Status of Meson Spectroscopy in the PDG

Hadron 2021 Roundtable

July 30, 2021

Ryan Mitchell (Indiana University)

"Unstable Mesons" are curated by the PDG Meson Team:

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Citation: P.A. Zyla *et al.* (Particle Data Group), Prog. Theor. Exp. Phys. **2020**, 083C01 (2020) and 2021 update

$\pi_1(1600)$ $\quad I^G(J^{PC}) = 1^-(1^{-+})$

See the review on "Non-$q\bar{q}$ Mesons" and a note in PDG 06, Journal of Physics **G33** 1 (2006).

$\pi_1(1600)$ T-Matrix Pole $\sqrt{s}$

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
$(1564 \pm 24 \pm 86) - i\,(246 \pm 27 \pm 51)$	[1] RODAS	19	JPAC	191 $\pi^- p \rightarrow \eta^{(\prime)} \pi^- p$

[1] The coupled-channel analysis of both the $\eta\pi$ and $\eta'\pi$ systems using ADOLPH 15 data.

$\pi_1(1600)$ MASS

VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
1661^{+15}_{-11} OUR AVERAGE	Error includes scale factor of 1.2.				
1600^{+110}_{-60}	46M	[1] AGHASYAN	18B	COMP	190 $\pi^- p \rightarrow \pi^- \pi^+ \pi^- p$
$1664 \pm 8 \pm 10$	145k	[2] LU	05	B852	18 $\pi^- p \rightarrow \omega \pi^- \pi^0 p$
$1709 \pm 24 \pm 41$	69k	[3] KUHN	04	B852	18 $\pi^- p \rightarrow \eta \pi^+ \pi^- \pi^- p$
$1597 \pm 10^{+45}_{-10}$		[3] IVANOV	01	B852	18 $\pi^- p \rightarrow \eta' \pi^- p$

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$f_0(980)$ $\qquad I^G(J^{PC}) = 0^+(0^{++})$

See the review on "Scalar Mesons below 2 GeV."

$f_0(980)$ T-MATRIX POLE $\sqrt{s}$

VALUE (MeV)	*DOCUMENT ID*	*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •			
$(1003^{+5}_{-27}) - i(21^{+10}_{-8})$	[1] GARCIA-MAR..11	RVUE	Compilation
$(996 \pm 7) - i(25^{+10}_{-6})$	[2] GARCIA-MAR..11	RVUE	Compilation
$(973^{+39}_{-127}) - i(11^{+189}_{-11})$	[3] PELAEZ 04A	RVUE	$\pi\pi \to \pi\pi$

[1] Reanalysis of the K_{e4} data of BATLEY 10C and the $\pi N \to \pi\pi N$ data of HYAMS 73, GRAYER 74, and PROTOPOPESCU 73 using Roy equations.
[2] Reanalysis of the K_{e4} data of BATLEY 10C and the $\pi N \to \pi\pi N$ data of HYAMS 73, GRAYER 74, and PROTOPOPESCU 73 using GKPY equations.
[3] Reanalysis of data from PROTOPOPESCU 73, ESTABROOKS 74, GRAYER 74, and COHEN 80 in the unitarized ChPT model.

$f_0(980)$ MASS

VALUE (MeV)	*EVTS*	*DOCUMENT ID*	*TECN*	*COMMENT*
990 ±20 OUR ESTIMATE				
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$992.8 \pm 0.8 \pm 1.0$		[1] ALBRECHT 20	RVUE	$0.9\ \bar{p}p \to \pi^0\pi^0\eta$, $\pi^0\eta\eta$, $\pi^0 K^+K^-$
$992.0^{+8.5}_{-7.5} \pm 8.6$		[2] AAIJ 19H	LHCB	$pp \to D^\pm X$

[1] T-matrix pole, 5 poles, 5 channels, including scattering data from HYAMS 75 ($\pi\pi$), LONGACRE 86 ($K\bar{K}$), BINON 83 ($\eta\eta$), and BINON 84C ($\eta\eta'$). Second solution $977.8 \pm 0.6 \pm 1.6$ MeV.
[2] From the $D^\pm \to K^\pm K^+ K^-$ Dalitz plot fit with the Triple-M amplitude in the multi-meson model of AOUDE 18.

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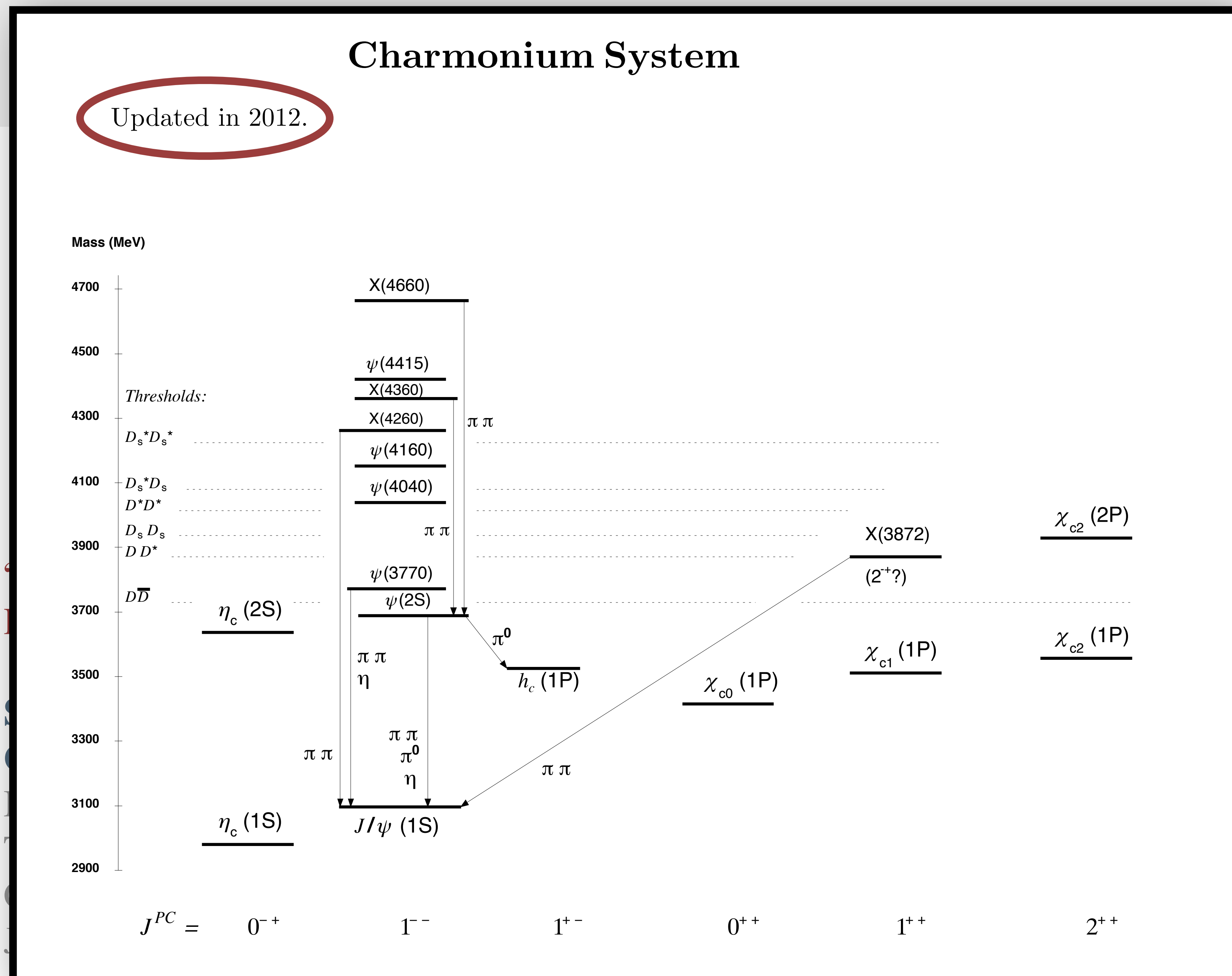

the PDG

sity)

rescriptive (generally descriptive)

gs and reviews

rds (e.g. naming scheme) and
s (e.g. moving beyond BW parameters)

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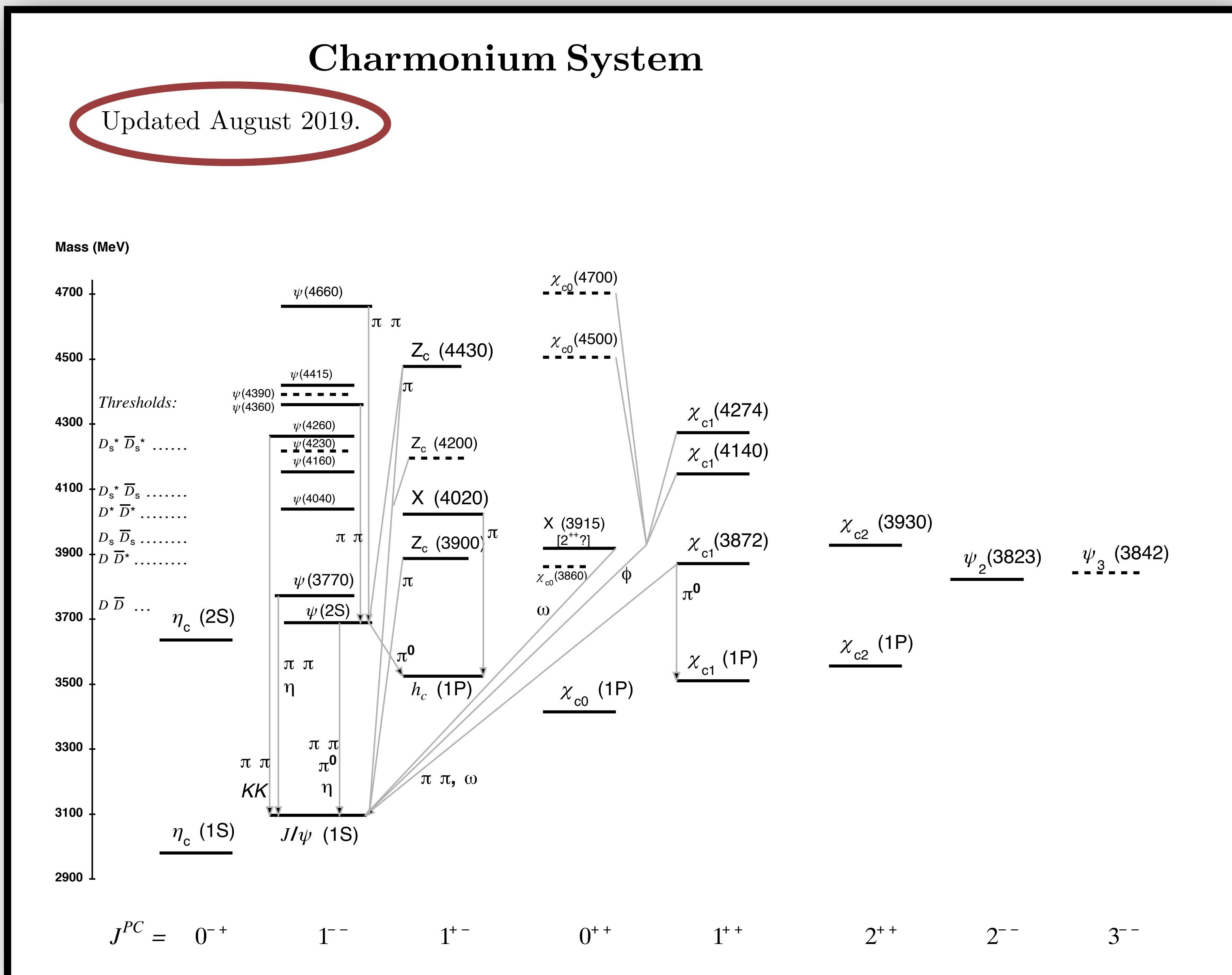

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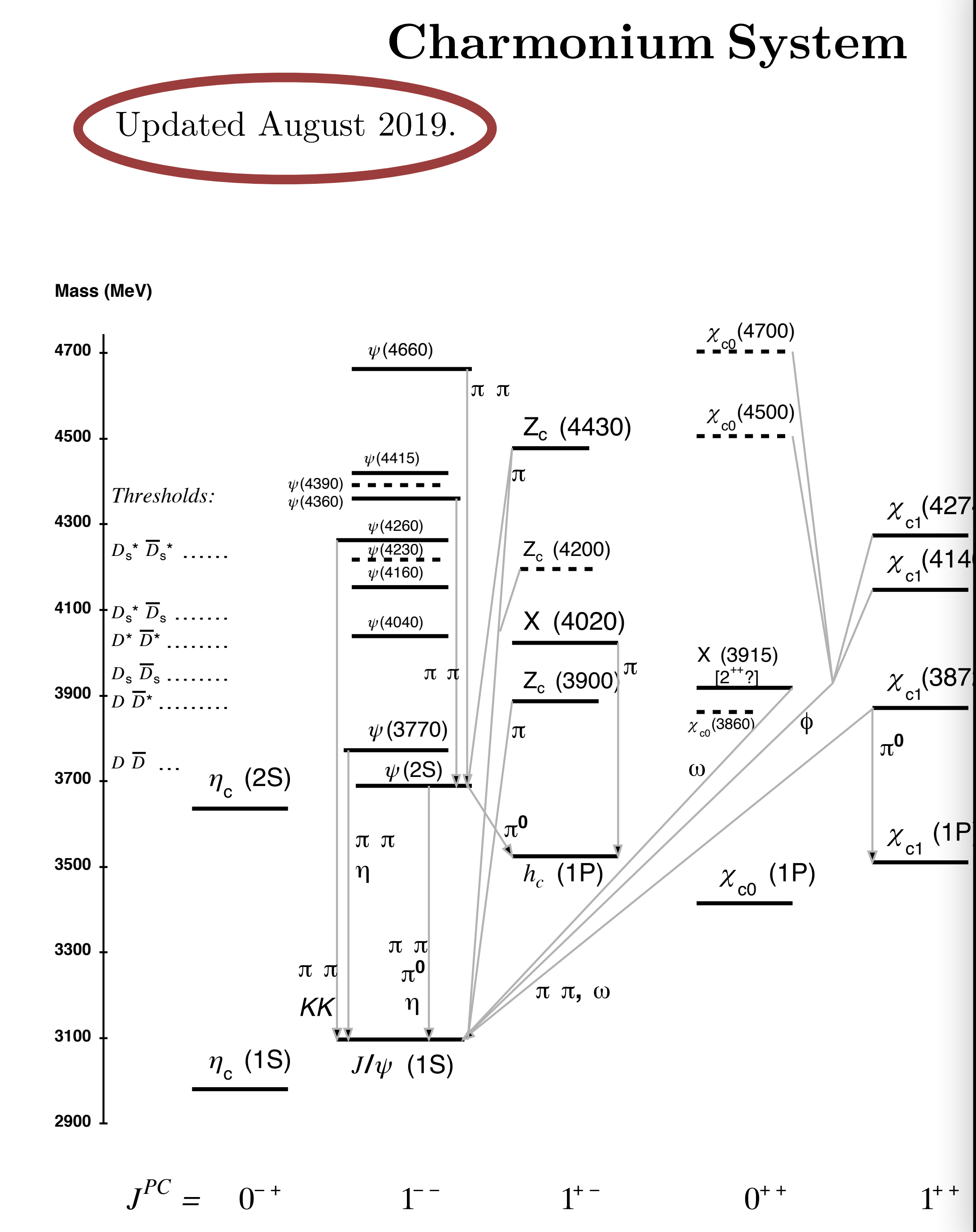

Observation of new resonances decaying to $J/\psi K^+$ and $J/\psi\phi$

arXiv:2103.01803v1 [hep-ex] 2 Mar 2021

LHCb collaboration[†]

$B^+ \to J/\psi \phi K^+$

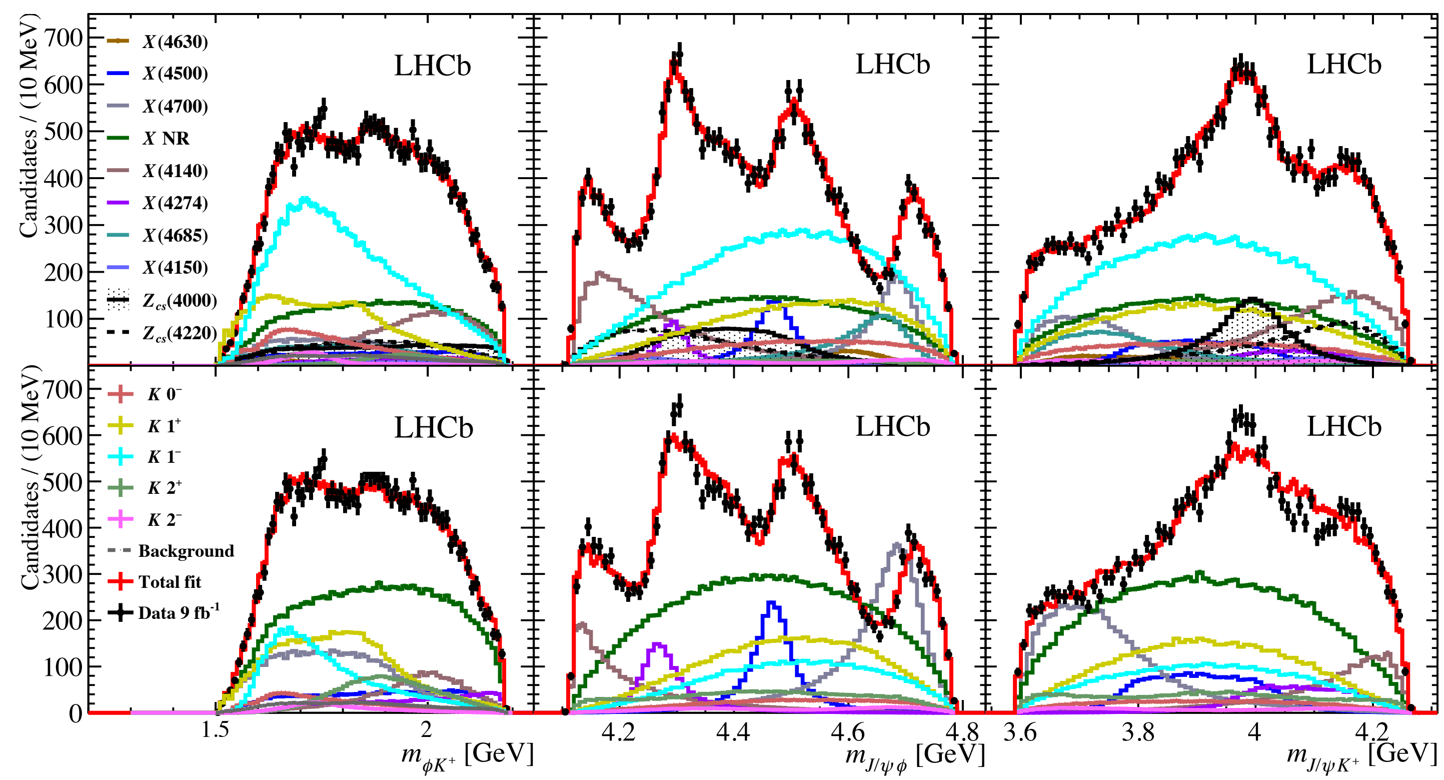

Figure 3: Distributions of ϕK^+ (left), $J/\psi\phi$ (middle) and $J/\psi K^+$ (right) invariant masses for the $B^+ \to J/\psi\phi K^+$ candidates (black data points) compared with the fit results (red solid lines) of the default model (top row) and the Run 1 model (bottom row).

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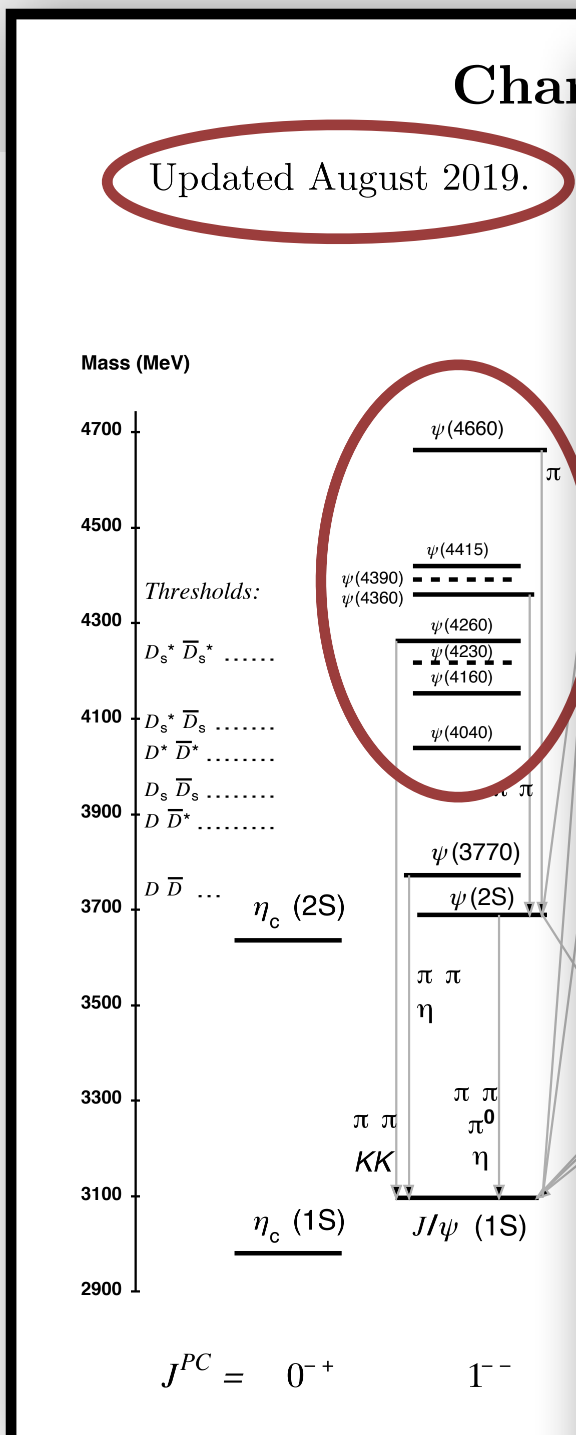

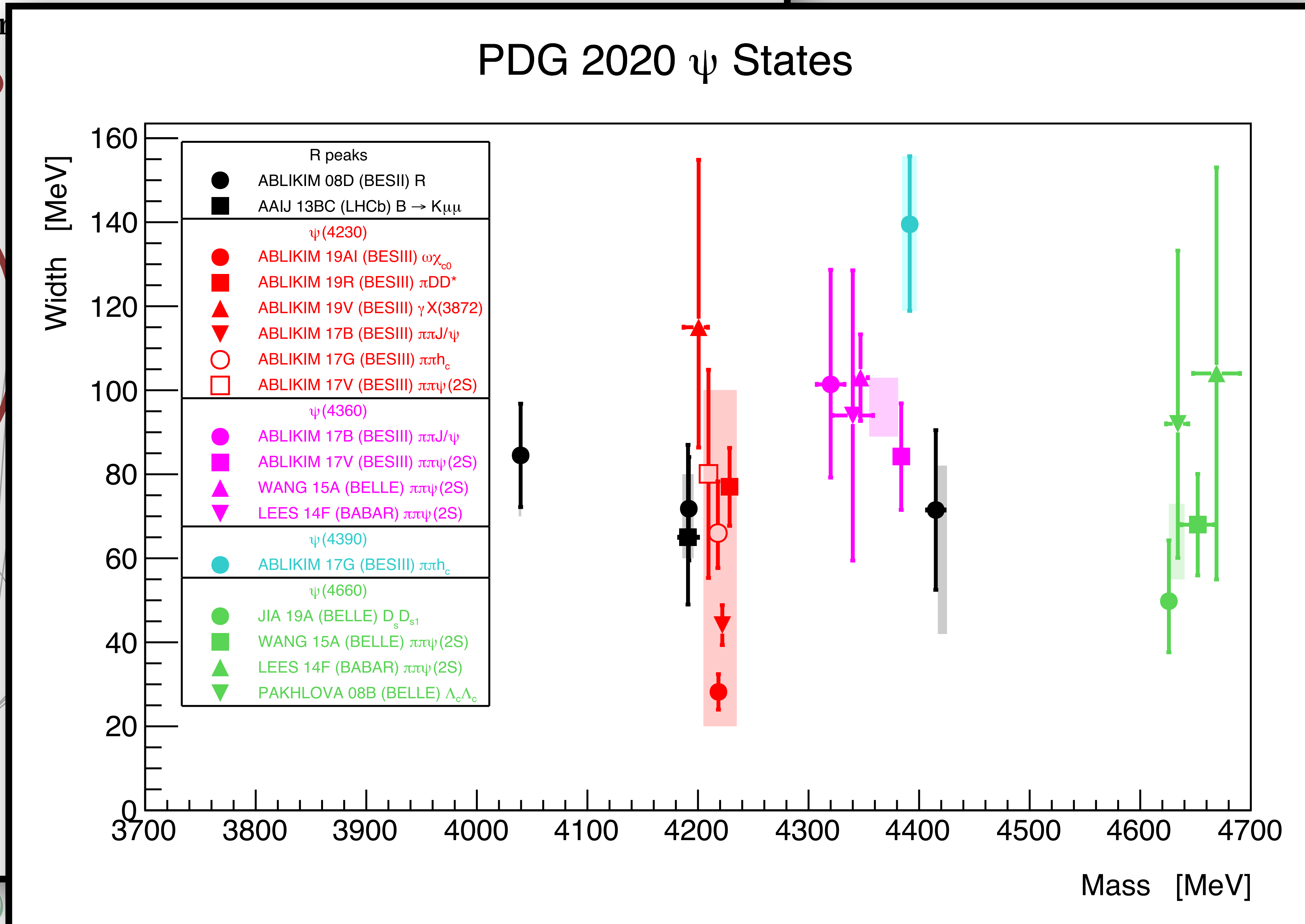

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Status of M

8. Naming Scheme for Hadrons

Revised August 2019 by V. Burkert (Jefferson Lab), S. Eidelman (Budker Inst., Novosibirsk; Novosibirsk U.), C. Hanhart (Jülich), E. Klempt (Bonn U.), R.E. Mitchell (Indiana U.), U. Thoma (Bonn U.), L. Tiator (KPH, JGU Mainz) and R.L. Workman (George Washington U.).

Citation: P.A. Zyla *et al.* (Particle Data Group), Prog. Theor. Exp. Phys. **2020**, 083C01 (2020) and 2021 update

$\chi_{c1}(3872)$ $\qquad I^G(J^{PC}) = 0^+(1^{++})$

also known as $X(3872)$

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.

Table 8.1: Symbols for mesons with strangeness and heavy-flavor quantum numbers equal to zero. States that do not yet appear in the RPP are listed in parentheses.

$J^{PC} =$	0^{-+}, 2^{-+}, ⋮	1^{+-}, 3^{+-}, ⋮	1^{--}, 2^{--}, ⋮	0^{++}, 1^{++}, ⋮
Minimal quark content				
$u\bar{d}, u\bar{u} - d\bar{d}, d\bar{u}$ $(I = 1)$	π	b	ρ	a
$d\bar{d} + u\bar{u}$ and/or $s\bar{s}$ $(I = 0)$	η, η'	h, h'	ω, ϕ	f, f'
$c\bar{c}$	η_c	h_c	ψ	χ_c
$b\bar{b}$	η_b	h_b	Υ	χ_b
$I = 1$ with $c\bar{c}$	(Π_c)	Z_c	R_c	(W_c)
$I = 1$ with $b\bar{b}$	(Π_b)	Z_b	(R_b)	(W_b)

meson names are based solely on quantum numbers
(but original names are also kept)

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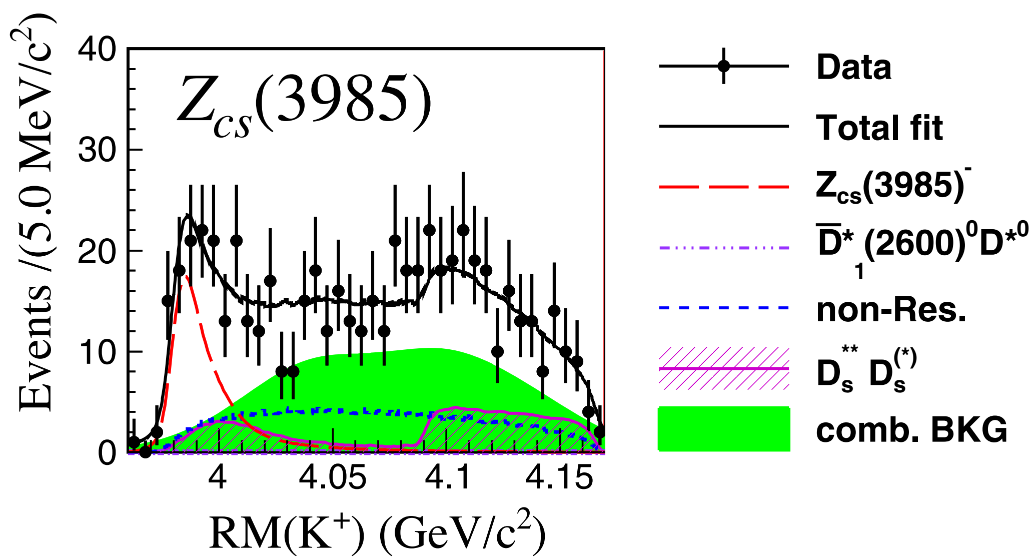
PHYSICAL REVIEW LETTERS **126,** 102001 (2021)

Editors' Suggestion | Featured in Physics

Observation of a Near-Threshold Structure in the K^+ Recoil-Mass Spectra in $e^+e^- \to K^+(D_s^- D^{*0} + D_s^{*-} D^0)$

(BESIII Collaboration)



easy extension from Z_c, Z_b, etc. to Z_{cs}, Z_{bs}, etc.

8. Naming Scheme for Hadrons

) by V. Burkert (Jefferson Lab), S. Eidelman (Budker Inst., Novosibirsk; Novosi- rt (Jülich), E. Klempt (Bonn U.), R.E. Mitchell (Indiana U.), U. Thoma (Bonn I, JGU Mainz) and R.L. Workman (George Washington U.).

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$J^{PC} = \{$	0^{-+}	1^{+-}	1^{--}	0^{++}
	2^{-+}	3^{+-}	2^{--}	1^{++}
	$\vdots$	$\vdots$	$\vdots$	$\vdots$
Minimal quark content				
$u\bar{d}, u\bar{u} - d\bar{d}, d\bar{u}$ $(I = 1)$	π	b	ρ	a
$d\bar{d} + u\bar{u}$ and/or $s\bar{s}$ $(I = 0)$	η,η'	h,h'	ω,ϕ	f,f'
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Science Bulletin 65 (2020) 1983–1993

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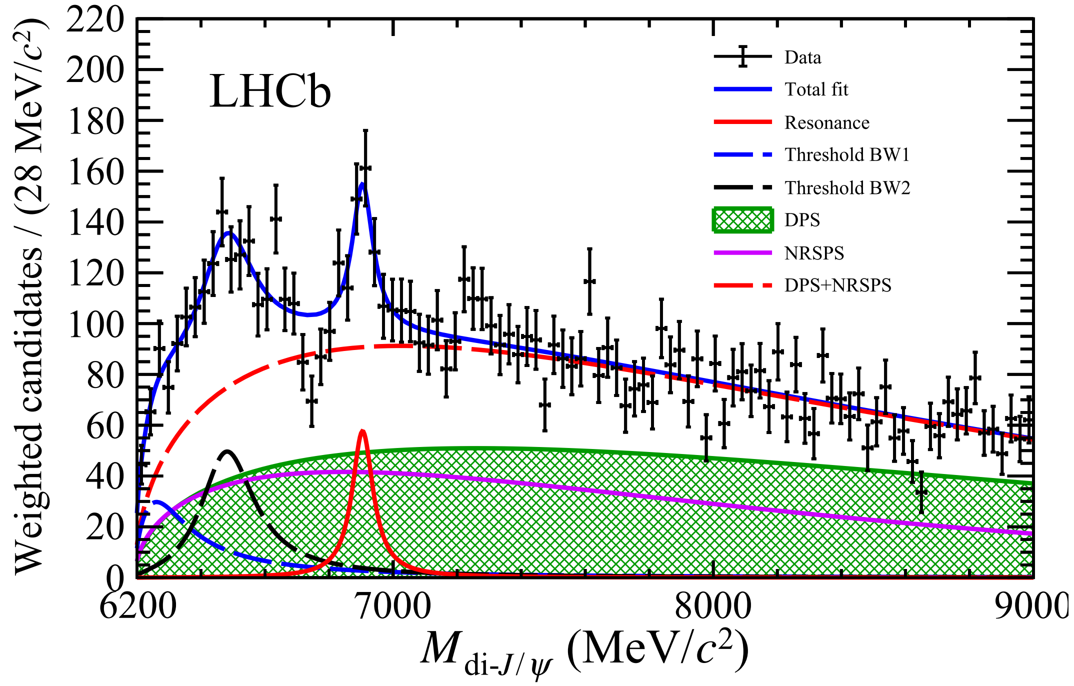
Article

Observation of structure in the J/ψ-pair mass spectrum

LHCb collaboration [1]



harder extension to $T_{cc\bar{c}\bar{c}}$ (ongoing) and T^+_{cc} (!!)

[and also $X_{0/1}(2900) \to D^- K^+$ (??)]

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Select upcoming reviews for meson spectroscopy

Spectroscopy of Light Meson Resonances (new)
C. Amsler, S. Eidelman, A. Masoni, G. Venanzoni

Heavy Non-qqbar Mesons (new)
S. Eidelman, T. Gutsche, C. Hanhart, R. Mitchell

Scalar Mesons below 2 GeV
C. Amsler, S. Eidelman, T. Gutsche, C. Hanhart, R. Mitchell, S. Spanier

Spectroscopy of Mesons Containing Two Heavy Quarks
S. Eidelman, J. J. Hernández-Rey, C. Lourenço, R. Mitchell, S. Navas, C. Patrignani

Quark Model
C. Amsler, T. DeGrand, B. Krusche

Naming Scheme for Hadrons
V. Burkert, S. Eidelman, C. Hanhart, R. Mitchell, U. Thoma, L. Tiator, R. Workman

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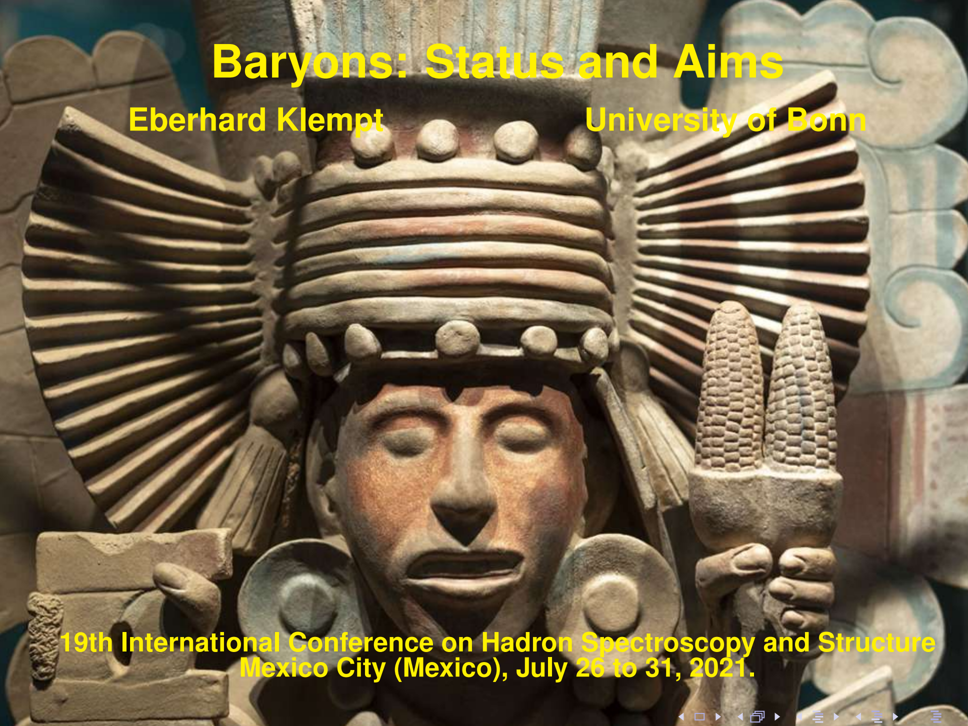
Baryons: Status and Aims

Eberhard Klempt University of Bonn



19th International Conference on Hadron Spectroscopy and Structure
Mexico City (Mexico), July 26 to 31, 2021.

Status: Baryon@PDG

	2010 edition	2012 edition	2014 edition	2016 edition	2018 edition	2020 edition
	Charles Wohl	Charles Wohl	Mike Pennington	Mike Pennington	Eberhard Klempt	Eberhard Klempt
	Ron Workman	Eberhard Klempt	Volker Burkert	Volker Burkert	Volker Burkert	Volker Burkert
		Ron Workman	Eberhard Klempt	Eberhard Klempt	Lothar Tiator	Lothar Tiator
			Lothar Tiator	Lothar Tiator	Ron Workman	Ulrike Thoma
						Ron Workman

2021: E. Klempt $\longrightarrow$ Volker Crede

Tables:		$N(1440)P_{11}$ $\rightarrow$ $N(1440)1/2^+$	Why $\Lambda_c(2880)$ not $\Lambda_c(2880)5/2^+$?		Pole position first	
Reviews:		Minireview on N and Δ revised	Note on electro-production	Two-pole structure of $\Lambda(1405)$	Resonances E.K. + D.Asner C. Hanhart	Minireview on Λ and Σ revised

The impact of photoproduction on baryon resonances		Decay modes of nucleon resonances	****	Existence is certain.
	black:	PDG 2004	***	Existence is very likely.
	red:	PDG 2018	**	Evidence of existence is fair.
	blue:	BESIII resonances	*	Evidence of existence is poor.

		overall	$N\gamma$	$N\pi$	$\Delta\pi$	$N\sigma$	$N\eta$	ΛK	ΣK	$N\rho$	$N\omega$	$N\eta\prime$	$N_{1440}\pi$	$N_{1520}\pi$	$N_{1535}\pi$	N_{1680}
N	$1/2^+$	****														
$N(1440)$	$1/2^+$	****	****	****	****	***										
$N(1520)$	$3/2^-$	****	****	****	****	**	****									
$N(1535)$	$1/2^-$	****	****	****	***	*	****									
$N(1650)$	$1/2^-$	****	****	****	***	*	****	*					*			
$N(1675)$	$5/2^-$	****	****	****	***	***	*	*	*					*		
$N(1680)$	$5/2^+$	****	****	****	****	***	*									
$N(1700)$	$3/2^-$	***	**	***	***	*	*			*						
$N(1710)$	$1/2^+$	****	****	****	*		***	**	*	*	*				*	
$N(1720)$	$3/2^+$	****	****	****	***	*	*	****	*	*	*					
$N(1860)$	$5/2^+$	**	*	**		*	*									
$N(1875)$	$3/2^-$	***	**	**	*	**	*	*	*	*	*	*	*			
$N(1880)$	$1/2^+$	***	**	*	**	*	*	**	**		**				*	
$N(1895)$	$1/2^-$	****	****	*	*	*	****	**	**	*	*	****	*			
$N(1900)$	$3/2^+$	****	****	**	**	*	*	**	**		*	**				
$N(1990)$	$7/2^+$	**	**	**	*	*	*	**	**							
$N(2000)$	$5/2^+$	**	**	*	**	*	*				*					
$N(2040)$	$3/2^+$	*		*												
$N(2060)$	$5/2^-$	***	***	**	*	*	*	*	*	*	*		*	*		*
$N(2100)$	$1/2^+$	***	**	***	**	**	*	*		*	*	**			***	
$N(2120)$	$3/2^-$	***	***	***	**	**		**	*		*	*	*	*	*	
$N(2190)$	$7/2^-$	****	****	****	****	**	*	**	*	*	*					
$N(2220)$	$9/2^+$	****	**	****			*	*	*							
$N(2250)$	$9/2^-$	****	**	****			*	*	*							
$N(2300)$	$1/2^+$	*		*												
$N(2570)$	$5/2^-$	*		*												
$N(2600)$	$11/2^-$	***		***												
$N(2700)$	$13/2^+$	**		**												

E. Klempt, 2019

The impact of photoproduction on Δ resonances

Decay modes of Δ resonances
black: PDG 2004
red: PDG 2018

****	Existence is certain.
***	Existence is very likely.
**	Evidence of existence is fair.
*	Evidence of existence is poor.

		overall	$N\gamma$	$N\pi$	$\Delta\pi$	ΣK	$N\rho$	$\Delta\eta$	$N_{1440}\pi$	$N_{1520}\pi$	$N_{1535}\pi$	$N_{1680}\pi$
Δ(1232)	$3/2^+$	****	****	****								
Δ(1600)	$3/2^+$	****	****	***	****							
Δ(1620)	$1/2^-$	****	****	****	****							
Δ(1700)	$3/2^-$	****	****	****	****	*	*		*			
Δ(1750)	$1/2^+$	*	*	*		*						
Δ(1900)	$1/2^-$	***	***	***	*	**	*		*	*		
Δ(1905)	$5/2^+$	****	****	****	**	*	*	**				*
Δ(1910)	$1/2^+$	****	***	****	**	**		*	*		*	
Δ(1920)	$3/2^+$	***	***	***	***	**		**				
Δ(1930)	$5/2^-$	***	*	***	*	*						
Δ(1940)	$3/2^-$	**	*	**	*			*	*	*	*	
Δ(1950)	$7/2^+$	****	****	****	**	***						*
Δ(2000)	$5/2^+$	**	*	**	*		*					
Δ(2150)	$1/2^-$	*		*								
Δ(2200)	$7/2^-$	***	***	**	***	**						
Δ(2300)	$9/2^+$	**		**								
Δ(2350)	$5/2^-$	*		*								
Δ(2390)	$7/2^+$	*		*								
Δ(2400)	$9/2^-$	**	**	**								
Δ(2420)	$11/2^+$	****	*	****								
Δ(2750)	$13/2^-$	**		**								
Δ(2950)	$15/2^+$	**		**								

E. Klempt, 2019

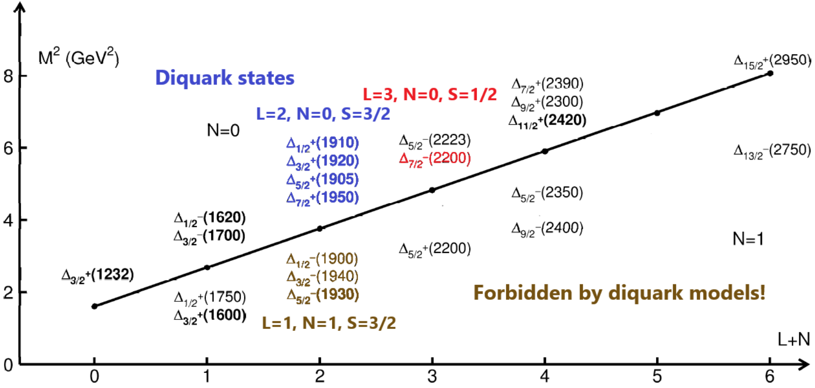
► Test of quark models

- Number of baryon states (frozen diquarks?)

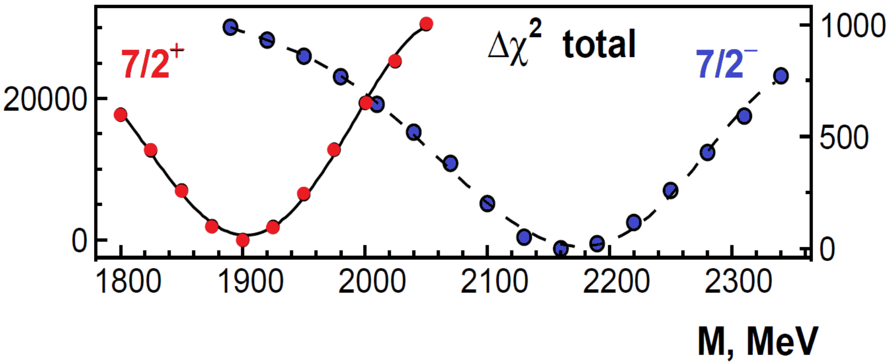
  Number of states rules out frozen diquarks,

  Cascade decays evidence 3-quark dynamics

- $M^2 \propto L + 2N$ (harmonic oscillator) or $M^2 \propto L + N$ (string models)



- **Parity doublets**
  - $M(J^+) = M(J^-)$? **unlikely!**



Aims

- **More baryons:**

  Hyperons, cascades, charmed baryons, beautiful baryons

(D, L^P_N)	S	J^P	Singlet	Octet			Decuplet	
$(56, 0^+_0)$	$\frac{1}{2}$	$\frac{1}{2}^+$		$N(939)$	$\Lambda(1116)$	$\Sigma(1193)$		
	$\frac{3}{2}$	$\frac{3}{2}^+$					$\Delta(1232)$	$\Sigma(1385)$
$(70, 1^-_1)$	$\frac{1}{2}$	$\frac{1}{2}^-$	$\Lambda(1405)$	$N(1535)$	$\Lambda(1670)$	$\Sigma(1620)$	$\Delta(1620)$	$\Sigma(1900)\dagger$
		$\frac{3}{2}^-$	$\Lambda(1520)$	$N(1520)$	$\Lambda(1690)$	$\Sigma(1670)$	$\Delta(1700)$	$\Sigma(1910)\dagger$
	$\frac{3}{2}$	$\frac{1}{2}^-$		$N(1650)$	$\Lambda(1800)$	$\Sigma(1750)$		
		$\frac{3}{2}^-$		$N(1700)$	$\ominus$	$\ominus$		
		$\frac{5}{2}^-$		$N(1675)$	$\Lambda(1830)$	$\Sigma(1775)$		
$(56, 0^+_2)$	$\frac{1}{2}$	$\frac{1}{2}^+$		$N(1440)$	$\Lambda(1600)$	$\Sigma(1660)$		
	$\frac{3}{2}$	$\frac{3}{2}^+$					$\Delta(1600)$	$\Sigma(1780)$
$(70, 0^+_2)$	$\frac{1}{2}$	$\frac{1}{2}^+$	$\Lambda(1710)$	$N(1710)$	$\Lambda(1810)$	$\Sigma(1880)$	$\Delta(1750)$	$\ominus$
	$\frac{3}{2}$	$\frac{3}{2}^+$		$\ominus$	$\ominus$	$\ominus$		
$(56, 2^+_2)$	$\frac{1}{2}$	$\frac{3}{2}^+$		$N(1720)$	$\Lambda(1890)$	$\Sigma(1940)$		
	$\frac{1}{2}$	$\frac{5}{2}^+$		$N(1680)$	$\Lambda(1820)$	$\Sigma(1915)$		
	$\frac{3}{2}$	$\frac{1}{2}^+$					$\Delta(1910)$	
	$\frac{3}{2}$	$\frac{3}{2}^+$					$\Delta(1920)$	$\Sigma(2080)$
	$\frac{3}{2}$	$\frac{5}{2}^+$					$\Delta(1905)$	$\Sigma(2070)$
	$\frac{3}{2}$	$\frac{7}{2}^+$					$\Delta(1950)$	$\Sigma(2030)$

$(70, 2_2^+)$	$\frac{1}{2}$	$\frac{3}{2}^+$	$\Lambda(2070)$	⊖	⊖	⊖	⊖	⊖
		$\frac{5}{2}^+$	$\Lambda(2110)$	$N(1860)$	⊖	⊖	$\Delta(2000)$	⊖
	$\frac{3}{2}$	$\frac{1}{2}^+$		$N(1880)$	⊖	⊖		
		$\frac{3}{2}^+$		$N(1900)$	⊖	⊖		
		$\frac{5}{2}^+$		$N(2000)$	⊖	⊖		
		$\frac{7}{2}^+$		$N(1990)$	$\Lambda(2085)$	⊖		
$(20, 1_2^+)$	$\frac{1}{2}$	$\frac{1}{2}^+$	⊖	⊖	⊖	⊖		
		$\frac{3}{2}^+$	⊖	⊖	⊖	⊖		
		$\frac{5}{2}^+$	⊖					
$(56, 1_3^-)$	$\frac{1}{2}$	$\frac{1}{2}^-$		$N(1895)$	$\Lambda(2000)$	$\Sigma(1900)\dagger$		
		$\frac{3}{2}^-$		$N(1875)$	$\Lambda(2050)$	$\Sigma(1910)\dagger$		
	$\frac{3}{2}$	$\frac{1}{2}^-$					$\Delta(1900)$	$\Sigma(2110)\dagger$
		$\frac{3}{2}^-$					$\Delta(1940)$	$\Sigma(2010)\dagger$
		$\frac{5}{2}^-$					$\Delta(1930)$	⊖
$(70, 3_3^-)$	$\frac{1}{2}$	$\frac{5}{2}^-$	$\Lambda(2080)$	$N(2060)$	⊖	⊖	⊖	⊖
		$\frac{7}{2}^-$	$\Lambda(2100)$	$N(2190)$	⊖	$\Sigma(2100)$	$\Delta(2200)$	⊖

Caution:

- **Are there "bumps" beyond the quark model?**

  $P_c's \to J/\psi N$, $N(1685 \to N\eta$

  $\Lambda(1380)1/2^- + \Lambda(1405)1/2^-$

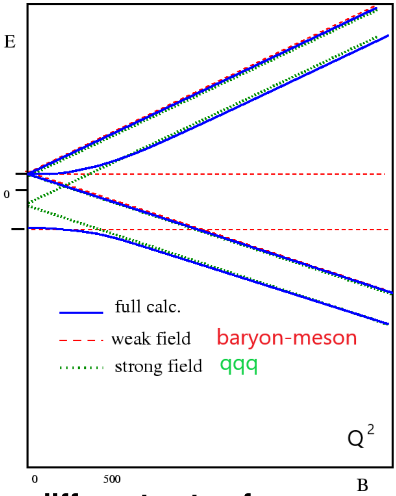
- **Nature of "bumps":**

  True resonance or rescattering?

  Factorization of prod. and decay

  Quark-model state or dynamically generated resonances?

  Weinberg criterium



(Baryon plus meson) and (*qqq*) can be different sets of wave functions. The true wave function is a superposition! There is no extra state, e.g. there is only one $N(1535)1/2^-$.

Round table: Present and future of hadron spectroscopy

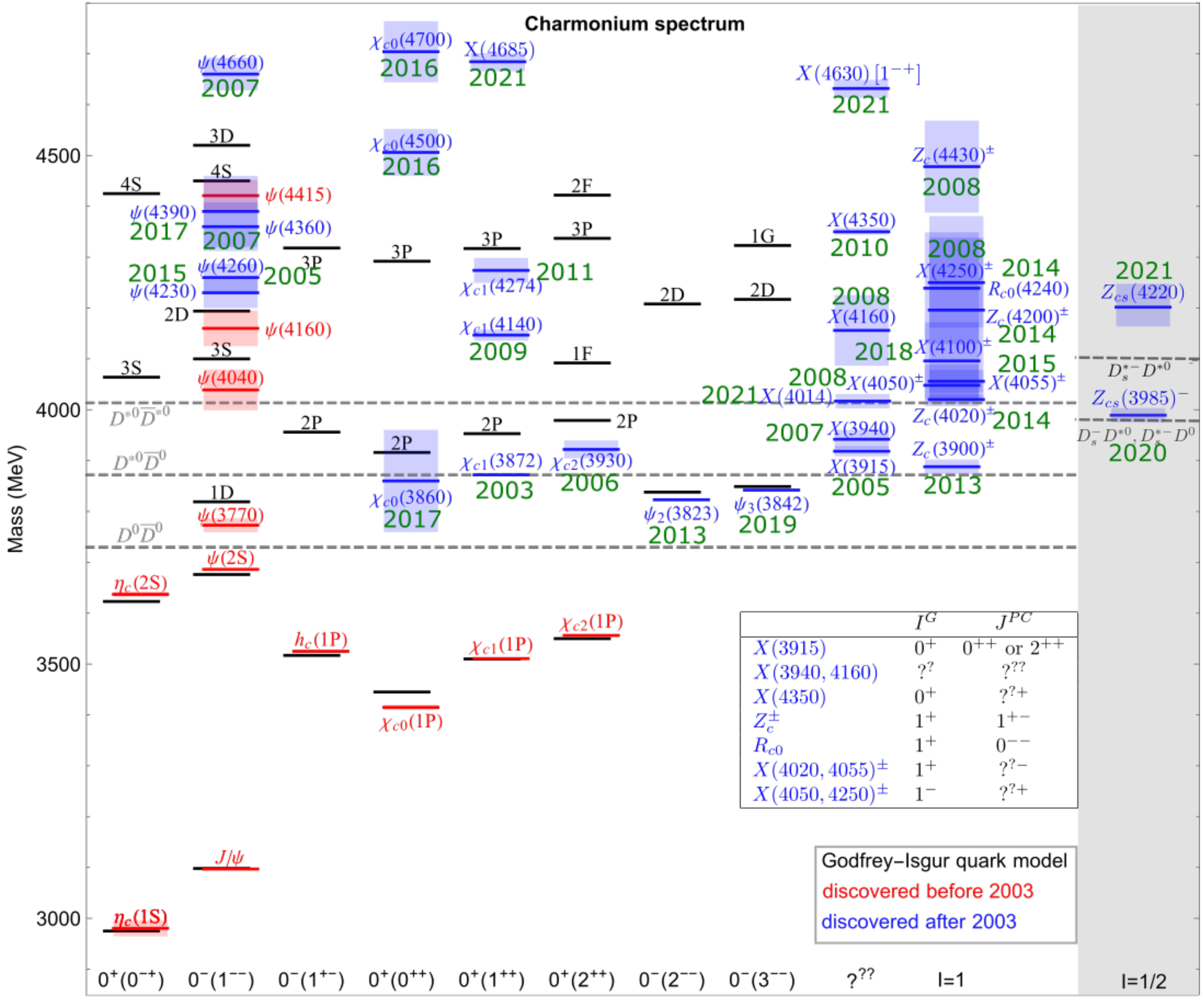
Feng-Kun Guo
Institute of Theoretical Physics, CAS

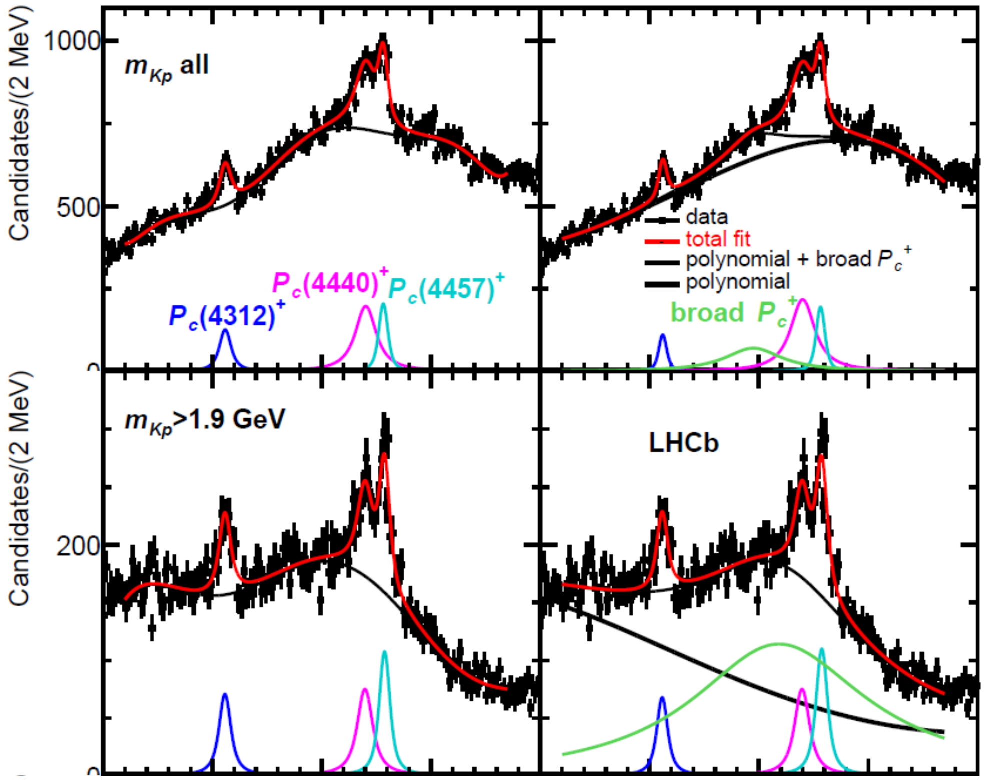
HADRON 2021

19th International Conference on Hadron Spectroscopy and Structure in memoriam Simon Eidelman

26 July – 1 Aug., 2021

Hidden-charm



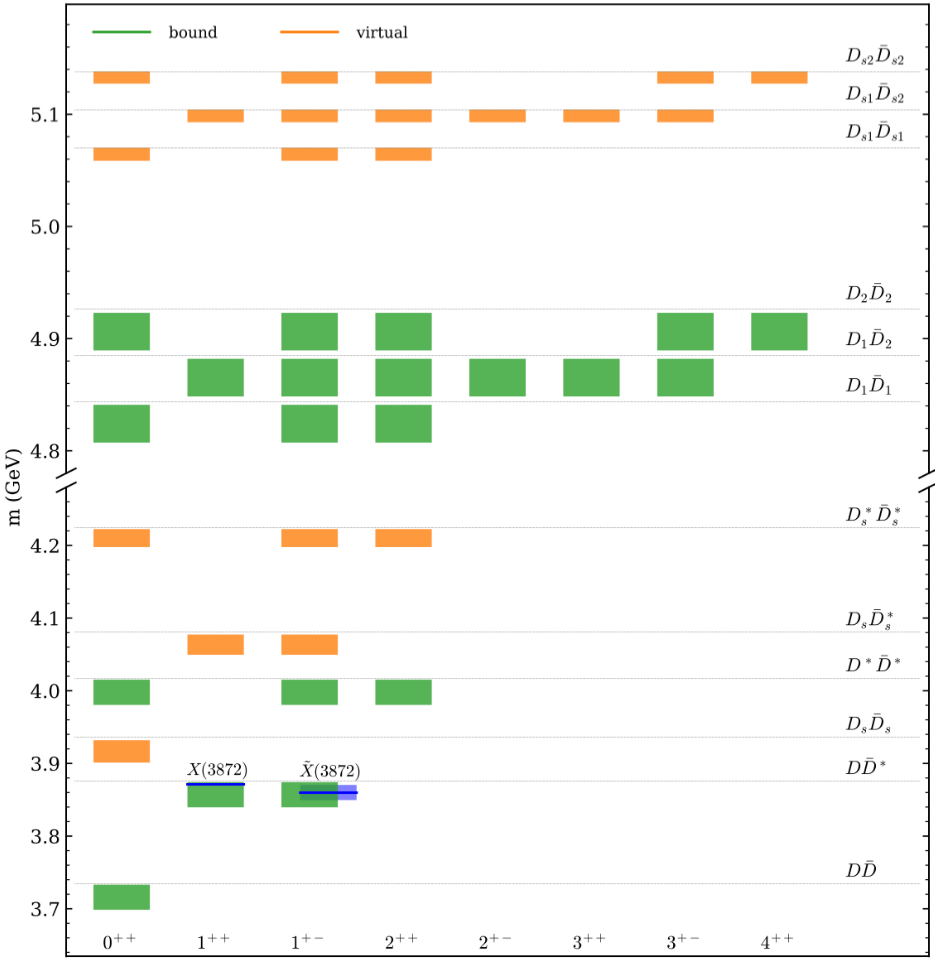


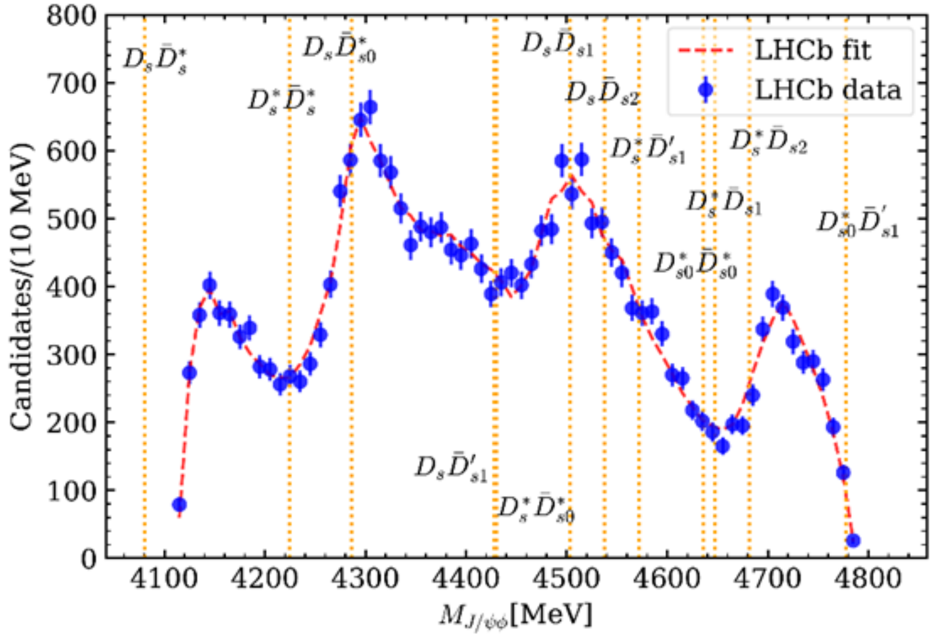
LHCb, PRL122,222001(2019)

Hidden-charm spectrum: One of the foci of hadron spectroscopy at present and in the near future

Hidden-charm: spectrum to be corrected

- Many charmonium-like structures, some are close to thresholds, and the others do not. Any pattern?
- In most cases, resonance parameters extracted using Breit-Wigner
  - Coupled channels and thresholds not considered



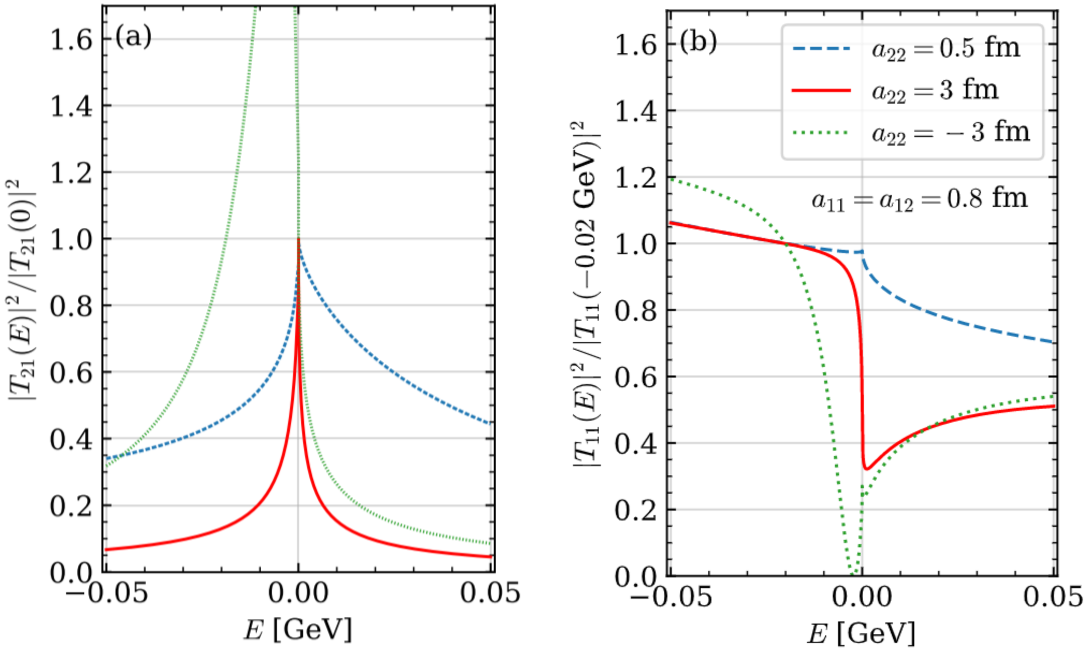


LHCb data: arXiv:2103.01803

Molecular spectrum predicted in
X.-K. Dong, FKG, B.-S. Zou, Progr.Phys. 41 (2021) 65 [arXiv:2101.01021]

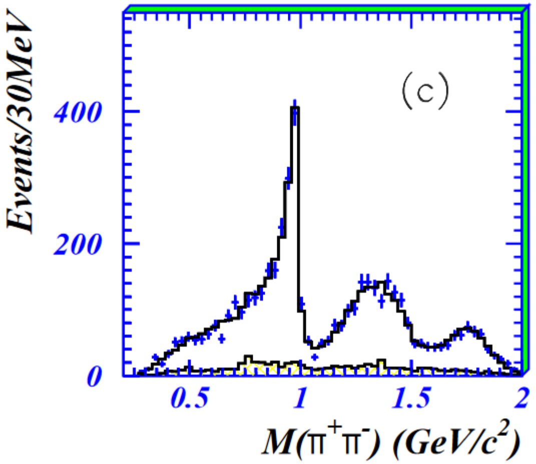
Hidden-charm: spectrum to be corrected

- Many charmonium-like structures, some are close to thresholds, and the others do not. Any pattern?
- In most cases, resonance parameters extracted using Breit-Wigner
    - Unitarity: the same resonance may behave completely different in different processes



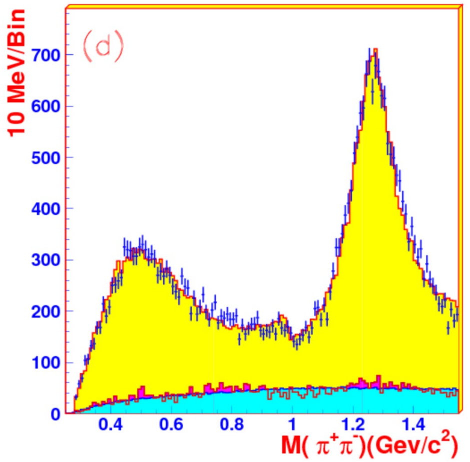
Line shapes of the same poles in different processes
X.-K. Dong, FKG, B.-S. Zou, PRL126,152001(2021)

E.g., $f_0(980)$: peak in $J/\psi \to \phi\pi^+\pi^-$, dip in $J/\psi \to \omega\pi^+\pi^-$



BES, PLB607(2005)243

$K\bar{K} \to \pi\pi$



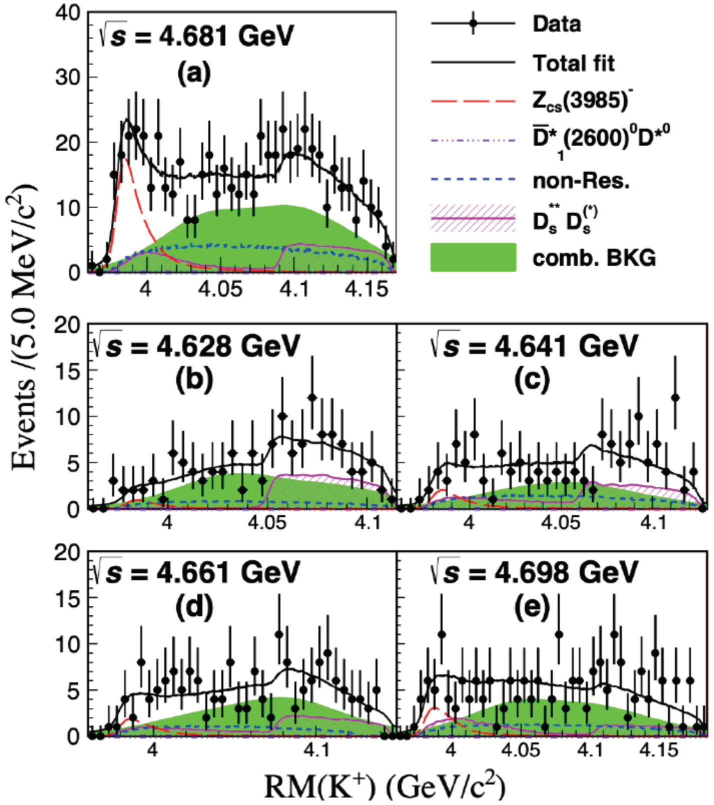
BES, PLB598(2004)149

$\pi\pi \to \pi\pi$

Hidden-charm: spectrum to be corrected

E.g., $Z_{cs}(3985)$ @BESIII;

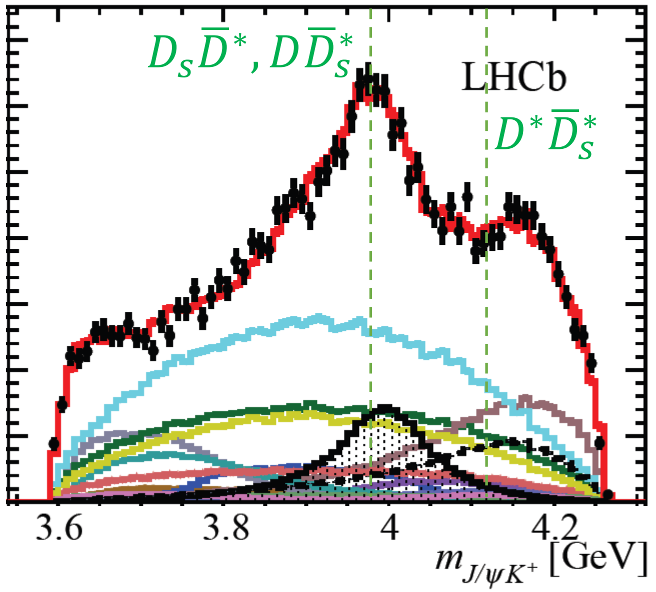
BESIII, PRL 126, 102001 (2021);
talk by P.-G. Ping, Session-Exotics, 29.07



$$M_{Z_{cs}(3985)} = (3982.5^{+1.8}_{-2.6} \pm 2.1)\mathrm{MeV}/c^2,$$
$$\Gamma_{Z_{cs}(3985)} = (12.8^{+5.3}_{-4.4} \pm 3.0)\mathrm{MeV},$$

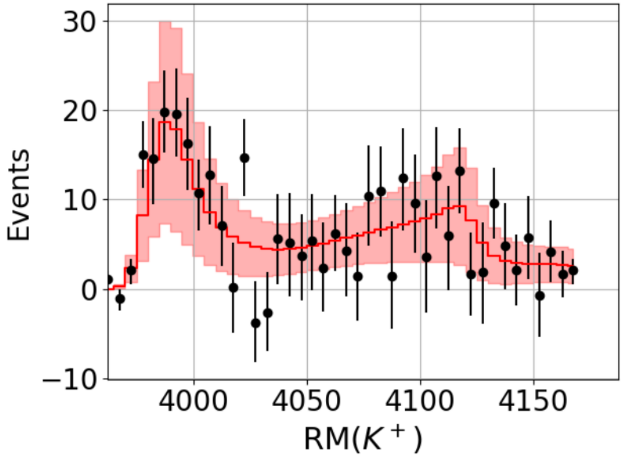
$Z_{cs}(4000, 4220)$ @LHCb

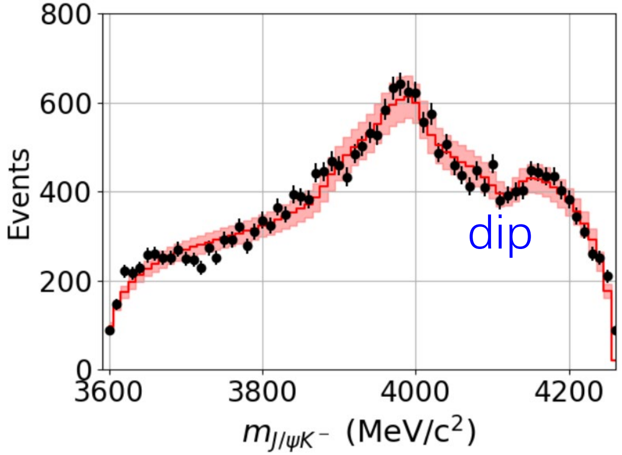
LHCb, arXiv: 2103.01803



$$M_{Z_{cs}(4000)} = (4003 \pm 6^{+4}_{-14})\mathrm{MeV}/c^2,$$
$$\Gamma_{Z_{cs}(4000)} = (131 \pm 15 \pm 26)\mathrm{MeV},$$

$$M_{Z_{cs}(4220)} = (4216 \pm 24^{+43}_{-30})\mathrm{MeV}/c^2,$$
$$\Gamma_{Z_{cs}(4220)} = (233 \pm 52^{+97}_{-73})\mathrm{MeV},$$



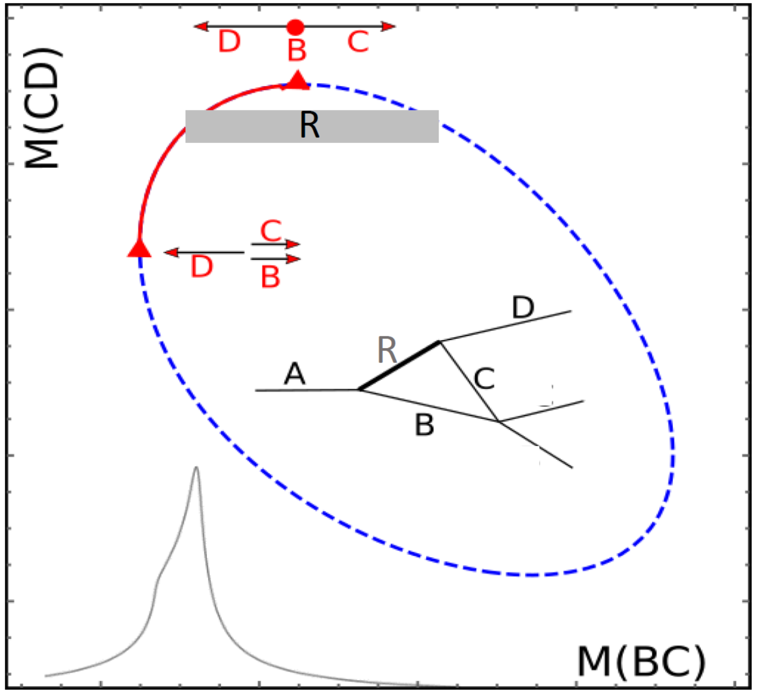


	$Z_{cs}(3985)$	$Z_{cs}(4220)$
Model a	3970	4110

Ortega, Entem, Fernandez, 2103.07781;
talk by Ortega, Session-Exotics, 28.07

Hidden-charm: spectrum to be corrected

- Many charmonium-like structures, some are close to thresholds, and the others do not. Any pattern?
- In most cases, resonance parameters extracted using Breit-Wigner
  - Triangle singularities not considered



  - Triangle singularities are sensitive to kinematic variables ⇒ energy dependence, more processes
  - Narrow peaks for S-wave coupling

Review: FKG, X.-H. Liu, S. Sakai, PPNP112, 103757 (2020)

Talks:
- P_c states:

E. Swanson, Session-Exotics, 28.07;
S. Nakamura, Session-Exotics, 28.07;

- In production of $X(3872)$:

L. He, Session-Exotics, 28.07;

- $d^*(2380)$:

R. Molina, Session-baryon, 27.07;

- $a_1(1420)$:

M. Wagner, Session-Exotics, 31.07;

- Structure at $M_{p\eta} \approx 1710$ MeV:

M. Nanova, Session-Baryon, 28.07;

- In $p\Sigma^- \to K^- d$:

A. Feijoo Aliau, Session-Baryon, 31.07;
…

Round table on "present and future of hadron spectroscopy" – lattice QCD

Christopher Thomas, University of Cambridge

c.e.thomas@damtp.cam.ac.uk

19th International Conference on Hadron Spectroscopy and Structure
(Hadron 2021), 26 July – 1 August 2021

Present and future – lattice QCD – 1

- Precise results for low-lying (stable) hadrons in each flavour sector, physical quark masses, $a \to 0$, isospin breaking ($m_u \neq m_d$ and QED).

- Huge progress in using lattice QCD to study resonances etc in hadron-hadron scattering in the last decade.
- ρ resonance in (approximately) elastic ππ – many calculations by different groups, physical quark masses, $a \to 0$.
- Other elastic scattering channels, e.g. $K\pi$, $D\pi$, DK
- Coupled-channel scattering, e.g. light scalars, b_1, π_1

[Plenary by Dave Wilson on Thursday and parallel talks]

Present and future – lattice QCD – 2

- Charmonium and bottomonium sector, “XYZ”s – very limited calculations so far.
- Exotic flavour: $J^P=1^+$ $\bar{b}\,\bar{b}\,u\,d$ (I=0), $\bar{b}\,\bar{b}\,u\,s$ bound states – charm analogues, resonances?

[Many parallel talks at Lattice 2021, e.g. Brian Colquhoun, Nilmani Mathur, Martin Pflaumer]

- Baryon-meson and baryon-baryon systems, e.g. Roper, Δ, deuteron, *H* dibaryon, P_c – so far conclusions less clear.

[Plenary by Ben Hörz at Lattice 2021]

- Glueballs?

Present and future – lattice QCD – 3

- Formulation exists for 3-hadron scattering (for now some restrictions); so far only a few applications (e.g. I=3 πππ and I=3/2 KKK). Connection with experimental analyses.

  [Plenary by Fernando Romero-Lopez on Thursday and parallel talks]

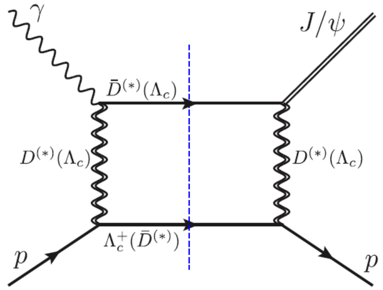
- Additional probes/tests from form factors and transitions. Formulation exists for resonances, very few applications.

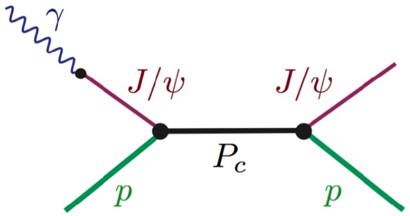
- Lattice QCD can provide other interesting ways to probe the physics, e.g. by varying light-quark mass (m_π), $SU(3)_F$ symmetry.

Questions

- What is the dominant mechanism for J/ψ near-threshold production?

1) Production mechanism in most literature assumed to be VMD
2) The current reconciling the GlueX and LHCb results on P_c relies on VMD, leading to an upper limit of the $P_c \to J/\psi p$ branching fraction. If the mechanism is different, the Br limits would be different.





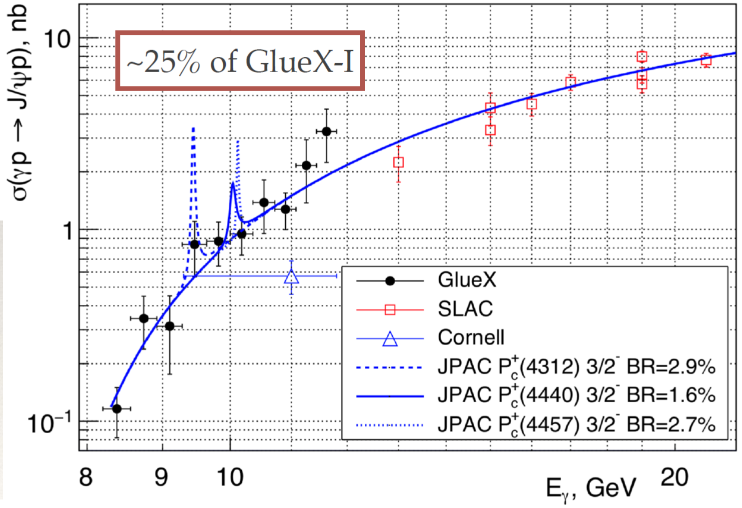
model dependent upper limits at 90% CL

$BR(P_c(4312) \to J/\psi p) < 4.6\,\%$

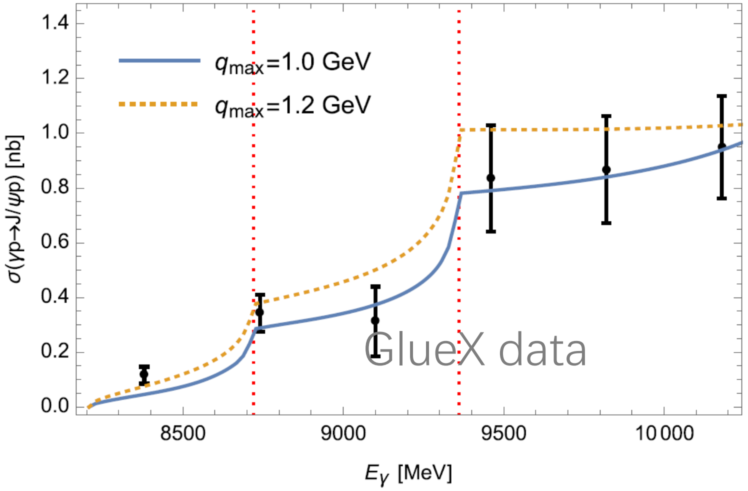
$BR(P_c(4440) \to J/\psi p) < 2.3\,\%$

$BR(P_c(4457) \to J/\psi p) < 3.8\,\%$

Taken from talk by P. Pauli, 29.07



GlueX, PRL123, 072001 (2019)



M.-L. Du, V. Baru, FKG, C. Hanhart, U.-G. Meißner, A. Nefediev, I. Strakovsky, EPJC80(2020)1053

- As for the exotic π_1 on lattice, a $\bar{q}Gq$ operator is needed to get the correct mass, and it couples strongly to $b_1\pi$ [talk by D. Wilson, 29.07]; as for $X(3872)$, both $\bar{c}c$ and $D\bar{D}^*$ operators are needed [Prelovsek, Leskovec, PRL111, 192001, 2013]. On the other hand, the coupling contains structure information. How can we learn about internal structure of the hadron states from such lattice information?