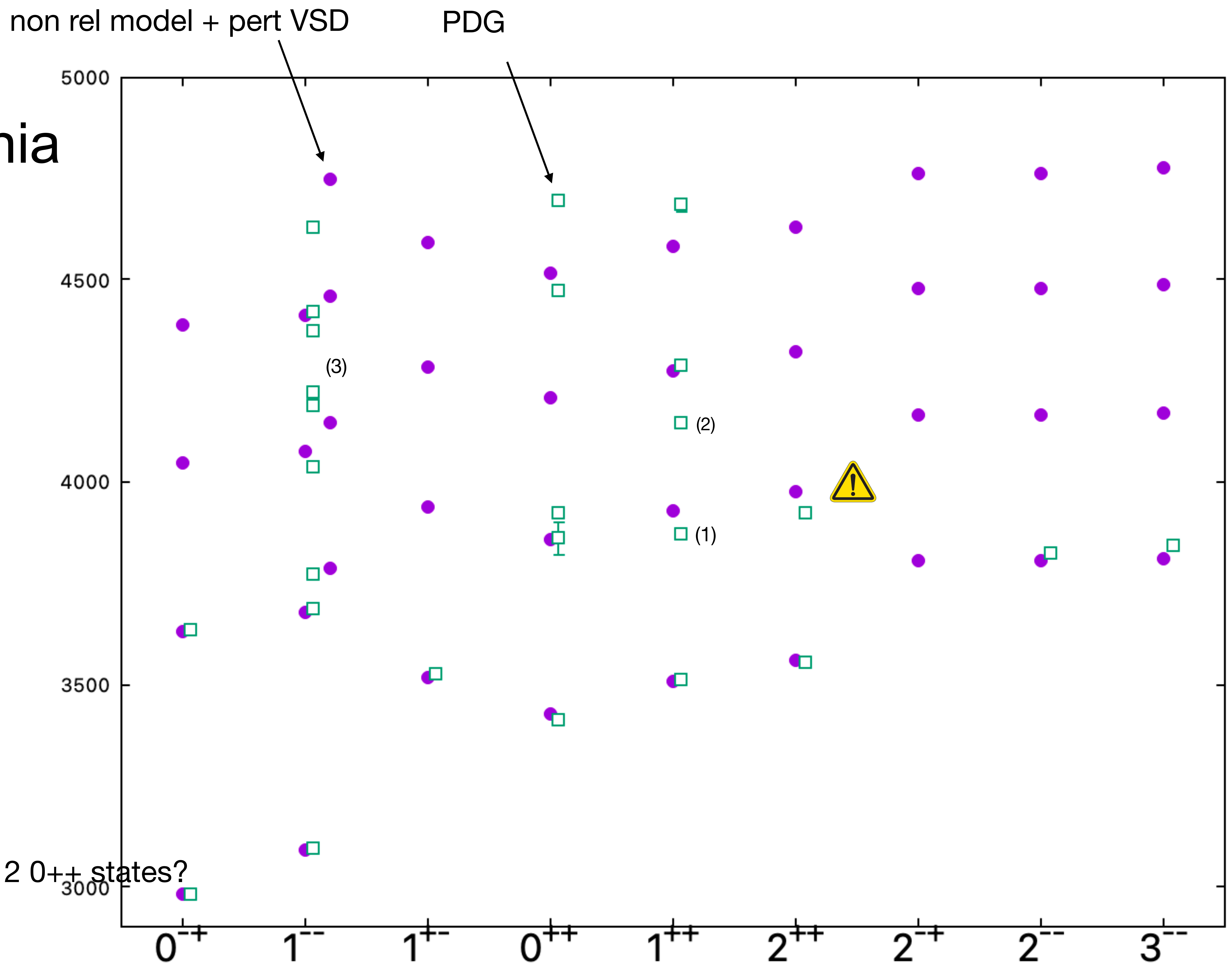
mass (GeV)
4.75
4.50
4.25
4.00
3.75
3.50
3.25
3.00
J^PC
0−+
1−−
1+−
0++
1++
2++
?^?−
?^?+
?^??
ηc(1S)
ηc(2S)
J/ψ(1S)
ψ(2S)
ψ(3770)
ψ(4040)
ψ(4160)
ψ(4230)
ψ(4360)
ψ(4415)
ψ(4660)
hc(1P)
Tccs1(4000)
Tcc1(3900)
Tcc1(4200)
Tccs1(4220)
Tcc1(4430)
χc0(1P)
χc0(3860)
χc0(3915)
χc0(4500)
χc0(4700)
χc1(1P)
χc1(3872)
χc1(4140)
χc1(4274)
χc1(4685)
χc2(1P)
χc2(3930)
Tcc̄(4020)
Tcc̄(4055)
X(4150)
Tcc̄(4250)
X(4630)
X(3940)
Tccs1(3985)
Tcc̄(4100)
Tcc̄(4240)
Ds*+Ds*−
Ds*+D̄*
Ds*+Ds−
D*D̄*
(DsD̄)*
Ds+Ds−
D*D̄
DsD̄
DD̄
quark model
exp: QQ̄
exp: QQ̄-like
exp: QQ̄qq̄′
exp: QQ̄qs̄ *
N. Hüsken, E. S. Norella, I. Polyakov
*these are not C-parity eigenstates

Lattice Charmonia



HadSpec, 1204.5425

Model + PDG Charmonia



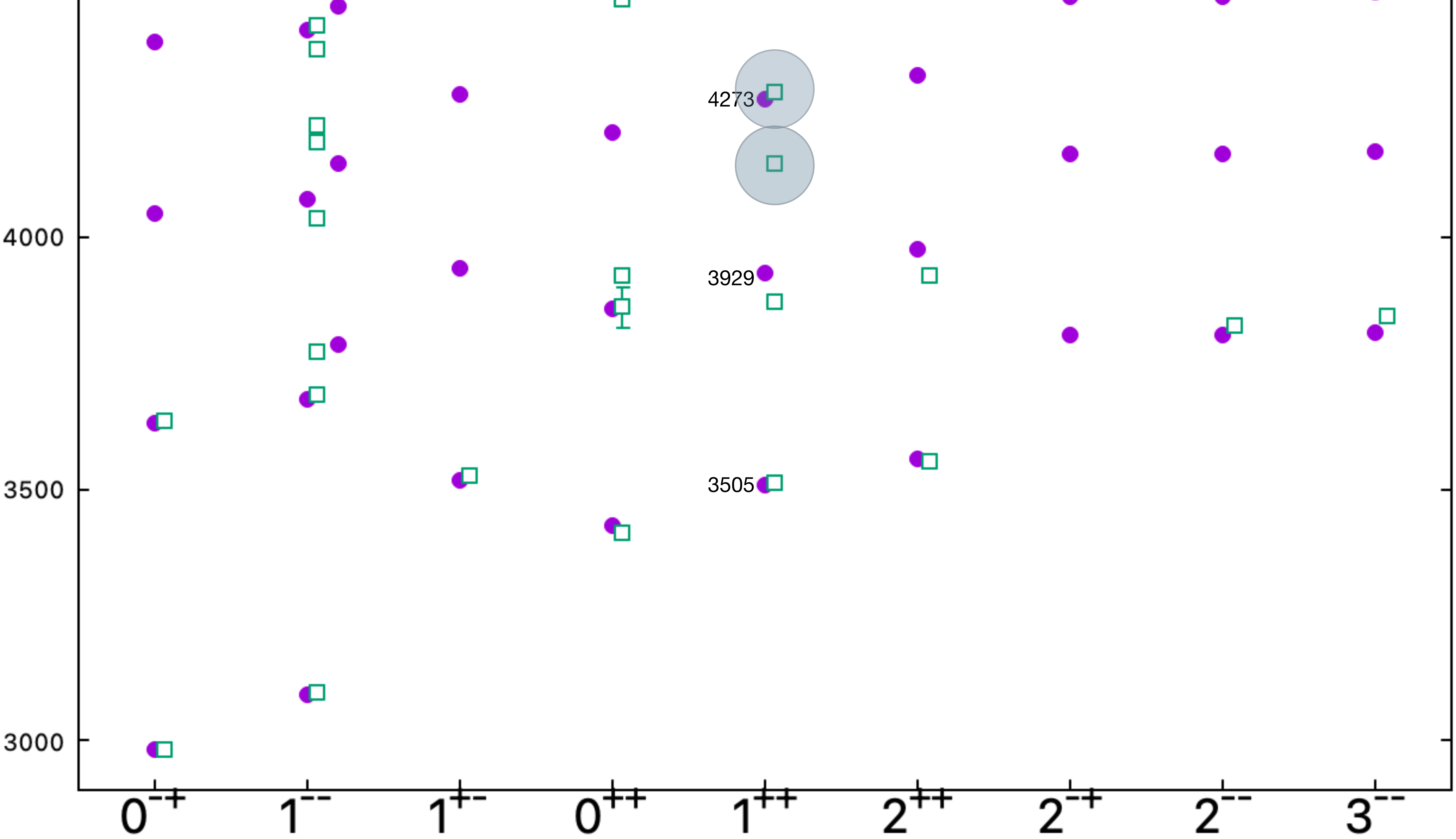
(1) 3872 = DD*, but 2++ is equally off, also 2 0++ states?

(2) could this be the 3P1(2P) shifted up?

(3) something of a fiasco here

charmonia.dat / charmonia.plt ***hybrids/spectrum/bb/fitBBc.cpp***

axials



4273
3929
3505
4000
3500
3000
0-+
1--
1+-
0++
1++
2++
2-+
2--
3--

$\chi_{c1}(4140)$ $I^G(J^{PC}) = 0^+(1^{++})$

was $X(4140)$

This state shows properties different from a conventional $q\bar{q}$ state. A candidate for an exotic structure. See the review on non-$q\bar{q}$ states. Seen by AALTONEN 2009AH, ABAZOV 2014A, CHATRCHYAN 2014M, AAIJ 2017C in $B^+ \to \chi_{c1} K^+$, $\chi_{c1} \to J/\psi\phi$, and by ABAZOV 2015M separately in both prompt (4.7 σ) and non-prompt (5.6 σ) production in $p\,\bar{p} \to J/\psi\phi +$ anything. Not seen by SHEN 2010 in $\gamma\,\gamma \to J/\psi\phi$ and ABLIKIM 2015 in $e^+\,e^- \to \gamma J/\psi\phi$ at $\sqrt{s}$ = 4.23, 4.26, 4.36 GeV.

$\chi_{c1}(4140)$ MASS	4146.5 ± 3.0 MeV (S = 1.3)
$\chi_{c1}(4140)$ WIDTH	19^{+7}_{-5} MeV

$\chi_{c1}(4140)$ DECAY MODES

	Mode	Fraction $(\Gamma_i\,/\,\Gamma)$	Scale Factor/ Conf. Level	P(MeV/c)
Γ_1	$J/\psi\phi$	seen		216
Γ_2	$\gamma\gamma$	not seen		2073

$\chi_{c1}(4274)$ $I^G(J^{PC}) = 0^+(1^{++})$

was $X(4274)$

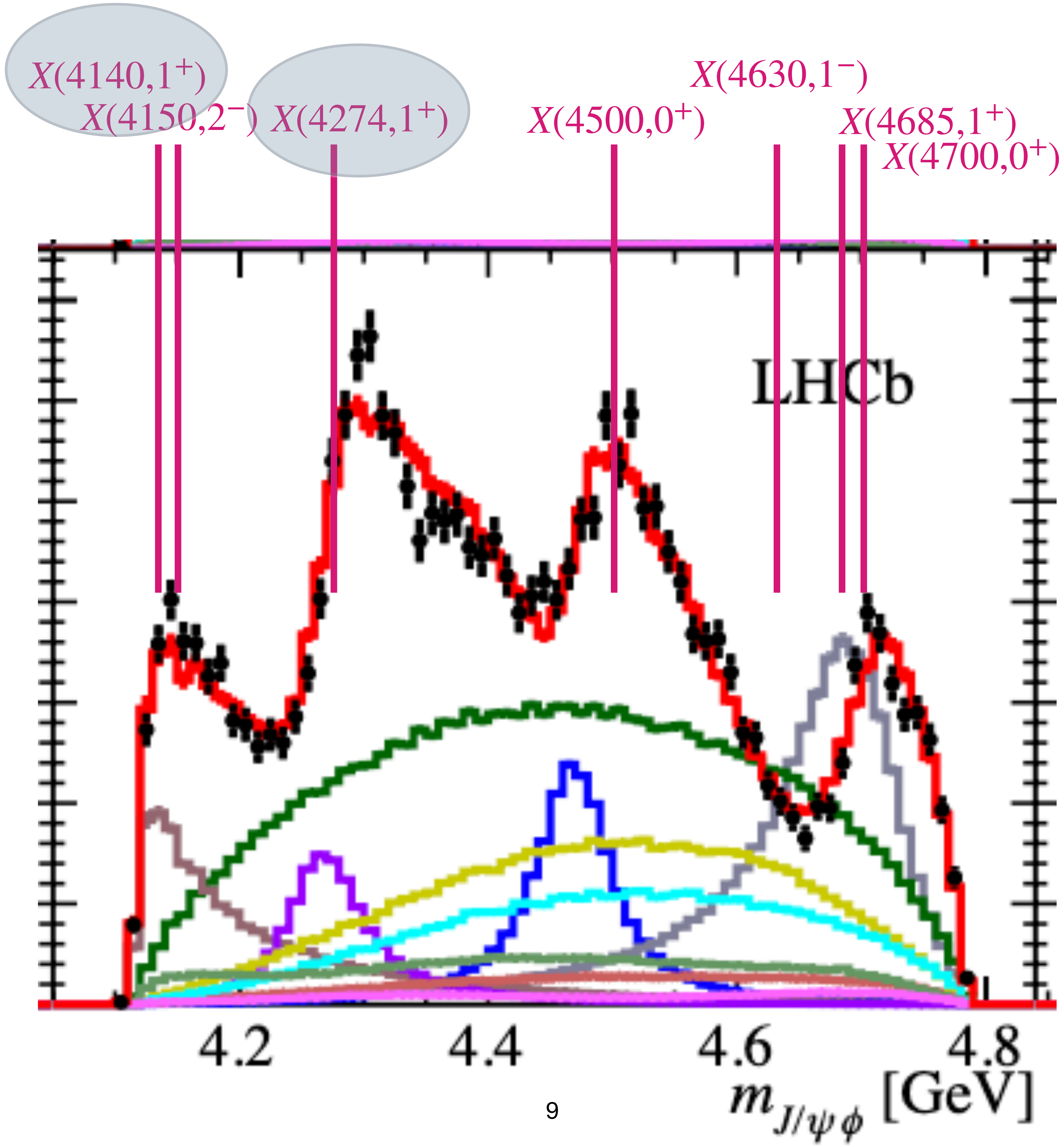
This state shows properties different from a conventional $q\bar{q}$ state. A candidate for an exotic structure. See the review on non-$q\bar{q}$ states. Seen by AAIJ 2017C in $B^+ \to \chi_{c1} K^+$, $\chi_{c1} \to J/\psi\phi$ using an amplitude analysis of $B^+ \to J/\psi\phi K^+$ with a significance (accounting for systematic uncertainties) of 6.0 σ.

$\chi_{c1}(4274)$ MASS	4286^{+8}_{-9} MeV (S = 1.7)
$\chi_{c1}(4274)$ WIDTH	51 ± 7 MeV

$\chi_{c1}(4274)$ DECAY MODES

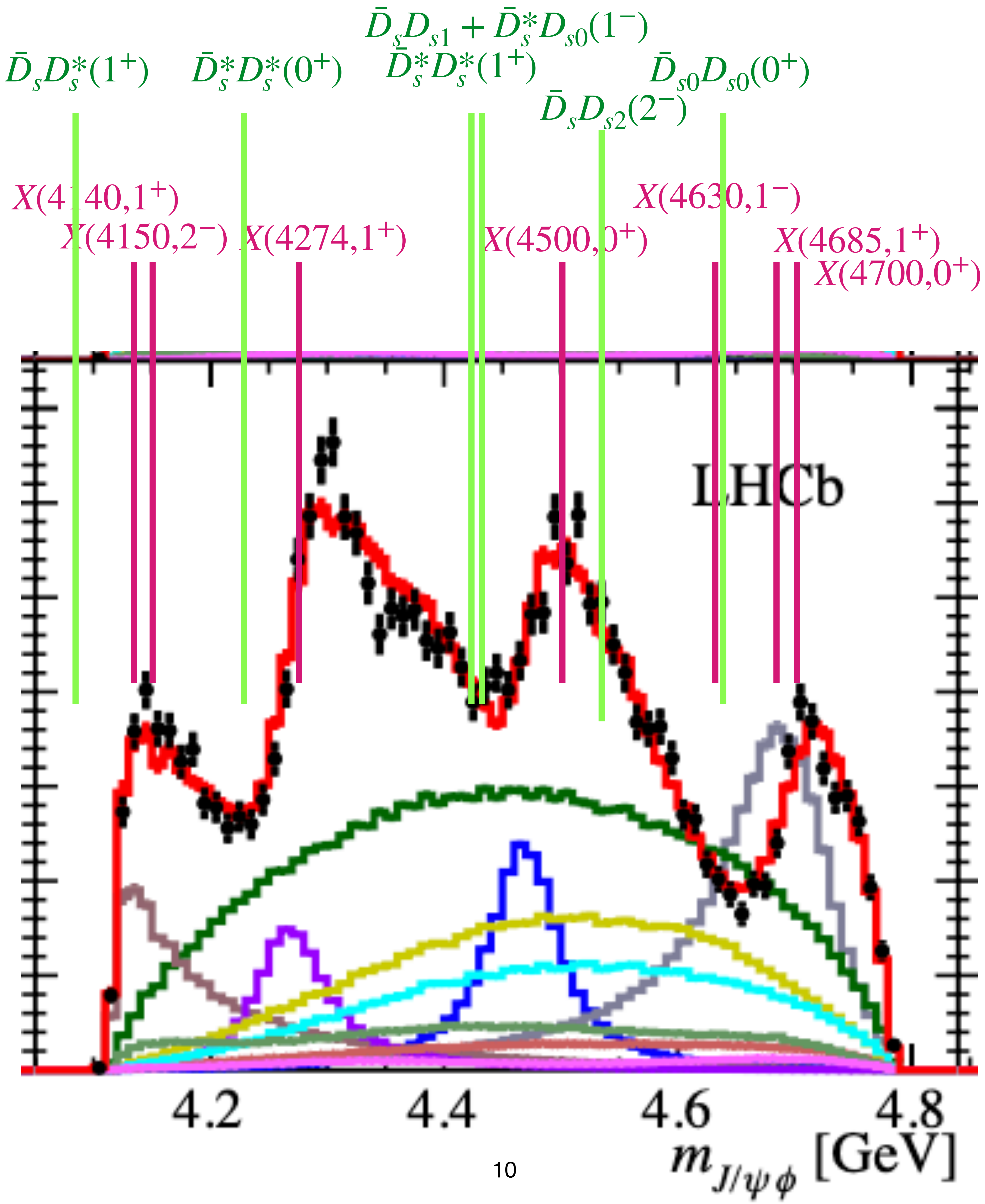
	Mode	Fraction $(\Gamma_i\,/\,\Gamma)$	Scale Factor/ Conf. Level	P(MeV/c)
Γ_1	$J/\psi\phi$	seen		522

X in $J/\psi\phi$



X(4140,1⁺)
X(4150,2⁻)
X(4274,1⁺)
X(4500,0⁺)
X(4630,1⁻)
X(4685,1⁺)
X(4700,0⁺)
LHCb
4.2
4.4
4.6
4.8
m_J/ψφ [GeV]

X Thresholds



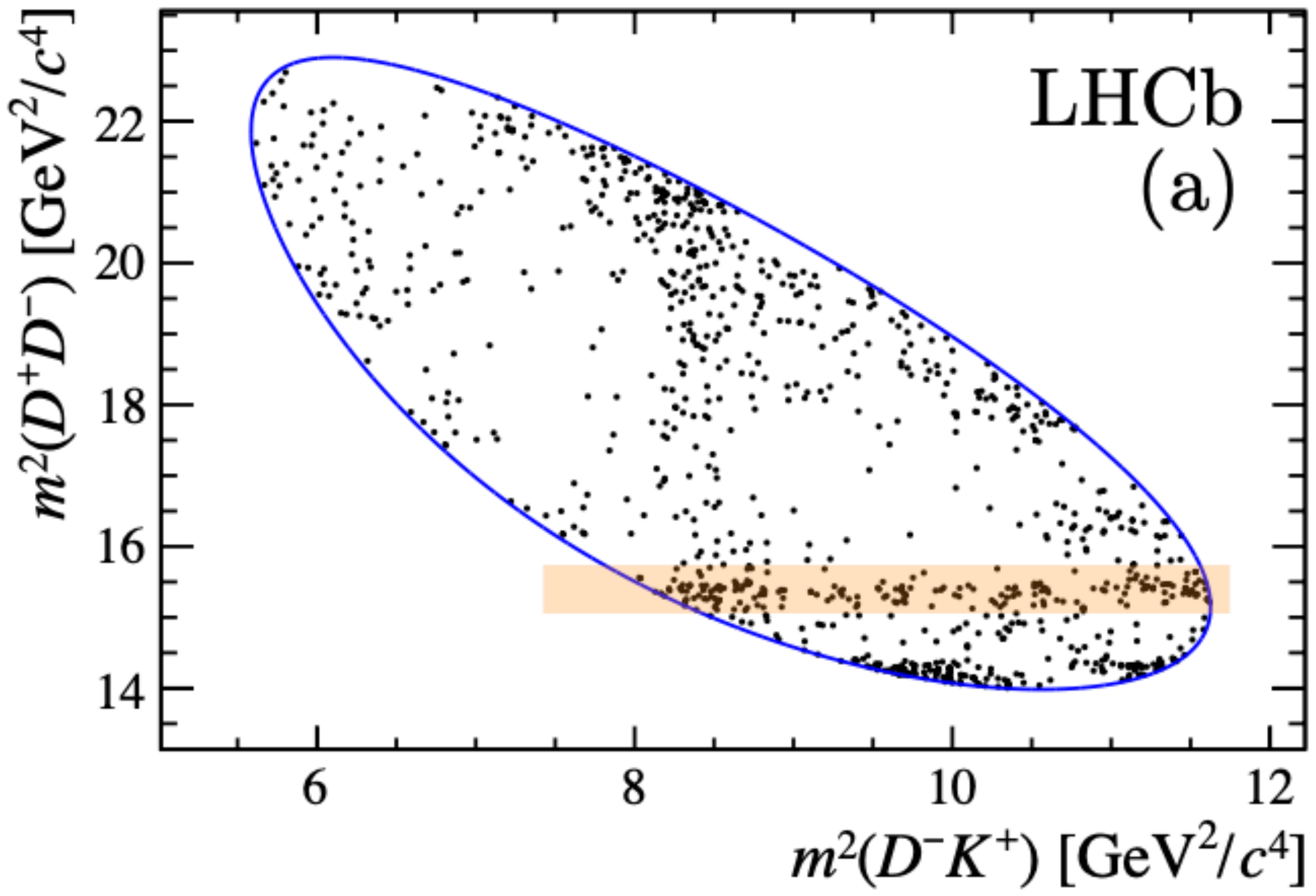
4273
3929
3505
4000
3500
3000
0⁻⁺
1⁻⁻
1⁺⁻
0⁺⁺
1⁺⁺
2⁺⁺
2⁻⁺
2⁻⁻
3⁻⁻

4273
3929
3505
4000
3500
3000
0-+
1--
1+-
0++
1++
2++
2-+
2--
3--

Two $\chi_c(3930)$

LHCb: PRL 125 (2020) 242001
LHCb: PRD 102 (2020) 112003

$B^+ \to D^+D^-K^+$ Dalitz Plot

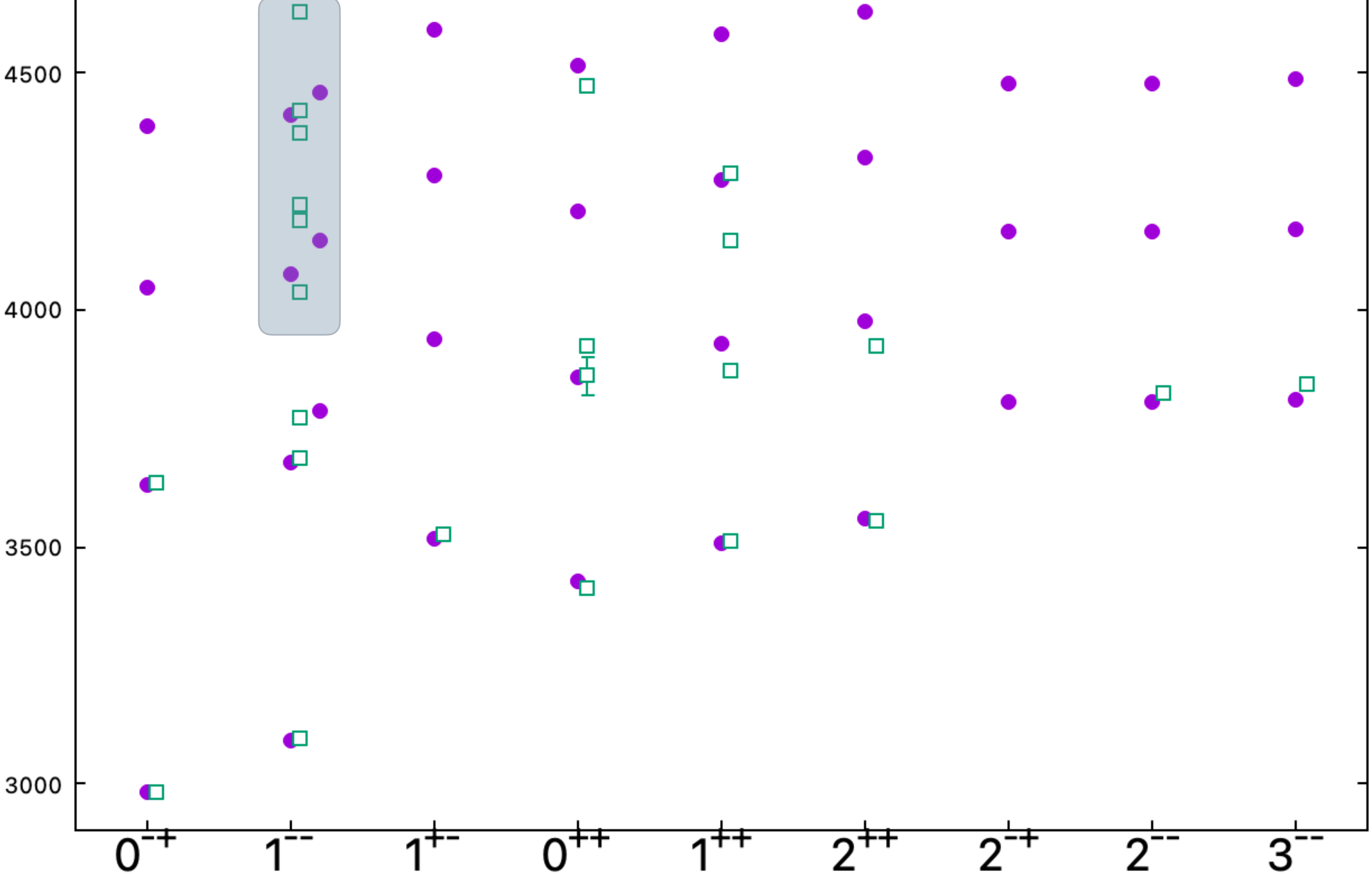


Previously observed $\chi_c(3930)$ seen as two states

$\chi_{c0}(3930)$

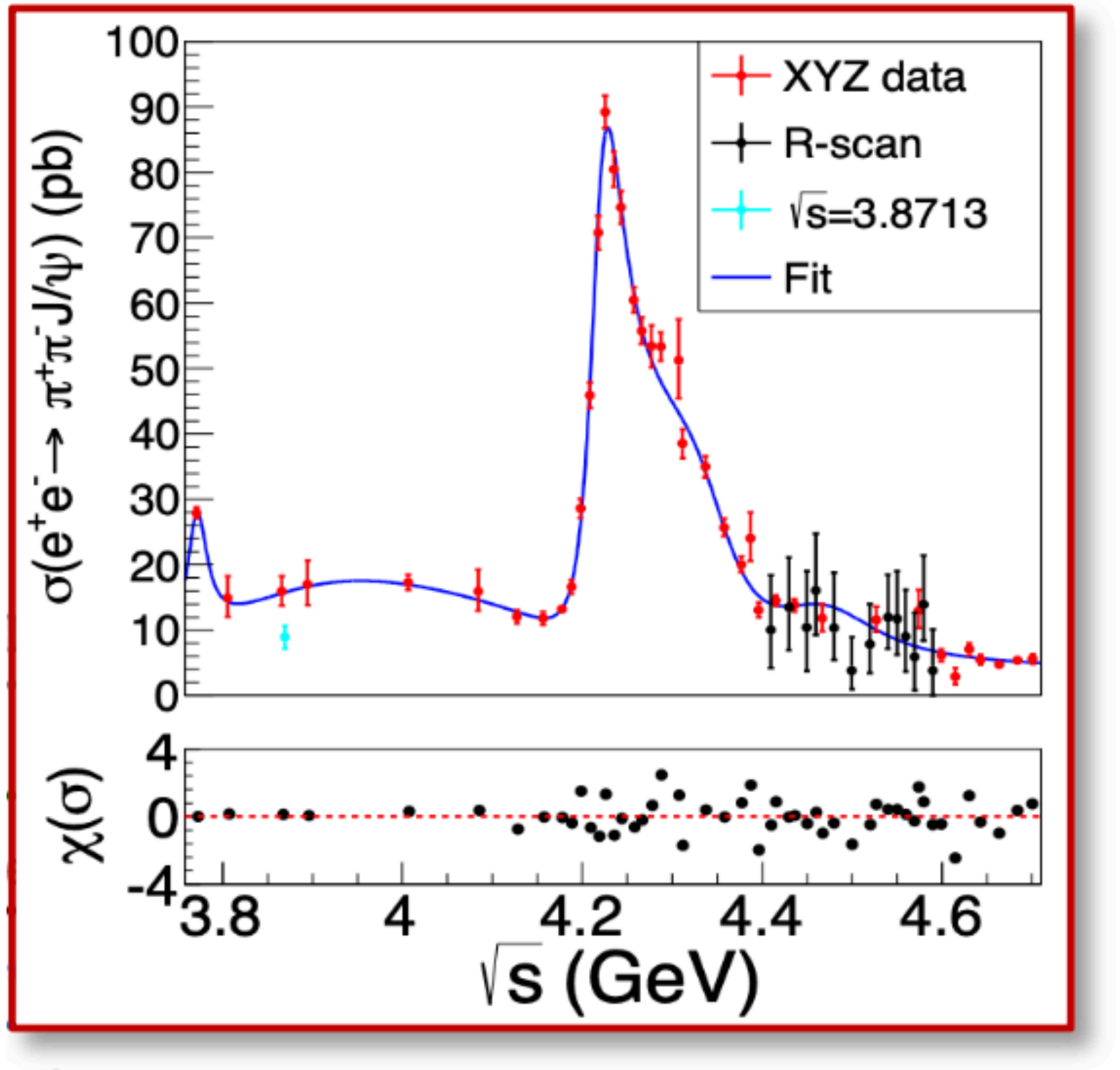
$\chi_{c2}(3930)$

vectors

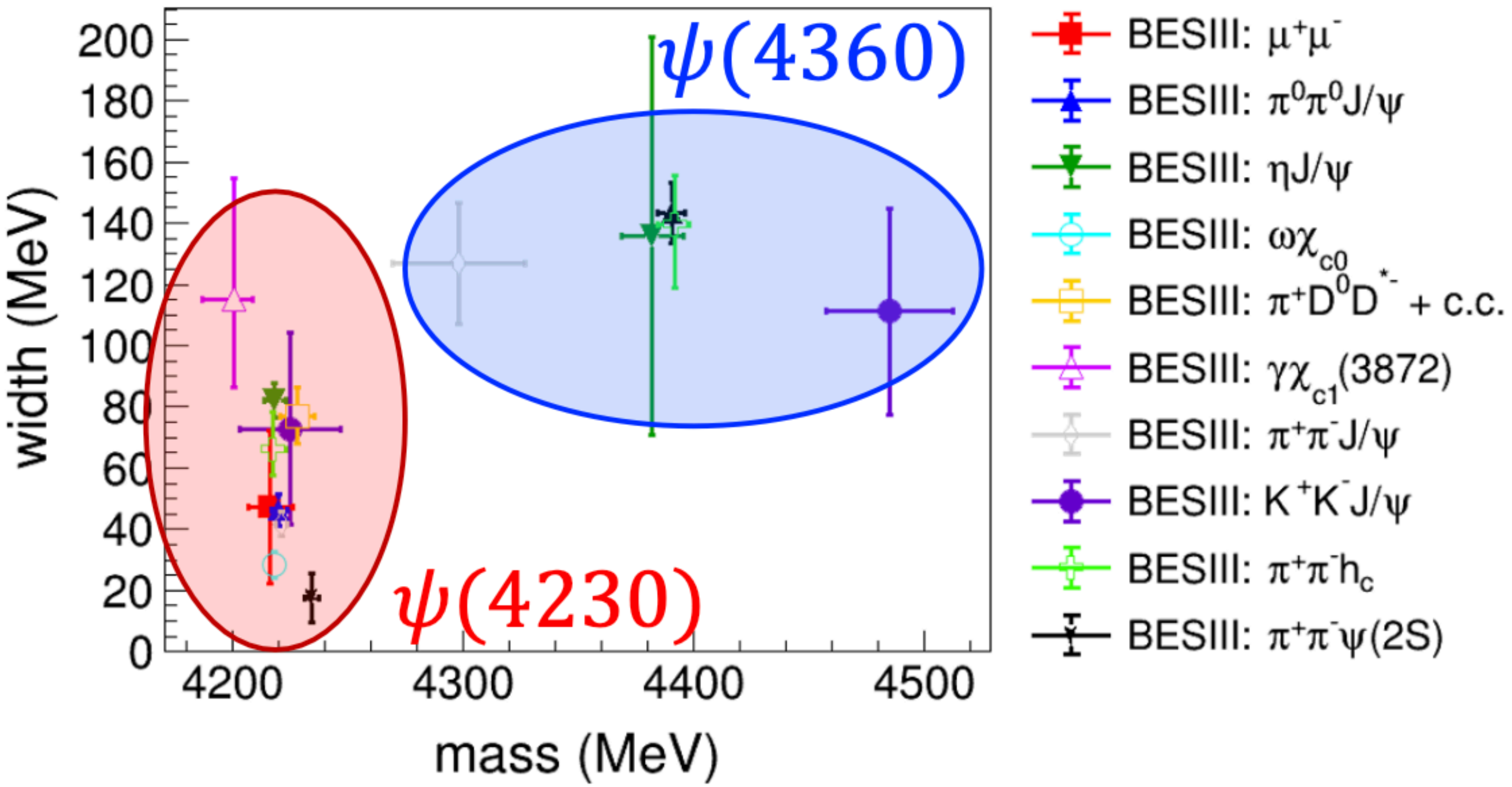


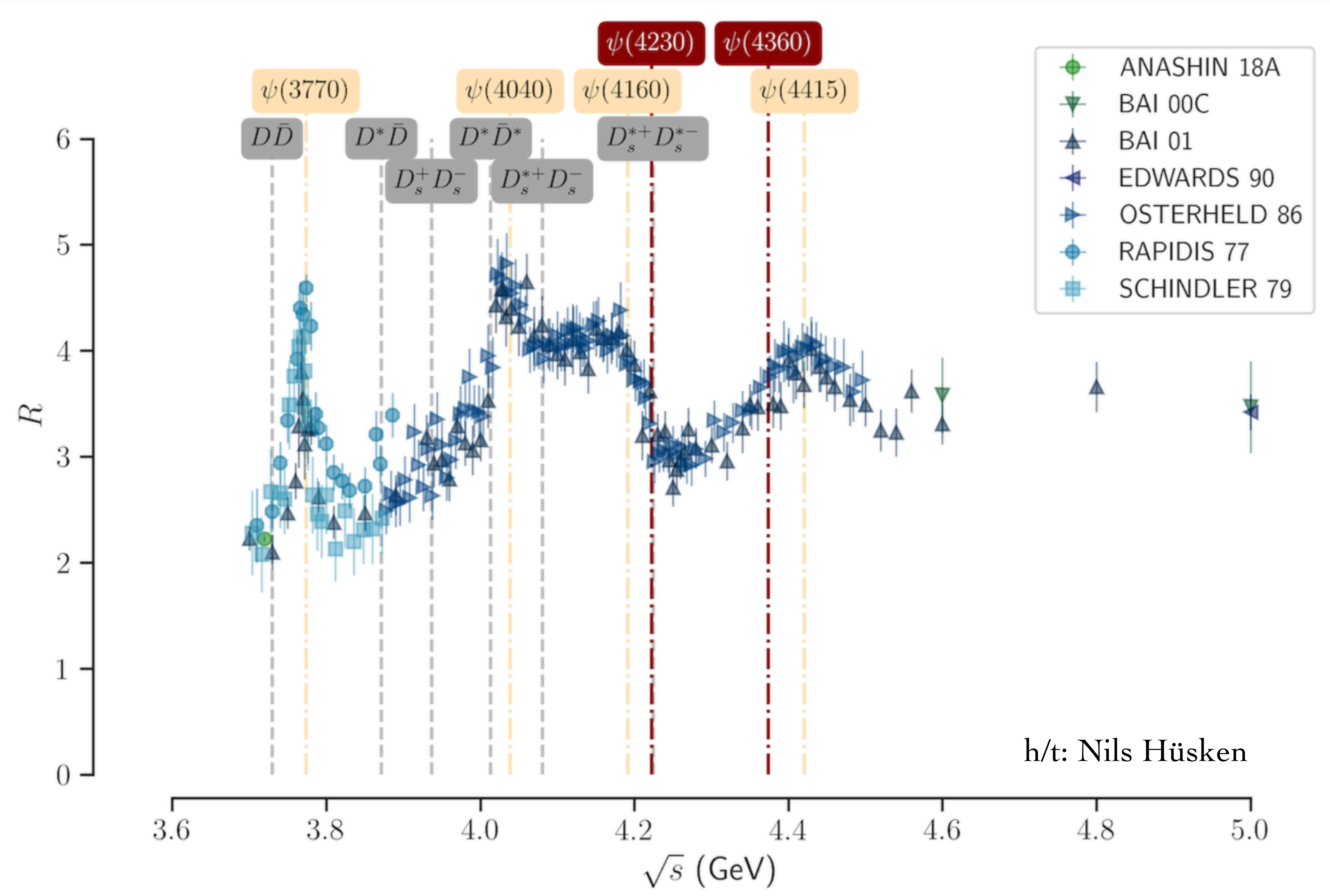
4500
4000
3500
3000
0-+
1--
1+-
0++
1++
2++
2-+
2--
3--

$\psi(4320)$ & $\psi(4360)$



PRD 106 (2022) 7, 072001

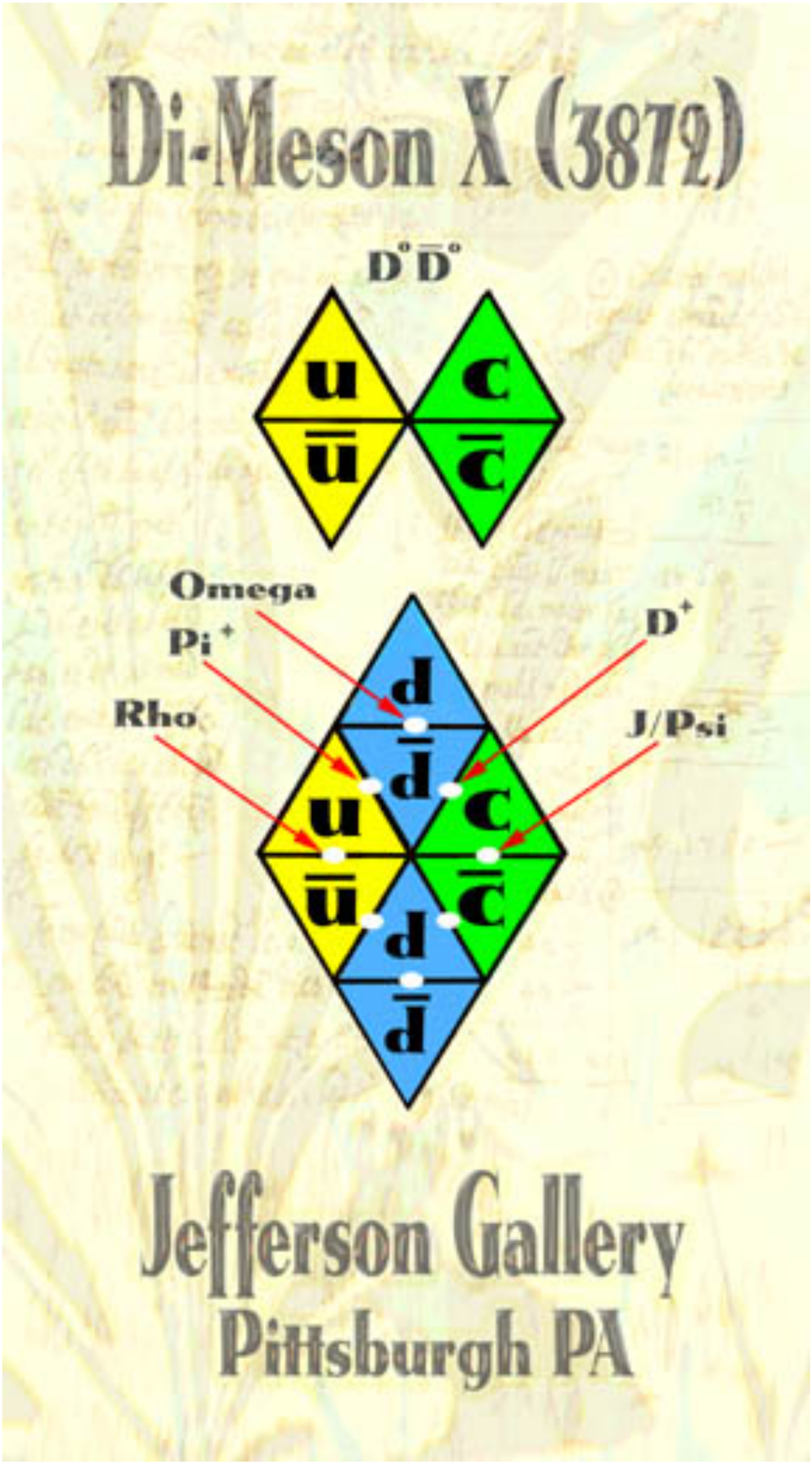




h/t: Nils Hüsken

The situation is even worse: we rely on R for much information! This is not robust!

The X



Di-Meson X (3872)
D°D̄°
u
ū
c
c̄
Omega
Pi+
Rho
D+
J/Psi
d
d̄
u
ū
c
c̄
d
d̄
Jefferson Gallery
Pittsburgh PA

The X


CHAMPIONS
PLACED #1
meggaphase25
Kills / Assists / Knocks
8 / 4 / 9
Damage Dealt
2789
Survival Time
20:27
Revive Given
1
Respawn Given
0
ID:16043157706755618580
DrX3872
Kills / Assists / Knocks
4 / 6 / 4
Damage Dealt
1295
Survival Time
20:27
Revive Given
3
Respawn Given
0

4.2. The $\chi_{c1}(3872)$ (also known as $X(3872)$)

MESON-LIKE/HIDDEN CHARM/ISOSCALAR

quantum numbers: $I^G(J^{PC}) = 0^+(1^{++})$

minimal quark content: $[c\bar{c}]$, more likely $[c\bar{c}(u\bar{u}+d\bar{d})]$

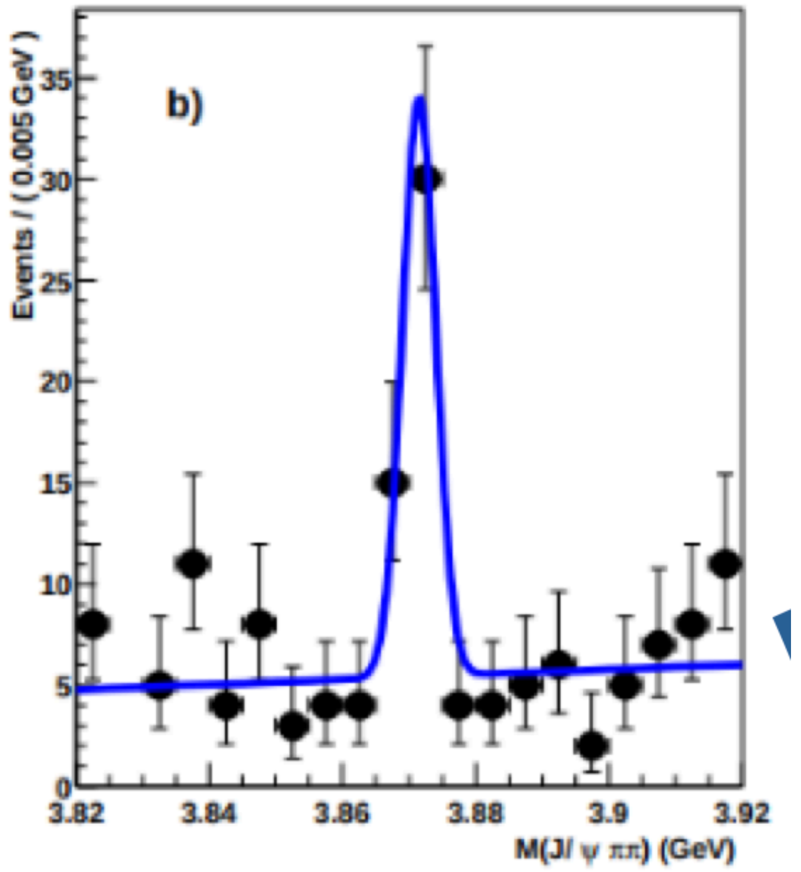
experiments: Belle, CDF, D0, BaBar, LHCb, CMS, ATLAS, BESIII (and potentially E705, COMPASS)

production: B^+, B^0, B^0_s and Λ^0_b decays, prompt pp, $p\bar{p}$, pPb (Pbp) and PbPb collisions, $e^+e^- \to \gamma\chi_{c1}(3872)$, $\omega\chi_{c1}(3872)$ potentially via ψ- or χ_c-like states

decay modes: $\pi^+\pi^- J/\psi$, $\omega J/\psi$, $D^{*0}\bar{D}^0$, $\pi^0\chi_{c1}(1P)$, $\gamma J/\psi$, $\gamma\psi(2S)$

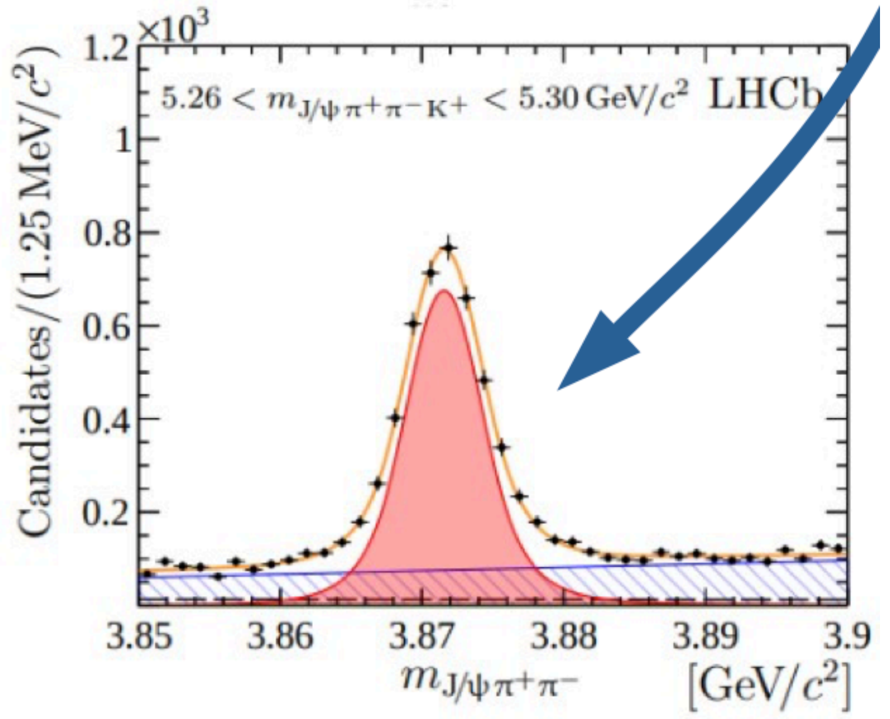
nearby threshold: $D^{*0}\bar{D}^0$

width: 1.19 ± 0.21 MeV *(Breit-Wigner)*



Belle, PRL 91 (2003) 262001

$36 \to 20\times10^3$ signal events



$m(\chi_{c1}(3872)) - m(D^0\bar{D}^{*0}) = -0.07\pm0.12$ MeV

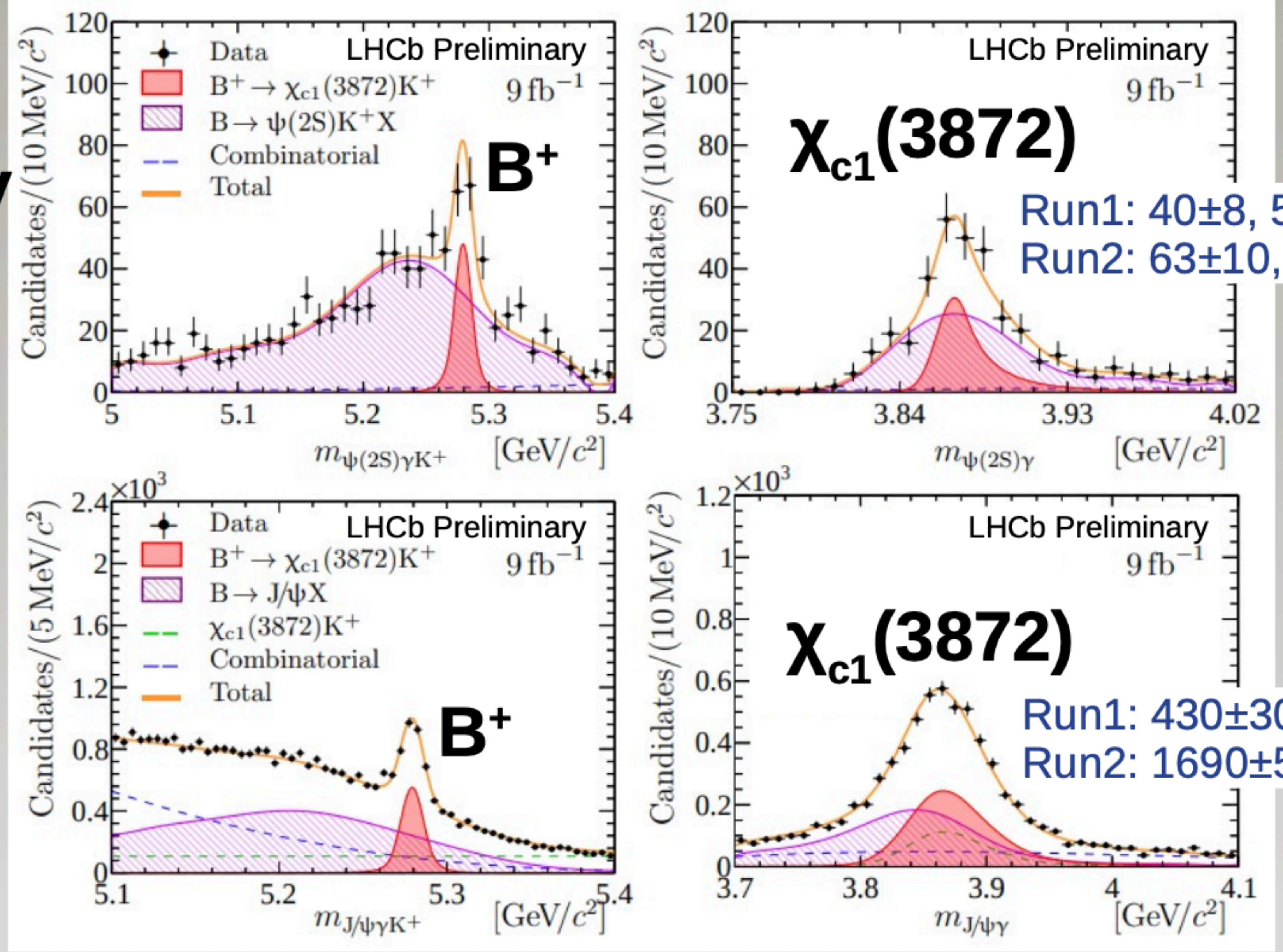
LHCb, JHEP 08 (2020) 123

First observation of $\chi_{c1}(3872) \rightarrow \psi(2S)\gamma$

- Projections in signal regions   LHCb-PAPER-2024-015, in prep.

$\psi(2S)\gamma$ mode

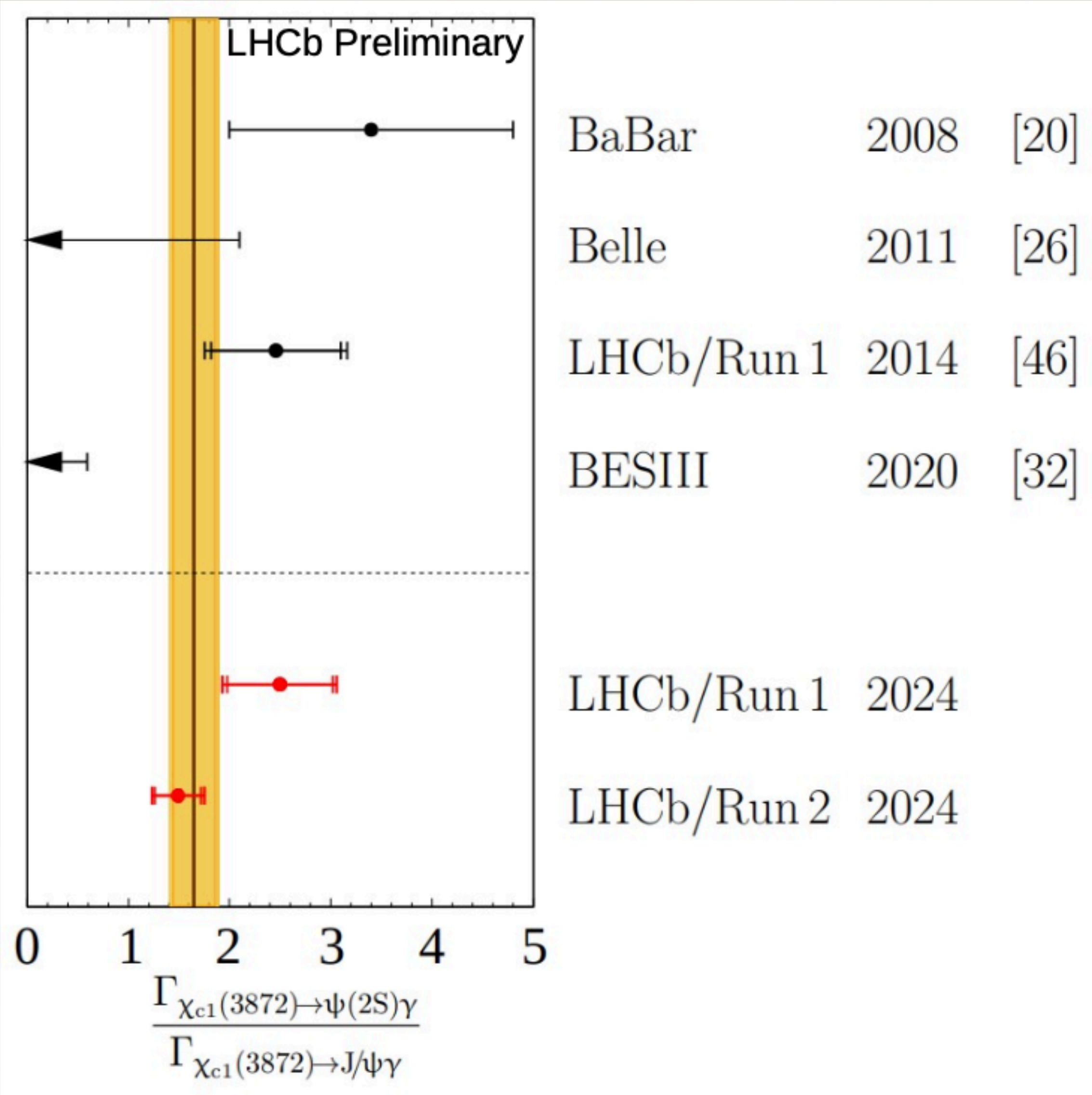
$J/\psi\gamma$ mode



Results

- LHCb/Run1 2014 measurement:
  $R_{\psi\gamma}$ = 2.46 ± 0.64 ± 0.29
  NPB 886 (2014) 665
- New measured BR ratios:

$$\mathscr{R}_{\psi\gamma}^{\text{Run 1}} = 2.50 \pm 0.52 \,^{+0.20}_{-0.23} \pm 0.06$$
$$\mathscr{R}_{\psi\gamma}^{\text{Run 2}} = 1.49 \pm 0.23 \,^{+0.13}_{-0.12} \pm 0.03$$



- Run1&2 average:

$$\mathscr{R}_{\psi\gamma} = 1.67 \pm 0.21 \pm 0.12 \pm 0.04$$
(stat, syst, $BR(\psi \rightarrow l^+l^-)$)

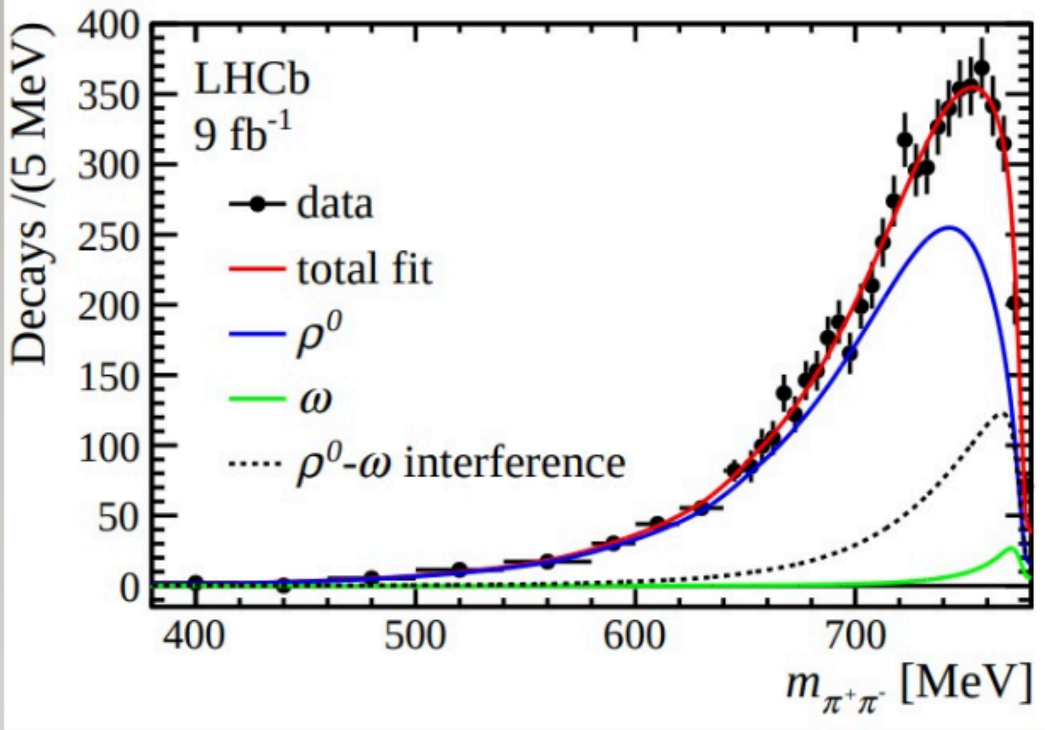
LHCb-PAPER-2024-015, in prep.

Isospin violation

- $\chi_{c1}(3872)\to J/\psi\pi^+\pi^-$ decay is dominated by $\rho^0\to\pi^+\pi^-$ indicating strong isospin violation
- LHCb has accessed $\omega\to\pi^+\pi^-$ (BR~1.5%) admixture in the same final state

LHCb, PRD 131 (2023) L011103

$$\frac{g_{\chi_{c1}(3872)\to\rho^0 J/\psi}}{g_{\chi_{c1}(3872)\to\omega J/\psi}} = 0.29 \pm 0.04$$



- ~10x larger than typical isospin violation in conventional charmonium

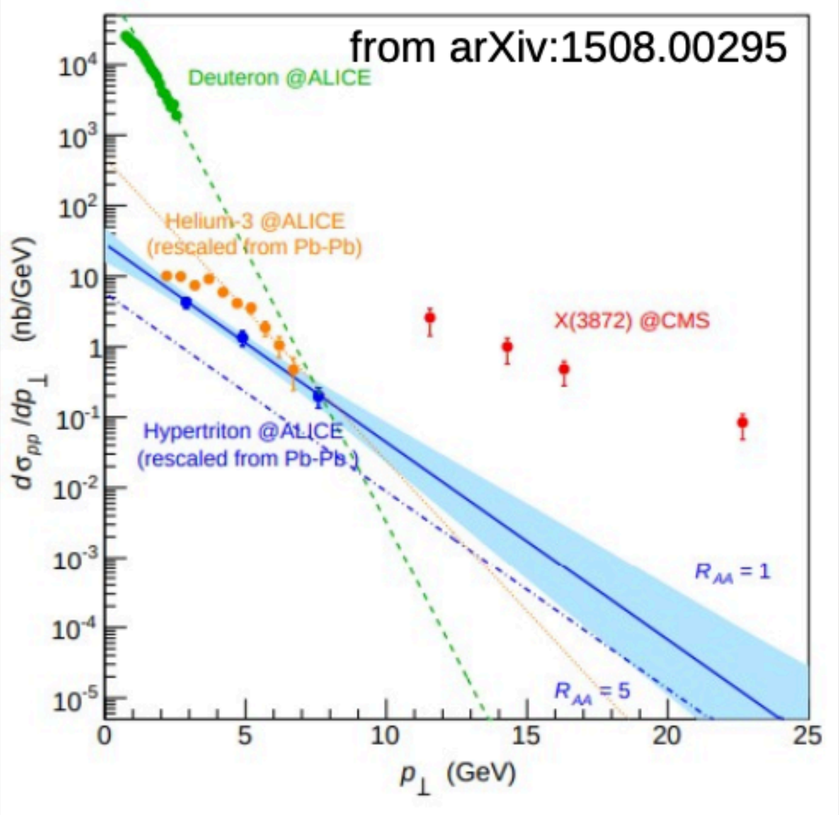
$$\frac{g_{\psi(2S)\to\pi^0 J/\psi}}{g_{\psi(2S)\to\eta J/\psi}} = 0.045 \pm 0.001$$

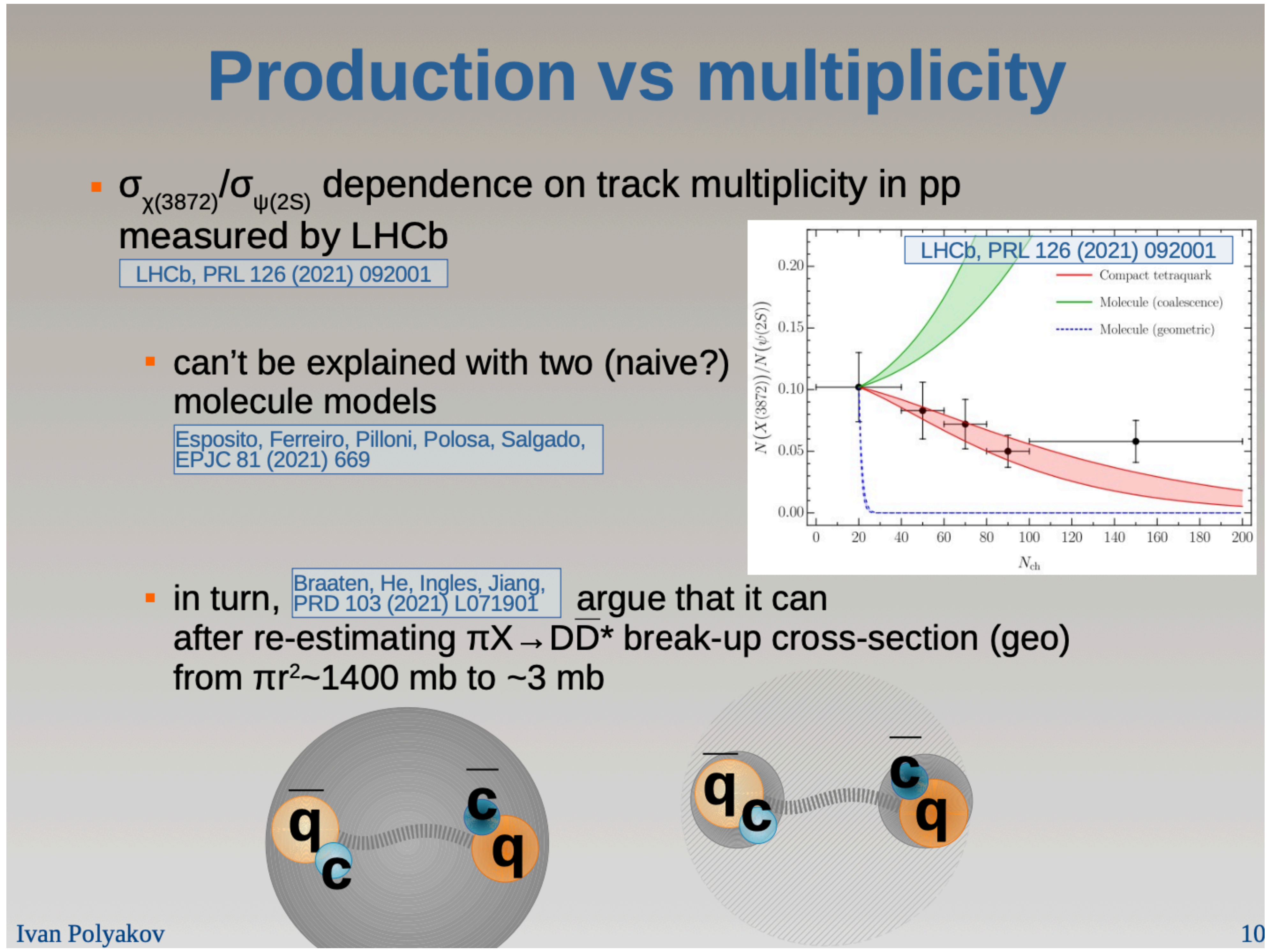
- Likely related to 8 MeV splitting between $D^0\bar{D}^{*0}$ and D^+D^{*-} thresholds

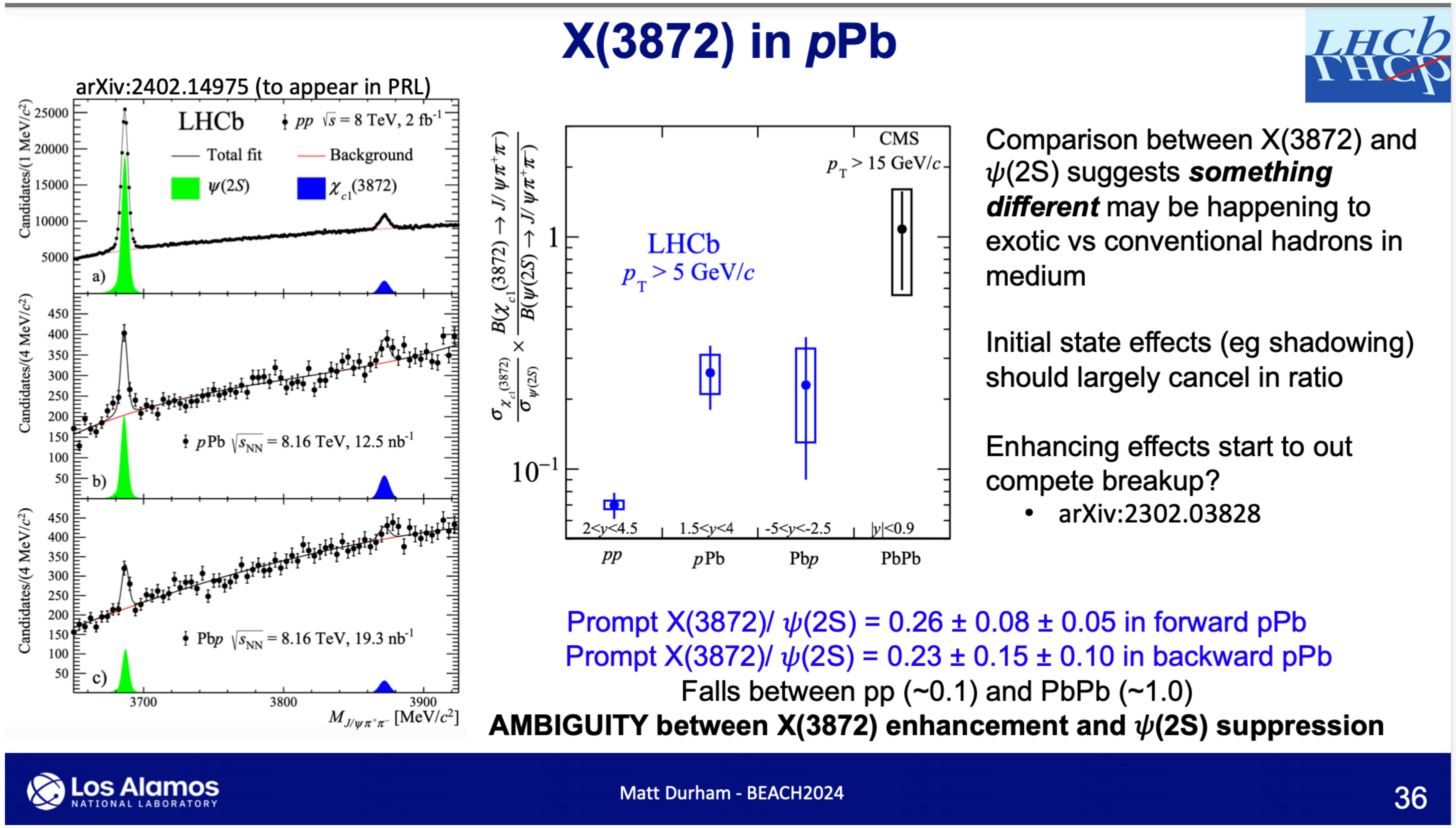
Production in hadron collisions

- $\sigma(p\bar{p}\to\chi_{c1}(3872)[\to J/\psi\pi\pi]+\ldots) > 3.1$ nb at $\sqrt{s}$=1.98 TeV
  CDF note 7159 (2004)
  - while Bignamini, Grinstein, Piccinini, Polosa, Sabelli, PRL 103 (2009) 162001 estimations for loosely bound (E_B~0.25 MeV) $D\bar{D}^*$ molecule give only ~0.085 nb
  - in turn, Artoisenet, Braaten, PRD 81 (2010) 114018 argue that $D\bar{D}^*$ re-scattering can raise it up to 4–200 nb

    also see Albaladejo, Guo, Hanhart, Meißner, Nieves, Nogga, Yang, CPC 41 (2017) 121001
- $\sigma(pp\to\chi_{c1}(3872)+\ldots)$ at high p_T at LHC
  - Indication of non-molecular component Esposito, Guerrieri, Maiani, Piccinini, Pilloni, Polosa, Riquer, PRD 92 (2015) 034028
  - or feature of charm?




Production vs multiplicity
σχ(3872)/σψ(2S) dependence on track multiplicity in pp measured by LHCb
LHCb, PRL 126 (2021) 092001
can't be explained with two (naive?) molecule models
Esposito, Ferreiro, Pilloni, Polosa, Salgado, EPJC 81 (2021) 669
in turn, Braaten, He, Ingles, Jiang, PRD 103 (2021) L071901 argue that it can after re-estimating πX→DD̄* break-up cross-section (geo) from πr²~1400 mb to ~3 mb
LHCb, PRL 126 (2021) 092001
Compact tetraquark
Molecule (coalescence)
Molecule (geometric)
N(X(3872)) / N(ψ(2S))
Nch
q
c
c
q
Ivan Polyakov
10


X(3872) in pPb
LHCb
arXiv:2402.14975 (to appear in PRL)
LHCb
pp √s = 8 TeV, 2 fb⁻¹
Total fit
Background
ψ(2S)
χc1(3872)
pPb √sNN = 8.16 TeV, 12.5 nb⁻¹
Pbp √sNN = 8.16 TeV, 19.3 nb⁻¹
Candidates/(1 MeV/c²)
Candidates/(4 MeV/c²)
MJ/ψπ+π− [MeV/c²]
CMS
pT > 15 GeV/c
LHCb
pT > 5 GeV/c
2<y<4.5
1.5<y<4
-5<y<-2.5
|y|<0.9
pp
pPb
Pbp
PbPb
Comparison between X(3872) and ψ(2S) suggests something different may be happening to exotic vs conventional hadrons in medium
Initial state effects (eg shadowing) should largely cancel in ratio
Enhancing effects start to out compete breakup?
arXiv:2302.03828
Prompt X(3872)/ ψ(2S) = 0.26 ± 0.08 ± 0.05 in forward pPb
Prompt X(3872)/ ψ(2S) = 0.23 ± 0.15 ± 0.10 in backward pPb
Falls between pp (~0.1) and PbPb (~1.0)
AMBIGUITY between X(3872) enhancement and ψ(2S) suppression
Los Alamos NATIONAL LABORATORY
Matt Durham - BEACH2024
36

Multi-quark States

“Vi har nu en model, der på smukke ste vis forklarer data og for første gang indeholder alle de begrænsninger, data giver,” sagde fysikeren Tim Burns fra Swansea University ved offentliggørelsen.

Multi-electron States

1946: Wheeler suggests that Ps_2 might be bound

Wheeler, J. A. Polyelectrons. Ann. NY Acad. Sci. 48, 219–238 (1946).

1946: Ore proves it is unbound

1947: Hylleraas & Ore prove it is bound

Hylleraas, E. A. & Ore, A. Binding energy of the positronium molecule. Phys. Rev.71, 493–496 (1947).

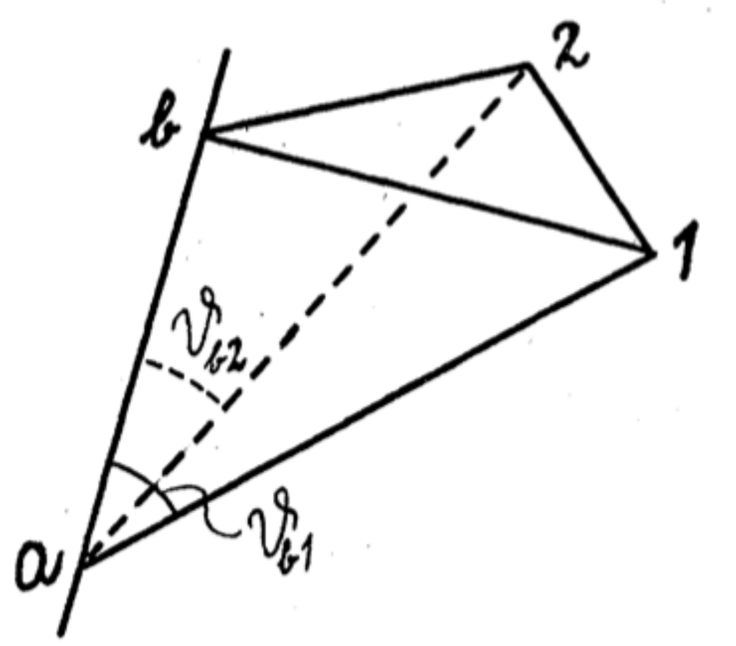


FIG. 1. Coordinate system for the positronium molecule.

2007: Ps_2 is observed

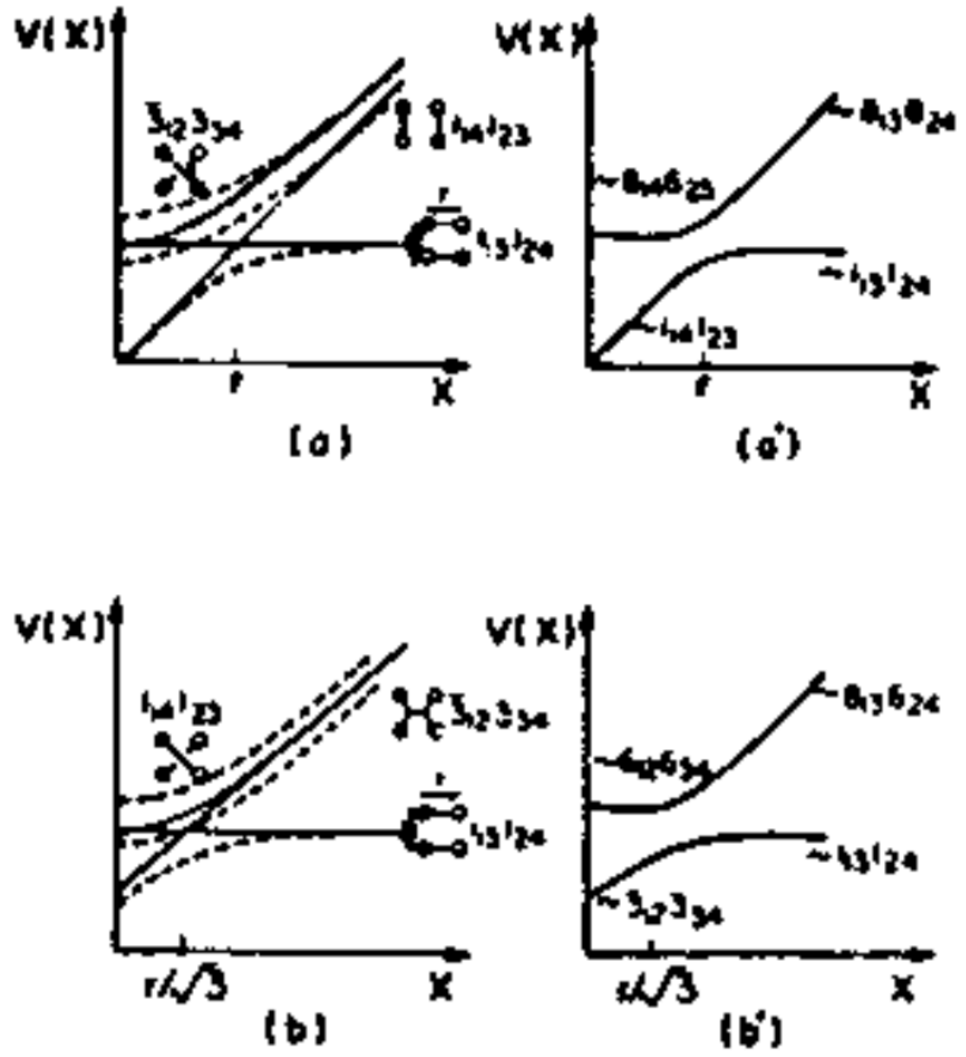
Cassidy, D.B.; Mills, A.P. (Jr.) (2007). "The production of molecular positronium". Nature 449 (7159): 195–197

Multi-quarks through the ages

B. The Multiquark Fiasco

Multiquark physics has a somewhat unfortunate history. A confluence of dubious experimental results and dubious theoretical models in the late 1970's and early 1980's created, indeed, a multiquark fiasco. I am not competent to discuss what went wrong experimentally, but let me review the theoretical side of this fiasco in order to place it in perspective and thereby, I hope, point the way toward a better understanding of multiquark systems.

The story is basically one of throwing caution to the winds. Modelers from at least four different camps were, it seems to me, guilty:



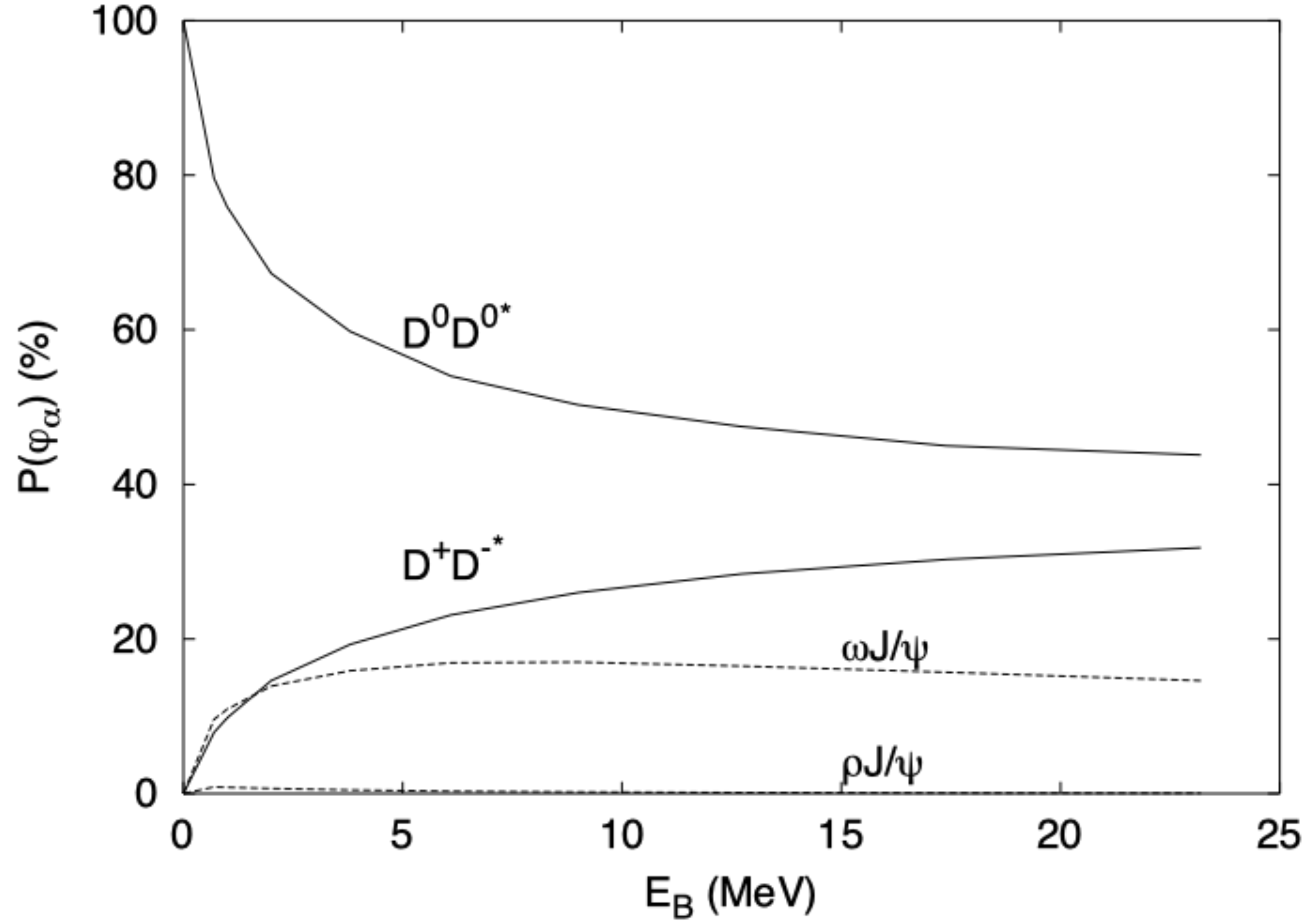
UTPT-85-18
March,1985

X Structure

$$\mathcal{L} = \frac{1}{2}\int d^3x d^3y\, \psi^\dagger \psi V(x-y)\psi^\dagger \psi + \int d^4x \bar{\psi}\gamma^\mu \gamma_5 \tau^a \psi \partial_\mu \pi^a$$

constituent quark interaction   quark-pion interaction

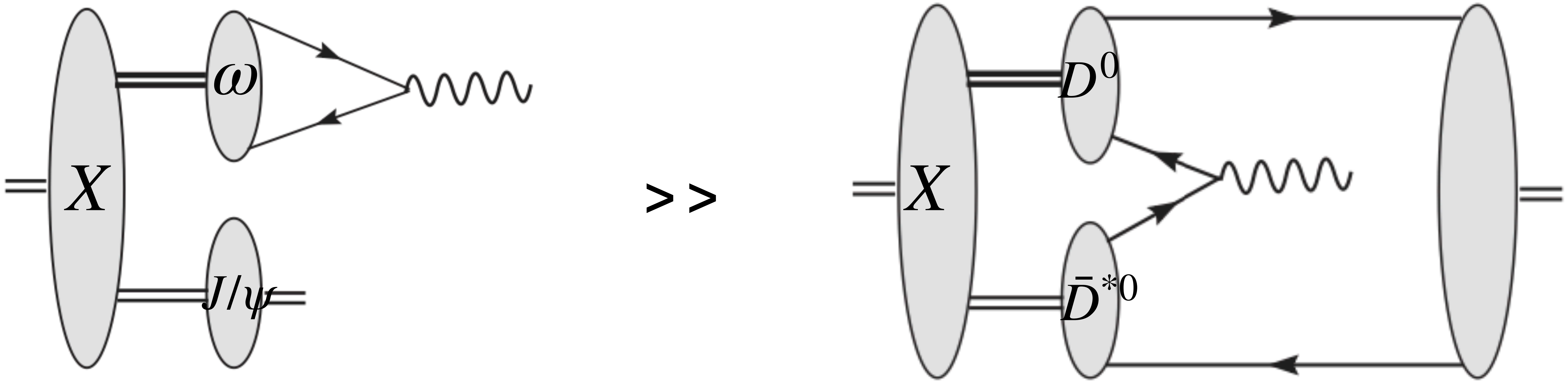
V	$\rho\psi$	$D^0\bar{D}^{0*}$	D^+D^{-*}	$\omega\psi$
$\rho\psi$	–	V_q	V_q	–
$D^0\bar{D}^{0*}$		V_π	V_π	V_q
D^+D^{-*}			V_π	V_q
$\omega\psi$				–



X Radiative Decays

Γ_{18}	$\pi^0\pi^0\chi_{c0}$	$< 6\%$	CL=90%	347	⌄
Γ_{19}	$\pi^+\pi^-\chi_{c0}$	$< 2.0\%$	CL=90%	340	⌄
Γ_{20}	$\pi^+\pi^-\chi_{c1}$	$< 7 \times 10^{-3}$	CL=90%	218	⌄
Γ_{21}	$p\overline{p}$	$< 2.2 \times 10^{-5}$	CL=95%	1693	⌄
▾ **Radiative decays**					
Γ_{22}	$\gamma D^+ D^-$	$< 3.5\%$	CL=90%	502	⌄
Γ_{23}	$\gamma\overline{D}^0 D^0$	$< 6\%$	CL=90%	519	⌄
Γ_{24}	$\gamma J/\psi$	$(7.8 \pm 2.9) \times 10^{-3}$		697	⌄
Γ_{25}	$\gamma\chi_{c1}$	$< 8 \times 10^{-3}$	CL=90%	344	⌄
Γ_{26}	$\gamma\chi_{c2}$	$< 2.9\%$	CL=90%	303	⌄
Γ_{27}	$\gamma\psi(2S)$	possibly seen		181	⌄
▸ **C-violating decays**					

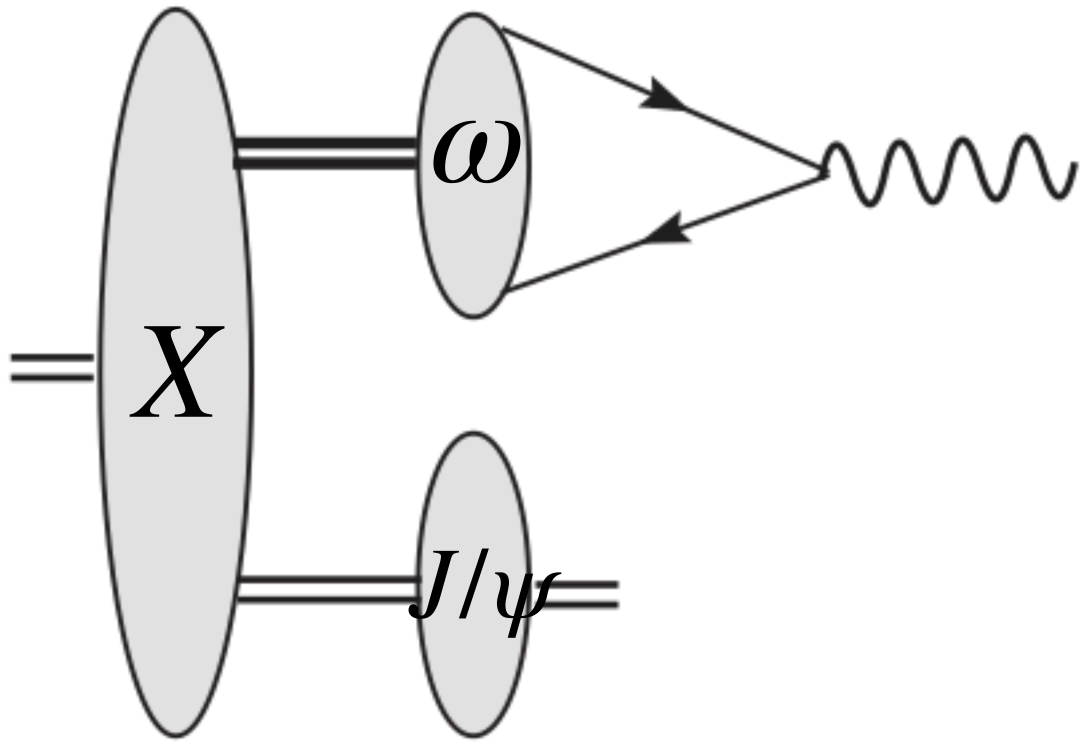
X Radiative Decays



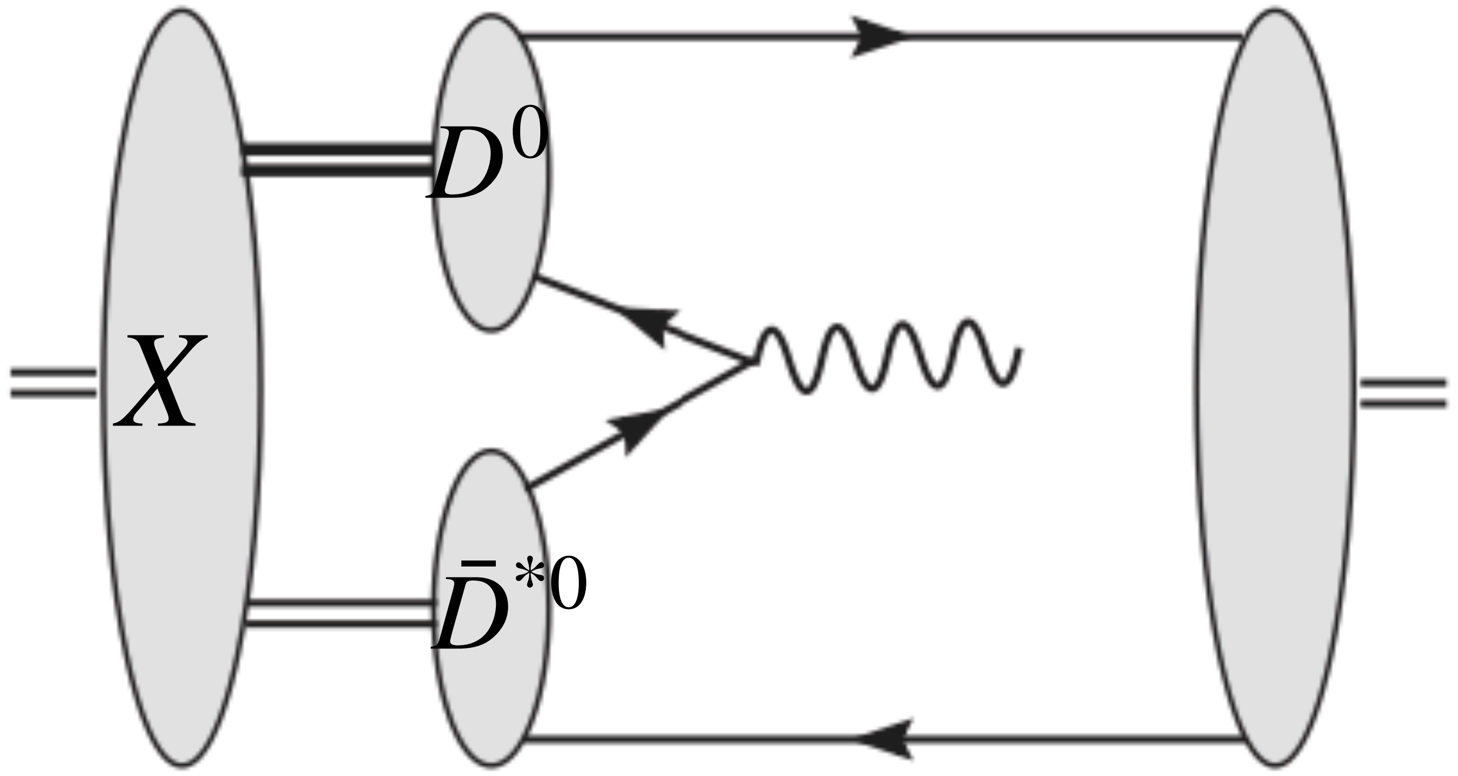
$$\Gamma_{\text{VMD}} = \frac{4}{27}\alpha\frac{qE_\psi}{m_\chi}|\psi_\omega(r=0)|^2(Z_{\omega\psi}^{1/2}\phi_{\omega\psi}(q) + 3Z_{\rho\psi}^{1/2}\phi_{\rho\psi}(q))^2.$$

/Users/SWANSONE/products/tex/HeavyLightPapers/B-decays/code/radTrans.f

X Radiative Decays



>>



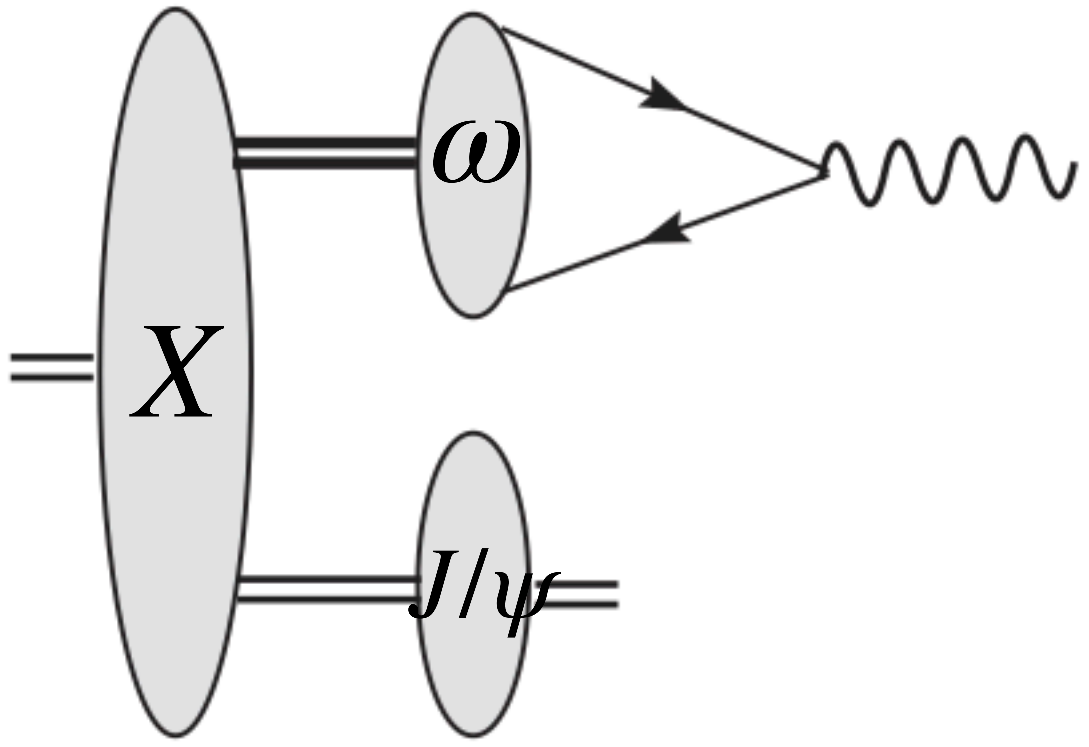
[SHO, dipole, NR, zero recoil, impulse]

E1 decays of the $X(3872)$

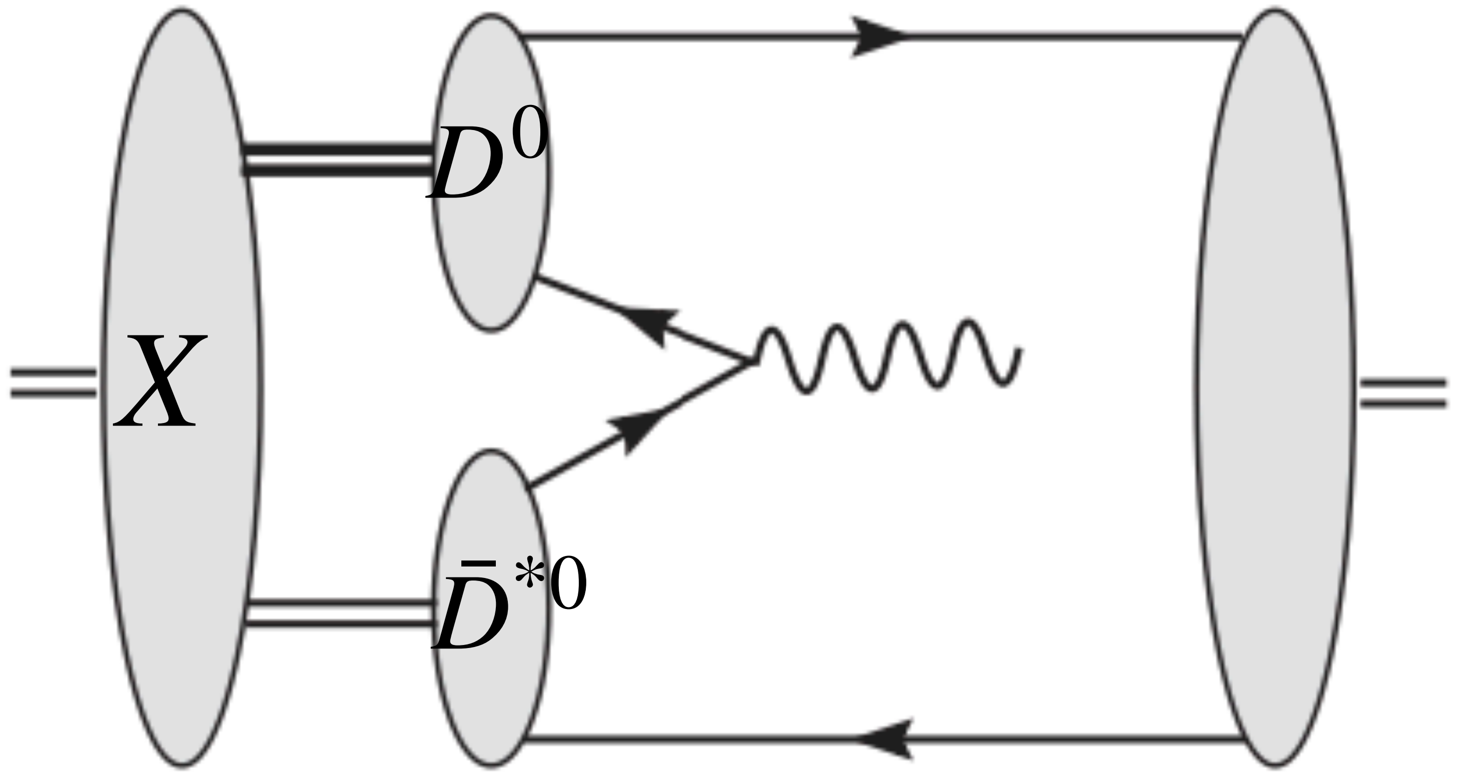
Mode	m_f (MeV)	q (MeV)	$\Gamma[c\bar{c}]$ (keV) [B&G]	$\Gamma[c\bar{c}]$ (keV) [A]	$\Gamma[c\bar{c}]$ (keV) [B]	$\Gamma[\hat{\chi}_{c1}]$ (keV)
$\gamma J/\psi$	3097	697	11	71	139	8
$\gamma\psi'(2^3S_1)$	3686	182	64	95	94	0.03
$\gamma\psi''(1^3D_1)$	3770	101	3.7	6.5	6.4	0
$\gamma\psi_2(1^3D_2)$	3838	34	0.5	0.7	0.7	0

/Users/SWANSONE/products/tex/HeavyLightPapers/B-decays/code/radTrans.f

X Radiative Decays



>>

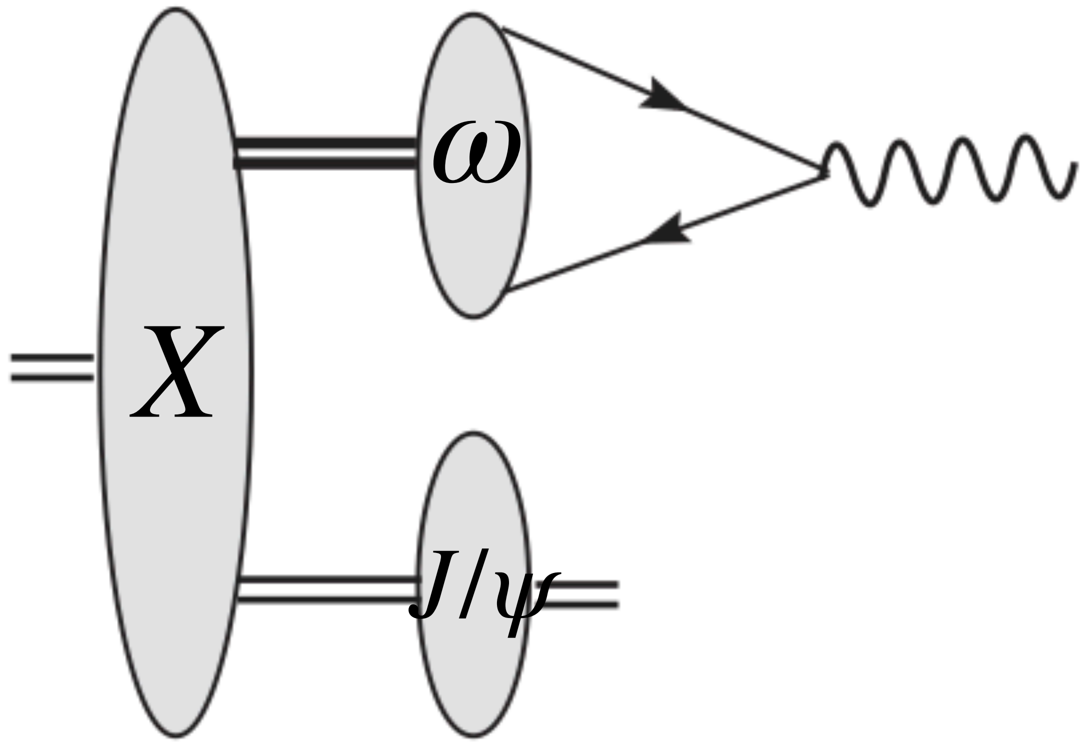


E1 decays of the $X(3872)$

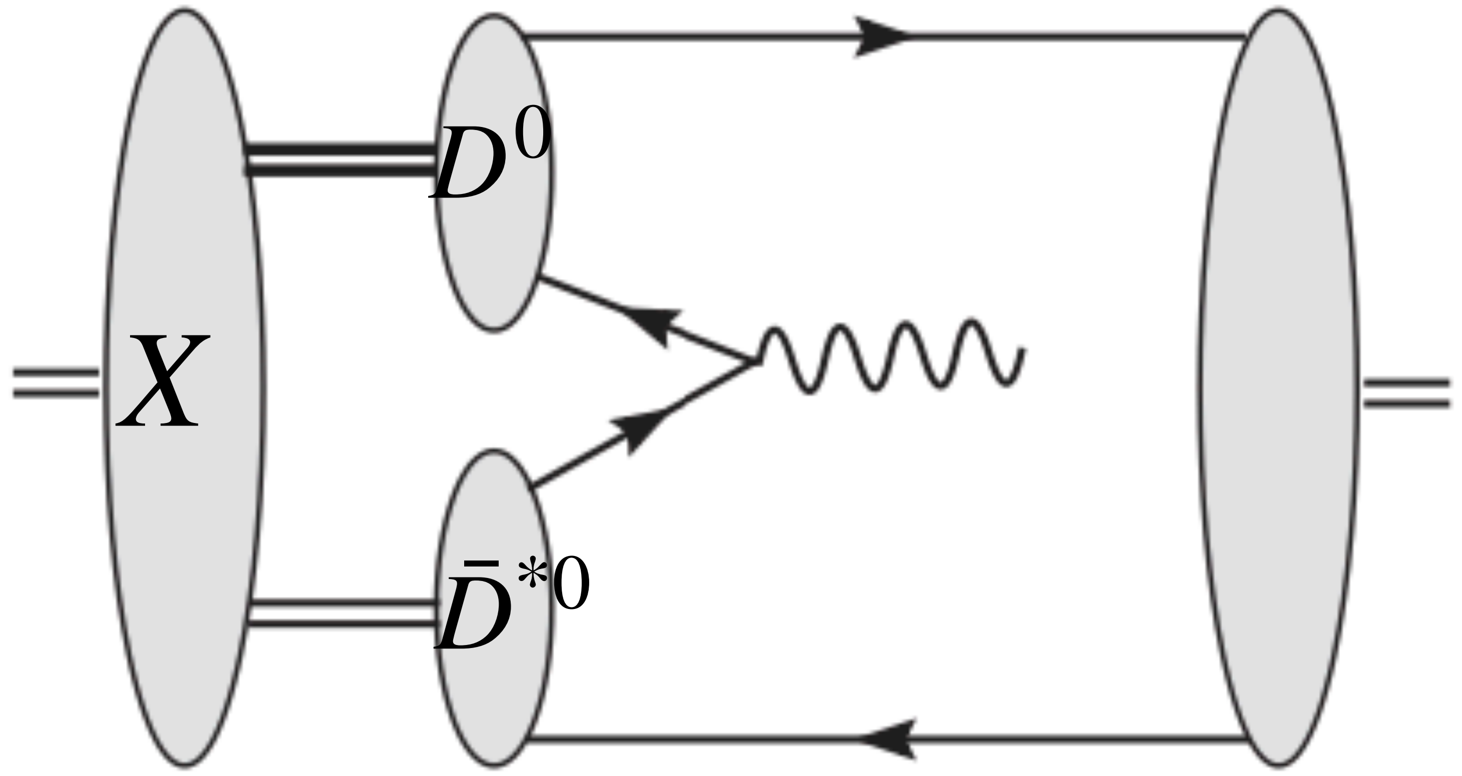
Mode	m_f (MeV)	q (MeV)	$\Gamma[c\bar{c}]$ (keV) [B&G] [SHO, dipole, NR, zero recoil, impulse]	$\Gamma[c\bar{c}]$ (keV) [A] [C+L, dipole, NR, zero recoil, impulse]	$\Gamma[c\bar{c}]$ (keV) [B]	$\Gamma[\hat{\chi}_{c1}]$ (keV)
$\gamma J/\psi$	3097	697	11	71	139	8
$\gamma\psi'(2^3S_1)$	3686	182	64	95	94	0.03
$\gamma\psi''(1^3D_1)$	3770	101	3.7	6.5	6.4	0
$\gamma\psi_2(1^3D_2)$	3838	34	0.5	0.7	0.7	0

/Users/SWANSONE/products/tex/HeavyLightPapers/B-decays/code/radTrans.f

X Radiative Decays



\>>



[SHO, dipole, NR, zero recoil, impulse]

[C+L, dipole, NR, zero recoil, impulse]

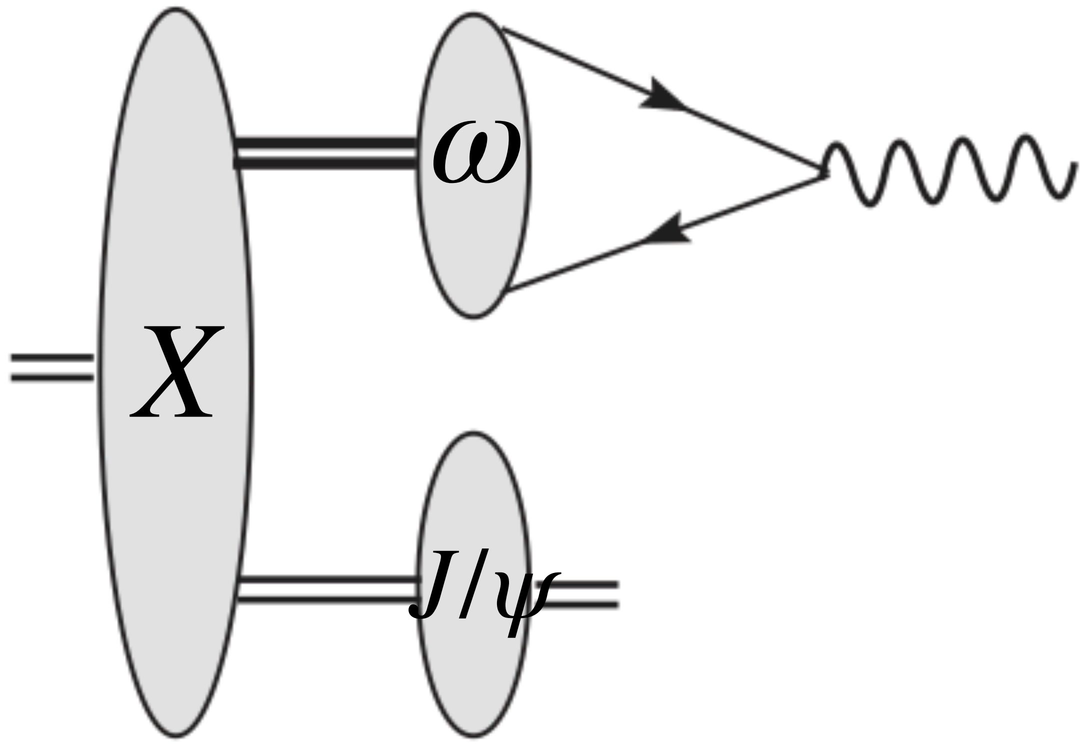
[C+L, ~~dipole~~, NR, ~~zero~~ recoil, impulse]

E1 decays of the $X(3872)$

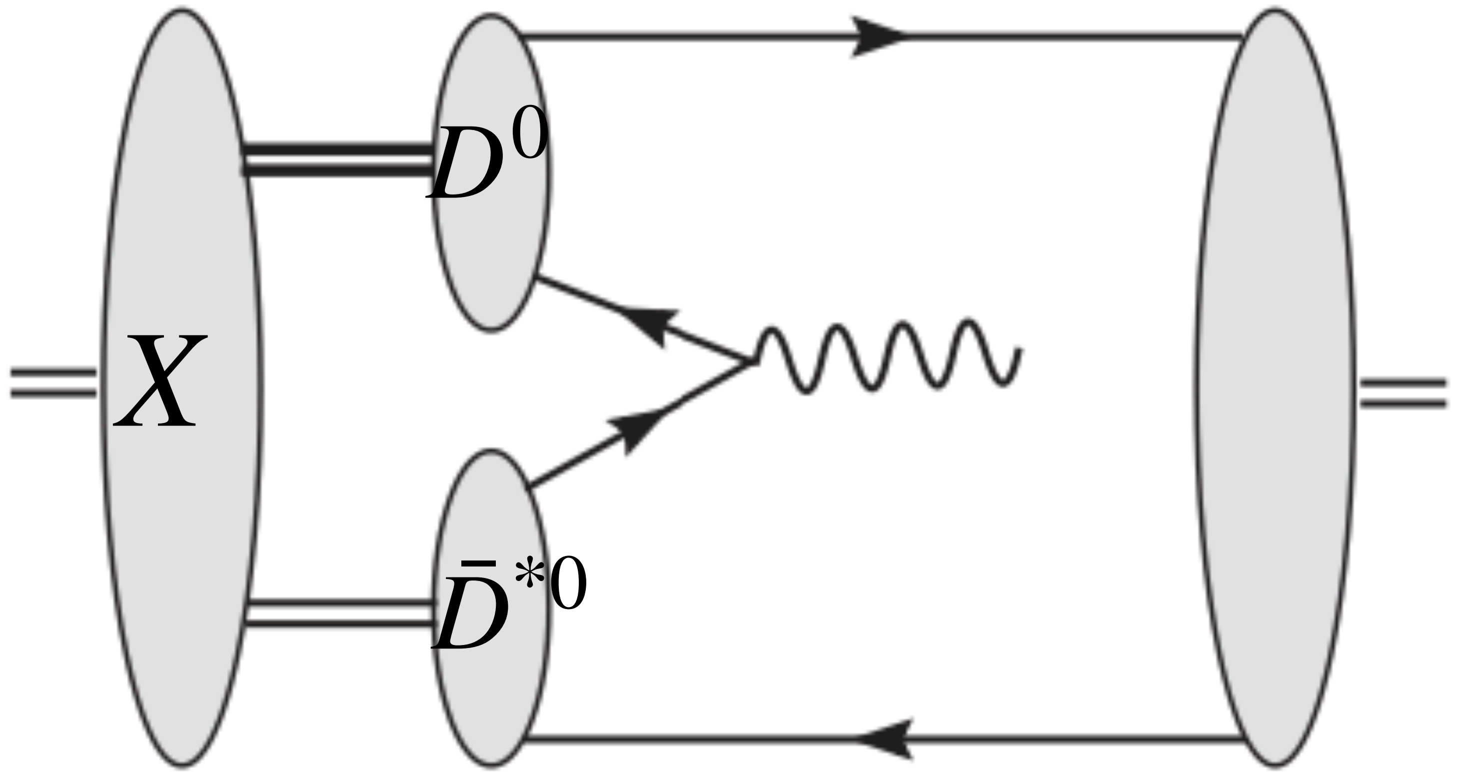
Mode	m_f (MeV)	q (MeV)	$\Gamma[c\bar{c}]$ (keV) [B&G]	$\Gamma[c\bar{c}]$ (keV) [A]	$\Gamma[c\bar{c}]$ (keV) [B]	$\Gamma[\hat{\chi}_{c1}]$ (keV)
$\gamma J/\psi$	3097	697	11	71	139	8
$\gamma \psi'(2^3S_1)$	3686	182	64	95	94	0.03
$\gamma \psi''(1^3D_1)$	3770	101	3.7	6.5	6.4	0
$\gamma \psi_2(1^3D_2)$	3838	34	0.5	0.7	0.7	0

/Users/SWANSONE/products/tex/HeavyLightPapers/B-decays/code/radTrans.f

X Radiative Decays



>>

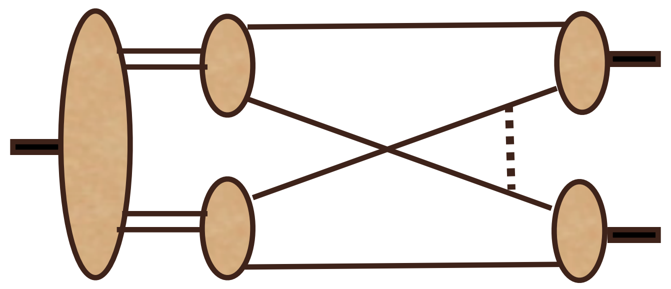


E1 decays of the $X(3872)$

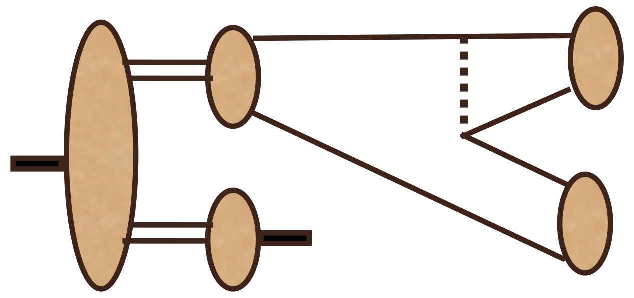
Mode	m_f (MeV)	q (MeV)	$\Gamma[c\bar{c}]$ (keV) [B&G]	$\Gamma[c\bar{c}]$ (keV) [A]	$\Gamma[c\bar{c}]$ (keV) [B]	$\Gamma[\hat{\chi}_{c1}]$ (keV)
$\gamma J/\psi$	3097	697	11	71	139	8
$\gamma\psi'(2^3S_1)$	3686	182	64	95	94	0.03
$\gamma\psi''(1^3D_1)$	3770	101	3.7	6.5	6.4	0
$\gamma\psi_2(1^3D_2)$	3838	34	0.5	0.7	0.7	0

/Users/SWANSONE/products/tex/HeavyLightPapers/B-decays/code/radTrans.f

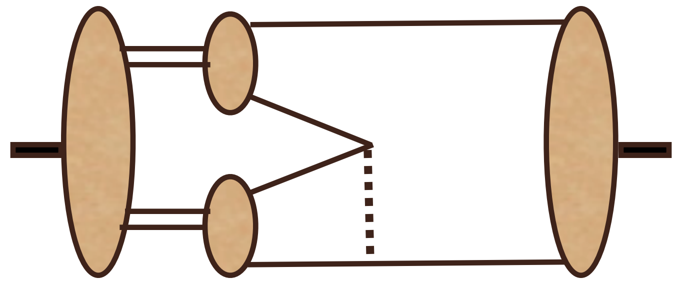
X Decays



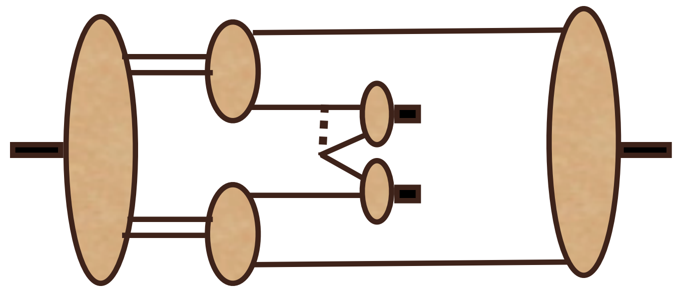
rearrangement



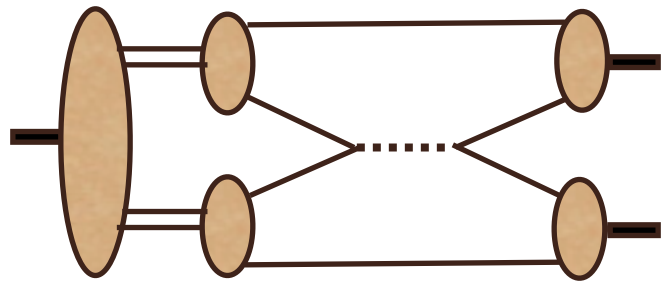
dissociation



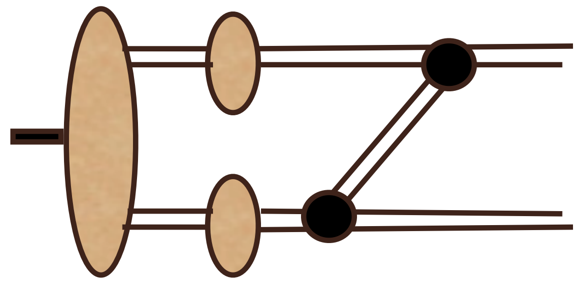
mixing



$\pi\pi$ production



annihilation



pion induced

X Hadronic Decays

$\chi_{c1}(3872)$ **DECAY MODES**

Expand all decays

Mode		Fraction (Γ_i / Γ)	Scale Factor/ Conf. Level	P(MeV/c)
Γ_1	e^+e^-	$< 2.7 \times 10^{-7}$	CL=90%	1936
Γ_2	$\pi^+\pi^-\pi^0$	$< 8 \times 10^{-3}$	CL=90%	1924
Γ_3	$\pi^+\pi^- J/\psi(1S)$	$(3.5 \pm 0.9)\%$		650
Γ_4	$\pi^+\pi^-\pi^0 J/\psi(1S)$	not seen		588
Γ_5	$\omega\eta_c(1S)$	$< 30\%$	CL=90%	368
Γ_6	$\rho(770)^0 J/\psi(1S)$	$(2.8 \pm 0.7)\%$		
Γ_7	$\omega J/\psi(1S)$	$(4.1 \pm 1.4)\%$		-1
Γ_8	$\phi\phi$	not seen		1646
Γ_9	$D^0 \bar{D} \pi^0$	$(45 \pm 21)\%$		116
Γ_{10}	$\overline{D}^{*0} D^0$	$(34 \pm 12)\%$		-1
Γ_{11}	$\gamma\gamma$	$< 10\%$	CL=90%	1936
Γ_{12}	$D^0 \overline{D}^0$	$< 26\%$	CL=90%	519
Γ_{13}	$D^+ D^-$	$< 17\%$	CL=90%	502
Γ_{14}	$\pi^0 \chi_{c2}$	$< 4\%$	CL=90%	273
Γ_{15}	$\pi^0 \chi_{c1}$	$(3.1^{+1.5}_{-1.3})\%$		319
Γ_{16}	$\pi^0 \chi_{c0}$	$< 13\%$	CL=90%	411
Γ_{17}	$\pi^+\pi^- \eta_c(1S)$	$< 13\%$	CL=90%	745

X Hadronic Decays

predicted isospin violation
due to D+D-*, D0D0* mass splitting

$$\frac{Br(X \to \pi^+\pi^-\pi^0 J/\psi)}{Br(X \to \pi^+\pi^- J/\psi)} = 1.0 \pm 0.4 \pm 0.3.$$

✓

[old]

X Hadronic Decays

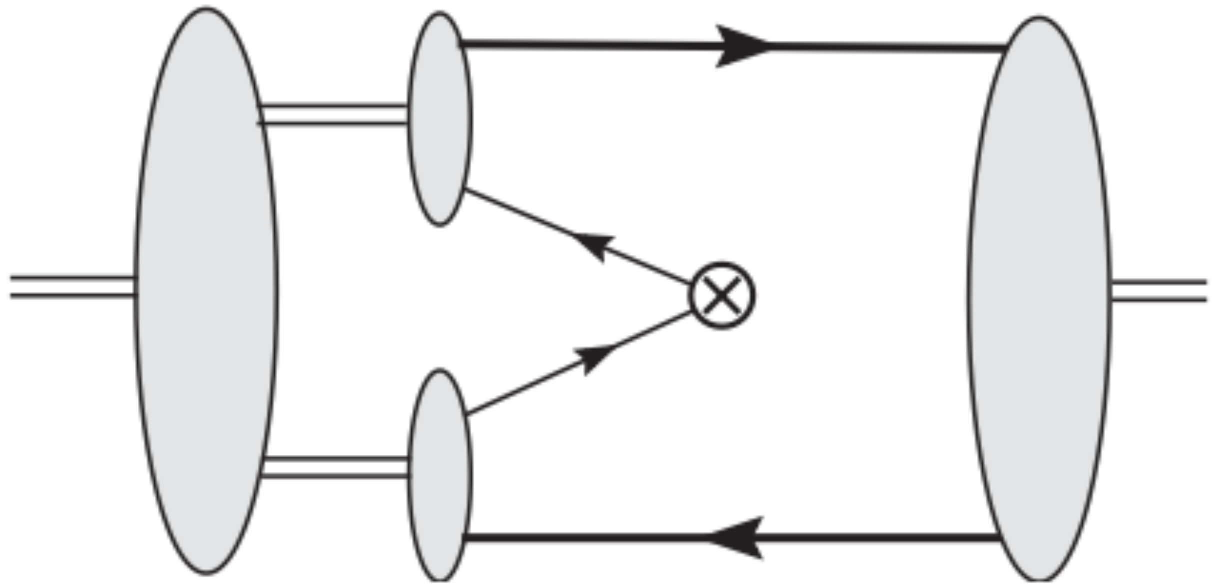
$$R = \frac{Br(X \to D^0 \bar{D}^0 \pi^0)}{Br(X \to \pi^+\pi^- J/\psi)} = 22 \pm 13. \qquad \text{[old]}$$

$$= 12.8 \pm 6 \qquad \text{[new]}$$

Molecular picture:

$$R = \frac{2 Z_{00} \Gamma(D^{*0})}{Z_{\rho\psi} \Gamma(\rho)}. \quad \approx 0.08 \quad ✘$$

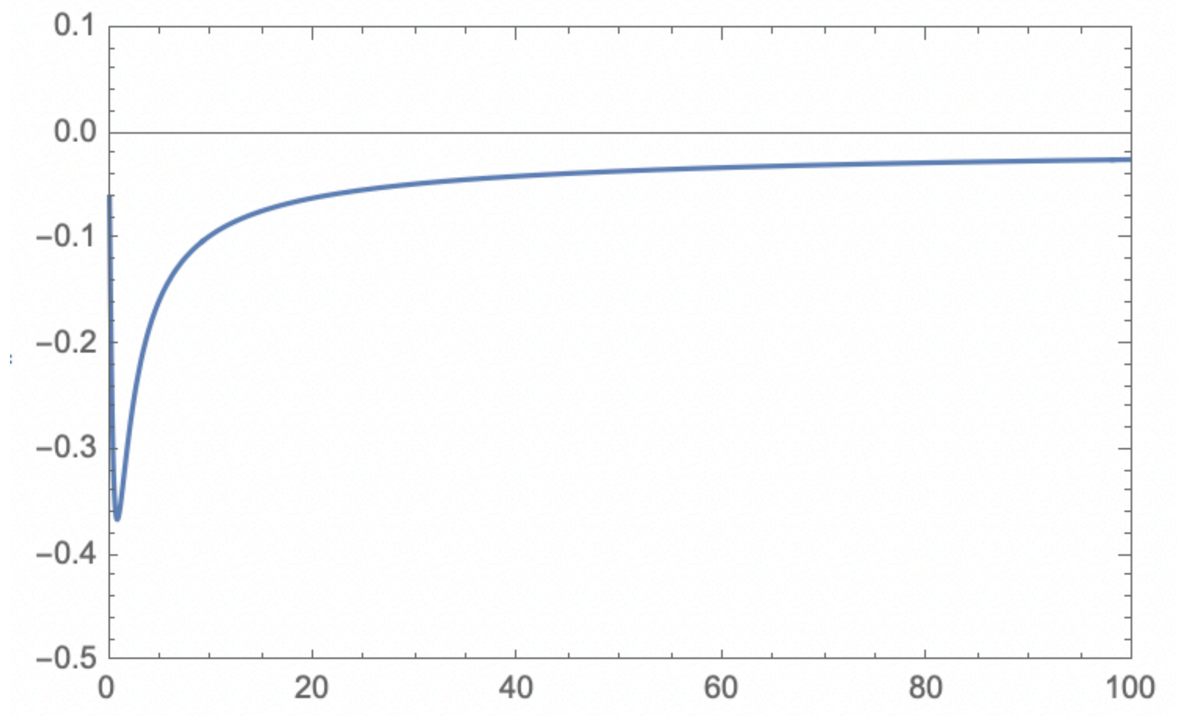
X Mixing



$$a_\chi = \sqrt{2} Z_{00}^{1/2} \int d^3k\, \psi_X(k) \mathscr{A}(-k),$$

$$\psi_X(k) = (\pi\sqrt{a})^{-1}(k^2 + a^{-2})^{-1}$$

a_χ $[GeV]$



a $[1/GeV]$

$X - \chi_{c1}$ Mixing

State	E_B (MeV)	a (fm)	Z_{00} (%)	a_χ (MeV)	Prob (%)
χ_{c1}	0.1	14.4	93	94	5
	0.5	6.4	83	120	10
χ'_{c1}	0.1	14.4	93	60	100
	0.5	6.4	83	80	> 100

/Users/SWANSONE/products/tex/HeavyLightPapers/B-decays/code

X Mixing ~ New Ratios

$$\frac{\Gamma(\gamma\psi(2S))}{\Gamma(J/\psi)} = 0.7 - 1.3$$ ✓

$$\frac{\Gamma(D^0\bar{D}^0\pi^0)}{\Gamma(\pi^+\pi^-J/\psi)} = ?$$ 😕

Conclusions

Physics Reports 429 (2006) 243–305
www.elsevier.

The new heavy mesons: A status report

Eric S. Swanson*
Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, PA 15260, USA

2.6. Summary

It is possible that all of the new experimental data may be explained if the coupling of the X to the χ'_{c1} is correctly incorporated in the coupled channel formalism. This would increase the $\gamma J/\psi$ branching fraction, permit the large $D^0\bar{D}^0\pi^0$ decay mode, and allow the charmonium-like production characteristics. A detailed phenomenology of this scenario remains to be constructed.

There should be a partner, mostly $c\bar{c}$, state with unusual properties, including large isospin violating decay modes.

~fin~

weak binding vs. full wavefunction